Dusty disks in evolved stars?

- Post-AGB (Asymptotic Giant Branch) stars
- Planetary Nebulae (PNe)

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What are post-AGB stars, planetary nebulae (PNe)?

The evolutionary tracks of 1, 5 and 25 Msun stars on the HR diagram (Iben 1995)

- Late stage of stellar evolution for low mass stars (1-8 Msun in main sequence)
Some examples of unique shapes and common-names

NGC 6537
Spider Nebula

OH 231.8+4.2
Rotten Egg Nebula

NGC 2392
Eskimo Nebula

NGC 6542
Cat’s Eye Nebula
Current problems in the field of PNe research

- Change in shapes

Main Sequence (MS) → AGB stars → Planetary nebulae (PNe)

Mass loss

1-8 Msun → Central star: ~0.6 Msun
Post-AGB stars and PNe

- Asymmetric structure
  - Round
  - Ellipse
  - Bipolar
- AGB stars: spherical symmetry

Balick & Frank (2002)
Formation mechanisms of bipolar outflows

- Circum-(binary) disk
- Remnant of AGB mass loss
- Magnetic field

Balick & Frank (2002)
Disk model

- Hydrodynamic model by Icke (2003)
- A warped disk
Two cases

- NGC 6302 (Bug Nebula)
- OH 231.8+4.8 (Rotten Egg Nebula)
Butterfly nebula

- Icke’s model resemble to the shape of NGC 6302
- About 8 arcsec disk?

Matsuura et al. (2005)

NGC 6302
HST optical image (Hα, Nell composite)
Dense disc

Extinction map $A(H\alpha)$ [mag]

$H\alpha$ - 6 cm

Matsuura et al. (2005)
JCMT 450 µm image

- Central core
- Bipolar
Source of 450 µm flux

Core

$I_{450\mu m} = 3\,\text{Jy per beam}$

$I_{450\mu m}\,(\text{ff}) \approx 0.4\,\text{Jy per beam}$

$\rightarrow 450\mu m$ dust excess

Lobe

$I_{450\mu m} \approx 1\,\text{Jy per beam}$

$I_{450\mu m}\,(\text{ff}) < 0.1\,\text{Jy per beam}$

6 cm image (free-free emission)
Results for NGC 6302 study

- A warped disc
- Expanding disc
- Formation mechanism of the disc
  - Circum(-binary) disc. Binary? Too large inner radius?
  - Magnetic field can form the bipolar, however, the presence of the disc is not necessary
Compact disks

- Icke’s model’s
  - Too large disk compared with the size of outflow
  - In most of the case, disk is more compact, especially at early phase of post-AGB

HST Optical image of the post-AGB star, OH 231.8+4.2
The post-AGB star, OH 231.8+4.2

- HST optical image
  - Red: 791nm (cont.)
  - Green: 675 nm (cont.+ionise lines)
  - Blue: combination of Ha (656nm) and NeII (658nm)
- Collimated outflow
- Shocked bubble
- Dense torus
Infrared images of OH 231

Bujarrabal et al. (2002)
Infrared images of OH 231

- Infrared
  - Ionized lines
  - Less dust extinction
  - Central region is more apparent
- Very compact and bright object at the centre

Matsuura et al. ApJL accepted
Infrared images of OH 231

(b) L-band

11.7 micron
Jura et al. (2002)
Very compact disk

- Jura et al. (2002)’s fitting to SED
- Compact disk
- The emission from blackbody at 130 K from a cylinder of radius $5 \times 10^{15}$ cm at a tilt angle of 54 degrees
MIDI VLTI observations

- MID-infrared Interferometric instrument (MIDI)
- UT3 - UT4 62.4 metre baseline
MIDI VLT observations

- Observing log
- Small angular information
- Variation in projected length

<table>
<thead>
<tr>
<th>OB</th>
<th>UT time</th>
<th>Airmass</th>
<th>Projected baseline Length [metre]</th>
<th>PA [degrees]</th>
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<tbody>
<tr>
<td>OB1</td>
<td>02:04–02:07</td>
<td>1.02</td>
<td>61.7</td>
<td>112.0</td>
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<tr>
<td>OB2</td>
<td>02:53–02:55</td>
<td>1.06</td>
<td>58.9</td>
<td>116.2</td>
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<tr>
<td>OB3</td>
<td>03:55–03:57</td>
<td>1.19</td>
<td>52.8</td>
<td>123.8</td>
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<tr>
<td>OB4</td>
<td>04:38–04:40</td>
<td>1.35</td>
<td>47.4</td>
<td>131.2</td>
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</tbody>
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Spectra from MIDI

Flux [Jy]

Wavelength [micron]
Visibilities (correlated flux)

![Graph showing correlated flux vs wavelength for different telescopes.]

- OB1 (61.7m)
- OB2 (58.9m)
- OB3 (52.8m)
- OB4 (47.4m)
Distance 1.3 kpc, member of open cluster M46 (Jura & Morris 1985)
Model fit (preliminary)
Comparison with other observations

- MIDI : 40-50 AU
- SiO : 3 AU
- MIDI
  - Circumstellar material (probably disk)
  - Not the central star

R(star) ~ 3 AU
Sanchez Contreras et al. (2002)
Binary disk model

- Binary with a separation of 10-100 AU
- Binary disk may be formed

Mastrodemos & Morris (1999)
Conclusion & Future work

- Circumstellar material with a radius of 40-50 AU (upper limit)
- Very compact: binary disk?
- Future: measurements of visibilities in different uv-plane
Model for far-infrared excess

- Dust $\sim 0.03\text{Msun}$
- $T_{\text{dust}} < 100\text{K}$
- $1 \times 10^{16}\text{cm} < R_{\text{dust}} < 10 \times 10^{16}\text{cm}$