SOFIA – past, present, and future

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OUTLINE

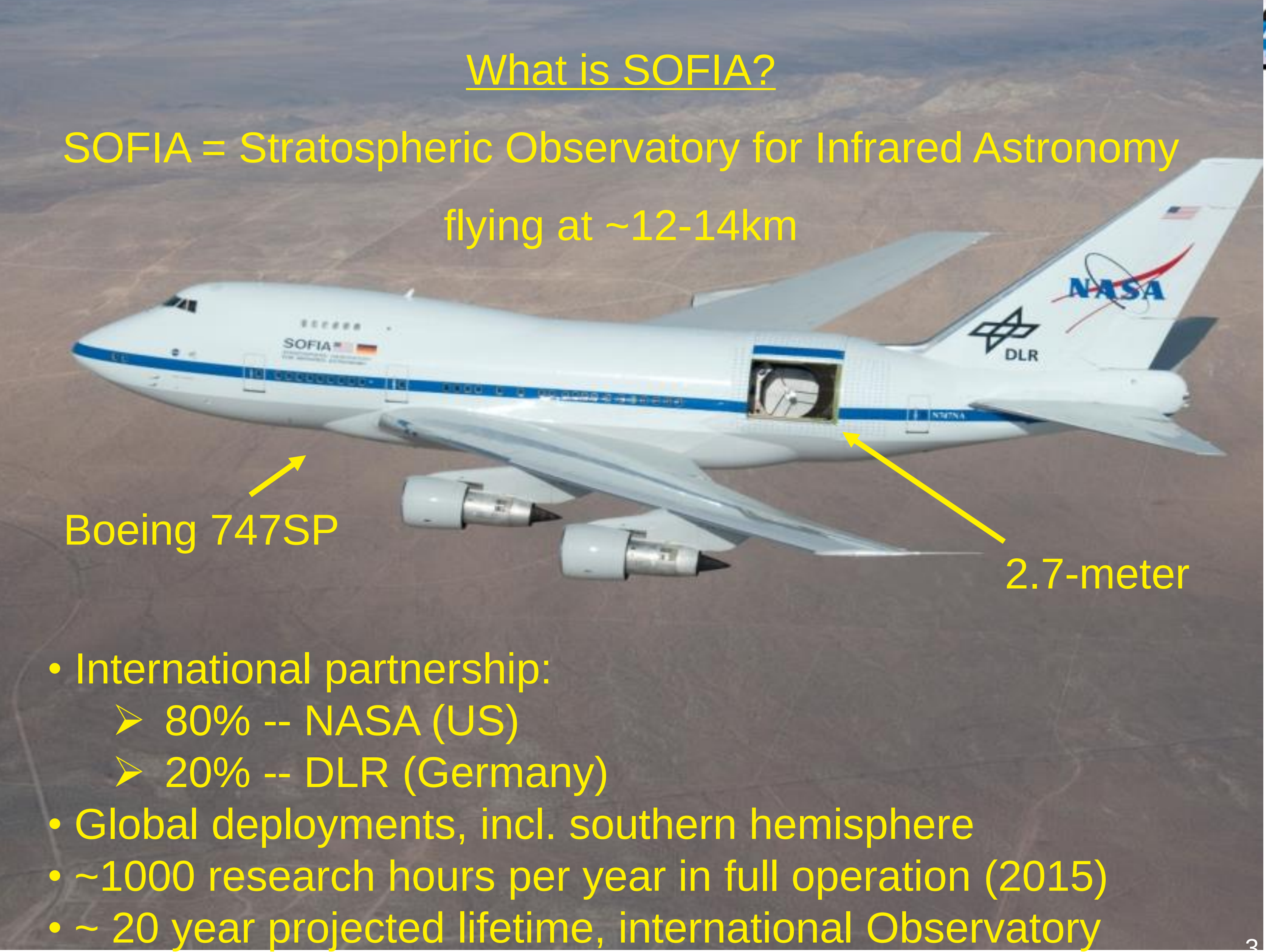
What is SOFIA?
The SOFIA Instrument Suite
Motivation for SOFIA
Science Vision

Recent Science Highlights
Southern Hemisphere Deployment
future scientific potential
public outreach

What is SOFIA?

SOFIA = Stratospheric Observatory for Infrared Astronomy

flying at ~12-14km



- International partnership:
  - ➢ 80% -- NASA (US)
  - ➢ 20% -- DLR (Germany)
- Global deployments, incl. southern hemisphere
- ~1000 research hours per year in full operation (2015)
- ~ 20 year projected lifetime, international Observatory

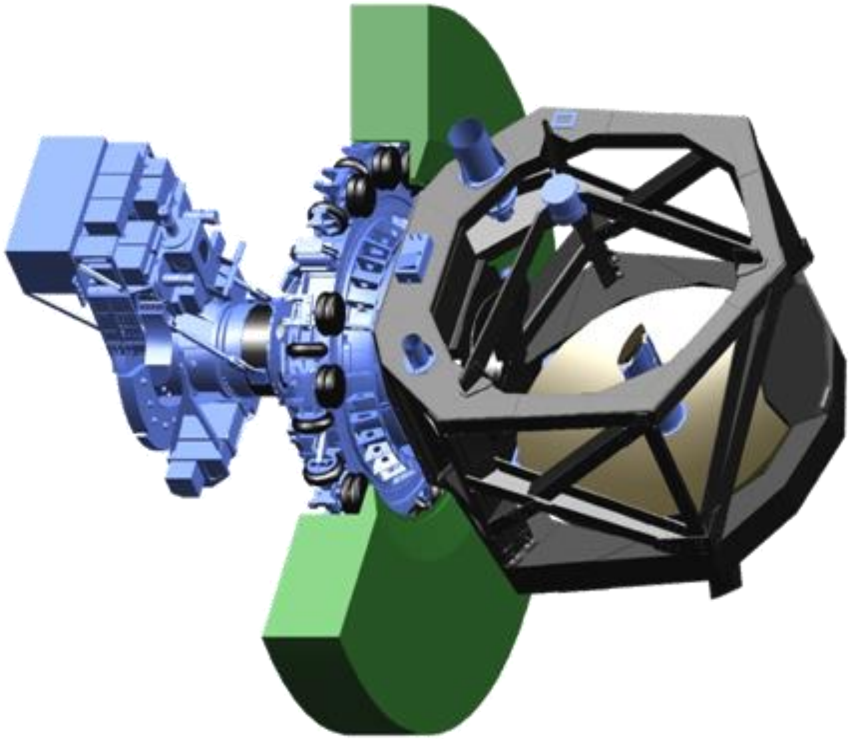
The SOFIA Aircraft

SOFIA is a highly modified Boeing 747SP

- Length: 177 feet
- Wingspan: 196 feet
- Service ceiling: 45,000 feet (13.7 km)
- Airspeed at 41,000 feet: 450 knots (Mach 0.8 or 520 mph)
- Range: 6,625 nautical miles
- Mission duration: 8 to 10 hours (standard); 12.2 hours (maximum)
- Cavity door (18 feet by 14.3 feet)

- Fuel usage: 150,000 to 250,000 pounds (standard duration mission)

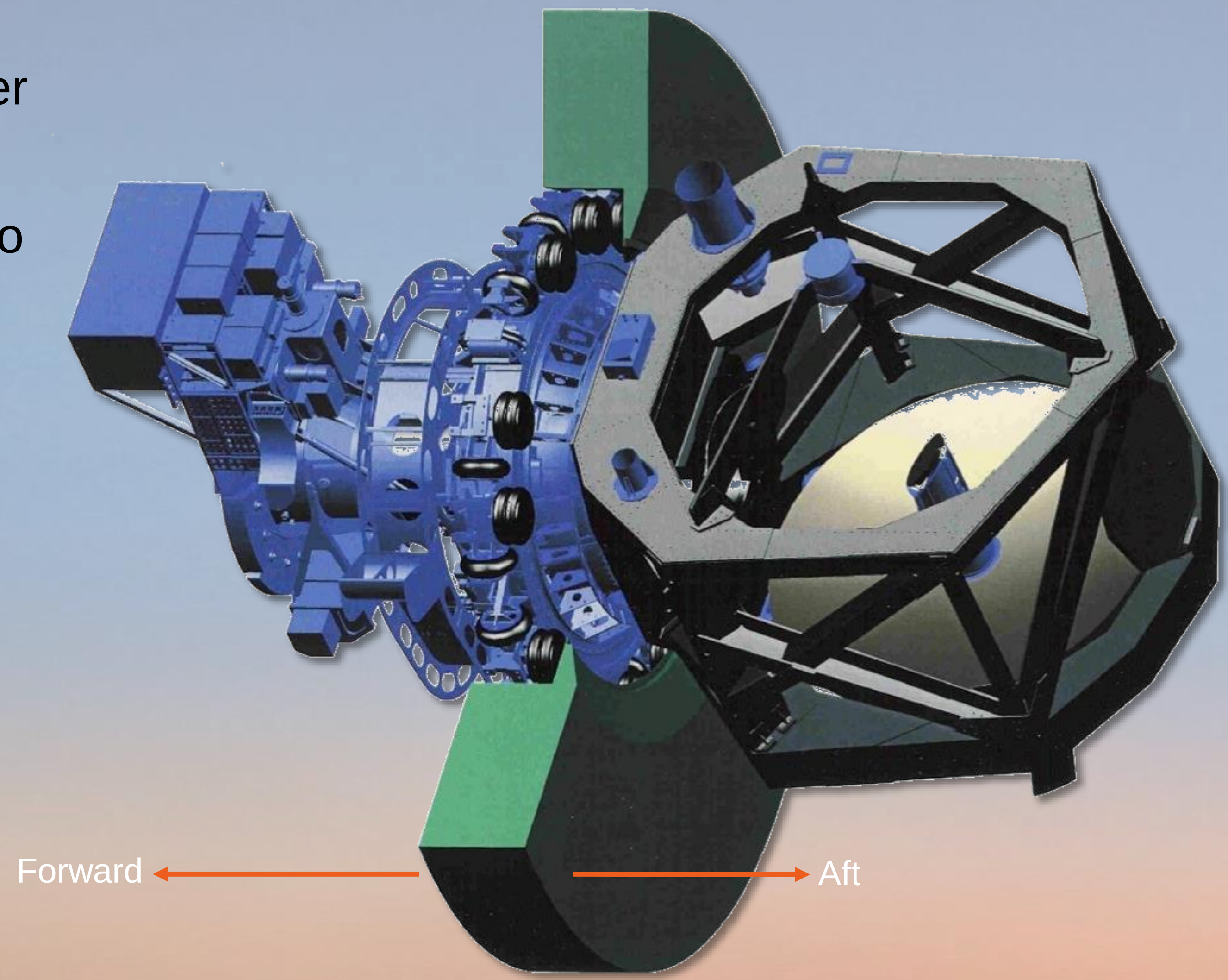
The Telescope Assembly – A Major German Contribution



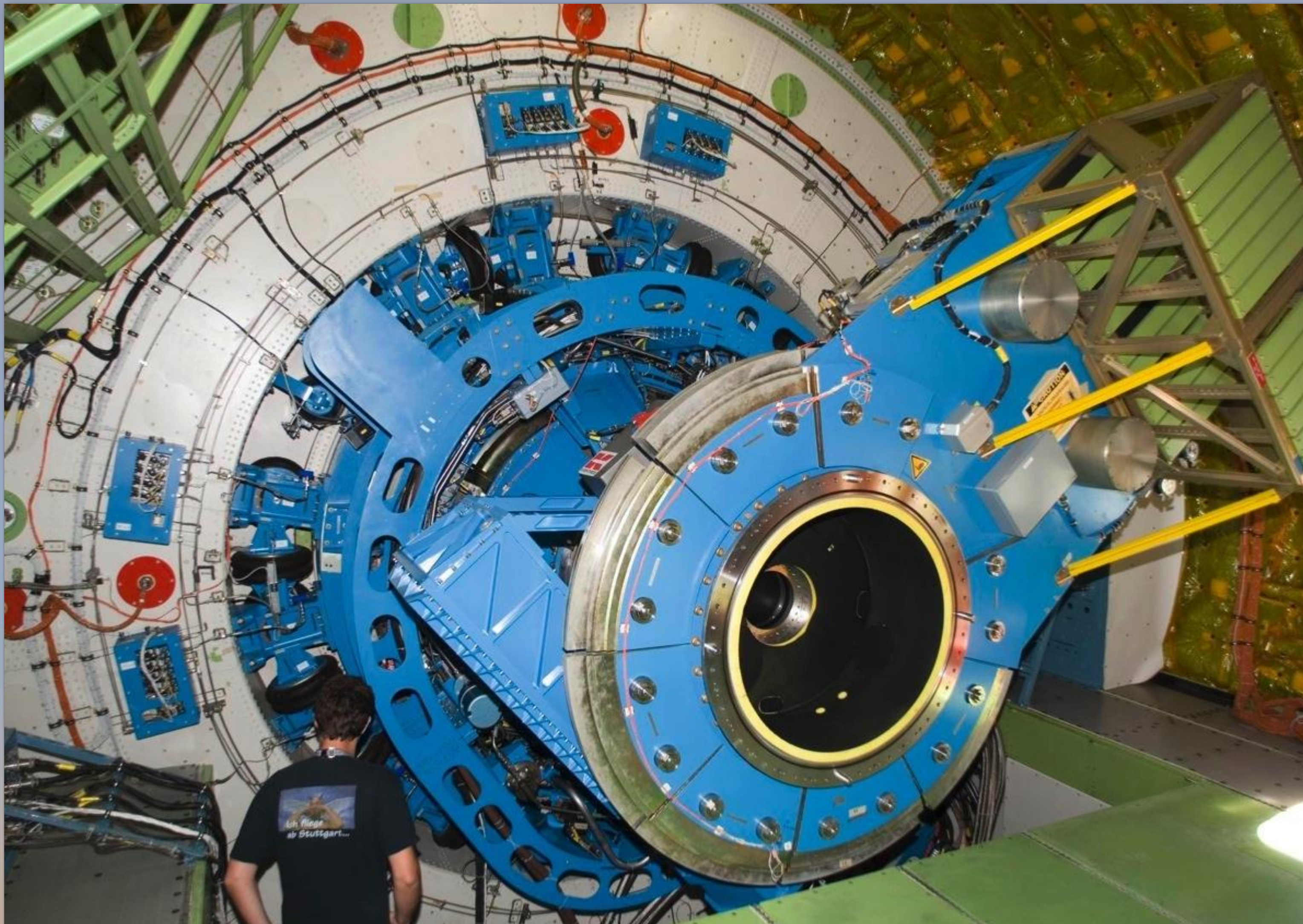
The SOFIA Telescope

Onboard telescope

- Bent Cassegrain, 2.7 meter diameter mirror (~10 feet)
- Wavelength: 0.3 to 1,600 microns
- Installed weight: 17 metric tons (37,478 pounds)



Interior (Main Cabin) View of Telescope Assembly

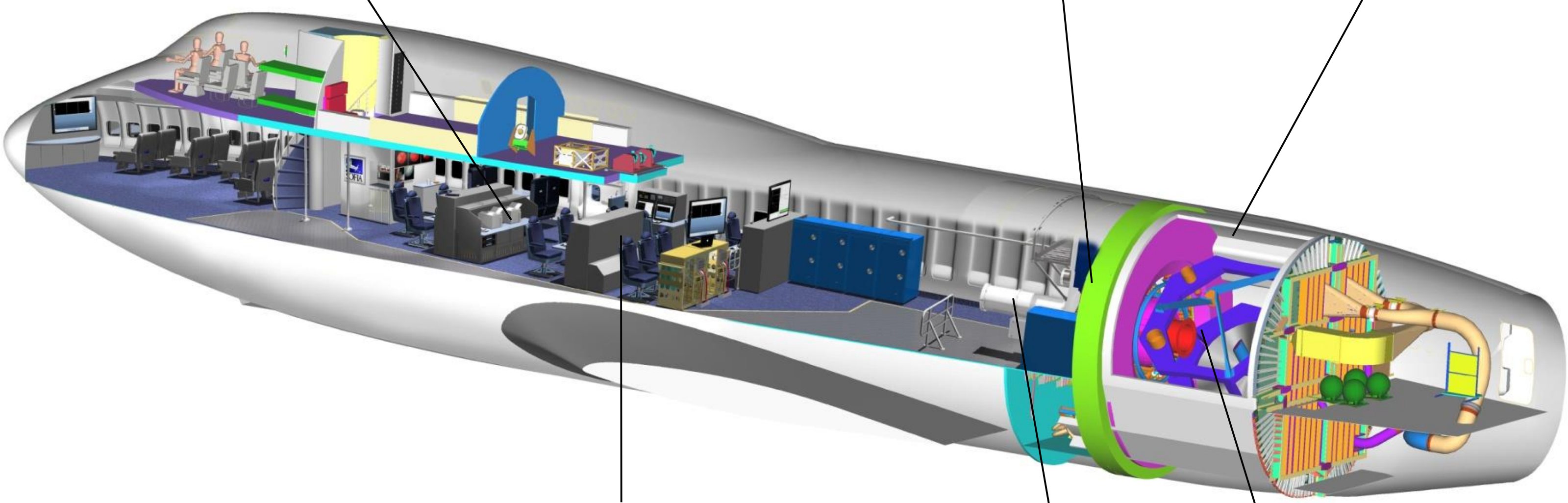


White is pressure bulkhead

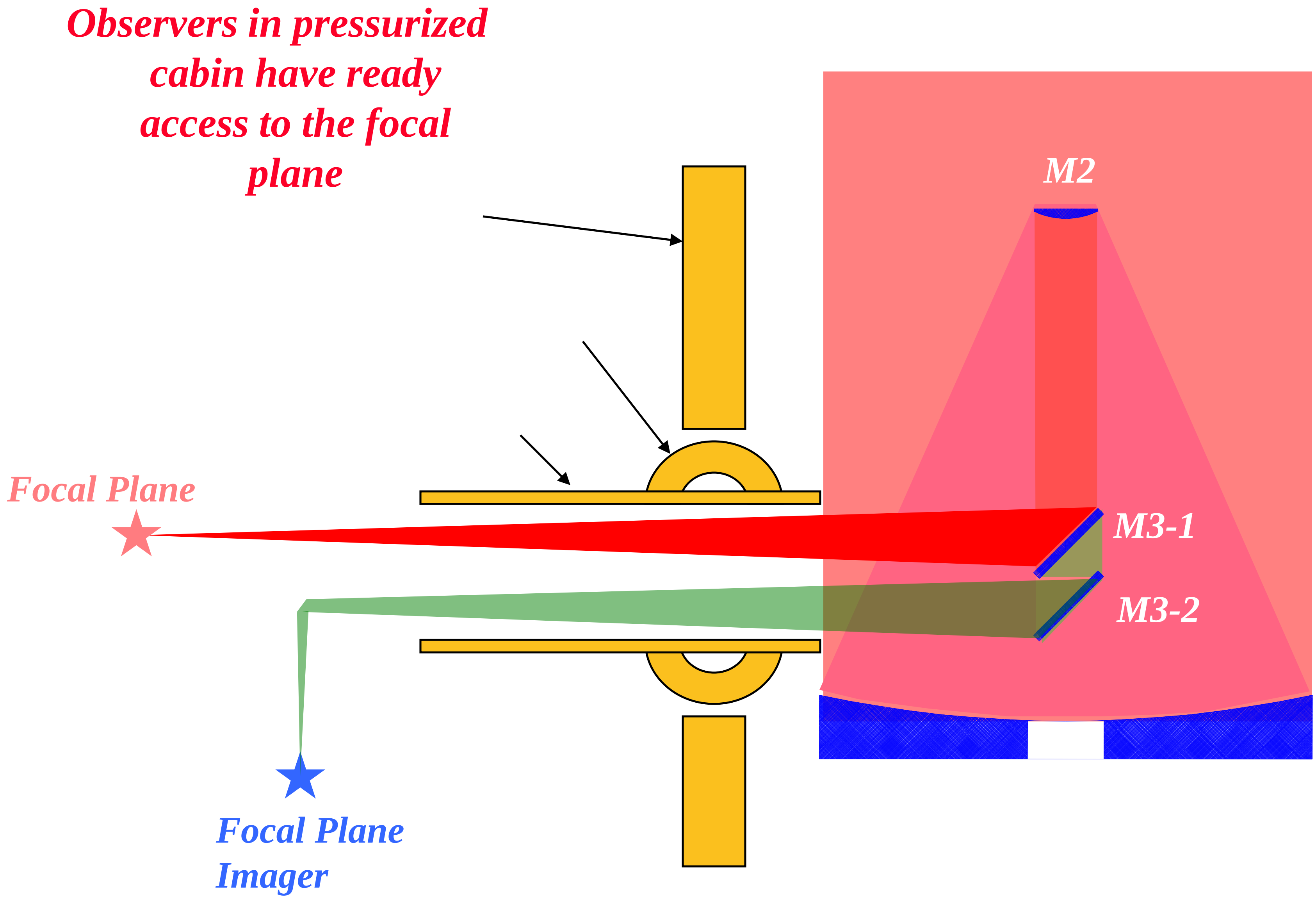
Blue is DLR-supplied telescope

SOFIA First Science Flight (FORCAST, Dec 2010)

SOFIA – The Observatory



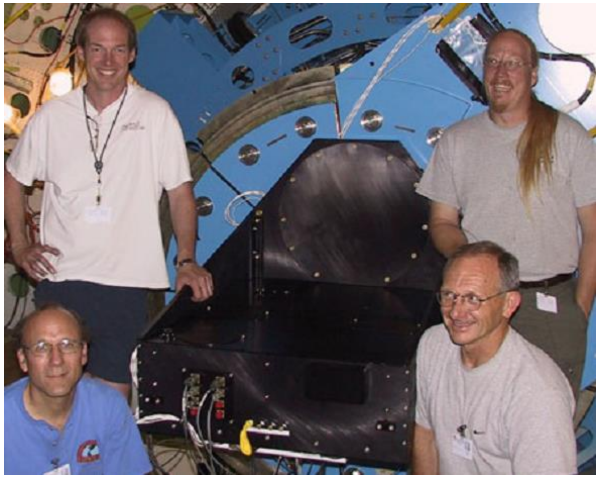
Nasmyth: Optical Layout



SOFIA instrument suite

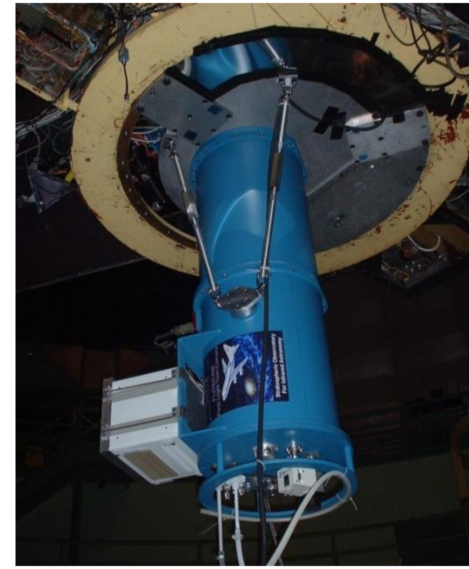
- FORCAST
- GREAT
- HIPO
- FLITECAM
- FIFI-LS
- EXES
- HAWC ++

Four Completed 1st Generation Instruments



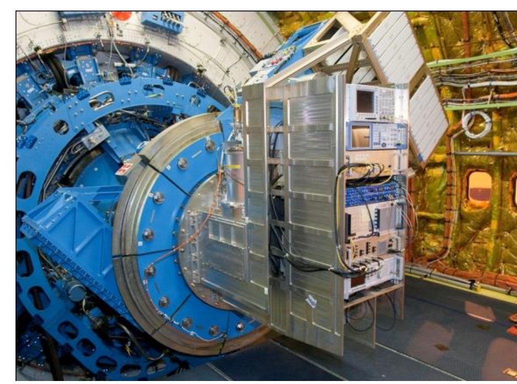
HIPO
High Speed Photometer

FLITECAM
Near IR Camera
(at Lick)



FORCAST
Mid-IR Camera

GREAT
Heterodyne spectrometer



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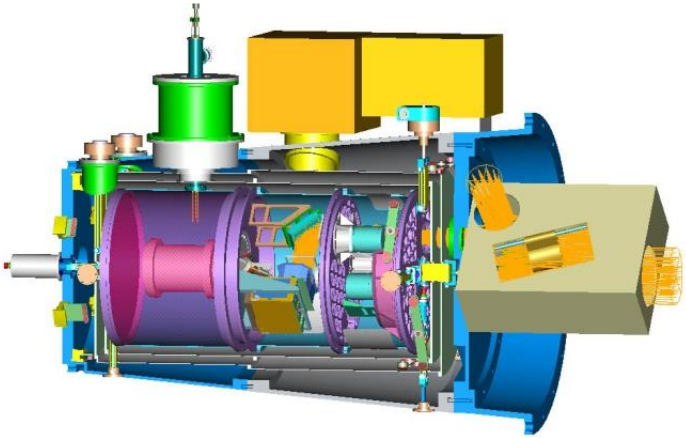
Instruments in development

HAWC

Bolometer Camera

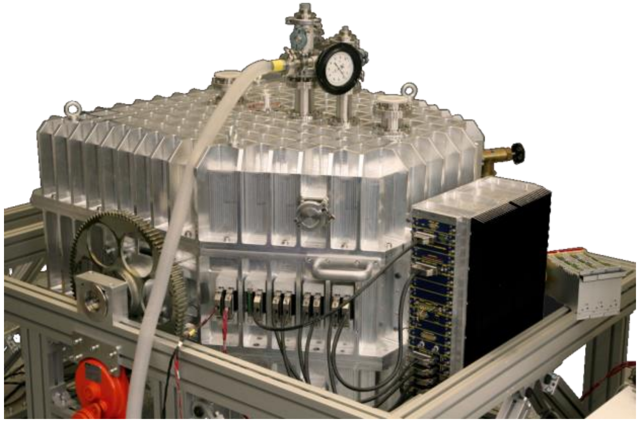


EXES

Mid- IR Spectrometer

FIFI LS

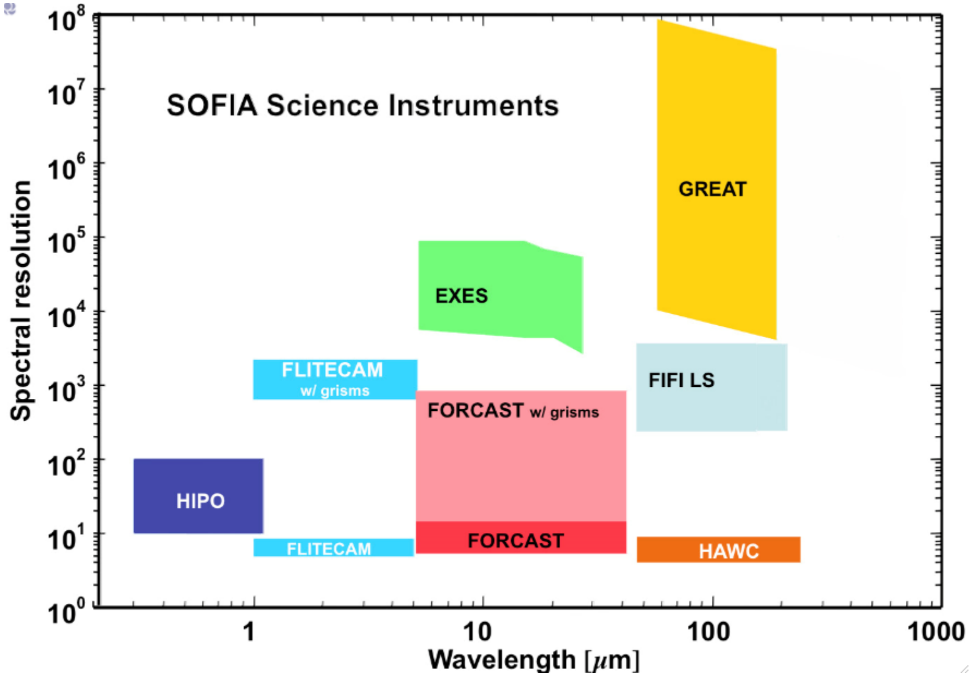
Integral Field Spectrometer



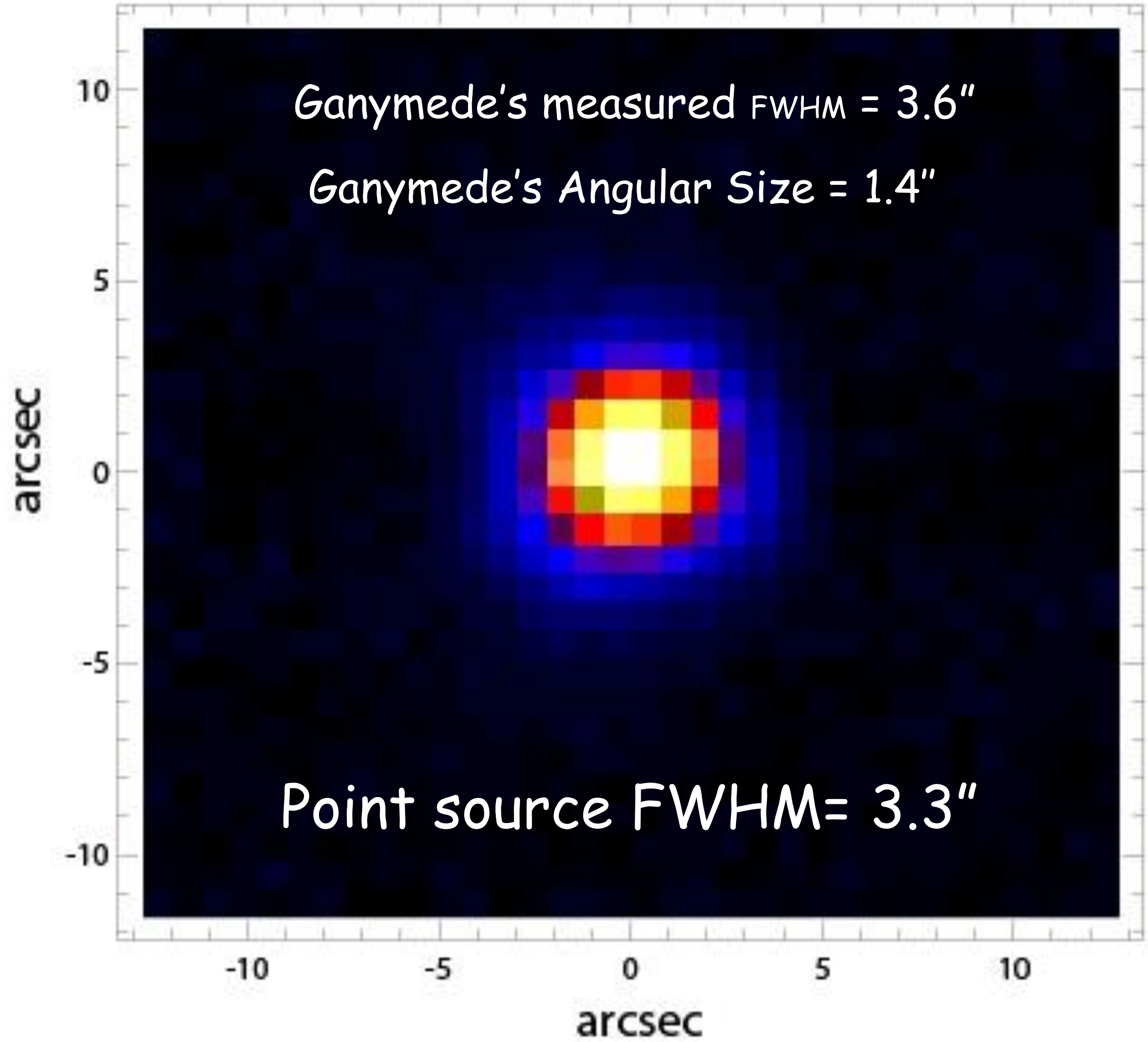
SOFIA's Instrument Complement

- FORCAST
- GREAT, upGREAT
- HIPO
- FLITECAM

- FIFI-LS
- EXES
- HAWC-POL (2nd gen)

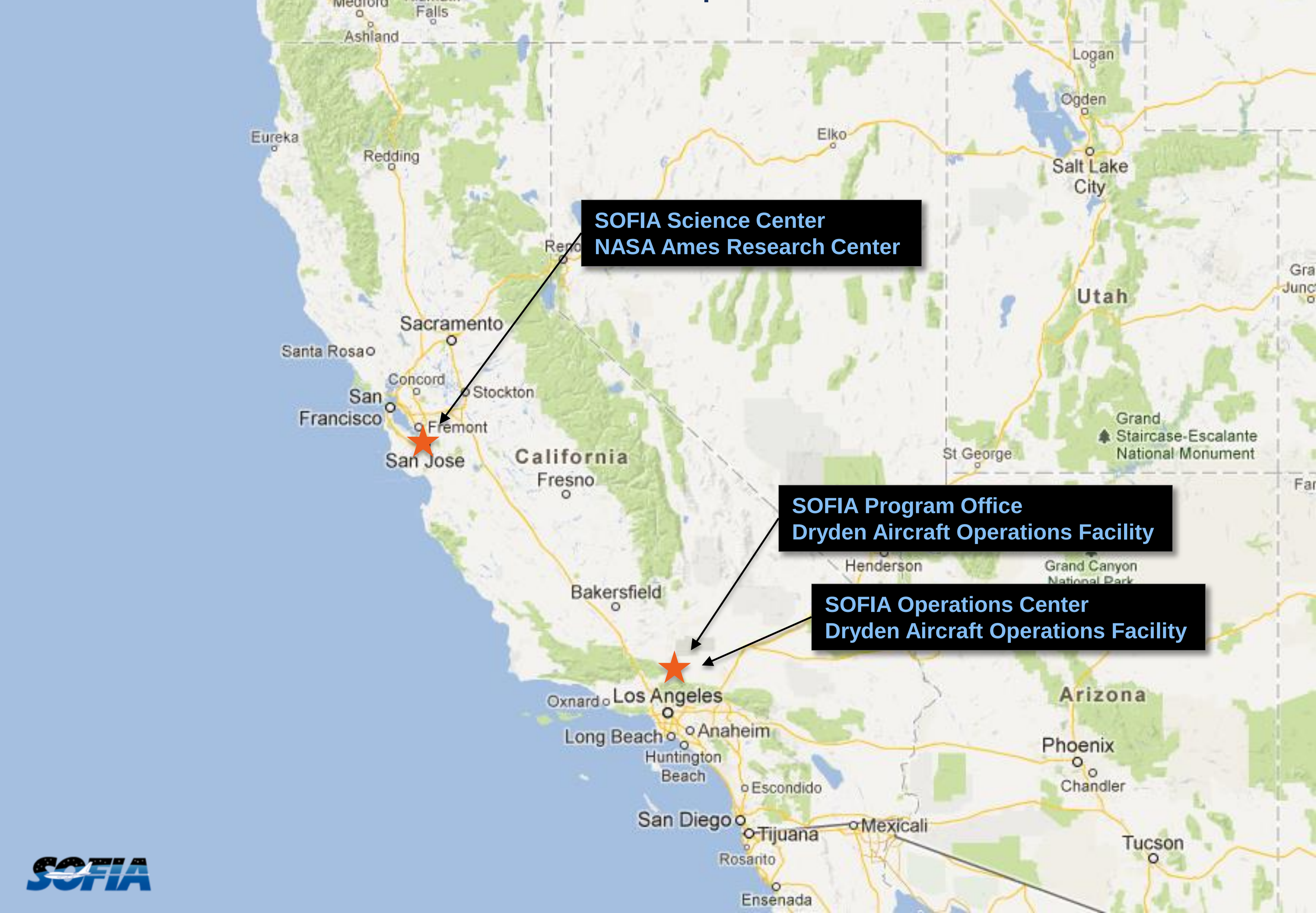


SOFIA image quality at 24 microns

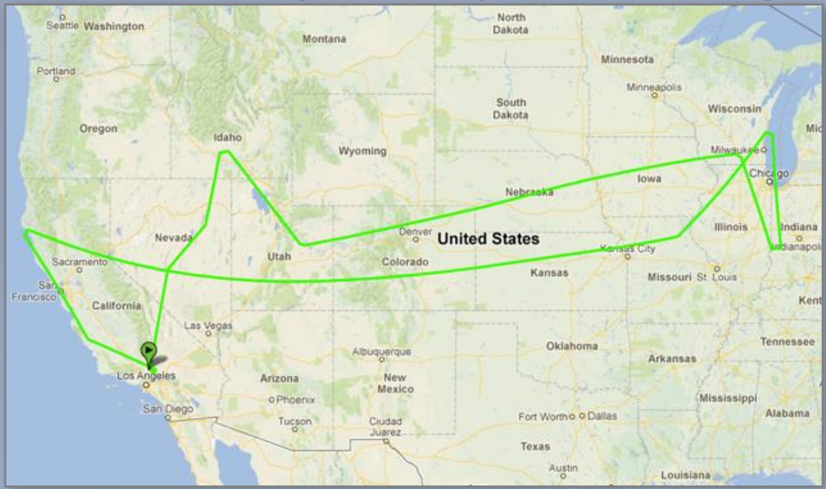


Close to the diffraction limit (ca. 2.4")

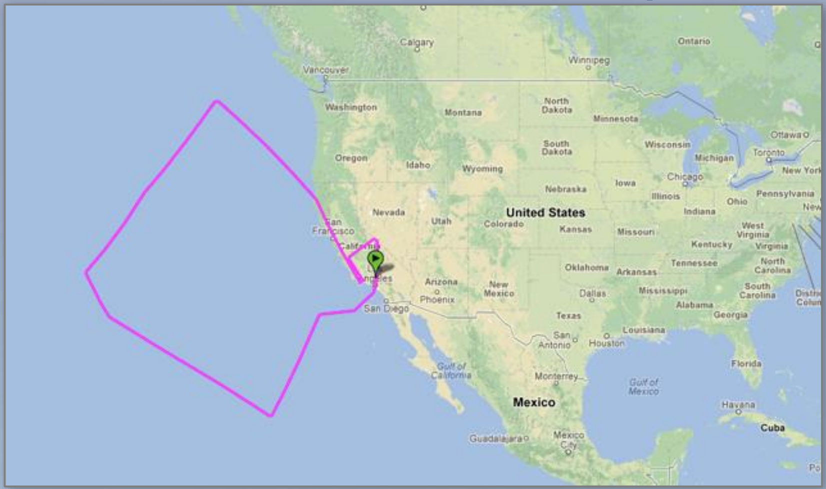
SOFIA Science and Operations Centers



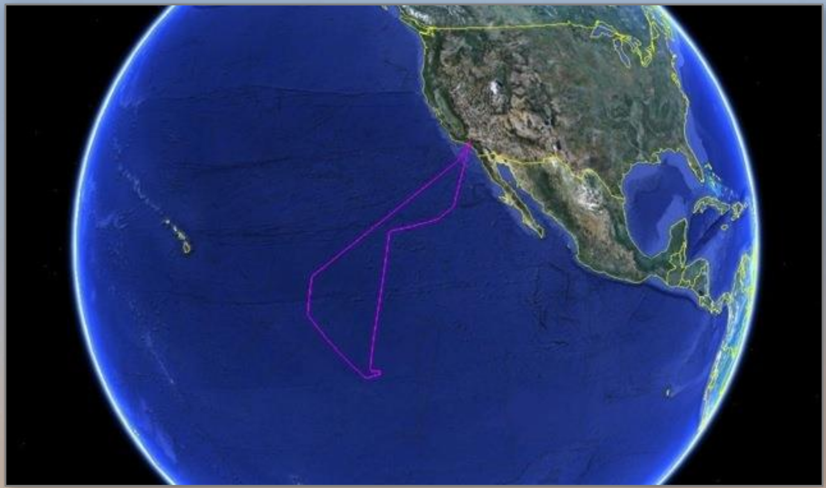
Sample Flight Plans (Palmdale and New Zealand)



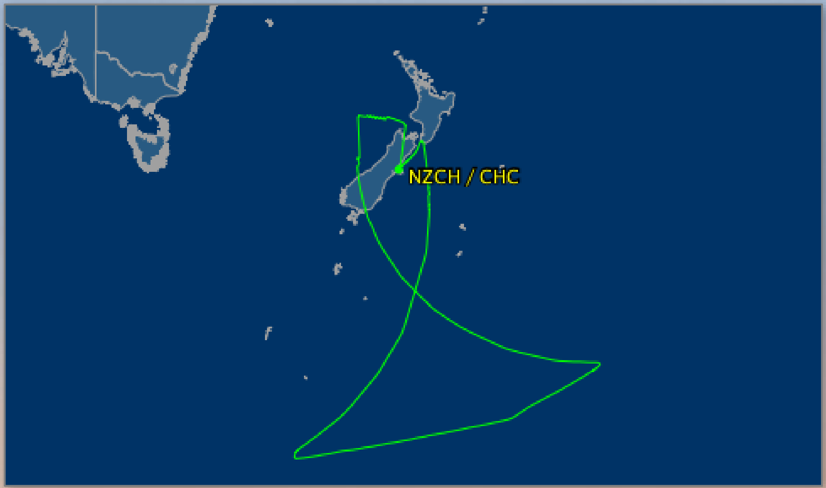
May 24, 2011: Basic Science 1 Flight (FORCAST)



May 21, 2011: Basic Science 2 Flight (GREAT)



June 22, 2011: Pluto Occultation Flight (HIPO)



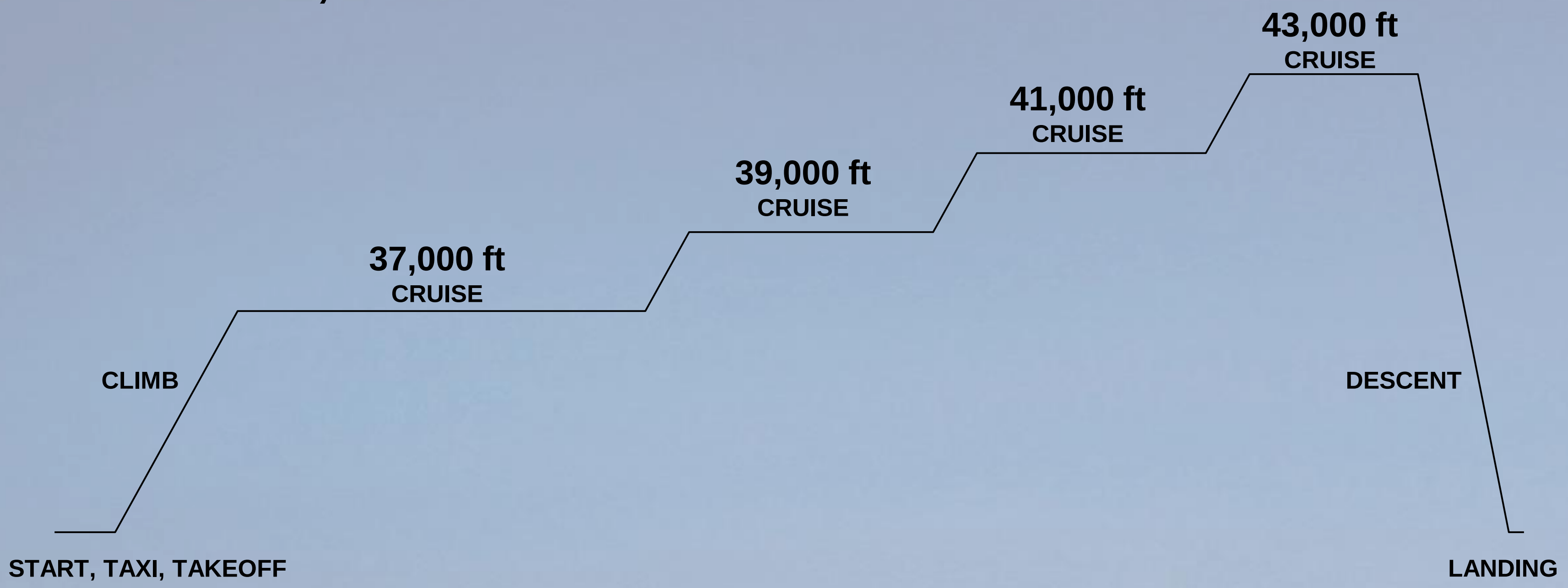
July 17, 2013: New Zealand Science Deployment Flight (GREAT)

Flight Paths

Geographic Distribution of SOFIA Science Flights (2010-2011)

Observing Flight Profile

Starts at ~37,000 feet



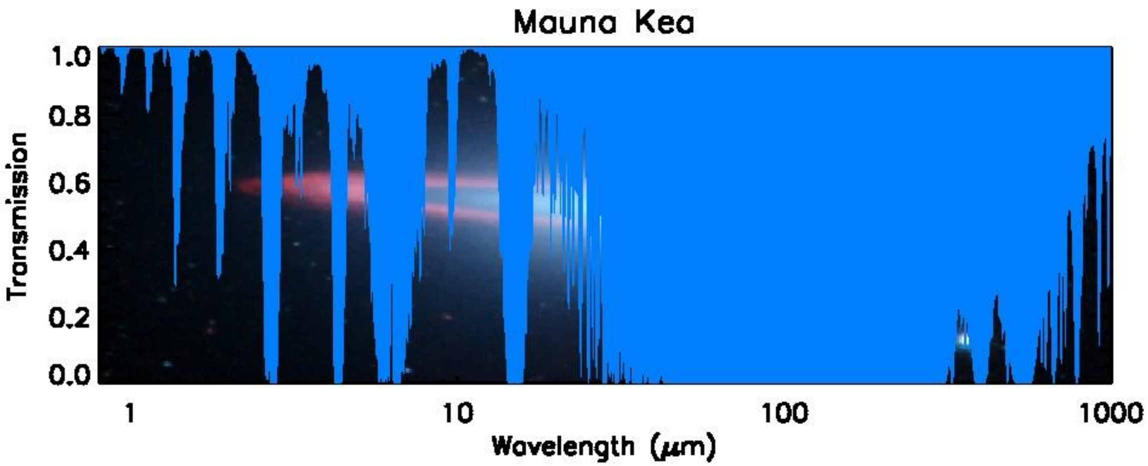
Total cruise time – 9 hours

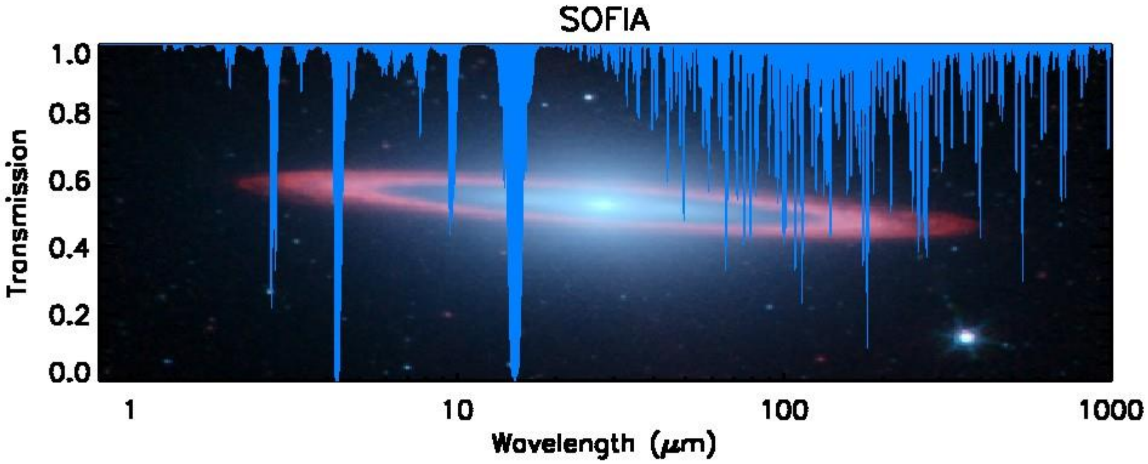
Total flight time – 10 hours

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

Motivation for Airborne Astronomy





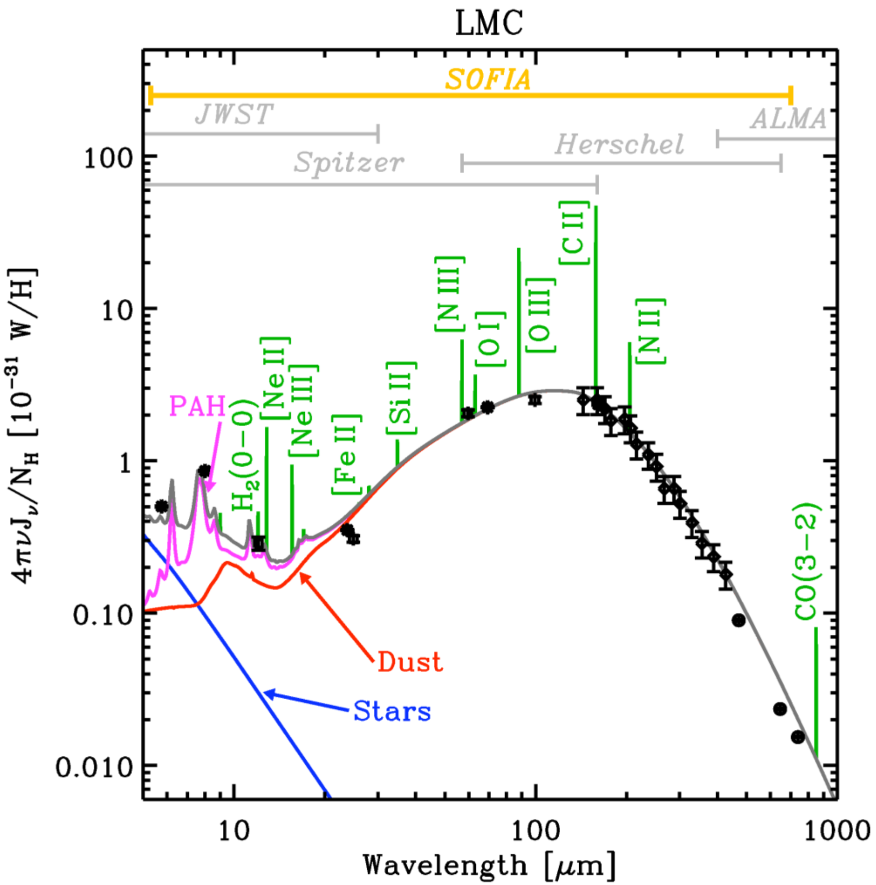
- For much of the infrared, the Earth's atmosphere blocks all transmission.
  - The problem is water vapor

If we can get above this water vapor, much more can be observed (average PWV is 10-20 mu, < 0.2%)

50x better than Mauna Kea
20x better thanAPEX/ALMA

Importance of Far IR / Sub-mm

- Most of the energy of star formation regions, external galaxies, and cooler objects in the universe is in the far-IR and Sub-mm
- The most important cooling lines in the ISM fall in this spectral region

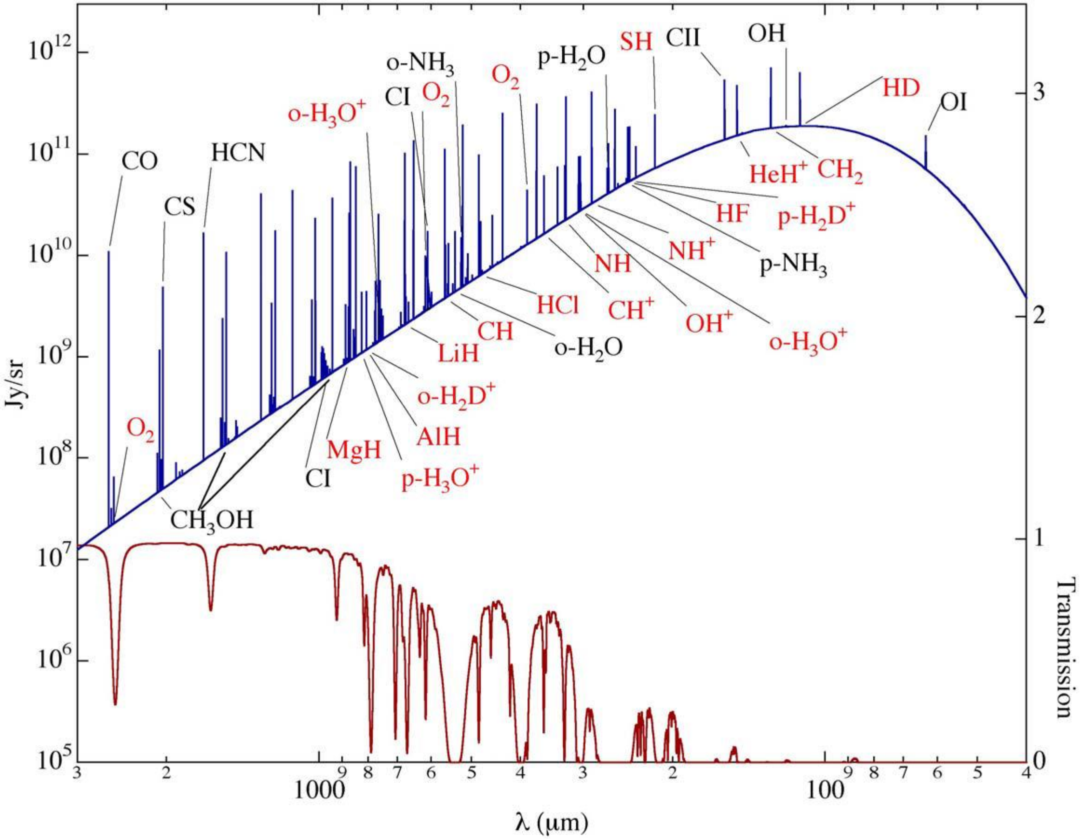


The spectral energy distribution of the entire LMC, based on data from Spitzer, IRAS and FIRAS (Bernard et al. 2008). SEDS are fitted with the dusty PDR model of Galliano et al. (2008). Figure courtesy of Galliano.

Importance of Far IR / Sub-mm -2

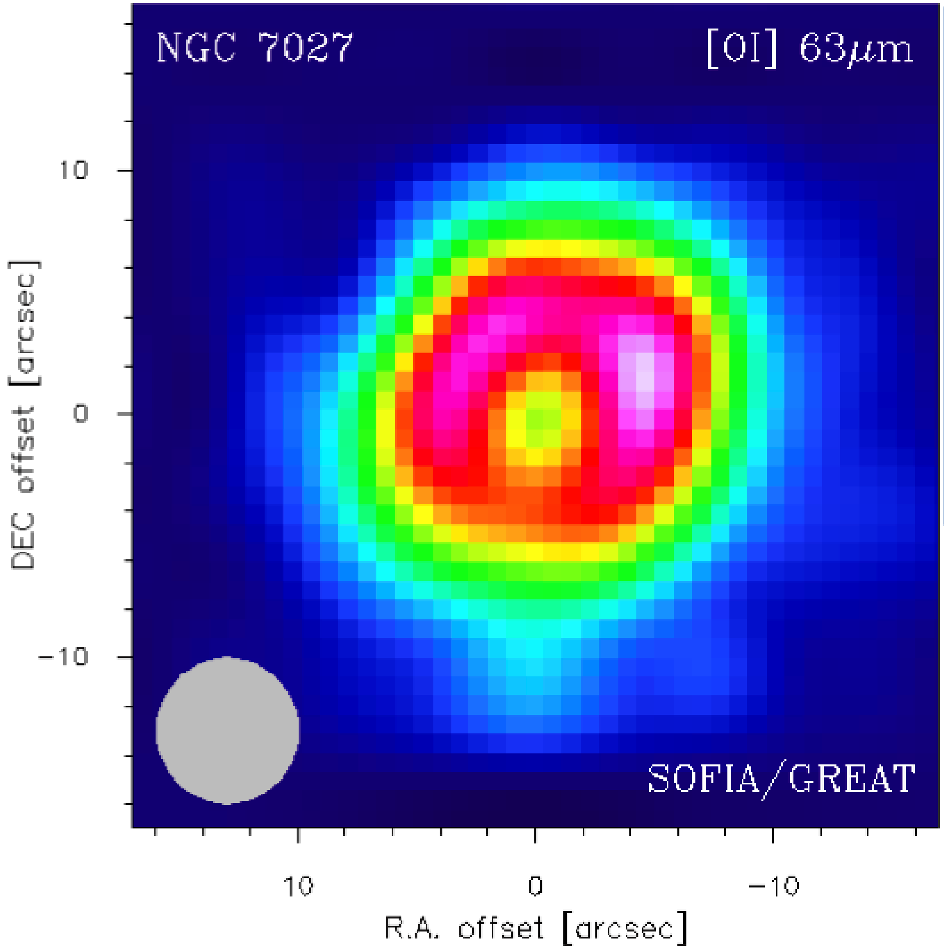
- Most of the key atomic and molecular tracers of the Interstellar Medium are in the Far Infrared and Sub-mm

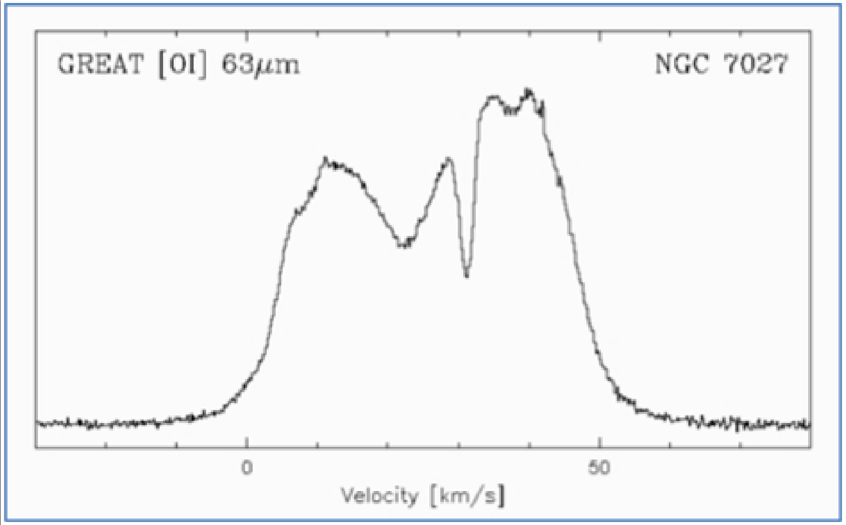
Molecular Cloud Spectrum



Ted Bergin, 2008

GREAT 4.7 THz First Light



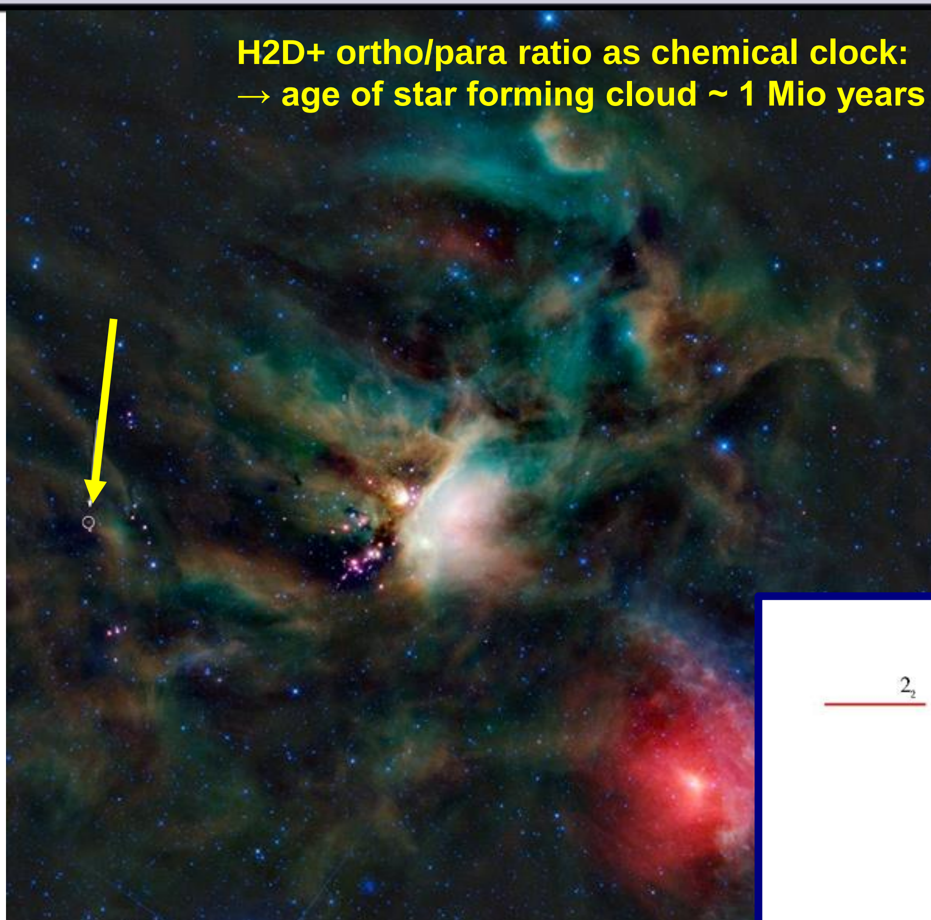


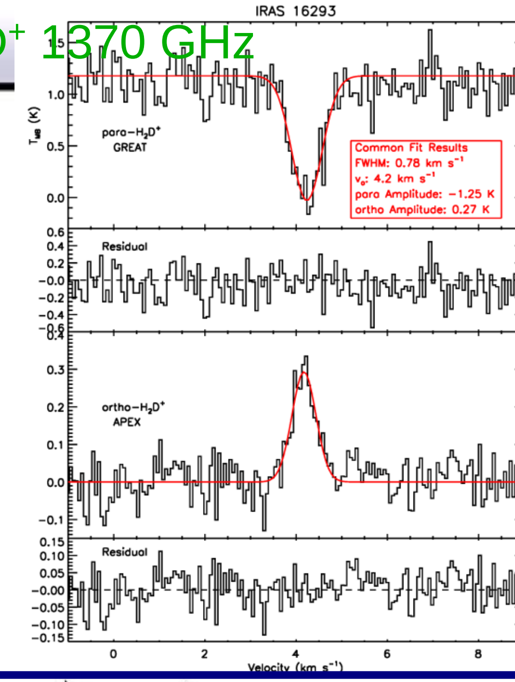
(Rolf Güsten & the GREAT Team)

(Many observing proposals in Cycle 3 for [OI] GREAT fine structure line obs.)

USRA

GREAT: first firm detection of para H_2D^+ 1370 GHz

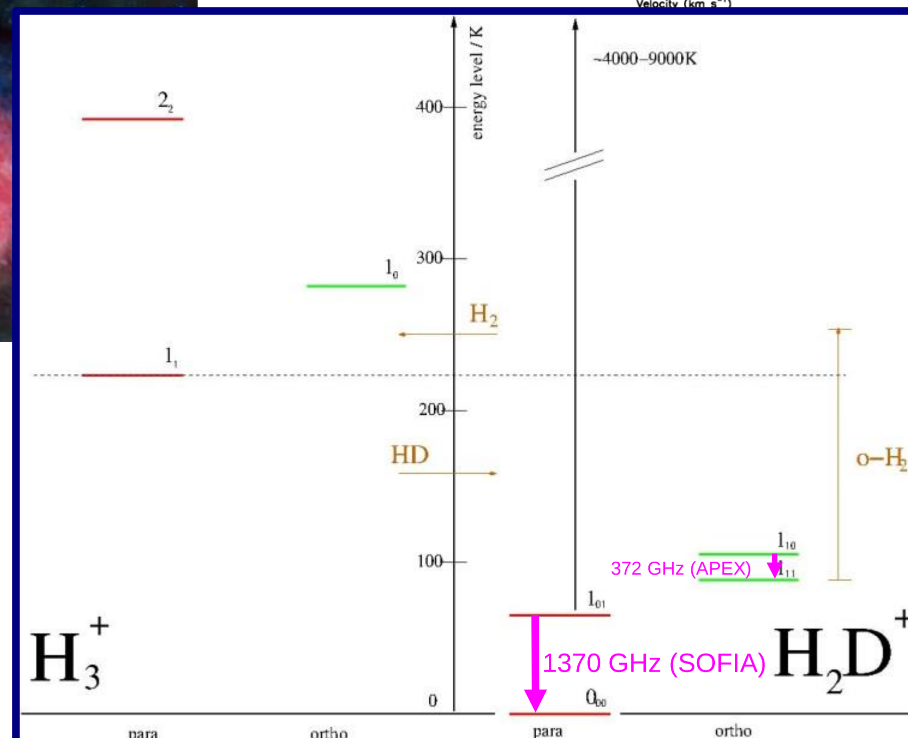




$$
\begin{aligned}
H + H &\xrightarrow{\text{dust}} H_2 \\
H + \text{cr}/\gamma &\longrightarrow H^+ + e \\
C + \text{cr}/\gamma &\longrightarrow C^+ + e \\
H_2 + H^+ &\longrightarrow H_3^+ \\
&\longrightarrow H + H + H^+ \\
H_3^+ + HD &\longrightarrow H_2D^+ + H_2 \\
H_2 + C^+ &\longrightarrow CH^+ + H \\
CH^+ + O &\longrightarrow CO + H^+ \\
OH + C &\longrightarrow CO + H
\end{aligned}
$$

Nature paper:
Brünken et al, 2014

NOTE:
KAO Betz et al.
tentative detection Orion
T_{rec}=30000 K



SOFIA science vision (excerpt)

SOFIA is a long-term ISM Observatory for studying the interstellar matter cycle + feedback processes:

-molecular gas spectroscopy: collapse, outflows, turb.

-dust emission broad-band, narrow-band, pol. imaging

SOFIA's suite of instruments comprehensively covers the wide range of wavelengths and spectral resolution (1 -250 microns, spectral resolution up to 10,000,000)

Successor to the Kuiper Airborne Observatory (1974-1995)

Follow-up of IRAS, ISO, Spitzer and Herschel observations

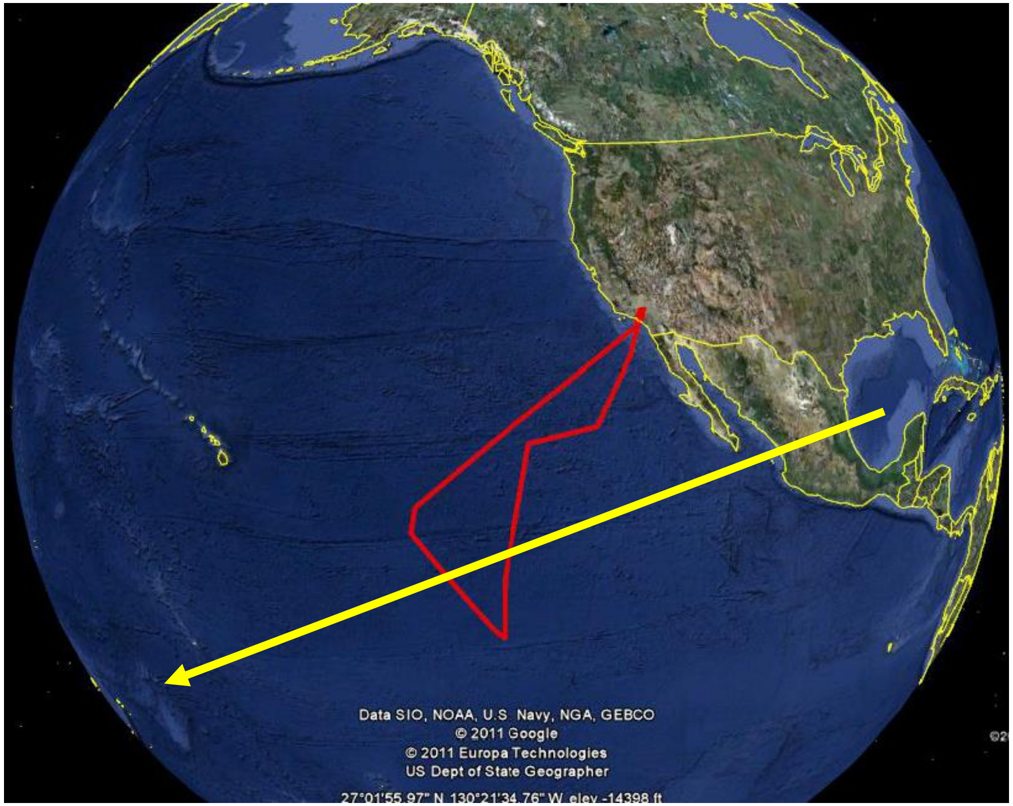
KAO - SOFIA's predecessor (1974-1995)

NASA's Kuiper Airborne Observatory (KAO) C-141 with a 36-inch telescope onboard, based at NASA-Ames near San Francisco, flew from 1975 - 1996

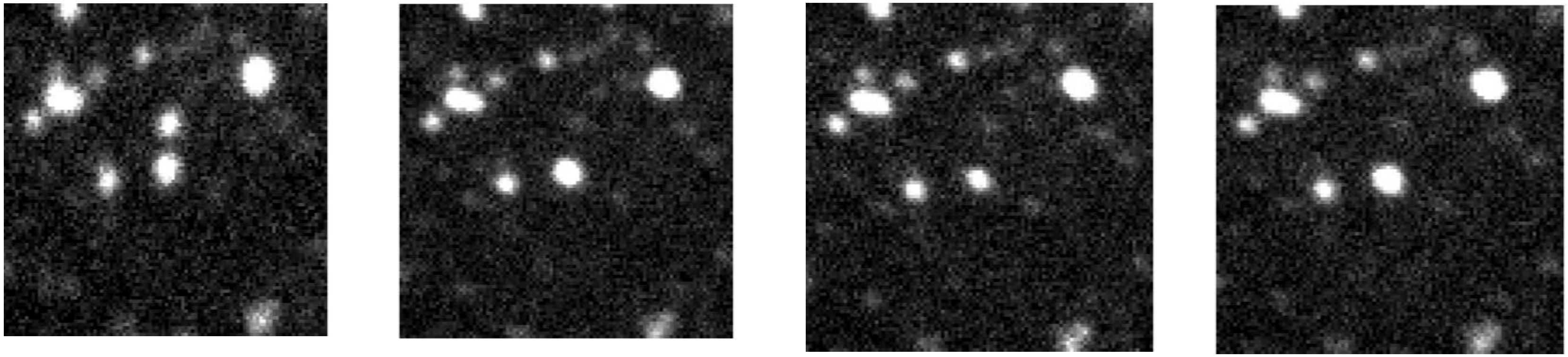
- **High-flying aircraft -- above 40,000 ft -- can observe most of the infrared universe**
- **Airborne infrared telescopes can be more versatile -- and less expensive than space infrared telescopes**

Occultation by Pluto 2011 June 23

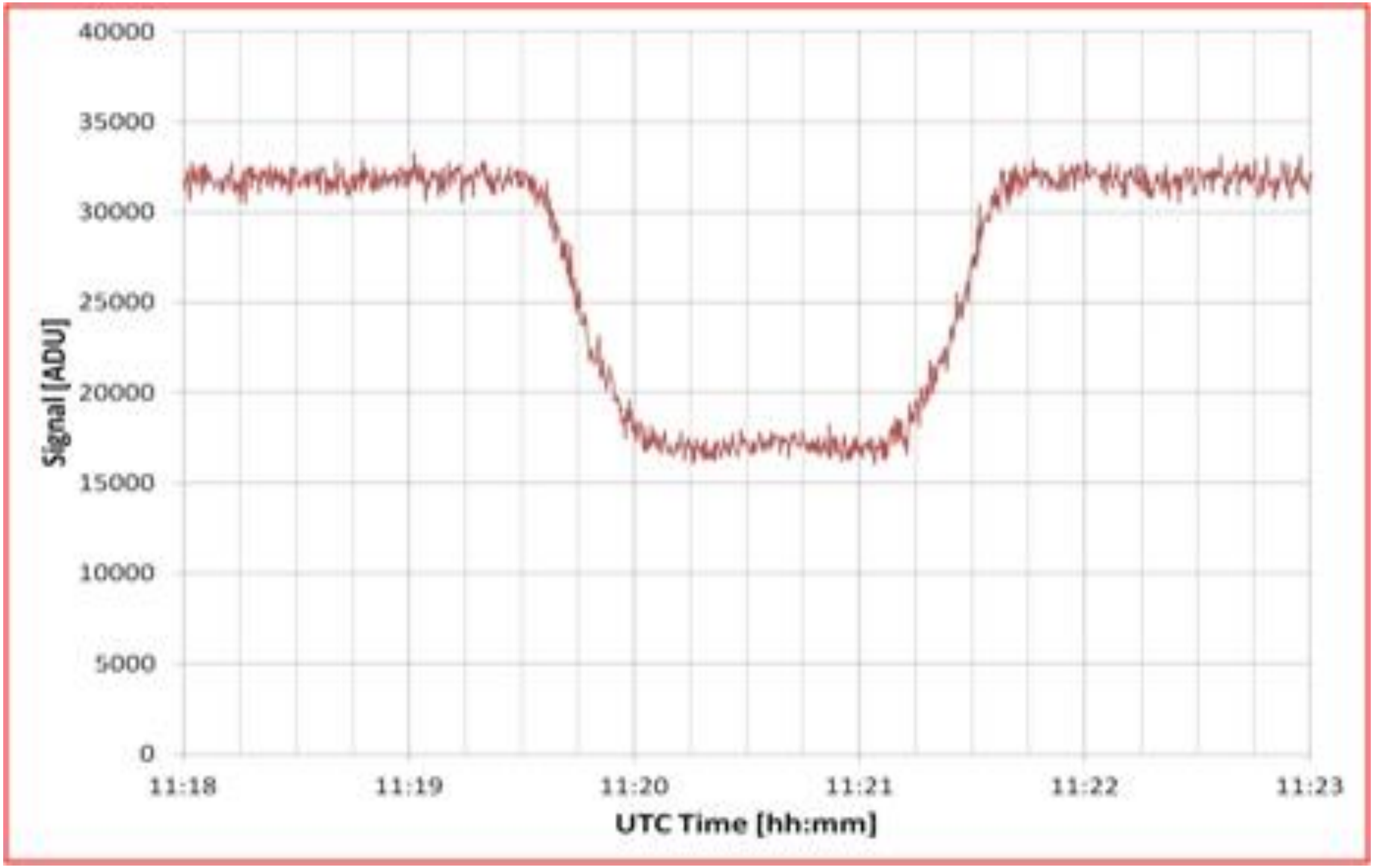
- Observation of Pluto passing in front of a bright star is used to provide highly detailed information about the atmosphere
- Mobility of SOFIA is key to successful observations



Pluto Occultation: 3 hours before, just before, during and just after.



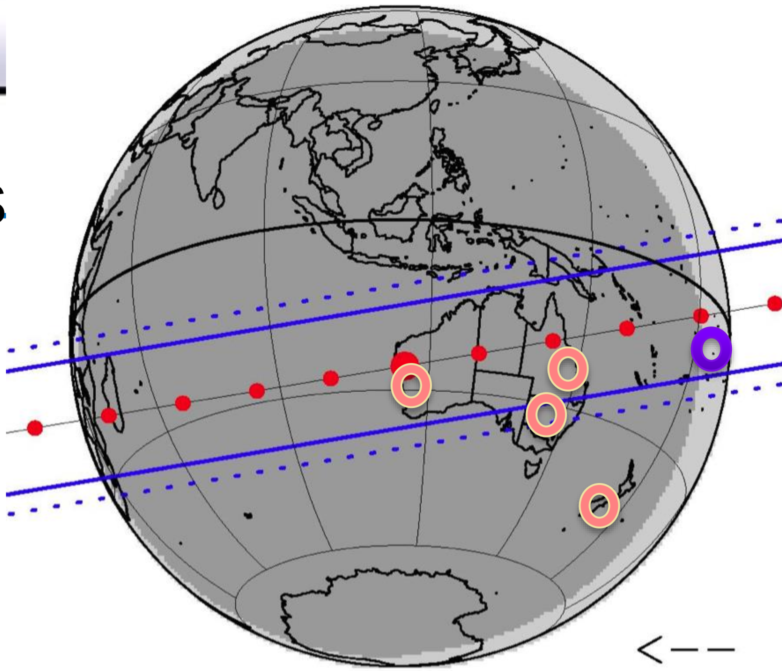
SOFIA/Pluto occultation lightcurve



Pluto with SOFIA

A case for a dedicated observation to support the *New Horizons* mission

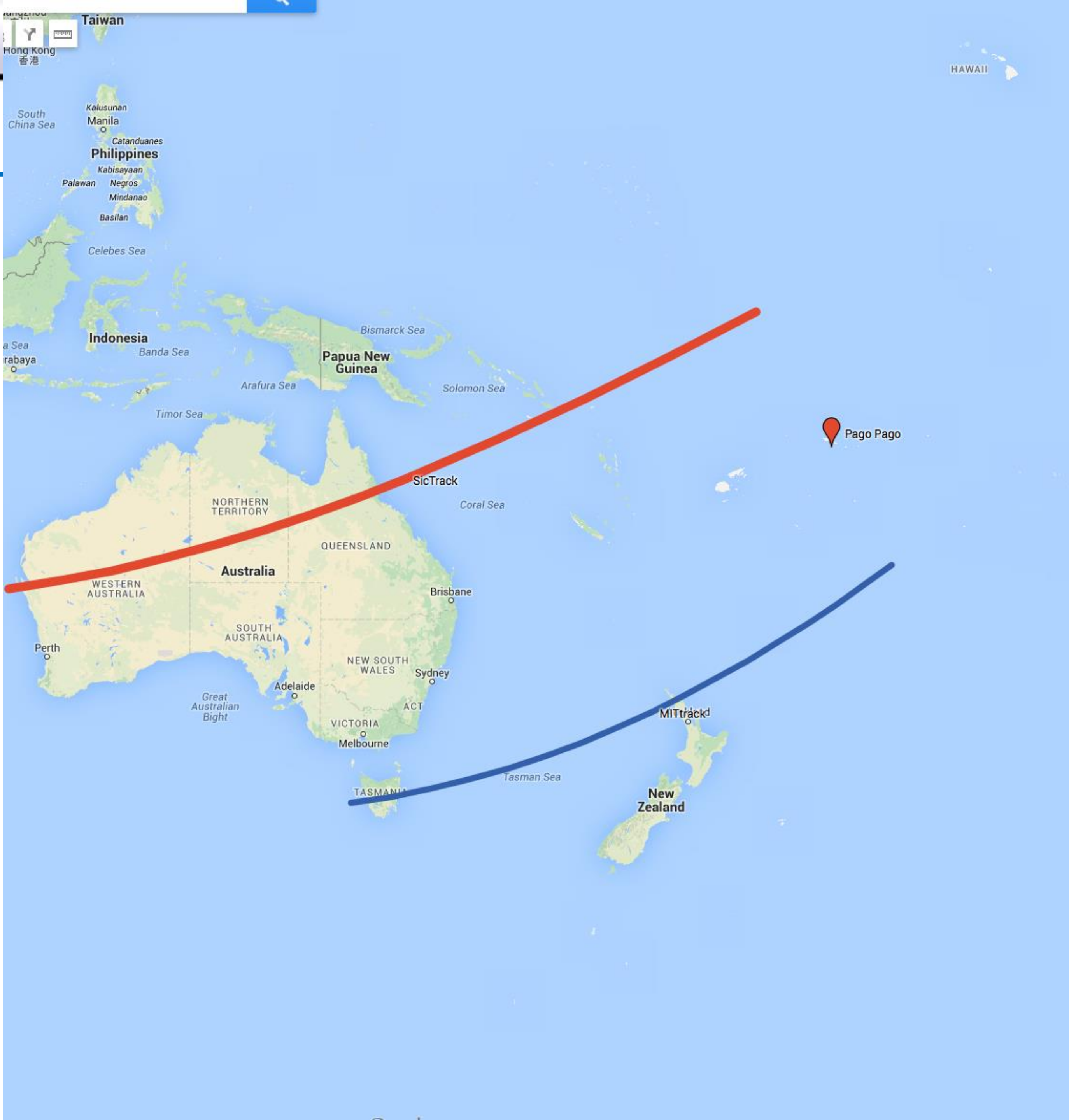
Pluto occultioation June 29, 2015 SOFIA versus other observatories



- New Zealand
  - *Mt John, NZ* (Pasachoff): off southern edge of shadow
- Australia
  - *Siding Spring (E. Young; 4m telescope+CCD),* Mt Stromlo (2.3m, CCD only): southern edge; 14 days rain/month average
  - Mt. Kent (0.5m+CCD): well situated; 11 clear days/month
  - ANU, Perth (0.6m+CCD): very well situated; 7 clear days/month

SOFIA Occultation Observing Configuration

- Minimal configuration
  - Use FPI+ with one filter
  - Any science instrument could be at Nasmyth
- Optimal configuration: FLIPO
  - Choose FPI+ filter useful for guiding and Pluto
  - Choose two HIPO filters spanning blue to red visible light
  - Choose FLITECAM filter that is likely long enough wavelength to see through the haze
  - Ability to measure the occultation simultaneously (same chord through Pluto’s atmosphere) with FOUR FILTERS is unprecedented
- SOFIA can fly through the center of the shadow and measure the central flash
  - Very likely, only SOFIA will be able to do this for the June 29 event

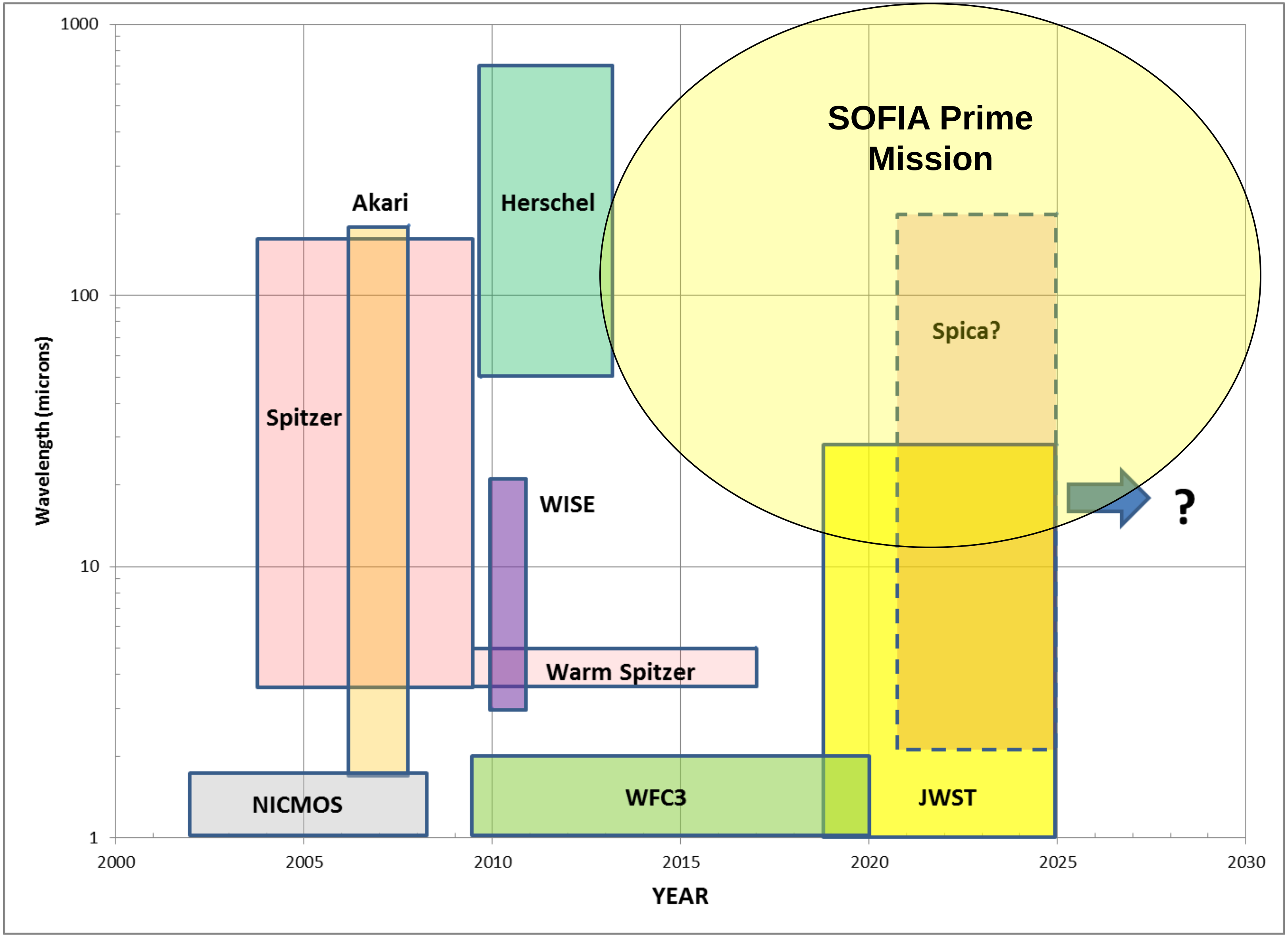

Taiwan
Hong Kong
香港
South China Sea
Kalusunan
Manila
Catanduanes
Philippines
Kabisayaan
Palawan
Negros
Mindanao
Basilan
Celebes Sea
Indonesia
Banda Sea
Bismarck Sea
Papua New Guinea
Arafura Sea
Solomon Sea
Timor Sea
HAWAII
Pago Pago
SicTrack
Coral Sea
NORTHERN TERRITORY
QUEENSLAND
Australia
WESTERN AUSTRALIA
Brisbane
SOUTH AUSTRALIA
Perth
NEW SOUTH WALES
Sydney
Adelaide
Great Australian Bight
ACT
VICTORIA
Melbourne
MITtrack
Tasman Sea
New Zealand

SOFIA Schedule (Major Milestones)

- First Test Flight with Open Door — 18 Dec 2009
- First Light and heat (Jupiter) — 26 May 2010
- First Community Early Science — Nov 2010-Nov 2011
- 30 Letters in ApJ and A&A — May/June 2012
- Avionics (cockpit) upgrade — Jan-Dec 2012
- Cycle 1 Observing — April 2013-Feb 2014
- 9 of 9 Flights from NZ with GREAT — July 2013 (3 weeks)
- Cycle 2 Call fP, TAC results public — April, Oct 2013
- Cycle 2 Observing ~40 flights — Feb 2014-Feb 2015
- DDT observations of SN2014J/M82 — Feb/Mar/Apr 2014
- Commissioning of FIFI-LS & EXES — Feb/Mar/Apr 2014
- Heavy Maint. visit to LHT Hamburg — June-Dec 2014
- Cycle 3 Call fP deadline, TAC@DSI — July, Sept 2014

Courtesy: Erick Young

Mind the Gap



SOFIA Context with Other Observatories

- Herschel ran out of cryogens in Spring 2013: SOFIA natural successor, Herschel community using SOFIA
- Depending on the development of SPICA and Mmtron, SOFIA will provide the only access to the far-infrared and sub-sub-millimeter for the better part of a decade
- Synergy with ALMA and APEX (submm spectroscopy)
- CCAT (25m single dish submm) and JWST (5-28 mu)

Early Science Highlights

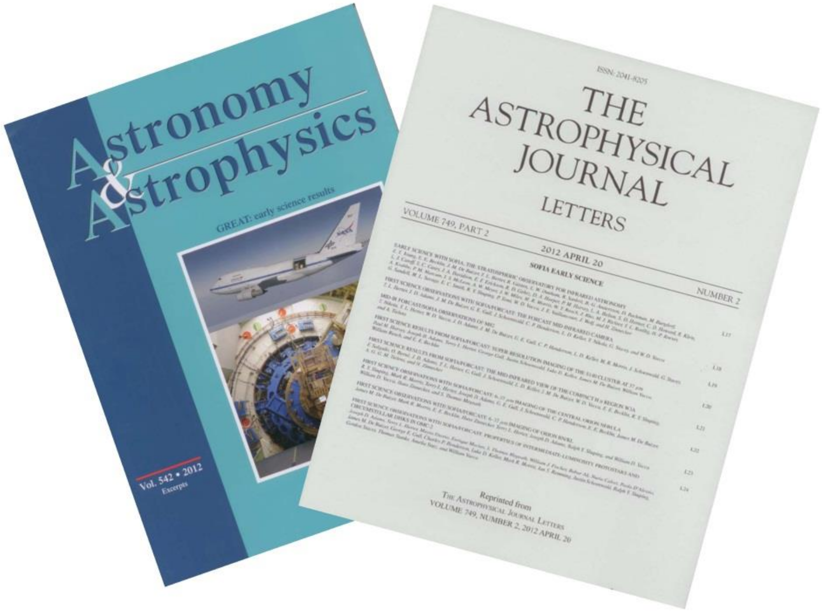
FORCAST: Orion Trapezium region warm dust clouds
BN/KL-Nebula energy sources (SEDs),
Galactic Center circumnuclear dust disk/ring

GREAT: M17 photodissociation region (C+/CO map)
G5.89 ultracompact HII region (CO outflow)
G34.3 accreting massive star (NH3 inflow)
W49N: new molecules SH, OH/OD (in abs.)
Galactic Center circumnuclear CO disk/ring

First extragal. systems: M82/FORCAST, IC342/GREAT
Pluto occultation of a star (out over Pacific) successful !

Recent Results

- SOFIA has published two special issues that highlight the science accomplished during the Early Science period
- HZ SOFIA review in Proc. Hamburg AG (AN 334, 558, 2013)



FORCAST: Mid-IR Imager

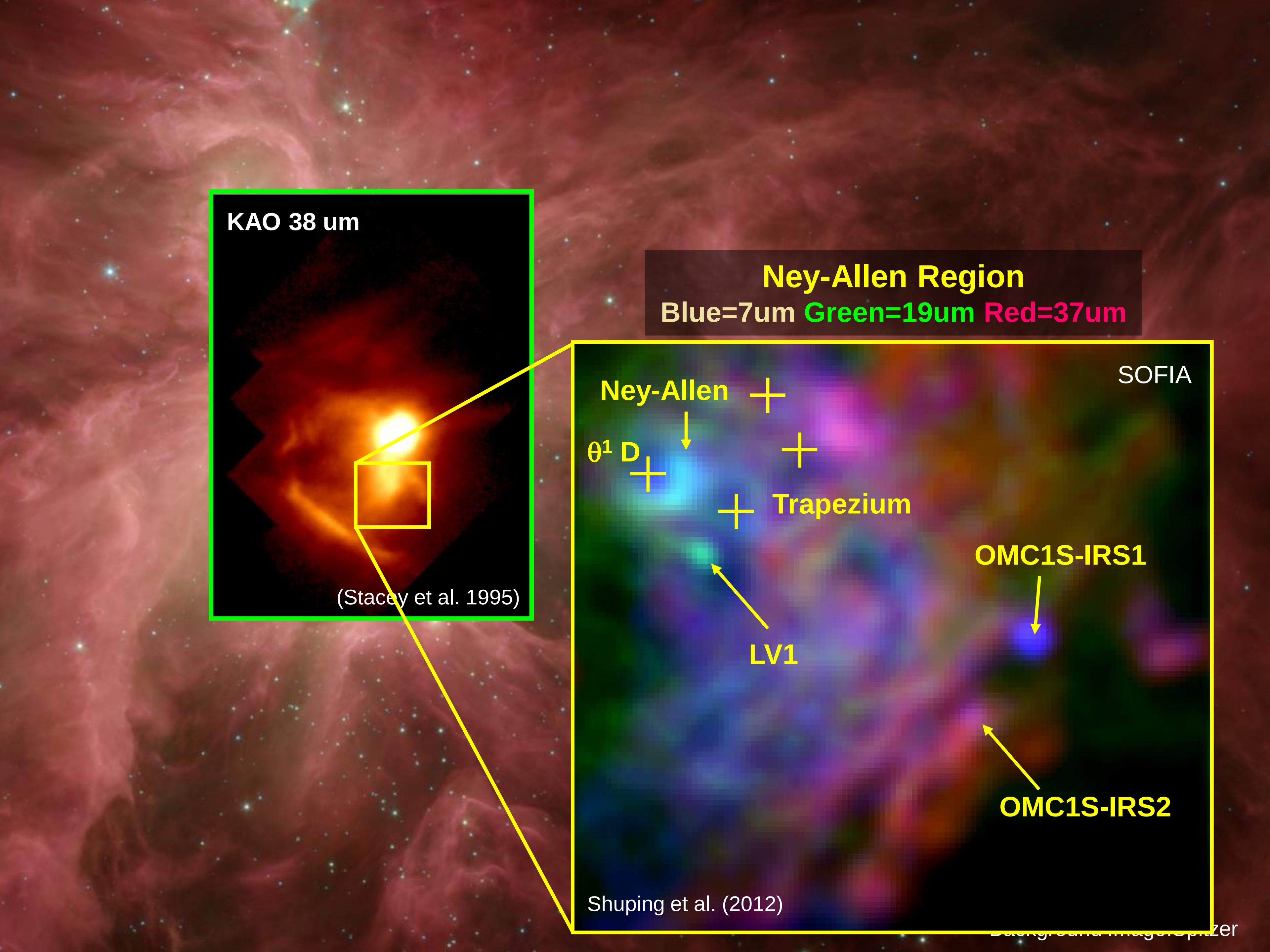
PI: T. Herter (Cornell Univ.)
herter@astrosun.tn.cornell.edu

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’
Pixel scale: 0.75 arcsec/pix

Science: Thermal and narrow band imaging

Targets: Circumstellar disks, Galactic Center,
Galactic star formation regions (Spitzer sat.)

NB:
at present Diffraction Limited > ca. 30 microns;
There are various low-res grism modes (→PAH)

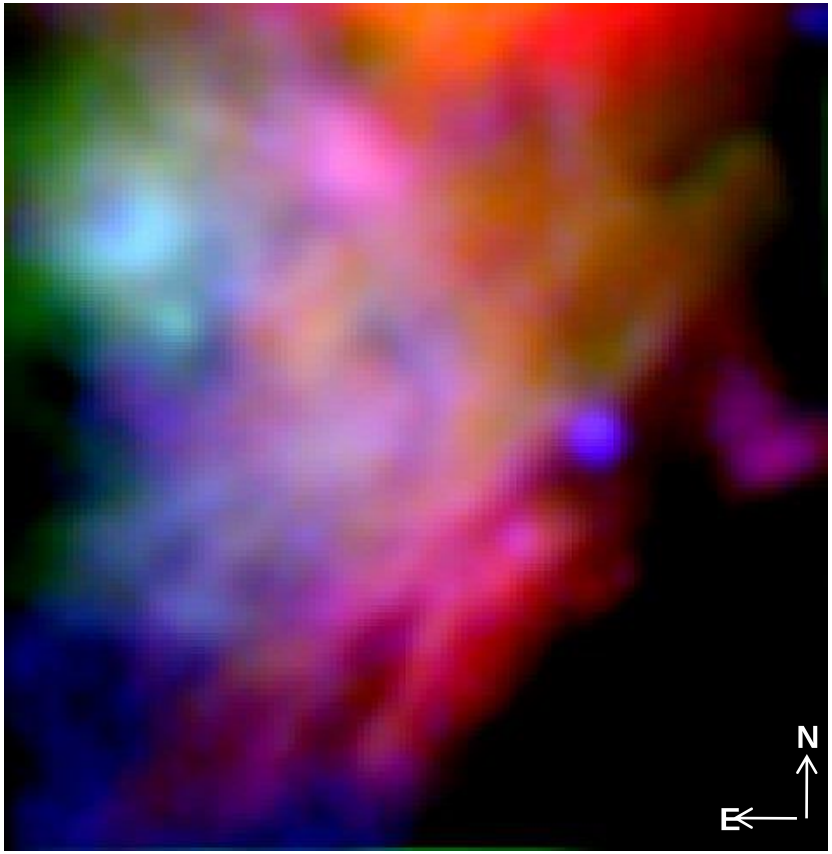


KAO 38 um
(Stacey et al. 1995)
Ney-Allen Region
Blue=7um Green=19um Red=37um
SOFIA
Ney-Allen
θ1 D
Trapezium
OMC1S-IRS1
LV1
OMC1S-IRS2
Shuping et al. (2012)
Background image:Spitzer

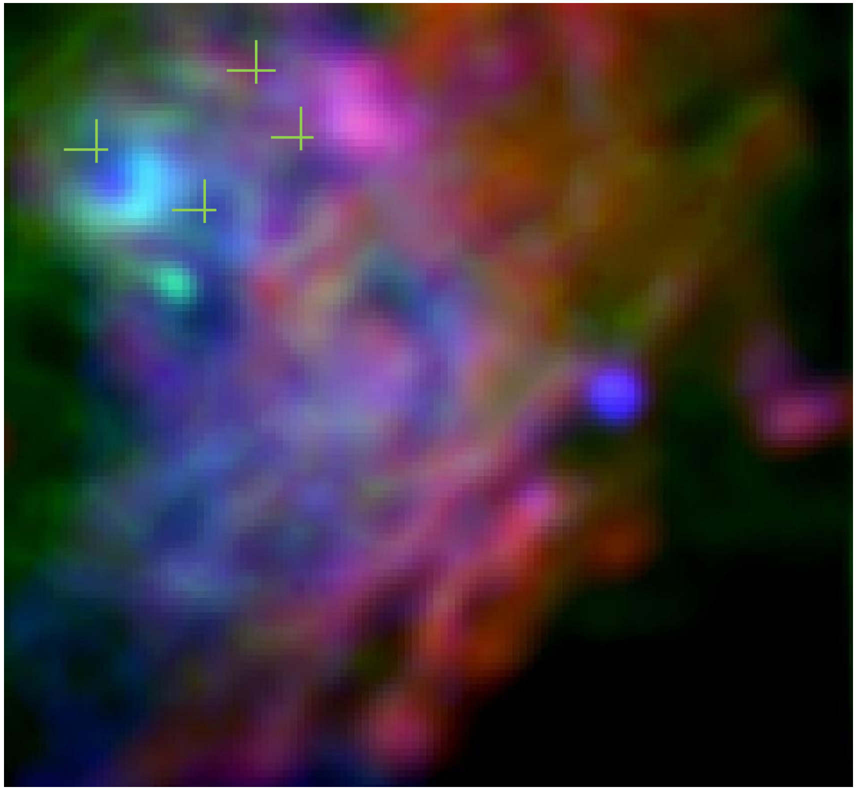
3-color images of Trapezium region

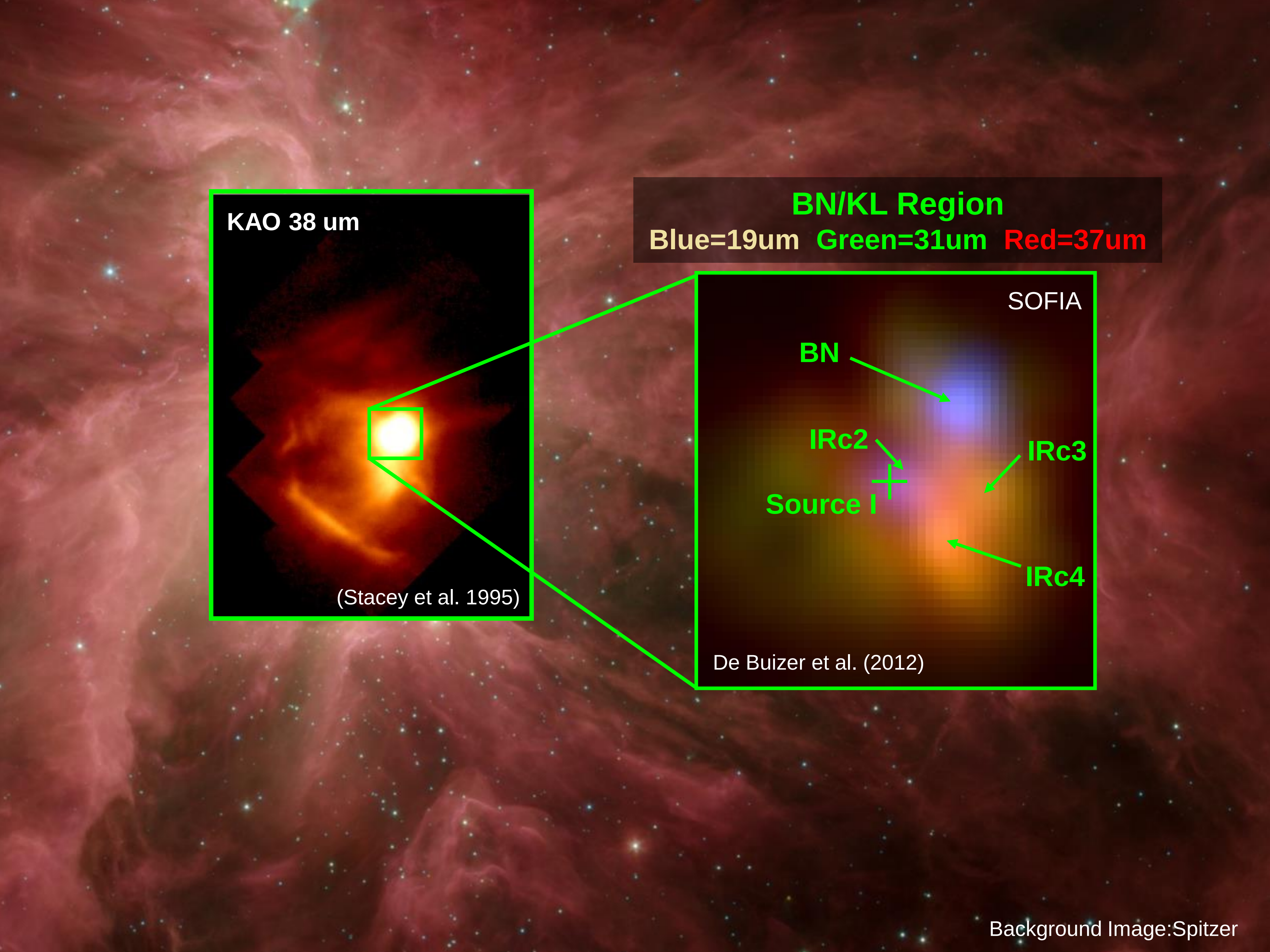
7um, 19um, 37 um

Natural Resolution



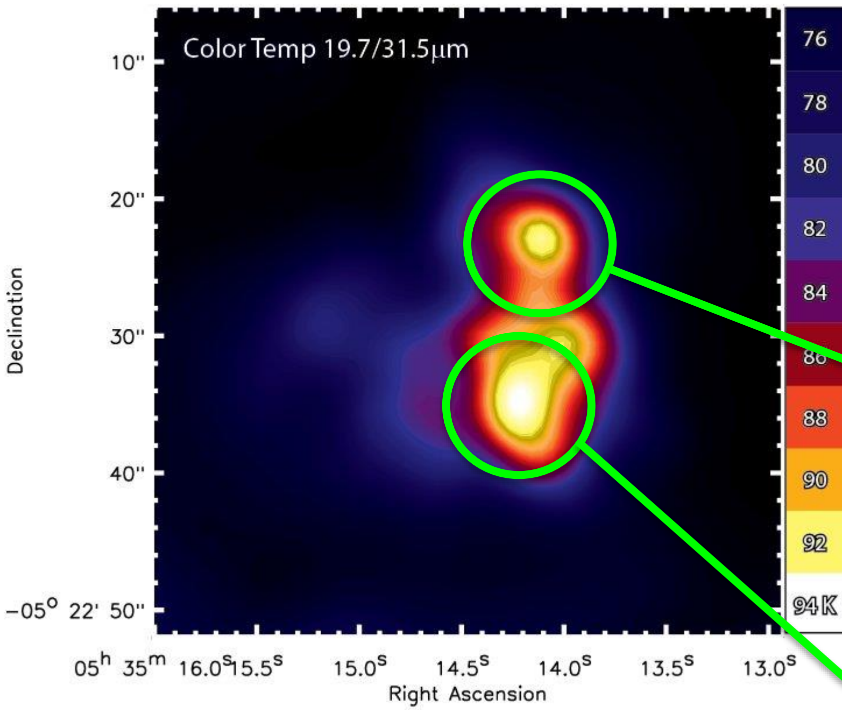
DMRM Deconvolution

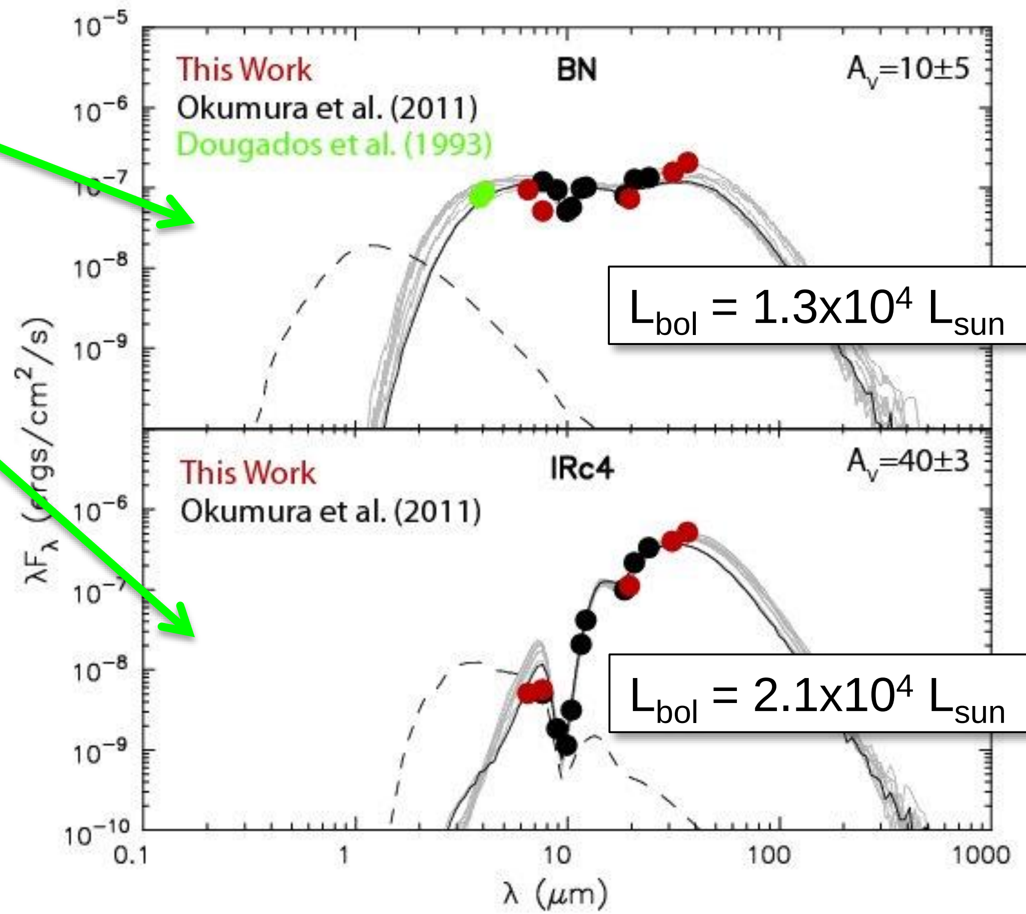




BN/KL Region
Blue=19um Green=31um Red=37um
KAO 38 um
(Stacey et al. 1995)
SOFIA
BN
IRc2
IRc3
Source I
IRc4
De Buizer et al. (2012)
Background Image:Spitzer

Like BN, IRc4 is a self-luminous source





IRc4 luminosity is too high to be caused by external heating

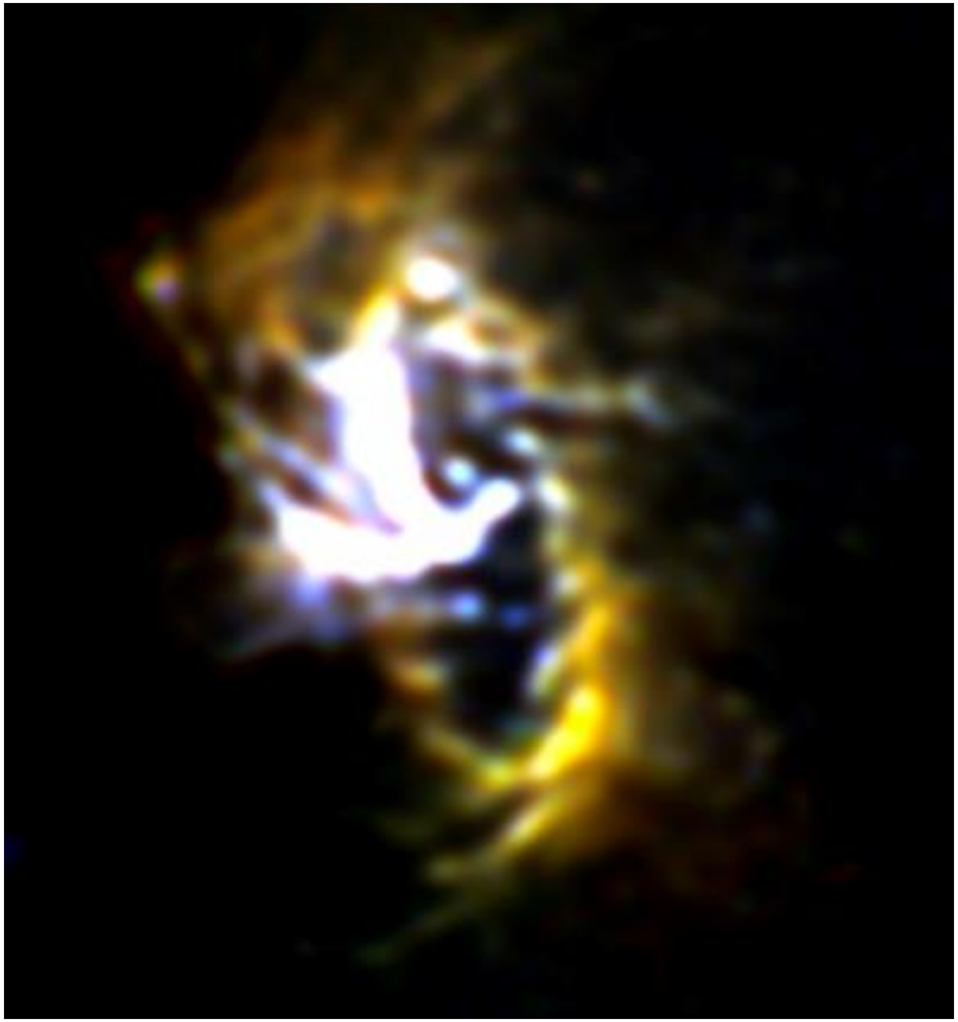
BN+IRc4 accounts for ~50% of the ~10^5 L_{sun} of the BN/KL region

De Buizer et al. (2012)

GC-CNR at 19(blue), 31(green) and 37(red) microns

This is the highest resolution image of the CircumNuclear Ring ever obtained with ~3 arcsec FWHM (R. Lau et al. 2013, ApJ)

- White central emission is from the hot dust heated by ionized gas of the northern and eastern arms
- Almost perfect 1.5 pc radius ring is seen in cooler dust (T~100K) centered on the Massive Black Hole and tilted about 18 degrees to the LOS and The Galaxy
- The ring is resolved with a width of about 0.3 pc (no star formation along the ring)
- There is interesting small structures along the ring, almost periodic in nature.



II. DIATOMIC RADICALS AND IONS

A. ENERGY LEVELS AND EIGENFUNCTIONS

In a first approximation, the energy of a molecule can be represented as the sum of three parts—the electronic, the vibrational, and the rotational energy:

$$E = E_e + E_v + E_r. \qquad (1)$$

In Fig. 10 the vibrational and rotational levels in two electronic states are represented schematically. Corresponding to the three

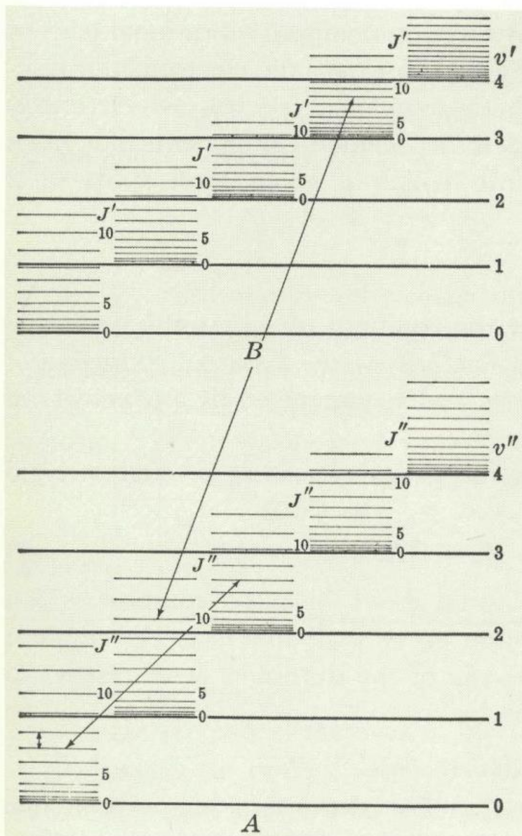
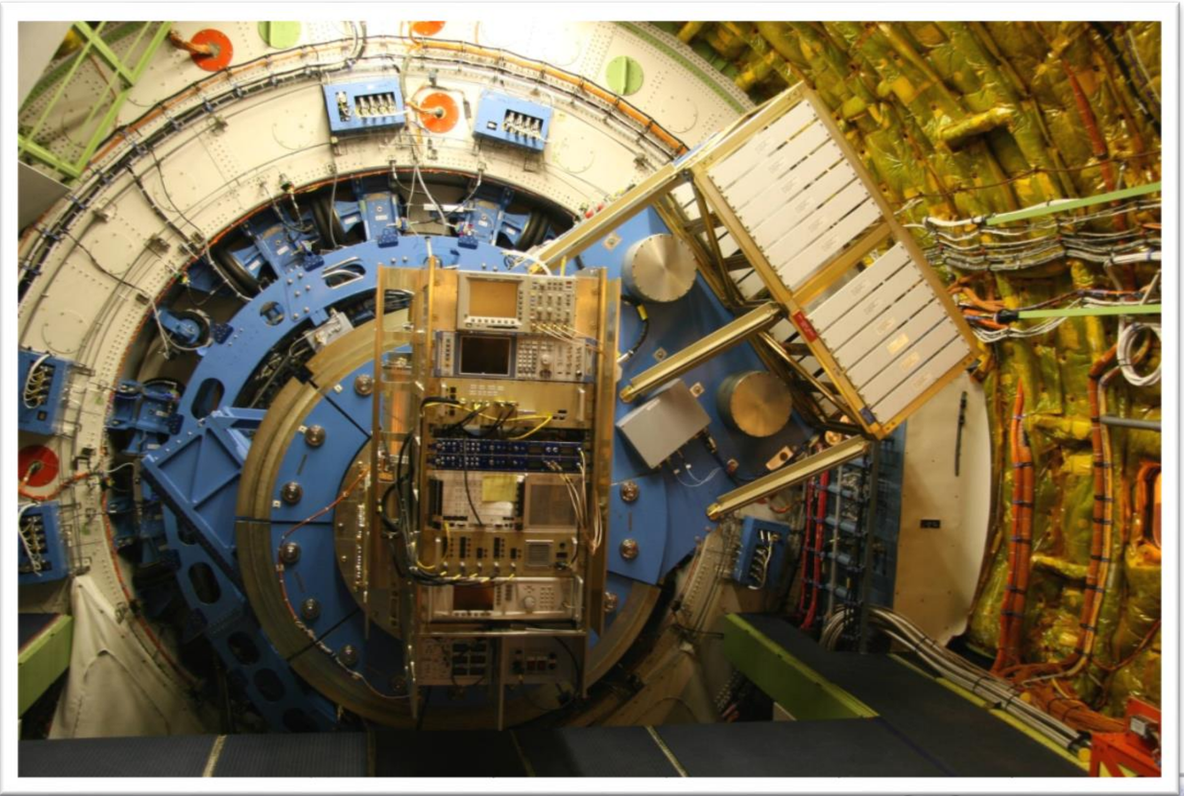


Fig. 10. Vibrational and rotational levels of two electronic states A and B of a molecule (schematic).

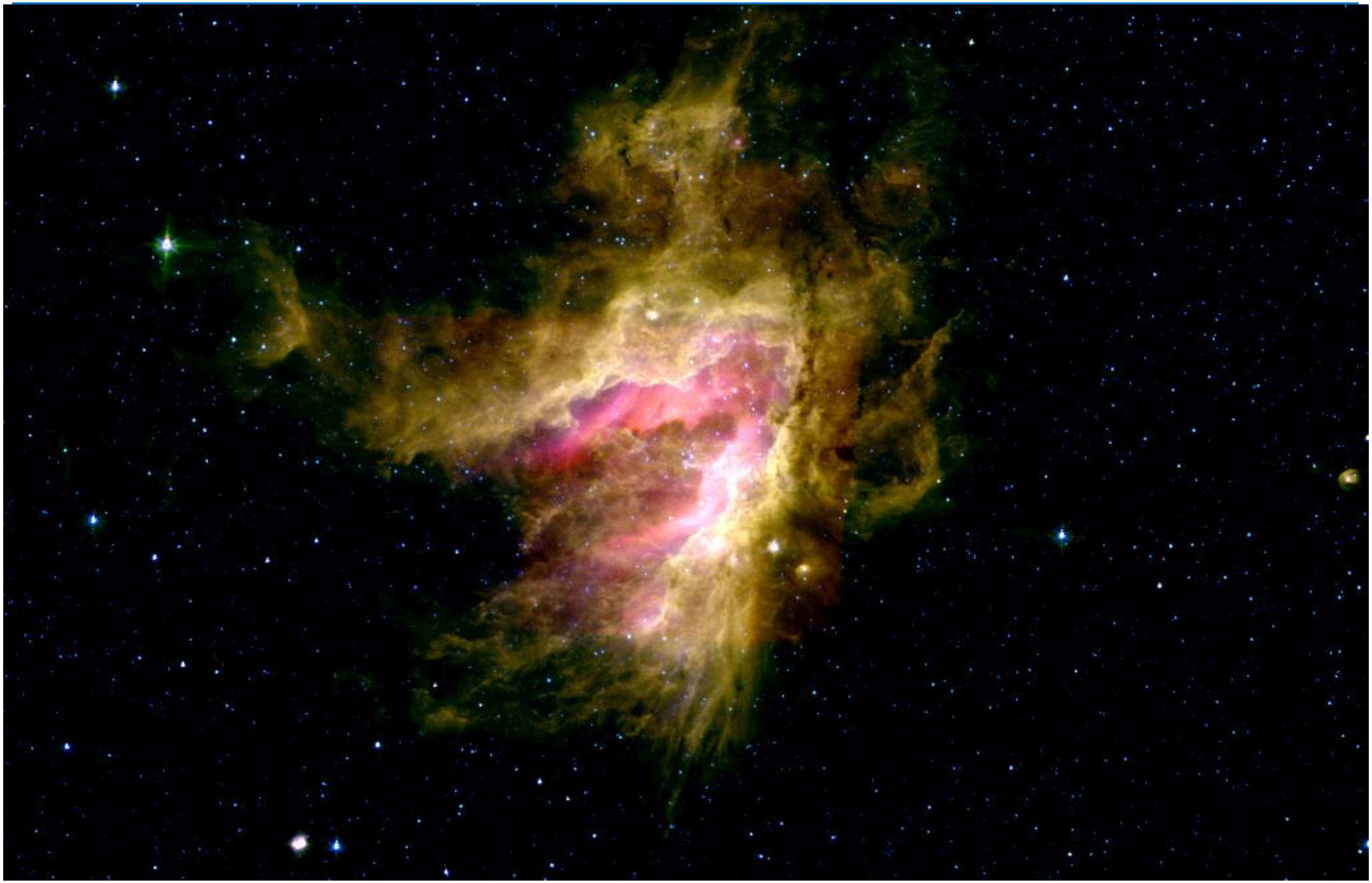
The three double arrows indicate examples of transitions in the pure rotation spectrum, the rotation-vibration spectrum, and the electronic spectrum of the molecule.

German REceiver for Astronomy at Terahertz frequ. (PI: R. Guesten, MPIfR/Bonn)

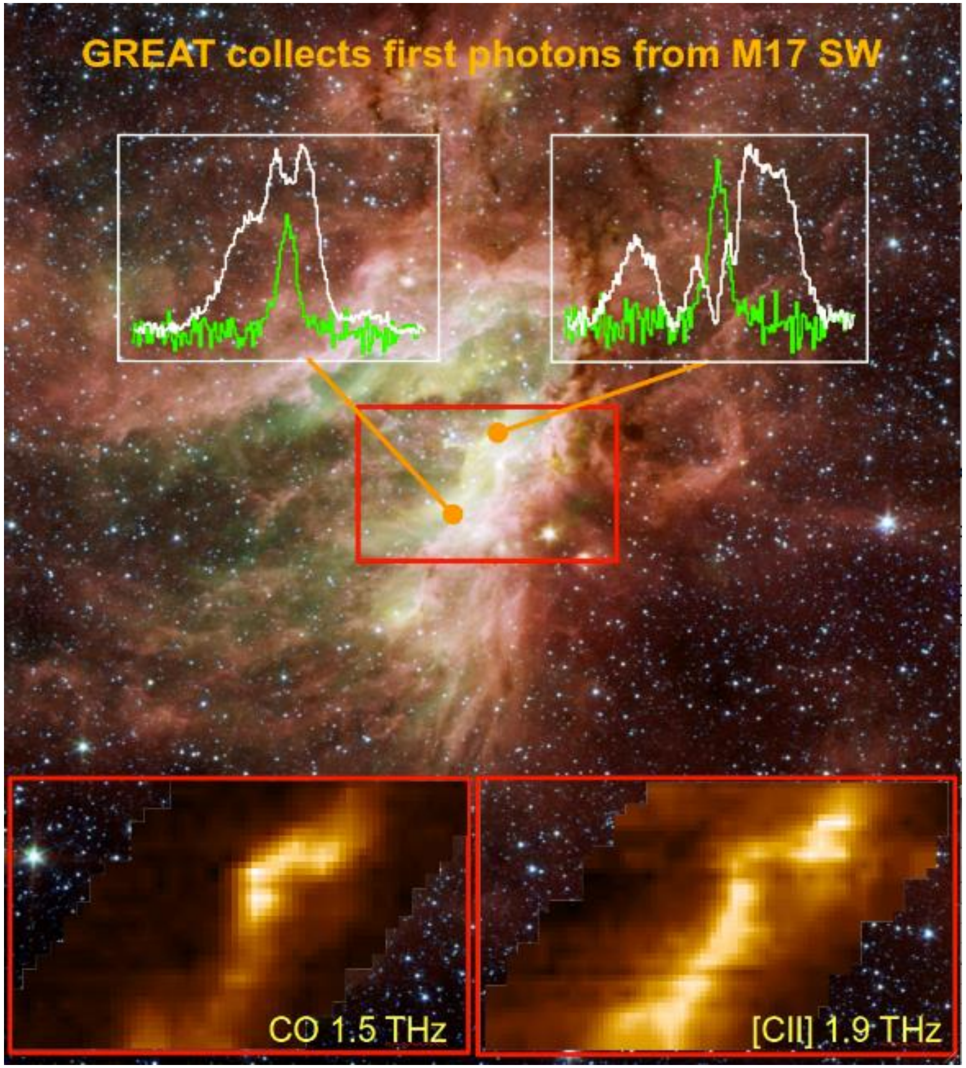
Channel	Frequencies [THz]	Astronomical lines of interest
low-frequency #1	1.25 – 1.50	[NII], CO(12-11), $^{(13)}$CO(13-12), HCN(17-16), H_2D^+
low-frequency #2	1.82 – 1.92	[CII], CO(16-15)
mid-frequency	2.4 – 2.7	HD, OH($^2\Pi_{3/2}$), CO(22-21), $^{(13)}$CO(23-22)
high-frequency	~ 4.7	[OI]



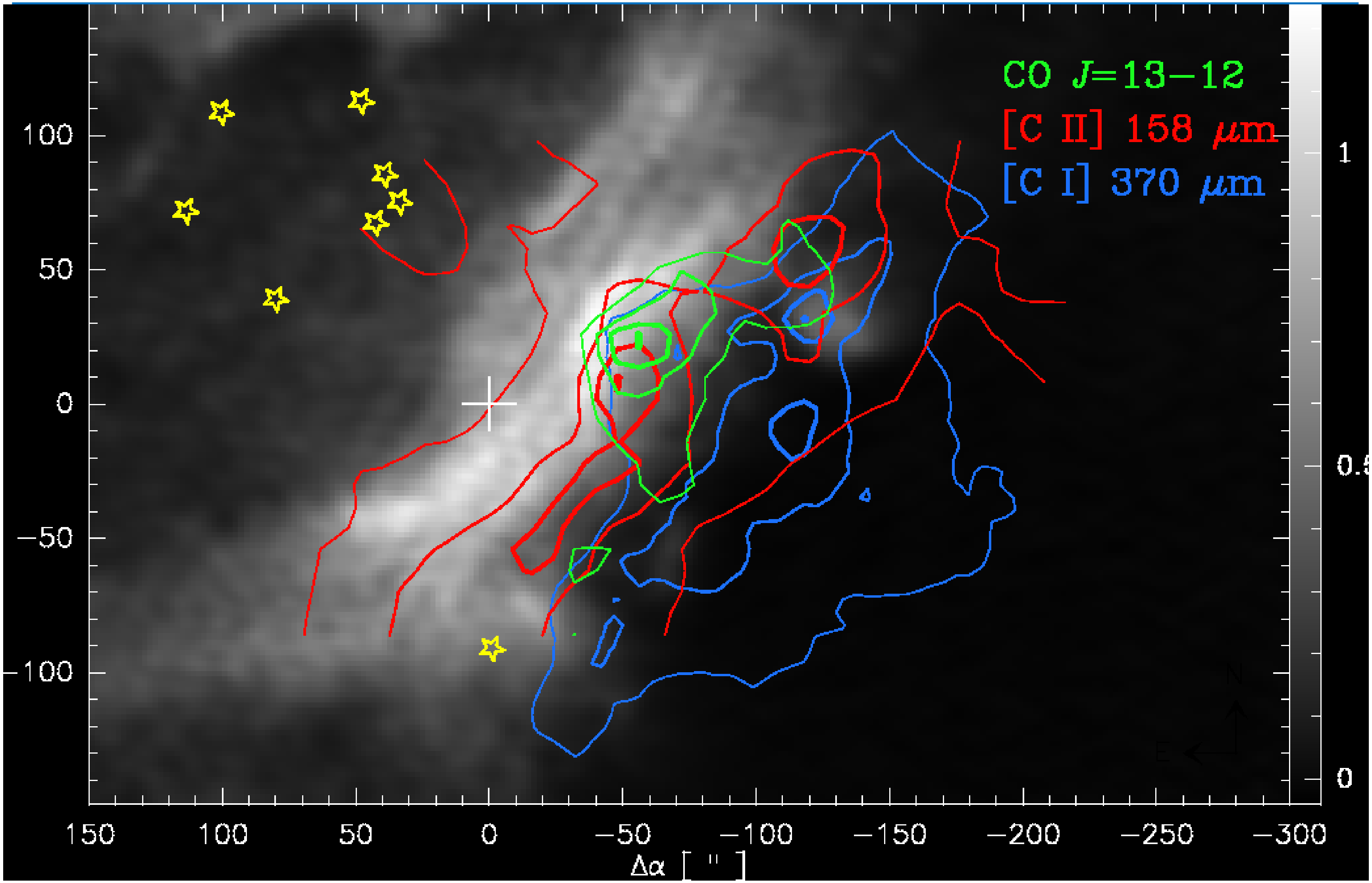
M17 HII region and young star cluster



First Science with GREAT (white [CII], green CO) M17 photodissociation region



M17SW photo-dissociation region (GREAT/APEX)

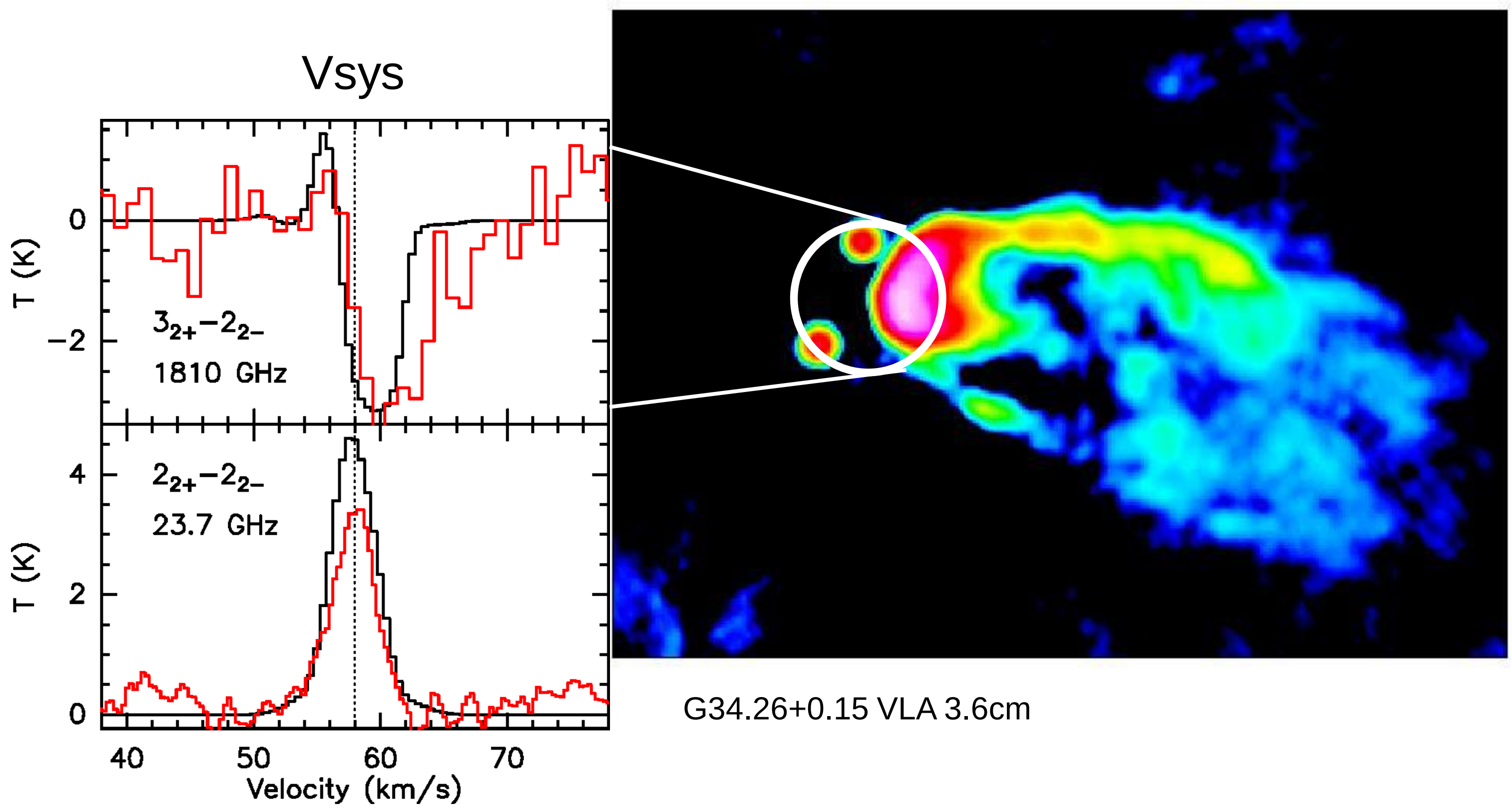


Science Results: probing infall

Probing infall with ammonia absorption against dust continuum

-- case study: UCHIIR G34.3 → red-shifted absorption detected

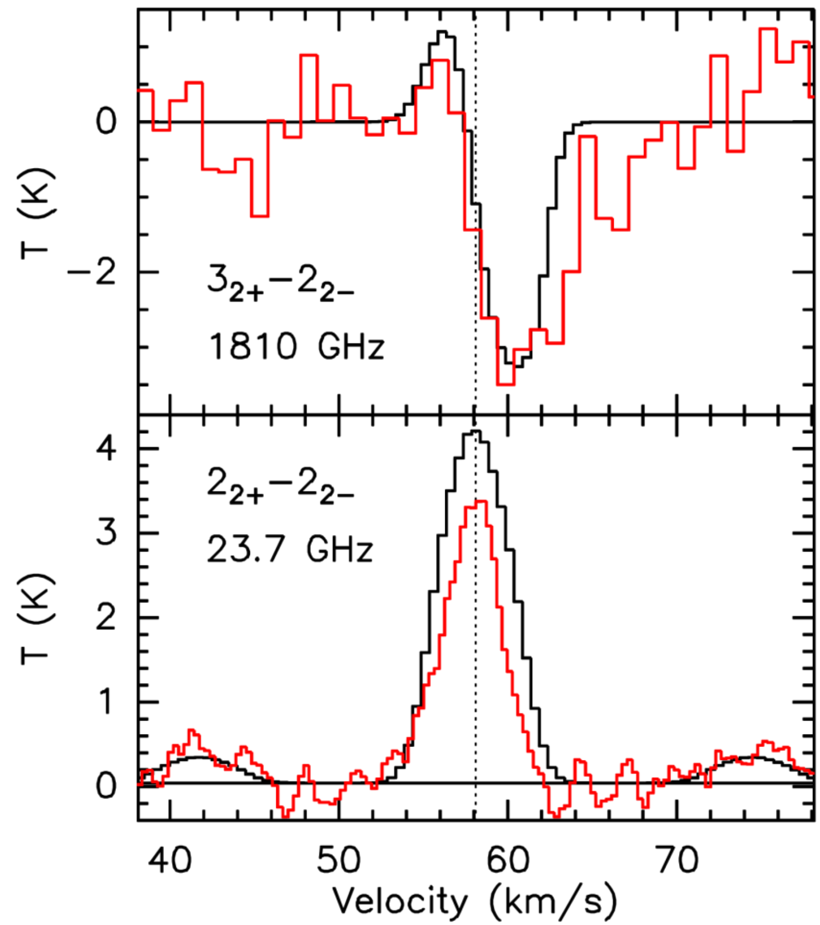
-- modeled with infalling envelope with a high accretion rate



G34.26+0.15 VLA 3.6cm

THz NH_3 as a Probe of Protostellar Infall (collapse)

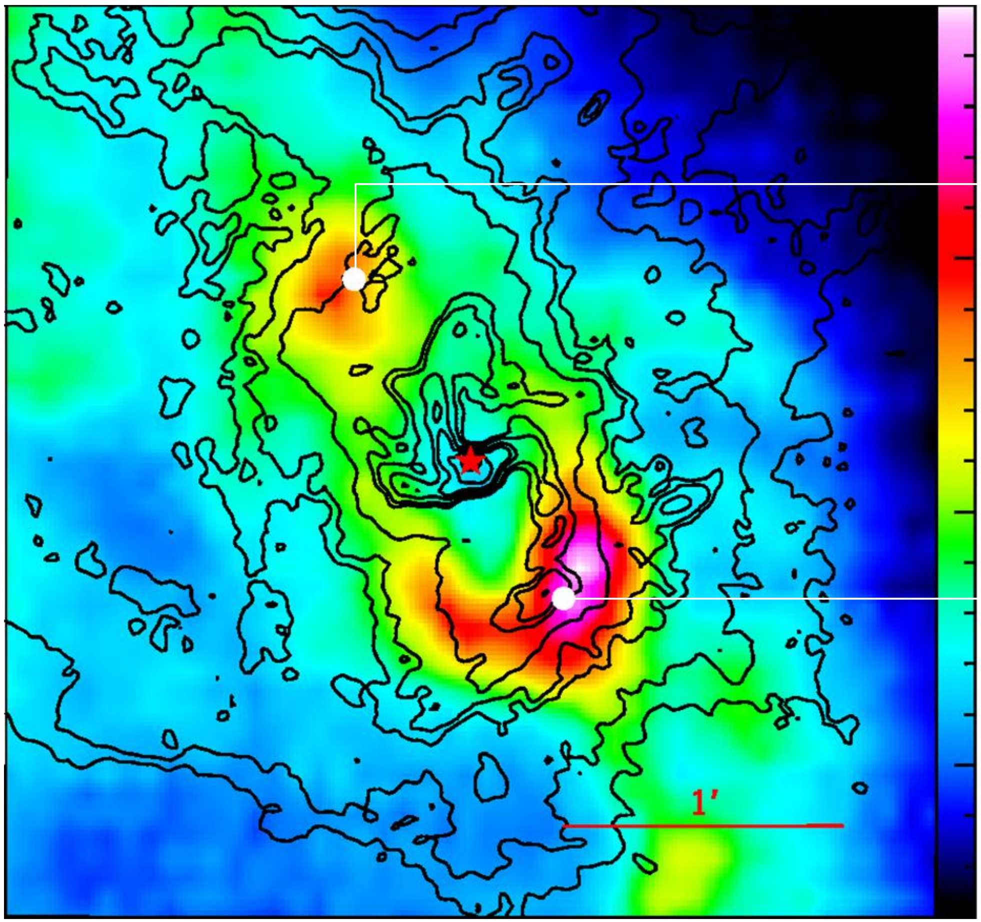
- Observations of NH_3 $3_{2+} - 2_{2-}$ line at 1810.4 GHz in G34.26+0.15 (UCHII region)
- Systemic velocities from $C^{17}O$ J=3-2 (APEX); optically thin
- Modeled ammonia line profiles (inverse P-Cygni profile): absorption against continuum
- Derived very high infall rates of 3 – 10 x 10^{-3} M_{sun} yr^{-1}

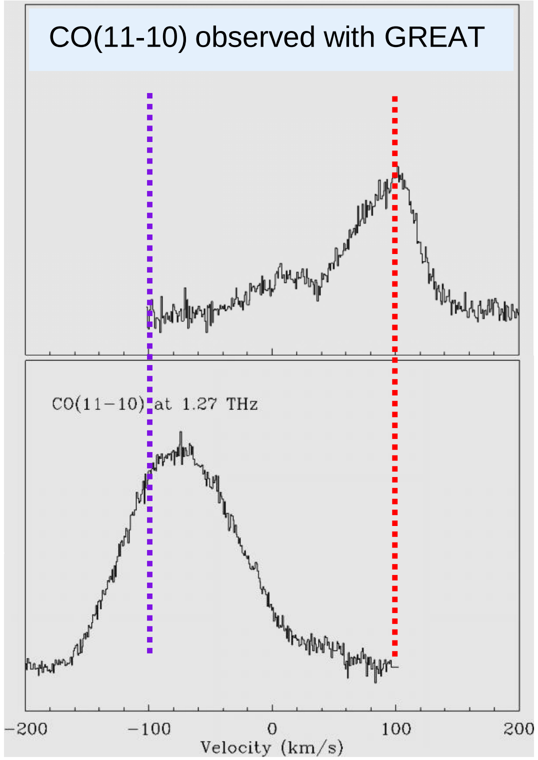


G34.26+0.15 NH_3 SOFIA and Effelsberg (Churchwell et al 1990) spectra in red compared with rad transfer model calculations

Wyrowski, et al 2012, A&A

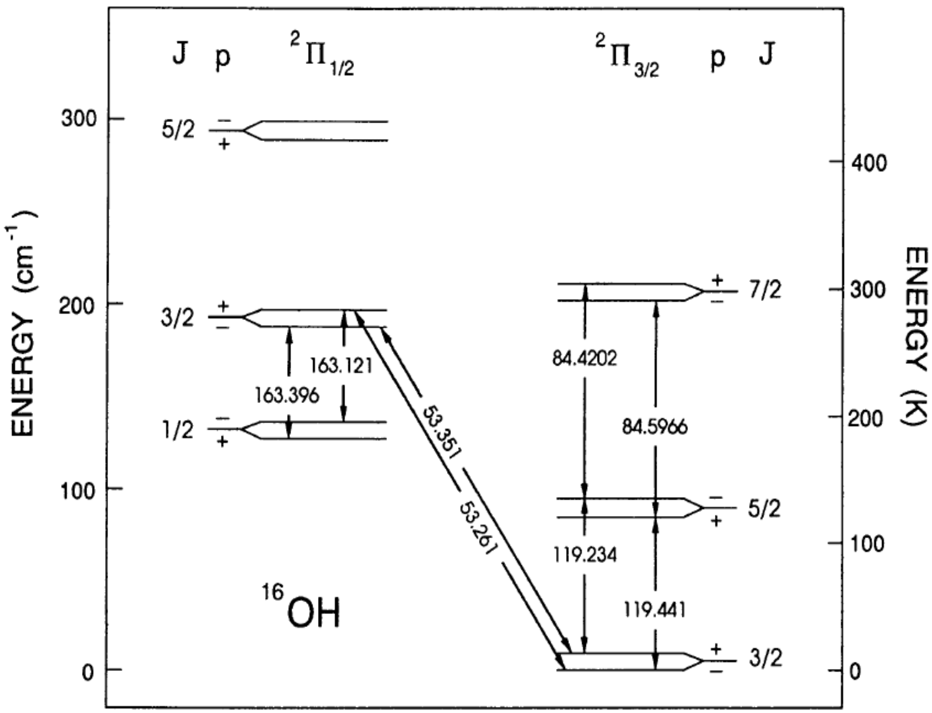
The circum-nuclear disk in the GC





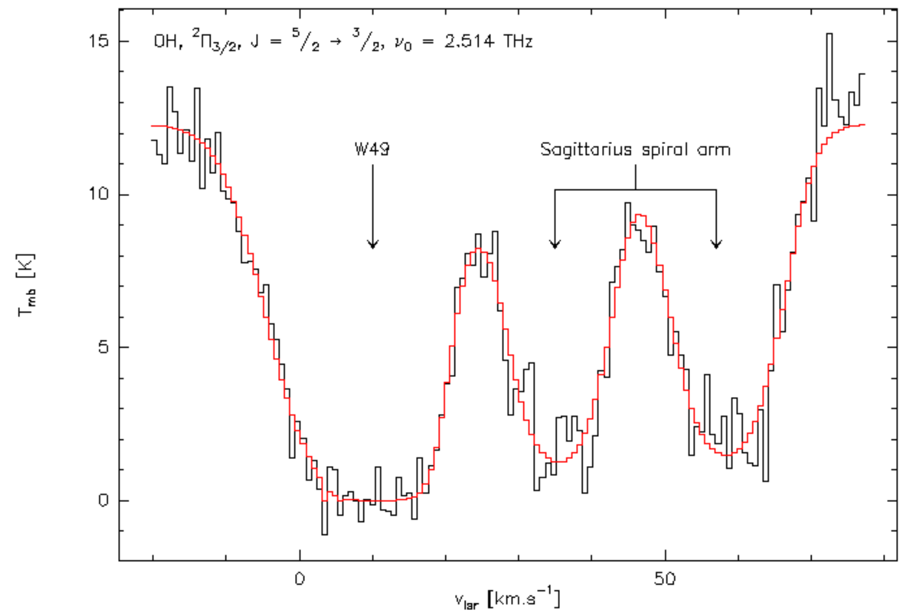
Requena-Torres et al. 2012, A&A

Science Results: 2.5 THz **OH absorption**



First >2 THz spectroscopy from SOFIA

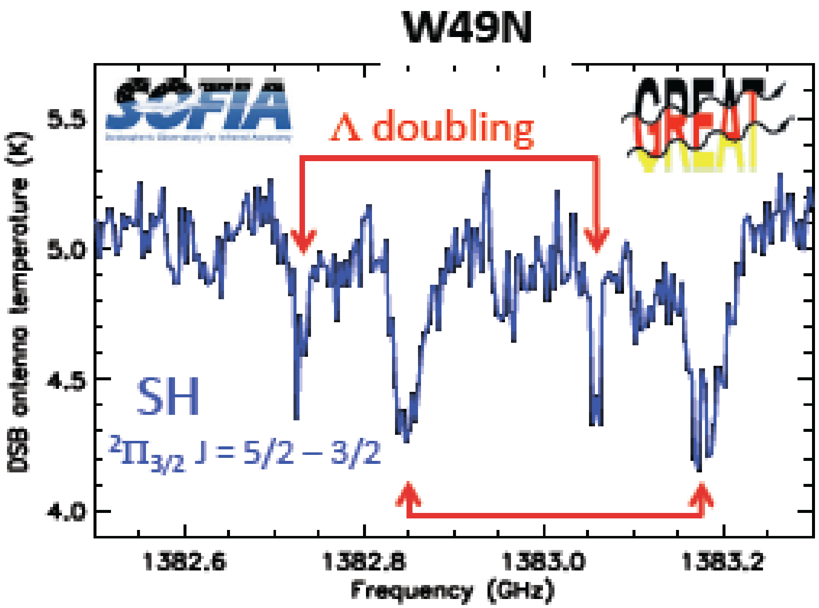
- OH ground-state absorption against W49N
- spectral features of Sagittarius spiral arm



- discovery of ^{18}OH towards W49N core (Wiesemeyer et al. 2012, A&A 542, L7)

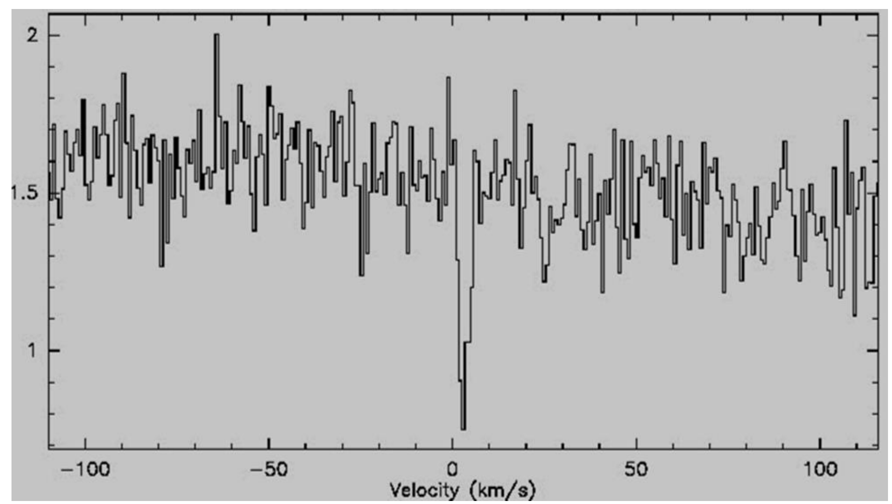
H. Wiesemeyer

GREAT science highlights (new molecules)



Neufeld: discovery of interstellar mercapto radical SH (1.383 THz) in absorption against W49N cont.

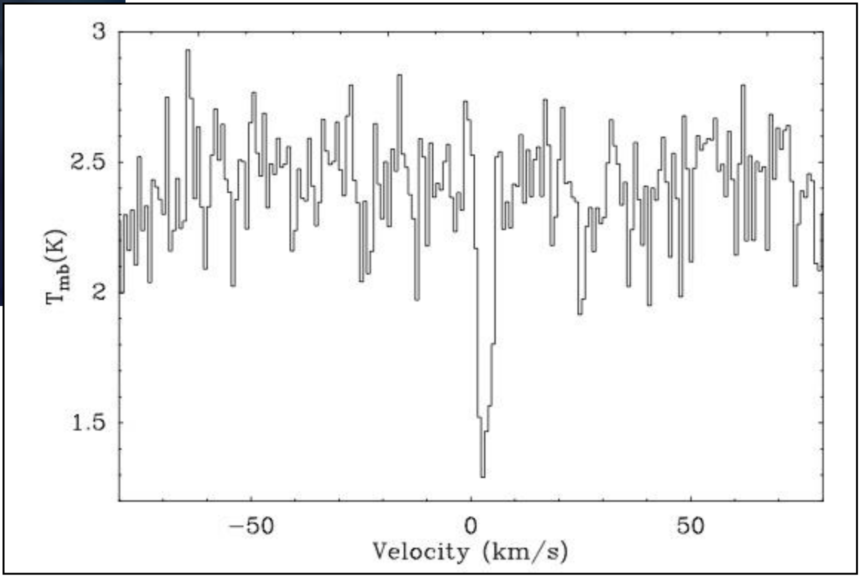
Parise: most beautiful detection of deuterated hydroxyl OD (1.39Thz) towards the low-mass protostar IRAS1629A in the RhoOph cloud



Detection of OD Toward the Low-Mass Protostar IRAS16293

Detection of the OD ground state line at 1.39 THz in absorption toward the line-of-sight of a low-mass protostar.

First detection of OD outside of the solar system.



Analysis is ongoing, but high OD abundance suggests a higher than predicted OH fractionization

Work of B. Parise and the GREAT Team

NZ Deployment

1st Southern Hemisphere Deployment
Christchurch (NZ)
July 12th – August 3rd 2013
with GREAT

Deployment to New Zealand

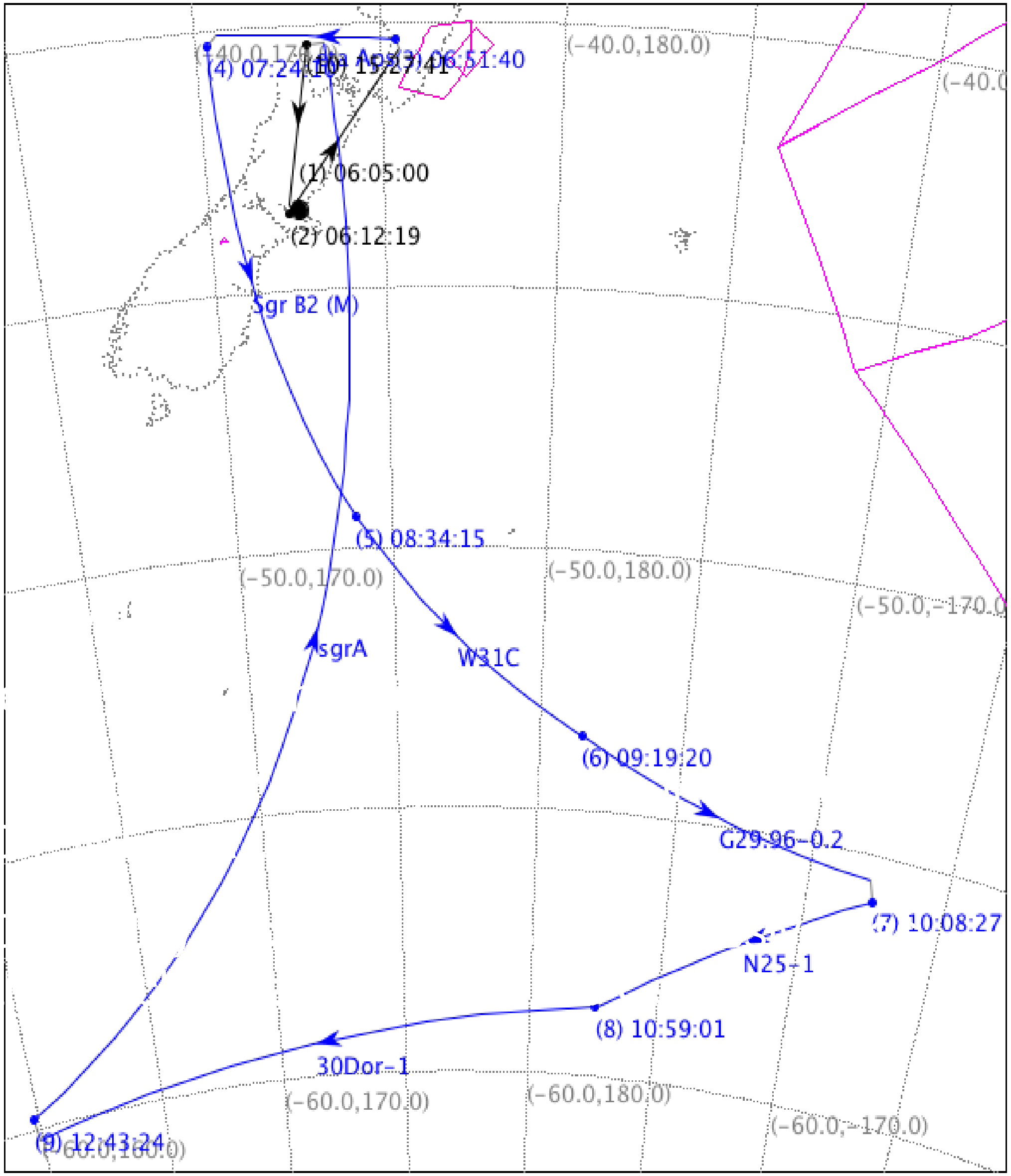
SOFIA came from Palmdale, CA (home base)
to Christchurch, NZ (deployment base)

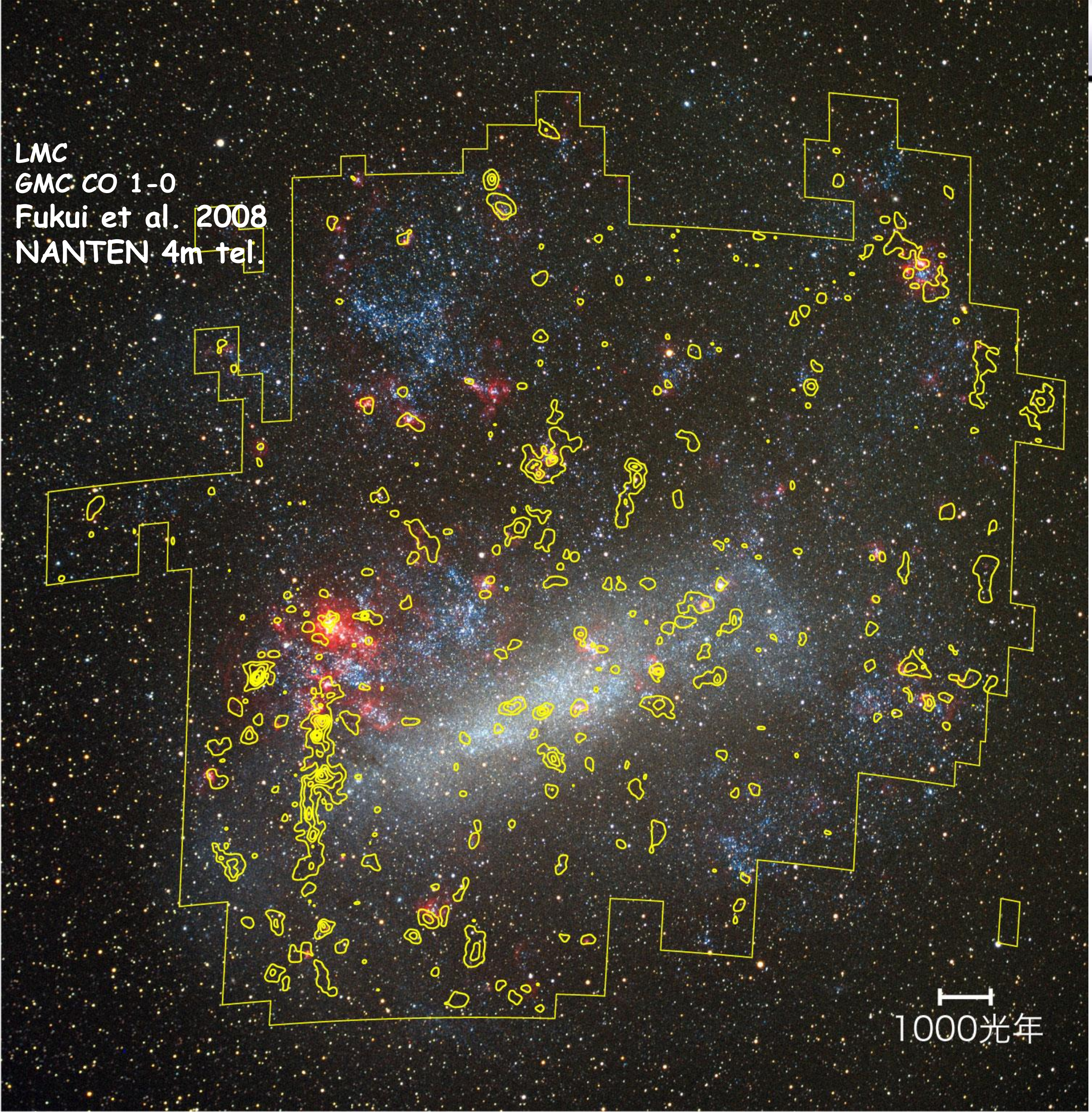
for its first series of southern hemisphere obs.
(in this case with the GREAT/MPIfR instrument)

9 flights, all of which were amazingly successful
(16OH, 18OH, H2D+, CO high-J, C+, N+, HD ...)

NGC3603, LMC (30 Dor, N11), SMC (NGC 346)

New Zealand Deployment: flight path GC/30Dor




LMC
GMC CO 1-0
Fukui et al. 2008
NANTEN 4m tel.
1000光年

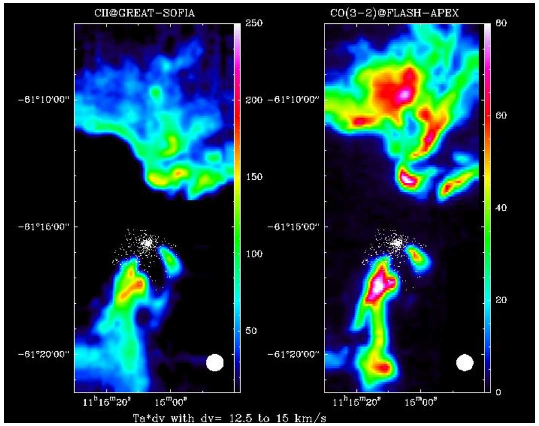
NGC3603 – GREAT Observes a Local Starburst

M. Requena & R. Güsten (for the GREAT Consortium).

Discovered almost 200 years ago by John Herschel as a "remarkable" nebulosity in the constellation Carina, only studies in the last decades have revealed NGC3603's hidden nature as the Milky Way's most active stellar nursery. This densely packed condensation of young stars, with an equivalent mass of a few 10000 suns in a volume with a diameter of only 3 light-years across, contains some of the most massive stars known. Their violent winds and ultraviolet radiation have cleared a cavity in the surrounding gas that now allows unobscured views of the cluster.

While during this rapid star forming episode ("starburst") NGC3603 churned out young stars with, for the Milky Way, unmatched efficiency (making it a scaled-down twin of 30Doradus in the Large Magellanic Cloud) fireworks are far from being over. Deeply embedded in the extended cloud of gas and dust that gave birth to the visible cluster some 1 million years ago, the next generations of stars are forming already. Still invisible in the optical, these sites of ongoing star formation shine bright at far-infrared wavelengths and were the subject of study for GREAT during SOFIA's southern deployment (NGC3603 is visible only from southern skies).
The GREAT far-infrared spectrometer was tuned to the frequency of the ionized atomic carbon [CII] at 1.9 Terahertz (or 159 µm wavelength), which is the main coolant of the ionized interstellar gas, and at the same time, to the frequencies of excited transitions of carbon monoxide. The latter probe the warm dense gas from the close surroundings of the embedded stars (their cooling radiation heats the surrounding gas to elevated temperatures of several 100 degrees).

While calibration of the data is ongoing, the movie offers a first impression of the violent kinematics of the gas in the associated cloud complex, extending north and south of the young star cluster. Several "hot spots", mostly sites of embedded star formation, are seen.



klick here to see the movie:

NGC3603_GREAT_CII_APEX_CO32.mp4

Superimposed on a Hubble image of the young star cluster (Hubble Legacy Archive) is the distribution of the ionized carbon as observed at 1.9 Terahertz with the GREAT spectrometer during SOFIA's first southern deployment is shown. For comparison in the right panel the warm gas probed in the CO(3-2) line with the APEX telescope is given. In the movie we display "velocity channels", providing the emission at different gas velocities.

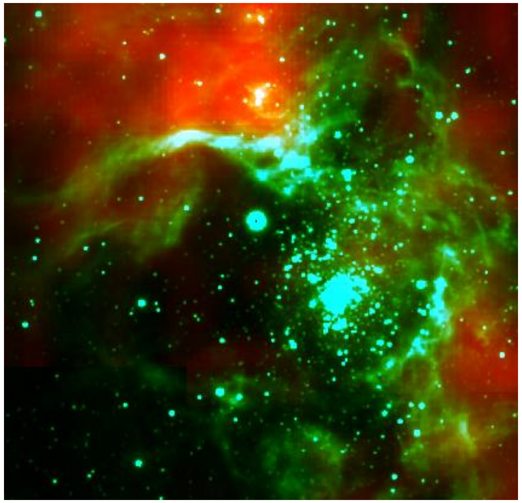
30 Doradus - GREAT observes a region of extreme star formation

M. Requena & R. Güsten (for the GREAT Consortium).

The 30 Doradus complex (also called the *Tarantula* nebula by early astronomers) is the most productive massive star forming region in the Local Group of galaxies. Located in the Large Magellanic Cloud, a neighbor galaxy to the Milky Way, this region has been churning out stars at a rate of several 100 $M_\odot$/Myr for at least the last 4 million years. R136, the young star cluster close to the center of the nebula, contains the most massive stars found in the local universe. 30 Dor is unmatched by any star forming cloud in the Milky Way.
The intense ultraviolet light of the young massive stars interacts violently with the parental gas clouds from which the stars were born, engraving those spectacular images of the ionized gas. 30 Dor is therefore the perfect laboratory to study the - still ongoing - star formation process in the extreme environment of a low metallicity gas bathed in a strong UV radiation field.

SOFIA on its southern deployment was pointed for several science projects to the Magellanic Clouds (uniquely visible only from southern skies), with priority to 30 Dor. The GREAT far-infrared spectrometer was tuned to the frequency of the ionized atomic carbon, [CII], at 1.9 Terahertz (or 159 µm wavelength), which is main coolant of the ionized interstellar gas.

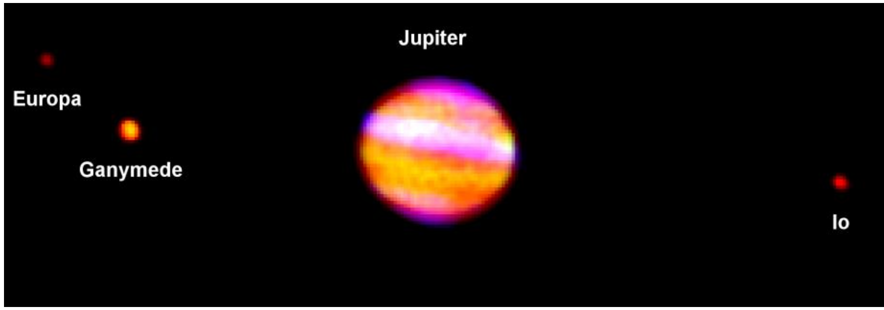
Calibration of the data is ongoing, but the attached figure already displays the basic findings: [CII] traces – as expected – the transition layers where the surrounding material is exposed to the UV radiation field of the young star cluster, but also outlines closely the dense gas condensations that - from our complementary APEX data – are identified to host the next generation of stars, while still heavily embedded in their parental clouds.



Color composite near-infrared image taken (Ks filter) towards the central part of 30 Dor, extracted from ESO's VISTA Magellanic Cloud survey (Cioni et al. 2011, A&A 527). Superimposed in red is the velocity-integrated emission of the ionized carbon [CII], observed at 1.9 Terahertz with the GREAT spectrometer during SOFIA's first southern deployment. By combining the data from different observatories, astronomers are better able to account for the different phases of the interstellar material forming stars.

SOFIA early science successes (2011-2012)

- Early Science with FORCAST and GREAT was a great success
- Some 30 science flights in 2011
- 30 papers subm. to ApJL + A&A
- Discoveries: BNKL energy source, new molecules in abs. (SH, OD; OH)
- Aircraft handles well, even with door open (unnoticable in flight)
- Aircraft now cleared to 45,000 feet
- Successful Occultation of Pluto in June 2011 over the Pacific (paper)
- Cycle 1 proposals being executed Cycle 2 call and selection for US/German Open Time Proposals done, TAC results publ. in October 2013
- Southern deployment (NZ) July 2013: 9 out of 9 GREAT flights successful
- Premier facility for mid-IR and far-IR-astronomy (post Herschel era)



New call for proposals (Cycle 3, TAC results)

CYCLE 3 PROPOSALS WERE DUE JULY 18

~60 flights, including southern deployments

(garanteed time and open=community time)

many Cycle 1 proposals observed in 2013,

when SOFIA was still in development phase

Cycle 2 (flights in 2014, 1 year observing cycle)

Commissioning of new instruments: FIFI-LS + EXES

Cycle 2 proposals being observed, but HMV@LHT

SOFIA workshop Ringberg Castle March 2015

SOFIA may land in Honolulu for IAU-GA 2015

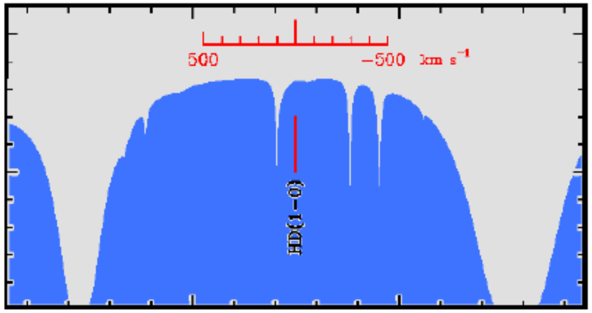
FUTURE SCIENTIFIC POTENTIAL

[OI] @ 4.7 THZ
HD J=1-0 @ 2.7 THZ
(PROXY FOR H_2)

EXOPLANET TRANSITS

Sofia Breakthrough: Cold Molecular Hydrogen using HD

SOFIA will study deuterium in the Galaxy using the ground state HD line at 112 microns (2.7 THz). This will allow the determination of the cold molecular hydrogen (H2) abundance.



Atmospheric transmission around the HD line at 40,000 feet

Deuterium in the universe is created in the Big Bang.
(D/H ~ 1/100,000). Most D is expected to be in HD, but some in deuterated molecules.

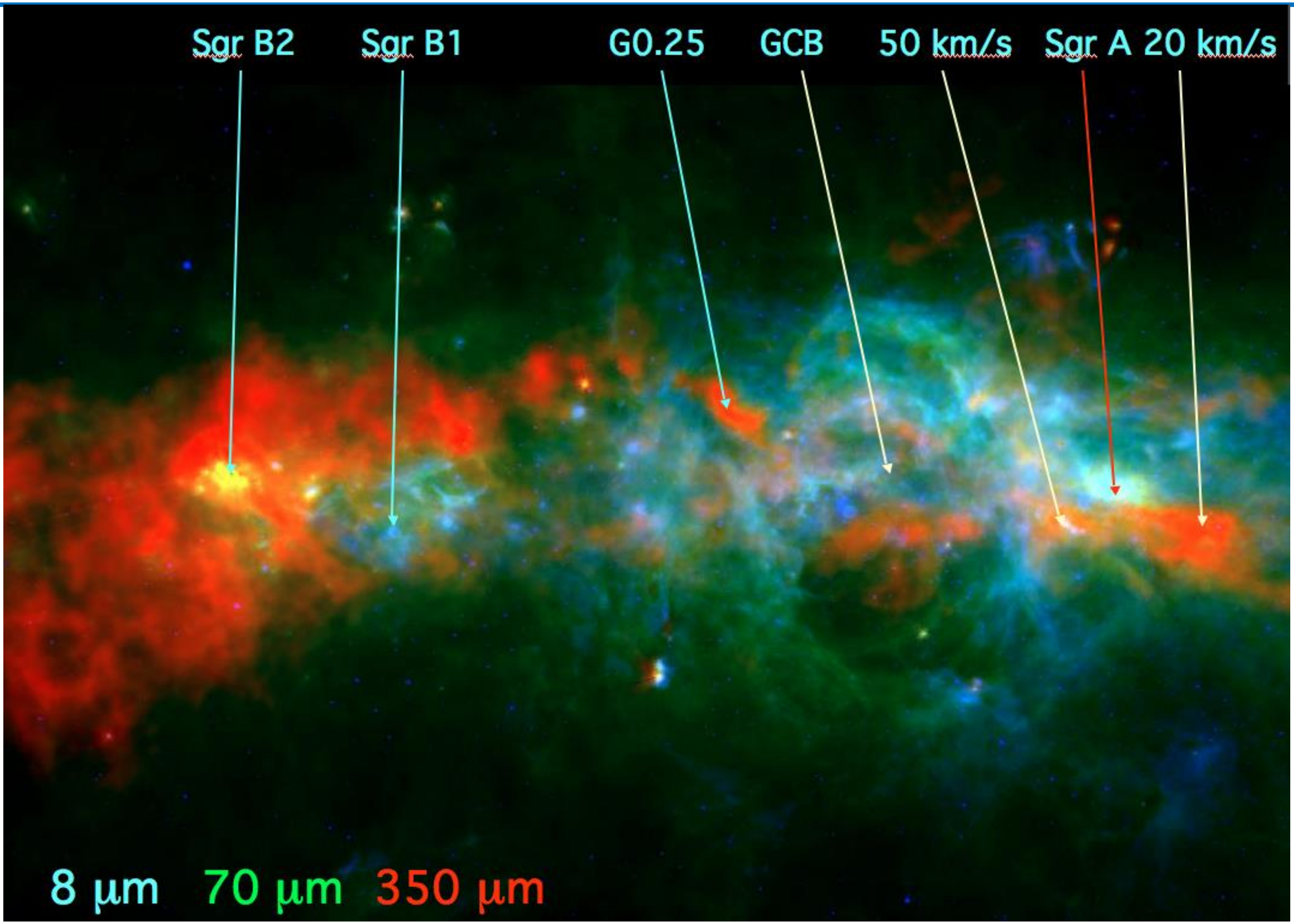
Measuring the amount of cold HD (T<50K) can best be done with the ground state rotational line at 112 microns accessible with SOFIA (absorption line towards continuum)

HD detections with ISO means GREAT high resolution spectroscopic study is possible.
HD line is weak, so we may need better 2.7 THz detectors to obtain high S/N HD data.

HD has a much lower excitation temperature (128 K) than H2 (512K)
and a dipole moment that almost compensates for the much higher abundance of H2.

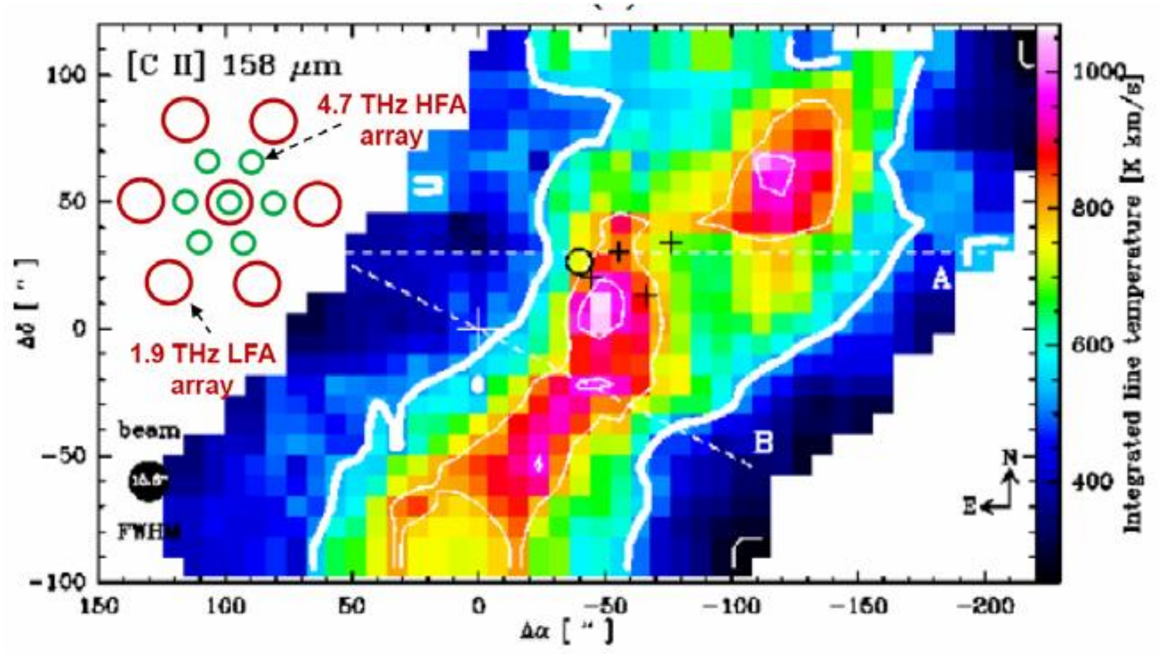
HD absorption is expected to trace the cold molecular hydrogen. Or is it in emission?
GREAT in New Zealand made an attempt to detect it – and probably did. Stay tuned!

Galactic Center IR/submm image (Bally)



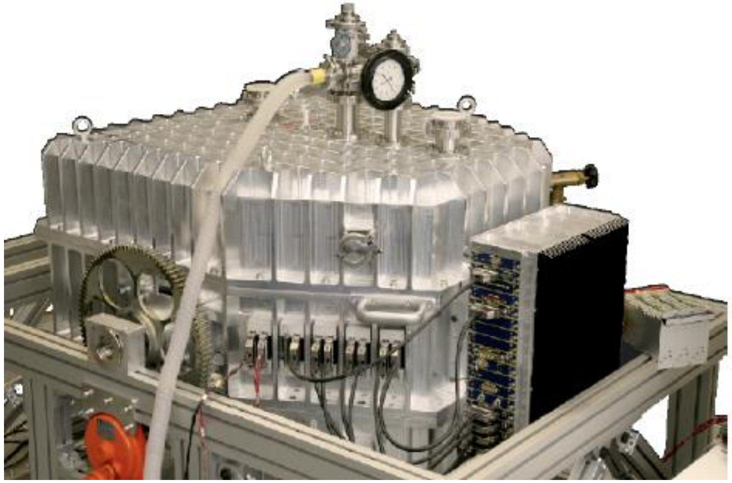
German Instrument Developments

- upGREAT, an enhancement of the GREAT heterodyne instrument, is under development by Rolf Güsten et al.
- Compact heterodyne arrays
  - 7 pixels x 2 polarizations @ 1.9 to 2.5 THz
  - 7 pixels @ 4.7 THz [O I]



FIFI-LS: Far-IR integral field Spectrometer

new PI: Krabbe@DSI



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

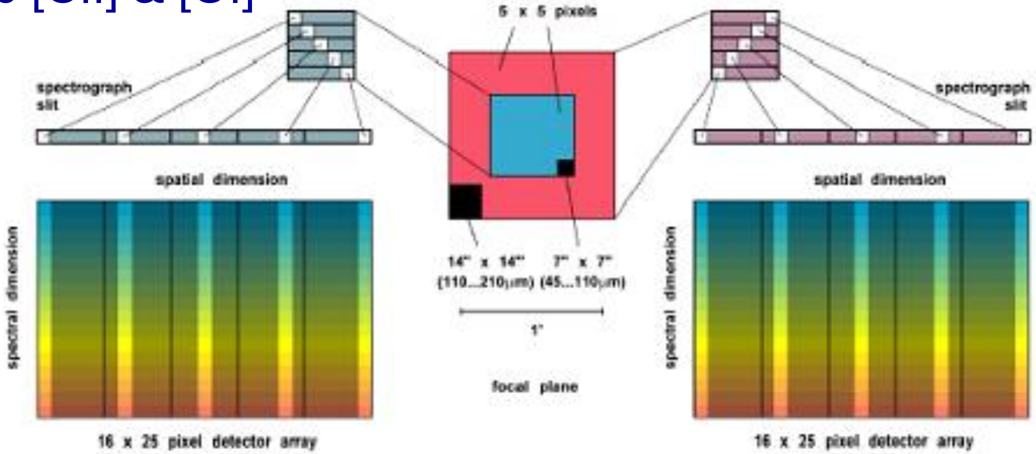
Field of View: 30” x 30” (blue), 60” x 60” (red)

R= 1500 - 6000

Science: Imaging of extragalactic [CII] & [OI]

Targets: Extragalactic systems

NB: Imaging array is 5 x 5 pixels



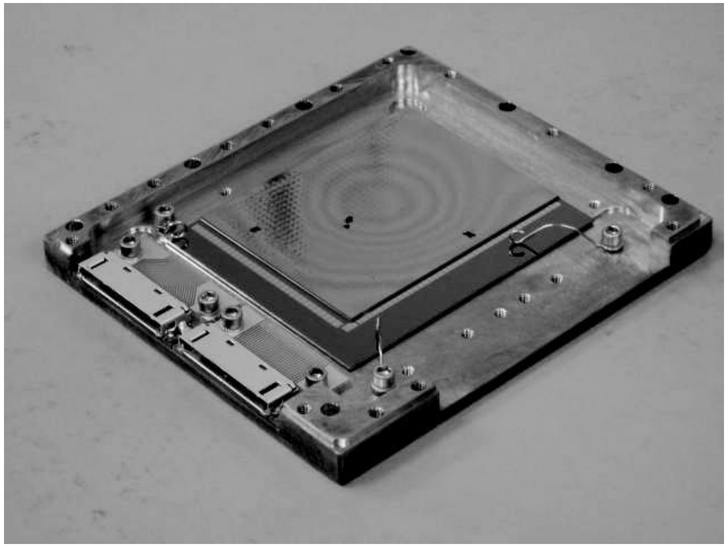
On sky orientation of ‘blue’ and ‘red’ channels

HAWC Upgrades

- HAWC-POL
- PI- Darren Dowell (JPL)
- Polarizer mechanism replaces existing pupil wheel on HAWC

HAWC-POL Mechanism
Novak & Dowell (2009)

- HAWC++
- PI Johannes Staguhn (Johns Hopkins)
- Increases detector format on HAWC from 384 to 2560 pixels per polarization



PIPER 32x40 Prototype detector
Chuss et al. (2010)

FIR Dust Continuum Emission Polarimetry

- Far Infrared polarimetry will help elucidate the role of magnetic fields in the energetics of the interstellar medium
- SOFIA will have a unique polarimetric capability that was recently selected for the Second Generation Instruments NASA AO

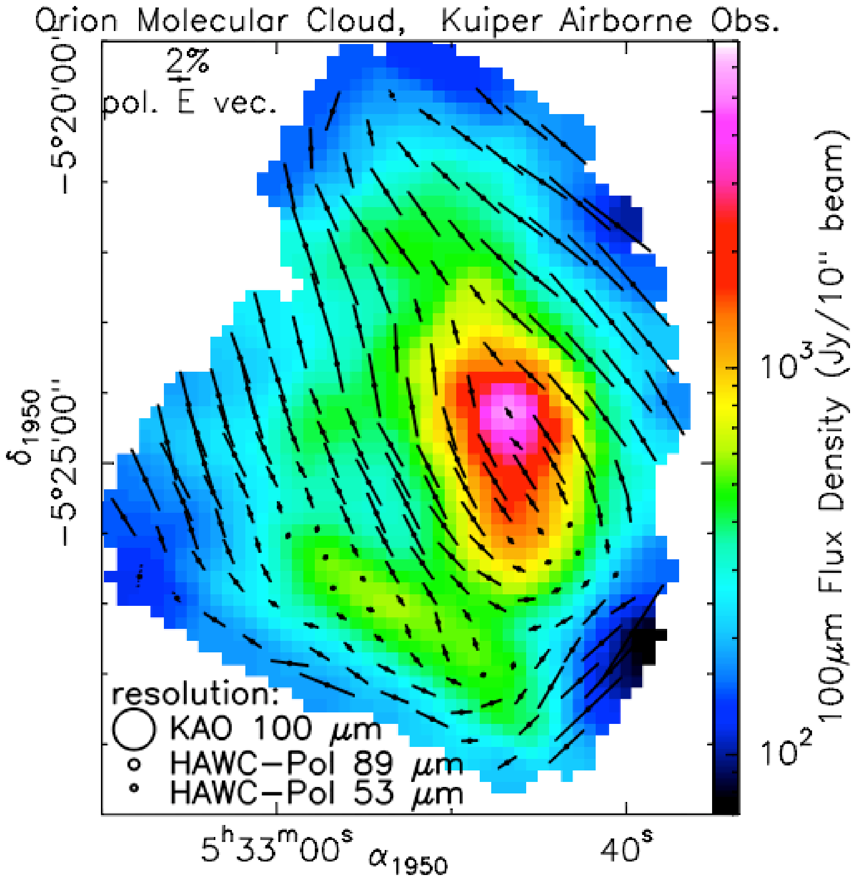
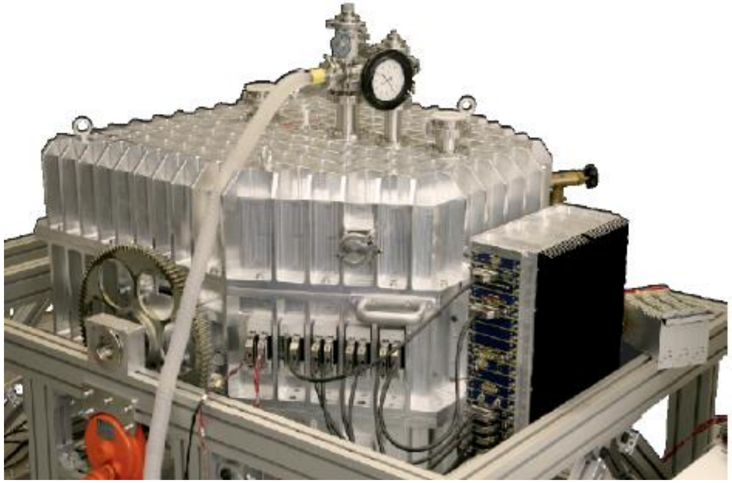


Figure 5. Linear polarization of the Orion Nebula at 100 μm measured with the KAO by Schleuning (1998) . Shown are the beam sizes of the KAO polarimeter and HAWC upgrade. (Dowell et al. 2007)

FIFI-LS Commissioning Science

Integral Field Spectrometer R~2000

FIFI-LS: Far-IR integral field Spectrometer



new PI: Krabbe@DSI

Detectors: Dual channel 16 x 25 arrays;
50 – 110 μm (Ge:Ga)
120 - 200 μm (Ge:Ga stressed)

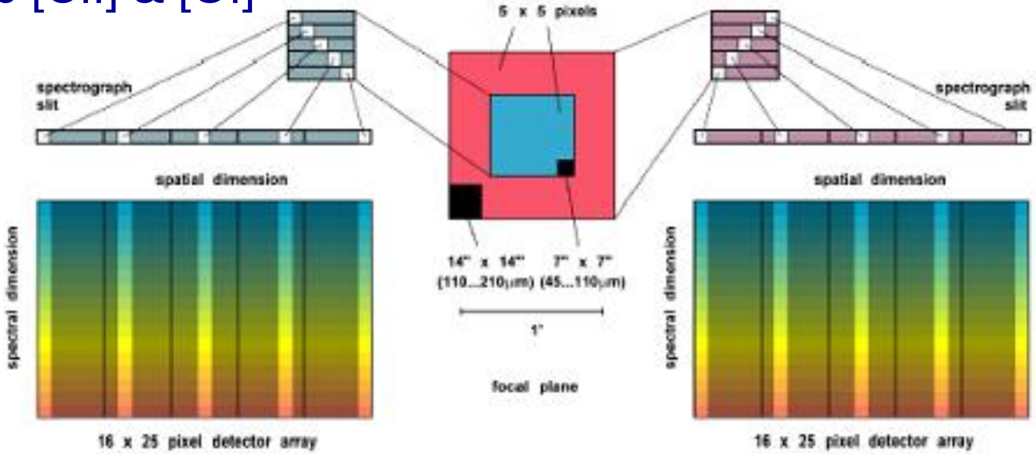
Field of View: 30” x 30” (blue), 60” x 60” (red)

R= 1500 - 6000

Science: Imaging of extragalactic [CII] & [OI]

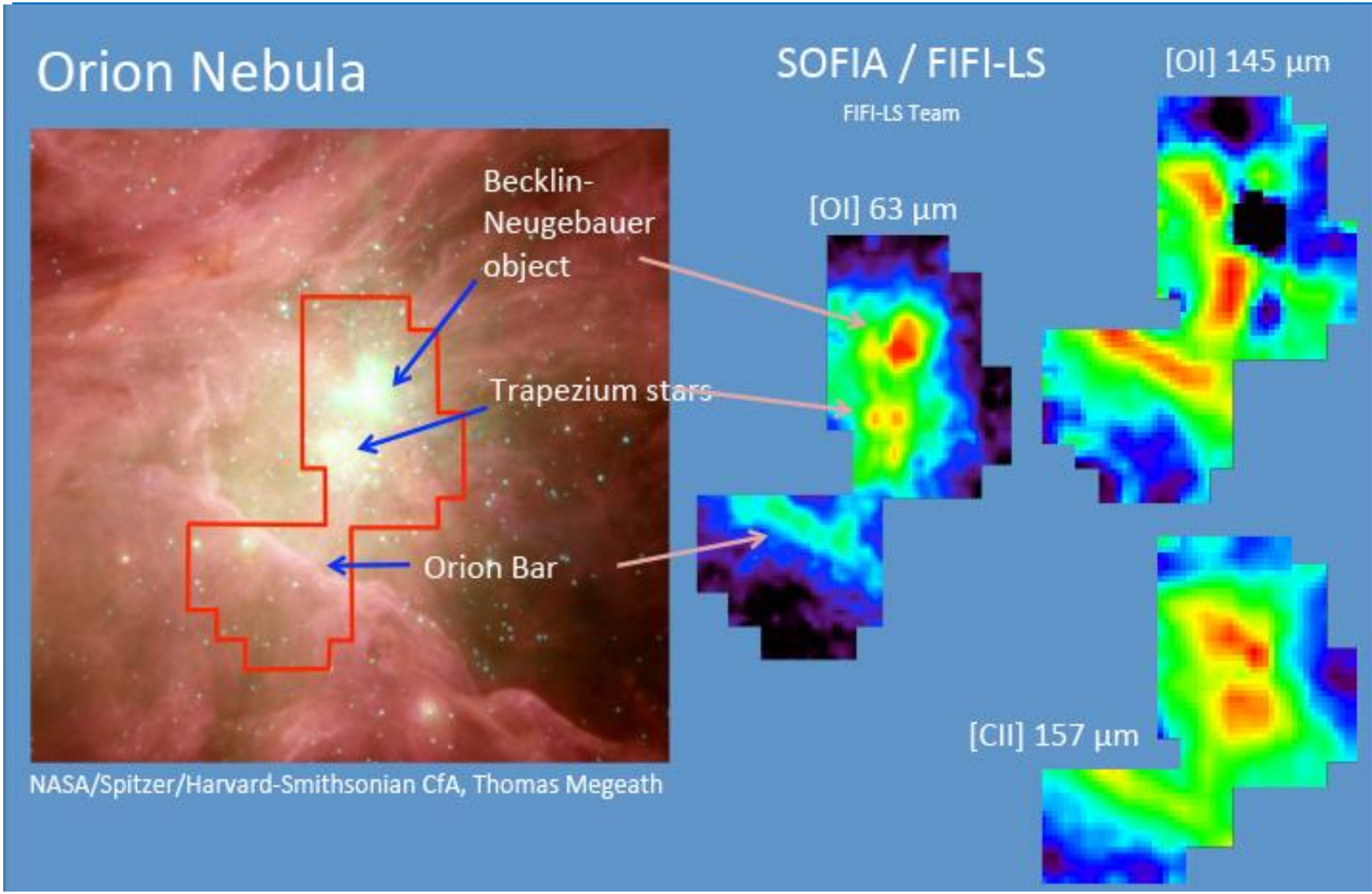
Targets: Extragalactic systems

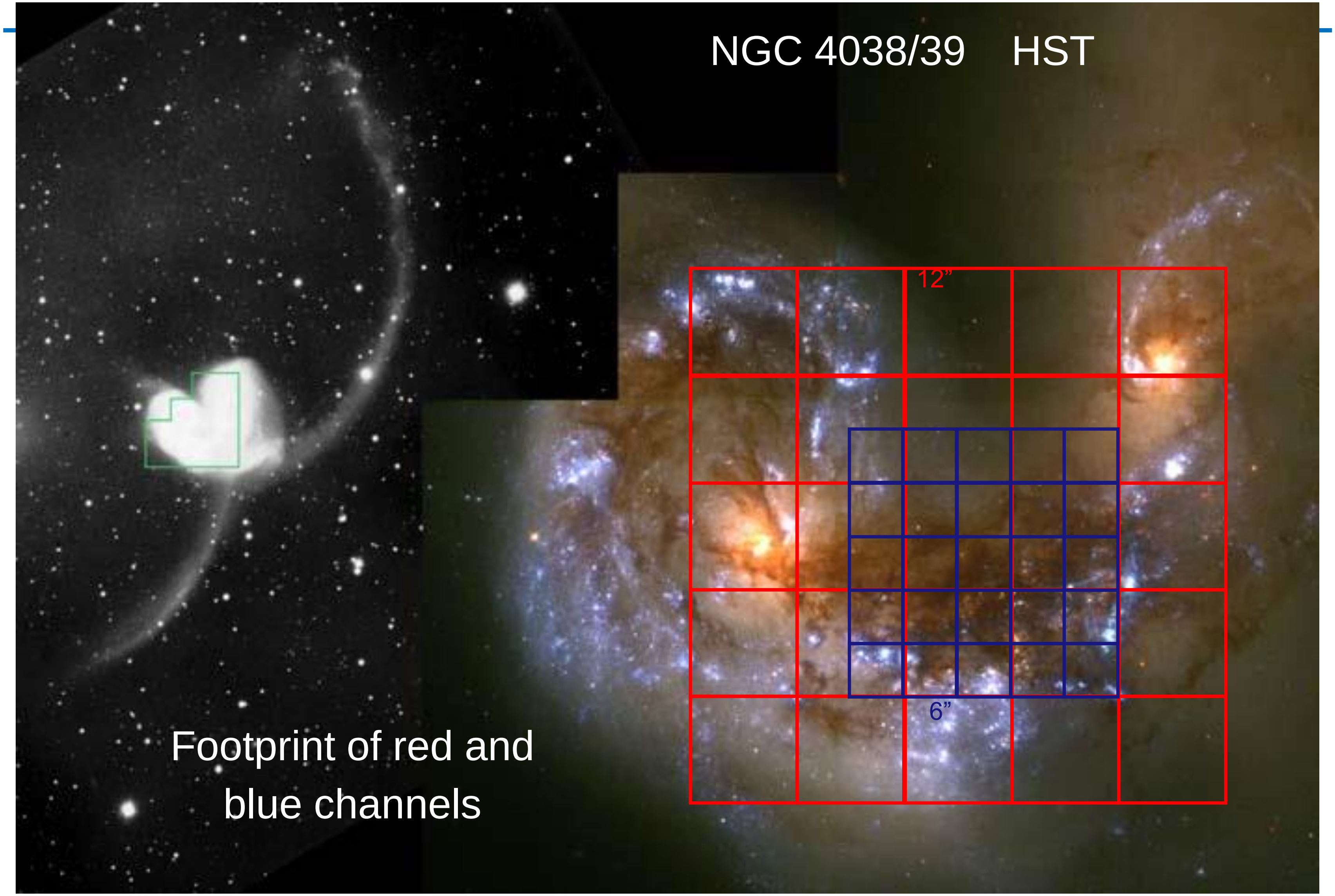
NB: Imaging array is 5 x 5 pixels



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

FIFI-LS Orion Nebula Observations




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

EXES Commissioning Science

R~100,000 Slit Spectrometer

EXES

1k x 1k, Si:As

5-28 mu (like JWST)

cross-dispersed echelle spectrograph

R = 10^4 to 10^5 spectral resolution

Instrument: PI Matt Richter (U.Davis)

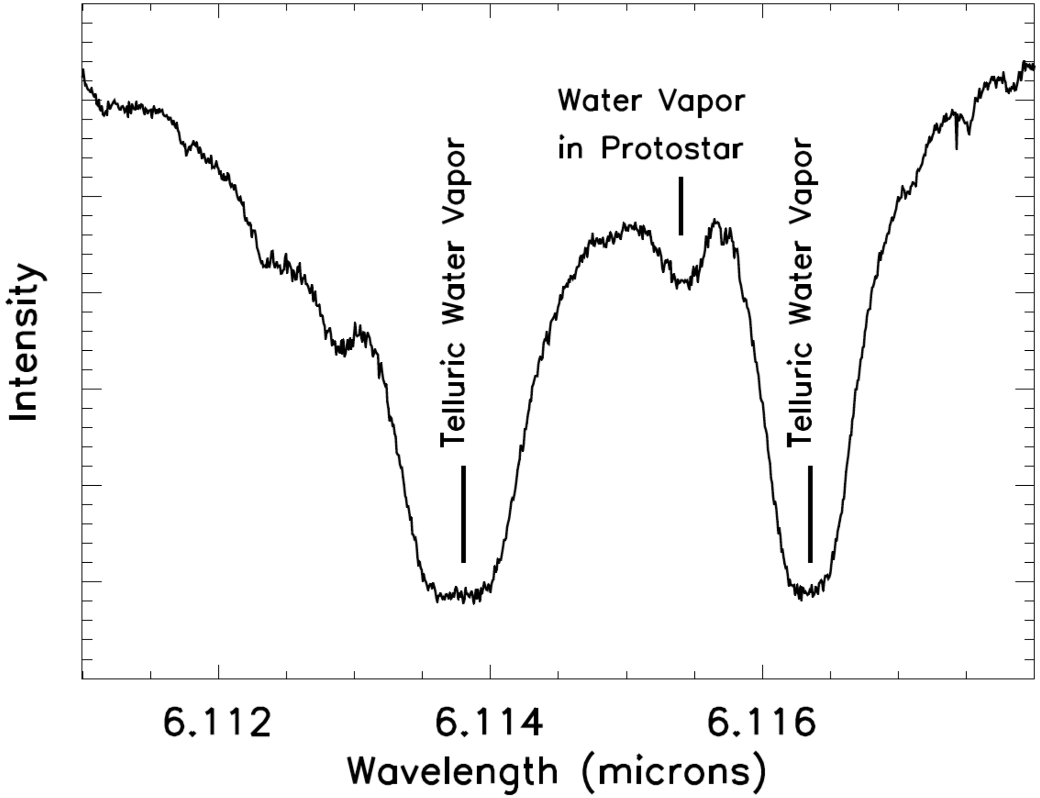
to be commissioned in spring 2014

to be used in Cycle3 (shared risk)

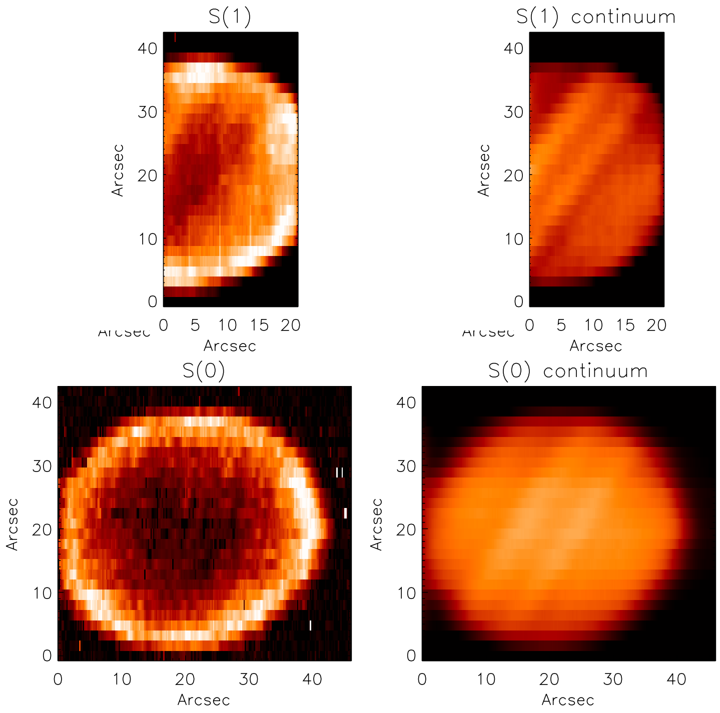
likely to be a new SOFIA workhorse

(science: circumstellar disks, water, CH4)

Commissioning Science 1: Water Vapor in AFGL 2591



Commissioning Science 2: Ortho/para H_2 maps on Jupiter



FLITECAM and HIPO together (FLIPO)

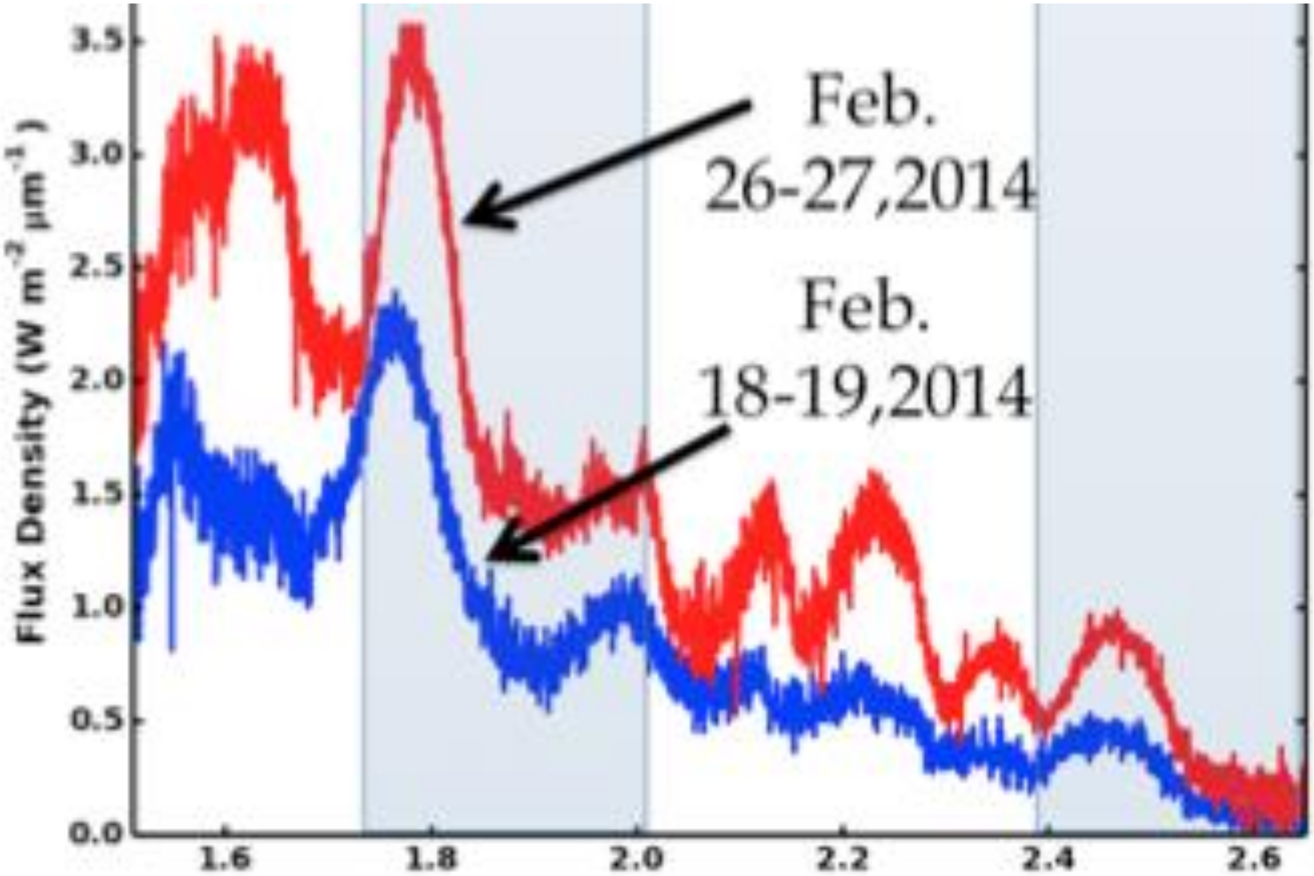
- FLITECAM(1-5 micron) camera with a GRISM spectrometer was commissioned this spring in FLIPO mode.

- Four cycle 2 observations also carried out

  -- An Exo-planet transit at 4 simultaneous wavelengths including 1.9 microns were made.

  -- Two independent spectra of type Ia Super Nova 2014J in M82. 1 to 2.8 microns with R~1200.

FLITECAM and HIPO together (FLIPO): Supernova 2014J in M82 (Vacca etal in Prep)



Education and Public Outreach

Cycle 0 Airborne Astronomy Ambassadors “Pilot” Program

May 26-July 15, 2011

Mary Blessing, Herndon, Va.; Cris DeWolf, Remus, Mich.; and Dana Backman (SETI)

Cecilia Scorza (DSI); Wolfgang Vieser, Munich, Germany; and Jörg Trebs, Berlin, Germany

Terry Herter (Cornell); Jim De Buizer (USRA);

Theresa Paulsen, Mellen, Wis.; and Marita Beard, San Jose, Calif.

Pamela Harman (SETI); Margaret Piper, Frankfort, Ill.; and Kathleen Fredette, Palmdale, Calif.

2014: SOFIA development phase → operations phase

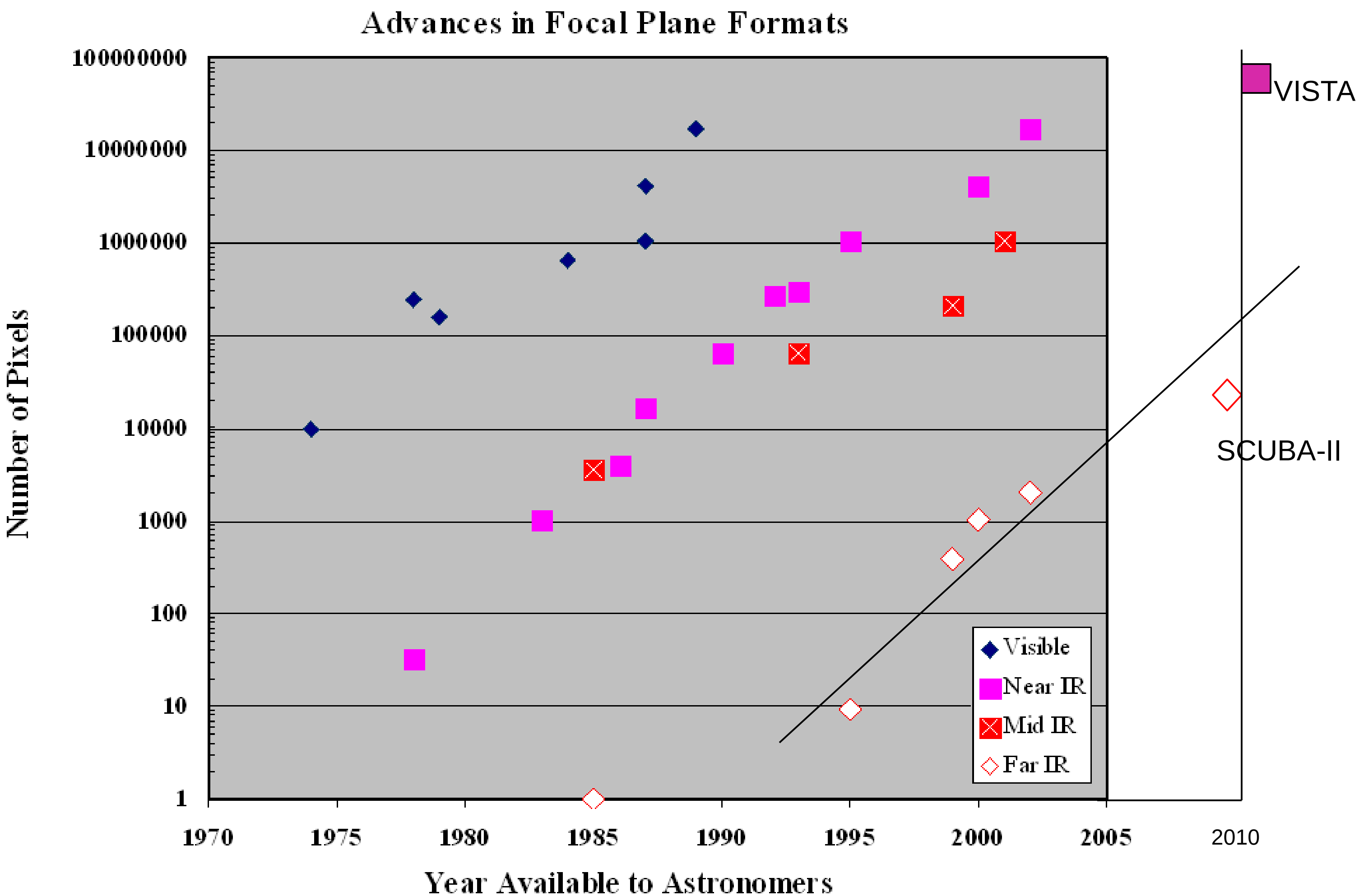
http://www.sofia.usra.edu

http://www.dfrc.nasa.gov/Gallery/Movie/SOFIA/index.h

SOFIA Ringberg workshop: 15-18 March 2015

Eric Becklin (SOFIA chief scientist) + HZ

Moore's Law for Infrared Detectors



Detector Needs for Long Wavelength Astrophysics (2002), courtesy Erick Young

SOFIA Management structure

Program Manager (NASA/DLR)

Project Scientist (NASA) , PMB

SOFIA Science Center at Ames (USRA/DSI)

Science Mission Operations director (USRA)

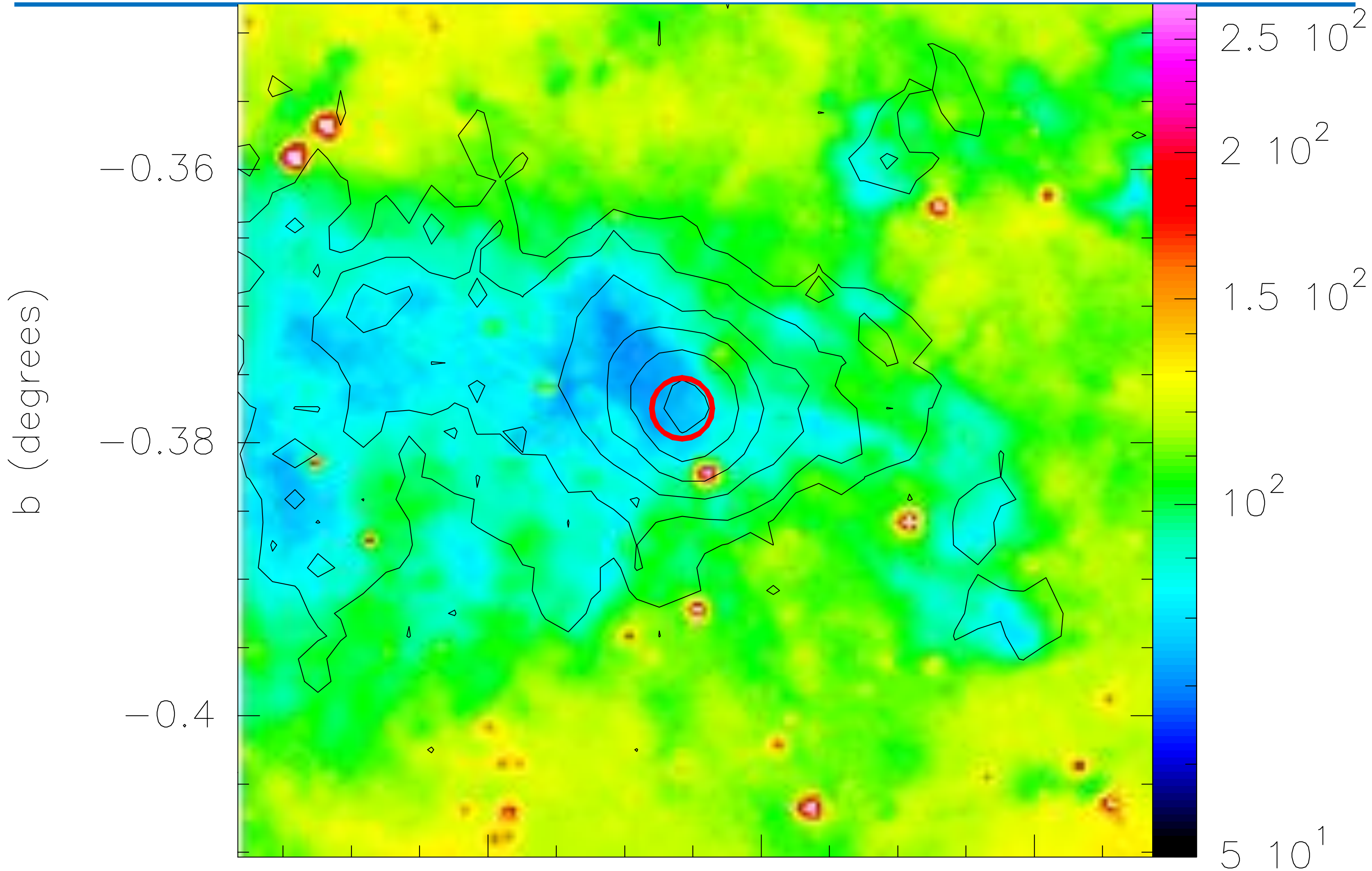
-deputy director (DSI), chief advisor (USRA)

-associate directors (science, prog mgm, ops)

Deutsches SOFIA Institut (DSI, Univ. Stuttgart)

- delegates technical staff to US (Palmdale, Ames)
- organizes call for proposals, TAC proposal reviews
- selects German proposals through deputy director

ATLASGAL submm clump G23.21



G23.21 gas clump: protocluster infall