Harvesting ALFALFA

The Arecibo radio telescope's ALFALFA survey is seeking cool hydrogen gas in tens of thousands of galaxies.

By Mary Crone Odekon, with assistance from Rebecca A. Koopmann, Aileen O'Donoghue, and Martha P. Haynes

The Arecibo Observatory dish is 1,000 feet across and built into a large limestone sinkhole in Puerto Rico. *[Courtesy National Astronomy and Ionosphere Center Arecibo Observatory, a facility of the NSF.]*

Radio astronomers who detect neutral hydrogen atoms like to call their work cool. Their excuse is that the hydrogen itself must be literally cool — if it were hot, it would become an ionized plasma and glow in visible light instead of radio. But while seeing things that are invisible may feel satisfyingly countercultural, it does pose a challenge for radio astronomy: How to compete with images from the Hubble Space Telescope? Is it possible to use radio astronomy to excite the next generation of potential scientists, not to mention the general public?

The UAT Team

One answer is to show people the largest radio dish in the world, ideally in person. It's not easy to feel bored about radio astronomy when you're climbing across a swinging jungle walkway to a 900-ton platform suspended 450 feet over a telescope dish that covers 20 acres. As the student behind me said when I took a tour of the Arecibo radio telescope in Puerto Rico in 2008, "This is the coolest thing I've ever done."

UAT members climb the Arecibo Observatory platform suspended 450 feet above the main dish. *[Courtesy Mike Jones]*

Annual UAT workshops incorporate a series of scavenger hunts where students learn data analysis and interpretation, culminating in group presentations. They also allow students from smaller institutions to collaborate closely with a larger community of faculty, graduate students, and fellow undergraduates. *[Courtesy Parker Troischt]*

By itself, touring Arecibo is hardly a practical way to reach the masses. But it can play a key role as one component of a program to promote undergraduate research and, through the students and faculty in the program, promote excitement about astronomy in society at large. The UAT, or Undergraduate ALFALFA Team, is a consortium of 19 primarily undergraduate-focused institutions, designed to broaden participation in astronomy research by a diverse group of students and faculty across the country. Students

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perform all aspects of research from proposal writing, to controlling the telescope on-site and remotely, analyzing data, and presenting results. The National Science Foundation has provided funding for UAT workshops, student stipends and travel, and computer equipment for the past seven years.

Crucially, the effectiveness of the UAT as a serious research experience hinges on linking to a major legacy project — the ALFALFA survey, which taps the high sensitivity of Arecibo to see cool hydrogen gas in tens of thousands of galaxies out to a distance of 250 million parsecs. The name for the project, which is headed by Riccardo Giovanelli and Martha Haynes at Cornell University, is an acronym where two of the A's stand for Arecibo: the *Arecibo Legacy Fast-ALFA* survey, where *ALFA* is the *Arecibo L-Band Feed Array*, a seven-pixel radio camera. Among the mysteries addressed by the survey is the "missing satellite" problem — a lack of small galaxies compared with the predictions of theoretical models. The ALFALFA survey can see galaxies that remain hidden because they have not yet turned on in visible light by forming stars.

Operating the Arecibo telescope is a key part of the UAT experience, whether on-site in Puerto Rico or remotely from offices, labs, and classrooms at participating institutions. *[Courtesy Rebecca Koopmann]*

Galaxies Large and Small

One unexpected outcome is the degree to which UAT members have taken over the sometimes tricky data-collection procedure used by ALFALFA. Ann Martin, a former Cornell graduate student who was heavily involved with training both students and faculty, recalls, "The UAT experience had a huge impact on data quality, because participants were well-prepared to run the telescope." By now, hundreds of undergraduates have helped operate the telescope, either on-site or remotely, under the guidance of faculty from the array of UAT institutions.

The UAT has several observing projects that follow up on the ALFALFA survey. Only sources with a very clean signal are included in the official ALFALFA catalog. This leaves many almost-detections — galaxies that are probably there but need additional telescope time to be sure. Some are especially interesting objects such as small galaxies on the hard-to-see, but probably common and cosmologically important end of the mass spectrum.

Large, not-pristine galaxies also present puzzles pursued by the UAT. Why are there spiral galaxies and elliptical galaxies? One clue is that elliptical galaxies tend to show up in denser environments, such as big clusters filled with hot plasma that can strip galaxies of their loose star-forming material. But even quite far out from the centers of clusters, galaxies look surprisingly cluster-like, suggesting that galaxies are pre-processed in less-dense environments before

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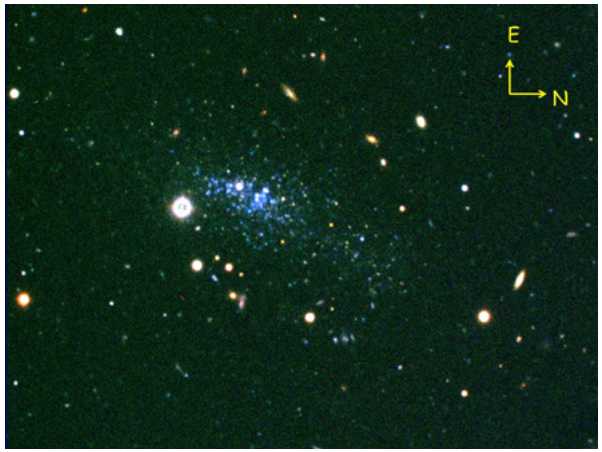
they fall into clusters. (A related effect is called "galactic conformity" — galaxies somehow conform to the environments that are *nearby*, not just the environments they're *in*.) The UAT is analyzing the cool hydrogen gas content in intermediate-density environments to look for this pre-processing.

There are also dark galaxies that have not yet formed many stars from their initial collection of loose gas. Some of them are puzzling specifically because they show evidence of star formation, but there is very little cool hydrogen gas from which stars can form. UAT collaborators are running follow-up observations at Arecibo to verify the detections, as well as observations at other telescopes to assess the star-formation properties of these dark galaxies.

Leo P

An exciting follow-up observation was the discovery and characterization of the extreme galaxy Leo P. In 2012, Riccardo Giovanelli noticed a cloud of hydrogen gas with the characteristics of an especially tiny and nearby galaxy. No galaxy was previously known to exist at this location. The "team" aspect of the full ALFALFA collaboration kicked into high gear as collaborators with expertise and connections at various telescopes came together to confirm the object's position and radio characteristics, look for evidence of rotation, and find stars associated with it.



An optical image of Leo P. *[ALFALFA team]*


The UAT workshop at Arecibo always has something exciting going on. Although these participants are pretending to see Godzilla, something exciting did happen during this particularbworkshop — a 6.5-magnitude earthquake! *[Courtesy Parker Troischt]*

Leo P is a "new" galaxy in two important ways. It is newly discovered, despite the fact that it is quite nearby, essentially at the edge of the Local Group, the loose collection of galaxies that our own Milky Way inhabits. It is also new in having formed very few stars so far — that is, *only* hundreds of thousands of stars. Not only that, but the stars have left their primordial gas cloud largely uncontaminated by heavy elements. (The "P" in its name stands for Pristine.) For now, Leo P is special. But tiny pristine galaxies may be common! They are just hard to see.

An Ideal Collaborative Project

Any project of this size poses challenges to organization, decision-

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"I still love spending nights at a telescope with a couple of good cookies to snack on, which is a tradition that started on my Arecibo observing run that I have continued to this day." says Jamie Lomax, here observing as an undergraduate from St. Lawrence University with Tom Balonek of Colgate. *[Courtesy Jeff Miller]*

making, and focus. But the longevity and broad impact of the UAT may be credited to the way it has been simultaneously coherent and flexible.

The coherence comes from having a core of truly dedicated leaders, most notably Becky Koopmann of Union College and Martha Haynes of Cornell University, who link the scientific leadership for the full ALFALFA survey to the many regularly scheduled events specific to the UAT. The flexibility comes from a structure where faculty, many with heavy responsibilities in teaching and administration at their home institutions, can participate in the ways that work best for them.

It's also not very expensive. While a minimum level of funding has been crucial for holding the collaboration together, this is not a funding-intensive endeavor, especially since it links and provides mutual leverage with a major existing project. Participants share rooms at conferences and workshops, faculty do not receive stipends, much of the observing can be performed remotely from our own offices and classrooms, and data analysis can be done on a laptop. (It also helps that expenses for student research and travel are shared by foundations and participating institutions.) Because it builds on the existing ALFALFA survey, the scientific infrastructure is already there.

The excitement of having control (now and then) of a world-class telescope cannot be dismissed, of course, even for the faculty. As Aparna Venkatesan, Chair of the Department of Physics and Astronomy at the University of San Francisco says, "As a theorist, it's been nothing short of thrilling for me to be at Arecibo, learning to take data, be on observing shifts and tours, and use this data in my theoretical work."

Classroom teaching is refreshed by the UAT experience too, from UAT-inspired activities for introductory laboratories to current research embedded in advanced courses.

Following Students Post-UAT

Perhaps most exciting for UAT faculty is the opportunity, seven years into the program, to follow the paths taken by UAT students. In many cases it is clear how their love of astronomy is rippling outward to a broader community. Haley Sharp, who remembers "that the group of undergrads bonded instantly over our mutual love of astronomy," graduated from the University of San Francisco and then earned a master's in planetary astronomy from San Diego State. She is currently Planetarium Director at the Science Factory Museum in Eugene, Oregon. Also from USF were Long Yan Yang, currently

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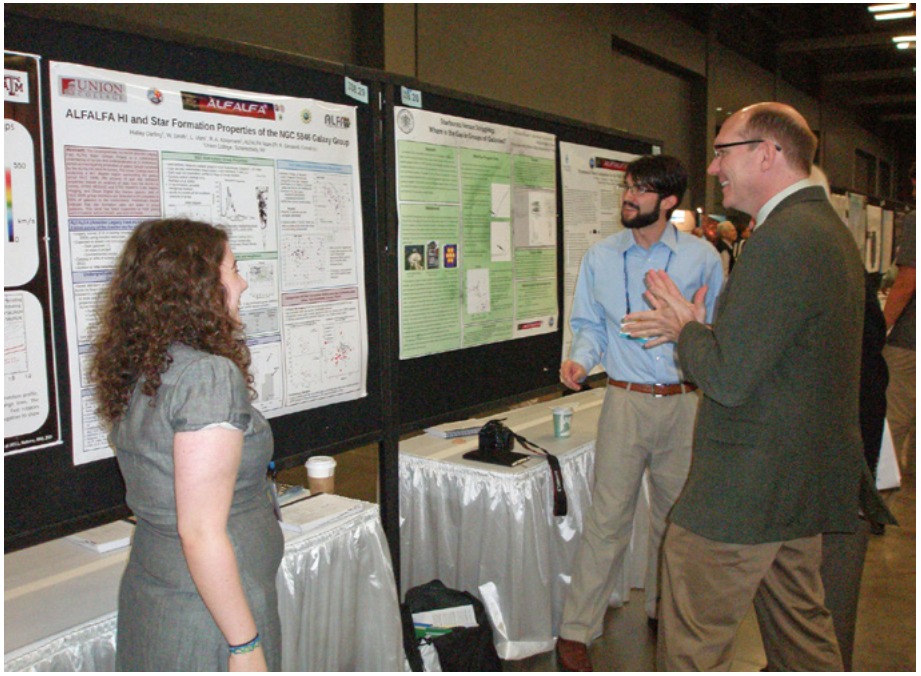

Haley Darling of Union College and Lyle Reed of Skidmore explain their work to NSF program officer Scott Fisher at the Austin, Texas, meeting of the American Astronomical Society in January 2012. Every year, dozens of UAT students present work at conferences and workshops. *[Courtesy Tom Balonek]*

pursuing a PhD at Rutgers, who remembers turning 21 at the largest telescope in the world, and Ben van Kleeck, currently a counselor at Astrocamp in Idyllwild, California.

Cornell graduate students recall the UAT as a turning point as well. Ann Martin, the graduate student heavily involved in training others to use the telescope, remembers: "I had to get pretty comfortable being an expert resource for faculty members….That kind of responsibility reaffirmed for me that I knew what I was doing, that I brought strong skills to the table as a scientist and a researcher, and that the best career path for me was going to involve helping people find their pathways to science." She now works at NASA Langley as a contractor in education and public outreach.

As of June 2014, more than 210 undergraduates had participated in the UAT, with more than 80% of alumni now in graduate school or employed in STEM disciplines. There is evidence that the program is especially valuable for underrepresented groups. For example, 50% of former UAT participants attending graduate school in physics or astronomy are women, and non-Caucasian participants report larger gains for learning measures during the annual workshop.

Regardless of their specific paths, we hope these students carry a vision that many of us experience daily, but that differs from the ivory tower, lone genius stereotype: that science is a collaborative venture, that it is okay not to know everything already as long as you're ready to work hard (!), that generously sharing what you do know is socially rewarding and can lead to new insights, and that radio astronomy is much more than cool. ✪

Acknowledgements

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