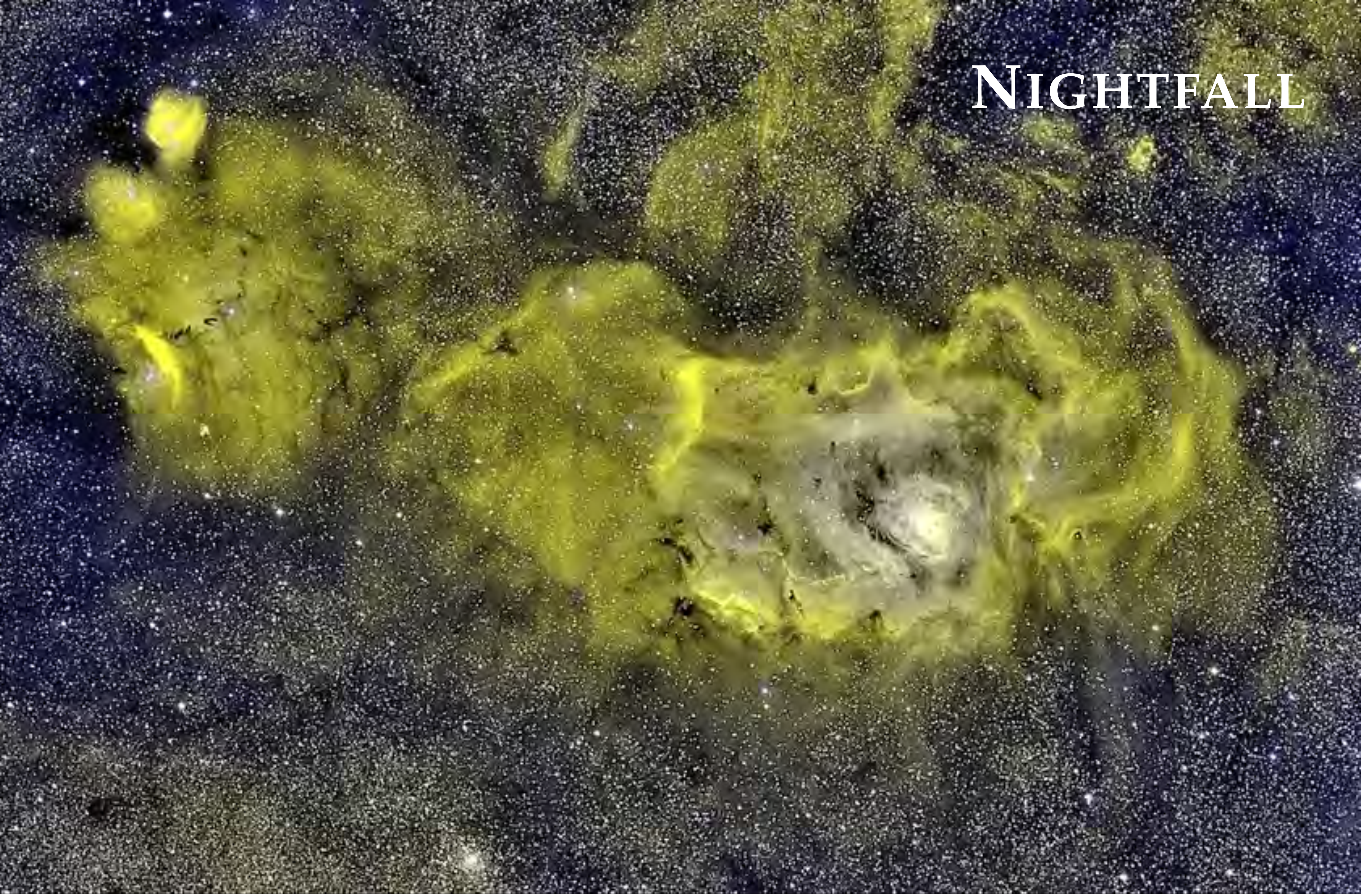
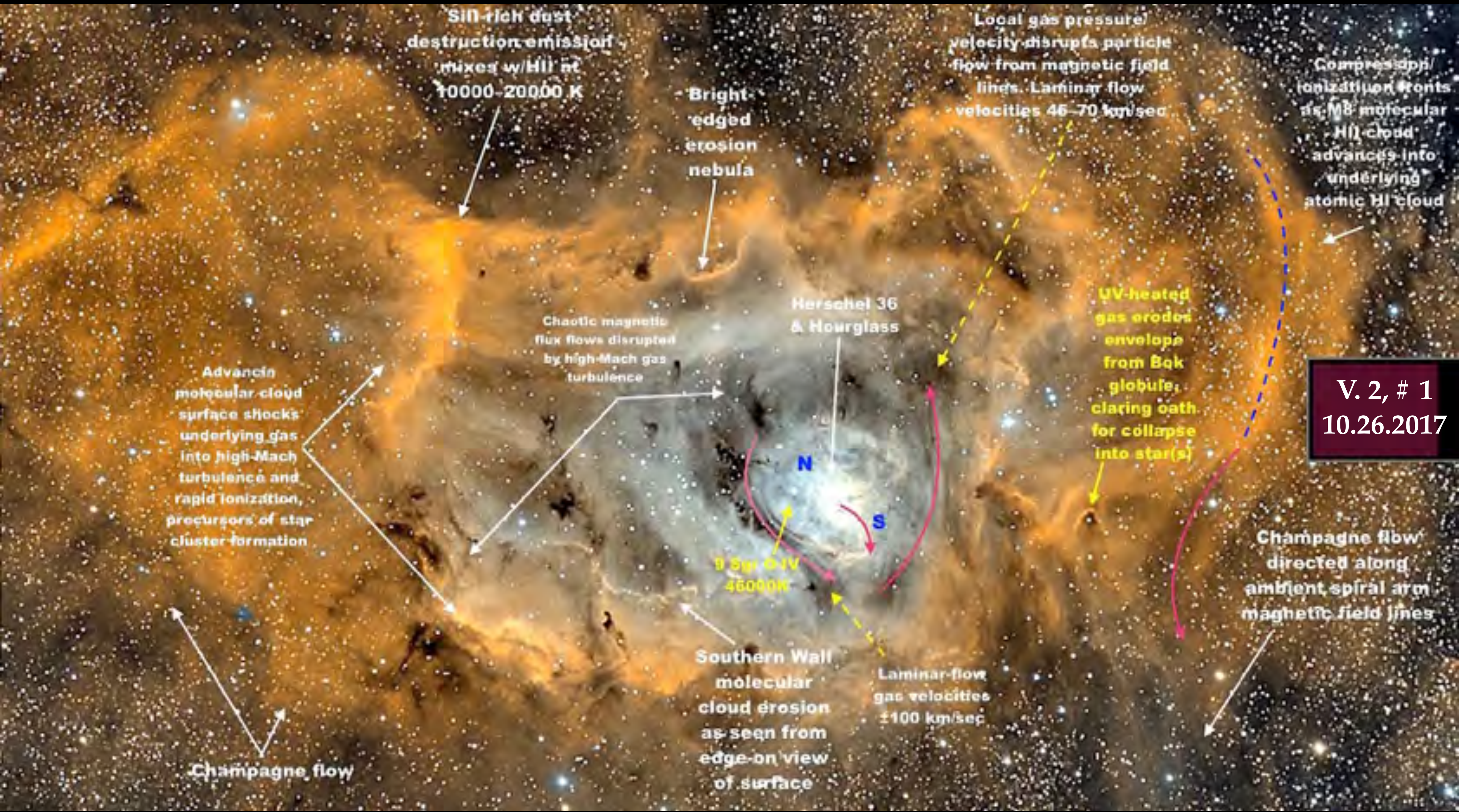
# Nightfall




SiII-rich dust destruction emission mixes w/HII at 10000–20000 K
Bright-edged erosion nebula
Local gas pressure/ velocity disrupts particle flow from magnetic field lines. Laminar flow velocities 46–70 km/sec
Compression/ ionization fronts as M8 molecular HII cloud advances into underlying atomic HI cloud
Herschel 36 & Hourglass
Chaotic magnetic flux flows disrupted by high-Mach gas turbulence
UV-heated gas erodes envelope from Bok globule, claring oath for collapse into star(s)
Advancin molecular cloud surface shocks underlying gas into high-Mach turbulence and rapid ionization, precursors of star cluster formation
N
S
9 Sgr O-IV 46000K
Champagne flow directed along ambient spiral arm magnetic field lines
Southern Wall molecular cloud erosion as seen from edge-on view of surface
Laminar-flow gas velocities ±100 km/sec
Champagne flow
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# NIGHTFALL

**OFFICIAL NEWSLETTER OF THE ASSA DEEP-SKY SECTION**

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*Cover image Copyright © 2017 by [Murray Parkinson](). *

*Televue NP127is refractor with f/4.2 reducer, Astronomik 12-nm H alpha and OIII filters, and QSI683wsg camera cooled to -20 Celsius.*
*The image is a two-panel mosaic built from many individual 600-second exposures, all recorded with 1x1 binning.*

*H alpha east panel: 31 exposures*
*H alpha west panel: 33 exposures*
*OIII east panel: 16 exposures*
*OIII west panel: 10 exposures*

*The "yellow" image was built using the following LRGB colour palette:*

*Luminance = H alpha, Red=H alpha, Green= H alpha, Blue=OIII*
*The "orange" image was built using the following LRGB colour palette:*
*Luminance = H alpha, Red=H alpha, Green=(H alpha + OIII)/2, Blue=OIII*

*See more of Murray's astrophotography here.*



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# A Memorable Visit to the Canary Islands

MAGDA STREICHER

Always striving for new challenges and fulfillment, a passion for the starry skies, stirred this amateur into reaching further into the starry skies. Being familiar with the southern skies that are packed with jewels of the night, I decided to opt for a search of Polaris and its surrounding companions. Portugal in the Algarve seemed to be the ideal destination. Those who do not dare, cannot win, I reminded myself as I started investigating the possibilities of a visit to the Spanish Observatory in La Palma. My joy at the friendly confirmation of this visit was immense! With the Great Bear high in the northern hemisphere, I left – well-prepared and filled with expectation – on the flight to Portugal and Spain.

The south of Portugal was wonderfully warm during May and the night skies were bright and clear. Soon the constellations Giraffe, Dragon, Lynx, Cepheus, the Great and Little Bear with the northern star Polaris became familiar. Two nights of observations were highly successful. Naturally, the visit to the two most northerly Messier objects, the well-known M81 and M82, top my list. With these complete additions, I can, rightfully boast a variety of objects in all the constellations. Considerably enriched, I greeted new friends - who share my appreciation and love for the night skies – and departed for the Canary Islands.

The dangerous runway of La Palma airport, which is directly adjacent to the sea, could engender no fear in me; my thoughts were focused on the Isaac Newton Telescopes on the beautiful island. I traveled slowly up the winding road of the volcanic mountain. The island which rises sharply from the ocean is framed by large fields of wild flowers and dense bush. The jagged rocks in the distance and the apparent desolation unfolded gradually to reveal incredibly blue skies beyond the white cloud mass. At a height of 2 426 meters above sea-level, the view was truly exceptional and the cluster of observatories, perched on the edge of the crater, a definite highlight.

I stared at the amazing white round domed structures, realizing that this is probably a once-in-a-lifetime privilege to be nurtured for ever. René, the friendly engineer in charge of the Isaac Newton Telescopes, explained the operation of the enormous space-guards to me. The control rooms are equipped with the latest technology. The telescopes are electronically controlled.

The Isaac Newton group, together with various others like the 3.6 metre Galileo, 2.5 metre Norwegian, 60cm Swedish telescopes, as well as the Germany Sun and Gamma projects are situated North +28 45′ 43″ and West 17 52′ 39″. With up to 90% clear skies per year, the "Observatorio del Roque de los Muchachos" is regarded as one of the best astronomical destinations in the world.

From descriptions, Las Palmas probably sounds like a group of sentinels on the edge of a volcano, but it is, in fact, situated more towards the east of the island group. At the southern end lies the volcano Cumbre Vieja whose western flanks may someday collapse into the Atlantic triggering a mega-tsunami. For a moment, I try to put the fiery thoughts to rest.

It all started here in 1688. Two inches aperture, 35x, and a single-lens eyepiece.

The stately Isaac Newton Telescope originally came from England in May 1984 and has a new 2.5 metre mirror and upgraded instruments. The telescope is used mainly for wide field spectra observations. Isaac Newton was born in Woolsthrope, England on 25 December 1642 and died in March 1727. His success story is well-known in science and optic works.

The white Jacobus Kapteyn Telescope, with its 1 metre mirror, is used to study the brighter objects. Jacobus Kapteyn was born in the Netherlands on 19 January 1851. After obtaining a doctoral degree at the young age of 27, he was appointed as Professor in Astronomy at Groningen in the Netherlands. He served in this position until he turned 70. During his lifetime, Kapteyn recorded about half a million stars.

At the time a few years ago, the William Herschel Telescope with a mirror of 4.2 metre in diameter was the largest telescope in Western Europe. The telescope is housed in a round domed structure of 22 x 30 metres and first saw the light in August 1987.

Sir Friedrich Wilhelm Herschel was born in Hanover on 15 November 1738. Initially, a successful musician, he turned to astronomy with the discovery of the planet Uranus in Gemini in 1781.

What an awe-inspiring moment when Rene opened the 4.2 metre and lowered it to enable me to have a closer look! A crystal-clear search discovers space for the known, yet unknown. A wonderful feeling of being at home and total satisfaction washed over me. What more can anyone ask for? Imagine my jubilation when I learnt that the astronomer on duty would allow me


It's OK to have the lights on at night if you're in between imaging sessions. Photo courtesy *Instituto de Astrofísica de Canarias - IAC.*

to be present at the observations which were to take place on the night of 24 May with the Herschel telescope! The William Herschel Telescope is already fulfilling its promise of elucidating the structure of the universe, as did the great William Herschel himself.

Astronomers, like Max Pettini, study young galaxies of magnitude 25 and higher to find what they might have looked like during the formation process. The most in-depth observations are done with the William Herschel and Isaac Newton telescopes. With “Ingrid the CCD red-projected equipment” who shot in different red-band spectra during a duration of 10 minutes to indicate the thousands of galaxies which reflect like minute specks of light. According to Pettini this target area is similar to certain Quasars, dense distributions of galaxies and approximately three-quarters of the way towards the outer red glow. This is then referred to as galaxies that are situated approximately 12 billion light-years to the exterior. He was interested in learning more about my contributions and studies of astronomy in South Africa and to my delight asked numerous questions.

Going down is even scarier than going up!

We had a cup of coffee in the early morning hours and I left with the wishes for a good night’s rest from the day-shift team coming on duty. The friendliness once again underlined the fact that astronomers support each other on many levels, even if it is only Magda who passionately explores the skies with an ordinary telescope. The time sped past like a light-year, although fresh and new that would last a lifetime in my memories.

When the Dutch navigators Pieter Dirkszoon Keyser and Frederick de Houtman celebrated with stars the exotic animals that they encountered in faraway southern lands, they had no idea how apt the peacock with its spectacular tail filled with beautiful eyespots would be for us observers sitting at our telescopes… for Pavo is filled with galaxies floating in space like the eyespots in the peacock's magnificent plumage.

Apart from being beautiful, the peacock's feathers are an extraordinary evolutionary trait that, fittingly for a constellation, involves light… the feathers' bright colours are produced not by pigments, but rather by tiny, intricate two-dimensional crystal-like structures. Slight alterations in the spacing of these microscopic structures cause different wavelengths of light to be filtered and reflected, creating the feathers' many different iridescent hues.

Not surprisingly, the brilliant teal eyespots (also known as ocelli) have long fascinated scientists. Charles Darwin found them to be especially striking, and he wrote: "As no ornaments are more beautiful than the ocelli on the feather of various birds… they deserve to be especially noticed."

Pavo's galaxies, too, deserve to be especially noticed. But because they are in the faint-to-extremely-faint and fuzzy category, they are all too often overlooked – other than the impressive face-on spiral NGC 6744. (And even then, one can get lead astray by the published magnitude of 8.3. Since this galaxy is very large, 13'x20', the light is spread over a large area, producing a surface brightness of just 14.1.)

*Pavo's beautiful tail feathers with its multitude of island universes*

However, as a galaxy groupie, so to speak, observing galaxies is not only about what I am seeing in the eyepiece - a faint glow of silky grey light with, if I am lucky, the delicate swirl of a spiral arm, or smaller structure like bright knots, dark rifts or mottling - but also about *what* I am seeing in the eyepiece - faint light from a vast aggregate of gas, dust, and billions of stars and their solar systems, that has travelled millions of light years in an expanding universe. Knowing that incredibly ancient light has ended its inconceivable journey by being processed by my eyes, my brain and my mind, involves me directly in the great immensity and evolution of the universe… which pretty much pushes my brain and imagination to their limits.

Indeed, observing galaxies, more than any other objects, pushes one to discover new limits. Certainly, taking a journey to some far distant island universe pushes your eyes and equipment to their limits. But it pushes other limits, too, those of curiosity and comprehension; patience and perseverance. And beauty… galaxies push the limits of commonly accepted conventions of beauty when you find immeasurable beauty in the diversity of incredibly pale grey smudges of light floating in the great void of space.

Thus it was with Pavo's galaxies; an evening of pushing limits. As a semantics aside, the collective noun for a family of peacocks is a bevy… and at the eyepiece, I cannot think of a better collective noun for Pavo's galaxies. I used my 16" f/4.5 Dobs, and have recorded the galaxies I found most fascinating and beautiful. I began with a galaxy that could almost be a beautiful snapshot of our own Milky Way sent by an extragalactic friend…

*Image credit ESO*

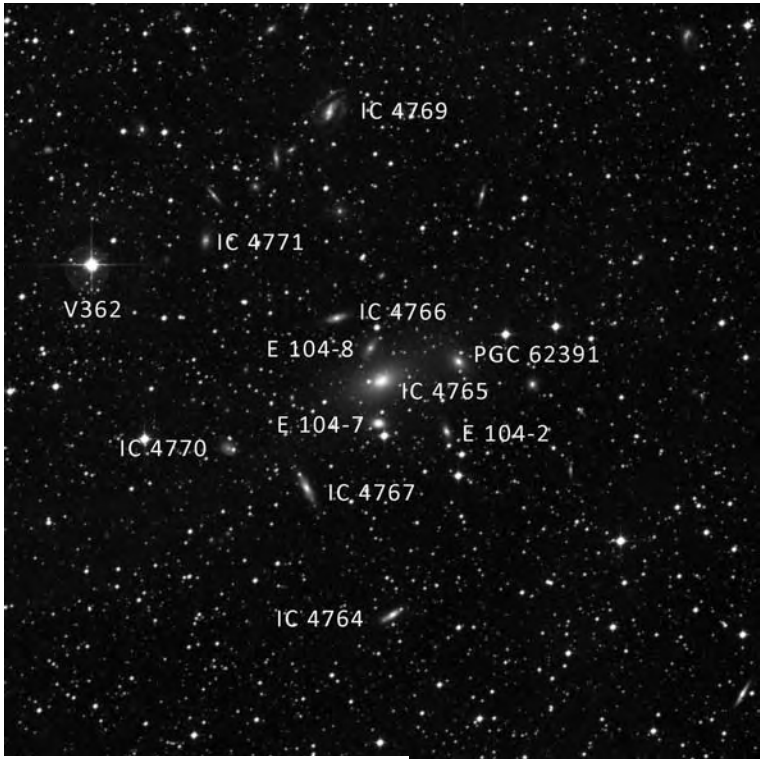
### NGC 6744 Galaxy Type SAB(r)bc II

***$19^h09^m46.4^s$ -63°51'28"***

***Mag 8.5 Dim 20.1' x 12.9' SB 14.4***

This massive face-on barred spiral galaxy, closely resembling the Milky Way, gives one the tantalizing sense of how a distant observer might see our galactic home, and I have to confess that my observation of this galaxy wasn't entirely objective! I really strove to get a sense of our own galaxy's striking spiral arms wrapping around a dense, elongated nucleus and a dusty disk; imagining how our spiral arms would lie… and where our solar system would be. Unfortunately, with NGC 6744's low surface brightness, it wasn't possible to see any structure at all. It shows as a faint, large oval, elongated north-south, with a large bright core, but no sign of a nucleus. A half dozen faint foreground stars are superimposed on its halo. The galaxy even has a distorted companion galaxy - NGC 6744A - which in images is reminiscent of the Large Magellanic Cloud. This galaxy lies 12' NW of NGC 6744, but despite a diligent search, I couldn't see it.

## ACO S805




*DSS image annotated*

This is a superb observing experience! It's always thrilling to look at members of a massive galaxy cluster, never mind one that itself is a member of a super-cluster – in this case the gargantuan Pavo-Indus super-cluster of galaxies that includes more than a dozen other similar galaxy clusters. (The Pavo-Indus super-cluster is believed to contain well over a thousand galaxies.)

The *Uranometria All Sky Atlas* plots six cluster members – IC 1464, IC 1465, IC 1466, IC 1467, IC 1469 and ESO 104-7. I spent a tremendous couple of hours identifying and observing them, as well as five additional galaxies that I could see clustered around with the clustered members. What a view! ACO S805 lies around 220 million light years away… the light reaching one's eye set out when the first mammals were evolving from the nearly extinct Therapsids; which pushed this mammal's imagination to its absolute limits.

### IC 4765 Galaxy Type E+4

***$18^h47^m417.8^s$ -63°19'57" Mag 11.2 Dim 3.5' x 1.9' SB 13.9***

I began with IC 4765 at the centre, which is presumed to be the gravitationally dominant cluster member. It is the brightest galaxy in the eyepiece, surrounded by a host of faint companions – a lovely sight! It shows as a fairly faint oval glow elongated ESE-WNW. It has diffuse edges, and brightens to a small, well-concentrated core, but with no sign of a nucleus.

### IC 4766 Galaxy Type S0-a

***$18^h47^m07.8^s$ -63°29'06" Mag 13.6 Dim 1.2' x 0.3' SB 12.3***

This galaxy shows as a very faint oval glow that brightens to a surprisingly bright, albeit it very small, core.

### IC 4767 Galaxy Type S0+: pec sp

***$18^h47^m41.8^s$ -63°24'21" Mag 13.4 Dim 1.5' x 0.5' SB 12.9***

This galaxy shows as a very faint, exceedingly thin and diffuse slash of light elongated NNE-SSW, with a tiny brighter core.

### IC 4764 Galaxy Type S?

***$18^h47^m07.8^s$ -63°29'06" Mag 13.6 Dim 1.2' x 0.3' SB 12.3***

This galaxy looks remarkably like IC 4767, only it is about a third smaller and elongated NNW-SSE. But it shows the same very faint, exceedingly thin and diffuse slash of light, with an exceedingly tiny, very slightly brighter core.

### IC 4769 Galaxy Type (R') SB(s)b pec
***18$^h$478$^m$44.4$^s$ -63°09'26" Mag 13.1 Dim 1.9' x 1.2' SB 13.9***

This galaxy shows a faint, oval gossamer glow, elongated NW-SE. It brightens to the centre to a small core.

### ESO 104-7 Galaxy Type E?
***18h47m18.3s -63°21'35" Mag 12.9 Dim 0.8' x 0.7' SB 12.2***

This galaxy lies roughly 2' south of IC 4765 with a 10$^{th}$ mag star directly south of it. It is faint, very small, and round. Averted vision showed it to brighten very slightly to the centre.

### IC 4770 Galaxy Type (R)SAB(rs)a:
***18$^h$48$^m$10.4$^s$ -63°23'01" Mag – Dim 0.8' x 0.5' SB –***

This galaxy appears as an extremely faint, extremely small, round glow. Averted vision showed it to brighten marginally towards the centre.

### IC 4771 Galaxy Type Sc
***18$^h$48$^m$23.8$^s$ -63°14'52" Mag 14.5 Dim - SB 13.7***

This galaxy shows as an extremely faint, tiny round glow. Averted vision shows a very small and very slightly brighter core.

### ESO 104-8 Galaxy Type L
***18$^h$47$^m$23.1$^s$ -63°18'35" Mag 15.6 Dim 0.9' x 0.4' S.B –***

This galaxy required averted vision to pick up. It appears as an exceedingly faint, round puff of faintest grey light.

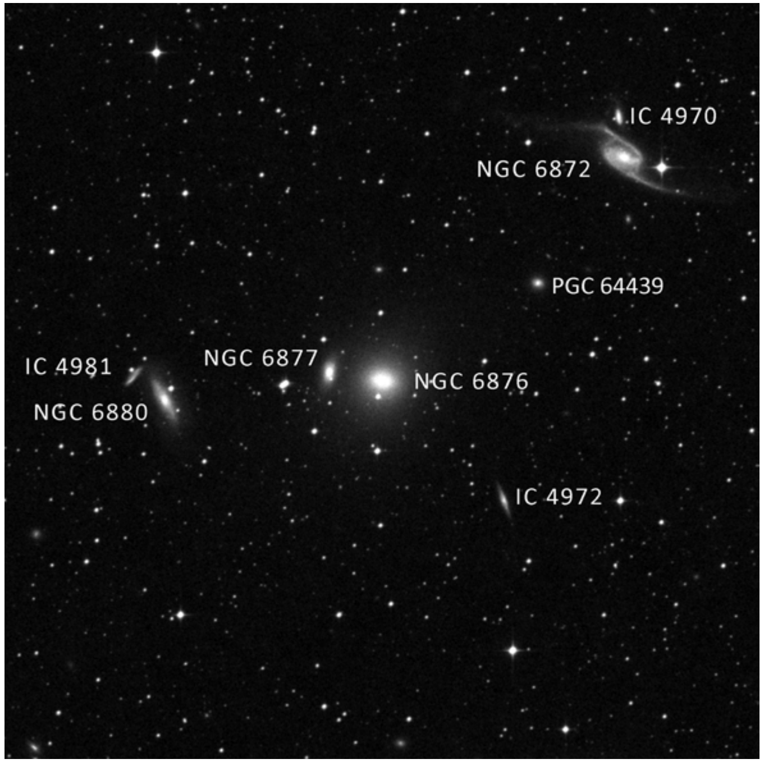
### PGC 62391 Galaxy Type –
***18$^h$46$^m$51.6$^s$ -63°18'51" Mag – Dim 0.4' x 0.3' SB –***

This galaxy shows as an extremely faint, extremely small round glow. It is an even glow; averted vision didn't reveal any brightening to the centre.

### ESO 104-2 Galaxy Type S0?
***18$^h$46$^m$53.9$^s$ -63°21'39" Mag 14.1 Dim 1.0' x 0.3' SB –***

This little galaxy shows as an extremely faint round glow. It is an even glow; with averted vision I could detect no brightening to its centre.

## The Pavo Group of Galaxies




*DSS image annotated*

Lying 190 million light years away, this is a very attractive group of galaxies. To the west lies the famed NGC 6872 and its interacting companion, and to its east lie the other six members of the group.

### NGC 6872 Galaxy Type SB(s)b pec
***20$^h$16$^m$58.0$^s$ -70°46'06" Mag 11.8 Dim 6.0' x 1.5' SB 14.0***

### IC 4970 Galaxy Type SA0" pec:
***20$^h$16$^m$57.6$^s$ -70°44'59" Mag 13.9 Dim 0.7' x 0.2' SB 11.6***

NGC 6872 is an amazing galaxy! Not only is this galaxy one of the most elongated barred spiral galaxies known, it is also the second largest spiral galaxy discovered to date, measuring over 500,000 light-years from tip to tip. (In terms of size it is beaten only by NGC 262, a galaxy that measures a mind-boggling 1.3 million light-years in diameter!) The galaxy's unusual shape is caused by its interactions with the smaller galaxy, IC 4970. They both lie roughly 300 million light-years away from Earth… when their light left, reptiles were evolving, and about 75 million years into the light's voyage the first creature to dominate the planet were evolving… the mighty dinosaurs.

As the second brightest of the Pavo Group, this galaxy shows as a moderately bright, small oval glow, elongated NE-SW. It brightens to a small core. With averted vision I managed to pick up small curves of the two lengthy spirals. The arm that curves NE was extremely faint and extremely thin and very short, the merest curve that a curve can do. The arm that flows SW was also extremely faint and extremely thin, but it was a touch longer than the other arm. IC 4970, lying just north, required averted vision to pick up; and it appears as the smallest, faintest little round daub of dim light.

### NGC 6876 Galaxy Type SB(s)b pec

***$20^h18^m18.8^s$ -70°51'31" Mag 11.3 Dim 2.8' x 2.2' SB 14.0***

This galaxy is the brightest member of the Pavo Group, and it appears as a moderately bright round glow that brightens to a slightly brighter core.

### NGC 6877 Galaxy Type E6

***$20^h18^m36.0^s$ -70°51'14" Mag 12.2 Dim 1.1' x 0.6' SB 11.8***

This galaxy lies a mere 1.5' east of NGC 6876, and it appears as a very faint, very small oval glow elongated north-south.

### NGC 6880 Galaxy Type SAB(s)0+:

***$20^h19^m30.0^s$ -70°51'35" Mag 12.1 Dim 2.0' x 0.9' SB 12.6***

This galaxy shows as a faint, small oval glow elongated NNE-SSW. Averted vision shows a very slight brightening to the centre.

### IC 4981 Galaxy Type I pec sp

***$20^h19^m39.3^s$ -70°50'54" Mag 13.1 Dim 0.9' x 0.3' SB 11.5***

This galaxy lies just east of NGC 6880's NNE tip, and it appears as a very faint, and very narrow, and very small diffuse streak elongated NW-SE.

### IC 4972 Galaxy Type Sb

**$20^h17^m42.7^s$ -70°54′54" Mag 14.5 Dim 1.1′ x 0.3′ SB 12.7**

This is an extremely faint, extremely thin, streak of dim light, elongated NNE-SSW. No sign of a central brightening.

## KTS 59 – A lovely southern triplet

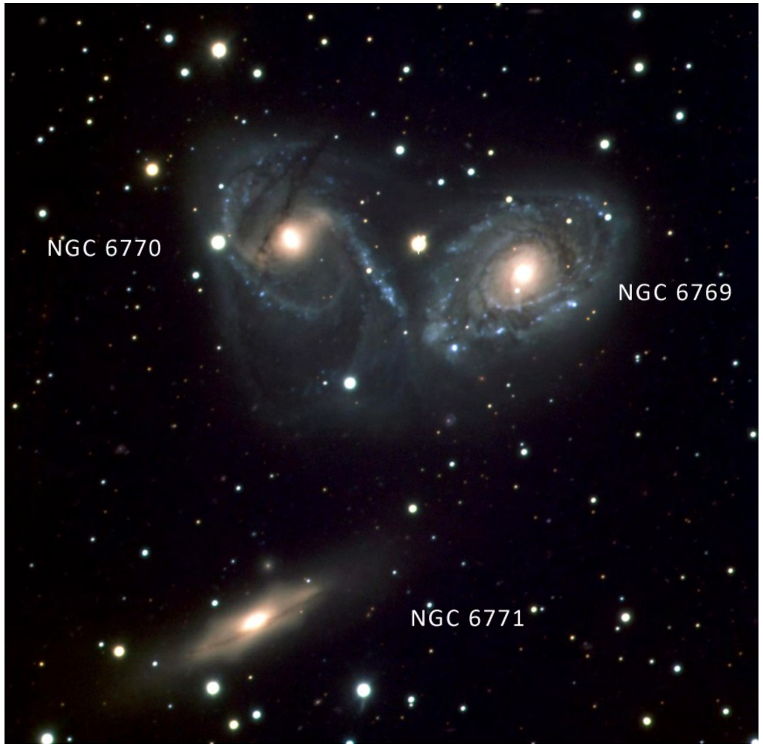



*Image credit ESO annotated*

A trio of galaxies in the same field of view is always a treat. And this one, albeit rather faint as it lies 190 million light years away, doesn't disappoint. It lies just over one degree southeast of the gorgeous dazzler of a globular cluster – Pavo's showpiece, NGC 6752 (which always warrants an extended visit on your way to this trio… even on a bevy of galaxies night!)

## NGC 6769 Galaxy Type SAB(r)b pec II

***$19^h18^m22.7^s$ -60°30'04" Mag 11.8 Dim 2.3' x 1.5' SB 12.9***

This is the brightest of the trio, and appears as a faint round glow that brightens to a somewhat brighter core. On the gorgeous image you can see that it and NGC 6770, that lies just 1.9' to the east, are clearly interacting. No sign of the interaction in the telescope, but as always, it is extraordinary to know what is going on between the objects you are holding in your eyepiece, even if you can't see it.

## NGC 6770 Galaxy Type SB(rs)b pec

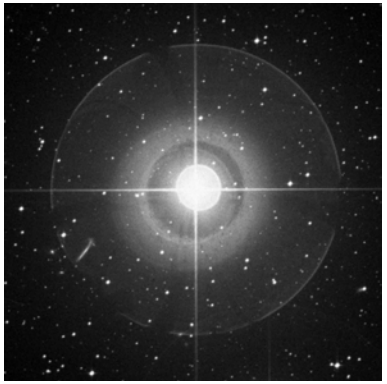
***$19^h18^m37.3^s$ -60°29'47" Mag 11.9 Dim 2.3' x 1.7' SB 13.3***

This galaxy, a mere 1.9' to the east of NGC 6769, is almost identical to it, being a little smaller and a little fainter. They really look lovely together… their brighter cores remind me of a car with dodgy headlights coming through the mist.

## NGC 6771 Galaxy Type SB(r)0°? Sp

***$19^h18^m39.5^s$ -60°32'46" Mag 12.5 Dim 2.3' x 0.5' SB 12.5***

This galaxy, lying 3'S of the dodgy headlights, is a lovely faint, slim streak, elongated NW-SE. It brightens to an extended central area. While examining the galaxy with averted vision, I thought that a very faint stellar nucleus popped into view, but alas, only once, so not logged as a stellar nucleus; may well have been wishful thinking.



*DSS image*

## McLeish's Object Galaxy Type S pec

***$20^h09^m28.1^s$ -66°13'00"***

***Mag 15.1 Dim 1.0' x 0.3' SB 13.7***

The name "McLeish's Object" has a wonderful air of mystery to it, and alas, it has remained a wonderful mystery… even at the highest magnification I wasn't able to pick up even a hint of this strange little galaxy; its size and magnitude just couldn't beat the glare from yellowy-white mag 3.56 Delta Pavonis.

*DSS image*

## NGC 6943 Galaxy Type Sbc

***$20^h44^m33.6^s$ -68°44'51"***

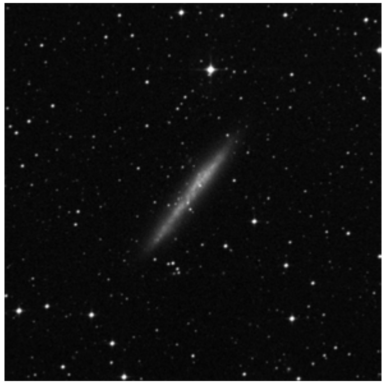
***Mag 11.4 Dim 4.0' x 2.0' SB 13.5***

This galaxy is a lovely sight because spiral structure is evident in the halo. Although I couldn't trace distinct arms, I could see the faintest knotty-like appearance of structure wrapping around the inner core and moving out to the NW and SE edges. The halo itself is a fairly bright oval elongated NW-SE. It brightens gradually toward the centre to a small, elongated, and surprisingly bright core.

A mag 9.5 star lies 5' NE.

## IC 5052 Galaxy Type Sb

***$20^h52^m06.3^s$ -69°12'14" Mag 11.2 Dim 5.9' x 0.8' SB 12.7***



*DSS image*

*Image credit EAS/Hubble*

And to end… the galaxy that turned out to be the highlight of my night in Pavo. I really enjoy observing edge-on galaxies; there is something so very elegant about them… and this is a real little beauty. It is a gorgeous, bright narrow NW-SE streak; evenly luminous, with no central concentration. It is very slightly spindle shaped, with a very slight bulge at the centre, and tapering to the tips at both ends. Lovely!


NGC 4945 SB(s)cd Centaurus © 2017 Dale Liebenberg

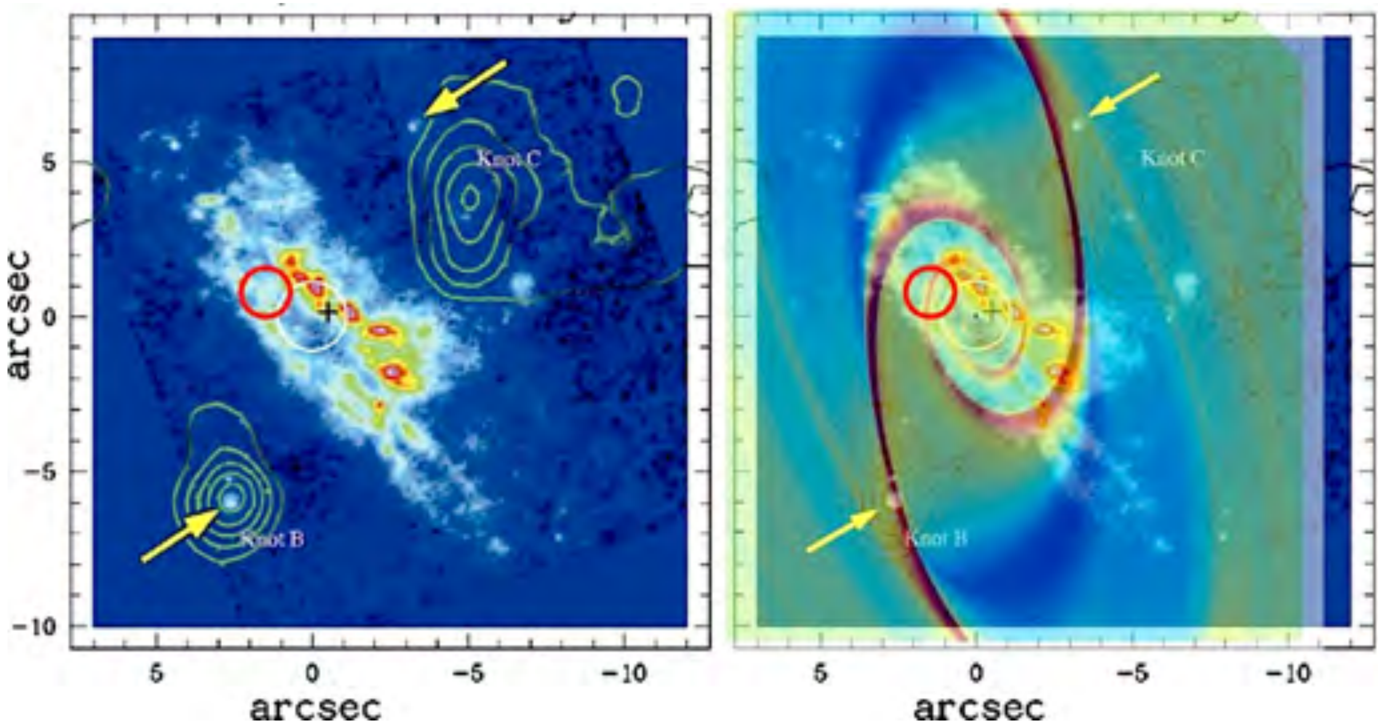
NGC 4945 is a visually subtle galaxy, but just the opposite in astro images. At 40x in an 8 inch telescope it is a feathery whisp of light that calls to mind a young girl blowing dandelion seeds into the zephyrs so we will have more of them next year. A faint smear angles across one corner of a stellar triangle five degrees W of Omega Centauri, the core of a tidally de-haloed dwarf galaxy. Raise the magnification to 90x–120x and the delicate phorescent surface becomes an ephemera of mottles and hesitant filamentary bands. This will-o'-the-wisp floats amid a tremulous scatter of field stars that elevates the visual field into one of the comeliest in southern skies.

Aggregated photons show a very different galaxy than one-at-a-time photons, as we see in Dale Liebenberg's image. NGC 4945 is a chaotic mix of density clumps peppering a salad of dust clouds. It's a brash, bright unkempt muppet of a galaxy with little to offer in the way of finesse. Its extreme contrast densities make NGC 4945 a favourite among astrophoto-graphers keen to eke out every last photon.

NGC 4945 has the reputation among amateur astronomers as one of the galaxies most like the Milky Way. That's a bit misleading. For one, NGC 4945 has an extremely active Seyfert-type central core. Seyferts are prodigious energy emitters because a central supermassive black hole gobbles infalling matter at a withering rate around its equator, ejecting much of it as extremely hot magnetic flux jets from the poles. Our galaxy is cheerily quiescent by compare. But both galaxies have a common property: a massive galactic bar converts the rotational spin of the galaxy's vast wheeling spiral arms into a giant funnel of matter flowing into the core.

Galactic bars are structurally complex but energetically simple. They transfer the angular momentum along spiral arms into linear momentum toward the core. There they redistribute it in two ways. Much of it flows past the core into the opposite spiral arm. The rest is caught into a density perturbation which redirects the momentum into an arcsec (i.e. kiloparsec) scale spiral or a circular ring whorling rapidly around the core. [Watch it happen here.]

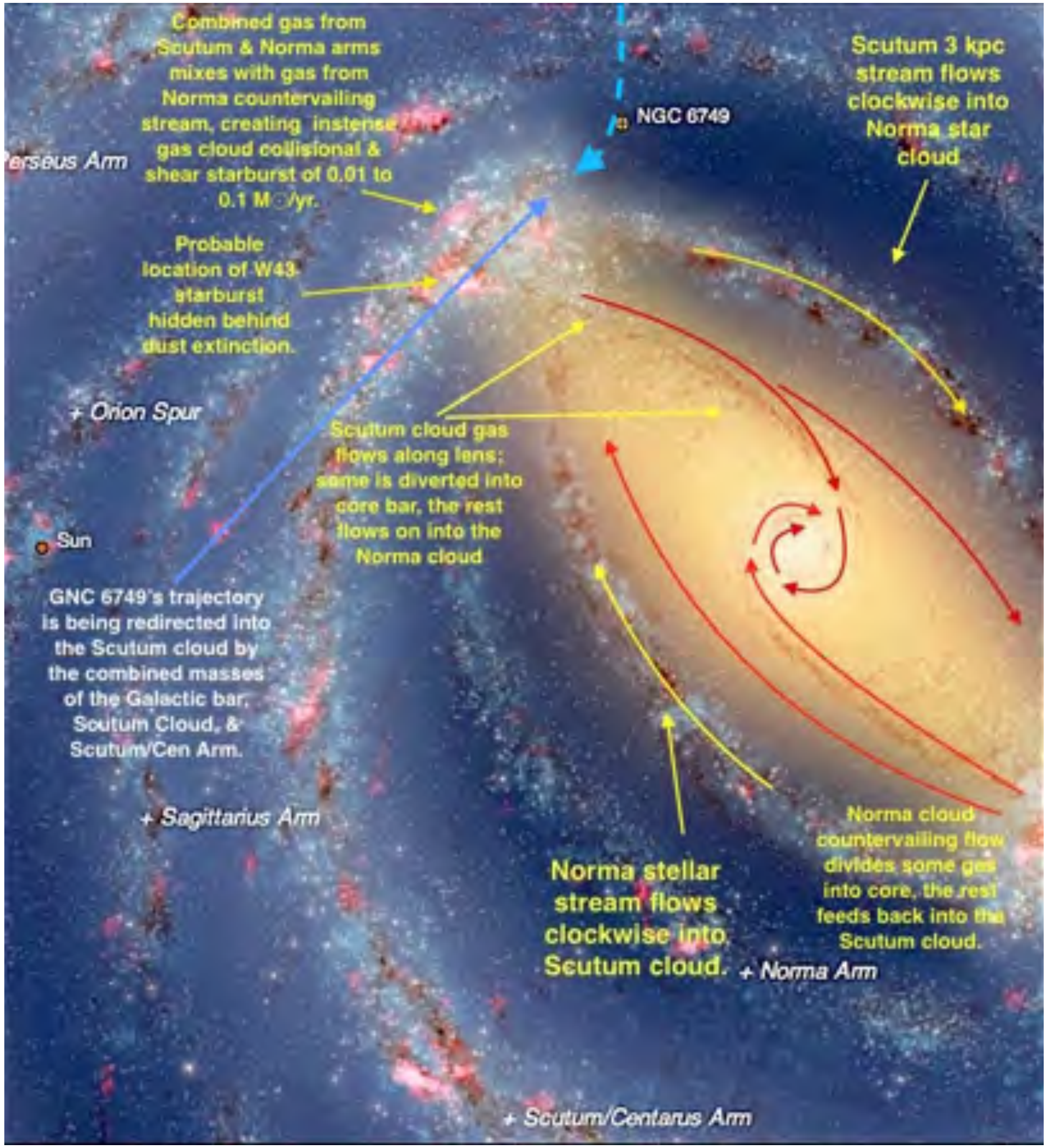
Since NGC 4945 is seen edge-on, we intuit none of this. Bar structures in edge-on galaxies are traced via the velocity distribution of gas and dust emission in the IR and millimetre radiation bands.



# Meet NGC 4945 Centaurus by Dale Liebenberg

NGC 4945's beehive of stars is a spiral galaxy much like our own, with swirling, dust-beclotted arms and a diffuse central region. NGC 4945 appears cigar-shaped from our perspective on Earth (as the Milky Way would appear from NGC 4945), but the messy-looking mélange in Dale's image is actually a normal, if dusty, spiral galaxy. Stars, dust, and shock-heated molecular hydrogen synchronise into density waves rotating at near-constant velocity around the centre. Bars rotate circularly as a unitary body around the core, but the gas and stars within in them orbit horizontally along the bar in giant flattened ovals. NGC 4945's dense thicket of bright blots and dark clots earmark dense clouds of star formation — as do those same features do in our own galaxy, M51, Andromeda, and most spiral galaxies.

NGC 4945 differs from the Milky Way in having an active galactic nucleus. Its central bulge emits far more energy than galaxies like the Milky Way. Scientists classify NGC 4945 as a Seyfert galaxy, named after the American astronomer Carl K. Seyfert, who suggested in 1943 that intense light signatures emanating from certain galactic cores might indicate some unknown form of extreme energy at work there. Today we know the energy to be supermassive black holes hoovering enormous quantities of gas and dust into them. The matter is heated to extreme temperatures, emitting high-energy X-rays and ultraviolet light. When the UV photons encounter an HII molecule, their energy is absorbed by HII gas, which absorb a portion of the photon energy and re-emits the rest as lower-energy infrared. A barred galaxy's torque and shear forces radically re-vector spiral arm gas down into and along the bar. Note how differential angular momentum shifts the denser dust clouds toward the leading edge of the bar, while the low-mass HII gas streams in smooth, broad rivers towards the core. Much of the gas overshoots and ends up in the spiral arm/bar clump on the far side. Read more at 1, 2, 3, 4 5, 6.




*Previous page*: The barred spiral structure in NGC 4945 is heavily obscured at visible wavelengths. It is a visual analogue of the dust obscuration in our own Milky Way disc (*above*). Today's orbiting Herschel IRAC camera captured NGC 4945's IR emission, revealing a velocity distribution consistent with a galactic bar (visualised here in our own Milky Way). The globular cluster NGC 6749 at the top is on an infall vector that may end up in its dissolution as it passes through the wrenching shears of the arm/bar junction.

## *Dale Liebenberg, in his own write*

I am an electrical engineer by profession, specialising in power transmission and distribution and utility operations and maintenance. My lovely wife Tania and I live in Port Elizabeth. We delight in our four children and eight (at last count!) 😊 grandchildren.

### *How I got involved in astrophotography*

About 15 years ago, my youngest son and I were out doing our Christmas shopping when we saw a small 90mm Meade go-to telescope. We decided that was *exactly* what we needed for Christmas. The bug bit well and hung on. I was already interested in photography, so I bought a small astro imager, which was soon upgraded to a Canon 20Da astro DLSR. The obvious next step up was a 8″ SCT on an alt/az mount and a proper colour-cooled astro camera.

Living near the wet, cold Southern Ocean, weather conditions are seldom good for astrophotography. I eventually tired of setting up my equipment for a night of imaging, only to have to pack it all away again as the clouds glowered in for yet *another* evening. The clouds I couldn't do much about, but the incessant setup and tear-down was solved by building a room above my garage with a roll-off roof and telescopic pier. Later I added a glass-fibre dome for wind and dew protection.


### *Current equipment*

I currently have a 14″ Celestron EdgeHD SCT scope mounted on an ASA direct drive equatorial mount. The ASA features very accurate gearless tracking. I replaced the optical tube's factory aluminium tube with a carbon fibre tube for improved focus stability and reduced weight. I use an FLI ML1102 camera with 7 filter wheel. The camera is cooled to –30 C all year long to obviate repetitious calibration rounds. The focuser is an FLI Atlas unit and the tracking done with an Astrodon off-axis guider (OAG) with guide camera built by the Santa Barbra Instruments Groups (SBIG) in California. I use a Takahashi 106mm refractor mounted on the main telescope for wide field imaging.

All this exotic gear kept the customs assessors beside themselves with glee as they totted up rates and fees for scientific instrumentation imported from places like Austria, USA, Spain, UK, and Canada.

My observatory is now fully automated, using an ACP Scheduler with a cloud sensor. I can monitor everything from a PC in my study. and even remotely, using Teamviewer software.

### *How I do my imaging*

I started off imaging The Usual Suspects M42 Orion Nebula, M20 Trifid cloud-collision starburst nebula, etc. I am pleased to report that I provided images for Magda Streicher for her various articles.

To date I have completed 150 objects of acceptable quality. (Let's not mention all the unsuccessful ones, shall we?). These days I keep myself busy ticking off the Top 100 deep sky images and 130+ objects in the Bennett catalogue. Each and every single one presents a new challenge of one kind or another. The skies do keep us on our toes!

Once I have identified a candidate for imaging, I look it up in my planetarium app. I then set up field-of-view (fov) indicators for the chosen image scale. This system uses an image-overlap array consisting of a rectangle representing the camera's fov plus double-fov rectangles to the east and west for the guide camera fields. I then adjust these to capture the best view of the object plus a suitably bright guide star to the east and the west of the image-field meridian for the auto-guider.

Next I establish an imaging plan that includes the object coordinates, number of observations, and image duration sequence for each filter. Different filters absorb and pass different fractions of the total luminance, so exposure times and numbers must be normalised to a common mean.

This plan is imported into ACP Scheduler, which then schedules the imaging sessions according to atmospheric conditions.

When I have acquired sufficient data, I then go through the "stacking" process of calibrating, aligning, and combining, first to to a base luminance and then to a RGB composite if the final image is to be a traditional multi-band composite. If the goal is a narrowband image, I set up the composites for Hα, OIII, or SII composites). This I usually do with MaximDL. If more manual intervention is required, I use CCDStack. These base composites are imported into Photoshop for processing.

### *Why do I do this?*

Astrophotography challenges and rewards at many levels.

Firstly there are the technical and practical challenges — planning and building the observatory, installing the electrical and computer processors inside, then trouble-shooting all the bits and pieces till they work together properly. This is largely an exercise in simple mechanics — electrics, structure, IT, etc. Probably the most vital step is fault-finding. If something goes wrong on the southern tip of Africa, is not easy getting hands-on help from manufacturers.

Secondly, there are the challenges of determining the type and amount of data necessary for each object, getting the calibration and stacking as accurate as possible for good raw images.

Finally, once all the technical issues are sorted, there comes the most enjoyable component: the artistry in the image. There is really no such thing as an accurate, objective rendition of an object. A base image after stacking is a rather raw, unpromising thing, a dim, dull, noisy, colourless assemblage of smudges and glows. I have to stretch, sharpen, noise-reduce, then merge technical skill with artistic nuances to best bring out the object's features.

Nowhere are the results of this so vivid than when doing narrow band work. If I had to assign each of the filters a colour that matched the bandwidth of the filter, I wouldn't be able to distinguish the various emissions. I have to choose colours that highlight structural features that give the object its scientific importance.

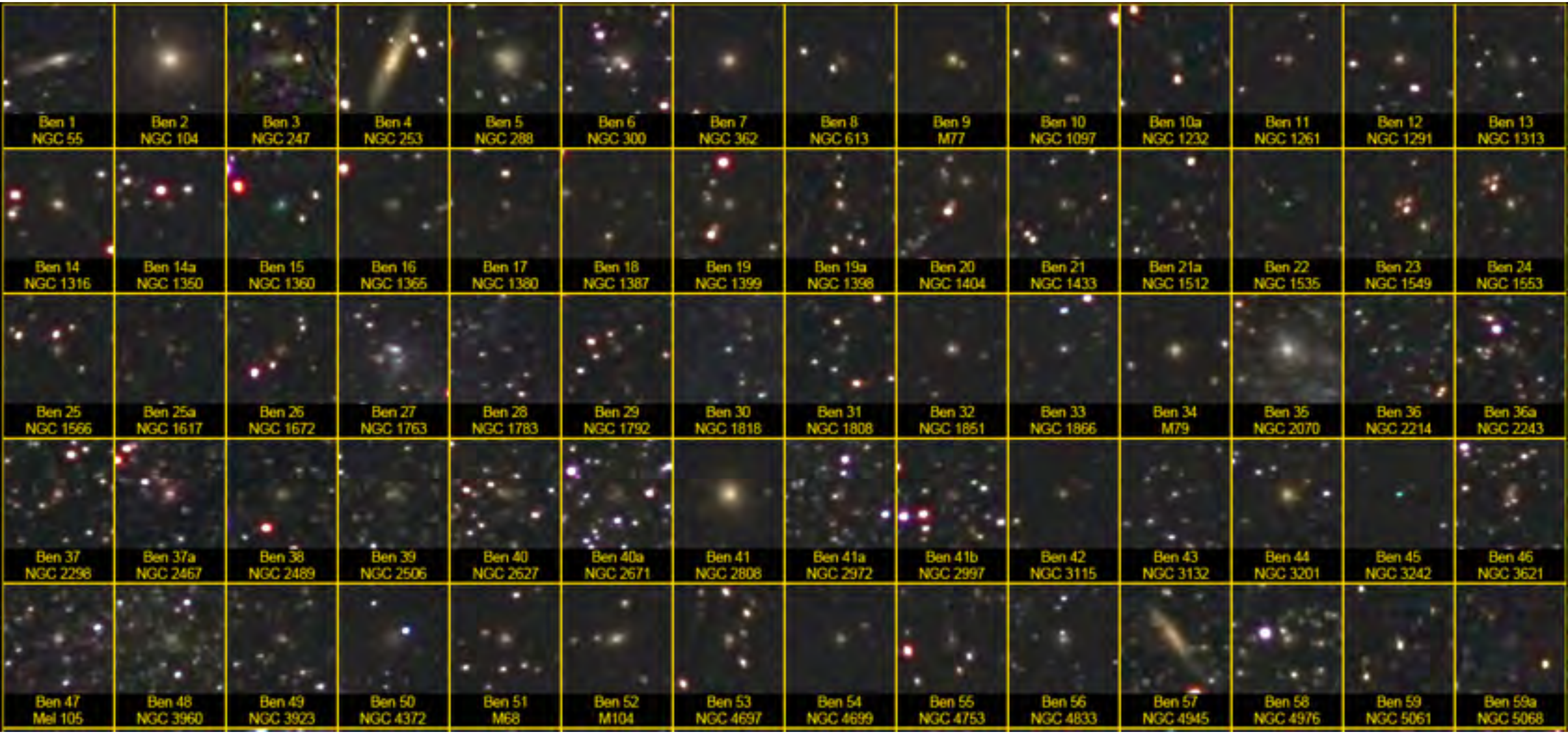
I have even been able to bring my other hobby, software development into astrophotography. After all, if those marvellous NASA ladies could do the calculations manually back in the '60s, how difficult could it be?

The moon's position was particularly challenging. The longitude and distance has a calculation that includes 59 periodic terms with a further 30 for the latitude. This makes one really appreciate what those NASA ladies achieved "back in the day".

# The Complete Jack Bennett Catalog photographed by Barbara Cunow, Pretoria

I have always been "the astronomer". I grew up in Germany and became interested in astronomy as a teenager when I started observing the night sky with a small telescope. After matric I studied physics and astronomy at the University of Münster, Germany, where I got my PhD in astronomy in 1994. Then I moved to South Africa and worked at Unisa in Pretoria as an astronomer from 1996 until 2008, first as Lecturer, then as Senior Lecturer and finally as Associate Professor. At the beginning of 2009 however, I lost my career when I was forced to go on early retirement due to ill health. But even though I cannot work anymore, my interest in astronomy is as strong as ever.

In 2010 I started doing astrophotography with a DSLR on a tripod from my home in Pretoria. Using just a tripod is the easiest way of obtaining images, and it is surprising what is possible with this small equipment, even under a heavily light-polluted sky. The key to success is stacking, stacking, and more stacking. Because of the sky rotation I can take only a few seconds of exposure time for the individual images. But if I take hundreds of images of the same sky field and stack them, the background noise will be reduced significantly and the objects will become visible. This is what I did with the Bennett objects and also with the ASSA Top-100 objects last year.




I take my images from my home in urban Pretoria with a DSLR on a tripod with no tracking. The focal lengths I use are 55 mm or 100 mm (with a few exceptions of about 150 mm). So the objects appear very small in my images, and I used the original sizes when I put together the collage.


**The complete Bennett Catalog of 130 objects plus 21 supernumerary "a" and "b" objects is available here. Review Jack Bennett's entry in the archives of the ASSA here.**

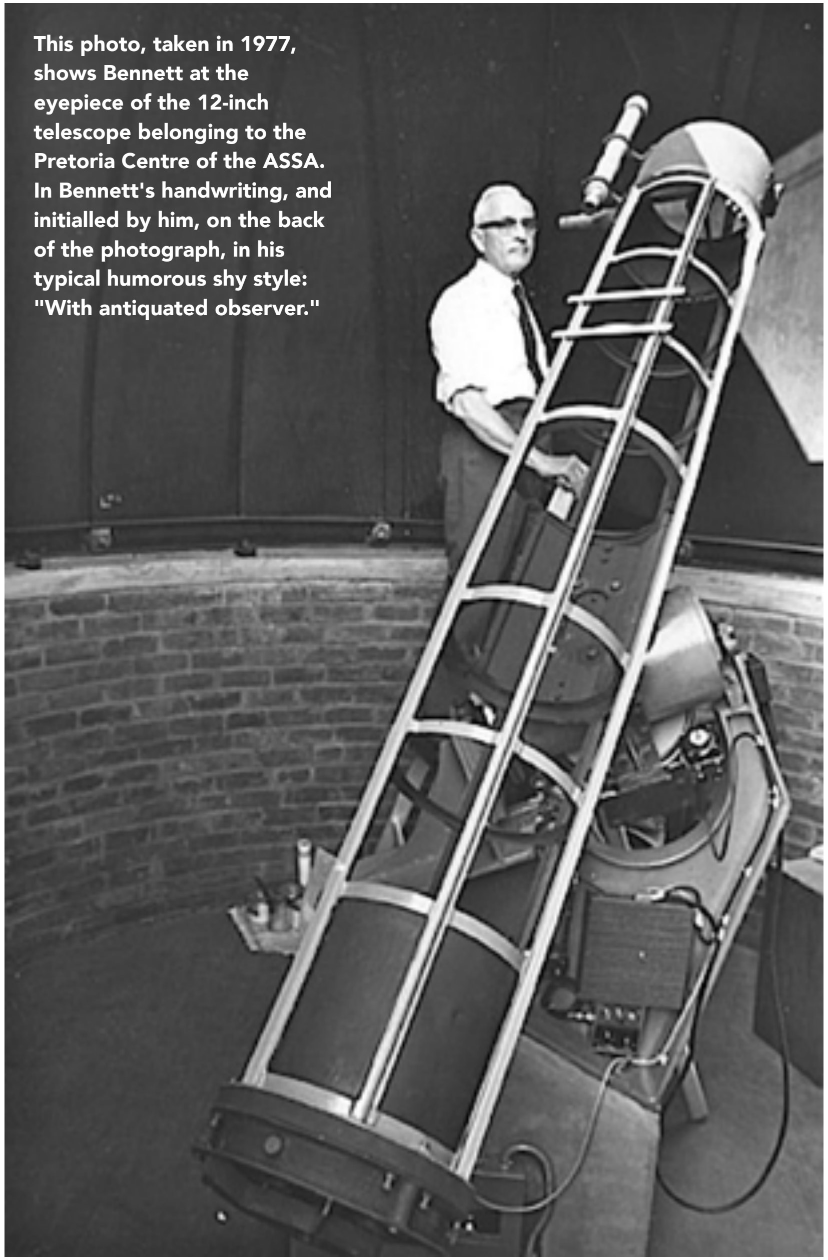
## About Jack Bennett

For two decades, starting in the late 1960s, the southern sky was patrolled by a dedicated South African comet-hunter named Jack Bennett. Using a 5-inch low-power refractor from his backyard he discovered two comets. Jack also picked up a 9th magnitude supernova in NGC 5236 (M83), becoming the first person ever to visually discover a supernova since the invention of the telescope.

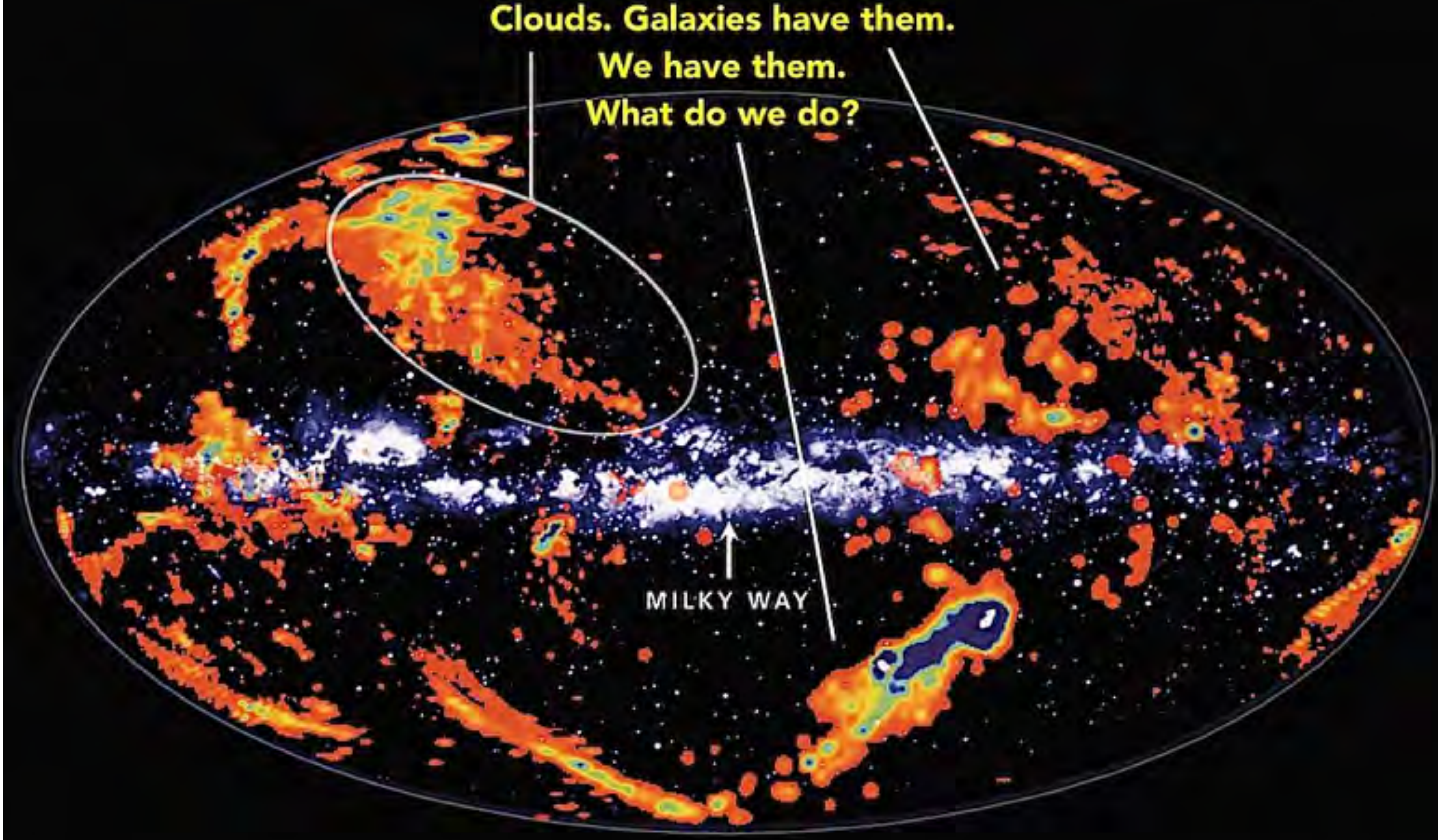
He was born John Caister Bennett on April 6th, 1914 in Estcourt Natal. His mother was British and his father was from Longford, Tasmania.

A long-standing member of the Astronomical Society of Southern Africa (ASSA), he was elected President in 1969. The Society awarded him the prestigious Gill Medal for services to astronomy in 1970 and in 1986 he received an Honorary Degree of Master of Science from the University of Witwatersrand. In 1989, at the recommendation of Rob McNaught of Siding Springs Observatory, the asteroid VD 4093 was named after him

Although christened John Caister Bennett, he was known to all as Jack. His modest list of 85 cometary imposters was born in the spirit of Charles Messier. He pounced on an amazing array of objects given that his primary telescope was a 5-inch refractor at 21x mounted on an undriven alt-azimuth mount. With this he discovered the first supernova since the telescope was invented. He was the veritable model of the meticulous log-keeper. He reported having spent 815 hours fighting off dew, mozzies, and bats, all for the sake of fuzzy bits in an eyepiece. Jack Bennett passed away on May 30th, 1990 in Pretoria



This photo, taken in 1977, shows Bennett at the eyepiece of the 12-inch telescope belonging to the Pretoria Centre of the ASSA. In Bennett's handwriting, and initialled by him, on the back of the photograph, in his typical humorous shy style: "With antiquated observer."




NASA and B. Wakker (University of Wisconsin-Madison) • STScI-PRC99-46

# Cloud-Avoidance 101: Online Observing

**Dana De Zoysa**

Does the weather portend glum nights the rest of the week? And ***of course*** this is during the best nights of the dark-moon time. Such oft-heard refrains are the dour tune of many a stargazer.

Courage, lads. The Siren of the Stars sings in the distance. Alas, this Siren goes by the most nonmelodic name of ***Slooh***. This siren is a remote-controlled observatory, sited high in the fabled Atacama Plateau in Chile — yes, *that* Atacama. Where the 8-metre telescopes Paranal, Melipal, XX, and XX open their 8-metre eyes to the skies at night. Slooh takes you there. What's more: you can take a peek through not one, but two Atacama telescopes. *PLUS*, five more in the Canary Islands. (See Magda Streicher's memoire of her visit to the Isaac Newton Telescope in the Canaries on page ___ of this *Nightfall* issue.)

### *Open Access Astronomy*

Online observing is a new experience for many of us. Here at Nightfall, we were graciously introduced to Slooh by our colleague Carol Botha, who has penned many an observing report for South African visual observers and sketchers.

* See also the article "Live 24/7 observatory webcams around world" immediately following this article.

A bit of a Google crawl revealed the world of open-access astronomy observatories to be a big one. Google has long lists of them *here* and *here*.*

*Slooh* enthusiasts can join as an *Apprentice* at US$ 4.95 [~R65.00] a month which gives you five observing slots per month and a list of 500 objects to choose from. You can upgrade to the *Astronomer* level for US $24.95 a month [~R325.00], which gives you basically everything except shipping that beautiful telescope from the Canary Islands to your front stoep. Slooh thoughtfully allows you to take your own


AWB's global reach is astounding. Visit their website, become a member (plans from free upward to Sustaining Members at US$150 [R1950] a year. Details *here*.

astrophotos and post your observations on the website.

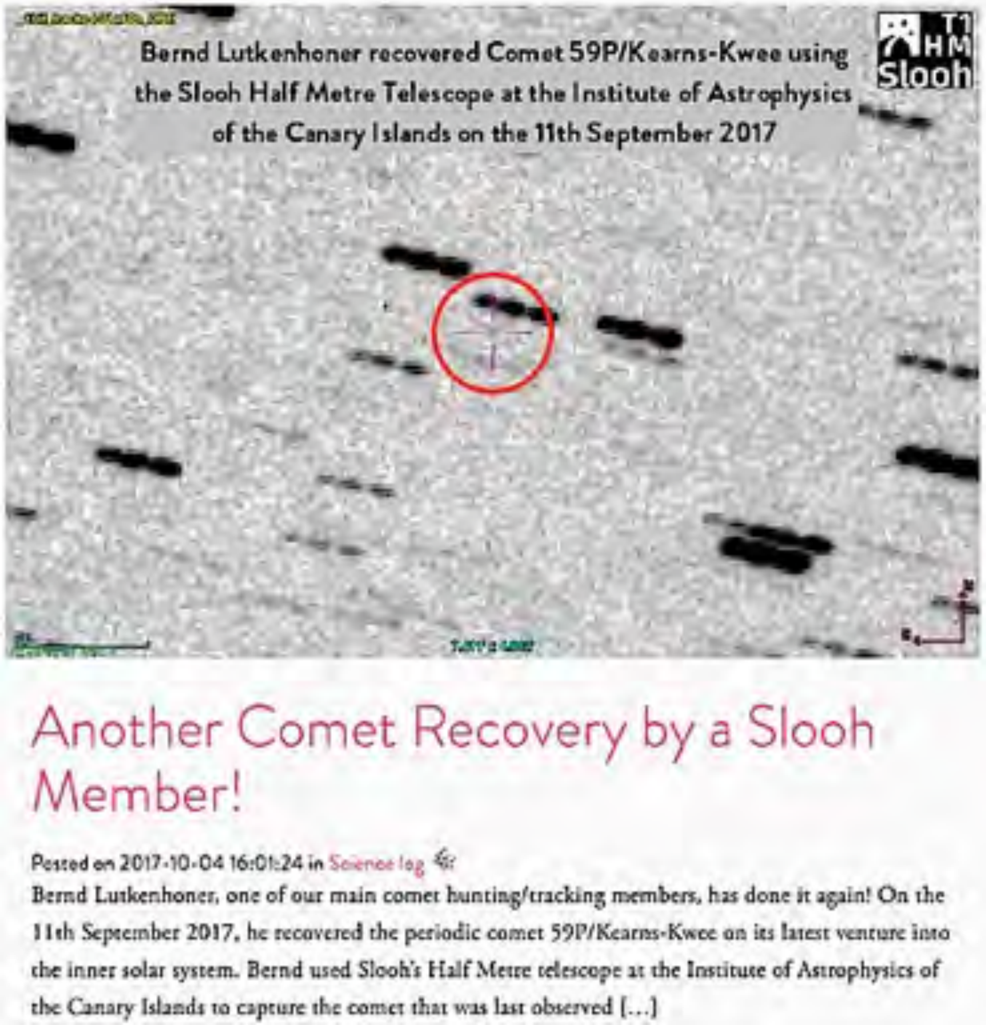
If you prefer to dip your toe in the water before reaching for the wallet, you can tag along for a free wide as a Crew Member. You won't have access to the robotic telescope controls, but you can observe with the paying members, peeking over their shoulders, and in real time. They pay the subscription, you go along for the ride. Read the *Slooh* membership and other *FAQs* here.

Alas, even *Slooh* scopes can be clouded over too. Their website thoughtfully provides an alert system: a green light for clear and red for cloudy. The administrators link this "Go/No-go" page to other offline pages of readings and information — scads of interesting stuff to explore while waiting for the little "Cloudy/Clear" dots to turn green.

For the South African astronomer, Slooh is the most straightforward of the several live visual observing websites available. But there are others, so shop around: *1, 2, 3, 4*.

*Slooh* is affiliated with *Astronomers Without Borders* (AWB), a well organised group of amateurs and professionals which acts as a gathering ground for astronomy enthusiasts around the world. AWB operates under the "One People One Sky" rubric, beckoning first-time visitors with the comely motto, "Boundaries vanish when we look skyward." Since users search out their objects via R.A. and Dec, it seems constellation boundaries have vanished along with the more earthly borders.

For those who aspire to ProAm, the introduction of online access to large-aperture equipment equipped with imaging capability give amateurs an unprecedented opportunity to work alongside the professionals. Hobbyists can now devising their own research initiatives, becoming fully-qualified ProAm astronomers. A few contribute a lasting legacy. It's all there if we want it:




Another Comet Recovery by a Slooh Member!

Posted on 2017-10-04 16:01:24 in Science log

Bernd Lutkenhoner, one of our main comet hunting/tracking members, has done it again! On the 11th September 2017, he recovered the periodic comet 59P/Kearns-Kwee on its latest venture into the inner solar system. Bernd used Slooh's Half Metre telescope at the Institute of Astrophysics of the Canary Islands to capture the comet that was last observed [...]

### *It's astronomy, but is it stargazing?*

Observing online is a far cry from looking directly through our own telescopes. Once away from the light pollution of our major metropolises, South Africa's night sky quality stands alongside Namibia, the high Andean desert in Chile, and the Australian Outback as premier dark site locales. There is also our air quality: The output of sky-dimming emissions and dust in the entire southern hemisphere is less in total mass than that of Europe or Japan/Korea.

Even so, when it comes to the intangibles of observing — the world immediately around us and our telescopes, on-screen astronomy is simply no match for in-eyepiece astronomy. Out in the night, we feel as much as we see — the immense tremor of the sky filled with minute trembles from dazzle to feeble cannot be seen the way we see them by any other instrument than my eye.

The feel of the night zephyrs on the skin, the calls of nocturnal birds; moos and meows and b-a-a-a-hs; the frogs, the bats, the rustling grasses. The scents of damp or dry grass as different as the hues of Antares and Aldebaran. Spring is perfumed, summer smells like flax, autumn reminds us of damp mushrooms. Those homey touches do not accompany sitting in a chair at my computer watching the Carina Nebula glow in my laptop. Even if it is delivered to me from Chile, Trumpler 14 or Eta Carinae seems more a glitter than a dazzle. Nuance is everything in visual stargazing, and that does not go away merely because of the intercession of a few electrons in a silicon wafer.

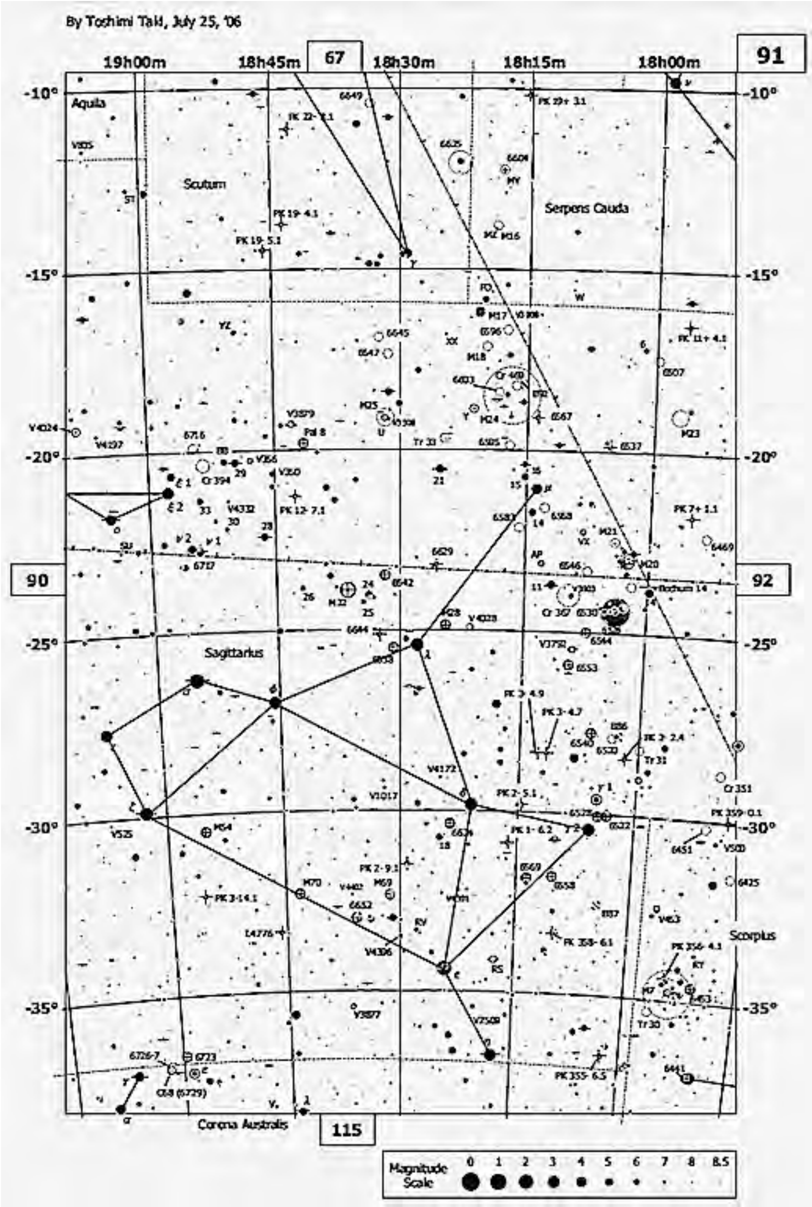
I feared the loss of those lovely glimpses which set my heart racing, that the *oohs* and *wows* and the siffle of my indrawn breath might never be heard again out there in the lonesome lightless Karoovian solitude.

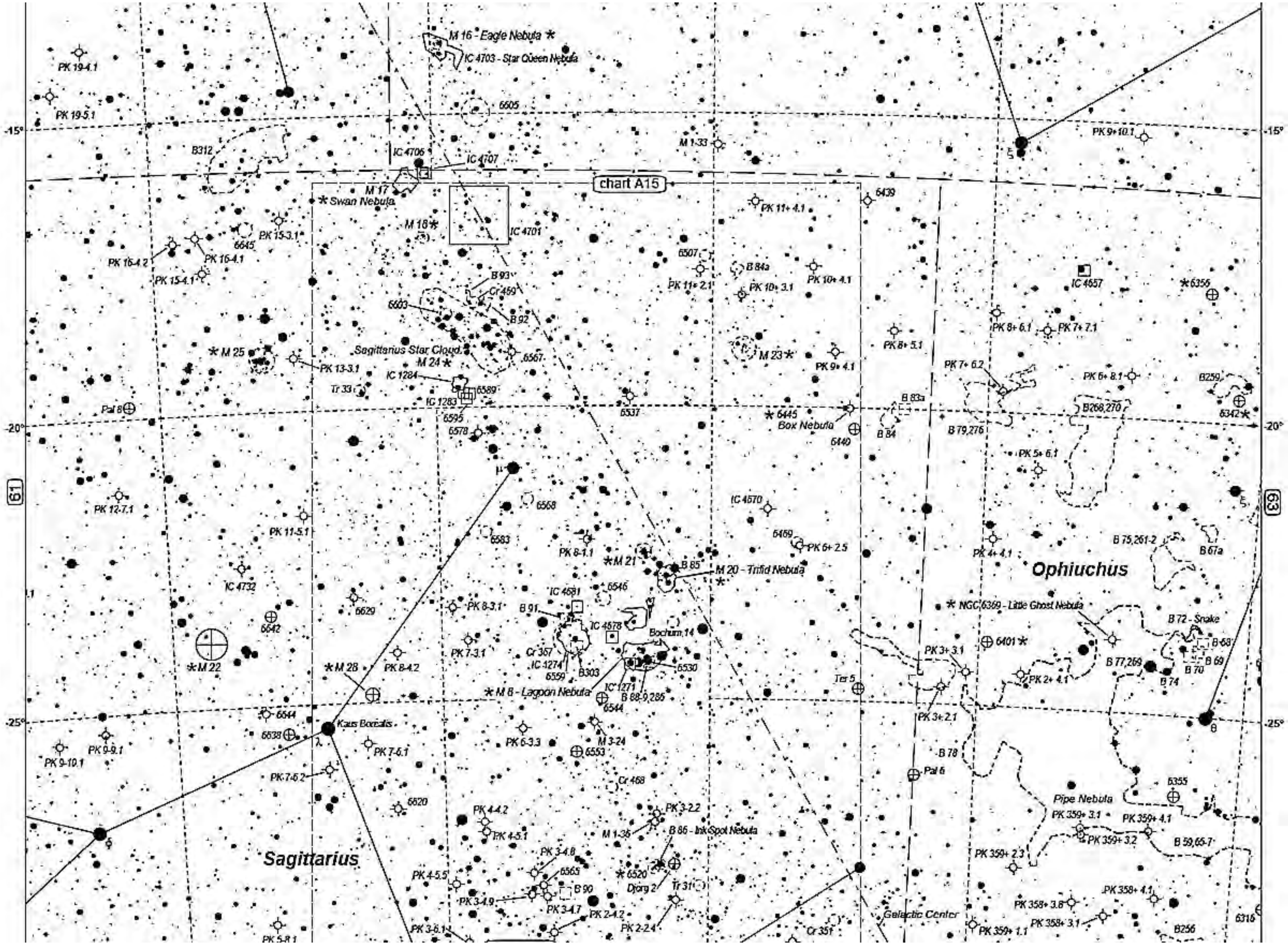
But the night I joined *Slooh* my skies were sodden to the ground. I came in from the *stoep* (verandah) feeling like an atom in the middle of a giant molecular cloud where it is utterly lightless and as cold as the Universe can get, 3 degrees K. Welcoming me on my screen was M81, glowing its nearly perfect hues of pale blue. It wears perhaps the most magisterial spiral garments the realm of the skies can weave. Without *Slooh*, I might never have observed it.

# Free Downloadable Sky Atlases

Tiny smartphone and tablet screens are not always the right cuppa tea when out at the eyepiece. The best dark sites in South Africa are often remote from Internet and cell phone coverage. And for non go-to equipped observers, large maps printed on old-fashioned paper gives a better feel for the sky than tiny numbers on a tiny screen.

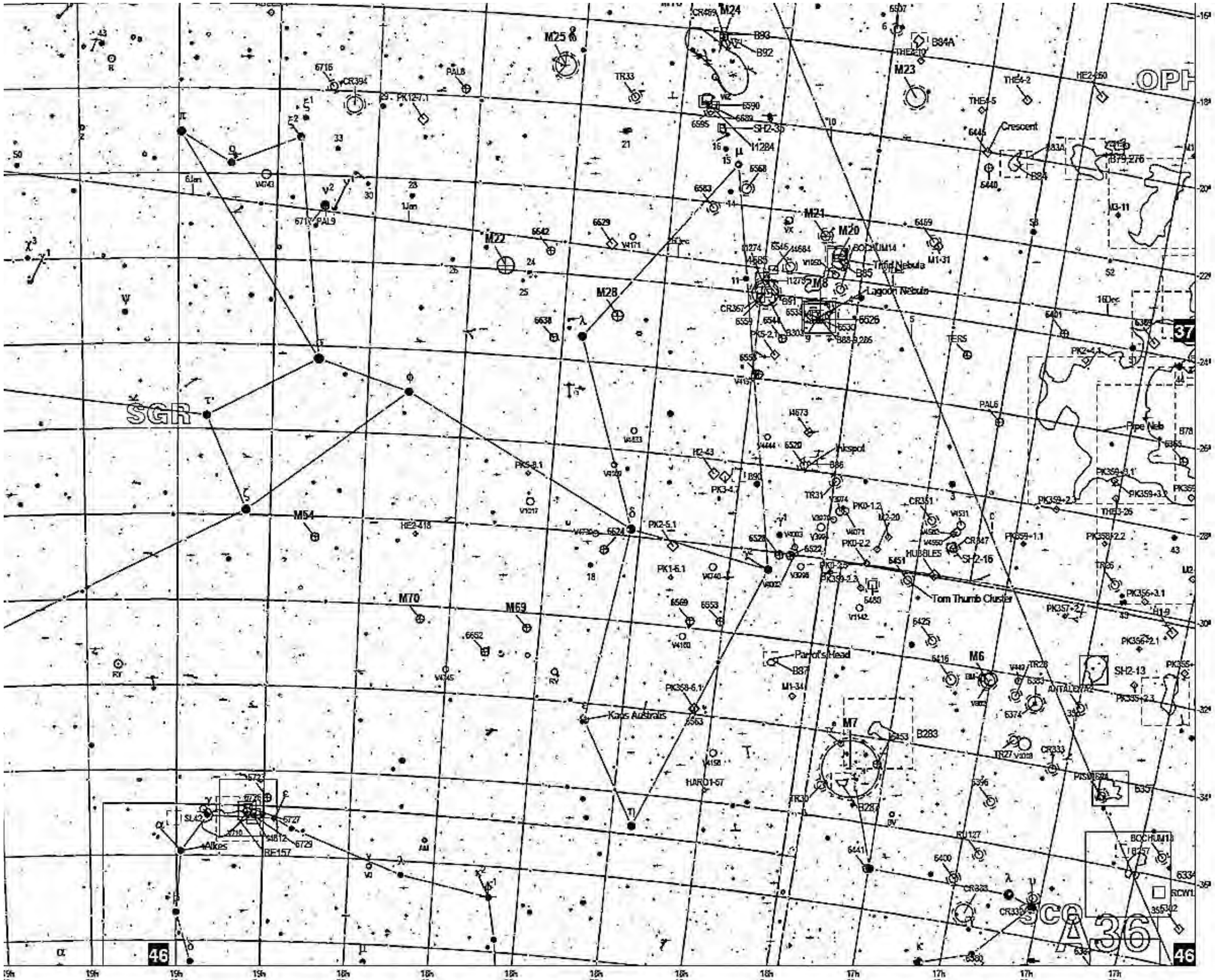
**Toshimi Taki's** [8.5 Magnitude Star Atlas] is everyone's starter set. Printed on A-4 paper and bound into a set, any observer with a scope up to 6 inches has everything to be seen right there in a handy volume. The page layout is very clean, with a generous amount of blank space around each map to serve as a ready-made Observing Notes scribble pad. It took me 5 years to yellow-highlight all the attainable DSOs in my viewing site. You can put it into a glass frame and mount it alongside your varsity diploma and finally call yourself a matric-ready astronomer.






***Michael Vlasov's*** chart set ***Deep Sky Hunter*** is very cleanly designed. It adopts smallish san-serif fonts in a condensed form to designate objects. Deep Sky Hunter makes sparing use of dotted lines to outline shapes. They are highly readable at telescope-side if one illuminates the page using a red bicyclists's lamp or small reddened flashlight. At 101 pages total, it was designed for A-3 paper and in eminently readable in that size. Stars to Mv 10.2 and DSOs to Mv 14. These specs make it a perfect field accessory for viewers with scopes up to 8 inches. Michael's website also has some very useful illustrated object lists to aid object identifying at the eyepiece, and NGC/DSO data spreadsheets that list visual mags, RA & Dec, object classification, and many observer's notes. Perfect for pre-session planning.

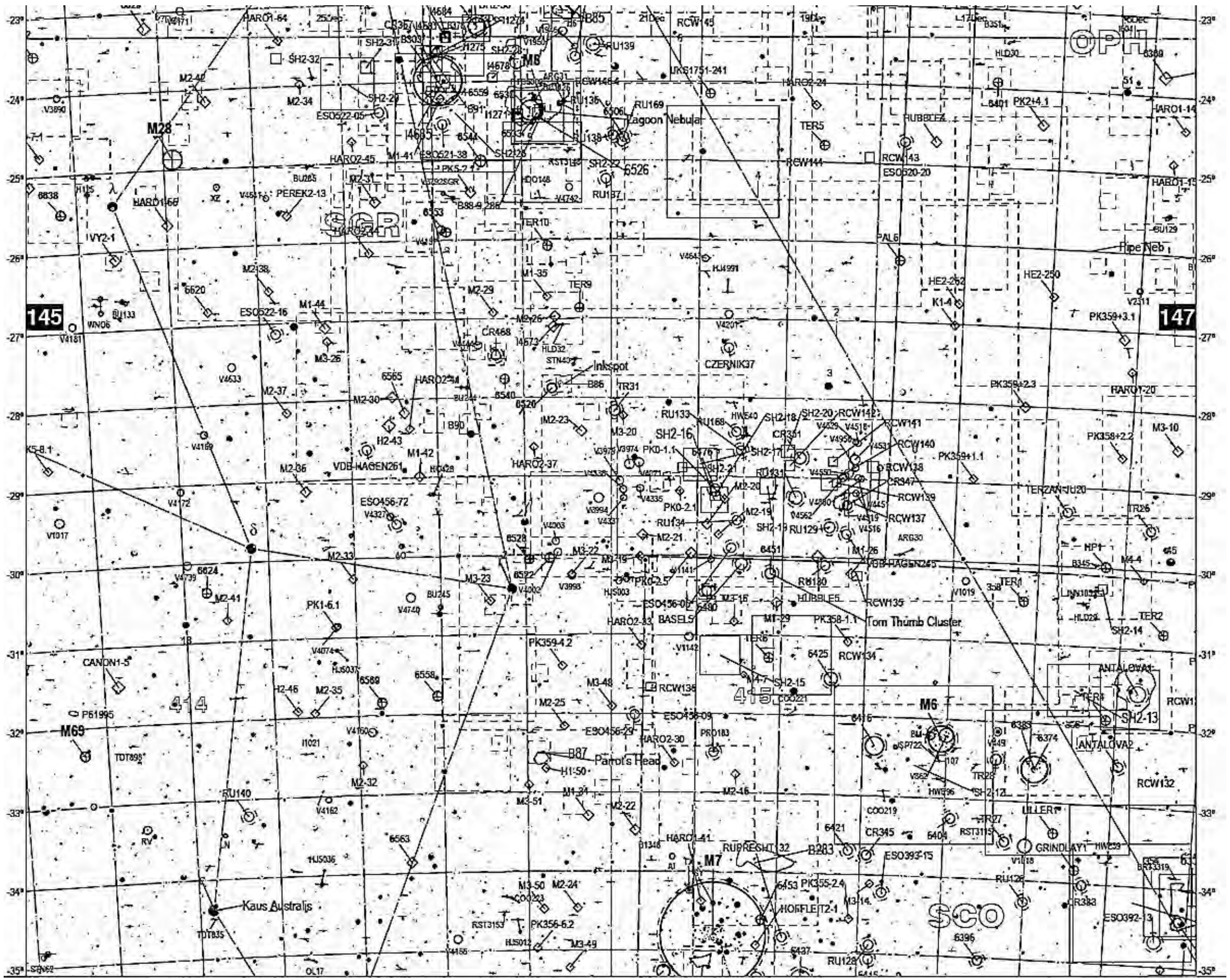
Michael has also prepared an invaluable set of PDF lists that any astronomer from beginner to old hand can use. See list at end of this article.




***José Torrès*** has distilled 30+ years of enthusiasm and mapping into three superb sky atlases, titled **TriAtlas A, B, & C.** These are top of the line in the world of free star atlases. All three are available as PDF downloads ***here*** (click on the "*TriAtlas Project*" link in the top right overbear).

***TriAtlas A*** comprises 25 charts covering 47° x 67° per map in the portrait format, stars to Mv 9.0; plus the Index chart which shows the sky boundaries of each chart.

All of José Torrès' charts reproduce beautifully in the oversize A-3 format. Bound on the side or end with a coil (not a comb!) and a thick plastic cover, these soon become the workhorse of most people's pre-observing track-down, and under-the-stars finder aids.




***Tri-Atlas B*** is 3 downloadable PDFs, ***1, 2, 3*** plus the ***Index)*** consisting of 107 charts covering 21° x 30° in the landscape format, stars to $M_V$ 11.0, DSOs to $M_V$ 13.0).

The TriAtlas B set is highly detailed, more suitable for the advanced observer who knows the sky well enough to not be confused by the many rectilinear boxes José uses to indicate the boundaries of bright emission nebulae and the dotted boxes that indicate dark clouds.

***Tri-Atlas C*** is a whopper, the largest printed sky atlas around; if pasted together it would fill a wall. Its 571 charts in the portrait format cover 12° x 8.5°, stars to $M_V$ 12.6, DSOs to $M_V$ 15.5. The ***Index chart is here*** but the 19 charts themselves are more easily downloaded directly from the web page.

The full *TriAtlas C* needs to be bound into three huge A-3 volumes to use as an indoor search set; out of doors users will find José's *TriAtlas* B set easier to work with.

## Other useful free downloadable guides from Michael Vlasov

***Illustrated Messier objects list*** — *thumbnail images of Messier objects sorted by name, with descriptions (PDF, 4.9MB, 7 pages).>*

***Illustrated NGC objects list*** — *thumbnail images of NGC objects (from 650 DSO list) sorted by name, with descriptions* (PDF, 15.7MB, 33 pages).

***Cover and Notes*** — *front cover page, notes, tag descriptions and copyright notices* (PDF, 290KB, 2 pages)

***List of 7000 DSO (name)*** — *list of 7000 objects from SAC database sorted by name* (PDF, 1.1MB, 109 pages).

***List of 7000 DSO (magnitude)*** — *list of 7000 objects sorted by magnitude* (PDF, 1.1MB, 109 pages).

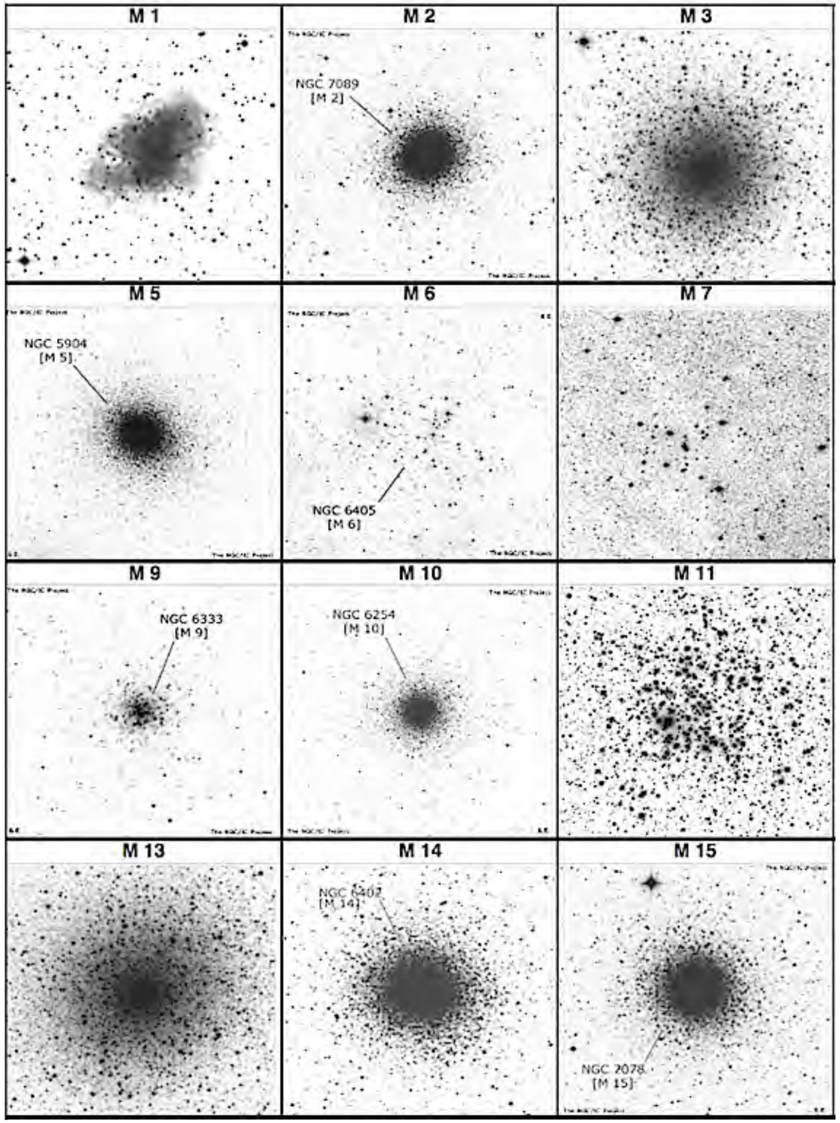
***List of 7000 DSO (const-mag)*** — *list of 7000 objects sorted by constellation and magnitude* (PDF, 1.1MB, 109 pages).

***List of best 650 DSO (const-mag)*** — *list of hand-picked best ~650 DSOs sorted by constellation and magnitude* (PDF, 120KB, 11 pages).

***List of best 650 DSO (name)*** — *list of hand-picked best ~650 DSOs sorted by name* (PDF, 120KB, 11 pages).

***List of best 650 DSO (const-name)*** — *list of hand-picked best ~650 DSOs sorted by constellation and name* (PDF, 120KB, 11 pages).

**All lists combined** ***in ZIP form*** — (ZIP file, 22.9MB, 8 files).




Sample of page from *Illustrated Messier Objects List*. Actual resolution in downloadable PDF if much sharper.

NGC 1300 barred spiral in Eridanus, Hubble Space Telescope

# Stargazing Tonight?

**Is it clear up there?**

**Oy, walked out the door,**

**looked up.**

**Stars !**

**No clouds !$^2$**

**Let's g - o - o - o   o    o !$^3$**

## FAQs

- *How long will it stay that way*?
- *Should I go shirtsleeves for the night or bundle up a bit*?
- *The stars looked a little wobbly,* so *will I see pinponts or slobs*?
- *What is that satellite passing over?*
- *How do I find the satellites above me on my Android phone?* (If that fizzles, *try this one*. Jump through all the hoops, then go outside and point the thing at the first moving dot.
- *That airliner, too*; I wonder who could be on it and where they're going? (Slide the screen over till it's above your locale.)
- When will *The Moon rise or set*? (also check *IceInSpace*)

OK, the scope is set up and cooling down. Is the observing table stocked and ready? Observing table is all arranged like I want it?

## Now, while we let our eyes dark adapt . . .

*How far away* are the objects I see?
*How old are they?*
*Is it the same everywhere as it looks from here*?

## Online Catalogs to Help You Find Things

*ASSA Top 100 Observing List*
Alvin Huey's *Downloadable Observing Guides*
Alvin Huey's *Printed Observing Guides* (spiral or coil bound)
Alvin Huey, *Herschel 400 Observing Guide I* (downloadable PDF)
Alvin Huey, *Herschel 400 Observing Guide II* (downloadable PDF)
Alvin Huey, *Herschel 300 Observing Guide III* (downloadable PDF)

## Sharpless emission nebulae & SNRs

Stewart Sharpless, *A Catalogue of H II Regions*, 1959.
*Life & Work of Stuart Sharpless*
*Sharpless Catalogue by Reiner Vogel*, fully illustrated with positions & observing notes.
Dean Salman's *Best of the Sharpless Catalogues*.

## Young Stellar Objects (YSOs) and Herbig-Haro Objects

*Rainer Vogel*, Hubble's Variable Nebula and NGHC 1999 Orion.

## Wolf-Rayet expansion shells

Reiner Vogel, *Wolf-Rayet Shells* with analyses by *Lionel Mulato*.
Agnès Acker, *Nebulueses autour d-etoiles Wolf-Rayet*, *l'Astronomie* 2015.

## Dark Nebulae & Barnard Objects

Edward Emerson Barnard, *A Photographic Atlas of Selected Regions of the Milky Way*, Carnegie institution of Washington, 1927 (lists citations only, see *A-J 41, I-24 1919* and *Mikkel Steine's messier45.com* for versions with images and text).

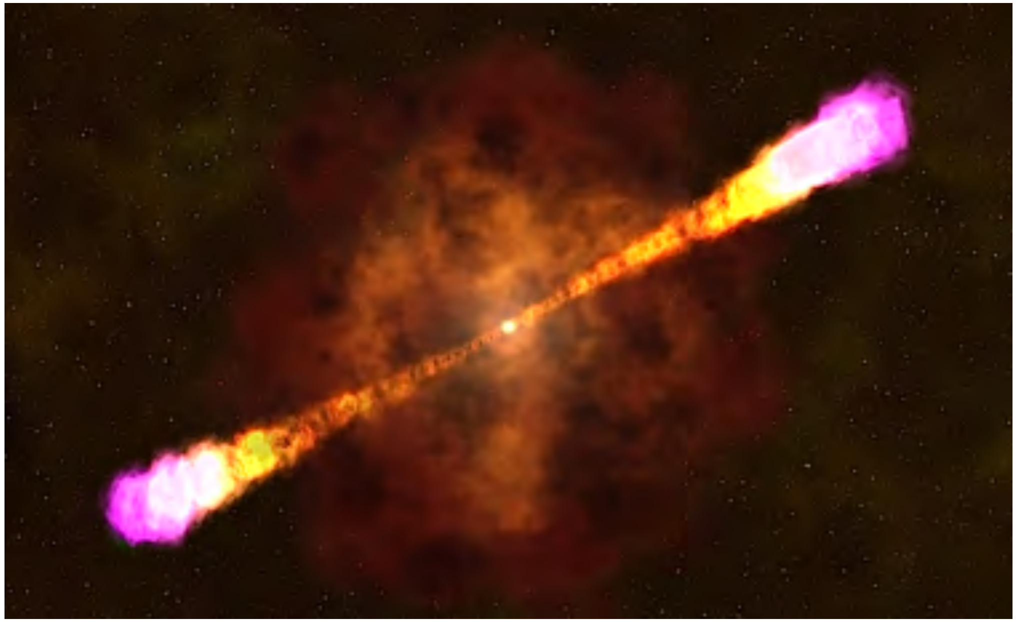
## Galactic Cirrus & Integrated Flux Nebulae

Steve Mandel, *Unexplored Nebulae Project*
Lynds *Catalogue of Dark Nebulae*, Astrophysical Journal Supplement, vol. 7, p.1, 1962. Beverly Lynds' list of 1802 dark nebula N of –33° compiled from the National Geographic-Palomar Sky Atlas (POSS).

## Catalogs of Catalogues

SEDS *List of Common Deep Sky Catalogs* (many links)
*Deep Sky Catalogues,* last edited Sept 2015 by SkyNomad
Danilo Pivato, *List of Astronomical Catalogues - Nomenclature, Acronyms & Abbreviations* (last update Apr 2016)

**NASA** *Collection of Weird HI Galaxies*. Too good to pass by.



Gamma-ray burst GRB 130427A. In April 2013 a blast of light from a dying star in a distant galaxy became one of the brightest ever seen. Source: NASA.

## Amateur radio astronomy

*What, actually, are we talking about here?*

*Beginner's Introduction to Radio Astronomy*

*Society for Amateur Radio Astronomy*

*Amateur Radio Astronomy Projets*

*Galaxy Zoo Forum: Build a Radio Telescope*

*Starter Kit for Amateur Radio Astronomy*

*Mike Brown's Build a Radio Telescope At Home*

*How to Build a Radio Telescope*

*An affordable everyday radio telescope*

*Is It Possible to Build a DIY Radio Telescope?*

*For the well-heeled: Commercial vendor: SPIDER 300A - Advanced radio telescope*

*AARL (USA) National Association for Amateur Radio (mainly HAM enthusiasts, but contains radio astronomy guides, too.)*

***The Three Hills Observatory*** equipment consists of a Ku band (approx 12GHz) analogue satellite TV setup with an offset fed 750x850mm elliptical dish. The dish is Alt Az mounted on a photographic tripod. Note the counterbalance weight added to balance the dish. The receiver is an inexpensive "satellite finder" meter. (The satellite receiver is just used to supply 18v power to the LNB and satellite finder.) The meter has an audible output with the sounder voltage varying with the signal shown on the meter. This signal was disconnected from the sounder and fed to a digital multimeter which has a serial PC interface to log the signal.

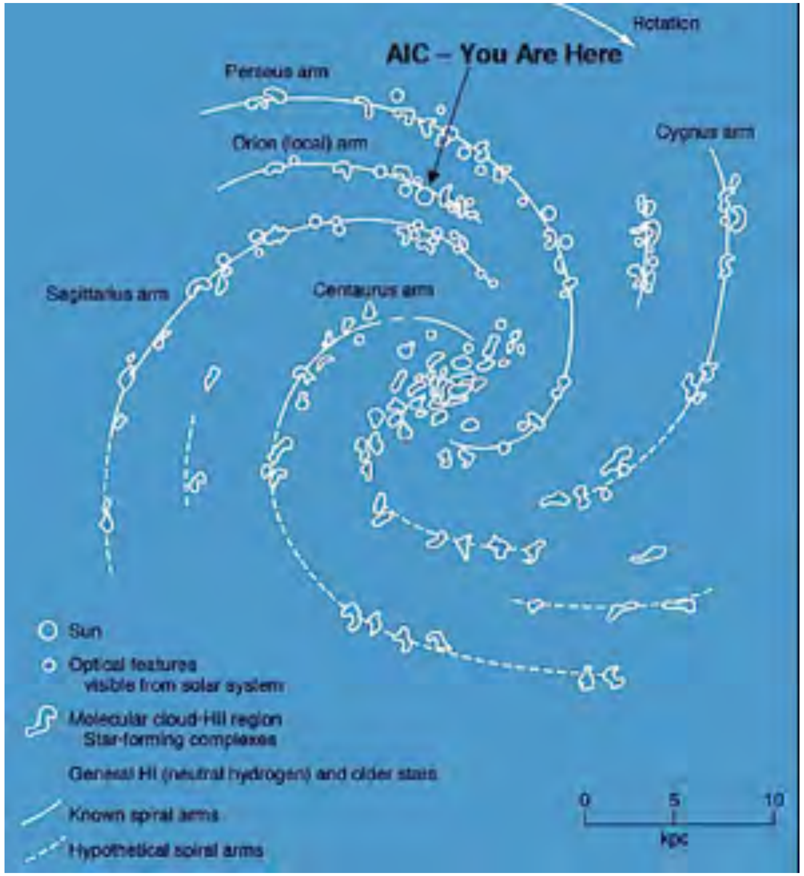
*FIRST LIGHT* 20th December 2007: The setup proved easily capable of detecting the different levels of radio flux from the frozen ground at approximately 273 deg K and the cold sky at the zenith (~5 deg K ?). A person standing in the beam 2m away from the dish also produced a good signal (this signal was less than the ground signal as the dish was not fully illuminated) The satellite finder bandwidth is very wide (over 1GHz) which means that any Ku band transmissions in the beam will be picked up. Geostationary satellites are easily avoided by aiming the dish at a vacant part of the sky. Moving sources (eg other satellites, planes) pose a problem however as do trees, rooftops, overhead wires etc which all produce a thermal signal.

## Source Catalogues for the Open Clusters we like most

**About 2100 galactic open clusters are known. Most of them have been observed in at least one of the five commonly used photometric systems. The number of stars per cluster ranges from several thousands for the most prominent clusters down to as few as a dozen stars for the poorest clusters.**

***Wiki has a nice list*** in the "Best & Brightest" style. It's a crossover list, some GCs are included. Each cluster number has a link to a more detailed Wiki page about the cluster. A good example is ***Hodge 301*** in the LMC. It is part of the same massive ***Tarantula Nebula*** star-forming complex but is offset several arc minutes from the super-massive R136 cluster at the heart of the Tarantula.

The ***Open Clusters and Galactic Structure*** catalog was compiled and then systematised data from numerous other catalogues, particularly the "Big Four": proper motion, radial velocity, distance, and age.



Low-resolution chart of some Milky Way giant molecular clouds; all are potential star-formation sites. Many more smaller ones are known to exist.

**Bruno Alessi**, ***Open Clusters and Galactic Structure.*** (Also **1**, **2**). Alessi succinctly states the case for observing open cluster in the lead-off paragraphs of the website above: "The open cluster system is of great value for the study of The Galaxy dynamics, because they span a relatively wide range of ages, that can be determined with more precision than any other spiral arm tracer. They are the key objects to understand the motion of spiral arms and moving groups of stars, to derive the rotation curve and distinguish between star formation processes."

**Jack Bennett** (1960s), ***Bennett Catalogue.*** Although christened John Caister Bennett, he was known to all as Jack. His modest list of 85 cometary imposters was born in the spirit of Charles Messier. He pounced on an amazing array of objects given that his primary telescope was a 5-inch refractor at 21x mounted on an undriven alt-azimuth mount. With this he discovered the first supernova since the telescope was invented. He was the veritable model of the meticulous log-keeper. He reported having spent 815 hours fighting off dew, mozzies, and bats, all for the sake of fuzzy bits in an eyepiece. As eccentricities go, Jack Bennett was well ahead of everyone else. So is astronomy, come to think of it.

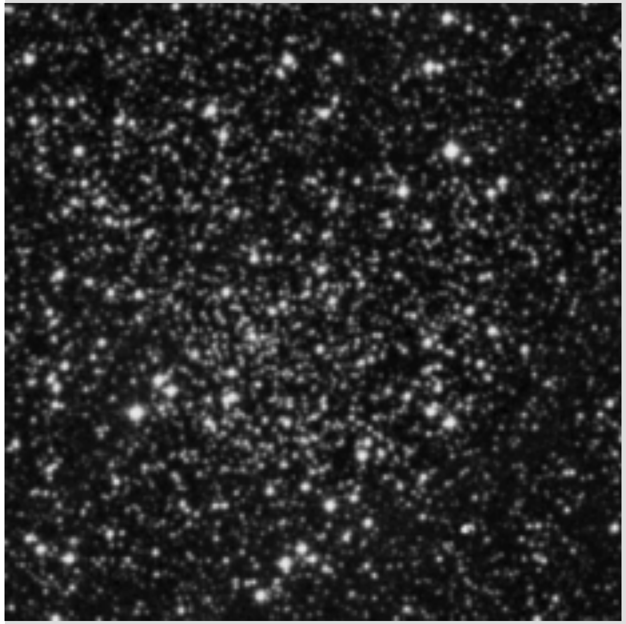
***Berkeley Open Cluster Catalogue*****,** compiled by Gosta Lyngå 1979, 90 open clusters numbered between 1 and 104, original source: Alter, G.; Ruprecht, J.; Vanýsek, V. ***Catalogue of star clusters and associations***, Prague, Pub. House of the Czechoslovak Academy of Sciences, 1958. **Sydney van den Bergh 2006**, ***Diameters of Open Star Clusters***, A-J v131, No.3.

***Abbe Nicholas Louis de la Caille*** (1750s) was the first observer to systematically catalog the entire southern sky. A remarkable achievement in itself, which morphs into an astonishment when we consider his optical aid, a tube about 25 cm long with an objective lens 13 mm in diameter and magnification of 25x. That is only about 4 times the light-gathering power of the naked eye. ASSA's own Auke Slotegraaf laboriously put together a small sampler list available free ***here*** and in spreadsheet form ***here.***

***Caldwell Catalog***, 109 mostly Northern objects compiled by Patrick Moore as an additional challenge list to the Messier Objects.

**Per Collinder 1931**, *Catalogue of Open Galactic Clusters*, 471 clusters listed by 16 classification parameters, with second non-tabular observational and original sources. Source plates were Franklin-Adams (1953).

**Anton Czernik 1966**, *New Catalog of Clusters*. The source paper is an *Acta Astronomica* paper from Czechoslovakia available only in PDF.

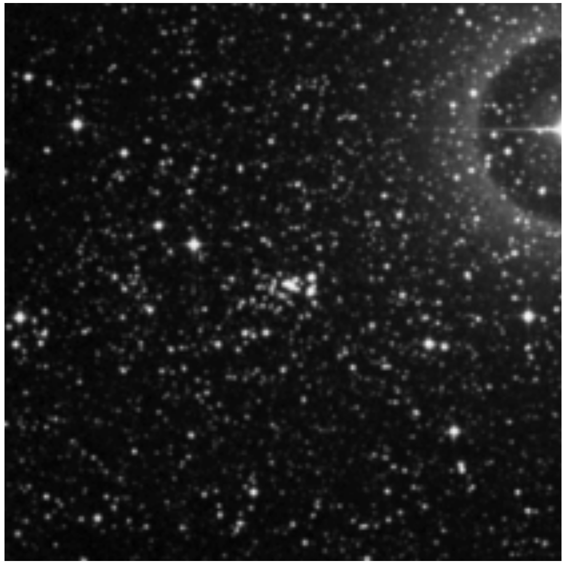


Collinder 261 (Harvard 6) Musca is the Southern Hemisphere skies' oldest open cluster, at *log* 9.95 or 8.9 billion years. It has managed to survive so long because, like the Sun, it lies near the Milky Way's co-rotation radius, where stars circling the Milky Way core travel at nearly the same velocity as the spiral arm density wave travels in the same direction. The result is a net forward velocity shear of nearly zero. Collinder 261 also enjoys a position of considerable distance from the centreline of the Galactic disc, at Galactic latitude of –5.528° or 1,800 light years removed from the nonstop torque and shear of daily life in the middle of our Galaxy.

Czernik's paper gives some source information, but beyond his mention of them as being "faint" he does not mention why the catalog was prepared. SIMBAD lists the 45 Czernik clusters on an ***HTML linked fully researchabe database here***.

***James Dunlop*** 1826. Downloadable PDF of the cluster numbers and the Dunlop story ***here.*** There's a fine article about the Dunlop clusters by James Cozens, ***James Dunlop's Historical Catalog of Nebulae and Clusters*****.** This is a long article about the errors and inadequacies of James Dunlop's 1826 catalog. It also reproduces the original catalog.

Star forming region in the Small Magellanic Cloud in infrared light from the Herschel Space Observatory and the Spitzer Space Telescope. The image was coloured to show different dust temperatures. The coldest objects appear in red, corresponding to infrared light at 250 microns, or millionths of a meter. Herschel's Photodetector Array Camera and Spectrometer fill out the green mid-temperature bands at 100 and 160 microns. Warm regions in blue are from the Spitzer telescope's 24- and 70-micron data. *Source*: NASA.



Hogg 15 lies on the near side side of the Coal Sack dark nebula at 2262 parsec (7375 lyr). At 5.88 million years of age Hogg 15 has expelled its natal gas and is about to undergo its first core-contraction cycle. It will slowly dissolve into the spiral medium in 15 to 20 million years.

Since many of the object positions were erroneous or the objects averted imagination, the Dunlop Catalog s better seen as a reference tool than a list to chase after.

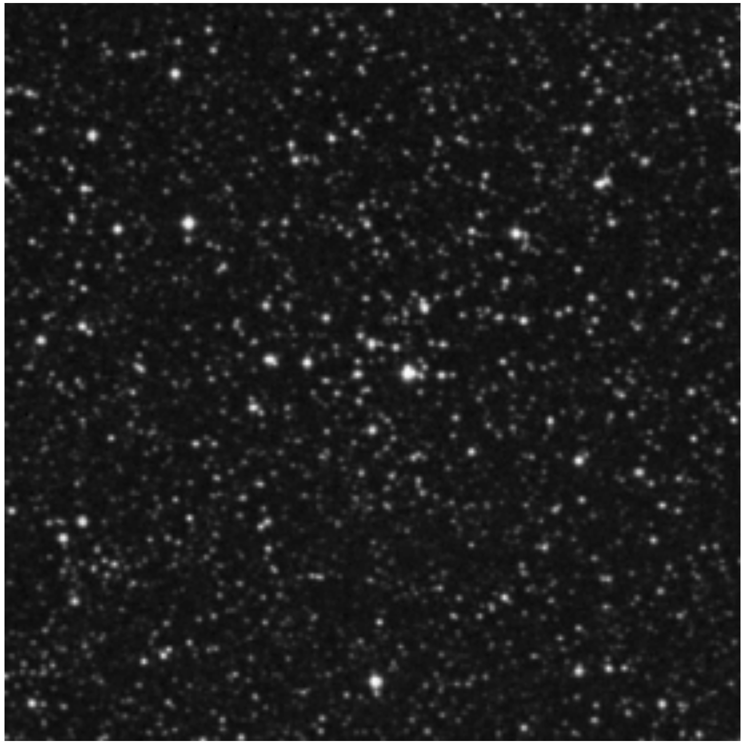
***Harvard Catalogue***, WEBDA lists 6 out of the 21 Harvard open clusters compiled in 1930 by Harlow Shapely. Half of the clusters are not listed in any other prior catalog. Harvard clusters are generally faint and sparse. Harvard 3 has absconded somewhere. If you find it, let us know. For southern observers, Harvard 6 in Musca (also Collinder 261) is the oldest open cluster (8.89 Gyr) in the Southern Hemisphere. It can be seen in dark skies using a pair of binoculars, but requires 8 inches aperture and very dark skies for its brightest stars at $M_v$ 14.8.

**Haffner** clusters are much studied because they are mostly over 1 billion years old and in advanced states of dissolution into the Galactic medium. Rather little is known about their catalog compiler Hubert Haffner. His original paper containing the classifications is in the German-language *Zeitschr. Astrophys*., 43, 89-94 (1957), "Neue galaktische Sternhaufen in der sudlichen Milchstrasse". If you are rather more keen on just having a squizz (look) at them, *WEBDA* lists the positions and data for 23, all of which are faint and rather high in the Galactic plane due to disc heating processes that tend to ease old star clusters ever outward into the disc from the centreline where most clusters are born. If you want to know more you can search for individual Haffners by typing the cluster name into the search box on SIMBAD.

**Hogg** star clusters were catalogued by Helen Sawyer Hogg during her research into the variable stars in the Large Magellanic Clouds. It was this research that led her to discover the period-luminosity relationship of variables whose light curves ascended rather sharply but descended more slowly. The progenitor of λ Cephei prompted these stars to be named Cepheid Variables. Hogg's discovery was one of astronomy's most important. It enabled astronomers to more precisely estimate the distances of stars. *WEBDA* lists all 23 of them.

**Jim Kaler**, ***Open Clusters Visible to the Naked Eye*** (includes three globulars).

**Kharchenko et al 2013, *Global Survey of Star Clusters in the Milky Way***, the most complete source of astrophysical data thus far and a substantial improvement over previous catalogs based on Hipparchos & Tycho data. Not for the faint-hearted. Lists 3784 objects surveyed, 3006 confirmed. Individual star data from 2MASS, PPMXL, USNO-B1.0, & ICRS, to $M_v$ 20.0, Padova stellar models w/ *J H K* isochrone fits. Also lists 142 GCs, 19 moving groups, 21 associations, 221 cluster



King 26 in DSS image on *WEBDA* website.

remnants. Most proper motions in mas/yr.

**King** *WEBDA* lists all 26 of them. King 17, 18, 20, 23, 26 were recently studied for the first time by *A.L. Tadross.*

**Loden** *WEBDA lists 54* of the over 2300 clusters identified with the Loden name. (Many of these WEBDA don't connect to supporting data; it's push the little mouse button and hope for the best. And once you do get to a Loden, they are ferociously hard to identify on the basis of photo image — and not a great deal easier at the eyepiece. Loden clusters are for that rare soul, the passionate cluster collector with the patience of a saint, endurance of a tardigrave, and eyes of an owl.

**Melotte** ***Catalogue of Star Clusters shown on Franklin-Adams Chart Plates*** contains both open clusters and globular clusters. The English amateur astronomer John Franklin-Adams (1843–1912) created an early photographic atlas of the sky, based on plates taken at Johannesburg, South Africa, and in England, published 1913–1914 by P. J. Melotte. 206 charts 15° square each with stars to $M_v$ 17, covering the entire sky.

**J. Ruprecht (1963),** ***Classification of Open Star Clusters*** (to $M_v$ 20.3 based on the POSS blue plates; images S of –12° were taken with the 10" f/12 Metcalf refractor. Czech astronomer Jaroslav Ruprecht published a definitive list of OB associations compiled from several observatories, all classified following the Trumpler system; 852 true open clusters with 116 not definitively bound systems.

**Stock** (clusters 1 & 2, 1956), (3 to 23, 1959), (24, 1970). In the early 1960s the German astronomer Jürgen Stock was asked by the university of Chicago to test sites in Chile for for astronomical telescope suitability. Stock already had published two lists of 23 sparse star clusters he had identified in papers on photographic photometry of open clusters and stars in the North Polar Sequence. His three-years of searching eventuated in today's array of the world's largest astronomical instruments being constructed in Chile. He also discovered ***three minor planets now named after him***, (4388) Jurgenstock = 1964 VE = 1982 UA = 1999 LG.

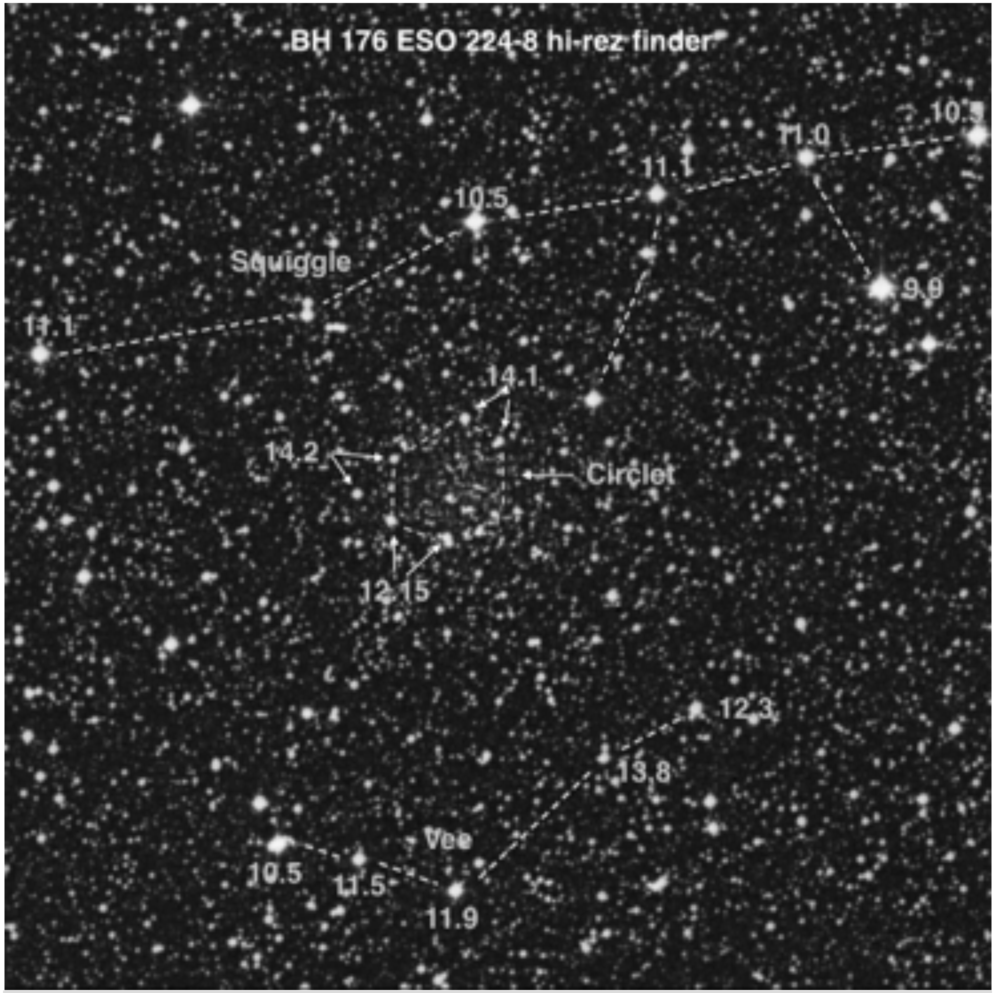
**Clyde Tombaugh (*1938* and *1942*)** of Pluto fame discovered 5 loose aggregations that were eventually shown to be bound clusters while he was using the photographic plates from the 13" Lawrence Lowell astrograph. The modern observer/writer Max Radloff wrote a report on the Tombaugh clusters in the now-defunct Deep Sky Magazine in Dec. 1990/91. There is also a ***Google Group*** for the Tombaugh objects.

***Trümpler*** Born in Switzerland, Robert Trümpler emigrated to the United States in 1915. Trümpler used telescopes at the Allegheny (Pennsylvania) and Lick observatories (California) to discover that the brightness of distant open clusters was lower than expected. He suspected this dimming was caused by interstellar dust, even the reality and chemistry of cosmic dust was not commonly understood. His 1930 analysis of 334 open star clusters included 37 that were not previously listed at that time. These 37 bear the Trümpler name. Trümpler's system of classifying star clusters is still used today. For Southern observers, Trumpler 14 in the Carina Nebula is one of the most dazzling in the sky. Appearing very compact, it contains over 2,000 stars weighing about 4,300 M . Its brightest star HD 93129AB (the AB means it is a spectroscopic binary) is the most luminous star known in the Milky Way, radiating a fearsome 1.3 million times the luminosity of the Sun from a surface temperature of 53,000 K.

***vdB–Ha*** (S. van den Bergh – G.L. Hagen), Uniform survey of clusters in the Southern Milky Way, 1975. (*See image of VdB-176 Norma at right.*)

## Globular Cluster Catalogs

Alvin Huey free downloadable PDF ***Globular Clusters***.
The original 13 ***Palomar globular clusters*** were first identified on Palomar Observatory Sky Survey (POSS) plates by George Abell in the 1950s. They got their Palomar name (and soon nicknamed Pal globulars) by Helen Sawyer Hogg. The final two, Pal 14 and Pal 15, were added later.




One of the more challenging van den Bergh-Hagen) clusters is VdB-Ha 176 (in SIMBAD *ESO 224-8*) an open cluster in Norma. Highly reddened, its large population of >$M_V$ 14 stars led to its being classified as a globular for a time. Stellar dispersion studies showed it to be an ancient open cluster in a state of slow diffusion into the Galactic medium. Nightfall writer Dana De Zoysa has published detailed articles about this cluster *here* and *here.*

## Planetary Nebula Catalogs

***The Planetary Nebulae*** from Jim Kaler's ***Stars***.
Reiner Vogel, ***Large Planetaries Observing Guide***.
Reiner Vogel, ***Proto PN Observing Guide***.
Reiner Vogel, ***Abell Planetaries Observing Guide***.
George Abell, description of 86 objects in ApJ 04-1966, ***Properties of Some Old Planetary Nebulae***. See also Globular Clusters and Planetary Nebulae Discovered on the National Geographic Society-Palomar Observatory Sky Survey (POSS).
George Abell, Publ.Astro.Soc.Pacific 08-1955, ***GCs & PNs discovered on POSS plates***.

## Dwarf Galaxy Catalogs

Alvin Huey free downloadable PDF ***The Local Group***.
Sydney van den Bergh, ***Luminosity classifications of dwarf galaxies***.

## Hickson Galaxy Groups

Paul Hickson, ApJ 04-1982, ***Systematic properties of compact groups of galaxies***.
Paul Hickson, A&A 00-1997, ***Compact Groups of Galaxies***.
Paul Hickson's ***webpage***.
Reiner Vogel, ***Hickson Catalog of Compact Groups of Galaxies***.
Gottlieb & Shields, ***32 Interesting Hickson Groups***.

## Abell Galaxy Clusters

Alvin Huey, ***Abell Galaxy Clusters*** (free downloadable PDF).

The ghostly sphere of *Abell 39 in Hercules* (PN A66 39) is thought to be one of the most perfect planetary nebulae in the sky. It's even boundary testifies to the very low, homogenous underdense interstellar medium in its 2.5 light year radius. The nebula's Galactic coordinates tell us why: at 047.0517 +42.4827, it is very high above the Galactic plane, at 6.8 ly away, will up into the thin medium of the Galactic halo. Halo stars are very old, in keeping with Abell 39's estimated mass of about the same as the Sun when it finally shed the last of its atmosphere into this shell. The white dwarf core star visible in the centre is $M_V$ 15.6. The shell's integrated magnitude is 13.7. At only 2 arcmins dia, good luck spotting it.

## From our mates at IceInSpace in Oz:

**John Bambury** has created his BAM600, a variation on the Herschel 400 compiled especially for southern-skies observers.

**Stephen Saber** has a ***list of 110 doubles*** accessible with a 6-inch.

**Glen Cozens** has a ***150 Dunlops list***.

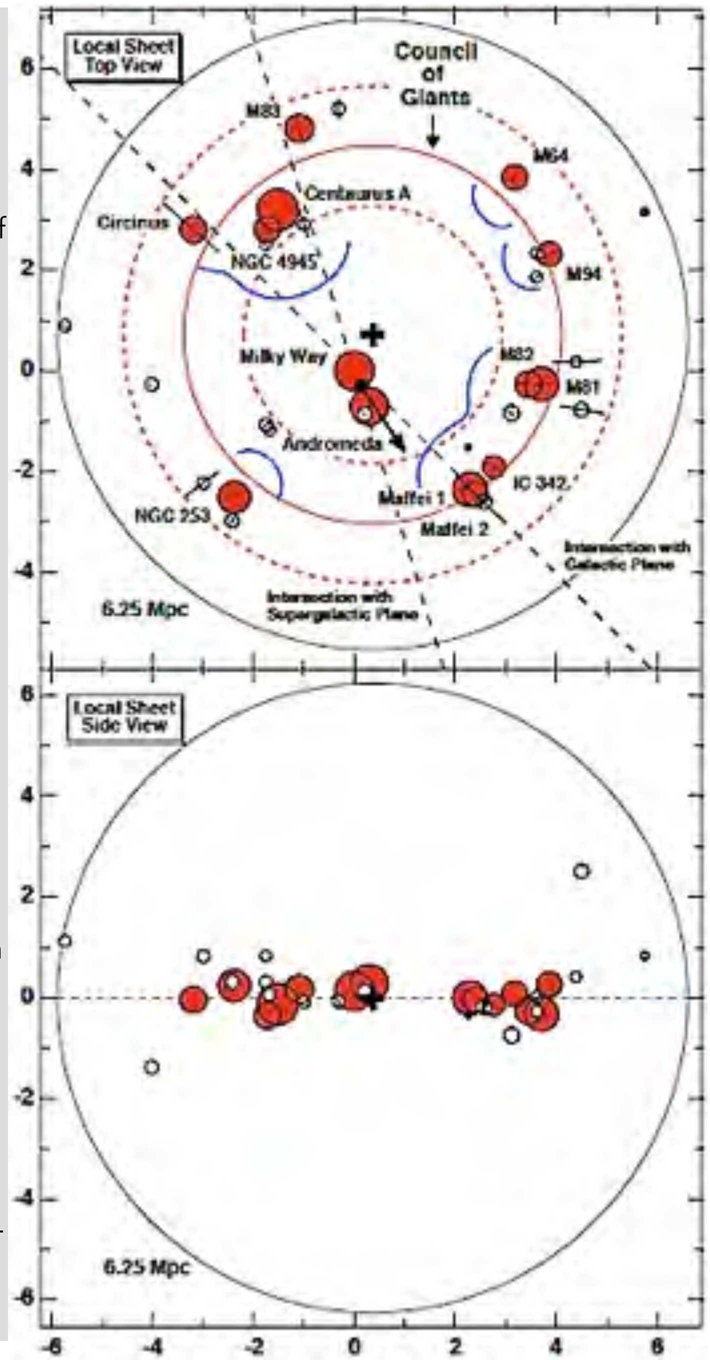
**Paul Mayo** has a ***100 Brightest Galaxies for Southern Observers list***.

**Ian Cooper** has a wonderful ***hirez SMC chart*** detailed enough to list even the SMC's hardly-ever-observed GC & YMCs cluster L1 & L2 below 47 Tuc and L113 in the middle of the SMC's quadrant of SE Nowhere. **Excel spreadsheet of 235 SMC objects.**

**Patrick Cavanaugh** has a magnificent set of ***14 LMC and SMC hirez photo charts*** with object IDs, plus another zip file of observing notes.

***The Council of Giants***

Tracking down the galaxies in the image on the right can be the hobbyist astronomer's first foray into visualising galaxies visible in a 6 or 8 inch telescope as part of a much larger structure than our familiar Local Group (LG) of the Milky Way / M31 Andromeda / M33 Triangulum neighbourhood. The LG is in fact a small part of the next larger cosmic structure, the Local Sheet. The Canadian Astronomer Marshall McCall colourfully rebadged the Local Sheet as the "Council of Giants" after the way small seedlings grow up in a circle around a giant redwood or sequoia tree. When the grand old giant dies, the small ones then grow to giants themselves, hence the "Council" name. In 2014 McCall published an analysis of how the Council itself is but a small part of a much larger structure called the Local Volume. Many such 100 megaparsec-scale structures in turn are but strands on a thread that merges into a common stream flowing toward the Virgo Supercluster. The universe is a gigantic web of such filaments, sheets, and walls, separated from each other by enormous voids which are nearly empty of matter. None of these assemblies is static: they are like huge rivers, constantly changing their courses, merging new tributaries, spreading into wide aprons. The physical laws governing large scale structure are very different from motions inside our own galaxy. More here: *1, 2, 3, 4, 5, 6*.



## *A bit more technical . . .*

***Openstax.org*** is a repository of varsity-level textbooks available for free and totally legal under the auspices the ***Creative Commons Licence***. You can even preview them by clicking on a specific title's box. Give their ***Astronomy*** textbook a click.

## Stars

Jim Kaler, ***The Natures of the Stars***
The ***Morgan-Keeler Catalog of 1943***

## Spectroscopy

Visual starlight tells us what an object looks like. The object's spectrum tells us what it is—and much, much more. We can deduce what the object has been and will become, and what will be the object's effects on its surroundings.

Spectroscopy is no piece of cake; it's the most demanding of the non-mathematical aspects of astronomy. You can stick your toe in the water with **Richard Walker & Marc Trypsteen**'s ***Twin Book Project, Astronomical Spectroscopy***. It's a beginner's guide for advanced amateurs with a yen for physics.

***Astronomical Spectroscopy*** (a website of links to numerous other resources)

***The Spectra of Stars on the Hertzspring-Russell Diagram***

The distant galaxy cluster MACS J0717 as seen in diffuse blue of light emitted by gas at millions of degrees (Chandra X-ray Observatory). The diffuse pink colour is from gas excited by shock waves and turbulence (Jansky Very Large Array in New Mexico USA). Source: NASA, ESA, CXC, NRAO/AUI/NSF, STScI.

**Jim Kaler, *Spectra*.** The splash screen shows a box with 30 rectangles, each with a property about spectra inside. Click on any box and the page opens to a long list of all 30 topics, with the topic you clicked on art the top of the page.

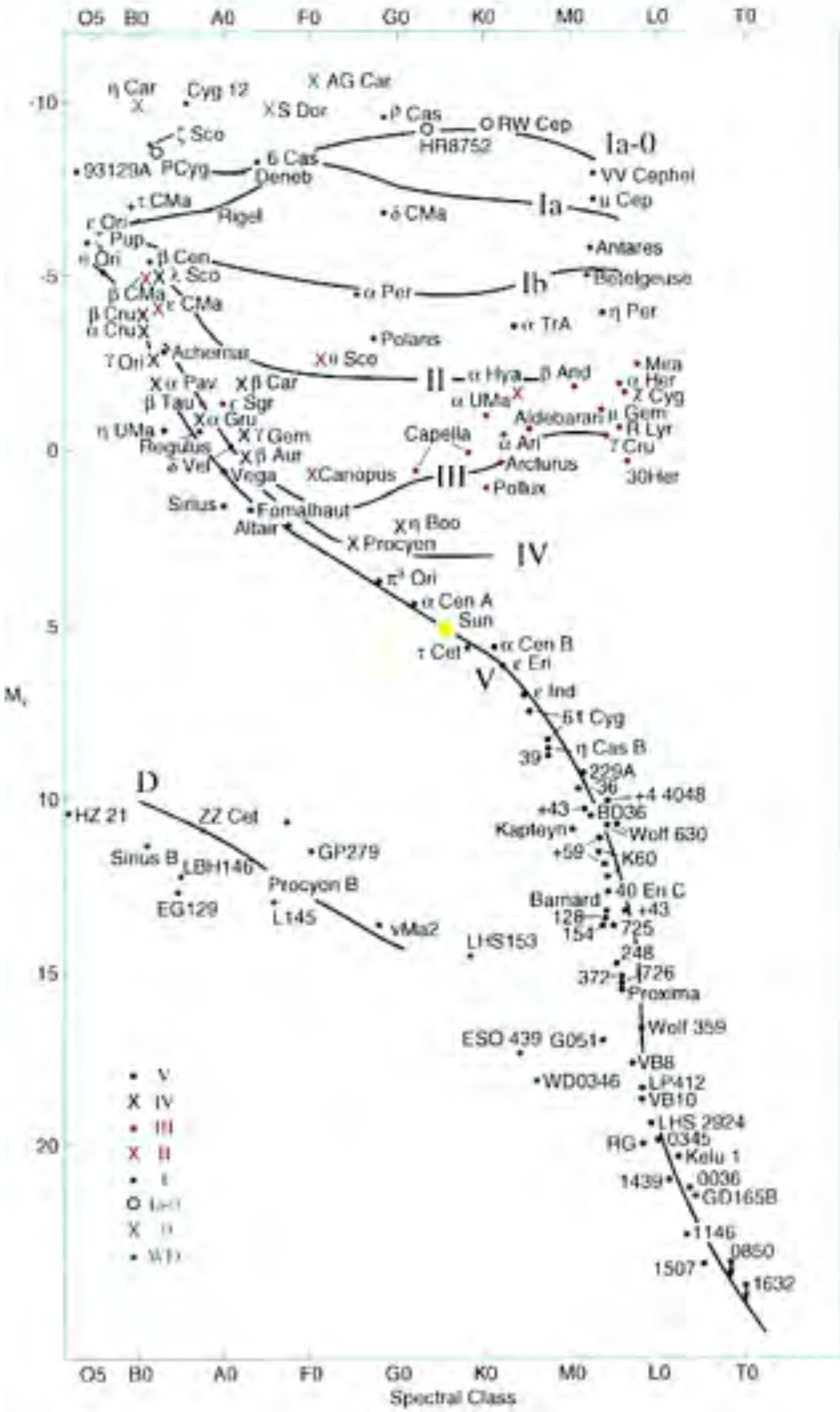
There is a broad overview of the subject from ***Cloudy Nights***, one of the online astro-forums for amateur astronomers.

- ***Richard Walker*** has produced two superb technical guides: ***Spectroscopy for Amateur Astronomers*** (equipment and methods of spectroscopy)
- ***Spectral Atlas for Amateur Astronomers*** an illustrated guide to what spectrograms reveal about stars and other objects.

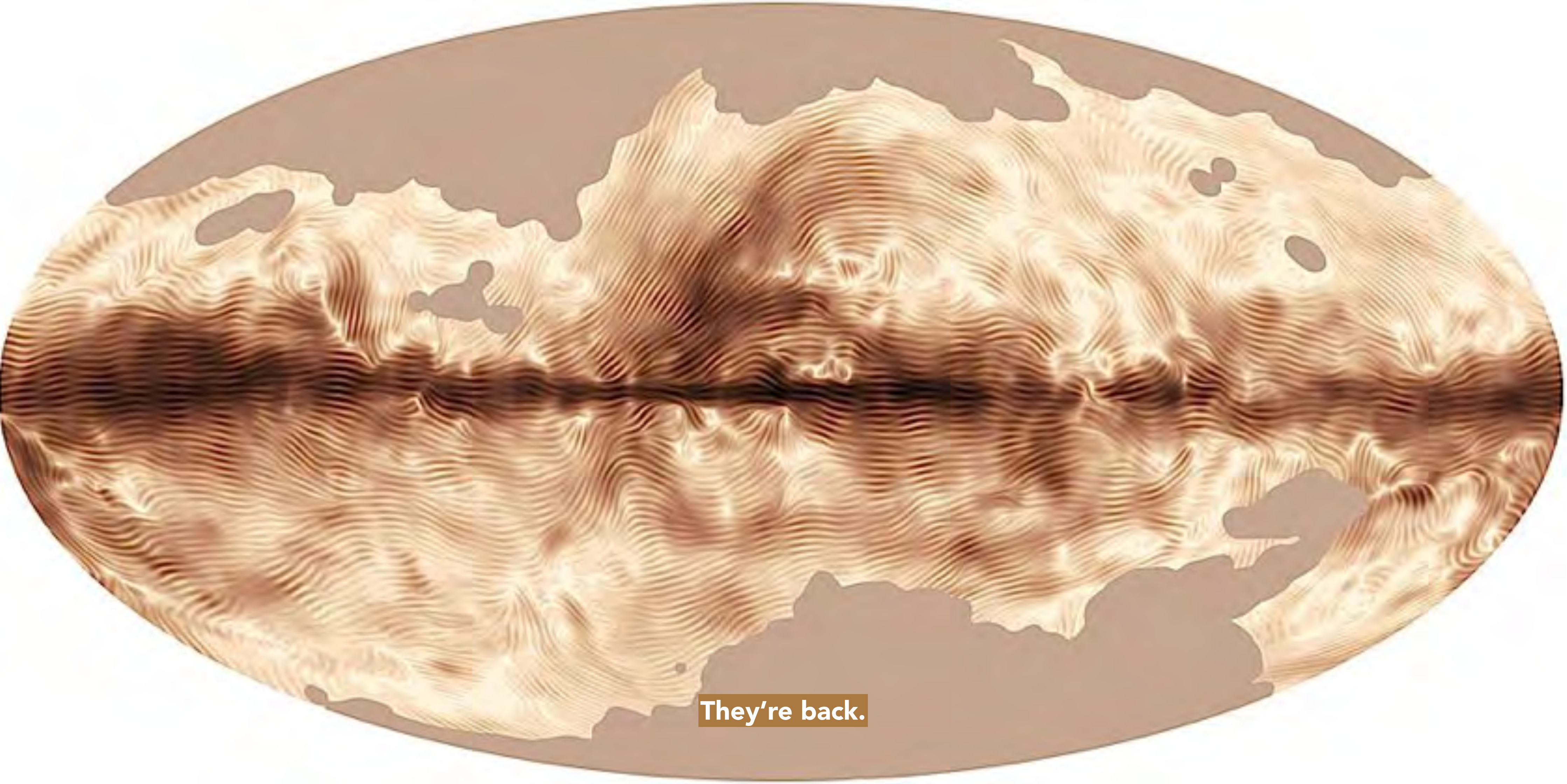
You can resolve individual lines on the NIST ***Atomic Spectra Database Lines Form***.

## The Hertzsprung-Russell Diagram and its many derivatives

Jim Kaler's ***The Hertzsprung-Russell (HR) Diagram*** opens to a box of 56 rectangles, each of which references a particular topic. Click on any one topic and a main page opens up which discusses all 56 options, showing the specific option you clicked at the top of the screen. *(Image at right copied from Kaler source file.)*



# Remember iron filings in those boring Matric classes??




Magnetic field of our Milky Way galaxy as seen by the Planck satellite, compiled from the first all-sky observations of polarised light emitted by interstellar dust. Darker regions correspond to stronger polarised emission, and the striations indicate the direction of the magnetic field projected on the plane of the sky. the magnetic field lines being predominantly parallel to the plane of the Milky Way. *Source*: NASA.

# Live from La Silla – Observatory Webcams from High in the Andes

Live webcams have long been standard fixtures at observatories. Now we, too, can watch ESO's Chilean telescopes located in one of the driest deserts in the world. Clock onto the ESO website's blue links and there you are high atop Atacama. Even Superwoman/Man/Favourite Pet couldn't scoot you there faster. Several 24/7 *Apical NEOS360* webcams (shameless plug) take you to the observatories, and more impressive, to see the inky skies above them.

La Silla ("the Saddle") is 2400 metres up into Chilean Atacama Desert, 600 km north of Santiago, the Chilean capitol. Like the Paranal Observatory, home of the Very Large Telescope VLT, La Silla enjoys one of the darkest night skies on the Earth.

The ***La Silla Night Cam*** puts breathtaking night views of the Milky Way from La Silla right there on your computer or tablet. It operates during Chilean night hours only, so check your watch. La Silla is five hours *earlier* than South Africa. Astronomical dark in Chile starts about midnight in Blikkiesdorp in the East Cape where I live. During the day the La Silla webcam shows the last frame before sunrise — check out the gorgeous view there whenever you're sogged out in S. Africa.

Like the ***Slooh online-observatory***'s system mentioned in the Online Observing article earlier in this *Nightfall,* the La Silla Night Cam uses red letters to indicate which telescopes are observing right now. **T** is the ESO 3.6-metre telescope, **N** is (surprise) the New Technology Telescope, and **D** is the MPG/ESO 2.2-metre telescope. For more facts & figures, check out ***La Silla All Sky Camera***.

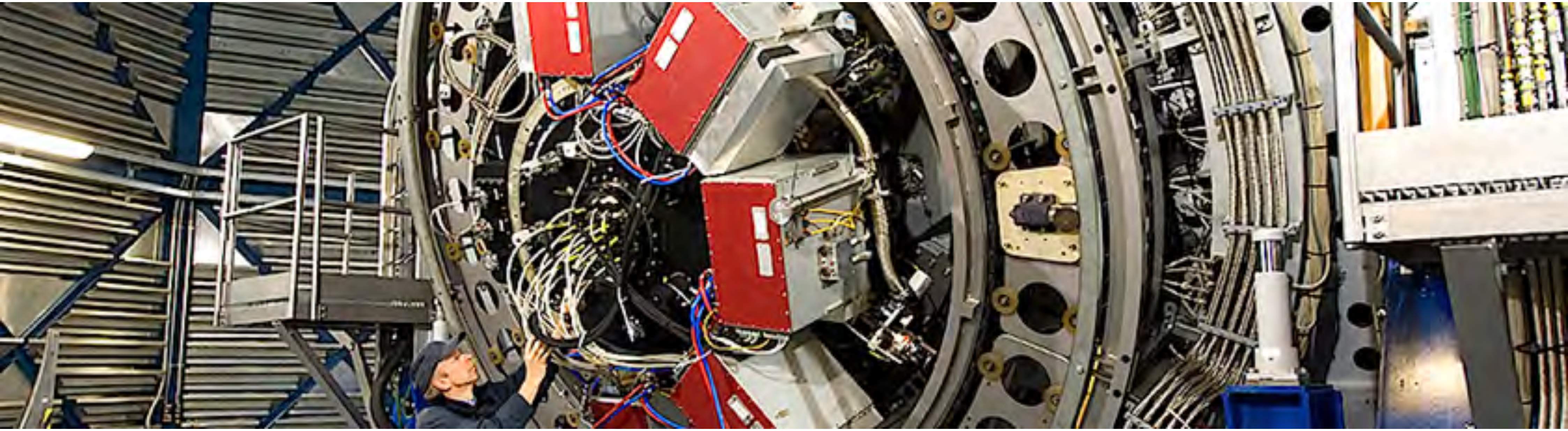
La Silla's ***Rapid Eye Mount (REM) telescope*** sneak-a-peek is pretty nifty: four webcams monitor the REM telescope. During Chilean night hours the REM webcams go dark — it IS an observatory, isn't it?

Then there's the ***La Silla's all-sky fisheye at the Danish 1.54-metre telescope***: Refreshes every 10 mins.

The La Silla observatory complex has been an ESO outpost since the 1960s. Two of the most productive 4-metre class telescopes in the world operate there.

The 3.58-metre New Technology Telescope (NTT) broke new ground for telescope engineering and design. It was the first in the world to have a computer-controlled main mirror, termed active or sometimes adaptive optics. The technology was innovative but risky when first developed by ESO. The pairing of segmented mirrors with active optics is now considered standard-issue and is installed on most of the world's large telescopes. The VLT at Cerro Paranal and the CHFT and Herschel 8-metre scopes on Mauna Kea in Hawaii, the scopes on Kitt Peak, and many others, perform far better when atmospheric turbulence is corrected within milliseconds everywhere on the mirror's surface during imaging runs.

The design of the octagonal enclosure housing the NTT was another technological breakthrough. The dome had to be quite compact due to prevailing wind conditions and terrain. Its somewhat claustrophobic interior (for a large telescope) is ventilated by a system of flaps and louvres. These direct air flow smoothly (laminar flow) to reduce turbulence across the mirror.



## *Take a Tour of Paranal with Melipal and Antu*

Before departing La Silla, lest we forget our *Nightfall* techno-nerd community that just can't get enough details about the endlessly fascinating telescopic doodads and image-capturing thingamabobs that go *whizz*. As a kid I always wanted things like this under the Christmas tree. Between then and now I retired from chopping down little trees to put doodads on the branches. Instead I got two 6-inch pieces of glass and some gritty stuff. The thing actually worked.

### *The multi-scope array on Cerro Paranal*

Ever wanted to peek over the shoulders of astronomers and engineers as they worked? The VLT is the largest visible-light telescope in the world. By (Chilean) day you can look on as the four telescopes are maintained. See the VLT Trailer documentary here and check out the event-by-event timeline history of the ESO's installations around the world. Peruse the ESO's many videos of observations and astronomy news. And for those who aren't yet exhausted by the subject, here's the latest news about the colliding neutron star kilonova. You can watch the VLT trailer as well.

The VLT's four 8.2 m (25.4 ft) dia. main telescopes are named *Antu* (Sun), *Kueyen* (Moon), *Melipal* (Southern Cross) and *Yepun* (Evening Star) were adopted as a sign of respect for the Mapuche language of the indigenous peoples who live south of Santiago, the capitol of Chile.

The four can observe either as a coordinated team or on individual observing runs. Each scope can record down to magnitude 30 in a one-hour exposure. That is 2.4 billion times fainter than we can see with our bare eyes on a very dark, clear night (for most people $M_v$ 6.5).

When all four telescopes work in unison they become an interferometer (VLTI). Astronomers capture details 25 times (3.5 magnitudes) dimmer than the individual telescopes can achieve by themselves. Putting together a unified, in-phase signal from four telescopes at different distances requires a complex system of mirrors in underground tunnels whose light paths achieve a phase coherence < 0.001 mm over a 100 metres. The VLTI can reconstruct images with milliarcsecond resolution, equivalent to splitting the two headlights on a car driving on the Moon.

Take a tour. And if you're a tech buff with a yen for instrument design and function, this list will take care of your next few cloudy nights.

A number of smaller Paranal scopes are designed for special-purpose imaging. One is the rapid-imaging superwide (and aptly named) ***Omega Cam***. If you are a photography buff saving up for your very own 67 megapixel digital camera with a 13 000 mm f/3.25 mirror-lens design, catch a plane to Paranal instead and check out the ***Vista near-infrared scope***.

Plus, if you've always fantasised looking through a huge telescope and seeing somebody (or more likely -thing) looking back, SPECULOOS is just the ticket. You can buy that ticket starting with a Ph.D in planetary studies and putting about five hard years in as a general dogsbody for somebody else.

Everyone wants a squizz at Paranal. ESO file from website.

**Thinking of a career in astronomy so you too can observe at Paranal?**

**Read these first. Yes, the whole 3,000.**

**If astrophysics or spectroscopy are a bit much, aim for a Ph.D in Astronomy Public Relations Management.**

### *Meanwhile, over on the Chajnantor Plateau. . .*

The Atacama Large Millimetre/submillimetre Array (mercifully shortened to ALMA) is a linkage of radio telescopes acting as an astronomical interferometer in northern Chile. Atmospheric water vapour absorbs millimetre and submillimetre wavebands in the lower tropopause, ALMA was built on the Chajnantor plateau at 5,000 metres (16,000 ft) altitude, near Llano de Chajnantor Observatory and Atacama Pathfinder Experiment (APEX).

ALMA helps us study cold dust and gas in our own Milky Way and in distant galaxies. Tracing the thermal continuum emission and analysing high frequency spectral lines improve our understanding of the structure and chemistry of planetary atmospheres, dying stars, regions of star formation, and distant starburst galaxies. We can address issues from the vast scales of the structure of the large-scale Universe down to the physics and chemistry of nearby comets.

ALMA was conceived and built to specifically target the wave bands associated with star birth during the early universe and local Galactic star and planet formation. Fully operational since March 2013, the huge 115-tonne ALMA antenna dishes must be moved across the desert plateau in arrays spanning from 150 m to 16 km — the millimetre-band version of zoom lenses.

And all this time we thought the leprechauns did it.

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The idea of moveable antennae was pioneered at the Very Large Array (VLA) site in New Mexico, USA. However, it requires a large number of individual antenna dishes to achieve the high information density that millimetre imaging requires. Each of ALMA's 66 antennas are equipped with multiple detectors — another name for highly sensitive radio receivers. Each receiver is tuned to a particular waveband range of wavelengths.

Data can only be acquired one band at a time, so ALMA is equipped with the broadest array of antenna farm equipment specifically built to acquire tightly defined wavebands between 0.3 and 3.0 mm.

### BAND 3 – 2.6–3.6 MM

This is the longest wavelength range of all the bands available at ALMA. Band 3 observes small scale structure in molecular clouds in our nearby spiral galaxy arms. This bandwidth range is sensitive to radiation emitted by exotic carbon-based, pre-biotic molecules associated with the amino acids which underlie life forms. These bands also look for molecular gas in disks around young stars. Beyond our local galaxy, Band 3 provides the data to construct images of molecular cloud complexes in nearby galaxies at high resolution, to probe the cold interstellar medium of galaxies, and to peer into dust-obscured galaxies to observe star formation. In 2015–2016 ALMA discovered traces of methyl isocyanate — another chemical building block of life — in early main sequence stars in the infancy of their formation. This is the first ever detection of this prebiotic molecule towards solar-type protostars, the sort from which our Solar System evolved. The discovery could help astronomers understand how life arose on Earth.

**ALMA's Megamonster Vehicles**

Moving 115 tonne antennas from the Operations Support Facility at 2900 m altitude to the site at 5000 m, or moving antennas around the site to change the array size, presents enormous challenges. The solution was to use two custom 28-wheel self-loading heavy haulers. The vehicles were made by Scheuerle Fahrzeugfabrik in Germany and are 10 m wide, 20 m long and 6 m high, weighing 130 tonnes. They are powered by twin turbocharged 500 kW Diesel engines. The driver's cabin includes an oxygen tank to aid breathing the thin high-altitude air. Driverless vehicles aren't coming to Chajnantor Plateau anytime soon.

### BAND 4 – 1.8–2.4 MM

ALMA observations with the band 4 receiver provide data about interstellar matter and increase our understanding of the formation of stars and galaxies. The first target of band 4 was the protostar system IRAS16293-2422 some 400 light-years away from us. This star-forming system is surrounded by a large amount of gas that provides the natal hydrogen gas to fuel emerging protostars. Band 4 receivers captured emission from carbon sulfide (CS) molecules in the gas, plus several other molecules such as formaldehyde (H2CO), molecular compounds containing deuterium, and carbon-chain molecules. These substances are found in cold star-forming regions. The configurations of complex molecules can tell astronomers how many periods of star formation a particular region has undergone.

**BAND 5 — 1.4–1.8 MM**

This waveband traces the faint signals of water in the nearby Universe. Water, or more accurately $H_2O$, is formed in considerable abundances in molecular clouds. ALMA's Band 5 receivers were designed specifically to detect $H_2O$. Water, of course, is a prerequisite for life as we know it, whether we find it in our Solar System or in distant regions of our galaxy and even in galaxies beyond. Band 5 also enables ALMA to search for ionised carbon in the very early Universe when carbon was only beginning to accumulate in interstellar gas as the first stars released it into the intergalactic medium. ALMA detects the faint levels of emission from ionised carbon created during the earliest epoch of galaxy formation after the Big Bang.

**BAND 6 — 1.1–1.4 MM**

This waveband is emitted by molecular gas in planetary nebulae, molecules on active comets, the heating mechanisms of red giants, and the afterglows of gamma-ray bursts. Used in conjunction with Band 3, astronomers construct detailed images of our Sun's dark,writhing sunspot cores. In pictures of sunspots showing the entire solar disk the individual spots seen tiny. In reality they are on average nearly twice the diameter of the Earth (more details here).

**BAND 7 — 0.8–1.1 MM**

Using Band 7 astronomers can create images the disks of gas and dust around newborn stars, see into star-forming clouds, and observe early galaxies obscured by dust in optical light but bright in certain submillimetre bands. Band 7 is also used to measure the global wind patterns on Mars and the water content in the atmosphere of Venus.

**BAND 9 — 0.4–0.5 MM**

This is the second highest frequency (shorter wavelength) bands in the ALMA lineup. Band 9 delivers the telescope's highest spatial resolution, which makes for very detailed structure mapping of the dense regions of molecular cloud gas and dust where new stars are born. Band 9 is especially useful for studying higher temperature/ density behaviour at high angular resolution. Band 9 also studies the "comet factories" around new stars, whose properties have long been a mystery stage of planet formation mystery.

**BAND 10 — 0.3–0.4 MM**

This receiver array extends ALMA's vision deeper into the realm of the submillimetre wavelengths where cosmic radiation left over from the earliest epoch of the Universe reveals intriguing information about the cold, dark, and frankly miserable place it really was. Band 10 enables astronomers and planetary scientists to monitor temperature changes at different altitudes above the clouds of Uranus and other giant planets in our Solar System.

**Check out *ALMA Observatory* antennas as they operate. The camera looks at the Chajnantor Plateau at the Operations Support Facilities near San Pedro de Atacama, Chile.**

**Watch this fabulous 52-minute video of how ALMA and its antennae get around.**

***Hubble and ALMA see things differently***

The Antennae in near-infrared wavebands from Hubble's Wide Field Camera 3 (WFC3).


NGC 4038/4039 composite image courtesy of ALMA (ESO/NAOJ/NRAO) and the NASA/ESA


## *Different drummers in the galaxy world*

The Antennae Galaxies NGC 4038 and 4039 are well known to amateur and professional astronomers alike. They lie about 70 million light-years away in the constellation of Corvus (The Crow). This view combines ALMA observations made in two different wavelength ranges with visible-light observations from the NASA/ESA Hubble Space Telescope, HST. The HST image is the sharpest view of this object ever taken. The HST's visible light image was recorded in the blue end of the spectrum to highlight the bright, hot newborn stars in the galaxies. ALMA observes recorded much longer millimetre light waves to reveal enormous, relatively cool diffuse gas masses rather than pinpoint stars. This was the best submillimetre-band image of the Antennae Galaxies when it was recorded in 2012.

Submillimetre emission emits broad patches of red and yellow in the ALMA image on the right. This reveals dense clouds of cold gas at 5 K to 10 K out of which new stars form. It is ironic that a galaxy's hottest stars must be born in the galaxy's coldest gas. The red, pink and yellow patches were recorded in ALMA Band 3 (2.6–3.6 mm) and Band 7 (0.8–1.1 mm) wavelengths. These bands are detect carbon monoxide (CO) molecules within hydrogen (HII) clouds, where new stars are forming. CO has long been used as a tracer of HII because HII emits very little radiation on its own. The red CO emission is as prominent between the main masses of the galaxies as it is in the starry regions. This is gas that has been torn loose from the individual galaxies by magnetic and tidal shock. While the stars interact very little and move on as if not much had happened, the HII clouds have been thoroughly mixed by high-Mach shock wave turbulence. The total amount of gas between the galaxies amounts to billions of times the mass of the Sun — a rich reservoir of material for future generations of stars.

Taken together these images reveal the Antennae Galaxies to be undergoing several different forms of convulsion. In the Hubble image on the left, HII clouds are seen in bright pink and red. These mix clumpily in and near the bright bursts of blue star-formation. The streaky patches are dense filaments of dust which obscure stars that lie behind them. The broad HII patches are not very affected and hence emit a diffuse glow. The rate of star formation in the blue regions is so high that the Antennae Galaxies are enduring a multi-million year starburst episode. Gas mixing that occurs under conditions as intense and chaotic as these will convert far more of the available gas into stars than is normally the case in comparatively easygoing spiral arms. So much of the galaxies' gas will be used up (there being no nearby filling stations). Once there is too little gas left to convert into stars, the galaxies will quickly flame-out. ("Quickly" is several hundred million years in these cases.) Worse for these once-beautiful spirals, they are now locked into a permanent gravitational clench. As billions of years pass, the chaos seen here will smooth into a featureless elliptical galaxy. From young and beautiful to red and dead, alas, is a fact of fate in the galaxy world.

# Dr. Ian Glass's visit to La Silla Twenty-Seven Years Ago

## *Visiting the European Southern Observatory*

**Ian S. Glass**

The writer (ISG) had the opportunity recently (July) to re-visit the European Southern Observatory in Chile for an observing run. This is now the largest astronomical installation in the southern hemisphere and probably even in the whole world, its nearest rival being Kitt Peak in the USA.


Reproduced verbatim from MNASSA, the Monthly Notices of the Astronomy Society of South Africa, Vol.49, Nos 9 & 10, October 1990.

After arriving in Chile's capital, Santiago, following the two long flights from Cape Town (via Rio), it was a great pleasure to relax in the quiet of the ESO Guest House in the suburbs for a day. Although Santiago's climate is not very different from Cape Town's, on going north to the La Serena region where the observatories are, it is noticeably much drier - more so even than the Karoo. Taking the ESO station-wagon up from La Serena to La Silla (the Saddle), the mountain where ESO's telescopes are situated, I had the company of an old acquaintance, John van den Brenk, an Australian electronics technician who has been working in Chile since before my last visit in 1981.

There had been some threat that I might have to share accommodation, owing to overcrowding on the mountaintop, but luckily this turned out not to be the case. After settling into my motel-like room with central heating, a private shower and effective blackout blinds, I went in search of Andrea Moneti, the Italian ESO astronomer with whom I collaborate. Our first few nights were with the infrared CCD camera on the 2.2m Max Planck telescope. We had, in fact, been given an extra night which had originally been set aside for test purposes. The camera, although designed for a 64 x 64 array, possesses only a 32 X 32 at present, but this did not stop us from making some very interesting observations of obscured sources near the centre of the Milky Way galaxy.

Support work, such as setting up the equipment and keeping it filled with cryogens, was taken care of for us by the staff of three infrared support scientists and technicians.

The second part of our observing run was with the Infrared Spectrometer (IRSPEC) on the 3.6m equatorial telescope. This is a truly impressive piece of equipment. Unlike most infrared instruments, which are cooled by liquid nitrogen or liquid helium reservoirs, this spectrometer has a sophisticated continuous-flow liquid nitrogen system. Although the technical details are very complicated, they fortunately were not the concern of the observers, who found the instrument in a prepared state, all ready to operate. Our observations were mainly of the Brackett gamma line in the 2 micron band. Since my last visit in 1981, the main additions to La Silla have been the Max Planck 2.2m telescope already mentioned, the SEST sub-millimetre dish, and the NTT.

The SEST, or Swedish-ESO Sub-millimetre Telescope, is a 15-metre radio telescope with a surface accuracy of +/- .07mm rms, good enough to perform well to wavelengths of 0.8mm or less. It stands in the open air and its surface appears to be of almost optical quality. Care has to be taken to avoid pointing in the direction of the sun!

SEST is the first large sub-millimetre telescope in the southern hemisphere, and observing time on it is at a high premium. One high-priority programme, which was being conducted during my visit, is to map the Large Magellanic Cloud in detail in the emission of the Carbon Monoxide molecule, one of the best tracers of molecular gas.

The NTT (New Technology Telescope) is an alt-azimuth instrument with active control of the shapes of its Ritchey-Chretien optics. Some early results, taken on a night of particularly fine seeing, were reported in MNASSA inAugust 1989. With the failure of the Space Telescope optics, the NTT is optically the best telescope in existence. At present, it has the EFOSC, a combination camera/spectrograph on one Nasmyth focus, and a similar but much more sophisticated instrument, the EMMI (ESO Multimode Instrument) on the other. The intention is that the EFOSC will be replaced by the IRSPEC, mentioned above, when the EMMI is ready.

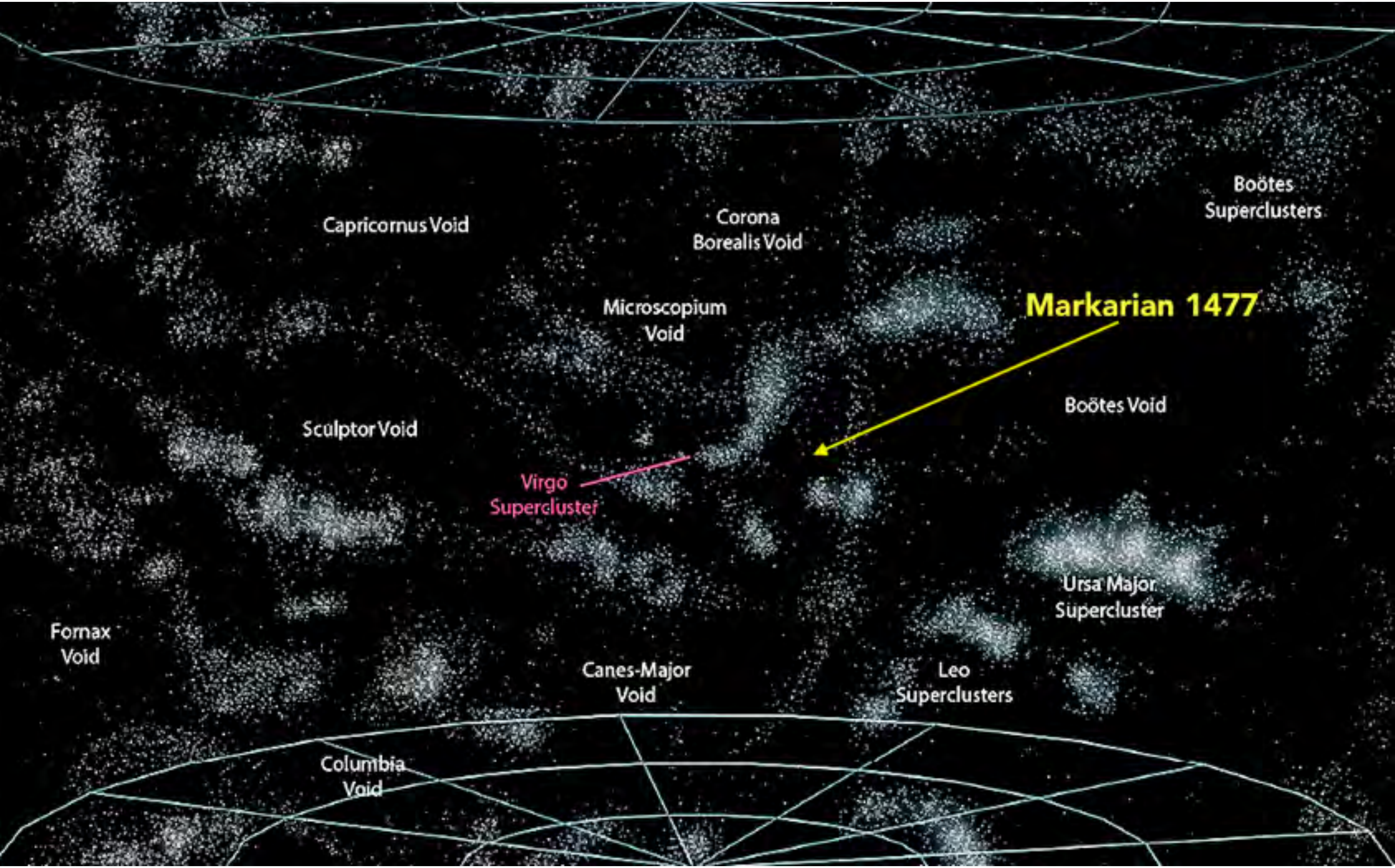
During my visit, the EMMI was being tested and the results appeared very promising. A serious question facing ESO at the moment is where to put the VLT or Very Large Telescope, an array consisting of four 8-m telescopes whose light can be combined to give the effect of a single 16m instrument. Gossip at the dinner table favoured a site near La Silla, but it appeared that another site, Cerro Paranal, an isolated mountain near the coast just below Antofagasta in northern Chile had a greater percentage of clear nights. This was offset.however, by the fact that it is a much windier site than La Silla.

The original idea of using inflatable domes, as described in ray article in MNASSA in June, 1987, has been given up. It appears that structure similar to that of the NTT will be used.

Happily, ESO's famous cuisine has continued at its high standard, renowned throughout the astronomical world. Catering for astronomers from most of the European nations can be no easy task! The famous gastronome Brillat- Savarin once remarked "The cook who invents a new dish does more for human happiness than the astronomer who discovers a new star." Well, no doubt, it all depends on which dish and which star.

Dr. Glass at the Peking Observatory during the 28th General Assembly of the IAU in Beijing, 2012.

# Observing Challenge: Galaxies in Cosmic Voids



## Markarian 1477: The Loneliness of the Long Distance Cluster

Cosmic voids are enormous bubbles of near-emptiness that can be seen in all-sky maps and full-motion simulations of the large-scale structure of the Universe. They look like a snapshot of the large bubbles that form in a pot of boiling water. View the pot in slow-motion video and the bubbles begin as tiny pips which rapidly expand as they rise to the surface. Despite the appearances, little heat is actually exchanged between the inside and outside of the bubble; it is instead converted to the work of expanding the gas bubble into the denser liquid medium. Thermal pressure overcomes density pressure and the bubble expands.

A boiling pot bubbles very rapidly. A boiling universe bubbles very slowly. So slowly, indeed, that we can discern the underlying tempest of energy and mass interaction only by setting the clock of cosmic simulations to one second equals, e.g., five million years. This is not uncommon. Astronomers resort to the term "instantaneous" to describe events whose completion time occurs in 100,000 years (in the case of star cluster evolution, see 1, 2, 3, 4), and 10 million years (in the case of cosmology simulations, see 1, 2, 3, 4, 5).

Markarian 1477 is the most massive and active galaxy in the VGS 31 group. This tiny trio lies in one of the remotest regions of the Local Void, 289 million light years away in Canes Venatici.

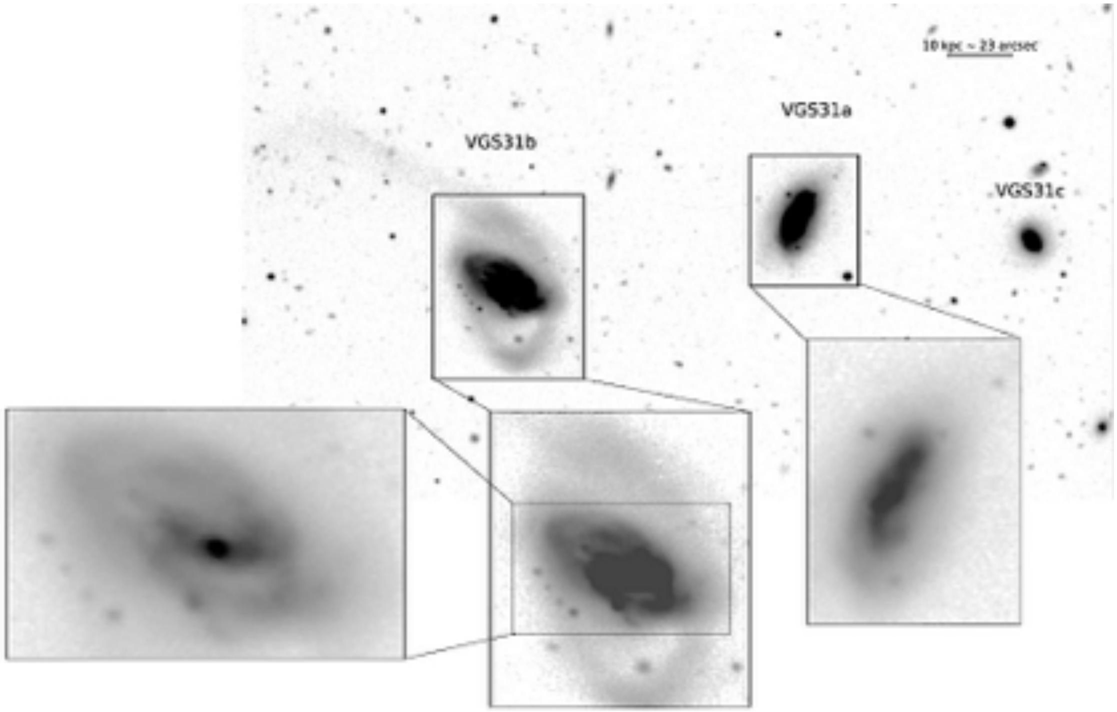
Cosmic voids exert an important negative energy potential in Universe. Voids have little gravitational potential within but they are surrounded by walls and sheets which, being much denser, have a high gravitational potential. Gas still residing in the voids is naturally pulled in the direction of higher potential. Hence voids slowly empty while walls, sheets, filaments, and their connection points, called nodes, fill.

While void emptying is a slow diffusion outward, gas transport along filaments is rapid. So rapid, indeed, that when filaments meet at what are termed nodes, the shock effects of so much gas colliding nearly head-on gives rise to extreme turbulent heating. Since much of the gas flow is in electrons and ions, this naturally generates magnetic fields. Shock turbulence is by nature small-scale, rapid, and tremulous while magnetic energy (called ambipolar diffusion because it has no preferred direction of polarity) is large-scale and slow. Magnetic fields act to weaken turbulence. Eventually turbulence grows so ineffectual that gravitational potential can initiate free-fall. Star clusters begin this way. Galaxies redistribute angular momentum this way. Galaxy cluster form this way. All these are so gigantic and slow-moving that we don't easily see them as analogues to a boiling kettle.*

The most comprehensive series of maps of the Universe's structure can be found here. Early in the universe, space was pockmarked with voids surrounded by microstructures of threads and walls. The primordial voids slowly emptied out as their matter migrated toward the higher gravitational wells of wall-like structures. As the walls deformed and flattened into sheets, the voids got larger and emptier. The denser parts of the sheets then repeated the emptying process and the sheets thinned into ever more slender filaments. The filaments in turn collapsed towards their densest points where they formed clumps. These merged with other clumps to form massive galactic superclusters. The *Bullet Cluster* in Carina is one of these.

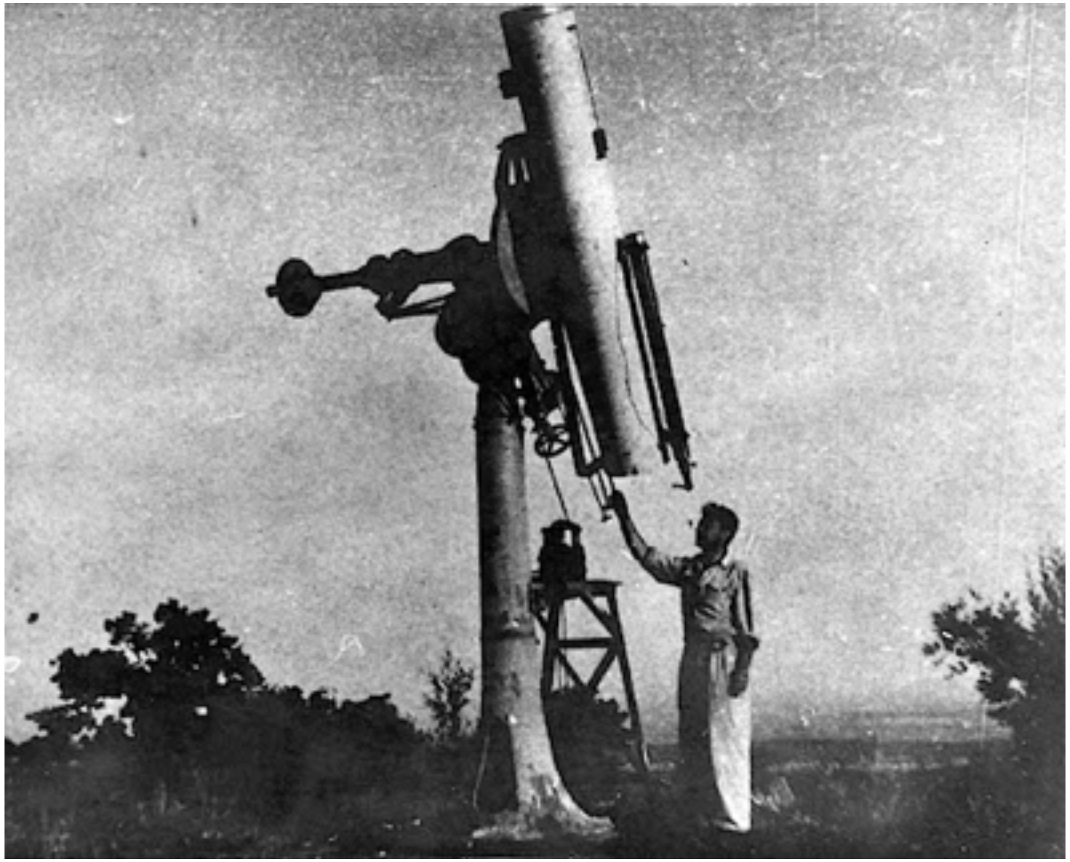
Void emptying has been going on ever since before the reionization era at $z = 6$ when atomic matter began to collapse into stars in significant numbers. A depleting void creates a negative gravity gradient which accelerates its depletion and expands its size.* Today the average void has only about one particle per four cubic meters (357 cubic feet) — about the volume of a suburban tract-home kitchen. The Local Void is larger than the Local Sheet yet has only 0.07 the Sheet's mass density per $Mpc^3$.

* Beware the term "negative gravity gradient". Some have interpreted this to mean "negative gravity", and conclude that the emptiness of a void is actually expelling its peripheral gas and "pushing" the formation of sheets and walls. The tea kettle bubble analogy breaks down here. In the kettle the bubble is actually a positive pressure gradient. Cosmic voids are a negative gradient.




Markarian 1477 (VGS 31b) is an interacting pair of galaxies in Canes Venatici, 13 16 14.7 +49 29 41.4, 280 million light years from Earth.

# 1965 – 1985 Beniamin Markarian and the Era of High-Luminosity Galaxies



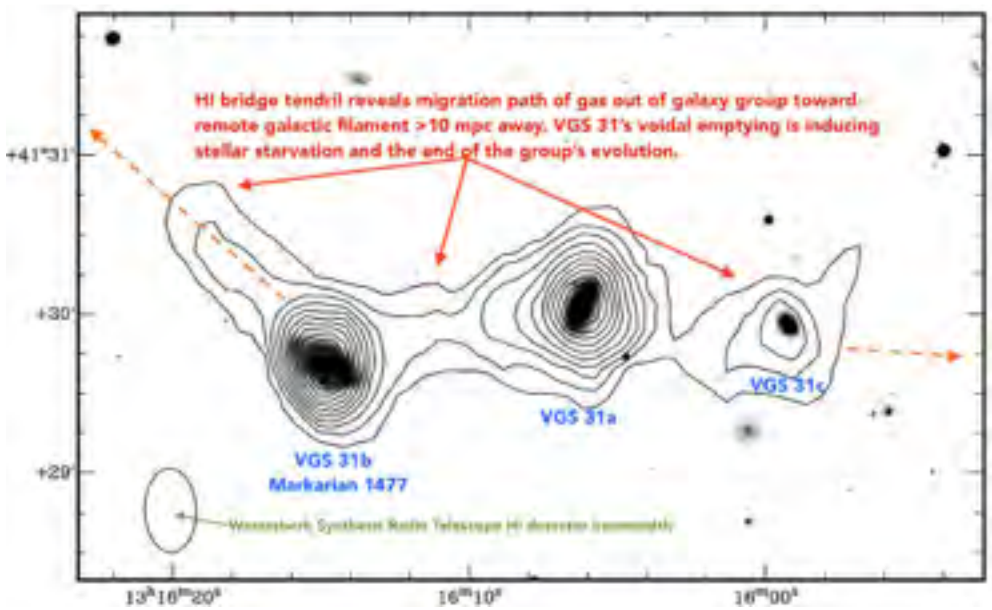
From information on the *Byurakan Observatory* and *Beniamin Markarian* websites, this appears to be the 10-inch spectrograph / nebular astrograph installed during its initial assembly period in 1951–52. The astronomer is not identified but is either the observatory's founder (in 1946) Viktor Ambartsumian or Beniamin Markarian.

Markarian galaxies are a class of galaxies that have nuclei with excessive amounts of ultraviolet emissions compared with other galaxies. Benjamin Markarian drew attention to these types of galaxies starting in 1963. The nuclei of the galaxies had a blue colour, associated to stars in the classes from O to A. The blue colour did not match the emission profile of the rest of the galaxy. The spectrum shows a continuum band from Hydrogen and Helium that Markarian concluded was produced non-thermally, which is to say, not from the stars' own internal fusion. Most of the objects Markarian identified have emission lines characterised by highly energetic non-fusion activity. This caused them to radiate exceptional amounts of ultraviolet light — a property called UV excess, or UVC.

UVC radiation is nonthermal, i.e., not produced by stellar heating of ambient gas such as we see in young open clusters with a few hot O stars heating large amounts of birth gas to HII incandescence. The "C" in UVC signifies "Continuum" meaning the radiation has low emission levels from specific atomic excitation states such as OIII or SiII. (See the 27 March APOD to see this in action.) *Markarian objects* emit very high UVC from large populations of O and B stars, whose ages are typically 5 to 10 million years. Most UVC objects are now classified as *Seyfert galaxies*. One of Markarian's objects, the famous chain in Virgo, is simply an unusual structure of mutually interactive galaxies whose disturbed halo gases radiate elevated UV levels.

For northern observers one of the most exotic challenges is Markarian 1477. It is the brightest member (at $M_v$ 14.3) of a 3-galaxy interacting group VGS 31 deep within the emptiness of an intergalactic void called the Local Void. Astronomers have long suspected that some galaxies would get left behind as the thin gas in voids is hoovered away. In the last decade better equipment and computer modeling tools have shown this is indeed the case.

Mrk 1477 is one of them. It is the brightest galaxy of a tiny three-galaxy group called VGS 31. "VGS" stands for "void galaxy survey". A cosmic void would seem the last place to look for galaxy clusters, but it turns out that there a modest but significant percentage of void clusters in any large-scale survey of cosmic voids (see Panel 3 in Fig. 1 *here*). The chief problem from our point of view is that they are so far away. Mrk 1477 is 88.6 Mpc or 289 million light years distant.




## A man, a plan, Byurakan.

Today large-scale cosmic structure is arguably the most active arena of astrophysical research — though the clamour for funding by the planetary science community forms its own chorus of the multitudes. Cosmic studies barely existed in the 1960s (see *Legacy Library* in this issue of Nightfall). Instead of cosmic flow on the largest scales, the study of individual galaxy structure and galaxy evolution predominated. Today cosmological simulation is a prolific paper-producer; in the 1960s the focus was on classifying galaxies according to their inherent physical properties.

Quasars were discovered only in 1963. Their intense luminosity and vast distances inspired astronomers to search for objects whose spectra were a blend of high-energy radiation in the blue and UV bands, but often reddened down into the infra-red band by exceptional recession velocity.

In the West, and particularly California in the USA, astronomers had large-plate, wide-field scopes like 48-inch Schmidt camera at Palomar to work with. There was a tremendous demand for their time, though. Behind the so-called Iron Curtain, a large 102 cm (40 inch) Schmidt camera was constructed at the Byurakan Observatory in Armenia. It recorded first light in 1965 at the hands of one Beniamin Markarian.

Earlier that decade one of the observatory directors, Viktor Ambartsumian, had become intensely interested in radio galaxies which were just then being identified. He foresaw the need to locate those galaxies' optical counterparts. He convinced the Armenian Academy of Sciences to splurge for the largest Schmidt camera in

Eastern Europe. Naturally, nationalist pride had as much to do with the success of his efforts as any public interest to be served by so arcane a topic as remote galaxies broadcasting on the radio. Politicians in those days did quite enough of that as it was, thank you.

In 1965 a new Byurakan director was appointed, Beniamin Markarian. He was no less as passionate about galaxies which emit prodigious amounts of energy without any startlingly obvious reason to do so. But to undertake an all-sky survey for hitherto unexamined waveband properties was an enormous prospect. Building a prestigious observatory is one thing in a financier's eyes, paying for it to do quotidian duties like collecting spectra is another. Markarian cut through the fiscal barrier by adopting one of spectroscopy's earliest tricks: the objective prism. These can amass a huge database of spectra, but at very low resolution. That was no problem, either, because Markarian was after high-intensity UV radiating in the hydrogen and helium continuum of hot O, B, and A stars. Markarian's 102 cm objective prism was the largest optical pour ever made by the Eastern European glass foundries; its dispersion angle was only 18° and its resolution 1800Å/mm. That was good enough because the galaxies Markarian sought radiated largely in their core regions, which at their distances made the emission region nearly stellar.

Even for well-equipped amateur astronomers, spotting Mrk 1477 will not be easy. Its coordinates are RA 13 16 14.7 Dec +41 29 40.05. It is tiny at 22 x 14 arcsec dia. and the brightest of the three is an anemic mag 14.3 in the visual band.  If you r-e-a-l-l-y want to get exotic, you can use Markarian's original paper as a finder chart, p. 328 *here*. It's a challenge object for 12-inch and up (way up) owners, but for those who do spot it, one of the rarest objects in our night sky.

Markarian's first catalog *Galaxies with an Ultraviolet Continuum* was released in 1967; it comprised only 70 galaxies. Catalogue releases continued all the way into the late 1980s, finally calling it quits at 1544 objects. It is interesting to note that about the time the Ultraviolet Continuum catalogs petered out, there was a matching rise in the number of Byurakan papers devoted first to Seyfert galaxies (which were first identified there) and quasars. Somebody over there knew a thing or two about how to hand out observing slots. The last paper with Markarian's name on it was 1989.

Unnoticed at the time, several galaxies in the Byurakan series were later found to lie inside the enormous cosmic voids. On the mid 1980s – mid 1990s cosmic voids were a newly identified object class of interest to barely a handful of astronomers. Only recently with the inauguration of the *GAMA (Galaxy And Mass Assembly)* survey, has enough information become available about near-scale structure (1 Kpc to 1 Mpc) to accurately map void galaxies and their peculiar structures. The GAMA project also has produced some of the most informative — and mesmerising — fly-through sims of cosmic structure to be found. If ever you've been mesmerised by snowflakes flying toward your auto lights in a blizzard, imagine what would happen if you flew through a blizzard of galaxies, 1, 2, 3.

*Clockwise from top left:* Markarian at eyepiece of off-axis guide scope; spectroanalysis the old-fashioned way; Mrk 848 Boötes; Mrk 266 UMajor; data processing c. 1970 in Armenia.

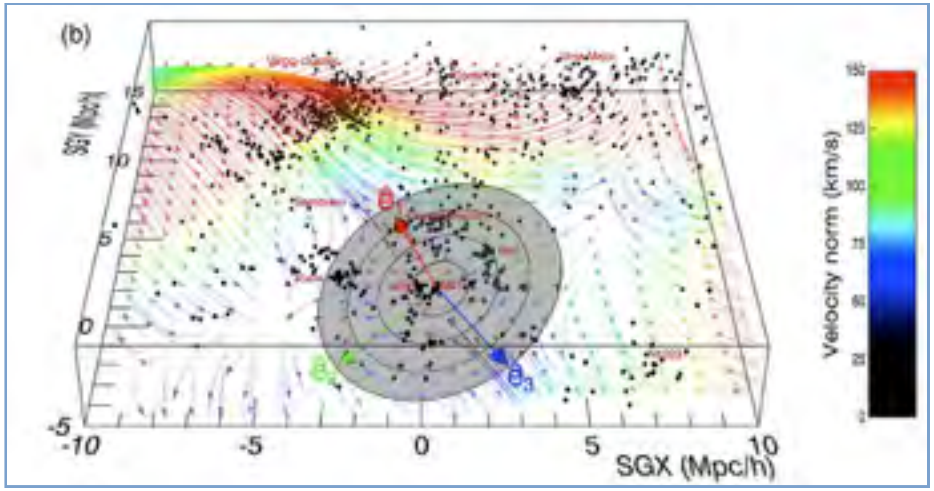
### *Beniamin Markarian – The Remarkable Legacy of a Forgotten Astronomer*

Recently the astronomer Mehmet Alpaslan at the University of St. Andrews in Scotland was the lead author of a study which identified a new class of galaxies called "tendril galaxies". These are perhaps the loneliest galaxies in the universe. They reside in very small groups averaging about six galaxies and are strung along threads or tendrils averaging 10 Mpc or 32.6 million light years long. Most of the tendrils connect on one or both ends to the more familiar cosmic filaments that join massive galaxy clusters like Centaurus, the M81–82 Group, the Sculptor galaxies, with the far more massive Virgo Supercluster.

Astronomers like Alpaslan are interested in tendril galaxies because they have evolved in complete isolation from the environmental stresses that affect galaxies like the Milky Way, Andromeda, and Triangulum. The great proportion of all known galaxies are member of large groups like the 33-member Local Group on up to superclusters like Virgo which have thousands of galaxies. Galaxies in such dense environments exchange matter and energy in numerous ways,

There is even a recently formed special study group for such galaxies, the VGS or [*Void Galaxy Survey*](). VGS seeks to understand what the raw material of the infant Universe was like at the beginning, and how it has changed over time. VGS looks into the emptiest places in the universe to find the last surviving members of galaxy populations that formed very early, and without being contaminated by normal galaxy interactivity.

VGS in turn is part of a larger consortium called GAMA or Galaxy and Mass Assembly. Initiated in 2007, GAMA's goal is to study structure on scales of 1 kpc (3260 lyr) to 1 Mpc (3.26 million lyr). This regime is sometimes called "near-field" astronomy. GAMA studies how individual galaxies form groups through mergers and how the back-and-forth flow of normal (baryonic) matter is affected by the massive galaxies around and within it. Studying events at the local scale is critical to understanding how evolutionary processes work elsewhere in the universe. Even the properties of dark matter and gravity can be studied on a local scale.




The Local Void emptying toward the Local Group and thence to the Virgo Supercluster. Mrk 1477 is located near the 1:00 o'clock position above the bulls-eye circle. *Source:* Libeskind 2015 Fig 1b.

Mehmet Alpaslan 2014, *Galaxy and Mass Assembly (GAMA): Fine filaments of galaxies detected within voids*, MNRASL 440, L106–L110.

Krekel, Platen et al 2012, *The Void Galaxy Survey: Optical Properties And H I Morphology And Kinematics*, Astronomical Journal 144:16.

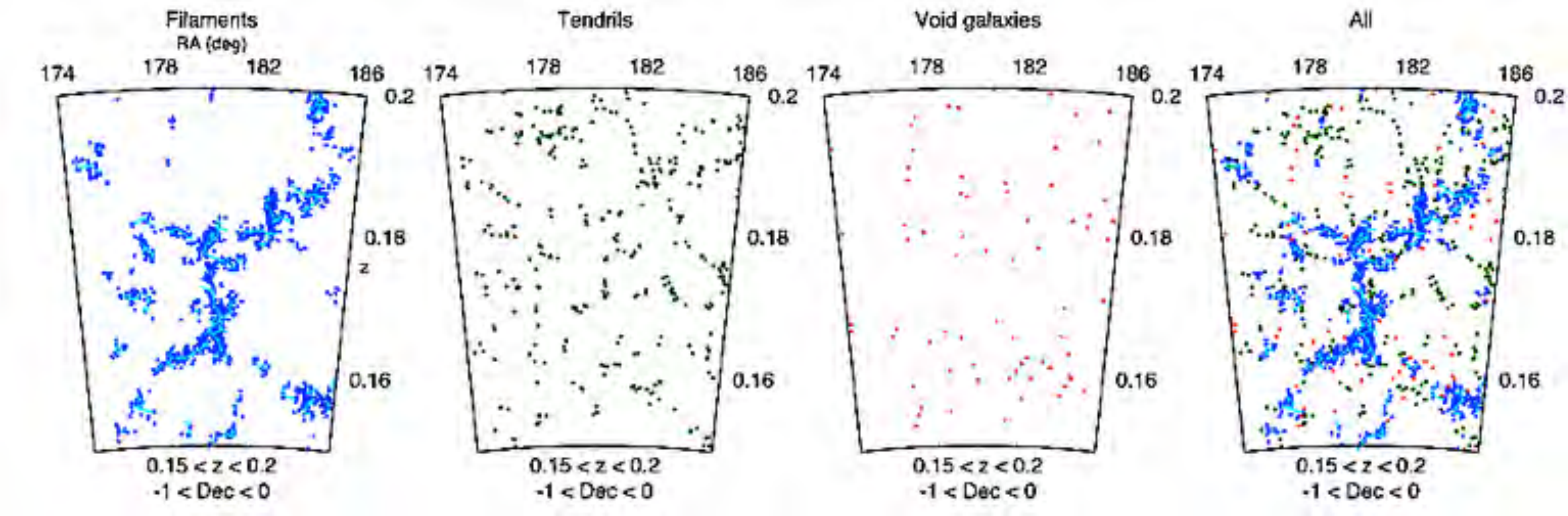



**Figure 1.** A section of the G12 field with different galaxy populations shown in each panel. From left to right, the populations shown are galaxies in filaments with the filament MST (blue and cyan respectively); galaxies in tendrils (green); galaxies in voids (red); and all three populations in their respective colours.

*Source*: Alpaslan MNRAS-L 2014.

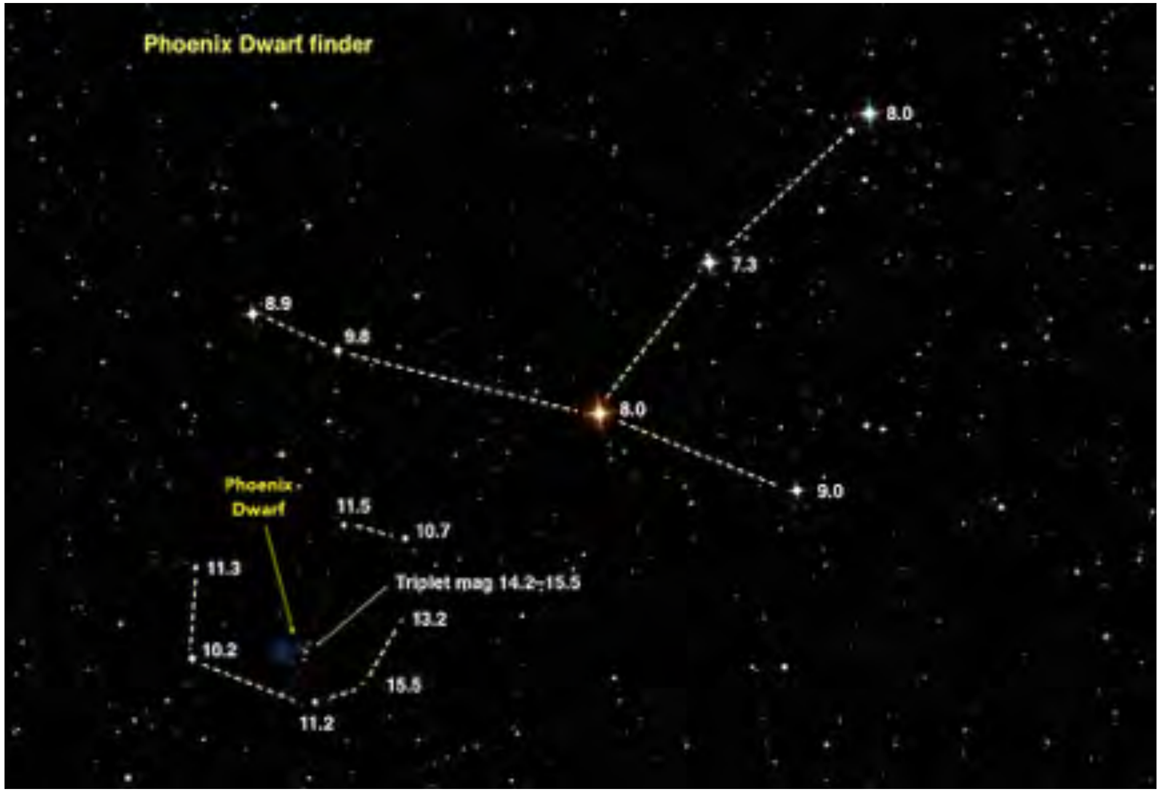
Readers interested in learning more about Markarian's career and his contributions to astronomy may consult this website devoted to the man and his work. The ten biographical sketches by astronomers who knew and worked with Markarian (nine of them Armenian or Russian) are a revealing glimpse into the way astronomical research was conducted behind the so-called Iron Curtain during and after World War II, and continuing up until Markarian's passing in 1985.

# And Yet It Rises

*IMAGE:* PHOENIX DWARF GALAXY, COURTESY ESA/ESO.

# The Phoenix Dwarf

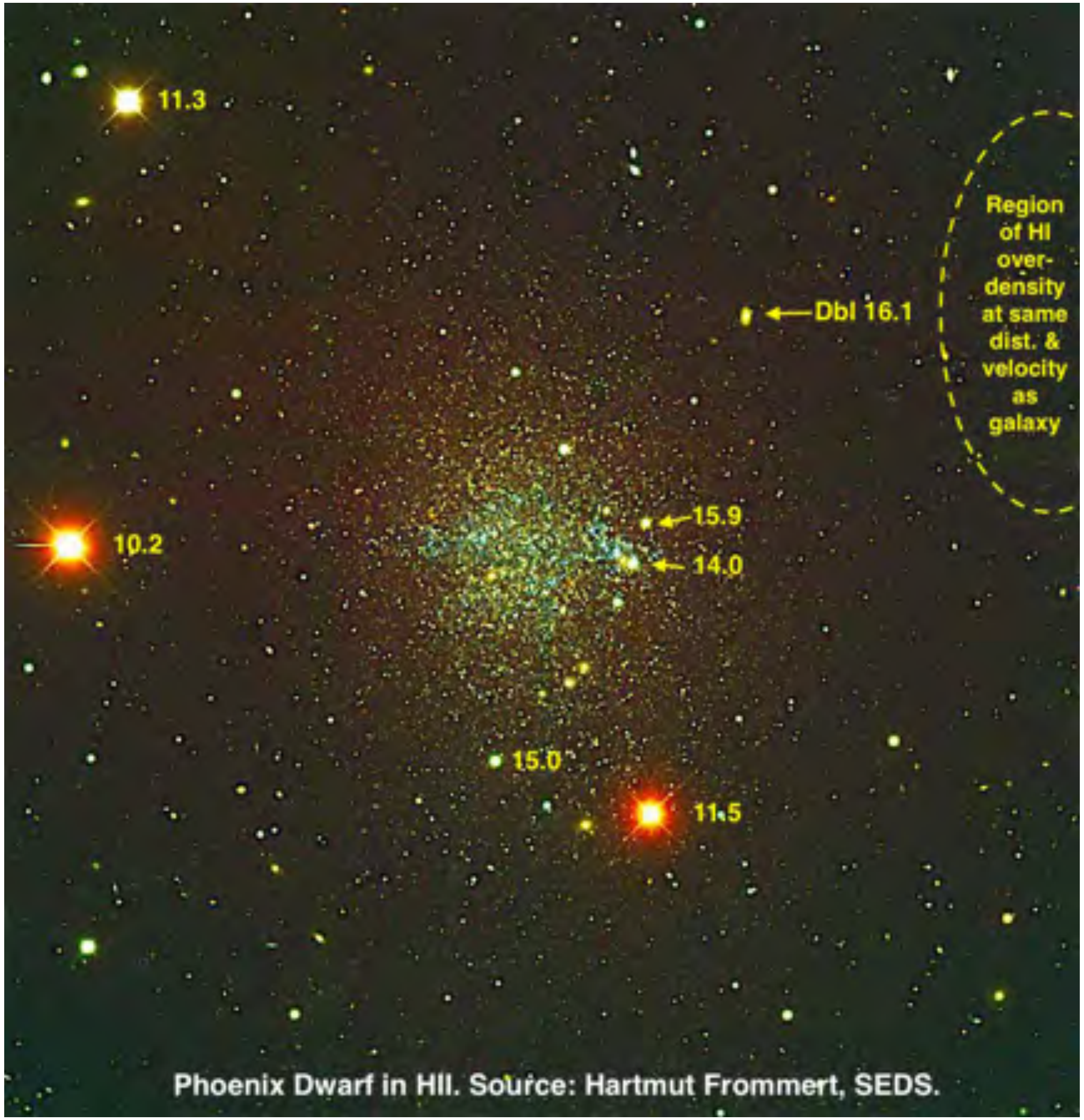
Dwarf galaxies are the most common type of galaxies in the nearby Universe. They and high-mass *in situ* globular clusters like NGC 2419, Omega Cen, and the G1 globular in Andromeda were among the first systems to form in the early mass-accretion phase of galaxy assembly of the Universe. But at higher redshifts, dwarf galaxy halo populations such as those observed surrounding the Local Group (LG), Centaurus, M81, NGC 3109, and M94 galaxy groups cannot be observed. We must rely upon detailed observations of those dwarfs which we can study, and then infer what happened to these galaxies at very high redshifts as far back as $z$ = >6, the Reionization Era. The picture is becoming clearer, but what see in that picture is through a glass darkly. Astronomers are uncertain why the evolutionary paths of dwarf galaxies are so dramatically different.




To hobbyist astronomers the Milky Way and Andromeda dwarfs look much alike — soft hesitant fuzzies. Few amateurs pause to consider the implications that their eyes are processing less than one percent of the total energy those fuzzies are sending our way.

Local Group and Andromeda dwarf galaxies are classified into two main categories: the *late-type* (also dwarf irregulars, dIrr) which contain gas reserves and are still forming stars. Barnard's Galaxy NGC 6822 in Sagittarius is the most easily observed. Like other dIrr galaxies NGC6822 has a ragged appearance in the optical that shows up even using binoculars (in dark skies). Owners of larger glass can spot several active HII star-forming regions — and even globular clusters!

The other dwarf galaxy class is the *early-type* (dwarf spheroidals, dSphs). These have very low reserves of star-forming hydrogen gas and exhibit no current star formation. In amateur telescopes they are soft, smooth, and vary significantly in the ease with which they can be seen.




Phoenix Dwarf in HI. Source: SEDS.

A less-populous category is the *transition type* (dTs) dwarf galaxies with no current star formation but known reserves of gas which under the right circumstances could blossom into a very late-phase starform episode.

A still unsolved question today in galaxy studies is whether these various types of dwarf galaxies are intrinsically different objects, or whether they descend from the same progenitors and have evolved through different paths because of environmental and/or internal processes. Nature -versus-nurture plays out in the sky, too.

The Phoenix Dwarf is one of the transition dwarfs. Hence is worth a closer look — even though it is admittedly a very tough galaxy for observers with apertures under 8 inches. (I have spotted it in a 6-inch Intes Maksutov in the darkest Karoo skies South Africa has to offer, but that was an exceptional circumstance.)

For amateurs Phoenix is one of the more difficult of the Milky Way's dwarf galaxies. At only 8° away from Achernar, it is easy to track down. The most propitious availability period is November–April when it rises to a sky elevation of ±60° above the horizon. It nestles within an easily identifiable triangle of mag 10–11 stars amid several unrelated 14th mag field stars, of which three form a ragged line .

To find the galaxy, follow Eridanus from its source in Achernar past the first dogleg of three stars, then shift N to a pair of 4th mag stars. Equidistant beyond them to the W, an asterism of 8$^{th}$ mag stars shaped like an old wooden plough is an easy binocular object. The plowman has dropped a few seeds below, first a wide pair floating down toward the target, then a circlet of five mag 8 – 11 stars that conveniently cradle the Dwarf. This Galaxy 'neath the Plough takes at least an 8-inch and dark skies. It's uniform, pallid, featureless glow testifies that Phoenix is HII-quiet. Indeed, it has not experienced any star formation for >200 million years. It is 440 kpc (1.43 Mly) from us and receding at 300 km/sec. It is a notably metal-poor galaxy [Fe/H] = −1.8 or 0.0067 the metals content of the Sun. In my 8-inch scopes Phoenix doesn't look metals-starved; it looks photon starved.

The subtext of this observing report is the dyspeptic relations between dwarf galaxies and their gas clouds. Go to the bottom of this report to full-page reproduction of Daniel Weisz's reconstruction of the starform histories of the brightest dwarf galaxies in the Local Group. The graphs are writ small but their tales loom large. These galaxies started very early, before the Reionization Era at z = 6, or roughly within a pinch of the first half-billion years in the infancy of the Universe. The vertical red bar on the left represents this era. Diapers, in a way.

The Reionization Era had a smothering effect on the subsequent eight billion years of galaxy formation. Before Reionization the Universe was so kinetically energetic (hot) that electrons and protons could not form lasting bonds. Light — photons — mediates the energy exchange between electrons and protons. If the photons are very high-energy (over 8,000 K), a couple of swooning particles eager to bind would be repelled before they had a chance. Better opera plots have been written, but none have survived like this one.

Consider all those movies where the winsome couple finds a way to escape the clutches of social convention to ride off into the sunset of everlasting happiness. Another good example that film writers do not pay much attention to the Universe. The total energy of the hot soup of particles all across the universe had to cool below the 13.6 eV of hydrogen's binding energy. Hence the ionically estranged proton/electron couples duly waited for the Universe to duly cool. It did. Starting $z = 6$ starry hydrogen families formed in staggering abundances in a relatively brief time. First stars, then large aggregations, finally self-bound assemblages. Watching this in the many sims that illustrate the era is like watching the course of modern civilisation rise out of a simple crossroads in the forest which aggregated people, markets, and exchange into what we now call Times Square or Piccadilly Circus or the Rond Point in Paris.

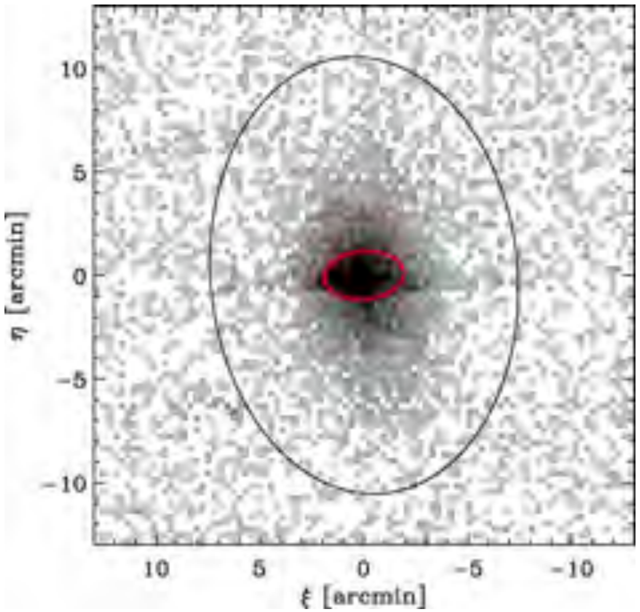
Stars, like cities, radiate considerable energy. High-mass O and B class radiate more in the ultraviolet band than any other. In their copious abundances they ionised a high proportion (>80%) of unbound hydrogen atoms back into their constituent protons and electrons. UV was the major, but not the only culprit — high-Mach shock waves, magnetic fields, extreme-energy cosmic rays, shear, torque, and gravity, created an incandescent bath of radiation and relativistic particles which quenched the supply of star forming gas.

It astonishes non-astronomers to learn that interstellar gas in galaxies is commonly in the 1 million to 10 million K range, intergalactic gas can be 10 million to 100 million K, and the gas in colliding cosmic filaments easily exceeds 100 million K. But in the exceptional tenuities of space where individual particles have many cubic meters each within which to flex their wings, the wonder is not how long they stay hot, but why they can cool at all.

But then, a few billion years can chill many a hotshot, and the Universe had both to spare. Hydrogen could again recombine once the local thermal kinetic energy dipped below 8,000 K. But now, unlike the primordial era of hydrogen formation, the recombinant Universe was riddled with overdensities of gas which had aggregated around Dark Matter (DM) mass concentrations. Small DM aggregations converged into larger, those in turn aggregated upward into protogalaxies, fish eating fish until there was little left to consume. The term "little left to consume" means masses on the other of 10 billion solar masses and up, the threshold for dwarf galaxy formation. Below that mass the Universe was peppered with barely-bound gas clouds lacking DM cores. These, as today, were entirely atomic, since no HII could form at their low densities and high temperatures. HII typically forms in the dark cores of dust-laden gas clouds where temperatures reach down into the single digits Kelvin; such conditions didn't exist in a Universe still seething with UV radiation.

If one observes Dan Weisz's chart carefully, some dwarfs like Leo IV, Andromeda VIII, Draco, Hercules, and Sculptor aggregated and consumed nearly all their primordial gas very early in their history; these have been quiescent or "red and dead" ever since. Most of the dwarfs evidence jagged staircase star formation histories with quiet plateaux erupting into frenetic star-making. A considered look at this starform profile might inspire the curious astro enthusiast to look into the known orbital dynamics of these galaxies using the plate solving websites astrometry.net and remote-astrophotography.com combined with data sourced through Hipparchos and Gaia data. Bring a good calculator, because the task is to determine whether the galaxies' sudden bursts of activity occurred about the time the galaxies crossed the dwarf galaxy planar structures that were identified in 2013–2015. [1 *(discovery paper)*, 2, 3, 4, 5, 6].

Three galaxies in Dan Weisz's chartset have escalator-style star




This Hess Diagram from Battaglia 2012 (analysed in detail below) shows Phoenix to have a dense elliptical core whose stellar population includes nearly all of the galaxy's young populations of MS, RGB, BL, and RC(r) stars. The halo is a separate elliptical structure, angled at 80° to the core, and comprising the galaxy's older RC(b), RHB, and BHB stellar populations. The outer ellipse marks the 10.56 arcmin tidal radius (S/N >5)

formation histories: Phoenix, Fornax, and somewhat less smoothly, Leo I. Their graphs speak of continuous but low-level star formation from the earliest times to almost today. Fornax has a few stars in the 100

* EEOT = Everything Else Out There.

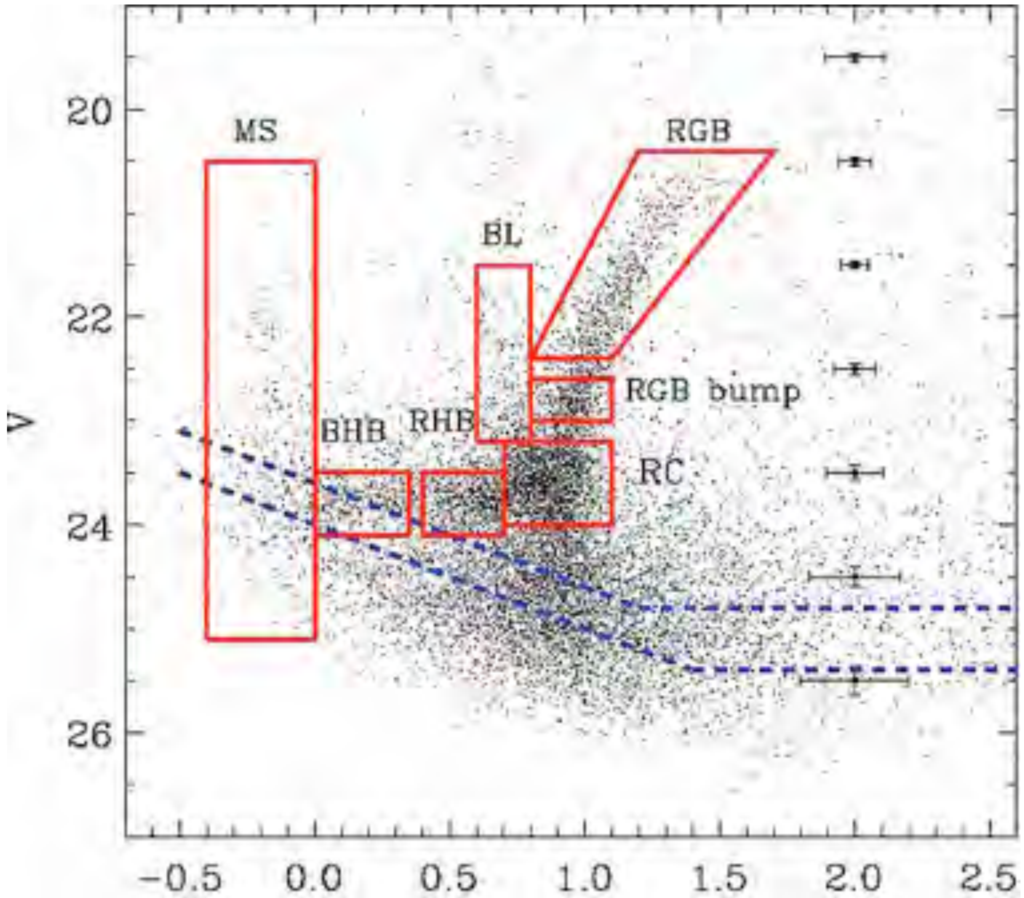
million-year age bin; Phoenix's youngest stars are in the 500 Myr range. The galaxies seem to arrived at their composite populations today in a remarkably even process that is difficult to explain given known high-velocity cloud (HVAC) abundances in the Local Group (1, 2, 3) and the orbital dynamics of dark matter aggregates as seen in cosmic simulations. (1, 2, 3, 4)

### Why is Phoenix so different?

Position is certainly one reason. Phoenix and Fornax lie in the remote outskirts of the Local Group, near the ZVS or zero-velocity-surface at which the inward pull of gravity in the Local Group is balanced by the outward tug of EEOT.*

One clue to Phoenix's starform history is the galaxy's metallicity, [Fe/H] = –1.49 (0.032 of the Sun's). Stars older than 6 Gyr have *Z* between 0.0002 and 0.0004, while the stars younger than 2 Gyr have *Z* between 0.001 and 0.002. Dwarf galaxies near large giants like the Milky Way and Andromeda evidence metallicities between –1 and –0.5 (the accepted benchmark of 0.00 is that of the Sun.)

Another clue is purely physical: Phoenix's older stars rotate around its oblate equator. But the galaxy's youngest stars ("young" at half a billion years old, which means F class stars and below) are rotating in a polar-orbit "prolate" direction. A plausible reason for this is that around one billion years ago Phoenix accreted a massive gas cloud hurtling toward it perpendicularly from above or below. The cloud would have interacted not with Phoenix's stars, but with its central gas. Enough of the cloud's inertial momentum was transmitted to the newborn stars to preserve their polar orbits after all this time.



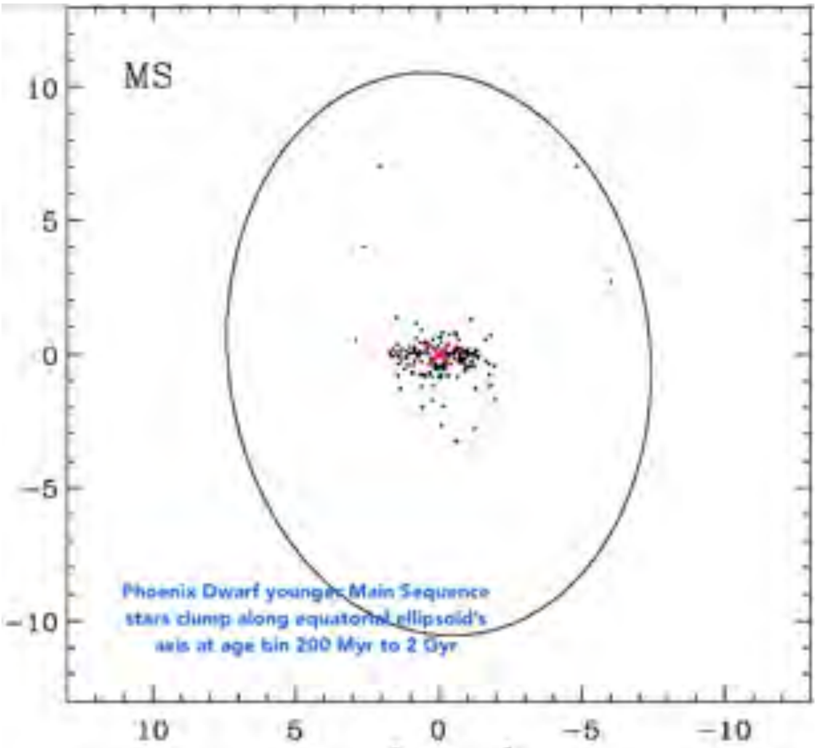

The only other Local Group galaxy that has a prolate orbital population is Andromeda II. Andromeda II was once two closely orbiting dwarfs that merged. Two merged dwarfs preserve traces of the stars' original orbital direction, plus whatever lateral vectorisation occurred in the spectacular melée of two galaxies undergoing a slow collision (transverse velocities of >10 km/sec). Think of the two populations as sea otters in a school of fish.

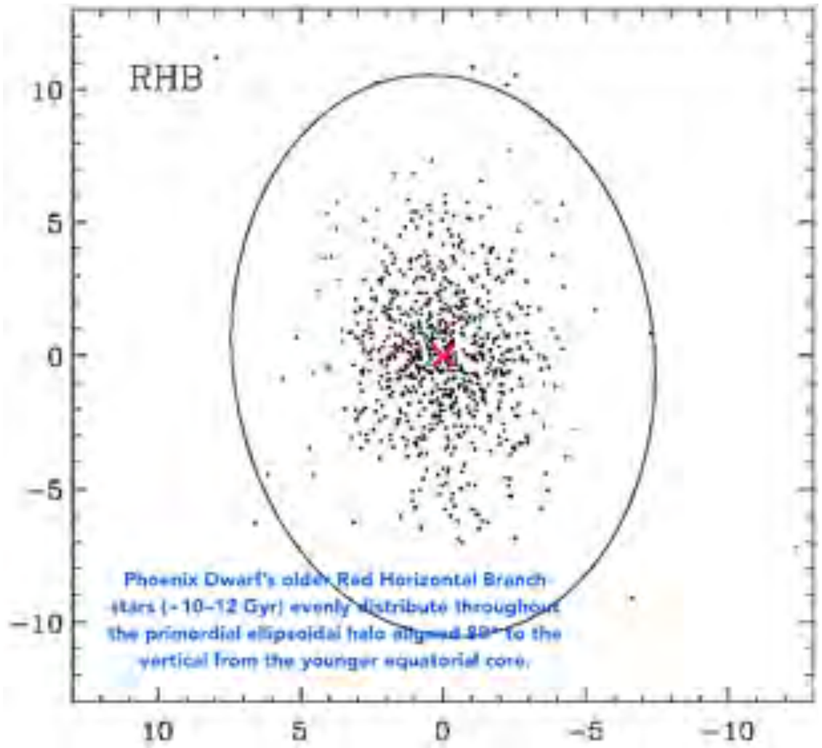
In Phoenix only the younger stars shuttle pole to pole. This suggests Phoenix had a late-stage starbirth cycle from a gas cloud that entered the galaxy on a polar path, i.e., it fell in from directly above or below. Step back and look at other Local Group dwarfs and a class; a lot of them show signs of irregular growth spurts — those punctuated equilibrium growth diagrams dotted through this report. Can there really be huge numbers of huge gas clouds lumbering about in the depths of space?

Well . . . *1, 2, 3, 4, 5*. Take the dog for a walk first.

Let's zero in on Phoenix for a better picture of these million $M_\odot$ gas clouds gadding about the galactic reach. These days Phoenix has only 3700 $M_\odot$ of HII within — not enough to form stars any more. But is surrounded by 240,000 $M_\odot$ of atomic HI gas. HI is quite unreactive; it can't form star clusters on its own. It needs an external energy source to compress it to several thousand K, where, depending on its density, it will become more energetically reactive HII molecular gas. A slide-by encounter with a galaxy will do the trick.

Phoenix appears to have four such large H clouds nearby. But are they really nearby? It's difficult enough just to detect the presence of weakly-emitting HI clouds. You need 2.6 x $10^{18}$ atoms of HI surface density to generate one Jansky of radio-band emission. By compare, our Earth's atmosphere has 1.1 x $10^{19}$ atoms per cc — but that's per



cubic centimetre, not square centimetre $cm^2$. HI clouds with $2.6 \times 10^{18}$ surface densities have three-dimensional densities of only 3 to 5 atoms per cc.

> Surface density (SD) is a square, not a cubic measure such as our own atmosphere's cc density. SD is the total number of the measured atoms (HI in this case) in a 1 $cm^2$ column between the detector and the limits of its observational sensitivity. In most cases the result is the SD of the object in question; the residual from nearby or farther sources is negligible and statistically subtracted using spectral energy distribution.

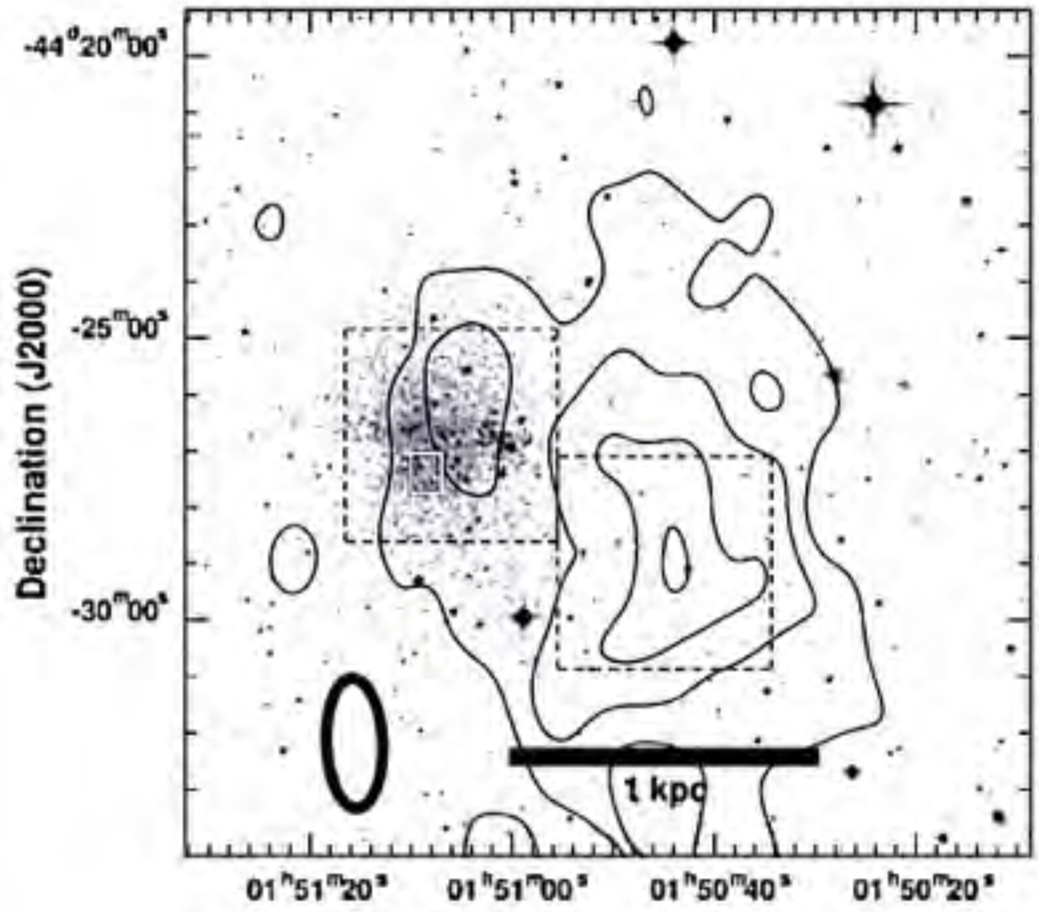
Hence while it's a challenge to find and weigh HI clouds, it is extremely difficult to pinpoint their distances. Astronomer resort to emission from water and methane masers that inhabit gas clouds in regions near stars, and OVI and OVII molecular absorption lines in background light from far far away quasars. Over 17,000 such quasars are listed in catalogs developed specifically to detect gas components of molecules which do not turn up in the gas's spectrum. (Want a fun job? Get into an astrophysics master's-degree program and you'll have two years to learn all about counting quasars in square degrees of space.)

Phoenix's radial velocity is 21 km/sec toward us. But of the four HI clouds near it, one has a heliocentric velocity of 7 km/sec, which puts it within the Milky Way. The second is receding at 140 km/sec and turns out to be part of the Magellanic Stream — an immense streamer of gas torn loose from the Small Magellanic Cloud during its most recent (100 Myr) orbital brush-by past the Large Magellanic Cloud. (See box at the top pf the next column.)

> * The SMC rotates around the LMC in 2.6 billion year cycles. At their last apogalacticon ~100 Myr ago ~40% of the SMC's remaining gas was ram-pressured from the SMC and now streams away behind it all the way to the constellation Andromeda (though not the distant galaxy there). This gas trail, the Magellanic Stream, stretches nearly 200° across the sky. Gas like this from disturbed galaxies can reveal the most unexpected histories. Today we can trace the orbit of the Magellanic Clouds around our own Milky Way all the way from where they were 100 million years ago near the Andromeda constellation. Until 2007 astronomers opined that the LMC punched through the Milky Way's outer disc, which is why the MW has a warp in its disc called the Canis Major Overdensity. Only in the last 10 years have Gurtina Besla and Nitya Kallivayalil demonstrated that the LMC–SMC duo are just now reaching apogalacticon with the MW at 160,000 ly out. (See also *1*, *2*, *3*.)

The third Phoenix HI cloud once seemed to be actually associated with the Phoenix Dwarf; it is receding from us at 59.7 km/sec — nearly the same velocity as the galaxy itself. In 1999 St-Germain et al. found that this cloud's mass and location 3900 ly south of the optical galaxy is too far away to be associated with Phoenix; it just happens to be out there, yet another CHVC face in the crowds of countless others dotted all over the Local Group and beyond.

The isophotal contours outline Phoenix's associated HI cloud 1000 pc (3260 ly) to the SW. Its wobbly cored structure is typical of the free-floating HI clouds. The shapes reflect the contours of carbon monoxide CO($1 \rightarrow 0$) transition in the 3 mm band. Carbon monoxide is the preferred tracer for HII density because it sheds emission easily, while




HII is a little less reader-friendly. The thick ellipse at bottom left is the detection field of the Australian Mopra radio telescope. It is elongated because Phoenix was at a low declination at the time of the observation. The location and –23 km/sec relative velocity of the HI cloud suggest that it was detached from the galaxy ~100 Myr ago during an encounter with another galaxy that also initiated Phoenix's most recent starburst episode.

Phoenix stellar populations mark it as a metals-poor. HB will contain stars predominantly >10 Gyr old (ancient), while the RGB stars will sample the whole stellar population mix, with the exception of the stars younger than about 1 Gyr. The younger end of the age distribution can be explored using the BL and MS stars: the MS stars above the V10, I10 limit, selected as in Fig. 8, are consistent with ages between 0.1 and 0.5 Gyr, while the selected BL stars are sampling slightly older stars, mainly 0.5–1 Gyr old. The RC contains 1–10 Gyr old stars, in a proportion changing with the SFH and metallicity of the stellar population. Stars older than 6 Gyr have Z between 0.0002 and 0.0004, while the stars younger than 2 Gyr have Z between 0.001 and 0.002. Source, Battaglia 2012.

And the fourth HI cloud? Despite a space velocity –23 km/sec slower than Phoenix, its trajectory and chemical content are consistent with having been associated with Phoenix in the past. It eased away from the galaxy after the galaxy's last star formation episode ~100 Myr ago. Astronomers suspect that the cloud was stripped by ram pressure, not from Phoenix's stars, but the thin, unrelenting, hot 2 x $10^6$ K intergalactic medium.

Galaxies, too, have their heat waves. They take more than 500 years, but rise the Phoenix does.

## Updates from the more recent papers

**Kacharov N. et al 2017, *Prolate rotation and metallicity gradient in the transforming dwarf galaxy Phoenix*; 2017MNRAS.466.2006K.**

Transition type dwarf galaxies are thought to be systems undergoing the process of transformation from a star-forming into a passively evolving dwarf, which makes them particularly suitable to study evolutionary processes driving the existence of different dwarf morphological types. Here we present results from a spectroscopic survey of ~200 individual red giant branch stars in the Phoenix dwarf, the closest transition type with a comparable luminosity to 'classical' dwarf galaxies. We measure a systemic heliocentric velocity $V_{helio} = -21.2 \pm 1.0$ km s−1.

Our survey reveals the clear presence of prolate rotation that is aligned with the peculiar spatial distribution of the youngest stars in Phoenix. We speculate that both features might have arisen from the same event, possibly an accretion of a smaller system. The evolved stellar population of Phoenix is relatively metal-poor ([Fe/H] $= -1.49 \pm 0.04$ dex) and shows a large metallicity spread ($\sigma$[Fe/H] $= 0.51 \pm 0.04$ dex), with a pronounced metallicity gradient of $-0.13 \pm 0.01$ dex arcmin$^{-1}$ similar to luminous, passive dwarf galaxies.

We also report a discovery of an extremely metal-poor star candidate in Phoenix and discuss the importance of correcting for spatial sampling when interpreting the chemical properties of galaxies with metallicity gradients. This study presents a major leap forward in our knowledge of the internal kinematics of the Phoenix transition type dwarf galaxy and the first wide area spectroscopic survey of its metallicity properties.

**Battaglia et al 2012, *A wide-area view of the Phoenix dwarf galaxy from Very Large Telescope/FORS imaging*, MNRAS 424:2 1113-1131.**

We present results from a wide-area photometric survey of the Phoenix dwarf galaxy, one of the rare dwarf irregular/dwarf spheroidal transition-type galaxies (dTs) of the Local Group (LG). These objects offer the opportunity to study the existence of possible evolutionary links between the late- and early-type LG dwarf galaxies, since the properties of dTs suggest that they may be dwarf irregulars in the process of transforming into dwarf spheroidals.

Using FORS at the Very Large Telescope (VLT), we have acquired VI photometry of Phoenix. The data reach a signal-to-noise ratio (S/N) ~ 10 just below the horizontal branch of the system and consist of a mosaic of images that covers an area of 26 × 26 arcmin$^2$ centred on the coordinates of the optical centre of the galaxy.

Examination of the colour–magnitude diagram and luminosity function revealed the presence of a bump above the red clump, consistent with being a red giant branch bump.

The deep photometry combined with the large area covered allows us to put on a secure ground the determination of the overall structural properties of the galaxy and to derive the spatial distribution of stars in different evolutionary phases and age ranges, from 0.1 Gyr to the oldest stars. The best-fitting profile to the overall stellar population is a Sérsic profile of Sérsic radius RS = 1.82 ± 0.06 arcmin and m = 0.83 ± 0.03.

We confirm that the spatial distribution of stars is found to become more and more centrally concentrated the younger the stellar population, as reported in previous studies. This is similar to the stellar population gradients found for close-by Milky Way dwarf spheroidal galaxies. We quantify such spatial variations by analysing the surface number density profiles of stellar populations in different age ranges; the parameters of the best-fitting profiles are derived, and these can provide useful constraints to models exploring the evolution of dwarf galaxies in terms of their star formation.

The disc-like distribution previously found in the central regions in Phoenix appears to be present mainly among stars younger than 1 Gyr, and absent for the stars ≳5 Gyr old, which on the other hand show a regular distribution also in the centre of the galaxy. This argues against a disc—halo structure of the type found in large spirals such as the Milky Way.

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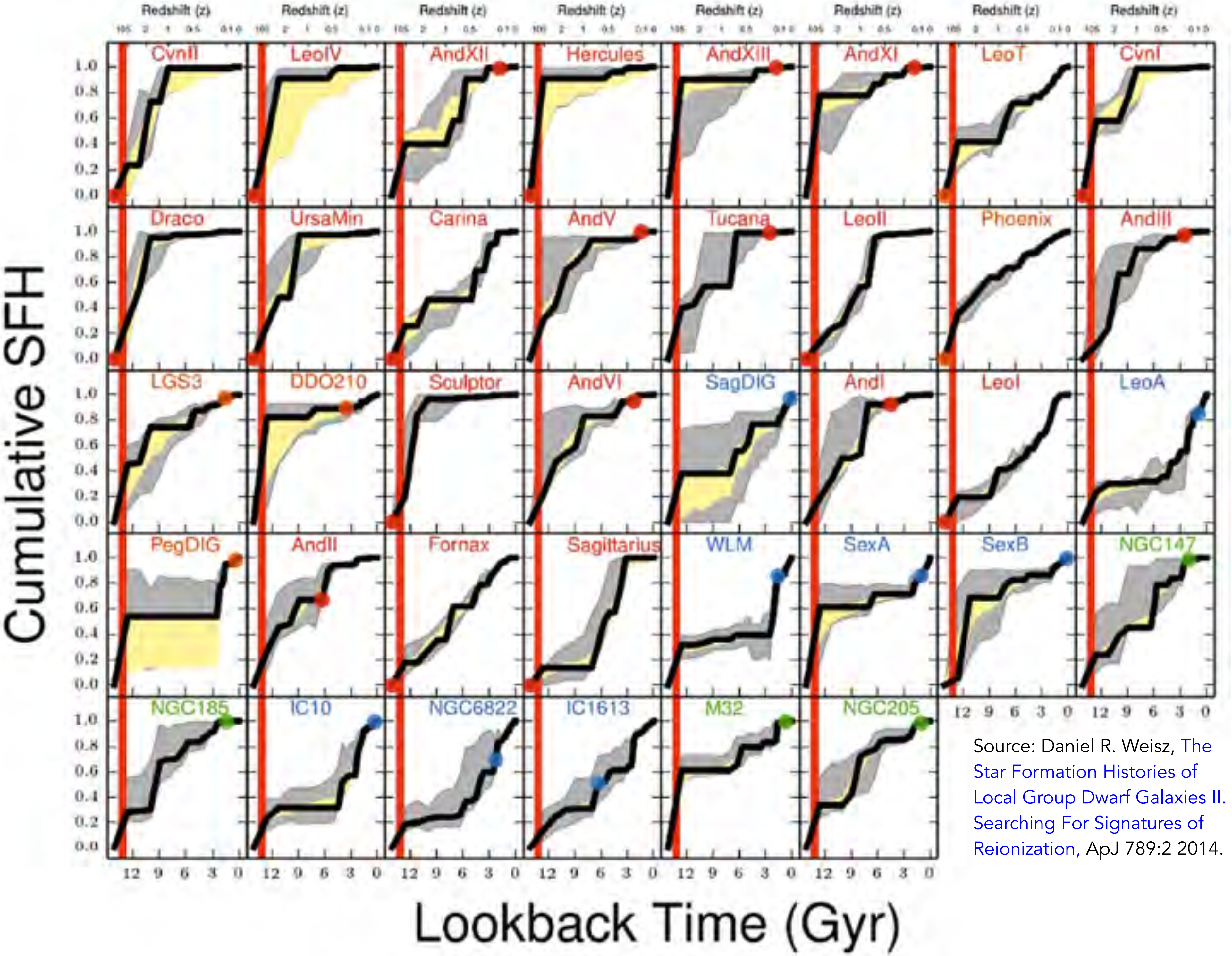
**More information about dwarf galaxies can be found on "Local Group Galaxies" in the NED IPAC Level 5 series of detailed astronomy information resources. Every Local Group dwarf is listed, with links to further research sources. Level 5 is an invaluable research tool especially for non-professionals, as it provides professional-level information without expecting you have a Ph.D. to understand it.**




Source: Daniel R. Weisz, The Star Formation Histories of Local Group Dwarf Galaxies II. Searching For Signatures of Reionization, ApJ 789:2 2014.

# Riding with the Valkyries

DOUGLAS BULLIS

Hubble Space Telescope,Hubble Heritage Team (STScI/AURA).


# O Runaway Stars
# A *Nightfall* Observer's Challenge List

Zeta Ophiuchi is traveling through the galaxy faster than our sun, at 24 km.sec (54,000 mph) relative to its surroundings.

## Who doesn't want something new to look at?

Our usual instinct is to go for objects faint and far away. But there is an observing challenge sitting before our very eyes which we haven't paid much attention to: O runaway stars. These are giant, furiously hot Class-O stars, unaccountably speeding along in near-solitude in parts of the Galaxy where they shouldn't be. They are easy to find, bright even in a pair of binoculars. They also tell a tale about stellar life styles within galaxies that we could discover no other way.

The oddities of high-velocity O stars have led some astronomers into some physically improbable dead-ends of surmise, the pursuit of which cost them considerable time, argument, and reputation, only to be vindicated by today's most advanced detection and analytical capabilities. O runaway stars may be an allegory for our belief that truth is what we insist it is.

Why should we even bother with them? They are big, bright, obvious. We can see the ones listed in *Table 1* at the end of this article, either naked eye or using inexpensive binoculars. So why the fuss? What kind of physics could we possibly learn with a pair of binoculars?

Let's take an oft-told example: The stars AE Aurigae and Mu Columbae are flying directly away from each other at velocities of over 100 km/sec each. By compare, the Sun moves through the local medium of the Milky Way at only about 20 km/sec. Tracing the two stars' motions backward to their origin, astronomers end up in the Orion Nebula about 2 million years ago. (Barnard's Loop is believed to be the remnant of the supernova that launched the other stars.)

## An O Primer

Let's begin with what is an O star, then why it left the nest to become a field star or runaway, and finally what it's going to do for the rest of its days.

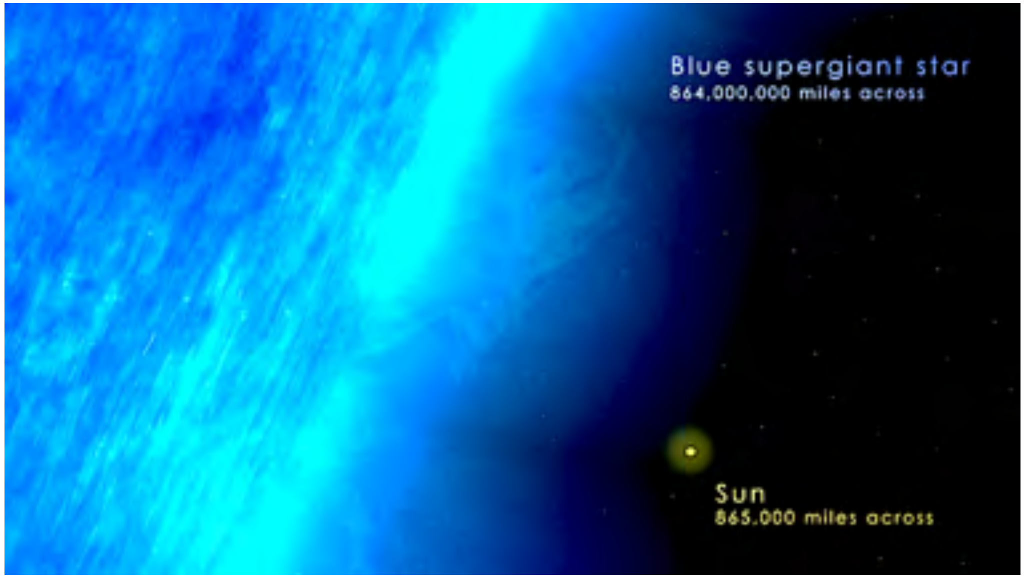
At least 634 O stars in the MW disc are considered "detached," meaning they don't appear to be associated with another object such as a star cluster.

There are many many more in our Galaxy, but the 634 catalogued examples mark the detection limit of the equipment we have today. For stars as bright as O stars, 500,000 to 1.2 million times that of the Sun, the extinction limit along the Galactic disc is roughly 6500 light years (lyr) in the $M_v$ visual band. Our lines of sight along the disc are significantly affected by dust extinctions up to 10 visual magnitudes. *(1, 2, 3, 4.)* The ***O star table*** at the end of this report lists 45 that can be seen from Earth either naked eye or in binoculars.

Massive stars are defined as stars with initial masses larger than 8 solar masses, $M_{\odot}$. They have short lives — 4 to 20 Myr — and explode as core-collapse supernovae. They change appearance and size while traversing various phases of their evolution. Born as O and early B stars, they become blue supergiants. Rigel is a blue supergiant O star, shining 117,000 time brighter than the Sun.

The most massive O stars enter the unstable phase of luminous blue variables (LBV). This class is rare, only about 20 are known; a famous one is Eta Carinae. Other O stars of various mass levels evolve into yellow hypergiants, Wolf-Rayet stars, or red supergiants before they expire in the titanic death throes of a supernova.

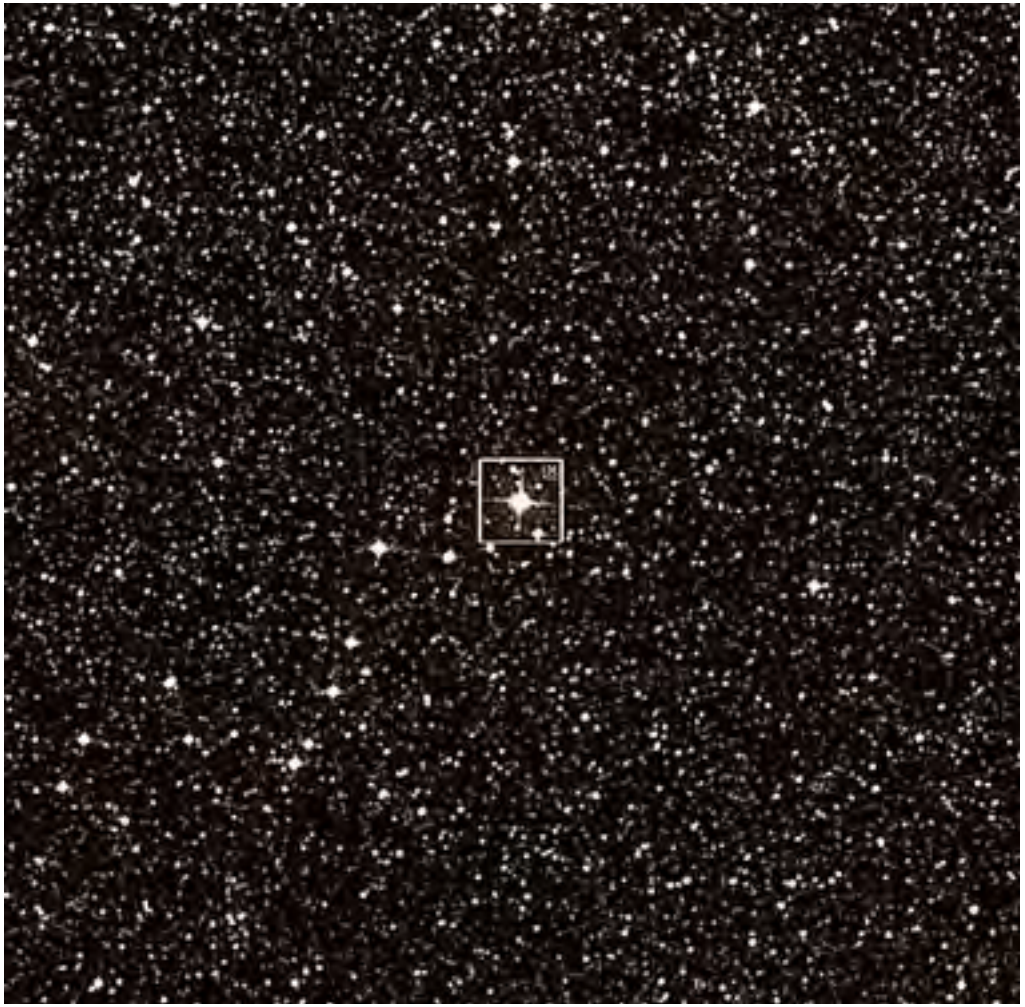
Blue supergiants play a critical role in the origins of life as we experience it. They seed their galactic garden with enormous amounts of alpha-process elements C, O, Ne, Mg, Si, S, and Ca. Any of these elements can synthesise the next heavier element (i.e., to the right on the Periodic Table) by capturing a helium nucleus or alpha particle, a reaction called alpha capture. Helium nuclei exist in great numbers in the cores of stars, but once outside the heat and density of a star core, the nuclei quickly capture free electrons to become atoms or ions. Moreover, O stars supply future star generations with heavy elements such as technetium, barium, strontium, yttrium, and even lead by convectively dredging heavy atoms up from the fusion furnace of the star's core where those elements are forged.




**Two Make a Tango, Three Make a Tangle, Four Make a Mess**

A concert pianist will tell you that Mozart is the easiest composer for a child to learn but the most difficult for a master to play. O field & runaway stars tell us the same thing. A youngster suitably equipped with a good set of charts could find many in *Table 1*. To professional astronomers those bright, intensely blue wandering pinpoints conceal perplexities that once seemed fairly straightforward, but have been revealed as far more complex by recent observations and calculations.

A few examples: Why do the most massive star clusters produce the most massive binaries? These objects dominate all other populations in the cluster, 50% to 70% of the cluster's most massive stars. Why do ~20% of them get ejected from the cluster before the cluster is a million years old? Why do small handful of supermassive O stars wander the far meridians of the Galactic reach so slowly they cannot be back-traced to a home cluster?



HD 091452 in Carina. See De Bruijne, J.H.J, & Ehlers 2012, Radial velocities for the HIPPARCOS-Gaia Hundred-Thousand-Proper-Motion project, A&A 546A, 61-61 (2012). Image courtesy of WikiSky.

Twelve years ago slow-movers like HD 091452 to the left inspired a team of astronomers (*1*, 2) to suggest that the only explanation for their solitude is that they were born as O stars *in situ* (in place) not far from where they are now. The term *in situ* implied that a very massive star formed all by itself in the middle of nowhere in what the team referred to as "one-star clusters". The implication that a ±50 $M_{\odot}$ star was somehow born in near-emptiness bearing no clues to its origins. The reaction was quick and caustic: "*Wh-a-a-t?* No gas clouds? No dust? No companion stars? *Balderdash!*"

Unfortunately for the critics, the de Wit paper was one of many published after a 2005 conference in Grenoble, *Massive Star Birth: A Crossroads of Astrophysics*, sponsored by the International Astronomical Union. (The IAU is a clearing house for international astronomy conferences.) Reading the many papers produced at that conference reveals that the *in situ* idea was advanced as a possibility and not a conjecture. Much of the negative reaction to the idea that a 25 $M_{\odot}$ star can be born all by itself was based on perception rather than a close read; moreover, most of the critics hadn't attended the conference.

The first decade of this century was a time in which one school of star cluster formation held fast to the assumption that molecular clouds are near-spheres when they enter into a spiral arm and that subsequent collapse due to shear effects takes place in a gravitationally spherical environment that gets twisted and then fragmented by torque.

The second school opined that the complex mix of forces that act on a molecular cloud were too powerful, ubiquitous, and unpredictable for any single-cause formation theory to prevail universally. Cloud collapse trends toward filamentary and clotted structures in which cluster formation occurs in multiple regions spanning millions of years, each of which significantly impacts the others. (The Lagoon Nebula, M8, is an excellent example of this broad brush painting near-chaos; see the image parsed on pages 1 & 2 of this month's *ASSA Nightfall.)* Watch it happen here.

These forces greet an innocent, pure, gas sphere like an an unschooled youth arriving at a bus station in a colossal, inhospitable city:

- torque
- shear
- tremulous high-Mach* turbulent shocks
- acting violently but on small scales
- broad density waves advancing outward from nearby star cluster gas expulsion phases
- nova and supernova blast waves
- pencil-thin polar jets from large stars undergoing initial collapse in the protostar stage; these jets are enormously corrosive to things they hit
- multiple interacting magnetic fields caused by events as diverse as cosmic ray outflow from colliding-wind binaries and cloud-scale flux tubes as the clouds flatten into other gas clouds nearby

* The term *supersonic* means that the velocity of a moving object is greater than that of the velocity of sound in the surrounding medium. While it is about 343 m/sec in the Earth's lower atmosphere, it is about 10 km/sec in the nearly empty interstellar space. Only when gas bodies traveling at supersonic velocities with respect to their medium slow to subsonic speeds can the forces of magnetic fields and gravitation act on the cloud, leading to free-fall collapse and, if there is sufficient mass, cluster formation.

The list goes on. Star formation occurs under anisotropic, stringy, clumpy, unpredictable conditions with multiple rates of change occurring concurrently throughout the cloud. It's an unholy mess.

The author W. J. de Wit added plenty of caveats for uncertainty. However, more fastidious astronomers (a category which includes quite a number of them) took exception to the very idea and published rebuttals (*1*, *2*). Some merely tut-tutted, others patronised (*3*).

Today that teapot tempest was long ago and far away. We enthusiasts with a pair of binoculars can chase O stars to our heart's content. Bright as they are in *Table 1* ($M_v$ 2.7 to 10.1), we see only a few percent of the total radiation these stars produce. Most O star radiation is emitted as ultraviolet (UV), which is beyond our visual range. We bino-bearing budding *Mozartistes* learning about the sky's bounty are rewarded in two ways: First, O stars are uncommon and unusual objects to start with. Second, they are so easily detected that we can spend many inspiring evenings under the stars armed only with a good star chart or cellphone app.

Unbound O stars in the Milky Way and other galaxies are often called "*O runaways*". The exact definitions are rather more strict. True runaways are defined as having space velocities of >40 km/sec (some argue for >30 km/sec). High-velocity runaways are fairly easy to trace backwards to the birthplace, even though they might be hundreds of light years away. Either they were ejected from their parent cluster by dynamical interactions, or they were a binary system in which one of the pair exploded in a supernova. It's not all that difficult to become a runaway — the escape velocity from a 10,000 $M_\odot$ cluster's potential well is roughly 6.5 km/sec, while ejection velocities easily attain 40 km/sec up to hundreds of km/sec.

## O B A Wandering Star

Four mechanisms can give rise to an O runaway star:

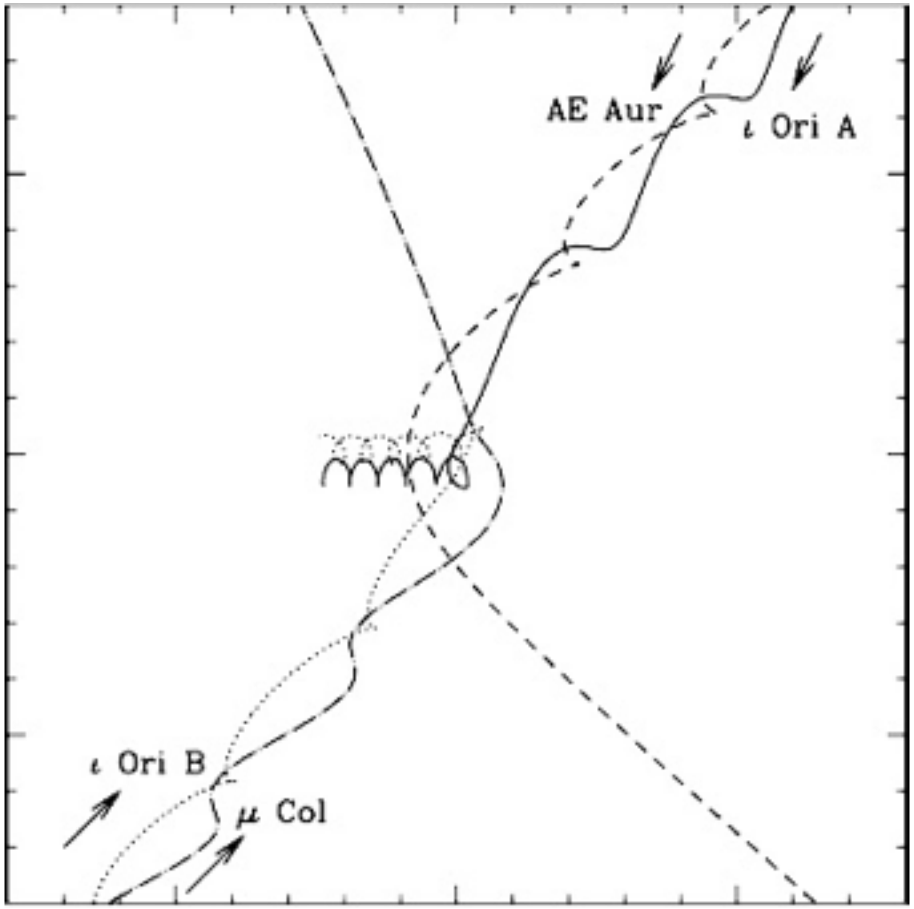
- **A close encounter between two massive binary systems** may result in the disruption of both systems. Two of the four stars are ejected at high velocities in opposite directions from each other. The other two form a new binary. The oft-cited duo Mu Columbae and

AE Aurigae both originated in a binary-binary ejection near M42.

- **A close encounter between a binary and a star more massive** than the binary's individual stars results in the binary being split apart, the least-massive star being ejected at moderate velocity, and the remaining stars forming a new binary with a wide elliptical orbit. The binary NGC 3603-A1 is an example (see linked article § 4).

- **A three-way encounter** between a massive binary and a less massive star ends up with the binary losing about 40% of its orbital energy. The energy accrues to the third star by angular momentum transfer, propelling it off on a high-speed journey at right angles to the centreline that connected the two systems. This mechanism is is referred to as dynamic ejection. Two scenarios can result. In the first, all three stars can merge into a supermassive, very short-lived star of the blue-straggler type. In the second scenario, two very massive stars of >60 $M_{\odot}$ each interact with a star even more massive, ejecting a wandering binary. If this happens in the centre of a very massive cluster, the wanderer can be accelerated to a disproportionately high velocity considering the masses involved. The 83 $M_{\odot}$ and 82 $M_{\odot}$ binary WR20a presently moving away from the 2-million-year-old, 15,000 $M_{\odot}$ cluster Westerlund 2 at 65 km/sec. (Wd 2 is the cover image on this article.)

- **In a binary supernova**, one of the two stars in a massive binary goes supernova before the other. The surviving member gets double-whammy energy injection — first, a massive shove from the detonation itself; second, when when the surviving star's angular momentum suddenly shifts from a circle to a line. The directional shift is immediate. The shock wave arrives later, depending on how far apart the stars were. It becomes a glancing blow that kicks the




Mu Col and AE Aur scattered off the massive binary Iota Orionis to become high-velocity runaways. This image shows only a small portion of the core of the cluster, where the orbits crossed paths and then scattered. Source, Gaulandris & Portegies Zwart 2004.

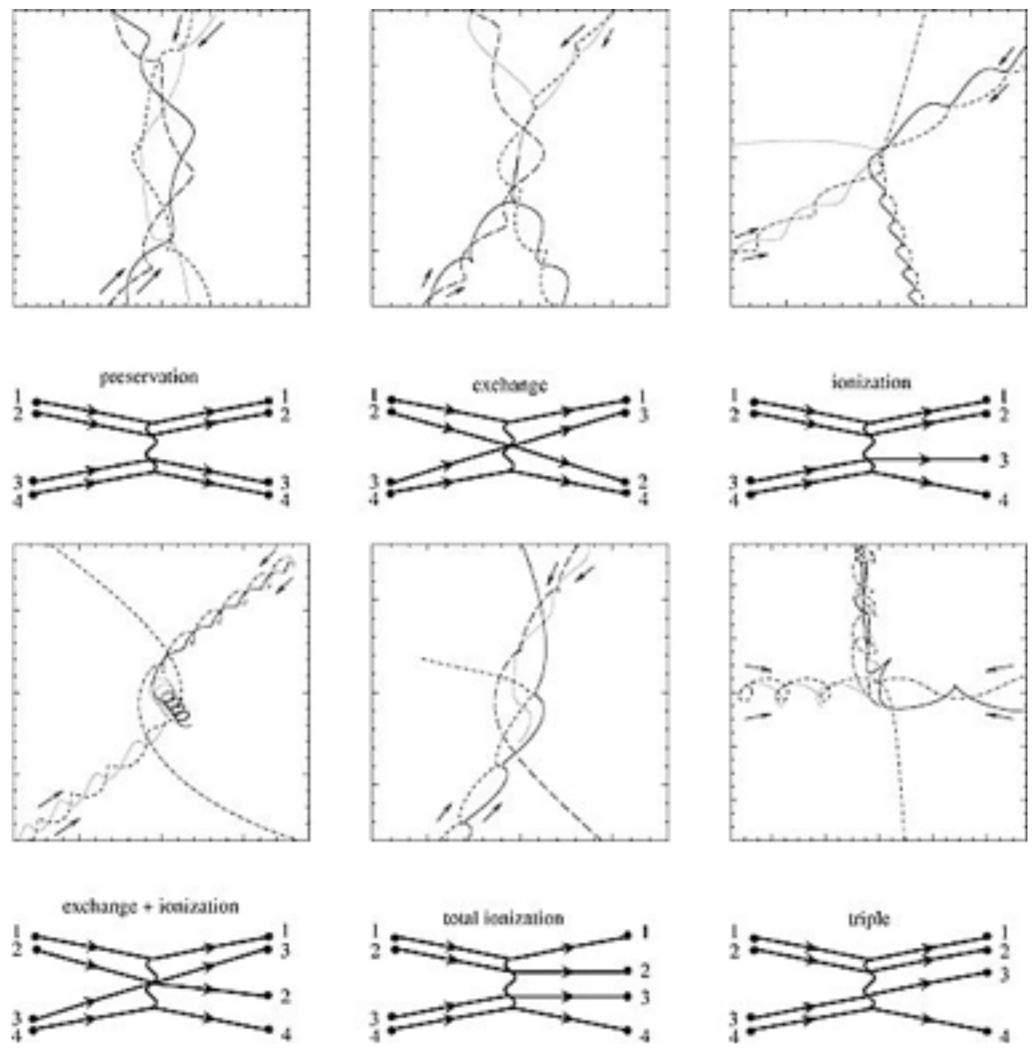
star so far off its trace-back path that we cannot deduce where the star originated. The space velocity of the O stars released in this process is the vector sum of the ejection velocity of the binary system, the orbital velocity of the star, and the kick velocity imparted to the star by the supernova remnant, a neutron star or black hole. Your guess is as good as mine where the thing ends up

> A well-known example of a related set of runaway stars is the case of AE Aurigae, 53 Arietis and Mu Columbae, all of which are moving away from each other at velocities of over 100 km/sec. For comparison, the Sun moves through the Milky Way at about 20 km/sec faster than the rotational velocity of the local spiral arm. Back-tracing the AE Aur and Mu Col motions to a common origin, their paths intersect (see high-resolution visualisation here) in the Orion Nebula Trapezium Cluster (p.9) some 2 million years ago.

## Rabbit, Run

Isolated massive O stars in the general field population tend to fall into three different categories. These roughly reflect the mass -vs- velocity structure of the original cluster stars.

**True runaways** hurtle along at velocities of >40 km/sec and are mostly the 40–120 $M_\odot$ heavyweights. Table 1 lists all the runaways we can see in a small telescope. They start their lives in a massive star cluster, from which they were ejected in wrangling scrums between a very massive binary and a wandering interloper (which might also be a binary). Commonly, this occurs within the first million or so years during the formation of a 4,600 to 20,000



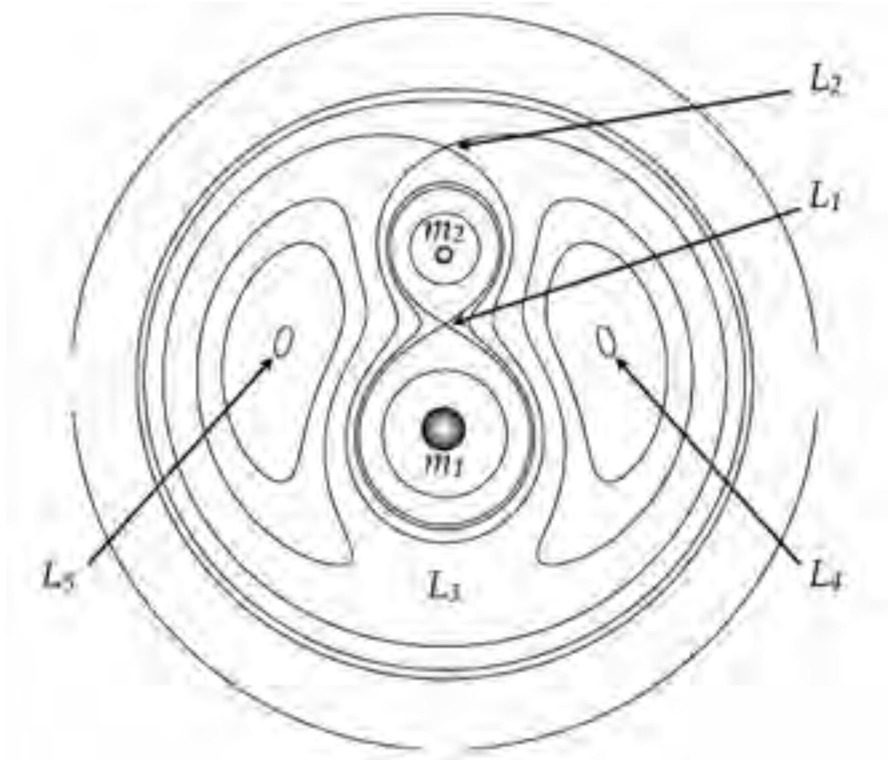

N-body simulations of stars escaping from the Orion nebula. *Source:* See Gualandris, A., Portegies Zwart, S., Eggleton, P.P., 2004, MNRAS v. 350, # 2,615–626, Fig. 2.

$M_\odot$ cluster when the cluster contracts so rapidly that astronomers refer to the process as core collapse. See Mark Krumholz's excellent series of video-like simulations of star and cluster formation: 1, initial molecular fragmentation and collapse (edge-on, face-on); 2, stars lighting up & clustering between 134,606 years and 213,752 years after free-fall collapse begins; the stars exiting offscreen are runaways ejected during the earliest stages of cluster formation; 3a, 6-panel sequence of trinary formation, 3b, sim of the same formation.

It's not difficult to become an O runaway, but very difficult to understand how they get that way. In 2011 Michiko Fujii and Simon Portegies Zwart conducted an N-body simulation which began with a pair of 16 solar-mass O stars orbiting around each other in 500 to 1000 days. The team introduced two 16 $M_\odot$ stars into the core of the cluster and assigned them ages of 1 to 4 million years. They ran various scenarios within the sim, setting the initial cluster mass, for example, at 2000 up to 4500 $M_\odot$. Sims typically compute several dozen to several hundred individual runs so astronomers can assess the interactive effects of all the parameters.

Fujii & Portegies Zwart studied star interactions only, ignoring the enormous mass of the original natal gas cloud that never made it into stars. On average a star cluster only uses up 3% to 5% of the total gas supply of the molecular cloud from which it was made. The rest diffuses back into space to eventually be reused. In most cluster formation, the unused natal gas is blown away within the first couple of million years.

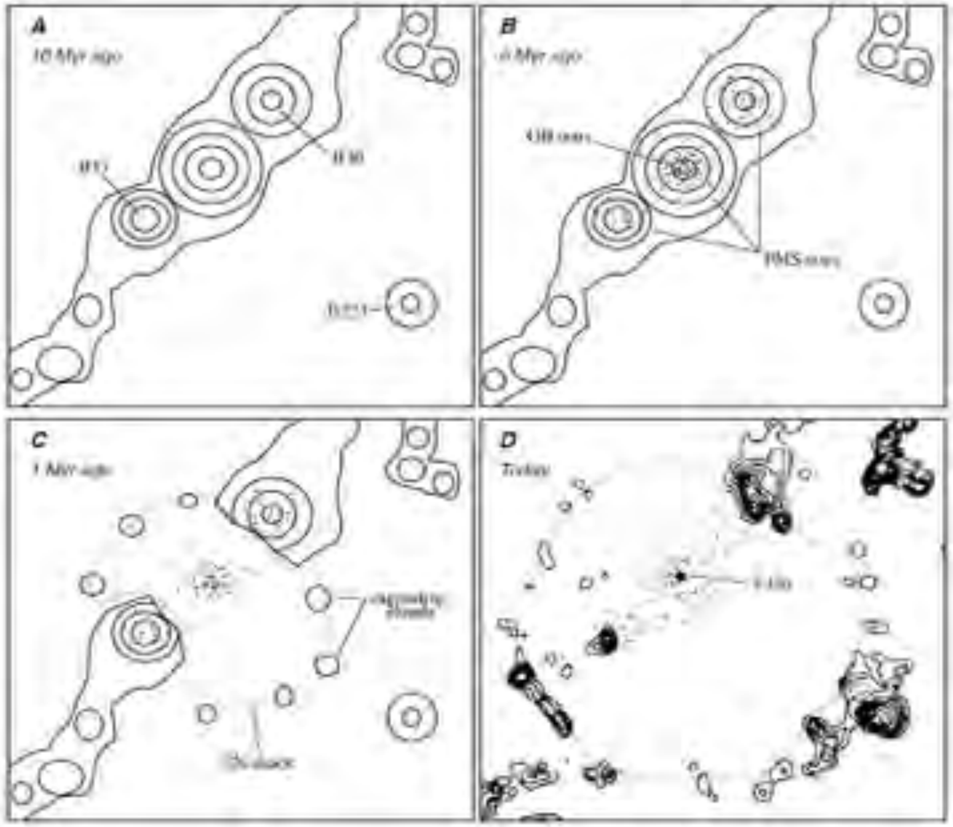
Roughly half the O and B stars in the Fuji & Portegies Zwart *N*-sim were binaries, about average for a mid-sized cluster. One of those core binaries outweighed the rest. It became the dominant force affecting all other stars in the cluster core. In real star clusters there is always one most-massive binary living at the heart of the cluster. The orbits of core binaries are circularised by nonstop interactions with other massive stars, a process called "hardening". Eventually the most massive pair becomes so hard it well earns its sobriquet Bully Binary (BB).




A binary star's dynamical cross-section is the region defined by the outer figure-8 encircling the two stars in this drawing. The inner figure-8, called the Roche Lobe, is almost congruent with the dynamical cross section but a bit smaller. The *Roche Lobe* defines the region within which orbiting material is gravitationally bound to that star. Conversely, the *dynamic cross-section* defines the potential capture radius of stars approaching from outside. L1 through L5 are Lagrangian points where the net gravitational potential of the two large masses nulls out the centripetal force required to orbit with them. See this article by M. J. Benacquista & J. M. B. Downing for comprehensive details of binary star dynamics. Their article is nominally about globular binaries, but binaries in massive young clusters live by many of the same rules. The MODEST web group is a consortium of computation and analytical specialists devoted to modelling the dynamics of multi-star system.



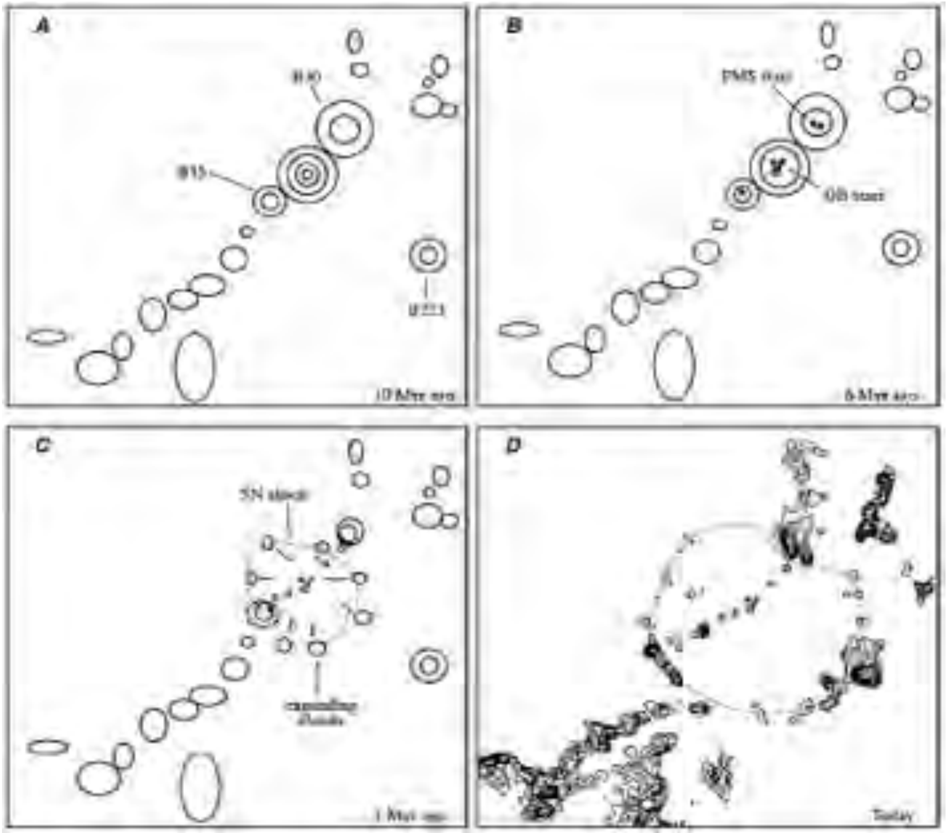
Then Fujii and Portegies Zwart injected a third 16 $M_{\odot}$ star, aimed directly at the core BB. The three stars entered into a complex lissajous dance whose final thank-you-ma'am was one of the three (usually the lightest) being flung clean out of the cluster at >30 km/sec. The remaining pair lost up to 40% of their binding energy. The lost energy was transferred to the ejectee by the angular momentum. The BB's orbit then shrank and hardened again.




Most star clusters originate in dense filamentary gas threads so often seen in astro-images. The most massive and thus hottest cluster creates a bubble of hot gas that crunches into the cold gas around it, triggering second-generation clusters.

## Neighbourhood toughs

Since a cluster's heaviest stars naturally gravitate to the core of the cluster, a resident bully binary will eventually reduce a significant amount of the cluster's overall mass. A BB can eject up to 23 smaller stars before it loses so much binding energy it can't hold itself together any longer. It then either self-ejects as a wandering binary, or melts into the cluster's general




Very compact high-mass gas clouds collapse into clusters of high-mass O and B stars which radiate enormous amounts of UV radiation. This initiates a rapid gas-clearing shock wave. Supernovae compress the ring into arcs of clusters.

population. But by then the BB's havoc has devastated the cluster. It loses so much stellar mass in the core that it can no longer retain all its small-fry stars (like our Sun) out in the halo. The lightweight stars diffuse into the galaxy's disc, first as a moving group, then an association, and finally footloose and fancy-free (like our Sun).

There's a local angle to all this. The Sun once belonged to a star cluster of about 4,000 $M_\odot$. Today, after considerable effort and pricey computer time, astronomer's have found exactly one star out of those several thousand Solar siblings — the star F Hercules. You can spot it in a pair of binoculars.

The $M_V$ 6.8 star HD124314 in Centaurus is a post-supernova binary (not a single star as is usually the case) that was turned from a typical fast-mover to a slowpoke. The pair were ejected along with a more massive single star as a trinary. When the massive star detonated into a supernova, the smaller star's velocity was reduced by the kick of the supernova explosion and redirected into a different, untraceable vector.

The orbital diameters and differing masses of a bully binary play a significant role in how many stars it will eject, how frequently, and for how long. The region in which a BB can be destructive is called its orbital cross-section. The most prolific type of binary producing massive runaways are supermassive stars in the central core with relatively wide orbits between 1000 and 10,000 AU (astronomical units). A long-radius orbit has a greater cross-section within which to interact, but its effective energy density $E_{eff}$ weakens with distance.

Binaries are produced naturally by the cluster formation process, or more accurately the kinetic heating effect of gravitational collapse. Once a binary enters the centre of the cluster, it hardens by ejecting hapless interlopers, becoming more circular, less elliptical, and therefore more impenetrable, or "hard". A hardening binary in turn hardens the cluster's core by more efficiently ejecting the cluster's most massive stars and circularising the orbits of the other stars. A cluster core density of 47,000 $M_\odot$ per cubic parsec (34.6 cubic light years) is typical for a cluster after its first core collapse. You can view the dynamics of star cluster core collapse in this 3-D ESO sim.

Core collapse has the unintended consequence of rendering the cluster gravitationally weaker. Low-mass stars evaporate from the halo through the funnels of the L1 and L3 Lagrange points. This in turn induces core to contract ever further, again and again, in a fruitless attempt to achieve gravitational balance. It's like entering a casino with a fat wallet: every time you spin the roulette, your wallet gets thinner. There's a limit to just how many stars a bully binary can eject before its own orbit and potential (gravitational well) are weakened. Since energy is never destroyed, the binary's binding energy (angular momentum) adds to the kinetic energy (velocity) of the ejected star; that's where ejected stars get their whizz. For more information about *N*-body sims, see *1, 2, 3*.

Massive binaries with very short periods <10 days have such small gravitational cross-sections that most never undergo a dynamical energy exchange with another cluster member. Such binaries are considered primordial and likely to remain bound for their entire lives. Only a very strong interaction with a high-mass star can cause a merger of all three stars into a blue straggler. Stars can merge if their orbits become smaller than the stars' Roche limits. They begin to exchange envelope mass via their Roche Lobes, until so much has exchanged their cores finally melt into each other as blue stragglers. By the time the exchange is complete the stars have ejected a considerable proportion of their mass; their combined masses are, on average, 70–80% of their mass as a pair. See *1, 2, 3*.

There is a less-common class of blue straggler called yellow straddlers. These originate when the binary comprises one large massive star that has gravitationally captured a second much smaller star. If they eventually merge, they do not continue up the main sequence like blue stragglers, but rather burn longer at the same temperature and luminosity — that is, they rise straight up by 0.7 magnitude on their colour-magnitude diagram before hydrogen flame-out initiates the long haul up into the red giant phase.

Relatively wide and massive binaries whose orbital periods are ±1000 days are the most efficient at ejecting stars from the cluster. Between 25% & 35% of O stars are ejected from very young clusters <1 Myr. The mass loss is greatest if the cluster was highly concentrated at the time of its free-fall collapse. Since a cluster generates one runaway-producing Bully Binary during each core collapse, the relative fraction of runaways is inversely proportional to the mass of the cluster. Massive star ejection begins before its gas ejection phase, between 300,000 and two million years.

A star cluster loses a considerable proportion of its mass when its O stars are ejected. Typically the mass loss is 60–80% of the cluster's initial mass during the first 260 Myr of its evolution. Around half that occurs in the first 5 to 10 million years when its first hot young stars eject the cluster's natal gas, the portion of the original cloud that wasn't consumed during star formation.

Gas-clearing is not the only mass loss a star cluster endures in its youth. Dynamical loss includes stars ejected in binary encounters as described above and supernovae ejecta. Additional mass loss occurs from the stars' fusion processes, i.e., atoms and ions hurled out by the star's hot surface radiation. Even more mass is lost to dynamical evaporation as individual stars wreak havoc on each other during random-walk interactions. When the cluster core collapses its larger stars sink toward the centre, allowing the low-mass stars in the halo to drift away from the outskirts into the galaxy as a whole.

Those stars just don't wander off willy-nilly. Their orbital vector must be aimed at one of the cluster's Lagrangian Points, L1 or L3, and also exceeding the escape velocity from the cluster's potential well. This is a rare occasion where you can escape the clutches of the law by exceeding the speed limit. ("Officer, I was just obeying the Virial Theorem. Mr. Clausius said I could." You've got problems if the officer replies, "Sir, the law says 1/2 $mv^2$ and you were going more than twice that.")

In the first 10 million years the overall toll on the cluster is fierce. A cluster's half-life — the period in which half the original cluster members are lost — ranges from 150 to 800 million years, depending on the cluster's initial stellar density. More tightly packed clusters persist longer. The Double Cluster in Perseus is about 12.8 Myr old, the Pleiades about 110 Myr old (estimates vary), and at the opposite end of the scale, M67 in Cancer, NGC 6791 in Lyra, and Collinder 261 in Musca are over 6 billion years old. It comes as little surprise when observing the latter three clusters that they look very sparse, dim, and frail. Looks are deceiving. You have to be a pretty tough old buzzard to survive what a galaxy throws at you.

M67 lies at such a high angle from the Galactic plane (31.8°) that it was either stripped from an accreted dwarf galaxy, or it formed from a very massive high-velocity cloud penetrating into the nascent Milky Way from far above or below. (Blanco I in Sculptor is another of these, although it is only a few hundred million years old.)

NGC 6791 likewise lies well above the Galactic plane, but, like Collinder 261 in Musca, it also resides near the Milky Way's co-rotation radius. That is where the rotational velocity of stars circling the galaxy matches the rotational velocity of the spiral density wave. Our Sun likewise resides near the corotation radius, whose tangent vector is 1.06 times the Sun's.

In most cases, the cluster eventually thins into a stream of unbound stars too distant from each other to be a cluster but still a group moving in similar directions at similar speeds.

## *Bullied stars turn into bullies themselves*

Morality isn't quite the same out there in space space as it is down here amid your average church bake sale. Even laze-along O field stars are tough customers. Gas dynamics differs from social dynamics in several ways.

First, stars ejected by multi-star interaction in a cluster are runaways in a very real sense: a 20 or 30 $M_{\odot}$ star moving at 40 to several hundred km / sec

### Lonesome Cowboys

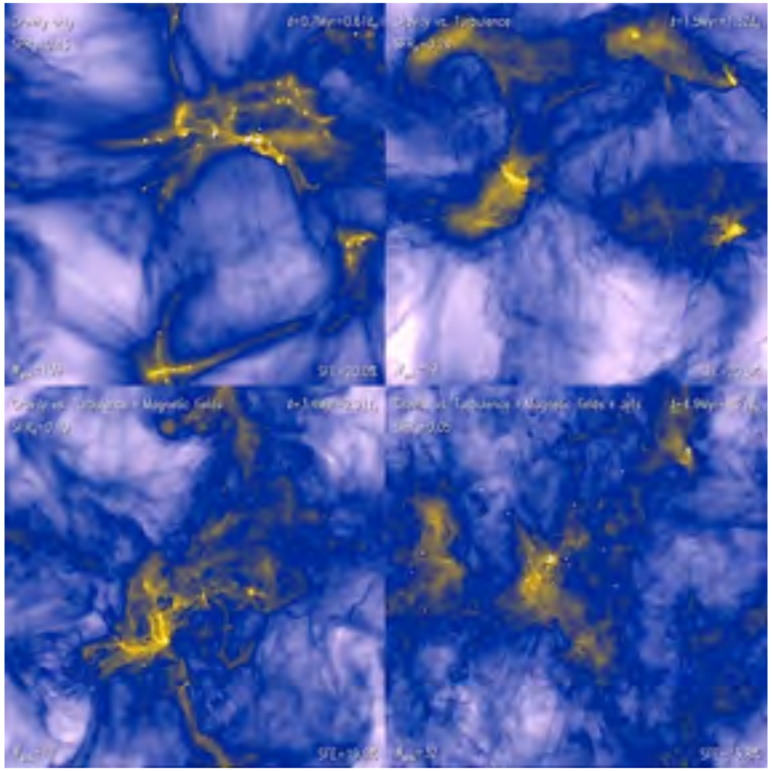
**Field runaways** are the high-velocity club's more leisurely cousins. They travel between >5 and <40 km / sec. Many can be traced to their birth clusters, but a subclass of them can't be traced to anything.

O stars just passing through would be perfect neighbours — except that they shine at 500,000 to 1.2 million times the intensity of the sun. If one plunked down in place of the Sun, we would be toast before we knew it. The world's oceans would evaporate in a few weeks.

To we backyard observers at our telescopes, high-velocity O stars are almost — but not quite — motionless. If we had, say, a spare century available on our observing schedules, we might note that a few are moving along at a pretty fair clip — 3 or 4 arc seconds per 100 years for the fastest ones in the accompanying table. Theirs is a race where the lithe, limber chaps haven't as keen a chance as the heavyweights.

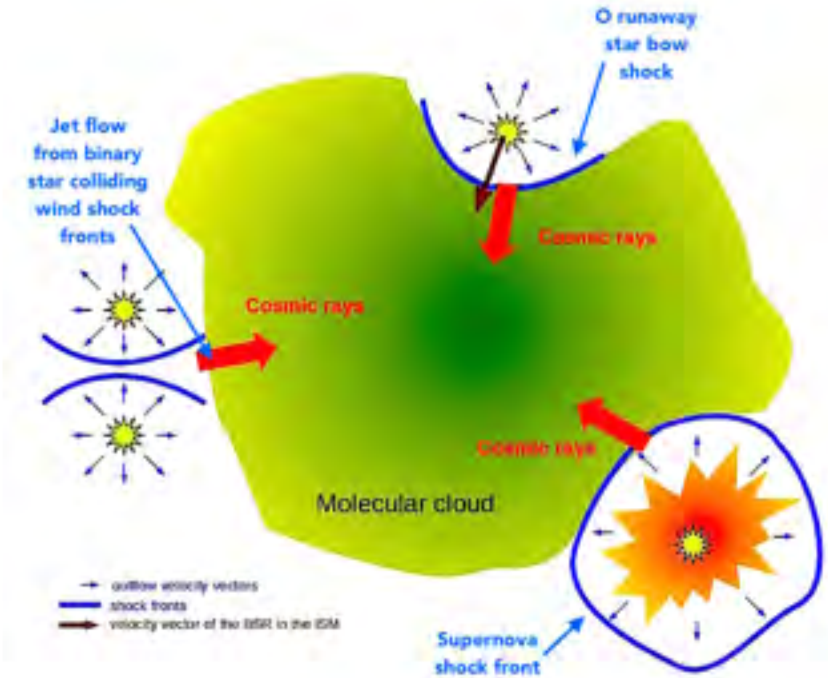
### O Solo Mio

***In-situ* field stars** are such slow movers (<10 km / sec) that they are, along our sight lines, not doing much. "*In-situ*" means "in place". They are true O Solo Mio objects that can't be traced to an origin. In the early 2000s a number of astronomers advanced the view that these slow-movers did not travel there, they formed there. This proved unsupportable given the ground-based equipment and limited capability of modelling algorithms available at the time. Many of the wanderers were found to evidence bow wakes, which seemed like a definitive refutation of pre-Hipparcos vector-estimating methods. But today, with millimetre- and micron-band radio telescope arrays like ALMA and Plateau de Bure, plus x-ray telescopes like GALEX and Spitzer in orbit; as well as sophisticated adaptive mesh algorithms, the idea of massive star living and dying alone is being revived. Watch this space.



Interaction of four star-forming forces on a proto cluster. Each force is considered in isolation, then added to the previous ones to show the net effect on the final cluster. *Top L*: gravitation only. *Top R*: Grav. & magnetic fields. *Bot.L*: Grav & magn fields plus turbulence. *Bot.R*: The divisive affects of polar jets on all other influences. From Federrath 2012 & also 2013.


This O runaway is the well-known Alpha Camelopardalis (α Cam), an easy naked-eye runaway. α Cam is moving supersonically at 60–70 km/sec relative to the gas in front of it. Like most shock fronts, Alpha Cam's bow can't be seen in visible light. This WISE IR image reveals its arc of heated gas and dust. The heating isn't caused by the star's high velocity because the gas medium through which a Cam is hurtling is so thin (interstellar gas averages 5 to 10 particles per $cm^2$). α Cam is an O supergiant that emits a powerful high-velocity wind which in effect multiplies the forward velocity of the star. When α Cam's furiously outflowing wind slams into the interstellar medium, the effect is like the shock wave in front of a supersonic airplane. An arc of superheated gas forms, which we detect in near and IR wavebands.




Large hydrogen clouds pepper interstellar space. Most originate outside a galaxy and are pulled in by gravity. When they enter the galaxy disc plane it is not a friendly place. The disc is rotating, so torque and shear compress and twist the cloud. It is penetrated by a weak but all-pervasive magnetic field that threads the spiral arms. Supernovae blasts compress and heat the cloud along bubble-like shock front. Any wandering O or B supergiants that hurtle through also produce a shock front that shock-heats the cloud. Binary stars radiate energy and particles. Compact, fast rotating, high-mass binaries create colliding-wind fronts which stream jets of high-velocity, high-temperature gas into the cloud like a drill. The cloud is attacked by blast waves of hot gas from star-clusters' gas clearing phase. These forces all act to compress and break up the cloud into filamentary structures and dense lumps. As divisive as these forces are, they are necessary for the cloud to compact in multiple tiny pockets, where gravity can overcome all other forces until the cloud free-falls into a star-forming region. Half a million later the first star cluster is shining.

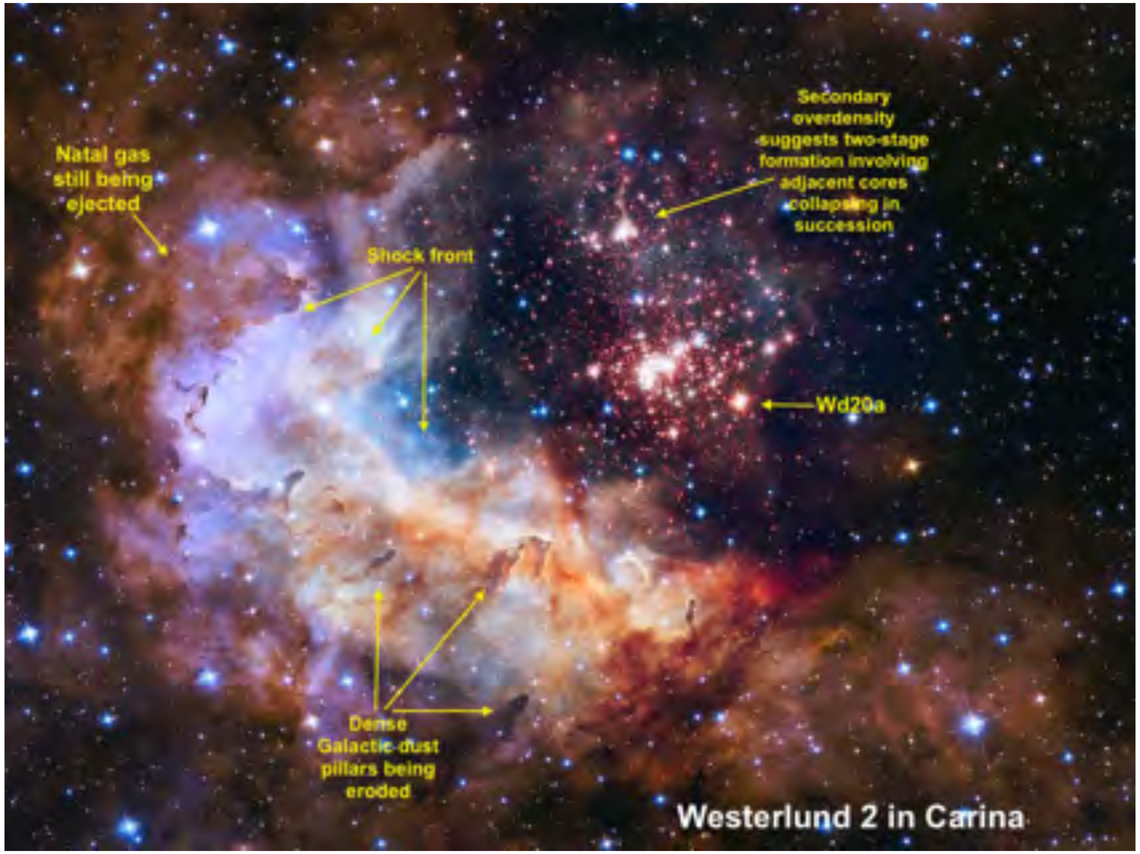
## *The Thousand Stings of Withering Linger*

The star cluster Westerlund 2 is >2 million years old and resides in the Gum 29 star-forming overdensity 20,000 light-years away in the Scutum-Carina spiral arm. Wd2's colour-magnitude diagram (CMD) looks more like a ladder than a main sequence. It contains some of the brightest, hottest, most massive stars in our Galaxy. As can be seen in the image, Wd2's birth gas has been cleared entirely from the main body of the cluster, though some remains mixed with one of the multitude of dense gas and dust clumps of the region.

Dense, dusty gas clouds in the Wd2 environs are numerous and severely fragmented. This points to a region undergoing considerable high-velocity turbulent shock fronts from supernovae, magnetic fields, shear and torque forces from the underlying spiral arm, and jets from infant stars ejecting excess accretion matter. Watch all these processes going on at once here.

Astronomers are uncertain whether a second stellar overdensity visible on the image is actually associated with the main Wd2 cluster; the uncertainty is associated with the complex dust extinction structures in the area. The main cluster is reddened by 2.3 *E*(*B* – *V*) photometric magnitudes, while the stellar overdensity N of it is reddened *E*(*B* – *V*) = 4.7 magnitudes.

Wd2 is one of the three hottest, densest supermassive young clusters (SSCs) in our Galaxy. The others are Westerlund 1 and NGC 3603. [The Milky Way bulge sports five more super star clusters like Wd2, named Arches, Quintuplet, Central, RSCG1, and RSCG2. These were formed by entirely different galaxy formation physics than the disc SSCs and will be treated in a future *Nightfall* article.]

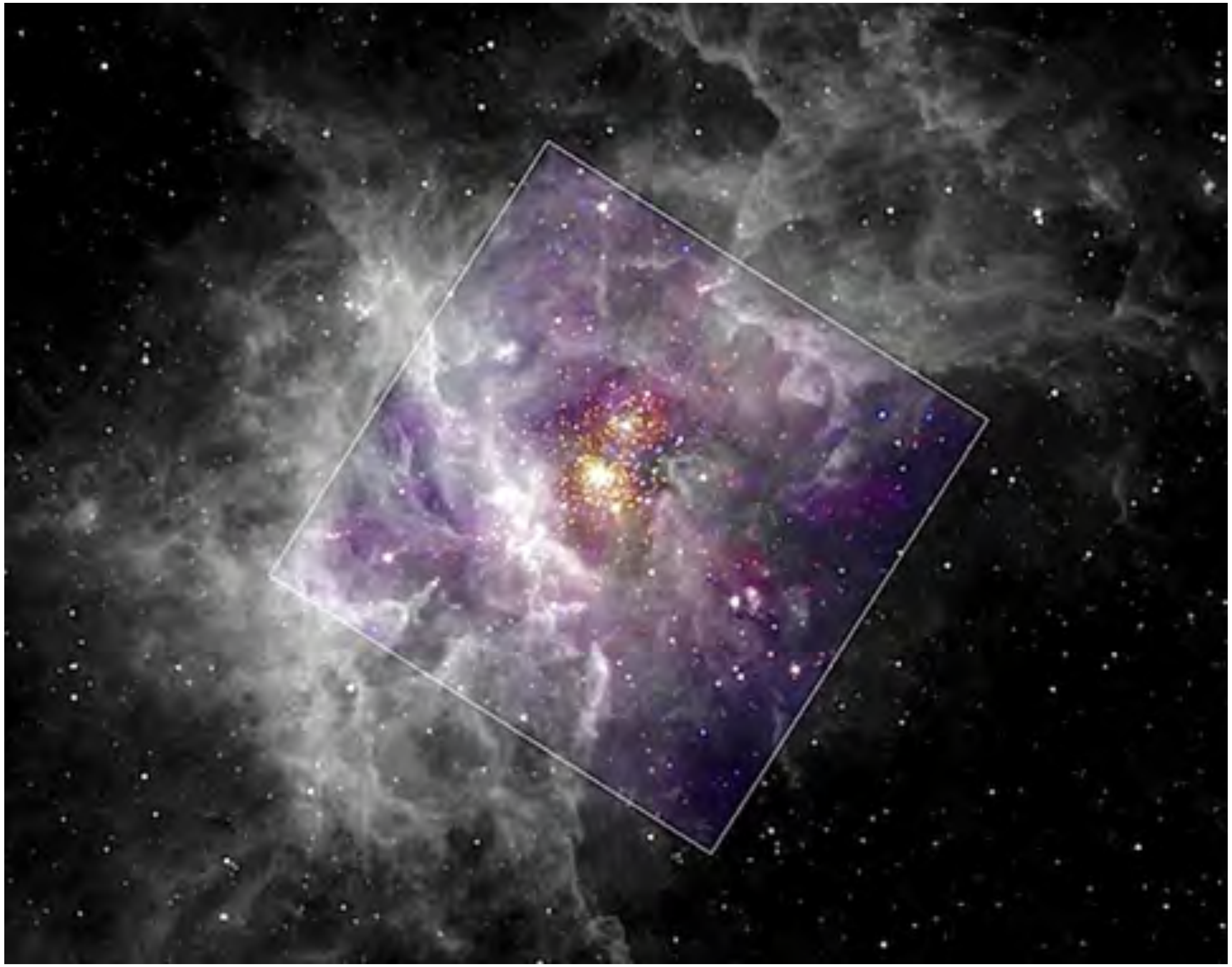



Source: Hubble Space Telescope, STSI.

To the amateur, Westerlund 2 is a difficult object. It is so faint that it looks more like an asterism. The eyepiece impression looks like somebody stomped on the Trapezium. The cluster contains at least a dozen early O stars whose $T_{eff}$ surface temperatures are >38,000 K and more luminous than 230,000 Suns ($L_\odot$). There are 20 older and less luminous O class stars in the cluster, all main sequence objects, plus a very large number of <2.5 $M_\odot$ pre-main sequence stars whose cores have not yet ignited into hydrogen fusion. These latter stars constrain the age of the cluster to ± 2 Myr.

Some of Wd2's progeny are spectacular. Several Wolf–Rayet stars are associated with the cluster, although not in the core. WR20a is a binary of two Wolf-Rayet (WR) stars (which we will look at more closely below),WR20aa, WR20b, and WR20c are all single massive stars whose photometric vectors suggest they are very early runaways from the cluster. The Wolf Rayets are extremely young massive objects of the OIf*/WN spectral types, which makes them amongst the most luminous stars in the Galaxy. Stars of this category are very massive hydrogen-burning stars that are dredging nitrogen and helium to the surface in giant convection bubbles. WRs are very unstable, hurling off violent stellar winds which seed the galactic medium with Nitrogen; WRs are a significant source of this element on Earth.

The image to the right shows Wd2's significant micron-band emission that highlights dust, and far IR emission, which traces thermal densities and therefore gas cloud densities. Now we can clearly see that the secondary overdensity to the N is indeed an associated cluster, likely brought about when a pair of gravitationally associated high-mass gas clouds both initiated free-fall collapse at about the same time. Unfortunately, this region is so riven with differential dust extinction that meaningful conclusions cannot be drawn without more detailed thermal photometric data.



Here we easily notice the effects of differential extinction caused by nonluminous filamentary and pillar-like structures. The paired-cluster appearance of Wd2 is due in good part by a band of dust dividing them. Wd2 has begun to expel its natal gas, but it's no Pleiades yet. Image source: *NASA*, *APOD.*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**Get your gear, mates.**

**We got riding to do.**

| Observer's Challenge Catalog of O Field & Runaway Stars | | | | |
|---|---|---|---|---|
| **ID / link to CDS portal** | **Mag, Class, Distance LY, Surface temp K** | **RA** (*link = SIMBAD page*) **Dec** (*link = Aladin page)*<br><br>**Constellation** | **Binarity / Proper Motion (PM) in km/sec** (where 0–39 km/sec = field star, 40 more more km/sec = runaway) | Additional data, sources, references. *Note: Refs to nearby star overdensities lack metallicity data, so relation to star cannot be determined.* |
| HD 001337 (AO Cass) | $M_V$ 5.90 O9.5 III + O8V 6846 ly $T_{eff}$ 33,000 K | 00 17 43.06 +51 25 59<br><br>Cassiopia | Single, PM -31.1 km/sec receding | 750 pc below the Galactic plane, no young clusters within 65 pc (212 lyr) radius (Bagnuolo & Gies 1991, Gies & Wiggs 1991). |
| HD 015137 | $M_V$ 7.87 O9.5II 11080 ly $T_{eff}$ 33,000 | 02 27+52 32 57.5 59.8<br><br>Perseus | Double-line spectro binary PM -48.4 km/sec receding | No young stellar clusters or stars earlier than B5 within a 65 pc (212 lyr) radius.(Prinja et al. 1997). |
| HD 036879 | $M_V$ 7.57 O7V(n) 5210 $T_{eff}$ 36,500 | 05 35 40.5 +21 24 11.7<br><br>Taurus | Spectro single, irreg Si IV lines sugg hot stellar winds evap nearby PAH / dust clouds. PM +26.60 km/sec approaching | Lone B2 star HD 24310 22.8 lyr dist, no vector avail, T-Tauri star 32.5 lyr (de Kool & de Jong 1985). No clusters within 65 pc (212 lyr) radius. |
| HD 039680 | $M_V$ 7.94 O6V(n) 8800 $T_{eff}$ 28,500 | 05 54 44.7 +13 51 17.0<br><br>Orion | Double-peak Balmer spectr double PM +18.4 km/sec approaching | Emission line double (Gies & Bolton 1986) w/IR excess, fm free-free emission. Marchenko et al. (1998) sugg Be-type photometric variation; no cluster w/in 65pc or visual radius 100 arcmin (70 pc, 227 lyr). |
| HD 041161 | $M_V$ 6.77 O8Vn 15520 $T_{eff}$ 34,500 | 06 05 52.4 +48 14 57.4<br><br>Auriga | Vis binary 9.8 arcsec, PM = -16.4 km/sec receding | IR bow shock near this system sugg high lateral spatial velocities lateral to PM; located rather above Galactic plane. V.likely multi-body ejection runaway. (Noriega-Crespo et al. 1997). |
| HD 048279 | $M_V$ 7.86 O8V 6520 $T_{eff}$ 34,500 | 06 42 40.5 +01 42 58.2<br><br>Monocerous | Poss 4-star multiple, IRAS 06400+ 0146 hints bow shock, unconfirmed in mm band, PM -19.80 km/sec receding | Lies 1.6 kpc (5216 lyr) behind MonOB2 field (Mel'Nik & Efremov 1995); membership is not clear. Young cluster Dolidze 25 lies 6.5 pc (20,500 ltr, radial vel -70 km/sec) SW, no other clusters in 65 pc 212 lyr radius. |
| HD 052266 | $M_V$ 7.23 O9IV(n) 1580 $T_{eff}$ 33,000 | 07 00 21.0 -05 49 35.9<br><br>Monocerous | Poss spectro binary. | Lies 1 kpc (3260 lyr) fm CMa OB1 Assn (Kaltcheva & Hilditch 2000). Poss stellar overdensity in Hipparchose not vis. in 2MASS density maps. |

| Observer's Challenge Catalog of O Field & Runaway Stars | | | | |
|---|---|---|---|---|
| HD 052533 | $M_V$ 7.67<br>O8.5V<br>10540<br>$T_{eff}$ 34,000 | 07 01 27.0<br>-03 07 03.2<br><br>Monocerous | Optic & spectro multiple;<br>PM +74.6 km /sec receding | HD 052533 is 3.3-day spectro binary (Gies & Bolton 1986), 50 arcsec fm B1 star HD 052504 w/60 micron excess (Noriega-Crespo 1997). 2MASS image & NTT $K_s$ band sugg cluster-like overdensity. |
| HD 057682 | $M_V$ 6.43<br>O9IV<br>5216<br>$T_{eff}$ 33,500 | 07 22 02.1<br>-08 58 45.7<br><br>Monocerous | Single,<br>PM +24.0 km/sec receding | Runaway, bow shock vis. in IR, slow rotation of 33 km/sec @ equator sugg strongly magnetized variable Oe star w/polar align. toward Earth |
| HD 060848<br>BN Gem | $M_V$ 6.87<br>O8V<br>1620<br>$T_{eff}$ 34,500 | 07 37 05.7<br>+16 54 15.2<br><br>Gemini | Unknown multiplicity,<br>PM 5.47 km/sec receding | Variability in the emission line continuum sugg classical Be rapid rotating egg-shaped star (Divan et al 1983); w/ rotational velocity V*sin*I= 240 $kms^{-1}$ (Penny 1996). |
| Zeta ζ Puppis<br>HD 066811 | $M_V$ 2.26<br>O4I(n)<br>978 lyr.<br>$T_{eff}$ 42,000, 14 time the dia., & 22 times the mass of the Sun. | 08 03 35.0<br>-40 00 11.3<br><br>Puppis | Single,<br>PM -23.9 km/sec appoaching.<br><br>ζ Puppis is the nearest O star to the Sun. | ζ Puppis ejected fm Trumpler 10 1.8 Myr ago and is presently 7.1 pc (23 lyr) away from Tr 10. The star's intense UV excites (lights up) the entire Gum Nebula supernova remnant. One day ζ Puppis's own remnant will join the mix. |
| HD 075222 | $M_V$ 7.42<br>O9.7ab<br>1400<br>$T_{eff}$ 30,500 | 08 47 25.1<br>-36 45 02.6<br><br>Pyxis | Single,<br>PM +64 km/sec approaching | Runaway, peculiar space velocity of +57. 2 $km^{/sec}$ measured by Hoogerwerf et al. 2001. Schilbach 2008 traces HD 75222 as ejected fm Collinder 205 6.6 Myr. |
| HD 089137 | $M_V$ 7.93<br>O9.5III<br>9780<br>$T_{eff}$ 33,500 | 10 15 40.1<br>-51 15 24.0<br><br>Vela | Single,<br>PM +17.0 km/sec receding | Possible single-line spectroscopic binary (Levato et al. 1988). Extended 60 μm emission detected by IRAS may be bow wake;. |
| HD 091452 | $M_V$ 7.50<br>BOIII<br>10106<br>$T_{eff}$ | 10 31 50.6<br>-63 56 25.6<br><br>Carina | Single,<br>high $A_V$ extinction of 1.5 mag,<br>PM -25.4 km/sec receding- | Visually lies 10106 lyr away, 1.3 degrees fm θ Carinae cluster IC 2602, which is 3 times closer. no known clusters within 65 pc (212 lyr). |
| HD 093129<br>AB | $M_V$ 6.90<br>O2If* +<br>O3.5V((f))<br>7.19<br>$T_{eff}$ 43,500 | 10 43 57.5<br>-59 32 51.4 | Trumpler 14 double, responsible for ejecting 16 other stars of m>8 Msol. | Hands-down top baddie in the Tr 14 Bully Binary sweepstakes—most of the cluster's 16 O & B ejections greater than $8M_{\odot}$. |

# Observer's Challenge Catalog of O Field & Runaway Stars

**The southern sky's big bad boy, Trumpler 14.** This dense, young cluster, lying in the same telescopic field with η Carinae, is responsible for at least 16 O-star ejections—including three on this list. About 6 Myr the bright, young star HD 116852 decided to leave home early. And no wonder: "home" was Trumpler 14. Today Tr 14 is a beauty, a favourite high-magnification cluster whilst perusing the boundlessly surprising Carina Nebula. HD 116852 was pretty breezy about it as well: it started its sojourn at 180 km/ sc. At the time Tr 14 wasn't even fully formed, and was located 50 pc (163 lyr) below the Galactic plane. Over the next 6 Myr Tr 14 cluster moved upward toward the Galactic plane by 60 pc (195 lyr). HD 116852 kept the pedal to the metal and today is more than 1 kpc (3260 lyr) above the Galactic plane and heading out toward the halo. Tr 14 lost a second O star 1.5 Myr later, HD 93652; it is now 40 kpc (130 lyr) from Tr 14. In yet another 1.5 Myr, HD 91651 (also 40 pc away now) and HD 305539 (75 pc or 244.5 lyr) were given the boost. By now Tr 14 is responsible for 16 O and B star ejections, not to mention all the unknown smaller fry.

| | | | | |
|---|---|---|---|---|
| HD 096917 | $M_v$ 7.21<br>O8.5Ib,<br>8800<br>$T_{eff}$ 35,000 | 11 08 42.6<br>-57 03 56.9<br><br>Centaurus | Candidate single-line spectroscopic binary, PM +2.0 km/sec receding; motion so slow it sugg candidate in-situ O star formation w/o massive cluster | Photometric variable (Balona 1992). Like HD91452 (above) & HD96917 (below), moving into inner side of Carina Spiral arm. Nearest early type star is B2 star HD96088 51 pc (166 lyr). |
| HD 105627 | $M_v$ 8.19<br>O9.V<br>10430<br>$T_{eff}$ 33,500 | 12 09 44.6<br>-62 34 54.6<br><br>Crux | Visual binary 14 arcsec,<br>PM +2.00 km/sec receding | Dense-looking field is mostly foreground Scutum-Sagg arm features, nearest O star is 1.44 degrees on visual sky, but 80 pc (260 lyr) physically. |
| HD 112244 | $M_v$ 5.32<br>O8.5Iab<br>1885<br>$T_{eff}$ 34,000 | 12 55 57.1<br>-56 50 08.9<br><br>Crux | Soctro binary w.visual blue supergiant, PM +18.50 km/sec receding | Emission line object, visual binary (Lindroos 1985), secondary is K0III star, poss optical, not real (Huélamo et al. 2000). Primary O star poss single-line spectro. binary. Photometric variability with multiple periods (Marchenko et al. 1998); star is associated with IRAS 12529-5633 (also HR 4908, an X-ray source). Nearest O star is emission line Be star HD112147 57 pc (185 lyr). |
| HD 113659<br>V340<br>Muscae | $M_v$ 7.90<br>O8 &<br>9III eclipsing binary<br>$T_{eff}$<br>35,000/30,000 | 13 06 32.3<br>-65 04 49.5<br><br>Musca | Poss spectro Algol type binary | Variable radial velocity, poss mbr Cen OB1 association (Humphreys & McElroy 1984; Mathys 1988). Doubtful this is a field O star & instead part of unident. association. |
| HD 117856 | $M_v$ 7.41<br>O9.5III<br>5550 lyr<br>$T_{eff}$ 33,000 | 13 34 43.4<br>-63 20 07.6<br><br>Centaurus | Visual 1.6 arcsec binary visual<br>PM -20.0 km/sec receding.<br>Strong magn. field<br>35 Simbad refs | Runaway ejected from 4 Myr-old Stock 16 @ 60 pc (195 lyr) & presently punching its way through interstellar dark clouds and HII regions consistent w/ outer tendrils of the Coal Sack in Crux 180 pc (586 lyr) away. |

## Observer's Challenge Catalog of O Field & Runaway Stars

| | | | | |
|---|---|---|---|---|
| HD 120678 | $M_V$ 8.20<br>O9.5V<br>unk<br>$T_{\text{eff}}$ 33,000 | 13 52 56.4<br>-62 43 14.3<br><br>Centaurus | Single, Shell eject<br>51 SIMBAD refs | Variable emission line rapid rotator with *V*sin*I* *equat.veloc.* 350 kms$^{-1}$ (Conti & Ebbets 1977). HD120678, spectroscopic multiplicity unconfirmed. Crowded field incls. B2 HD120634 4.5 pc (14.7 lyr) & B5 HD120578 3.3 pc (10.7 lyr) |
| HD 122879<br>HR 5281 | $M_V$ 6.0<br>BOIaE<br>unk<br>$T_{\text{eff}}$ | 14 06 25.2<br>-59 42 57.2<br><br>Centaurus | Single,<br>134 refs | 1.58 day variable (Marchenko et al. 1998). Spectral type prob. B0Ia (Garrison et al. 1977; Walborn & Fitzpatrick 1990). Prob. mbr of Cen OB1 (Pawlowicz & Herbst 1980) |
| HD 124314 | $M_V$ 6.64<br>O6Vn<br>2310 lyr<br>$T_{\text{eff}}$ 41,500 | 14 15 01.6<br>-61 42 24.4<br><br>Centaurus | Visual 2.7 arcsec binary w/ poss single-line spectro binary, 111 SIMBAD references.<br>PM -17 km/sec receding | Emission-line star ionizing RCW 85 HII region. Poss blue straggler. Gvaramadze 2012 considers this the only true unresolved candidate for *in-situ* status. |
| HD 125206 | $M_V$ 7.92<br>O9.5IV<br>1700<br>$T_{\text{eff}}$ 33,000 | 14 20 09.04<br>-61 04 54.6<br><br>Centaurus | Double-line spectro. binary. | Less than 65 pc (210 lyr) fm young cluster NGC 5606 & only 10 pc (32.6 lyr) N of RCW 85 star forming HII region at similar distance (Yamaguchi et al. 1999); may belong to Clust 3 Group of Mel'Nik & Efremov (1995)—see esp locator maps in Mel'Nik etc Figs 4, 5, & 10. |
| HD 130298 | $M_V$ 9.29<br>06.4III<br>$T_{\text{eff}}$ 40,500 | 14 49 33.7<br>-56 25 38.4<br><br>Circinus | Bow shock w/ wind velocity 500 km s$^{-1}$*<br>sugg runaway status | Noriega-Crespo 1997, Bow Shocks Around Runaway Stars, A-J, 113, 780 |
| HD 135240 | $M_V$ 5.09<br>O8Vc<br>920<br>$T_{\text{eff}}$ 34,500 | 15 16 57.0<br>-60 57 26.1<br><br>δ Circinus | Double-line ellipsoidal spectro. O7III-V & O9.5V binary w. Poss. 3$^{rd}$ B0.5V (Penny et al 2001). | Different evolutionary ages 2.5 Myr primary & 5.1 Myr secondary sugg poss. acquisition. Source associated with X-ray source d Circinis 1RXS J151658.5-605730. Early-type Be star HD135160) at 1 pc & 3rd early-type B3 @ 1.3 pc. May belong to Pismis 20 group (Mel'Nik & Efremov 1995; Turner 1996; Vasquz 1996). |

| Observer's Challenge Catalog of O Field & Runaway Stars | | | | |
|---|---|---|---|---|
| HD 135591 | $M_v$ 5.46<br>O8IV<br>1100<br>$T_{eff}$ 35,000 | 15 18 49.1<br>-60 29 46.8<br><br>Circinus | Triple w/ pre-MS A8III component @ 44.5 arcsec.<br>PM -3.10 km/sec receding | Crowded region. HD 135591 associated w/ X-ray source 1RXS J151848.4-602952. May belong to Mel'Nik & Efremov's (1995) Pis 20 group. Pismis 20 has ejected 6 known O runaways (Turner 1996; Vasquz 1996). Numerous early-type stars nearby, e.g. HD 135786 (3 pc, 9.78 lyr) but young clusters are absent w/in 65 pc (212 ltr) radius. |
| HD 153426 | $M_v$ 7.47<br>B8.5III<br>2100<br>$T_{eff}$ 35,000 | 17 01 13.1<br>-38 12 11.9<br><br>Scorpius | Double-line spectro binary, runaway w. bow shock, ejected fm Hogg 22 (58 SIMBAD refs).<br>Strong magn.field<br>PM -6.4 km/sec receding | Located 28 arcmin fm Sharpless 2-91 HII region; poss related to runaway HD 153919 (follow. entry– (Ankay et al. 2001) at linear distance of ~24 pc (78 lyr) in projection. NTT imaging sugg HD153426 associated with off-axis stellar overdensity not amounting to cluster. |
| HD 153919 | $M_v$ 6.51<br>O6.Iafcp<br>1700<br>$T_{eff}$ 36,000<br>surface rotation vel. = 70 km $s^{-1}$ | 17 03 56.7<br>-37 50 38.9<br><br>Scorpius | Aka HMXB 4U1700-37 (Ankay et al. 2001), single-line eclipsing spectro. Binary located by chance in same visual field as OC NGC 6281.<br>PM -75 km/sec km/sec receding | Runaway X-ray binary ejected 1.1 Myr ago fm NGC 6231 in Sco OB-1 by SN progenitor of present neutron star 4U1799-37 presently being spun-up by wind accretion. May eventually acquire enough mass to collapse into BH. |
| HD 154368 | $M_v$ 6.13<br>O9.5Iab<br>1100<br>$T_{eff}$ 33,000 | 17 06 28.36<br>-35 27 03.8<br><br>Scorpius | Visual blue supergiant binary w/16.1 day period,<br>PM -3.5 km/sec receding | Located near the Sco OB1 assn. IR source IRAS 17031-3522 & young cluster Bochum 13 poss. associated. Spectro. distance estimate 800 pc (2600 lyr). (Snow et al. 1996). |
| HD 154643 | $M_v$ 7.15<br>O9.7III<br>1300<br>$T_{eff}$ 31,000 | 17 08 13.9<br>-35 00 15.7<br><br>Scorpius | Spectro. Binary, strong magn. field.<br>PM -27 km/sec receding | Poss ejectee fm Hogg 22 1.4 Myr ago. Young cluster Bochum 13 within 65 pc (212 lyr) but not associated. Few refs in literature. |
| HD 154811 | $M_v$ 6.93<br>O9.7Ib<br>1370<br>$T_{eff}$ 29,000 | 17 09 53.1<br>-47 01 53.2<br><br>Ara | Single star (Levato et al. 1988); uncertain Hipparcos distance 420 pc (1370 lyr).<br>PM -24.5 km/sec receding | 2MASS data shows a number of bright K-band objects with J − K > 1.5, sugg. evolved low-mass stars in Giant Branch region of CMD unassoc. w/ HD 158186. |

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|---|---|---|---|---|
| HD 158186 | $M_v$ 7.04<br>O9.5V<br>1100 | 17 29 12.9<br>-31 32 03.4<br><br>Scorpius | Variable V1081 Sco eclipsing Algol binary.<br>PM –9 km/sec receding | Busy field w/ signs of active star formation. HD158186 ass'd w/ IR source IRAS 17260-3129 & illuminating source of nearby BBW 32300 HII region (Noriega-Crespo et al. 1997). LDN 1732 dark cloud lies on far side. emission. neb. Sh 2-13 & RCW 133 & dusty filaments in optical images. Three young Sgr OB1 assn clusters within 65 pc radius, e.g. NGC 6383 @ est. age of 1.7 Myr, 1.5 kpc (4890 lyr) from Sun (Fitzgerald et al. 1978). |
| HD 161853 | $M_v$ 7.92<br>O8V(n)<br>1600<br>$T_{eff}$ 33,000 | 17 49 16.5<br>-31 15 18.0<br><br>Scorpius | Single-line spectroscopic binary.<br>PM –52 km/sec receding | Candidate PN based on IRAS colours & radio continuum emission, therefore 4–10 Gyr old. Also associated with 1RXS J174916.5-311509 young X-ray source. OC Collinder 347 < 10 Myr lies 1.5 kpc distant. |
| HD 163758 | $M_v$ 7.33<br>O6.5iafp<br>3600 | 17 59 28.3<br>-36 0115.6<br><br>Sagittarius | Single component Wolf-Rayet star.<br>PM –48 km/sec receding | Located in spare stellar field; nearest early-type star is B2 star Mv 8.9 HD163924, ~25 pc (81 lyr) away. No young clusters w/in 65 pc (212 lyr) radius. |
| HD 165319 | $M_v$ 8.04<br>O9.7Ib<br>2100<br>$T_{eff}$ 33,000 | 18 05 58.8<br>-14 11 52.9<br><br>Sagittarius | Well-known double-line massive eclipsing binary.<br>PM –25.4 km/sec receding | Some extinction from 23 x 23 arcmin RCW158 HII region (Rodgers et al. 1960); colour excess of E (B−V ) = 0. 79 (Winkler 1997), likely associated w/ or located behind RCW 158. No young clusters observed wi/in 65 pc (212 lyr). |
| HD 169515<br>(RY Scuti) | $M_v$ 9.12<br>O9.7Ibe<br>2000<br>$T_{eff}$ 30,500 | 18 25 31.4<br>-12 41 24.1<br><br>Scutum | RY Sct massive B Lryae type eclipsing binary.<br>Original ejection velocity was <100 km/sec more than 9 Myr ago. Today PM is -145 km/sec receding, one of highest known runaway velocities. | Rich region of dark clouds, masers, HII regions; nearby is young <2 arcsec nebula w/ unusual concentric ionized rings (Smith et al. 1999). High-mass proto-stellar candidate IRAS 18223-1243 5 arcmin east. NGC 6604 aged ~4Myr lies 1.1 kpc away in Sharpless 2-54 (Battinelli et al. 1994). |

| Observer's Challenge Catalog of O Field & Runaway Stars | | | | |
|---|---|---|---|---|
| HD 175754 | $M_V$ 7.03<br>O8II(n)<br>2700<br>$T_{eff}$ 30,000 | 18 57 35.7<br>-19 09 11.3<br><br>Sagittarius | Emission line single star.<br>PM -11.4 km/sec receding | Similarity of HD 175754 & HD 175876 (next entry) sugg physical association (Walborn & Fitzpatrick 2000). HD 175754 is located 400 pc below Galactic plane. See effect on outer thin disc here. |
| HD 175876 | $M_V$ 6.94<br>O6.5III<br>2300 | 18 58 10.7<br>-20 25 25.5<br><br>Sagittarius<br><br>9th mag "companion" is unrelated superposition | Faux visual binary.<br>PM +6.1 km/sec approaching | Optical binary (Lindroos binary catalog 1985) @ 420 pc (1370 lyr) below Galactic plane. Both HD 175754 & HD 175876 are O-type stars 1.3 arc degree (±50 pc,163 lyr) apart. Both poss. related to GS 018-04+44 "Scutum Supershell" blowout described in Callaway et al. (2000). |
| HD 188209 | $M_V$ 5.63<br>O9.5Iab<br>2000<br>$T_{eff}$ 33,000 | 19 51 59.0<br>+47 01 38.4<br><br>Cygnus | Binary status uncertain, considered single blue supergiant. Ejected fm NGC 6871 10.1 Myr, 1 Myr before the cluster had fully formed.<br>PM -8.0 km/sec receding; peculiar velocity 40 km/sec. | True runaway, peculiar space veloc. 40 km/sec & 330 pc (1978 lyr) below Galactic plane, poss binarism sugg. by complex line-profile variations (Fullerton et al. 1996). Inconclusive ($\sigma$ = 1) echelle spectra re. 6.4 days period (Israelian et al. 2000). Poss.associa. w/ 1RXS J195159.2+470133 x-ray source B0.5 III HD188439 @ 28 pc. |
| HD 193793 | $M_V$ 6.85<br>WC7p+05<br>$T_{eff}$ | 20 20 27.9<br>+43 51 16.3<br><br>Cygnus | Triple system w/ a 6 arcsec visual binary & spectro WR-O binary WR 140. One star in binary is WR carbon type.<br>PM -3.1 km/sec receding | WR binary has strong colliding-wind spect sigs (Monnier et al. 2002). IRAS 60 µm images sugg periastron-related variable dust formation in expanding-shell emission rings (Williams 1995). Optical field reveal wisps of ionized gas. |
| HD 195592 | $M_V$ 7.08<br>O9.7Ia<br>1400<br>$T_{eff}$ 28,000 | 20 30 34.9<br>+44 18.54.8<br><br>Cygnus. Nearby visual "com-panions" are unrelated. | Single emission-line runaway w/bow shock.<br>PM -27.8 km/sec receding | Loc. in Cyg X dense w/ ionized gas & high dust extinct. (Noriega-Crespo et al. 1997). IRAS bow shock strongly sugg runaway. Signatures of Keplerian disc present. H II emission in field is unrelated. |

| Observer's Challenge Catalog of O Field & Runaway Stars | | | | |
|---|---|---|---|---|
| HD 201345 | $M_V$ 7.76<br>ON9IV<br>6190 lyr<br>$T_{eff}$ 31,000 | 21 07 55.4<br>+33 23 49.2<br><br>Cygnus | Single, field. Ejected fm Cyg OB2 5.8 Myr & now trav. S @ -19.2 km/sec receding. The O runaway HD 189857 was ejected fm Cyg OB2 5.9 Myr and is trav. N in reverse sling-shot path. Cyg OB2 has ejected 3 of the O stars on this list. | Veloc. 29.5 km/sec @ −300 pc (978 lyr) below Galactic plane (Gies & Bolton 1986) stellar photosph; enhanced nitrogen abundance (Walborn 1976). Schilbach 2008 showed HD 201345 was ejected fm Cyg OB2 ~ 5.8 Myr. No associated objects w/in 65 pc (212 lyr). |
| Possible in-situ star formed w/o cluster (de Wit 2004). | $M_V$ 7.76<br>O9Iab<br>3500<br>$T_{eff}$ 31,000 | 21 12 28.4<br>+44 31 54.1<br><br>Cygnus | Single, blue super-giant.<br>PM -24 km/sec re-ceding | Located near Cygnus super-bubble structure, in turn relat. to local Orion Spur OB assns (Uyaniker et al. 2001). No young cluster seen w/in 65 pc (212 lyr) Early B2 type star ±30 pc (97 lyr). *Discussed as pos-sible* in-situ *O star formed in isolation (de Wit 2004).* |
| HD 328856 | $M_V$ 8.50<br>O9.7II<br>4250<br>$T_{eff}$ 31,000 | 16 46 33.3<br>-47 04 50.9<br><br>Located in Ara adjacent to v.pretty, com-pact bright OC Hogg 22. | Single, eject fm Hogg 22 Ara (Hubrig 2011)<br>PM 1.54 km/sec re-ceding | Hubrig, S. et al 2011, *Exploring the origin of magnetic fields in massive stars: a survey of O-type stars in clusters and in the field*, https://arxiv.org/abs/1102.2503 |

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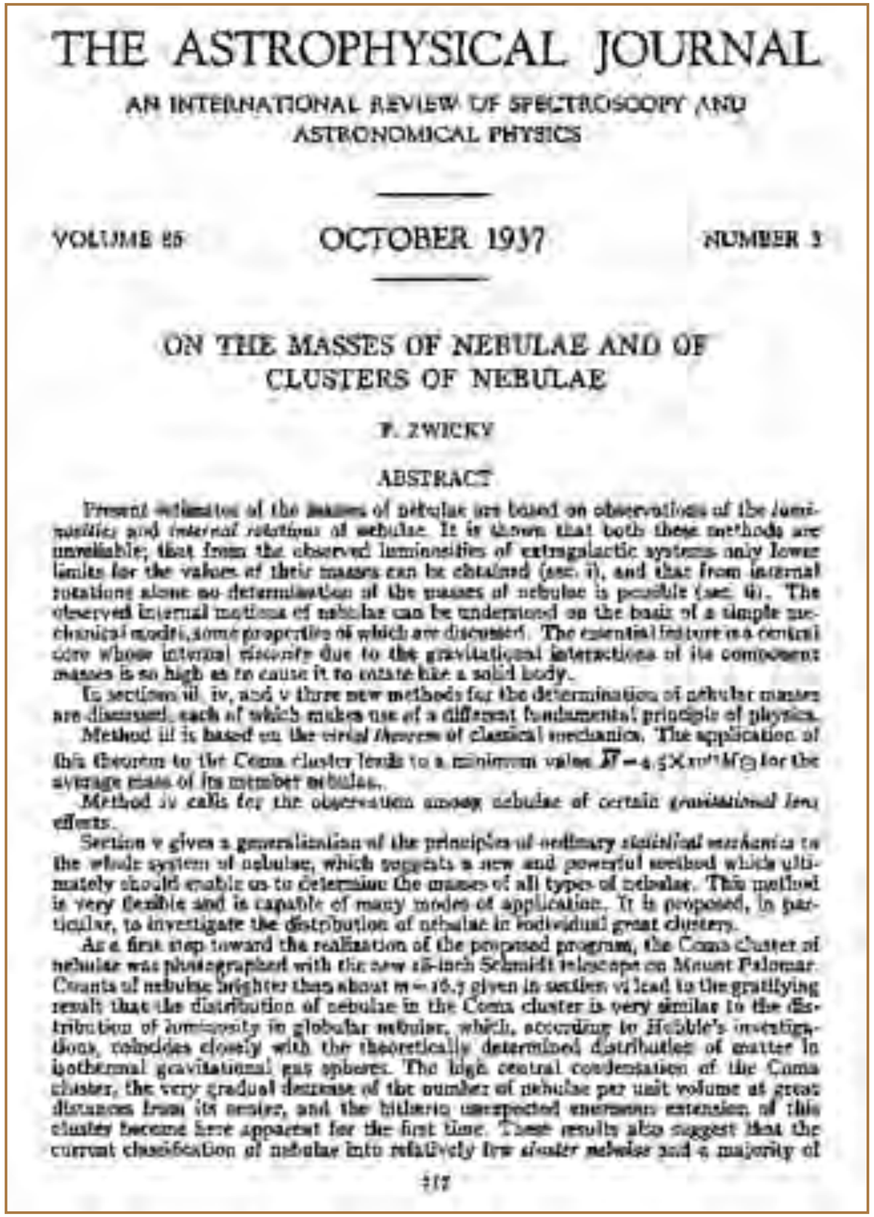
# Legacy Library

In each issue of Nightfall we will take a closer look at the many legacy papers that undergird modern astronomy. In this issue:

## Fritz Zwicky

## *On the Masses of Nebulae and of Clusters of Nebulae*

*Astrophysical Journal*, Vol. 85 No. 3, October 1937



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ON THE MASSES OF NEBULAE AND OF CLUSTERS OF NEBULAE

F. ZWICKY

ABSTRACT

Present estimates of the masses of nebulae are based on observations of the *luminosities* and *internal rotations* of nebulae. It is shown that both these methods are unreliable; that from the observed luminosities of extragalactic systems only lower limits for the values of their masses can be obtained (sec. i), and that from internal rotations alone no determination of the masses of nebulae is possible (sec. ii). The observed internal motions of nebulae can be understood on the basis of a simple mechanical model, some properties of which are discussed. The essential feature is a central core whose internal viscosity due to the gravitational interactions of its component masses is so high as to cause it to rotate like a solid body.

In sections iii, iv, and v three new methods for the determination of nebular masses are discussed, each of which makes use of a different fundamental principle of physics.

Method iii is based on the *virial theorem* of classical mechanics. The application of this theorem to the Coma cluster leads to a minimum value $\bar{M} = 4.5 \times 10^{10} M_{\odot}$ for the average mass of its member nebulae.

*Method iv* calls for the observation among nebulae of certain *gravitational lens* effects.

Section v gives a generalization of the principles of ordinary *statistical mechanics* to the whole system of nebulae, which suggests a new and powerful method which ultimately should enable us to determine the masses of all types of nebulae. This method is very flexible and is capable of many modes of application. It is proposed, in particular, to investigate the distribution of nebulae in individual great clusters.

As a first step toward the realization of the proposed program, the Coma cluster of nebulae was photographed with the new 18-inch Schmidt telescope on Mount Palomar. Counts of nebulae brighter than about $m = 16.5$ given in section vi lead to the gratifying result that the distribution of nebulae in the Coma cluster is very similar to the distribution of luminosity in globular nebulae, which, according to Hubble's investigations, coincides closely with the theoretically determined distribution of matter in isothermal gravitational gas spheres. The high central condensation of the Coma cluster, the very gradual decrease of the number of nebulae per unit volume at great distances from its center, and the hitherto unsuspected enormous extension of this cluster become here apparent for the first time. These results also suggest that the current classification of nebulae into relatively few *cluster* nebulae and a majority of

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## Fritz Zwicky, *On the Masses of Nebulae and of Clusters of Nebulae*, ApJ 86:3 1937

The cosmological paradigm as we think of it today evolved incrementally across five decades between 1920 and 1970. In 1922 Ernst Öpik asserted that stellar systems beyond our Milky Way appeared to be not diffuse nebulae but island universes composed rather like the Milky Way itself. That same year Alexandre Friedmann interpreted Einstein's 1917 Theory of Relativity to suggest that the universe was infinite in size (*Zeitschrift für Physik*, 10, 377).

In 1925 Edwin Hubble) confirmed Öpik's notion of island universes by resolving individual stars in M31 the Andromeda Nebula. (The term galaxy as we use it didn't come into common use until the late 1930s.) Four years later Hubble demonstrated that those nebulae were receding from us without any particular preference to direction; the distribution was isotropic. The inescapable conclusion was that the Universe is expanding. In the popular imagination the inevitable conclusion was that we were still the centre of the universe. That belief gave the word "isotropic" a longer lease on life than astronomical reality supports. Look at an illusion long enough and one will see little beyond how real it seems.

Originally the expansion velocity was expressed in terms of the Hubble constant, $H_0$. There were competing values for the velocity, with Sandage & Tammann (1975) determining it to be $H_0$ = ~50 km/sec per Mpc–1 while Sydney van den Bergh (1972) and Gèrárd de Vaucouleurs (1978) plumping for 100 km/sec Mpc$^{-1}$. Today the Hubble constant is often expressed in dimensionless units *h*, defined as: $H_0 = \Omega = 70\,h$ km/sec $\mathrm{Mpc}^{-1}$.

By 1933 and working separately at Princeton, the Swiss-American astronomer Fritz Zwicky had concluded that the internal motions of the nebulae in the northern skies' Coma Cluster behaved as though they were immersed in some form of invisible mass of considerable density which emitted no luminous energy. He formalised his analysis in a 1937 paper in the *Astrophysical Journal.* The paper faded into obscurity for three decades. Today the paper is regarded as a sort of debutante's ball for dark matter as we understand the term today.

His use of the term "donkere materié" ("darker material") is often misconstrued to mean "dark matter" as we use the term. Throughout his 30 page analysis he was at pains to employ the term "dark matter" to signify baryonic mass below the $M_v$ 16.5 detection threshold of the equipment at his disposal (a custom 18" Schmidt camera on Mt. Wilson built specifically for his nebula-mass research). "Dark" would include a normal-matter mass range from dust particles on one end to white dwarfs on the other; with non-luminous gas, rocky objects, and stars of such modest mass they fizzled instead of sizzled.

Today Zwicky's invisible *materié* would more plausibly point to detector shortcomings rather than some exotic state of matter. Still, the amount of missing mass was so drastic it was beyond credulity that the observable universe conspired to conceal 200 times as much mass as it deigned to reveal. Zwicky prudently employed the term "gravitational viscosity" to hypothesise a property which could produce the results of his analysis.

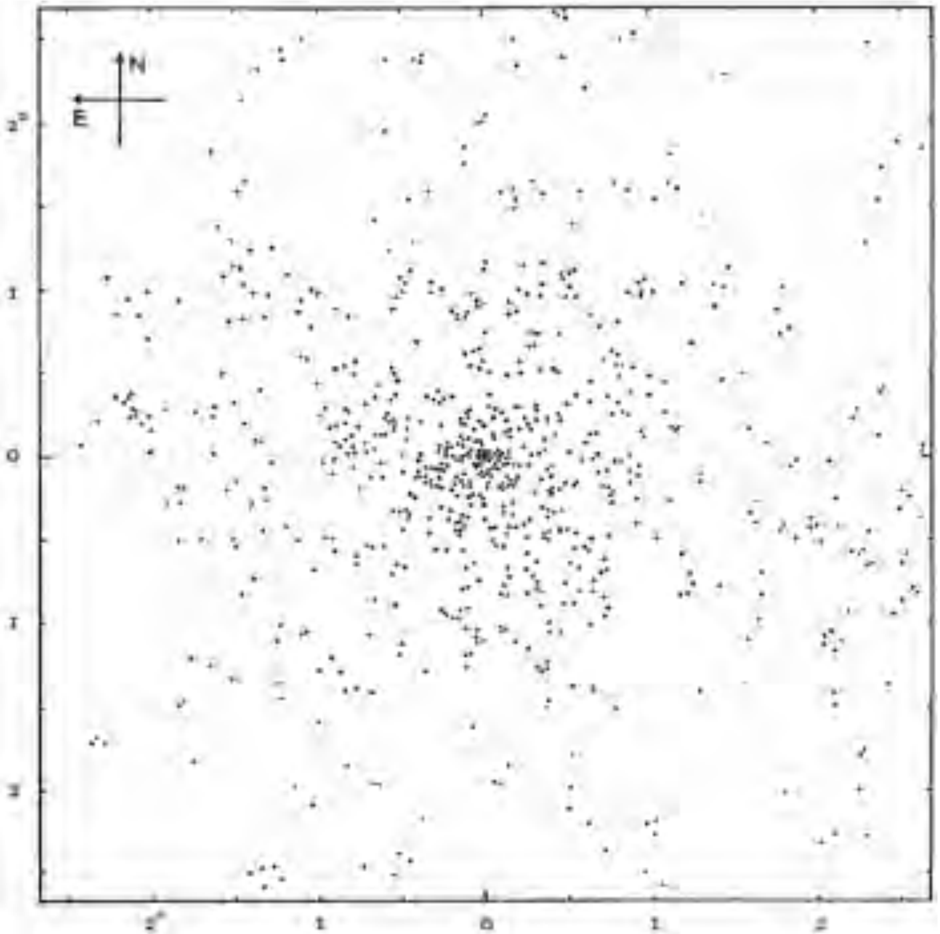
Zwicky began his analysis by comparing two hypothetical systems whose nebular material behave much like stars. In the first system, what he termed "internal viscosity" was negligible, i.e., was frictionless in today's terminology. The result was, "the observed angular velocities in themselves give no clue regarding the mass of the system".

In the second model the internal viscosity was considerable; changes in energy and momentum of any component occured in times very short compared with the time taken to traverse the system. The rates of motion of individual components gave no indication of the system's mass or rate of rotation. Combining the best features of both models, Zwicky wrote:

> Good mechanical models of actual nebulae may presumably be constructed by combining the distinctive features of the two limiting cases described in the preceding sections. Such a combined model will possess a central, highly viscous core whose relative dimensions are not negligible but are comparable with the extension of the whole system. If the outlying, and among themselves little interacting, components of the nebula had no connection with the central core, we might, at a given instant, observe average angular velocities Ω which, as a function of the distance *r* from the center of rotation, would be given by
>
> $$\Omega(r) = \Omega_0 = \text{const.} \longrightarrow \text{for } r < r_1\,, \qquad (1)$$

Zwicky suggested that such nebulae behaved analogously to the equipartition of rotational energy of molecular masses compared with their atomic components' translational energy:

> "Star clusters are in some ways analogous to gas spheres built up of monatomic gases, where clusters of nebulae may be likened to gas spheres




Zwicky's Fig. 3 depicting the Coma Galaxy Cluster is a dot scatter rather than a halftone because the coarse-fibred paper journal printers used in those days produced "ink bleed". Coarse 54 dpi halftone plates had a contrast overdensity threshold from ink seeping outward on the paper's fibres before it dried. When faced with Zwicky's Coma Cluster plates, the printer plotted the nebulae in Zwicky's plates on a metal plate similar to a line engraving rather than halftone. Stars and field galaxies were ignored.

built up of polyatomic gases.* The difference in internal characteristics may lead ultimately to serious consequences. We are confronted with processes which are analogous to the dissociation of polyatomic molecules when their average kinetic energy of translation — that is, the temperature of the gas — becomes too high. . . . the total energy of a stationary cluster of nebulae should be positive. The rotational energy $k_R$ of a nebula cannot become equal to its observed translational energy $k_T$."

Zwicky in essence analysed the Virial Theorem in terms of the statistical properties of polyatomic gases. The visionary quality of Zwicky's paper is impressive given the knowledge base of the times. The foundation stones of numerical calculation during that era were one pencil, one eraser, some sheets of paper, and one slide rule. Properties take for granted today were unimaginable. The calculated value of the Hubble Constant suggested that the universe could be no more than 1 billion years old. Terms like ***Local Sheet***,* ***Local Volume***, and ***Local Group*** (n.b. click on "***Essay***") didn't exist.

Important nearby dwarf galaxies had not yet been discovered, e.g. Sculptor and Fornax (disc.1937), Ursa Minor (1955), Draco (1954), etc. Of M31 Andromeda's retinue of dwarfs, only M32, NGC 205, NGC 147, NGC 185. The remote Pegasus Dwarf was known, but no one has any idea what it was or why it might be there. The ***Gould Belt*** stellar association had been identified as far back as 1879 but was not seen as part of a larger system. Even common benchmark terms as "crossing time" were ill-defined: Zwicky used, "time intervals which are comparable with the time it takes one nebula to traverse the whole

* The analogy to giant molecular clouds is prescient considering that galactic gas clouds comprising molecular hydrogen cores surrounded by atomic hydrogen halos were not discovered until the early 1970s.

system" to qualify the indifference of large-scale motion to small-scale components.

Zwicky took pains to distinguish between "cluster nebulae" and "field nebulae", the latter meaning fore- and background galaxies that happened to be in the field. The word "galaxy" as we know it was just coming into common parlance. Zwicky stuck with the more commonly used term "nebulae", through he framed the term in a context that clearly implied triaxial morphologies as a distinct class not be confused with amorphous or diffuse nebulae like HII complexes or PN/SN shells. Zwicky couldn't have known that most "field" galaxies were actually components in galaxy clusters whose large-scale structure was not evident because few grasped the reality of the universe's size.

Zwicky's distinction arose because he noticed nebulae clusters have more spherical and elliptical components in their central regions, while field nebulae were mostly spirals. Today even an undergrad would spot the small-sample problem Zwicky faced. Zwicky had very few nearby galaxy clusters from which to extract reliable spectra—and even with Coma he complained of line crowding and low S/N ratios.

Zwicky's method and its maths were simple by today's standards. He applied the ***Virial Theorem**** to derive the Coma Cluster's ***Virial Mass***.† After pruning out "field nebulae" and image artefacts, he calculated the radial velocity distribution of 670 "nebulae" down to $M_v$ 16.5 from their the Doppler shifts.

Today the elementary mathematical argument in his paper likens more to a line drawing than a portrait. He assumed what he saw was isotropic — individual masses distributed evenly throughout a rotating sphere whose velocity distribution could be averaged over density and mass. He calculated that the mass of the entire Coma Cluster was $9 \times 10^{46}$ g. Divide by 670 and the average mass of any galaxy would be $4.5 \times 10^{10}\ M_\odot$. His calculations showed that a galaxy in the cluster had a mass/luminosity ($M/L$) ration of $8.5 \times 10^7\ M_\odot$ — a discrepancy of $\gamma = 500$ from the putative average nebula's mass. Here the small-

* ***Virial Theorem***: For a bound gravitational system the long-term average of the kinetic energy is one-half of the potential energy.

† ***Virial Mass***: The mass of a cluster of stars or galaxies in statistical equilibrium derived by using the virial theorem that the mean square velocity of all the stars or galaxies in a cluster is proportional to the mass of the cluster divided by its radius.

* See *Tully, R. Brent et al*, ApJ 676:1 2008, and *McCall, Marshall, MNRAS 440:1 2014* Fig.3.

sample problem loomed over Zwicky's thesis like the spectre in *Phantom of the Opera*: the $M/L$ ratio Zwicky used for comparison was the nearby Kapteyn Stellar System (known today as a stellar stream from the disrupted Sagittarius Dwarf Galaxy), whose $M/L$ ratio was $\gamma = 3$.

> V. STATISTICAL DISTRIBUTION IN SPACE OF DIFFERENT TYPES OF NEBULAE
>
> It will be shown elsewhere that the number of clusters of nebulae actually observed is far greater than the number that might be expected for a random distribution of non-interacting objects. This tendency of nebulae toward clustering is no doubt due to the action of gravitational forces.

Type "*swarming behaviour in star clusters and galaxy clusters*" into Google Images and see if what you get supports Zwicky's *ansatz above*.

Today Zwicky might be regarded as having erroneously compared apples with oranges, the velocity fields of nearby Kapteyn stars -vs- the velocity field of remote nebulae. That didn't obviate the fact that there was a 166:1 discrepancy between the M/L ratio of the Coma nebular system compared with the Kapteyn stellar system. In a universe thought to be only 1 billion years old, the Coma Cluster should have flown apart long ago. His solution was startling: call the mass viscosity.

> "The tremendous increase in surface brightness from the edge $r = r_0$ of the core of the nebulae to their centre $r = 0$, indicates a correspondingly large increase in mass density. The erroneous idea that the constancy of the angular velocity of the core necessitates the assumption of a constant mass density therefore created an apparently insoluble paradox. This paradox disappears as soon as we introduce the idea of an internal gravitational viscosity of stellar systems, which equalises the angular velocity throughout such systems." [*See image next col.*]

Tut-tutting today about Zwicky's small-sample limitations serves more to highlight, not diminish, Zwicky's foresight. His tiny data set was like a child's line drawing that went into a drawer, unnoticed for decades till a true artist came along to turn the sketch into a masterwork of portraiture. The artists did come along: Vera Rubin. We will examine her landmark paper in a future issue of *Nightfall*.

Certain implications hide between the lines of his 1937 paper that were never sufficiently examined. One is whether swarming behaviour and anisotropy are local decouplings from a larger velocity field.

The fact that all Zwicky's Fig. 3 "nebulae" were rendered the same size inadvertently highlighted a feature we wouldn't notice in a photograph: it suggests localised "swarming" among the Coma Cluster's nebulae, which would imply turbulence acting on scales a

crease of mass density. The erroneous idea[2] that the constancy of the angular velocity throughout the core necessitates the assumption of a constant mass density therefore created an apparently insoluble paradox. This paradox, however, disappears as soon as we introduce the idea of an internal gravitational viscosity of stellar systems, which equalizes the angular velocity throughout such systems re-

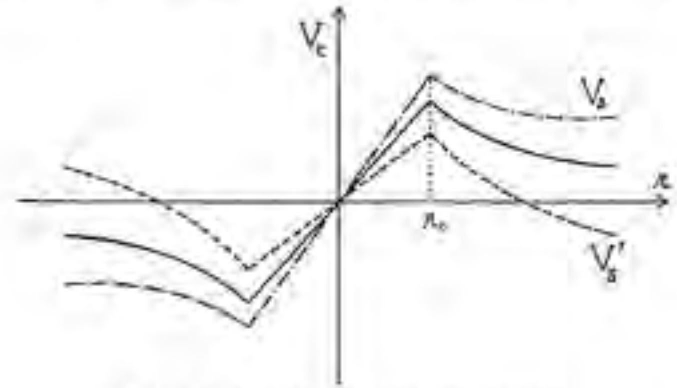



Fig. 1.—Velocity of rotation in nebulae

gardless of the distribution of mass. How this viscosity may be expressed in terms of the gravitational interactions of stars will be discussed in another place.

The next time we were to see a system-rotation profile anything like this was in the Vera Rubin – Kent Ford galactic rotation papers of the 1970s.

significant fraction of crossing time. Irregular patterns of small clumps are self-evident in Zwicky's Fig. 3, comprising a few to a dozen dots each, a seemingly random pattern of localised binding. Zwixky's equipoment capabilities gave him little aid here: he had no way to know whether gas clumping or intra-cluster extinction existed. The only motion detector he had was Doppler shifts from his rather coarsegrained spectra. He could constrain apparent radial velocity, but not peculiar motion. Were the nebular clumps in his Fig. 3 stochastic or did they have a physical cause? He had access to only about 2% of the electromagnetic radiation associated with any object he saw, violet to near IR. He did now know that things like giant molecular clouds existed, or that kinetic temperatures in the “nebular” medium of the Coma Cluster were $10^6 – 10^7$ K.

Another question posed by the dot scatter in Zwicky’s Fig. 3 is whether apparent swarming behaviour is the same thing as anisotropy. Ever since Plato there has been an idealised vision of the sphere as an analogue of perfection. In space, the default binding configuration for self-gravitating gas was the sphere. Astronomers assumed that all events occurring within a sphere could be modelled by selected properties and laws applied within. (What happens when $N$-body interaction are constrained in a cube?)

Zwicky's 1937 paper was an early retirement party for spherical symmetry as the default container for matter-energy interactions. Irascible, contrarian Fritz would have been delighted by what modern astronomy has done with his 1937 idea — see *1* (esp. §3–5 for velocity fields and Figs 4–7), 2 (3D graphic *here*) , *3*, *4*, *5,* and for the really waaayy-out-there buffs: *6.* The implicit suggestion in such sims as these is that localised “swarming” behaviours are magnetic and turbulent effects that can be modelled by $N$-body interactions, while anisotropy is a global-scale behaviour better modelled using eigenvectors and the shear stress tensor. See ***Libeskind 2014*** and *2017*).

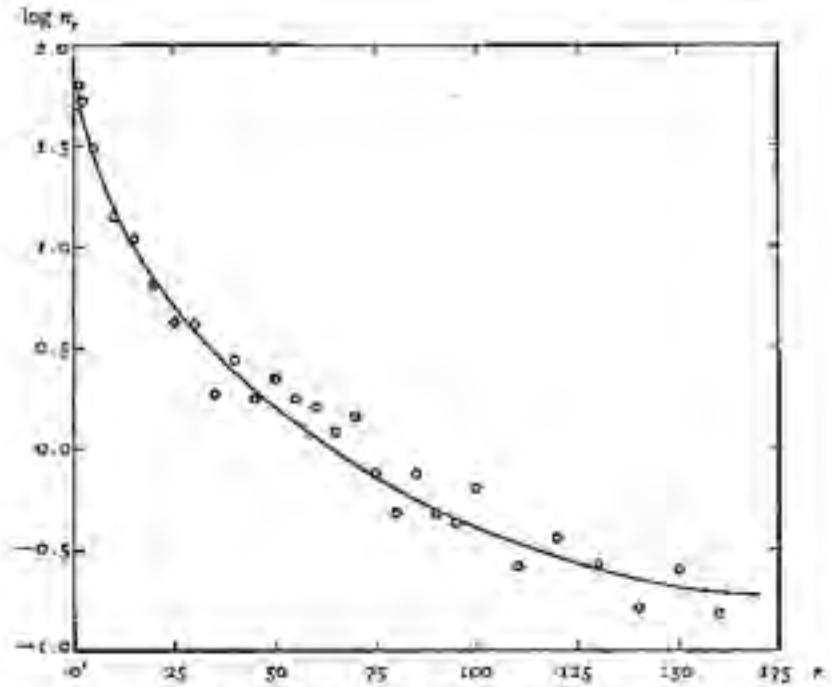



Fig. 4.—Counts of nebulae in the Coma cluster

The high central condensation, the very gradual decrease of the number of nebulae per unit volume at great distances from the center of a cluster, and the great extension of this cluster become here apparent for the first time. It is quite as we should expect from the considerations of section v. According to these considerations, a cluster of nebulae analogous to an isothermal gravitational gas sphere may in some cases be expected to extend indefinitely far into space, until its extension is stopped through the formation of independent clusters in the regions surrounding it.

*WHAT WOULD FRITZ HAVE DONE WITH THESE . . .*

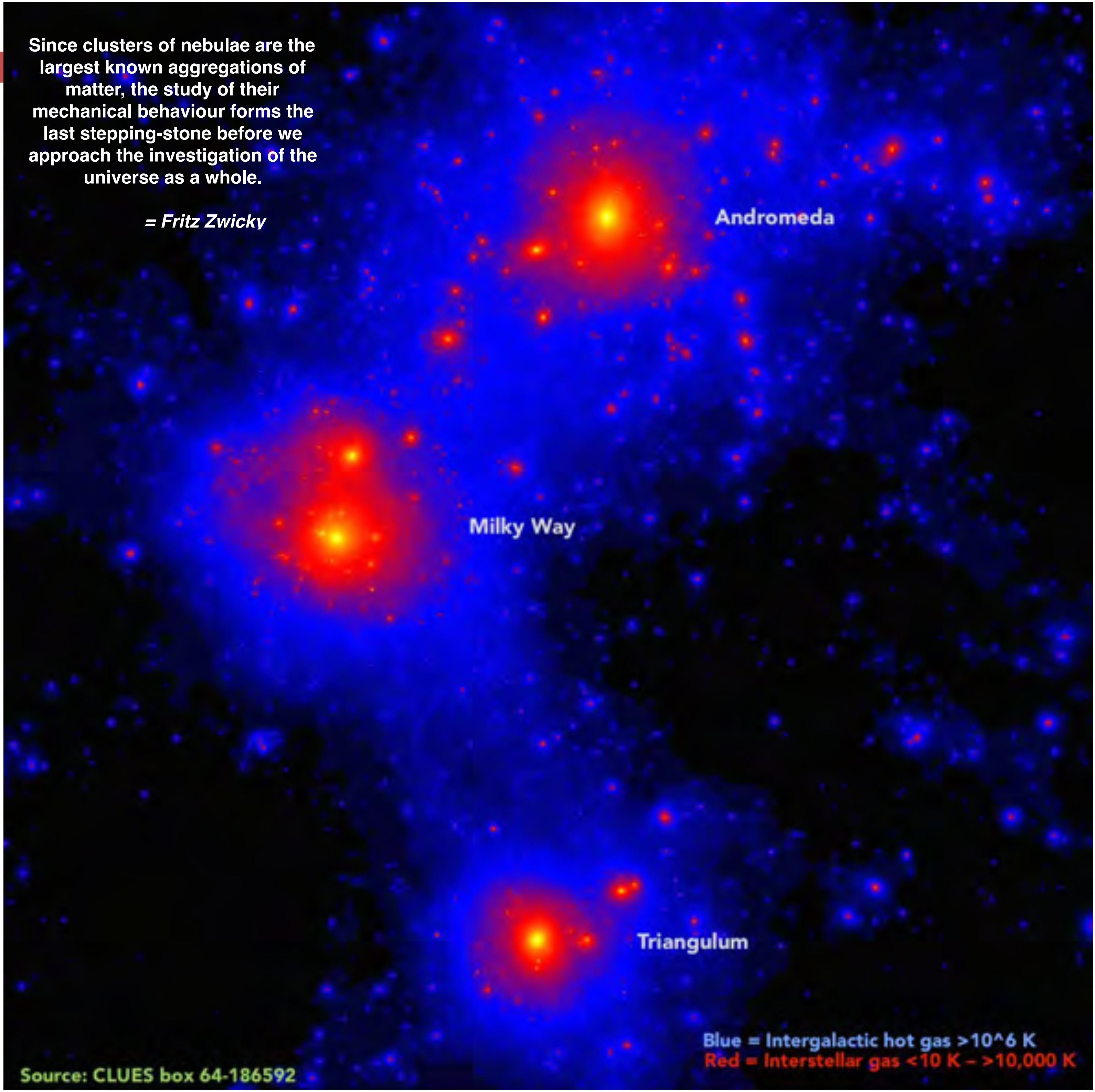
*Understanding the cosmological context of the Milky Way and its neighbours*, Inter-relation between gas, dark matter, and stars. *Source:* Creasey 2015.

Dark Matter evolution of the Local Group in full-dome planetarium projection, 2:24s 45 MB MP4, *Source:* Henze, McCurdy, & Primack, CLUES. (DM density in early universe built up slowly, please be patient.)

Evolution of Local Group DM density z=42 – 0, *Source*: Riebe, CLUES.

Different evo of cold & warm DM in 64 Mpc cube
Khalatyan, CLUES.

*DIY*: Obtain & learn how to use the GADGET-2 code used in most large-scale cosmology sims.



# The African Connection


## ECKHART SPALDING



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## Tapping the untapped Pool

"Africa is the greatest untapped pool of scientific talent anywhere, and no one realises this." These are the words of Neil Turok, the South African cosmologist and founder of the African Institute for Mathematical Sciences (AIMS) graduate program. Despite this, Africa's ballooning population is undergoing rapid technological change.

The tech sector is blowing wide open. Cell phone infrastructure has spread like lightning and supports the widespread use of WhatsApp, Facebook, and mobile money. People are more connected and technology-dependent than ever before.

The International Astronomical Union (IAU) marked Sub-Saharan Africa for "special attention" in a Strategic Plan to use astronomy for global development in 2010-2020. This was followed in 2011 by the founding of the Office of Astronomy for Development (OAD) to help implement the Plan's ambitions.

### SOUTH AFRICAN CONNECTION

I asked OAD Director Kevin Govender what astronomically-related skills are most needed in sub-Saharan Africa. In an email, he notes that there are three major ongoing projects. They include the optical


At the inauguration of the West African Regional Office of the IAU-OAD in 2015. First from the left is Bonaventure Okere (as Regional Coordinator for the West African Regional OAD node, Nigeria), second from the left is Kevin Govender (as Director of the IAU-OAD, South Africa), and fifth from the left is Zacharie Kam Sié (as Country Coordinator for Burkina Faso). Looming on the screen in the background is IAU General Secretary Piero Benvenuti. (Image credit IAU/ Dele from the Centre for Basic Space Science, Nigeria.)

facilities of the South African Astronomical Observatory (SAAO) like the South African Large Telescope (SALT); radio facilities including the Karoo Array Telescope, the Square Kilometer Array, and the African Very Large Baseline Interferometer (VLBI); and the High Energy Stereoscopic System (HESS) gamma-ray facility in Namibia.

The SKA alone is a rising behemoth that will require human infrastructure to handle staggering data management and transfer challenges from remote locations in eight other African partner countries. (Much ado has been made about the ~200 petabytes of data that the Large Synoptic Telescope (LSST) will generate. But the SKA is expected to generate *more than twenty times as much*.)

The great thing is that the skills that will be fostered and demanded by these projects can be applied to other things. “Big data is the buzz word here,” writes Govender. “Anyone with data analysis skills would be able to move into the tech industry”–like mobile phone services–“or the development sector” where social data is analysed, such as at the South African Stats SA and the Human Sciences Research Council.

If you’re interested in becoming involved in astronomically-based capacity building in Africa, you can get ideas from the list of projects the OAD has partially funded in the past. There’s also a list of ways you can help the OAD in particular.

Now let’s take a closer look at two initiatives in Africa that are making a difference.

### The West African International Summer School

Margaret Ikape was in high school in Nigeria when she first heard a passing reference to astronomy. In college she was among a small number of students who were actually studying the subject when she heard about a West African International Summer School for Young Astronomers (WAISSYA). She decided to apply.

The idea for WAISSYA germinated in 2012 among discussions at the IAU General Assembly in Beijing, China, between the Nigerian radio astronomer Bonaventure Okere, and Michael Reid and Linda Strubbe of the University of Toronto. Okere was excited about developing radio astronomy in West Africa, and hoped to establish a regional OAD node in Nigeria. Strubbe had previously done outreach work with children in South Africa, and was excited to collaborate with him on a summer school project.

WAISSYA is now a biannual workshop involving between 50 and 70 participants, mostly from West Africa, from college kids to teachers to engineers from Nigeria’s space program. The workshop met in Nigeria in 2013, 2015, andAugust 2017 at the Ghana Space Science and Technology Institute.

The undergraduates have lectures, inquiry activities, and community-building sessions. “Lecturers” try to speak as little as possible and let students respond to questions and pose questions of their own. Participants discuss open-ended questions like “How do we know how far away things are?” and argue their views.

The postgraduates work on research techniques. Radio astronomer and WAISSYA instructor James Chibueze tells me that this year they plan to learn Python scripting, database querying, and scientific writing skills. The will also observe methanol masers with Ghana’s 32-m radio telescope.

Throughout the workshop, participants build community by socialising and networking over cups of that all-important pan-African elixir: very, very sugary tea.

WAISSYA students doing a parallax inquiry activity this week at the School of Nuclear and Allied Sciences building, Ghana Atomic Energy Commission. (Image courtesy of T.D.C. Nguyen.)

Ikape participated in WAISSYA in 2013 and 2015. As a participant, the inquiry activities would “make you think on your own.” Surveys of other participants also found that the sessions could be frustrating and difficult, but ultimately rewarding. They learned to ask questions, work as a team, and realised that silly-sounding questions may turn out to be important. Ikape also got advice at WAISSYA about applying to graduate schools.

Now she is a peer of WAISSYA instructor Jielai Zhang as a graduate student at the University of Toronto, and is now returning to WAISSYA as an instructor herself. Other workshop alumni are pursuing graduate studies at the University of Nigeria and the University of Waterloo in Canada. The experience can also prod participants towards engineering careers, which Chibueze says can include software development, machine learning, data handling, and design of hardware and automation processes.

What is the workshop in need of? It might benefit from more instructors from the continent who could supplement the representation from Nigeria, and perhaps other Westerners who could mentor alumni online. Currently, though, the most pressing thing that WAISSYA needs are donations.

## Astronomy in Burkina Faso

On a UN list of the least-developed countries in the world, Burkina Faso is number six from the bottom. During work there in the 2000s, a Rwandan medical worker mentioned her astronomer-husband Claude Carignan in a conversation with the country's Minister for Higher Education. The Minister paid him a visit at the Université de Montréal in Canada, and asked if he would like to help start an astrophysics program at Burkina Faso's flagship university. To test the waters, Carignan spent a sabbatical in 2007 in the Burkinabe capital Ouagadougou.

Carignan found that the classes at the Université de Ouagadougou were adequate, but the lab facilities were non-existent. He agreed to participate on the condition that six future Burkinabe astronomers be hired onto the faculty. "The critical mass of six is important," Carignan tells me, in order to sustain an active research program. The condition was accepted. Carignan chose six students for advanced studies, and he and some of his colleagues from Quebec taught graduate classes at the Université de Ouagadougou. In due course, an IAU conference was also held in Ouagadougou in 2010.

Jean Koulidiati, the university's Director of the Laboratory of Physics and Chemistry of the Environment, assisted Carignan in navigating the myriad cultural, logistical, and bureaucratic obstacles for laying groundwork for the program. "He opened me all the doors," says Carignan. "By myself I'm sure I would never have been able to do all that."

*Bon voyage!* The MarLy telescope is packed up and ready to depart La Silla Observatory in Chile for the long voyage to Burkina Faso. (Image courtesy of C. Carignan.)

As of now, two of the students have completed their PhDs, and more are in the pipeline. One graduate, Zacharie Kam Sié, graduated from the Université de Montréal and is already on the faculty in Ouagadougou. Kam Sié is juggling heavy teaching responsibilities, paper-writing, and outreach initiatives. He tells me in an email that they are also in the process of developing a master's program in Ouagadougou in astrophysics and photonics instrumentation "to contribute to the development of our country via astronomy."

Indeed, this is why the impoverished Burkinabe government has sunk money and resources into the development of astrophysics at home– it's useful for all kinds of things! Already, the astrophysics program has led to links between the government and photonics companies interested in shifting contract work from China to Africa.

But how does one avoid facilitating a brain drain of researchers overseas? "There has to be an attraction," says Carignan. "And if the labs are empty, they won't come back."

Accordingly, Koulidiati, Kam Sié, and Carignan are working on building a 1-m optical research telescope on a mountain called Djaogari. The site has been characterised, the dome itself is ready, and a disused telescope (the former MarLy) was packed in from La Silla in South America. "Even if it's not that big of a telescope, there's a niche for such a telescope," says Carignan. Science goals could include surveys of hydrogen-alpha in the Milky Way and in the diffuse interstellar gas.

Stay tuned. Soon Africa will see more areas of localised skill sets attain critical masses, and both massive and niche astronomy facilities will come on line. If WAISSYA and the Université de Ouagadougou are showing what is already possible at the ground level, imagine what else is to come.

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Eckhart's other recently published articles are:

Illusion and reality in the atmospheres of exoplanets, *astrobites* 12 Oct 2017
A black hole with kick, *astrobites* 11 Sept 2017
Clouds over the sunlit arch, *astrobites* 15 June 2017
New information from an old result: planets in globular clusters, *astrobites* 8 May 2017
New Horizons in Astronomy and Astrophysics: a mid-term assessment, *astrobites* 31 March 2017
Getting a peek at exozodial dust belts, *astrobites* 4 March 2017