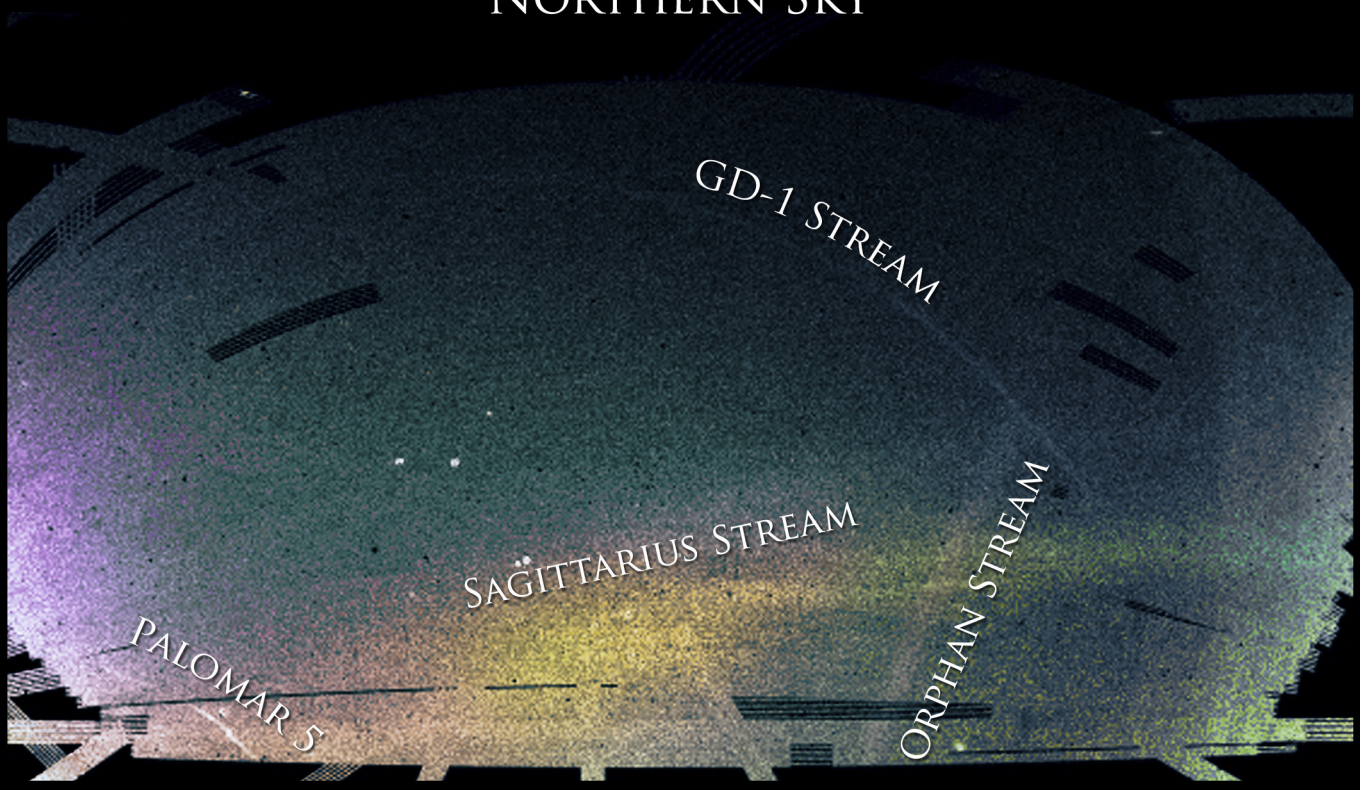
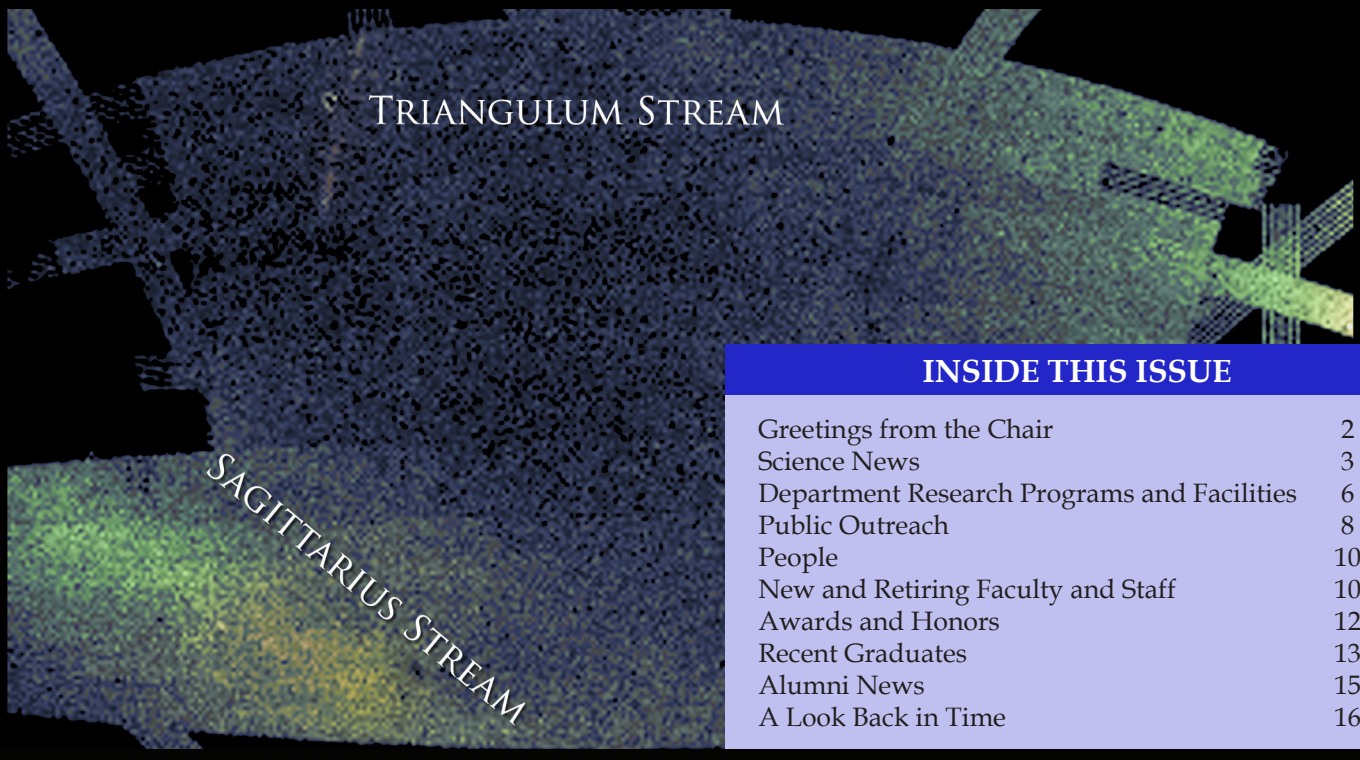
Yale University Astronomy Department Newsletter

Vol. 4 Fall 2012 No. 1

Northern Sky



Southern Sky



SDSS DR8 / Bonaca, Giguere, Geha

INSIDE THIS ISSUE

Greetings from the Chair

Welcome to the new academic year! And for some of you, welcome to Yale - you made the right choice in coming here. This past year saw many changes and achievements. Sabatino Sofia left the department so he could better focus on the many aspects of his life that are not related to astronomy; we all wish him and Tara the very best. On the other end of the career timeline Marla Geha, Frank van den Bosch, and Hector Arce were all promoted from Assistant Professor to the rank of Associate Professor. These promotions recognize their research and teaching accomplishments, but also the roles they have played in various major new initiatives and their contributions to the vibrancy of the department. Along with several excellent new students, postdocs, and research scientists we also welcomed Louise Edwards last year. In her role as Lecturer, Louise has been teaching several courses as well as contributing to the research and outreach of the department. She is helping out while Charles Bailyn avails himself of his important work for the Yale - NUS campus in Singapore the coming years. Speaking of faraway places, the transit of Venus was an unparalleled success. Venus did her job admirably. Closer to home, we had big crowds at the Leitner Planetarium and it was really remarkable to see how enthusiastic everyone was about seeing the little dot.

Owing to a fortuitous set of circumstances and generous support from the Provost's office we were able to expand our Keck access from 15 to 20 nights per year. Let's make sure we "repay" this investment of the Provost with awesome science and press releases!

Looking back at this past year our building should also be mentioned. I'm sure it feels better now that it has been reinforced to better withstand earthquakes and the occasional outburst of a faculty member. Those inside of it feel better too as the construction noise has finally subsided. I realize many of us have developed habits of working elsewhere, as too often it was the only way to cope with the noise and chaos. Now that things have quieted down I really hope everyone who found hiding places outside of the building will return: I firmly believe the pleasant atmosphere and the interactions between people are a large part of what makes our department so successful.

I hope this year will be productive and, most importantly, fun for everyone. I'm afraid there will be some more construction but it is for a good (and visible) cause: an area of the library is in the process of being converted to an undergraduate work space. This is part of an effort to better integrate the Astronomy majors in the department and expose them to more department activities.

Behind the scenes we're doing a major upgrade to the computing and data storage facilities. A related aspect has already been completed: the little boxes that appeared everywhere over the past few months improve the wireless signal. I should deny a persistent but entirely unsubstantiated rumor that they contain cameras whose signal is fed directly into my office.

This will also be a year of planning and a fresh look at our priorities; the faculty kicked this off in May during a retreat out West, and this will continue during the year. It is very nice to be able to do this planning from the position we're in: we are an active and enthusiastic department, with top notch people and facilities. If you have ideas on how to make things even better don't hesitate to speak up!

Front page image caption

Stellar streams are found throughout the outer region of the Milky Way. They are presumed to originate from disrupting dwarf galaxies or globular clusters. We have discovered a new stellar stream in the Milky Way using the Sloan Digital sky survey 3 all-sky imaging, which we call the Triangulum Stream. Kinematic studies of this and similar streams will provide tight constraints on the strength, shape and lumpiness of the Galactic gravitation potential. From *A Cold Milky Way Stellar Stream in the Direction of Triangulum*. Bonaca, A., Geha, M., and Kallivayalil, N. 2012 ApJL submitted.

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Basu determines properties of perplexing planets

Yale astronomy professor Sarbani Basu is part of a team that has discovered a unique planetary system about 1200 light-years away using data from Kepler. Two planets, one rocky and the other a gas giant, have been detected around the star that has now been given the designation Kepler-36. The planets are extremely close to each other, which is extremely unusual for two planets of such varying composition. It is not clear how the planets with markedly different compositions and densities fell into their remarkably close orbit, thus posing new challenges to planet formation theories.

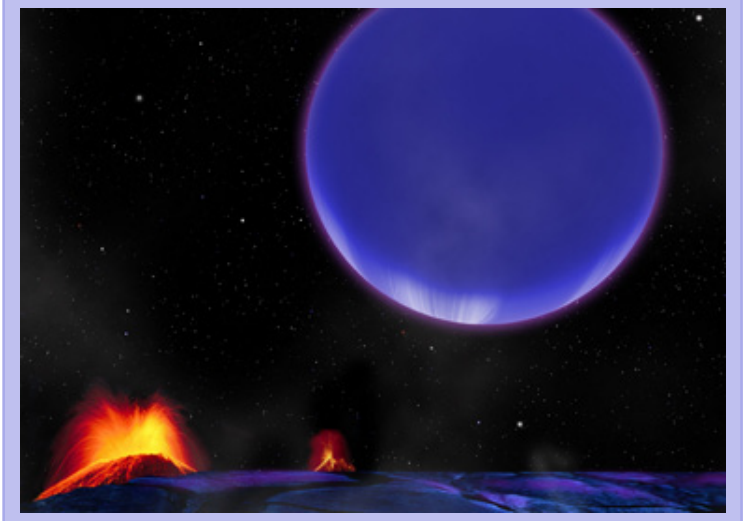
Basu said "We have never known of planets like this. If you were on the smaller planet looking up, the larger planet would seem more than twice the size of Earth's full moon. It would be jaw-dropping." In addition, the planets are so close that even someone positioned on the bigger planet would see the small planet as large.

The rocky inner planet orbits its star every 14 days, at an average distance of 11 million miles. The outer gaseous planet orbits every 16 days, at an average distance of 12 million miles. Every 97 days they move into perfect alignment, a position known as conjunction. At that point they are separated by a mere 1.2 million miles, less than five times the distance between Earth and its moon. By contrast, Venus, Earth's nearest neighbor, never comes closer than 26 million miles.

Being close together creates some disadvantages (from the point of view of organic life anyway). Both planets are hot (the equilibrium temperature for each planet is somewhere between 900-1000 degrees Kelvin) and the big planet creates constant tides, earthquakes and volcanoes on the smaller planet.

Basu explained how the team gleaned information about the properties of the Kepler-36 planets. The planets were first detected using transit data from Kepler. With the transit data, the team was able to determine the size of each planet in relation to the size of its host star. The absolute estimation of the mass and radius of the planets, however, required a precise estimation of the properties of the host star around which the planets were revolving. This is where Basu's expertise in asteroseismology came into play.

Stars like the Sun pulsate or quake constantly, and such pulsations were also detected on Kepler-36. The frequencies of the pulsations allow one to measure various properties of the structure of a star, including the star's mass, radius and density. In general, bigger stars pulsate at lower frequencies than smaller stars. The only way to obtain a mass of a star not in a binary system is by measuring the pulsations of the star.



This image suggests how the newly discovered gaseous planet would look like from its nearby neighbor, a rocky, volcanic planet. (Illustration by David Aguilar, Harvard-Smithsonian CfA)

Basu and other asteroseismologists on the team analyzed the pulsation frequencies of the host star and determined that Kepler-36 is 7% more massive than the Sun and has 1.6 times the radius of the Sun. The star is also older than the Sun--its age is estimated to be more than 6 Gyr and it has already exhausted all hydrogen in its core. Using this information and the characteristics of the transits allowed the rest of the team to calculate the actual radii and masses of the two planets.

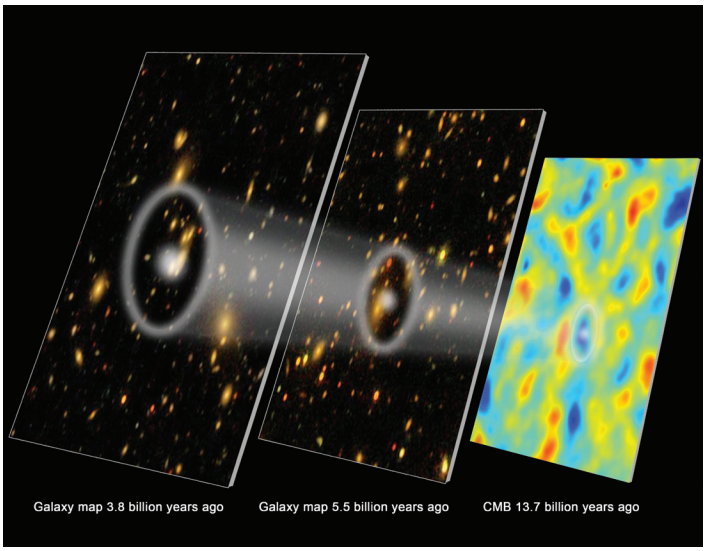
The masses of the two planets, Kepler-36b and Kepler-36c, were determined to be 4.45 and 8.08 times the mass of the Earth. Additionally, the team could determine that the radius of Kepler-36b was 4.45 that of the Earth and that of Kepler-36c was 8.08 times that of the Earth.

Once the masses and radii of the planets were determined, their densities could be determined. The density of a planet can be used to determine its composition. The smaller of the two planets, Kepler-36b, has a density greater than that of Earth and hence it must be rocky. The density of the larger planet, Kepler 36-c, is smaller than that of Jupiter (which has a density only slightly higher than that of water) and hence, it must be a gas giant.

"The precise determination of the planet's properties was possible because the star around which they revolve could be characterized precisely," said Basu.

The team analyzing the Kepler-36 system includes 46 members from around the world and is led by astronomers at Harvard and the University of Washington.

Padmanabhan improves cosmic distance measurements



The Baryon Acoustic Oscillation (white rings) in galaxy maps helps astronomers retrace the history of the expanding universe.
E.M. Huff, the SDSS-III team, the South Pole Telescope team, Z. Rostomian.

Driven by a mysterious dark energy, the expansion of the Universe is accelerating. This increased rate of expansion is one of the most puzzling issues in astronomy in the last two decades. The most promising way to understand the nature of dark energy is to measure the expansion history of the Universe by determining distances to when the Universe was younger.

The Sloan Digital Sky Survey (SDSS-III) collaboration, of which Yale is a full member, has made the most accurate measurements yet of the distances to galaxies in the faraway universe, giving an unprecedented look at the time when the universe first began to expand at an ever-increasing rate. This measurement is the culmination of more than two years of work by the team of scientists and engineers behind the Baryon Oscillation Spectroscopic Survey (BOSS), one of the SDSS-III's four component surveys. Yale Professor Nikhil Padmanabhan is a leader of the BOSS analysis team, co-chairing the galaxy clustering group with Will Percival, a professor at the University of Portsmouth in the United Kingdom.

BOSS is producing the most detailed map of the universe ever made, using a new custom-designed spectrograph of the SDSS 2.5-meter telescope at Apache Point Observatory in New Mexico. With this telescope and its new spectrograph, BOSS will measure spectra of more than a million galaxies over six years. Maps of the universe like BOSS's show that galaxies and clusters of galaxies are clumped together into walls and filaments, with giant voids between. These structures grew out of subtle variations in density in the early universe, which bore the imprint of baryon acoustic oscillations (BAO) — pressure-driven (acoustic) waves that passed through the early universe.

Billions of years later, the record of these waves can still be read in our universe. In a graph of the number of galaxy pairs by separation distance, 500 million light years shows up as a peak, so astronomers often speak of the "peak separation" between galaxies. The distance that corresponds to this peak depends on very simple and well understood physics in the Universe when it was a few 100,000 years old, giving astronomers a yardstick with which to measure the expanding Universe. Measuring the peak separation between galaxies depends critically on having the right distances to the galaxies in the first place.

That's where Padmanabhan comes in. "We've detected the peak separation more clearly than ever before," says Padmanabhan. "These measurements allow us to determine the contents of the Universe with unprecedented accuracy."

Padmanabhan, along with his collaborators from Yale and other SDSS-III institutions, used the BAO wavelength of 500 million light years as a "cosmic yardstick" to measure distances to galaxies in a sample from the SDSS-III data release 9 (DR9). By measuring the BAO on the sky at various cosmic epochs, Padmanabhan and his team measure the distance to each of those epochs, thus mapping the expansion history of the Universe.

The SDSS-III survey used a sample of luminous red galaxies to detect for the presence of the BAO and measure its extent on the sky. The specific size of the BAO is imprinted in the separation of the overdense regions of the Universe. As the Universe evolves with time, these overdense regions will form galaxies. However, the positions of the galaxies are distorted by gravitational interactions between the large overdensities over time. In order to accurately measure the BAO extent at different epochs, one would need to measure the undistorted positions of the galaxies, washed away by gravity.

Using the DR7 sample, Padmanabhan and his team have applied, for the first time, a novel technique to estimate the displacement of each galaxy due to gravitational effects. Subtracting these displacements effectively moves the galaxies back in time, thereby undoing a majority of the gravitational distortions and reconstructing the original matter distribution. This reconstruction technique sharpens the focus on the standard ruler and increases the precision of cosmic distance measurements. In fact, reconstruction reduces the distance error from the previous iteration of the SDSS (SDSS-II) sample from 3.5% to 1.9%, a gain which would have otherwise taken a survey three times larger. These results will pave the way for even more precise measurements from the Baryon Oscillation Spectroscopic Survey.

"The result is phenomenal," says Percival "We have only one-third of the data that BOSS will deliver, and that has already allowed us to measure how fast the Universe was expanding six billion years ago — to an accuracy of 2%."

van den Bosch enhances understanding of galaxy formation through statistical models

How galaxies originate and evolve is a puzzle that astronomers are working to solve. Yale Professor Frank van den Bosch believes that a crucial piece to this puzzle lies in understanding the statistical connection between galaxy properties and the dark matter haloes that encompass the galaxies.

The currently accepted theory of galaxy formation is that galaxies form inside dark matter haloes when gas cools and forms stars under the influence of a number of (poorly understood) feedback processes. Therefore, understanding the connection between galaxies and their haloes can provide insight about how the galaxies might have been formed.

Because dark matter haloes cannot be observed directly, van den Bosch has developed state-of-the-art mathematical and statistical models to investigate properties of galaxies and their relation to their haloes. In particular, he and his collaborators Houjun Mo from the University of Massachusetts and Xiaohu Yang from Shanghai Astronomical Observatory have developed a statistical tool called the Conditional Luminosity Function (CLF), which describes how galaxies of different luminosities are distributed over halos of different masses.

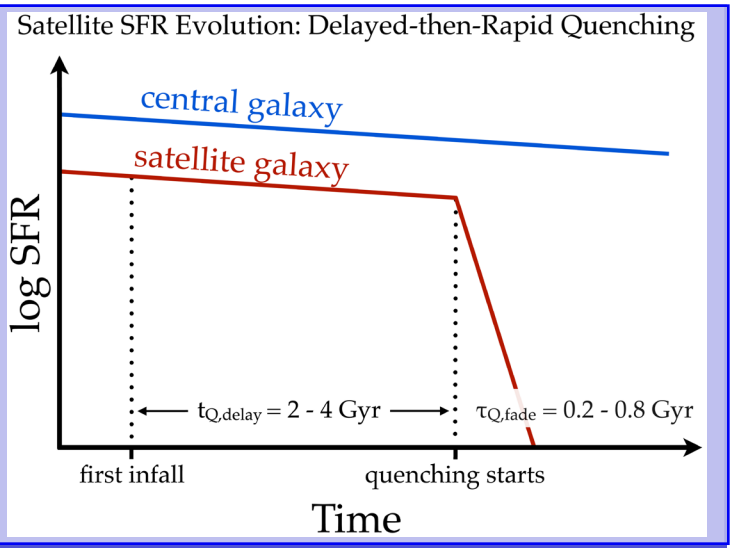
van den Bosch uses data from large galaxy redshift surveys, such as the Sloan Digital Sky Survey (SDSS) and the 2dF Galaxy Redshift Survey (2dFGRS), in a variety of different methods—satellite kinematics, gravitational lensing, galaxy clustering and generating galaxy group catalogs—in order to constrain the CLF. By starting from the data to create his models, van den Bosch is breaking away from the traditional theoretical approach of modeling physical properties of galaxy formation from the Big Bang to the present. Instead, he starts with the known present and then uses "reverse engineering" to learn how it came to be. His approach has been so successful that many other research groups have adopted this method for their work.

The work of van den Bosch and his team shows that the efficiency of galaxy formation is a very strong function of the mass of the dark matter halo in which the galaxy resides. This has led them to identify a characteristic mass scale at which galaxy formation is most efficient, which happens to be roughly the mass of a Milky Way-sized halo. Lower mass halo galaxy formation is believed to be less efficient due to supernova feedback, while, at the massive end, feedback from actively accreting black holes is believed to suppress the rate at which gas can cool and hence form stars.

As part of this work, van den Bosch and his team have created a tool that is optimized for grouping galaxies that reside in the same dark matter halo. They have used it to generate group catalogs of the 2dFGRS and SDSS datasets. These catalogs are valuable resources that allow the team to study how galaxy properties scale with group mass. The catalogs are now public and many researchers outside of van den Bosch's team have also been able to use these catalogs for their own science.

Using these galaxy group catalogs, van den Bosch, working with Postdoctoral Associate Andrew Wetzel, have been able to investigate the evolution of star formation in galaxies that have fallen into more massive dark matter halos. Their work shows that these "satellite" galaxies continue to form stars for several billion years after infall as they orbit, but then the group environment causes their star formation to shut down rapidly. van den Bosch, Wetzel, and their collaborators have placed the tightest known constraints on the evolution of these satellite galaxies, and their work suggests that the star formation "quenching" behavior is caused by satellite galaxies being unable to accrete gas to fuel their star formation after infall.

The figure on the right shows the group's work on star formation rate evolution. The blue curve shows the evolution of the star formation rate in galaxies that remain independent / isolated, while the red curve shows the evolution for satellite galaxies after they fall into a group. Courtesy of A. Wetzel



Facility Updates from Yale's Observatories

Yale has increased its share in the **W.M. Keck Observatory** (Keck) from 15 nights to 20 nights per year, providing more observational time on two of the largest and best telescopes in the world for Yale astronomers.

Keck has made several important upgrades to its instrumentation. The observatory successfully commissioned a new instrument, an IR Multislit Spectrograph, MOSFIRE, which Yale astronomers are eager to use. MOSFIRE arrived on Mauna Kea on February 16, 2012.

MOSFIRE at Keck

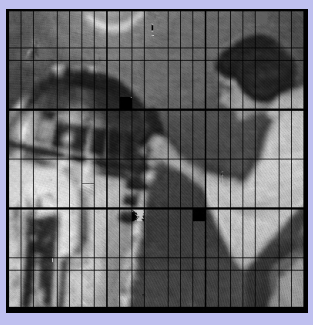
MOSFIRE provides near-infrared imaging and multi-object spectroscopy over a 6.12′ x 6.12′ field of view. It can also be used as a long-slit spectrograph. MOSFIRE features a cryogenic configurable slit unit that allows a observers to design or alter their slitmasks in real time. MOSFIRE will be available for shared-risk observing on Keck I in semester 2012B. By providing the ability to observe many objects at once in the near-IR, MOSFIRE will make such challenging observations feasible for the first time.

Other upgrades include the move of OSIRIS to Keck I in order to maximize the newly commissioned Keck I Laser-Guide-Star Adaptive Optics system, new filters for NIRC2, a new HIRES slit guider and some software upgrades.

The **WIYN Observatory** has made much needed upgrades to the facility this year. Repairs to the dome, which had been damaged in a storm in January 2010, are on-going and the dome floor has been replaced. WIYN has also upgraded the capabilities of its computer room and expanded capabilities for remote observations.

pODI mounted on the WIYN telescope

WIYN will be offering two new instruments within the next year. The One Degree Imager (ODI) now exists with a partially populated focal plane (called pODI). pODI was installed onto the WIYN telescope in July 2012 and WIYN expects to complete the scientific commissioning of two operational modes, traditional static imaging and coherent guiding by the end of February 2013. WIYN will offer pODI for shared risk observing in semester 13A.



The central array of pODI has captured some unusual visitors during a laboratory test.

pODI consists of a central 3 x 3 array of Orthogonal Transfer Array (OTA) detectors that is about 24′ by 24′ with five additional OTA detectors in outlying areas to measure and understand image quality at all radii within the one degree field of view. It is the hope that pODI will allow WIYN to learn better about how to use the full ODI, while also offering WIYN a substantial imager with good image quality in order to produce science while the consortium finds more funding to complete ODI.

Secondly, WIYN will be offering two new IFUs, GradPak and Hexpak, which were built at the University of Wisconsin and will be commissioned in the Fall of 2012.

Yale continues to hold a 17% share of WIYN.

LFOP planetarium gets state of the art upgrade

When the Leitner Family Observatory and Planetarium (LFOP) opened in 2009, its HD Spitz SCIdome projector was state of the art. LFOP was the best digital planetarium in Connecticut and one of the best in the world. In fact, Spitz, the company that makes planetarium projectors, frequently comes to Yale to show LFOP's system as a model to potential buyers. Since 2009, other institutions have obtained their own Spitz projectors and the Spitz technology has improved so LFOP decided it was time to upgrade the system.

At the end of June, Craig Amore, Senior Field Service Technician at Spitz, installed two new 155 degree "fisheye" lenses into the projector at LFOP. These lenses are larger than the previous ones and they allow more of the pixels that come out of the projector to be projected onto the dome, leading to much brighter (about 3 times brighter than the old lenses) and sharper images. This upgrade has brought LFOP once again to be the best planetarium in Connecticut.

Jim Leitner and the Yale Provost's office shared the costs of the upgrade.

Yale and U de Chile meet to foster collaboration

ALMA in progress: ALMA (ESO / NAOJ / NRAO) W. Garnier Acknowledgement: General Dynamics C4 Systems.

Yale University and the University of Chile (U de Chile) have fostered a collaboration with each other since 1999. The annual meeting of this collaboration took place on December 12 to 14, 2011 at Yale. The first two days consisted of executive meetings, where faculty of both departments discussed the past, present and future of the Yale-U de Chile collaboration, and scientific talks. The third day was used for different research groups to meet and plan for future research projects.

During the executive meetings faculty members from both institutions renewed their support for both the education and research components of the Yale-U de Chile Joint Research Program and they decided to work towards a new MOU.

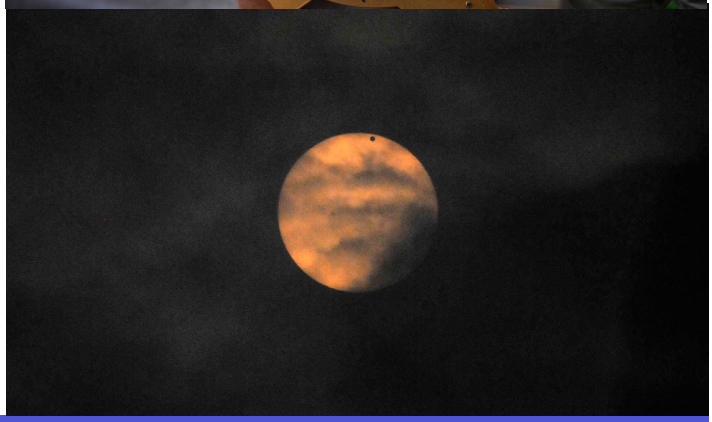
The scientific talks showed the diversity of the fields among the participants, but also showed areas of common interest between members of both departments. Several research areas of common interest were identified: Star formation, Local Group and galaxy centers.

The newest telescope in Chile, The Atacama Large Millimeter/sub-millimeter Array (ALMA) was of especial interest, leading to discussion and planning among several of the groups with regard to future projects with ALMA.

Five faculty members from U de Chile were present in person: Diego Mardones, José Maza, Ricardo Muñoz, Paulina Lira, and Gonzalo Palma. René Mendez, the current chair of the astronomy dept. at U de Chile and director of the Calán observatory, was also present via Skype. Two postdocs from U de Chile were also present: José Gallardo and David Rodríguez. With the meeting located in New Haven, the Yale astronomy department was represented in full.

This article contains contributions from Hector Arcé.

Hundreds flock to Yale to witness transit of Venus



The Leitner Family Observatory and Planetarium (LFOP) hosted a public event for the transit of Venus on June 5, 2012. Despite being partly cloudy, about 400 people were present to view the once- (or twice-) in-a-lifetime occurrence.

LFOP offered several methods of viewing the eclipse. There were four solar telescopes on hand as well as a live feed from a telescope in Hawaii playing on two screens inside LFOP. In addition, guests were given special solar eclipse glasses to view the event with the (almost) naked eye. There were also some indirect methods of viewing the eclipse. James Newton of East Haven High School brought his souped-up Galileoscope and was showing visitors the eclipse via reflection on a piece of paper. A similar technique was used with wooden Sunspotter folded Keplarian telescopes from LFOP.

In addition to the viewing, there were several other family-friendly hands-on activities available. NASA donated 150 informational and activity packets, each of which also included eclipse glasses. David Heiser from the Peabody Museum monitored a table where children molded Playdough to fit templates in order to create a scale model of the planets in the Solar System. Younger children enjoyed making a sunflower from photographs of the sun in different wavelengths. Victoria Gardner from the Astronomy Department led tours of the Reed 8" refractor, which was originally purchased to view the 1882 transit of Venus. And 240 people watched planetarium shows, which were constantly playing throughout the event.

Overall the event was a great success, thanks to Michael Faison, Heidi Herrick and the numerous volunteers from both the department and the community, who made this possible.

All photos on this page were taken at the LFOP transit event by John Woike of the Hartford Courant.

New Haven youth create and present astronomy instruction cart at Yale Peabody Museum

Beginning in the summer of 2010, Dr. Héctor G. Arce of the Yale Astronomy Department supervised three high school students in a project to design and build an astronomy cart called Illuminating our Universe that explains the electromagnetic spectrum and multi-wavelength astronomy to the visitors of the Yale Peabody Museum of Natural History (Peabody).

The students, Joshua Copeland, Matahari Kesadaran and Sebastian Moraga, were part of a free after-school program run by the Peabody called EVOLUTIONS (the acronym signifies "EVOking Learning and Understanding Through Investigations of the Natural Sciences"). Previous to Arce's involvement, most EVOLUTIONS (or, as it is more commonly known, EVO) projects focused on the earth sciences, but Arce used part of his NSF CAREER grant to start the astrophysics component of EVO.

Arce began by teaching the students enough astronomy to get started on the project and how to use the World Wide Telescope (WWT). The students used the WWT to produce a video (a.k.a. "tour") of the star forming region in the constellation of Orion. This tour showed what can be learned about star and planet formation by observations of Orion at different wavelengths. Arce decided that this video would be accompanied by various gadgets that help explain the electromagnetic spectrum to the public: an infrared camera, an ultraviolet lamp with beads that change colors when ultraviolet light shines through it, and spectral tubes that show the spectra of different gases at optical wavelengths.

The students ordered the equipment for the cart and wrote up explanations about why each item was relevant to the electromagnetic spectrum and to astrophysics. Jamie Alonso, who was at that time the EVO program coordinator, helped Arce direct the students in staying on track to complete the project. In addition, Alonso and the Peabody machine shop helped the students design the cart and its layout.

Since the cart has been completed, the students regularly take the cart out for Peabody visitors and explain the contents using their descriptions. They have also taught other students in the EVO program to demonstrate the astronomy cart to visitors.

The original plan was to share the cart between the Peabody and the Leitner Family Observatory (LFOP) and Planetarium, but the trip between the two venues is difficult so Arce says that he is contemplating having future students create a second cart for LFOP.

Funding for the cart came from the National Science Foundation, through CAREER grant AST-0845619 to Héctor G. Arce.

EVO students present the museum instruction cart that they created with Professor Arce and Jamie Alonso from the Yale Peabody Museum of Natural History.

A closer look at the museum instruction cart the EVO students created at the Peabody Museum. The UV lamp is on the front left, with spectral tubes front and UV camera on the right.

Frontiers in Star Formation conference to honor Richard Larson

The Yale University Astronomy Department will host a celebratory conference for Dr. Richard Larson, who has retired after serving at Yale for 43 years. *Frontiers in Star Formation* will be held at Yale on October 26-27, 2012. The goal of this meeting is to bring together observers and theorists in the field of star formation, at all cosmic scales, to discuss the latest discoveries and the exciting research that will be conducted in the near future. In so doing, we will celebrate Larson's great contributions to this field.

Twenty-five invited speakers have confirmed to speak on a variety of topics that have been split into four sessions:

- The First Stars
- The Heydays of Cosmic Star Formation (SF at z~2-3)
- Towards a Complete Picture of Galactic Star Formation
- Bridging the Gap Between Galactic and Extra-Galactic Star Formation

There will also be a poster session during the conference and a banquet in honor of Richard on Friday night.

More information on the conference can be found at: http://www.astro.yale.edu/sf_frontiers/.

Valerie Robalino joins department staff as assistant to the Chair

Valerie Robalino has joined the astronomy department as the Chair's assistant. The position was previously held by Nicole Whitcher, who left the department to join the new Yale Faculty Research Management Services (FRMS) as a grants portfolio assistant.

Valerie not only assists the Chair, helping him to manage the volume of duties that come with the office, but she also helps keep the rest of the department together with her great people skills, brilliant smile and her willingness to help anyone in need.

In her spare time, Valerie enjoys spending time with family and friends and hiking and being outdoors.

Asteroid named in honor of Michele Dufault (1988-2011)

An asteroid that was discovered on January 5, 1994 by Spacewatch at Kitt Peak has been named (15338)Dufault. The asteroid is named in honor of Michele Dufault, an outstanding astronomy and physics student at Yale who died in an accident just weeks before graduation. Michele was passionate about science and about encouraging others, especially young women, to pursue science careers. (See also the Fall 2011 Astronomy Newsletter, p. 21 for more about Dufault.)

The asteroid is a 5 to 10 kilometer diameter object in orbit 2.92 AU from the Sun on average but gets as close at 2.55 AU and as far as 3.29 AU from the Sun (1.0 AU is approximately 150,000,000 kilometers; the average distance of Earth from the sun). It is located in the middle of the asteroid belt between Mars (at 1.52 AU) and Jupiter (at 5.20 AU) and has a very low inclination to the ecliptic; about 2.94 degrees.

P L E

Sofia retirement celebration remembrance by Valerie Robalino

On Friday, March 2nd, 2012, I had the honor of planning and executing a celebration in honor of Sabatino Sofia, a very special Emeritus professor whom has been teaching Astronomy at Yale for over 25 years. Being brand new to the department I was welcomed by everyone and especially by Sabatino Sofia. He shared with me his devotion to Yale's Astronomy connections with Latin America. Being Latin American myself, it sparked my interest and I was happy to see how enthusiastic and willing Sabatino was to share his knowledge with me.

This wonderful event started at the Leitner Family Observatory and Planetarium (LFOP), with a gathering of the Astronomy department and some of his close friends and family. His loving colleagues Pierre Demarque and Richard Larson shared speeches rich with history and fun knowledge about Sabatino's career. Being long-time colleagues they also reminded all of the attendees of the progress in Astronomy at Yale from the time he was Chair in the early 1990's. We then got a chance to hear some nice words from Sarbani Basu, who came into the department as a professor when Sabatino was chair, and we enthusiastically presented him with gifts of a set of Yale martini glasses and a gold Yale watch.

After a fun celebration with the entire department, we proceeded to have an intimate dinner with faculty and family at Sage American Grill, where Jeff Kenney closed out the festivities with a wonderful speech. It definitely was a night to remember, and I am completely honored to have been a part of it all.

For more information on Sabatino Sofia and his retirement, please see the 2010 Astronomy Newsletter, page 16.

Sabatino Sofia with Pierre Demarque, Sofia's son and Sofia's wife

Members of the astronomy department celebrate with Sofia

Valerie Robalino poses with Sabatino Sofia and his wife

Yale University Prizes

Charles Baldner, PhD '11 was awarded the 2012 Dirk Brouwer Prize, which is awarded to a student in the Yale Astronomy Department for a contribution of unusual merit to any branch of astronomy. Normally this is awarded to a graduate student for an outstanding thesis.

Joseph O'Rourke, BS '12 was the 2012 recipient of the George Beckwith Prize. The Beckwith Prize is awarded annually to undergraduates who are the most proficient in some branch of astronomy or mathematics

HONORS

Camille Avestruz[1], GRD '15 received the AAS Beth Brown Memorial Prize for the poster she presented at the 2011 Joint Meeting of the National Society of Black Physicists and the National Society of Hispanic Physicists.

Professor **Debra Fischer**[2] has been elected to the American Academy of Arts and Sciences.

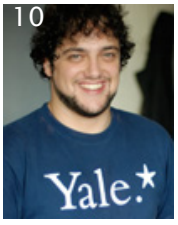
Jedidah Isler[3], GRD '13 was inducted into the Edward Alexander Bouchet Graduate Honor Society at the ninth annual Bouchet Leadership Conference on Diversity in Graduate Education, held at Yale in March. The honor is named for Bouchet (PhD 1876, Physics), the first African American doctoral recipient in the United States. She also was awarded a Ford Foundation Dissertation Fellowship.

Postdoctoral associate **Britt Lundgren**[4] and PhD student **Tomer Tal**[5], GRD '12, were each awarded an NSF Astronomy and Astrophysics Postdoctoral Fellowship. Lundgren will be doing her research at the University of Wisconsin-Madison and Tal will be at the University of California, Santa Cruz.

Professor **Daisuke Nagai**[6] has been awarded the 2011 International Union of Pure and Applied Physics (IUPAP) Young Scientist's Prize in Astrophysics. He has also been named a 2012 Cottrell Scholar by the Research Corporation for Science Advancement, which supports scientific innovation and research in U.S. colleges and universities.

Stella Offner[7] and **Erik Tollerud**[8], 2012 Hubble Fellows, are undertaking their fellowships at Yale.

Adele Plunkett[9], GRD '15, won a graduate student Chambliss Astronomy Achievement Award at the 2012 winter AAS in Austin for her poster titled *The Impact of Molecular Outflows in the Protostellar Cluster NGC1333*. **Zachary Kaplan**[10], '13 won one of the six undergraduate Chambliss prizes at the June meeting in Anchorage. The Chambliss award recognizes "exemplary research by students who present at one of the poster sessions at the meetings of the AAS".



Postdoctoral associate **Christian Schwab**[11] was awarded a prestigious Sagan Postdoctoral Fellowship. His proposal described innovative technology design and development to push radial velocity precision towards 10 cm/s here in the Yale Exoplanet Lab. The Sagan Fellowships support outstanding recent postdoctoral scientists to conduct independent research that is broadly related to the science goals of the NASA Exoplanet Exploration program.

Professor **C. Megan Urry**[12] is the 2012 recipient of The George Van Biesbroeck Prize, which honors a living individual for long-term extraordinary or unselfish service to astronomy. She won "for her tireless efforts to enhance the participation of women in astronomy and other scientific disciplines, through the organization of meetings, written works, lectures, and effective mentoring, done outside and in addition to her work as a scientist."

Professor **Frank van den Bosch**[13] secured a Lady Davis Visiting Professorship at the Hebrew University in Jerusalem in Fall of 2011.

Professor **Pieter van Dokkum**[14] has been awarded the prestigious 2012 Marc Aaronson Memorial Lectureship, which promotes and recognizes excellence in astronomical research. The prize is awarded to an individual or group who, by his passion for research and dedication to excellence, has produced a body of work in observational astronomy which has resulted in a significant deepening of our understanding of the universe.

Recent astronomy department graduates

Charles Baldner, '11 PhD
Currently a research associate at the Hanson Experimental Physics Laboratory,
Stanford University.
Dissertation: *The Magnetic Fields of the Solar Interior* (S. Basu, advisor)

Measuring the internal magnetic fields of the Sun would provide important constraints on our understanding of the mechanisms that underly solar activity. The properties of the solar interior can be probed using a technique known as helioseismology, analogous to seismic studies of the Earth's interior. In my thesis, I used full solar cycle's worth of high quality helioseismic data from the Michelson Doppler Imager (MDI) instrument onboard the SOHO spacecraft to explore changes in the interior thermal structure of the Sun as well as attempting to directly probe the internal magnetic fields. I found evidence for a small but significant change in sound speed at the base of the solar convection zone correlated with surface activity. If magnetic fields are responsible for this change, the fields strengths necessary would not be detectable at this depth in our data. I did find evidence for shallow toroidal fields at depths of 0.996R_sun and 0.999R_sun, as well as a poloidal field component that was correlated with surface activity. Studying the thermal structure below a large number of active regions, I broadly confirmed earlier results that found a two layer sound-speed structure below sunspots.

Andrew Davis '11 PhD
Currently a Postdoctoral Fellow, TMoX Group, Max-Planck-Institut für Extraterrestriche Physik
Dissertation: *The Role of Angular Momentum in the Formation of the First Stars and Galaxies*
(P. Natarajan, advisor)

We present results from N-body and hydrodynamical simulations following the formation and evolution of high redshift halos which host the earliest stars and galaxies. Our N-body simulations have both the high resolution and cosmological volume required to measure several physically important properties of dark matter halos, such as spin, shape, concentration, and environment for halos in the mass range $M=10^6$ - 10^9 solar masses. We find that the mean of the spin distribution is lower at higher redshifts. We report that higher spin halos are more clustered and are in over-dense regions compared to low spin halos of the same mass at all redshifts in our study.

In order to explore further the role played by angular momentum in the collapse process, we use adaptive mesh hydrodynamical simulations to follow in detail the collapse of baryons in three high spin halos. This allows us to study the role angular momentum plays in modulating the formation of Population III stars. We report that two of the three simulations show indications of fragmentation. One run has two bound clumps, separated by 400 AU. The second run has a gravitationally unstable disk with radius 2 pc and a Toomre Q parameter of Q = 0.7. The fragmentation arises from the turbulence and high rotational energies due to the high angular momentum environment.

Our findings have impact in understanding how angular momentum modulates galaxy formation at these early epochs. Feedback from Population III stars depends critically on their initial mass function. If there are multiple low mass stars, the radiative and kinetic feedback will be substantially different than that from one 200 solar mass star. Galaxies forming in the high spin environments studied in this thesis may evolve substantially differently than their counterparts in low spin environments. Future observatories, such as the JWST and LOFAR, plan to observe these early stars and galaxies. Our research provides critical insight into what results may be expected from these future observations.

2012 Astronomy Department undergraduate senior projects

Joseph O'Rourke, B.S. *Thermal and chemical evolution of Venus and super-Venus planets* (Jun Korenaga, advisor). O'Rourke is spending his summer as an intern at the Space Studies Board of the National Research Council and will enter graduate studies in planetary science at the California Institute of Technology in Fall 2012.

Charlie Sharzer, B.S. *Modeling Captures of Potentially Habitable Exomoons* (Debra Fischer, advisor). Sharzer is currently teaching physics in New Jersey through Teach for America.

Morris Davis, '50 PhD writes, "At 92 years of age and in somewhat frail health, I keep up with my major interest principally in dynamical astronomy. Naturally, I follow the activities of Yale astronomers with a great deal of attention."

Doug O'Handley, '67 PhD writes "After sixteen years of teaching in the Physics Department at Santa Clara University, I am finally closing my tenure. I still remain active at NASA Ames Research Center as Director Emeritus of the Academy for Space Exploration. We have had 170 students pass through this program since 1997. We will have 17 new students this summer. The interaction with these stellar students is very invigorating. Over half of the 170 have or are working on PhD's. Many are working in tenure track academic positions. We also have Rhodes Scholars, Truman Scholars, and Marshall Scholars among the alumni. I continue to successfully battle prostate cancer. We expect to visit New Haven in the fall."

Julian Palmore, '67 PhD will teach his seminar "Spaceflight" to campus honors students at the University of Illinois, Urbana for the third time next fall. The emphasis will be on commercial developments by SpaceX and other companies that are trying to provide interim transportation to the international space station for freight and astronauts.

Ted Snow, '69 BA has been on the faculty of the University of Colorado for 35 years (he helped form CASA, which is still thriving, in 1985), but will retire next year due to health issues related to a stroke he suffered in 2005. He will continue with his research in the interstellar medium, using both space and ground-based observing. Ted and his wife managed to produce three boys, none of whom are interested in astronomy.

Alan Hirshfeld, '78 PhD, professor of physics at the University of Massachusetts, Dartmouth, recently published a popular science book, Eureka Man: The Life and Legacy of Archimedes (Walker/Bloomsbury, 2011). His Astronomy Activity and Laboratory Manual, a history-based series of exercises for college-level introductory astronomy courses, was published last year by Jones and Bartlett.

Christopher Carosa, '82 BS has just published a new book, 401k Fiduciary Solutions. More information can be found here: http://www.401khelpcenter.com/press_2012/pr_carosa_041712.html.

Benjamin Mazin, '97 BS just welcomed his second child, Tyler Mazin. He also won the PECASE (Presidential Early Career Award for Scientists and Engineers) award last September. His group has recently published its work on MKID's (microwave kinetic inductance detectors).

Volker Bromm, '00 PhD is an Assistant Professor at the University of Texas at Austin. Some of his group's first star and galaxy simulations were incorporated in the movie The Tree of Life, directed by Terrence Malick. The movie won the Cannes 2011 Palme d'Or and was nominated for the 2012 Oscar for Best Picture.

Dimitri Veras, '01 BS is now a Postdoctoral Researcher at the University of Cambridge in England. He has been working on several interdisciplinary projects involving merging exoplanetary dynamics with stellar and Galactic dynamics in order to understand "the big picture" regarding exoplanets: where in the Milky Way can we expect to find these planets, in what quantities, and with what orbital parameters?

Belina Mizrahi, '02 BS writes, "I've ended up in the field of theatrical production management - I live in Philly and work for Pig Iron Theatre. Are any of you in this lovely town? I miss astronomy dearly and would love a glimpse back into that world. Get in touch: belinae@gmail.com."

Dan Kelly, '03 BS is in his 9th year of teaching middle school, including 4 years of teaching science in Harlem through Teach for America, a year in Newark, and four years in New Rochelle, NY teaching 8th grade math. He writes "I continue to love the challenges and the progress and am actually excited by the trend toward giving teachers better quantitative feedback on their teaching quality, despite some of the flaws in the system. So, I'm not exactly doing any exciting research in the field of astronomy, but I am teaching kids who might do so one day!"

Brendan Cohen, '05 BA is in his second year at Stanford Law School, though he is trying to integrate his interest in astronomy with his work in law. He spent last summer at the UN Office for Outer Space Affairs and last term working at the Office of Chief Counsel at NASA Ames Research Center. His main interest is in international space law, specifically looking into legal guidelines to help mitigate the space debris problem and investigating the question of lunar property rights.

Kathy Kornei, '06 BS is finishing her astronomy PhD at UCLA. She has been enjoying cooking, exploring Los Angeles, and tending a little garden. She writes, "It was great to see Yale again when I visited New Haven last year for my 5th reunion."

M N I

Hugh Crowl, '06 PhD, writes "After a postdoc position at Columbia University, I accepted a job as a faculty member at Bennington College, a small liberal arts college in southwest Vermont. I am the one and only astronomy/physics faculty member and am enjoying teaching intro physics and an astronomy class that combines Stellar Evolution (thanks, Bob & Sarbani!) and Astrobiology (thanks, Sabatino!). We also have a new addition to our family. Finn Albertson Crowl was born shortly after our move up to Vermont, on February 10, 2012. All are doing well, albeit with less sleep than we're used to."

Eric Murphy, '07 PhD is a postdoctoral fellow at the Observatories of the Carnegie Institution for Sciences, where he is spearheading a study of the physics of star formation.

Shanil Virani, '07 MPhil recently accepted the position as Director of the John C. Wells Planetarium at James Madison University. The John C. Wells Planetarium is a $1.3 million, state-of-the-art hybrid planetarium whose mission is astronomy education and public outreach. Shanil, wife Ashley, and son Rohan, also recently welcomed daughter Zaida Elise Virani to the family!

Greg Mosby, '09 BS, now an astronomy graduate student at the University of Wisconsin, Madison, won one of the ten graduate student Chambliss Astronomy Achievement Awards at the 2012 winter AAS in Austin. The awards are given to recognize exemplary research by undergraduate and graduate students who present at one of the poster sessions at the meetings of the AAS.

Adam Solomon, '10 BS is obtaining his PhD at the University of Cambridge, working with Professor John Barrow on modified gravity and dark energy. He was awarded the Tyson Medal last June after the Cambridge Part III exams.

Carie Cardamone, '10 PhD is a postdoctoral associate at MIT, where she studies the co-evolution of black holes and galaxies.

Gabriel Brammer, '10 PhD is a fellow at the European Southern Observatory in Chile, where he studies galaxies in the distant universe.

Laura Kreidberg, '11 BS has just finished her first year of graduate school at the University of Chicago. She is involved in a research project related to estimating planet occurrence using Kepler data. She has recently submitted a paper to ApJ "Mass Measurements of Black Holes in X-Ray Transients: Is There a Mass Gap?"

Jon Richardson, '11 BS has just finished his first year of graduate study at the University of Chicago. He is working with Profs. Craig Hogan and Steve Meyer on the Fermilab Holometer Experiment. He has recently submitted a paper on his Yale senior thesis to ApJ.

SPITZER ***(Cot'd from p. 16)*** in December 1938 (at the age of 24), even before Hans Bethe's papers on the subject had been published. Spitzer pursued studies of the interstellar physics needed to understand star formation while on the Yale faculty during 1939-42, but at the advice of unnamed "various astronomers," his papers on the subject in 1941-42 said nothing about star formation, which they considered much too speculative a topic. In his later interviews with DeVorkin, Spitzer said he regretted following that bad advice, since understanding star formation had really been the motivation of his work.

In December of 1946, as a Yale professor, Spitzer attended a symposium at Harvard University. It was at this meeting that Spitzer first presented formally his ideas about star formation and gave an account of the work he had been doing on the subject up to that point (some of it probably done "offline" during the war years). The proceedings of the Harvard symposium were published in 1948 in a book called Centennial Symposia, and Spitzer's contribution, *Formation of Cosmic Clouds*, was the first published account by Spitzer of his studies of star formation. It was a major work; and the first to address many of the basic issues in the theory of star formation that have kept theorists occupied ever since. This work and its many ramifications seem to have motivated much of Spitzer's scientific career, including his major contributions to plasma physics as well as astrophysics.

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The Astronomy Department pursues a wide array of activities, ranging from the Leitner Family Observatory and Planetarium to innovative instrumentation projects and observing nights with the world's largest telescopes. These represent an equally wide array of funding opportunities, and together with Yale's Development Office we are committed to finding optimal matches between donors and initiatives. These include naming opportunities for instruments, telescopes, and programs. For more information please contact Philip Duffy at philip.duffy@yale.edu or 203-432-5505.

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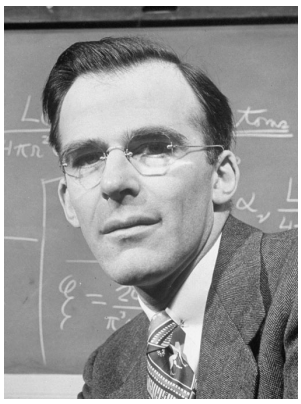
A Look Back in Time: Lyman Spitzer Jr. at Yale

Modern ideas about star formation in the interstellar medium began in about 1941 with the work of Lyman Spitzer, Jr, B.S. '35. Emeritus professor Richard Larson has noted Spitzer's Yale connections several times, as compiled below. Larson obtained much of his information about Spitzer from three long interviews with Spitzer that Yale astronomy alumnus David DeVorkin, M.S. '72 undertook in 1977, 1978, and 1991. These interviews are available online, thanks to the American Institute of Physics.



Spitzer was an undergraduate Physics major at Yale from 1931 to 1935. While at Yale, he was a member of both the staff of the Yale Daily News and Skull and Bones. He left to study at Cambridge, eventually obtaining his PhD from Princeton in 1938. He then returned to become a faculty member in the Physics and Astronomy Departments at Yale from 1939 to 1942 and again from 1946 to 1947. In the interim, during World War II, he worked on underwater sound research that eventually led to the development of Sonar.

In his first tenure at Yale, Spitzer lived on Whitney Avenue, most likely in a small house with columns at the corner of Whitney Avenue and East Rock Road. During the second term he lived on Ridge Road in Hamden, but he and his wife never completely finished furnishing that house because at the time he was really hoping to become Henry Norris Russell's successor at Princeton, a job which he eventually did get in 1947. Yale was actually very supportive of Spitzer, and promised Spitzer most of what he wanted to try to entice him to stay at Yale, but he was more interested in Russell's job.

Thus, Spitzer was at Yale when he did his early work on interstellar matter and star formation in 1941-42 and also in 1946 when he wrote his now-famous paper, *Astronomical Advantages of an Extra-Terrestrial Observatory*, which first proposed the idea of a placing a telescope in space to get rid of the blurring effect caused by Earth's atmosphere.

Spitzer was the first person to consider the implications of nuclear energy generation in stars for stellar lifetimes and the need for ongoing star formation. Apparently he gave a lecture on this subject while a postdoc at Harvard ***(see SPITZER, p. 15 for more)***