Caltech Astronomy Program

- Ay Option Representative
- Lynne Hillenbrand

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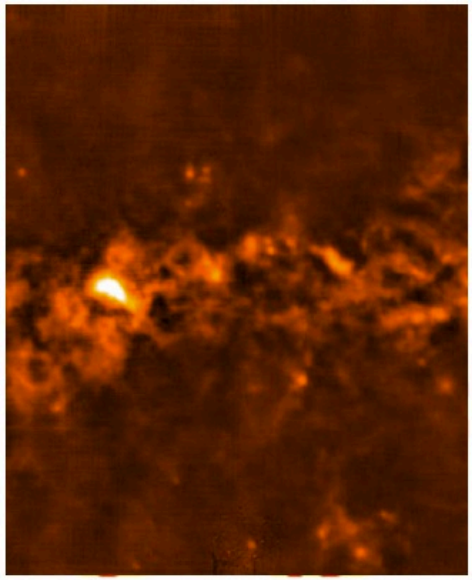
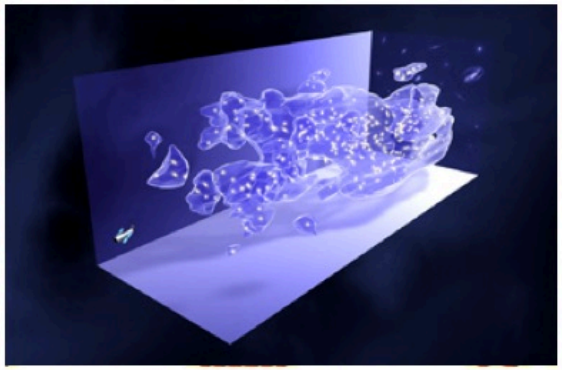
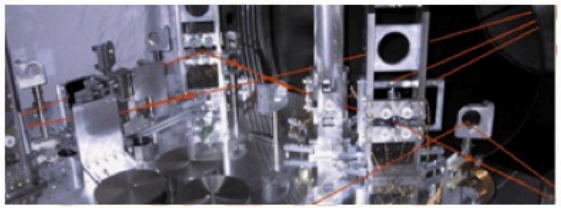

CALTECH ASTRONOMY



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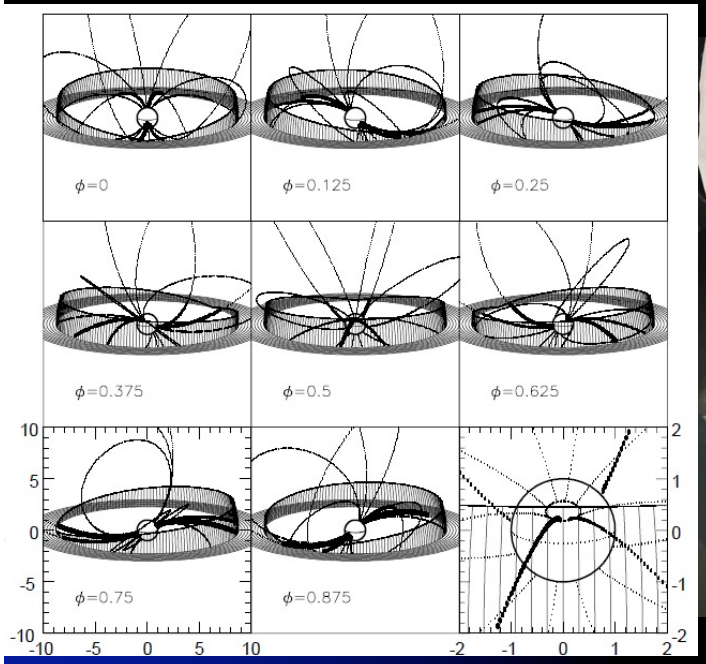
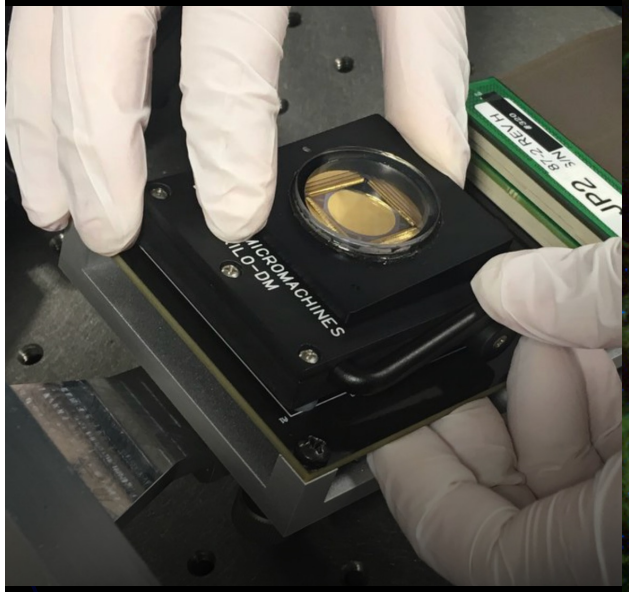
Astronomers use our understanding of micro- to macroscopic physical processes to interpret what we see in electromagnetic observations (from telescopes) of stars, galaxies, and planets.

Eager to learn about the universe?

Interested in astro theory, instrumentation, or observations?

Consider astronomy!





Why astronomy **at Caltech?**

- Solid background in physics and math enables your understanding of the astrophysics.

- Lots of electives, including options for graduate level coursework and/or senior thesis during final year.

- Frontier research opportunities in theory, labs, and data analysis.

- Prospects for graduate study or employment upon graduation.

Academic Information:

http://www.astro.caltech.edu/~lah/option/

Caltech Astrophysics Option

Option Representative: Lynne Hillenbrand

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While most universities and colleges consider the major area of concentration the "Major," at Caltech we call that the undergraduate "Option".
We also have a first-rate graduate program.

The Option Rep is the professorial faculty member who serves as:

- a point of general consultation for undergraduate students, who also have individual academic advisors as per the registrar.
- the official academic advisor for graduate students in the first and second years, until they sign up with a thesis advisor.
- a resource as needed for more senior graduate students, who also have a research/thesis advisor/s.

As a Caltech Ay student, you are welcome at any time to come and talk to me, especially if you have a problem.
These days, send me an email and we can arrange to either meet in person on campus somewhere, or ZOOM.

If you are looking for information regarding **admissions**, try:

- Ay grad admissions and Caltech application
- Caltech undergrad admissions. Also note that we have a summer research program for local high school students.

Information on **courses**:

- Ay course descriptions
- Ph course descriptions
- All Caltech courses
- Caltech Academic Calendars

Information for **everyone**:

- The official Caltech Catalog (all the rules are contained herein)
- The Honor Code -- undergrad honor system and graduate student honor system
- The Astronomy/Astrophysics Library (link is now a more general PMA page)
- Lynne's definitely outdated (but maybe some useful nuggets survive) links and advice for Ay students

Information for **undergraduate students**:

- The Ay option is fairly similar to the Ph option, with the basic difference being four required Ay courses: Ay20, 21, 101, 102, and consequently fewer required lab courses. For a more complete desription of the Ay undergrad program, see the relevant chapter in the Catalog.
- There are ample opportunities for undergraduate research in all of: theory, experimental, and observational astronomy. Ask professors about how to get involved, for example in working with our many research facilities. Research can be conducted for course credit (Ay 142 generally, Ay 78 for senior thesis) or as part of work-study, or as a summer SURF project.
- For those students interested in pursuing graduate study, please feel free to consult with the Option Representative in addition your formal Academic Advisor. Important components to a graduate school application include: your CIT transcript; GRE test scores (the General and often also a Subject test, usually in Physics); a personal statement; and letters of recommendation (typically three). Graduate schools like to see research experience, so you should aim to participate in the SURF program; this also gives you something to write about in the personal statement, and access to potential letter writers. One letter should come from your Academic Advisor who can speak broadly about your Caltech experience and academic preparation. Please note that we *never* accept our own undergraduates into our graduate program -- not because you are not well-qualified, but because you really should go out into the world and thrive at another institution. So save your application fee money. However, for general familiarity with the process, it may be useful to look at the CIT graduate admissions office FAQ for prospective applicants.
- Upperclass students are also a good resource for advice on courses or applying to graduate schools. Your compatriots are listed in the compilation of current undergraduate students in Ay

ASTROPHYSICS

Caltech's "astronomy for everyone" menu course

Ay 1. The Evolving Universe. *9 units (3-3-3); third term; This course is intended primarily for freshmen not expecting to take more advanced astronomy courses and will satisfy the menu requirement of the Caltech core curriculum.* Introduction to modern astronomy that will illustrate the accomplishments, techniques, and scientific methodology of contemporary astronomy. The course will be organized around a set of basic questions, showing how our answers have changed in response to fresh observational discoveries. Topics to be discussed will include telescopes, stars, planets, the search for life elsewhere in the universe, supernovae, pulsars, black holes, galaxies and their active nuclei, and Big Bang cosmology. This class will be offered in a "flipped classroom" mode: the students will be required to watch the video lectures first, and then discuss them and work out problems in the classroom. A field trip to Palomar Observatory will be organized. Not offered on a pass/fail basis.

FS/Ay 3. Freshman Seminar: Automating Discovering the Universe. *6 units (2-0-4); second term.* For course description, see Freshman Seminar.

Ge/Ay 11 c. Planetary Sciences. *9 units (3-0-6).* For course description, see Geological and Planetary Sciences.

Ay 20. Basic Astronomy and the Galaxy. *10 units (3-1-6); first term. Prerequisites: Ma 1 abc, Ph 1 abc or instructor's permission.* The electromagnetic spectrum and basic radiative transfer; ground and space observing techniques; "pictorial Fourier description" of astrophysical optics; Kepler's laws; exoplanets; stellar masses, distances, and motions; the birth, structure, evolution, and death of stars; the structure and dynamics of the Galaxy. Lessons will emphasize the use of order-of-magnitude calculations and scaling arguments in order to elucidate the physics of astrophysical phenomena. Short labs will introduce astronomical measurement techniques.

Ay 21. Galaxies and Cosmology. *9 units (3-0-6); second term. Prerequisites: Ma 1 abc, Ph 1 abc or instructor's permission.* Cosmological models and parameters, extragalactic distance scale, cosmological tests; constituents of the universe, dark matter, and dark energy; thermal history of the universe, cosmic nucleosynthesis, recombination, and cosmic microwave background; formation and evolution of structure in the universe; galaxy clusters, large-scale structure and its evolution; galaxies, their properties and fundamental correlations; formation and evolution of galaxies, deep surveys; star formation history of the universe; quasars and other active galactic nuclei, and their evolution; structure and evolution of the intergalactic medium; diffuse extragalactic backgrounds; the first stars, galaxies, and the reionization era.

Ay 30. Introduction to Modern Research. *3 units (2-0-1); second term.* Weekly seminar open to declared Ay majors at the discretion of the instructor; nonmajors who have taken astronomy courses may be admitted. Course is intended for sophomores and juniors. This seminar is held in faculty homes in the evening and is designed to encourage student communication skills as they are introduced to faculty members and their research. Each week a student will review a popular-level article in astronomy for the class. Graded pass/fail.

Ay 31. Writing in Astronomy. *3 units (1-0-2); third term.* This course is intended to provide practical experience in the types of writing expected of professional astronomers. Example styles include research proposals, topical reviews, professional journal manuscripts, and articles for popular magazines such as Astronomy or Sky and Telescope. Each student will adopt one of these formats in consultation with the course instructor and write an original piece. An outline and several drafts reviewed by both faculty mentor familiar with the topic and the course instructor are required. This course is most suitable for juniors and seniors. Fulfills the Institute scientific writing requirement.

Ay 43. Reading in Astronomy and Astrophysics. *Units in accordance with work accomplished, not to exceed 3.* Course is intended for students with a definite independent reading plan or who attend regular (biweekly) research and literature discussion groups. Instructor's permission required. Graded pass/fail.

Ay 78 abc. Senior Thesis. *9 units. Prerequisite: To register for this course, the student must obtain approval of the astronomy option representative and the prospective thesis adviser.* Previous SURF or independent study work can be useful experience. Course is open to senior astronomy majors only. Research must be supervised by a faculty member. Students wishing assistance in finding an adviser and/or a topic for a senior thesis are invited to consult with the astronomy option representative. The student will work with an advisor to formulate a research project, conduct original research, present new results, and evaluate them in the context of previously published work in the field. The first two terms are graded pass/fail and the grades are then changed at the end of the course to the appropriate letter grade for all three terms. In order to receive a passing grade for second term, a work plan and a preliminary thesis outline must be submitted. The written thesis of 20–100 pages must be completed and approved by the adviser and the option representative before the end of the third term.

Ay 101. Physics of Stars. *11 units (3-2-6); second term. Prerequisite: Ay 20 is recommended.* Physics of stellar interiors and atmospheres. Properties of stars, stellar spectra, radiative transfer, line formation. Stellar structure, stellar evolution. Nucleosynthesis in stars. Stellar oscillations.

Ay 102. Physics of the Interstellar Medium. *9 units (3-0-6); third term. Prerequisite: Ay 20 is recommended.* An introduction to observations of the inter-stellar medium and relevant physical processes. The structure and hydrodynamic evolution of ionized hydrogen regions associated with massive stars and supernovae, thermal balance in neutral and ionized phases, star formation and global models for the interstellar medium.

Ay/Ph 104. Relativistic Astrophysics. *9 units (3-0-6); second term. Prerequisites: Ph 1, Ph 2 ab.* This course is designed primarily for junior and senior undergraduates in astrophysics and physics. It covers the physics of black holes and neutron stars, including accretion, particle acceleration and gravitational waves, as well as their observable consequences: (neutron stars) pulsars, magnetars, X-ray binaries, gamma-ray bursts; (black holes) X-ray transients, tidal disruption and quasars/active galaxies and sources of gravitational waves. Interested students are encouraged to take Ay 125.

Ay 105. Optical Astronomy Instrumentation Lab. *10 units (0-6-4); second term. Prerequisite: Ay 20.* An opportunity for astronomy and physics undergraduates (juniors and seniors) to gain firsthand experience with the basic instrumentation tools of modern optical and infrared astronomy. The 10 weekly lab experiments are expected to include radiometry measurements, geometrical optics, optical aberrations and ray tracing, spectroscopy, fiber optics, CCD electronics, CCD characterization, photon counting detectors, vacuum and cryogenic technology, and stepper motors and encoders.

Ay 111 ab. Introduction to Current Astrophysics Research. *3 units; first, second terms.* This course is intended primarily for first-year Ay graduate students, although participation is open and encouraged. Students are required to attend seminar-style lectures given by astrophysics faculty members, describing their research, to attend the weekly astro-nomy colloquia, and to follow these with additional readings on the subject. At the end of each term, students are required to summarize in oral or written form (at the discretion of the instructor), one of the covered subjects that is of most interest to them.

Ge/Ay 117. Statistics and Data Analysis. *9 units (3-0-6); third term.Prerequisites: CS 1 and instructor's permission.* For course description, see Geological and Planetary Sciences.

Ay 119. Methods of Computational Science. *9 units (3-0-6); third term.* Open to graduate and upper-division undergraduate students in all options. Practical computational science methods useful in disciplines dealing with large and/or complex data sets. Topics include: Scientific databases and archives; data mining and exploration; data visualization techniques; practical techniques for physical modeling, including numerical and stochastic models; data sharing over networks, Web services, computational and data grids; design and understanding of scientific computational systems and experiments, and good software practices. Instructor:

Ay 121. Radiative Processes. *9 units (3-0-6); first term. Prerequisite: Ph 125 or equivalent (undergraduates).* The interaction of radiation with matter: radiative transfer, emission, and absorption. Compton processes, coherent emission processes, synchrotron radiation, collisional excitation, spectroscopy of atoms and molecules

Ay 122 abc. Astronomical Measurements and Instrumentation. *9 units (3-0-6); in 2014–15, only 122 a is offered, first term. Prerequisite: Ph 106 or equivalent.* Telescopes, optics, detectors, radiometers, photometry, spectroscopy. Active/adaptive optics. Interferometers/arrays. Imaging devices and image processing. Antennae, receivers, mixers, and amplifiers. Space telescopes. Signal analysis techniques and probability and statistics as relevant to astronomical measurement. Some lab work and observatory field trips. Ay 122 a concentrates on infrared, optical, and ultraviolet techniques. Ay 122 b (not offered 2014–15) concentrates on radio through submillimeter techniques, and Ay 122 c (not offerece 2014–15) concentrates on X-ray through gamma-ray techniques.

Ay 123. Structure and Evolution of Stars. *9 units (3-0-6); second term. Prerequisites: Ay 101; Ph 125 or equivalent (undergraduates).* Thermodynamics, equation of state, convection, opacity, radiative transfer, stellar atmospheres, nuclear reactions, and stellar models. Evolution of low- and high-mass stars, supernovae, and binary stars.

Ay 124. Structure and Dynamics of Galaxies. *9 units (3-0-6); first term. Prerequisites: Ay 21; Ph 106 or equivalent (undergraduates).* Stellar dynamics and properties of galaxies; kinematics and dynamics of our galaxy; spiral structure; stellar composition, masses, and rotation of external galaxies; star clusters; galactic evolution; binaries, groups, and clusters of galaxies.

Ay 125. High-Energy Astrophysics. *9 units (3-0-6); third term. Prerequisites: Ph 106 and Ph 125 or equivalent (undergraduates).* High-energy astrophysics, the final stages of stellar evolution; supernovae, binary stars, accretion disks, pulsars; extragalactic radio sources; active galactic nuclei; black holes.

Ay 126. Interstellar and Intergalactic Medium. *9 units (3-0-6); second term. Prerequisite: Ay 102 (undergraduates).* Physical processes in the interstellar medium. Ionization, thermal and dynamic balance of interstellar medium, molecular clouds, hydrodynamics, magnetic fields, H II regions, supernova remnants, star formation, global structure of interstellar medium.

Ay 127. Cosmology and Galaxy Formation. *9 units (3-0-6); third term. Prerequisites: Ay 21; Ph 106 or equivalent (undergraduates).* Cosmology; extragalactic distance determinations; relativistic cosmological models; galaxy formation and clustering; thermal history of the universe, microwave background; nucleosynthesis; cosmological tests.

Ge/Ay 132. Atomic and Molecular Processes in Astronomy and Planetary Sciences. *9 units (3-0-6).* For course description, see Geological and Planetary Sciences.

Ge/Ay 133. The Formation and Evolution of Planetary Systems. *9 units (3-0-6).* For course description, see Geological and Planetary Sciences.

Ge/Ay 137. Planetary Physics. *9 units (3-0-6); second term.* For course description, see Geological and Planetary Sciences.

Ay 141 abc. Research Conference in Astronomy. *3 units (1-0-2); first, second, third terms.* Oral reports on current research in astronomy, providing students an opportunity for practice in the organization and presentation of technical material. A minimum of two presentations will be expected from each student each year. In addition, students are encouraged to participate in a public-level representation of the same material for posting to an outreach website. This course fulfills the option communication requirement and is required of all astronomy graduate students who have passed their preliminary exams. It is also recommended for astronomy seniors. Graded pass/fail.

Ay 142. Research in Astronomy and Astrophysics. *Units in accordance with work accomplished.* The student should consult a member of the department and have a definite program of research outlined. Approval by the student's adviser must be obtained before registering. 36 units of Ay 142 or Ay 143 required for candidacy for graduate students. Graded pass/fail.

Ay 143. Reading and Independent Study. *Units in accordance with work accomplished.* The student should consult a member of the department and have a definite program of reading and independent study outlined. Approval by the student's adviser must be obtained before registering. 36 units of Ay 142 or Ay 143 required for candidacy for graduate students. Graded pass/fail.

Ge/Ay 159. Planetary Evolution and Habitability. *9 units (3-0-6).* For course description, see Geological and Planetary Sciences.

Ay 190. Computational Astrophysics. *9 units (3-0-6); second term. Prerequisites: Ph 20–22 (undergraduates).* Introduction to essential numerical analysis and computational methods in astrophyics and astrophysical data analysis. Basic numerical methods and techniques; N-body simulations; fluid dynamics (SPH/grid-based); MHD; radiation transport; reaction networks; data analysis methods; numerical relativity.

Ay 211. Contemporary Extragalactic Astronomy. *9 units (3-0-6); third term. Prerequisites: Ay 123, Ay 124, and Ay 127.* Topics in extragalactic astronomy and cosmology, including observational probes of dark matter and dark energy; cosmological backgrounds and primordial element abundances; galaxy formation and evolution, including assembly histories, feedback and environmental effects; physics of the intergalactic medium; the role of active galactic nuclei; galactic structure and stellar populations; future facilities and their likely impact in the field.

Ay 215. Seminar in Theoretical Astrophysics. *9 units (3-0-6); second term.* Course for graduate students and seniors in astronomy and planetary science. Students will be required to lead some discussions. Topic will be selected based on student interest.

Ay 218. Extrasolar Planets. *9 units (3-0-6); third term.* Close to 2,000 planets have been identified in orbit around normal stars. Astronomers are now embarking on understanding the statistics of extrasolar planet populations and characterizing with great precision individual planets, namely, determining their masses, radii, and in some cases, diagnosing their atmospheres. The course will review the state of extrasolar planets, take up case studies, and anticipate findings.

Ay 219. Elements in the Universe and Galactic Chemical Evolution. *9 units (3-0-6); second term. Prerequisites: Ay 121, 123, 124, 126.* Survey of the formation of the elements in the universe as a function of cosmic time. Review of the determination of abundances in stars, meteorites, H II regions, and in interstellar and intergalactic gas. Overview of models of galactic chemical evolution. Participants will measure elemental abundances from the Keck spectrum of a star and construct their own numerical chemical evolution models.

Astro Major Course Requirements

- 1. Basis in Mathematics & Physics: Ma 2, Ma 3, Ph 2 abc or Ph 12 abc, Ph 125 ab, and Ph 106 ab, Ph 106 c or Ph 107.
- 2. Astronomy: Ay 20, 21, 101, 102 + communications (Ay 30 or one term of Ay 141, Ay 31)
- 3. Labs: Any three of Ph3 or Ph8 bc, Ph5, Ph6, Ph7, Ph 77, Ay 105. APh 23 plus APh 24 or 123 may be substituted for one of these labs.
- 4. Electives in Physics and Astronomy: 63 additional units of Ay or Ph courses. Ph 127 a, Ph 136 bc and one of Ph 21, Ph 22, Ph 121 abc are strongly recommended.
- 5. non-PMA Electives: 27 additional units of science or engineering electives, of which 18 must be outside the Division of Physics, Mathematics and Astronomy. Core classes or other introductory-level courses such as CS 1 do not count toward fulfillment.
- Passing grades must be earned in a total of 486 units, including courses listed above. Courses satisfying requirements 1, 2, and 3 must be taken for grades unless they are pass/fail only.

The Astro Minor (relatively new)

1. Basis in Physics: either Ph2ab or Ph12ab **(18 units)**

2. Introductory Astronomy: any two of Ay/Ge11c, Ay20, or Ay21 **(18 units)**

3. In-depth study: any two among astrophysics theory courses Ay101, Ay102, Ay104, Ay/Ge 133, and/or instrumentation and data courses Ay105, Ay107, Ay122 **(18 units).**

4. Research: both Ay 142 (9 units) and Ay 144 (3 units) ⇒ **(12 units)**

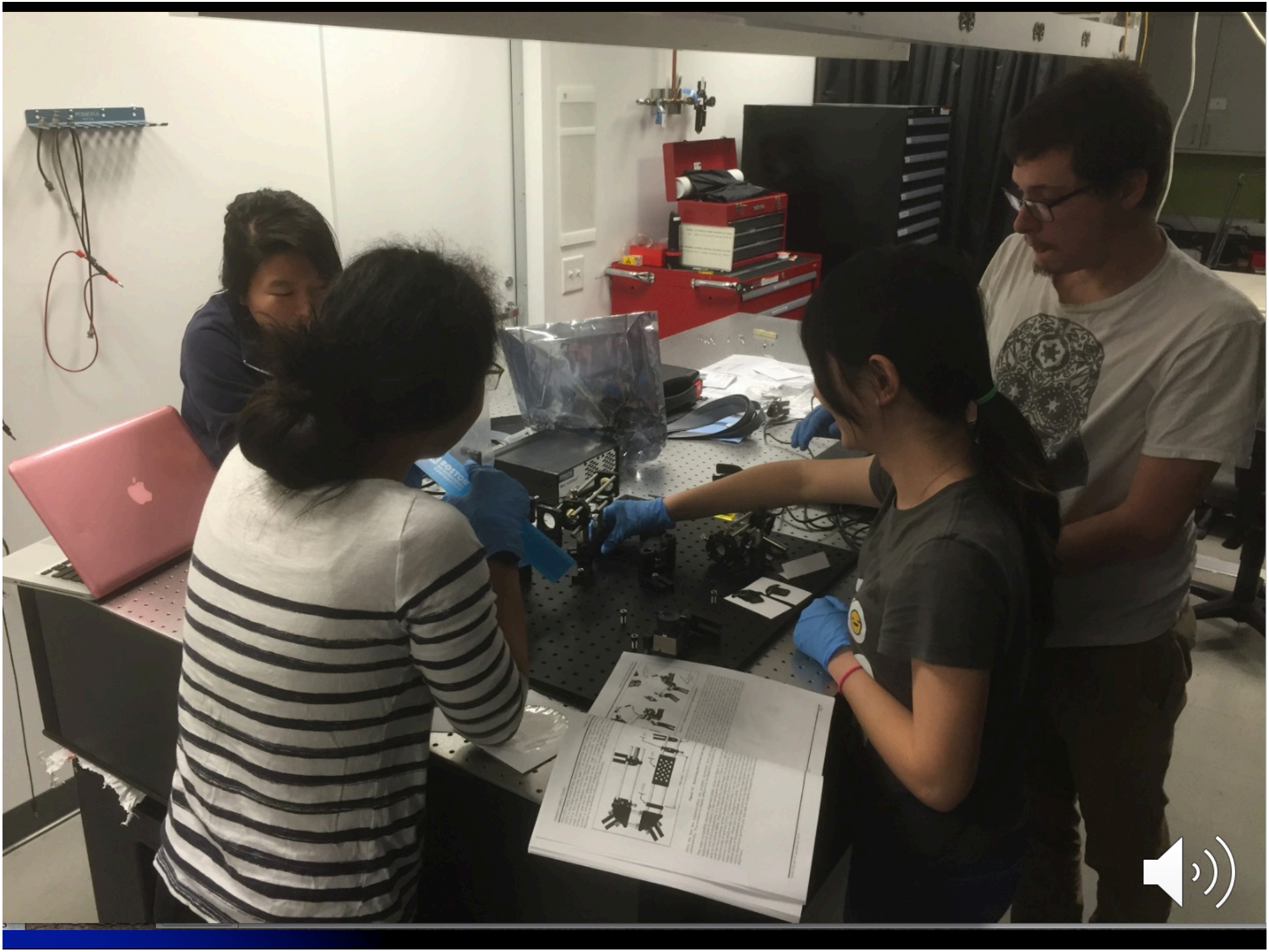
Ay minor coursework is designed to prepare the capable student to undertake cross-disciplinary research involving astronomy.

What are the differences between the Ay and the Ph Options?

- The options are pretty similar.
- Ay has four required courses – Ay 20, 21 (usually taken sophomore year) and Ay 101, 102 (usually taken junior year).
- Consequently, Ay has fewer required labs.
- It is possible to major in Ph and take all four of these or other Ay courses as electives.

What are the real differences between Ay and Ph?

- Ay has smaller classes – typically 4-12.
- Ay major leaves room in senior year for a Senior Thesis and/or graduate level courses.
- Ay undergrads/year : faculty is about 1:3.
- Ay has cool(er) research opportunities.



Model Course Schedule

Second Year				
Ph 12 abc or Ph 2 abc	Sophomore Physics	9	9	9
Ma 2, Ma 3	Sophomore Mathematics	9	9	-
Ay 20	Basic Astronomy and the Galaxy	9	-	-
Ay 21	Galaxies and Cosmology	-	9	-
Ay 30	Intro. to Modern Research	3	-	-
Ph 3[1] or 5[1]	Physics Laboratory	9	-	-
ACM 95 ab[2]	Intro. Methods of App. Mathematics	-	12	12
Ph 21 or 22[3]	Computational Tools	-	-	6
	HSS Electives	9	9	18
	Total	**48**	**48**	**45**

Third Year				
Ph 125 abc[4]	Quantum Mechanics	9	9	9
Ph 106 abc	Topics in Classical Physics	9	9	9
Ay 101	The Physics of Stars	9	-	-
Ay 102	Physics of the Interstellar Medium	-	9	-
Ay 104[3]	High Energy Astrophysics	-	-	9
Ph 127 a[3]	Statistical Physics	9	-	-
Ph 6[1], 7[1], or APh 23/24[1]	Physics Laboratory	-	9	9
	Other Electives	-	9	-
	HSS Electives	9	-	9
	Total	**45**	**45**	**45**

Fourth Year				
Ay 31	Written Communication	-	-	3
Ay 105[1]	Astronomy Instrumentation Lab	-	-	9
	Ay/Ph Electives	9	9	9
Ay 78	Senior Thesis	9	9	9
Ph 121[3] or Ay 117	Computational Analysis	-	6	-
Ay 141 b[3]	Research Conference in Astronomy	-	3	-
	Other Electives	18	9	9
	HSS Electives	9		9
	Total	**45**	**45**	**48**

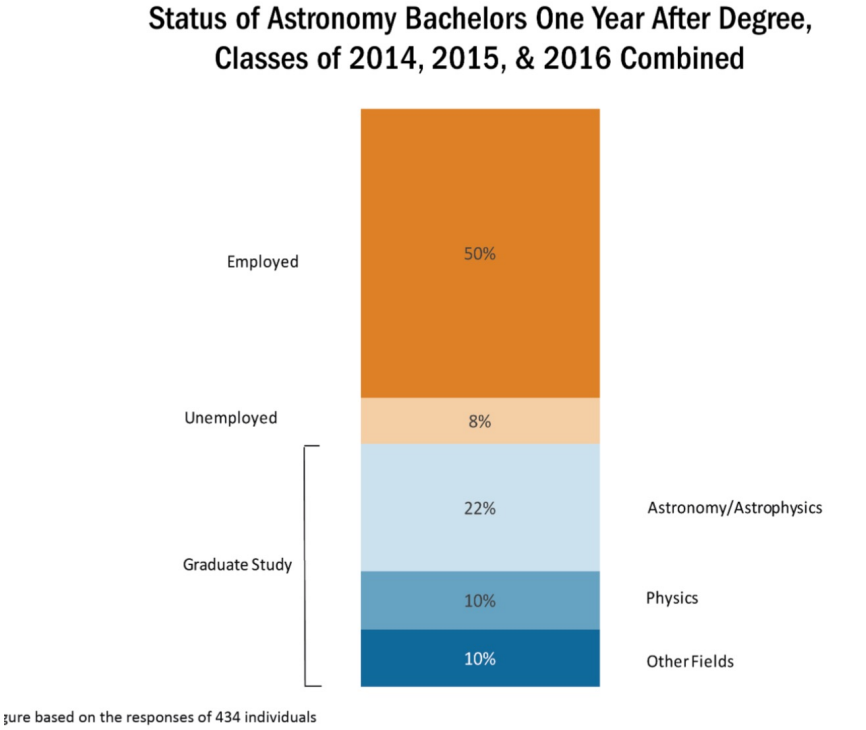
What do Ay Majors do after CIT?

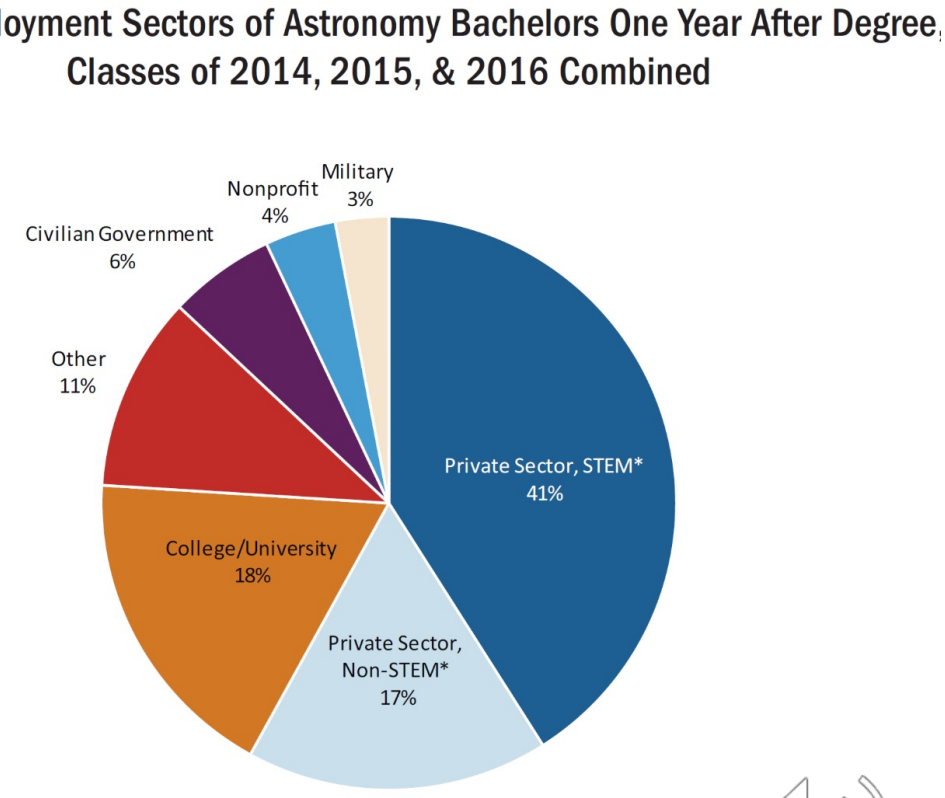
- About 50% go to Ph.D programs in astrophysics or related fields. Some students take a “post-bac” year in research to make sure a Ph.D is the right path for them.

- A few % go to other graduate programs, e.g. data science, science policy or science education.

- About 50% take jobs, mostly in the tech sector:
  - data science (e.g. visualization, food science, biotech startups)
  - aerospace (e.g. spaceX)
  - web analytics
  - financial modelling
  - finance
  - security and defense (e.g. NSA or related government contractors)
  - science policy (e.g. OMB)

Compare to National Statistics





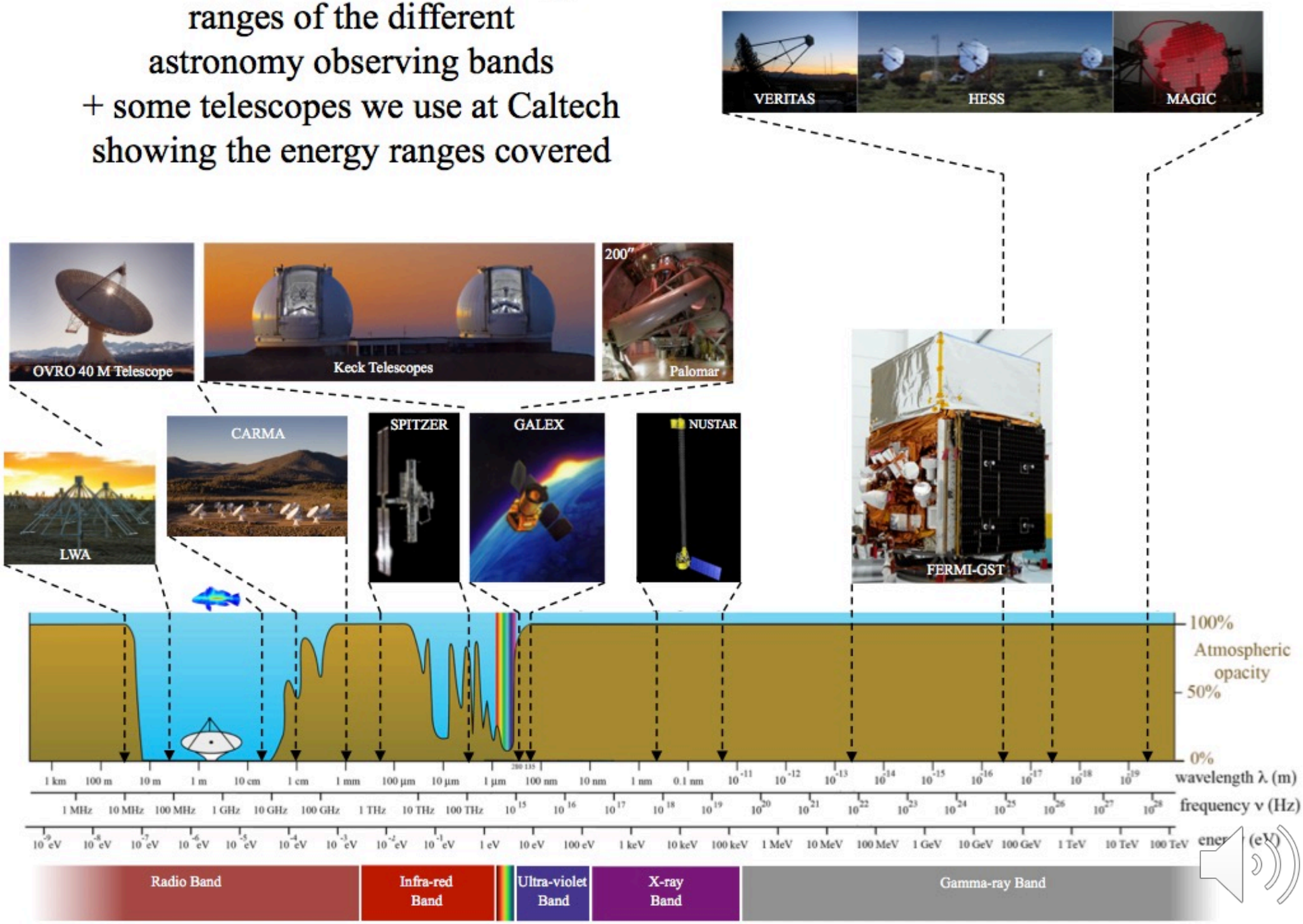
AIP | Statistics aip.org/

The "Other" category is mostly comprised of middle and high schools, medical facilities, and nonprofit organizations.
*STEM refers to positions in science, technology, engineering and math.

Wavelength-Frequency-Energy ranges of the different astronomy observing bands + some telescopes we use at Caltech showing the energy ranges covered

Credit: Tony Readhead

Figure 0



PALOMAR OBSERVATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

PALOMAR MOUNTAIN