NIGHTFALL

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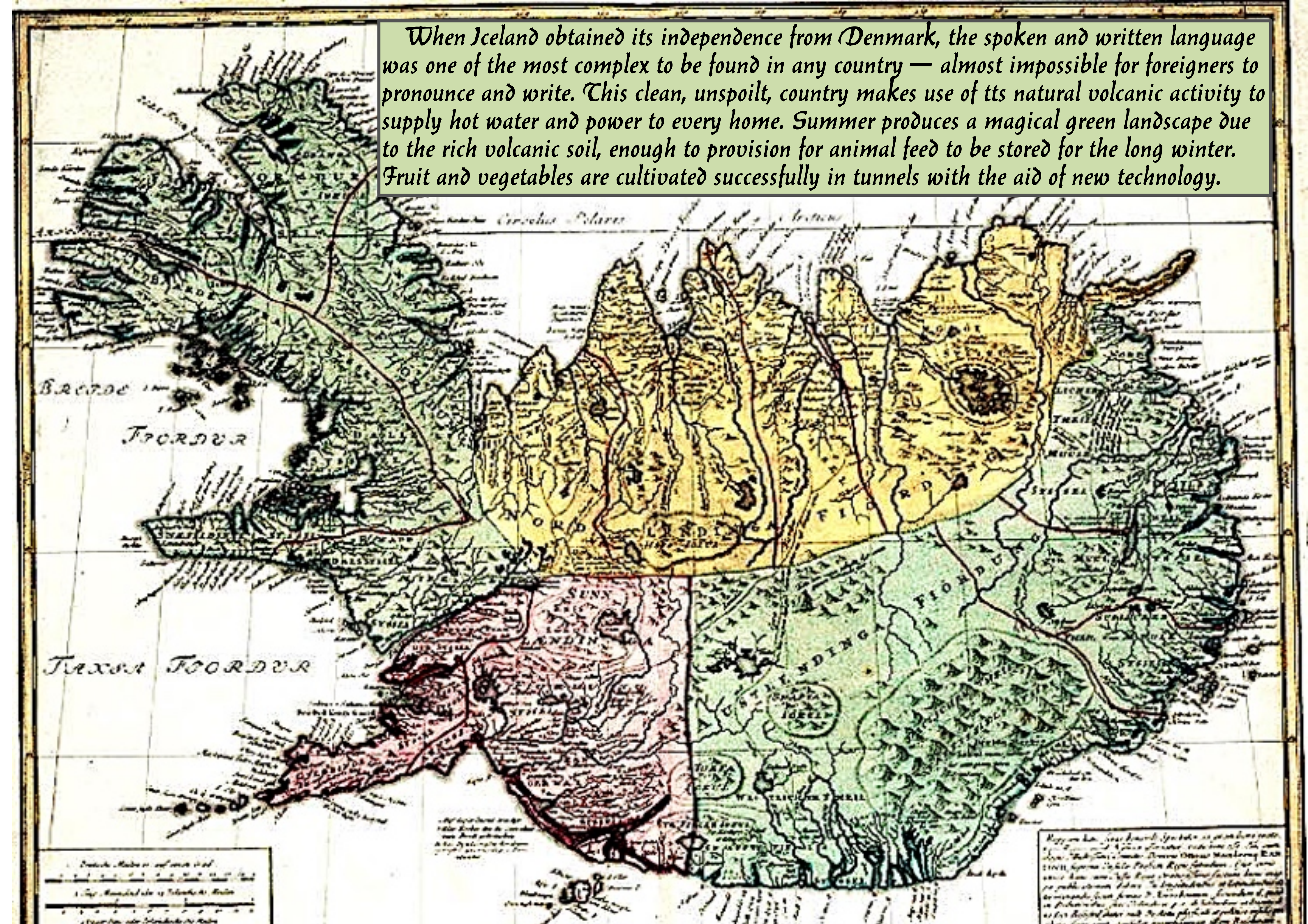
Star plot of the Pleiades from Galileo's *Sidereus Nuncius*, 1610.
Courtesy of the *Galileo Musem, Florence, Italy*.

Image: Comet Wirtanen November 2018 by Martin Heigan

In This Issue


Magda Streicher
Journey into the cold

When Iceland obtained its independence from Denmark, the spoken and written language was one of the most complex to be found in any country — almost impossible for foreigners to pronounce and write. This clean, unspoilt, country makes use of tts natural volcanic activity to supply hot water and power to every home. Summer produces a magical green landscape due to the rich volcanic soil, enough to provision for animal feed to be stored for the long winter. Fruit and vegetables are cultivated successfully in tunnels with the aid of new technology.



Sometimes when you don't get what you want, you get what you need.

Some events in life remain with us forever, while others disappear with time. What is beyond doubt, is that a visit to the extraordinary country of Iceland would be difficult to replace and impossible to forget – the memories would never fade.

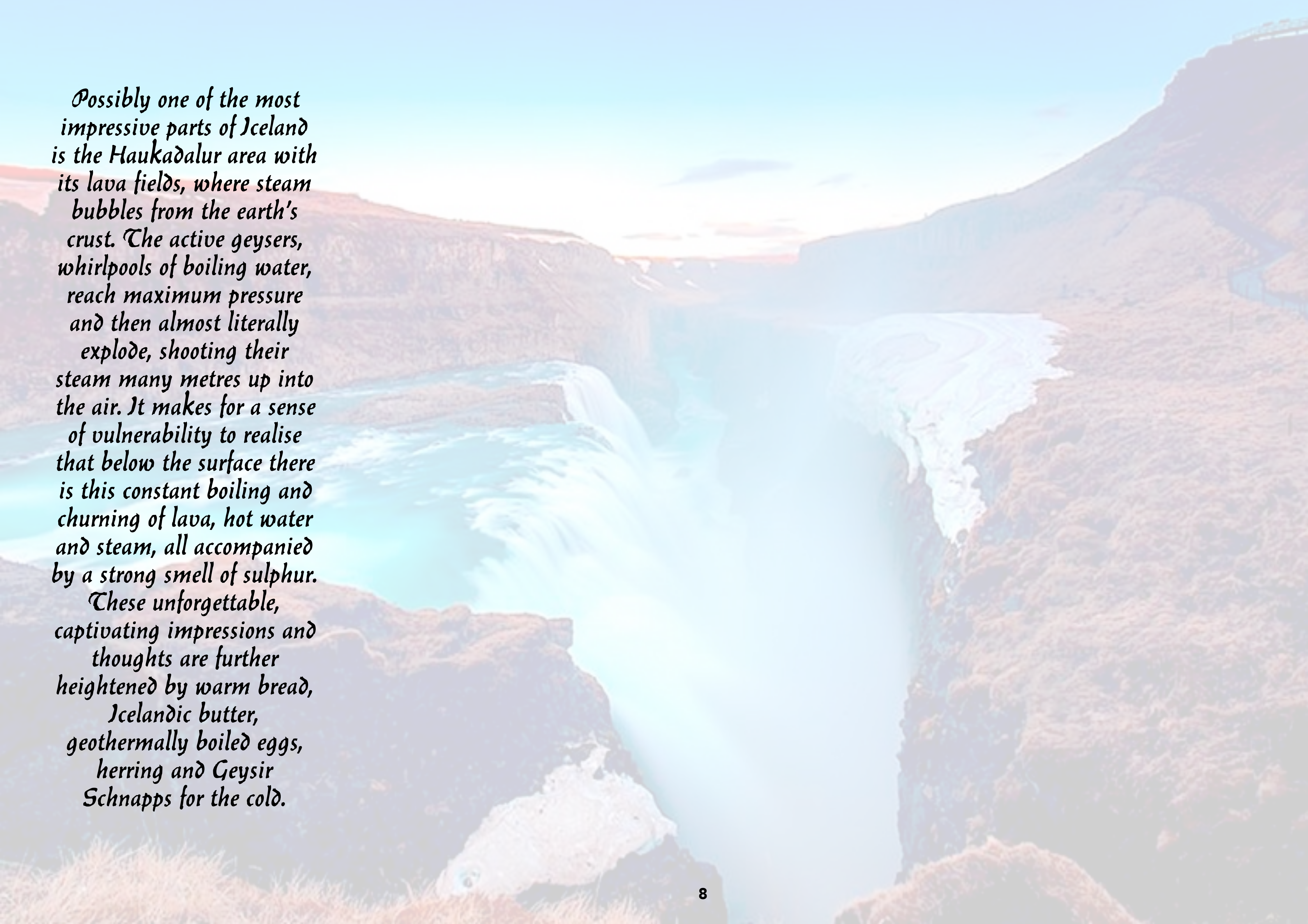
"Excited" would be understating how I felt at the prospect of visiting that multifaceted country. Knowing that we could expect icy cold weather I packed everything that would effectively protect me against the cold – or so I thought! But freezing aside, there was a huge excitement in me and full confidence that I would get to see the Aurora Borealis (northern lights). This natural wonder seen against a dark night sky must surely be the purest and cleanest form of miraging, dancing with paint strokes of bright colours. The best and rarest phenomena in the night skies are not always freely available and frequently observable – think of solar eclipses and the Aurora Borealis or Aurora Australis as examples. The polar circles are where the hot particles of the sun collide with the magnetic fields to create and display the latter two spectacular phenomena.

Grabok Crater

I have never been so cold in my life, but the great expectation somehow served to calm that cold and make it more bearable. Iceland was in the throes of winter, and the extensive white landscape was covered with snow and ice. The bus offered wonderful warmth – until we had to alight at the Grabok Crater. The beauty was overwhelming, and the sight of the flowing lava far exceeded our expectations. In the distance a majestic crater could be seen which was dormant at the time, but which, as we were told, was capable of a mighty eruption at any time. Iceland has the greatest number of volcanoes, waterfalls, glaciers and geysers because of its particular location on the earth's crust. The impressive Atjaflatjayoka glacier, the largest of its kind in Europe, forces its frozen way through mountain peaks to pit itself against the earth's forces.

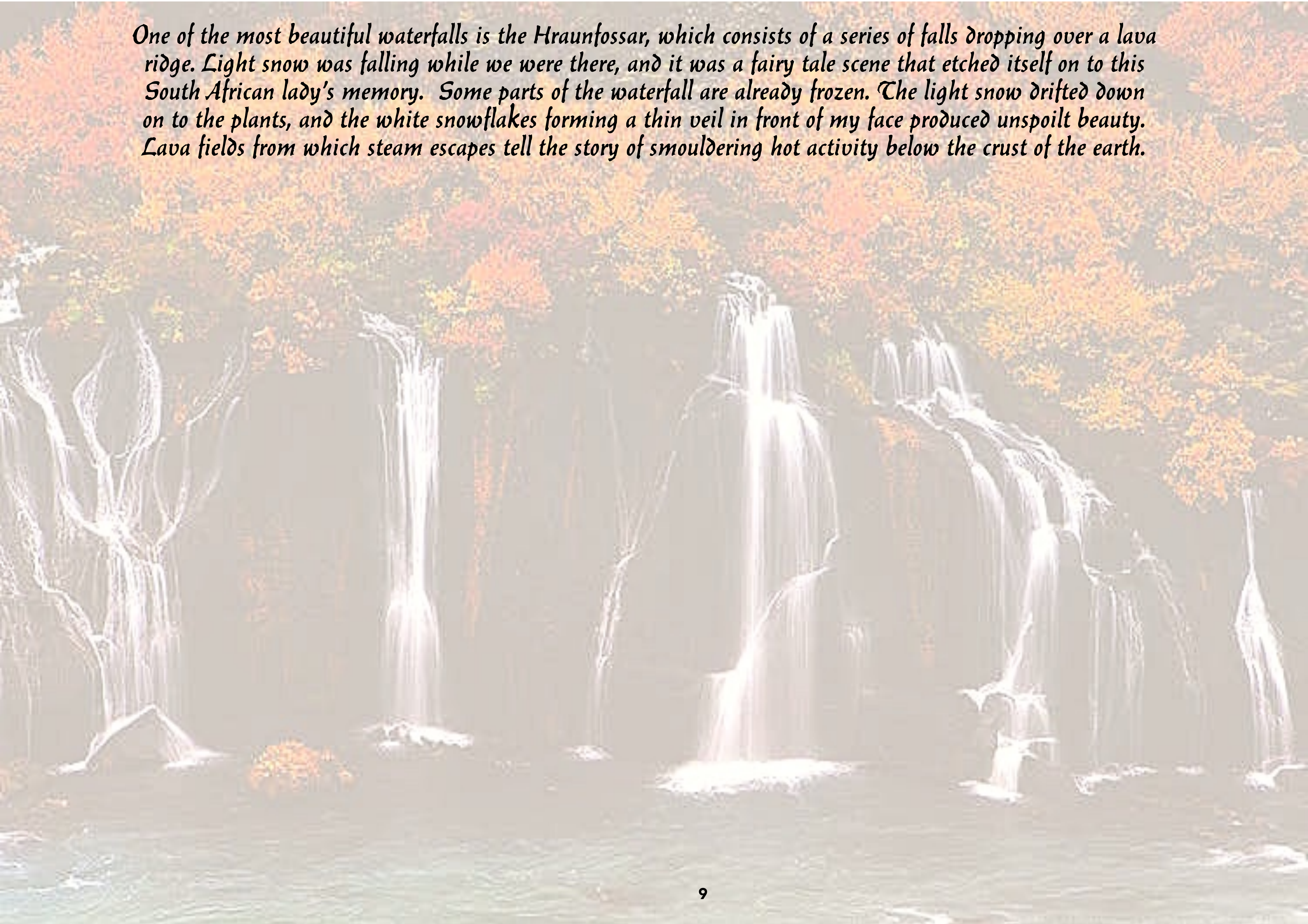
We journeyed through hot springs terrain (97 Celsius), travelled through snow storms, pondering the unique country and exceptional countryside. Every evening we braved the cold, below-freezing night air in search of the elusive Aurora Borealis. But the weather remained overcast and we learned that this has been one of the coldest weeks yet during Iceland's winter this year.

Probably the best-known of the many volcanoes in Iceland is Hatla, which in 2010 showed what the seething magma of molten rock deep in the earth is capable of in terms of blasting its way up into the sky. Our excellent Icelandic tour guide had many stories to share about survival in and adaptation to the conditions of this multifaceted, wonderful country.



Possibly one of the most impressive parts of Iceland is the Haukadalur area with its lava fields, where steam bubbles from the earth's crust. The active geysers, whirlpools of boiling water, reach maximum pressure and then almost literally explode, shooting their steam many metres up into the air. It makes for a sense of vulnerability to realise that below the surface there is this constant boiling and churning of lava, hot water and steam, all accompanied by a strong smell of sulphur. These unforgettable, captivating impressions and thoughts are further heightened by warm bread, Icelandic butter, geothermally boiled eggs, herring and Geysir Schnapps for the cold.

One of the most beautiful waterfalls is the Hraunfossar, which consists of a series of falls dropping over a lava ridge. Light snow was falling while we were there, and it was a fairy tale scene that etched itself on to this South African lady's memory. Some parts of the waterfall are already frozen. The light snow drifted down on to the plants, and the white snowflakes forming a thin veil in front of my face produced unspoilt beauty. Lava fields from which steam escapes tell the story of smouldering hot activity below the crust of the earth.

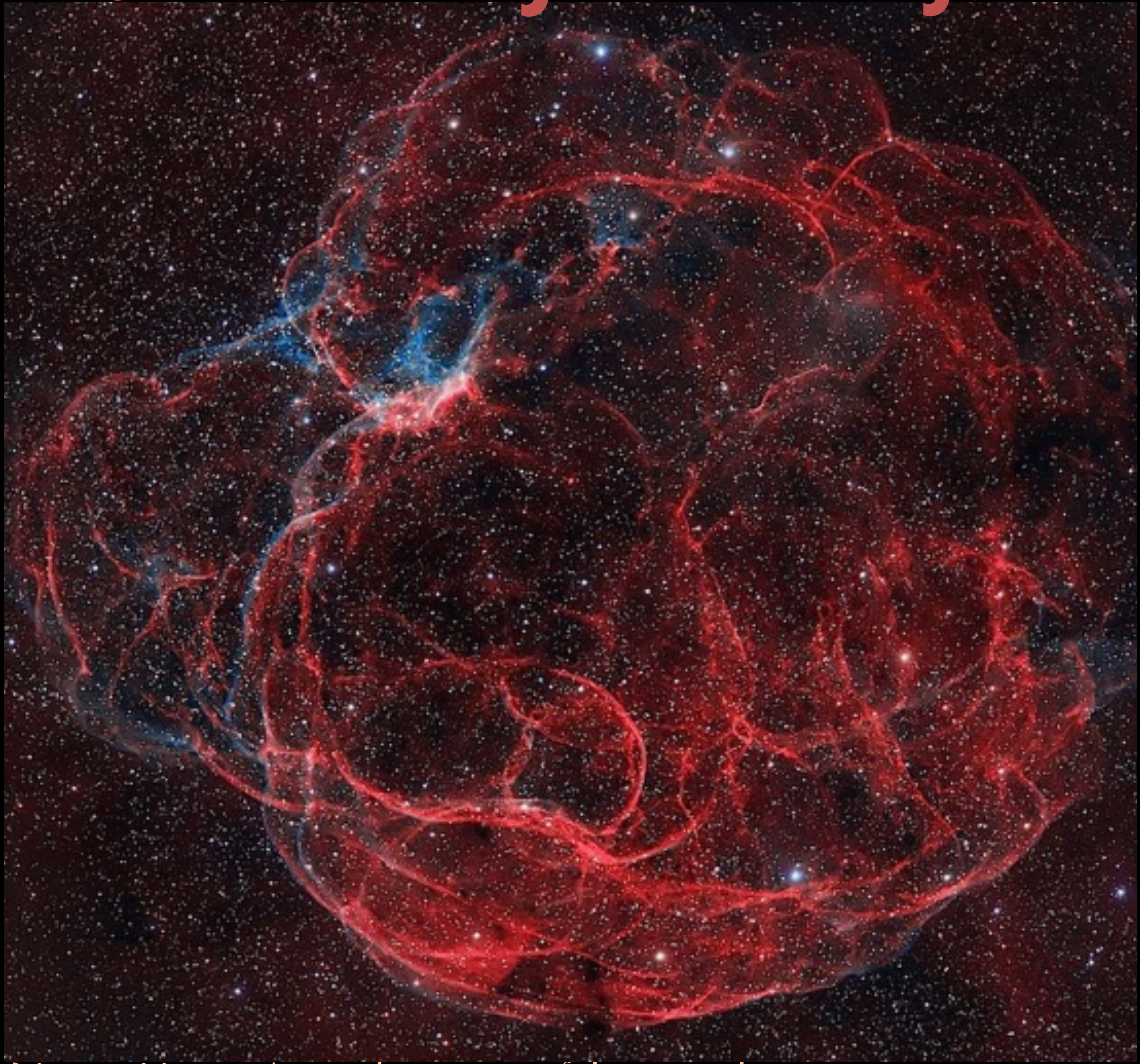


The Vatnajökull Park is the largest in Europe at about 12 000 square kilometres. The enchanting, incredible, white snowy landscape is infinite, the beauty overwhelming. The crackling of crispy snow and ice underfoot added to this once-in-a-lifetime experience which will forever remain etched in my memory.

The Skaftafell National Park is where the true beauty of Iceland can be seen, with the Jökulsàrlòn glacier with its floating icebergs and black sandy beach, aptly named the Diamond Beach with its beautiful ice fragments appearing like glistening jewels on the black velvety sand. Icy crystals sparkle in the sun like diamonds, and in the distance the snow resembles whipped cream topped with grated dark chocolate for miles on end. The beauty and splendour of the lagoon are indescribable, a wonderful image forever captured in the memory.

But finally, on our second to last night in Iceland, the bright starlight broke through and the Aurora Borealis appeared as a bright green band against the dark night sky. Stars shone through the flimsy veil stretching from north to east in a graceful band. Here and there a hazy kink appeared and it looked as though the blowing steam was playing a concertina, shimmering and dancing, almost ebbing and flowing in glowing, graceful red and purple lines painting the sky.

Simeis 147 by Martin Heigan



Martin Heigan's vivid portrait of the complex supernova remnant Simeis 147 begs two questions: What is it? How did he do it?

Imaging the Simeis 147 Supernova Remnant

Martin Heigan

The Nitrogen in our DNA, the Calcium in our teeth, the Iron in our blood, the Carbon in our apple pies were made in the interiors of collapsing stars. We are made of starstuff.
- Carl Sagan, *Cosmos*

Imaging Simeis 147 was one of the most challenging — and thus rewarding — objects I have ever attempted.

Technically it is a wide-field Narrowband HOO Palette mosaic (*R*=Hα, *G*=OIII, *B*=OIII) of the faint supernova remnant Simeis 147. This delicate tracery of near-nothingness halfway between us and the Perseus Arm of our Galaxy is also known as the Spaghetti Nebula, Sharpless 2-240 or SNR G180.0-01.7.

The nebulous area is very large, about 3° in the long dimension, with an irregular cumulus-like shell of filamentary dust and gas. The remnant is about 3,000 light-years away and is approximately 40,000 years old.

After the star exploded, a rapidly spinning neutron star (Pulsar PSR J0538+2817), was left behind in the Nebula core, emitting a powerful radio and even more powerful X-ray signal.

About this image

This image is the result of photographing during the 2018 Christmas/New Year festive season in the Southern Hemisphere, over several nights as the weather permitted, in locations and ambient light conditions ranging from my Telescope Pier at home to dark rural skies.

Deep Sky Objects like this push the limits of my modest telescope gear, especially my mount. It is rewarding when you have to work hard for an image, and wide-field mosaics are a challenge redoubled.

Simeis 147 in Taurus/Auriga is a good example of how difficult very faint but large wide-field Deep Sky Objects can be, and yet how breathtakingly beautiful they are when everything comes out right.

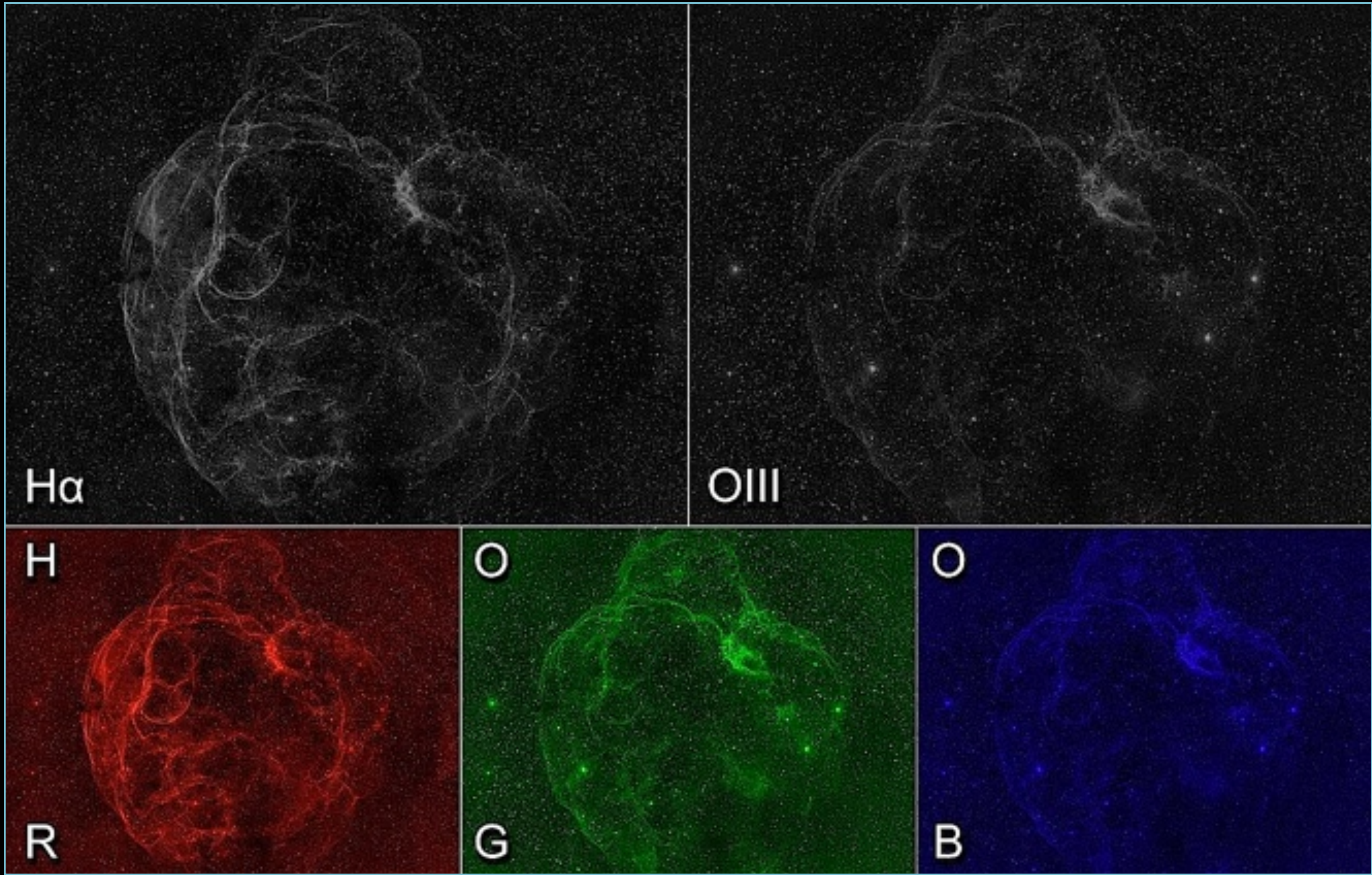
Technical Info

- 4 panel wide-field mosaic.
- 16 x 600 sec. 7nm hydrogen-alpha (Hα) per panel.
- 16 x 600 sec. 6.5nm doubly Ionized oxygen (OIII) per panel.
- William Optics Star 71mm f/4.9 Imaging APO Refractor.
- Sensor cooled to -15°C on my QHY163M.
- Calibration frames: bias, darks and flats.
- SGP Mosaic and Framing Wizard.
- Astrometry.net ANSVR Solver via SGP.
- Pre-Processing and linear workflow in PixInsight, finished in Photoshop.

Astrometry Info

- Center RA, Deg: 85.239, 27.931
- Center RA, hms: 05h 40m 57.427s
- Center Dec, dms: +27° 55' 52.133"
- Size: 4.76 x 3.65 deg
- Radius: 2.998 deg
- Pixel scale: 10.7 arcsec/pixel
- Orientation: Up is 263 degrees E of N
- View an Annotated Sky Chart for this image.
- View this image in the *WorldWideTelescope*.

Balancing the data/palette mix is where the artist takes a bow.



The elements in a Deep Sky Object dictate which Narrowband wavelengths will give the best results. As there is not much happening in the green part of the spectrum in this type of object, Hydrogen-Alpha and Oxygen III is a good choice for SNR bi-colour Astrophotography. Narrowband also makes it possible to image in light polluted skies, as it blocks everything except the desired wavelengths of light. Imaging a vast multi-panel mosaic with only 2 Narrowband filters, also saves a lot of time. Hα falls in the red part of the spectrum, and OIII in the blue part of the spectrum. I didn't want to mess with that in the processing, so I chose to use the HOO Palette. The OIII blue channel is simply mapped to the green channel as well, leaving the red and blue colours unchanged. I like to call this enhanced colour, as the colour is not false but only boosted due to the amount integration time.

Spaghetti in the sky

Dana De Zoysa & Doug Bullis

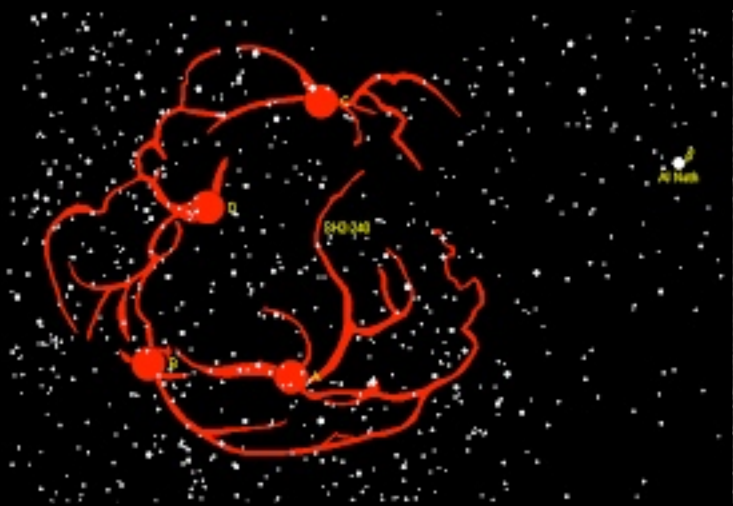
Simeis 147 is colloquially known as the Spaghetti Nebula. In loftier circles it is SNR G180.0-01.7, Shajn 147, or Sharpless 2-240. In HII the sauce looks a bit rich on the red sauce. In Hα the noodles are soap bubbles in the sunset. In OIII pearls on a black dress.

Sim 147 is a supernova remnant (SNR) directly astern of the Galactic anticentre as the sun rudders into the Sagittarian Sea. Viewed from the disc plane (our perspective) it is barely two degrees south of the centreline. Viewed from above it straddles Auriga and Taurus very close to the Galactic S polar axis. It does not appear on many star maps 20 years or older because it is one of most difficult extended objects to spot and has not been much of an amateur target till the last decade. Only four small pockets rise above the 25 mags per sq. arcsec (25 MPSAS) threshold, the lowest luminance most human eyes can see. The images below show the approximate locations. How do we prepare for the search?

Warmer-uppers

The best preparation a hobbyist can make to tackle S147 is to log a lot of dwarf galaxies in the observations book. Dwarfs share Sim 147's qualities of very faint threshold, luminosity density gradient, and star-thick background confusion. A "Con-firmed" sighting in these conditions means three unquestionable glimpses repeated two times in a given night over three different nights.

Suitable warmup candidates are the Ursa Minor Dwarf, the Draco Dwarf, Fornax and 4 of its globulars, Phoenix, Sculptor, WLM, IC 1613, Leo X, Leo T, and for patient observers, the Pegasus Dwarf, and Andromeda VI. Since you're in the area, Pal 2 in Auriga makes a nice side-trip, but faint GCs aren't as helpful as dwarfs because their round glow is easier to spot than an extended filament when using averted vision. (You can always use poor luminosity threshold as an excuse to buy a larger scope.)



Plot courtesy of Rich Jakiel in *astronomy-mall.com*.

The big picture

Simeis 147 is a middle-age supernova remnant ≈40,000 years old. Some of S147's filaments have a different chemical composition on one side than filaments on the opposite side. That's a clue to its origin. There is also a velocity gradient favouring the upper-left filaments but not the lower right. A velocity gradient in an extended thin nebula point to angular momen-tum left over after a binary decoupling.

Image adapted from *Thomas W Earle, 2007*.

Bubble breakout in CBT1 Abell 85

Lopsided gradients are hard to explain because of their large surface areas and low gas densities. Clue #2.

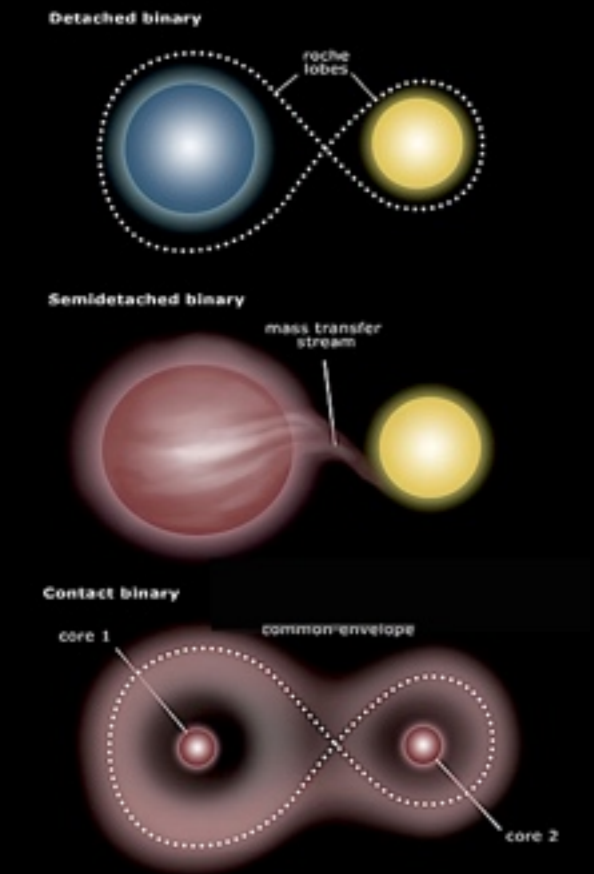
Aladin Lite multiband images show that the old supernova remnant PSR J0538+2817, visible mainly in XMM Newton X-ray, is also located well off-centre in the direction of the most rapid filament expansion. This suggests bubble breakout in which the expansion velocity of a gas parcel exceeds the binding energy of its bubble surface and breaks out into champagne flow.

The Gordian Knot solution to these clues is that Sim 147's original progenitor star was a part of binary O system whose components were so close to each other that they exchanged material via contact Roche Lobes. Type O similar-mass binaries closer than 1 AU (the Earth-Sun distance) are close enough that they exchange surface ejecta gases via their Roche lobes. When one of the pair goes supernova, the drastic and sudden loss of mass on one side releases the second star to wander off as an O runaway star. The runaway's new transverse velocity is its original orbital velocity minus the momentum transfer losses donated to the overall association as the runaway departs.

Moreover, the shock wave from a binary supernova blasts across the surviving O star, stripping material from the star's surface and shallower envelope layers. That would account for Sim 147's metallicity anomaly. Roche lobe gas would be more hydrogen-rich while envelope gas would be more helium-rich. Excess helium in a remnant's spectra implies envelope stripping. Calculations show that predicted metallicities in models approximate what real metallicities are in Sim 147. With these clues in hand, astronomers went O runaway hunting. It was a brief chase. A high-velocity >13 $M_{\odot}$ was located 4 arcmin away.

Sim 147's nebulosity is ±3° diameter. The SN remnant is an estimated 3000 (±350) light-years distant — about half again further out toward the Perseus arm than the young open star clusters M35-36-37-38 in Auriga and Gemini. That puts it in the interarm region between the Orion Spur and Perseus Arm. The progenitor star's explosion left a 9 RPM neutron star packed so densely that it is 2.3 times the density of an atomic nucleus. It is seething in magnetic fields so powerful they'd tear off your belt buckle around Pluto. Heaven help you if you have those old mercury-amalgam tooth fillings. Not for nothing are pulsars, black holes, and magnetars called "exotics" in the astrophysics literature.

Sim 147 is a roughly oblate spherical shell dense with pendulous filamentary loops. The leading edges glow because they are expanding



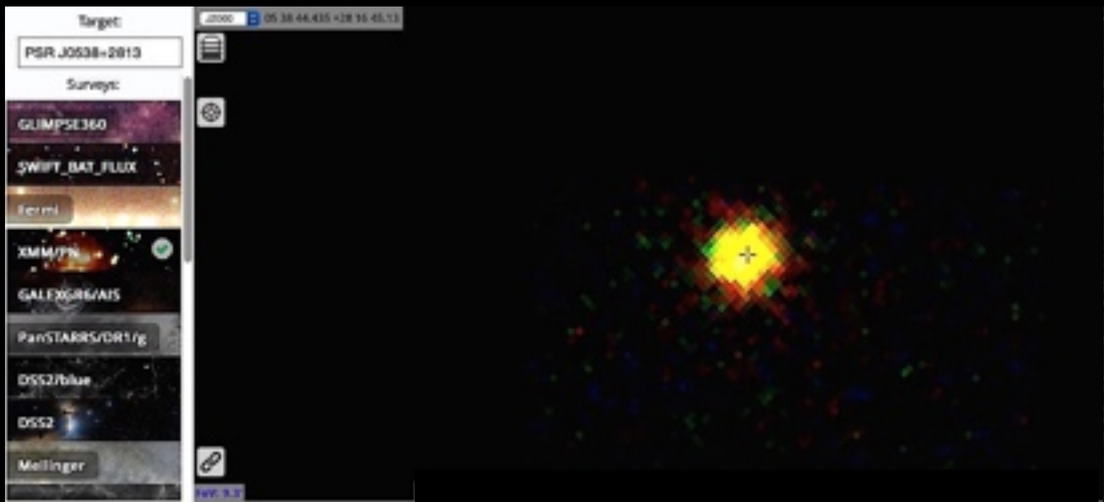
In a binary system, a pair of stars close enough to be inside their Roche limit become gravitationally unstable. The instability initially affects surface layers, which detach from the stars and fall into a Roche lobe. Mass transfer occurs in two of the three situations where a Roche lobe exists. In a simple detached binary there is no exchange between the stars because the Roche lobes do not fill with gas. In semi-detached binary one star fills its Roche lobe and transfers mass to the denser star. In a contact binary both stars fill their Roche lobe and have a common envelope (CE). CE's are gravitationally unstable and transfer mass from the less dense to the more dense star. This can lead to an oscillatory imbalance when mass transfer see-saws back and forth. In O and B star binaries the dance ends when one of the stars goes supernova.

supersonically through a low-density interstellar medium. Glider and ultralight aircraft pilots experience the same density shock in the subsonic regime when they fly from clear air into and though a cumulus cloud.

Lustrous wallflowers

Pulsars revel in the luminance version of anonymity. Simeis 147 is no exception. They emit feebly in any but a few wavebands, mainly radio, X-ray, and gamma. Simeis 147's pulsar, PSR J0538+2817, is as close to anonymous you can get in general astronomy website searches. Aladin Lite (below) reveals emission at its position only in the XMM Newton image set, but in that band the star blazes in the 9.3 arcmin field of *ESA / SSC XMM-Newton* X-ray images at Red=0.5-1 Kev, Green=1-2 Kev, Blue=2-4.5 Kev. It also It emits in the *1.4 GHz radio band at 1.432 mJy*. The Landoldt V extinction here is 3.86 magnitudes, which is less an issue here than it is with visual observers, but of great interest to *SNR physicists* keen to know what exactly they are seeing.

PSR J0538+2817 in the XMM Newton 9.3 arcmin field. The star does not present an image in any of the other Aladin Lite bands shown on the partial list to the left.



The WikiSky screen shot below shows the location of Simeis's supernova remnant, the pulsar PSR J0538+2817. Most pulsars are strong X-ray emitters, but the radiation is not thermal energy from a hot star but rather *synchrotron radiation* emitted when relativistic electrons spiral around magnetic field lines. The emission direction propagates as a forward-pointing "beaming" cone of radiation around the field line (see *¶4 here*). Pulsars have powerful poloidal magnetic fields. Since around 70% of O stars were binaries at birth, in 2015 *Dincel, Neuhauser et al* searched the nearby field for an O runaway star. The team indeed found an early type runaway star inside SNR S147. *HD 37424* is a B0.5V-type star with a peculiar velocity of 74±8 km/s. Tracing its trajectory back via Monte Carlo simulations, they calculated that HD 37424 was at the same position as the central pulsar *PSR J0538+2817* some 30±4 kyr ago. This position is only 4 arcmin away from the geometrical centre of the SNR. HD 37424 was the pre-supernova binary companion to the star that went supernova. HD 37424 is 1333 pc (4345 ly) from Earth.

The team was then able to calculate that the progenitor to the supernova had a mass of >13 $M_\odot$. HD 37424 is 30 ±4 thousand yr. The team then calculated what the pre-supernova binary was like. They found via

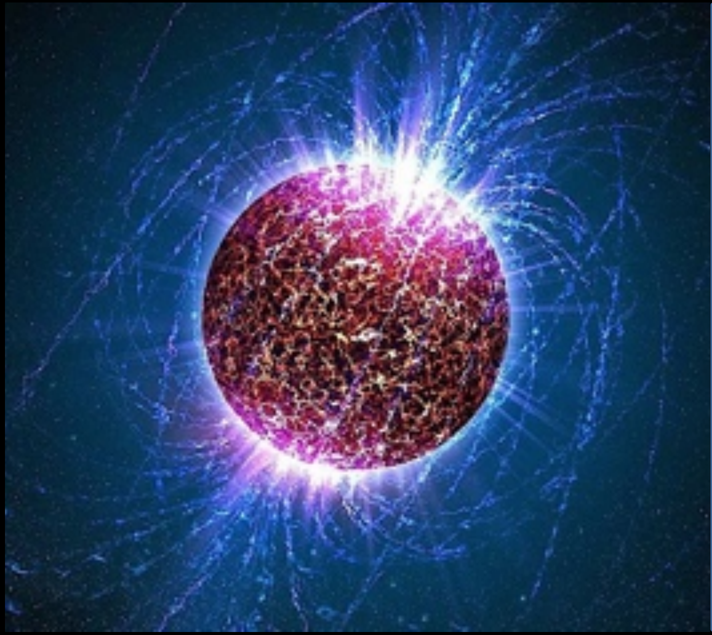
Magnetic attraction is romantic, but not with a magnetar

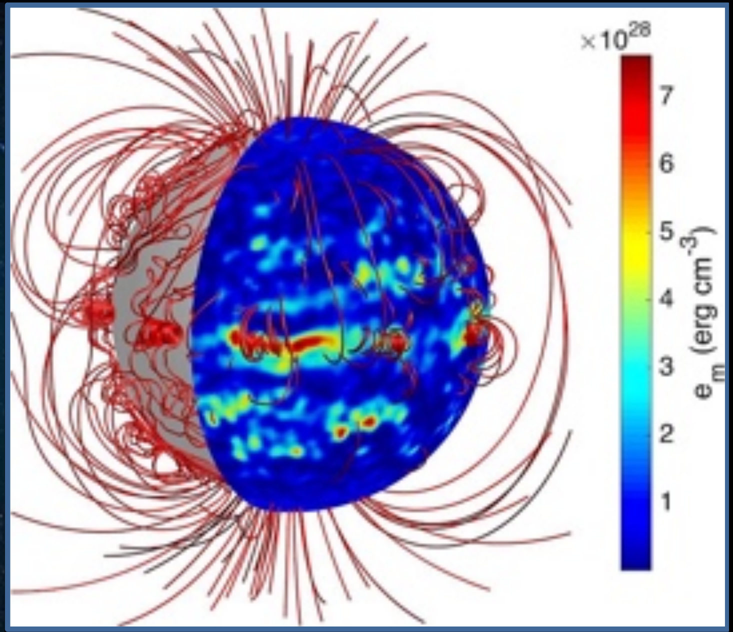
Of the 30 known Galactic magnetars, eight are in supernova remnants. PSR J0538+2817 in Simeis 147 is one of them.

Roche lobe simulations that the two stars were within an AU of each other's surfaces during the late stages before the progenitor went supernova.

Close O binaries put on quite a tit-for-tat mass exchange dance via Roche-lobe transfer. The initially larger star donates gas to the smaller one until it swells to larger than the first star. The gas flow then reverses until the newly smaller star becomes the larger one again. The cosmic doe-si-doe goes on until one of them detonates. When such an event happens to two very close stars, the supernova blasts away around half of the binary's total mass, sending off its former companion to wander the heavens in splendid solitude. Don't get in its way.

The Sim 147 shell is expanding at 80–120 km s^{-1}. Using GAIA parallax data, the pulsar locates the original supernova at 1.47 kpc (4790 ly) from Earth. It extends about 150 light-years at this distance. The remnant is estimated to be about 40,000 years old. The remnant's fragile, tenuous appearance in the optical and near-IR are consistent with other SNRs.





Magnetar poloidal field lines are so dense that they interact with each other at 10^{15} times the field strength of the Earth's 25 gauss.

At visual mag 9.0 PSR J0538+2817's runway O companion star is an easy find for a go-to system.

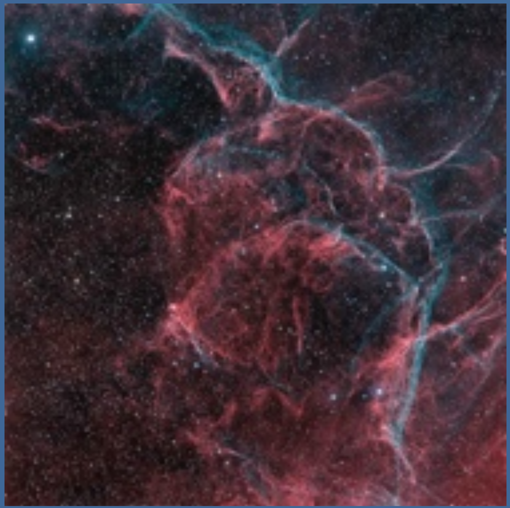
History

Simeis 147 was discovered in 1952 by Grigori Abramovich Shajn and V.T. Hase at the Crimean Observatory on Mount Koshka, Crimea in the former U.S.S.R. (See more about the observatory below.) The discovery was made using photographic plates taken with a 25-inch Schmidt camera.

Sim 147 was catalogued by Stewart Sharpless, an astronomer at the Unites States Naval Observatory in Flagstaff, Arizona. Sharpless compiled his oft-used SNR reference database by examining Palomar Observatory Sky Survey (POSS) plates for HII regions. His second and final catalogue of 313 objects was published in 1959. Simeis 147 appears in his list as Sh2-240.

Simeis 147 was first classified as a possible shell-type supernova remnant (SNR) by Walter Minkowski just one year earlier.

Strolling the Galleria Galactica : Supernovae Remnants

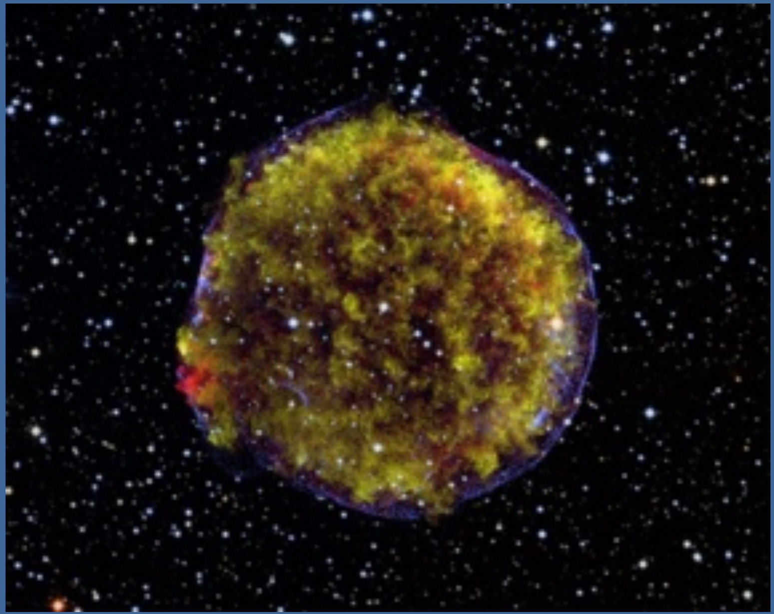


Vela SNR Hα OIII 11-12000 yro.

G34.7-0.4 Aquila SNR bl=Xray, gr-shell, r=MOC.

SNR B0519-69.0 T 1a SNR in LMC 600 yro.

Type 1a white-dwarf SNR B0509-67.5 in the LMC.



Tycho Brahe's 1522 SNR in Cassiopeia.

RCW 86 Circinis, the oldest known SNR.

Why does Simeis 147 look like this?

When we see a painting on the wall, we ask,
"What's going on in this thing?" (the picture)
"What is going around this thing?" (the frame)

In galaxies we ask,
"What's happening to the mass?"
"What's happening to the energy?"

Mass is the picture in the frame of Martin's Sim 147 portrait. Supernova remnants are observed to propagate in three successive phases of expansion:

- The first phase is the *explosive expansion* of the star's envelope mass as a spherical detonation field. The matter moves outward at high velocity, typically ~10,000 km s^{-1}. It slows inverse exponentially as it spreads out. The remnant associated with SN1987A is in the early explosive expansion phase. The ~300 year old remnant of Cassiopeia A is nearing the end of the free expansion phase, moving radially outward on average at 6000 km s^{-1}. The internal knots visible in OIII images are oxygen-rich clumps of matter ejected from the depths of the star's internal convection currents at the time of the detonation.

- The second phase of ejection is the *blast wave phase*. This phase begins when the mass of interstellar gas being compressed in front of the bubble becomes about equal to the mass of the bubble itself. The remnant of Tycho's Supernova is a Type 1a supernova shock in the blast wave phase (see case study below). The Crab nebula is a Type IIb core-collapse supernova in the blast wave phase; its expansion velocity is ~ 900 km s^{-1}.

- The third phase is the *snowplow phase*. When the energy on the lee side of an expanding shock front expands into the cloud of gas previously ejected by the star as stellar wind, it forms a dense cool layer directly behind the shock front. This gives a large energy rebound kick propagating back toward the centre of the shell. The 1006 Type 1a supernova recorded as a "guest star" by the Chinese shows how the layers of a snowplow shock front hit the density and temperature shell of the initial shock blast and rebound backwards toward the still-expanding gas below (see SNR 1006 case study below). The 40,000 yro Cygnus Loop (Veil Nebula) is in the snowplow phase; its expansion velocity is 120 km s^{-1}. The The reverse shock agitates the vacated interior where the progenitor exploded, which fragmented into many small low-density gas pockets. Since the pockets are thermally unstable, turbulent cells in the inward-moving rebound transfer energy into the irregular density clumps of gas in the old core region. The result is flocculent puffs that we see in both the SN 1006 and Tycho 1572 SNR images below.

The three phases are generalised examples. Many variants arise because of the diversity of local conditions. The progenitors of Type II core-collapse SNRs are massive hot stars that expel powerful high-velocity winds. A supernova in such a star occurs in a relatively low-density bubble that has been excavated by the pre-supernova star's intense stellar wind. If the supernova ejecta expands into a low-density bubble it encounters rather little mass ahead of it, hence its free expansion phase is prolonged and the shock shell weakens as it grows larger. When the shell arrives at the more rarefied gas of a spiral arm or interarm region, it weakens into champagne flow, which enters a regime of widely varying atomic and molecular clouds, and local low-density pockets.

In most cases, within a spiral arm the interstellar medium is not very uniform, while in the interarm regions the medium is relatively smooth. Local inhomogeneities large and small blur the propagation of both blastwaves and snowplow shells. The parts of a shock front passing through an irregularly clumped volume of gas enter some density pockets conducive to forming a snowplow shell, while other parts of the front nearby may encounter a locally rarefied region, and hence remain in blastwave phase.

Moreover, massive stars are born and die while still in stellar associations. The most massive stars go supernova before they have had time to move very far from the cluster or association's central region. In any large cluster or association the most massive stars will supernova within the first ±20 million years. In an environment in which events spanning a million years are considered "instantaneous", the expanding shells of multiple supernovae will eventually merge into a common *superbubble* that can reach sizes in the hundreds of parsecs in diameter. Superbubbles are the primary source of the hot ionized gas in a galaxy's interstellar medium. See these SILCC sims (*1*, *2*, *3*)

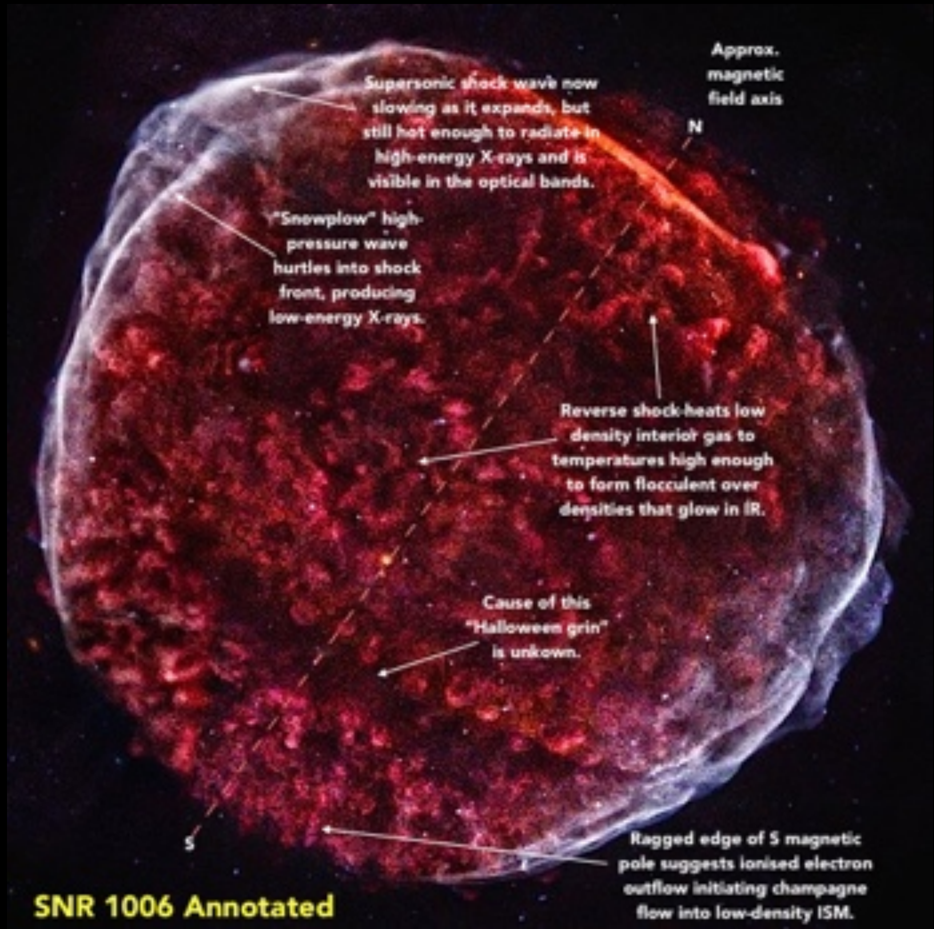
It's the year 1006 and guess who came for dinner

In the year 1006 a "new star" appeared near what is for us Beta Lupii. In just a few days it became brighter than the planet Venus. We now know that the event heralded not the appearance of a new star, but the cataclysmic death of an old one. It was likely a white dwarf star that had been pulling matter off an orbiting companion star. When the white dwarf mass exceeded the Chandrasekhar stability limit, it exploded. Material ejected in the supernova produced tremendous shock waves that heated gas to millions of degrees and accelerated electrons to extremely high energies.

Wiki: SN 1006 was a supernova that is likely the brightest observed stellar event in recorded history, reaching an estimated −7.5 visual magnitude, and exceeding roughly sixteen times the brightness of Venus. Appearing between April 30 and May 1, 1006 ACE in the constellation of Lupus, this "guest star" was described by observers across China, Japan, Iraq, Egypt, and Europe, and possibly recorded in North American petroglyphs. Some reports state it was clearly visible in the daytime. Modern astronomers now consider its distance from us to be about 7,200 light-years.

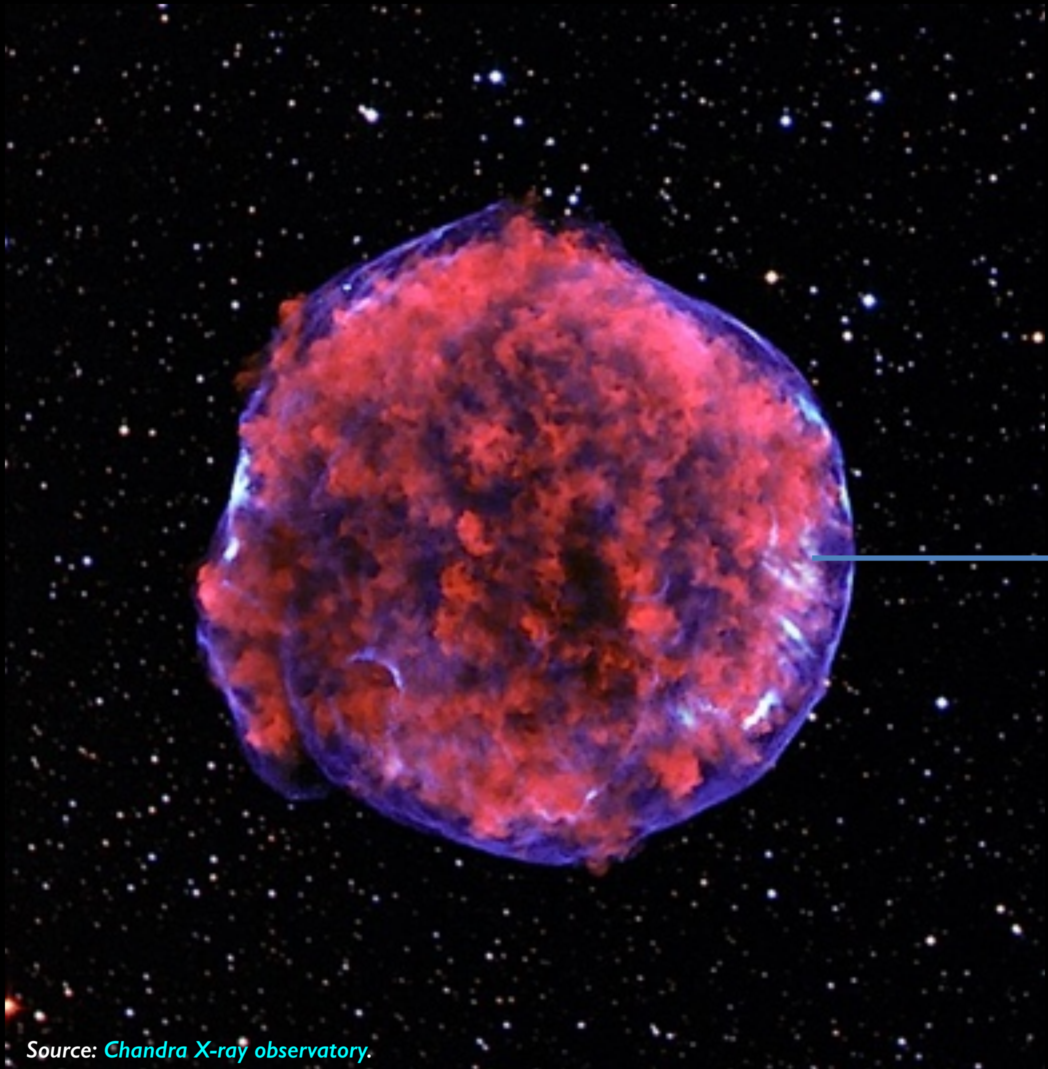
The 1006 supernova produced a *shell-type remnant*. In these, the initial detonation hurls hypersonic star ejecta in a roughly spherical ball. At first the ball expands at up to Mach 20, or >10,000 km s^{-1}. This is the *free expansion phase* and it lasts many hundreds of years. Eventually the ejecta cools to about 200 K and is expanding 20 km s^{-1}. The shock front continues to expand, but the internal heat is no longer driven by the pressure of fiercely hot gas trying to come to thermal equilibrium with the space around it. For the next 10,000–20,000 years. the gas expansion is driven by adiabatic cooling, expanding at a pace which keeps the interior temperature nearly constant.

Eventually the shock front slows to 20 km s^{-1}, which is the average speed of sound (Mach 1) in the interstellar medium (ISM) in a spiral galaxy. When a shock front goes subsonic it slowly diffuses into the general gas medium of the galaxy, the Disappearance phase. Overall, the entire process can take a million years or more.



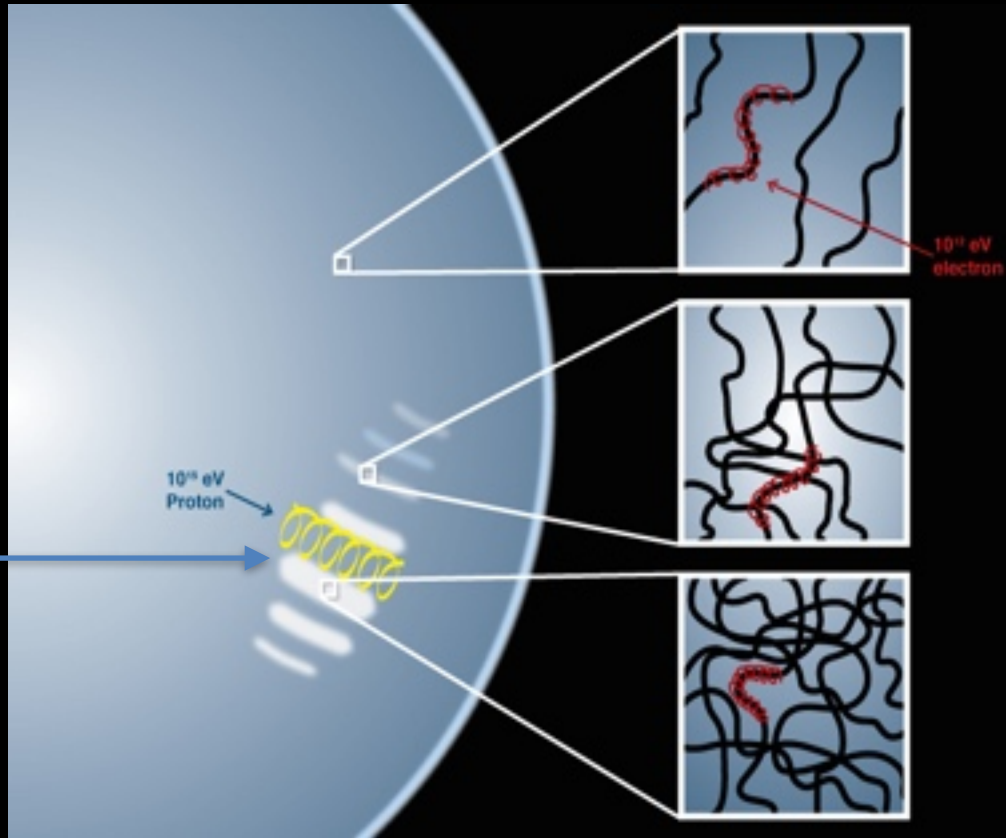
Located about 7,000 light years from Earth, SN 1006 was likely a mass-transfer binary in which a white dwarf star that had been pulling matter off a larger but lower-mass companion star exceeded the stability limit known as the Chandrasekhar limit and detonated. The bright outer shock front does not spherically encircle the remnant because of the orientation of the interstellar magnetic field is roughly perpendicular to the visible shock front. Immediately behind the frontal shock wave is a dense counter-shock or reflection wave pushing backwards towards the centre of the remnant. The forward shock experiences temperatures in excess of 10,000 K as it expands into the thin gas of space, but the reverse shock slams into the ejecta still flowing outward. The backshock's temperature soars into the millions of degrees K. The fluffy red features seen throughout the interior are dense gas pockets heated by the reverse shock.

Case study: Tycho SNR 1572



Source: Chandra X-ray observatory.

We've come a long way since Tycho Brahe recorded an unusually bright star in 1572. Today we know such "guest stars" are mostly supernovae or bright novae. SN ejection clouds like this and the many others shown earlier are abundant sources of newly-formed elements. These "metals" are why we can breathe air made of oxygen and nitrogen, and use carbon atoms n more different ways than we can count. SNRs are also the primary source of cosmic rays which hurtle around space, packing outsize amount of mass into their tiny protons.



Recently the Chandra telescoped recorded odd-looking stripes in the Tycho supernova remnant that had not been noted before. Image analysis and computer modeling showed that these were the probable origination source of the most intensely energetic cosmic rays known to science. Above, the blue circle on the edge of the circle represents the outer shell of the blast wave of the supernova remnant. The lighter features are the stripes. The upper square box to the right is a close-up of a region far away from the stripes; the black lines show twisted but not tangled magnetic field lines. The red squiggle shows an electron spiralling around one of these lines. Electrons with energies of a trillion electron volts (10^{12} eV) produced the X-ray emission seen by Chandra. The middle panel shows a close-up of a faint stripe. The magnetic fields are much more tangled and the particle motions are much more turbulent, producing higher energy X-ray emission. In the bright stripe the tangling of the magnetic fields and the turbulence is even stronger. Very energetic tangled fields do not radiate efficiently, but are believed to be the origin of the most energetic cosmic rays in our galaxy.

White dwarf Type 1a supernova shock fronts like Simeis 147 show us how cluttered "empty" space really is.

Why does Sim 147 look like a see-through cumulus cloud?

Mentally freeze-frame a boiling kettle and you have a pretty good image of the invisible density structure of "empty" space. Instead of steam bubbles, space has gas/dust bubbles. They don't rise to a top, they swim in a thin soup. We've been conditioned to think of interstellar space as a steaming consommé of cold atoms and hot photons. In reality the space between stars — e.g., the vast volume between us and Alpha Centauri — is more like a watery vegetable broth. It is filled with long, slender, noodle-like dust filaments, wraith-like atomic clouds hundreds of times the diameter of the Solar System, egg-yolk sacs of molecular hydrogen clouds surrounded by an albumin of atomic hydrogen. Not to mention the 411 to 413 photons spanning radio to gamma energies zipping through any given cubic centimetre every second. (The numbers differ because so do opinions.)

The mechanism of Type 1a SN explosions is far from settled science. See *here*, *here*, and *there*; and videos *1* (adiabatic expansion) and *2* (surface He ignition).

Moreover, the motions of dust filaments don't necessarily relate to the motions of gas bubbles. Dust filaments and gas bubbles tend to co-exist rather than commingle. Dust particles in space are aerodynamic. They fly through the interstellar medium under the influence of magnetic fields, while magnetism doesn't affect gas unless it is ionised. Some dust is siliceous (sand, basically) because it was seeded with silicon from Type 1a supernovae and late-stage AGB stars. A larger proportion (57%) is carbonaceous because it formed from carbon molecules in the atmospheres of low surface-temperature AGB red giants and Cepheid variables. The two types co-mingle but don't respond to space's multitude of forces in the same way. Carbon dust is blobby and amorphous while siliceous dust is needle-shaped and responds to magnetic fields. Carbon dust is soot that plays a vital catalytic role in the formation of the molecular hydrogen which collapse into stars. (Atomic hydrogen can't make stars). Dust is vapourised as protostars are being made

The inverted-colour image above was produced to emphasise the bubbly-foam appearance of Sim 147's outermost shock fronts. When a Type 1a supernova detonates, its shock wave propagates at high velocity as a hot spherical compression wave. In some cases, e.g., the Bubble Nebula near M52 in Cassiopeia, the sphere expands into a low-density region of space with few atomic or molecular cloud overdensities and little magnetic field pressure.

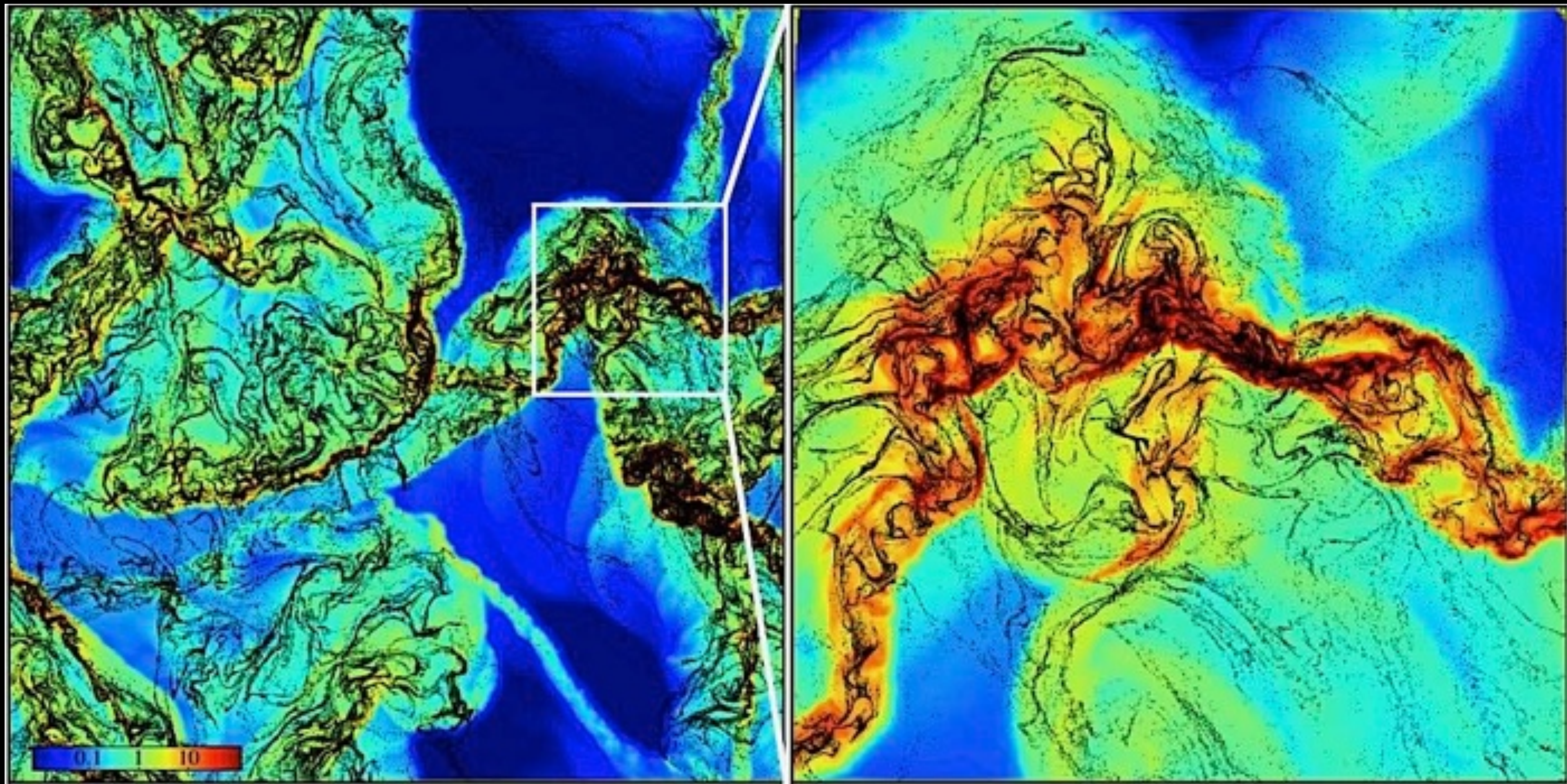
As a Type 1a SN shock expands outward it cools and slows down. When it is dense, hot, and fast, it plows into gas/dust overdensities and compress them into hot lenses with the same curvature as the shock front. Dust filaments respond to an incoming hypersonic shock wave by *compressing into remarkable thin sheets* (tens of centimetres thick) that are pushed to the very front surface of the shock wave. That is why long-slit spectra of shock fronts acquired perpendicular to the curve of those bulbular cumulus bubbles in the above image show the signatures of alpha and transferric elements instead of H_1, Hα, and H_2.

The leading edge of a gas bubble being blown outward by a shock wave heats to incandescence, which is how we know where the shock wave is. The front surfaces of expanding shock wave the brightest part of the bubble — hence their prettily lace-like look in astro-images. Eventually, though, the shock will cool and slow down enough that the it is deformed by any gas overdensity into which it billows. The overdensity, too, will deform, and will respond by bouncing backward into itself, compressing to densities sometimes great enough to make small star clusters. That is why powerful supernovae spawn a round shell of small star clusters. The process is called *triggered star formation*.

Do this fifty times across a fifty light years and the outermost edge of the original shock sphere looks a lot like Sim 147. That wobbly set of crescents and striations in the picture above was once a perfect round sphere. It takes but an instant for a supernova shock wave to appear. It takes a million years for it to disappear.

If you wonder what all this feels like to Luke Skywalker, ask a small airplane pilot to fly you into a cumulus cloud on a hot summer day. Tighten your seat belt. You can be forgiven for imagining yourself alongside Luke as you whoop it up on a helluva hyperwarp through Sim 147.

Dust is just as messy in space is as it is in your house or your optical system



2D simulation of aerodynamic grains in supersonic turbulence. In this simulation by *Hopkins & Lee 2015*, the grain sizes are 0.001 to 1 µm and Mach number is M5. At the instant this “snapshot” in the simulation was frozen, Mach speed and magnetic energy were in equilibrium. The colours show local gas densities relative to the mean gas density of the parcel (blue). The thin black steaks show how the compression and rarefaction of a multitude of small shock fronts (turbulence) tends to flatten a rather chubby filamentary network of dust particles into very thin sheets. Notice the fractal-like coherence in filament patterns. These show that turbulent shocks affect dust pretty much the same on large scales and small. Nearly all the dust lies along razor-thin filaments. In this simulation the dust filaments are not associated with the gas clumps.

Where does a galaxy's dust come from?

Cepheid variables are an often overlooked source.

RS Puppis is a beauty, and it tells a great tale. (*1*, *2*, *3*, *4*.)

Dust is one of the least-told stories in popular accounts of why things in the sky look the way they do. Dust is most often described as carbon nanoparticles smaller than soot or cigarette smoke (technically 0.001 to 0.1 μm) that originate in the cool atmospheres of AGB red giants. Late-stage AGB stars dredge up large amounts of nuclear material from their cores. Their outer envelopes become abundant with carbon, nitrogen, oxygen, and other low-mass α elements.

But that doesn't explain the presence of siliceous dust, which is mainly silicon, calcium, and sulphur. Some of that comes from late-AGB stars, some originates in Type II supernovae, and some comes from the gas expelled by winds expelled from the surfaces of Cepheid variables as they expand and contract.

This striking Hubble image of the Cepheid variable RS Puppis is a vivid study in Cepheid mass loss through wind ejecta. Classic Cepheids are 10 times more massive than the sun and 200 times larger. RS Puppis's surface gravity is only ~0.016 of Earth's (and about half that of the Sun's). Its higher-velocity ejecta escapes ballistically into the Galactic medium, forming a huge cocoon of dust. Some particles will escape forever; slightly lower-velocity ejecta will arch high above the star's disc, slow, and fall back into the maelstrom.

The atoms that escape merge into the Galactic medium. Over great periods of time the atoms absorb enough incoming electrons and photons that chemical reactions produce complex molecules. The energy consumed in these processes have a cooling effect in the Galactic medium. By virtue of their absorption they remove the energy from incoming photons and electrons, cooling their surroundings.

Star formation requires intensely cold conditions in the depths of molecular clouds. Those clouds are abundant with dust, which does two things: (a) acts as a coolant that slows particle velocities down to gravitational star-forming energies, and (b) eventually deposits their complex mix of elements into new stars, which end up with a higher metallicity than the generation that came before them.

Watch how an AGB giant seeds the Galaxy with dust here.

Jaco Brink's Mission Impossible

N49's unique filamentary structure has long set it apart from other supernova remnants (SNRs). Most SNR's appear roughly circular in visible light (see the Simeis 147 article in this issue). The N49 remnant looks to misshapen because it is expanding into a local medium that has wide variations in its gas density. The "empty" space in galaxies is actually rather thickly populated, but most of the gas blobs are cold and do not emit light. Hence N49's asymmetrical wrung-out-rag look.

The N49 supernova remnant in the LMC

A picture is worth a thousand words. 2,479 of them in this case.

Many years ago I read a book in which there was a picture of N49. It stated that the neutron star left after the supernova was an exotic kind of neutron star called a 'magnetar'. Since then I've been fascinated by that object. But I never knew where the remnant was located.

A couple of weeks before I took this image I started researching N49 again. I discovered that N49 was located in the LMC. I searched online to learn its angular size and magnitude. To my delight I found that it might be within my imaging range.

I could hardly wait for the next clear night to take a crack at it. In mid-December 2018 while the Moon was not yet in a crescent phase I used Aladin to find the coordinates of N49 – and also as my reference image when I started imaging it myself.

Since I live in a very light polluted area suburb of Johannesburg, I was pleasantly surprised to see the nebula showing up on the view screen of my camera after only a 13-second exposures. I spent the rest of the evening capturing multiple light frames.

My imaging scope is a Celestron C11 f/10 SCT on a Celestron AVX mount. The camera is a pretty straightforward Fujifilm X-T1 with no mods for astro work.

I do not yet have autoguiding, so the maximum exposures I can take are about 13 seconds before the star images became elongated. Altogether I captured 958 images of 13" each at ISO 3200. I set the camera's intervalometer to capture 20 frames at a time, Then I re-centred the FOV and then repeated the sequence. Next day I took 50 flat frames and a matching number of 50 frames. That evening I took 958 dark frames.

I use DSS 3.3.2 for my stacking. Since DSS does not read my camera's RAW files properly, I had to import all the images to Lightroom, then export them as TIFF files, which I then imported into DSS. I expected hiccoughs stacking 947 light frames to produce the final image, but was delighted (and relieved) when I found myself looking at the image you see here.

A bit of Photoshop's levels colour and saturation adjustments to pip up the final result, and here we are.

=Jaco Brink

The supernova remnant N49 (aka SNR J052559-660453) is only a few thousand years old. Because N49 lies in the Large Magellanic Cloud it took the light in this image over 160,000 years to reach Jaco Brink's telescope.

N49 is a supernova remnant (SNR), the debris left over by a massive star whose overburdened core collapsed in less than one second into a neutron star. The huge mass of the star's overlying gas collapsed at velocities above 10,000 km sec^{-1}. It squashed into the neutron star, reaching densities almost as immense as the neutron star itself, which is a few times denser than the nucleus of an atom on Earth and in space. The shock rebounded back out at 7200 to 9600 km s^{-1}. All this happened so fast that the surface of the star had no idea anything was amiss until the shock wave arrived at its surface several minutes later. This type of shock is called a detonation because the wave is speeding at many times the local sound speed. If a shock front is propagating subsonically it is called deflagration.

At this point it can accurately be said that all hell broke loose. The exploding shock wave first sped into the rather thick and sludgy shell of dense gas that had collected around the star for tens of thousands of years. Over the next few thousand years the shock wave slowed to 100 – 300 km s^{-1}. All these pressures and densities created massive hot spots and dense filaments, which brings us up to today when Jaco set up his camera and merrily started shooting away.

A decade ago images of N49 by the Chandra X-ray Observatory revealed a bullet-shaped object traveling at about 8.1 million km hr^{-1} (2250 km s^{-1}) away from a bright X-ray and gamma-ray point source. The had the earmarks of a neutron star with an extremely powerful magnetic field, or magnetar. Objects with this behaviour and orogeny are often soft gamma repeaters because their magnetic fields are twisted by the star's rotation until they periodically release the pent-up energy in a blazing flash of photons so bright we see them mainly in gamma and hard X-rays.

The gas shocks we see are is about 75 light-years from one side to the other. N49 is the brightest supernova remnant in the Large Magellanic Cloud. It still has million-degree gas in its centre but cooler gas at the outer parts. “Cooler” is a relative term: here it can be somewhere between 8,000 and 300,000 K.

The yellow-white filaments in this image were acquired in July 2000 using the Hubble’s Wide Field Planetary Camera 2. Colour filters were used to sample light emitted by sulphur, oxygen and hydrogen. Source: Hubble Heritage Team (STScI/AURA).

On March 5, 1979, the R49 magnetar emitted a titanic and still incompletely understood gamma-ray burst. The energy packed into a photon is inversely proportional to its wavelength. Gamma photons are shorter than the width of an atomic nucleus. They have a million or more times the energy of visible light photons, which is why they are so good at worming their way between protons and neutrons in fragile nuclei like Uranium 238 to split them apart and make atomic bomb blasts. The neutron star in N 49 has had several subsequent gamma-ray emissions. It is called a soft gamma-ray repeater (SGR) for this reason. SGRs are an oddball subclass of neutron stars. They produce gamma rays that are less energetic than most gamma-ray bursters, and they repeat the show on irregular time scales. The SGR’s neutron star spins one revolution every eight seconds. Its magnetic field is about 10^{15} (a million billion) times more powerful than the Earth’s. Your fancy smartwatch would be ruined if you were approaching from the orbit of Uranus.

M49’s magnetar zooms through the supernova debris cloud at over 1,200 km per second. The star also emits X-rays whose energies are slightly less energetic than soft gamma rays. High-resolution X-ray satellites have resolved a point source near the centre of N 49 as the likely X-ray component of the spectral signature of the soft gamma-ray repeater. This helps locate the original supernova site because it cannot be traced using gamma rays due to the design limitations of grazing-incidence gamma ray telescopes like Chandra. (See the *X-ray version of the design* here.)

The delicate filaments and knots throughout the supernova remnant — visible in IR, the visual band, and X-rays — are sheets of debris from the stellar explosion. This filamentary material will eventually be recycled into new generations of stars. Our own Sun and planets are constructed from similar debris of supernovae that exploded in the Milky Way billions of years ago.

This composite N49 image combines Hubble Space Telescope optical light with Chandra X-ray imaging in blue and Spitzer data in red. The Chandra satellite camera was designed to capture high-energy short wavelength photons generated by gas in the central regions in the region around the original supernova (now a neutron star). This gas was heated to millions of K by the SN shock wave and has lost little of that heat — more properly, particle excitation — since. Its present temperature is in the million-degree K range.

How does gas in regions like this stay so hot? In the supersonic shock and twisted magnetic regime of gas heated by a SN shock wave, gas has very few ways to bleed off the energy imparted by the blast wave. The main method of gas cooling in such a regime is particle collision in which two particles, e.g., a proton-neutron or electron-neutron pair, convert some of their pre-bounce energy into slower rebound velocities. The atoms are simply too far apart to collide very often.

When they do collide, both particles lose some velocity, and emit a photon. Those photons are what we see as the pinkish glow.

The outer parts of the remnant, being more distant from the blast and the passing wave, had cooled and slowed by the time the shock wave reached them. Today the outer regions have cooled to infrared-emitting temperatures. The Spitzer space telescope was the preferred instrument for capturing IR photons at the time this image was assembled. Those photons were interpreted as blue in the image.

The Hubble telescope captured the SN remnant's filament-like shock patterns (white & yellow here). The tremulous interlaced quality of SN remnant filaments reflects several ambient conditions. One is pre-existing pockets of dust squeezed from blobs into wavelike ropes by the blast wave. Another is a complex interaction of magnetic fields and free-flowing electrons originally set free by the passing shock blast. A third explanation for the twisty mess is the way small local shock waves interact with other when there are a great many supersonic shocks mixing it up in a given volume. All by itself a supersonic wave expands spherically. But when dozens of them exist at varying strengths, velocities, and stages in their expansion, each wave front collides with others in very intricate ways. The net effect over time is to distribute pressure more evenly and reduce overall tumult. Next time you boil a pot of water, before you put the veggies in to cook, look closely at what happens to the shapes of the bubbles and they pop out at the surface of the water. Watch how they merge, interfere with each other, and pop. Now go look at one of those fabulous HST shots of fine details in the Crab Nebula M1. Whether on the surface of a boiling pan or in a given volume of a shocked gas cloud, multiple shock collisions act to relieve internal pressure differences. Its hot at that surface, but also smoother than the seethe of upwelling bubbles below. In M49 much of the energy propagates in the optical bands. In the image above the optical emission is shown in yellow-white.

All this raises a question. Why did the astronomers who planned on this image choose these particular telescopes and the bandwidths of the filters they needed to pictorialise the energy levels so they come out like this image? Little ink has been expended in the amateur astronomy journals about how the ravishingly beautiful pictures on their pages were planned in such a way that they would come out looking the way they do.

When groups of astronomers prepare their proposals for telescope and computer time to acquire their various data, they are really looking for the best way to capture the energy levels that will answer their questions about physical activity in the object. But first they have to plan ahead by looking behind: How well did images in the past record capture the desired information, and how could they design the next image to do a better job? For example, in the Chandra/Spitzer/HST N49 image above, if one of the team members wanted data on synchrotron radiation from X-rays generated by electrons spiralling at near-light-speed velocities around magnetic field lines, they want telescopes that capture photons with energy levels of 0.1 to 1.0 keV (thousand electron volts). It so happens that XMM Newton (still operating, BTW!) and Chandra record those energies. Voila! That'll be 3 hours, please.

Then the astronomers have to decide which energy level they want that both delivers the info but also does not overwhelm the data which their colleagues want in the IR and visual. There's a lot of give-and-take in these colloquies. Plus, they usually aren't able all this telescope time on one night. It might take months before any particular instrument has enough time to gather the desired info. That is one reason why so many astronomers have multiple projects underway at any given time — and why their names appear as co-authors in so many papers published in the astro lit in any given month.

If you can't wait another minute before nailing your own Chandra or Hubble Telescope proposal for an observing slot, visit *Liénard-Wiechert Field*. Take the dog out for a walk first.

Early in N49's days in the crosshairs of interested astronomers it was tagged as a breed apart from other well understood supernova remnants. Most supernova remnants appear roughly circular in visible light. Early mapping of the molecular clouds in the region surrounding N49 suggested that the supernova remnant was expanding into regions of varying density, particularly to the southeast. Differential expansion would explain its asymmetrical appearance, but also its non-uniform temperature regime. It's not a sphere, OK, but the remnant is cooling in thermal isopleths that didn't match the filamentary structures that we see in the optical. Hence something is causing what amount to heat shimmer (IR) that doesn't match its optical shimmer. X-ray data show the SNR brightening in the southeast, confirming the the remnant is colliding with denser non-emitting clouds in that sector, but the IR thermal shimmer is not fully understood.

What we DO understand is that Jaco has given us a good enough image to cut some research teeth on. Thanks, Jaco!

If you can't wait another minute without learning everything there is to know about photometric choices to provide specific data, here are a couple of good places to start: *Univ. of Rochester Lecture on filters and photometry;* ; and of course, we can't leave out everyone's favourite XYZ-Made-Easy resource, *Wiki* (go down to "Synchrotron radiation in astronomy").

Why are comets so green?

Martin Heigan

The image of Comet Wirtanen on the previous page was taken by ASSA astrophotographer Martin Heigan. His processing reveals a greenish hue that is not as obvious to the visual observer because our eyes do not accurately render colours when light levels are low. Some people can see the Orion Nebula as a faint greenish hue, yet others don't see that at all. Because of the long total exposure times of astro-images, colours become more apparent, just as faint nebulosities and stars do.

Comets are a mix of ices, rocky conglomerates ranging from grain-sized nubbins to extra-terrestrial Gibraltars, all coated with tiny space dust particles smaller that the particles in cigarette smoke. "Ices" are not just the H_2O water ice that we see in ice cube trays, but also components like dry ice (frozen CO_2), methane (CH_4), ammonia (NH_3), carbon monoxide (CO), plus a veritable chemical warehouse of silica-and sulphur-based compounds. Not to mention polycyclic aromatic hydrocarbons (PAHs) whose composition interests planetary astronomers because they reflect the chemical composition of space at the time the comets, planets, and stony debris of our solar system were formed.

Sigh – It was inevitable.

Out beyond the orbital circle of Jupiter, space is so cold and photons so few that the ices remain frozen. As comets enter the increasingly rich photon and gas broth nearer to the Sun, they heat up. The number of energy-laden ultraviolet photons striking the comet surpasses the threshold where electrons can be knocked free from the outer electron shells of certain atoms, ionising the atoms. The compound most vulnerable to ionisation is the weakly bound carbon monoxide or CO molecule. Incoming UV photons pack enough kinetic punch to make CO^+ molecules. They stream directly away from the comet in what we observe as a blue ion tail. Faint blue tails are the first signature of a comet warming up.

As the comet gets closer to the Sun, somewhere around the orbital diameter of Mars its surface heats up to the point where the comet's tiny dust particles are sputtered loose with enough energy to escape into space. Such particles make a second "dust tail", usually yellow/white in colour. The dust tail reflects enough light that spectrograms can reveal the precise chemical makeup of those particles.

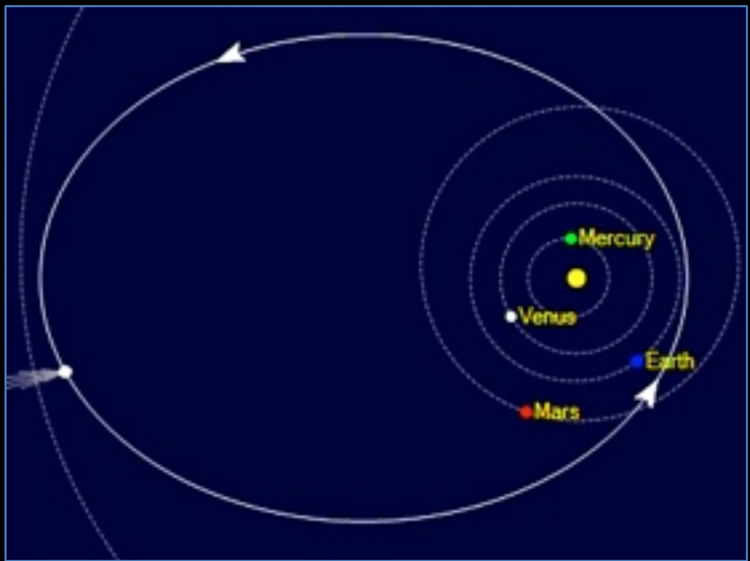
Comets are assembled from the complex molecules that existed in the solar system at the time many other Solar System bodies were made, roughly 4.57 billion yeas ago. That makes them superb chemical probes of the galaxy's hydrogen, oxygen, carbon, and nitrogen mix in that era.

Two molecules of particular interest to comet-watchers are the cyanide/cyanogen (CN) carbon-nitrogen group, and diatomic carbon (C_2). The word "organic" in astrochemistry means that the compound has carbon in it. Free ^{12}CO and ^{13}CO are key tracers of atomic hydrogen clouds that emit only weakly in the radio 21 cm radio band but are awash in ^{12}CO and ^{13}CO that glow brightly in the microwave band; the ratios between them are used as tracers of temperature and velocity.

A comet's teal or blue-green colour comes from gases stimulated by ultraviolet light when bound electrons are boosted to higher energy levels, but then drop back to lower energy levels. Some of those transitions result in an emission line that falls in the blue-green part of the electromagnetic spectrum to which human eyes are sensitive. When we see that green colour, it indicates that the coma contains cyanogen (CN_2, or more exactly N≡C—C≡N) and C_2 molecules. These show up when the comet is outgassing as it nears the Sun. Despite the prefix "cyan-", cyanogen isn't lethal like its chemical relative cyanide $(CN)_2$. The "cyan" derives from the same latinate root as the optical colour.

Known but unknown for 48 years

Comet Wirtanen acquired its name from the astronomer Carl Wirtanen in 1948. He specialised in Solar System physics. He earned a reputation as a skilled comet/asteroid spotter after devising his own system of scanning weekly photos of the night sky using a blink comparator to quickly spot moving objects. Blink comparison was a well known technique (Clyde Tombaugh discovered Pluto that way), but Wirtanen's approach was persistent and methodical. This was how he spotted and soon calculated the path of an unknown comet-like object in 1948. The orbital path he plotted over two weeks suggested that he was looking at a periodic comet with an orbit of 5 to 6 years. Its returns were recorded but unstudied between then and 1996. In that year a team led by Karen Meech of the University of Hawaii used a 2.2 metre telescope to image and take spectra of the comet during its relatively nearby Earth crossing that year. Its apogee was calculated to lie slightly exterior to Jupiter's orbit and its perigee lay approximately the Earth's orbital diameter.



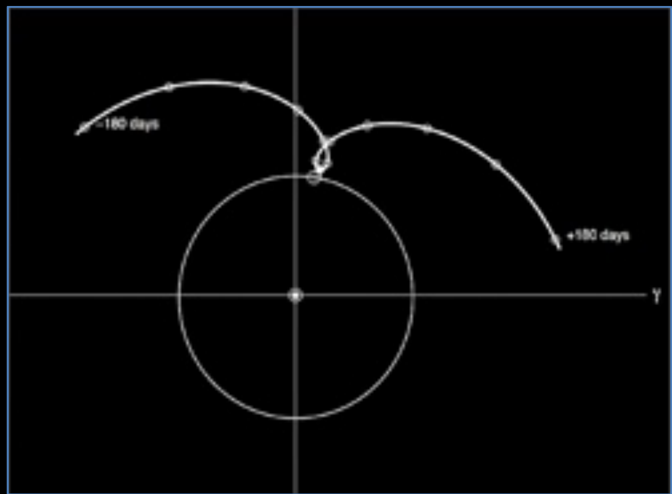
Comet 46P/Wirtanen's orbit keeps it fairly close to the sun. Its aphelion, or farthest point from the sun, is about 5.1 astronomical units (AU), which is slightly larger than Jupiter's orbit. Its perihelion, or closest approach to the sun, is about 1 AU, which is the Earth's distance from the sun. A full orbit takes 5.4 years. This image incorrectly suggests that the comet's orbit does not reach Jupiter's

How do grand plans turn into telescope time? The Wirtanen Observing Campaign.

From the moment 46P/Wirtanen's third return visit after its 1997 appearance was first spotted in images recorded by all-sky survey telescopes on 18 June 2018, planetary scientists saw the return as a historic opportunity to marshall the best available instruments and analysts in an all-embracing study that invited amateur astronomers to contribute. The Galaxy Zoo "citizen science" idea was bearing fruit in distant orchards.

Wirtanen's closest approach to Earth at 0.077 AU would take place on 16 December 2018, just four days after the comet's perihelion (closest approach) to the Sun. That made it one of the nearest comets in modern times. Its near-Earth trajectory meant it would be very bright, Early guesstimates suggested it could reach naked eye visibility.

The Wirtanen Observing Campaign *wirtanen.astro.umd.edu* knit together a team of over 100 professional and advanced amateur imagers and spectroscopists using 46 different instruments around the world. Their main goal was to refine and improve the evidence of the two-decades old study led by Karen Meech of the University of Hawaii. Her team had observed comet 46P/Wirtanen primarily during its more distant Earth crossing in 1996. Astronomy facilities and calculational prowess had evolved enormously during the 22-year time lapse.



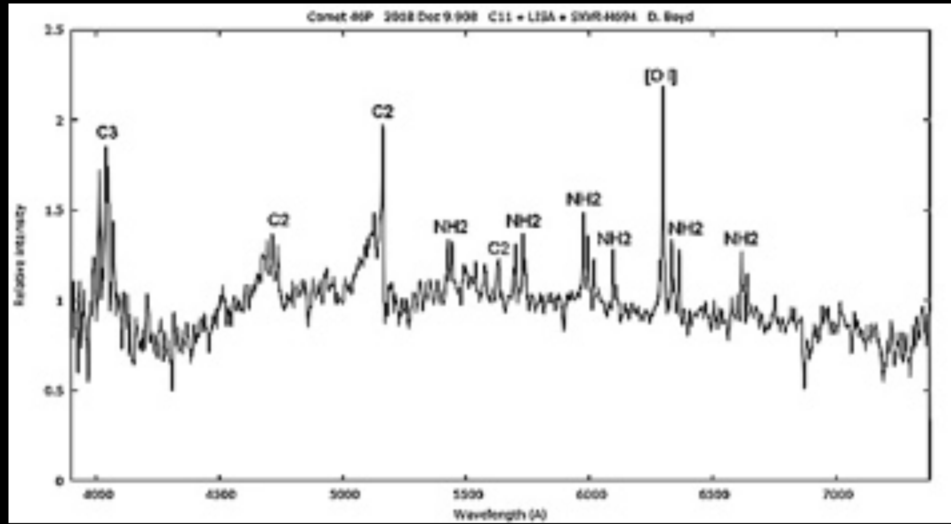
Wirtanen's projected orbital trajectory with respect to the Earth meant that it would be in observing range for most of a year.

Although Wirtanen was discovered in 1948 its only approach close enough to Earth for accurate spectroscopy occurred in 2013, when it was 907 million km from Earth. Fine-grained details of the coma nearest the rocky surface eluded astronomers, yet this information was the most important, Comet ejecta are important seedbeds of interplanetary gas composition across billion-year time spans. Whatever gases come off Wirtanen today closely correlate with overall species abundance ratios in the Earth–Jupiter belt going back millions of years.

Comets are frangible. To paraphrase Yeats, things fall apart, the centre cannot hold. Jupiter is often involved in orbital shifts while the Sun can break them to pieces. Comets add to their own woes with episodes of violent outgassing, as we saw in Comet Holmes in 200X. If the gas expulsion is one-sided it can alter the comet's orbit. The closer a comet's complete orbital ellipse is to Jupiter and the Sun, the lower its life expectancy. Periodic comets tend to fall into two groups: *Halley-type* with orbits 20 to 200 years, and *Jupiter family* with orbits less than 20 years and aphelions about the same distance as Jupiter's orbit. A less-heralded third family is the Centaurs, minor planets in comet-like orbits that never come close enough to the Sun to outgas.

Once Comet Wirtanen was re-spotted moving in toward the Sun on June 18, its orbit was refined to predict a Dec 16 closest approach to Earth. Astronomers were elated that it would pass only 11.7 million km away from Earth, only 29.25 times further than the Moon.

In the mid-1990s astronomy data crunching and storage capacity on the Internet was in its infancy by today's standards. By early 2018 the Internet was regarded as the primary vehicle for astronomical analysis in the same way the telescope mirror had come to be seen as the primary vehicle for data capture. The University of Maryland team 46P/Wirtanen observing campaign was set into motion when UMD's Lori Feaga et al. recovered the comet 18–20 June and circulated its images to cometary specialists around the world. The community responded by formulating the most comprehensive comet-study campaign in the history of the discipline. The campaign was finalised at the 50th Division for Planetary Sciences Meeting in late October 2018. *Here is the Powerpoint presentation assembled for that meeting.*



Spectroscopic seismograms

The peak lines in spectrograms can be thought of as a sort of seismogram of light. Instead of terrifying tremors of the land we have sighing tremors of the sky. Using the Arecibo Observatory 10–18 Dec 2018, a team led by Ellen Howell detected an extended, asymmetric skirt of large (>2 cm) grains in 46P/Wirtanen's coma consistent with a fiducial nucleus size 1.400 x 1.1 km. The image below shows the detection of the nucleus (spike) and the extended skirt of large grains surrounding it.

On Dec 16, Dave Schleicher put meaningful numbers behind the various emission peaks in the spectrogram above. On that date Comet Wirtanan was outgassing

(OH) = 5.37 x 10^{27} mol/s or roughly 8,917 hydroxyl molecules per second

(H_2O)= 7.24 x 10^{27} mol/s ≈ 12,055 water molecules per second

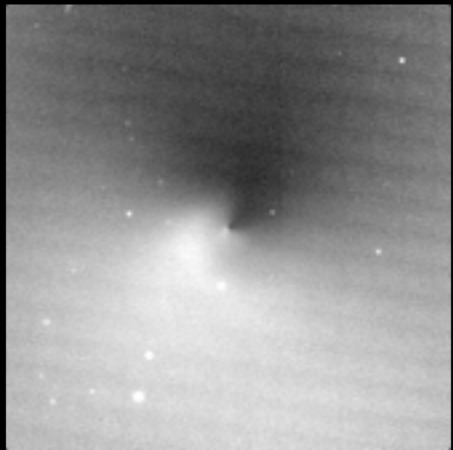
(CN) = 1.29 x 10^{25} mol/s ≈ 214 cyanide family molecules per second

(NH) = 3.36 x 10^{25} mol/s ≈ 557 nitrogen monohydride m.p.s.

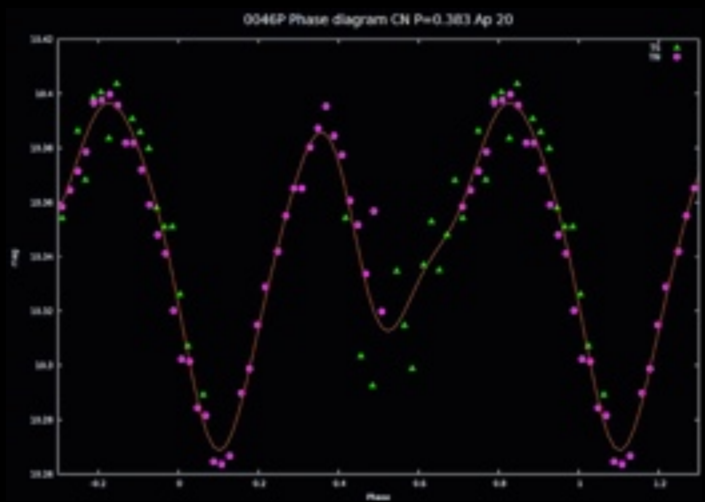
Doesn't seem like much – until you multiply by 86,400 seconds in a day, times the approx. 85 days the comet was outgassing, and that these gases were expanding into a region of space that contains about 10 to 100 atoms cm^{-1}.

Does 46P/Wirtanen rotate?

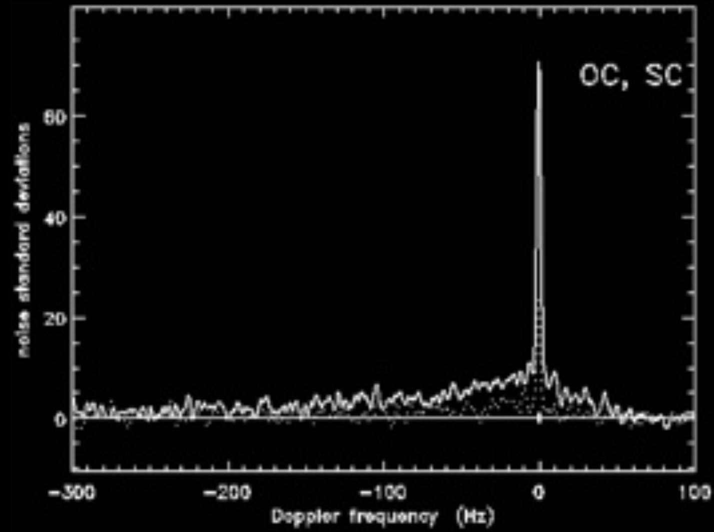
On 26 November Dave Farnham et al. reported a rotation period of 8.91 hr, based on the coma morphology seen in this figure. Repetition over at least eight rotations is consistent with a conjecture that the nucleus is in a state of simple rotation. (*Click on this link to see an 8-frame movie of the comet rotating.*)



Two weeks later on 9-10 Dec 2018 Emannuel Jehin et al. reported that a CN molecular light curve measured from photometry obtained at the TRAPPIST telescopes showed a 9.2 hr periodicity, which is assumed to reflect the rotation period of the nucleus.



On 21 December 2018 Ellen Howell et al. reported the detection of the nucleus of comet Wirtanen using the Arecibo Observatory. The group derives a nucleus of 1. 4 x 1.1 km and an extended, asymmetric skirt of large >2 cm grains in the coma. The image above shows the detection of the nucleus (spike) and the extended skirt of large grains surrounding it.

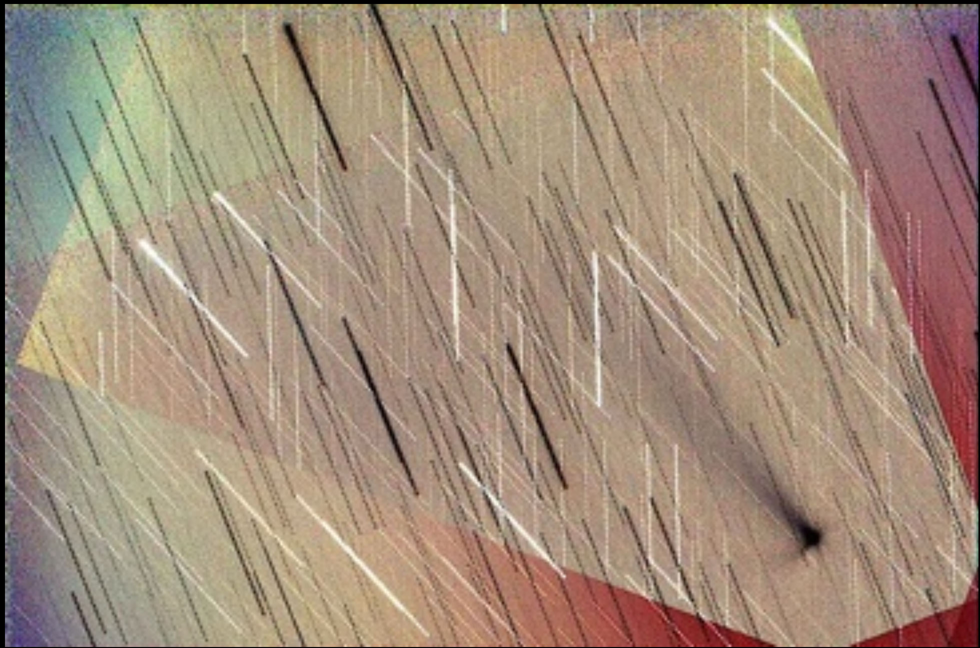


Another shining hour for citizen scientists

Wirtanen's observing conditions offered unique opportunities. During the comet's closest approach to Earth, 1 arcsec was less than 100 km on the face of the comet. Even small telescopes of 200 mm and up could access the inner coma at high power. At greater distances, the inner coma of a comet is amenable only to spacecraft or large telescopes with adaptive optics. Moreover, the comet was also diffuse and fast-moving, a challenge for professional and amateur imagers/spectrscopists alike.

The WOC project was especially noteworthy for the number of contributions made by citizen scientists — the comet was continuously observed when seeing conditions were suitable from early November 2018 till the end of January 2019. The amateur community provided monitoring and context imaging that yielded valuable rotational light curves and outburst photometry and spectra. The amateurs served on-call at any hour if professionals need quick observing response when their own telescopes were in the middle of monitoring or imaging.

Even students went wild about Wirtanen



This unusual image of Comet 46P/Wirtanen looks like it belongs in an art gallery. No, it came from Jost Jahn of the Observatoire de Haute Provence in France. Acquired on 10 December 2018, the image puts the comet in the lower right of the image, with its tail extending to the upper left. The image is a composite of 3x33 short, 15 second exposures using RBG filters on the ROTAT telescope, a coma-corrected 60cm f/3.2 Newtonian using an SBIG STL11000 full-frame CCD.

It was taken within the framework of a research project by 11th grade students from Mannheim, Germany at the Hector Seminar, an organisation that fosters gifted high-school students in STEM subjects.

The image was processed with a Larson-Sekanina rotational gradient filter to enhance the contrast and reveal the comet's tail. The diagonal stripes across the image are star trails at two of the rotational settings.

ROTAT (Remote Observatory Theoretical Astrophysics Tuebingen) is operated by the German Stiftung Interaktive Astronomie und Astrophysik (Foundation for Interactive Astronomy and Astrophysics) whose goal is to inspire young adults with hands-on science. From the looks of it, those students have done pretty well.

In the U.K., Helen Usher, a PhD student at the Open University and Cardiff University, works with the Faulkes Telescope Project in the UK. This is an effort to coordinate students from schools across Europe to collect and analyse data acquired from Comet 46P/Wirtanen.

Ms Usher was inspired by the Rosetta mission to do her PhD about involving school children in astronomical research. She recruited eight schools from the UK, Germany, France and Norway to pool their students' talents — including one primary school.

The Faulkes Telescope Project uses a worldwide network of 2-metre robotic telescopes in Hawaii and Australia that were built and operated by Las Cumbres Observatory. The Faulkes Telescope North in Hawaii is equipped with a series of filters especially installed by the European Space Agency (ESA) to study Comet 67P from the ground during the Rosetta Comet's visit, and are now being used to observe 46P. The filters were designed to separate the gas and dust content of the coma. .

High school students with images of Comet 46P/Wirtanen at Dodderhill Girls School near Droitwich Spa, in the UK. The students are analysing data about the comet as part of Helen Usher's Faulkes Telescope Project. The Open University in the U.K. and Cardiff University in Wales acquire their data using the robotically controlled Faulkes Telescope in Hawaii.

Turning the pages of the sky

Johan Moolman

I have had an interest in astronomy since my school years. I loved sci-fi. Isaac Asimov (1939 -1992) was one of my favourite authors.

My interest or rather love for photography started during my varsity years. I was always snapping pics. After graduating I purchased my first SLR, a Canon T50. I've stayed with the Canon platform ever since.

Initially I resisted the urge to capture ancient photons on a sensor. For many years only did visual observing. Then a few years ago the astrophotography mosquito nailed me. It left a terrible itch that grew itchier by the month until I just HAD to scratch. The itch miraculously vanished!

Unfortunately, the bedbug of image processing promptly took a bite, too. It will surprise no one but our wives that a new, faster computer with a lot of odd-named processing gear in it is the best bedbug balm there ever was.

I hasten to add, though, astrophotography just what the rumour says it is — two orders of magnitude more difficult and challenging than daylight photography. Quite often I have to stand back, take a deep breath, and remind myself that this *fun*.

The combination of my love to gaze at "eye candy in the sky", PLUS the opportunity to dabble with the nifty toys of technology, PLUS the thrill of capturing and processing images that please those who see them, PLUS the camaraderie and socialising with likeminded colleagues — all work together to fuel happiness in this hobby. End of itches? Probably not.

The Rho Ophiuchi region is a tough one to image. It throws everything at us at once — bright stars, dark clouds, red emission and bluish reflection nebulae, dense star fields next to star-poor ones, Herbig-Haro jets, gnat-cloud star clusters — any one of these is enough to keep us ascending the rungs of the learning curve. But all at once?

A major challenge point is learning how to bring out the nuances of all those different colours. They are not as simple as red, blue, and yellow. They are pastels made out of blended emission gradients, spiced up with a tapestry of inky darks that aren't really black and not really gray. Then there's the very bright objects – the globular cluster M4 and Antares here — as well as the dark nebulae. Put them in the same image and the word " challenge" is an understatement. I like to think that I'm making progress.

This is one of my early attempts. It was made with a Canon 5D3 unmodified DSLR and (I think) my Tele Vue 127mm refractor, f/5.2, fl 660mm. Focusing was pretty basic: I put on a Bahtinov mask and focused the image as it appeared on the DSLR screen. I controlled the image sequencing using Canon Intervalometer. The scope and imaging gear were mounted on a Celestron CGM-X. I didn't use auto-guiding because I hadn't bought one yet. Considering that it is a newbie pic with minimal gear, it didn't come too bad.

The Running Chicken is a wonderful challenge. I was first drawn to it after seeing an image on the Internet with a "chicken" doodled on top of it. The starkly dense Bok globules added further interest.

This image is more of a "headless" chicken though. I added the diffraction spikes with a diffraction mask on a Meade 14" SCT mounted on a Meade LX850 mount. Auto-guiding was done using Meade's Starlock system.

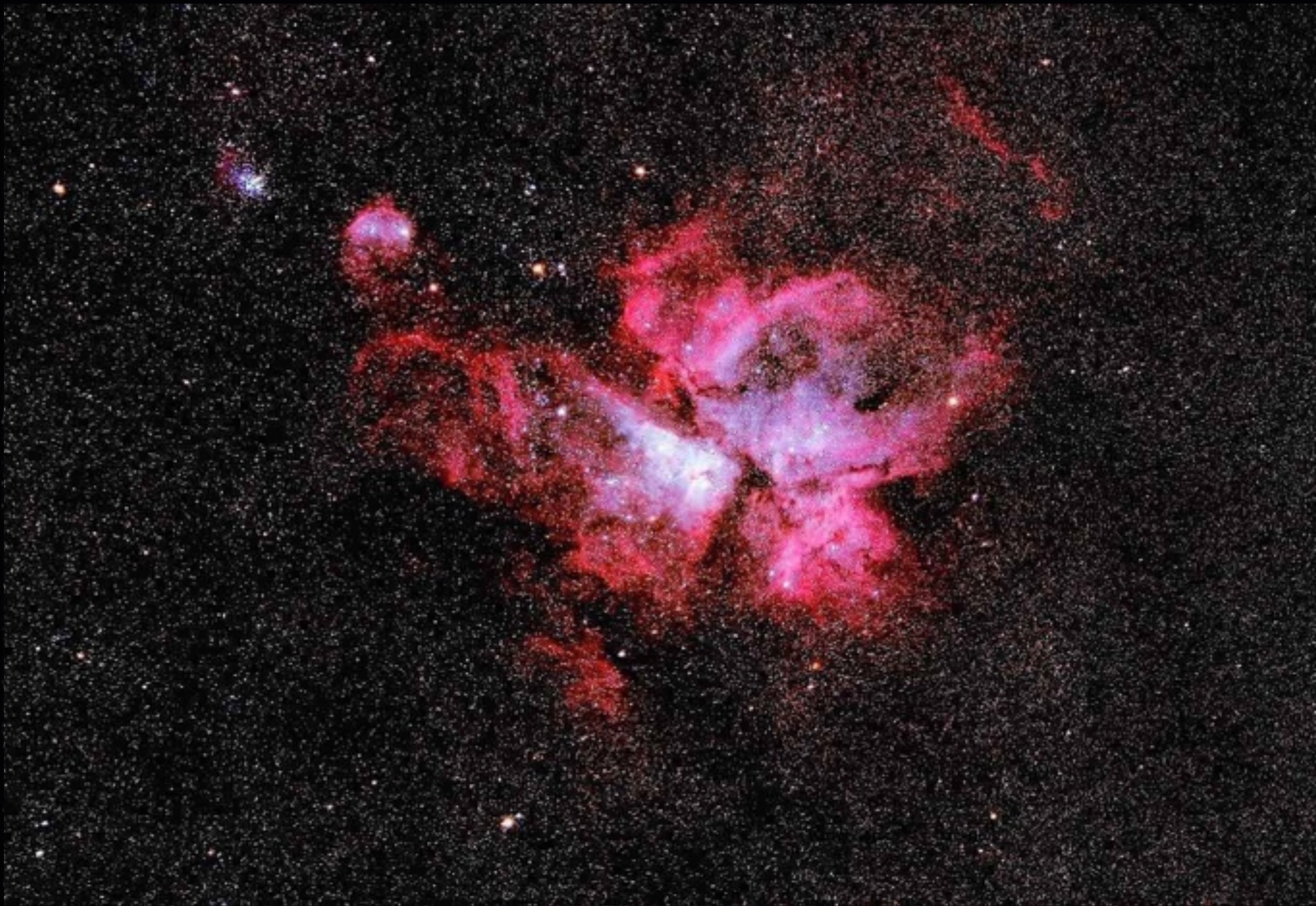
The camera was my trusty modified Canon 6D DSLR. Thirty x 120 sec exposures at ISO 3200. Camera control and focusing were done in Backyard EOS, followed by stacking several subs in DSS. Post production was done using Paint.NET and PICASA.

I don't adopt any of the standard colour pallets. It works better for me to just tweak the image step by step — saturation, levels, curves, sharpness, noise reduction, cropping out the defects — until I like what I see.

Some folks prefer o image for science value, others to post on the forums and get feedback and how-to tips. I do it because I love looking at the object in the image rather than looking at the image itself.

Also one of my earlier attempts – back in 2014. Canon 5D3 DSLR (Control and mount same as in "2"). 24 x 20 sec exposures, ISO 3200. Tele Vue 127mm refractor. (A colleague in the UK tweaked the image for me – adjusting saturation and adding Gaussian blur. The unmodified Canon 5D3 sensor produced the colour scheme.

At the time I was experimenting with external cooling: built different "boxes" that could fit around the camera body – either polystyrene, commercial cooler boxes etc – lined with ice packs. Limited success in cooling down the sensor to limit thermal noise. Fortunately, the camera body was weather sealed – and no damage inflicted by my experimenting!



IC 4628, the Prawn Nebula is an emission nebula ~6000 light-years from Earth in the Sagittarius Arm of the Milky Way. It lies in one of the most spectacular star fields in Scorpius, 2° NE of the bright young star cluster NGC 6231. The Prawn Nebula shines mainly in HII or ionised hydrogen, which emits radiation in the infrared band. Spectacular as the Prawn is in this image, it is nearly undetectable visually. HII nebula like the Prawn are young star-forming regions which glow this shade of red because the hydrogen gas is so hot it consists of unbound electrons and protons. The heating occurs when a slow-moving (subsonic) shock wave from early star formation is raised to incandescence by supersonic shocks from high-velocity stellar outflows (jets). We cannot see the stars forming here because of the glowing cloud of gas surrounding them. In perhaps a hundred thousand to a million years, the hot young stars hidden here will vaporise away the glowing gas visible here, leaving behind a sparkling new star cluster.

March 2017. Canon 6D modified, Meade LX850 mount, Starlock autoguiding. Tele Vue 127mm refractor. BackYard EOS. Pp as above.

My interest was drawn to this filamentary dark cloud because of its catchy name. I first came across it in Auke Slotegraaf's ASSA 100 list. Being only a few degrees SW of the Coal Sack makes it an easy star hop (or rather cloud jump). The Dark Doodad is more referred to simply as "DD". It got its name from the American amateur astronomer Dennis di Cicco in 1986 after he spotted it on an image he had taken in central Australia. It has several names in the professional astronomy community, but nothing can better "Dark Doodad" as an attention getter. It is best photographed in Karoo-quality skies in a location far from any urban light domes. A few eagle-eyed visual observers have seen it, but like faint galaxies, it "pops" into view for only a second or two before melting away. The nearby globular cluster NGC 4372 enhances its aesthetic appeal.

Canon 5D3 DSLR, tele Vue 127mm refractor, and a large tack of multiple subs.

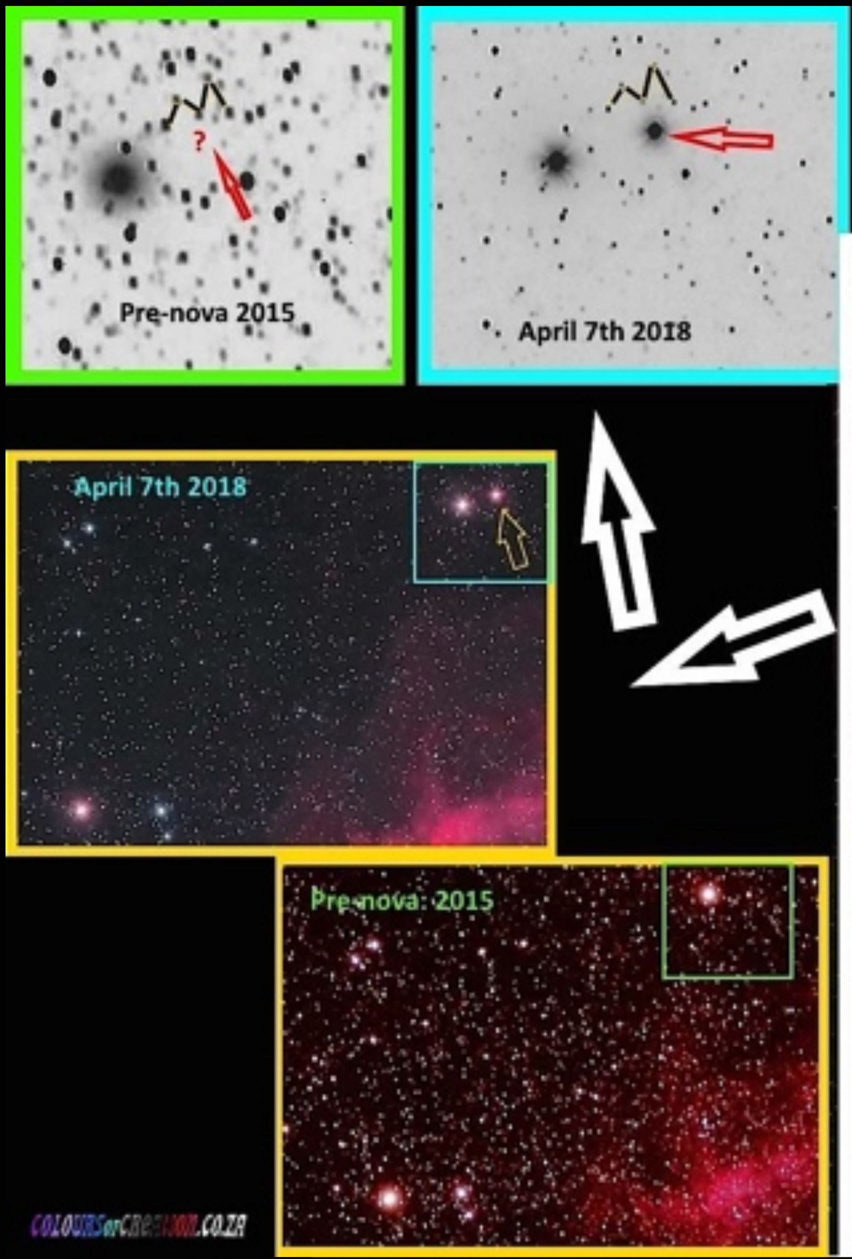
I captured these images at the Karoo 2018 Star party. The wide-field shot was taken with a Canon 200mm lens at f/2 on a Canon 1Dx DSLR, unguided but on an excellently tracking a Celestron CGX mount. The second image above shows me getting a precise level on the tripod baseplate, knowing the difficult shots I would be doing that night. The camera was controlled via a Canon intervalometer. The inset close up used an *Orion optics UK (OOUK)* 10" Optimised Dall Kirkham scope at f/6.8, mounted on a Celestron CGX-L. Auto-guided with a Tele Vue 85mm refractor, Orion Starshoot cam. Processed in PHD.

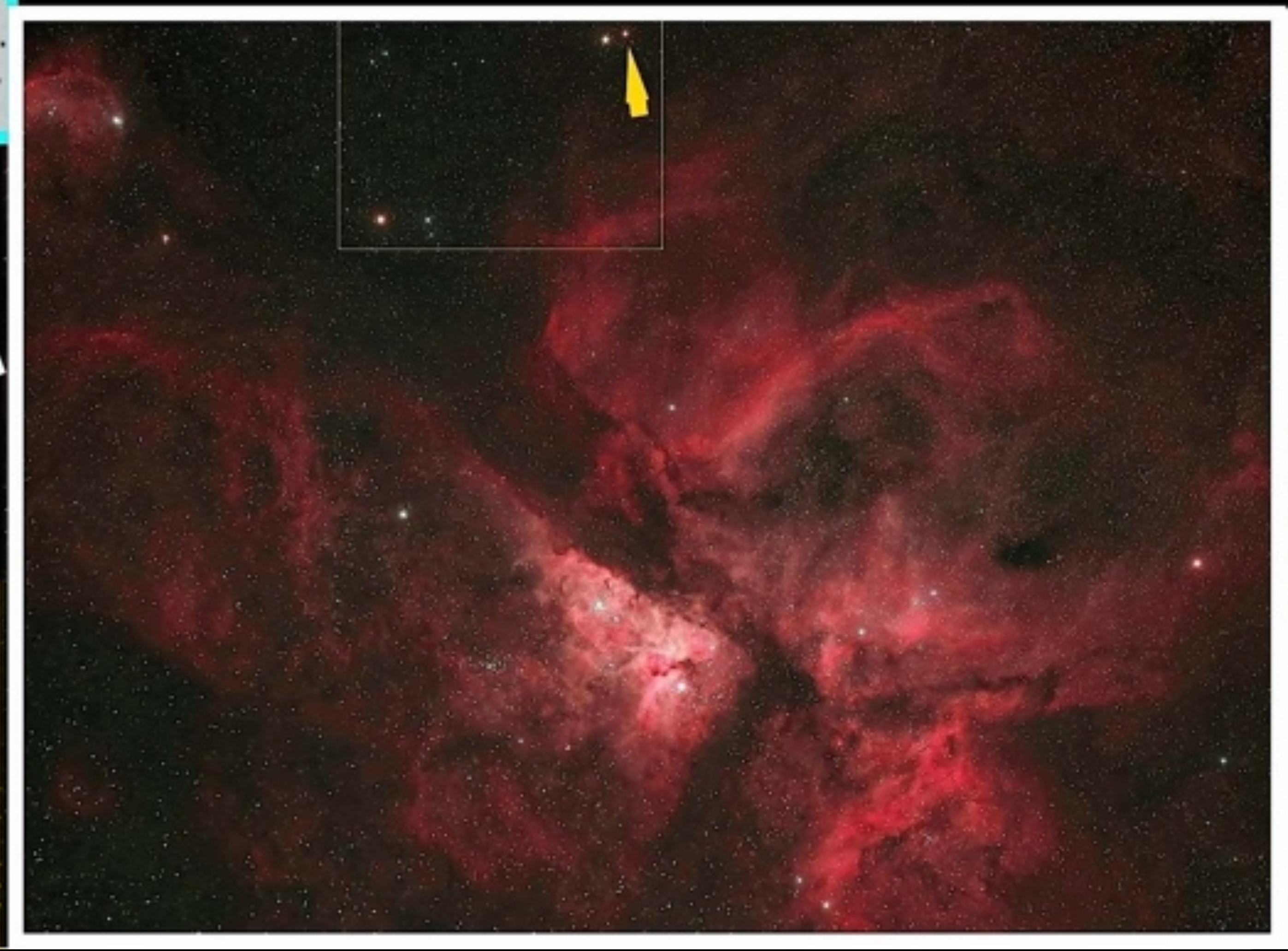
I often image an interesting object using different OTAs of different focal lengths. One image set puts the object in the context of its Galactic surroundings — near the centreline of the Galactic disc 1.4° W of Gamma Aquilae. The inset image was acquired with a 10-inch 1700 mm f.l. Dall-Kirkham to bring out the delicate structure.

The **U** shape occurs because it was once a more or linear filamentary cloud that was compressed by turbulence in the chaotic spiral arm disc plane until it twisted into the shape we see today.

Located about 2000 light years away toward the Scutum Star Cloud region, visually B143 is about the size of the full moon. It is very difficult to spot without optical aid. It shows up well in 15 x 70 calibre binoculars.

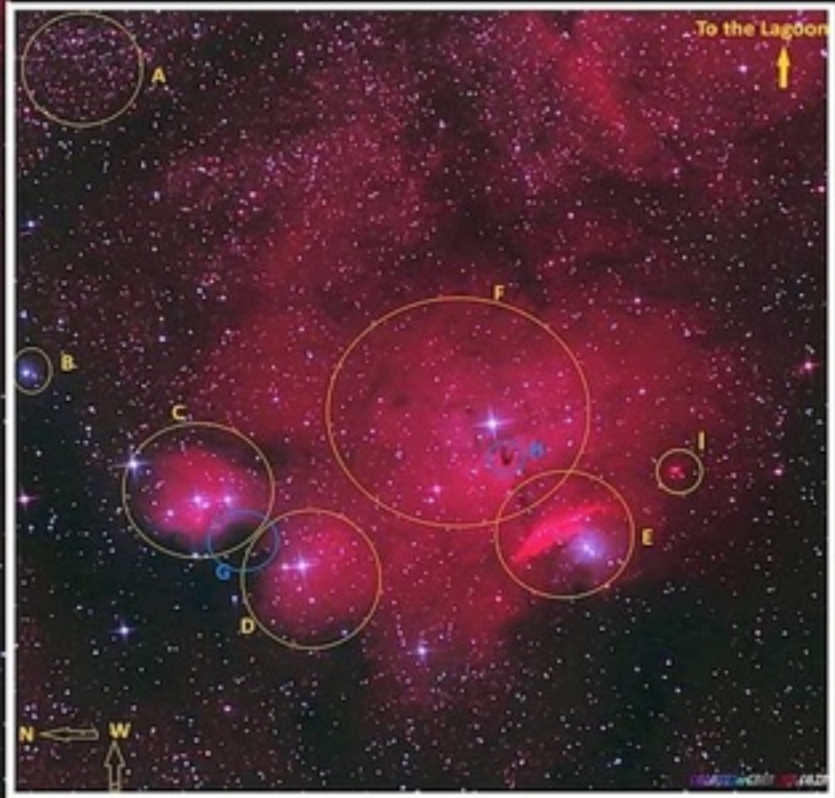
NOVA CARINA 2018





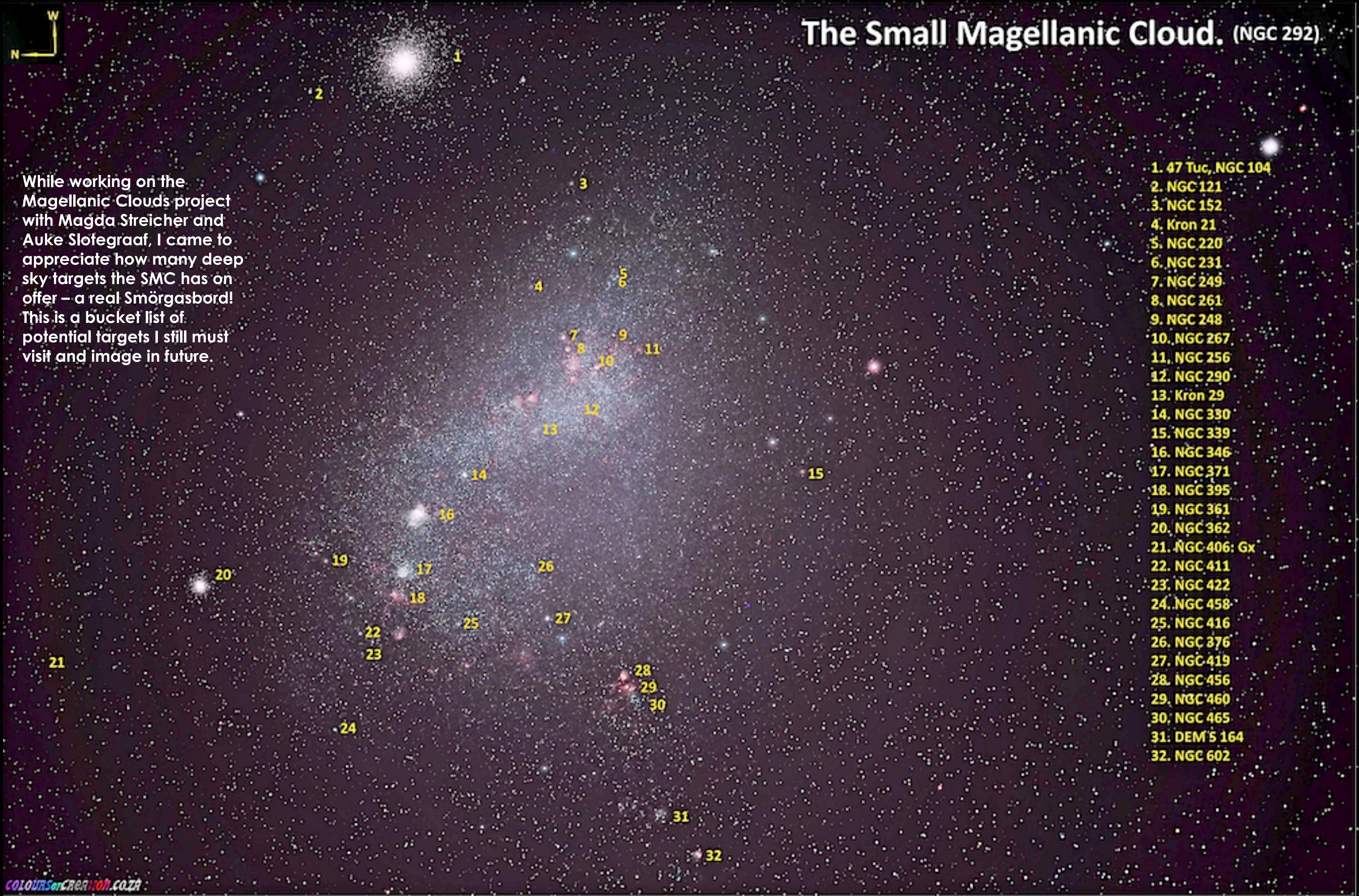
I've long been fascinated by what I call the "foot" of Simeis 188 – NGC 6559 and IC 4865. Although located only 1° from the M8 Lagoon Nebula, Sim 188 is much nearer to us and is a million years younger. When I read an APOD post about I was attracted by how beautiful was its chaotic mess of emission-, reflection-, and dark absorption nebulae, all mixed in with a sprinkle of open clusters. The bright red NGC 6559 is furiously forming stars deep inside and hidden by the red HII gas. Sim 188 is a smorgasbord of everything we like to explore and record.

"Pandemonium" one degree NE of the Lagoon



Star forming region SIMEIS 188 is a complex of emisson (red) and blue reflection nebulae of dust and dark absorption nebulae. Located 4000 light years away in Sagittarius.

A. NGC6546: open cluster in same FOV, 3000 ly,
B. IC 4684,
C. IC 1274, D. IC 1275
E. NGC 6559, bright cloud arc, F. IC 4685
G. Barnard 91, H. Barnard 303
I. GN 18.06.6.01



The Small Magellanic Cloud. (NGC 292)
While working on the Magellanic Clouds project with Magda Streicher and Auke Slotegraaf, I came to appreciate how many deep sky targets the SMC has on offer – a real Smörgasbord! This is a bucket list of potential targets I still must visit and image in future.
1. 47 Tuc, NGC 104
2. NGC 121
3. NGC 152
4. Kron 21
5. NGC 220
6. NGC 231
7. NGC 249
8. NGC 261
9. NGC 248
10. NGC 267
11. NGC 256
12. NGC 290
13. Kron 29
14. NGC 330
15. NGC 339
16. NGC 346
17. NGC 371
18. NGC 395
19. NGC 361
20. NGC 362
21. NGC 406: Gx
22. NGC 411
23. NGC 422
24. NGC 458
25. NGC 416
26. NGC 376
27. NGC 419
28. NGC 456
29. NGC 460
30. NGC 465
31. DEM S 164
32. NGC 602
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Why does an imager need so many OTAs? Building a personal library of object types implies wide-field gear for the "Big Picture" shots that show an object in its larger Galactic context; and high-resolution capability to get into the detailed hearts of objects. For the Southern Cross and Coal Sack, for example, I use the 200 mm f/2 Canon 1DX DSLR, while planetary nebulae, globulars, and galaxies are best imaged with the 10-inch long efl Dall-Kirkham. Its 1700 mm mandates a great many image, dark, bias, and flat expo-sures. Those in turn require dead-accurate tracking and guiding. The 127 mm TeleVue homesteads the terri-tory in between. The Dark Doodad image was captured using it. Yes, it is a large investment and each setup soaks up a huge amount of time for accurate setup, imaging, and process-ing after. The reward comes only at the very end when the final image pops up on my computer screen and I yelp, "Got it!" It's a heck of an investment for two short words, but those words are priceless.

Tele Vue 127mm f/5.2 refractor, fl 660mm, manual electronic focusing with Tele Vue focusmate (On laptop in backyard Eos). Red dot finder. Canon 6D, modified, DSLR. Celestron CGX mount. Auto-guiding: Canon 400mm f5.4 lens with ZWO ASI cam, on laptop, in PHD.

Optimised Dall Kirkham scope imported from Orion Optics UK, f/6.8, fl 1700mm. Canon 6D modified, Optec focuser. On a Celestron CGX-L mount. Auto-guiding: Tele Vue 85mm f/ 7.2 fl 600mm refractor (Brass tube – 8th last one produced), Orion Starshot cam. On Laptop, in PHD. Red dot finder.

Canon 200mm f/2.0 lens with a canon 1Dx DSLR. Control with canon Intervalometer, image capture and focusing with laptop in BYE. – as the others. Un-guided – just polar aligned. On a Celestron CGX mount.

ATMs in South Africa

Dirk Rossouw's Melkbosch Skies Observatory

Dirk Rossouw built his backyard observatory in the Melkbosstrand suburb 25 km from Cape Town

To earn your badge as a DIY stargazer, you start with a hole in the ground.

I was a "late bloomer" with respect to the purchasing of my first telescope. My first telescope was a Celestron NexStar 127SLT Mak. I soon, however realized that it wasn't enough. I subsequently bought an old Meade XL200 10" Classic and although I was very happy with its performance I jumped to it when I recently had the opportunity to acquire a 14" Meade LX200R GPS. While the 10" scope can still be described "mobile", the latter definitely is not. This lead to the construction of the Melkbosch Skies Observatory.

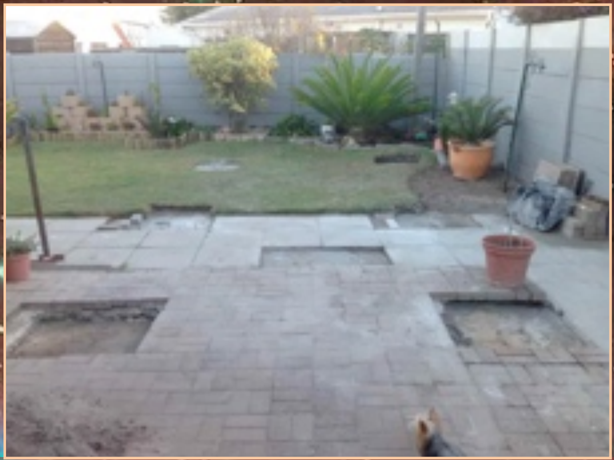
We dug seven holes. Four for the observatory structure itself, one for the pier and two for the columns that will eventually carry the stays for the roof to roll open. All in all we used some 22 bags of cement, 42 bags of gravel and 71 bags of sand. This structure will most probably be able to withstand anything!

Initial planning

I am not a handyman. My dear wife wryly describes me as, "Ten thumbs with a husband attached!" Constructing a small backyard observatory to accommodate my needs wasn't easy. There are no private companies in South Africa, or in the rest of Africa for that matter, that construct backyard observatories.

I considered ordering a pre-fabricated POD kit from Sky Sheds.com in the USA. Although they don't normally ship to South Africa, the chaps were extremely helpful and were quite willing to make a plan. Eventually I decided that the POD would be too small for my equipment storage needs. So I did the only sensible thing: I commissioned a private construction company.

Detailed planning for the Observatory continued for a few weeks before construction began. Being in a built-up area with relatively small 500 m² plots, finding a suitable spot for the observatory was difficult. The floor level had to be elevated to see over the adjacent roofs and trees, and there were other limiting factors.



Once poured, the concrete was left to set.

The first three rules of successful observatory construction are solid, solid, and solid. Base for floor constructed and shutter wood sheets being installed. Floor raised 80 cm from ground level to improve views over adjacent buildings.

Type of Building

The most important design choice to be made was roll-off roof vs. dome observatory. Domes have traditionally been the classic design for observatories, but roll-off roof designs provide an all-sky open view. Construction of a flat sliding roof is also less complicated. After review of the offerings for prefabricated huts, mostly wood and plastic, I chose the latest light steel frame construction method with flat roof running on wheels. It is 9 square meters (approx. 10 x 10 feet) in extent, which provides enough space for me, my equipment, and a couple of guests.

Steel columns supporting the channels on which the roof will eventually roll open.

Construction

We opted for a light steel frame construction on heavy steel base. The very able construction team of Global Construction Management were responsible for the actual construction of the Observatory. Des Palm, the owner of the company. predicted at the outset of the project, we would have a number of interesting "Oh sh@#!" moments throughout the project. We never, however failed to overcome any of these.

The floor was constructed on 306 x 306 mm UC steel columns, raised 800 mm from the ground. The floor surface consists of 21 mm shutter board flooring, with 25mm Isoboard insulation and 12 mm MagnaBoard sheets on top. I installed industrial grade carpet tiles on top.

The walls are 12 mm MagnaBoard (Magnesium Oxide) panels onto 90 mm x Z275 galvanized Light Steel frames with 63 kg mineral wool wall insulation and 18 mm shutter board on the inside. The corner posts are 150 x 150 x 6 mm steel columns.

The roof is Colourbond steel roof sheeting on industrial sisalation on 100 x 50 mm galvanized lipped channel purlins on 100 x 50 mm rectangular roof beams.

The exterior MagnaBoard panels were assembled with ample space between the inner and outer walls to install coax conduits for services. Thick layers of aluminised wall insulation filled the gap between the walls.

The exterior panels were painted with base coat followed by high quality Weather Guard outer paint to blend with the residence's outside walls. The interior walls are wooden shutter board panels. I treated the wood with three coats of clear Woodoc Indoor Polywax Sealer with a satin gloss. The electricity conduits within the wall and the port where the computer and video cables exit from under the floor from the telescope pier.

Utility Services

It made sense to install utilities at the outset than to add them later. For this reason, I planned on ample electrical and data/video services with provision for expansion. The major elements are:

- Eight circuit breaker distribution board with space for expansion if required
- Eight wall plugs installed in all four walls, with three in close proximity of my work station
- Special wall plug for roof motor
- Switched electrical outlets on each circuit, to control interior LED lighting
- Video cabling, to support video cameras and for LED video monitor (actually small TV)
- Conduits to the ports in the pier and wall plugs to eliminate trip hazards.

The observatory door had to be oriented to the north-east to keep the door opposite the prevailing south-wastern wind and also facing the residence. We have since decided to enclose our patio area, with the result that the observatory door now forms part of the enclosed patio area, thus improving access tremendously.

The roof opens and slides away to the south. We initially used a standard 500kg gate motor but soon realized that it wouldn't last with the heavy roof. We eventually opted for a workshop hoist crane motor that the contractor had available. Although rather too strong for this usage, I will never have to worry about not being able to open or close the roof.

1 000 kg (1,6 KW) electrical hoist motor adapted to open and close the roof. A gear was specially engineered to fit the motor and tracks for the roof. We had to install steel braces behind that part of the wall to handle the motor's movement.

Pier head and adjustment plates laser cut by a local engineering shop. All steel, including steel columns galvanised and subsequently painted with rust resisting Hammerite steel paint.

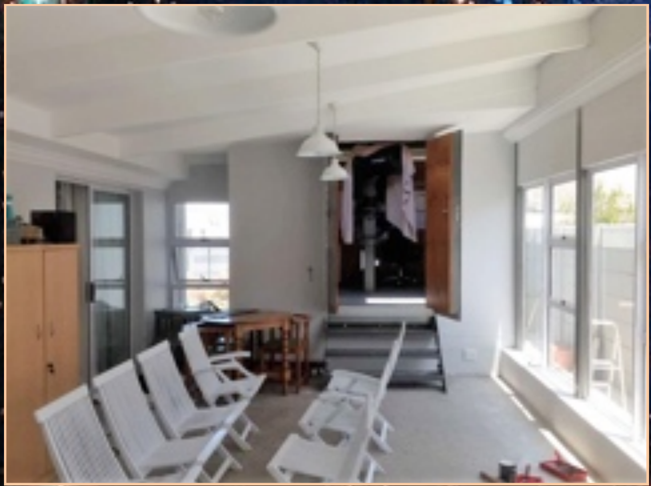
Telescope Pier

The telescope pier was constructed of heavy steel, 150x150x6 mm emplanted in a 1 cu. meter steel-renforced concrete. An opening in the floor slightly larger than the pier prevents floor vibrations from telegraphing to the pier. The hole is also a convenient aperture for the electricity, video, and computer cables. To keep electrical cables from littering the floor, they were channeled under the floor in separate conduits to rise inside the pier. They attach to a multi-plug distribution box on the side of the pier.

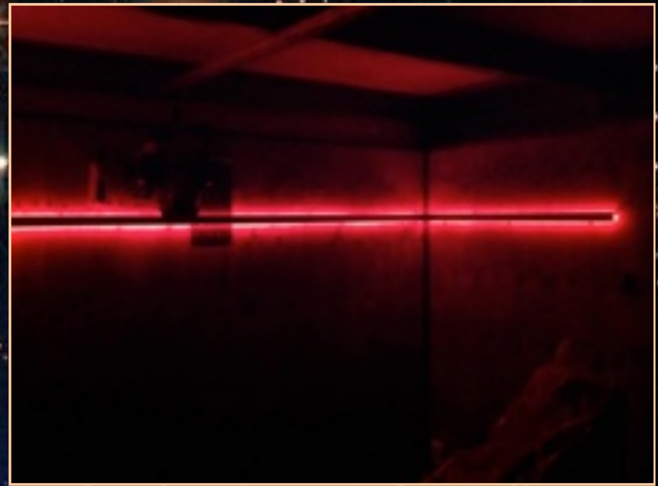
I bolted a heavy-duty Meade equatorial wedge on top of the pier for long exposure imaging sessions come the day my interested evolve that direction. Since I already had the telescope, it was easy to measure and calculate the optimal pier height. I held my breath the first time I closed the roof with the telescope in the "park" position, but was delighted to see it clear the top of the telescope by three cm when the telescope is pointed at the horizon.

Although I initially thought that the base was sturdy enough to prevent vibrations, I discovered that vibrations took about 3 seconds to dampen when the scope was bumped by accident. The solution was to not to weld larger and longer flanges onto the base but rather to encase it in a concrete pillar.

Note wall plugs in the background, plugs and video/ computer box on the pier shaft and heavy duty Meade equatorial wedge installed. The blue heavy duty carpet tiles provide a nice finish.



It didn't take too long for the distaff side of the Rossouw residence to notice that my new observatory was almost the same height as the living room floor of the house. It took even less time for me to be convinced what a topping idea it would be to extend the living room into a sun room attached to the stairs to the door of the observatory. Thus it came to be that in our house the "good life" is defined as my wife having her own sunny recreation and me having my starry hideaway. Note the Observatory's double doors open into the room. No more braving of the winter elements to get to my observatory.



Red LED strip lights with roof closed. The aluminum strips were painted the same colour Hammerite paint as the steel finishes, so as not to reflect light in my eyes when the lights are on.

First Light

The Observatory structure was completed by end October 2017. The telescope was installed late December 2017. On the night of Saturday, 13 January 2018 the telescope and observatory officially saw its "First Light". My good friend and astronomy hardware mentor, Martin Lyons and I duly celebrated the occasion with a glass of very good Pinotage.

A job extremely well done! And a glass of South Africa's finest Pinotage's to celebrate the occasion. Without Martin's invaluable assistance I would have battled to get it aligned so quickly and effectively.

http://melkbosch-skies.com/portfolio/observatory/

http://melkbosch-skies.com/

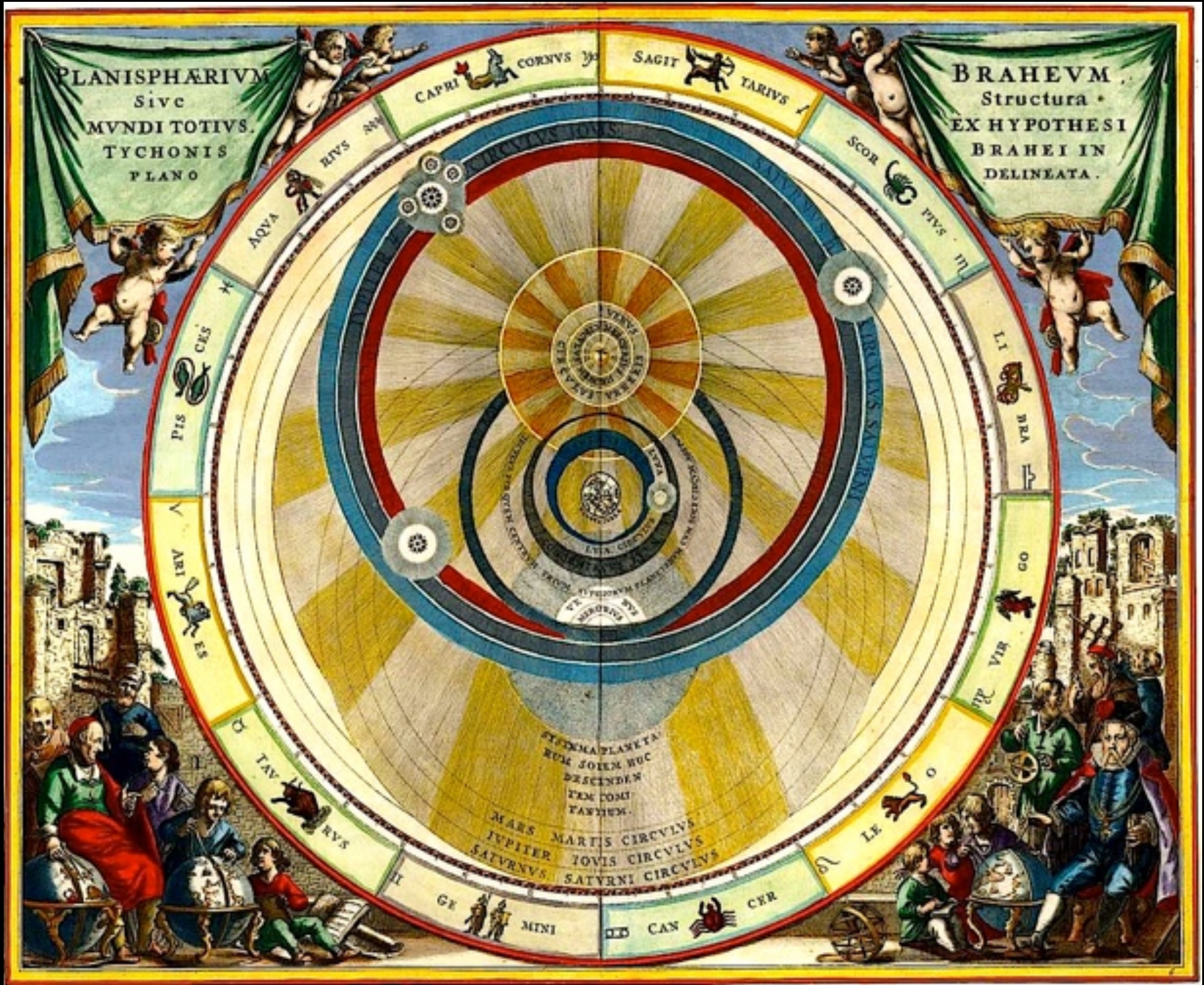
dirk.rossouw@gmail.com

A DIALOGUE BETWEEN

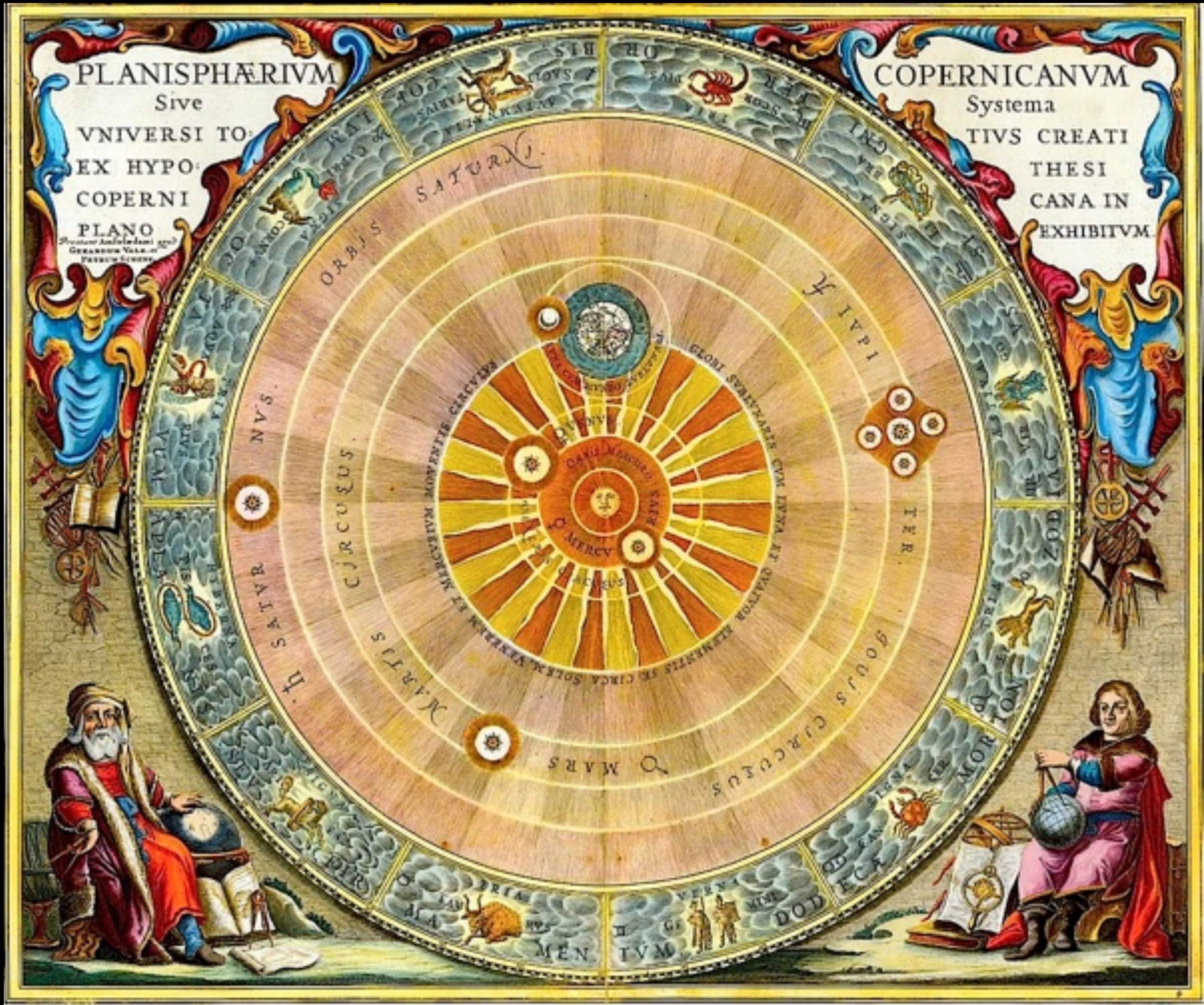
If ever there was a visual exemplar of Occam's Razor, this is it. The Dutch cosmographer Andreas Cellarius is best known for his spectacular celestial atlas, the *Harmonia Macrocosmica*. This plate and the next are from that work. Cellarius's atlas described ancient and contemporary astronomy as interpreted by the theories of Ptolemy, Copernicus, and Tycho Brahe.

Cellarius's rendering of Brahe's modified version of Ptolemy's epicyclic interpretation of celestial motions was an elegant summation of the unintended consequences of axiomatic logic. The axiomatic theory postulates that one is obliged to derive every aspect of a thought system from a single fundamental assumption and a single law of propagation – e.g., western linear logic.

In Brahe's geo-heliocentric system the sun and the moon orbited the earth while the remaining planets revolved around the sun. This chart depicts Brahe's model encircled by the twelve signs of the zodiac. The map is grandly titled *Planisphaerium Braheum, sive Structura Mundi Totius, ex Hypothesi Tychonis Brahei in Plano Delineata*. Cellarius even threw in Brahe himself as the munificently moustached gentleman in the lower right corner. *Source:* [Planisphaerium Braheum 3/28/2018.]



TWO WORLD SYSTEMS



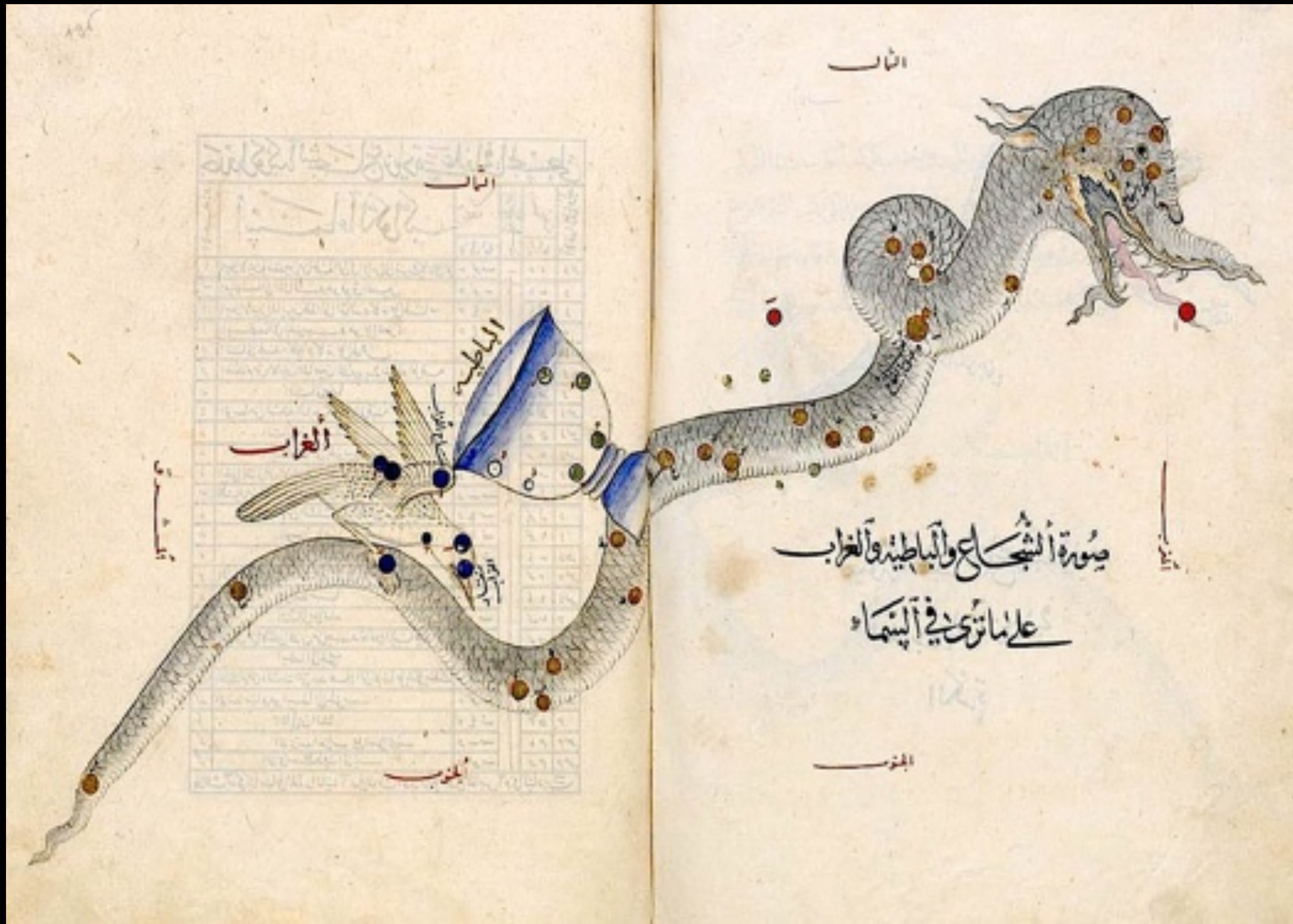
This striking example of the Copernican model of the Solar System was printed in a 1708 Valk & Schenk edition of Andreas Cellarius's *Harmonia Macrocosmica*.

Andreas Cellarius's version of Copernicus's heliocentric theory is regarded today as one of the most spectacular cosmographical atlases published in the 17th century. It was first issued in 1660/1661 by the Amsterdam publisher Johannes Janssonius (1588-1664), as a cosmographical supplement to his *Atlas Novus*. Andreas Cellarius had already started the atlas in 1647 and intended it to be a historical introduction for a two-volume treatise on Copernican cosmography but the second part was never published.

Cellarius' rendering of the Copernican concentric circles summarised the apparent movements of the planets around the sun, the moon around the Earth, and Jupiter's four known moons around the planet itself.

The original copper plate engravings were uncoloured. An entire industry of hand-colouring printed copies of engravings grew up to satisfy demand for more vibrant illustrations. Source: *Barry Lawrence Ruderman Antique Maps.*

THE BEAUTY IN OUR HISTORY



Hydra, Crater, and Corvus from *Zīj-i Sultānī*, an astronomical atlas published by Ulugh Beg of Samarkand in 1437. As with Western cartography, it was a collaboration between artists and astronomers. Unlike the West, where the artists sometimes were rather more liberal than the astronomers, Ulugh Beg determined the length of the tropical year as 365d 5h 49m 15s (an error of +25s and more accurate than Nicolaus Copernicus' error of +30s). Beg also determined the Earth's axial tilt as 23.5047 degrees. Hydra faces the opposite direction in the sky than as seen from Earth because this is the view Allah would have upon looking down from Paradise through the stars to Earth.

Humans have always been fascinated with the solemn parade of the celestial vault arching across the night sky. Even in the earliest-known texts of various ancient cultures, the stars were commonly grouped into anthropic figures which were believed to represent divine persons, sacred animals, and objects of religious importance. Crater was originally The Chalice, for example.

All of the major cultures in the Near East, the Far Eastern lands, and the New World developed an indigenous system of constellation figures and associated legends which were graven on stone, recorded in written texts, depicted on maps or on globes. Of these various constellation systems, the Sumerian/Babylonian system of constellation figures endured to become the most influential. Improbable and enigmatic as figures like Sagittarius, Capricornus, and Pisces may be, as art in the sky these constellation identities lived through adoptions, adaptations, aberrations, and additions by Greek, Roman, Islamic, and European astronomers, even as astronomy evolved into the disembodied mathematical coordinate systems of today. The only place astronomical objects are not located by constellation name is in the professional literature.

Up to the middle of the 19th century, celestial atlases and globes were considered to be art first and precision later. Nearly all historical sky atlases were collaborations of astronomers with artisans. Only the artisans, after all, could engrave on copper plates in reverse, and in intaglio. The astronomers sketched the positions of the stars and the constellation names; the artists took care of the presentation. The result was as much art history as astronomy history.

There are so many collections of celestial atlases that *Nightfall* could devote an entire issue to them. Since our goal is the deep-sky today and not in history, we rest content to open the door to the past just a crack for a peek inside. The rest is up to you and the good graces of Wiki and Google. "Celestial cartography" (*1*, 2) is a good place to start.

HAS A LONG LINEAGE

Haemisphaerium Stellatum Australe (Southern Hemisphere Constellations) published in 1660 by Andreas Cellarius depicted southern skies superimposed over North and part of South America. The chart is centred on the ecliptic pole 20 degrees into the northern hemisphere. The projection is as if gazing from deep space down through the constellations figures onto the terrestrial world below. Hence the constellations face in the opposite direction from the way we see them looking up from earth.

The unusual projection originated in Petrus Plancius's theory that the stars remained in a sphere-like configuration above the earth and moved in coordination with the earth.

Andreas Cellarius was born in 1596 in Heidelberg but emigrated to Holland in the early 17th Century Cellarius' best known work is his *Harmonia Macrocosmica*, first issued in 1660, by Jan Jansson as a supplement to Jansson's *Atlas Novus.*

Cellarius' charts are the most sought after of celestial charts, blending the striking – some say florid – imagery of the golden age of Dutch Cartography with contemporary scientific knowledge. The original was 50.8 x 43.8 cm (20 x 17 in) and coloured by hand using vegetable tints. (Tints are transparent; dyes are opaque.) *Source: Barry Lawrence Ruderman Antique Maps.*

Albrecht Dürer’s 1515 maps of constellations from the Northern and Southern Hemispheres combined the most up to date scientific knowledge of the stars in his time with Dürer’s pioneering skills as a woodcut illustrator. He created his pair of charts with the cartographer Johannes Stabius, based on the work of astrono-mer Conrad Heinfogel. The 48 Northern constellations named by Ptolemy in the 2nd century appear, as do the 12 Zodiacal signs.

Dürer’ss Southern chart depicted the complete Argo Navis, the Greek ship of Jason and the Argonauts, ploughing through the Southern seas in the sky. Today the old Argo Navis has been turned into Vela, Carina, Puppis, and Pyxis. The rest of the Southern Hemisphere is empty because it hadn’t yet been plotted by Europeans.

Throughout his career, Dürer viewed the mass production and commercial enterprise as the engine of what we call the information industry. Dürer intuitively understood that a permanently recorded image was a better way convey information than mere text.

Dürer wasn’t the first in the world to print a star chart — astronomer Su Song’s *Xin yixiang fayao* was printed in China in 1090. But Dürer was the first to combine existing factual knowledge with captivating visualisations that would endure permanently. Even today, five centuries later, we can readily recognise constellations in the sky exactly as they are depicted on Dürer’s maps.

This untitled celestial map of the southern skies was issued in 1674 by Ignace Gastone Pardies in Paris. Pardies (1636-1673), was a Jesuit astronomer whose manuscript star atlas shown here was published by his colleague Thomas Gouye just after Pardies' untimely death at the age of 37. The map is one of six in *Globi Coelestis Tabulas Planas Redacti descriptio ... opus postumum*, with engravings made by G. Vallet.

The vivid renderings of the constellation figures, e.g., Indus and Toucan, and now-obsolete constellations like the unnamed tree between Volans and Centaurus's tail, were modified from the depictions invented by Johannes Beyer in his landmark 1604 *Uranometria*.

Gouye's 1688 *Observations Physiques et Mathematiques* that included Pardies' maps was an important scientific work published by the Jesuits, a Catholic religious order. Gouye learned the lore and configuration of the southern skies during his embassy to Siam in 1685, which included a layover at the Cape.

Gouye's astronomical observations were noteworthy for being true to science rather than the rather travelogue-like air of terrestrial cartography in that era. Tables of astronomical data, instrumentation, and weather conditions, and astronomical positions (not shown here) were the equivalent of today's vast astronomical legacy data in computers servers at universities and observatories. Look closely near the celestial pole in the lower left quadrant, where Magellan's clouds are shown as "*Nebecula Major*" and "*Nebecula Minor*". *Map source: Bibliothèque Nationale, Paris*.

HOW DID THEY MAKE THESE MAPS?

At one time there were only three ways to reproduce reality in an enduring physical form. The earliest known was children; this method had a high ease-of-use factor and readily lent itself to the learn-as-you-go school of pedagogy. The other two methods were (a) *additive*: applying material to a supporting surface, usually as paint, ink, or mosaic; and (b) *subtractive*: removing material from a substrate, producing bas-relief or in-the-round sculpture.

One of the most difficult objects to reproduce accurately was the shape used to represent a sound, i.e., a letter. Words are easy to make with ink and a quill, difficult and time-consuming with a chisel. With the introduction of paper into Spain in 1056 and manufacture in France in 1190 words could be mass produced. With Johannes Gutenberg's Bibles in 1440 words on paper became viable commercially.

The transition from suit of armour to a map of the constellations reflects the wealth of the ultimate user as much as it does the lateral shift of a technology from one-off exotic to mass produced consumable.

There was little market for maps and charts until the boom in maritime exploration in the fifteenth century. India was hard to reach if you didn't know where it was. The need for maps inspired a technology for making them. Engraving on metal plates was the ideal solution but most maps were navigational; information for its own sake was a late bloomer. Only in 1515 was the first printed celestial chart of any consequence made, a pair of maps by Albrecht Dürer depicting the northern and southern skies.

Images graven on metal have a rather brief history as artistic matters go. The first images made by the transfer method (making a duplicate using an original) was the woodcut. Early attempts at image fidelity using the medium of wood were a net loss to the ideals of beauty.

Goldsmiths and ironmongers were the first to take advantage of the fact that wood does not easily aspire to elegance, but metal does so readily. The earliest notably attractive images on metal to come out of the Middle Ages were not monastic Bibles, but aristocrats' weaponry. By 1400 goldsmiths were engraving hammer-forged iron to decorate suits of armour. Metalsmiths were engraving hammer-forged iron to decorate suits of armour. Musical instruments and religious icons soon followed.

In one of history's more felicitous coincidences, ten years before Gutenberg's first Bible an artist named Martin Schöngauer experimented with engraving fine lines into soft copper sheets. While Gutenberg's transfer process used inked letters raised above an un-inked base, Schongauer's process was just the opposite: ink was applied to the surface of a flat copper sheet, filling tiny grooves incised into the copper. The excess surface ink was wiped away with starched cheesecloth, leaving only the ink in the grooves. When the plate was run through a press, the paper absorbed the ink in the grooves, reproducing the image reversed from side to side but otherwise accurate. The net effect was a much finer, more nuanced line. This new form of image transfer came to be called *intaglio* ("cut into").

Science's first multitask medium

There was a bit of prior technology to the use of copper plates. Decades before Martin Schöngauer, medieval bookbinders stamped gold-leaf letters into leather and parchment covered manuscript books. They used brass dies with protruding Latin letters. Struck with a fierce blow from a hammer the die compressed the gold leaf deeply into the leather. It was moveable type one letter at a time. Antiquarians and numismatists still use the term "strike" to describe decorative stamping a "blank" of paper or coin.

Martin Schöngauer was the first to hit on the idea of copper sheets as an imaging medium. The first words and illustrations to be depicted were neither saints nor hellions, but lowly playing cards. It's a miracle any survived, but about 100 still exist. The discovery of a new and unknown 1430s playing card is cause for champagne toasts in the rarefied circles that can afford to pay exotic sums for bits of old paper.

Quick to adapt were the prolific stampers of saintly medallions that rose out of the pilgrimage industry (for so it was). One of them was Herr Gutenberg. He printed locket-sized images of the Virgin & Child long before he devised moveable letters. A 1440 engraved image of the Passion of Christ on a small copper plate still has traces of ink in the grooves.

The modest copper plates used to produce playing cards were speedily enlarged into folio-size sheets that could be fit together to imprint 8 separate pages on a sheet of standard-size rag-mill paper. The first copperplate maps were two Italian editions of the geographer Ptolemy struck in 1472. Copper was far superior to wood because of the much finer detail that could be graven into a polished copper surface.

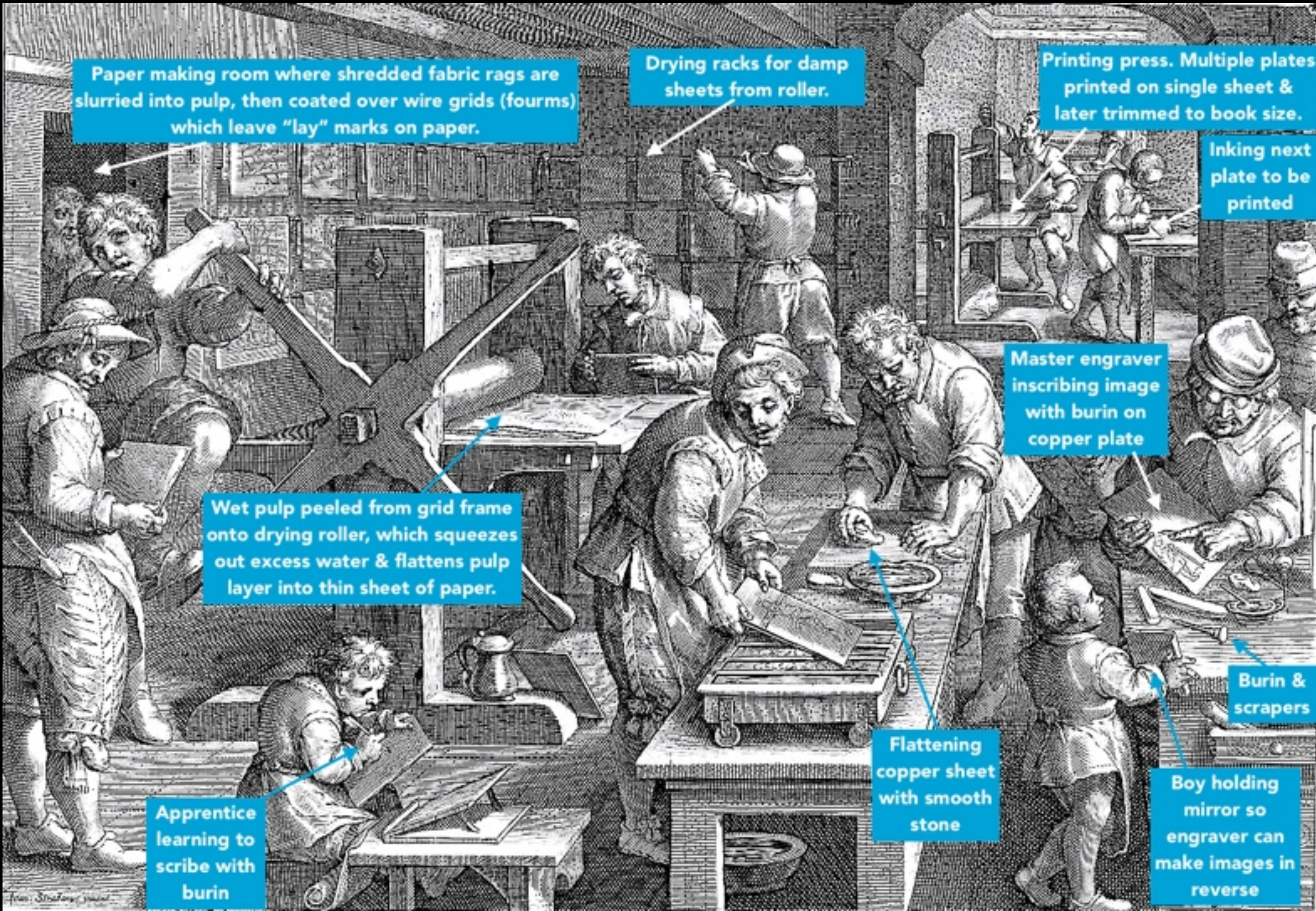
Elephantine has real meaning in the antiquarian book world. All the more so in the above example, which is the largest size paper used for printing, the double-elephantine folio. The word "folio" simply means "sheet".

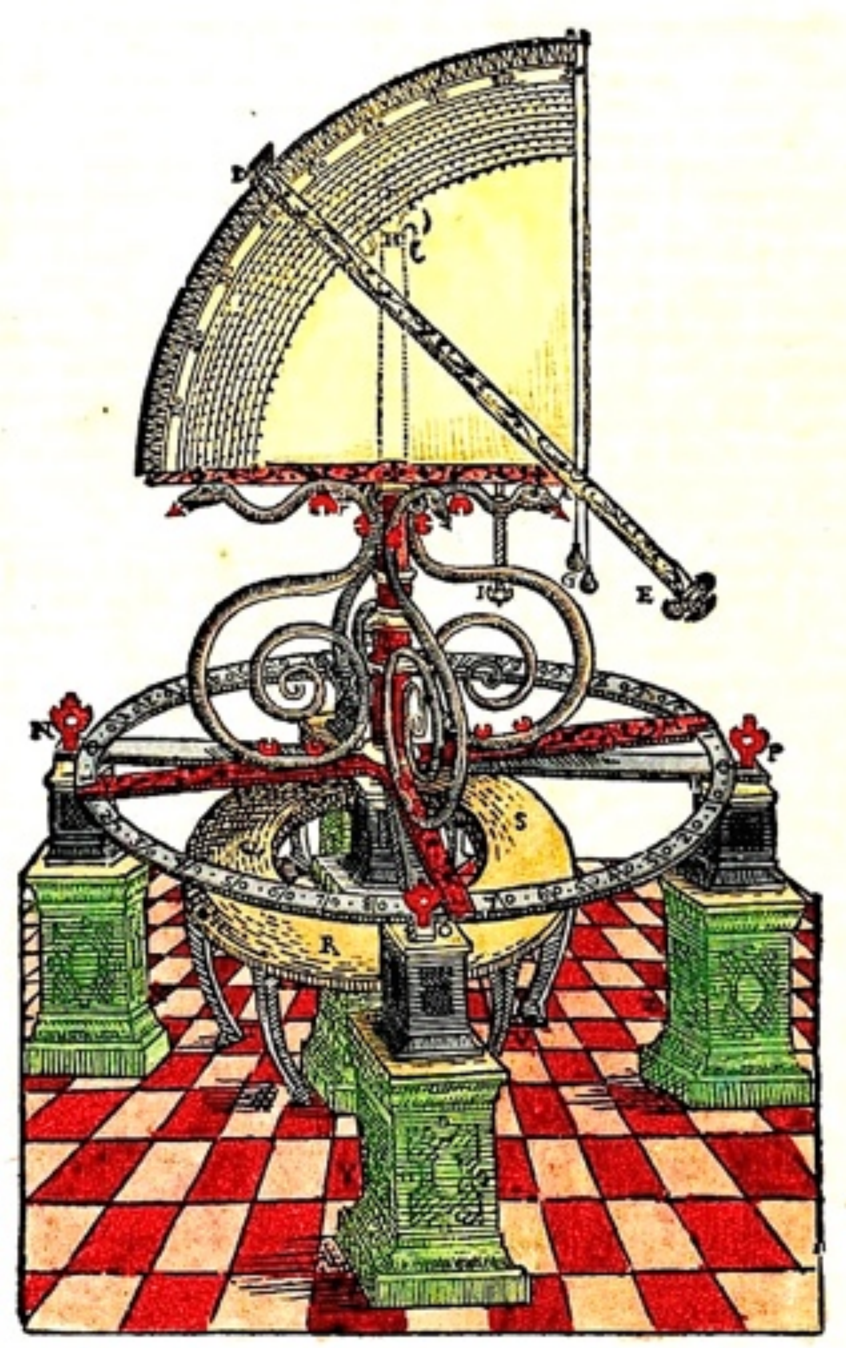
Most maps of the time were sold to the maritime trade as navigational aids. For the first time sea captains could compare their relative latitude on the sea with the landfall they were heading for. Close to shore, however, a wrongly plotted map could end in shipwreck. Lives and ships could be lost if underwater ledges or treacherous straits were inaccurately sounded. Hence every sea captain ordered plumb-bob soundings to be made (remember "full fathom five"?) as they neared the shore. They jotted changes to shoals on their charts, to be handed over to their home-port mapmakers when they returned. Numerous examples of scribbled re-soundings can be found in the archival charts of a maritime museum.

But since their corrections involved only a small portion of a large chart, re-engraving the entire plate was infeasible as too expensive. Copper was ideal for small-scale corrections. The map engraver simply flattened the old grooves with a smooth stone and incised new ones, numbers and all. Little did those mapmakers ever dream that centuries later entire master's theses would be produced tracking the exact sequence of undated corrections. Oceanographers today use the chronology of alterations of old maps to plot long-term current patterns in a given water body across time spans of a century. Geographers in turn have traced the changes in coastlines as a tool to understand more general thinking of respective eras. The French king Louis XIV made geographic history when he remarked upon first seeing Cassini's accurately replotted French coastline, "Why sir, you have robbed a sixth of my country from me." Cassini saved himself from a bad moment by responding, "No, Your Majesty, the ocean did."

Figure on overside: Amsterdam or Antwerp canal-side strollers would not have been surprised to pass the open doors of a print-making establishment like this. Dim, dank from damp paper and sweat, fetid from wood fire smoke in the winter. The shop urinal was a pile of wood shavings in a corner. Today these are called job shops. As then, they produce a small but vital component in a much larger work. It was easy to re-set a typo in the age of letter-by-letter typesetting; difficult and expensive to correct or update a harbour fathom chart in a nautical chart where, halfway around the world a year later an accidentally inverted 6 that read 9 could turn a proud ship into a catastrophic loss of all hands. The 16th century's great age of global exploration to fuel mercantilist economic ambitions spawned a myriad small trades like copperplate printing and sextant engraving. One modest corner of this burgeoning world of enterprise produced the works that so mesmerise us today: the cartographical plate. They were a mix of high art and high precision in a merger science begrudges no more. The modest folio-sized plates being prepared in this little *drukkerij* would have appeared in leather-bound books small enough to be read in one's lap. Cartographical plates, though, were the largest objects printed at the time. The aptly named elephantine folio 23 inches (58.4 cm) tall was surpassed only by the double elephantine folio at a colossal 50 in (127 cm) tall – eye-level or higher to most of the men working in this shop. It is also to be remarked that child labour was called 'apprenticeship' and lasted longer than grammar school today.

COPPERPLATE PRINTING IN 16TH CENTURY AMSTERDAM





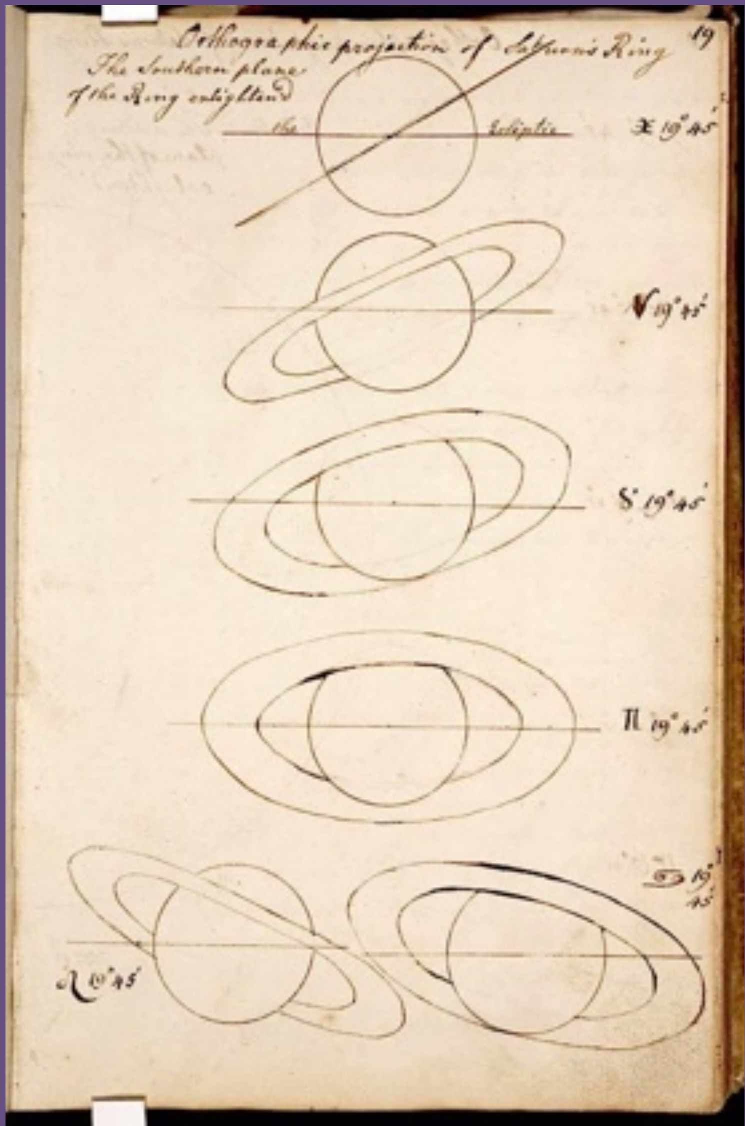
CELESTIAL CARTOGRAPHY ON THE WEB

- *Atlas Coelestis:* Comprehensive website by Felice Stoppa with digital editions of various celestial atlases and maps from the 15th to early 20th century.
- *Atlas Coelestis*: Collection of celestial atlases in the Biblioteca "Guido Horn d'Arturo" del Dipartimento di Astronomia dell'Università di Bologna.
- The Mercator Globes at *Harvard Map Collection*: 1541 terrestrial & 1551 celestial globe of Gerard Mercator in the Harvard Map Collection.
- Tycho Brahe (1546 – 1601): *The Astronomiæ instauratæ mechanica* (1602) digital copy of the instruments used by Tycho Brahe.
- Andreas Cellarius (c. 1596 – 1665): *Harmonia Macrocosmica* (1660, 1661, 1708).
- *Vincenzo Coronelli, (1650 – 1718)* 110-cm celestial globe (1693).
- Johann Gabriel Doppelmayr (1677 – 1750): *Atlas Coelestis* (1742).
- John Flamsteed (1646 – 1719): *Atlas céleste de Flamstéed* (1776 Paris ed.).
- Johann Elert Bode (1747 – 1826)*: Vorstellung der Gestirne auf XXXIV Tafeln* (1782).
- Franz Niklaus König (1765 – 1832) *Atlas Céleste (1826)* printed in reverse white upon black. Municipal and University Library of Berne.
- *The Earth & the Heavens: The Art of the Mapmaker*. *Collection of the British Library (London)*.
- *Ciel & Terre*: Based on the exhibition *Figures du ciel* held at the Bibliothèque nationale de France (Paris).
- *The Earth & the Heavens: The Art of the Mapmaker*. *Collection of the British Library (London)*.
- *Linda Hall Library of Science, Engineering & Technology*. Digital online editions of numerous historical star atlases (click on '*COLLECTIONS*').
- Dunhuang Star Chart, the Oldest Sky Atlas in the World, *International Dunhuang Project,* British Library

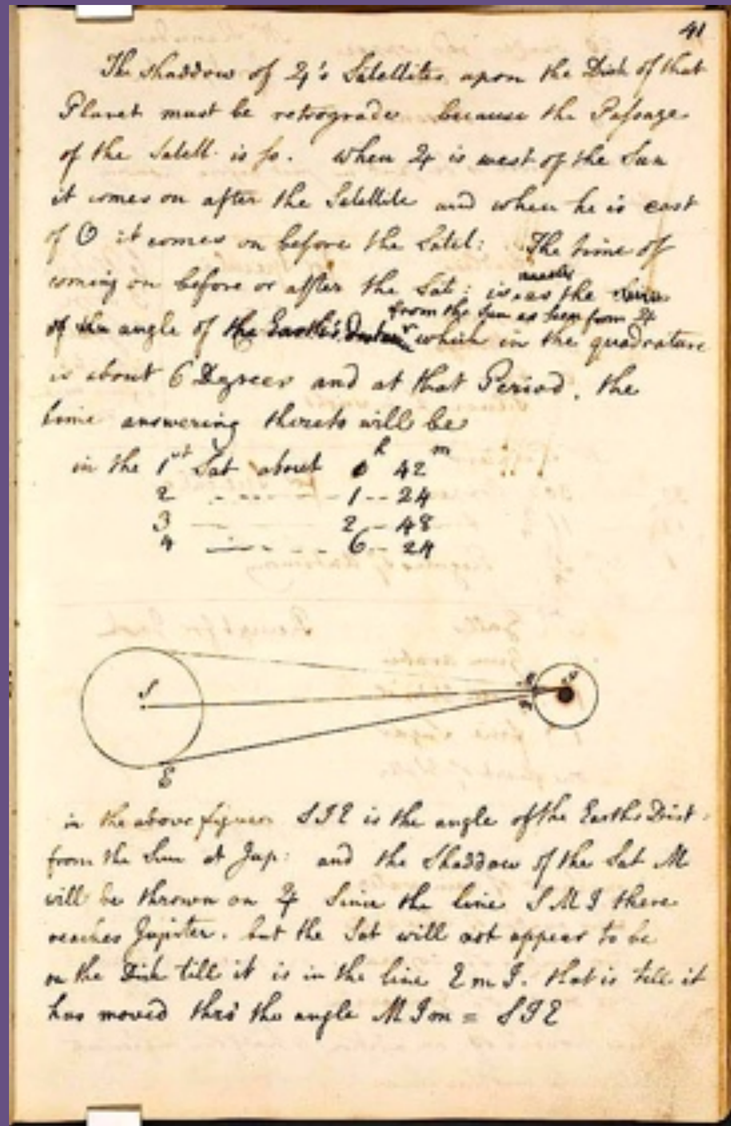
Tycho Brahe's first quadrant built in 1576 or 1577 was made of brass mounted on masonry pillars to give him foot room beneath so he could make measurements while seated. The vertical and horizontal arcs were 65 centimetres in radius. Its estimated accuracy was 48.8 seconds of arc in both azimuth and declination. It was one of the first instruments built at Hven, a small island that was to evolve into his famed Uraniborg Observatory. It was completed in time to observe and measure the path of a comet that appeared in 1577. The altitude axis of the quadrant rotated around the finely-graduated base circle, Brahe's positions for an object had to be labourously converted from alt-az to ecliptic coordinates. Brahe deemed the mathematics of this to be easier than to mount such a ponderous apparatus at the 55.9° angle needed to align with the Earth's rotational axis.

Mr. Herschel does his homework

William Herschel began keeping his *Commonplace book on Astronomy* in 1759, when he was in his early 20s, and its entries date into the 1770s. The 104 handwritten pages trace Herschel's work and thought while he learned to build his first telescopes. These would allow him to see farther into the heavens than humans had seen before. He discovered the planet Uranus in 1781 and both studied and speculated on nebulae and the evolution of the stars. Images courtesy of *Linda Hall Library*, Kansas City, MO, USA.

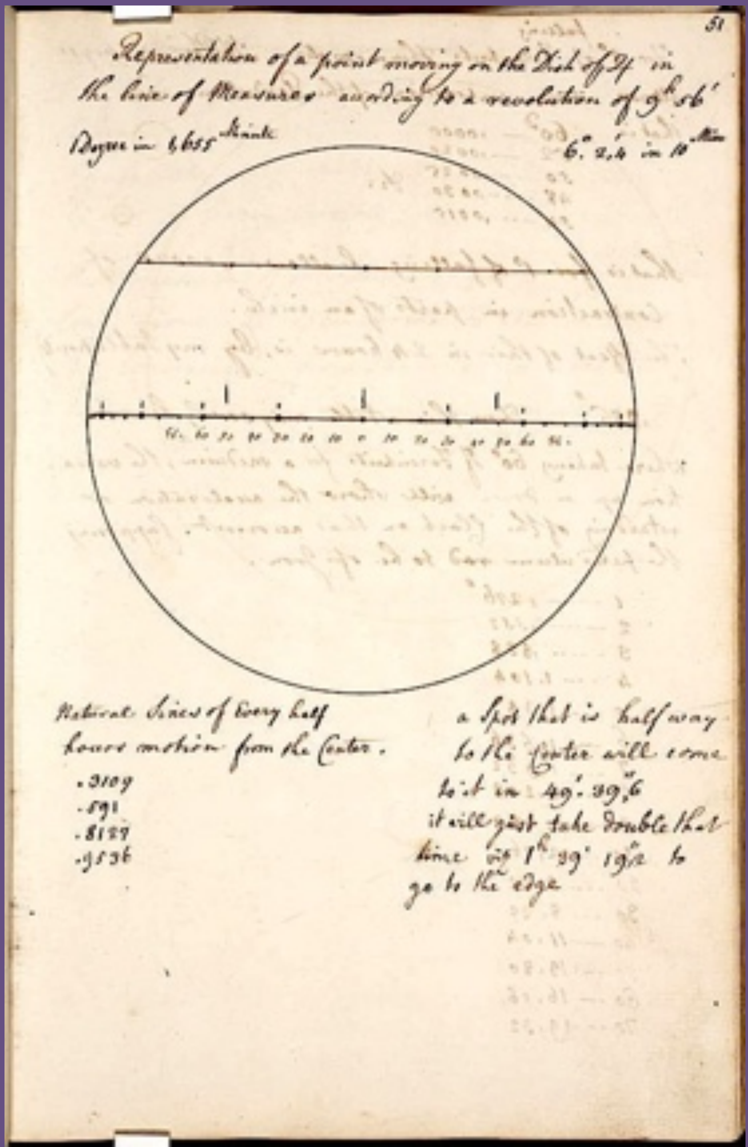


The orthography of Saturn's rings with respect to the ecliptic during one-half of a complete orbital cycle.



When Herschel wanted to pin down the orbital diameters of each of Jupiter's satellites, he calculated the parallax tangents of the position of the satellite at first or last contact with Jupiter's disc. The first-contact time difference introduced by the diameter of the Earth's orbit are shown for each satellite designated as 1, 2, 3, 4.

Calculating the position of an object moving across the disc of Jupiter during one 9 hr 56 min rotation (total 596 minutes). In 10 minutes the object moves 6° 2′ 40″ across the disc. Across the next two pages Herschel calculated the slowdown rate as the point receded toward the edge and out of view.


51

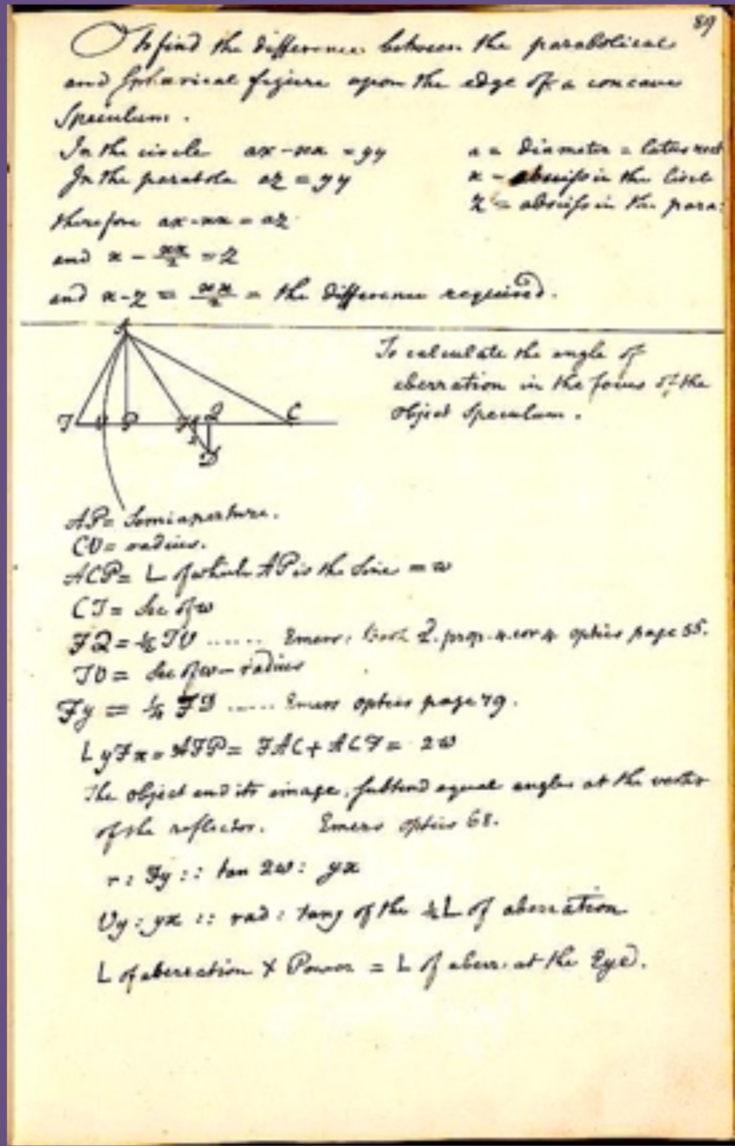
Representation of a point moving on the Disk of ♃ in the line of Measures according to a revolution of 9h 56′

Degree in 1,655 Minute 6°. 2,4 in 10 Min

Natural Sines of every half hours motion from the Center.

.3109
.591
.8127
.9536

a Spot that is half way to the Center will come to it in 49′. 39″,6 it will just take double that time viz 1h 39′ 19″,2 to go to the edge


89

To find the difference between the parabolical and spherical figure upon the edge of a concave Speculum.

In the circle $ax - xx = yy$ — a = Diameter = latus rect.
In the parabola $az = yy$ — x = abscissa in the circle; z = abscissa in the para:

therefore $ax - xx = az$

and $x - \frac{xx}{a} = z$

and $x - z = \frac{xx}{a}$ = the difference required.

To calculate the angle of aberration in the focus of the Object Speculum.

AP = Semiaperture.
CD = radius.
ACP = ∠ of which AP is the sine = w
CT = sec of w
FQ = ½ TD …… Emers: Book 2. prop. 4. cor 4. optics page 55.
TD = sec of w − radius
Fy = ½ FD …… Emers optics page 79.
∠ yFx = AFP = FAC + ACF = 2w
The object and its image, subtend equal angles at the vertex of the reflector. Emers optics 68.
r : Fy :: tan 2w : yx
Dy : yx :: rad : tang of the ½∠ of aberration
∠ of aberration × Power = ∠ of aberr. at the Eye.

Toward the end of the notebook, in 1772 Herschel endeavoured to calculate the differences between spherical aberration in a simple concave spheroid compared with the aberrations from a paraboloidal figure. Unfortunately he was unable to deal with the paraboloid's perennial nemesis, coma.

The Gamma Velorum Cluster

Source: *Paulo Cacella, Brazíia, Brazil*

Colliding-wind binaries raise hell in the heavens

and in the process teach us how to make better textbooks

The colliding winds produced by ultra-massive stars are the fiercest tornados a star cluster can make. They are so hot they radiate mainly in X-rays, which is why the beautiful multiple star *Gamma Velorum* (γ Vel) seems to us a serene and lonely quadruplet in the midst of a pretty, speckled star field. If we were closer — say gazing upon the scene from from the balcony seats of Jupiter's moons — we would see the region presently occupied by our Earth to the Sun as a blindingly hot maelstrom writhing like the most furious coronal flares shown in videos of our Sun, shivering the entire sphere where our Sun-Earth diameter would be. We would need X-ray and UV glasses to see this, though, because little light in our familiar visual band would reach us.

Hand-sketched colliding-wind image from *Feldmeier & Shlosman 2001* based on *Lucy & White ApJ 1980*.

Astronomers have identified two-dozen γ Vel-like multiple O-class supergiant systems in our Galaxy. γ Vel is one of them. To us, a pretty eyepiece of four brilliant stars in a truncated-arrow shape, a closer look using UV and X-ray spectroscopy shows it to be a six-star multiple whose combined luminosity make it the brightest star in Vela. The most luminous component γ^2 Velorum is a spectroscopic binary consisting of a massive blue supergiant and the closest known Wolf-Rayet star to Earth. They orbit each other in 78.5 days in an oblate ellipse whose a mean separation is 1 AU, the distance of Earth from the Sun. γ Vel's Wolf-Rayet is the nearest supernova candidate to Earth.

The hot evolved O star is about 25 times as massive than the Sun (25 $M_\odot$) with a surface temperature of 35,000 K, making it 200,000 times more luminous thank the Sun (2 x 10^5 $L_\odot$). Its Wolf-Rayet partner is 50,000 $L_\odot$ and a surface temperature of 60,000 K. This star, like other Wolf-Rayet stars, started out with a mass of about 40 times that of the Sun but has shed much of that original material; it is only about 10 $M_\odot$ today.

Alas for all their crash-diet efforts, Wolf-Rayets are doomed no matter how hard they try to lose weight. They are behind on the ejection-vs-evolution curve and will expire as core-collapse supernovae, not because they may or may not get below the supernova minimum-mass threshold of ~8 $M_\odot$, but because the nuclear reactions in their cores have advanced beyond the ability of their envelope mass to constrain. The typical evolutionary pathway for such stars is O supergiant becomes a luminous blue variable (e.g., η Carinae) ➞ Wolf-Rayet (nitrogen N or carbon C type depending on mass-to-luminosity ratio at the time) ➞ core-collapse SN1c (possibly gamma ray burst) ➞ black hole. No two ways about it, if you are fated by your birth girth to become a Wolf-Rayet, your future career prospects are pretty awful.

Next to γ^2 is the bright mag, 4.3 γ^1 Vel, a blue-white subgiant B star. γ^1 lies 41.2 arcsec from the Wolf-Rayet binary, easily resolved with binoculars. The multiple system has several fainter companions as well: γ Vel C, a white A star of mag. 8.5 some 62.3 arcsec from γ^2, and the binary pair γ Vel D and E about 93.5 arcsec away. The system is visible from Earth south of 35°N latitude.

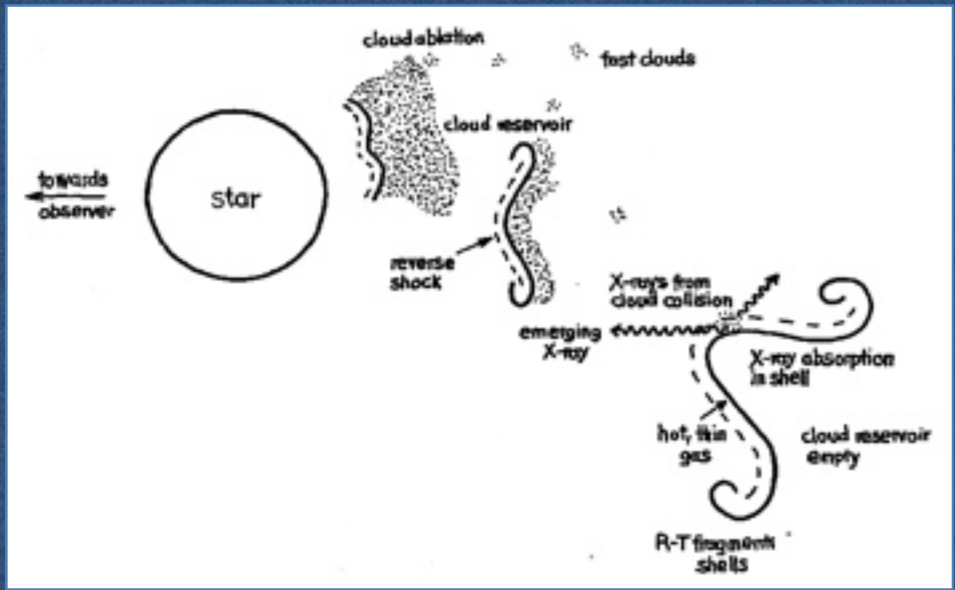
γ Vel has a traditional Arabic name, *Suhail al Muhlif*, and the modern name Regor. Neither name has been approved by the International Astronomical Union. Too bad, because the ancient Arabic translates as, "the glorious star of the oath."

Further reading:

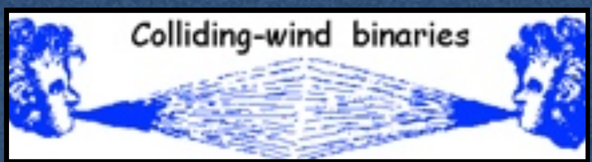
What is Gamma Velorum?
On the binary nature of massive blue hypergiants
Self-regulated shocks in massive binary systems

Where do the X-rays come from?

Gas from O-star surfaces erupt brilliantly in X-rays. Add this to the fearsome UV radiation produced by the stars themselves at their surfaces, plus the fact that the winds are driven from the stars at 1000 to 4000 km s^{-1}, it is hard to imagine an environment more inimical. A fraction of the wind's energy is driven by radiation pressure (heat transfer when photons hit dust); some comes from the kinetic pressure of ionised protons colliding with heavier ions such as carbon, nitrogen, oxygen, etc.; and some comes from momentum transfer (which differs from energy transfer) as high-speed helium ions strike the more massive metal ions in the heat-shocked gas. X-rays are generated mainly during the helium particle/metal ion energy exchange.



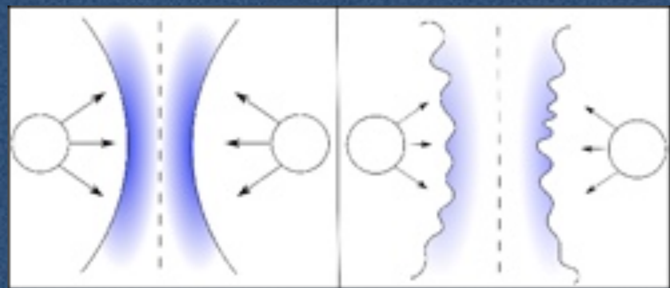
X-rays are generated at the end-stage of a chain of ablation/reverse shock dissipations in which some X-rays are re-absorbed, heating the gas, while other X-rays escape, cooling the gas. Shock front deformation is strongest at the edges of the front while X-ray emission is strongest hear the central peak. *Source:* *Hydrodynamics of astrophysical winds.*



This alternative colliding-wind model is provided by courtesy of the Flat Earth Society.

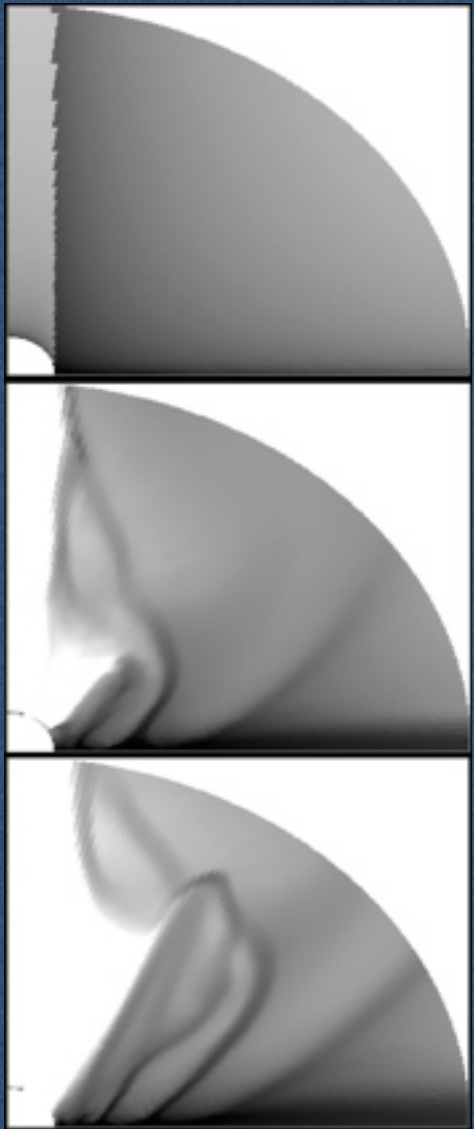
The relatively close proximity of γ^2 Vel creates *high-energy colliding stellar winds* as the two stars orbit each other. A *recent study* of gamma-ray energies from seven Wolf-Rayet systems in the Milky Way determined that γ^2 Vel is the most energetic gamma, X-ray, and UV emitter. The only other gamma-emitting stellar system in the Milky Way is the Eta Carinae system. However, where η Carinae lies in a seething bath of shocked gas and magnetic fields, γ^2 Vel shows no discernible nebulosity in the 2MASS optical, XMM Newton, or AKARI 140, 65, and 30 μm bands as far out as a 30 arcmin radius from the cluster. With this stellar content, the Vel system is oddly bereft of formation ejecta. The dearth of nebulosity is all the more remarkable because Vel is one of the most fulminous colliding-wind binary systems in the sky. There should be scads of gas flying all over the place. Where is it?

One possibility is that the normally abundant dust that is found in a star-forming nebula is simply incinerated by the incredibly hot environment around a system as massive and hot as γ^2 Vel. All by itself, the γ^2 Vel binary puts out more light in ten minutes than our Sun generates in an entire year. Their winds are so powerful that they eject an Earth's worth of material roughly once every month. Imagine those two winds as colliding head-on. Wind collisions of any kind generate a lot of heat, and therefore light, but the γ^2 Vel system produces gas temperatures on the order of 4 to 10 million K. Galactic dust particles begin to boil away their atoms at about 6000 K, thousands of times cooler than the gas around γ^2 Vel.



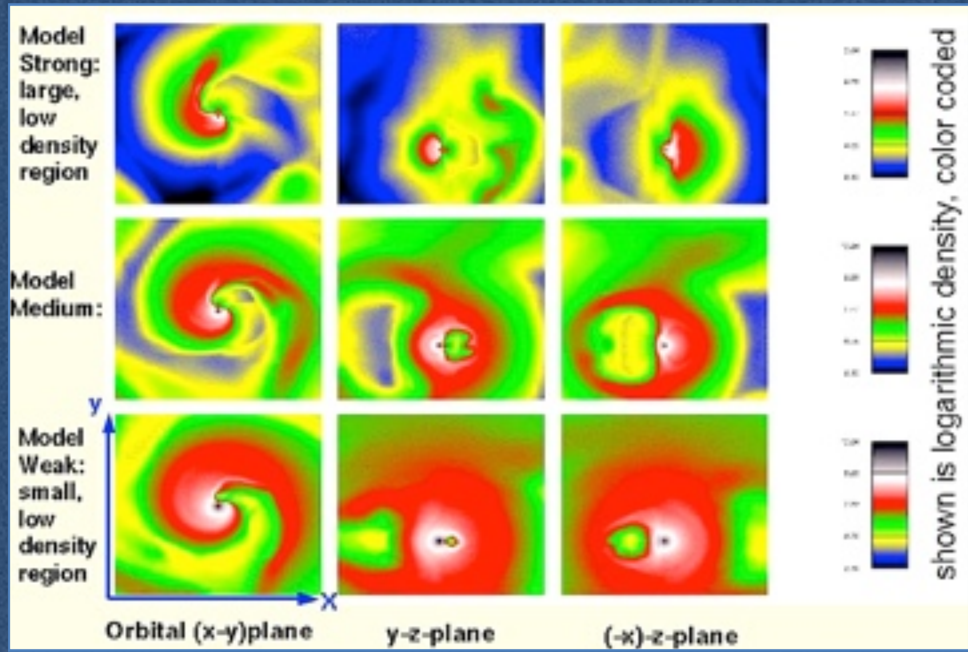
The difference between subsonic (l) and supersonic (r) colliding winds.

If it's a-blowin' in the wind, which way is the wind blowing ?



Simulation of particle driven wind from an accretion disk, looking down along the star's polar axis. *Click this link to see the full animated gif of the wind in action.*

The fearsome hydromagnetic winds which originate in the envelopes of massive hot stars are ejected directly away (radially) from the star disc at hypersonic velocities. They also carry a rotational component from the equatorial surface rotation of their stars. Moreover, the superheated gas at the surface of the star is not constant and even. The relatively shallow convection zones of massive hot stars churn and boil with gigantic bubbles that pop when they reach the surface. They hurl varying amounts of superheated interior gas into the stars' corona, where the gas enters the stars' ejection disc. There the gases are spun up by the shear torque of the whirling disc. Since the gases are so highly ionised, they acquire an additional magnetic vector from the magnetic fields of the disc, which aligns not with the equatorial plane of the disc but rather the star's magnetic polar axis. To make life even more complicated, the escaping gas bubbles flow at one speed while the disc is rotating at another. An interface between two gas flows quickly develops small wavelets, then large waves, and finally giant turbulence cells. You can watch this as a breeze crosses a still pond, setting up rows of ripples that grow in size as the wind



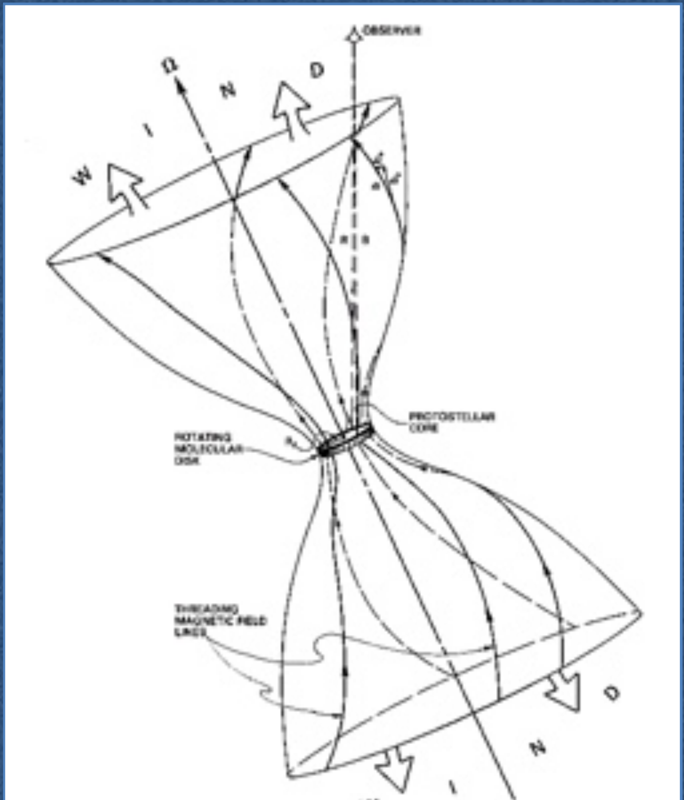
Significant variations from the basic Wolf-Rayet/O supergiant colliding-wind model occur because of the wide disparity of star types involved and the proximity of nearby stars.

blows along the "fetch" of the total water expanse. In gas bodies, differential wind shears set up a looping set of wave-like perturbations called Kelvin-Helmholtz instability. We are familiar with K-H instabilities right here on Earth when we watch videos of a flat cloud layer erupt into large gyres as the layer blows past a mountain peak or island below. (See *1*, *2*, *3*.)

The superheated gases are so hot (>10,000 K) they are entirely ionised. That means a lot of electrons (flux density) moving at high speed (flux velocity). They are easily channeled by the already-existing poloidal magnetic field of the stars themselves. A poloidal magnetic field is open-ended along the the polar axis so it takes on an "hourglass" configuration (see image next page). This geometry evolves because stellar gas expulsion flows along magnetic field lines readily but strongly resists flowing across them. The overall result is a deeply curved flow field that looks rather like a bow shock. Unlike bow shocks, these flows become turbulent.

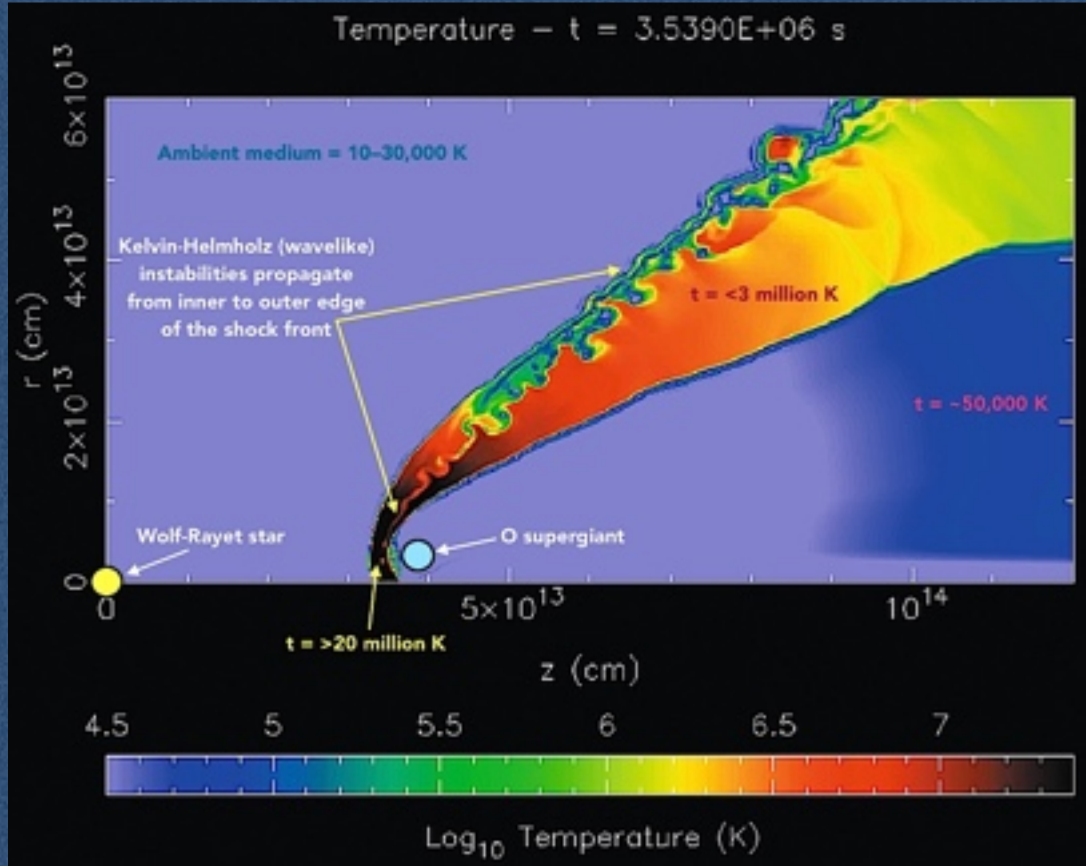
Why do so many colliding winds end up looking like hourglasses?

The flux threading the molecular disk acquires an hourglass shape due to preferential contraction of gas along magnetic field lines. However, real systems don't always follow idealised models such as the model below. Most studies show that outflow and magnetic field axes are aligned to within only withint ±20° of the disc plane. When a star's rotational axis and magnetic field axis are offset (as our Earth's is) the gas flow adds a spin vector which corkscrews the wind.



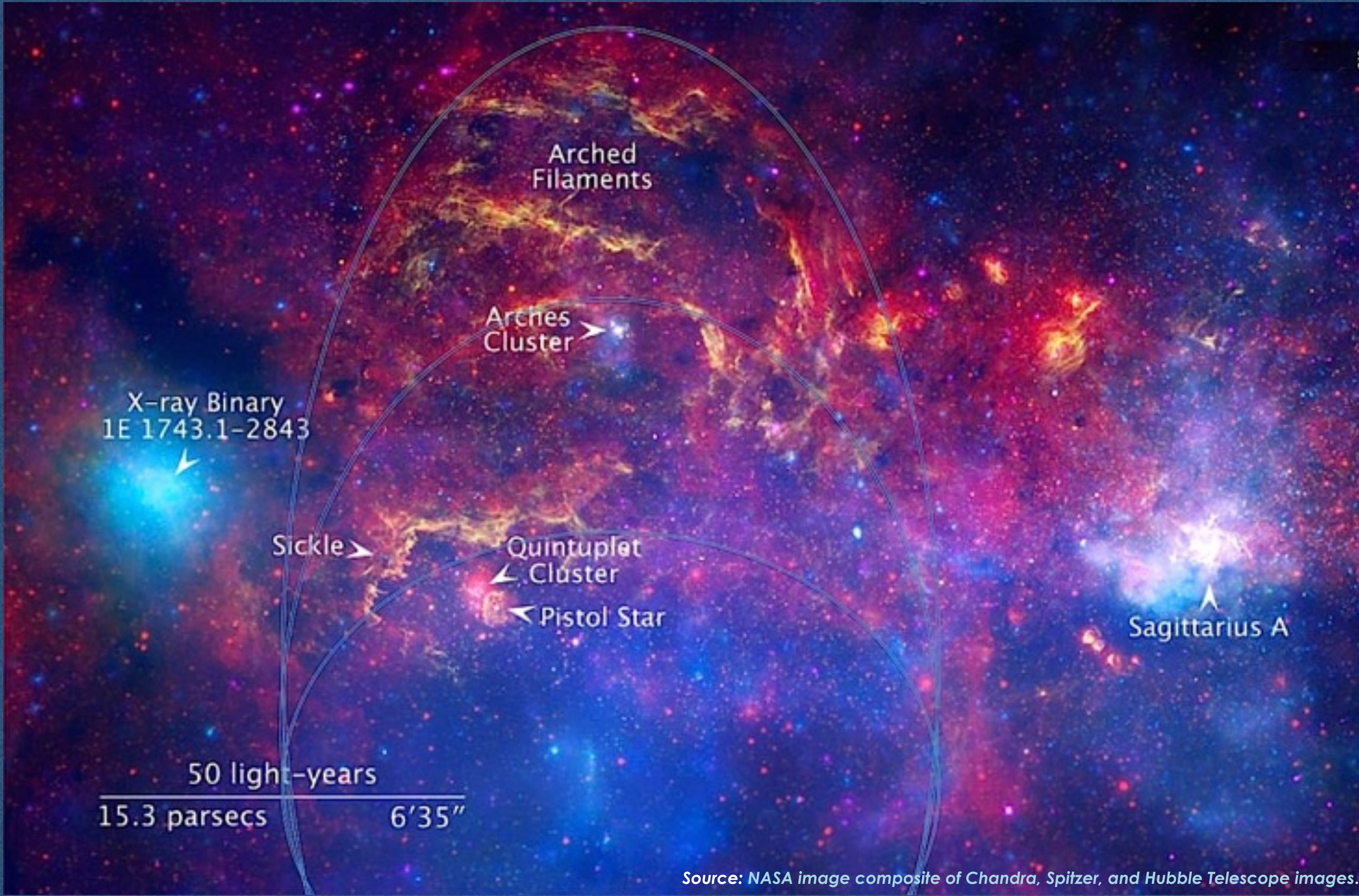
Source: Pudritz & Norman

Astronomers have a major job untangling the spectral signatures of colliding-wind binaries since we are looking through an optical straw passing through a complex set of flow paths, shock fronts, and magnetic field lines. The lines are blue-shifted toward us in their approach direction and redshifted where they recede. Moreover, γ^2 Vel's Wolf-Rayet ejection bubble spectral lines are broad and tend to overwhelm weaker lines from the O supergiant companion. The situation is even worse if the star is a close binary with two very different stellar signatures, as is the case with γ^2 Vel's poor choice of bed partners. They're an odd couple veering between amusing and disastrous. Lucky us that we have back-row seats!



Hydrodynamical simulations of the colliding winds in the binary system WR 22 when the pair are at apastron (furthest apart). Temperature differences in the absorption-wind band of expelled gas move the Kelvin-Helmholtz frontal surface from the inner to outer edge of the ablation surface. X-rays are generated in the black-tinted portions of the absorption wind. *Source:* Gosset, Nazé et al 2009.

Three-D astronomy simulations of star cluster evolution are a veritable cottage industry these says. There's even *a DIY recipe book*. Here is a sampler: *Matthew Bate*, *Mark Krumholz*; *Max Planck Institute*; *SILCC Project*; *Auriga Project*; *Chris Federrath*; *J-P Metsävainio*; *Jim Stone*, *Bouy & Alves*; *Pelupessy*, *CLUES*, *Daniel Pomarède* & *Hélène Courtois*. Plus *these*.



Source: NASA image composite of Chandra, Spitzer, and Hubble Telescope images.

Shock fronts on scales as small as a supernova blast wave and as large as a galaxy cluster are prolific star producers. Near the centre of the Milky Way three successively larger superbubbles from the massive young clusters Quintuplet and Arches, and Central expand outward, compressing gas into smaller clusters as they enlarge but also weaken.

The bright edges can be in the millions of Kelvins and several light years thick at their highest densities. A less known side effect of these kinetic temperatures is the dissolution of bound atoms into ions, which reassemble into new and more complex chemical molecules as they cool. The new molecules become the soup that makes planets like Earth.

Source: Antonio Vargas

The Great Orion Nebula

By invitation to our friends across the pond: Andrew James from his Southern Astronomy Delights

Early History of the Orion Nebula

The telescopic history of the Orion Nebula and the M43 region is quite an interesting story and contains one of the greatest conundrums in astronomy, worthy of a decent detective mystery. First realised by Alexander von Humboldt, none of the observers before Galileo had noted the particularly bright nebulosity, although to the naked-eye today, it is obviously bright and definitely not stellar. Why this was not observed has yet to be properly explained, meaning either that the Orion Nebula was simply not noted or the seemingly highly unlikely possibility that the nebula was not as bright in the time of Galileo. More strange is that nobody else prior to him has written down the visibility of this particularly famous 'Grand Nebula' of the entire sky.

The first written deep-sky observations, like those of **Abd al-Rahman Al Sufi** or Azophi, who in 986 A.D. published his "*Kitab suwar al-kawakib*" or "*Book of Fixed Stars*", were highly detailed, He even noticed for the first time the extragalactic spiral galaxy — Andromeda Nebula (M31). Yet he does not mention or show any nebulosity within Sword of Orion. M42 is obviously not a star, even with the naked eye, though one explanation of this discrepancy nebula may not have been as bright during this time.

By 1603, Johann Bayer in his *Uranometria* made his highly detailed star chart of the region, and this also does not show any nebulosity within the Sword of Orion. Yet, Bayer had noted the two stars in the Sword as an optical double, and named them as Theta (θ^1) Orionis and Theta (θ^2) Orionis.

Orion in a 1280 edition of Rahman al-Sufi's *Book of Fixed Stars*, written c. 986 ACE.

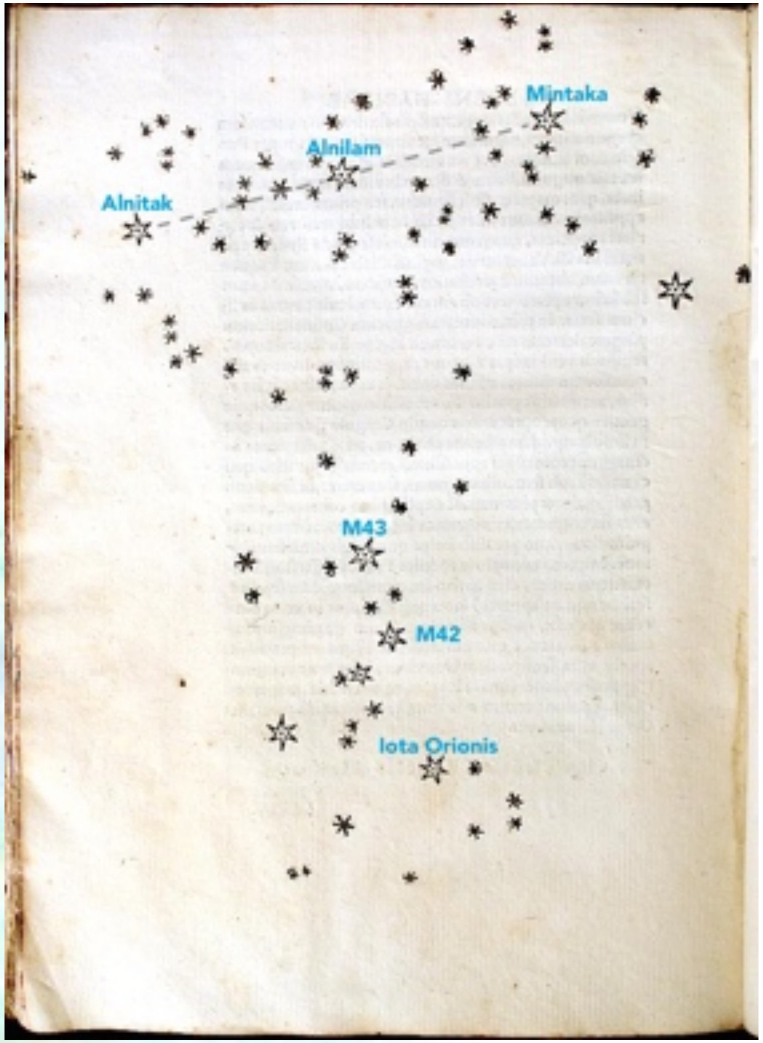
Amazingly, the renown Italian scientist and astronomer **Galileo Galilei** never mentions it, even though it was one of the first areas for his telescopic sweeps. In December 1610, he extensively observed the constellation of Orion, merely noting an increase in the number of stars in the region. (See Fig. 2 prev. page) Added were an additional eighty stars or so within the sword, which Galileo made in the subsequent drawn figure in his *Sidereus Nuncius* or *The Sidereal Messenger*.

Nicholas Peiresc in November 26th, 1611 made the first known telescopic observations, which continued between 6th to 10th December. Written observations of Peiresc states he was 'surprised' to find 'a small illuminated cloud'.

This was followed by **Johann Baptist Cysat** (Cysatus), a Swiss Jesuit priest, made the next known observation in 1618, while comparing the nebulae with a nearby comet visible at the time.

Christian Huygens gave the first detailed description using a Galilean telescope in 1656. Huygens thought he had discovered M42 for the first time, and subsequently published observations in his *Systema Saturnium*, a few months after the original observation. It contained his full description and drawing, and told of the remarkable star Theta (One) Orionis (θ_1 Ori) in the very heart of the nebula. His original sketch, contains seven stars inside the nebula, with five lying just beyond it. The stars of the Trapezium, he curiously only notes as three stars, though for the telescope aperture used, he should have easily seen all four.

> *For the Galaxy is nothing else than a congeries of innumerable stars distributed in clusters. To whatever region of it you direct your spyglass, an immense number of stars immediately offer themselves to view, of which very many appear rather large and very conspicuous but the multitude of small ones is truly unfathomable." Galileo, Sidereus Nuncius*



Galileo's Telescopic Drawing of Orion, with our annotations. The figure shows the whole asterism of *Venus's Mirror* — including Orion's Belt and Sword. This drawing clearly shows the missing Orion Nebula, which should have been easily seen by the naked-eye but was somehow missed or was simply not annotated.

Later History and General Observations of the Orion Nebula

Perhaps the first detailed descriptions of the Orion Nebula was by the Sicilian amateur scientist Giovanno Batista **Hordierna** (1597-1660), whose observations have only recently came to light in 1985. In his small catalogue of forty objects, he list and drew the Orion nebulae as No.5. Hordierna describes in his 1654 "De systemate orbis cometici; deque admirandis coeli characteribus" [Systematics of the World of Comets, and on the Admirable Objects of the Sky.]

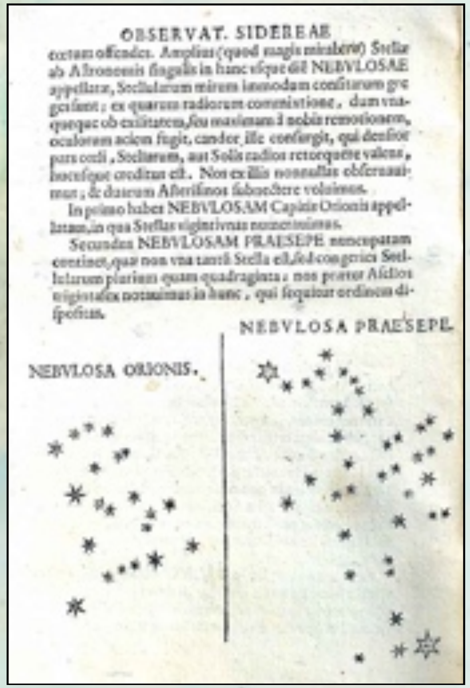
> *"...in the sword of Orion and includes 22 stars as one can see with the telescope. But this Luminosa is more admirable because of some unresolvable luminosity in whose middle can be seen three stars."*

Another description of importance appear by Edmond Halley in Philosophical Transactions "An Account of Several Nebulae or Lucid Spots Like Clouds, lately Discovered Among the Fixt Stars by Help of the Telescope." (Phil.Trans., XXIV, pg.390-391 (1716); here Halley (here partly translated) describes;

> *"The first and most considerable is that in the Middle of Orion's Sword, marked with Theta by Bayer in his Uranometria, as a single Star of third Magnitude; and is so accounted by Ptolemy, Tycho Brahe and Hevelius: but is in reality two very contiguous Stars environed with a very large transparent bright Spot, through which they appear with several others. These are curiously described by Hugenius [Christiaan Huygens] in his Systema Saturnium page. 8, who there calls this brightness Portentum, cui certe simile aliud nusquam apud reliquas Fixas potuit animadvertere [a wonderful object, which is certainly unique among the fixed stars]: affirming that he found it by chance in the Year 1656. The Middle of this is at present at*

The brightest stars within the nebula were noted early and cataloged as one bright star of about fifth magnitude: In about 130 AD, Ptolemy included it in his catalog, as did Tycho Brahe in the late 16th century, and Johann Bayer in 1603 – the latter cataloging it as Theta Orion in his *Uranometria*.

In 1610, Galileo detected a number of faint stars when first looking at this region with his telescope, but didn't note the nebula. Some years later, on February 4, 1617, Galileo took a closer look at the main star, Theta[1], and found it to be triple, at his magnification of 27 or 28x, again not perceiving the nebula.



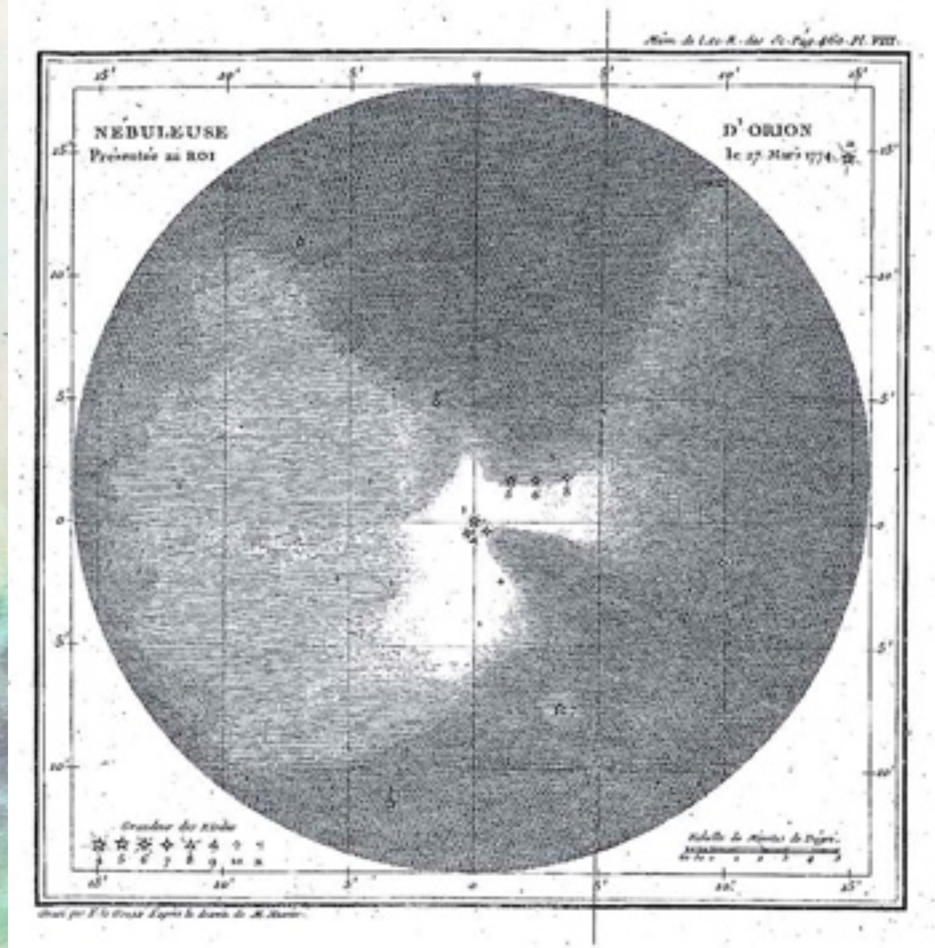
A later star plot in Galileo's *Sidereus Nuncius* shows a "Nebulosa Orionis", but upon closer inspection the star patterns don't match the Orion Nebula's stars. The middle paragraph in the text above makes it clear that Galileo was referring instead to the asterism which we call Lambda Orionis, the head of Orion.

In March 1769, Charles Messier placed Orion's Great Nebula in his famous catalogue of 103 objects; as M42 and M43. He separated the nebula into two parts because he thought they were different objects, and even made a drawing of them. Messier described the Orion Nebula region in the first version of the Messier Catalogue in the French Mem. Acad. for 1771, pg. 450-451 (1772), just two years prior to William Herschel in 1774;

"I have examined a large number of times the nebula in the sword of Orion, which Huygens discovered in the year 1656, & of which he has given a drawing in the work which he has published in 1659, under the title Systema Saturnium. It has been observed since by different Astronomers. M. Derham, in a Memoir printed in the Philosophical Transactions, no. 428, page 70, speaks of that nebula which he has examined with a reflecting telescope of 8 feet [ft]. Here is the translation of what he has reported in this Memoir."

"...only that in Orion, hath some Stars in it, visible only with the Telescope, but by no Means sufficient to cause the Light of the Nebulose there. But by these Stars it was, that I first perceived the Distance of the Nebulosae to be greater than that of the Fix'd Stars, and put me upon enquiring into the rest of them. Every one of which I could very visibly, and plainly discern, to be at immense Distance beyond the Fix'd Stars near them, whether visible to the naked Eye, or Telescopick only; they seemed to be as far beyond the Fix'd Stars, as any of those Stars are from Earth."

"M. le Gentil also examined this nebula with ordinary refractors of 8, of 15 & of 18 feet length; as well as a Gregorian telescope of 6 feet, which belongs to Mr. Pingré. He has published his observations in a Memoir which can be found printed in the Volumes of the Academy, year 1759, page 453. There is a joint of the drawings which he had made of it at that time, as well as those of Huygens & of Picard; these drawings differ from each other, so that one may suspect that this nebula is subject to sort of variations. Here is what I have reported about that nebula in the Journal of my Observations. On March 4, 1769, the sky was perfectly serene, Orion was going to pass the meridian, I have directed to the nebula of this constellation a Gregorian telescope of 30 pouces [83cm.] focal length, which magnified 104 times; one saw it perfectly well, & I drawed the extension of the nebula, which I compared consequently to the drawings which M. le Gentil has given of it, I found some differences.



"This nebula contains eleven stars; there are four near its middle, of different magnitudes & strongly compressed to each other; they are of an extraordinary brilliance: here is the position of the brightest of the four stars, which Flamsteed, in his catalog, designated by the greek letter Theta, of fourth magnitude, 80° 59′ 40″ in right ascension, & 5d 34′ 6″ in southern declination : this position has been deduced from that which Flamsteed has given in his catalog."

In March 1774, **Sir William Herschel** observed M42, and later in the successive years of 1801, 1806 and 1810. His theory, written in *The Nebula Hypothesis*, realising for the first time the true nature of the Orion nebula. He wrote on M42;

"...which would see here an unformed fiery mist, the chaotic material of future suns."

Noting that the observations made by him were different from Huygens, William Herschel stated in December 1810 the belief that the nebula had actually changed. Some thirty-seven years later, he was absolutely convinced that several stars had actually dissipated their nebulosities. By comparing his sketches, he also noted changes in the appearance of the nebula's internal structures. It seems, by our knowledge of the meticulous detail of his observations, it is likely that these changes were real. Later other were to question the same thing about other nebulae like Eta (η) Carinae.

Compared to modern observations, several prominent and obvious stars of the Trapezium are missing. i.e. The 'E' and 'F' stars. **Wilhelm Struve** discovered the fifth 'E' star of the Trapezium in 1826. His magnitude estimations, show it has brightened considerably in the last 180 years. Some have speculated that many of these stars are very very young. The 110 stars discovered in the inner portions of the nebulae each show embryonic material, and proto-planetary disks which are being 'shredded' over a short time. In 1936, observations the variable star FU Orionis was found to have brightened by at least six magnitudes over a short period of several months! Ever since this star shows small fluctuations in brightness but has remained at an elevated average of 10.3 magnitude. Another two fainter variables of V1057 Cyg and V1517 Cyg also have shown similar phenomena.

It is possible that these stars may have switched to a more energetic process, or that the star has suddenly ejected the incipient nebulosity that surrounds them. This may be the case with other stars observed in this region. Observation using infra-red wavelengths and the Hubble Space Telescope (1994-95) have revealed many observational details of the formation and cause of such brightening.

In 1826 **Sir John Herschel** made observations whose descriptions remain as the standard, and even today are still quoted in most of the astronomical texts. His most poignant description was written in 1837, and says;

"I know not how to describe it better than by comparing it to a curdling liquid, or to the breaking up of a mackerel sky where the clouds of which it consists beginning to assume a cirrus appearance."

Reverend Thomas Webb in his "Celestial Objects for Common Telescopes." (1859)

"The Great Nebula, one of the most wonderful objects in the Heavens;..."

Richard A. Proctor also in the late 1870s, described it as follows:

"...the thought that seemed so impressive, so thrilling, as to surpass even the feeling of awe with which is the solemn darkness of night we see some mighty group of suns sweep into the field of view of the telescope... that here on this tiny square inch of shoreline, with its thin film of chemical sands, has been traversing the solemn depths of space... Here we have mirrored by Nature herself that marvellous round of milky light below Orion..." (* as observed from the northern hemisphere.)*

Several years later Proctor again wrote, in his charming; "*Half-Hours With the Telescope : Being a popular guide to the use of the telescope as a means of amusement and instruction*", in which he beautifully describes the finding and observing of the Orion Nebula as;

"For a change we will now try our telescope on a nebula, selecting the great nebula in the Sword. The place of this object is indicated in Plate 2. There can be no difficulty in finding it since it is clearly visible to the naked eye on a moonless night... [being] the only sort of night on which an observer would care to look at nebulae A low power should be employed.

The nebula is shown in Plate 3 as I have seen it with a 3-inch aperture. We see nothing of those complex streams of light which are portrayed in the drawings of Herschel, Bond, and Lassell, but enough to excite our interest and wonder. What is this marvellous light-cloud? One could almost imagine that there was a strange prophetic meaning in the words which have been translated " Canst thou loose the bands of Orion?" Telescope after telescope had been turned on this wonderful object with the hope of resolving its light into stars. But it proved intractable to Herschel's great reflector, to Lassell's 2-feet reflector, to Lord Rosse's 3-feet reflector, and even partially to the great 6-feet reflector. Then we hear of its supposed resolution into stars, Lord Rosse himself writing to Professor Nichol, in 1846; "I may safely say there can be little, if any, doubt as to the resolvability of the nebula; all about the trapezium is a mass of stars, the rest of the nebula also abounding with stars, and exhibiting the characteristics of resolvability strongly marked."

It was decided, therefore, that assuredly the great nebula is a congeries of stars, and not a mass of nebulous matter as had been surmised by Sir W. Herschel. And therefore astronomers were not a little surprised when it was proved by Mr. Huggins' spectrum-analysis that the nebula consists of gaseous matter. How widely extended this gaseous universe may be we cannot say. The general opinion is that the nebulae are removed far beyond the fixed stars.

If this were so, the dimensions of the Orion nebula would be indeed enormous, far larger probably than those of the whole system whereof our sun is a member. I believe this view is founded on insufficient evidence, but this would not be the place to discuss the subject.

I shall merely point out that the nebula occurs in a region rich in stars, and if it is not, like the great nebula in Argo, clustered around a remarkable star, it is found associated in a manner which I cannot look upon as accidental with a set of small-magnitude stars, and notably with the trapezium which surrounds that very remarkable black gap within the nebula. The fact that the nebula shares the proper motion of the trapezium appears inexplicable if the nebula is really far out in space beyond the trapezium. A very small proper motion of the trapezium (alone) would long since have destroyed the remarkable agreement in the position of the dark gap and the trapezium which has been noticed for so many years.

But whether belonging to our system or far beyond it, the great nebula must have enormous dimensions. A vast gaseous system it is, sustained by what arrangements or forces we cannot tell, nor can we know what purposes it subserves. Mr. Huggins' discovery that comets have gaseous nuclei, (so far as the two he has yet examined show) may suggest the speculation that in the Orion nebula we see a vast system of comets travelling in extensive orbits around nuclear stars, and so slowly as to exhibit for long intervals of time an unchanged figure. "But of such speculations" we may say with Sir J. Herschel "there is no end."

To return to our telescopic observations: The trapezium affords a useful test for the light-gathering power of the telescope. Large instruments exhibit nine stars. But our observer may be well satisfied with his instrument and his eye-sight if he can see five with a 3½-inch aperture. A good 3-inch glass shows four distinctly. But with smaller apertures only three are visible. The whole neighbourhood of the great nebula will well repay research. The observer may sweep over it carefully on any dark night with profit. Above the nebula is the star-cluster 362 H. [Herschel]

The star below the nebula is involved in a strong nebulosity. And in searching over this region we meet with delicate double, triple, and multiple stars, which made the survey interesting with almost any power that may be applied.

Mary Proctor, daughter of Richard Proctor, added her own apt description;


Gt Nebula in Orion

'This is an irregular square with a star in each corner, and is situated in the midst of a dark gap in the nebula, within in which the 4 stars gleam brightly... (The Trapezium) The radiant mist surrounding them has a greenish tinge, revealing the vast stellar cloud known as the 'Nebula in Orion' with its Isles of light and silvery streams, and gloomy gulfs of mystic shades.'

E. J. Hartung in his 1968 "*Astronomical Objects for Southern Telescopes*" describes the Orion Nebula as thus;

"One of the most attractive objects in the sky, this great nebula is too well known to need description; ..."

These possible changes in the whole area are certainly curious. It is hard to reconcile how the observers before Pieresc could have missed such an obvious object, unless there was a sudden brightening of M42/M43 at the time of the introduction of telescopic observations. It is possible, if this hypothesis is correct, that the nebula started rapidly to brighten a few years before the observations of Huygens. An explanation of the mechanism could be the simultaneous 'throwing off' of the embryonic nebulosity of the stars in the Orion Nebula. This would cause the stars to brighten suddenly, like FU Orionis. They would then expose the surrounding nebulosity of the whole region to the intense UV radiations of the stars. Over perhaps a few decades or centuries, the material contained in the nebula begins to shine by its own light, becoming the brightest of all emission nebulae.

The Orion Nebula Today

Now at the beginning of the twenty-first century, the Orion Nebula or NGC 1975-1980 is visually one of the brightest of the nebulae seen in the sky. This magnificent object is a bright emission nebula that is still spectacular even in light-polluted skies. The most modest telescopes can make out the general shape, and its greenish colour. Using even the largest of telescopes, we can observe something new that we have not noticed before. Commonly we call it the Great Nebula in Orion M42 is found lying in the middle of the sword of Orion, or the handle of the saucepan, as seen from the southern hemisphere. In even moderate telescopes it is a truly grand object and words cannot adequately describe this nebula as it truly appears.

My own impression of the Orion Nebula is firmly fixed in my head. As the one of the first objects that I observed with a small 60mm refractor, I can still recall being fascinated by the faint, but highly delicate nebulosity. A sharp boundary to darker portions contrasts the 'bowl' of the nebula. The most obvious feature is the boundary of light call the Bright Bar. Naturally, when observing it with a much larger telescope, the subtle differences in the surface brightness become obvious, with a mottled surface inter-dispersed with faint filaments.

One of the first astronomical photographs taken of this object was allegedly made by American spectroscopist, Henry Draper, at the Harvard College Observatory in 1880. Even today it is a favourite object among those interested in astrophotography or imaging and is truly the most photographed object in the sky! A small telescope, with the short time in guiding, produces truly magnificent results. For the amateur astrophotographer it is likely the first object attempted. It remains a popular photograph in astronomical periodicals, advertising materials and in books.

Illumination of the Orion Nebulosity

Many parts of M42 we see in the bright nebulosity are illuminated by stars associated whose structure making the individual parts of the nebulosity appear so luminescent. In reality, this nebula brightness is because of the molecules and atoms contained within the nebula itself. Excitation of this ionised material is by the energies from the many nearby hot stars that are radiating strong UV radiation — causing the familiar fluorescent glow.

A large proportion of M42 is possibly illuminated by the star known as *Becklin-Neugebauer Object* (BNO) or sometimes just *Becklin's Object,* which remains visually unseen due to significant absorption of light by the bulk of the nebulosity. Discovered by Eric Becklin and Gerry Neugebauer in 1967, this hidden object appears as the brightest star in the sky at near infrared (NIR) wavelengths (or thermal infrared) at about 2µ to 10µ (microns). Such wavelengths are equivalent to temperatures emitted by the human body. The nature of this star is thought to be a high mass protostar that is in the process of emerging from its embryonic nebulosity from which it recently formed. In more recent times (1993), there was found also another very close object known as **IRc2** which seems likely to be a trapezium-like multiple star. Both these stars are some 0.5 pc (1.6 ly.) behind the bright bowl of the Orion Nebula. Origin of the BHO protostar is uncertain and there are several options being considered by astronomers.

Visual Appearance of the Orion Nebula as seen in 20cm telescope. The pale green colour is approximately the colour seen in the telescope. Older observers might not seen this colouration at all due to the colour loss under darkened conditions, which is mainly due to the ageing process.

This image clearly shows the curve along the edge of the bowl, with the Trapezium near the centre of the frame — pointed to by the small protuberance of dark nebulosity from the curve of the bowl. Deep colour images reveal this region around the Trapezium has carved out by the hot energetic radiation from the new blue stars, producing the distinct hollow bowl.

Size of the Orion Nebula

In true size of the nebula covers about 1¼ square degrees of the sky, roughly equivalent to be between seven and eight times the apparent area of the Moon. M42 is 66′×60′ in size, while to the north is M43 that measures some 20′× 14′. Combined magnitude of the nebula for M42 is equal to any 2nd magnitude star, while the star known as θ_1 Orionis has the combined visual magnitude of 2.9v. This star is also known as the multiple star **HJ 4581** / h.4581, which was first catalogued by John Herschel.

Astronomers have estimated that the nebula's total masses, is somewhere between 3,000 $M_\odot$ and 5,000 $M_\odot$.

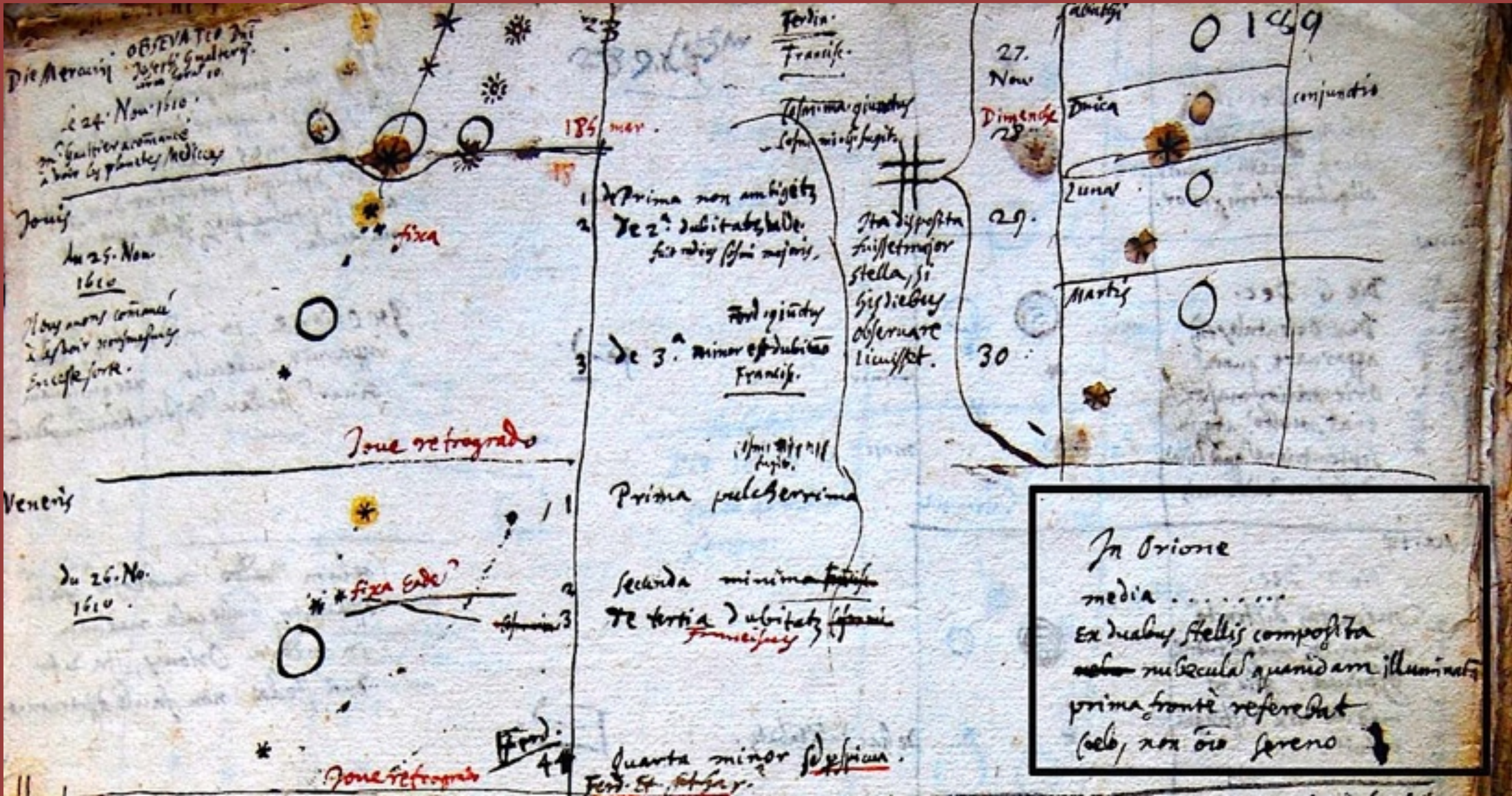
The distance to the nebula has been presently estimated to be between 430 ±60 pc (370 pc to 490 pc) or roughly 1,400 ±200 ly. Most of the literature now often tends towards 1340 ly. In true size, the bright 'fan-shaped' section of M42 is estimated to be about 8 to 15 ly across, while the maximum size revealed by the photographic process, measures at about 30 to 35 ly. We have measured the nebula to approach the Earth at 25 km s^{-1} (8 km s^{-1} less than stated by Hartung). The Trapezium is travelling at a slower velocity of –11 km s^{-1}.

Using the distance to the Orion Nebula as 410 parsecs or 1340 ±76 light years, means that the trigonometric parallax is 2.571 mas (milliarcsec). If the principal stars in the Trapezium are at this distance, based on the relative position of STF 748A at 6.55$_V$ magnitude, then the nature of the system is listed in Tables 1 & 2 (Below.)

No one knows for sure about the future of the nebula of M42, but it seems the stellar creation process is still going on. Some have suggested that the nebulosity will become even more brilliant perhaps sometime within the next million years or so.

The first photographic image to successfully reveal the structural features of the Orion Nebula was this glass-plate image taken 26th February 1883 by Andrew Ainsle Common (1841-1903), an acclaimed early pioneer of astrophotography. This image was made using Common's 36-inch reflecting telescope at his home in Ealing, West London in England. This is the first high-resolution photograph of the nebula and clearly shows details invisible to the unaided eye.

The man who discovered the Orion Nebula



Leaf from the notebook of Nicolas-Claude Fabri de Piersec describing observations he made on or around November 10, 1610. Only the left portion of the page shows his sketch of the Orion Nebula. The right portion diagrams the passage of a planet near a star, though he text identifies neither by name. The boxes labeled “Luna” and “Martis” mean “Monday” and “Tuesday”. The telescope he used for these observations has a magnification of 27 or 28 an an apparent field of only about 15 arcmin or half the diameter of the full moon.

In his own time, Nicolas-Claude Fabri de Peiresc was known as a *savant* — French for "a knowing person", especially a distinguished scientist. Today he would be known as a polymth. He is known to us as the discoverer of the Orion Nebula. a diffuse nebula situated south of Orion's Belt in the constellation of Orion, in 1610. It is one of the brightest nebulae, and is visible to the naked eye in the night sky.

De Peiresc's interests as a scholar were widely dispersed. He collected ancient gems and coins, he promoted young artists by giving them commissions. Among other things, he ordered from them copies and casts of antiquities, for which he demanded careful accuracy, so that later one or the other copy could be traded as an original. Of equal importance was his interest in the natural sciences. In 1916 Guillaume Bigourdan attributed him the discovery of the Orion Nebula in November 1610. He was also interested in deciphering the hieroglyphs.

Peiresc came to travel around Europe with his patron Guillaume du Vair, a French author and lawyer. In 1610, du Vair bought a refracting telescope which Peiresc was able to use to observe the skies, especially the Jupiter moons. Probably in the same year, Peiresc discovered the Orion Nebula. He served in many capacities — advocate, counsellor, judge, professor, benefactor to many promising young scholars. He had also been awarded an income-yielding benefice, the Benedictine abbey of Guîtres, near Bordeaux. That income would help to finance his non-stop collecting of books, manuscripts, and antiquities of all kinds, as well as his very active correspondence.

Nicolas-Claude Fabri de Peiresc, Black chalk drawing by Claude Mellan c. 1636–37. 20 by 14.8cm. Source: The State Hermitage Museum, St Petersburg.

Peiredc published almost nothing of his own work. Everything we know was gleaned fom his handwritten notes — sometime a tedious job, as the drawing on the previous page attests. His huge archive of carefully filed notes contained the materials for many potential works of scholarship. In every field of learning to which he gave his attention — i.e. almost every field studied in that period. He corresponded with leading practitioners, applying to every topic his sharp critical intelligence, prodigious memory, and remarkable open-mindedness.

Pieresc was a man of his time, and what a time it was. On a tour of Italy in 1599–1601 he met a wide range of scholars, including Galileo. This was well before Galileo had begun looking at the sky with his new "far-seer". Pieresc's discovery of Otion was his own doing. After observing the nebula for the first time, de Peiresc referred to it as a "cloudy nebulosity". He was not the only one to notice the nebula in the night sky. It is assumed that the first published work regarding the nebula appeared in 1619 and was written by Johann Baptist Cysat of Lucerne in his 1619 monograph on the comets (describing observations of the nebula that may date back to 1611). Also, the nebula was independently discovered by Christiaan Huygens in 1656, who published his findings in 1659. Charles Messier later categorised the Orion Nebula as M42 in his catalog of deep sky objects.

The Horsehead flings its mane

Doug Bullis

What we see.


What we don't.
© Martin Heigan

Wait, wait . . . there's more

It's hard to beat astronomy when it comes to contrarian canons. It seems that no sooner is a set of facts thoroughly established, than a newer set of facts throws them out the window. Theorems clash with measurements and go off in a sulk — William Herschel was convinced to the end that stars evolved toward nebulae and not the other way around. Once-certain evidence is downgraded from parameter to fond memory. Optical images that suggest stars and galaxies are *prima facie* evidence that mass shines are shown in other wavebands to be the progeny of energy that doesn't shine (negative specific heat and angular momentum, for example).

In the 1860s physicists were forced to devise an invisible element they called Nebulium to explain the many glowing clouds in the sky that couldn't possibly glow by themselves. The physicists could not otherwise explain certain lines in the spectra of nebulae that couldn't be traced to a traditional source. This was, coincidentally, about the same time that James Clerk Maxwell wrote, "All fallow land is to be ploughed up and a regular system of rotation followed." His off-topic agrarian truism was as important to the future course of science as his formulation of his laws of electromagnetism across the following decade.

One needn't look to the far-off nebulae to see the impossible to be shown as not just feasible but necessary. Any glow-in-the-dark wristwatch will do. The dial's phosphorescent glow fades across several minutes to several hours. In the 1860s the state of the science was convinced that light should stop emitting immediately when the exciting source goes off. Physicists had to invent Nebulium because nothing else could explain the long-lasting glows of nebulae far brighter than the stars within them — M27 the Dumbbell for example.

Barely a decade later James Clerk Maxwell had mathematically shown the opposite. A phosphor is an energised electron that can occupy an energy state whose duration is determined by the pace of energy transfer — today we explain it as old-fashioned angular momentum in a quantised form called atomic spin.

The bones of canon litter the landscape of fact. Survey the myriad examples of good laws gone awry a bit more closely and they trace to a root cause: Energy recorded in the blue-to-red optical band of our eyes is roughly 1% of the full electromagnetic spectrum. We eyepiece-huggers and our grand and glorious gear (mine being among them) can call an object in the sky many things, but a fact in the sky isn't one of them. We simply cannot see the full set of facts with the eyes and telescopes we have.

Contrarians we can see

To our eyes, the Horsehead Nebula is a huge daub of shadow upon shadow. In infrared it turns into a patchy glow. Absorption in the visual band V is caused by the same thing that causes emission in IR — gas/dust density. To get a rough idea of how gas and dust interrelate, one dust particle per 1000 gas particles is a good rule of thumb — though thumb sizes vary hugely in this garden. Since astronomer can't go out there and collect a litre of the stuff, they gauge gas density via adding up the density of all the gas that lies between us and the cloud, then deducting the known amounts of local dust extinction in our locality. Nearly all of the gas/dust in a cylinder with a diameter of the telescope dish stretching to the cloud lies in the cloud itself. If we were to look through an eyepiece, the cloud would look like a flat sheet of a particular light density stretching across the field of view. Fifty shades of gray has a more prosaic connotation here.

The measurement of that density is called gas surface density. It is a term that shows up constantly in molecular cloud studies. Gas surface density measurements are commonly made using the 160, 250, 350, and 500 μm bands in the infrared. Since a micron is 1/1000th of a millimetre, this is what the term "submillimetre" in spectral bands refers to. The reports in the literature look a bit arcane, e.g. "Data cubes of ^{13}CO 1→0 (110.2 GHz) and ^{12}CO 3→2 (345.8 GHz) were taken from the Galactic Ring Survey archive (GRS)". We will elaborate a bit on the technical jargon of molecular cloud studies in the discussion below, but if you can't live another moment without knowing what all this means, *this lecture* is a fairly digestible technical analysis of the exact same region we are examining in this report.

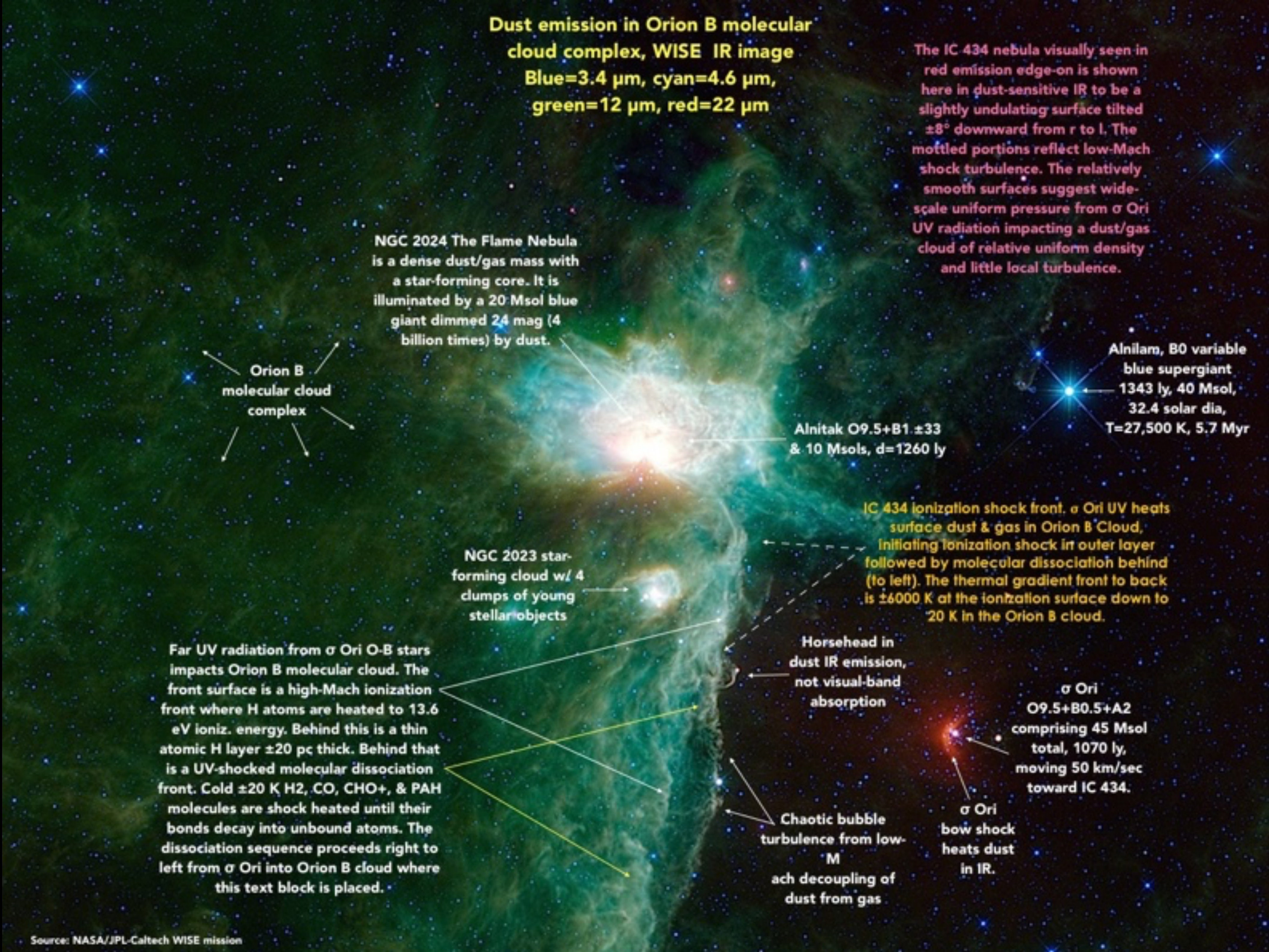

Dust emission in Orion B molecular cloud complex, WISE IR image
Blue=3.4 μm, cyan=4.6 μm, green=12 μm, red=22 μm
The IC 434 nebula visually seen in red emission edge-on is shown here in dust-sensitive IR to be a slightly undulating surface tilted ±8° downward from r to l. The mottled portions reflect low-Mach shock turbulence. The relatively smooth surfaces suggest wide-scale uniform pressure from σ Ori UV radiation impacting a dust/gas cloud of relative uniform density and little local turbulence.
NGC 2024 The Flame Nebula is a dense dust/gas mass with a star-forming core. It is illuminated by a 20 Msol blue giant dimmed 24 mag (4 billion times) by dust.
Orion B molecular cloud complex
Alnilam, B0 variable blue supergiant 1343 ly, 40 Msol, 32.4 solar dia, T=27,500 K, 5.7 Myr
Alnitak O9.5+B1 ±33 & 10 Msols, d=1260 ly
IC 434 ionization shock front. σ Ori UV heats surface dust & gas in Orion B Cloud, initiating ionization shock in outer layer followed by molecular dissociation behind (to left). The thermal gradient front to back is ±6000 K at the ionization surface down to 20 K in the Orion B cloud.
NGC 2023 star-forming cloud w/ 4 clumps of young stellar objects
Far UV radiation from σ Ori O-B stars impacts Orion B molecular cloud. The front surface is a high-Mach ionization front where H atoms are heated to 13.6 eV ioniz. energy. Behind this is a thin atomic H layer ±20 pc thick. Behind that is a UV-shocked molecular dissociation front. Cold ±20 K H2, CO, CHO+, & PAH molecules are shock heated until their bonds decay into unbound atoms. The dissociation sequence proceeds right to left from σ Ori into Orion B cloud where this text block is placed.
Horsehead in dust IR emission, not visual-band absorption
σ Ori O9.5+B0.5+A2 comprising 45 Msol total, 1070 ly, moving 50 km/sec toward IC 434.
Chaotic bubble turbulence from low-M ach decoupling of dust from gas
σ Ori bow shock heats dust in IR.
Source: NASA/JPL-Caltech WISE mission

Fig. 1 (on previous page): Gas temperature map of the Horsehead, NGC 2023, NGC 2024, and IC434-435 region of L1630 molecular cloud complex. The σ Orinis star that excites the IC 434 H II region is located 0.5° east of the Horsehead nebula.The colours are ^{12}CO (blue), ^{13}CO (green), and $C^{18}O$ (red). From Fig.1 Pety et al 2017: *The anatomy of the Orion B giant molecular cloud: A local template for studies of nearby galaxies*. Astronomy & Astrophysics Vol. 599, March 2017.

Lynds 1630: The Orion B molecular cloud complex

Lynds 1630 is the southern part of the Orion B giant molecular cloud complex. The 1962 *Lynds Catalog* was compiled by *Beverly Lynds*, drawing on Palomar 48-inch Schmidt plates. Most of the 1802 entries are data tables, but pages 184A through F of the *1965 edition of her catalog* charts of both bright and dark nebulae on a sky projection.

L1630 is a dark gas/dust cloud that is discernible by stellar underdensities in visual band images which emit strongly in IR and sub-mm bands. As shown in Fig. 1 above, the eastern wall of L1630 becomes IC 434, a large HII region being simultaneously compressed and ablated by ionising UV radiation from σ Ori. IC 434 appears edge-on in the visual but sub-mm images reveal it to be an uneven compression/ablation surface tilted downward and to the west (left) at about 8°. Hα and near-IR images reveal a vivid array of threadlike streamers emitted from the IC 434 surface and speeding away from the surface in the opposite direction from the impacting radiation. (Hence the "Horsehead's mane".) The streamers are an effect of σ Ori photoionisation along the outer surface of the Orion B gas/dust wall. A UV ionisation front is a complex 3-layer dissociation field commonly found when O and B stars strongly ionise a molecular cloud surface. IC 434 is in effect being shoved *en masse* into the Ori B cloud by UV and is shoving back

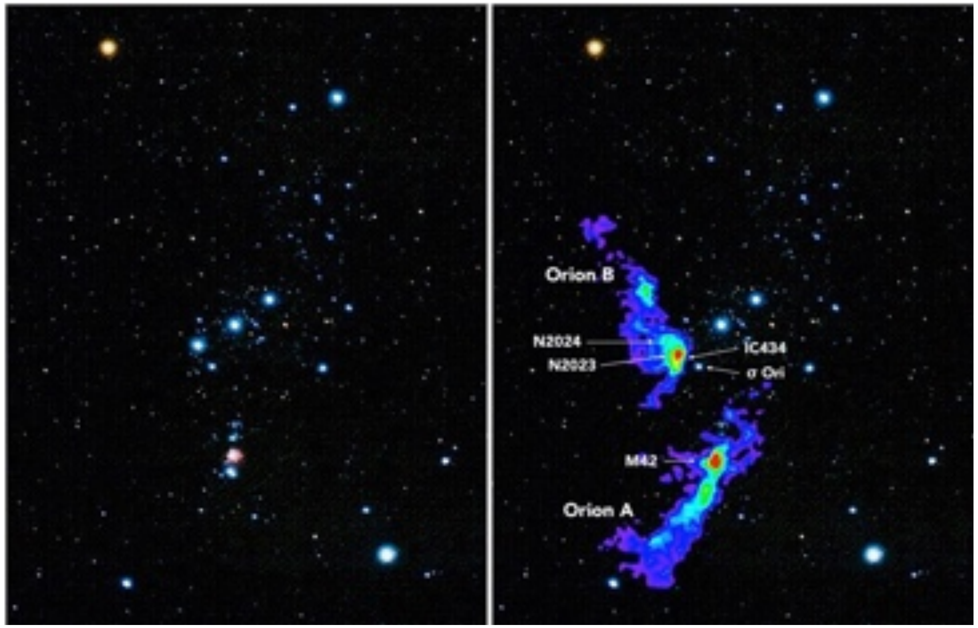


Fig. 2: The world we are about to explore.

Gas/dust pockets of varying density give it a bubbling-asphalt look at the ablation surface. A complex webwork or corrugations lie between IC 434 and the Earth, seen in silhouette against the bright nebulosity. ("Bright" is an astringent irony in the eyepieces of visual observers.) In consequence B33 looks like it juts directly towards the quintuplet σ Ori system. Reality is in fact just the opposite: σ Ori is eroding the Horsehead from the top down. Fig. 8 below shows the dust-density structures inside the Horsehead. Although intermingled, B33's dust clouds are distinct from its gas structures. The latter are slim "Pillars of Creation" type columnar star-forming filaments presently making low-mass protostars.

The IC 434 compression front is advancing into the dense (n = 10–100 particles cm^{-3}) Orion B cloud at ~7 km s^{-1}, triggering the formation of low-mass stars in the densest pockets. The compression front is tri-layered and parsed in Figs. 12 and 14 below. The shock front pushing IC 434 into the Ori B cloud has already triggered a minor wave of star formation in pockets near the frontal surface.

The gas surface density threshold for star formation in L1630 is about 129 $M_{\odot}$ pc^{-2}.

For an extended discussion see Spezzi et al 2015: *The VISTA Orion mini-survey: Star formation in the Lynds 1630 North cloud*.

The Orion B gas density field

There are a number of noteworthy clusters in lower Orion B. The richest, with over 300 stars still embedded in their natal gas, lies behind the halloweenish dark streak that gouges across the NGC 2024 Flame Nebula. This cluster is one of those anti-canonical objects mentioned at the beginning. We take it for granted that the brightest and heaviest stars in a cluster are the first to form and that they stay put in the centre while the lower-mass, fainter stars dwindle in mass and brightness the further out we go. The NGC 2024 cluster is decidedly contrarian: its oldest and brightest stars are spread across the cluster and are about 1.5 million years old. The low-mass infant stars speckle the central region. These are stars only about 200,000 years old.

On the other end of the cluster scale, the poorest Orion B cluster comprises 21 embedded X-ray emitting sources inside NGC 2023. In our eyepieces, NGC 2023 is a bright reflection nebula about 400 pc (1304 ly) from Earth that is so unassertive that we regard it more as a signpost pointing to the Horsehead than a target in its own right. Its modest display belies a complex heart. The whitish glow we see is actually reflected light from nearby luminous stars. Inside, NGC 2023 is a heavily dust-obscured seething nursery of four star-forming cores. The brightest is illuminated by the B1.5 M_V 7.8 star *HD 37903*. There is a blister pocket in NGC 2023 (pictured in the discussion below) that somewhat resembles the θ Orionis (Trapezium) blister we see as the billowy beauty called the Orion Nebula. Several mm-band spectral signatures in NGC 2023 cannot be identified with optical or near-IR counterparts. This suggests the presence of a more deeply embedded population of protostars hidden within the densest molecular cloud cores surrounding NGC 2023.

In case you are seized with an urgent desire to become a gas/dust specialist, here are a few brush-up papers: 1, 2, 3. If you remain so inspired and your study habits match your ardour, take our word for it, you will be welcomed with open arms and a steaming cup of coffee at any radio observatory.

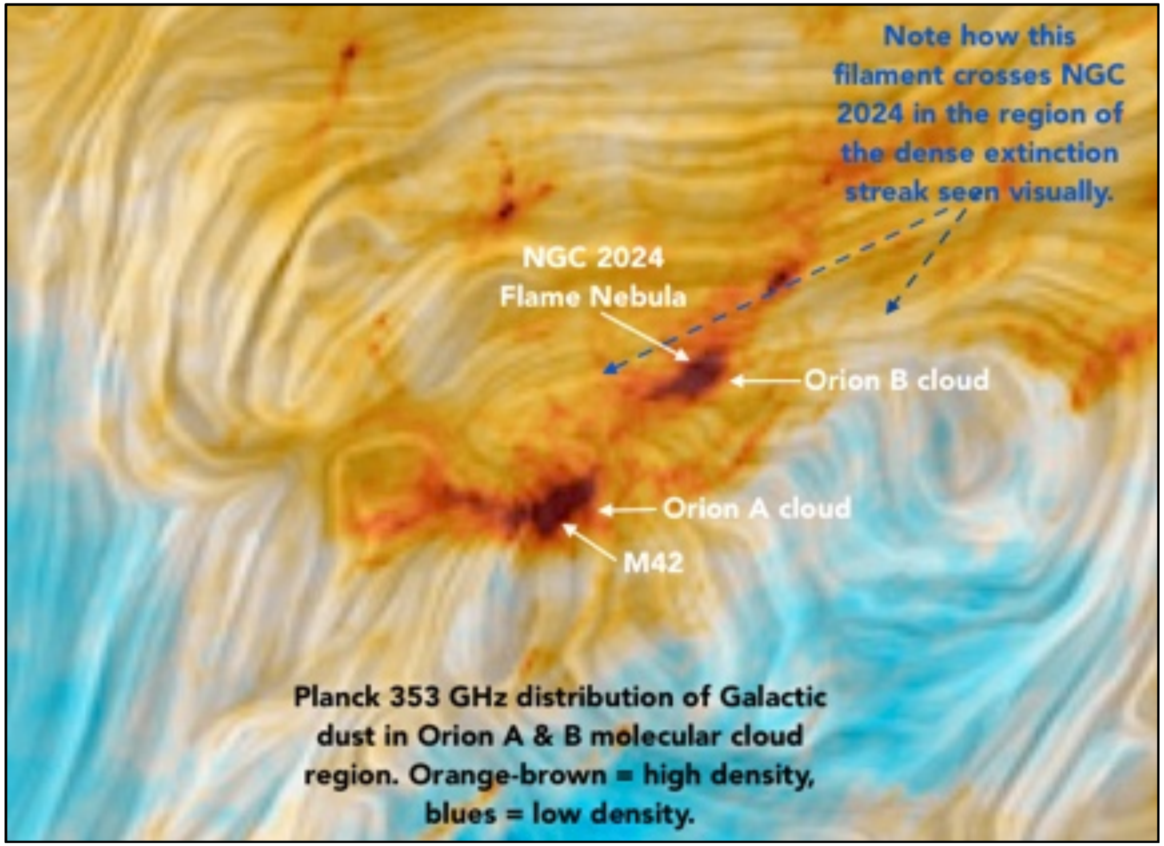


Fig. 3: The Galactic magnetic ß-field is markedly warped and twisted throughout the Orion-Monoceros molecular complex. Since electron transport along magnetic fields carries dust with it, measuring the dust emission is a tracer of electron density. Electron density in turn indicates the strength and direction of the ß field. When the Planck mission data-delivery component was first being designed, the parameters included a sensor for the 353 GHz emission band, which arises from the interaction of polarised dust particles with the local magnetic field. The dust tends to align its axis with the field's poloidal axis (the N - S line). Hence dust alignment is a probe of magnetic field alignment. The density of the dust in turn traces the local temperature. The above cutout from the Planck whole-sky map is actually a dust density/ temperature map which also tells us what we want to know about the Galactic magnetic field in this region. Source: *ESA Planck 353 Ghz* polarised emission from Galactic dust.

Star Clusters 101

We need to step back a bit to understand why star formation in photo-compressed features like IC 434 differs from the other three main types of star cluster formation, *free-fall collapse*, *triggered*, and *cloud-collision*. Entire volumes have been written about each of these because their different physical processes produce different types of star clusters.* A 1000 light year diameter pancake-shaped volume inside a spiral arm (e.g., the Orion A and B molecular complexes) will show past and present evidence of all three. Learn how these processes produce different types of star clusters, and with some practice you will be able to simply look at a cluster and you can make a fair guess how it was formed and how old it is simply by knowing the origins of the star distribution and magnitude patterns that put it there.

Free-all collapse The traditional image of star cluster formation in a coffee-table book is *free-fall collapse*. Here, a large molecular cloud entering a spiral disc from above or below fragments first into large lumpy filaments, and then denser clumps and finally very dense cores. What the coffee-table images don't show you is that a galaxy disc is a hostile, violent place filled with divisive supersonic shocks and meandering magnetic fields. Turbulent shocks advance at many times local sound speed (rule of thumb: $\mathcal{M}1 = 200$ m s^{-1} in a 10 K gas parcel of 10–100 atoms cm^{-3}). Turbulence fragments a gas cloud, magnetic fields tend to redirect its ions. A given clump of gas/dust of $n = 10^4$ atoms cm^{-3} cannot free-fall into star-making densities of 10,000 to 1 million atoms cm^{-3} until the ambient velocity field around the cloud goes subsonic. Turbulence and magnetic fields must wear each other down until free-fall densities and subsonic surroundings match, a point at which you can start believing the coffee-table depictions again.

Triggered star formation typically occurs along the rims of expanding bubbles of gas ejected from the cores of very hot, O-star dominated young clusters. The ejected gas occurs in two stages: first, gas clearance or stellar

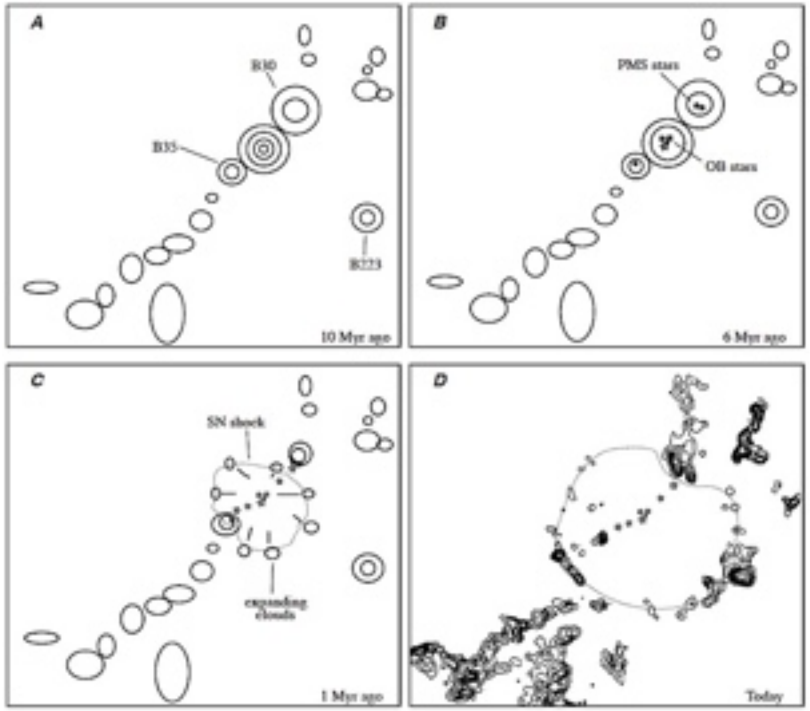


Fig. 4: In triggered star formation, compact high-mass gas clouds collapse into clusters of high-mass O and B stars which radiate enormous amounts of UV radiation. This initiates a rapid gas-clearing shock wave. Several million years later, supernovae compress the ring into arcs of clusters.

feedback by radiation pressure (as we see happening in the Rosette Nebula right now) is followed by supernova shock waves as the cluster's most massive stars detonate. The shock waves *sweep into the previously expelled gas*, driving it into the surrounding gas of the galaxy. Smaller local clusters then *collect and collapse* out of the expanding shells (see drawing above).

Cloud collision occurs when two massive molecular clouds smash into each other at high speed (>10 km s^{-1}). Star clusters form along the compression zone. M20 the Trifid is a low-mass example. The supermassive young clusters Westerlund 1 & 2 and NGC 3603 were high-mass collisions.

* Their popularity is enhanced no end by the fact that thousands of Ph.D theses remain to be mined from so complex and mathematically intricate a phenomenon.

Out of the murk: How astronomers turn dark into bright

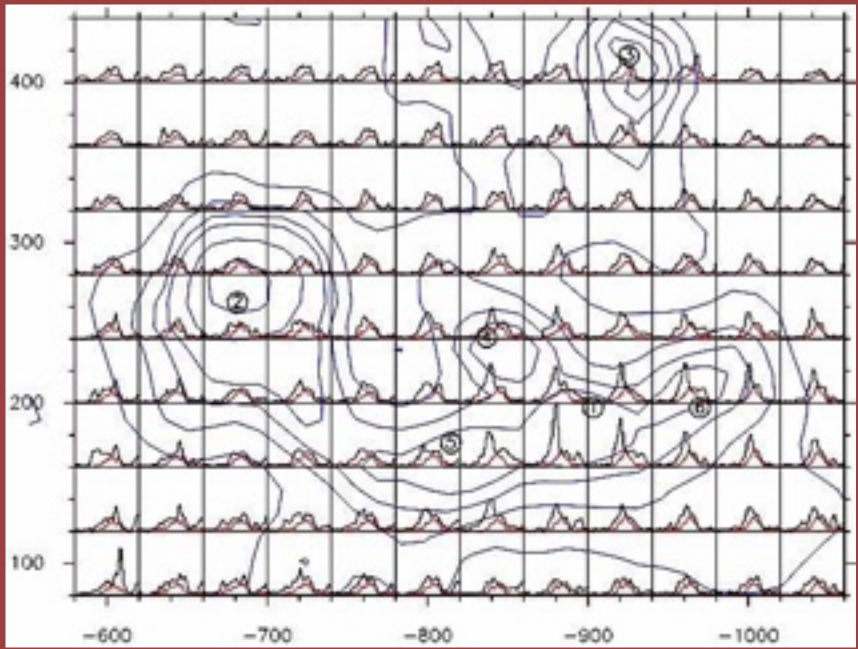


Fig. 5: After all the radio receiver numbers are crunched, a typical gas surface density plot looks like this. The data compressed into each square is called a data cube. When all the data cubes are plotted into a flat sheet, a computational algorithm translates the individual wave band densities (squiggles above) into contour lines, which then reveal the actual shape and density of the clouds. The one decisive component missing in this type of measure is the local temperature inside each data cube. Temperature is vital because the atomic reactions that make molecular hydrogen out of atomic hydrogen take place mainly on the surfaces of brutally cold (<10 K) dust particles.

The most important takeaway from these two images is how thready and clumpy the realm of dark molecular clouds is when seen in perspective. The Orion B cloud shares these same properties, which is why we take such delight in the contents of such a small region. From afar it looks like Fig. 2. Close in it is filled with such visually dissimilar objects as the Horsehead, IC 434, the Flame Nebula IC 2024, the star-making cloud IC 2023, and Sigma Orionis.

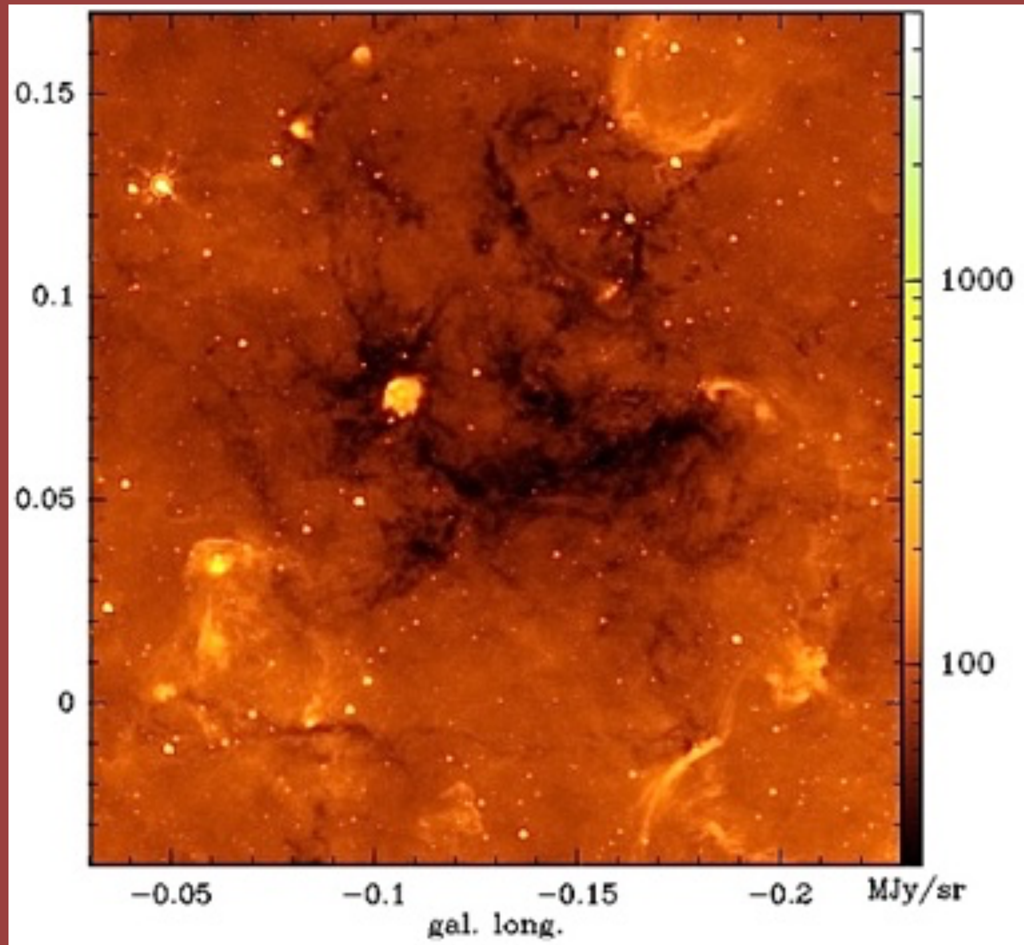


Fig. 6: Even dark clouds behind bright clouds can be measured using infrared. Infrared dark clouds (IRDCs) are a hot topic in galactic astronomy these days because they are future star-forming regions that we would otherwise have no other way of knowing. Here is one of the most massive IRDCs nearby, named G28.37+ 0.07 because of its position very close to the Milky way equator and in the densest part of the Galactic disc. If we were at the same distance to G28.37+0.07 as we are to the Horsehead, it would be much larger and very much darker.

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The Horsehead Nebula

For all its vaunted status as a prize catch among amateur astronomers, the Horsehead is an even better catch to devotees of star formation. It is a half-million year old gas/dust cloud with a virial mass of ~56 $M_\odot$, divided about equally between the two clumps shown in Fig. 6 on the next page and the less-dense gas in the "head" and "neck". The upper gas/dust core is called SMM1 and has a mass of ~22 $M_\odot$; the lower core SMM2 is 34 $M_\odot$. The two cores are gravitationally self-bound. This is important for our understanding of the way star formation occurs in "pillars of creation" types of structures in which a dense column is being eroded by UV radiation on one end while at the same time the column is forming stars in dense cores in the middle.

The gas column density of the SMM1 core is densest on its east (top) side while its temperature is the warmest on its west or bottom side. These facts suggest that both the column density and velocity width of the core are greatest at the core centre. This in turn suggests that infalling motion into the centre is about 3.0 km s^{-1}, which is well above the free-fall value.

It seems counterintuitive given the HH's appearance that it is not a static structure. It is losing mass thanks to σ Ori's UV. Surprisingly, the Horsehead also has a rotational moment. Its emission in radio bands are Doppler shifted as different parts of the nebula move toward or away from us. The horse's nose is turning toward us and part of the mane is turning away. The Horsehead's rotation has deformed an otherwise unremarkable gas/dust pillar into a distinctive trope that attracts us like no other shape in the sky. Shorn of the visual poetry, the cloud's rotation introduced a centrifugal component into a gas mass that torques it normal to the axis of rotation. The horse's nose and mane turn anticlockwise from the neck, thereby giving the nebula its distinctive liveliness. Without rotation, we mightn't be seeing a horse.

Fig. 7: The Horsehead and IC 2023 from the VISTA (Visible and Infrared Survey Telescope for Astronomy) J, H and Ks filter set in the near-IR, processed by *Robert Gendler*. The distance from the tip of the nose to the back of the neck is ~4 ly, about the same as between the Sun and Alpha Centauri. Note the prominent blister formation in NGC 2023 caused by photon pressure from its central O star SAO 132464.

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* The term "virial" is important to an understanding of gas dynamics and star cluster evolution. The underlying principle is easy: An object's potential energy is twice its kinetic energy, under the sensible idea that if it takes a certain amount of energy to move an object from point A to point B it takes the same amount of energy to move it back. P = 2K. Works great, till the mathematicians get hold of it.

Star forming cores in the Horsehead

The renowned "Pillars of Creation" in M16 were long ago discovered to be forming stars inside those dense clumps. Over the years many other photo-ablated columnar dark clouds have been to found as actively forming stars inside even as they are being withered away from the outside.

The Horsehead is no exception, Core A in the Horsehead Nebula (the top of its head, SMM1) has a mass of ±22 $M_\odot$. The column density of this core is densest on its east side (brow), while the temperature is highest on its west side (the crown of the head) at 22 K . These observations suggest that ionisation of the Horsehead's molecular gas by IC 434 behind it proceeds from the west side of the core. That in turn suggests that the Horsehead is not the vertical column we perceive it to be, but that its head is slanted away from us.

Core B (the "neck" overdensity, SMM2) lies not in the columnar centre but in the boundary region between the Horsehead and NGC 2023, i.e., nearer to us. That, too, would be more likely if the column was slanted with the bottom end nearer to us than the top.

In both clumps the column density and velocity width of the core increase toward the core centres. This is a signature of infall, which means the ionising disturbances affecting the Horsehead's exterior do not much change events going on inside. The velocity of the infalling is estimated to be ~3.0 km s^{-1}, consistent with the free-fall velocity of a gas mass of 25 to 30 $M_\odot$. In addition to the gravitationally bound state of both cores (suggesting ongoing star formation) the temperature of the cores also increases toward their centres.

All these are signatures of gas infall leading to star formation, which in turn suggests that the ionising disturbances affecting the Horsehead's exterior do not much change events going on inside. Despite the fragile look in Fig. 5, there's a lot of life left in those flaring nostrils.

The Horsehead is a very complex place chemically, especially in its organic molecules. ("Organic" in astronomy only means that the molecule contains carbon.) Just a few of these are H_2CO, CH_3OH, CH_3CN, CH_2CO, CH_3CHO. The production of molecular species like these occurs via grain surface reactions in a UV-dominated *photo-dissociation region*.

What makes a molecular cloud "molecular"?

Molecular clouds (MCs) are dense pockets of self-bound gas whose masses range between 10^4 $M_\odot$ to 6 x 10^6 $M_\odot$ and whose sizes range from 10 to 100 pc (32.6 to 326 ly). There are about 4000 known MCs in the Milky Way. MCs are inhomogeneous, comprising multiple thready filaments of varying shapes and sizes and a number of higher-density regions termed clumps and cores. While they are called "molecular", most of them are composed of approx. equal parts of atomic H_1 and molecular H_2 gas, plus varying amounts of dust. The molecular gas condenses in a core, while the atomic gas forms a thick shell around it. The shell absorbs starlight, which allows the core to become extremely cold, ~10 K. While they may be large dimensionally they are also very airy, with average densities of only about 100 atoms per cubic centimetre. As a rule of thumb, the densities of clumps range from 100 to 1000 atoms cm^{-3}, while cores range upward of 1,000 to a million or more atoms cm^{-3}. While local conditions vary dramatically, in general the density required for a molecular cloud to begin inward free-fall into star-forming densities occurs when a given core reaches 10,000 atoms cm^{-3} and the two divisive forces of supersonic turbulence and magnetic field pressure have weakened each other so neither can impede free fall.

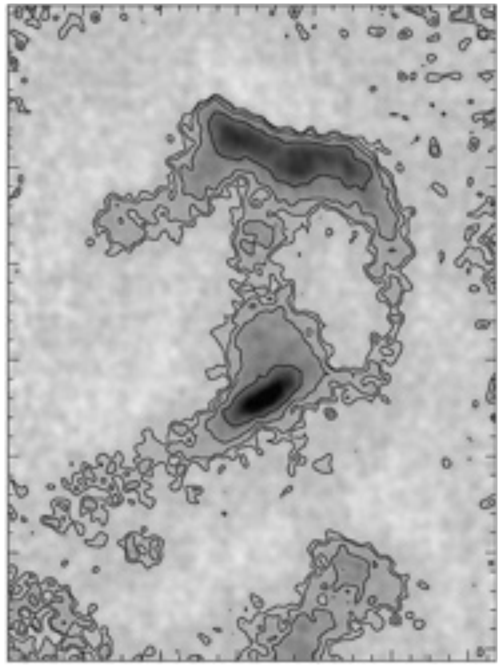

Fig. 8: The Horsehead in 850 μm IR showing emission from two prominent dust clouds labeled SMM1 and SMM2. Photoionisation from σ Ori at the surface of SMM1 projected a shock front into the cloud and compressed it, forming the two clumps shown here. These will eventually become gravitationally unstable and collapse into new stars. *Source:* Meyer et al 2008.

Alnitak

The easternmost star in Orion's belt is a triple star (A-B-C) system at the end of Orion's belt. The triplet is energetically associated with both IC 434 and IC 2024 the Flame Nebula. Alnitak A is a mag 2.0 type O9.5 blue supergiant of 33 ±10 $M_\odot$, T_{eff} 29,100 K and 250,000 $L_\odot$. It is 6.4 Myr old, ripe middle age for an O9.5 supergiant. Its spectroscopic companion Alnitak B is a 14$M_\odot$ BIIV blue subgiant with a T_{eff} 29,000 K which is 7.2 Myr old.

Alnitak's third companion C is a blue type BIII subgiant, barely within the emission threshold for the far UV radiation that is the most destructive to nearby gas/dust clouds. A star cluster containing Alnitak-mass stars would have cleared its natal gas by about 3–4 Myr after initial formation. Hence the Alnitak triplet's UV radiation today is fully available to fluoresce nearby dust. Is the Flame Nebula within Alnitak's fluorescing radius? Hipparcos distances for Alnitak A-B-C triplet are 1260 ± ly, while IC 2024 the Flame Nebula is 900–1500 ly distant. This casts doubt on Alnitak being the Flame's only flame. This fact inspired a deeper look using the Chandra X-ray and Spitzer IR imagers. The actual Flame's flame turned out to be an O star obscured by 24 magnitudes of overlying dust. We see 0.000,000,000,255 of what's actually there. You get better odds with a single Lotto ticket than with seeing a photon from the middle of the Flame.

σ Orionis

σ Ori is a bound quintuplet containing an O9.5, B0.5, two B2, and an A2 star with a FUV luminosity of 2 × 10^{49} photons each second and a total luminosity of 76,000 suns. It is about 385 pc (1250 ly) from us while the Horsehead is a little closer at 350 pc (1140 ly).

σ Ori AB are responsible for energising the seemingly far-off IC 434 emission nebula. The pair is a 3 Myr old close spectral type O9.5V and B0.5V binary. The closest pair AB are only separated by 0.2″– 0.3". In 2011 σ Ori A was shown to be a spectroscopic pair. σ Ori B, the least massive member, is B2. Their total luminosity $L \approx 7.6 \times 10^4\ L_\odot$, most of which is in the FUV.

What besides these 5 stars makes up the σ Ori cluster? The initial mass function (IMF) of star clusters divides into two classes: stars heavier or lighter than 0.5 $M_\odot$. To trim the frills a bit, most gas masses large enough to form multiple supermassive stars also form a great many brown dwarfs, red dwarfs, and sub-solar mass stars. Because of the bright stars' glare, few of these can be spotted visually (see Fig. 10 next page), and sometimes vex even millimetre and X-ray band specialists. The σ Ori cluster was first resolved down to the M_V 19 T-Tauri X-ray emitters in 1994 when over 100 were pinpointed within the σ Ori virial radius. In 1994–1995 Frederick Walter and 3 other astronomers successfully traced 104 σ Ori pre-main sequence infants out of some 300 candidates. Their discovery image is on the next page. None of the image's circled stars are visible above mag 16 in the optical, but a handful of brighter cluster members were conveniently plotted on a sky image on Wiki.

Fig. 9: Gentlemen, when it comes to star cluster formation in giant molecular clouds, it's turtles all the way down.

Clusters of clusters

Clusters form in clusters. The filament–clump–core hierarchy of gas masses in giant molecular clouds implies that as the cloud enters into the Galactic disc, the multiple shock fields in the disc will interact with the infalling gas and initiate a multi-million year sequence of star cluster formation. The overall process can be described as a 3-way tug-of-war between the disc's supersonic turbulence bubbles, magnetic fields, and the cloud's own self-gravity. A specific gas cloud's gravity needs only to hold up against the pressures until turbulence and magnetic fields wear each other down. The cloud can then infall into a star cluster whose mass and number of stars depends on the cloud's initial mass (IMF = initial mass function). Extrapolate this over dozens of clumps and you have the 20- to 30-million year cycle of star cluster formation of the Orion complex.

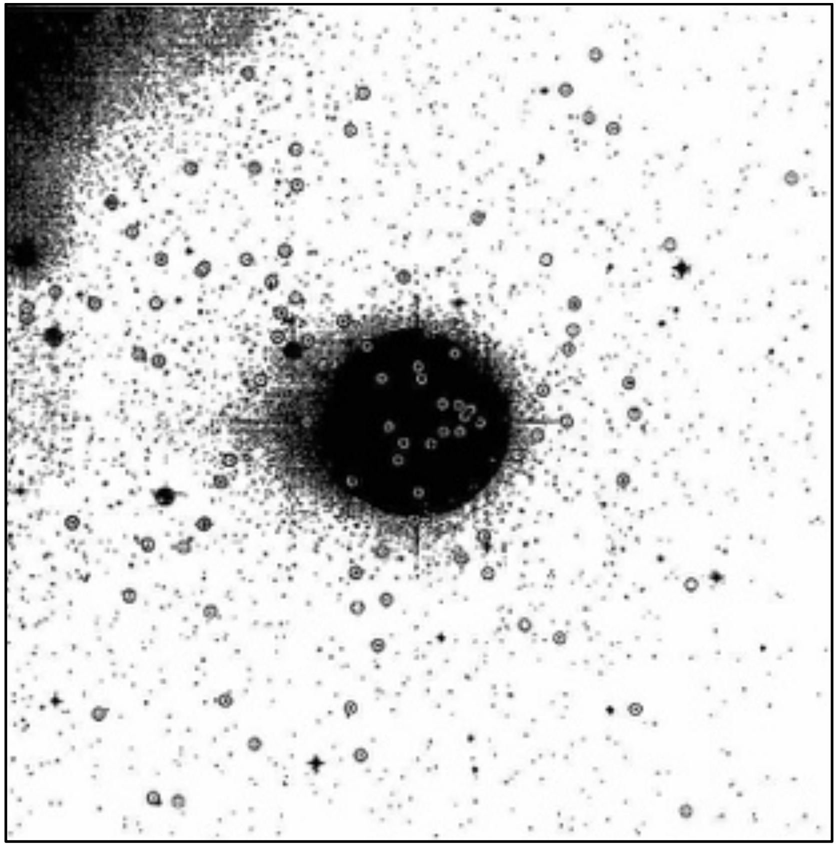

Fig. 10: The σ Orionis star cluster, taken from the *1997 discovery paper*. The mag 3.8 σ Ori triplet is vastly overexposed here to bring out the faint, low-mass members. Visually we see 7 stars, though two are non-cluster stars. The circled stars above are members of the cluster. The cluster is very young at c. 3.6 Myr old. Along with the few higher-mass and brighter stars shown in Fig. 9 to the right, there are 104 pre-main sequence stars in the cluster, a sign of its youth. Young it may be, but the σ Ori AB UV-emitting duo has still managed to ionise the entire IC 434 nebula and driven a large quantity of its gas deep into the Orion B cloud.

Fig. 11: This *image map from Wiki* shows the σ Ori cluster stars visible in typical amateur telescopes of 6" and 8" aperture. The original Wiki image identifies the stars more clearly. This image also reveals the fine structure of the magnetic field lines jetting away from IC 434's photo-ablation surface as champagne flow. (See p.16 below.)

Next time you visit the dentist How did the "X" in X-ray get there? When an unidentified form of electromagnetic radiation that could penetrate human soft tissue but not bone was discovered by the German physicist Wilhelm Röntgen in 1895, the nature of the rays was a mystery. He named them "Strahl" rays. In German the orthographic form for the letter X is "Strahl" (in English it is "ɛks").Translators into English and other language dispensed with the formalities and used the letter instead, *Strahl* rays became X-rays.

IC 434

Sigma Orionis (σ Ori) AB's massive UV wind has been pushing against the nearly perpendicular surface of IC 434 for several million years. During that time the wind has gradually accelerated the entire IC 434 wall toward the west and into L 1630, the whole huge thing including the *z*-axis surface fore and aft across which we gaze. Its present velocity is 3.5 km s^{-1} into L 1630.

If we were astride the Horsehead, σ Ori would be a stellar dot about as bright as the gibbous moon. If we were on σ Ori looking back the Horsehead would be a round blob larger than the Coal Sack and very much darker, while the front surface of IC 434 would look a bit like a faint red Aurora Borealis covering nearly half of the sky.

IC 434 is squeezing into L 1630, the Orion B cloud, shrinking out features like NGC 2024 the Flame Nebula, the star-forming reflection nebula NGC 2023, the Horsehead, and all the other structures we see to the west (left side) of IC 434.

One seemingly feckless star in our eyepieces is responsible for the whole shebang: σ Ori.

The velocity of the wind that leaves σ Ori AB is 35 km s^{-1}. The σ Ori AB system itself is moving toward IC 434 at 15 km s^{-1} — creating a rare dust bow wave instead of a more common gas shock front (pointed out in Fig. 1 above). Hence its particle wind arrives at IC 434 ± 50 km s^{-1} as a supersonic shock moving at Mach 5 with respect to the local sound speed c_S. While σ Ori's photons arrive at IC 434 in ~4 years, its ionised gas takes roughly 150,000 years to get there. Even given dramatic difference in time scales, today σ Ori's never-ending onslaught of UV radiation and supersonic particles arrives at IC 434's surface as a two-component fluid of dust and gas particles acting as a single energy field. Each component — photons and particle wind — has its own density, temperature, velocity, mass, and response to magnetic fields, but their concomitant effect is a nonstop wavefront wall forcing its way into IC 434 at Mach 5.

When the field arrives at IC 434's surface, three sequential interactions occur: *photo-ionisation*, *photo-irridation*, and *photo-dissociation* (commonly acronymed

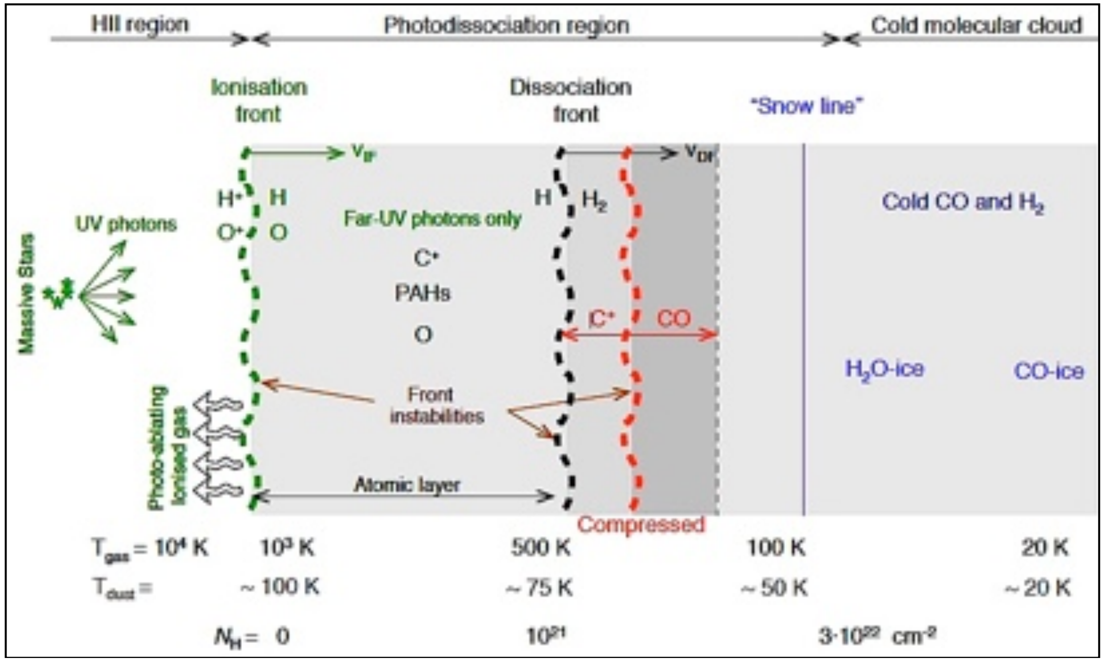

Fig. 12: This is a somewhat oversimplified, depiction of what happens when ultraviolet radiation from a hot O or B star arrives at the surface of a cold molecular cloud. The incident stellar UV radiation from σ Ori arrives from the left at the cloud surface as a vast front, much the same as starlight enters a telescope as a flat wavefront before it is refracted or reflected. In a molecular cloud the *ionisation* or *photo-ablation front* forms the outermost surface of the cloud. Incoming FUV and EUV photons interact with atomic hydrogen and oxygen there, ionising the hydrogen to ~10,000 K. FUV photons that pass through the surface penetrate into a 1500 AU (0.03 pc) buffer zone of atomic hydrogen mixed with ionised carbon, atomic oxygen, and dust at between 500 and 1000 K. Dust surfaces are formation sites for H_2 and polycyclic hydrocarbons (PAHs) when the dust is a cold 10 K, but when heated to 500 K up to 1000 K in the buffer zone, the dust particles lose into their surface layers of atoms and ions but remain intact as dust particles. At the base of the atomic hydrogen layer lies the *dissociation front*, where photons with enough energy to break the 4.75 eV binding energy of H_2 into two H atoms. By now, so much incoming energy has been absorbed that the cloud cools to its core molecular temperature ~10 K. IC 434 can be likened to a celestial game of Pacman in which the munching monster chomps its way through the whole cloud. *Source*: Goicoechea et al 2016.

PI, H_1, and PD). Each one is responsible for one of the end-game phenomenon that we marvel over when seen in an eyepiece: an emission gas/dust cloud, a dust clump, an emission gas nebula, and a reflection nebula. This eye candy is high-energy but low-cal.

It is easiest to understand what happens to IC 434 under σ Ori's photon barrage by likening IC 434's surface to the three colour emulsion layers in pre-digital photographic film: cyan, yellow, and, magenta. Incoming light passed through the film's pigment layers, but the specific emulsion layers absorbed only the light whose energy corresponded with that layer — cyan, yellow, etc. Similarly, if we follow the wavefront of σ Ori UV radiation as it enters and passes through IC 434, the UV passes through three layers of physical reaction. Each has its own effect on the photon wavefront.

Photo-ablation (PA, aka photo-ionisation PI)

Compression and fragmentation of UV-irradiated cloud fronts is a common event in the vicinity of young massive stars. Far-UV (FUV) radiation with wavelengths between 912 Å and 2,000 Å heats the surface layers of a molecular cloud. The radiation's penetration depth is determined by the amount of light the dust absorbs and re-emits at a lower wavelength. FUV radiation heats the gas/dust surface to ~10,000 K. The topmost interaction layer stretches from just above the surface of IC 434's atomic hydrogen layer all the way out into deep space.

This is the origin of the Horsehead's mane that we see streaming away from the high-density, high-temperature surface of IC 434 into a low-density, low temp medium of not much, really, at all. The name for IC 434's ejective energy transport is "*champagne flow*" because it is a gigantic version of what happens when you pull the cork on a bottle of bubbly. Fizz. Lots of it.

Call it what you will, the reality is that it's just heated gas expanding away from the hydrogen ionisation layer and back towards the UV source (σ Ori). It travels at roughly the local sound speed, in this case ~10 km s^{-1}.

For further reading see Bally et al 2018: Kinematics of the Horsehead Nebula and IC 434 Ionization Front in CO and C+. *Astronomical Journal*, Vol 155, No 2.

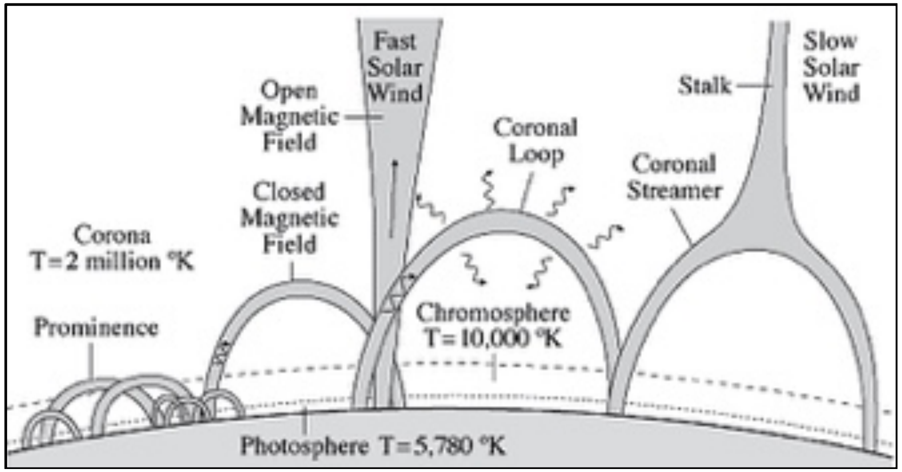

Fig. 13: The ionisation surface of a molecular cloud is somewhat analogous to the chromosphere of a star. Magnetic fields anchored in the photosphere at one end are carried by the solar wind into space, resulting in open magnetic fields and a channel for the fast solar wind. *Source:* *Prof. K. Lang, Tufts University*.

Iron filings in space

Where there is electron flow there is a magnetic component. Roughly 95% of the particles streaming away from IC 434 are negatively charged electrons. At ±10,000 K the charged particle wind of electrons plus heavier ions of other atoms is too energetic to recombine with protons back into hydrogen. They flow out into space perpendicular to the surface where they were generated — which hurls them back toward σ Orionis. We can't see the electrons, but we can see their radiation as HII in near IR. The thready "horse's mane" effect we see is caused by magnetic field lines induced by parallel electron flow. For astrophotographers those parallel filaments make a challenging fine-grained target. The ancestral roots of parallel flow lines trace back to André-Marie Ampère, who noticed that parallel wires with currents attract one another if the currents flow in the same direction. In space the analogous effect is magnetic confinement within flux tubes.

Photo-dissociation (PD)

The next reaction to take place is photo-dissociation. The actual surface, the leading edge, of IC 434 is atomic hydrogen. It is about half to a tenth of a light year thick, with minor local variations (Fig. 14 right).

Photodissociation is a chemical reaction in which energetic UV or X-ray photons break down chemical compounds. In molecular clouds like Orion B, photo-dissociation mainly affects H_2, which is broken into one hydrogen atom and a free proton plus energy. Photodissociation is not limited to gas clouds in space. Any energetic photon can affect the valence bonds of a chemical compound. Closer to home, photo-synthesis via chlorophyll in plant tissue and sunburn on unprotected skin are also photodissociation effects.

In IC 434, some of the photons that penetrate through the surface of the cloud's atomic hydrogen "skin" interact with atoms in the 0.8 pc (0.25 ly) atomic hydrogen layer beneath. The H layer sees a temperature drop from 1000 K to between 300 and 500 K and the next layer down, the molecular hydrogen H_2 layer. Any photons that reach this far into the cloud have enough energy to dissociate H_2 into H_1, but they do affect ionised carbon C^+ and carbon monoxide, CO. By the time photons have made it through the dissociation layer, their energy has been so depleted that they end up merely compressing the gas surface instead of dissociating it. Further inward toward the cloud core, the temperature drops rapidly below "freezing" at 100 K, till a few pc further inward the cloud is ~20 K and 30 times denser than the atomic hydrogen layer at its surface.

Taken together, the PI, H_1, and PDR layers somewhat resemble geological strata on Earth. Folding and buckling affects all the strata, not just the individual layers. Out in space, the undulating surfaces of molecular clouds in astro images are caused by varying density and composition in small-scale local structures. Each structure responds in its own terms, but they are all impacted by the relentlessness of an O-B star's wind.

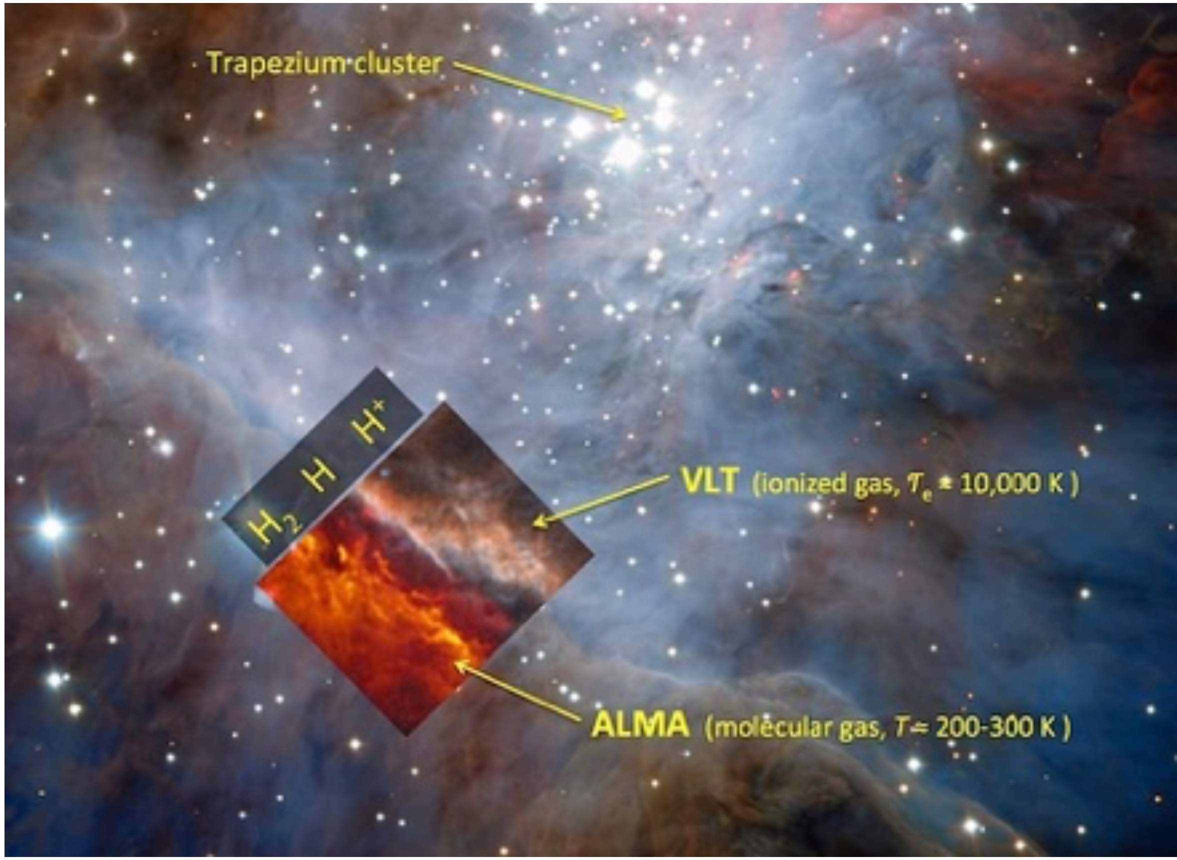

Fig. 14: This simulated cross-section of the photo-reactive layers across a molecular cloud surface depicts the Orion Bar molecular structure near the Trapezium in M42. There is no comparable image-based sim for IC 434, but the basic cloud orogeny is similar. The incident stellar UV radiation comes from the Trapezium. The temperatures of the advancing ionisation and dissociation fronts are reconstructed from VLA mm and ALMA sub-mm bands. The dusty photoionisation layer and the red molecular photodissociation layer are clearly separated by the atomic hydrogen gap. *Source*: *Goicoechea et al 2017*.

Champagne flow

When a atomic hydrogen shell of a molecular cloud is ionised by UV radiation, the pressure balance between the cloud and its surrounding gas is disrupted. Typically, gas at the ionisation surface reaches ~10,000 K. The hot gas exerts enough pressure on the ambient gas to punch through the gas at supersonic velocity into the surrounding low-density medium. IC 434's pressure imbalance will continue until σ Ori's energising UV radiation stops. Since the L 1630 molecular cloud is very large and σ Ori's lifetime is not, one day, in time out of mind yet to be, the horse's mane will stop flailing.

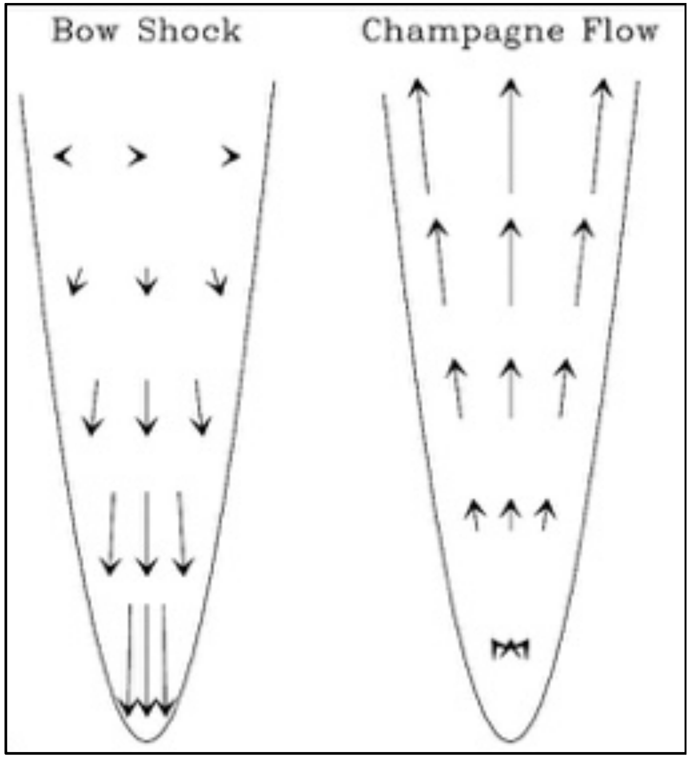

Fig. 15: Champagne flow can be describe as an unconstrained pressure field of magnetically vectored ballistics. The difference between bow shock compression and champagne flow release is a study of contained versus unobstructed flow. Flow fields in space are not constrained by the walls of celestial flute glasses, but they are affected by local gas overdensities and magnetic fields. *Source: Cyganowski 2003.*

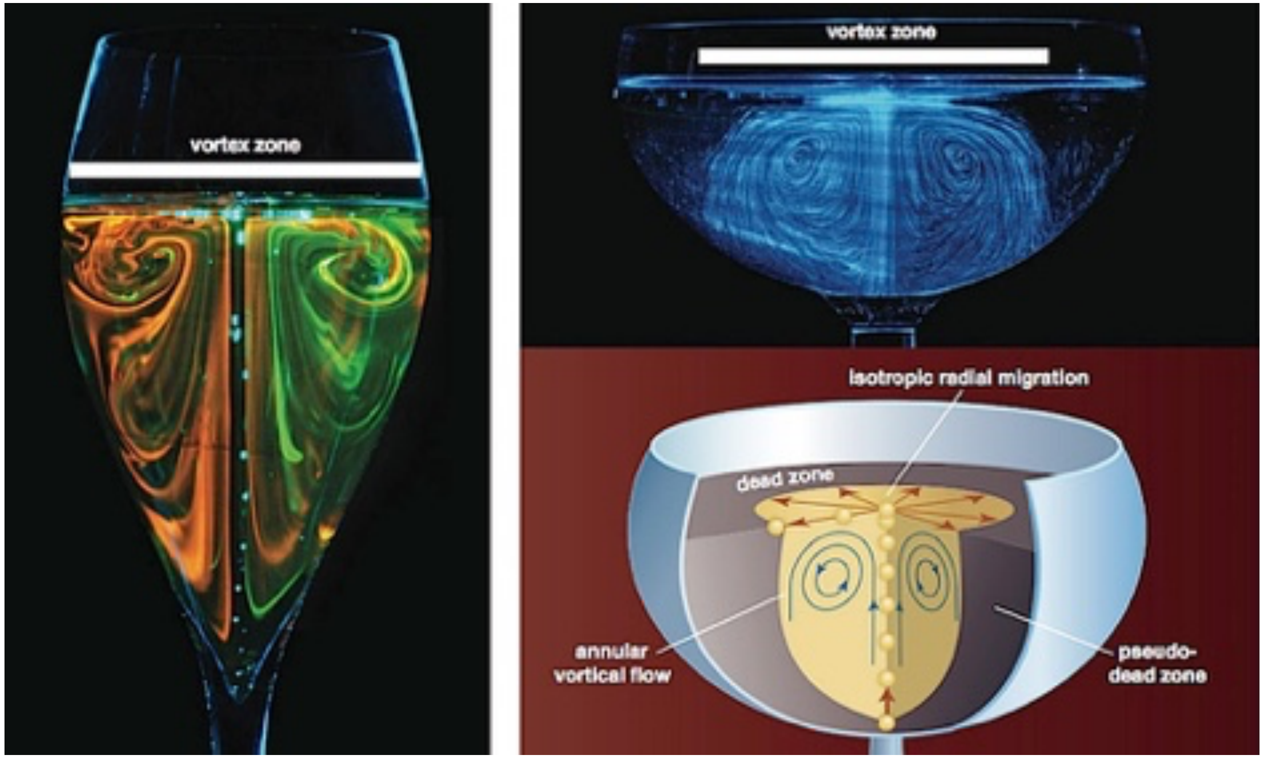

Fig. 16: Most people might think that sampling 20 different styles of champagne to better understand the behavioural differences in their bubbles would be a rather jolly affair. Scientists take a more straight-laced approach. The *source paper for this image* is, to turn a phrase, dry. Astronomers might do well to learn how terrestrial studies of champagne flow dynamics provide a richer knowledge experience than a study of the gas expansion parameters derived from ALMA data. There is really no other way to arrive at wink-of-the-eye conclusions such as, "empirical relationships reveal the bubble diameter to be proportional to the cube root of the vertical displacement". Would that ApJ, A-J, A&A, JASP, and MNRAS could be such an entertaining read.

NGC 2024 The Flame Nebula

At 415 pc (1350 ly) the Flame Nebula is outside the reach of the Alnitak triplet's fierce far-UV radiation. What then lights up the Flame? There being no other bright stars nearby, the illumination must come from within. The task of finding the illuminating source is not helped by that bleak gash of black lying in front of the emission nebula. Alnitak's dazzle doesn't help.

At the centre of the Flame Nebula Chandra X-ray data found a cluster of newly formed stars; 86% of them evidence circumstellar disks which suggest very young star clusters still in the mass assembly stage. The cluster's total estimated population is about 800 stars, most of them low mass cluster members a mere fraction of the mass of the Sun. Standard cluster IMF functions predict a large population of red and brown dwarfs.

An *ESO Chandra X-ray and NASA Spitzer Space Telescope survey* of NGC 2024 revealed that the stars on the outskirts of The Flame's central cluster are about 1.5 million years older than the stars in the centre, which are roughly ~200,000 years old. Chandra data trace the brightness of stars in X-rays, which is a direct probe of their masses. Combining those data with Spitzer and 2MASS data for the stars' brightness in three IR bands revealed the central stars were faint and young while the bright stars in the outskirts were the bright and old.

A similar outside-in star-forming sequence replicates in the M42 Orion Nebula cluster. The 1.2 million year old Trapezium lies in a cluster whose outlier stars are aged 2 million years. The Flame's second-gen stars are dim dwarfs while M42's are intensely bright supergiants.

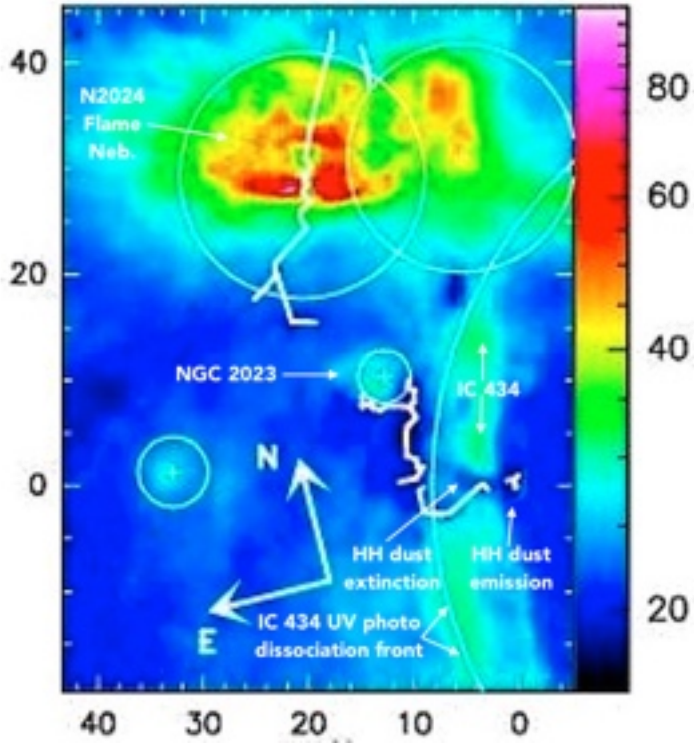

Fig. 17: Gas temperatures in the Orion B molecular complex. The scale on the right is in Kelvin. The crack-like features are centrelines of dense dust clouds. The IC 434 photo-dissociation zone is suggested by the pale green arc on the right. Note that the Horsehead absorbs radiation along its "neck" but emits millimetre-band radiation at the top of its "head". We can also see why the name "Flame" Nebula is such an apt name.

Innies -vs- outies

Outside-in star formation sequences are well known in dwarf spheroidal galaxies. There, gas ejection from the bright first-gen stars loops high above the galaxy but infalls gradually back into the core. Many dwarf galaxies exhibit a dual- or triple-tier metallicity ratio that trace this history. The majority of dwarf star formation occurred 10–12 billion years ago when the universe's gas was much denser but also much hotter. Dwarfs accreted abstemious quantities of fresh gas, but did it for billions of years.

Star clusters are quite different. The standard scenario is that they accrete large amounts of fresh gas over a few hundred thousand years, then eject the excess over the next few million years.

There are several explanations for the inverted stellar distribution in NGC 2024. One is that the older stars have had more time to drift away from the centre of the cluster, or be kicked outward by 2-body interactions with other stars. But that does not answer the question of why there are two generations. Why didn't all the stars form at once like most other clusters?

Another plausible explanation is that star formation continues in the inner regions because of gas, not stellar, migration. Such would happen if the gas in the outer regions of a star-forming cloud is thinner and more diffuse than in the inner regions. Over time, the outer gas density infalls till it reaches the critical density to collapse into stars, thus explaining the outside-in evidence. Star formation ceases in the outer region, but there is still enough gas in the interior to form the sparse population of low-mass stars in the Flame's baby crèche in the middle.

Fig. 18: The dark gash in the Flame Nebula that we see in our eyepieces and images is caused by a massive dust filament which is not associated with the Flame Nebula but simply lies in front of it. It is the optically visible shadow of a much larger, longer filament hat spans the entire lower Orion B cloud complex. Much of the Flame's optical glow is emitted when free-free electrons and protons fall below the 13.6 eV ionisation threshold and recombine, emitting visual Hα and Hß lines.

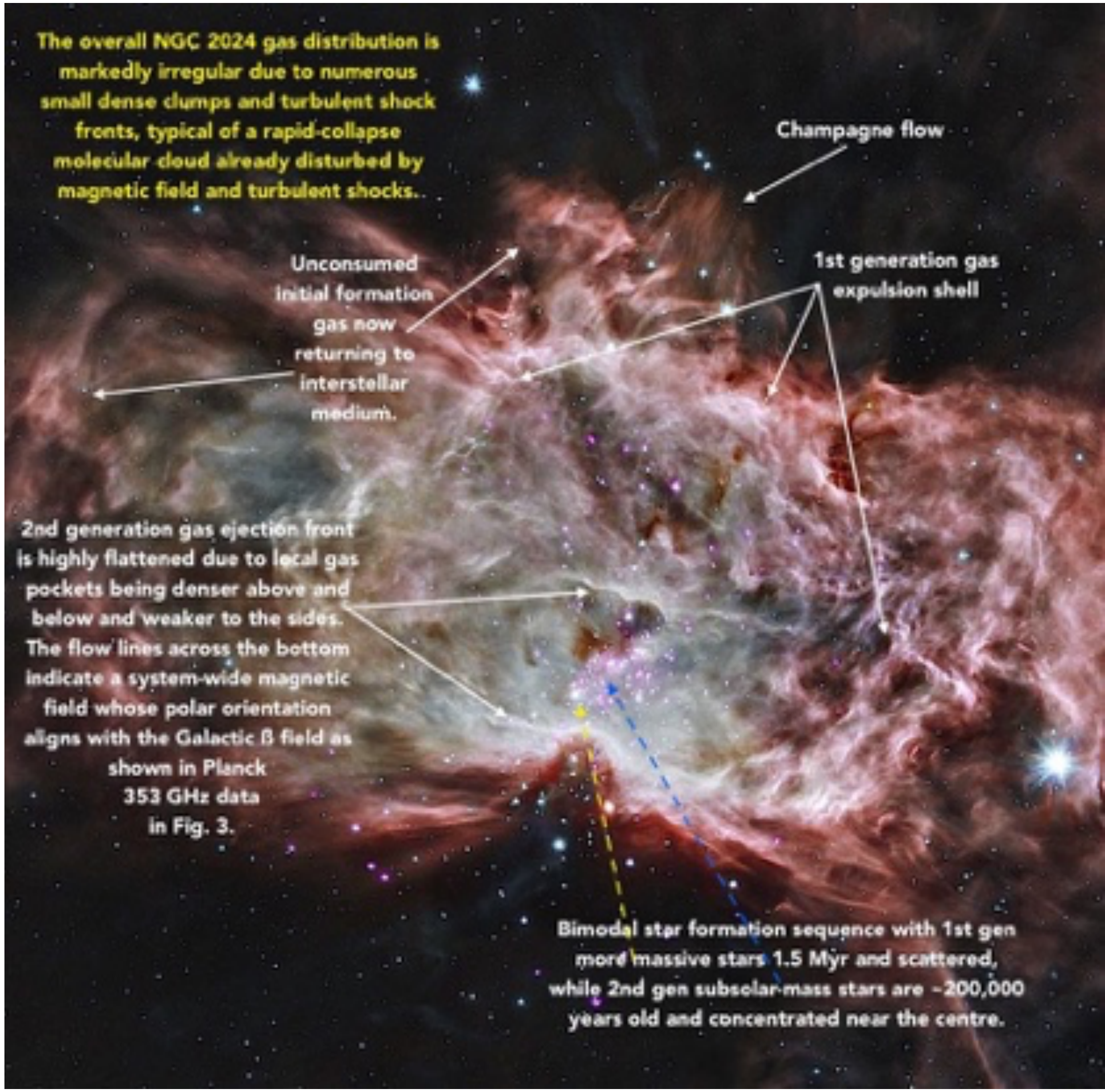

Fig. 19: The Flame's bimodal distribution of a few bright giant stars amid a large number of petite subsolar stars and very few mid-mass stars in between is obvious even in a simple visual examination. The bright star IRS 2b pointed out with the yellow dashed arrow is responsible for illuminating the entire Flame Nebula. It exhibits the IR flux density typical of a late O9/early B0 star. The entire central cluster is obscured a remarkable 24 visual magnitudes by the overlying gas/dust filament shown in Fig. 16 left. Without the overlying dust IRS 2b would be a dazzling blue-white rival to nearby Alnitak.

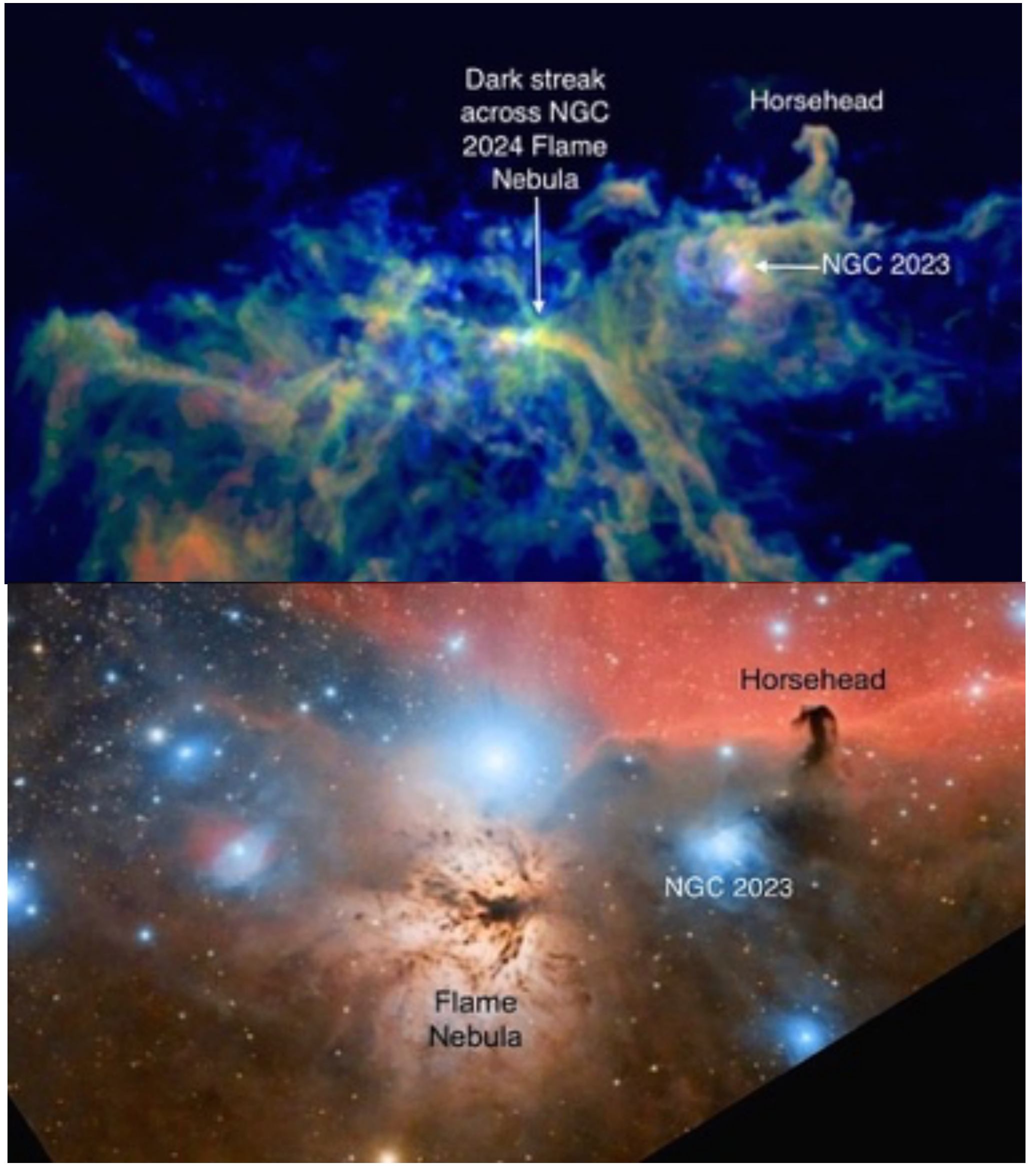

Fig. 20 Diffuse gas, filaments, and dense condensations are analogues of muscles, bones, and vital organs in our bodies. Emission from carbon monoxide, water, hydroxyl, methanol, and other organic molecules reveal molecular secrets the way Magnetic Resonance Imaging (MRI) reveals the internal constitution of our bodies. Source: Natalie Ruiz, *Molecular Astrophysics Group*, 03/07/2017.

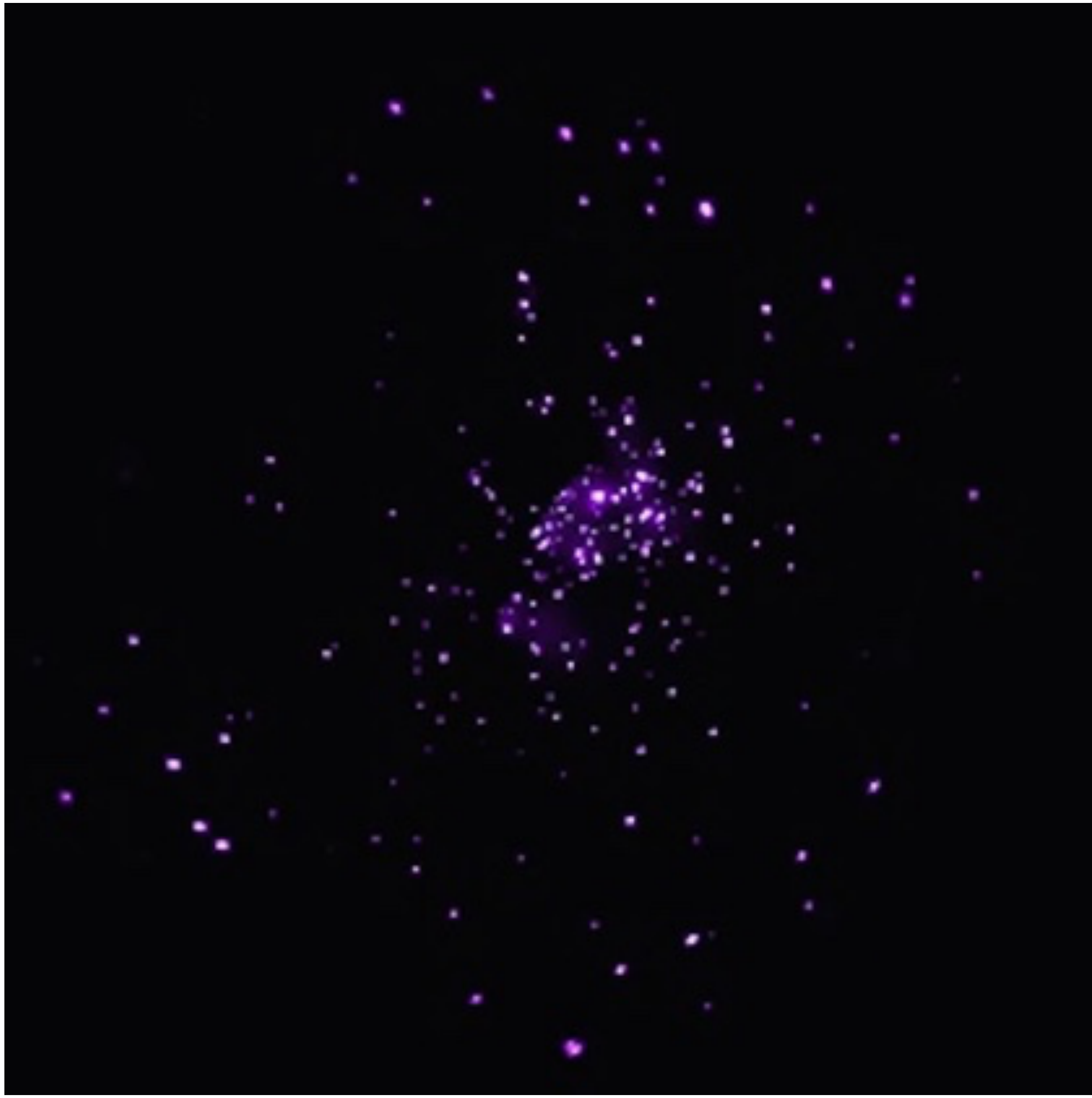

Fig. 21: The Chandra probe detected 283 X-ray sources typical of T-Tauri and earlier protostars in the Flame's central cluster. Such stars would be low-mass (<0.1 – 0.8 $M_{\odot}$) stars only a few hundred thousand years old. They are distinct from the cluster's 1.5 million year old giant stars.

NGC 2023

NGC 2023 is the Orion Nebula's wallflower cousin. Both are essentially big billowy bubbles, though M42 goes about the matter a bit more gaudily attired. Both are illumined by an overwhelmingly bright star — O supergiants suffer from terminal dazzle. Both have closets full of comely clothes — bright emission veils, ink-dark globules, jewelbox sparklers, a taste for subtle spectral pastels. While M42 tries its best to outshine the neighbourhood, NGC 2023 enjoys the prettier view — who wouldn't want a towering dark horse flinging its lucent mane as a next-door neighbour?

And yet NGC 2023 is resoundingly ignored, even by the professional community: Simbad cites 3557 papers with "M42" in the abstract; NGC 2023 makes do with a modest 553. (OTOH, take a look at those author names as a testimony to astronomy as a beacon of nonparochial thinking.)

Step a couple of centuries back and William Herschel's discovery note on Sweep 352 dated 6 Jan 1785 described it as "A bright star with a very considerably milky chevelure [nebulosity]; a little extended, 4′ or 5' in length, and near 4' broad; it loses itself insensibly. I suspected some extensive milky windings in the neighbourhood but could not verify them; other stars of equal magnitude are perfectly free from this chevelure." Even so indefatigable an observer as America's Steve Gottlieb gave it short shrift: "13.1-inch telescope: fairly prominent nebulosity surrounds mag 7.8 SAO 132464. The Horsehead nebula lies 15' SW".

Poor thing, upstaged yet again by its vexatious but beguiling neighbour. Let's redress the imbalance a bit. NGC 2023 is the site of the first detection of fluorescent H_2 emission in IR in the mid 1980s (1, 2, 3, 4). Half a decade later the first optical detections of *rotational H2 transitions* were made there, some 30+ spectral lines from highly excited H_2. It is also where *Extended Red Emission* (ERE, 6000–7400 Å) was discovered. It is one of the reflection

Fig. 22: The NGC 2023 gas clearance expansion shell is often referred to as a blister nebula, but the two terms describe the same type of event. These are champagne flow still in the bottle. All star clusters end their active star formation era with an excess of unused mass. High stellar-mass clusters with stars more massive than B3 shed the excess by photo-evaporation. These stars radiate mainly in energetic UV whose radiation pressure ejects the gas at high velocity. Here the ejecta bunches up as it works its way through the natal cloud. When it encounters the low ambient medium outside the star-forming cloud it will burst free into champagne flow. Try this with your pals after your next star party and you'll agree.

nebulae in which the infrared features at 3.3, 6.2, 7.7 and 11.3 μm were first traced to *polycyclic aromatic hydrocarbons (PAH)* (1, 2, 3, 4). PAHs may sound arcane and abstract, until you realise that they make up much of the Earth's coal and oil — and therefore forest fire smoke. Impressive record indeed for a wallflower.

NGC 2023 is a bright photoionisation nebula illuminated by the B1.5 star HD 37903. Contrary to its low-key presentation, NGC 2023 is one of the brightest reflection nebulae in the sky. Even so, it is used more often as a guidepost to the Horsehead than an an intrinsically interesting object in it own right. In 3D space it is located just east of the Horsehead nebula but somewhat behind it, in between the Horsehead and the deformation surface that gives us IC 434. It was born 8–10 million years ago out of the same class of high-density compact molecular hydrogen cores that lie quietly in waiting while magnetic fields and turbulence battle for dominance in the surrounding region. There are quite a number of these objects in our galaxy; they commonly go by the name of *compact high-velocity clouds* (CHVCs). See 1, 2, 3, 4 to understand why they are more important than they seem, NGC 2023 being a case in point.

When turbulence and magnetism both lose in their battle and lapse into quiescence, clouds like NGC 2023 free-fall into clusters. NGC 2023's proto-cloud was massive: between 100,000 and a million $M_\odot$. The B1.5 star HD37903 has a surface temperature of 22,000 K and is responsible for the excitation of gas and dust within the nebula. It lies near the front side facing and near the edge of its molecular cloud. Off-centred progenitor stars are not uncommon: the Trapezium stars in M42 are even further off-centre. We can readily see why in both cases: one side of the expanding shell is encounters more resistance from dense gas, while the other side is pushing into lower density. No matter where you are, space has its hills and hollows.

A unique feature of NGC 2023 is a shell of neutral hydrogen (H_2) surrounding HD 37903 out to a radius of about 0.65 light years. The shell amazingly emits light not by the photoionisation of hydrogen but by a unique process called *vibrational fluorescence* (1, 2, 3, 4). It is the first reflection nebula known to exhibit this type of emission.

In addition to the reflection component, a number of Herbig-Haro objects (HH) which are associated with pre-main-sequence stars exist in the surrounding dust clouds. Two HH objects, HH4 and HH5 in the southeastern part of the nebula are illuminated by a star designated star C. Star C is thought to be a T-Tauri star. The presence of these very early stars suggests that NGC 2023 is still an active star forming cloud.

Despite its timid showing of only 21 stars, NGC 2023 is one of the most complex nebulae in the entire Orion A and B Cloud complex. This wallflower is the queen of the garden.

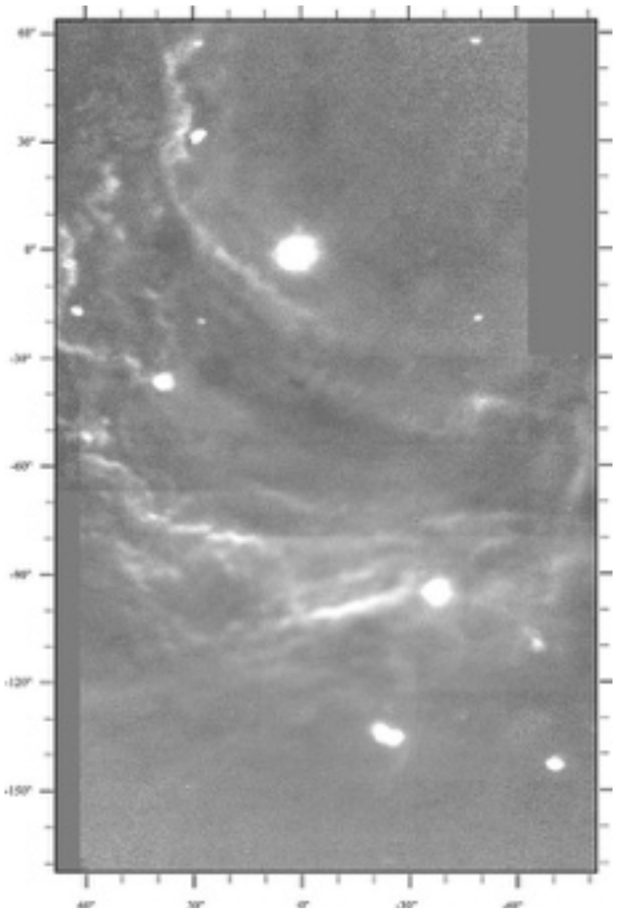

Fig. 23: This narrowband image of vibrational fluorescence in N2023 is just one spectral line in the over 30 lines arising from high-excitation levels of H_2 found in NGC 2023. This was the first image to reveal an H_2 line in the optical CCD regime. It depicts molecular gas at the highest excitation level known (>44,000 K) above the ground state. The vertical scale here covers only 2.4 arcmin of the sky and the emissions here are so far into the red end of the spectrum as to be unobservable by humans. Be grateful you are not a graduate student who gets stuck with parsing out spectral lines in objects like these. OTOH, it's an A in Spectroscopy 404b. *Source:* McCartney 1999 Fig.3.

How to know champagne flow when you see it: photo-ablation caused by NGC 6193 Ara

Source: **Peter Ward, Barden Observatory, Australia**

Multiple gas flow fields in M8 Lagoon Southern Wall

Bright edges are HII fluorescence, as described on p.21.

Champagne flow

4 stages of pillar erosion

The M8 "Lagoon" is a dense stream of gas & dust being transported toward bottom of image by magnetic flux tube confinement pressure. This portion is part of the side lobe of the Lagoon magnetic loop. Part of the dust stream crosses the Southern Wall ridge, partially eroding it as seen here.

Illuminating source of this image is NGC 6530 out of image at top. N6530 is a ~2 Myr cluster shedding its natal gas visible as red HII here. N6530 has 2 O-type & 21 B-type stars & lies in a larger region of "conveyer belt" sequential star formation from ongoing fresh gas infall, with 1523 X-ray emitting T-Tauri or proto stars hidden behind natal gas & dust. The wall of dense dust shown here lies closer to us & is not massive or cold enough to initiate star formation. The erosion surface seen here will continue abating surface gas through the HII fluorescence mechanism until N6530's O and B giants go supernova.

Envoi

If the human eye can detect only one percent of what's there, what else are we missing?

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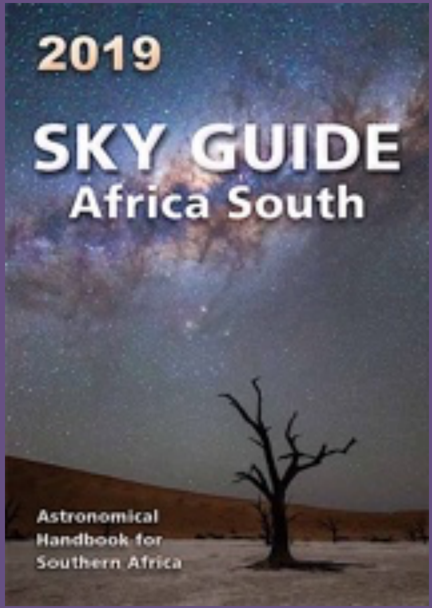

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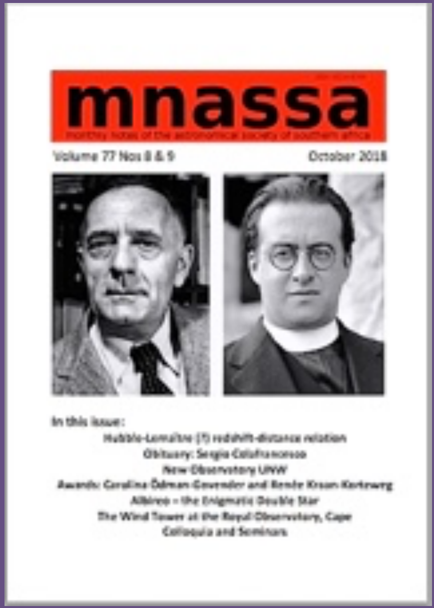

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