Nightfall

Astronomical Society of Southern Africa

Every time we look up at night, there's something we haven't seen before.

Reflecting telescope made by Johann Gottlob Rudolph, c.1750

Mathematisch-Physikalischer Salon, Staatliche Kunstsammlungen Dresden

Photographer: Jürgen Karpinski

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Astronomical Society of Southern Africa
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In this issue of Nightfall we introduce live-stream videos.

Click on any link in cyan.

Come fly with us ...

Drone flight over Sutherland

Willie Koorts

Click here to fly with Willie

When I was a kid I used to daydream, 'One day when I'm grown up, I want a camera drone.' But life seemed to have other plans. With twin daughters at university, I could not justify splashing big money on a 'toy'.

So you can imagine my surprise when my son gave me a real-life *DJI Spark* drone for my 60th birthday. I was over the Moon! Unlike today's youngsters, I did not grow up with a game controller in my hand ... in fact, I always said that if a computer game had more than two controls, I was not interested. I prefer plain old brain power. But in the end, the learning curve to master flying 'Sparkie' turned out to be a lot of fun.

My astronomy work takes me up to South Africa's complex of observatories near Sutherland in the Western Cape. Thanks to the huge open spaces and safe flying conditions, a trip to Sutherland is always a good excuse to take Sparkie along. Sutherland is quite a windy place, but I discovered that the best footage can be captured during the golden hour around sunset. That is also a good time to catch the big white domes opening up for action, which adds excitement to the footage. Ahhh, but bad luck again! – the telescopes are robotically controlled from afar and don't listen to any commands from me. Just as I would think I had worked out their pattern and whisk Sparkie over to hover in position … nothing would happen! But then I would see another one open and I would rush over to catch it! But then just as I arrived, the bigger dome I really wanted in the first place would suddenly spring into action! I played Whack-a-Dome for weeks this way!

I ended up gathering hours of footage only to find that a small percentage was usable. Even so, it was still enough for the videographer Chantal Fourie to include in her wonderful video, *Sutherland – by Day and by Night*.

Come see us at SALT

We're home pretty much any time.

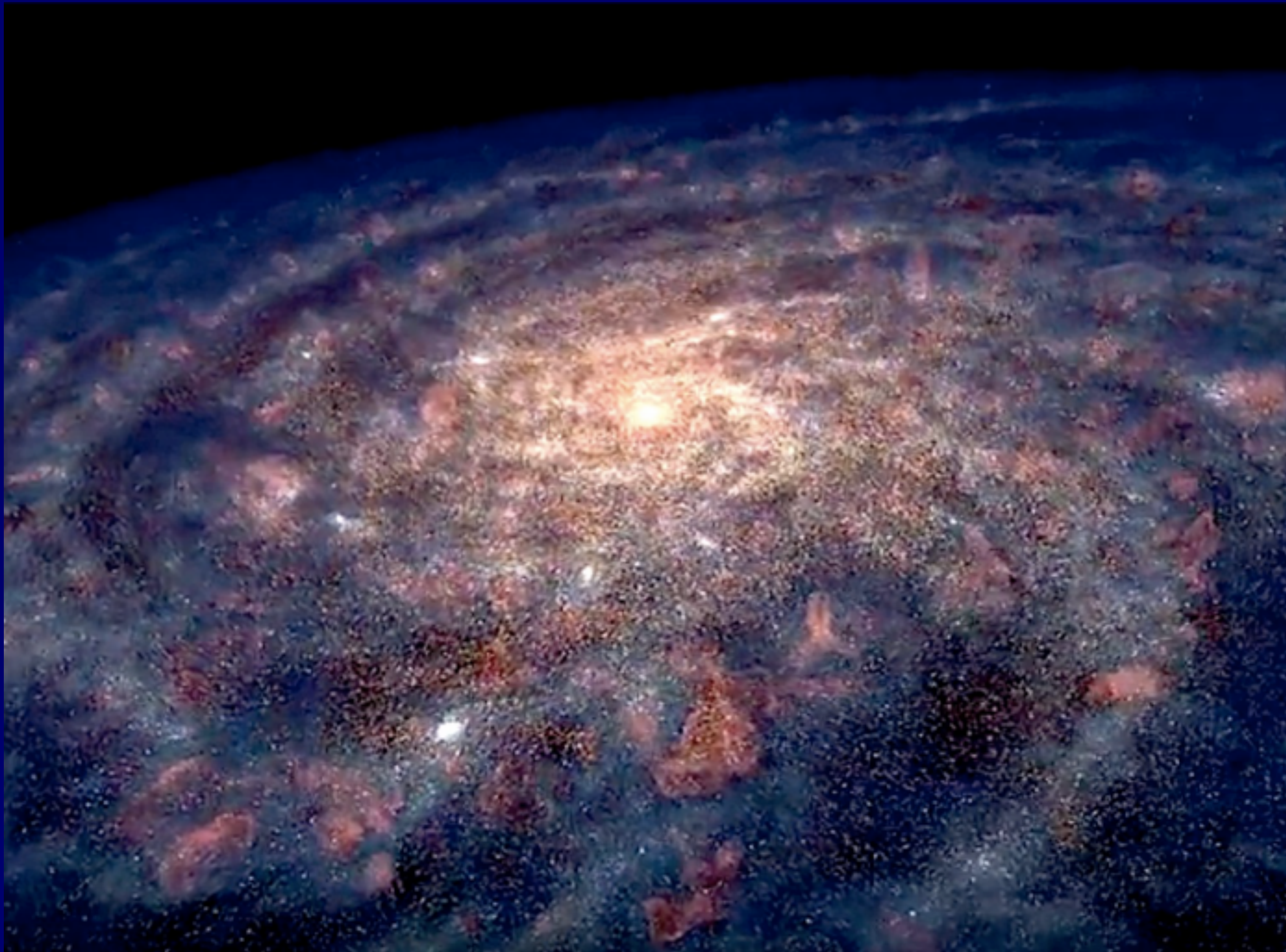

ENCOUNTER

In this issue

Something happened one day at $z = 1089$

The dawn of our world

Stefano Della Bella, 1656
Frontispiece to
Opere di Galileo Galilei



There comes a time in our majestic search for certitude when we can stop seeking and start enjoying.

Under the Dancing Sky

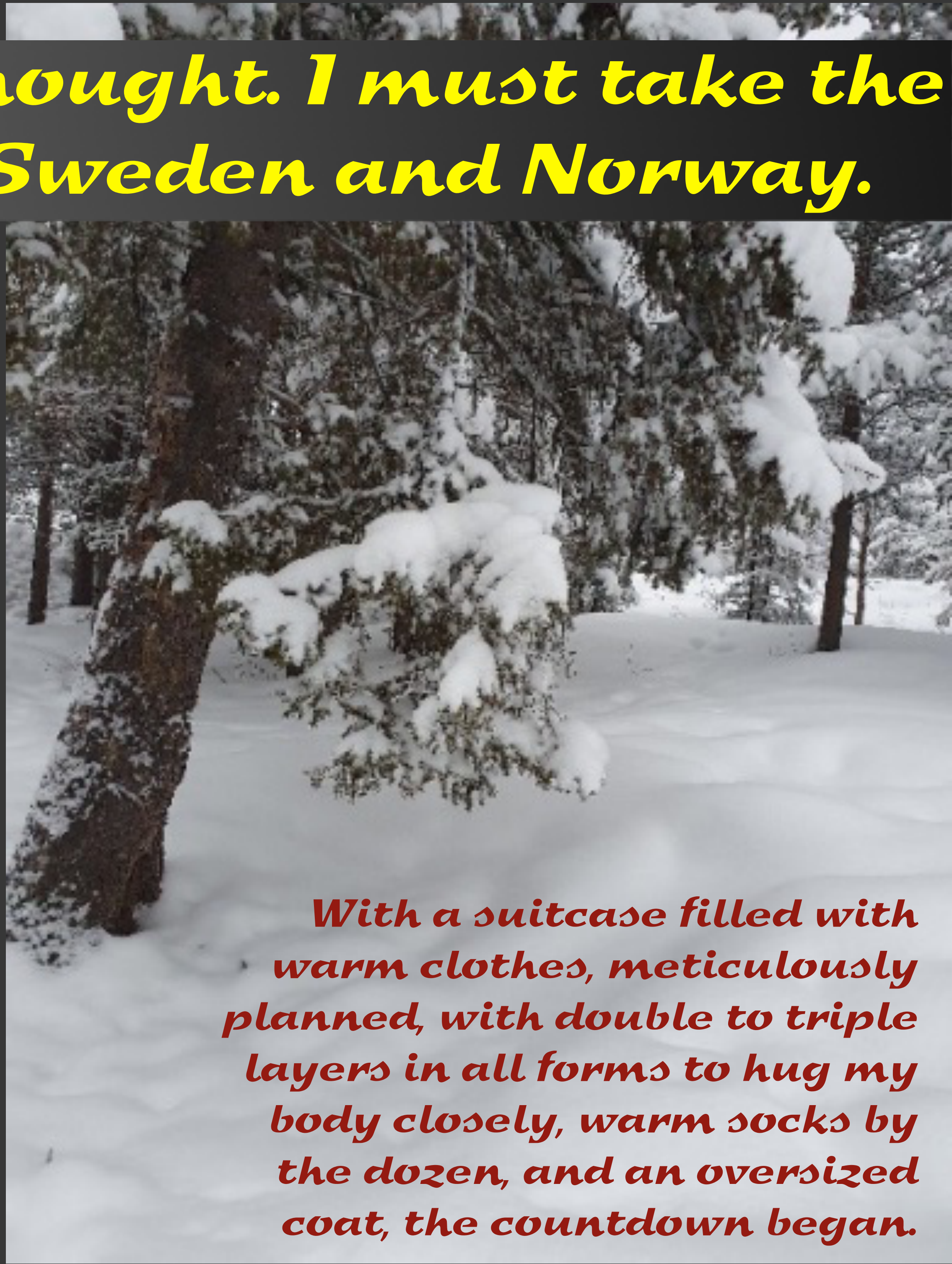
Click on the cyan links in this article to open the underlying videos.

Magda Streicher

Undertaking a tour, especially to distant countries, is a challenge, but it is also very exciting to head into what is frequently the unknown. Winter months in the northern parts of the world definitely require courage and perseverance, but mind wins over matter when the will is there. And when the natural wonder of dancing, playful lights is on the agenda it is all the more reason to muster the courage to face whatever the unknown might hold.

It's now or never, I thought. I must take the plunge and go to Sweden and Norway.

It is winter at the end of January in the Scandinavian countries, with icy cold temperatures cheerfully frolicking around way below the zero mark. Widely known in those regions is arguably one of the most spectacular phenomena, the Aurora Borealis (Aurora Australis in the southern hemisphere) which makes its appearance very close to the Arctic circle. The sun not only heats our beloved earth, but the hot particles also conveniently collide with the earth's magnetic field to produce the light show in all its glory as these particles interact with oxygen molecules in the earth's upper atmosphere to produce the ghostly greenish arcs, we are so fortunate to witness. Thoughts about this natural wonder had been milling around in my head more than most thoughts usually would – over several years – and that is what finally tested my courage to undertake a tour to the north.



With a suitcase filled with warm clothes, meticulously planned, with double to triple layers in all forms to hug my body closely, warm socks by the dozen, and an oversized coat, the countdown began.

And so, from sunny South Africa I stepped out into the beautiful city of Stockholm … to be greeted by a temperature of -12 C.

Straining against the snowy assault on my body I made it to the bus with its glorious, welcoming warmth.

Stockholm is described as a floating city which forms part of 14 islands situated off the coast of the greater Swedish land mass. The narrow little Medieval streets are explored up to the imposing royal palace. It is snowing and I am fascinated by the piles of white snow being bulldozed away. This has to be done every day during the winter months.

It was cold – very cold – but nothing could have prepared me for the flight to Kiruna, the northern-most city situated in Swedish Lapland, north of the Arctic circle. The landscape is adorned in an icy blanket of white. How does one describe the landing of an aeroplane on a snow-covered runway with a strong wind whipping up a haze of snow into the air? Every moment of beauty is observed with thoughts that survival is clearly possible in this part of the world despite the merciless cold.

"What have I let myself in for?" was my first thought as I tried to shield myself against the icy cold wind

The days are short, with an oblique sun appearing late in the morning and then disappearing again in the early afternoon behind the northern horizon. To explore the night sky requires, first of all, heavily protective overalls and boots that are far too big – the only way to tackle the night air. This essential appropriate clothing proved to be heavy going for me, boots sinking deep into the downy snow and almost getting stuck there. I imagined this was how a moon suit would have felt, but I could barely walk as I tried to free myself from 50 cm deep snow with every step. Fortunately, most of my fellow travellers had the same problem, so despite the extreme weather conditions we laughed together as we talked about the exquisite terrain which concealed its secrets under the snow, shielding them against the moist night air. A record six snow sticks were bought in ten minutes at a sports shop.

I find myself thinking: This the home of the polar bears – how did **people** end up here?

In this part of Lapland one finds mainly small settlements. We left for a remote village that boasts ice sculptures and also prides itself on its processed antelope meat, which is fairly widely available here. The freezing cold was unbearable and I was frequently very close to tears. But the striking beauty of the region left an indelible impression which my shivers could never shake away.

And then I attempted a dogsled ride, feeling terribly sorry for the fabulous huskies speeding along on the frozen lake as if they were having the time of their lives.

The ride through the snow-white fairy-tale world was accompanied by an icy wind hitting me full in the face. I shut my eyes tightly, knowing this had to come to an end sometime.

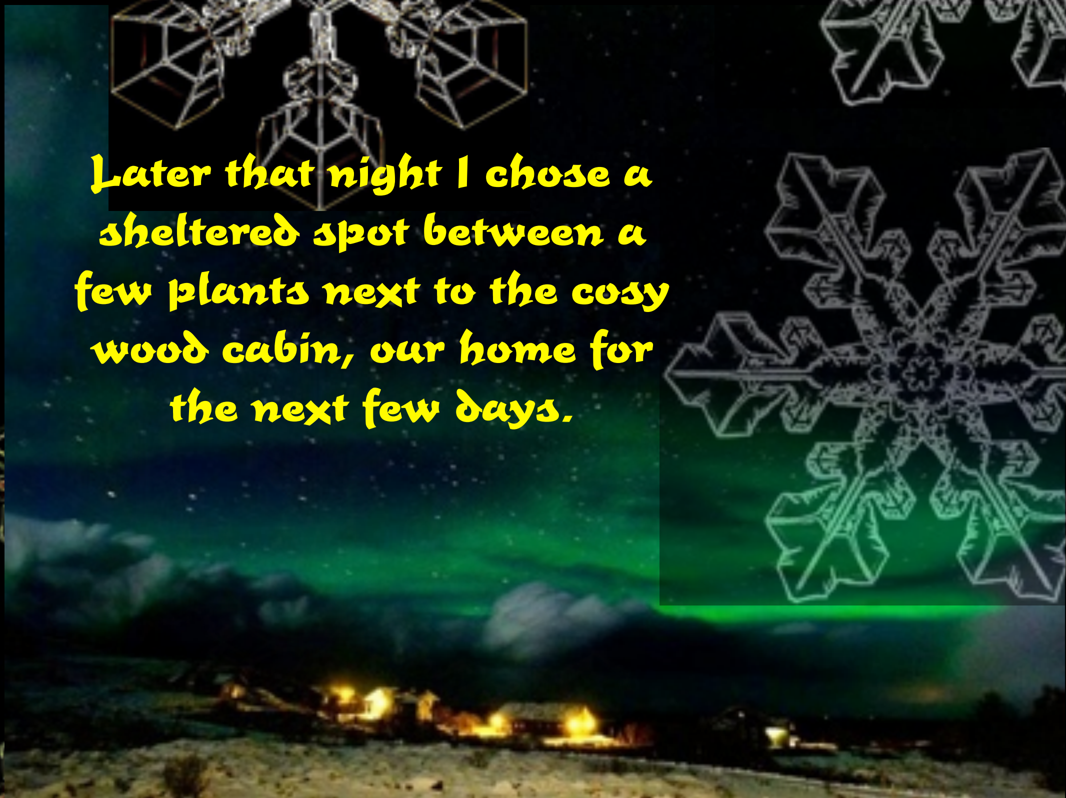
Cold we forget,
warmth lingers on.

With much excitement we left for the Norwegian border to travel from Narvik along the many arms of the Ofotfjord lakes and further on to the Lofoton islands, where we would stay for a few days. Against the dark night sky now peeping out from behind the clouds I spotted a few stars for the first time. I could see Ursa Major clearly and without any effort, with the northern star Polaris almost overhead. This brought home to me how close to true north we really were.

The Lofoten islands were originally settled by the Vikings. Today it is a centre of the Norwegian fishing industry. The town of Harstad is a picturesque harbour village perched seemingly precariously on the Vagsfjord. Locals call it the Pearl of Northern Norway This northerly region is in the middle of the northern lights belt.

From there we travelled through the strikingly beautiful fjords and islands to the well-known city of Tromso. The city was experiencing a snowstorm and I wondered if I would ever survive this trip.

Tromso is on the coast, surrounded by pristine mountains and other scenic views. Waterfalls of ice are everywhere; even little water streams on the stones have tentacles of ice on them. The city also houses the northernmost wooden cathedral in its centre. Tromso with its 73 000 inhabitants is also known as one of the most likely places from which one will be able to observe the Aurora Borealis, or northern lights. My place was already booked to tackle a night trip with a tour guide which would take us further north of Tromso up to near Finland.



Later that night I chose a sheltered spot between a few plants next to the cosy wood cabin, our home for the next few days.

Gossamer snowflakes appeared with their unique, finely woven lace patterns on my coat sleeves, and my enlarged photo of them subsequently showed each one's unique precision.

Unrecognisably wrapped up in protective wear to shield us against the extreme cold we strain our eyes to search among the clouds threatening to occupy the night sky. The guide stops at the side of the road which winds between the piles of snow. The view alone is enough to create a feeling of icy coldness. Inside the vehicle it is slightly cold because, the guide explains, we have to adapt to the cold awaiting us. Using a shovel he creates a seating area on the slope of a pile of snow and places an antelope skin over it. And so, we sit there drinking hot soup, while with some effort a small fire is made on top of a few stumps of wood, its light almost out of keeping with the area around us adorned in white.

Then, as if from nowhere, a beautiful glow appeared on the northern horizon which soon transformed itself into long streaks of light appearing to play in the wind.

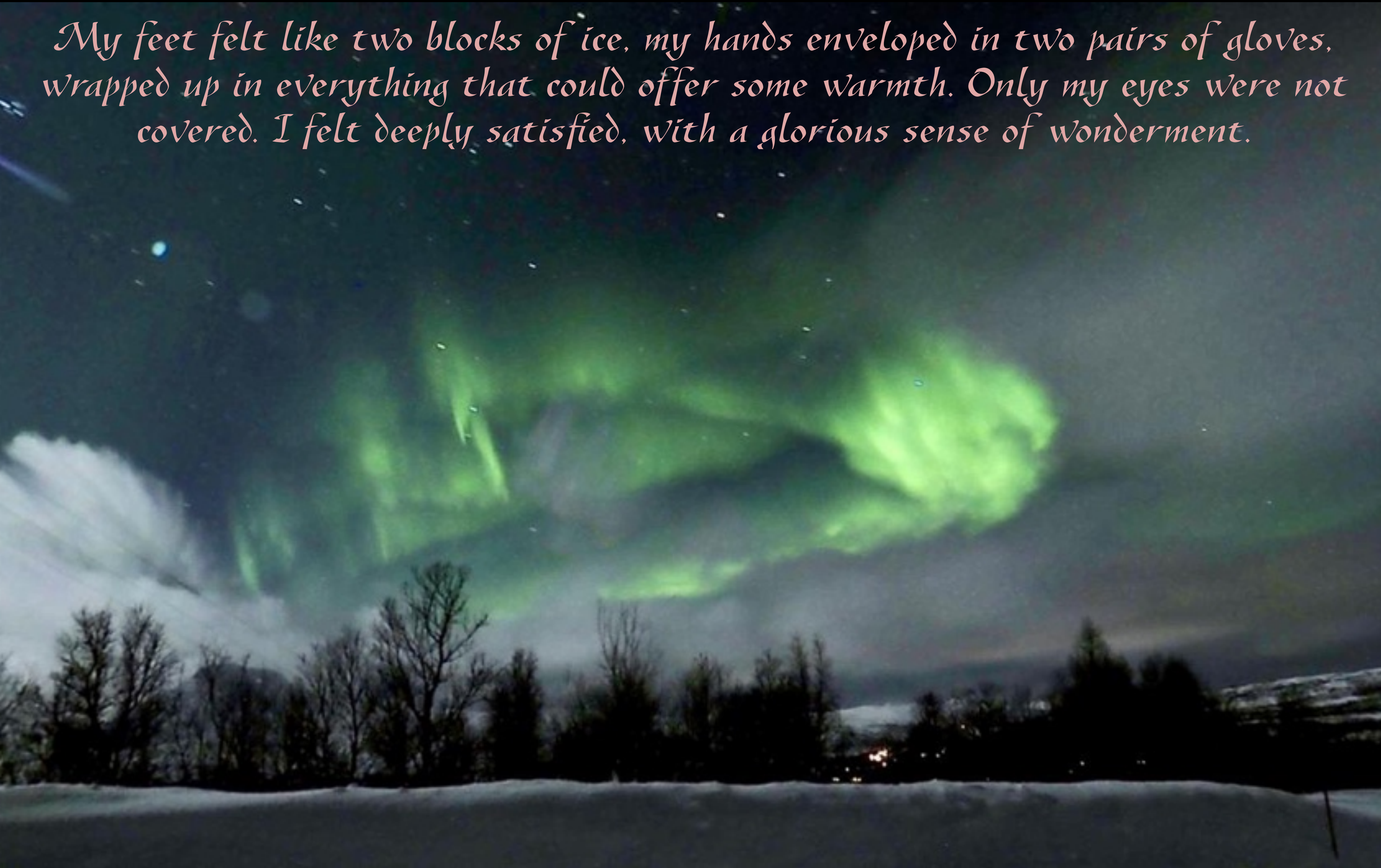
At first, I wasn't sure, but I finally understood that the light green band resting on the horizon could be none other than the shy Aurora now introducing itself to me. Slightly concealed in amongst fleecy clouds. We photographed the Aurora's 'first light' to confirm what we believed the light green band really was.

Like a fire starting up against the horizon, the dancing light suddenly appears like flames slowly reaching up into the sky. We're ecstatic! Streaks of green light grow longer and longer, the hazy Aurora light starting to fold into itself, waving around gracefully against the dark night.

What look like pen-drawn lines and curls reach to the further ends of the heavens, some parts brighter with faint red glows here and there. The coloured light dances as if in a musical fountain, with total abandon.

The guide explains the phenomenon and assures us of our good fortune in being able to witness this spectacle – not everyone is always this lucky. The photos, taken by one of our party with an impressive camera and kindly shared with the rest of us, tell something of our fairy tale experience.

My feet felt like two blocks of ice, my hands enveloped in two pairs of gloves, wrapped up in everything that could offer some warmth. Only my eyes were not covered. I felt deeply satisfied, with a glorious sense of wonderment.



Because of snow and moisture in the air the Aurora is not very clear, but it does show up as a definite contrast against the clouds which at times would completely cover the sky.

The night was already far advanced when Tromso's lights appeared at the far end of the pale landscape.

Not only had I been able to survive all the hardships, my heart was left warm with memories to treasure forever.

This will be with me always

Moonset over the Atlantic, digitally enhanced image from NASA International Space Station archives

Carol's Space

This issue of Carol's Space comes at a time of a major pandemic affecting every human being on planet Earth.

Back in 1955 Pete Seeger pondered the consequences of human behaviour and now we're in 2020 and still the question remains: When will we ever learn?

Knowledge will give us the capacity to respond effectively to challenges.

I firmly believe that by gaining an understanding of the universe we may learn to appreciate our own planet and respect all living beings.

In my small way I hope to encourage others to look up at the night sky with enquiring minds.


Where have all the flowers gone Long time passing?
Where have all the flowers gone Long time ago?
Where have all the flowers gone? Young girls picked them every one
When will they ever learn? When will they ever learn?
© Mike Shaw, 2020

I started off by observing the night sky with the naked eye and got great satisfaction from determining which one of all the crosses was the actual Southern Cross!

One by one I found other constellations and became acquainted with the brightest stars.

I soon realised that I was about to go on the most amazing journey of discovery.

No matter how stressful the day, looking up at the night sky seemed to wash all my troubles away.

Stepping up to binoculars revealed objects not visible to the naked eye.

Breathtakingly beautiful, open star clusters glistened like diamonds and globular clusters like faint blobs of cotton wool. I could even spot a galaxy or two although they seemed just breaths of mist.

Ultimately my telescope opened up a whole new universe. Globular clusters became splashes of stars and galaxies showed more structure.

Nothing beats reverting back to binoculars to scan the heavens from horizon to horizon.

Way back in 2008, I was set for a dawn to dusk marathon of deep sky observing.

In a quarry on the outskirts of Sutherland in the Karoo, I pointed my Dobsonian at the familiar open cluster M46. There was something different about the cluster.

All the while I had thought that planetary nebulae were beyond the reach of my 8" telescope.

With no light pollution and in temperatures below zero, I plucked my first planetary nebula, NGC 2438, from the sky.

Since that night, I have paid close attention to certain individual stars, which seem to have a slight bluish-greenish tint, looking like Uranus.

I have always liked adding sketches to my observing logs.

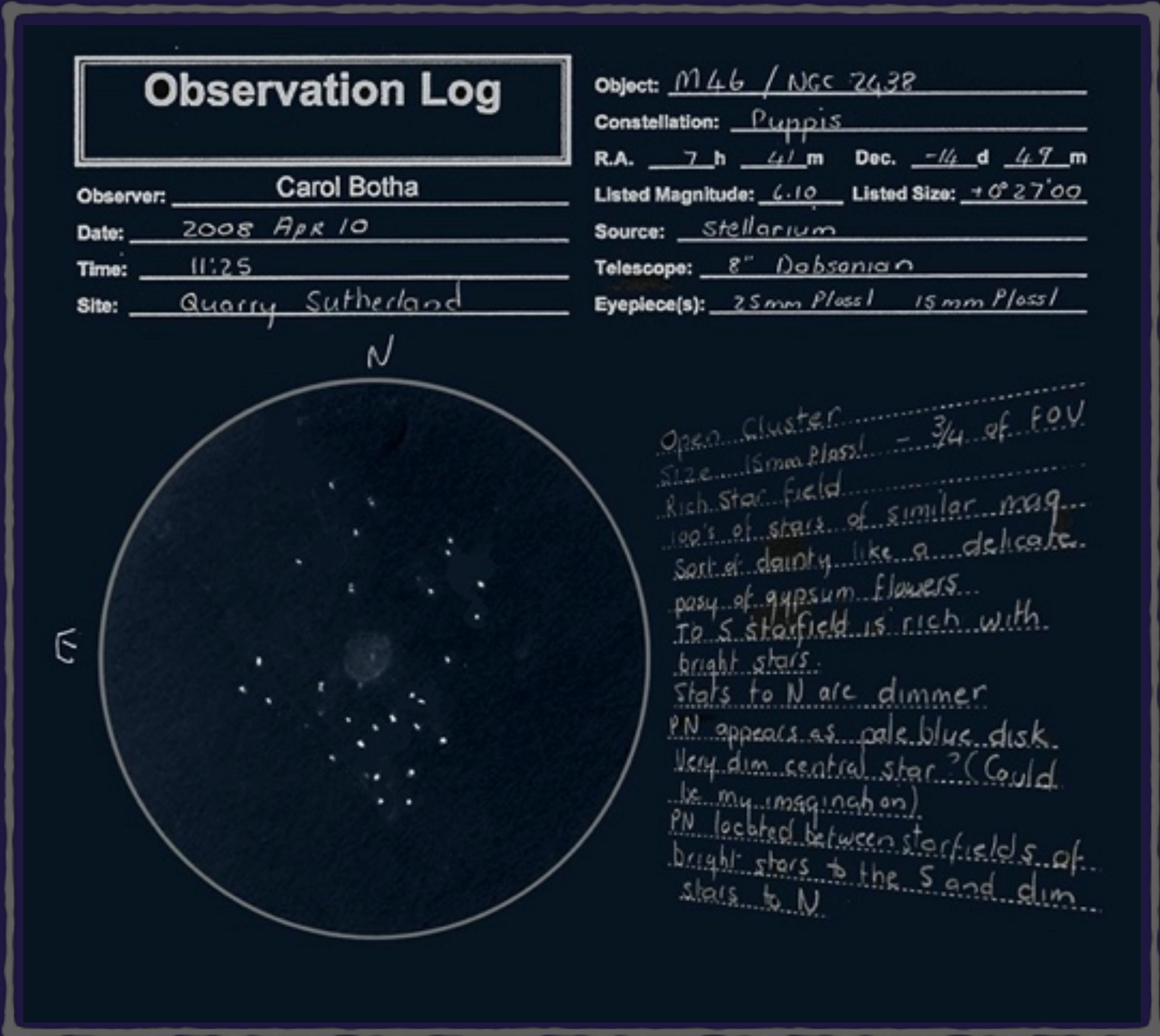
This old school tradition has helped me develop keen observation, not only at night but in the daytime too.

It is definitely a mental workout which improves concentration.

I designed a red lightbox to fit a tripod and sketch on 200gm translucent paper.

At one stage I changed my glasses into a monocle – right sans lens into the eyepiece, left with lens for sketching!

Finally putting my very own stamp on my log is most fulfilling.



Observation Log

Observer: Carol Botha
Date: 2008 Apr 10
Time: 11:25
Site: Quarry Sutherland

Object: M46 / NGC 2438
Constellation: Puppis
R.A. 7 h 41 m Dec. -14 d 49 m
Listed Magnitude: 6.10 Listed Size: +0°27'00
Source: Stellarium
Telescope: 8" Dobsonian
Eyepiece(s): 25mm Plossl 15mm Plossl

Open Cluster
Size 15mm Plossl – 3/4 of FOV
Rich star field
100's of stars of similar mag.
Sort of dainty like a delicate
posy of gypsum flowers.
To S starfield is rich with
bright stars.
Stars to N are dimmer
PN appears as pale blue disk.
Very dim central star? (Could
be my imagination)
PN located between starfields of
bright stars to the S and dim
stars to N

As some may know, my astro-adventures have taken a new direction.

After years using Dobsonians and not budging when computerised telescopes became the norm, I took an extreme step to online observing.

After doing some research, I decided Slooh would provide the perfect platform for my gravity- assist-manoeuvre to venture further in to space.

In Sept 2017, I tiptoed into virtual space. Since then Slooh's telescopes have been at the mercy of a granny down in South Africa.

I wrapped my head around the rand-exchange-rate and waited for the opportune moment. My husband had taken on an Audi S4-Quattro-something project.

I climbed on the equal rights bandwagon and the universe was at my fingertips with the click of a Paypal button.

I remember outreach events, being on a roll to distant objects, when someone in the crowd would ask. ”What did this thing cost?” Talk about slamming on the brakes when you are travelling at the speed of light!

Astronomy is my passion thus I’ve now built Slooh into my budget as a basic necessity and thus it is not up for discussion.

Night after night I observed missions by other members eventually plucking up courage to set up my own.

Out of all the magnificent objects that I could have chosen from the Slooh 500 list I chose Kapteyn's Star as my first-light object.

Maybe it was because the star was much in the news when Kapteyn b, a potentially habitable rocky planet five times the size of Earth, was discovered in 2014.

Maybe I was putting Slooh's Chile One Telescope to the test, figuring if I could find the teeny tiny M1-class red dwarf, then online observing would be the way to go yielding results that up to then I could only dream of.

Image from the archives: Slooh's Chile Observatory before the major revamp in 2019

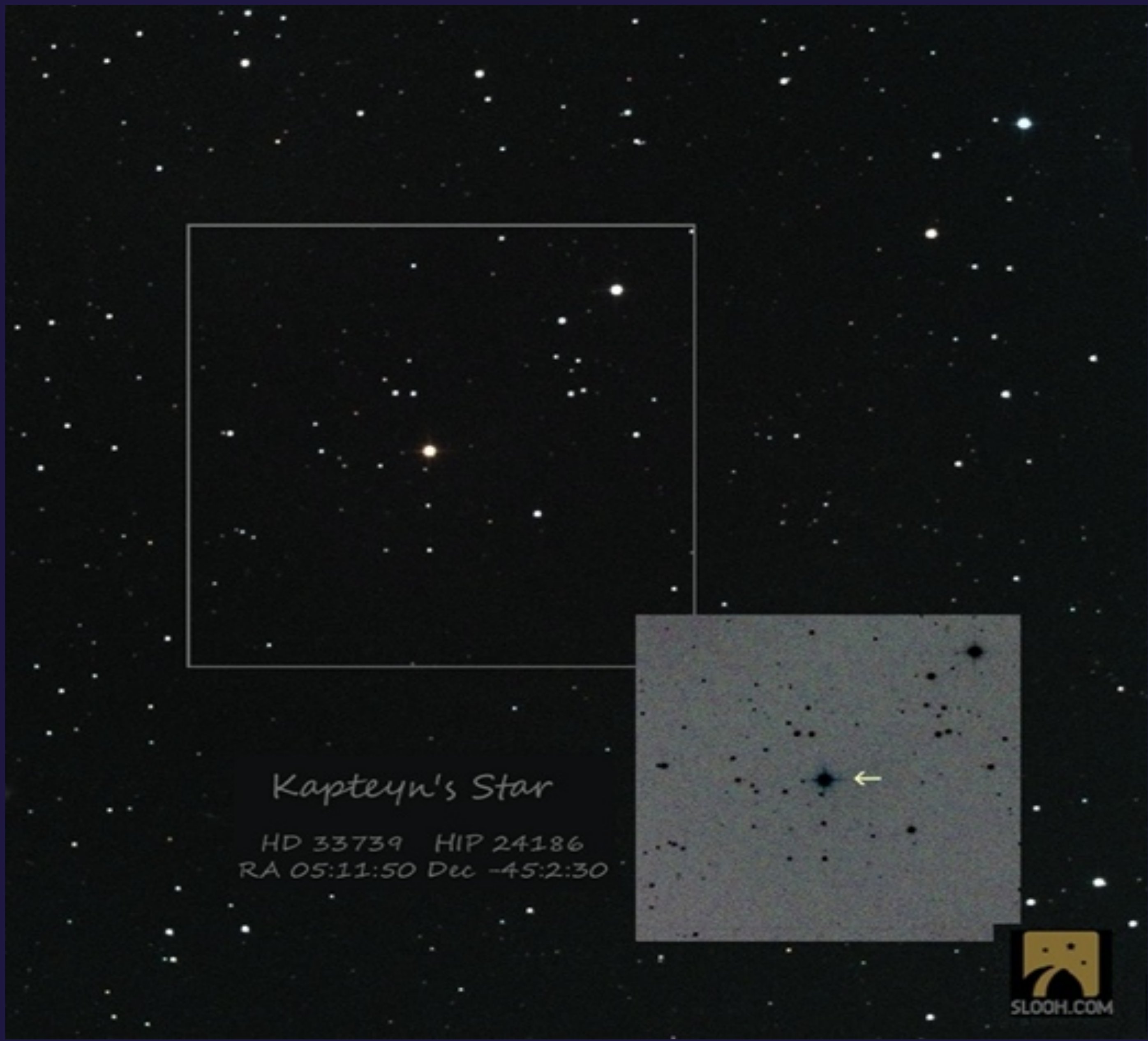
My heart pounded as I set up my first mission. I was sending a telescope on a mountain in Chile on a joyride to Kapteyn's star.

On top of that, my mission would be seen by hundreds of Slooh members. What if there was nothing to see!

My very first image of Kapteyn's star is still sitting proudly in my photo roll.

The Slooh best list now includes 1000 objects – some additions have been attributed to me!

Always a firm favourite to remind me of nights, spent with friends, under the stars is M46 with planetary nebula ngc 2438 in line of sight.



Just when I thought life could not get better I heard that a huge box had arrived at Slooh headquarters.

I designed a box, posted my pic in discussions with heading: What's in the box? This resulted in a guessing game, some even wondering whether Paul Cox could be hiding in there!

Everyone played along. We were kept in the loop throughout. From the moment the box was loaded on a flight, to the anxious moments when riots in Santiago threatened the safety of the Slooh team, to the preparation of the pier where jack hammers were involved, to the installation and unveiling.

At astronomical twilght, weather permitting, a four shutter clamshell dome at the La Pontificia Universidad Católica de Chile (PUC), Santa Martina Observatory, La Dehesa, Santiago,Chile opens .

All available mission slots have been booked. For the 17” Planewave Instrument, it will be a busy night as it slews from object to object across the southern skies.

Its CCD CAMERA, Finger Lake Instruments Proline PL16803, will be recording every mission.

I will watch in awe.

I love the community vibe at Slooh and how input from each member is welcomed and appreciated. Seasoned astronomers and beginners encourage and inspire one another.

When there's a live show or a major happening like Chile Two's first light night, there's a total buzz in the chat box as friends gather from all over the world.

Slooh Astronomer and observatory manager, Paul Cox, captured Cen A on Chile Two's first night of operation. This is how we saw it without any processing.

I just knew that working on this scope was going to be special.

Centaurus A. Chile Two. Mission Paul Cox

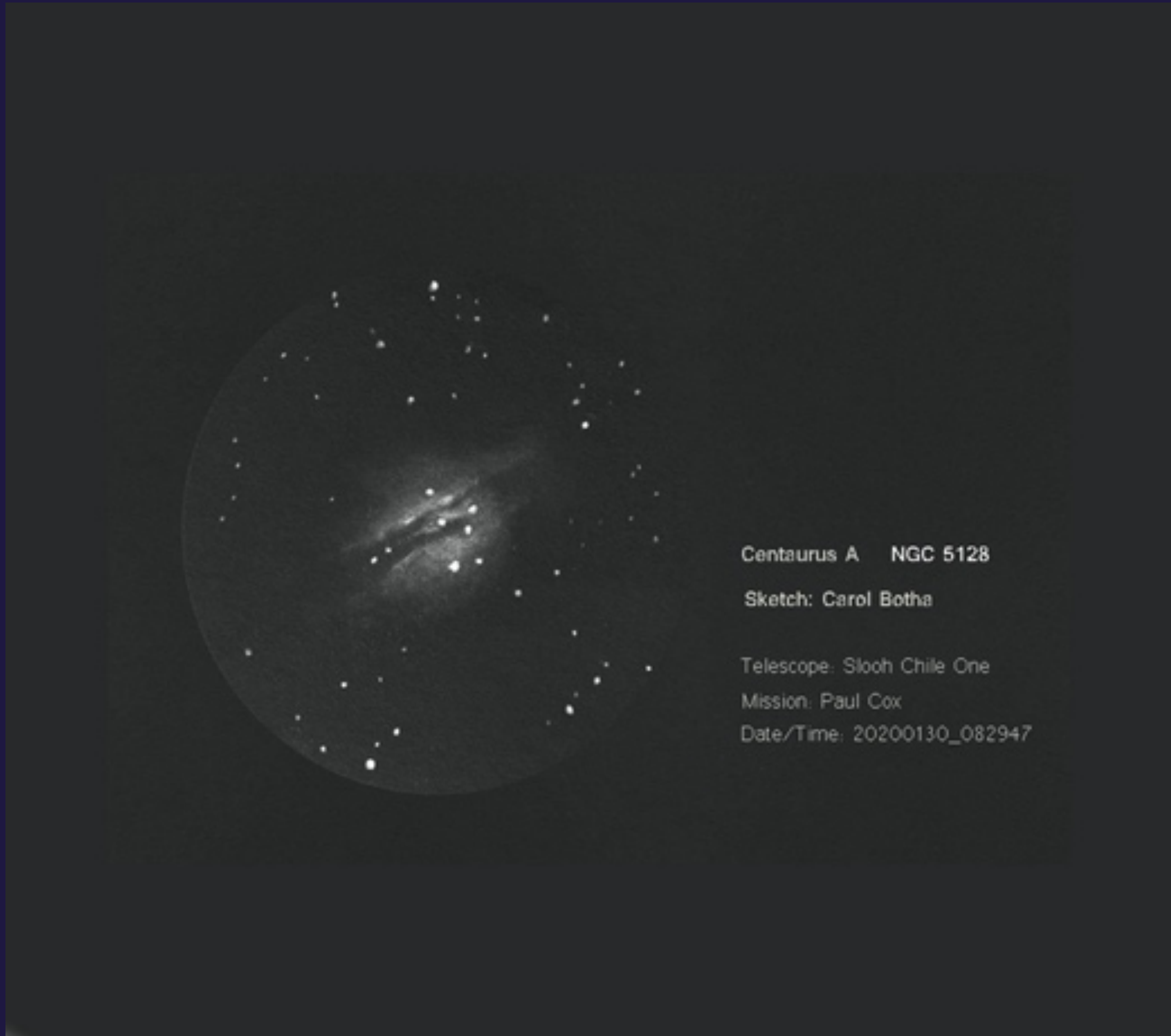
I had my sketchpad and pencils ready.

Sketching live while online is somewhat different. I only have 5 minutes to do a basic sketch which I then hone during subsequent missions.

However, on first light night, I had ample opportunity to observe this awesome galaxy.

Somewhere, something incredible is waiting to be known. For small creatures such as us the vastness is bearable only through love.
We're made of star stuff.
We are a way for the cosmos to know itself.

-Carl Sagan-



Some of my Slooh friends are doing amazing astro-photography and are a true inspiration.

I'd like to share the Eta Carina Nebula (ngc 3372)
Mosaic March 14th, 2020 by Jarmo Ruuth (@jarmoruuth)

Jarmo Ruuth used the Chile Two Wide-Field CDK17 telescope to create this astonishing 4-panel mosaic of the colossal Eta Carinae Nebula.

Each of the four panels was processed in PixInsight, ICE and Photoshop using only 2 x 50-second luminous filtered images and 2 x 20-second Red, Green and Blue filtered images.

Another favourite of mine is this image of the Pencil Nebula (ngc 2736) by David Mihalic.

It is part of the enormous Vela Supernova Remnant.

David Mihalic used Slooh's new Planewave CDK 17 based at its Chile observatory to capture the Pencil Nebula (ngc 2736) April 3rd, 2020.

Processing was done with PixInsight, Photoshop (w/Annie's Actions, Astronomy Tools) and Topaz Studio.

The image was made up of 37 x 50-second Luminance filtered images and 4 x 20-second Red, Green and Blue filtered images.

Carol Botha

Observer of the deep sky

Member of the Orion Observation Group,
Astronomical Society of Southern Africa,
Slooh.com online robotic telescopes

I don't go far in the beginning
I go some distance and come back again
Then in another direction
and come back,
then again in another direction
Gradually I know how everything is,
then I can go out far
without losing my way

-Australian Aborigine –

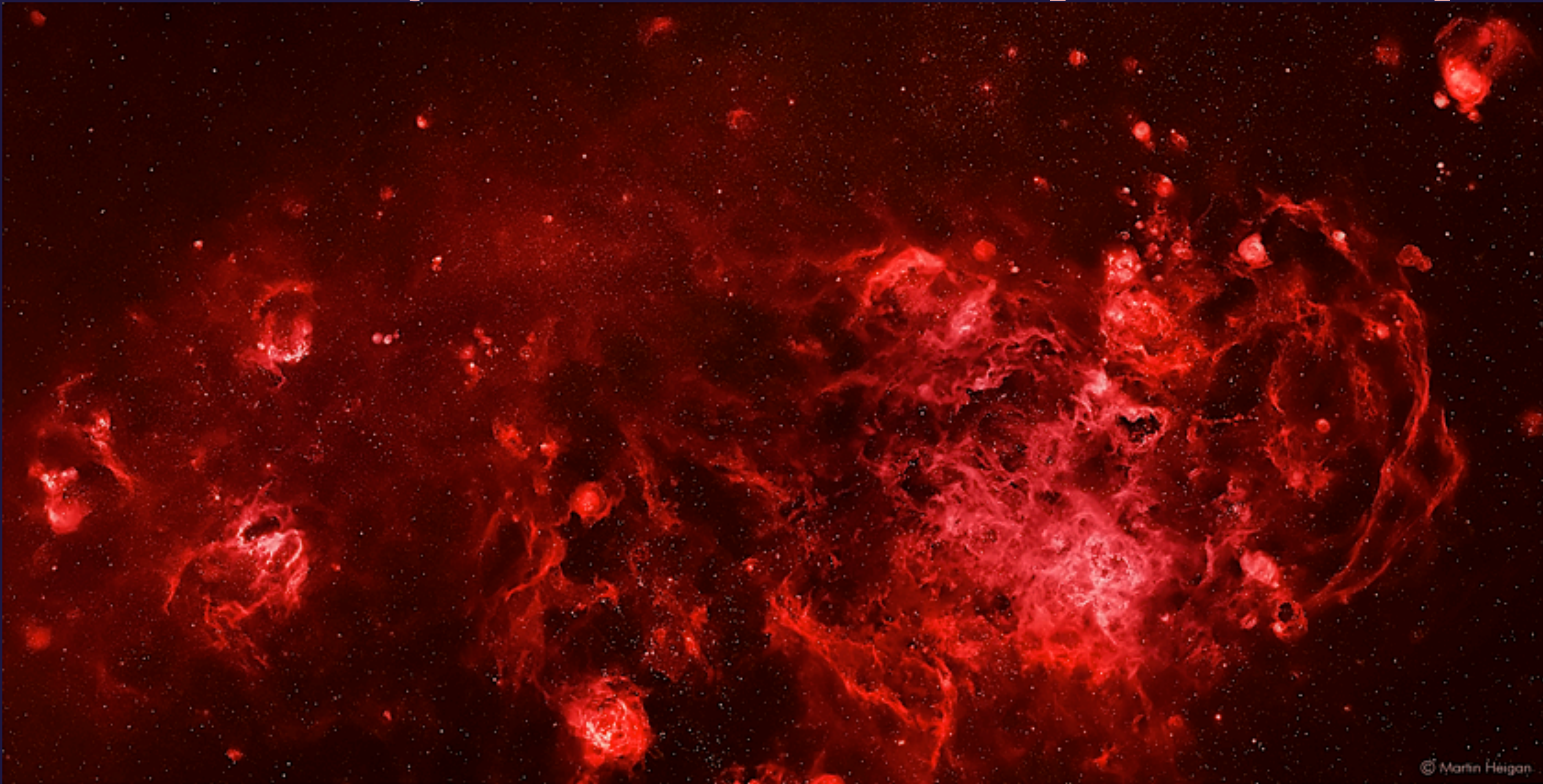
Quoted by Anthony Aveni in People of the Sky

I would like to thank Slooh, Paul Cox, Mike Shaw, David Mahalic, Jarmo Ruth and Auke Slotegraaf for their image contributions


excursion Doringboom, Sutherland
©Auke Slotegraaf


When I follow the serried multitude of the stars in their
circular course, my feet no longer touch the earth.
-Ptolemy

Martin Heigan's LMC – the Conveyor Belt Galaxy

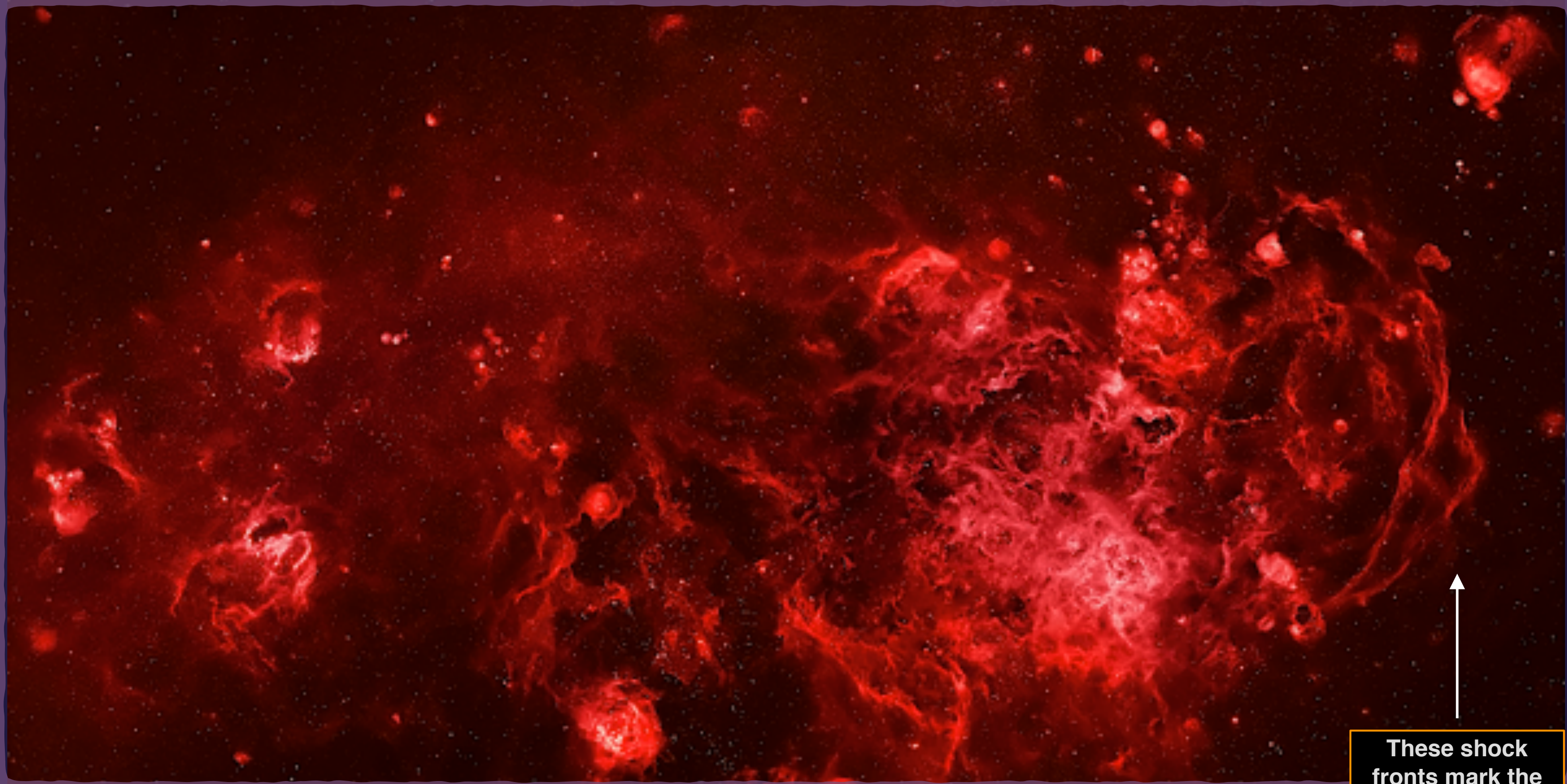


The Magellanic Clouds are two tomcats that have been stealing from each other's food dishes for billions of years. They have 'interacted' with each another four times in the last 6.3 billion years. Usually the Small Cloud comes our the poorer — it has lost around 90% of its primordial hydrogen gas and around 60% of its stars in that time. However, some 300 million years ago the two tangled again.

This time the smaller galaxy whacked the Large Cloud so hard that it ripped one of the massive galaxy's arms completely off, then pried the central bar loose from the central bulge, home to the galaxy's oldest stars. Today the middle-aged bar stars teeter 3200 light years above the one-armed spiral disc at a lopsided 8° angle. The collision shredded vast clouds of primordial hydrogen gas, which is now forming star clusters.

The hydrogen gas clouds that pervade space are not simply atomic gas alone. Every species of atom in the Periodic Table is found in space — which is, after all, where they came from here on Earth. Significant quantities of minute dust particles also occupy the same volumes of space as the gas. The dust originates in the cool atmospheres of certain stars and can assemble into quite complex molecules. Space dust comes in two basic types: *aromatic* carbon-based ring structures, and *aliphatic* linear molecules based on carbon, silica, sulphur, and other atoms. All these atoms were made inside stars and ejected later into space.

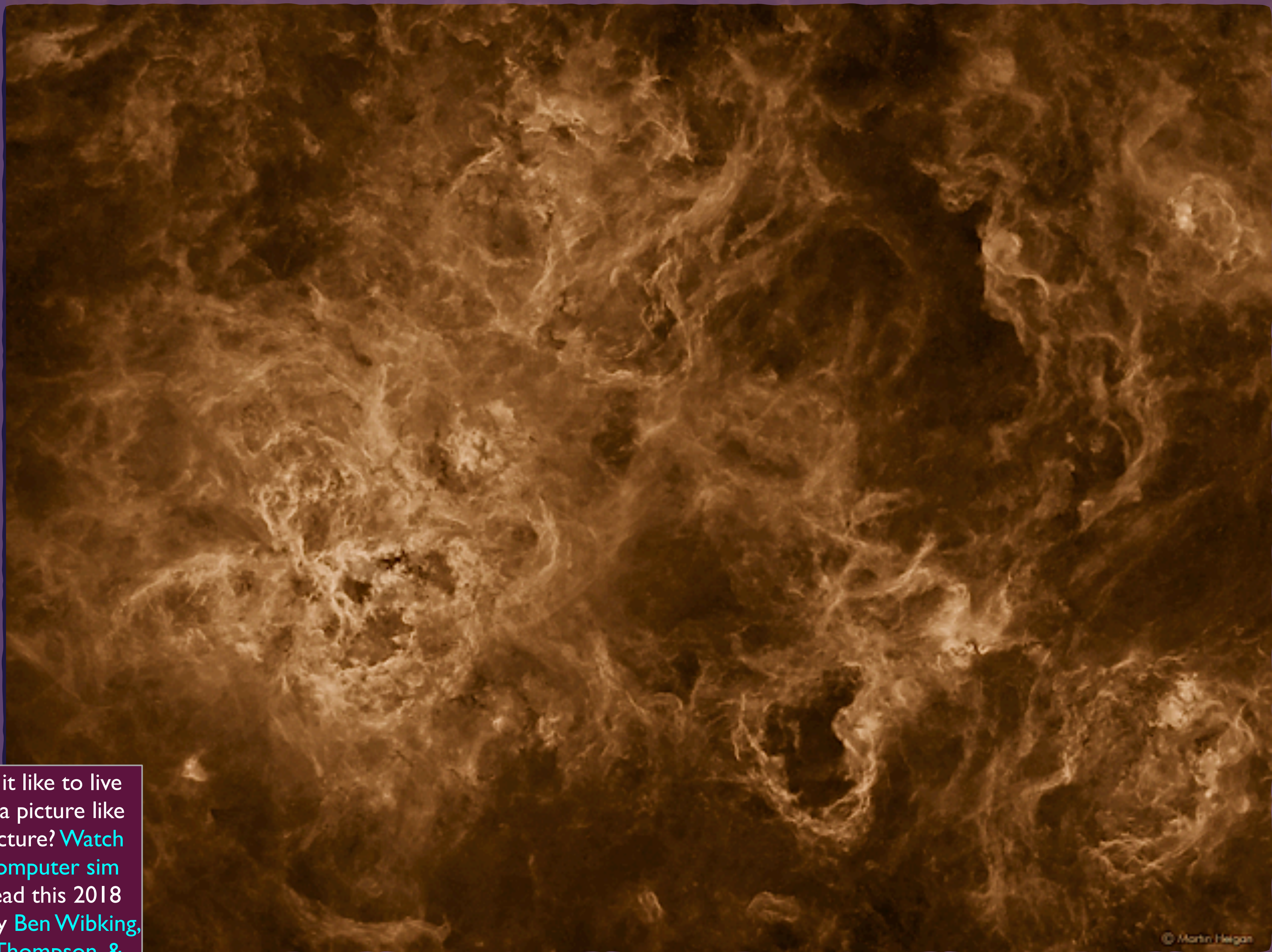
Dust particles in space, like those in the Earth's atmosphere, respond to physical forces rather differently than the gas in which the particles are embedded. For one, space literally trembles everywhere with supersonic shock waves whose energy is propagated by gas atoms. The shock waves come mainly from stars ejecting gas at velocities much higher than the local sound speed, Mach 1. It may come as a surprise to learn that space is filled with supersonic shock waves when we commonly think of it as a near-vacuum. Yet it is true: local Mach 1 varies according to the medium through which a shock wave passes. A handy rule of thumb is that in space filled with 1 particle per cubic centimetre, Mach 1 is 200 metres per second, or 720 km/hour. At sea level on Earth Mach 1 is 1225 km/hour.



These shock fronts mark the boundary where the LMC gas is colliding with the thin halo gas of the Milky Way at 350 km/second.

Shock waves in space are like those on Earth: they trace the passage of a compression and rarefaction pressure wave speeding through the local medium. It makes no difference whether the medium is dense like water or thin like space: Mach 1 is how fast the pressure wave travels through it at a given point. In Martin's picture we see the evidence of these shock waves as compact arcs and stringy filaments that permeate all through the nebula. Star clusters containing very massive stars profoundly affect their environment. They both mix and disrupt their natal clouds of gas and dust, leaving enduring traces for us to ponder in the composition and patterns of their debris rings.

What does star stuff look like before it gets to be stars?



In star-cluster studies, the term ‘conveyor belt’ refers to multiple episodes of single-cluster formation sequenced over a long epoch of a giant molecular cloud’s collapse. A single star cluster formation episode extends across cloud collapse, star ignition, and gas clearance.

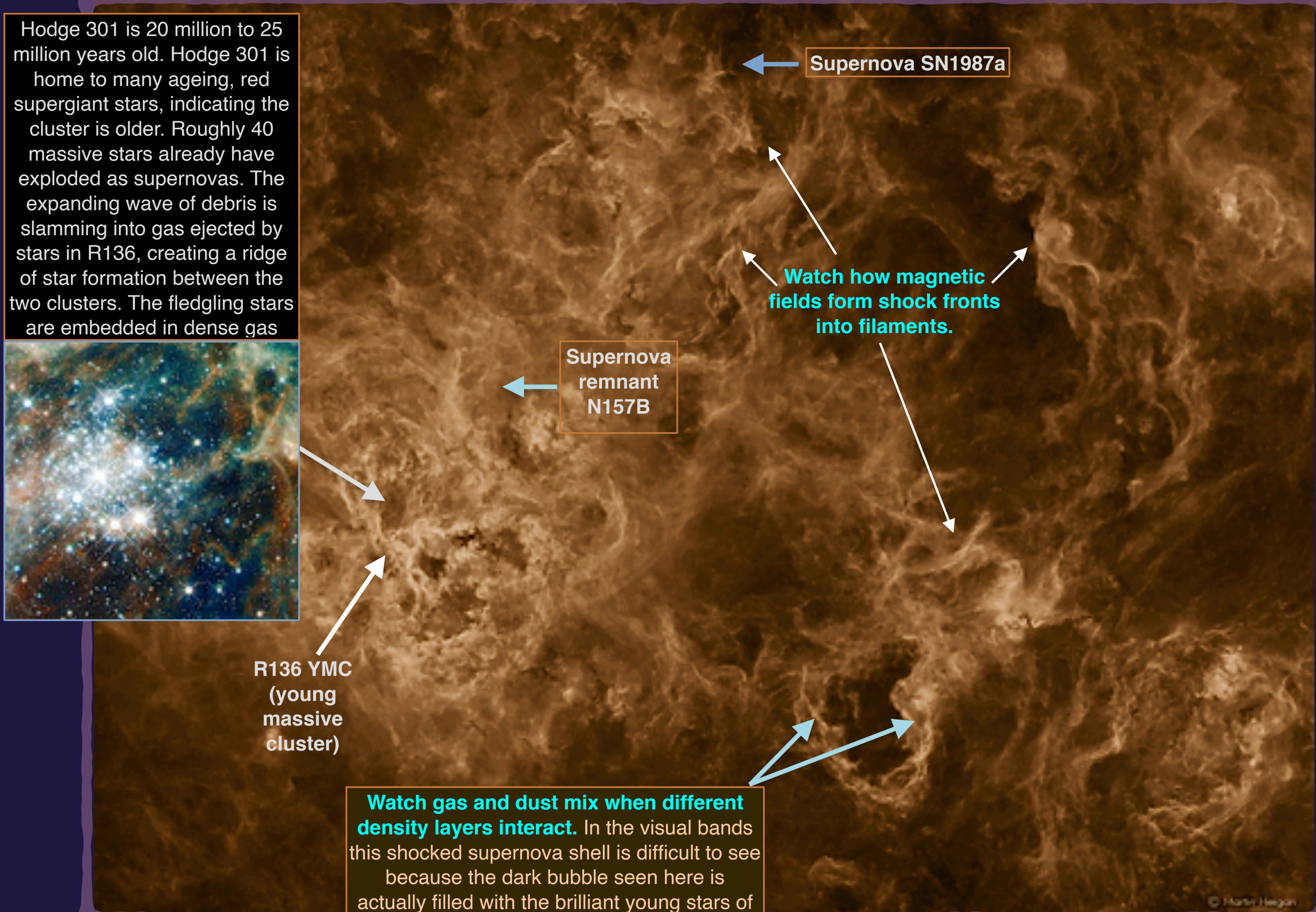
A handy rule of thumb is that a typical cluster episode is ten to fifty million years long.

The cycle is complete when the brightest, most massive stars have been lost into supernova, the last traces of dusty gas are gone, and the remaining stars are ‘in the clear.

What it like to live inside a picture like this picture? Watch this computer sim and read this 2018 paper by Ben Wibking, Todd Thompson, & Mark Krumholz.

Martin's hydrogen-alpha image of the Tarantula Nebula reveals the hidden glow of dust we cannot otherwise see.

Hodge 301 is 20 million to 25 million years old. Hodge 301 is home to many ageing, red supergiant stars, indicating the cluster is older. Roughly 40 massive stars already have exploded as supernovas. The expanding wave of debris is slamming into gas ejected by stars in R136, creating a ridge of star formation between the two clusters. The fledgling stars are embedded in dense gas



Watch gas and dust mix when different density layers interact. In the visual bands this shocked supernova shell is difficult to see because the dark bubble seen here is actually filled with the brilliant young stars of NGC 2074. The diameter of this ring is five times the distance between our Sun and the nearest star to us, Proxima Centauri.

In astronomy, if we want to see the forest, sometimes we have to remove the trees. That's especially true if we want to see stars that will not come into existence for millions of years in the future.

Martin removed the stars in this hydrogen-alpha (Ha) image in order to show us where the LMC's dust is hiding. Galactic dust is intimately associated with Ha gas, but dust is clumpy while the gas is smooth.

Clotty dust threads like those shown here reveal the dense patterns of turbulent shocks that permeate hot, tumultuous star forming regions like the Tarantula Nebula, the knotty complex centre-left here. While visible-light images show the centre of the nebula to be a large cavity filled with stars, this image reveals it to be filled with patchy blobs. The dust is invisible in visual-band images. This suggests that the dust lies on the near and far sides of the R136 star cluster cavity. We need 3-D glasses to see forest the Tarantula lives in.

A one-glance lesson in conveyor-belt cluster formation

The backyard astronomer who can glimpse both R136 and Hodge 301 in the same view at, for example, 150x to 200x, can see both clusters at once. R136 has the air of a youth sprawled all over an easy chair, while Hodge 301 more resembles a shy 19th century maid demurely gathering her petticoats about her knees. Alas, such a winsome image does not last long under the scrutiny of astrophysical reality. Computer models from the SILCC Project show us a vivid variety of scenarios with which we can imagine the future fate of the Tarantula today.

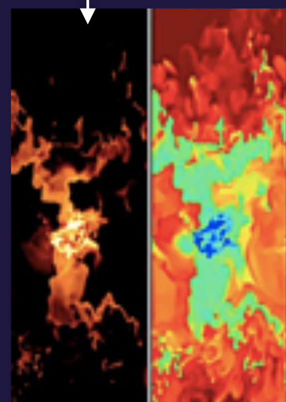
Martin Heigan's Hα image of the Tarantula region is wide-scale not only in arc-degrees per centimetre. It is wide-scale in terms of the time spans we can infer from the distribution of luminosity densities in the various bright clumps and darker cores. Careful inspection reveals that the dust clump distribution in Martin's image does not match the starlight distribution.

The region to the left of the massive R136 cluster which illumines the entire nebula appears empty in visual images like the above. Martin's image suggests that it is obscured by dust clumps. Conversely, the star field to the left of Hodge 301 in the right-hand image is relatively free of emission glow. So it is also in Martin's image. What's the difference?

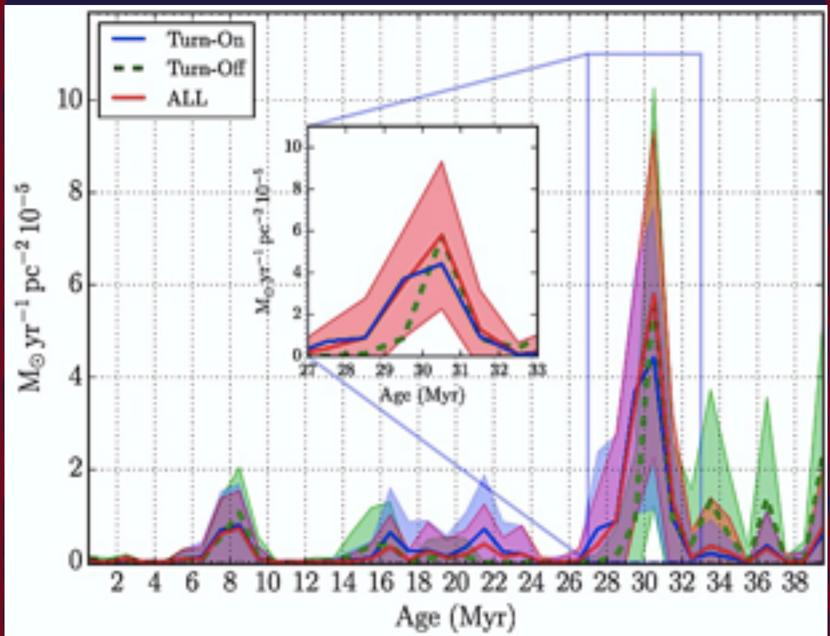
There are two differences. First, the R136 close-up renders the cluster almost as a plane because the image was processed to reveal the rather smallish cluster itself. (Small by Magellanic distance standards.)

Martin's Hα image is more self-evidently a 3D depiction because of the enormous volume enclosing the emission we see. The dust clumps obscuring R136 are in fact in front of and behind the visual cluster, but in Ha light they appear as a thick soupy sheet on all sides of the cluster.

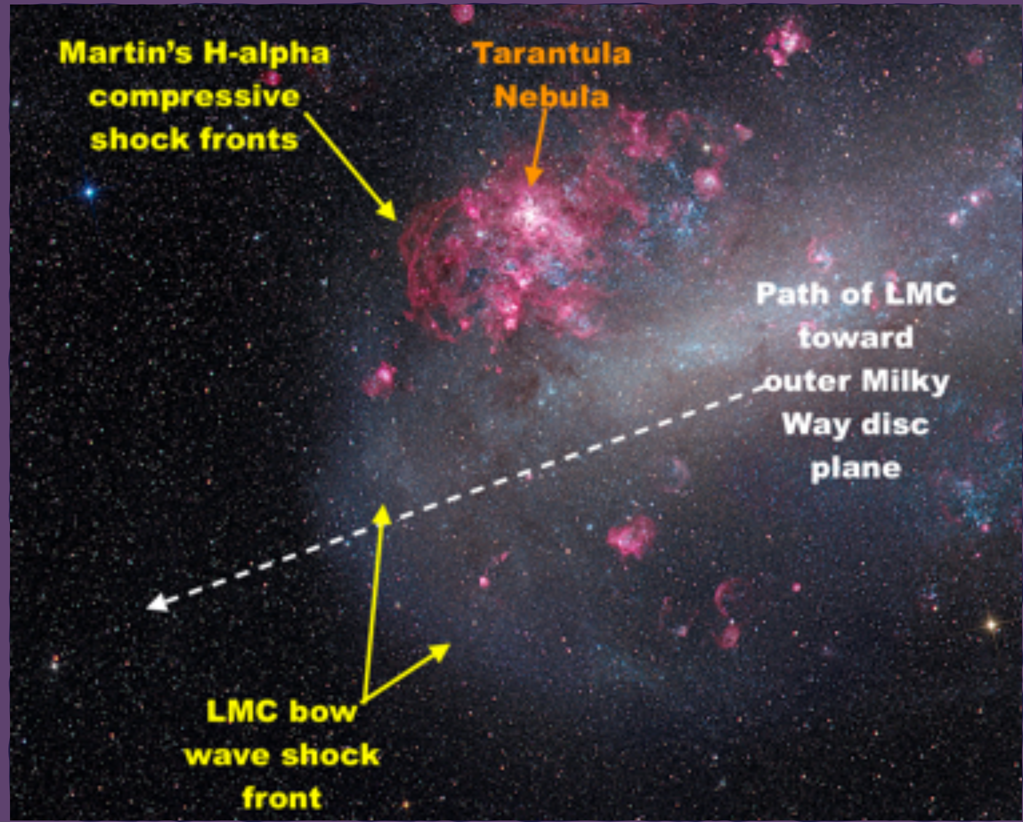
The second difference is time. R136 is a massive young (<2 million year) cluster at the heart of the Tarantula Nebula. Hodge 301 on the right is 38–42 million years old. The two are not really so close to each other inside the vast environs of the Tarantula nebulosity. R136 is so young it has not unleashed the fire storm of its brood of massive stars, due to go supernova across the next 10 million years. The sparsely populated pocket bereft of stars to its left shows us gas clearance by searingly hot ultraviolet radiation. Hodge 301 passed through its brash feisty supernova phase roughly 30 to 40 million years ago. The rather poorly defined nebulosity we see was cleared by supernova shock waves, long since dissipated into wisps and diaphony.



SILCC S10-lowSN-mix 5 SN/myr, mixed-driving 1:1.



The 40 million year conveyor-belt of star formation in the Tarantula Nebula can be traced in peaks and troughs like these. Each new starburst crescendos into supernovae starting 3 to 5 million years after the cluster forms. The cluster's dwindling supply of excess energy then propagates outward to initiate new young clusters. If our ears could listen, we would hear the universe toll like a church bell in the distance. The tolling of a bell, near or far, dwindles to the silence of entropy. Hear it we cannot, for have not the ears. But see it we can, for we do have the eyes.



Galaxies are not tomcats, but they do steal from each other's food dishes. The Small and Large Magellanic Clouds (SMC/LMC) have been tussling and sideswiping for billions of years. We get to watch the show by sheer luck — they are not part of the Milky Way, they just happen to be passing through. In about 80 million years they will elbow their way past the Milky Way's gas-dense disc, then be on their way. No one truly knows when, or if, we will all meet up again.

Alas for the smaller of the pair, their social call on our environs has cost it dearly. In the wrestling ring of the galaxies, the little guys always lose. In the last 200 million years the SMC has been stripped of enough of its primordial hydrogen to make over one billion stars like our Sun.

And who was the lucky beneficiary of all this gas? The Milky Way, of course. It's the biggest of the three, isn't it? Ironically, whatever beings may be gazing up into the sky five hundred million years from now will not be seeing some wondrous new realm of stars whose chemistry resembles the gas of the SMC. Nearly all the gas the Milky Way inherits from the SMC will remain in the halo; rather little will ever find its way down to the disc plane where stars with planets like ours reside. Those eyes far in the future might look up one fine day, and see a wobbly round smudge in the remote reaches of their vision.

What would they say if they saw the picture we know of it, taken by Martin Heigan one fine night in May?

It was all going fine until we pushed the little blue button.

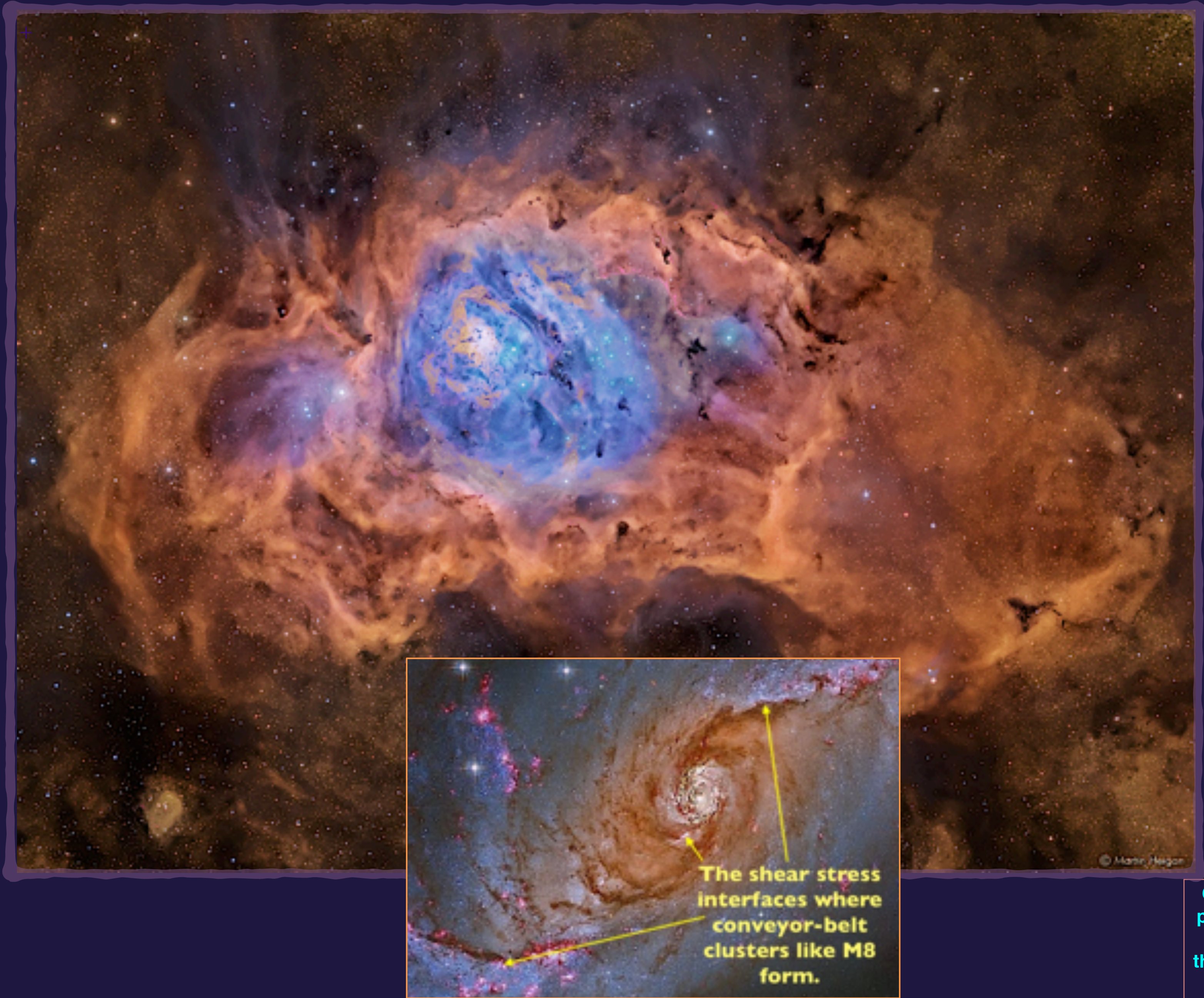
How about another conveyor-belt collapse a little closer to home?

OK ... here's Martin Heigan's M8 Lagoon Nebula

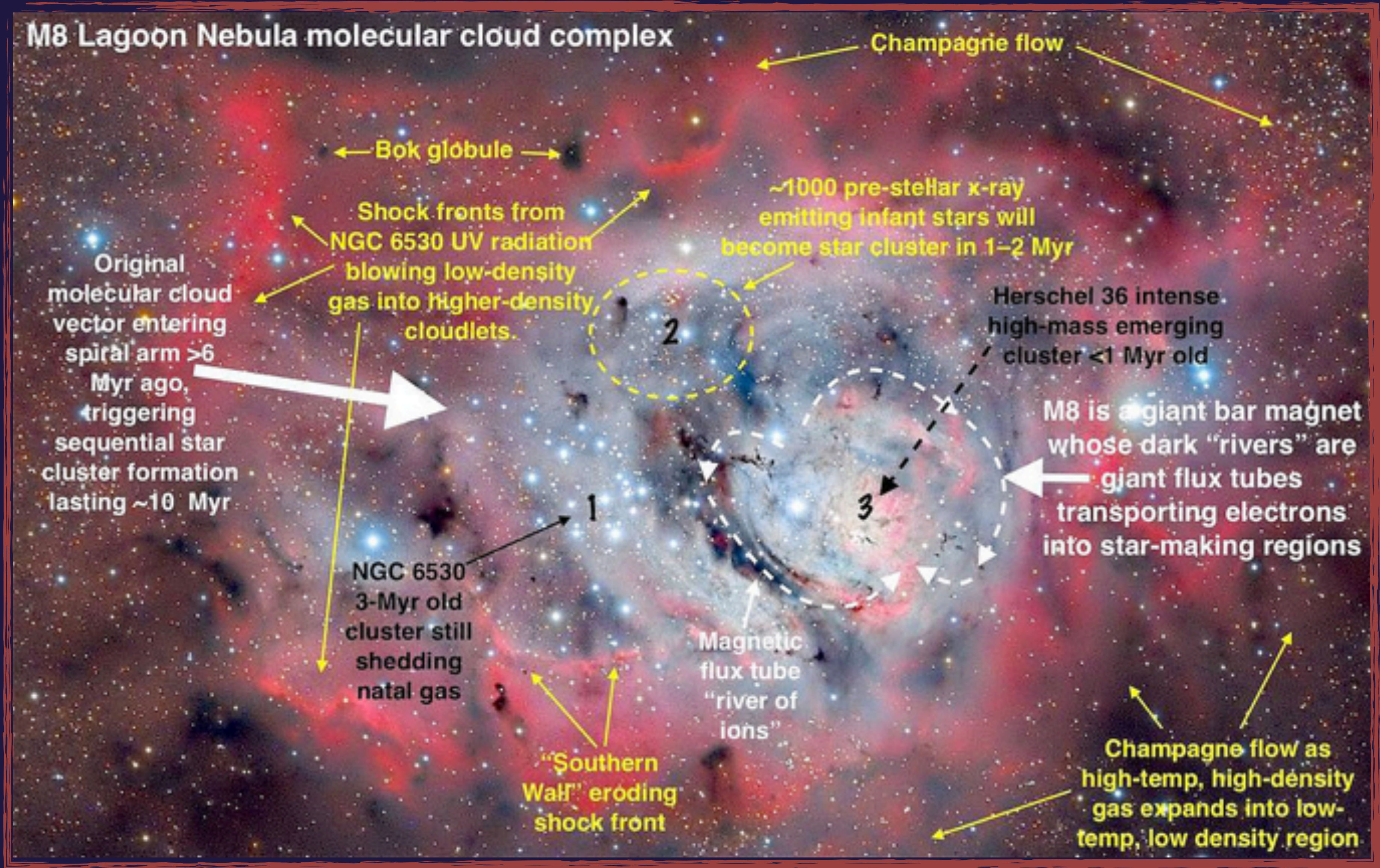
In spiral galaxies like the Milky Way, the mix of hydrogen gas and cosmic dust which comprises the interstellar medium rotates around the centre faster than the spiral-like arms. The arms are not fixed structures, they are density waves like a highway traffic jam. They come, they go.

When a massive clump of cold gas squashes into the inner side of a density wave, the gas squashes out, flattens into a lumpy 'fried-egg sandwich', and curdles into star-forming proto-clusters of several thousand solar-mass stars. The first collapse took about 3 million years. When the most massive stars imploded into supernovae, the shock waves initiated secondary cluster collapses. So far, three massive clusters have coalesced.

The M8 Lagoon Nebula's first massive cluster, NGC 6350, is about 5 million years old. Its nephew Herschel 36 shows here as the bright white spot in the bluish central region of the 'lagoon'. H36 is only about a million years old in still forming stars ferociously.



Get in the pilot's seat and fly through the Lagoon.



Our eyes see stars readily but gas only with difficulty. Indeed, even under ideal late-night sky conditions, we see only about 1% of what really lies out there. Vivid as they are, even Martin Heigan's Ha images add just a few percent to the total amount of radiation coming toward us.

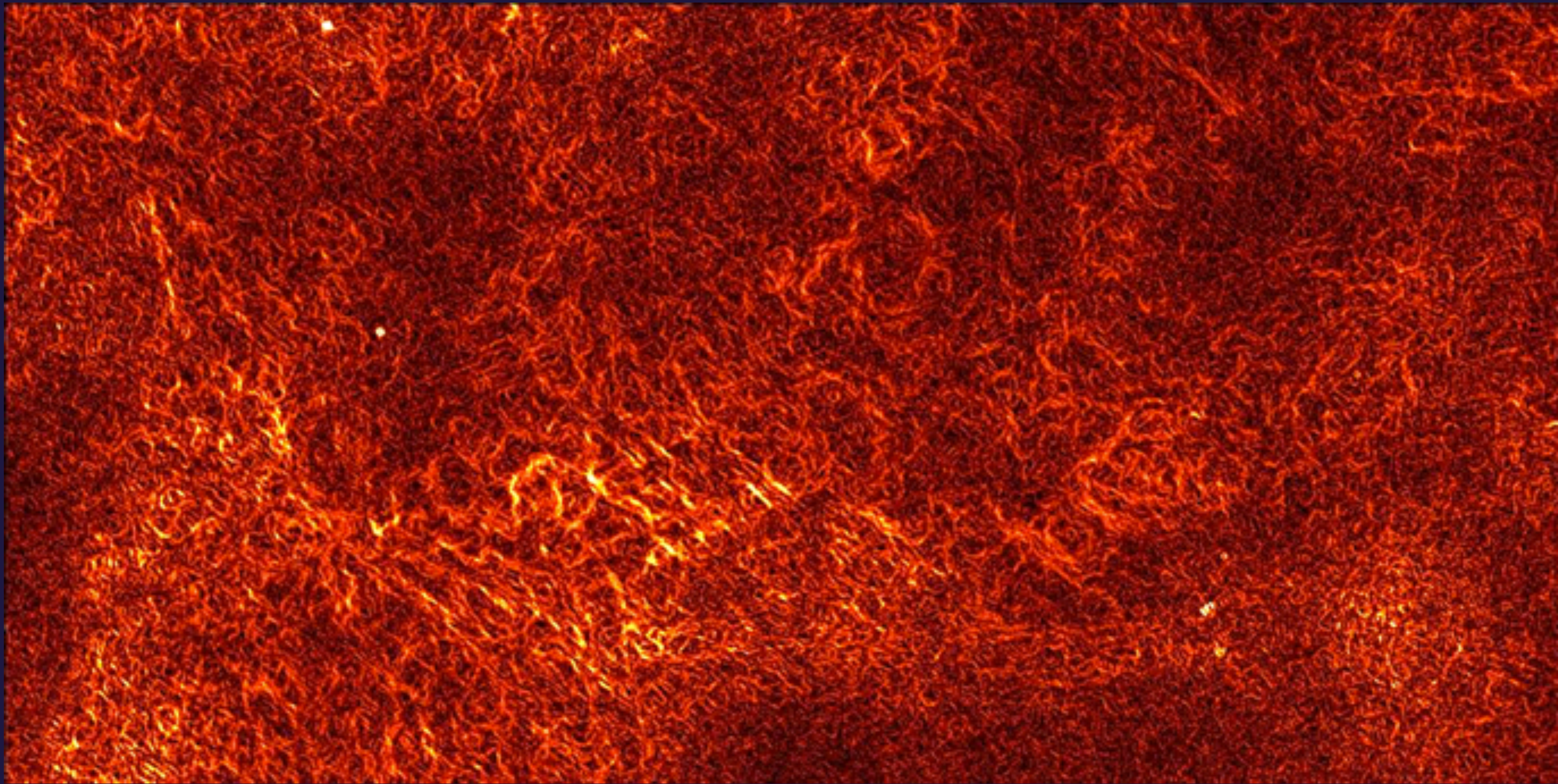
The image to the left adds three other tracers to the traditional night time stars — gas density, dust density, protostellar stars too dim to see, and magnetic fields. The latter cannot be seen directly. Instead, we trace them using the densities of dipolar dust grains using the [C ii] 158 μm and [N ii] 205 μm lines.

Nor can we see the infant protostars, so we look for the hot gas coming from their polar jets, which reveal their presence in X-rays.

Starting about 10 million years ago a massive cold cloud of gas and dust squashed into the Sagittarius-Carina density wave. It smeared itself into the fried-egg sandwich we see in Martin's first image. About 3 million years later the young cluster NGC 6538 (#1 above) reached the coming-of-age hallmark of its first supernova. That was 3 million years ago. From out of its now-cooling embers a small pocket of about 1000 smallish stars (#2 above). Unseen to our eyes, it sparkles in the X-ray spectrum.

About 1.3 million years ago a very hot and large mass of gas collapsed into what is now the Herschel 36 star cluster complex (#3). Through a complex interaction of gas, dust, shock waves, and magnetic fields, Herschel 36 is re-orienting itself from a toroidal (donut-like) magnetic structure into a solenoidal 'flux tube'. Electron flow along the flux tube powers the high-velocity outflow seen on the next page. Perhaps 50 million years will pass between the original 'shear squish' that initiated all this ferocity and the glittery star clusters we will see.

The M8 Lagoon Nebula in Sagittarius is one of the most-photographed regions of the sky. It’s hard to spot something new in here. Yet Martin Heigan’s wide-field image did just that. By applying his own formulation of the standard Hubble Telescope HOO (hydrogen-oxygen-oxygen) palette, his image reveals the entire region around the ‘Lagoon’ to glow with O-III radiation. The region is ‘warm’ at 10,000 to 12,000 K. The fulminous energy source Herschel 36 is seen in both images, but the left-side Hubble Telescope image above reveals the fierce gas outflow from the new-born O supergiant embedded deeply inside.

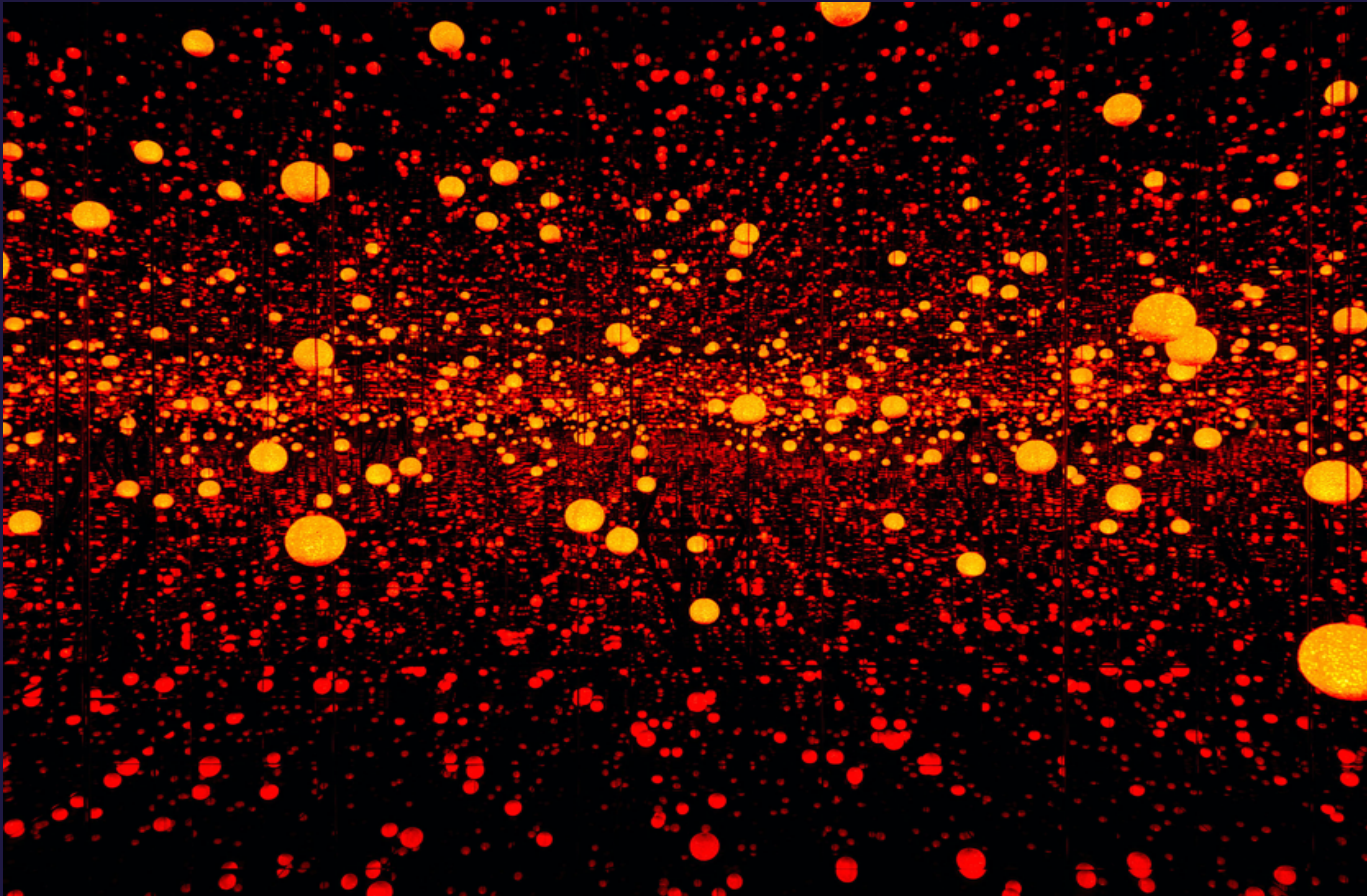


Martin Heigan's magical camera can show us many wondrous things, but it can't show us what would happen if we hurled a jar of science-class iron filings into the giant magnet that is our Milky Way. This picture is actually our familiar old Milky Way, but seen through the eyeglasses of magnetic fields.

Galaxies are a bit more complicated than the iron filings and toy magnets of our school days. Unfortunately, our eyes are not equipped to show us the sky as seen in magnetic fields. Martin's magical cameras can't do that, either, because magnetic fields can be seen directly only when vast numbers of magnetised particles clump together in filamentary structures like the above.

Fortuitous indeed it is that Martin's camera can reveal to us that magnetic fields are just as ubiquitous up there in the night's darkness as the rainbow colours we can see with our eyes. This is because certain species of space dust are dipolar — they are electrically positive on one end and negative on the other. That means they line up with magnetic fields just the same way our iron filings did in school. Since space dust swims amid the tides of hydrogen gas in a galaxy like pepper grains swim in a spicy hot soup, space dust that is aligned magnetically shows up as streaks and threads — just as we see in the picture above.

The image was assembled using observations taken by South Africa's Square Kilometre Array (SKA) Pathfinder telescope. While it surely is an impressive feat of imaging technology, the one thing that the SKA telescope will never show us is the good old fashioned red-to-blue rainbow seen after a storm. SKA can't see rainbows any better than we can see magnetic fields. Win some, lose some.



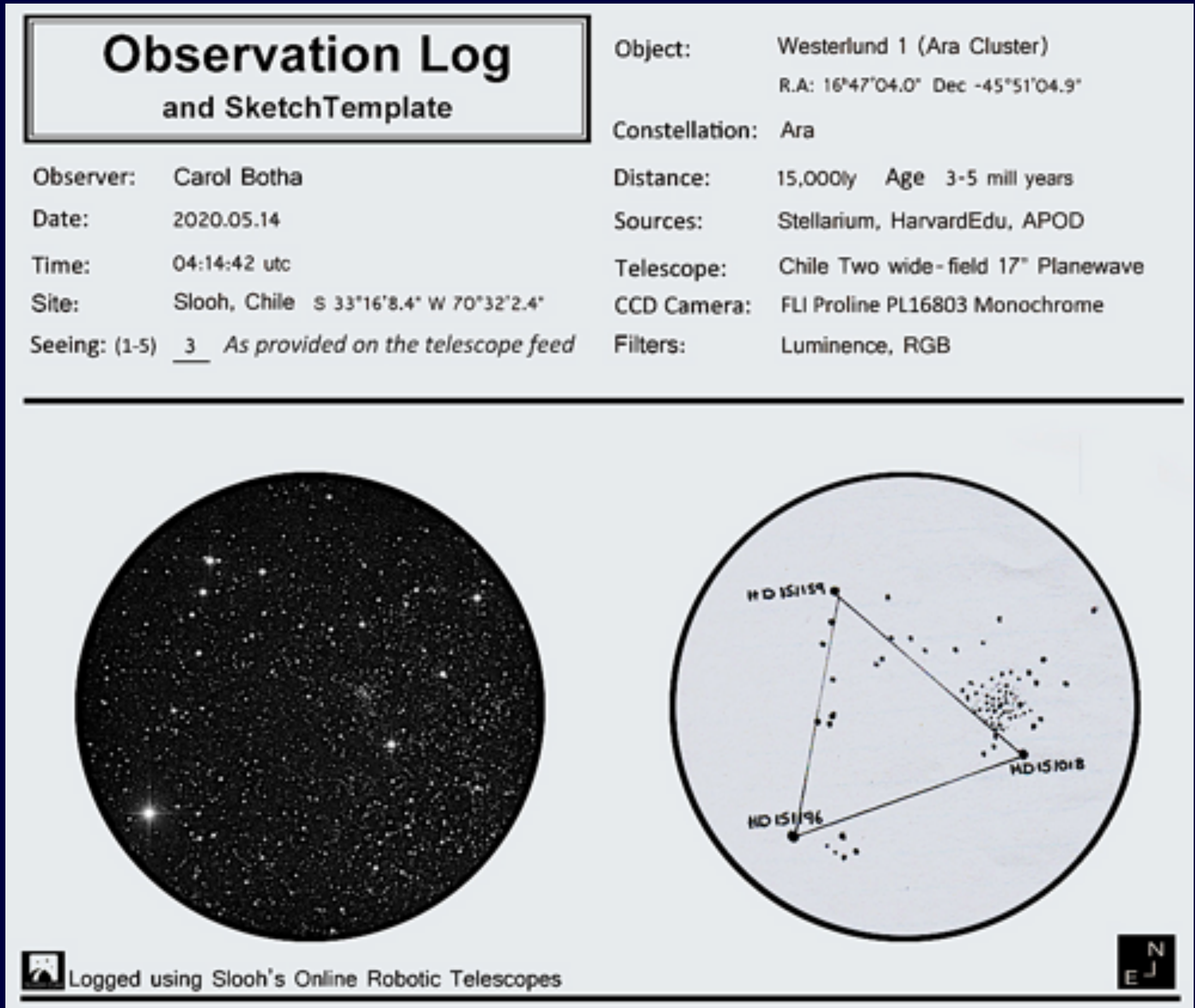
Installation art work *The Soul of Millions of Light Years Away* by Yayoi Kusama, Eli Broad Museum, Los Angeles


Blue Moon by Bastien Foucher

Carol Botha corrals the toughest clusters in the southern sky

WESTERLUND 1

Observations & Notes by Carol Botha



Observation Log
and SketchTemplate

Observer: Carol Botha
Date: 2020.05.14
Time: 04:14:42 utc
Site: Slooh, Chile S 33°16'8.4" W 70°32'2.4"
Seeing: (1-5) 3 *As provided on the telescope feed*

Object: Westerlund 1 (Ara Cluster)
R.A: 16h47'04.0" Dec -45°51'04.9"
Constellation: Ara
Distance: 15,000ly Age 3-5 mill years
Sources: Stellarium, HarvardEdu, APOD
Telescope: Chile Two wide-field 17" Planewave
CCD Camera: FLI Proline PL16803 Monochrome
Filters: Luminence, RGB

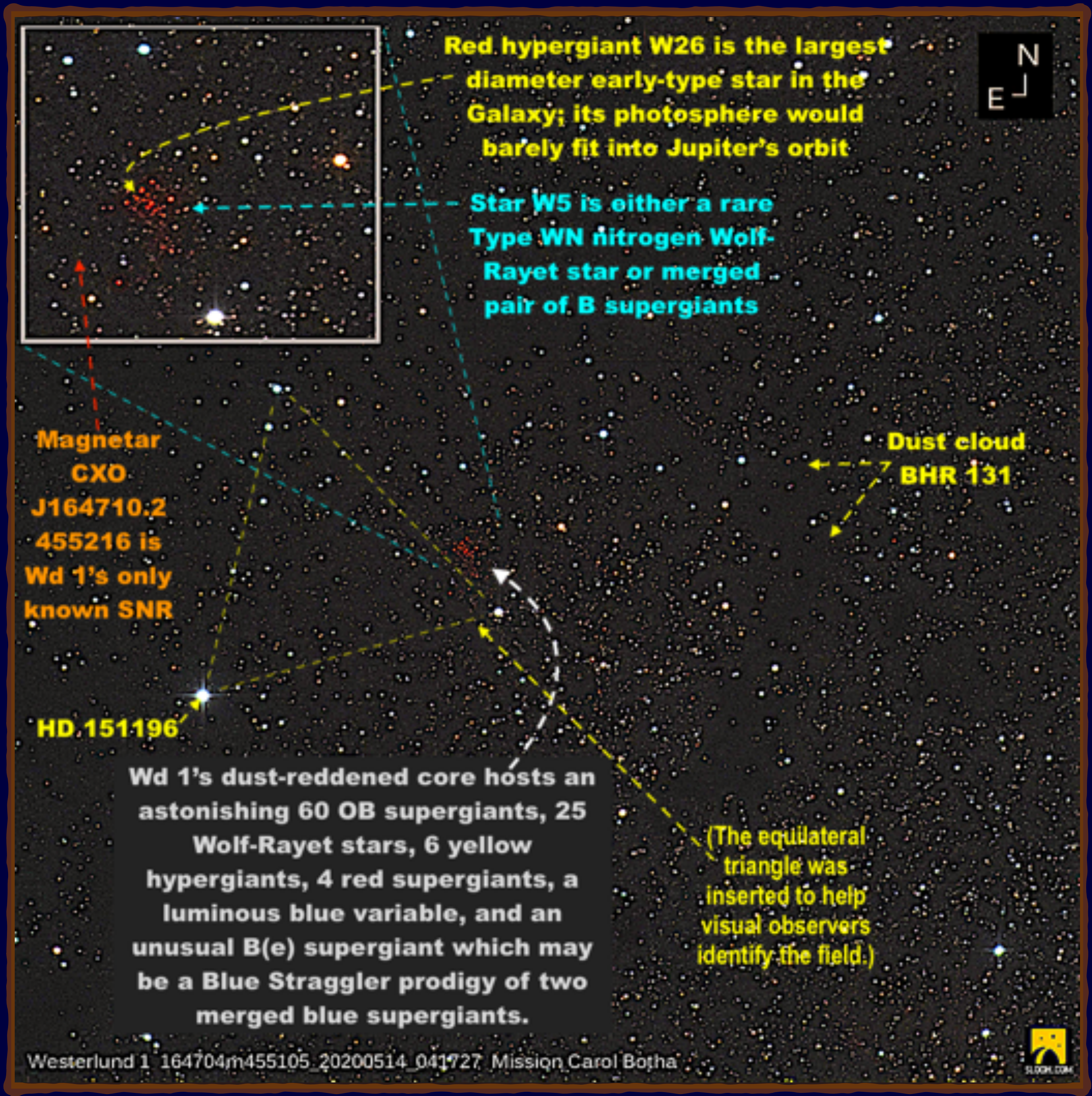
Logged using Slooh's Online Robotic Telescopes

For this observation, I set up a co-ordinate mission on Slooh's Chile Two Planewave 17-inch CDK located near Santiago. My setup was right on target at $16^h\ 47^m$ 04s, 45° 51′ 04.9″ S (Galactic l=339.5, b=0.4). The observing mission ran in an open slot closest to transit time. Slooh's telescopes are set up such that observers cannot view objects within half an hour each side of sidereal transit due to meridian switching and image rotation requirements of the mount.

The total mission time to capture the RGB and luminance images was five minutes. In the grayscale image it is easy to spot the 'tiny' cluster in the rich local star field. The most noticeable pattern in the image is a nearly equilateral triangle of bright stars. In the eyepiece this is a very pretty view. Wd 1 is located opposite the brightest star in the field HD 151196. To the N and E of the cluster is a looping string of stars that looks like the numeral 5 fell over and is lying on its side!

One nice thing about working with Slooh's Chile Two telescope is the large visual field of view and excellent contrast. I noticed a prominent hook shaped dust cloud towards SW, later identified as BHR 131 The contrast on the grayscale image is striking.

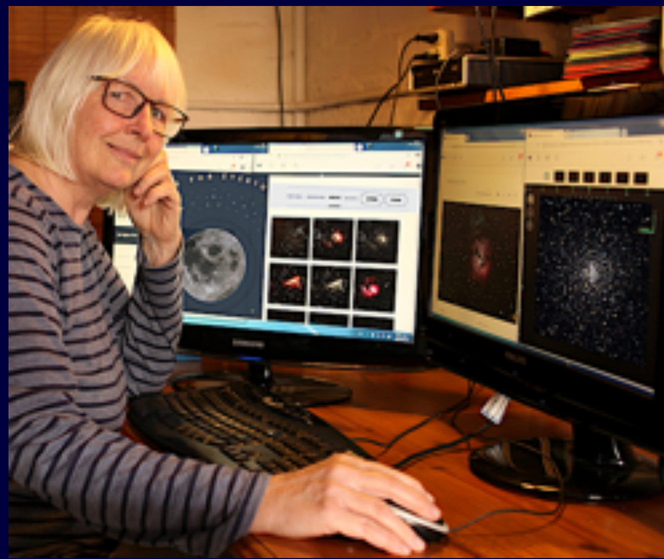
When zooming in to actual pixels, the cluster seems compact. The cluster's stars lie in an elongated rhomboid shape rather than the circular pattern we usually associate with star clusters. In the RGB image (shown with annotations on the next page), the cluster pops out dramatically. Red stars predominate. The cluster's kite-like shape is accented by four red stars straggling off to the SE. Closer and E of the cluster are two smaller stars that may be a double.



Annotations to original image by Nightfall editors.

Behind the scenes on my silver screen

Here I am at home in South Africa. My computer screen is directly connected to the live feed of SLOOH's 17-inch Planewave CDK telescope camera located at the Santa Martina Observatory in Santiago, Chile.



Astronomy using robotic telescopes connects me to observatories in Chile and the Canary Islands that I could not visit any other way. I can schedule time slots to target and capture images of any object in which I am interested. I can also 'RoboSnap' an object on the live feed of another Slooh member who happens to have something in view that I'd like to save into my own folder. It's like having a look through every telescope in the star party of the universe.

WESTERLUND 2

Observation Log
and SketchTemplate

Observer: Carol Botha

Date: 2020.05.14

Time: 00:38:01 utc

Site: Slooh, Chile S 33°16'8.4" W 70°32'2.4"

Seeing: (1-5) 3 *As provided on the telescope feed*

Object: Westerlund 2 (ngc 3247)

R.A: 10°23'58.11" Dec -57°45'49.0"

Constellation: Carina

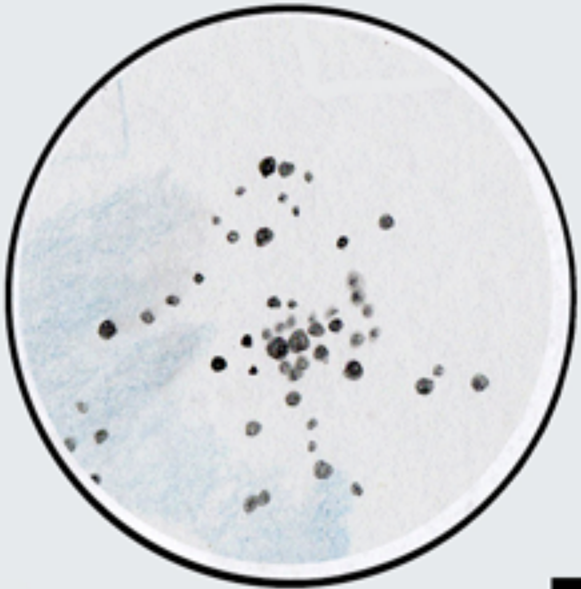
Distance: 20,000ly Age 2 mill years

Sources: Stellarium, NASA.gov, Chandra

Telescope: Chile Two wide-field 17" Planewave

CCD Camera: FLI Proline PL16803 Monochrome

Filters: Luminence, RGB



N E

Logged using Slooh's Online Robotic Telescopes

I set up a mission to Westerlund 2 from Slooh's best 1000 list. The mission ran in the available time slot closest to transit time. The total mission time was 5 minutes. Two png files were obtained: Luminance and RGB. This object would lend itself to astro processing with FITS files, though for my deep sky observing goals the PNG results were perfect.

In the RGB image, the open cluster did not appear to be centred in the Chile Two field. There is significant differential reddening within with the cluster itself associated with winds from the cluster's many O-B giants carrying away natal gas from the core region. The gravitational centre of the cluster is not the same as the visual centre shown in the RGB image and my drawing. The small group of stars seen in the upper portion of the field are in fact part of the cluster; the dark gap between them is due to a dust absorption in the cluster's outskirts. There is also some large-scale reddening across the entire field due to dust absorption between the cluster and Earth.

What do I see here? The open cluster is clearly visible in my images. I could see faint nebulosity surrounding the cluster. The bright part of the nebula lies adjacent to the cluster. The western boundary between the nebula and cluster is defined and looks like a wide mouthed 'something'. I'm one to go for hearts and bees - this time I would say more like an ornate S. Bright stars are arranged on the curve of the 'S'. The shoulder has three in a row, one bright along the spine and four in a close row on the southern boxy tail! With lots more fainter stars squashed into this box as well (no social distancing being practiced here!).

NGC 3603

Observation Log

and SketchTemplate

Observer: Carol Botha

Date: 2020.05.18

Time: 01:19:58 utc

Site: Slooh, Chile S 33°16'8.4" W 70°32'2.4"

Seeing: (1-5) 3 *As provided on the telescope feed*

Object: NGC 3603

R.A: 11h15'23" Dec -61°15'00"

Constellation: Carina

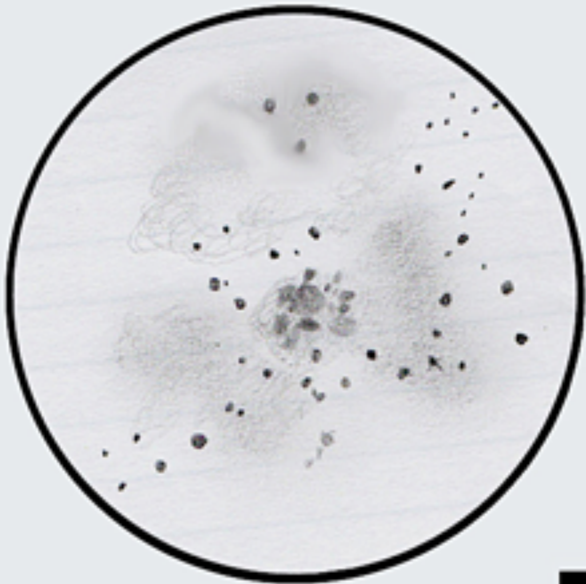
Distance: 20,000ly Age 300 000 - 1 mill years

Sources: Stellarium, Research Gate, Hubble Site

Telescope: Chile Two wide-field 17" Planewave

CCD Camera: FLI Proline PL16803 Monochrome

Filters: Luminence, RGB



N

E

Logged using Slooh's Online Robotic Telescopes

My search for NGC 3603 began after seeing an image published on the Hubble Telescope website. I chose Slooh's Chile Two Telescope for this mission. I scrolled through Slooh's available catalogues, chose NGC, inserted 3603, checked visibility for my chosen time slot and applied Slooh's pre-set filter for 'open clusters'. (One would use a different pre-set to observe the nebulous regions or for astrophotography.)

In my images a very bright and compact cluster of stars lies nestled in a huge nebula. The nebula is divided into lobes by dark patches and lanes in between. At the center there is an extremely bright star (which could be more than one star and not split in this image)

To remember an object's visual appearance, I look for patterns in the surrounding star field as well. The triangle of bright stars towards the W of the cluster and two loops of stars towards the SE and NE looks like … let's say - a fruitfly!

The brightest parts of the nebula are S and SW of the cluster. The lobe to the SE is less bright and towards N it is quite faint.

The most enjoyable part of this hobby is sharing my experiences with others.

My first gateway to the stars was a pair of binoculars. Within a few months I progressed to my first telescope. Realising that Astronomy was becoming my passion, I followed the conventional advice and two Dobsonians were added to my gateway gear.

By using non-computerised telescopes with reasonable aperture, sky maps, a planisphere, plus help and encouragement from like-minded friends, I learned about the sky.

Dobsonians can be quite heavy. Having a semi-permanent observing site was a blessing. But with a suitable vehicle and a little help from family and friends I could also hit the road.

I loved being able to set up my telescopes quickly and being able to move from one object to another in a jiffy – especially when I started doing sidewalk astronomy.

Lifting heavy loads is not a good idea. Eventually I designed a barrow-wheel rig for my 12" Dobsonian and my husband, Meurant, did the construction. Setting up for observing was so much easier.

With a setup like this, why did I then venture into the world of Slooh? On several occasions when I would be watching a solar or lunar eclipse via online streaming, I would see the Slooh logo pop up as a live stream option. Normally I used streaming connections that did not require me to set up an account. But in the back of my mind I kept wondering about Slooh's 'Join Today' button and what would happen if I clicked on that button!

One day I did – and have never looked back. Even so, making the transition from my 12" Dobsonian with its barrow wheels to Slooh felt a bit weird in the beginning. Today, my astronomy life is very different. As an 'Astronomer'-level member I can choose to set up observing missions from a list of catalogues beyond the Messier and NGC objects.

Slooh's telescopes are programmed to slew to any object that the member might fancy on a given night. For this article I reserved NGC 3603 simply by entering its NGC catalogue number into the Slooh database. Other times I have used the object's co-ordinates, such as I did for the Westerlund 1 observation above.

To reserve a mission you can choose one of Slooh's 1000 most interesting objects, which are divided under the different types of objects. Even seldom-visited objects like quasars and supernovas are in the database. That is how I found Westerlund 2 for this report.

Some nights I reserve missions to well-known objects and simply enjoy the objects in the live feed instead of imaging them. I take comfort knowing that there may be new members beginning their journey to the stars thanks to my mission. I imagine how they are using the word 'W-O-W' just like I did when I first saw the magnificent Orion Nebula, Centaurus A, and Omega Centauri.
We really are all in this together.

On those nights when I book an imaging instead of sightseeing mission, all my images will automatically be saved as PNG's and FITS data to my photo roll. There they will reside waiting for me to download them any time I sign in.

For the observations in this article I used the new Chile Two 17" Telescope manufactured by Planewave Instruments. This beautiful instrument is shown here being installed six months ago under guidance of Paul Cox, Slooh's Chief astronomical Officer, at their observatory in La Dehesa, near Santiago in Chile.

NOW GO TO THE SLOOH PAGE TO SEE THE FAR SIDE OF THE MOON.

Maybe some day more South Africans will join me on Slooh. I can't wait for us to start our own club.

Slooh™
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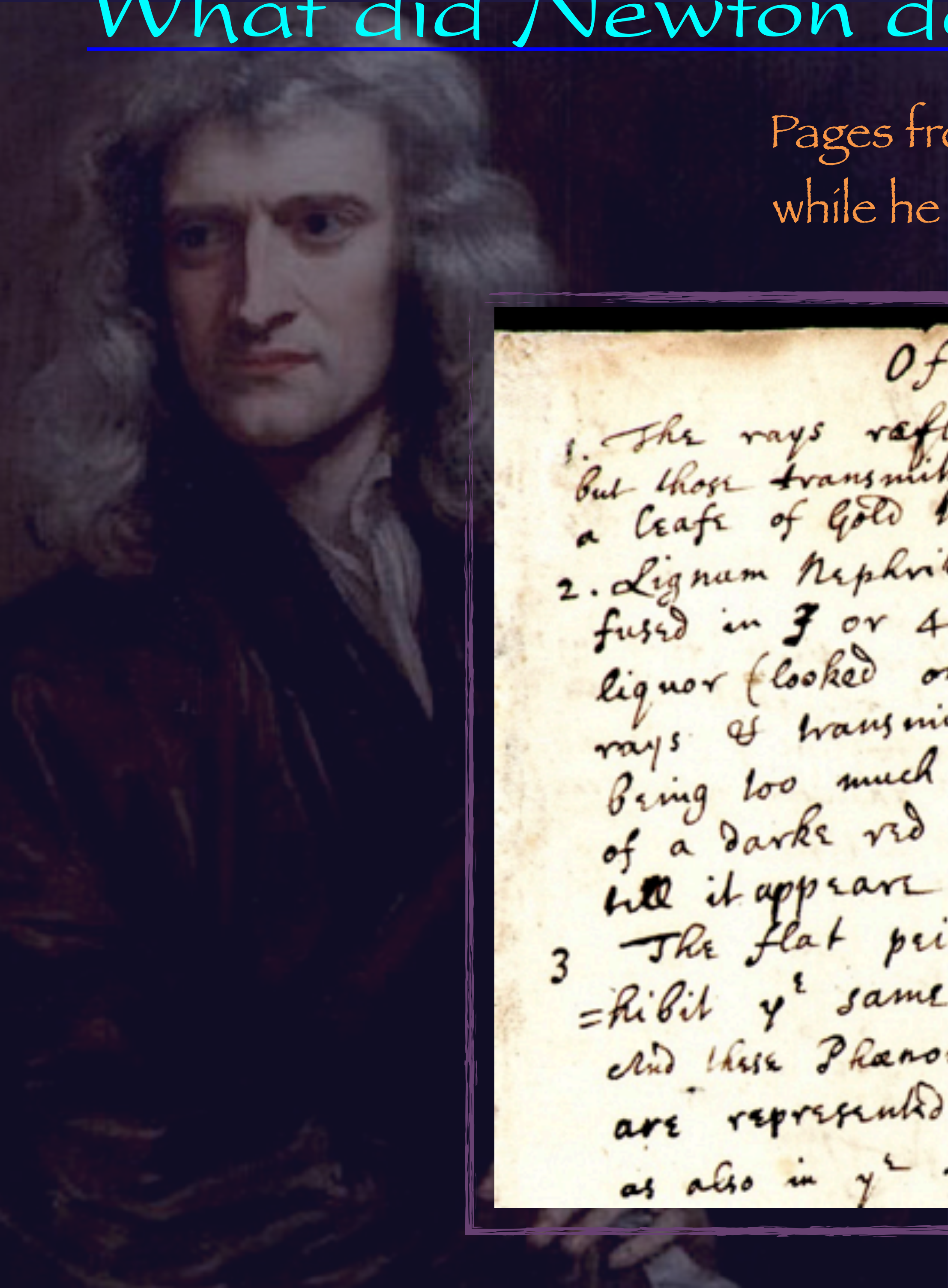
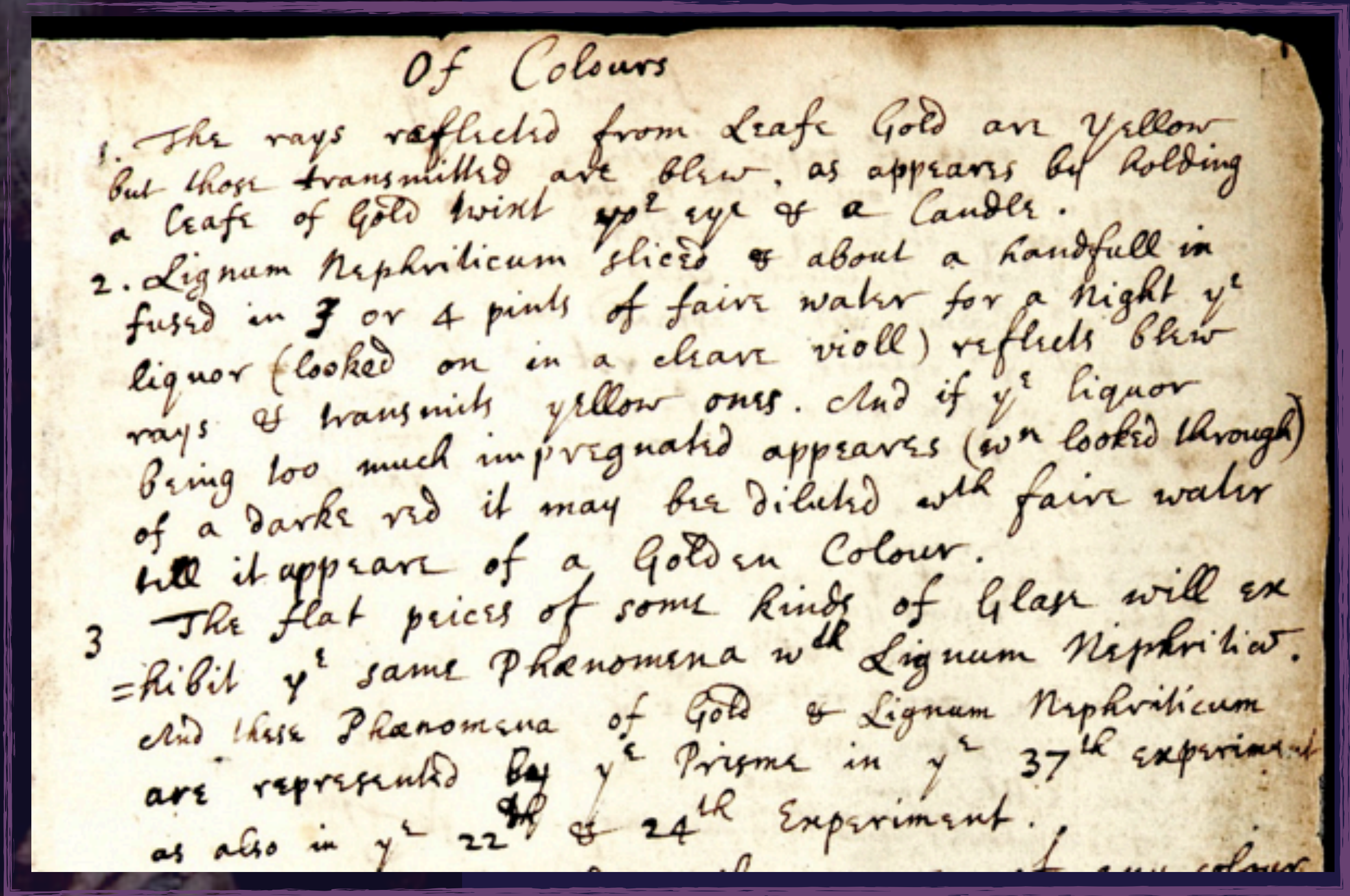
What did Newton do during quarantine?



Pages from Isaac Newton's notebooks
while he was in quarantine in 1665-1666


Of Colours

1. The rays reflected from Leafe Gold are yellow but those transmitted are blew, as appears by holding a Leafe of Gold betwixt yor eye & a Candle.

2. Lignum Nephriticum sliced & about a handfull infused in 3 or 4 pints of faire water for a night ye liquor (looked on in a cleare viall) reflects blew rays & transmits yellow ones. And if ye liquor being too much impregnated appeares (wn looked through) of a darke red it may bee diluted wth faire water till it appeare of a Golden Colour.

3 The flat peices of some kinds of Glasse will exhibit ye same Phænomena wth Lignum Nephriticum. And these Phænomena of Gold & Lignum Nephriticum are represented by ye Prisme in ye 37th experiment as also in ye 22th & 24th Experiment.

Image: Issac Newton, *Of Colours*, Cambridge University Library

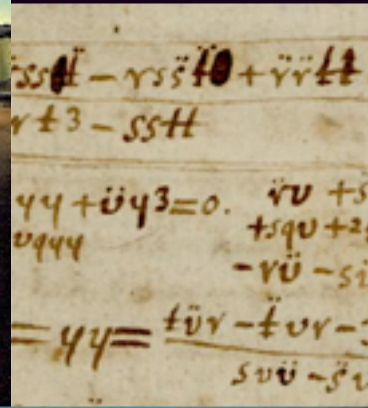
It takes a keen mind indeed to convert the tedium of isolation in quarantine into scientific concepts that explain the world in an entirely new way.

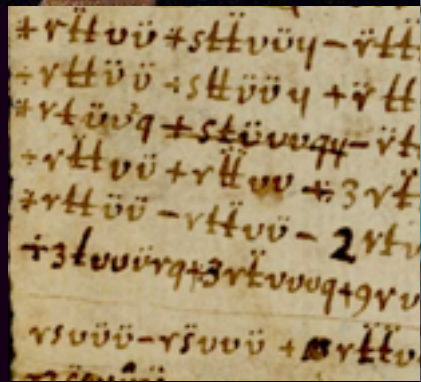
Isaac Newton had a unique talent for turning seemingly trivial observations into mathematical proofs. He was born in 1642 and passed his varsity years at Cambridge Trinity College. During the 1660s several waves of the flea-borne bubonic plague washed over England, turning in the rat-infested urban areas into flotillas of caskets. When Cambridge's colleges closed during the outbreak of 1665–67, Newton went to his home in Woolsthorpe and studied on without benefit of tutors, colleagues, or clergy to divert him. Bountiful years they were indeed: they resulted in his theories of calculus, optics, and the law of gravitation.

Newton dealt with the obstacle of being cut off from his friends, family, and academic colloquies by conversing with his notebooks. He turned blank pages into theoretical tomes. They were his only available companions.

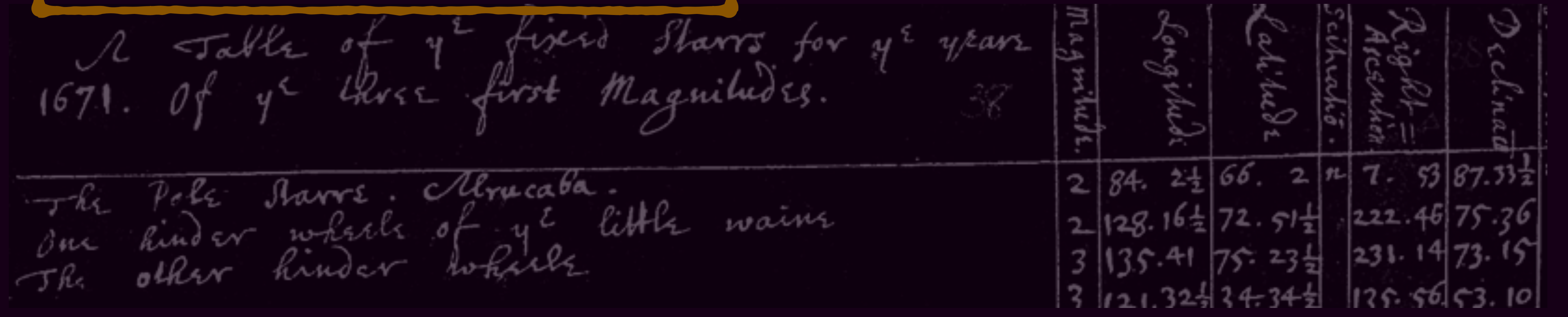
Sometime in 1665 he spotted a curious bit of glass at a country fair. It looked like a somewhat stretched-out triangle. When he put it to his eyes, everything in view turned into long smears of colour that rather resembled the watches in Salvador Dali's surreal painting *Persistence of Memory*.

This curious effect had been noticed before — that's why the chatterbox at the country fair had it on display in the first place. The man told Newton that the prism 'corrupted' light in some way. Such a glib definition didn't impress Newton. He was interested in causes, not effects. He coined the word 'spectrum' to define the effect the prism produced, took the object back home and turned his engineering skills into mechanical devices to manoeuvre the prism as he wished, and his mathematical ingenuity into quantifying what he observed.





This is what happens when a mathematician looks at an art work.



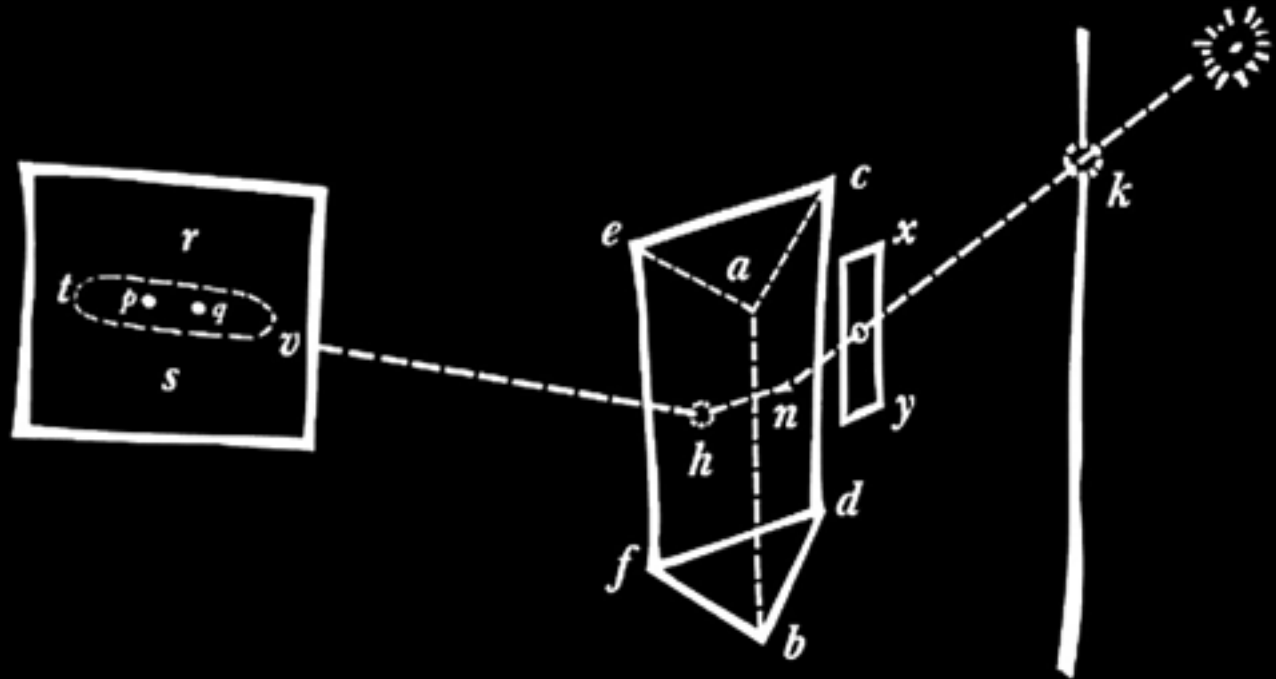
Newton's first experiment was simply to shine the colourful light onto a sheet a bit farther from the prism. In his first prism experiment in *Of Colours*, he held the prism near a hole in the wall, and let the sunlight pass through the prism and land on a sheet of paper (right). He noted that 'The colours should have been in a round circle were all the rays alike refracted.' Instead, the circle became an elongated smear red on one end and blue on the other. This showed that prisms separate colours out of white light; the angle of their refraction was related to the colour of the light.

From this Newton deduced that the prism did not change the properties of the object itself. Whether red, green, or blue, the object retained its shape and size. In the next experiment, he isolated a coloured beam and directed it onto various surfaces. Regardless of whether the light was reflected, scattered, or transmitted, the light remained the same colour. He interpreted this to mean that objects interacting with light were given their colour by light rather than being coloured themselves.

The resulting series of notes — some 190 pages of densely packed sketches and mathematics — formulated what is today known as Newton's theory of colour.

It all started with a toy at a fair

Experiment 7 in *Of Colours was* Newton's first attempt to use prisms to show the refraction of light.

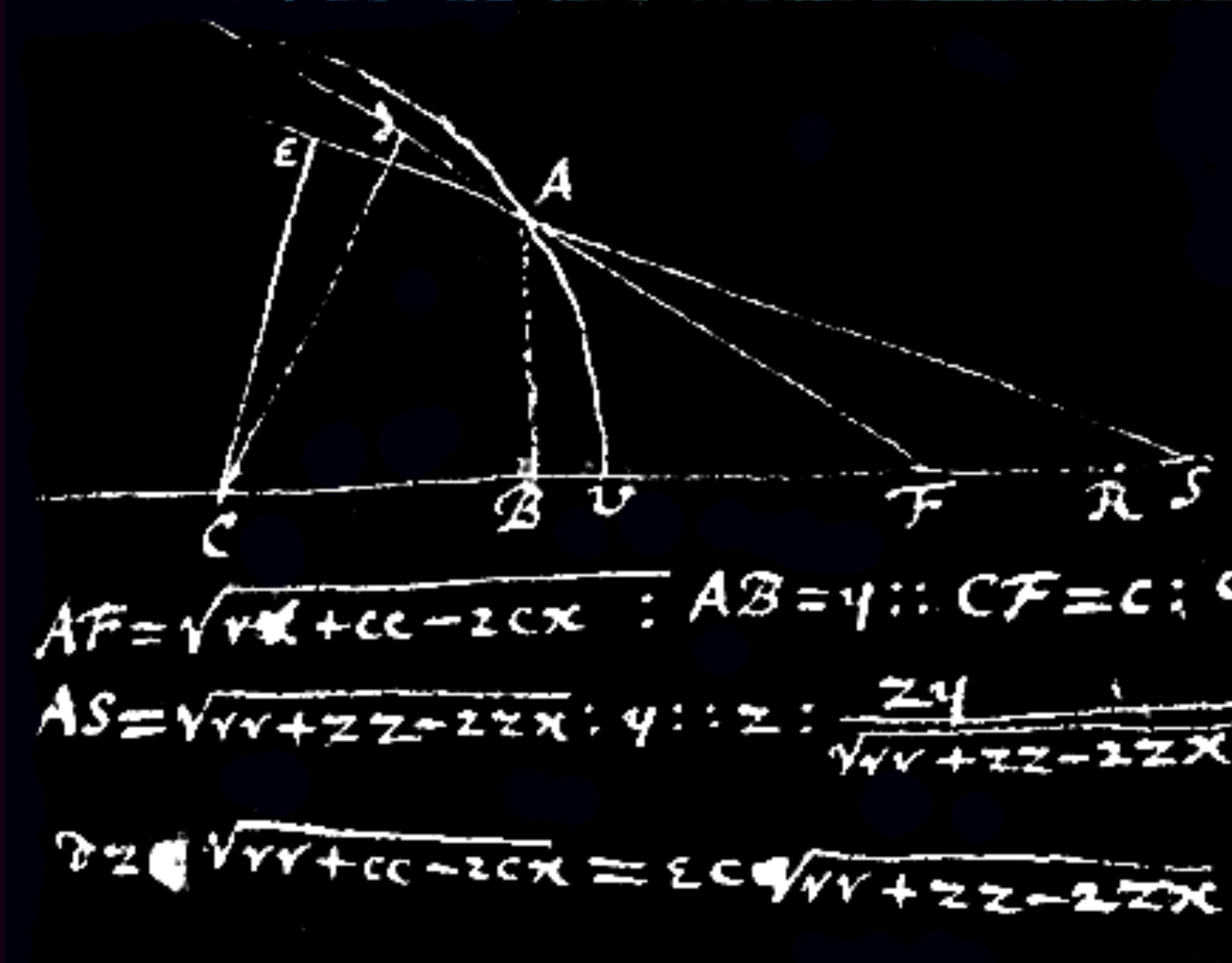


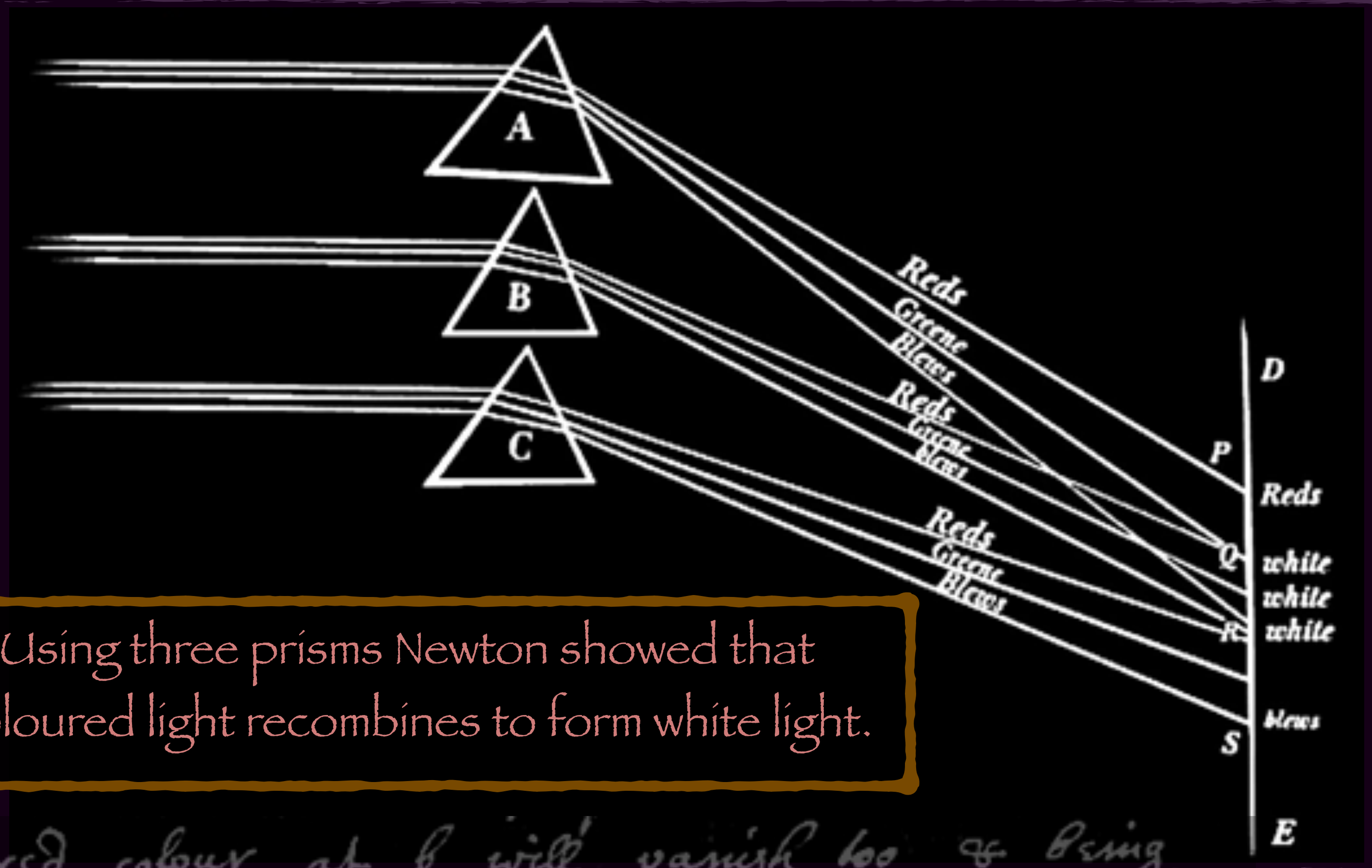
Seeing the prism as a tiny slice of sphere

Newton made diligent use of his time while in isolation. This drawing shows a drawing from one of the 64 experiments with light in his notebook. The 190 pages of his essay *Of Colours* are some of the densest equations a maths lover can behold. Indeed, most of the letters in the essay are equation terms instead of the sound particles that make up words — and in Latin as well as English, and even a few tidbits of French. His penmanship was (mostly) legible, but what he did with it is all but inscrutable. In this tiny sketch off in one corner of an otherwise overcrowded page, he illustrates how the flat face of a prism can be understood as an infinitesimal of a sphere. He had discovered and explained the concept of Fluxions only one year before. (Today we call these derivatives or the rates of change as a variable moves through time.) Drawings like this are our deepest glimpse into a mind that can prove that an infinitesimal can substitute for the whole — at least mathematically.

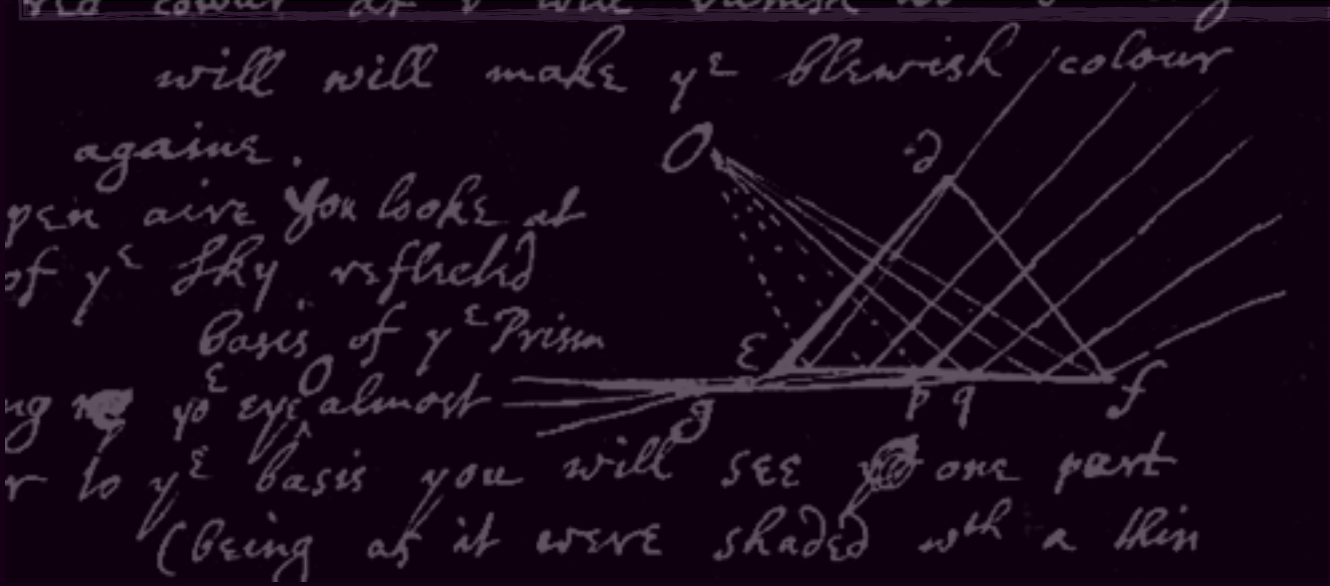
One the 1665 wave of bubonic plague ebbed, Newton returned to Cambridge. It was refreshing to be back among friends and eager students. He decided to distill his often chaotic notes in *Of Colour* down into a series of lectures on optics. He delivered these between 1670 – 72. Modern scholarship has revealed that Newton's analysis and resynthesis of white light was an unintended validation of the theory of Corpuscularism — a theory that supposes all matter to be composed of minute particles — which had only recently come back into vogue after the ancient Greek formulation called atomism had been forgotten for nearly two millennia.

Corpuscularism held that corpuscles could be divided. This was important to alchemists because it suggested that, for example, mercury could penetrate into metals and modify their inner structure, a step on the way towards transmuting base metals into gold.





Using three prisms Newton showed that coloured light recombines to form white light.



Objects do not have a colour, they reveal it.

Newton's 'Plague Year' experiments were precursors to what is now known as his quest for an *Experimentum Crucis*, or crucial experiment. This was outlined in his first publication, 'A Letter of Mr. Isaac Newton … containing his New Theory about Light and Colors' in *Philosophical Transactions* in 1671/1672. The paper's aim was to prove that colour was a property of light itself.

To be scientifically rigorous, a proof has to show not merely that the theory works under all the conditions set forth at the outset, but that the theory also does *NOT* work if one applies a different set of conditions.

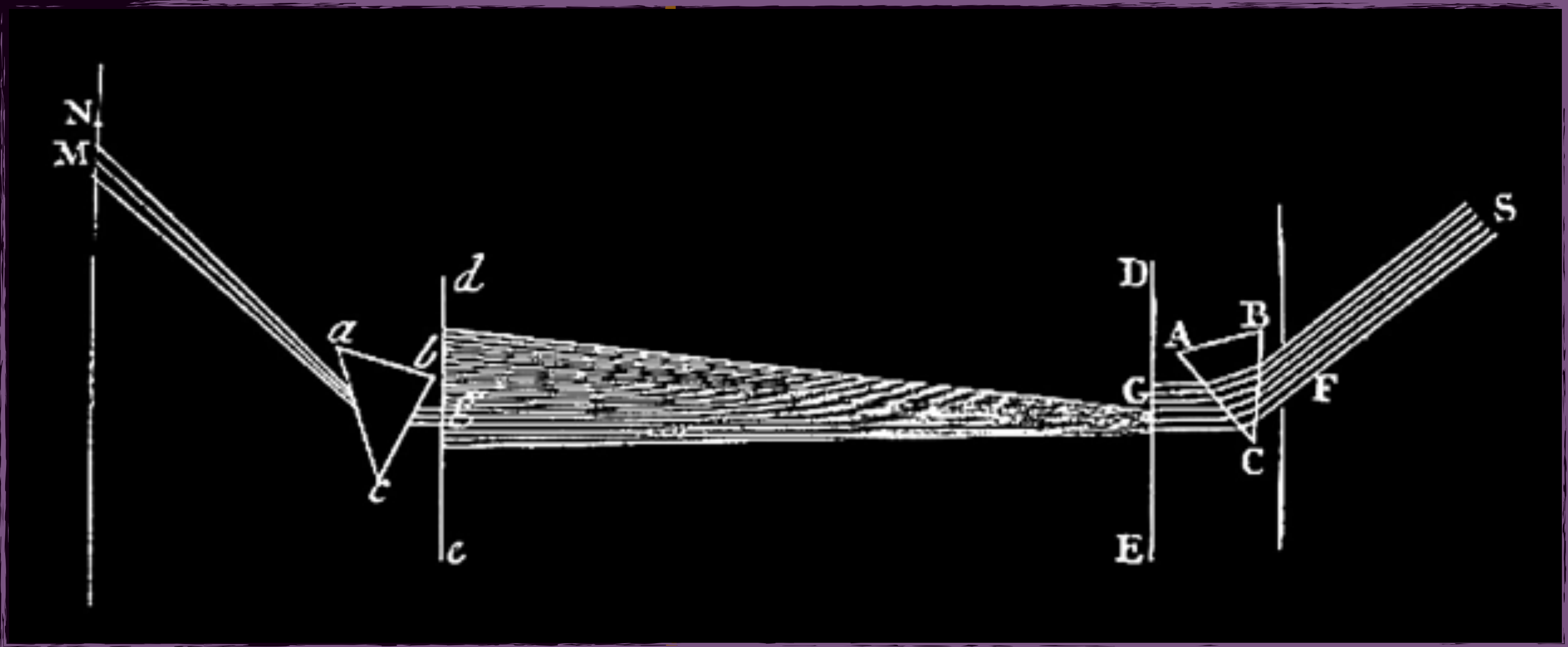
The experiment shown are diagrams Newton's 1704 treatise *Opticks*. Th the experiment illustrated here, Newton let sunlight pass through a hole in the wall. He placed a prism *ABC* in front of the beam, and then blocked all but a small amount of the light that passed through this prism with board *DE*. After letting this light beam spread out over 12 feet, he again only let a small amount of light through board *de*, which he passed through a second prism, *abc*. The final beam hit the wall on the right.

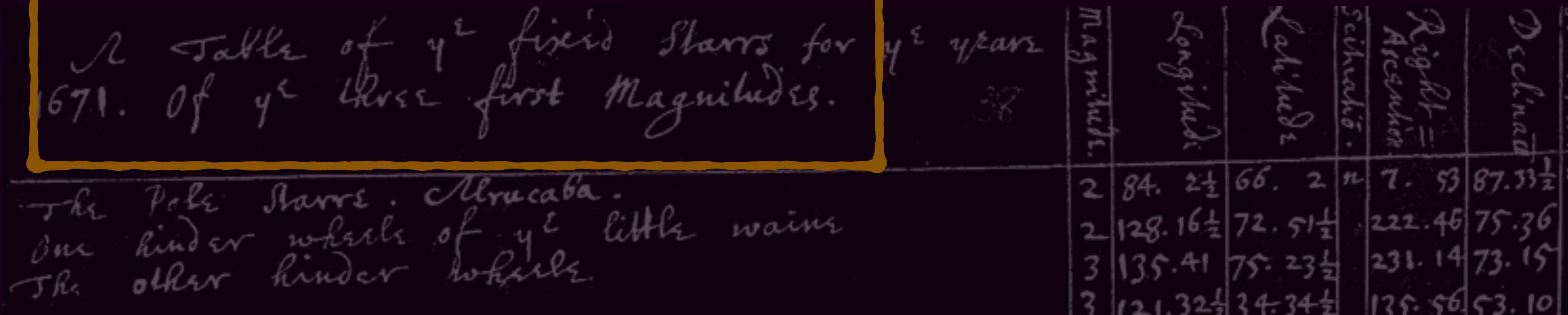
The next experiment was to rule out the material composition or the triangular shape of the prisms themselves as the source of the colours in the spectrum.

Newton allowed a beam of sunlight S (right) to pass through the hole *G*. The prism passed the red end of the spectrum toward the far wall on the left edge of this drawing. The red beam ended up at point *M* on the wall. Newton then rotated the right-hand prism *ABC*, which would shift the beam falling on the hole *G* toward the bluer end of the spectrum. The blue beam would pass through hole *g* (in the middle of the flat sheet between *d* and *c*) onto prism *abc*. The final beam now hit point N. There was a measurable distance between M and N. This he called *spectral spread*.

Newton's point was to show that the initial colour of the incoming light determined the final refraction angle, no matter what material made the prisms or their thickness at the point where the light passed through them. Refraction must be due to the properties of light itself, not the medium through which they passed. In Newton's words, 'not by any virtue of the glass, or other external cause, but from a predisposition, which every particular Ray hath to suffer a particular degree of Refraction'.

Newton's experimentum crucis showed that refraction and colour are properties of light itself. The diagrams reproduced here are from Newton's 1704 edition of 'Opticks'.



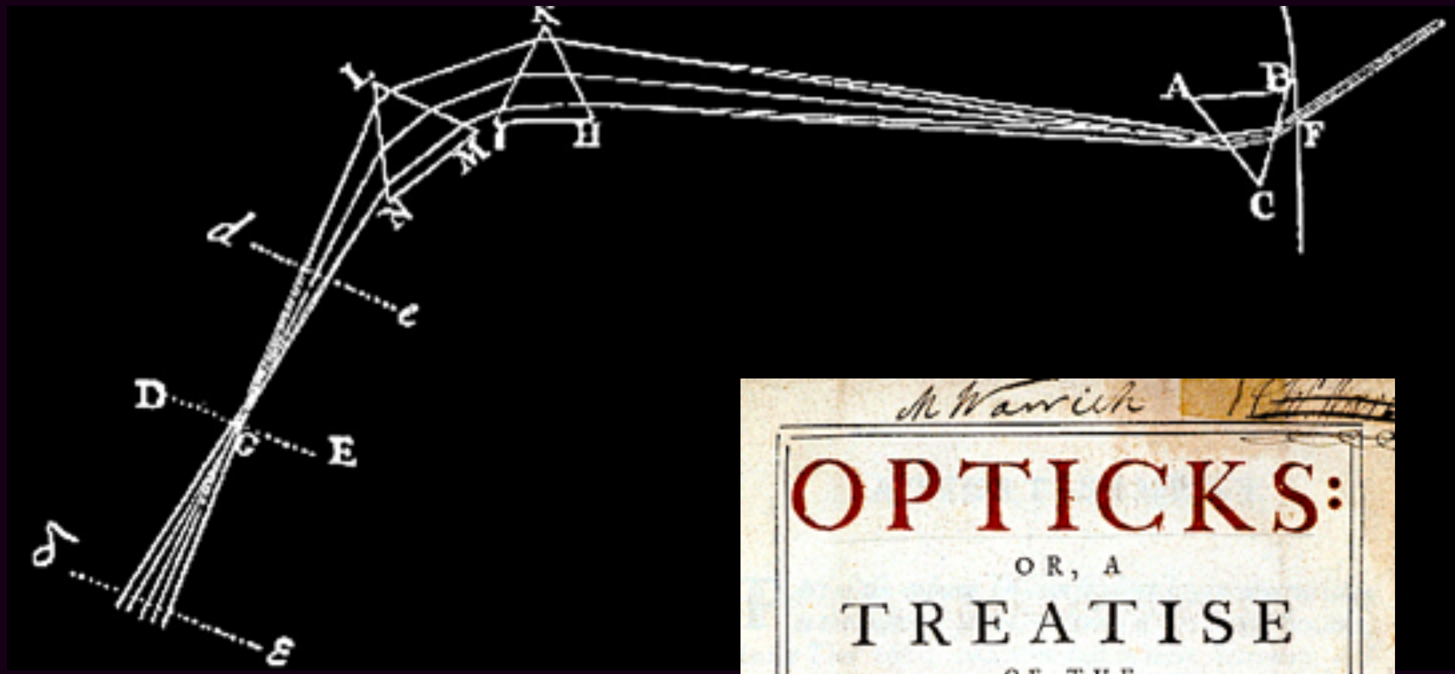


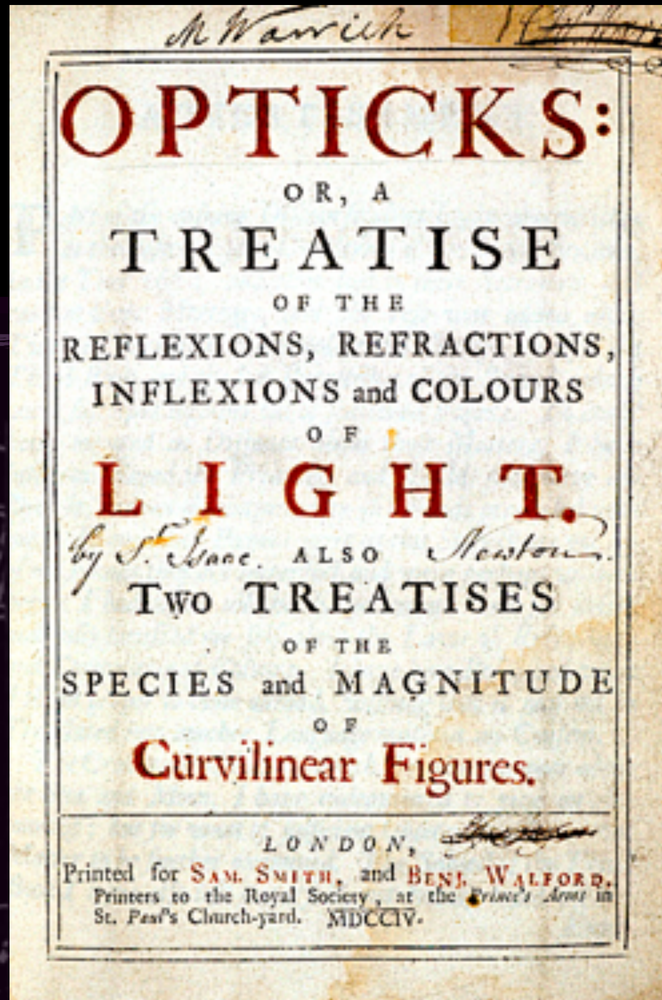
A Table of ye fixed Starrs for ye yeare 1671. Of ye three first Magnitudes.

	Magnitude	Longitude	Latitude	Septentrio.	Right Ascension	Declinat.
The Pole Starre. Alrucaba.	2	84. 2½	66. 2	n	7. 53	87.33½
One hinder wheele of ye little waine	2	128.16½	72. 51½		222.46	75.36
The other hinder wheele	3	135.41	75. 23½		231. 14	73. 15
	3	121.32½	34.34½		125. 56	53. 10

Newton took this a step farther in one of the final prism experiments in his notebook. He lined up three prisms and let light pass through all of them onto a wall (right). On the edges, he observed pure red and pure blue light. However, in between these end points ('betwixt' in the terminology of Newton's times) the wall appeared white. To Newton this meant that the colours blended together into white. Hence the light was not permanently corrupted by the prisms; rather, the coloured light from different prisms could be recombined into white light.

In this experiment, he showed that coloured light can be recombined into white light by passing it through another prism.




M Warwick

OPTICKS:

OR, A

TREATISE

OF THE

REFLEXIONS, REFRACTIONS, INFLEXIONS and COLOURS

OF

LIGHT.

by Sr Isaac Newton

ALSO

Two TREATISES

OF THE

SPECIES and MAGNITUDE

OF

Curvilinear Figures.

LONDON,

Printed for SAM. SMITH, and BENJ. WALFORD, Printers to the Royal Society, at the Prince's Arms in St. Paul's Church-yard. MDCCIV.

Cambridge University Library holds the largest and most important collection of the scientific works of Isaac Newton (1642-1727). They range from his early papers and College notebooks through to the ground-breaking Waste Book and his own annotated copy of the *first edition of the Principia Mathematica*.

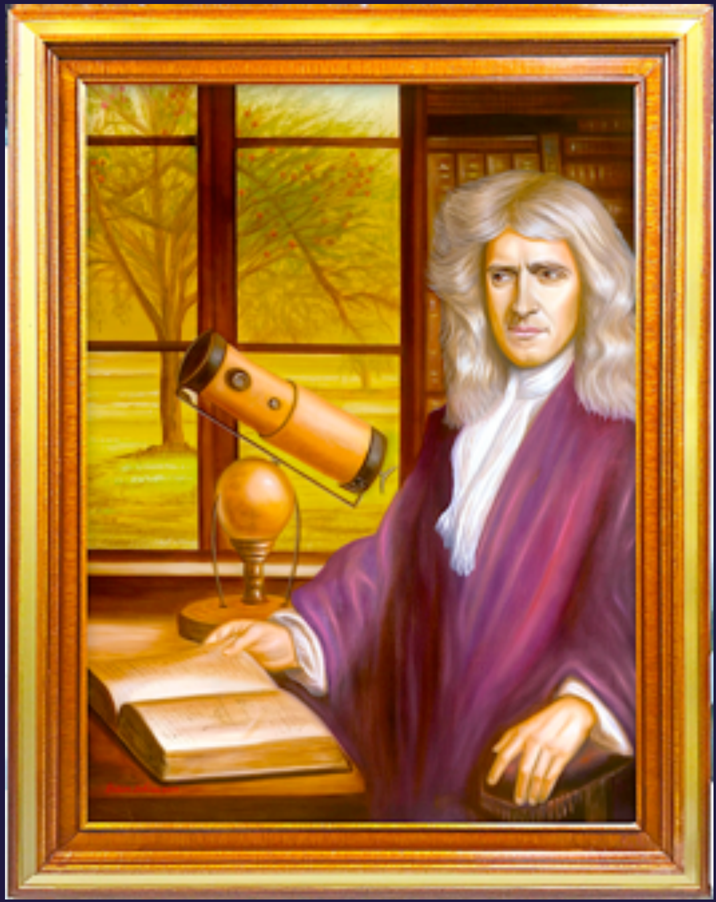
The drawings and facsimile pages for this article were sourced from the Cambridge Digital Library.

For an excellent look into the thinking of Newton and the 'natural philosophers' at the dawn of modern scientific inquiry, the David Brewster 1833 *The Life of Newton* is available for reading and downloading from Project Gutenberg.

Newton was closely associated with Cambridge University all his life. He was admitted to Trinity College of the University as a student in 1661. He graduating in 1665. From 1669 to 1701 he held the Lucasian Chair of Mathematics, a position resembling what we would today call an endowed chair.

Under the regulations for this Chair, Newton was required to deposit copies of his lectures in the University Library. That is why we can read his complete set of handwritten notes titled 'Of Colour' in their original edition written 1665–66.

In 1703 Newton he was elected President of the Royal Society, a post he occupied until his death. His complete treatise Opticks was collated from all his earlier publications and printed in 1704.



Next time you see a rainbow after it has rained, take a moment to think about Isaac Newton. He didn't put the rainbow there, of course, but he did tell us why the rainbow has its colours. The idea didn't just fall out of the sky onto his head like the proverbial apple. He first had to discover what, exactly, colours really are, and the only way to do that was experiment with the stuff.

Newton chose a propitious time to start his investigation. In 1665 he had confined himself at his small manor home Woolsthorpe in the country near Cambridge, England. All across the decade of the 1660s, successive waves of bubonic plague swept across England. The death toll was always far higher in the towns than the countryside. Even in that medically unsophisticated era people know the best way to avoid infection was to stay away from creatures who already had it — namely other people. No one dreamed that the actual culprit was a minute species of flea whose preferred dining hall was the skin of a rat.

And there one day he happened to buy a glass prism at a local town faire.

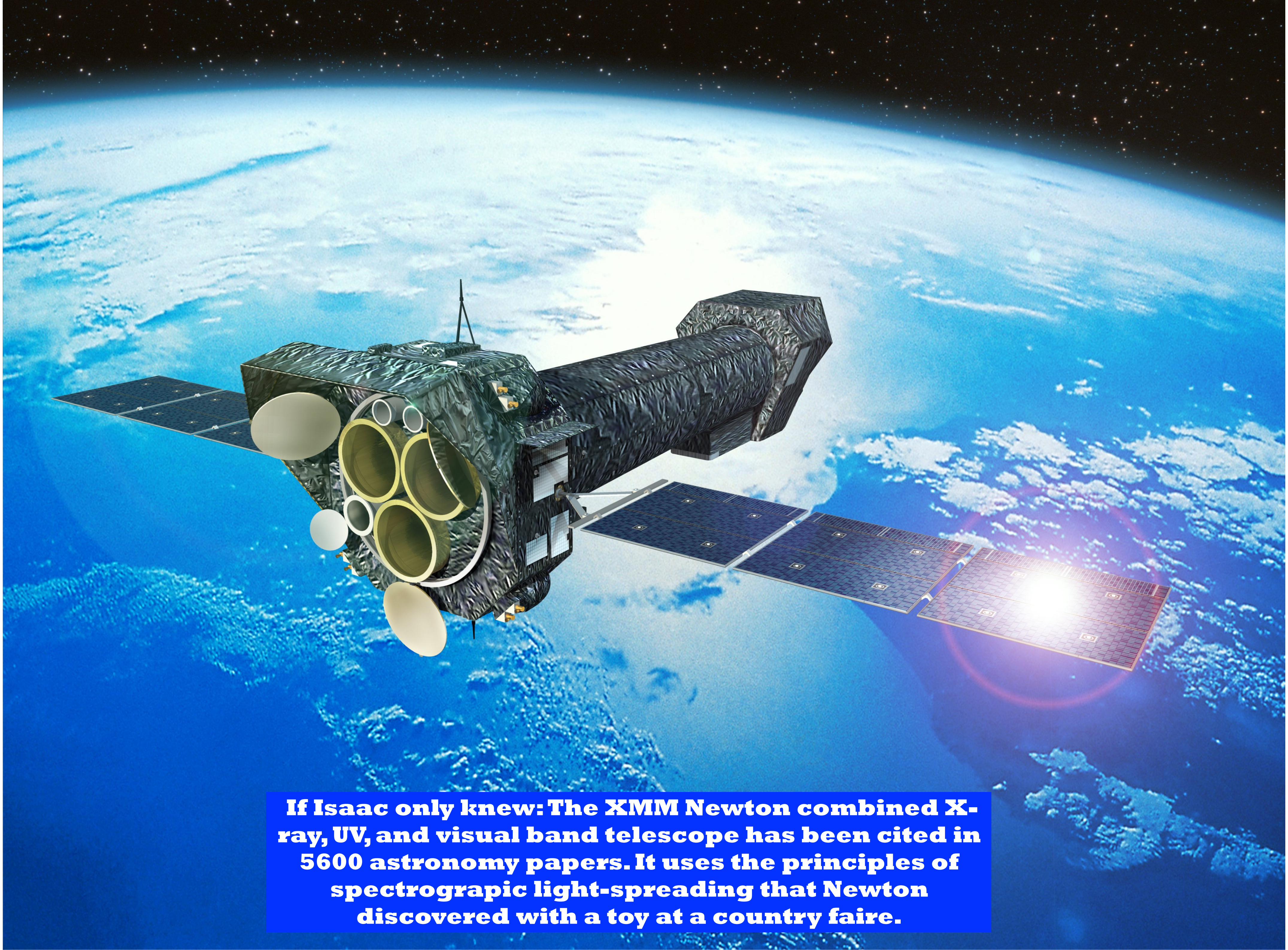
As he pondered his newly acquired three-sided bit of glass, Newton moved it into a thin shaft of sunlight that happened to enter through a gap in the curtains. He saw a lustrous spray of rich colours appear on a paper-covered easel next to his desk.

Up to that time the newly emerging class of 'natural philosophers' (today's 'scientists') followed the theoretical speculations of Aristotle, who averred that colours derived from mixtures of lightness (white) and darkness (black). In medieval times this was interpreted to mean that the colours of the rainbow were an inherent property of rain — it was the rainwater that gave colour to. the mixed black/white rays of sunlight.

But then Newton asked himself, 'Why rain? Colours exist when it's not raining, don't they?'

Newton took advantage of his quarantine time to invent a methodical sequence of experiments whose goal was to isolate the nature of colour itself rather than the objects which reflect it.

First he had to eliminate all the possible false positives. He decided the only way to prove what colours were was to first take them apart and then put them back together again.

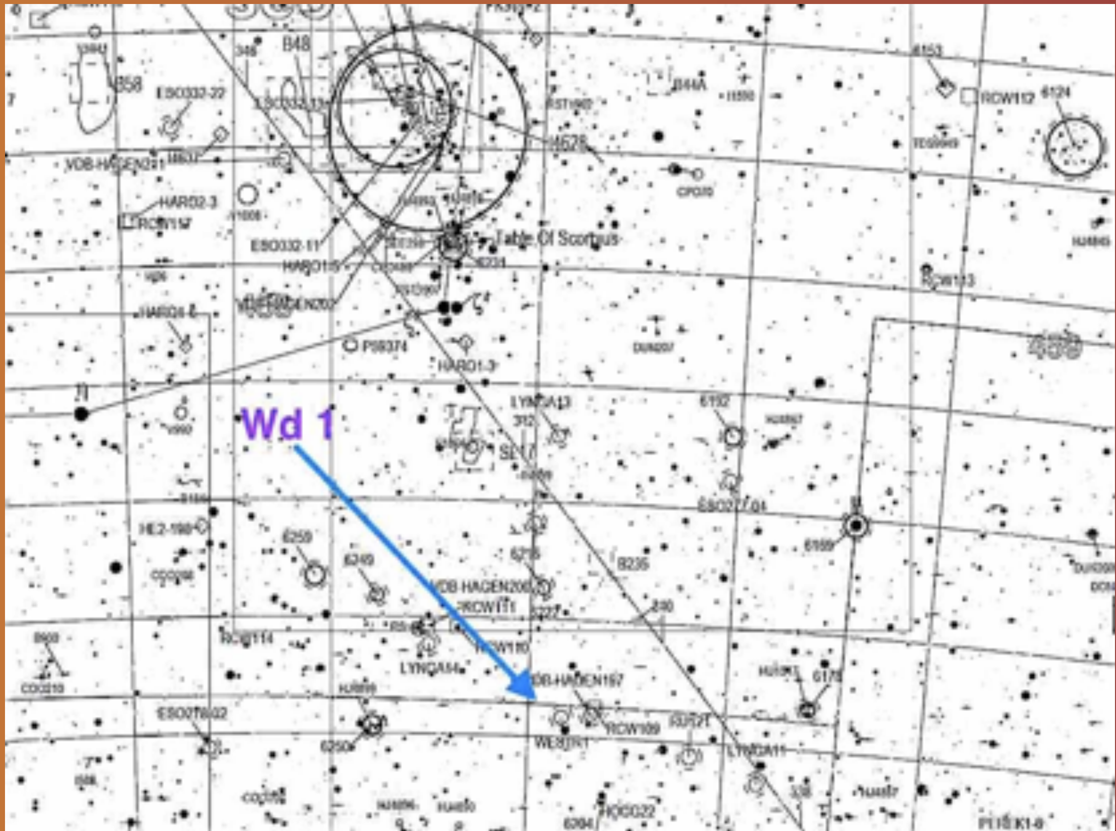


If Isaac only knew: The XMM Newton combined X-ray, UV, and visual band telescope has been cited in 5600 astronomy papers. It uses the principles of spectrograpic light-spreading that Newton discovered with a toy at a country faire.


If we lived near a red giant star,
would this scene look the same?

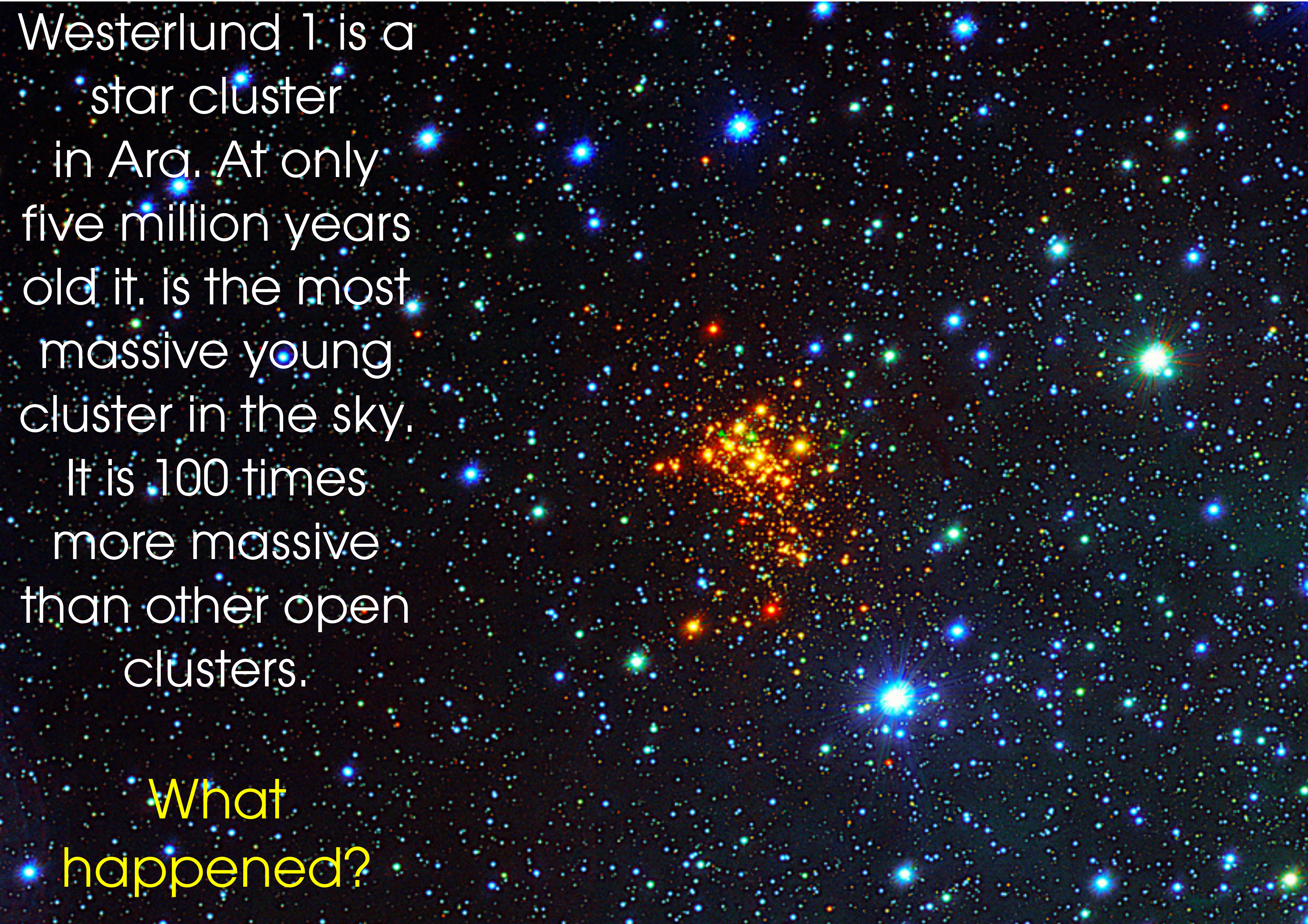
A Heavily Reddened Cluster in Ara

Bengt Westerlund

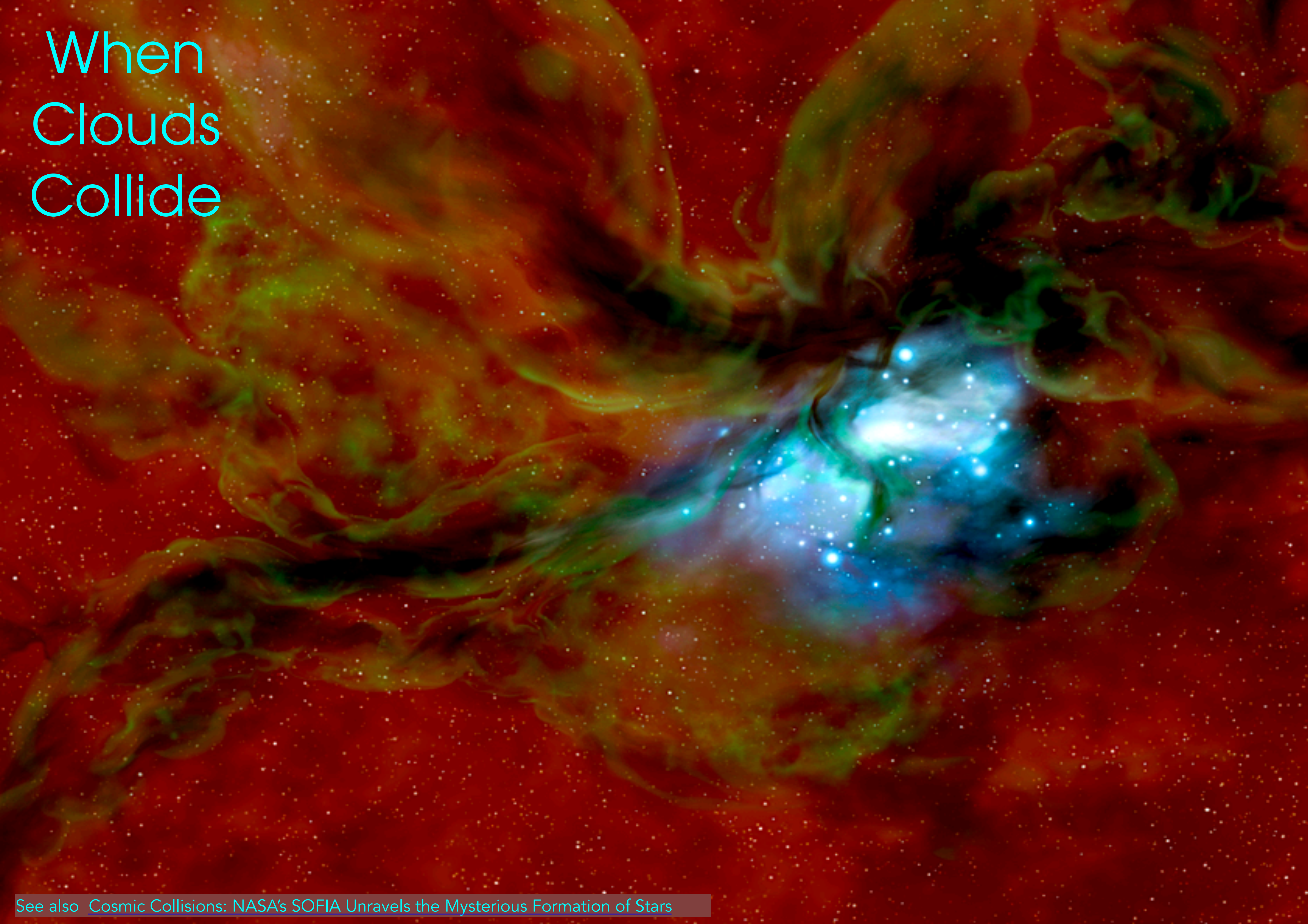


During a survey of the southern Milky Way with the 20/26-inch Schmidt telescope at Uppsala Southern Station a heavily reddened cluster has been found in Ara at R.A.=16h45i˜i3, Dec.=-45046'.3 (1960). The region shows some very dark lanes and a few emission patches. The brightest stars in the cluster are found at V= 14 mag. No stars can be seen in the cluster region on plates reaching B =19 mag. From a preliminary photometry in infrared and visual light of 80 stars inside of circle of 2' in diameter a mean total visual absorption of 11.2 mag. has been found. The color-magnitude array indicates that the cluster is very young. It appears likely from the photographs that most of the absorption is caused by dust in the same volume of space as the cluster.

Astronomical Journal, Vol. 70, p. 57-57
March 1961

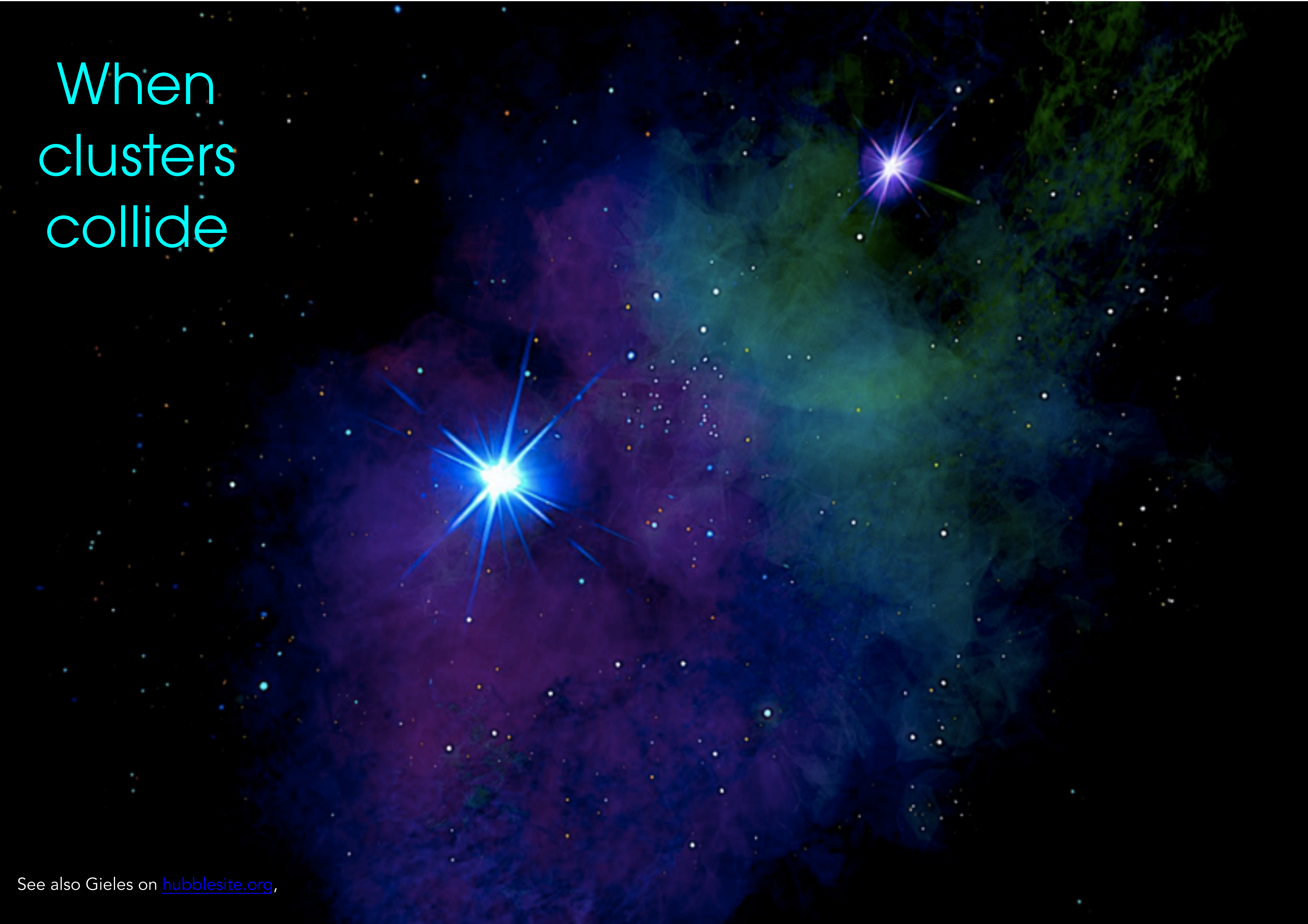

Westerlund 1 is a star cluster in Ara. At only five million years old it. is the most massive young cluster in the sky. It is 100 times more massive than other open clusters.
What happened?

When Clouds Collide



See also Cosmic Collisions: NASA's SOFIA Unravels the Mysterious Formation of Stars

When clusters collide



See also Gieles on hubblesite.org,

Wd 1 is huge, hot, and bright. Why is it so hard to see?

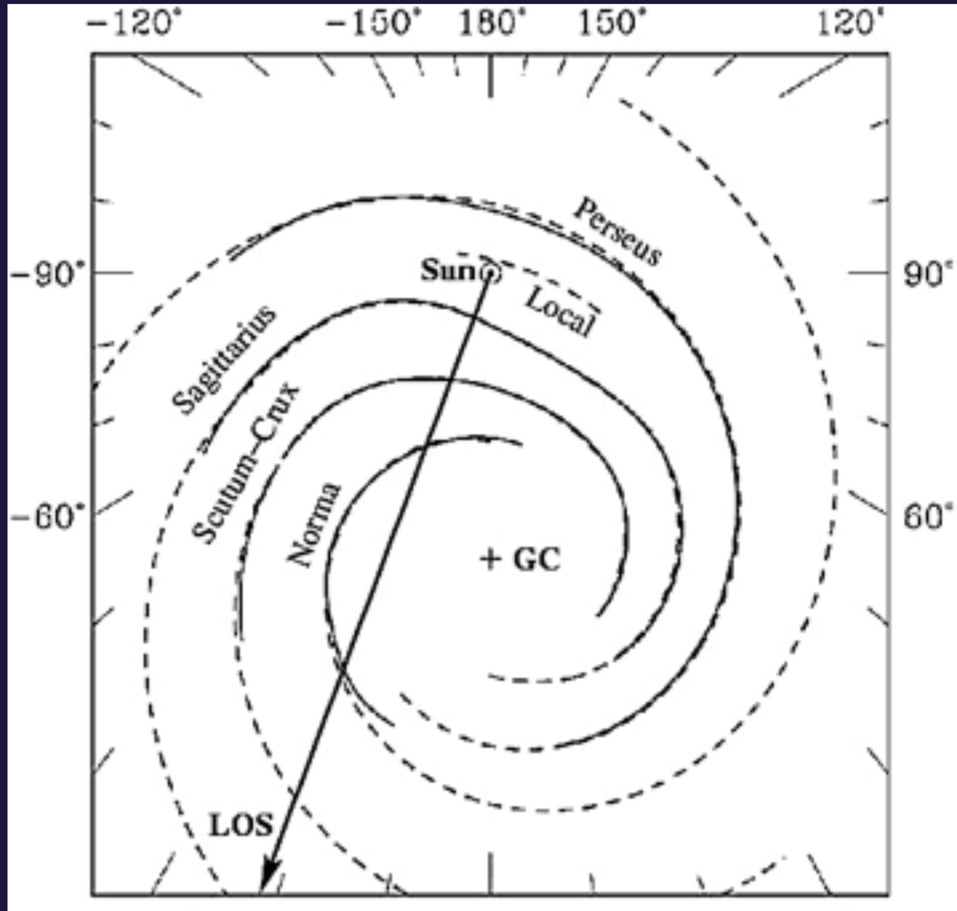
Text by Nightfall editors

Bengt Westerlund's initial 'heavily reddened cluster' report raised no eyebrows at the time. Most astronomers would take note of the object's Galactic coordinates and conclude that it lies in the dense tangent sightline of a Galactic arm and in the densest layer of the Galactic dust plane. Though Westerlund classified 80 stars, he put the project aside for the next 25 years.

Dust-to-gas densities in the Galactic plane can amount to 1% dust to 99% gas (gas-to-dust ratio of 10^{-2}). That might sound rather spare until we consider the optical cross-section diameter of those dust grains compared with the optical cross-section of atoms. Today we know that Wd 1 is dimmed by 11 magnitudes of visual extinction. A budding astronomer with a science fair project in mind might ponder the volume of dust in a cylinder the diameter of a six-inch telescope lens that extends 10,430 light years to Westerlund 1, then derive an equation to calculate the depth of household biscuit-flour particles required to dim the reflection in a six-inch diameter bathroom mirror 11 magnitudes. (If the experimental proof involves blowing flour particles at the mirror through a (non-plastic) soda straw, better ask Mom first.)*

* An unintended lesson from this precaution would be the aspiring astronomer learning the principle behind the marketing-department stratagem, 'If you want to kill an idea without being seen as the person responsible, suggest running it past Legal.'

At the time of Westerlund's announcement, gravitationally bound gas systems were modelled as blob-like because gravitation was thought to be the dominant force in galactic dynamics – spherical bubbles as affected by density gradients from spiral arm torques, gas clouds, and supernova shocks. The roles of intersecting turbulence shells and magnetic confinement were known in the early 1960s but not well understood. The fissy spraycan hysterics of protostellar jets were all but unknown. This 2015 simulation by Christoph Federrath [paper here] reveals the behaviour of gas-dust structures as they are each in turn affected by gravitation, turbulence, magnetic fields, and protostellar jets.



Wd 1's light passes through the Sagittarius. Scutum-Crux, and Norma arms of the Milky Way twice for each arm before it arrives on our tender shores. That is a staggering amount of dust in the way by any standard. Moreover, Wd 1 also has its own internal dust to deal with. Hence Wd 1's light is reddened by 11 magnitudes before we see it. For every Wd 1 photon we see, 24,912 photons have been absorbed along the way. That would turn the star Regulus into a mag 11 speck just above the visual threshold of a four-inch telescope under suburban skies. The only reason we can visually sight it at all is because Wd 1's 10,000+ stars include 140 or the brightest stars in the Galaxy. Moreover, the entire cluster is jam-packed into a sphere that would locate us on one side and Alpha Centauri on the other.

In a place like the Milky Way, you need a good house cleaner.

Westerlund 1's superlatives are formidable even in the rarefied world of the Milky Way's massive young star clusters. Super Star Clusters (SSCs) are an evolving category in star cluster astronomy. The name was coined in the mid 2010s to describe newly-born extreme-mass open clusters that will evolve into globular clusters after an equilibration process called virialisation. That rather formidable term can be more readily understood if we consider it as a mass-versus-energy version of an orchestra whose instruments are out of tune. In an orchestra, the oboe plays the musical note Middle A at 440 Hz and the other instrument re-tune themselves in alignment with it. The conductor walks to the podium wearing a smile instead of a glower.

This might seem a trivial way to summarise the extremely complex set of mass and energy interactions which produce those beautiful globular clusters that grace our skies. However, the basic idea of orchestral harmony as a fundamental theme of many events in astronomy becomes clear if we simply re-badge it as equilibration – or more precisely, virialisation. Super Star Clusters are a good example of the way in which the basic laws of physics tend towards harmony by smoothing the jagged edges of chaos. The universe tends towards entropy – which can be classified a form of harmony by dissonance smoothing. In the case of globular clusters, virialisation can take 250 million years. Globulars also tend to have two generations of stars within them, spaced roughly 250 million years apart. These are not statistical accidents, they are processes of the universe at work and it is for us to figure out why those processes exist to do so.

A common myth about globulars is that they are the oldest bound objects in the universe – they were here before the galaxies. Quite so. Nearly all known globulars are ancient. But not always. Globular clusters are a process, not merely an object. At only 40 million years old the cluster NGC 1818 in the Large Magellanic Cloud (readily visible in a 4-inch telescope) is classified as a transition SSC on its way to becoming a globular cluster.

SSCs begin when extremely large amounts of mass becoming compressed very rapidly into an extremely small volume of space. As a handy rule of thumb: 100,000 solar masses in filaments colliding at 20 km/sec within a sphere the size of the distance between the Sun and Alpha Centauri.

The early universe was unimaginably tumultuous – vast quantities of mass and energy flew about so chaotically that it is difficult to simulate these early processes even with today's blazingly powerful supercomputers. It took a German supercomputer 26 MONTHS to calculate the oft-cited Illustris Simulation, which embraced a relatively slender 10 megaparsec sphere of physics in motion from the era z=12 to z=0.

The boundaries around the term 'SSC' became even more constrained as astronomers gradually refined their knowledge of the different way SSCs come into existence compared with ordinary star clusters. Traditional open clusters that astro-hobbyists enjoy at the eyepiece form in variants of an overall evolutionary process called 'conveyor-belt' formation. This is time-linear and usually visualised face-on as seen on a TV screen.

The standard picture is that star clusters gravitationally collapse in sequential groups over millions of years from a single mass of gas and dust. To give an example, the star forming regions of M16, M17, M8, and M20 appear to be part of a conveyor-belt that is squeezing stars out of a long gas-dust filament within the Scutum-Sagittarius spiral arm. The duration of a conveyor belt cluster cycle can be ten to a hundred million years, with the average of 50 million years being a handy norm.

In 2014 the team of cluster specialists led by Yi Feng and Mark Krumholz calculated what would happen if the masses of gas and dust were two surfaces of dense gas that slammed into each other rather like a head-on car crash. The result was, predictably enough, a godawful mess.

There are only six bona-fide SSCs in the Milky Way galaxy. South Africa's Carol Botha has undertaken to tidy up this house full of cosmic dust bunnies, using the innovative new technique of online access to an observatory in Chile. (See the article 'Carol's Pages' earlier in this issue.)

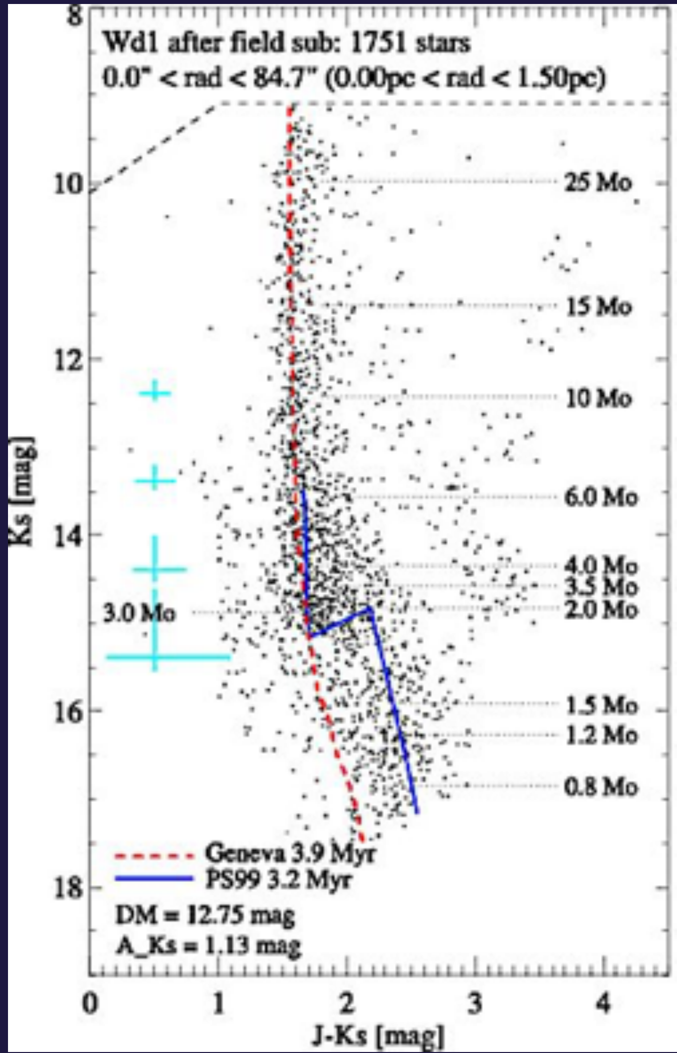
Wd 1 has a sibling brother named Westerlund 2 in Carina, and a new baby sibling, NGC 3603. N3603 ia an astronomical toddler at a mere 2 million years of age. The other three Galactic SSCs are Arches, Quintuplet, and Central in the Milky Way's core, but these are embedded in so much dense gas and dust that they can be observed only in infrared and radio wavelengths.

This stairway to the stars looks more like a rock-climbing wall

If we lived in the middle of Westerlund 1 we would have no trouble reading the newspapers at night. The night sky would be ablaze from 60 OB supergiants, 25 Wolf-Rayet stars, 6 yellow hypergiants, 4 red supergiants, a luminous blue variable, and an unusual B(e) supergiant which seems to be the showcase prodigy of the Blue Straggler world. Two blue supergiants essentially melted into each other in a spectacular frenzy that hurled into space considerable portions of their outer layers in great, searing streamers. B(e) stars rotate so fast they blimp outwards into egg-like shapes. So frantically do they spin that their surface velocity is only slightly below the star's escape velocity.

While all this sounds impressive, gee-whiz recitals like this distract from the truly important aspects of Wd 1 and its siblings. Type O supergiant stars are only 0.0006 % of the typical demographic profile of a star cluster. These stars will be somber embers by the time the cluster's multitude of young, ordinary stars sweep away the debris of the cluster's youth and turn this stellar upstart into the leafy beauty of an old genteel globular cluster. Dwelling on the big-bigger-biggest statistics of a star cluster like Wd 1 is like making goo-goo eyes at the sleek red beauties in an auto race-car show hosted in the cafeteria of a retirement community. The long future that lies ahead in that cafeteria is crafted not the race cars under the spotlights and flashing lasers, it is perpetuated by the hundreds of staid citizens who dutifully pay their fees to reside there.

Even so, we all know the shiver of envy and fantasy at the sight of a red Ferrari that happens to pull alongside at a traffic robot. Wd 1's Ferrari is as red as stars can get. It has the numbers Wd 1-26 painted on the door. Wd 1-26 is a red hypergiant and arguably the largest star in the Milky Way. (Opinions vary hugely in the debating societies of stellar hugeness.) Wd 1-26 has been calculated as 3000 times the diameter of the Sun. It would j-u-s-t fit if we plopped it into the orbit of Jupiter. If we lived nearby (the Oort Cloud would be a good choice) we would have to reside at the bottom of a lake of UV-block cream, for nearly all of Wd 1-26's emission is in the ultraviolet band. Call it a flash-in-the-pan star and you'd be right.



Wd 1 CMD from Brandner 2008. *Original source*: Natalia Kudryavtseva, *Instantaneous starburst of the massive clusters Westerlund 1 and NGC 3603 YC*. Ph.D. Thesis 2012.

The Westerlund 1 Motley Media Crew proudly proclaims ...

Meet My Magnetar

it's hard to make a magnetar seem sexy. So be a decent chap and cheer !

Westerlund 1's only known supernova is a rare neutron magnetar. It was the more massive star of a binary system whose total mass was about 60 Suns. The ALMA array's discovery that the magnetar's erstwhile companion (today rebadged as Westerlund 1-5) had been hurled all the way across the cluster solved the mystery of how a star that started off too massive to avoid hypernova collapse directly into a black hole could end up as a magnetar instead. Check out this Powerpoint presentation on the complex physics of magnetars in general and the Wd 1-5 magnetar in particular. See also Salvatore Orlando's 3-D fully interactive magnetar/pulsar model on Sketchfab.

A cluster crammed with conundrums

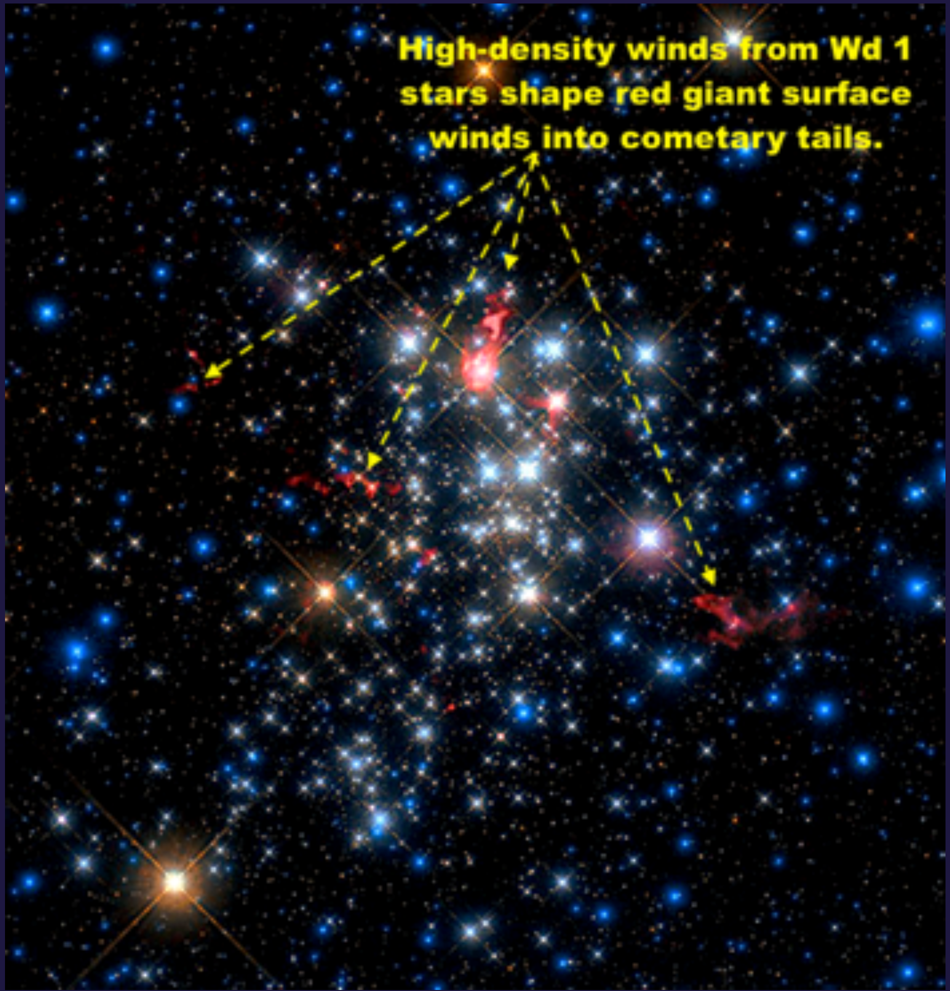
On the previous page we noted that Westerlund 1 evidences only one indubitable post-supernova remnant, the magnetar Wd 243. Yet the cluster's colour-magnitude diagram shown earlier resembles no other cluster in the Galaxy. Stars in the mass range near the top left-centre of the 'stepladder' CMD begin to go supernova starting around 4 million years. Wd 1 has over a hundred of these, and they show few signs of immanent-supernova behaviour. The high number of extreme-mass stars well past their explode-by dates defies explanation. For one, there should be abnormal numbers of neutrino events in underground detectors and X-ray excess in H.E.S.S. cosmic-ray detectors, but the telltale signals have not appeared.

At approx. 5.5 million years, Wd 1 should have experienced between 50 and 150 supernovae by now, roughly calculated at one SNE every 7000 to 10,000 years. Additionally, Wd 1 has some 24 Wolf-Rayet stars and six yellow hypergiants that are presently shedding mass from their outer envelopes at furious rates in a futile attempt to lose excess mass to balance their mass-energy budgets. A large proportion of these should have detonated* by now. Moreover, Wd 1 has an abnormal number of high-mass X-ray binaries which can't be explained. Infra-red observations reveal the presence of late-O main sequence stars, which go supernova starting 3.5 to 4 million years. They haven't, so why not? Wd 1 also has a sizeable population of ordinary main sequence stars in the mass range of the Sun and below, whose spectra suggest they should be about 3.5 million years old, not 5 million years.

In sum, Wd 1 doesn't behave like it's supposed to. Parts of it suggest that they are 5 million years old; nearby parts suggest they are 3.5 to 4 million years old. There is either something wrong with the cluster, or something wrong with the way we understand it. If the fault is in our thinking, how do we trace it?

Let's begin with an assumption we make about Wd 1 and other known super star clusters – supermassive clusters form very rapidly from a singly body of molecular material. In astrophysical jargon they formed 'instantaneously'. (In star cluster circles, 'instantaneously' means 'within 100,000 years'.)

Do we need Sherlock to tell us that there is a dog here that didn't bark.



This striking image was produced by the Atacama Large Millimetre Array (ALMA) in Chile. It shows comet-like tails of hot atoms and dust grains from some of the stars in Wd 1. High-velocity winds blasting out of the cluster's hottest stars abrade thick streams of gas and dust off the outer envelopes of their nearby stars in much the same way a sandblaster peels and blows away paint from a concrete wall. In the case of Wd 1's stars, the effect is more like a blowtorch than a sandblaster, but the net destructive effect is the same. A similar process makes the comet tails that we see from Earth. Just as with comet tails, Wd 1's 'star tails' point away from the core of the cluster. The tails extend many times the diameter of the orbits of the Solar System's outer planets. From the measured lengths of the tails and spectroscopic observations of local gas velocities, astronomers have calculated that the winds have been blowing for millions of years. Source: NASA/CXC/UCLA/ M.Muno 2005.

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* A star detonates if its ejecta move supersonically compared with the Mach 1 velocity of the local gas medium. If a star's ejecta move subsonically in the local density field, the explosion is a deflagration. At initial 'kick' velocities of 7500 to above 10,000 km/sec, supernova ejecta are more accurately described as hypersonic, meaning they are moving faster than local Mach 5.

How does a hypermassive all-at-once monster like this get made?

We last heard from the astronomer Christoph Federrath four pages ago. He was describing various physical properties that affect collapsing gas-dust masses as they become dense and more internally energetic. His traditional front-view canvas portrays the collect-and-collapse and turbulent-shock driven epochs in star formation history that culminates in gravity finally gaining the upper hand amid all the contrarian mass-energy interactions that keep a gas mass in a fractious, quivery state. The word 'supercritical' designates a specific mass-energy balance at which gravity becomes strong enough to initiate irrevocable free-fall into a bound volume of gas and dust. Once this starts, little can hinder it except a nearby supernova explosion or random encounter with another gas cloud.

And how fast can gravity do its work? In star cluster formation, there is a speed-limit sign called Mach 1, the sound barrier. It constrains the pace of physical movement. But as with humans on the highway, it's obeyed mainly when there's a police car around.

Westerlund 1 changed our understanding of star cluster formation from a view based on accretion dynamics to a view based on collision dynamics.

If we look past a portrait's details and instead observe the canvas it is on, we see its underlying reality we hadn't noted before. If we shift from the traditional portrait view seen in every museum to a lateral view as seen from the side, the first thing we find is that paintings are made up of layers, not surfaces.

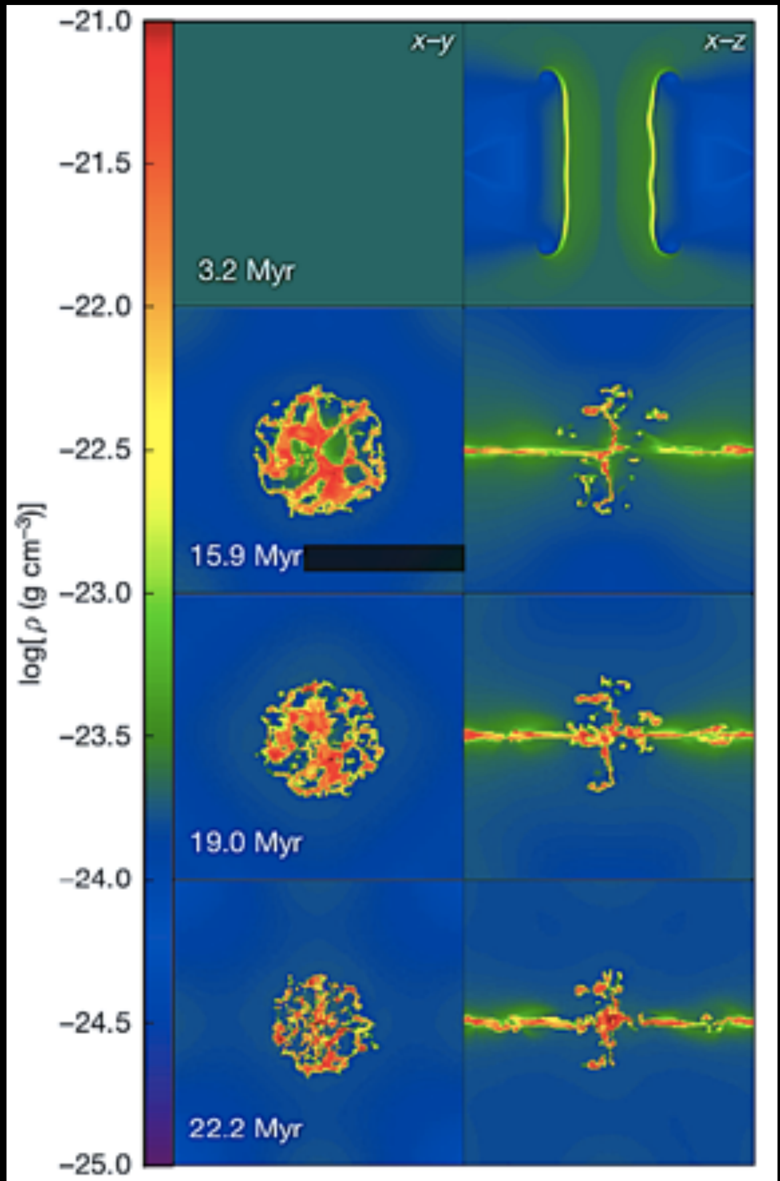
Up until the mid-2010s the standard star formation picture was that when a gas mass 'goes supercritical' into free-fall collapse, certain parts are denser than others. Cluster evolution isn't all-at-once. The cloud fragments into smaller clumps, within which compact dense cores evolve. The cores in turn collapse into individual protostellar clumps. These turn into stars. The critical mass for star-making is 0.08 the mass of the Sun. Below that, the gas core's internal pressure doesn't generate enough energy to initiate deuterium fusion, the coolest ignition temperature of fusion reactions. Subcritical cores end with a freeze, not with a whimper.

The limitation of this view is that it assumes the gas clumps act like blimpy gravitational blobs. In such structures the supersonic shocks of turbulence hinder star formation, making it inefficient, typically 1% to 3%. But Westerlund 1's star formation efficiency was 30%.

Physics was seriously challenged by Wd 1. All the way across the 1960s through early 2000s various simulations describing the physical interactions in a star-forming region budded, blossomed, and lost their petals as the winds of change filled the sails of technology. The line of precision trended ever upward. Yet behind the scenes of all those computer room and database ruminations, observational astronomy was advancing in directions whose implications few foresaw at the time. Spitzer Infrared Nearby Galaxy Survey 24 μm emission maps revealed that dust in galactic spiral arms was neither blobby nor beclotted: it was perplexingly filamentary. At the other end of the energy spectrum, ultraviolet observations from the Galaxy Evolution Explorer (GALEX) revealed rates of protostar formation in distant galaxies to be comparable to rates in our own galaxy. Very Large Array (VLA)[4] observations of atomic hydrogen emission and the BIMA Survey of carbon monoxide emission using the 30 m IRAM telescope mapped the gas content of distant galaxies at resolutions comparable to the sizes and masses we see in the Milky Way. Objects nearby were indistinguishable from objects afar.

Between 2009 and 2012 Mark Krumholz, Christopher McKee, and others refined the rules of cluster behaviour to elegant exactitudes. But they still gazed upon the scene from the front. It might as well have been an art work in a gallery.

Then in 2014 Yi Feng and Mark Krumholz looked at Westerlund 1 from the side. This is what they saw: FRONT. SIDE. BOTH.



Source: Feng & Krumholz 2014.

The point of Feng and Krumholz's paper was that, given the chaotic conditions of gas clouds in a galaxy's spiral arm, there are occasions when two massive clouds do not collapse, they collide. When they do, the total energy released into star formation is far greater than the individual clouds could make on their own. Westerlund 1 was the poster-child example of just such an event – its star-formation efficiency was 30%, not 1% or 2% like most clusters.

Astronomers soon added two other clusters to the 'Super Star Cluster' list: – Westerlund 2 and NGC 3603, both in nearby Carina. Clusters of this type are rare because the chances of two clouds with the huge mass and head-on collision angle are very low. Head-on collisions in the sky are as rare as they are on Earth.

The clouds' collision dynamics have to be seen from the sides as the two masses penetrate into each other. The effect is hard to detect if we are watching from the traditional portrait frontal view.

Barely one year later the community of star cluster astronomers was startled yet again when Australia-based astronomers Diane Salim, Christoph Federrath, and Lisa Kewley proposed that the most important factor in cloud-collision cluster formations was not the gas masses or cloud vectors involved, but rather the sound speed of each parcel as it absorbed the impact of the collision and free-falls into a protostar.

Hence Westerlund 1 inspired three new ideas which changed everything we know about star clusters all across the universe:

- The predominant form of mass aggregation in a gas-dust region was the filament, not the ball.
- The standard unit used to measure evolution was not the time it took for an event to travel across the object ('crossing time'), it was the local sound speed.
- Star clusters are not always conveyor belts; they can also be monoliths.

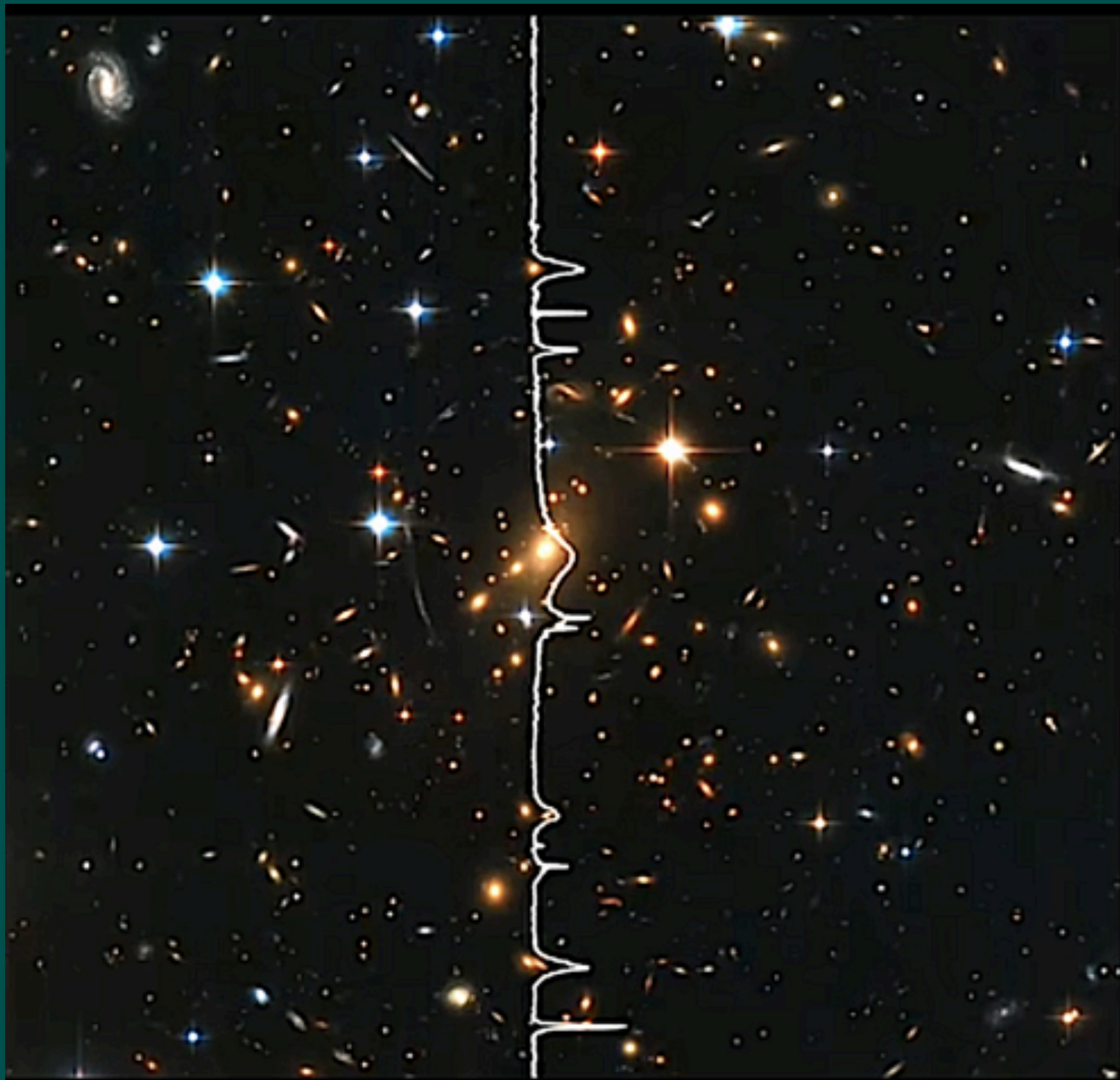
Kepler's Music of the Spheres could not have heard the sound of Westerlund 1's collision

'The star formation rate (SFR) of molecular clouds and galaxies is key to understanding galaxy evolution, but the physical processes which determine the SFR remain unclear. Uncertainty about underlying physics has resulted in various star formation laws. All have intrinsic scatter.

If we redefine the column density of star formation by the gas column density, we derive a multi-freefall description of gas that correlates the probability density function (PDF) and the sonic Mach number of the turbulence in the star-forming clouds. The star formation rate (SFR) in turn correlates with the molecular gas mass per multi-freefall time, rather than single-freefall time.'

Salim, Federrath, & Kewley 2015.

Article here.
Movie here.
Astrobites here.



It turns out there IS a Music of the Spheres after all. Kepler couldn't hear it because we need galactic ears tuned to scales many octaves below what human ears can detect.

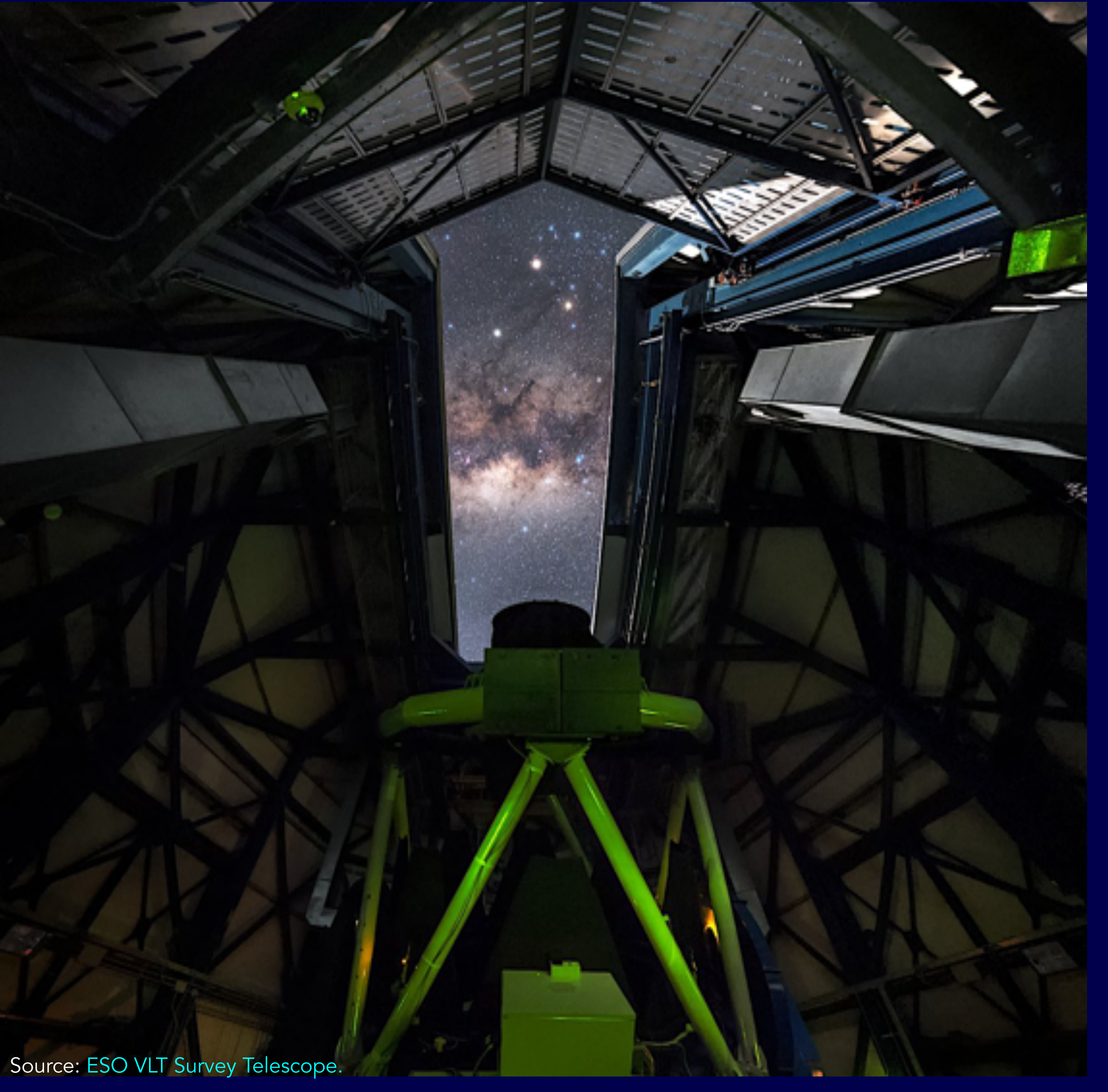
Undeterred by that modest limitation, NASA/Hubble sound engineers Matt Russo and Andrew Santaguida found a way to create the sound Kepler never heard (and probably wouldn't have liked). Taking the image of a remote galaxy cluster with the hapless name of RXC J0142.9+443, the due created this sound portrait based on the brightness and position of the fuzzy galaxies splayad across the page.

Listen here

Their message? — 'Listen my children and you shall here/of the midnight ride of marimba'd spheres'.

Filaments are the rutted paths, country roads, leafy lanes, scenic byways, neural nets, cosmic capillaries, the prodeutero-ontologies of resonance and spin, the archestrades of time and mind and sky, on which the universe directs its traffic.

So little fuel has been used to make the universe as beautiful as it is suggests that beauty will survive no matter how many or how elegant the theories we dream up in our attempts to confine it.

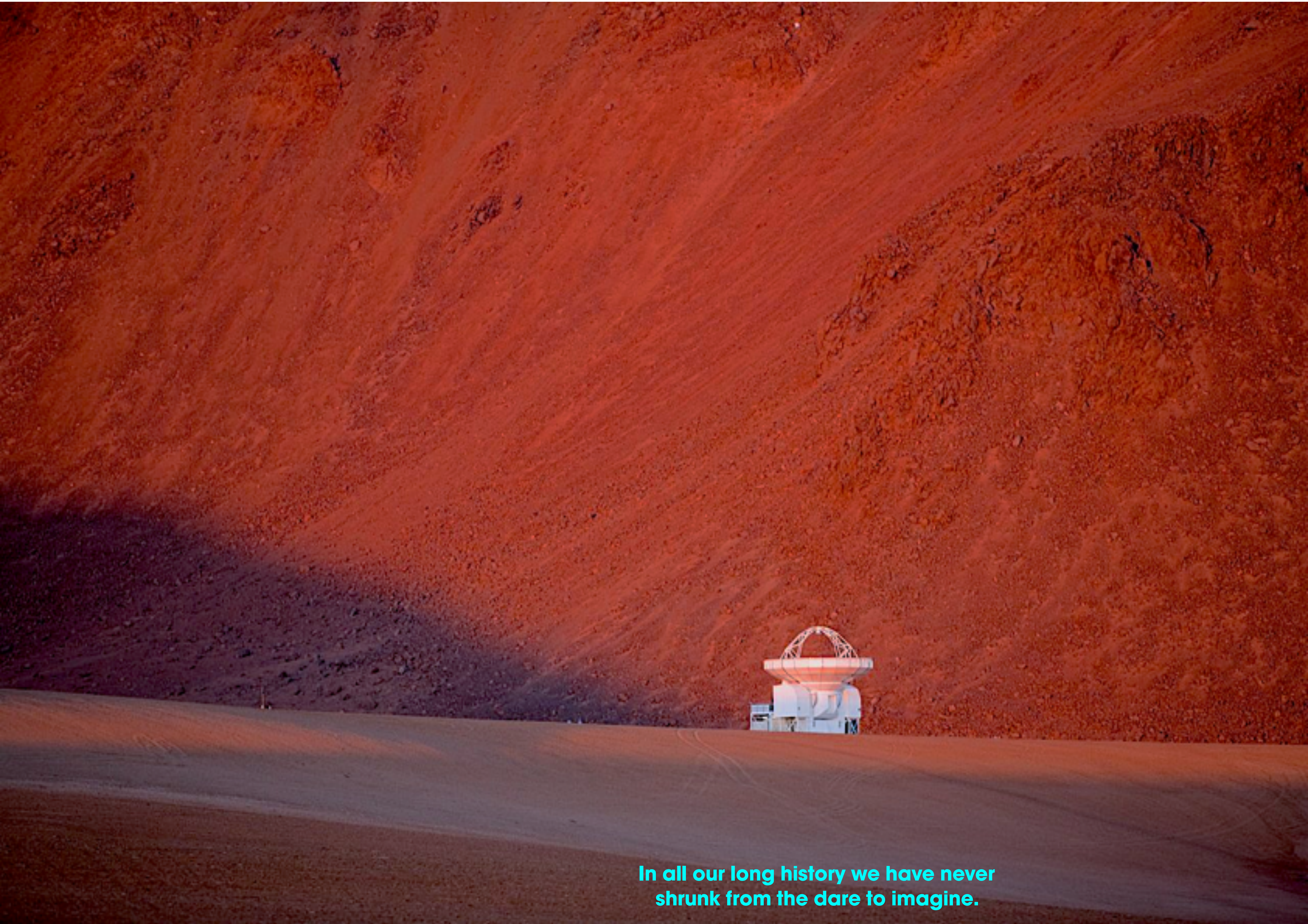


Source: ESO VLT Survey Telescope.

Source: Sandro Botticelli, Primavera, c.1480, Uffizi Gallery

The aesthetics of star-cluster formation have a grace and balance reminiscent of Botticelli beauties in sumptuous garments celebrating the arrival of spring.


NEBULAE

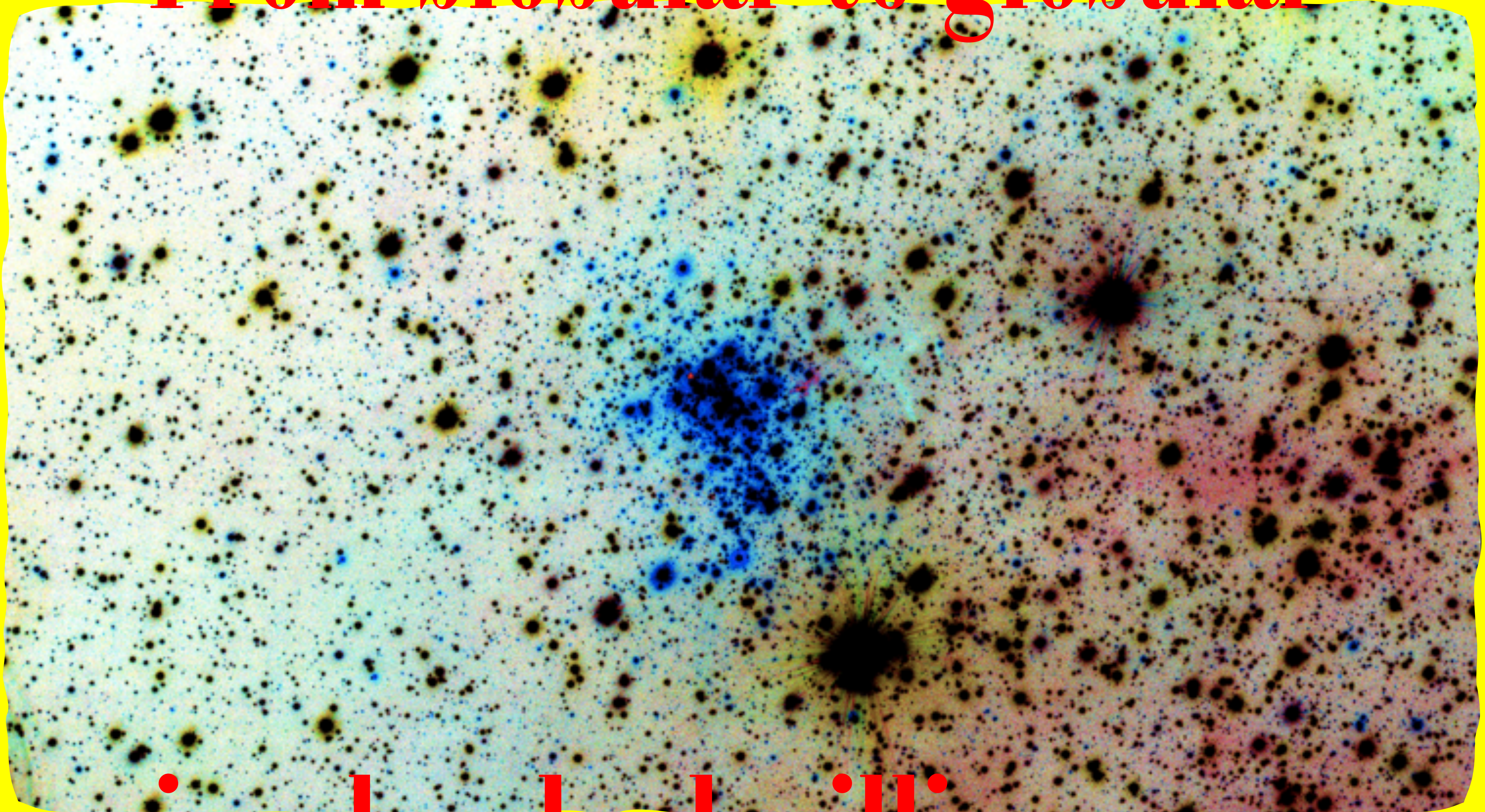


In all our long history we have never
shrunk from the dare to imagine.

KIKO • FAIRBAIRN

Brazil Astrophotography Meeting • 08/2019

From blobular to globular



in a hundred million years

Why are star clusters so messy?

Super star clusters (SSCs) are studies in violent origins that end in serenity. They are born by accident through the sheer chance of two exceptionally massive molecular clouds colliding nearly head-on. The masses of their parental clouds may not be exceptional (1 to 10 million solar masses), nor their velocity through the Galactic arm notably faster than nearby clouds (e.g., 25 km/sec). If two such clouds interact at grazing angles, or well off their centrelines, the result might be one or more fairly ordinary star clusters of a few tens to hundreds of solar masses. The result could also be nothing more notable than two clouds tearing each other's hair out before moseying on into their sunsets.

But if two clouds happen to be aimed directly at each other, when they mix it up they are just supple enough to squash deeply into each other's central densities, but just gravitationally firm enough that they end up wrenching each other apart while simultaneously mixing their contents together at extremely high pressures. Each cloud will already have density pockets, varying amounts of non-hydrogen atoms (metals), and temperature gradients. A relatively benign mix of gases whose densities are a few thousand to a million atoms per cubic centimetre become raging furies when their densities soar to 100 million particles per cc or more. Here is what it would look like if we were watching from one side.

The stochastics (chances) of a direct head-in interpenetration are small. Only six such clusters exist in our own Galaxy.* Two of the three are visible to amateur astronomers with ordinary telescopes about 6-inches of aperture and up, though all three described in this article have been logged by the author using an 8-inch Newtonian under South Africa's lucid, zero-LP skies in the Karoo highlands.

*The contingent of Orion Nebular Cluster enthusiasts who agonise that their darling is not on the official IAU list of SSCs can take courage that the ONC has been advanced as a candidate SSC by several groups of 'cluster-buster' professionals who take these things apart and put them together again rather like magneto-hydrodynamic Tinker-Toys. Patience, *Orionistes*, your voice is being heard.

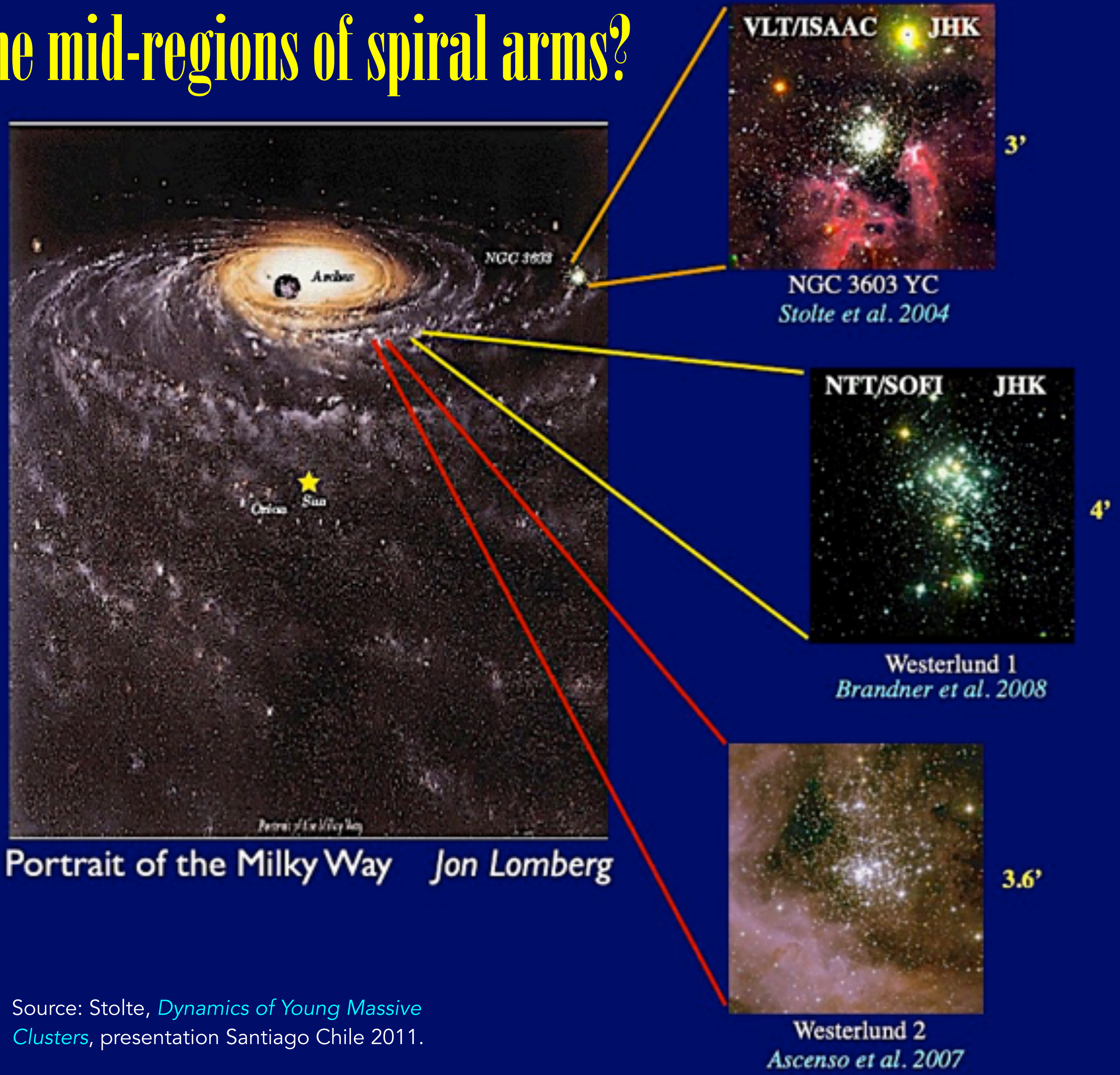
Why are SSCs in the mid-regions of spiral arms?

It may seem odd that three of the six most massive star clusters in our galaxy are all located in the middle regions of just two of its spiral arms, Carina–Sagittarius and Scutum-Crux. Moreover, they were all found at about the same time, 1 to 5 million years ago, and nearly the same radius from the Milky Way's core.

Super Star Clusters occur from a serendipitous stroke of luck when two unusually massive clouds of gas and dust manage to get into a high-speed, head-on collision. That may seem an improbable likelihood given the seemingly smooth, incurving flow lines of bright clumps and dark blobs in spiral arms.

But hurricanes look serene from distant astronauts, too, but down at sea level the story is different. The clumpy masses in spiral arms are bound by their own gravity, so a spiral arm is more like a swirl of soft, oozy bubbles that can swerve, merge, or bounce off each other depending on their masses and motions. They are beautiful chaos.

Stars and gas masses rotate around the Galaxy faster than the spiral waves. As they move into, across, and out of the wave, turbulence and collisions squeeze star clusters. Clusters have predictable life cycles that go through three basic stages.



Source: Stolte, *Dynamics of Young Massive Clusters*, presentation Santiago Chile 2011.

Premature ejeculation

Extended dusty filaments are common sights on the inner sides of galaxy spiral arms and along the leading edges of galaxy bars. SSCs make very large numbers of hot, massive stars in a very short time – 'short' being 100,000 to a million years. Astronomers use the word 'instantaneous' here, which to them means anything that happens in 100,000 years. Ultraviolet radiation from the hot stars in turn ionises their surroundings into an ultra dense HII regions that also contain a large component of dust. During the early phase up to 2 million years of age when a young SSC still lies within its opaque dust cocoon, the infant stars are poorly visible in the visual spectrum. Astronomers record radio and infrared spectra to quantify SSC starlight and gas intensity, and millimetre to micron band telescopes such as ALMA to record dust types and density.

Once the central dust is evaporated or expelled and astronomers can see the central stars within in the visual band, enthusiasts using medium to high magnifications with high-contrast filters can easily detect the expelled dust remnants around NGC 3603 and Wd 2. While they are faint daubs at the eyepiece compared with the brilliant spangles of central stars, large observatory cameras reveal SSC gas ejection envelopes to be complex cloud structures that also happen to be strikingly attractive just to look at. You can pay very dearly in an art gallery for an abstract expressionist painting that, when framed alongside a large print of Wd 2, looks rather vapid.

While we see these clusters as very pretty eye candy to behold, the clusters see their gas clearance era as a major change in their destiny. Getting rid of all that gas means they are also losing half their gravitational grip. This initiates a cycle of core contraction and envelope expansion. The end result is a denser core of bright stars while the lightweights out in the halo ease their way into the galaxy at large. Here is a computer simulation that shows the ebb and flow of hydrogen gas into and out of stars whose infancy starts at 25 times the mass of our own Sun (see Rosen at al 2016 for the full article).

What if we did to a Rembrandt what magnetohydrodynamics does to two molecular clouds colliding at 20 km. sec.?

Rembrandt molecular cloud from front (recto).

Rembrandt molecular cloud from back (verso).

Rembrandt molecular cloud recto and verso both compressed to 1 pc thick interpenetrating at a fiducial age oF 100,000 yr.

Rembrandt cloud fully merged fiducial age 300,000 yr.

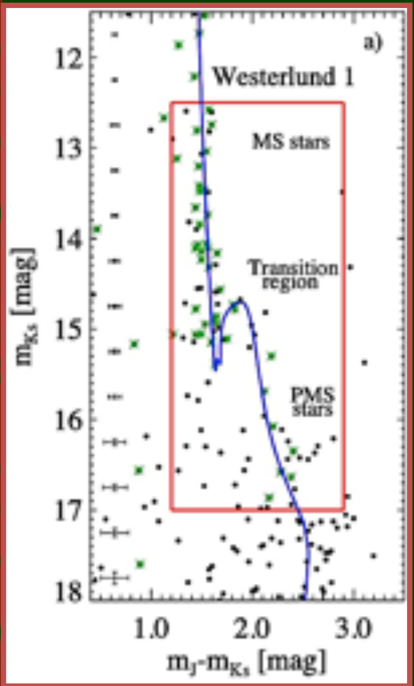
Image: Rembrandt, *Portrait of sleeping woman*, c. 1611. Collection N. Israel, Anriquaar., Amsterdam c. 1973.

When massive gas-dust clouds collide, they shred into a myriad of clumps. Their swirling motions twist them into filamentary threads perhaps the diameter of the Solar System and many light years long. When these threads cross or brush into each other, they form very dense clumps that implode rapidly into massive stars. Hundreds to thousands of stars can shrink out within 100,000 years.

WESTERLUND 1

Westerlund 1 is one of the two or three most difficult clusters to observe. Yet it is also one of the two or three star clusters so important that our knowledge would be incomplete without it. If all this sounds a bit disconnected, we can thank dust for obscuring more than just the view.

Wd 1 is a unique natural laboratory for the study of extreme stellar physics. No other star cluster is quite like it. Its massive stars are a compendium of overweight exotics. Yet it is this unabashed weirdness that helps astronomers pin down how the most massive stars in a galaxy live and die. Wd 1's total number of stars from 0.08 solar masses (*msol*) to 120 *msol* is between 20 000 to 45 000 *msol*. Add the smaller stars and the total swoops quickly past 100,000 stars – this is true globular cluster territory. All this makes Wd 1 about 10 times the stellar mass of the Orion Nebula cluster, and 2 to 4 times the mass of the very young super star cluster NGC 3603 (below).



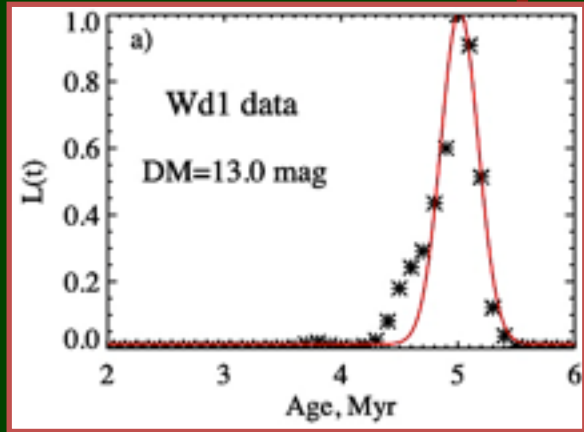
CMDs and stellar age profiles used in this article from Brandner et al 2008.

Wd 1 is an oddity in many regards. At roughly 5.5 million years old it has experienced only 1 supernova. In most clusters this massive, supernovae usually get underway at about 3 to 3.5 million years, and Wd 1 should have experienced around 40 to 60 of them by now. Why are there so many slowpokes? One reason could be the cluster's high proportion of tightly packed binaries and multiple stars. Several other plausibilities exist, but so far none has proven to be the sole actor in this starry stage set.

Many of Wd 1's hundreds of very massive stars shine with a brilliance of almost one million suns. Several are two-hundred to a thousand times larger than the Sun. Wd 1's truly whopper star is a red giant whose photosphere is the size of Jupiter's orbit.

It is hard to imagine life in a star system like Wd 1. If the Sun were located at the heart of this glittery monster, the sky would bedazzle with hundreds of stars as bright as the full Moon. We would not be able to read a newspaper at night because the sky would be hotter than the ignition temperature of paper, and we would be sizzling cinders.

The mass-segregation phase of Wd 1's evolutionary cycle is well underway, meaning that the heaviest stars are converging into the middle while the least massive are easing outward toward the very edges of the cluster's halo. The cluster has thus begun the stellar mass loss phase of its evolution, which can go on for billions of years. The end result will be a quiescent, nearly sempiternal globular star cluster whose stars are all 0.8 *msol* and less.

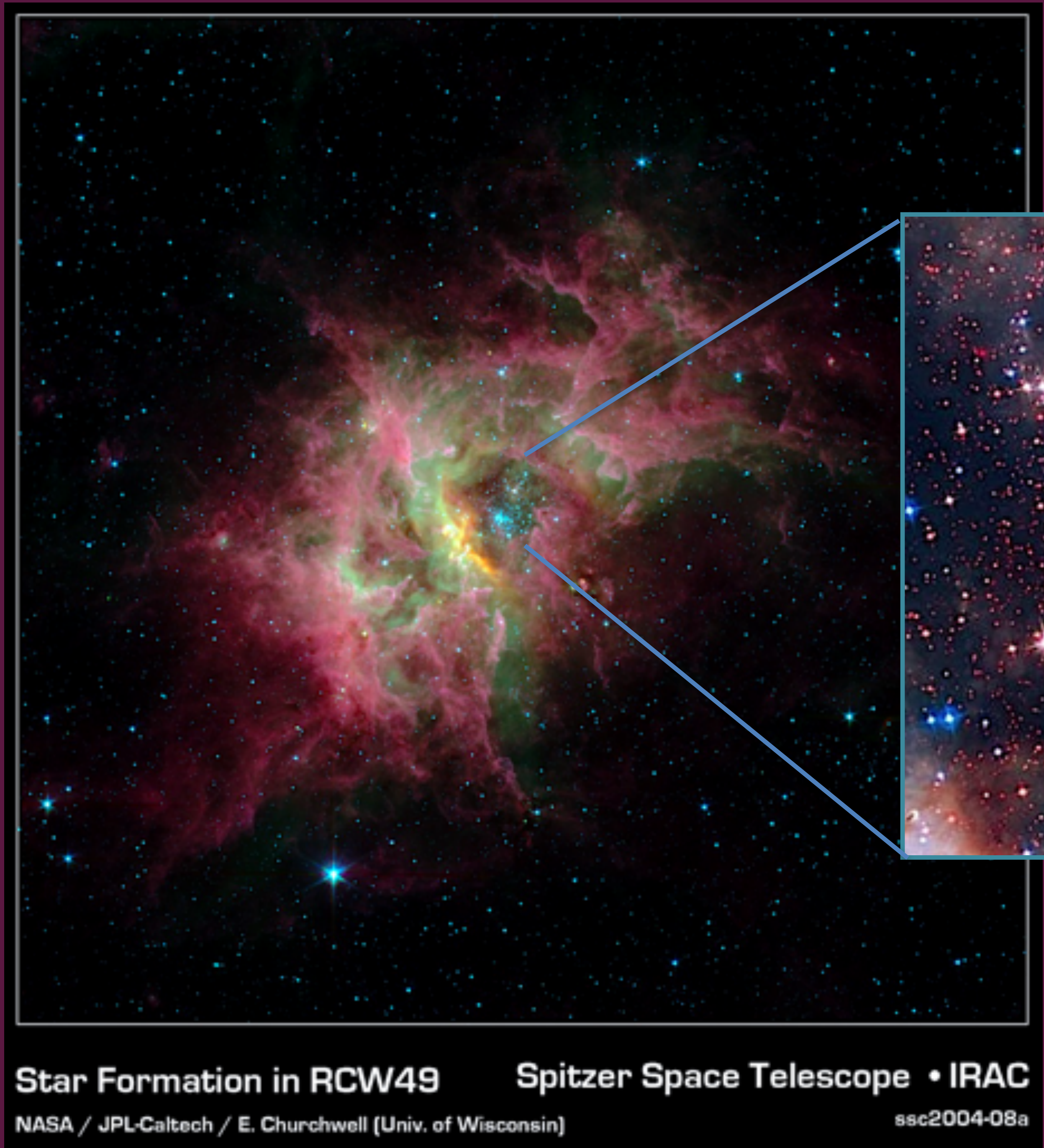


Wd 1's bimodal 2-stage star formation sequence. The smooth curve is a Gaussian plot of the averages of all the 'x' stars at an assumed age of 5 million years.

If the above photo suggests that the cluster is elongated, that's because it is. It has one elongation with an eccentricity of 0.2 for stars with masses between 10 and 32 *msol* and another of 0.15 for stars with masses in the range 3 to 10 *msol*. Barring external shocks like supernova shells passing through, the stars in isolated, ageing clusters naturally evolve toward more perfect circles as the clusters they lie within get older — the stellar version of settling into staid suburban life. The fact that Wd 1 has two distinct settlement patterns going on points to two distinct phases of progenitor cloud collapse out of a single huge cloud.

Such a bimodal collapse structure is most logically explained by the cloud-collision genesis of massive star cluster formation. Here is an example of turbulence shocks when two clouds collide head-on: Side view. Face-on view.

WESTERLUND 2

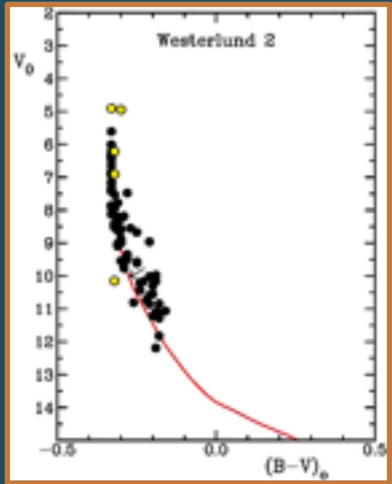


Wd 2 has such a complex structure that astronomers figured it out only in 2017-18. The vast gas blob in the left image is RCW 49, the parent cloud for the three generations of stars in the round Rosette-like core. There are really two dense clusters here, as seen in the right-hand image. The upper one is called the North Core, is coeval (the same age) with the Main Core, but has only 2/3rd the star mass.

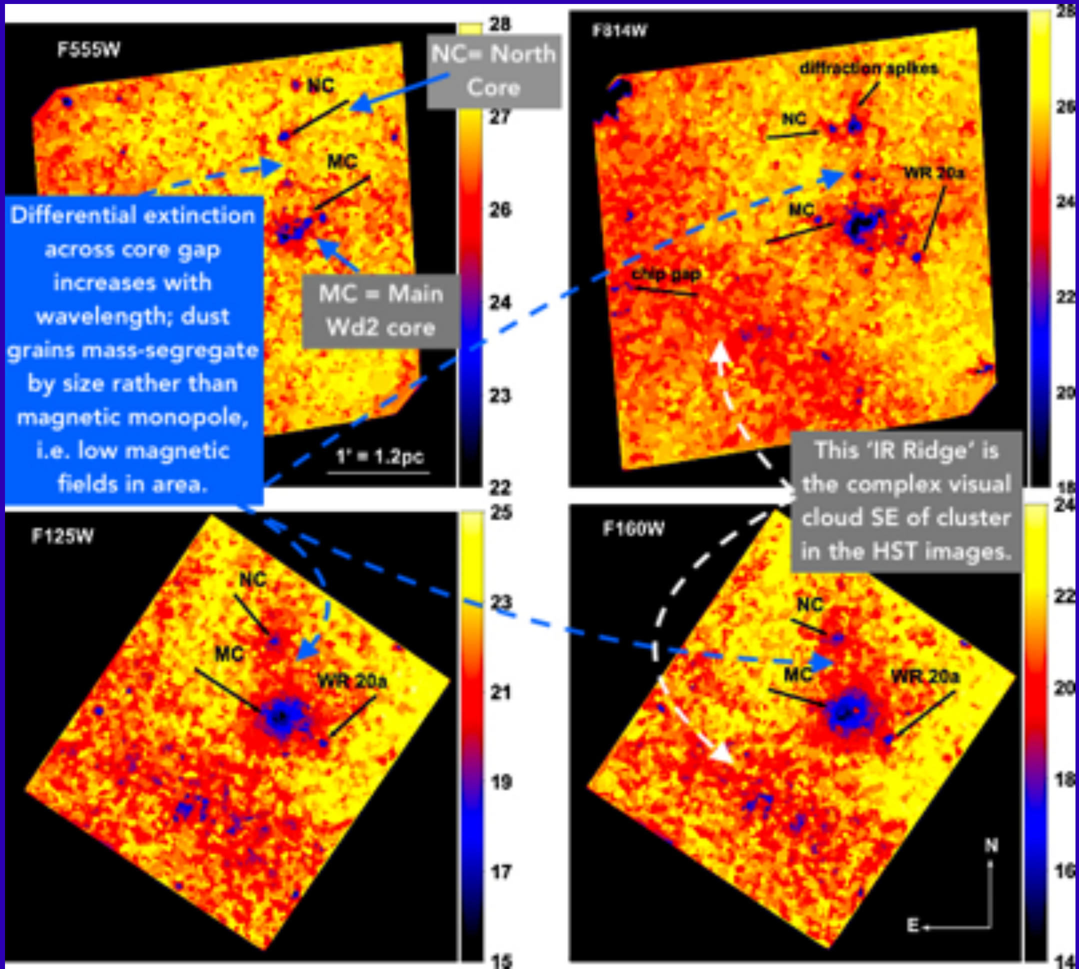
The gauzy region in between is caused by a large but optically thin dust cloud that is not part of the Wd 2 cluster system, but rather lies between us and Wd 2. Without that dust cloud, this entire field would be as star-bedazzled as the Main Core. Off to the SE (lower left) the large, dense gas ridge is now forming pre-stellar cores triggered by the intense radiation, mass outflow, and turbulent shocks generated as Wd 2 radiates away its youthful exuberance. Off to the lower right is an invisible cloud of low-mass infant protostars presently visible only as specks in X-ray images.

The rare Super Star Cluster class of star formation results from an exceptionally rapid pressure build-up when two dense, massive gas clouds collide head-on at high velocity. Up to a million solar masses of gas can be shocked into stars, a high proportion of which have 20 or more times the mass of the Sun. In the more common conveyer-belt mode of cluster formation such as we see in the M8 Lagoon and Carina Nebula, the original cloud's gas depletion cycle can span three generations of stars across 30 to 50 million years. Westerlund 2 took less than 100,000 years to make the brilliant blaze of stars we see here. Now, a bit over 1 million years later, the heat and turbulence-shocked ridge to the SE (l. left) is compressing pressure pillars that will collapse into low-mass second-generation clusters. The reddish emission regions are warm hydrogen and dust; the blue areas are reflection nebulae in which light from the cluster stars angles off the flat faces of aliphatic dust particles and into our eyes and cameras.

Westerlund 2 garnered celebrity status on 13 April 2015 when this image was chosen as the poster child for the Hubble Space Telescope's 25th anniversary.



Wd 2.s CMD is typical for a high-mass Super Star Cluster (SSC). Note the topsy-turvy mass distribution in which most of the mass is at the high-amass end of the stellar distribution, compared with the more traditional situation of a few high-mass stars and a great many stars below that of the Sun. . Source: Carraro 2018.



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

Until 2017 astronomers were uncertain whether the second stellar overdensity visible to the north of the obvious main cluster is actually associated with the main Wd2 cluster. Their uncertainty was caused by the complex dust extinction structures in the area. The main cluster is reddened by 2.3 $E(B-V)$ photometric magnitudes, while the stellar overdensity to the north of it is reddened $E(B-V) = 4.7$ magnitudes.

The cluster contains at least a dozen early O stars whose *Teff* surface temperatures are >38,000 K and more luminous than 230,000 Suns (*L*). There are 20 older and less luminous O class stars in the cluster, all main sequence objects, plus a very large number of <2.5 $M_\odot$ pre-main sequence stars whose cores have not yet ignited into hydrogen fusion. These latter stars constrain the age of the cluster to ± 2 Myr.

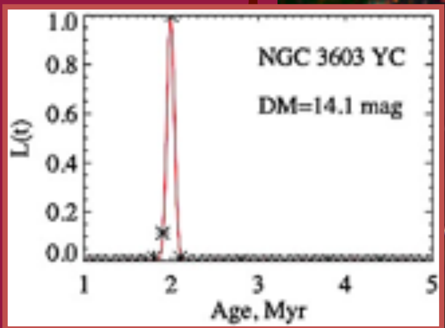
Some of Wd2's progeny are spectacular. Several Wolf–Rayet stars are associated with the cluster, although not in the core. WR20a is a binary of two Wolf-Rayet (WR) stars (which we will look at more closely below),WR20aa, WR20b, and WR20c are all single massive stars whose photometric vectors suggest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

The image to the right shows Wd2's significant micron-band emission that highlights dust, and far IR emission, which traces thermal densities and therefore gas cloud densities. Now we can clearly see that the secondary overdensity to the N is indeed an associated cluster, likely brought about when a pair of gravitationally associated high-mass gas clouds both initiated free-fall collapse at about the same time.

To the amateur, Westerlund 2 is a difficult object. It is so faint that it looks more like an asterism. The eyepiece impression looks like somebody stomped on the Trapezium.

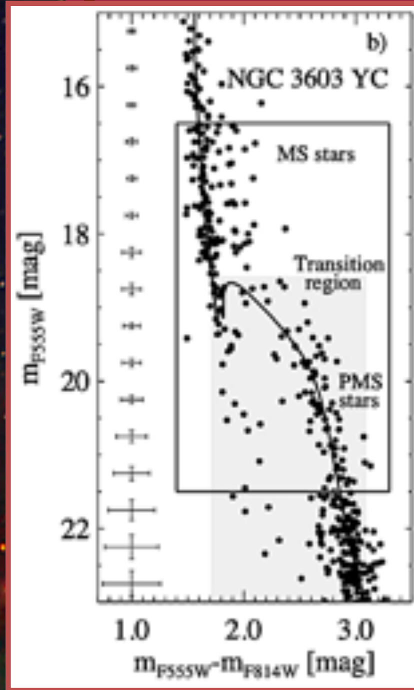
NGC 3603

NGC 3603 is the densest concentration of massive O-B type stars in the Milky Way. Strong ultraviolet radiation and stellar winds have cleared the original colliding-wind nebula's gas and dust, giving an unobscured view of the cluster. And what a view — its three brightest stars weigh in at 92, 120, and 132 times the mass of the Sun. N3603 can be likened to a giant cage of lions surrounded by a colosseum of tigers and hyenas, all of them ravenously hungry.



Read between the dots and you get 100,000 stars in 100,000 years. A pity that we are 1.9 million years too late for the show. Learn more here, here, here, and here.

Source: ESO HST.



NGC 3603's CMD looks more like a rock-climber's challenge wall than an overfed star cluster in a galaxy arm far far away. But overstuffed it was – and still is.

R 136 in the Tarantula Nebula

As we gaze at the Tarantula Nebula in our telescope eyepieces and images, we are mesmerised by the sheer glory of the thing. Two readily visible pockets of glittery stars (R 136 and the adjacent, somewhat subdued Hodge 301) lie in a seething billow of tendrils and blotches. As astronomical beauties go, it is a glory of slovenliness, a cosmic Petrouchka tangled in his strings, a Kokopelli playing a flute made of wisps to an audience made of eons.

Yet in the larger-scale panoply of our Milky Way and its nearby dwarf companions the Magellanic Clouds, the Tarantula is a wimpy little sideshow lasting but a figment in the vast drama of cosmic flow. Consider the Tarantula as a comedy skit, Act 3 from an astrophysical Shakespeare. Act 1 started roughly 6.3 billion years ago when the two Magellanics — a couple of bit actors, really, on a stage set filled with other bit actors which later got the honorific 'dwarf galaxies' dubbed upon their foreheads by some rather piffling human sightseers — first engaged each other in a gravitational food fight. Four times over the next six billion years they tangled and then parted, edging ever closer each time, gaining little, losing much. Few stars survive to narrate those scenes, but they sing clearly and we trace an Orphic trill from them. They were, after all, star witnesses.

Some 500 million years ago the pair slipped into the Milky Way's virial radius, the outer reach of its galactic grasp. Two hundred million years later the pair tangled with each other yet again, only this time the Milky Way was there to blot up the blood. Both galaxies now lie grievously wounded — the SMC is practically eviscerated while the LMG has lost an entire arm and most of its cohesive composure. Its lost arm's stars were flung as far as Carina.

Yet the two rushed on. Heedlessly, it seems, because at 350 km/second, the Milky Way's diaphanous halo is more like a beehive wall. The advancing front of the LMC imploded into the Tarantula Nebula, yet the story has only begun. An astounding 14 more Tarantula Nebulae are now forming invisibly deep within the gas and dust where the LMC bow wake is elbowing everyone aside. If this were drama the fool would die. But it's not, it is rather staid galactic hydrodynamics. In a final scene unwritten in a drama unseen, the shock front of the LMC looms out of luminous dark.

NGC 346 in the Small Magellanic Cloud

Image: NASA, ESA and A. Nota (ESA/STScI, STScI/AURA).

NGC 346 is a young cluster which is positioned in the middle of this image. The somewhat dimmer, dust-free, cluster at the top is an unrelated, older traditional collect-and-collapse cluster now slowly dissolving as it ages. It lies behind the younger NGC 346 below it, has by now cleared away its birth gas, and thus lies 'in the clear'. Numerous amateur astronomer observing reports describe this cluster as a distinctly fainter object giving the visual impression of lying much further away.

NGC 346 is a cloud collision cluster caught by the Hubble Telescope camera in the midst of its mass-segregation and natal gas ejection phase. As yet no supernovae have detonated in NGC 346, so the gas-clearance features shown here are straightforward gas-dust decoupling emissions. The reddish arc across the front of the cluster region is actually a partial bubble whose inner surface is excited hydrogen-alpha gas being driven outward by UV radiation from the hot O and B stars in the cluster. UV excitation affects hydrogen by injecting enough energy to nudge its ground-state electron orbitals to the second and third quantum orbitals. When electron loses enough energy to drop back down to the 2nd quantum shell, they emit a hydrogen-alpha light ray at 636 nm, which we see here as tinged warmly red. The hue is optically thinned by the presence of many different atom species like silicon, sulphur, and sodium, among others. Parsing the spectrum of a region like this keeps graduate students majoring in spectroscopy at work till the cockerels begin to crow.

The ragged dark streak running along the H-alpha ridge tells of a very different kind of gas-clearing process — searing hot atoms being ejected off the surfaces of stars typically 25,000 K to 50,000 K. These atoms travel at many times the local sound speed until they strike one of the myriad dust particles that were part of the original molecular parent cloud. The dust absorbs part of the energy and converts it into heat (kinetic energy), then re-radiates some of the energy as faint micron and millimetre emission. Here the dust is so dense that we see only its shadow, the ragged streak. The twisted, convoluted shape of the streak is the signature of a strong magnetic field that has been fractured by shock waves from multiple blasts of high-speed particles.

The present shell whose arc is so prominent and relatively smooth will soon be shredded by supernova blasts as those hot blazing giants in the centre start to detonate in the next few million years. In another 10 million years all the gas-clearing action will be over, and NGC 346 today will look a lot like the old, faint ball hovering placidly behind it.

The other three Galactic SSCs are in the Milky Way core, where they are hidden by gas, dust, and crowding from multimillions of stars scattered in all directions. The numbers of SSCs goes up rapidly once we get to distant galaxies (NGC 253, NGC 5253) and the remoter environs of the early universe, starting at about 10 billion years ago when the Universe itself was a 4 billion year tyke. You can watch the entire show for free, here, here, and here.

SSCs are called 'super' because they are so much more luminous than other young star clusters. They have more stars, but unusually high numbers of ultra-massive and hence ultra-luminous O-type stars. As baseline a parameter, think of an O star as 25 solar masses minimum, a few million years old, and fusing helium in their cores so that they are spectrally categorised by the Helium lines in their spectra. There are numerous subclasses of O stars — blue and red supergiants, yellow and red hypergiants, Wolf-Rayet stars in several subcategories, but they all share the fate of being exotic, dazzling, and short-lived.

The exceptional mass and O-star populations of SSCs suggest they do not originate following the traditional star cluster aetiology of collect-and-collapse or sequential triggered star formation. Most ordinary clusters form in one or another variant of the conveyor-belt mode, in which medium-to-large clusters form sequentially across a time span of multi-millions of years when an extended filament of gas/dust pushes into the dense underarm of a galactic wave. The large-scale pressures at work include torque and shear from the sliding interfaces of dense filament matter moving across and forward into each other like sliding laminae of decks of cards.

The Feathers of Grandfather Fire

In the first year
in the time of Chih-ho
the fifth moon
on the day of Chi-ch'ou
a Guest Star appeared
southeast of Tien-Kuan.
It could be seen in the day like Venus
with rays pointing in the twenty-three
    directions
and remained for twenty-three days.

On the day of Hsin-wei
in the third month
of the year of Chia-yu
the Guest Star was no longer to be seen;
this was interpreted as an omen
that the harmattan wind had blown.
If you had witnessed that Guest
in your year of One Thousand Fifty-Four,
would you have realised you had seen
the feathers of Grandfather Fire
and thereafter needed no more?

That night in the Year of the Guest
the wind siffling about your robes,
the bamboo chrysanthemíng your ears,
you would have needed no words
to know what the star advised:

Seek truth in the water stilled
not the hour upon the waves.

Eye Candy

this issue's selection

Source: Chandra image of runaway white dwarf CW Leonis near UV in yellow far UV in blue.

of the weird and the wonderful

Haste, haste, into the dying of the light

Runaway stars do not go gently into space's vast night. They hurl all aside as they plow into the dark. They squash atoms ahead of them so tight they finally glow. Then they wad their ancient atmosphere into sooty shells. As messy neighbours go, runaway stars are the worst.

In the image above, CW Leonis in the centre hurtles through space at 91 kilometres per second (204,000 miles per hour, which comes out to roughly Mach 265 if it was flying past your door right now). But out in the thin gas of interstellar space, a handy number to keep in mind is that Mach 1 is 1/5 km (200 m) per second – a number that would prevail if the average density of 'empty' space in the region was about 1 atom per cubic centimetre.

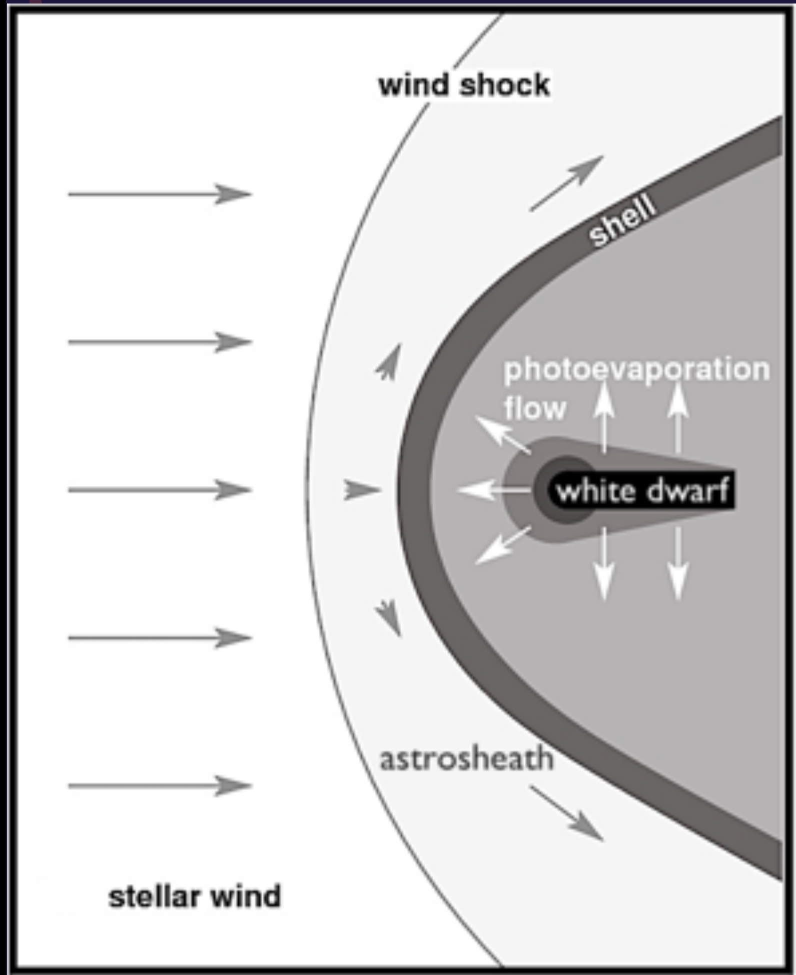
If that is the gas density near CW Leonis, the runaway is still smashing the local sound barrier, albeit at a rather more tepid Mach 15. You *CAN* hear a scream in space, you just need galaxy-sized eardrums.

The ancient white dwarf star is mooshing through the gas in front of it so rapidly that a semi-circular bow shock has formed in front of it – much like the bow wave of an old barge wallowing through a calm pond. Here, the fore edge of the bow shock marks the transsonic 'astrosheath', a superheated bubble around which the star shoves whatever lies in front of it. The onrushing shock is so brutal that it becomes incandescent. The star itself is quite tiny, nearly invisible even on this limiting magnitude 23 image. The transsonic half-sphere of the bubble is 2.7 light-years across – roughly 2,100 times the size of Pluto's orbit.

CW Leonis has been shedding its atmosphere for about 70,000 years in the end game of the star's natural life cycle. It has run out of hydrogen fuel and is now a colossally hot ball of carbon-oxygen ashes. White dwarfs like CW Leo are the last gasps of low-mass stars between 0.8 and 2.3 times the mass of our Sun.

CW Leonis is not a household name among amateur astronomers. Stand it alongside its near-twin brother Mira, though, and you would instantly spot the family resemblance.

While the star at the upper left has the bright-looking front edge of a similarly racing runaway, the effect is an illusion. The GALEX Galaxy Evolution Explorer satellite data team made this rampaging monster into this beautiful palette of blues by combining near-ultraviolet (NUV) light shown in yellow with far-ultraviolet (FUV) photons shown in blue.



It's a bird! ... It's a plane! ... It's ... Super Mira!!

In this GALEX unltraviolet image, Mira is the pink dot in the rounded dome near the right edge.

Mira is moving so fast that it creates a bow shock ahead of it, which we see as the broad arc at the far right edge.

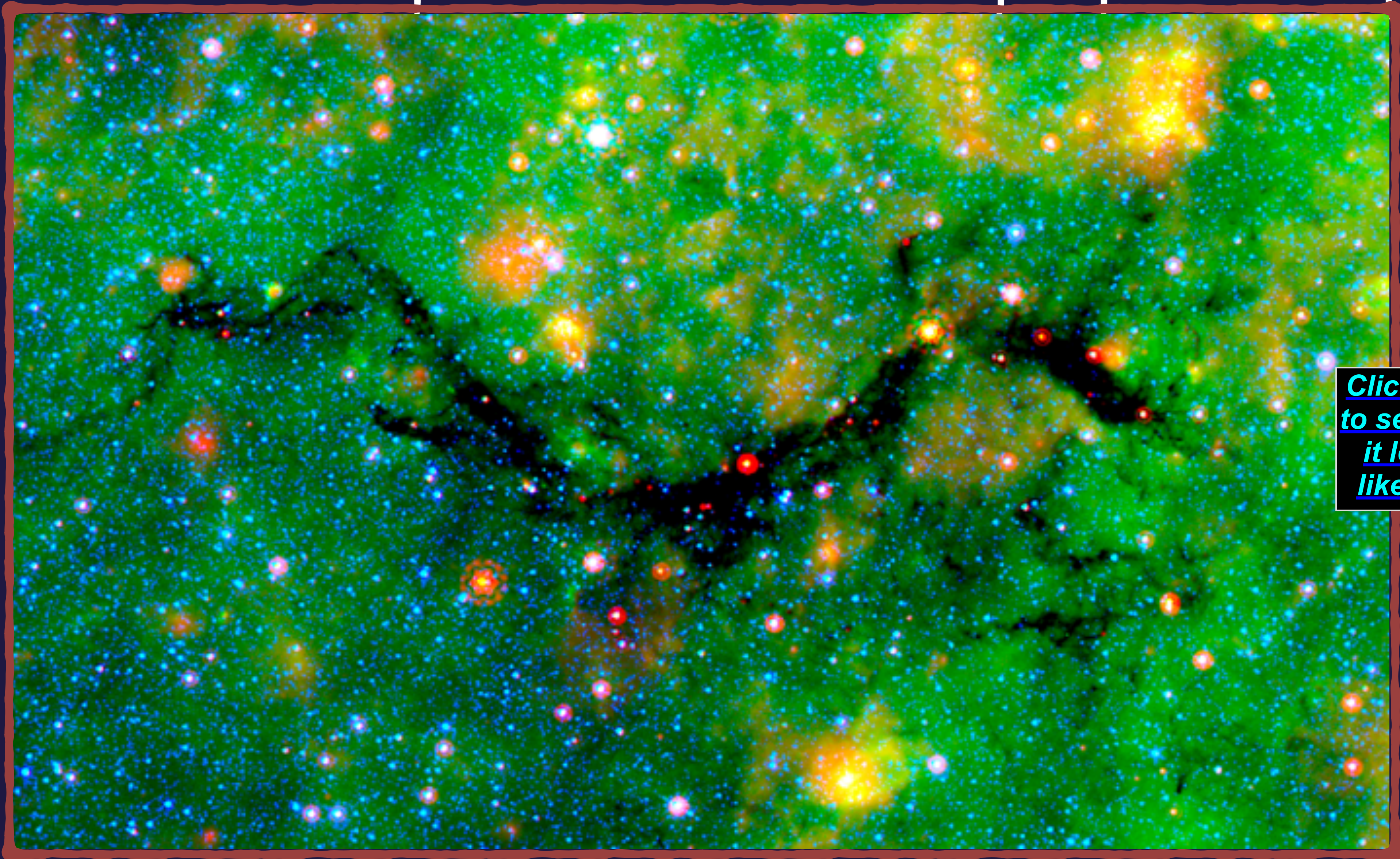
The pale comet-like glow that trails away to the left is hydrogen gas that was blown off the surface of Mira by its searing temperature. While the gas looks blue in this image, to our bare eye it would glow with the familiar dull red of hydrogen alpha light. Here it appears as blue because GALEX's sensors interpret it as gas heated into a higher-than-normal energy state. The atoms shed the heat when its excited electrons cascade down through their quantum shells. An electron that slows down from shell 3 into shell 2 emits a reddish photon of hydrogen-alpha light. If the electron pops down from shell 4 to shell 2, the photons are a deep blue hydrogen beta (Hß) hue.

Mira is moving at an angle across our field of view at a calculated velocity is 130 kilometres per second, or 291,000 miles per hour. As it hurtles along, it leaves a wake of hydrogen and oxygen gas that will eventually be recycled into new stars and planets

The GALEX near- and far-ultraviolet (FUV) cameras required 3 hours of total acquisition time to gather the photons that ended up on this page before you.

Watch how hydrogen works here.

the bottom of the sea at the top of the sky



Click here to see why it looks like this.

The Snake is a serpentine-shaped, extremely filamentary cloud. In this infrared image from the Spitzer Space Telescope, the blue dots are stars relatively undimmed by dust, while the red dots are embedded, forming stars.

Source: NASA James Webb Telescope 10 Apr 2020.
Space sim by Teun van der Zalm.

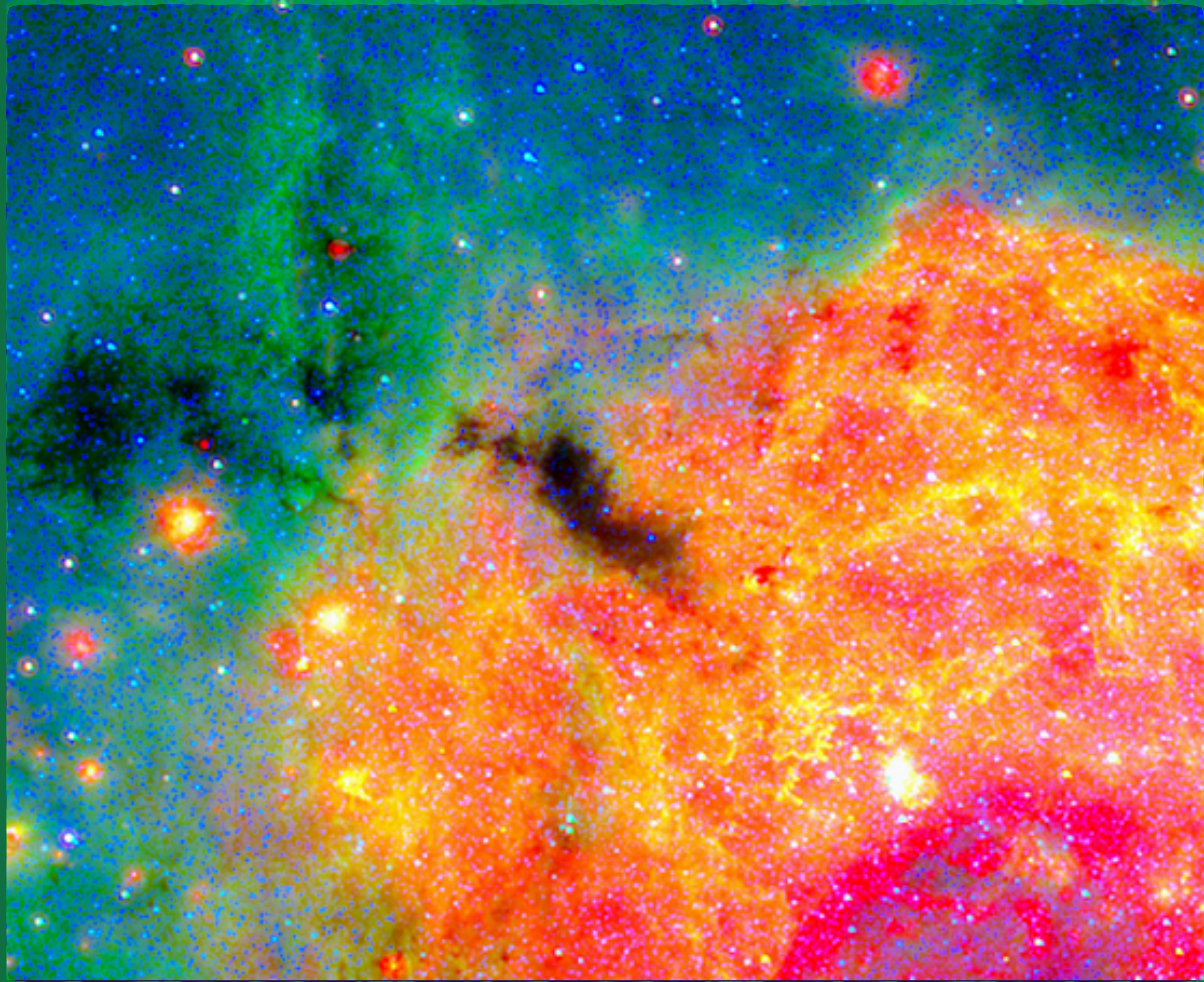
The Blob and the Brick

Galactic building blocks don't come in compact, tidy, Euclidean bundles. Yet put them all together and the end result is much the same — an awe-inspiring edifice that illumines as it beautifies.

High-mass stars might die as dazzling supernovas, but their births are mysteries garbed in murk. They form in very dense, cold clouds of gas and dust that can have up to 100,000 times the mass of the Sun. Little is known about these regions. They are so dense that they often seem like vacuous ink blobs in the sky. Initially devoid of stars, these molecular clouds obscure the light from background stars.

Made of gas with a dash of dust, molecular clouds are the baptismal fonts of baby stars. When their densities reach 1 million atoms per cubic centimetre ($n = 10^6$), they can even block out the infrared light which usually propagates through dusty environments — hence their name: IRDCs or infrared-dark clouds.

Given the moniker 'The Brick', the IRDC centred here weighs in at over 100,000 times the mass of the Sun. It isn't yet forming any stars, but based on its density and volume, when it does form stars it will become a YMC – Young Massive Cluster.

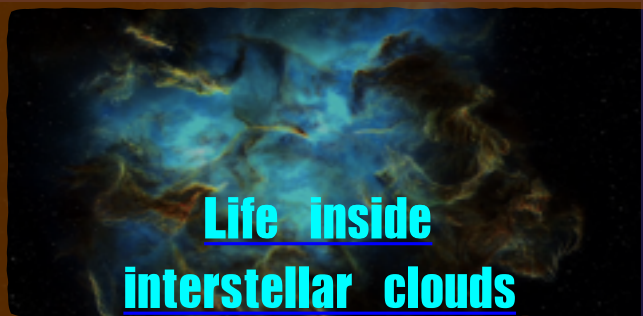


Source: NASA James Webb Telescope 10 Apr 2020.

Here is the future that awaits the Brick.

HH 901 'Mystic Mountain' erosion pillars, Carina Nebula

Even after so many years of gazing through our telescopes, looking at the starry sky still thrills us with the mystery of so much immensity. Why is it all there? We wouldn't see the stars and planets deep within these gravid clouds of dust and gas, but we would certainly feel their heat. So me make infrared receivers.

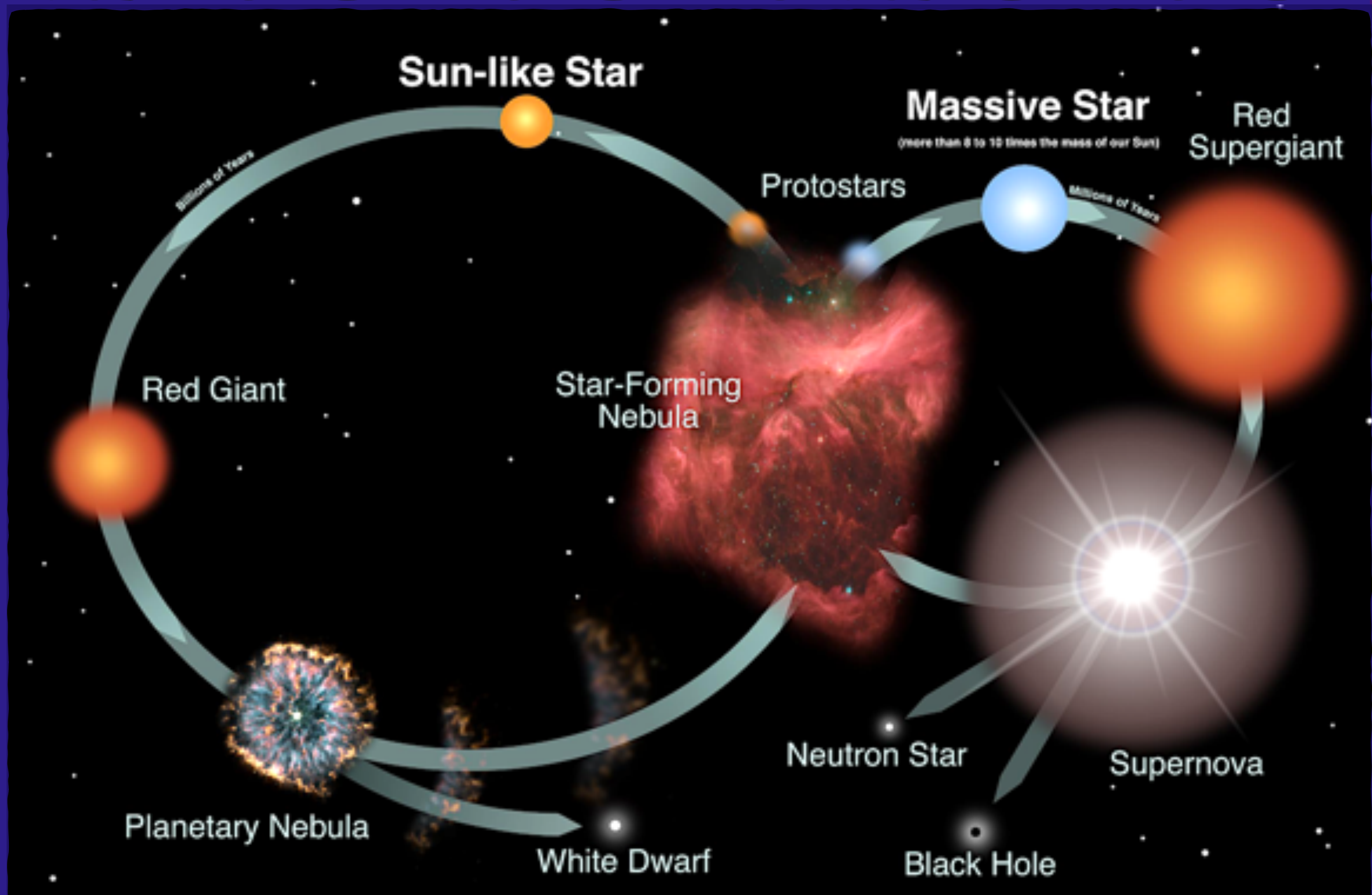


Infrared light travels little hindered by dense dust. Image this same area in IR . Ddim glows are transformed into veils of silk and gauze streaming in the winds. By observing worlds very different from our own, we grasp the nature of our home in the universe. Why that home was built is the mystery we seldom ask.

Cosmocycling

Stars populate the universe with elements through their "lifecycle"—an ongoing process of formation, burning fuel, and dispersal of material when all the fuel is used up. Different stars take different paths, however, depending on how much matter they contain—their mass. A star's mass depends on how much hydrogen gas is brought together by gravity during its formation. We measure the mass of stars by how they compare to the "parent star" of our system, the Sun. Stars are considered high-mass when they are five times or more massive than the Sun.

When high-mass stars have no more fuel to generate outward energy, their iron cores begin to collapse until the pressure overcomes the inward push of gravity and they explode in a spectacular supernova, dispersing elements into space to recombine as **future stars**, **planets**, asteroids, or even eventually life like us.



Source: JWST Cosmic Recycling

After supernova, massive stars can go one of two ways. If the remnant of the explosion is about 1.4 to 3 times the mass of our sun, it will collapse into a very small, very dense core of neutrons called a neutron star. If the remnant is more than three times as massive as the Sun, gravity overwhelms the neutrons and the star collapses completely into a **black hole**—so-called because the matter within is so compressed and the pull of gravity is so intense that even light is drawn in and not reflected, so that area is "black" or unobservable.

Starburst galaxy NGC 1569

[And if you think this is messy, here's how it gets that way.]

Source: NASA/ESA Hubble.

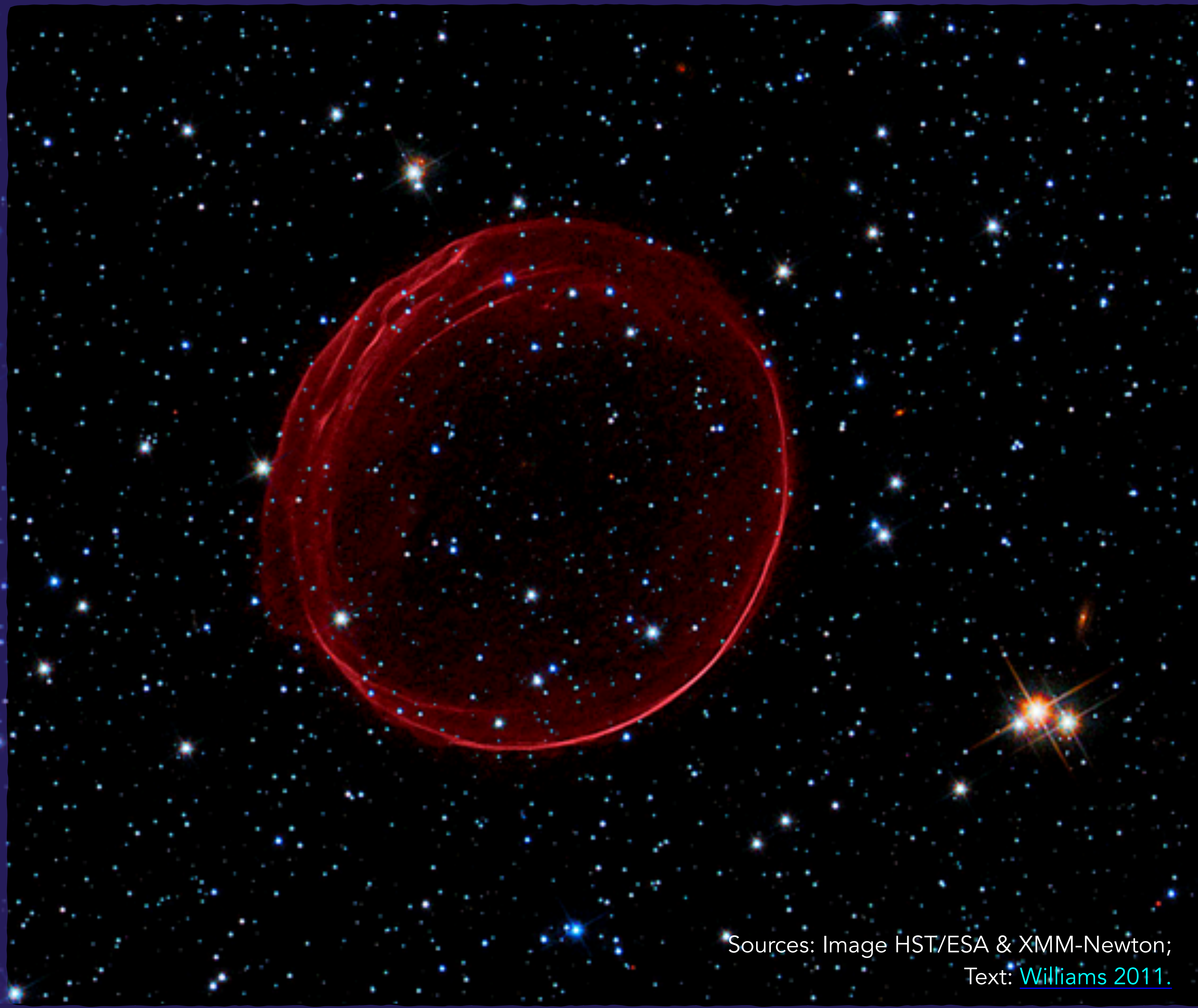
NGC 1569 in the northern constellation Camelopardalis has been erupting with stars 100 times faster than the Milky Way's starform rate. This has been going on almost nonstop for over 100 million years. NGC 1569 is part of the closely knit IC 342 galaxy group of 10 galaxies. The group's ferocious gravitational tides and magnetic fields compress and shear gas in NGC 1569, igniting the star-making frenzy.

Watch a starburst sculpt a galaxy here.
Source: SILCC.

NGC 1569's crowning glory is a trinity of three massive young star clusters. Each has over a million stars. The clusters reside in a large, central cavity whose gas in the cavity has been blown out by hundreds of massive, young supernovae. Such a large, continuous gas clearance episode also produced the violence that is sculpting the galaxy's giant gas bubbles. As tumultuous as this process may appear, it is a natural part of the life cycle of galaxies in groups

Nearly perfect: SNR B0509-67.5

The cumbrously named supernova bubble SNR B0509-67.5 is one of the most comely serenities in the sky. Yet in space, even serenity is not what it seems. Only about 400 years old, this delicate bubble is expanding at over 6000 km/sec into a thin mix of gas and silicate-based dust. The stratifications on the left are explained as density gradients of 2 to 4 times ambient densities. The delicate thinness of the shells suggests a low local gas-to-dust ratio and dust that is largely grainy (silicon-based) rather than porous (carbonaceous with water ices). There is scant evidence of blueish O-III emission in the 500.7 μm band but significant O-III, Fe, and Si emission in X-ray. The front edge of the shock compresses the local medium to 12 times its base density, a higher-than-normal ratio that implies that the shell efficiently accelerates proton-rich cosmic-rays generated in the initial SN 1a detonation. The wobbly segments suggest the dust density gradients were perturbed by pre-SN subsonic waves passing through. Strong Fe and Si emission ines may come from both the ejecta and the shocked ambient gas. The dust-to-gas mass ratio of the ambient medium is significantly lower than what is expected in the ISM. All these data reinforce the notion that in astronomy great beauty can result from the most modest of means.



Sources: Image HST/ESA & XMM-Newton;
Text: Williams 2011.

It's those pillar kids again, only this time in IR

The giant Eagle Nebula M16 is a huge bubble of gas and dust. Inside it these growing clouds are spectacular star bursts making an open star cluster. The dark sculptures seen here are evaporating as UV ultraviolet starlight abrades away their woolly cumulus shapes.

This Hubble Telescope IR image reveals striking dust pillars of the Eagle Nebula that might be described as a gigantic icebergs of gas and dust. These bergs, thought, are ten light years tall. Their bluish radiation is much hotter than the gas, hence their glow. The pillars here are about 7,000 light years away. They will evaporate completely in about 100,000 years.

The image uses was released in 2005 as part of the fifteenth anniversary celebration of the launch of the Hubble Space Telescope.

More than you will ever want to know about dust pillars in molecular clouds

Martin Heigan's LND 122 Ophiuchus

star-forming cores detaching from molecular clouds

The Pleiades and its southerly sibling IC 2602 are glitterbox gems that will shine for multi-millions of years. Yet on the way to today's splendour they left behind a dreadful amount of debris.

Only a few percent of a cold molecular cloud eventually becomes a star. The rest is eroded, dissipated, vaporised back into warm (5000 K) atoms and molecules to try again another day. In Beverly Lynds' dark cloud #122 we see the ferocious ultraviolet sear of nearby hot stars blowing dust back into the universe.

A hundred million or more years from now, the gas and dust seen here will return to much this same state, only to be blown away again. Again, again, again, till one day they can finally ignite. Patience is a job description in a star's resumé.

Source: Martin Heigan.

Watch this snapshot turn into a movie

NGC 1512 Barred Spiral in Horologium

[More complicated than it looks.](#)

NGC 1512 is a classic study in the dynamics of galactic bars. Several hundred million years ago this galaxy was a modest-sized flocculent spiral, with many short armlets and rotationally stretched star-forming clumps. The bulge was not very massive. At some point a tiny perturbation or bump occurred at the bulge's Inner Lindblad Resonance (ILR), a ring-like region where the gravitational balance between the bulge mass and the mass of the arms balanced. The bump grew over time into the giant, diffuse bar we see here. The pattern speed of a galaxy bar rotates faster than the pattern speed of the spiral arms, so N1512's bar has raced through the arm it connects to several times. During any given pile-up, a large portion of the spiral arm's gas, dust, and stars are diverted in a giant swerve to orbit in long ellipses around the bulge. A portion of the infalling matter is diverted when it reaches the bulge. There it bursts into hot, blue stars. This zone is the same ILR that started the process so very long ago.

IRAS 05437+2502 Vader's Ghost

The little-known nebula IRAS 05437+2502 billows out among the bright stars and dark dust clouds that surround it in this striking image from the Hubble Space Telescope. It is located in the constellation of Taurus (the Bull), close to the central plane of our Milky Way galaxy. Unlike many of Hubble's targets, this object has not been studied in detail and its exact nature is unclear. At first glance it appears to be a small, rather isolated region of star formation, and one might assume that the effects of fierce ultraviolet radiation from bright, young stars probably were the cause of the eye-catching shapes of the gas. However, the bright, boomerang-shaped feature may tell a more dramatic tale. The interaction of a high-velocity young star with the cloud of gas and dust may have created this unusually sharp-edged, bright arc. Such a reckless

Source: NASA/HST

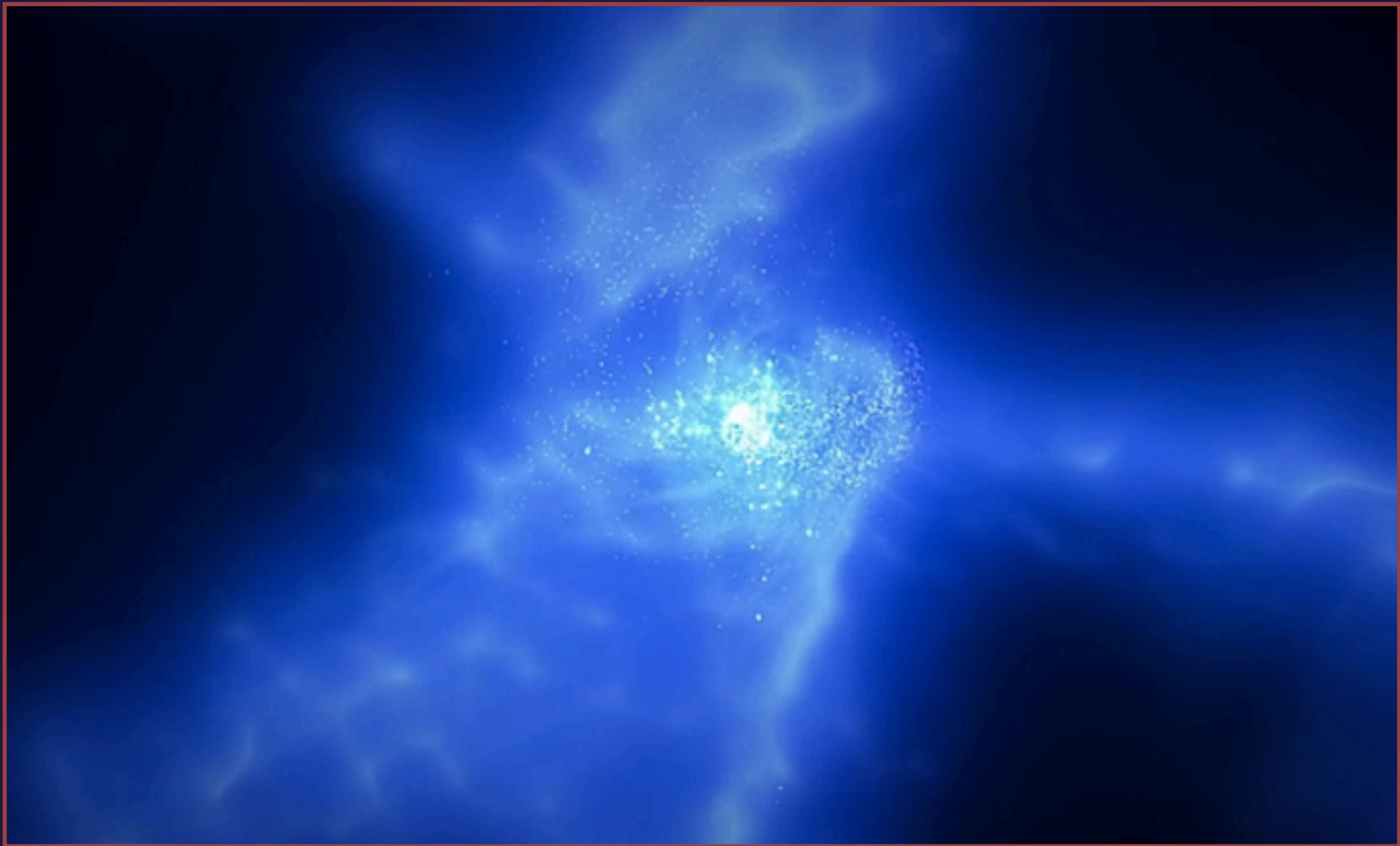
Dim Light in a Bright Room

Dimmed nearly to invisibility by the dust of our galaxy, the Circinus Galaxy is actually a next-door neighbour — 13 million light years (4 Mpc). Although it is a bright Seyfert Galaxy with a fulminously fierce core, it lies only four degrees above the Galactic Plane and is dimmed by five magnitudes of equatorial dust. At magnitude 12.1, it can be spotted in a six-inch telescope, but lies in a field so rich with stars that it wasn't noticed until 1977. Even today it is seldom visited. For those who go to the trouble, it's a meagre meal indeed: a faint oval patch six arcmins in length, with the barest hints of a spiral structure. It looks more like a planetary nebula than a galaxy.

In X-ray and infrared the tale is very different. In this Chandra/Hubble image we see what looks like a one-armed spiral. Closer examination shows hints of a bar structure and two arms massive with dust. It is also expelling large quantities of gas from the bulge region (a hallmark of Seyfert galaxies), which shows here as the bluish tinge beneath the bulge. Circinus is so obscure that it hosted a supernova in 1996 which wasn't even noticed for five years — and took another five to confirm.

[Fly through Circinus with Teun van der Zalm.]

This is the way the galaxies began

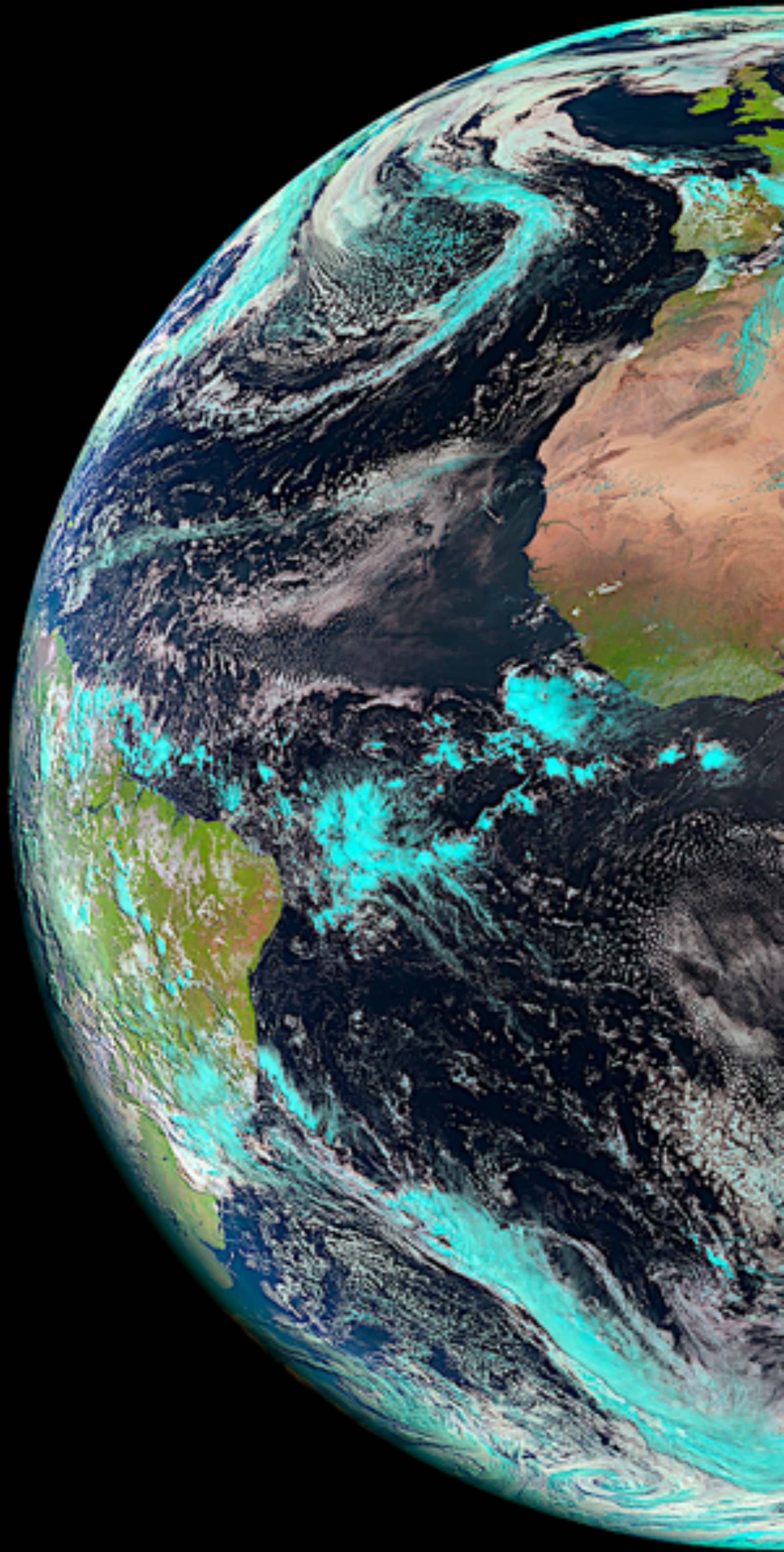


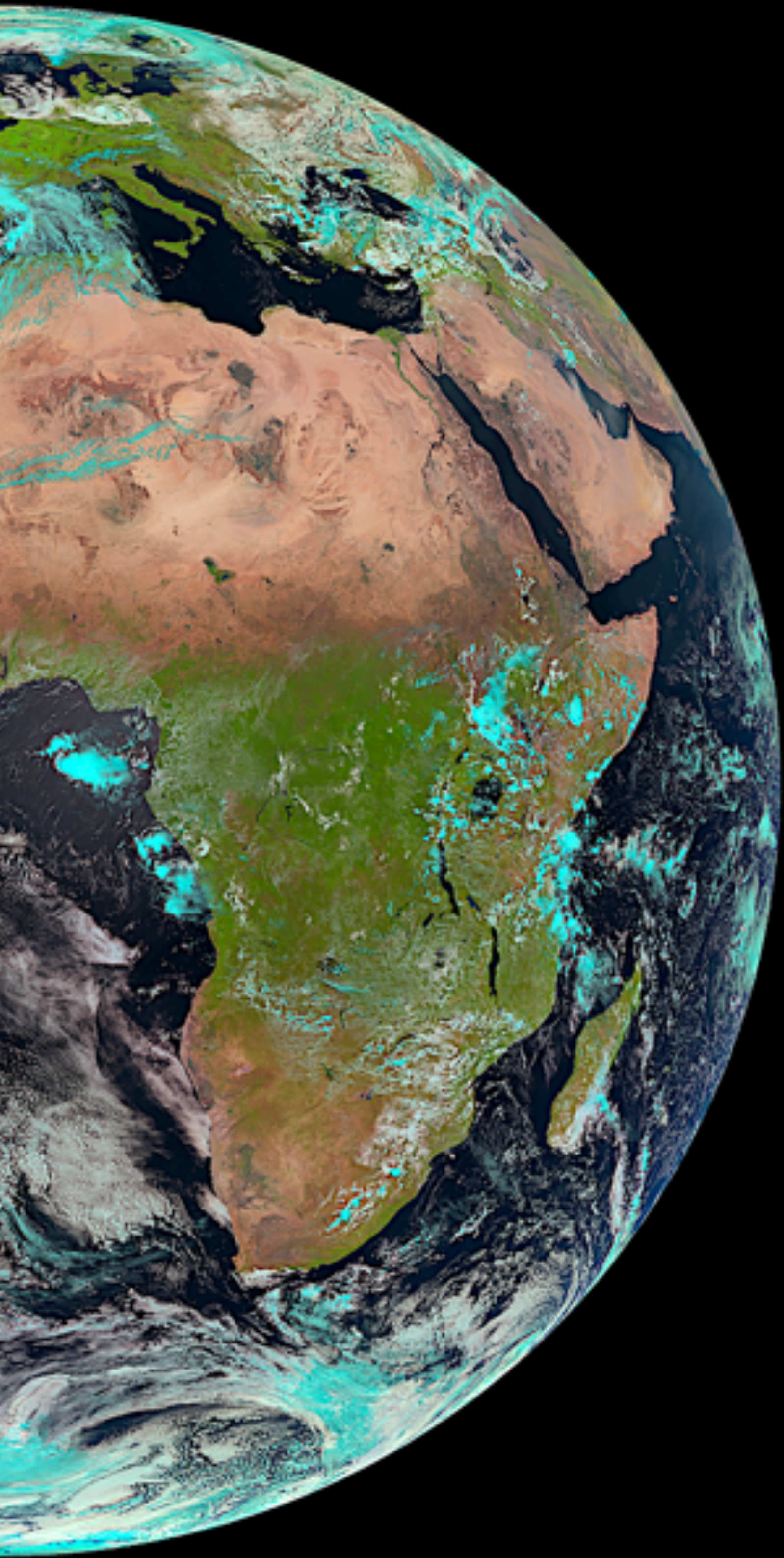
Here's how the Hubble sees it.

The next section is best viewed in the 'open book' form. Please change your PDF reader to the 2-page spread setting.

Why us?


There once was a time
when the entire universe
was body temperature.






What next?

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