External shaping of circumstellar envelopes of evolved stars.

Nick Cox (KU Leuven)

Why Galaxies Care About AGB Stars III. Vienna. July 29th, 2014
Motivation.

Wind-ISM interaction can

• be a **proxy of (history of) stellar winds** (mass-loss rates, epochs of enhanced mass-loss).

• serve as a **proxy of the local ambient medium** (density, temperature, magnetic field).

• **uncover stellar motion** (through size & shape).

• reveal physics of **grain-gas coupling** and **dust grain processing** (from the circumstellar to interstellar environments).
Today.

I will focus on these questions

• What are **bow shocks & bow waves** (asterospheres)?

• How does this relate to **evolved stars**?

• **Morphologies** of bow waves/shocks for cool stars?

• Inferring **(inter)stellar properties**?

• Deciphering imprints of **stellar evolution**?
Asterospheres: concept.

Basic idea: Expelled wind (gas and mass loss) interacts and sweeps up the surrounding interstellar medium. i.e. Wind-ISM interaction

**bow shock:**
where $v_{\text{ISM}}$ goes from supersonic to subsonic values

**asteropause:**
where $P_{\text{ISM}} = P_{\text{CMS}}$ [P=pressure]
→ inner (CSM) & outer (ISM) astrosheath

**termination shock:**
place where $v_{\text{wind}}$ goes from supersonic to subsonic values

[Figure credit: Dries Nicolaes]
Asterospheres

Wind-ISM ram pressure balance dictates:

\[ R_0 = \sqrt{\frac{\dot{M} v_{\text{wind}}}{4\pi \rho_{\text{ISM}} (c_{\text{ISM}}^2 + v_{\text{star}}^2)}} \]

Wilkin 1996, Weaver 1977

<table>
<thead>
<tr>
<th></th>
<th>Old cool star</th>
<th>Young hot star</th>
<th>G star</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{\text{wind}} ) (km/s)</td>
<td>10-30</td>
<td>500-2500</td>
<td>400 - 700</td>
</tr>
<tr>
<td>( M ) (M$_{\odot}$/yr)</td>
<td>10$^{-7}$ - 10$^{-5}$</td>
<td>10$^{-7}$ - 10$^{-5}$</td>
<td>10$^{-15}$ - 10$^{-13}$</td>
</tr>
<tr>
<td>( V_{\text{star}} ) (km/s)</td>
<td>30</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>( n(H)_{\text{ISM}} ) (cm$^{-3}$)</td>
<td>1</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td>( R_0 ) (pc)</td>
<td>~ 0.1 – 1</td>
<td>~ 0.5 – 10</td>
<td>~0.001 (200 AU)</td>
</tr>
</tbody>
</table>

PACS 70μm
Asterospheres: stability.

Dgani et al. (1996)

(M=∞, isothermal)

Bow shocks with

\( \frac{v_\star}{v_w} \ll 1 \rightarrow \text{stable} \)

\( \frac{v_\star}{v_w} \gg 1 \rightarrow \text{unstable} \)

Van Marle et al. (2011)

Hydrodynamical model

PACS 70μm
Dust & gas in cool star astrospheres.

– early results –

- Betelgeuse - IRAS 60μm
  - Noriega-Crespo et al. 1997

- R Hya - MIPS 70μm
  - Ueta et al. 2006
  - + some evidence for R Cas and Mira (Ueta+ 2009).

- Betelgeuse - AKARI 60+90μm
  - Ueta et al. 2008
Dust & gas in cool star astrospheres. – early results –

MIRA – GALEX FUV

Martin et al. 2007

CW Leo – GALEX FUV

Presence of extended HI interacting with ISM inferred from line profiles by e.g. Gerard & Le Bertre (2006).

Sahai & Chronopoulos 2010
Herschel far-infrared survey of AGB/RSG.

Mass-loss of Evolved Stars (Groenewegen et al. 2011)
Herschel far-infrared survey of AGB/RSG.

Jorissen et al. (2011)
**Herschel** far-infrared survey of AGB/RSG.

IR-imaging 70 & 160 um:

32 O-rich AGB/RSG, 9 S-stars, 37 C-stars

Mass loss rate: $10^{-4} - 10^{-8}$ M$_\odot$/yr,
slow winds: $v_w = 5$-20 km/s

<table>
<thead>
<tr>
<th>Type</th>
<th>N</th>
<th>N (d &lt; 500 pc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fermata</td>
<td>24</td>
<td>22</td>
</tr>
<tr>
<td>Eye</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Ring</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>Irregular</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Point source</td>
<td>28</td>
<td>13 (35%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13 (20%)</td>
</tr>
<tr>
<td>Total</td>
<td>81</td>
<td>61</td>
</tr>
</tbody>
</table>

53 out of 81 objects reveal complex CSE morphology!
Imaging circumstellar HI gas.

Matthews et al. (2013); Matthews & Reid (2007) present VLA imaging of HI. Few targets in common with MESS but comparison difficult due to lower spatial resolution of HI maps.
Imaging circumstellar HI gas.

Matthews et al. (2013); Matthews & Reid (2007) present VLA imaging of HI. Few targets in common with MESS but comparison difficult due to lower spatial resolution of HI maps.
Hydro-dynamical models.

Villaver et al. (2012)  Following evolution (change $dM/dt$) – snapshot at 0.5 Myr.

$v_* = 10 \text{ km/s}$  $v_* = 30 \text{ km/s}$

$v_* = 50 \text{ km/s}$  $v_* = 100 \text{ km/s}$

$M_{\text{AGB}} = 1 \, M_{\odot}$  $M_{\text{AGB}} = 3.5 \, M_{\odot}$
MESS results: *External* shaping of CSE.
From $R_0 = 0.26$ pc $\rightarrow n_H > 2$ cm$^{-3}$ $\rightarrow v_* < 75$ km/s

From Ladjal et al. 2010 (Herschel), Sahai & Chronopoulos 2010 (GALEX).
Intensity profiles of offset along minor axis of ellipse increasing from west to east. Normalised to intensity at 558” (shifted for clarity) – from Ladjal et al. (2010).
Neither [O I] line emission at 63 µm nor [C II] at 157 µm

$\frac{v_*/v_w}{v_w} > 1$

$\rightarrow$ unstable bow shock

RT instabilities may fragment bow shock in direction of motion.

Magnetic field may suppress some modes but accentuate others, leading to 'RT stripes' (Dgani & Soker 1998).

Arcs separated by 30” at distance of 330” yields (Eq 4 in Dgani 1998). Alven speed of pre-shock ISM of ~4 km/s.

For $n_{\text{ISM}} = 4 \text{ cm}^{-3} \rightarrow B = 3 \mu\text{G}$. 

Decin+2012
Le Bertre et al. (2012)

HI gas associate to the bow shock.

Betelgeuse.
Probe of ISM density.
Protection of shells & spirals.
Eyes in the Sky.

Van Marle, Cox & Decin (2014)

start eye-shape at 20,000 years
jets appear after 60,000 years

\[ M_{\text{dot}} = 10^{-7} M_{\odot}/\text{yr}, \quad v_{\text{wind}} = 10 \text{ km/s}, \quad B = 10 \mu\text{G}, \quad n_{\text{ISM}} = 2 \text{ cm}^{-3} \]
Some answers & new questions.

- Herschel demonstrated the **ubiquitous occurrence of dusty asterospheres around AGB stars** (including resolving KH and RT instabilities!)

  → Independent tools to **estimate stellar and/or interstellar parameters**.

  → Shape affected by **binarity** and **magnetic field**.

  → Shells related to **circumstellar chemistry** (thermal pulse history).

  → ISM dust mass ~1 to 25 % for evolved stars (cf. ~100% for O/B stars).

- **AGB/RSG asterospheres primarily detected via their dust** (exception: CW Leo).

- No detection of Hα yet; a few HI detections of CSE. Possibly HI co-spatial with dusty arcs of Betelgeuse!
Some answers & new questions.

- Herschel demonstrated the ubiquitous occurrence of dusty asterospheres around AGB stars (including resolving KH and RT instabilities!)
- AGB/RSG asterospheres primarily detected via their dust (exception: CW Leo).

- Multi-wavelength imaging AND spectroscopy of larger sample of asterospheres to understand bow shock physics, interplay gas and dust, and origin of varying morphologies.
- Work in progress: Introducing dust grains (size distribution, formation/destruction), chemistry, and magnetic fields in the hydrodynamical simulations.
- Asterospheres around later type (post-AGB/proto-PNe) or solar-type stars?
Parting words.
Parting words.

Context is important!

or

Why AGB (RSG) stars care about galaxies.