Interferometric survey of southern class I methanol masers

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Two classes of methanol masers

- Class I methanol (CH_3OH) masers
  - Scattered around YSOs (up to a parsec or so)
  - Many maser spots at arcsec resolution
  - Collisional excitation (e.g. by shocks)
  - Regions of star formation (high & low mass)
  - Common masers: 36, 44, 84, 95 GHz, …
  - Rare/weak: 9.9, 23.4, series at 25, 104.3 GHz

My main interest

- Class II methanol (CH_3OH) masers
  - Located in the nearest vicinity of YSOs
  - Usually just one maser spot at the arcsec scale
  - Radiation excitation (by infrared from YSO)
  - Regions of high mass star formation only
  - Common masers: 6.7, 12 GHz
  - Rare/weak: 19.9, 23, 28, 85/86, 37/38, 107, 108 GHz

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ATCA – 36 and 44 GHz

Class I methanol masers from two different transition series

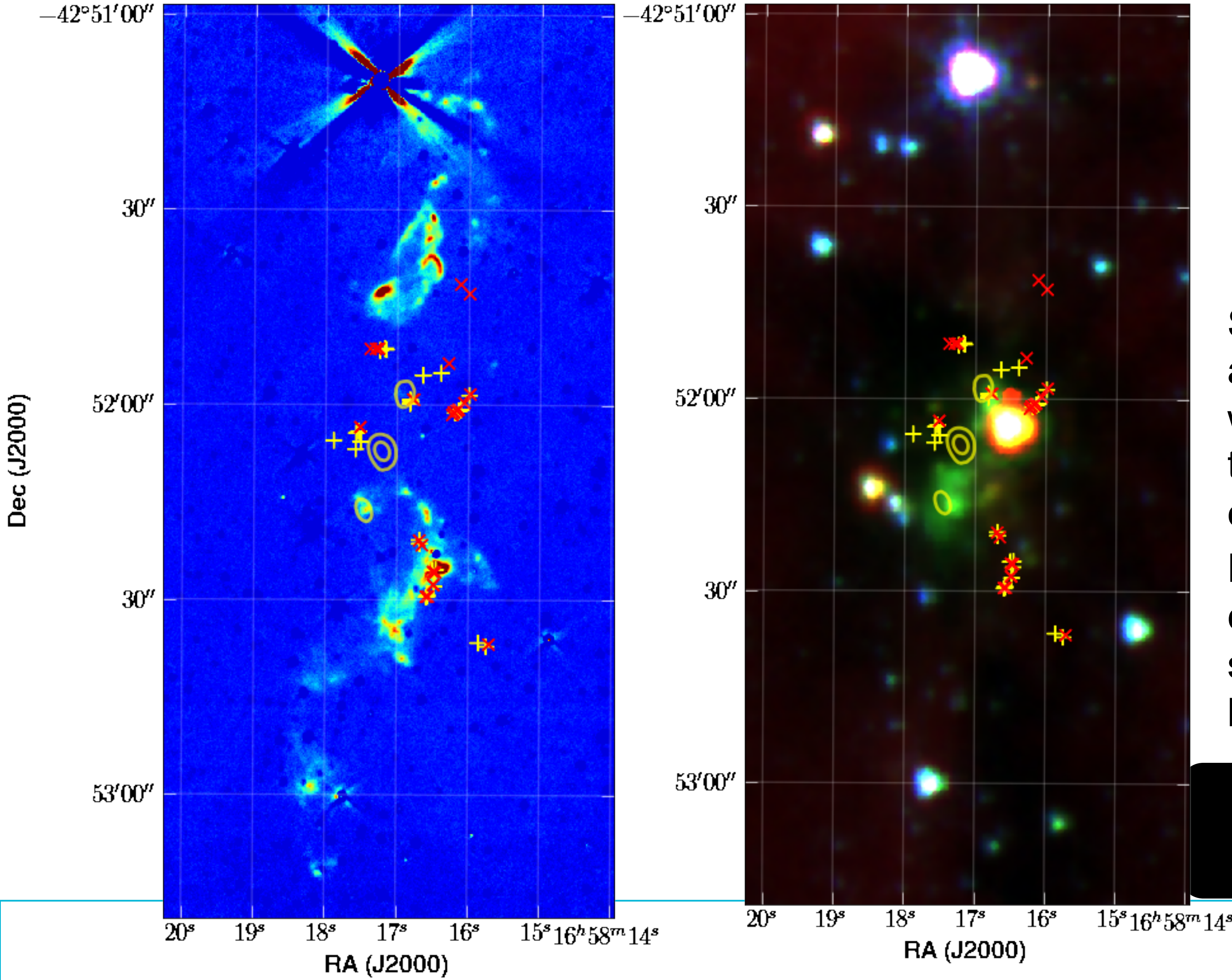
ATCA 36 and 44 GHz survey

- Masers reported by Slysh et al. (1994), Val'tts et al. (2000) and Ellingsen (2005) which are located south of -35^{o} declination; 71 unique targets in total.
- Largest interferometric survey to date, the first of this kind in the Southern hemisphere, the first interferometric survey at 36 GHz

- Most sources show complex spatial and kinematic structure
  - First, we decomposed all emission into a collection of Gaussians in the spectral domain (each with a position measurement assuming point source)
  - Then, we grouped the Gaussians co-located in both position and velocity within 3σ (referred to as *groups* later on)
  - More than 85% of such *groups* are simple (i.e. just one Gaussian)
- In total, there are 740 groups at 36 GHz and 817 groups at 44 GHz
- Only 292 (or ≈23%) of them are common *groups* for both transitions

G343.12-0.06 (IRAS16547-4247)

See Voronkov et al. (2006, MNRAS, 373, 411) for more info on the source



These are new results from the 36/44 GHz ATCA survey

Some maser spots are associated with the outflow traced by H_2 emission

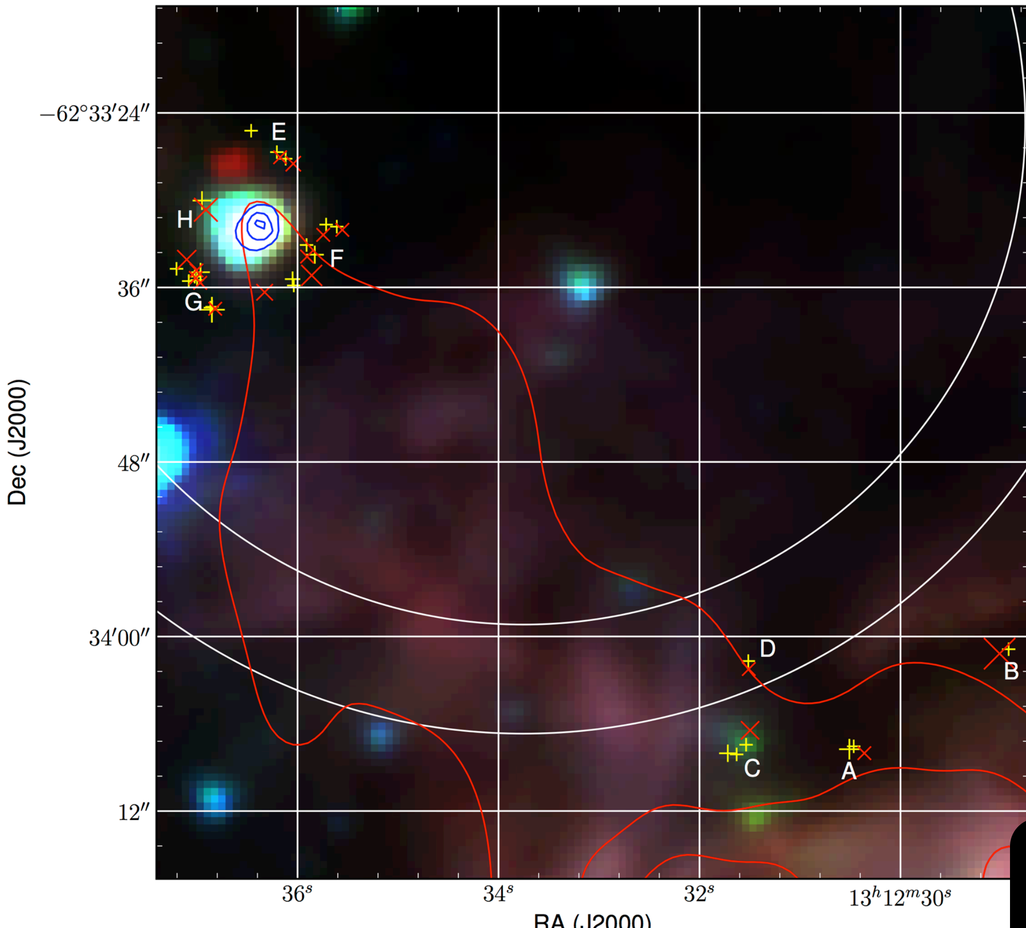
Rare masers are confined to a single spot near the brightest H_2 knot

+ 44 GHz masers
x 36 GHz masers

H_2 image from Brooks et al. (2003, ApJ, 594, L131); See also ALMA data in Higuchi et al. (2015, ApJL, 798, L33)

Association with expanding HII regions?

Class I masers may be associated with ionisation shocks driven by an expanding HII region into surrounding molecular cloud, not just outflows. The analysis was originally based on rare 9.9-GHz masers (see Voronkov et al., 2010, MNRAS, 405, 2471), but 36/44 GHz masers can illustrate it better.



G305.37+0.21

Red contours: 18-cm radio-continuum from MAGMO

Blue contours: 3-cm spatially filtered radio-continuum (Hindson et al., 2012, MNRAS, 421, 3418)

Background: 3-colour GLIMPSE image

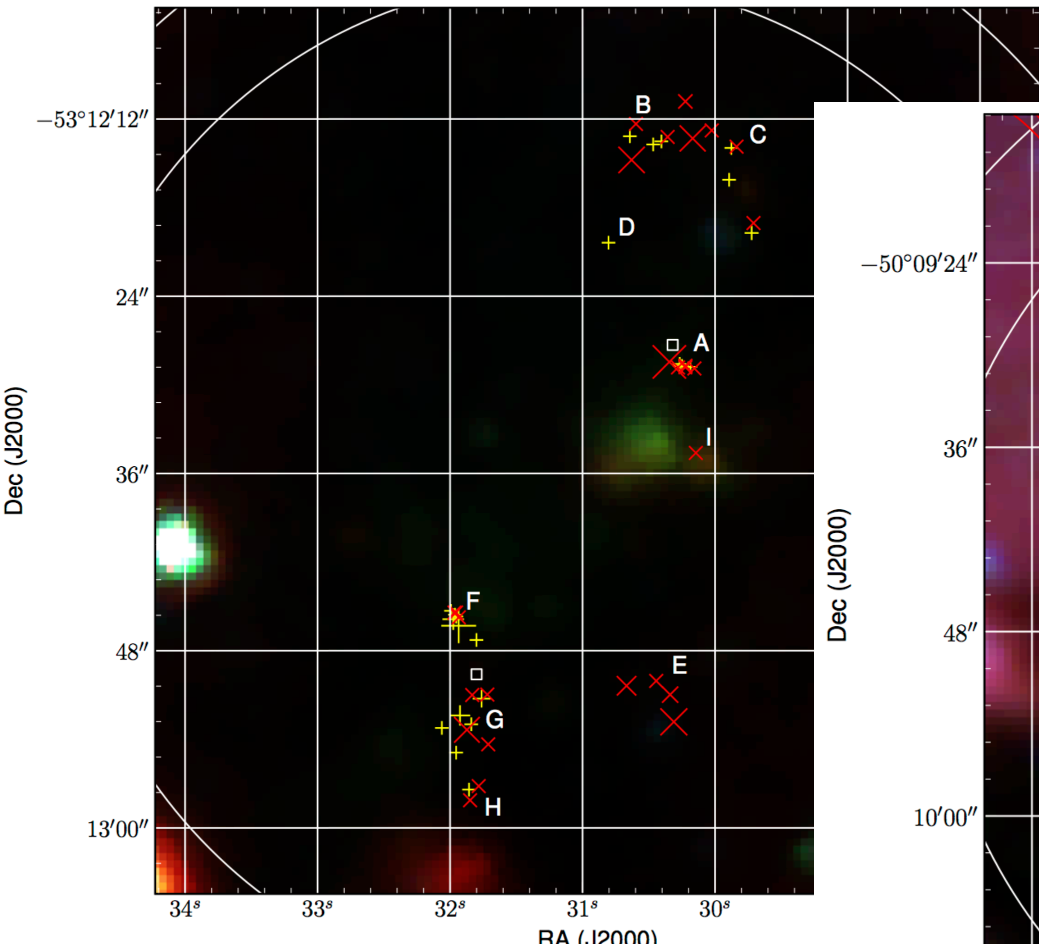
White circles: 50% sensitivity region at 36 and 44 GHz

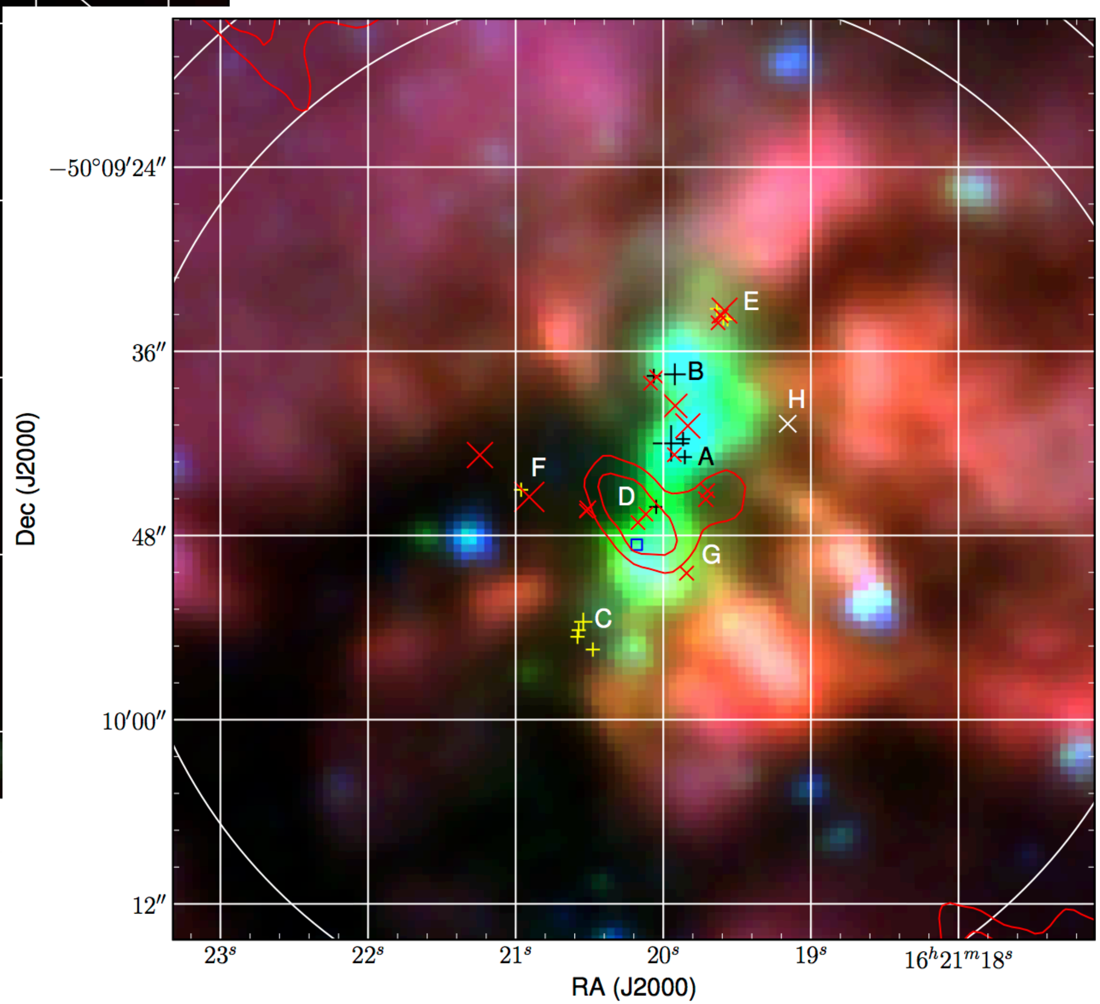
+ 44 GHz masers

x 36 GHz masers

G329.03-0.20 (left) and G333.47-0.16 (right)

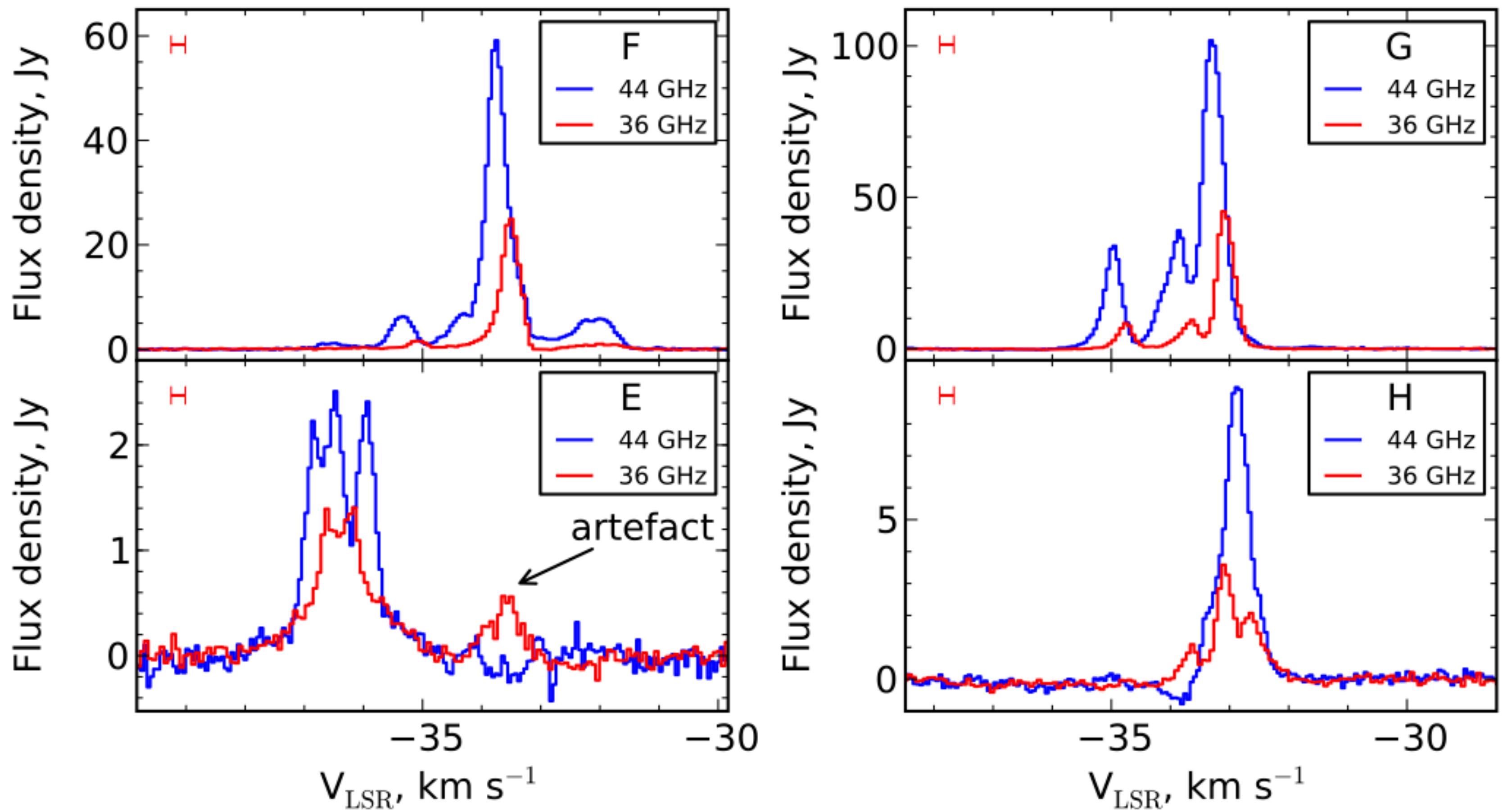
Transitions from different transition series are highly complementary





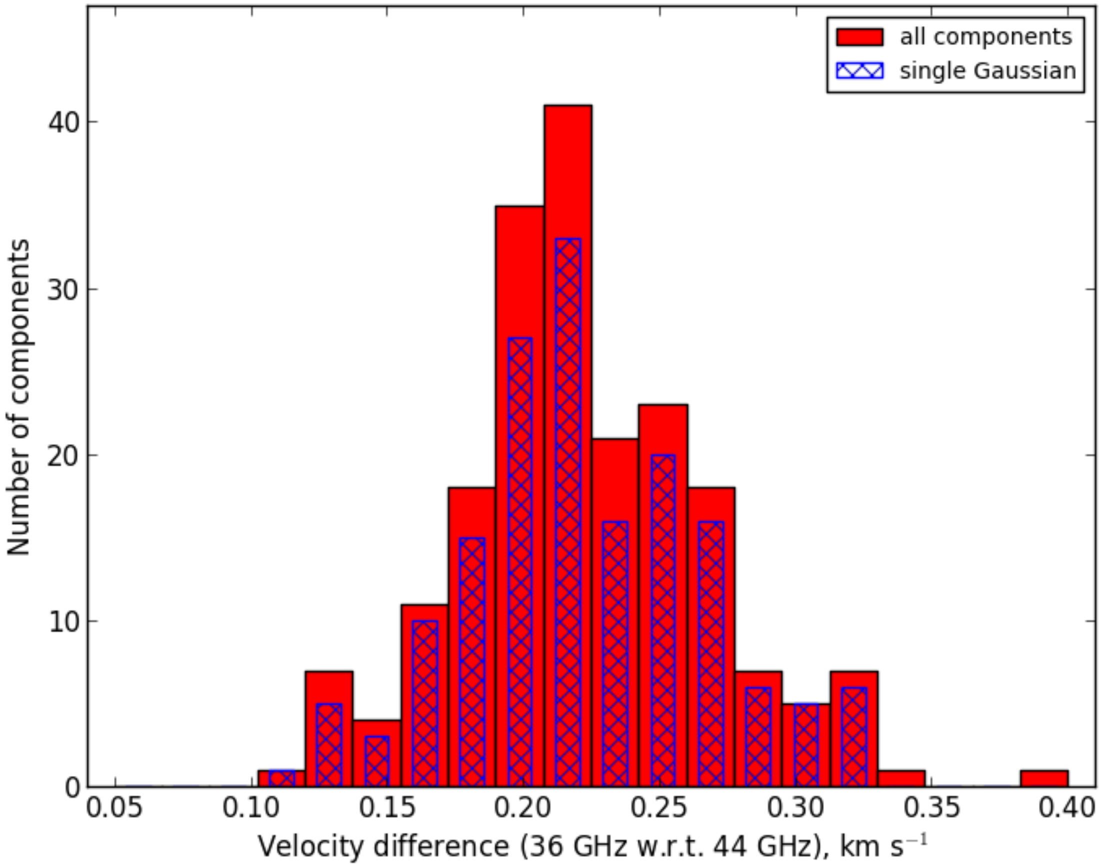
Velocities of 36 and 44 GHz masers

G305.37+0.21 (selected components)



Need statistics over all matching components

Velocity match and rest frequencies



Adopted rest frequencies (from Müller et al. 2004)

44069.41 ± 0.01 MHz

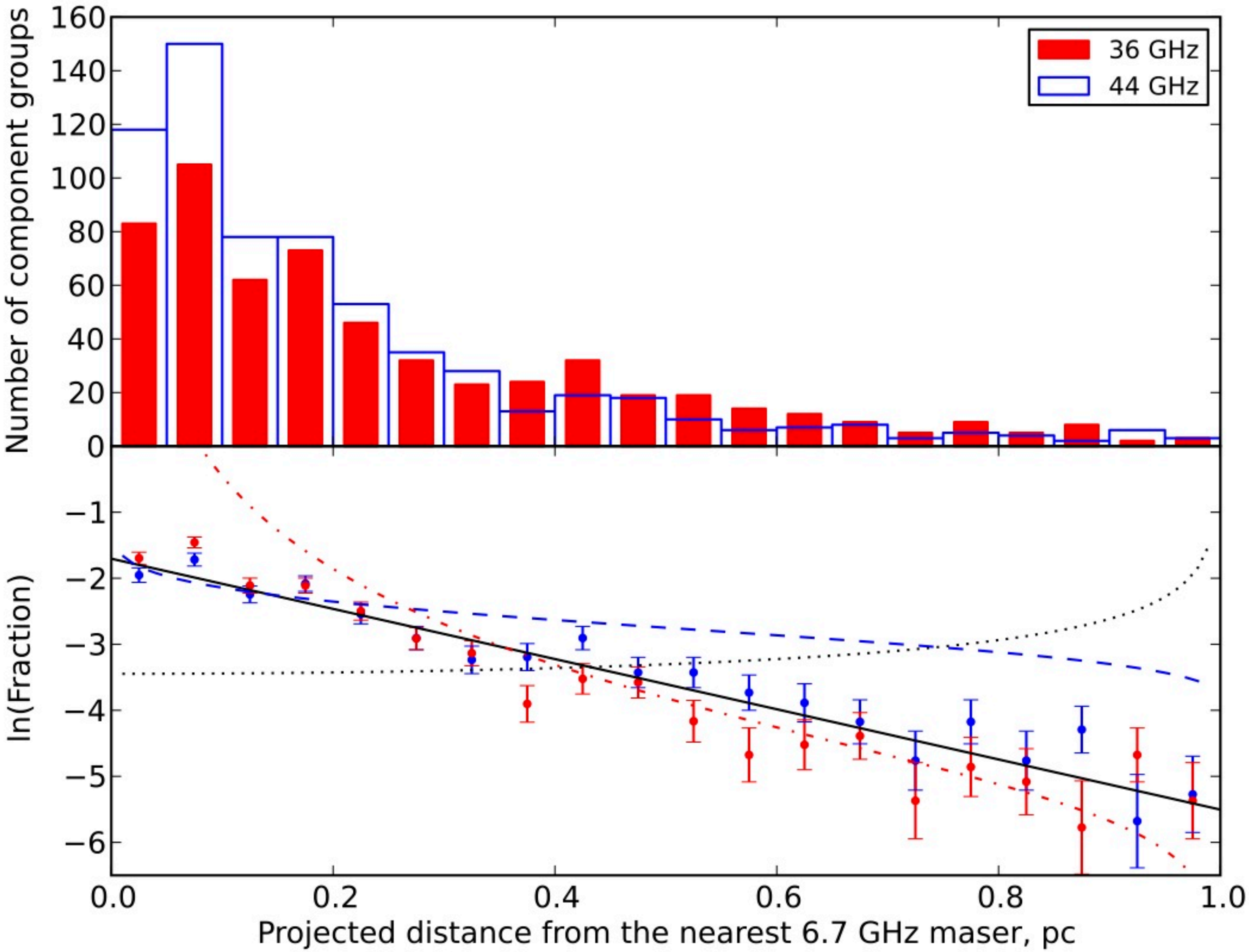
The uncertainty is equivalent to velocity uncertainty of 0.068 km s^{-1} (about the spectral resolution)

36169.265 ± 0.030 MHz

The uncertainty is equivalent to velocity uncertainty of 0.24 km s^{-1}

Velocity difference: 0.22 ± 0.03 km s^{-1} Suggest: 36169.238 ± 0.011 MHz

Distribution of the separations from YSO



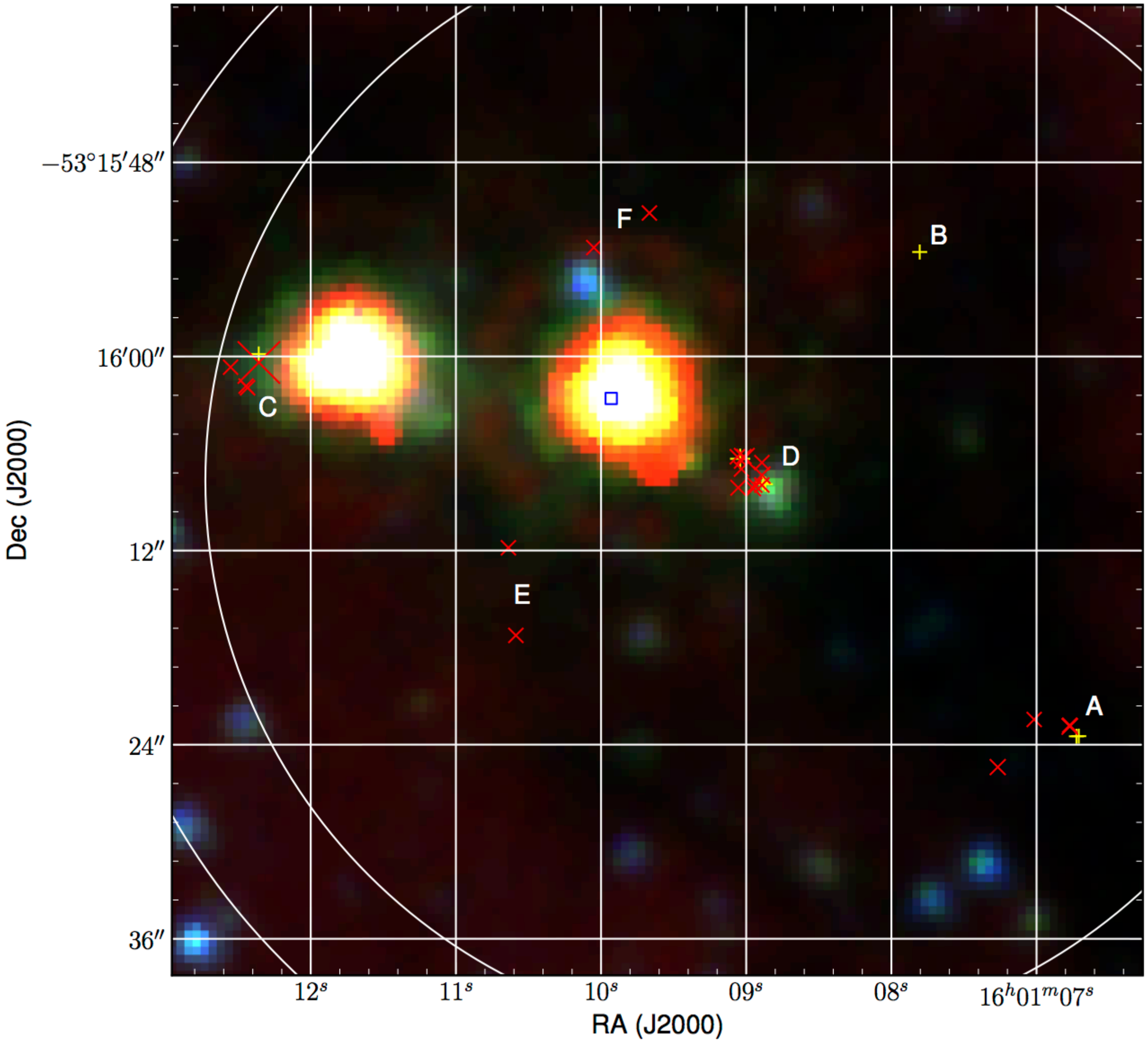
The class II methanol maser at 6.7 GHz traces the YSO location

The distribution is well fitted as an exponential decay with a scale of 263±15 mpc

The same distribution within uncertainties for 36 and 44 GHz masers

However, there might be an excess of detections near YSOs (projected distances about 0.05-0.1 pc)

Spatial spread and near/far distance



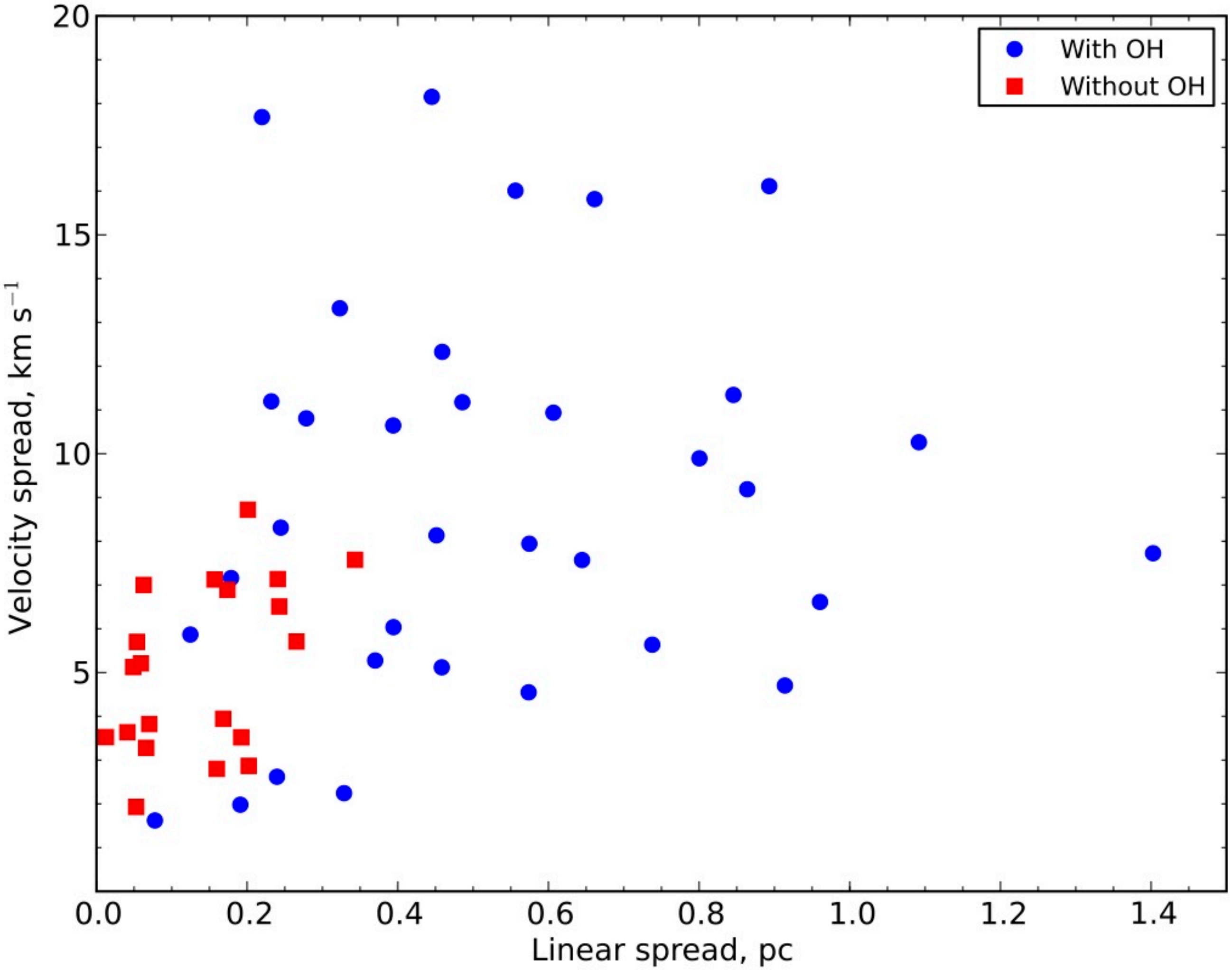
G329.07-0.31

Class I masers can serve as a “statistical ruler” to help with near/ far distance ambiguity resolution

Linear offsets are expected to be well below 1 pc

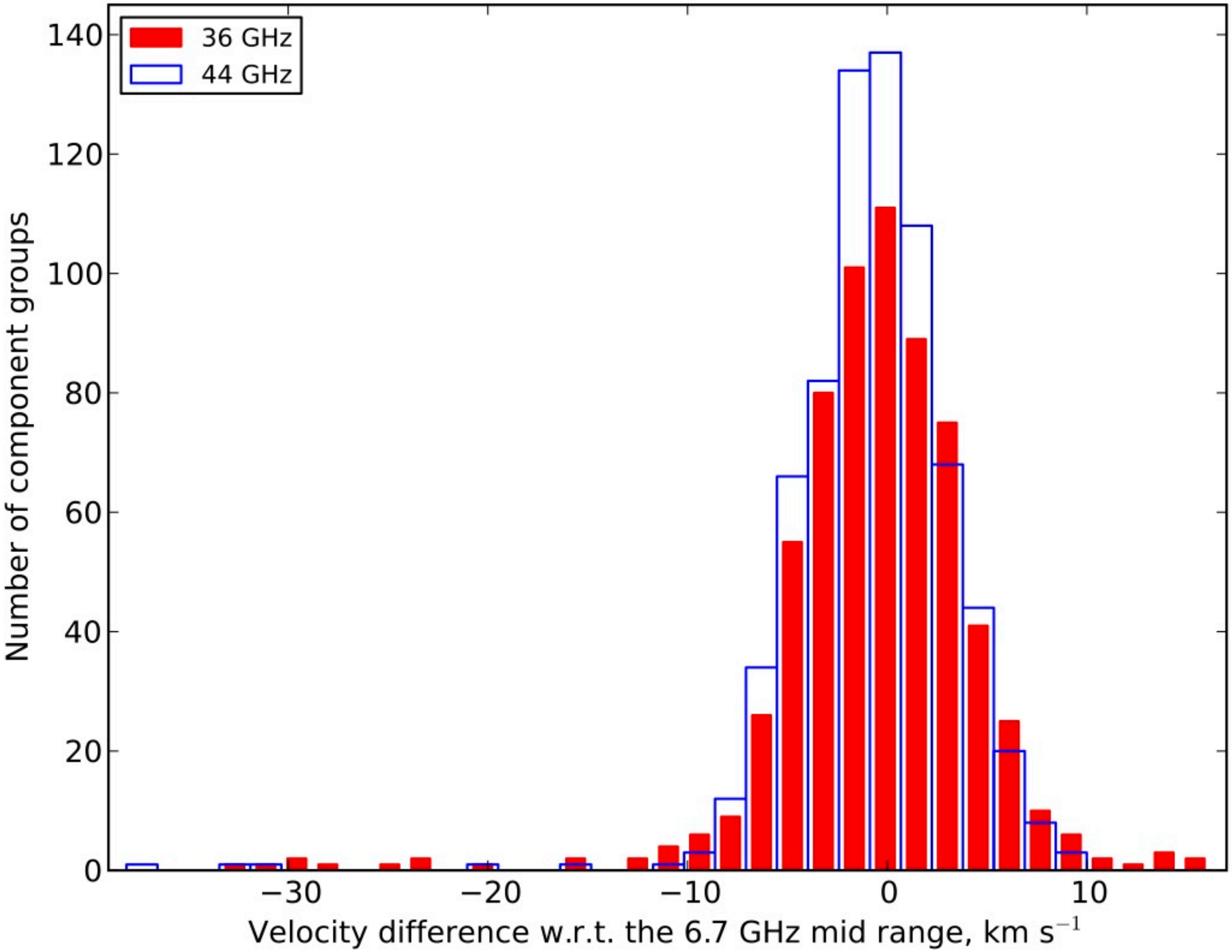
Larger offsets probably mean that a wrong distance has been assumed

Velocity and spatial spread



More evolved sources (with OH masers) have more spread out class I masers, both spatially and in velocity domain

Velocity distribution

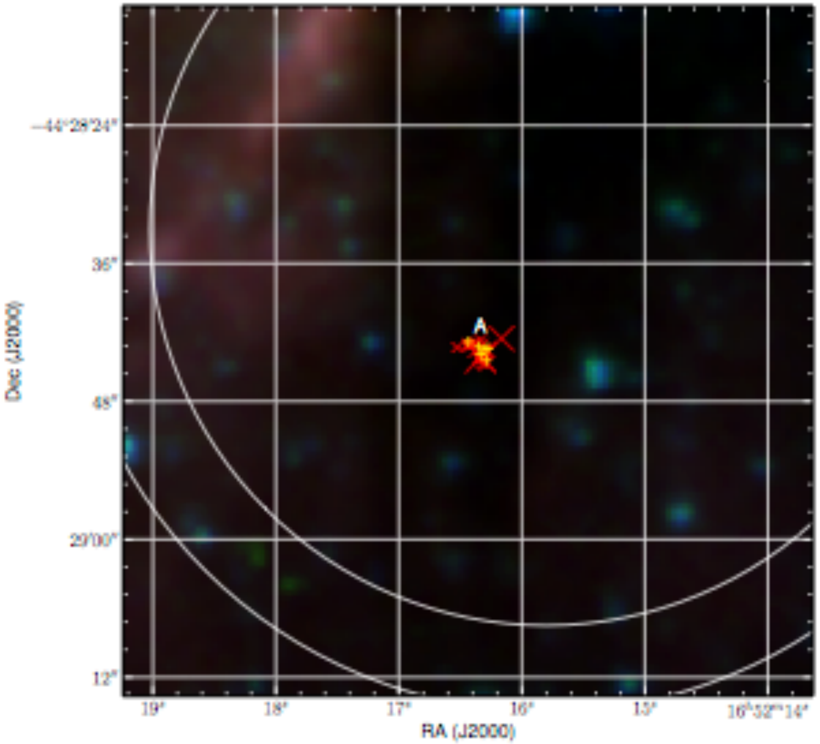


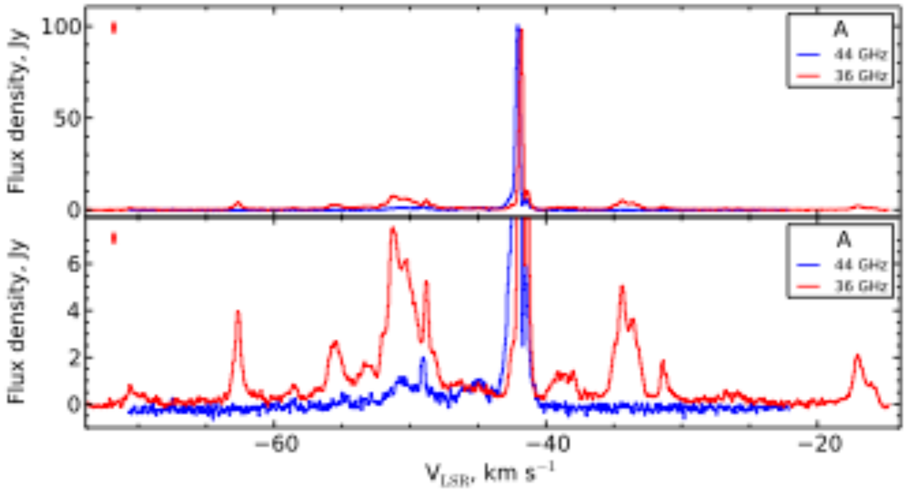
- Middle of the 6.7 GHz velocity range seems to be a good estimate of the systemic velocity
- Small but significant mean
- High-velocity components are blue-shifted and seen predominantly at 36 GHz

36 GHz: mean -0.57±0.06 km s^{-1}, σ=3.65±0.05 km s^{-1}

44 GHz: mean -0.57±0.07 km s^{-1}, σ=3.32±0.07 km s^{-1}

G341.19-0.23: 55 km/s velocity spread





- Possible example of a very young source
  - Associated with an infrared dark cloud
  - No other masers detected (although constraint on the H_2O maser is quite weak)

Summary

- Studies of different transitions are very complementary
  - Filling the dots in morphology, high-velocity features
  - Distribution of projected offsets of class I masers from YSOs traced by the 6.7 GHz methanol masers falls off exponentially with the scale of 263±15 mpc
  - The velocity distribution w.r.t the middle of velocity range of associated 6.7-GHz maser is Gaussian (with the exception of high-velocity features) . Mean has a small but significant blue-shift offset of -0.57 km/s (uncertainties are 0.06 and 0.07 km/s at 36 and 44 GHz, respectively). The standard deviations are 3.65±0.05 and 3.32±0.07 km/s, respectively.
- Outflow shocks vs. shocks caused by other mechanisms
  - Some class I masers may be caused by expanding HII regions
  - Implications for maser-based evolutionary sequence

For more details see Voronkov et al. (2014, MNRAS, 439, 2584)

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Thank you

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