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

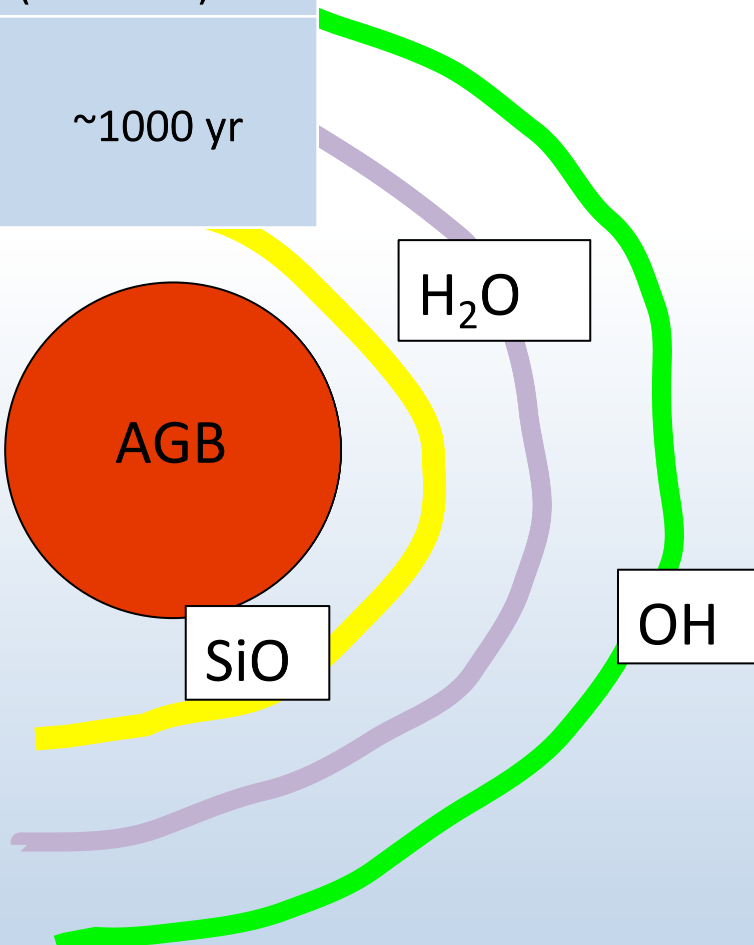
- Which physical processes ?
  - Hyperfine transition between two rotational states: $6_{16} \rightarrow 5_{23}$
  - Excitation mainly by shocks

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

- Advantages :
  - Information about position, velocity, and proper motions

Masers in AGB stars

	SiO	H_2O	OH
Location	Several stellar radii (< 10 AU)	Inner regions of envelopes (10 - 100 AU)	Hundreds of stellar radii (~ 10^4 AU)
Extinction (years after entering AGB)	~10 yr	~100 yr	~1000 yr

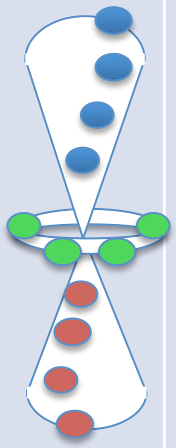
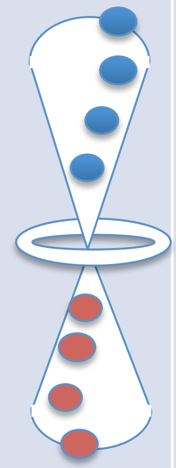
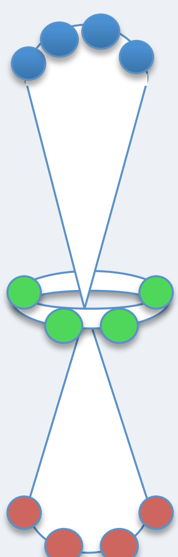
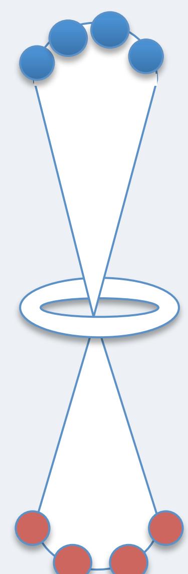


H_2O masers in evolved stars

	AGB	Post-AGB	PN
Location	Around the star	Around the star In the jets	Around the stars (In the lobes)
Velocity	~ 20-30 km/s	~ 20-30 km/s ~ 100 km/s	~ 20-30 km/s ~100 km/s
Number of objects	Many	~20 spherical emission 14 *water fountains*	5 emission central star 1 *water fountain*

The « water fountains »

- 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)

	Masers at the equatorial outflow		No masers at the equatorial outflow	
Masers on the jet		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)*

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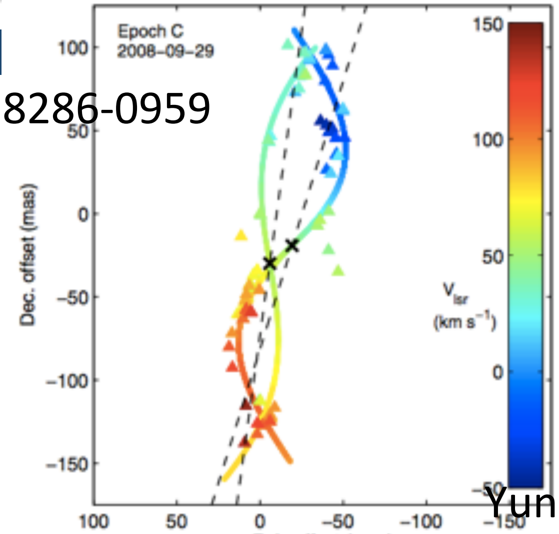
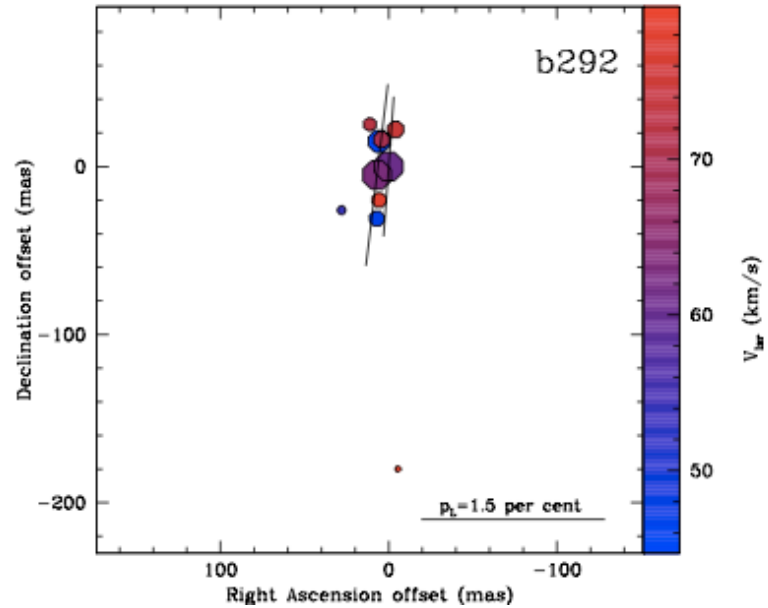
I18286-0959

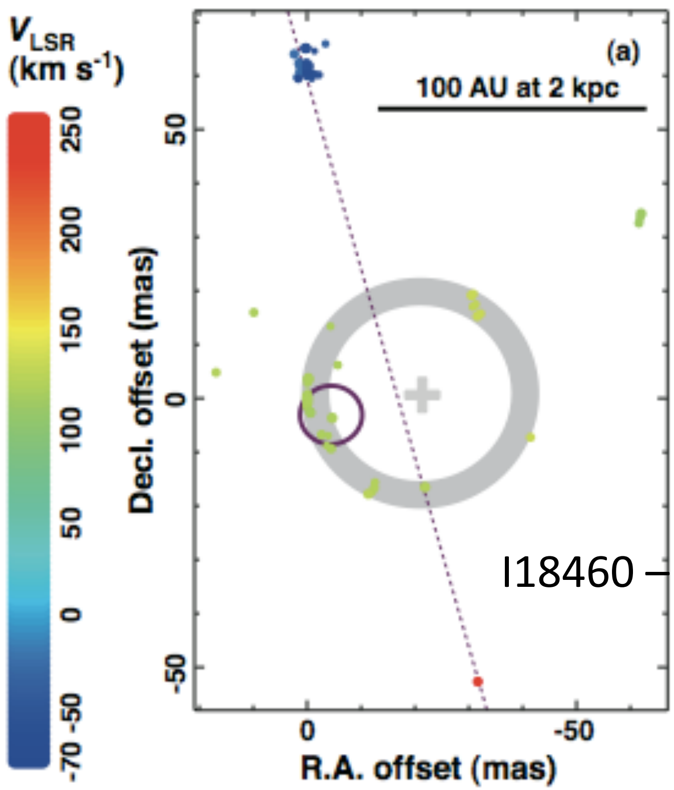


Yung et al. 2012

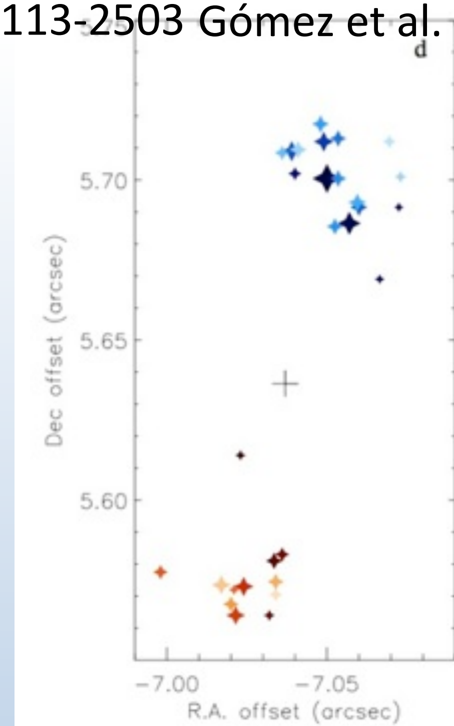
Pérez-Sanchez et al. 2011



I18113-2503 Gómez et al. 2011



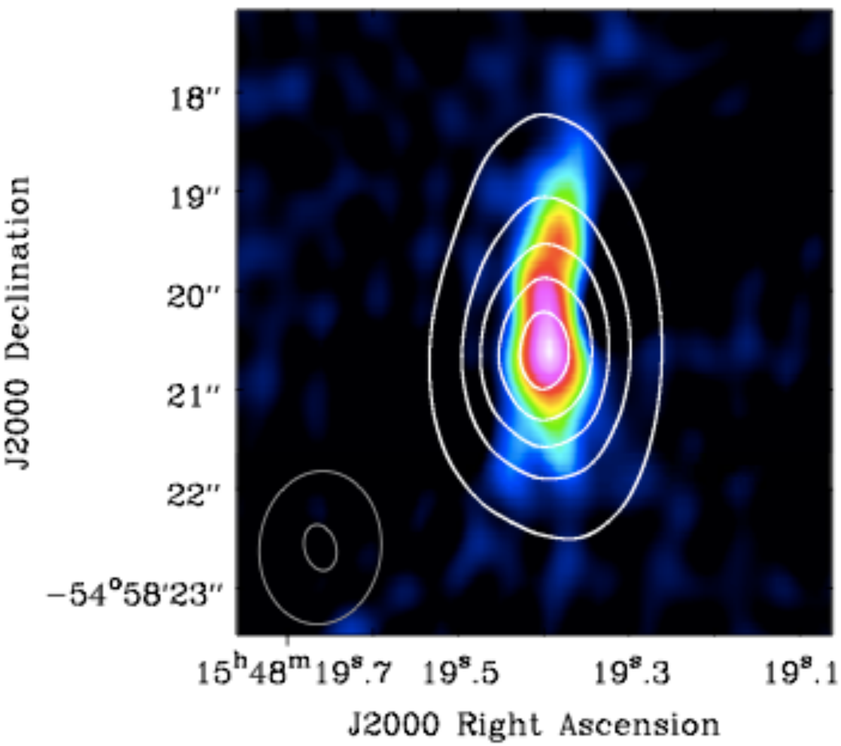
I18460 – Imai et al. 2013



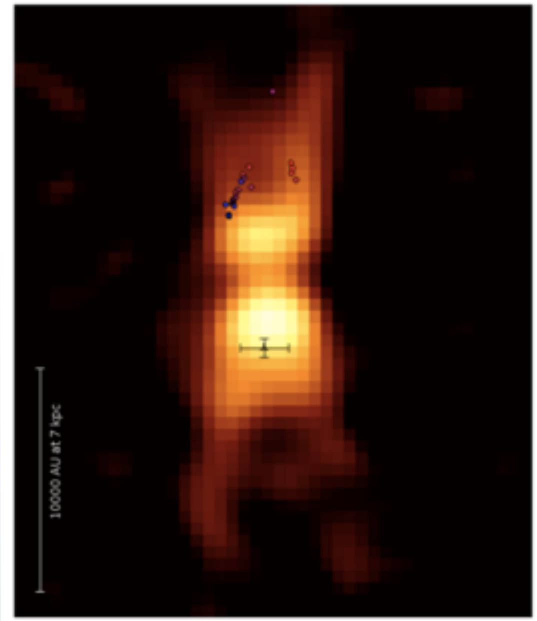
The driven mechanisms of the jets

- Magnetically collimated jet - synchrotron radiation – *Perez-Sanchez et al. 2013*

ATCA – 22 & 5 GHz



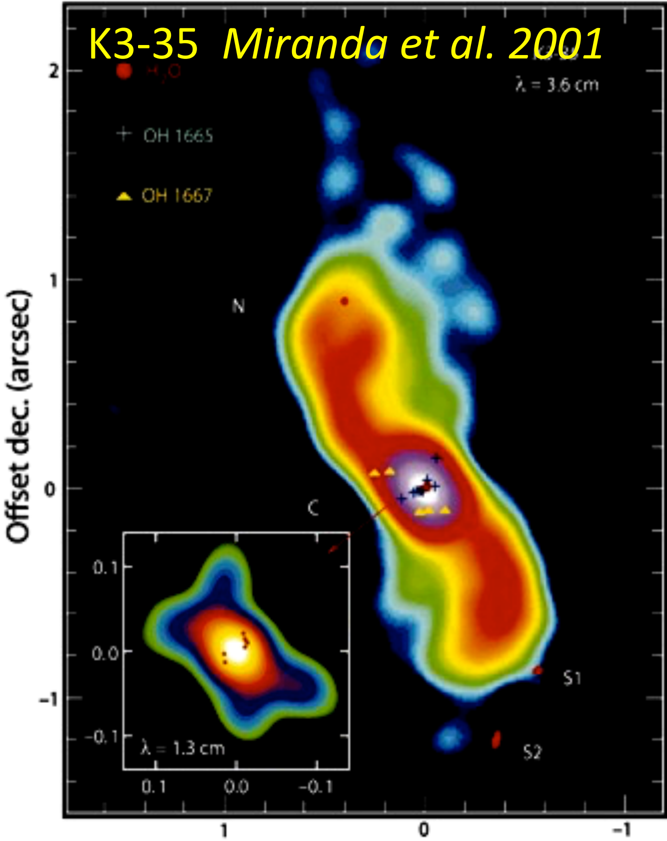
IR (Lagadec et al. 2011) +
ATCA (Perez-Sanchez et al. 2011)

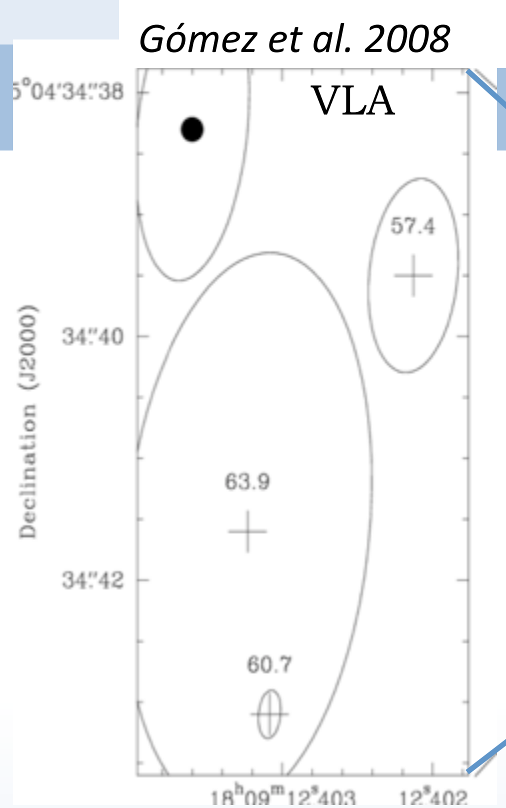


- Jet precession – sign of binarity ?

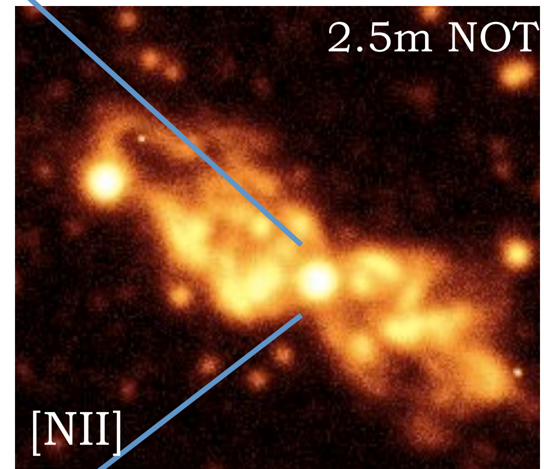
Water masers in PNe

- Believed impossible before 2001, now 5 H_2O-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



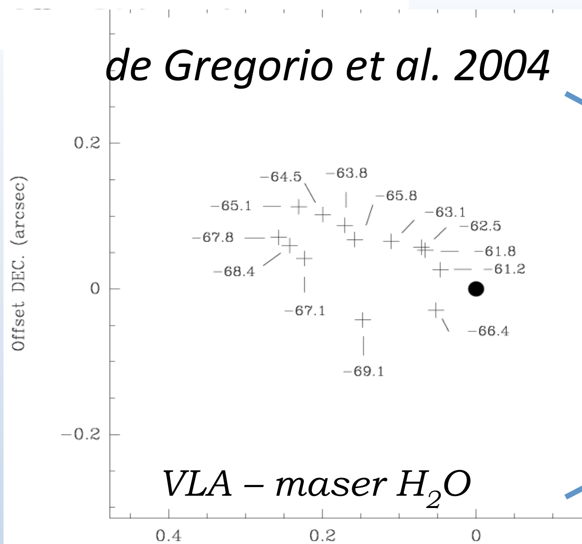


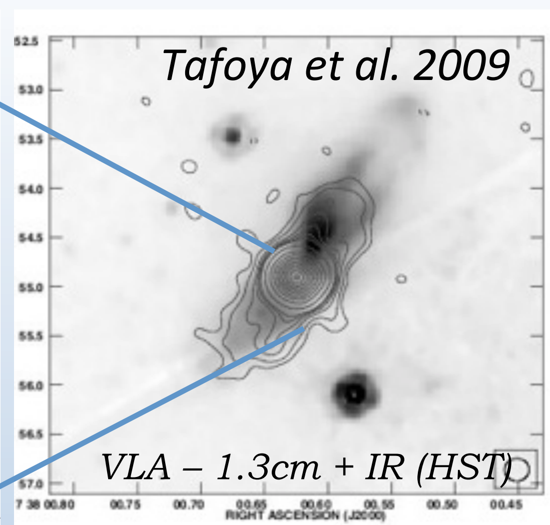
I18061



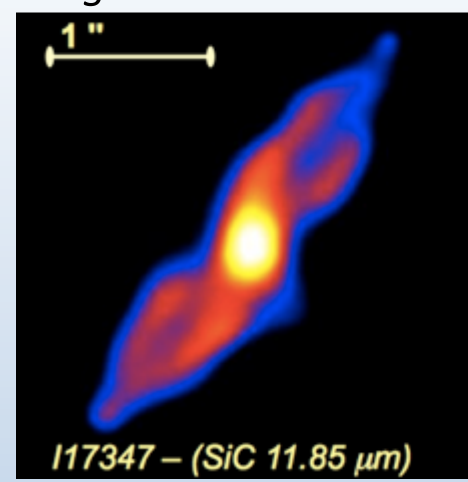
Suárez et al. (2006)

I17347

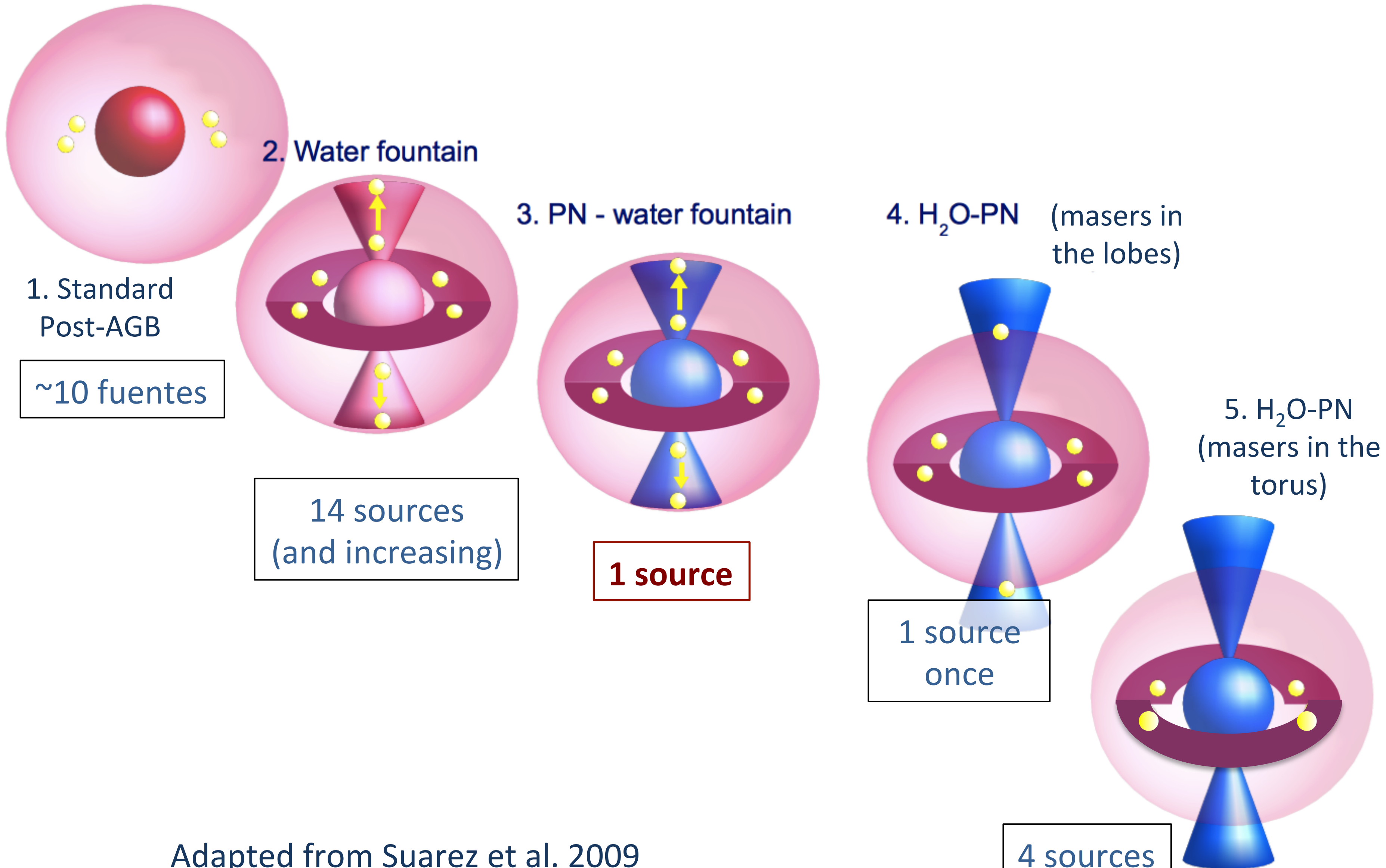




Lagadec et al. 2011

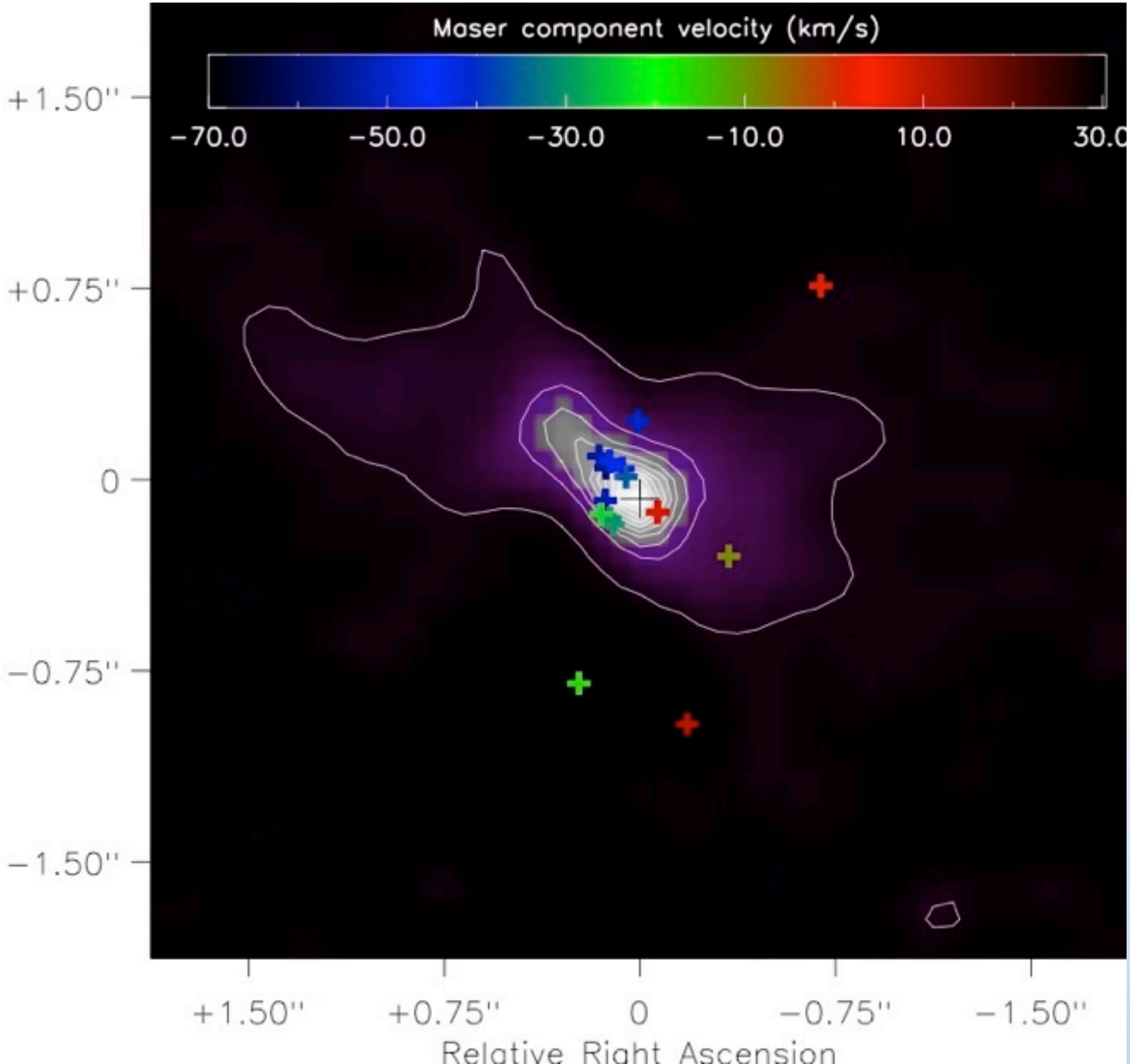


Sketch of the possible water maser evolution



Adapted from Suarez et al. 2009

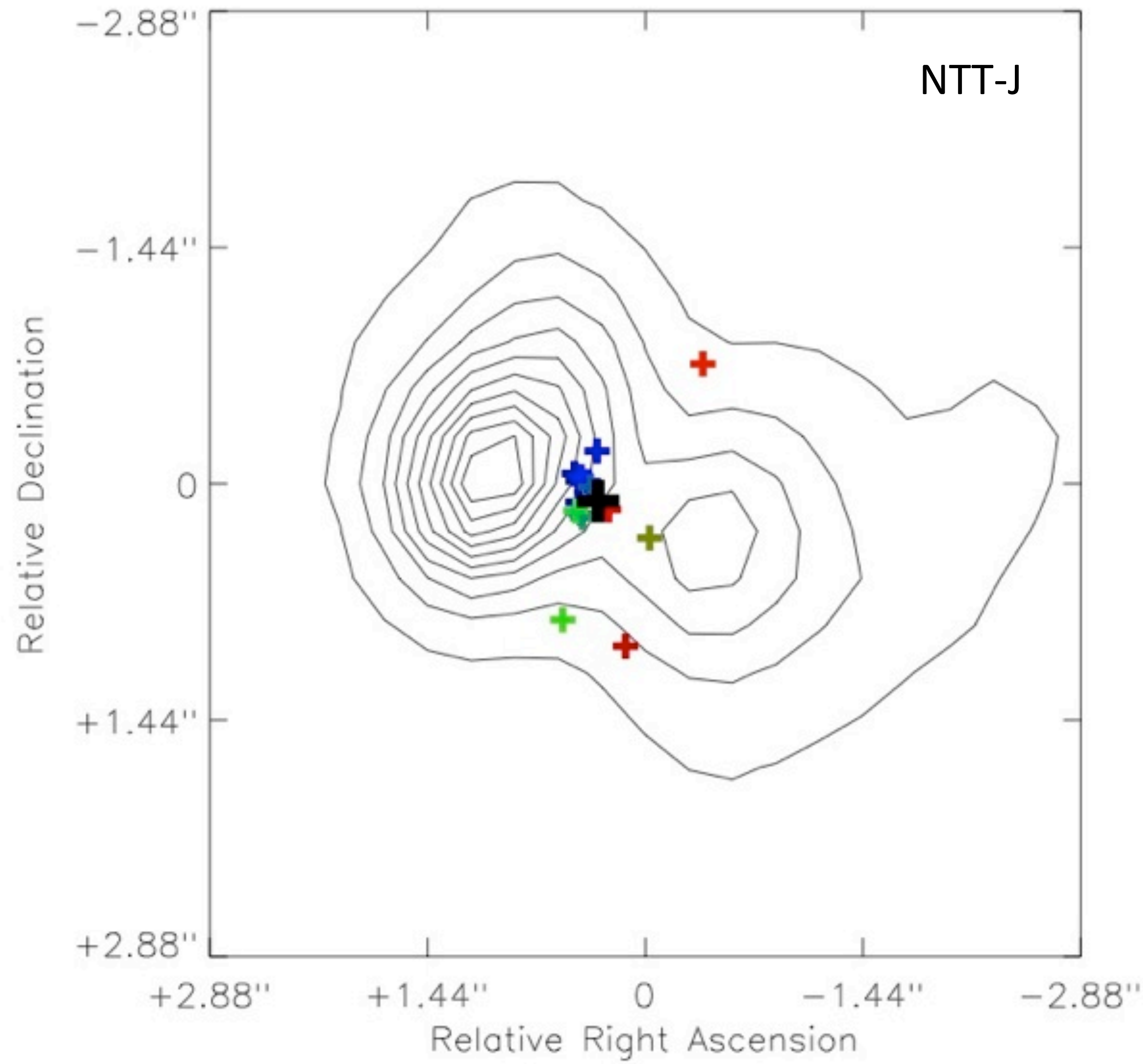
The missed link: IRAS 15103



Water masers – ATCA
Gómez et al. 2015

[NII] image (12.8 μm) from Lagadec et al. 2011

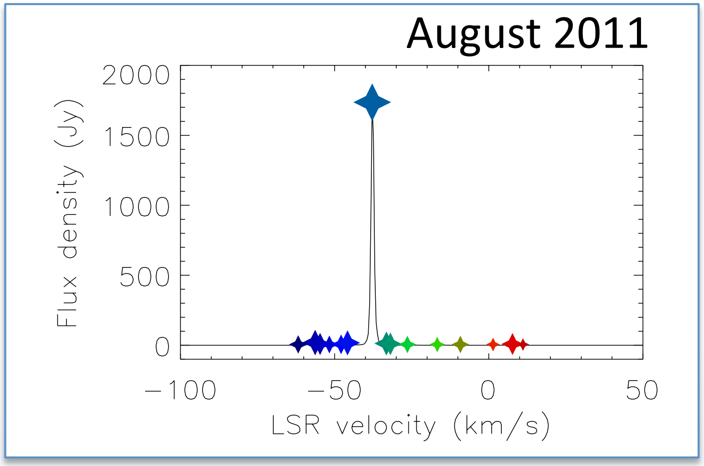
The missed link : IRAS 15103

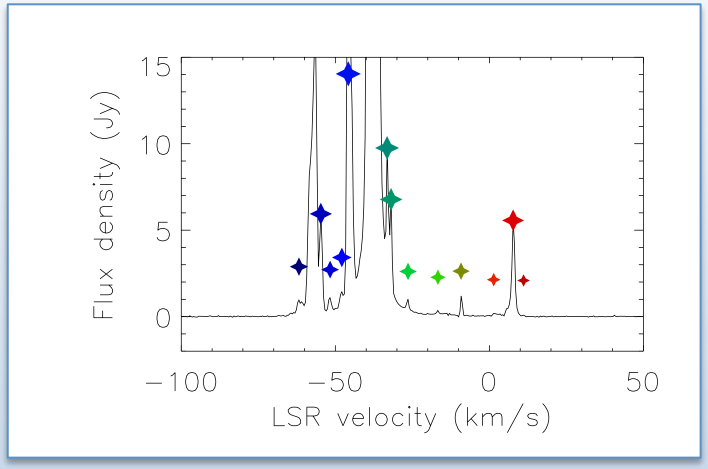


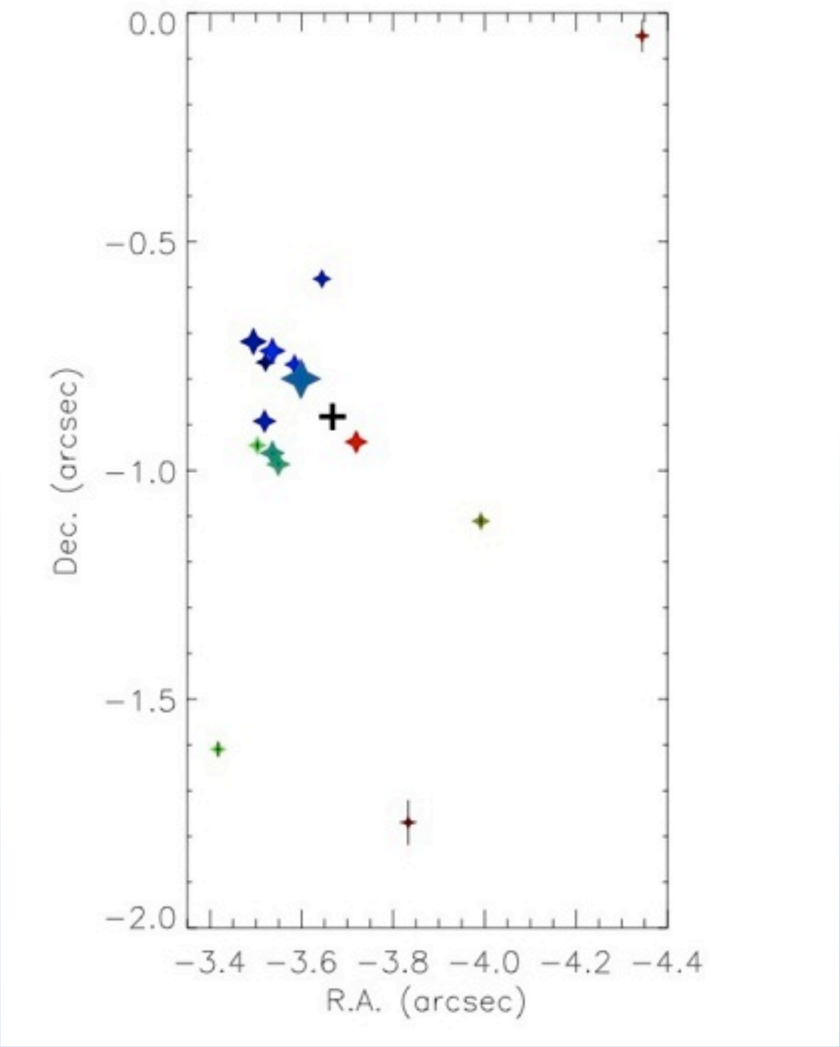
NTT - J image
Ramos-Larios et al. 2012

Maser distribution

Water masers - ATCA

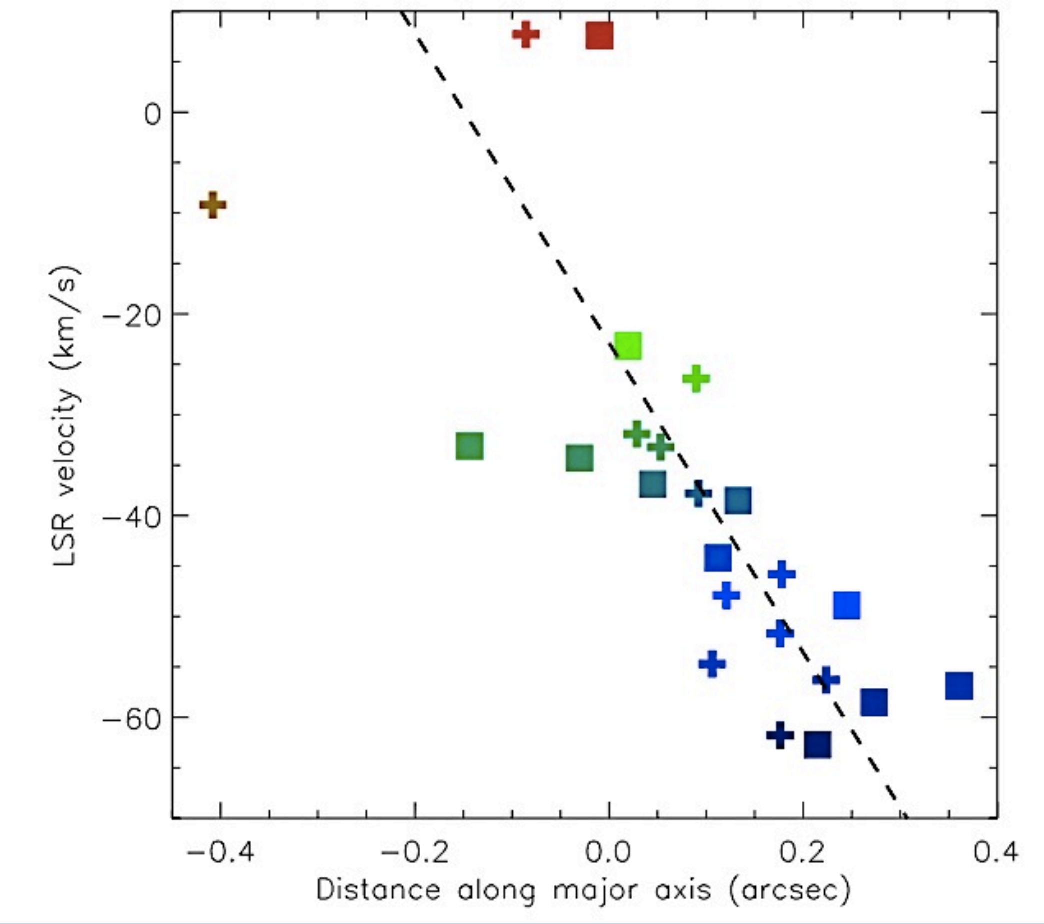






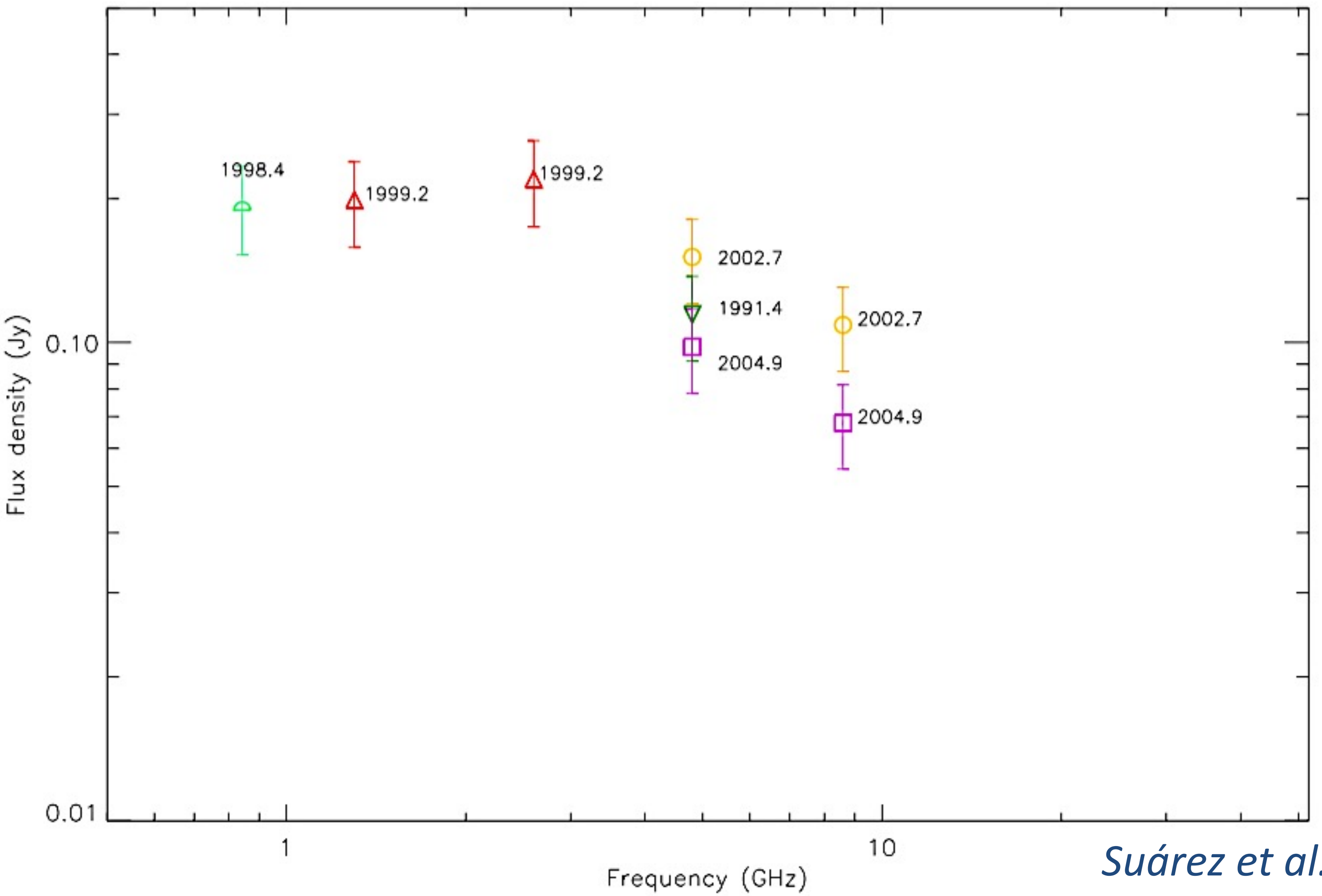
Hubble-flow jet

- Faster components further from the center
- Explosive emission of the jet



Radio continuum in I15103

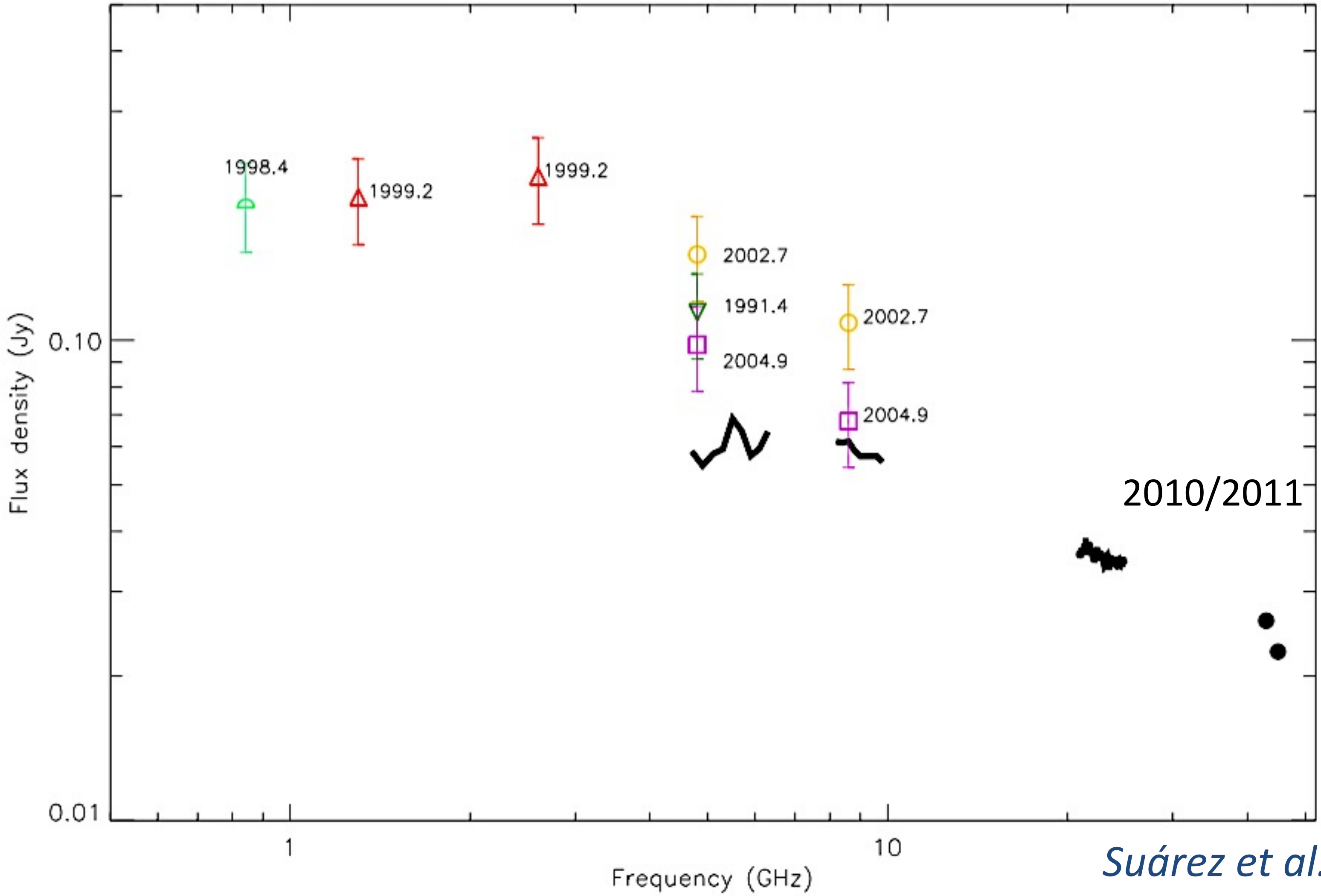
- Witness of the explosive formation of the PN – ATCA archive + observations



Suárez et al. 2015

Radio continuum in I15103

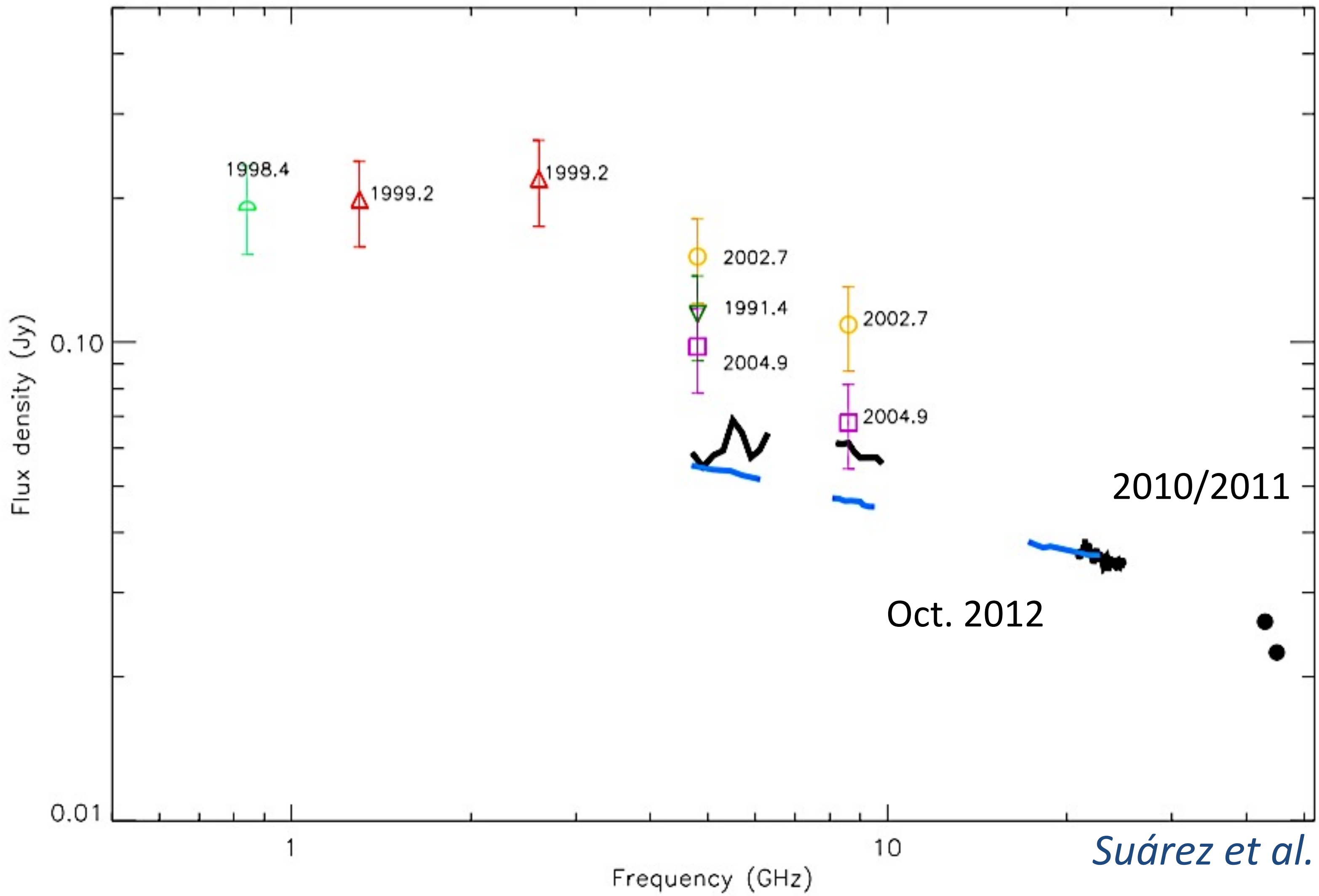
- Witness of the explosive formation of the PN– ATCA archive + observations



Suárez et al. 2015

Radio continuum in I15103

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



Suárez et al. 2015

Radio continuum in I15103

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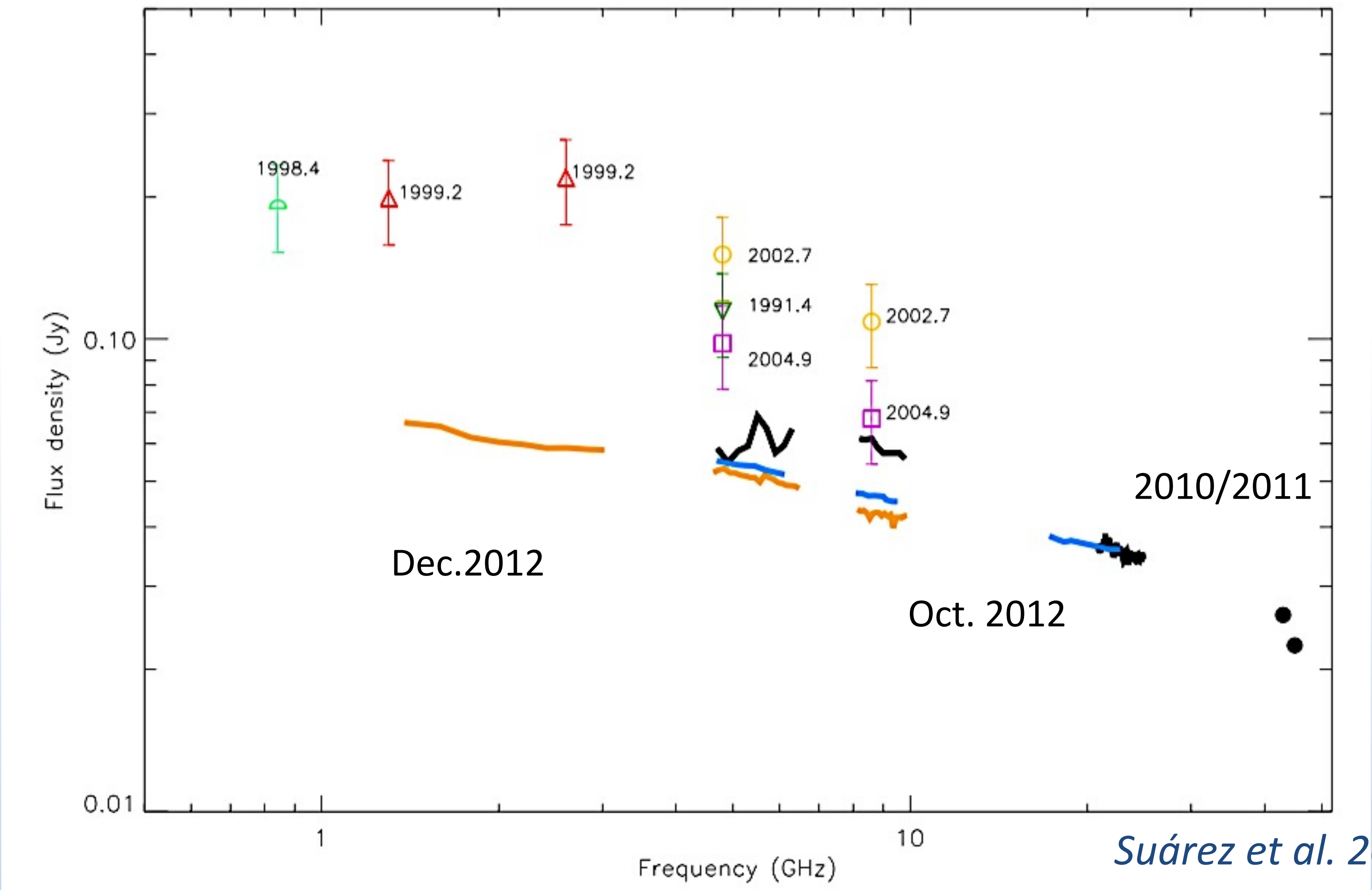
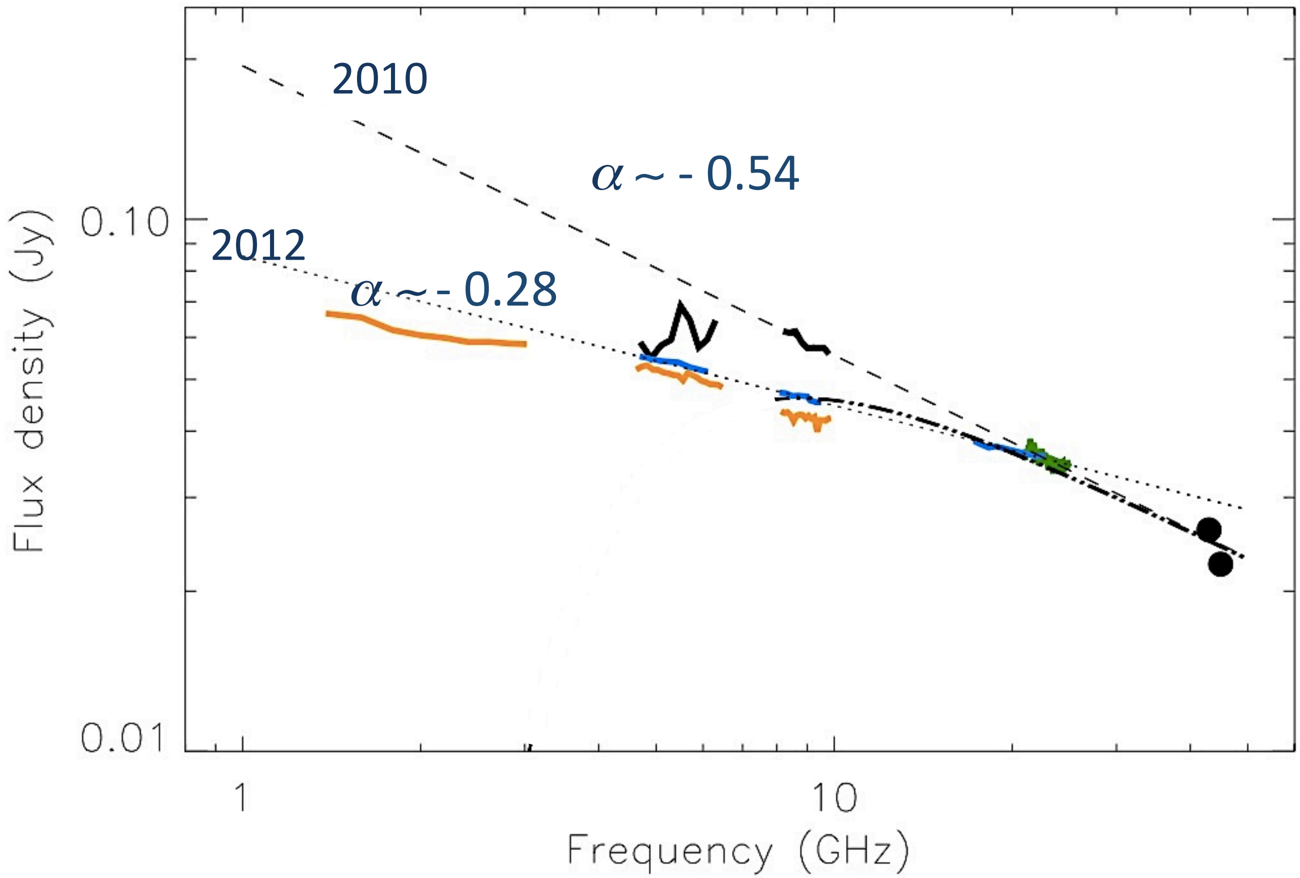


Suárez et al. 2015

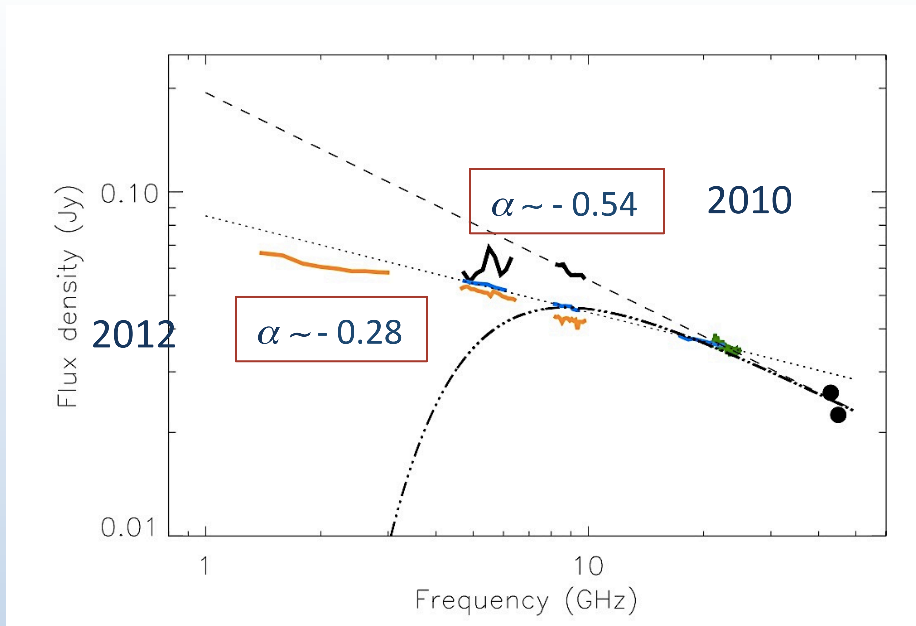
Spectral index variation

$S\nu \propto \nu^{\alpha}$, α spectral index



Changes in spectral index

- Classic PN – thermal emission (free-free) - a ~ 2 for n ≤ 10 GHz
  a ~ - 0.1 for n > 10 GHz
- **2010**: a ~ - 0.54 – compatible with synchrotron emission – Fermi first order acceleration (e- accelerated to high velocity in non-relativistic schocks)
- **2012**: a ~ - 0.28 – no synchrotron compatible



Possible explanations

- Possibilities :

a) 1. Explosive emission of a jet that produces synchrotron radiation

2. **Coulomb colissions** 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)

I15103 – in the future

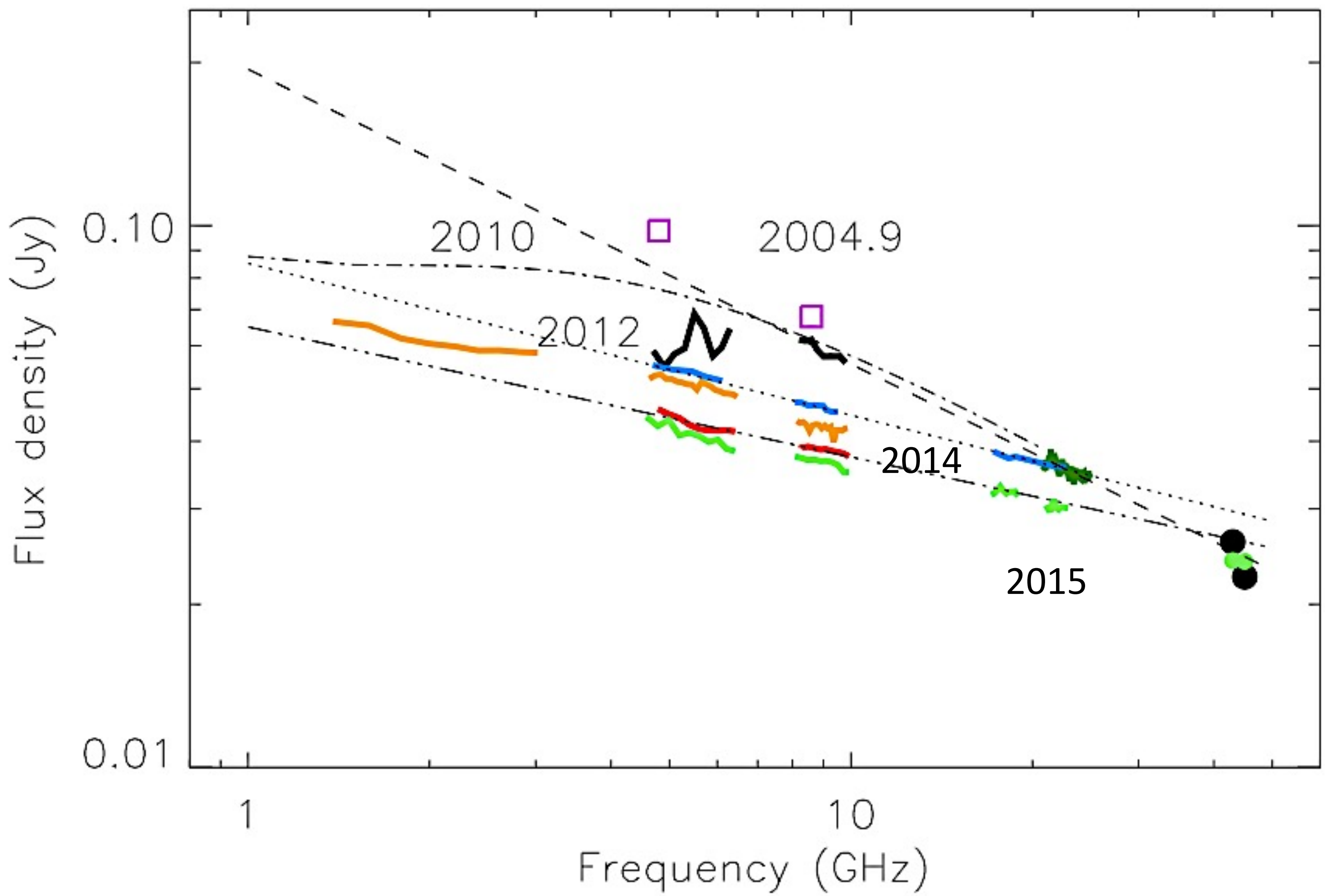
- Both possibilities imply the recent onset of ionization – **witness of the formation of a PN « in live »**
- The real cause of the disappearance of synchrotron ? – in several years…

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



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