Masers!
What can VLBI do for you?

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IAUS336 Astrophysical masers – Cagliari, September 4-8 2017

Contents

- Introduction
- Masers everywhere!
- New prospects
- Summary

Introduction

- Masers are bright
- Masers have compact structures
- Masers are great for VLBI !

- Masers are in evolved stars
- Masers are in star-forming regions
- Masers are seen in other galaxies

Introduction (2)

Environment	Maser molecule	Tool for:
AGB envelopes	SiO H_2O OH HCN	Inner shell, rings Outer shell Caps, distance In C-rich envelopes
Star-forming regions	SiO, H_2O, OH, CH_3OH	Structure Astrometry Parallaxes
Galaxy megamasers	OH, H_2O, CH_3OH	Galaxy structure Distances

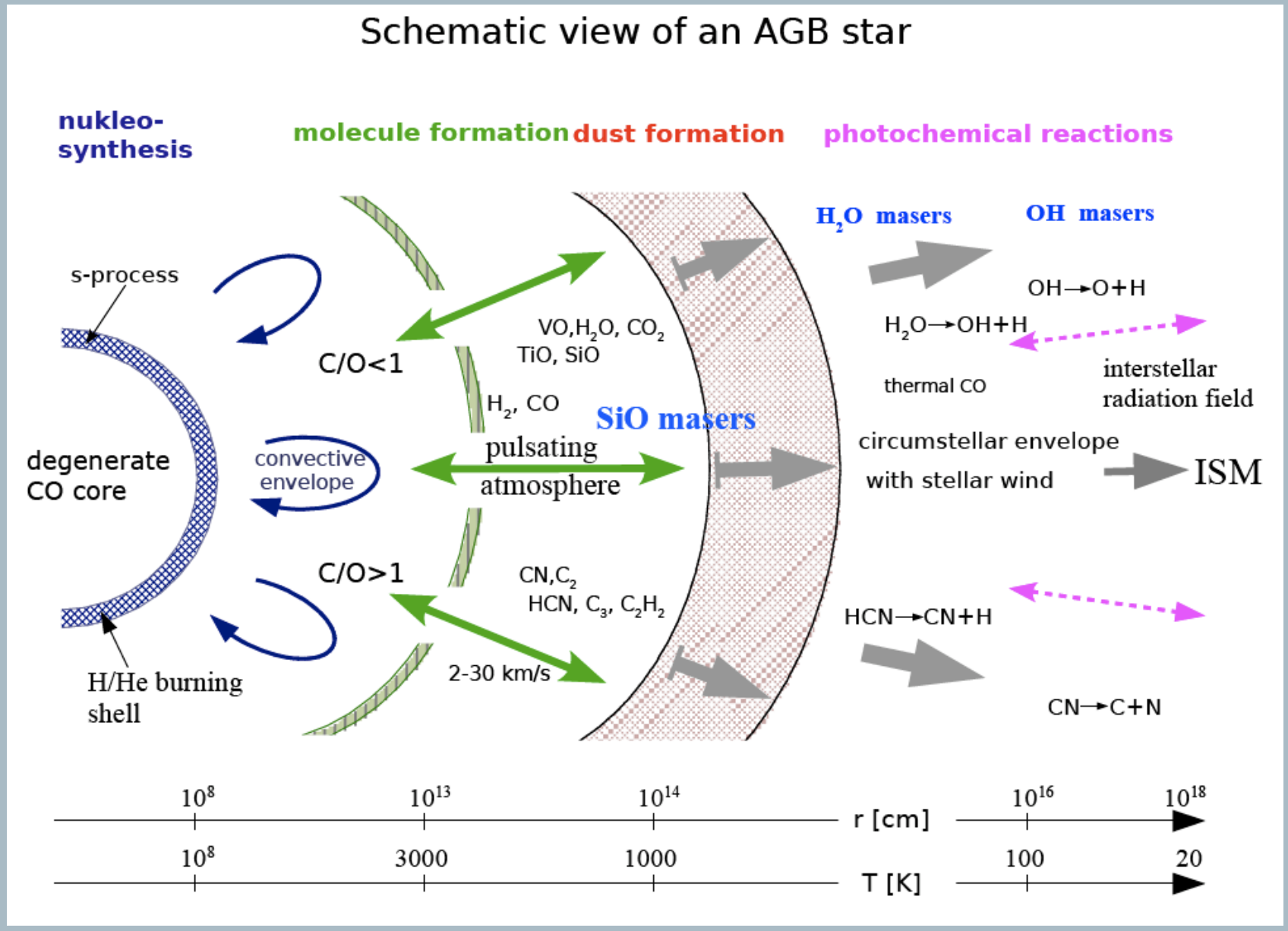
Introduction (3)

- **OH**: 1.6 GHz, 4.9 GHz, 6.0 GHz
- **H_2O** (water): 22 GHz
- **SiO**: 43 GHz, 86 GHz, 129 GHz
- **CH_3OH** (methanol):
  - Class I: 36 GHz, 44 GHz, 95 GHz
  - Class II: 6.7 GHz, 12 GHz,
- **HCN**: 89 GHz

Masers! What can VLBI do for you?

EVOLVED STARS

Masers in evolved stars



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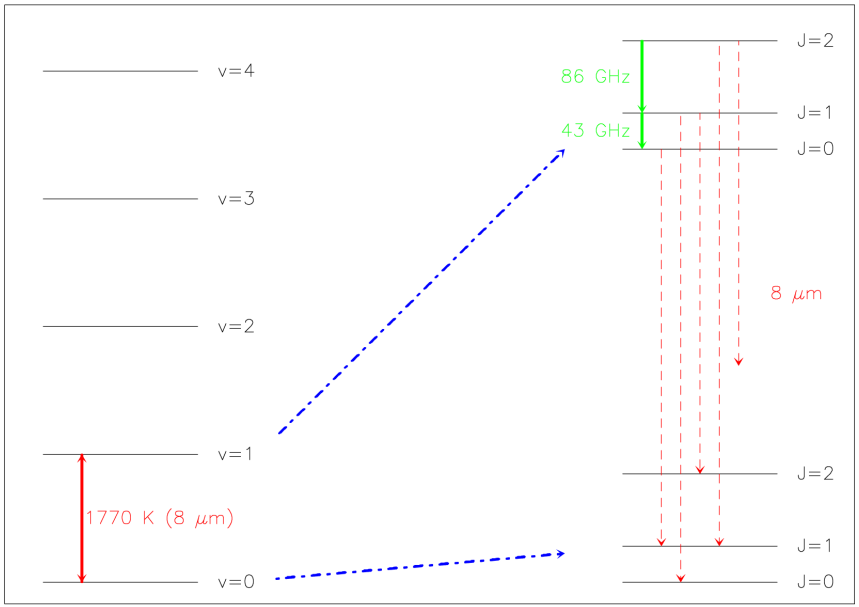
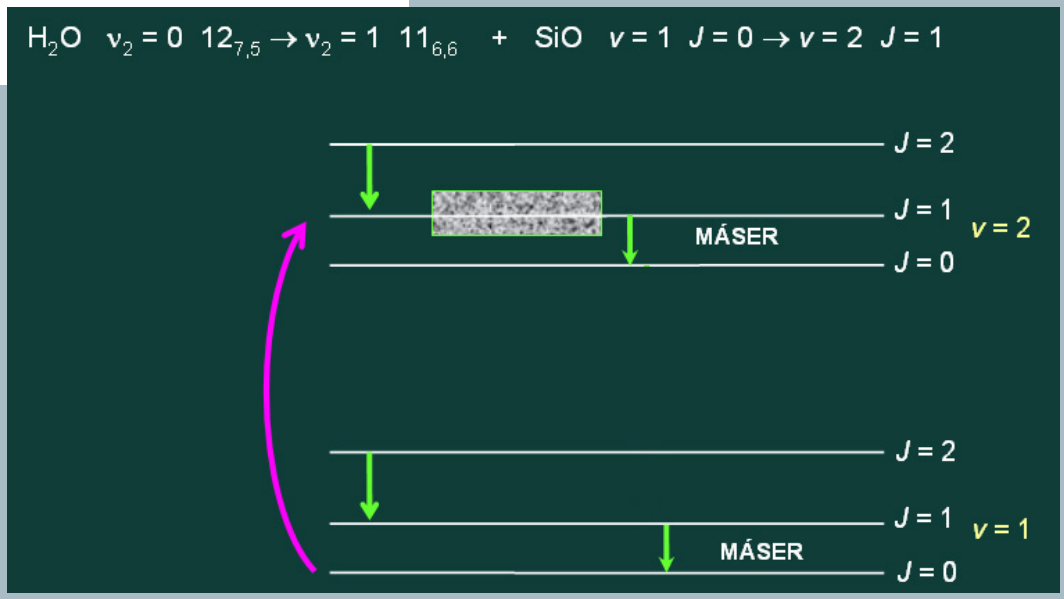
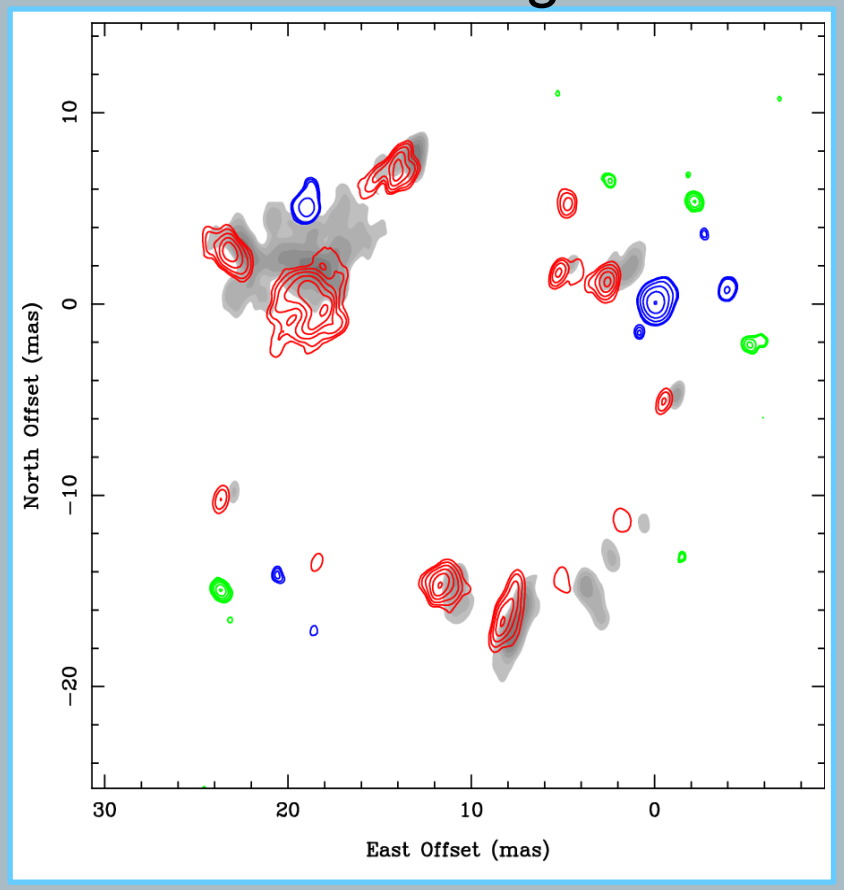
SiO masers

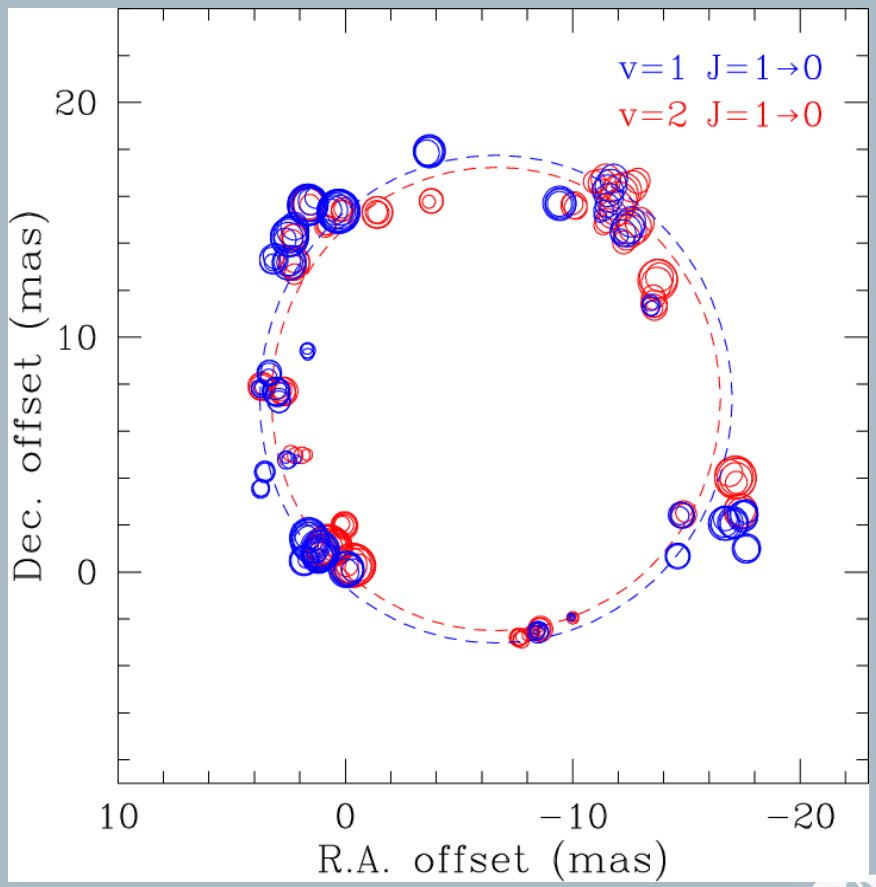

SiO : LEVELS AND TRANSITIONS
v=4
v=3
v=2
v=1
v=0
1770 K (8 μm)
86 GHz
43 GHz
J=2
J=1
J=0
8 μm
J=2
J=1
J=0


H2O ν2 = 0 12 7,5 → ν2 = 1 11 6,6 + SiO v = 1 J = 0 → v = 2 J = 1
J = 2
J = 1
MÁSER
J = 0
v = 2
J = 2
J = 1
MÁSER
J = 0
v = 1

SiO masers in AGB stars

- Ring-like structure, clumpy distribution
- v=2 and v=1 J=1-0 are similar, with v=2 slightly smaller
- v=1 J=2-1 is larger





WX Psc

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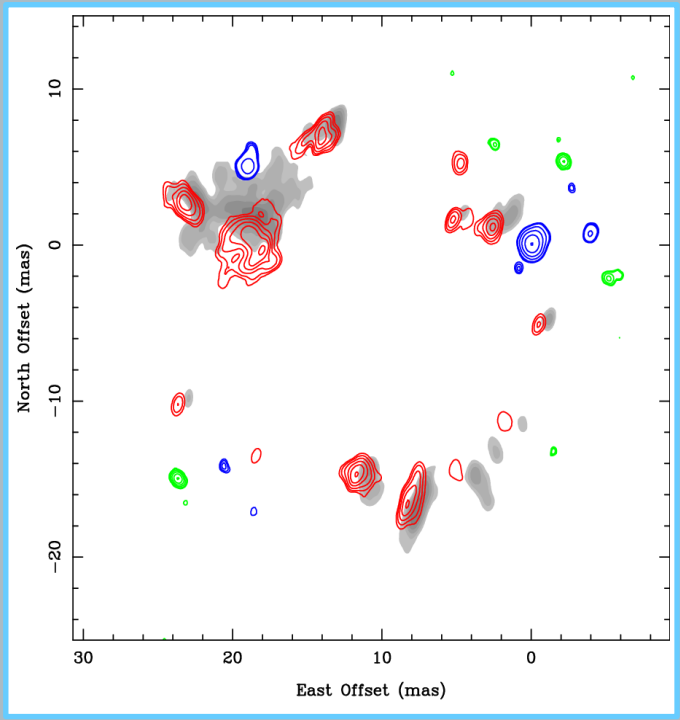
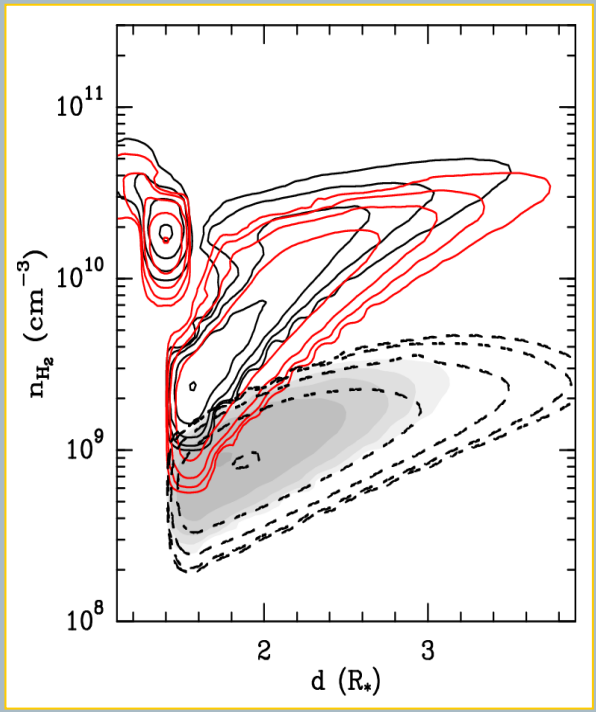
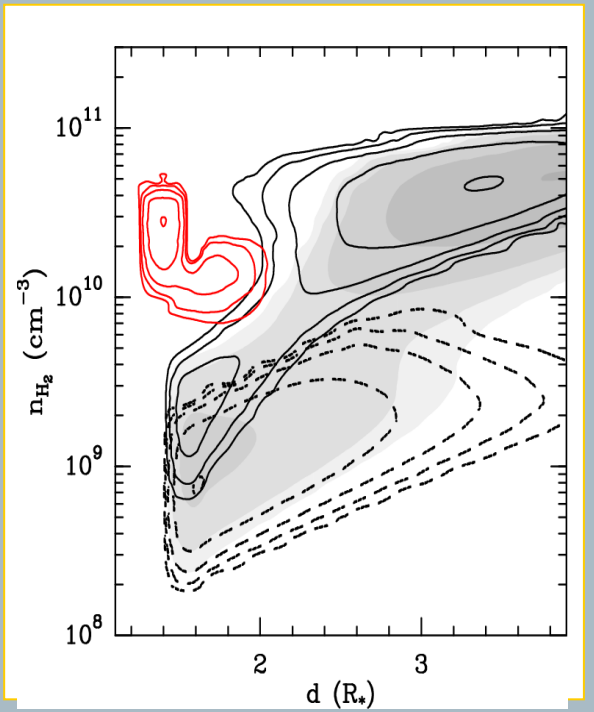
The alignment problem







Greys	$v = 1$ $J = 1–0$	———	$v = 2$ $J = 1–0$
- - - - - - - -	$v = 1$ $J = 2–1$	———	$v = 2$ $J = 2–1$

Soria-Ruiz et al. (2004), A&A 426, 131

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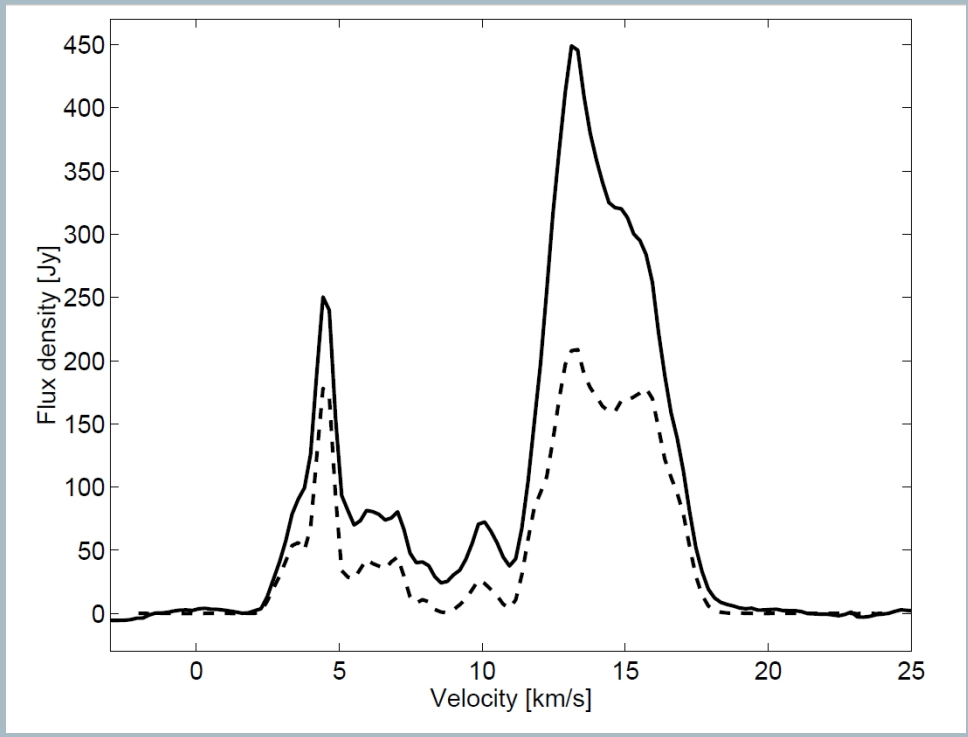
The missing flux problem

- Large difference between SiO masers total flux (solid line) and crosscorrelated flux (dashed line).

- Is there emission which is undetected by VLBI?
  - Many small and weak spots?
  - Extended weak emission?

- Sensitive arrays needed to find the answer !



See poster #12 by J.F. Desmurs et al.

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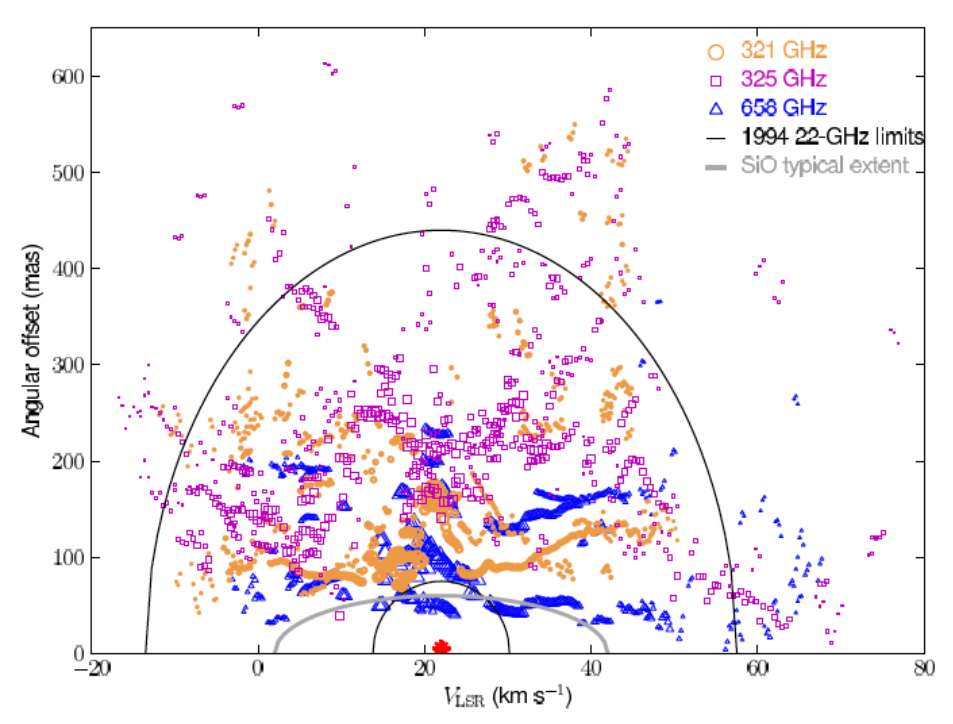
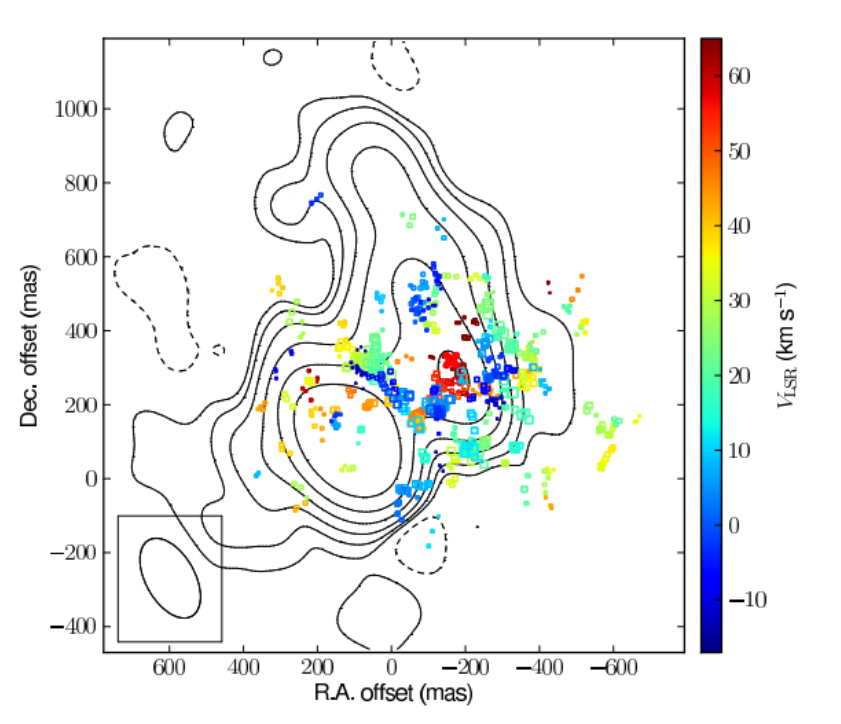
Water masers in AGB envelopes





Richards et al. (2014), A&A 572, L9

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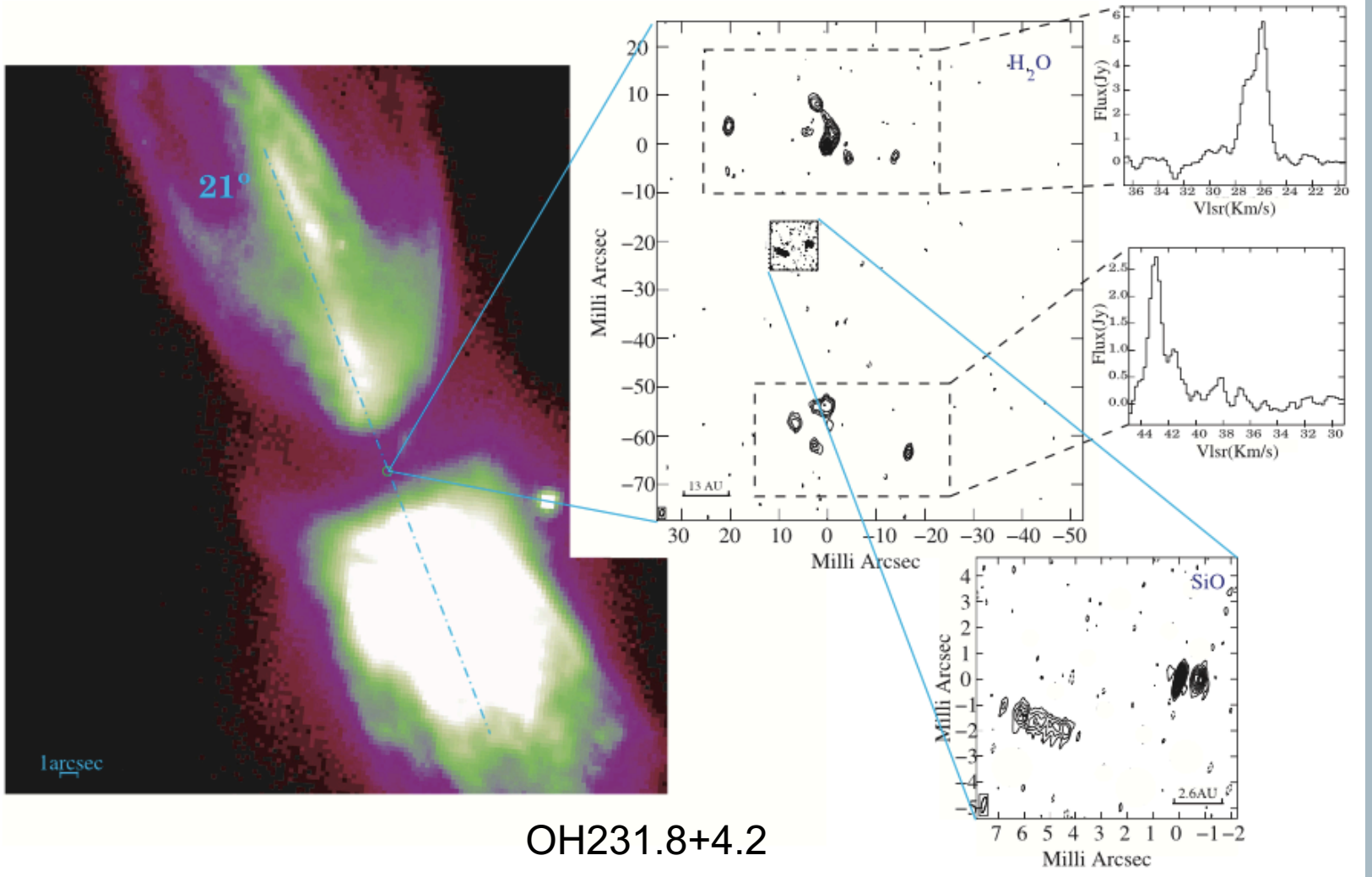
How does axial asymmetry appears?



OH231.8+4.2

Desmurs et al. (2007), A&A 468, 189

Absolute positions are needed !

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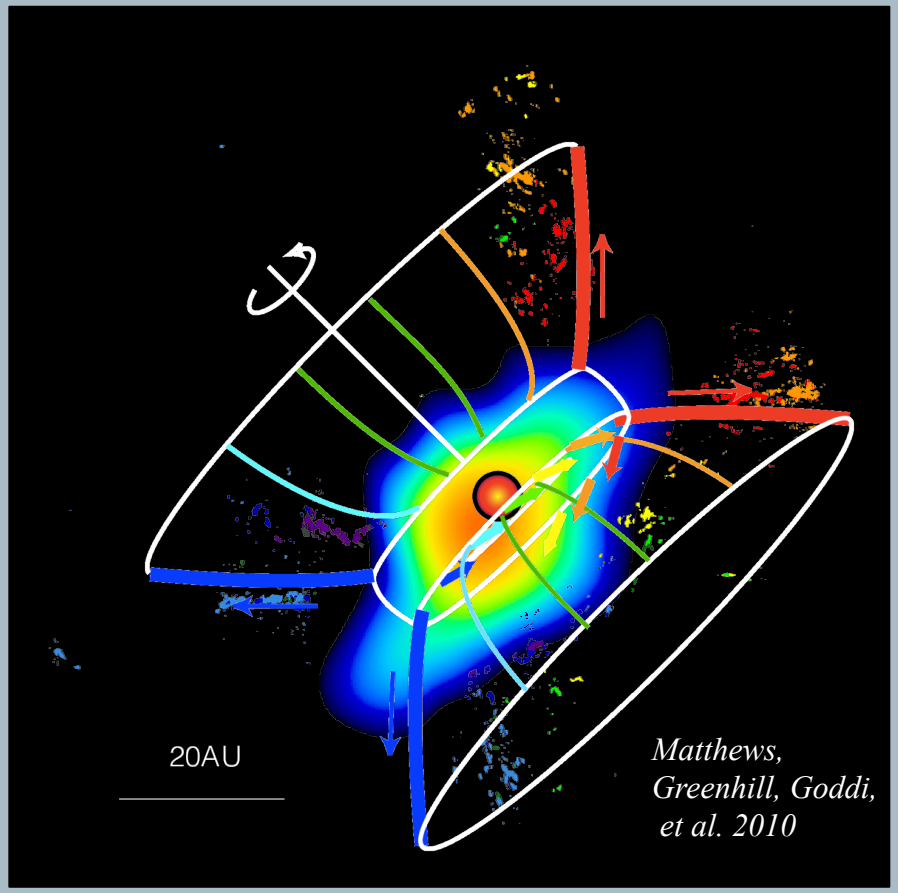
Masers! What can VLBI do for you?

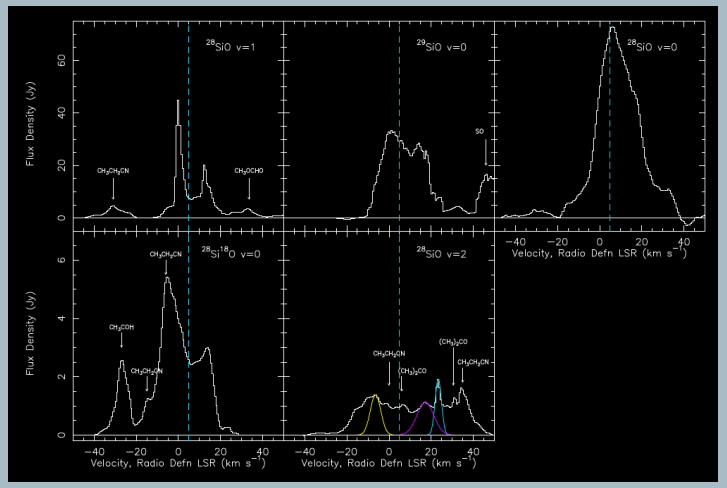
STAR FORMING REGIONS

Orion BN/KL powering source



mm-VLBI can :

- Probe closer gas to YSO, i.e. R<15 AU
- Establish maser nature of high-J lines
- Constrain radiative transfer models to make T/dens. maps



ALMA Cycle 0
Band 6 J=5-4
SiO lines
(~220 GHz)

Niederhofer, Humphreys, Goddi 2012

- SiO emission at R=15-70 AU
- No SiO emission *in* the disk midplane

Our best chance to resolve the root of a disk/jet system in a YSO !!

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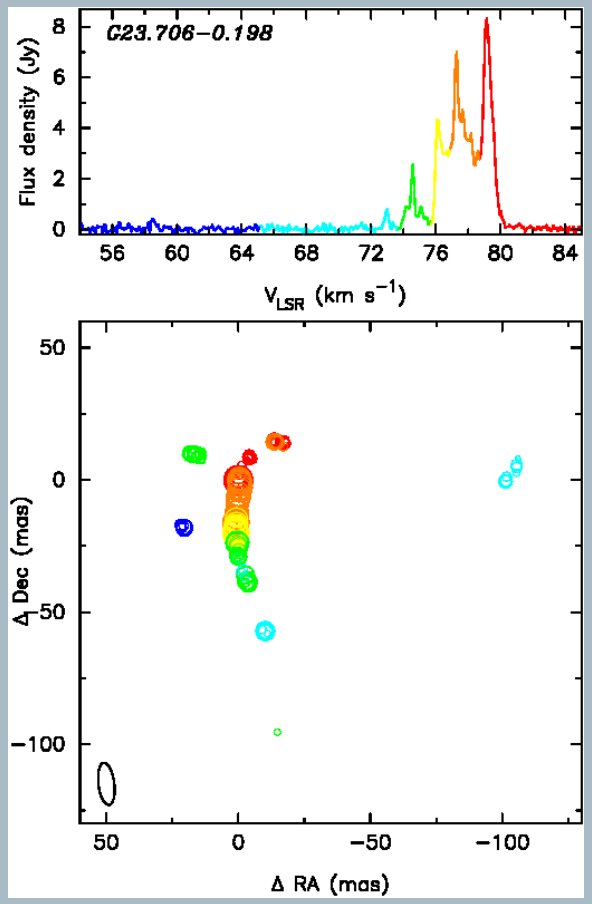
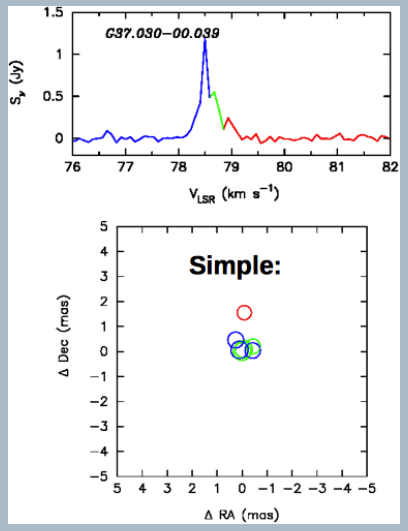
Methanol (CH_3OH) masers

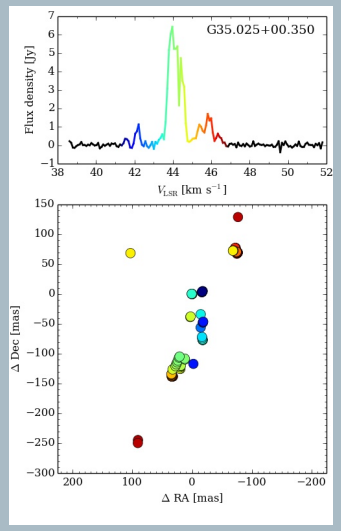
EVN imaging of the Class II **6.7 GHz methanol masers** in HMSFRs.

Maser morphology does not easily give a clue on phenomena going-on – an outflow, a disc, shocks.

The EVN missing flux: 30-50% of that detected by single-dish (not depends of the source distance).







Bartkiewicz+ (2016), A&A 587, 104

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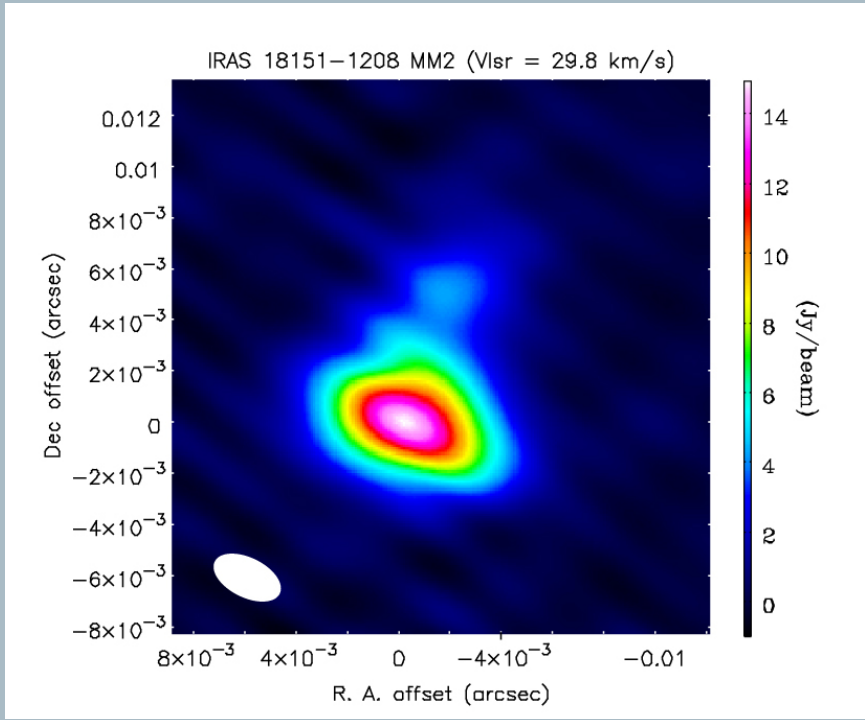
Other methanol masers

44GHz methanol maser detected by KAVA

Matsumoto, N. et al. 2014, ApJL, 789, L1



Title: VLBI Observations of Methanol Masers at 95 GHz

Authors: Lonsdale, C. J.; Doeleman, S. S.; Liechti, S.; Slysh, V. I.; Alcolea, J.; Bujarrabal, V.; Colomer, F.; Goluber, V. V.; Kalenskii, S. V.; Phillips, R. B.; Pratap, P.; Predmore, C. R.; Val'tts, I. E.; Devicente, P.

Affiliation: AA(MIT Haystack Obs.), AB(MIT Haystack Obs.), AC(Centro Astr. de Yebes, Spain), AD(Astro. Space Ctr., Russia), AE(Centro Astr. de Yebes, Spain), AF(Centro Astr. de Yebes, Spain), AG(Centro Astr. de Yebes, Spain), AH(Moscow State University), AI(Astro. Space Ctr., Russia), AJ(MIT Haystack Obs.), AK(MIT Haystack Obs.), AL(FCRAO), AM(Astro. Space Ctr., Russia), AN(Centro Astr. de Yebes, Spain)

Publication: American Astronomical Society, 193rd AAS Meeting, id.71.01; Bulletin of the American Astronomical Society, Vol. 30, p.1355

Publication Date: 12/1998

Origin: AAS

Bibliographic Code: 1998AAS...193.7101L

Abstract

Several strong class-I methanol maser sources have been observed using a short VLBI baseline, from Haystack Observatory in Westford MA to the FCRAO 15m telescope in Quabbin MA, in the 8_0 - 7_1A(+) 95.2 GHz transition. Despite total maser flux densities of order 100 Jy, the masers were not detected on this baseline, indicating maser spot sizes in excess of several milliarcseconds. This result is consistent with previous studies, which suggest spot sizes of several tens of milliarcseconds for class-I masers, and at least rough cospatiality between the many transitions associated with class-I methanol masers. This is in contrast with the milliarcsecond scale sizes of class-II methanol masers, of which the 6GHz and 12GHz masers are members.

36 GHz and 95 GHz methanol masers not yet detected by VLBI.

Masers! What can VLBI do for you?

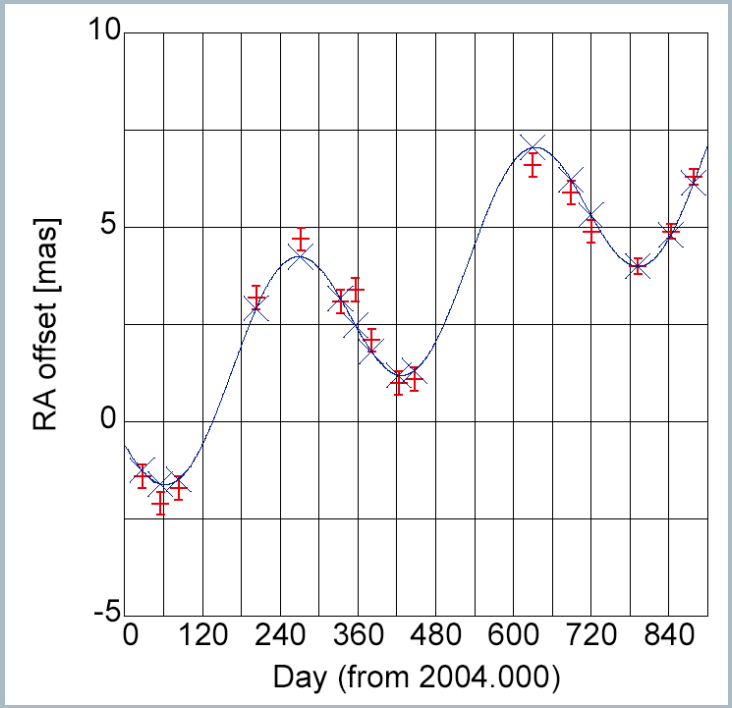
ASTROMETRY

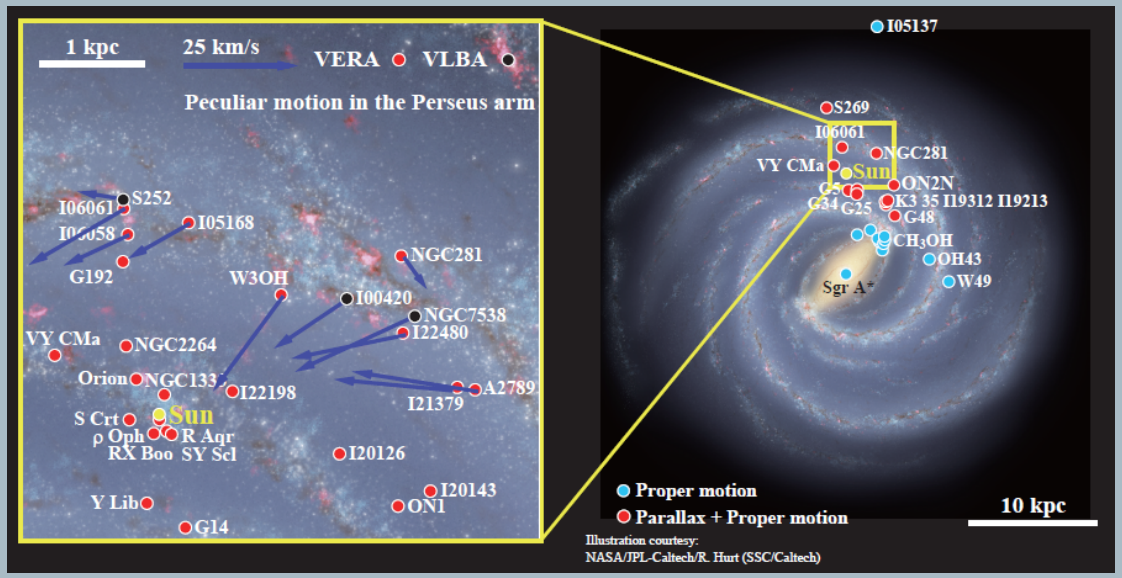
Measuring distances and galaxy dynamics

Distance to Orion KL

D = 437 +/- 19 pc

Hirota et al. (2007)





Spiral structure, comparison with theories will discriminate if the spiral arms are density wave or material wave (e.g., Sakai et al. 2015)

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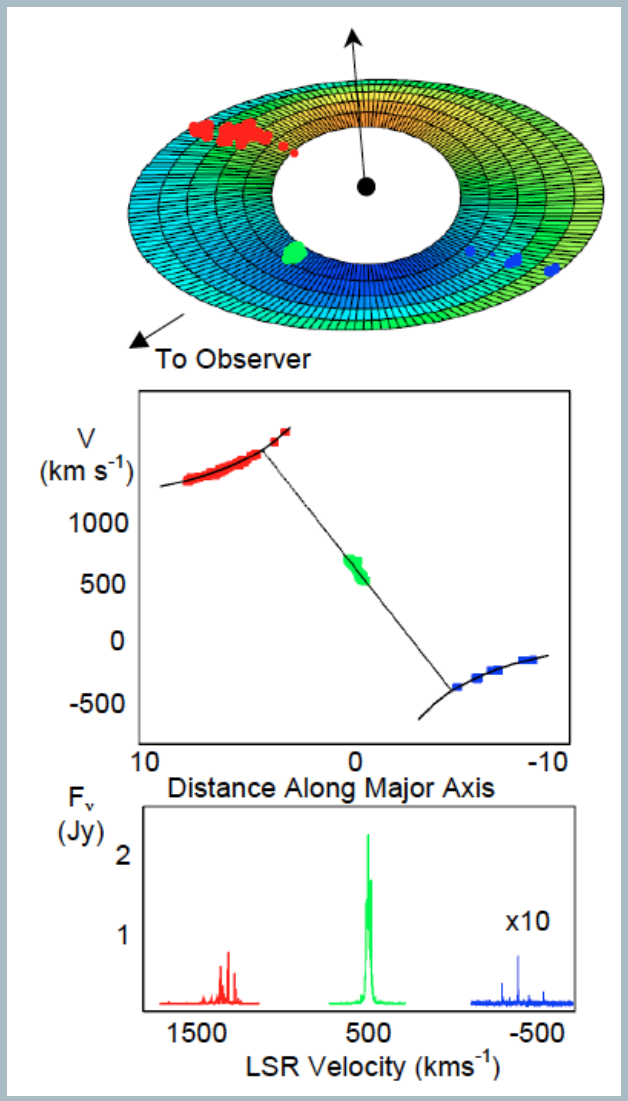
EXTRAGALACTIC MASERS

Cosmology and determination of H_o



For distant AGN (> 50 Mpc), water maser geometric distances can yield a high accuracy H_0 and constrain Dark Energy.

Humphreys et al. (2013)

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Masers! What can VLBI do for you?

FUTURE PROSPECTS

JIVE
Joint Institute for VLBI ERIC

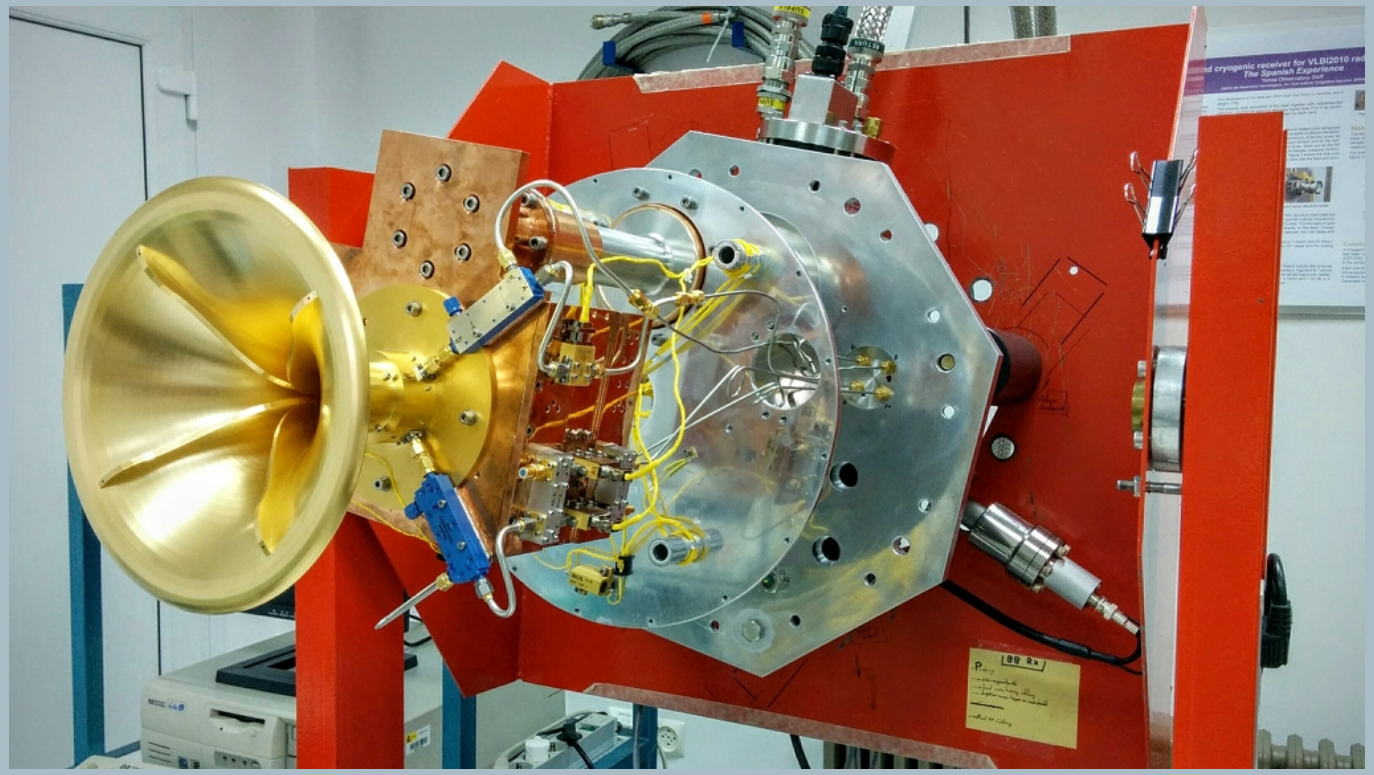
EUROPEAN VLBI NETWORK



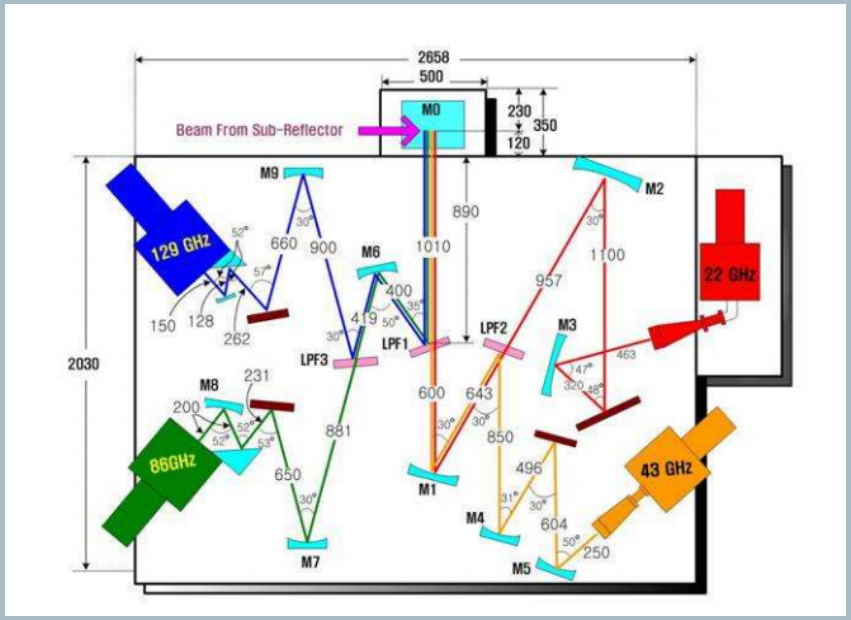
www.jive.eu / www.evlbi.org

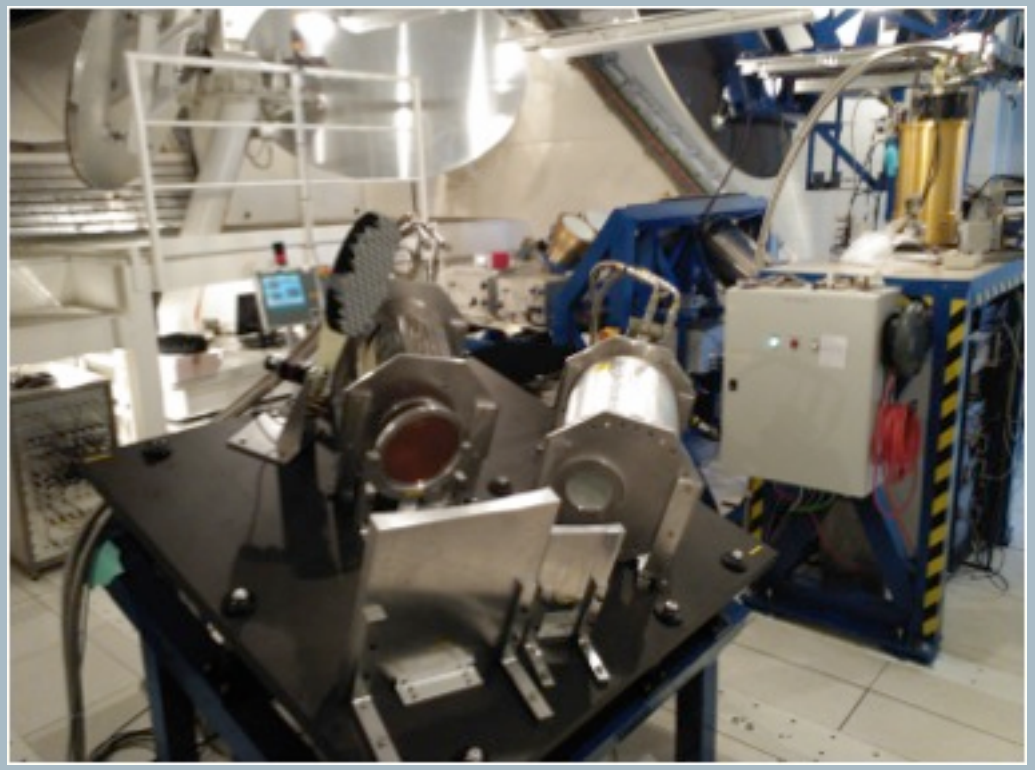
RADIONET BRAND receiver for EVN

- Broadband receiver to cover 1.5-15.5 GHz.
- Simultaneous registration of masers of OH (1.6, 1.7, 4.7 and 6.0 GHz), and CH_3OH (6.7 and 12.2 GHz).



Simultaneous multi-frequency observations





K band (21-26 GHz)
Q band (41-49 GHz)
W band (76-100 GHz)

Water masers
SiO masers
HCN masers
Some methanol masers

Allows alignment of maser maps !



K/Q at IGN-Yebes 40-m RT

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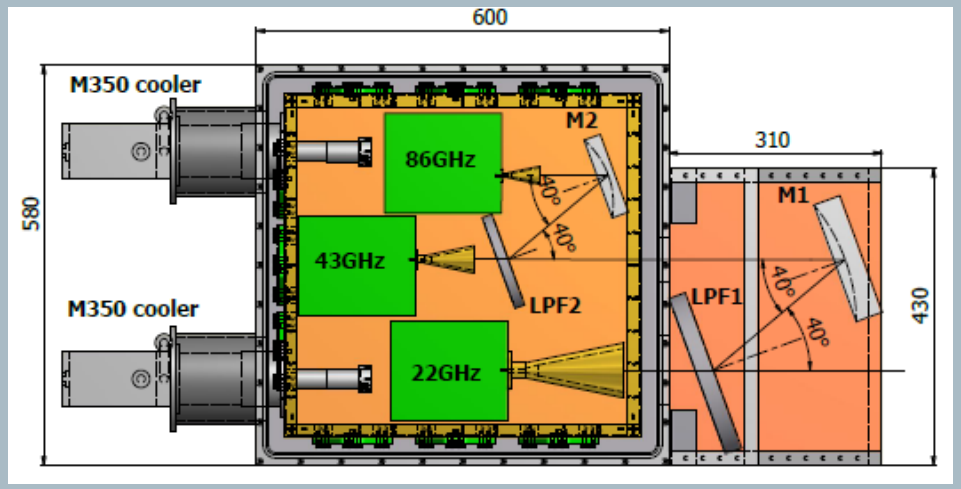
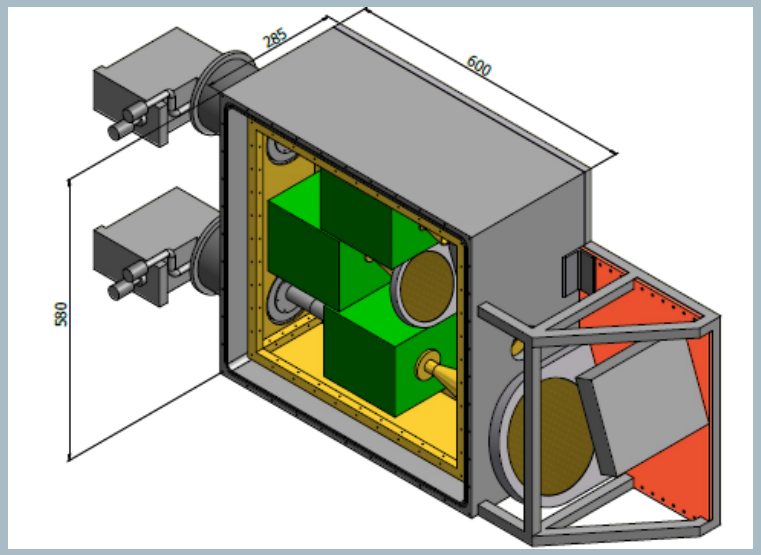
Compact K/Q/W bands receiver







See talk on multifrequency calibration methods, by Maria Rioja !

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What can we do for masers?

- EVN is a very sensitive VLBI array, some of its telescopes can observe up to λ=3mm, also *in real-time*.
- **The Joint Institute for VLBI ERIC (JIVE)** correlates the EVN data and **provides expert support to EVN users**.

- *EVN CALL FOR PROPOSALS deadline on October 1st 2017 !*
  See details in

  http://www.evlbi.org/

- JIVE coordinates the EC H2020 "JUMPING JIVE" project, one of its goals is to increase awareness of the potential and opportunities of the EVN to scientists of any discipline.



JIVE

Joint Institute for VLBI ERIC (JIVE)

- Supports the European VLBI Network
  - Radio astronomy at its highest spatial resolution
  - operations
  - **correlation**
  - data acquisition
- Research & development
  - software
  - hardware
  - e-VLBI
- **Science support**
- Training

JIVE headquarters in Dwingeloo, the Netherlands.

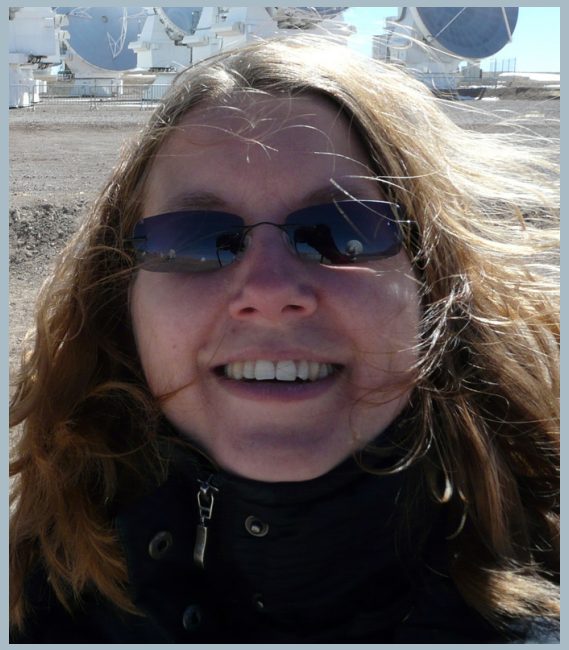


JIVE

The JIVE staff support group for masers



Ross Burns



Katharina Immer

Visiting JIVE?: http://www.jive.eu/visiting-jive

Summary

- Masers everywhere!
- VLBI is a great technique to study masers.
- EVN/JIVE offers users support to all astronomers.



"On the fringe of great discoveries"



Grazie !

Francisco ”Paco” Colomer

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