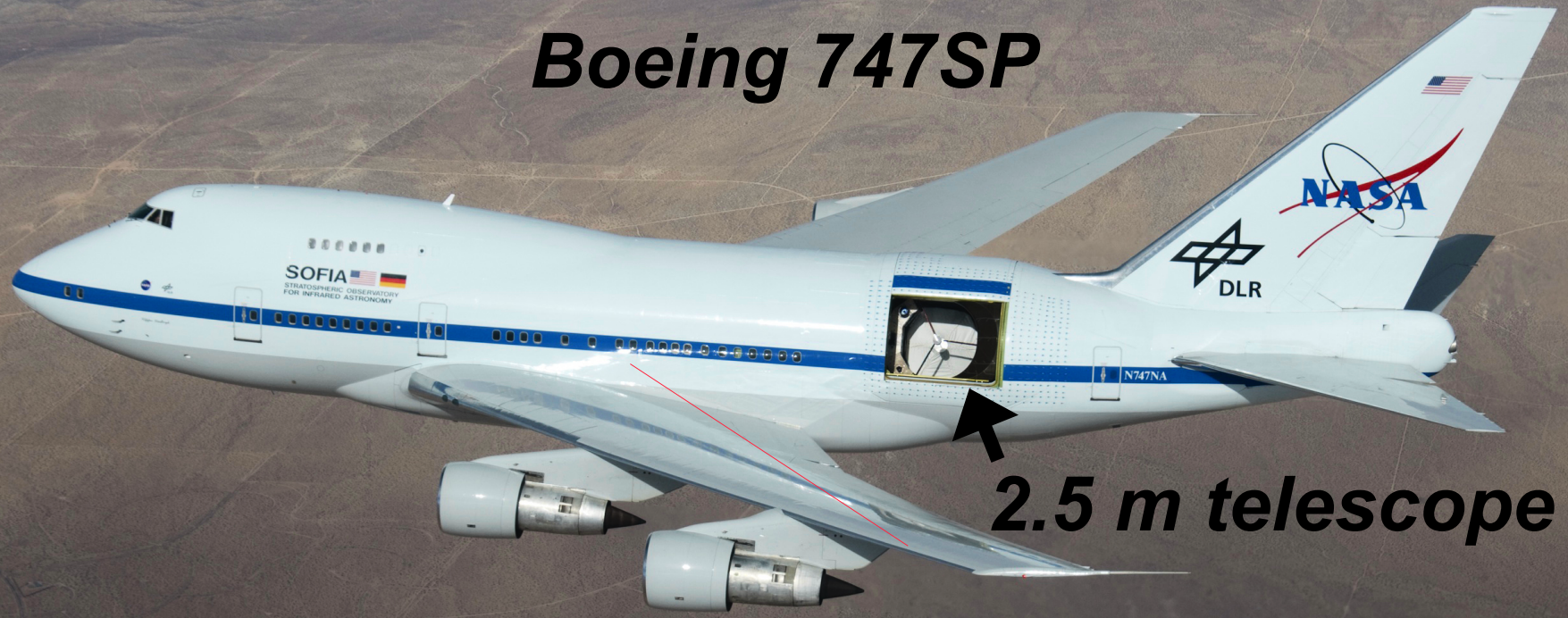
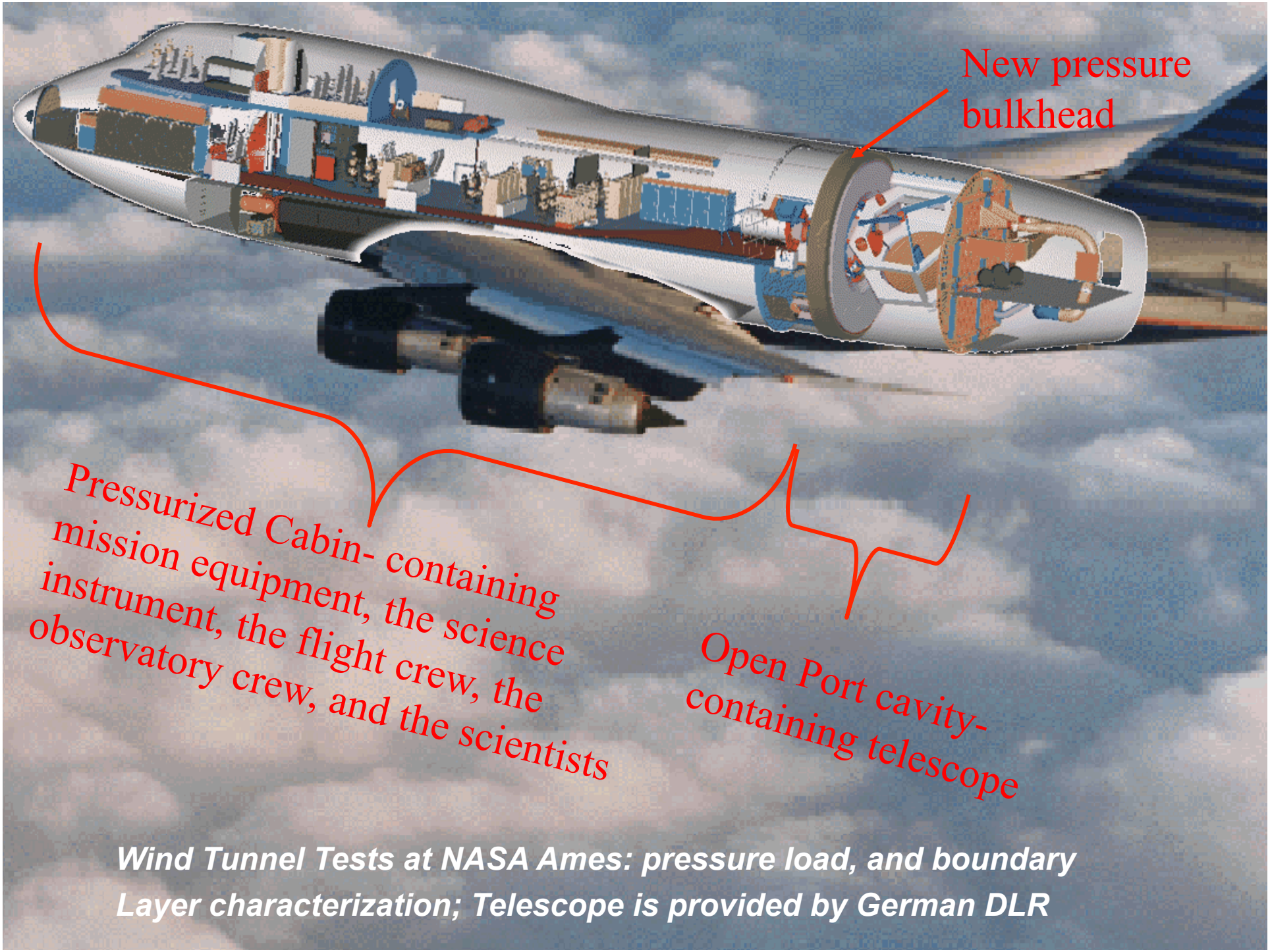
The Stratospheric Observatory for Infrared Astronomy (SOFIA)



Capabilities for Studying Dust and the ISM in the Herschel Era and Beyond

J. Rho, H. Zinnecker and SOFIA team

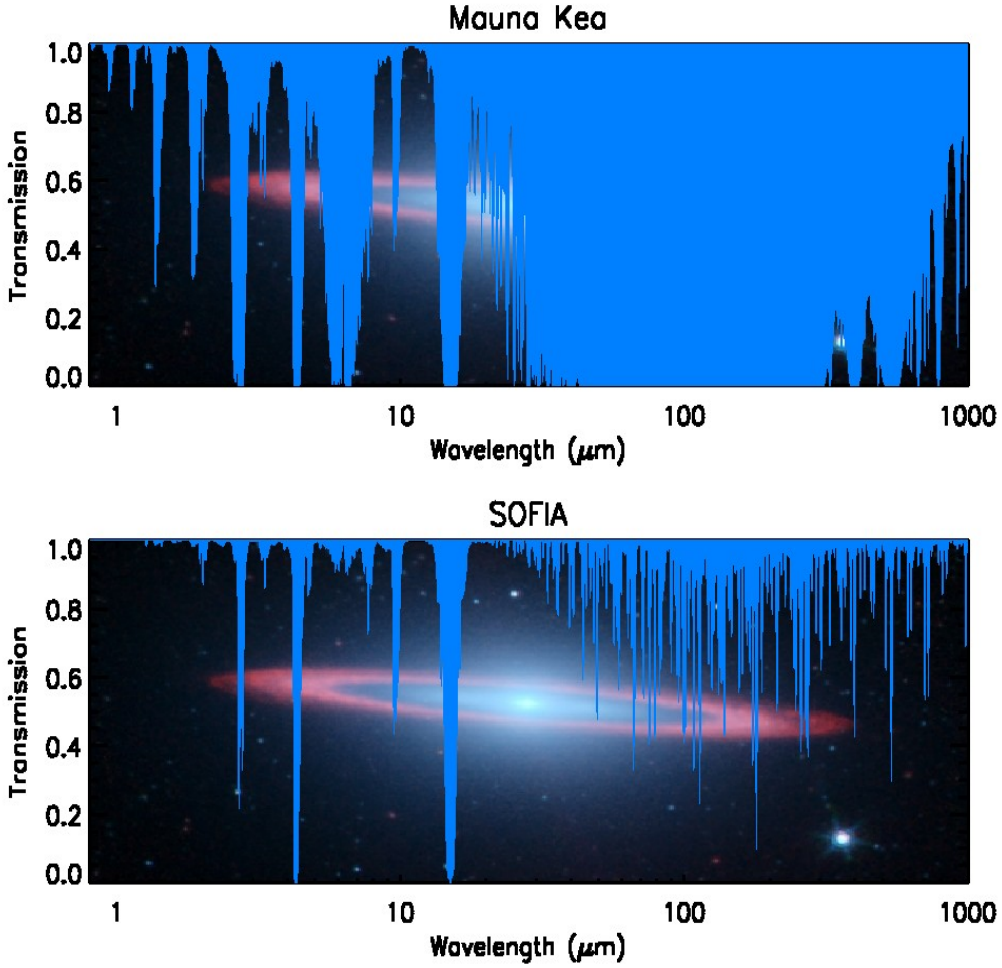

New pressure bulkhead
Pressurized Cabin- containing mission equipment, the science instrument, the flight crew, the observatory crew, and the scientists
Open Port cavity- containing telescope
Wind Tunnel Tests at NASA Ames: pressure load, and boundary Layer characterization; Telescope is provided by German DLR

Outline of the talk

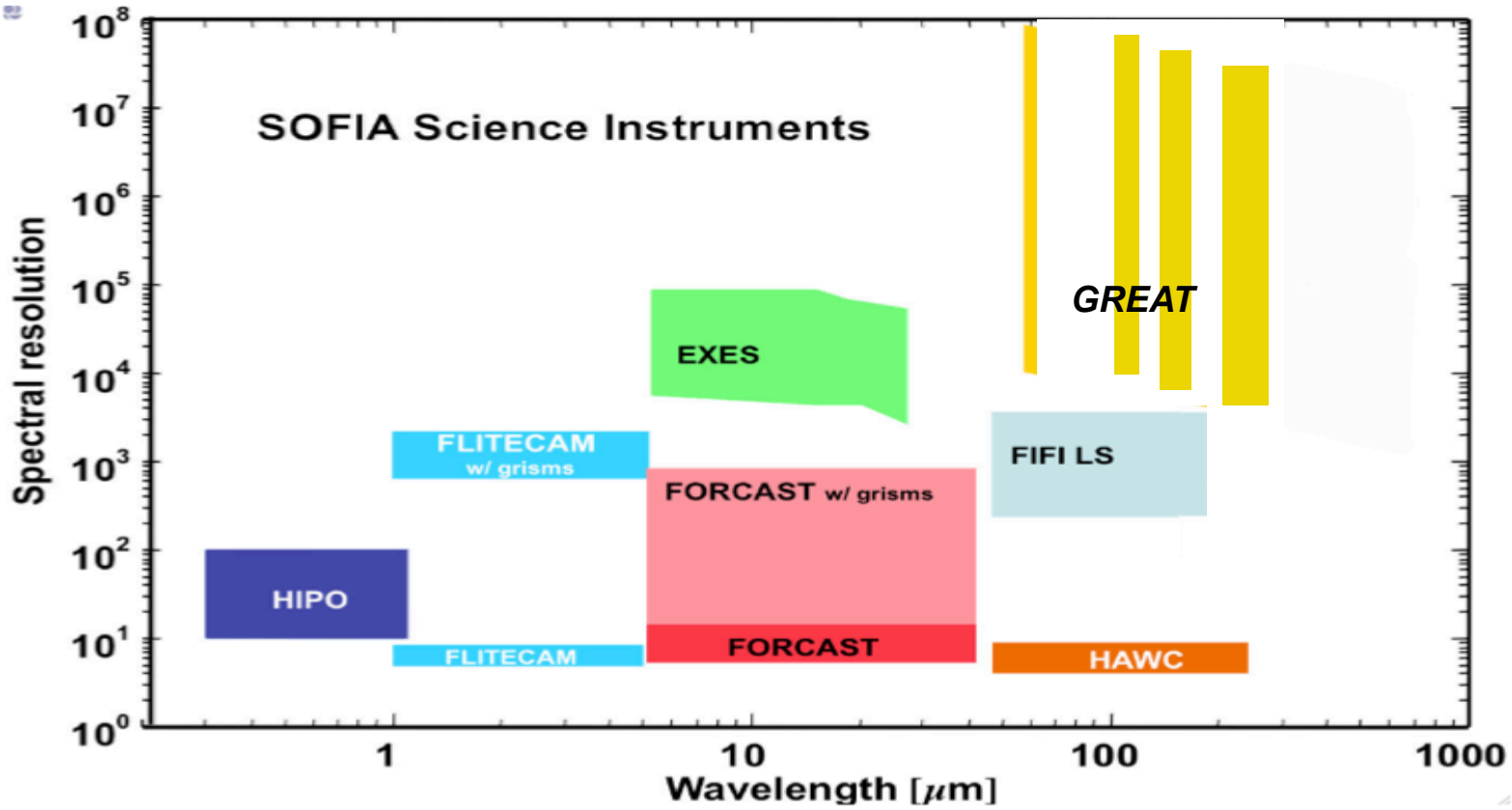
- Overview and Advantage of SOFIA
- Overview of SOFIA Instrument capabilities
- Science results with mid-IR camera FORCAST:
  Jupiter and Orion
- Science results with heterodyne spectrometer GREAT:
  [C II] and CO emission of M17 SW
- SOFIA Far-IR and Submm Instrument Capabilities:
  Comparison with those on the Herschel
- SOFIA mid- and near-IR Instrument Capabilities
- Upcoming Calls for Proposal
  - 2nd Generation Instrument Call (Just released)
    http://nspires.nasaprs.com
    (SOFIA Second Generation Instruments: NNH08ZDA009O_SOFIA)
  - Call for Observing Proposals (Cycle 1)

Overview and Advantages of SOFIA

- *Above 99.8% of the water vapor; transmission at 14 km >80% ; emphasis on the obscured IR and submm regions from 30 to 300 µm*
- *Instrumentation: wide variety, rapidly interchangeable, state-of-the art – SOFIA is a "new" observatory every few year*
- *Observatory comes back to base every night*



Excellent Spectroscopy Capabilities: R=10^2 to 10^8

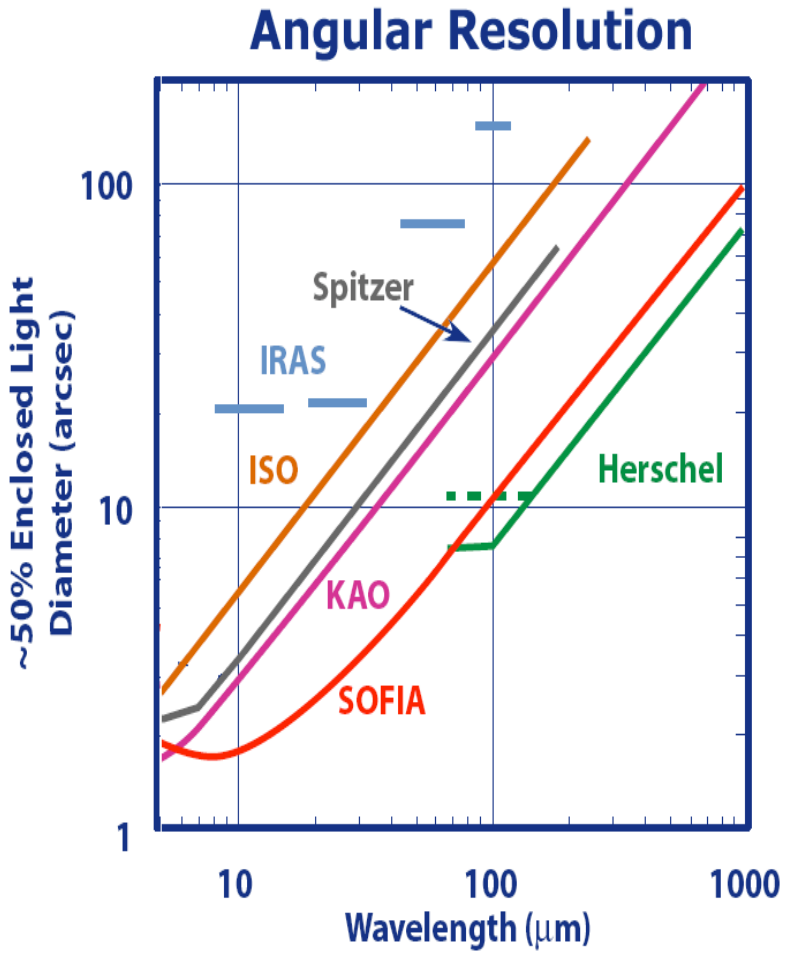


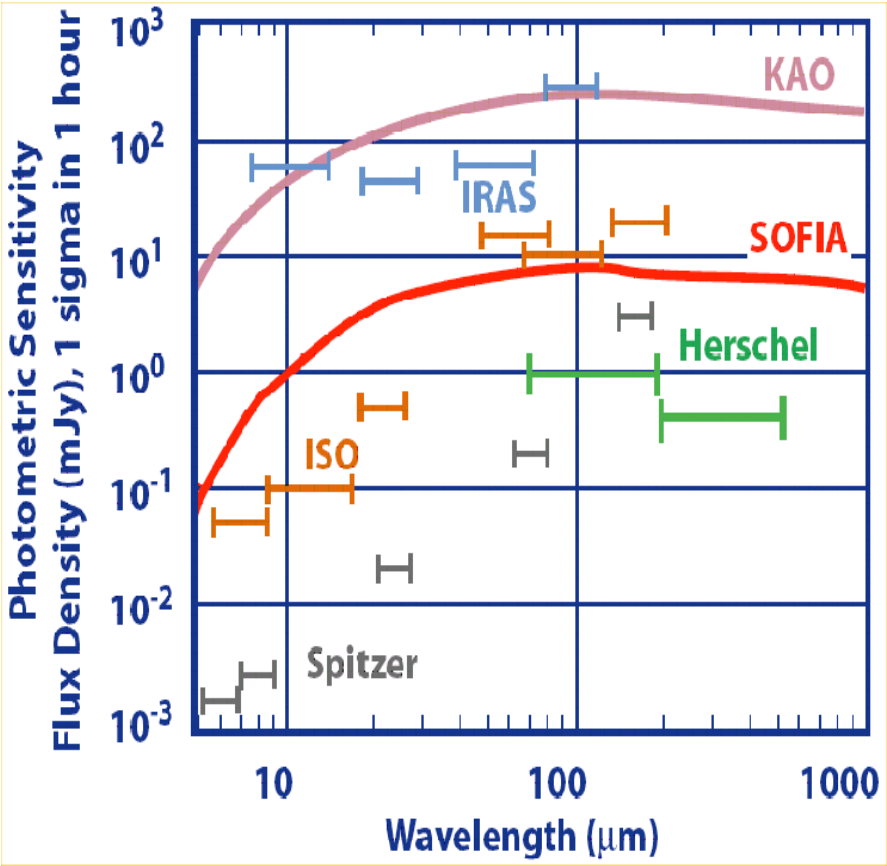
I. *Far-IR: SOFIA is comparable to Herschel; spectral mapping is efficient.*

II. *Mid-IR: sensitivity is comparable to ISO, but produce a higher spatial resolution including high spectral resolution*

III. *Near- to mid-IR (1-5 micron): less atmospheric absorption than ground*

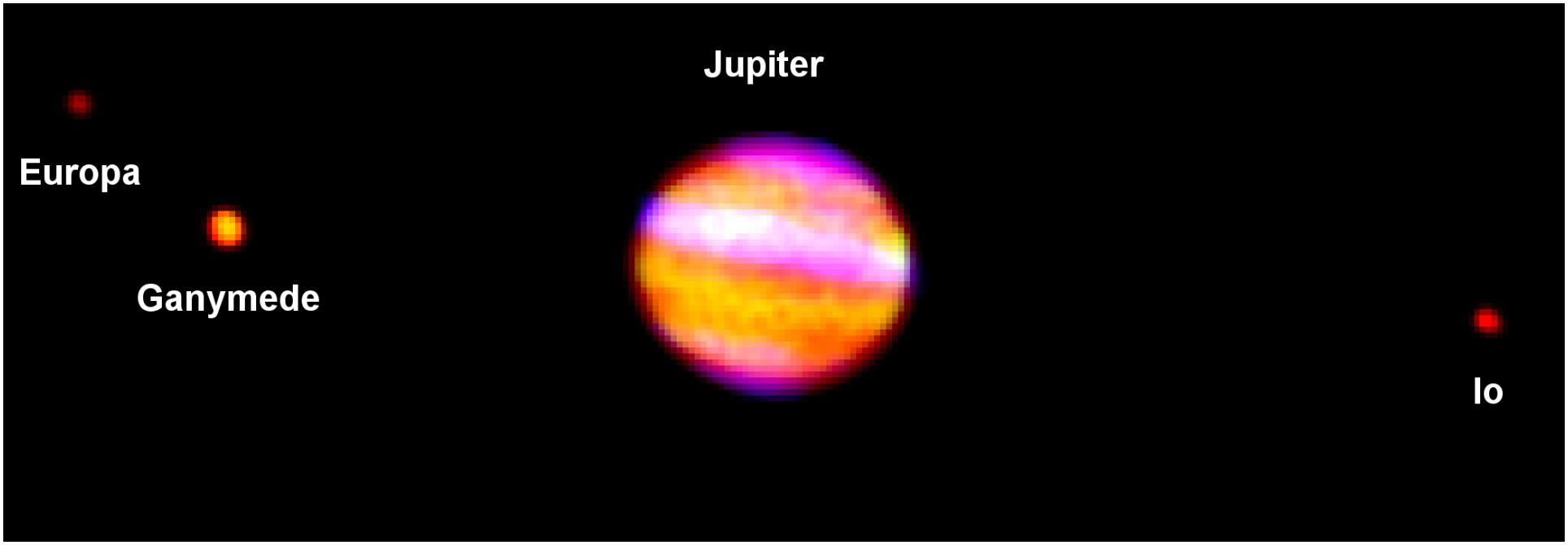
Photometric Sensitivity and Angular resolution





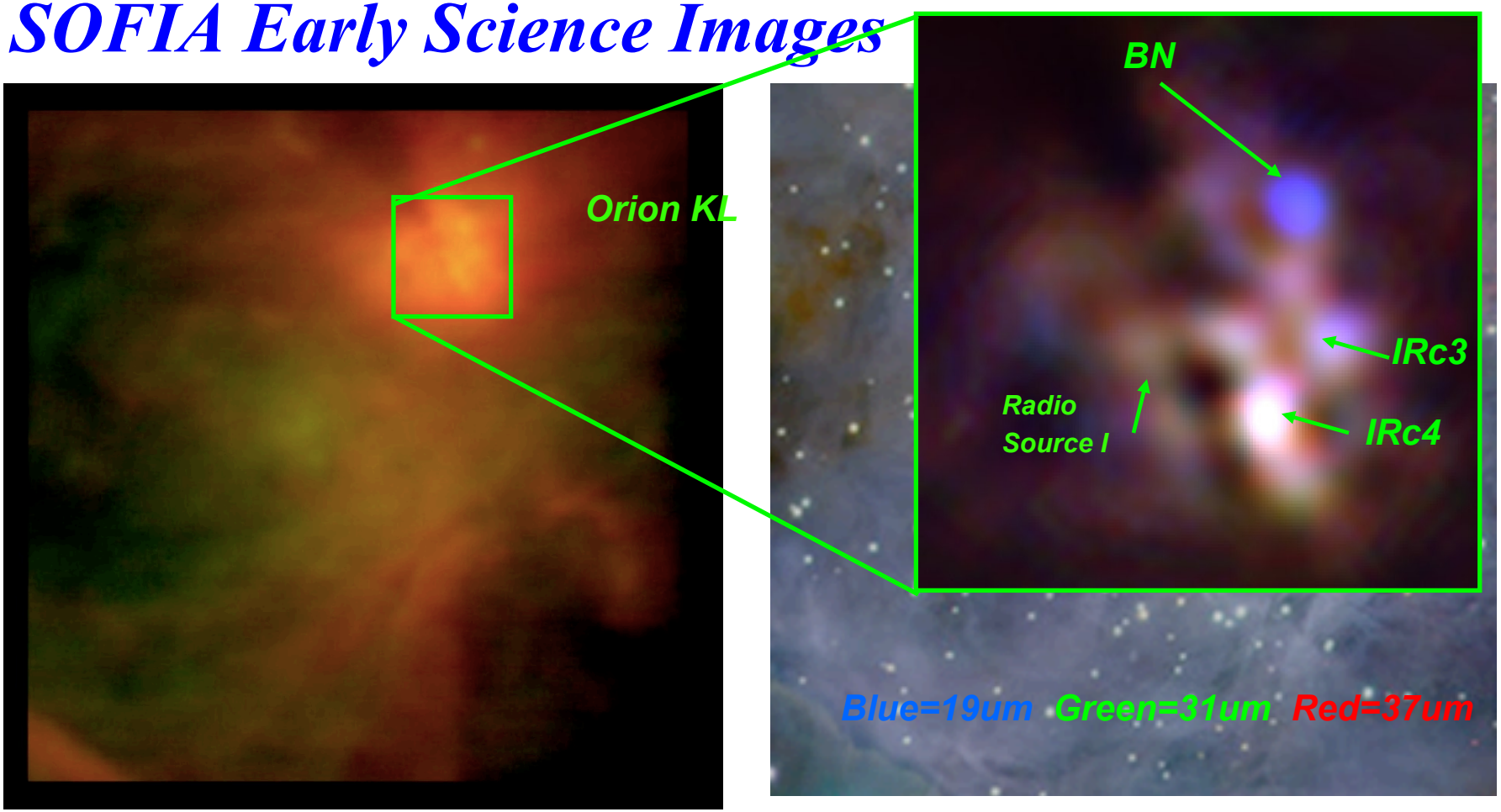
SOFIA is comparable to Herschel within a factor of 3-8 sensitivity.

First Light on May 26, 2011 UT: We demonstrated imaging capability of FORCAST from 5 to 37 microns with 3-4 arcsecond FWHM



Red = 37.1 μm, Green = 24.2 μm, Blue = 5.4 μm

SOFIA Early Science Images

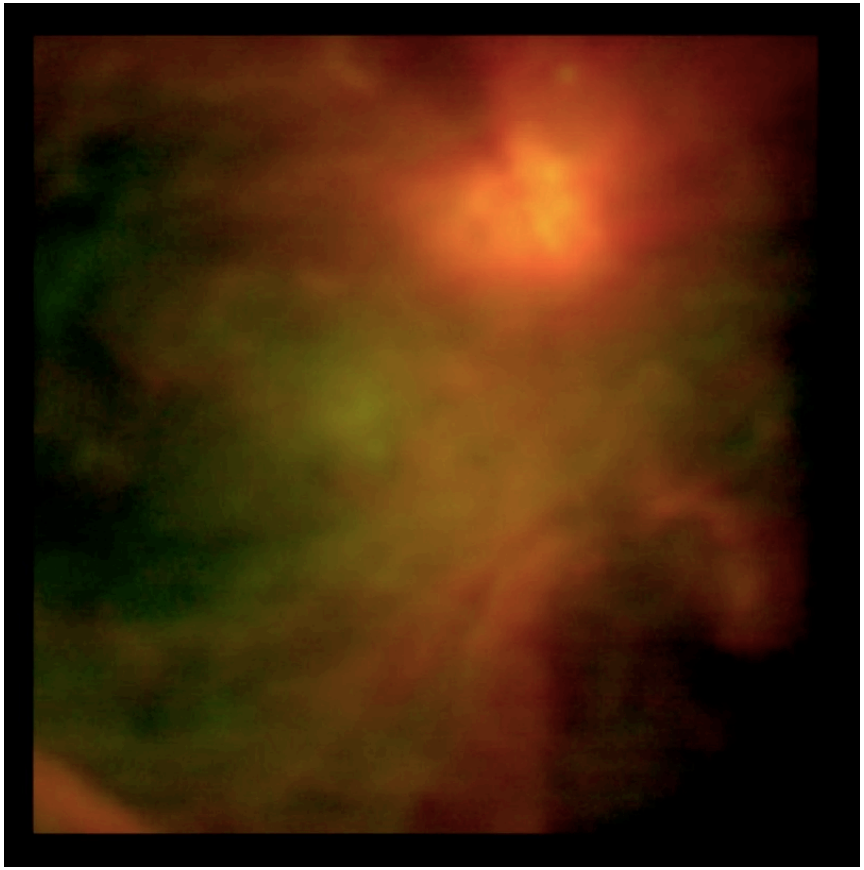


Orion with FORCAST:

Red = 37.1 μm, Green = 24.2 μm

De Buizer et al. in prep.

SOFIA Early Science Images



Orion with FORCAST:

Red = 37.1 μm, Green = 24.2 μm

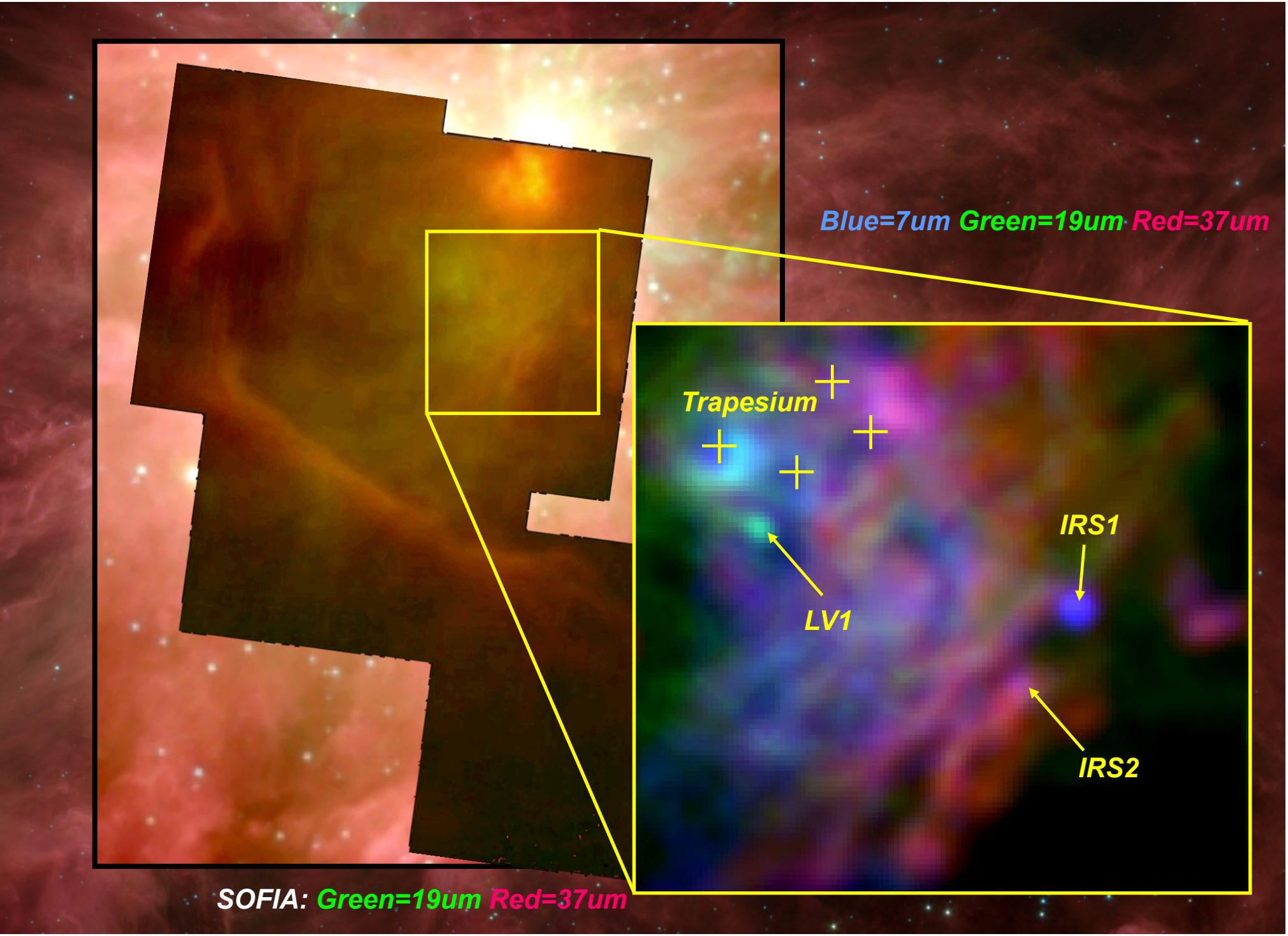
Orion Nebula at Mid IR with 3" resolution

BN is the hottest source and is not see at 37 μm.

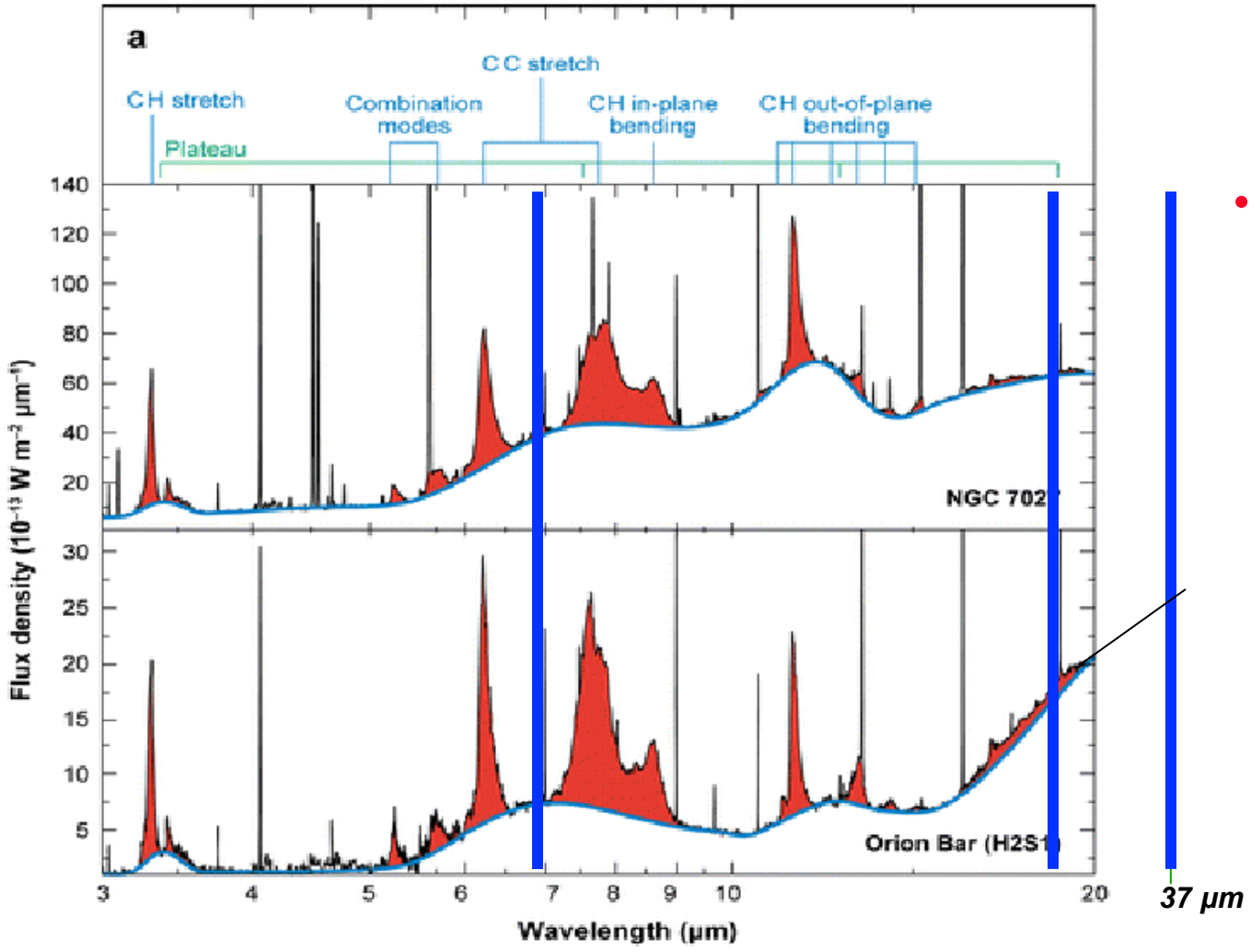
The source IRc2 (bright at 12 microns) and radio source "I" are not seen at 37 μm. This is a surprise.

The brightest source at 37 μm is IRc4; one of the coldest (~100 K) and the most luminous

(FORCAST team, in preparation)

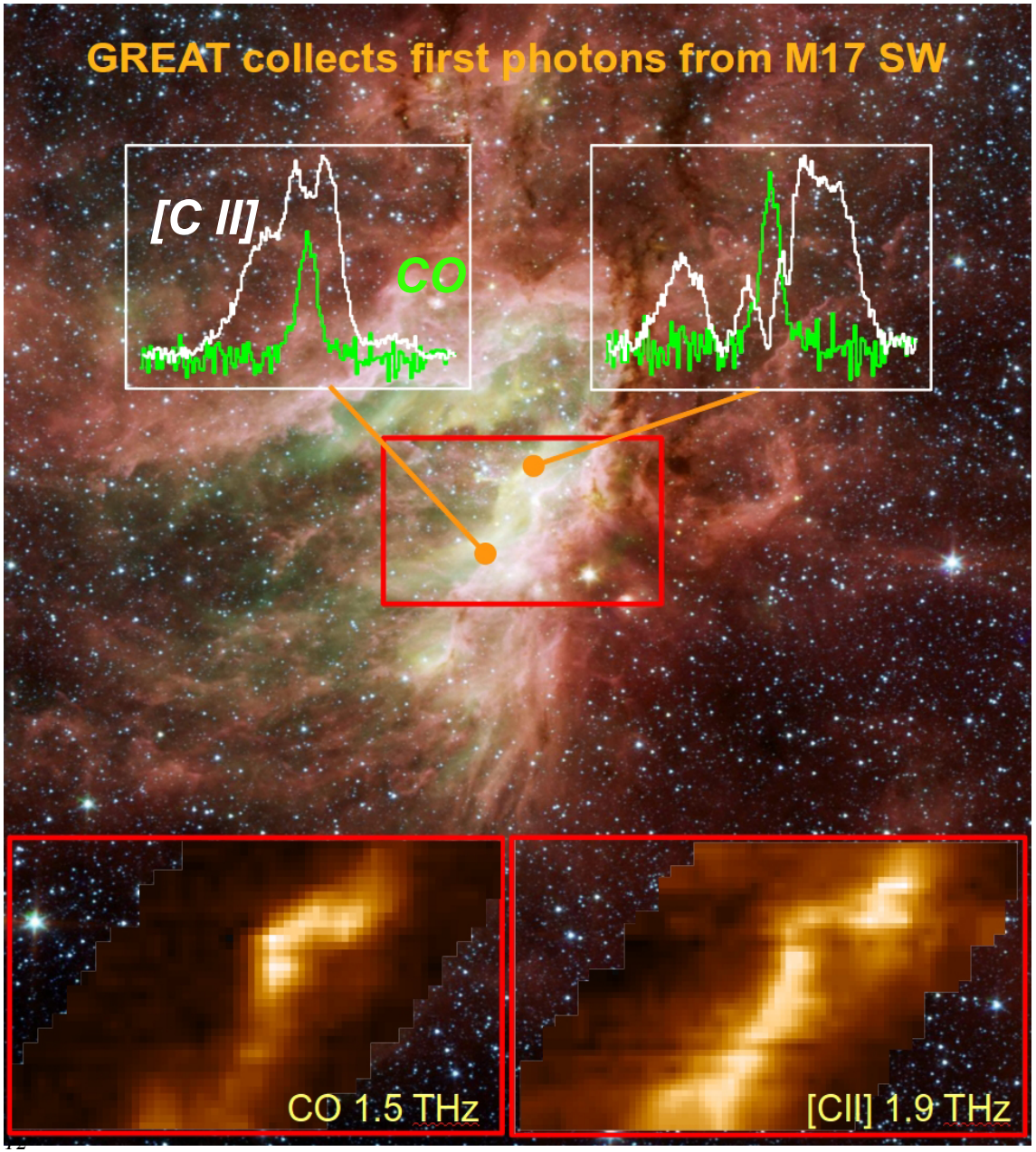

Blue=7um Green=19um Red=37um
Trapesium
IRS1
LV1
IRS2
SOFIA: Green=19um Red=37um

Thermal Emission from PAH Rich Objects



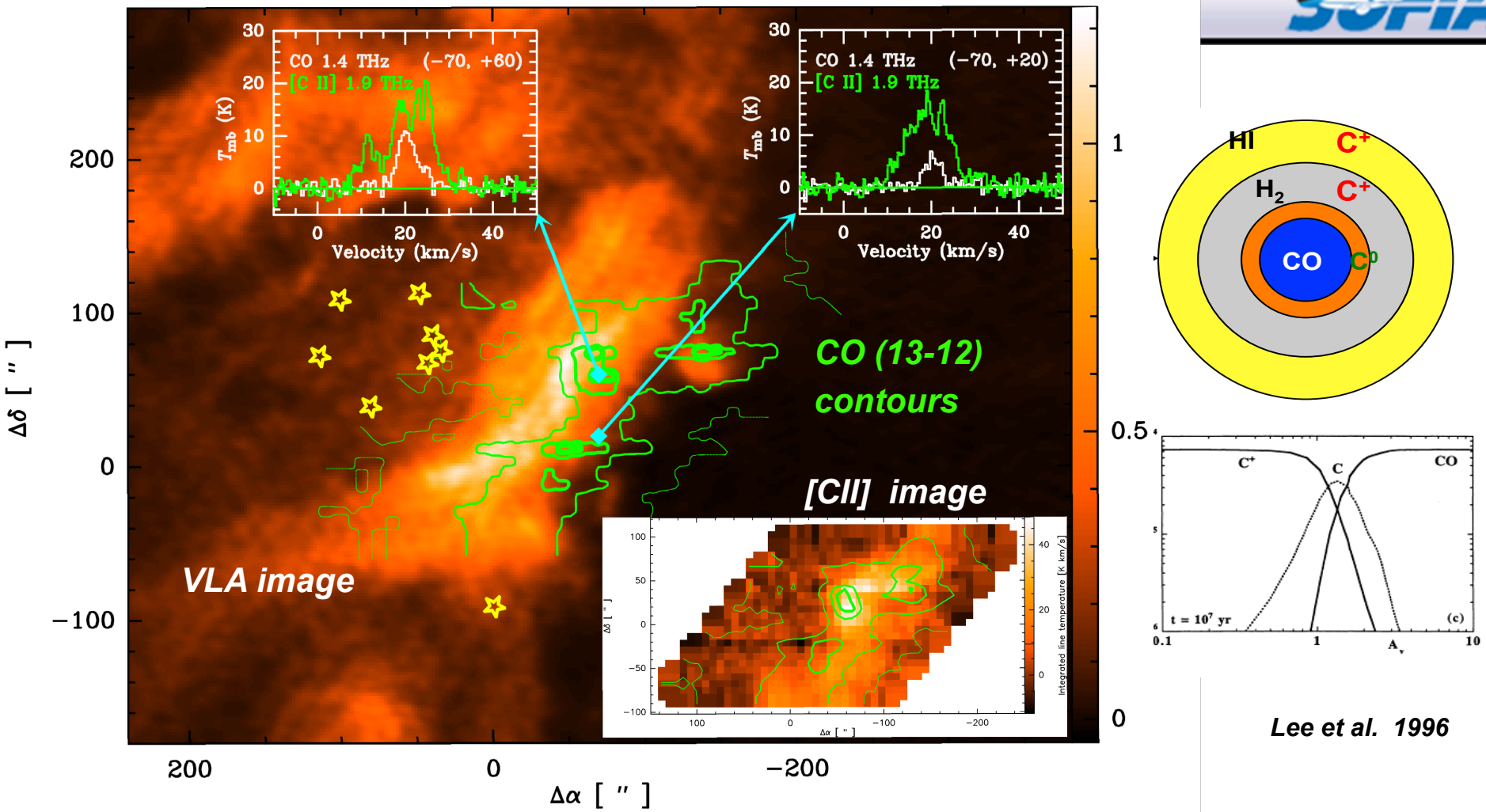
- *A key question is whether portions of the aromatic population of PAHs are converted to species of biological significance*

Vibrational modes of PAHs in a planetary nebula and the ISM (A. Tielens 2008)



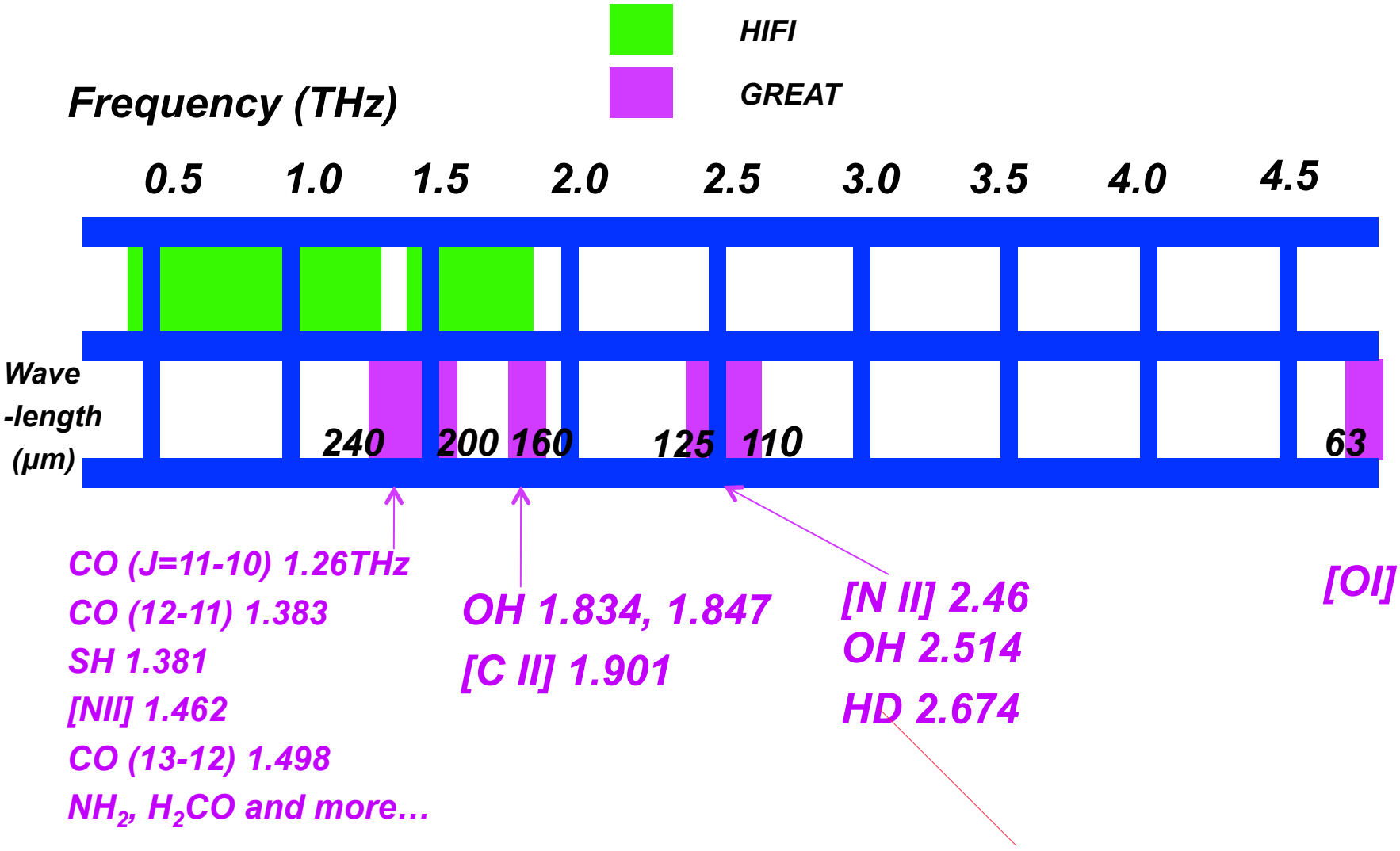
GREAT First Light

- German REceiver for Astronomy at Teraherz Frequencies (GREAT)
- PI: Rolf Güsten, MPIfR in Bonn
- **M17 (Omega Nebula)** CO (J=13-12, green) and [C II] (white) spectra
- Velocity (x-axis): from -10 to 50 km/s
- GREAT Spectral resolution is ~10^7.
- Efficient Scan mapping capability.



- OB (yellow) stars, [CII] (green) contours on VLA image (ionizing flux). Inserted CO (J=13-12) image with [CII] contours.
- [CII] is ionized gas at the boundary of dense warm CO. (Perez-Beaupuits, Güsten, and GREAT team, in preparation)

Frequency coverage and Molecule lines
Herschel HIFI and SOFIA GREAT



Comparison between Herschel and SOFIA far-IR instruments

	PACS spec	FIFI-LS	HIFI	GREAT	PACS imager	HAWC
Wavelength range (μm)	55-210	42-110, 110-220	157-213, 240-625	60, 110-125, 156-165, 200-240	55-210	53, 89, 115, 216
Field of View	47”x47”	30”x30” 60”x60”	Single pixel	Single pixel (7 pixels in future)	47”x47”	27”x72”, 42”x112”, 72”x192”, 96”x256”
Pixel size	9”	6”, 12”	13”, 39”	20”	9”	2.3”,3.5”, 6”, 8”
Sensitivity	2-5x10^{-18} Wm^{-2} 100-250mJy	Similar to PACSspec within a factor of 3-5, but efficient mapping	A few to 100 mK	Similar to HIFI within a factor of 2-8, but efficient mapping	2-5x10^{-18} Wm^{-2} 100-250 mJy	60-120 mJy
Spectral Resolution	2600-5400 (55-72μm) 900-3000	1000-5000	1000-10^{7}	10^{6}-10^{8}	2600-5400 (55-72μm) 900-3000	None

SOFIA's First-Generation Instruments

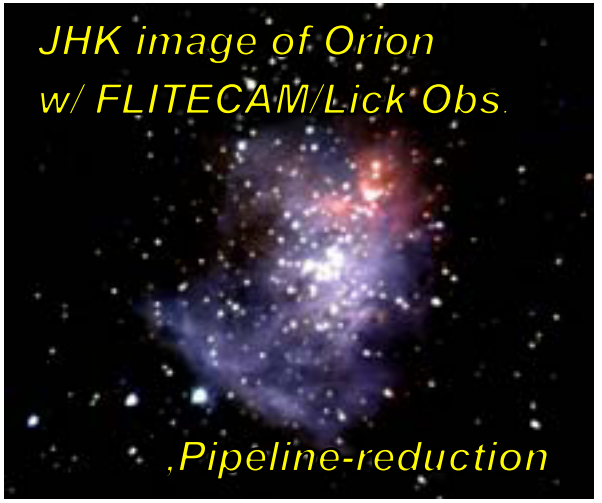
(http://www.sofia.usra.edu/Science/instruments/)

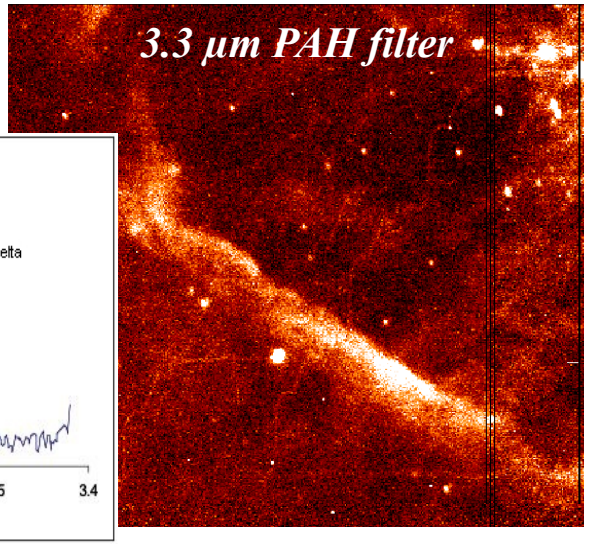
see also Gehrz et al. 2011 (Adv. Space Science)

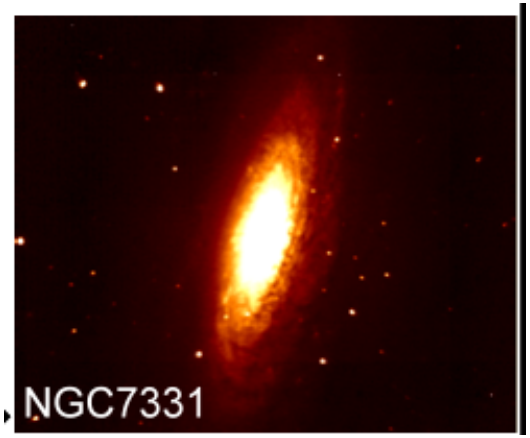
Instrument	Type	λλ (μm)	νν (THz)	Resolution	PI
FORCAST (in operation)	imager / (grism)	5.4 - 37	8.1 - 56	filters / (R~2000)	T. Herter / Cornell U.
GREAT (H-Freq.) (M-freq. -- June 2011) (L-freq.'s -- operating)	heterodyne spectrometer	 (62 - 65) (110 - 125) 156 - 165 200 - 240	 (4.6 - 4.8) (2.4 - 2.7) 1.82 - 1.92 1.25 - 1.50	$R \sim 10^4 - 10^8$	R. Güsten / MPIfR
HIPO (summer 2011)	fast imager	0.3 - 1.1		filters	E. Dunham / Lowell Obs.
FLITECAM (summer 2011)	imager / (grism)	1.0 - 5.5		filters / (R~2000)	I. McLean / UCLA
FIFI-LS	imaging grating spectrograph	42 - 110 110 - 210	2.7 - 7.1 1.4 - 2.7	R ~1000 - 2000	Poglitsch,Krabbe /MPE,IRS
EXES	imaging echelle spectrograph	4.5 - 28.4	10.6 - 67	$R \sim 3000 - 10^5$	M. Richter / UC-Davis
HAWC	imager	45 - 270	1.1 - 6.6	filters	D. A. Harper / U. Chicago

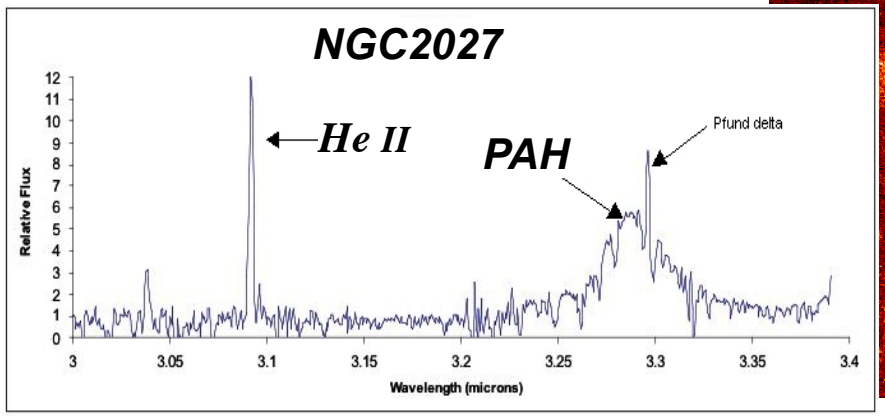
FLITECAM (PI: Ian McLean, UCLA)

- A Facility-class camera at 1 – 5 μm
- Seeing/diffraction limited (2" – 5"), 8 arcmin FOV
- Filters: *J, H, K, L, M*, PAH, Water-ice, Pa-α, Pa-cont
- Grisms: R ~ 2000 across 1 – 5 μm band, 1" & 2" slits
- Lines and molecules: H, He, Fe, H_2, PAH, warm CO
- FLITECAM is complete, has been field-tested on 3-m telescope at Lick observatory; can be used with HIPO
- 1st test flights Fall 2011 and FLITECAM available 2012









SOFIA successfully observed challenging Pluto Occultation (Jun 24, 2011)

SOFIA Will Study the Diversity of Stardust

Herbig AeBe

Post-AGB and PNe

Mixed chemistry post-AGB

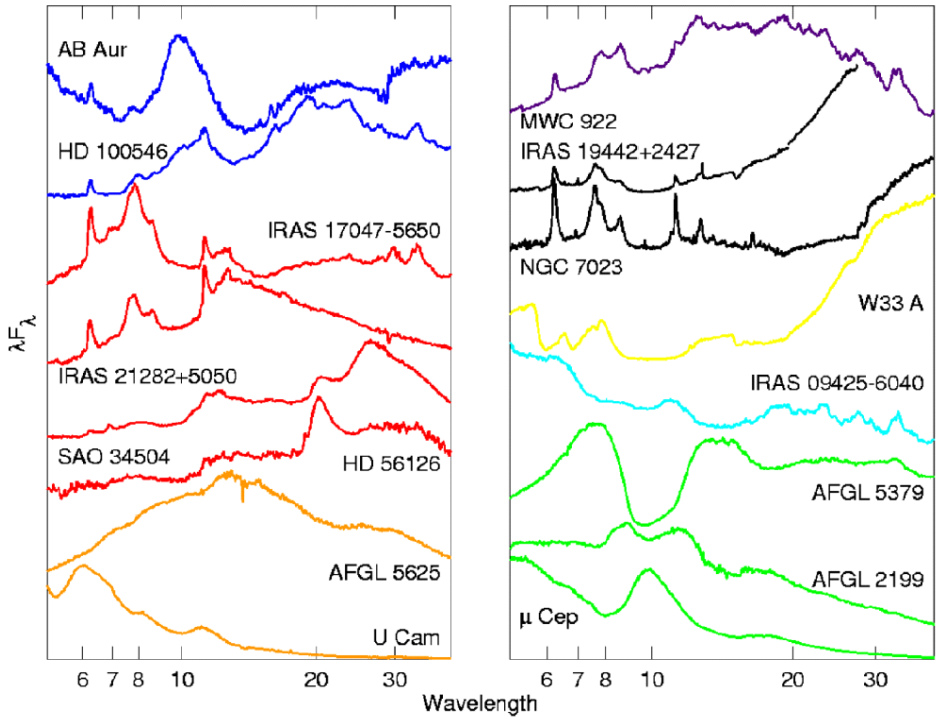
C-rich AGB

O-rich AGB

Mixed chemistry AGB

Deeply embedded YSO

HII regions/reflection nebulae

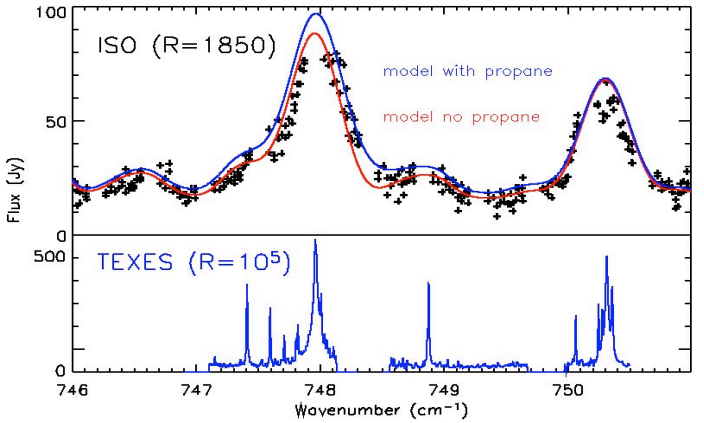


- *ISO SWS Spectra: stardust is spectrally diverse in the regime covered by SOFIA*
- *Studies of stardust mineralogy*
- *Evaluation of stardust contributions from various stellar populations*
- *Implications for the lifecycle of gas and dust in galaxies*

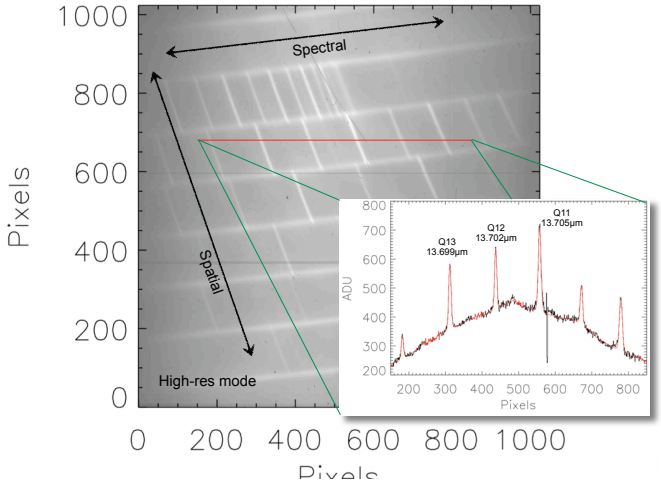
EXES (PI: Matt Richter, U. Calif.-Davis)

- High spectral resolution in mid-IR: 4.5 – 28.4 μm
  - R = 50,000 – 120,000 cross-dispersed
- Single order long slit (~100” long)
  - R = 3,000 with 5% coverage
  - R = 20,000 with ~0.7% coverage
- Sensitivities: 0.2-1 Jy at 5μm and 2-15 Jy at 30μm depending on spectral resolution
- Designed primarily to study gas phase using
  - molecular ro-vibration bands that provide multiple energy levels in single observation
  - kinematic information that resolves structure and multiple components
  - Diverse star dust
- General availability: Cycle 2 (2013)

EXES and SOFIA



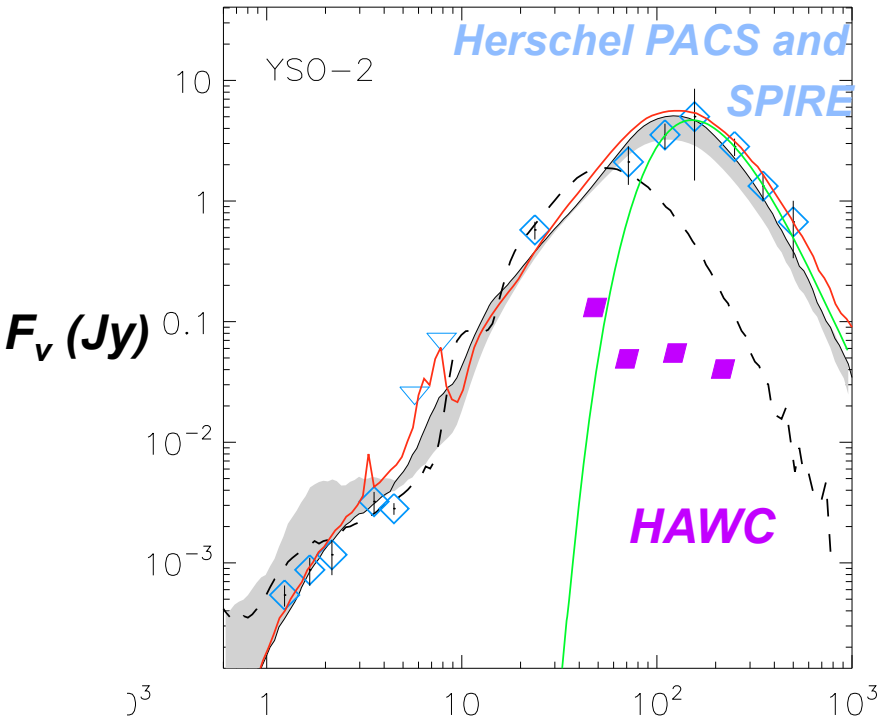
Why High Resolution Matters *(above): A comparison of ISO observations with ground-based observations with EXES' sister instrument TEXES for detection of propane in Titan's atmosphere (see Roe et al. 2003) EXES performance from the SOFIA platform will exceed that of TEXES.*



Lab Spectra: C2H2 low-pressure gas cell spectra obtained with EXES. Hi-res mode gives R=110k @ 13.7μm and best spectral focus.

HAWC (PI: Al Harper, U. Chicago)

- ***Four passbands at 53, 89, 154, and 214 μm***
- ***Commissioning 2012 / 2013***
- ***Dust properties of protostars and diffuse emission***



Protostar SED in LMC (Sewilo et al. 2010)

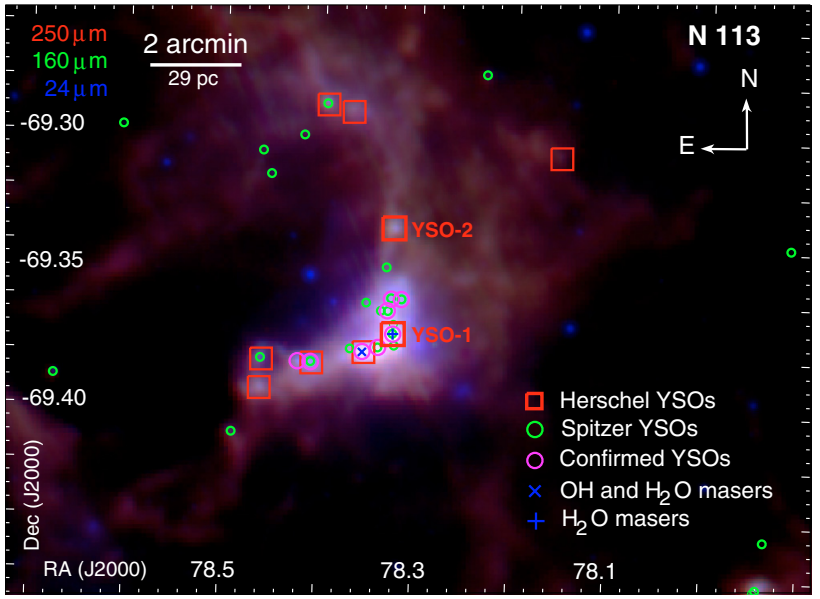


Fig. 2. Three-color composite image of the H II region N 113 combining SPIRE 250 μm (red), PACS 160 μm (green), and MIPS 24 μm images. Our reliable *Herschel* sources are marked with red boxes. *Spitzer-*

SOFIA will fly to Southern Hemisphere!

Current Schedule

- FORCAST Basic Science Flights: May to June 2011
- GREAT Basic Science Flights: July and September 2011
- FLITECAM Verification flights: Aug 2011

AO for 2nd Generation Instruments

- Draft AO: http://soma.larc.nasa.gov/SOFIA/sofiapbtelecon_agenda.html
- AO announcement: ***http://nspires.nasaprs.com***

  (SOFIA Second Generation Instruments:NNH08ZDA009O_SOFIA)
- Asilomar meeting proceeding

http://www.sofia.usra.edu/Science/workshops/asilomar.html

Next Science Proposal Call

- Fall to Winter 2011, 300 hours observing time: open internationally
- FORCAST and GREAT
- FLITECAM, FORCAST grisms and HIPO are expected to be available.
- Data Analysis funding is available for US Investigators

Merci

Please visit http://sofia.usra.edu/

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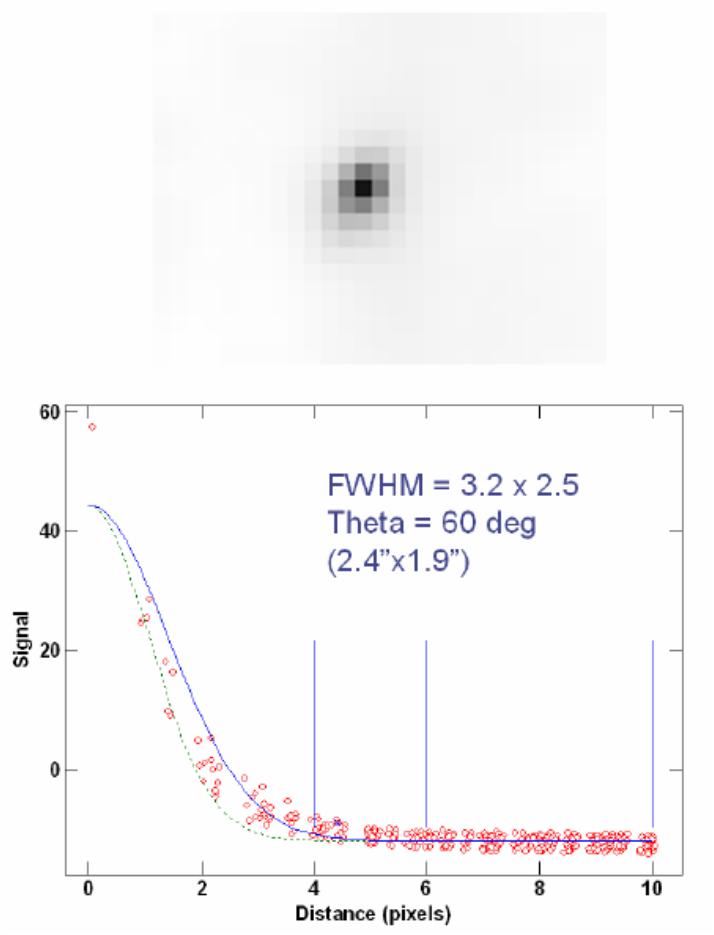
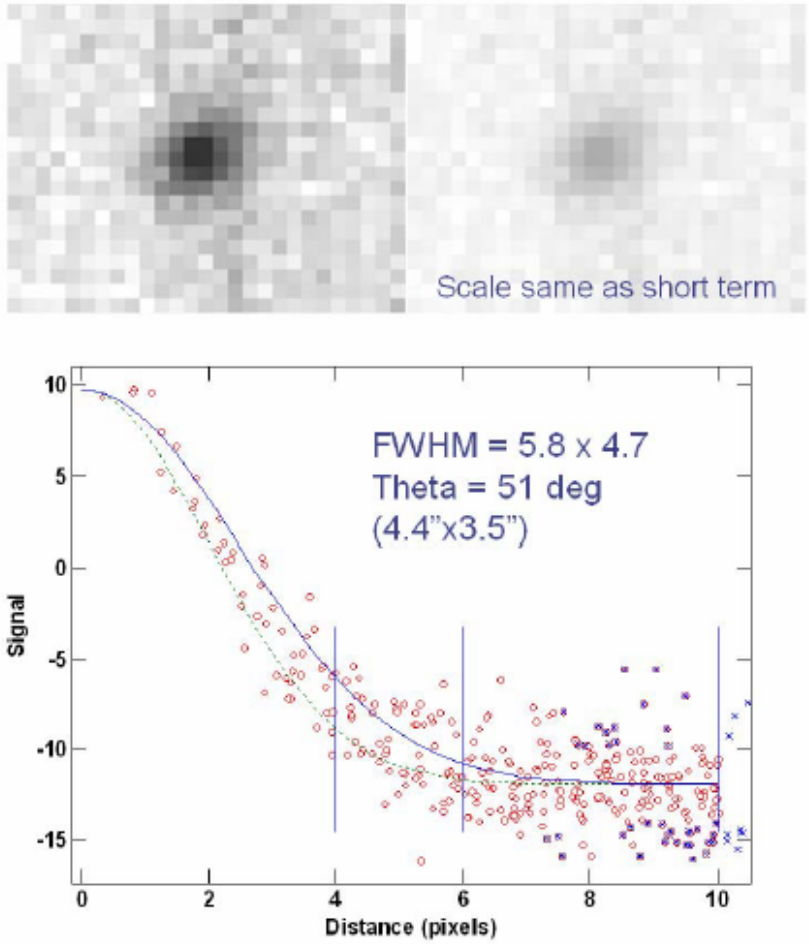
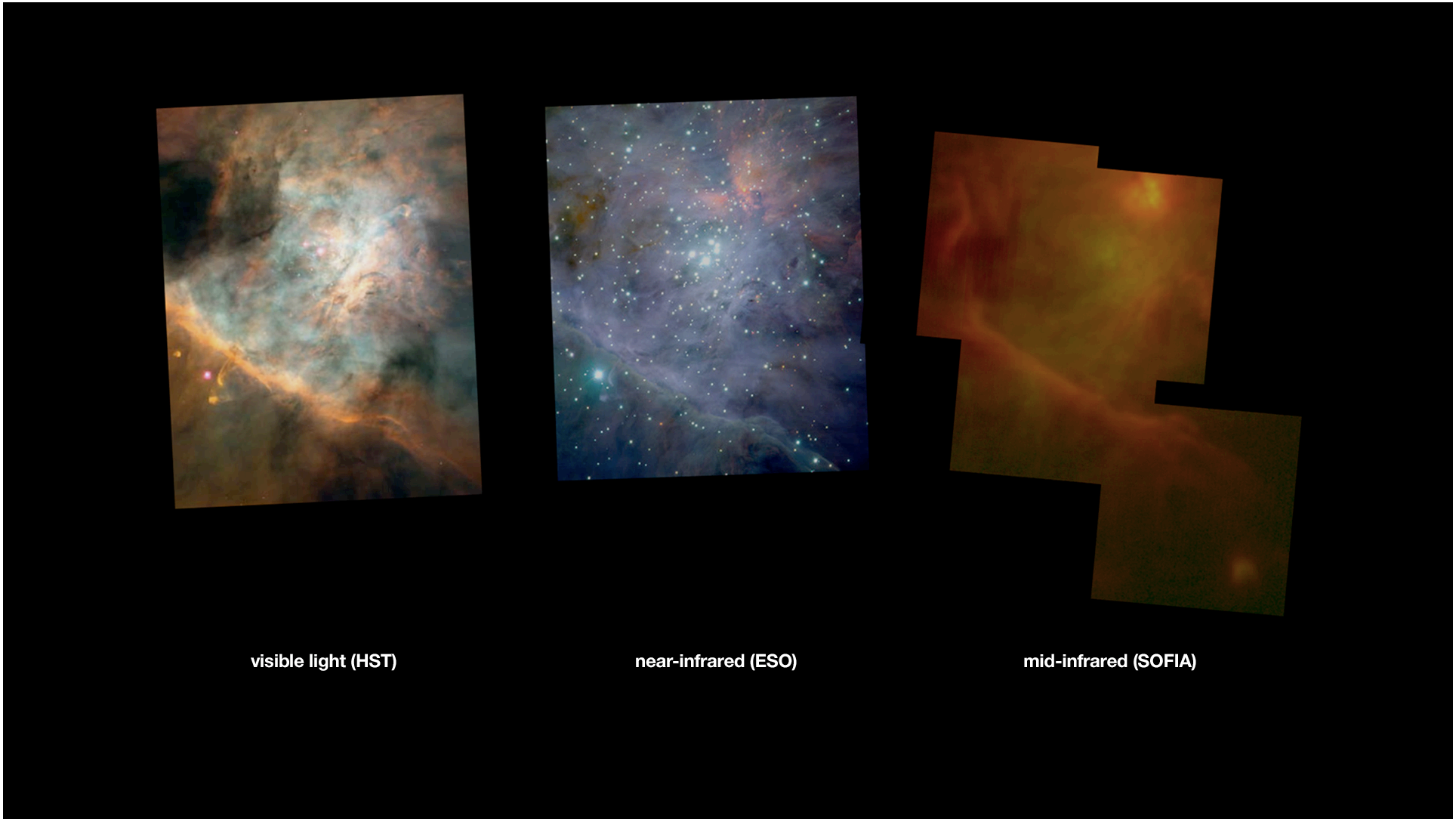
PSF and Jitter from Images of γ Cygni





2,800 2.5 ms images shifted and co-added

Same data w/o shift and add


visible light (HST)
near-infrared (ESO)
mid-infrared (SOFIA)