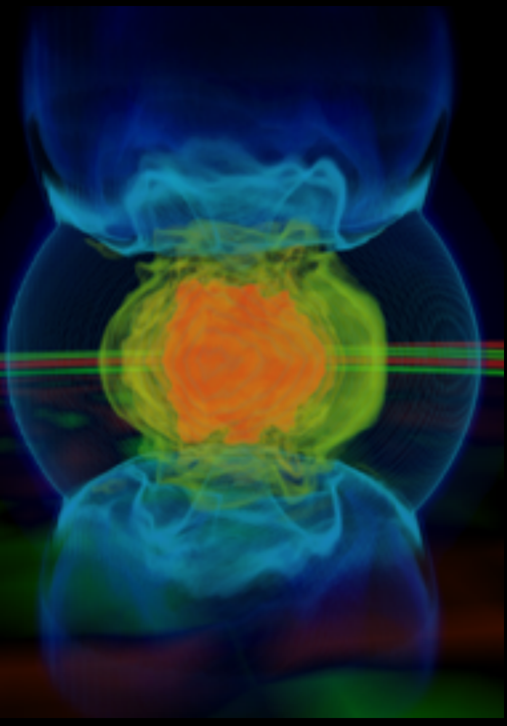
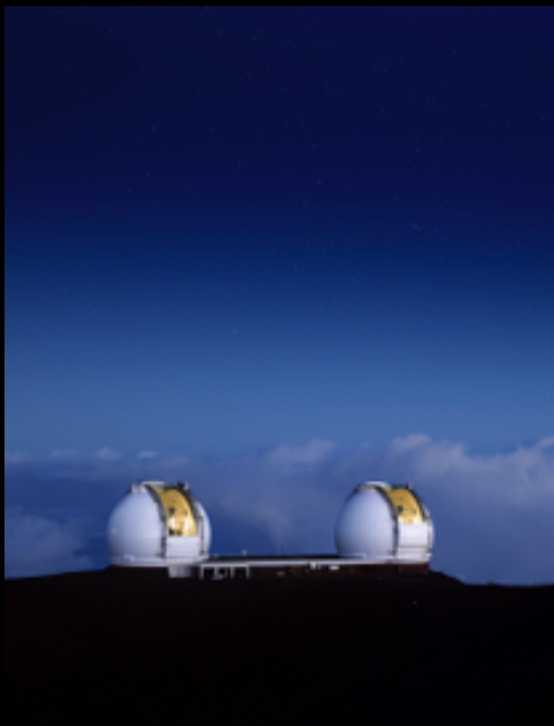
CALIFORNIA INSTITUTE OF TECHNOLOGY

ASTROPHYSICS





Welcome to

ASTROPHYSICS at

CALIFORNIA INSTITUTE OF TECHNOLOGY

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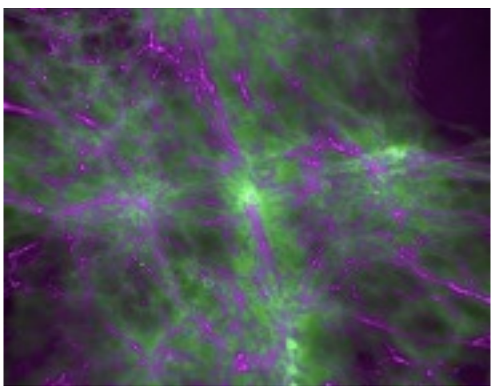
CALIFORNIA INSTITUTE OF TECHNOLOGY

ASTROPHYSICS



Contents

Welcome!

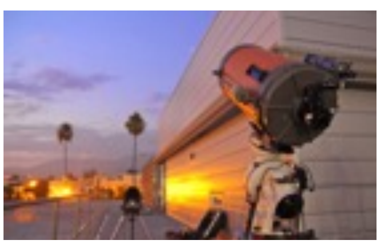
The California Institute of Technology is a world-renowned research university, specializing in science and engineering. The extended Caltech family includes 33 Nobel Prize recipients and over 100 members of the National Academies of Sciences and Engineering. Although big in impact, Caltech is small in size. Just under 1000 undergraduates, 1200 graduate students, and 300 faculty members collaborate on some of the most pressing scientific challenges of the day. Caltech is located on a 124-acre campus in sunny Pasadena, California – part of the greater Los Angeles area, home to numerous cultural, sporting, entertainment, and natural outdoor activities.

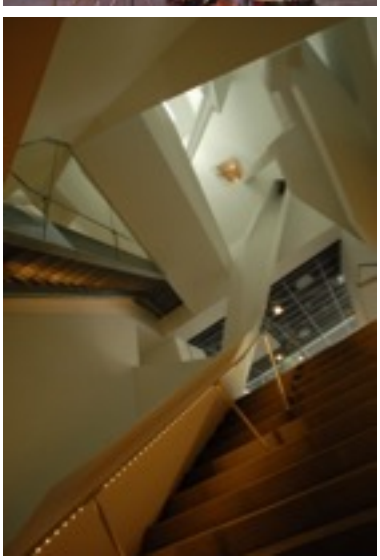
We are located at the Cahill Center for Astronomy and Astrophysics, with an address at 1216 E. California Blvd., that is, not coincidentally, also the wavelength of the Lyman-alpha line of hydrogen. The 100,000 square-foot building designed by the architectural firm Morphosis (led by Pritzker Prize winner Thom Mayne) is the new home for all things astrophysical at Caltech. Cahill houses both the Astronomy Department and the large number of Physics faculty members who work on astrophysical research. Additional faculty in Planetary Science are located just across the street. In total, 10% of teaching faculty at Caltech consider themselves astronomers and astrophysicists.

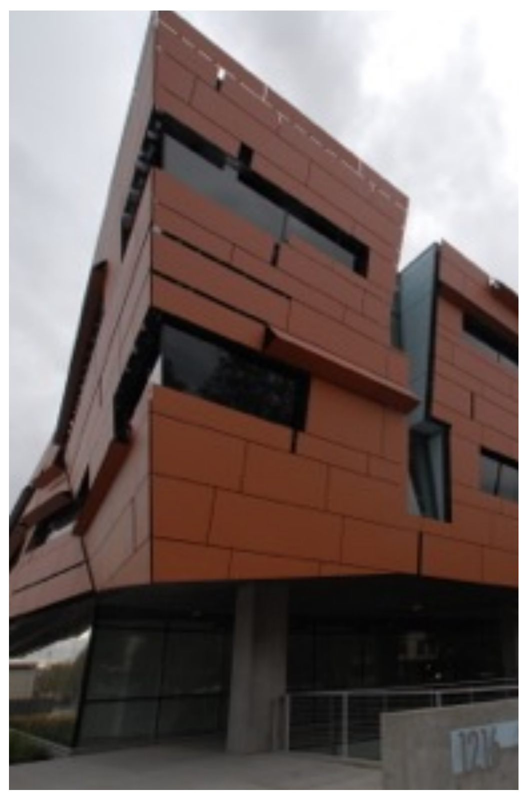
Cahill's residents are engaged in the operation and use of space and ground astronomical observatories, in the technical development of the next generation of such facilities, and in the theoretical interpretation, simulation, and prediction of the full gamut of astrophysical objects and phenomena. The Cahill building houses over 250 teaching and research faculty, technical and administrative staff, postdoctoral scholars, and graduate students, with the 20-30 astronomy graduate students mostly occupying a block of offices on the south side of the building (an example is pictured at the top right of the next page). The building boasts a modern lecture hall and reading room, dedicated space for a sizable theory group, a remote observing facility for Caltech's ground-based optical telescopes, and an operations center for one of Caltech's space missions, as well as laboratory space for the construction and testing of state-of-the-art space and ground astronomical instrumentation.

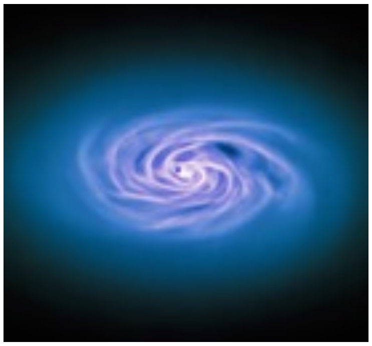
Astrophysics is a naturally synergistic discipline that cuts across various sub-areas of physics, chemistry, planetary science and biology. Fundamental questions regarding the origin and evolution of the universe and its seen (galaxies, stars and planets) as well as unseen (dark matter and dark energy) components are addressed daily in our lab spaces, offices, lecture halls, and classrooms.

Astronomy and astrophysics have been historical strengths at Caltech, beginning with George Ellery Hale's role in the Institute's founding and his subsequent work towards realizing the Palomar 200" telescope – the largest optical telescope on the planet for over 40 years. Today, Caltech has an impressive suite of world-leading ground and space-based observational facilities along with strong instrumental and theoretical groups. Graduate students from both physics and astronomy pursue Ph.D. degrees in Caltech's highly-ranked programs.









Major paradigm-shifting science has been the norm at Caltech for decades. Early optical/infrared astronomers Greenstein, Oke, Zwicky, Schmidt, Munch, and Neugebauer collected pioneering observations at Palomar Observatory. Meanwhile radio astronomers Cohen, Leighton, and Bolton worked at Owens Valley Radio Observatory (OVRO), and Fowler and Hoyle published seminal theoretical papers. "Rocket Science" was started at Caltech by von Karman. The first infrared telescopes, astronomical x-ray detectors, and submillimeter arrays were all matured by Caltech physicists.

Caltech's early visionaries were followed by those who developed and now maintain next-generation observatories including the optical/near-infrared Keck 10m telescopes, the Caltech Submillimeter Observatory (CSO), and the Owens Valley Long Wavelength Array, capable of taking radio images of the entire sky at MHz frequencies. Across the electromagnetic spectrum, Caltech's facilities provide platforms used to carry out forefront scientific investigations and to develop and deploy new instruments and techniques. In addition to its ground-based astronomical observatories, Caltech manages NASA's Jet Propulsion Laboratory (JPL). This partnership has led to close collaboration in developing space missions to explore the solar system and study the cosmos, presently including the Spitzer and Herschel observatories, the Planck surveyor, and the NuSTAR Explorer mission. Beyond the electromagnetic spectrum, Caltech is a lead institution in the Laser Interferometer Gravitational Observatory (LIGO), which soon may be the first to study cosmic phenomena using gravitational radiation. These unique facilities lie at the forefront of science today, enabling Caltech's students, postdocs, and faculty versatile access to our universe.

For the future, Caltech astrophysicists are currently developing the next generation of telescopes and instruments. They are actively involved in the Thirty-Meter Telescope (TMT), an optical/near-infrared telescope, and in building upon the success of the Palomar Transient Factory (PTF) in exploring time domain astronomy with it's successors iPTF and ZTF.

Caltech physicists will continue to lead the way in developing state-of-the-art instrumentation for ground, suborbital (airplane, balloon, rocket), and space observatories. The Observational Cosmology (ObsCos) group, for example, has been at the forefront in investigating the beginnings of the universe with their involvement in projects such as BICEP-2 and the forthcoming BICEP-3.

As in the past, Caltech continues to be a leading center of astrophysics theory. The Theoretical AstroPhysics Including Relativity (TAPIR) group has been prominent for many decades in theoretical studies of compact objects, planetary systems, high energy processes, gravitation and relativity, and cosmology. Their current efforts are focused on supernova theory, relativity (especially predicting signals detectable by LIGO), cosmology, and compact objects.

Past, present, and future graduate students play critical roles in all of these endeavors. In the process, they apprentice as forefront scientists and full participants in many prominent scientific results. Some Caltech highlights over the years in observation include, the first evidence for dark matter in clusters of galaxies, recognition of the importance of supernovae, discovery that quasars are at cosmological distances, the first direct evidence for spatially resolved protoplanetary disks, the definitive evidence that gamma-ray bursts are located beyond our galaxy, the discovery from measurements of the cosmic microwave background radiation that the universe has a flat geometry, discovery of the first brown dwarf, discovery of the largest solar system object found since Neptune, and the first evidence of supermassive black holes in the centers of nearby galaxies.

Meanwhile, Caltech theorists, first predicted that the supernova explosions of massive stars produce neutron stars, generated the first theory of pulsar radiation, deduced how gaps in the rings of Saturn are formed, and developed the theory of nucleosynthesis.

The Astronomy Graduate Program

Program Scope

The Caltech Astronomy program aims to prepare students for productive and creative careers in astrophysical research, and has a track record of training the next generation of leaders in the field. We have 2-5 undergraduate majors per year, almost all of whom participate in multiple summers of research here at Caltech. One-half to two-thirds of our majors go on to graduate study in astronomy or physics. At the Ph.D. level, we graduate typically between 2 and 7 Astronomy Ph.D.s per year, plus a similar number of Physics Ph.D.s with primary research in astrophysics. There are currently about 30 Astronomy graduate students.

The vast majority of our graduate students come from undergraduate astronomy or physics programs, though some arrive from related majors such as engineering or computer science. In addition to those admitted directly to the Astronomy option, students from the Physics option may conduct astrophysical research with either Astronomy or Physics faculty. Conversely, Astronomy students may take the opportunity to work with faculty in Astronomy, Physics, or Planetary Science. A discussion of the Astronomy option is contained in the following text; for more information on the requirements in other departments, see the Caltech graduate school's website.

"I couldn't have asked for a better combination of incredible research opportunities and life-long friendships."

Alumna Alice Shapley (Ph.D. 2003)
Associate Professor, UCLA

Admission

At the bachelors degree level, nationally over the past decade there has been close to 100% growth in the number of undergraduate astronomy majors and 60% growth in physics majors, compared to essentially constant (within 15%) numbers over the previous two decades. The increased pools for graduate admission have been accompanied by a smaller yet very substantial 50% increase in the number of available first-year graduate student positions nationwide. At the same time, the number of doctorate degrees awarded from U.S. institutions has remained stable (+/-15%).

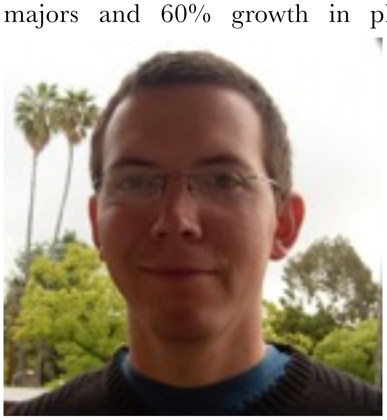
Students admitted to Caltech have a solid background in physics, and although in-depth preparation in astronomy is helpful, such training is not required for admission. All applicants submit Graduate Record Examination scores for the general aptitude tests, plus the advanced test in physics. Transcripts, letters of recommendation, and a personal statement round out the application package. Additional scores from the TOEFL exam are required for citizens of non-English speaking foreign countries who are not already living in the U.S.

Academic Program

In astrophysics, we strive to understand the physical processes that govern the universe and its constituents. We use the apparatus of engineering and methodology of physics to gather and interpret data, and to conduct theoretical studies. Caltech Astronomy students are embedded in a large and diverse department with interesting talks, seminars, and conferences happening nearly every day. This helps them acquire broad knowledge and good scientific practices. They receive intensive classroom training, including exposure to all aspects of modern astrophysics.

There are six astronomy classes to be completed during the first year of graduate study: Radiative Processes, Structure and Evolution of Stars, Structure and Dynamics of Galaxies, High-Energy Astrophysics, Interstellar Medium, and Cosmology and Galaxy Formation.

Also during their first or second year, students focusing on observational astronomy take the Astronomical Measurements and Instrumentation sequence and four courses in physics or another appropriate subject. Theory students, on the other hand, select six classes in physics, mathematics, or other applicable fields. All first-year students participate in Introduction to Modern Research which exposes them to available research opportunities.



"My Caltech Astronomy education has given me a unique preparation for my career in Silicon Valley. I developed a breadth of physics, programming, hardware, and data analysis experiences which have proven incredibly valuable. All of these skills are being put to good use in my current work on human interface devices."

Alumnus Matthew Stevenson (Ph.D. 2014)
Senior Algorithm Architect at Synaptics, Inc.

After their first year, students are encouraged to enroll in upper-level special topics courses, which are offered according to student demand and professor interest. All students second-year and beyond take a journal club seminar course to hone their presentation skills. For more information on courses, please see pr.caltech.edu/catalog/courses/listing/ay.html.

As with most graduate departments, Caltech has a qualifying exam. Here, the exam is an hour-long oral examination given at the start of the second year and focused on a presentation on the student's first-year research plus the required first-year astronomy courses.

After passing the qualifying exam, graduate students transition to a teaching-assistant position for the duration of their second year. The teaching assignments are agreed upon by the students themselves and include assisting with undergraduate courses, first-year graduate lecture classes, recitations and laboratory classes at all levels. After the one-year teaching requirement, most students move to full-time research positions.

For students interested in additional mentoring and teaching experience, there are ample opportunities to continue working as a teaching assistant, especially for the freshman-level introductory astronomy class, or help lecture for the more advanced courses. In addition, graduate students often co-mentor summer research students through the Caltech Summer Undergraduate Research Fellowship (SURF) Program.

"The large number of scientific talks, black board lunches and discussions made being a graduate student at Caltech a very stimulating experience; the interactions were a great foundation for my academic life."

Alumna Hilke Schlichting (Ph.D. 2009)
Assistant Professor, MIT

Research

The Caltech graduate program emphasizes independent research, and students are free to pursue study in virtually any area of astrophysics. They are encouraged to sample several different research projects before embarking on thesis work. Research may be supervised by any of the teaching or research faculty, and can be performed in collaboration with other graduate students, postdocs, or larger consortia. Faculty members advise, on average, 1-2 postdocs and 1-2 graduate students in research. Many faculty also take on one or more undergraduate students each summer. The 1st and 2nd-year graduate students, along with the undergraduates, have an additional advising resource in the Option Representative.

Caltech's extensive, world-class observational facilities span a wide range of wavelengths. The suite has always been an important component of our graduate education program, and our students learn the trade from the active example of their peers and advisors. The access students have to use and help develop capabilities at these observatories is simply unmatched by any other institution. Our deep connections to the JPL and the "Greater IPAC" communities, which develop, operate, and serve data from space missions, add to the large list of opportunities open to Caltech students. In theoretical astrophysics, Caltech has an excellent group – TAPIR – that spans the Physics and Astronomy options. Students in TAPIR work alongside leading scientists in many venues of theoretical astrophysics and also benefit from proximity to leading observers and instrumentalists.

Thesis Projects

Many Caltech theses represent substantial, even milestone, results in their sub-fields. Recent examples of Ph.D. theses over the past five years reflect the breadth and diversity of research pursued by students at Caltech.

In the realm of theoretical astrophysics, the latest research areas included studies of new physics in the CMB, the beginning evolution and present days of the universe, large scale structure, particle dark matter, spinning dust radiation, and cosmological consequences of low energy phenomena.

In extragalactic observations, recent work has focused on galaxies as the source of reionization, cosmological foreground emission, high redshift galaxies, blazars, the assembly history of massive galaxies, the intergalactic and circumgalactic medium, early star formation and quenching, explosions in the local universe, and Lyman radiation from high redshift galaxies.

"As an observational astronomer, Caltech offered me research opportunities that were unparalleled at any other graduate school. While a student, I led programs working with observations from Hubble, Keck, Palomar, HET, and the VLT, and I presented the results of those programs at many conferences around the world."

Alumnus Adam Kraus (Ph.D. 2009)
Assistant Professor, University of Texas at Austin

"My time as a graduate student at Caltech gave me an exposure to the front-line of astronomy research. I bring my experiences observing at world-class facilities and interacting with the tremendous people at Caltech into my classes, giving my students a feel of the way astronomy really works! I believe that a Ph.D. from Caltech helps open doors into education."

Alumnus Micol Christopher (Ph.D. 2008)
Professor, Mt. San Antonio College

In galactic observations, the latest theses have involved aperiodically variable young stars, demographics of extrasolar planets, magnetar proper motions, grain growth in protoplanetary disks, neutron star masses, precision photometry in young brown dwarfs and low mass stars, and multiple star formation.

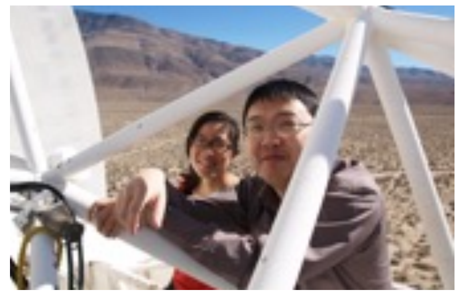
Progress in astronomy relies upon the invention and implementation of new instruments, and instrumentation work has formed an important part of many Caltech theses. Recent examples include work on radio instrumentation at Owens Valley Radio Observatory including the building of the Long Wavelength Array, development of a robotically operated adaptive optics system at Palomar Observatory, software and hardware development for the MOSFIRE instrument at Keck Observatory, and x-ray instrumentation work for the NuSTAR space mission.

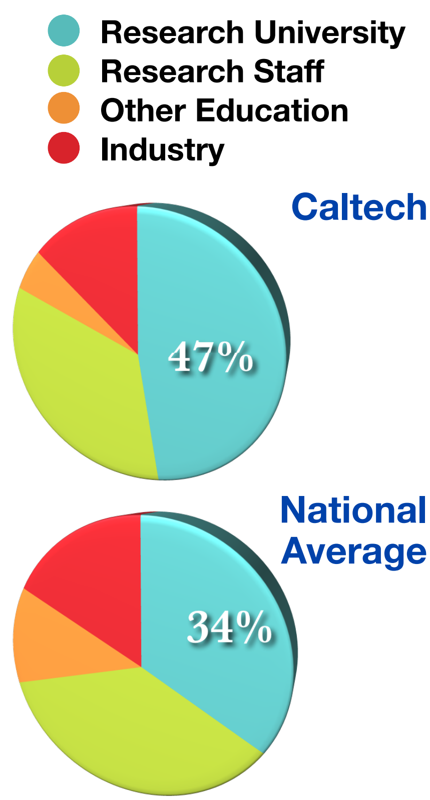
The above are just a small sample of the revolutionary developments enabled by the ingenuity of the Caltech students and faculty, and allowed by the observational and theoretical resources of the Institute.

Alumni & Job Placement

Eighty percent of our graduate program matriculants receive Ph.D. degrees, within a mean time of 5.5 years. This accomplishment positions our graduates well for long term careers in astrophysics. Overall, our graduates do very well in the postdoctoral job market, and typically several per year win prestigious fellowships. Other Ph.D. recipients who choose a different path, and those who graduate from Caltech with an M.S. degree, find employment in fields including education, public policy, data science, technology, finance, aerospace/defense, or broader industry.

Caltech Astronomy boasts a long and impressive list of its Ph.D. alumni. Details on our many graduates can be found at http://www.astro.caltech.edu/people/grad_alumni.html along with their current employment and links to archived theses. Among alumni graduating over the past 30 years, close to half (47%) have found long-term employment as professors at Ph.D.-granting universities, with an additional 34% employed as staff at observatories or national laboratories. 13% are in business or industry, 2.5% are professors at 4-year or community colleges, and another 2.5% work in other education-related careers.





"Caltech is a truly unique place, where big ideas are given room to grow. It is a fantastic place to be a graduate student."

Alumnus Benjamin Mazin (Ph.D. 2004)
Associate Professor, UCSB

Weekly Talks and Seminars

At Caltech, there are numerous opportunities for graduate students to learn about cutting-edge science happening around the world and to discuss it with the large community of astronomers in the greater Pasadena area. Talks and seminars are held not only in the department's building, but also in the neighboring Spitzer Science Center, Carnegie Observatories, and Jet Propulsion Lab (JPL).

The Caltech postdocs and graduate students organize an informal discussion of recent papers from the arXiv for half an hour every morning; the attendance and topics discussed vary, but it is a good way to remain abreast of recent advances and important developments across many sub-disciplines. Also of general interest are the tea talks held on Monday afternoons, which are generally given by postdocs and senior graduate students from departments across the world. These talks begin with wine and cheese in our library and tend to be less formal than the regular colloquia. The colloquia, which are at the heart of the weekly talk schedule, occur on Wednesday afternoons and are attended by almost all faculty, students, and postdocs. The speakers are typically visiting faculty members or senior scientists, whom the graduate students are able to meet a few hours before the colloquium at a department-sponsored lunch at the faculty dining club every week. These lunches are a relaxed forum for networking, discussing life in academia, and learning about research happening at the speakers' home institutions.

Most Friday afternoons, two graduate students deliver talks on their own research or a recent article from the literature. These journal club talks are a wonderful chance to develop strong public-speaking skills and receive feedback from members of the department; as a result, our graduate students often receive compliments on their speaking presence when giving professional talks elsewhere! After journal club, the department gathers on the patio to socialize over beer, soda, and other refreshments before parting ways for the weekend.

There are also a number of more targeted discussions throughout the week, including Monday pizza lunches, which bring together observers and theorists across a range of disciplines and are hosted by Professors Shri Kulkarni and Phil Hopkins. Wednesday mornings, members of the extragalactic community gather to discuss recent conferences, papers, and other topics of general interest at GalCafe. The Theoretical AstroPhysics Including Relativity (TAPIR) group invites speakers to give seminars every Friday, which focus more heavily on the analytical and numerical aspects of astronomical research.

In addition to the events in the astronomy department, the physics and planetary science departments at Caltech also host weekly colloquia on Thursdays and Mondays, respectively, with the Carnegie Observatories colloquium held on Tuesday afternoons — just a short drive from Caltech's campus. There are certainly enough talks and seminars in the Pasadena area to keep the dedicated talk-goer busy all week!

A Day in the Life

Get tea or coffee

Chat with postdocs

Check Astro-ph and read email

Go to Astro-ph discussion

Write some code

Have lunch with grads or with the colloquium speaker

Meet with advisor

Analyze results

Walk to the Red Door coffee shop for a snack

Go to group meeting or attend colloquium or do some more research

Grab dinner

Go to pottery class or play on the softball team or practice guitar

Astro Outreach

Caltech has several education and public outreach programs that span the full breadth of Caltech research such as the Caltech Classroom Connection, while each of the space missions (Spitzer, GALEX, etc.) has its own outreach efforts that host events for schoolchildren and the public. There is also Caltech Students for the Exploration and Development of Space (SEDS), an amateur astronomy club, which organizes regular stargazing trips.

Besides these, an informal astronomy outreach group of graduate students, postdocs, staff, and faculty members with varied backgrounds gets together to share their interests with others. Activities include giving talks to school children, setting up telescopes on the sidewalks of Old Pasadena to show heavenly bodies to passers-by, holding public viewing parties for events such as eclipses and supernovae, and participating in an "Ask an Astronomer" session at the Griffith Observatory. We've even participated in curriculum planning for the Pasadena Unified School District.

Our resources include the Cahill Rooftop Observatory, which has a fully automated 16" telescope for astrophotography as well as eyepiece viewing and, for outside activities, a portable 10" telescope, a Celestron 8" telescope, 3 smaller telescopes, and a few pairs of binoculars. We are also usually stocked with freebies (posters, postcards, bookmarks, etc.) to give away during outreach sessions. If you have new ideas for bringing Caltech Astronomy to the public, we'd love for you to join in!

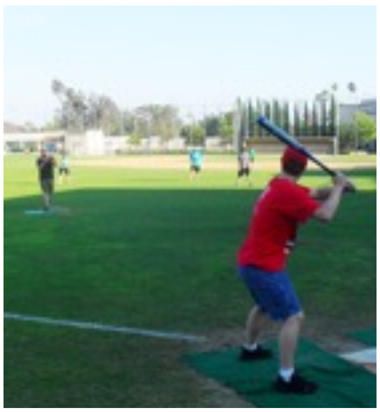
"For the Venus transit in June of 2012, we hosted a viewing party for the public. Almost 2,000 people came by to look through our telescopes and listen to lectures by faculty and grad students explaining the phenomena. My favorite moment was watching a group of 3-4 year-olds realize excitedly that they were really looking at another planet through the telescope."

Swarnima Manohar
Outreach Participant

"After visiting a fifth-grade class the kids gave us cards they had made; a few of these 10 year-olds had written that they now wanted to do a Ph.D. when they were older! One of the best things about outreach is that though you can spend weeks stuck on some small piece of your own work, forgetting about the bigger picture, when you explain what you do to someone who has never heard of it before, you share their excitement in it and remember how awesome your work is."

Donal O'Sullivan
Outreach Participant





Grad Student Life

Caltech Astronomy graduate students certainly enjoy great research using top-tier facilities. But they also make time to have fun and socialize with other students, postdocs, and faculty. Within the department, a time-honored tradition is Thursday donuts, when everyone gathers for bagels, drinks, and donuts (sprinkled with a bit of gossip). Tuesday afternoon teas bring together Cahill's astronomers and physicists for tea and cookies. We also host a beginning-of-year barbecue to welcome all the newcomers to Cahill. Cahill has a spacious back patio that opens onto the athletic field, which is an excellent venue for all kinds of fun events from Friday social hour to whiskey tasting to pickup frisbee games!

One of the first events that new students experience is the annual Halloween party. Every October, all the grads take pride in planning an evening full of good food, drinks, and crazy Halloween fun (start planning now for the costume contest!). Another department-sponsored highlight of the year is the annual ski trip, planned by and for the students. In February or March, grads and their significant others spend three fun-filled days prancing in the snow at Mammoth Lakes. Some work on their downhill or cross-country skiing skills, others go tubing and snowshoeing, and everyone savors the taste of hot cocoa by the fire. Not only that, but we have largely managed to avoid broken bones! Back on campus, rumor has it that various Astronomy students have also been spotted sneaking in a board game or two in their spare time, or heading down into the basement for an exciting game of foosball or ping-pong. Astro grad students also participate in many facets of campus life, playing in concert band, serving as an RA, arbitrating student cases on the Honor Council, and advocating for grad student families and faculty professional development as part of the Graduate Student Council. And for the athletically-inclined, Caltech astronomers participate with gusto in a variety intramural sports: softball (we are the league champion Big Bangers), soccer (the Cataclysmics), and ultimate Frisbee (the Protostellar Disks).

While the department provides ample extracurricular opportunities, it's no secret that the Los Angeles area is full of outdoor, cultural, and social activities too. Outside of Caltech, Astronomy students have been known to surf the waves of Malibu, grapple with jiu jitsu and spar in tang soo do, play at local open mic nights, rock climb and backpack in the peaks of the San Gabriels and Sierra Nevadas, go wine tasting, and learn tango and salsa dancing. Some just sit back and enjoy the ever-present sunshine, while others take to the skies to earn their pilot's license as part of the Caltech flying club or mingle with octopuses and starfish while earning their SCUBA certification. For the musically inclined, Caltech boasts a number of choirs and instrumental ensembles. Grad school is also a great time to adopt an animal; many astro students petsit for each other and even get together for kitten play dates. For those looking to bond with fellow Caltech students, the Graduate Student Council, Caltech Y, and a number of other campus organizations arrange quite a few events and trips during the year. There are also classes of all sorts taught by the Institute. A department favorite for many years has been a weekly pottery class which always seems to have a few astronomers enrolled. And for those who prefer to discover Southern California on their own, many museums, theme parks, markets, waterfalls, and even gilded movie stars' mansions are just a brief car or train ride away.

The Grad Student **Perspective**

"When I was deciding on where to attend graduate school, my goal was to find an astronomy department where I could conduct cutting-edge observational research in a fun, friendly environment. In the end, I chose Caltech and I could not be happier with my decision. I am currently working on a thesis project studying protoplanetary disks with data from both ALMA and Keck Observatory- a combination of the best submillimeter and optical facilities in the world only possible at a place like Caltech. Outside of my research, I enjoy taking part in numerous department social activities, many of which I now organize. Whether I need to find an expert in a field I'm interested in, someone to go to for advice, or just someone to hang out with, I can find that person at Caltech."

Scott Barenfeld

"The access to incredible observational resources at Caltech is more than met by the wealth of research opportunities here. My focus is primarily on low frequency radio transients, including the direct detection of hot Jupiters through their magnetospheric emission with the Long Wavelength Array at Caltech's Owens Valley Radio Observatory. Within my first two and a half years here, I've been able to participate in the building of the LWA, from installation of antennas to production of science-quality data. The LWA will soon be continuously monitoring the entire visible sky for exoplanets and other transients, and I'm looking forward to the exciting work ahead of me, as well the continued support of the amazing graduate student community here!"

Marin Anderson

"I came to Caltech because I love observational astronomy, and I was lucky to arrive around the same time that MOSFIRE (the multi-object near-infrared spectrograph on Keck) was commissioned. Not only was I involved in the very first observing runs during my first year as a grad student, but my thesis is built on what is now one of the largest samples of rest-optical spectroscopy of high-redshift galaxies in the world, all of which has only recently been made possible with MOSFIRE. It is extremely humbling to be part of such a big project that will be so important for understanding the conditions in early galaxies, and I feel fortunate to be able to see things through from beginning to end: I help run the galaxy survey, lead most of the observing runs, reduce and analyze the data, *and* get to report on the science results. On top of the unparalleled access to observing resources I've had as a student here, I found the environment at Caltech to be rich with other benefits as well, including mentorship and advice from some of the top minds in our field."

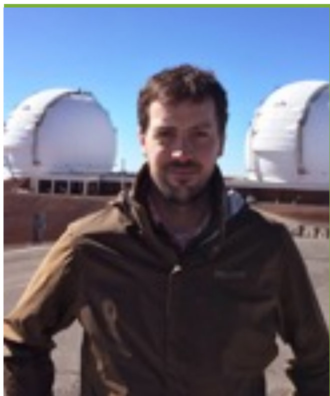
Allison Strom

"Caltech access to telescope time has been crucial in allowing me to pursue the science that I want to do. The opportunities are remarkable and diverse, allowing you to work on just about anything you're excited about. I'm interested in the magnetic activity of very low-mass stars and brown dwarfs. These objects are extremely faint but through Caltech facilities I've gotten the opportunity to explore important questions in this field. I had seven nights of Keck time just last year and now I'm swimming in data."

J. Sebastian Pineda

The Postdoc **Perspective**

At Caltech postdocs play an integral role in facilitating communication, learning, and interaction within the department. They often serve as mentors for graduate and undergraduate students within their research groups, providing expertise and assistance when faculty are not available, and a forum for casual interactions. Additionally, a few postdocs also run a daily astro-ph discussion group which brings together faculty, grad and undergrad students to discuss astronomy news and current papers in a relaxed and informal setting. Here are some words from some current postdocs to give you a flavor of the work being done.



"I am part of the TAPIR (Theoretical Astrophysics Including Relativity) group. I use cosmological hydrodynamic simulations to study galaxy evolution and cosmic structure formation. Caltech offers access to state-of-the-art computational resources, including supercomputing clusters and cutting-edge simulation codes. I also strive to make close connections with observations, and again, Caltech allows access to some of the best observatories available, which I have used. I help to organize the weekly Monday lunch discussion, which enables faculty, postdocs, and graduate students working in both theory and observation to interact in an informal and productive atmosphere."

Andrew Wetzel
Moore Fellow in Theoretical Astrophysics

"I am a postdoc at Caltech working to understand the rich variety and formation mechanisms of exoplanets. In my research, I primarily focus on studying planets that are Neptune-size and smaller using numerical models of their interior structure, formation, and evolution. One of my current goals is to constrain the composition distribution of planets from the accumulating statistical sample of exoplanets that have mass and radius measurements. As part of these endeavors, I have been advising a couple of undergraduate researchers. I have also enjoyed interacting with grad students at the morning astro-ph discussions, at group meetings, through the Caltech Women Mentoring Women program, and by collaborating on outreach initiatives. Overall, my time at Caltech has been a truly productive and inspiring experience."

Leslie Rogers
Hubble Fellow

"As a postdoc at Caltech, I've been able to take a leadership role in developing new and groundbreaking instrumentation. I'm the Project Scientist for the Zwicky Transient Facility, a next-generation optical time-domain survey, and I've contributed to other projects at Palomar as well as the NuSTAR X-ray space telescope. Caltech Astronomy's unparalleled observational resources allow grad students and postdocs to have a major impact in producing cutting-edge science.

Eric Bellm
Postdoctoral Scholar

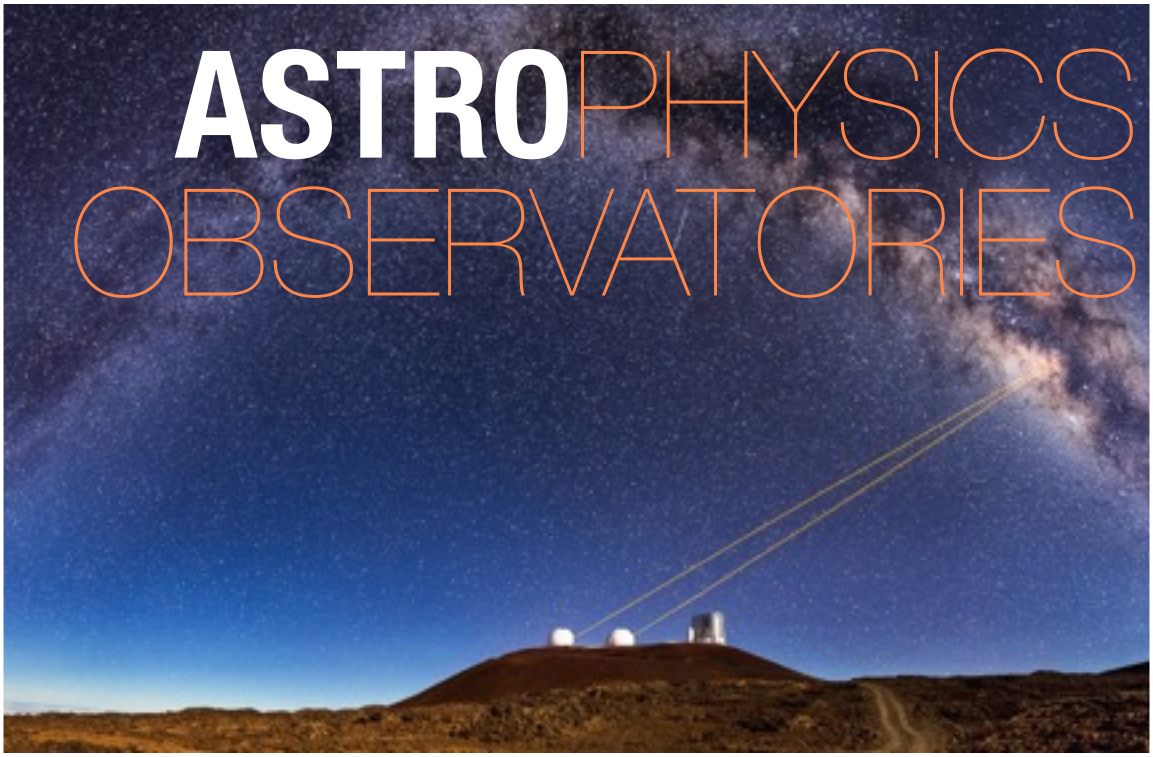
"I am a postdoc in the TAPIR group and a visiting research fellow at NASA's Jet Propulsion Laboratory. My current research involves using arrays of millisecond pulsars to search for low frequency gravitational waves (GW). The pulsars beam radio waves to the Earth as they rotate, creating a lighthouse effect. Deviations from the expected time of arrival of these radio waves could signal the presence of GW from e.g. supermassive black hole binary systems with masses in the range of millions to billion of solar masses. There are so many of these binary systems that we expect them to form a diffusive GW background, which may soon be detectable. At Caltech, I have access to state-of-the-art computing facilities to search for these GWs, as well as exceptional colleagues and graduate students who are a pleasure to collaborate with. Indeed, the innovative and diverse environment here encourages excellence and is truly unique. "

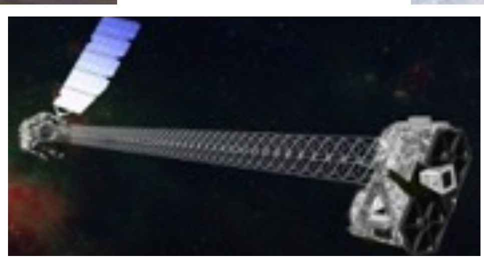
Chiara Mingarelli
Marie Curie Fellow in Theoretical Astrophysics

The observational resources available to the Caltech community can only be described as unparalleled. From the historic Palomar 200", for which graduate students can propose projects as the principal investigator, to the twin 10-m Keck telescopes, students wishing to perform optical or near-infrared observational projects easily gain access to world-class data. Students can participate in the rapidly evolving transient science across the electromagnetic spectrum. If you are more interested in longer wavelengths, Caltech operates Owens Valley Radio Observatory which includes the Long Wavelength Array. If your interest is in higher-energy photons, Caltech built and operates the first focusing hard X-ray telescope, NuSTAR.

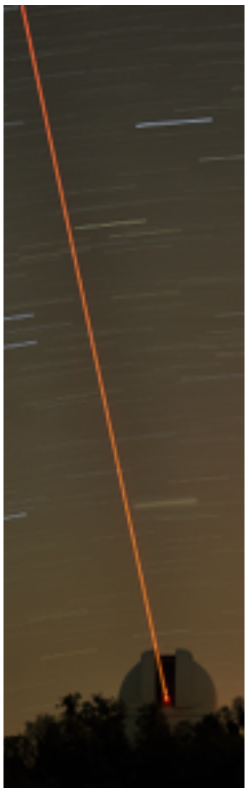
For students more interested in instrumentation, there are always new telescopes, space missions, and instruments being built in the many labs in Cahill or in other places across the campus. In the following pages, we detail the unrivaled observational capabilities of the department — facilities that you will have access to as a Caltech graduate student.

ASTROPHYSICS OBSERVATORIES





Palomar Observatory



Located in southern California, Palomar Observatory was established in 1948. It has a distinguished history as the site of tremendous astronomical innovation and discovery, and continues today as a world-class research center. The observatory is owned and operated by Caltech and is home to a suite of optical/infrared telescopes that are used nightly, not only as workhorses of modern astronomy, but also as active testbeds for instrument development.

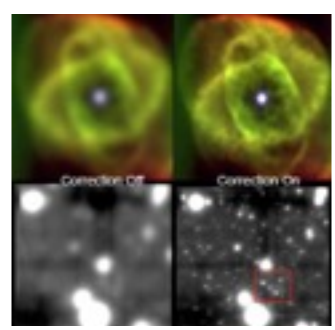
The gem of Palomar Observatory is the 200" Hale telescope - the world's largest until the Kecks came online in the 1990's. The Hale's diverse instrumentation suite is utilized by astronomers from Caltech, JPL, Yale, and NAOC. The 48" Samuel Oschin and 60" telescopes have more specialized instrumentation with large blocks of time allocated to Caltech-led collaborations, most notably the highly productive Palomar Transient Factory (PTF). Several smaller domes are also available for innovative uses and have hosted searches for comets, other solar system objects and transiting extrasolar planets.

The 200" Hale telescope is equipped with high-sensitivity, moderate-dispersion spectrographs in both the optical and near-infrared, together covering 0.3-2.5 microns and complementing two moderately wide field of view imagers for these same wavelengths. The science being pursued is wide-ranging and includes the characterization of objects across the Universe - from gamma-ray burst afterglows, quasars, primeval galaxies, intermediate-redshift Type Ia supernovae, young star clusters, all the way to stellar populations in nearby galaxies, galactic star formation, nearby brown dwarfs, and solar system objects. The Hale's facility adaptive optics system, PALM-3000, uses the world's largest format deformable mirror (3,568 actuators) to correct for the image blur caused by turbulence in the Earth's atmosphere. This enables diffraction-limited resolving power of 0.025-0.050 arcseconds at red optical and near-infrared wavelengths. Taking advantage of these extremely sharp images are imagers and visible and near-infrared integral field spectrographs capable of suppressing starlight to reach contrast levels of 1:105 to 1:107. With AMNH partnership, Caltech researchers are leading the search for exoplanets via direct imaging, supported by a robust program of adaptive optics technology development. A recent example of this is Robo-AO, the first robotic laser guide star adaptive optics system in the world which was developed on the Palomar 60" telescope.

Beginning in 2017, the Zwicky Transient Facility (ZTF) will replace PTF on the Samuel Oschin Telescope, for the first time filling the 47 deg^2 focal plane with world-class CCD sensors. ZTF will be have the highest volumetric survey speed for spectroscopically accessible transients in history. Coupled with a new integral field spectroscopic characterization engine on the Palomar 60" (the SED Machine), ZTF will identify the most interesting targets to trigger rapid follow-up with the Palomar 200" or Keck telescopes.

In addition to producing high impact science and training students in observations and instrumentation, Palomar Observatory also hosts a prominent visitor center and education/outreach program in which Caltech students can participate.

Clockwise from the top: Palomar telescopes, demonstration of the resolving power of the adaptive optics system on the Hale 200", WaSP's guide CCDs, Hale 200" telescope, Robo-AO with the adaptive optics laser



Palomar Transient Facility (PTF)

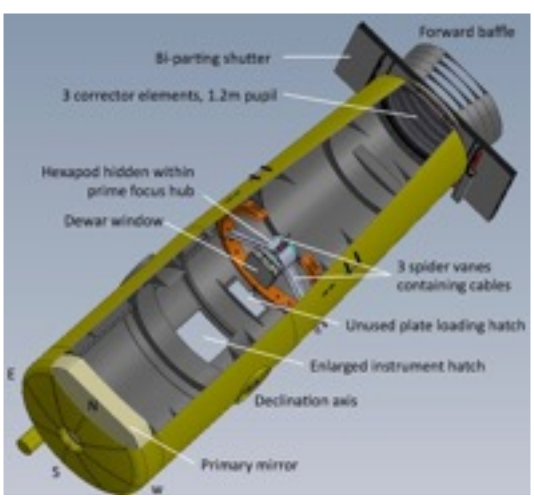
Palomar Observatory has pioneered celestial cinematography for many decades The legacy began with the Samuel Oschin 48" Schmidt telescope undertaking the POSS I survey (1950s) and POSS II survey (1980s) with photographic plates and more recently, the digital QUEST survey (2000s).

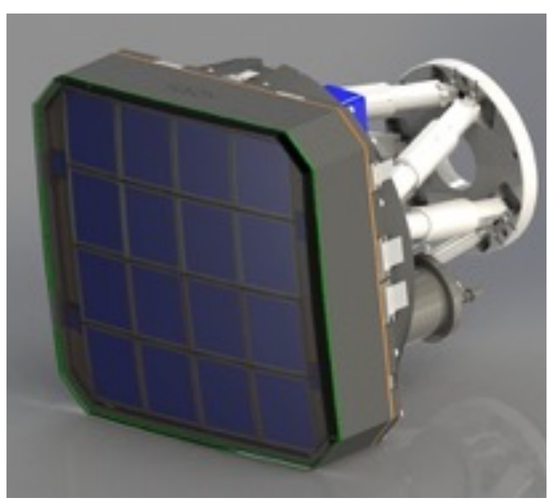
In July 2009, Caltech commissioned the Palomar Transient Factory (by a small group on a shoestring budget). PTF was designed with the single, focused goal of systematically charting the transient sky. The concept was telescopes in an assembly line, with each telescope assigned one task, so that the factory could efficiently churn out transient discoveries. The robotic Palomar 48", equipped with a 7.1 deg^2 camera attaining a depth of 21 mag every 60 seconds, is the discovery machine. Next, the robotic Palomar 60", equipped with a pencil beam multi-color camera, is the classification engine. Next, the Palomar 200" and Keck telescopes serve as the workhorses for spectroscopic follow-up.

In January 2013, the intermediate Palomar Transient Factory (iPTF) was commissioned. The hardware was the same as PTF but the software was entirely re-written. Superior algorithms for reference image generation, database queries, and machine learning were implemented. Software constitutes the backbone of such a big data project. The new system enabled unprecedentedly rapid panchromatic follow-up. iPTF also holds a summer school annually designed for advanced undergrads and graduate students about survey operations and a thorough introduction to time domain science.

In the first five years, PTF/iPTF discovered and spectroscopically classified over two thousand supernovae. The PTF team has written over 101 papers with over 3200 citations. Some of the most notable discoveries include flash signatures of newborn supernovae, rare classes of gap transients and superluminous supernovae, orphan relativistic explosions, near earth asteroids and young star outbursts.

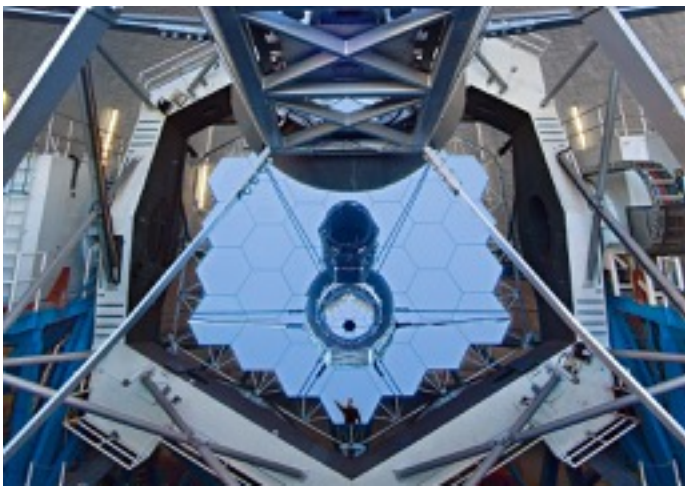
In January 2017, we plan first light for our next-generation Zwicky Transient Facility. Equipped with a 47 square degree camera and faster readout electronics, the Palomar 48" will be imaging the sky at 3750 deg^2 per hour — a factor of 12 faster volumetric survey speed than PTF. The Palomar 60" will have a robotic spectrograph (SED Machine) for classification. The science potential is incredible and limited only by one's imagination!





Clockwise from top left: SN 2011kly found by PTF, Palomar 48" discovery telescope, Palomar 60" classification telescope, Zwicky Transient Facility camera design

Clockwise from top right: the Keck domes with the adaptive optics laser fired from Keck I and Keck II, the summit of Mauna Kea at night, the Keck II primary mirror, and a look inside the domes from above.



The W. M. Keck Observatory (WMKO)

Built close to the 13,600 ft summit of Mauna Kea in Hawaii, the W. M. Keck Observatory is an invaluable and unrivaled resource for Caltech students and scientists. Operational for over 20 years, the two Keck 10-meter mirrors are the largest optical telescopes in the world. Each mirror consists of 36 hexagonal segments that work together to form a single reflective surface.

Access to the Keck Observatory is highly prized. Observing time at the two telescopes is divided among Caltech (which holds 36.5% share), the University of California, NASA, and the University of Hawaii.

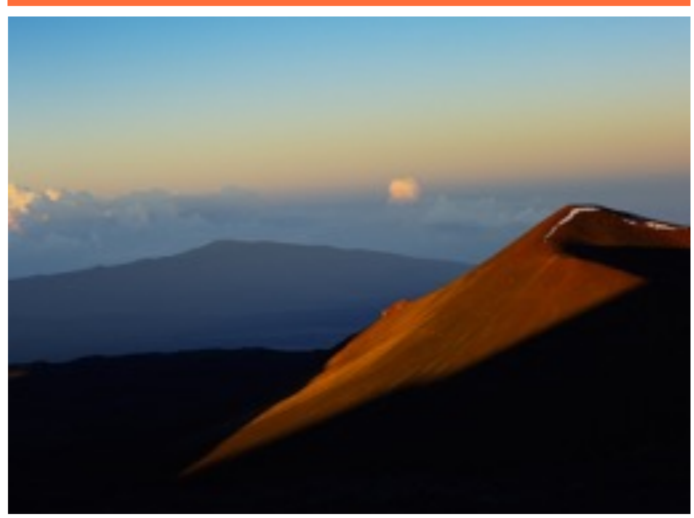
Keck is one of the – if not the – most influential ground-based observatory operating today. The observatory leads all others in scientific publications per telescope, and even more importantly, leads in the impact of those publications on the field of astronomy. Keck has been essential in seeking answers to the most fundamental questions in science: How did the universe evolve to its present state? How, and when, did galaxies form? What is the rate of star formation in galaxies far away, and far back in time? How much does the expansion rate of the universe vary over its history? How old are the oldest stars in our own galaxy? How much matter is in the form of very low luminosity brown dwarfs? How do solar systems form? What is the census and demographics of planets around stars other than the Sun? Where is the missing mass of the universe? What is the ultimate fate of the universe? In just the past few years, astronomers at the W. M. Keck Observatory have made tremendous progress in answering these and other questions.

Among numerous ongoing research projects, Keck astronomers are using gravitational lenses to discover galaxies at the edge of the universe, using supernovae to determine the expansion rate of the universe, searching for atomic gases in the immense regions of space between galaxies, helping to solve the riddle of gamma ray bursts, uncovering the nature of obscured galaxies, finding the most metal-poor stars, studying accretion and outflow processes in young stellar populations, deciphering the composition of objects in the outer solar system, and discovering planets around other stars, pushing downward toward Earth-mass objects, and recently obtaining the first direct “family portrait” images of such planets.

Carrying out all of this spectacular science requires not only a telescope and its infrastructure, but a suite of back-end instruments that sort and collect the photons. Keck incorporates a wide range of instruments. Included in the optical arsenal is the world's most powerful multi-object spectrograph (DEIMOS), the world's most sensitive spectrograph (LRIS), and a very stable echelle spectrometer (HIRES). Keck's performance is extended into the near-infrared with a suit of advanced instruments. NIRSPEC is a sensitive spectrograph operational at both high and low resolution. A recent example is the new Multi-Object Spectrometer for Infrared Exploration (MOSFIRE), an ambitious near-IR multiobject spectrograph and imager that has been developed, integrated and tested in the highbay lab at Caltech, and saw first light in Hawaii in 2012. NIRC-2, a second generation near-infrared camera, works with the Keck Adaptive Optics (AO) system to produce the highest spatial resolution ground-based images and spectroscopy in the 1-5 micron range. Additionally there is the OH-Suppressing Infrared Imaging Spectrograph (OSIRIS) which is also fed by the AO system and obtains a spectrum at every diffraction limited position across its field of view. Each of the two 10-m Keck telescopes has an AO system that is operational in either a "natural guide star" mode, which requires bright objects near the field of interest, or by making use of a laser launch telescope and return system which provides a "laser guide star" mode in any part of the sky. The combination of adaptive optics and large mirrors enables Keck to exceed the imaging quality of the Hubble Space Telescope, and with greater photon-gathering power.

Caltech takes a leading role in the development of new instruments for Keck. The Keck Cosmic Web Imager (KCWI) is an integral field spectrograph designed to be extremely efficient so that it can image and obtain spectra for the very faint filaments believed to be the major components of the cosmic web of material from which galaxies collapsed. KCWI is currently in its final stages of design and assembly at Caltech. A number of graduate students and postdocs are participating in this effort. The instrument with its blue channel optics is expected to be delivered to the Keck Observatory for installation and commissioning in 2016. The red side optics will follow about 2 years later. Also a new single object moderate resolution IR spectrograph which will provide full spectral coverage from 0.9 to 2.5 microns in a single exposure (NIRES) is in the final stages of integration and test at Caltech and should be shipped to Hawaii in 2015. AO performance at Keck 2 will be significantly improved by the new much more powerful Toptica laser, which will be able to produce a much brighter laser guide star. The laser has been delivered to Waimea for testing prior to installation on the telescope. It is performing extremely well in the lab and will be installed in the Keck 2 AO system shortly. Other advanced instrumentation concepts are being discussed, with the goal of keeping Keck firmly placed as the forefront facility for ground-based optical astronomy.

Clockwise from bottom right: the summit of Mauna Kea, the mirror of Keck I from the side, and one of the Keck domes alongside the Subaru Telescope during a lunar eclipse.



The Owens Valley Radio Observatory (OVRO)

Caltech's Owens Valley Radio Observatory (OVRO), located in the stunning Owens Valley, California, is home to Owens Valley Long Wavelength Array (LWA - described on another page) which surveys the sky at MHz frequencies as well as a suite of telescopes observing at GHz frequencies. These telescopes perform experiments in the fields of transient monitoring, stellar flares, blazar jet physics, the interstellar medium, and the cosmic microwave background. OVRO staff take part in research and engineering to develop cutting-edge radio astronomy instrumentation and mentor students who work on these projects.

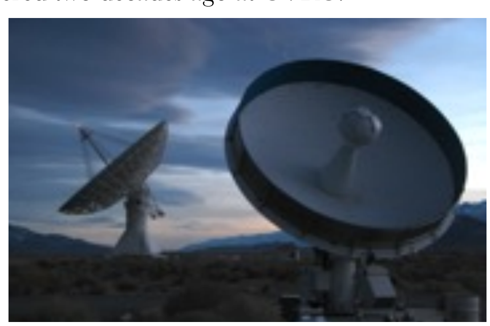
In the summer of 2014 a new polarimetric receiver (KuPol) debuted on OVRO's 40m telescope, improving the telescope's sensitivity and bandwidth and enabling polarimetric observations. The 40-m telescope is currently monitoring the 15 GHz flux densities of more than 1800 blazars: active galactic nuclei jets aimed directly at us. Each source is being observed at least twice a week. These measurements, interesting in their own right, are being correlated with brightnesses across the EM spectrum (and gamma radiation monitored by NASA's Fermi Gamma-Ray Space Telescope in particular) in order to explain the emission mechanisms in the highly-relativistic blazar jets. The 40-m is also used to follow up on transients detected by the Palomar Transient Factory and by VLA transient surveys.

The two 27-m telescopes are currently being outfitted with cooled receivers that will enable them to make sensitive, broadband observations from 1 to 18 GHz. These telescopes are being refurbished as part of the Owens Valley Solar Array (a New Jersey Institute of Technology project hosted at OVRO). When not used for calibrating solar observations, these two telescopes will be used by Caltech's Starburst Program for observations of stellar flares and brown dwarfs and for follow-up to the 40-m blazar program and the Zwicky Transient Facility. Two Caltech grad students are currently working on the Starburst Program as part of their thesis work, developing a high-speed broad-bandwidth correlator that will be able to observe a 5-GHz-wide spectrum every 10 milliseconds. Future developments may include incorporating the 40-m into this system to form a three-element interferometer.

The C-Band All Sky Survey (C-BASS) is now underway in an effort to map the polarized synchrotron emission from the Milky Way. The map will help astronomers to understand the Galactic magnetic field while aiding in the foreground subtraction from CMB maps. Such subtraction will enable OVRO to measure the CMB's elusive B-mode polarization, a relic of the inflationary period. The map is being made at 5 GHz using one of the 6-m telescopes in Owens Valley and a 7.6-m telescope in South Africa. OVRO has played a key role in the design and assembly of this experiment.

Caltech is currently leading the design and fabrication of the CO Mapping Array Pathfinder (COMAP). COMAP is a pathfinder experiment of nineteen 30-GHz imaging elements on a 10.4-m antenna being developed in the Caltech Radio Astronomy Lab and at OVRO, Stanford, Miami, and Maryland. This aims to measure the CO total intensity due to galaxy clusters in the redshift range 2-3. This will be followed by a 100-element array that aims to detect CO in the redshift range 5-7 and hence to study the formation of galaxies at this early epoch. In addition COMAP will study Galactic anomalous microwave emission, a form of emission likely produced by spinning dust grains, which was first discovered two decades ago at OVRO.

Clockwise from bottom right: the C-BASS experiment and 40 meter telescope, the 40 meter telescope, one of the 27 meter dishes, the two 27 meter dishes.



The Owens Valley Long Wavelength Array (LWA) is a new low-frequency (20-80 MHz) radio interferometer located at the Owens Valley Radio Observatory (OVRO). Consisting of 288 broadband dual-polarization dipole antennas, the LWA images the entire visible hemisphere every few seconds with 10 arcminute resolution. The Owens Valley LWA houses the Large Aperture Experiment to Detect the Dark Ages (LEDA) correlator, which was built by our Harvard collaborators. The LEDA correlator is the largest correlator in the world when measured by the number of input signal paths.

The LWA uses its 20,000 square degree field of view to survey the sky for low-frequency radio transients. The brightest of these transients is Jupiter, which lights up a cone through electron-cyclotron maser emission. When the emission cone sweeps over the Earth, Jupiter becomes the brightest object in the low-frequency radio sky. Hot Jupiters (large gas-giants that orbit very close to their host star) are expected to pulse in a similar manner. The LWA is scanning the skies to look for the faint glow of these extrasolar planets.

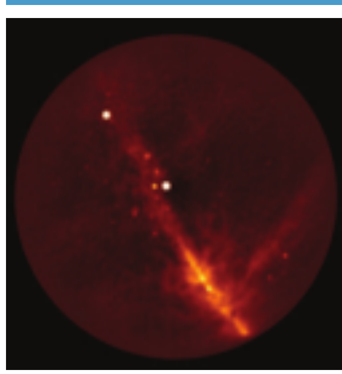
Further from home, the LWA is studying the intergalactic medium (IGM) from when the universe was just 200 million years old ($z \sim 20$). At this time, the very first stars and galaxies were born into the infant universe. The radiation emitted from these stars actually cools the spin temperature of the IGM, allowing the IGM to be studied in absorption against the cosmic background radiation. This takes advantage of the fact that the 21 cm line of neutral hydrogen is redshifted into the LWA band. However, this is a particularly challenging measurement due to the brightness of the foreground radiation (~1000 K) compared with the faint theoretically expected signal (~0.1 K). A sensitive measurement like this can only be made while the sun is down.

While the sun is up, the LWA performs dynamic imaging spectroscopy of solar flares and coronal mass ejections. Monitoring solar coronal mass ejections is important to predict damage to satellites and to safeguard Earth's power grid. Furthermore, the LWA is sensitive enough to detect flares from other nearby stars. Coronal mass ejections from these stars can impact the habitability of any planetary systems housed by them. The search for nearby stellar flares also makes use of the two OVRO 27-m antennas as part of the Starburst project.

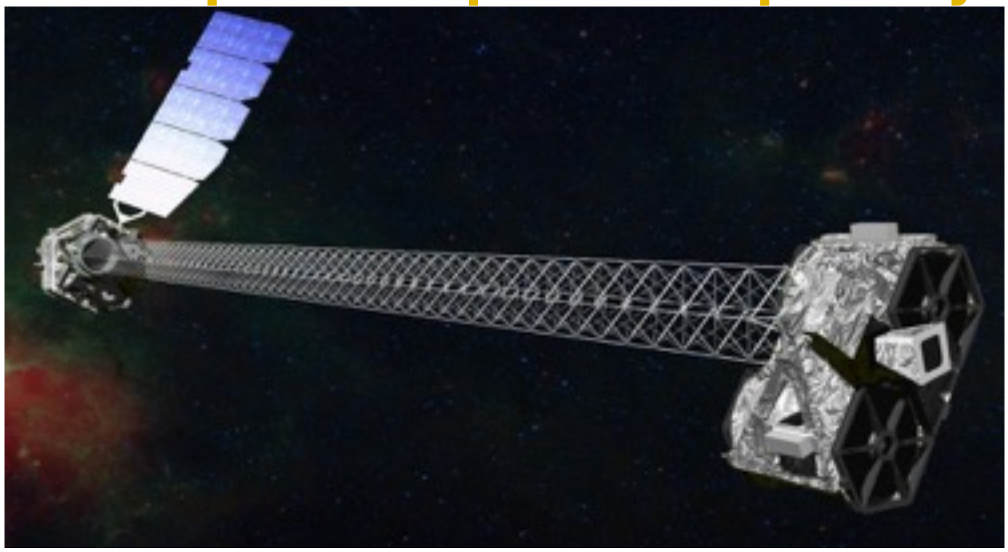
Finally, low frequency radio waves are attenuated, refracted, rotated, and generally corrupted by propagating through the Earth’s ionosphere. In fact, the ionosphere completely reflects radio waves below about 10 MHz (the exact frequency depends on the time of day). It is impossible to study longer wavelengths without going to space. The ionosphere is very annoying for astronomers using the LWA; however, the LWA is simultaneously a very rich source of information on the ionosphere. From the ionosphere, to nearby stars and planets, and finally to the distant IGM, the LWA has opened up a new window for discovery.

Looking forward, the Deep Synoptic Array (DSA) is a new radio telescope being developed for construction at the Owens Valley Radio Observatory. Typically one associates the term radio telescope with the iconic image of behemoth dishes slewing and pointing in unison as they collect astronomical data from a small pencil beam field of view. The DSA is a complete paradigm shift relative to this iconic but outdated type of instrument. Instead, the DSA will combine the signals from thousands of stationary, small, low-cost dishes and dipoles distributed over a 6 km diameter area, relying on modern-day digital signal processing and computing to handle the resulting avalanche of data. For example, the DSA will rely on large numbers of the same kind of Graphics Processing Units (GPUs) that lie at the heart of modern-day gaming systems, like the Sony Playstation and Microsoft Xbox, to deliver the highest quality images of the radio sky yet achieved. By using thousands of small antennas, the DSA replaces the narrow pencil beam of older radio telescopes with a vast instantaneous field of view that allows the DSA survey the sky with unprecedented speed. It is this tremendous survey capability, as well as a wide frequency range covering 20 - 2000 MHz, that allows the DSA to deliver unique science. Through repeated mapping of the sky every day, the DSA will search for new transient sources ranging from pulsing planets in the solar neighborhood to stars exploding at cosmological distances. It will catalog the radio emission from a 100 million galaxies and provide the first observational window on a critical period in our cosmological history, our Cosmic Dawn, when the first stars formed and began to light up the universe.

Middle: An image produced from a 9 second integration with the LWA. The two bright sources are Cassiopeia A and Cygnus A respectively. The galactic center is also visible to the lower right. Other Photos: Images of the LWA.



NuSTAR: Nuclear Spectroscopic Telescope Array



The Nuclear Spectroscopic Telescope Array (NuSTAR) is a NASA Small Explorer (SMEX) spacecraft successfully launched on June 13, 2012, and deployed into a 600 km, near-circular, low-inclination orbit. It carries the first orbiting telescopes to focus light in the high energy X-ray region of the electromagnetic spectrum (3-79 keV). Our view of the universe in this spectral window has been limited because previous instruments employed coded apertures that have intrinsically high background and approximately 100 times lower sensitivity. Caltech is the lead institution on NuSTAR and is partnering with JPL and an international team. The state-of-the-art focal plane detectors and instrument electronics have been developed in laboratories on the Caltech campus.

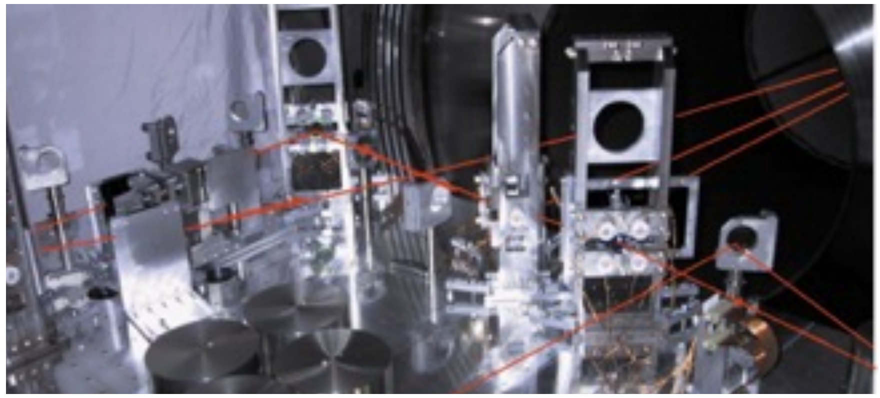
Using its unprecedented combination of sensitivity and spatial and spectral resolution, NuSTAR is pursuing five primary scientific objectives:

1. Probing obscured active galactic nuclei (AGN) population out to the peak epoch of galaxy assembly in the universe by surveying selected regions of the sky;
2. Studying the population of hard X-ray-emitting compact objects in the Galaxy by mapping the central regions of the Milky Way;
3. Studying the non-thermal radiation in young supernova remnants, both the hard X-ray continuum and the emission from the radioactive titanium;
4. Observing blazars contemporaneously with ground-based radio, optical, and TeV telescopes, as well as with Fermi and Swift, so as to constrain the structure of AGN jets; and
5. Observing line and continuum emission from core-collapse supernovae in the Local Group, and from nearby Type Ia events, to constrain explosion models.

NuSTAR has an expected orbital lifetime of 10 years. During the first two years, it has been undertaking a broad program of targeted observations addressing the primary objectives listed above, planned and executed by the NuSTAR science team. NuSTAR will begin observing targets proposed by the community in its first competitive Guest Observer cycle on April 1, 2015. In addition to its core science program, it offers opportunities for a broad range of science investigations, ranging from probing cosmic ray origins to studying the extreme physics around collapsed stars to mapping micro-flares on the surface of the Sun.

Clockwise from top left: NuSTAR observatory, artist's conception of NuSTAR in orbit, M82 with two ultra luminous X-ray sources, illustration of a supermassive black hole

The Laser Interferometer Gravitational Wave Observatory (LIGO)



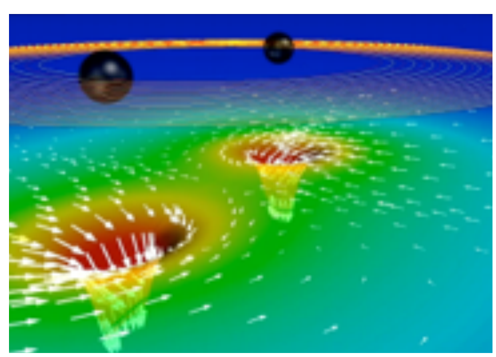
The Laser Interferometer Gravitational Wave Observatory (LIGO), headquartered at Caltech, consists of two four-kilometer-long laser interferometers, one located in Hanford, Washington, and the other in Livingston, Louisiana, 10 light-milliseconds apart. LIGO is dedicated to the detection of gravitational waves and the harnessing of this new window to the Universe for research in astrophysics and relativity. Gravitational waves are ripples in the fabric of space and time produced by violent events in the distant universe, involving strong, highly dynamical gravitational fields. These waves will make tiny motions (much smaller than an atomic nucleus) in the mirrors at opposite ends of these interferometers, and coincident detection of the resulting fringe shifts will encode the passing gravitational wave signals in the 10Hz – 2kHz band. Astrophysical sources of gravitational waves include the final minutes of extra-galactic merging binary neutron stars (proposed as models for short gamma-ray bursts), disruption of neutron stars by stellar-mass black holes, merging binary black holes of stellar mass, galactic core-collapse supernovae, neutron star-quakes, rapidly spinning neutron stars (millisecond pulsars), and more speculatively, cosmic superstrings.

Co-founded in 1992 by Kip Thorne and Ronald Drever of Caltech and Rainer Weiss of MIT, LIGO lab is run jointly by Caltech and MIT with funding by the NSF. The LIGO Scientific Collaboration is a multinational effort involving more than 900 scientists from 16 countries, and includes joint data analysis with the GEO600 and VIRGO detectors in Europe and KAGRA in Japan.

Initial LIGO operated until 2008. Its reach was such that signals due to neutron-star binary inspiral and merger from the Virgo Cluster (15 Mpc distance) could have been detectable. Enhanced LIGO, operating in 2009-2010, incorporated new detector hardware and a more powerful laser, extending the reach of Initial LIGO by a factor of 1.5-2 in distance. The Advanced LIGO detectors replace all the optical and mechanical parts of Initial LIGO and are designed to improve its sensitivity and bandwidth. This upgrade will increase LIGO's reach by another order of magnitude, covering 1000 times the volume, and thus 1000 times the event rate of initial LIGO. When Advanced LIGO begins operation in 2015, it will have the reach to detect known sources such as merging binary neutron stars (even assuming conservative estimates of their event rate), and test models of the engines of gamma-ray bursts and supernovae, and of black hole formation. It will also enable us to test general relativity in the strong-field regime for the first time.

Approximately 80 LIGO scientists and staff work at Caltech, carrying out research, development and operations on the interferometer systems, data analysis methods and operation, and astrophysical modeling. The Caltech theoretical astrophysics and analytical and numerical relativity groups have close connections to LIGO data analysis. Preparations are being made to cross-trigger searches for electromagnetic counterparts to gravitational wave sources (and vis versa), involving the Zwicky Transient Factory and Caltech's other observatories.

Top: Two views of the LIGO optics. Bottom Left: Aerial view of the 4km arms of the LIGO Louisiana site. Bottom Right: The spacetime geometry of a binary black hole system during inspiral.



Antarctic Astronomy

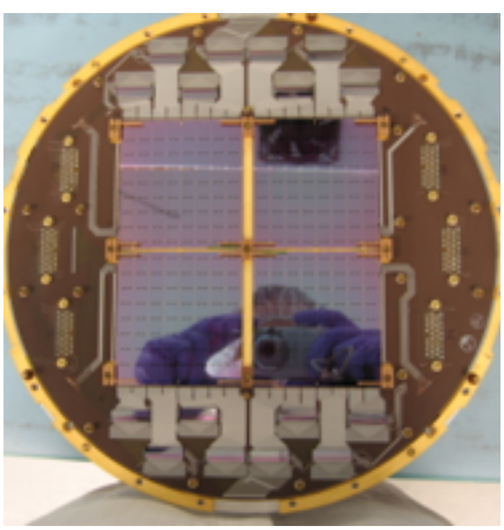
For more than 20 years Caltech has been leading the study of the properties of the cosmic microwave background (CMB) from Antarctica. CMB observations have hinted strongly at an inflationary epoch in which the size of the universe underwent rapid exponential expansion during its first 10^{-38} seconds, producing the near isotropy of the horizon, the flat geometry of the universe, and the pattern of peaks and valleys in the CMB power spectrum that we observe today. Understanding inflation, from both theoretical and experimental perspectives, is a major direction of research at Caltech. The critical test of this theory would be the detection of inflationary gravitational waves (IGW), a unique prediction of inflation. The IGW's most promising signature is its imprint on the polarization of the CMB, with a characteristic "B-mode" pattern. New CMB telescopes such as the Keck Array, BICEP3 and Spider were designed at Caltech and share detector technology fabricated at JPL.

The BICEP/Keck Array program is a series of experiments at South Pole designed to measure the polarization of the cosmic microwave background to unprecedented precision, and in turn answer crucial questions about the beginnings of the universe. These experiments consist of extended arrays of polarization-sensitive detectors mapping a large region of the sky around the South Celestial Pole. In 2014, BICEP2 reported the first detection of a positive B-mode signal. The Keck Array and BICEP3 are collecting data at different frequencies, enabling the effective removal of galactic foregrounds to test inflation with unprecedented accuracy.

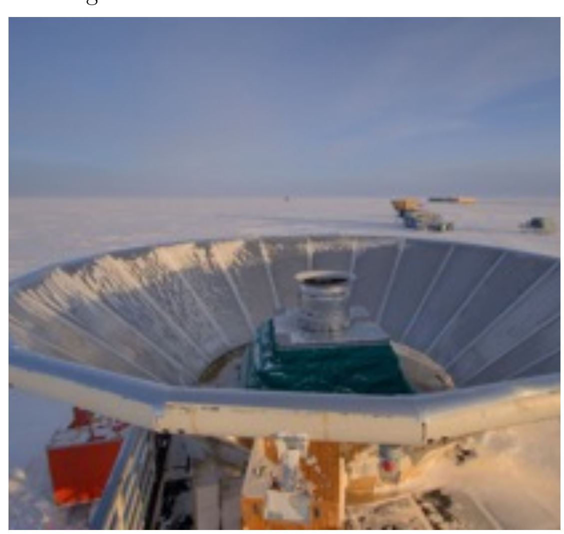
Spider is an ambitious new balloon-borne experiment that combines multiple frequency coverage over a wide field to make a definitive search for the IGW. Spider successfully launched from McMurdo Station in 2015, measuring CMB temperature and polarization.

Caltech has played an active role in other recent Antarctic telescopes, including Gattini and SuperTIGER. The Gattini UV cameras are pathfinders for the proposed Antarctic Cosmic Web Imager to measure Lyman-α emission of the intergalactic medium. SuperTIGER is a balloon-borne galactic cosmic ray telescope, which has measured atomic nuclei heavier than iron.

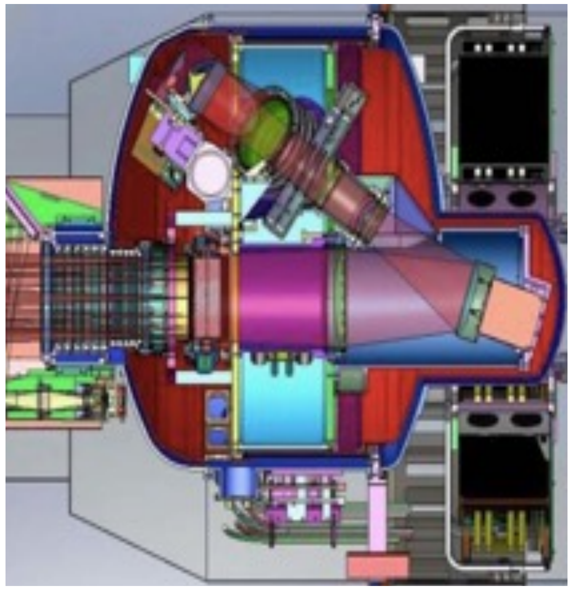
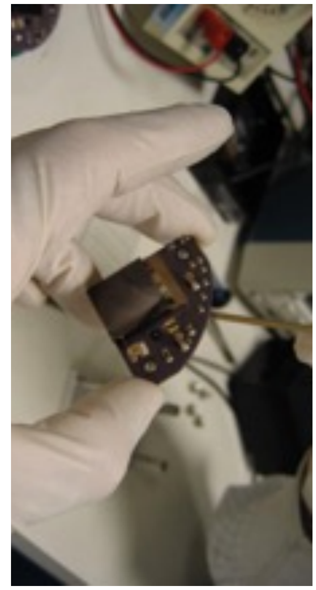
Caltech and JPL are also involved in other major CMB telescopes, including the Planck satellite.



Left: BICEP2 focal plane. Right: The BICEP environmental enclosure and ground shield.



Instrumentation

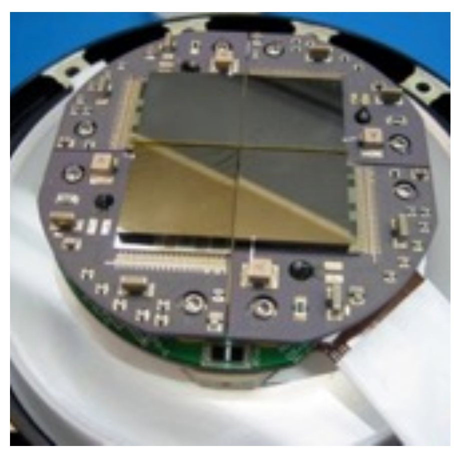
The pursuit of science including radiometric studies ranging from the cosmic microwave background to objects in our own solar system, particle astrophysics, cosmic rays, and gravitation requires not only functioning telescopes and facilities but also sensitive back-end instrumentation. The Cahill Center for Astronomy and Astrophysics hosts an entire floor of laboratory space that is allocated to various groups in experimental physics and astronomy where state-of-the-art instrumentation is built. Each of these labs is staffed by engineers and technicians who work alongside faculty, research associates, and students.

The Caltech Optical Observatories (COO) conduct work relevant to the current operations of and future developments at the Palomar, Keck, and Thirty-Meter telescopes; high contrast imaging for exponent studies and adaptive optics are a particular area of expertise. The Caltech Radio Astronomy Laboratory (CRAL) develops state-of-the-art mm-cm wavelength detectors and is currently working on novel detectors for ALMA, the GBT, and the OVRO. In the submillimeter lab, there is work ongoing to develop the first very large cameras in the submillimeter (more than 10^5 pixels) and the first submillimeter multi-object spectrometers and integral field units for high-redshift astronomy. The Observational Cosmology (ObsCos) lab builds hardware for cosmic background radiation studies in microwave and infrared as well as new cryogenic dark matter detectors. The UV lab works on instrumentation for both spaceflight and ground-based optical telescopes. The Space Radiation Lab (SRL) is involved in the development of hard X-ray detectors and grazing incidence focusing optics, as well as balloon payloads like EXCALIBUR and satellites such as NuSTAR. SRL also develops particle detectors for satellites (e.g. Solar Probe).

Graduate students are involved in nearly every single one of these groups. Cahill also hosts a teaching lab that is used mainly for undergraduate course work.

In addition to the above, there is close coupling of many Cahill faculty with engineering and technical development at the Jet Propulsion Laboratory (JPL), especially in the area of detectors and interferometry, and some students spend part of their time there.

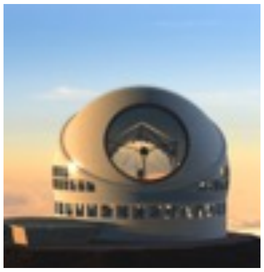




Future Facilities

Caltech is involved in the design and construction of several major ground-based facilities and instruments, as well as satellites slated for completion during this decade.

The Thirty-Meter Telescope (TMT)



The Thirty-Meter Telescope (TMT) is one of the most ambitious ground-based optical/IR astronomical projects that has ever been undertaken. TMT will be sited atop 14,000-ft Mauna Kea on Hawaii's "Big Island" and will join the Keck telescopes, among many other observatories built on the best astronomical site in the Northern hemisphere, and possibly the world. TMT will operate over the wavelength range 0.3-28 microns, taking advantage of Mauna Kea's stable atmospheric conditions, cold ambient temperatures, and low water vapor.

The 30-m diameter primary mirror is made up of 492 segments actively controlled to maintain a near-perfect optical figure. Adaptive optics (AO) capability is fully integrated into the design, providing diffraction-limited spatial resolution from the beginning of operations. The collecting area of TMT is nearly ten times that of the twin Keck telescopes (144 times that of Hubble Space Telescope), and with diffraction-limited performance TMT will be over one hundred times as sensitive as the current generation of 8-10m telescopes and will have a spatial resolution over ten times better than HST.

TMT will address scientific questions across all of astrophysics, from cosmology and the first galaxies and black holes in the early universe, to the formation and evolution of galaxies and the intergalactic medium over the last 95% of the age of the universe, to star formation, the detection and characterization of planets around nearby stars, and the exploration of the outer solar system.

The TMT partnership currently consists of Caltech, University of California, Japan, China and India (the latter through their national observatories). Canada has been with TMT since inception of the project and expected to become a construction partner in early 2015. Construction is expected to start in Spring 2015 and the Observatory fully operational by 2024.

Prime Focus Spectrograph (PFS) at the Subaru Telescope

Astronomy is entering an era of massive multiplexing. No longer satisfied with one or a few objects per exposure, some planned spectrographs will obtain spectra of thousands of objects simultaneously. The PFS will distribute 2400 fibers over a hexagonal field of view 1.3 degrees wide. Each fiber will be pointed to a pre-selected star or galaxy, and the spectrum from each fiber will span 380-1300 nm.

The PFS has three primary science goals. Galactic archaeology: PFS will measure the dark matter content of dwarf galaxies, identify tidal streams in the Milky Way, and excavate the chemical history of the Milky Way, Andromeda, and nearby dwarf galaxies. Cosmology: PFS will measure the expansion rate of the universe through baryon acoustic oscillation--the imprint of sound waves from the Big Bang. Coupled with the Subaru Hyper SuprimeCam, PFS will additionally measure the weak gravitational lensing signal from the universe's dark matter distribution. Galaxies and AGN: PFS will deduce the star formation and gas flow histories of galaxies throughout cosmic time, including galaxies up to a redshift of 7. It will also find and characterize the oldest AGN (massive black holes) in the universe.

Ultraviolet Transient Satellite (ULTRASAT)

ULTRASAT, a proposed space mission from Caltech/JPL-Weizmann Institute of Science (Israel), aims to explore the dynamic ultraviolet (UV) sky. The initial phase the project was funded by the Keck Institute of Space Studies (KISS) at Caltech and by the Israeli Space Agency (ISA) at the Weizmann Institute of Science (WIS). ISA has prioritized the mission for implementation, and Caltech/JPL are seeking funding from NASA to participate (via the Explorer Mission of Opportunity program).

ULTRASAT consists of a JPL-designed Schmidt telescope with a field of view of 200 deg^2. The focal plane consists of five CCDs treated with "delta-doping", a key JPL technological process, that doubles the quantum efficiency in the UV (220-280 nm). The rest of the hardware — the spacecraft bus, communications and integration — will be undertaken by the ISA. ULTRASAT will be placed 300 km above geosynchronous orbit (benefitting from a "ride share" with a commercial satellite launch).

In a given year, two fields (one close the North Ecliptic Pole and the other to the South Ecliptic Pole) will be observed for six months each with a basic cadence of 3x300 seconds (21.5 mag, 5 sigma). This ultra-dense sampling will be revolutionary and we expect to make great advances in shock breakout and shock cooling of supernovae (leading to inferring properties of the progenitor stars) and measuring masses of accreting nuclear black holes and disk tomography of active galactic nuclei. The mission will have rich returns in other fields: tidal disruption events, stellar activity, relativistic explosions, etc.

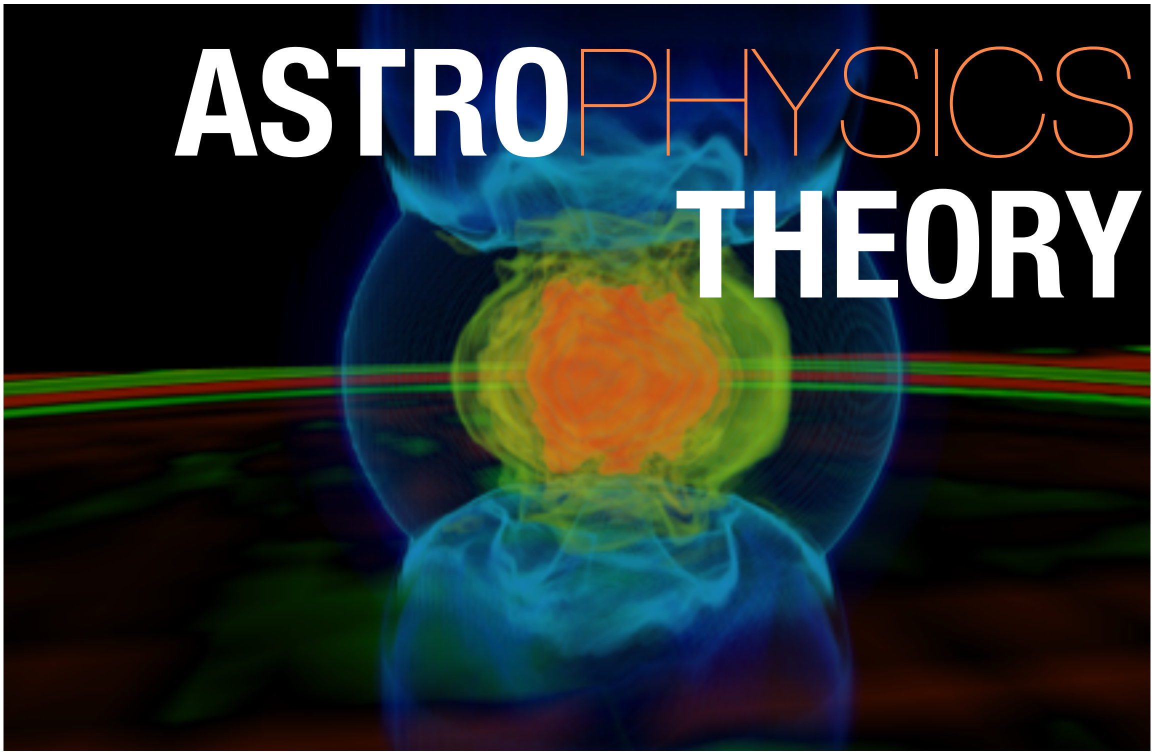
If funded by NASA we expect a lunch in 2021 followed by a 2-year prime phase. Alerts for transients will be issued in real time (from WIS) and light curves will be available from IPAC (Caltech). In order to maximize the returns from the mission we will dedicate ZTF to ULTRASAT during the prime phase. The principal investigators are: S. Kulkarni (Caltech, US) and E. Waxman (WIS, Israel).

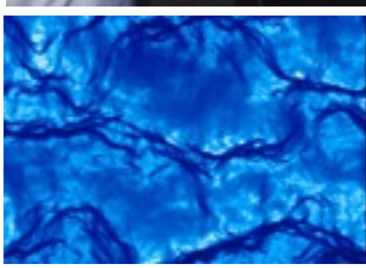
Starting from its very first days, Caltech has been known as a leader in theoretical astrophysics. Traditions of excellence are well maintained by the team of bright scientists that comprises Caltech's group for Theoretical AstroPhysics Including Relativity (TAPIR). TAPIR welcomes new students and, through active participation in group meetings, provides them with a strong theoretical background beyond the scope of their coursework and research.

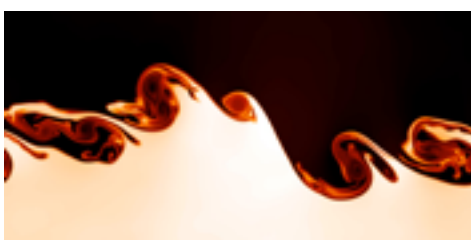
Students working in the TAPIR group benefit from the diversity of the group members: professors in the group work on a wide range of topics including formation and evolution of galaxies, general relativity, compact objects, supernovae and many others. Students are free to choose their own research topics and propose research programs to an adviser. This stimulates creative thinking and provides enormous opportunity for students to excel and grow professionally.

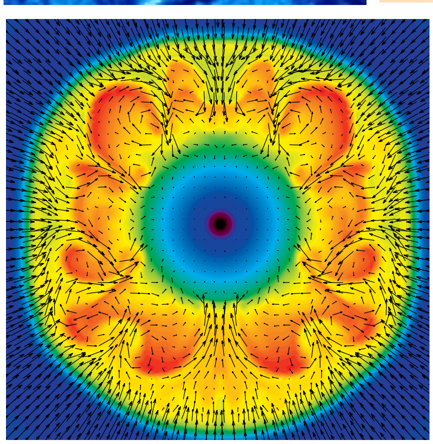
In the pages to follow we will describe research areas of the TAPIR group in more detail and emphasize the diversity and collaborative spirit of our group.

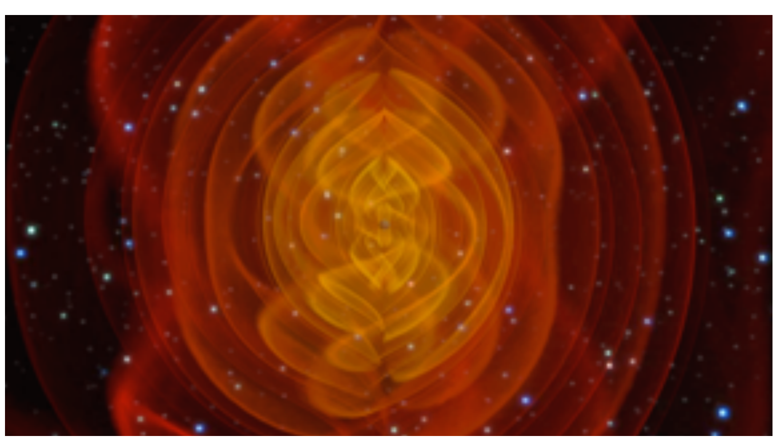
ASTROPHYSICS THEORY



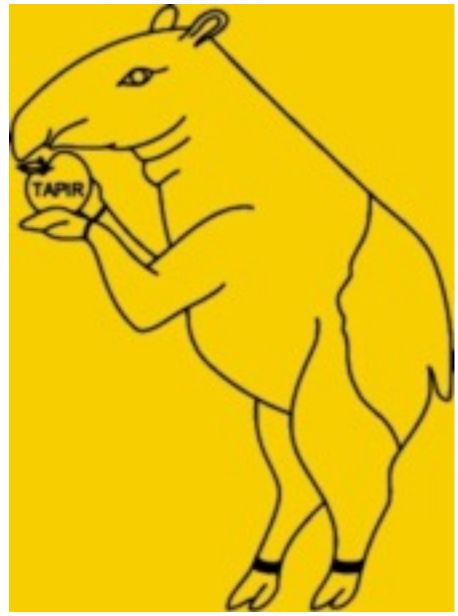








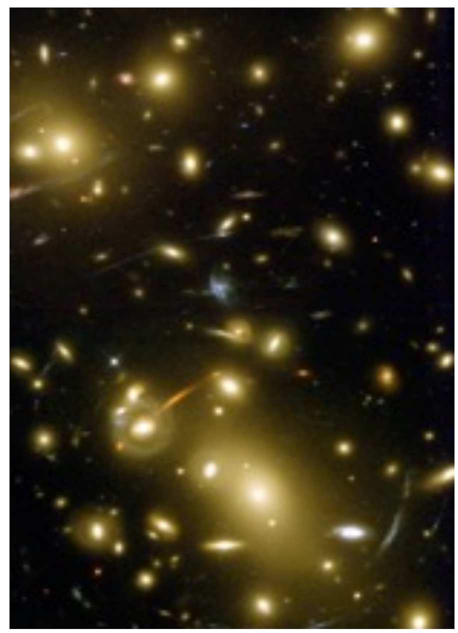
TAPIR: Theoretical AstroPhysics Including Relativity



Theory and observation work hand-in-hand to advance astrophysics. Theorists develop hypotheses and physical models which suggest new observational tests and searches; observational discoveries confirm or refute theories and force the development of revised hypotheses and new models. In earlier decades, Caltech theorists and observers worked together to develop the theories of stellar nucleosynthesis and stellar evolution, interstellar masers, and solar and white dwarf oscillations. Caltech theorists were instrumental in developing now-standard models of black holes, pulsars, relativistic accretion disks, relativistic jets, the extraction of energy from rotating black holes and gravitational wave generation and detection.

Now the theoretical astrophysics and relativity group at Caltech focuses on the death and rebirth of stars as compact objects, the development of the new fields of numerical relativity and gravitational wave detection and their exploitation for physics and astrophysics, and cosmology from the earliest moments of the universe to the formation and evolution of galaxies, including their mutual interactions and the interplay with the surrounding intergalactic medium.

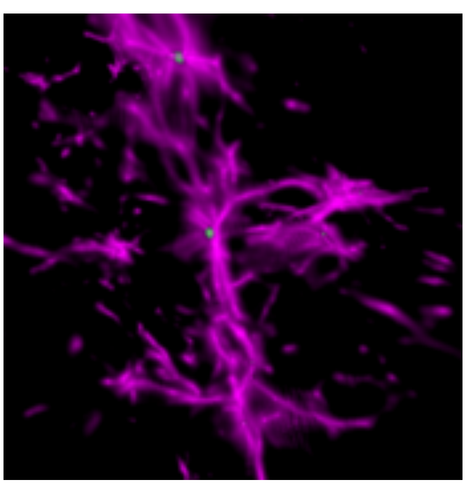
TAPIR includes faculty members Yanbei Chen, Philip Hopkins, Christian Ott, and Sterl Phinney, emeritus faculty Peter Goldreich and Kip Thorne, senior researchers Sean Carroll, Curt Cutler, Marc Scheel and Bela Szilagyi, about 20 postdoctoral fellows, and around 25 graduate students drawn from both physics and astronomy.

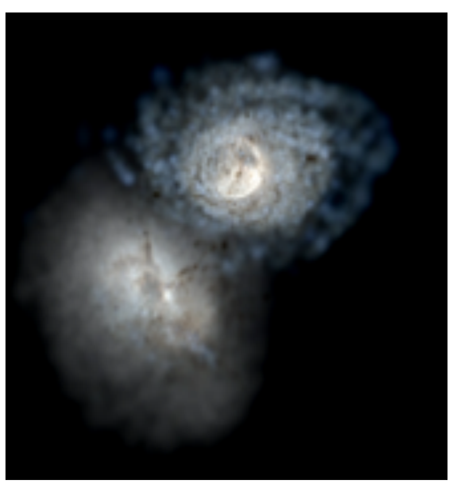


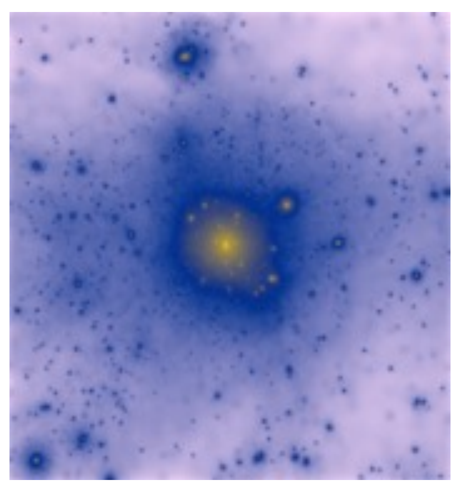
Galaxy Formation and Evolution

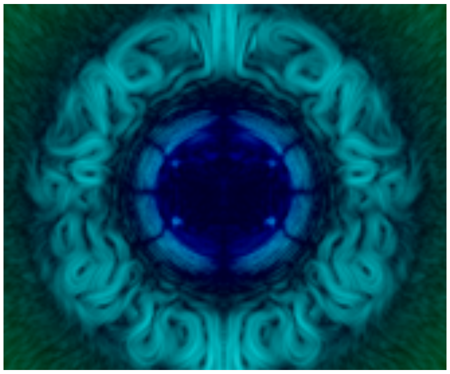
One of the most active areas of research in modern cosmology is the study of how galaxies form and evolve throughout cosmic history. The goal is to achieve better understanding of all physical processes responsible for the transformation of small density perturbations in the early universe to present-day galaxies, such as gas accretion, star formation, formation of massive black holes, interaction with the intergalactic medium, mergers, etc.

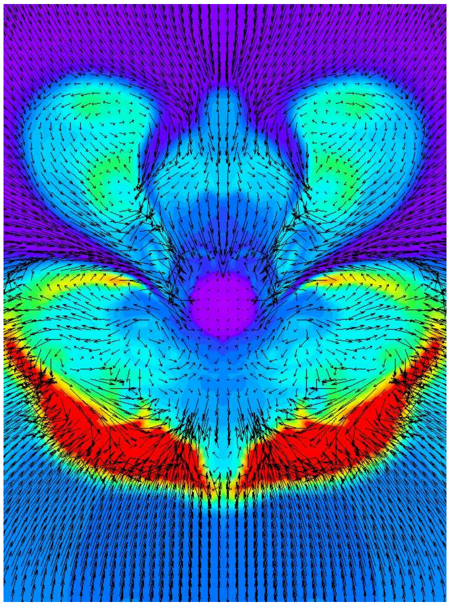
Phil Hopkins and his group of students and postdocs develop cosmological simulations capable of directly resolving the main structures in the interstellar medium of individual galaxies, thus capturing the key processes that govern galaxy evolution on a wide range of scales. Some key questions these simulations will help to address are: what is the role of galaxy mergers in shaping star and black hole formation? What is the nature and impact of feedback from massive stars and active galactic nuclei on the host galaxy? What effect does feedback have on dark matter halos? What are the main properties of galactic inflows and outflows? How does the quenching of star formation in massive galaxies proceed? How did the first galaxies form and what was their role in the reionization of the universe?

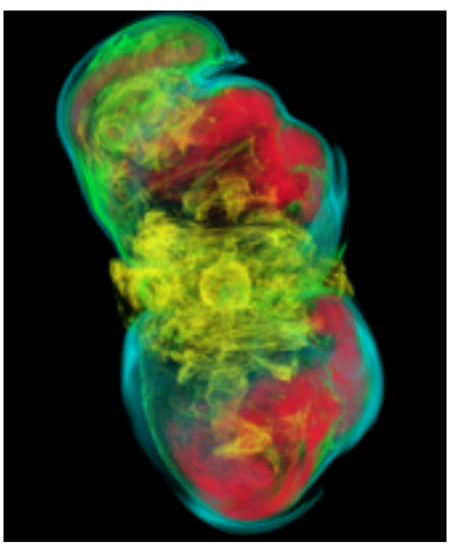












The Death and Rebirth of Stars: Compact Objects

As they exhaust their nuclear fuel, most stars swell dramatically while their core contracts to form a compact object: a white dwarf, a neutron star or a black hole. The strong gravity and high energy densities of these compact stellar remnants mean that extreme physics is required to understand them, and their observational manifestations can be spectacular. Since most stars are in binary systems, the end-of-life swelling often brings the two stars into contact, and mass transfer or a common-envelope phase begins. This leads to the formation of cataclysmic variables, X-ray binaries, binary pulsars and black hole binaries, among other things. These phenomena of extreme physics are of great interest in their own right, are detected electromagnetically now, and will soon be among the prime gravitational wave sources detected by LIGO.

Sterl Phinney and his students have studied many aspects of the evolution and nature of compact objects: the formation of millisecond pulsars, stellar collisions and interactions in globular clusters and galactic nuclei, white dwarf cooling, gamma-ray bursts and the merger rates of compact objects throughout the universe. Current research focuses on white dwarf binaries, pulsar binaries, and the gas and stellar dynamics of dense galactic nuclei.

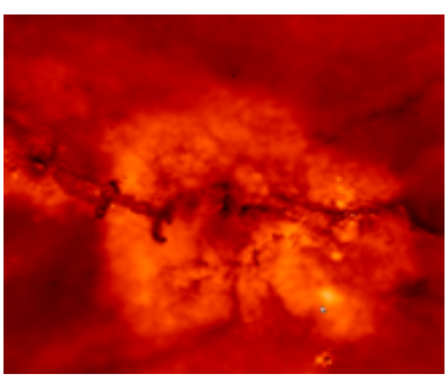
Work in this area often involves close collaboration with observational astronomers, in particular with Shri Kulkarni's group, which is now concentrating on the discovery of new types of transient events and cosmic explosions.

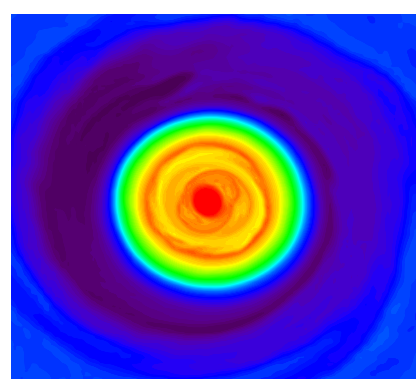
Christian Ott and his students focus on core-collapse supernovae, gamma-ray bursts, their mechanisms of explosion and their signatures in gravitational waves, neutrinos, and electromagnetic waves. In collaboration with the numerical relativity group, he is also studying the tidal disruption of neutron stars by black holes. Much of Ott's research is performed via large-scale general-relativistic magneto-hydrodynamics and radiation-hydrodynamics simulations on supercomputers.

Relativity and Gravitational-Wave Science

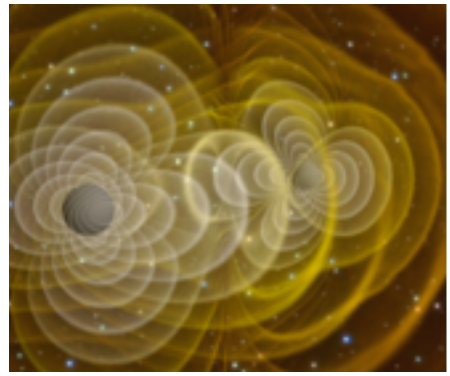
Einstein's general theory of relativity makes some of the most dramatic predictions in physics: singularities in the early universe, inside the event horizons of black holes, and perhaps even naked singularities; extractable energy in the vacuum of rotating space-times; cosmological constants with negative pressure; the potential for warp drives and time travel. New physics, such as string theory or other quantum gravity theories, modifies these predictions. General relativity is well tested in weak gravity (binary pulsars, solar system), but still only circumstantially tested in strong gravity.

The best hope for precise, quantitative tests of general relativity in strong gravity comes from another prediction of general relativity: the existence of gravitational waves, ripples in the structure of spacetime that propagate across the universe at the speed of light. Kip Thorne, Sterl Phinney and students and postdocs of the Caltech TAPIR group have for decades led the development of the scientific case for the Laser Interferometer Gravitational Wave Observatory (LIGO), headquartered at Caltech. An enhanced version of the initial LIGO is now searching for these waves, and instrumentation for Advanced LIGO, virtually certain to detect gravitational waves, is funded and under construction.

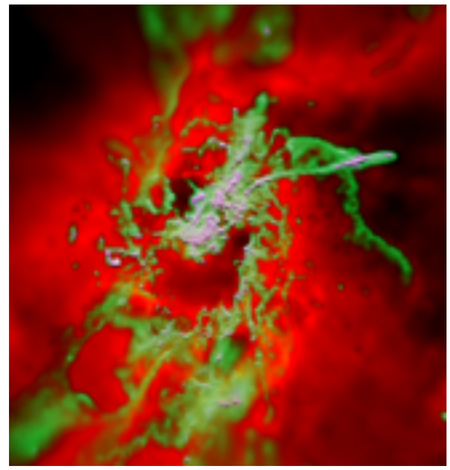




Gravitational waves precisely encode details (with a simplicity inconceivable for electromagnetic signals) of the mass, spin, motion and gravity of their sources. That new information will be greatly enriched and complemented by electromagnetic and neutrino observations of those sources, which in turn tell us things the gravitational waves cannot, such as their composition, precise location, and environment.



Now is a special time, not just because of imminent LIGO detections, but also because (1) after decades of work, our numerical relativity codes have reached a stage of maturity where they can compute both accurate final states and the gravitational waves from merging black hole binaries and core-collapse supernovae to the accuracy that LIGO will measure, and will soon do so for neutron star and mixed neutron star-black hole binaries; and (2) improvements in computing power are on the verge of enabling relativistic radiation magnetohydrodynamics in 3D, at last revealing the true behavior of the formation and destruction of neutron stars in core-collapse supernovae, binary mergers, and gamma-ray bursts.

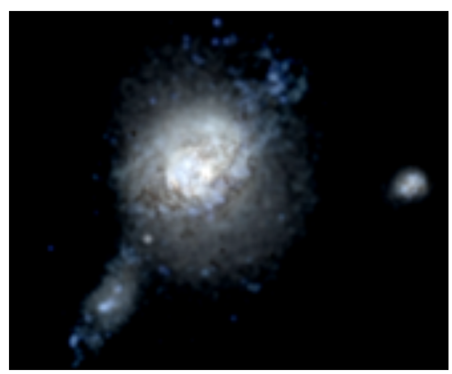


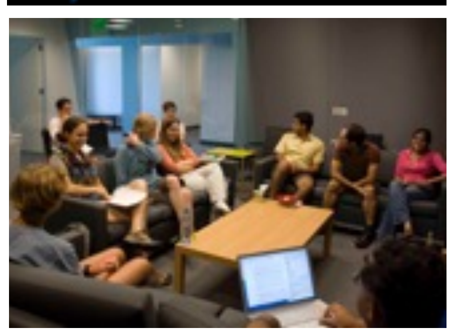
The research groups of Yanbei Chen, Curt Cutler, Christian Ott, Sterl Phinney, Mark Scheel, Bela Szylagyi and Kip Thorne lead the effort in studying the astrophysics, phenomenology and modeling of gravitational-wave sources, development of data analysis methods for LIGO, and modeling of Advanced LIGO and future detectors. The group is also involved in the search for optical counterparts of compact objects that are expected to produce strong gravitational-wave signals. The relativity group has close ties to, and shares students and postdocs with, the LIGO lab at Caltech. They develop data analysis methods, astrophysical triggers, and use the gravitational wave signal predictions of TAPIR's numerical relativity group. The Simulating eXtreme Spacetimes (SXS) project, the world's most precise numerical relativity effort, is carried out in collaboration with researchers at Cornell University.

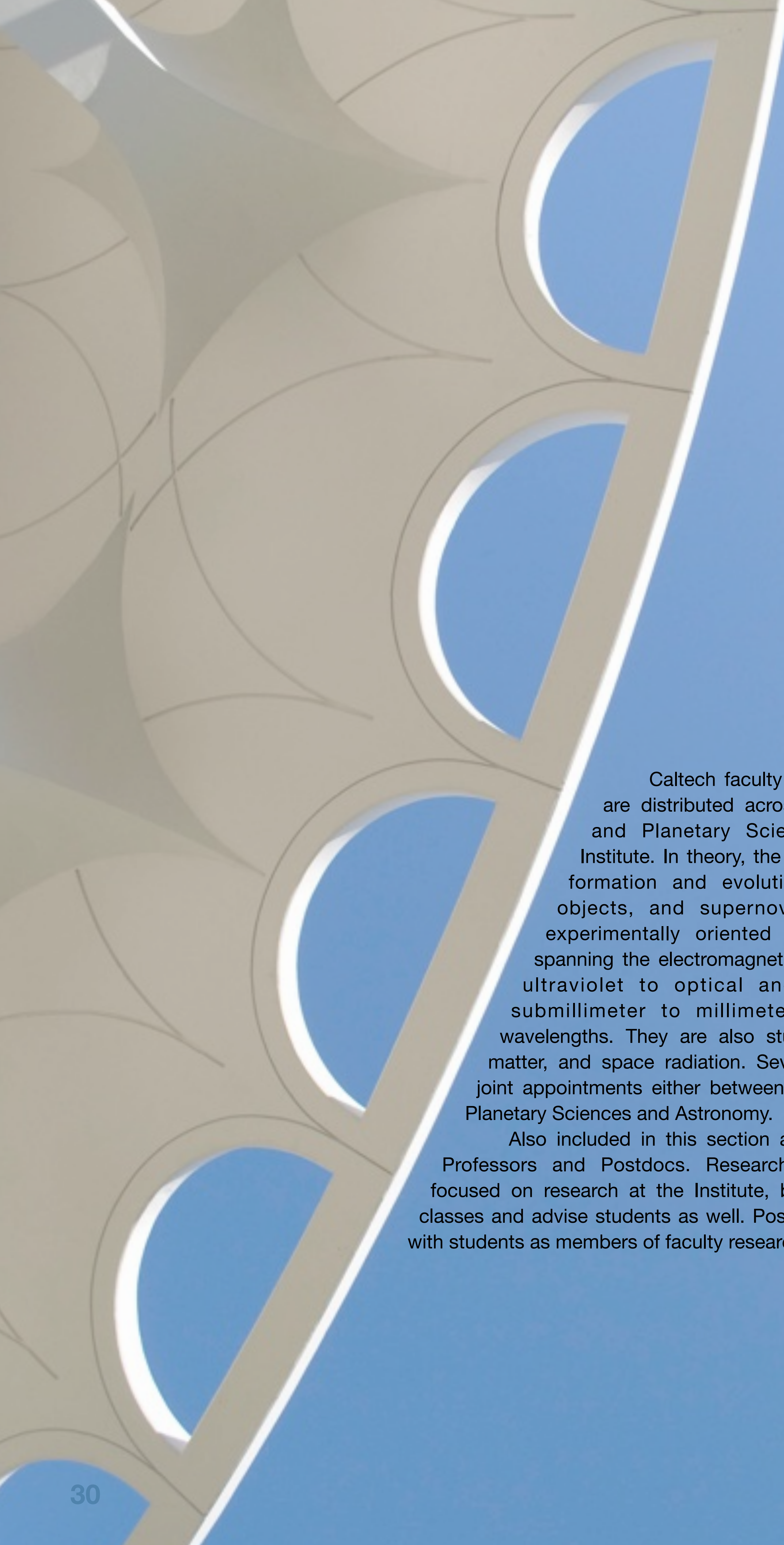
TAPIR's Zwicky high-performance compute cluster enables SXS to produce runs of full LIGO gravitational wave templates for black hole mergers, explore new areas of strong-field relativity, and understand the physics of neutron star disruption in mergers. Zwicky is also used for simulations of galaxy evolution, star formation, and supernova explosions. It currently boasts 2560 CPU cores, high-throughput, low-latency Infiniband networking, 5.6 TB of main memory, and more than 350 TB of disk storage.

Group Activities

A hallmark of the TAPIR group is its history of close collaboration with observational astronomers: understanding existing observational puzzles, suggesting future observations, and helping to shape major initiatives like LIGO and PTF, and space missions such as NuSTAR, JWST, and many others. TAPIR is extremely dynamic and has a great emphasis on collaboration between faculty, students and postdocs, as well as with researchers at other schools and institutions. Year-round all the subgroups of TAPIR hold weekly meetings where various projects and current research are discussed between group members and visitors. There is also a weekly lunch meeting organized by Shri Kulkarni, Phil Hopkins and Sterl Phinney which brings together scientists actively working at the interface of theoretical and observational astronomy. A TAPIR student lunch is held every Thursday and provides an ideal atmosphere for students to share research ideas and discuss a broad range of questions.



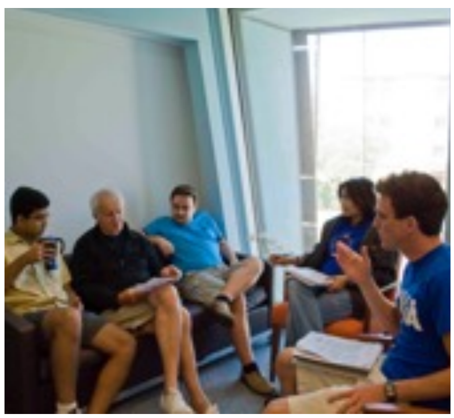


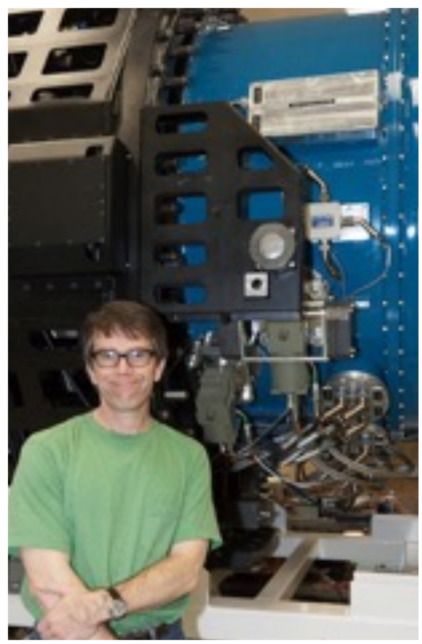


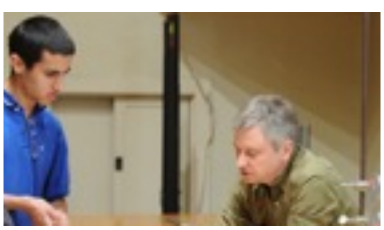
Caltech faculty with interests in astronomy are distributed across the Astronomy, Physics, and Planetary Science departments at the Institute. In theory, the major efforts at present are formation and evolution of galaxies, compact objects, and supernovae. Observationally and experimentally oriented faculty conduct research spanning the electromagnetic spectrum from X-ray and ultraviolet to optical and infrared and through submillimeter to millimeter and centimeter radio wavelengths. They are also studying gravity waves, dark matter, and space radiation. Several faculty members have joint appointments either between Physics and Astronomy or Planetary Sciences and Astronomy.

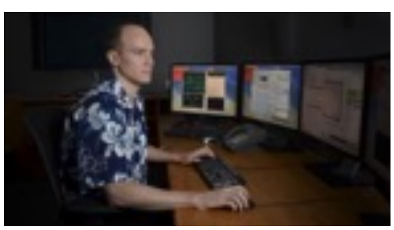
Also included in this section are a selection of Research Professors and Postdocs. Research Professors are primarily focused on research at the Institute, but they occasionally teach classes and advise students as well. Postdocs frequently collaborate with students as members of faculty research groups.

ASTROPHYSICS FACULTY









Dimitri Mawet: High Contrast Imaging of Extra-solar Planetary Systems

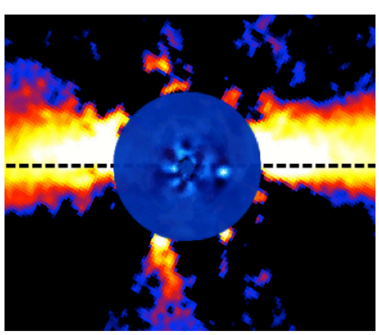
At the frontiers of science and technology, my students, postdocs, collaborators and I design, build, commission, and use innovative techniques to seek and characterize other worlds. Our fundamental motivation is comparative planetology, i.e. put the Solar system's planets and their formation into universal perspective. We also ultimately want to take the first images and spectra of rocky planets, similar to or (preferably) surprisingly different than our Earth.

Our angle of attack is high contrast imaging (HCI), an exciting technique in the study of extra-solar planetary systems. HCI aims at finding and characterizing exoplanets, filling out the parameter space inaccessible to indirect detection techniques. Isolating the signal of planets from the glare of their host stars enables us to measure and constrain orbital motions with astrometry, analyze their atmospheres through spectro-photometry, and understand interactions between planets and the circumstellar disks in which they were born.

HCI requires excellent image quality, and thus exquisite wavefront control capabilities. On ground-based telescopes, adaptive optics measures the incoming wavefront corrugated by our turbulent atmosphere, and flattens it with a deformable mirror changing its shape a thousand times per second. In space, we use similar tricks to take out aberrations induced by imperfect optics and thermal drifts, though at a much slower pace.

The contrast between stars and planets is enormous, so the starlight has to be suppressed in order to reveal its close environment. For that, we use coronagraphs, a century-old invention to image the Solar corona outside of natural eclipses. My focus is the so-called vortex coronagraph (VC), which I invented when I was a grad student. Today, as a result of more than 10 years of development, the VC is the most advanced coronagraph in operation, opening a new parameter space at small separations. It is available at major observatories (Palomar, Keck, VLT, LBT, Subaru), and has demonstrated contrasts of a few parts per billion at JPL, sufficient to image exo-Earths. The vortex is a candidate for HCI instruments for extremely large telescopes (TMT) and space-based coronagraphs (Exo-C).

Please come chat with me if you would be interested in helping to design, build, and commission what might be the ultimate tool allowing us to take the first pictures and spectra of Earth-like worlds!



Lynne Hillenbrand: Young Stars & Exoplanets

For the first several hundred thousand years or so, the process of star formation is totally hidden from view due to obscuration by intervening gas and dust. Subsequently, however, the newborn stars and their accompanying circumstellar gas and dust disks — the sites of planet formation — are revealed, and hence amenable to study.

Young stars that are still accreting up to their final mass from disks are interesting sources from x-ray through ultraviolet, optical, infrared, on out to millimeter and radio wavelengths — and they are enigmatically variable. Using photometry and spectroscopy, especially high cadence and high dispersion, we can study the physical processes of accretion, outflow, disk dispersal, and planet formation. I am also interested in the detection of young exoplanets through various methods.

Other research activities include work on the fundamental properties of young stars (masses, radii, rotation rates) and star clusters (the initial mass function, age spreads, angular momentum evolution). A careful and robust census of the membership in star forming regions enables us to address questions regarding cluster structure/dynamics and stellar evolution in the pre-main sequence phase, and to make progress on mapping the evolution of dust and gas disks into the planets that we know exist around older stars.

Tools utilized in this research include ground-based (e.g. Palomar and Keck) and space-based (all varieties) telescopes. Observing is always engaging, but after extracting the astronomically useful information from the data comes the analysis, creative thinking, paradigm testing, concluding, and packaging of results.

I enjoy collaborating with undergrads, graduate students, and postdocs. Rather than a coherent "group" all working on a single science problem or using one observational technique, we are a collection of individuals with diverse scientific and technical interests, all studying related aspects of young stars and planets. I especially like being led into new research areas by motivated students.

Mansi Kasliwal: Transients in the local universe

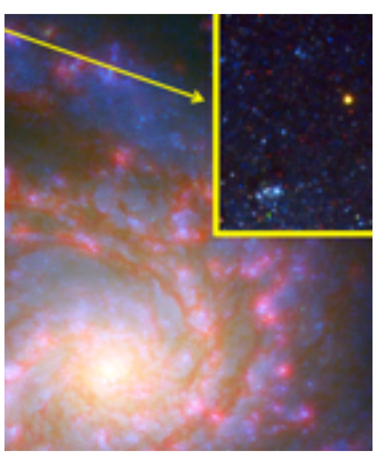
I enjoy discovering cosmic fireworks. The advent of wide-field synoptic imaging has re-invigorated the venerable field of time domain astronomy. Our framework of optical transients is no longer limited to novae and supernovae. Multiple distinct classes of rare explosions have been recently discovered, paving the way to learn new physics. We are finding missing pieces in two fundamental pictures: the fate of massive stars and the evolution of compact binaries.

While a student at Caltech, I helped build the Palomar Transient Factory. The robotic Palomar 48" and 60" telescopes have been churning out thousands of optical transients. We are now building the Zwicky Transient Facility with a whopping survey speed of 3800 deg^2 per hour (12x leap). We aim to find neutron star coalescence and the birth of black holes.

The pristine infrared dynamic sky is now ripe for systematic exploration. At least three new classes of transients are extremely red: stellar mergers, birth of massive star binaries and collapse of extreme AGB stars. I am currently undertaking an infrared transient search using the Spitzer Space Telescope called SPIRITS. Leveraging alternative semiconductors and innovative optical design, I am working on the first square degree near-infrared camera.

Both my optical and infrared transient pursuits are designed to build the capability, capacity and celerity to solve the grand challenge in time domain astronomy this decade: seeing the electromagnetic signature of gravitational waves. Thanks to heroic efforts spanning three decades, advanced LIGO is expected to now routinely detect gravitational waves from neutron star mergers. However, these interferometers will only be able to tell “when” the merger happens but not “where” it happened. Astronomers are planning to hunt for the associated electromagnetic emission to pinpoint the location. Nucleosynthesis (r-process) in the neutron-rich ejecta is expected to synthesize elements with mass numbers ranging between 120 and 200. Indeed, the majority of gold and platinum in the universe may be produced here and the search is dubbed the 21st century gold rush.

I am looking forward to returning to my alma-mater as a professor for many reasons. Above all, I am most excited about working with the guaranteed-awesome students!



Phil Hopkins: Theories of the Formation and Evolution of Galaxies, Black Holes, and Stars

My work focuses on building theories and models which can tie together a diverse array of questions related to galaxy, star, planet, and black hole formation and evolution. This involves a range of approaches, including old-fashioned pencil-and-paper theory but also the design and running of large-scale, massive computer simulations. I'm particularly interested in how a range of distinct and complicated physics in each of these processes somehow give rise to orderly structures, well-defined correlations, and the wildly different but (in other ways) regular properties of the Universe today.

Some major themes of my research include:

Galaxy formation: Understanding how galaxies from giant ellipticals to tiny dwarfs form, make stars, and reionize the Universe links basic questions in cosmology, gravity, and the nature of dark matter, with fluid dynamics, stellar and black hole formation and evolution, chemical enrichment, and plasma physics. Understanding these questions is the key to answering the question: “How did we go from Big Bang to Milky Way?”

Star Formation and Evolution: Stars represent the basic constituents of galaxies, and yet we don't understand how massive stars form, particularly under extreme conditions common in the early Universe. This brings together questions in the general theory of turbulence, magnetohydrodynamics, chemistry, and radiation-hydrodynamics. And it is also fundamental to understand high-energy phenomena such as supernovae and gamma-ray bursts.

Planet Formation: Many of the same processes play a role in the formation of planets. I'm particularly interested in how planets can form in turbulent, young disks around stars. The conventional wisdom used to be that this turbulence would prevent planet formation - but new observations suggest it may actually be the reason why there are so many planets.

Black Hole Formation and Evolution: Supermassive black holes and quasars represent some of the brightest and most distant objects we know. Recent discoveries that the black holes are tightly correlated with their host galaxies has led to an explosion of work in studying how these small, relativistic scales can dramatically impact a galaxy a million times larger.

There's a lot more info on my website: www.tapir.caltech.edu/~phopkins

Tony Readhead: Observational Cosmology and Active Galaxies

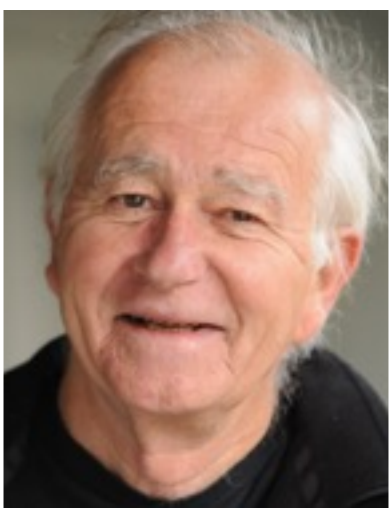
My main areas of interest are observational cosmology - the Epoch of Reionization (EoR) - active galaxies, the structure of the galactic magnetic field, the effects of foregrounds on CMB observations, and developing state-of-the-art instrumentation for all four areas.

I led the Cosmic Background Imager (CBI) project in Chile, followed by the QU Imaging ExperimenT (QUIET) project at the same site. Both of these instruments made seminal contributions to cosmology. In cosmology I have now switched my focus to the EoR and we are pioneering CO Total Intensity Mapping (COMAP) at redshifts 2-3 and 5-8. Our radio laboratory in Cahill is working closely with JPL and Northrop Grumman Corporation to improve the sensitivity of the MMIC amplifiers for use on COMAP and for providing state-of-the-art receivers to the GBT and ALMA.

My group developed the Very Long Baseline Interferometry (VLBI) imaging techniques that are in wide use today, and we are using VLBI to study a sample of blazars that are also being observed with Fermi-GST. In addition we are observing the TeV sources being monitored by VERITAS, MAGIC, and HESS. Our program of 15 GHz monitoring of ~1830 blazars on the Owens Valley Radio Observatory (OVRO) 40-m telescope twice a week is the most comprehensive variability study of active galaxies ever, and is providing key information that has led to over 60 publications in refereed journals in the last four years. In a completely different approach to both cosmology and AGN research we have developed a novel optical linear polarimeter capable of making extremely sensitive measurements of optical polarization in individual blazars as well as of all the stars in wide fields. We are now gearing up for the All Sky Polarization Survey (ASPS), using dedicated telescopes in Crete, India, and South Africa. The objective is to combine these results with the results from the GAIA satellite, which give the distances to the stars, to determine the 3-D structure of the magnetic field throughout the galaxy — of great interest for the astrophysics of the galaxy and interstellar medium and of critical importance to future CMB B-Mode experiments.

I work closely with my students and postdocs. They get a lot of experience on different instruments — and in the radio and optical regimes participate in instrument development. After leaving my group we keep in touch and often continue collaborating for many years.

Nick Scoville: Early Universe Galaxy and AGN Evolution



The major focus of my recent research is the Cosmic Evolution Survey (COSMOS) which focuses on the assembly and evolution of galaxies and their central black holes (AGN) at redshifts from 0.2 to 6. This survey was started in 2004 with 600 orbits on HST to image a 2 square-degree equatorial field, but it now includes imaging and spectroscopy from virtually every large space and ground-based telescope. Over a million galaxies are detected out to redshift 6 when the universe was only a billion years old; the survey is therefore equivalent to the Sloan survey of the local universe but covering the period of maximum galaxy and AGN evolution at $z > 1$. My major personal interest has been in mapping the large scale structures for the first time at high redshift and relating galaxy properties and their rates of evolution to their environments.

In the last two years, I have had several projects with the ALMA mm/submm array in Chile. This new instrument will revolutionize observational astronomy with an impact equivalent to that of HST over the last 2 decades. One of my projects has been using the long wavelength dust continuum to analyze the evolution of galaxy interstellar medium (ISM) masses from redshift 6 to the present, encompassing 90% of the universe's history. This project has now observed a sample of 250 galaxies and we see large increases in the ISM masses at $z \sim 2$-4. My second ALMA project consists of subarcsec imaging of the two ultraluminous IR galaxies — Arp 220 and NGC 6240. In the former, we find 2 billion solar masses of H_2 with the central 25 pc of each of the two merging nuclei.

Judy Cohen: Near-Field Cosmology and the Chemical Evolution of Galaxies

My general area of research is near-field cosmology, studying our Galaxy and the Local Group to try to understand the properties of the distant Universe. My current major interest is exploring the outer halo of the Milky Way using RR Lyrae variable stars as tracers of the mass distribution (primarily in the form of dark matter) in the extreme outer envelope of our galaxy. We have selected a large sample of RR Lyr extending out to about 110 kpc from the Galactic center. This is a selection via variability achieved by data mining of the Palomar Transient Survey archive. A large follow up spectroscopic program is currently underway at the Keck Observatory.

I have a long-term interest in the chemical evolution of our Milky Way galaxy, its globular clusters, and the outer halo field stars. I try to use detailed abundance analyses based on high-dispersion and high signal-to-noise ratio spectra obtained from the Keck Telescope to infer the formation details, timescales, present chemical inventory and past history of star formation and chemical evolution in "nearby" stellar systems of various types ranging from within our own galaxy to throughout the Local Group.

Galactic globular clusters have long been viewed as large stellar systems composed of stars of a constant age and fixed initial chemical inventory, but it has become clear over the past 15 years that this picture is too simple. Recently this has become a very hot topic with models that tie together the properties of the star-to-star variations among the light elements with the extent in color of the horizontal branch in a specific globular cluster. Current scenarios suggest the culprit is ejecta from AGB stars, which also would lead to large variations in helium content from star to star within a particular globular cluster. Understanding the details of all this has turned out to be much more challenging and interesting than I thought when I first embarked on work in this area.

The other main goal of my effort for the past 7 years has been to determine the properties of supernovae in the young proto-Galaxy as inferred from the chemical inventory of extremely metal-poor halo stars. These stars are so metal-poor that they must have come from that very early epoch before the enrichment of the gas by more than one or two stellar explosions. The search for a suitable sample of such stars has taken a long time to reach fruition – they are very rare and hard to isolate from the multitude of much more metal-rich stars in other components of the Galaxy such as the thick disk.

I was heavily involved in the development of the Keck Observatory from its start to its completion. The late Bev Oke and I led the team that designed and built the Low Resolution Imaging Spectrograph, one of the three first light Keck instruments. When I walk around Palomar or Keck it gives me great pleasure to see the many things I have helped design and build, including major software as well as hardware projects.

Tom Prince: Compact Object Astrophysics

My research currently involves use of large area sky surveys such as the Palomar Transient Factory (PTF) and the Catalina Real-Time Transient Survey (CRTS) for detection and characterization of galactic sources. I am particularly interested in systems containing compact objects, i.e. a white dwarf, neutron star, or black hole. Graduate students and postdocs working with me have been using PTF and CRTS to discover new ultracompact binaries systems through their time variability. We are particularly interested in systems with orbital periods less than about 1 hour that will shed light on a wide range of astrophysics including common envelope evolution, stability of mass transfer in close binary systems, and tidal effects on the white dwarf constituents. General relativity plays a significant role in the evolution of these systems and we will eventually see many of them as gravitational wave sources using space-based gravitational wave detectors such as the Laser Interferometric Space Antenna (LISA).

I have a long-standing interest in compact objects and high-energy astrophysics. This includes research work on radio pulsars, gamma-ray astrophysics, and cosmic-ray astrophysics. I have also dabbled in algorithms and computing, in particular techniques for detection and characterization of time-variable systems. I was involved in the development of the first massively parallel computing systems and was one of the founders of the Virtual Observatory movement.

A new project for me in 2015 is radio pulsar detection using a new high-frequency high-bandwidth receiver on the 70m Deep Space Network antenna in Canberra, Australia. This telescope will be especially powerful for detecting magnetars in the vicinity of the Galactic Center.

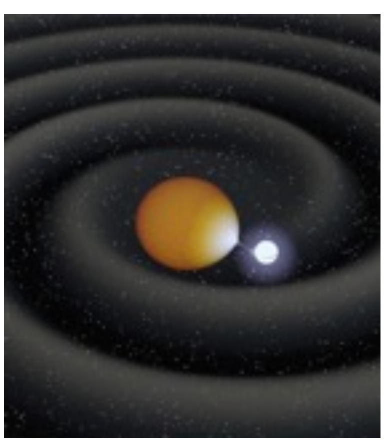
Sterl Phinney:
Theoretical High-Energy and Gravitational Wave Astrophysics

My students, postdocs and I use pencils, chalk and computers to explore the extremes of the universe: the deepest potential wells, the densest matter, the hottest plasma; i.e. black holes, neutron stars and the early universe. The goals are to understand how they work, and how they came to be.

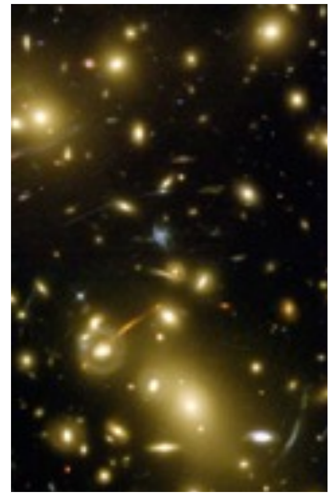
Over the course of my career, I have worked on the theory of black hole accretion, active galactic nuclei, relativistic magnetohydrodynamic jets, galaxy mergers, stellar dynamics and multiple star interactions in globular clusters, tidal disruption and extreme mass-ratio inspirals on black holes, predictions of sources of gravitational waves at nHz, mHz and kHz frequencies, the LISA space mission (I chaired the US Mission Definition Team 1997-2001, and served on the LISA International Science Team and chaired its Sources and Data Analysis Working Group 2001-2011, and was PI of the Big Bang Observer study), X-ray binaries and binary pulsars.

My current research is on the formation and evolution of millisecond pulsars, and the relations between and physics of black widow/redback pulsars and low mass X-ray binaries, on magnetars and exotic supernova interactions, and on the aftermath of tidal disruption of stars by black holes. This work combines in individual problems high-energy physics, plasma physics, magnetohydrodynamics, stellar structure and atmospheres, climate physics and gravitational physics, and has close connections to observations at wavelengths from radio through gamma-ray. I also spend some time trying to decipher mysterious objects found by iPTF, and find new uses for upcoming space missions like Ultrasat. So many ideas and so little time mean there is always room for another good student.

Besides trying to understand the extremes of the universe, I also have a hobby of figuring out simple quantitative explanations of phenomena, in everyday life, and beyond. This is fascinating, makes for good conversation and financial investments, and is valuable practice for research in astrophysics. Try it out in my course Order of Magnitude Physics (a former student, now a Professor of Astronomy at Berkeley, says it changed his life!) and my upcoming monthly column in the American Journal of Physics.



Richard Ellis:
Galaxy Formation and Evolution, Observational Cosmology, and Large-Scale Structure



My main interests are galaxy formation and evolution, observational cosmology and large-scale structure. I enjoy working with graduate students and have supervised 30 to date, nearly all of whom are now in academic research.

In cosmology, I am building a new instrument, the Subaru Prime Focus Spectrograph, which will chart the large-scale distribution of 4 million faint galaxies and chart the rate at which the Universe has expanded since a redshift of 2.5 or so. This will determine whether the dark energy invoked to explain the cosmic acceleration is a constant property of spacetime or one that is evolving. In concert with weak gravitational lensing data, which can measure the rate at which structure grows, our survey will also determine whether dark energy might be an illusion caused by an incorrect theory of gravity on large scales.

Gravitational lensing also offers opportunities in the study of distant galaxies. I am using clusters as natural “magnifying glasses” to zoom in on the detailed internal properties of selected distant galaxies. With the Keck adaptive optics system, we can secure dynamical and chemical data with exceptionally good resolution for early galaxies and these are being interpreted in the context of the FIRE simulations being undertaken by Professor Phil Hopkins.

I am also using lensing in Spitzer and Hubble data to explore the earlier galaxies which may be responsible for cosmic reionization. The launch of the James Webb Space Telescope is imminent and I am interested in working with Keck and Hubble to prepare for this new facility; both to trace the duration of the reionization era and better understand the remaining uncertainties in the physical processes involved.

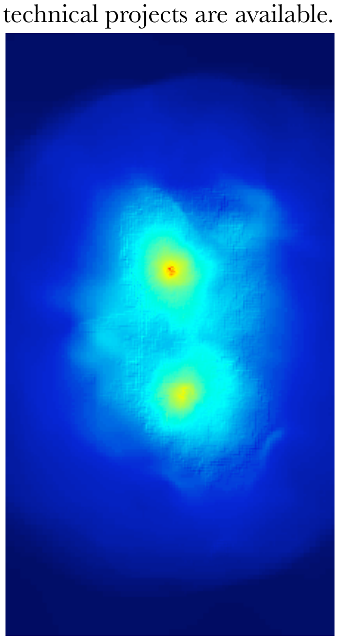
I'd welcome new students who wish to work in any of the above topics or related areas. Although we usually work in a small group, we maintain strong ties with international collaborators, particularly in the UK, France, Canada and Japan. We receive telescope time on telescopes throughout the world and all of my students use Keck and Palomar on a regular basis.

Sunil Golwala:
Observational Cosmology and Instrumentation

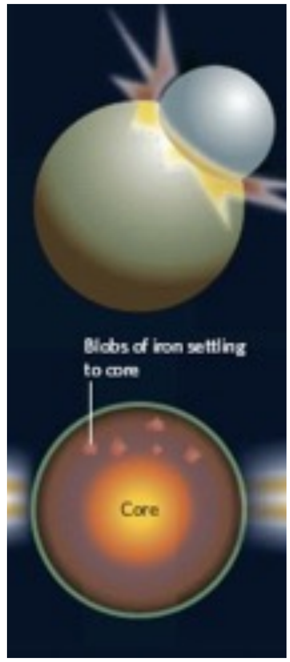
I work at the intersection of particle physics and cosmology on observations and instrumentation to understand the nature of the dark matter and dark energy that dominate the evolution of our universe.

One effort is to develop and use millimeter-wave instrumentation to map the Sunyaev-Zeldovich effect in galaxy clusters with the goals of studying cluster astrophysics, calibrating cluster masses for cosmological applications, and studying the cosmological peculiar velocity field. The former lets us study the distribution of dark matter in clusters, while the latter two can constrain dark energy. We have in hand SZ observations of a sample of 50 clusters, with which we have measured the pressure profile out to the virial radius, calibrated the relation between SZ flux and hydrostatic equilibrium mass, and detected the kinetic SZ effect in an single object for the first time. We are embarking on a project to use these data to test for similar effects in a larger sample of clusters, and are exploring other applications of these data. We are also developing technologies for future observations of this type: we have developed a four-band mm/submm camera and are working on upgrades of the instrument, including devices that can observe in 6 bands simultaneously as well as anti-reflection structures for silicon optical elements. Observational and technical projects are available.

A second effort is on the direct detection of dark matter with the SuperCDMS experiment, which uses extremely sensitive detectors to search for scattering of dark matter particles with terrestrial nuclei and have the world's best sensitivity to date for dark matter particles below 10 GeV mass. We are analyzing data from the SuperCDMS Soudan experiment and are building the SuperCDMS SNOLAB experiment. For the latter, Caltech is responsible for screening of the ionization amplifier chips for the experiment and for comanaging construction of the detectors and their associated hardware. We also are working to develop next-generation dark matter detectors. Data analysis and technical projects are available.



Dave Stevenson:
Planetary Structure and Evolution



Most of my work concerns the interiors of planets and satellites in our solar system, but I am also interested in exoplanet structure, motivated by the startling results from transit data including those from Kepler. The goals of my research include trying to relate how bodies form and evolve to their present properties (density, gravity field, magnetic field, heat flow, volcanism, whatever) and the data are typically from spacecraft (e.g., Galileo, Cassini). The tools include a good understanding of condensed matter physics and continuum mechanics (fluid dynamics), and most of my work does not involve large numerical simulations. Good ideas are the essential ingredient. I am also involved in a future mission: Juno, a spacecraft scheduled for launch in 2011 and orbital insertion around Jupiter in 2016.

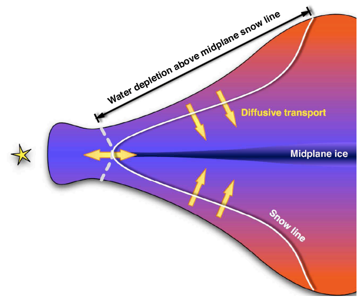
Here are some examples of recent and ongoing research: Earth's moon is thought to have formed through a giant impact between the proto-Earth and a body that was roughly the size of Mars. I have been involved in efforts seeking to explain the isotopic and chemical nature of the Moon based on this impact model. Jupiter's zonal flow in the atmosphere extends to some unknown depth and will couple to the magnetic field and cause excessive Ohmic dissipation if they extend to great depth. Titan's gravity field has been measured during several flybys of the Cassini spacecraft, and these data show that Titan is incompletely differentiated with the deep interior perhaps consisting of a mixture of ice and rock. Enceladus is tidally heated, perhaps in excess of equilibrium models, suggesting the need for an oscillatory time evolution of its orbital eccentricity.

I enjoy working with undergraduate and graduate students. Typically, they will have a strong physics background, a lot of self-motivation and enjoy the challenge of working on problems where many physical effects are in play.

Geoff Blake: Molecular Astrophysics and Star/Planet Formation

The research interests of the students and postdoctoral fellows with whom I work are broadly centered on star and, especially, planet formation. While we carry out observational, theoretical and laboratory programs, the common tool we wield most effectively is spectroscopy. We use molecular spectra both as probes of the environments in which solar systems are assembled and to investigate the fascinating chemistry that occurs long before planetary surfaces are available.

Our observing programs couple data sets from the wonderful suite of telescopes available to Caltech astronomers and planetary scientists, most importantly the Keck telescopes, with dedicated surveys and archival results from the Spitzer and Herschel Space Telescopes. Our observations have shown that the mid-IR spectroscopy of the disks around young stars can be used to examine both the dust and gas content of their near-surface regions at all radii important to planet-forming. These extraordinarily rich spectra contain clues as to the movement and fate of volatile CNO-containing species such as water in the disk (see figure at right), and are thus providing a new window into the processes that build planetary systems and provide potentially habitable worlds. Follow-on work with ALMA and Herschel will extend our reach into the outer regions of disks analogous to our own Kuiper Belt. We have recently coupled our disk program with studies of the volatile content of non-transiting exoplanetary atmospheres to investigate the formation and dynamical evolution of hot Jupiters using the NIRSPEC instrument at Keck.



In the laboratory, we have developed state-of-the-art TeraHertz-Time Domain Spectroscopy (THz-TDS) systems that can interrogate the optical properties of materials from wavelengths ranging from 50 to 1000 microns and over a temperature range of 10-600 K. The temporal resolution of the spectrometers is <100 femtoseconds. We are using these new tools to examine the long wavelength properties of interstellar dust analogs along with the large amplitude vibrational modes of complex molecules that are uniquely available to instruments aboard Herschel, SOFIA and ALMA.

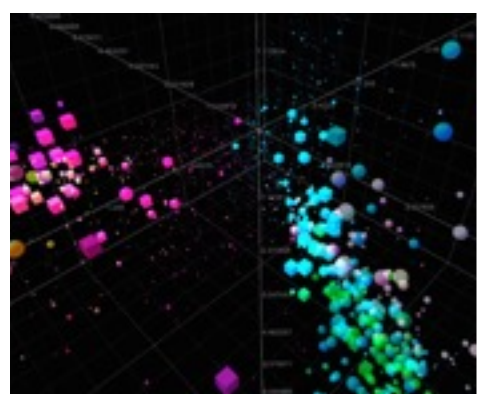
Though I have recently stepped down as Caltech's Master of Student Houses (MOSH), my wife and I remain dedicated to promoting student-faculty interactions around campus. We hope to see you both in and out of the office!

George Djorgovski: Digital Sky Surveys and Computational Science

I have worked on a broad variety of topics, including structure and dynamics of globular clusters, fundamental properties of galaxies and their evolution, gamma-ray bursts, early phases of galaxy and structure formation, distant quasars, dark energy, etc.

More recently, I have been concentrating on large digital sky surveys and Virtual Observatory, and how these large and complex data sets can be used to explore systematically the observable parameter space, and possibly even discover new types of astrophysical objects and phenomena. I am currently focusing on synoptic sky surveys, where large areas of the sky are imaged repeatedly, looking for highly variable sources and transient events. Their follow-up and interpretation pose many interesting challenges and scientific opportunities.

About a half of my time is spent on the development of computational, mostly data-driven science, beyond astronomy proper. Broadly speaking, I am interested in the ways in which computational and information technology changes the ways we study and understand the world around us. This ongoing revolution is changing all of the science and scholarship, along with nearly every other aspect of modern society. As all fields of sciences face the challenges of an exponential growth of data volumes and complexity, and extraction of knowledge and understanding from the data, we are essentially forging new, general tools for the scientific methodology in the 21st century.

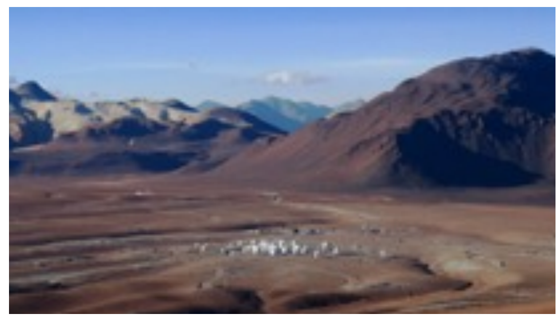


I enjoy working with undergraduate and graduate students, postdocs, and other junior scientists, and have many collaborators world-wide. I appreciate self-motivated, enthusiastic people with a real passion for research.

Anneila Sargent: Star Formation and Evolution

My research focuses mainly on how stars are born and evolve in our own Milky Way and in other galaxies. How are new stars created in the cores of dense molecular clouds of dust and gas? How do the new stars emerge from this obscuring material? How is the material itself dissipated? Could planetary systems form around some of these stars? Direct millimeter, submillimeter, and infrared observations of the dust and gas associated with collapsing clouds, or surrounding newly-born stars, provide important information about the physical and chemical properties of these interstellar and circumstellar regions. I am especially interested in the evolution of the circumstellar disks of gas and dust that are an integral part of very early stellar evolution and are potential sites for planetary system formation.

Studies of proto-planetary disks at all stages of development need very high resolution measurements. Pioneering detections were made with Caltech's original millimeter-wave array and subsequently with CARMA in California's Owens Valley. This prepares the way for ALMA, the new international millimeter/submillimeter-wave array now being completed in northern Chile. I have been closely involved with ALMA throughout its development along with Caltech former students. Caltech students, past and present are already making the most of this amazing array and can continue to do so. ALMA's first high resolution image of a circumstellar disk confirmed that the array will revolutionize our understanding of star and planet formation. In fact, the disk was originally identified at Caltech. It's a great place to get a head start on the latest problems – I found that out for myself as a graduate student here.



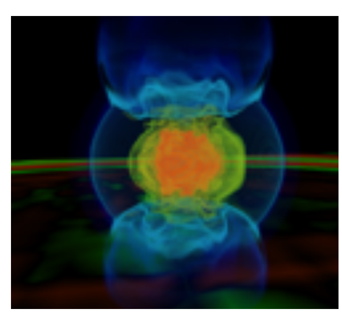
Currently, I'm also Vice President for Student Affairs at the Institute. Being an astronomer can take you in all sorts of directions.

Christian Ott:
Computational and Theoretical Relativistic Astrophysics

I am currently most interested in very energetic astrophysical phenomena – basically, things that blow up. These include dying massive stars that explode in core-collapse supernovae and/or gamma-ray bursts, binary systems of compact stars (neutron stars/black holes) that merge and make a gamma-ray burst, accreting white dwarfs and merging white-dwarf binaries that explode in a supernova, accreting neutron stars that burn accreted material and make x-ray bursts, and soft-gamma-ray repeaters – neutron stars, that experience re-arrangement of their ultra-strong magnetic fields, leading to repeated outbursts of soft gamma rays.

We are trying to understand the physics and dynamics of the 'engines' of such energetic and explosive events. This is a challenging, but exciting task – these problems are so complicated and involve physics from so many different areas (e.g., general relativity, magnetohydrodynamics, nuclear and particle physics, transport theory) that they must be simulated on supercomputers. These simulations can then guide our theoretical understanding and, perhaps more importantly, give us predictions that can be tested by observation. We run our simulations on some of the world's finest and fastest supercomputers on the XSEDE, at National Labs, and we have our own 2500-core supercomputer here at Caltech.

Observing phenomena that occur in strongly curved spacetime and at ultra-high matter density is notoriously difficult. One of our main tasks is to produce detailed estimates which we furnish to neutrino and gravitational-wave observers. We work closely with neutrino physicists at Caltech and elsewhere, and have very close ties to the LIGO Laboratory at Caltech. Of course, we also interact with Caltech's observational astronomy groups, in particular NuSTAR and PTF/ZTF.



There are many unsolved problems in relativistic astrophysics and all involve a broad range of physics and complicated multi-dimensional dynamics of matter, radiation, gravity, and magnetic fields. There is a virtually countless number of exciting research projects! So, if you are interested in the stuff we do or just want to learn more about our work, please just drop by my office whenever you like.

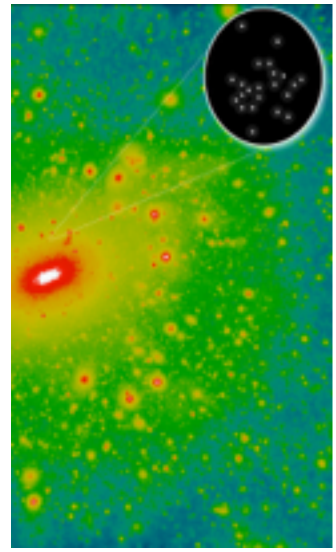
Tom Soifer: Galaxy Evolution & Infrared Instrumentation

I am interested in the evolution of galaxies, particularly galaxy evolution that is hidden from view in the optical band because the galaxies are heavily dust obscured. Long ago with the IRAS survey, we found extremely dusty galaxies in the local universe. Using the Spitzer Space Telescope, my collaborators and I have found a corresponding kind of galaxies, Dust Obscured Galaxies (DOGs), which are quite common at high redshifts (z>2). The DOGs are a substantial contributor to the energy output in the universe a few Gyr after the big bang. The questions I am trying to address revolve around where DOGs fit into the bigger picture of galaxy evolution, whether this dusty phase is a part of the life experience of every galaxy, and how much of the star formation in the universe is hidden behind a veil of dust.

The platforms I use include space telescopes (most notably the Spitzer Space Telescope, which happens to be the best Observatory NASA has ever launched, and for which I am the Director of the Science Center), and the ground-based facilities of Caltech – the Keck telescopes, the 200" telescope at Palomar, the CSO and CARMA. Part of my interest is in building infrared instrumentation for Caltech's ground-based telescopes. In the past I have been involved in several instruments that are used on the 200", as well as the Near Infrared Camera (NIRC) for Keck I and the Near Infrared Camera 2 (NIRC2 for Adaptive Optics observations) on Keck II. Currently, with Keith Matthews, the infrared instrumentation guru here at Caltech, I am involved in building a Near Infrared Echelle Spectrometer (NIRES) for Keck. This instrument will observe a target simultaneously from 1.0-2.4 microns at a spectral resolution of ~2500. NIRES is designed to study the faintest objects that are reachable with the Keck telescopes. We expect to have this instrument on the telescope this year.

Outside of astronomy I amuse myself with music (mostly old war-horse operas) and tennis.

Evan Kirby: The Origin of the Elements, Galactic Chemical Evolution



The universe began with hydrogen, helium, and a tiny bit of lithium. Every other element was made inside of stars. As time elapsed, stars manufactured more and more of these heavier elements. Different types of stars created different amounts of each element. The ratio of two elements, such as magnesium to iron, indicates the types of stars that were contributing to the rise of the elements.

I use stellar spectroscopy to measure the elemental compositions of stars, and I use those measurements to infer which types of stars existed long ago and how quickly those stars were forming and dying. My favorite type of galaxy is a dwarf galaxy. Dwarf galaxies are near enough to be studied in detail and simple enough to make straightforward interpretations about their elemental evolution. For this work, I use a variety of spectrographs on the Keck telescopes in Hawaii.

The picture above shows a representation of the dwarf galaxy Segue 2. The color portion of the image shows simulations of how dark matter is expected to be distributed around the Milky Way. Segue 2 inhabits one of the smallest clumps of dark matter. When I weighed Segue 2 by measuring the motion of the 25 stars shown in the inset, I found that it is the least massive galaxy known.

I'm also involved in designing the Galactic Archaeology survey for the Prime Focus Spectrograph on the Subaru telescope. Furthermore, I am planning a Stellar Isotope Survey at Caltech (SISC). SISC will measure not just the amount of elements in stars in our galaxy but also how those elements are distributed among their constituent isotopes. SISC will be one of the most detailed surveys of galactic chemical evolution.

Other than astronomy, I really enjoy classical music. I play the clarinet, and I love to attend chamber music and orchestra concerts. I also occasionally go hiking or road biking in the San Gabriel mountains.

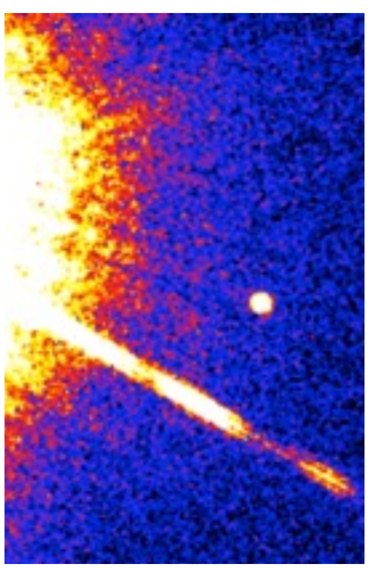
Shri Kulkarni:
Compact Objects, Transients, Planets, and Instrumentation

I like to focus on a field for a period of three to five years and then move on. I also like to develop new techniques, novel instruments and methodologies. Finally, I avoid working on popular fields. Given these boundary conditions, I let my graduate students choose their research topics.

Over time I have wandered from the study of Galactic interstellar, millisecond pulsars, pulsars in globular clusters, brown dwarfs, soft gamma-ray repeaters, gamma-ray bursts and cosmic explosions. I have a life-long interest in interferometry, having developed a 10-km radio linked interferometer at Arecibo Observatory (during my youth). This interest has now culminated in the Space Interferometry Mission (for which I am the Interdisciplinary Scientist and Chairman, Science Team). My main focus with this mission is a broad survey for planets and astrophysics enabled by precision astrometry.

I think that the next big area is transient object astronomy (mainly because of tremendous technological growth in sensors and computing). I am the Principal Investigator of the Palomar Transient Factory — an innovative project based around the Palomar 48" Oschin Schmidt and the automated Palomar 60" telescope and designed to explore the transient sky. Within the first semester of first light we discovered a new class of ultra-bright supernovae (which we dub as "spasmanova"). Likely these arise from very massive stars. The future for transient object astronomy is bright and exciting.

I love music and like my research I switch my focus every few years. I have successively been a fan of Salsa, Qawali, Latin Jazz and music from Mali. I am a great student of macro-finance and especially financial meltdowns. Finally, I love rabbits since they best reflect my personality.



Heather Knutson:
Properties of Exoplanets

For centuries, astronomers had expected that planetary systems around other stars should echo our own, with small, rocky planets orbiting close to the star and more massive gas giant planets farther out. It therefore came as a surprise when the first planets discovered around nearby stars turned out to be massive gas giants similar to Jupiter orbiting extremely close to their parent stars. Nearly two decades later, these "hot Jupiters" have turned out to be merely the tip of the iceberg; we currently know of more than four thousand extrasolar planets and planet candidates with a diverse array of properties that continue to defy our expectations of what should be out there.

For many of these planets, we know little more than their masses, orbital periods, and sometimes their radii. I use observations of eclipsing systems, where the planet periodically passes in front of its host star, to build up a more detailed picture of the properties of these alien worlds. Although much of my present-day work focuses on gas giant planets, which are more easily observed due to their large sizes and high temperatures, we are also starting to study the atmospheres of planets as small as 5-10 times the mass of the Earth.

Current research topics include:

1. Atmospheric circulation on short-period, tidally locked hot Jupiters. By comparing circulation patterns on a diverse sample of hot Jupiters, I aim to learn more about the physical processes that shape these atmospheres.

2. Compositions of exoplanet atmospheres as a function of planet mass. I am interested in the transition from gas giant planets to "super-Earths", which are 1-10 times the mass of the Earth. We expect that smaller planets should have less hydrogen and helium in their atmospheres, but the exact nature of this transition is poorly understood.

3. Companion-driven migration mechanisms. It has been suggested that many of the massive extrasolar planets in short-period orbits probably did not form in place, but rather migrated in from farther out in the disk. This program searches for massive outer companions in known planetary systems in order to test dynamical migration theories.

Gregg Hallinan: Search for Radio Transients

My group primarily studies various classes of transient radio sources, i.e. anything that is pulsing, exploding, flaring or flickering in the radio sky. The discovery, classification and study of such transients offers enormous potential to uncover a wide range of new physics and astrophysics, the canonical example being the discovery of pulsars in 1968.

I lead a range of programs that make use of large telescopes like the Very Large Array (VLA) in New Mexico to survey the sky for events ranging from stellar flares in the nearby universe to exploding stars at cosmological distances. However, much of our research makes use of novel instrumentation built to survey the radio sky continuously at Caltech's Owens Valley Radio Observatory (OVRO).

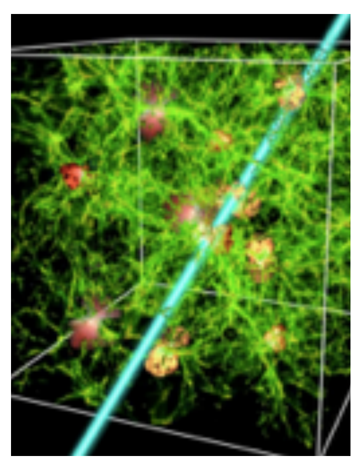
At the heart of this effort is the Owens Valley Long Wavelength Array (LWA), a new array of 288 antennas that images the entire viewable radio sky every few seconds in the search for transient radio emission, producing enormous amounts of data in the process. As part of this search, the LWA aims to provide the first detection of the radio emission from a nearby extrasolar planet as it enveloped in the intense stellar wind produced during a coronal mass ejection event, similar to the space weather events that can dominate the Earth's local space environment. This will allow us to detect and characterize the magnetic fields of exoplanets for the first time and potentially investigate their role in planetary habitability. My group is also working towards a much larger array, the Deep Synoptic Array, which will be the most powerful radio survey instrument yet developed.

Chuck Steidel: Observational Cosmology and Galaxy Formation

My general area of research is observational cosmology, with particular interest in galaxy formation and the nature of the circumgalactic and intergalactic medium. Whereas the large-scale structure of the universe is dictated primarily by dark matter, the behavior of the normal, baryonic matter embedded in the dark-matter structure is what shapes the observable universe. We use extremely sensitive imaging and spectroscopic observations of distant galaxies and quasars to directly probe the physical properties of the young universe (both galaxies and the gaseous reservoirs between them) during the most explosive period of growth, 10-12 billion years ago.

We are interested in measuring key physical parameters of galaxies such as mass, chemistry, large-scale spatial distribution, and the impact of energetic processes (collectively known as ``feedback'') such as black hole accretion, star formation, and supernova explosions on both the galaxies and their environments. Our main tools are the twin 10m Keck telescopes in Hawaii, supplemented by Hubble, Spitzer, Chandra, and Herschel observatories in space, as well as ground-based submilimeter and millimeter-wave facilities. Our observational programs are designed to inform state-of-the-art cosmological simulations, constraining complex baryonic processes that are most difficult to model, but which nevertheless shape the formation and evolution of galaxies over cosmic time.

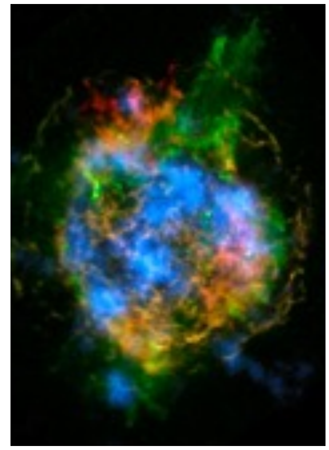
I spend a fair fraction of my time on the development of new observatories and state-of-the-art instruments for both current and future telescopes. Most recently, we built and commissioned MOSFIRE (Multi-Object Spectrometer for InfraRed Exploration) on the Keck 1 telescope. MOSFIRE is currently the most powerful near-IR spectrometer in the world, and an exciting new tool for the study of galaxies and the intergalactic medium in the young universe. I am currently involved in the design of an ambitious first-light wide-field, multi-object optical spectrometer for the Thirty Meter Telescope (TMT), which entered the construction phase in late 2014.



I particularly enjoy working with graduate students, and those working in my group are encouraged to become deeply involved in both the science and instrumentation efforts. I still collaborate with all of my former students well after they have moved on to the next step in their careers. I was a Caltech graduate student myself back in the day (Ph.D. 1989), returning as a faculty member in 1995.

Fiona Harrison: Observational and Experimental High-Energy Astrophysics

My research focuses on observational and experimental high energy astrophysics. I am the Principal Investigator of NASA's NuSTAR mission — the first telescope in orbit to focus high energy X-rays. NuSTAR is more than 100 times more sensitive than any telescope that has operated in this region of the electromagnetic spectrum. The technologies for the telescope were developed in my laboratories in Cahill together with an international team of collaborators. The mission was developed in collaboration with the Jet Propulsion Laboratory, and was launched June 13, 2012.



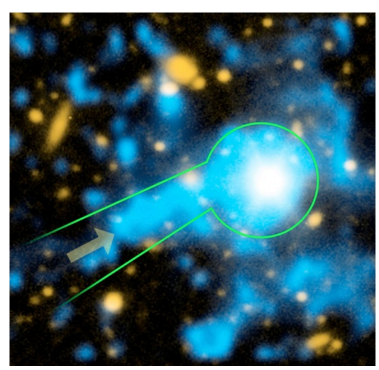
Since launch my group has been leading observations of accreting black holes, neutron stars and supernova remnants in the Galaxy and beyond. We have used NuSTAR to measure the spins of black holes, study pulsars and magnetars, to understand the nature of ultra luminous X-ray sources, to map supernova remnants in radioactivity to understand the core collapse explosion mechanism, and to study the co-evolution of black holes and galaxies. I also have an observational effort with Keck and Palomar to perform spectroscopic followup of serendipitously discovered sources, largely active galactic nuclei, in NuSTAR fields.

In addition to observational efforts I continue to develop next-generation detectors for future X-ray missions. My group is involved in a balloon experiment and mission that will measure the X-ray polarization of black holes, magnetars and neutron stars. This will provide unique constraints of the inner regions near black holes, and probe the physics of the strongest magnetic fields in the Universe.

Chris Martin: Galaxy Evolution, Intergalactic Medium, and Experimental Astrophysics

I would like to understand the history of star formation in galaxies and the physical conditions that govern this history. I am particularly interested in how the baryonic gas that begins as the intergalactic medium (IGM) ultimately finds its way into galaxies and stars, and how those galaxies feed energy and material back into that natal gas. In order to do this we are exploiting various observational tools to study star formation history. I was the Principal Investigator of the Galaxy Evolution Explorer (GALEX), a NASA satellite that mapped the sky in the UV. The ultraviolet provides one of the most sensitive ways to detect the low levels of star formation that occur in the outskirts of galaxies, in low mass systems, in galaxies that are shutting down their star formation, and in young galaxies with few heavy elements. Many of our GALEX studies require follow-up observations with Palomar, Keck, HST, and other facilities. Measuring star formation laws and history in these diverse physical environments will help to construct a theory of baryonic structure formation, but new and challenging observations are also needed.

We are therefore pursuing several new experimental programs to detect and map emission from the intergalactic medium. These maps could delineate the baryonic reservoirs of gas that fuel ongoing galaxy formation and evolution over time, reveal the direct impact of galactic feedback on the surrounding medium, and provide a new cosmological tool. In space, we are currently flying a balloon UV imaging spectrograph (FIREBALL) designed to detect and map IGM emission at z~0.7. This is a prototype of a satellite experiment that would detect and map IGM emission over the 0<z<1.5 redshift range. The Palomar Cosmic Web Imager has already obtained spectacular data on emission from filaments of the cosmic web and a giant proto-galactic disk, and the Keck Cosmic Web Imager (KCWI-Blue) is about to be commissioned in Fall 2015, with KCWI-Red to be built 2015-2018. KCWI will detect and map IGM emission from redshift 2 to the reionization redshift of z~6-7. All of these experiments can be used to make many other new and path-breaking measurements.



Our projects are perfect for graduate student mentoring and leadership. We are seeking students who are interested in combining experience building new instruments with frontier science observations.

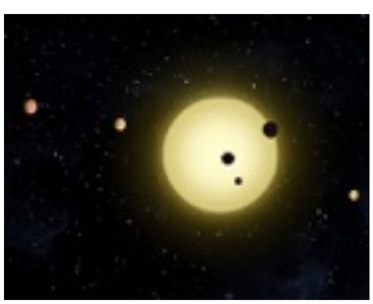
Konstantin Batygin: Planetary Astrophysics

My primary research interests lie in the field of planetary astrophysics. I am fascinated by a wide variety of problems related to the formation and evolution of the Solar System, dynamical evolution of exoplanets, as well as physical processes inherent to planetary interiors and atmospheres.

Driven by the rapid pace of observational detection of novel planetary systems, as well as continued characterization of the solar system's minor body population, the interest in the study of orbital dynamics has been greatly reinvigorated. In turn, the formulation of a substantial aggregate of new models has shed light on the dramatic processes responsible for shaping planetary systems, including our own. Within this realm, our work is concentrated on developing a theoretical understanding of the dynamical structure (and its origin) of planetary systems as well as the characterization of their long-term tidal evolution, dynamical stability and the onset of chaotic motion.

The first discoveries of extrasolar planets around main-sequence stars revealed the widespread presence of planetary bodies that reside in close proximity to their host stars. Through the process of thermal ionization, intense stellar irradiation renders close-in planetary atmospheres electrically conductive. Accordingly, the interactions between such atmospheres and the background planetary magnetic fields lead to induction of electrical currents which act to heat the planetary interior and perturb the large-scale circulation patters. Our efforts have been focused on understanding these phenomena by utilizing semi-analytic and numerical models.

The accelerating quantification of exoplanetary orbital obliquity (i.e. the misalignment between the stellar spin axis and the planetary orbit normal) has been interpreted as being among the most information-rich relics left over from the epoch of planet formation. Unexpectedly, the recurrent identification of large spin-orbit misalignments have called into question our understanding of planet-disk interactions and planet-formation in general. To this end, our research activities have been aimed at understanding the evolution of proto-planetary disks and stellar spin-axes (subject to gravitational torques from the stellar birth environment, magnetic disk-star coupling, accretion, etc) in an effort to reconcile significant orbital obliquities and conventional mechanisms responsible for large-scale orbital migration of young planets.



Mike Brown: Planetary Astronomy

I spend most of my time looking for and intensely studying the small icy objects at the edge of our solar system, in the Kuiper Belt. These Kuiper Belt objects are fascinating to me in two ways. First, as the debris left over from the formation of the solar system, they are a fossil record of the very earliest history of the planets. The bodies in the Kuiper Belt tell a history of rapid accretion, quiescent growth, violent perturbation, and giant impacts, all tied to the growth of the giant planets. Trying to understand solar system history by looking only at the small number of remaining planets is hard, but the imprint left on the thousands of objects in the Kuiper Belt is a fossil record that we can slowly piece together. The tools used for this forensic work include large surveys with facilities like the Subaru telescope on Mauna Kea and also massive dynamical simulations that explore different possibilities for the formation and evolution of the solar system.

In addition to being simple dynamical tracers, some of these objects in the outer solar system – particularly the largest ones – are fascinating worlds in their own right. We are trying to understand the basic geophysics of large icy bodies by studying atmospheric creation, surface chemistry, interior differentiation, and impact resurfacing on these bodies, all by gleaning observational hints from telescopes like Keck, Hubble, and CARMA.

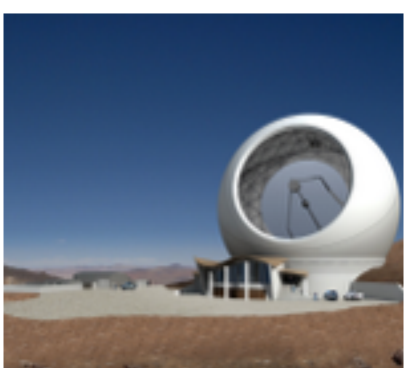
As a hobby, I also use images and spectra from the Cassini spacecraft, in orbit around Saturn, to study Titan. Titan has long fascinated me for its methane hydrological cycle, in many ways similar to the Earth's but in many other ways completely alien. For years our best tool to study Titan was the Keck telescope, but these days we use Cassini. While building bigger telescopes is always better, sometimes it is easier just to fly your telescope to the place you want to study and look from there.

Jonas Zmuidzinas:
Submillimeter Astronomy and Instrumentation

I am an experimentalist working at the intersection of astronomy, engineering, and physics. I like to find astronomical problems that demand technical innovation for their solution, problems that cannot be solved using existing techniques or instruments. New technology and instrumentation open up new possibilities for discovery, and that is what excites me. I focus primarily on the submillimeter (submm) band, which is still poorly explored and offers plenty of technical challenges. I have worked on ground-based, airborne, and space-based astronomy projects.

In 1999, my JPL colleague Rick Leduc and I invented a new type of superconducting detector known as the MKID (microwave kinetic inductance detector). MKIDs provide a relatively simple solution to the problem of making large arrays of very sensitive detectors operating at low temperatures, and may be adapted for use across the electromagnetic spectrum, from millimeter waves to x-rays. Roughly two dozen research groups around the world are now developing various versions of MKIDs spanning the spectrum and targeting a very diverse set of applications, from CMB polarization measurements to exoplanet imaging and spectroscopy to submm surveys of the high-redshift universe. At Caltech, we have fielded prototype submm MKID cameras at the Caltech Submillimeter Observatory in Hawaii, and are working on MKID technology to allow 3D (spatial/spectral) imaging of the high-redshift universe ($z>4$) in the millimeter band. Our long-term goals are to build a large wide-field ground-based submm telescope, and also to put large MKID cameras and spectrometers on a cold space telescope to perform surveys in the far-infrared.

The work is highly interdisciplinary and has strong connections to electrical engineering, condensed matter physics, and superconducting quantum circuits. We work closely with JPL and our MKID arrays are fabricated at JPL's Microdevices Laboratory. Our students come from a wide variety of backgrounds – astronomy, physics, applied physics, and electrical engineering. Some students focus primarily on astronomical projects; others lean more heavily toward instrumentation. Similarly, some graduates stay in astronomy; others migrate to other fields. Research projects can range from one-person efforts, to large instrument teams with multiple collaborating institutions.



Jamie Bock: Unique Experiments to Study Cosmology

My research program develops unique experiments to study the early universe.

The experimental cosmology group is leading a new generation of instruments to search for inflationary polarization. The Keck Polarimeter Array (above) and the coming BICEP3 experiment are making polarization measurements on degree angular scales from the South Pole, an excellent site for millimeter-wave measurements. The SPIDER balloon experiment studies polarization on larger patches of sky from an Antarctic long-duration balloon-borne platform. We are now in a very exciting phase of this program, achieving sensitivity levels that will either detect inflationary polarization or supply new constraints on inflationary theory.

I have also developed an interest in experiments to study galaxy formation and the epoch of reionization in atomic form since the recombination epoch associated with the CMB. These measurements are based on 'intensity mapping', using information in the spatial structure of intensity variations to measure galaxy clustering. Our group pioneered some of the first measurements of this kind with data from Herschel and Planck satellites.

The CIBER sounding rocket experiment applies intensity mapping to study the near-infrared extragalactic background, to search for the component of the background associated with stellar emission from the epoch of reionization. CIBER uses wide-field cameras in two bands, and has had four successful flights. These results have motivated us to develop a new camera system with improved sensitivity and expanded wavelength coverage in multiple bands.

Finally, we have recently embarked on a new program, an epoch of reionization experiment (TIME) that studies fluctuations in line emission from singly ionized carbon, redshifted from 158 um rest frame into the millimeter-wave. Measuring fluctuations in line emission requires higher sensitivity, but unlike continuum measurements give 3-dimensional information in redshift slices.

Additional info can be found at http://www.astro.caltech.edu/~lgg/.

Emeritus Faculty

Marshall Cohen

Peter Goldreich

Tom Phillips

Maarten Schmidt

Kip Thorne

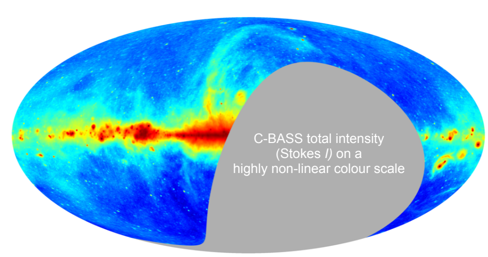
Research Professors

Below are a small selection of the many Research Professors that are involved in Astrophysical projects at Caltech. Research Professors often help to organize and operate research groups, labs, and facilities at Caltech. They perform their own research and occasionally teach classes and collaborate with graduate students and postdocs.

Tim Pearson: Radio Astronomy and Cosmology

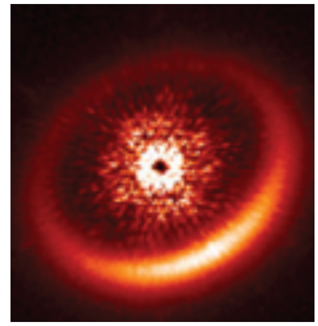
My work is centered in observational radio astronomy and cosmology. Projects for studying the CMB include the Cosmic Background Imager (CBI), developed with Tony Readhead and Steve Padin, a small interferometer array operating at 30 GHz that we deployed for a few years in the Chilean Andes, and QUIET (the Q/U Imaging Experiment), a focal-plane array receiver at 40 and 90 GHz that followed at the same site. I am also part if the US team analyzing data from the ESA/NASA Planck satellite. Since 2005, I have been leading a project at OVRO called "C-BASS: The C-Band All-Sky Survey" to map the sky at 5 GHz in intensity and polarization. The maps have similar resolution to Planck, and C-BASS can be regarded as a low-frequency complement to Planck: it will allow the synchrotron component of the Galactic foreground, which is poorly constrained by the higher frequency observations, to be modeled and removed from Planck images.

Also at OVRO, Tony Readhead and I have been monitoring the flux densities and polarizations of about 1800 active galactic nuclei (mostly blazars) in parallel with observations by the NASA Fermi Gamma-Ray Space Telescope. I am also involved in an international program (RoboPol) to monitor the optical polarization of blazars. The combination of radio, optical, and gamma-ray time-series is being used to motivate and test theoretical models of the relativistic jets from AGN.



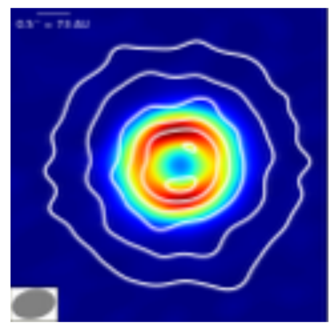
Charles Beichman:
Infrared, Exoplanets, Instrumentation, and Space Astronomy

Dr. Charles Beichman is Executive Director of the NASA Exoplanet Science Institute (NExScI) , a joint Campus/JPL organization. With a long history in infrared astronomy (IRAS, Spitzer, WISE) and exoplanet missions, his interests cover many areas. In the past few years he has focused on the nature of debris disks using ground- and space-based data, the nature of the coldest brown dwarfs discovered by WISE as analogs of Jovian mass planets, searches for young planets using coronagraphy at Palomar, the discovery and follow-up of planets orbiting nearby M stars with the Kepler/K2 mission, and a Spitzer program to study planets via microlensing with the Ohio State group. He is working with Prof. Kerry Vahala (Applied Physics) to develop an innovative laser comb to used as a precision wavelength reference (<0.3 m/s) for near-IR radial velocity studies with the Keck NIRSPEC spectrometer. He is a member of the James Webb Space Telescope NIRCam instrument team and leader of the that team's exoplanet efforts. His observing program with NIRCam will focus on transit spectroscopy and coronagraphy to search for Saturn mass planets orbiting nearby young stars and to investigate the composition and structure of debris disks.



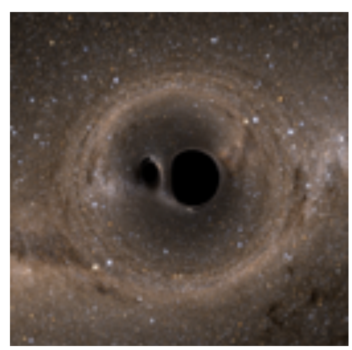
John Carpenter: Millimeter-wave Astronomy and Circumstellar Disks

The broad goal of my current research is to understand how circumstellar disks evolve to form planetary systems. Using the CARMA, ALMA and VLA interferometers, my students, postdocs and I have obtained high resolution images of the rotating disks of the cold gas and dust that surround young stars. These images have traced the density structure of disks, revealed the initial stages of planet formation as dust grains coagulate into large particles, resolved large holes in disks that are likely caused by newly formed planetary systems, and measured the lifetime of disks to estimate the timescale to form planets. In the near future, ALMA will be capable of resolving gaps in disks that are carved out by individual planets. By observing gaps in large samples of disks, we will be able to determine when and where planets form, and reveal the diversity of planetary architectures.



Mark Scheel: Numerical Relativity and Simulations of Compact Binaries

My research is concerned with computing and studying numerical solutions of Einstein's equations for highly relativistic systems such as colliding compact objects (black holes and neutron stars). A current focus is to compute the detailed gravitational-wave signals emitted by binary systems consisting of compact objects. By comparing these signals with data from gravitational-wave observatories such as LIGO, it will be possible to directly test general relativity in the fully nonlinear regime, and to study the physics and astrophysics of compact binaries. I also use numerical relativity for exploring properties of highly-distorted curved spacetime, and for furthering our understanding of issues like momentum flow during black hole collisions, the dynamics of event horizons, and the mechanism for the generation of gravitational waves.



In addition to research, I occasionally teach courses such as Computational Physics and General Relativity. I also mentor students and postdocs on projects that have included topics like gravitational lensing, nearly-extremal black-hole spins, and numerical investigations of cosmic censorship.

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