# Tri-band maser studies of star-forming regions

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# Massive stars form deeply embedded in their natal cloud

*How do young stellar objects gain mass to evolve into high-mass stars?*

image: *Herschel*/ESA

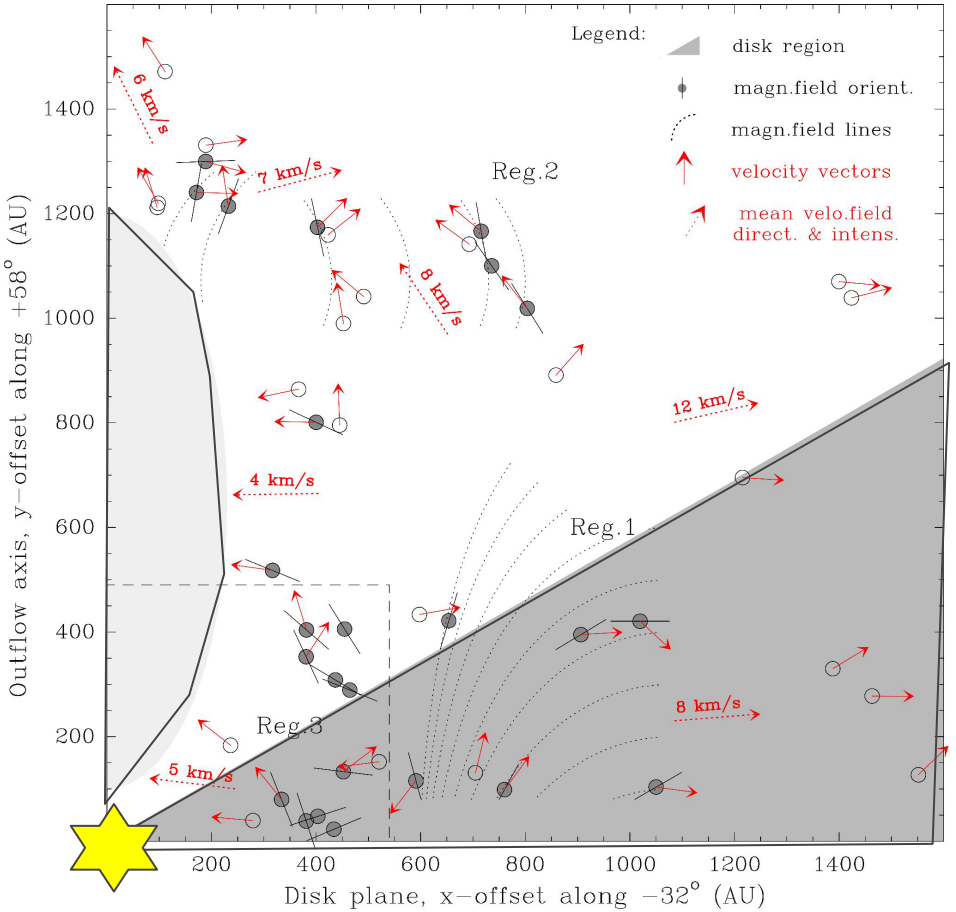
# MYSO: a complex system

disk, outflow, envelope,
Bfields, size scales < 1000 au

high densities~ $10^4$-$10^7$ $cm^{-3}$

evolution is fast ~ $10^5$ yrs

and dynamic

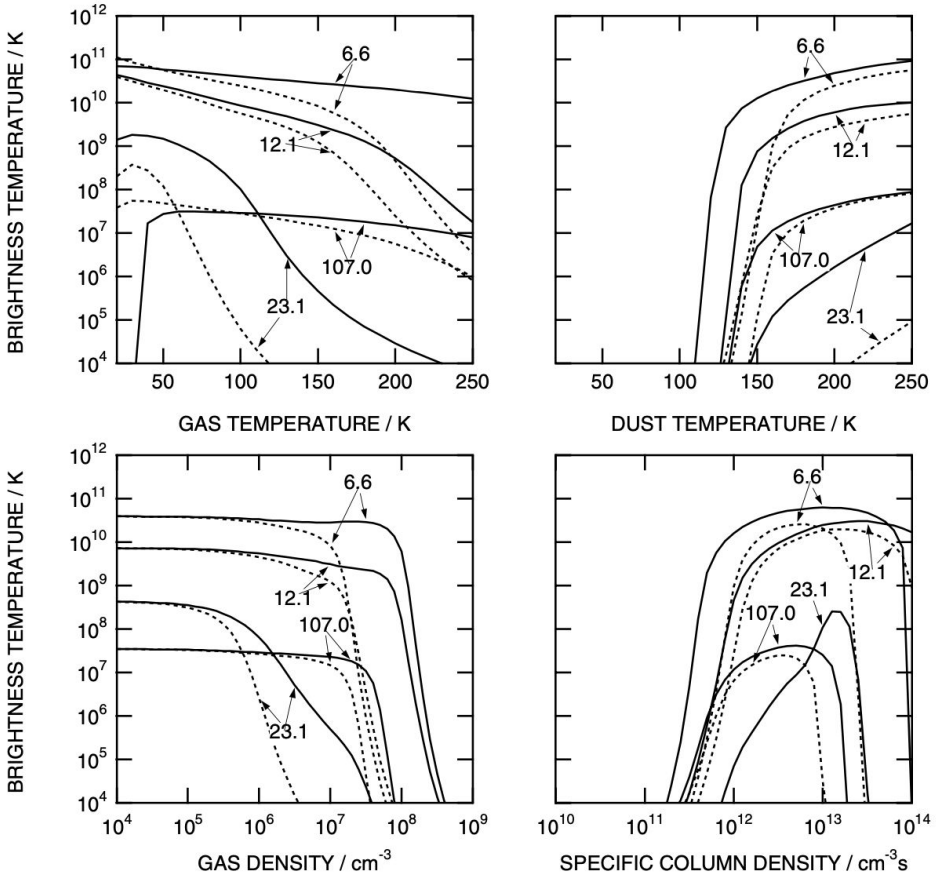



Sanna et al. 2005

# Maser eyes

Can access high-extinction regions and small angular scales (VLBI).

They trace regions with specific physical properties (n, $T_{dust}$, $T_{kin}$) plus provide kinematic and polarimetric information!




Class II methanol maser models
Cragg et al. 2005

# Maser species available in MYSO system

Class II methanol

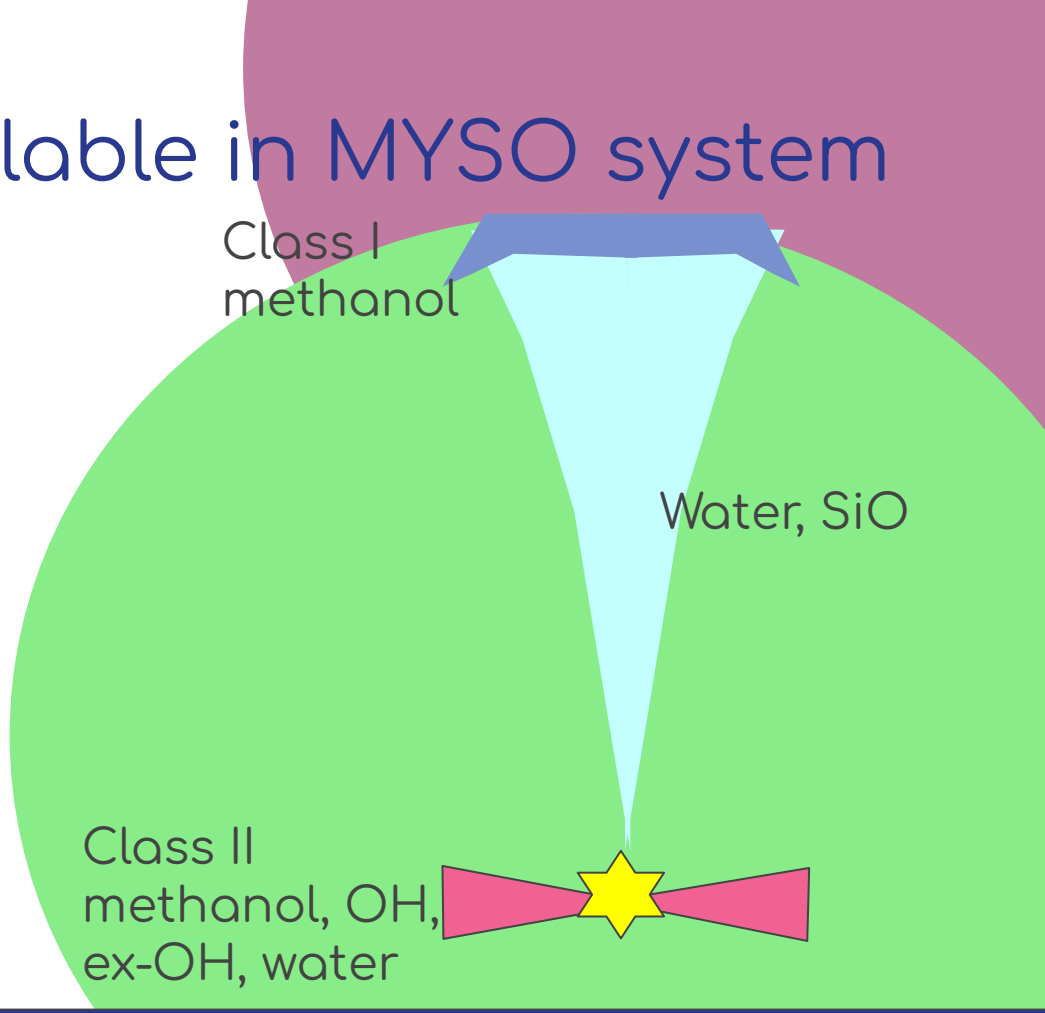
Class I methanol

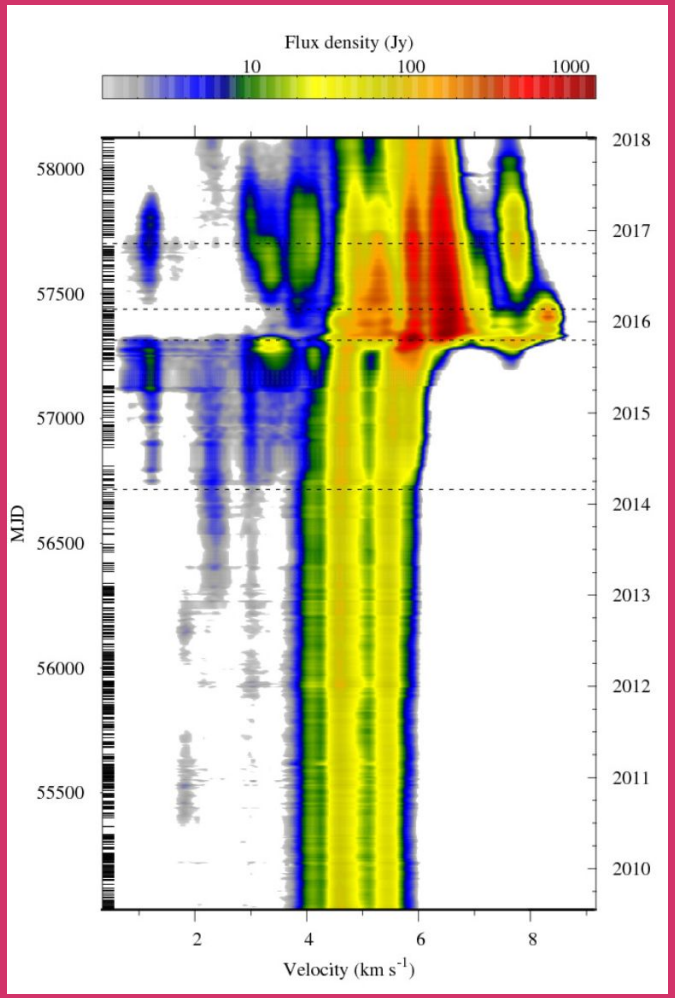
Water

OH/ex-OH

SiO

(and other less common ones)






# Episodic accretion events

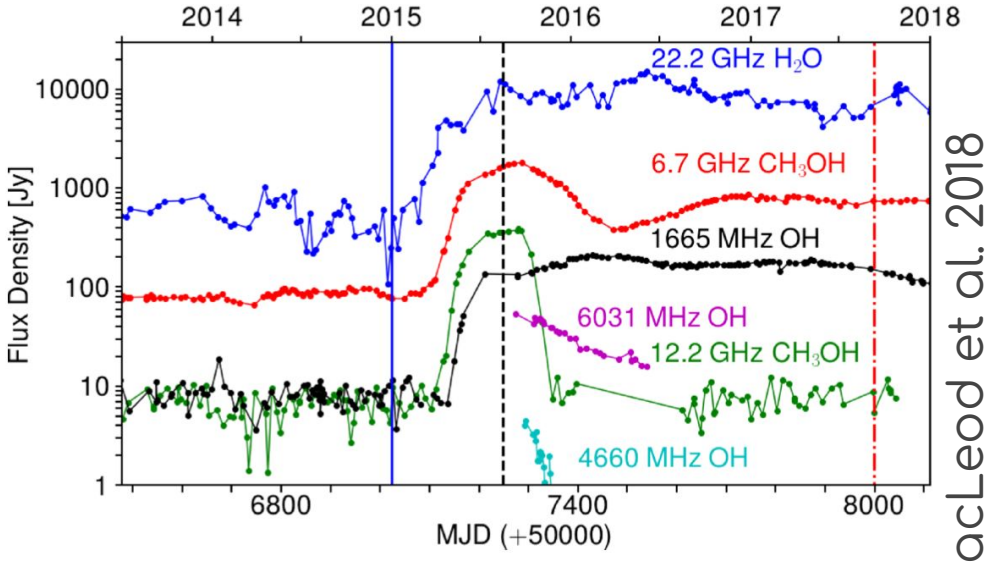
traced by 6.7 GHz methanol masers

Szymszak et al. 2018

# Accretion flares light up the surroundings

Brightening of many maser species in the disk, but also in the outflow.

**Maser monitoring** to find and study such events




MacLeod et al. 2018

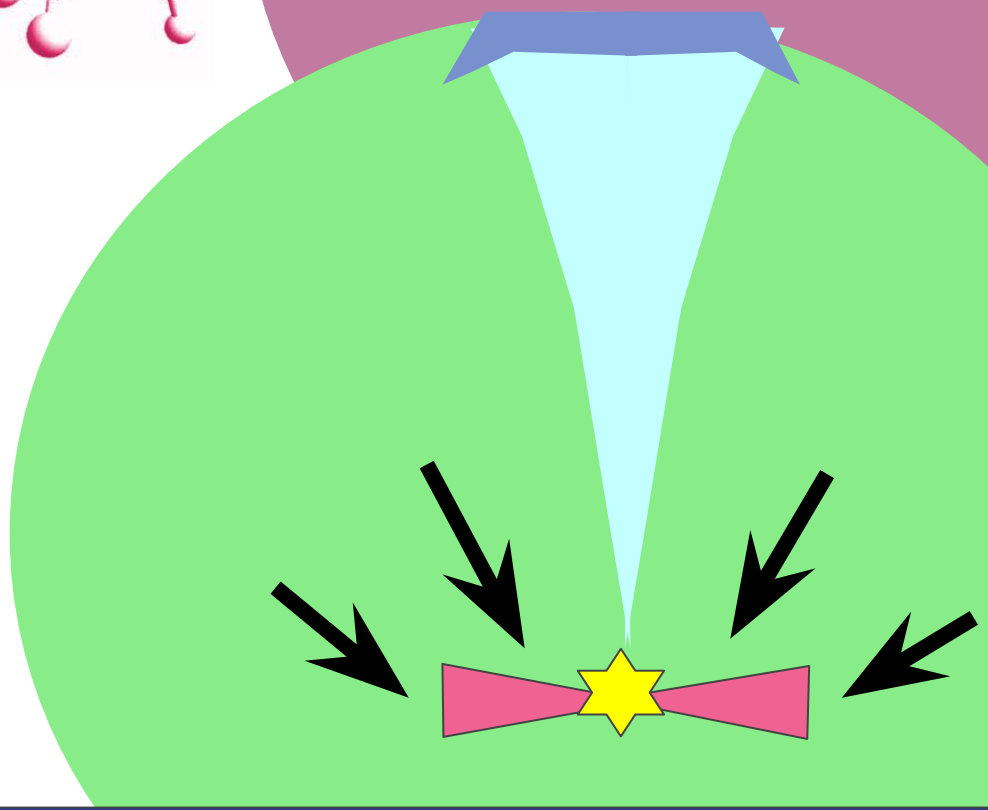
# Triband masers

**Class II methanol:** sensitive to warm dust, nearby the YSO

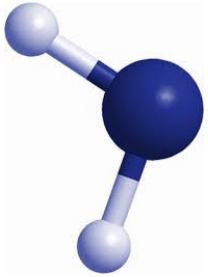
23.1, 37.7, 38.3, 38.4, 86.6, 86.9, 107.0 GHz

to combine with 6.7 and 12.2 GHz to constrain physical parameters,

polarimetry



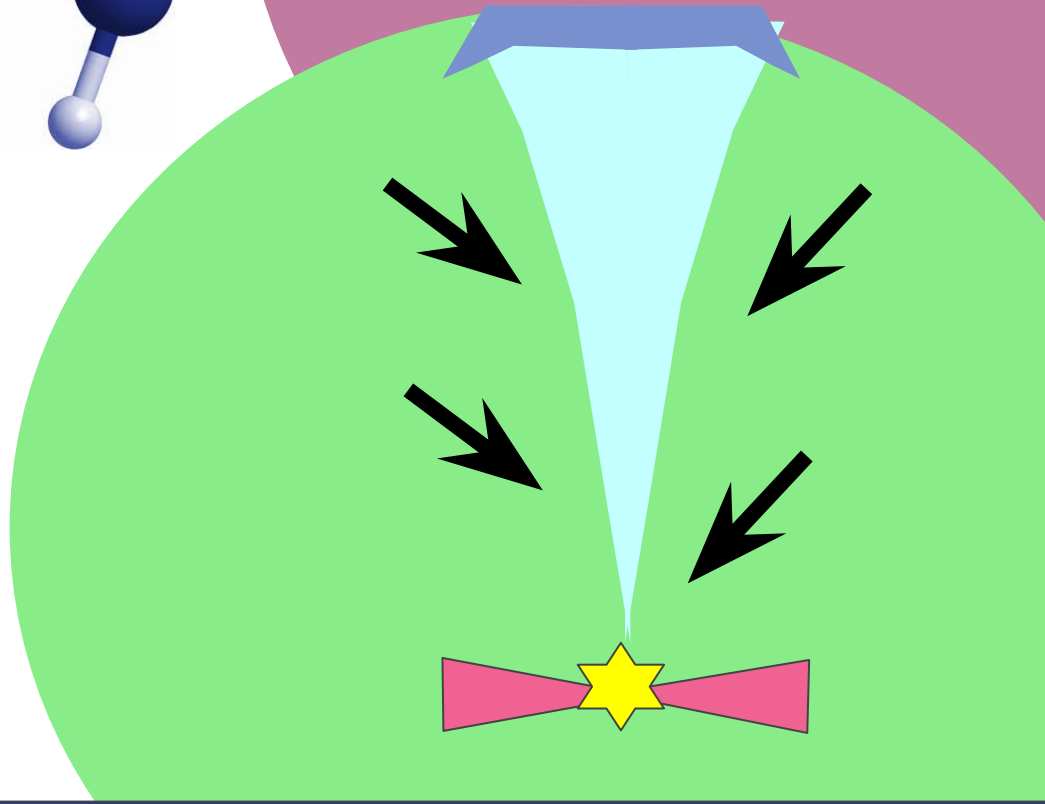
# Triband masers



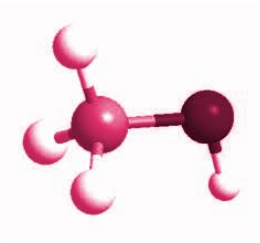
**Water masers:** shocked gas in jet and interaction of jet/envelope

22 GHz

very bright and variable, often polarised



# Triband masers

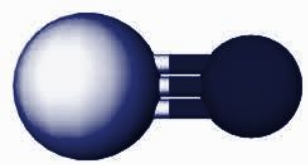


**Class I methanol:** in post-shock gas, displaced from the YSO

**24.9, 36, 44, 84.5, 95, 104.3 GHz**

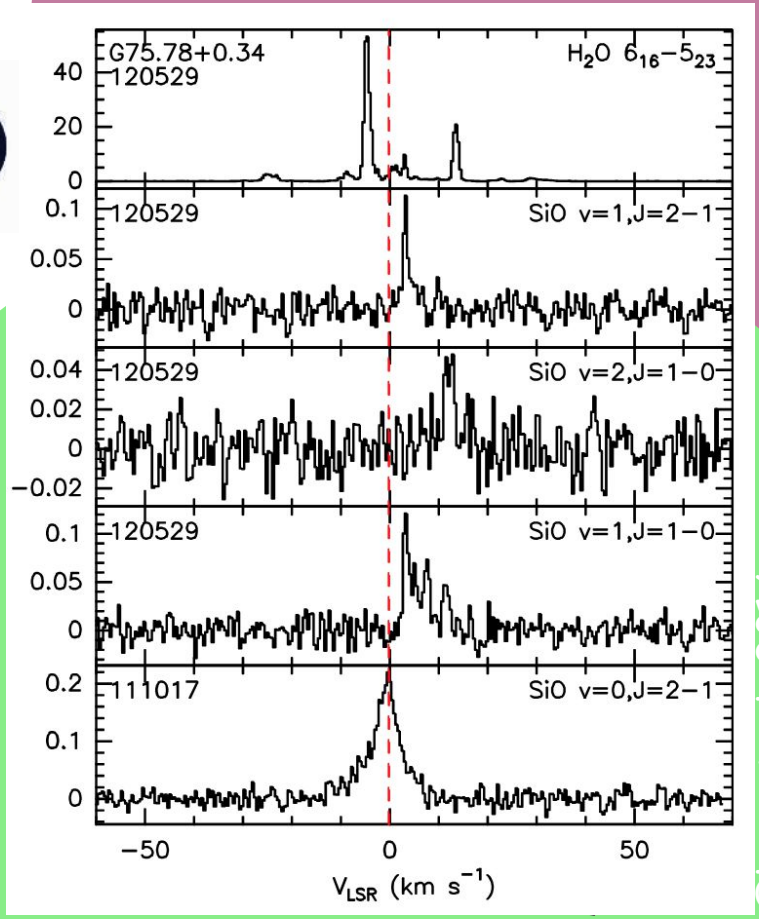
impact of jet with ambient gas, B fields

# Triband masers



SiO masers 44, 86 GHz

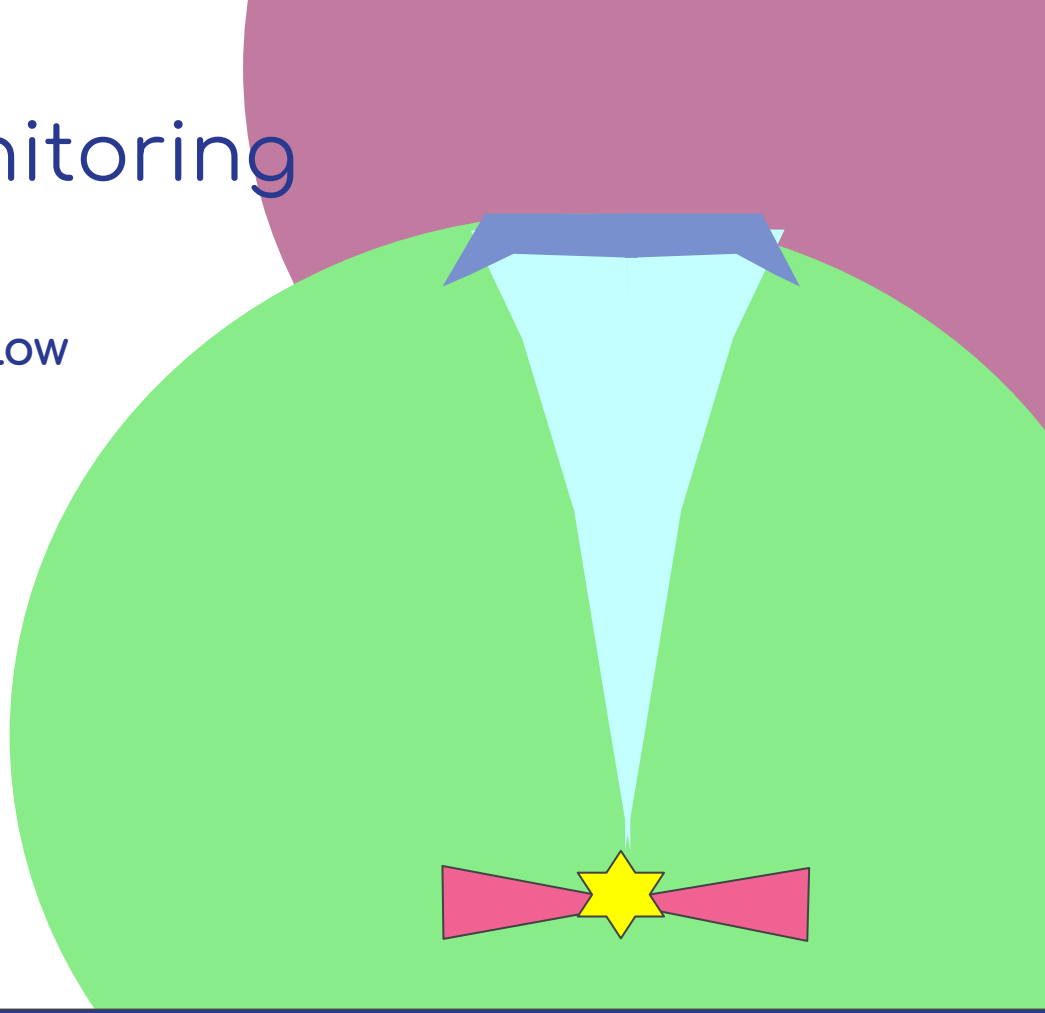
Rare in SFRs (require $n>10^9$ $cm^{-3}$) but if present, associated with jet/outflow in earliest stage




Cho et al. 2016

# Triband maser monitoring

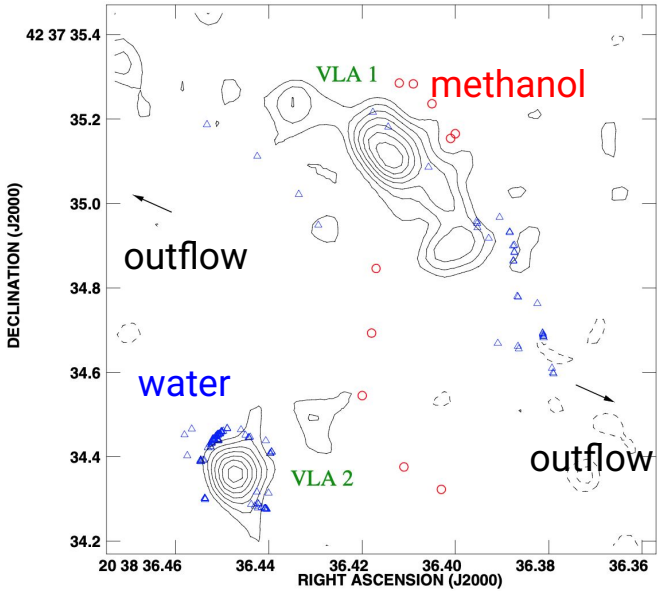
Follow mass accretion and outflow characteristics of a MYSO through various maser species



# Triband VLBI maser imaging

## Distribution of maser species astrometrically registered with respect to each other

Surcis et al. 2011




# EATING polarised water masers in W75N

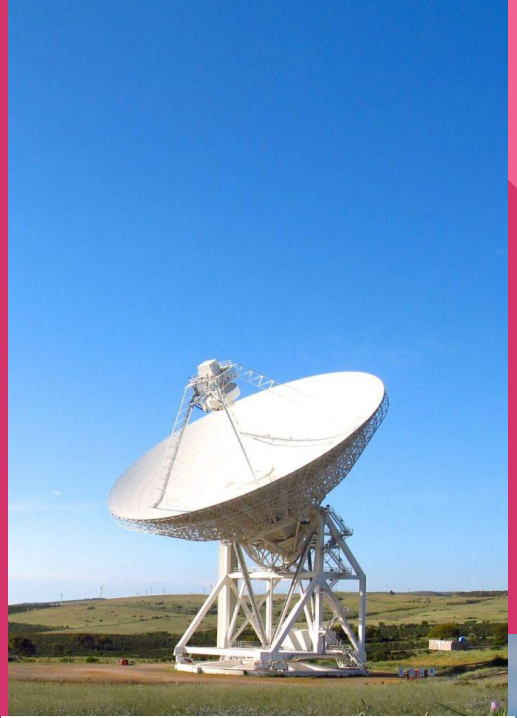
2024- Srt,Mc,3KVNs

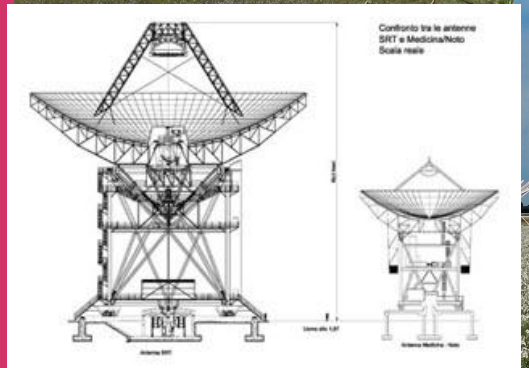
2025- 4KVNs triband (water and methanol class I)

resubmit with VERA antennas (K/Q)

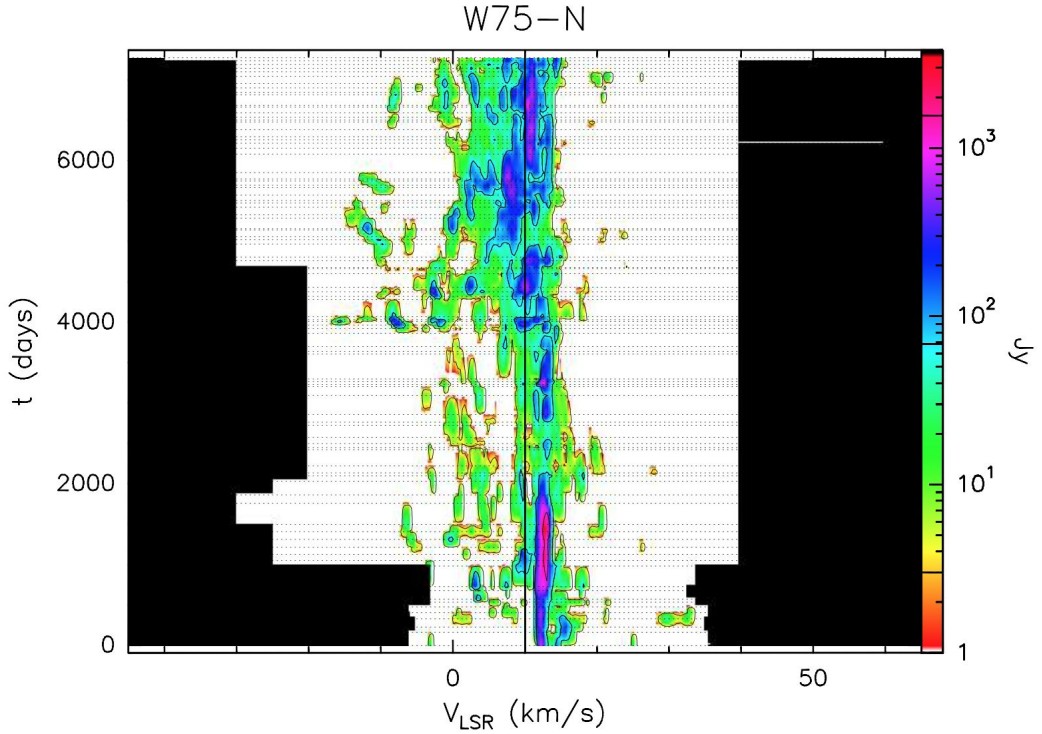
Project with Gabriele Surcis, Olga Bayandin, Luca Moscadelli, Taehyun Jung, Jan Brand

# INAF Maser Monitoring






# 22 GHz water maser monitoring




Felli et al. 2007

20 yrs
Medicina
monitoring

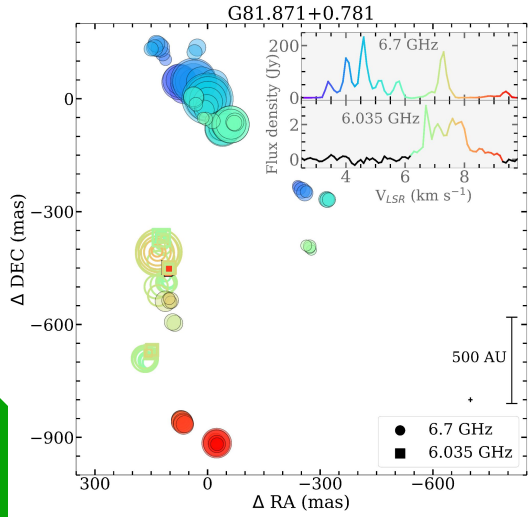
Still ongoing

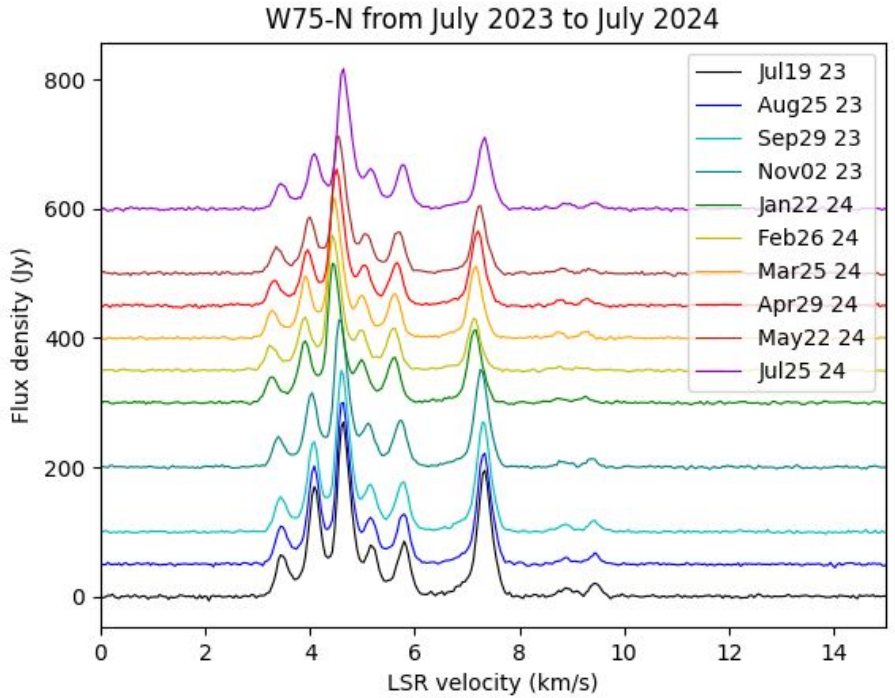
# 6.7 GHz methanol maser monitoring

Medicina (7/2023-7/2024, 10/2025-) and SRT (12/2024-)

monitoring 23 SFRs

Kobak et al. 2025

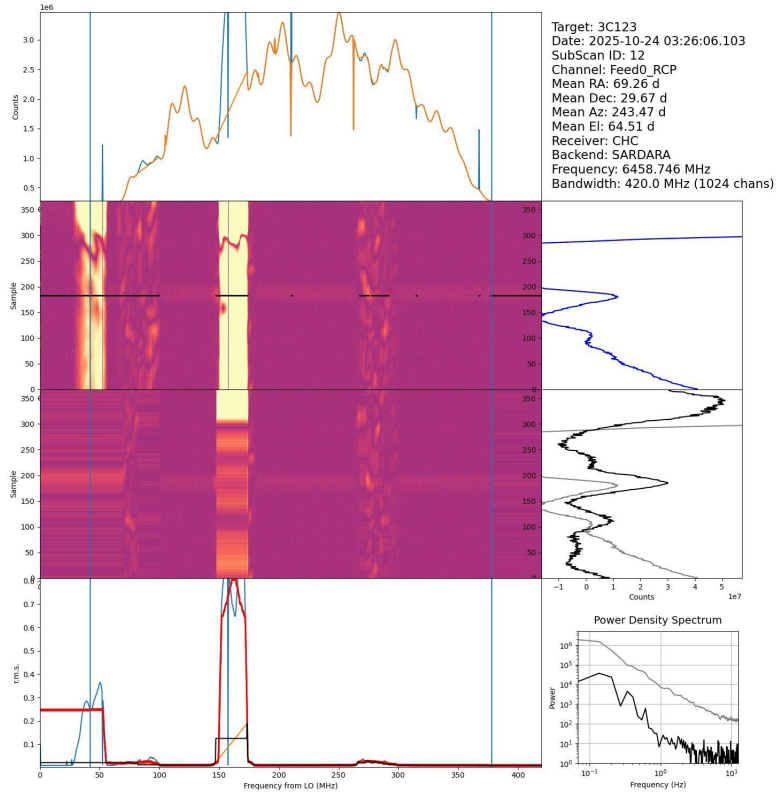


# Non astronomical emission C band

C band is not protected, methanol maser range avoided upon agreement.

3C123 300 MHz continuum, needs flagging!



First results from the

# INAF *tri-band* Maser Monitoring

Someplace sometime in 2027