Water masers as signposts of extremely young planetary nebulae

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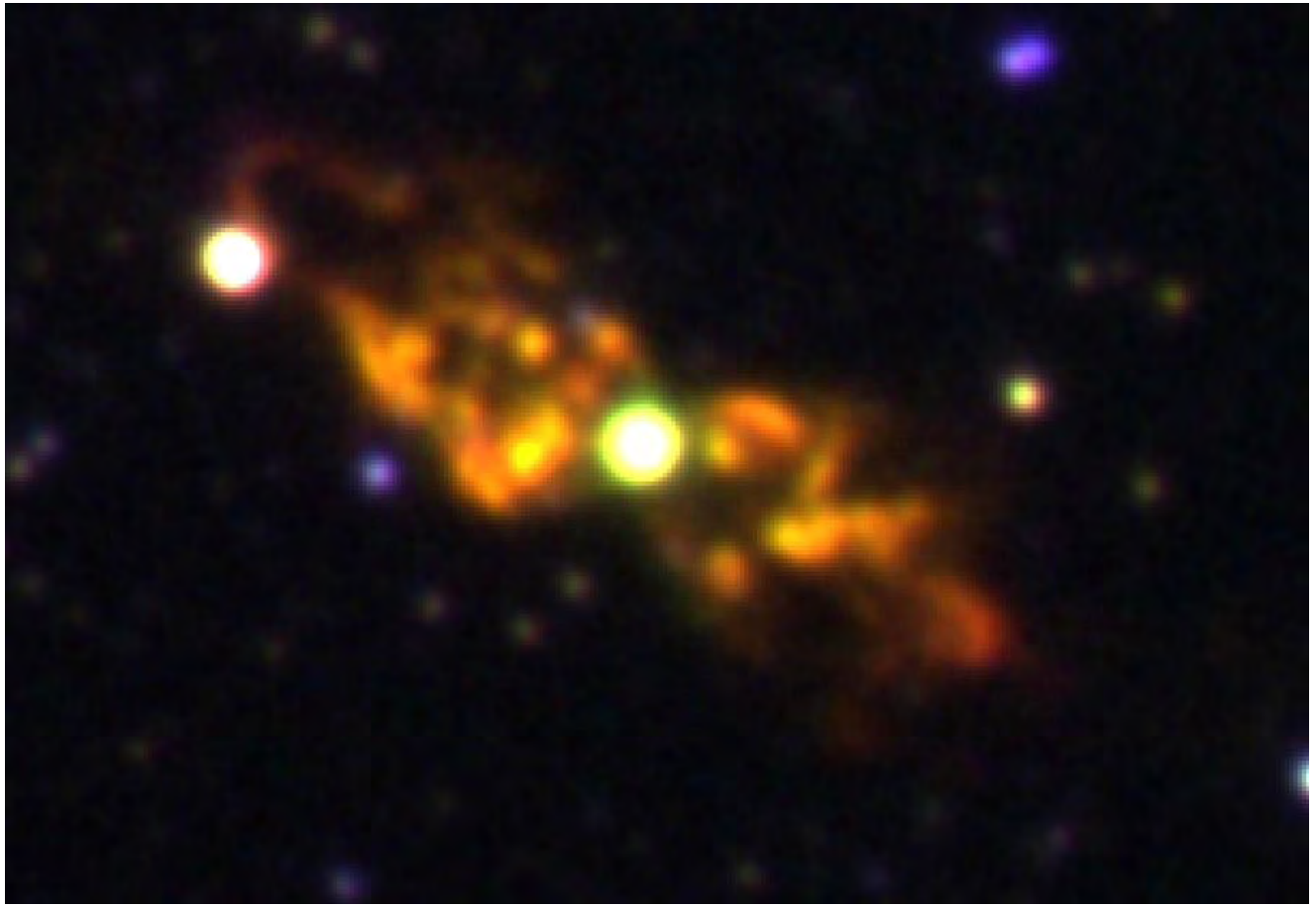

Some collaborators:

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J.A. Green (CASS, Australia)

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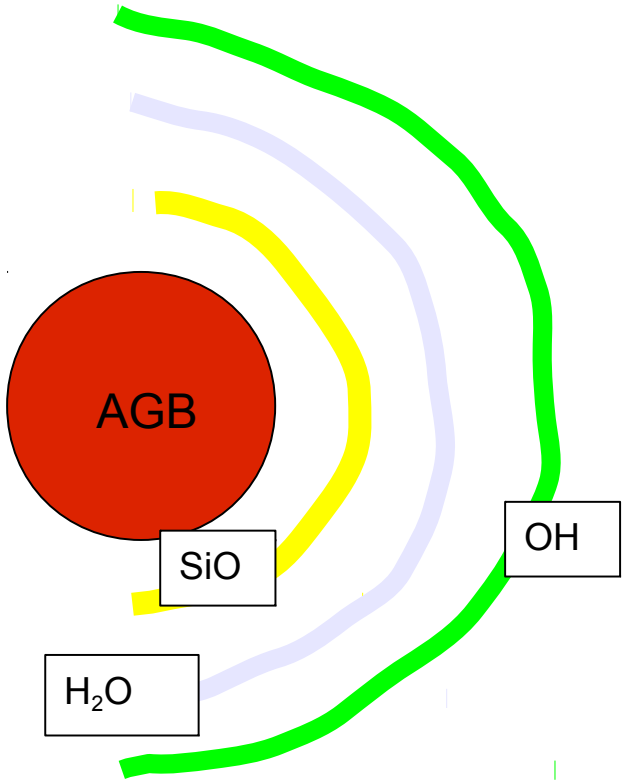
I. de Gregorio-Monsalvo (ALMA)

End of < 8 M⊙ stars

t

AGB	post-AGB	PN = photoionization

$\dot{M} \leqslant 10^{-4}$ M⊙

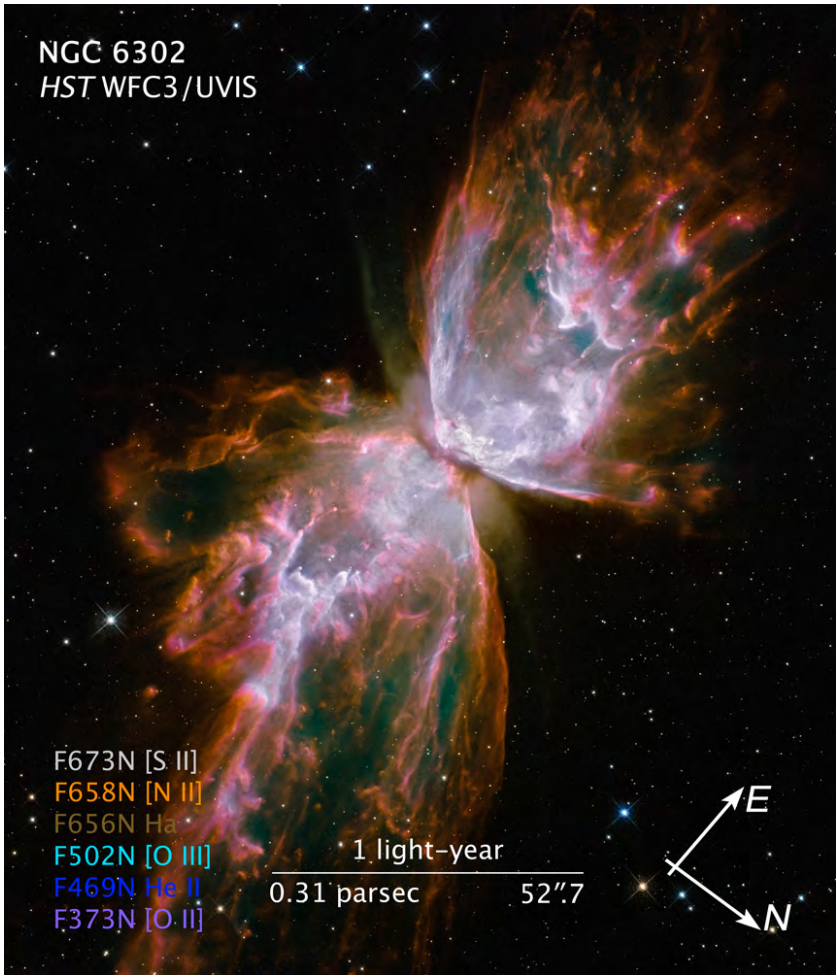


Masers trace expansion of envelope

$\dot{M} \leqslant 10^{-7}$ M⊙

Non-spherical mass-loss (e.g. jets)
e.g., Water fountains

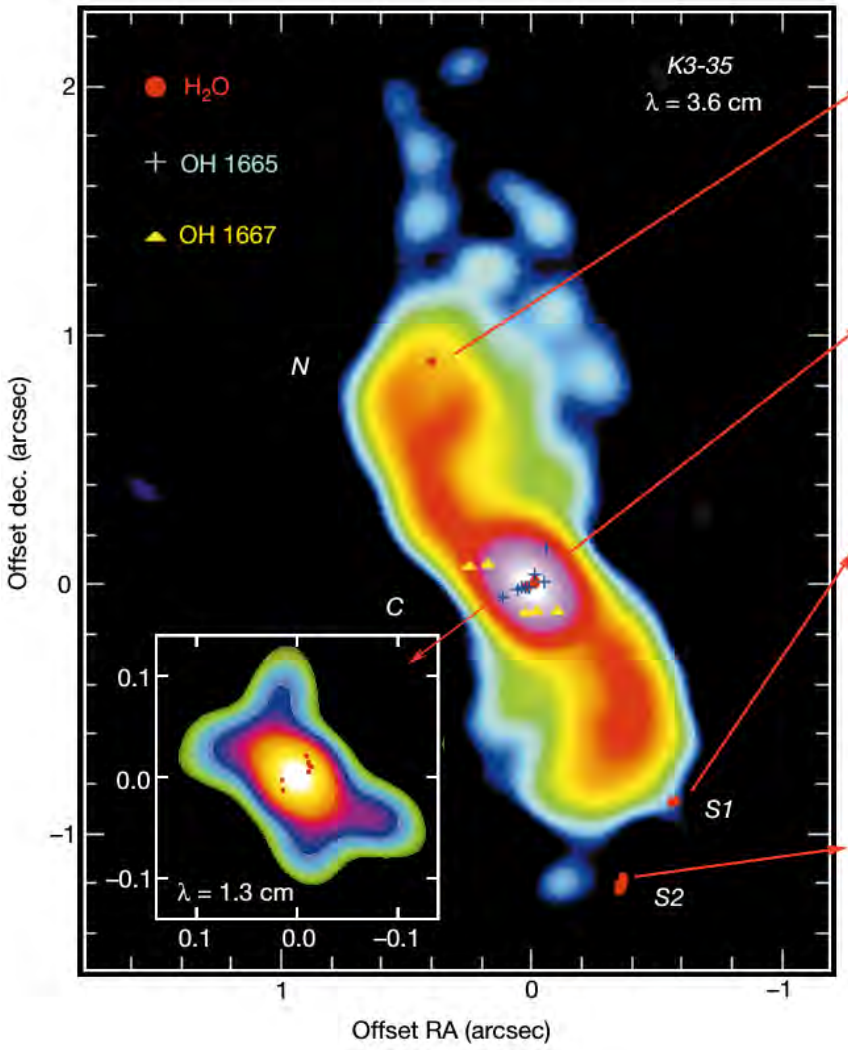
T increases



Masers in PNe:
SiO: 0
OH: 7 ← Uscanga et al. poster
H_2O: 5

Masers are useful tools to understand mass-loss in evolved stars

First detection of water masers in a PN
K 3-35 (Miranda et al. 2001)

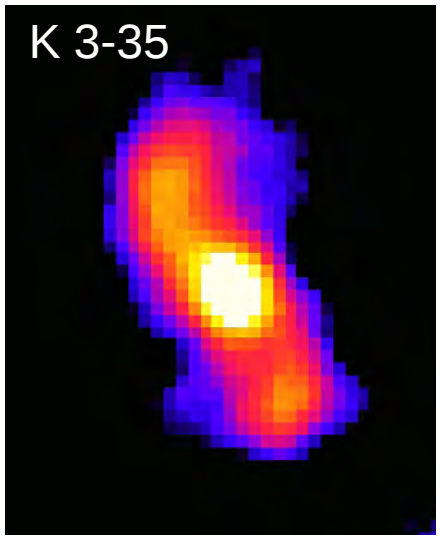


Photoionization will eventually dissociate water molecules in a few hundred years.
Water-maser emitting PNe are expected to be young.

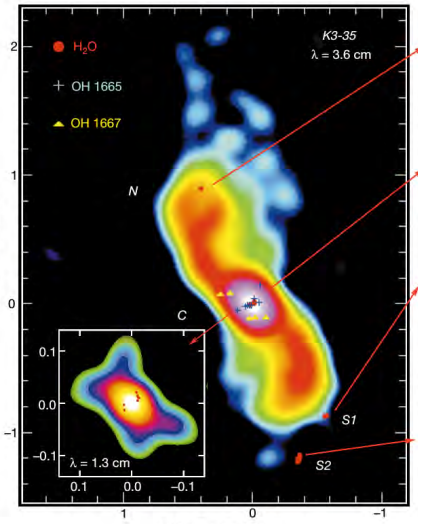
Interesting objects to study the formation and early evolution of PNe

Do (most) PNe go through a short water-maser-emitting phase?
Do they belong to a peculiar class of objects?

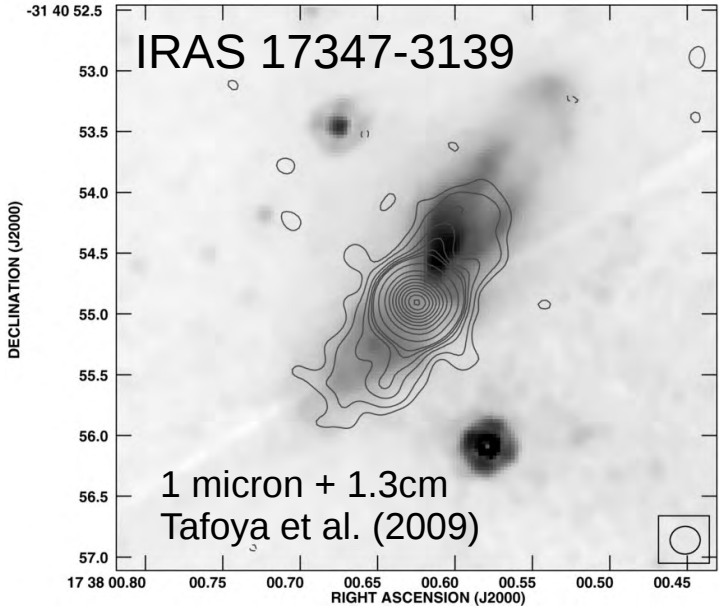
Water-maser-emitting PNe: IR and radio morphology



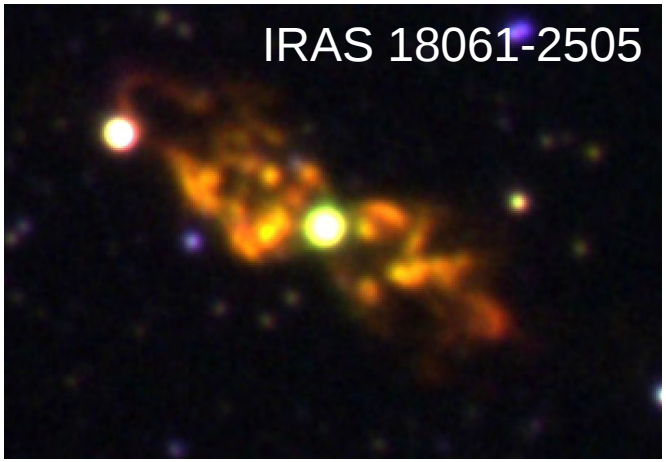
[S IV] 10.5 micron
Blanco et al (2014)



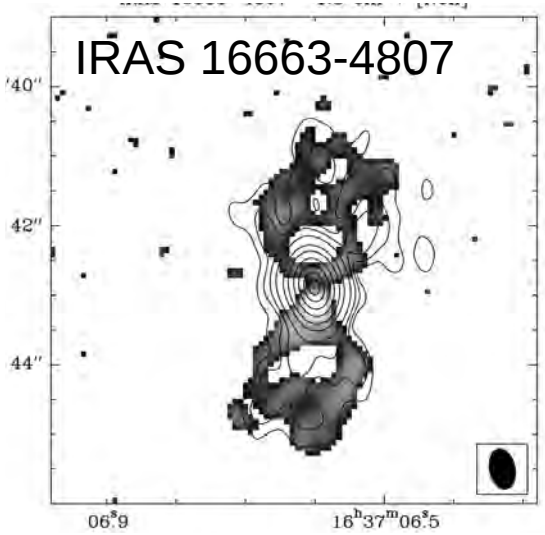
Radio (3.6, 1.3 cm)
Miranda et al (2001)



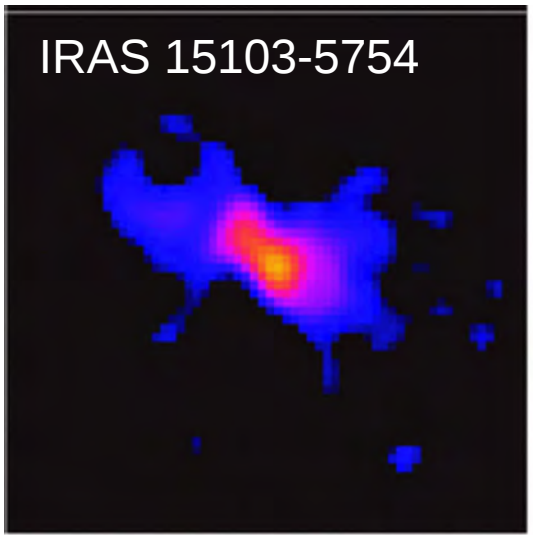
Bipolar, point-symmetric
This suggests binary central stars



[N II], Hα, [O III], Miranda et al (2017)



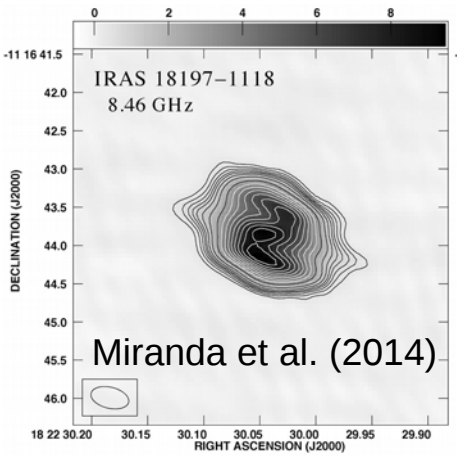
1.3 cm: Uscanga et al. 2014
12.8 micron: Lagadec et al. (2011)

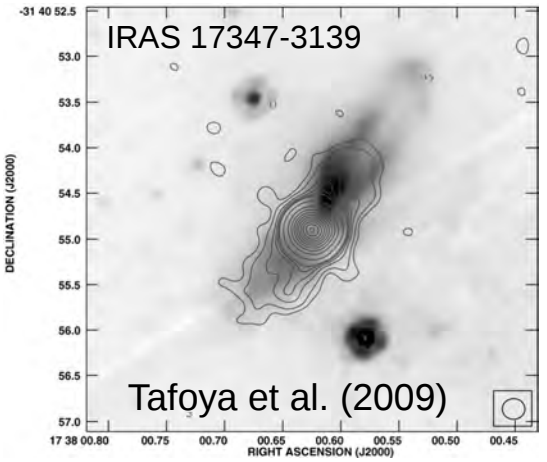


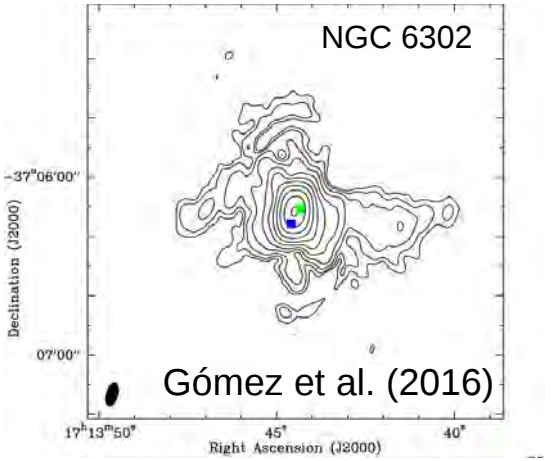
12.8 micron: Lagadec et al. (2011)

Important difference in planetary nebulae with respect to previous phases: photoionization of the envelope
An "HII region" is created.

Free-free (bremsstrahlung) radiation, strong emission at radio wavelenghts

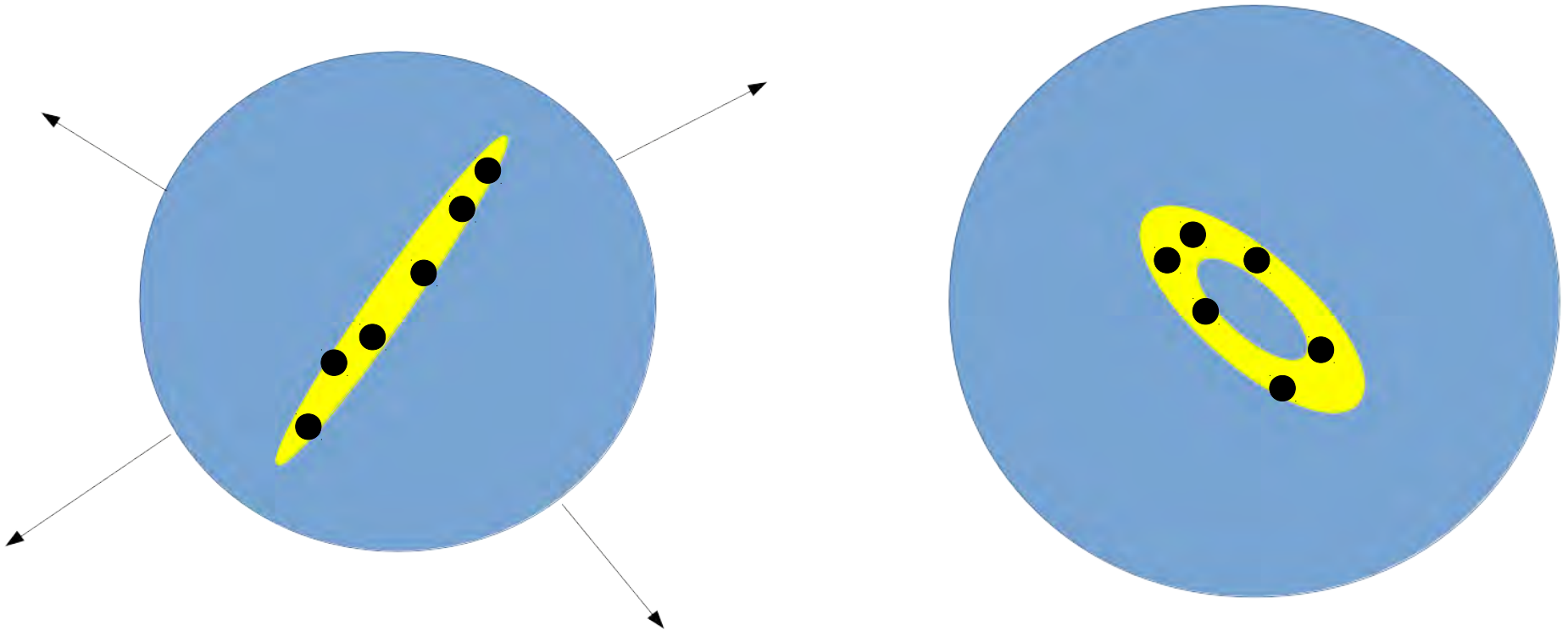






In young PNe:
Growth of photoionized region.
Change in size, morphology, flux density
of radio continuum.
This may influence maser emission.

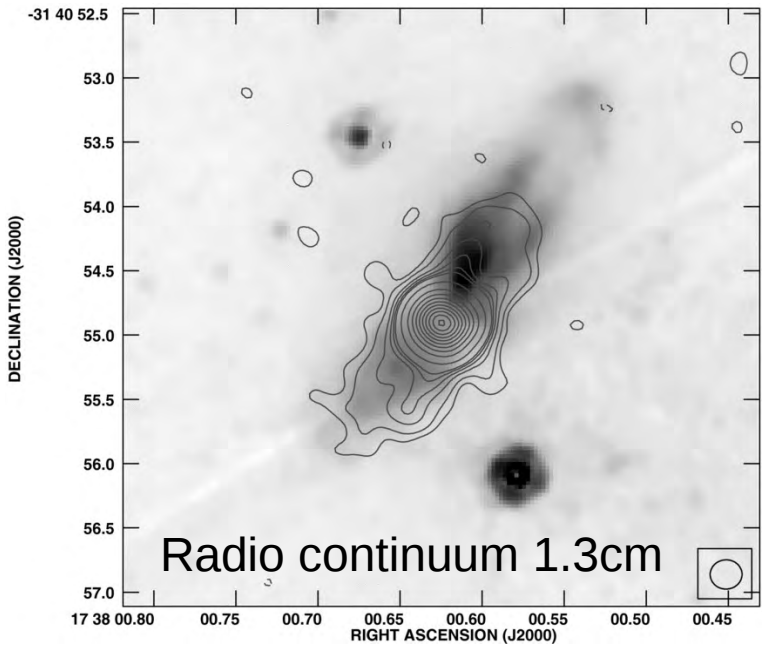
The presence of radiocontinuum emission may be important.
It favors maser emission, since it provides a background to be amplified.
Morphological/kinematical structures may be difficult to interpret.

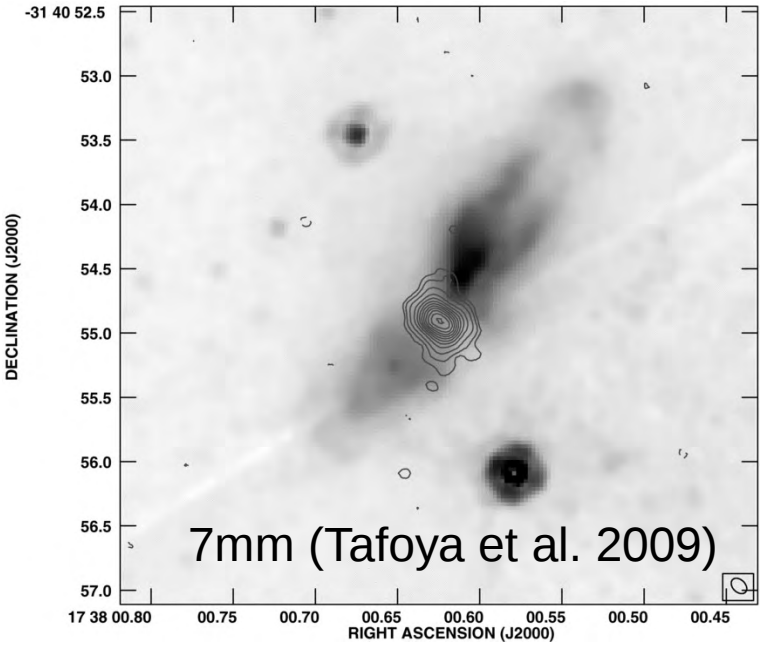


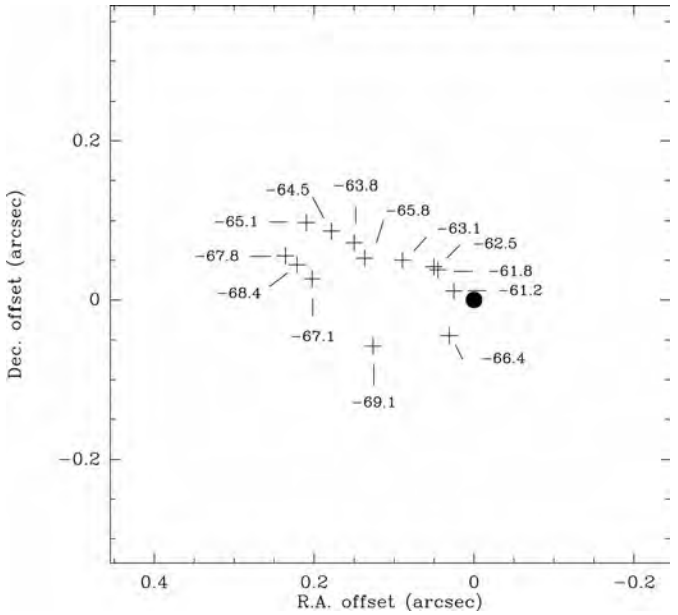
In that case, blueshifted bias
If radiocontinuum changes rapidly, maser distribution may do so.

Masers in PNe tend to trace equatorial structures. And sometimes (rarely) "jets" (but with low velocities, ~5 km/s)

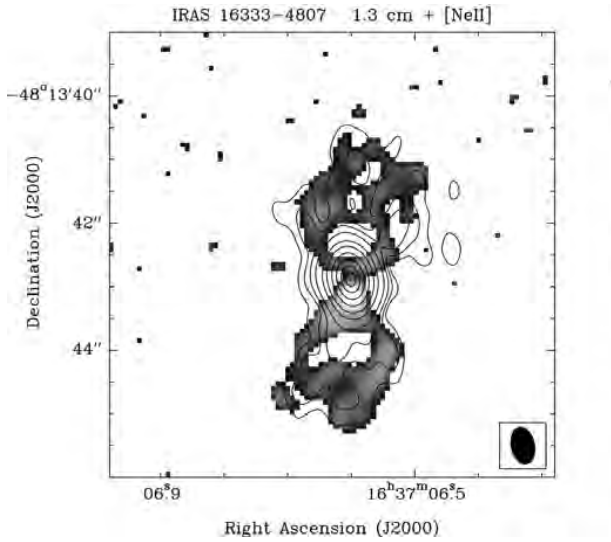
IRAS 17347-3139

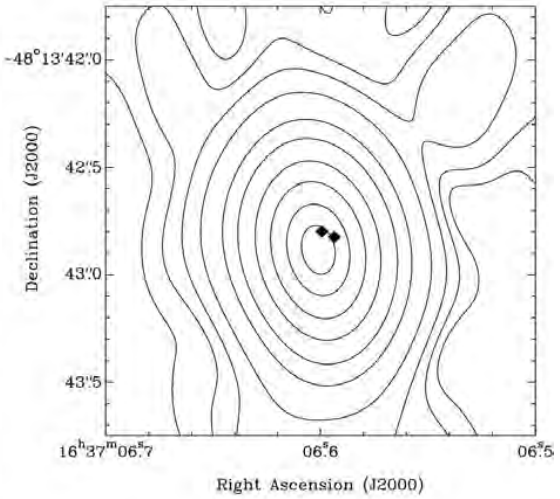




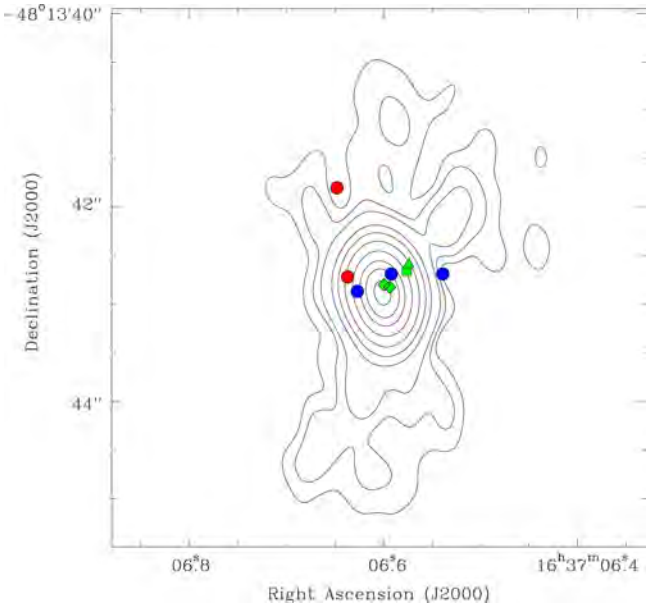


De Gregorio-Monsalvo et al. (2004)





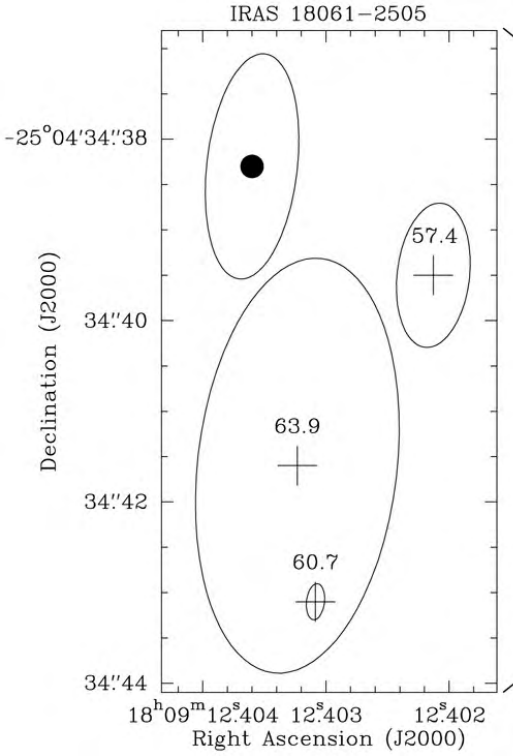
Uscanga et al. (2014)

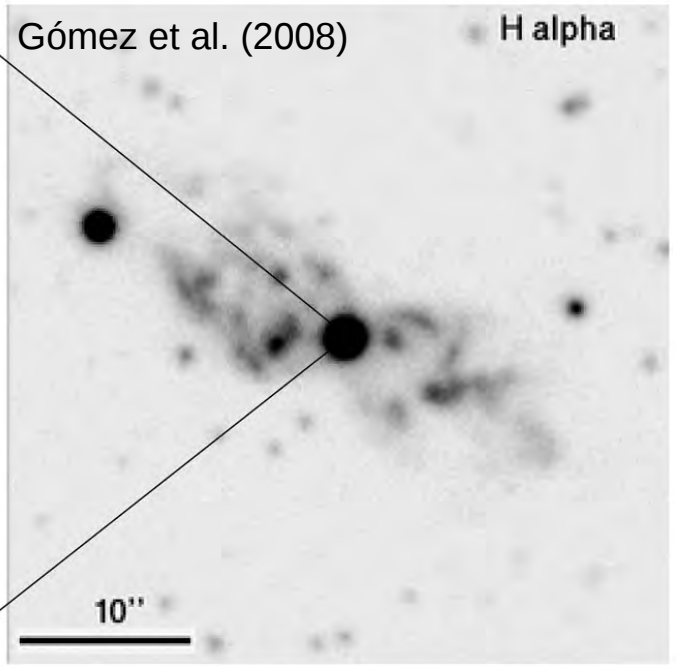


OH 1720 MHz: Qiao et al (2016)

Toroids may be key structures in these objects.
Expected in binary systems.

Similar to post-AGB stars like water fountains.
Descendants?



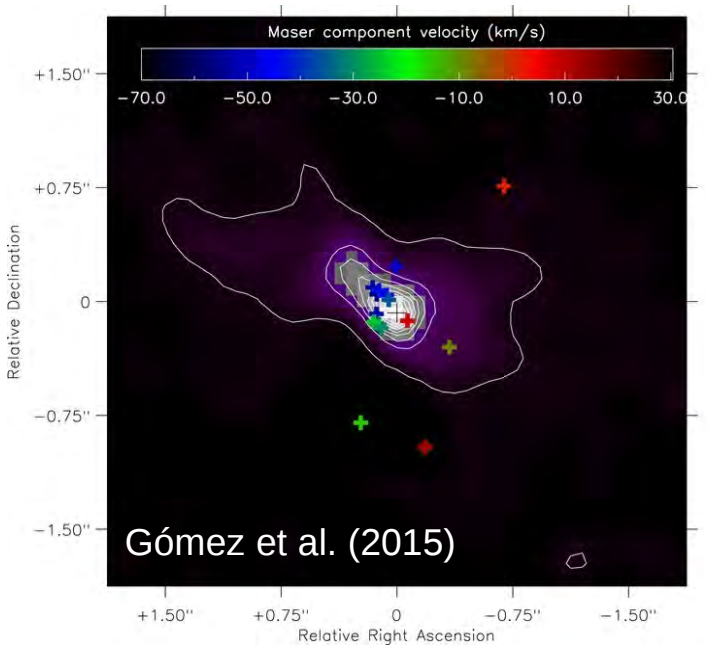


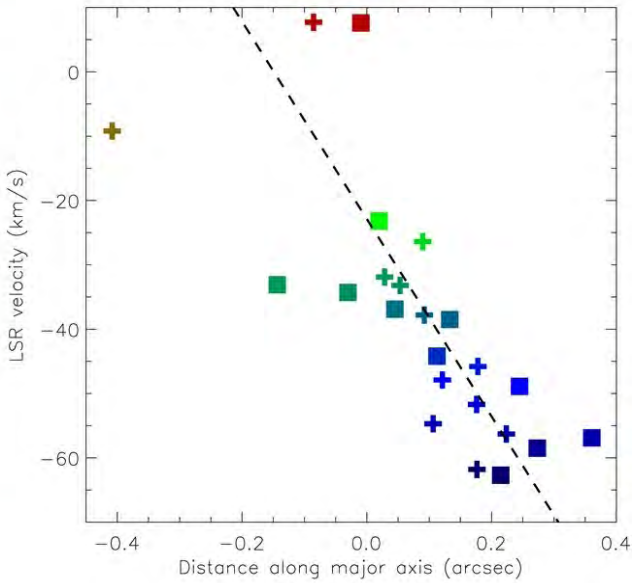
IRAS 15103-5754
Probably the youngest PN known.

Two unusual characteristics:

- The only PN with high-velocity water masers (velocity spread of 75 km/s) = water fountain source
- The only PN with confirmed non-thermal radiocontinuum emission (seen in post-AGB, Pérez-Sánchez' talk

ATCA observations



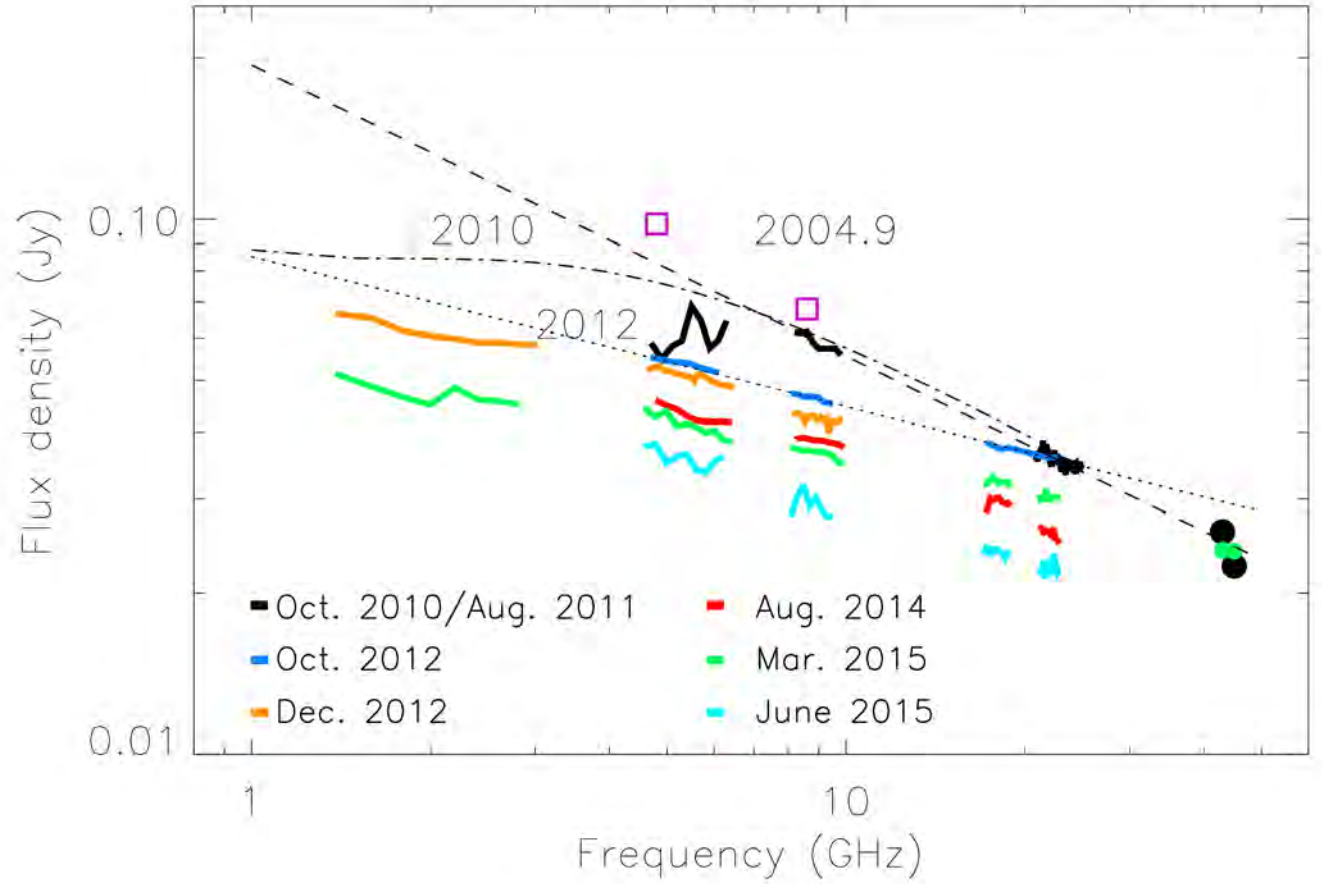


L~800 AU

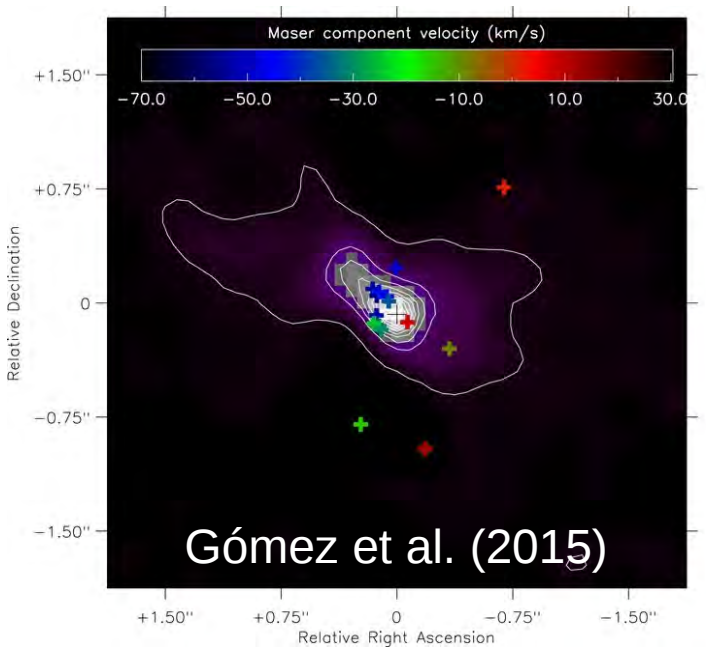
Linear increase of velocity with distance, suggesting ballistic motions

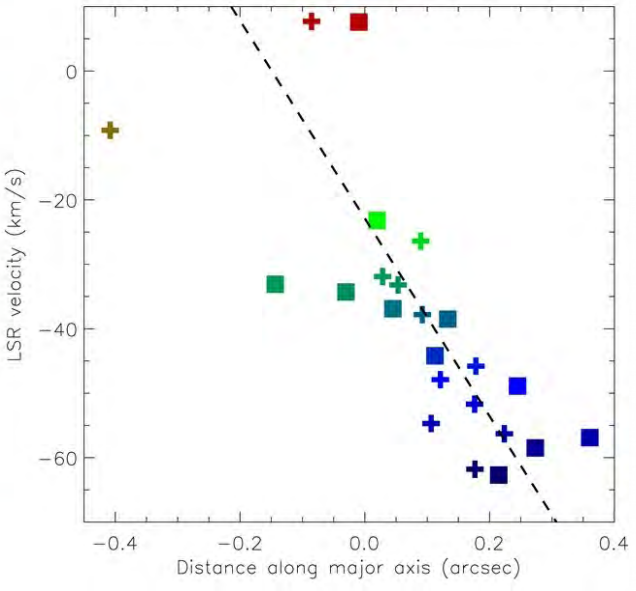
Dramatic change in **non-thermal radio continuum**.
Historical data + ATCA monitoring

Suárez et al. (2015) + new data

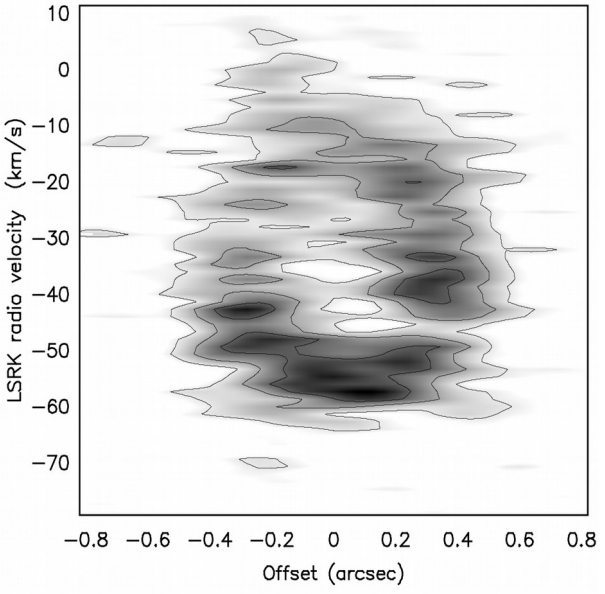


We interpret it as synchrotron emission (shocks in a magnetized environment)
Changes due to the growth of the newly created ionized region.
(Coulomb collisions against plasma slow electrons down
or synchrotron suppression due to Razin effect)

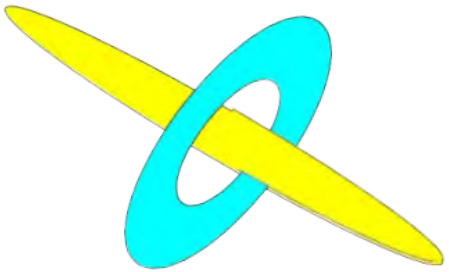




ALMA data, C18O

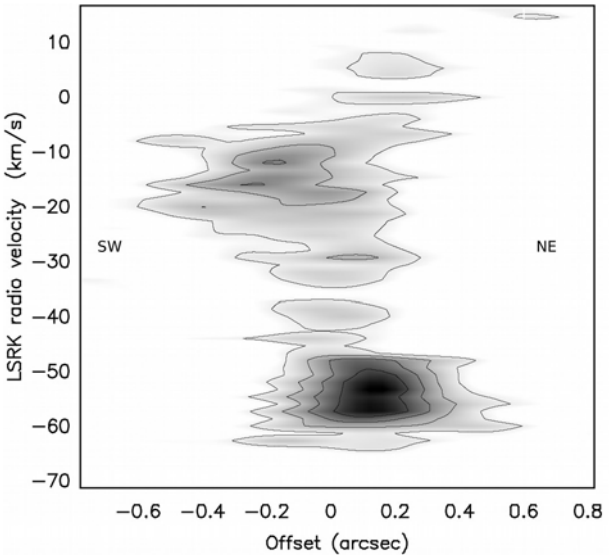


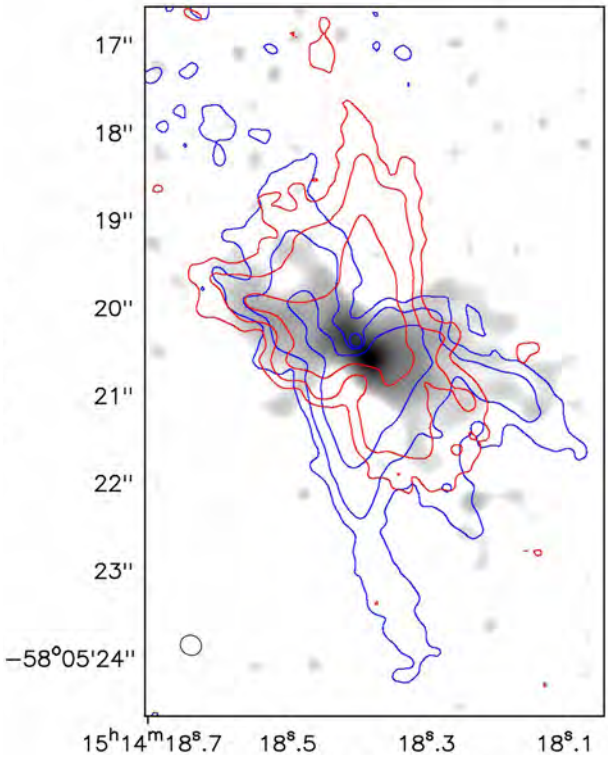
Major axis of toroid



Molecular gas is tracing an expanding toroid.
But its suggested geometry (orientation) is opposite to that indicated by masers (blueshifted to the NE)

Minor axis

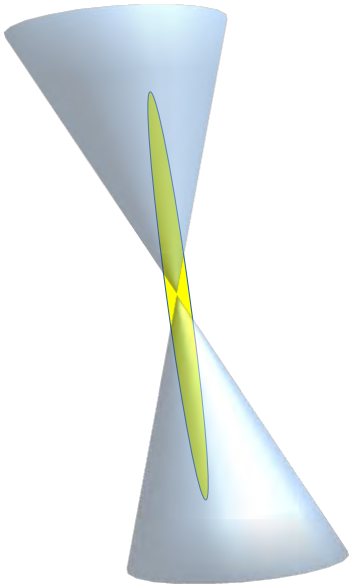


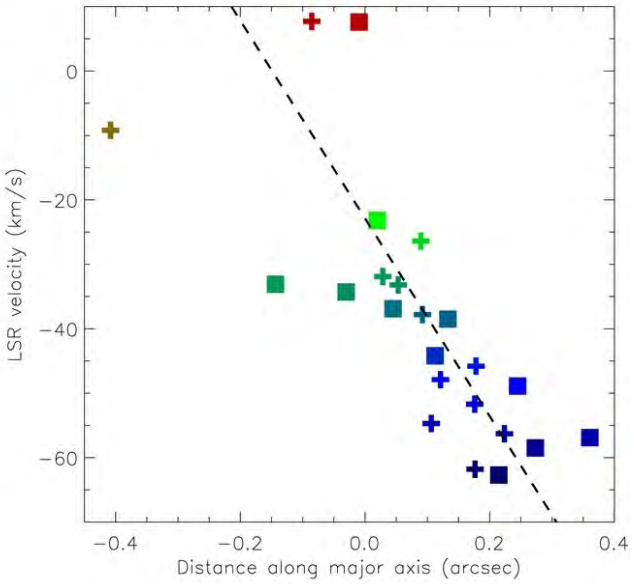


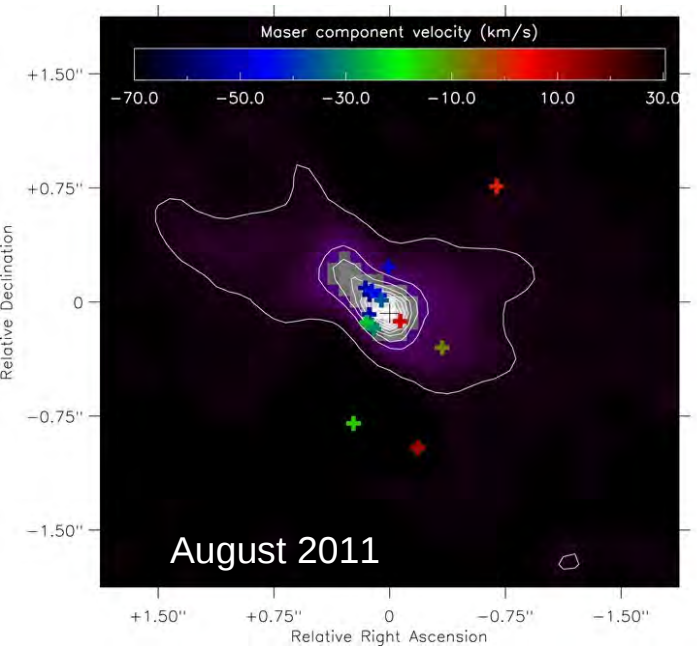
CO(3-2), 0.85 mm
Outflow (up to 200 km/s) close to the plane of the sky
Linear increase of velocity
Total extent of 20000 AU
Conical flow.

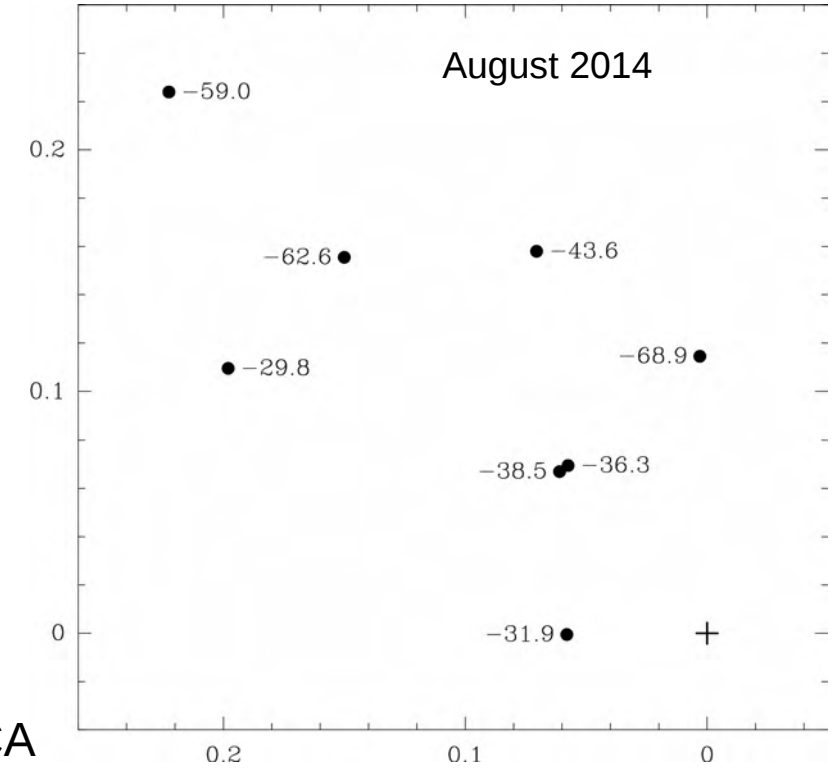
Are masers tracing the foreground gas of a conical ejection?

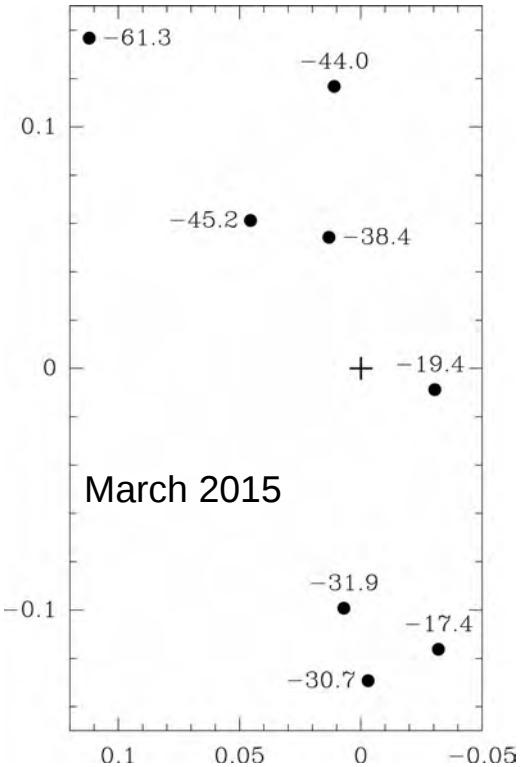
But… The maser distribution is changing rapidly!



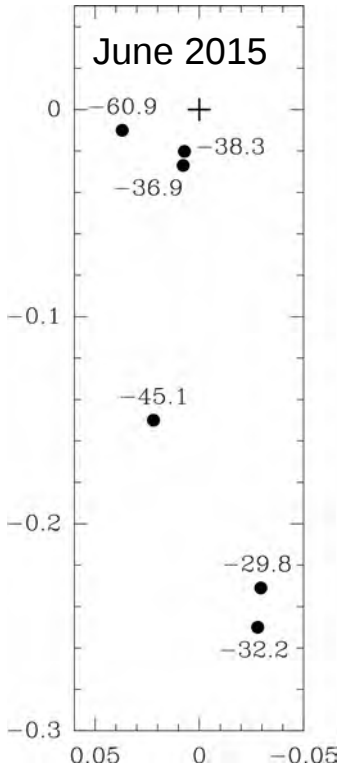


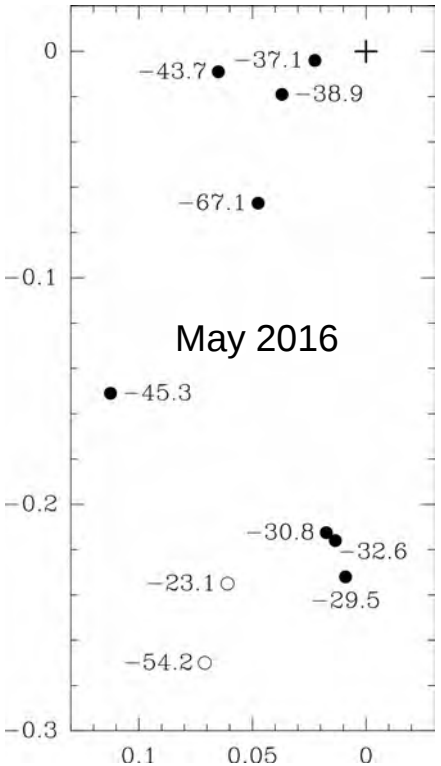


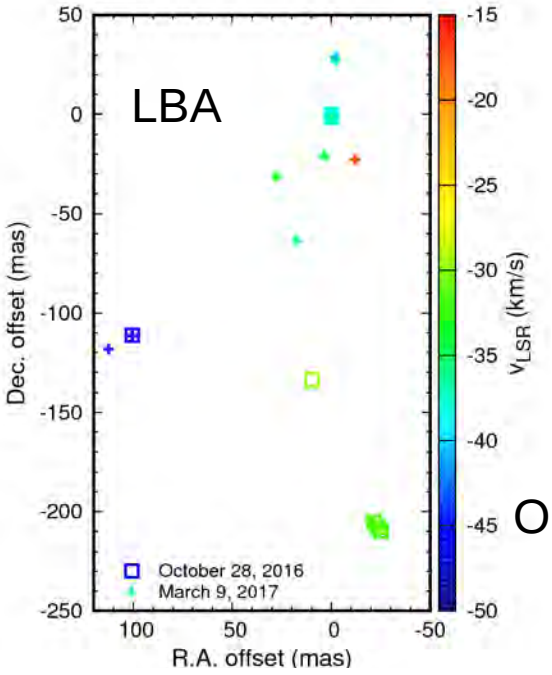




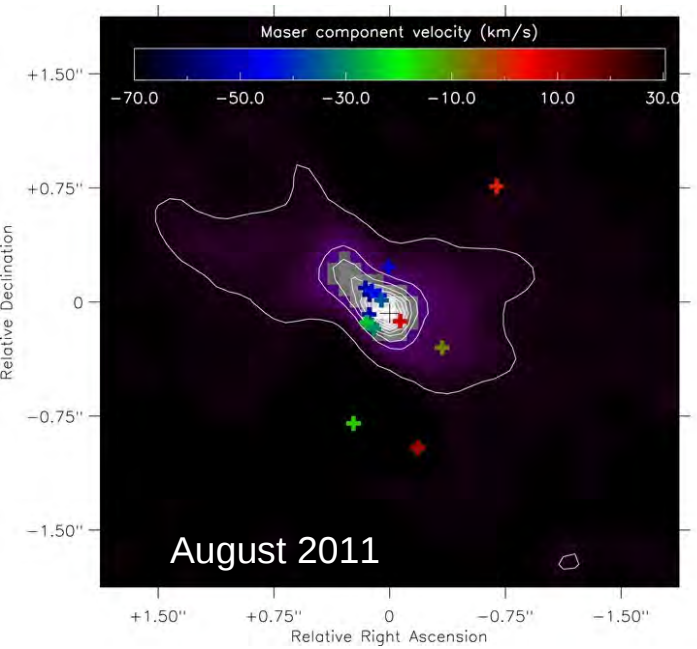
Monitoring with ATCA

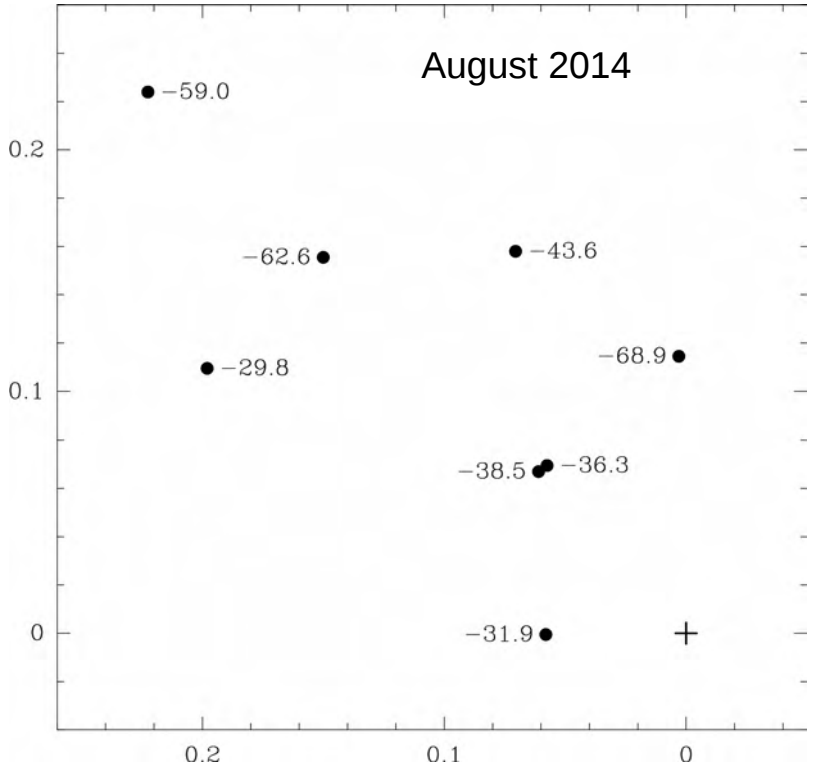


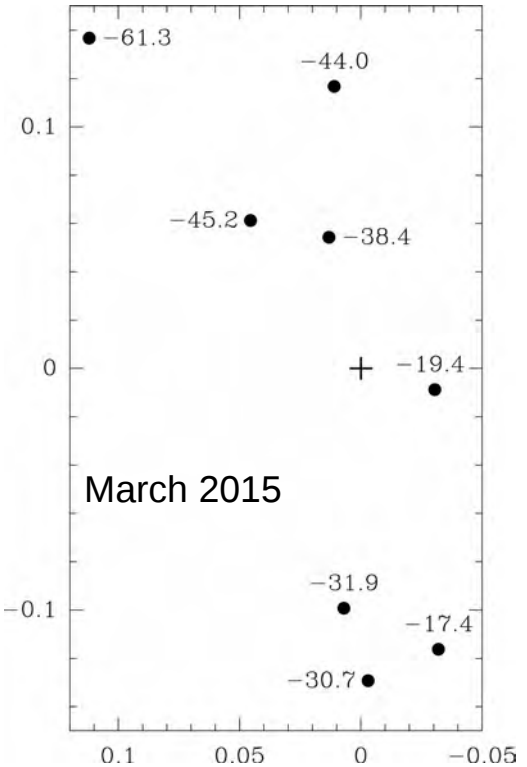


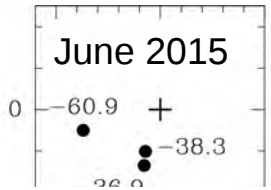


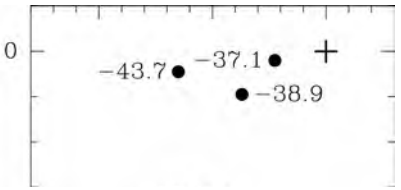
Orosz et al.





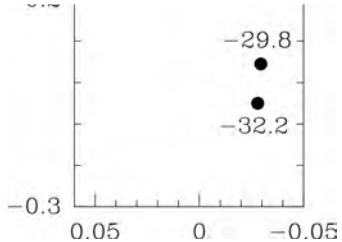


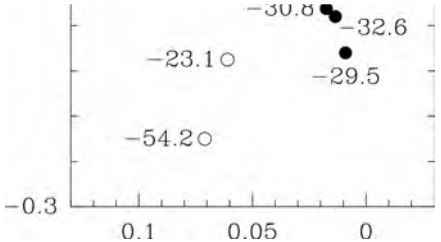


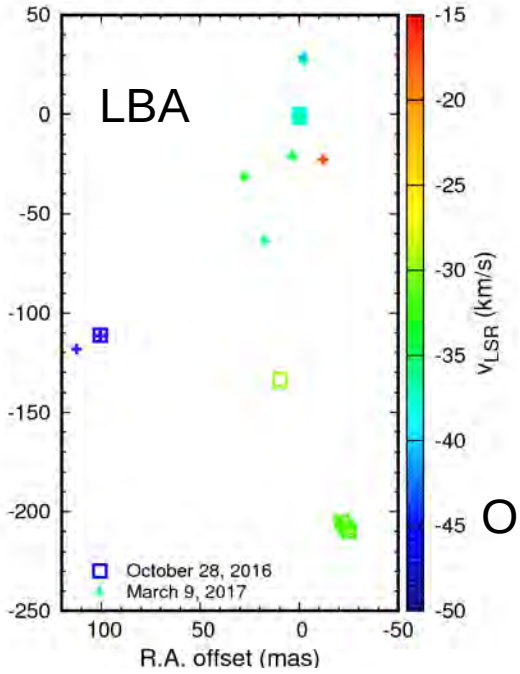


Are masers changing from tracing a jet to tracing as disk? As in other PNe.
Is the changing continuum influencing how the maser distribution looks? We cannot resolve continuum.

Is this just a precessing jet?



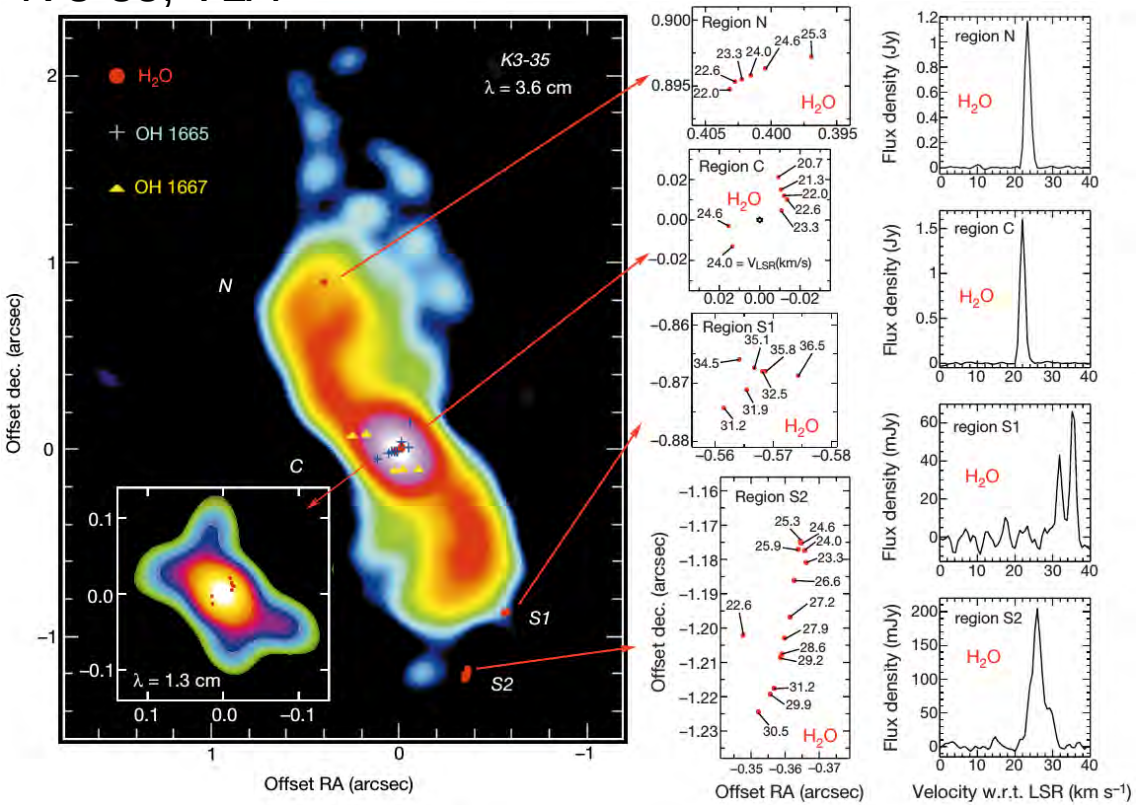




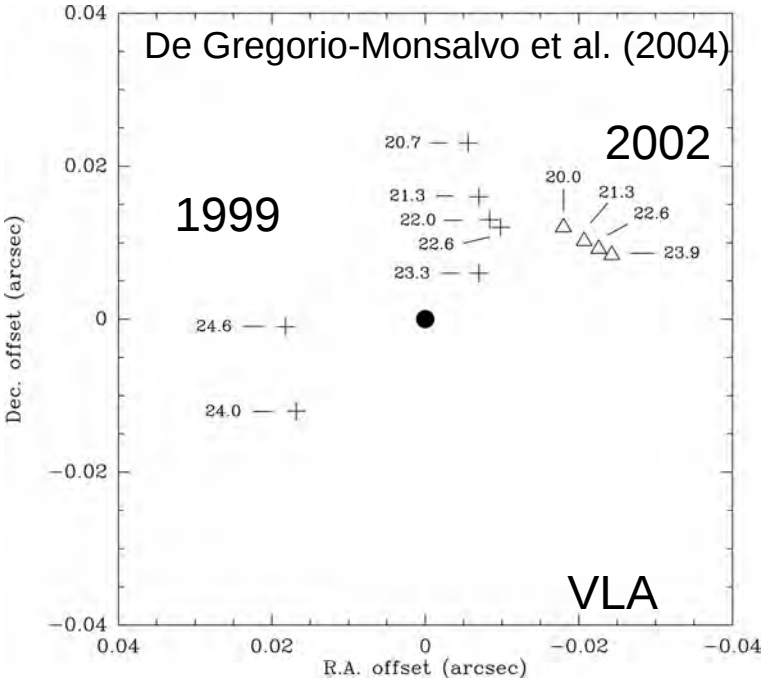
Orosz et al.

K 3-35, VLA

Miranda et al. (2001)

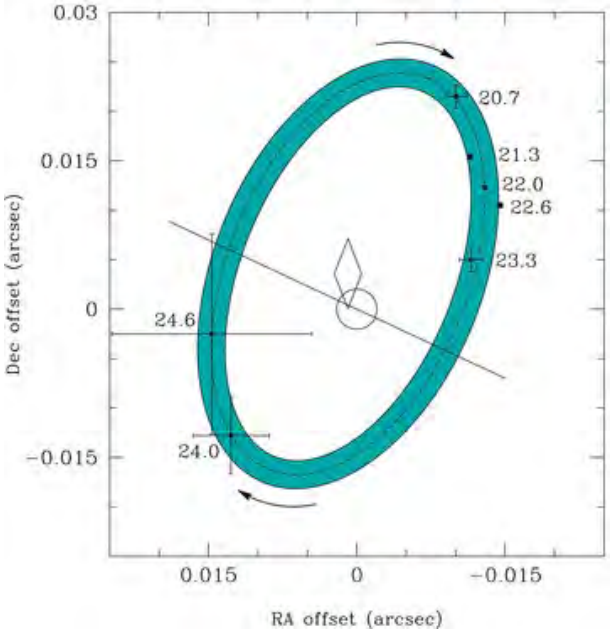


Central masers: rotating torus?



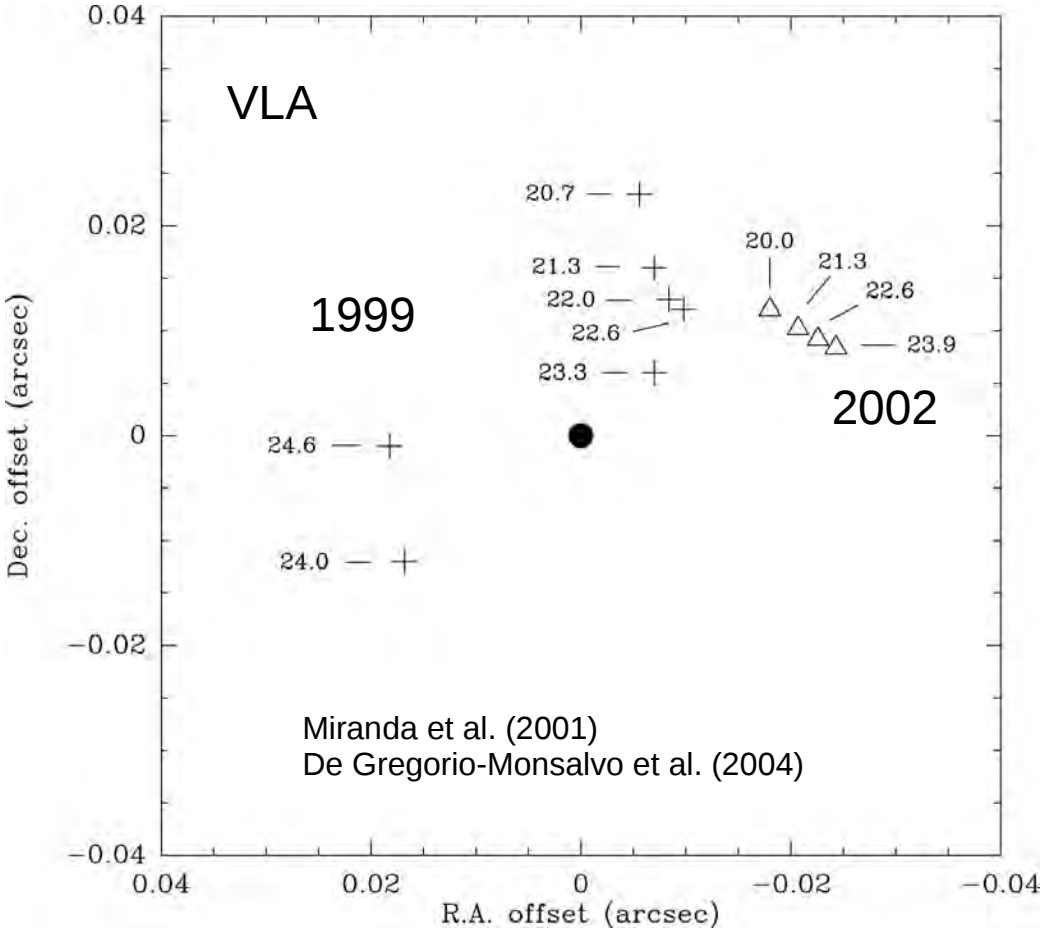
R=80 AU

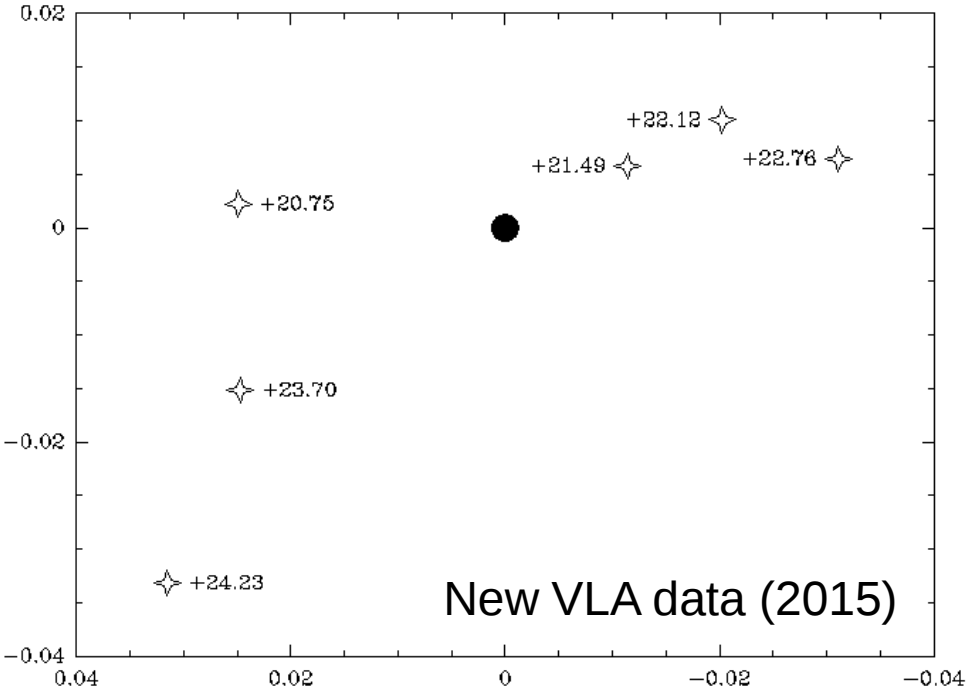
Uscanga et al. (2008)

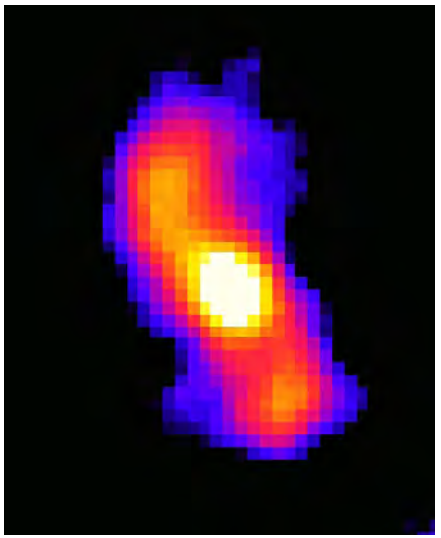


Proper motions with VLBA (Tafoya et al. 2011) and VLA observations at different epochs (de Gregorio-Monsalvo et al. 2004) are not consistent with the torus model.
Different locations as ionized nebula expand? Ionization front?

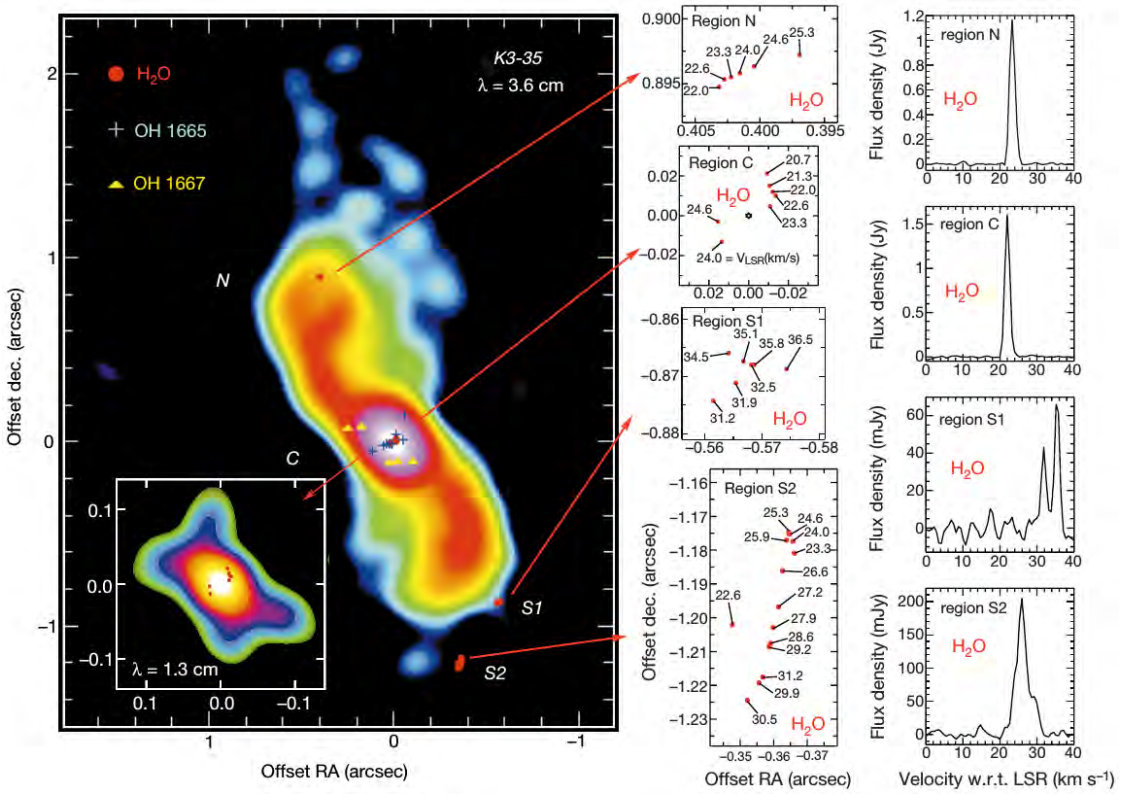
Masers at the tip of the nebula not found in De Gregorio-Monsalvo (2004), Tafoya et al. (2011)
Short-lived structure

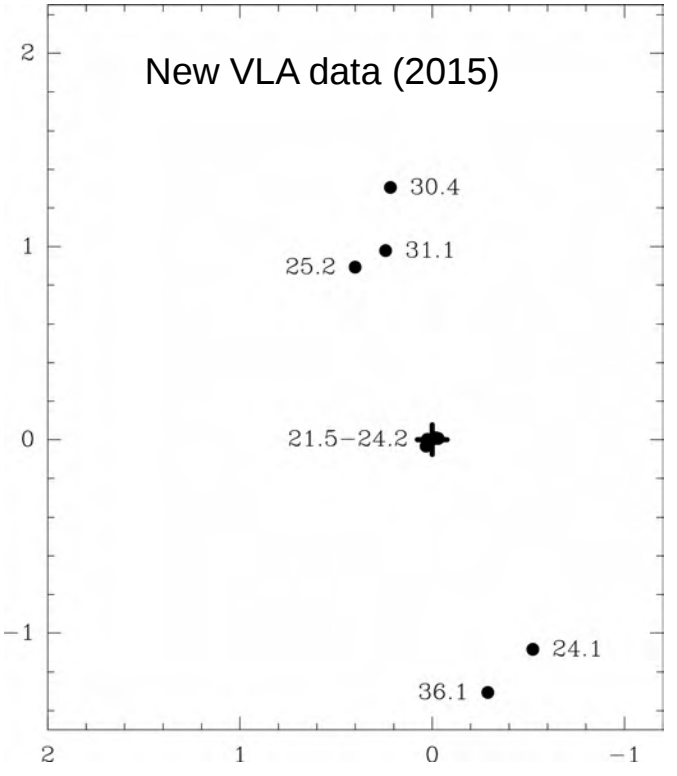


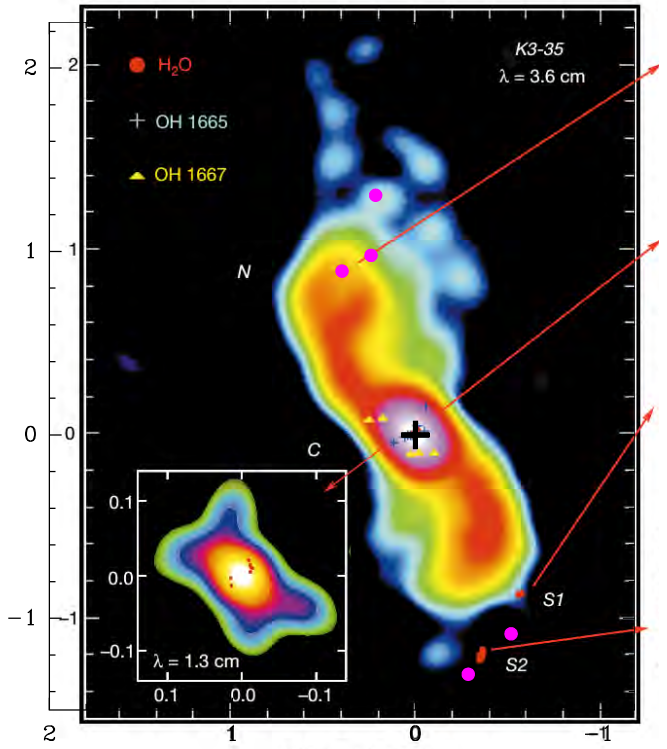




Masers over a larger region
(r~190 AU)
Growth of ionized region
along the equatorial direction.







They follow the point-symmetric morphology of the ionized nebula.
Precessing jet hitting the walls of the nebula?
Ionization front of the nebula?

Summary

- Water maser emission associated with extremely young **bipolar** PNe.
- Related with **binary central stars.**
- Tends to trace **equatorial structures**, but the distribution and kinematics of the maser-emitting gas is very uncertain.
- **Rapid evolution** of the newly created photoionized gas may influence maser emission, which shows high variablity in their morphological and kinematical distribution.
- **High-resolution observations of radio continuum** (SKA?) and and molecular gas (ALMA) would be necessary to understand maser emission in these objects.