International Centre for Radio Astronomy Research

KVN astrometric observations of H_2O and SiO masers in Calabash Nebula

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Outline:

- The Calabash nebula; why it is important
  - SFPR method; why it is helpful
- Previous observations & New observations
  - Results from the SiO masers
  - Results from registering SiO and H2O masers
  - Results from the expansion of H2O masers, from previous observations
- 3-D reconstruction of maser emission
  - Conclusions

Calabash Nebula OH231.8+4.2

Calabash nebula provides the reference point our models for Proto-Planetary Nebula (pPN) formation.

Classic bi-polar structure

transition from spherical AGB

A binary system,

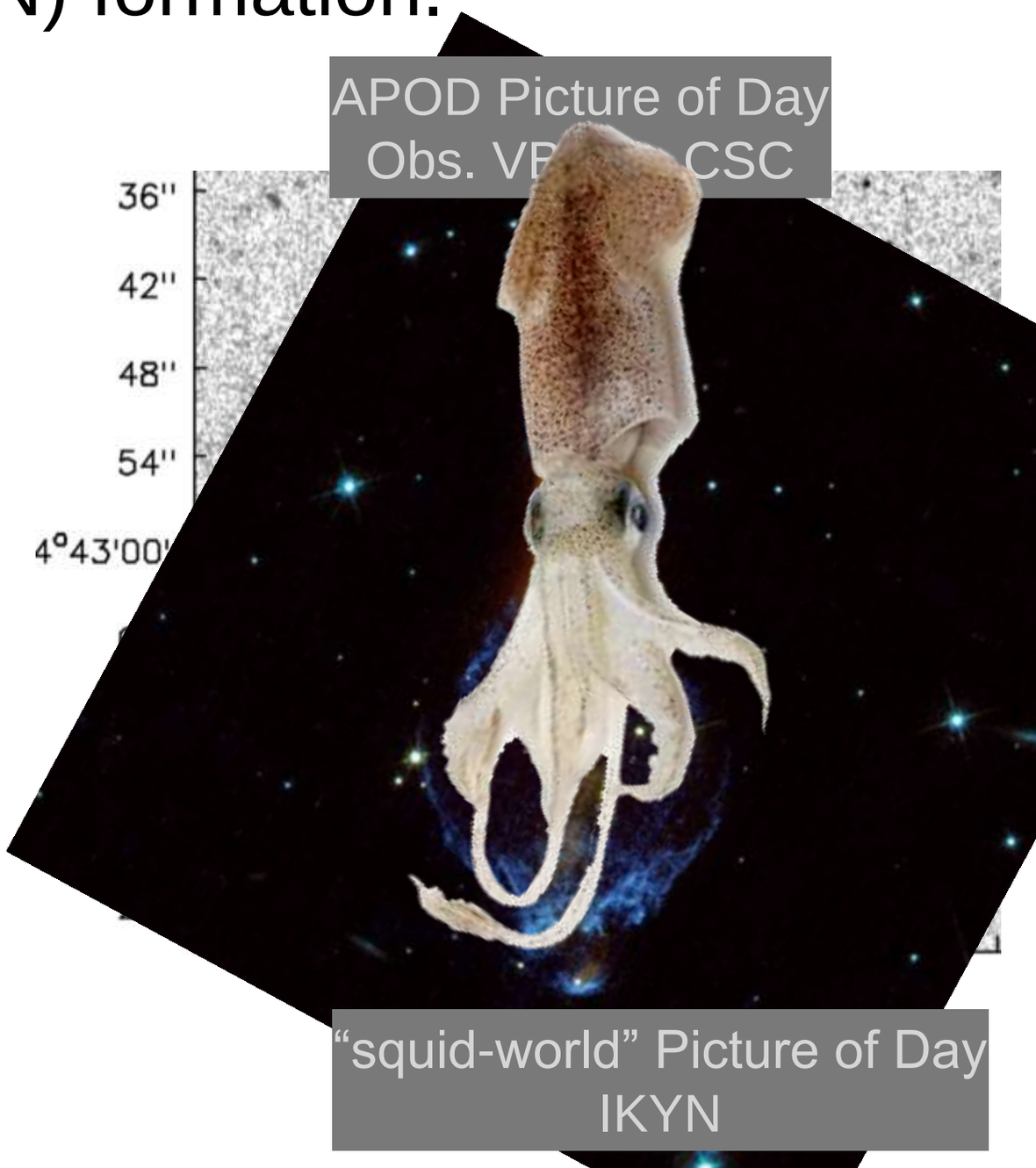
required to drive the outflow

Fast out-flows

200-400km/s

Shocked chemistry

HCO+, H13CO+, SO+, N2H+, H3O+



Source Frequency PR

Rioja etal 2011 & onwards

Source/Frequency Phase Referencing (SFPR) analysis consists of two calibration steps.

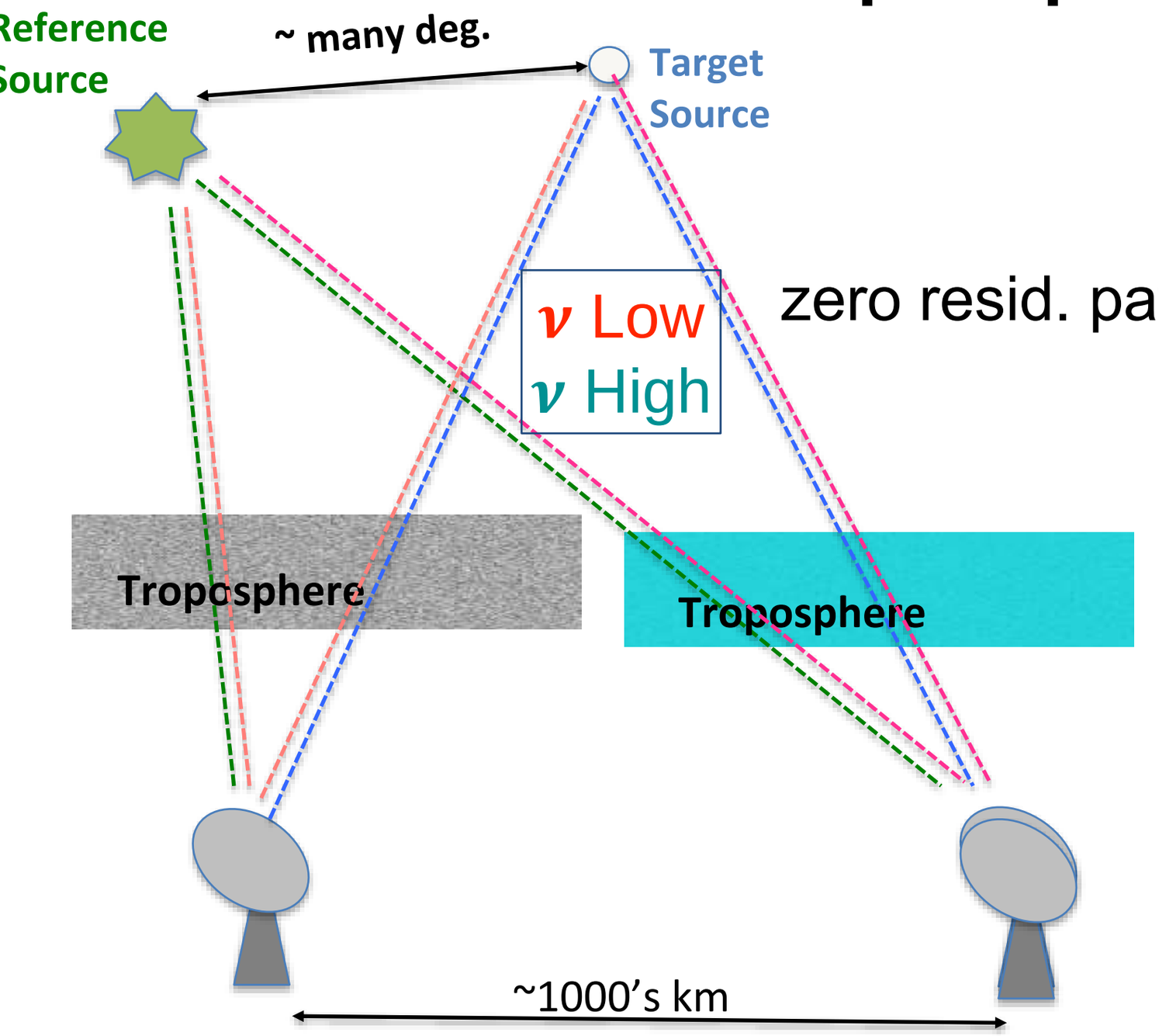
1) the observations at the higher frequency bands are calibrated using the simultaneous observations at a lower frequency band

removes rapid fluctuating non-dispersive terms

2) Second calibrator source, obs. occasionally (~10min), eliminates ionospheric and instrumental terms.

removes slowly changing dispersive terms

High Frequencies & Troposphere



Simultaneous (or Fast Freq Switched) mm-VLBI observing.
Phase & Delays scaled and transferred (Freq Phase Transfer FPT)
All non-dispersive terms removed

zero resid. path length $\Delta\ell$

Second source visited on long timescales (~10min)

Fast Non-Dispersive and Slow Dispersive terms removed

Rioja, Dodson 2011, +etal 14, 15

Previous Work:

2000 VLBA SiO (v=2 J=1→0, 43.1GHz) Sanchez-Contreras 2002

Emission Traces a `ring',
which is better described as in-falling.
Self-Calibrated image, so without registration

2002 VLBA H_2O (22.2GHz) Desmurs 2007

Phase Referenced, so astrometrical valid

2003 VLBA SiO (43.1GHz) Desmurs 2007

Phase Referenced, but `tentative'; no image/spectrum

2009 VLBA H_2O (22.2GHz) Choi 2012

Phase Referenced parallax measurement

2009 VLBA H_2O (22.2GHz) Leal-Ferreira 2012

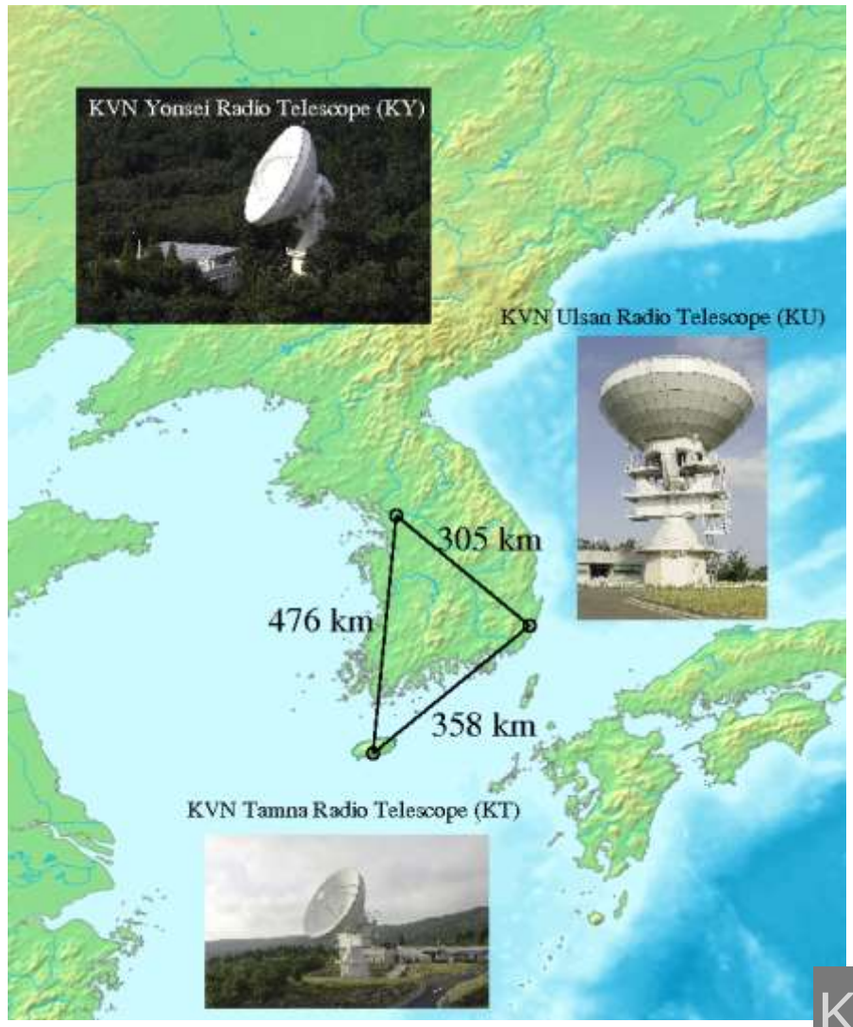
Self-Calibrated polarisation observations.

KVN Observations:

Simultaneous Multi-Frequency observations Jan 2017
22GHz and 42.8/43.1GHz
Phase referenced to J0746-1555

KVN baselines are ~500km
resolution is only 3mas
@43GHz

1 Gbps dual pol 64MHz @each freq
1 min cycle between target/cal
(for 22GHz PR)
Both SiO (v=1, v=2) transitions covered
10 hours of observing



KASI

SFPR between H_2O & SiO

SFPR (even non-integer) has been fully demonstrated:

Delay & Phase from Calibrator

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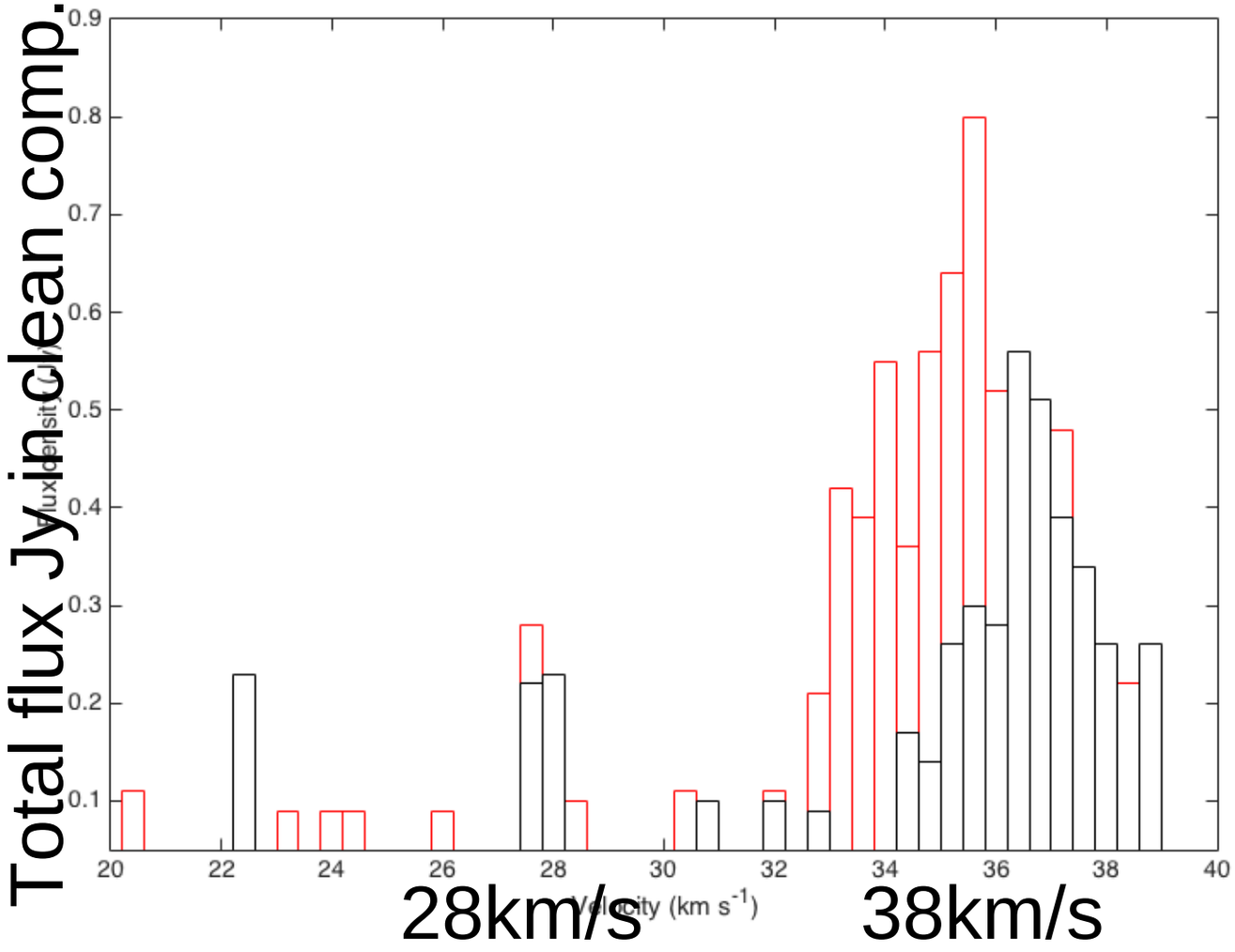
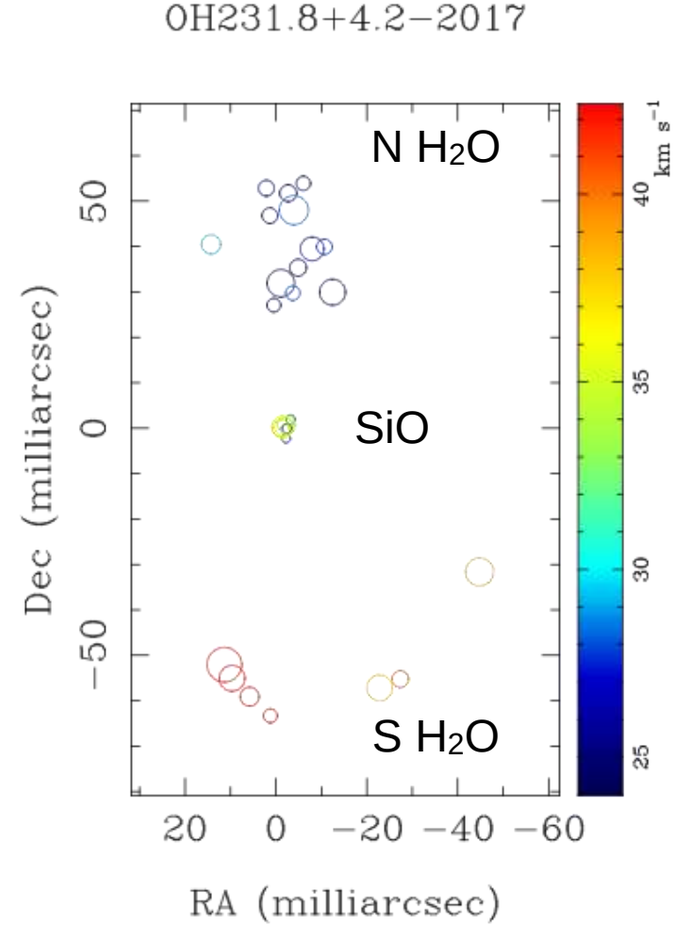
43.1GI

nasers c

and 40

to H_2O position

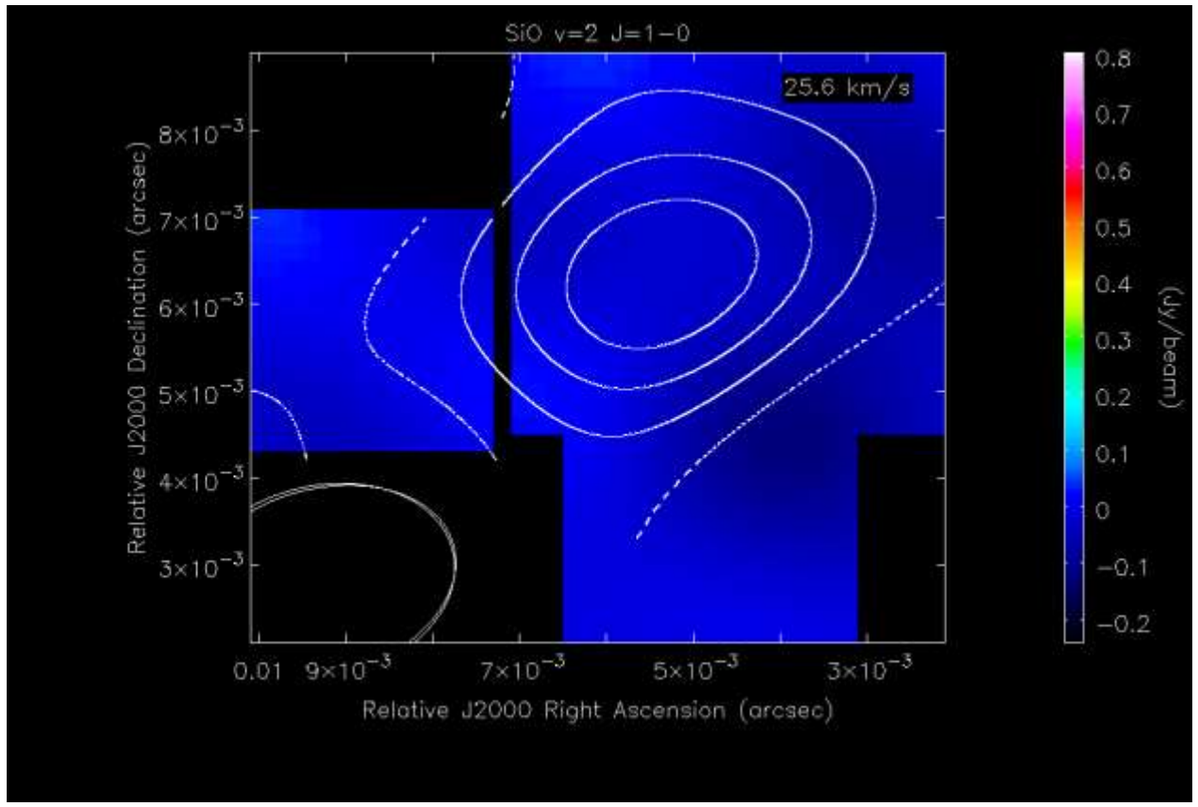


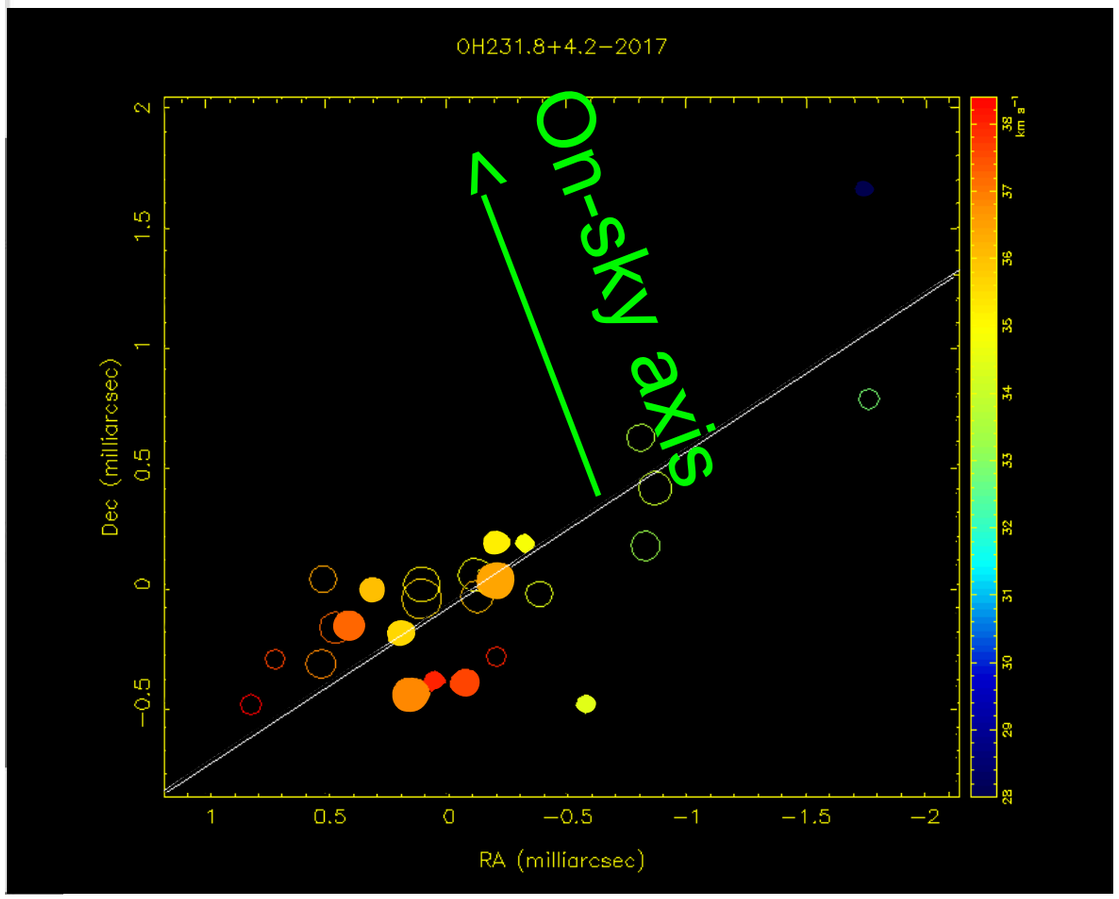


KVN Observations:

KVN baselines are ~500km
resolution is only 3mas @43GHz
Not able to resolve the disk structure

SiO spots are linear — and align with disk seen by Sanchez-Contreras (but smaller).
Approx. perpendicular to sky axis



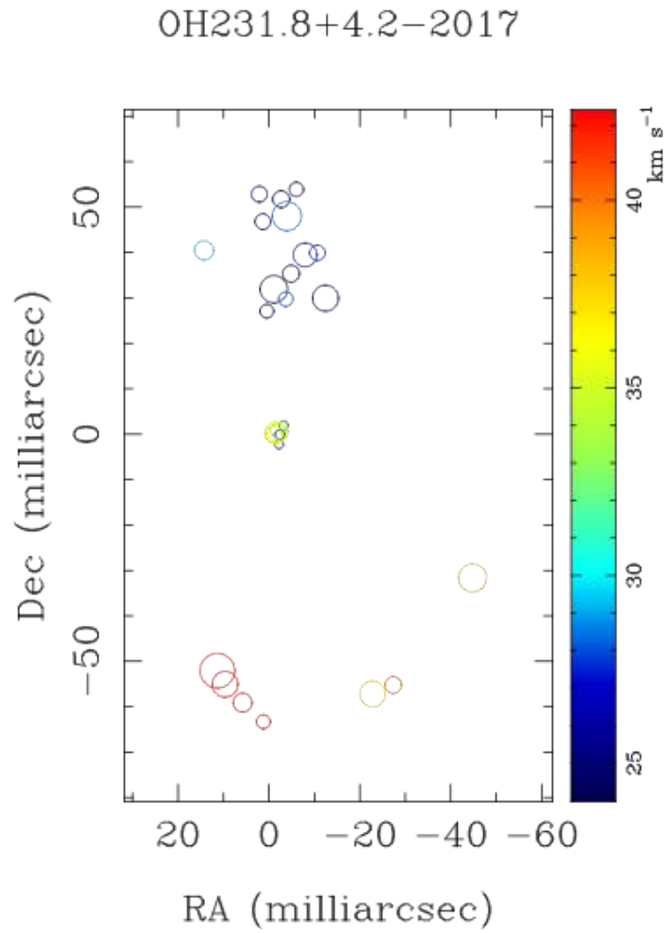


SiO J=1-0 masers in OH231
Open v=1: Filled v=2

SFPR between H_2O & SiO

Allows us to confirm that:

- Results compatible with previous
- SiO surronds central star



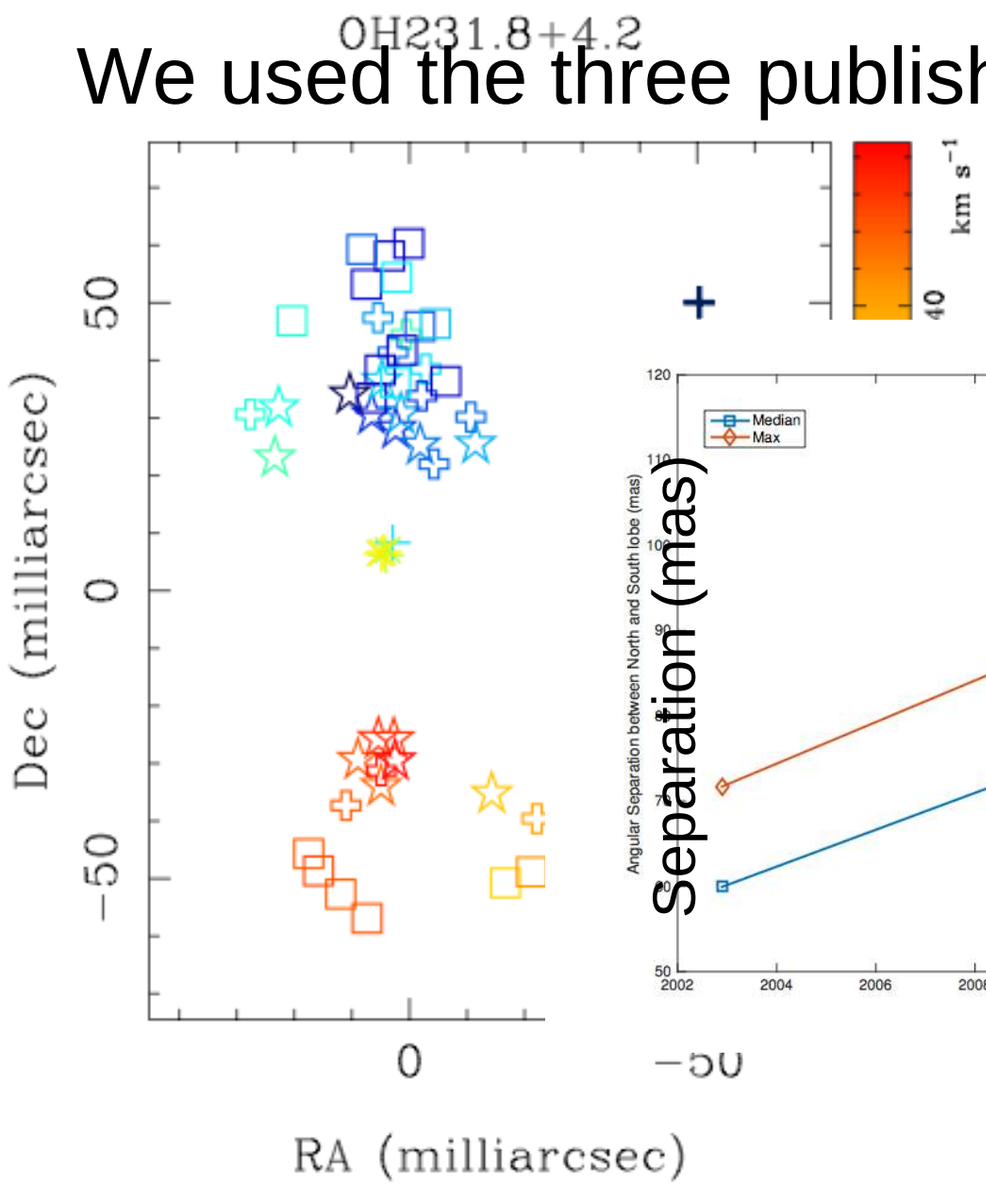
Now both v=1 and v=2 masers detected
Velocities between 28 and 40 km/s

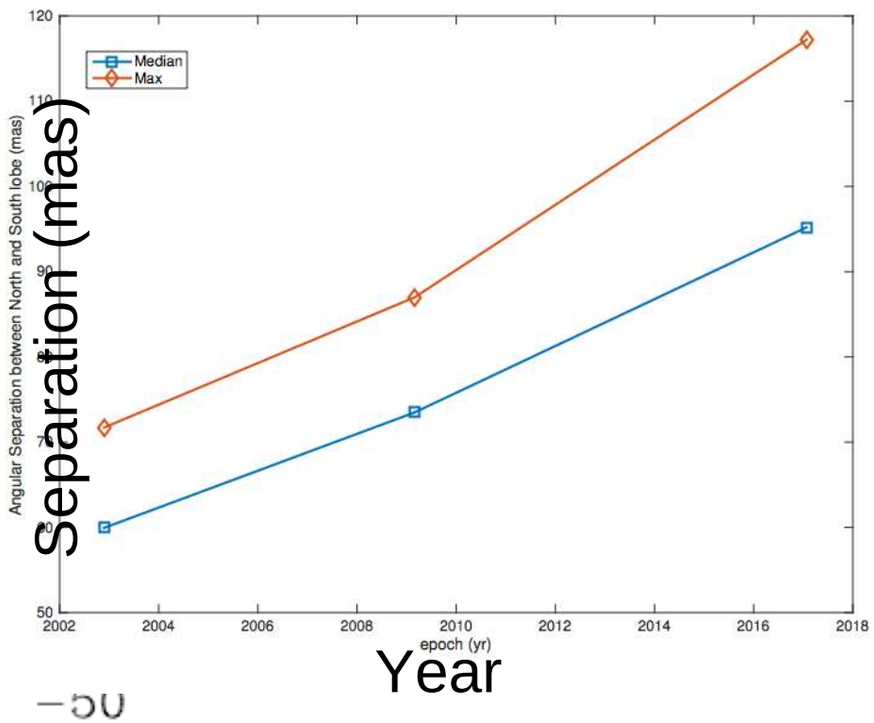
Astrometrically registered to H_2O position

Leveraging Previous Work:

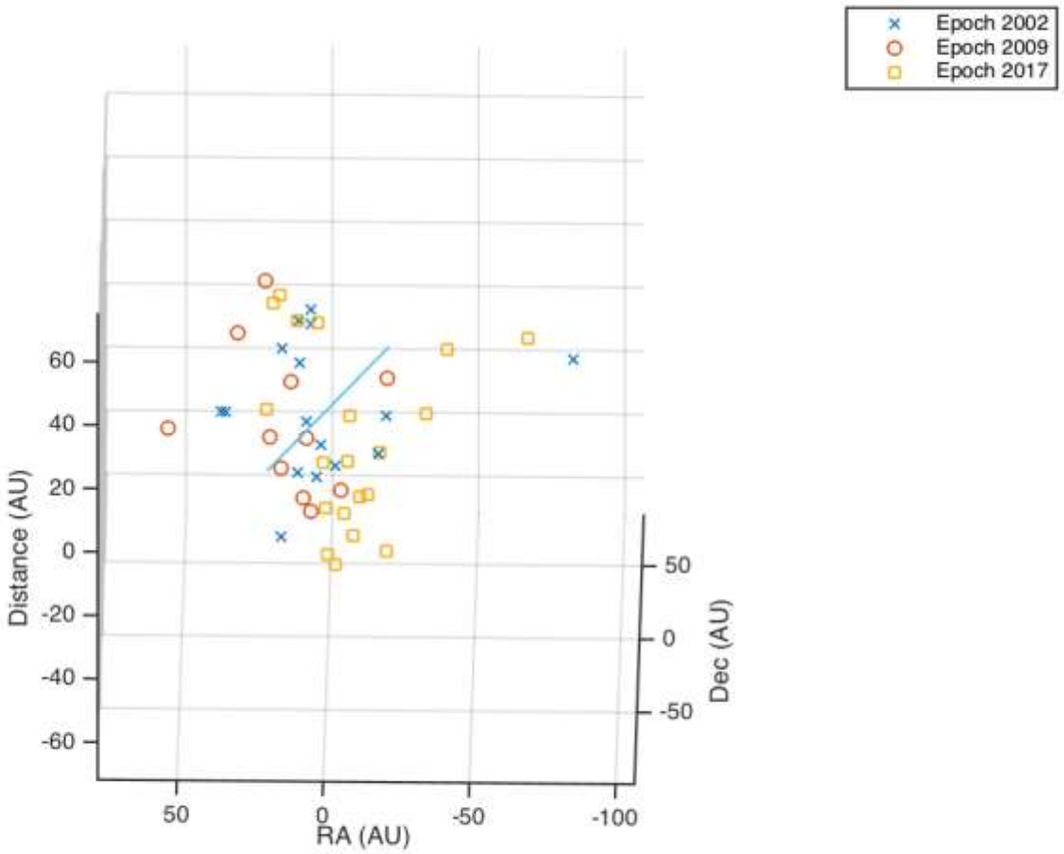
We used the three published H_2O masers to measure the expansion

- Use distance (max, median) from N to S
- Non-astrometric





3D reconstruction



- 3 epochs of H_2O shown
- Spanning 15 years
- Lie on known nebula axis
- Expansion velocity 19km/s

- H_2O masers are tied to the large scale outflow

A Global multi-Freq. mm-VLBI

KVN 13/7/3/2mm VLBI

9,000km

2,300km

7,300km

7,900km









Simultaneous VLBI with KVN @13/7mm



201?: Nobeyama funded Tests with MK TianMa & TVN prob @13/7mm



Installed KVN-QO for Simultaneous 13/7&3mm VLBI

x-KVN project 2014-2016



Simultaneous 7/3mm mode



google maps, KASI, NRAO, CSIRO, NAOJ, others

Conclusions

Another SFPR demonstration — making mm-VLBI easy

- Bona-Fide astrometric registration of masers in OH231
- SiO is at the centre, marking the location of central star
- Expansion of H2O masers dates core of nebula to be 40yr
- Expansion is outwards from central star, along symmetry axis, linking macro and micro-scales
- SiO disk structure below resolution …

  x-KVN or VLBA, to monitor source over a year (PM, π)