AstroTalk: Behind the news headlines of January 2015

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New insights into the structure of the nearest galaxies in our "Local Group"

The American Astronomical Society (AAS) usually organizes its winter conference in the second week of January. Since I am the Deputy Editor of *The Astrophysical Journal Letters*, one of the professional astronomy journals owned by the AAS, participation in the AAS winter meeting is part of my annual scientific schedule. Except for the General Assemblies of the International Astronomical Union, which are held every three years, these AAS meetings are the largest gatherings of professional astronomers in the world at any one time, attracting up to 3,000 participants who attend numerous parallel scientific sessions on a huge variety of topics.

This year, at the conference in Seattle, I chaired a scientific session on star-forming galaxies, and I attended a few sessions that focused on new developments in our understanding of the structure of the galaxies in what is commonly referred to as the "Local Group" of galaxies. The Local Group is comprised of the Milky Way and Andromeda galaxies, the somewhat smaller galaxy Messier 33 (the "Triangulum Galaxy"), as well the Large and Small Magellanic Clouds and numerous smaller, so-called dwarf galaxies. For all practical purposes, the volume of the Local Group is generally understood to include all galaxies within 1 million parsecs (approximately 3 million light years) of the Milky Way and Andromeda. Some of the new developments presented at the AAS meeting were very exciting indeed, so I decided to devote this month's Amateur Astronomer article to some of these highlights.

One of the most exciting new results I saw in relation to the Andromeda galaxy was the largest *Hubble Space Telescope* image of the galaxy ever assembled, a product of the Panchromatic Hubble Andromeda Treasury (PHAT) programme. The sweeping, bird's-eye view of a portion of the Andromeda galaxy is the sharpest large composite image ever taken of our galactic nextdoor neighbour. Alhough the galaxy is over 2 million light years away, the *Hubble Space Telescope* is powerful enough to resolve individual stars in a 61,000 light-year-long stretch of the galaxy's pancake-shaped disk. It's like photographing a beach and resolving individual grains of sand. And there are lots of stars in this sweeping view—over 100 million, with some of them in thousands of star clusters seen embedded in the disk.

This ambitious photographic cartography of the Andromeda galaxy represents a new benchmark for precision studies of large spiral galaxies that dominate the Universe's population of over 100 billion galaxies. Never before have astronomers been able to see individual stars inside an external spiral galaxy over such a large contiguous area. Most of the stars in the Universe live inside such majestic star

cities, and this is the first data that reveal populations of stars in context to their home galaxy.

Hubble traces densely packed stars extending from the innermost hub of the galaxy, seen at the left. Moving out from this central galactic bulge, the panorama sweeps from the galaxy's central bulge across lanes of stars and dust to the sparser outer disk. Large groups of young blue stars indicate the locations of star clusters and star-forming regions. The stars bunch up in the blue ring-like feature towards the right side of the image. The dark silhouettes trace out complex dust structures. Underlying the entire galaxy is a smooth distribution of cooler red stars that trace Andromeda's evolution over billions of years.

Because the galaxy is only 2.5 million light years from Earth, it is a much bigger target in the sky than the myriad galaxies *Hubble* routinely photographs that are billions of light years away. This means that the *Hubble* survey is assembled together into a mosaic image using 7,398 exposures taken over 411 individual pointings. The scientist presenting the new image told his audience that the image itself, if displayed at full resolution, would cover over 5,000 wide-screen, high-resolution television sets!

A second result from the meeting that I would like to highlight concerned a detailed study of the motions of different stellar populations in the disk of the Andromeda galaxy. The authors found striking differences from the motions in our own Milky Way, suggesting a more violent history of mergers with smaller galaxies in Andromeda's recent past.

The structure and internal motions of the stellar disk of a spiral galaxy hold important keys to understanding the galaxy's formation history.

"*In the Andromeda galaxy, we have the unique combination of a global yet detailed view of a galaxy similar to our own. We have lots of detail in our own Milky Way, but not the global, external perspective*," said Puragra Guhathakurta, professor of astronomy and astrophysics at the University of California, Santa Cruz (USA).

The new study, led by Guhathakurta's graduate student Claire Dorman, combined data from two large surveys of stars in Andromeda, one conducted at the W. M. Keck Observatory in Hawai'i and the other using the *Hubble Space Telescope*. The Spectroscopic and Photometric Landscape of Andromeda's Stellar Halo (SPLASH) survey used the Keck/DEIMOS multi-object spectrograph to measure radial velocities of more than 10,000 individual bright stars in Andromeda. The recently completed PHAT survey provides high-resolution imaging at six different wavelengths for more than half of these stars.

"*The high resolution of the Hubble images allows us to separate stars from one another in the crowded disk of Andromeda, and the wide wavelength coverage allows us to subdivide the stars into sub-groups according to their age*," said Dorman during

her talk at the conference. Her study presents the velocity dispersion of young, intermediate-age, and old stars in the disk of Andromeda, the first such measurement in another galaxy.

Dorman's analysis revealed a clear trend related to stellar age, with the youngest stars showing relatively ordered rotational motion around the centre of the Andromeda galaxy, while older stars displayed much more disordered motion. Stars in a "well ordered" population are all moving coherently, with nearly the same velocity, whereas stars in a disordered population have a wider range of velocities, implying a greater spatial dispersion. "*If you could look at the disk edge-on, the stars in the well-ordered, coherent population would lie in a very thin plane, whereas the stars in the disordered population would form a much puffier layer*," Dorman explained.

The researchers considered different scenarios of galactic disk formation and evolution that could account for their observations. One scenario involves the gradual disturbance of a well-ordered disk of stars as a result of mergers with small satellite galaxies. Previous studies have found evidence of such mergers in tidal streams of stars in the extended halo of Andromeda, which appear to be remnants of cannibalized dwarf galaxies. Stars from those galaxies can also accrete onto the disk, but accretion alone cannot account for the observed increase in velocity dispersion with stellar age, Dorman said.

An alternate scenario involves the formation of the stellar disk from an initially thick, clumpy disk of gas that gradually settled. The oldest stars would then have formed while the gas disk was still in a puffed up and disordered configuration. Over time, the gas disk would have settled into a thinner configuration with more ordered motion, and the youngest stars would then have formed with the disk in a more ordered configuration.

According to Dorman, a combination of these mechanisms could account for the team's observations. "*Our findings should motivate theorists to carry out more detailed computer simulations of these scenarios*," she said. The comparison to the Milky Way revealed substantial differences suggesting that Andromeda has had a more violent accretion history in the recent past. "*Even the most well ordered Andromeda stars are not as well ordered as the stars in the Milky Way's disk*," Dorman said.

In the currently favored paradigm of structure formation in the Universe, large galaxies such as Andromeda and the Milky Way are thought to have grown by cannibalizing smaller satellite galaxies and accreting their stars and gas. Cosmologists predict that 70% of disks the size of Andromeda's and the Milky Way's should have interacted with at least one sizable satellite in the last 10,000 years. The Milky Way's disk is much too orderly for that to have happened, whereas Andromeda's disk fits the prediction much better.

"*In this context, the motion of the stars in Andromeda's disk is more normal, and the Milky Way may simply be an outlier with an unusually quiescent accretion history*," Guhathakurta said.

I was also pleased to learn about new results pertaining to the Magellanic Clouds, the two brightest nearby satellite galaxies to our own Milky Way galaxy, for which I have a personal fondness driven by my own research interests. From a new study, it appears that not only are they much bigger than astronomers previously calculated, but also have nonuniform structure at their outer edge, hinting at a rich and complex field of debris left over from their formation and interaction. This is an early result from the "Survey of the MAgellanic Stellar History" (SMASH), carried out by an international team of astronomers using telescopes that include the Blanco 4-meter at Cerro Tololo Inter-American Observatory (CTIO) in Chile.

The Large and Small Magellanic Clouds are dominant features in the Southern hemisphere sky. Although named after explorer Ferdinand Magellan who brought them to the attention of Europeans, they were already known to every early culture in the Southern hemisphere. The Large Magellanic Cloud (LMC), covering about 5 degrees in angular size (10 lunar diameters), appears to the naked eye like a detached piece of the Milky Way. At a distance from us of about 160 thousand light years, even the brightest stars in these galaxies can't be seen without a telescope.

As principal investigator David Nidever (University of Michigan, USA) said, "*We have a decent understanding of how large galaxies like the Milky Way form, but most galaxies in the Universe are faint, distant, dwarf galaxies. The Magellanic Clouds are two of the few nearby dwarf galaxies, and SMASH is able to map out and study the structures in them like no other survey has been able to do before*."

"*We knew from the earlier work of SMASH team members that the LMC was larger than we thought, but those observations probed only 1% of the area that we need to explore. SMASH is probing an area 20 times larger, and is confirming beyond doubt that the LMC is really large while also giving us a chance to map its structure in detail*." said Knut Olsen (National Optical Astronomy Observatory, Arizona, USA) one of the leaders of the SMASH team. The team has identified stars belonging to the LMC at angular distances up to 20 degrees away, corresponding to 55 thousand light years. This was done using a new camera, dubbed DECam, mounted on the CTIO Blanco telescope, which allows the SMASH team to identify faint stars over a much larger area than ever before.

With the Blanco telescope, SMASH can detect exceptionally diffuse stellar structures – up to 400,000 times fainter than the appearance of the faint band of the Milky Way in the night sky. This is possible because DECam can distinguish individual faint Magellanic stars over a huge area. That allows the team to detect stellar structures that were previously much too faint to see.

The team is also exploring the Magellanic Stream, a gaseous structure that connects

the two Clouds and extends in front and behind them. The existence of the Magellanic Stream, first detected with radio telescopes over 30 years ago, clearly indicates that the two galaxies are interacting with each other and with our Milky Way. Astronomers have long expected to also find stars in the Stream but so far none have been detected. It's likely this is because the stellar component of the Stream is too faint to have been detected until the availability of the new camera. As David Nidever said, "*SMASH's ability to reveal superfaint stellar structures should not only allow us to finally detect the stellar component of the Magellanic Stream but also map out its structure which will give us a much better understanding of the Magellanic Clouds' interaction history*."

And finally, January saw the release of new insights about the structure of our own Milky Way galaxy, based on a careful study by Chinese astronomers. Given that our Solar System is located inside the Milky Way, getting a clear picture of what it looks like as a whole can be quite tricky. In fact, it was not until 1852 that astronomer Stephen Alexander first postulated that the Milky Way was spiral in shape. And since that time, numerous discoveries have come along that have altered how we picture it.

For decades astronomers have thought that the Milky Way consists of four arms—made up of stars and clouds of star-forming gas—that extend outwards in a spiral fashion. Then in 2008, data from the *Spitzer Space Telescope* seemed to indicate that our Milky Way has just two arms, but a larger central bar. But now, according to a team of astronomers from China, one of our galaxy's arms may stretch farther than previously thought, reaching all the way around the galaxy. This arm, known as Scutum–Centaurus, emanates from one end of the Milky Way bar, passes between us and the Galactic Centre, and extends to the other side of the galaxy. For many decades, it was believed that was where this arm terminated.

However, back in 2011, astronomers Thomas Dame and Patrick Thaddeus from the Harvard–Smithsonian Center for Astrophysics (USA) spotted what appeared to be an extension of this arm on the other side of the galaxy, placing it outside of our Solar System as well. But according to astronomer Yan Sun and colleagues from Purple Mountain Observatory in Nanjing (China), the Scutum–Centaurus Arm may extend even farther than that. Using a novel approach to study gas clouds located between 46,000 to 67,000 light years beyond the centre of our galaxy, they detected 48 new clouds of interstellar gas, as well as 24 previously observed ones.

For the sake of their study, Sun and his colleagues relied on radio telescope data provided by the Milky Way Imaging Scroll Painting project, which scans interstellar dust clouds for radio waves emitted by carbon monoxide gas. Next to hydrogen, this gas is the most abundant element to be found in interstellar space—but it is easier for radio telescopes to detect. Combining this information with data obtained by the Canadian Galactic Plane Survey (which looks for hydrogen gas), they concluded that these 72 clouds line up along a spiral-arm segment that is 30,000 light years in length. "*The new arm appears to be the extension of the distant arm recently*

discovered by Dame & Thaddeus as well as the Scutum–Centaurus Arm into the outer second quadrant," according to the new report.

This would mean that the arm is not only the single largest in our galaxy, but is also the only one to effectively reach 360° around the Milky Way. Such a find would be unprecedented given the fact that nothing of the sort has been observed with other spiral galaxies in our local Universe. Thomas Dame was quoted by *Scientific American* magazine as saying that "*It's rare. I bet that you would have to look through dozens of face-on spiral galaxy images to find one where you could convince yourself you could track one arm 360 degrees around*."

Naturally, the prospect presents some problems. For one, there is an apparent gap between the segment that Dame and Thaddeus discovered in 2011 and the start of the one discovered by the Chinese team—a 40,000 light-year gap, to be exact. This could mean that the clouds that Sun and his colleagues discovered may not be part of the Scutum–Centaurus Arm after all, but an entirely new spiral-arm segment. If this were true, then it would mean that our galaxy has several "outer" arm segments. On the other hand, additional research may close that gap and prove that the Milky Way is as beautiful when seen from afar as any of the spirals we often observe from the comfort of our own Solar System.

Figure 1: This sweeping bird's-eye view of a portion of the Andromeda galaxy is the sharpest image ever taken of our galactic nextdoor neighbour. *Credit: NASA, ESA, J. Dalcanton, B.F. Williams, and L.C. Johnson (University of Washington), the PHAT team, and R. Gendler.*

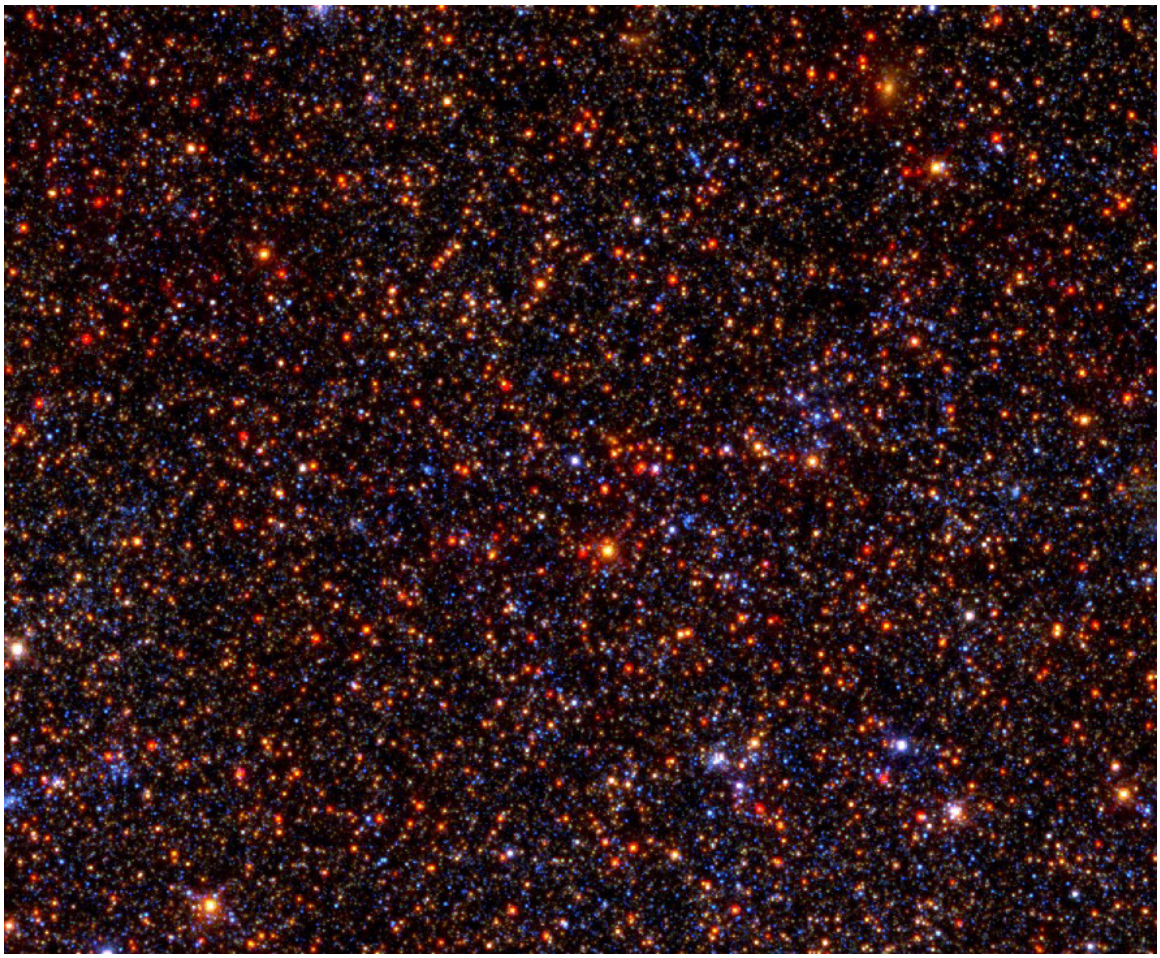

Figure 2: This *Hubble* image of a crowded star field in the disk of the Andromeda galaxy shows that stars of different ages can be distinguished from one another on basis of temperature (as indicated by colour) and brightness. *Credit: Ben Williams, PHAT collaboration*

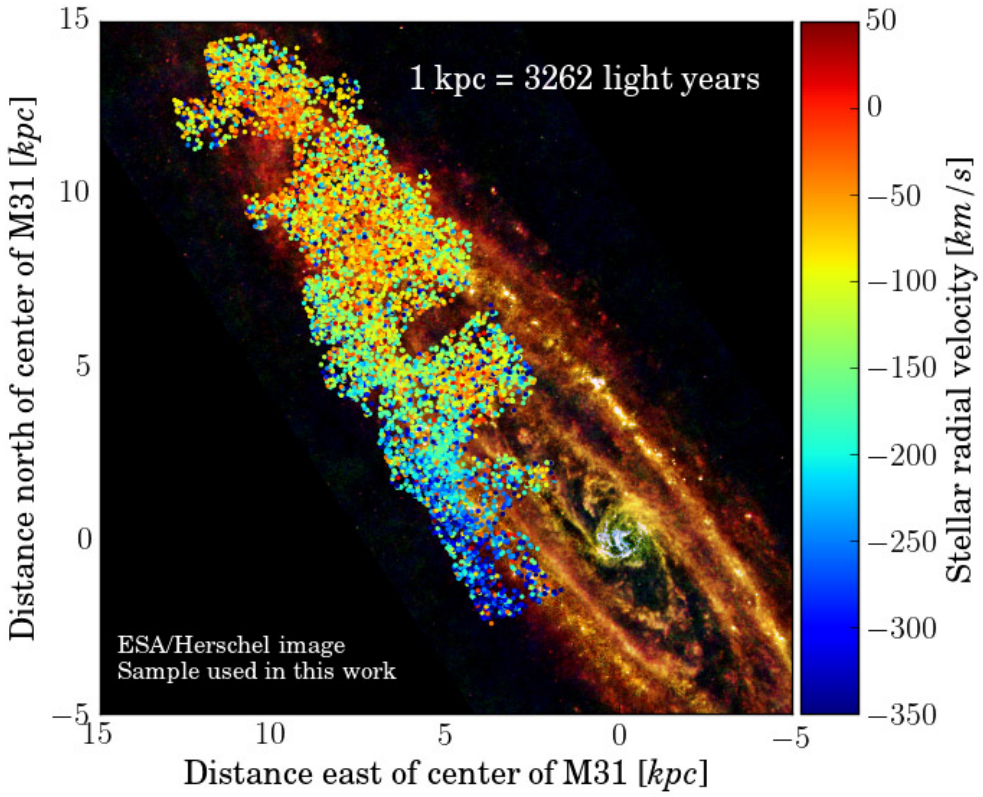

Figure 3: Dots show locations of stars in the spectroscopic survey superimposed on an image of the Andromeda galaxy (M31). Dots are colour-coded according to their velocity relative to the Milky Way, as measured using the DEIMOS spectrograph on the Keck II telescope. The centre of M31 is moving towards us at 300 km s^{-1}, whereas stars to the northeast of the centre have more positive velocities, indicating that they are moving away from us relative to M31's centre. *Credit: Claire Dorman, European Space Agency*

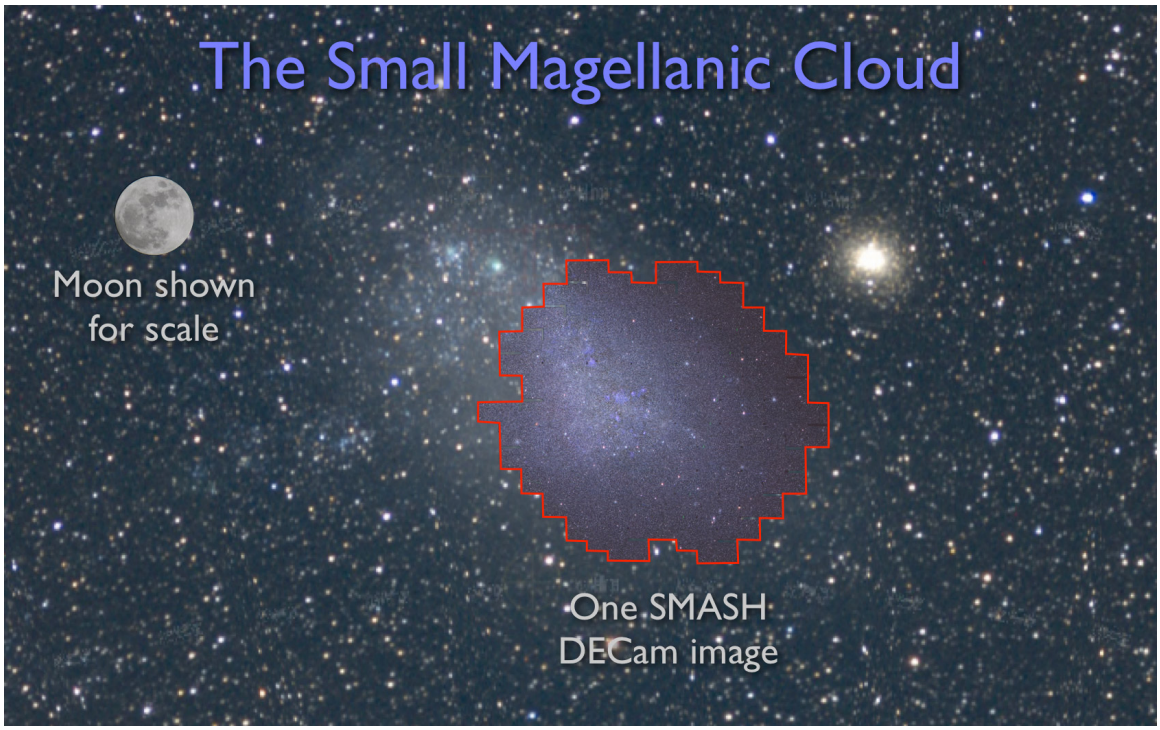

Figure 4: SMASH DECam image in the Small Magellanic Cloud with Moon for scale.

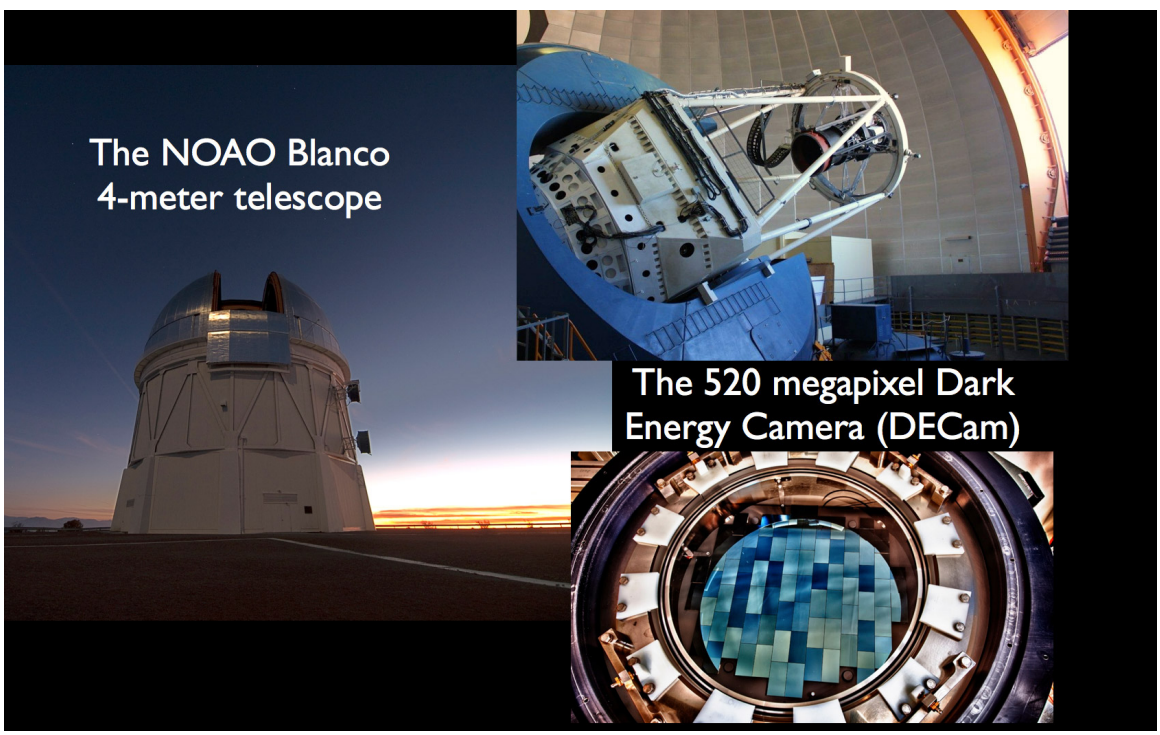

Figure 5

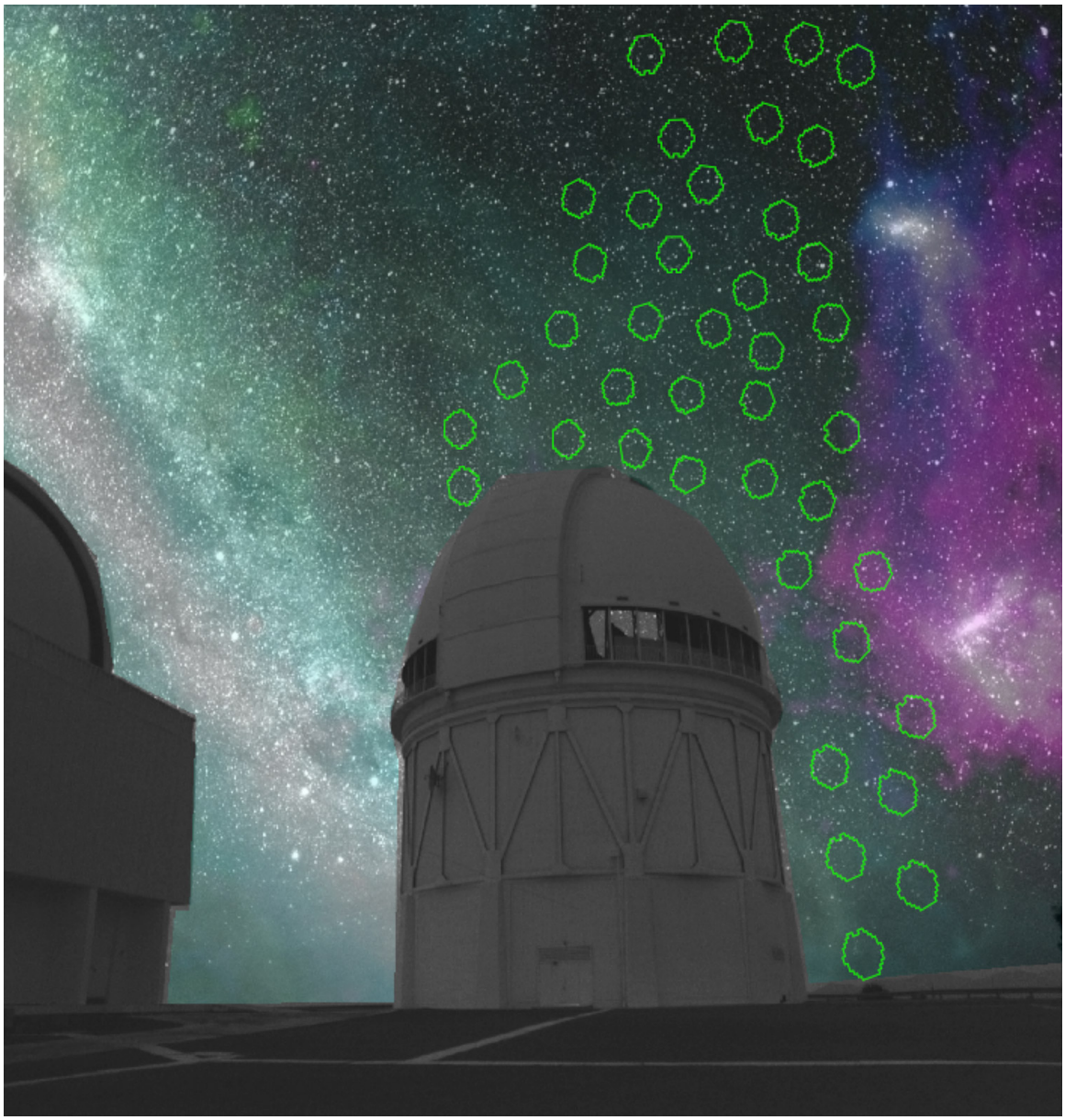

Figure 6: The CTIO Blanco telescope and the sky as it would appear if your eye could see both optical and radio wavelengths. Blue and purple nebulosity shows hydrogen gas, which connects the Small Magellanic Cloud (at top right) and the Large Magellanic Cloud (middle right) and also stretches across the sky. Green circles show some of the DECam pointings of the SMASH survey, indicating the area over which Magellanic Cloud stars have been found. *Credit: K. Olsen (NOAO/AURA/NSF), SMASH team, Roger Smith, and N. McClure-Griffiths.*

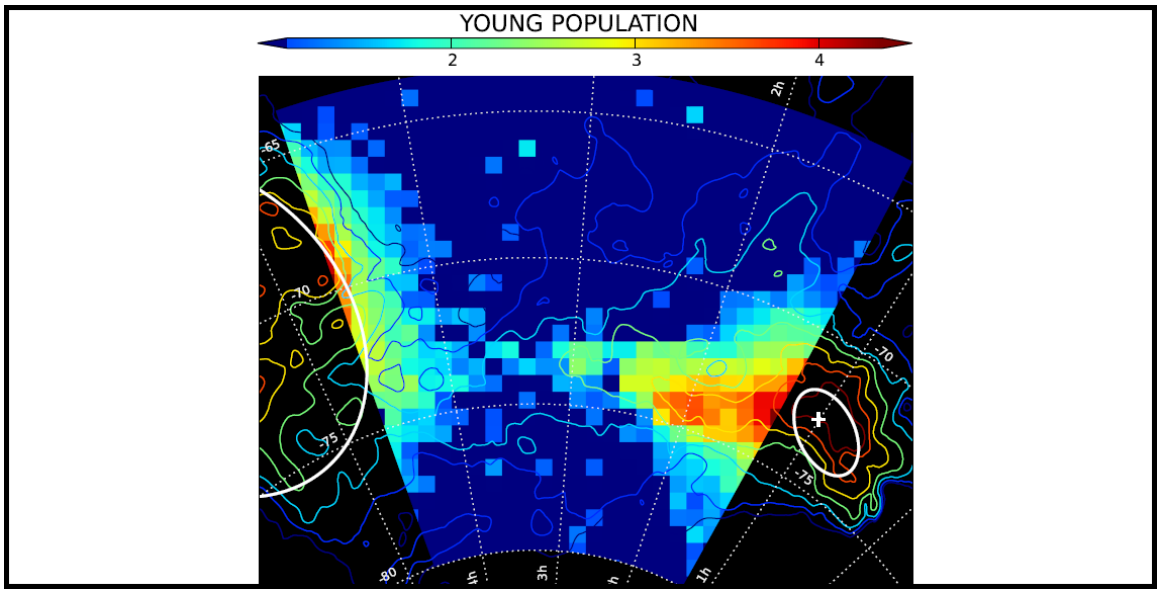

Figure 7: Polish astronomers from the Optical Gravitational Lensing Experiment (OGLE) discovered a young stellar bridge in 2014, which forms a continuous connection between the Magellanic Clouds (right: SMC; left: LMC).

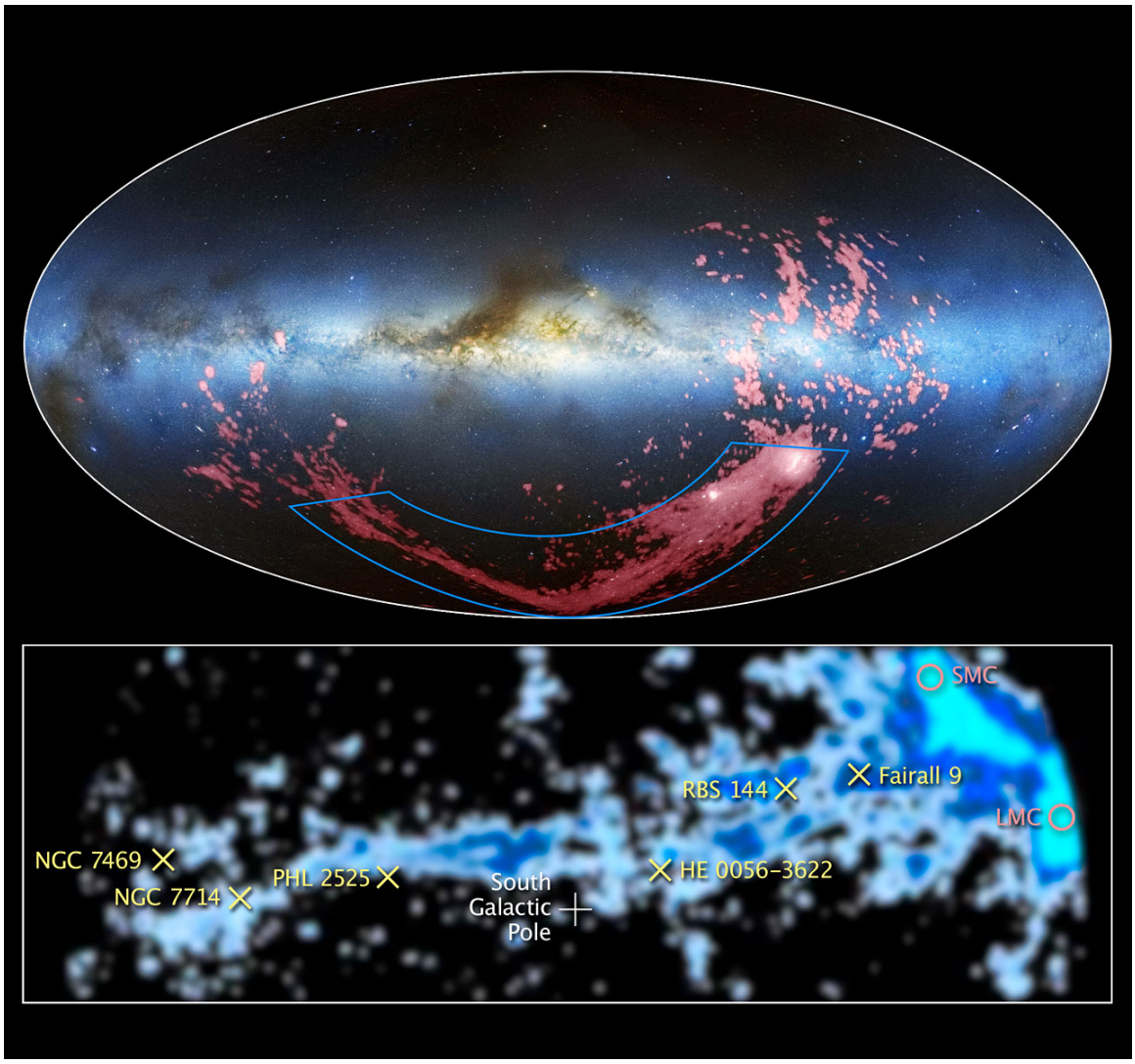

Figure 8: These images show wide and close-up views of a long ribbon of gas called the Magellanic Stream, which stretches nearly halfway around the Milky Way. *Credit: Credit for the radio/visible light image: David L. Nidever, et al., NRAO/AUI/NSF and A. Mellinger, LAB Survey, Parkes Observatory, Westerbork Observatory, and Arecibo Observatory. Credit for the radio image: LAB Survey*

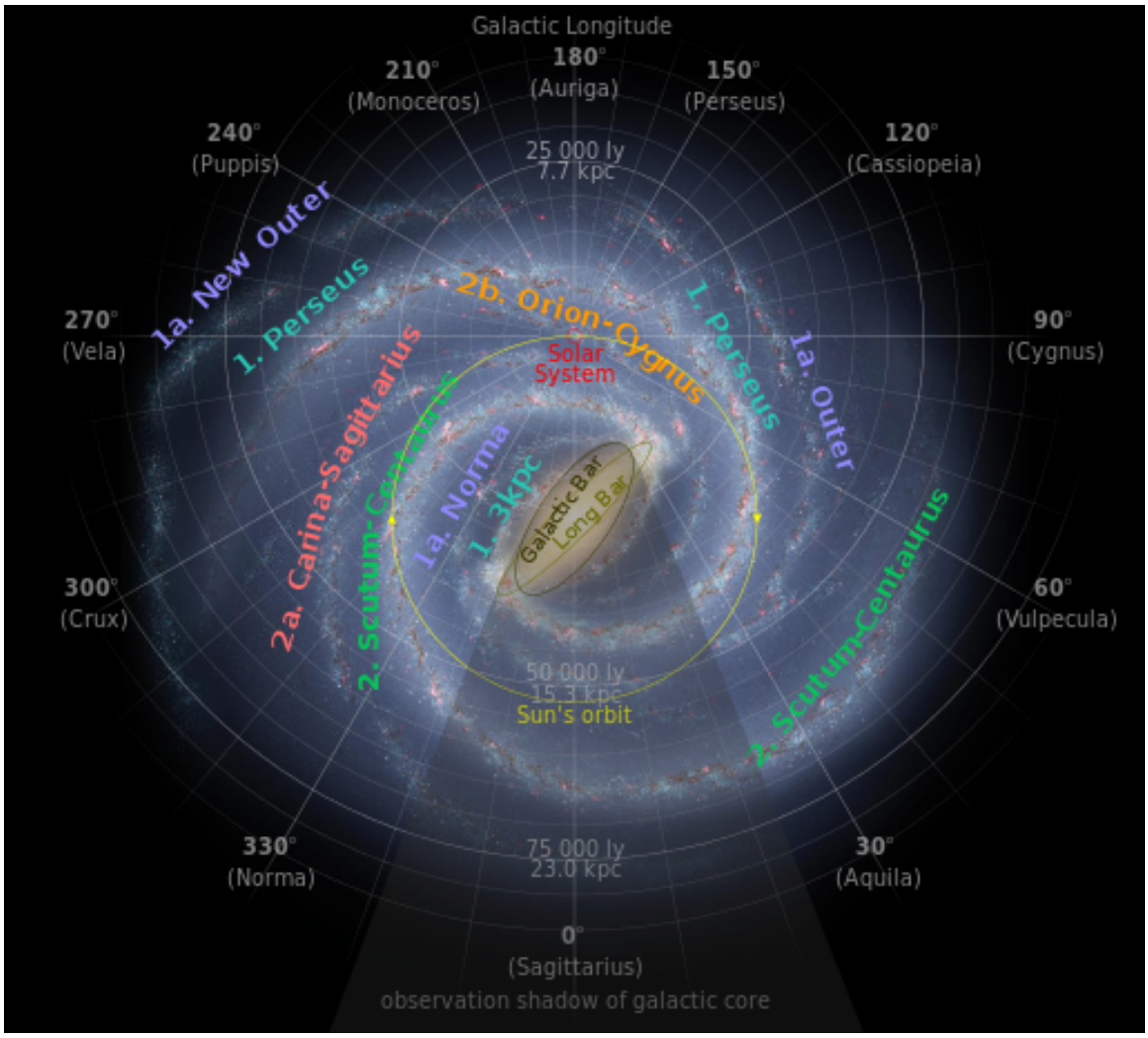

Figure 9: Artist's conception of the Milky Way galaxy as seen from far Galactic North. *Credit: NASA/JPL-Caltech/R. Hurt*

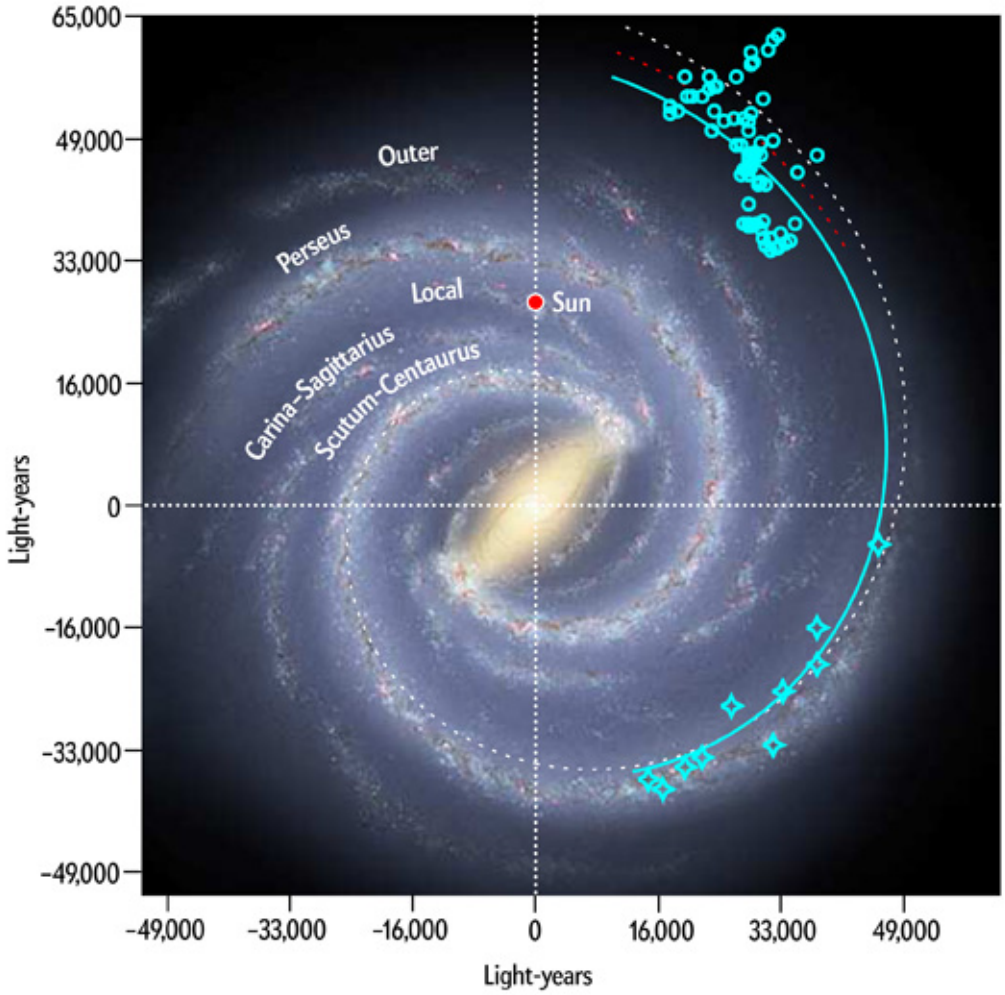

Figure 10: Illustration of our galaxy showing the possible extension of the Scutum–Centaurus Arm.
Credit: Yan Sun/The Astrophysical Journal Letters/Robert Hurt. NASA/JPL-Caltech/SSC