

SOFIA FORCAST Images of the Bipolar Planetary Nebula M2-9

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Compact Planetary Nebula are ideal initial targets for FORCAST:

- Bright in the infrared – often too bright for Spitzer
 - infrared emission known to peak in the 30um region
- Well matched in size to FORCAST 3.2 arcmin field of view
- Werner, Morris and Sahai were awarded 4 hours of SOFIA time to observe four such targets:
 - NGC7027, M2-9, NGC6543, Frosty Leo

Minkowski 2-9

Classic bipolar nebula

- Previous work estimates $L=2500$

L_{sun}

❖ Stellar temperature 15000K

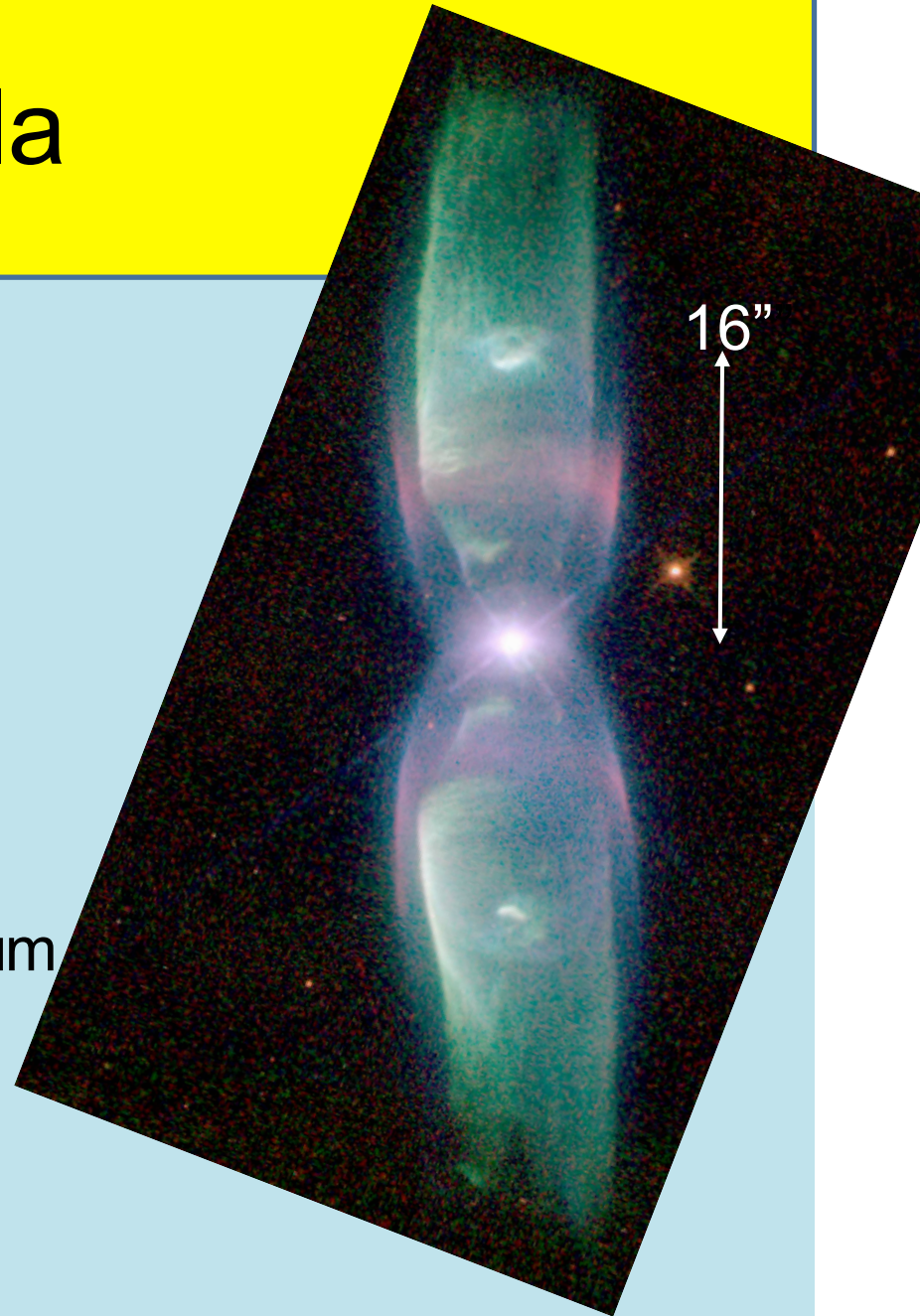
- Distance = 1.2 Kpc

- 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

- Photometry done on SOFIA
Science Center Level 3 data
products



SOFIA Images of M2-9

6.6

11.1

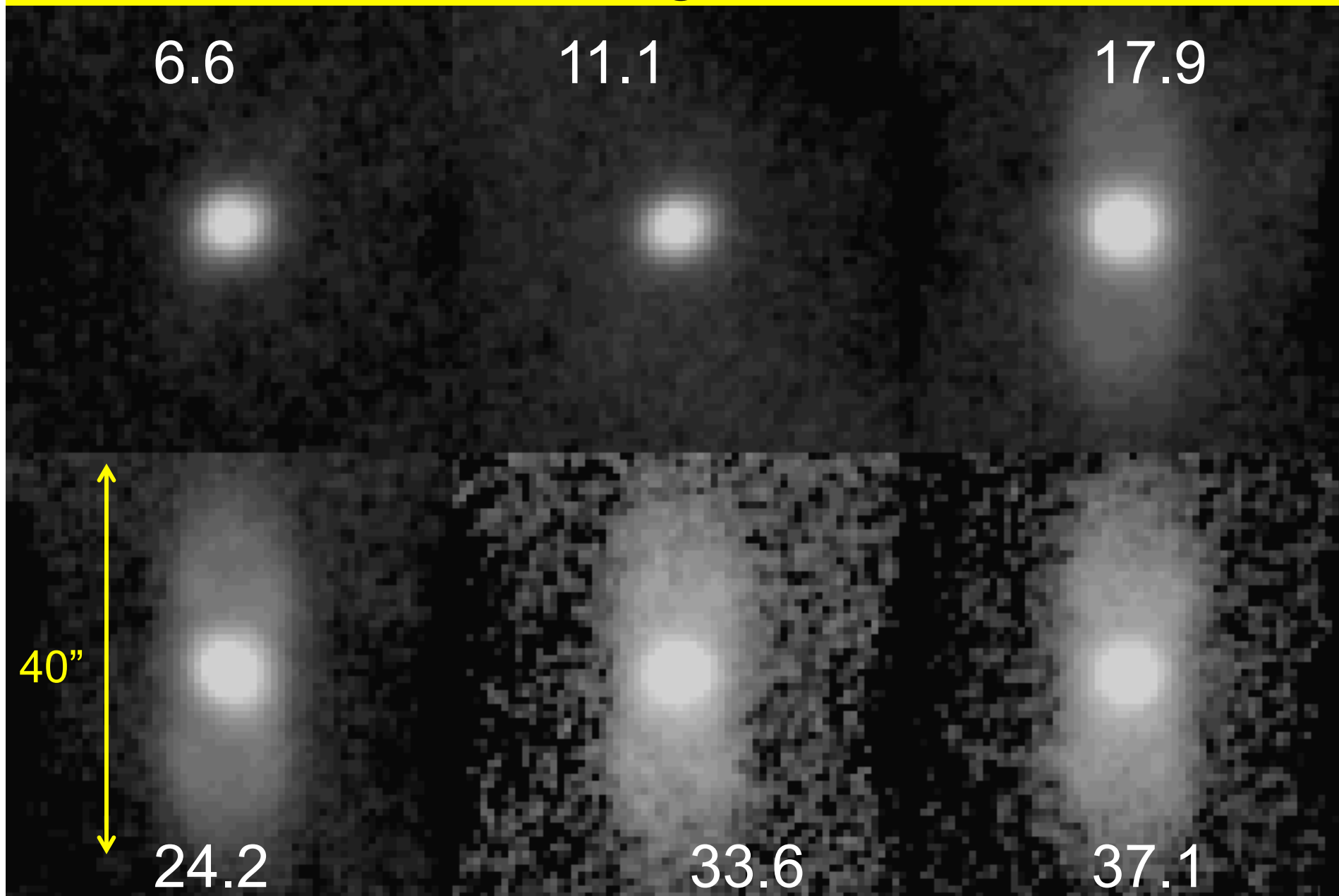
17.9

40"

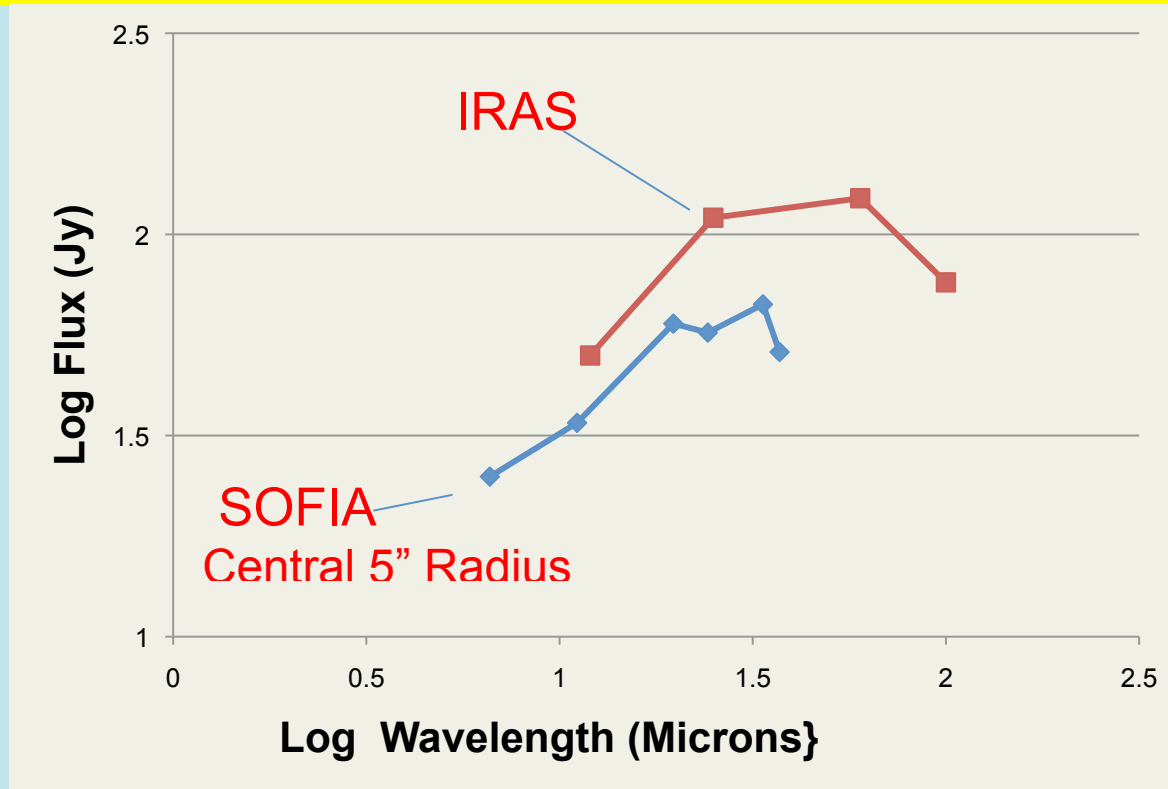
24.2

33.6

37.1



Properties of Central Point Source

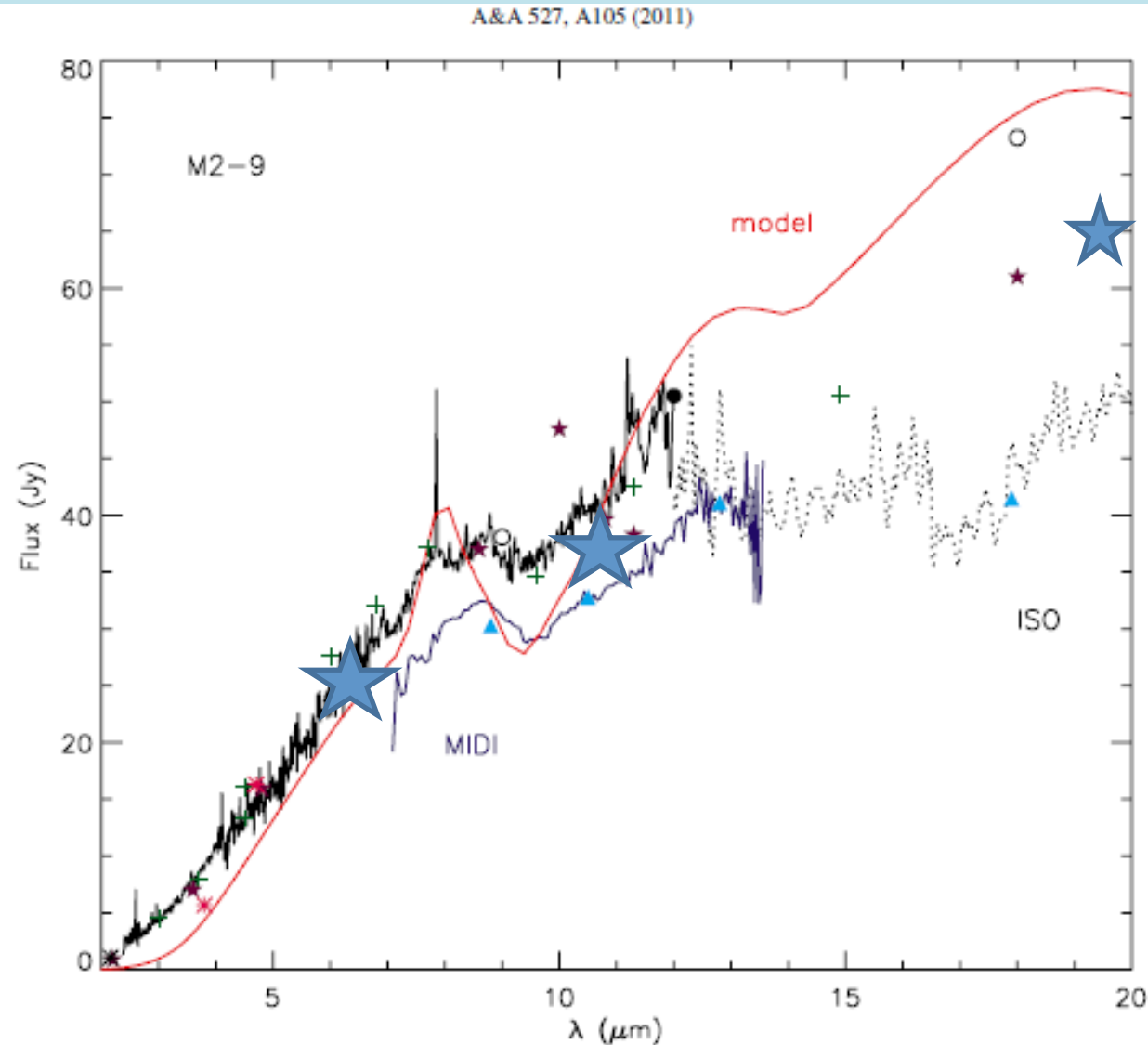


- FWHM = 3.5 to 4.7 arcsec, increasing with wavelength – not resolved

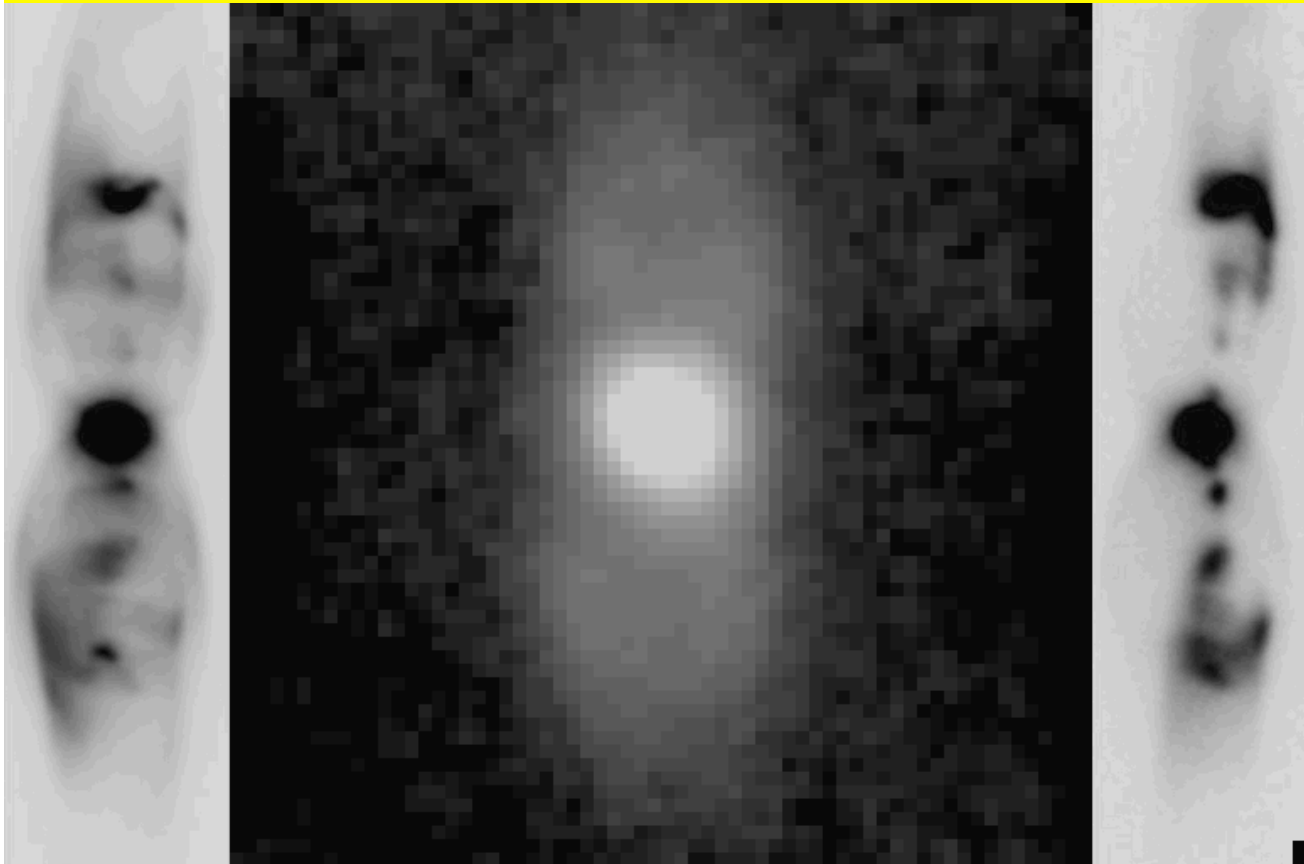
- Luminosity = $760 L_{\text{solar}}$. IRAS measured $1100 L_{\text{solar}}$

- 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)

SOFIA Photometry () of Central Source Compared to Lykou et al Disk Model



Turning to the Lobes



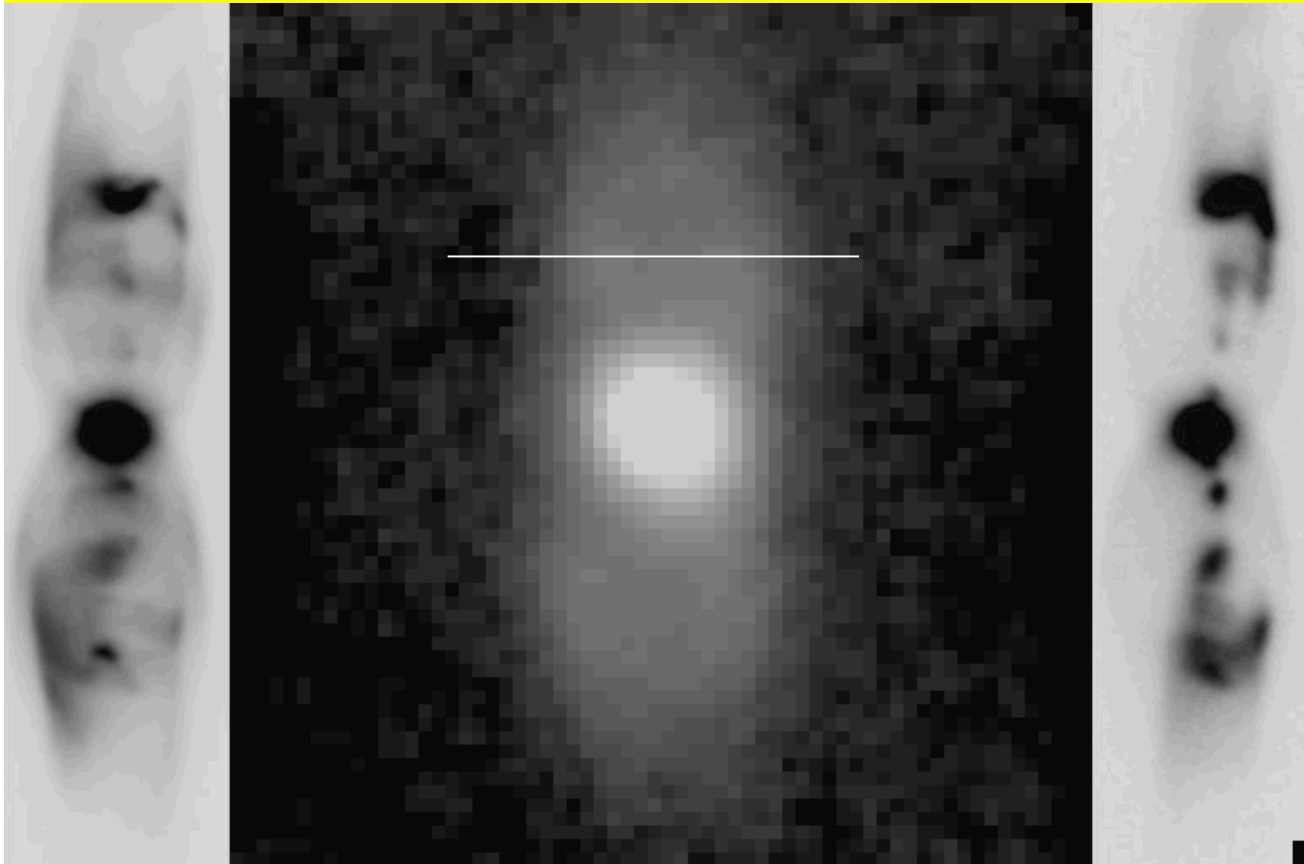
Halpha+[NII]
(2010)

24.2um

[OIII]
(2010)

- 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

Turning to the Lobes



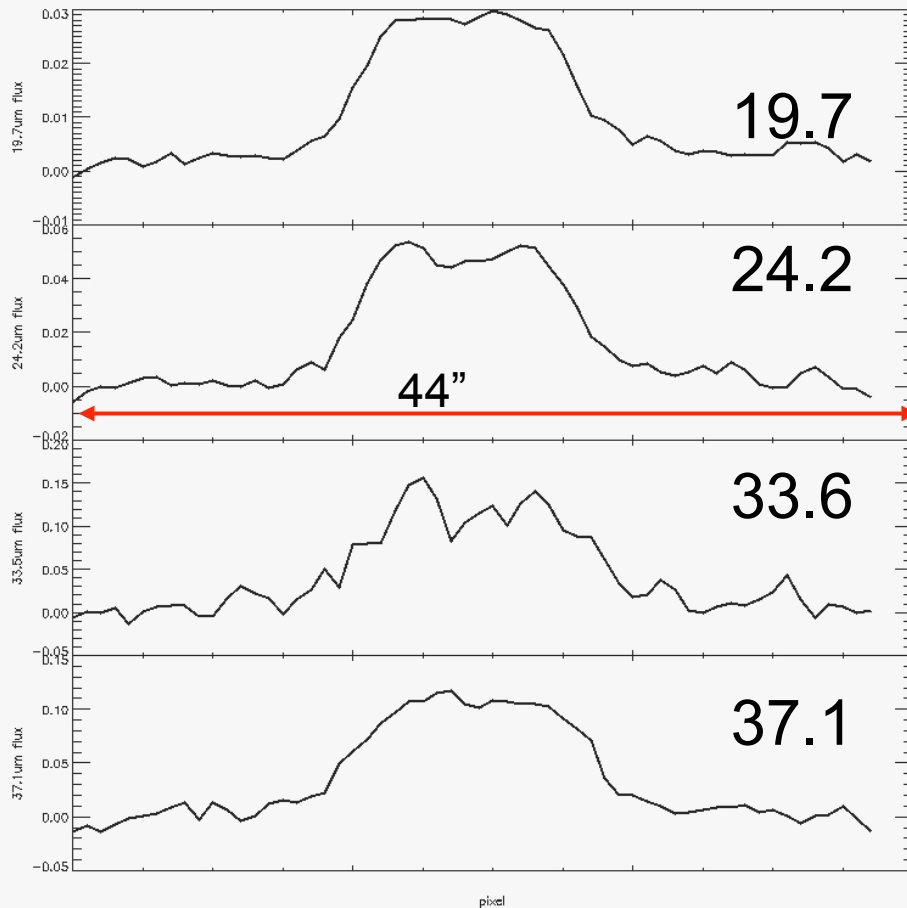
Halpha+[NII]
(2010)

24.2um

[OIII]
(2010)

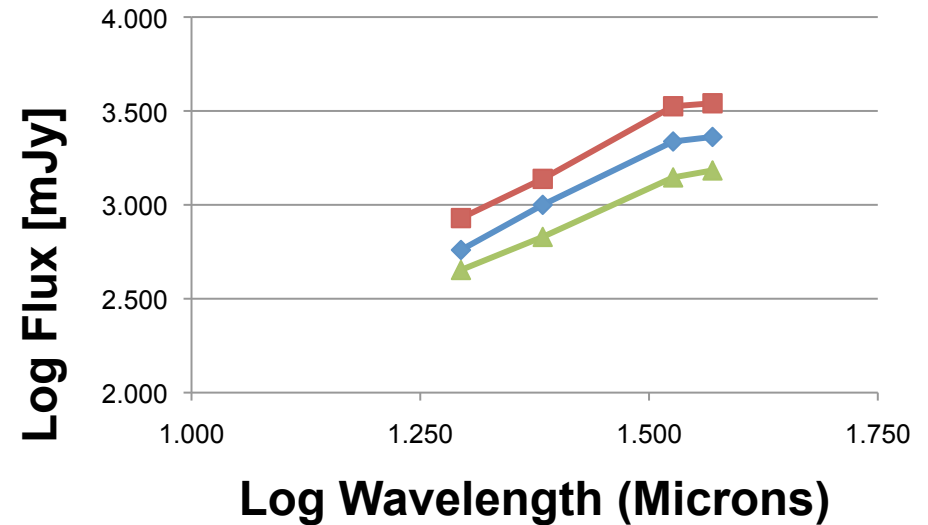
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Turning to the Lobes (2)



Horizontal scans through lobes, 10" N. of central source

- Profiles suggest lobes not uniformly filled with dust but modestly "limb brightened"

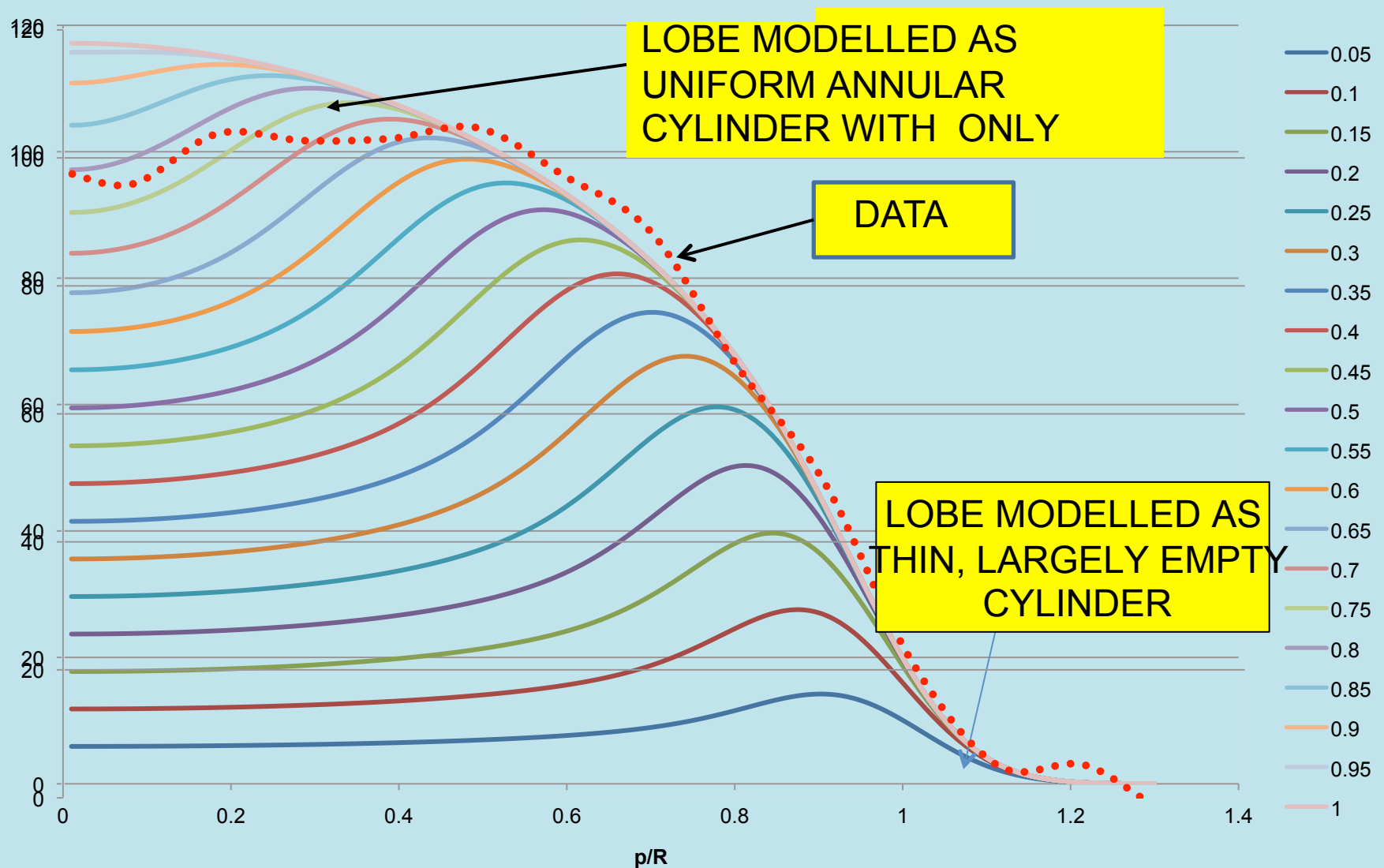


SED of 3.75"x3.75" areas centered 7.5, 11.25, 15" S of central source.

- Color Temperature about 100K
- Assuming emission due to dust....
 - Particle size <0.1 um
 - Total dust mass in lobes 0.004 solar masses

Modeling Lobe Structure

Cross Section #4, 24.2 μm , convolved with beam



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