Imaging with FORCAST, FLITECAM, and HAWC+

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USRA

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Quintuplet Cluster, Hankins et al. 2013, Imaged with FORCAST
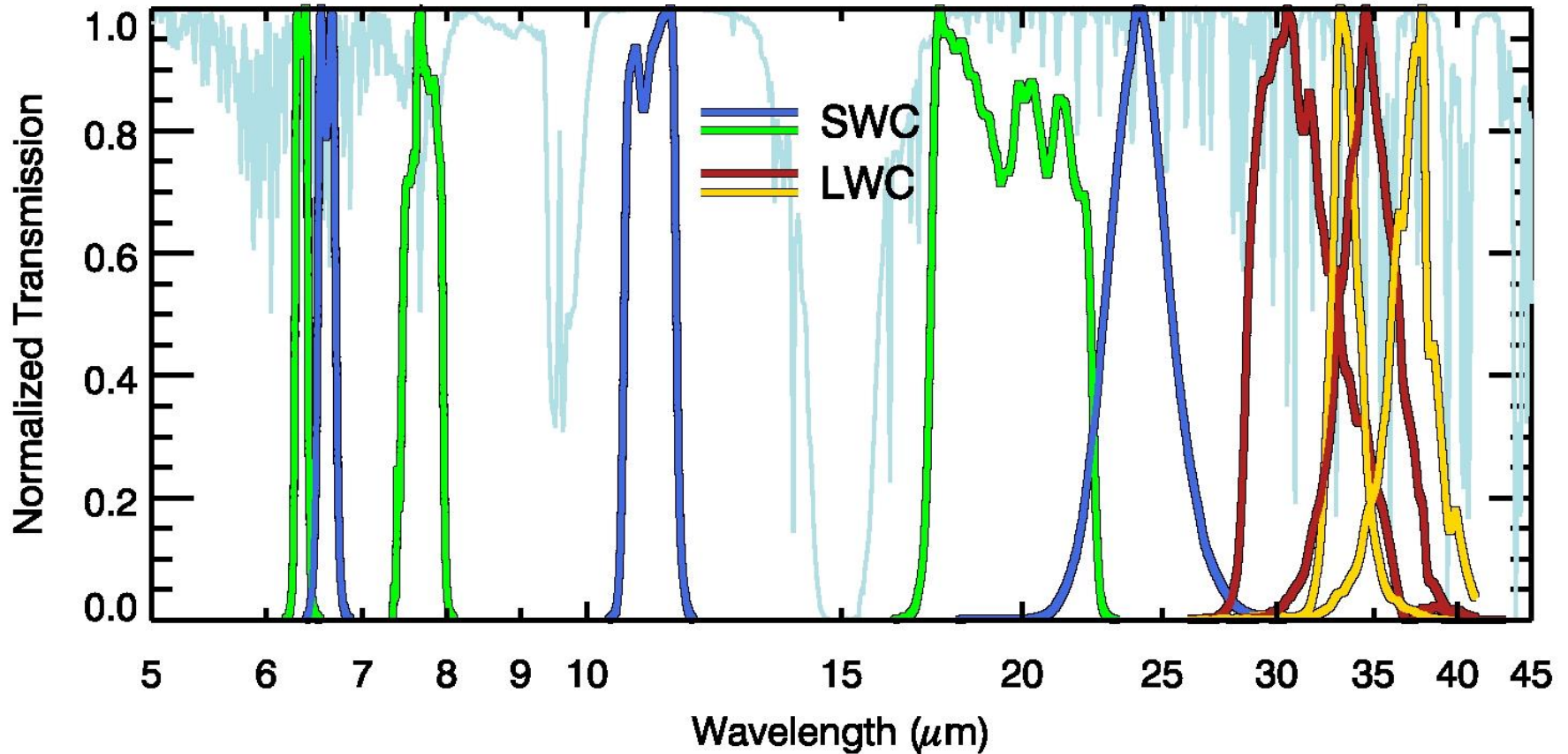
SOFIA's imaging suite covers 1 to 250um

FLIGHTCAM Imaging Filter Profiles
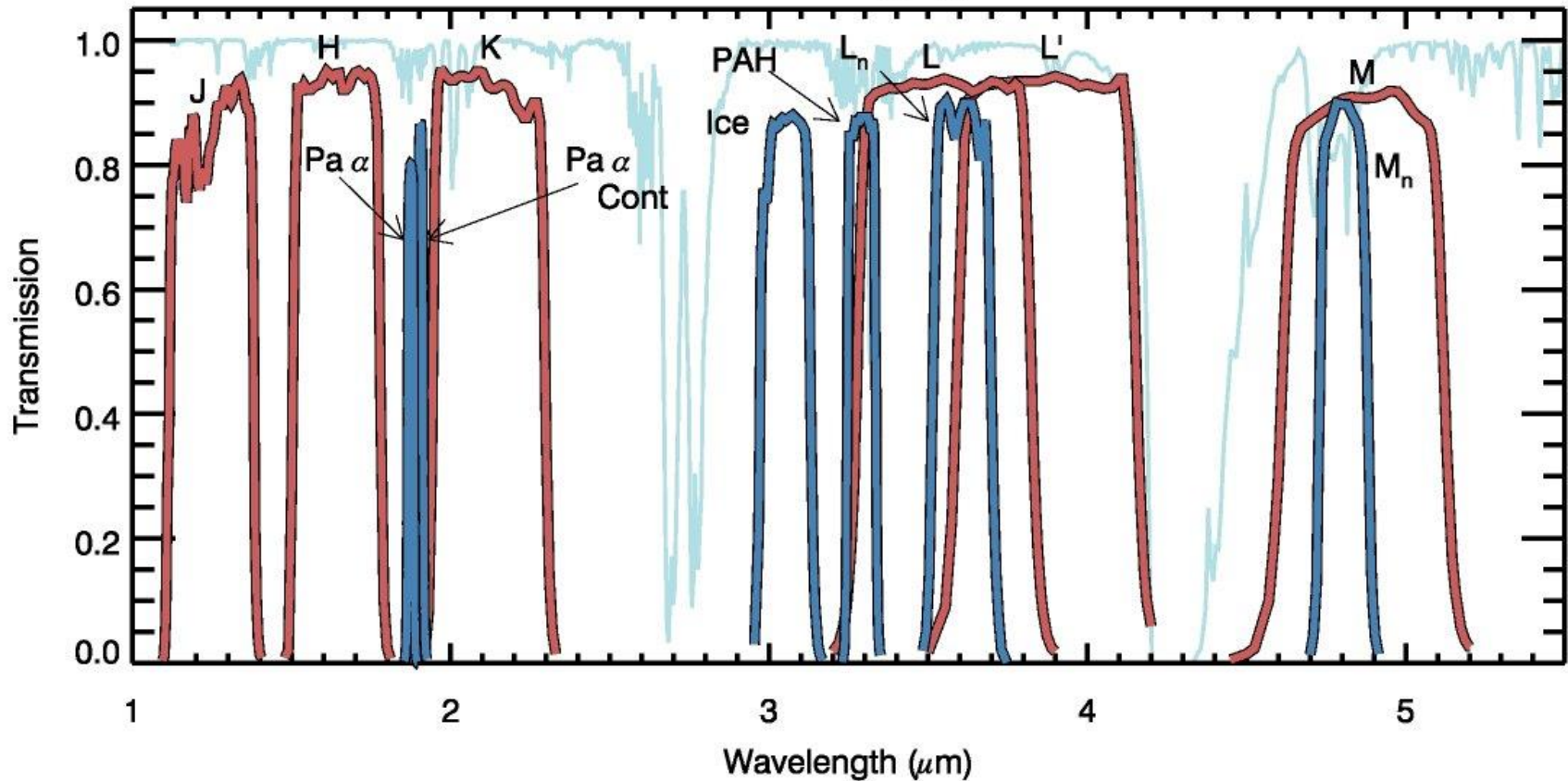
J (1.24um), H (1.63um), Pa Alpha (1.87um), Pa Alpha Cont (1.9um), K (2.10um),
Ice (3.05um), 3.3um PAH, L (3.53um), L' (3.85um), M (4.84um)

SOFIA's imaging suite covers 1 to 250um
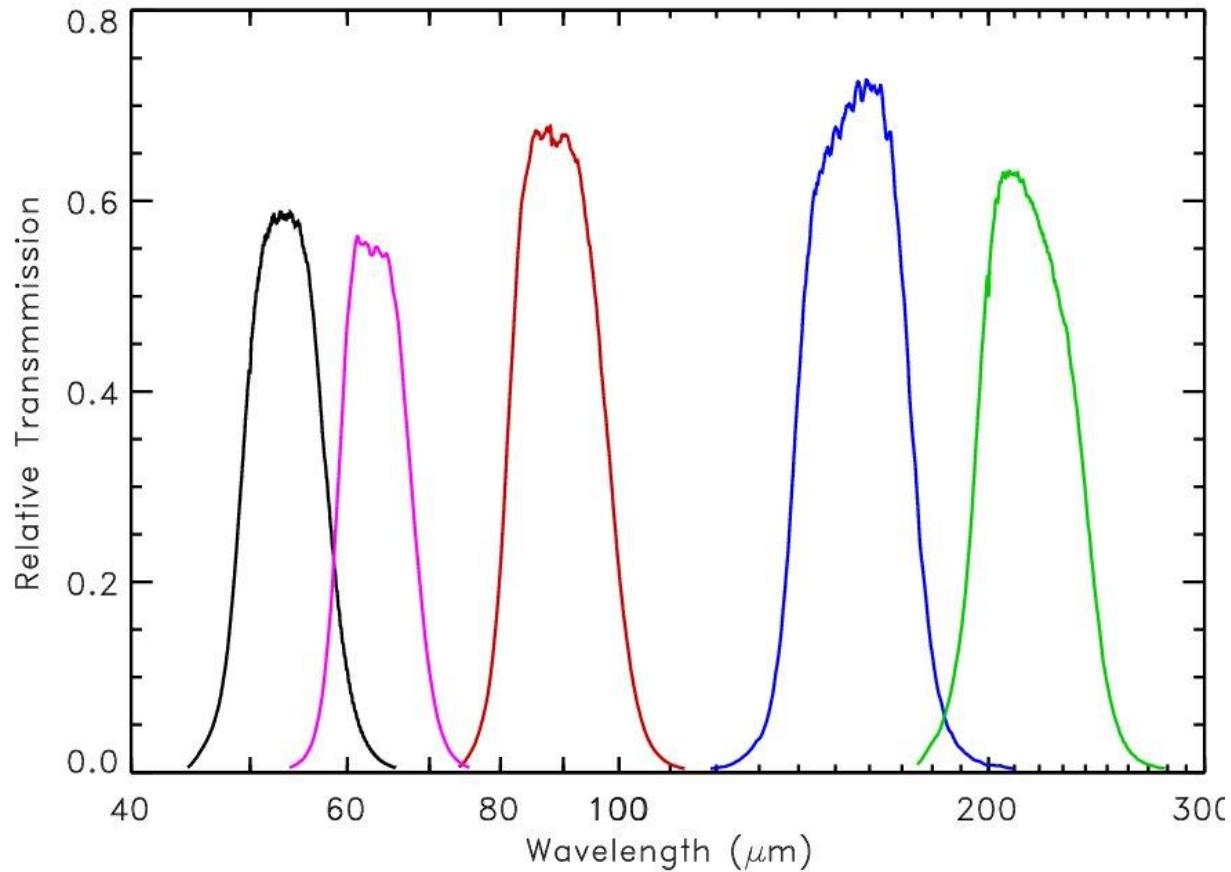
FORCAST Imaging Filter Profiles

5.4um PAH (ns), 5.6um (ns), 6.4um PAH, 6.6um, 7.7um, 8.6um PAH (ns), 11.1um, 11.3um PAH, 11.8um, 19.7um, 24.2um, 25.3um (ns), 31.5um, 33.6um, 34.8um, 37.1um

"ns" means not shown in plot above

# SOFIA's imaging suite covers 1 to 250um

HAWC+ Imaging Band Profiles

Band A (53um), Band B (63um), Band C (89um), Band D (154um), Band E (214um)

Concepts covered in this talk

- SOFIA can image regions too bright for space telescopes
- SOFIA can chop and nod with very large throws
- SOFIA offers unparalleled spatial resolution at 28-65um
- SOFIA's diffraction-limited images can be deconvolved
- SOFIA imaging data are well-suited for obtaining accurate color temperatures
- SOFIA imaging data covers wavelengths most critical for SED modeling
- SOFIA is well-suited for mapping PAH chemistry

SOFIA can image regions too bright for space telescopes
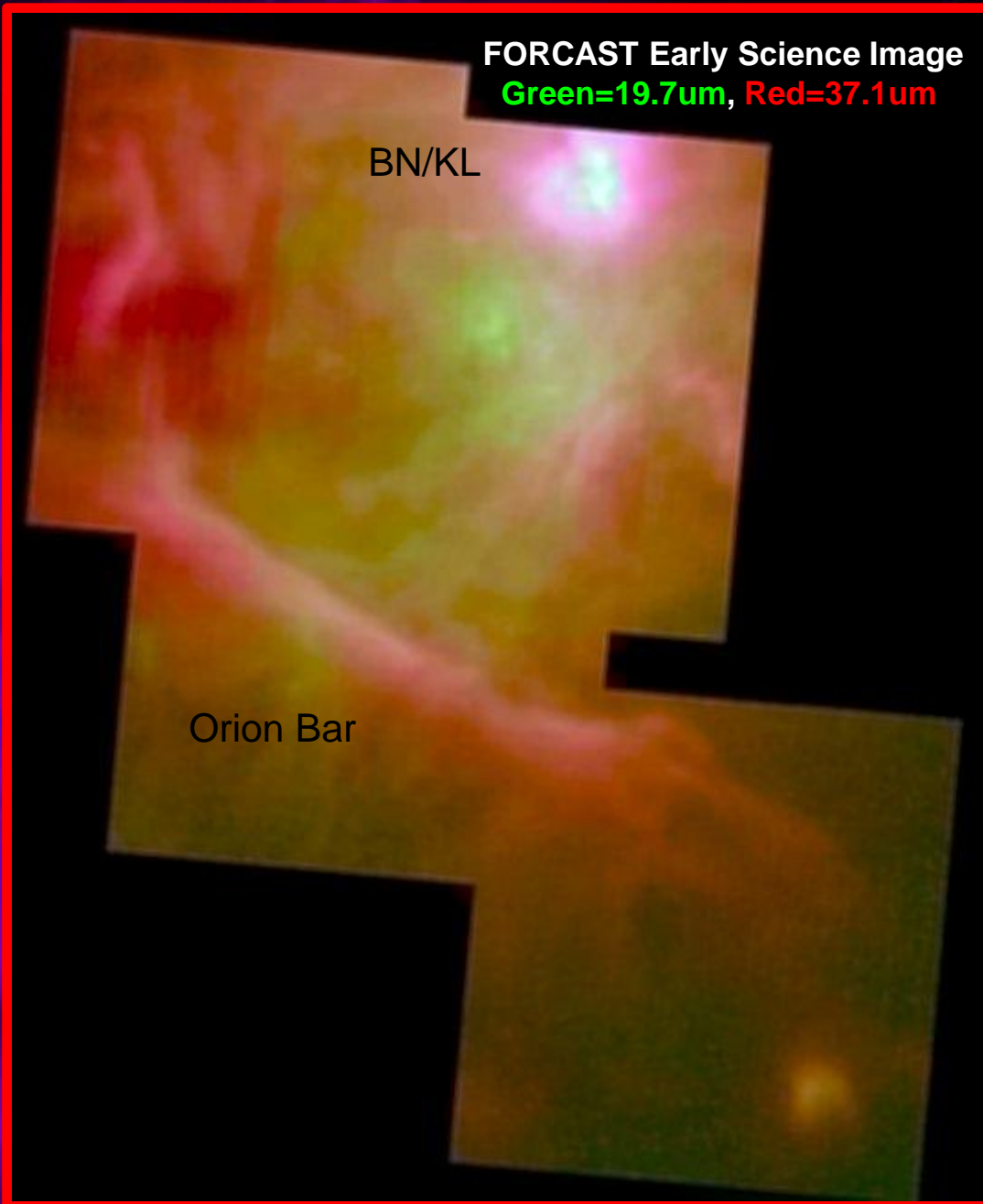

Region observed by FORCAST
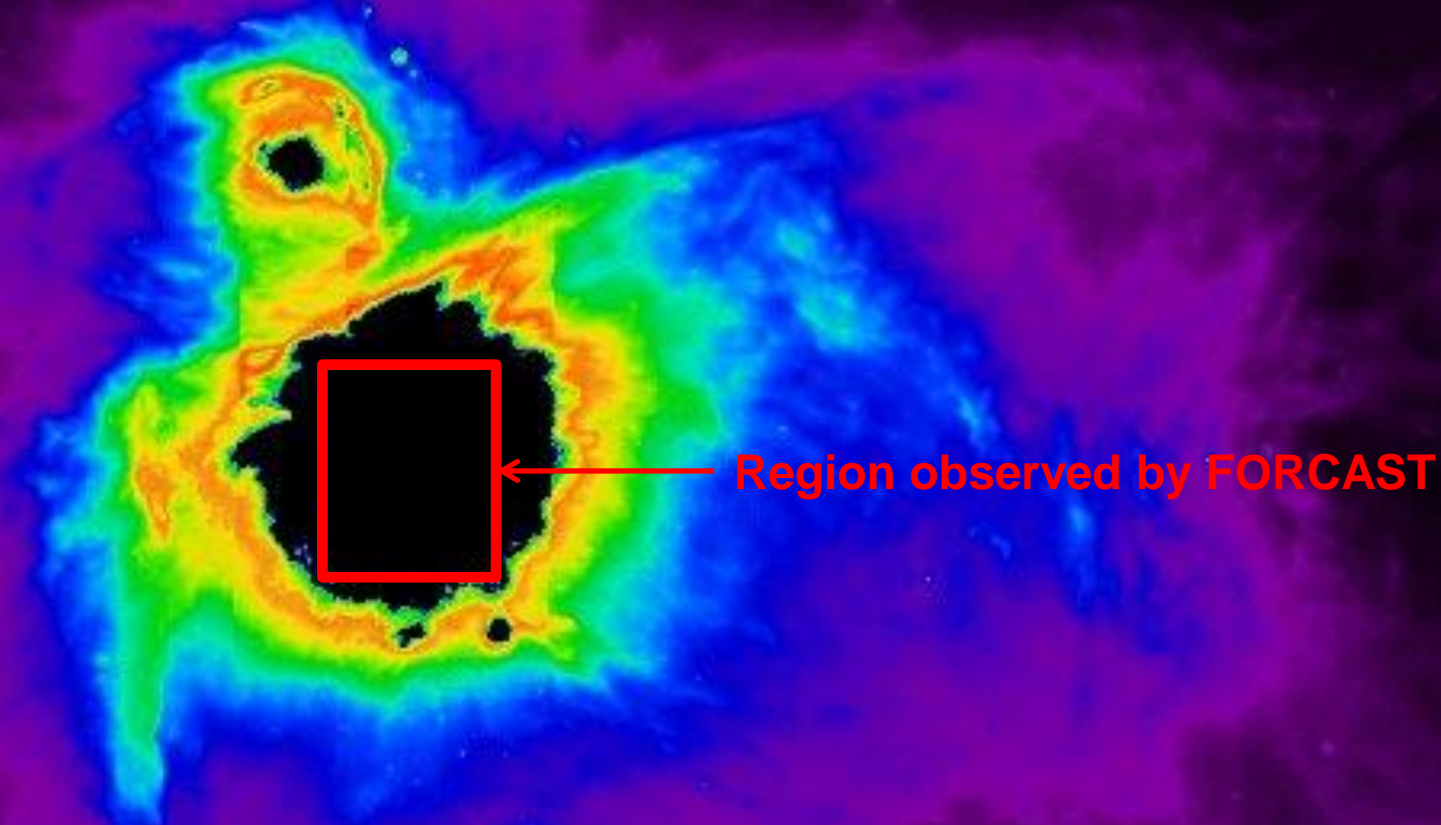
Spitzer 24um MIPS image of Orion Nebula. All areas that are black are saturated.

JWST will only cover out to 28um and will saturate on most Galactic star-forming regions

FORCAST Early Science Image
Green=19.7um, Red=37.1um

BN/KL

Orion Bar

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SOFIA can chop and nod with very large throws

SOFIA can chop asymmetrically up to 7'
and can nod up to 0.5 degrees, allowing
imaging in very large/crowded regions

Nod throws can be up to 0.5 degrees!
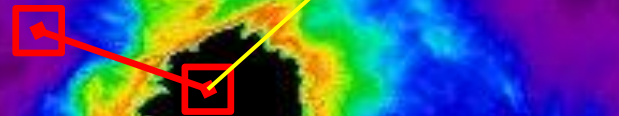
Nod B

Nod A

Ground-based O/IR telescopes
only chop-nod with throws <30"

This form of chop-nod (C2NC2)
is highly inefficient

However, this form of chop-nod
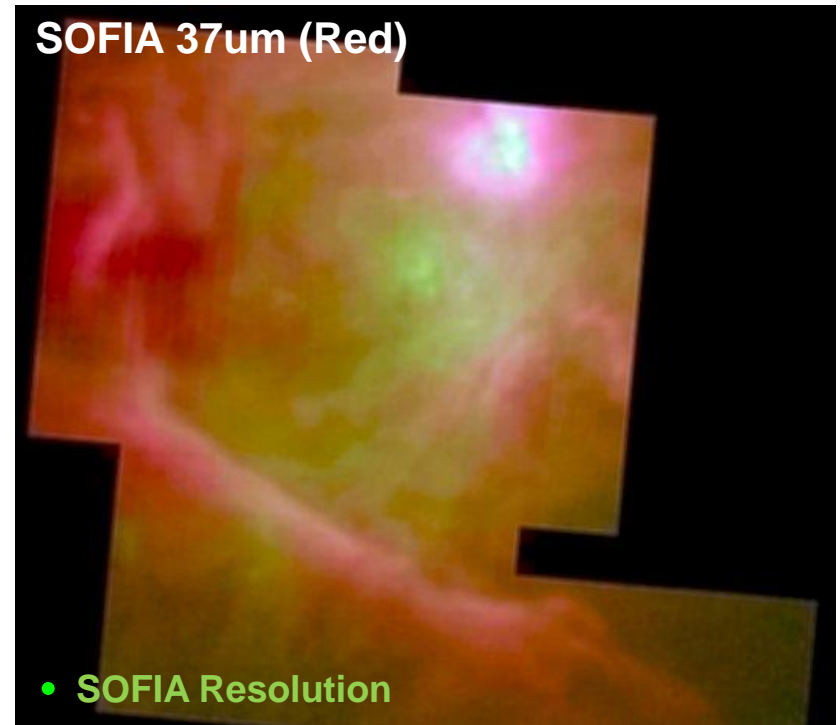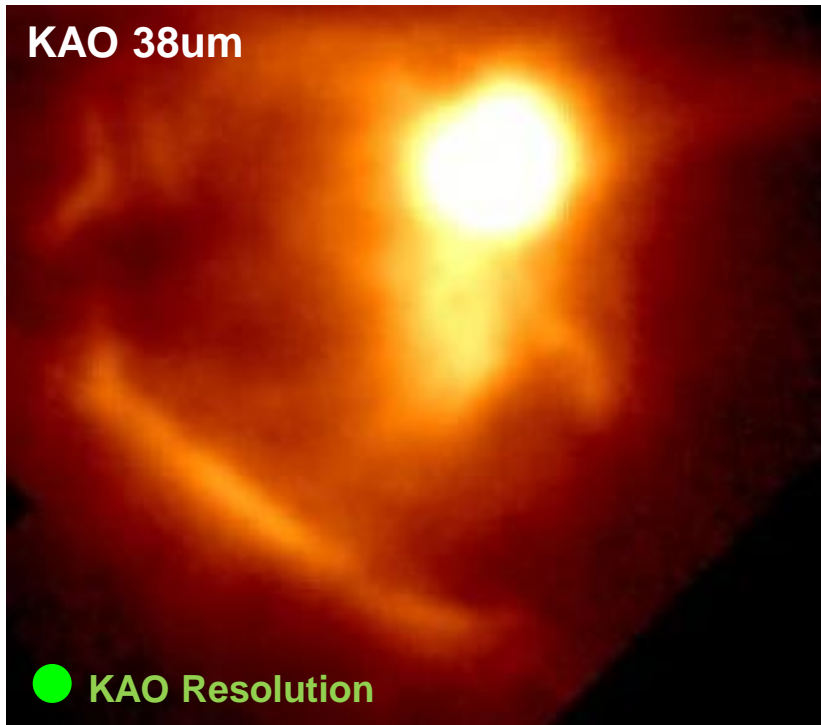delivers the best image quality

General lesson when preparing observations: Check Spitzer, WISE, MSX,
IRAS, or Herschel images to make sure your chop-nod scheme will work!

SOFIA offers unparalleled resolution from 28-65um

KAO 38um

SOFIA 37um (Red)

● KAO Resolution

• SOFIA Resolution

SOFIA has >5x better resolution than IRAS or ISO

SOFIA has >3x better resolution than KAO or Spitzer

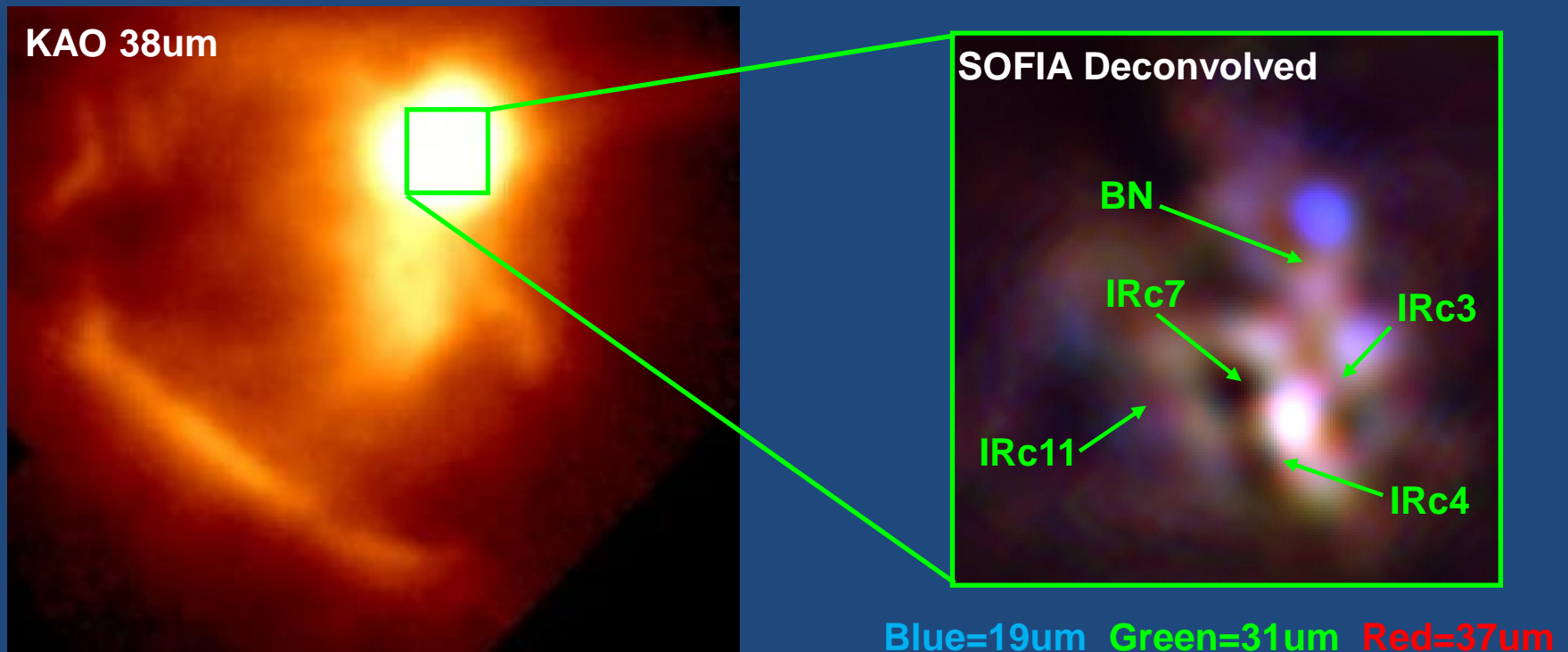SOFIA comparable resolution to Herschel (from 65-250um)

SOFIA's diffraction limited images can be deconvolved

This allows one to further enhance resolution
- SOFIA is diffraction limited beyond ~20um
- can reliably achieve 2-3x better resolution over the diffraction limit
Deconvolution programs are available in the standard NASA IDL library
- e.g. Frank Varosi's "Max_likelihood.pro"

KAO 38um

SOFIA Deconvolved

BN

IRc7

IRc3

IRc11

IRc4

Blue=19um   Green=31um   Red=37um

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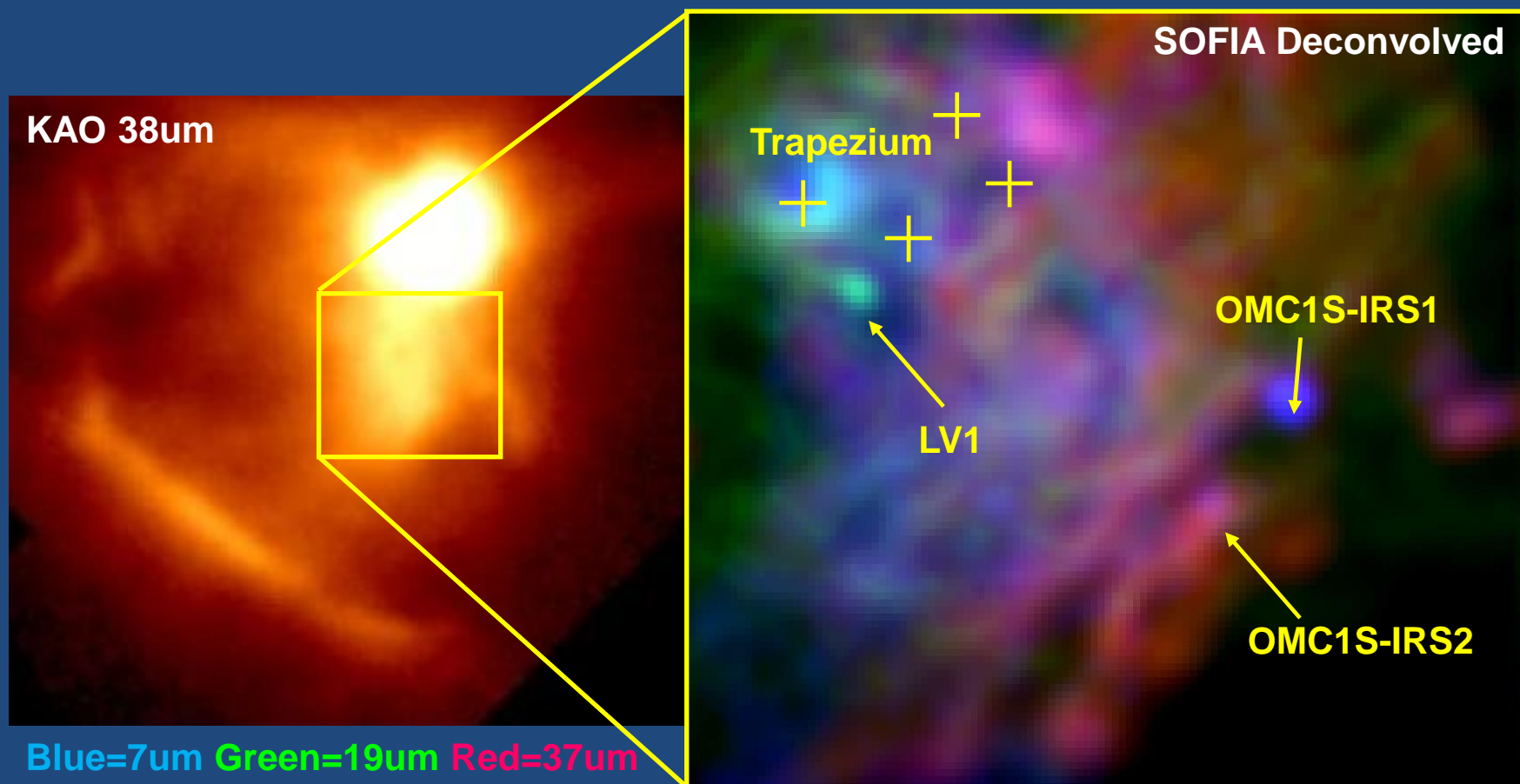- e.g. Frank Varosi's "Max_likelihood.pro"

KAO 38um

SOFIA Deconvolved

Trapezium

OMC1S-IRS1

LV1

OMC1S-IRS2

Blue=7um Green=19um Red=37um

SOFIA's diffraction limited images can be deconvolved
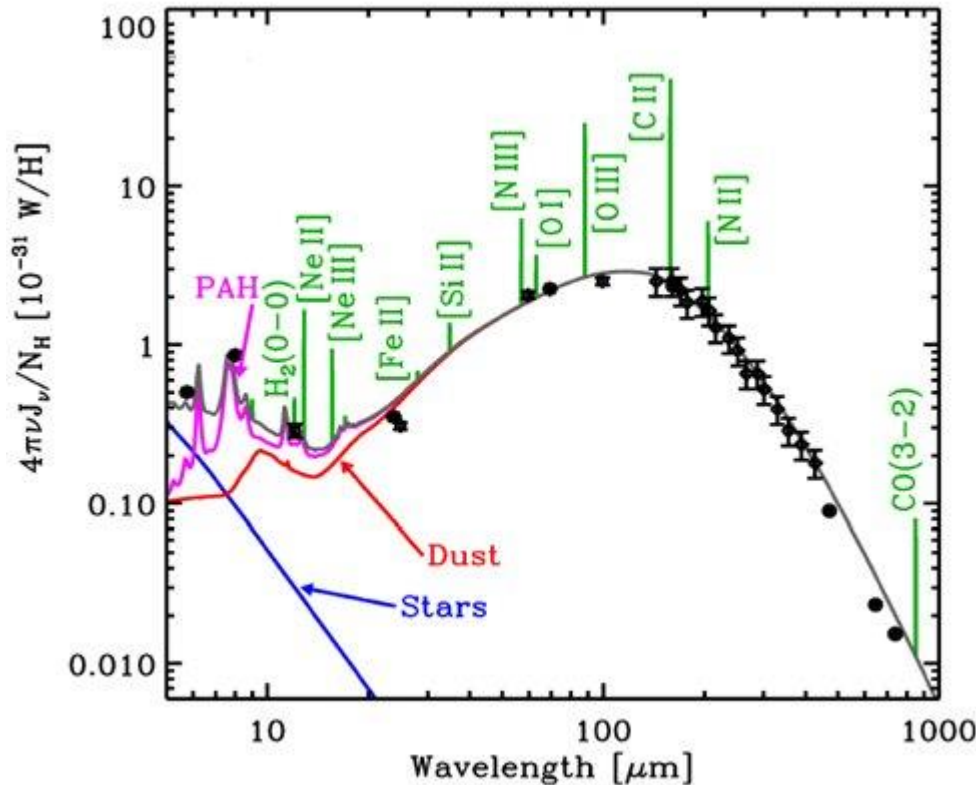
Deconvolution techniques require a PSF as input

- Ideally use an image of a point source (like a standard star)
  + However, SOFIA's PSF is highly variable
- Alternatively, one could use a synthetic PSF

In either case, one can only reliably perform a modest level of deconvolution before artificial features can arise (e.g. 20-30 iterations of Max_likelihood.pro)

It is useful to compare deconvolved images to other images at nearby wavelengths and better resolution to convince yourself details are real, and/or to an unsharp masked image (i.e. dividing image by a smoothed image)
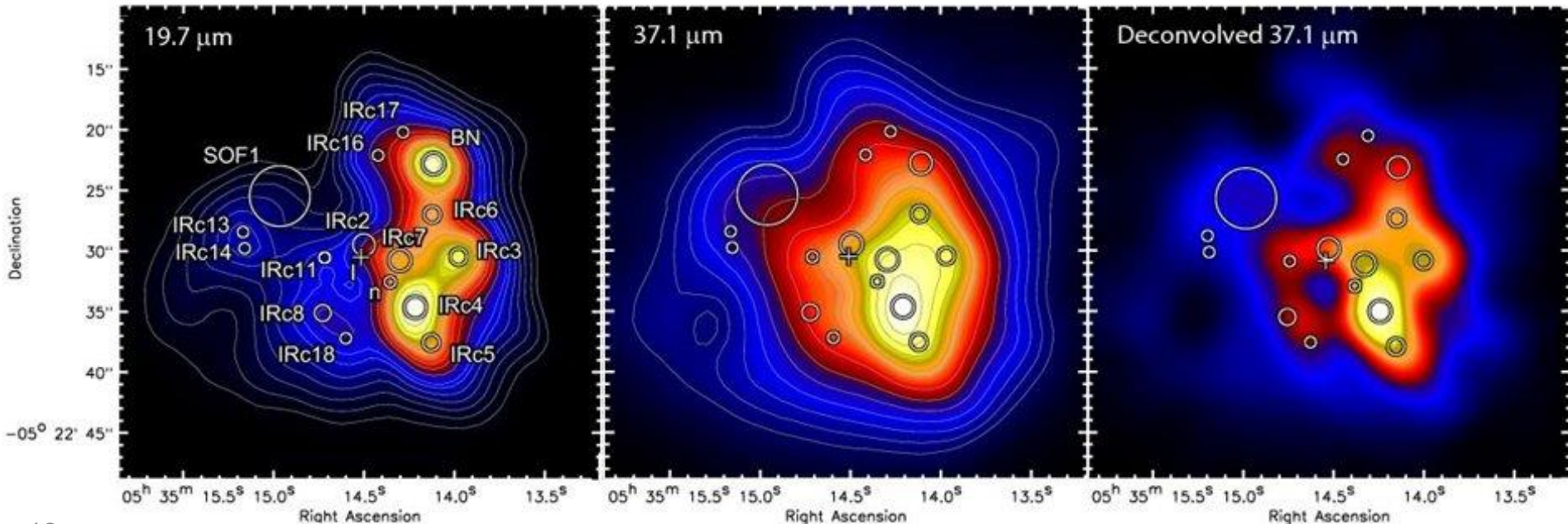
De Buizer et al. 2012

SOFIA imaging data are well-suited for obtaining accurate color temperatures

Spectral Energy Distribution (SED) of the entire LMC at SOFIA wavelengths (courtesy of F. Galliano)

Beyond ~20um SEDs tend to be dominated by dust continuum

Color temperatures of sources can be found by obtaining continuum fluxes at two wavelengths and fitting those with a blackbody or SED fitter

FORCAST (longer than 20um) and HAWC+ broad band filters are perfect for this

SOFIA imaging data are well-suited for obtaining accurate color temperatures

Color Temp 19.7/31.5μm

Using images at two wavelengths one can create a map of color temperature (and optical depth)

How do you know if your thermal IR source is just a quiescent, externally heated knot of dust or a protostar?

Flux peaks that also are color temperature peaks indicate sources that are self-luminous
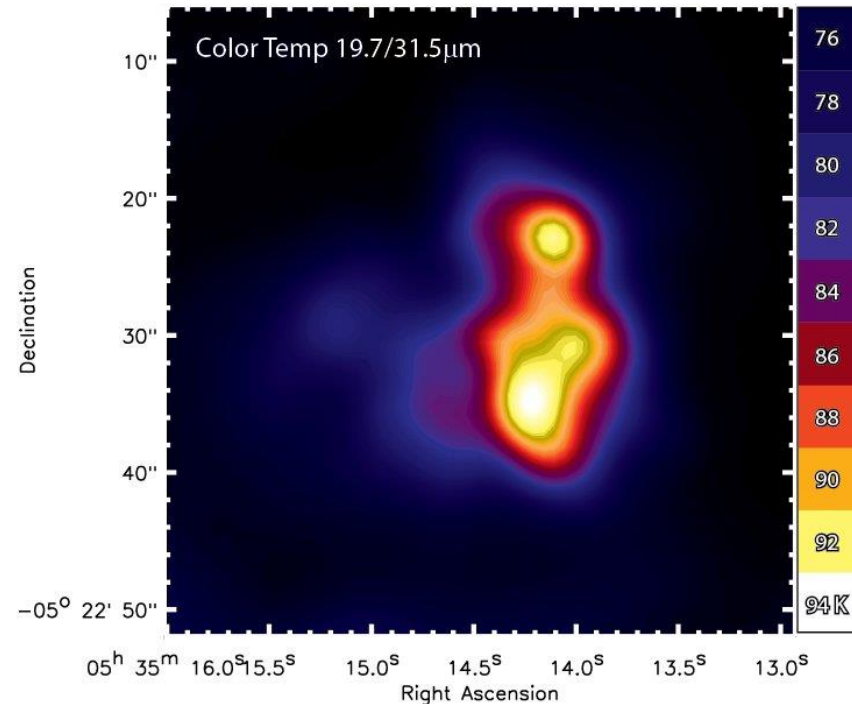
Details: Temperature and optical depth maps can be produced using a least-squares procedure to fit the observed surface brightnesses in each pixel at two different wavelengths to the equation:

$$I_\nu = (1 - e^{-\tau_{ref}(\tau/\tau_{ref})}) \times B_\nu(T_c)$$

where *B* is the blackbody function. Adopt the Mathis extinction law for the wavelength dependence of tau (i.e. tau/tau$_{ref}$) and choose a wavelength at which tau$_{ref}$ is to be evaluated.

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De Buizer et al. 2012

SOFIA imaging data covers wavelengths most critical for SED modeling

The most fundamental property of a source is its luminosity

Obtaining data at or near the peak is vital to measuring accurate luminosity
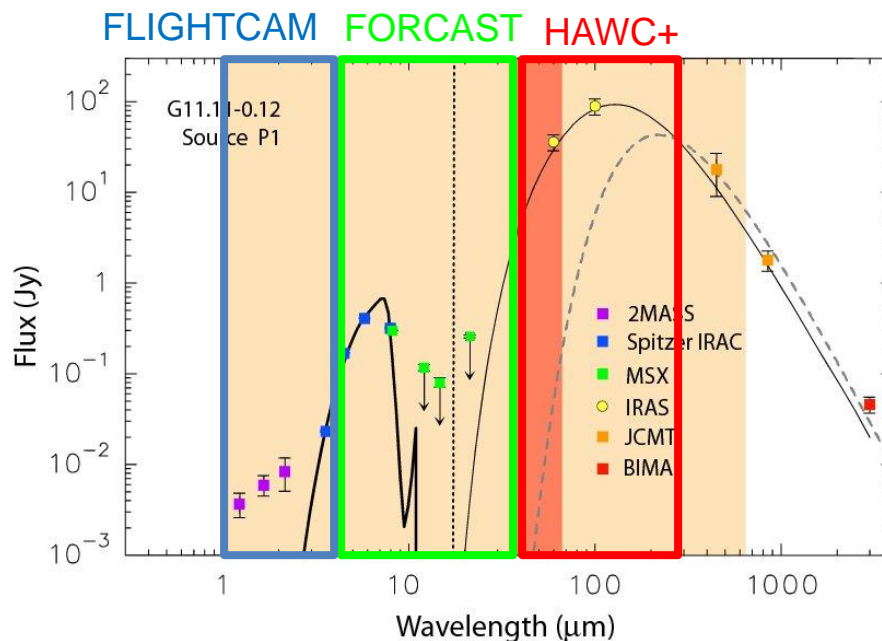
Above: Highly embedded massive protostars have their peak brightnesses at wavelengths >25um, and many have detectable emission ONLY at wavelengths >25um (i.e. their shortest wavelengths can only be observed by SOFIA)

SOFIA imaging data covers wavelengths most critical for SED modeling

Most astronomical sources have peaks in their thermal emission in the wavelength range of SOFIA's imaging instruments
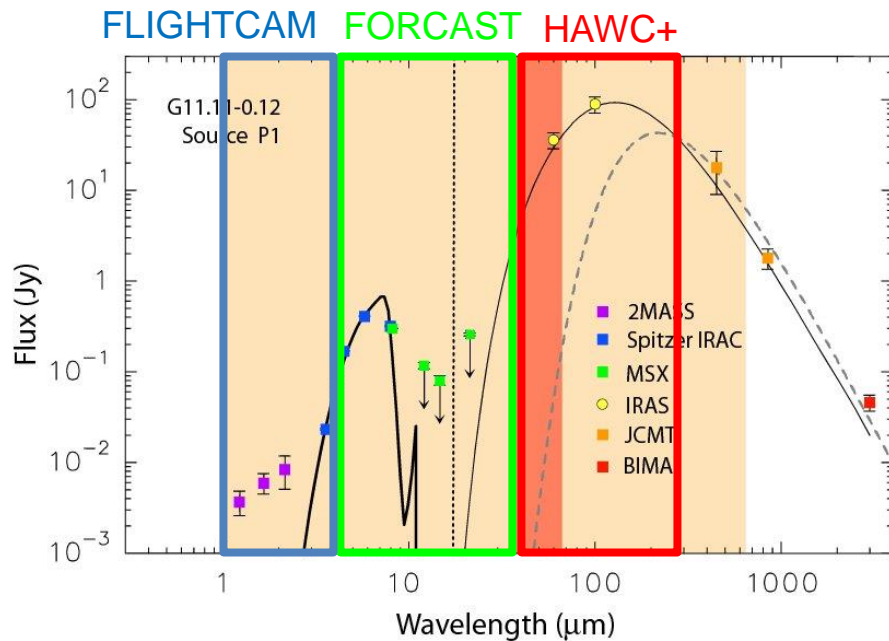
Object	Peak (um)
Brown dwarfs	3
Protoplanetary nebulae & Post-AGB stars	25
Comets and asteroids	25
Transitional circumstellar disks	30
AGN galaxies	50
LMC	70
Jupiter	90
Protostellar objects & Young circumstellar disks	100

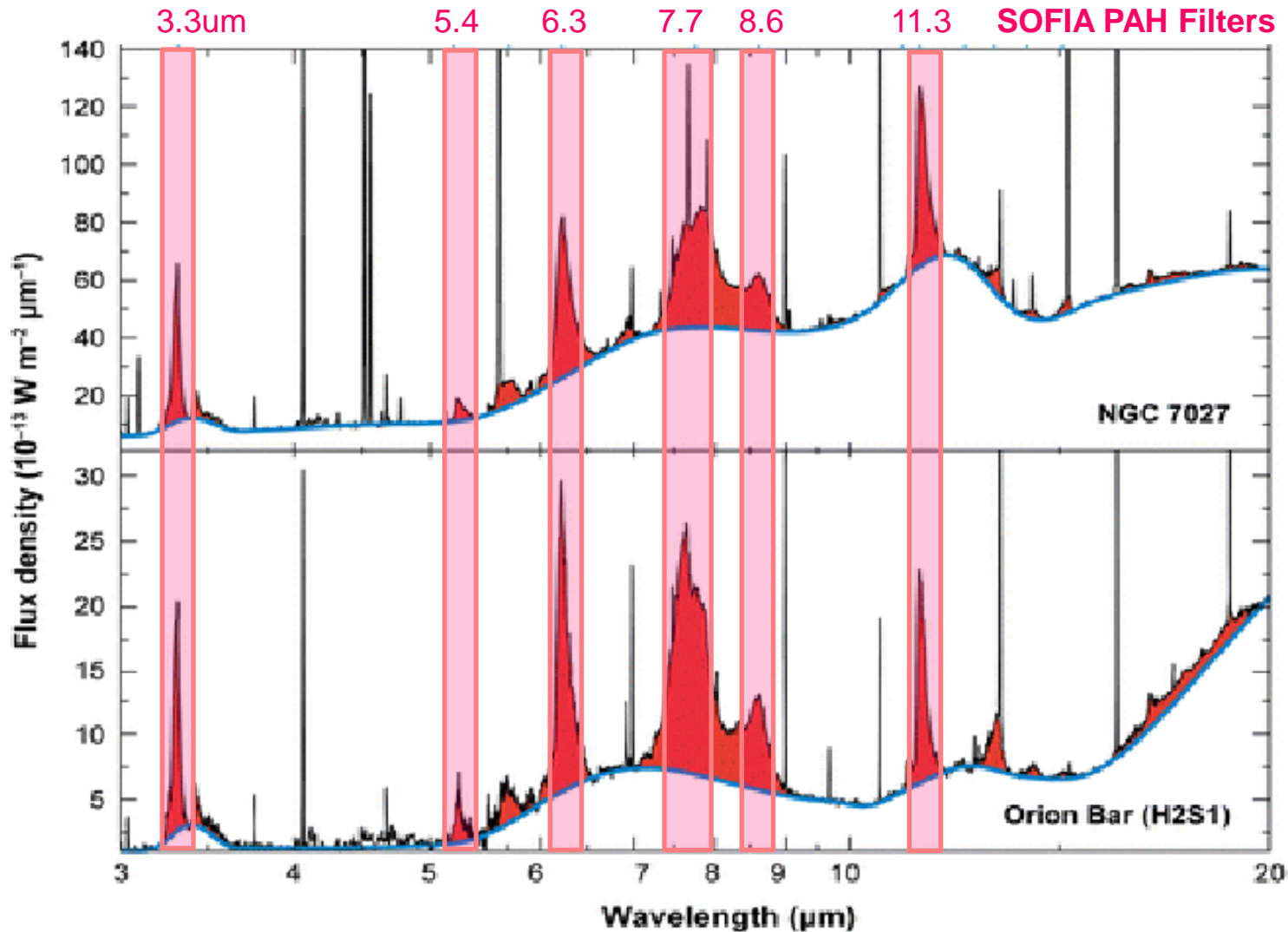# SOFIA imaging data covers wavelengths most critical for SED modeling
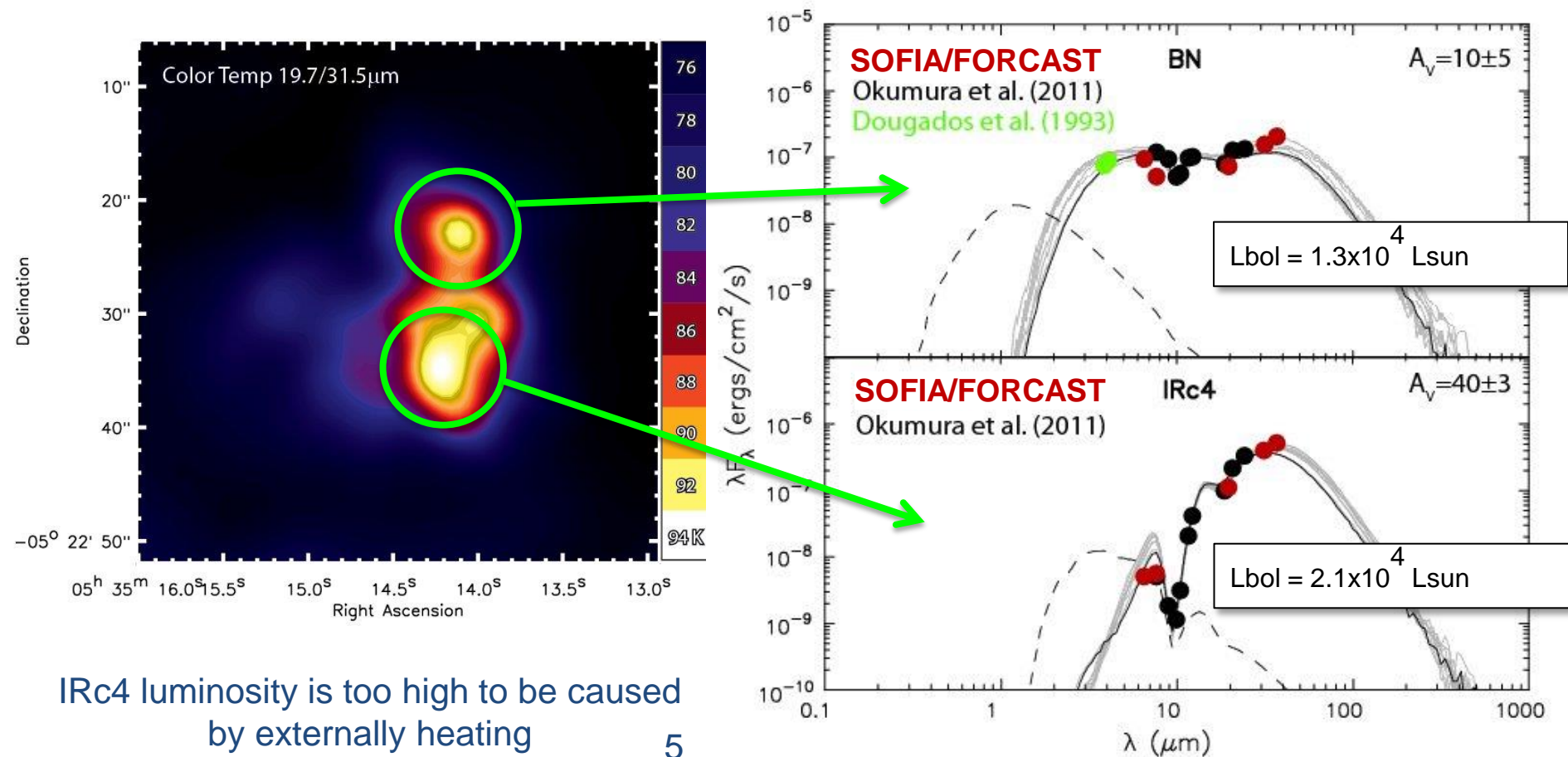
IRc4 luminosity is too high to be caused by externally heating
BN+IRc4 account for ~50% of the ~10^5 Lsun of the BN/KL region
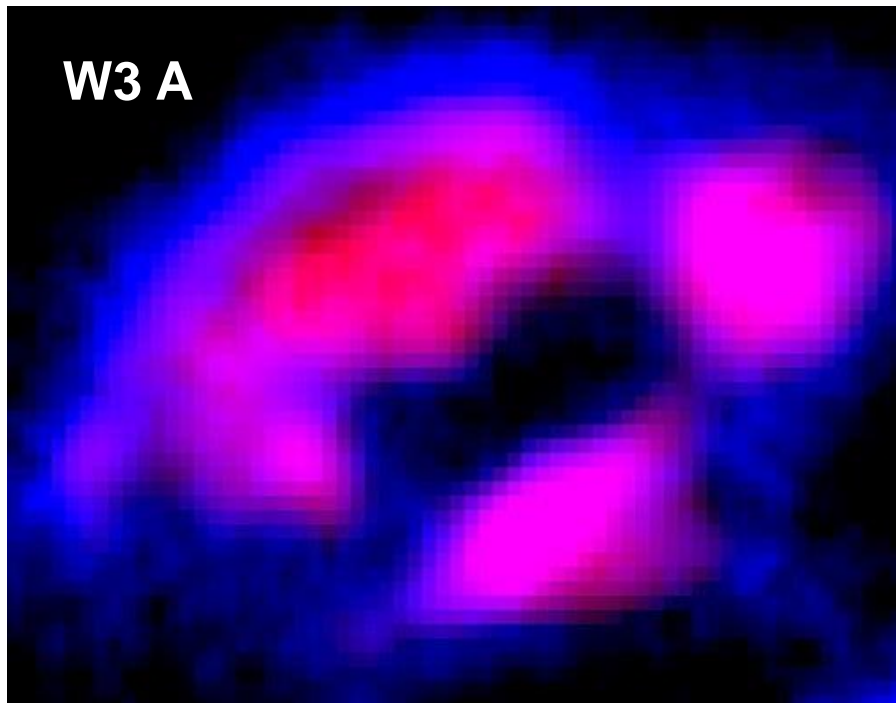Like BN, IRc4 is a self-luminous source

Details: The fits above are from the method described by Robataille et al. 2007. They offer a easy-to-use web-based version of their software at: *http://caravan.astro.wisc.edu/protostars/sedfitter.php*

Lbol = 1.3×10^4 Lsun

Lbol = 2.1×10^4 Lsun

De Buizer et al. 2012

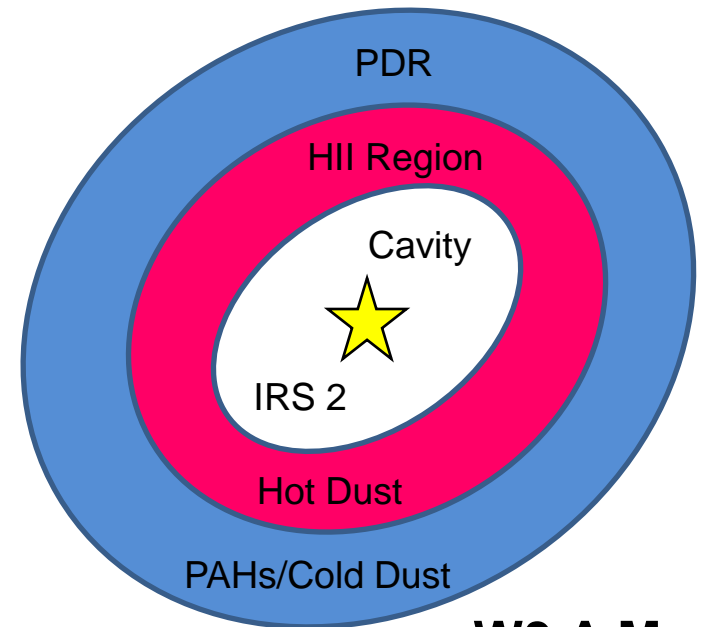# SOFIA is well-suited for mapping PAH chemistry

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

SOFIA is well-suited for mapping PAH chemistry

W3 A

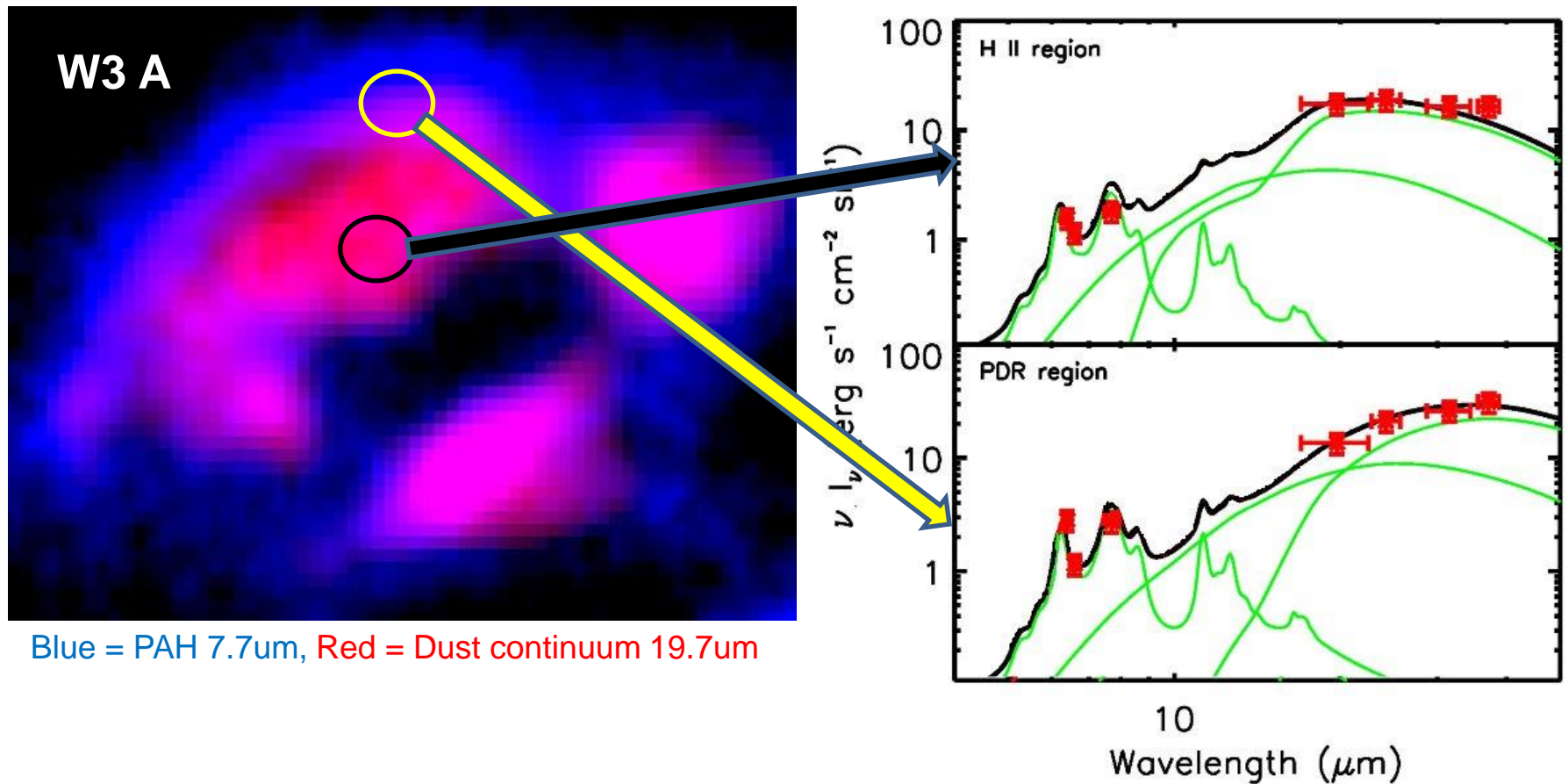Blue = PAH 7.7um, Red = Dust continuum 19.7um

PDR

HII Region

Cavity

IRS 2

Hot Dust

PAHs/Cold Dust

W3 A Model

Using images at multiple wavelengths, a model of the 3-D structure of the W3 A HII region was derived

From Salgado et al. 2012

SOFIA is well-suited for mapping PAH chemistry

W3 A

Blue = PAH 7.7um, Red = Dust continuum 19.7um

SOFIA-derived fluxes (red boxes in plots) at multiple wavelengths were extracted for the areas within the PDR (yellow circle) and within the HII region (black circle). Models were used to obtain the relative abundances of dust and PAHs in the two regions.

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From Salgado et al. 2012

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