Astronomy News

Case Western Reserve University Department of Astronomy

Fall 2017

Dwarf Galaxies and Dark Matter

In June 2017, CWRU Astronomy hosted the international research conference *Dwarf Galaxies on the Shoulders of Giants*. Organized by Professor **Stacy McGaugh**, Benoit Famaey (Strasbourg), and former CWRU postdocs Marcel Pawlowski (UC Irvine) and Federico Lelli (ESO), the workshop brought together observers and theorists to discuss the latest research on the formation and evolution of dwarf galaxies, and their connection to the dark matter question.

Attendees at the CWRU workshop on dwarf galaxies.

Dwarf galaxies provide natural laboratories for studying the dark matter content of the universe. These galaxies are typically dark matter dominated, with their rotation speeds almost completely determined by the mass distribution of their dark matter halos. The speed at which they rotate in their inner regions thus determines their central dark matter density, and observations are often at odds with the predictions from dark matter models — the so-called "cusp-core problem."

On larger scales, the distribution of dwarf companion galaxies around their host galaxy also constrains models of galaxy formation and dark matter. Growing evidence suggests that dwarf companions are not randomly scattered around their hosts, as predicted by dark matter simulations, but instead are often found orbiting aligned on planes, as if they came from a common origin. These objects may be formed from the tidal debris of ancient galaxy collisions, and such "tidal dwarfs" should be devoid of dark matter as a result of dynamical segregation during these collisions.

CWRU undergrads Kaelee Parker, Nathaniel Starkman, and Chris Carr at the workshop.

Even the number of dwarf galaxies provides constraints on models of dark matter. Simulations have long shown that galaxy formation is hierarchical, with small galaxies merging to-

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Case Western Reserve University
Department of Astronomy
10900 Euclid Avenue
Cleveland, OH 44106
Office: 567 Sears Library
Phone: (216) 368-3728
Email: dept@astronomy.case.edu

On the Web:
astronomy.case.edu

On Facebook:
facebook.com/cwruastro

On Twitter:
twitter.com/cwruastro

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Dwarf Galaxy Workshop

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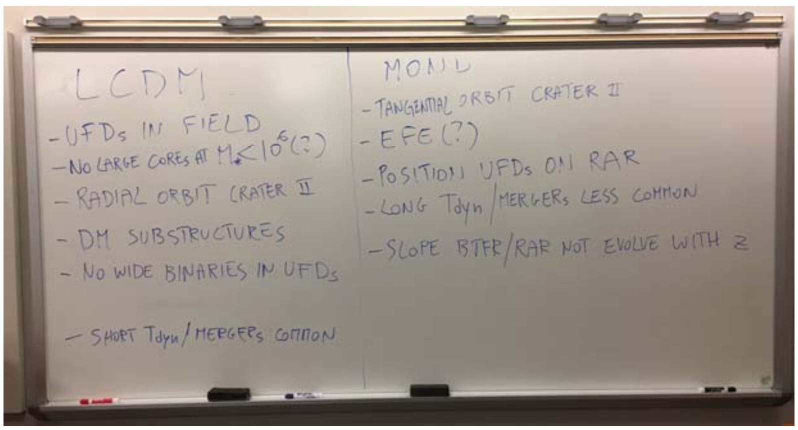
gether to form bigger ones. This scenario argues that big galaxies should be teeming with hundreds of low mass satellite galaxies, and yet we haven't found anywhere near that number in our Milky Way. At the workshop we heard updates on observational searches for faint satellite galaxies, as well as theoretical models for squelching the formation of dwarfs at early times. Will these be enough to reconcile the discrepancy? Too soon to tell.

A large focus of the conference was the "radial acceleration relationship" — a new development in the study of galaxies found by McGaugh, Lelli, and University of Oregon astronomer Jim Schombert. In this relationship, dwarf galaxies and their more massive siblings all follow a tight correlation between their internal rotation speeds and the amount of normal baryonic matter (gas and stars) they contain. While the connection between rotation speed and baryonic mass had been known to act on galaxy-wide scales, the work by McGaugh and collaborators showed that it also applied in detail inside galaxies — that a galaxy's detailed rotation curve could be predicted simply by knowing the distribution of baryons inside the galaxy. This was entirely unexpected under dark matter models, and gives to two possibilities, both of which require new physics. Either dark matter and baryons couple tightly together in ways we don't understand, or dark matter itself is non-existent and our understanding of gravity itself must be modified. The conference saw spirited debate on this issue, leading to the development of a scorecard of future predictions of "Lambda Cold Dark Matter" (LCDM) scenarios and "Modified Newtonian Gravity" (MOND) models. The coming years should see many updates to this scorecard!



The LCDM vs MOND scoreboard

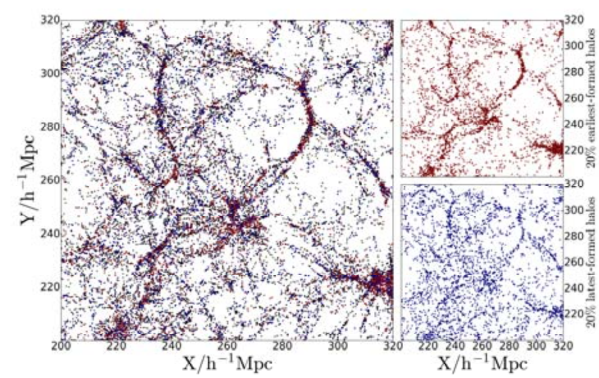
To close the workshop, astronomer David Merritt (Rutgers) led a thought-provoking discussion on the philosophy of science. Using both historical examples and logical philosophy, he explored how scientific paradigms (such as LCDM cosmology) are properly tested, evaluated, and — if necessary — overthrown. Whether or not we are at that point with the existing LCDM cosmological model remains to be seen.

The workshop was sponsored by Templeton Foundation, and presentations can be seen at astroweb.case.edu/dwarfs2017/

Research Notes

Idit Zehavi: Galaxies and Dark Matter Halos

In a new paper to appear in *The Astrophysical Journal*, CWRU astronomer **Idit Zehavi** and collaborators study the dependence of the galaxy content of halos on environment and halo formation time, using semi-analytic galaxy formation models applied to a large cosmological simulation of structure formation. Zehavi worked with collaborators in Chile and England, including graduate student Sergio Contreras and former CWRU undergraduate student **Nicholas Smith** (now a graduate student at the University of Indiana; the project evolving in fact out of Nick's senior capstone with Zehavi).



A simulation of galaxy formation in the universe

The image to the right shows the spatial distribution of dark matter halos in a slice from the simulation, highlighting the different clustering properties of early-formed halos (in red) and late-forming halos (blue). Zehavi and collaborators characterize how the galaxies' occupation of these halos varies with the age of the halos and other related properties. They find, for example, that early-formed (older) halos are more likely to host central galaxies also at lower halo masses. This is because, at fixed

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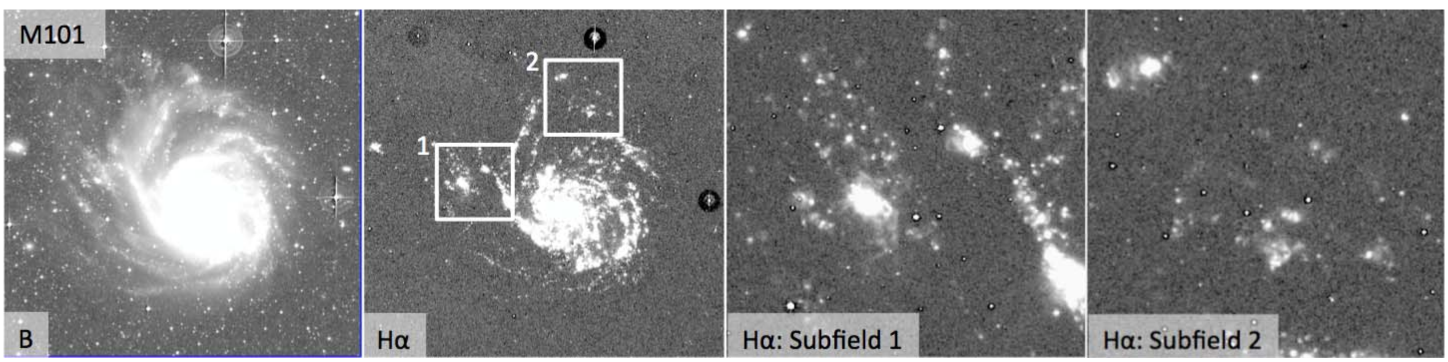
halo mass, older halos preferentially host more massive central galaxies. In contrast, older halos tend to have fewer satellite galaxies, likely due to having more time for satellite destruction.

This study sheds light on the origin of these different trends and has important implications to our understanding of galaxy formation and to contemporary analyses of galaxy clustering. This research has been supported by a multi-year grant awarded to Zehavi by the National Science Foundation to study the detailed relation between galaxies and dark matter halos. It was also supported by a CWRU Faculty Seed fund to further develop Zehavi's international collaboration.

Aaron Watkins: The Outskirts of Nearby Disk Galaxies

In his doctoral thesis, CWRU graduate student **Aaron Watkins** worked with his advisor **Chris Mihos** and Observatory Manager **Paul Harding** to consider how galaxies form and then change over time from a still little-considered perspective: that of their faint outer regions. First, because a galaxy's outskirts are far away from the galaxy center, they are only loosely bound to their host galaxy and so are very susceptible to disruption by a passing neighbor galaxy. Stars are easily torn away into long, loose streams or diffuse plumes that can persist long after the interaction is over, making them a long-lived tracer of the host's tidal history. Aaron thus searched for these kinds of streams around galaxies in a variety of different environments. While he did find such streams in obvious places — for example, he uncovered several new, extremely faint tidal tails around the famous interacting pair M51 (the Whirlpool Galaxy) — other galaxies had almost no signs of recent interaction. Most oddly, he found very little evidence of tidal interaction throughout the Leo I galaxy group, host to four roughly Milky Way-size galaxies all in mutual gravitational attraction. Despite being in such close proximity, none of the group galaxies seem to be strongly interacting with one other.



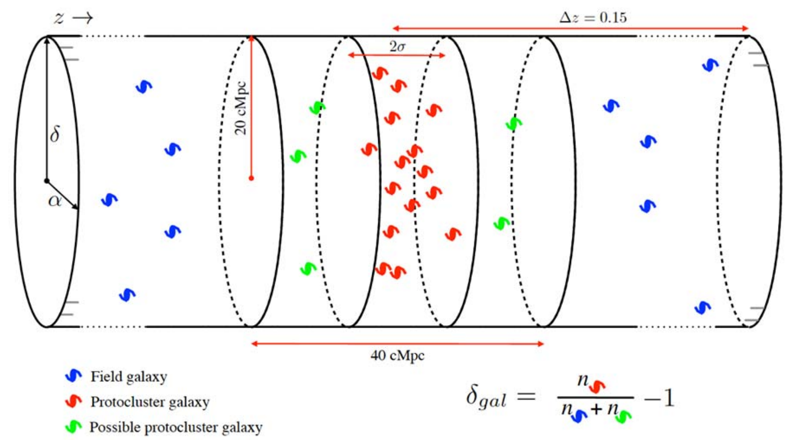
Deep imaging of M101, showing (from left to right) a deep broadband (B) image showing the galaxy's starlight, an Hα image showing the ionized star-forming gas, and two insets showing details in the diffuse star-forming regions in the galaxy's outer disk.

Typically, the galaxies Aaron examined looked mostly undisturbed, similar to many other disk galaxies where previous studies had shown to have extended outer disks populated mostly by old, evolved stars. Because old outer disks appear common, their lack of young stars suggest that the environment of disk outskirts must somehow inhibit the formation of new stars compared to inner disks. These old outer disk stars must therefore come from somewhere else, migrated, perhaps, from the inner disk through interactions with spiral arms. While this is the prevailing theory to explain these old outer disks, Aaron's work showed that, at least in the handful of galaxies he observed, the spiral arms end exactly where the old outer disk begins. If this is common — that outer disks lack both new star formation and spiral arms to migrate stars — some new explanation for how outer disks form is required.

But spiral arms and new star formation can be found in at least *some* galaxies' outer disks; one example is the nearby spiral M101 (see the image above). It begs the question: what, if anything, is different about M101's outer disk compared to the majority of other disk galaxies? To address this question, Aaron compared the young stellar populations in M101's outer disk with those in its inner disk (and in its two smaller companion galaxies) to seek out evidence of any physical difference between star-forming regions from environment to environment. He found that, while star formation is weaker in low density environments like outer disks, the populations of stars that form in individual star-forming clouds do not seem to change. Star formation thus seems to proceed in a similar fashion no matter where it takes place, and the only remaining question is: why does it sometimes take place and sometimes not?

Research Notes

Jay Franck: Protoclusters of Galaxies in the Early Universe



Protocluster searches: by cataloging the redsihifts of galaxies, Franck looked for peaks in the redshift distribution indicating clustering along the line of sight.

Nearby galaxy clusters can have thousands of galaxies, most of which are spheroidal in shape with only a few spiral galaxies such as our own Milky Way. It has been known for decades that galaxies in groups and clusters look significantly different than those in less dense environments. There have been a number of physical mechanisms proposed that can drive these changes. It has been challenging to point to a single pathway that explains all of the observations that we see, however.

Jay Franck's thesis focused on galaxy protoclusters. A protocluster is simply a group of galaxies that may eventually become a galaxy cluster as gravity begins to pull the members together (e.g., a forming cluster). These objects are typically found at very large distances from Earth, and are therefore seen as they existed more than 10 billion years in the past. By examining these protoclusters, are we able to determine the process that drives cluster galaxies to look different than their isolated counterparts? Are we able to distinguish the two populations only a few billion years after the Big Bang?

The work of Jay and his thesis advisor, **Stacy McGaugh**, suggests that at the present time, astronomers cannot answer either of these questions. The core component of Jay's thesis involved identifying more than 200 protoclusters using open data sets. This was a large increase, as previously only 30 or so such systems existed. With this expanded list, the team analyzed the light received from thousands of galaxies in protoclusters using the Spitzer Space Telescope. This telescope measures infrared light, a good tracer of the mass of stars in a galaxy. When they compared their results to galaxies not in protoclusters, they found no difference between the two groups. This is in contrast to what theoretical simulations suggest should be observed, where galaxies in these dense regions will be brighter. Their work also identifies a number of other discrepancies between what exists in real data and what galaxy formation models predict should be true: observations suggest older, brighter galaxies born in a large burst that then evolve slowly, while theory implies very rapid evolution in these systems. In summary, his thesis strongly suggests a careful consideration of our current galaxy formation models.

Earle Luck: Abundances in the Solar Neighborhood: What is Normal?

Earle Luck presents at the STScI symposium.

An on-going question in the study of Galactic chemical evolution surrounds how the metallicity of the Sun compares to nearby stars. Using high-resolution spectroscopy, CWRU astronomer **Earle Luck** derived abundances for a sample of 1,002 F, K, and G stars, and found the sample to be modestly metal rich relative to the Sun, by about 0.05—0.2 dex (a 10—50% enhancement) across a wide range of elements. The consistency of the results across such a large sample of stars argues that *they* define the "new normal" and that Sun is in fact somewhat metal-poor for its position in the Galaxy. The sample also included more than 100 stars known to host extrasolar planets, and while these planet-hosting stars tend to be more metal-rich than average, they show wide variation in the metallicities, with some being lower in abundance by a factor of five compared to the Sun.

Luck was assisted in this work by CWRU Astronomy major **Gregory Tobar Gomez** (BS 2015), who helped develop the algorithm for fitting absorption line profiles to the spectroscopic data. Luck presented these results and more in an invited talk delivered at the Space Telescope Science Institute April symposium "*Lifecycle of Metals Throughout the Universe*"; his presentation can be viewed at webcast.stsci.edu/webcast/detail.xhtml?talkid=5537.

Eclipse Day 2017

The scene on the KSL quad, where hundreds of students, families, and visitors congregated to view the eclipse.

Like the rest of the country, CWRU astronomers eagerly awaited the August 21 solar eclipse. While we were not in the path of totality, at maximum eclipse in Cleveland the Moon would cover 80% of the Sun's disk. The eclipse also happened to coincide with the first day of new student orientation, and campus was filled with new students and their families, ensuring a lively crowd for our campus-wide eclipse party.

The moon, closing in on maximum eclipse, about to cover up a sunspot group on the solar disk.

With only a few scattered clouds in the sky, the Cleveland weather was perfect for the eclipse. We set up two observing stations for eclipse viewing. On the oval in front of the university's Kelvin Smith Library, we set up three telescopes, two equipped with solar filters for direct viewing, and a third projecting an image of the eclipse. Across campus on the main quad, the 9.5" rooftop observatory was also projecting the eclipse for public viewing.

As the eclipse proceeded over the course of three hours, hundreds of people gathered to watch the spectacle. Eclipse glasses, provided by both CWRU Astronomy and the Alumni Association, were at a premium, and lines were long at all the telescopes. People were treated to views not just of the eclipse, but of a group of sunspots, giving us the opportunity to give crash courses in both planetary dynamics and solar magnetic fields!

It was a festive occasion enjoyed by all, and a good warm-up for the solar eclipse of April 8, 2024, where the path of totality runs right across Cleveland. We're keeping our fingers crossed for clear skies on that day!

Left: Charley Knox uses the 9.5" Warner & Swasey refractor to project the eclipse image. Right: Paul Harding (left) and Chris Mihos (right) show visitors the view through telescopes set up at Kelvin Smith Library.

Frontiers of Astronomy Lecture Series

Since the 1920s, CWRU Astronomy has sponsored the Frontiers of Astronomy public lecture series. These free talks are presented at the Cleveland Museum of Natural History and supported by the Arthur S. Holden, Sr. Endowment, along with cosponsor support from the Cleveland Astronomical Society and the Cleveland Museum of Natural History. Last year we had well over 2000 visitors attend this very popular lecture series.

Cleveland Museum of Natural History

This year's talks span a wide range of topics, from our new understanding of the formation of the Moon and the origins of life to observational and theoretical studies of the formation of galaxies and structure in the early universe. If you are in the Cleveland area, please join us for these free public lectures — see the schedule below and check out our website astronomy.case.edu for more information.

Oct 12, 2017	David Silva (NOAO)	Mapping the Universe: New Vistas, New Lands
Nov 16, 2017	Philip Hopkins (Caltech)	The Universe on a Computer
Dec 14, 2017	Mark Vogelsberger (MIT)	Simulating the Universe
Mar 1, 2018	Brett Denevi (JHU/APL)	The New Moon
Apr 12, 2018	Dimitar Sasselov (Harvard)	Other Earths and Origins of Life

Chair's Space

Stacy McGaugh

The past year has been a busy one for the department. It has also been a transformative time, with a number of successful departures. As usual, our seniors successfully competed their Bachelor degrees. This year's graduates are Heather Pantell and Khalil Saleh.

Graduate students Aaron Watkins and Jay Franck both completed their Ph.Ds in the summer of 2017. Aaron's thesis pushed the boundaries of deep surface photometry in both broad and narrow bands, characterizing star formation and stellar populations in the outer reaches of the disks of nearby spiral galaxies. Dr. Watkins received a number of offers for postdoctoral positions, ultimately choosing to accept a position at the University of Oulu in Finland. Jay's thesis used data mining techniques to identify protoclusters of galaxies at high redshift, resulting in the largest catalog of such objects to date. Dr. Franck took a position as a Machine Learning Engineer with Playstation in San Francisco.

Postdoctoral fellows Federico Lelli and Marcel Pawlowski also moved on to new positions. Dr. Lelli joined the European Southern Observatory where he continues his research and contributes to the scientific operation of the Atacama Large Millimeter Array, the premier international radio telescope collaboration. Dr. Pawlowski was awarded a Hubble Fellowship which he took to UC Irvine where he continues his trailblazing research on planar structures of dwarf galaxies in the Local Group and beyond.

As Fall classes begin, we welcome new graduate student Joseph Curro and welcome back Pengfei Li, who kindly brought back a supply of homemade tea after visiting home in China. The school year begins with a major solar eclipse. Coinciding with the first day of freshmen orientation, members of the department handed out eclipse glasses on the oval in front of KSL and opened the 9.5" telescope on top of A.W. Smith. Though not in the path of totality, Cleveland witnessed 80% obscuration of the sun and a deluge of interest in this rare event. This marks the start of another exciting year for CWRU Astronomy. — **Stacy**

Alumni Updates

Kim Cartier

Kimberly Cartier (formerly Kimberly Star, BS 2012) moved to central Pennsylvania after graduating from CWRU and joined the Department of Astronomy and Astrophysics at Penn State. She received her masters in 2015, a teaching certificate in 2016, and a PhD just recently in June 2017. Kim spent her graduate career researching photometric techniques for characterizing exoplanets, making use of the Hubble and Kepler space telescopes and ground based telescopes at Kitt Peak and Whipple Observatory. Her thesis included her work in characterizing planet hosting stellar binary systems, emission and transmission spectroscopy of exo-atmospheres, and even a brief foray into SETI.

Kim also spent her graduate career developing her skills as a science writer and communicator. She has written articles for Scientific American, The Atlantic, and Nautilus, was an expert exoplanet blogger for Sen.com, and completed a writing internship in Penn State's Office of Strategic Communications. She has given public astronomy talks, made local radio appearances, and is a regular panelist on Universe Today's Weekly Space Hangout news program. Kim has just started a job as a news writing and production intern at *Eos* magazine, an Earth and space science magazine sponsored by the American Geophysical Union. Kim plans to continue applying her astronomy education to a career in science communication and is a strong believer in making science accessible to everyone.

Stuart Robbins

Stuart Robbins (BS 2005) is a Senior Research Scientist at the Southwest Research Institute (SwRI) in Boulder, Colorado. After leaving the grey, overcast skies of Cleveland, he moved to Colorado for graduate school (PhD 2011) and gradually migrated from the University of Colorado to SwRI in late 2014. There, he assisted with mission planning for NASA's New Horizons spacecraft that flew by Pluto and Charon in July 2015 and is currently en route to 2014 MU_69 with a target encounter of January 1, 2019. His work on New Horizons has expanded from helping with the mission planning to helping to coordinate between the science teams and science operations, and he was recently named to a one-year "trainee" project scientist on the mission. He has also led three research projects using the Pluto-Charon data, one on impact craters across the system, another on a rare type of crater ejecta on Charon that was first observed on Mars, and a third on geologic mapping the diverse landforms on Charon.

Besides working on New Horizons, Robbins is involved in several other research projects, all focusing on the study of impact craters across the solar system. He is best known in the field for producing a global impact crater database for Mars of over 600,000 craters and was just awarded a large NASA grant to continue efforts on his catalog of nearly 2 million lunar craters. These catalogs are used in a wide variety of research by him, his collaborators, and the broader planetary science community. In addition to research, Robbins still works on public outreach efforts that he started while an undergraduate at CWRU. These efforts are focused on the citizen science portal "CosmoQuest" and his blog and podcast, "Exposing PseudoAstronomy" where he tackles fringe topics to demonstrate how we know what we know. This work has also lead to popular talks at skeptics conferences and ComicCon.

We want to hear from you!

Let us know about your job changes, awards, honors and life events. Please email your news and contact information updates to dept@astronomy.case.edu.

The Rededication of the Nassau Station

On August 19, 2017, the 36” reflector at the Nassau Station in Montville, OH was rededicated in its new role as a public observing facility in the Geauga Parks district’s Observatory Park. After many years of service as part of CWRU’s Warner and Swasey Observatory, the telescope was acquired by the Geauga Parks District in 2008 as part of their new development of Observatory Park, an innovative astronomical park (one of only 10 worldwide) designated by the International Dark Sky Association as a dark sky preserve for the public to visit and observe the night sky.

The ribbon cutting at the rededication ceremony. Charley Knox is seen second from right.

As part of the project, The telescope was refurbished and upgraded for public observing, and the observatory building was remodeled to accommodate park visitors. CWRU Astronomy’s Charley Knox played a major role in the restoration and upgrade of the telescope.

The newly refurbished Nassau Astronomical Station at Observatory Park.

More information about Observatory Park and the refurbished Nassau Astronomical Station can be found on the Geauga Parks website at www.geaugaparkdistrict.org/parks/observatorypark.shtml

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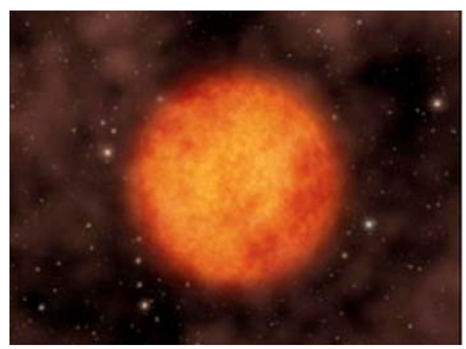
Red Giants in the Milky Way’s Halo

Red giants are the most luminous old stars, and are particularly useful to study the early history of the Milky Way. “We use these stars like fossils, because in many cases their chemistry and motions have been unchanged since they were formed more than 10 Gyr ago”, says CWRU astronomer **Heather Morrison**. She and her collaborators have spent more than a decade identifying these rare red giants as part of the Sloan Digital Sky Survey’s SEGUE project, and have found over 5,000 giant stars, some of them as far away as 100 kiloparsecs. In 2016, former CWRU Astronomy undergraduate **Bill Janesh,** now a graduate student at Indiana University, first-authored a paper using this sample of stars to find traces of the formation of the halo in streams of stars shed by satellites as they fell into the Milky Way.



Artist’s conception of the M giant star Mira.

The coolest and largest of these red giant stars are M giants. Morrison and her collaborators have stayed away from studying these stars, preferring to target the slightly warmer K giants whose spectra are easier to analyze. “An M giant spectrum looks like the top of a picket fence,” says Morrison. “There are so many molecular lines that it is hard to get a handle on the basic properties of the star.” However, recently Morrison thought that it might be worthwhile searching for warmer K giants in the M giant sample, just in case some of them had slipped through due to uncertainties in their measured colors. And in doing so, she found an unexpected bonus: 8 more stars from the outer halo, with distances of more than 50 kpc. These outer halo stars are quite rare, so the serendipitous extras are very welcome; Morrison and her collaborators are now using these stars to study the assembly history of the Milky Way in ever more detail.