Observing and modeling disks inside pre-PN

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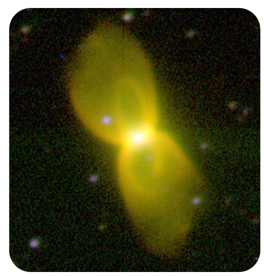
The Overarching Question

- What is the cause of the non-spherical morphologies seen in PNe?

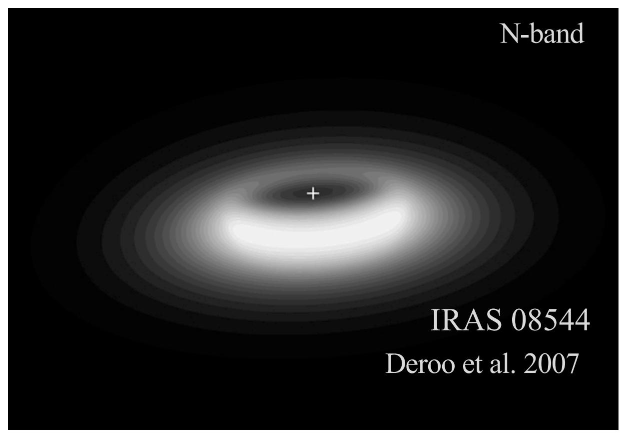


Spherical AGB mass-loss

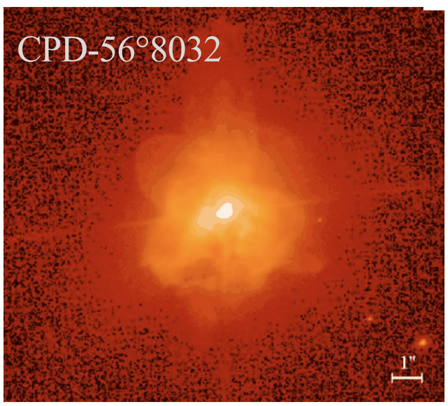
Elliptical & bipolar PNe

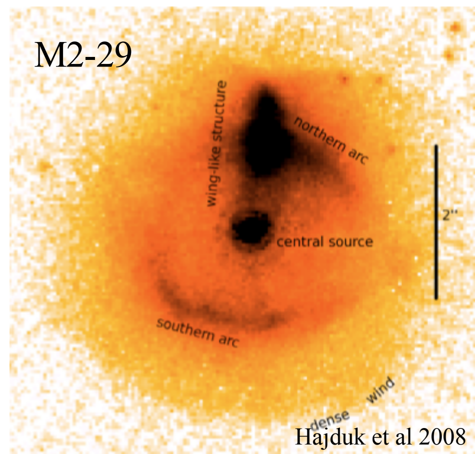
Why Study Disks?

- Scenarios to produce asymmetric PNe, such as single vs. binary star systems and long vs. short binary periods.
- Characteristics of disks can tell us about PN formation engine:
  - Size and shape
  - Mass
  - Chemical composition
  - Kinematics (Chesneau et al. 2010)
    - Torus expansion
    - Keplerian, stable disk rotation



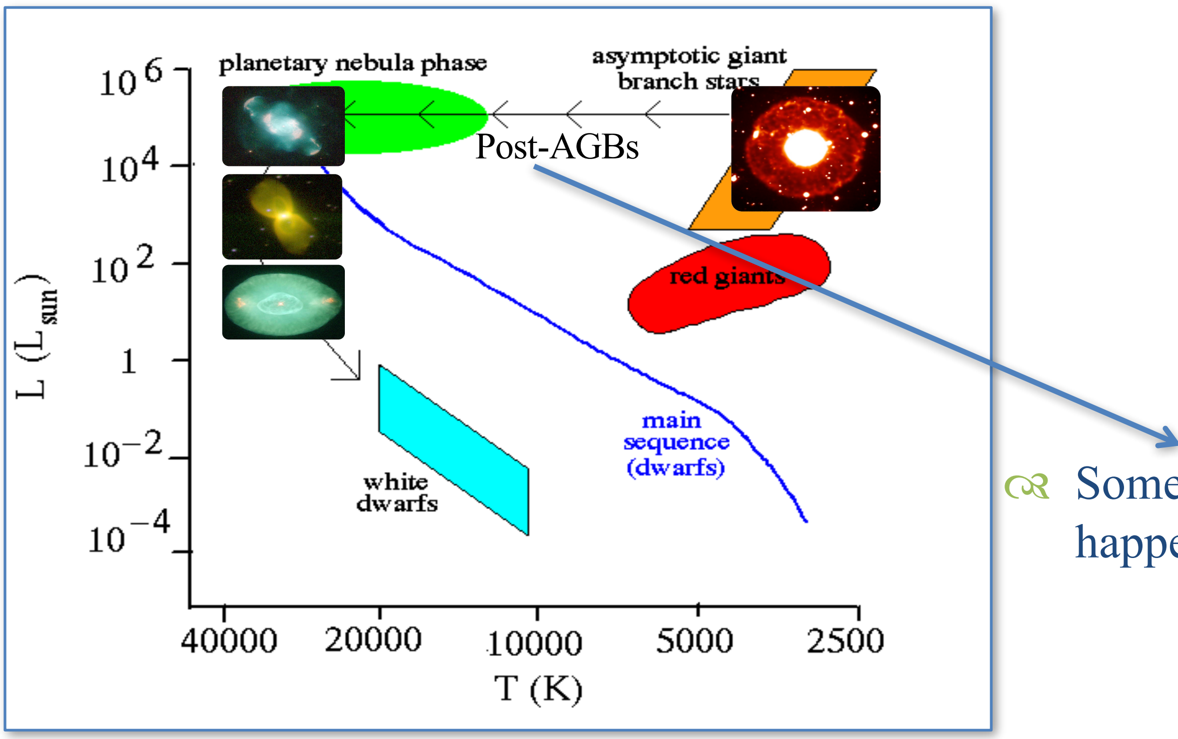
Disks found in PNe





CPD-56°8032 & M2-29
Young PN
Ring structure with inner radius, R~100AU
Dual-dust chemistry (O and C rich)
Binary period, P=17 years (M2-29 only)
Total dust mass = $1x10^{-3}$ to $1x10^{-6}$ $M_\odot$
(Chesneau et al. 2006, Gesicki et al. 2011, Miszalski et al. 2011)

Look to post-AGB objects for the answer

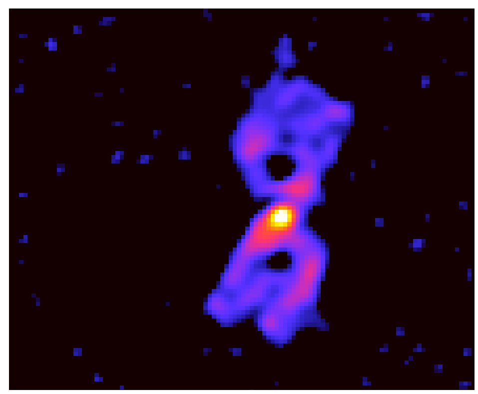


- Something must happen here!

Post-AGB objects

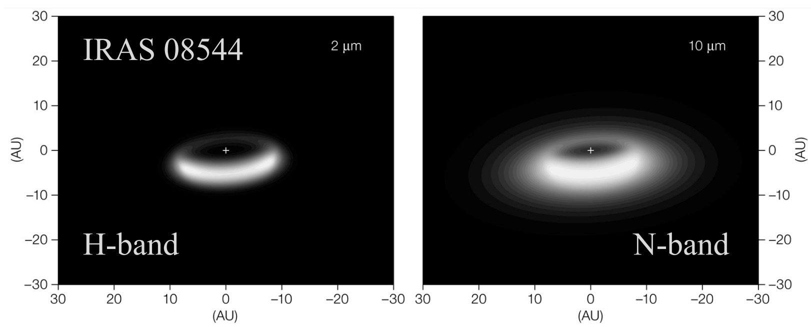
- Two Groups:
  - Naked Post-AGBs
    - Post-AGB stars *without* a refection nebula
  - Pre-PNe
    - Post-AGB stars *with* a reflection nebula
- The reason why some post-AGBs have a nebula and others don't is unknown

Pre-PN IRAS 16333



Lagadec et al. 2011

Compact Disks Around Naked Post-AGBs



Deroo et al. 2007

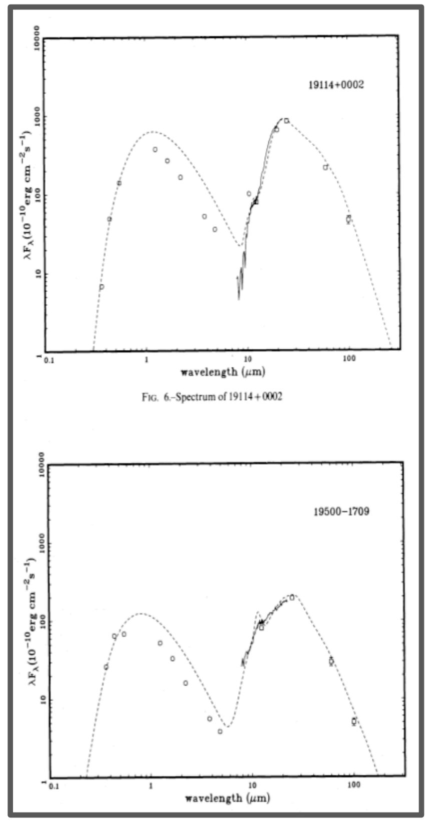
Sizes: Radius ~ 15 AU
Dust masses ~$1x10^{-2}$ $M_{\odot}$

-No reflection nebula, so likely never to become a PN
-Short period binaries found (~100-1000days)
-Strong crystalline silicate features (implying older age)
-No present day mass loss (i.e. dust is gravitationally bound)
-Keplerian rotation indicates it is likely a relic of a strong interaction phase when the primary was an AGB
-Stalling the evolution along HR diagram (possibly due to accretion)

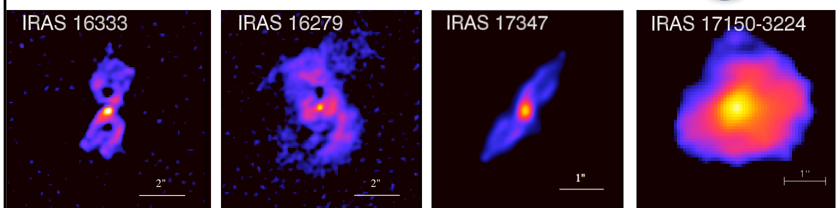
Pre-PNe

Hrivnak et al 1989

- Reflection nebulae present so will become PN
- SEDs typically have a double peak indicating a detached shell, but little is known about disks for pre-PN
- Do not have close binaries, though wider binaries may be present (Hrivnak 2011), ~6-22yrs
- Key to unlocking the mechanism to shape PN

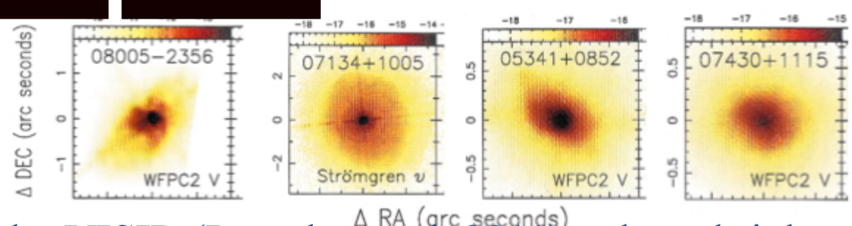


Observing Pre-PNe



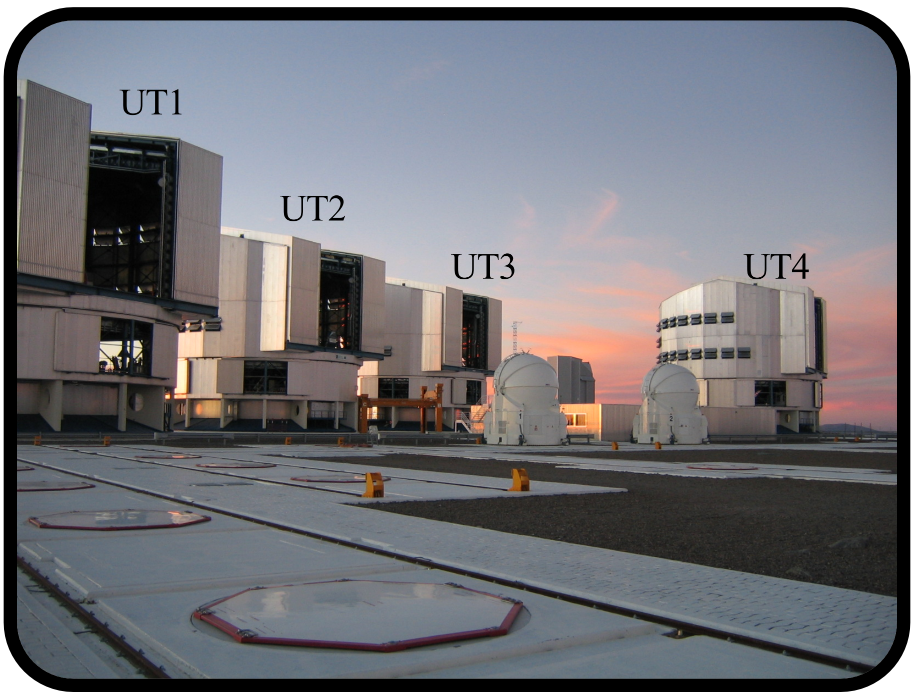
8 targets observed

UTs required because faint in the mid-IR



- All previously observed by VISIR (Lagadec et al. 2011) to have bright, unresolved or slightly resolved cores.
- Classified as post-AGB star from SED
- No confirmed binaries (though IRAS 08005 likely binary P=6yr)
- Range of morphologies and inclinations:
  - Intermediate: inner system will not be blocked by the dusty discs or
  - High: disks will be observed edge-on.

The VLTI



MIDI

Mid-IR recombiner (8-13μm)
Spatial Res=10mas
(10AU at 1kpc)

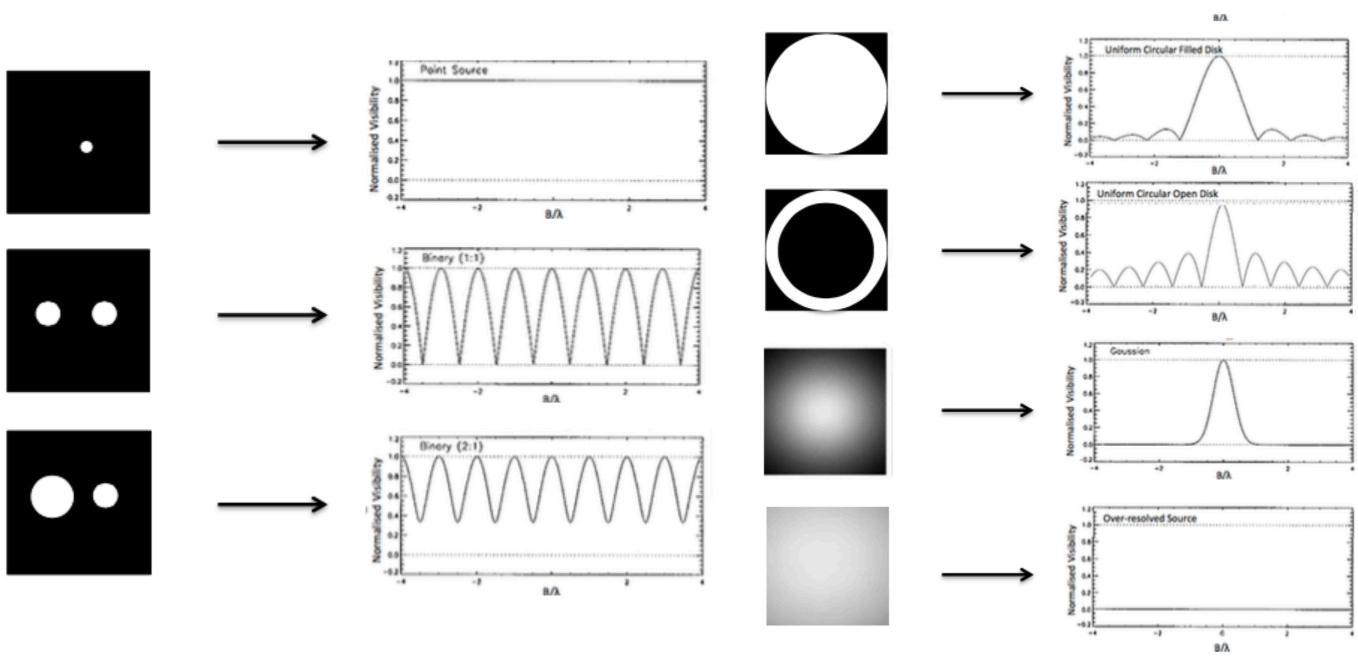
AMBER

Near-IR recombiner (1-2μm)
Spatial Res=2mas
(2AU at 1kpc)

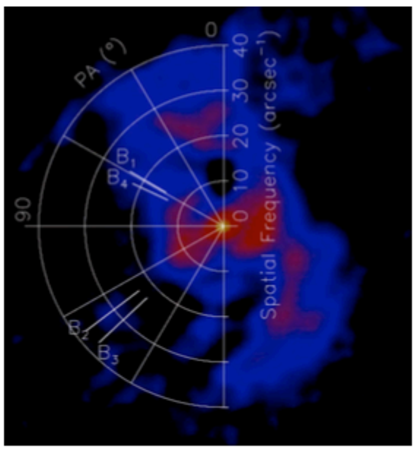
Measures VISIBILITY

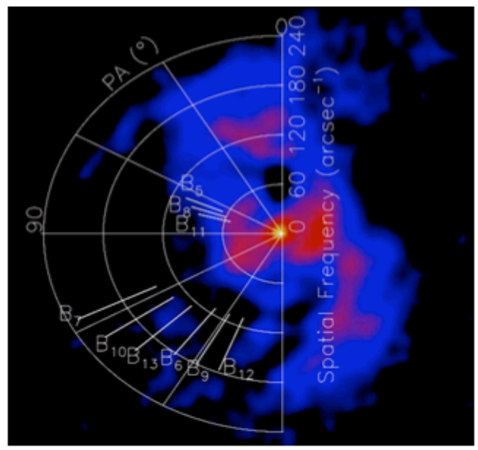
(The Fourier Transform
of the 2D flux
Integrated perpendicular
to the baseline)

Understanding Visibility Curves



IRAS 16279-4757

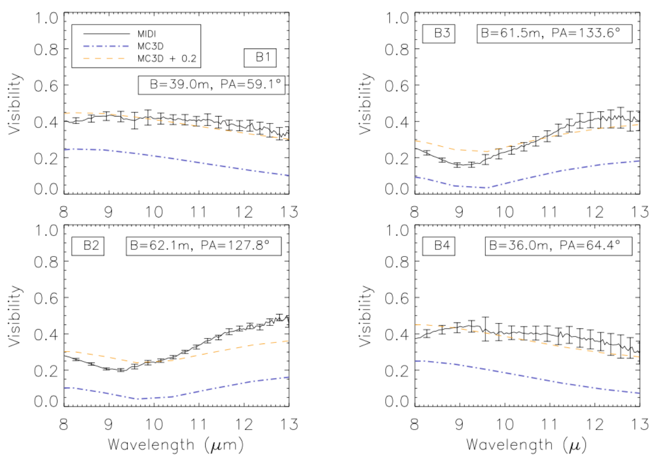


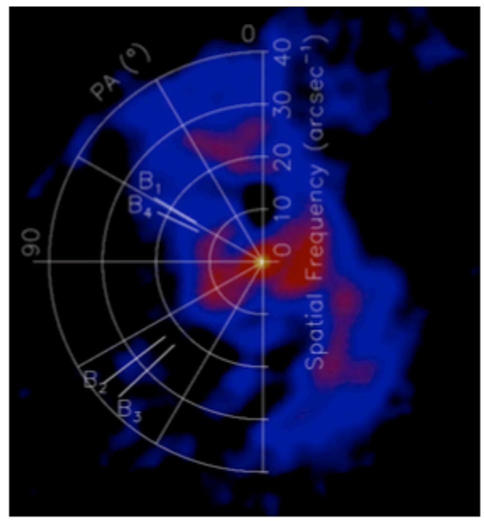


Lagadec et al. 2011

- Complex axis-symmetric nebulae with intermediate inclination
- Distance ~ 2 kpc
- 12 baselines: 4 Mid-IR, 8 Near-IR

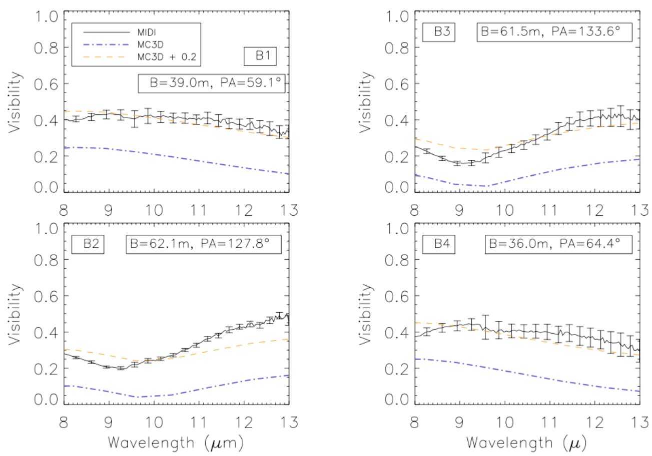
MC3D Models of IRAS 16279

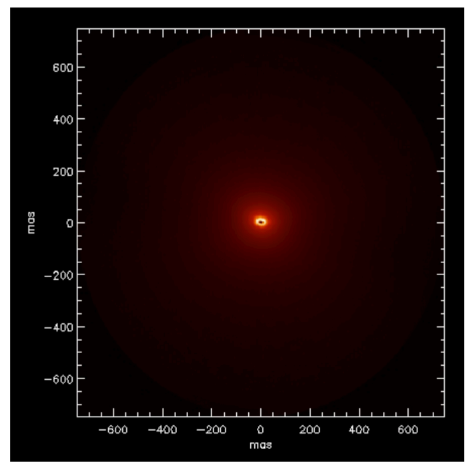




- Used DUSTY, a radiative transfer modeling code
- Parameters Include:
  - Distance, temperature of central star, luminosity, disk inner and outer radius, 3D density parameter, inclination, dust mass, composition

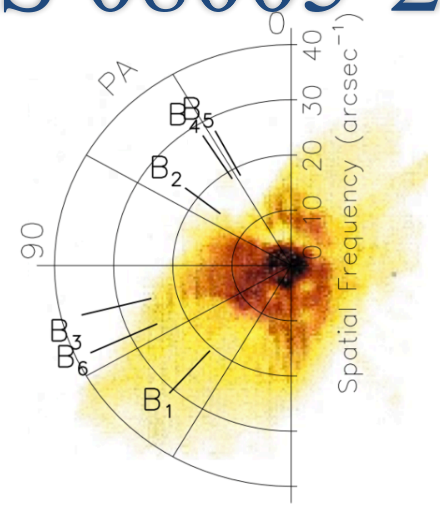
MC3D Models of IRAS 16279





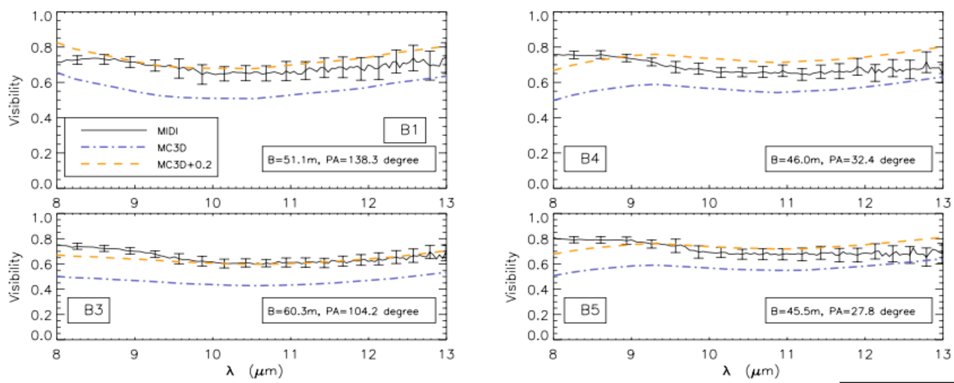
- Sinusoidal pattern indicates a "ring-like" disk
- Amorphous Carbon
- Inner Radius ~ 60AU
- Conclude that it will continue to evolve on HR-diagram and become an ionised PN

IRAS 08005-2356

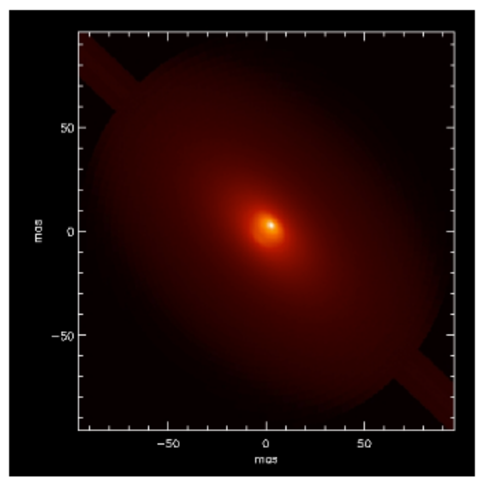


- Bipolar nebulae with inclination 60° to the line of sight
- Strong P Cygni profile – losing mass at 10-6 Msun/yr, implies companion
- Dual-dust chemistry implies there is a disk in its center
- 6 baselines in Mid-IR

MC3D Models of IRAS 08005

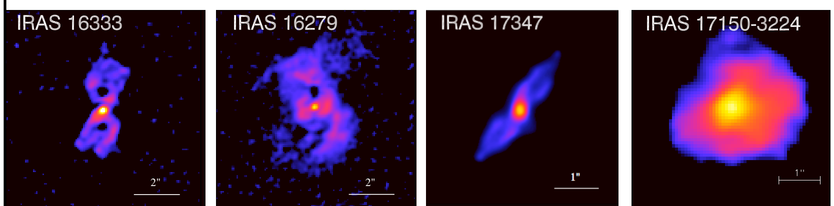


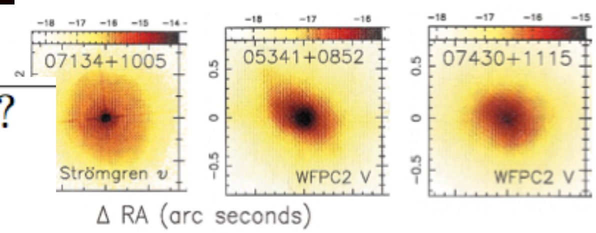
- Looks like naked post-AGB disks
- Silicate dust
- Mass = 1.5x10-5 Msun (less massive than naked post-AGBs)
- Inner Radius 5 AU
- Conclude it's a cross-over object and will stall on the HR diagram



(b) 10 μm

Observed Pre-PNe





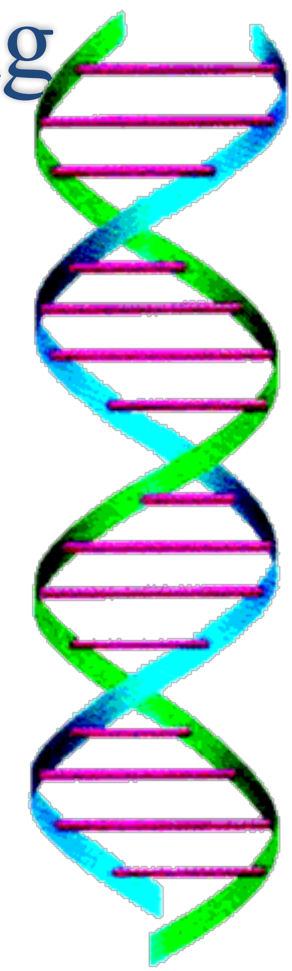
Source	Fringes?	Disk?
IRAS 05341+0852	slight	?
IRAS 07134+1005	no	no[b]
IRAS 07430+1115	slight	?
IRAS 08005-2356	yes	yes
IRAS 16279-4757	yes	yes
IRAS16333-4807	no	yes
IRAS 17150-3224	slight	?
IRAS 17347-3139	slight	yes

- Disks detected in the bipolar or multipolar nebulae
- No disks in elliptical nebulae

Genetic Modeling

- DUSTY has many free parameters which are hard to constrain (and hard to be impartial)
- We need a global, repeatable, efficient solution
- Instead use a heuristic approach, implementing a learning method via a genetic algorithm

Genetic Modeling



- Genetic algorithms are inspired by biological evolution
  - Use inheritance, mutation, selection, recombination (i.e. breeding)

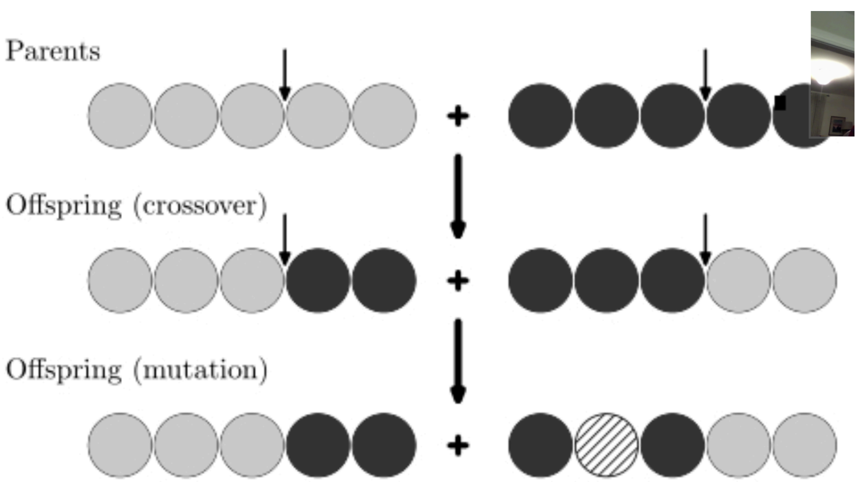
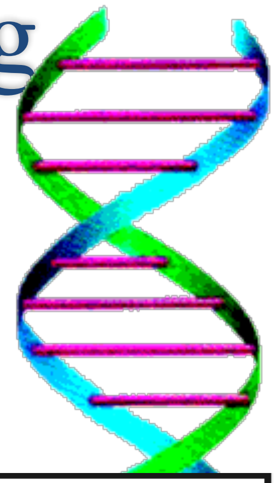
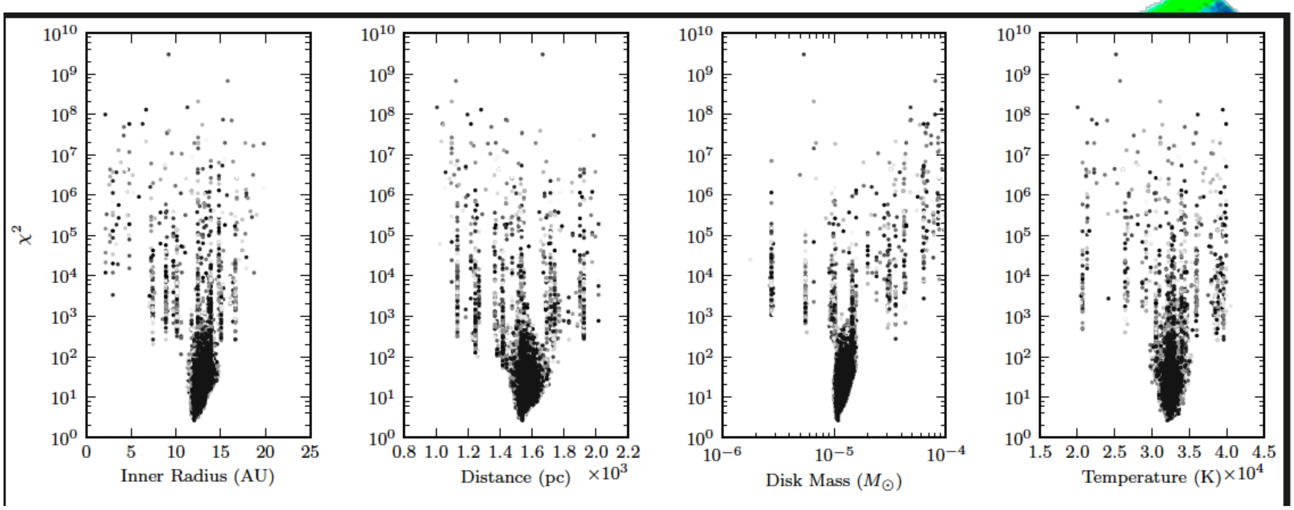


Figure 2.6: Genome

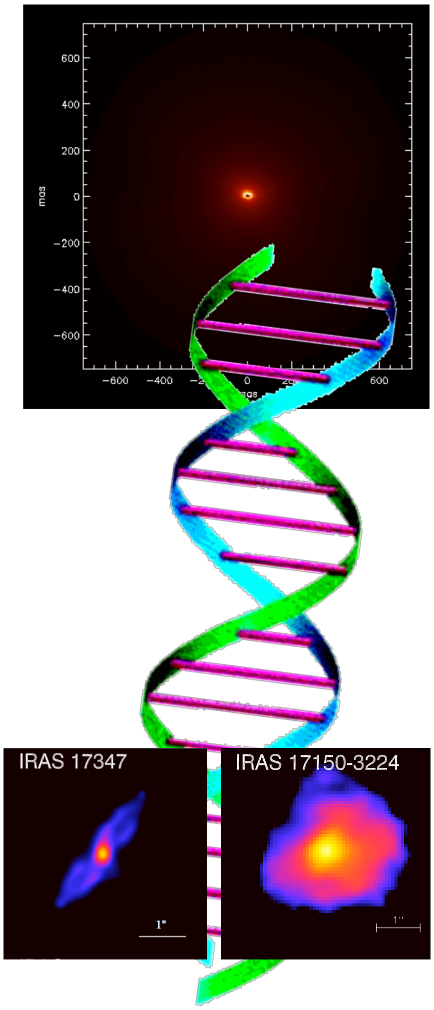
Genetic Modeling



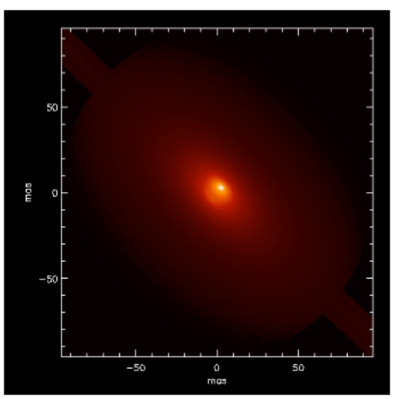
- Recreated a model with known parameters
  - Each run produces 250 generations
  - Run at least 50 times to get a solution (goal is 100 times to get good errors)

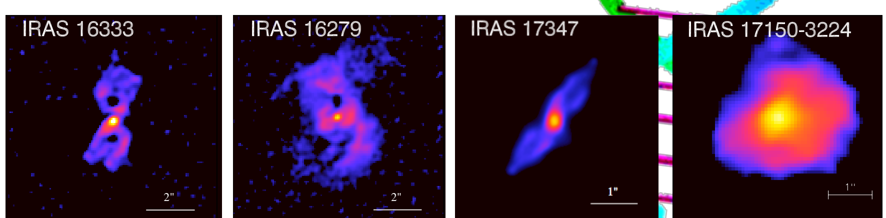


Conclusions



- Disks are found in pre-PN and driving the non-spherical morphologies
- Good modeling is key to determining the characteristics of the disks
- Will use the disks found as prototypes of post-AGB objects and how they evolve

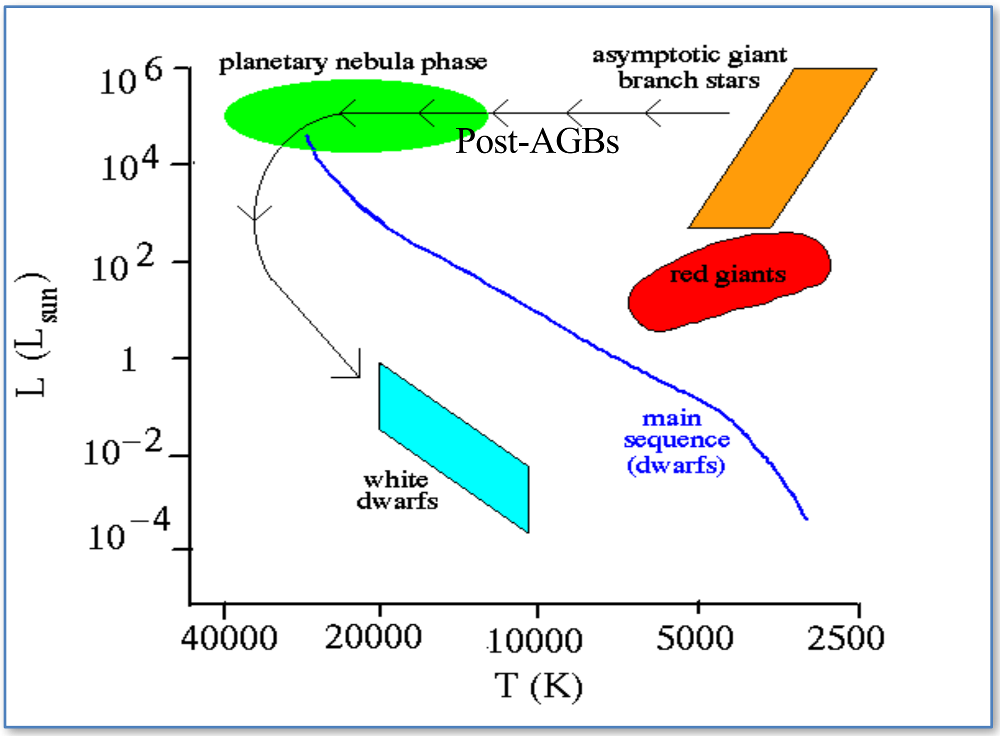




QUESTIONS

- Do compact disks exist inside typical pre-PNe? Are they common?
- What is the connection between the older, compact, stable disks found in naked post-AGBs and the younger, lower-mass toroidal disks in PNe?
  - Ex: Were naked post-AGBs once pre-PNe, but evolved too slowly along the HR-diagram (possibly due to accretion onto the primary) so the nebulous material was never ionized before it dissapated?
  - Can only longer-period binaries make the pre-PNe we see?
- What is the role of these disks in collimating (or preventing!) the subsequent nebula?

What is a Planetary Nebula (PN)?



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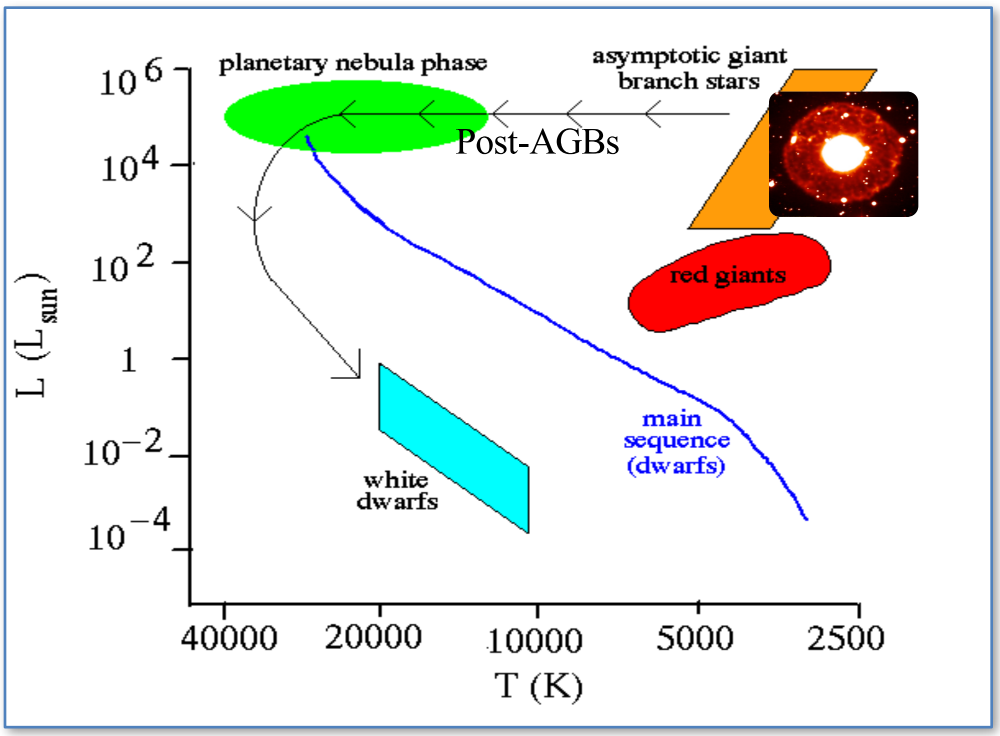

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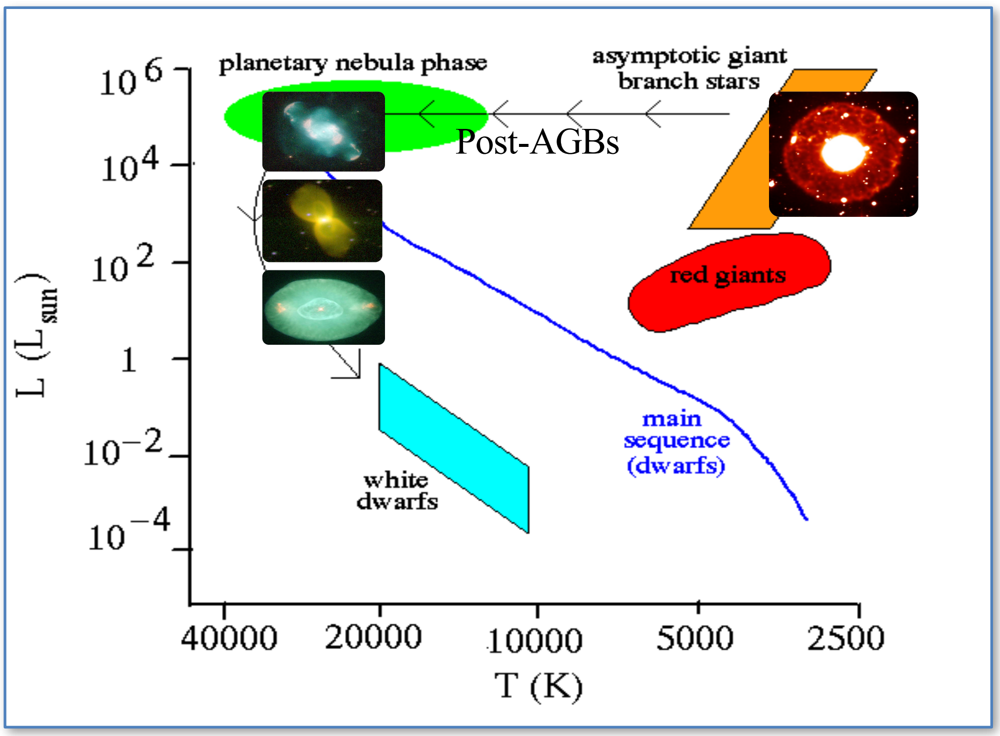
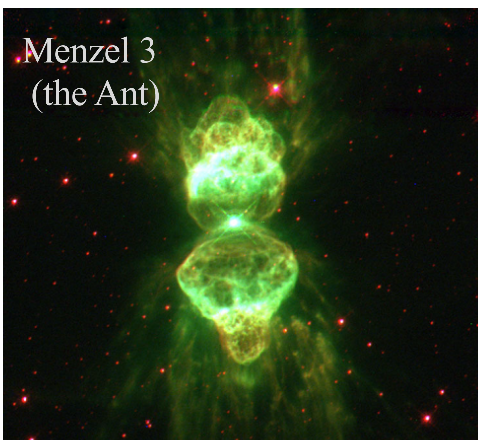


Disks found in PNe



Menzel 3 & M2-9

Bipolar PN

Disk structure with inner radius, R=9-15 AU

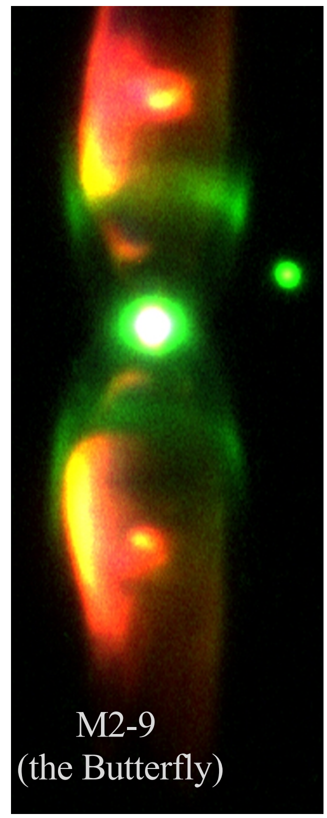
Amorphous silicate dust
(implying young age)

Binary System:
P ~ 90 yr (M2-9 only)

Total dust mass = $1x10^{-5} M_{\odot}$

(Lykou et al. 2011, Corradi et al 2011, Chesneau et al. 2007)

Probable Mimic (Frew. & Parker 2010)

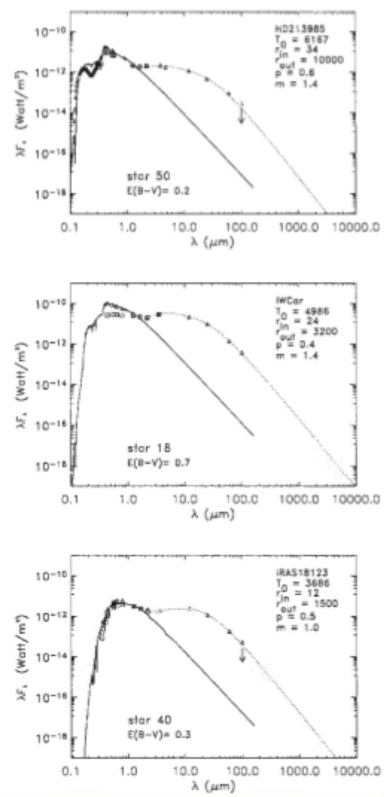


Mechanisms to produce non-spherical PNe

- Single Star with a Magnetic Field
  - Can AGB stars affect the shaping process via rotation, magnetic fields, interacting winds? (Soker 2006, Nordhaus et al. 2006, Blackman 2001)
- Binary System with a Magnetic Field
  - A binary companion can spin up the circumstellar envelope that can create a strong enough magnetic field to have a shaping effect (De Marco 2009, Soker 1997)

Naked Post-AGBs

- Characteristics:
  - NO reflection nebulae. As such, will likely not evolve into PNe
  - SEDs show large IR-excess with BB shape at near/mid IR wavelengths (signature of compact disk)
  - Link between binarity and disk formation:
    - Keplerian disks found to be common (De Ruyter et al. 2006)
    - Binaries found to be common (De Ruyter et al 2005, 2006, Van Winckel et al 2009)
      - P = 100-2000 days



De Ruyter et al. 2006

Mechanisms to produce asymmetric nebulae

- A binary companion can focus the mass-loss in the orbital plane
- Types of binary systems:
  - Short period Binaries:
    - P=100s days – few years
    - Go through a common envelope on the AGB, which can result in a very close binary inside the PN (or a merger)
    - A stable *Keplarian disk* may form

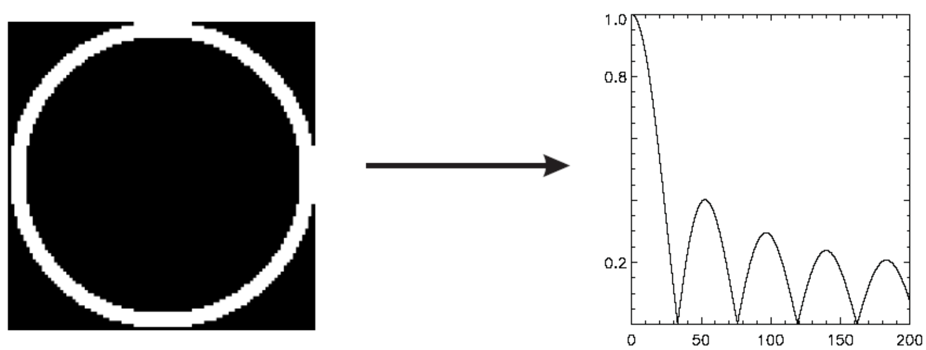
Mechanisms to produce asymmetric nebulae

- A binary companion can focus the mass-loss in the orbital plane
- Types of binary systems:
  - Long period Binaries:
    - P ~ 10s of years
    - No common envelope, but the companion is close enough to affect shaping
    - An expanding *torus-like disk* may form in the orbital plane

Disk Comparison Across Groups

	PNe (sample size ~6 targets)	Naked Post-AGBs (sample size > 20 targets)	Pre-PNe (sample size 1-2 targets)
Disk Inner Radius	~100 AU	~ 15 AU	?? (crossover ~15 AU)
Disk Mass	$10^{-3} – 10^{-6}$ M$_\odot$	~ 10^{-2} M$_\odot$	?? (crossover = 10^{-4} M$_\odot$)
Disk Composition	Amph. Silicates or dual dust	Crystalline silicates	?? (crossover= dual dust)
Binary Period	17 – 90 years	100 days – 5 years	?? 22 years (Hrivnak et al) (crossover ~400 days)

Understanding Visibility Curves



Pre-PNe

Hrivnak et al 1989

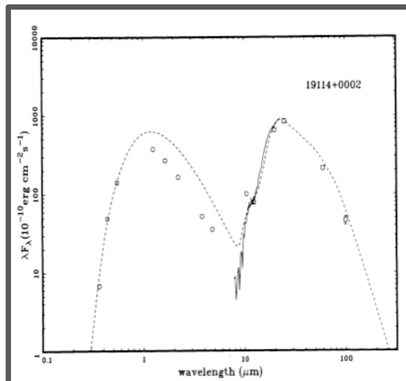


FIG. 6.–Spectrum of 19114+0002

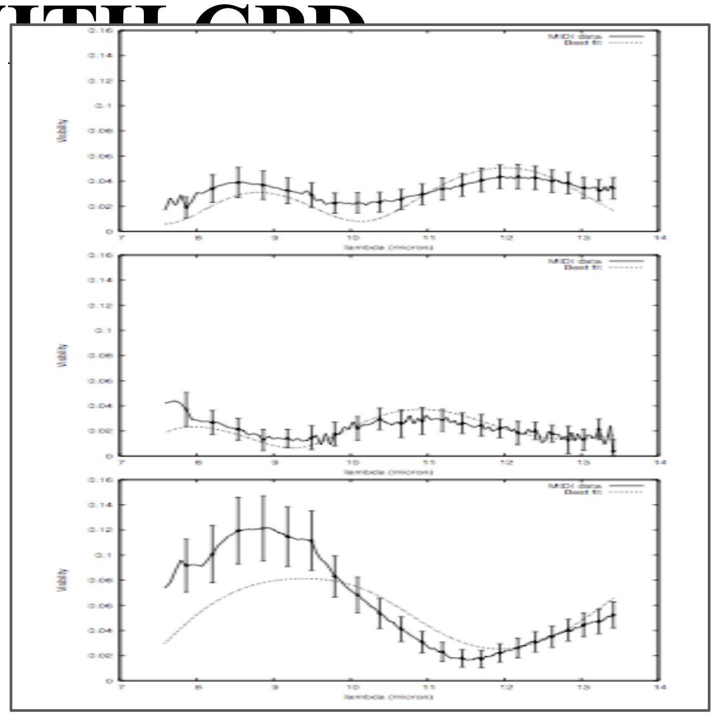
- Reflection nebulae present so will become PN
- Key to unlocking mechanism to shape PN
- SEDs typically have a double peak indicating a shell, but little is known about disks for pre-PN
- Do not have close binaries, though wider binaries may be present (Hrivnak 2011)
- Red Rectangle and HR 4049 only two to have compact disks, but they look like naked post-AGB, not typical pre-PN
    - These are cross-over objects likely to become naked post-AGB

QUESTIONS

- So far, there are not many studies of compact disks inside *typical* pre-PNe, but there is a striking difference between these objects and naked post-AGBs
- Do compact disks exist inside typical pre-PNe? Are they common?
- What is the connection between the older, compact, stable disks found in naked post-AGBs and the younger, lower-mass toroidal disks in PNe?
  - Ex: Were naked post-AGBs once pre-PNe, but evolved too slowly along the HR-diagram (possibly due to accretion onto the primary) so the nebulous material was never ionized before it dissapated?
  - Can only longer-period binaries make the pre-PNe we see?

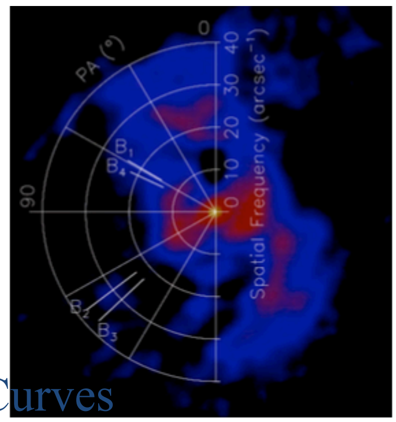
IRAS 16279-4757 INITIAL RESULTS-- COMPARISON WITH CPD-56°8032

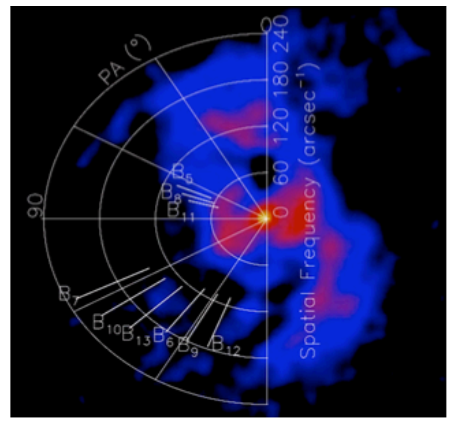
- Similar Sinusoidal pattern in visibilites, but lower signal
- Similar size of disk
  - IRAS 16279 ~70-150 AU
  - CPD-56 = 97±11 AU
- Similar inclination
  - IRAS 16279 ~30-60°
  - CPD-56 = 28±7°



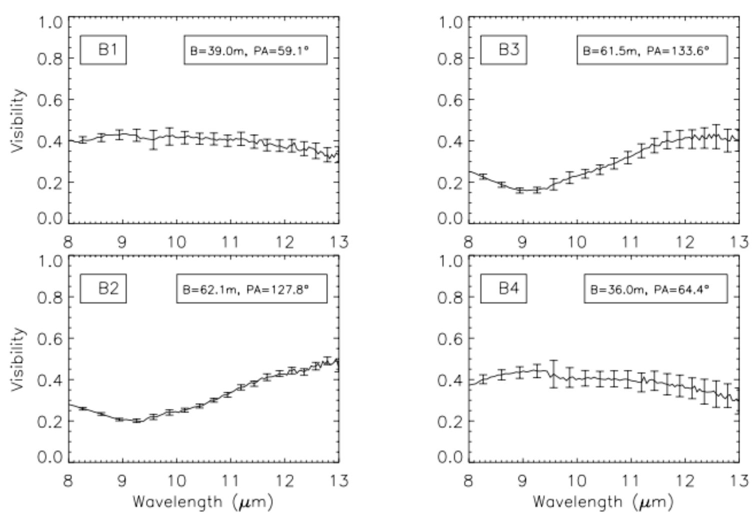
Chesneau et al. 2006

IRAS 16279-4757





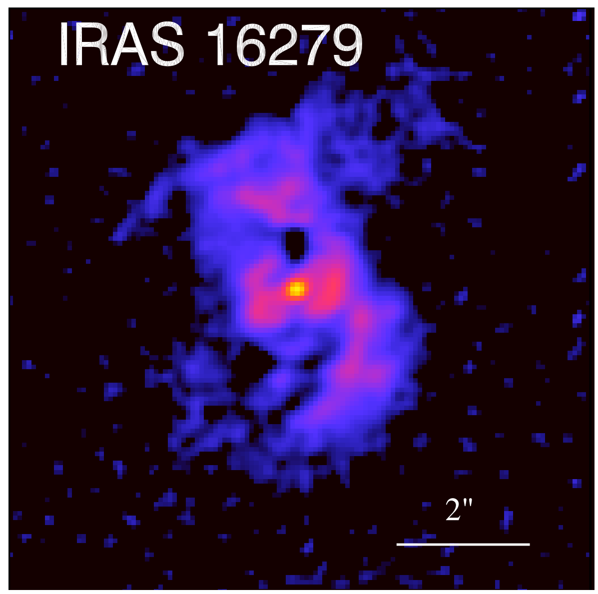
MID-IR (MIDI) Visibility Curves



- Sinusoidal pattern indicates a "ring-like" disk
- High visibility (~0.4 - 0.6), indicating a compact source in the center (stellar or otherwise)

IRAS 16279-4757

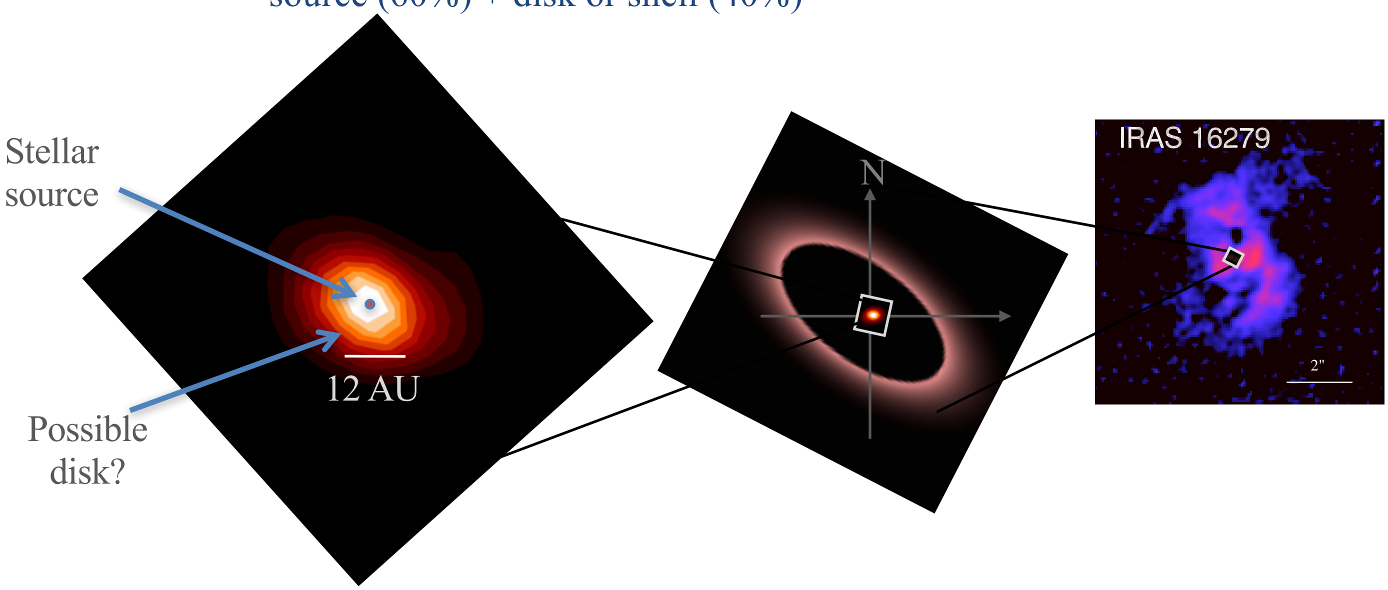
- Complex axis-symmetric nebulae with intermediate inclination
- Classified as PAGB object based on SED (van der Veen, Habing & Geballe 1989)
- Optical spectra suggest spectral type of G5 (Hu et al 1993)
- Has PAHs and crystalline silicates like the Red Rectangle (Matsuura et al. 2004)
- Distance ~ 2 kpc



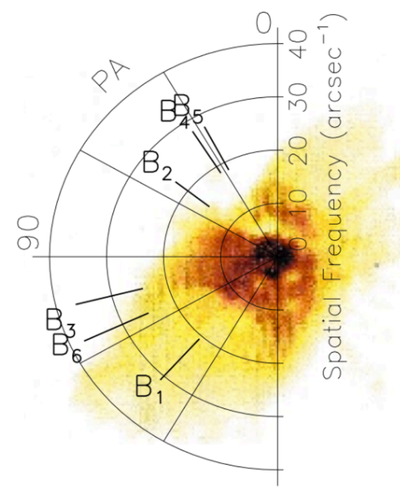
Lagadec et al. 2011

IRAS 16279-4757

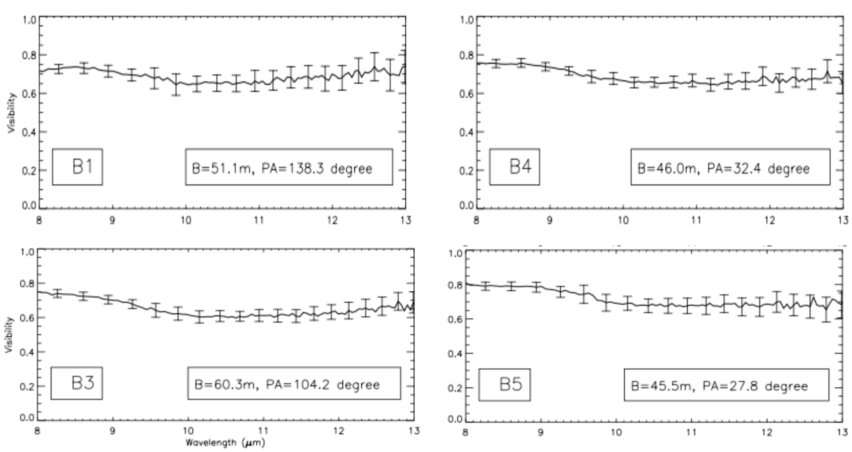
- Observations with AMBER (near-IR)
  - HK-band visibilities show a 2-component source inside the ring: stellar source (60%) + disk or shell (40%)



IRAS 08005-2356

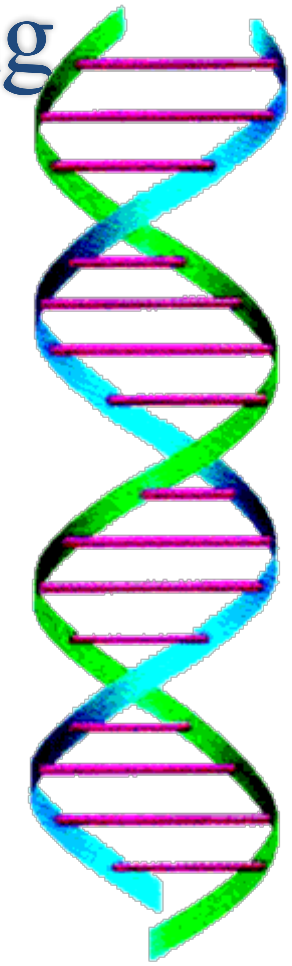


MID-IR (MIDI) Visibility Curves



- Flatness across wavelengths indicates a disk 40% larger at 13micron than 8 micron
- Inner rim not resolved (i.e. no jump at 8-9micron as seen before)

Genetic Modeling



- Running models now
  - Repeatable, reliable
  - Run at least 50 times to get a solution (goal is 100 times to get good errors)