Yale University Astronomy Department Newsletter

Vol. 6 | Spring 2016 | No. 1

Yale Astronomy Department moves to Hillhouse Avenue mansions

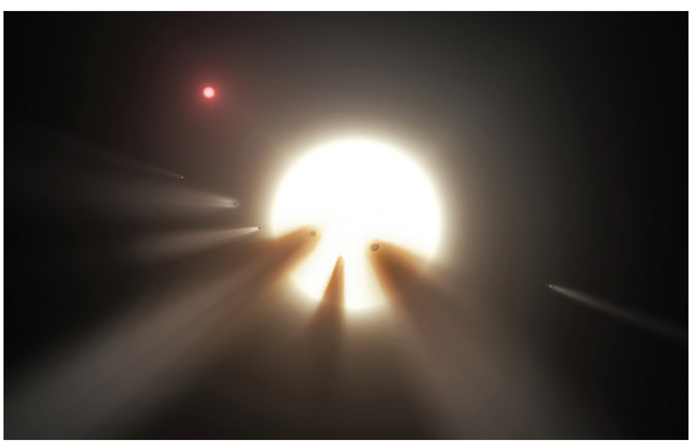
The Astronomy Department and the Yale Center for Astronomy and Astrophysics (YCAA) have moved from the Josiah Willard Gibbs Laboratory (Gibbs) to the three former School of Management (SOM) mansions on Hillhouse Avenue: 56 Hillhouse (Thomas M. Evans Hall, or EVN), 52 Hillhouse (Steinbach Hall, or STN) and 46 Hillhouse. The department opened in its new home on Monday, August 24, 2015.

Gibbs, a modernist structure built in 1955, will be demolished to make way for construction of the new Yale Science Building (YSB). Therefore, all occupants of Gibbs needed to be moved to other locations.

The move took a little over a year to plan and involved many people from all over the University as well as from external companies. The move coordination company was Richard L. Hoffman and Associates and the moving company was Clancy Relocation & Logistics. The mansions were beautifully renovated by Standard Builders to prepare for the coming of the astronomers. (***SEE MANSIONS, p. 12***)

Steinbach Hall, the new administrative home of the department. *Photo by Michael Marsland, Yale University Photographer.*

Yale Postdoc's paper illuminates possible history of strange star; sparks viral speculation of evidence for extraterrestrial life



Artist's impression of an orbiting swarm of dusty comet fragments, which is Boyajian's current theory for the cause of the unusual light curve of KIC 8462852. *Credit: NASA / JPL-Caltech*

Yale Postdoctoral Associate Tabetha Boyajian and Planet Hunters, a team of citizen-scientists founded in 2010 to analyze data from the Kepler space telescope, have discovered a very normal star, KIC 8462852, with very unusual behavior.

Boyajian said "We found a very interesting light curve in the Kepler data and we went through and learned everything about the star we could, using ground-based observations, Kepler photometry, etc.; everything we learned pointed to the star being absolutely normal for a star of this type except for the observations made in the Kepler light curve."

The light curve in the Kepler data showed several large dips, which demonstrates that something has been blocking the light of the star on several occasions. A dip in a light curve is normal when an object passes a star, but the dips in KIC 8462852 showed that something was asymmetrically blocking abnormally large amounts—up to 20 percent—of the star's light. (***SEE STAR, p.4***)

INSIDE THIS ISSUE

Greetings from the Chair

Pieter van Dokkum, Chair

Welcome to the latest edition of the Astronomy Department Newsletter – the first that is written in our new home on Hillhouse Avenue! In September, the Department moved from the Gibbs building on Science Hill to the recently-vacated "S.O.M. mansions." There was a lot of anxiety surrounding the move, but in the end things worked out well: the spaces work well for us, and the informal daily coffee gathering proved to be a great way to stay in touch.

Since the last Newsletter there have been many noteworthy research results, some of which are described in the following pages. Many of these results were accompanied by press releases, and were covered in the media. One of the big "hits" was the discovery of the most distant known object in the Universe, by YCAA Fellow Pascal Oesch. Another was Tabetha Boyajian's analysis of mysterious dips in the light curve of the star KIC 8462852. The star was observed with the Kepler satellite to search for planets, and was flagged as an unusual object by citizen-scientists in the Planet Hunters project.

The exoplanet group will be strengthened and broadened with the arrival of Professor Greg Laughlin, who will join the faculty this summer. Greg develops theories for the formation and evolution of planetary systems, thus covering an area of astronomy that has seen explosive growth over the past decade.

Over the past year, a movie was produced that highlights the work and passion of astronomers at Yale. The movie debuts in February and will be available on our website. As is evident from the movie, and from the wealth of information in this Newsletter, the Astronomy Department is doing remarkably well: we could not be happier with our students, postdocs, faculty, and excellent support staff. The mansions have been a delight, and we enjoy access to the world's best observing facilities. The challenge will be to maintain this level of excellence into the future, by continuing to invest in game-changing projects and technologies.

Astronomy alumni Michael West, PhD '87; Katherine Rhode, PhD '03; Michael Gregg, PhD '85; and Peter Stetson, PhD '79 pose for a group picture while advising REU summer student projects at the Maria Mitchell Observatory. In addition to being alumni, all four were awarded the department's Brouwer Prize for their dissertations. For more alumni news, see p. 32. *Photo courtesy of Katherine Rhode.*

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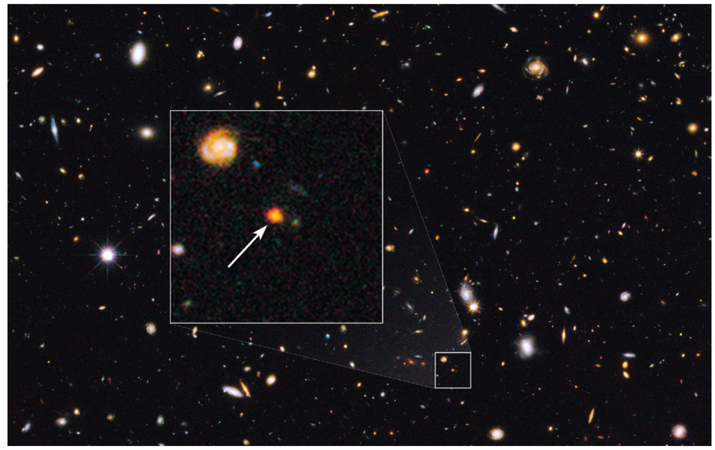
3D-HST Survey adds new dimension to galaxy research



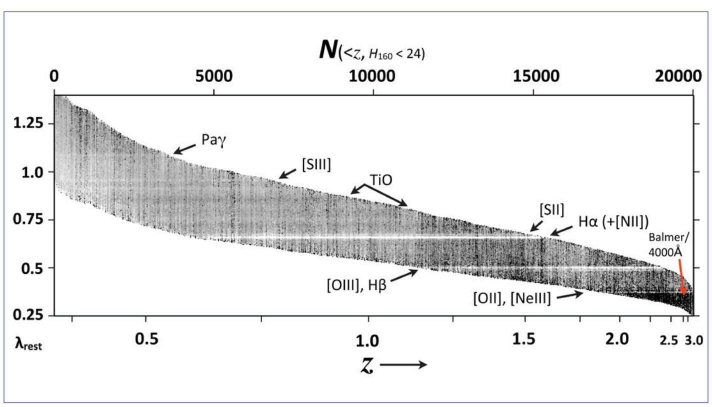
Erica Nelson, GRD '16 used 3D-HST to discover a galaxy in a never-before captured stage where the dense galactic core is still furiously churning out newborn stars. *NASA, ESA and E. Nelson*

Professor Pieter van Dokkum and his research team have completed a large near-infrared spectroscopic survey with the Hubble Space Telescope (HST) that is designed to study the physical processes that shape galaxies in the distant Universe.

The survey, called 3D-HST, used 248 orbits of observing time with the Wide Field Camera 3 (WFC3) instrument on Hubble to obtain infrared spectra of all objects within four well-studied extragalactic fields—AEGIS, COSMOS, GOODS-S and UDS—covering a total area of ~600 square arcmin. In parallel, observations were also done with the Advanced Camera for Surveys (ACS) which obtained optical spectra, effectively doubling the observing time and maximizing the use of Hubble. The spectroscopic information allows for a critical third dimension—the distance, which can be derived from the measured redshift—for some ~10,000 galaxies at $1<z<3$.

Due to the atmospheric opacity, infrared spectroscopy is still very challenging from the ground. By adding space-based spectroscopy on a massive scale to the data that already exists from photometric images, 3D-HST gives us a qualitatively new view of galaxies, specifically at redshifts from 1 to 3.

Former Yale Associate Research Scientist Ivelina Momcheva (now a support scientist at the Space Telescope Science Institute) and project manager for the 3D-HST survey, said, "3D-HST is exciting, because this is the first time we are getting a glimpse in this way at the Universe." She continued, "when you look at images from Hubble, you are seeing a 2-D view and you don't know what is distant and what isn't. By obtaining images at different wavelengths, we can get a good idea of the distances of galaxies. In 3D-HST, we combine images with spectra to obtain an order of magnitude better distance measurement than previously possible. Distance in astronomy is also time, because of the finite speed of light. If you can get the third dimension, not only can you get precise distance measurements, but you can also draw evolutionary links between distant and nearby galaxies to see what galaxies today may have looked like in the past."



The spectra for 20,000 3D-HST galaxies are collapsed into a single figure, above. Arrows point out absorption lines that indicate star formation activity, active galactic nuclei activity, and stellar age. A galaxy at z=3 is observed when the universe was 11.6 billion years younger. *Image by Gabriel Brammer, PhD '10.*

van Dokkum added, "Thanks to 3D-HST, we now have a pretty good idea of what the Universe looked like 10 billion years ago."

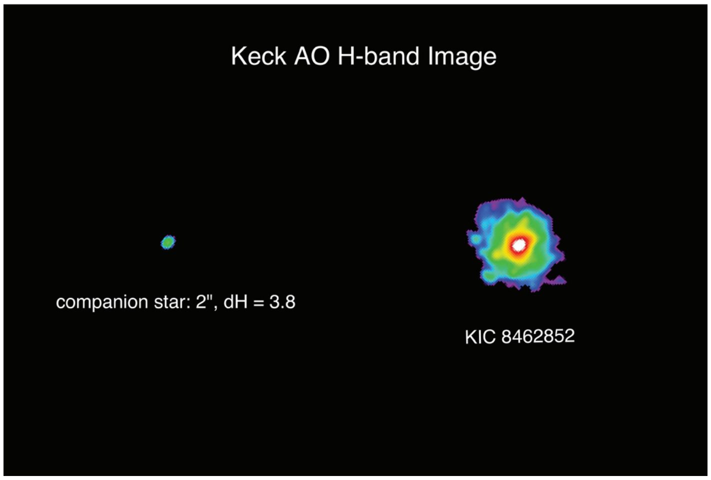
In addition to providing distance measurements of galaxies, the 3D-HST data allows astronomers to obtain measurements of physical properties such as galaxy masses, star formation rate, the rate of building metals in gas, and the rate of galaxy growth, information which is key to studying the creation and evolution of galaxies.

"Because of 3D-HST," Momcheva said, "we can now study the physical processes that shape galaxies at redshifts greater than 1, which is where most of the interesting things in the history of the universe happened, such as a peak in star formation and the growth of black holes. We are still trying to paint a coherent picture of what we are looking at and are starting to get glimpses of interesting scientific results."

Some of the science objectives that require the unique combination of high spatial resolution, deep near-IR (and supporting optical) spectra provided by 3D-HST include disentangling the processes that regulate star-formation in massive galaxies, evaluating the role of environment and mergers in shaping the galaxy population, and resolving the growth of disks and bulges, spatially and spectrally.

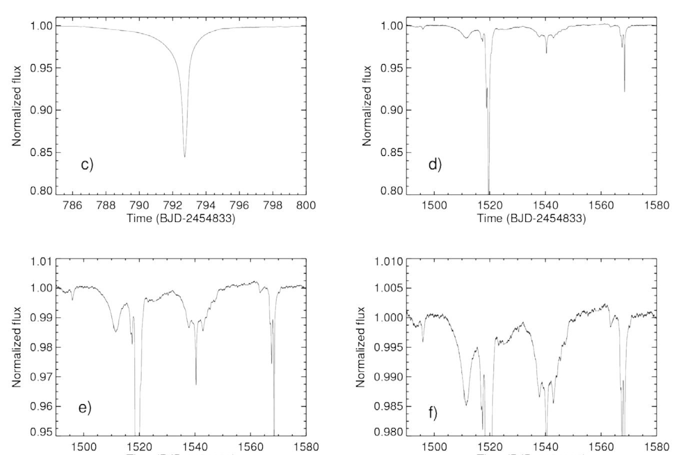
According to Momcheva, the data from 3D-HST give astronomers the same types of information for distant galaxies at high redshift that is already known about galaxies in the nearby universe, and make it possible for researchers to do an "apples to apples" comparison (***SEE 3D-HST, p. 7***)

“Tabby’s star” baffles astronomers and ignites the imagination



(***FROM STAR, p.1***) Boyajian tested as many possibilities and scenarios as she could think of for the cause of the anomaly. She investigated causes of intrinsic variation, such as a star rapidly rotating with an accretion disk (as Be stars do), and extrinsic variation, such as materials orbiting the star or collisions in an asteroid belt of two planetesimals. She even investigated possible technical issues and instrument artifacts with the assistance of the Kepler science team, who verified that the data is good and without technical issue.

The hypothesis that Boyajian came up with, after ruling out all other possibilities, was that something very large – or, more likely a large number of large objects – had to be orbiting the star in an eccentric orbit. Therefore, she decided that a swarm of comets was the most likely possibility, although she said, “it would have to be hundreds of comets that are all lined up perfectly at the same time in the transit that you can see.”



Plots showing the flux time series for different segments of the 4-year Kepler observations of KIC 8462852. Panel (c) is a blowup of the dip near day 793, (D800). The remaining three panels, (d), (e), and (f), explore the dips which occur during the 90-day interval from day 1490 to day 1580 (D1500). *Images courtesy of Boyajian.*

As is customary in astrophysical research, Boyajian posted her paper discussing her theory on the ArXiv pre-print server in September of 2015, with the hope that the astronomical community might weigh in on the issue and see if there were any other plausible theories of which others may have thought.

A fellow astronomer from Penn State University, Jason Wright, cited Boyajian’s paper in a paper that he wrote about the search for extraterrestrial civilizations as an example of possible evidence of alien megastructures. This claim was investigated in an article in the Atlantic, and was then picked up in a viral media storm of articles about the possibility. Even Saturday Night Live featured a spoof of the claim in its October 17th “Weekend Update.”

“Things got crazy for a while,” Boyajian said. “The story hit, it went viral, it was very overwhelming. I was getting texts from CNN, from people all over the world, and hundreds of Facebook friend requests. There’s even a Wikipedia page on the star now.”

Boyajian said that there is not enough information in the current data taken of KIC 8462852 to consider the possibility posed by Wright, and Wright himself said that the oddity of the star is not likely due to alien megastructure – that is the farthest possible hypothesis of his.

Since the media storm started in October, the American Association of Variable Star Observers (AAVSO) put out an alert on the star and about 50 or so amateurs are now monitoring it. There have been several other studies and papers from the astronomical community on the star, and Boyajian’s comet swarm scenario is still the leading idea of what astronomers think is happening.

“This is exactly what we wanted,” Boyajian said, “for the community to put in their efforts and try to figure out what it is.”

Boyajian will continue to study the star KIC 8462852 to gain more data to test her hypothesis of the comet swarm. She will have an observing run in early 2016 on a new instrument on the Green Bank Telescope, funded by Breakthrough Initiatives, to test the star some more to see if signs of extraterrestrial life can be ruled out as the cause of the anomaly. She also has proposed for Spitzer space telescope Director’s Discretionary (DD) time to study the infrared brightness of the star, which can be used to constrain information about any dust that may come from orbiting objects.

Because it is unknown whether the dips are periodic, and when the next one may occur, Boyajian needs all the telescope time she can get, in as many wavelengths as are possible, to monitor the star’s behavior. She is working to coordinate the community efforts to study the star by putting together an E-mail list of people interested in monitoring the target by using DD or Target of Opportunity (ToO) time.

How do you feed a hungry quasar?

The universe's oldest, brightest beacons may have gorged themselves in the dense, cold, gas flows of the early cosmos — creating a kind of energy drink for infant black holes in the young universe — according to new research by Yale Astronomy Professor Priyamvada Natarajan and fellow researcher Tal Alexander from the Weizmann Institute in Israel.

For years, scientists have tried to explain the intense luminosity of quasars in the early universe. Quasars' light is powered by swirling gas that is pulled in from the gravity of black holes. Located in the deepest precincts of space, the energy emitted by this infalling gas reveals the presence of black holes.

Yet the earliest quasars — those dating from when the universe was barely a billion years old (today the universe is 13.8 billion years old) — have proved baffling. Their brightness suggests they harbor black holes with a million times more mass than the Sun; scientists have been at a loss to understand how these behemoths assembled so rapidly, by cosmic standards.

"The first black holes are believed to be remnants left behind after the first stars burned out completely," said Natarajan. "The puzzle has been how these 'seed' black holes grew into the monsters that we now see within the time available, a few billion years at best."

Natarajan and Alexander have come up with a possible answer. Their analysis shows that early quasars took in a "super boost," feasting from large reservoirs of gas that were part of early star clusters.

The research appears in the journal *Science.*

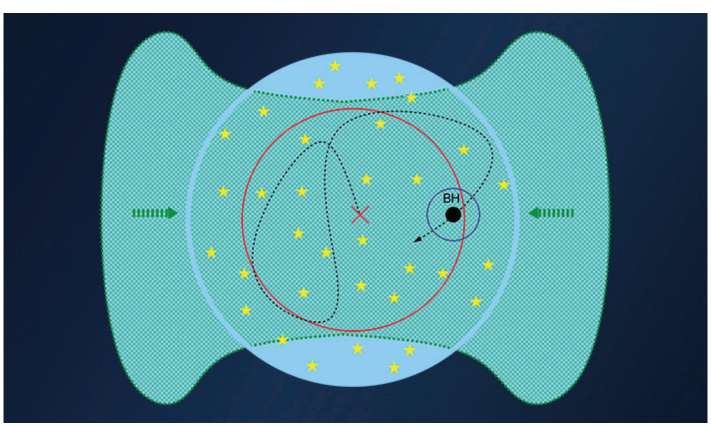
Natarajan and Alexander found that the robust, volatile nature of the early universe made such conditions quite likely. New black holes, they explain, were swept up into a celestial smorgasbord of gas in the star clusters that harbor them. This motion, in turn, circumvented normal restrictions that would prevent black holes from gorging on gas at a much-accelerated rate.

"There is a new way to super boost the growth of early black holes and make them very massive within a very short time in the early universe," Natarajan said.

The scientists discovered the mechanism for this feeding frenzy by combining their areas of expertise. Alexander works in stellar dynamics, and Natarajan has long studied the growth history of black holes.

"We realized that the setting where this kind of unbridled growth of initial seeds can occur was found to be commonplace in numerical simulations of the early universe," Natarajan said.

The research was supported in part by the National Science Foundation, with a grant from the Theoretical and Computational Astrophysics Network.



This graphic shows the center of a newly formed star cluster (stars are in yellow), within which the seed black hole gets its super boost of gas (shown in blue).

An artist's depiction of the heart of a quasar in the early Universe. *From spitzer.caltech.edu.*

Oesch goes the distance

Yale Postdoctoral Associate Pascal Oesch spends his days and nights working to find and confirm the most distant galaxies. Recently, his work has paid off in a record-breaking fashion.

In 2014, Oesch led an international team of astronomers in discovering four of the most luminous galaxy candidates yet seen, at a time when the Universe was only ~700 million years old, using photometry from combined images from NASA's Hubble Space Telescope (HST) and Spitzer space telescope.

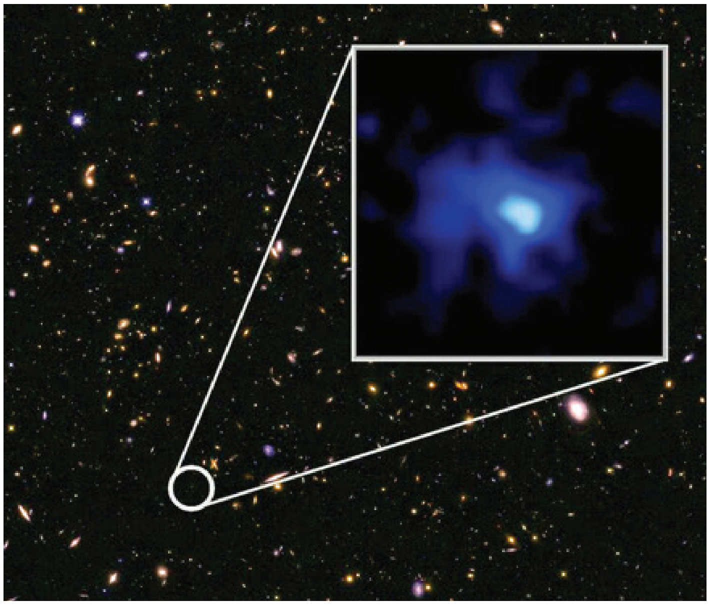
Oesch and his team then used MOSFIRE at the W. M. Keck Observatory in Hawaii to confirm the redshift of these four candidates.

In May 2015, Oesch revealed in a publication in *Astrophysical Journal Letters* (ApJL) that one of these galaxy candidates, EGS-zs8-1, was the most distant galaxy ever measured and confirmed spectroscopically. Oesch's discovery therefore pushed back the frontier of galaxy exploration to a time when the universe was only 5 percent of its present age of 13.8 billion years.

Oesch found that EGS-zs8-1 was born about 670 million years after the Big Bang and had been forming stars very rapidly for at least 100 million years, at a rate 80 times faster than our Milky Way galaxy today (which has a star formation rate of one star per year). He also determined that EGS-zs8-1 is one of the brightest and most massive objects in the early universe.

"We saw the galaxy as it was 13 billion years ago; it had already built more than 15 percent of the mass of our own Milky Way today," said Oesch. Still, Oesch continued, these galaxies "are tiny compared to today's."

According to Oesch, the galaxies in the early Universe were very different than those in the present time. Back then, the young galaxies had just started to form their first stars. The peak of star formation in galaxies happened at about 3.5 billion years after the Big Bang (z~2) and, since then, galaxies have formed fewer and fewer new stars. Understanding this so-called "cosmic star formation history" is a major goal for extragalactic astronomy.



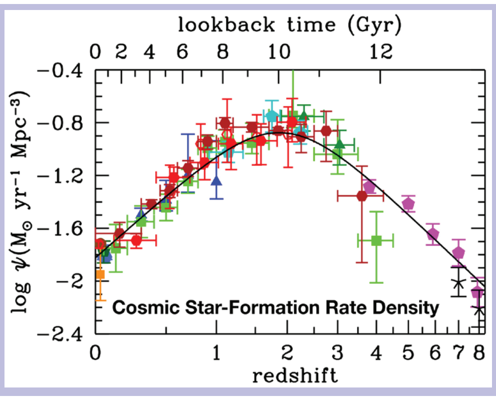
The galaxy EGS-zs8-1 sets a new distance record. *Image by NASA, ESA, P. Oesch, I. Momcheva, & the 3D-HST and HUDF09/XDF teams.*

Oesch said that there were very few chemical elements beside hydrogen and helium in the intergalactic medium of the early Universe, and that he and other astronomers are working to understand when and how star formation started in these primordial galaxies.

"It appears that the young stars in the early galaxies like EGS-zs8-1 were the main drivers for . . . reionization," said Oesch's collaborator Rychard Bouwens of the Leiden Observatory. The epoch of reionization marks a pivotal time when the Universe underwent its last major phase transition from being neutral to being ionized.

Only a handful of galaxies currently have accurate distances measured in this very early Universe. Finding these earliest galaxies, which are progenitors of the galaxies that exist today, and analyzing their properties may help to determine the origin of galaxies and everything that exists in the Universe.

"Every confirmation adds another piece to the puzzle of how the first generations of galaxies formed in the early universe," said Yale Astronomy professor Pieter van Dokkum, the second author of the May 2015 paper.



The rate at which galaxies form stars and build up their mass changed dramatically over cosmic history. Yale astronomers are pushing these measurements to the most distant galaxies, reaching as far back as 97% of cosmic history. In the early Universe, galaxies were much younger and less massive than today, but they were producing stars at a comparable rate to galaxies today. The peak epoch of star-formation activity was about 10 billion years in the past, or at redshift z~2. It is still an active area of research why and how this activity slowed down to today's Universe. *Figure adapted from Madau & Dickinson 2014.*

Ivelina Momcheva, then a Yale Associate Research Scientist, conducted part of the MOSFIRE observations for the May 2015 result.

In September of 2015, Oesch's collaborator, Adi Zitrin, from the California Institute of Technology published, again in ApJL, that the team had spectroscopically confirmed an even more distant galaxy, EGSY8p7 from the same sample of candidates they had used to find EGS-zs8-1.

Measuring galaxies at extreme distances and characterizing their properties will be a major objective over the next decade, the researchers said.

"In the past, it was really difficult to measure distances," Oesch said. "Candidate galaxies at these epochs have been known for a while, but measuring them has been very hard work. It seems that we've found a good way to select a subsample for which distance measurements are possible – highly star forming with strong emission lines."

In addition to discovering and measuring the distance of galaxies, Oesch analyzes their physical properties to build a more accurate and complete picture of how galaxies across cosmic time were building up as a population. In July of 2015, he published a result in *The Astrophysical Journal* that constrained the cosmic star formation rate density (SFRD) between z~8 and z~10 in the first 500 million years of cosmic history.

Oesch is also the PI for the Hubble Deep UV (HDUV) Legacy Survey, a program that uses HST to obtain deep UV images and provides the first complete census of low-luminosity star forming galaxies at z~0.5-2. Understanding how these galaxies evolve across the epoch of peak cosmic star-formation is key to a complete picture of galaxy evolution. In addition, the data from the survey are made public for others in the astronomical community to use.

"The HDUV survey directly connects the most distant galaxies at z~10 with the faint star-forming sources at the peak of cosmic star-formation by enabling a homogeneous selection across cosmic time," Oesch said.

Oesch's work is record-breaking, but it is also crucial to answering the questions currently being asked by extragalactic astronomers about how star formation began, why it peaked and why it has steadily declined to the present time.

Oesch and his collaborators have also recently created a new image of the Hubble Ultra Deep Field, called XDF, that provides the deepest view of the Universe ever. *Image by G. Illingworth, D. Magee, P. Oesch, R. Bouwens and the XDF Team.*

New department website

The Astronomy Department has a completely revamped website, with a new URL of astronomy.yale.edu, which came online in October of 2015.

The new website was created on Yale's Drupal 7 platform, called YaleSites. Users report that it is much more user-friendly and up to date than the previous website.

3D-HST survey goes public

(***FROM 3D-HST, p.3***) by studying the same properties and probing the same diagnostics that have been done at lower redshifts for large, representative and complete samples of galaxies.

Thus far, there have been 43 publications from the 3D-HST team, with 10 additional papers coming from collaborators in the MOSDEF, VIRIAL and KMOS3D surveys.

The 3D-HST team organized a special session at the January 2015 American Astronomical Society meeting and a conference at Yale in October of 2015 (see article, p. 17) to highlight the scientific endeavors possible with the new dataset.

3D-HST's international team of 48 scientists is led by van Dokkum. One third of the team have been members of the Yale Astronomy Department during the time of the survey. Along with Momcheva and van Dokkum, the main architects of the survey and its data products were Gabriel Brammer, PhD'10, Katherine Whitaker, PhD'12, and Rosalind Skelton (then a Postdoc at Yale). Also involved were Britt Lundgren and David Wake (then Postdocs at Yale), as well as Rachel Bezanson, PhD '13, Tomer Tal, PhD '12, Erica Nelson, GRD '16, and Joel Leja, GRD '16.

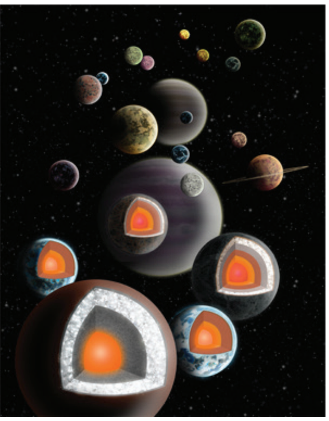
The data products from 3D-HST include extracted spectra, redshifts, emission line fits, stellar masses, images, redshift catalogs, spectroscopy catalogs, photometry catalogs, and multiwavelength ancillary images based on publicly-available datasets. 3D-HST data products are available to the public on the 3D-HST website at: 3dhst.research.yale.edu.

YALE ASTRONOMY

Arce featured in CBS show "60 minutes" for ALMA study *(March 9, 2014)*

"ALMA: Peering into the Universe's Past" aired Sunday March 9, 2014 on the CBS show "60 Minutes." The work of Yale Astronomy professor Hector Arce was shown several times during the segment.

Diamond planets may be more common than astronomers thought *(May 12, 2014)*


Haven Giguere

Carbon-rich planets may be more common than previously thought, according to new research by Yale astronomers, led by John Moriarty, GRD '16. Some of these planets, all located far beyond Earth's solar system, could contain vast deposits of graphite or diamonds, and their apparent abundance prompts new questions about the implications of carbon-intense environments for climate, plate tectonics, and other geological processes, as well as for life. (*The Astrophysical Journal*)

Through the cosmic looking glass: Astronomers confirm farthest lensing galaxy *(July 31, 2014)*

Yale Postdoctoral Associate Ivelina Momcheva sifted through a maze of data, piecing together clues that allowed her and her colleagues to confirm the existence of the farthest known example of a "gravitational lensing galaxy," a phenomenon caused when a galaxy's gravity warps and magnifies the light from objects located behind it. In this case, the discovery also offers hints at early galaxy formation.

How do you feed a hungry quasar? *(August 7, 2014)*

The Universe's oldest, brightest beacons may have gorged themselves in the dense, cold, gas flows of the early cosmos - creating a kind of energy drink for infant black holes in the young universe - according to new research by Yale faculty member Priyamvada Natarajan and Tal Alexander of the Weizmann Institute in Israel. Their analysis shows that early quasars took in a "super boost," feasting from large reservoirs of gas that were part of early star clusters. (*Science*)

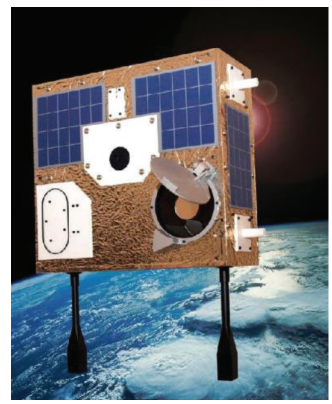
Yale scientists see the birth of a massive galaxy, hidden by dust *(August 27, 2014)*

Galaxy formation theories have suggested that the Universe's heaviest galaxies develop from the inside out, forming their star-studded, central cores during early cosmic epochs. Scientists had, as yet, never been able to observe this core construction. Erica Nelson, GRD '15 and her collaborators used combined Hubble and Keck observations to discover a galaxy with the most rapidly orbiting gas clouds ever measured, definitive evidence of a massive galaxy in the midst of core formation. (*Nature*)

Planet Hunters v2.0 now online *(September 18, 2014)*

A team, led by Professor Debra Fischer, has released Planet Hunters v2.0, which enables the public to assist in searching data from NASA's Kepler spacecraft (K2) for potential planet candidates, with the aim to derive planet occurrence rates as a function of spectral type. Version 1 has already discovered a large number of planet candidates as well as confirmed several planets, with the assistance of nearly 300,000 volunteers from all around the world.

Yale astronomers take over operation of MOST satellite to gain precision in exoplanet discovery *(October 9, 2014)*



Yale exoplanet hunters took over operation of the Canadian Microvariability Oscillation of STars (MOST) space satellite from October 10th to December 10th, 2015 to observe two bright stars: tau Ceti and epsilon Eridani. They simultaneously observed these stars with the ground-based CHIRON spectrometer that they had built for the SMARTS 1.5-m telescope in Chile. The synergy of high precision photometry from space and high precision velocity measurements from the ground is a first for astronomers in the exoplanet field. The goal is to understand photospheric signals that are obscuring the precision of velocity measurements.

Fireball in space reveals nature of novae *(October 28, 2014)*

For the first time, scientists have measured the size and structure of a nova's nuclear blast as it happened - thanks, in part, to Yale Postdoctoral Fellow Tabetha Boyajian's timely observations of Nova Delphini 2013 just after its explosion on August 14, 2013. The data collected on this nova could well sharpen or reshape our understanding of the nature of such blasts. (*Nature*)

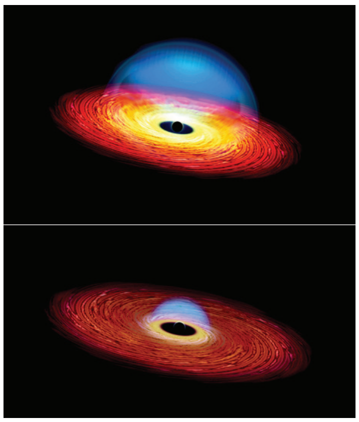
Yale Planet Hunter team discovers low-density planet that won't stick to a schedule (*October 29, 2014)*

Yale astronomers, led by Joseph Schmitt, GRD '18, and the Planet Hunter program have found a low-mass, low-density planet with a punctuality problem. The new planet, called

IN THE NEWS

PH3c, nearly avoided detection because of a highly inconsistent orbit time around its sun, due to the gravitational influence of other planets in its system, which kept it from being picked up by automated computer algorithms that search stellar light curves and identify regular dips caused by objects passing in front of stars. (*The Astrophysical Journal*)

Black hole on a diet creates a 'changing look' quasar *(January 22, 2015)*



Michael S. Helfenbein

Yale University astronomers, led by Associate Research Scientist Stephanie LaMassa, have identified the first "changing look" quasar, a gleaming object in deep space that appears to have its own dimmer switch. Until now, scientists have been unable to study both the bright and dim phases of a quasar in a single source. The findings may prove invaluable because they both provide direct information about the intermittent nature of quasar activity and they hint at the sporadic activity of black holes. (*The Astrophysical Journal*)

Astronomers discover a replica solar system *(January 27, 2015)*

An international research group, including Yale professors Sarbani Basu and Debra Fischer, has located an ancient solar system, dating back to the dawn of the Galaxy, which appears to be a miniature version of the inner planets in our own solar system and the oldest known system of terrestrial-sized planets. (*The Astrophysical Journal*)

Yale joins new NASA team searching for life outside the solar system *(April 23, 2015)*

NASA has enlisted Professor Debra Fischer and her research group in the Nexus for Exoplanet System Science (NExSS), a national collaboration of scientists that seeks a new approach for discovering life on extrasolar planets.

van Dokkum discovers "fluffiest galaxies" *(May 15, 2015)*

Pieter van Dokkum has discovered the most diffuse class of galaxies known in the universe, along with his team of international researchers. These "fluffiest galaxies," found in the Coma cluster, are nearly as wide as our own Milky Way galaxy – about 60,000 light years – yet harbor only one percent as many stars. Additionally, these galaxies seem to be made almost entirely of dark matter, with less than 2% of the mass in the form of normal matter; the cause is still a mystery, but the most likely scenario is that they are "failed galaxies." The findings were made using van Dokkum's own Dragonfly Telephoto Array and the W.M. Keck Observatory. (*The Astrophysical Journal Letters*) (See page 16 for more.)

Galactic crashes fuel quasars, study finds *(June 18, 2015)*

Professor C. Megan Urry's research team has solved the mystery of the origin of quasars. Using infrared imaging from the Hubble Space Telescope, they confirmed that quasars are born when galaxies crash into each other and fuel supermassive, central black holes. (*The Astrophysical Journal*)

Astronomers find a massive black hole that outgrew its galaxy *(July 9, 2015)*

An international team of astronomers, including the research group of Yale Professor C. Megan Urry, have spotted a super-sized black hole in the early universe that grew much faster than its host galaxy. The black hole, located in the normal-sized galaxy CID-947, is among the most massive black holes ever found, measuring nearly 7 billion solar masses. The discovery runs counter to most observations about black holes. In most cases, black holes and their host galaxies expand at the same rate. The team's findings also challenge earlier suggestions that the radiation emitted by expanding black holes curtails the creation of stars, as stars were still forming in CID-947. (*Science*)

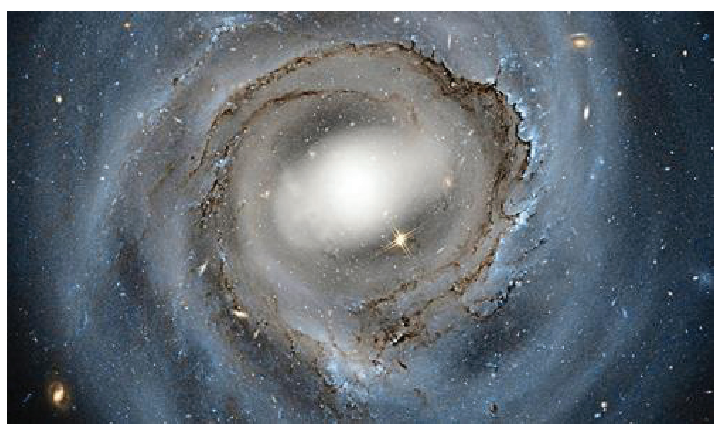


Image courtesy of NASA, ESA, and Roberto Colombari

Dust pillars of destruction reveal impact of cosmic wind on galaxy evolution *(July 27, 2015)*

Yale astronomer Jeffrey Kenney has developed an unprecedented, clear snapshot of how powerful cosmic winds can blow through galaxies, sweeping out interstellar material and stopping future star formation. Kenney analyzed Hubble images of a spiral galaxy in the Coma cluster. (*The Astronomical Journal*) - ***NEWS CONTINUES on p. 10.***

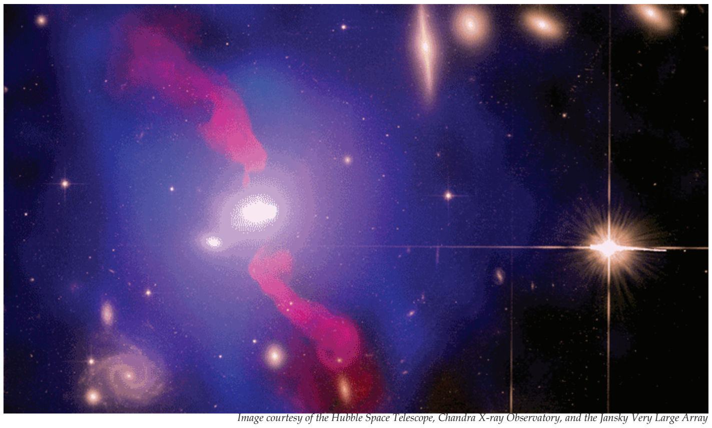


Image courtesy of the Hubble Space Telescope, Chandra X-ray Observatory, and the Jansky Very Large Array

Sorting through thickets of stars in elliptical galaxies *(August 6, 2015)*

Postdoctoral Associate Grant Tremblay has helped untangle the cosmic knots of stars at the center of giant, elliptical galaxies. Two studies, one led by Tremblay on galaxies in the nearby universe and the other led by Michigan State University researcher Megan Donahue on galaxies in the more distant universe, are providing new information about why the Universe's largest elliptical galaxies ratchet down their star production despite having plenty of available star-making material. The researchers detect a self-regulating cycle of star births within elliptical galaxies, indicating that galactic collisions and other extreme cosmic events are not always necessary for the creation of showers of new stars. (*Monthly Notices of the Royal Astronomical Society*)

NASA, ESA and the HST Frontier Fields Team

Smallest galaxies yielding big answers *(October 22, 2015)*

An international research team led by Postdoctoral Associate Hakim Atek recently discovered more than 250 distant galaxies, including some of the faintest, smallest galaxies in the universe. The team relied upon new images from the Hubble Space Telescope, focusing on a trio of cosmic magnifying glasses. The research represents one of the largest samples of dwarf galaxies ever discovered from the early universe. The data suggests the Universe became fully transparent about 700 million years after the Big Bang. (*The Astrophysical Journal*)

"Star Gazing at the Yale Observatory" featured on CT STYLE *(October 20, 2015)*

Dr. Michael Faison, the Director of Yale's Leitner Family Observatory and Planetarium spoke to CT STYLE about Yale's White House Astronomy Night star watch party, Mars, life in the Universe and telescopes.

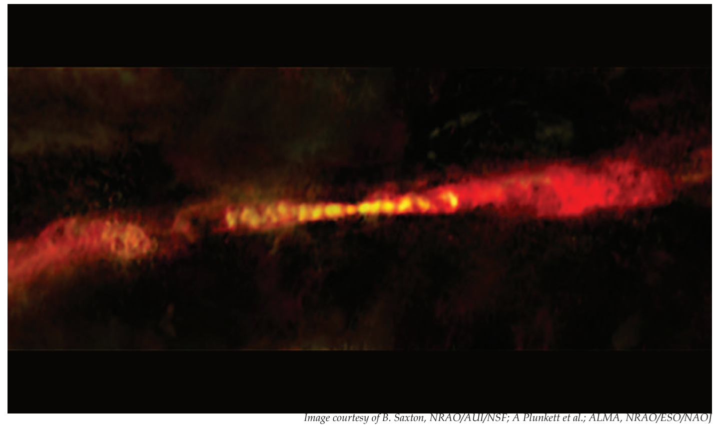


Image courtesy of B. Saxton, NRAO/AUI/NSF; A Plunkett et al.; ALMA, NRAO/ESO/NAOJ

Growing pains in a cluster of protostars *(November 4, 2015)*

A Yale-led study has found a cluster of young stars that develop in distinct, episodic spurts. It is the first time astronomers have seen such a growth pattern within a star cluster. Previous observations have focused on stars forming in more isolated regions of space. The first author of the paper is Adele Plunkett, PhD '15. (*Nature*)

We've got the beat: Astronomers measure the pulse of a distant galaxy *(November 16, 2015)*

For the first time, astronomers at Yale and Harvard, including Professor Pieter van Dokkum, have measured the effect that pulsating, older red stars have on the light of their surrounding galaxy by studying a series of HST images of the galaxy M87. At later stages in their lives, stars begin to pulsate, increasing and decreasing their brightness every few hundred days. Until now, no one had considered the effects of these stars on the light coming from more distant galaxies. The researchers found that 25% of the pixels in the HST image of M87 go up and down in brightness, as if the galaxy had a heartbeat. The mean pulse of the stars in M87 is about one beat every 270 days. (*Nature*)

Yale renews agreement with University of Chile for joint research program; extends offerings to all Chilean institutions

The Yale Astronomy Department has renewed its agreement with the Astronomy Department of the University of Chile (Calán) for a comprehensive program of research collaboration for another three years, effective May 19, 2015.

The program includes support for graduate student visits between Yale and Calán; shared Postdoctoral Associates; short-term visits of students, postdocs and faculty to Chile; and Yale's undergraduate summer research program in Chile.

"This agreement marks a new milestone in the long period of working together to continue to deepen the ties between our departments of astronomy," said Dr. Guido Garay, the Director of the astronomy department at Calán.

Yale and Calán have run a joint program of graduate education and research in astronomy since 1999. Successes of the joint research program include PhDs for Chilean students, many scientific publications, and significant recognition for both departments throughout both South and North America.

Garay and Yale Astronomy Chair Pieter van Dokkum.

From 1999-2006, the program was jointly funded by Yale, The University of Chile, and Fundación Andes, which sponsored cultural and educational enterprises in Chile. In 2006, Fundación Andes dissolved. Yale University has been supporting the program since 2006.

As of May 2015, two aspects of the program are now also offered to researchers from all Chilean institutions: the Yale-Chile Graduate Student Visiting Scholarships in Astrophysics and the Yale-Chile Joint Postdoctoral Fellow Program in Astrophysics.

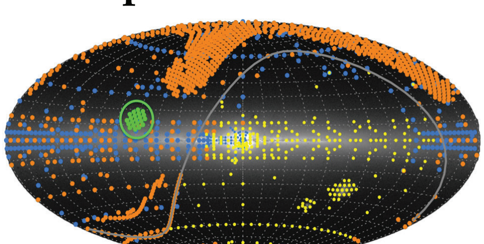
The **Yale-Chile Graduate Student Visiting Scholarships in Astrophysics i**nvites Chilean students to apply to come to Yale for 5-10 months to attend courses, do a research project, or both.

Accepted students are awarded a stipend supplement to their Chilean stipend so that the student's total stipend is comparable to that of a Yale graduate student, round trip airfare between Chile and New Haven, and payment of student visa and health insurance fees.

Faculty members from Yale and any Chilean institution can jointly propose for funding to help support **Yale-Chile Joint Postdoctoral Fellows**. Postdocs will spend their appointment period partly in Chile and partly at Yale, with the host institution paying the expenses of the Postdoc (i.e., salary, health insurance and visa fees) during the Postdoc's stay.

For more information on the renewed and expanded joint research programs, please see the website at http://astronomy.yale.edu/research/joint-research-programs.

Yale expands access to astronomical resources with SDSS-IV membership



The planned APOGEE-2 survey area overlain on an image of the Milky Way. Each dot shows a position where APOGEE-2 will obtain stellar spectra. *From sdss.org.*

The Yale Astronomy Department has become a fully participating member of the Sloan Digital Sky Survey (SDSS) IV.

SDSS has had four iterations, beginning in 2000. Yale joined SDSS-III in 2010 and has greatly benefited from the immediate access to the data—since 2010, Yale authors have been on 495 refereed papers using SDSS data—so it was a logical move to continue membership in SDSS-IV, which began in 2014. According to the SDSS website, www.sdss.org, SDSS-IV has three sub-surveys within it: eBOSS (surveying galaxies and quasars to measure the Universe), APOGEE-2 (Exploring the Milky Way from both hemispheres), and MaNGA (mapping the inner workings of thousands of nearby galaxies).

New Astronomy mansions provide sense of community, history

(***MANSIONS, from p.1***) While the astronomers are now physically separated from each other by being in different buildings, there is still a great sense of community and collaboration that unifies them. One thing that helps with this is the newly established daily morning coffee hour the Astronomy Department hosts in the Steinbach Hall "coffee house."

The Astronomy Department had been in Gibbs since 1975. Previous to this, the department was headquartered in a brick building at 135 Prospect Street, and before that, at the Yale University (Winchester) Observatory on the corner of Prospect and Canner Streets. (See also history article, p. 28.)

Josiah Willard Gibbs Laboratories.

Bibliography

http://nhpt.org
http://historicbuildingsct.com
http://www.architecturalcomponentsinc.com

Thomas M. Evans Hall at 56 Hillhouse Avenue.
Image from http://historicbuildingsct.com.

The Skinner-Trowbridge house at 46 Hillhouse Avenue.
Photo by Michael Marsland, Yale University Photographer.

More on the mansions:

In 1792, James Hillhouse developed a residential street on his farmland, which then became Hillhouse Avenue. Yale eventually acquired all but two of the buildings on the street for University facilities.

Aaron N. Skinner built what is now known as the **Skinner-Trowbridge house** at 46 Hillhouse Avenue in 1832 using the Greek Revival design of the architects Ithiel Town and Alexander Jackson Davis. Skinner founded and ran a boys' school in the house. He sold the house in 1858 to Judge W.W. Boardman, who had the house renovated, likely by Henry Austin, adding a second story and Victorian detailing. In 1907, Rutherford Trowbridge bought and expanded the house once again, adding a dining room, a porch and a two-story kitchen.

In 1978, Yale acquired the Skinner-Trowbridge mansion after the passing of Rachel Trowbridge. In 1999, the building was renovated again by Helpern Architects, and the Yale School of Management (SOM) opened its International Center for Finance in the mansion.

Steinbach Hall at 52 Hillhouse Avenue was built in 1849 for John Pitkin Norton according to a design by the architect Henry Austin that was inspired by a drawing of an Italian villa by Andrew Jackson Downing. Yale purchased the building in 1923 and renovated the exterior in 2003 for SOM.

Thomas M. Evans Hall, built in 1837 at 56 Hillhouse Avenue, was also designed by Alexander Jackson Davis for the widow Elizabeth Apthorp. Davis described the house as an "Etruscan Villa," although it originally combined Greek Revival and Egyptian Revival features. It has since been renovated a lot, with a variety of architectural styles. At one point, Yale President Timothy Dwight lived in this building with his family. Evans Hall was renovated in 2001 by Yale for SOM.

SOM moved out of these three mansions when its new building, Edward P. Evans Hall, opened in January 2014.

Yale Astronomy Department will offer summer program in astrophysics

Yale's Department of Astronomy is launching the Yale Summer Program in Astrophysics (YSPA), an innovative program for high school students that combines rigorous study and research with an immersive learning environment. The inaugural program will be held at Yale's Leitner Family Observatory and Planetarium July 10 through August 7, 2016.

YSPA is a four-week residential research and enrichment program for 28 rising high school seniors who are interested in math, science, computer programming, and other tech fields. Students will take classes in physics, math, and astronomy; complete a scientific research project using telescopes at Yale; learn the basics of computer programming and data science; and present their results at the end of the program, which will be offered annually.

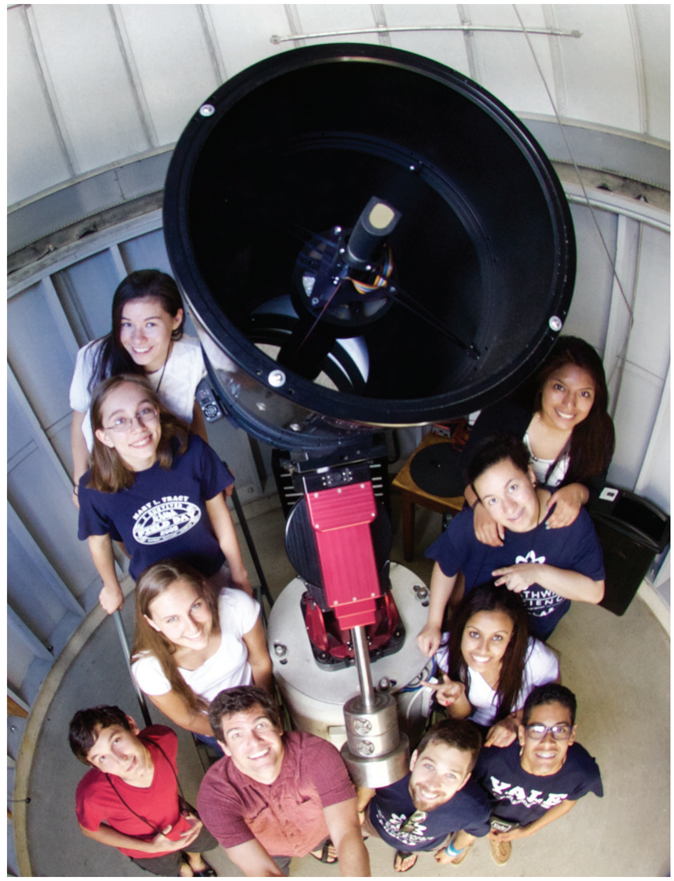
Michael Faison, YSPA's academic director and founder, said the program is designed "to find exceptionally bright high school students from around the world who maybe haven't been challenged at their home schools, bring them to Yale, let them interact as much as possible with each other and our talented faculty, give them a challenging curriculum and research project to complete, and let them find out for themselves what they can accomplish. This type of experience can be a huge boost to their self-confidence, and it gives them a big head start on college and a career in science."

The main goals of YSPA are: to provide students with the opportunity to be academically and personally challenged in a professional scientific research setting; to accelerate the personal growth of students by giving them the opportunity to live and work in a university environment with other high school seniors from around the world who have similar interests in math and science; and to teach students practical skills in math, computer programming, data analysis, statistics, writing, and research methods—skills that are essential in all science, engineering, and tech fields.

"In the YSPA curriculum, we do teach practical skills," Faison said, "but even more importantly, we teach the students patience, attention to detail, teamwork, and how to plug away at a real scientific research problem and make progress when the answers aren't in the back of the textbook."

YSPA program coordinator Kimberly Nucifora said that in addition to academics, the program's social environment will be unique. "YSPA sets up a close community of scholars for the duration of the program, and this community will continue with students and faculty keeping in touch with each other long after the program is over," Nucifora said. "There are quite a few opportunities for fun enrichment activities embedded into the YSPA program, including guest lectures, movie nights in the planetarium, field trips off campus, and lots of other fun activities around Yale and New Haven."

Yale's on-campus observatory and planetarium gives the program an added dimension, according to Faison. "The Leitner Family Observatory and Planetarium at Yale is a fantastic facility for an intensive summer program like this," he said. "We will have classes in the planetarium theater, which will allow us to use the planetarium projector as an instructional tool. Students will use our 16-inch and 12-inch telescopes to collect data with their research teams in our computer lab. Having everything we need in one place will make things go much more smoothly, and the students can take over the building for the four weeks of the program and make the space their own."



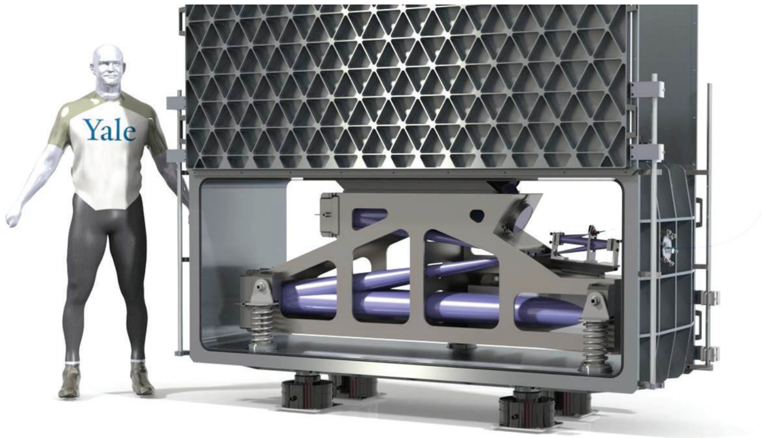
YSPA academic director Michael Faison with summer students in front of the 16-inch Ritchey-Chrétien telescope at the Leitner Family Observatory and Planetarium. *Photo by Michael Faison.*

Students in the program are required to complete a two-week online study course before the residential program begins. The YSPA application deadline for students in the United States is 8 pm ET on March 6, 2016; for international students, the application deadline is February 7, 2016. Need-based financial aid of up to 50% is available for those accepted into the program.

For more information, visit yspa.yale.edu.

This article includes text written by Michael Faison.

Yale Exoplanet group on EXPRES train to finding 100 Earths



The Yale Exoplanets instrumentation group, led by Yale Astronomy Professor Debra Fischer, is developing technologies that support the discovery and characterization of planets in the solar neighborhood for Fischer's 100 Earths Project.

According to group project manager and systems engineer Dave Sawyer, an Associate Research Scientist at Yale, there are three categories of technologies that the Exoplanets group is currently developing: instruments for high precision radial velocity measurements, wavelength calibrators (called a tunable Fabry-Perot Frequency comb) that provide accurate reference lines for the instruments, and the software and algorithms that allow for calibration, reduction and analysis of the data obtained by such instruments.

The team designed and built the CHIRON spectrometer that is on the SMARTS 1.5m telescope at the Cerro Tololo Interamerican Observatory in 2011 and the MAO spectrometer for the 1.65m telescope at the Moletai Astronomical Observatory in Lithuania in 2015.

Currently, the team is designing an extremely stable high resolution spectrometer for the 4.3m Lowell Observatory Discovery Channel Telescope (DCT) in Arizona, called the Extreme Precision Spectrometer (EXPRES).

The design of EXPRES applies the lessons the team learned from building the two other spectrometers, combined with lessons learned from other high precision radial velocity spectrographs that have been built by the planet-hunting community.

Because EXPRES is being designed to be able to detect and characterize extrasolar planets, with an even more specific intention to search for Earth-like planets, it needs extraordinary resolution, wavelength coverage and radial velocity precision. The instrument, when completed, will have an extremely high resolution of 150,000 and aims for an unprecedented radial velocity precision of 10 centimeters per second using a laser frequency comb for broad wavelength calibration from 390-680nm. The EXPRES instrument is therefore well-positioned to discover and characterize the first Earth analog planet.

Sawyer said, "EXPRES will take radial velocity measurements to the next level of precision and provide an unprecedented resolution to allow absorption line structures to be probed in more detail than any other spectrograph."

A velocity variation of 10 cm/s is the goal for a spectrometer searching for Earth-like planets because 10 cm/s is equivalent to the force the Earth exerts on the Sun, as detectable by a wobble in the spectrum of the Sun. Achieving this type of precision is challenging, especially as the surfaces of stars have gases that have much larger velocity variations of hundreds of meters per second that can obscure the smaller velocity variations. Only an instrument with very high resolution, such as EXPRES, may make it possible to distinguish between the "noise" from the surface of the star and a wobble caused by a planet. EXPRES also goes further than previous spectrometers because it is designed to track, measure, and decorrelate the sources of stellar noise.

The design of EXPRES is also unique because it is using a novel frequency comb that is inherently precise. Due to time and funding constraints, a laser frequency comb is being provided by an external vendor, but the Exoplanet Lab, led by Tyler McCracken, an Associate Research Scientist, is currently developing cutting-edge technology for a next-generation wavelength calibrator: a stabilized Fabry-Perot, which creates a regular pattern of emission lines, locked to a hyperfine laser line.

According to Sawyer, EXPRES will be delivered to the DCT in two parts so that they can perform some testing and optimization of the "front end" module and be able to simply plug in the "back end" module when it arrives. The team is in the final design stage of and starting to build the front end module— the part of the instrument that attaches to the telescope and focuses the light into the fiber that feeds the spectrometer. This module includes a fast tip-tilt adaptive optics system that decreases image motion and keeps the light stable on the fiber as well as an atmospheric dispersion compensator to correct for atmospheric refraction. The front end will be installed in September 2016. The back end module, which includes the spectrograph, calibration sources and a double scrambler for the fiber, is in the preliminary design phase and is due to be delivered to DCT in May or June of 2017.

Colby Jurgenson, also an Associate Research Scientist, is the instrument PI who oversees all aspects of the instrument design. Jurgenson is in charge of the optical design of EXPRES. Astro Electro-Mechanical Engineering does the mechanical design around the optical design and develops the fabrication drawings to the specifications set by the team. Once designed, the drawings are sent out to be fabricated – some to the machine shop at Yale and some to external vendors. All pieces and parts of the instrument come back to Yale and the Exoplanet team assembles and tests the instrument in the lab before shipping it to the telescope.

Parts of the instrument that take a long time to fabricate have already been ordered. These include the Echelle grating, which was recently delivered to Yale, the CCD system, and the laser frequency comb.

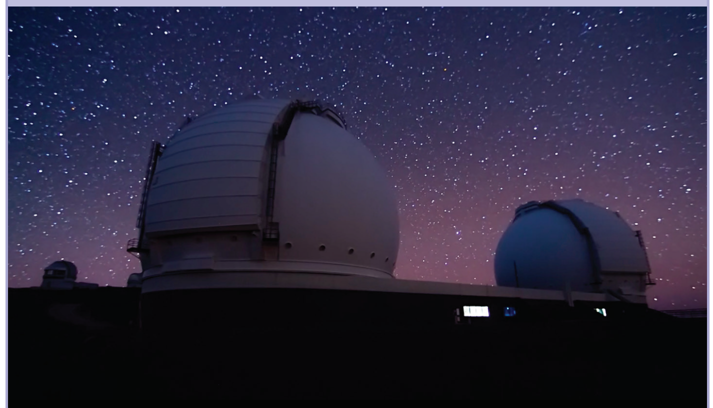
Excellent instrumentation such as EXPRES will make Fischer's 100 Earths project – a program searching for "100 Earths" in the solar neighborhood – possible. Nothing like this has ever been done before in the field of exoplanets, and finding such a large sample size would allow scientists to study the occurrence of carbon-based life on other rocky planets, and might even provide direction for human space exploration.

Fischer said, "In the last two decades, exoplanets have exploded onto the scene in astronomy. The future of exoplanet science has very different trajectories depending on the precision that can ultimately be achieved with Doppler measurements and we are pioneering extreme precision in the Exoplanet Lab at Yale. We hope to detect analogs of Earth around nearby stars so that the next generation of space missions can literally detect the weather—and perhaps life—on these worlds. "

EXPRES is funded by the NSF MRI program with co-PIs Fischer and Jurgenson.

Screenshot from a time-lapsed video of the Exoplanets team assembling the MAO spectrometer. *Courtesy of Yale Astronomy Department and Build Pictures.*

Yale Astronomy film premiere



The Yale University Astronomy Department has engaged Jonathan Robinson of BuildPictures to produce a film featuring the work and life of the department.

The film, titled *Astronomy at Yale*, shows how Yale astronomers are working to answer some of the biggest questions in Astronomy, ranging from the structure of the Universe to the search for Earth-like planets orbiting other stars. It is narrated by the people who are doing the science, and highlights how Yale's unique environment and resources are key to the success of the program.

Astronomy at Yale will premiere at the department on February 5, 2016 and will be made available to the public on the Astronomy Department website in March 2016. There will also be two private screenings in mid-February.

The film is intended to appeal to a wide audience and be of interest to prospective students, alumni and people with a general interest in contributing to Yale. It was made possible by the generous support of Pieter van Dokkum, Debra Fischer, Marla Geha, the Yale Astronomy Department and the Yale Provost's office.

van Dokkum's Dragonfly keeps an eye on the sky

Professor Pieter van Dokkum of Yale and Roberto Abraham of the University of Toronto have designed and built an innovative and unique telescope optimized for ultra-low surface brightness imaging at visible wavelengths. The telescope has moved the boundaries of what kind of phenomena in the night sky astronomers are able to explore.

The Dragonfly Telephoto Array (Dragonfly) is a robotic imaging system located at New Mexico Skies, consisting of 24 Canon telephoto lenses with unprecedented nano-fabricated coatings to suppress internally scattered light (which hides faint galaxy structure in even the largest, most advanced research telescopes).

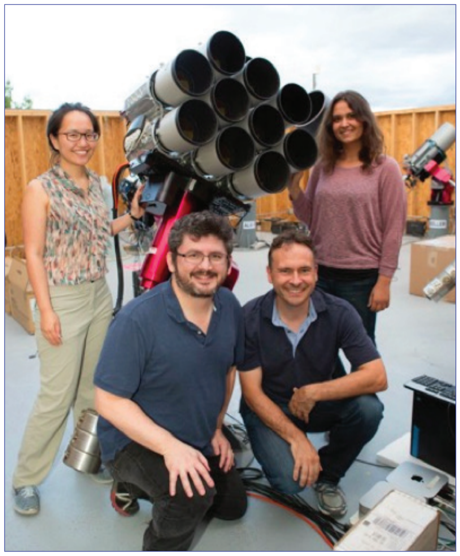
"These are the same kind of lenses that are used in sporting events like the World Cup. We decided to point them upward instead," van Dokkum said.

Each lens is paired with its own science-grade commercial CCD camera, and the telescope has custom software for instrument control and robotic operation. The system is mounted on a common framework on an equatorial mount with all lenses co-aligned and pointing at the same position in the sky.

Dragonfly was commissioned in 2013 with only three lenses. The array currently is undergoing an upgrade to bring the total to 48 lenses. According to Abraham, this will make Dragonfly the largest all-refracting telescope in the world.

In addition to the structure of the optics, the way that Dragonfly images a galaxy through multiple lenses simultaneously—akin to a dragonfly's compound eye—enables further removal of unwanted light. The result is an image in which extremely faint galaxy structure is visible.

According to the January 2014 *PASP* paper by Abraham and van Dokkum, "The Dragonfly Telephoto Array is capable of imaging extended structures to surface brightness levels . . . considerably deeper than the surface brightness limit of any existing wide-field telescope . . . The detection of structures at these surface brightness levels may hold the key to solving the 'missing substructure' and 'missing satellite' problems of conventional hierarchical galaxy formation models."



L-R: Jielai Zhang, Abraham, van Dokkum and Merritt with the Dragonfly telescope. *Photo courtesy of the researchers.*

"We knew there was a whole set of science questions that could be answered if we could see diffuse objects in the sky," van Dokkum said. In addition to discovering new galaxies, the team is looking for debris from long-ago galaxy collisions.

"It's a new domain. We're exploring a region of parameter space that had not been explored before," van Dokkum said.

Dragonfly is being used for a multi-year imaging survey of nearby galaxies in order to complete the first census of ultrafaint substructures in the nearby universe.

The first scientific result from Dragonfly proved its usefulness with a discovery of seven new dwarf galaxies that had previously been overlooked because of their diffuse nature. These new galaxies may yield important insights into dark matter and galaxy evolution, while possibly signaling the discovery of a new class of objects in space.

The discovery came quickly, in a relatively small section of sky. "We got an exciting result in our first images," said Allison Merritt, GRD '17, the lead author of a paper about the discovery in *The Astrophysical Journal Letters*. "It was very exciting. It speaks to the quality of the telescope."

Merritt and van Dokkum will tackle a key question next: Are these seven newly found objects dwarf galaxies orbiting around the M101 spiral galaxy, or are they located much closer or farther away, and just by chance are visible in the same direction as M101?

If it's the latter, Merritt said, these objects represent something entirely different. "There are predictions from galaxy formation theory about the need for a population of very diffuse, isolated galaxies in the universe," Merritt said. "It may be that these seven galaxies are the tip of the iceberg, and there are thousands of them in the sky that we haven't detected yet."

Merritt stressed that until they collect more data and determine the distances to the objects, researchers won't know their true nature. The possibilities are intriguing enough that the team has been granted the opportunity to use the Hubble Space Telescope for further study.

"I'm confident that some of them will turn out to be a new class of objects," van Dokkum said. "I'd be surprised if all seven of them are satellites of M101."

Meanwhile, there is also more work to be done with the new telescope. "We are collecting new data with the Dragonfly telescope every clear night. We're all curious to see what other surprises the night sky has in store for us," Merritt said.

Recent Astronomy Conferences at Yale University

Cosmology on Scales Small and Large *(October 2, 2014)*
http://gruber.yale.edu/2014-gruber-cosmology-prize-conference

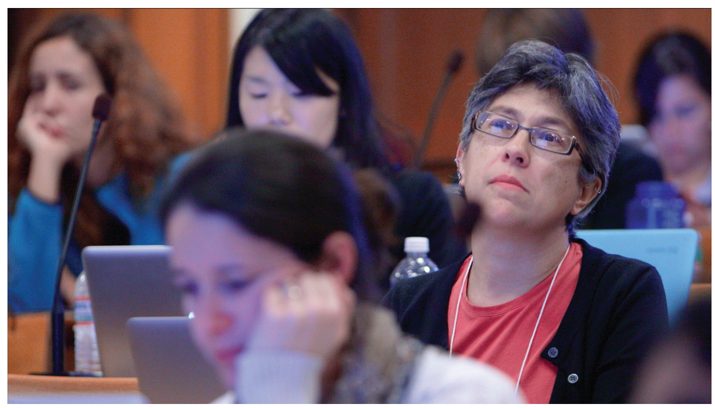
This one-day conference was organized in conjunction with The Gruber Foundation in honor of the 2014 Gruber Cosmology Prize, which was awarded to Jaan Einasto, Kenneth Freeman, R. Brent Tully, and Sidney van den Bergh. It took place at the new Yale School of Management's Evans Hall. The speakers at the event were Nima Arkani-Hamed (Institute for Advanced Study, Princeton), Jaan Einasto (Tartu Observatory), Douglas Finkbeiner (Harvard University), Kathryn Johnston (Columbia University), Jim Peebles (Princeton University), Brent Tully (Institute for Astronomy, University of Hawaii) and Neal Weiner (New York University).

Yale Frontier Fields Workshop: Shedding light on the dark ages and dark matter *(November 12-14, 2014)*
http://www.astro.yale.edu/yale_frontier_workshop/

This workshop was an opportunity for observers and theorists to discuss their work on Frontier Fields data obtained by Hubble, Spitzer, and other telescopes, and to prepare for the remaining data yet to come. Topics included: high-redshift galaxies, cluster lens modeling, galaxy cluster masses and dynamics, intracluster light, supernovae, and future science. The workshop was held at Yale's Maurice R. Greenberg Conference Center.

Extreme Precision Radial Velocities *(July 5-8, 2015)*
http://exoplanets.astro.yale.edu/workshop/EPRV/Home.html

This workshop focused on critical requirements for instruments, statistical techniques for detecting low amplitude signals, methods for distinguishing stellar noise from Doppler shifts, and the need to move from 1 m/s to 0.1 m/s precision in the coming years. It took place at Yale School of Management's Evans Hall.



Towards a Standard Model of Cosmology *(October 2, 2015)*
http://gruber.yale.edu/2015-gruber-cosmology-conference

This one-day conference was organized in conjunction with The Gruber Foundation in honor of the 2015 Gruber Cosmology Prize, which was awarded to John E. Carlstrom, Jeremiah P. Ostriker, and Lyman A. Page Jr. Each award recipient gave a talk and they were joined by speakers John Kovac, Neelima Seghal, Amber Miller and Max Tegmark. The conference was held at the Yale School of Management's Evans Hall.

Census, Evolution, Physics *(November 16-19 2015)*
http://3dhst.research.yale.edu/conference/

This meeting marked the public release of the entire 3D-HST dataset. The conference discussed the state of the field: now that we have all of this great data from 3D-HST and from other surveys, along with ever more realistic simulations, do we actually begin to understand how galaxies evolve? The main program was 3 days with an extra day for people who would like more information on the 3D-HST dataset. Each day of the main program had a theme: Census (the inventory of the Universe as a function of cosmic time), Evolution (how individual galaxies move through time), and Physics (what processes drive this evolution). The meeting was held at Yale University's Maurice R. Greenberg Conference Center.

Yale Astronomy makes changes to B.S. major

The Yale Astronomy Department reviewed the curriculum for the undergraduate major and implemented changes to the Bachelor of Science degree (B.S.) curriculum beginning in Fall 2014. The Bachelor of Arts degree (B.A.) requirements remain unchanged. Feedback from current undergraduates and faculty members was considered in the review. The following changes to the B.S. major were implemented:

1. The B.S. major was renamed from "Astronomy and Physics" to "Astrophysics." The name change was intended both to prevent confusion about whether the B.S. is a double major and to accurately reflect the strong physics education that B.S. majors receive.
2. The course requirements were clarified with specific course requirements named to ensure that courses taken towards the major are relevant and allow students to be prepared for further study in astrophysics.
3. One of the physics course requirement slots was changed to allow for another upper-level astronomy elective. The amount of electives available increased.
4. The introductory major classes (ASTR 210 and 220) were made more challenging to distinguish them from the non-major introductory classes.
5. The repetition of material between courses was decreased.
6. A class was added, Astrostatistics and Data Mining (ASTR 356), that focuses on computer programming and statistical analysis.
7. ASTR 255 now includes a field trip to an observatory during Fall break.

"I think the redesigned curriculum prepares the students better for anything they want to do," former Astronomy Director of Undergraduate Studies (DUS) Debra Fischer said. "They will hit the ground running if they decide to go to grad school."

Hannah Alpert '15, who participated in a focus group her sophomore year to discuss possible changes for the major, said she was happy to see that many of the concerns voiced by students in the group had been resolved.

Adrian Gutierrez '16 said he is happy the name of the B.S. degree will now properly reflect the major, as he had often been mistaken as a double major in the past. The name "Astrophysics" will not only be more accurate, but also sound more impressive to others, he added.

Professor Louise Edwards said that she hopes the major's new name will help employers recognize that Yale's program develops strong analytical skills in its students.

Zachary Wilson '18 said he hopes to be an astronaut one day and feels the Yale astrophysics program is the perfect preparation. He said the new requirements have a more mathematical focus, though the changes still allow enough flexibility in math courses.

"The major was absolutely intense before, and it is still going to be just as challenging with the changes," Wilson said.

Fischer noted that these kinds of changes could not happen without complete support from the whole department.

The Astrophysics major requires 12 courses for completion, not including prerequisites. The current number of declared Astrophysics majors as of the writing of this article is 22.

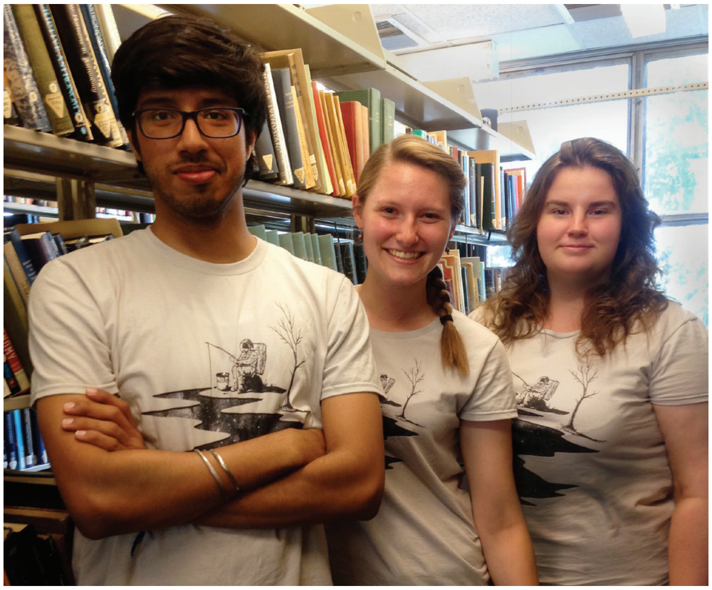
This article has been adapted from a Yale Daily News *article from October 27, 2014 by Emma Platoff and Stephanie Rogers.*

Classes of 2014 - 15 Senior Thesis Projects

Tara Abraham, BS '14: *Visualizing the Stellar Populations of Brightest Cluster Galaxies*, advisor Edwards
Liang Yu, BS '14: *On the Origin of Bias, Scatter and Evolution in Sunyaev-Zel'dovich Effect Scaling Relations*, advisor Nagai
- Yu was also awarded the 2014 Beckwith Prize and Special Distinction in the Major.

Hannah Alpert, BS '15: *First Results from an IFU Survey of Brightest Cluster Galaxies*, advisor Edwards
Miranda Kephart, BS '15: *Protostellar Core Depletion Due to Outflows in the Perseus Region*, advisor Arce
Rachel Perfecto, BS '15: *H-alpha/8-micron ratios as tracers of active ram pressure stripping in Virgo Cluster galaxies*, advisor Kenney
Akshaya Suresh, BS '15: *A Catalog of Low-Mass Star-Forming Cores Observed with SHARC-II at 350 microns*, advisor Arce
- The 2015 Beckwith Prize was split between Hannah Alpert and Rachel Perfecto.

Astronomy department buzzes with student activity in summer



During the summer of 2015, 14 undergraduates and one high school student were in the department daily, each doing research with one of eight participating faculty members.

10 of the undergraduates were from Yale. Sydney Young, YC '18 came with a STARS fellowship.

Daniel LaFlamme did research as part of the Warrior-Scholar Project, which is an academic program designed to prepare military veterans for college.

The remaining three undergraduates comprised the second class of the Astronomy Department's Dorrit Hoffleit Scholars: Rohan Naidu from Yale-NUS College, Leah Fulmer from the University of Wisconsin-Madison, and Vanja Sarkovic from the University of Belgium (see photo, left).

On July 1, 2015, all summer students were invited to the Bootcamp for Undergraduates in Yale Astronomy (BOUYA). BOUYA included a half a day of talks given by Yale Astronomy graduate students and postdoctoral associates on science, as well as scientific methods and tools such as: Python, LaTeX, UNIX, SIMBAD, image manipulation, and workflow organization.

The day was intended to culminate in a night of observing and fellowship at the Leitner Family Observatory and Planetarium, but it was rescheduled to a later date due to weather.

Astrophysics undergraduates build telescopes and rockets with YUAA

Seven Astrophysics majors are currently members of the Yale Undergraduate Aerospace Association (YUAA), and several of them are in the upper management of the club.

Pratik Gandhi, BS '18 is the Director of Public Relations; Isabella Trierwiler, BS '18 is the Treasurer and Secretary; Lauren Chambers, BS '17 is the Optical Telescope Project Second; Michele Lapadula, BS '18 and Michael Machado, BS '19 are members of the Optical Telescope team; and Archie Kinnane, BS '18 is a member of the rocket team, which is building a rocket to compete in the Intercollegiate Rocket Engineering Competition (IREC).

According to the YUAA website, "YUAA members work in teams to build and fly rockets, planes, quadcopters, and unmanned aerial vehicles. From first idea to finished aircraft, YUAA projects are entirely student-run. Since 2010, YUAA has helped foster Yale's engineering community by welcoming students of any experience level or background and hosting events to promote aerospace engineering on campus."

In addition to the telescope and rocket, YUAA teams are also working on constructing a CubeSat intended for low earth orbit as well as building a high performance unmanned aerial vehicle (UAV). *Photos from yaleaerospace.com.*

Yale Astronomers join White House in national Astronomy Night celebration

A constellation of stargazers stretched from Yale's Leitner Family Observatory and Planetarium (LFOP) to the White House lawn on October 19, 2015.

Yale was invited by the White House to host a satellite event for a national Astronomy Night, which was intended to highlight advances in space exploration and stress the importance of expanding science opportunities for students and adults. Professor Priyamvada Natarajan, the Director of Undergraduate Studies for the Yale Astronomy Department, led the organization of the New Haven events.

In Washington, D.C., President Barack Obama hosted a group of scientists and engineers from the space industry to talk with students and teachers gathered on the South Lawn of the White House, including the following members of the Yale community: undergraduate Astrophysics major Lauren Chambers, '17, who was present as a co-leader of the Yale Undergraduate Aerospace Association; professor Meg Urry, President of the American Astronomical Society; and alumna Jedidah Isler, PhD '14, NSF Astronomy & Astrophysics Postdoctoral Fellow at Vanderbilt University.

The D.C. event was live-streamed to LFOP at a "Starry Night Watch Party," which also offered continuous free planetarium shows, observing with LFOP's telescopes, and kiosks with slide presentations given by Yale astronomers on topics such as gravitational lensing, gravity, Pluto and the motion of the solar system throughout the galaxy.

The Yale astronomers running the event at LFOP were busy until late into the night with the high turnout from the Yale community and the public.

Angelo Ricarte, GRD '19 said, "I was impressed by the public turnout and happy to see that they were as enthusiastic about science as we were."

Bhaskar Agarwal, a Yale Astronomy Postdoctoral Associate said that "the astronomers at the kiosks were asked lots of good questions, especially from kids."

Other volunteers at the event included Professor Michael Faison, graduate students William Cramer, GRD '20, Allen Davis, GRD '20, Jesse Feddersen, GRD '19, Johannes Ulf Lange, GRD '20, and Darryl Seligman, GRD '21; Postdocs Fabio del Sordo, Mireia Montes Quiles, and Grant Tremblay; and undergraduates Kristoffer Acuna, '17, Mariona Badenas, '16, and Archie Kinnane, '18.

The White House Astronomy Night was the second stargazing event organized by the Obama administration; the first was in 2009.

Image caption: Pablo Martinez Monsivais, AP

Michelle Collins featured as "The Running Astronomer"

Yale Hubble Fellow Michelle Collins is featured in a 2.5 minute documentary called *The Running Astronomer* as part of the Saucony Seekers campaign, a marketing effort by the Saucony shoe and apparel brand. The documentary depicts Collins in Hawaii as she discusses astronomy, as well as how running helps stimulate her research. See the video at: https://www.youtube.com/watch?v=nDbnKM_ZMSI

Astronomy on Tap pairs science and beer

Astronomy on Tap was originally founded by former Yale Postdoctoral Associate Meg Schwamb in New York City. Since then, it has branched out to several other cities including New Haven (and even Chile!)

Because, as the motto of Astronomy on Tap says, "Science is better with beer."

The New Haven Astronomy on Tap was aptly organized from 2014-15 by another Yale Postdoctoral Associate, Stephanie LaMassa at BAR on Crown Street. With the departure of LaMassa from Yale in Fall 2015, the reins were passed to Postdocs Grant Tremblay and Bhaskar Agarwal.

Each Astronomy on Tap program lasts two hours and has several informal talks given by members of the Yale Astronomy Department and other local institutions in a bar setting. There are also prize giveaways, astronomy-themed cocktails, and glow sticks.

Examples of recent talks have been *Illuminating the Darkness, Mars: an Era of Discovery, Black Holes in the Milky Way: Your Neighbors that Want to Eat You*, and *Hubble: The Little Telescope That Could*.

Yale Astronomers host international space party

The Yale Astronomy Department hosted a Yuri's Night celebration at the Leitner Family Observatory and Planetarium (LFOP) for the second time on April 12, 2015.

Yuri's Night was founded as an annual celebration in 2001 to celebrate human spaceflight. The event is named for Russian cosmonaut Yuri Gagarin, who was the first human in space on April 12, 1961. The first space shuttle was launched 20 years later, also on April 12.

According to yurisnight.org, the intent is to have an annual "world space party" that is both fun and educational. All Yuri's Night events are listed on the website each year.

Ivelina Momcheva, then a Yale Astronomy Postdoctoral Associate, came across the Yuri's Night website in 2014. She said, "I thought it would be a cool idea to do publicity for space. Everyone loves space! LFOP is the perfect venue."

Momcheva got several volunteers to help create and organize an event in 2014 and, as it was a great success, they decided to do it again in 2015.

Inspired by a suggestion from Associate Research Scientist John Parejko, after the 2014 event, Jesse Feddersen, GRD '19, James Davies and Momcheva designed and organized a bottle rocket launch of hundreds of bottles on a launchpad they built. Momcheva said, "It was a big hit."

Rachel MacDonald, PhD '14 and Stefano Marchesi created a "comet core"with dry ice and discussed the different materials that are in comets, as well as the history of the solar system talking about where the materials come from.

Postdoctoral Associate Bhaskar Agarwal demonstrated how a gravitational field and gravitational lensing work with a blanket, table and balls.

SMARTS Data Manager Imran Hasan ran an "ask the astronomer" table and showed videos of Gagarin launching into space.

Urmila Chadayammuri, GRD '21 ran a space photo booth.

There were also four showings of two new planetarium shows that Michael Faison, Director of LFOP, had obtained specifically for the event. One was about the Google Lunar XPRIZE, which is a competition to land a privately funded robot on the moon. The second, *Dawn of the Space Age*, was about the Apollo and Gemini space programs and was loaned to LFOP by the Spitz planetarium company.

LFOP's telescopes were also available for observing.

Approximately 200 people came to Yuri's night. Momcheva said the night "gave us an opportunity to talk to people about what we do and to get people interested and excited about science. Astronomy is corollary to what we do when we go to space." She continued, "It was really fun and people enjoyed themselves."

Gregory Laughlin joins Yale Astronomy Faculty

Gregory Laughlin will be joining the Yale Astronomy Faculty as of July 1, 2016. Laughlin comes to Yale from the University of California, Santa Cruz (UCSC), where he has been a professor since 2001.

Laughlin received his PhD in Astronomy and Astrophysics from UCSC in 1994. He held an NSF/JSPS Fellowship in Tokyo, and also did postdoctoral research at the University of Michigan and the University of California, Berkeley. From 1999-2001, he worked for NASA as a Planetary Scientist at the Ames Research Center in Mountain View, CA.

In 2004, Laughlin was recipient of an NSF CAREER award.

Laughlin's research interests focus on numerical simulations and modeling of data. Current areas of interest include the detection and characterization of extrasolar planets, hydrodynamical simulations, and the extremely distant future.

Laughlin is a Co-I of the Lick Carnegie Exoplanet Survey, where he also organizes public participation in science through the Systemic and Transitsearch projects.

In order to communicate the latest news on the detection and characterization of extrasolar planets, Laughlin writes a frequently updated web log at oklo.org.

Ann Giangarra retires after 14 years of working in the Business Office

In May 2015, Ann Giangarra retired after 14 years of being the Financial Assistant in the Astronomy Department Business Office and a total of 27 years of working at Yale University.

Ann's responsibilities as Financial Assistant included keeping the department's finances in order, but she also helped keep the department in order by supporting faculty, maintaining and distributing keys, handling facilities requests, ordering supplies, and being a caring and understanding listener to all.

In regards to her time working at the department, Ann said, "I enjoyed the variety of the work I did through the years, getting to work with students, faculty members, post docs, research scientists, and working with great business office staff members who always pulled together to keep our Department running smoothly. I was deeply touched by many special friendships and meaningful conversations, and the on-going contact with all Department members that made my job such a blessing each day. "

In her new free time, Ann is still singing with the praise team at her church and she is waiting to find out if she has been accepted as a "Puppy Raiser" for the Fidelco Guide Dog Foundation in Bloomfield. If accepted, she will begin training (attending regular puppy classes) and socialization of an 8-week-old German Shepherd puppy for approximately one year. The puppy will then return to Fidelco to begin formal guide dog training for several more months, and then will be placed with a blind man or woman.

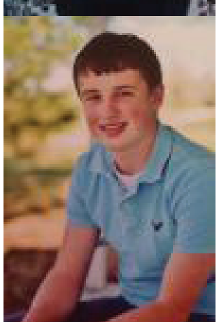
New faces in the Astronomy Department Business Office

Hannah Carroll is thrilled to join the Astronomy staff as the Lead Administrator and thankful for the opportunity. Along with the exceptional Astronomy staff, her goal is to provide support in Yale's administrative and financial systems, freeing faculty and students to focus on education and research. During her 25 years at Yale, she has served as the Operations Manager in Physics, was recruited in the Career Development Program, and developed the FRMS grant post award group. After her invaluable years in the Career Development Program and FRMS, being in Astronomy feels like coming home. In her non-Yale time, she enjoys attending her two teenagers' sporting and school events, and reading.

Susan Hart is the Operations Manager for the Astronomy Department. She oversees the finances of the department and is the manager of our great administrative staff. Susan has 24-year-old twin boys and enjoys hiking, dancing and painting in her spare time.

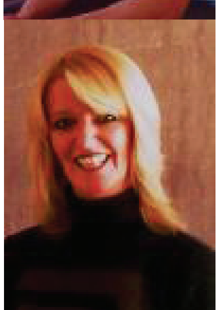
Teena Griggs joined the Astronomy Department in July 2015 as the Financial Assistant. Her responsibilities include assisting with the department finances along with faculty support & daily administrative tasks. The position was previously held by Ann Giangarra, who retired from the department after 14 years of service. Teena has worked at Yale University since 2002.

Teena has four children with her husband Tom and they are excited for a granddaughter arriving in April. She loves travel adventures, especially when they include hiking.



Eli Westerman has been working as a student assistant in the Yale Astronomy Department's Business Office since February 2015. He is in charge of making sure the speakers for colloquium make it to New Haven, the coffee shop is running smoothly, and that the supply closets are stocked.

Eli is a Sophomore at Yale, double majoring in Chemical Engineering and Classical Civilizations. He was born and raised in Hot Springs, AR, where he enjoys living a small-town American life. At Yale, he participates in the Yale Political Union and is a leader in Yale Outdoors. Eli said, "I really enjoy my job at Astronomy - sometimes I wonder whether I go to Yale for the education or for my student job!"



Nicole Whitcher has returned to the department as the Chair's Assistant. Nicole was originally the Chair's Assistant for Jeff Kenney, but she took a position in another department at the University in 2011. Nicole was very excited to return to Astronomy in December of 2014 to be the Chair's Assistant for Pieter van Dokkum. Her responsibilities include assisting Professor van Dokkum with daily administrative tasks and his travel calendar and coordination. While at home, Nicole enjoys spending time with her family.

RECENT ASTRON

Nhung Ho, PhD '13
Currently a Data Scientist at Intuit
Dissertation: *The Evolution of the M31 Dwarf Galaxies*, advisor Marla Geha

My thesis research focuses on understanding the evolution of dwarf galaxies, specifically those around the Andromeda Galaxy. We approach this using three methods: deep photometry to understand the structure of these galaxies, medium-resolution spectroscopy to determine the current internal dynamics of these systems, and chemical abundance studies to determine their integrated histories.

Joel Tanner, PhD '14
Currently working for the Canadian Government in Ottowa
Dissertation: *Simulating Convection in Stellar Envelopes*, advisor Sarbani Basu

The treatment of convection is one of the largest sources of uncertainty in stellar models. Convection, an intrinsically three dimensional phenomenon, is usually treated in a very simplified manner in the spherically symmetric stellar models that astrophysicists generally use. These treatments fail to account for many of the dynamical effects of convection, such as turbulent pressure and asymmetry in the velocity field. Thus a better mathematical description of convection would represent a substantial advance in stellar astrophysics. To this end, we perform three-dimensional radiative-hydrodynamic simulations of stellar convection for stars of different temperatures and chemical abundances. We show that convective properties depend on both temperature and abundances. We use the results to show that some of the properties of convection can be explained easily in terms of the surface temperature and gravity of the stars.

Jedidah Isler, PhD '14
Currently an NSF Fellow at Vanderbilt University, a Future Faculty Leaders Postdoctoral Fellow at Harvard University, Center for Astrophysics and a TED Fellow
Dissertation: *In Like a Lamb, Out Like a Lion: Probing the Disk-Jet Connection in Fermi Gamma-ray Bright Blazars*, advisors C. Megan Urry and Charles Bailyn

Blazars are active galactic nuclei whose relativistic jet is aligned at small angles ($< 5°$) with respect to the Earth line of sight. Their broadband emission is generally jet-dominated, but during quiescent periods the thermal contribution can often still be detected, making them an ideal laboratory to study the energetics of infalling and outflowing material. The simultaneously obtained, multiwavelength, long-term data we analyzed help to better evaluate the impact of jet power on the broadband spectral energy distributions of these sources via the OIR color variability analysis. Emission line variability studies we presented help constrain the location of the gamma-emitting region and set preliminary constraints on the minimum jet contribution necessary to significantly increase the photoionizing flux in the broad line region.

Camille Avestruz, PhD '15
Currently a KICP Fellow
Dissertation: *Modeling Galaxy Cluster Outskirts with Cosmological Simulations*, advisor Daisuke Nagai

The observational study of galaxy cluster outskirts is a new territory to probe the thermodynamic and chemical structure of the X-ray emitting intracluster medium (ICM) and the intergalactic medium (IGM). Cluster outskirts are particularly important for modeling the Sunyaev-Zeldovich effect, which is sensitive to hot electrons at all radii and has been used to detect hundreds of galaxy clusters to high-redshift ($z<1$) with recent microwave cluster surveys such as ACT, Planck, and SPT. In cluster-based cosmology, measurements of cluster outskirts are an important avenue for estimating the cluster mass, as the outskirts are less sensitive to astrophysical uncertainties associated with gas cooling, star formation, and energy injection from supermassive black holes. However, recent observations of cluster outskirts deviate from theoretical expectations, indicating that cluster outskirts are more complicated than previously thought. For instance, recent observations from Suzaku X-ray satellite showed clusters with flat entropy profiles and gas fractions exceeding the cosmic baryon fraction at large radii. Computational modeling of cluster outskirts is necessary to interpret these observations. In my dissertation, I present hydrodynamical cosmological simulations of galaxy cluster formation that follow the thermodynamic and chemical structures in the virialization regions of the ICM and transition to the IGM. Specifically, I show how observational signatures of galaxy clusters are affected by (a) gas density and temperature inhomogeneities in the ICM due to infalling gas clumps and large-scale filaments, and (b) non-equilibrium electrons generated by accretion shocks at the outer boundary of clusters.

Adele Plunkett PhD '15
Currently an ALMA Fellow at European Southern Observatory
Dissertation: *Multi-wavelength, Multi-scale Observations of Outflows in Star-Forming Regions*, advisor Hector G. Arce

During the early stages of star formation, an embedded protostar accretes mass while simultaneously expelling a fraction of this mass in the form of a bipolar outflow. In the common case of clustered star formation, outflows likely impact their surrounding environment and influence subsequent star formation. Numerical simulations have shown that outflows can sustain turbulence and maintain a cluster in quasi-equilibrium; alternatively, it was proposed that outflows may trigger rather than regulate or inhibit star formation. Observations of outflows and their impact on clusters are challenging because they must probe spatial scales over several orders of magnitude—from the size of an envelope (a few hundred AU, or 0.003 pc) to a cluster (a few pc)—and previous works generally focused on one scale or the other. This thesis incorporates high-resolution, high-sensitivity interferometry observations (with millimeter/sub-millimeter wavelengths) complemented by observations obtained using single dish telescopes in order to assess molecular outflow properties and their cumulative impact in young protostellar clusters.

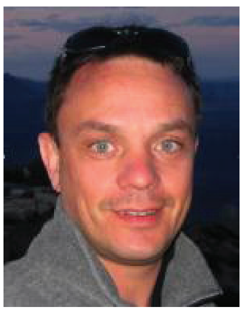
Luis Vargas, PhD '15
Currently a Data Scientist at SecurityScorecard
Dissertation: *A Spectroscopic Survey of Chemical Evolution in Local Group Dwarf Satellite Galaxies*, advisor Marla Geha

Dwarf spheroidal galaxies are the most abundant galaxy type in the Local Group. I set out to better understand the internal evolution of these galaxies. Using the chemical composition of their long-lived stars as fingerprints, I studied the internal evolution of a large ensemble of ultra-faint dwarfs (UFDs) around the Milky Way and relatively larger dwarf galaxies around M31. I developed a technique to measure both the overall chemical composition as well as the abundances of Mg, Si, Ca and Ti, using spectroscopic data taken with the Keck telescope. In the case of the UFDs, I found their chemical composition to be indicative of internal evolution on a timescale of at least 100 Myr, implying that these UFDs were able to retain a non-negligible fraction of their baryonic content after the initial burst of star formation, in spite of their shallow gravitational potentials. My analysis of the M31 dwarfs yielded a wider variety in the chemical properties (and thus evolutionary timescales) of these systems with respect to MW satellites of similar luminosities.

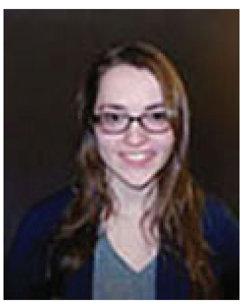
Matthew Giguere, PhD '15
Currently a Data Scientist at Rhumbix
Dissertation: *Slaying the Jabberwocky: Subtracting Stellar Signals and Improving Instrumentation on a Road Towards Other Earths*, advisor Debra Fischer

Detecting earth mass planets orbiting nearby stars at large separations will provide exciting insights into planetary occurrence rates, planetary formation and migration mechanisms, as well as clues to the possibilities of life elsewhere. Several obstacles currently stand in the way between the current state of the art in exoplanet detection, and the detection of earth-mass planets orbiting at habitable zone distances. For the radial velocity (RV) technique, these obstacles are both astrophysical and instrumental in nature. This thesis presents efforts on both fronts to address these issues. Methods of disentangling stellar signals were carried out using HIRES at the Keck Observatory in Mauna Kea. Additionally a new spectrometer was commissioned on the 1.5 m SMARTS telescope at CTIO in Chile, and used in conjunction with the MOST Space Satellite, to explore methods of disentangling stellar signals and abating instrumental error.

HONORS



Professors **Hector Arce** and **Frank van den Bosch** have both been promoted to Associate Professor of Astronomy with tenure.



Emily Sandford, BS Physics '14 was awarded the American Astronomical Society's Chambliss Student Poster Award for her poster, entitled "Machine Learning Identification of Dwarf Galaxy Satellites around Milky Way Analogs," which describes her work as a STARS II fellow in the research group of Astronomy Department Professor Marla Geha.

Associate Research Scientist **Tabetha Boyajian** has been elected as one of *Connecticut Magazine*'s 40 under 40 for 2016.

Professor **Louise Edwards** was selected to be a National Academies Education Fellow in the Sciences for 2015-2016.

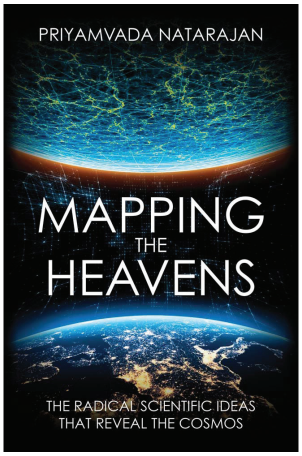
Professor **Sarbani Basu** has been elected a Fellow of the American Association for the Advancement of Science (AAAS) to recognize her work in the field of Astronomy.

Professor **Marla Geha** has been awarded a Guggenheim Fellowship for 2015. Often characterized as "midcareer" awards, Guggenheim Fellowships are intended for men and women who have already demonstrated exceptional capacity for productive scholarship or exceptional creative ability in the arts.

Jeremy Bradford, GRD '18 and **Allen Davis**, GRD '20 each were awarded an NSF Graduate Research Fellowship.

Professor **Pieter van Dokkum** was awarded an Eddington Memorial Lectureship in 2015 at the University of Cambridge.

Books by the Yale Astronomy community



Mapping the Heavens: The Radical Scientific Ideas That Reveal the Cosmos
By Professor Priyamvada Natarajan (Yale University Press, April 2016)

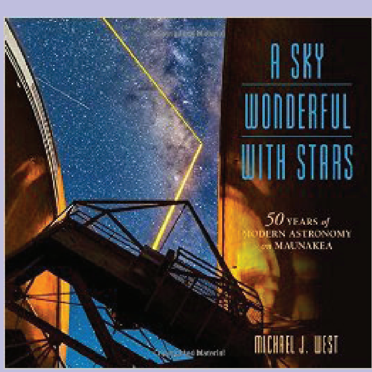
This book provides a tour of the "greatest hits" of cosmological discoveries—the ideas that reshaped our universe over the past century. The cosmos, once understood as a stagnant place, filled with the ordinary, is now a universe that is expanding at an accelerating pace, propelled by dark energy and structured by dark matter. Priyamvada Natarajan, our guide to these ideas, is someone at the forefront of the research—an astrophysicist who literally creates maps of invisible matter in the universe. She not only explains for a wide audience the science behind these essential ideas but also provides an understanding of how radical scientific theories gain acceptance.

The formation and growth of black holes, dark matter halos, the accelerating expansion of the universe, the echo of the big bang, the discovery of exoplanets, and the possibility of other universes—these are some of the puzzling cosmological topics of the early twenty-first century. Natarajan discusses why the acceptance of new ideas about the universe and our place in it has never been linear and always contested even within the scientific community. She affirms that, shifting and incomplete as science always must be, it offers the best path we have toward making sense of our wondrous, mysterious universe.

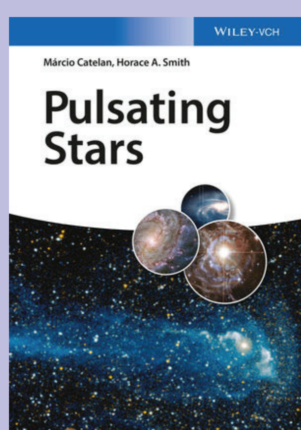
Dragonflies
By Professor Pieter van Dokkum (Yale University Press, 2015)

Almost without our noticing, dragonflies dart through our world, flying, seeing, hunting, mating. Their lives are as mysterious as their gossamer wings are beautiful. In this book, Pieter van Dokkum reveals many of the dragonfly's secrets, capturing the stages of this striking insect's life cycle in unprecedented close-up photographs. He documents scenes of dragonfly activity seldom witnessed and rarely photographed.

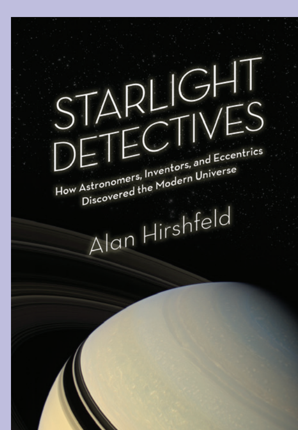
The book begins on a moonlit summer night, when an alien-looking larva crawls out of the water and transforms into a fully formed dragonfly. In the following chapters, we witness dew-covered dragonflies sparkling in the morning sun, then a pair of mating dragonflies moving through the air in a twelve-legged, eight-winged dance. In the final chapter, one generation dies as the next prepares to leave the water and begin its own winged journey. Each stage is documented through van Dokkum's inquisitive lens and accompanied by information on various species of dragonflies and damselflies, their metamorphosis, and their ecological importance as insect predators.



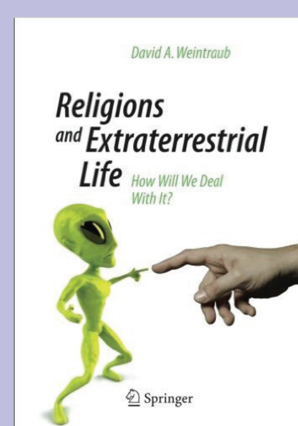
Michael West, PhD '87



Horace Smith, PhD '80
and Márcio Catelan



Alan Hirshfeld, PhD '78



David Weintraub, BS '80

Where were we? A history of the New

On the occasion of the move of the Astronomy Department and the YCAA to the Hillhouse mansions (see article, page 12) we look back at the the history of the Yale Astronomy Department, which can be traced back to the beginning of Yale University in 1701. Even though it was established as a liberal arts school with a primary objective of training ministers, Yale regularly offered at least one basic astronomy course.

In 1829, a 5-inch Dollond refractor was donated by Sheldon Clark and a tower was added to a building called the Atheneum to become Yale's first observatory. A cylindrical, revolving turret was added to the tower in 1870 to improve the field of view. The building was demolished in 1893.

In 1847, the (later named) Sheffield Scientific School was instituted at Yale to establish a program for the sciences and, in 1866, Joseph E. Sheffield donated a 9-inch Alvan Clark refractor that was housed in a turret of South Sheffield Hall at the corner of Prospect and Grove streets. In 1927, the Sheffield Telescope was moved to a dome on the roof of Yale's Charles W. Bingham Hall.

In 1858, Mrs. Cornelia Hillhouse and her daughters, Mary and Isaphene, donated six acres of land on Prospect Street to Yale University for the intended purpose of building an observatory, which never happened.

In 1871, Yale Mathematics professor Hubert Anson Newton persuaded firearms magnate Oliver Winchester to fund a private observatory to be named after him, and Winchester donated 32 acres of valuable land along Prospect Street (adjacent to the Hillhouse property) between Edwards and Canner streets. Proceeds from the sale of most of this land were to fund the observatory buildings on the remainder of the land.

In 1873, R.G. Russell drew up plans for Winchester Observatory that would have a central building with two symmetrical wings on each side, each having a dome.

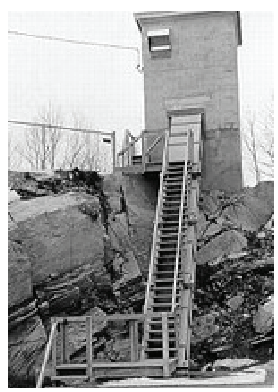
But shortly after that, a crash in real estate values (the Panic of 1873) greatly reduced the value of the land, and as a result, not much happened for a number of years. What was finally built in 1882 was only half of the original design. The building most notably housed the Yale Heliometer and the 8-inch Reed telescope, among other instruments.

Financed by E.M. Reed of New Haven, the telescope was first used for photographing the Sun during the transit of Venus on December 6, 1882, and it is still used today during public outreach events. The Yale Heliometer—the only one in America—was also purchased and used for measurements of the same transit of Venus.

Because of financial difficulty, the Trustees of the Winchester Observatory decided to let Yale administer the land on behalf of the observatory in 1880. The intent was that Yale would use proceeds from the land to fund an observatory and pay the salaries of the astronomers. Yale kept the land for itself, but also kept the spirit of the agreement, funding the observatory and the astronomers. The name of the observatory was officially changed in 1881 to The Observatory in Yale College, but it remained colloquially known as the Winchester Observatory.

The Observatory ceased operations completely in 1918 due to World War I.

In 1920, Frank Schlesinger was appointed as the Director of the Yale University Observatory, which reinvigorated astronomy at Yale and allowed Yale to lead the way in astrometry research.



In 1923, the Loomis Tower was erected at the Yale Observatory in memory of Elias Loomis. It housed what was, at the time, the largest polar telescope in America.

In 1932, upon the recommendation of Schlesinger, the Yale Corporation approved the dissolution of the Observatory's Board of Managers and the creation of the Yale Department of Astronomy.

In 1941, Dutch astronomer Dirk Brouwer was appointed Director of the Yale Observatory and Department Chair.

Brouwer founded the Yale Center for Celestial Mechanics in a house on Edwards Street. This most distinguished Center became a beehive of activity and a focus of world attention

Haven facilities for Astronomy at Yale

when the Space Age started. Yale was one of the few places left in the world where the science of celestial mechanics was practiced at its highest level.

In addition, the first Yale Computer Center, the ancestor of the current Yale ITS, had its beginnings at the Center for Celestial Mechanics.

Image from Wikimedia Commons.

In 1956, Yale sold the Canner Street property (where the Celentano Biotech, Health and Medical Magnet School is now located) and moved the Yale Astronomy Department and Yale University Observatory headquarters to 135 Prospect Street, a red brick building at the corner of Sachem Street that is now overshadowed by the School of Management complex. As part of the deal, Yale set up a new observatory designed by

Andrew F. Euston in Bethany, CT on land rented at $1 per year from the New Haven Water Company. The Bethany Observing Station opened in 1958 with various instruments, including the Loomis Telescope. In the 1960s, a new 40-inch (1-meter) Boller and Chivens reflecting telescope was installed, primarily intended for planetary research in the early days of the space program.

135 Prospect Street had previously served as a horse stable and, most recently, the Yerkes Laboratory of Primate Biology, which had just moved to Emory University, so the astronomers were not pleased by the move from their grand building on Canner Street to an actual "monkey house."

The operations that were moved to 135 Prospect included a machine shop with 3 machinists, the editorial offices of *The Astronomical Journal*, a plate collection and a large catalog project employing several people, later overseen by Dorrit Hoffleit. The Reed refractor was also moved to the roof of 135 Prospect Street, which made it conveniently located for undergraduate instruction and it was extensively used.

In 1968, Pierre Demarque was appointed the Chair of the Astronomy Department, with a mandate to build a new

Image from midcenturymundane.wordpress.com.

department with an emphasis on astrophysics rather than on celestial mechanics, which had been the previous emphasis under Brouwer. To house the reborn Astronomy Department, the Watson Computer Center, which had been built in 1961 at 60 Sachem Street, next door to 135 Prospect Street, was renovated to become the Watson Astronomy Center, and this became the new headquarters for the Astronomy Department and the Yale Observatory

The department also continued to occupy all of 135 Prospect Street, including the second floor and a telescope dome on the roof, so the Astronomy Department and the observatory occupied two adjacent buildings during that period. Faculty and business offices, as well as a nice library, were mostly at 60 Sachem Street, while other offices, shops, labs, plate collections, etc, remained mostly at 135 Prospect. The frame of the Watson Astronomy Center still exists but was completely swallowed up in the School of Management complex, and is now hard to identify.

With the new missive, the Yale Center for Celestial Mechanics slowly dispersed within a few years.

In 1972, the Bethany Observatory 1-m telescope was moved to a much better site for astronomical research—the Cerro Tololo Interamerican Observatory in Chile—and is now known as "the Yale 1-m." The Bethany Observatory ceased to be a research observatory, but continued to be used for student projects and public outreach nights. Eventually, the New Haven Astronomical Society, the main local amateur astronomy group, took over operations of the Bethany Observing Station.

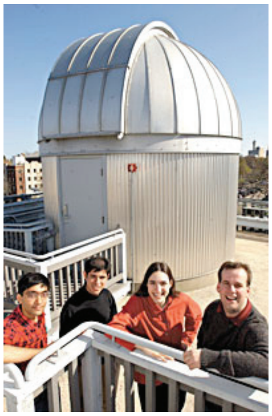
Soon after the 1-m telescope was moved, there was a budget crisis at Yale that led to major budget cuts, which resulted in the closing of the machine shop as well as the dismissal of the remaining observing staff. The effect of this was that the Astronomy Department no longer operated a research observatory at Yale, and the name "Yale University Observatory" gradually went out of use.

Image from Wikimedia Commons.

In 1975, the whole Astronomy Department was moved to the J.W. Gibbs Laboratory (Gibbs) to make way for the newly established Yale School of Organization and Management, which would take over the Watson Center and three mansions on Hillhouse Avenue.

The second floor of Gibbs was renovated to provide office, classroom, and library space for astronomy. Gibbs had been constructed for physics research facilities in 1955 in a modernist style by architects (***SEE FACILITIES, p. 30***)

(***FROM FACILITIES, p. 29***) Paul Schweikeher and Douglas Orr that was seen as futuristic, but also cost-effective. By the time the Astronomy Department moved in, the style was seen by many as too industrial-looking. However, the large offices with big windows and lots of space as well as subsequent renovations helped to make the building into a somewhat more desirable home for the department.



In the 1990's, Professor Charles Bailyn, BS '81 led the effort to install a student observatory with a new 16-inch Celestron reflecting telescope on the roof of Yale's Pierson-Sage parking garage on the corner of Whitney and Edwards Streets. (Ironically, the garage was built on the site of the former Yale Center for Celestial Mechanics.) The roof of the garage was not ideal, and Bailyn began to look for a better site for the student observatory.

In 2005, James A. Leitner, BA '75 and Sandra Leitner donated funds to turn a little-used maintenance building on the corner of Prospect and Edwards Street into the Leitner Family Observatory for student research and public outreach. This was a success, so the Leitners donated more funds to add a planetarium, which opened in 2009. The state-of-the-art facility is now called the Leitner Family Observatory and Planetarium and houses the Reed refractor, the 16-inch reflecting telescope, a radio telescope and several other different kinds of portable telescopes.

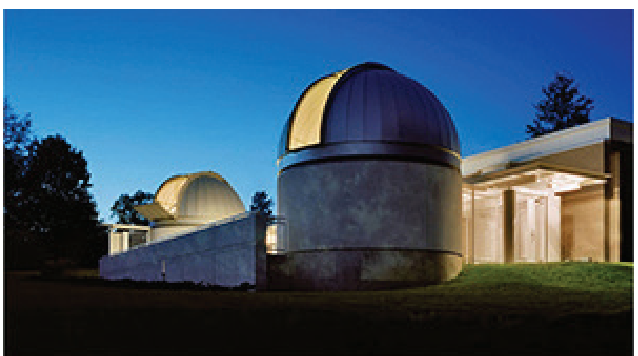


Image from David Thompson Architects

In 2015, the department left Gibbs and moved to the former School of Management complex of three mansions on Hillhouse Avenue.

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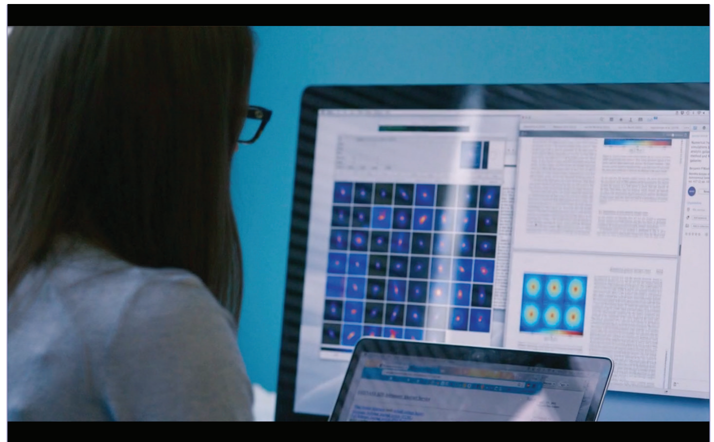
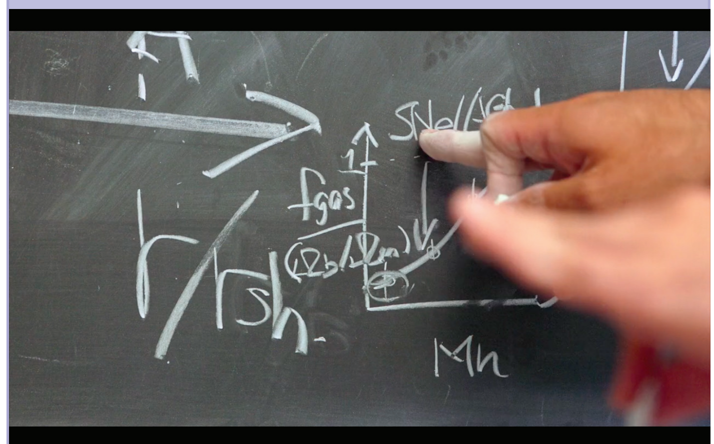
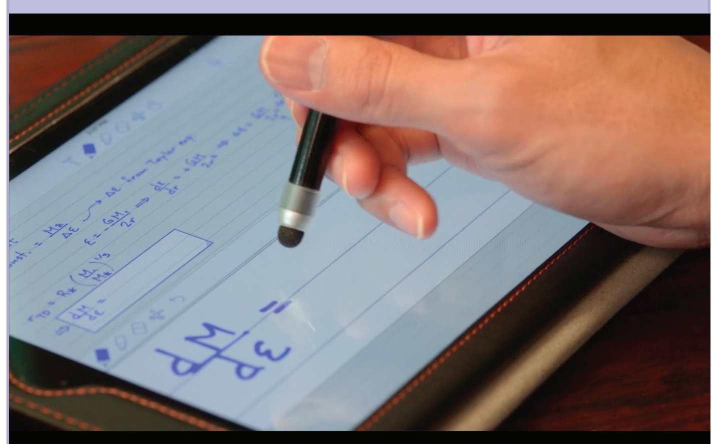
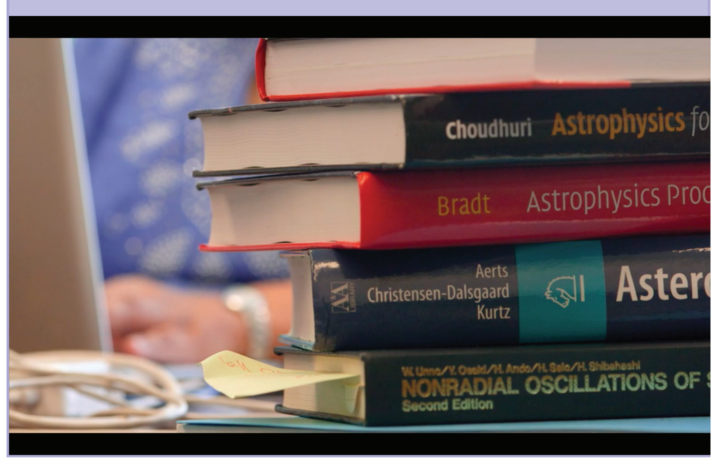
This article is by Victoria Misenti and Richard Larson, with input from Pierre Demarque and Kim Monocchi.

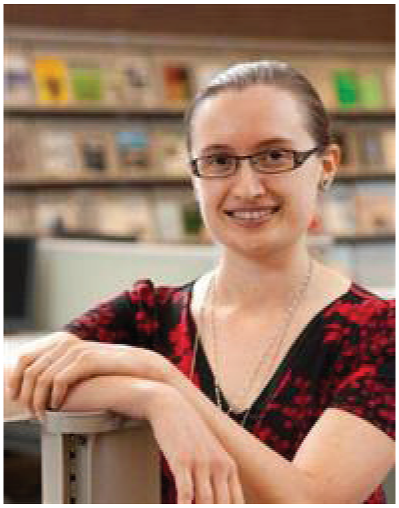








From the Librarian's Desk



By Kayleigh Bohémier

The Yale University Library has been bustling with activity over the past two years. Many of these changes have involved the library's digital presence. Meanwhile, our library IT department just launched a new search interface on the library home page, and our library subject guides switched to a new version of our content management software. We have digital software preservation efforts, enhancements to the archival finding aids, and a plethora of new resources (both print and electronic) for researchers to use at Yale.

As the subject liaison from the Yale Library to the Astronomy Department, I would like to highlight three areas: Connections between astronomy librarianship at Yale and the larger library community; the Yale University Library's collaboration with the departmental library collection during the Department's move to the mansions; and educational engagement that has had a positive impact on current students within the Department.

In Summer 2014, I flew to Naples, Italy, for the Library and Information Services in Astronomy VII Conference. While Naples is known for sunshine, we had a bizarre streak of torrential rain that turned the cramped city streets into rivers. During the opening conference logistics announcements, our host raised his arms to the sky to welcome us. Lightning flashed, thunder roared, and the conference Internet was no more. It was the most movie-like moment I have experienced in my entire career. While there, I connected with librarians and information specialists from around the world. A strong thread was the need for astronomy information specialists to increase access to collections that have been lost in the march towards web discovery. The Astrophysics Data System (ADS) has an initiative to make old observatory reports available, and one European observatory is digitizing data tables from its old collections. These collections represent unique observational data pieces, and the digitized works have already led to new scientific insights.

This past summer, the Special Libraries Association (SLA) Info-Expo conference was held in Boston, MA. A preconference on telescope bibliographies provided an excellent collaboration opportunity between academic and observatory librarians and the professional societies. One outcome was an initiative to update the prototype for a Unified Astronomy Thesaurus (UAT). The UAT draws from older terminology works used by IOP, AIP, and other societies for assigning keywords to papers and creating topical searches in the ADS. To update it, we had short meetings with researchers at our institutions to ensure that the terminology reflected the vocabulary they use to describe their research. The project leaders at the Harvard-Smithsonian Center for Astrophysics presented the consolidated update at the January 2016 AAS Meeting and discussed next steps with the AAS.

Back at Yale, the Astronomy Library transferred 6,438 print titles to the central library during its move to the mansions on Hillhouse Avenue in Summer 2015. Professor Sarbani Basu and Kim Monocchi identified key materials to remain in the collection, and three catalogers processed the remaining materials for transfer under the guidance of Kevin Merriman, our Head of Collection Management at CSSSI. For those who love statistics, those 6,438 titles consisted of 17,034 volumes of material. The team added 527 records to the library catalog and updated 16,666 records. These items are now available for borrowing across the entire library system from their new climate-controlled home at our offsite storage facility.

I highlight professional engagement beyond Yale so much because I have the privilege of bringing this new knowledge back to support current students and researchers. This past fall, I integrated what I learned about telescope impact reporting into a discussion with graduate students about scholarly impact and how that is measured. For undergraduates, I work with faculty to ensure that students learn how to use astronomy resources. Engagement with the team behind the ADS has given me new insights into interface changes and future developments that just make literature searching better. For the entire Yale community, I teach workshops on using LaTeX citation tools with library resources, and that has generated interest from many researchers in the sciences and social sciences.

So, in essence, the librarian's desk is very full — but it's the support of the community's scholarly work by providing relevant information services that ties everything together.

Julian Palmore, PhD '67 received a certificate of appreciation for 60 years of membership in the American Institute of Aeronautics and Astronautics (AIAA). He will teach Spaceflight in the fall semester in UIUC campus honors.

A new book by **Alan Hirshfeld,** PhD '78, called *Starlight Detectives: How Astronomers, Inventors, and Eccentrics Discovered the Modern Universe*, published in 2014, was named: *Discover* magazine "Top 5 Summer Read" of 2014; *Scientific American* "Favorite Science Books of 2014"; NBC News "Top Science and Tech Books of 2014"; *Kirkus Reviews* "Best Nonfiction Books of 2014"; and *Nature* magazine Books and Arts blog "Top 20 Reads of 2014." The book describes the dramatic transformation of observational astronomy during the late 19th and early 20th centuries. (More information at www.alanhirshfeld.com.) Alan is now in his 38th year as a faculty member in the Physics Department at UMass Dartmouth.

Horace Smith, PhD '80 writes, "I am still enjoying emeritus status at Michigan State University. Marcio Catelan and I wrote a book, *Pulsating Stars*, which was published last spring. Another book with a historical orientation is in the works, but far from finished."

David Weintraub, BS '80 is currently a Professor of Astronomy at Vanderbilt University. David has published a new book, *Religions and Extraterrestrial Life: How Will We Deal With It?* (October 2014, Springer). He also was awarded the 2015 Klopsteg Memorial Lecture Award by the American Association of Physics Teachers, which "recognizes outstanding communication of the excitement of contemporary physics to the general public."

Michael West, PhD '87 became the Deputy Director for Science at Lowell Observatory in August 2015. He has also authored a new book titled *A Sky Wonderful with Stars: 50 Years of Modern Astronomy on Maunakea*. (University of Hawaii Press, July 2015). This photo-rich book tells the fascinating story of how a remote mountaintop in the middle of the Pacific Ocean became home to one of the most powerful collection of telescopes in the world.

Douglas Tucker, PhD '94 is still in the job of calibrating large imaging surveys—a job he started while at Yale under Gus Oemler's supervision (Las Campanas Redshift Survey), and has since continued on the Sloan Digital Sky Survey (SDSS-I and SDSS-II) and now on the Dark Energy Survey (DES). He currently serves as the Dark Energy Survey's Calibrations Scientist, and will be celebrating 20 years at Fermilab later this year.

Dana Casetti, PhD '98 was awarded NASA's Connecticut Space Grant College Consortium award for her project, *Orbits of Milky Way Satellites*. Southern Connecticut State University, where she is currently teaching in the Physics department, matched the award. The project involves determination of absolute proper motions for two dwarf spheroidal galaxies, Draco and Sextans, using 8-m Subaru Suprime-cam data. Results for Draco were submitted to MNRAS in Dec 2015, and the paper is now under review.

Thomas Maccarone, PhD '01 writes, "about three years ago, after more than a decade of wandering around Europe, taking postdocs in Italy and The Netherlands for about 2 years each, and then a faculty position in Southampton, England, for about seven years, I had the opportunity to move back to the United States as the senior member of a new astrophysics group at Texas Tech University. Our group now has four faculty, and my fellow astronomers are great colleagues and great scientists. It's been a lot of work getting a new program up and running, both in terms of the internal efforts of starting from scratch, and doing a lot of travelling to go around and wave the flag to try to recruit PhD students, but it's been a great opportunity to see things grow, which has been a lot of fun. I've had the pleasure of having a very supportive work environment in a very pleasant city, and after almost a decade in northwestern Europe, it's really been great to see the sun shine on a daily basis!"

Katherine Rhode, PhD '03 has been on the faculty of Indiana University since 2007 and has recently become a member of the Board of Directors of the Maria Mitchell Association, which runs the observatory and several other natural science research and education activities on Nantucket (see mmo.org). She writes, "I have some terrific students working with me, and I'm transitioning from spending most of my time doing research on extragalactic globular cluster systems to working primarily on optical follow-up studies of sources from the ALFALFA neutral hydrogen survey. My first foray into this led to the discovery of the nearby dwarf galaxy Leo P and we're continuing to search for optical counterparts for ALFALFA HI sources."

Meredith Hughes, BS '05 writes, "I'm starting my fourth year as an assistant professor in the Wesleyan University astronomy department, which is a job that I've been enjoying immensely. This past fall, I was awarded the Harvard astronomy department's Bok prize for outstanding research by an alum under the age of 35. As I write this, I am busy with my role as co-organizer of this year's northeast regional Conference for Undergraduate Women in Physics, which is taking place at Wesleyan in a few days. And on the home front, my husband, Geir, and I are expecting a son to arrive sometime in the next few weeks."

Shanil Virani, MS '05, MPhil '07 writes, "I have created and host a new radio program that runs on NPR called #OurIslandUniverse. This is a 90-second look at all things space, how what goes on 'up there' affects us 'down here.' The goal is to promote the public understanding of science, to share the excitement of new discoveries made, and why science matters. You may subscribe to the show via iTunes or stream it online at www.wmra.org." He is also Director of the John C. Wells Planetarium at James Madison University, and has created 3 summer Space Explorers camps for youth. "Space Explorers use our incredible resources — from our $2M, state-of-the-art, hybrid planetarium to our Science on a Sphere installation — to learn that science is constantly changing, constantly uncovering new clues about why our universe is the way it is and not some other way! Learn more at: www.jmu.edu/planetarium."

Katherine Kornei, BS '06 is working as a freelance science writer, and her work has appeared in *Discover, Wired, Popular Science, Astronomy*, and *Sky & Telescope* magazines. She also designs science exhibits at the Oregon Museum of Science & Industry, and she is helping to develop space science teaching materials with the Lawrence Hall of Science. Katherine recently traveled to Cuba to learn about the country and practice her Spanish.

Carie Cardamone, PhD '10 has accepted a new position as Assistant Professor of Astronomy at Wheelock College.

Adam Solomon, BS '10 writes, "Last year, I finished my PhD in theoretical physics at Cambridge. After a few months last spring visiting collaborators in Heidelberg, at the start of the academic year, I came back to the States for a postdoc at UPenn. My research the last couple of years has centered on modified gravity as an alternative to dark energy, focusing on some newly developed and very interesting theories where the graviton has mass. I've been interested both in the theoretical development and in the comparison of these theories to observation. At Penn, I've continued studying these models, maintaining my collaborations in Europe, and have also been branching out into other areas of theoretical cosmology."

James Kim, BS '11 writes, "I have been working as an Assistant Director at Yale Undergraduate Admissions for the past year and a half, during which time I've admitted quite a few promising candidates interested in astronomy and astrophysics. I am getting married in Monroe, CT, this July, then moving to California to begin my MBA program at Stanford. Before I leave, I'd love to catch up with any astronomy alumni left in New Haven or chat with current students interested in a career in education and/or social entrepreneurship. My email address is: james.b.kim@aya.yale.edu."

Laura Kreidberg, BS '11 is studying exoplanet atmospheres at U. Chicago, and plans to defend her thesis in the spring. She is headed to Cambridge next fall as a Junior Fellow at the Harvard Society of Fellows.

Pedro Capelo, PhD '12 was recently awarded the Tomalla Fellowship, a Swiss national prize fellowship for research on gravitation and cosmology which the winner can take to any Swiss University (in his case, the University of Zurich).

Katherine Whitaker, PhD '12 was awarded a 2015 Hubble Fellowship. She is at the University of Massachusetts Amherst.

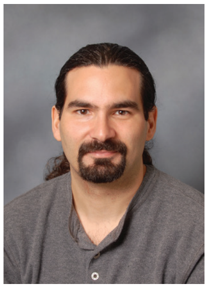
Zachary (Zak) Kaplan, BA '13 is currently working at Novantas, which is a management consulting firm specializing in the financial services industry. He joined the firm right after graduating. Zak is also happy to report that he married his wife, Caitleen Kahn, last summer (June 2015) and they are happily living together in NYC.

Adele Plunkett, PhD '15 writes, "Following my thesis defense in the summer of 2015, I began the ESO postdoctoral fellowship in Santiago, Chile. Half of my time is dedicated to the ALMA observatory, which means I will spend half of my work hours for the next three years in the Atacama Desert in northern Chile, at an elevation of 10,000-16,000 feet. I am excited to work for such an international organization, where I can hear many languages at the same time in the control room of the largest telescope project in the world. Many more telescopes are currently being constructed in Chile, so if you have the opportunity to visit or work at any of them, please also be in touch. My new email address is: aplunket@eso.org."

Giving to Yale Astronomy

The Astronomy Department pursues a wide array of activities, ranging from public outreach with the Leitner Family Observatory and Planetarium to creating innovative instrumentation and obtaining observing nights with the world's largest telescopes. These represent an equally wide array of funding opportunities, and together with Yale's Office of Development, 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 Angelika Hofmann at angelika.hofmann@yale.edu or 203-436-8510.

Yale Department of Astronomy Faculty



Hector Arce
Associate Professor of Astronomy

Star Formation and ISM, Radio / Millimeter Astronomy, Observations

Charles Bailyn
A. Bartlett Giamatti Professor of Astronomy & Physics

High Energy Astrophysics, Black Holes, X-Ray Binaries, Principal Scientist of SMARTS

Charles Baltay
Eugene Higgins Professor of Physics & Astronomy

Cosmology, Dark Energy, QUEST, Member of DESI Collaboration, WFIRST Science Definition Team

Sarbani Basu
Professor of Astronomy, Director of Graduate Admissions

Solar and Stellar Astrophysics, Asteroseismology, Helioseismology, Solar Structure, Dynamics and Activity, Stellar Populations, Exoplanets, TESS Board

Paolo Coppi
Professor of Astronomy & Physics

Extragalactic Astronomy, High Energy Astrophysics, Astro-H Science Working Group, QUEST

Louise Edwards
Lecturer of Astronomy

Cosmology, Large-Scale Structure, Extragalactic Astronomy, AGN, Galaxy Clusters, Galaxy Structure, Formation, & Evolution, Observations

Michael Faison
Lecturer of Astronomy, Director of Leitner Family Observatory and Planetarium, Academic Director of Yale Summer Program in Astrophysics

Star Formation and ISM, Public Outreach

Debra Fischer
Professor of Astronomy and Geology & Geophysics

Exoplanets, Observations, Spectroscopic Analysis, Instrumentation, PI for PlanetHunters

Marla Geha
Professor of Astronomy & Physics

Cosmology, Dark Matter, Extragalactic Astronomy, Galactic Astronomy, Galactic Structure

Jeffrey Kenney
Professor of Astronomy, Director of Graduate Studies

Galaxy Evolution, ISM and Star Formation in Galaxies, Clusters of Galaxies, Extragalactic Astronomy

Gregory Laughlin
Professor of Astronomy

Exoplanets, Theory, Formation and Orbital Dynamics, TESS Science Team Member

Daisuke Nagai
Associate Professor of Physics & Astronomy

Cosmology, Galaxy Clusters, Cosmological Simulations

Priyamvada Natarajan

Professor of Astronomy & Physics, Director of Undergraduate Studies

Cosmology, Extragalactic Astronomy, Dark Matter, Dark Energy, Theoretical Astrophysics, Black Hole Physics, High-Energy Astrophysics.

Pieter van Dokkum

Sol Goldman Family Professor of Astronomy & Physics; Chair

Extragalactic Astronomy, PI for 3D-HST and Dragonfly telescope

Nikhil Padmanabhan

Associate Professor of Physics and Astronomy

Cosmology, Dark Energy, Dark Matter, Large-Scale Structure

Robert Zinn

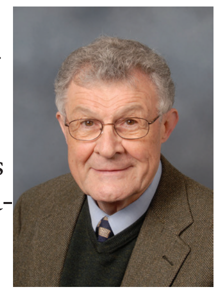
Professor of Astronomy

Stellar Populations of Galaxies, Near-Field Cosmology

Andrew Szymkowiak

Senior Research Scientist/Scholar of Physics

X-ray Spectroscopy of Diffuse Plasmas of Galaxy Clusters, Supernova Remnants and the X-Ray Background; Instrumentation; Astro-H Instrument Team



Pierre Demarque

Munson Professor Emeritus of Astronomy

Stellar Structure and Evolution, Solar & Stellar Astrophysics, Asteroseismology, Stellar Populations, Theory, Galactic Astronomy, Exoplanets, YaPSI, HST science

Meg Urry

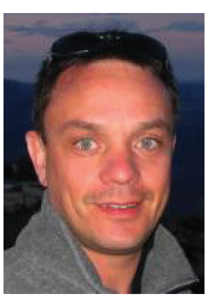
Israel Munson Professor of Physics & Astronomy, Director of Yale Center for Astronomy and Astrophysics, AAS President

Extragalactic Astronomy, AGN, Galaxy Structure, Formation & Evolution, High Energy Astrophysics, Black Holes, Astro-H Senior Advisor

Richard Larson

Professor Emeritus of Astronomy

Extragalactic Astronomy, Star Formation and ISM



Frank van den Bosch

Associate Professor of Astronomy

Cosmology, Dark Matter, Large-Scale Structure, Galaxy Formation, Galaxy Dynamics, Theory

William van Altena

Professor Emeritus of Astronomy

Galactic Astronomy, Galactic Structure, Kinematics, Instrumentation, Stellar Astrophysics, Stellar Populations

Yale University
Department of Astronomy
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Leitner Family Observatory and Planetarium
offers biweekly public events

The Leitner Family Observatory and Planetarium (LFOP) hosts public events every Tuesday night and Sunday afternoon throughout the year, except when Yale is on holiday breaks during the academic year.

The Tuesday public night includes two showings of a planetarium show and observing with telescopes when the weather permits.

The planetarium shows are all comprised of a “live show” (which is narrated by either Michael Faison, the Director of LFOP, or one of a host of graduate student and postdoctoral associate volunteers from the department) and a movie, which changes periodically. Some examples of the movies are *Black Holes*, *Astronaut*, and *Solar Superstorms*.

The telescopes used for public nights include three 8” reflecting Celestron telescopes, the 16” reflecting telescope that is used for undergraduate research projects and the 19th century Reed refractor.

The Sunday afternoon event features one planetarium show. Sunday shows are especially appropriate for younger audiences.

Weather permitting, LFOP’s solar telescope is brought out for observing on Sunday afternoons.

See leitnerobservatory.org, for more information.