Water maser emission toward Planetary Nebulae

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- Survey for water maser in PNe
- The case of IRAS 17347-3139
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Introduction

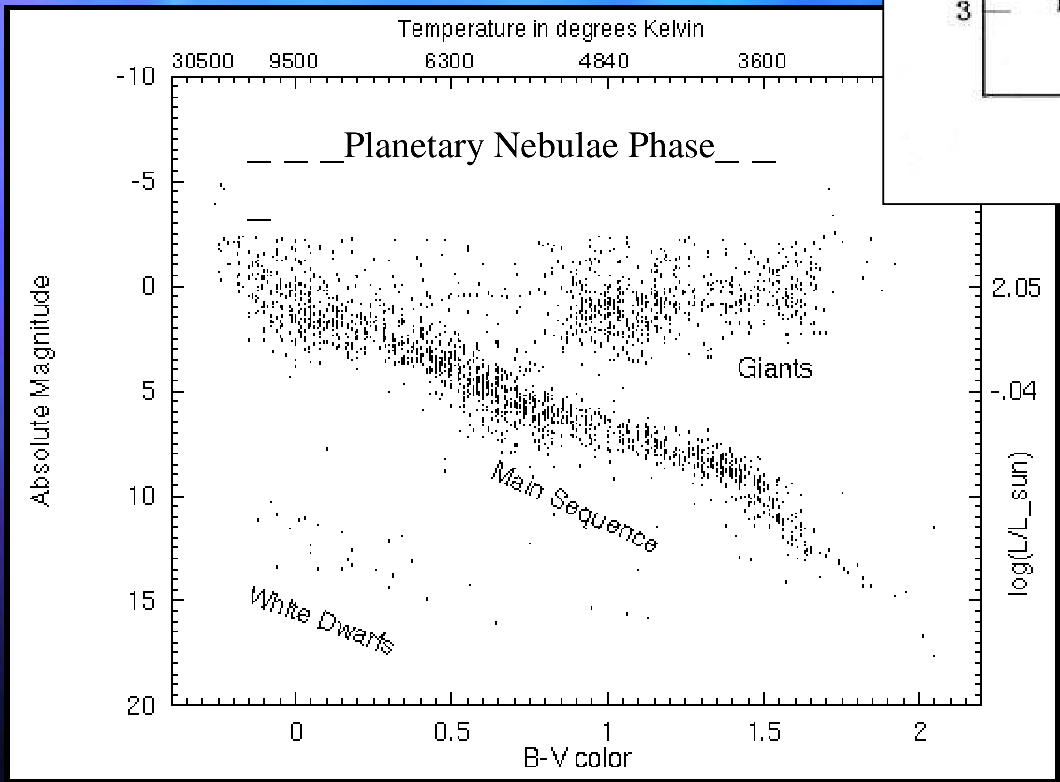
Planetary nebulae as a phase of stellar evolution

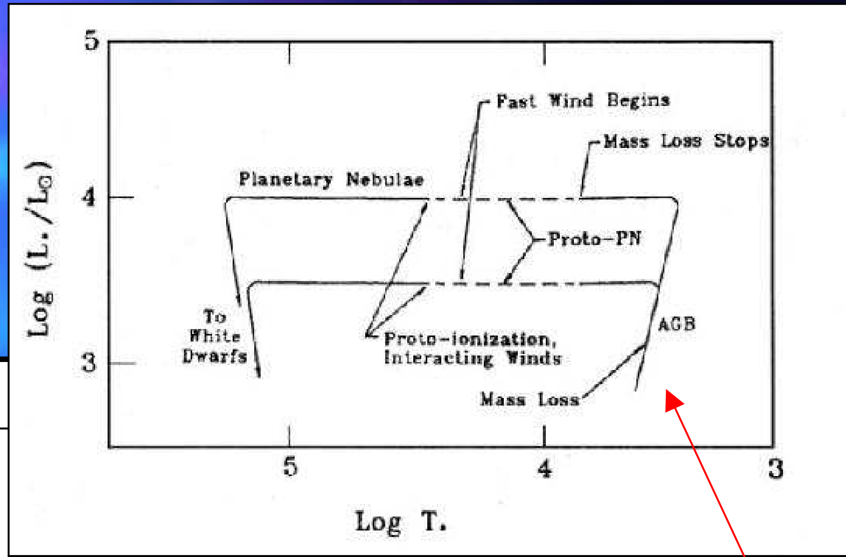
PNe are ejected shells of gas ionized by a very hot central star.

PNe galactic distribution and kinematics are similar to those of late-type stars (Curtis 1918; Shklovsky 1956; Abell & Goldreich 1966).

Red Giants ⟶ Planetary Nebulae ⟶ White Dwarfs

When a star leaves the main sequence it starts out on a long path through the HR diagram.

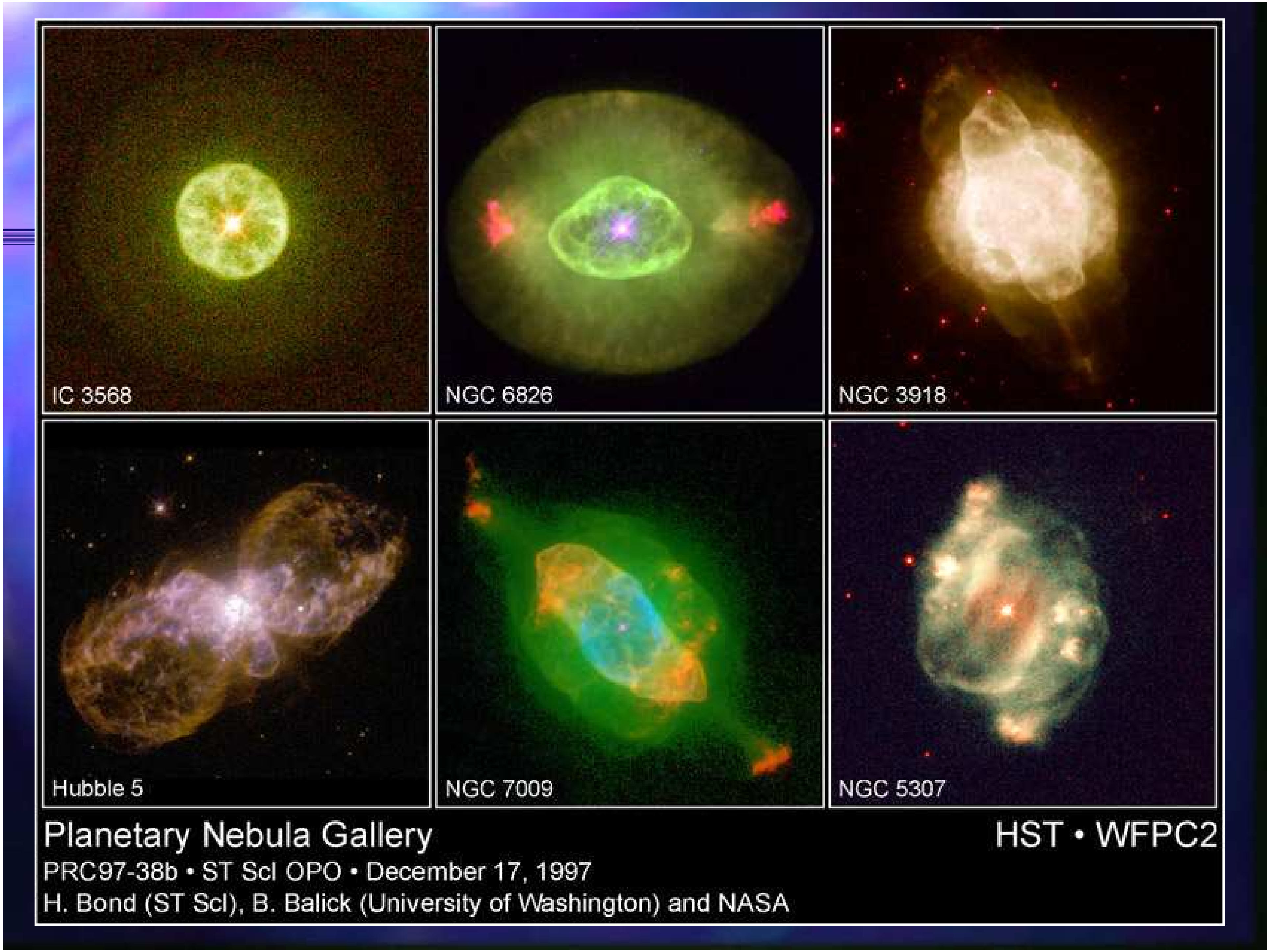




Stars with M<8 $M_{Sun,}$, reach a phase called the Asymptotic Giant Branch or AGB.

L~3000 L_{sun}, T_{eff}<4000 K, and M_{dot}~10^{-7} – 10^{-4} M_{sun}/yr.

The AGB star expel matter at high rate, but at low velocity (~10 km/s) creating an obscuring ``circumstellar envelope´´


IC 3568
NGC 6826
NGC 3918
Hubble 5
NGC 7009
NGC 5307
Planetary Nebula Gallery
HST • WFPC2
PRC97-38b • ST ScI OPO • December 17, 1997
H. Bond (ST ScI), B. Balick (University of Washington) and NASA

Formation of a PNe

- Proto-PNe are objects in transition between the AGB and PN phases of stellar evolution for intermediate mass stars (0.8-8 M_{Sun}).
- PN is formed when the envelope ejected during the Red Giant phase becomes photoionized.
- If the envelope of the Red Giant is oxygen rich it will produce maser emission from SiO, H_2O and OH (Goldreich & Scoville 1976; Elitzur 1976).

Red Giant:

$t \sim 10^{7}$ years

$\dot{M} \sim 10^{-7}\ M_{\odot}/yr$

Planetary Nebula:

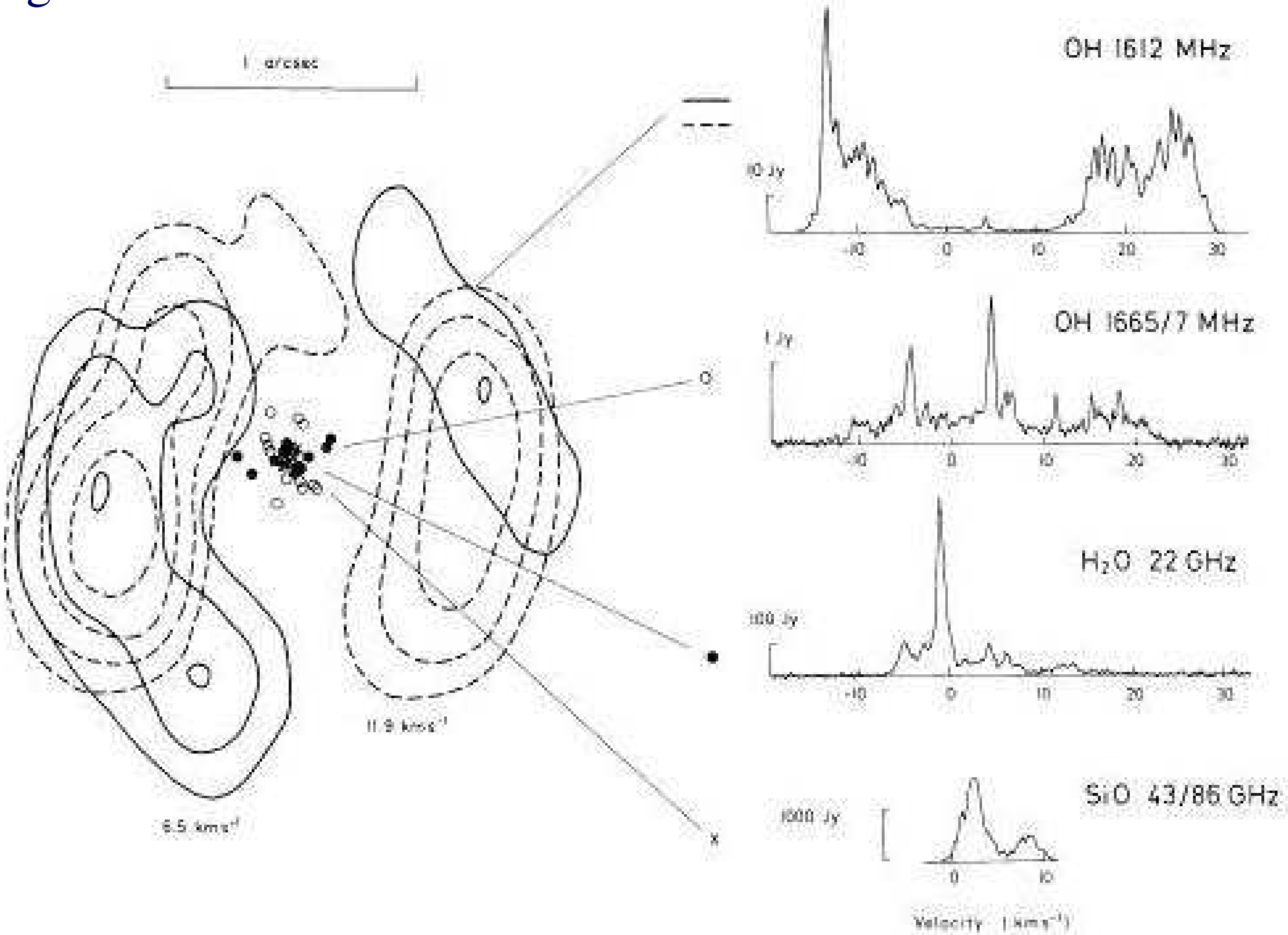
$t \sim 10^{4} - 10^{5}$ years

Transition RG → PN

$t \sim 1000$ years

$\dot{M} \sim 10^{-4}\ M_{\odot}/yr$

VXSgr



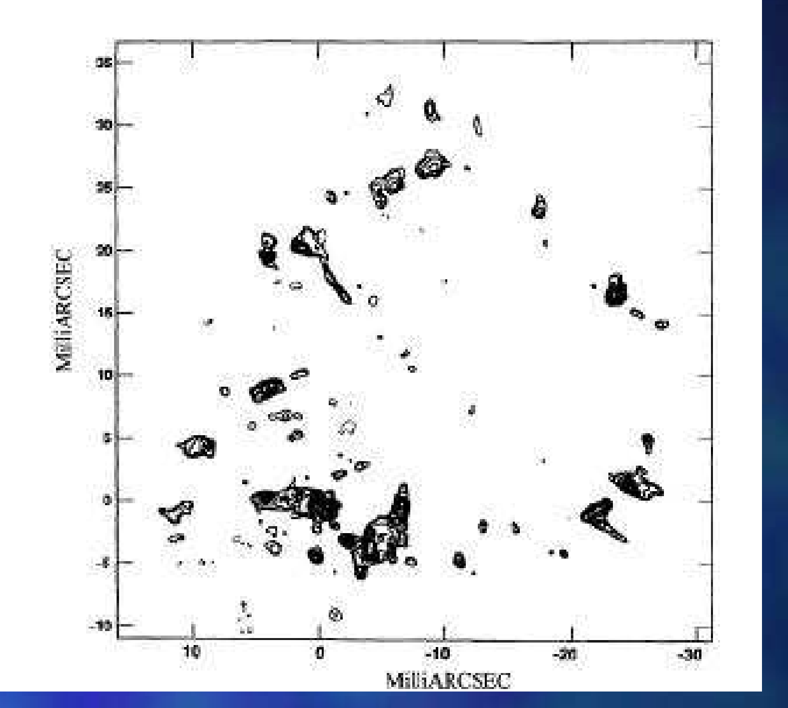
Chapman & Cohen 1986, MNRAS, 220, 513

SiO masers in TX Cam

Mira TX Cam
(D=0.39 kpc)

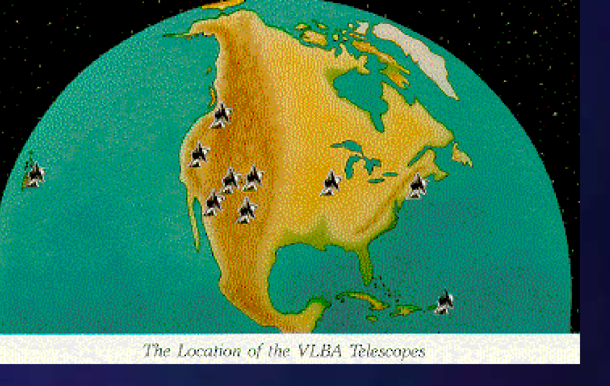
VLBA image of SiO masers.

Radial proper motions→ 5-10 km/s



(Diamond & Kemball 2003)

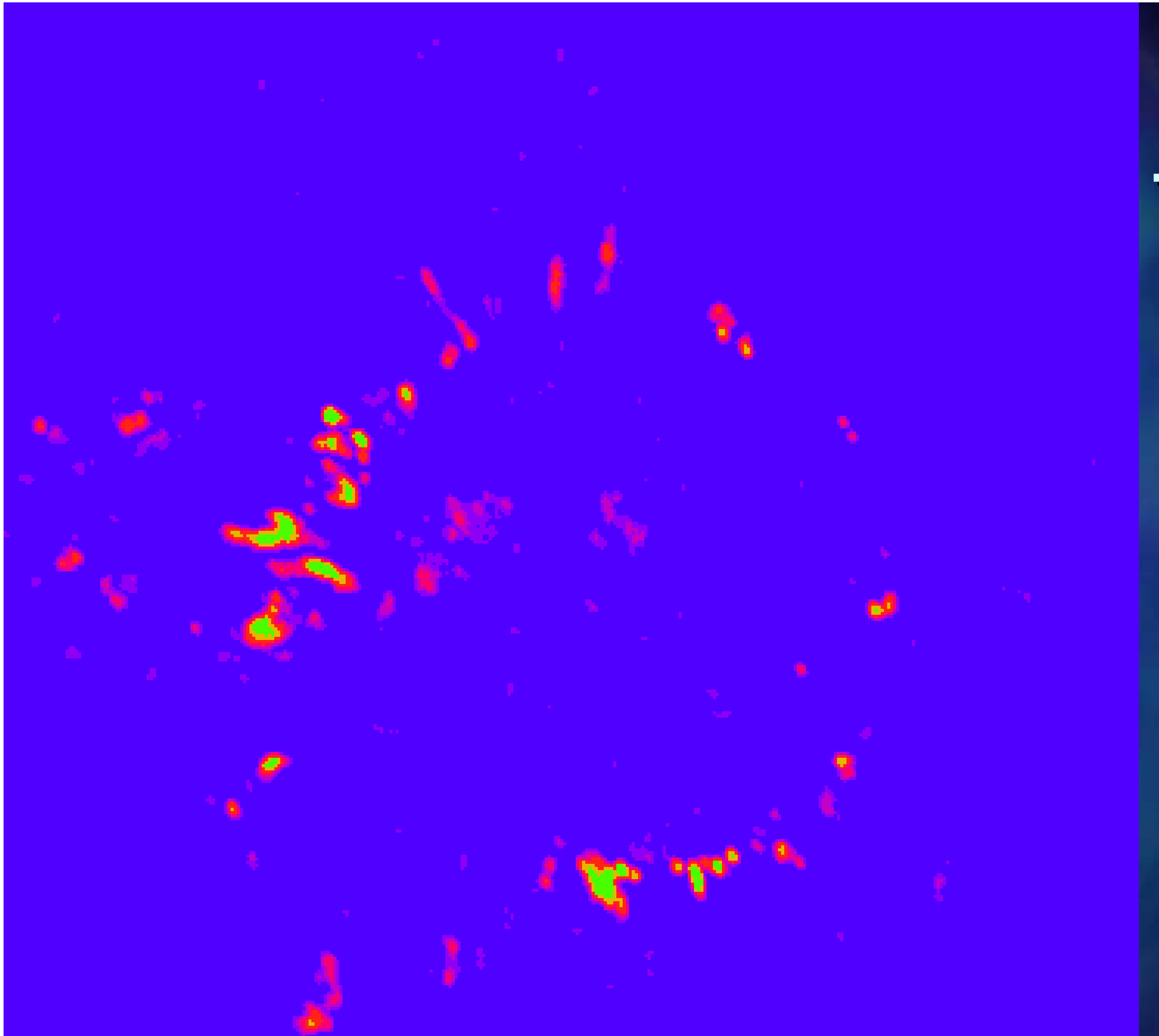
500 µas at 7 mm (43 GHz)



SiO masers arise from a region close to the stellar photosphere inside the dust formation point (Elitzur 1980).

TX Cam

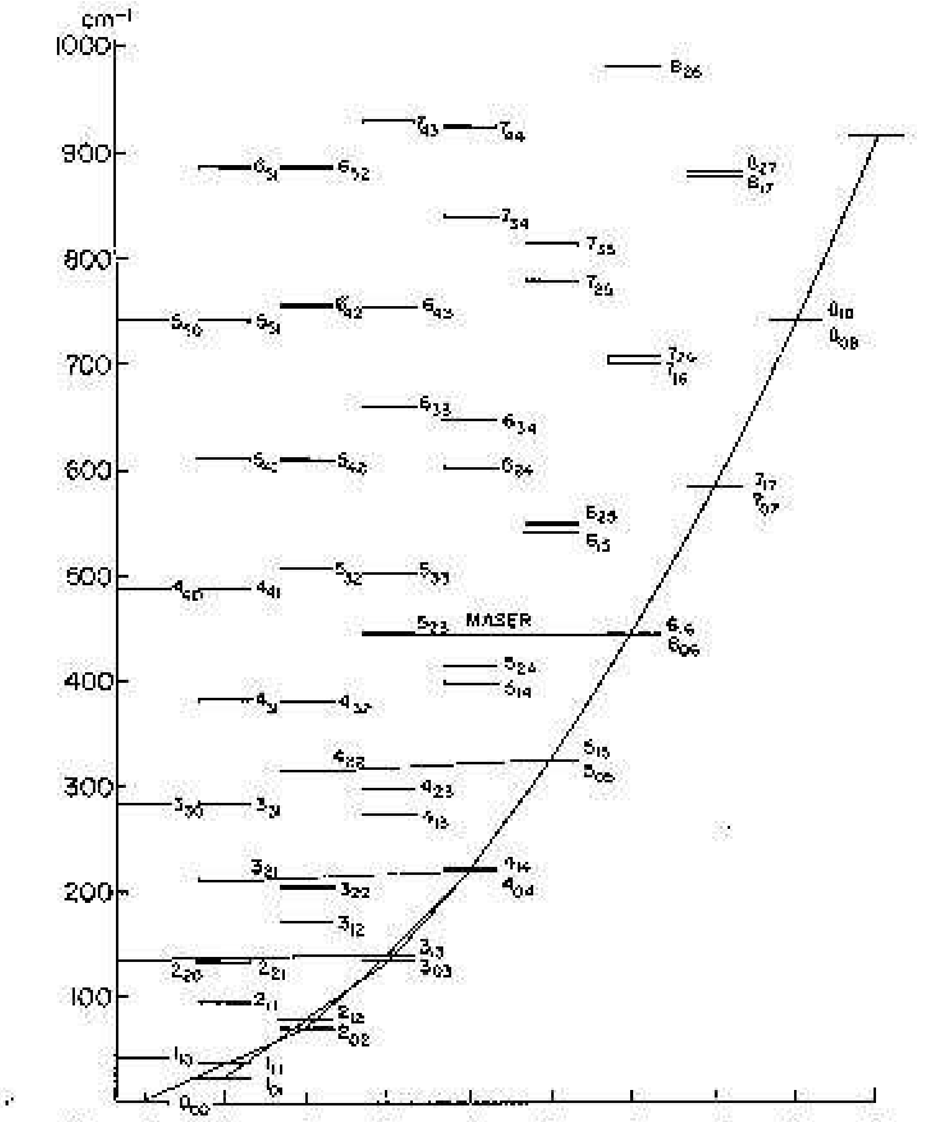
Radius~10^{14} cm



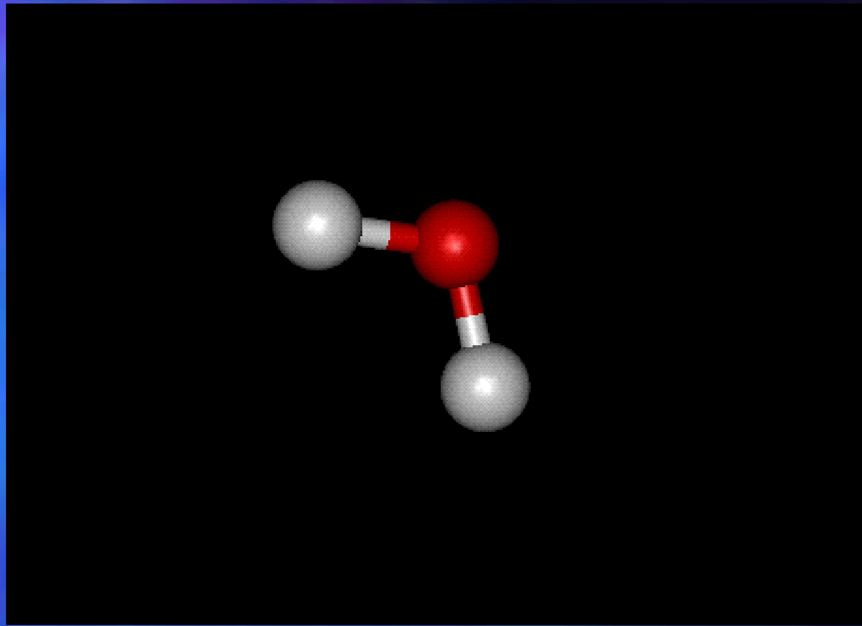
http://www.space.com/scienceastronomy/astronomy/star_movie_000814.html

Physical conditions for water maser emission:

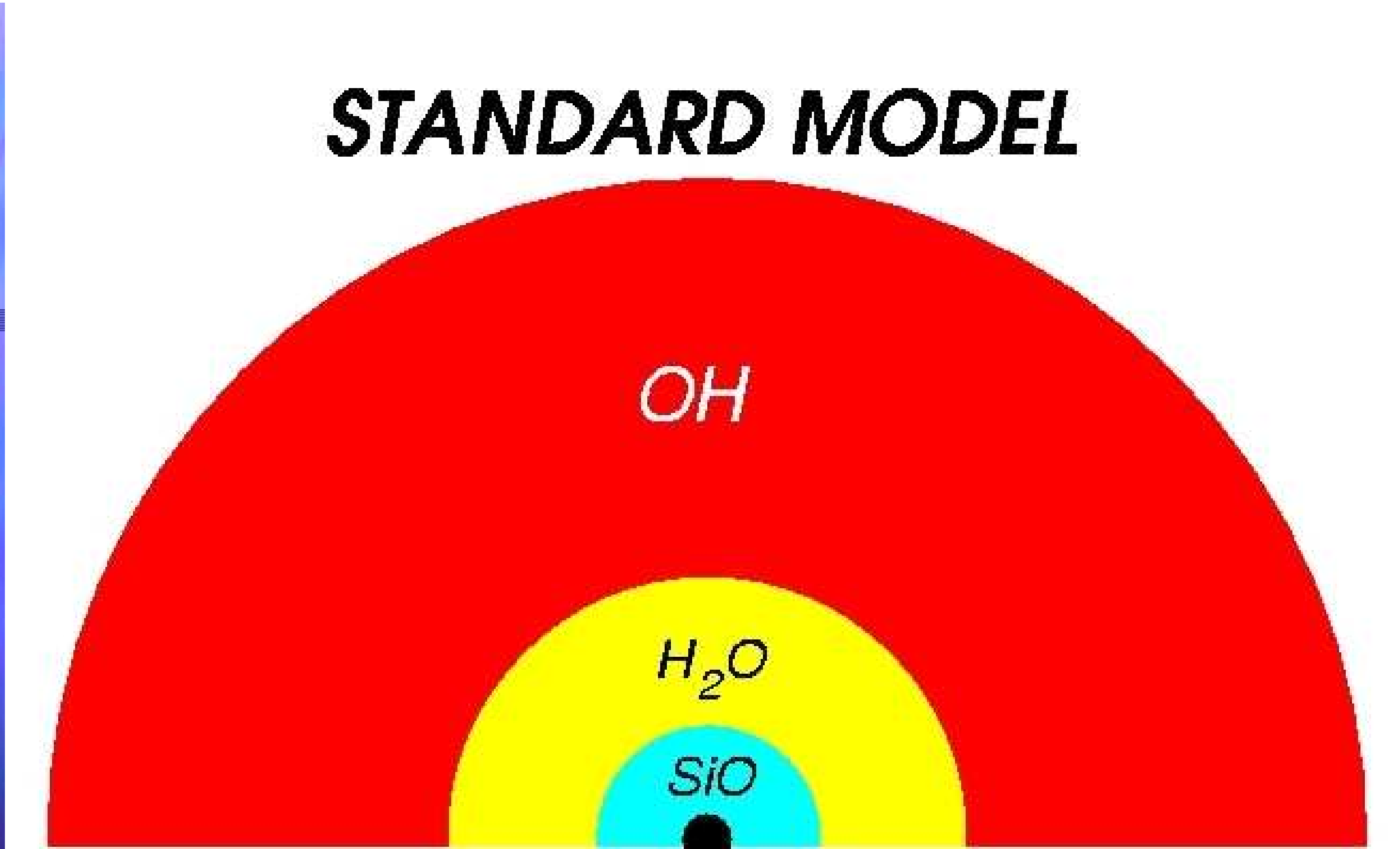
- H_2O molecules
- H_2 density ~ 10^8 cm^{-3}
- Temperature ~600 K
- Favorable velocity gradients



1. Rotational energy levels of H_2O molecules sorted out with K_c. The Group-A levels are composed of $J_{0,J}$ and $J_{1,J}$ levels which lie at the bottom of each column for a given K_c. The lines connecting various levels indicate spontaneous emission of the H_2O molecules. It should be noted that if molecules in Group-A levels relax from high energy levels the maser transition $6_{16} \rightarrow 5_{23}$ is the first connection between the Group-A and Group-B levels. Therefore if some molecular process depletes molecules in the Group-B levels there will be an inverted population between the 6_{16} and the 5_{23} levels.



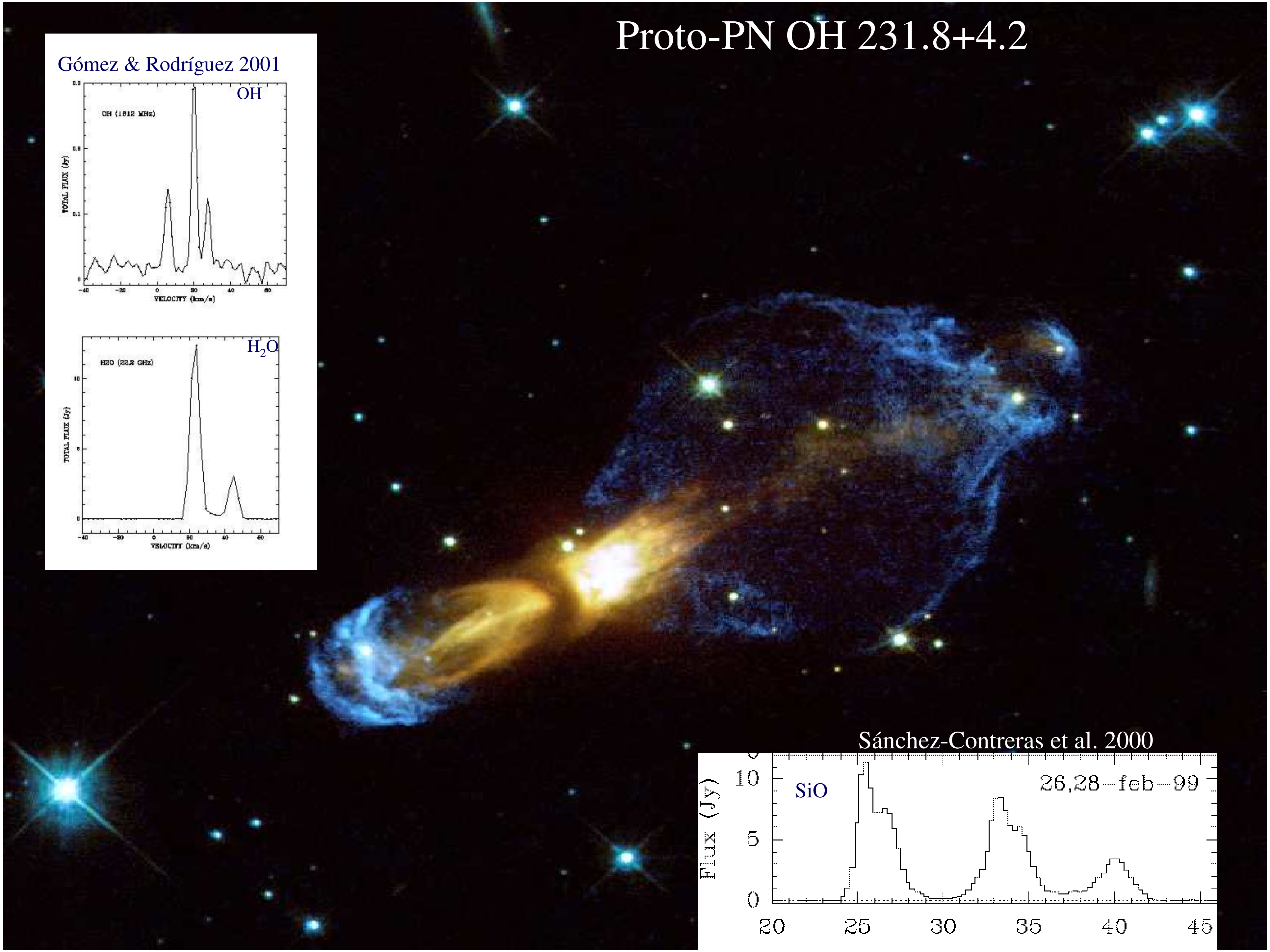
- Rotational energy levels of H_2O molecule between 6_{16}-5_{23} → maser emission
- ν=22.235 GHz
- λ=1.3 cm



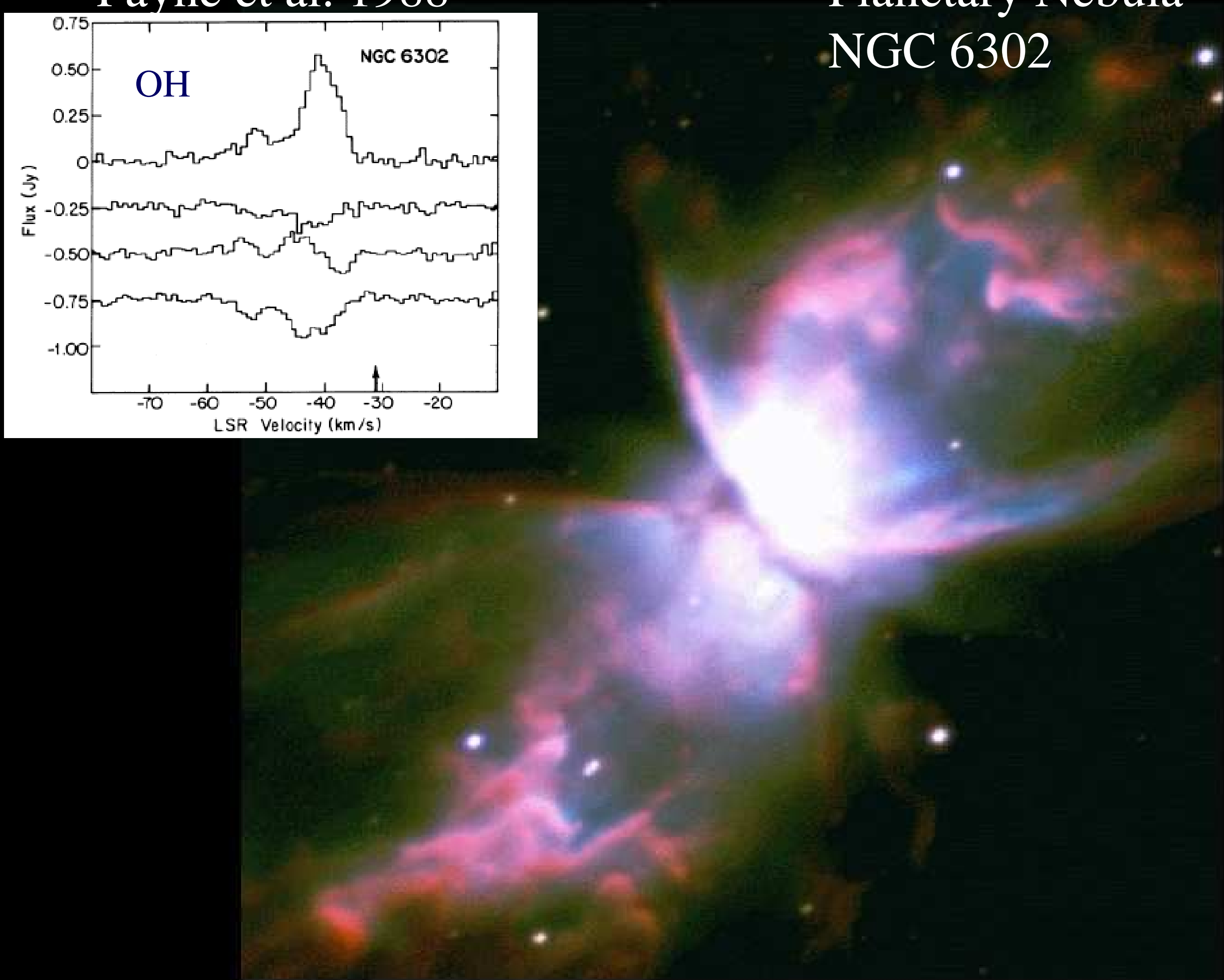
- Simple wind model V_{exp}~10 km/s
- SiO, H_2O, OH stratified in the envelope due to chemical and excitation conditions at ~$3x10^{14}$, $3x10^{15}$, and $3x10^{16}$ cm from the central star respectively.
- When ionization begins, masers will "disappear" in a time scale of 10, 100 and 1000 years.

(Lewis 1989; Gómez, Moran & Rodríguez 1990)

Proto-PN OH 231.8+4.2



Payne et al. 1988



Planetary Nebula
NGC 6302

NGC 6302 VLT

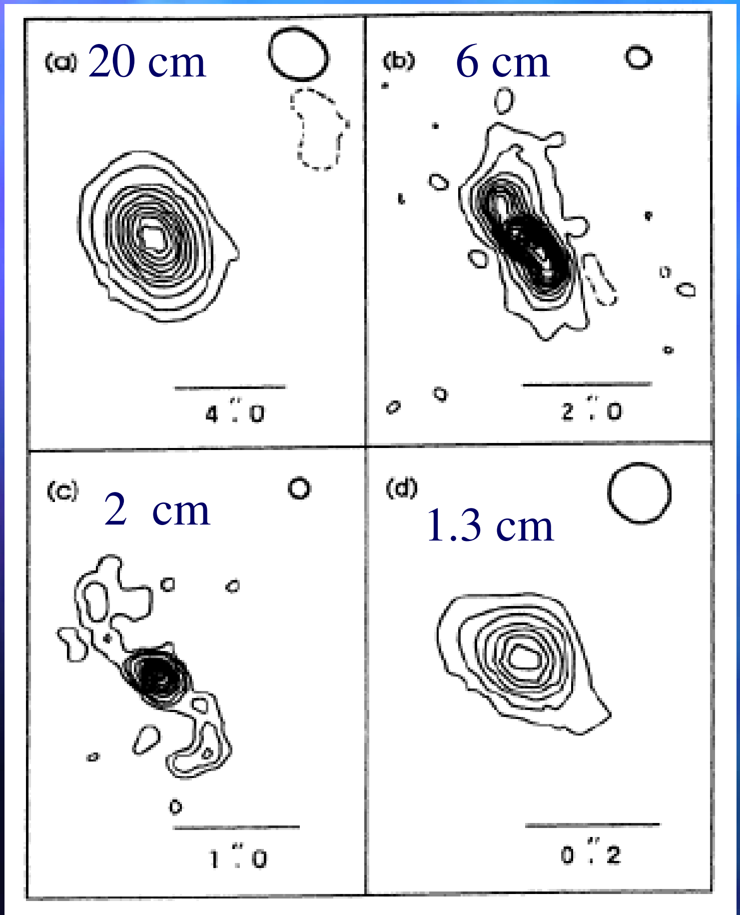
Water maser emission in PNe?

Water masers are not expected in PNe

Animation of the Helix Nebula

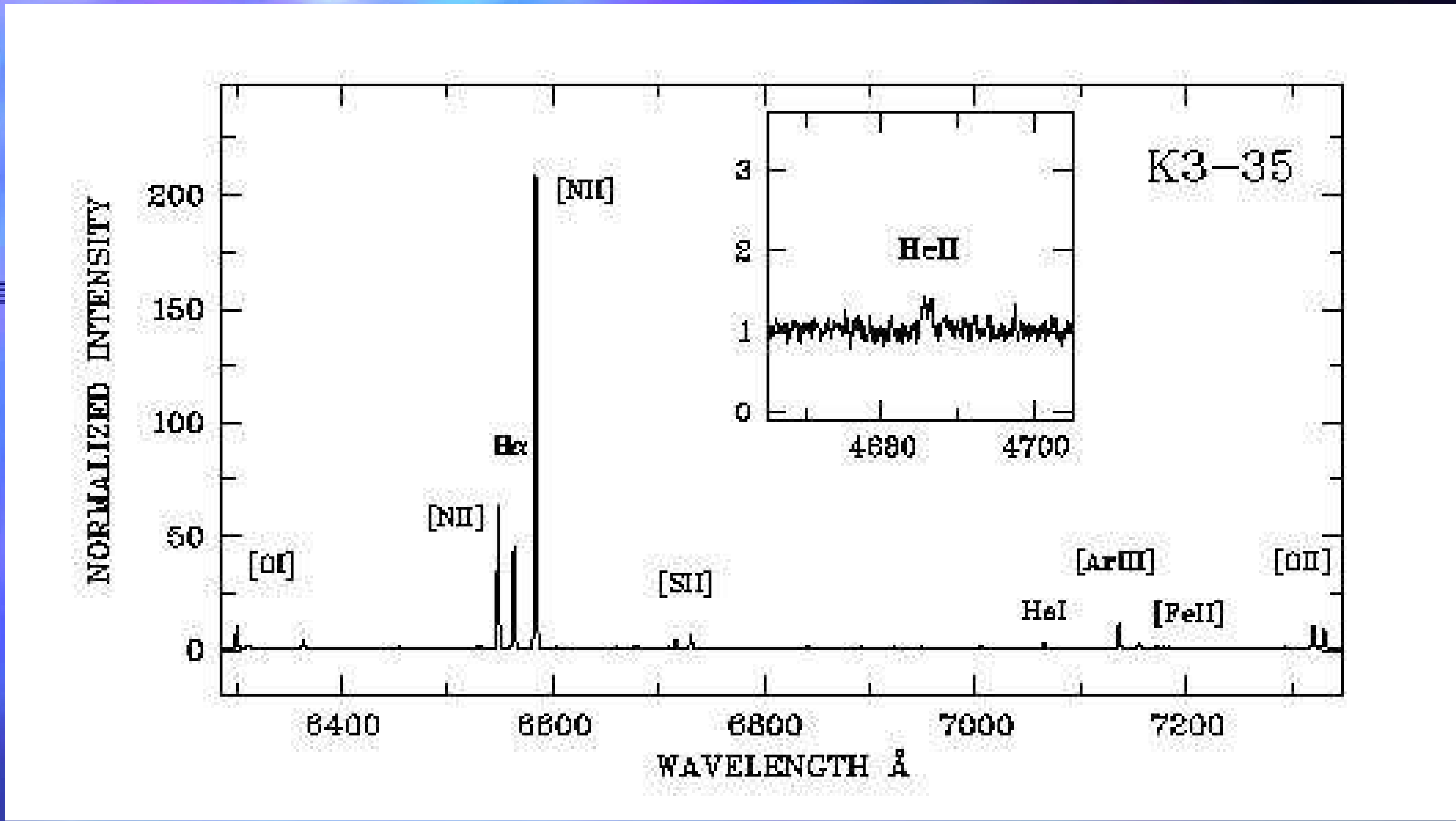
- Because water molecules are rapidly destroyed when photoionization begins.
- Even if molecules survive in outer parts of envelope, density (~$3x10^4$ cm^{-3}) and temperature (~100 K) are too low for H_2O maser emission.

The case of K 3-35



Aaquist 1993

- Is an emission nebula with bipolar jets (Aaquist & Kwok 1989; Aaquist 1993; Miranda et al. 2000)
- Narrow & broad CO lines (Engels et al.1985; Dayal & Bieging 1996)
- OH and H_2O masers were detected but the association was unclear (Engels et al. 1985; Aaquist 1993)
- Distance 5 kpc (Zhang 1995)



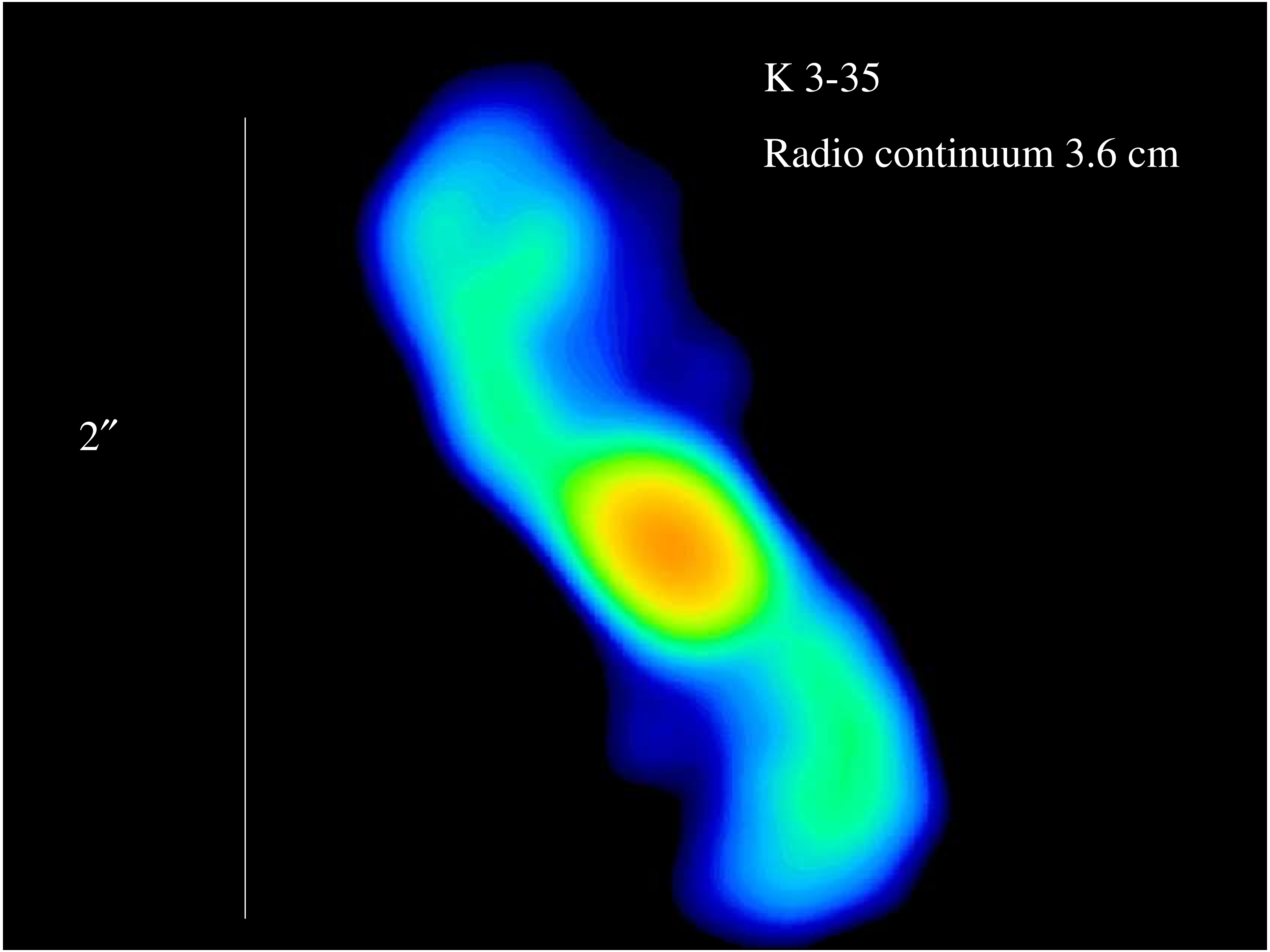
- HeII 4686/Hβ ~ 0.5
- [NII]/Hα ~ 5
- [OIII]/Hβ ~ 30

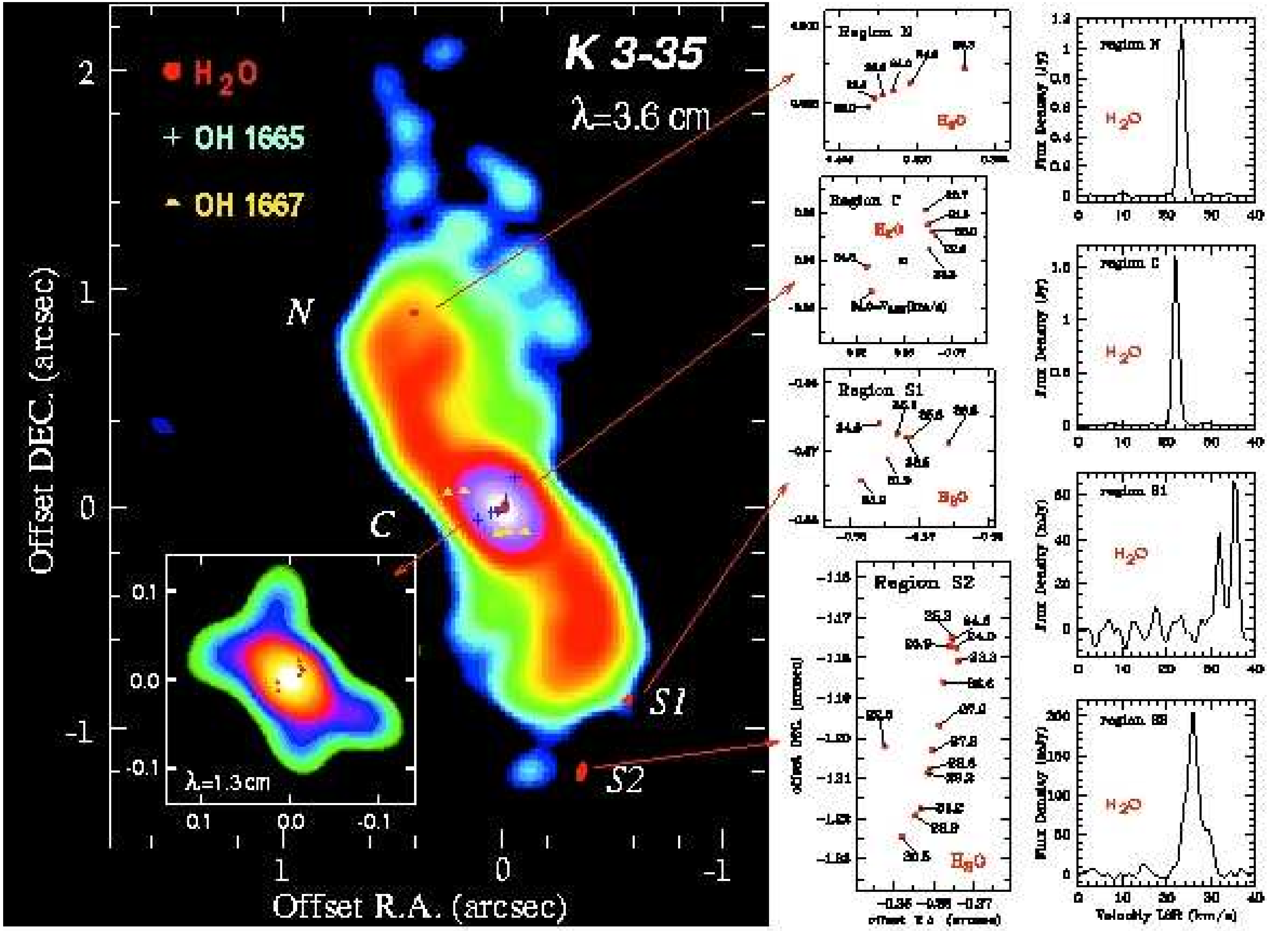
(Miranda et al. 2000, MNRAS, 311, 748)

Observations

Very Large Array (VLA), USA..

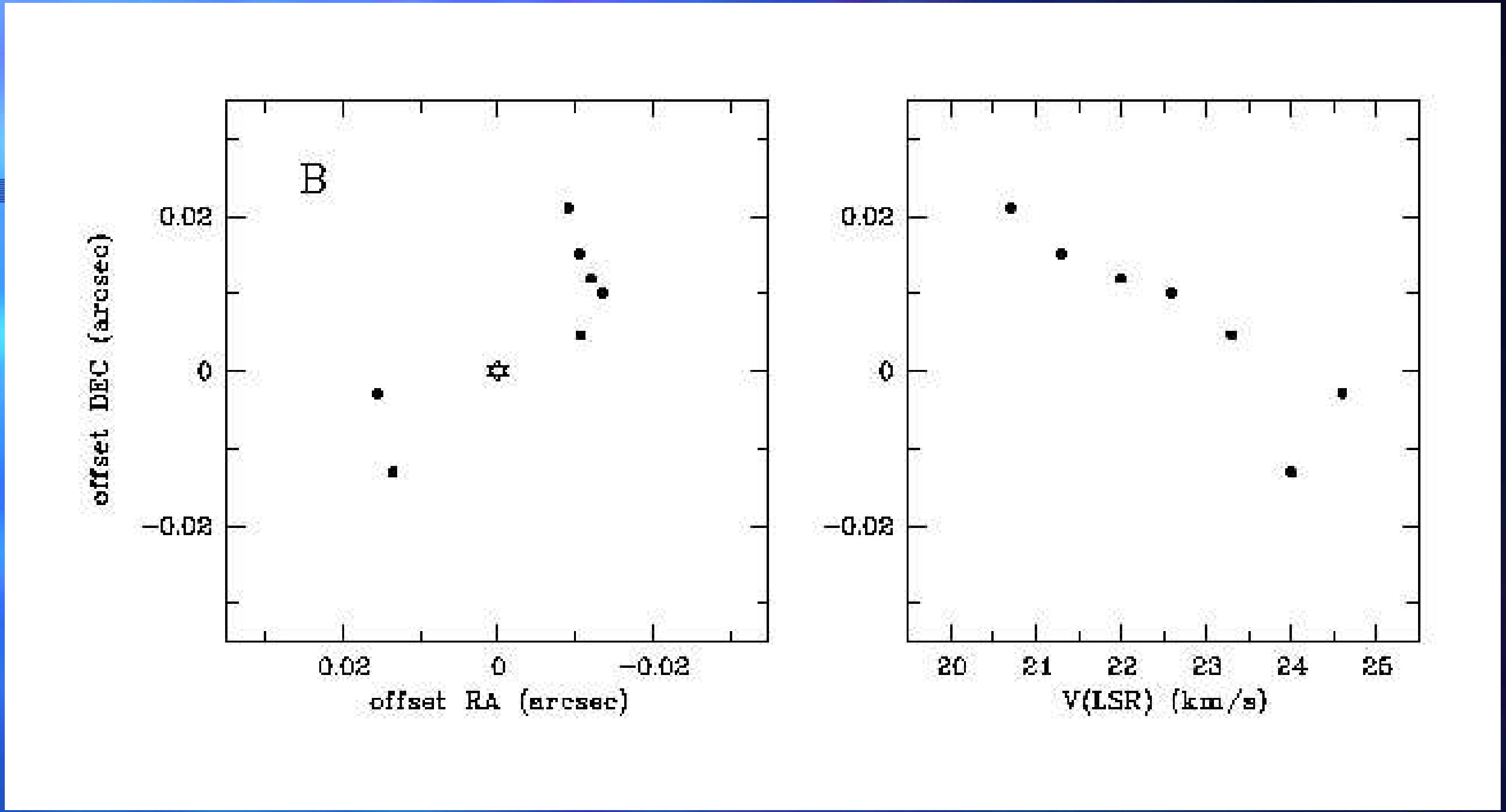
- Simultaneous VLA observations of H_2O maser and continuum from K3-35
- Spatial resolution ~0.1″
- Relative positional accuracy of masers of ~milliarcsec


K 3-35
Radio continuum 3.6 cm
2″



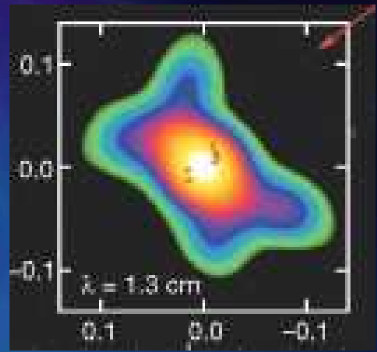
(Miranda, Gómez, Anglada & Torrelles 2001, Nature, 414, 284)

Water masers are located at a projected distance of 85 AU from the peak continuum emission

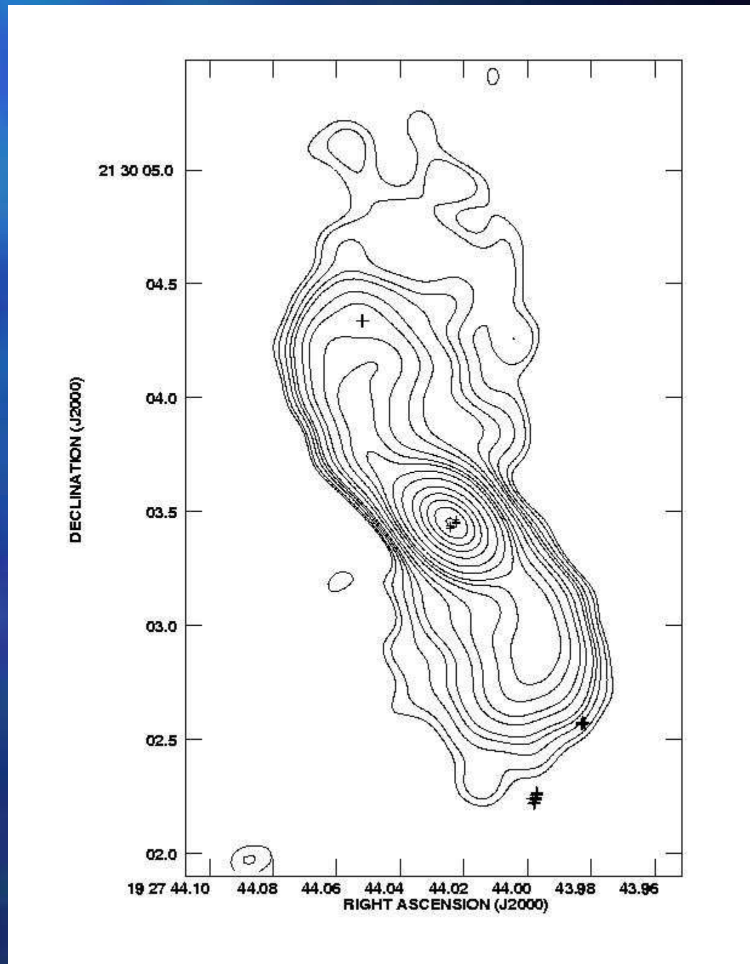


Velocity gradient of 4 km/s, if Keplerian rotation, an inner mass of 1 Mo is estimated.

K 3-35: first PN with water maser emission

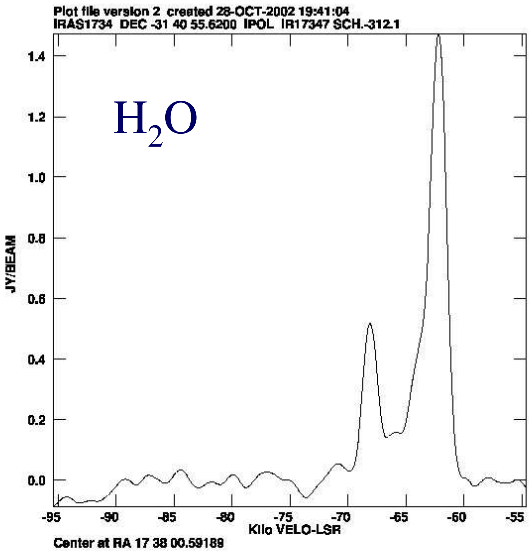


- At 85 AU from the core and at 5000 AU from the central star.
- K3-35 is among the youngest PNe ever identified.
- Assuming a birthrate of 1 PN per yr and a survival lifetime for H_2O molecules of ~100 yrs → tens of objects could be in this phase in our galaxy.



Survey for water maser in PNe

IRAS 17347-3139



- 27 PNe were selected from its association with dust and/or CO, OH lines, IR emission
- Observations:

70 m Robledo de Chavela antenna, Spain

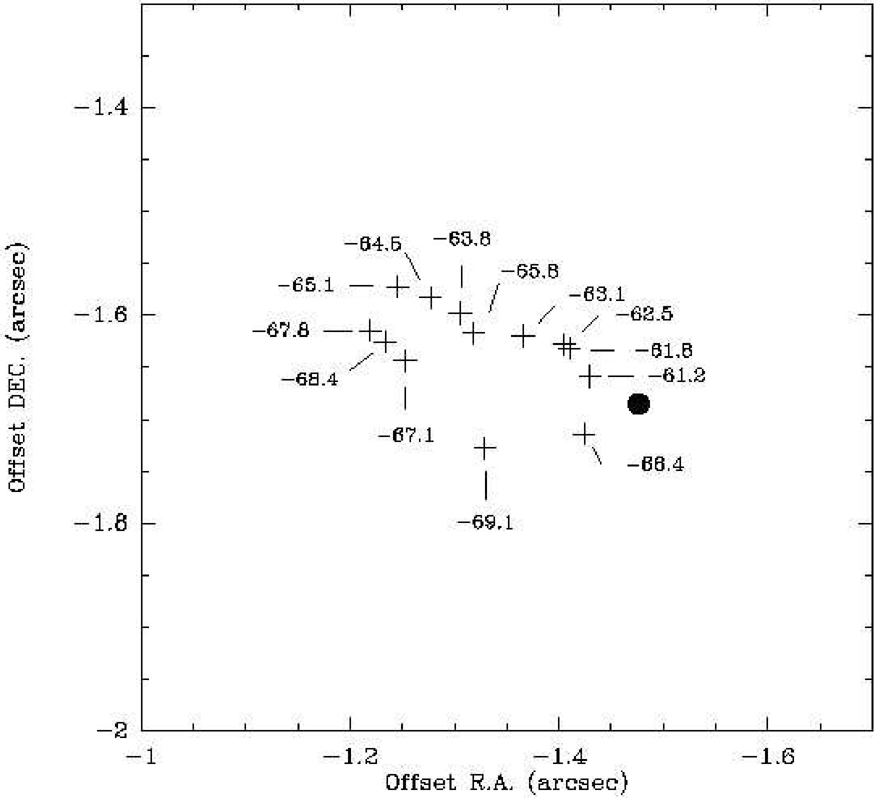
32 m antenna, Medicina, Italy

- A second PN was detected in H_2O.

The case of IRAS 17347-3139

- OH maser emission (Zijlstra et al. 1989)
- IRAS colors like PNe (García-Lario et al. 1997)
- No SiO maser associated (Nyman et al. 1998)
- Its IR luminosity (5×10^4 L_{sun}) and its low stellar temperature (1.5×10^4 K) $\rightarrow$ Proto-PN (Bobrowsky et al. In preparation)
- Free-free continuum emission ($S_\nu \sim \nu^\alpha$ with $\alpha \sim 0.8$) thermal nature (Gregorio-Monsalvo et al. 2004)
- Presence of IR lines: [NeII] and Brα suggesting a PN (García-Lario 2004)

H_2O masers toward IRAS 17347-3139

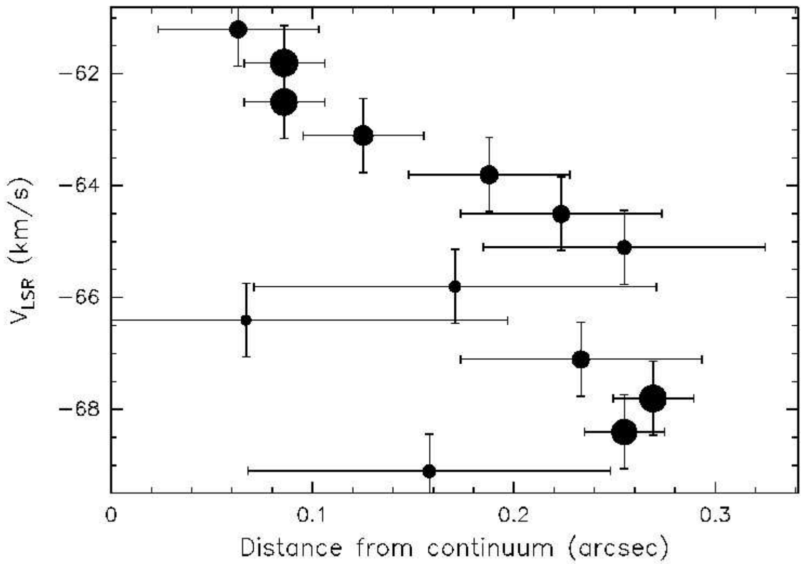


(De Gregorio-Monsalvo et al. 2004, ApJ, 601, 921)

Toroidal ring-like structure (radius=0.12″) separated ~0.15″ from the continuum peak.

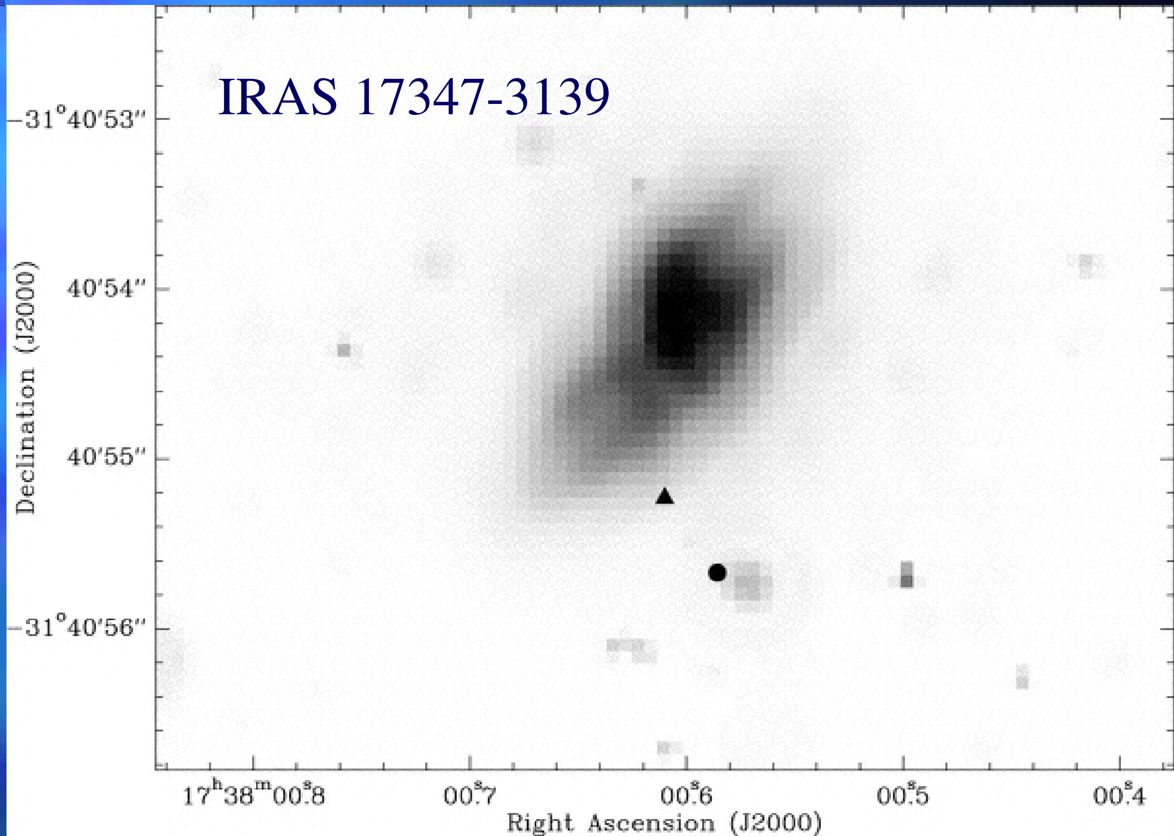
Assuming D=0.8 kpc, V=2.4 km/s and Keplerian rotation → M_*~0.6 M_{Sun}

Propose possible nature of IRAS 173473139: a binary system with radio continuum arising from a young PN and H_2O masers coming from a companion AGB star.



Relationship between H_2O masers and IR emission

- Bipolar 2.2μm NICMOS HST shows a dark lane suggesting the presence of a torus-like structure.
- There is a positional shift between the HST image and the radio continuum peak (circle) of ~1″
- The 2MASS peak position (triangle) is closer to the radio continuum peak.



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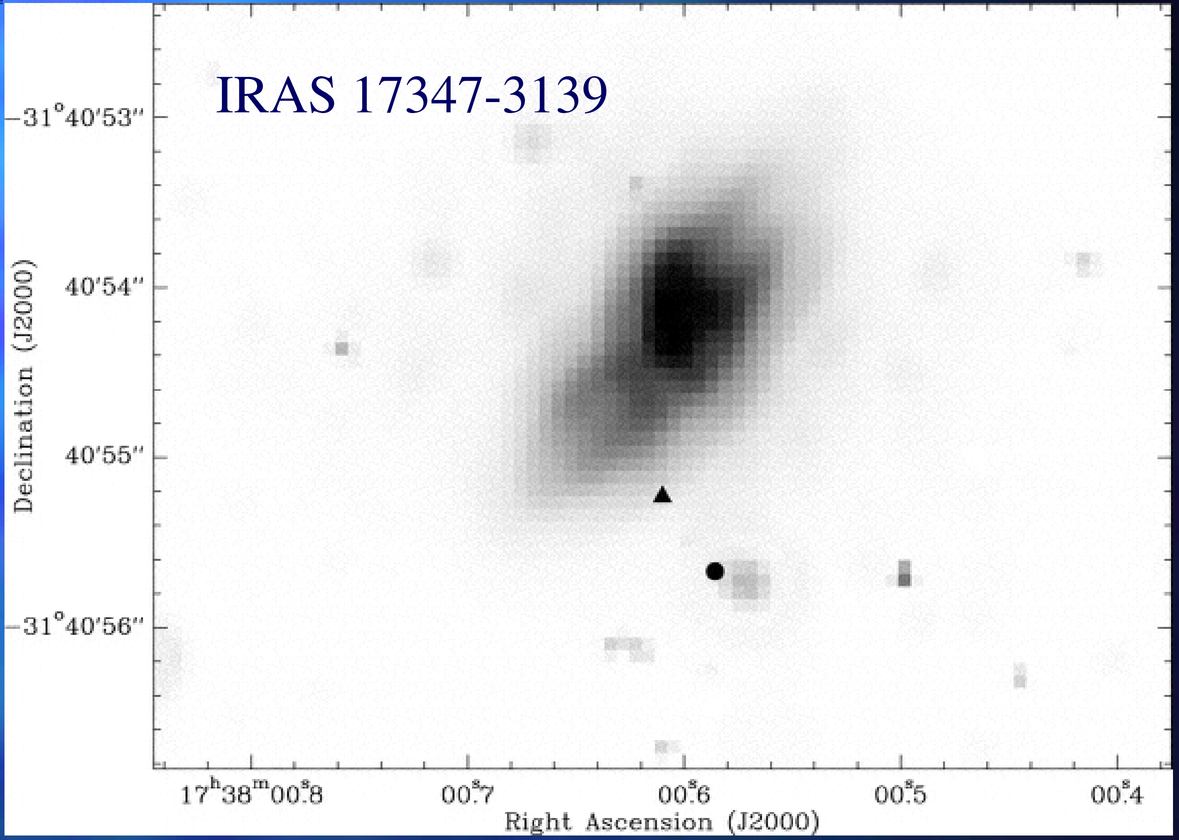
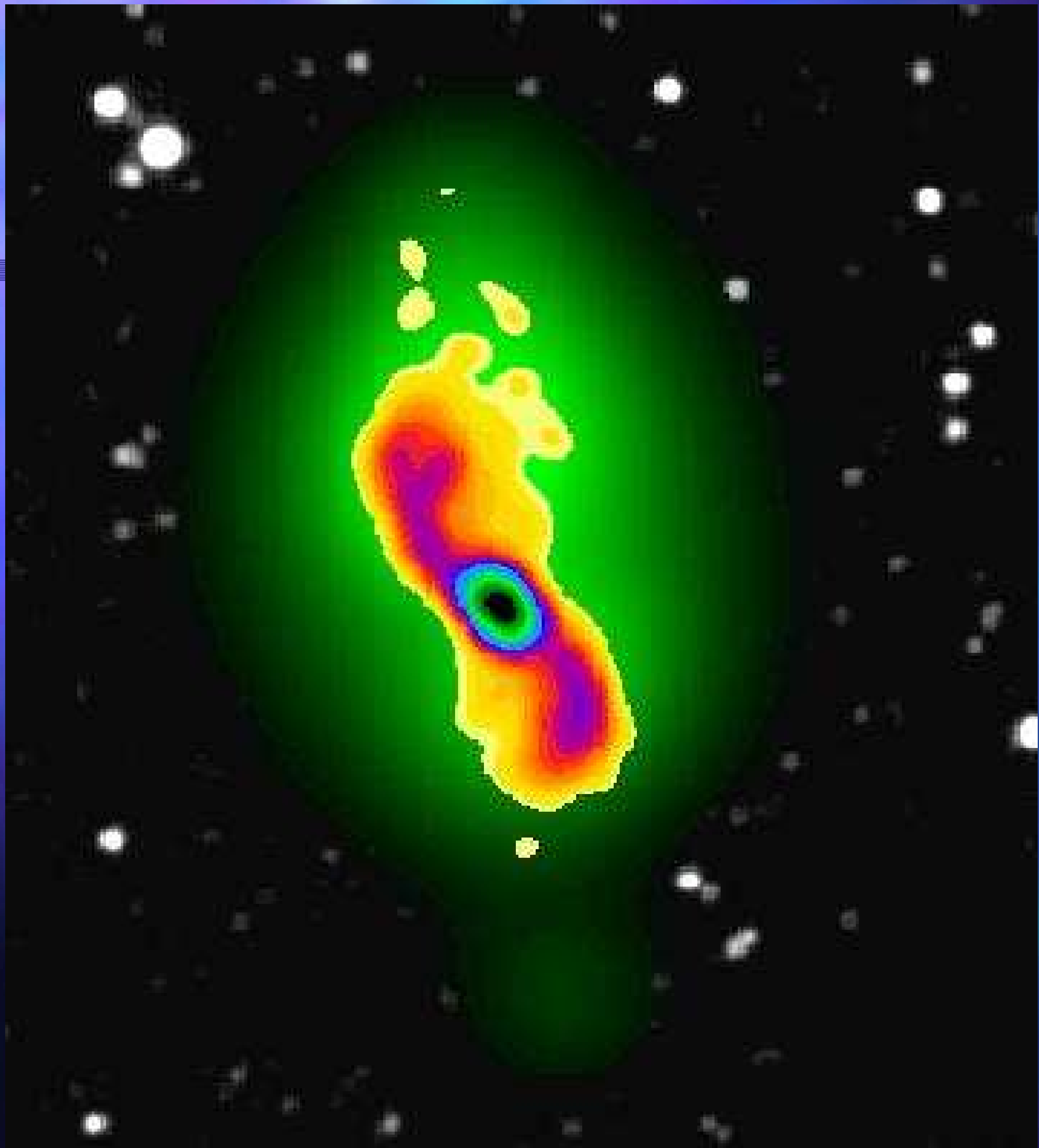


However, all these differences can be due to different frames of reference in the radio, IR and optical.

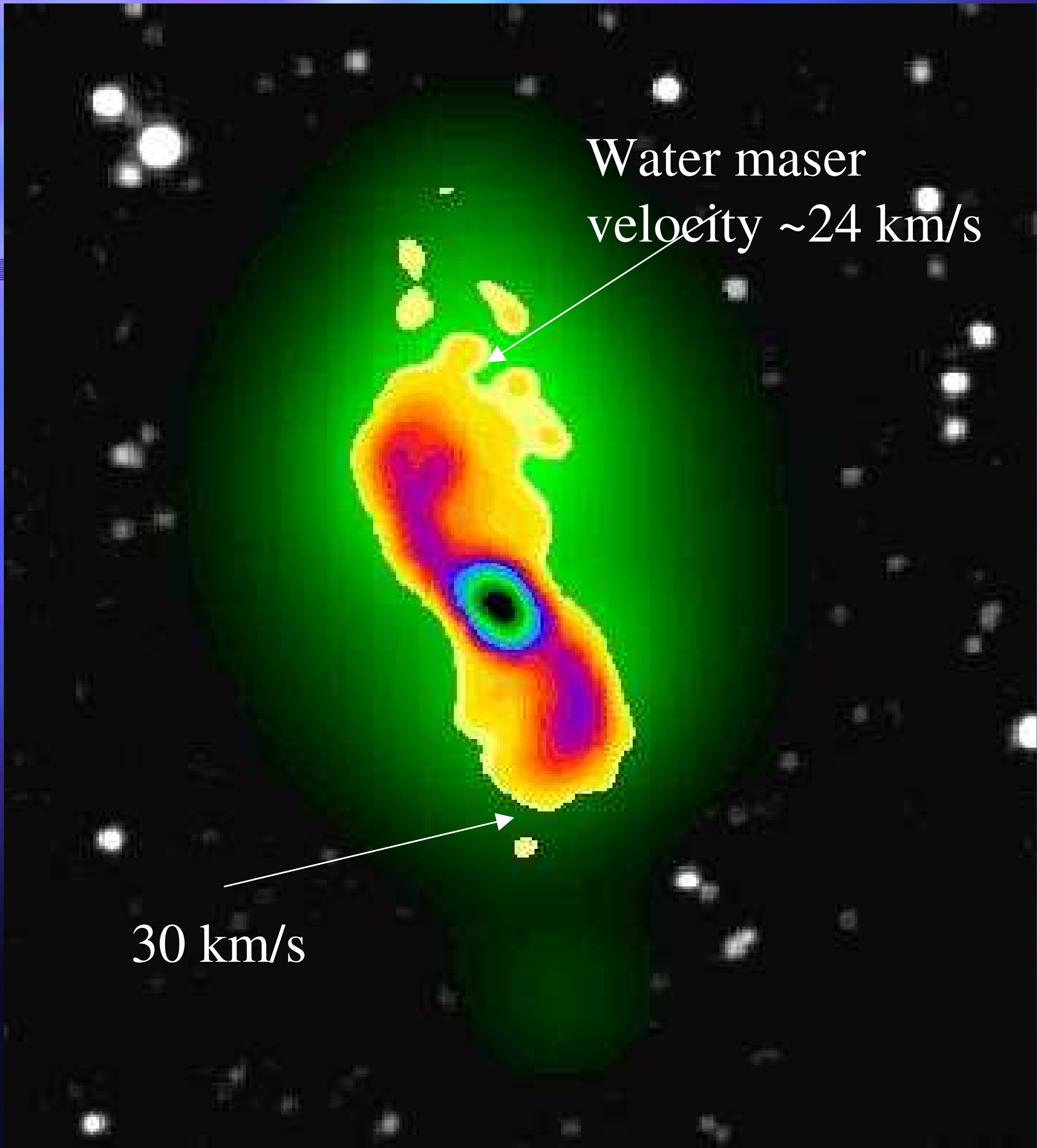
Are bipolar structures formed during the AGB phase ?



K 3-35

Green: [NII]6583 emission (~5´´)

Colors: 3.5 cm continuum emission (~2´´)

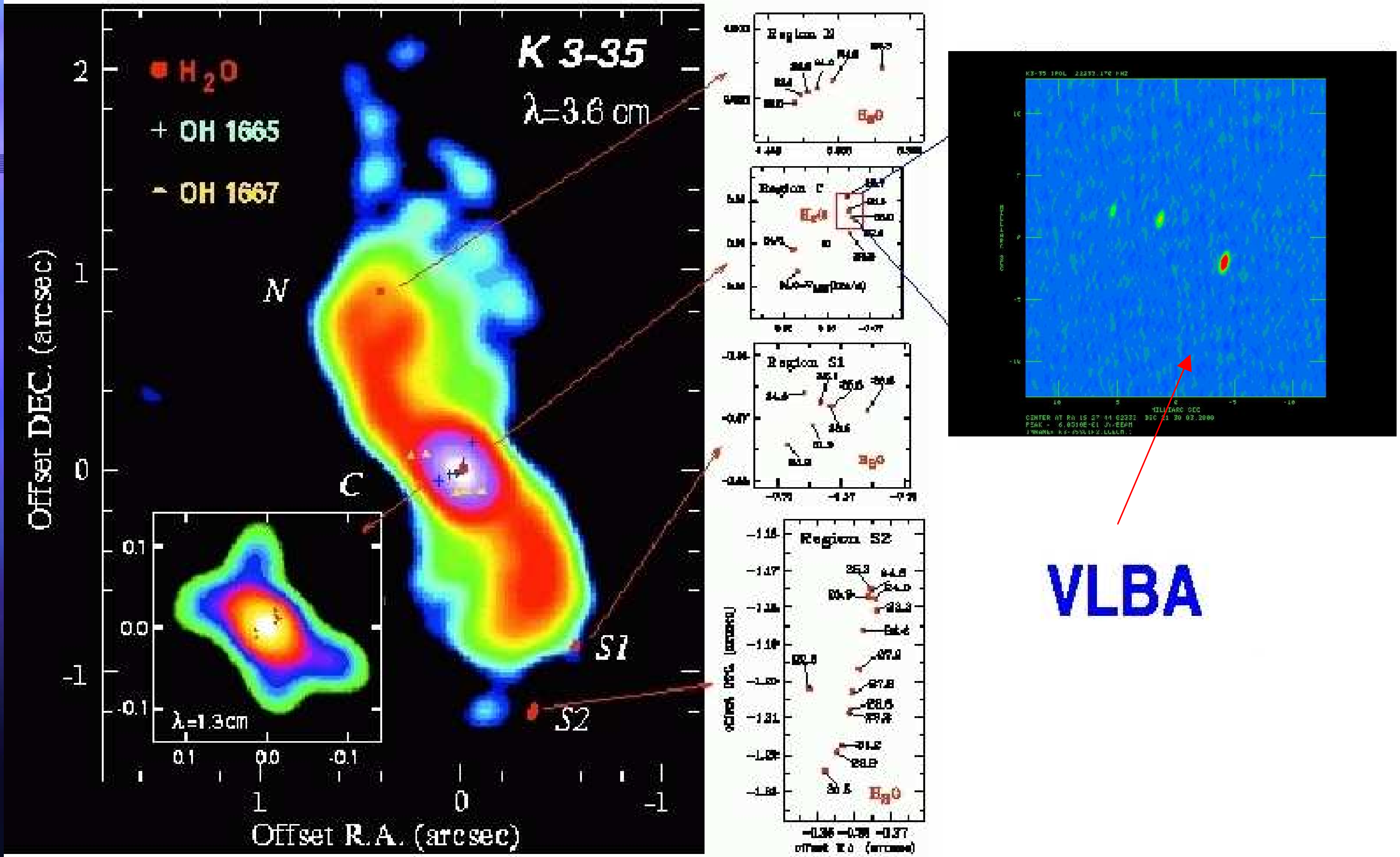


K 3-35

The jets can be traced up to 17,000 AU from the center using the [NII] (Miranda et al. 2000).

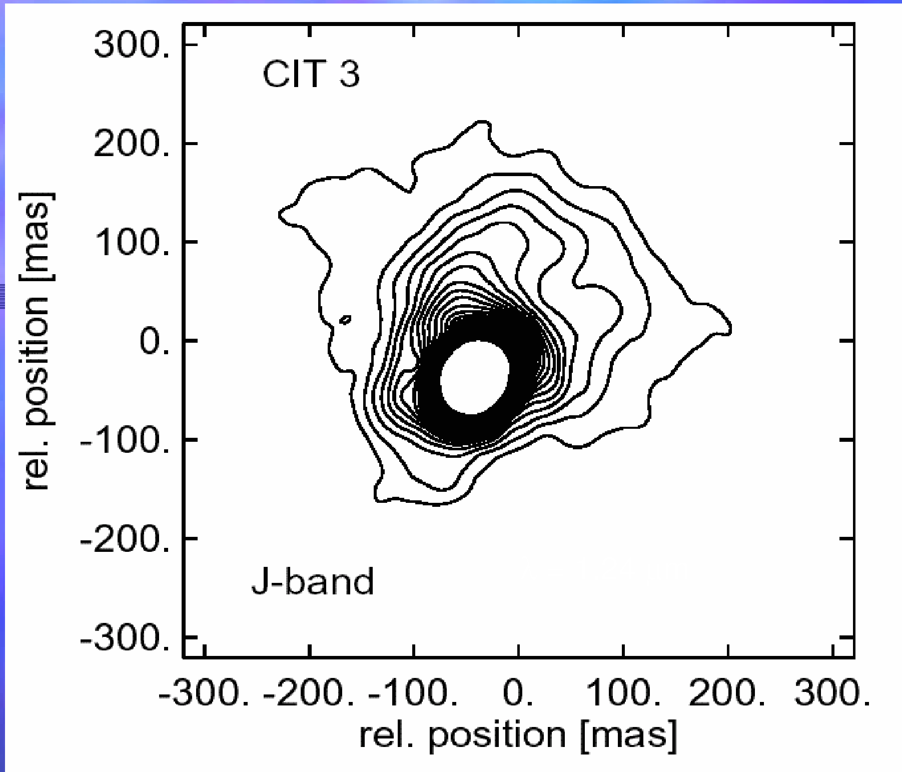
Assuming a jet velocity of ~100 km/s, their dynamical age is ~800 yrs, much older than the photoionized region.

Collimation and shock emission were present in the AGB phase of K3-35!



K 3-35
λ=3.6 cm
H2O
+ OH 1665
OH 1667
N
C
S1
S2
λ=1.3cm
Offset DEC. (arcsec)
Offset R.A. (arcsec)
Region N
Region C
Region S1
Region S2
VLBA

IRC +10011 (CIT 3)

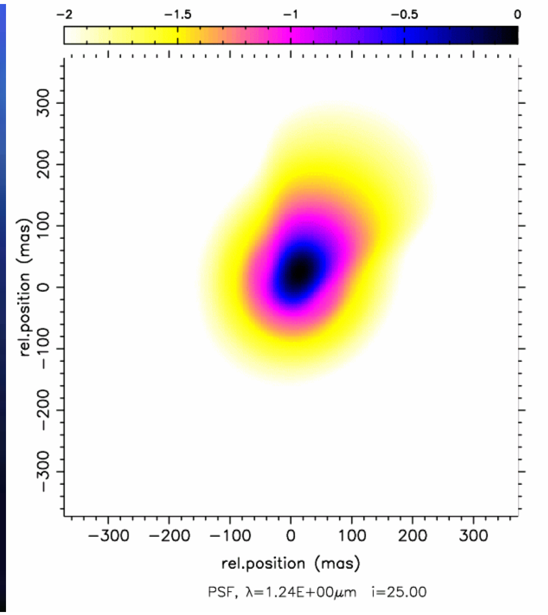


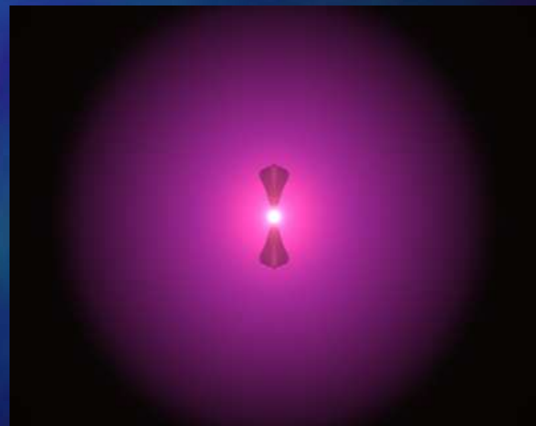
OH maser emission (Elitzur et al. 1976)

(Distance ~600 pc)

Prototype of spherically symmetric AGB wind

Hofmann et al. (2001) discovered asymmetries in the envelope in NIR J-band.

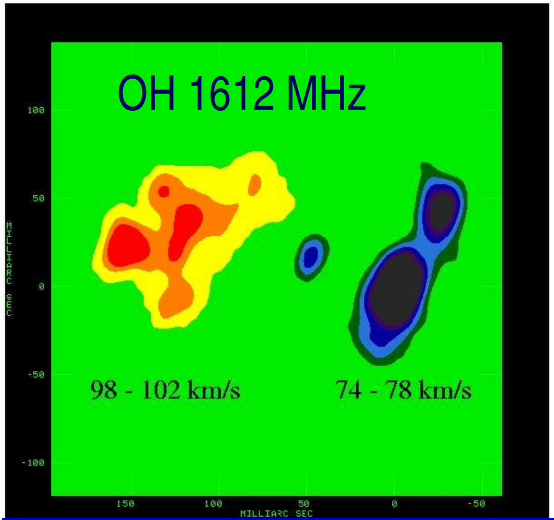




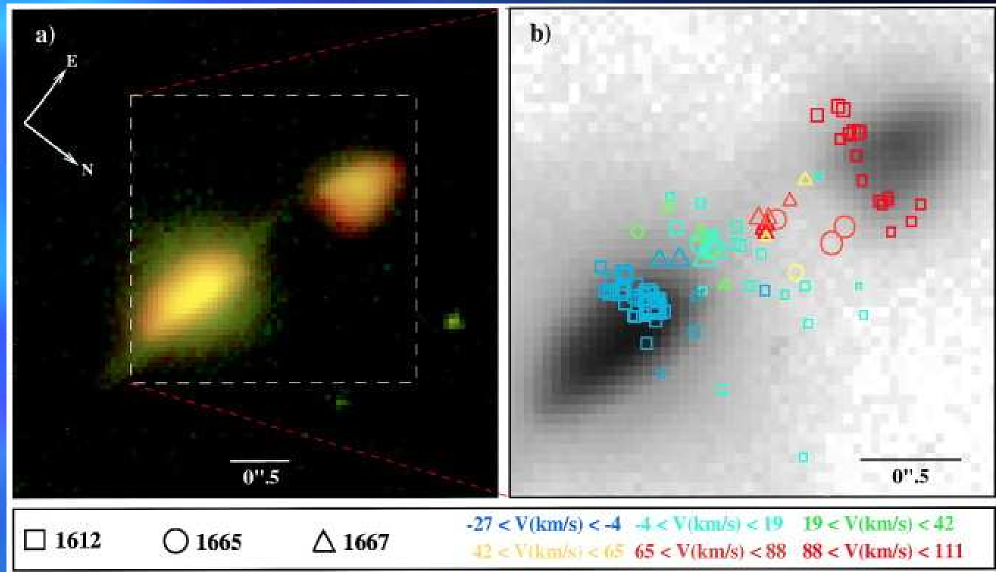
Jet age < 200 yrs

(Vincovic et al. 2004)

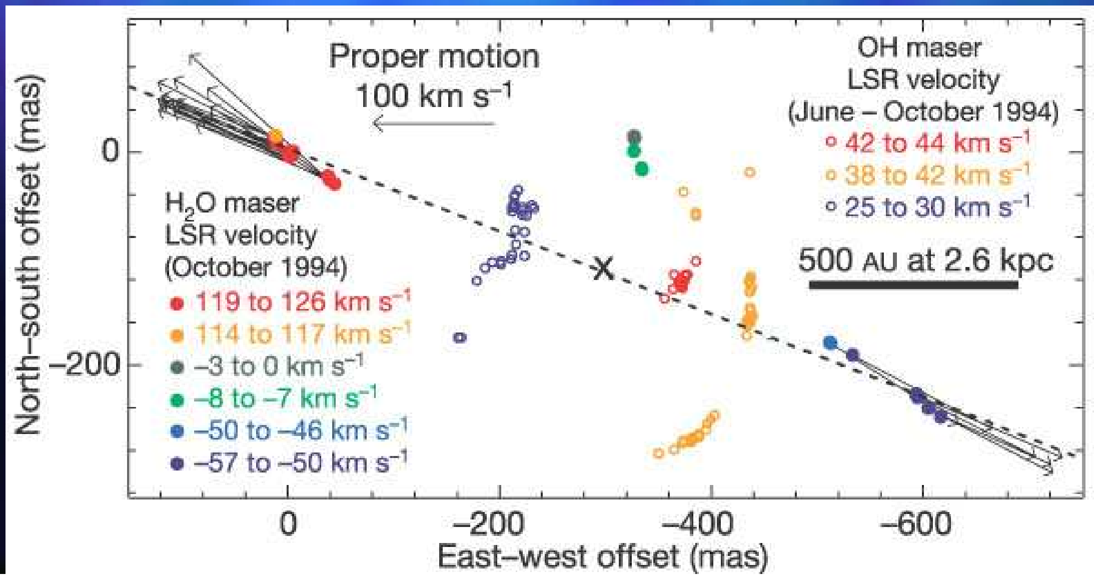
Progenitors of bipolar PNe like K3-35



OH37.1 (Gómez et al. 1999)



IRAS 16342-3814 (Sahai et al. 1999)



W43A (Imai, et al. 2002, Nature, 417, 829)

Summary

- K3-35 and IRAS 17347-3139 showed water maser emission in a torus-like structure.
- As photoionization begins, water masers survive only ~100 yr, then these PNe should be very young. They are just in their transformation to PNe.
- Other possibility is that water molecules have been shielded from the stellar radiation by some mechanism.
- More observations are needed in order to explain the presence of water molecules in these two planetary nebulae.