Class II 6.7 GHz methanol maser and early stage of HII regions

Puzzles of Star Formation II

Ringberg castle

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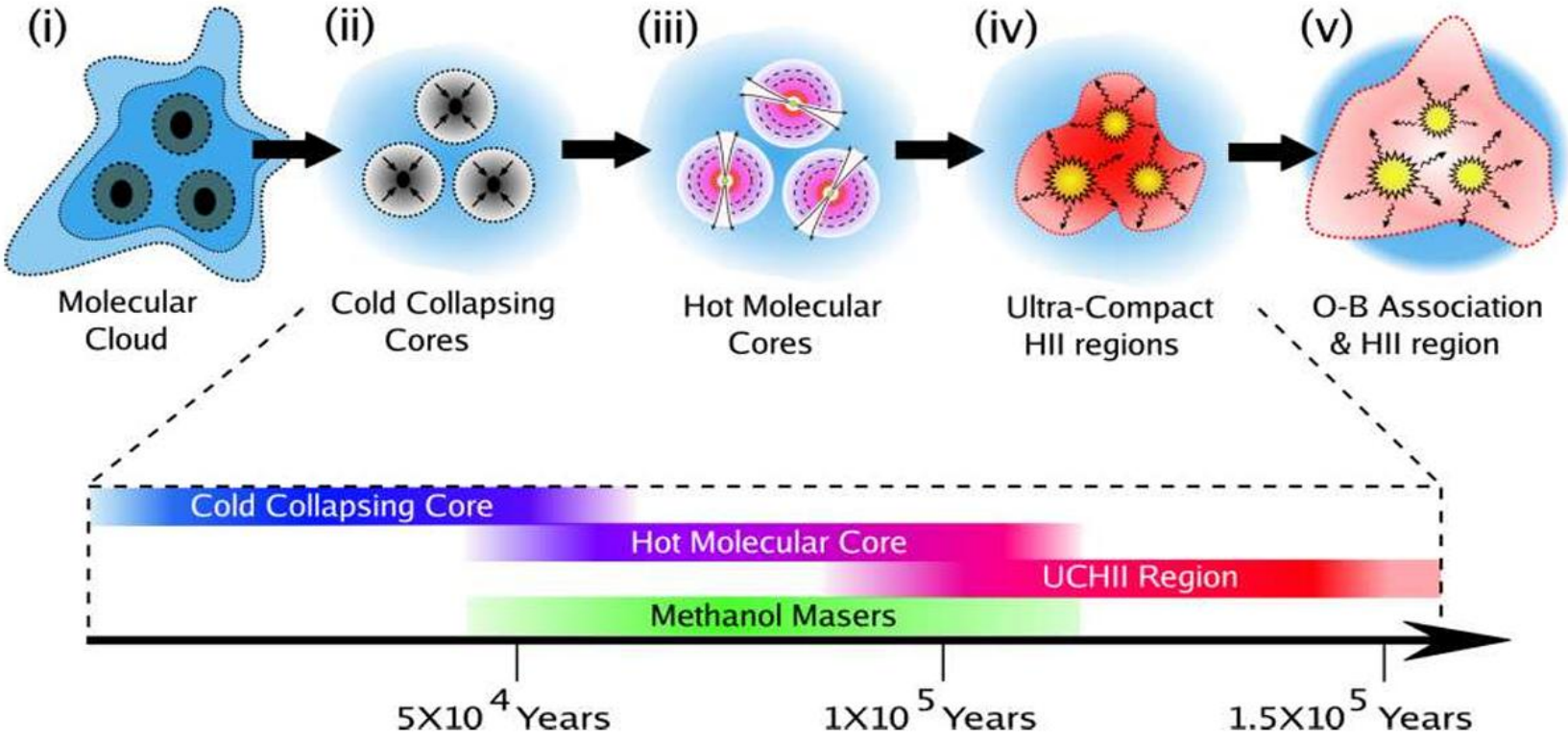
RGB image of G011.909+0.73:- R: Radio, G: MIPSGAL 24 µm, B: GLIMPSE 8 µm

Methanol Maser and HII regions



- Class II 6.7 GHz methanol maser appears during hot core phase of high mass star formation.
- Lifetime of 6.7 GHz methanol maser ~ 3 X 10^4 yr (de Villiers et al. 2015).
- Lifetime of ultra-compact HII region ~ 10^5 yr.

THE DISCOVERY OF A NEW, VERY STRONG, AND WIDESPREAD INTERSTELLAR METHANOL MASER LINE

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ABSTRACT

We report the first detection of very strong maser emission in the 6.6 GHz $5_1 \rightarrow 6_0 A^+$ transition of methanol toward a large number of star-forming regions. Essentially all 6.6 GHz maser sources found are associated with interstellar OH masers. Toward a number of sources, the 6.6 GHz emission has flux densities of several thousand Jy, exceeding that of any known OH maser. Since all known masers in the 12 GHz $2_0 \rightarrow 3_{-1} E$ transition observationally accessible to us have been found to have 6.6 GHz counterparts, the latter line is undoubtedly a Class II methanol maser transition. In all cases the 6.6 GHz luminosity exceeds the 12 GHz luminosity, often by large factors. Toward Class I methanol maser regions, the 6.6 GHz line is observed in absorption, as has been predicted by pumping models for this variety of sources.

Class I methanol maser sources, we also searched for the line toward Class II regions. The excitation of Class II methanol masers is poorly understood, and there seems to be no reliable way to predict maser action in any transition for these sources. Of course, *if* a centimeter-wave methanol transition *is* inverted by some process in a Class II region, this may lead to strong maser emission, because in these sources the methanol-emitting region appears frequently, if not always, projected against ultracompact H II regions whose continuum emission is optically thick at lower radio frequencies and can in principle be amplified by the masers. The strongest and most widespread Class II maser transition detected in the past is the 12

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Question: Are all 6.7 GHz methanol masers associated with the radio continuum emission? And does the physical properties of maser and ionized gas relate with each other?

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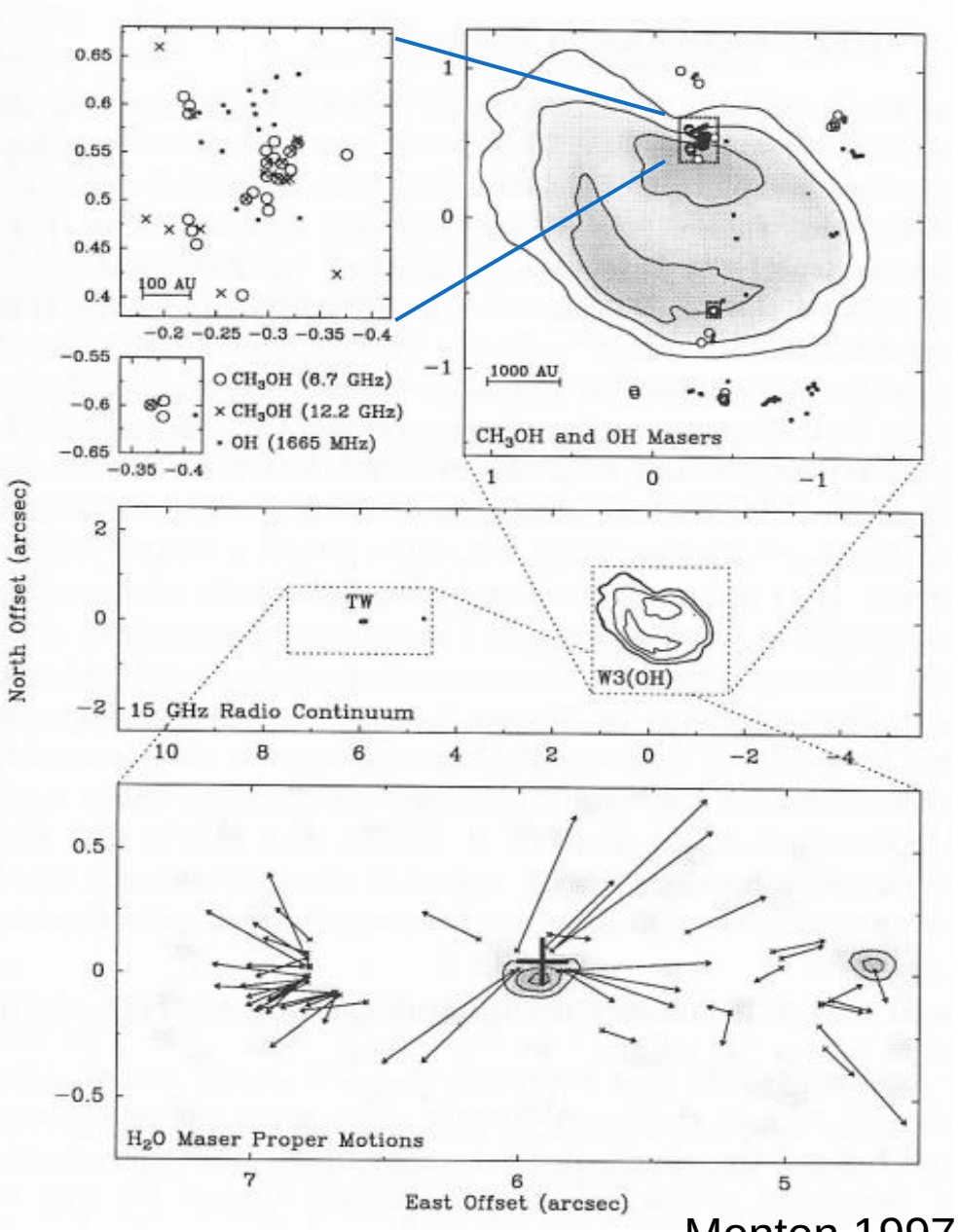
W3(OH) region as an example



Menten 1997

Pumping mechanism and variability

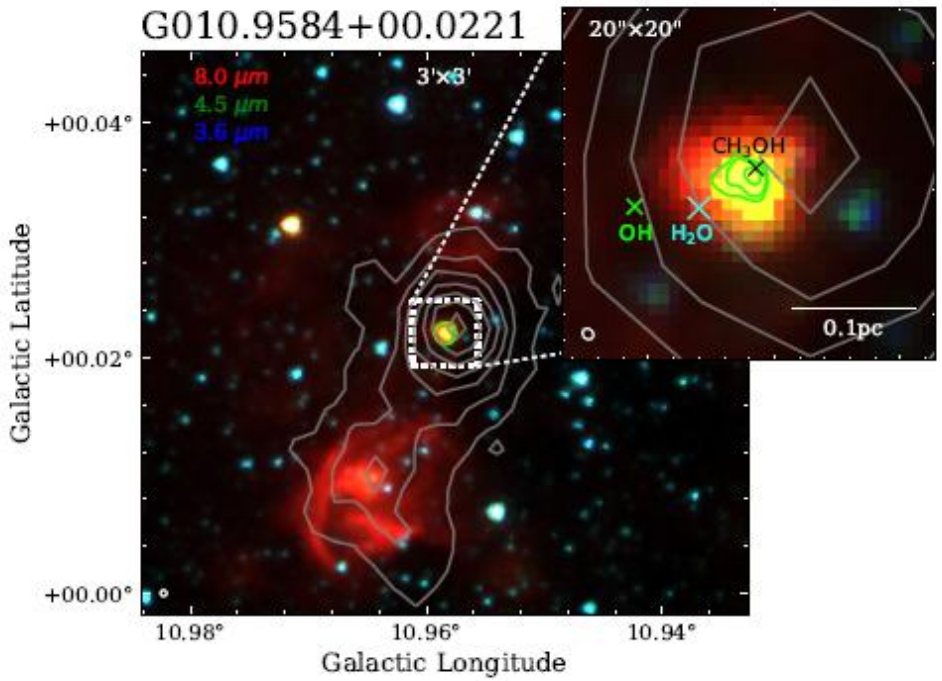
- Menten (1991) suggested to classify methanol masers into two groups, Class I and Class II.
- Class I seem to be collisionally pumped (Cragg et al. 1992) → outflows/jets and the quiescent ambient material.
- Class II are believed to be radiatively pumped specifically by absorption of infrared and far-infrared emission.

Class II 6.7 GHz methanol maser variability

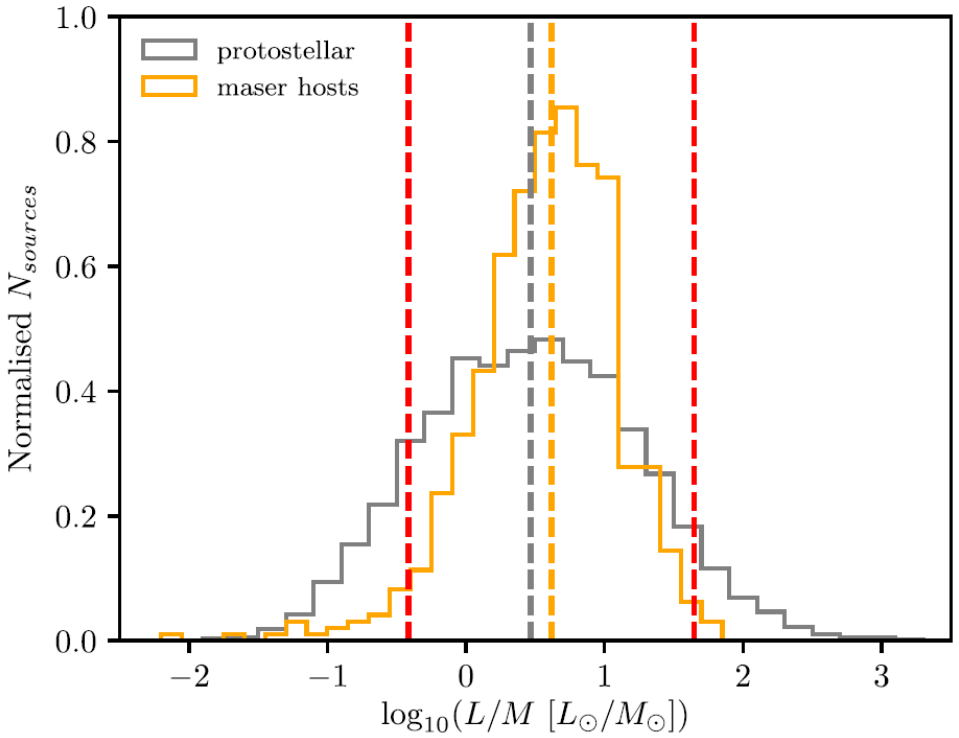
What causes this variability in the methanol maser?

Early tracer of Star formation

- 6.7 GHz methanol maser exclusively found to be associated with the high mass star forming region (Breen et al. 2013).
- No evidence of 6.7 GHz methanol maser associated with the low-mass star and evolved star.
- This suggest that the maser is the tracer of hot core phase.



Yang et al. 2021

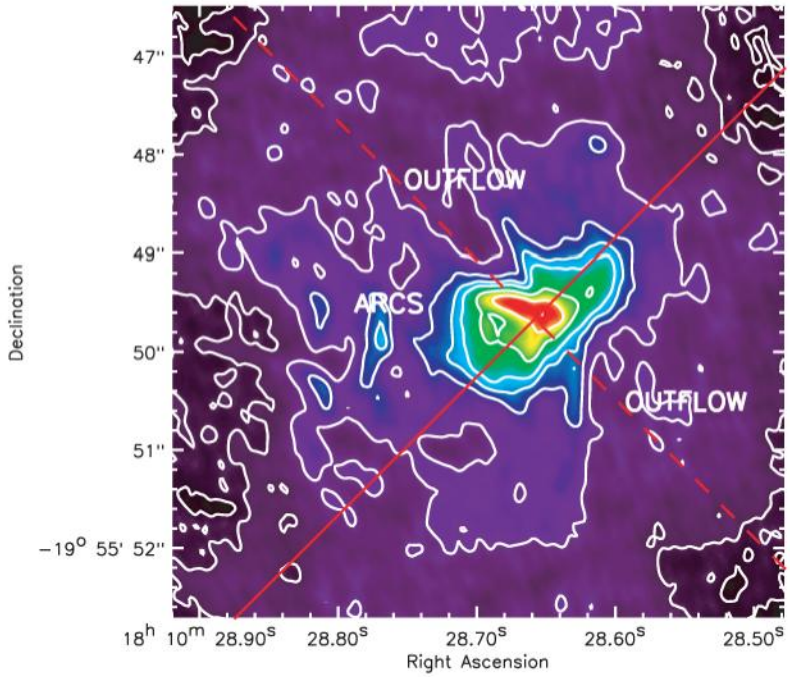


Jones et al. 2020

Early tracer of HMSF

- A revision to the evolutionary scheme for the hot core phase (de Villiers et al. 2015)
  - The earliest phase: outflow develops and grows with no methanol maser present; the infall process heats the dust grains and releases methanol into the gas phase,
  - Both methanol maser and outflow are present and detectable (sufficient column density for methanol maser to turn on),
  - Methanol maser emission disappears while the outflow remains,
  - Outflow switches off, only the UCHII region remains.

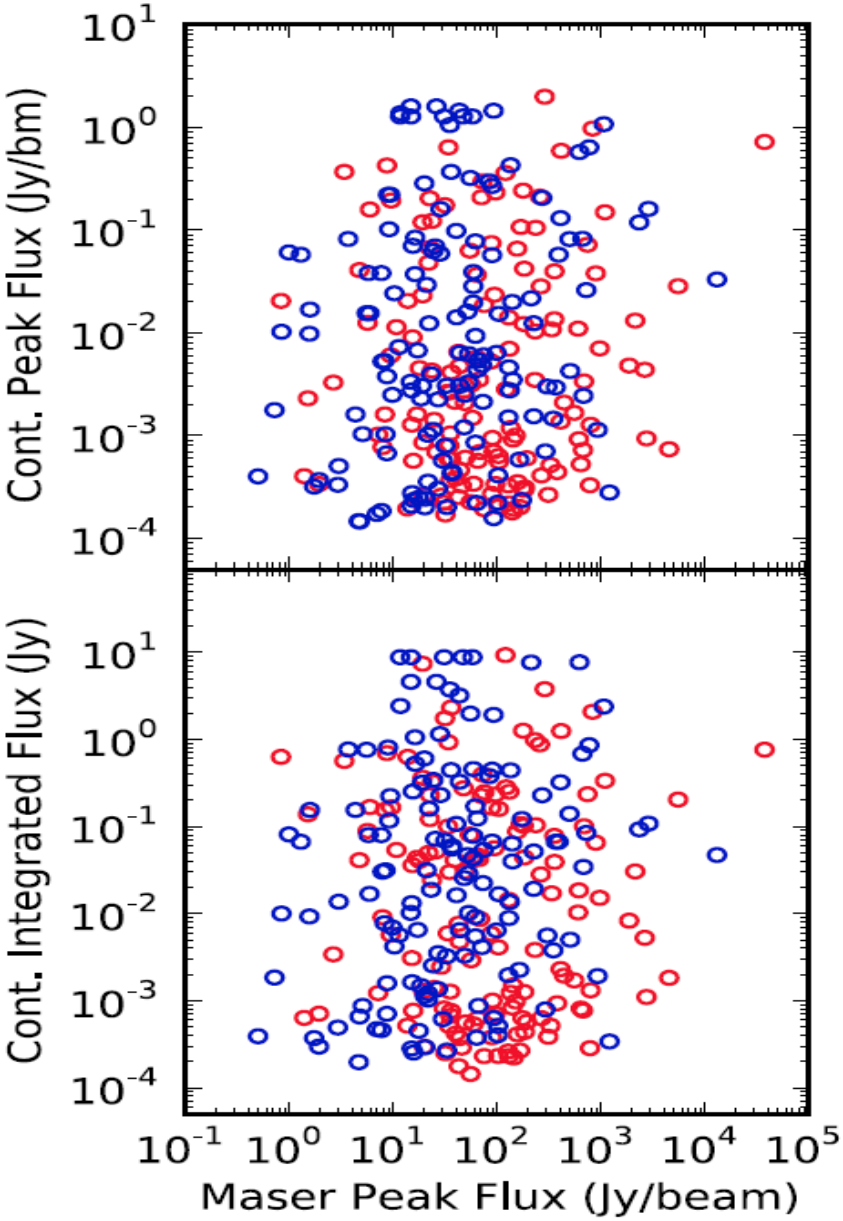
Keto et al. 2006



Confinement of hypercompact HII regions

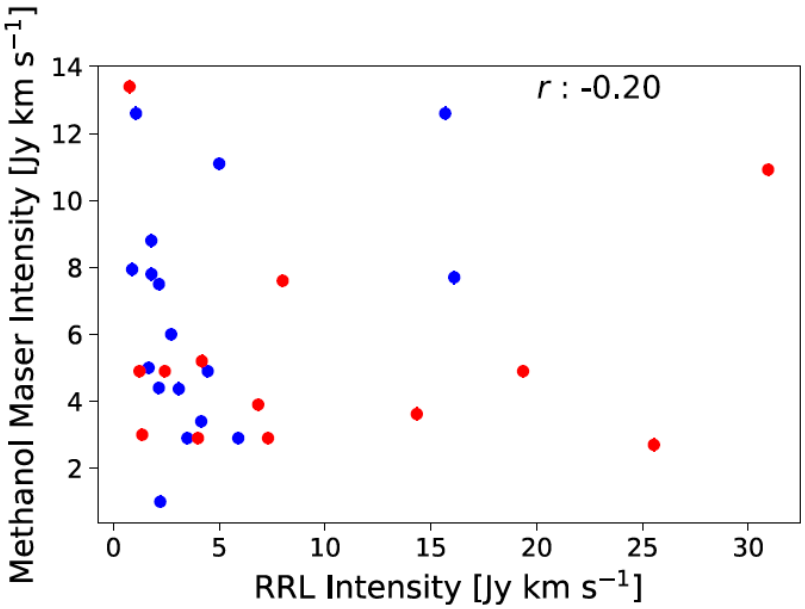
- **Accretion confinement? (keto et al. 200,2007..)**
- **Pressure confinement? (Khan et al. in prep)**

Methanol maser association with radio continuum



Hu et al. 2016

- 30% of methanol masers are found to be associated with radio continuum at a sensitivity of 45 µJy/beam (Hu et al. 2016).
- Properties of methanol maser does not correlate with properties of radio continuum and radio recombination line.
- 73% are association with all four band of Hi-GAL survey (Jones et al. 2020).

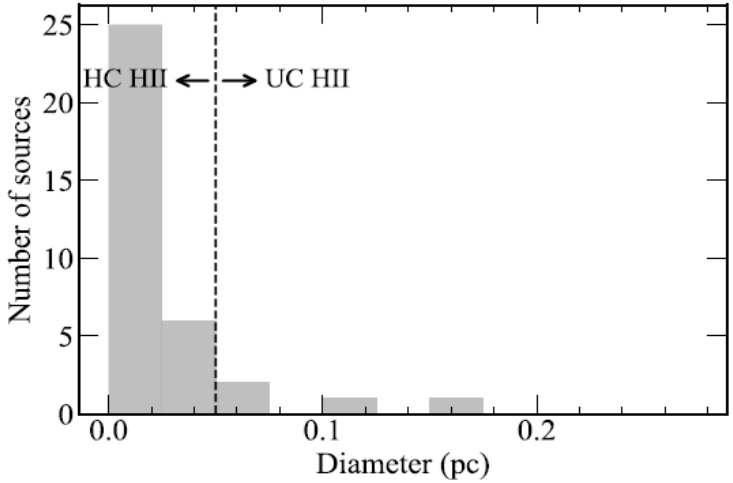


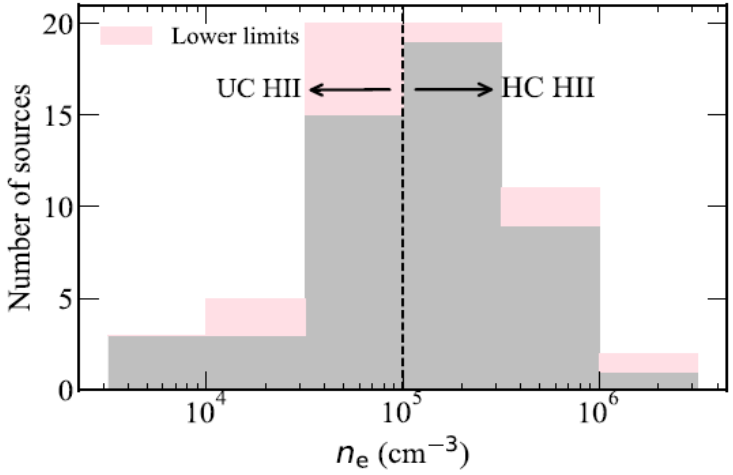
Khan et al. 2024

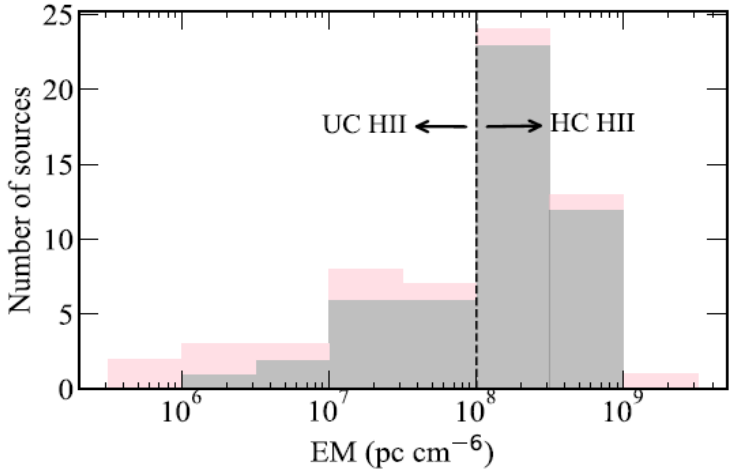
Search for hypercompact HII regions

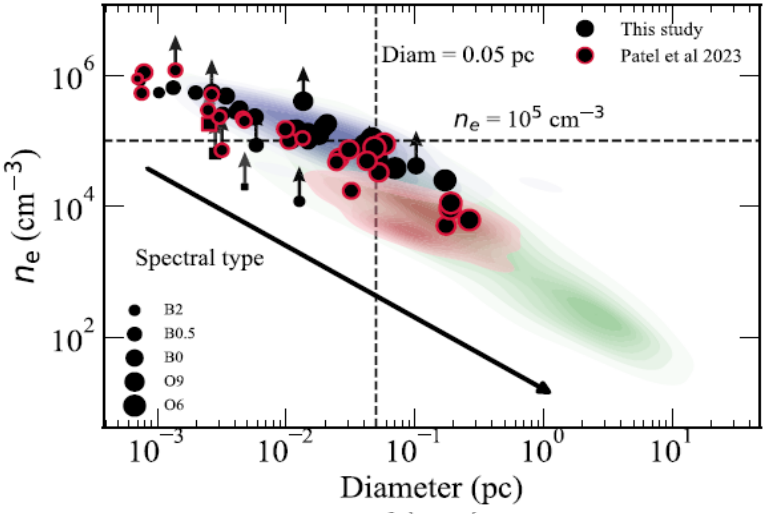
- Patel et al. 2024, observed 335 methanol maser site and found that 42 radio compact source associated with them at sensitivity of ~ 0.1 mJy/beam at 0.5 arcsec.

- Out off these 42 sources, they identified 20 hypercompact HII regions, 9 intermediate objects, 3 ultracompact HII regions, and 3 radio jet candidates.





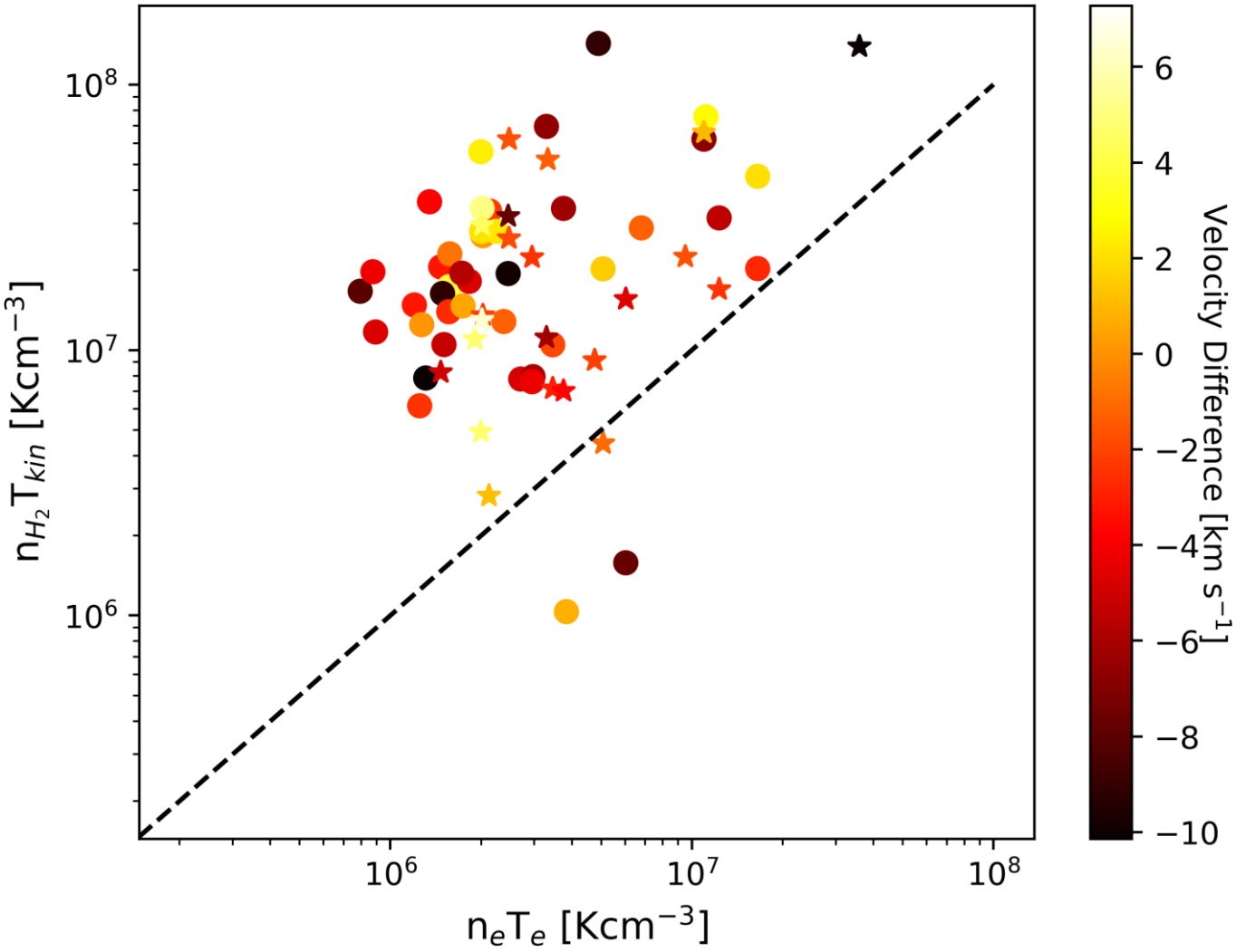




Questions?

Where are the radio counterpart of Class II 6.7 GHz methanol maser?

- Are all methanol maser associated with radio emission or not?
- Need to do a deeper and more sensitivity search?
- Is it optical depth effects, do we need to use higher frequency observations?
- Will next generation telescopes such as ngVLA help us in finding newer hypercompact HII regions?


10^8
10^7
10^6
$n_{H_2} T_{kin}$ [Kcm^{-3}]
10^6
10^7
10^8
$n_e T_e$ [Kcm^{-3}]
6
4
2
0
−2
−4
−6
−8
−10
Velocity Difference [km s^{-1}]