Astronomy News

Case Western Reserve University Department of Astronomy

Fall 2015

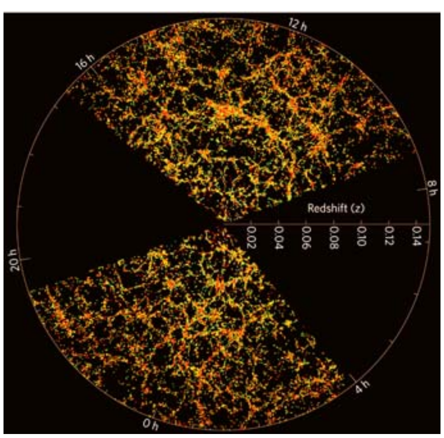
Galaxy Clustering in the Universe

The Universe we observe on large scales is depicted as a Universe filled with galaxies. The galaxies are not randomly distributed in space. There are major concentrations of galaxies we refer to as clusters and super-clusters, emptier areas termed voids, and other structures such as filaments and sheets. This intricate distribution of galaxies makes up what we call the cosmic web of structure. The cosmic web we observe today is the result of the gravitational growth over billions of years of the initial fluctuations in the Universe, as well as the complex processes of galaxy formation.

The galaxy cluster Abell 1689. (STScI)

Contemporary galaxy redshift surveys, most notably the Sloan Digital Sky Survey (SDSS) and its extensions, have transformed the study of large-scale structure, enabling high-precision measurements and detailed studies of galaxy clustering. The most fundamental statistic to characterize galaxy clustering is the two-point autocorrelation function, which measures the excess probability over random of finding galaxy pairs with varying separations. This galaxy correlation function reflects the underlying cosmology in the Universe (e.g., the amount and type of dark matter, which makes up most of the mass in the Universe) as well as the detailed relation of galaxies to the underlying dark matter. In the standard cosmological picture, galaxies form and reside within extended dark matter halos, and galaxy clustering is impacted by how galaxies populate their host halos.

Professor **Idit Zehavi** has been extensively involved in studying the large-scale structure observed with the SDSS, the largest 3D mapping of the galaxy distribution in the Universe to date. She has led the effort of studying the clustering of galaxies by measuring the two-point correlation function in the SDSS and other related statistics. The image to the left shows the cosmic web of SDSS galaxies in one of the samples analyzed by Zehavi. Each point represents a galaxy, color coded by its intrinsic color, in a slice from the survey. Zehavi and collaborators study in detail the distinct clustering pattern and its dependence on different galaxy properties such as color and luminosity. They interpret the measurements using contemporary models of galaxy clustering, which elucidate the features



The cosmic web as traced by galaxies in the Sloan Digital Sky Survey. (SDSS)

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Galaxy Clustering in the Universe

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of the observed correlation functions and constrain the relation between galaxies and dark matter halos, providing important insight into galaxy formation and evolution. Zehavi's results have become the standard comparison reference in the field, both for measurements from other surveys and for different modeling efforts.

Idit Zehavi at Durham's ICC

Professor Zehavi has just spent the first half of 2015 on sabbatical at the Institute for Computational Cosmology (ICC) at Durham University in England, a leading international center for research into the origin and evolution of the Universe. During her time there, Zehavi has established strong ties with several members of the ICC and initiated new collaborations and new projects that utilize the unique resources available at Durham. The focus of the work started there is to explore the galaxy-halo connection using simulations of physical models to build better empirical models to describe the data. This will be useful for the analysis and interpretation of upcoming large galaxy surveys, aimed at pinning down the nature of dark energy and dark matter.

One such project, motivated by recent intriguing clustering results, will study the kinematics of galaxies and the detailed relation of their motions to that of the dark matter in the new Eagle simulation, one of the largest hydrodynamical simulation available today for modeling the formation of galaxies in a cosmological volume. Another study is utilizing state-of-the-art galaxy formation models which were developed in Durham and applied to large cosmological simulations of the dark matter. Zehavi and collaborators are exploring the way in which galaxies populate halos evolves with time. Such halo occupation models are commonly used for interpreting the clustering measurements in large surveys. However, these empirical models offer no guidance as to how to treat evolution of the galaxy population. Incorporating evolution into the models will provide an important step toward a more physically motivated and consistent picture of the galaxy distribution across cosmic time. This in turn will provide deeper insight and better constraints on theories of galaxy formation and evolution.

Research Notes

Probing the Milky Way's Stellar Halo

Our Galaxy's stellar halo is its most ephemeral region: its stars contribute less than 1% of the Galaxy's light, and are spread through a much larger volume than the rest. Halo stars are very hard to find because they are so rare. So why do we bother? Because they are some of the oldest stars in the Galaxy .... and, because they orbit in the peaceful outer reaches of the Galaxy, they still retain quite a lot of information about their origins in their motions and their chemistry.

Heather Morrison

Case joined the Sloan Digital Sky Survey in 2005. A decade later we are reaping the harvest of our efforts to identify halo stars: efforts led by Professor **Heather Morrison**, working with graduate student **Zhibo (Real) Ma** and undergraduates **Tom Connor**, **Bill Janesh**, **Dave Meyer**, **Andrew Schechtman-Rook**, and **Dave Starinshak**. Real Ma's thesis work gave us a sample of more than 5,000 halo giants, spread throughout the halo. This is 100 times larger than the previous sample of giant stars.

What have we done with this stunning new sample? Bill Janesh's work on the velocities of the stars has shown that the halo is filled with streams of stars, which were ripped off satellites of the Milky Way as they were captured by its gravitational field. While cosmologists have suggested since the 1970s that structure in the universe grows first in small objects which then merge to form larger ones, it has taken much longer for us to find evidence of this happening in our own Galaxy. One of the first clues came in 1994 when the Sagittarius dwarf galaxy, the nearest of our satellites, was discovered. Despite being so close, it remained undiscovered because it is behind the bright disk and bulge of the Milky

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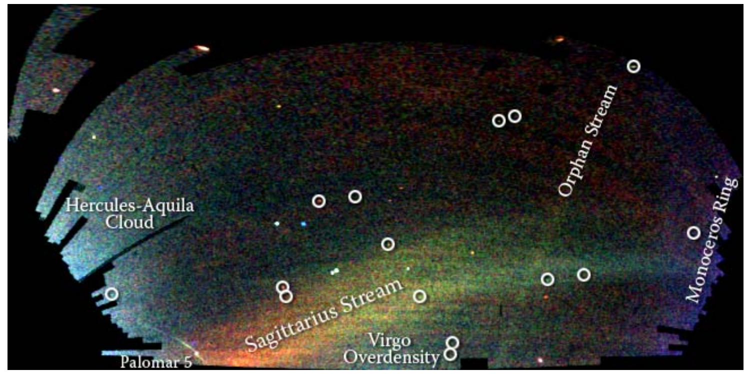
Way. Soon after Sgr was discovered astronomers found that, unlike the other satellites of the Milky Way, it is being torn apart by the gravitational pull of the Galaxy. The photo (made using the imaging data from the Sloan survey) shows some of the star streams pulled off from the Sgr dwarf galaxy as it orbits the Milky Way.

Some astronomers suggest that the satellite may have lost as much as 90% of its mass into star streams. Janesh's work has shown that these streams dominate the outer halo..... while the star streams from Sgr are not the only halo star streams by any means, they are a huge part of the outer, most undisturbed part. Bill is now working on his PhD at the University of Indiana.



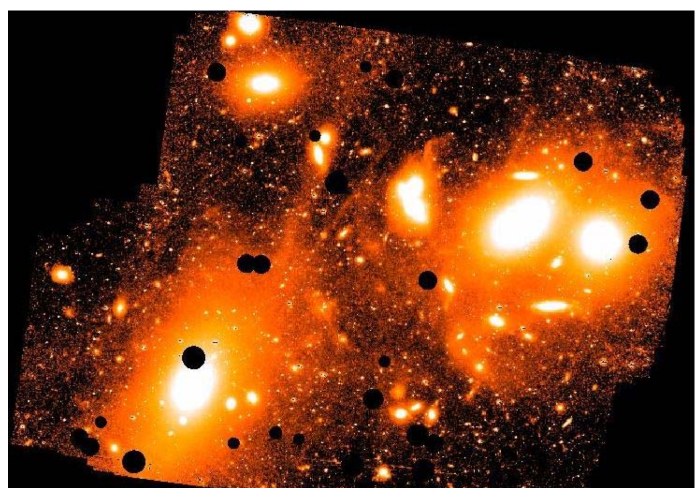
Star streams In the Milky Way's halo. Stars are color coded by distance, with redder colors showing more distant stars. Circles mark recently discovered Milky Way globular clusters and dwarf satellite galaxies. (V. Belokurov/SDSS)

Galactic Archaeology in the Virgo Cluster

Paul Harding and Chris Mihos

It's not just in our galaxy's halo that we find star streams — we find them in giant galaxy clusters as well, on titanic scales. Inside a rich galaxy cluster, the life of a galaxy can be quite violent: collisions and mergers act to shred stars from their parent galaxies, transform galaxies from spiral to elliptical types, and create massive elliptical galaxies that live at the heart of the cluster. Over the past decade, CWRU astronomers, led by Professor **Chris Mihos**, have been using our wide-field Burrell Schmidt telescope, located atop Kitt Peak, Arizona, to search for signatures of these processes in the nearby Virgo Cluster of galaxies.

Observatory manager **Paul Harding** has made extensive upgrades to the Burrell Schmidt to increase its sensitivity to extremely diffuse starlight. The image to the lower right shows our deep, wide field image of the Virgo core. The image spans 2.5 degrees across — five times the size of the full moon — and shows starlight as faint as 29 magnitudes per square arcsecond, or 100x fainter than the darkest night sky. In the image, we can trace the diffuse stellar halos of Virgo's giant ellipticals 100 kpc or more from the centers of the galaxies. We also find a myriad of faint star streams throughout the cluster, part of the vast web of diffuse intracluster starlight that permeates Virgo.



Deep imaging of the Virgo Cluster from the Burrell Schmidt. Black circles are foreground Milky Way stars which have been digitally masked from the image. (Chris Mihos)

We've been using the imaging to learn about the evolution of galaxies in Virgo. For example, **Craig Rudick** (PhD 2011) used the luminosity, color, and morphology of the star streams to show that they came from small galaxies ripped apart by their encounters with the massive galaxies in Virgo. Through careful modeling and subtraction of the light from the giant ellipticals, **Steven Janowiecki** (BS 2008) discovered a number of plumes and shells of stars surrounding those galaxiess, remnants of ancient encounters with their satellite galaxies.

Most recently we've used the imaging to discover a number of so-called "ultradiffuse galaxies" — galaxies as large as our own Milky Way, but 1000x lower in density. One of these galaxies is being tidally shredded, a process which will ultimately destroy the galaxy and leave behind only its dense nucleus to become a new Virgo "ultracompact dwarf galaxy." Close galaxy encounters and tidal stripping of stars have likely shaped many of the galaxies in Virgo and other massive galaxy clusters — Virgo's relative proximity gives us an unprecedented window on the nature of this dynamically-driven galaxy evolution in clusters.

Undergraduate Student Highlight: Gregory Tobar

Starting in the summer of 2014, I have been working with Professor **Earle Luck** in an attempt to find better models to approximate the equivalent widths of spectral lines in stars. One of our goals is to find an empirical model that better estimates the behavior of strong wings found in many spectral features. The main problem we wish to resolve is the fact that the commonly used method of applying a Gaussian model to the spectral lines does a poor job of predicting the behavior of prominent wings, since wings follow a more exponential behavior.


Gregory Tobar

It is important that the wings of the lines are modeled correctly since an imprecise model leads to great discrepancies in stellar composition estimates. As an example, take a line from the Sun that through direct integration has an equivalent width of 0.211 Angstroms. By applying a Gaussian model, an equivalent width of only 0.161 Angstroms is calculated. A comparison of the elemental abundance predicted by the Gaussian model to the established abundance value shows that the Gaussian fit underestimates it by a factor of two.

Our main focus in the attempt to find a better model was the pseudo-Voigt function. This function contains both Gaussian and exponential components, just as the spectral lines do. We applied the pseudo-Voigt function to an analysis of solar lines through non-linear least squares fits, as well as a technique that attempts to limit the parameters of the pseudo-Voigt function by using the full-width half-maximum and depth of the selected solar lines. Further methods also included modeling either the red or blue portion of the line, depending on which is considered to be the less perturbed, and mirroring it over the position of the central peak. We also applied extrapolation to the wings in an attempt to increase their significance when applying a model.

The results of our first attempts to solve the underestimation problem were not ideal due to the large variety of wing behavior and the presence of blending lines. Therefore, our next step in what has now become my senior project will be to further investigate the different types of wing behaviors and categorize them for optimization with the various models that were previously used, as well as new models that we will attempt. In finding a model that correctly estimates solar equivalent widths, we will have the required foundation for determining better equivalent widths in stars of all types and ages.

Gregory is a 4th year astronomy major.

Graduate Student Highlight: Jakub Prchlik

When most people think of our Milky Way Galaxy, they think of the roughly flat disk of stars. However, the stellar halo, a more spherical distribution of stars with a radius approximately twenty times that of the disk, also contains much information on how the Milky Way formed. Some stars in the stellar halo formed outside the Milky Way, as part of smaller galaxies the Milky Way gobbled up during its evolution. The Milky Way incorporates these stars into the stellar halo by tearing apart their host, creating streams of stars across the sky. The most prominent example of the Milky Way's affinity to accrete smaller objects is the Sagittarius dwarf galaxy and its stellar streams (see the figure on the next page). However, not all halo stars formed in dwarf galaxies like Sagittarius and their natal environment remains a mystery. Working with Professor **Heather Morrison**, I have been trying to decipher what are the natal environments of stars in the stellar halo.

I am currently using low resolution spectroscopic observations of approximately solar mass giant stars from the Sloan Digital Sky Survey (SDSS). Giants are used because they are intrinsically more luminous than dwarf stars of the same temperature, therefore we are able to probe deep into the stellar halo. The low resolution spectroscopic observations are useful for determining broad properties of a star and require less telescope time than high resolution observations.


Jakub Prchlik

The SDSS stellar spectra are analyzed via a data pipeline to determine stellar properties like surface gravity, radial velocity, temperature, and broad chemical composition for each star. However, the pipeline can create systematic offsets between the calculated stellar properties and the real properties of a star. The systematics in the pipeline and biases in the way stars are selected for observation must be understood if any meaningful science is to be extracted from the low resolution observations. This has lead me to travel to University of California Santa Cruz to work with the people in charge of determining the accuracy and consistency of the stellar properties in the Sloan Digital Sky Survey.

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Graduate Student Highlight: Jakub Prchlik

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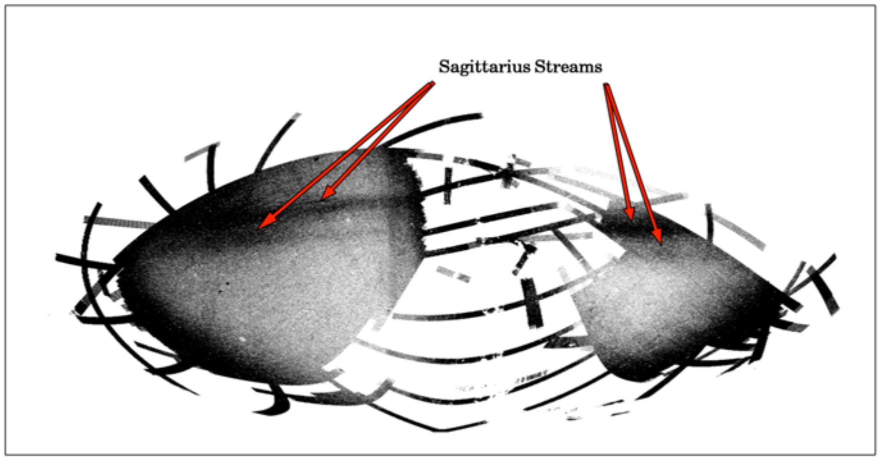


All-sky projection of star counts in the Sloan Digital Sky Survey . Darker areas show high stellar density, and streams of stars torn off of the Sagittarius dwarf

This calibration is important because the chemical composition of a star reveals its history. Since most elements heavier than Lithium are produced in stars, a star's chemical composition (i.e. how much of a particular element is observable in a star) tell us about the previous generations of stars whose elements have been incorporated into the stars being observed. This is because stars of different masses and chemical composition produce different but predictable chemical composition patterns in subsequent generations of stars. In addition, the radial velocities from the spectra are combined with the stars' positions, allowing us to build a database of halo stars and their membership in different stellar streams. After the low resolution analysis is complete, I will be able to follow up on stars in the stellar halo using high resolution spectroscopic observations. These high resolution observations will give detailed chemical abundances of the stars in the Milky Way stellar halo, therefore intimate environment history. This information will help us understand the natal environment of halo stars before that environment was disrupted by the Milky Way. —**Jakub**

Jakub is a 2nd year PhD student.

CWRU Astronomers at the NRAO Summer School

Ashley Shukayr and Elizabeth Tarantino

In July 2015, undergraduate student **Elizabeth Tarantino** and graduate student **Ashley Shukayr** had the opportunity to attend the 8th NAIC/NRAO Single-Dish and Interferometry school in Green Bank, West Virginia. The aim of the schools is to teach young astronomers about the details of observing in radio astronomy. The first seven days of the school covered single-dish radio astronomy while the next three focused on interferometry. During the day, we attended an intensive series of lectures given by experts in radio astronomy, ranging from signal processing, continuum and spectral line observations, and receiver technology. In the evenings, we were given hands-on projects that used the 305-meter Arecibo Telescope to observe and take data. Elizabeth's project was to detect and measure the period of a pulsar and Ashley's project was to observe OH masers. For the interferometry school, we were given an ALMA data set to learn about imaging and calibration techniques with the Combined Astronomy Software Applications (CASA) package. Additionally, the school also provided tours of the 100-meter Green Bank Telescope and its control room.

The Green Bank Telescope (NRAO)

Overall, the trip was an extremely educational and fun experience. We were able to meet other astronomers across the globe and connect with experts in the field. Elizabeth and Ashley would like to thank the organizers as well as our adviser, Professor Stacy McGaugh, for providing the funds for us to attend.

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 astronomy@case.edu.

Frontiers of Astronomy Lecture Series

Since the 1920's, CWRU Astronomy has sponsored the Frontiers of Astronomy public lecture series. These free talks are presented at the Cleveland Museum of Natural History; the Cleveland Astronomical Society and the Cleveland Museum of Natural History are co-sponsors, along with the support of the Arthur S. Holden, Sr. Endowment.

This years talks span the range from stars to galaxies, and include a celebration of the Hubble Space Telescope's 25th birthday. If you are in the Cleveland area, please join us for these free public lectures! See the schedule below and check out our (newly updated!) website astronomy.case.edu for more information.

Cleveland Museum of Natural History

Oct 15, 2015	Frank Summers (STScI)	25 Years of the Hubble Space Telescope
Nov 12, 2015	Jennifer Johnson (OSU)	The History of the Milky Way Written in Stars
Dec 10, 2015	Edo Berger (Harvard)	Gamma-Ray Bursts: The Biggest Explosions Since the Big Bang
Mar 3, 2016	Kathryn Johnston (Columbia)	Galactic Cannibalism
Apr 14, 2016	James Bullock (UC, Irvine)	Biography of the Milky Way

Chair's Space

Stacy McGaugh

This is a year of transition, as I take the reins of chair from the steady hand of Professor Chris Mihos. Chris has served in the role of chair for six years now. During that time, he has overseen the successful implementation of the departmental strategic plan, growing the graduate program and recruiting new faculty (including myself!). He has carefully managed departmental resources in difficult budgetary times, leaving us in a sound financial position despite many external challenges. Most importantly, he has been a constant presence every day in the department, conscientiously supporting students, staff, and faculty while diligently tending to the copious minutia encountered in the operation of a modern academic department. I cannot thank Chris enough for his service to the department and the university.

Going forward, we face a number of challenges. The university is entering its periodic accreditation review. This provides an opportunity for us as an academic unit to assess how to best serve our students. We have broadened our course offerings with the development of a course specifically on the topic of dark matter. With Chris's encouragement, the Physics Department has made it easier for double majors to pursue Astronomy capstones. The new Origins major provides the opportunity for further educational collaborations with other departments, like Earth, Environmental, and Planetary Sciences.

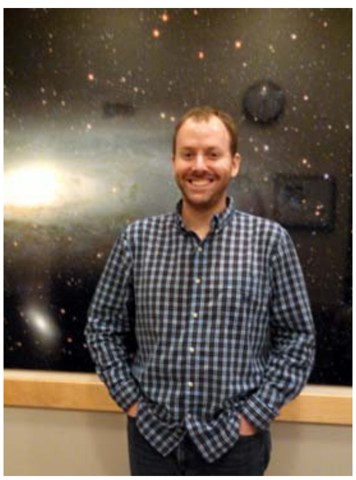
One of the historically strong points of the department is the involvement of undergraduates in cutting edge research. In order to continue and strengthen this tradition, we must give thought to our facilities. The Burrell Schmidt continues to be our work horse telescope, and Paul Harding has worked wonders in making this facility the top performer in deep, wide area surface photometry. Nevertheless, involvement with a larger, more generally capable telescope is essential to propel department research forward in an age increasingly dominated by giant collaborations. The identification of new resources will be necessary to realize this possibility.

Despite the many uncertainties that currently beset us, there is considerable reason for optimism. The recent visit by many of our alumni (including classmates of Charley Knox) reminds us of the strong and long lasting successes of the department. Our current students are talented and enthusiastic. We are lucky to have two very active young postdocs in the department in addition to our faculty. We look forward to continuing this positive trend with the good will and support of all of our friends and alumni. — **Stacy**

Alumni Updates

Jessica Gaskin

Jessica A. Gaskin (MS 1998) went on to get her Ph.D. in Physics from the University of Alabama in Huntsville in 2004. Upon graduating, Jessica was hired into the NASA Marshall Space Flight Center X-ray Astronomy Group, where she has focused on developing and testing instrumentation for high energy astronomy and planetary science. She is currently MSFC PI for the High Energy Replicated Optics to Explore the Sun (HEROES) payload, which is a balloon-borne focusing X-ray telescope for making astronomical and solar observations. When Jessica is not flying balloons, she is leading other instrument efforts such as the development of an X-ray Gamma-Ray Burst Polarimeter dubbed LEAP (LargE Area Polarimeter) for use on the International Space Station, and a Miniaturized Variable Pressure-Scanning Electron Microscope (MVP-SEM) for in-situ use on the surface of Mars. One of the most important pieces of advice that she received was from her CWRU Astronomy advisor Dr. Earle Luck, who essentially said that once you break something valuable, you tend be less fearful of trying something new. Jessica has since broken her share of valuable bit and pieces and as a result, has recently received a NASA Early Career Achievement Medal. Jessica is happily married to Val, a physicist and optical engineer, and has three sons who are ages 7, 6 and 4 (who also tend to break lots of valuable things).



Adam Ritchey

Adam Ritchey (BS 2002) is currently a research scientist at the University of Washington, supported by a Hubble Space Telescope grant that he obtained as principal science investigator for a general observer program, which was awarded 10 orbits of HST observing time. His research focuses on detailed spectroscopic studies of the diffuse interstellar medium of the Milky Way and of nearby galaxies through the analysis of atomic and molecular absorption lines at UV and visible wavelengths. His current interests include using absorption-line probes to study interstellar gas interacting with supernova remnants, and using bright extragalactic supernovae to study the ISM of nearby galaxies. His work on the recent bright Type Ia supernova in M82 (SN 2014J) was published earlier this year in the Astrophysical Journal. Preliminary results of his HST program on the supernova remnant IC 443 were recently presented at the IAU General Assembly in Honolulu. This fall he will take a position teaching introductory physics and astronomy courses at Seattle University.

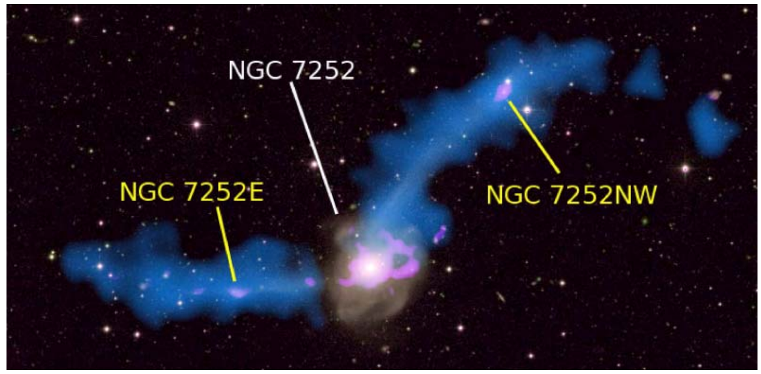
CWRU Astronomy Class of 1974

As part of last fall's CWRU Homecoming celebration, members of our 1974 graduating class returned to campus for their 40th reunion. As part the festivities, CWRU Astronomy hosted an afternoon mini-symposium where the alumni met with current faculty, staff, and students, presented new research results, and talked about their various paths through academia and industry since graduating from CWRU.

From left: Dave Sholle, John Stauffer, Larry Krumenaker, Anne Nolan (on screen via Skype), Charley Knox (kneeling), Ron Buta, Bruce Twarog, and Howard Fein. (Photo courtesy Larry Krumenaker)

Tidal Dwarf Galaxies: What You See is What You Get?

In reigning galaxy formation models, galaxies form inside halos of dark matter; this dark matter makes up most of a galaxy's mass. But a new study led by CWRU Astronomy postdoc **Federico Lelli** suggests that one class of galaxy — so called "tidal dwarf galaxies" — may be free of dark matter completely.



The galaxy NGC 7252, formed from the merger of two spiral galaxies. The hydrogen gas (blue) traces the galaxy's tidal tails, while ionized gas (pink) highlights star formation in the central body and the two tidal dwarf galaxies embedded in the tidal tails. (Federico Lelli)

Tidal dwarfs form when interstellar gas is compressed to the point of collapse in the tidal tails of colliding galaxies. Lelli and his collaborators used radio observations from the NRAO's Very Large Array in New Mexico to show that the motions of gas inside these dwarfs could be explained simply by the amount of normal matter they contained, with no need for any additional dark matter.

Lelli cautions that these tidal dwarfs may still be in the process of formation, making their mass estimates uncertain. But if these results hold up, it would mean that tidal dwarf galaxies are fundamentally different from their "primordial" dwarf galaxy cousins — who formed at early times inside halos of dark matter — and have profound implications for our understanding of galaxies and cosmology.

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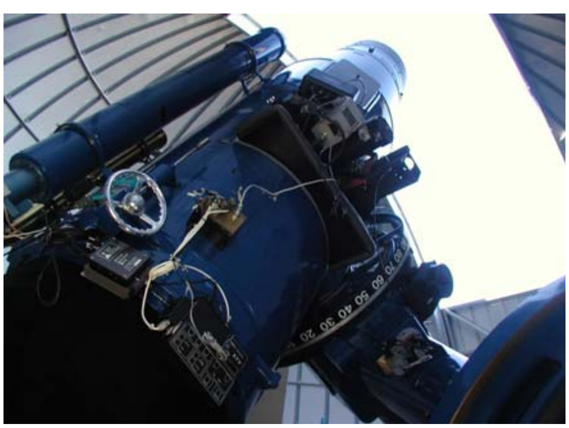

CWRU Astronomy's Burrell Schmidt telescope