The first water fountain in a PN with synchrotron emission

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Outline

- Water fountains in context
  - What are they?
  - Why to study them?
- Water masers in PNe
- IRAS 15103-5754
  - Masers
  - Radio continuum
  - Real-time changes
Water masers

- **Where are they found?**
  - In the environments of YSO and star forming regions
  - In AGNs
  - In evolved objects: AGB, post-AGB, PN

- **Which physical processes?**
  - Hyperfine transition between two rotational states: $6_{16} \rightarrow 5_{23}$
  - Excitation mainly by shocks

- **Which physical conditions?**
  - Special conditions in T and P -- $T \approx 100K$
  - Abondances: $n(H_2O)/n(H_2) \rightarrow 2-4 \times 10^{-4}$
  - $nH_2 \leq 10^{11} \text{ cm}^{-3}$

- **Advantages:**
  - Information about position, velocity, and proper motions
## Masers in AGB stars

<table>
<thead>
<tr>
<th></th>
<th>SiO</th>
<th>H₂O</th>
<th>OH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location</strong></td>
<td>Several stellar radii (&lt; 10 AU)</td>
<td>Inner regions of envelopes (10 - 100 AU)</td>
<td>Hundreds of stellar radii (~ 10⁴ AU)</td>
</tr>
<tr>
<td><strong>Extinction (years after entering AGB)</strong></td>
<td>~10 yr</td>
<td>~100 yr</td>
<td>~1000 yr</td>
</tr>
</tbody>
</table>
# H$_2$O masers in evolved stars

<table>
<thead>
<tr>
<th>Location</th>
<th>AGB</th>
<th>Post-AGB</th>
<th>PN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Around the star</td>
<td>Around the star</td>
<td>Around the star (In the lobes)</td>
<td></td>
</tr>
<tr>
<td>In the jets</td>
<td>~ 20-30 km/s</td>
<td>~ 20-30 km/s</td>
<td>~ 20-30 km/s</td>
</tr>
<tr>
<td>~ 100 km/s</td>
<td>~ 100 km/s</td>
<td>~100 km/s</td>
<td></td>
</tr>
<tr>
<td>Number of objects</td>
<td>Many</td>
<td>~20 spherical emission</td>
<td>5 emission</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14 water</td>
<td>central star</td>
</tr>
<tr>
<td></td>
<td></td>
<td>fountains</td>
<td>1 water</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>fountain</td>
</tr>
</tbody>
</table>
What are they?

- Evolved stars with water masers with components with velocities on the order of 100 km/s – tracing jets
- First named by Likkel & Morris (1988) for IRAS 16342 – 3814

Type of objects

- Late AGB stars, post-AGB... and PN
- Bipolar
- Obscured at visible wavelengths – “anonymous”
- Massive
- 14 “classic” water fountains known – phenomenon not so rare (?)

What do they imply?

- First manifestation of axisymmetric jets
- Key objects to trace the emission of the jets that shape the PNe
- Formation of the cavities present in the PNe (Koning et al. 2013)
<table>
<thead>
<tr>
<th>Masers at the equatorial outflow</th>
<th>No masers at the equatorial outflow</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Masers on the jet</strong></td>
<td></td>
</tr>
</tbody>
</table>
| I15103  
(Gómez et al. 2015)         |                                   |
| W43A – 50 yr  
(Vlemmings et al.2006)    |                                   |
| I18286 – 56-73 yr  
(Yung et al. 2011)          |                                   |
| I16342 – 100 yr  
(Sahai et al. 1999)         |                                   |
| **Masers in bow-shocks**       |                                   |
| I18460 – 6 yr  
(Imai et al.2013)          |                                   |
| OH12.8-0.9 – 70 yr  
(Boboltz& Marvel 2005)     |                                   |
| I19134 – 40 yr  
(Imai et al 2007)          |                                   |
| I19190 – 59 yr  
(Day et al. 2010)          |                                   |
| I16552  
(Suárez et al. 2008)    |                                   |
| I18113  
(Gómez et al.2011)       |                                   |
| I15445  
(Pérez Sanchez et al. 2011) |                                   |
| I18043  
(Pérez Sanchez et al. 2011) |                                   |
I18286-0959

Yung et al. 2012

Pérez-Sanchez et al. 2011

I18113-2503 Gómez et al. 2011

I18460 – Imai et al. 2013
The driven mechanisms of the jets

- Magnetically collimated jet - synchrotron radiation – *Perez-Sanchez et al. 2013*
  
  ATCA – 22 & 5 GHz

- Jet precession – sign of binarity?

IR (Lagadec et al. 2011) + ATCA (Perez-Sanchez et al. 2011)
Believed impossible before 2001, now 5 H$_2$O-PNe confirmed

- K3–35 (Miranda et al. 2001)
- IRAS 17347 – 3139 (de Gregorio Monsalvo et al. 2004)
- IRAS 18061 – 2505 (Suárez et al. 2007, Gómez et al. 2008)
- IRAS 15103 – 5754 (Suárez et al. 2012, Gómez et al. 2015)
- IRAS 16333 – 4807 (Uscanga et al. 2014)

Characteristics:

- All bipolar
- Masers close to the central star – not high velocity except for I15103
- 2 optically visible, 3 obscured
Sketch of the possible water maser evolution

1. Standard Post-AGB
   ~10 fuentes

2. Water fountain

3. PN - water fountain
   14 sources (and increasing)

4. $\text{H}_2\text{O}$-PN (masers in the lobes)
   1 source

5. $\text{H}_2\text{O}$-PN (masers in the torus)
   4 sources

Adapted from Suarez et al. 2009
The missed link: IRAS 15103

Water masers – ATCA
Gómez et al. 2015

[NII] image (12.8 μm)
from Lagadec et al. 2011
The missed link: IRAS 15103

NTT-J

NTT - J image
Ramos-Larios et al. 2012
Maser distribution

Water masers - ATCA

August 2011

Flux density (Jy)

Flux density (Jy)

LSR velocity (km/s)

Dec. (arcsec)

R.A. (arcsec)
- Faster components further from the center
- Explosive emission of the jet
Radio continuum in II5103

- Witness of the explosive formation of the PN – ATCA archive + observations

Suárez et al. 2015
Radio continuum in II5103

Witness of the explosive formation of the PN–ATCA archive + observations

Suárez et al. 2015
Radio continuum in II5103

 Witness of the explosive formation of the PN – ATCA archive + observations

Suárez et al. 2015
Radio continuum in I15103

 Witness of the explosive formation of the PN – ATCA archive + observations

Suárez et al. 2015
Spectral index variation

$S \nu^\alpha$, $\alpha$ spectral index

$\alpha \sim -0.54$

$\alpha \sim -0.28$

2010

2012
Changes in spectral index

- Classic PN – thermal emission (free-free) - $\alpha \sim 2$ for $n \leq 10$ GHz
  - $\alpha \sim 0.1$ for $n > 10$ GHz
- **2010**: $\alpha \sim -0.54$ – compatible with synchrotron emission – Fermi first order acceleration (e- accelerated to high velocity in non-relativistic shocks)
- **2012**: $\alpha \sim -0.28$ – no synchrotron compatible
Possible explanations

- Possibilities:
  
a) 1. Explosive emission of a jet that produces synchrotron radiation
   
   2. **Coulomb collisions** of e- with plasma produce a change in the spectral index (loss of low frequencies)

b) **Razin effect within a plasma** – plasma with ordered and turbulent (jitter) magnetic components. Ionization supresses ordered synchrotron leaving only « jitter » component (at high frequencies)
Both possibilities imply the recent onset of ionization – 
**witness of the formation of a PN « in live »**

The real cause of the disappearance of synchrotron ? – in several years...

1. Coulomb losses: spectrum flatter each year + possible cut-off at low frequencies
2. Razin effect: no significant modifications

♦ In any case – beginning of thermal radiation (free-free) at high frequencies

♦ Maybe a common process in the transition to the PN phase
Very preliminary results
ASTRONOMIE
Les phénomènes observables à expliquer