Gemini and Subaru Observations of Planetary Nebulae and Proto-Planetary Nebulae

in search for answers to questions on morphological transformation and chemical synthesis

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Origin of planetary nebulae

- PN are the result of dynamical interaction between the remnant of the AGB wind and a newly developed fast wind
- The interacting winds model has successfully predicted (i) the optical halo; (ii) fast wind (by *IUE*); (iii) dust envelopes (*IRAS*); and the X-ray bubble (*ROSAT, Chandra*)

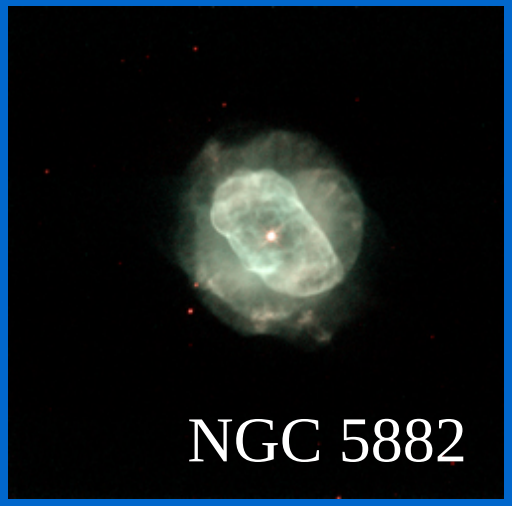
Shells, Rims, Crowns, and Haloes


NGC 6578


NGC 5979


NGC 2022


NGC 6629

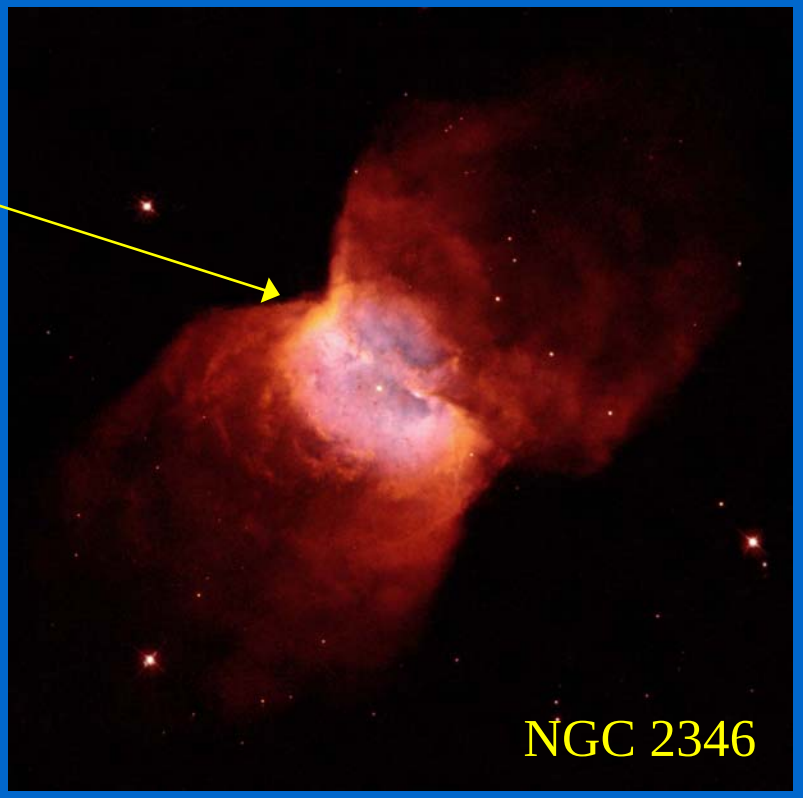

NGC 5882

Multi-shell morphology can be explained by 1-D interacting winds dynamics

Morphological transformation to Bipolar Nebulae

NGC 6302

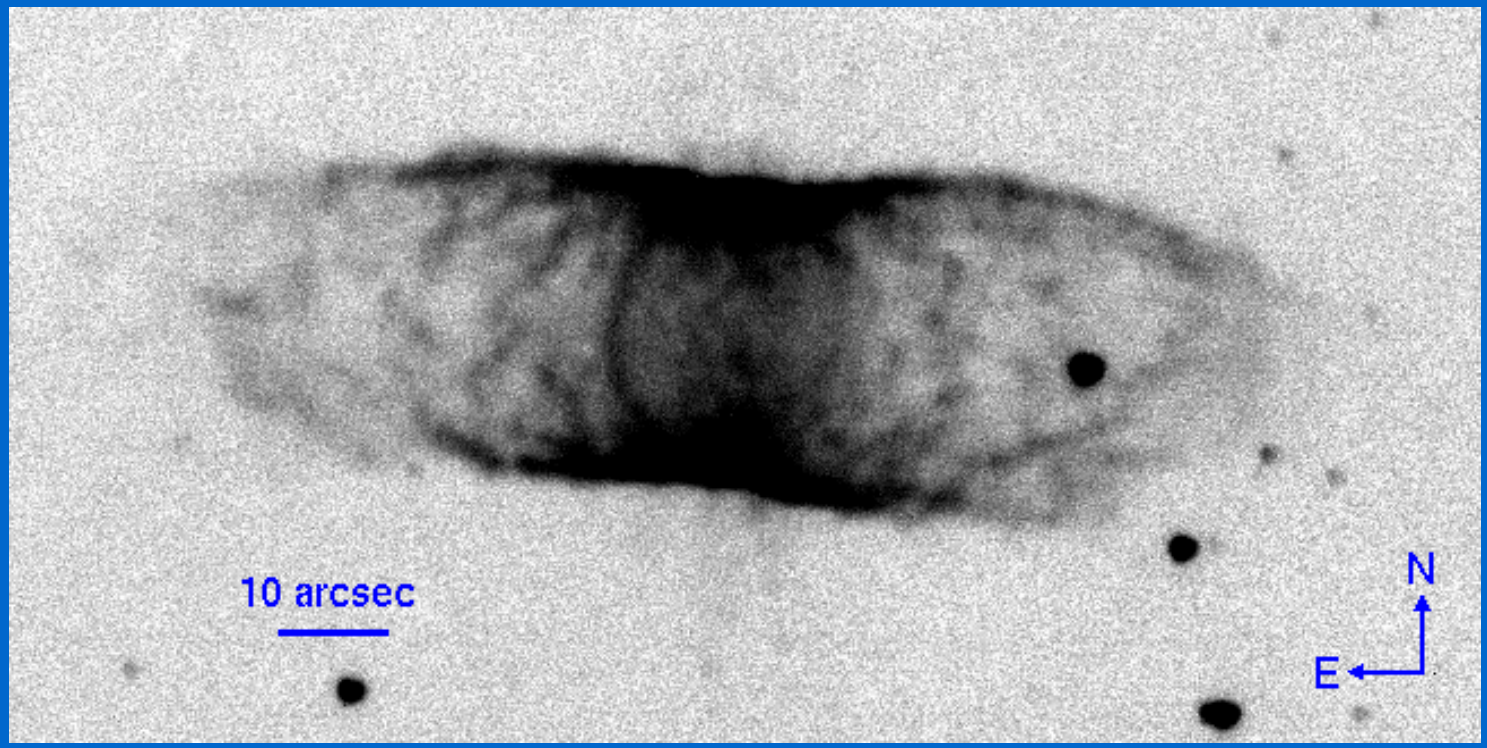
Confined by dust torus?



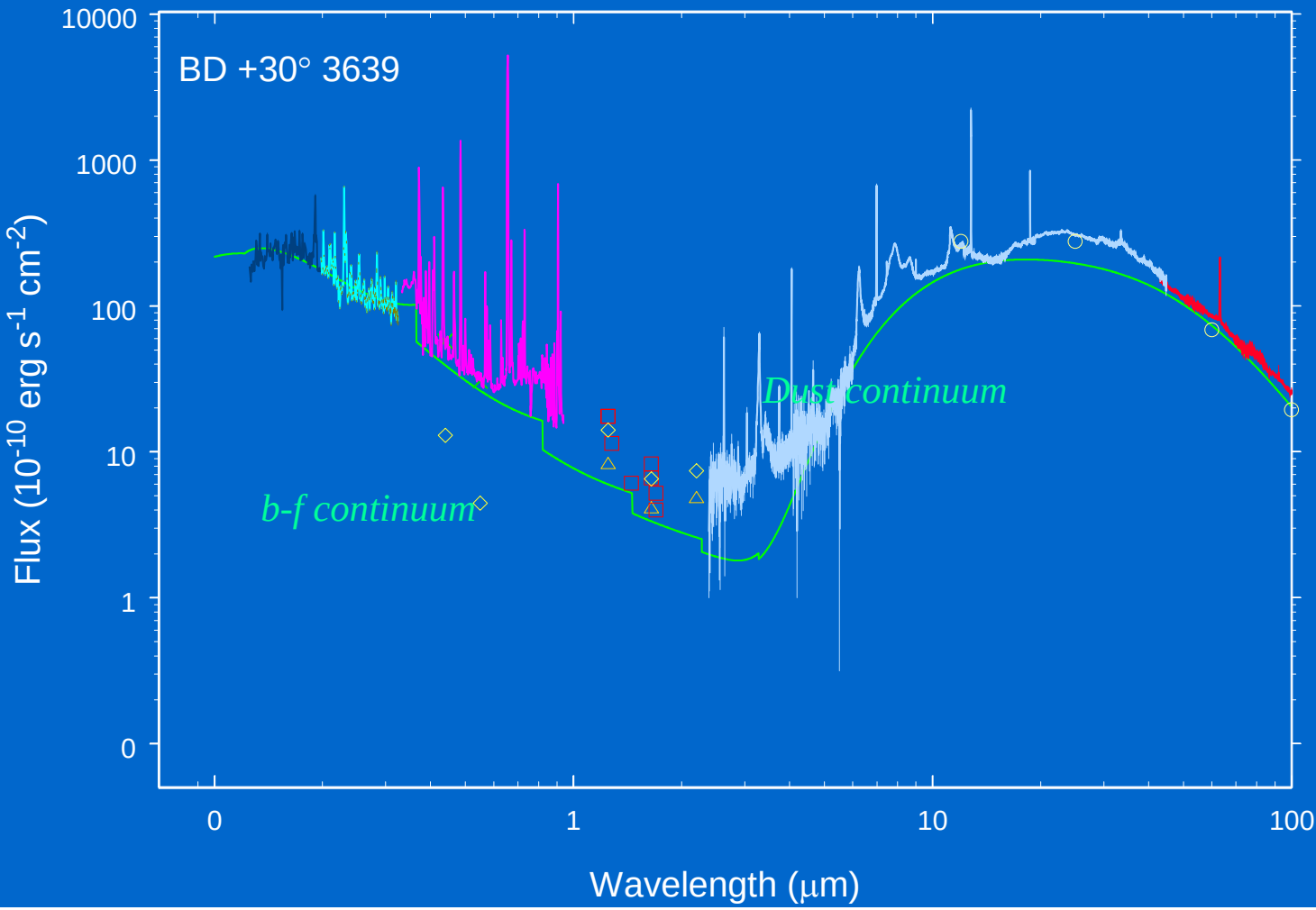
Eastern lobe

Many well-known PN, such as the Ring, the Dumbbell, the Owl, the Eskikmo, NGC 7027, are bipolars.

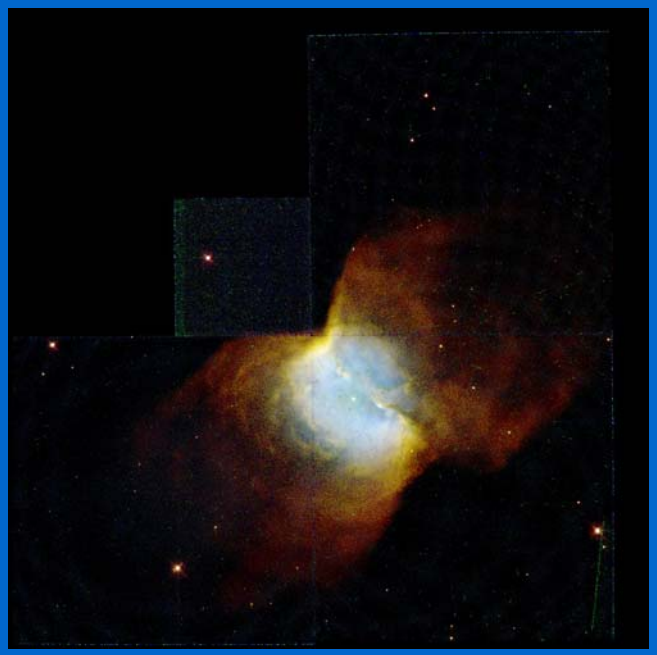
IC 4406 H_2



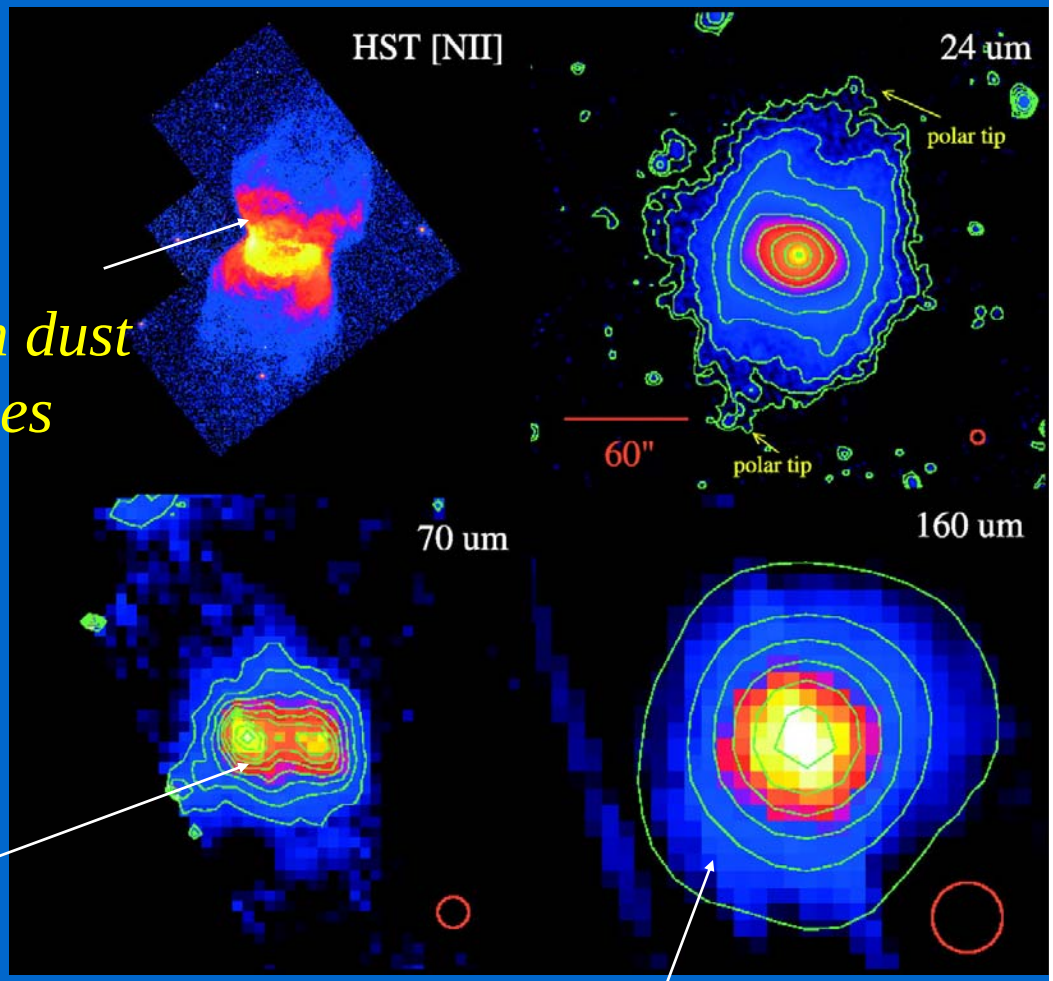
Ionized (10^4-10^6 K), molecular (10^1-10^2 K) and dust (10^2 K) components



Spitzer MIPS imaging of the dust components



NGC 2346



Warm dust in lobes

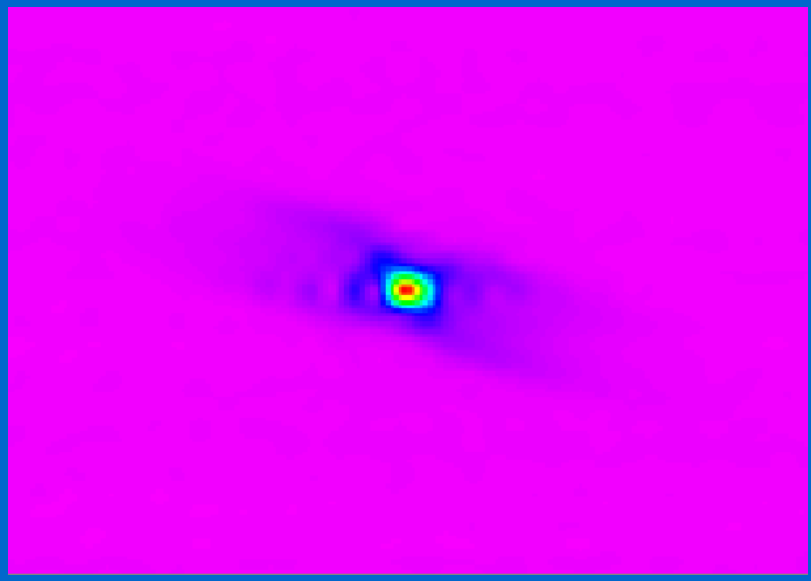
torus

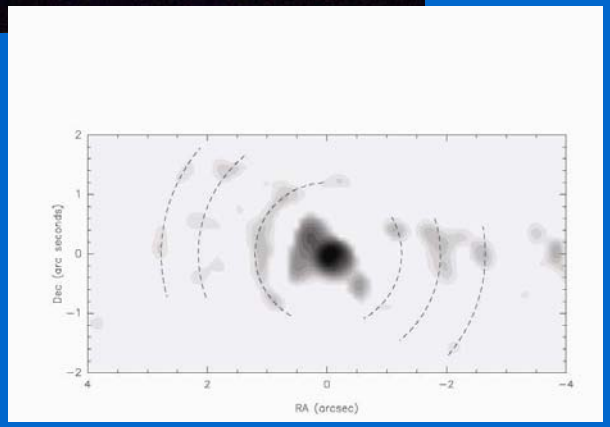
AGB remnant

Su et al. 2004

Mid-IR imaging of dust torus

T-ReCS at Gemini South (10.36, 10.38, 11.66, 12.33, 18.30, 24.56 μm)





Most of the fluxes emitted >30 μm, so at 20 μm we are still seeing warm dust

Subtraction of the 10.38 μm image from the 11.66 μm image gives the distribution of the 11.3 μm AIB feature.

Muthu et al. 2006

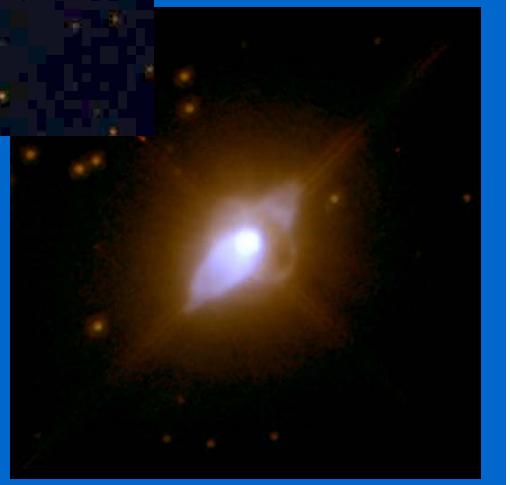
Shaping occurs early, in the PPN stage

The Silkworm Nebula

The Cotton Candy Nebula

The Walnut Nebula

The Water Lily Nebula



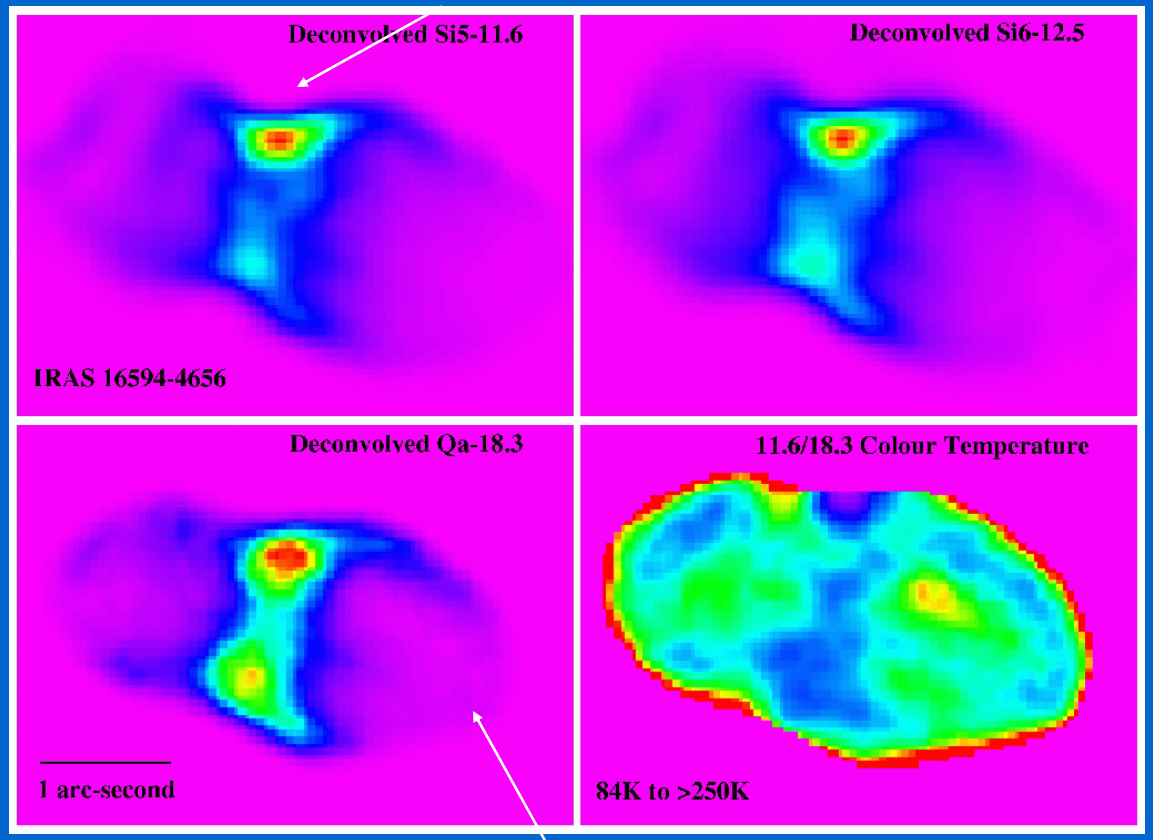
The Spindle Nebula

Dust in the torus and in the lobes

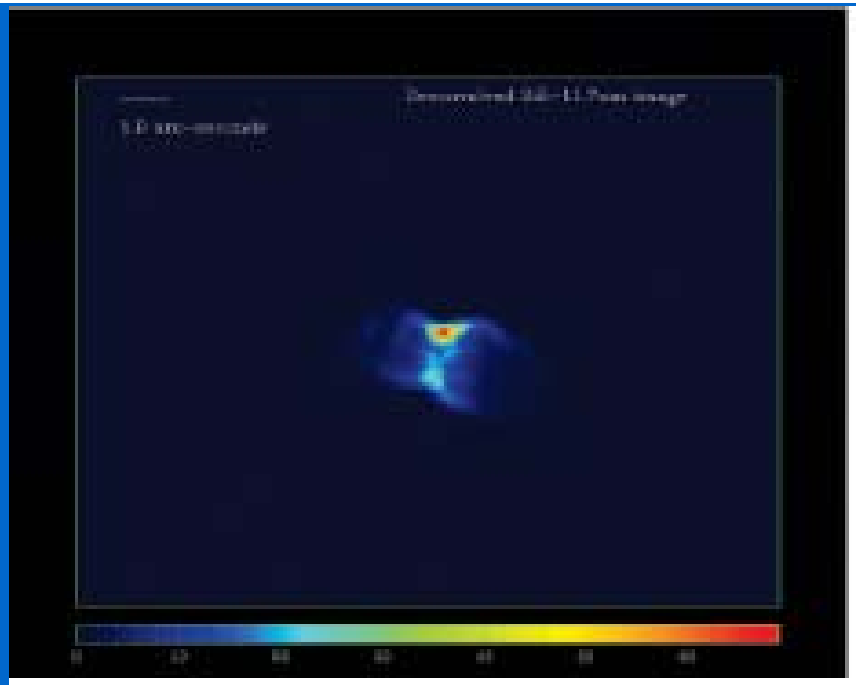
IRAS 16594-4656, the Water Lily Nebula

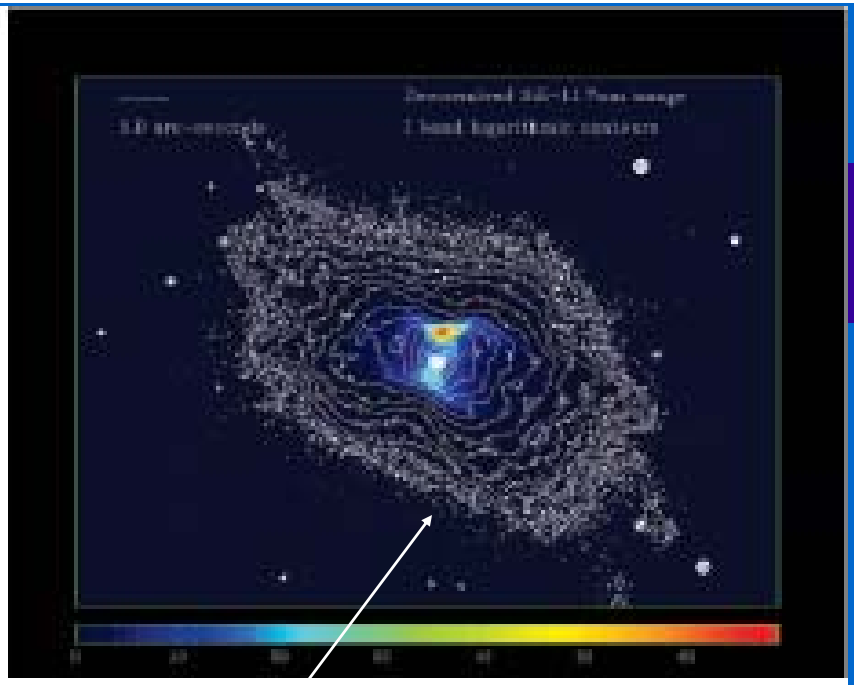
T-ReCS, Gemini South

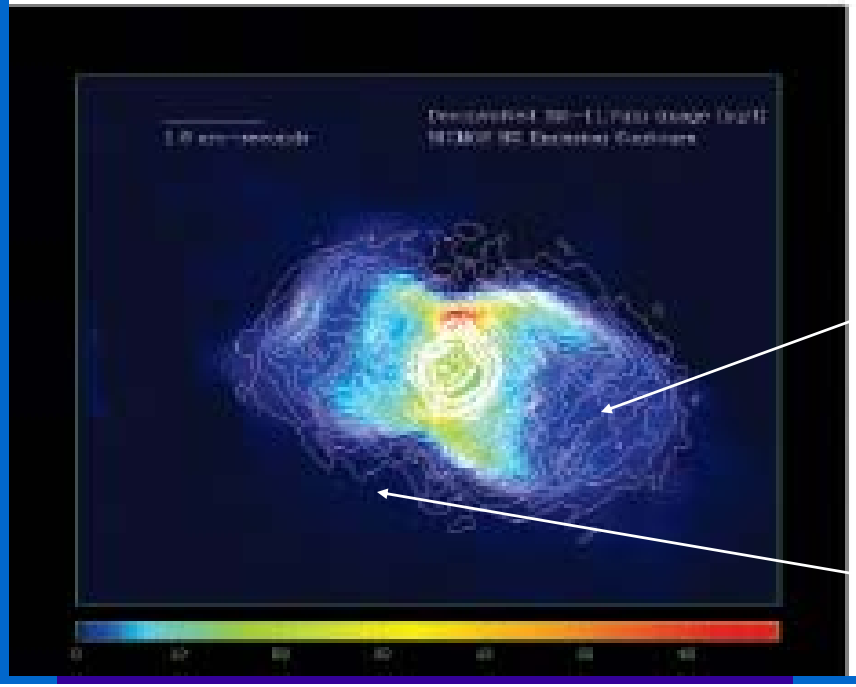
Edge-on torus



Closed lobes, fast wind yet to break through





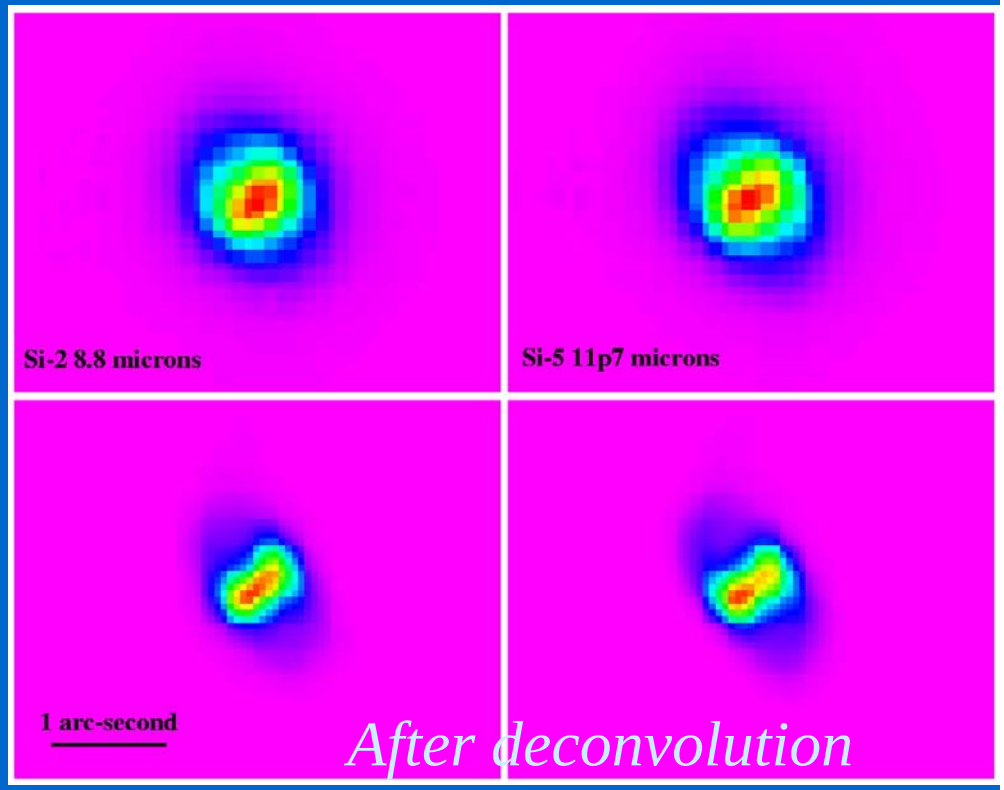


HST WFPC2 I band: all scattered light

HST NICMOS H_2

Confined by very low temperature dust

Imaging of edge-on torus in PPN

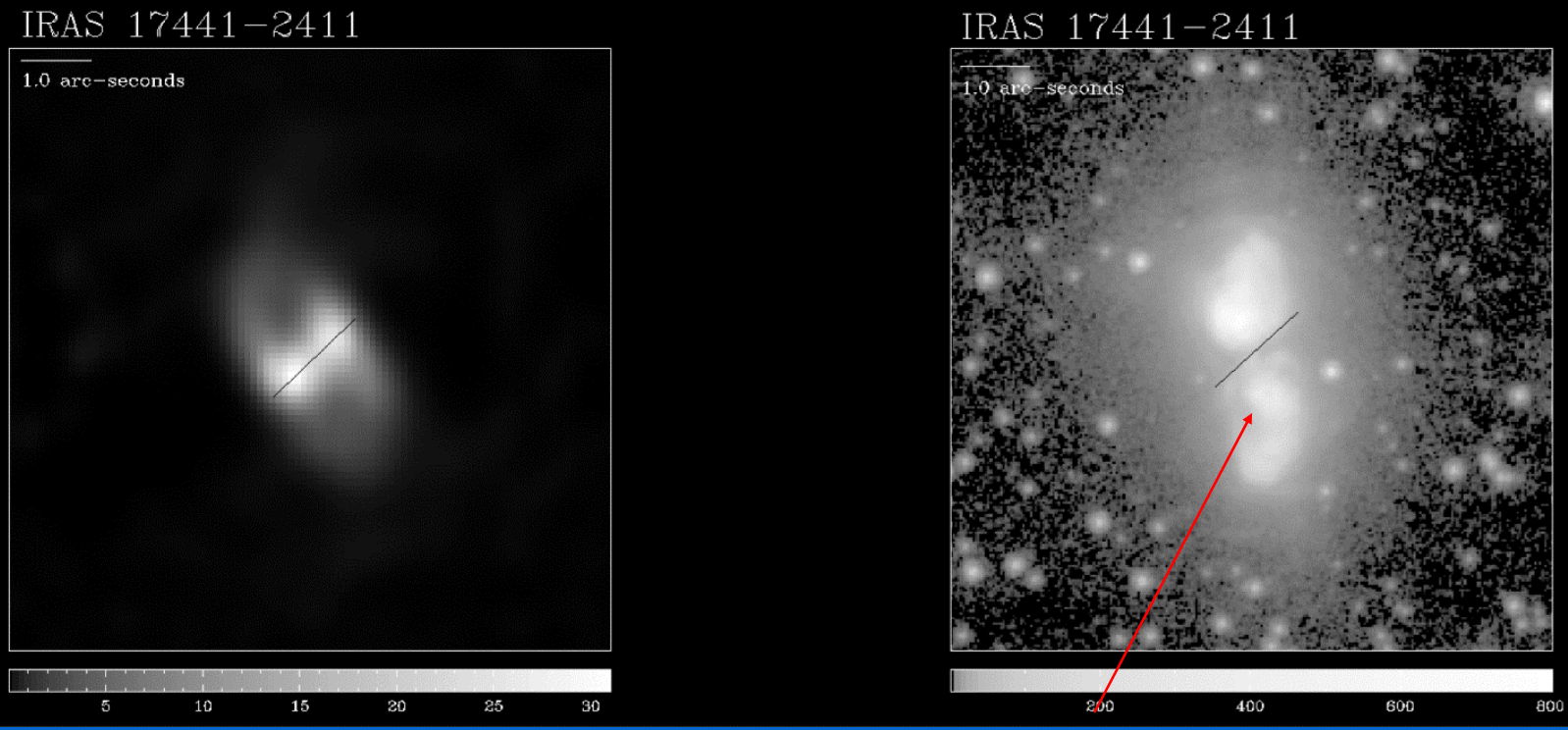


IRAS 17441-2411, the Silkworm Nebula

Volk and Kwok (2007)

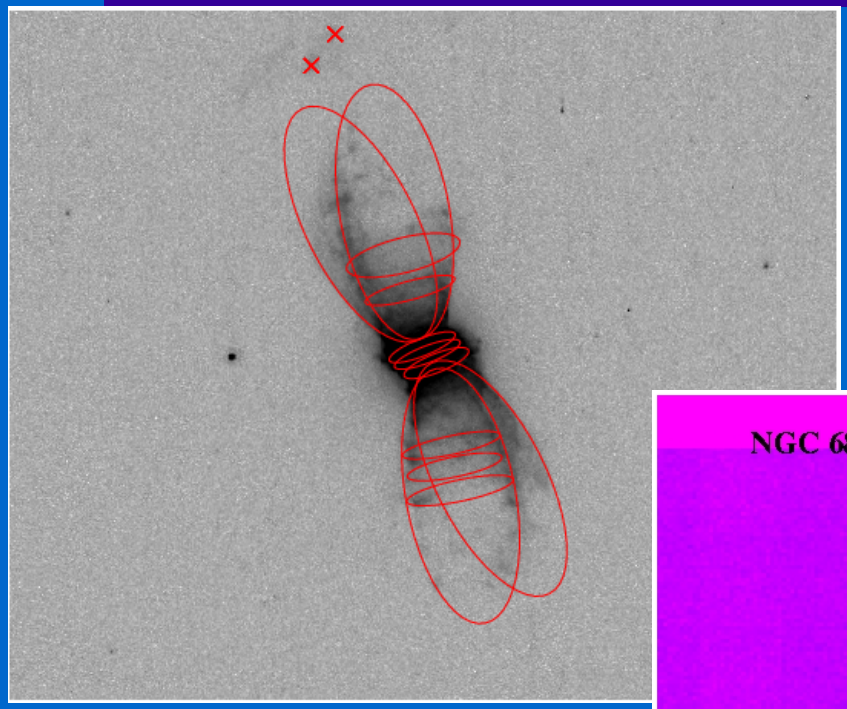
Equatorial disk as collimating agent

HST I-band image

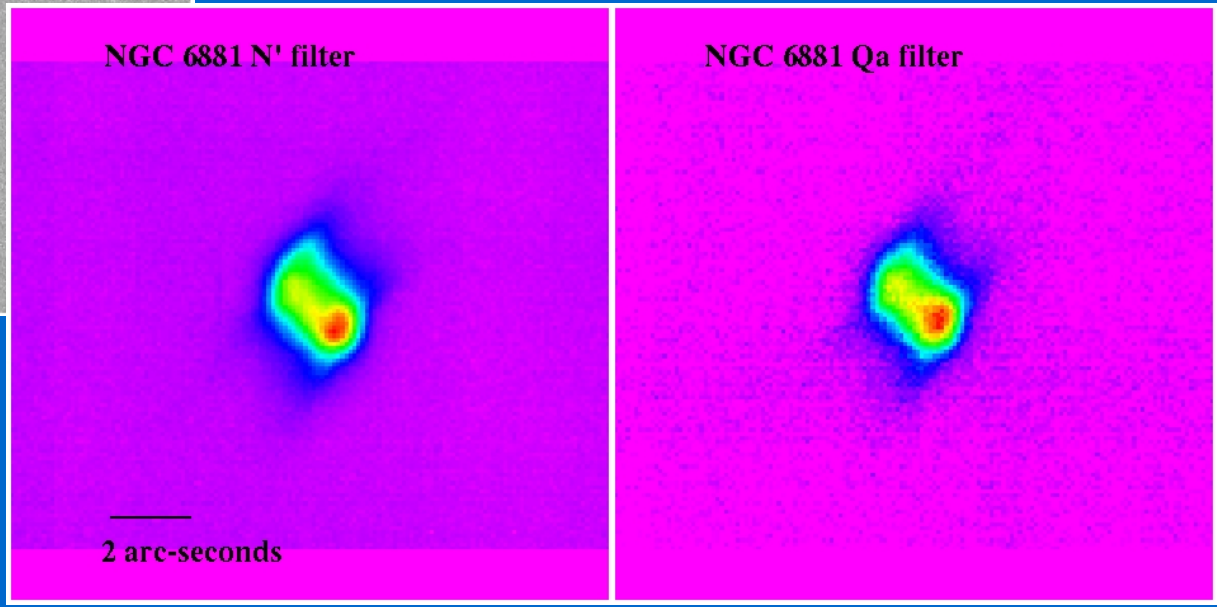


Misaligned by 23 degrees! A precessing outflow?

Multipolar Nebula



Gemini T-ReCS



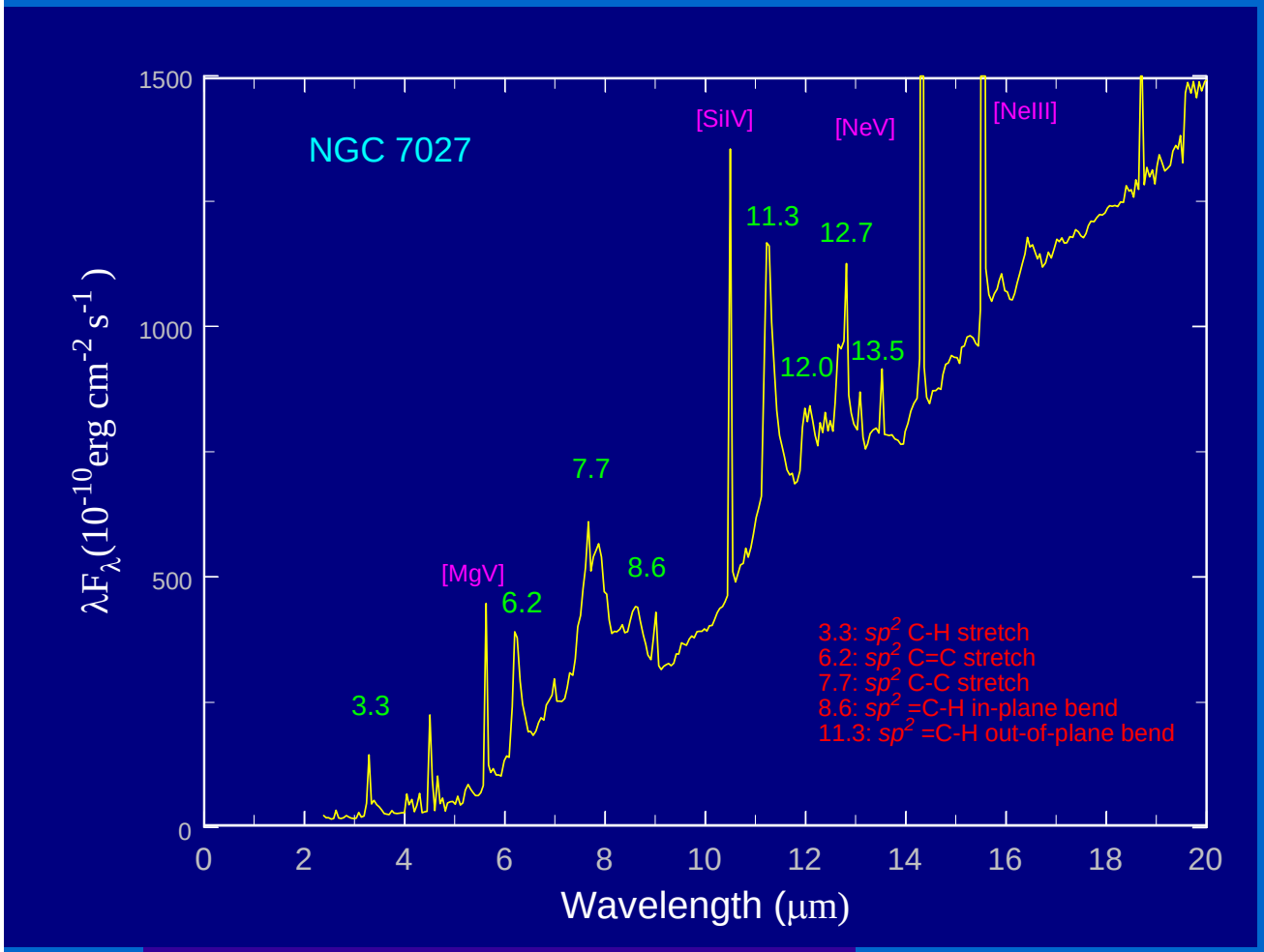
NGC 6881 (HST [NII], Kwok & Su 2005)

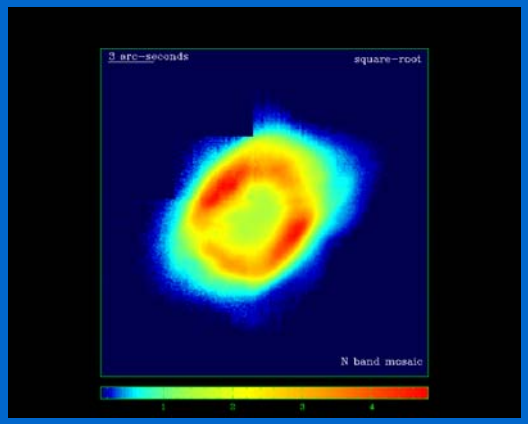
Synthesis of complex organic compounds in post-AGB evolution

- AGB: over 60 gas-phase molecules including chains and rings
- Late AGB (extreme carbon stars): acetylene
- PPN: aromatics and aliphatics
- PN: strong aromatics

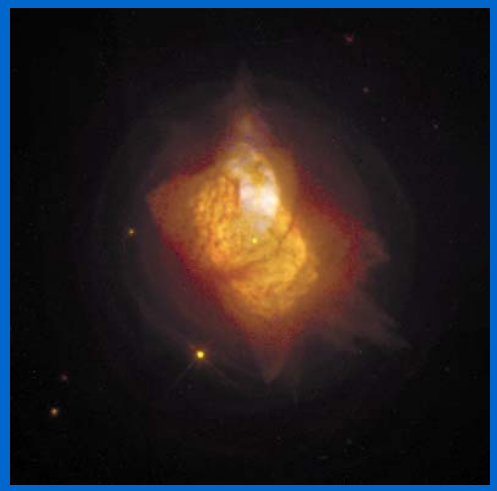
Kwok, Volk & Hrivank 1999, A&A, 350, L35; Kwok, Volk, & Bernath 2001, ApJ, 554, L87; Kwok 2004, Nature, 430, 985; Kwok 2009, ApSS, 319, 5

Aromatic Infrared Bands

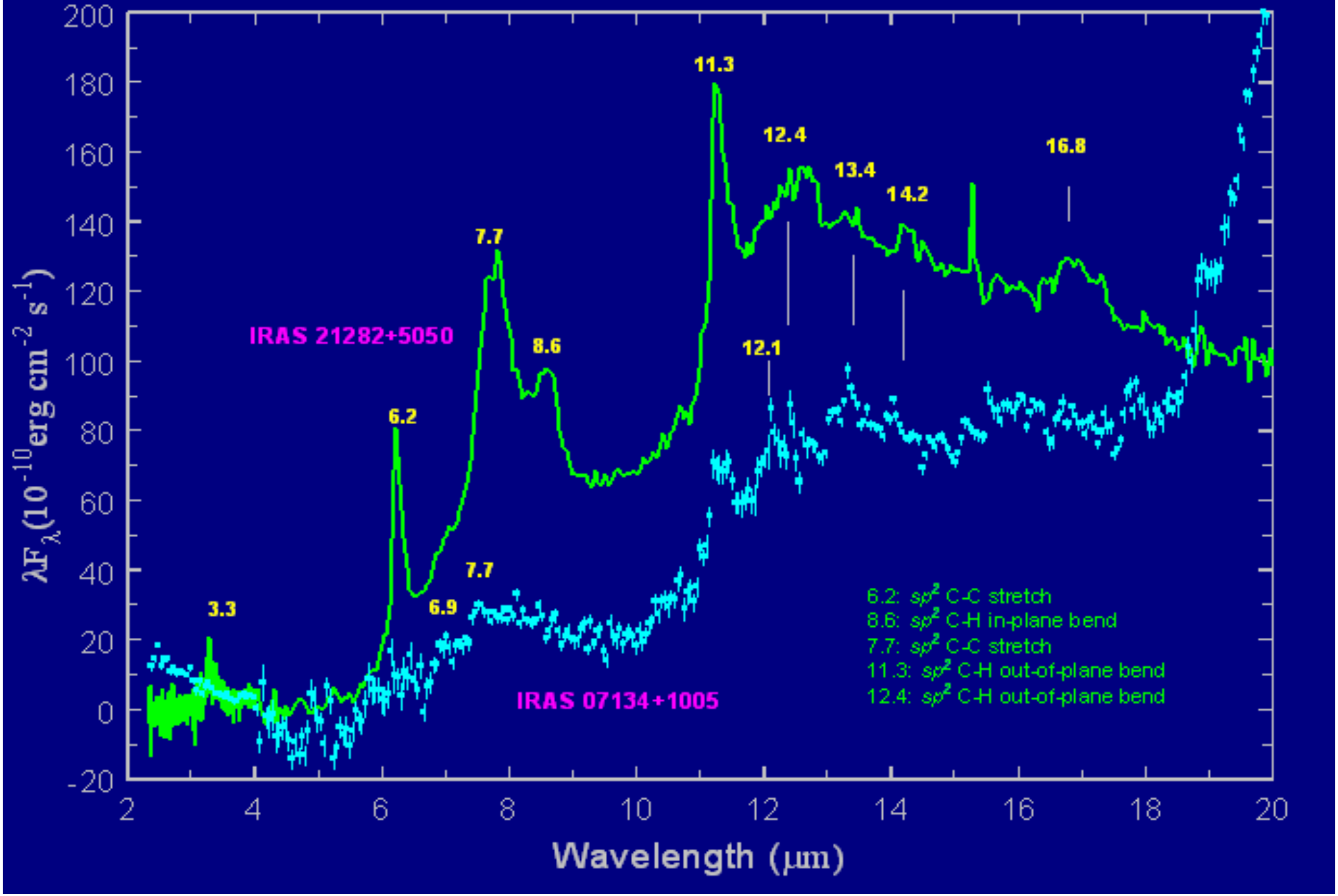




Gemini OSCIR



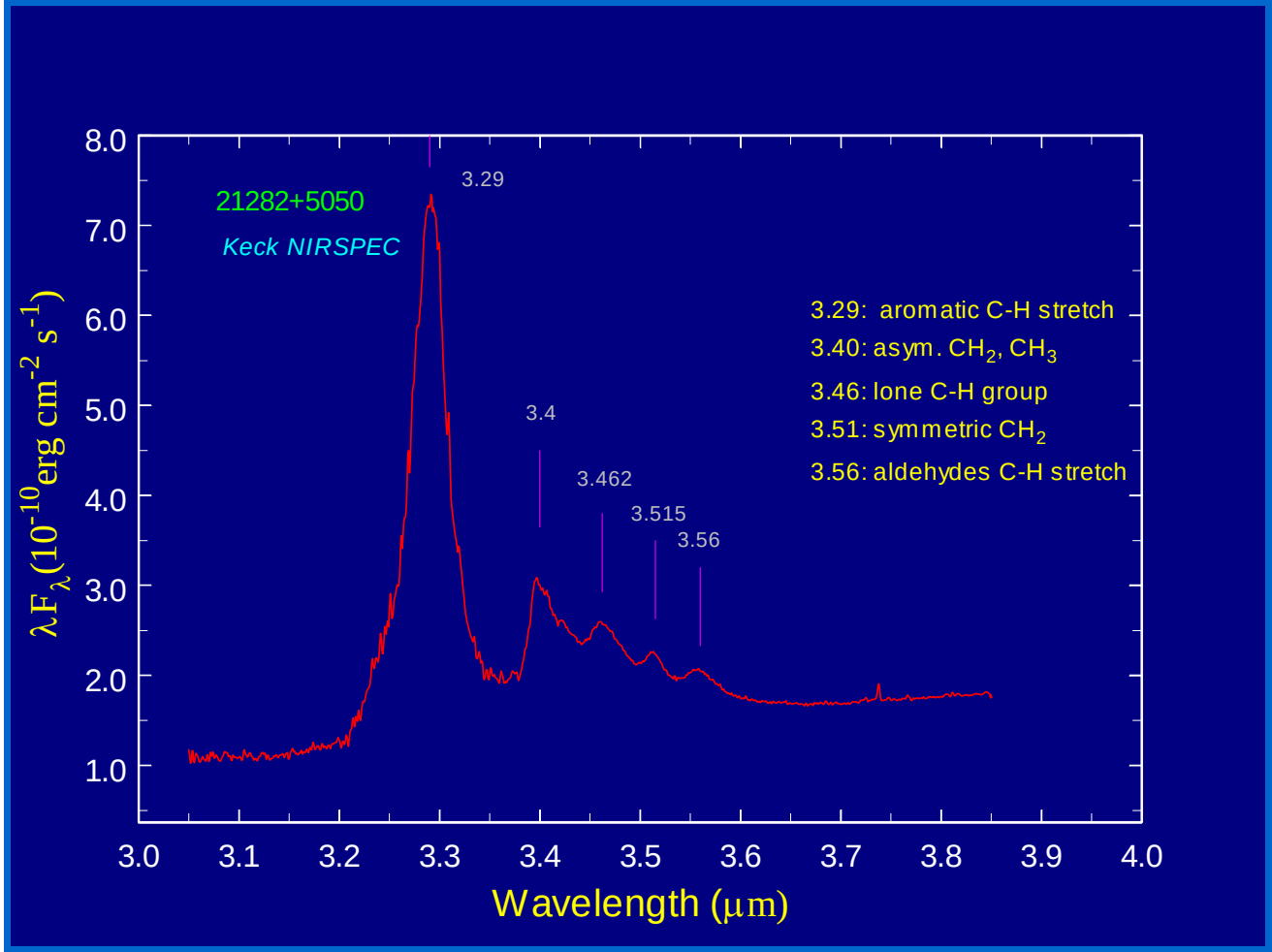
Aromatic and aliphatic features in PPN

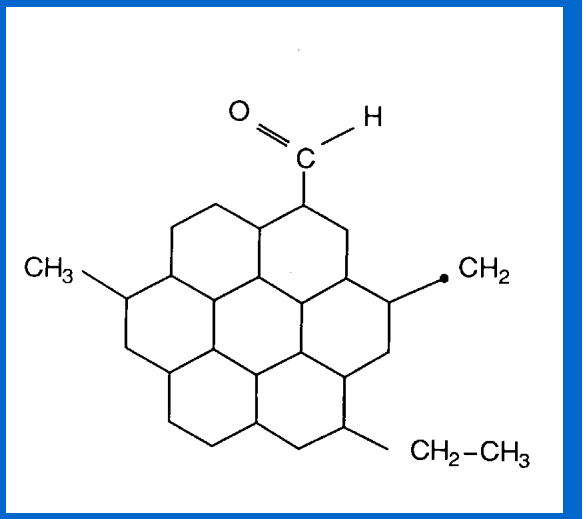


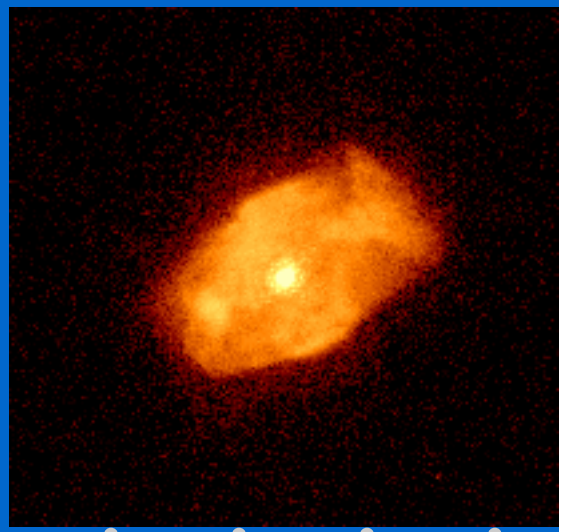
Observational confirmation of the chemical synthesis history

- When do the carriers of the AIB form?
- When do the transformation from aliphatics to aromatics occur?
- Narrow-band imaging (Kwok et al. 2001)
- Imaging spectroscopy (Goto et al. 2007)

Aliphatic sidegroups

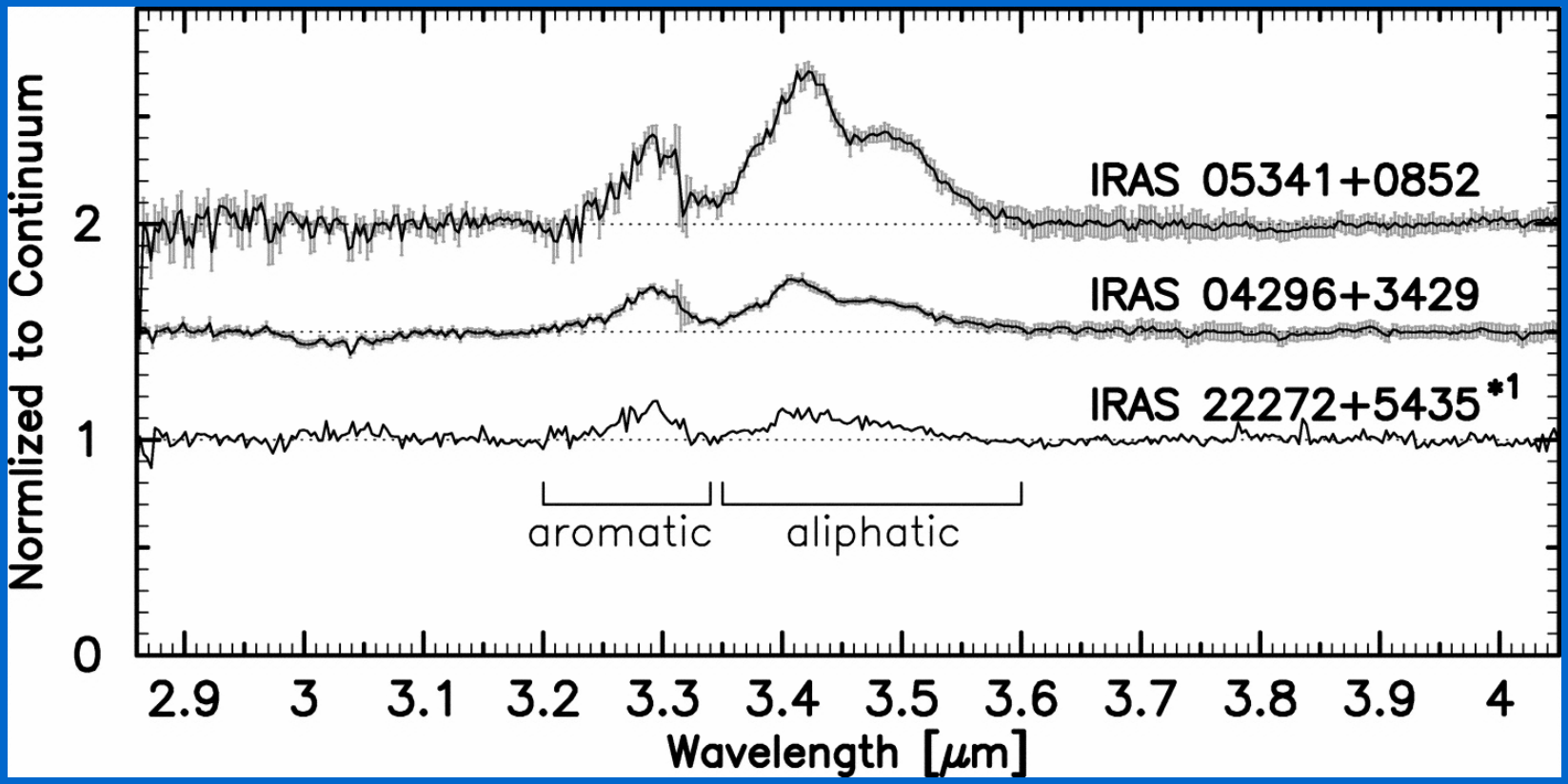






Diffraction-limited 3-μm spectroscopy

Subaru IR Camera & Spectrograph with AO



05341: unresolved, 04296: 400-640 AU, 22272: extends to 2000 AU

100-160 mas

Goto et al. 2007

Summary

- High-resolution mid-IR imaging can map out the distribution of “dark matter” in PN and help understand the origin of bipolar/multipolar morphology
- Imaging spectroscopy can map the distribution of aromatic/aliphatic organics and help understand the formation of these species