



First Science with the Stratospheric Observatory for Infrared Astronomy

Eric Becklin

Physics and Astronomy, UCLA

SOFIA Chief Science Advisor, USRA

KIPAC, SLAC, Stanford

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With Support from

- Jim DeBuizer
- Mark Morris
- Hans Zinnecker
- Bill Vacca
- Terry Herter and FORCAST Team
- The entire SOFIA team

Outline of Material

- Overview of SOFIA
- The SOFIA Observatory
- Science Capabilities and Instruments
- First Science with SOFIA
- Future Science
- Schedule and Future Opportunities
- Summary

OVERVIEW

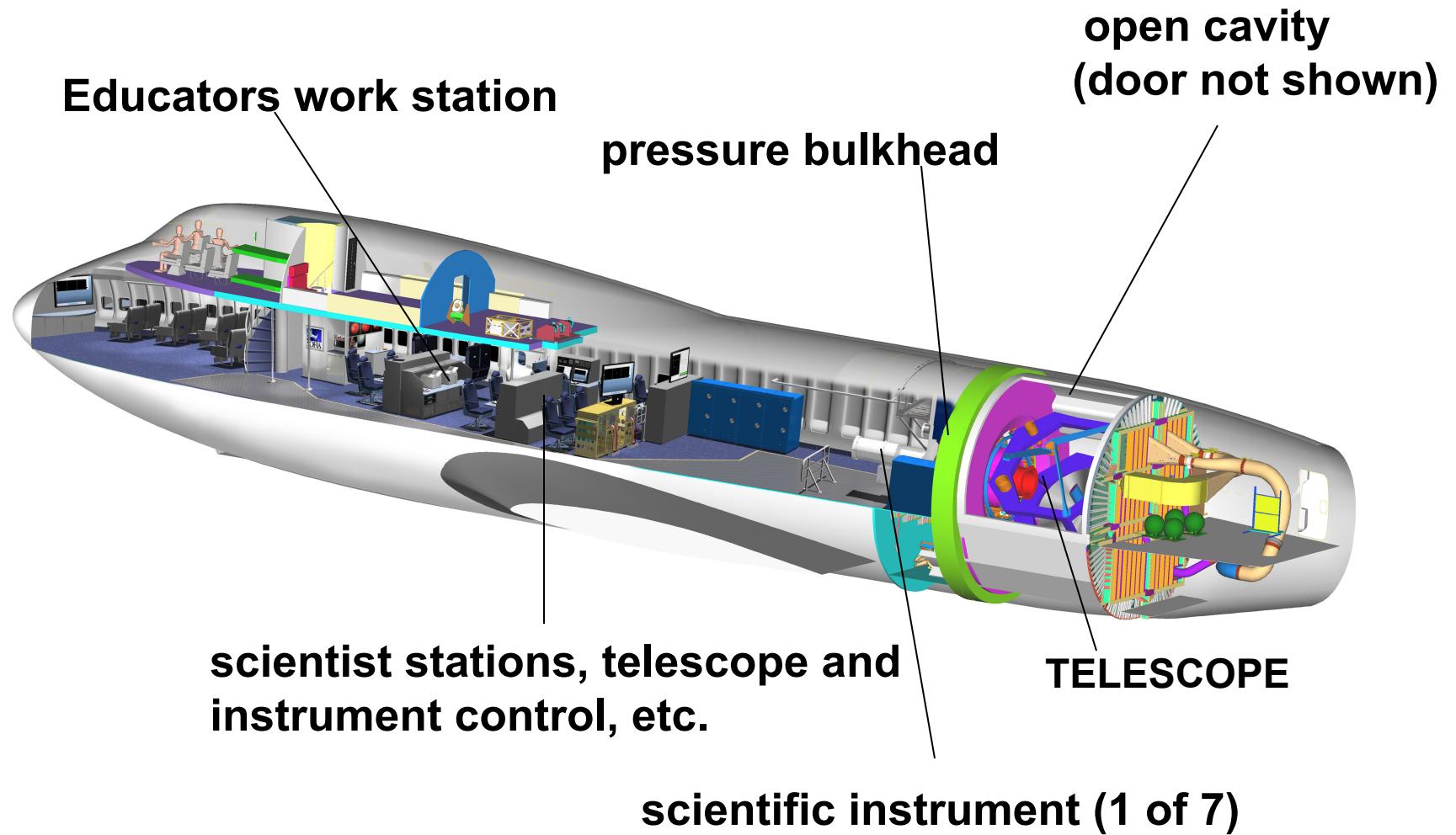
Overview of SOFIA

- SOFIA is 2.5 meter telescope in a modified B747SP aircraft
 - Optical-mm performance
 - Obscured IR (30-300 microns) most important
- Joint Program between the US (80%) and Germany (20%)
- First Science 2010 (NASA, DLR, USRA, DSI)
- Designed for 20 year lifetime

Overview of SOFIA (Cont)

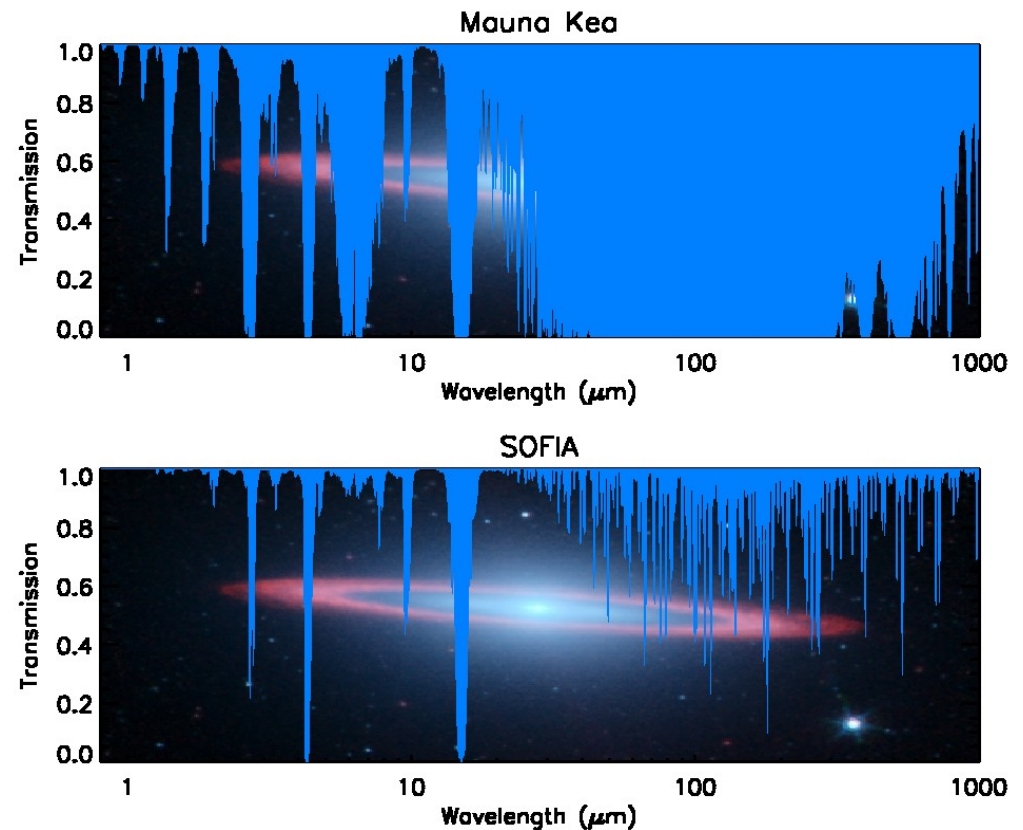
- Operating altitude
 - 39,000 to 45,000 feet (12 to 14 km)
 - Above > 99% of obscuring water vapor
- World Wide Deployments
- Ramp up to ~1000 science hours per year (12% of the time)
- Build on Kuiper Airborne Obs (KAO) Heritage with improvements (More flights, Facility Inst., Science Support)
- Science flights to originate from Palmdale, CAAircraft operation by NASA Dryden Research Center (DFRC)
- Science Center is located at NASA Ames Research Center in Mountain View, CA

SOFIA — The Observatory



Why SOFIA?

- Infrared transmission in the Stratosphere very good: >80% from 1 to 1000 microns
- Instrumentation: wide complement, rapidly interchangeable, state-of-the art
- Mobility: anywhere, anytime
- Long lifetime
- Outstanding platform to train future Instrumentalists
- Near Space Observatory that comes home after every flight



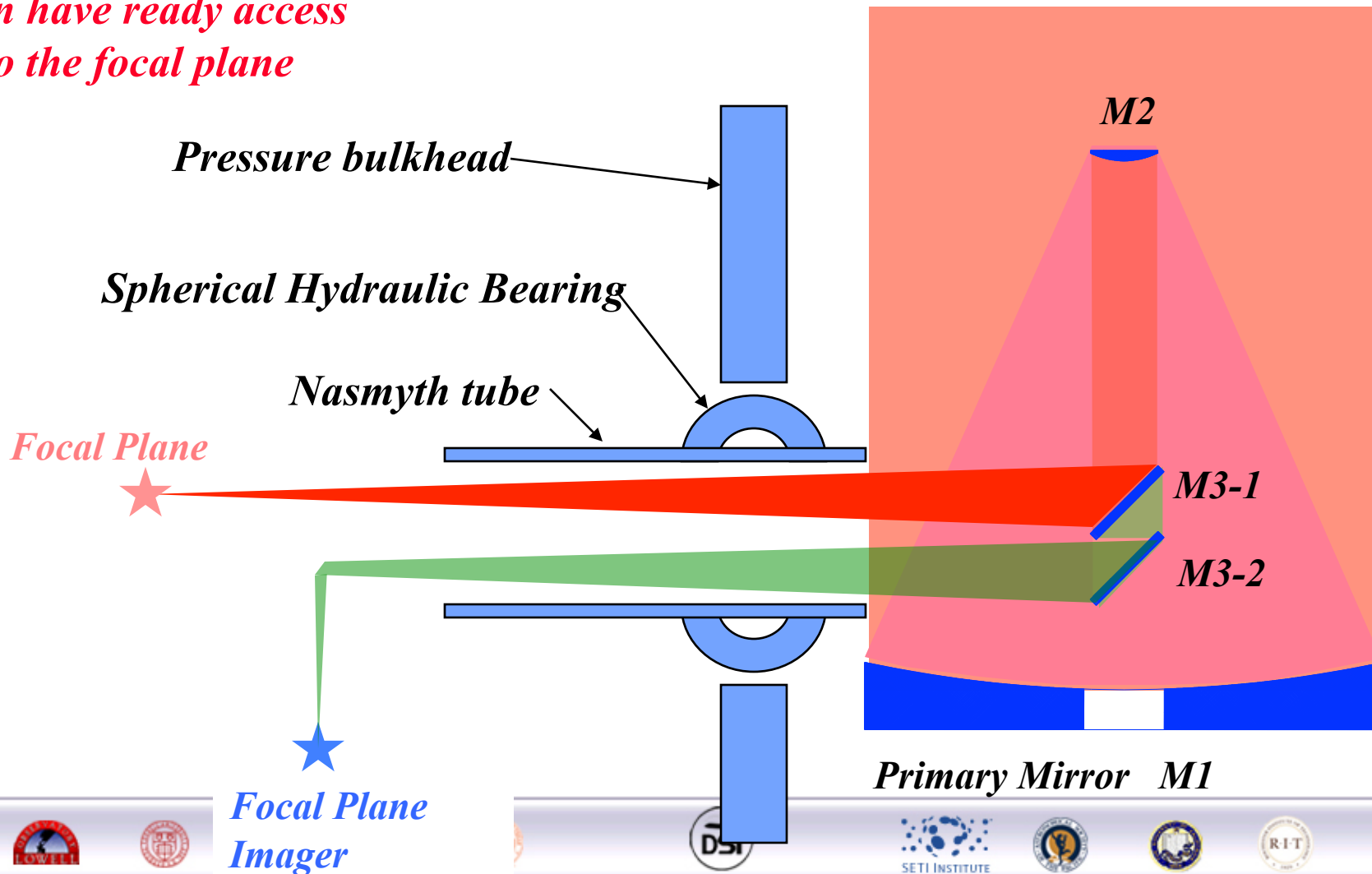
The SOFIA Observatory

SOFIA Open Door Tests 2009



Nasmyth: Optical Layout

Observers in pressurized cabin have ready access to the focal plane



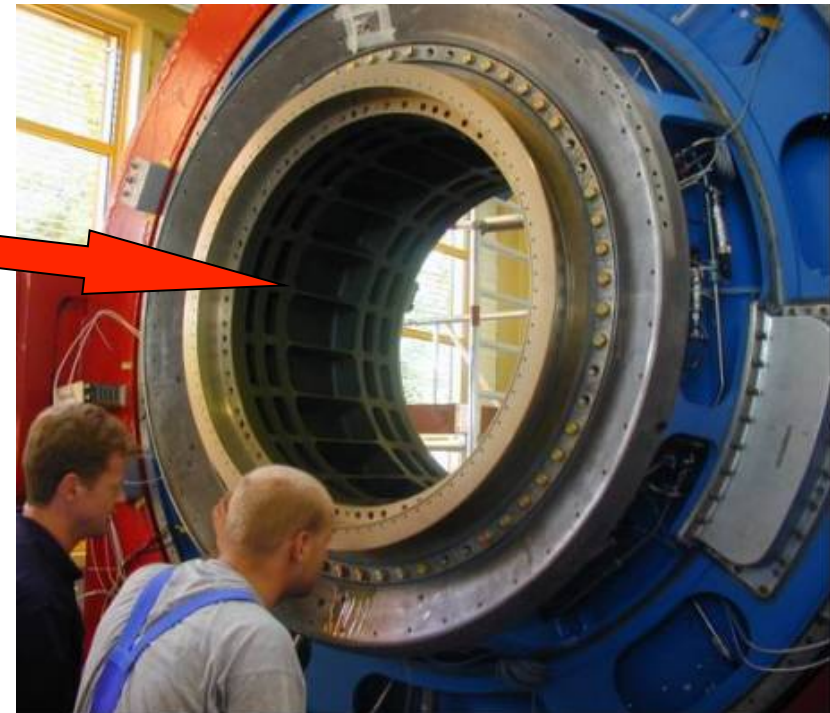
Rotation Isolation Subsystem

Spherical Bearing

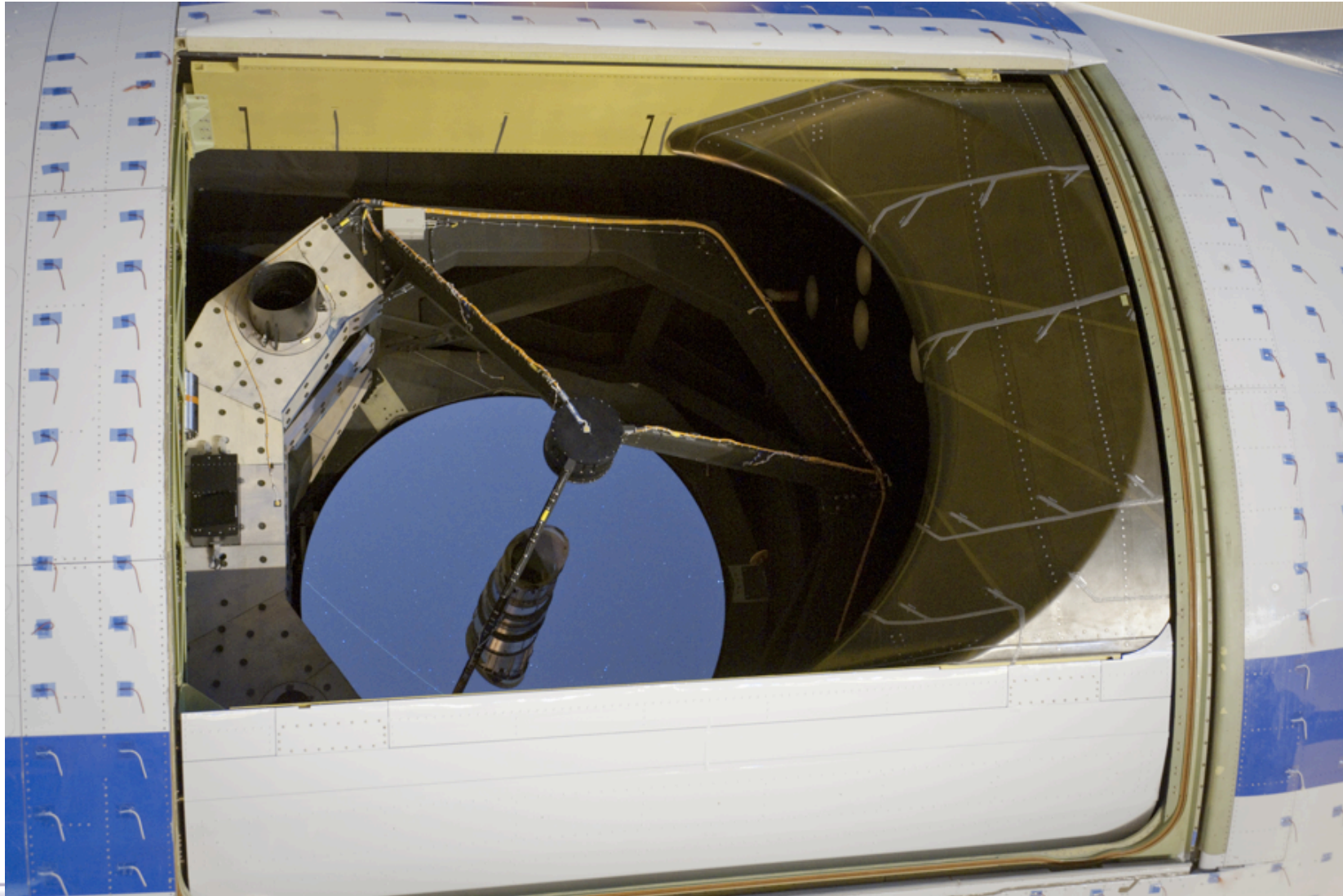
The Bearing Sphere on the Nasmyth Tube



“First Oil“



Coated Mirror and Aperture on SOFIA



Inside the Observatory

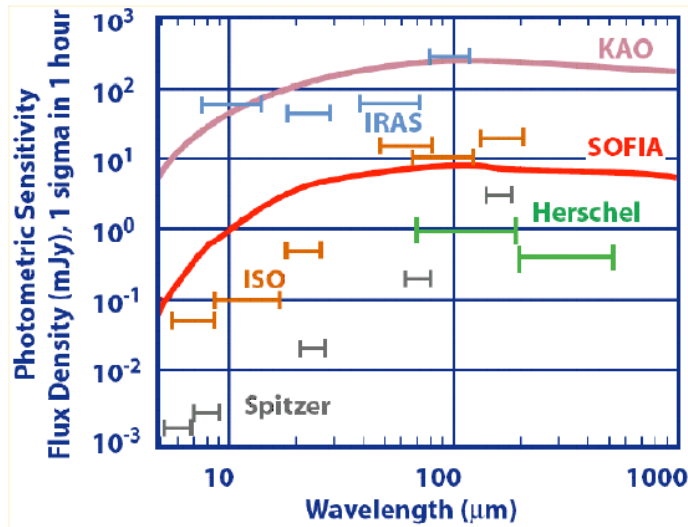


SCIENCE CAPABILITIES and INSTRUMENTS

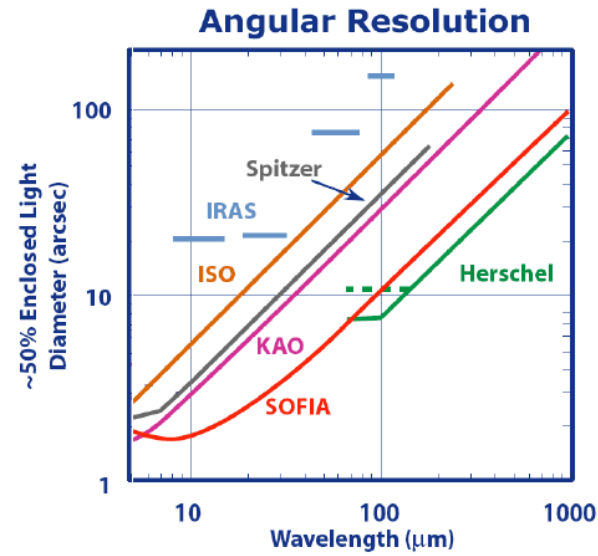
Science Capabilities

- Because of large aperture and better detectors, sensitivity for imaging and spectroscopy similar to the space observatory ISO
- 8x8 arcmin Field of View allows use of very large detector arrays
- Image size is diffraction-limited beyond 25 μm , making it 3 times sharper than the space observatory Spitzer at these wavelengths

Photometric Sensitivity and Angular resolution



SOFIA is as sensitive as ISO

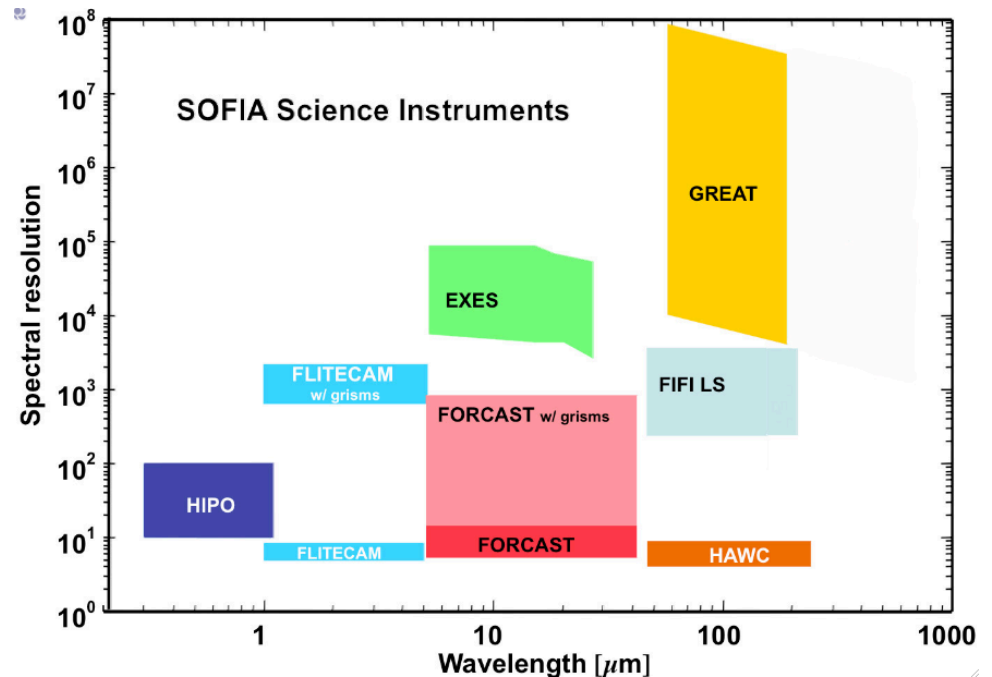


SOFIA is diffraction limited beyond 25 μm ($\theta_{min} \sim \lambda/10$ in arcseconds) and can produce images three times sharper than those made by Spitzer

SOFIA's Instrument Complement

As an airborne mission, SOFIA supports a unique, expandable instrument suite

- SOFIA covers the full IR range with imagers and low to high resolution spectrographs
- 4 instruments at Initial Operations; 7 instruments at Full Operations.
- SOFIA will take full advantage of improvements in instrument technology. There will be one new instrument or major upgrade each year.
- Will support both Facility Instruments and PI Class Instruments



FORCAST: Mid-IR Imager

PI: T. Herter (Cornell Univ.)
herter@astrosun.tn.cornell.edu

Detectors: Dual channel
256 x 256 arrays;
5 – 25 μm (Si:As)
20 – 40 μm (Si:Sb)
Field of View: 3.2' x 3.2'



Science: Thermal and narrow band imaging

Targets: Circumstellar disks, Galactic Center,
Galactic and extragalactic star formation

*NB: Diffraction Limited > 15 microns;
Grism upgrade funded (Ennico et al.)*

GREAT: Heterodyne Spectrometer

PI: R. Guesten, Max-Planck Institut,
Bonn

guesten@mpifr-bonn.mpg.de

Detector: dual channel mixer (HEB);
60 – 200 μm (2 – 5 THz)

Field of View: single element

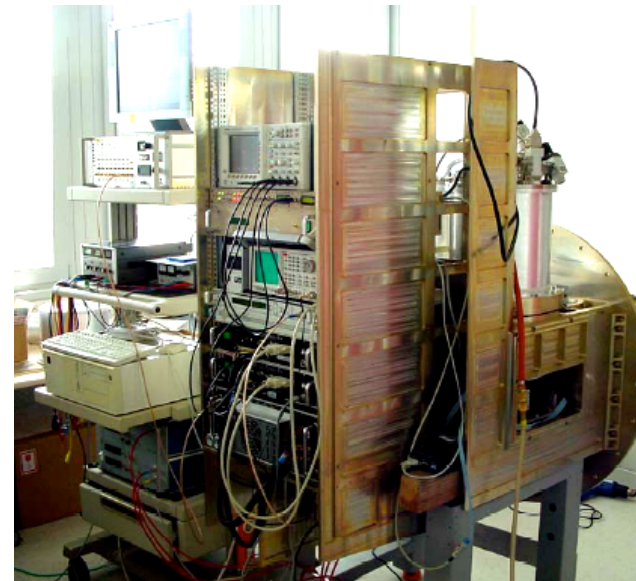
$R = 10^6 \rightarrow 10^8$

Science: Spectroscopy of CII (158 μm),
and HD (112 μm)

Targets: Galactic and extragalactic ISM,
circumstellar shells

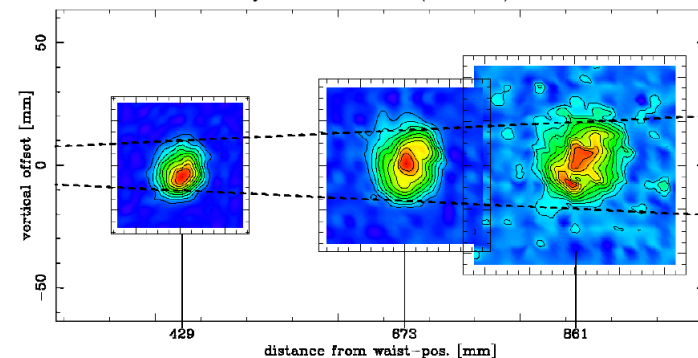
NB: $T_S \sim 1500 \text{ K}$ at 158 μm

High frequency upgrade at 4.7 THz
expected for OI (63 μm).



Theoretical beam-width @ focal plane: 2.55mm

Measured in x-direction : (2.2 \pm 0.2)mm
in y-direction : (2.5 \pm 0.2)mm



Successful lab demonstration of GREAT in Oct 2005

FIFI-LS: Far-IR Spectrometer

PI: A. Poglitsch, Max-Planck Institut, Garching
 alpog@mpe.mpg.de

Detectors: Dual channel 16 x 25 arrays;
 42 – 110 μm (Ge:Ga)
 120 - 210 μm (Ge:Ga stressed)

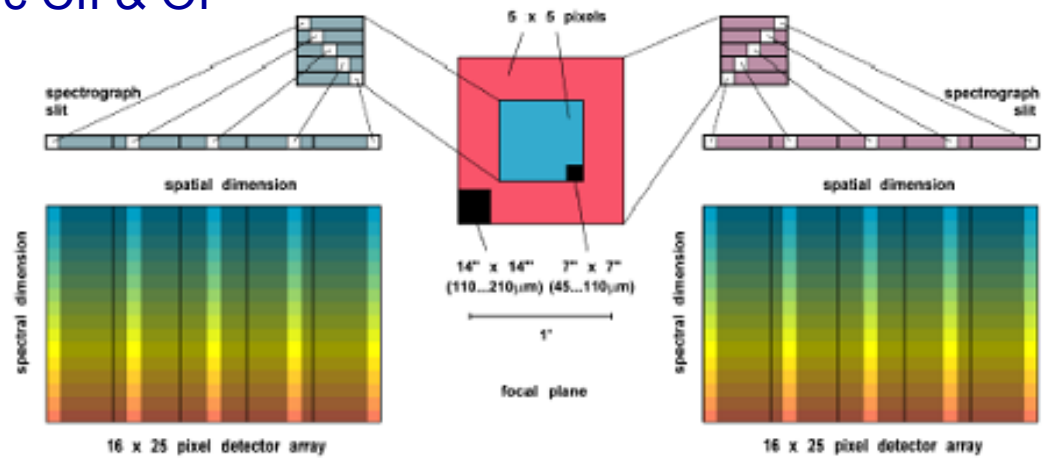
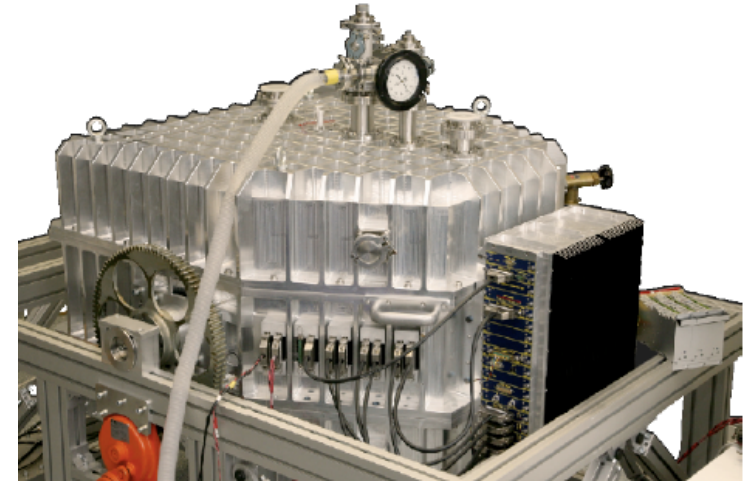
Field of View: 30" x 30" (blue), 60" x 60" (red)

R= 1500 - 6000

Science: Imaging of extragalactic CII & OI

Targets: Extragalactic imaging

*NB: Imaging array is
 5 x 5 pixels*



On sky orientation of 'blue' and 'red' channels

FIRST SCIENCE WITH FORCAST on SOFIA

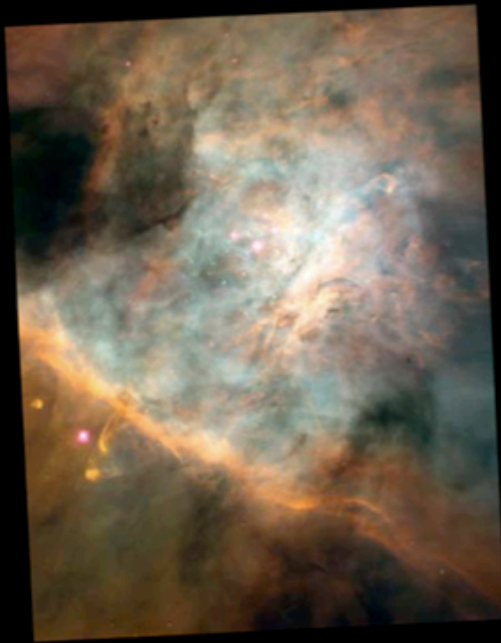
Science with FORCAST

- There was outstanding science from the FORCAST on three 10-hour science flights and an engineering flight in Nov/Dec.
- Observations included: a region where massive stars are forming: Orion (6 to 37 microns)
- An Infrared Galaxy (6 to 37 microns)
- A comet (11, 20, 31 and 37 microns)
- Results were presented at the AAS 1st week of Jan and also a press release. At least eight papers are being worked on and expected to be published this year.

Looking at the Data



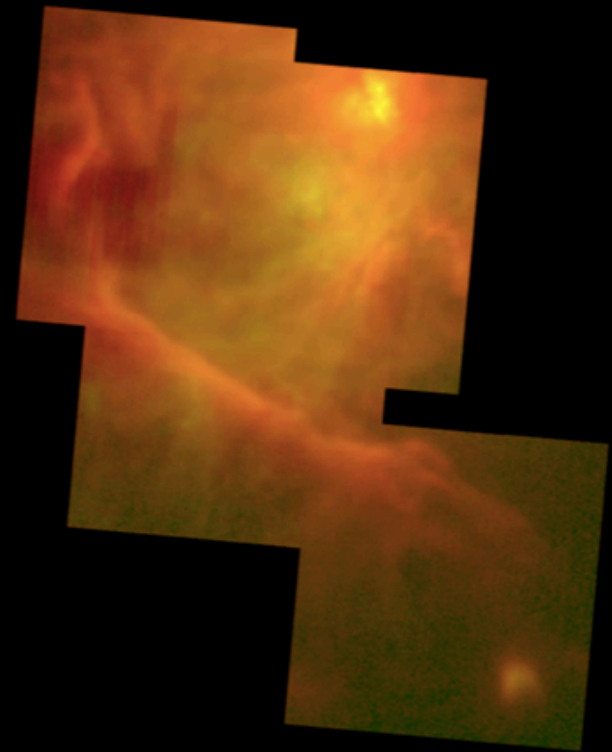
20 (Green) and 37 (Red) Micron Data of Orion Nebula



Visible light
(HST, C. O'Dell and S. Wong)



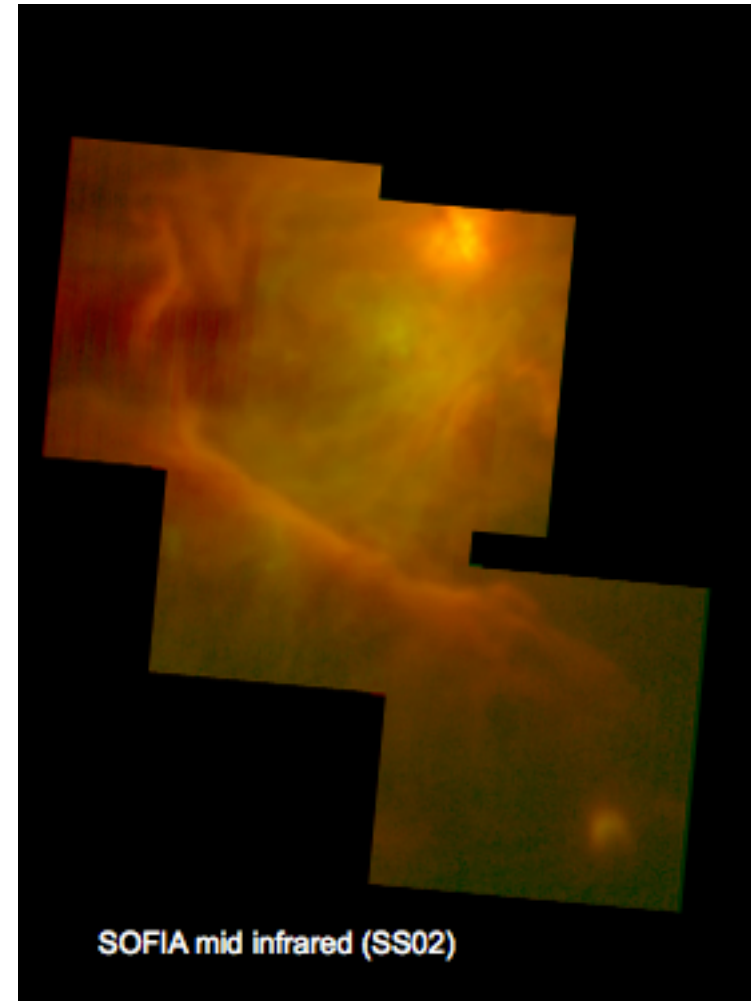
Near infrared
(ESO, M. McCaughrean)



SOFIA mid infrared
(SS02)

Orion Nebula at Mid IR with 3 arcsec Resolution

- Focus on the very bright and luminous BNKL region
- Total power output similar to the bright young trapezium stars
- But ALL of the radiation is in the IR.
- Major questions:
 - What is causing all the radiation?
 - Still forming stars converting gravity to luminosity.
 - Very young stars just starting their nuclear burning.
 - An explosive event 500 yrs ago.
- * Most radiation at wavelengths longer than 30 microns. Best view ever!!



What new do we find?

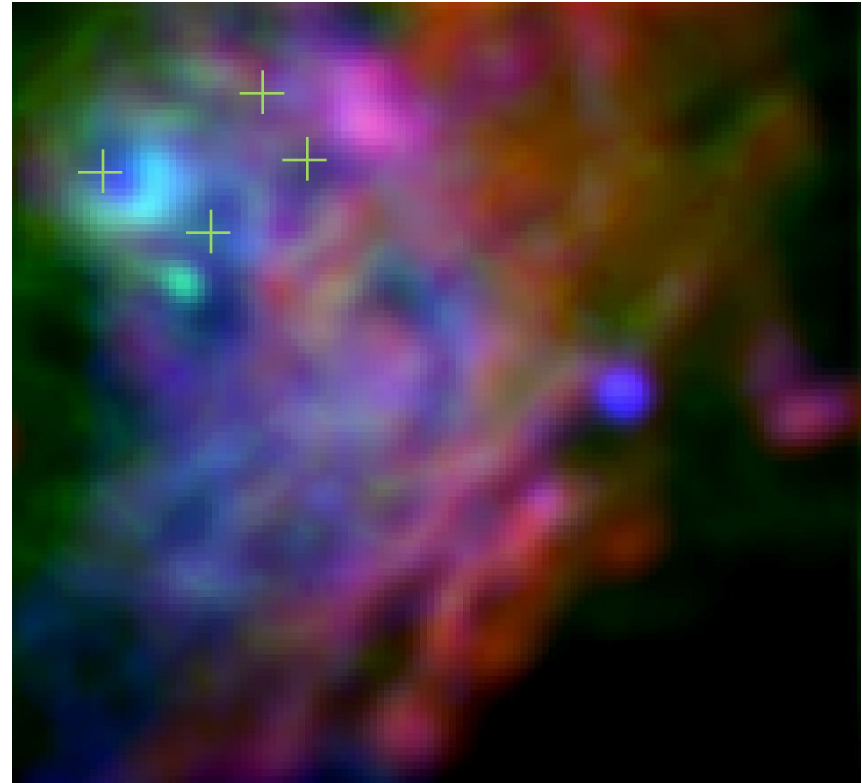
- BN is the hottest source and is not seen at 37 microns.
- The source IRc2 (bright at 12 microns) and radio source “I” are not seen at 37 microns. This is a surprise.
- There is in fact a hole in the emission at IRc2/“I”
- The brightest source at 37 microns is IRc4. Does seem to be heated from within (no color gradients) Also one of the coldest and is the most luminous. ($T \sim 100\text{K}$).
- Need more data. Results from Herschel or HAWC on SOFIA. Also Spectra... EXES. ALMA

3-color images of Trapezium region

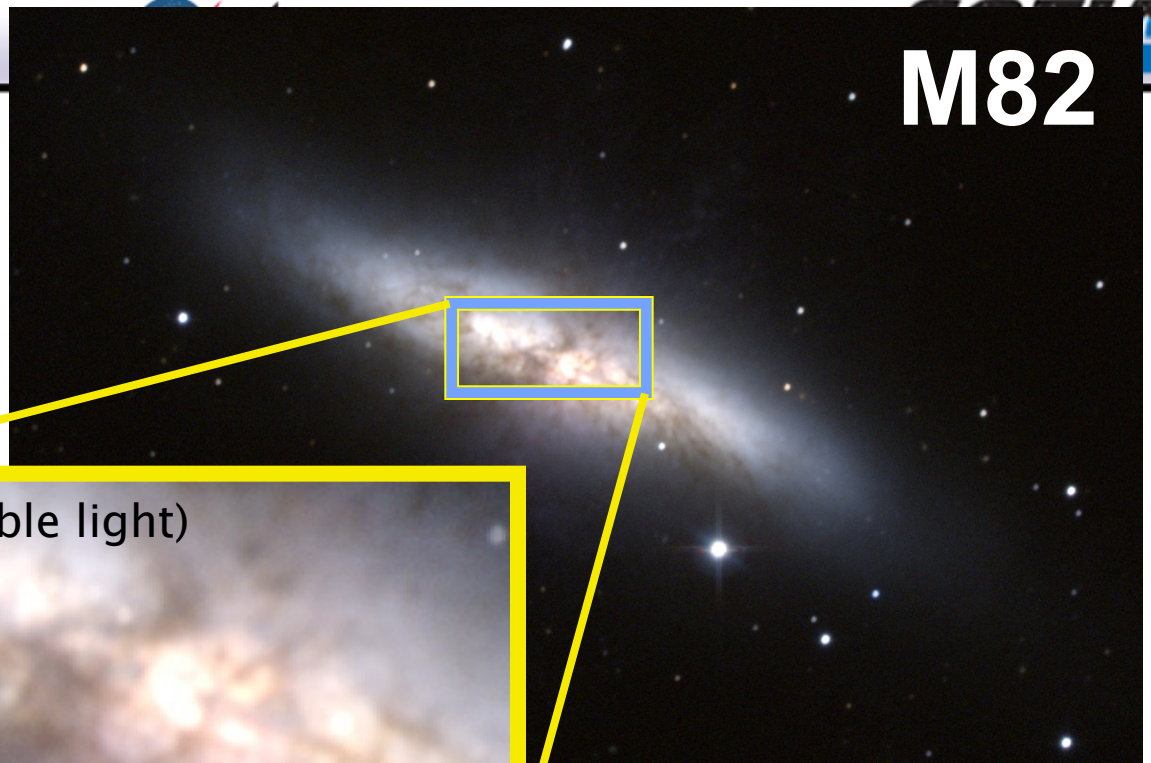
7um, 19um, 37 um

DMRM Deconvolution

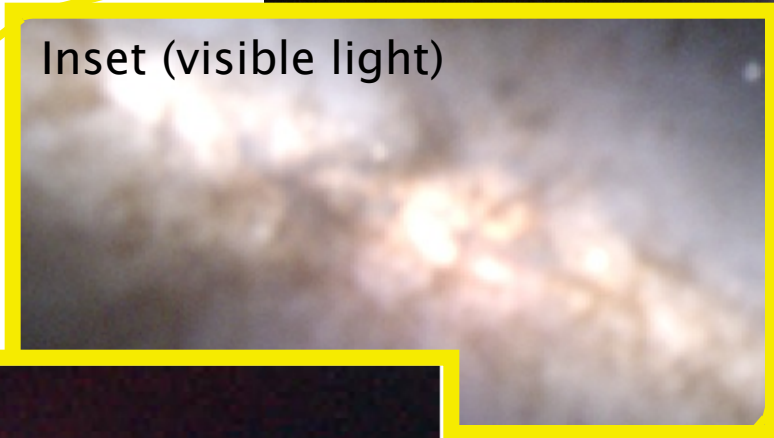
- New source is pink, just right of the Trapezium. It is cold and strong at 37 microns.
- Could be related to Trapezium or a dust and gas clump forming stars like IRc4.
- How do we tell which is correct?
 - Closer look at our data.
 - More data: Herschel or HAWC, FiFi LS, EXES. GREAT with SOFIA,
 - Association with radio or x-ray source.



M82



Visible light image

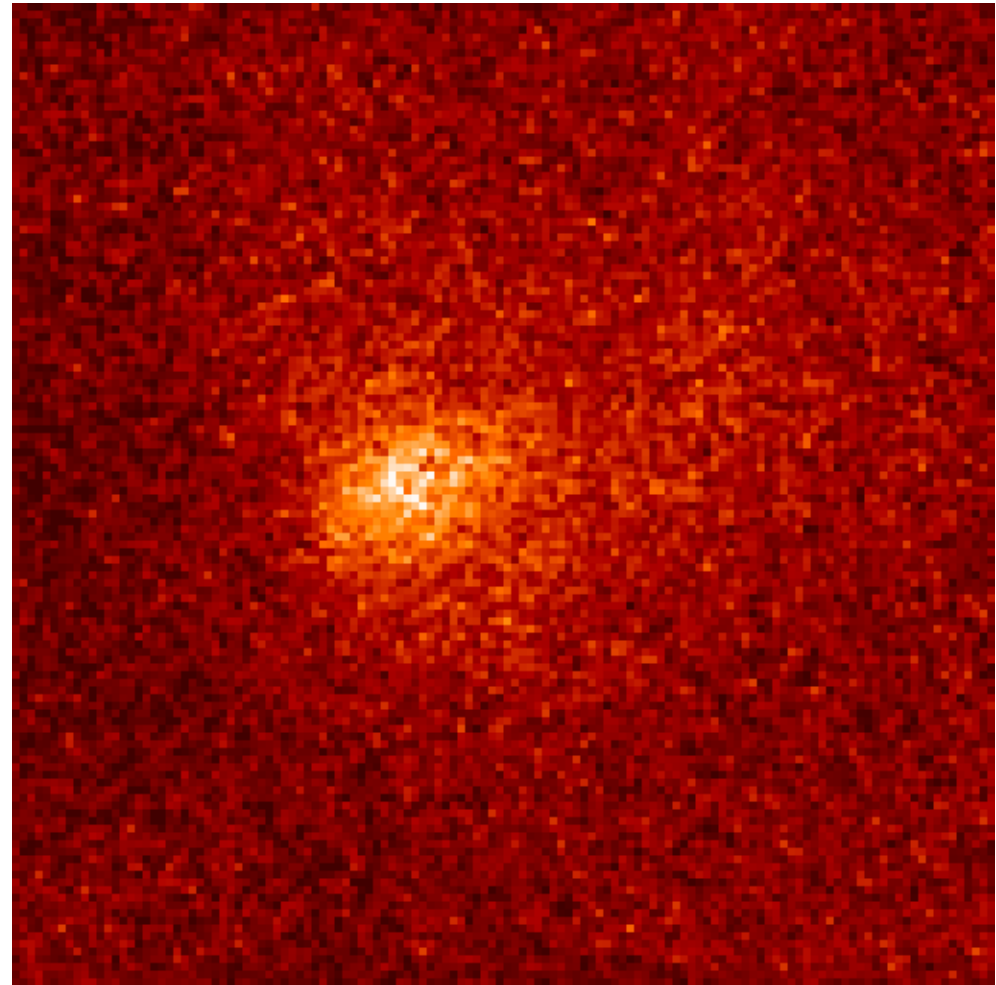


Inset (visible light)



SOFIA infrared image (19.7, 31.5, and 37.1 μm)

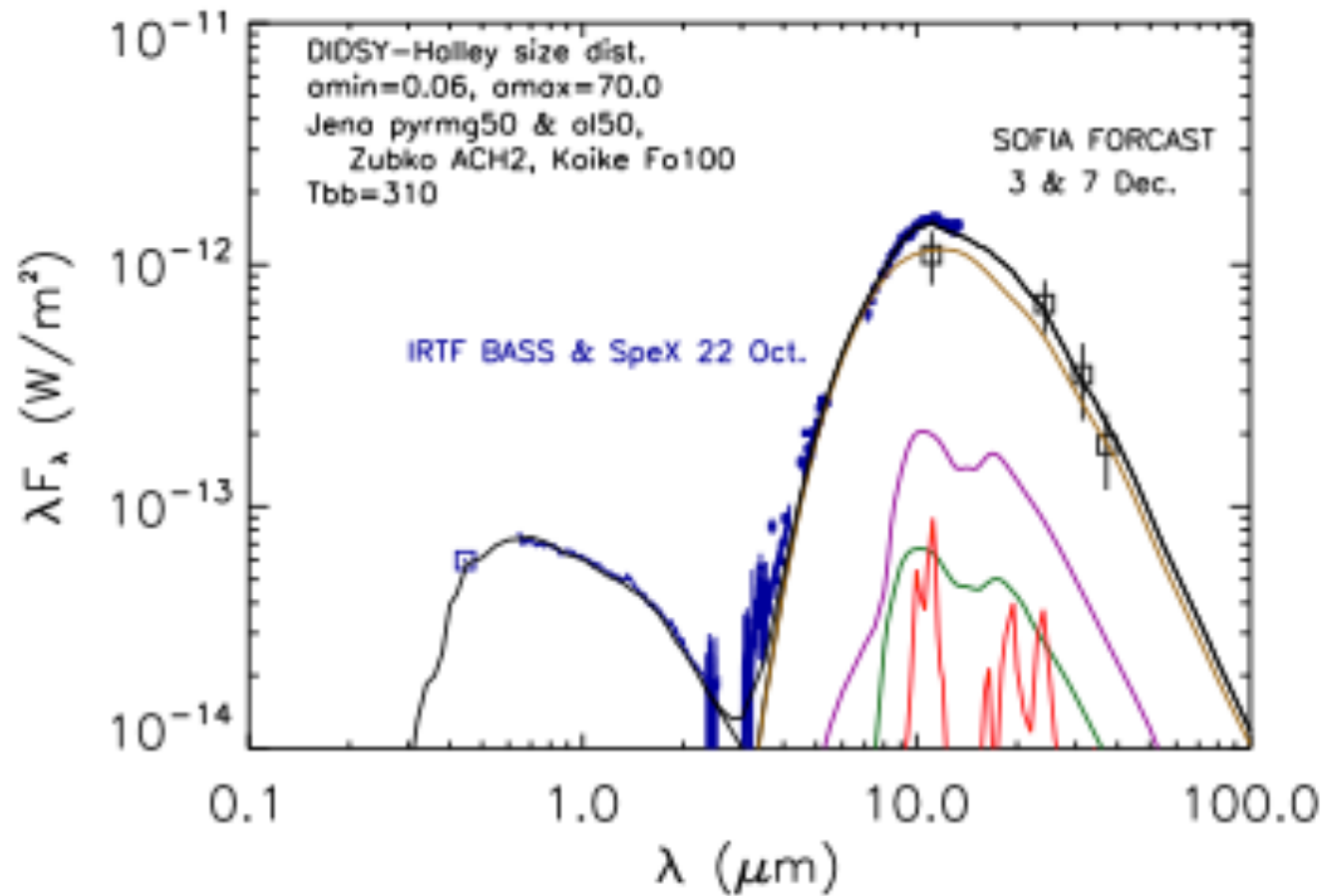
Comet Hartley 2



31.4 microns

- 31 and 37 Micron data of Comet that had a fly by in Nov.

Energy Distribution of Hartley 2 (Meech et al)

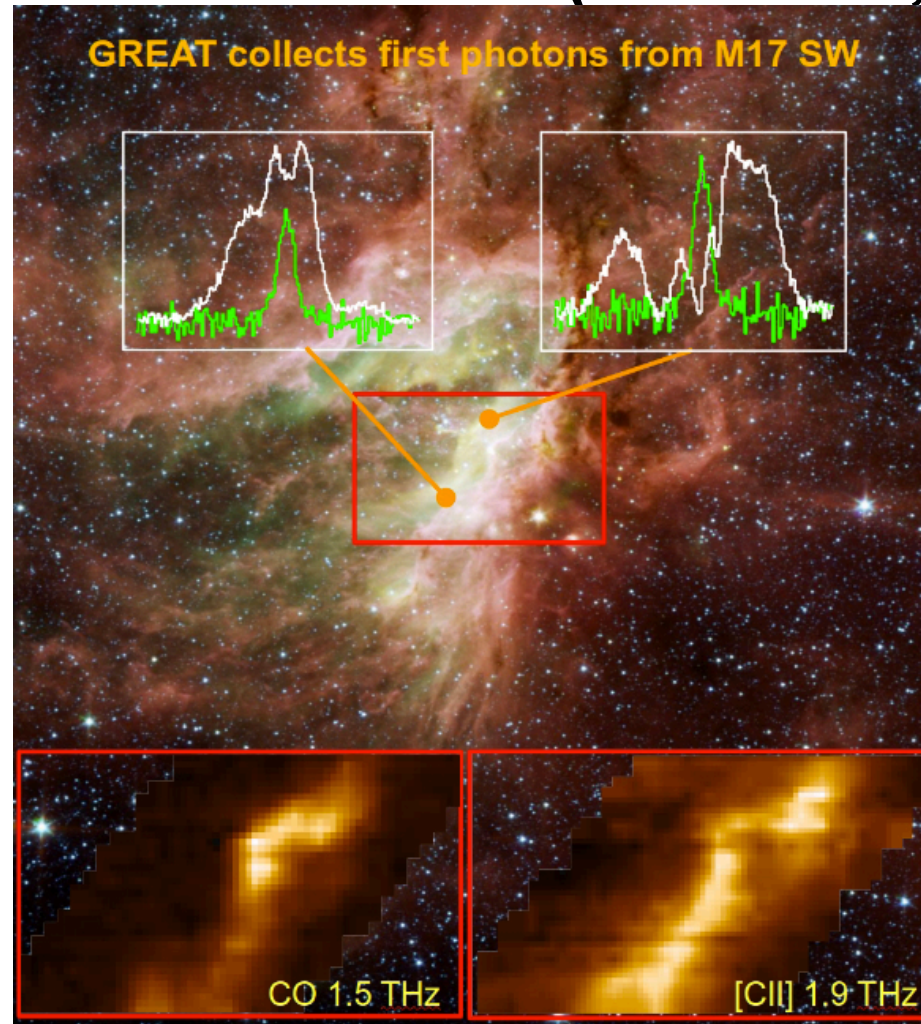


Technical Results from First Science

- Image Stability was very good. Allowed near diffraction limited imaging at 37 microns. FWHM images ~ 3 arcsec
- Infrared Sensitivity is what was expected.

FIRST SCIENCE WITH GREAT on SOFIA

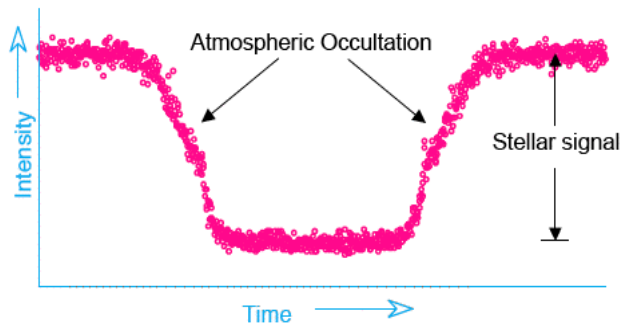
First Science with GREAT (White CII, Green CO)



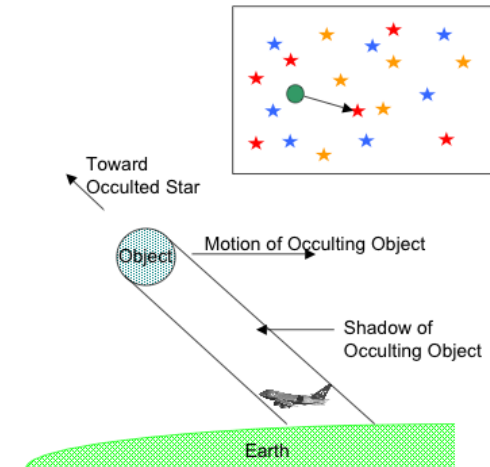
FUTURE SCIENCE

Occultation astronomy with SOFIA

SOFIA will determine the properties of Dwarf Planets in and beyond the Kuiper Belt



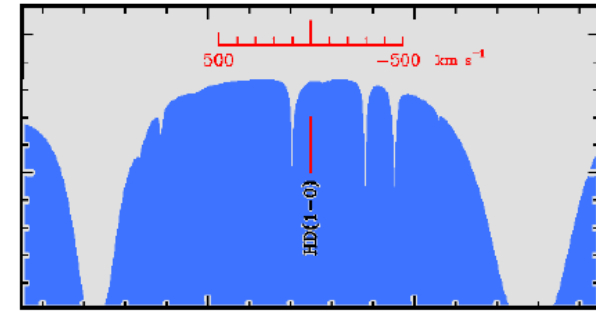
Pluto occultation lightcurve observed on the KAO (1988) probes the atmosphere



- SOFIA can fly anywhere on the Earth, allowing it to position itself under the shadow of an occulting object.
- Occultation studies with SOFIA will probe the sizes, atmospheres, and possible satellites of newly discovered planet-like objects in the outer Solar system.
- The unique mobility of SOFIA opens up some hundred events per year for study compared to a handful for fixed observatories.

Cold Molecular Hydrogen using HD

SOFIA will study deuterium in the galaxy using the ground state HD line at 112 microns. This will allow determination the cold molecular hydrogen abundance.



Atmospheric transmission around the HD line at 40,000 feet

Deuterium in the universe is created in the Big Bang.

Measuring the amount of cold HD ($T < 50\text{K}$) can best be done with the ground state rotational line at 112 microns accessible with SOFIA.

Detections with ISO means a GREAT high resolution spectroscopic study possible.

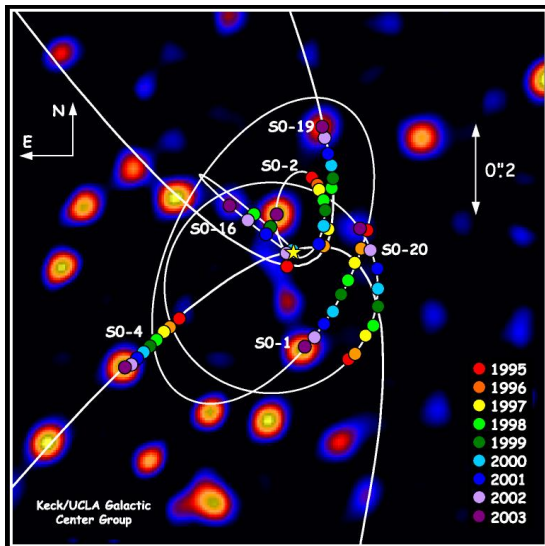
HD has a much lower excitation temperature and a dipole moment that almost compensates for the higher abundance of molecular hydrogen.

As pointed out by Bergin and Hollenbach, HD gives the cold molecular hydrogen

In the future could be used much like the HI 21cm maps but for cold molecular gas.

Star Formation in the Center of the Galaxy in the Presence of a Massive Black Hole

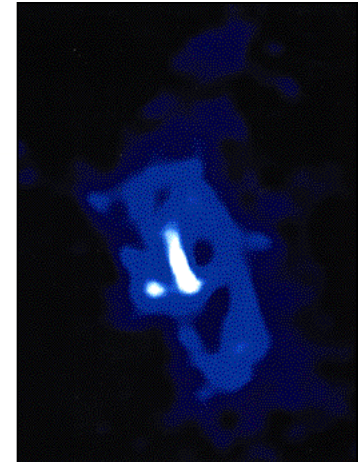
SOFIA will help determine how
Stars form in the presence of
a Massive Black Hole

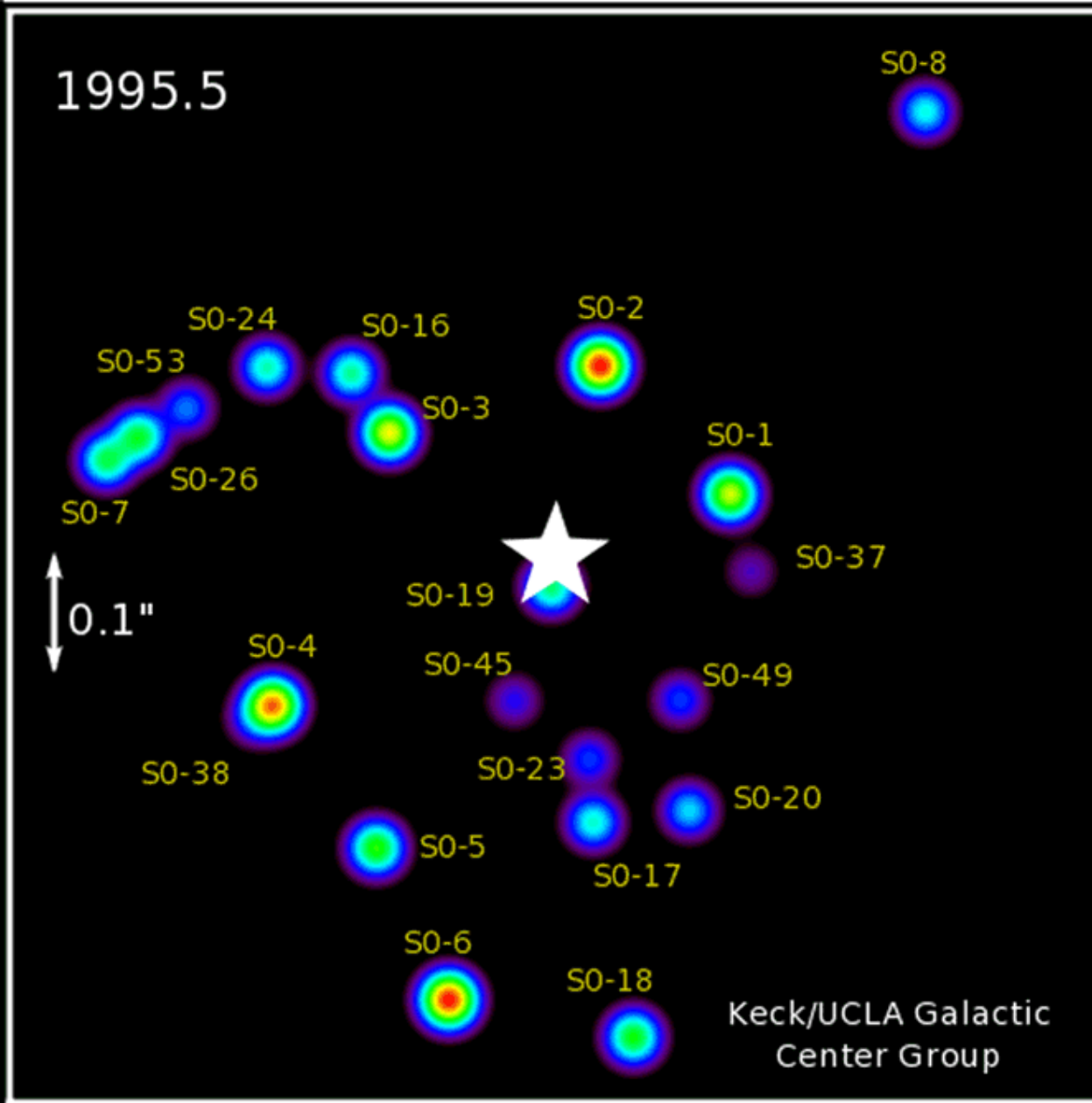


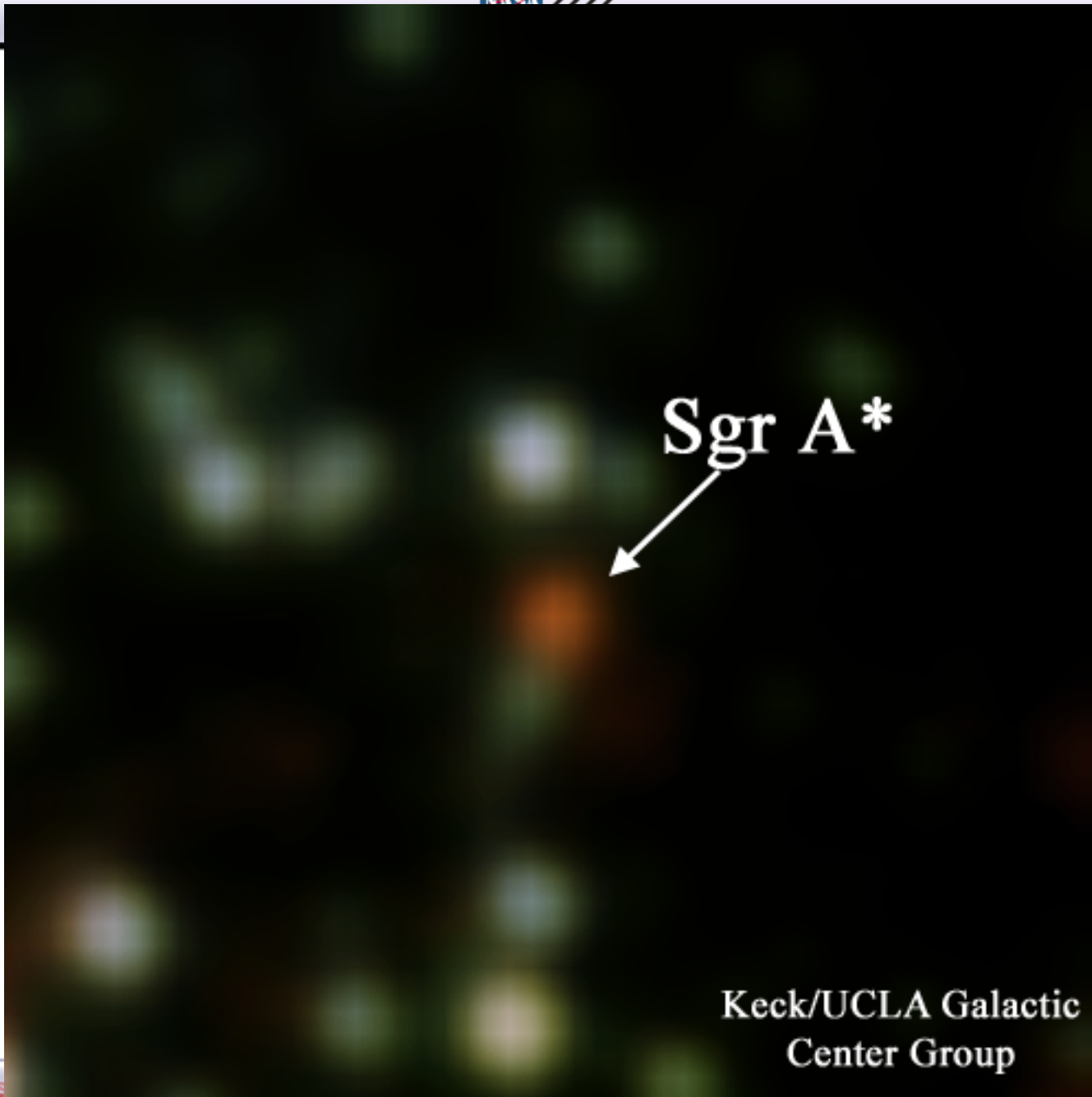
Astronomers at ESO and Keck have detected fast moving stars revealing a 4×10^6 solar mass black hole at the Galactic Center

One of the major discoveries of the KAO was a ring of dust and gas orbiting the very center of the Galaxy at $r=1\text{pc}$

Young newly formed stars have also been found orbiting the black hole within 1000au





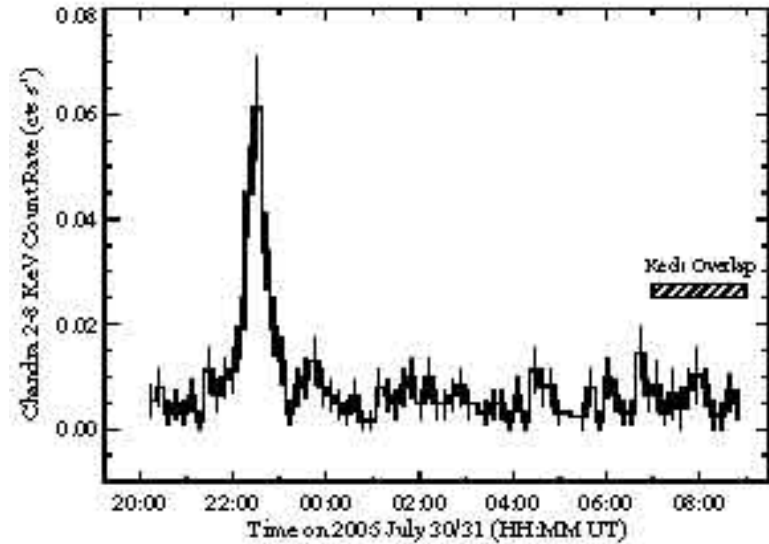
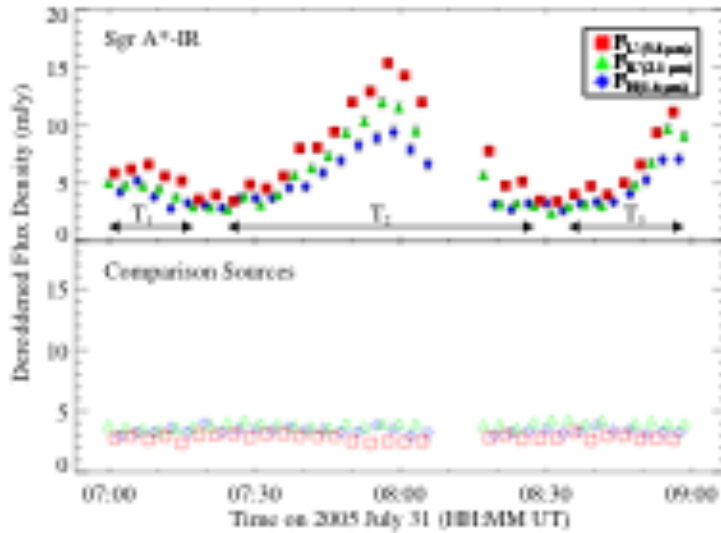


Sgr A*



Keck/UCLA Galactic
Center Group

Variability of Sgr A* in IR and X-ray



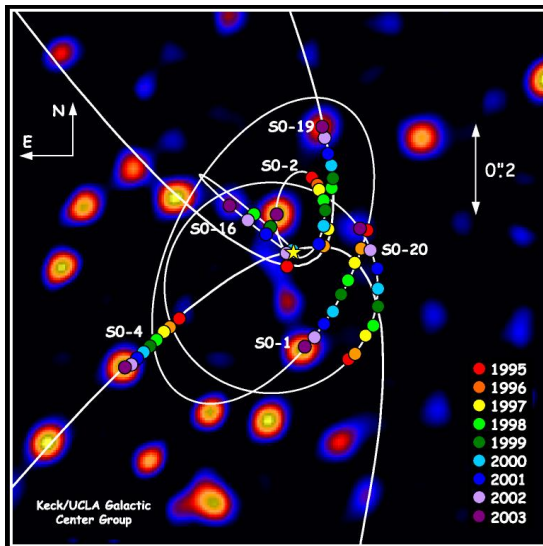
Hornstein et al, 2007 ApJ 667 p900

Sgr A* and IR Variability

- When ever we look we see 1-4 micron correlated variability
 - Changes on the order of a factor of a few
 - Little or no color change
 - No time frequency stands out
 - X-ray variability seems to be different with much larger flares >10 and longer time scales. However correlated X=ray and IR variability reported.
 - Submillimeter and IR correlation reported with a 100 sec delay
- Does it make sense to look for Sgr A* with SOFIA?
 - The source is red, but probably not red enough
 - Would require a major flare
 - We will look when ever we make an observation of the region
 - Polarization might help

Star Formation in the Center of the Galaxy in the Presence of a Massive Black Hole

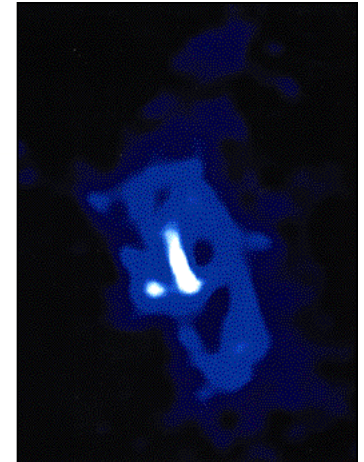
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- Did these young massive stars form in the ring of dust and gas?
- If so, how do they get so close to the black hole?
- Can we detect Sgr A* in a flared event?
- SOFIA with its high angular and spectral resolution is well placed to help answer these questions over the next 20 years

Schedule & Future Opportunities

SOFIA Schedule (Major Milestones)

- First Re-Flight Occurred April '07
- Mirror Coated July 08
- Door Drive Delivered Spring 09
- First Open Door Flights Dec 09
- First Light and Heat May 10
- Full envelope expansion to 45K ft Sept 10
- First Science FORCAST Dec 10
- First Science GREAT April 11
- Community Science May 11
- Next call for new Instruments 2011

Observer Opportunities

- Selection for Community support of Early Short Science with FORCAST and GREAT has been made. Paul Harvey (UC Boulder), Mark Morris (UCLA) for FORCAST, David Neufeld (JHU) for GREAT
- The Call for more extended observing (~18 Flights) in Basic Science in CY 11 with FORCAST and GREAT. Proposals Selected and being scheduled from Spring/Summer 2011.
- Future calls every year with additional 1st generation instruments. Next call in Fall 2011.
- Open Observatory with Facility Instruments

Next Call for New Instruments

- The next call for instruments will be after First Science CY '11. A workshop in 2010 June 6,7 and 8 was held Monterey CA. Call and selection of instruments will be done by NASA Headquarters.
- We are considering:
 - New Science Instruments both FSI and PSI
 - Studies of instruments and technology
 - Upgrades to present instruments
- There will be additional calls every 3 years.
- There will be one new instrument or upgrade per year
- Approximate funding for new instruments and technology is ~ \$10 M/yr

Summary

- Program making great progress!
 - Aircraft handles well even with door open.
 - Can now get Science up to 45,000ft
 - First Science with FORCAST was a great success.
 - GREAT First Science started.
 - Community science starts in May
- SOFIA will be one of the primary facilities for far-IR and sub-millimeter astronomy for many years

