Water Fountain PPNe

The Case of IRAS16342-3814

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Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

NRAO

The Extraordinary Deaths of Ordinary Stars

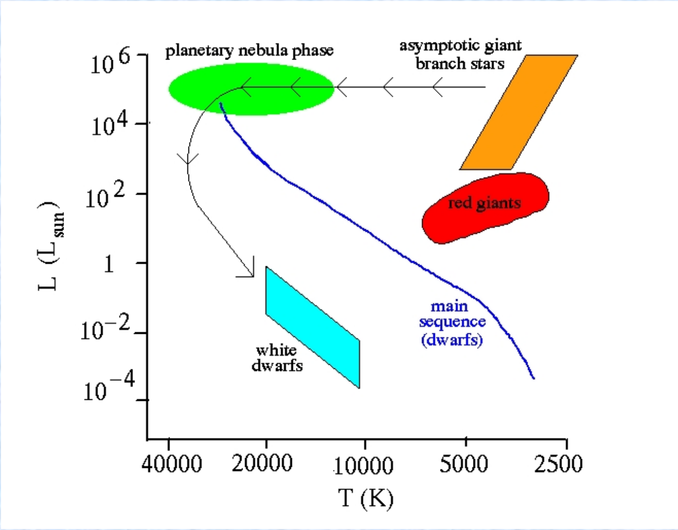
▪Planetary nebulae (PNe) evolve from 1-8 Msun stars that have moved off the main sequence to become asymptotic giant branch (AGB) giant stars

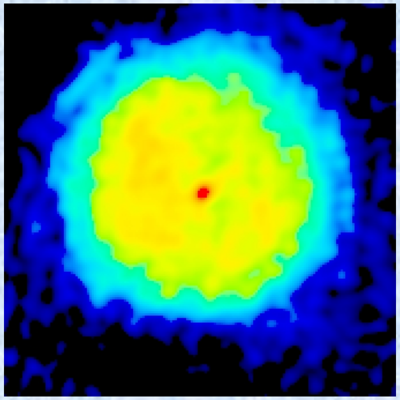
▪These mass-losing stars form circumstellar envelopes (CSEs) which appear to be mostly round.

▪But very few PNe are round. Most show a variety of bipolar, multipolar or elongated shapes, many with a high degree of point-symmetry.

One of the most interesting unsolved questions in stellar evolution is how the round AGB CSEs evolve into the myriad of shapes that are seen in the PNe stage.

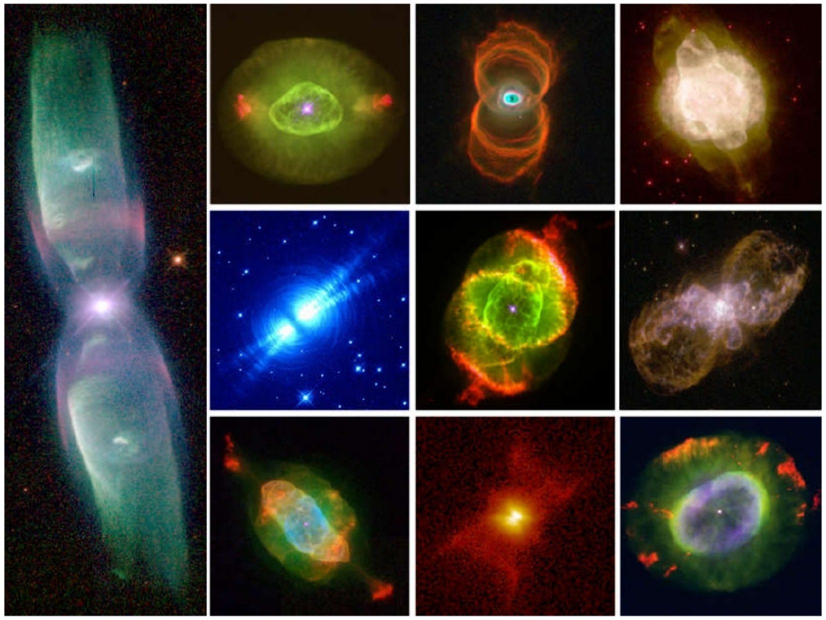
Based on the morphologies seen in an unbiased HST imaging survey, *Sahai & Trauger (1998)* proposed that (episodic) collimated fast winds or jets, operating during the Pre-PNe or very late-AGB phase, are the primary agent for producing asymmetric shapes in PNe





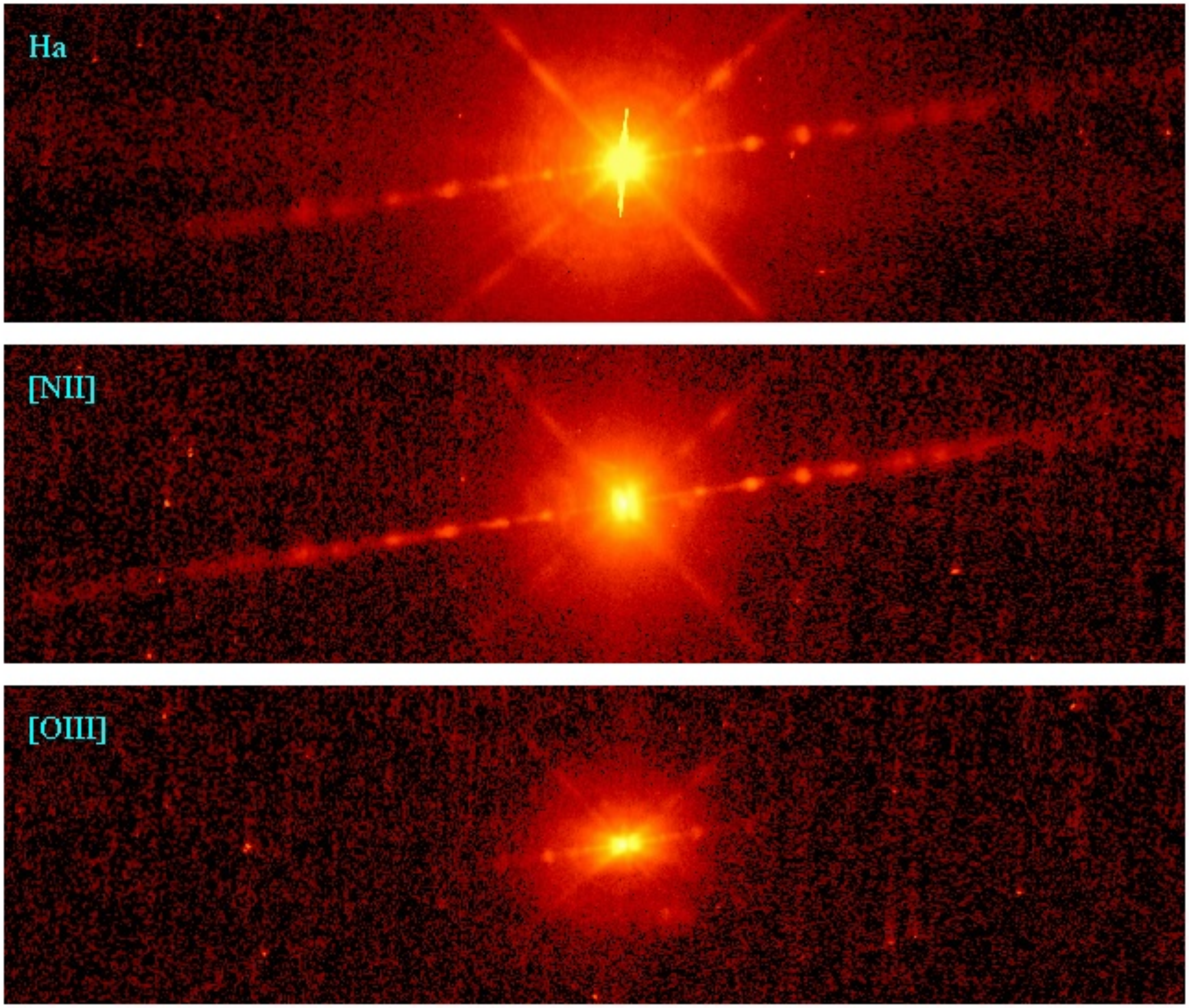
left: Molecular gas in AGB star IRC+10216.

right: A montage of PNe and PPNe imaged using the HST by Sahai, Balick, Bond and collaborators



A montage of images of planetary nebulae made with the Hubble Space Telescope. These illustrate the various ways in which dying stars eject their outer layers as highly structured nebulae. Credits: Bruce Balick, Howard Bond, R. Sahai, their collaborators, and NASA.

Bipolar Jet in the young PN He2-90 (Sahai & Nyman 2001)



Jets in PPNe or PNe generally never seen as clearly as here because they interact with ambient dense circumstellar matter (the AGB mass-loss rate in this object is inferred to be unusually low)

Such jets sculpt the AGB envelope from the inside out, producing the observed PPN/PN shapes

The Extraordinary Deaths of Ordinary Stars

To help understand this transition from AGB stars to PNe, a number of approaches have been taken: observational, theoretical, and numerical simulations.

We have been studying pre-planetary nebulae (PPNe), selected from far-infrared colors (mostly from IRAS), because this is the evolutionary phase where **the shaping process is carried out**. This group of objects are more evolved than AGB stars, but have not yet ionized the gas around them.

A subset of very young PPNe have been discovered to have water maser spectra with very high velocities (~100-200 km/s): **very important**

- water masers can be observed at very high angular resolution with VLBI techniques, and proper motions can be studied.
- determining trigonometric parallax distances: clearly, knowledge of distances very important, especially in understanding the evolution of the stars: luminosities, mass-loss rates, 3D velocities, and kinematic ages of the jets and outflows.

(parallax distances known for ONLY 3 PPNs; two of these are water-fountains with trigonometric distances using VLBA/ H2O masers observations: IRAS19134+2131: Imai, Sahai & Morris 2007, IRAS18286-0959: Imai et al. 2010)

Water Fountain PPNe

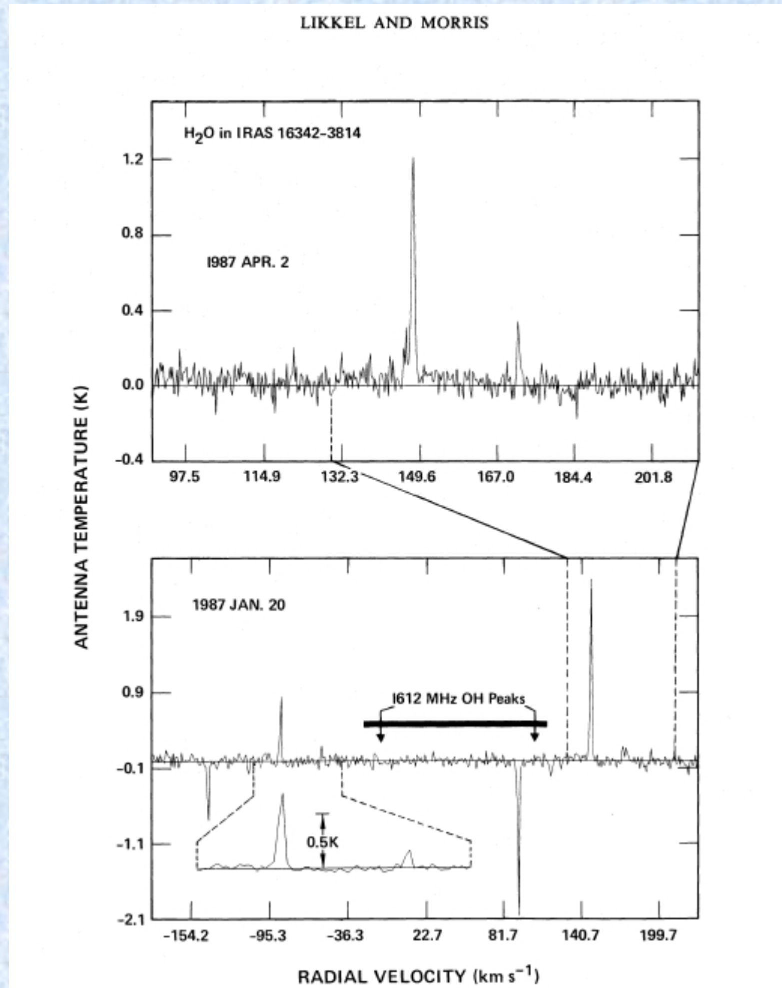
1. Very high radial velocity blue- and red-shifted water and sometimes OH masers.

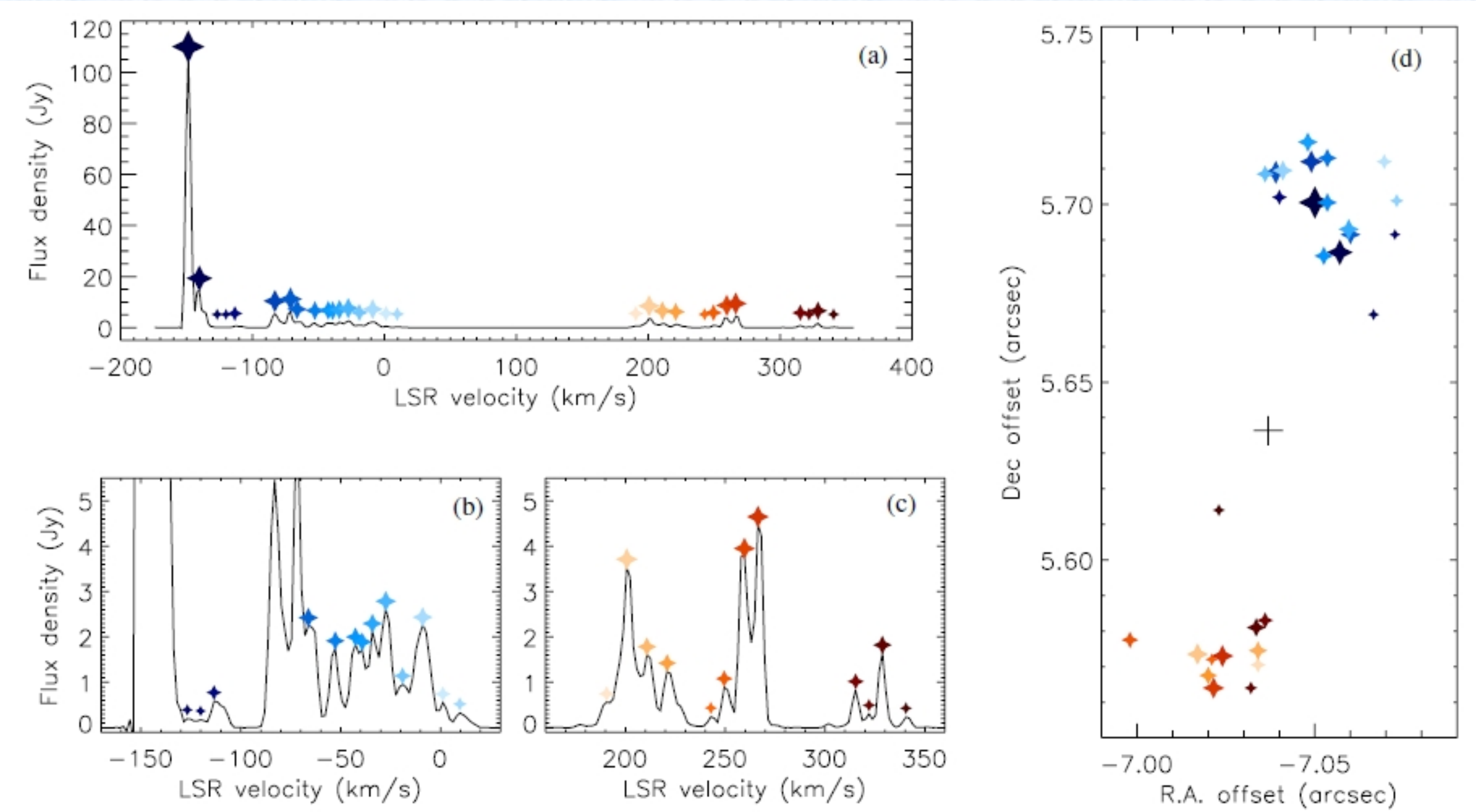
2. High angular resolution observations of the water masers show highly collimated, bi-polar flows.

3. There are ~1 dozen water fountain candidates know currently.
(The highest velocity range source , IRAS 18113-2503 was reported on in the ApJ EVLA special issue by Gomez et al.)

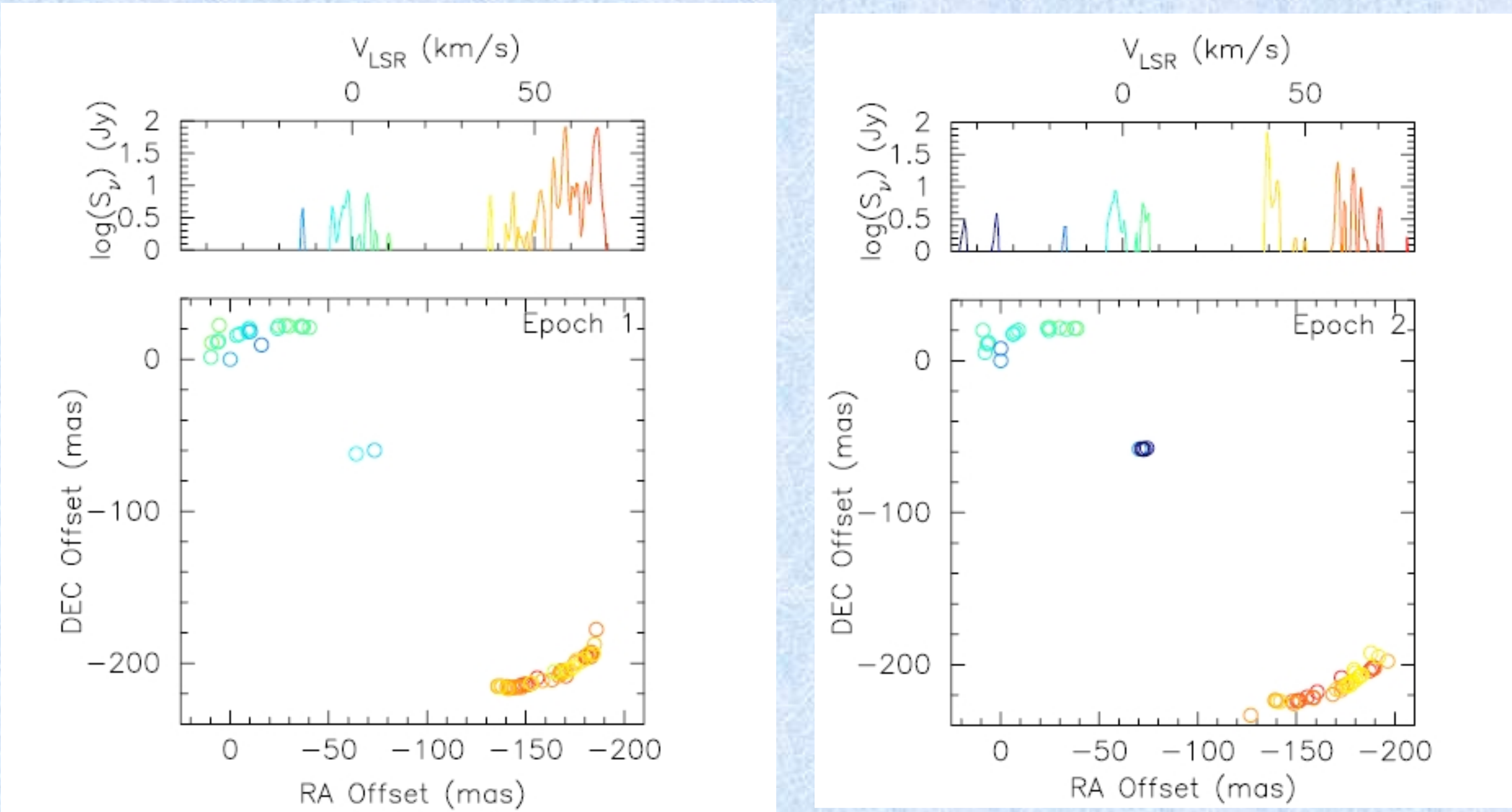
3. Lifetimes based on size and outflow velocity are 50 – 100 years.

Likkel & Morris 1988





Water masers from water fountain IRAS 18113-2503 (Gomez et al. 2011)



Two VLBA epochs of water masers from water fountain IRAS 19190+1102
(Day et al. 2010)

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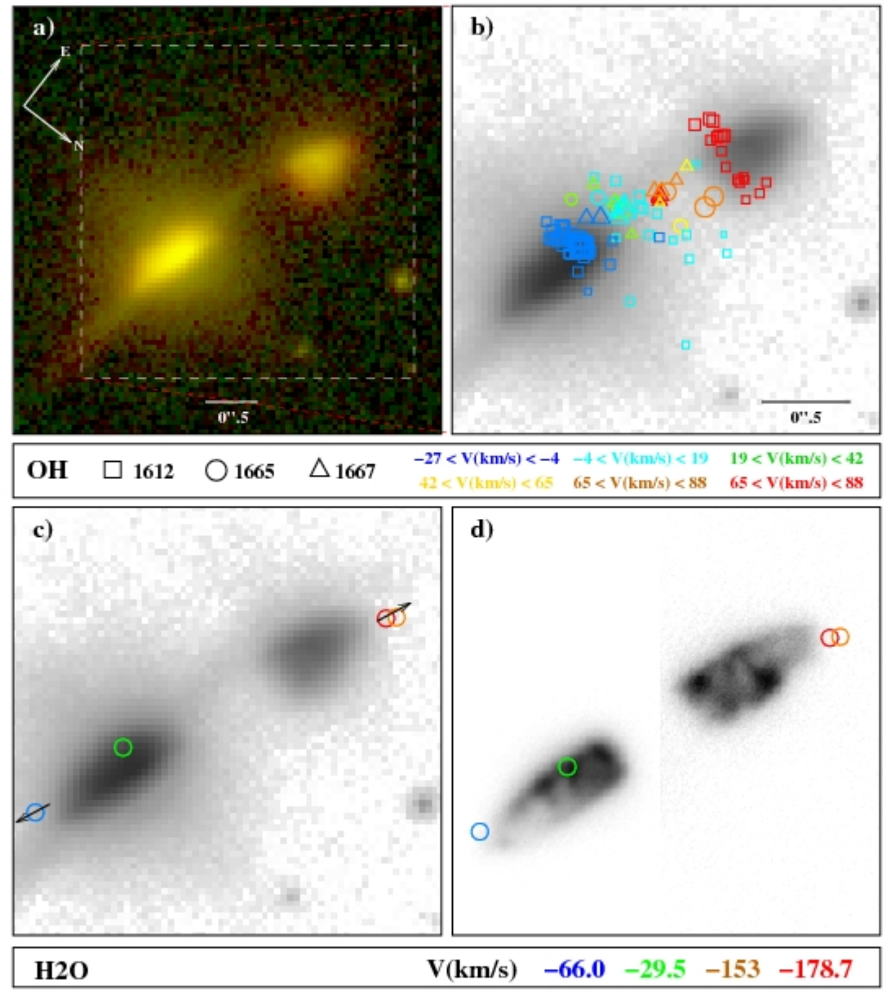
1. Source discovered by Likkel & Morris (1988); one of the original 3 water fountains and the closest.
2. HST image (scattered light) at 606/814 nm (top left). Overlaid with OH masers (top right). Water maser regions (bottom left). AO near-IR image using Keck (lower right).
3. Central velocity +43 km/s, from analysis of water maser “pairs” by Likkel, Morris, Maddalena (1992), and OH analysis by Sahai et al. (1999).



Note: **not** N up and E to left.

Sahai et al. 1999; Sahai et al. 2005

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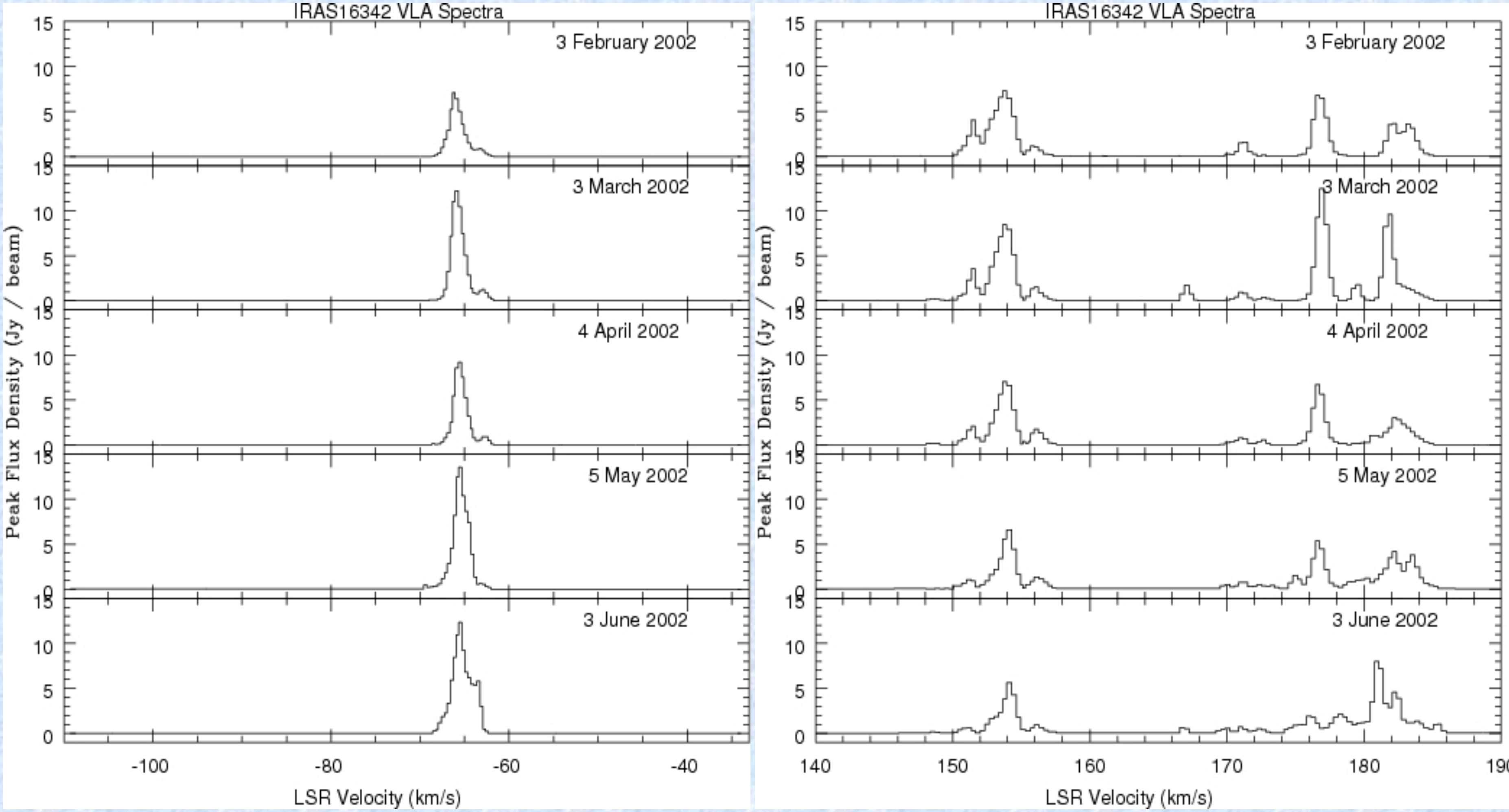
Spectra of water masers in IRAS 16342-3814 in 2002 using the VLA (note there is a coverage gap between -40 and 140 km/s)



Claussen, Sahai & Morris 2009

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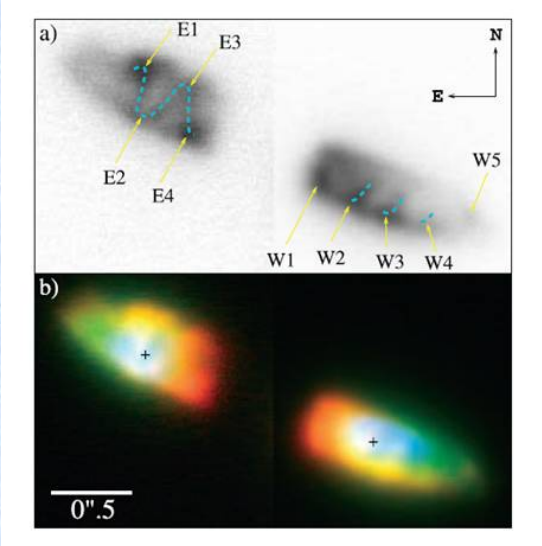
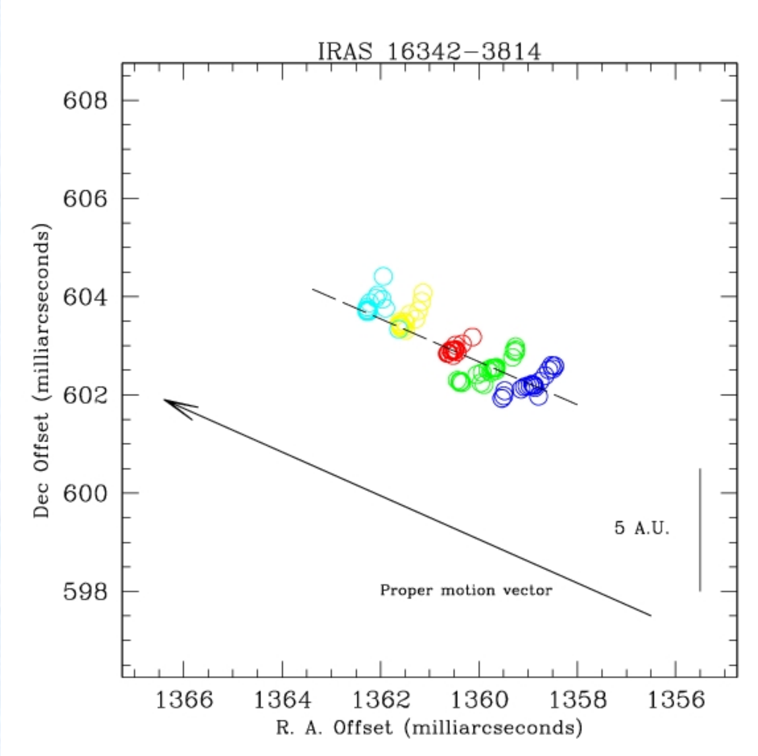
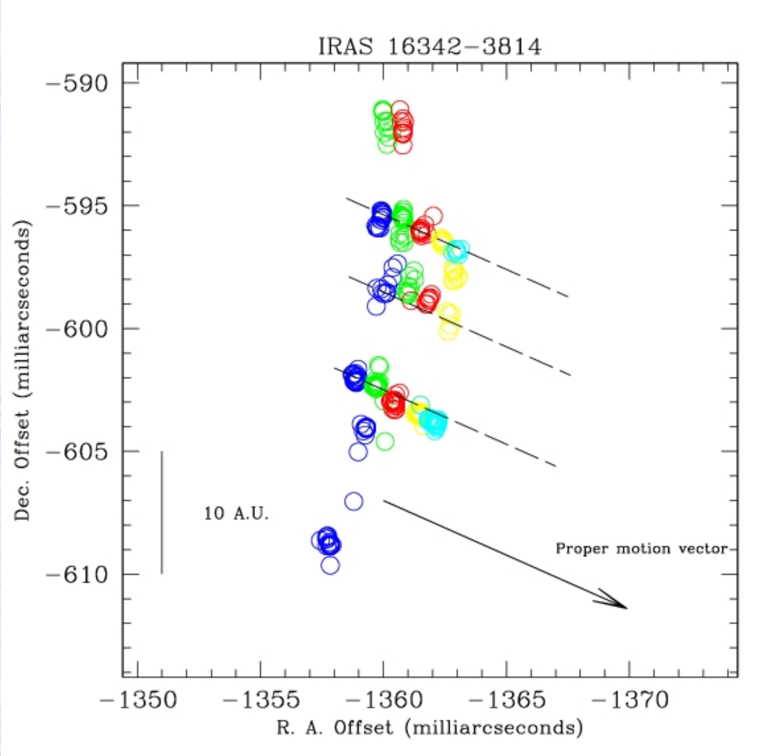
VLBA observations of the water masers over 5 epochs in 2002; different colors represent different epochs of observation.
(Claussen, Sahai, & Morris 2009)

(Left) Red-shifted masers +155.3 km/s group (furthest to the NE). Right: Blue-shifted masers -66.0 km/s group (furthest to the SW),



Keck AO J,H,Ks imaging showing corkscrew pattern due to a precessing jet

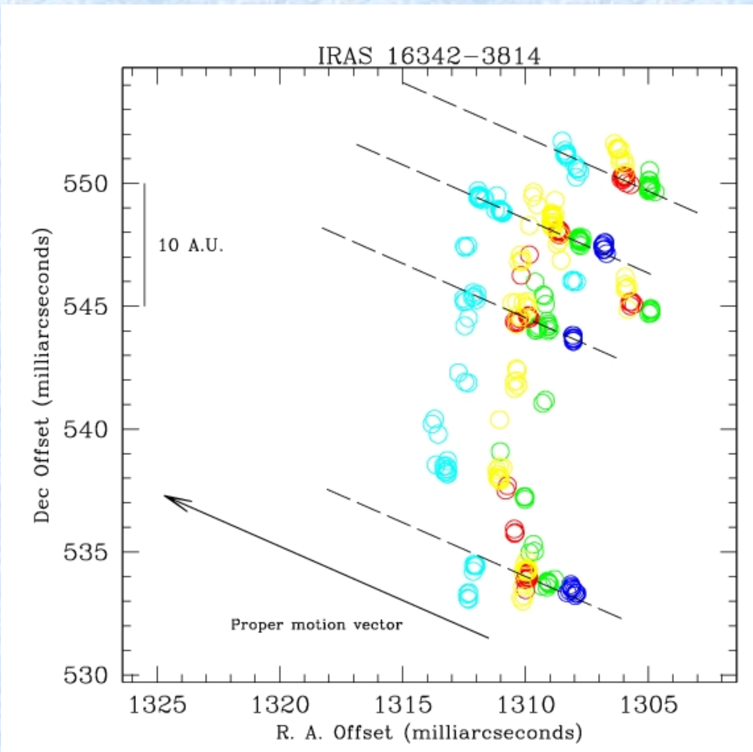




The Case of IRAS 16342-3814

1. Distribution of water maser features is generally tangential to the inferred jet axis, in contrast to, e.g. water-fountain W43A.

2. Comparing velocities of matching maser groups (see Table below) from our data to Likkel, Morris & Maddalena (1992), we find that outflow speed increased by about 5 – 6 km/s over ~13 – 14 years, implying an average acceleration of ~0.4 km/s /yr (similar to that seen in OH12.8-0.9).



Flux-Density-Weighted Velocity Groups

Claussen et al. 2009	Likkel et al. 1992
-66.0 km/s	-60.5 km/s
+155.3 km/s	+147.7 km/s
…. ……..	-56.5 km/s
+178.7 km/s	+172.7 km/s
-29.5 km/s	………….
…………..	-87.7 km/s

3. The +178.7 km/s group has very similar structure to the -66.5 km/s group.

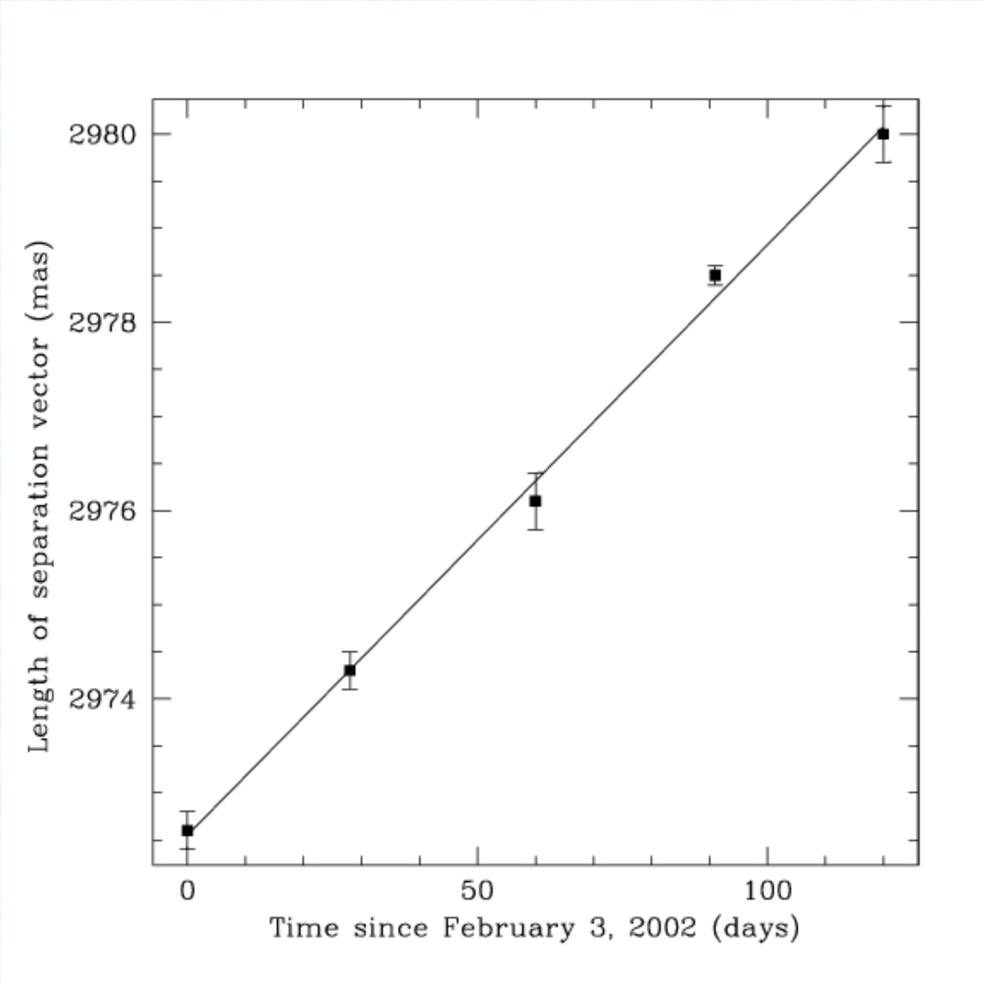
The Case of IRAS 16342-3814

1. Length of line connecting specific maser spots measured for each of 5 epochs separated by ~1 month (+154.2 and -65.2 km/s).

2. Length of line changes monotonically with time, while the position angle of the line remains constant . The error in these measurements are ~0.2 mas.

3. LLSQ fit to the change in the length of the line gives 23.0 mas/year for the separation of the maser spots.

Note: length of the "separation vector" is nearly 3 arcseconds.



Claussen, Sahai, & Morris 2009

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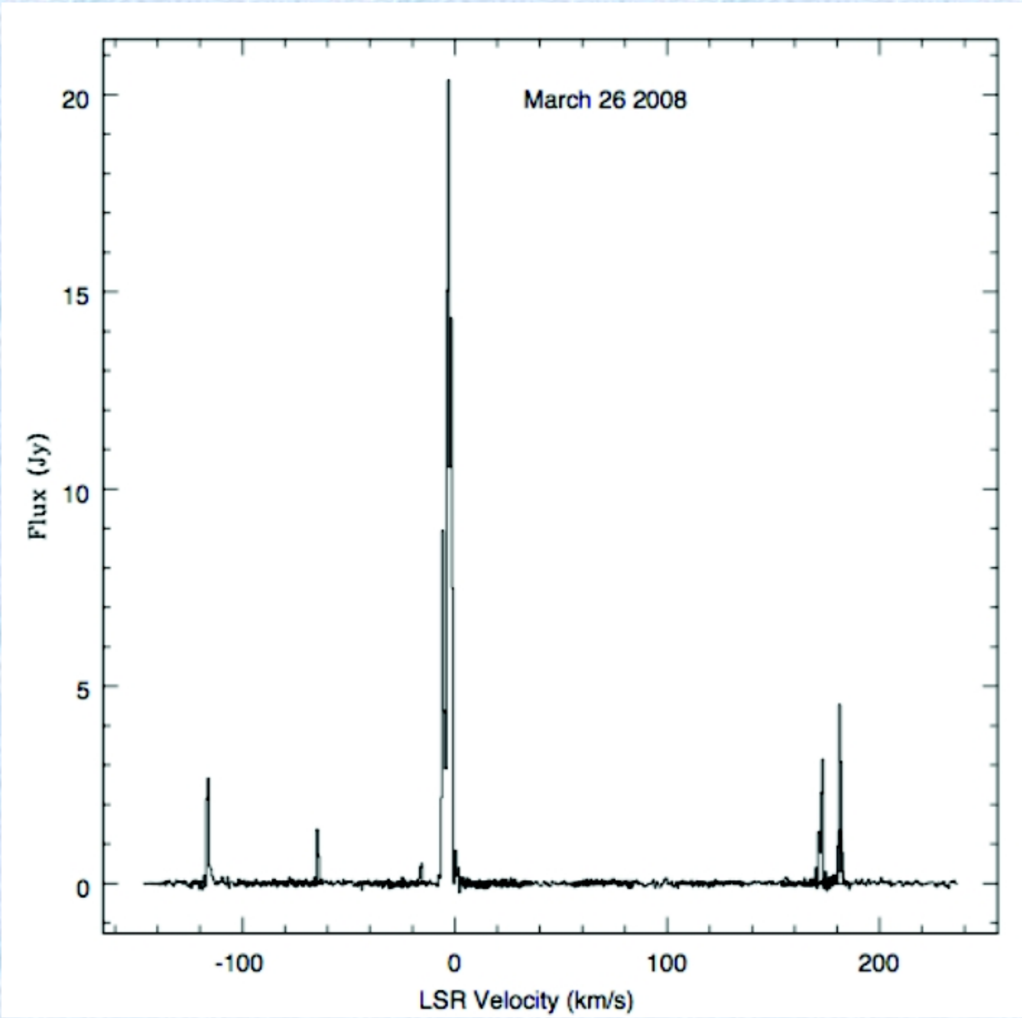
New VLBA data in 2008/9, 12 epochs observed, ~1/month, and accompanying VLA data taken to see spectrum.



March 26, 2008 spectrum. Work done this past summer by Hannah Rogers, REU student.

1. Spectrum is similar in general but different in specifics.

2. New features at -3 km/s (strongest) , -118 km/s and -172 km/s. Features at -66 km/s still there, along with +155 and +180 km/s.

3. In this particular spectrum +155 km/s feature is fairly weak, but is stronger in other epochs.

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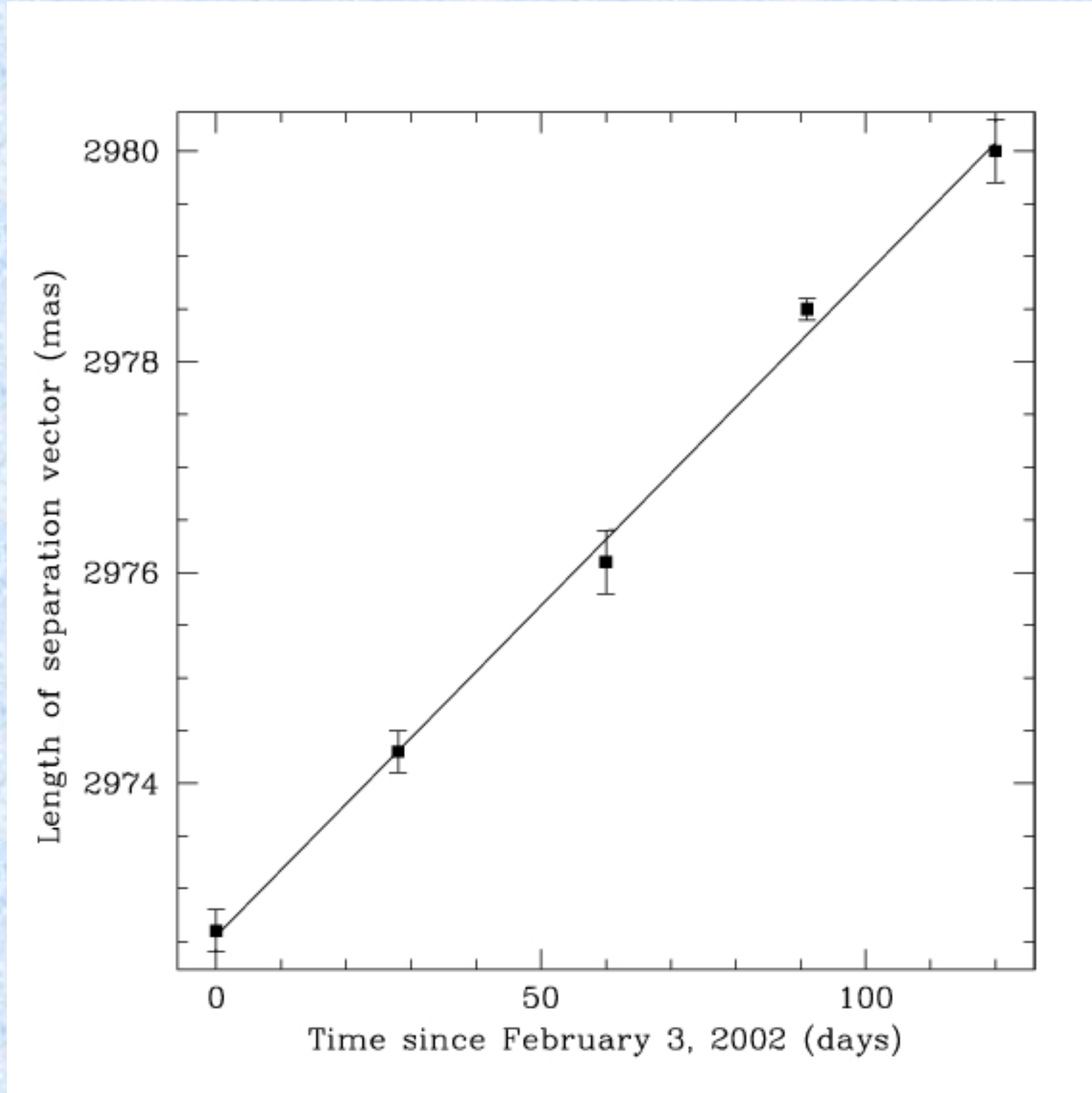
For the 12 epochs in 2008 and 2009, we made the same calculation of the length of the line between the +155 km/s feature and the -66 km/s feature.

The result is on the next slide.



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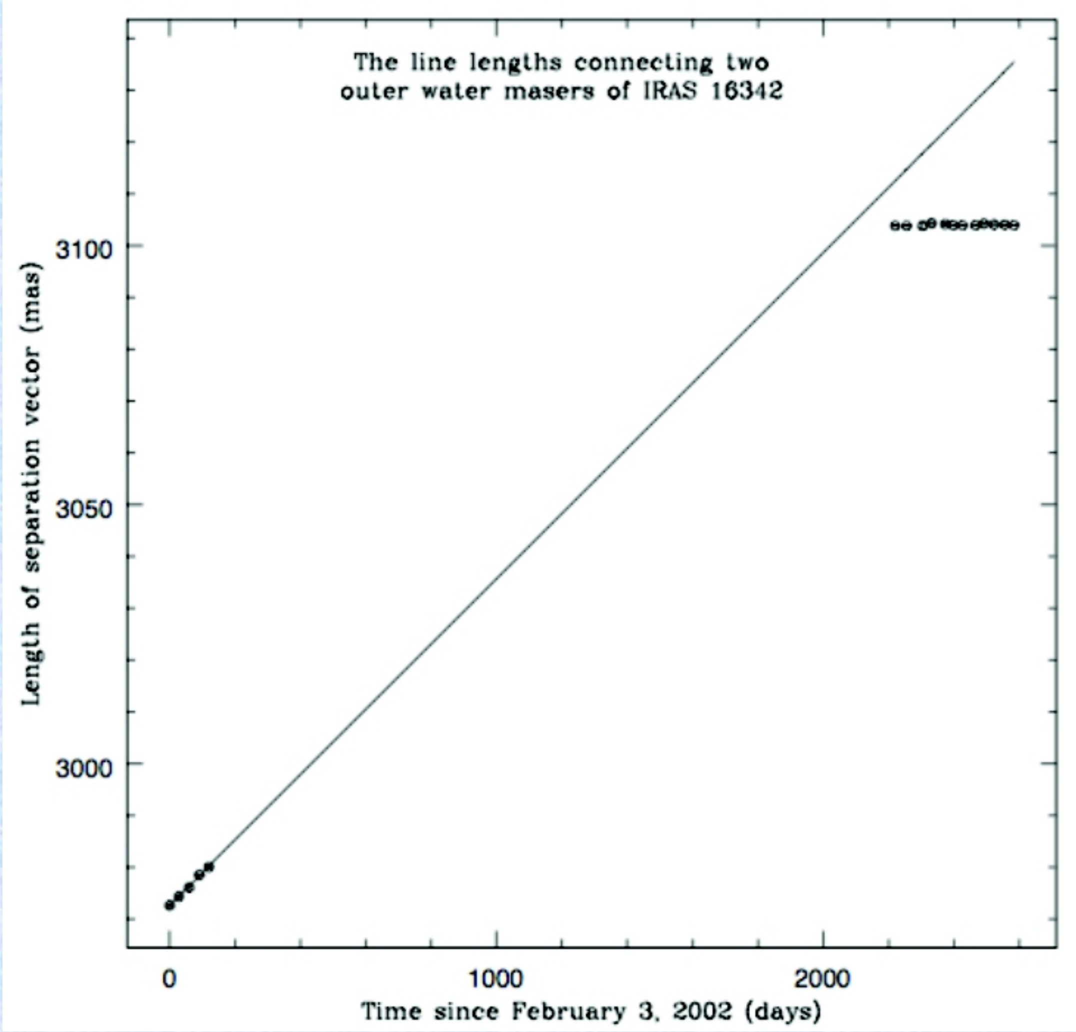
1. The maser motion in the plane of the sky appears to have stopped! Completely unexpected.

How can we explain this ?

1. data reduction issue:
   a. Some error in data processing ?
   b. Somehow picked wrong features, as compared with 2002 data ?
2. astrophysical:
   a. Masers don't trace physical motion at all ?
   b. Change in motion such that 3D motion of masers is now along the line of sight - but why have the radial velocities not changed at all?



Conclusions

1. VLBA observations of the high velocity water masers from IRAS16342-3814 show a bipolar outflow aligned with the scattered light emission; in general other “water-fountain” sources show similar structures.

2. The detailed structure of the water masers appear to be that of bow shocks on either side of a highly collimated jet.

3. Based on the 2002 data, the proper motions of the water masers are approximately equal to the radial velocities; the 3-dimensional velocities are approximately +/- 180 km/s, which leads to a very short dynamical time scale of ~100 years.

4. The newest data, taken in 2008/2009 does not appear to continue the proper motion of the water masers, and so far we do not have a good explanation of the apparent “stoppage” of the proper motions.

5. The water maser jets seem to be ubiquitous in those “water-fountain” sources that have been studied at high angular resolution; we conclude that the water masers are the manifestation of shocked gas as a high velocity jet strikes dense molecular gas. This jet could be responsible for the sculpting of the circumstellar gas.

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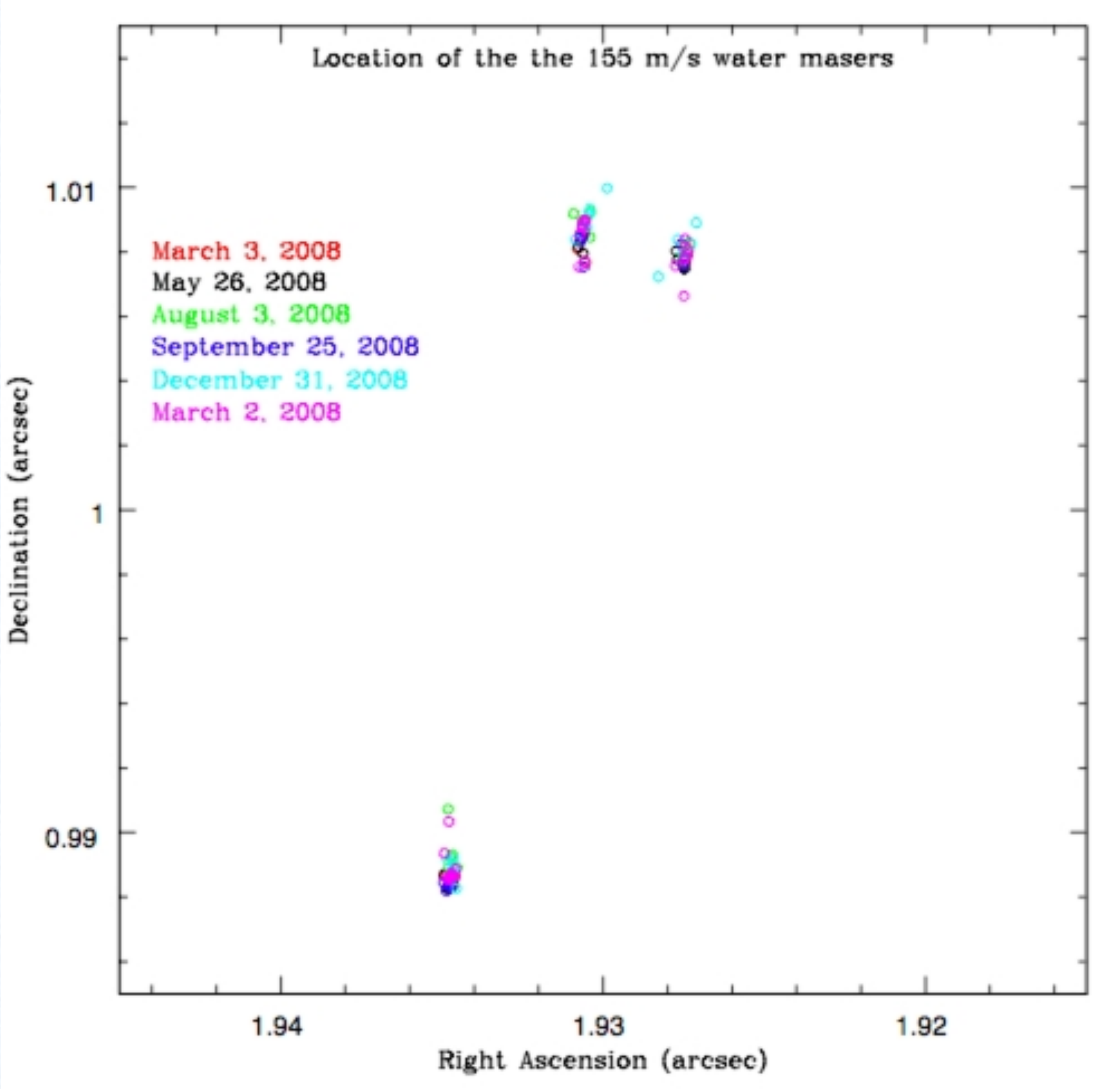

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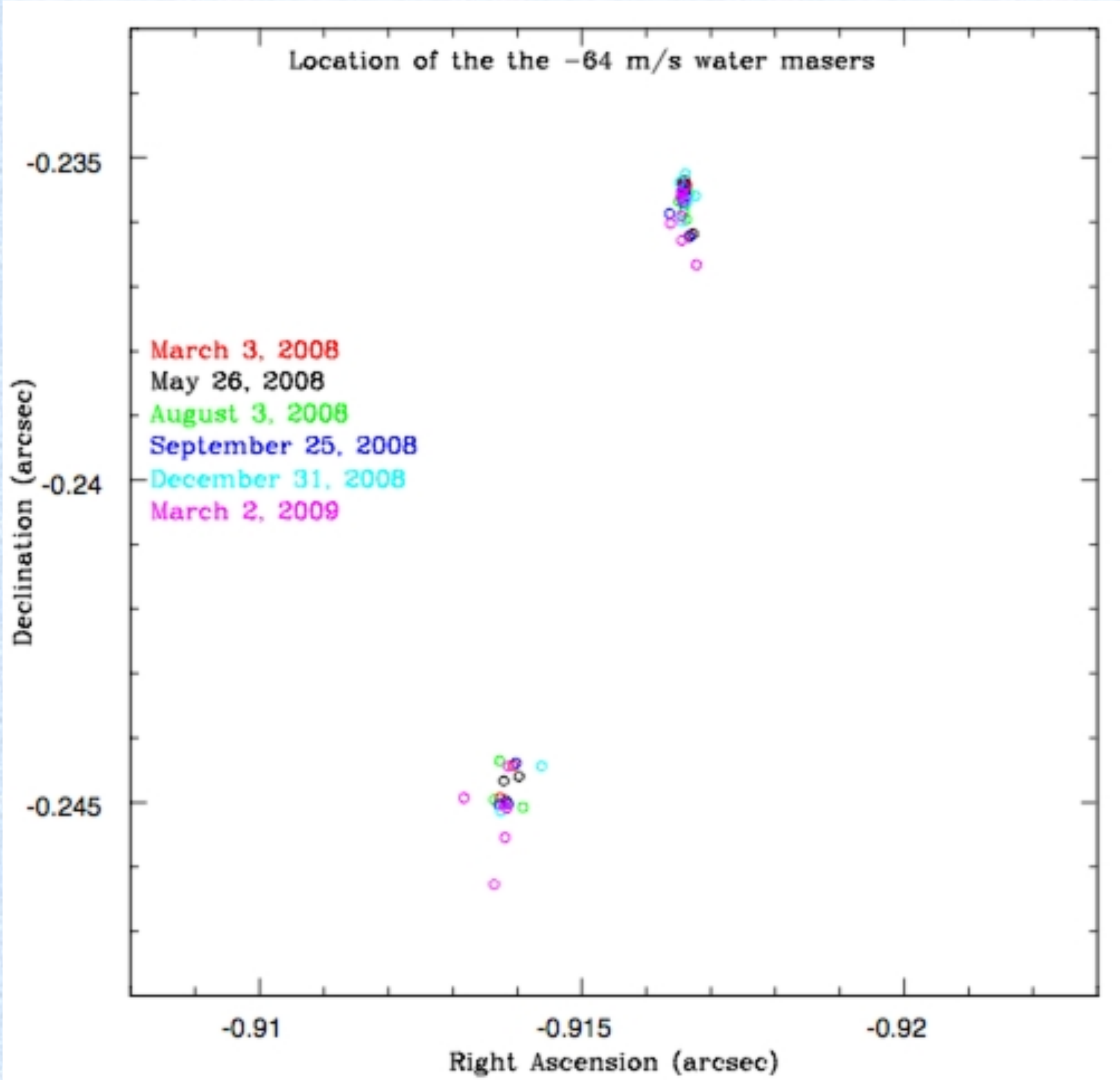

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