SOFIA and CCAT - synergies

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SOFIA and CCAT science themes

SOFIA:

ISM in Milky Way and nearby galaxies

Star formation and circumstellar disks

Outer solar system (asteroids, KBO, occultations)

Planetary atmospheres (e.g. Venus, Mars, Pluto)

CCAT:

Distant galaxies

ISM in nearby galaxies and Milky Way

Star formation and circumstellar disks

Outer solar system (asteroids, KBO, etc)

OUTLINE

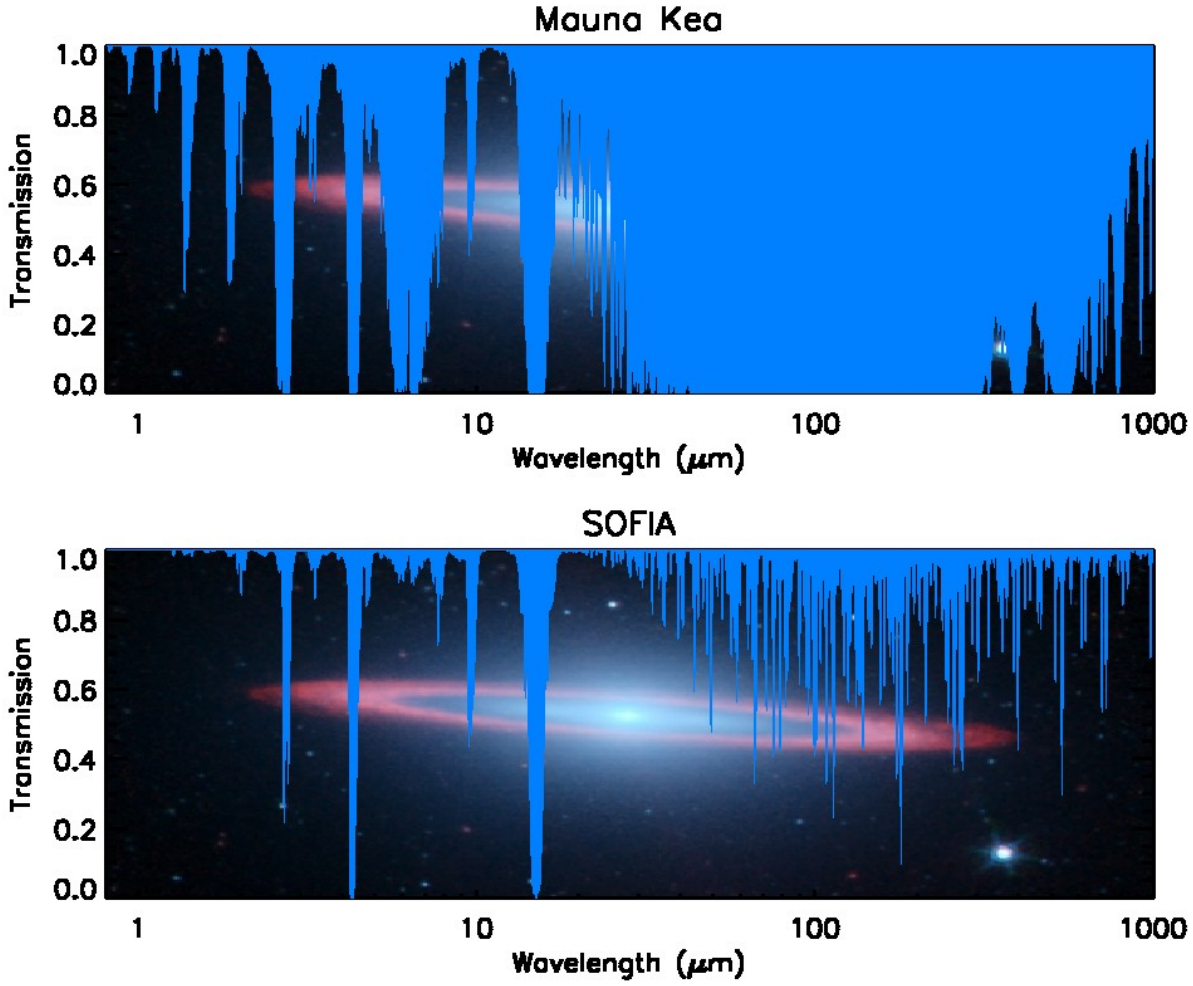
- Basic information about SOFIA and CCAT (status, transmission, instruments, lambda, spatial resolution)
- Technical similarities and differences (array sizes)
- Complementarity, operation time overlap (2017++)
- Spectroscopic science case examples (gal + extragal)
- Summary (strong synergy: FIR/submm GMC mapping)

- PS. 2nd gen SOFIA and CCAT → imaging polarimetry

Overview of SOFIA

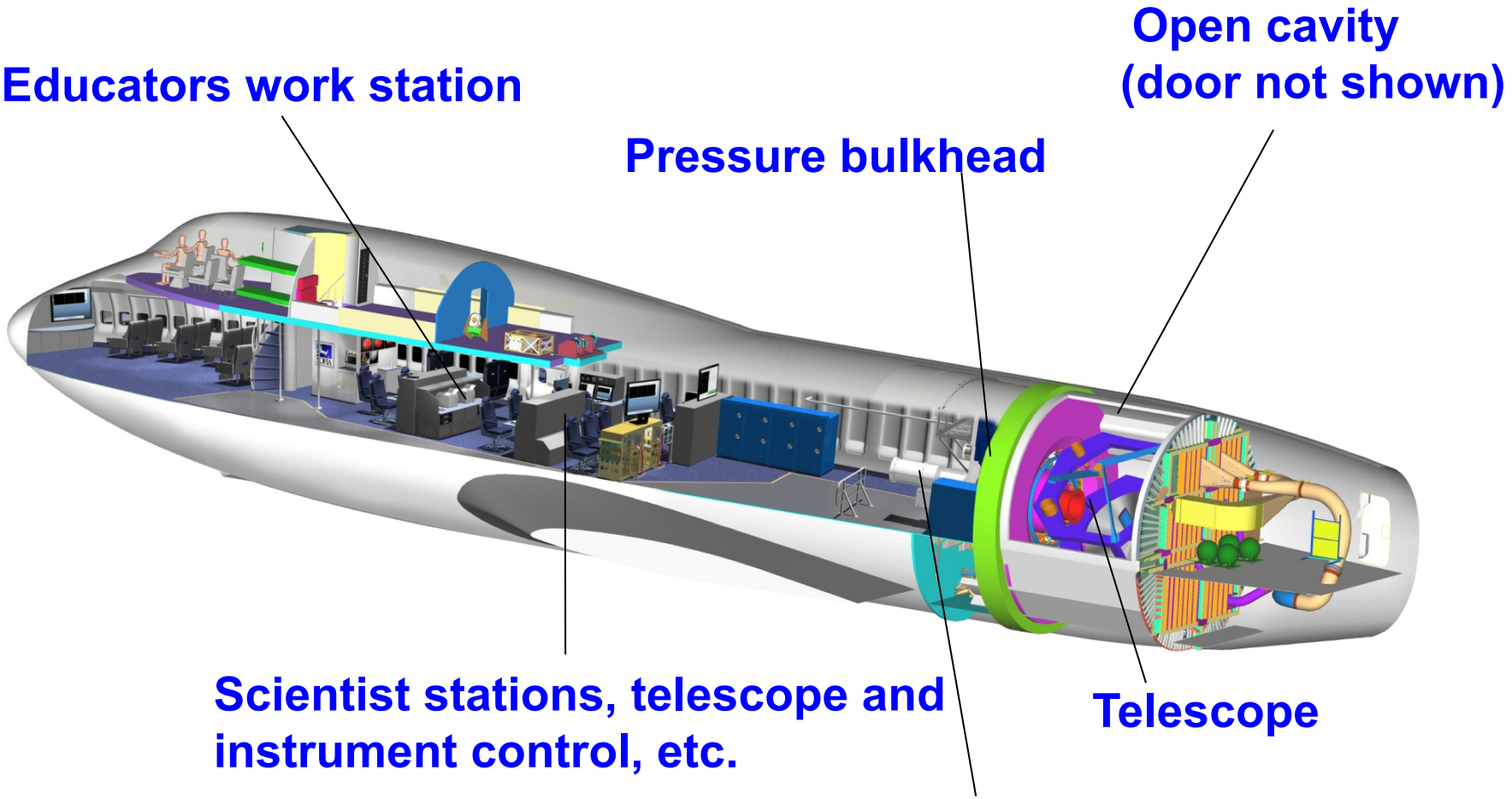
- SOFIA is a 2.7 m (2.5 m effective aperture) telescope in a modified B747SP aircraft, the biggest possible in a B747
  - Optical-mm performance
  - Obscured IR (30-300 μm) most important
- SOFIA is a joint program between the US (80%) and Germany (20%), both in terms of cost and obs. time
  -- largest bilateral science project between US and Germany
- Operating altitude
  - 39,000 to 45,000 feet (12 to 14 km)
  - Above > 99% of obscuring water vapor
- First science flights took place at the end of 2010, continuing
- Mobility: anywhere, anytime (including southern hemisphere)
- Designed for 20 year lifetime, only FIR platform after Herschel for years to come

Motivation for Airborne Astronomy

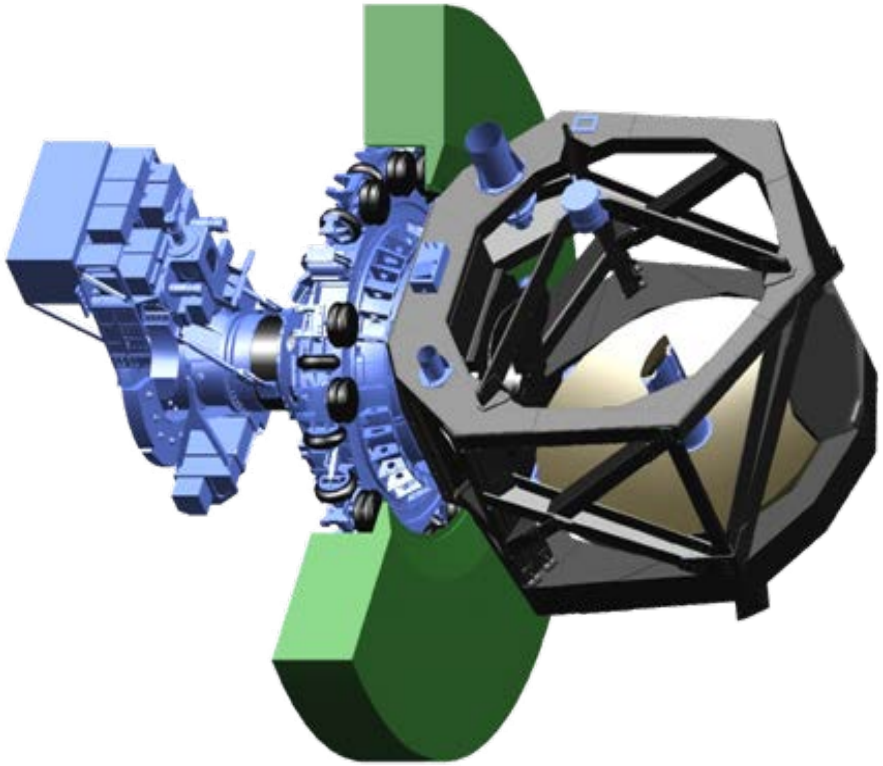


- For much of the infrared, the Earth's atmosphere blocks all transmission.
  - The problem is water vapor
- If we can get above this water vapor, much more can be observed.

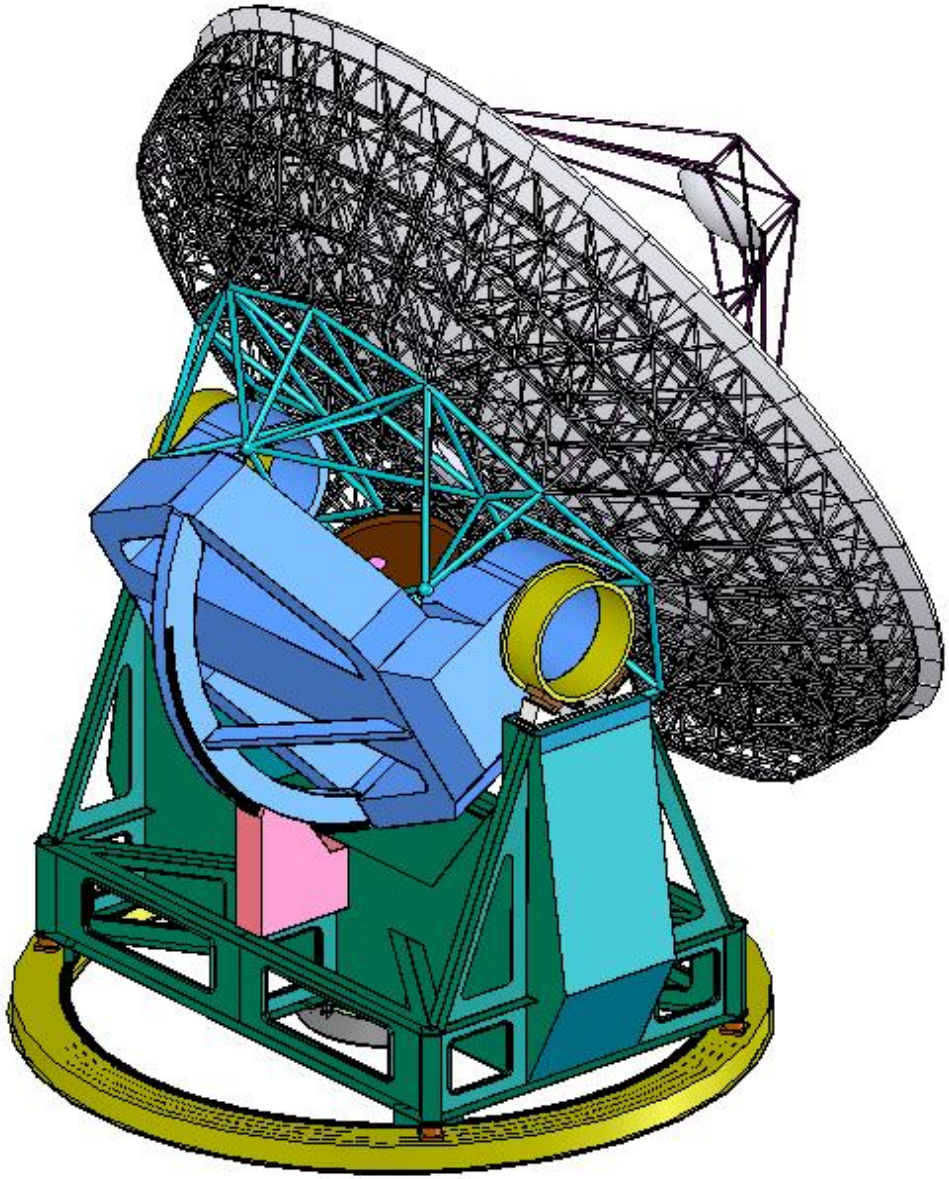
SOFIA – The Observatory



The Telescope Assembly – A Major German Contribution

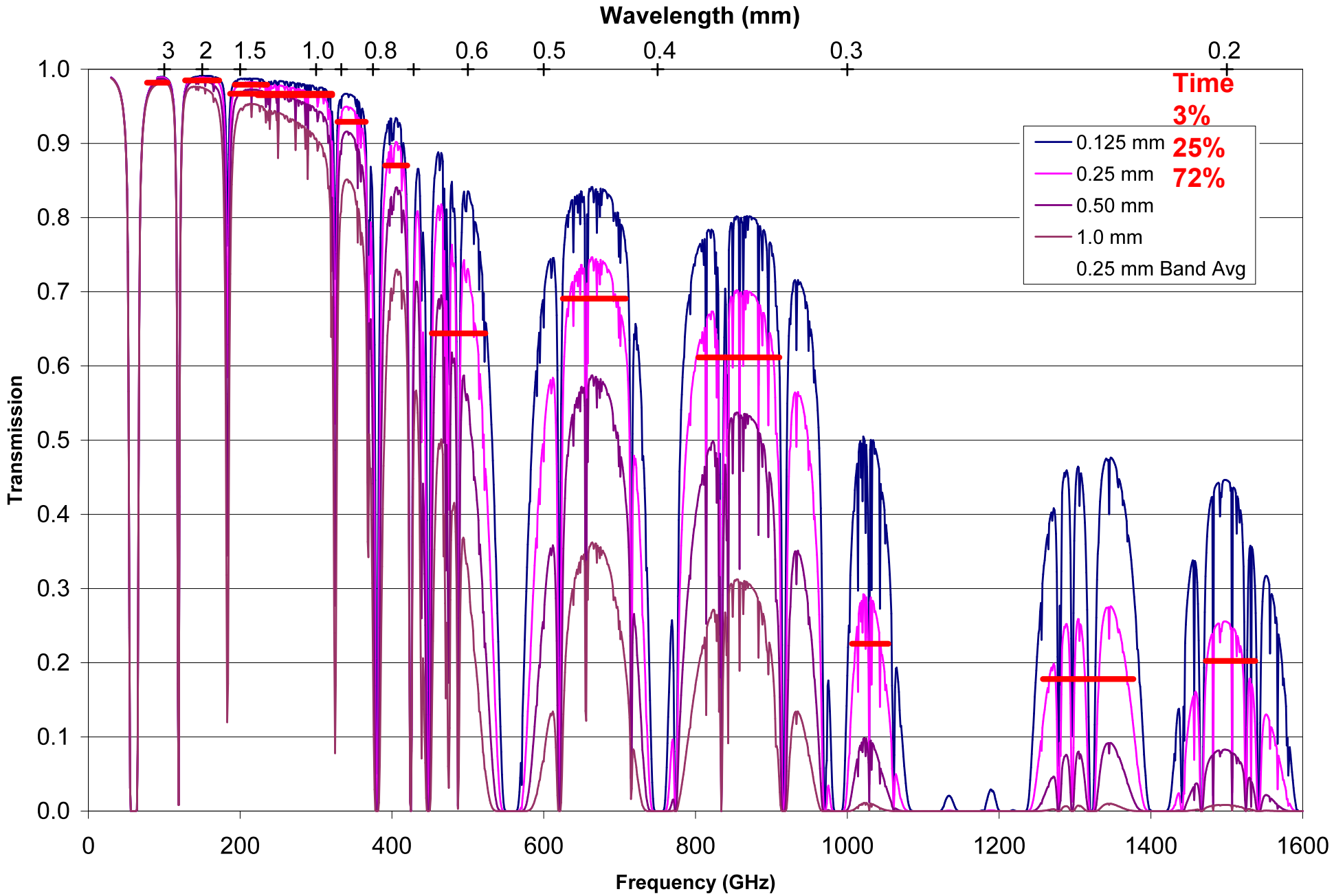


CCAT Telescope



Basics
- Aperture: 25 m
- Angular Resolution: 3.5″ beams @ 350 μm
- Wavelengths: 350 μm – 2.2 mm (200 μm goal)
- FOV: ≥ 20′ (1°)
- Surface: HWFE < 12.5 μm rms
- Cost: ~$110M U.S. (85€ million)

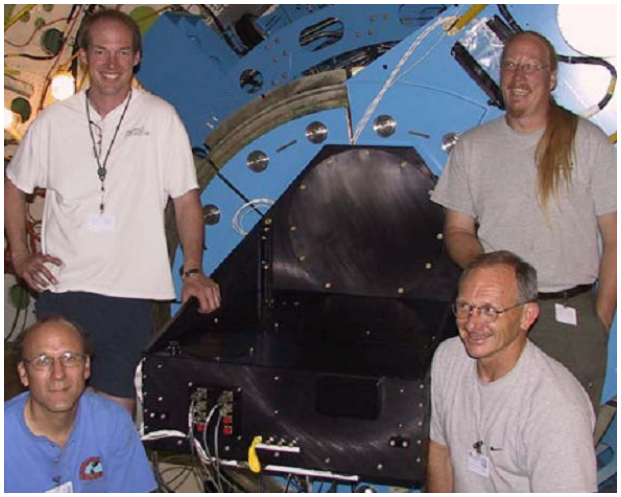
Atmospheric Transmission Cerro Chajnantor (5,600 m)



SOFIA instrument suite

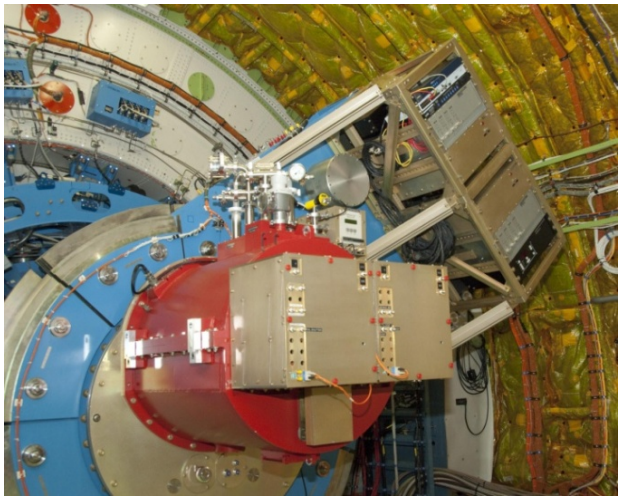
- FORCAST
- GREAT
- HIPO
- FLITECAM
- FIFI-LS
- HAWC
- EXES

Four Completed 1st Generation Instruments



HIPO
High Speed Photometer
(on SOFIA)

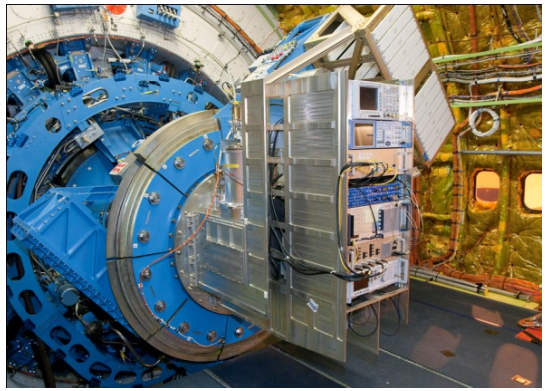
FLITECAM
Near IR Camera
(at Lick observatory)



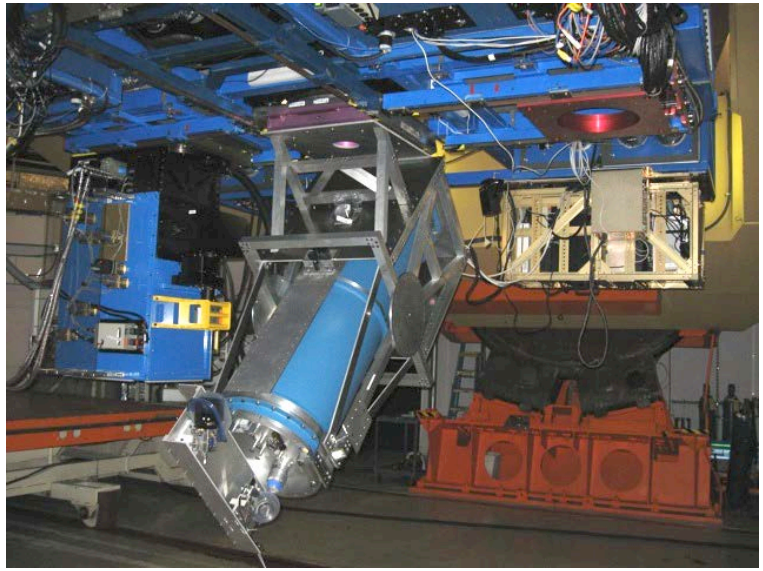
FORCAST
Mid-IR Camera
(on SOFIA)

GREAT
Heterodyne spectrometer

(on SOFIA)

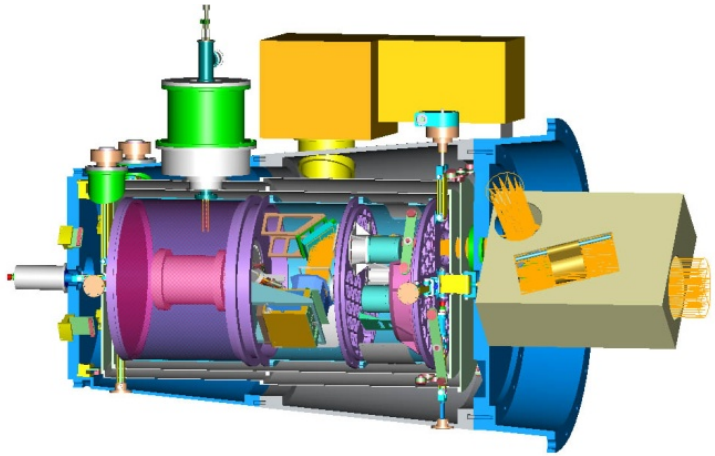


Instruments in development

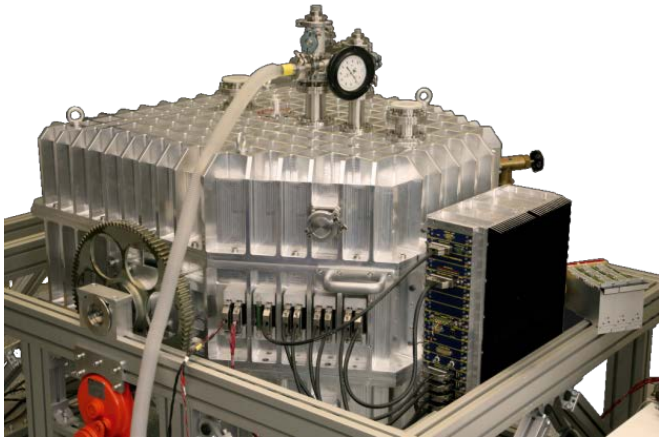


EXES
Mid- IR Spectrometer

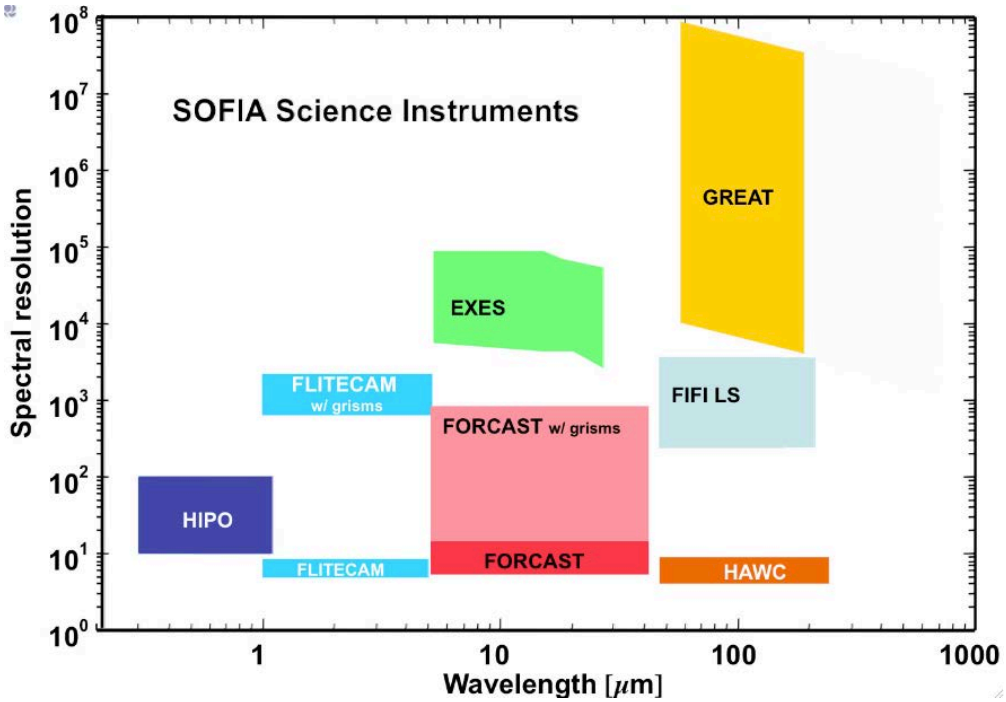
HAWC
Bolometer Camera



FIFI LS
Integral Field Spectrometer



SOFIA's Instrument Complement



GREAT details

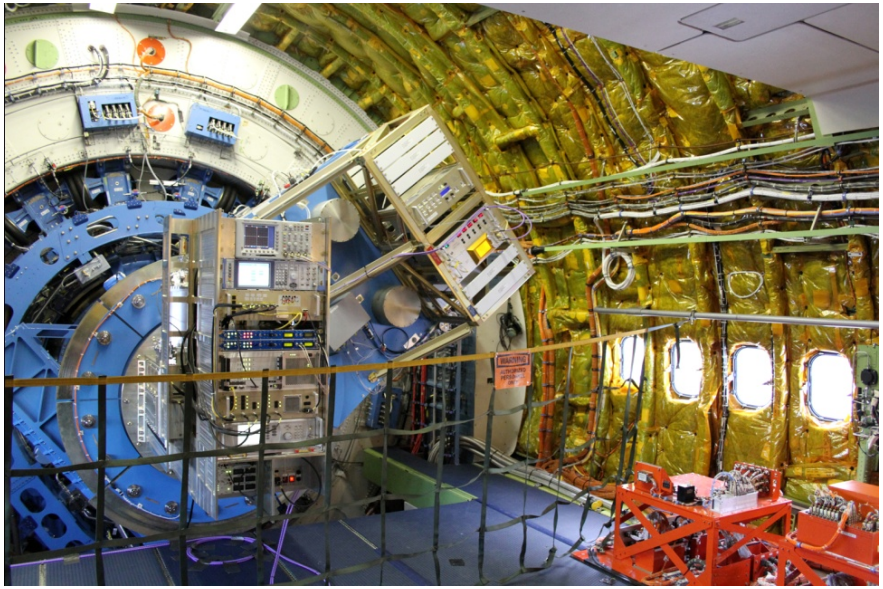
dual channel heterodyne spectrometer

L1 ab 1.25-1.50 THz: N+, CO, OD, H2O+, SH
L2 ab 1.81-1.91 THz: NH3, OH, CO 16-15, C+
M ab 2.5 THz, 2.7 THz: OH ground state, HD 1-0
H band 4.7 THz: [OI] 63 micron line (2013)

two out of 4 channels can be operated simultan.
Spectral resolution: sub km/s, IF bandwidth 1.2 GHz
beam=lambda/10 (16” for C+ 158 micron line)
upGREAT (funded): 2x7 pixel arrays

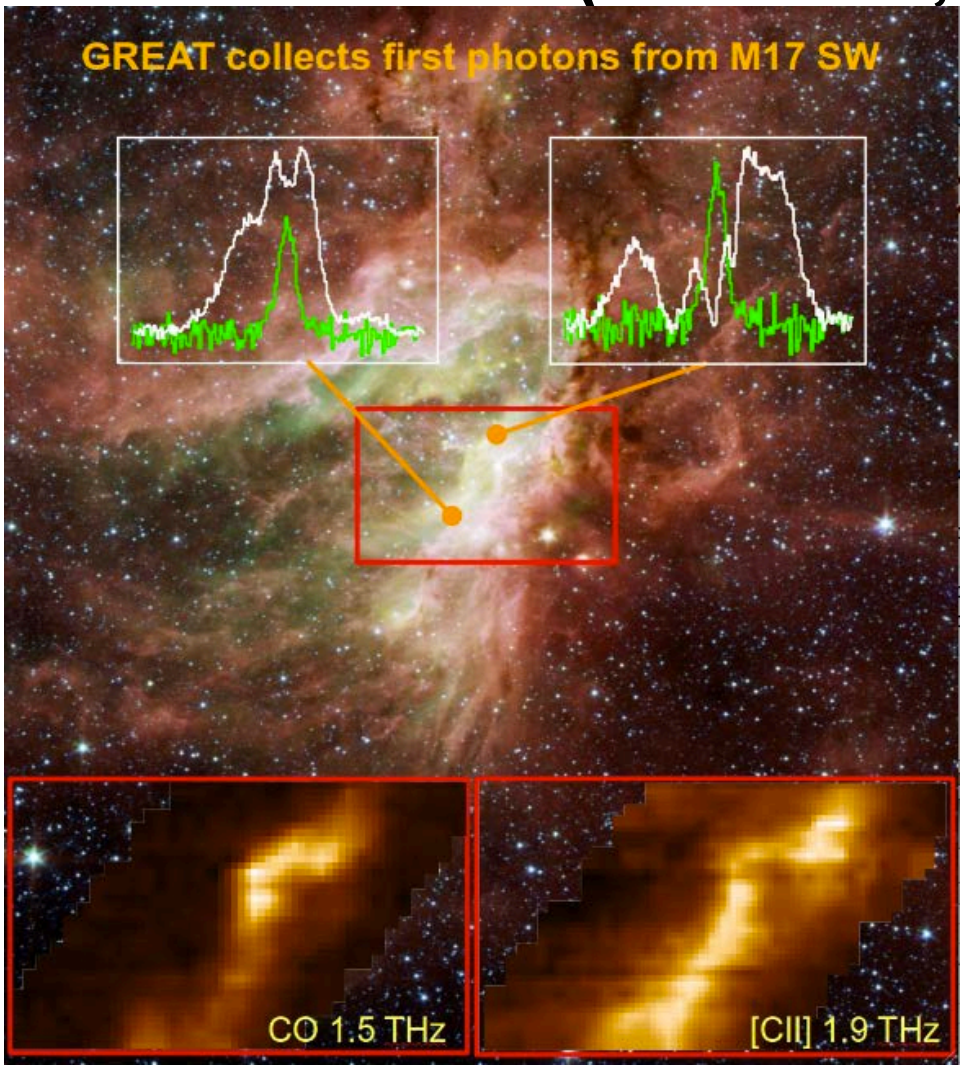
Successful Start of Science Program on SOFIA

- Short Science 2
  - Series of 3 flights with GREAT heterodyne spectrometer
  - Completed in April 2011
- Basic Science 1
  - Series of 10 flights with FORCAST mid-infrared camera
  - Included Guest Investigator programs solicited from the world astronomical community
  - Flight series completed in June 2011
- Pluto Occultation
  - Successful observation occultation of a background star by Pluto on June 23, 2011.
  - Demonstrates advantage of SOFIA mobility to get to the shadow path at the precise time of the event
- Basic Science 2 and German Science Demonstration Time
  - Series of 11 flights with the GREAT instrument
  - Includes substantial Guest Investigator program
  - First flight July 13, 2011



GREAT mounted in SOFIA

First Science with GREAT (White CII, Green CO)



GREAT dips into cradle of star formation

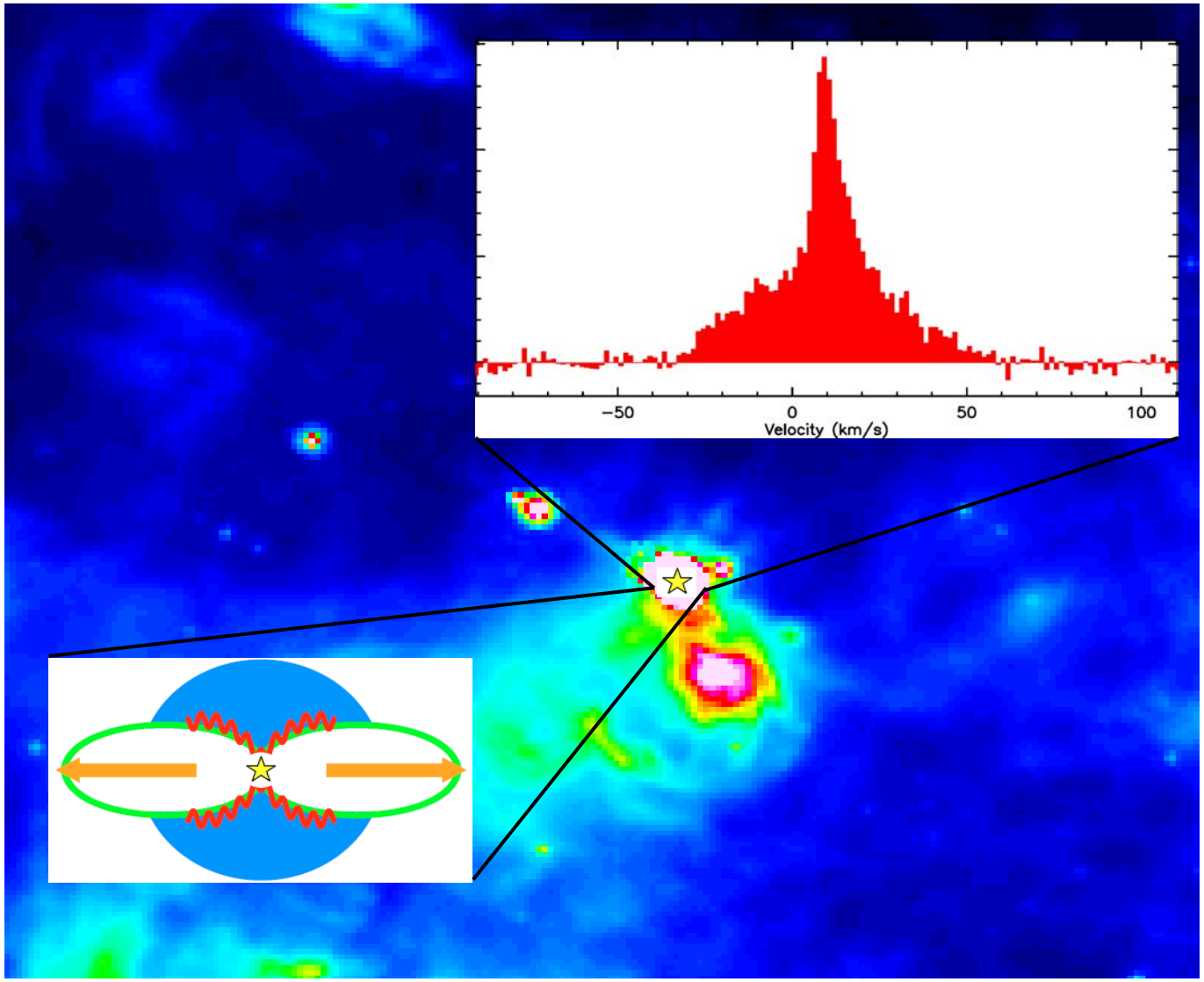
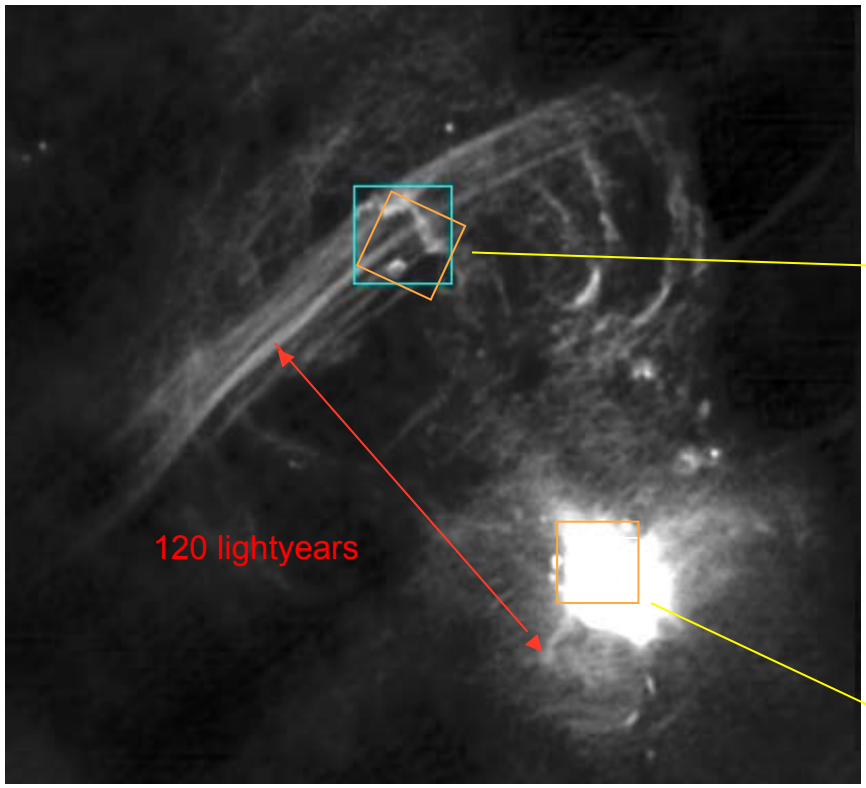
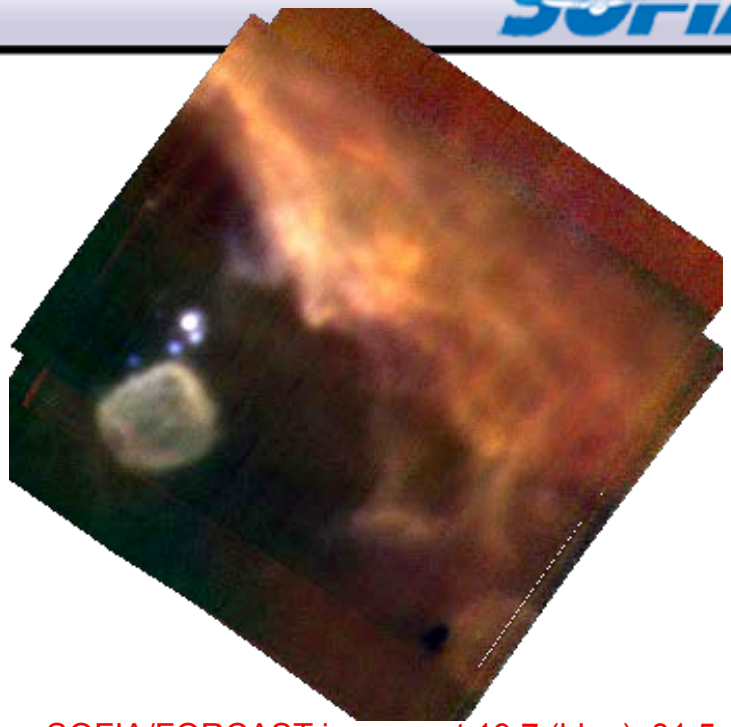


Image: Spitzer/GLIMPSE 8 μm

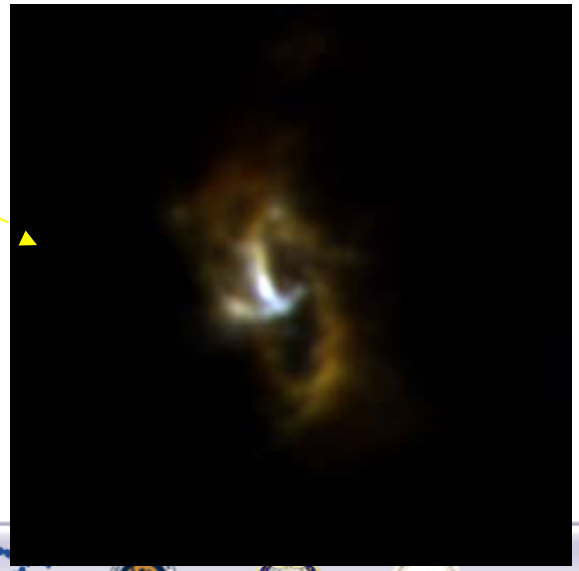
The Galactic Center



Radio image of Sgr A, pistol, sickle, filaments and arches



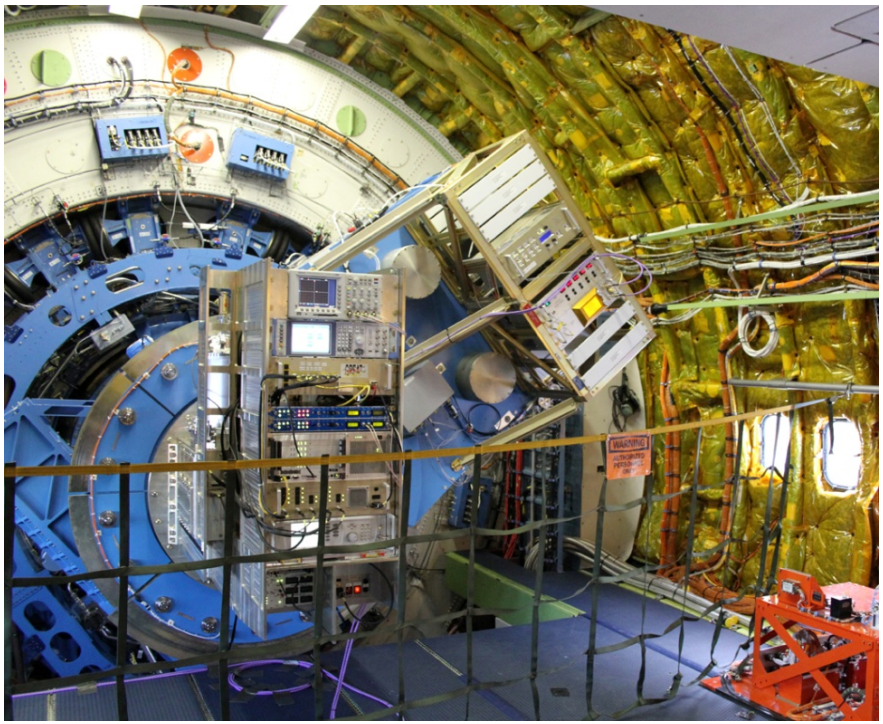
SOFIA/FORCAST images at 19.7 (blue), 31.5 (green), 37.1 (red) μm



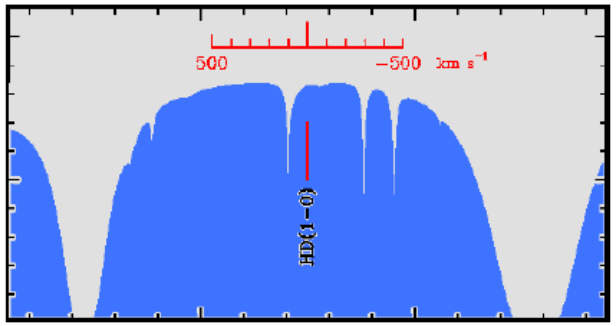
- At right are multicolor infrared images of two regions of the center of the Milky Way made with FORCAST SOFIA (courtesy of T. Herter)

GREAT Observations at 2.4-2.7 THz

- A key capability of SOFIA is to be able to take advantage of new technology.
- The GREAT instrument team, led by Rolf Güsten, has developed a receiver for the 2.4-2.7 THz band.
- Rapidly installed on the GREAT instrument, the first astronomical observations at these frequencies were conducted on July 26 & 29.

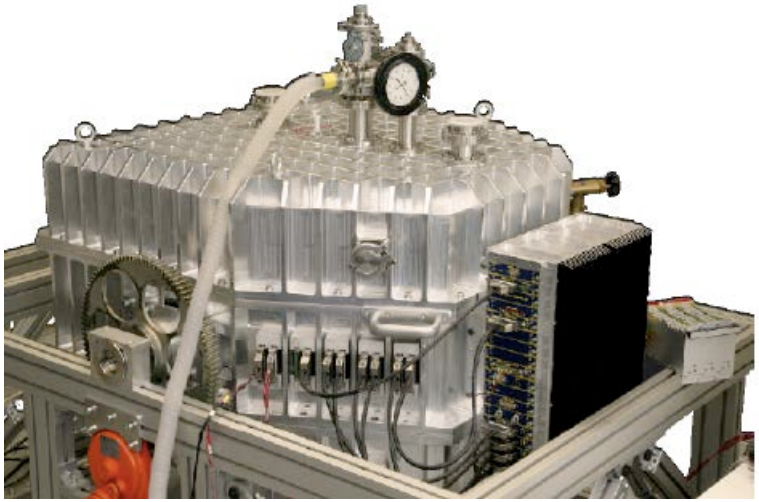


Cold Molecular Hydrogen using HD



FIFI-LS: Far-IR Spectrometer

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



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

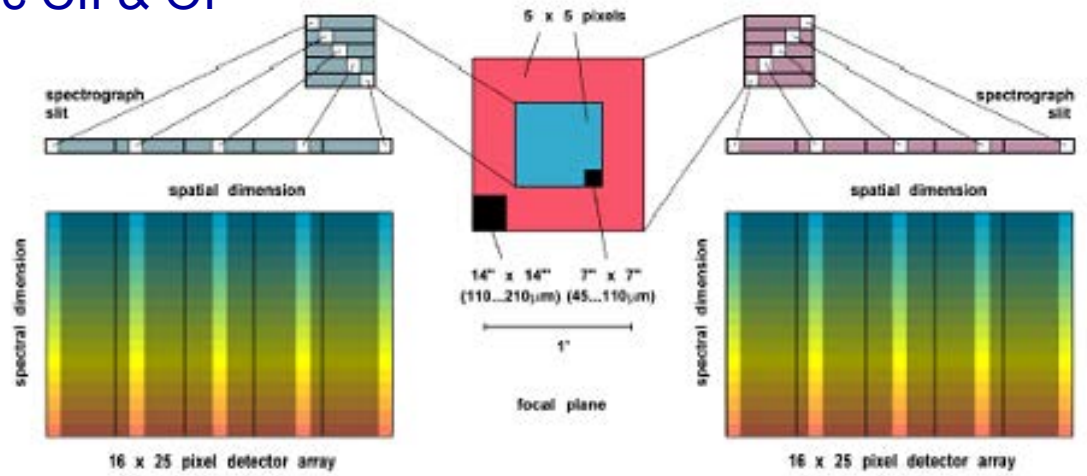
Field of View: 30” x 30” (blue), 60” x 60” (red)

R= 1500 - 6000

Science: Imaging of extragalactic CII & OI

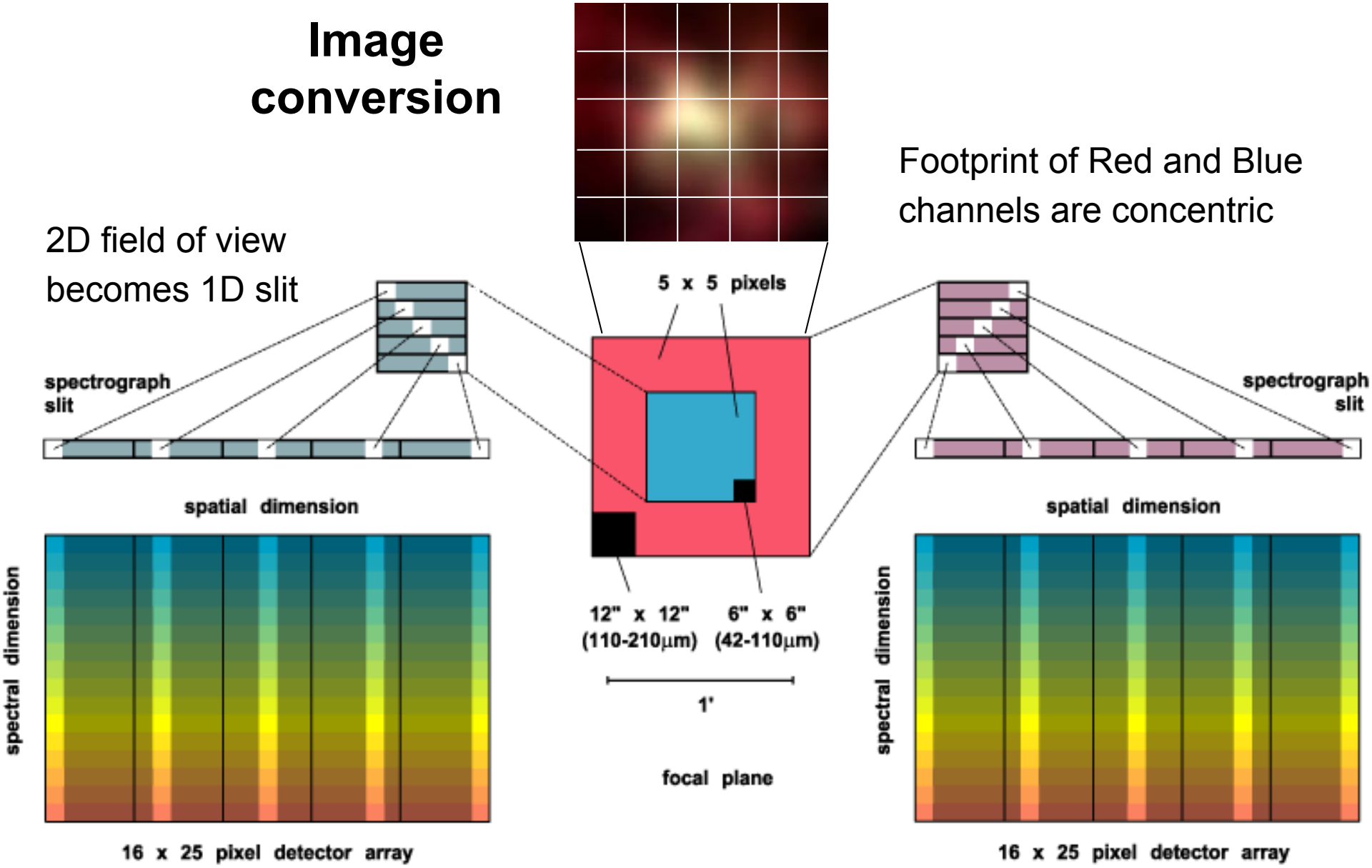
Targets: Extragalactic imaging

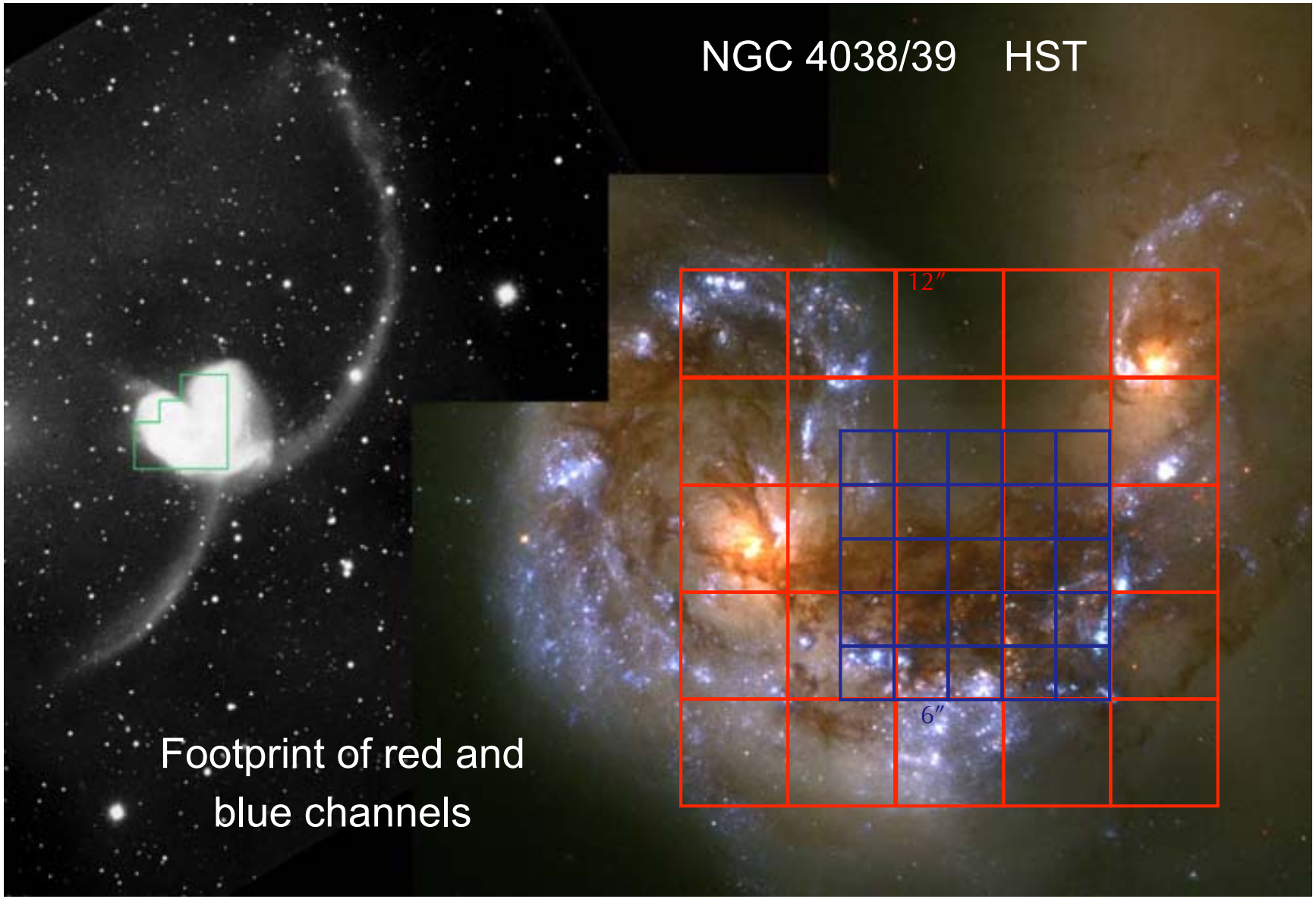
NB: Imaging array is 5 x 5 pixels



On sky orientation of ‘blue’ and ‘red’ channels

Image conversion




NGC 4038/39 HST
12″
6″
Footprint of red and
blue channels

Potential synergies between SOFIA and CCAT

EXAMPLES (southern hemisphere)

Carina region (LABOCA) → CO, CI, CII dark gas

Galactic Center (CMZ, Bolocam) → map HD J=1-0 in emission

Magellanic Clouds (NANTEN) → CI, CII dark gas

Antennae (ISO) → CO hot spots SED (low-J, high J), shocks

Centaurus A (SMBH) → central submm/FIR emission, PDR/XDR

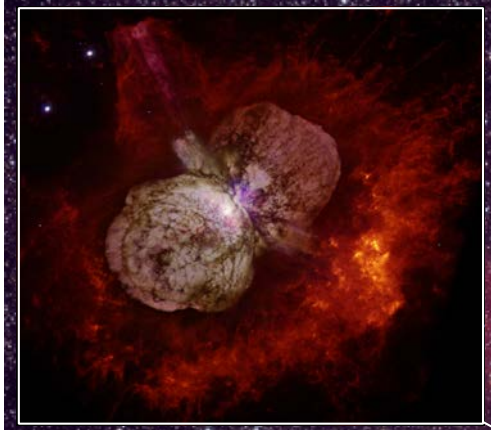
CCAT submm/wide-field mapping

SOFIA FIR-MIR 2-5 THz mapping

25mCCAT@350micron = 2.5mSOFIA@35micron = 3.5”resolution

absorption spectroscopy towards CenA: CO(CCAT)/HD(SOFIA)

The Great Nebula in Carina



η Car

the galaxy's most luminous star

Tr 15

Tr 14

Tr 16

D = 2.3 kpc

15 '

10 pc

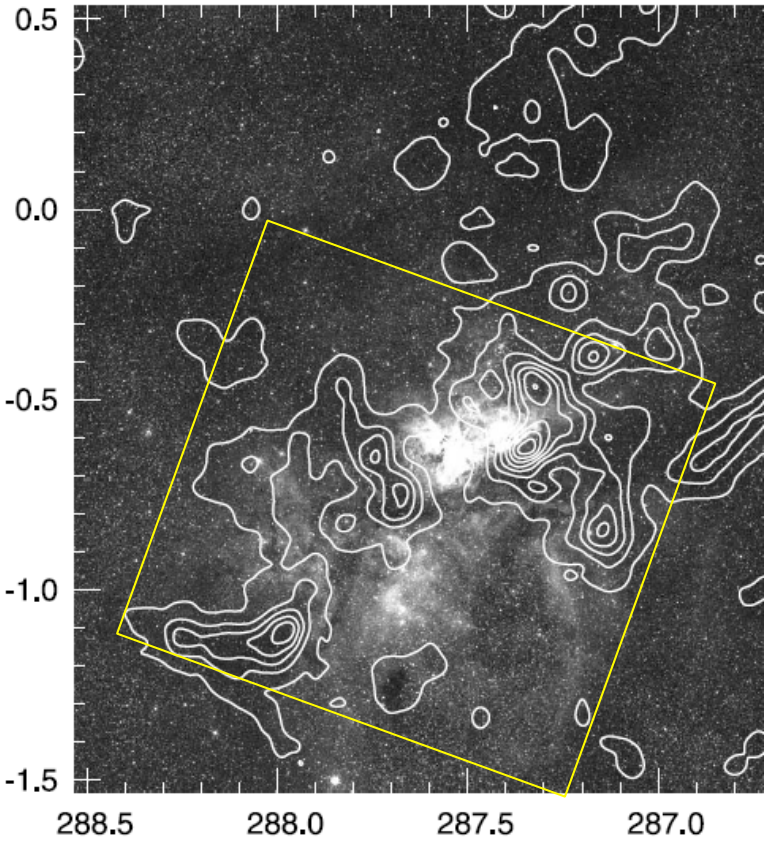
Orion Nebula at the same physical scale

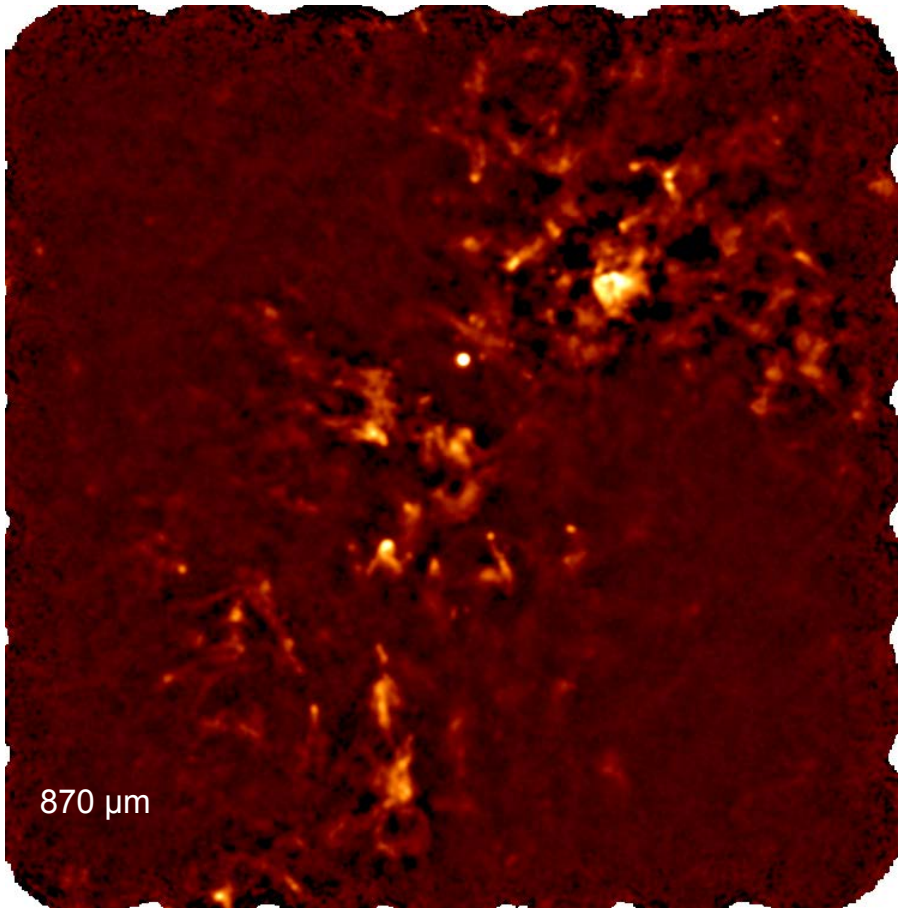
+ 70 O+WR stars

$M_{\star,max} \sim 120\ M_{\odot}$

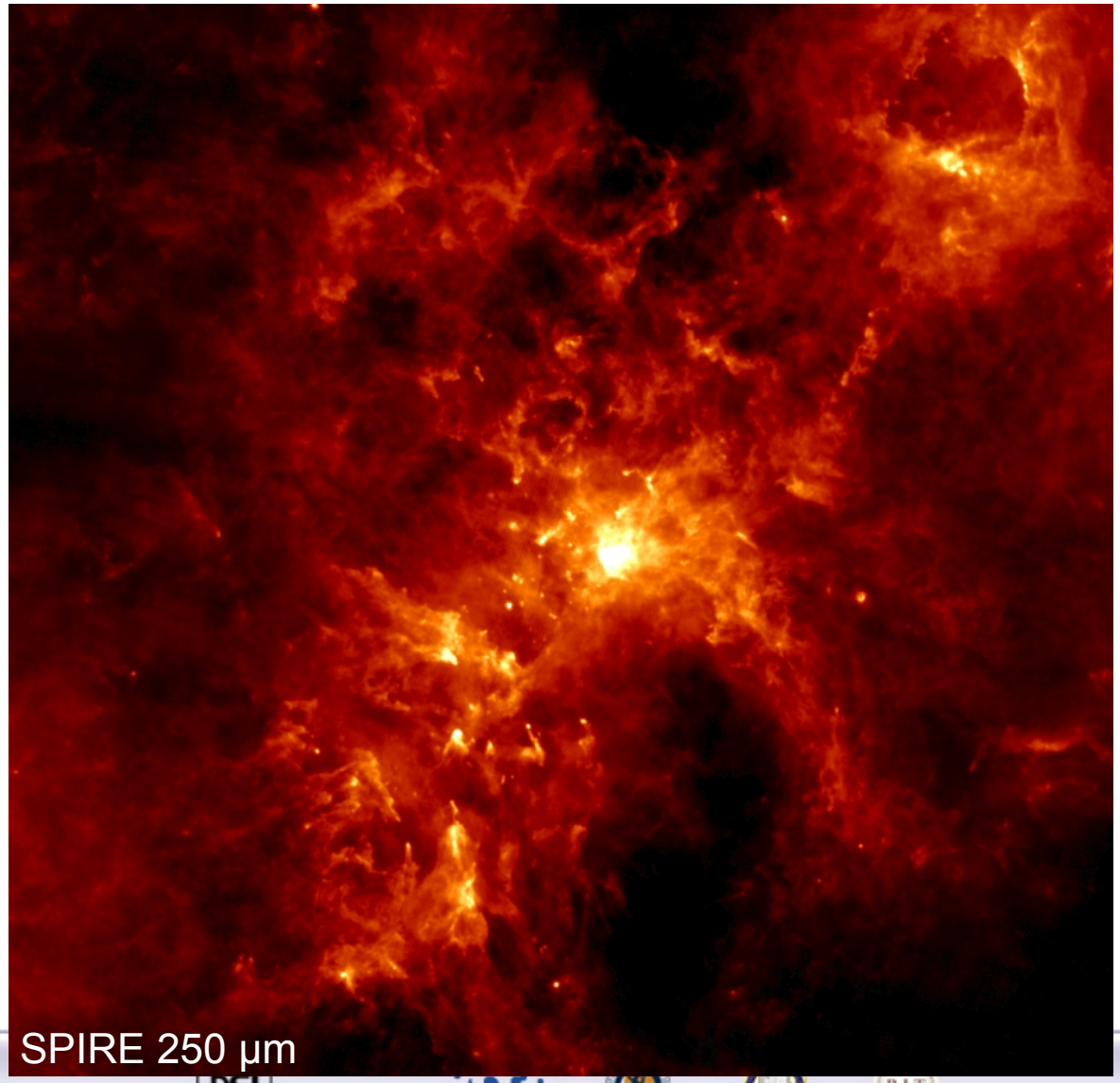
STEP 3: Characterization of the clouds

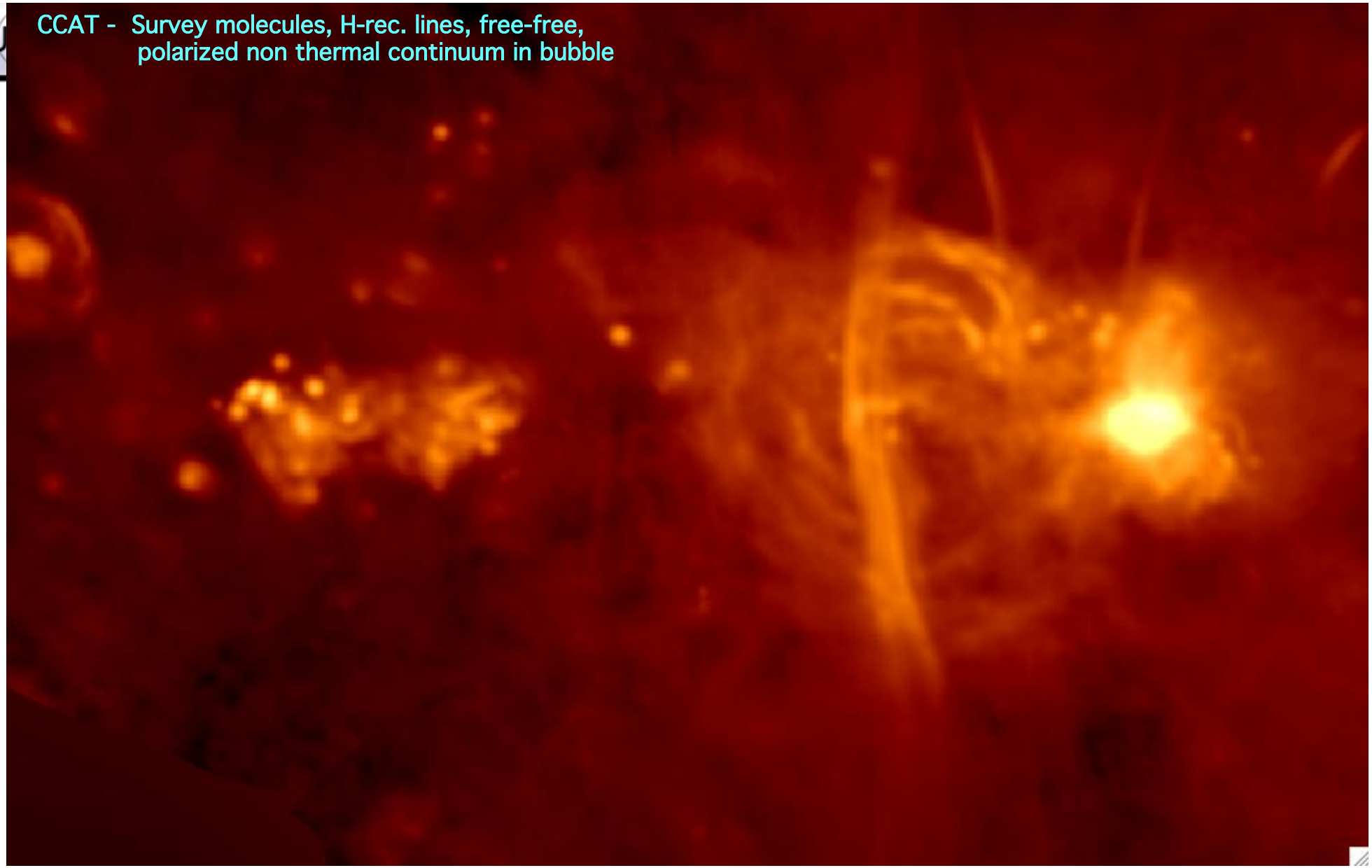
A: Sub-mm (870 μm) survey with LABOCA / APEX



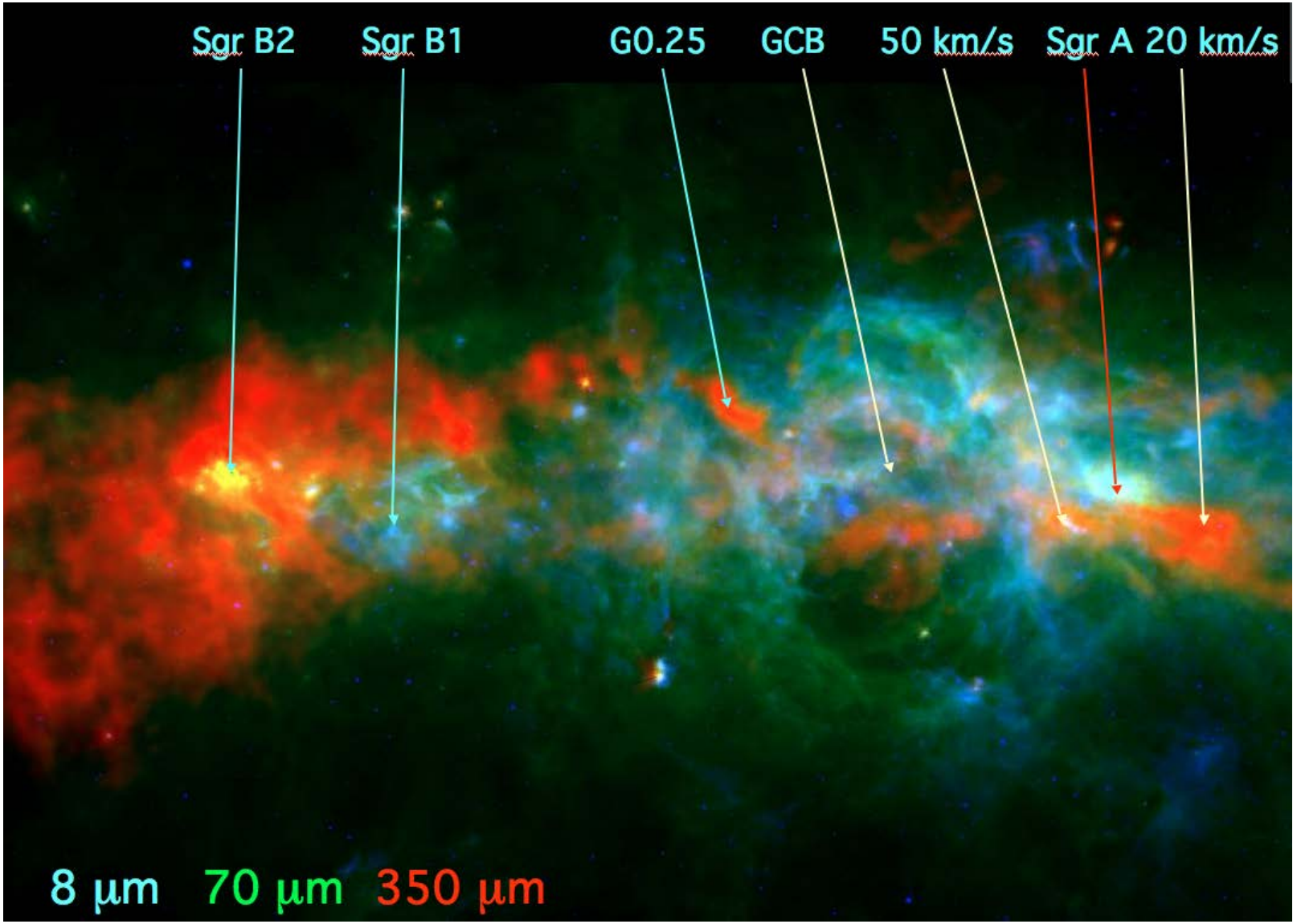


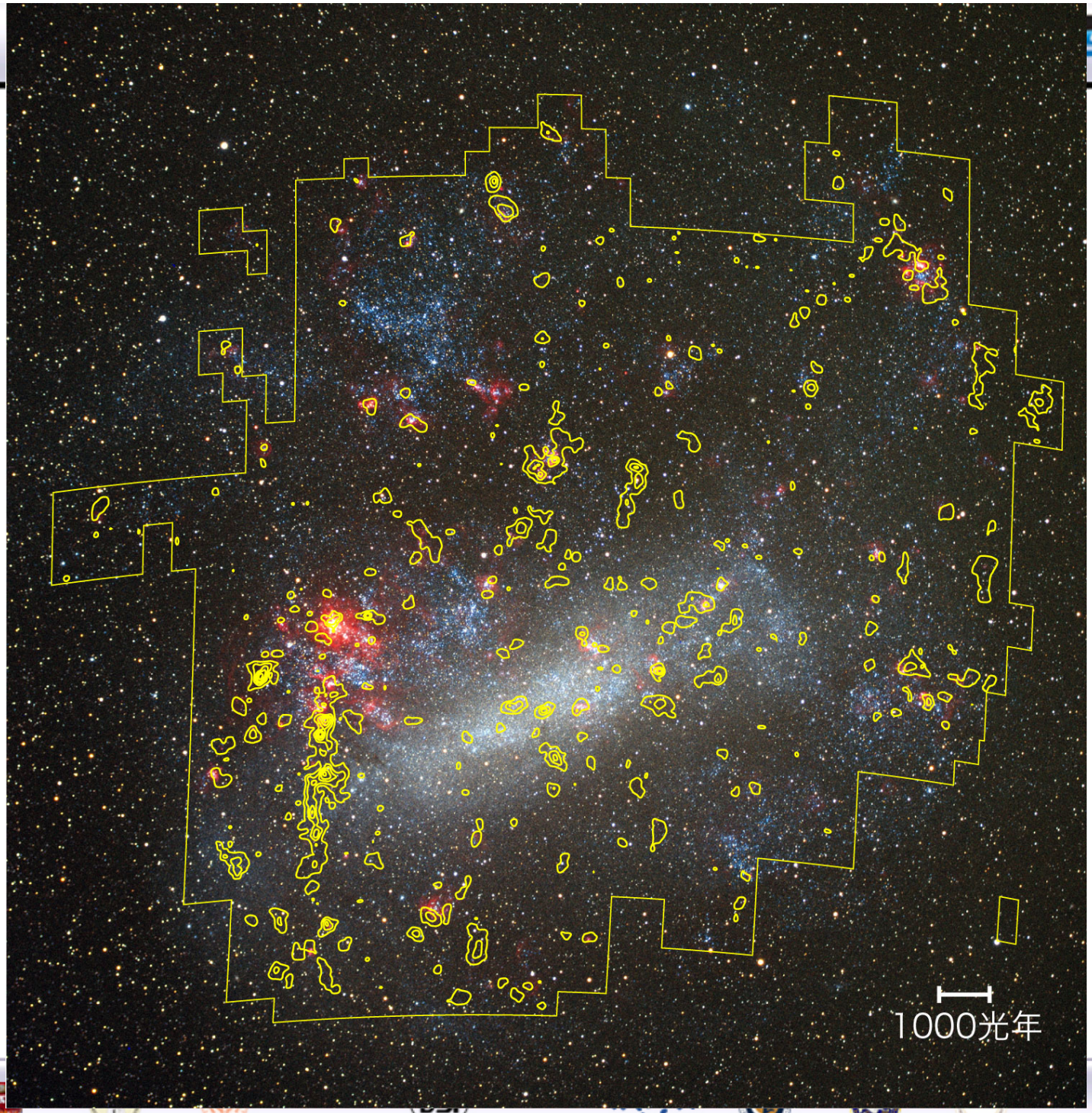
B: Herschel observations of the Carina Nebula

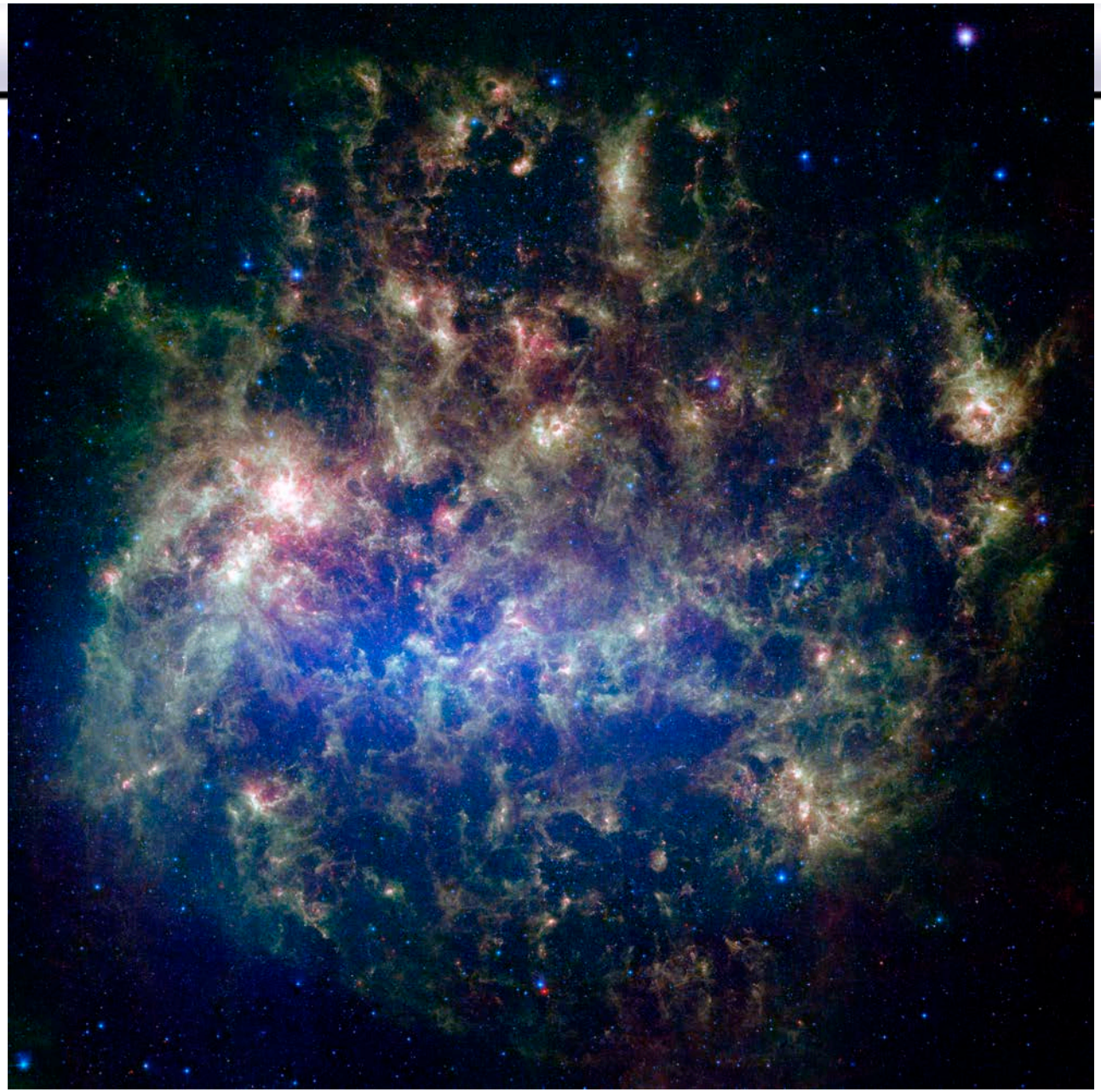


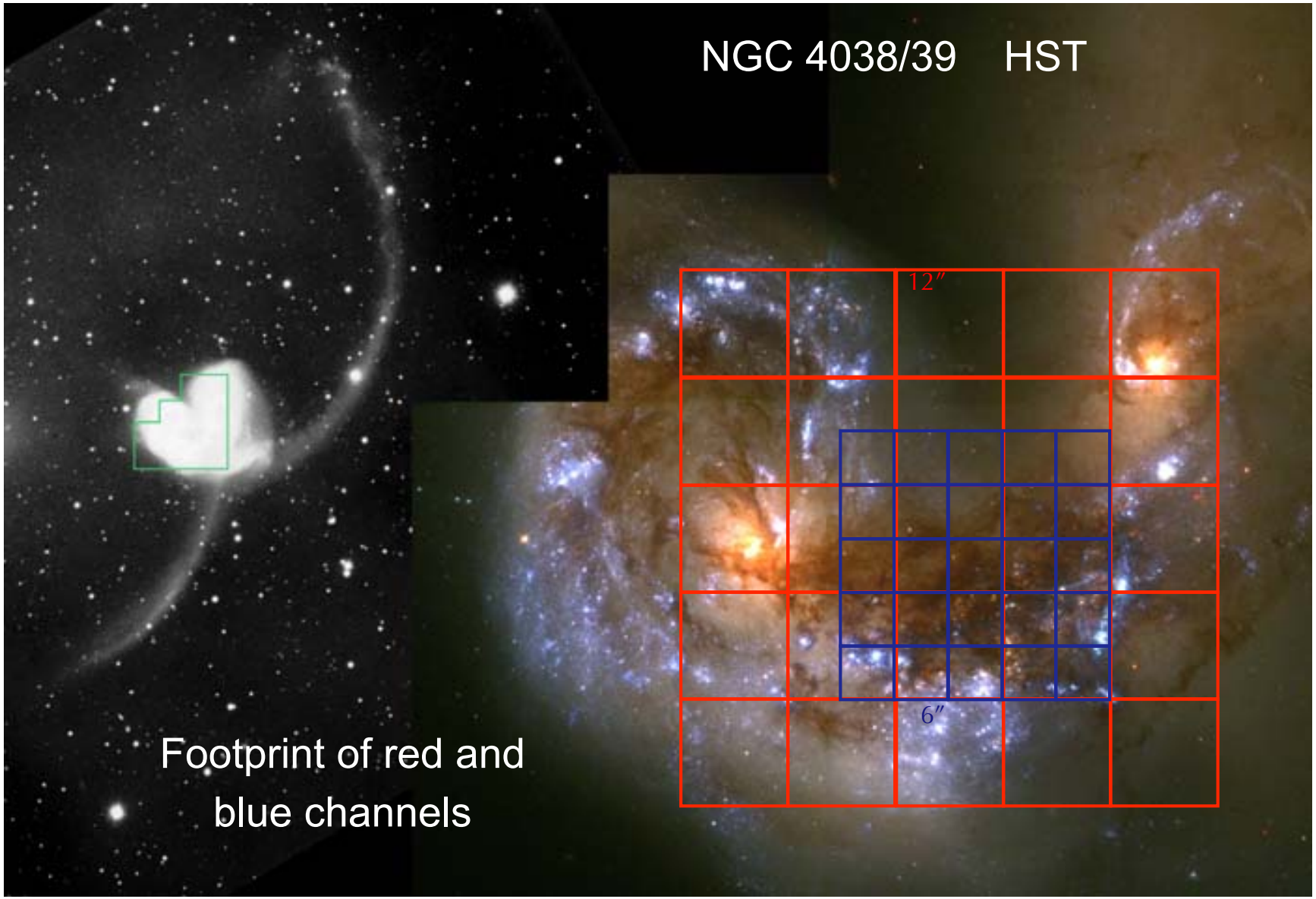

CCAT - Survey molecules, H-rec. lines, free-free,
polarized non thermal continuum in bubble
20 cm

Galactic Center IR/submm image (Bally)




1000光年




NGC 4038/39 HST
12″
6″
Footprint of red and
blue channels

Excursion to Orion (Becklin's Lemma)

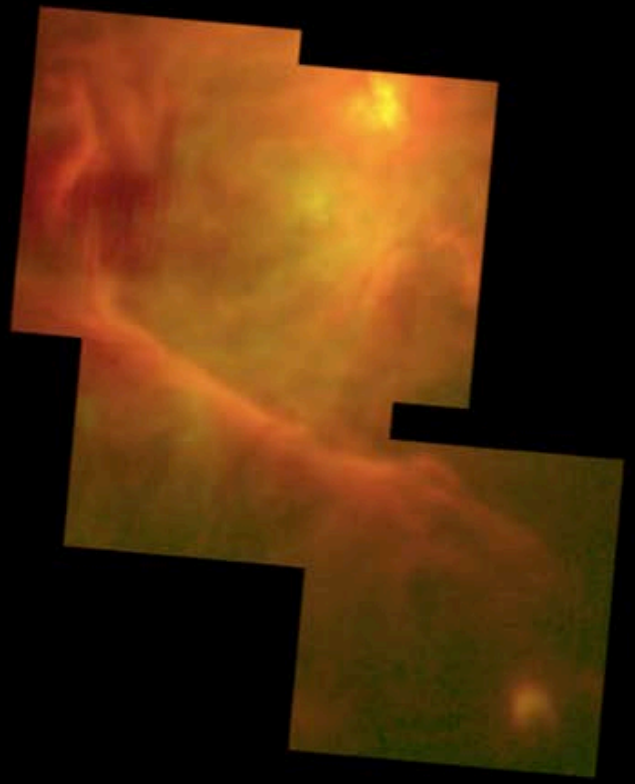
- SOFIA/FORCAST imaging results (ApJL ready to subm)
- What can CCAT do in Orion BNKL (200 micron imaging)?

- THz spectroscopic observations with GREAT next step
- What are the Herschel HIFI results for the Orion region?

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

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

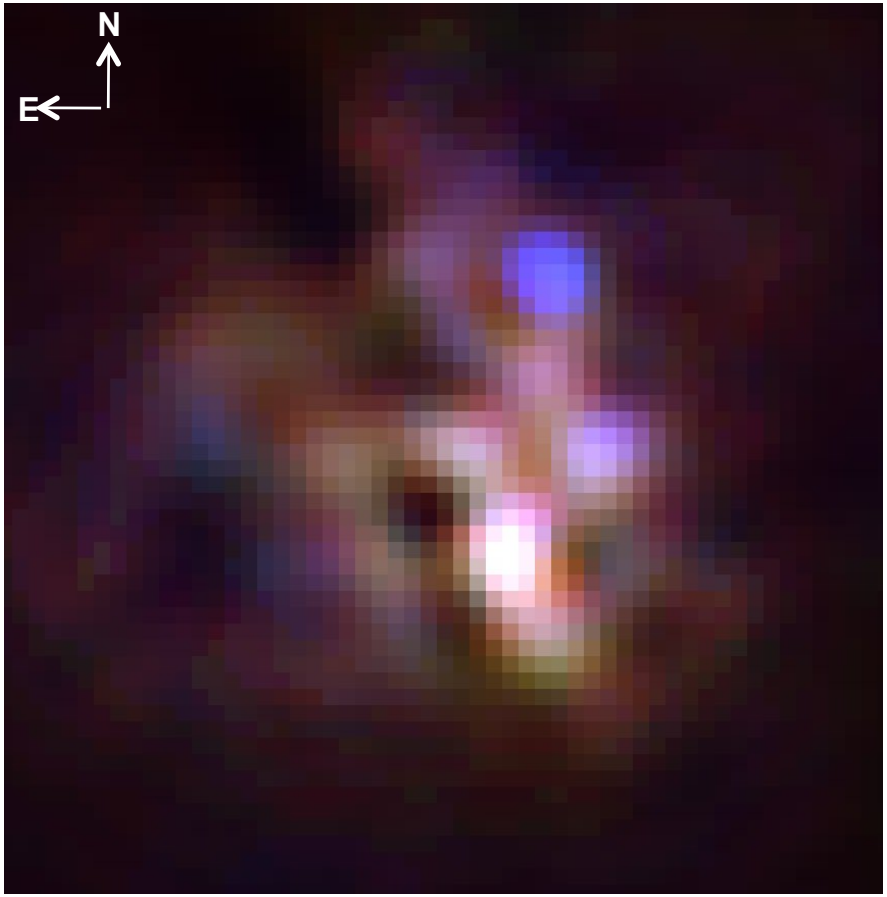
Near infrared
(ESO, M. McCaughrean)

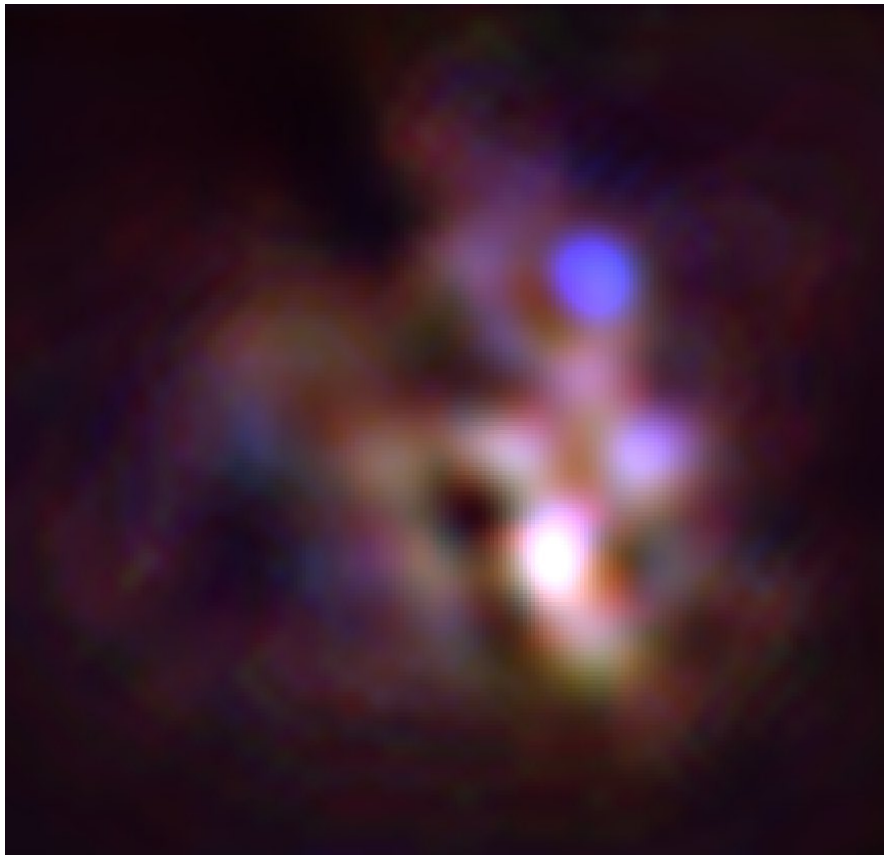


SOFIA mid infrared
(SS02)

3-color images of BNKL region

19um, 31um, 37 um



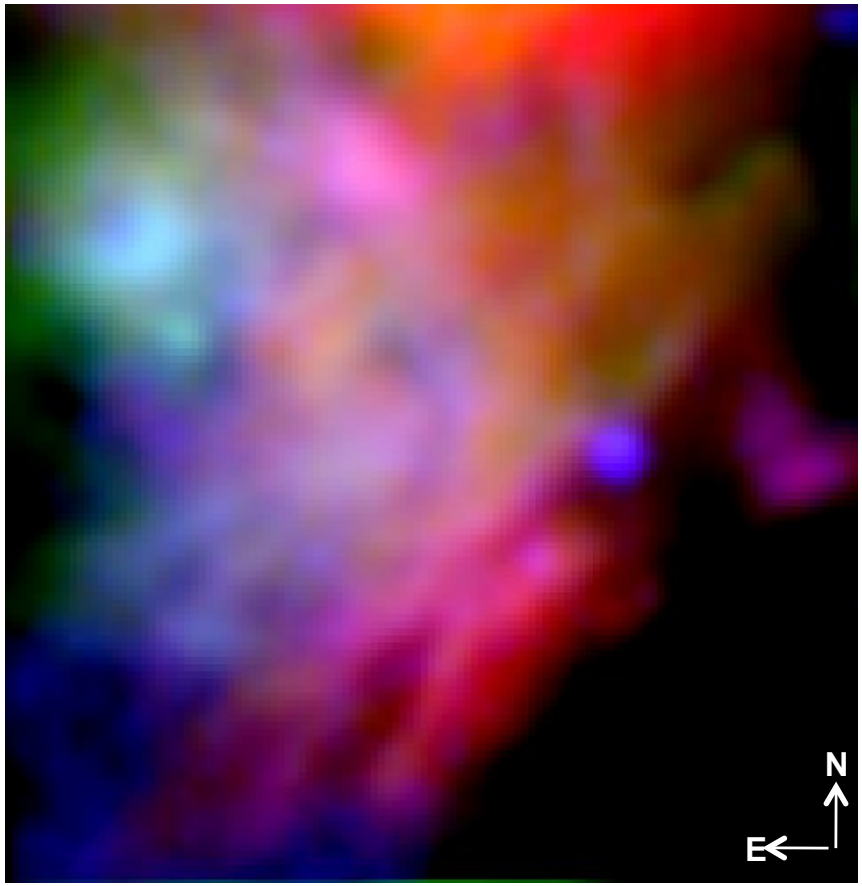


37

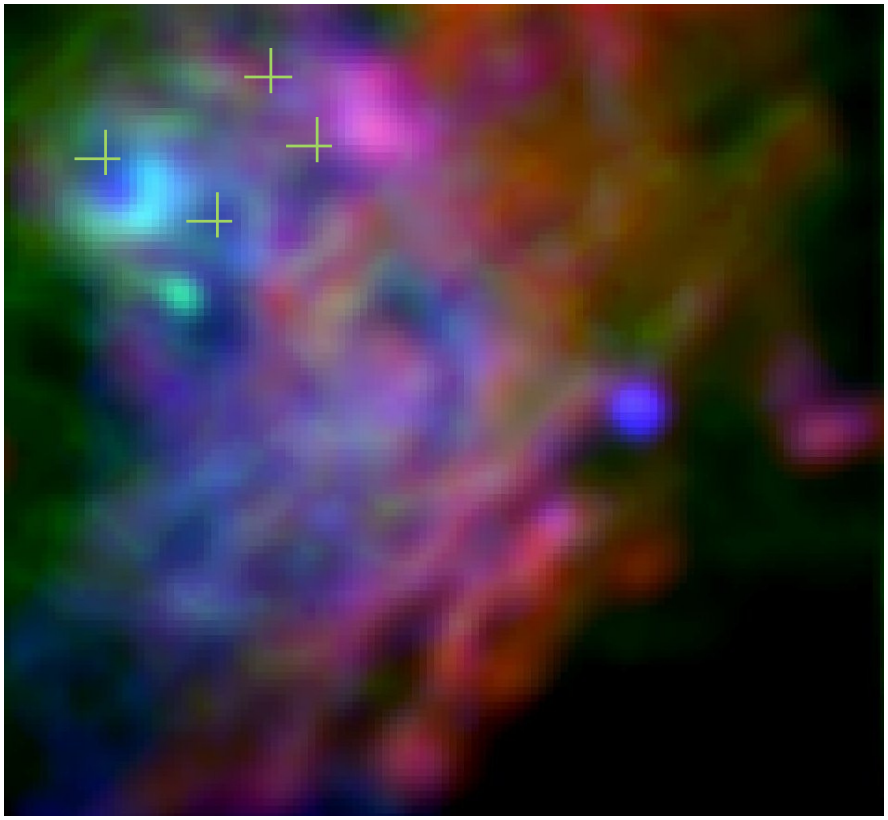
3-color images of Trapezium region

7um, 19um, 37 um

Natural Resolution



DMRM Deconvolution

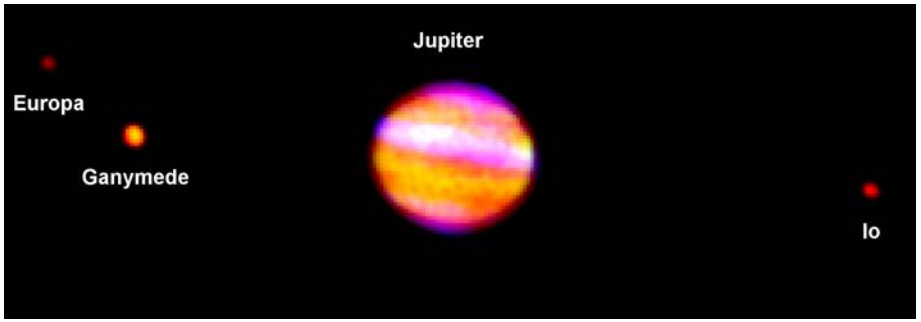


SOFIA Highlights 2011

- April 2011 GREAT Early Science Flights
- May 2011 FORCAST Basic Science Flights
- June 2011 Pluto Occultation Flight
- July 2011 Call for 2nd Generation Instruments
- July 2011 GREAT Basic Science
- Sept 2011 Deployment to Germany
- Sept 2011 E/PO Event at Andrews AFB
- Sept 2011 Completion of Basic Science (into Nov.)
- Oct 2011 2nd Generation Instrument Proposals Due
- Nov 2011 Call for Cycle 1 observing proposals (US)
- Dec 2011 Begin Maintenance Downtime (Seg 3).

Summary

- SOFIA program getting into gear!
  - First Science with FORCAST and GREAT was a great success
  - Aircraft handles well, even with door open (unnoticable in flight)
  - Aircraft now cleared to 45,000ft
  - Community science has started with 15 of 18 flights.
  - Successful Occultation of Pluto in June over the Pacific
  - Deployment to Germany and to Washington DC in Sept
  - Call for 2nd instruments due today
- SOFIA will be one of the prime facilities for mid-IR and far-IR-astronomy for many years to come



SOFIA EP/O

- Airborne Astronomy Ambassadors Program Launched
  - All 6 US educators in the first AAA class flew on Basic Science 1 flights
  - Parallel German AAA program flew their first educators during Basic Science 2
- SOFIA was deployed to Germany in mid-September to support the Cologne Air Show September 18, 2011, and to be seen at Stuttgart airport (more than 5000 people)
- SOFIA also had a stopover at Andrew AFB in Washington for viewing by NASA officials etc.

Educators from the first Airborne Astronomy Ambassadors flight. (l-r) Margaret Piper, Lincoln Way High School, Frankfort, Ill.; Theresa Paulsen, Mellen School District, Mellen, Wis.; and Kathleen Joanne Fredette, Desert Willow Intermediate School, Palmdale, Calif.

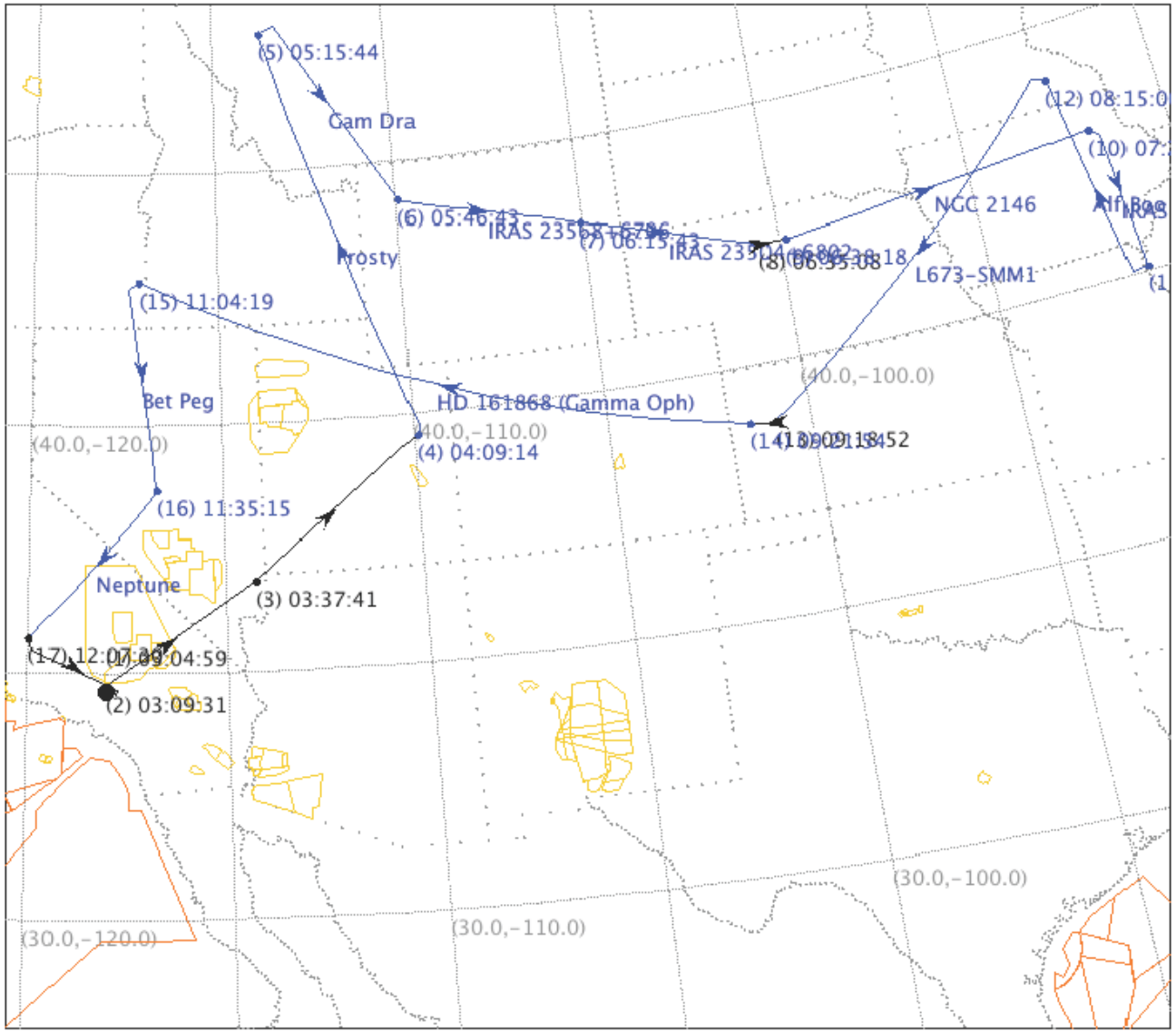
http://www.sofia.usra.edu

SOFIA in the Dryden Aircraft Operations Facility

SOFIA Operations

- Science flights originate from Palmdale California
  - Aircraft operation by NASA Dryden Research Center from the Dryden Aircraft Operations Facility (DAOF)
- Science Center is located at NASA Ames Research Center
  - USRA/DSI responsible for Science Operations on SOFIA
  - Support from Deutsches SOFIA Institut in Stuttgart (DSI)
- World Wide Deployments, including Southern Hemisphere
- SOFIA will ramp up to ~1000 science hours per year (2014)
- SOFIA will support the development of new generations of instruments, promising ever increasing capabilities (call for 2nd generation instruments to be answered by today Oct 7).

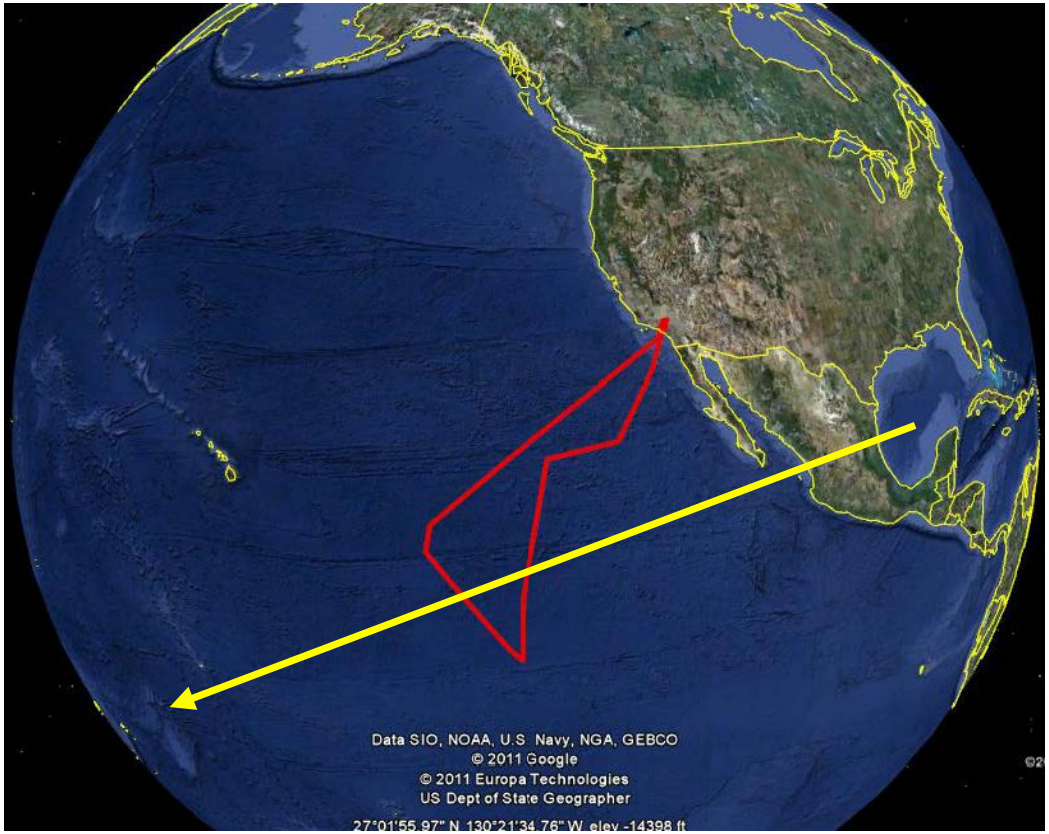
Sample Mission Plan



Basic Science 1
Flight #3

Occultation by Pluto 2011 June 23

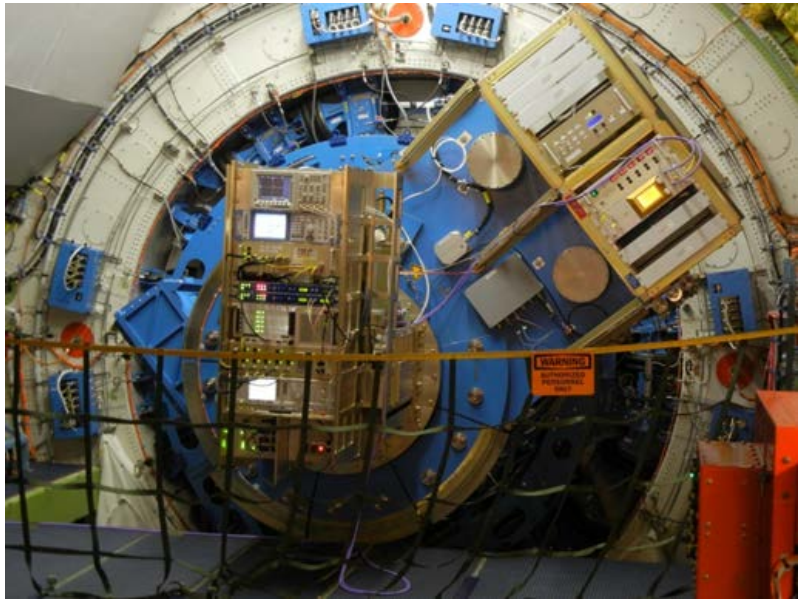
- Observation of Pluto passing in front of a bright star is used to provide highly detailed information about the atmosphere
- Mobility of SOFIA is key to successful observations

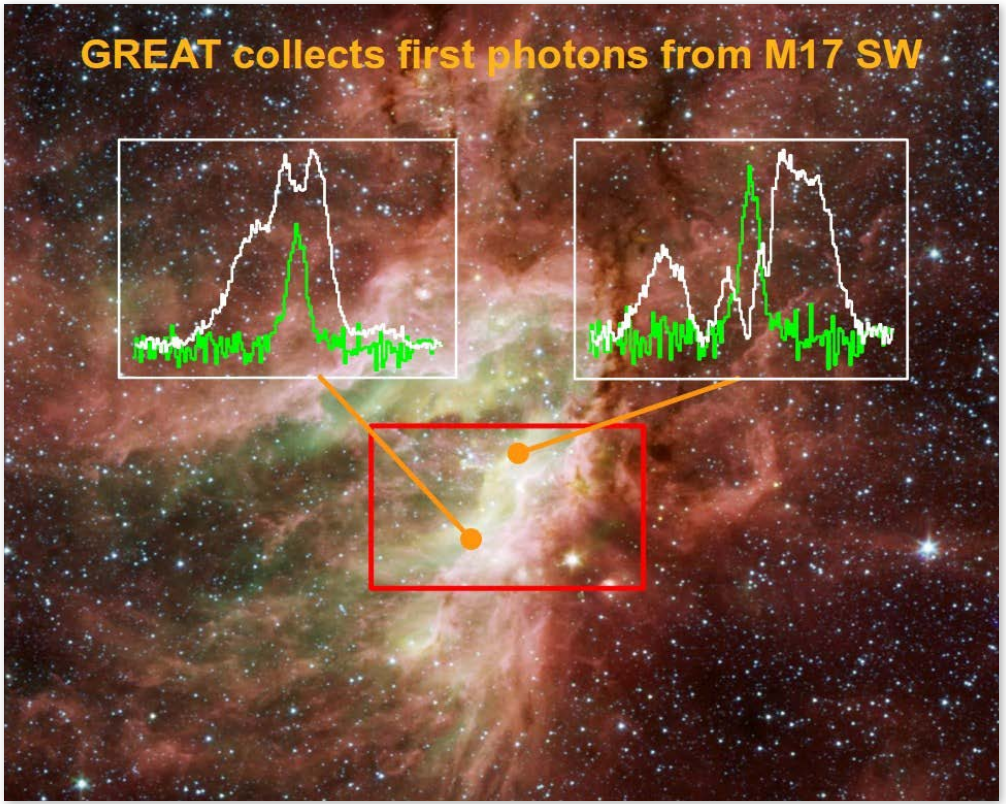


Motivation for SOFIA

- Infrared transmission in the stratosphere very good: >80% from 1 to 1000 μm
- Resolution and sensitivity is set by the size of the telescope
- Instrumentation: wide complement, rapidly interchangeable, state-of-the art
- Mobility: anywhere, anytime
- Long lifetime
- Outstanding platform to train future Instrumentalists
- SOFIA will have an important role in education and public outreach

Our first science flight





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