TMT
THIRTY METER TELESCOPE

History of Astronomy on Mauna Kea

CFHT: International Partnership

- Work on the 3.6-meter Canada-France-Hawaii Telescope (CFHT) began in 1973.
- CFHT began operations in 1979, establishing their headquarters in Waimea

- Observed most distant quasar and coolest brown dwarf
- Remains productive observatory with newly refurbished prime focus mega-camera

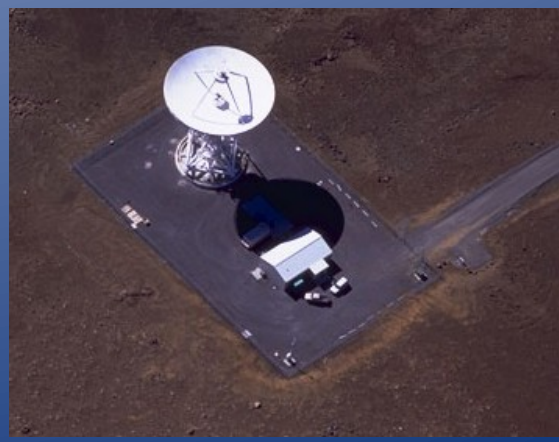
Radio Astronomy Arrives

- Reaching further into the electromagnetic spectrum, the 15-meter James Clerk Maxwell Telescope was dedicated in 1987.
- The JCMT is the largest single submillimeter telescope in the world, studying the portion of the spectrum between infrared and radio

- JCMT is used to study the coldest material in the universe, such as interstellar clouds of dust and gas
- SCUBA-2, the JCMT's newest instrument, can map the sky 1,000 times faster than its predecessor

The VLBA

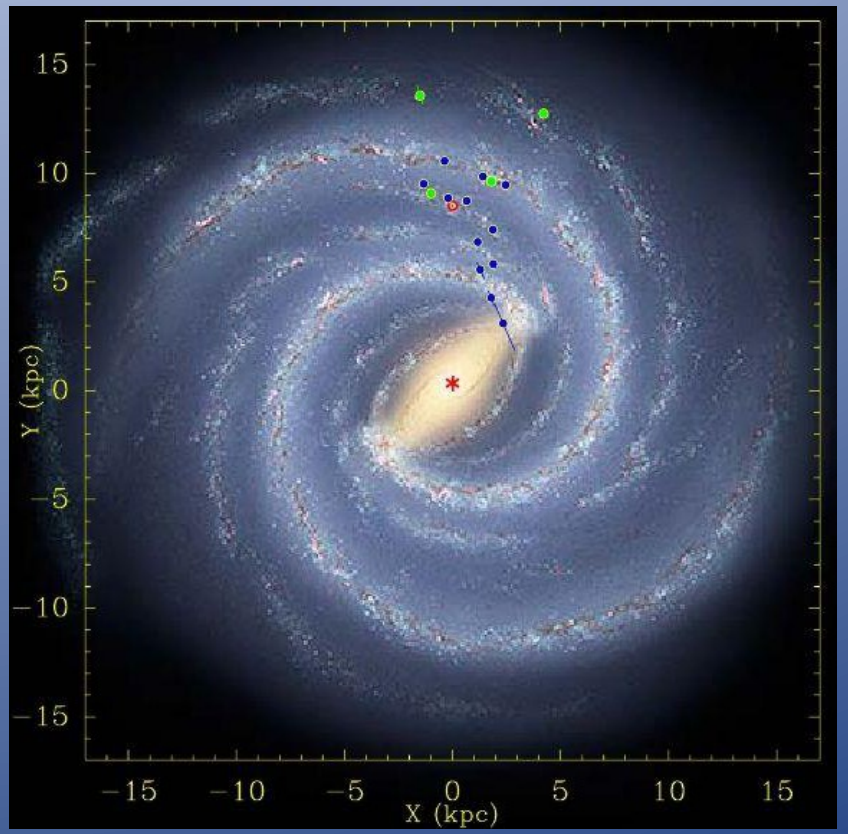
- A dedicated VLBI array since 1993
- Operated from Socorro, NM
- Covers frequency range 310 MHz to 90 GHz in full polarization
- 10 identical stations on U.S. territory:
  - Brewster WA, Hancock NH, Fort Davis TX, Kitt Peak AZ,
  - Los Alamos NM, Mauna Kea HI, North Liberty IA, Owens Valley CA,
  - Pie Town NM and Saint Croix, US Virgin Islands
- Each station has
  - 25-m Cassegrain antenna
  - Station building with maser, electronics, recorders
  - Weather station, GPS Rx, security camera
  - Staff of 2



Bar and spiral structure legacy survey (BeSSeL)

A VLBA Key Science Project

- Goal: determine structure and kinematics of the Milky Way Galaxy
- Perform astrometry on masers in star forming regions
  - Water masers at 22 GHz
  - Methanol at 11 and (soon) 6.7 GHz
- Early results have improved measurements of the distance to the Galactic Center and rotational velocity
  - $R_0 = 8.4 \pm 0.6$ kpc
  - $\Theta_0 = 254 \pm 16$ km/s
- Distances and kinematics of many star forming regions to be determined.

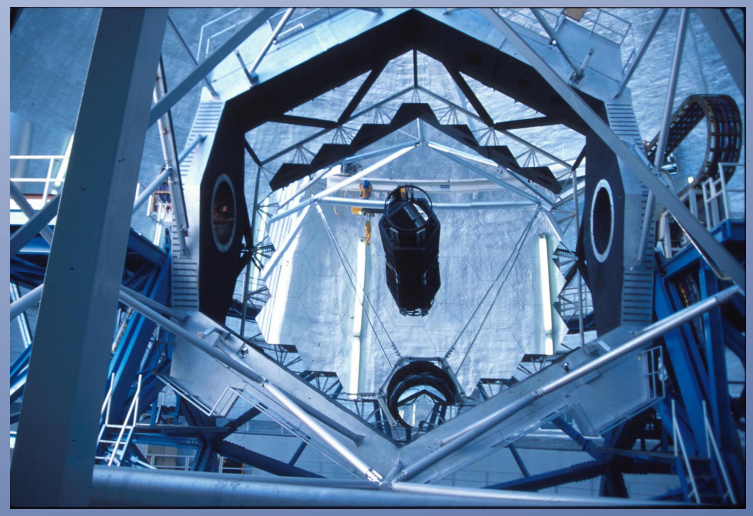


Some other ongoing VLBA science

- Megamaser Cosmology Project: Using megamasers around galaxy centers distances within the Hubble flow and black hole masses are being measured.
- The VLBA Fast Transient Search: Commensal project to look for dispersed pulses. 10 separated antennas will allow for precise localization upon detection.
- Gould's Belt Distance Survey: Astrometry of young stars is yielding precise distances to star forming regions and elucidating their 3-D structure. Multiplicity of young stars is being studied
- Monitoring Of Jets in Active Galactic Nuclei (MOJAVE): a multi-decade duration survey of AGN jet variability. There is a strong connection between radio and gamma-ray variability as shown by joint work with Fermi.
- *And many others…*

Era of the Keck Observatory

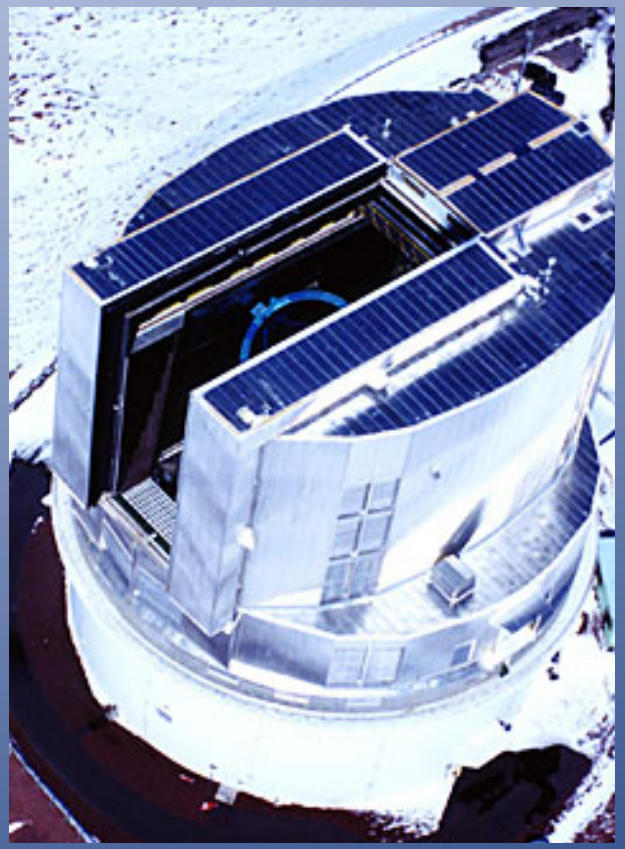
- Sparking a new era of optical astronomy, Caltech and the University of California with a grant from the Keck foundation, built new-generation telescope



- At 10 meters, the twin Keck telescopes are four times larger than any previous telescope
- Keck I began science observations in 1993; Keck II saw first light in 1996
- First telescope to use a segmented mirror design
- First large telescope laser guidestar adaptive optics installed in 2004

Subaru Telescope Arrives

- The National Astronomical Observatories of Japan's Subaru Telescope achieves first light in 1999.
- With an 8.2 meter primary mirror, it is the largest single mirror telescope
- A computer control system maintains the shape of the mirror



- Telescope named after the Subaru star cluster, also known as the Pleiades
- Conducting leading research into "dark" gamma ray bursts

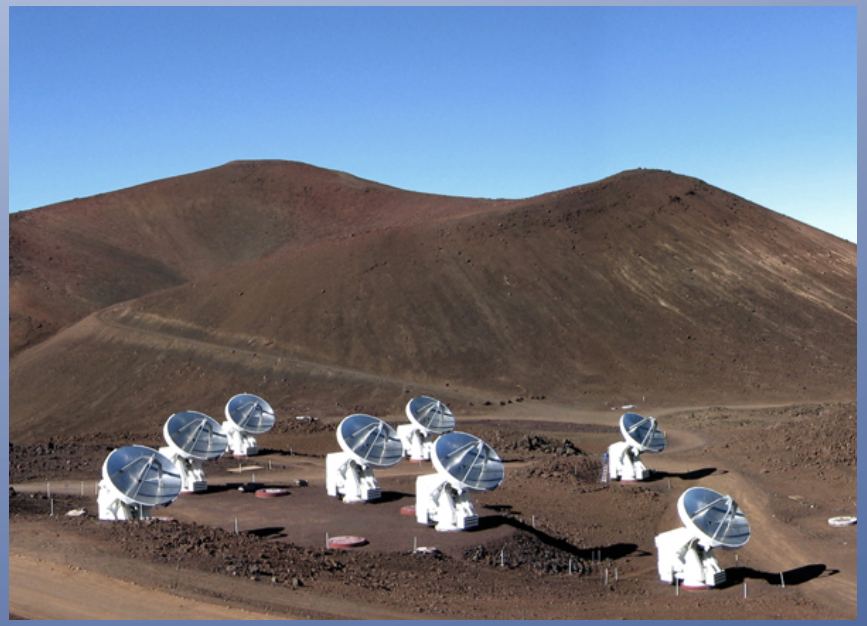
The Northern Twin of Gemini

- The Gemini North telescope, twin to Gemini South in Chile, is an optical/infrared telescope that became operational in 1999
- Gemini has a 8.1 meter primary mirror and a adaptive optics system

- Gemini is operated by a partnership of seven countries -- the U.S. partnership is through the National Science Foundation
- Gemini has conducted research from our solar system out to distant galaxies and produced the first image of a planet around a Sun-like star

The Submillimeter Array

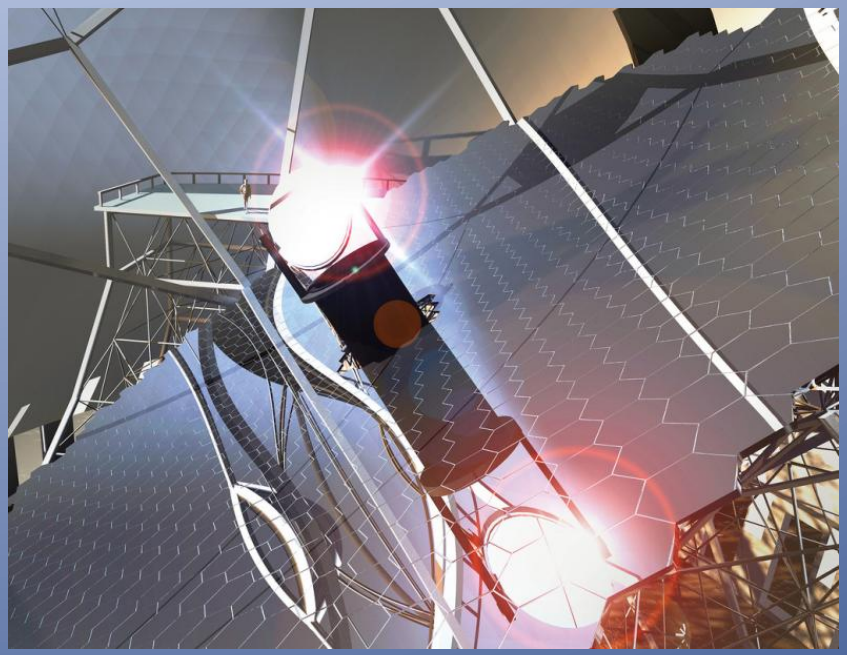
- The Harvard/Smithsonian Submillimeter Array (SMA) was completed and dedicated in 2003
- The telescope consists of eight, six-meter antennas that function as a single instrument



- The antennas can be moved to change configuration, at its widest the array is half a kilometer across
- The SMA studies newly forming planetary systems and stars, and red-shifted light from distant objects and the leftover radiation of the Big Bang

Thirty Meter Telescope

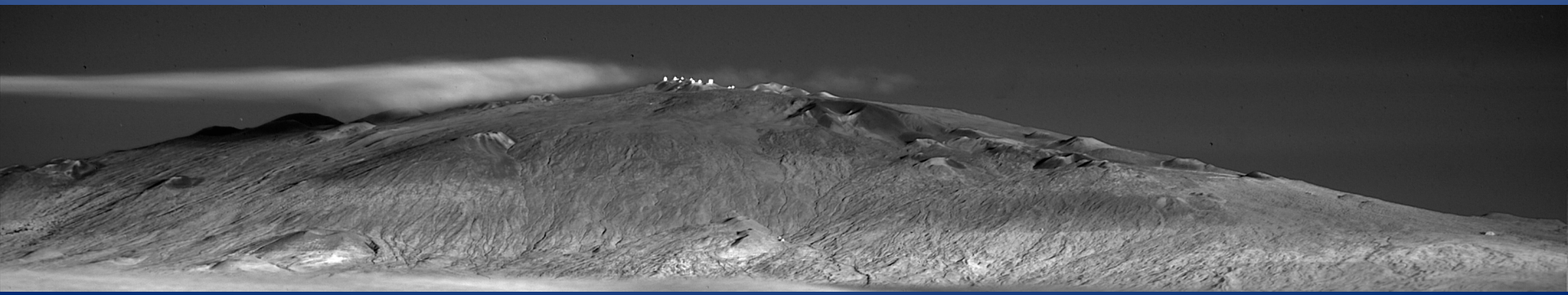
- When completed later this decade, TMT will be the world's most advanced and powerful observatory
- Comprised of 492 segments, TMT's primary mirror has 9 times the collecting area of today's largest telescopes



- The first telescoped specifically designed to harness the power of adaptive optics, TMT will see as clearly as if the telescope were in space
- TMT will probe the very first stars and galaxies, explore exoplanets, unlock the mysteries of star formation, and help us understand the prospect for life in the cosmos

Mauna Kea

- Mauna Kea, a dormant volcano, rises 13,600 feet above sea level and is the highest point in the Pacific
- The site is considered sacred and is home to culturally and historically important monuments and artifacts
- The mountain also has certain biologically and geologically sensitive areas, including glacial features from the last ice age
- In Hawaiian language, “Mauna Kea” can mean either “White Mountain” or the “Mountain of Wakea” – Wakea is the creator spirit



Shrines on Mauna Kea

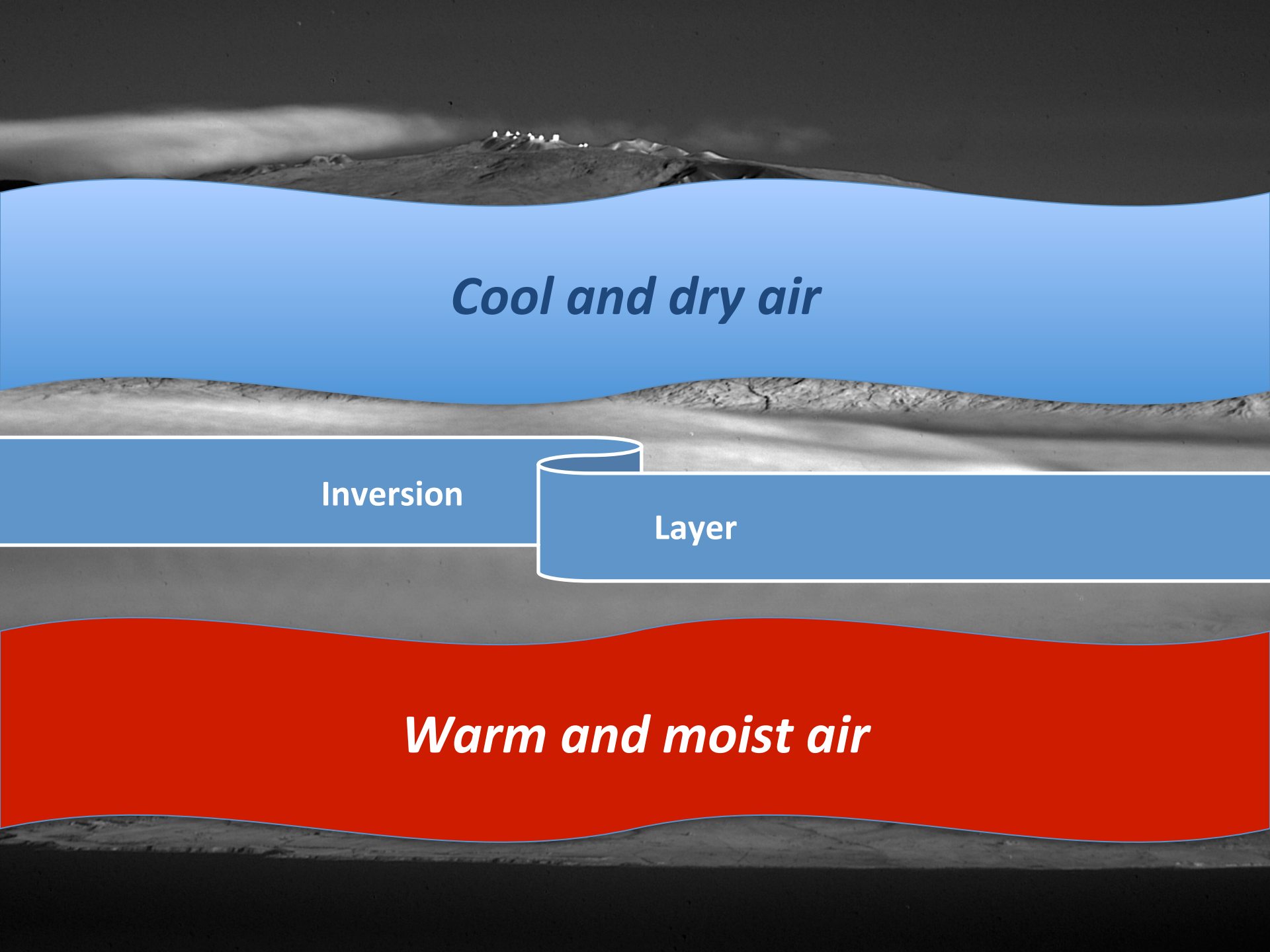
- Shrines are very prevalent archaeological features on Mauna Kea
- There are at least six types of shrines on Mauna Kea
- Some are used for burial, others have astronomical origins – marking certain celestial events such as the solstice and equinox
- 76 shrines were identified between 1975-1997, a few of them date back to 700-800 CE




Ideal Site for Astronomy

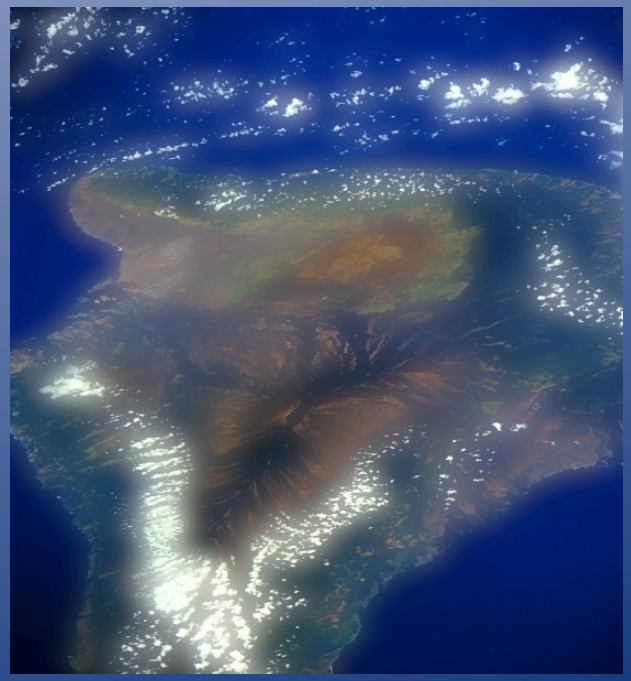
- The summit of Mauna Kea rises above inversion layer separating warm/moist and cold/dry air
- Less water vapor enables radio and millimeter wavelength astronomy

- Cold temperatures give clearer seeing in both the optical and infrared
- Temperatures near the summit remain relatively constant, minimizing distortion of telescope optics due to expansion and contraction
- The remote island location results in less light pollution


Cool and dry air
Inversion
Layer
Warm and moist air

Mauna Kea Beckons

- Mauna Kea's astronomy potential was realized in June 1963, when Mitsuo Akiyman of the Hawaii Island Chamber of Commerce asked international astronomy community about the potential of observing on Mauna Kea
- Gerard Kuiper, a pioneer in infrared astronomy who predicted the existence of icy bodies in outer solar system that now bear his name, enthusiastically responded
- In 1964, the State of Hawaii built first road to the summit; Kuiper installed site-testing telescope



UH 2.2 Meter: The First Step

- The University of Hawaii's 2.2 meter (88-inch) telescope (7th largest optical / infrared) saw first light in 1968 and began operations in 1970.

- First large observatory on Mauna Kea and established the mountain as the pre-eminent site for ground-based astronomy.
- Confirmed the existence of the Kuiper Belt in 1992
- Currently used as a teaching tool for UH-Manoa Graduate students

NASA and Infrared Astronomy

- In 1974, NASA awarded contract to build a 3-meter infrared telescope on Mauna Kea

- The IRTF – Infrared Telescope Facility – was commission in 1979, providing pioneering infrared observing techniques and dedicated support to NASA missions.
- Telescope is operated by the University of Hawaii's Institute for Astronomy

Infrared Astronomy from the UK

- The United Kingdom Infrared Telescope (UKIRT) is a 3.8-meter telescope, the largest dedicated to observing solely in the infrared
- UKIRT founded the Joint Astronomy Center, the first observatory headquarters in Hilo

- Has identified key molecules in interstellar chemistry, identified free-floating brown dwarfs, and studied active galactic nuclei

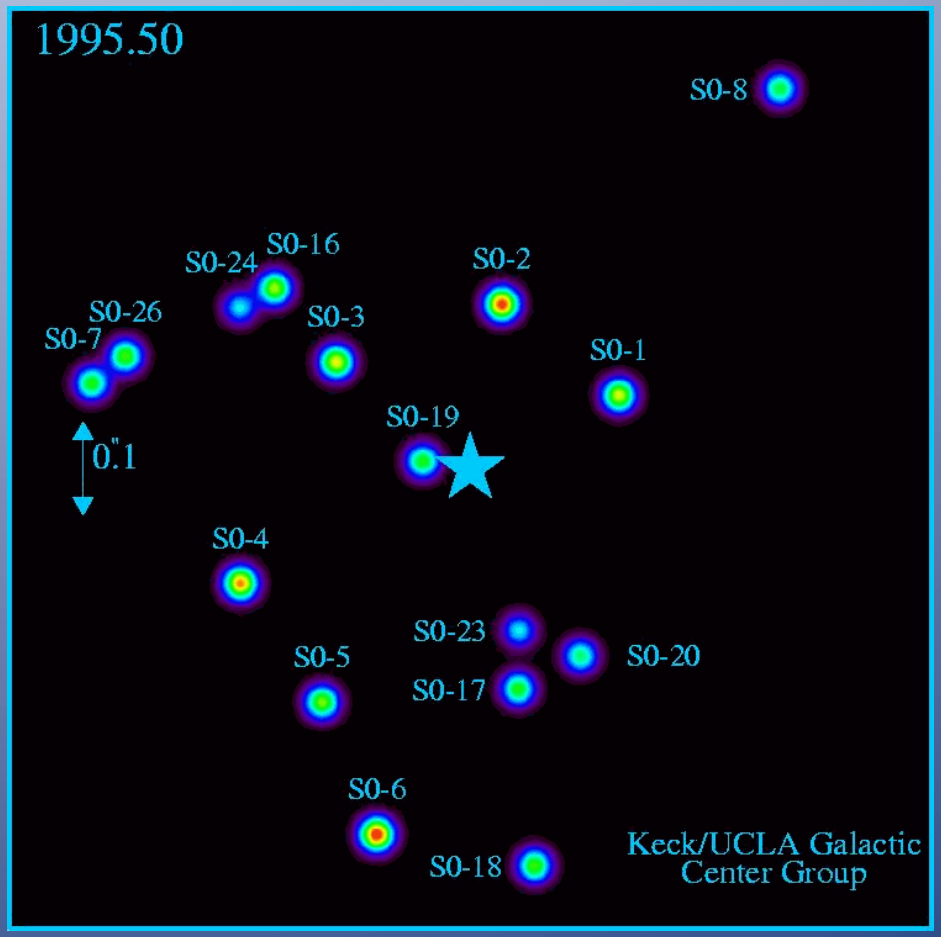
Caltech Explores Submillimeter

- In 1987, the Caltech Submillimeter Observatory became operational
- The 10.4m diameter radio dish studies the cold, dark and distant universe

- Using gravitational lensing, CSO recently revealed distant galaxies seen when the Universe was only 2 - 4 billion years old
- CSO will be decommissioned and its site restored to its natural state in 2018

Science with Keck

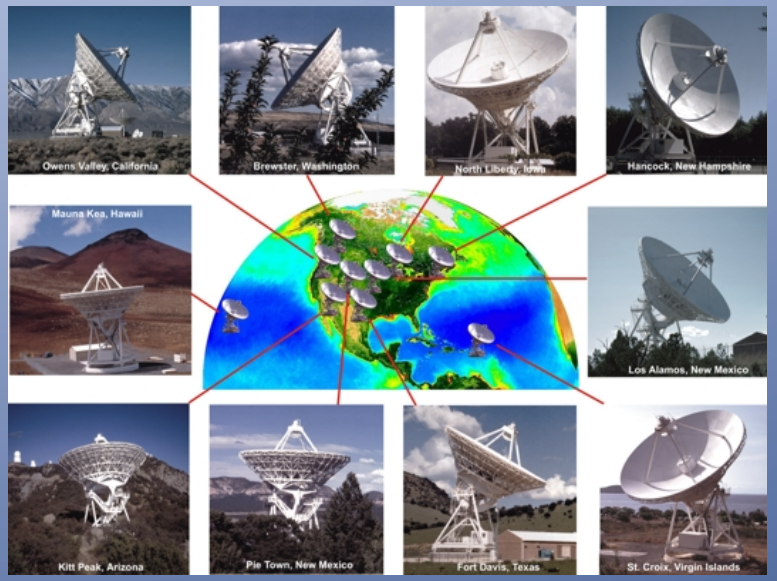
- More than half of all exoplanets were discovered using the Keck
- Helped discover accelerating expansion of universe due to dark energy
- Deployed first laser guidestar adaptive optics on large telescope



- Revealed mass of black hole at the center of the Milky Way Galaxy

Very Long Baseline Array

- The 25-meter dish of the Very Long Baseline Array is not a stand-alone telescope, but functions with nine other antennas to form a single instrument
- The VLBA spans more than 5,000 miles



- Dedicated in 1993, the VLBA offers the highest resolution and sharpest vision of any telescope on Earth or in space
- VLBA has revealed important new knowledge about magnetic fields, stellar winds, the motions of stars and galaxies, the jets of material emitted by black holes