A horizontal banner at the top of the slide. On the left, a spiral galaxy with a bright blue core. In the center, a small green planet. On the right, a molecular model with red, yellow, and blue spheres connected by grey rods, set against a background of the Earth from space.

# Far-IR Space-Based Astronomy An Overview

Thomas L. Roellig

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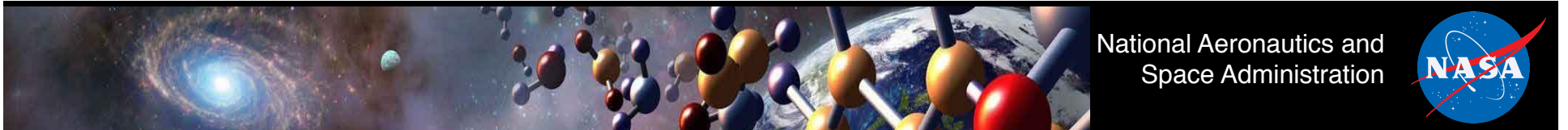
STDT Member – Origins Space Telescope



## Agenda

Set the context for this session, including a historical perspective, current facilities, as well as some planned facilities.

Compare the capabilities and science drivers from some of these missions in order to paint the landscape.

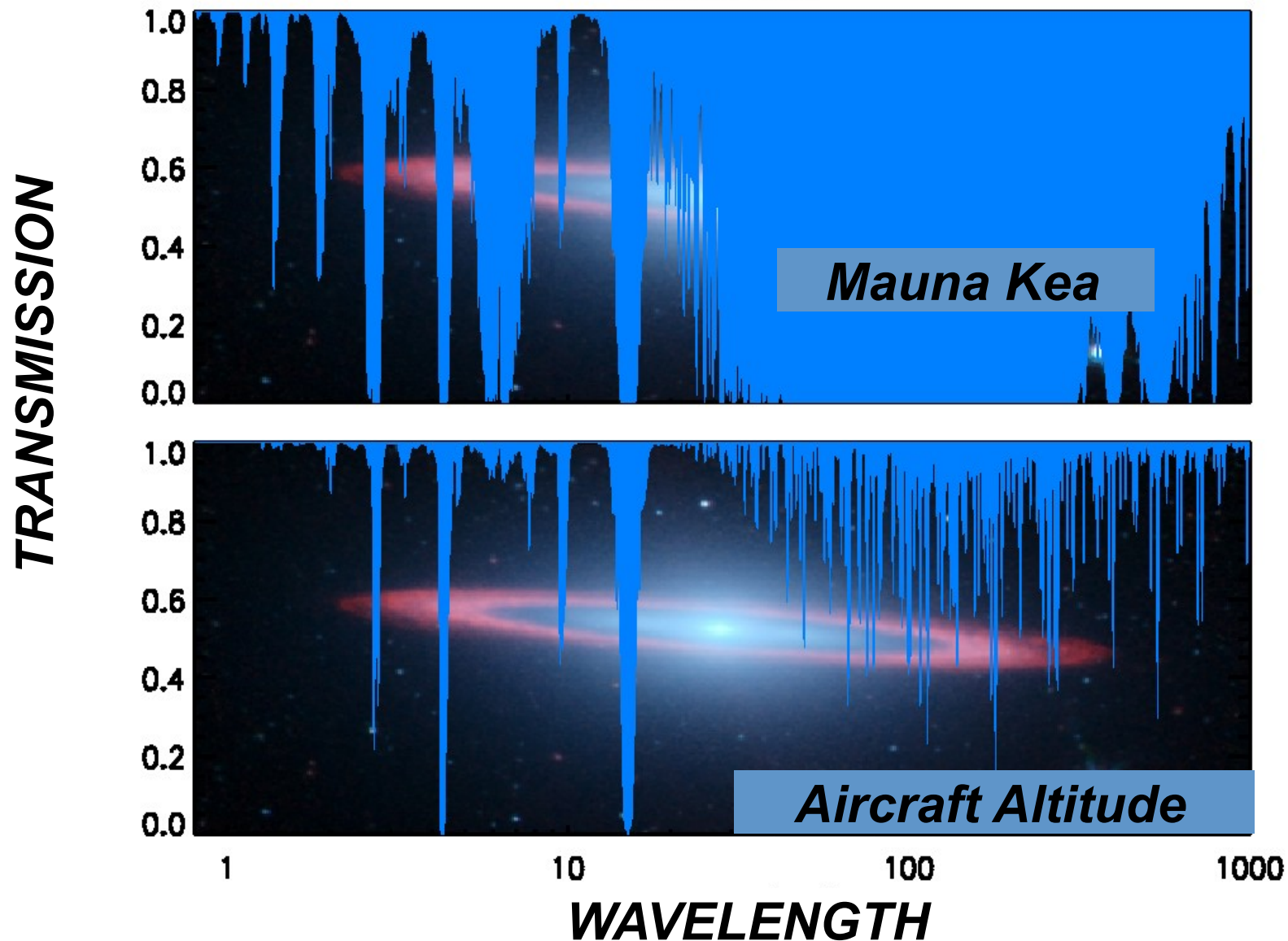


## Why the Far-IR?

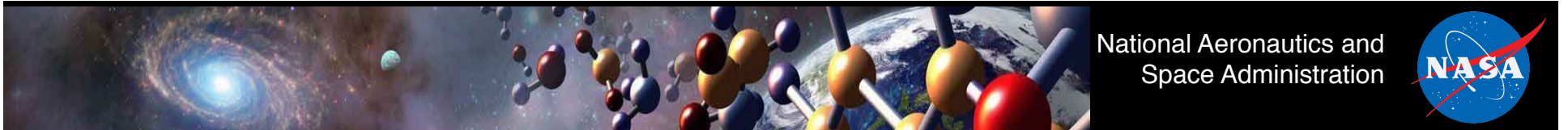
- If the IR is the study of the old, the cold, and the dirty, far-IR ( $\lambda > 20\mu\text{m}$ ) observations are of:
  - the *OLDEST* (cosmic structure shortly after the Big Bang)
  - the *coldest* (probing the structure, the dynamics, and the composition of the coldest molecular clouds, galaxies emit much of their energy in the far-IR)
  - the *dirtyest* (able to see through dust opacities that would stymie shorter wavelength observations)



# Why Space? The Far-IR and the Atmosphere

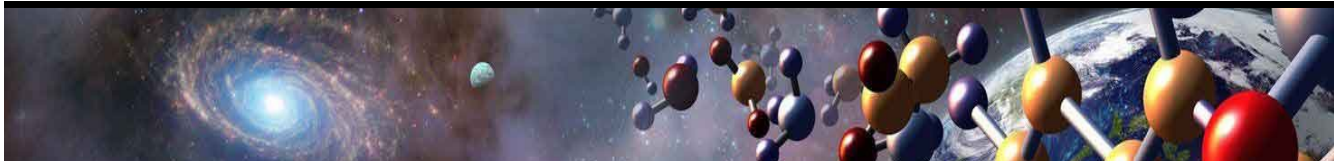






## Other Advantages of Space

- *Vacuum of space allows cryogenic telescope optics temperatures*
- *Space is dark in the IR – no atmospheric glow. IR background is limited by the Zody*
- *Space is dark in the visible – can always see guide stars*
- *Once in orbit, science operations can be very efficient with many thousands of observing hours per year running ~24/7*



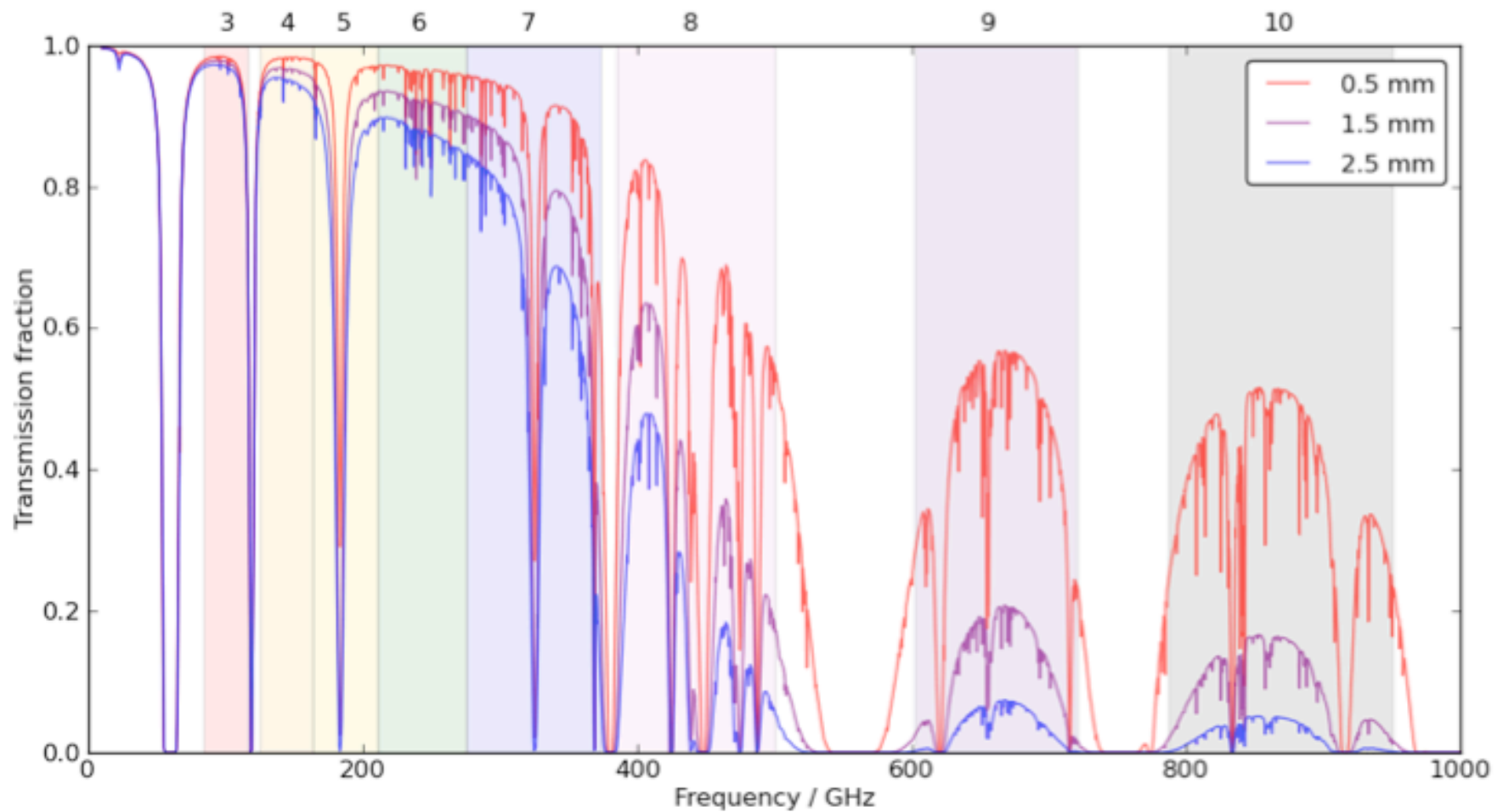
## Ground-Based Observatories - ALMA

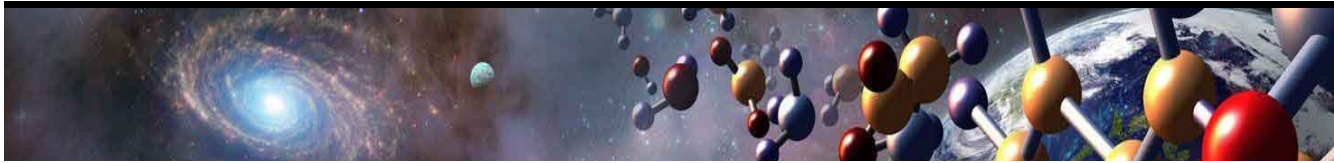
- ~5,000m altitude
- 66 dishes with a total of ~6,500m<sup>2</sup> collecting area
- Interferometer baselines up to 16 km
- Operates at wavelengths of 0.3 to 9.6 mm
- High sensitivity in its atmosphere windows
- Very high spatial resolution





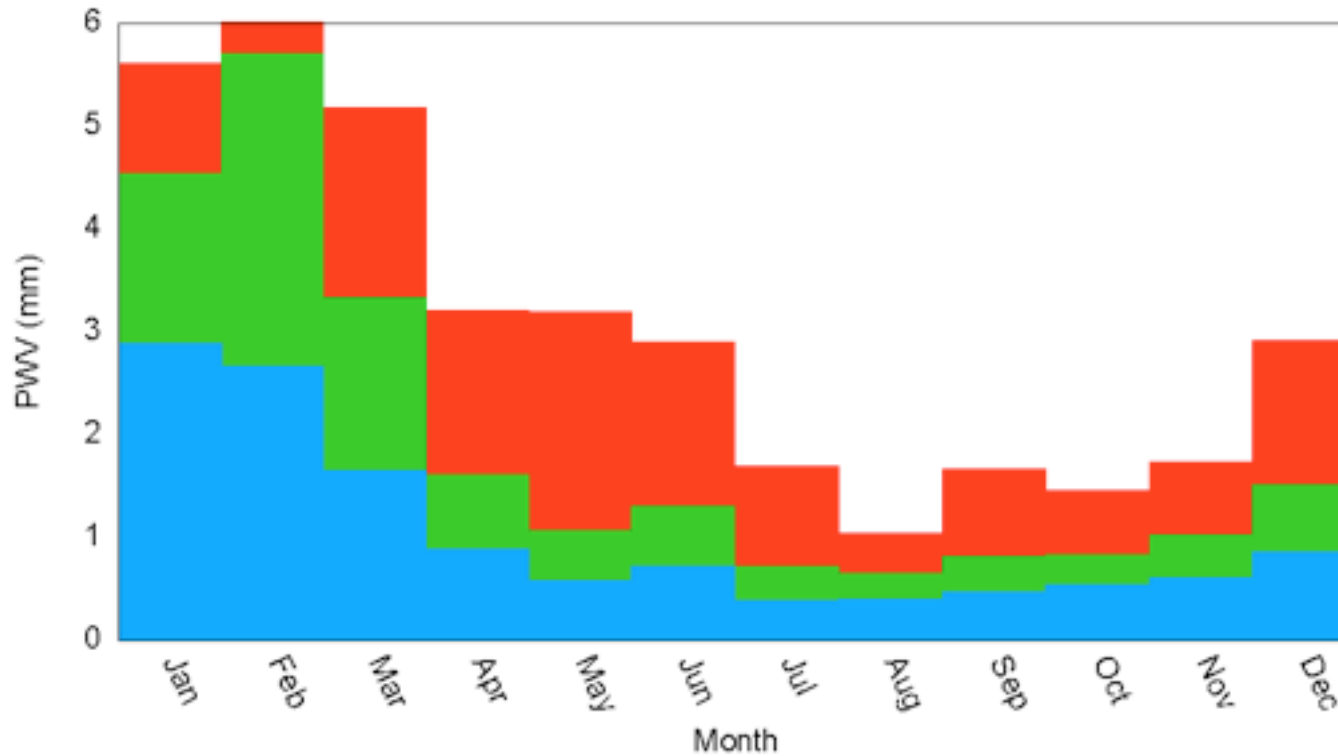
# ALMA Atmospheric Transmission



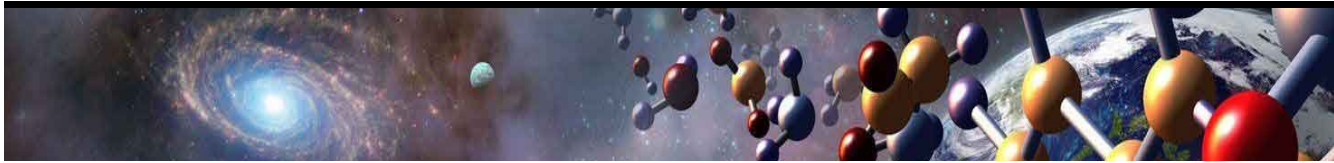


# ALMA Water Vapor

Chajnantor PWV 2007-2010



The blue, green, and red bars show the 1st, 2nd, and 3rd quartile of the data.



## Airborne – The Kuiper Airborne Observatory

- 0.9 meter infrared telescope in a C141 aircraft
- Operated from 1974 to 1995
- Optimized for far-infrared and submillimeter observations
  - Multiple science instruments over its career: visible to submillimeter cameras, infrared and submillimeter spectrographs
  - Instruments could be changed and upgraded over its lifetime
- Mobile platform provided a huge advantage for solar system occultations, including solar eclipses
- Provided hands-on training for young scientists and initiated the airborne teacher program now used with SOFIA



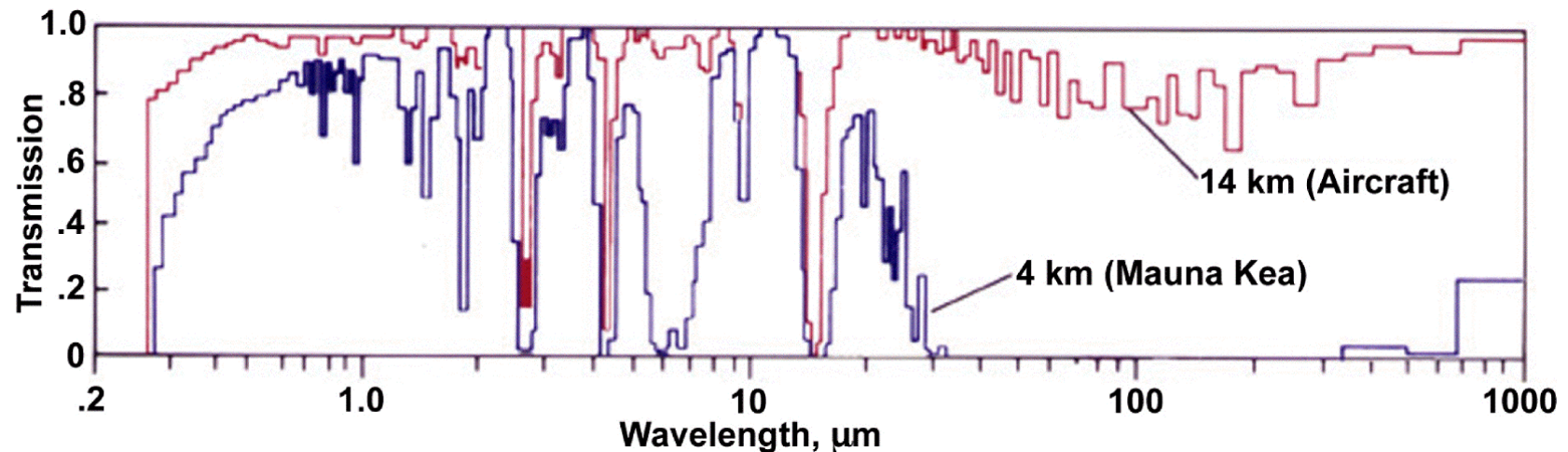
*A small sample of its major discoveries: rings of Uranus, watched the formation of heavy elements in SN1987A, studies of the ubiquitous PAH molecules*





## KAO - 2

- Most IR radiation from space is blocked by atmospheric  $H_2O$  at sea level
  - IR transmission at 14 km is very good:  $>80\%$  over 1- 800  $\mu m$
- Allows for flexible scheduling and deployment to take advantage of targets of opportunity, etc.
- Allows for development and maintaining state of the art science instruments; lower TRL needed than for space.
- Provides for frequent science/technology/community development in ways similar to sounding rockets and balloon programs

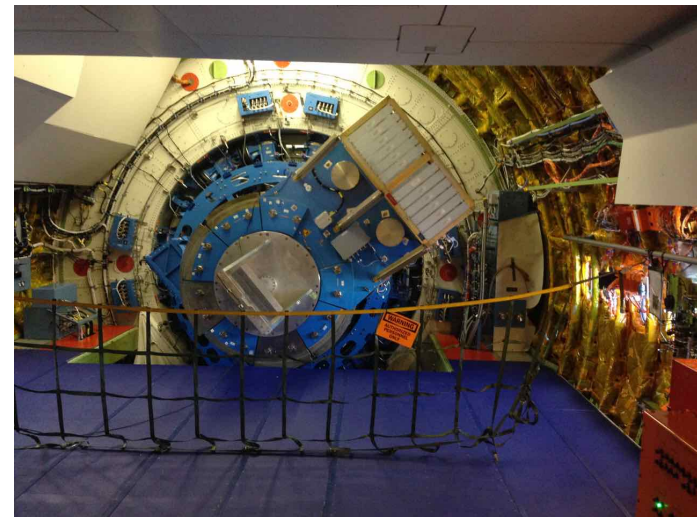


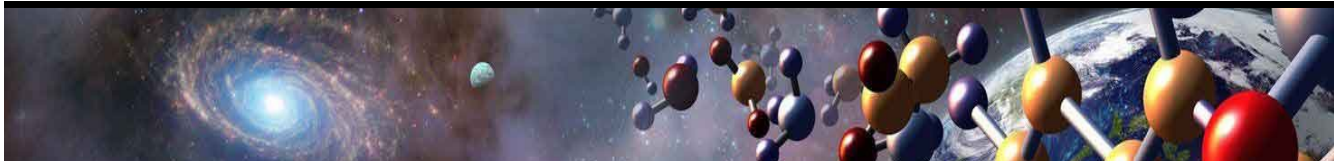




## SOFIA – The KAO's Successor

- 2.5 meter infrared telescope in 747SP aircraft
- Designed for 20 years of operation
- Similar flight altitude as KAO
- Nearly all observing time is for GOs - annual cycle
- Optimized for far-infrared and submillimeter observations
  - 8 current science instruments:
    - Visible to submillimeter cameras, infrared and submillimeter spectrographs, far-IR polarimetry, with unique time, spatial, and spectral resolution capabilities
    - Instruments will be changed and upgraded over lifetime
- Following talk with more details





## Balloon Far-IR Telescopes

- Telescope diameters up to  $\sim 2\text{m}$  (and potentially larger)
- Payloads up to 3,600 kg.
- Float altitudes up to 39 km (127,000 ft.)
- Durations up to 100 days
- Cosmology, ISM, and Star Formation



Stratospheric Terahertz  
Observatory (STO-II)



## Earliest Major IR Space Mission - IRAS

- 0.6m telescope operating at 2K
- All-sky survey lasting from Jan. 1983 to November, 1983
- Wavelength coverage 12-100  $\mu\text{m}$
- Revolutionized our view of the IR sky



*A small sample of its major discoveries: detected roughly 500,000 IR sources, more than doubling the number of cataloged objects, debris disks (no longer was Vega our stellar standard!), IR cirrus, determined that our Milky Way galaxy was a barred spiral, starburst galaxies*





## WISE – The Successor to IRAS

- 0.4m telescope cooled to 3K
- Took advantage of vastly larger arrays
- All-sky survey lasting from Dec. 2009 to Oct. 2010, added 4 months of first NEOWISE time
- Restarted the NEOWISE mission in Sep. 2013 for 3 more years
- Wavelength coverage 3.4-22 $\mu$ m in 4 bands



*A small sample of its major discoveries: the most luminous galaxy in the universe, numerous new brown dwarfs, ~250 Near Earth Objects, the first Earth trojan asteroid*



# First Major Pointed Space Telescope

## The Infrared Space Observatory

- 0.6m telescope cooled to 3K
- Operated from Nov., 1995 to April 1998
- 4 instruments, including both imagers and spectrographs
- Covered 2.5 to 240  $\mu\text{m}$
- Primarily pointed observations

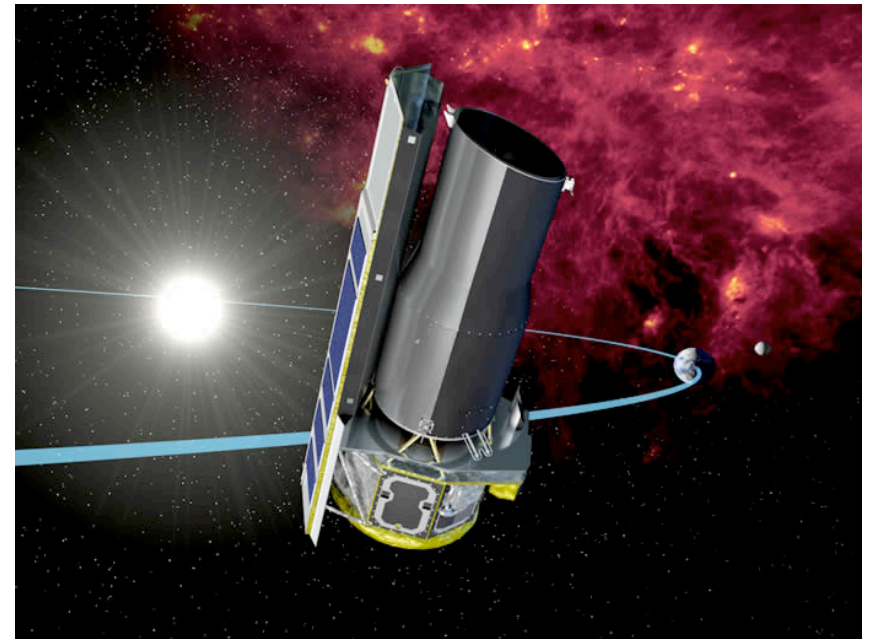


*A sample of its major discoveries: Water vapor in star formation regions, dust in the intergalactic medium, observations of proto-planetary disks*



# The Spitzer Space Telescope Going Deeper and Longer

- 0.85m telescope
- Cold mission: Aug, 2003 to May, 2009
  - Telescope temp 6K
  - Imaging from 3.6 to 160  $\mu\text{m}$
  - Spectroscopy from 5.3 to 40  $\mu\text{m}$
- Warm mission: From May 2009 to present
  - Telescope temp 30K
  - Imaging at 3.6 and 4.5  $\mu\text{m}$



*A small sample of its major discoveries: winds in exoplanet atmospheres and some composition information, largest of Saturn's rings, large size of the most distant galaxies, weather in brown dwarfs*





National Aeronautics and  
Space Administration

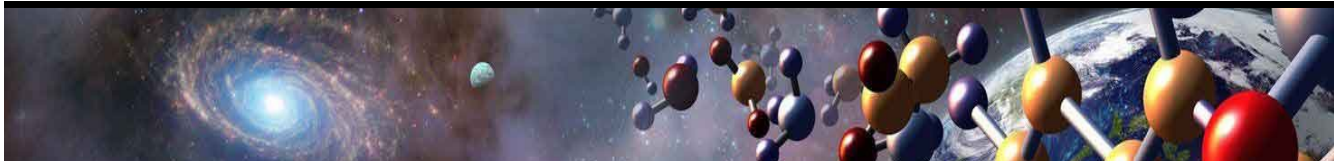


# Herschel Space Observatory

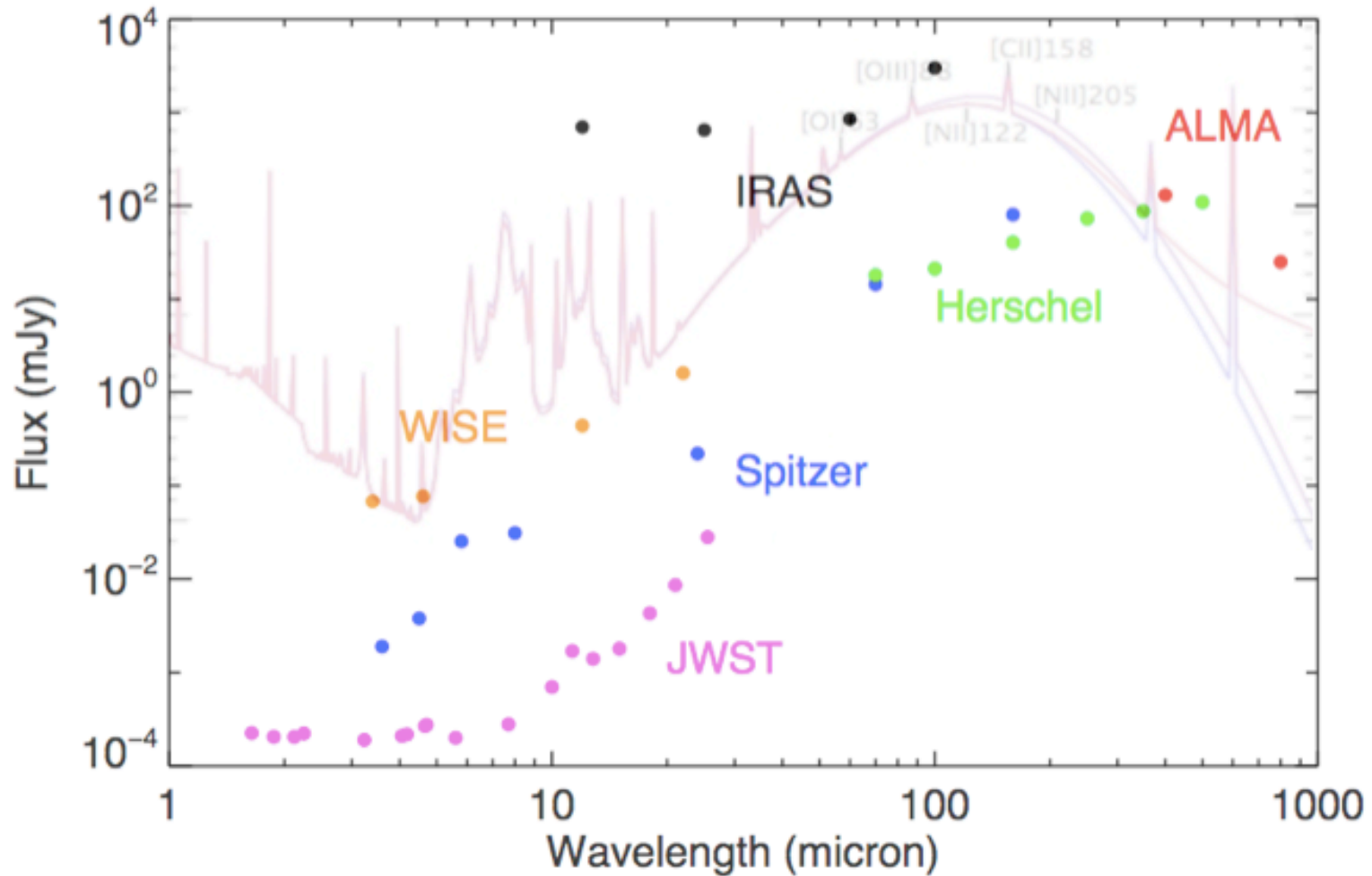
- 3.5m telescope cooled to 70-90K
- Operated May 2009 to April, 2013
- Three instruments, both imagers and spectrographs
- Operated from 55 to 672  $\mu\text{m}$
- Primarily pointed observations



*A small sample of its discoveries: water vapor around a dwarf planet, an asteroid belt in addition to the debris disk around Vega, molecular oxygen*

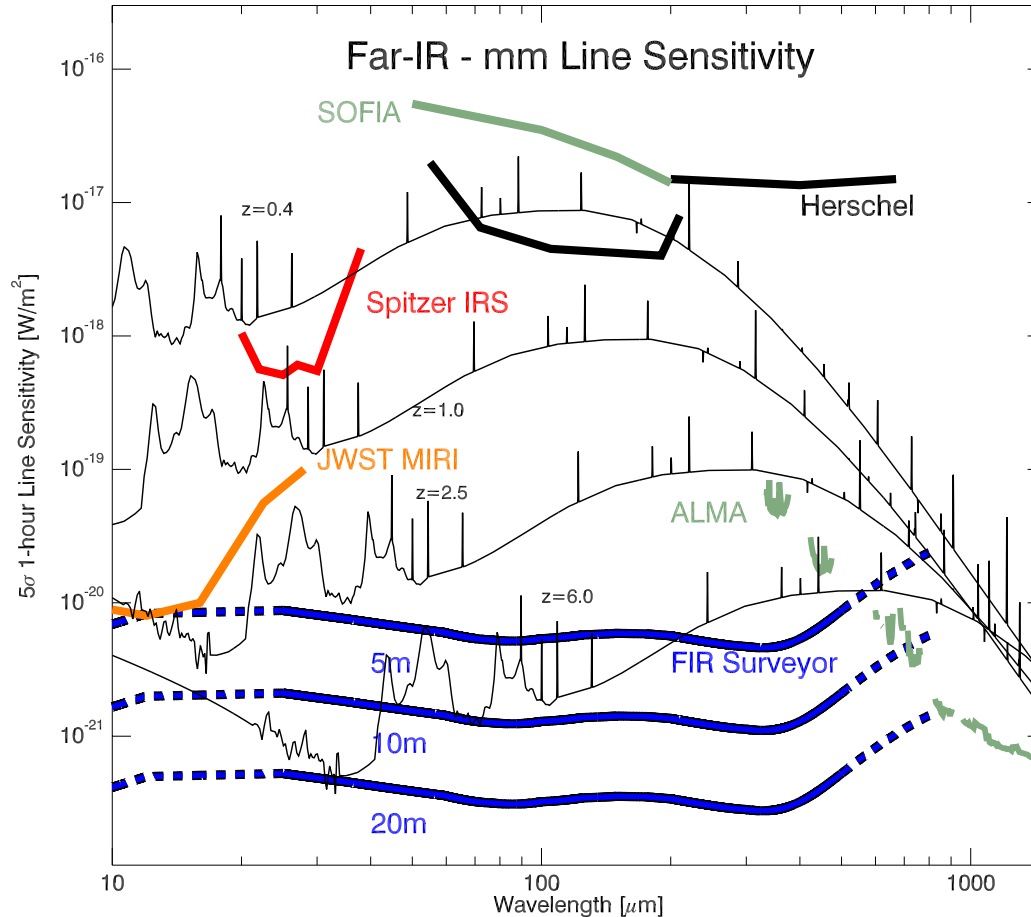


# Evolving Sensitivities

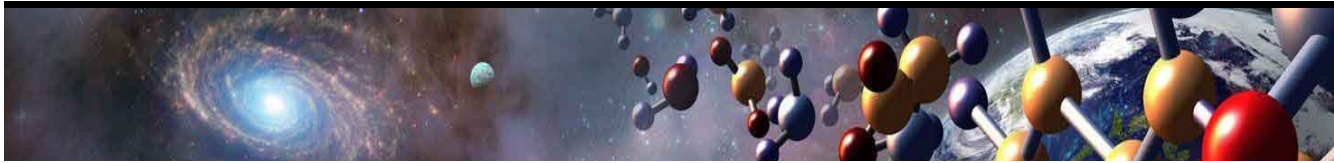




## Evolving Sensitivities - 2

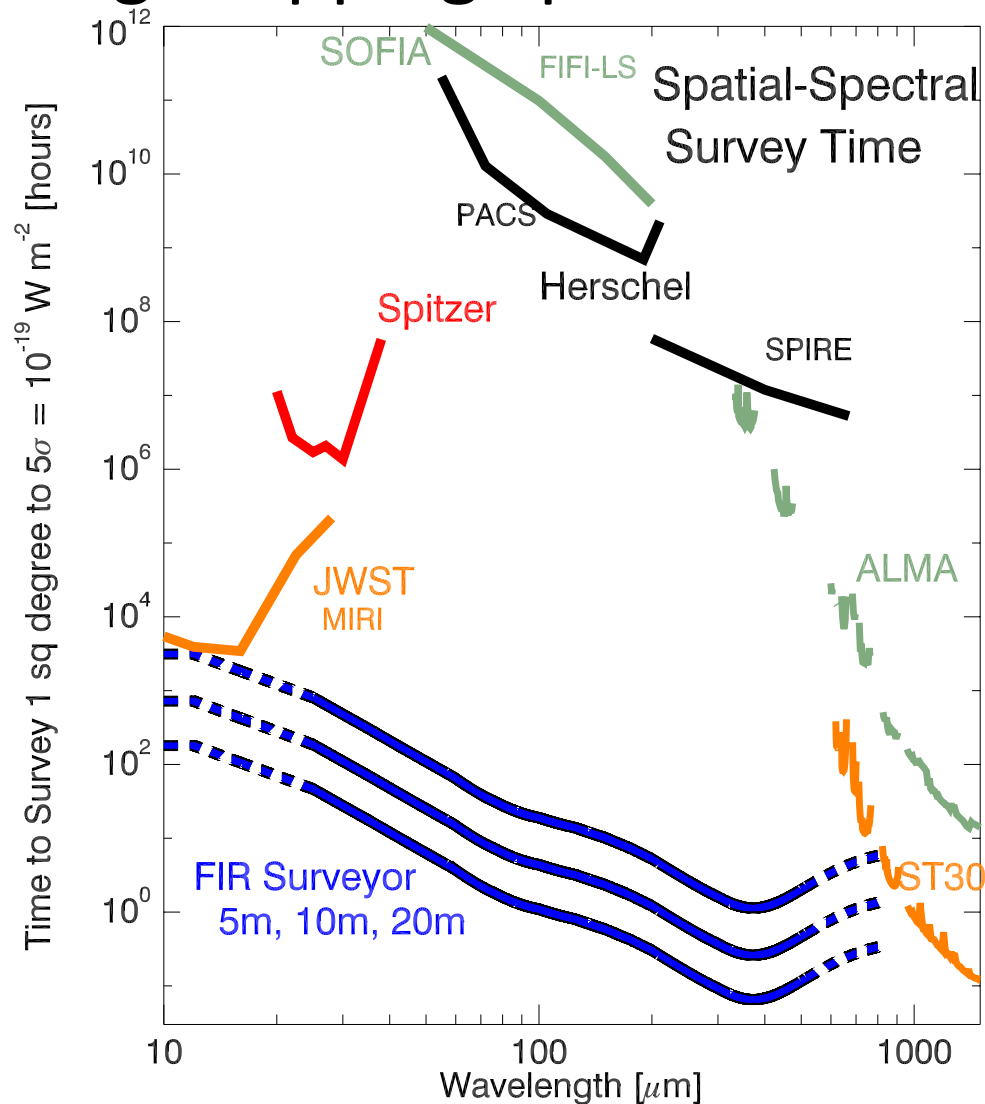


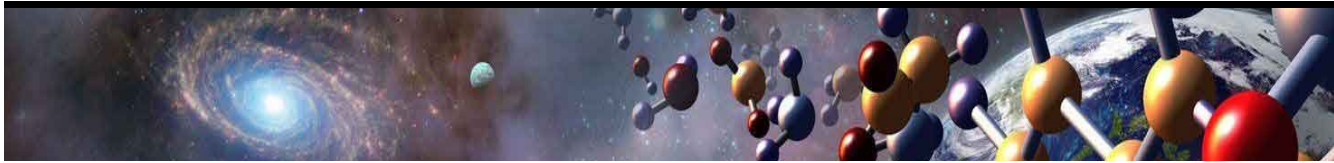
Line sensitivity including galaxy SEDs. Galaxies are  $1e12 L_{\text{sun}}$ . Resolving power is assumed to be 500.



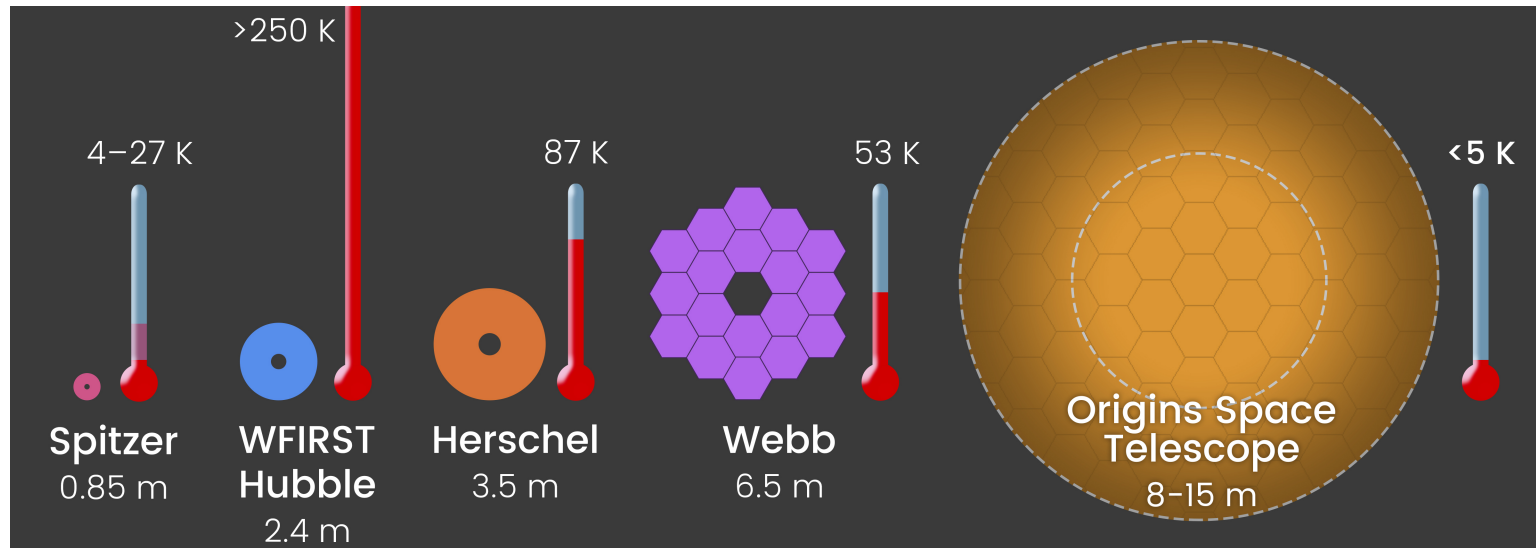
# Evolving Mapping Speed

Spectral survey speed. This assumes 100 beams of wideband spectroscopy at all wavelengths.

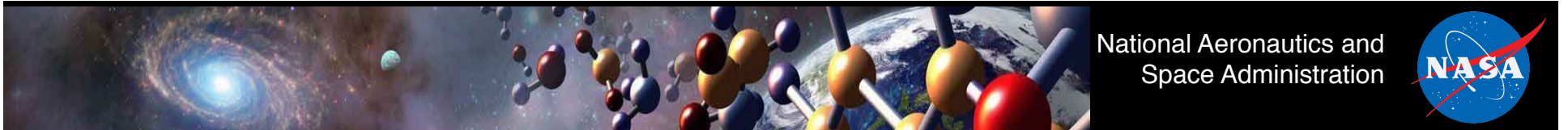




# Evolving Spatial Resolution







## Origins Space Telescope

- *More information:*
  - Following talks (also talk on SPICA)
  - Visit the NASA Science Mission Directorate Booth
  - Talk to anyone wearing one of these buttons:



- <http://origins.ipac.caltech.edu/>