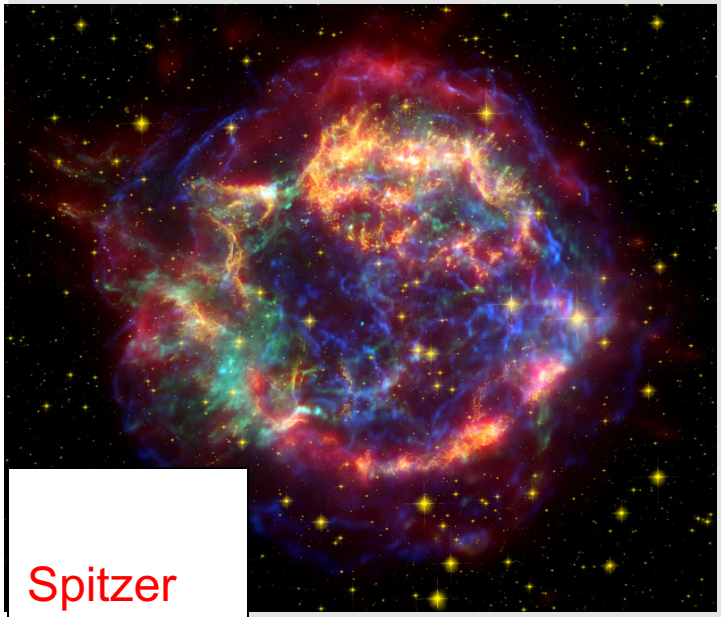
From Galileo to Hubble and Beyond: The Contributions and Future of the Telescope: The Galactic Perspective

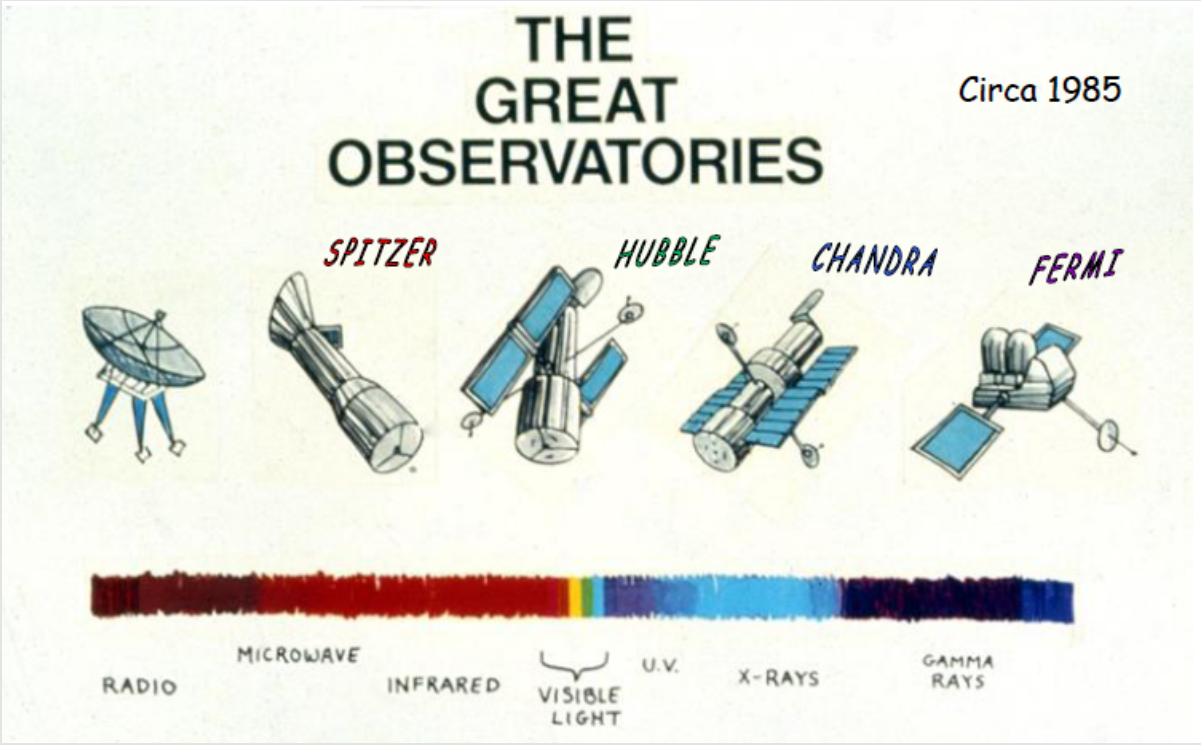
Michael Werner JPL/Caltech

November 17, 2009



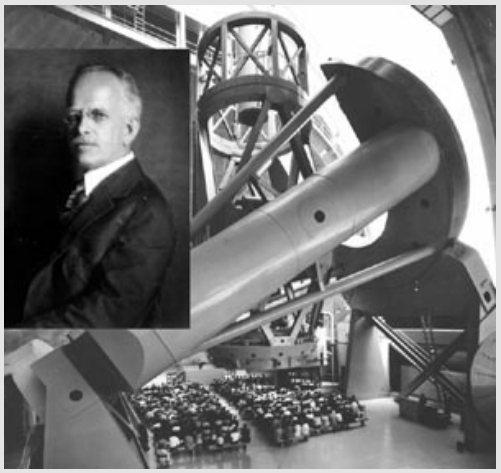
Spitzer
Hubble
Chandra
Chandra

Cassiopeia A Supernova Remant



George Ellery Hale (1868-1938)

He saw very clearly and very early that astronomy could only develop if much more powerful telescopes were constructed.

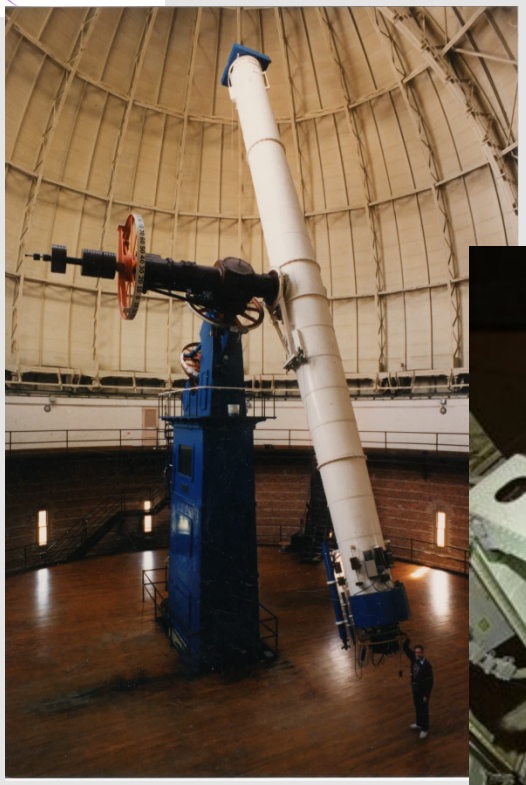


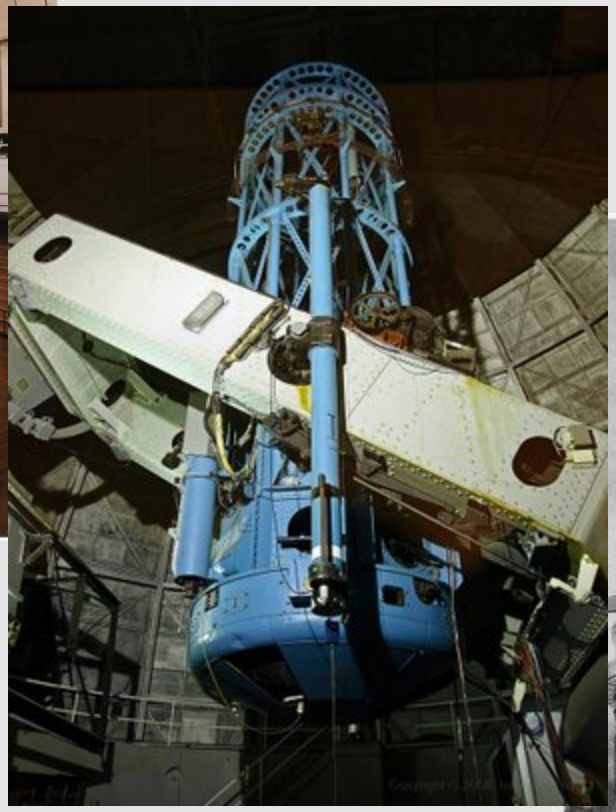
Prime mover in the development of:
Yerkes Observatory 40” refractor (1897)
Mt. Wilson Observatory 60” and 100” reflectors (1908, 1918)
Palomar Observatory 200” reflector (1948)

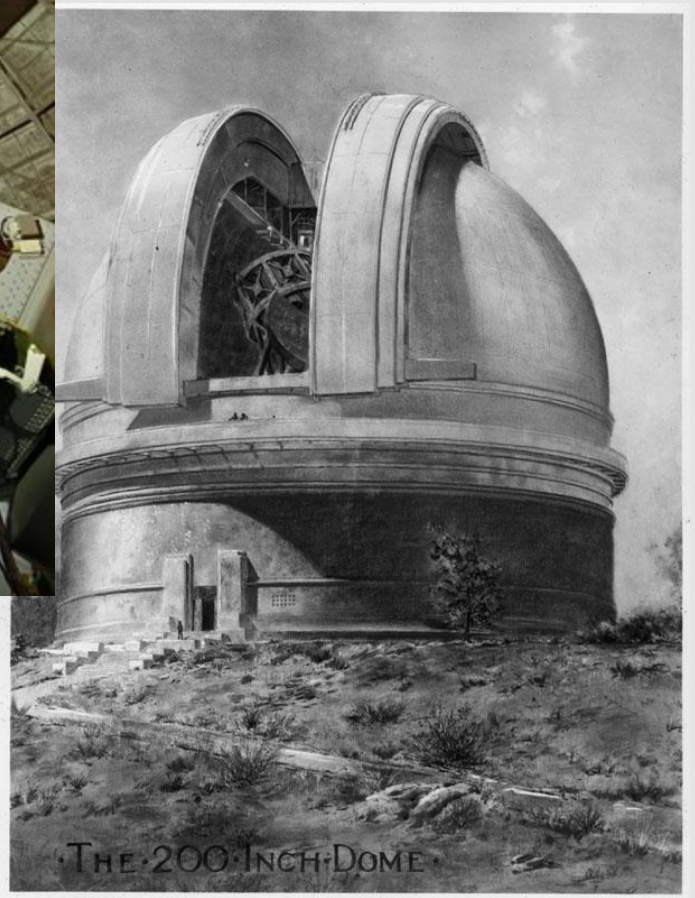
Founder/co-founder of:
The Astrophysical Journal (1895)
The American Astronomical Society (1899)
California Institute of Technology (1920)

Pioneering solar astronomer who invented the spectroheliograph and discovered that the sun has a strong magnetic field

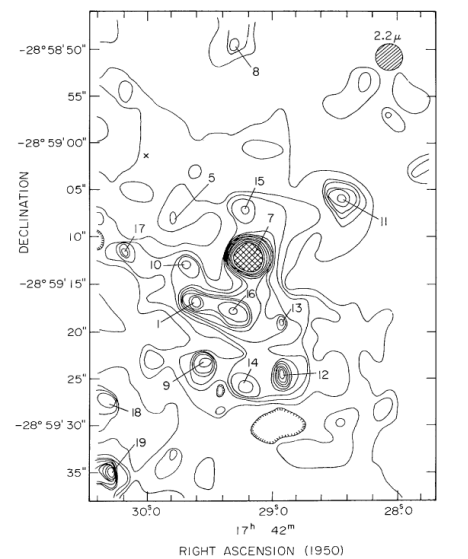
Hale's Telescopes



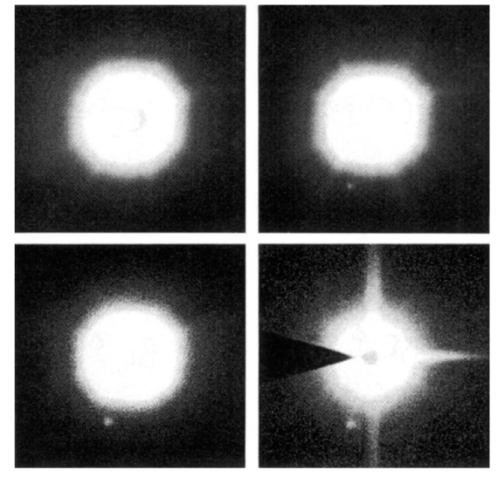




Galactic Astronomy from the Hale Telescope(s)



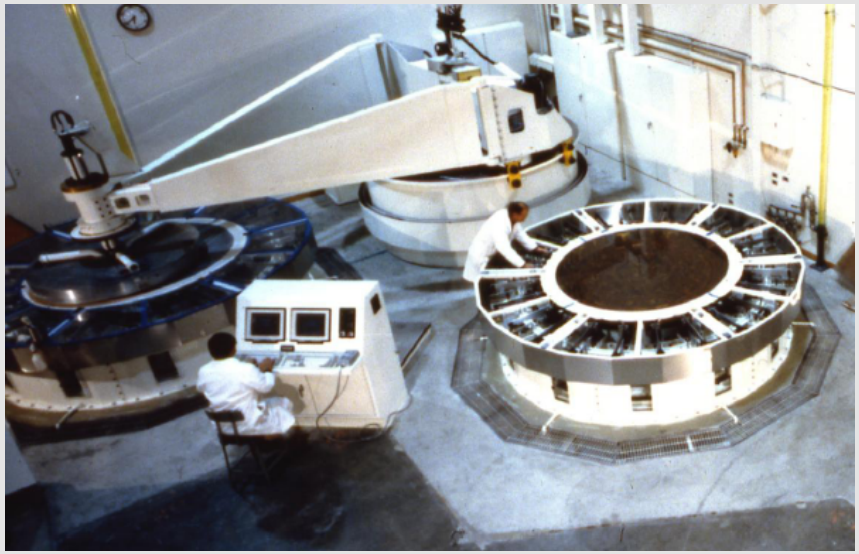
THE GALACTIC CENTER (1968) The dense stellar cluster at the center of our Milky Way galaxy, imaged in the near infrared by Becklin and Neugebauer using the 5-m telescope.



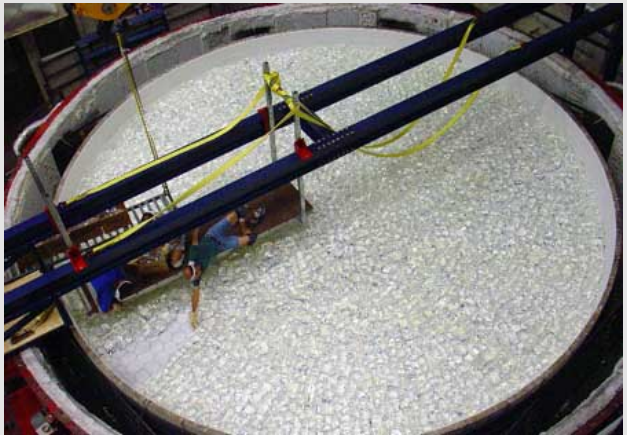
THE FIRST BROWN DWARF (1995) The 1.5 and 5-m telescopes of the Hale Observatory were used by Kulkarni et al to identify the first bona fide brown dwarf as a companion to a nearby, low mass star.

Jerry Nelson and Roger Angel

Developed and demonstrated new paradigms for the construction of 10m class optical telescopes. Both approaches are being proposed for extension to a new generation of 30m class telescope.



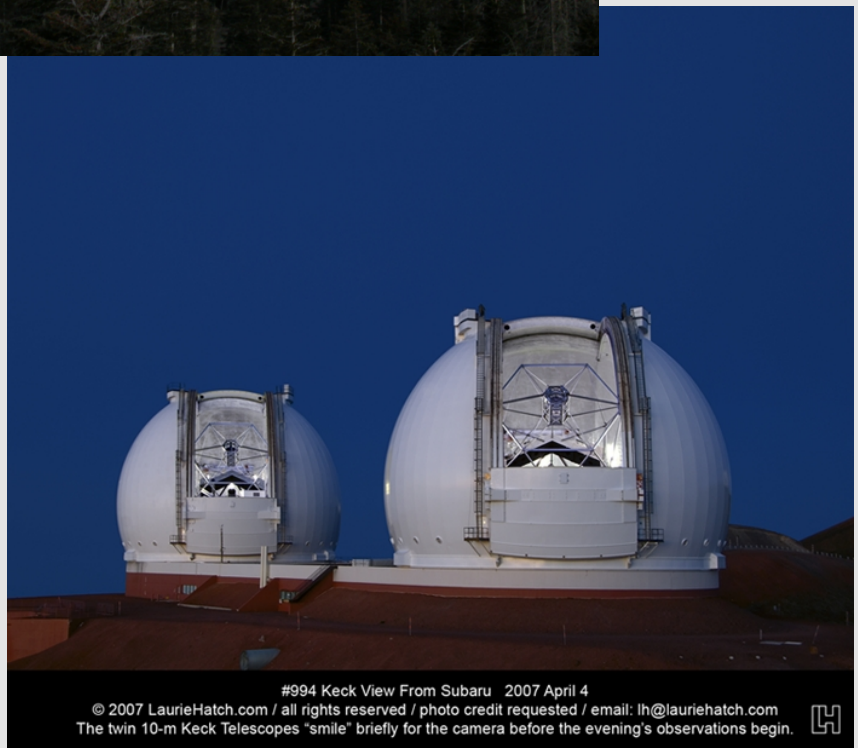
Jerry Nelson and two segments of the Keck primary in stressed mirror polishing jigs



Roger Angel and an 8.4 m blank being prepared for spin casting at the University of Arizona

The Fruits of Their Labors

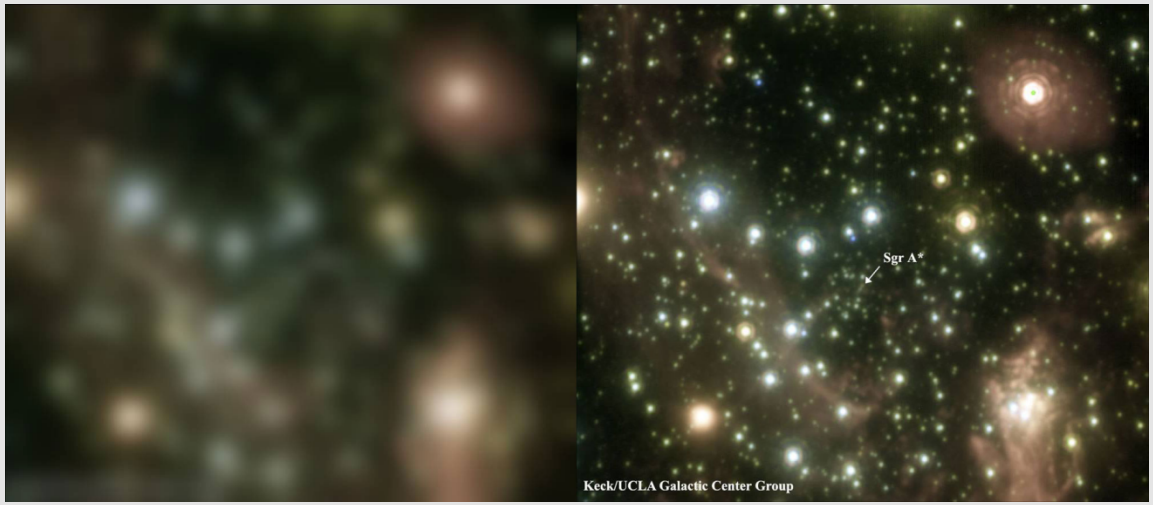
THE LARGE BINOCULAR TELESCOPE in Arizona features two 8.4m diameter spun cast primary mirrors mounted in tandem



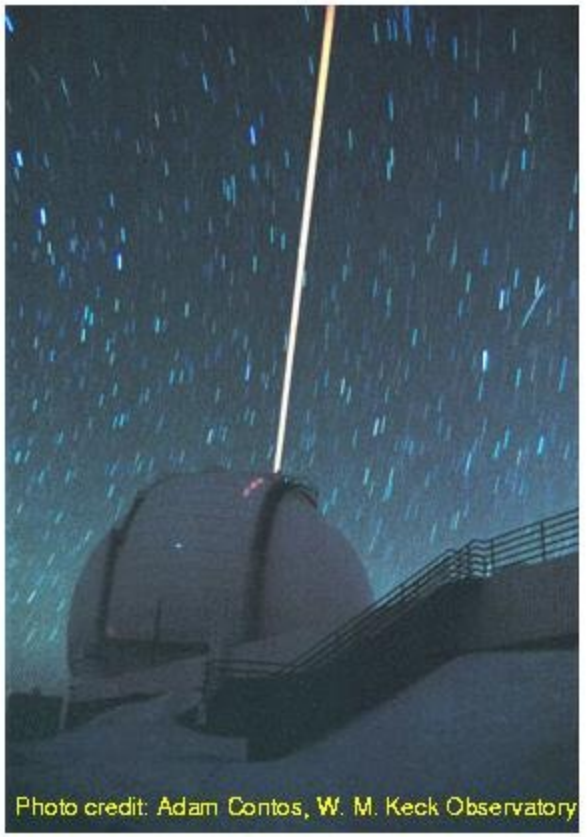
THE W.M.KECK OBSERVATORY in Hawaii incorporates two 10-m diameter telescopes, each with a primary mirror consisting of 36 segments produced by stressed mirror polishing

Galactic Astronomy from the Keck Observatory

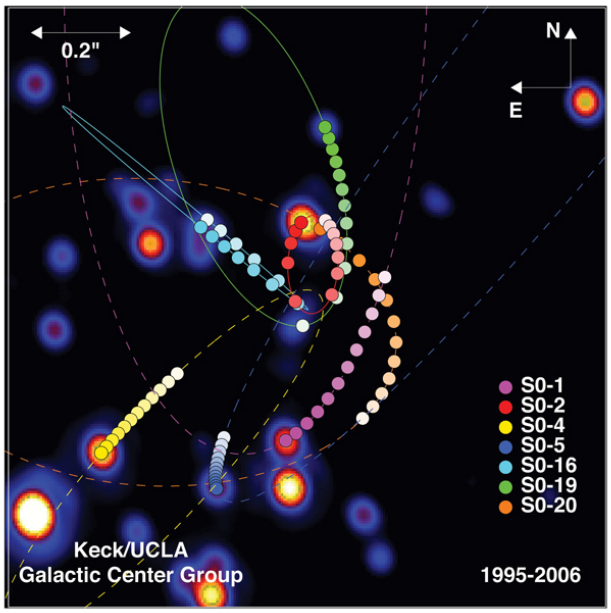
Andrea Ghez has used Adaptive Optics at the Keck Observatory to study the motions of stars at the Galactic Center

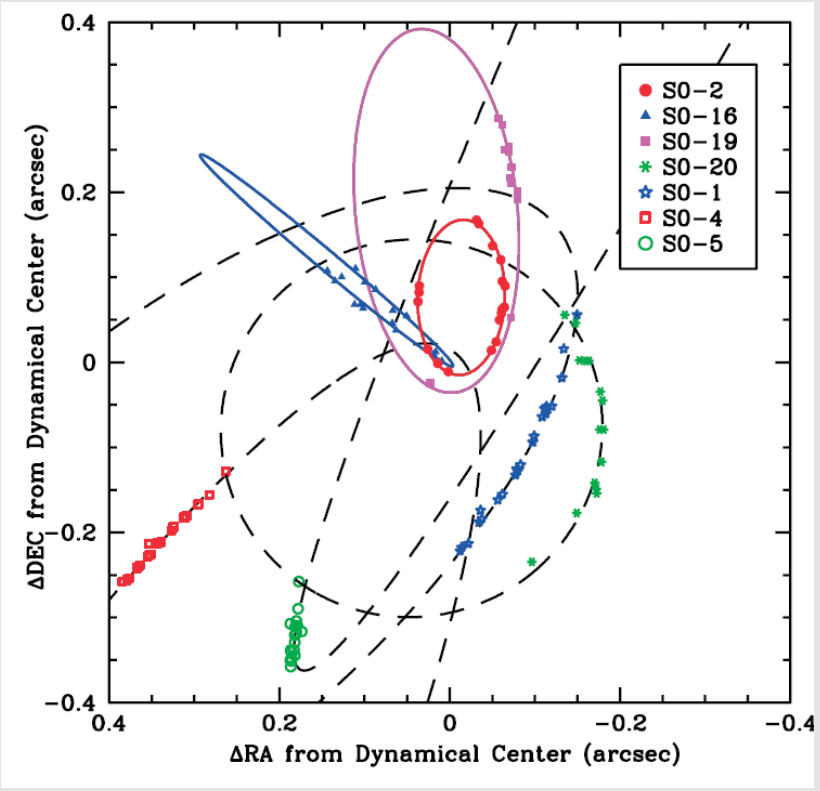


Laser Guide Star AO Image of the central ~8" of the Galaxy [R] allows detailed study of stellar motions.



Stellar Orbits at the Galactic Center





Observed [L] and extrapolated orbits of stars in the central 1" of the Galaxy provide compelling evidence for a central black hole of mass ~ 4 million suns. Detailed tests of general relativity will be possible with a ~30m telescope

STELLAR DYNAMICS AT THE GALACTIC CENTER WITH AN EXTREMELY LARGE TELESCOPE

Nevin N. Weinberg,[1] Miloš Milosavljević,[1] and Andrea M. Ghez[2]

Received 2004 April 28; accepted 2004 December 13

Lyman Spitzer (1914-1997)

Versatile, scientifically influential astrophysicist
Foresaw development and power of space observatories
Served as the Principal Investigator of the pioneering Copernicus ultraviolet observatory
Campaigned tirelessly for the Hubble Space Telescope

The Astronomy Quarterly, Vol. 7, pp. 1.31-142, 1990 0364-9229/90 $3.00+.00

ASTRONOMICAL ADVANTAGES

O F A N

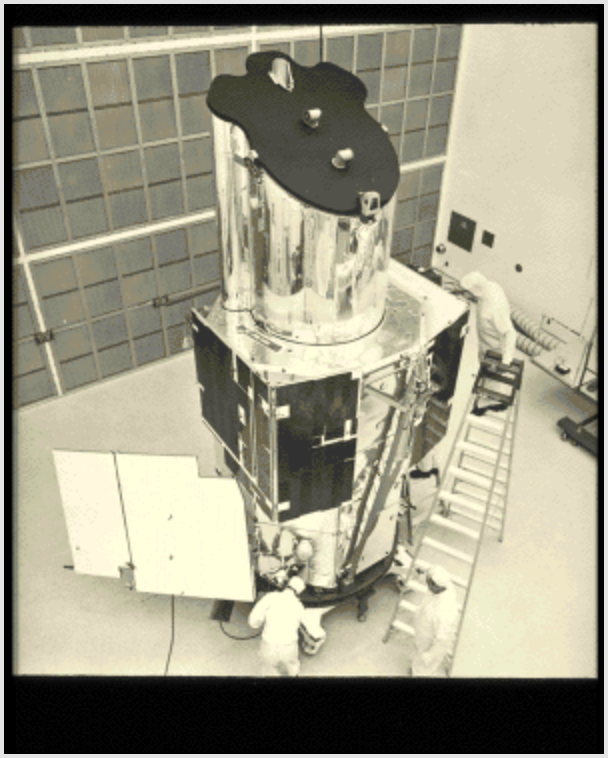
EXTRA-TERRESTRIAL OBSERVATORY

LYMAN SPITZER, Jr. 1

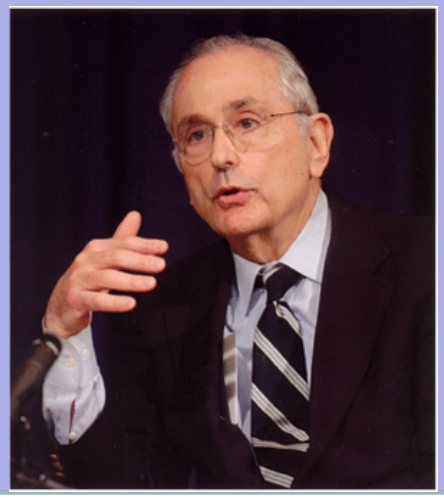
1 The report re-printed here appeared as Appendix V of a larger document prepared for the Project RAND of the Douglas Aircraft Co., on 1 September 1946. At that time, Prof. Spitzer was on the astronomy faculty of Yale University; he has been affiliated with the Princeton University Observatory since 1947.

"…NEW PHENOMENA NOT YET IMAGINED..."
"…OPEN UP COMPLETELY NEW VISTAS OF ASTRONOMICAL RESEARCH…"

Spitzer's Telescopes

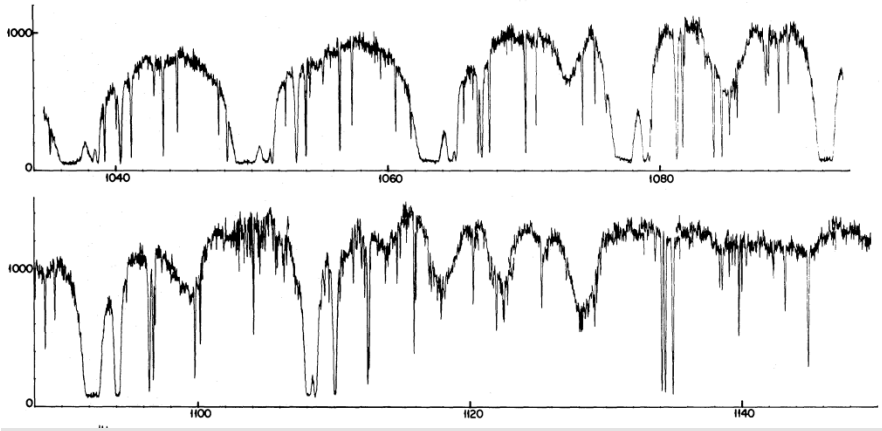


Spitzer's Partner– John Bahcall (1934-2005)



John Bahcall was one of the founding fathers of the Hubble Space Telescope. Without his tireless advocacy for the mission in the 1970's, Hubble likely would not have come into being,

Galactic Astronomy from Copernicus and Hubble



ULTRAVIOLET ABSORPTION BY INTERSTELLAR ATOMS, IONS, AND MOLECULES (1975) The narrow absorption lines of 27 different chemical species provided new insights into the physical, chemical, and dynamic processes in the space between the stars

L. HUBBLE'S ICONIC IMAGE of the Pillars of Creation in the Eagle Nebula highlights the dynamic sculpting of dense clouds which can also trigger the formation of new stars.
R. CIRCUMSTELLAR DISKS seen by Hubble in silhouette against the Orion Nebula dramatically support our basic paradigms for the formation of stars and planetary systems

Riccardo Giacconi

Pioneering X-Ray astronomer, whose work culminated in the Chandra Observatory
Nobel Prize in Physics (2002)
First director of the Space Telescope Science Institute
Director General of the European Southern Observatory

PHYSICAL REVIEW
LETTERS

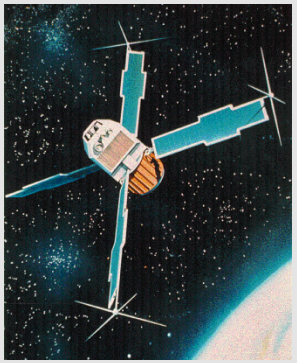
9 DECEMBER 1, 1962 NUM

EVIDENCE FOR X RAYS FROM SOURCES OUTSIDE THE SOLAR SYSTEM*

Riccardo Giacconi, Herbert Gursky, and Frank R. Paolini
American Science and Engineering, Inc., Cambridge, Massachusetts

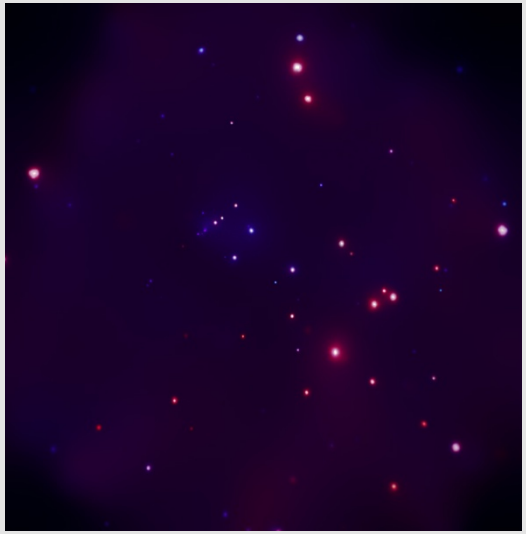
and

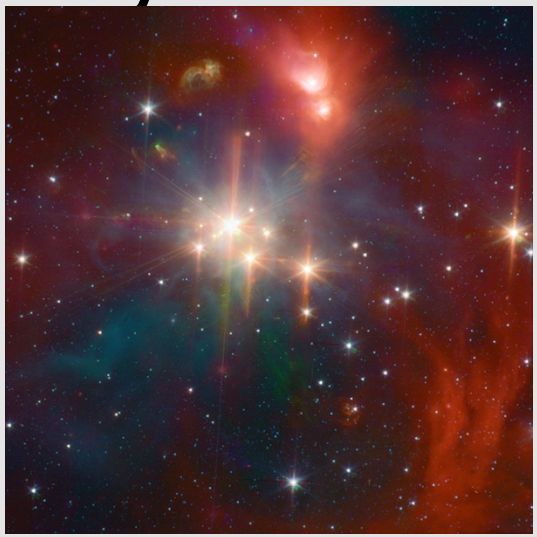
Bruno B. Rossi
Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received October 12, 1962)



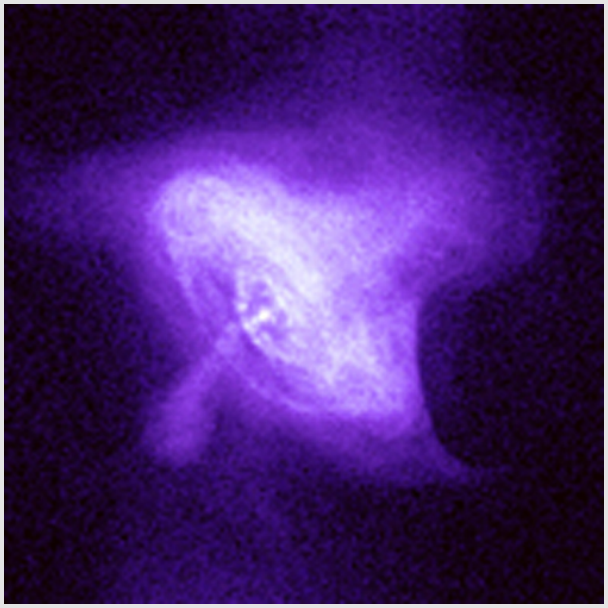
Uhuru, the first X-Ray Satellite, was launched by Giacconi et al in 1970

Galactic Astronomy from X-Ray Telescopes





YOUNG AND FORMING STARS of solar type are copious X-Ray sources, as can be seen by comparing X-Ray (L) and IR views.

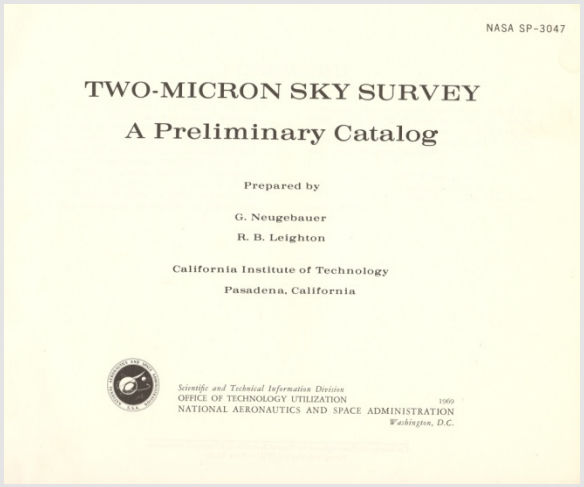


PULSARS, RAPIDLY ROTATING NEUTRON STARS, were discovered by radio astronomers in the 1960's. This X-Ray image from Chandra shows the pulsar at the center of the Crab nebula interacting with the surrounding medium. The pulsar is the remnant core of the star which exploded to produce the nebula.

:Robert Leighton (1919-1997)

Gifted, versatile experimental physicist
Discovered the solar 5-min oscillations
Conceived and built the 62-inch spun epoxy primary for the 2-um sky survey telescope
Led the imaging teams for Mariners 4,6 &7
Designed and built precision 10-m diameter microwave dishes, used at the OVRO interferometer and the Caltech Submiilimeter Observatory

Galactic Astronomy from Leighton's Telescopes


NASA SP-3047

TWO-MICRON SKY SURVEY

A Preliminary Catalog

Prepared by

G. Neugebauer

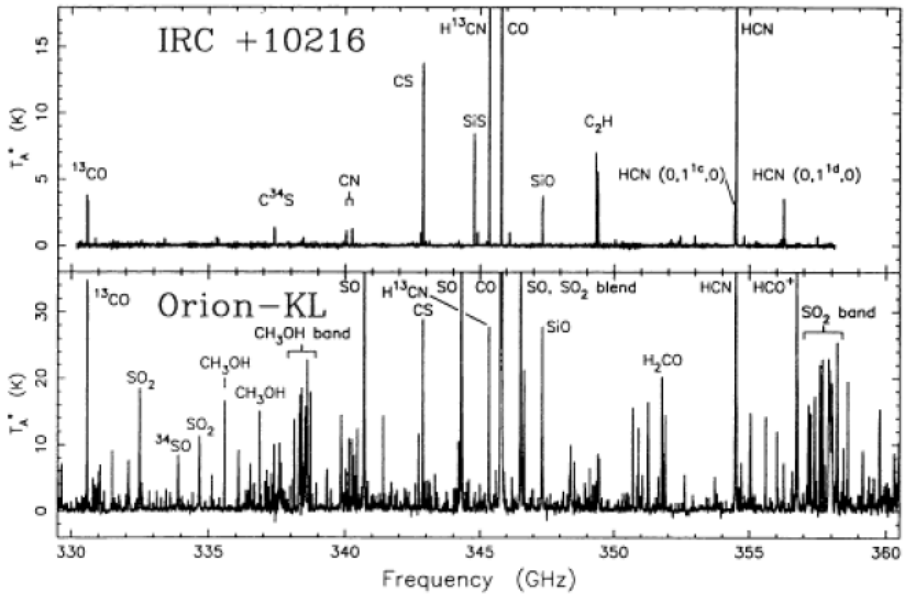
R. B. Leighton

California Institute of Technology

Pasadena, California

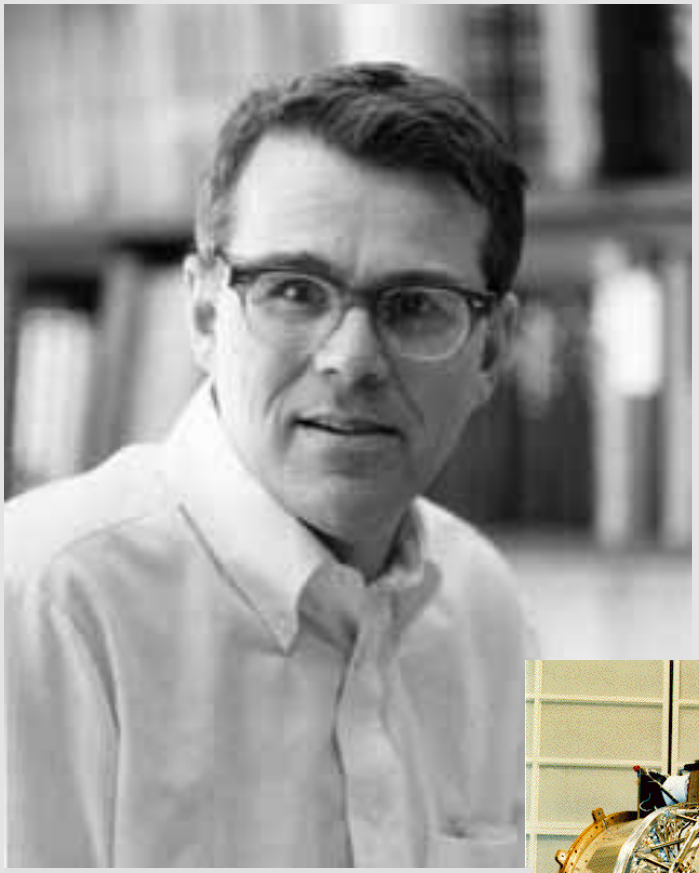
Scientific and Technical Information Division
OFFICE OF TECHNOLOGY UTILIZATION 1969
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

THE TWO MICRON SKY SURVEY CATALOG of some 5600 infrared sources, mostly dusty, mass-losing evolved stars throughout the Galaxy, has illuminated the late stages of stellar evolution and spawned many follow on studies.

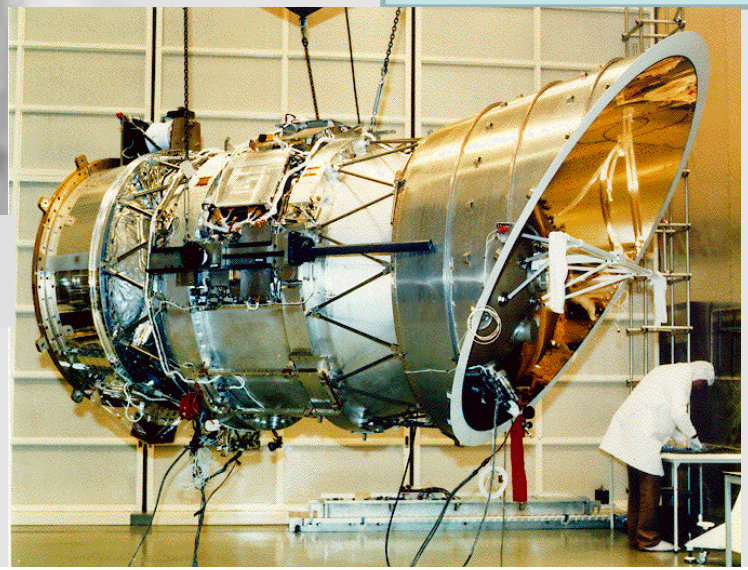


SPECTRAL LINE SURVEYS from the CSO reveal the complex details of interstellar molecular chemistry. IRC +10216 is a carbon rich object discovered in the 2-um survey

Gerry Neugebauer

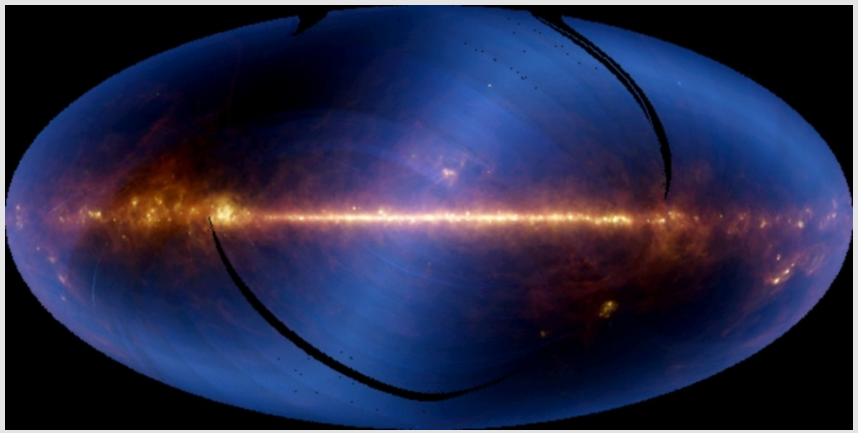


Pioneering Infrared Astronomer
Discoverer of the infrared radiation from the galactic center, with student Eric Becklin
Carried out the 2-Micron sky survey in collaboration with Bob Leighton
Headed the US Science Team for IRAS, the first cryogenic infrared observatory in space

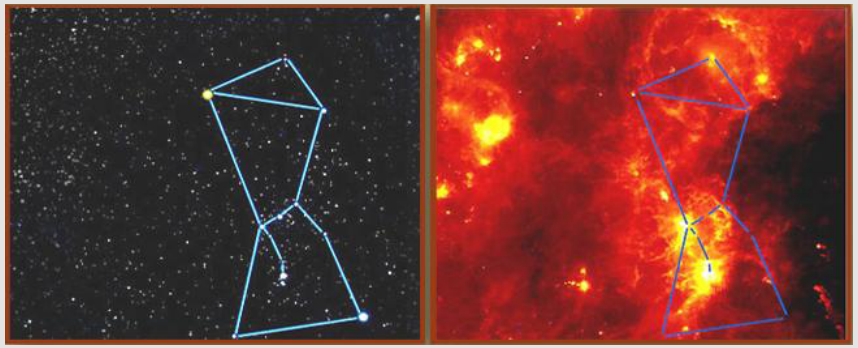


IRAS surveyed the entire sky in four infrared bands to unprecented depth

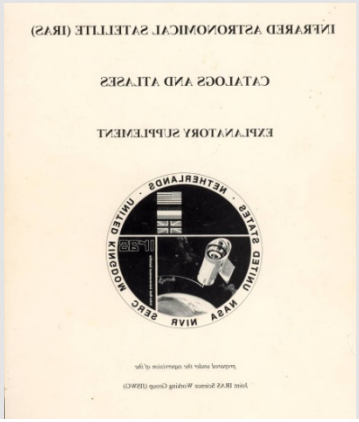
Galactic Astronomy from IRAS



IRAS' ALL SKY IMAGE shows the galactic plane as a thin streak of infrared emission, crossed by the zodiacal light in the Solar System.



IRAS IMAGE OF ORION shows dense clouds,of cool interstellar matter, and dozens of young and forming stars.



IRAS' CATALOGS were initially released in hard copy, but the IRAS data base, with its 250,000+ infrared sources, soon became one of the first examples of a well-maintained and supported computerized data base available to the entire astronomical community.

Frank Low (1933-2009)

Pioneering Infrared Astronomer and Technologist.

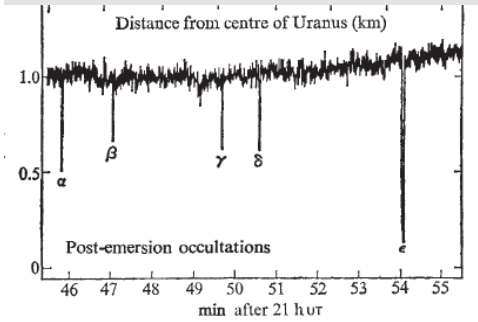
Inventor/Developer of:
The Germanium Bolometer
The Oscillating Secondary Mirror
Infrared Astronomy from High Altitude Aircraft

Instrumental in the development of IRAS, the first sensitive cryogenic system for infrared astronomy from space

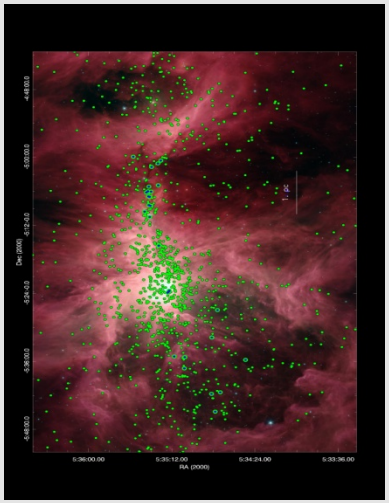
Conceived the novel warm launch architecture which enables the Spitzer Space Telescope

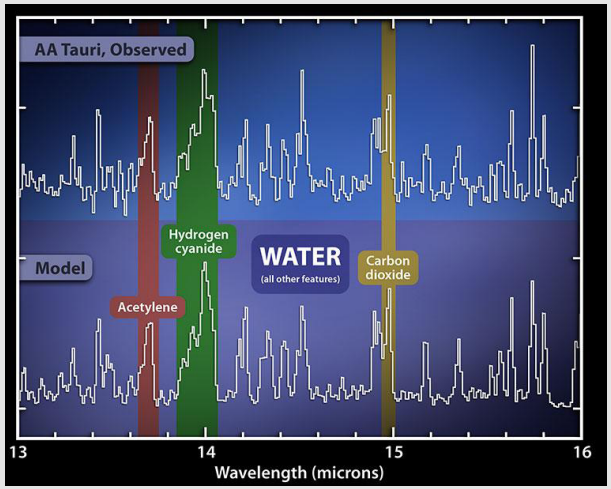
Low's Telescopes

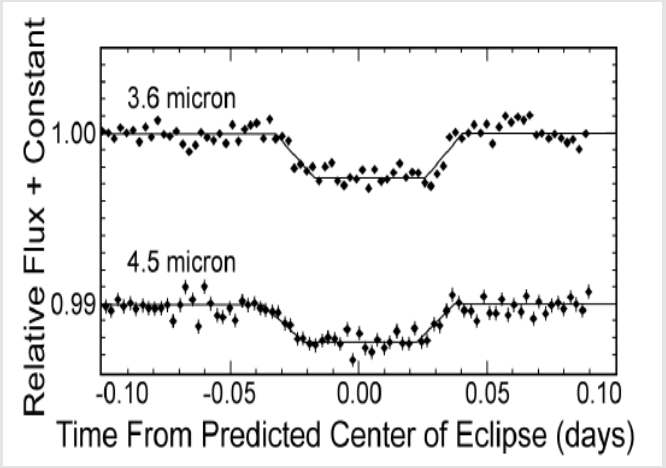
Galactic Astronomy from the KAO and Spitzer



THE RINGS OF URANUS The ability of an airborne observatory to observe from anywhere on Earth led to the serendipitous discovery of the rings of Uranus from the KAO in 1977







SPITZER HAS PRODUCED MAJOR ADVANCES in our understanding of the properties of protoplanetary and planetary systems in the Milky Way

Characteristics* of these "Galileos of the 20th Century"

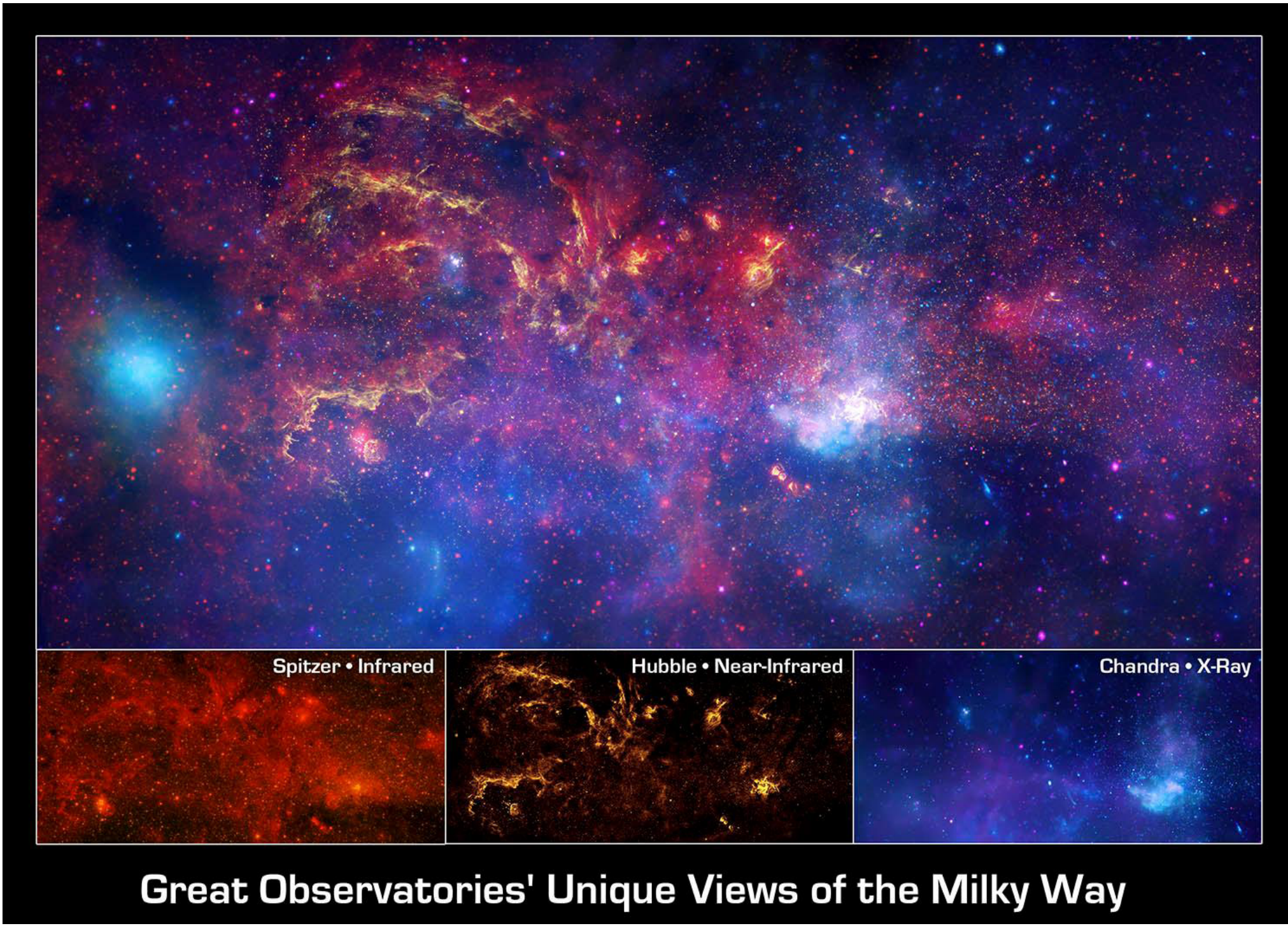
Technically Excellent and Ingenious
Opportunistic
Visionary
Evangelical
Ambitious and Driven
Daring and Self-Confident
Uncompromising

***Beyond the obvious one of being smart, or very smart, or even a genius**

A Review of our Galactic Astronomy Topics

- The diffuse interstellar medium
- Dense interstellar clouds
- Young and forming stars
  - Protoplanetary disks
  - Exoplanet systems
- Brown dwarfs
- Evolved stars undergoing mass loss
- Supernova remnants and neutron stars

- The center of the Galaxy
- Massive black holes



Great Observatories' Unique Views of the Milky Way