



SOFIA
STRATEGIC OBSERVATORY
FOR ADVANCED ASTROPHYSICS



DLR

N747NA



NASA
850

SOFIA Early Science Results

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SUG, NASA Ames

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Outline of Material

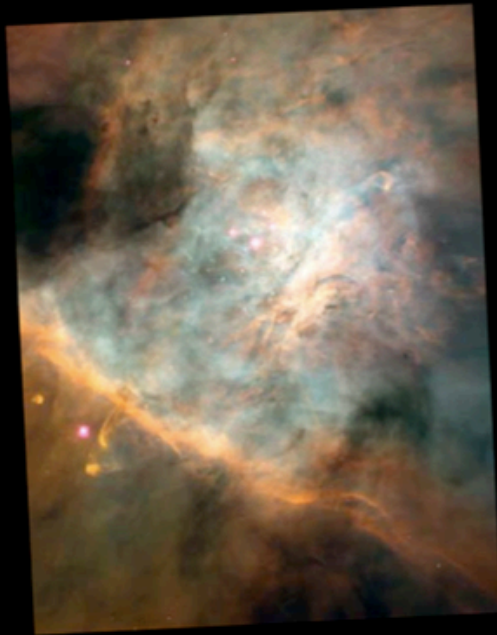
- FORCAST Observations
 - Orion Nebula
 - Galactic Center
 - M2-9
- GREAT Observations
 - Discovery of SH in ISM
 - Infall
 - First OD in ISM
- HIPO/FDC Pluto Occultation
- Summary

FORCAST Observations

ORION NEBULA

- Orion Nebula is the closest region to the earth of Massive Star Formation
 - Distance = 415 pc
 - Both Optical stars (Trapezium) and embedded star formation (OMC 1/BNKL)
- Studied on SOFIA with FORCAST at 6 to 37 microns.
- De Buizer etal ApJ Letters 2012 accepted
- Shuping etal ApJ Letters 2012 accepted
- Adams etal ApJ Letters 2012 accepted (OMC2)

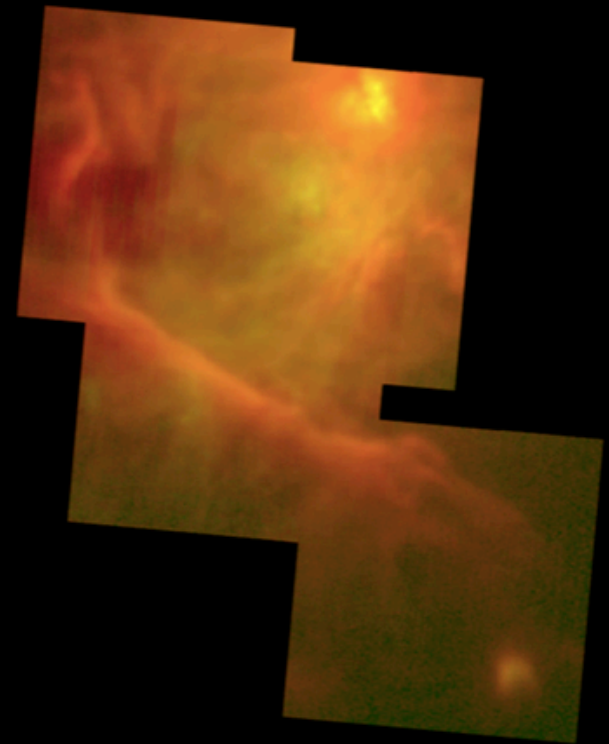
20 (Green) and 37 (Red) Micron Data of Orion Nebula



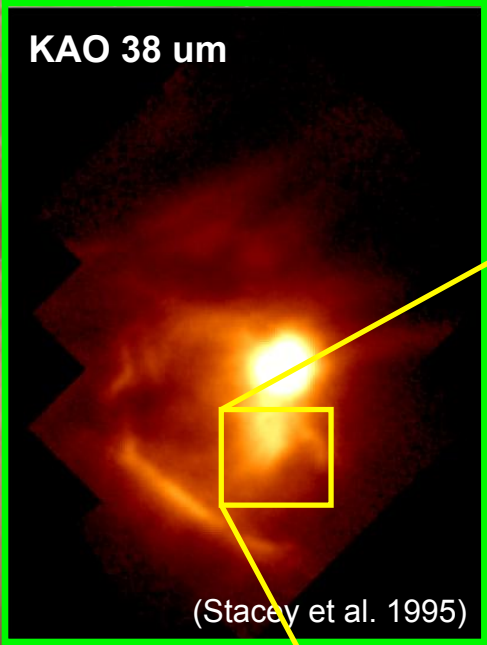
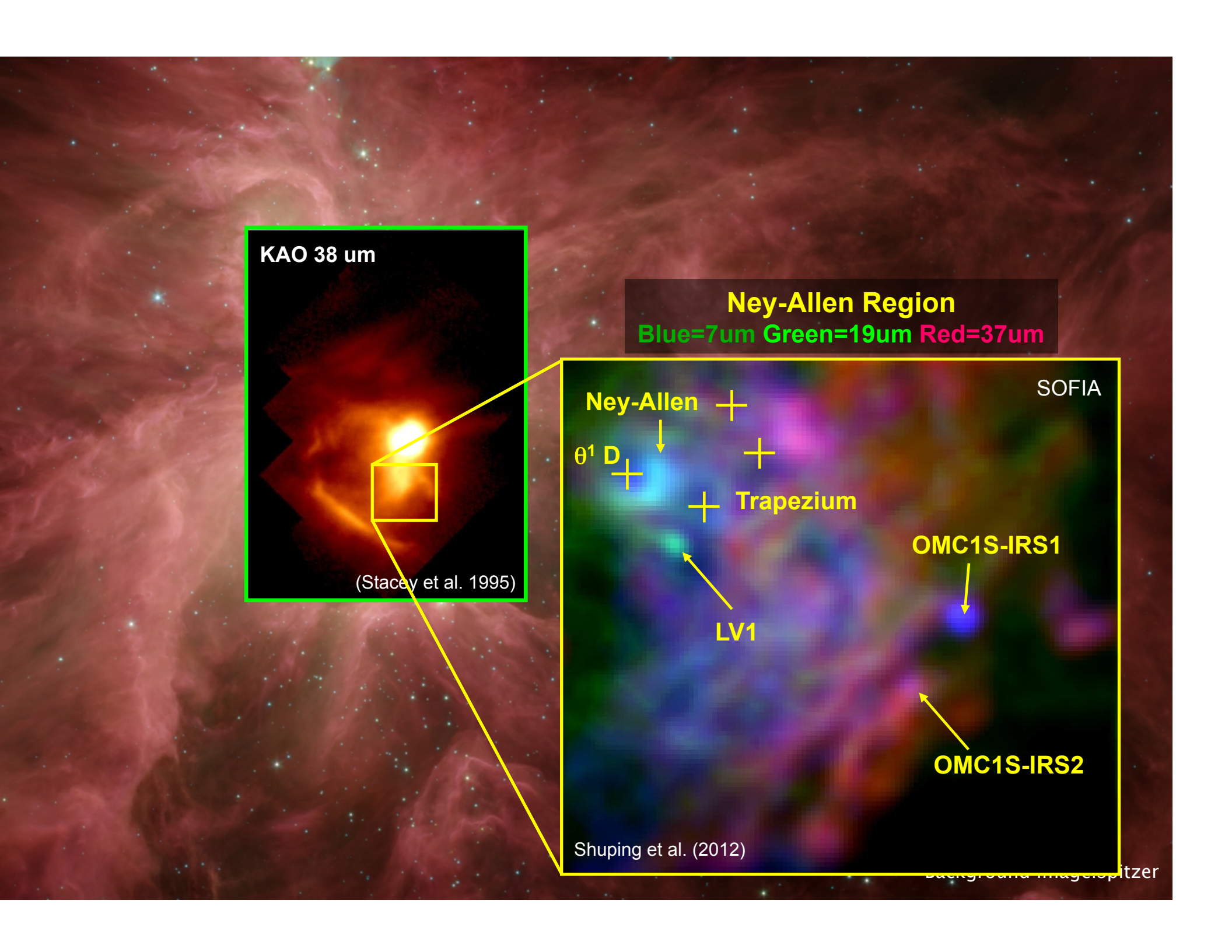
Visible light
(HST, C. O'Dell and S. Wong)



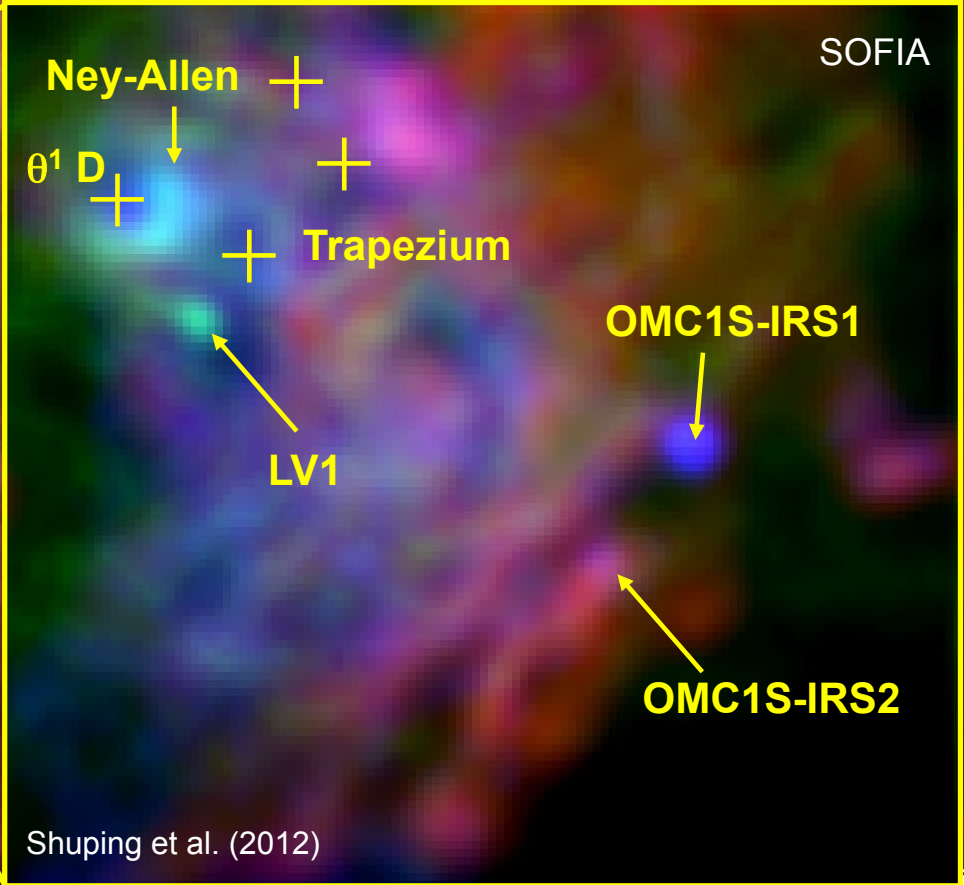
Near infrared
(ESO, M. McCaughrean)

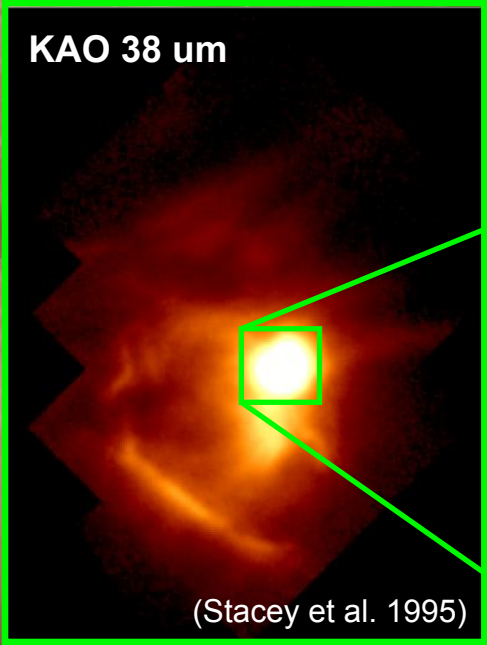
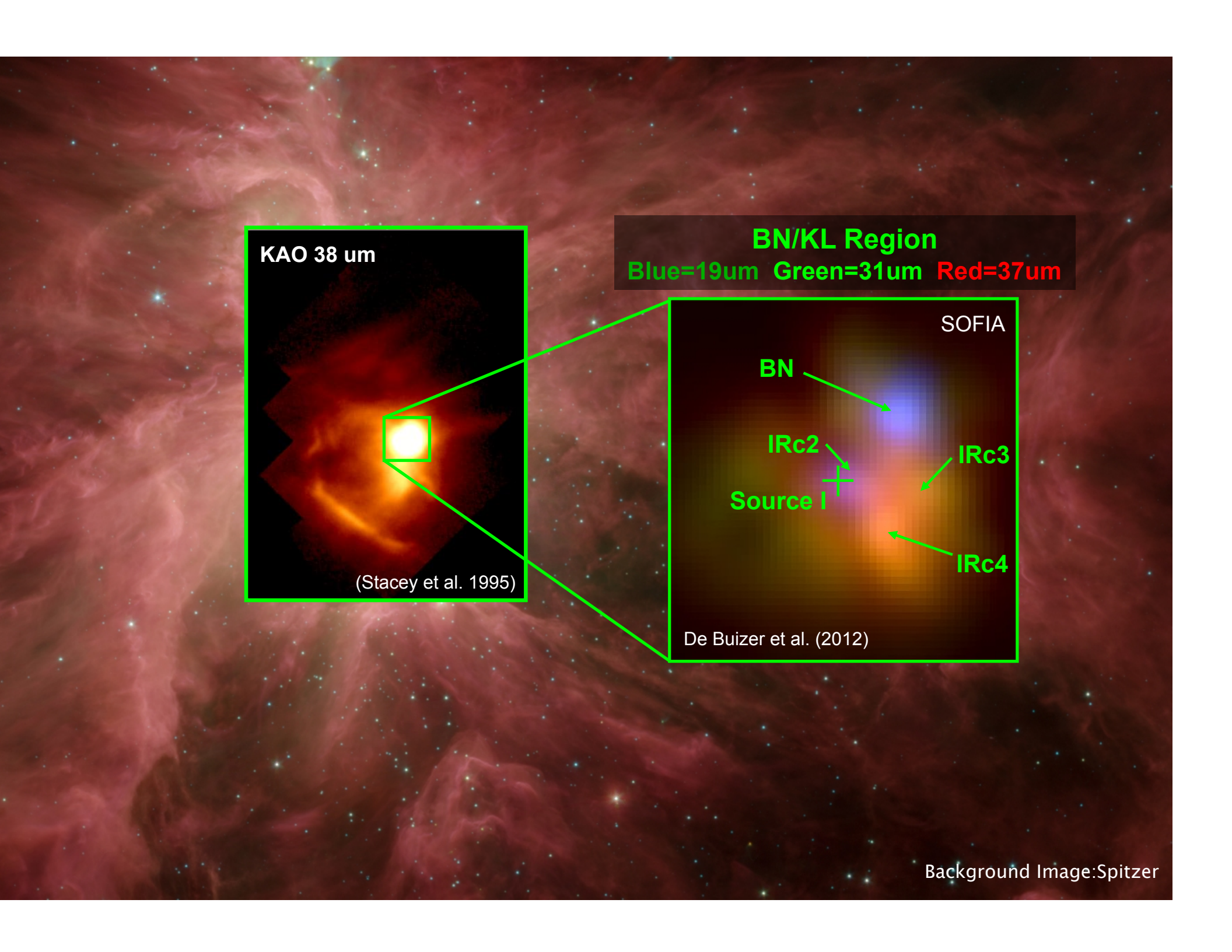


SOFIA mid infrared
(SS02)

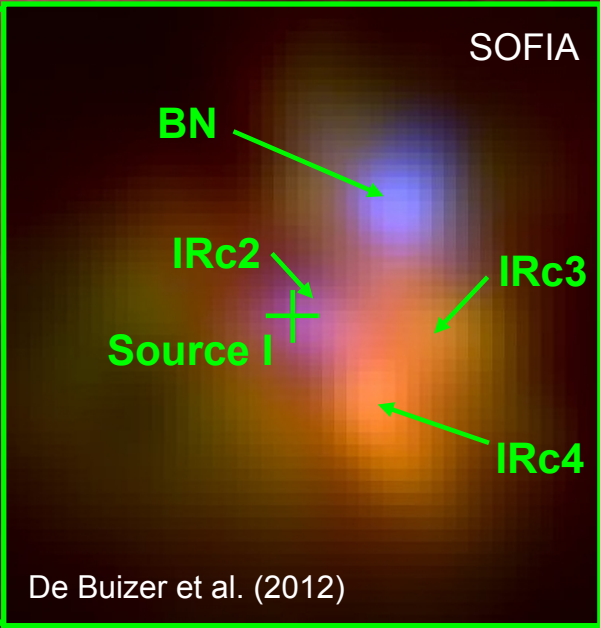


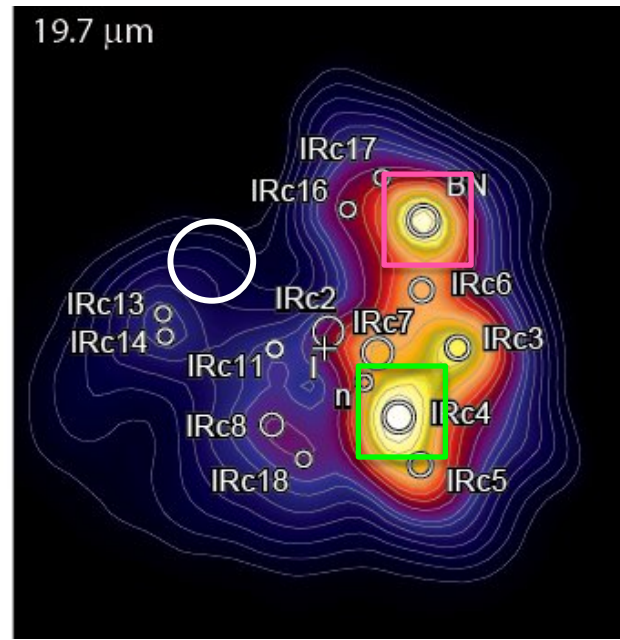
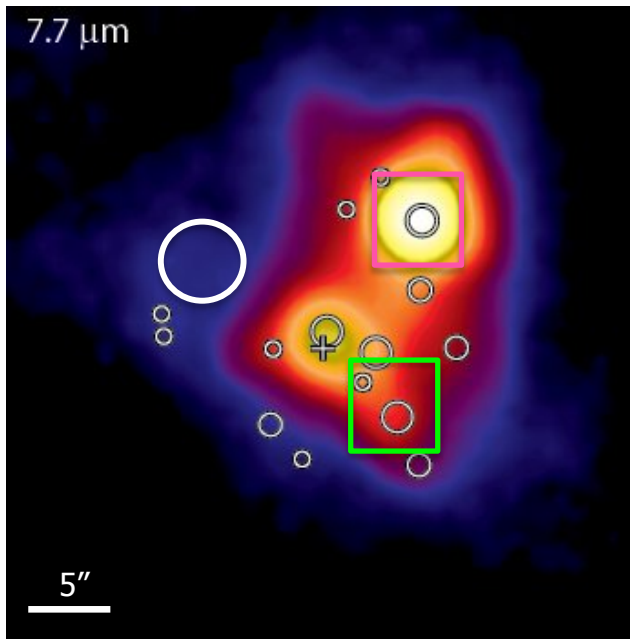
Ney-Allen Region
 Blue=7um Green=19um Red=37um





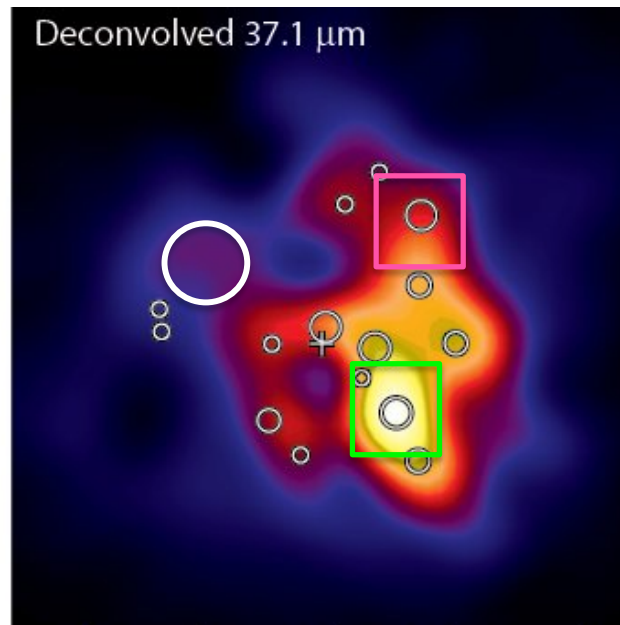
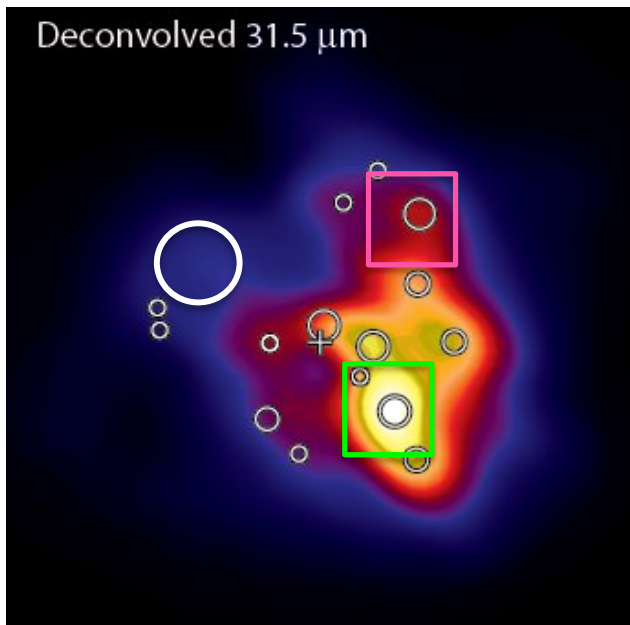
BN/KL Region
Blue=19um Green=31um Red=37um





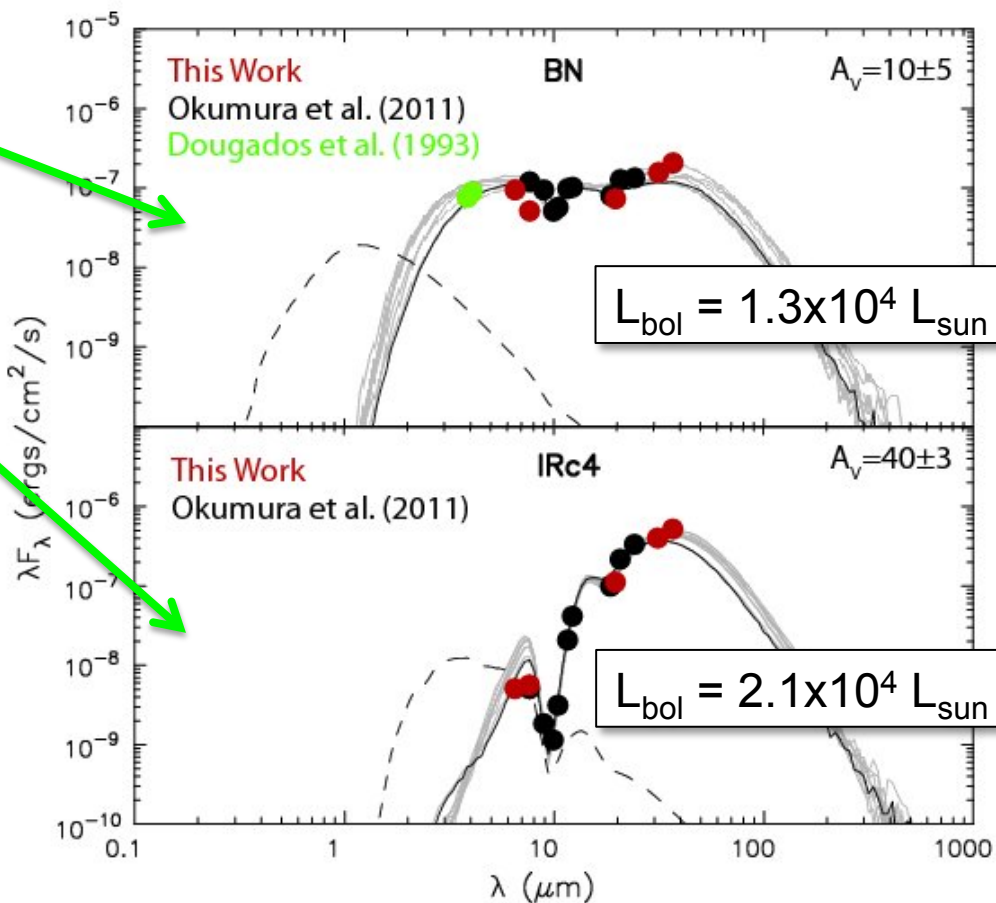
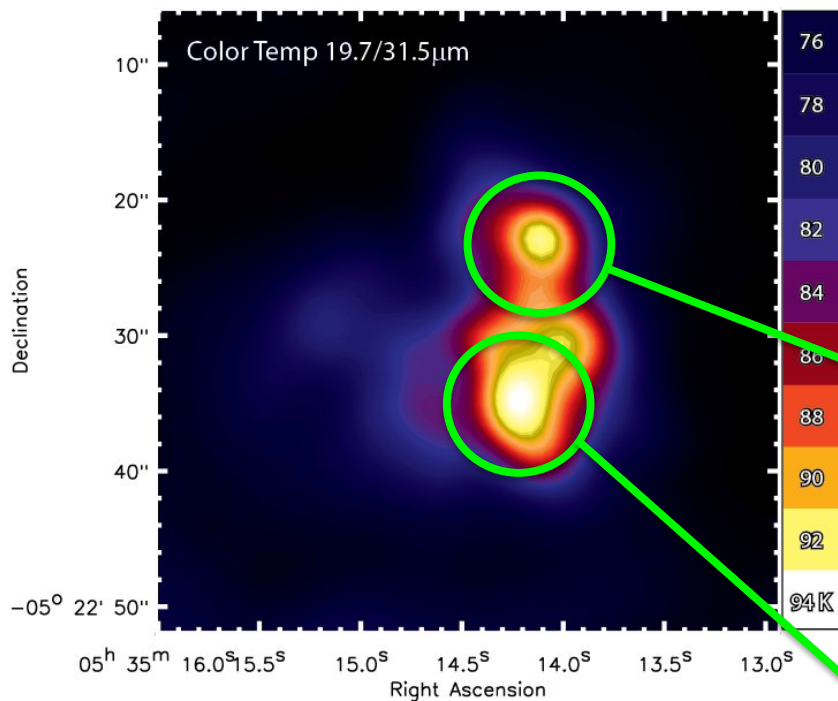
BN declines in prominence at longer λ 's

IRc4 dominates at $\lambda > 31\mu\text{m}$



A previously unidentified area of emission is apparent at $\lambda > 31\mu\text{m}$ (SOF1)

Like BN, IRc4 is a self-luminous source

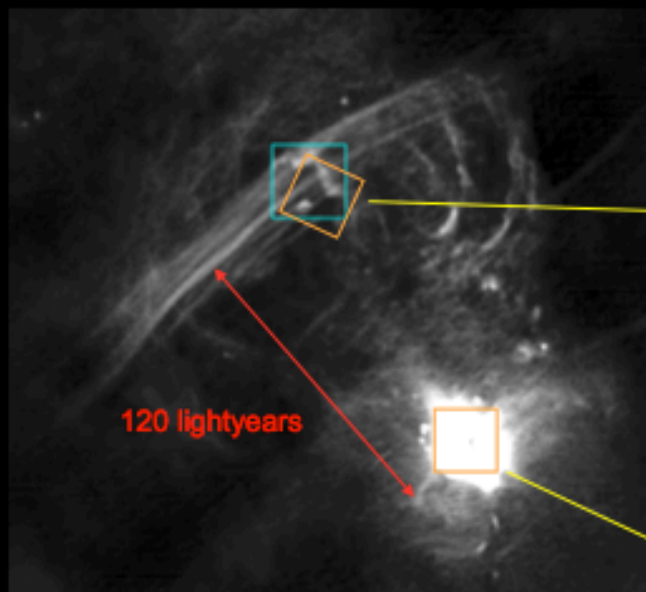


IRc4 luminosity is too high to be caused by externally heating

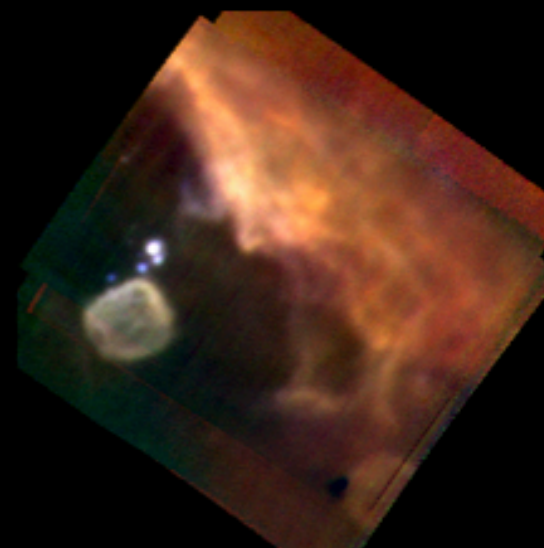
BN+IRc4 account for ~50% of the $\sim 10^5 L_{\text{sun}}$ of the BN/KL region

Galactic Center (Herter, Morris and others)

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 from SOFIA.

Sgr A - CND



- Multicolor image of circumnuclear disk (CND) in the Galactic Center.
- Scaling varies from left (scaled to central brightness) to right (scaled to emphasize ring)

CND Observations: What do they mean?

- Almost perfect $r \sim 1.5$ pc ring around the $4E6 M(\text{Sun})$ Black Hole
- Thickness/Diameter \sim only 1/10; inclination to galaxy ~ 18 deg
- Clear color gradient seen across the ring: internally heated.
- Probably by young stars interior to the ring.
- Where did they come from?
- Interesting structures seen on small scales.

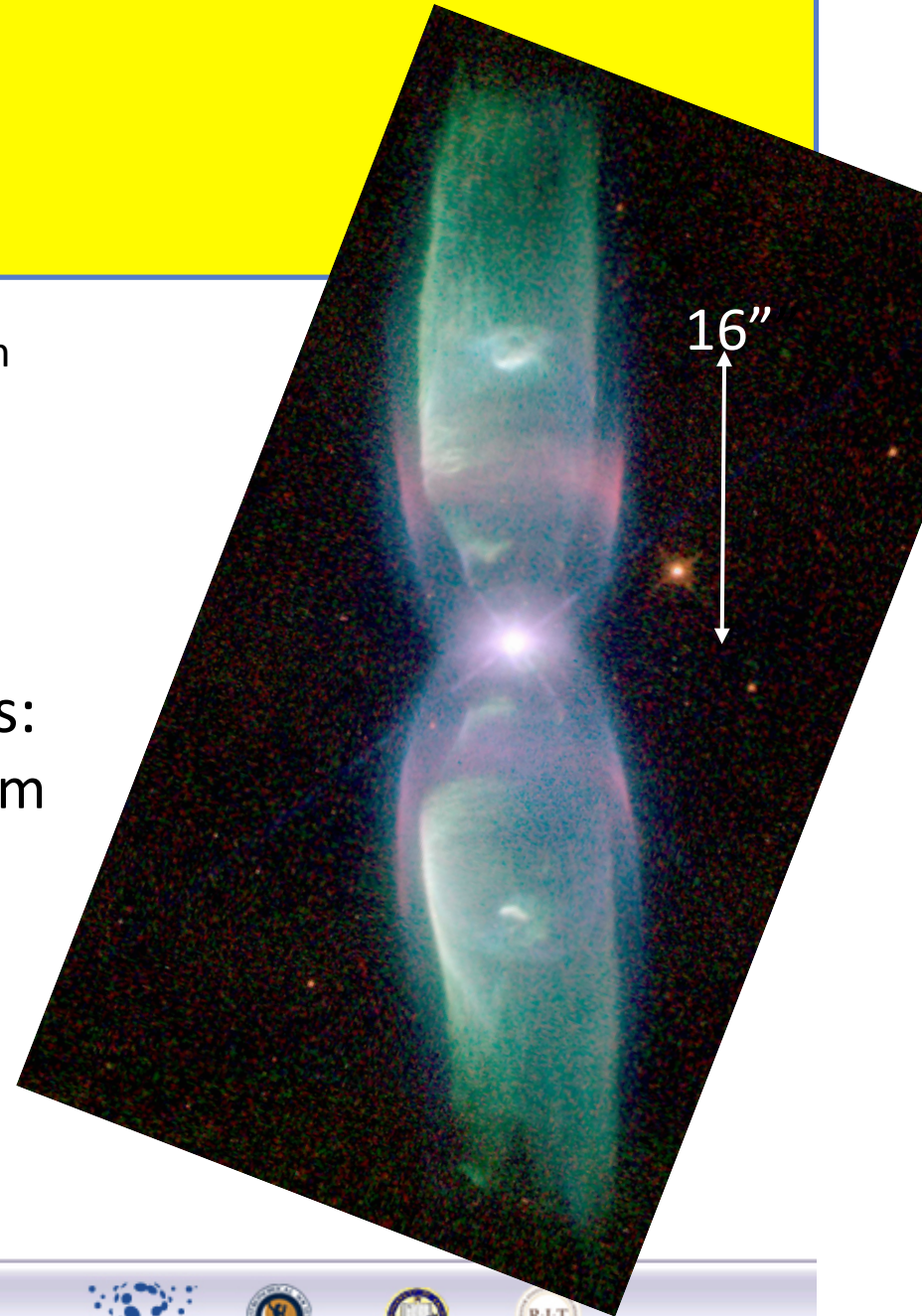
M2-9 (Pre-Planetary Nebula/Outflow)

Werner, Morris, Sahai

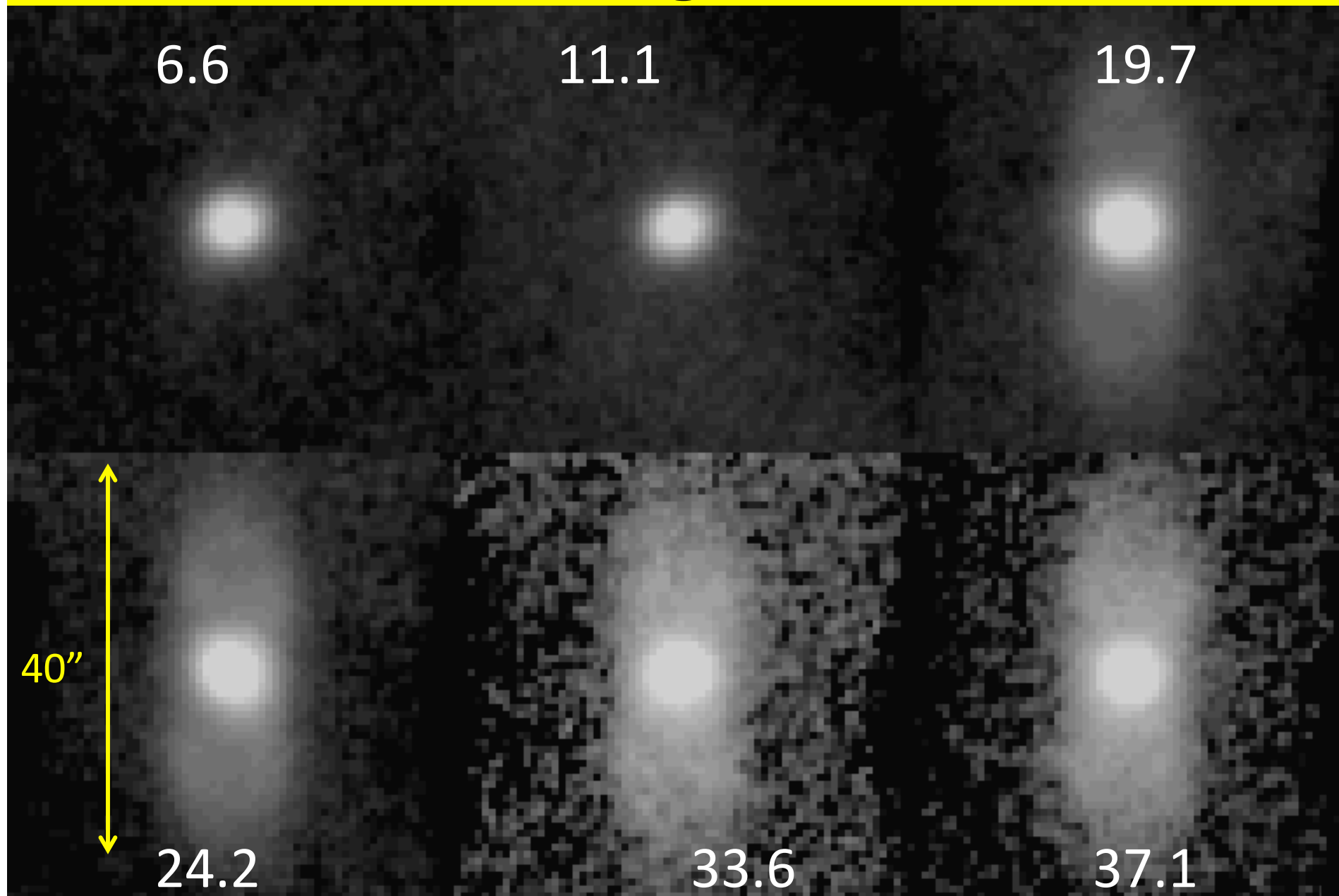
Minkowski 2-9

Classic bipolar nebula

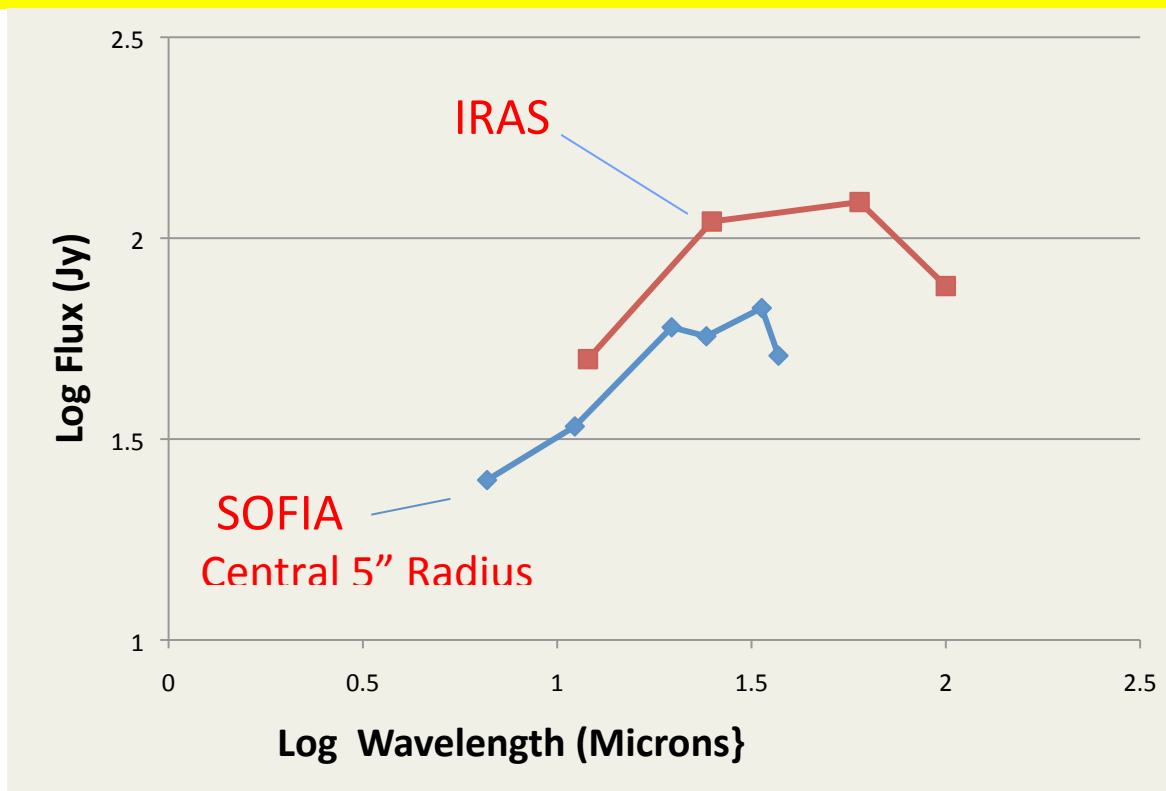
- Previous work estimates $L=2500 L_{\text{sun}}$
 - ❖ Stellar temperature 15000K
- Distance = 1.2 Kpc
- Observed with FORCAST in six bands:
6.6, 11.1, 19.7, 24.2, 33.6, 37.1 μm
6-to-10 min per filter



SOFIA Images of M2-9



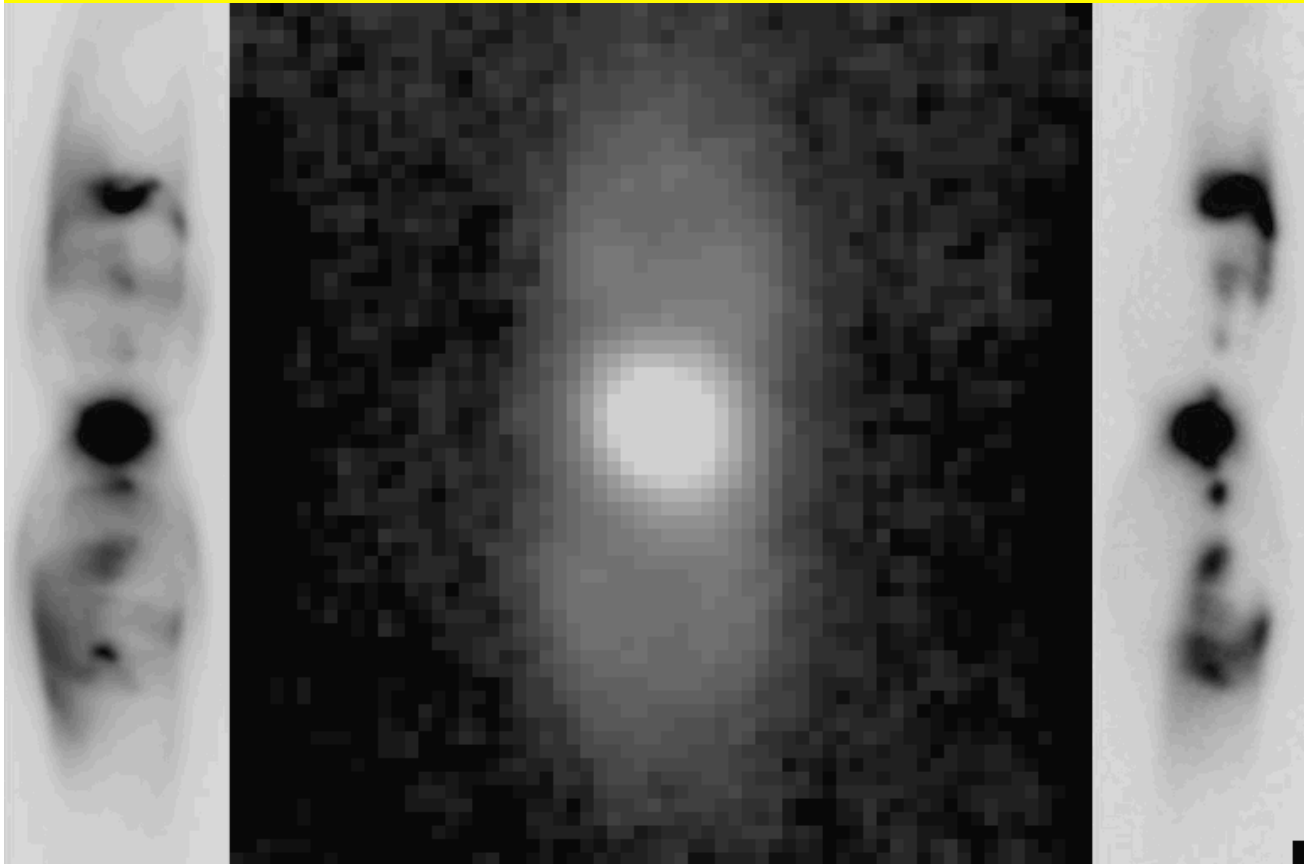
Properties of Central Point Source



- FWHM = 3.5 to 4.7 arcsec, increasing with wavelength – not resolved
- Luminosity = $760 L_{\text{solar}}$. IRAS measured $1100L_{\text{solar}}$

•Breadth of Spectral Energy Distribution indicates that we are seeing a disk rather than a thick spherical dust shell (Lykou et al, A+A , 2011)

Turning to the Lobes



- Infrared emission comes from region comparable in size to that seen in the optical
- Lobes show structure and limb brightening in visible
- Distribution smoother in the infrared, although some structure is seen
- Difference in spatial resolution partly, not totally responsible for this
- Temp ~100K

Halpha+[NII]
(2010)

24.2um

[OIII]
(2010)

Conclusions

- SOFIA images of M2-9 show not only a bright, compact central source but also emission from the lobes at 19.7 μ m and beyond.
- *The central source is not resolved by SOFIA at any wavelength, with angular size less than about 5 arcsec*
- The central source has a 5-40 μ m luminosity of 760 solar luminosities, more than half the luminosity measured by IRAS
- *The broad infrared SED of this source is more suggestive of emission from a disk than of emission from a spherical shell*
- **The emission from the lobes** extends +/- 20 arcsec from the center
- *The infrared emission is confined EW to a region comparable in width to the optical lobes*
- The emission can be attributed to a cylindrical distribution of dust within the lobes with a small central empty region but without extreme limb brightening as suggested by the optical images

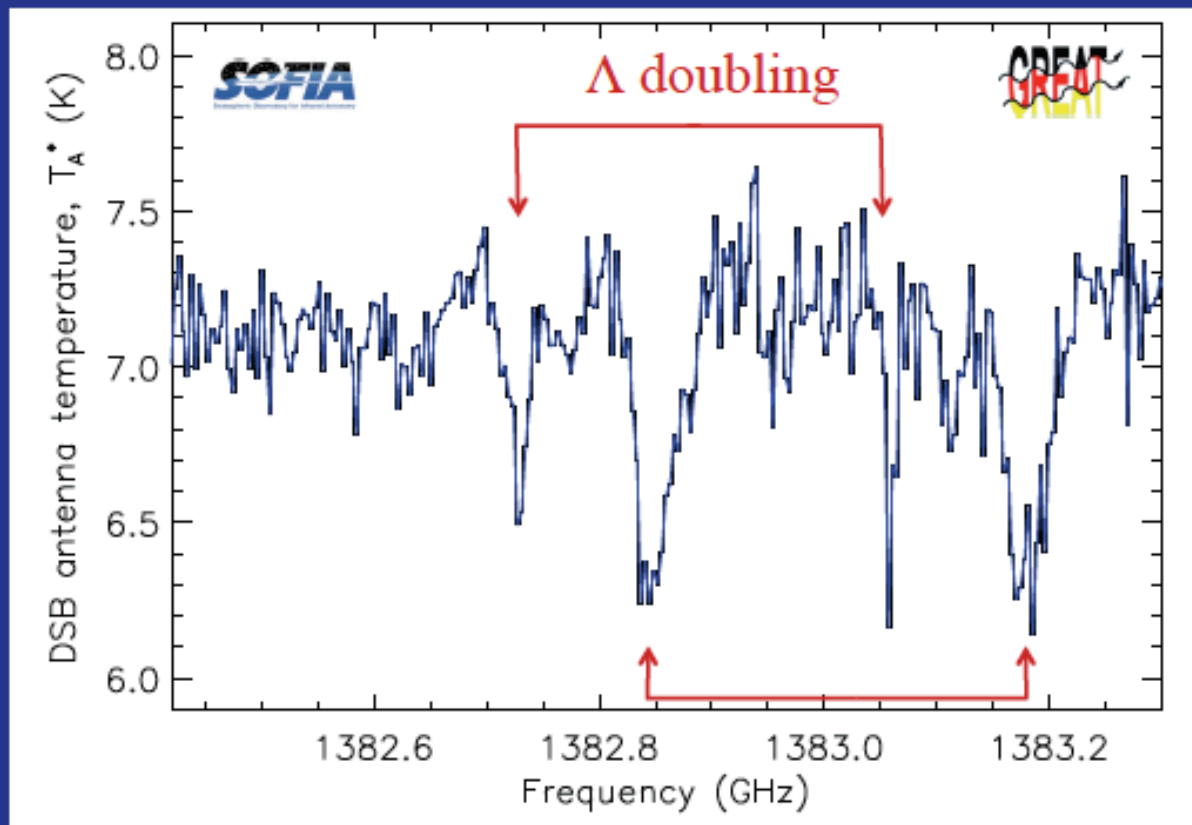
GREAT Observations

Discover of SH (Mercapto radicals) in Interstellar Space.

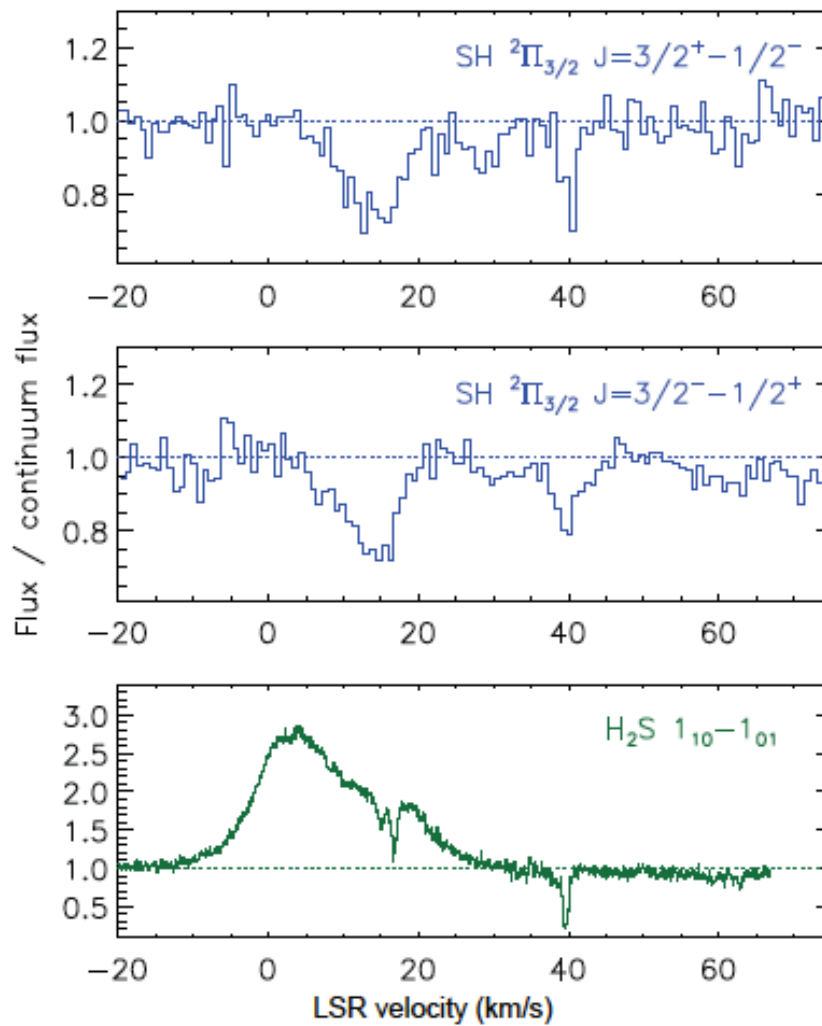
David Neufeld et al

- SH is one of the simplest Hydrides not detected in the ISM
- Its ground state rotation line is at 1.383 THz (217 microns)
- It lies between HIFI bands 5 and 6 and in GREAT band L1
- SH has lambda doubling which makes it easy to ID
- Observations were obtained last fall in a few min integration on the HII region W49N.
- W49N intersects several molecular clouds in it own and another spiral arm that cause absorption of the continuum.

Mercapto radicals were clearly detected in absorption toward W49N



SH

with H₂S from
the IRAM 30m

Summary

- We have obtained the first detection of interstellar mercapto radicals, using GREAT instrument on SOFIA
- The ground state ${}^2\Pi_{3/2} J= 5/2 \rightarrow 3/2$ transition at 1.383 THz was detected in absorption toward W49N
- Both components of this lambda doublet were unequivocally detected in material associated with W49N and in a foreground diffuse cloud
- The implied diffuse clouds abundance, $\text{SH}/\text{H}_2 \sim 10^{-8}$ suggests the presence of elevated gas temperatures ($\sim 1000 \text{ K}$)

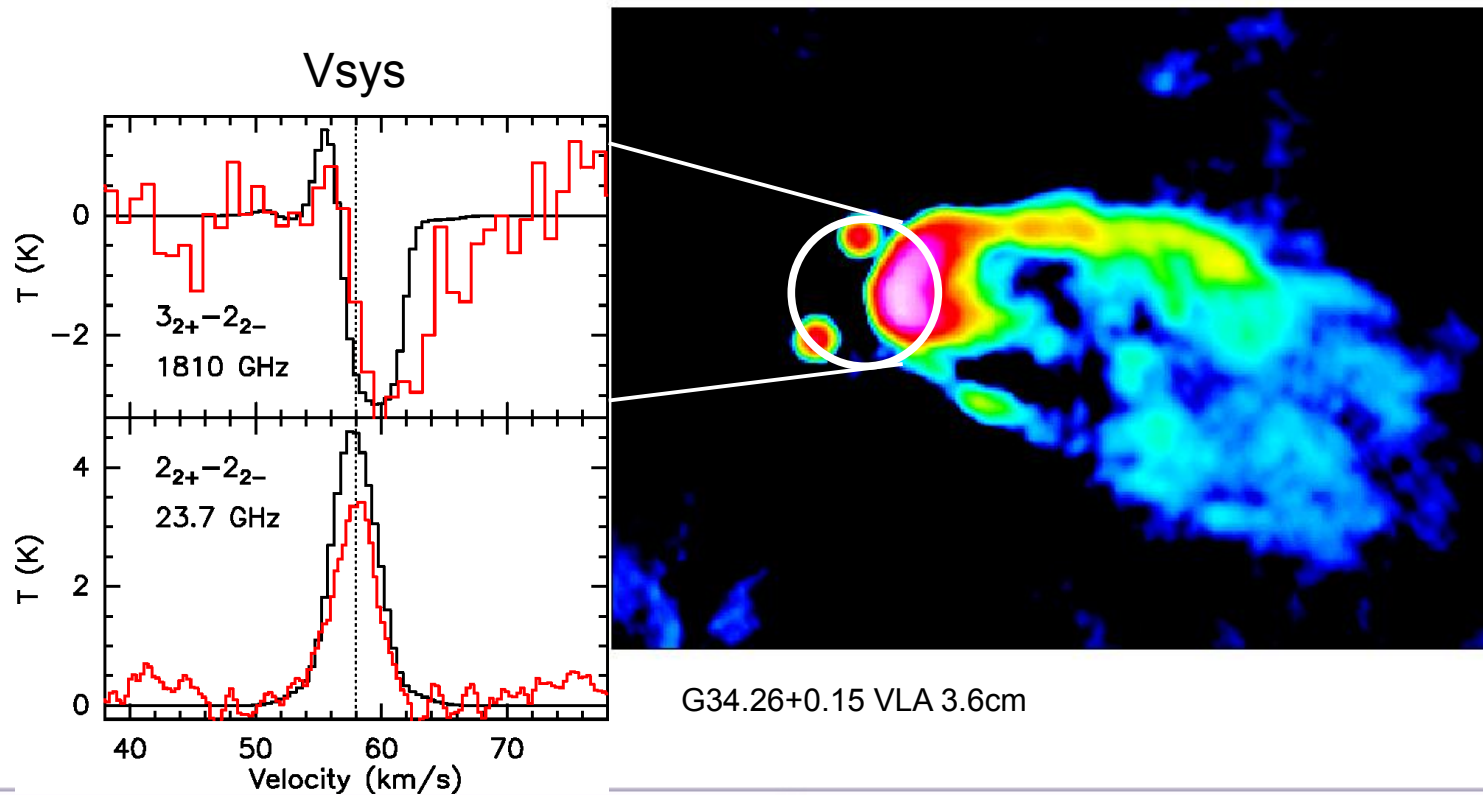
Other GREAT Results

- In Fall of Material in Star Formation (Wyrowski et al)
- First Detection of OD in the ISM (Parise et al)

Science Results: **probing infall**

λ Probing infall with ammonia absorption against dust continuum

- λ -- case study: UCHIIR G34.3 → red-shifted absorption detected
- modeled with infalling envelope



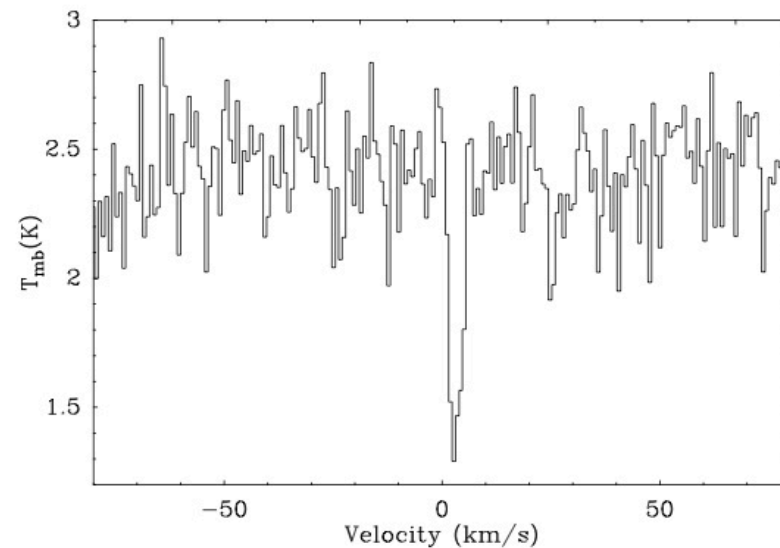
Detection of OD towards the low-mass protostar IRAS16293



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

First detection of OD outside of the solar system.

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



Pluto Occultation with HIPO/FDC

HIPO and FDC (Fast Diagnostic Camera) First scientific mission on SOFIA: Stellar occultation by Pluto June 23, 2011

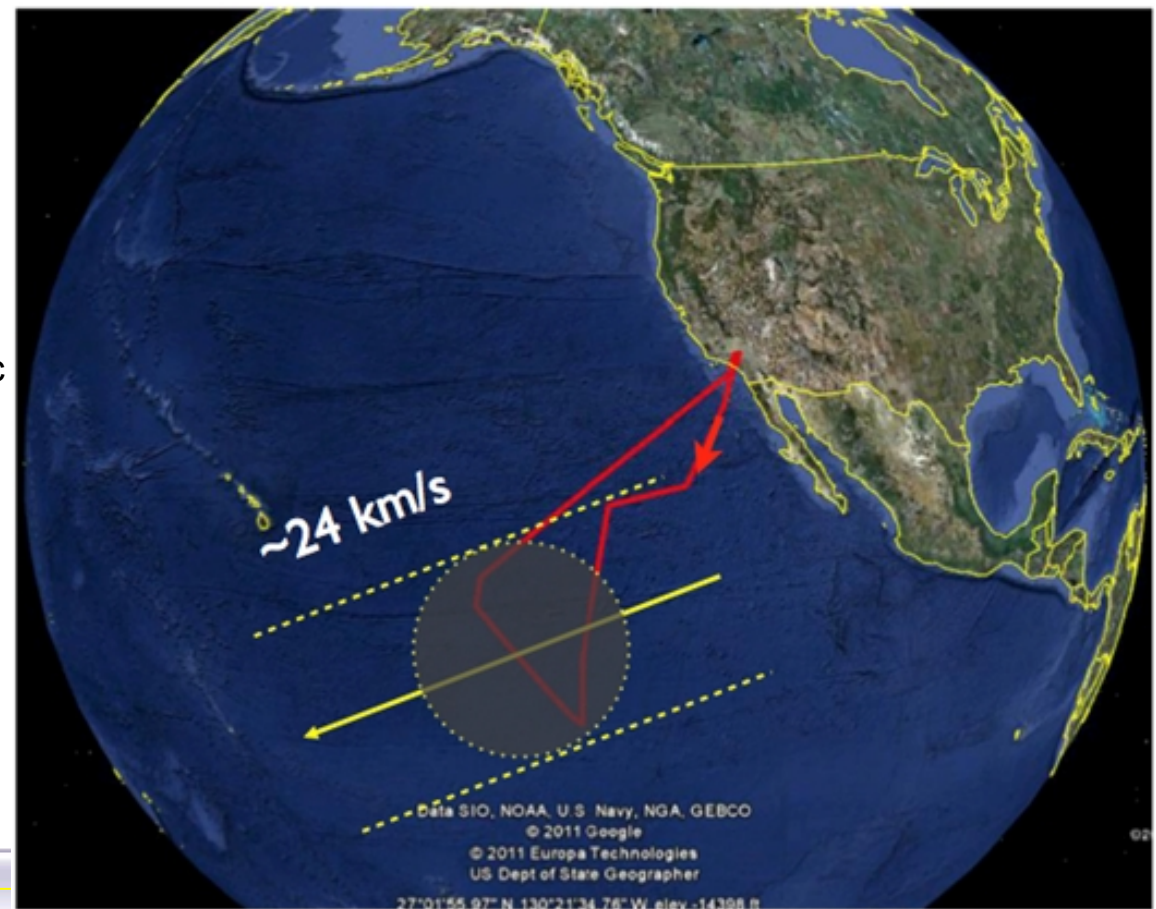
Ted Dunham et.al. (HIPO), Lowell Observatory, Jürgen Wolf (SOFIA DSI) & Mike Person et al., MIT

Scientific goals

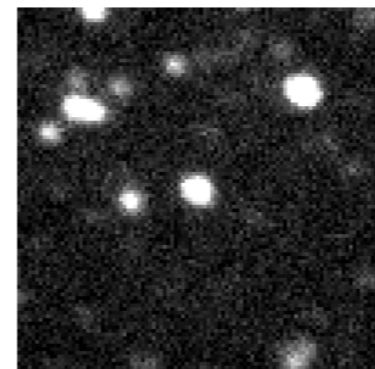
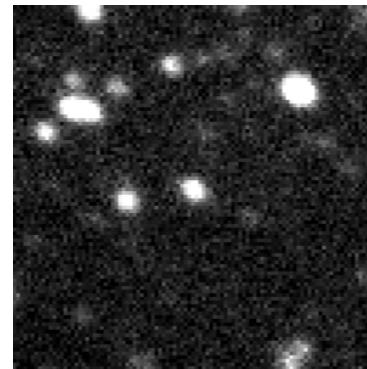
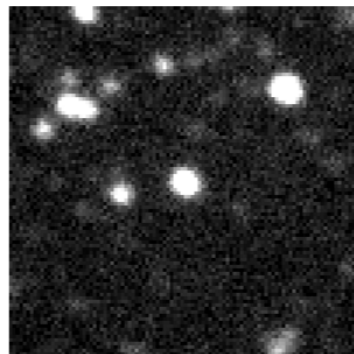
- ★ Measure temperature profile of Pluto's atmosphere
- ★ Test atmospheric freeze-out models
- ★ Target central flash – global atmospheric shape, possible extinction

Observational Details

- ★ Occultation observed with SOFIA at 11:20 UT on June 23, 2011
- ★ Successful in-flight prediction update and flight plan change



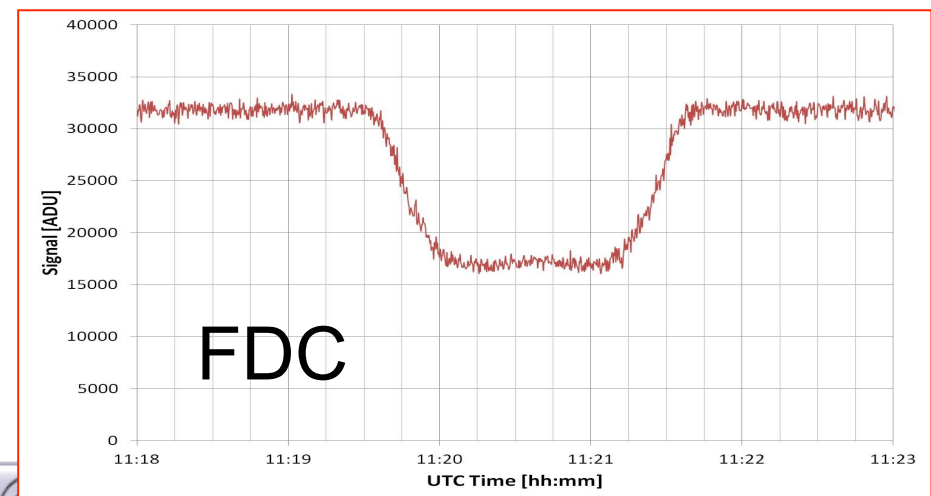
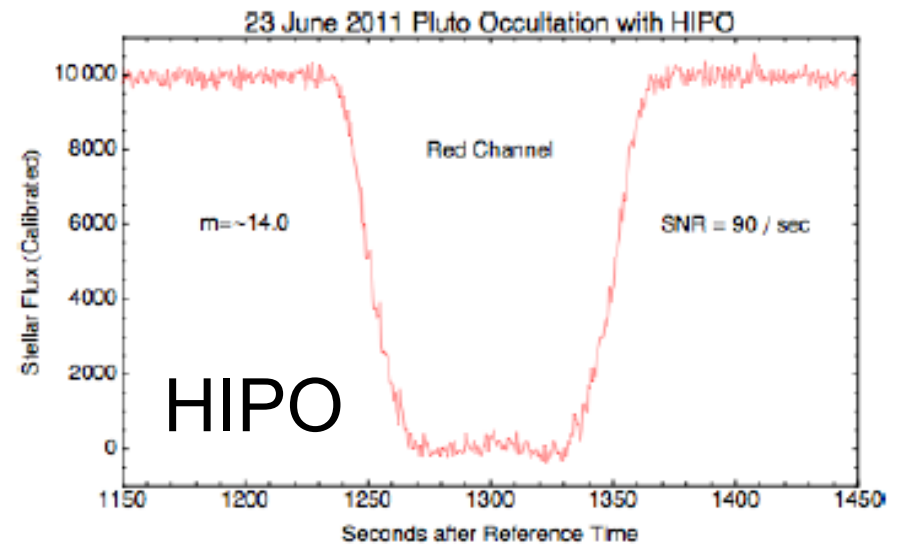
Pluto Occultation: 3 hours before, just before, during and just after.



Pluto Occultation

Central brightening seen in all lightcurves

- Post-event fit to three chords indicates impact parameter < 25 km!
- Should have seen much brighter and sharper central flash than this
 - Extinction?
 - Atmospheric asymmetry?
- Paper in development
- In-air prediction data obtained; need to evaluate for possible future use.
- Precisely targeted predictions a new capability



Summary

- Early Science with FORCAST
GREAT and HIPO/FDC on SOFIA
is producing Interesting results.
 - 8 Letters in a special edition of ApJ
Letters.
 - 22 Letters in the special edition of
A&A Letters
 - The Galactic Center results are
spectacular
 - Occultation of Pluto shows SOFIA
potential
- SOFIA will be one of the primary
facilities for far-IR and sub-
millimeter astronomy for many
years

