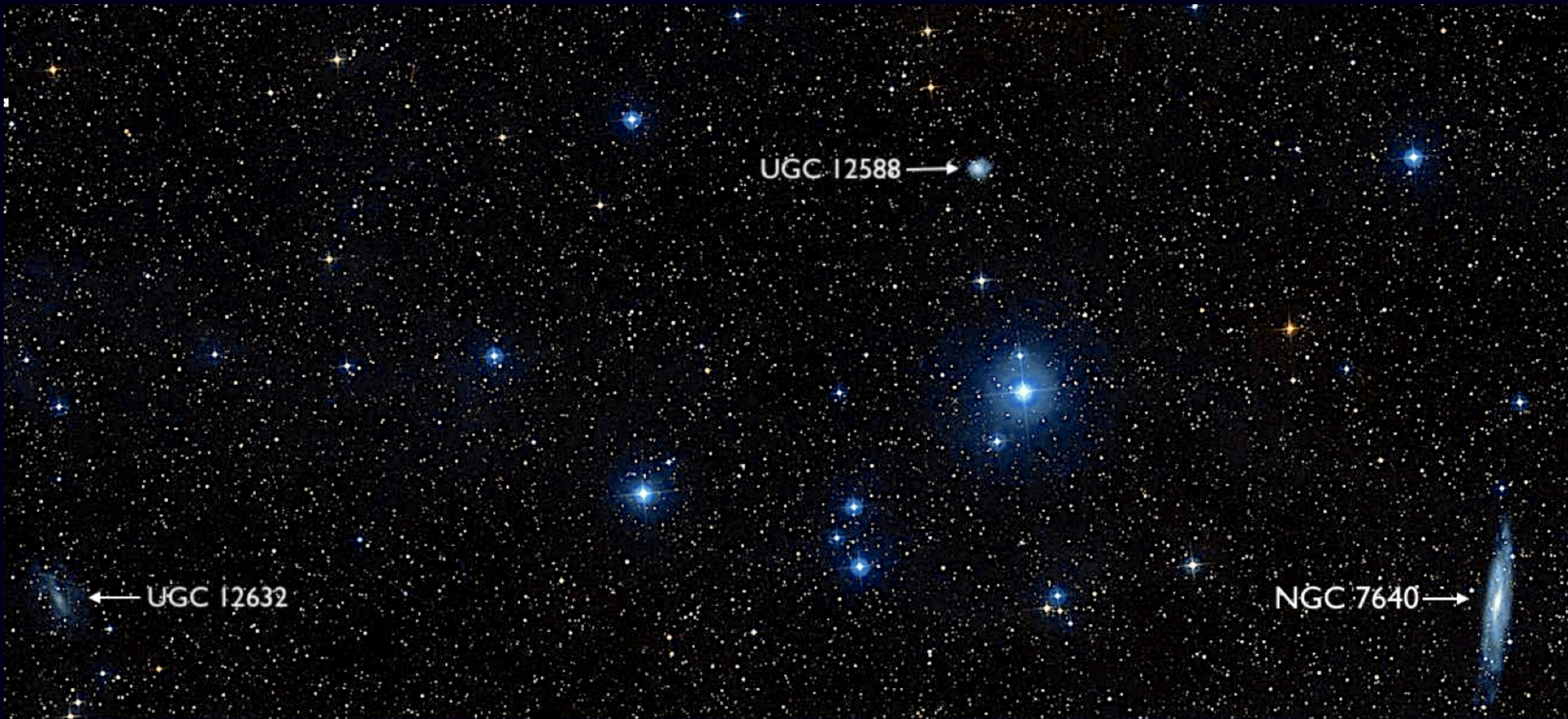
Nightfall

Astronomical Society of Southern Africa

Special Report No. 8, December 2020



The loneliness of the long-distance nobody

Douglas Bullis

Landscape with the fall of Icarus

Attributed to the Flemish painter Pieter Bruegel the Elder
c. 1558, Royal Museums of Fine Arts of Belgium, Brussels.

The 'Icarus' galaxy: UGC 12588

Then why does it?

NIGHTFALL

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Special Report No. 8 *December 2020*

Editor-in-Chief Douglas Bullis
Design, Layout, Production Dana De Zoysa

Published December 2020
by the Astronomical Society of Southern Africa
Observatory, Cape Town, South Africa
Editorial address: *https://assa.saao.ac.za/*
Website: *http://assa.saao.ac.za/sections/deep-sky/nightfall/*

Produced by Atelier Books LLC
Postnet 18, Private Bag X1672
Grahamstown 6140, South Africa
email: *assa.nightfall@gmail.com*

ISSN 2617-7331

En de boer ... hij ploegde voort

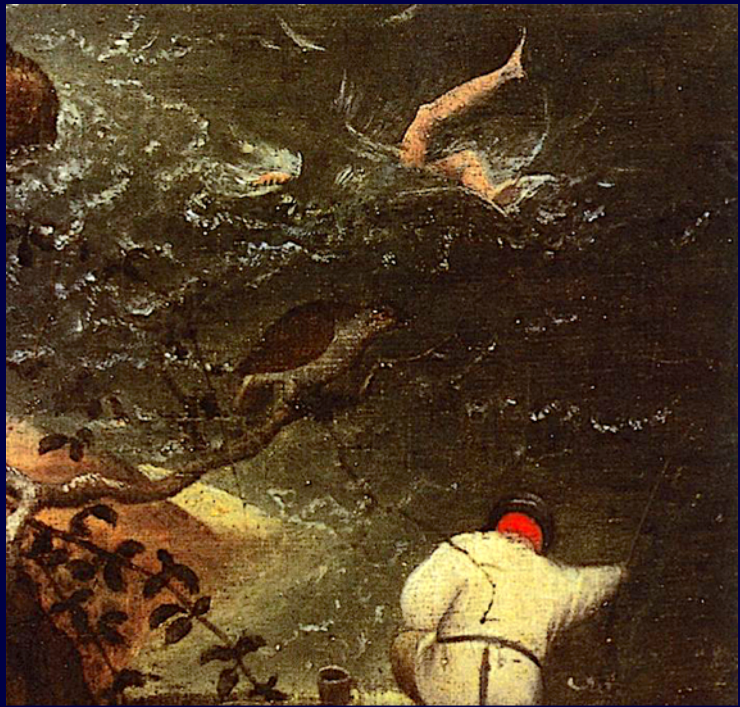
Pieter Breughel the Elder's painting *Landscape with the Fall of Icarus* is an iconoclastic revision of a heroic scene drawn from Greek mythology. The myth had it that a young man named Icarus, watching birds swoop and pirouette through the sky, took a fancy to somehow take wing himself. He and his father Daedalus contrived to make artificial wings out of real feathers and beeswax. With these he indeed succeeded in getting of the ground. A little too far, unfortunately.

Daedalus warned Icarus to not fly too close to the sun, lest the wax melt and the feathers fail. The Icarus morality tale of ignoring parental advice has passed down to us in the form of countless stories, moralisms, and paintings. The artistic interpretations commenced during the Italian Renaissance, a time when humanism was replacing theism as a portrait of the natural order of things. Greek myths cast human activities in heroic rather than Biblical form, initiating the Western tradition of seeing deeds of daring as a model of the human quest.

In the cooler climes of northern Europe, populaces were more familiar with the ways of clouds than the ways of the sun. A Flemish artist named Pieter Breughel was not fooled by the vainglory of Italianate self-projection. Nor was his son, also named Pieter. Both daubed their brushes into the original version of the work shown above. (Scholars differ whether they in fact were this work's painters.)

Instead of a gorgeous Adonis glorifying the centre of the image as the artist Joos de Momper portrayed it (above right), the Breughels portrayed a very ordinary sunset occupied by very ordinary people doing things not particularly grand or memorable. The fallen Icarus is a hard-to-spot pair of legs flailing under the ship with billowing sails (below right). Icarus might as well be a duck diving for slime mould at bottom of a pond. It's about as ignominious an end as a would-be high-flier can endure. The mordant irony of Icarus failing to even get near the sun was not lost on the canny art buyers of Flanders, who were stinging under the rule of Hapsburg Spain's Emperor Charles, who rather fancied himself as a god among mortals, but whose economic acumen bequeathed four imperial state bankruptcies in the next three decades.

The good folk of Flanders had a more parochial perspective. To them the great event of the late 1550s was that chocolate was introduced to Europe for the first time, July 7, 1550. Icarus? Pfui.



Now we have another high-flyer with wax wings

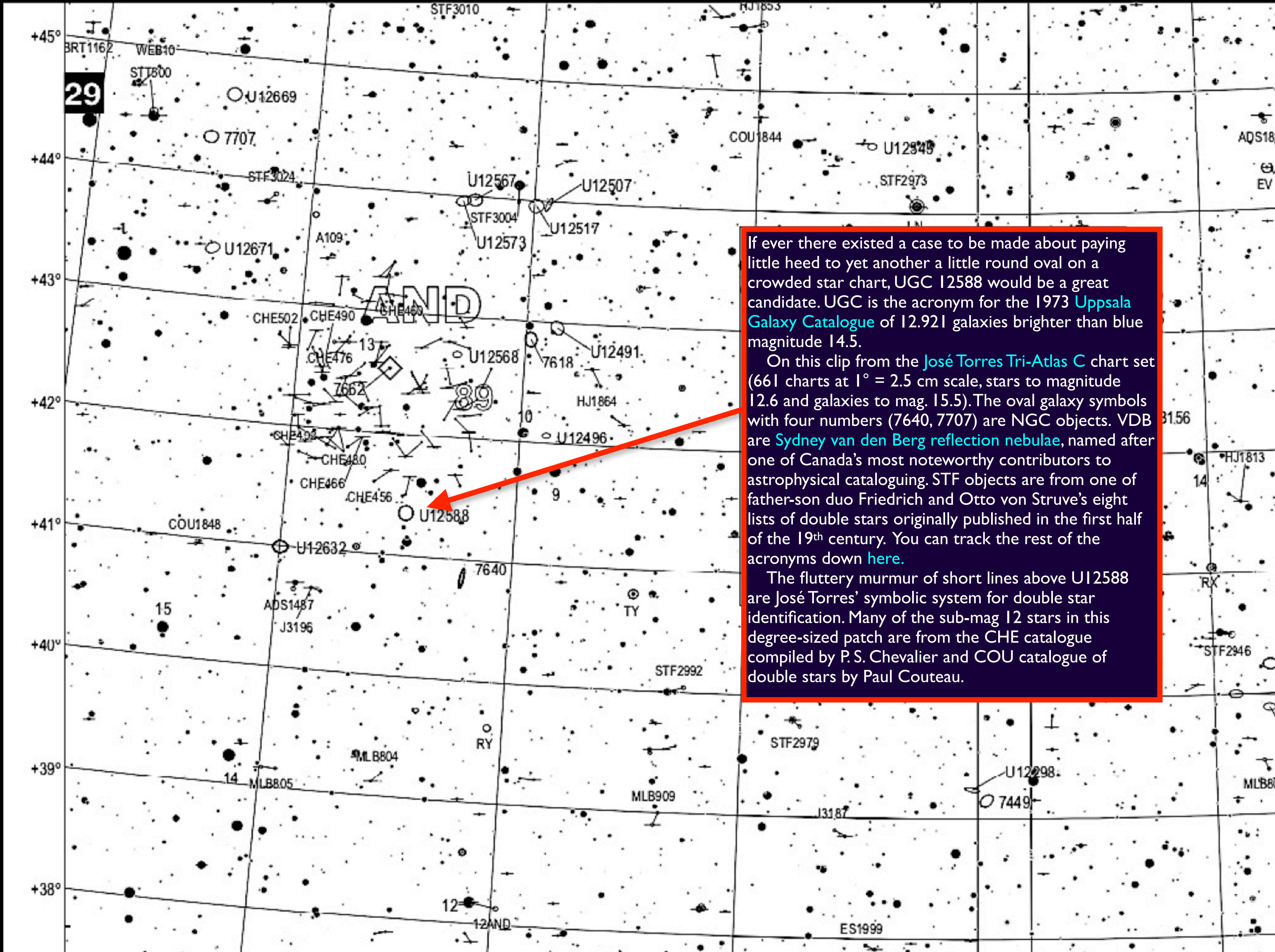
At 09:20:06 UT on 10 January 2020 the Hubble Space Telescope opened its shutter for a 760 second capture of an inconspicuous field of fuzzy fluffies near the Andromeda-Lacerta constellation boundary at 41degrees north. The brightest bit of fluff in the field was an odd-appearing galaxy on the outskirts of the Local Sheet, some 9.2 mpc (30 million light years) away. The only thing notable about it seemed to be that it is a spiral galaxy without a core or bulge. The central region was as flat as a pancake.

The image field was captured using the HST's F606W filter, which records a 0.1 μm-wide *g* band in the Johnson-Cousins *ugriz* photometric system. The *g* band is sometimes referred to as M_V, the so-called visual band, because our human eyes detect its yellow-green hue more readily than redder or bluer hues.

Nine minutes and 33 seconds later the Hubble commenced recording the same image field using its F814W filter, which is sensitive to light in the *r–i* (red–infrared) portion of the *ugriz* system. That exposure also was 760 seconds.

There is nothing unexceptional about these bands or exposure times. The *ugriz* filter set and 760-second exposures have been the Hubble's wide-field survey standard for some 25 years. The F606W–F814W images are commonly graphed as the *x* and *y* axes of colour-magnitude comparisons in doctoral theses and articles in the leading astrophysics journals.

What calls attention to this particular observation is the name on the camera-time proposal to the HST time allocation committee: one 'R Tully' from the University of Hawai'i.



If ever there existed a case to be made about paying little heed to yet another a little round oval on a crowded star chart, UGC 12588 would be a great candidate. UGC is the acronym for the 1973 Uppsala Galaxy Catalogue of 12.921 galaxies brighter than blue magnitude 14.5.

On this clip from the José Torres Tri-Atlas C chart set (661 charts at 1° = 2.5 cm scale, stars to magnitude 12.6 and galaxies to mag. 15.5). The oval galaxy symbols with four numbers (7640, 7707) are NGC objects. VDB are Sydney van den Berg reflection nebulae, named after one of Canada's most noteworthy contributors to astrophysical cataloguing. STF objects are from one of father-son duo Friedrich and Otto von Struve's eight lists of double stars originally published in the first half of the 19th century. You can track the rest of the acronyms down here.

The fluttery murmur of short lines above U12588 are José Torres' symbolic system for double star identification. Many of the sub-mag 12 stars in this degree-sized patch are from the CHE catalogue compiled by P. S. Chevalier and COU catalogue of double stars by Paul Couteau.

Astro-Sherlocking the DIY Sky

What could an inconspicuous galaxy out in the middle of nowhere tell us about the universe?

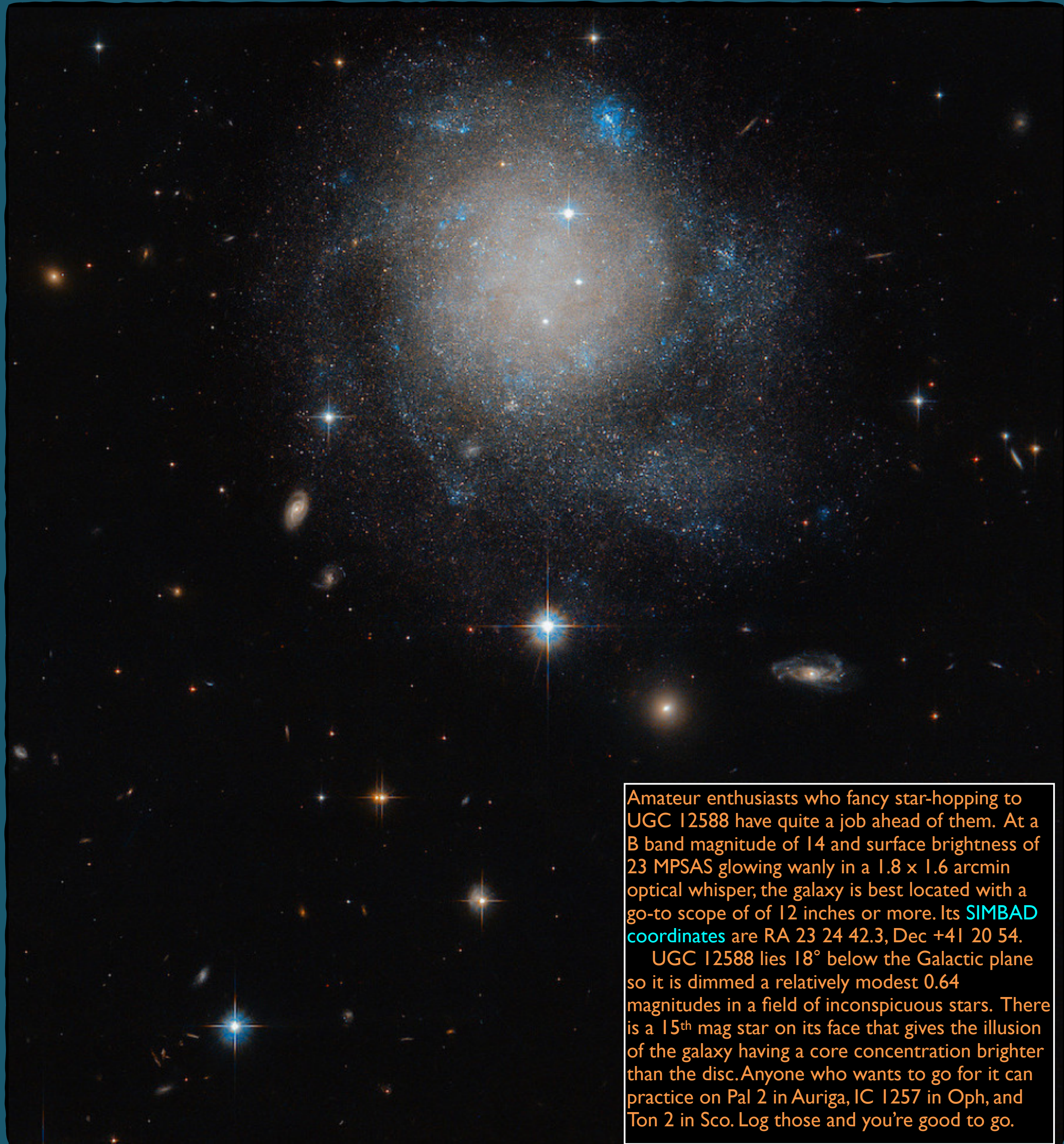
THE ONE TRIED-AND-TRUE WAY TO LEARN WHAT ASTRONOMY TELLS US IS TO LEARN IT THE WAY THE PROFESSIONALS DO.

Let's assume our interest in the 'Cosmic Cinnamon Bun' UGC 12588 wasn't prompted by the gastronomic fantasy dreamed up by NASA's PR department on what must have been an otherwise slow day.

Let's assume instead that we read the account that appeared on the weblog of the mass-circulation astro-enthusiast magazine *Astronomy*—a brief post that began, 'UGC 12588 isn't dripping in warm, gooey icing, but this tightly wound spiral galaxy is still a treat to look at!'. Lots of astronomy enthusiasts read the newsstand version of that magazine. But what, really, do they learn about astronomy there?

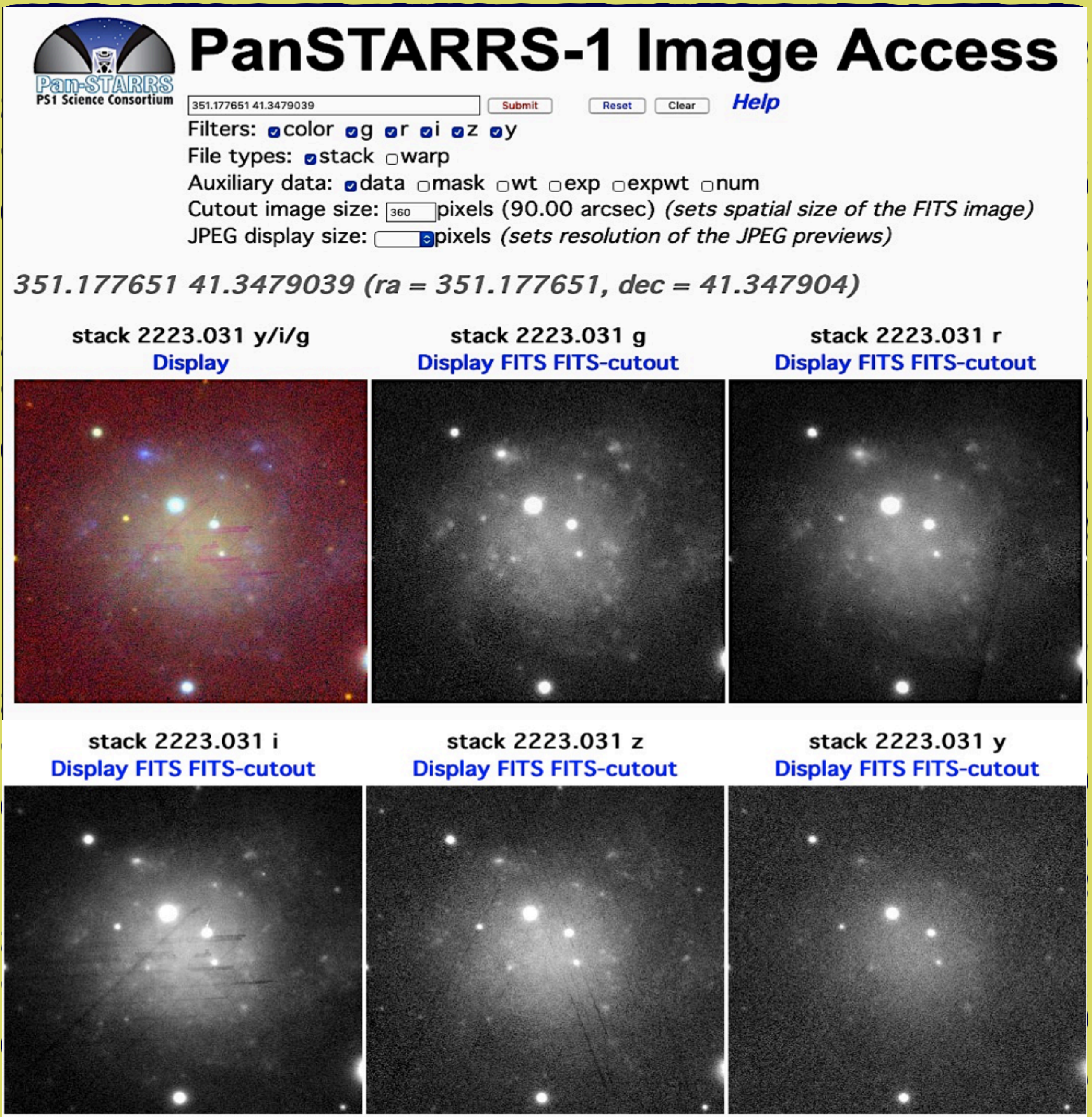
Not much: 'UGC 12588 doesn't have a visible bar of stars across the center and its arms aren't pronounced. Compared to other spiral galaxies, like our Milky Way, UGC 12588 is wound much tighter and the arms aren't reaching out into the depths of space. But look closely — young, blue stars outline the galaxy's arms in its outskirts.'

And that was that as far as *Astronomy* magazine was concerned.



Amateur enthusiasts who fancy star-hopping to UGC 12588 have quite a job ahead of them. At a B band magnitude of 14 and surface brightness of 23 MPSAS glowing wanly in a 1.8 x 1.6 arcmin optical whisper, the galaxy is best located with a go-to scope of of 12 inches or more. Its SIMBAD coordinates are RA 23 24 42.3, Dec +41 20 54.

UGC 12588 lies 18° below the Galactic plane so it is dimmed a relatively modest 0.64 magnitudes in a field of inconspicuous stars. There is a 15th mag star on its face that gives the illusion of the galaxy having a core concentration brighter than the disc. Anyone who wants to go for it can practice on Pal 2 in Auriga, IC 1257 in Oph, and Ton 2 in Sco. Log those and you're good to go.



One of the first stopoffs on any panchromatic ('all colour') object search is the PanSTARRS-1 Legacy Archive. The PS1 survey used a 1.8 meter telescope and its 1.4 Gigapixel camera (PS1 GPC1 camera) to image the sky in five broadband filters (*g, r, i, z, y*). Space Telescope Science Institute (STScI) in Baltimore Maryland, and can be accessed through MAST, the Mikulski Archive for Space Telescopes.

With all due regard to *Astronomy m*agazine as one of the leading astro enthusiast publications in the world, those paragraphs don't tell us much beyond what we can readily conclude just by looking at the thing. If we want to learn rather than look, we need to resort to higher authority. What *is* UGC 12588 and why does it look the way it does?

To expand the point: We can see how bright and big it is, but what colour is it? In astronomy, colour isn't about hue, it's about chemistry and energy. Hence, to learn more precisely what kind of energy this galaxy produces, we must find multiband images of it. Multiband image research is the starting point in learning about any celestial object. Colours tell us where its energy comes from and how much of it there is. Comparing those colours opens the door to a vast art gallery of fact combined with beauty that conceals a vast museum of knowledge.

The underlying reason for this is that our eyes see only 1 percent of the total electromagnetic emission that a celestial object emits or absorbs—the optical or visual band. Look a little closer and that 1 percent consists of many hues—blue, green, yellow-orange, red, and far red or infrared. These are the same colours in a rainbow.

A rainbow is a spectrum spread across a great arc in the sky. It's awe-inspiring, but not especially informative because rainbows tell us nothing about light except that it's there. Still, rainbow colours were adopted in the most commonly used scientific quantification of colours by electromagnetic wavelength: the Johnson-Cousins photometric system. In this, *u* stands for ultraviolet/blue at 365 nm or microns (μm); *g* for green-yellow (464 μm)*; *r* for red (658 μm), *i* for infrared (806 μm), and *z* for a mid-infrared hue (900 μm) we can't see visually but is important measure of a star's temperature.

*For reference, the often-mention visual band is at 551 μm. The American Cloudy Nights contributor Don Pensack charmingly refers to it as a teal hue.

The first step up the learning ladder is to Round up The Usual Suspects. In old police procedural movies, this ended in a dramatic line-up scene in which flustered witnesses pointed their accusing fingers at the wrong suspect. In the next scene the smirking guilty party walks out of the police jail and hails the first taxi out of there.

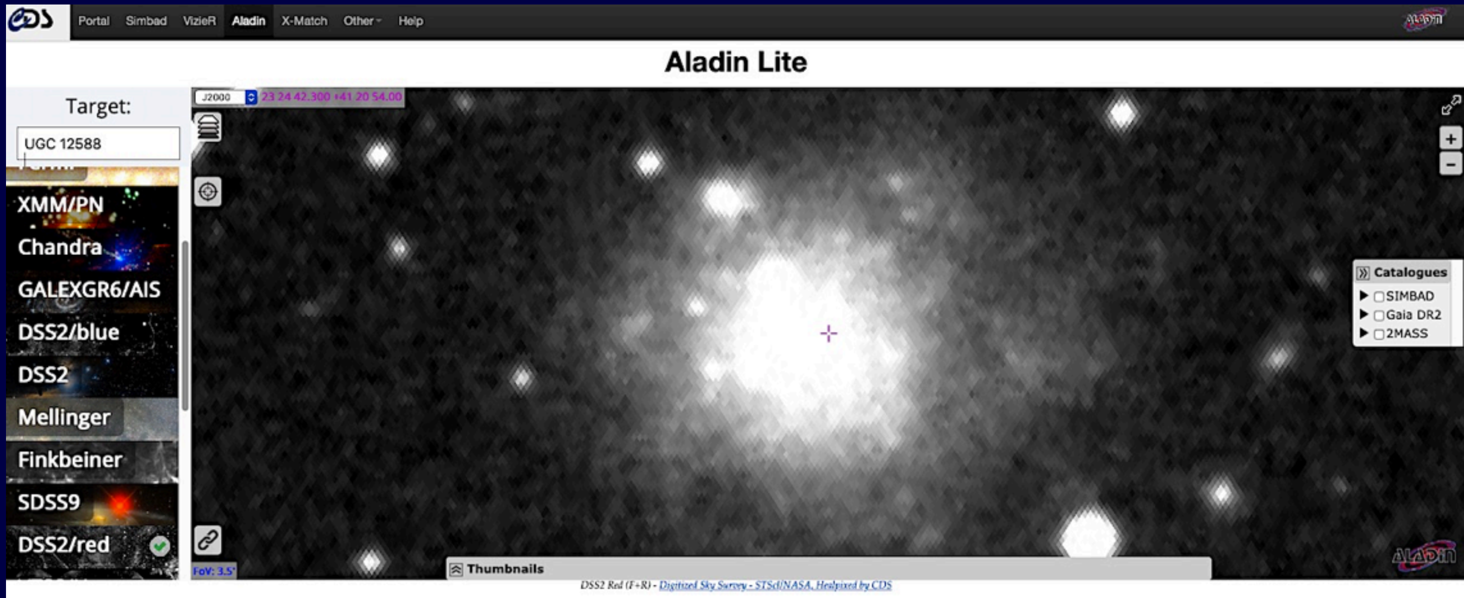
If we indulge in a bit of fantasy about UGC 12588 being the centrepiece in a police-procedural melodrama, the accusing finger has just pointed at a fuzzy blob whose name the police sergeant knows to be 'Dwarf Spheroidal Galaxy'.

What would bring the sergeant to conclude that?

If we want to dissect an astronomical object and put its parts under the microscope, we begin with its optical spectrum. This takes the form of a multiband *ugriz* survey based on images in several catalogs devised for the specific purpose of solving astronomical mysteries. The PanSTARRS image set *griz* + *y* is a good starting point. (The *IRSA object finder website* is likewise an excellent starting point.)

In the PanSTARRs images there is little evidence of a bulge or bar. (The bright star near the middle is in the nearby Milky Way, not UGC 12588.) A cross-check of the Aladin Lite image search website confirms the PanSTARRS image set, with the additional fillip that the DSS2/red image reveals a red, rather bright diffuse central luminosity with few traces of H-alpha activity. That is a signature of a dSph that hasn't formed new stars for multi-billions of years.

An ancient dwarf elliptical galaxy should also have a large population of sub solar-mass red giants. However, to spot a red giant population on a galaxy 30 million light years away, we need the original highest-resolution images of UGC 12588 acquired by the original Hubble high-res TIFF of UGC 12588 core in the F606W and F814W bands. These are presented on the next page. For this article we inverted both images (right side) to soften the effects of brightness crowding that can be distracting in densely populated images. Now we can see that the galaxy's central region is peppered with tiny low-luminosity dots. This is the low-mass red giant population typical of a dwarf galaxy that might be upward of 10 billion years old. (We could also look for RR Lyrae variable stars which begin to appear in this age range, though that requires several rounds of images.)



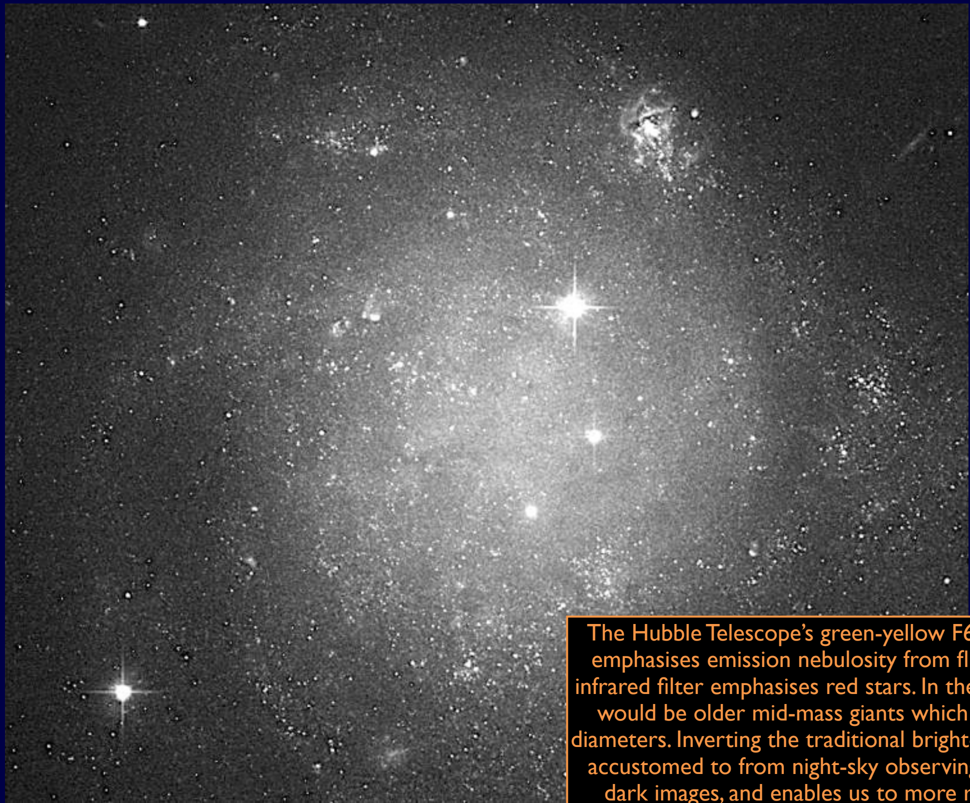
UGC12588 (search in the field) pgc = 71368

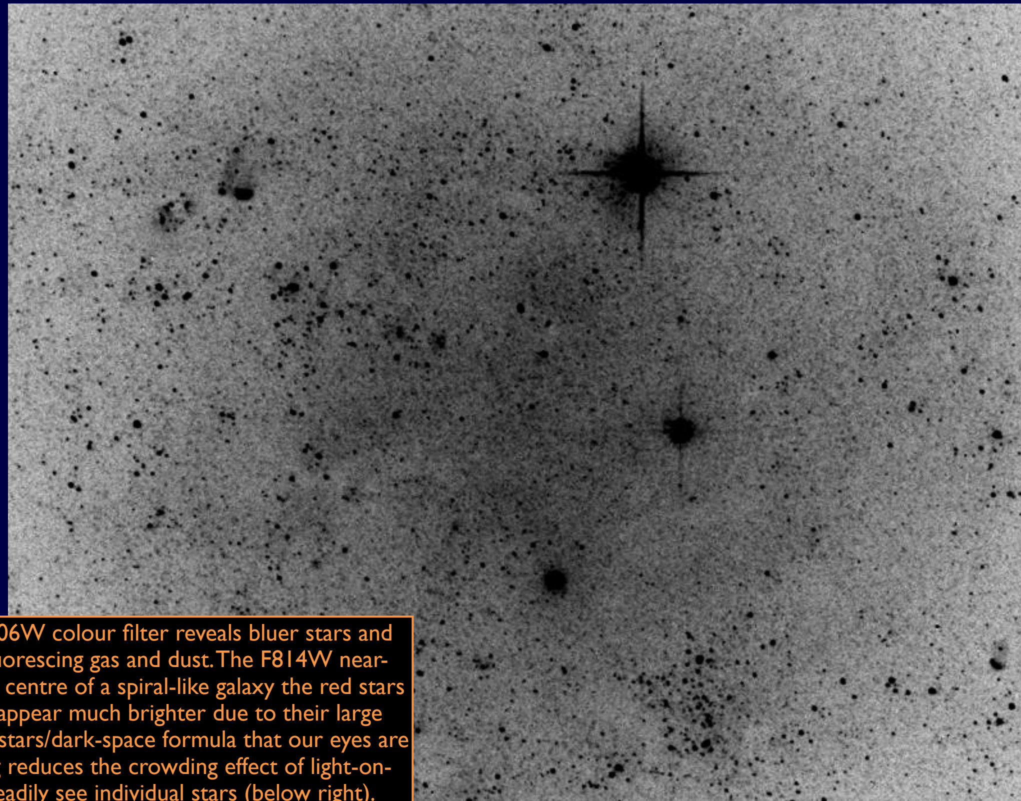
Celestial position		Alternate names	
J2000	J232442.65+412052.2	CGCG533-005	IRAS23223+4104
B1950	B232218.15+410422.8	MCG+07-48-005	PGC071368
Galactic (IAU1958)	G105.91191-18.63986	UGC12588	UZC232218+41040
Super Galactic (RC3)	SG335.27982+27.14933		
	Precision: about 10 arcsec		

Parameter	Value	Unit	Description
objtype	G		Type of object (G=galaxy; S=Star ...)
type	Sd		Morphological type
t	7.9 ± 0.9		Morphological type code
logd25	1.11 ± 0.04	log(0.1 arcmin)	log of apparent diameter (d25 in 0.1 arcmin)
logr25	0.17 ± 0.03	log	log of axis ratio (major axis/minor axis)
pa	109.0	deg	Major axis position angle (North Eastwards)
bt	13.93 ± 0.32	mag	Total B-magnitude
vmaxg	39.4 ± 1.5	km/s	Apparent maximum rotation velocity of gas
m21	14.91 ± 0.12	mag	21-cm line flux in magnitude
v	418 ± 3	km/s	Mean Heliocentric radial velocity (cz
ag	0.64	mag	Galactic extinction in B-band
ai	0.31	mag	Internal extinction due to inclination
incl	54.2	deg	Inclination between line of sight and
a21	0.03	mag	21-cm self absorption
logdc	1.17	log(0.1 arcmin)	log of apparent corrected diameter (d
btc	12.98	mag	Total apparent corrected B-magnitud
bri25	22.89	mag/arcsec2	Mean surface brightness within isopl
vrot	48.6 ± 1.9	km/s	Maximum rotation velocity correcte
m21c	14.88	mag	Corrected 21-cm line flux in magnitu
hic	1.90	mag	21-cm index btc-m21c in magnitude
vlg	716 ± 3	km/s	Radial velocity (cz) with respect to th
vgsr	625 ± 3	km/s	Radial velocity (cz) with respect to the GSR
vvir	597 ± 3	km/s	Radial velocity (cz) corrected for LG infall onto Virgo
v3k	113 ± 3	km/s	Radial velocity (cz) with respect to the CMB radiation
modz	29.81 ± 1.82	mag	Cosmological distance modulus (from vvir with ΛCDM)
modbest	29.81 ± 1.82	mag	Best distance modulus, combining mod0 and modz
mabs	-16.83 ± 1.846	mag	Absolute B-band magnitude

The HyperLEDA database lists UGC 12588's known parameters available today.

F606W & inverted

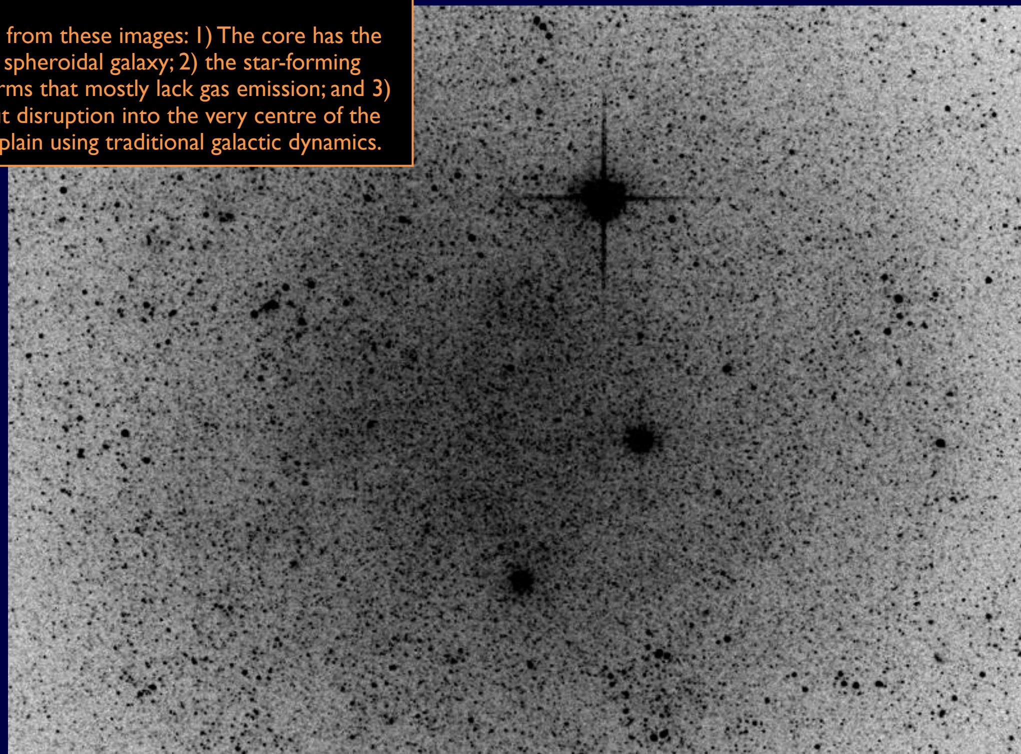




The Hubble Telescope's green-yellow F606W colour filter reveals bluer stars and emphasises emission nebulosity from fluorescing gas and dust. The F814W near-infrared filter emphasises red stars. In the centre of a spiral-like galaxy the red stars would be older mid-mass giants which appear much brighter due to their large diameters. Inverting the traditional bright-stars/dark-space formula that our eyes are accustomed to from night-sky observing reduces the crowding effect of light-on-dark images, and enables us to more readily see individual stars (below right).

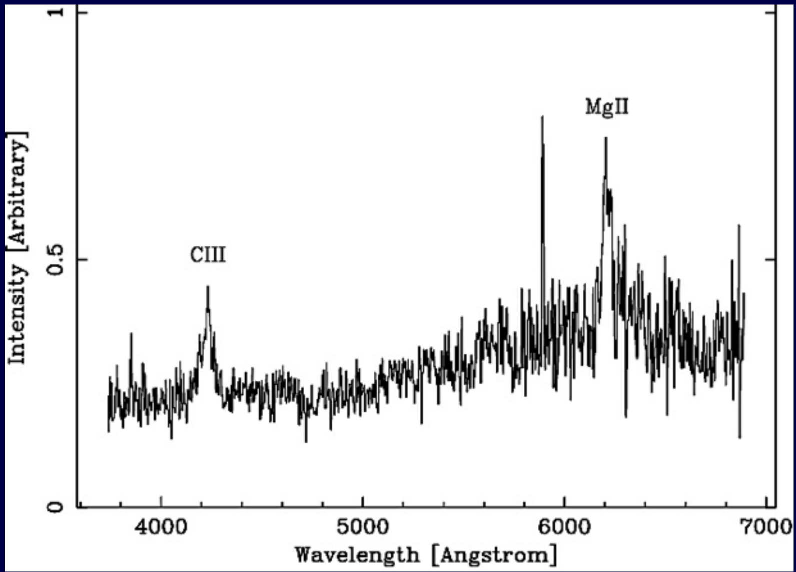
Three features are immediately evident from these images: 1) The core has the pancake morphology of an old dwarf spheroidal galaxy; 2) the star-forming periphery has the look of young spiral arms that mostly lack gas emission; and 3) the star-forming regions extend without disruption into the very centre of the galaxy. These features are difficult to explain using traditional galactic dynamics.

F814W & inverted



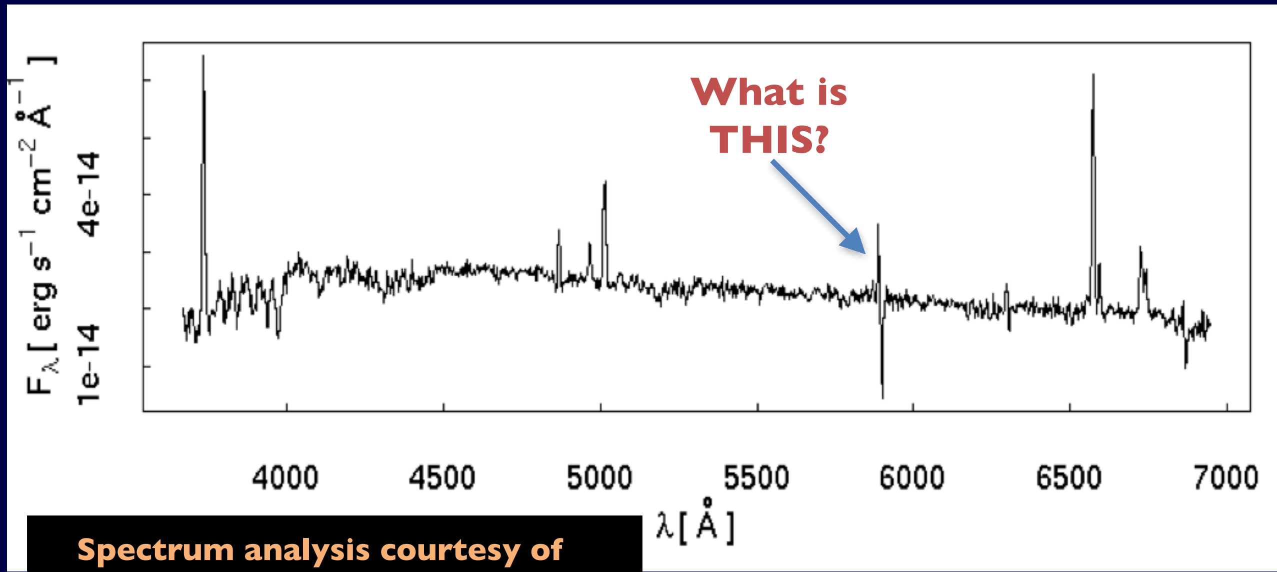
What does UGC 12588's visual spectrum tell us?

A 'typical' dwarf spheroidal galaxy spectrum resembles this composite example: *(source: Piatek et al 2005)*

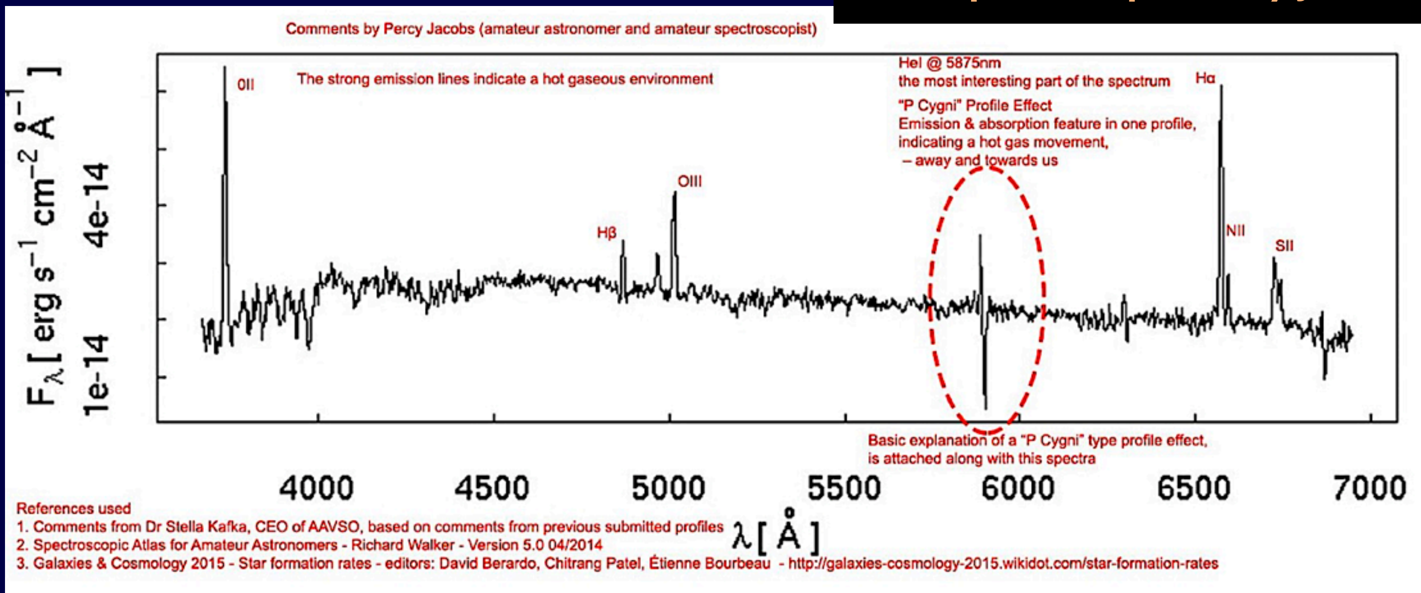


UGC 12588's spectrum looks like this:

(source: Moustakas & Kennicut ApJS 2006)



Spectrum analysis courtesy of ASSA spectroscopist Percy Jacobs



Dwarf spheroidal galaxies are largely populated with old, low-mass stars (upper left). They typically exhibit broad triple-ionised carbon and double-ionised magnesium emission which are signatures of large convection cells in older stars that reach down deep into the stellar layers where these elements are forged. UGC 12588's spectrum (above) exhibits very little of this emission. Contrarily, it exhibits a considerable amount of ß hydrogen beta, doubly-ionised oxygen OIII, and hydrogen-alpha emission—all typical features of large populations of young, massive B and A type stars that dwarf galaxies typically don't make.

UGC 12588 also has an unusually strong Helium I emission/absorption feature at 5875 nm. This is the signature of nitrogen-rich WN and carbon-rich WC Wolf-Rayet stars which have hurled off enormous amounts of their interior fusion gases in a frantic effort to achieve stability in the face of unsustainably high fusion rates. This class of stars have gathered too much mass in too short a time to stably process it like main-sequence O supergiants.

The fact that UGC 12588 has this strong 'P Cygni' profile testifies that the galaxy has undergone a rapid, massive recent starburst. Somehow this low-mass galaxy managed to acquire and pressurise several thousand solar masses of H_2 hydrogen into short-lived high-mass O stars which will soon destroy much of what we see here.

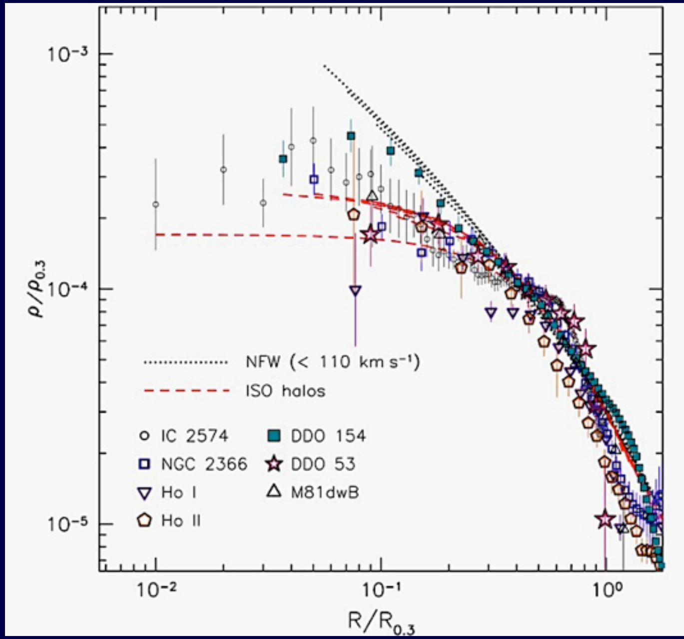
If UGC 12588 is a dwarf spheroidal galaxy, why does it have spiral arms?

The Hubble images suggest that UGC 12588 is a two-component galaxy. If we mentally subtract the bright overlay of young outer stars for a moment, the soft, diffuse centroid gives the impression of a cored dwarf spheroidal galaxy. Since galaxies of this type are composed of older stars (> 8 billion years) and diffuse atomic hydrogen gas retained by a massive dark matter potential, the density profile from the visible edges to the middle is a bell-shaped 'Gaussian' dome whose density falls off in proportion to the square root of the distance from the center to the edge, or $\rho = r^{-2}$ (see right).

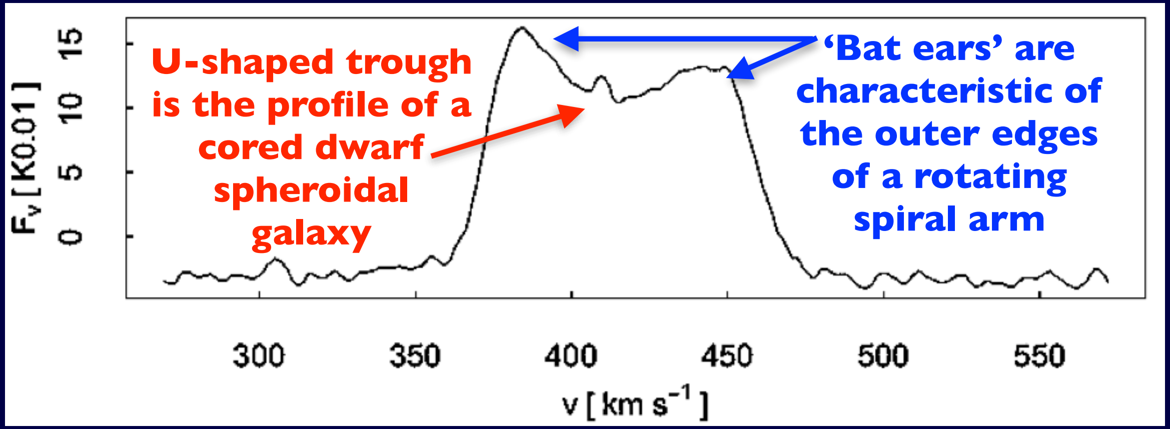
To check whether the density profile of UGC 12588 really is that of a dwarf spheroidal, we can look up the galaxy's Tully-Fisher velocity profile, available for all known nearby galaxies on the *NED (NASA/IPAC Extragalactic Database*. We find UGC 12588's *full particulars here*, and its *velocity profile here* (annotated copy below right).

The 'bat ear' profile in the lower right image records the combined velocity of the rotating arms of a spiral galaxy. Elliptical galaxies don't have 'bat ear' profiles because ellipticals do not rotate as a unit body; they are an orbital dispersion free-for-all. UGC 12588's set of apparently six equilinear (evenly spaced) arms rotate clockwise as seen from Earth — a direction confirmed in the higher value of the left bat-ear in the Tully-Fisher diagram. The rotational profile of a traditional dwarf spheroidal galaxy (centre of the saucer-like curve) in a galaxy that also shows spiral arms is a paradox because dwarf spheroidal galaxies have very little molecular hydrogen gas in their cores to make stars with.

Spiral galaxy arm growth requires large reserves of molecular H_2 hydrogen gas all across the galaxy, including cores and/or bars. That in turn implies that a galaxy with abundant star production is a galaxy with abundant cosmic dust.



If we trace the mass density of a dwarf spheroidal galaxy from the centre out to its edge, we obtain profiles like these seven galaxies from the *THINGS dwarf galaxy database*. This scale is logarithmic, not integer, so the seemingly large flat part of the light curve as it nears the left edge (the galaxies' centres) is actually small compared with the outskirts of the galaxy. If UGC 12588 has a dwarf spheroidal galaxy in its core, we would expect the dSph to have a linear fall-off towards the edges as traced in these galaxies



Galaxy velocity profiles like the above are acquired by analysing the spectrum of a galaxy across its longest axis with the slit of a spectrograph. The result is called a Tully-Fisher profile. Since the outer spiral arms of a galaxy rotate more rapidly than the central regions, a spiral galaxy's velocity profile has 'bat ears' of higher velocity. In a typical grand design or barred spiral, the ears drop off slightly to a shallow, more or less flattened floor. That is not the case with UGC 12588. This galaxy's centroid is a dish-shaped trough, typical of a dwarf spheroidal galaxy. (The little blip is an artefact caused by a bright foreground field star in our own galaxy.) UGC 12588's polar axis is tipped to the NE (upper left) by 52.4 degrees and the average rotational velocity of the gas in the spiral arms is 48.6 km/sec spinning clockwise.

Why dust?

Indeed: why dust?

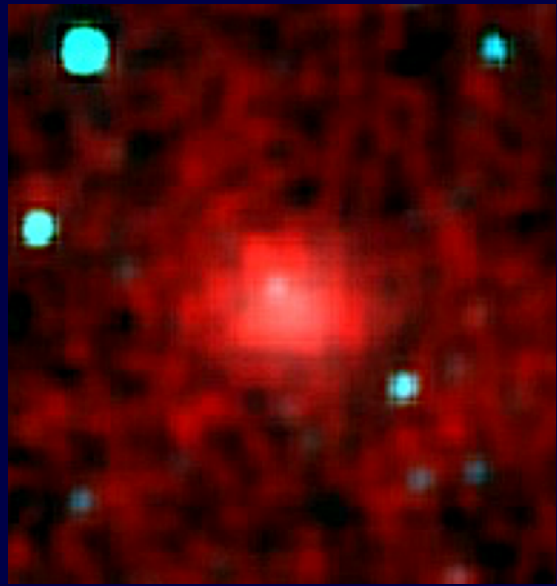
The simple hydrogen atoms of the primordial universe cannot easily make stars. The electrons circling hydrogen nuclei (protons) are negatively charged and hence repel each other. Only enormous gravitation can overcome the hydrogen atom's Coulomb force—which is why the universe's first stars were five or more times as massive as the top-of-the-line 80 to 100 solar-mass O supergiants that exist today.

H_2 molecules consist of two positively charged protons and one negatively charged electron. H_2 bonds easily with other H_2 and also with most other chemical elements—and notably well with carbon and oxygen. That is lucky for us because most space dust is made of hydrogen-carbon and dihydrogen monoxide (water) molecules. H_1 hydrogen reacts with CO carbon monoxide using carbon-rich dust particles as a catalyst to form H_2. That is why carbon monoxide is so often studied in connection with star forming clouds.

H_2 in turn attracts other H_2, and in a few million years a vast amorphous gas cloud can transform into glittery stars. The momentous event came knocking at UGC's spheroid door some 10 or 20 million years ago.

The major question with UGC 12588 is: Why did such a galaxy-wide starburst happen? What banged?

At present UGC 12588 has been so little-studied that we lack even elementary analytic tools like a metallicity or a colour-density profile across the spheroid's surface. (The Tully-Fisher profile to the right plots the velocity of light-emitting particles toward or away from the observer. Tully-Fisher profiles provide velocity information but not the colour or chemical composition of the objects they measure.)

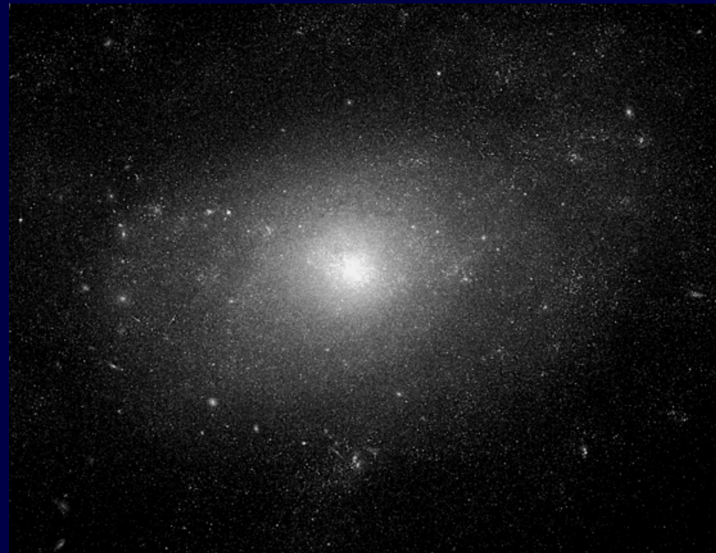


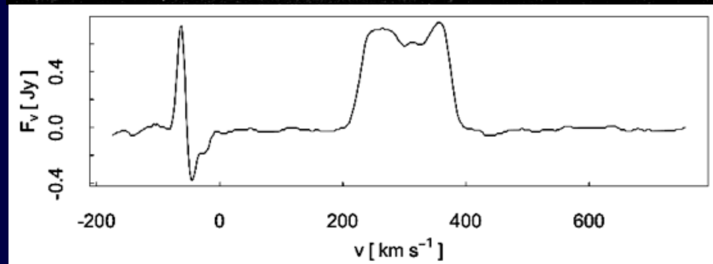
This *allWISE W3* 3.4 μm image of the UCG 12588 spheroid component suggests a somewhat brighter central core than the rest of the disc. The 3.4 μm line traces dust density in a hydrogen gas cloud. This image helps explain where UGC 12588's ancient dust has been hiding all these eons: in a tiny core dense enough to hold itself together in the relatively benign environs of an isolated dwarf galaxy.

The dust temperature in the core is between 22 and 44 K. At those temperatures the H_2 molecular gas is more centrally peaked in the galaxy's gravitational well, It cannot be easily disrupted by ram pressure from turbulence, or dispersed by photon pressure from O star UV radiation. The core of the galaxy may have retained up to 1000 solar masses of dust produced during the galaxy's initial star-forming epoch.

It is difficult to understand how minute dust particles could survive for multiple billions of years given the numbers of cosmic rays that pass through 'empty' space—3 or 4 particles per sq cm per second. The Cosmic Microwave Background photons contribute about 405–407 photons, while all the rest of the electromagnetic radiation produced in the universe's history contribute perhaps 3 to 5 photons per sq. cm per second. If the inner 100 pc of UGC 12588 exhibited a strong color gradient and a flattened surface brightness profile, a smooth dust distribution could be present and could be contributing to these photometric effects. Source: *Silva & Wise 1996*; *De Looze 2012, p.123.*

Core versus cusp





NGC 5585 in Ursa Major is an example of a cuspy cored galaxy. Unlike the saucer-shaped profile of UGC 12588's slow rotation, a cuspy core's velocity profile flattens across the middle on the side approaching us and appears higher on that side. It then drops away across the centre to a lower rotational velocity on the far side. The rotational velocity then rises rapidly again as the core ends and the spiral arms begin. The gas velocity across spiral arms is typically higher than across the cores of dwarf elliptical galaxies. The shape of the velocity profile does not reflect the galaxy's matter-density profile. The image above suggests that NGC 5585's dark matter has agglomerated contributions of new dark matter and gas from multiple absorptions of small galaxies and starless dark matter clumps. The overall process of galactic assembly is termed hierarchical assembly. Gravity is the dominant component. Other large-scale forces that influence the final mass distribution of a galaxy are magnetic pressure and turbulent shocks, though they play temporary roles that act over relatively brief time scales.

Ultra-violet and optical band light emitted by stars and absorbed and scattered by dust grains causes the well-known phenomenon of dust extinction. We trace dust's chemistry mainly using the infrared bands—the longer the wavelength, the less the extinction effect. This is also a way to trace grain size.

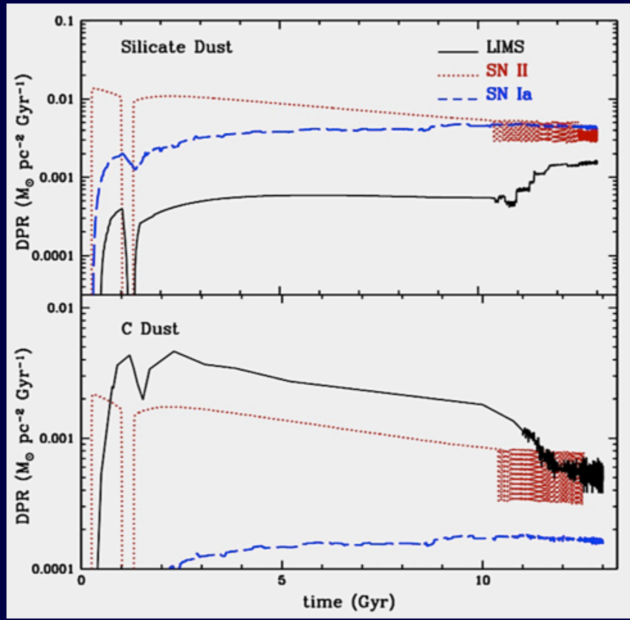
The average life span of a molecular cloud is 50 million years. The more complex its dust spectra, the longer it has been around. While dust is easily degraded by thermal radiation and sputtered by cosmic rays, dwarf galaxies are so cold that dust can endure for billions of years. During that time, particles might be fragmented through impact sputtering only to be accreted onto other grains nearby. This can happen many times in a galaxy's star-forming history. Dust's history is written with a crayon.

The chemical composition of the galactic interstellar medium (ISM) is strongly influenced by the presence of dust. Refractory elements such as Fe, Si, Mg, and Ni in the gas phase become depleted as they are incorporated into solid grains.

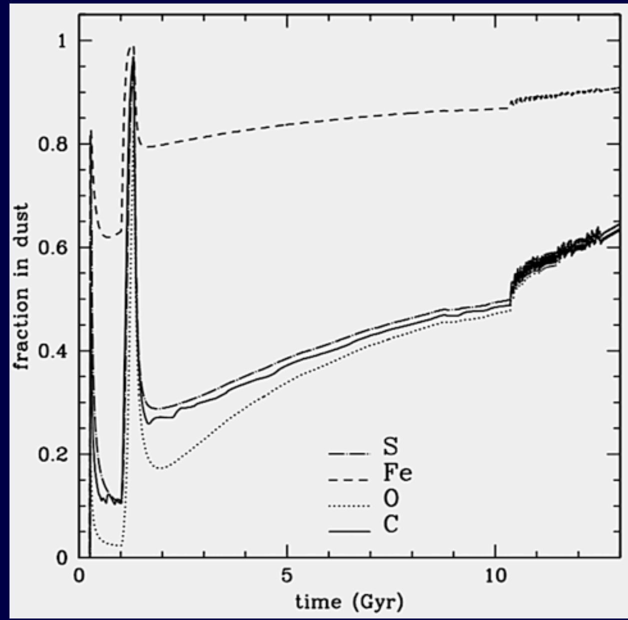
In elliptical galaxies, dust accretion occurs almost wholly during starburst epochs, where large amounts of cold gas and molecular H_2 are still available. Dust destruction is primarily caused by supernova shock waves. Astronomers trace the destruction by observing high-velocity clouds in the galaxies. There is an anti-correlation between the depletion levels and cloud velocities, which points to grain destruction by supernova shocks. Most of the silicon-based dust grains are made during a galaxy's energetic starburst eras. A few million years after massive O-type stars are formed, their Type II core-collapse supernovae expel their internal chemical elements in hot shock waves at hypersonic velocities (e.g., Mach 5 to 50). These shocks essentially rip a galaxy's gas and dust to shreds—adding to the galaxy's complex gas mix as they reverberate around the galaxy. Dwarf ellipticals pay dearly for their starburst tantrums—most H_1 is lost to the galaxy forever, while the dust safely concentrates in the central well.

Carbon dust is typically formed much later, when white dwarf Type 1a supernovae detonate, spewing massive amounts of carbon, nitrogen, and oxygen into the galaxy's gas.

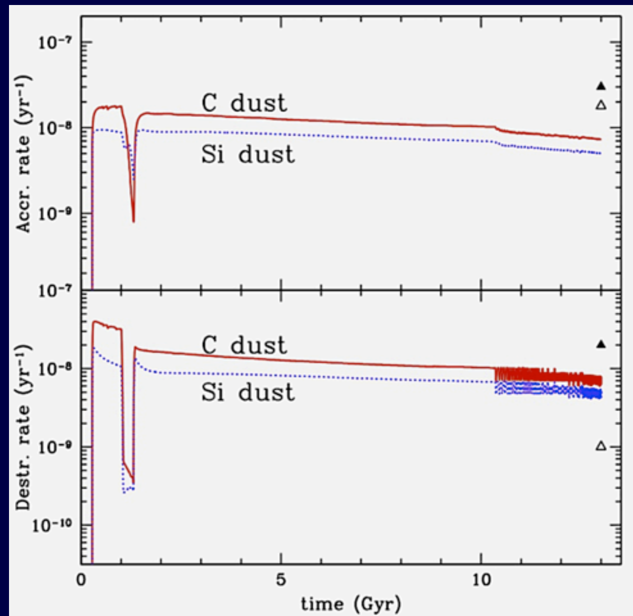
Source: *Calura et al, A&A#479 2008*.



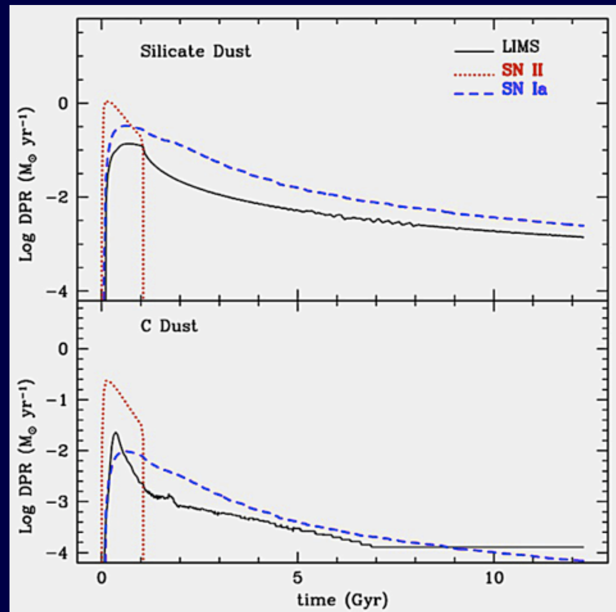
Predicted dust production rates from various sources for a chemical evolution model of a dwarf galaxy. ***Solid lines:*** contribution by low and intermediate mass stars. *Dotted lines*: contribution by type II SNe. ***Dashed lines***: contribution by type Ia SNe.



Time evolution of the fractions in dust for various elements. Dust is degraded by thermal sputtering, the dominant source of dust destruction in hot plasmas. Roughly 90% of the dust grains will evaporate in 100,000 years, only to be reassembled again in different form.



For type II SNe, dust destruction dominates dust production throughout almost all of the cosmic history. In early epochs, SNe inject more dust into the ISM than they destroy. Here, evolution of the dust accretion (upper panel) and destruction (lower panel) rates in the S.N.



Predicted dust production rates for an elliptical galaxy. ***Solid lines:*** contribution by low and intermediate mass stars (LIMS). ***Dotted lines:*** contribution by type II SNe. ***Dashed lines:*** contribution by type Ia SNe.

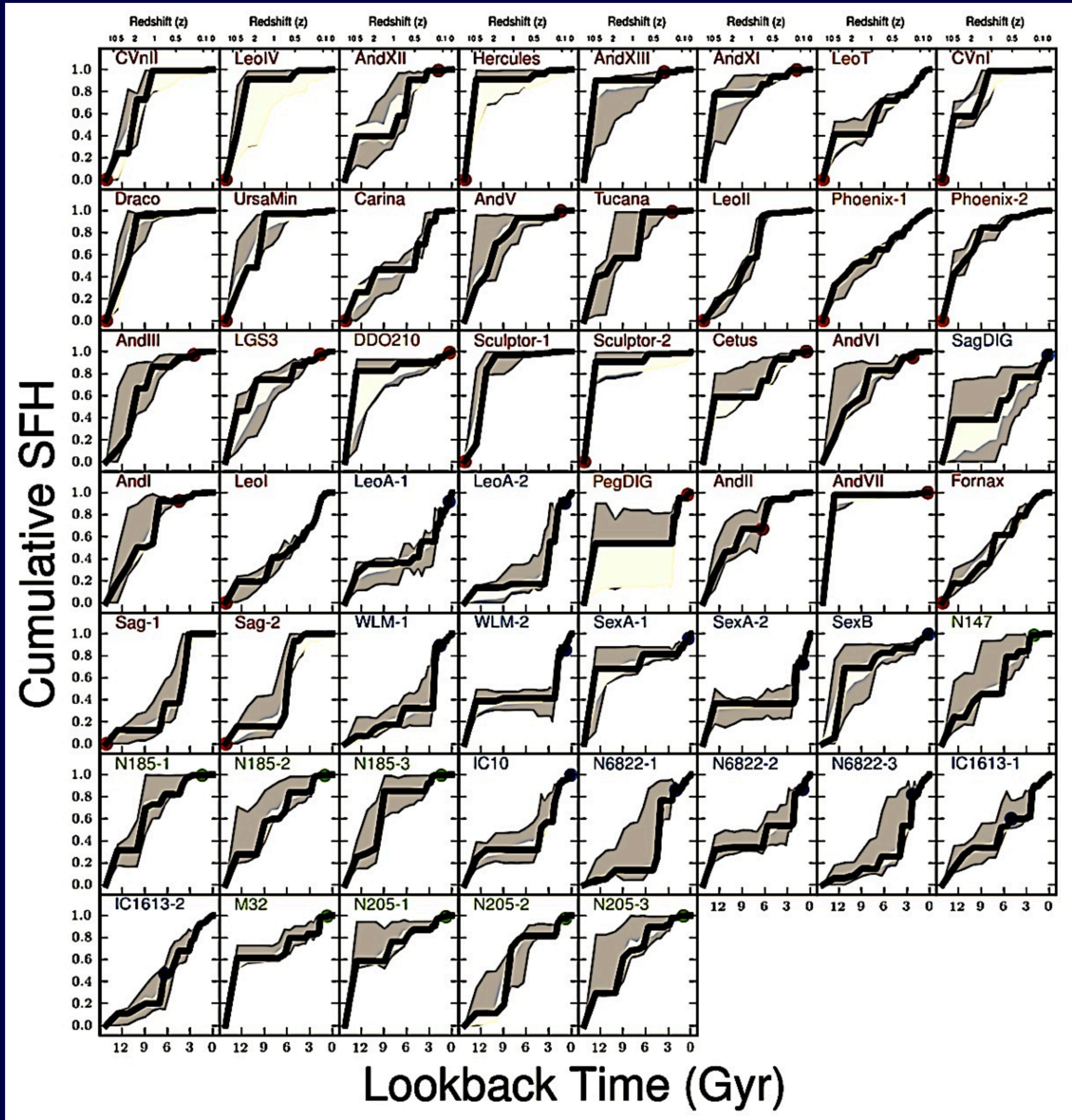
The wayward ways of wastrel waifs

Dwarf galaxies look like serene bits of fluff, but their lives are just the opposite. In low-mass dwarf ellipticals like UGC 12588, we can see from the chart to the right that dwarfs have a remarkably diverse star formation histories. The X-axis on the bottom is denoted in Gigayears, starting at the Reionisation era 13 billion years ago on the left edge. The Y-axis going upward is the percentage of the cluster's current population. The table reproduces the star formation episodes in Dan Weisz' 2014 study.

We can see that some galaxies had a rapid initial star formation phase, followed by billions of years of quiet snooze. The dwarfs Leo IV, Draco, and Sculptor are like that. Others formed stars in irregular bursts without any apparent pattern. Carina, Fornax, and NGC 185 in the Andromeda Group are examples.

The variations are explained by (a) shocks from interactions with other galaxies in dense groups, (b) backfall of supernova gas after a galaxy starburst period, and (c) infall of pristine hydrogen along cosmic filaments. Most star-forming epochs occur in the core and middle regions of the galaxies where cold gas can accumulate enough mass density to fire up the star-making engine.

UGC 12588's starform evolution may resemble the *Hercules* (2) and *Draco* (2) dwarf spheroidals more than any of the other 40 in Weisz' figure.



Location, location

UGC 12588 is a little bundle filled with big question marks. It is more notable for what it does not tell us than what it does. If it is a spiral galaxy, the spiral arms are very recent because there is little evidence of the disc perturbations typical of large, mature spirals. Resonances such as Lindblad resonances, bars, and co-rotation radius develop over multiple galaxy revolutions. Its Tully-Fisher velocity profile is not fine-grained enough to tell us much about U12588's spiral rotation rates out to large radii. If U12588 is a dark-matter dominated galaxy (as most dwarf ellipticals are) the rotation rate of the arms will be nearly flat from the edge of the old spheroid out to ends of the arms.

We also don't know where the onset of massive star formation occurred within the six apparent density waves. The galaxy's placid core versus energetic outskirts do not correlate with the dynamical processes that transform amorphous gas reserves into filamentary pressure waves. Where are the filamentary flux tubes that feed star cluster formation, for example? Perhaps this is what Professor Tully had in mind.

Icarus, Icarus, beware the wax on your wings

Long regarded as wallflower waifs in the galactic anterooms, dwarf galaxies have enjoyed a sudden bloom of attention thanks to the 2013 announcement that most of the Milky Way's dwarfs are aligned in a thin, corotating disc rotating high above our Galaxy's polar axis. But why there, straight overhead so to speak, instead of in the Galactic plane like the other proper, well-behaved objects rotating around our galaxy?

That same year produced a study that the M31 Andromeda Galaxy has *not one but two planes in which most of its dwarfs rotat*e—and both planes were not extensions of the disc but also high above M31's poles. 'High' in these instances means inside the galaxy's virial radius (337 kpc). Moreover, most of the M31 dwarfs co-rotate in the same direction as the disc.

Soon planes were discovered in the Centaurus A galaxy, followed by news that *M81 has it own modest brood* of 14 in a plane far out into the tenuous grasp of its galactic reach.

The location of a dwarf galaxy with respect to its neighbours has a profound influence on its history. The typical dwarf elliptical (DE) is 100,000 to 10 million solar masses with dust masses of perhaps 1000 times that of the Sun, at average dust temperatures of 16 to 20 K.

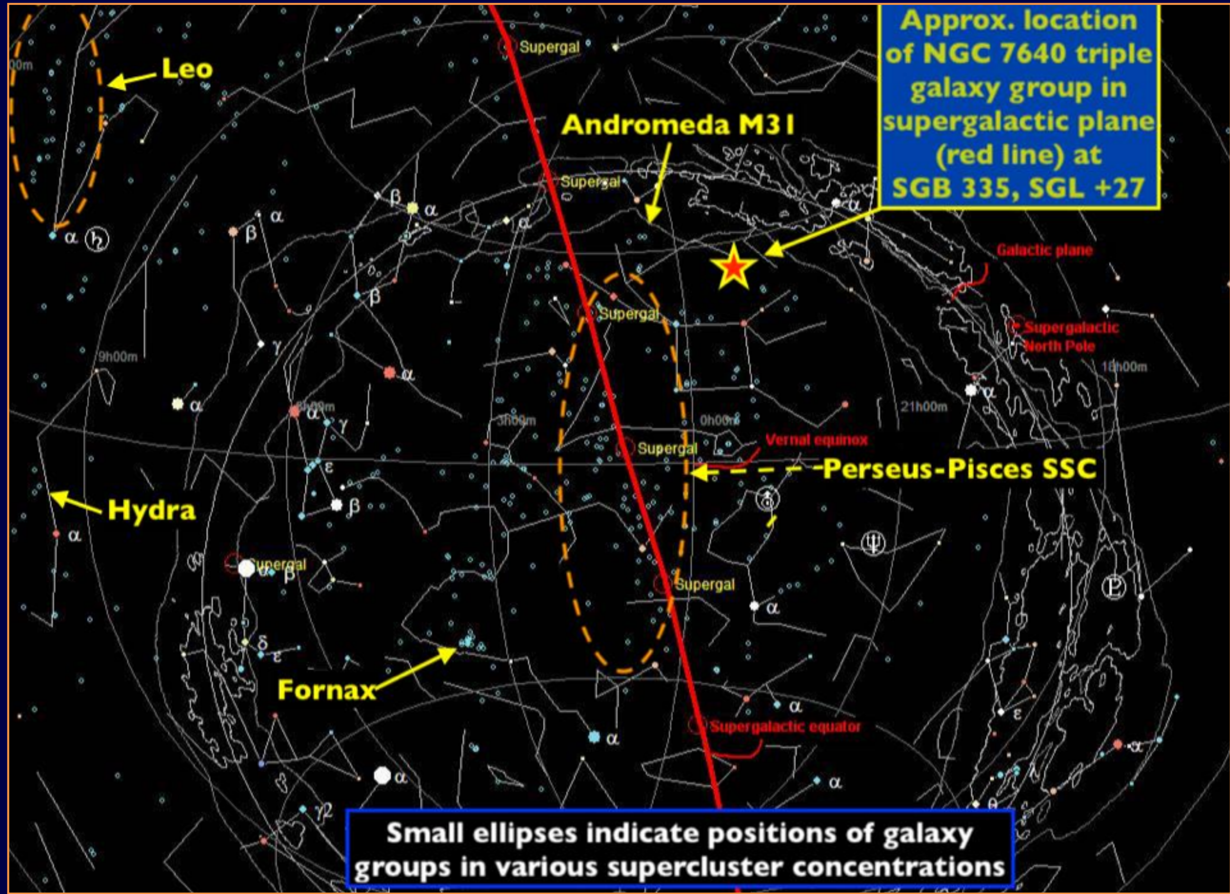
Much of a dwarf elliptical's primordial H_1 gas was expelled long ago as the galaxy underwent its initial gas clearance via supernovae blast waves. Much of the supernova gas also left for good, but enough remained in UGC 12588 to fuel one last grand wheeze. Lucky us to be around for the show.

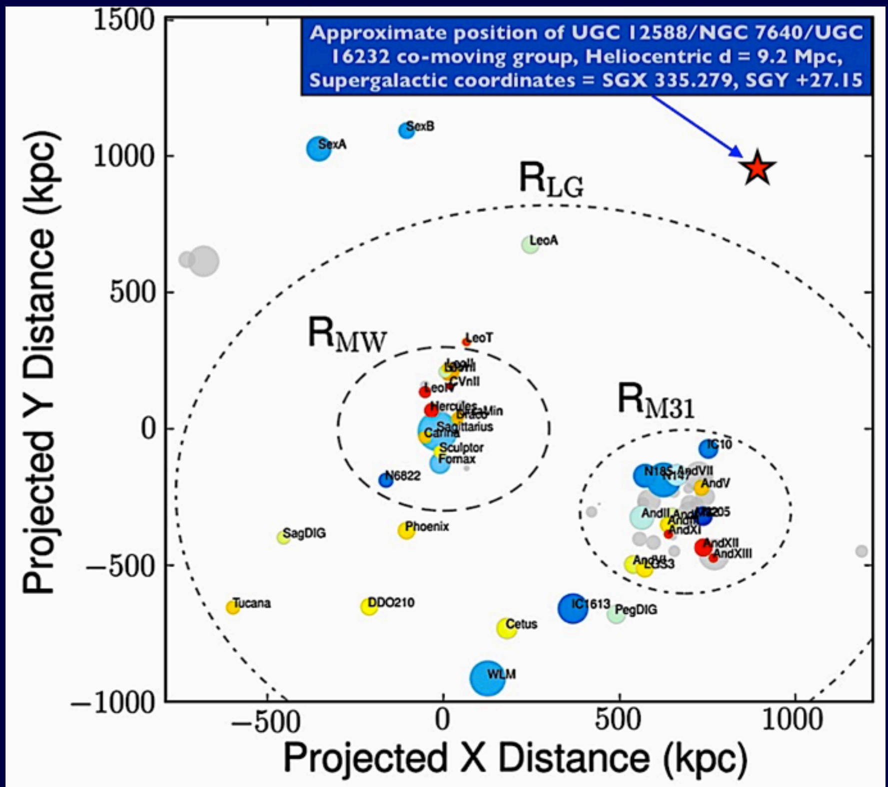
Its modest reservoir of H_2 gas and dust huddles close to the core, where it is somewhat immune to tidal shivers of interactions with other galaxies. But there just isn't enough gas in there to fuel the galaxy's ongoing starburst today. Where did UGC 12588 get its gas?

Galaxy ID	R.A. hr min sec	Dec hr min sec	Super-galactic SGB	Super-galactic SGL	Distance Mpc Tully-Fisher	Heliocentric velocity km / sec	Virgo–Great Attractor km / sec
NGC 7640	23 22 07	40 50 45	334.745	+27.66	8.5	360	624
UGC 12588	23 24 42	41 20 48	335.278	+27.15	9.17	415	665
UGC 12632	23 29 58	40 59 24	334.826	+26.17	9.25	442	667
Andromeda M31 dwarf sample							
NGC 205	00 40 22	41 41 07	336.536	13.06	0.78	–241	26 ±16
NGC 185	00 38 58	48 20 15	343.268	14.30	0.63	–202	73 ±17
Pegasus Dwarf	23 28 36	14 44 34	305.833	24.30	1.0	–183	53 ±15

If a dwarf galaxy falls into the capture radius of a massive galaxy (like the Sagittarius Dwarf has fallen into the Milky Way), its globular clusters disperse as newbies in the galactic neighbourhood. The welcome mat was out for Pal 8, Terzan 7, and Whiting 1. The hapless dwarf's stars stream along its former orbital trajectory around the host galaxy, where they can remain as Gaia-identifiable streams even as they wrap completely around the host. No end of papers results from our Galaxy's octopus appetite and grabby tentacles.

But is U12588 likely to endure such a fate? The NGC 7640 galaxy triplet roams in the emptiest quarter of the *Local Volume* (see right and below). When dealing with regions so far beyond the influence of the Local Group, astronomers have devised a *phase space* (a Cartesian-like 3-D graph with different units for *x-y-z*), which they dubbed 'Supergalactic Plane' to describe locations in the large-scale structure that exists between the massive Virgo Supercluster 'ahead' of us, the similarly massive Perseus-Pisces Supercluster 'behind' us, the M81 Group to the right, and Centaurus A Group to the left.





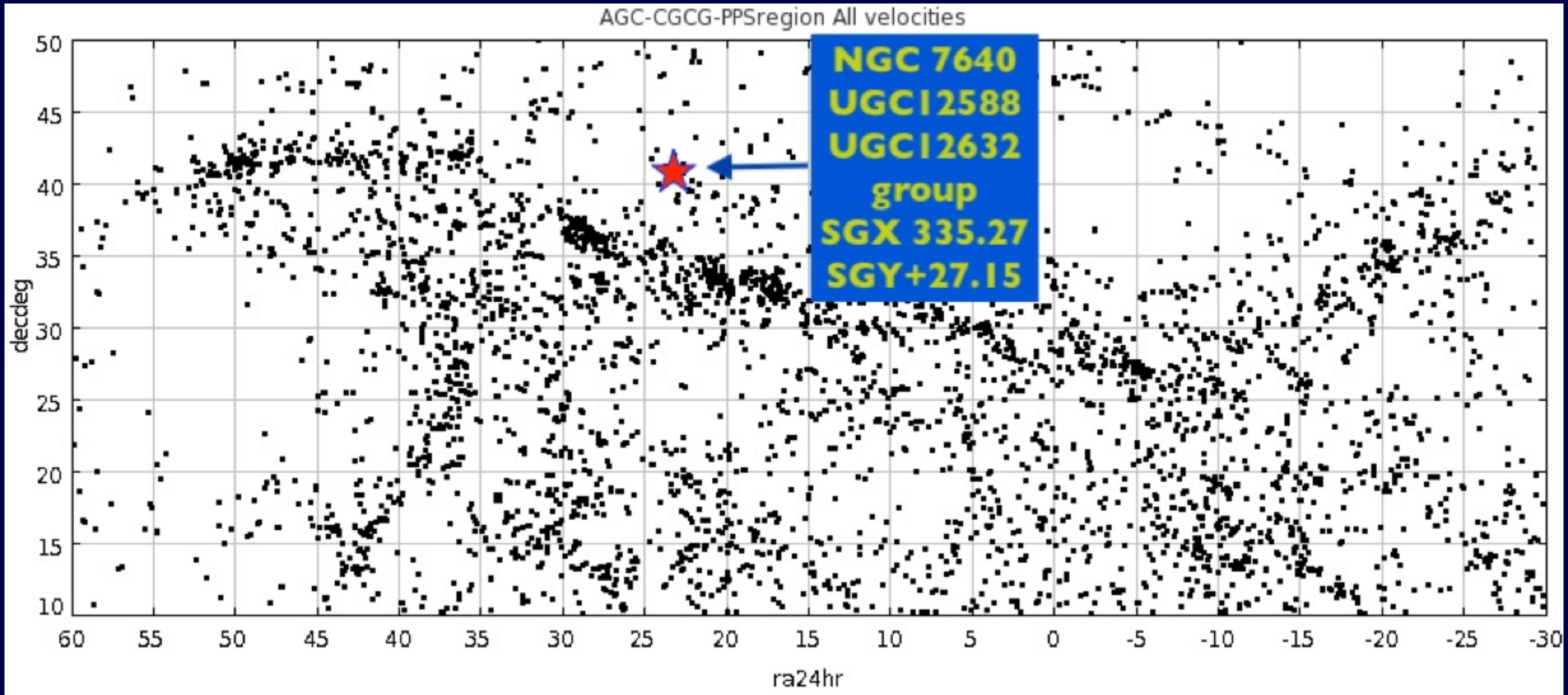
Clearly from the N7640 Group's positions on these charts, this threesome is pretty far out there. Supergalactic coordinates are denoted in decimal degrees with *B* being the equatorial circle and *L* the angle of elevation. (The Milky Way's Galactic nomenclature is *b* and *l*) . The N7640 group's Supergalactic coordinates are SGB=335°, SGL +27° elevation. The group is roughly 30 million light years away and receding at about 400 km/sec. Compare these velocities with the SGB and SGL of Andromeda's NGC 185 and 205. The two groups look close to each other as we look at them in eyepieces, but are very far apart in velocity and phase space.

If we similarly compare the N7640 group with the SGB and SGL coordinates of the 54 galaxy groups in the *NED Galaxy Groups within 10 Megaparsecs*, only the NGC 1023 group resides at about the same coordinates as N7640, but it is 3 times further away. UGC 12588 is so isolated it is the perfect spot for a criminal on the lam or the anchorite recluse who wants to *really* get away from it all.

Icarus fell unnoticed into the sea. Who wants to follow?

All this boils down to one simple fact: UGC 12588 and the NGC 7640 Group are so isolated that whatever happens to them internally or nearby is a neighbourhood kerfuffle, not a sly move in a grand chess game played from afar. UGC 12588's recent starburst must have come from its own internal and nearby gas resources.

So where are they?



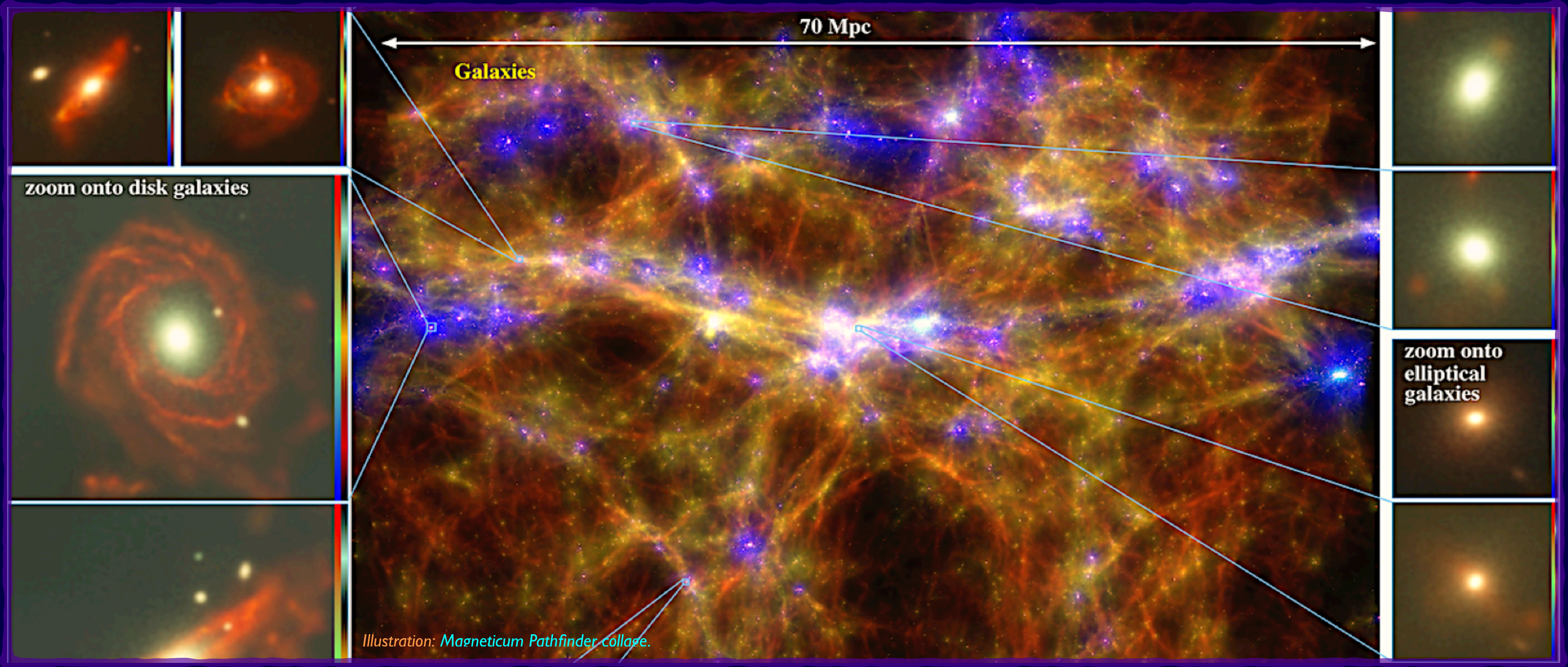
The conundrum we confront with UGC 12588 is that we see star-forming forces busily at work—all those new stars organised in density structures from core to outer edge—but we do not see an obvious forcing mechanism. What triggered the gas waves that ended up as spiral waves? What banged?

The Hubble F606W images show spiral-like waves of bright star formation, but there is no obvious density gradient to demark the transfer of angular momentum from the unit rotation of the old spheroidal to the gas clouds feeding those stars in the spiral arms. There are no nearby galaxies to exert tidal pressure or supply fresh gas. There is no central bar to mediate a gravitational torque. There is no apparent corotation radius at which the rotational velocity of the spiral arms (49.8 km/sec) decouples from the angular velocity of stars in the core (39.4 km/sec) such that stars inside the radius would tend to gravitate toward the centre while stars outside the radius would tend to shift outward with each spiral wave crossing. (Beyond a corotation circle the spiral density waves rotate faster than the stars.)

To add yet other mysteries, there appear to be six spiral arms—an unusual number that seems to have no ready explanation given the pancake cross-section and low mass of the central core. Six-arm spirals are an oddity in the nearby universe populated mainly with two-armed Grand Design spirals with or without bars, and a small proportion of lenticular or flocculent galaxies with multiple short, cramped partial arms and wispy filaments. Nearly two-thirds of spiral galaxies have bars, whose gas flow moves large amounts of gas and dust into active central bulges to feed black holes. Slim pickings for a massive black hole in this little wafer.

Surmounting all these is the problem of gas supply. We do not have a metallicity profile or colour-magnitude diagram with which to noodle out the galaxy's star-formation history and its populations. The N7640 Group is too far away for us to accurately map in 3-D the massive but tenuous H_1 gas clouds with which the N7640 Group might interact. Hence we are back to Square One: Why did star formation take so long? What suddenly kick-started its energy engine some twenty or thirty million years ago?

En de boer … hij ploegde voort



There are several theories why Pieter Breughel portrayed Icarus's heroic effort to use wax wings to reach wisdom as an unnoticed splash in a vast sea. We read about those theories in the Introduction above, so we needn't belabour further the already belaboured.

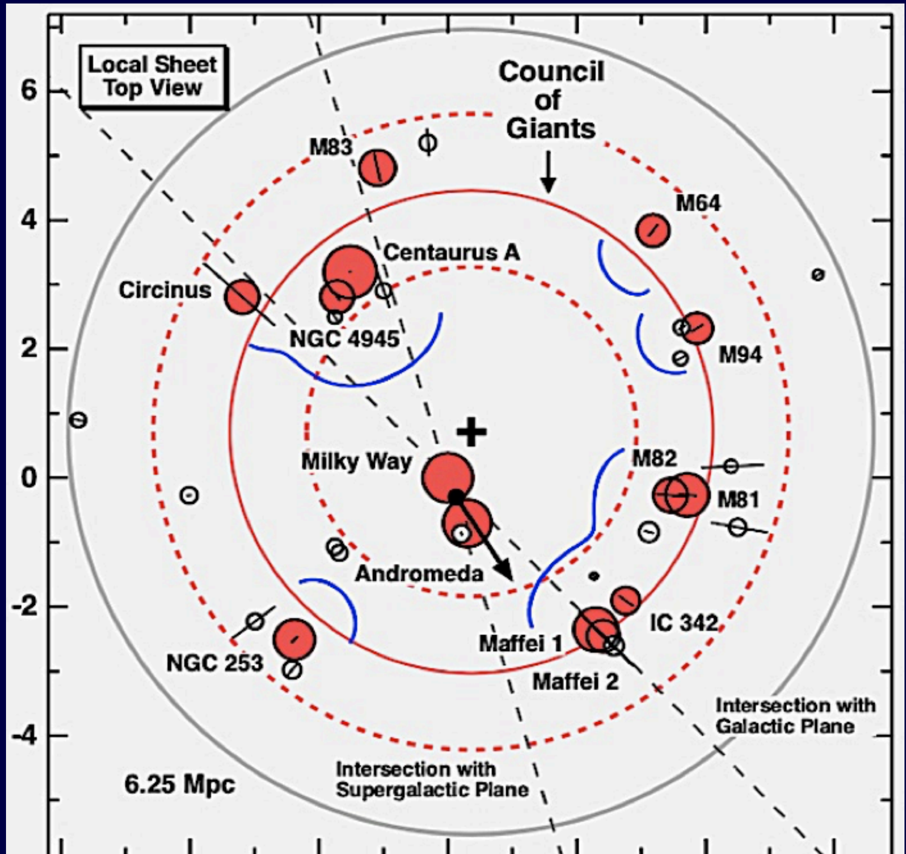
Rather, let's look at the implications of a phrase written by an art critic of the time, '*En de boer ... hij ploegde voort*' ('And the farmer … he plowed forth'). The quest for wisdom and glory, be it valiant or base, make but a splash for a moment. It is ox-dutiful human diligence that turns the soil of the future.

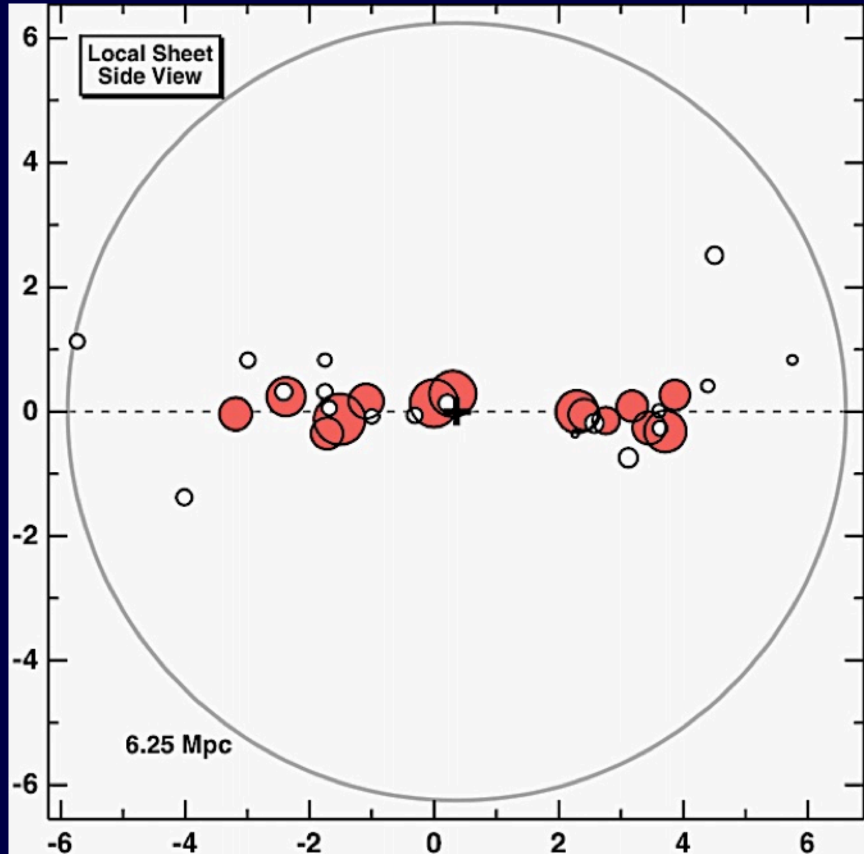
While the farmer plows the soil the great ship in the picture plows the sea. Between the anchorages of those two deeds, daily duty nourishes the world.

Similarly, while we Ooohhh and Aaahhh over the grand images of grand galaxies, we forget the dwarfs. The clusters that bedazzle us with O and B giants nourish the universe less than the lonely farmer behind his lowly plough, seeding G-K-M stars that populate the galaxies by consuming the least and contributing the most. What's the difference between the farmer and the buzzy retinues of dwarf galaxies ellipsing amid the giants when stars smaller than the Sun plough into the sky the universe's future food?

Our flight to the sun in search of wisdom about little UGC 12588 ended in an ignominious splash in the sea of unknowing. The question is not where a galaxy gets its gas, the question is what happens to make it *lose* its gas.

From minuscule to majuscule in one steppingstone



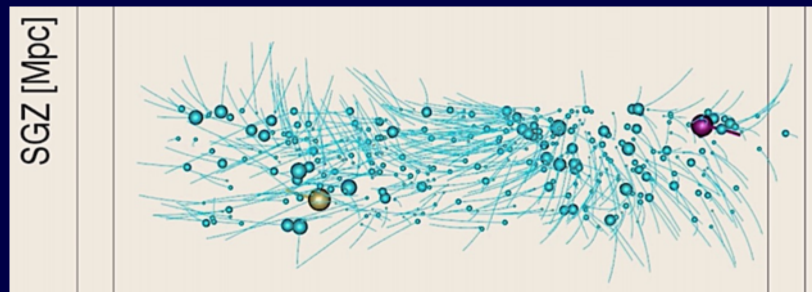


UGC 12588 lies 3 Mpc further out and well above the Local Sheet plane on a line that in the left-side box extends almost vertically beneath the Milky Way–M31 axis.

In 2014 the Canadian astronomer Marshall McCall published a paper, *A Council of Giants* whose title is an allegorical reference to a grove of redwood trees that grows in a circle around the trunk of an ancestral tree that had grown to immense size before it fell. The allusion has a majesterial ring, but mushrooms do the same thing—as do stars around the rim of a supernova shock wave that shocks-triggers star formation in molecular clouds.

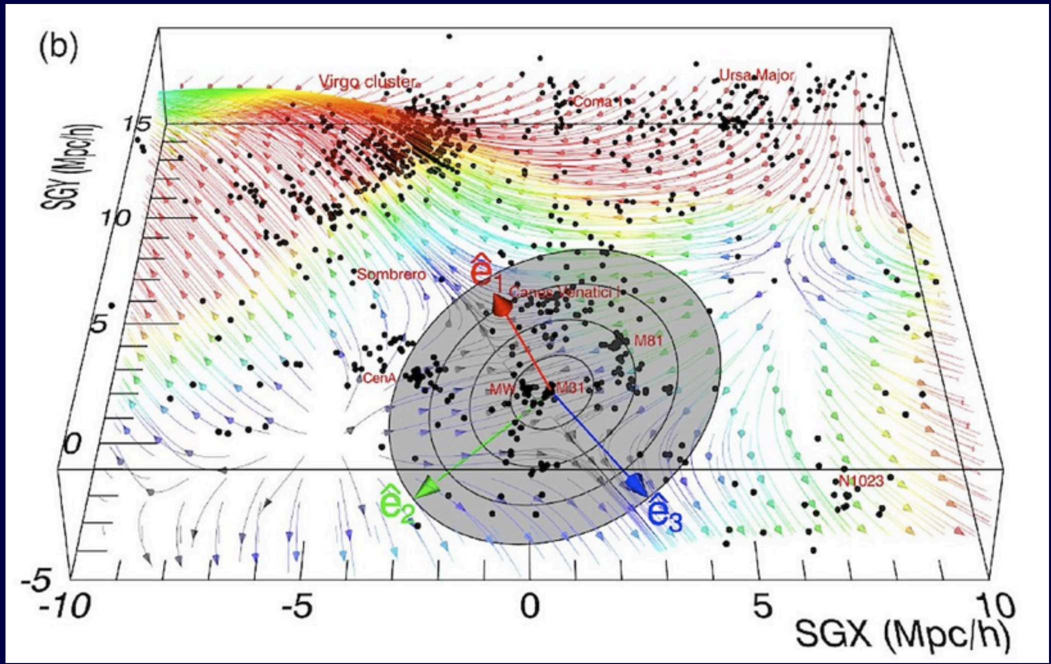
McCall's article was about the *Local Sheet*, the largest nearby isolated structure with its own gravitational well (above). 'Pancake' is a more apt term, because the Sheet's thickness is about one-sixth of its diameter. The obvious question is, '*Why is such a large structure so flat in only its vertical plane*? What flattens it?' *The process goes like this*.

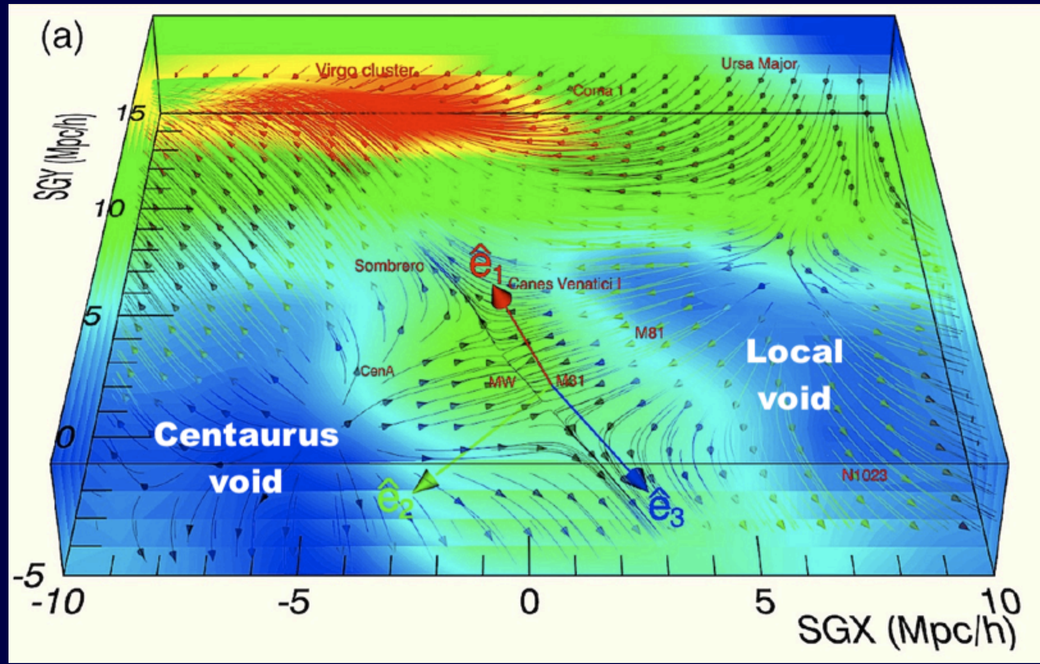
Unlike our problem of nondetection with UGC 12588, *the cause of the Local Sheet's flatness can be traced to a physical process*. Paradoxically, while the two structures are physically separate, they are related in circuitously surprising way: *the speed of sound (Mach number) in gas*.



Simulated infall vectors of galaxies in the Local Sheet, from *Shaya & Tully 2017*. The full motion graphic from which this cut was extracted shows a descending pattern on the left and the ascending pattern on this right. This suggests that the Local Sheet has a rotational component which is magnified by the shear stress tensor of the entire Local Sheet in the direction of the Virgo Supercluster. *Click on this link to run the video simulation* from which this truncated still image was extracted.

Urban development the supergalactic way





In the above pair of images from *Libeskind et al 2015*, the Milky Way and Local Group are tiny dots in the middle of the shaded disc. The Local Sheet is slightly smaller than the disc shown here, but angled as shown because the flat side of the Local sheet lies on the Supergalactic Plane. The thin lines with arrows are simulated (calculated, not empirical) vector lines illustrating the mass flow between the Milky Way, Centaurus A, M81, and other more distant galaxy clusters, all of which are converging toward the Virgo Supercluster (SSC). *This massive assemblage, in turn, is converging toward the even more massive Great Attractor off this image to the left* (see next page—to visual enthusiasts it is in the constellation Norma).

The Supergalactic Plane extends from the Virgo Cluster through the Local Group downward and right beyond the image box toward the Perseus-Pisces Supercluster. The *galaxies of the Local Sheet* are gravitationally infalling almost perpendicularly toward the Supergalactic equatorial line, which passes through the Local Group. *As the individual galaxy vectors approach the equatorial line* the vectors swerve sharply northward to converge toward the Virgo SSC.

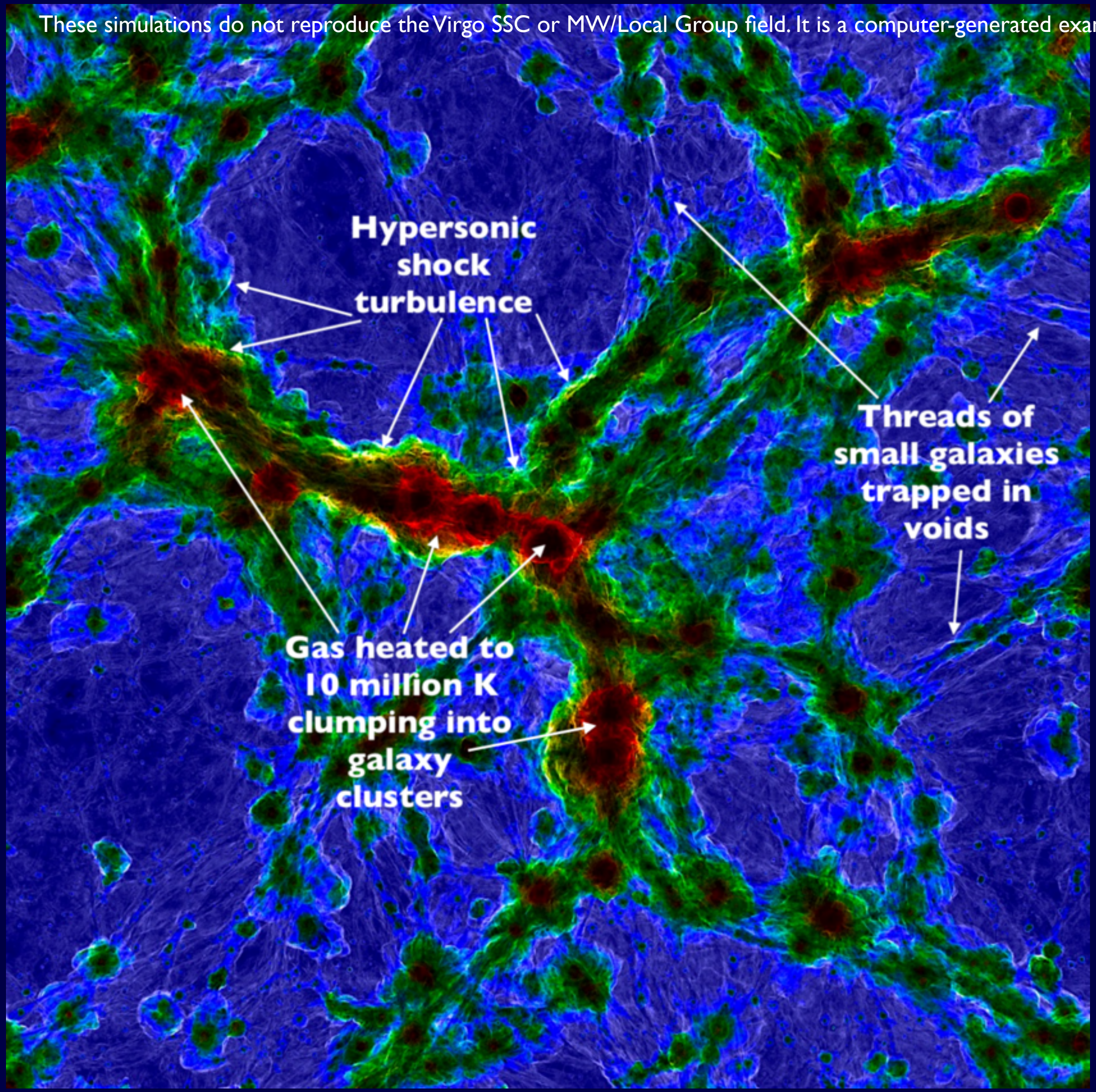
The primary energy source for all this curvaceous activity is gravity. Each galaxy can be taken as a point of mass which is attracted to and by every other galaxy point on the plot. *Regions that are already dense (e.g. the Virgo Cluster) steadily become denser*. Regions of few or no galaxies become emptier. In the broadest term, the *universe is emptying out underdense void regions in order to enrich overdense galaxy clusters.* It is urban development on the supergalactic scale, with intergalactic filaments mediating flow like urban freeways in cities.

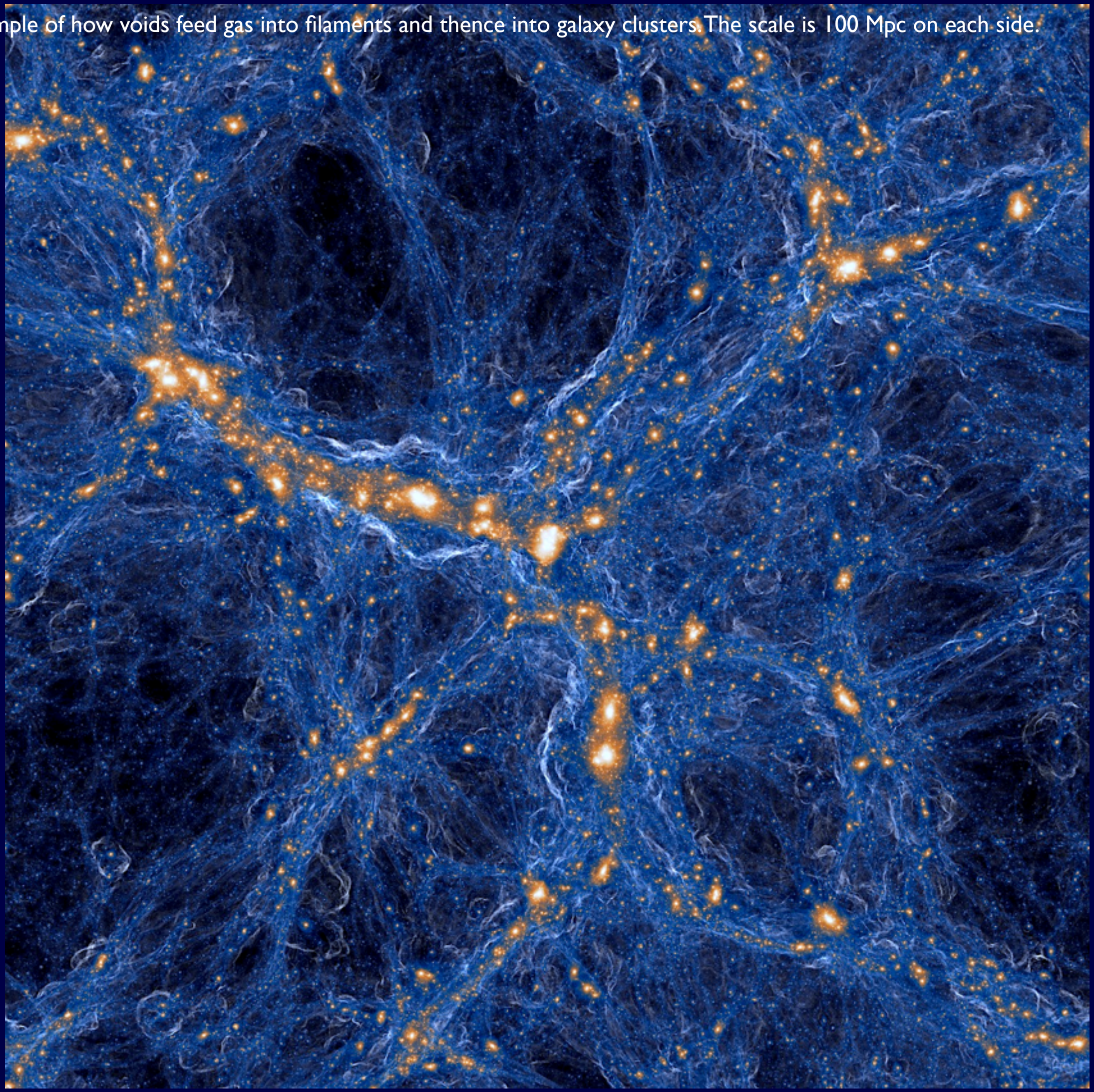
The vector lines and their adjacent vector curves converge in the much same way on-ramps feed vehicles onto freeways. The technical term for this flow is rather clunkily named *shear stress tensor*. If we pick that term apart, the *shear* describes the forces acting on each galaxy as its path is curved by the surrounding gravitational potentials (think of putting your palm on a deck of cards on a table and rotating your palm by 90 degrees). *Stress* is the amount of twisting torque in the space between each card. The *tensor* is the composite vector produced by all the stresses between each of the particles in every stack of playing cards that represents a galaxy. It sums to a single vector resulting from multiple other converging vectors. The Local Sheet shear stress tensor is the converging flow of all its galaxies into a filament leading to the Virgo SSC.

The infalling filament toward the Virgo SSC is the final stage in a process in a process that began with he *emptying-out of the Local and Centaurus Voids*. *The large-scale structure of the universe is a Swiss cheese of large void areas surrounded by sheets and filaments of matter*. Twelve billion years ago there were many more voids. They were modest underdensities in the dark matter ocean of the universe, amid which were overdensities of normal matter in the course of making galaxies. Gravity being what it is, in time the dense galaxies attracted each other and *pulled matter out of the voids* towards themselves. As sheets became more massive, their own internal gravity repeated the process, *collapsing large sheets into multiple filaments*. Filaments are gravitational and magnetic rivers that transport ionised hydrogen and other elements into galaxy clusters that grow where *multiple filaments cross each other*. Galaxy clusters are largest and oldest *at the confluence of filaments*. Galaxy clusters are effectively the universe's hoover (vacuum cleaner) bag. They suck the dust out of anything they get near.

The overall process has been a remarkable example of mass urban development in a supergalactic setting. Today voids have lost about *90% of their original density*. Not completely: they are threaded by *weak groups of small galaxies* (e.g. *Markarian 1477*), rather like rural roads with tiny towns and remote farmsteads. And oh yes: dust. It's more important than we think.

These simulations do not reproduce the Virgo SSC or MW/Local Group field. It is a computer-generated example of how voids feed gas into filaments and thence into galaxy clusters. The scale is 100 Mpc on each side.





This simulation shows the effect that shock sound speed (Mach number) along the edges of cosmic filaments has on *gas temperatures in galaxy clusters inside the filaments*. The blue regions are cold, very thin hydrogen that has been present in the voids since the beginning of galactic assembly 12–13 billion years ago. Over time the high density of filaments and clusters accelerates the *outflow of void gas into the filaments*. The void gas is moving hypersonically ($\mathcal{M}$>5) with respect to the density of gas in the filaments. The bright green structures are shock regions where *void gas at hypersonic velocities interacts* with the >10x denser boundary gas between cosmic voids and filaments. The collision shock induces turbulence that *slows down the gas inflow to subsonic velocity* (~200 meters/sec), but raises its temperature and pressure to millions of Kelvin as it does so. The red colour indicates where 10 million Kelvin gas clumps in the massive galaxy clusters. Note also the number of threads in the filaments. *These are still populated by small lines of low-mass galaxies* whose growth was cut off by the removal of nearby void gas. They've been left to starve, and they will. Watch how gravitation-induced shock fronts propagate through the Cosmic Web using this *Illustris 3-D Moving Slice simulation*. See also *these various presentation methods* for the same data.

This composite image portrays gravitationally collapsed structures (galaxies, clusters, filaments) in orange/white. These are surrounded by thin laminae-like layers of shock surfaces (blue) which reveal the succession of infall events in which a specific volume of void gas was shock-slowed when it encountered the mass pressure of the orange/white overdensities. Careful analysis suggests that the evacuation of voids occurs in clumpy events. This in turn suggests that void gas is not evenly distributed but exists in multiple massive clouds. The implication there is that the underlying dark matter in voids is also clumpy—although the density gradients would be very broad but shallow. Note that many of the *filaments inside voids are very thin*. This suggests their shape is guided into quite weak (10^{-17} Gauss) but highly elongated multiple megaparsec 'threads' which terminate when they merge into the >10x *higher electron density* in the ionised gas of the gravitationally bound fields. The resemblance to earthly biological cellular structures is striking, but also imaginary anthrocentrism. Far more important for our investigation of the structure of UGC 12588 is the fact that Mach speed is one of the most important, yet seldom mentioned, forces at work in shaping our universe. We can't hear the scream in space. Instead, we see it.

Icarus's problem wasn't the Sun, it was wax.

So far, we have established two facts with reasonable certainty: **One:** on the previous page we established that the speed of sound in space plays a major role in shaping gas/dust structures. Shock turbulence works to disperse; magnetic fields work to confine. The battle between the two see-saws for millions of years, and there are diverse examples to be found in which one or the other has prevailed. The prize is a cluster of stars. The referee wielding the whistle is gravity. The loser gets to play again.

Two:

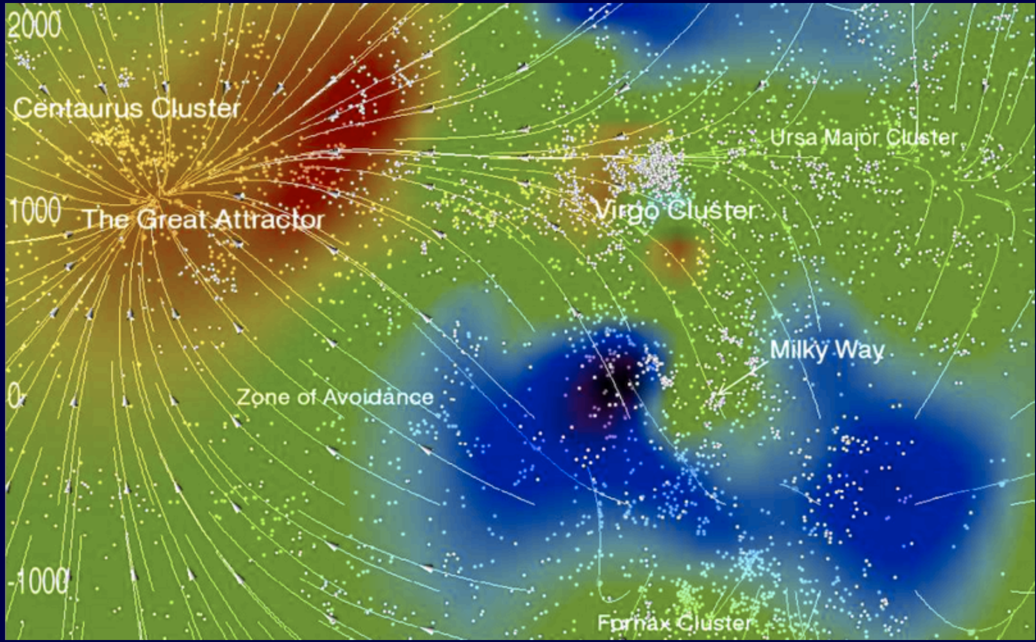
without dust the universe wouldn't look and behave as it does. Carbon-based dust provides the surface on which a catalytic reaction between carbon, hydrogen, and oxygen (the latter two in the form of water ices) produces molecular hydrogen H_2. Only H_2 can get cold enough to collapse into star-forming densities at temperatures below 10 Kelvin. Carbonaceous dust is opaque: in molecular clouds it absorbs enough galactic light that the denser molecular hydrogen can gravitate toward the centre of the cloud, while the atomic hydrogen rises into a shell around it. This is why molecular cloud cores are the coldest places in the universe. Only there can H_2 compact to densities great enough to collapse into stars.

Moreover, the lesser-known forms of dust (especially siliceous or silicon-based) play a role in reinforcing the self-confining properties of magnetically solenoidal flux tubes. Siliceous dust us dipolar; the particles are elongated and align with local magnetic fields. They also spin with astonishing velocities—up to 10 million rotations per *second*. Their collectively aligned angular momentum serves to reinforce the filamentary shape of gas/dust structures within which star clusters collapse.

Hence, if we are to explain UGC 12588's recent starburst and its morphology (physical structure) today we need to find the dust.

Dust — where do we look for it?

Ly-α clouds are large starless gas structures found in intergalactic dark matter haloes. They are difficult to trace because they are so far away and because only cold H_1 gas emits Ly-α radiation at 1216 nm UV wavelengths in dark matter clumps. They emit feebly in the 21 cm band and have no

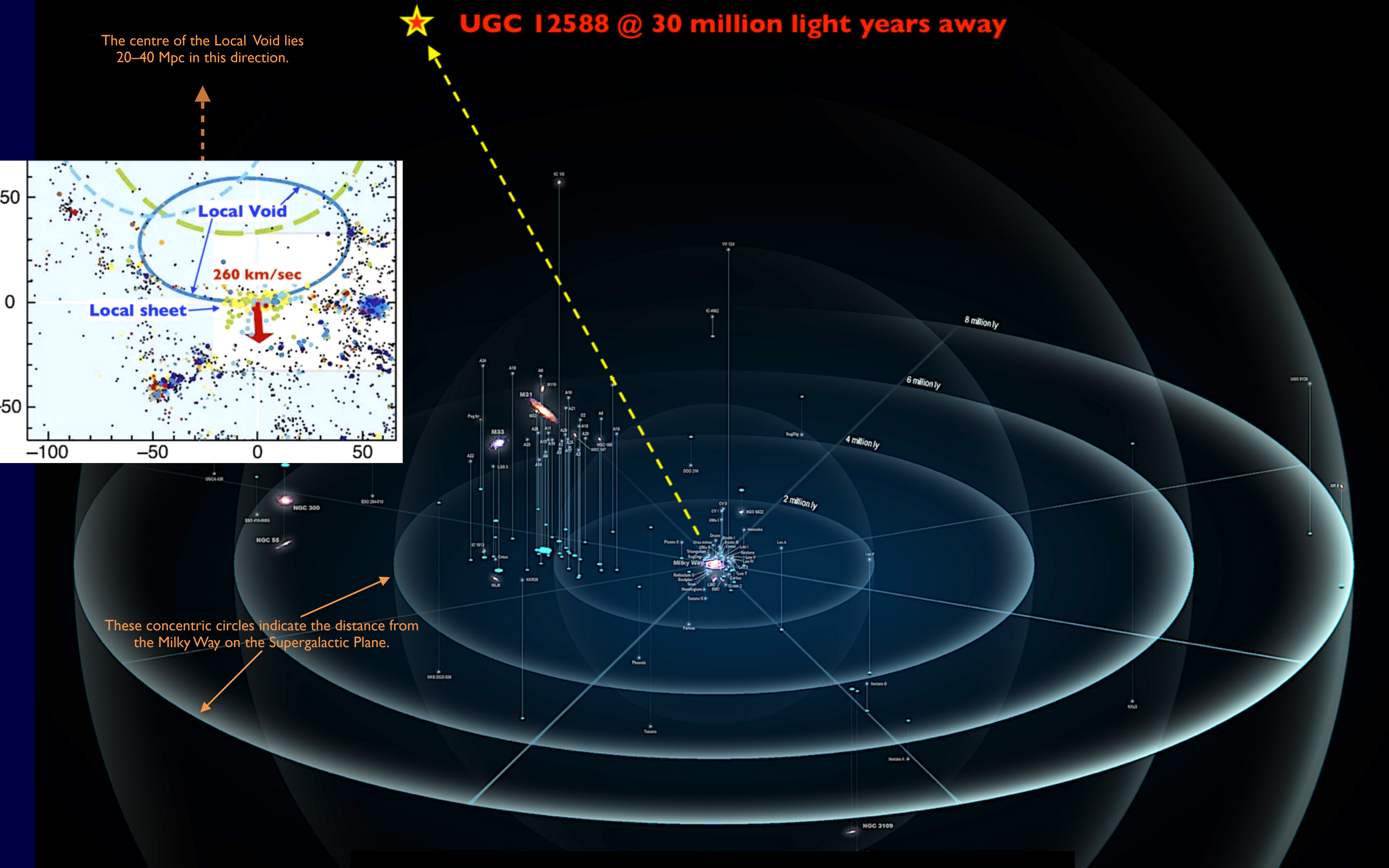


Simulation of velocity shear tensors from the Local and Centaurus Voids (in blue, right and left). The Milky Way and Local Sheet flow fall initially toward the Virgo SSC, but before merging into Virgo, the combined Local and Virgo clusters are sheared toward the Great Attractor. The flow lines are composites of individual galaxy vectors, collectively called velocity shear tensors. Source: *Courtois-Pomaréde-Tully, Cosmicflows 1* project. The several methods of visualising these complex flows are summarised in this *6 min 32 low-resolution MP4*, with higher resolution AVIs ***223 MB*** and ***760 MB***.

other markers such as dust or the CO emission associated with molecular clouds. Possible clue: *They weigh in at dwarf galaxy masses.*

High-velocity clouds (HVCs) are large gravitationally coherent masses of gas and dust found throughout the galactic halo of the Milky Way. Their bulk motions in the local standard of rest have velocities which are measured in excess of 70–90 km/sec. These clouds can be massive, up to a million times the mass of the Sun. Thousands have been observed in the Milky Way's halo. They are also detected in the halos of nearby galaxies.

Infrared Dark Clouds (IRDCs) are cold, dense regions within giant molecular cloud. They are seen in silhouette against bright diffuse mid-infrared emission from the Galactic plane. While nearly all known IRDCs share the filamentary structure of star-forming regions in spiral arms, IRDCs are mostly low-mass, able to form only a few stars.



This simulation shows the Local Group approximately as positioned on the Supergalactic Plane. Image courtesy of Antonio Ciccolella.

A candidate hypothesis where UGC 12588 got its gas

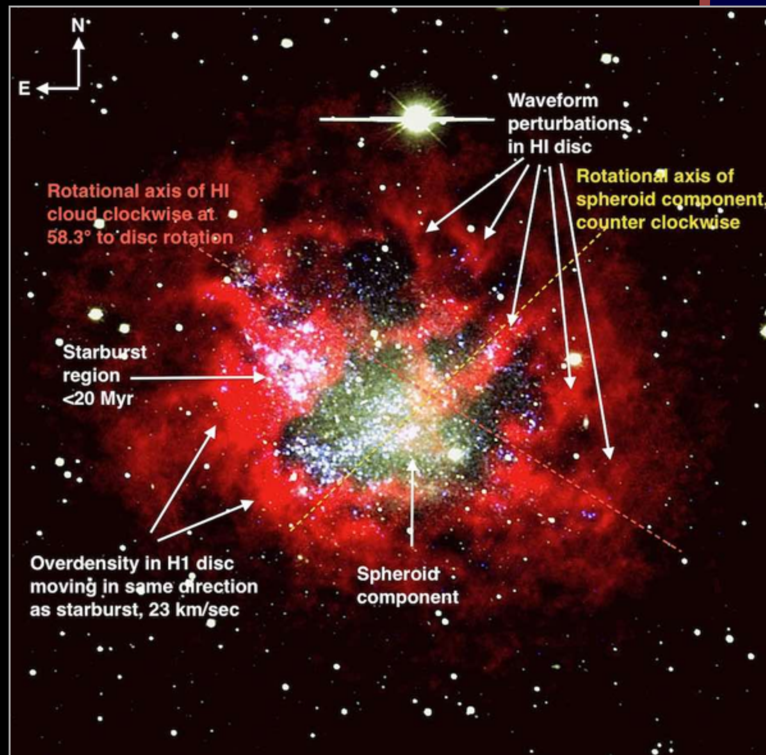
Of the three major types of dust clouds listed above, the class of HVC high-velocity clouds are the most likely candidate for the gas that has fuelled UGC 12588's recent star-formation episode. This must remain conjecture because the details of the galaxy's genesis are unknown due to the rather sparse availability of data.

The second factor that has been raised throughout the foregoing is the effect that Mach speed has on gas dynamics in structures at all scales. Three pages earlier we saw that high-velocity gas exiting the Local Void abruptly slows to subsonic compressible gas in a series of shock fronts in the Void-Filament transition zone. UGC 12588's notably high 27° SGY elevation would place it closer to the transition zone. We do not know with certainty how that relates to its recent starburst, but we can hazard a suspicion there is a mass-energy exchange relationship.

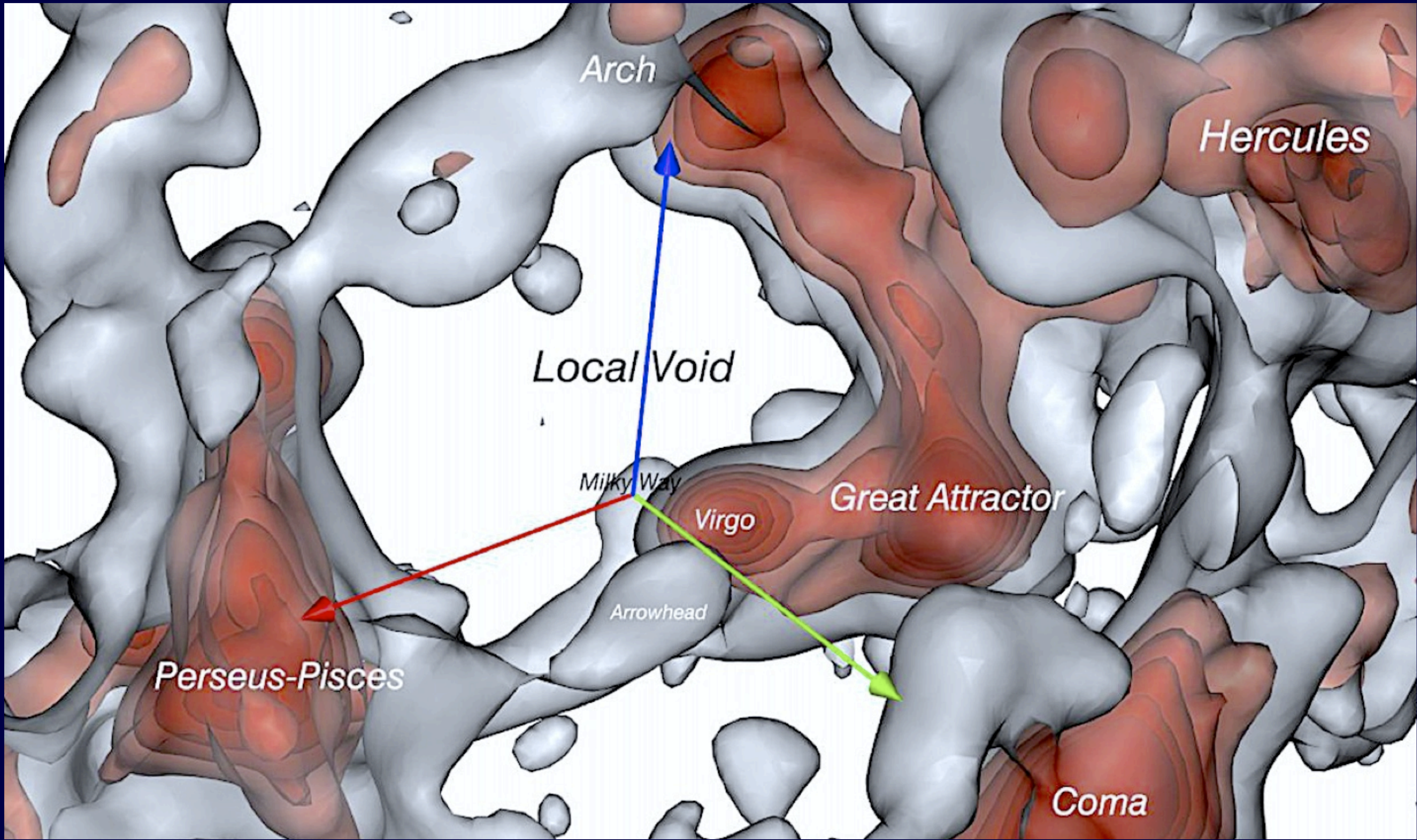
The IC 1613 cloud-cloud interaction hypothesis

There are few observationally supported explanations for UGC 12588's recent starburst event, so we must risk some informed guesses. The IC 1613 hypothesis suggests that UGC 12588, traveling at about 400 km/sec, encountered one or more HVC clouds of >10,000 solar masses on its path through the cosmos.

The *dSph IC 1613* has undergone *a starburst episode of this type*. The galaxy was *originally a dwarf spheroidal* that lived a placid, solitary existence in the LG outskirts for perhaps 10 billion years. About 150 million years ago it encountered a succession of two and possibly three *massive atomic hydrogen clouds*. These may have been primordial clouds lying within a dark matter halo, or weakly bound *HVC clouds from ancient star-forming events*. The spheroidal component's outer H_1 halo sideswiped the first of these HVCs between 100 and 150 million years ago, then more *abruptly interacted the second and possibly a third*. Today we see IC 1613 as a shallow spheroidal with three rather ferocious H_2 star-forming regions some 6 kpc from the old dSph core. The initial collisional shocks in turn triggered secondary collect-and-collapse shocks closer to the old spheroid, converting the entire assemblage into today's dIrr dwarf irregular galaxy. Our hypothesis is that this is occurring in UGC 12588 today.



If you don't want to fall, don't use wax. Use phase space.



Summarising the most recent journal articles on the subject (1, 2, 3, 4), the Milky Way lies in a thin plane called the Local Sheet. The Sheet in turn is a small section in a gigantic wall that rims a vast volume of primordial gas called the Local Void that is only about 10% of the average density of the universe. The Local Sheet lies within the Supergalactic Plane, on which most of the major galaxy clusters in the nearby universe spread out. There are few galaxy groups above or below the Supergalactic Plane.

The Local Sheet is part of a wall into which the Void's gas flows. The Local Sheet is receding from the Local Void at 260 km/sec. In effect, the Void is deforming the Local Sheet across the dense filament of the Supergalactic Plane which joins Perseus-Pisces with the Virgo SSC. Since the Local Sheet is effectively a fluid, like any fluid it splatters from round to flat when it hits something large and dense. One can imagine the Local Sheet's galaxies as water droplets splashing outward after the splatter.

NIGHTFALL

DEEP-SKY JOURNAL OF THE ASTRONOMICAL SOCIETY OF SOUTHERN AFRICA

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ISSN 2617-7331