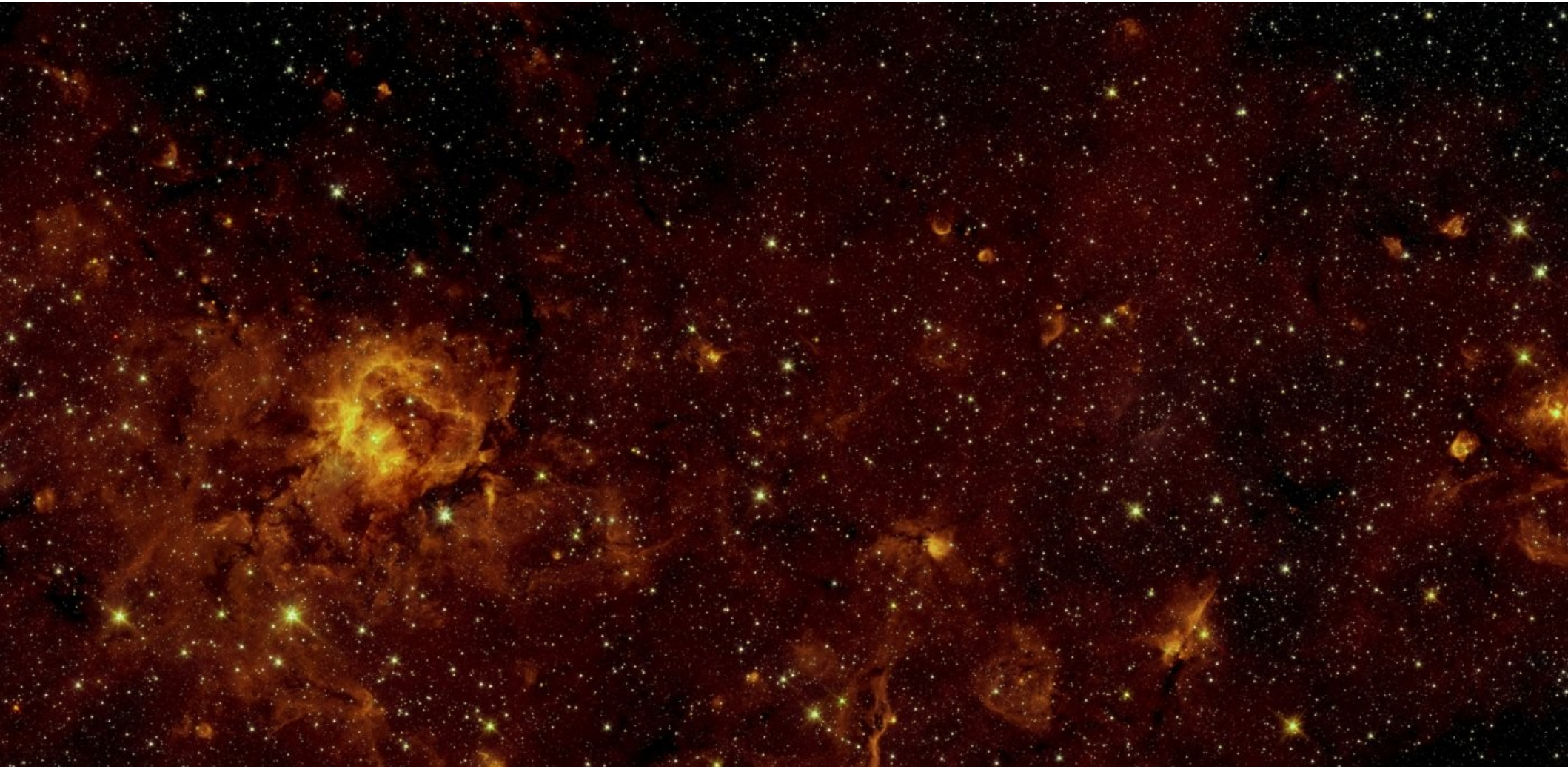
Molecules in Early Massive Star Formation

HMCs and MYSOs and UCHII regions



Cormac Purcell

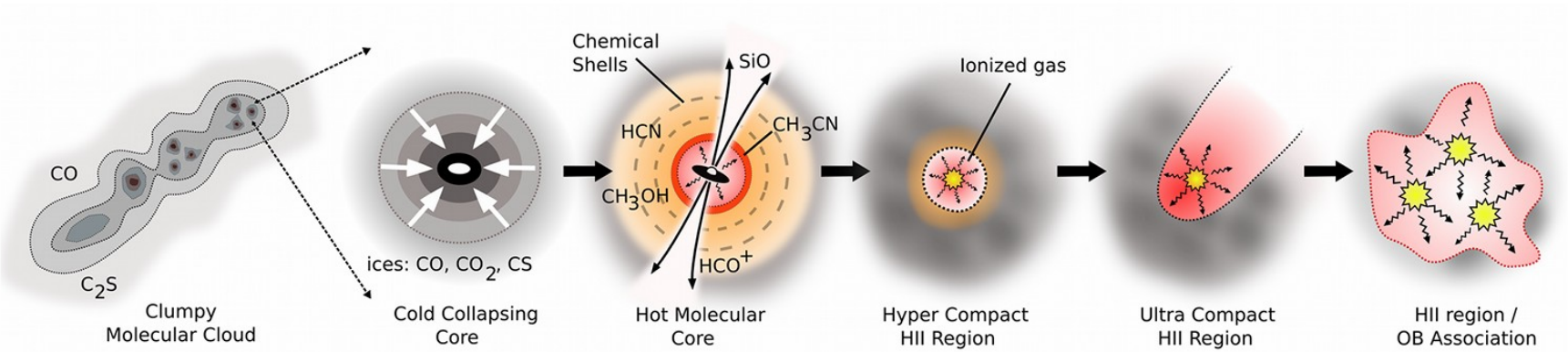
Hypercompact Workshop, September 8th 2010

UNIVERSITY OF LEEDS

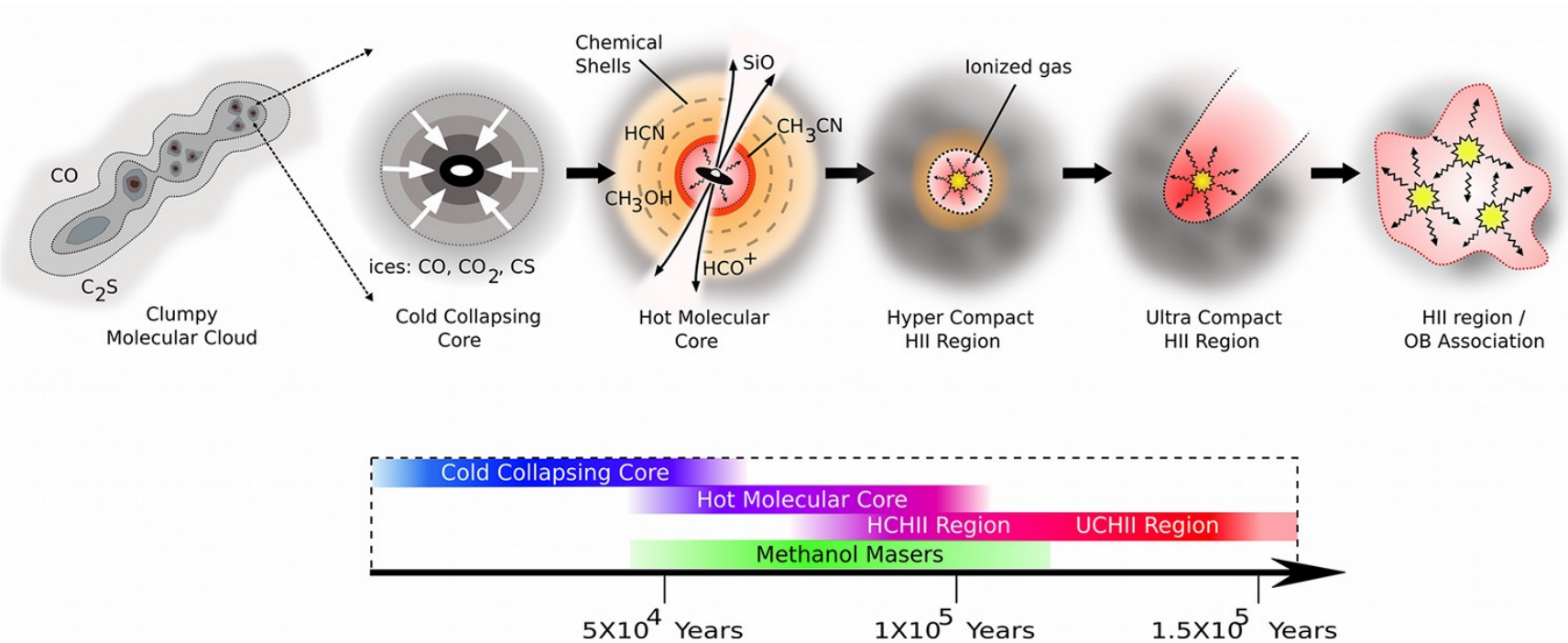
Talk outline

- Brief introduction
- Hot Cores, methanol masers and UCHII regions
- MYSOs from the RMS survey
- Summary

Paradigm for massive star formation



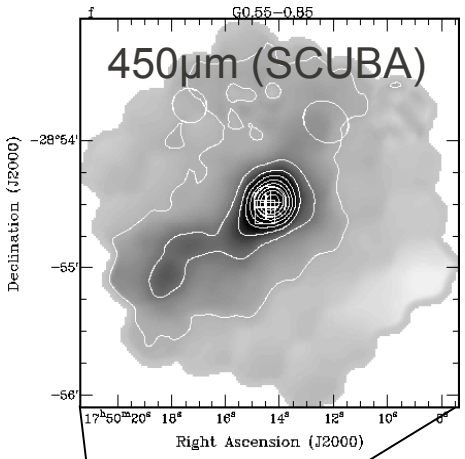
Paradigm for massive star formation



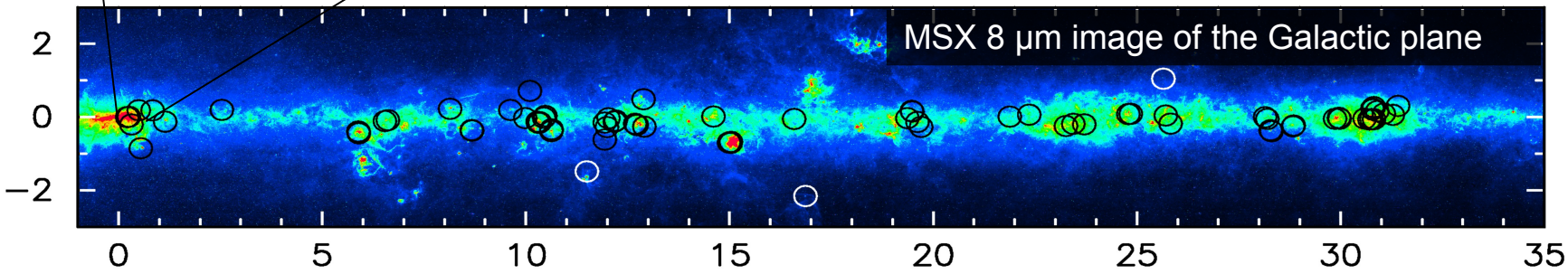
- Discrete phases or more of a continuum?

Mopra hot molecular core survey

Linking 6.7 GHz methanol masers, hot molecular cores and UCHII regions



- 82 methanol maser selected dusty cores
- All associated with thermal continuum emission
  - 1.2-mm (SIMBA, *SEST*), Hill et al 2005
  - 450 and 850 μm (SCUBA, *JCMT*)



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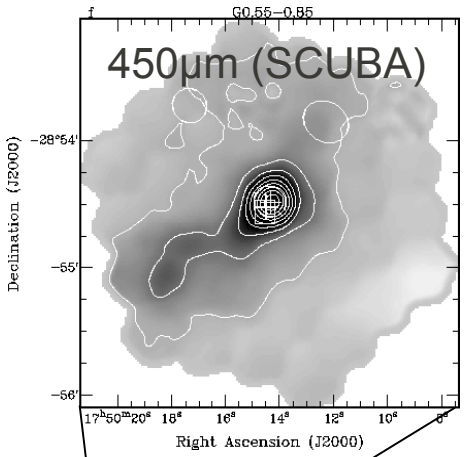

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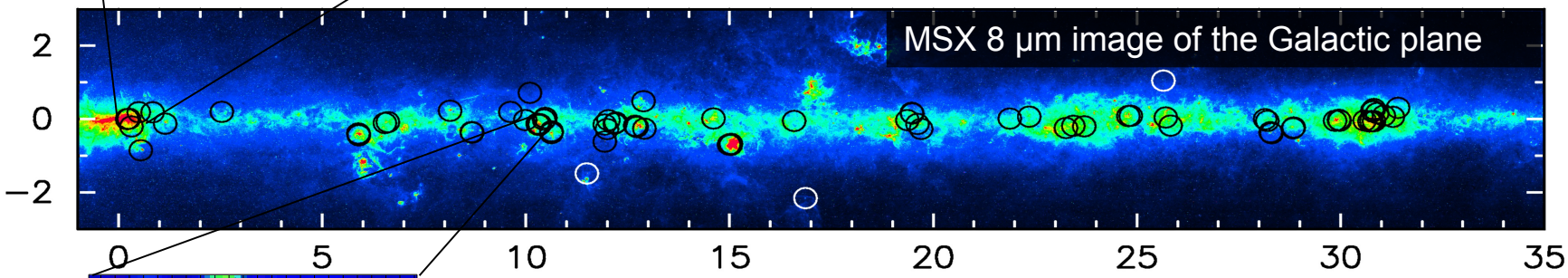
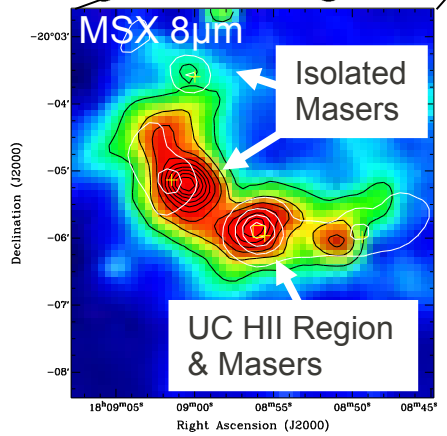




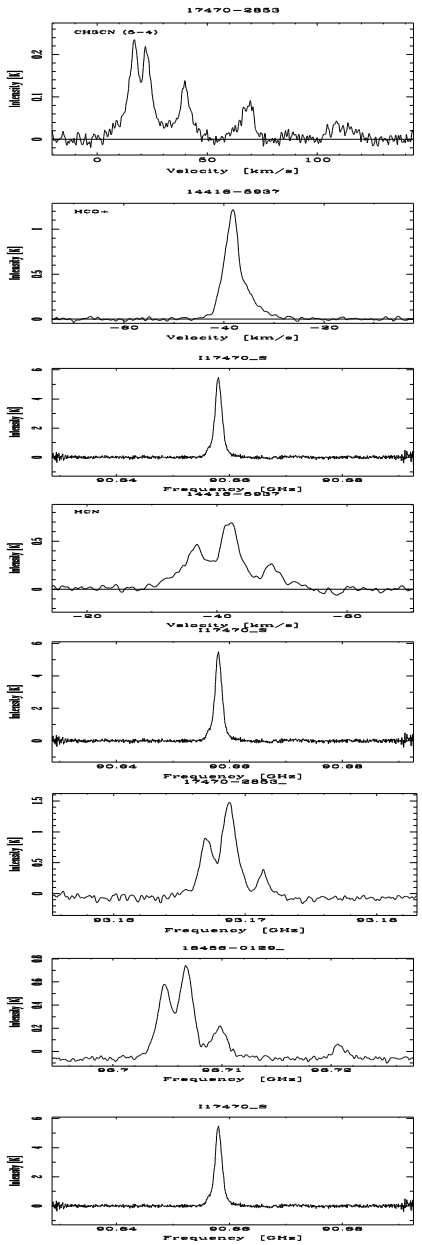
Different tracers – different evolutionary states?

- 19 UCHII regions (traced by 8.7 GHz radio)
- 58 Isolated maser sites
- 5 Dusty cores (seen in thermal emission only)

Walsh et al 1999, 2001, 2003 *Hill et al 2005*

Mopra hot molecular core survey

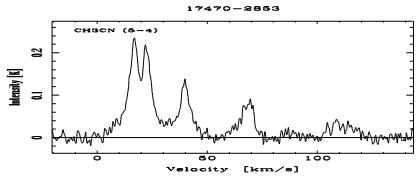
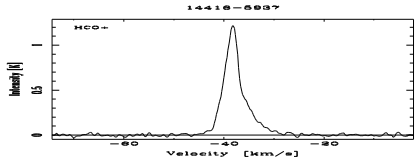
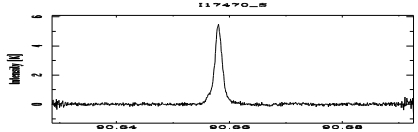
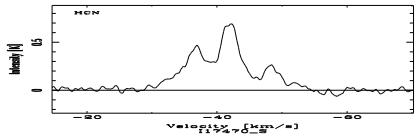
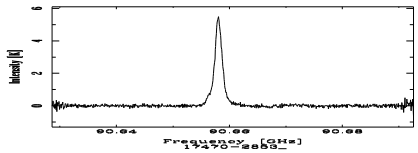
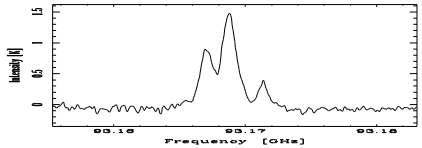
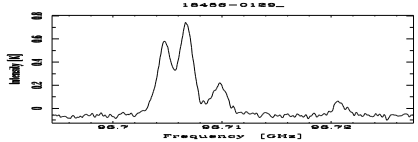
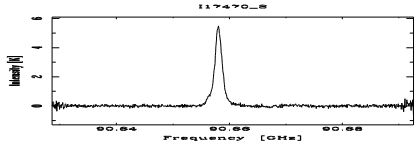
Linking 6.7 GHz methanol masers, hot molecular cores and UCHII regions



Molecule:	Usage:
CH_3CN (5-4) & (6-5)	Rotational Temperatures, Column Density **Positive indicator of hot core chemistry**.
HCO^+ (1-0)	Signatures or outfall & inflow, sensitive to optical depth.
$H^{13}CO^+$ (1-0)	
HCN (1-0)	Abundance ratio dependant on gas temperature, Critical density probes outer envelope.
HNC (1-0)	
N_2H^+ (1-0)	Excellent cool, dense-gas tracer..
CH_3OH (2-1)	“Temperature” probe (non-LTE).
^{13}CO (1-0)	Beam averaged mass, sanity check

Mopra hot molecular core survey

Linking 6.7 GHz methanol masers, hot molecular cores and UCHII regions

	Molecule:	Detections	Detection rate
	CH_3CN (5-4) & (6-5)	58/82	71 %
	HCO^+ (1-0)	82/82	100 %
	$H^{13}CO^+$ (1-0)	80/82	98 %
	HCN (1-0)	82/82	100 %
	HNC (1-0)	82/82	100 %
	N_2H^+ (1-0)	82/82	100 %
	CH_3OH (2-1)	79/82	96 %
	^{13}CO (1-0)	82/82	100 %

Mopra hot molecular core survey

Linking 6.7 GHz methanol masers, hot molecular cores and UCHII regions

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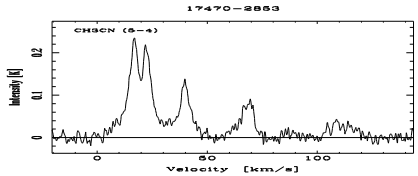	CH_3CN (5-4) & (6-5)	58/82	71 %

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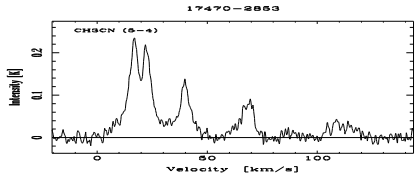

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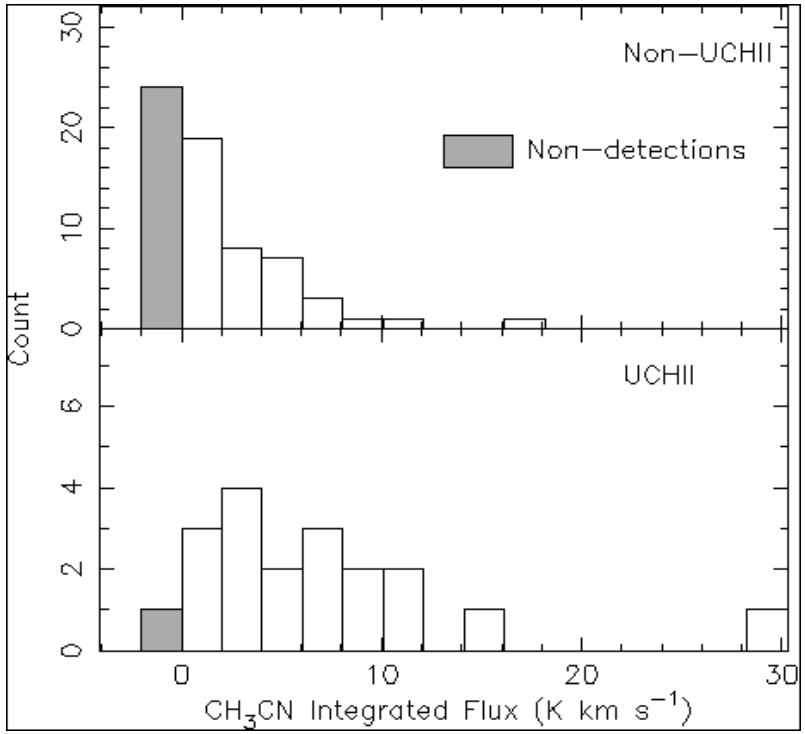
- CH_3CN is **brighter** and **more commonly detected** towards **UCHII regions** than towards isolated maser sources.
  - 18 / 19 UCHII regions
  - 40 / 64 Isolated masers



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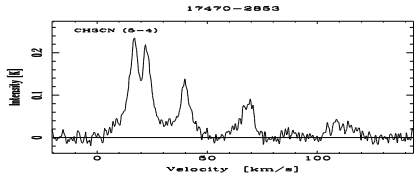

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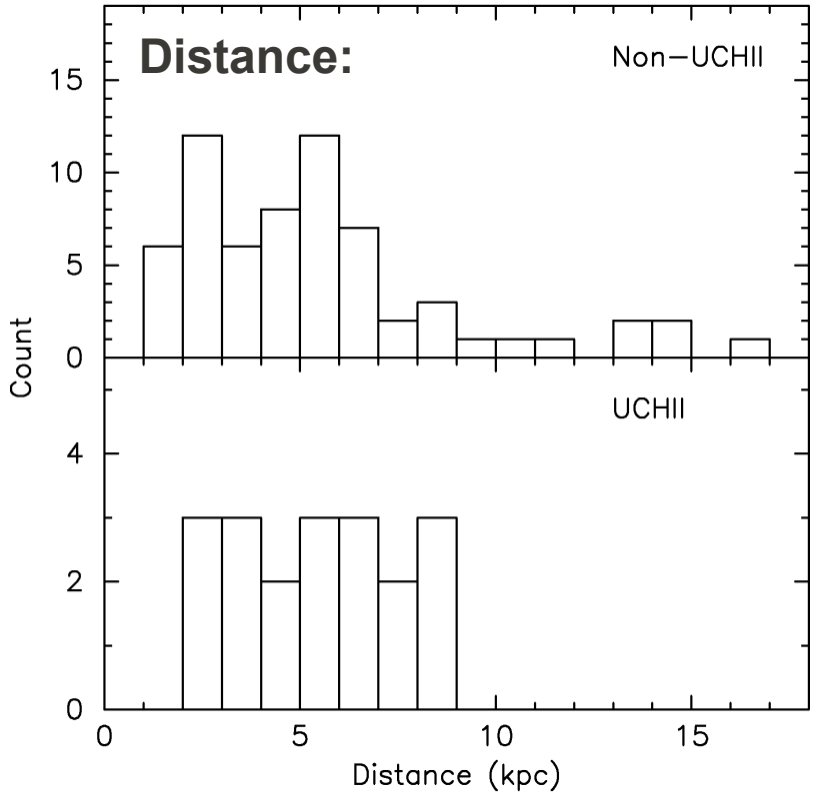
KS test:
Statistic = 0.48, Probability = 0.13%



- Could this be because Walsh '98 failed to detect UCHIIs?

Mopra hot molecular core survey

Linking 6.7 GHz methanol masers, hot molecular cores and UCHII regions

- Could this be because Walsh '98 failed to detect UCHIIs?
- Limiting distance at which a UCHII region is detectable:

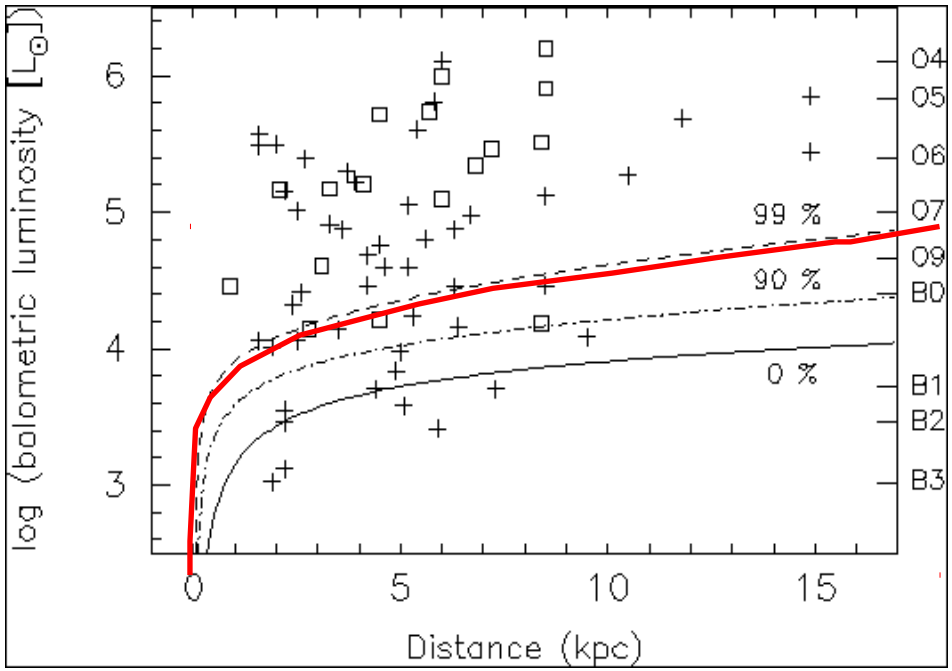
$$S_\nu = 1.32\times10^{-49} N_L \left(\frac{D}{kpc}\right)^{-2} a(\nu,T_e) \left(\frac{\nu}{GHz}\right)^{-0.1} \left(\frac{T_e}{K}\right) Jy$$

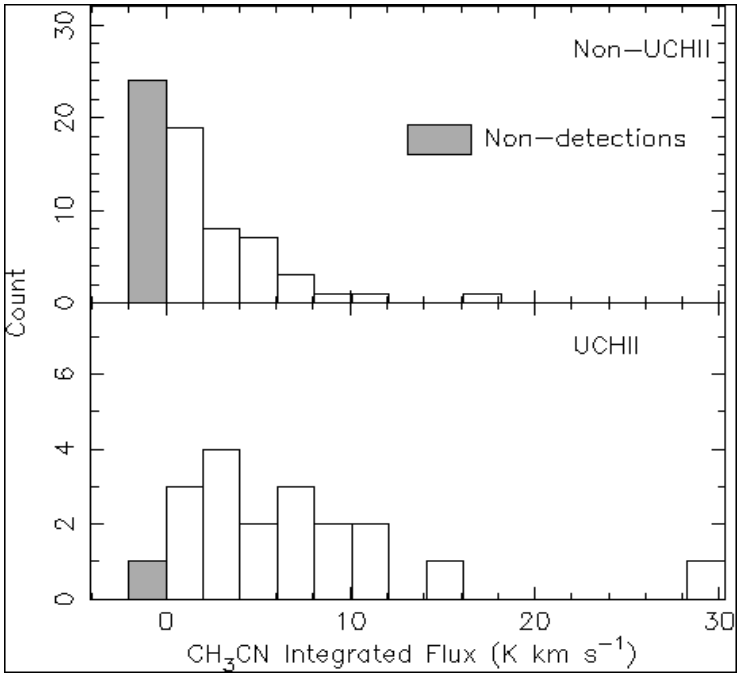
~ 1 mJy sensitivity

 # Lyman Photons ⟺ **Luminosity**

Kurtz et al 1994

KS test: Statistic = 0.48, Probability = 0.13%





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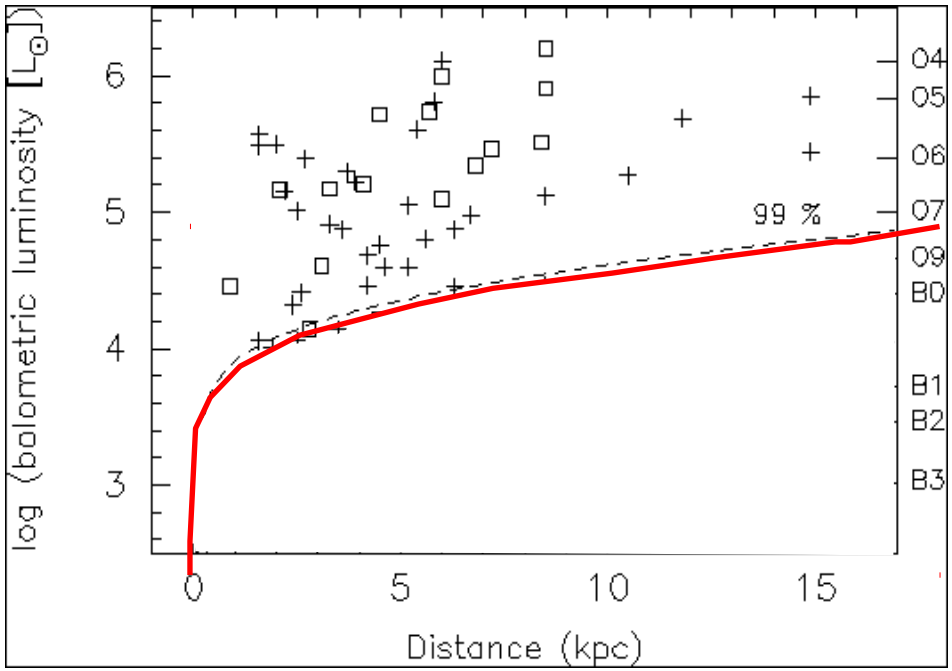
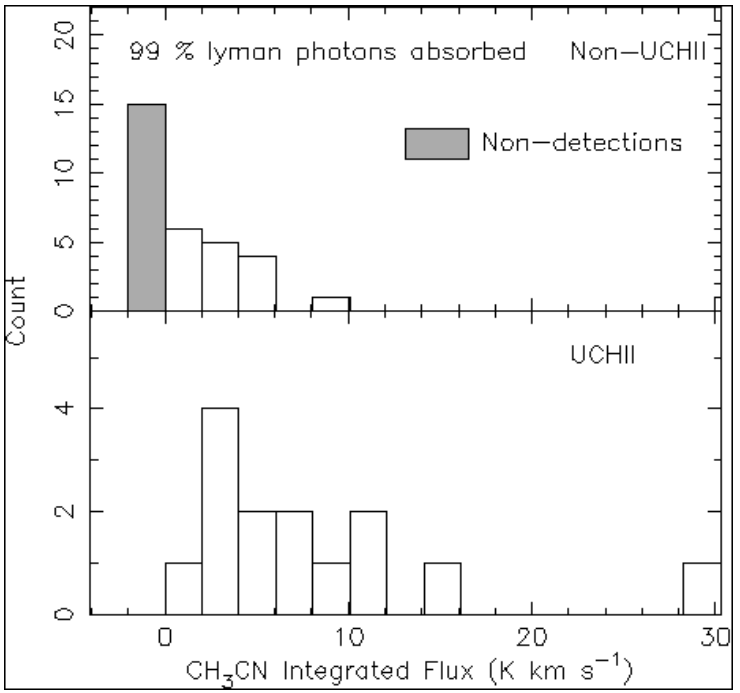
 # Lyman Photons ⟺ **Luminosity**

Kurtz et al 1994

KS test: Statistic = 0.50, Probability = 0.93%





- Why is CH_3CN more luminous and more abundant towards UCHII regions?
  - Externally heated clumps?
  - Warm shells around ionised gas?
  - Triggered star-formation within the beam?

Mopra hot molecular core survey

Linking 6.7 GHz methanol masers, hot molecular cores and UCHII regions

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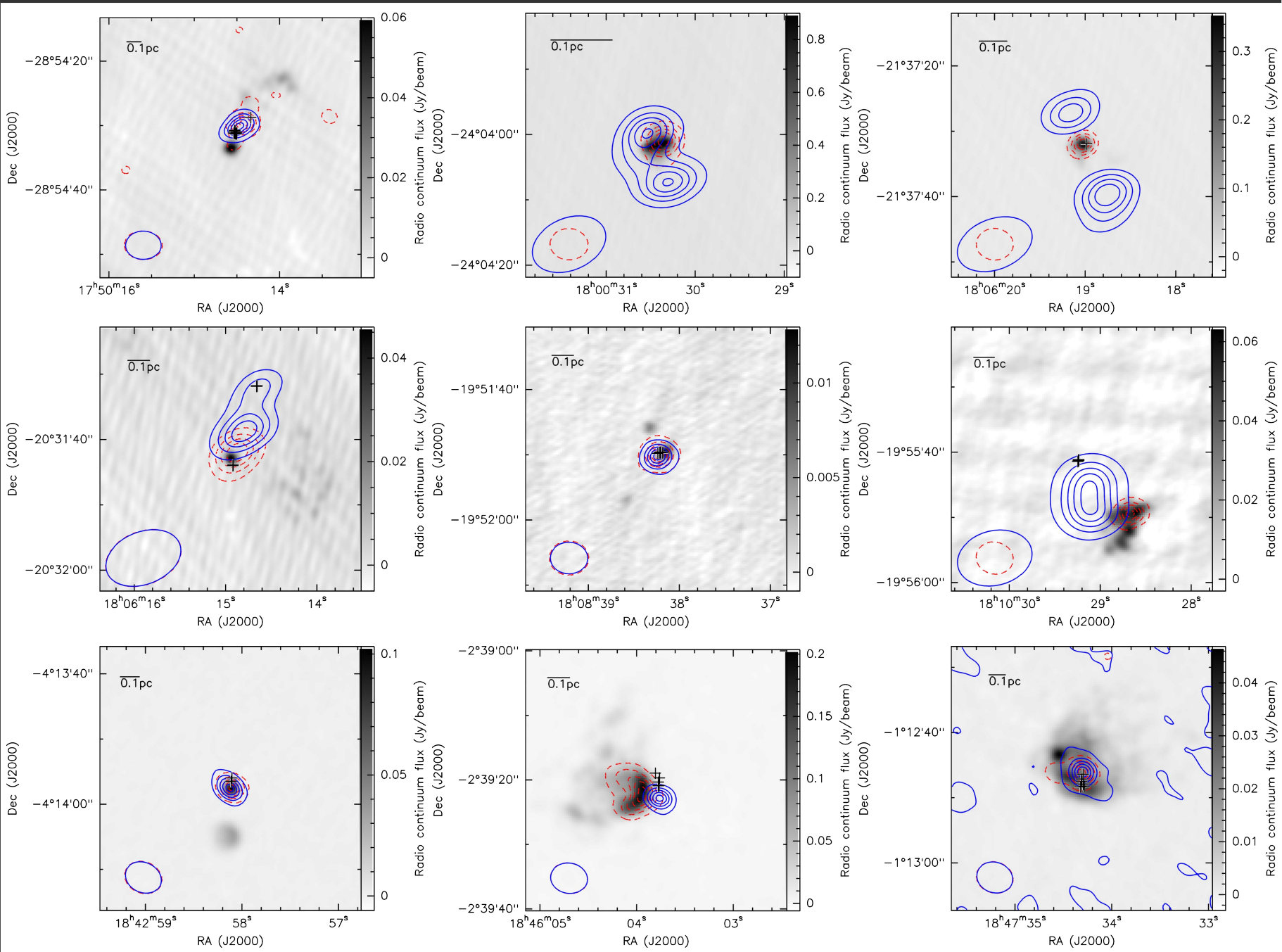
  - Triggered star-formation within the beam?

- Follow-up ATCA H75 + H214 observations:
  - CH_3CN & 3mm continuum, beam 4" $\rightarrow$ 10"
  - 10 brightest UCHII regions
  - 9 successfully imaged

Mopra hot molecular core survey

Linking 6.7 GHz methanol masers, hot molecular cores and UCHII regions



- Introduction
- Hot Cores
- **UCHIIs**
- MYSOs
- Summary

Mopra hot molecular core survey

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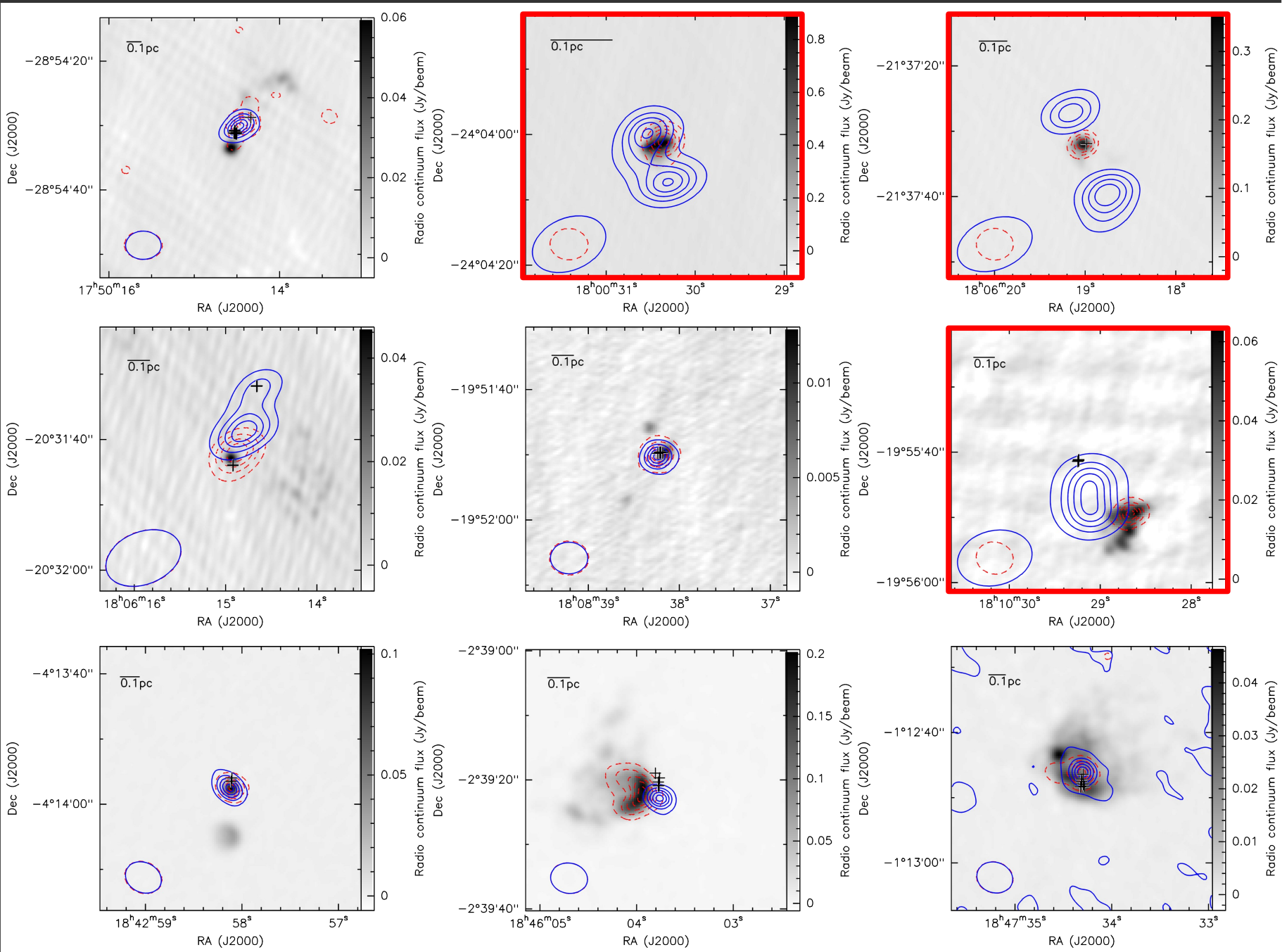

Introduction
Hot Cores
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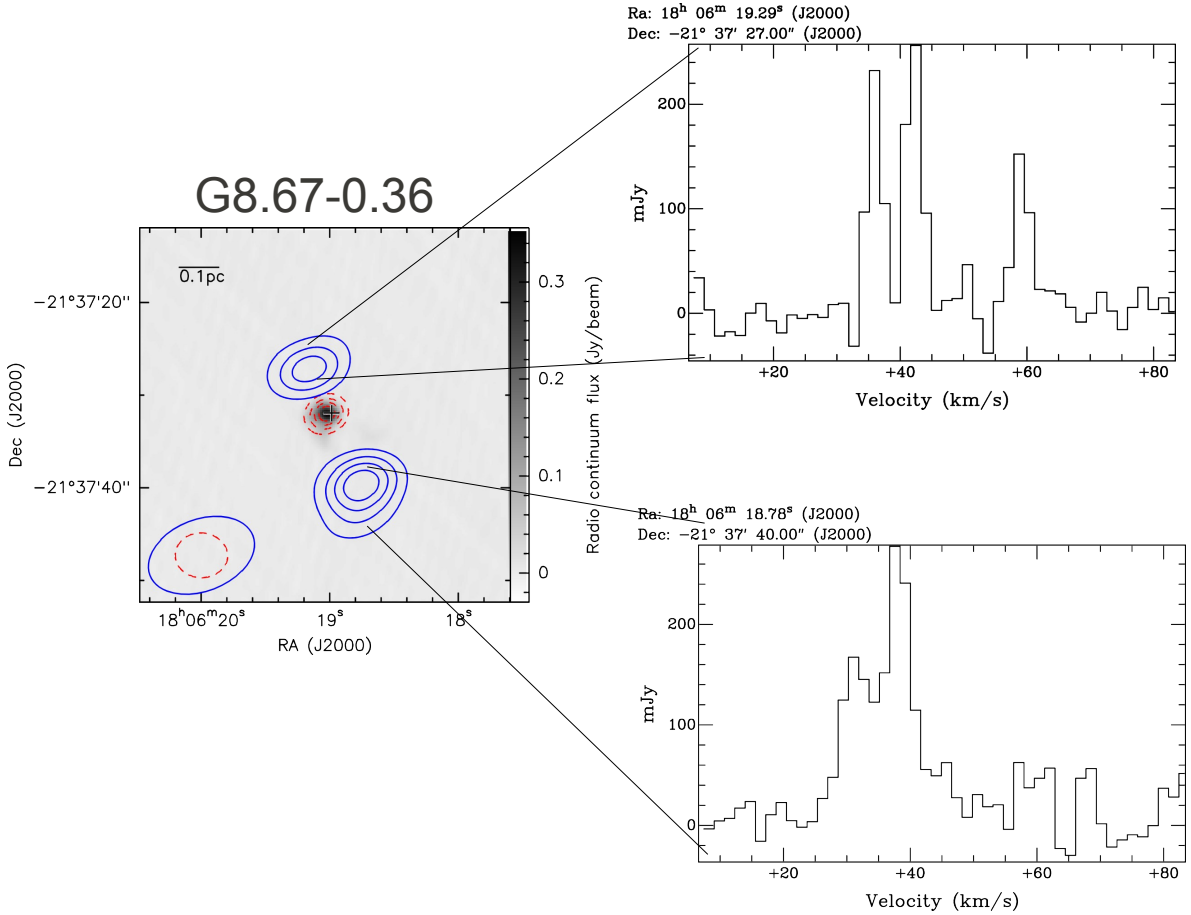
Mopra hot molecular core survey

Linking 6.7 GHz methanol masers, hot molecular cores and UCHII regions

- CH_3CN away from maser sites and dust continuum



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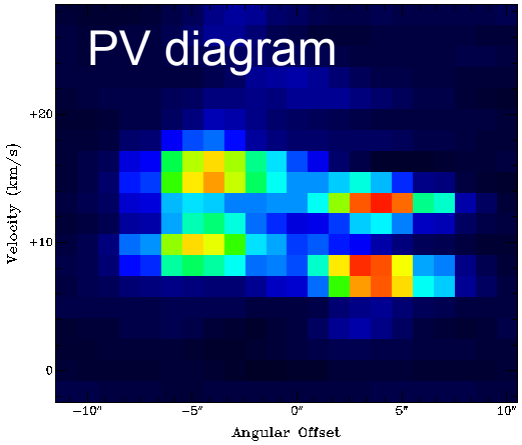

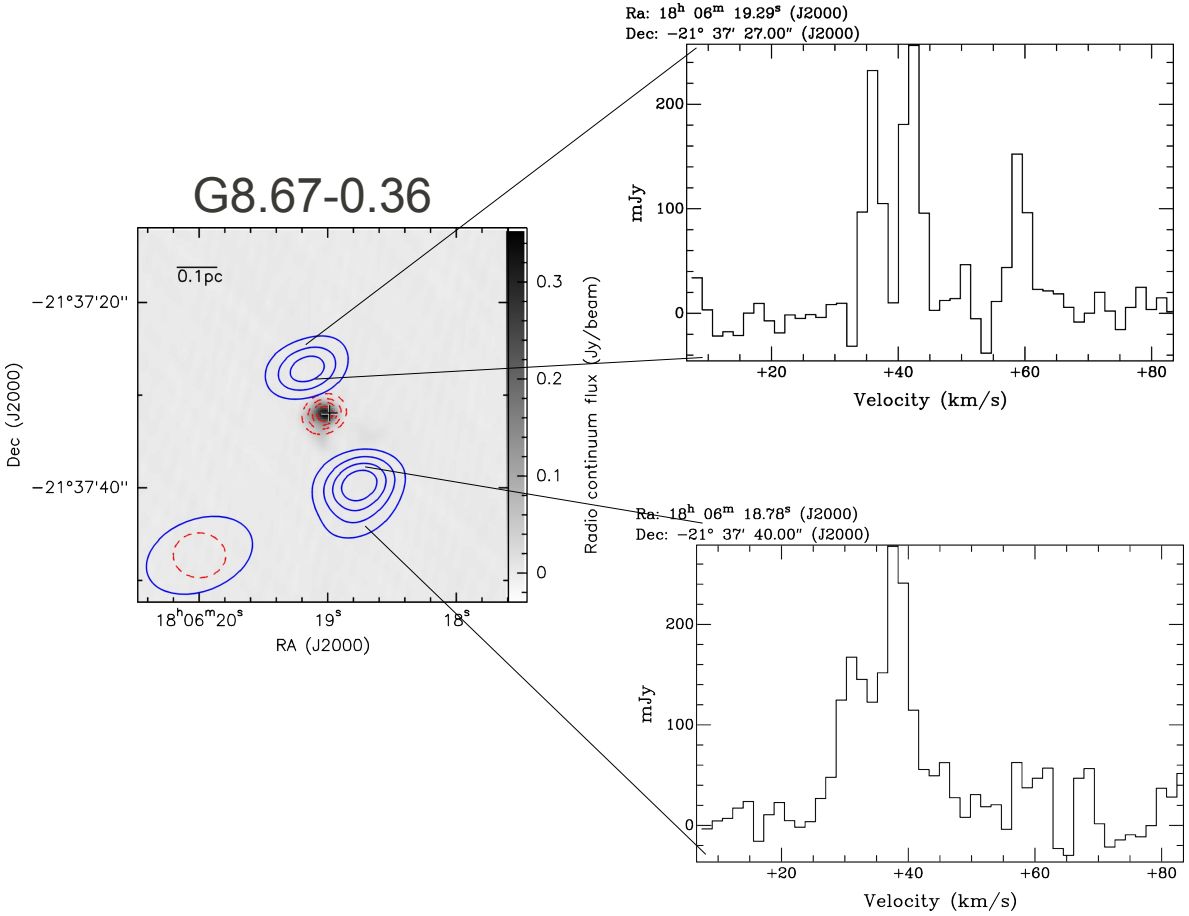

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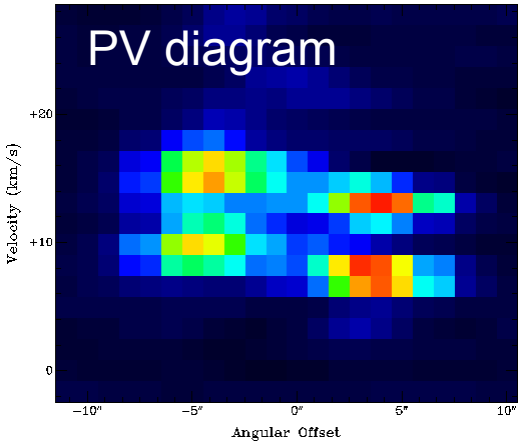
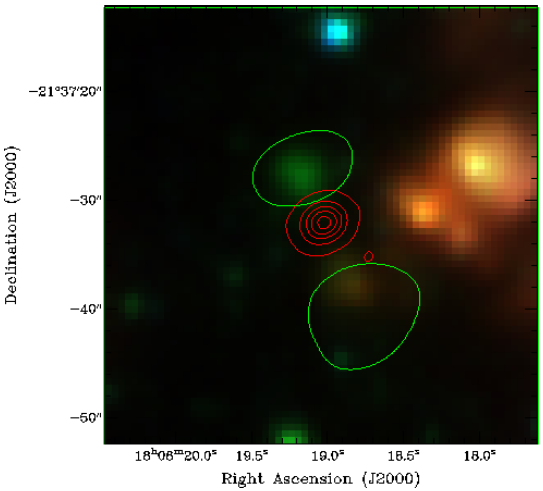
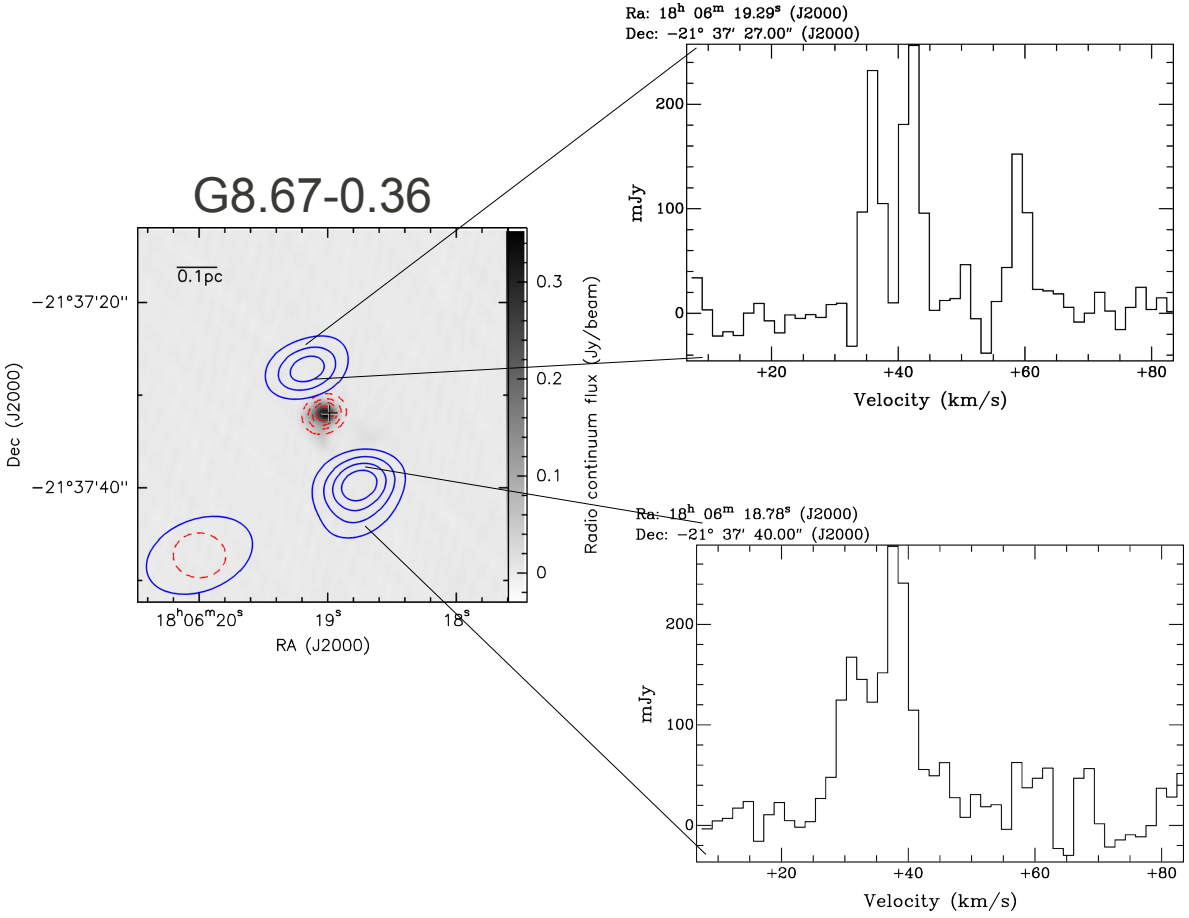






- Associated with 'green fuzzies' / EGOs in GLIMPSE?

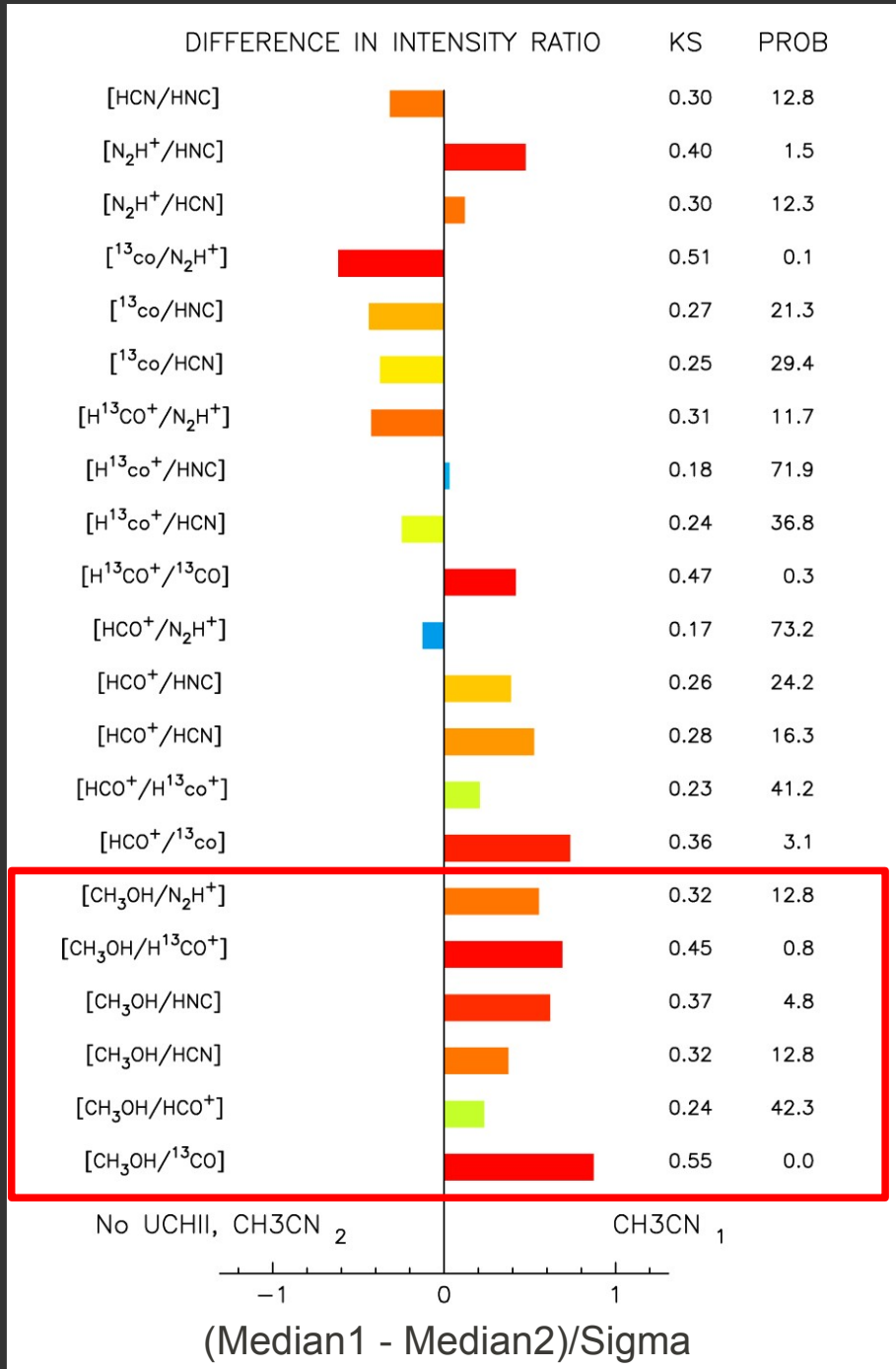
Mopra hot molecular core survey

Linking 6.7 GHz methanol masers, hot molecular cores and UCHII regions

- Divided the sample into groups:
  - Radio-loud versus radio-quiet
  - CH_3CN detected versus no CH_3CN detected
  - MSX-dark versus MSX bright
  - Presence or absence of high velocity line wings
  - Presence or absence of blue-skewed HC
- Compared distributions using a KS-test
- Looked for differences in the medians
  - coupled with a LOW probability that the distributions have the same parent

Mopra hot molecular core survey

Linking 6.7 GHz methanol masers, hot molecular cores and UCHII regions



- Compare line ratios for two subsamples
  - CH_3CN detected vs
  - CH_3CN not detected
- Most significant:
  - Ratios with CH_3OH

Mopra hot molecular core survey

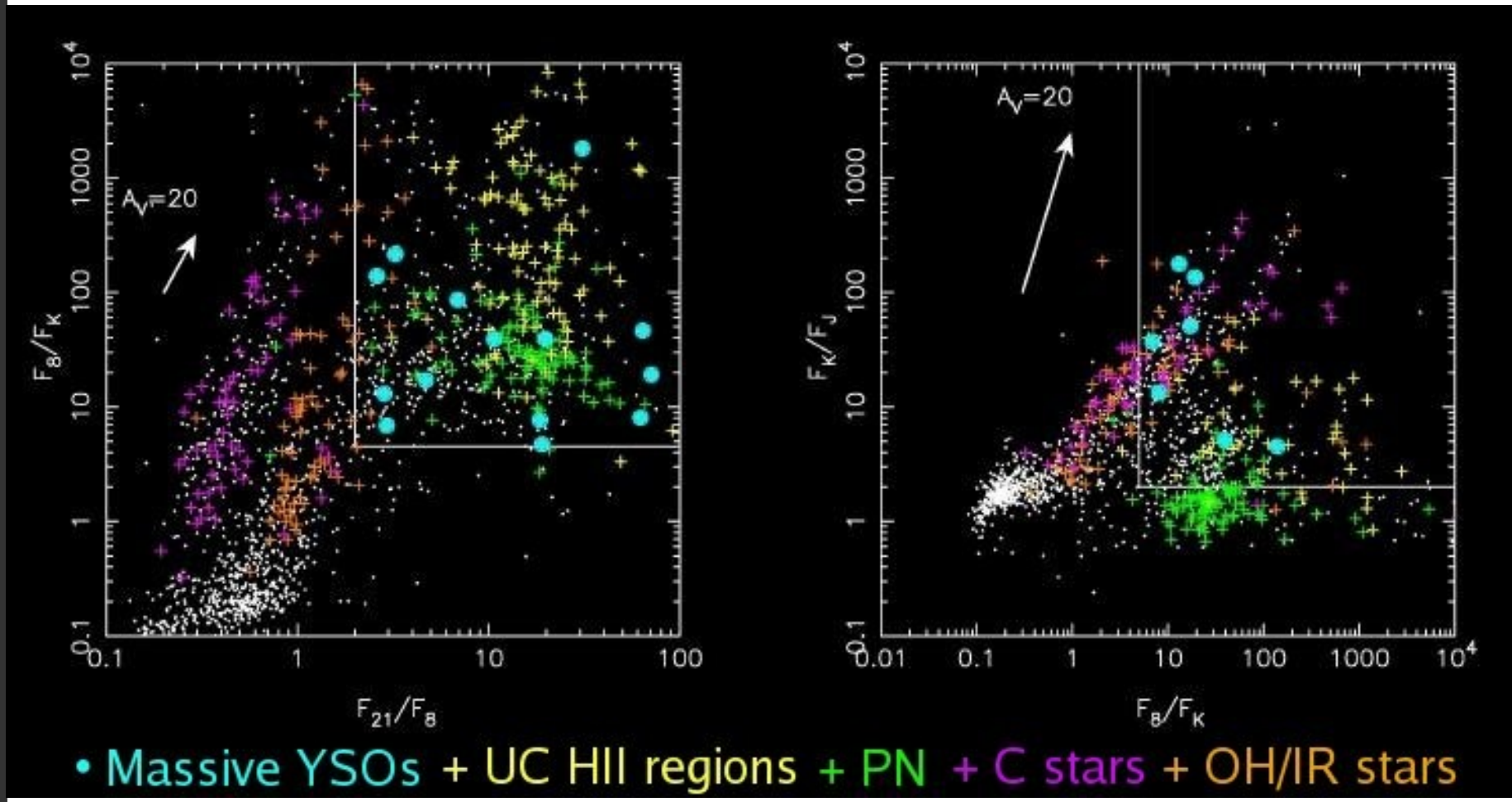
Linking 6.7 GHz methanol masers, hot molecular cores and UCHII regions

- Find:
- UHCII regions have the clearest differences
  - As expected: enhanced CH_3OH, Trot
- CH_3OH also enhanced where CH_3CN detected
- Sources with or without line-wings or infall profile show no significant differences.

Red MSX Source survey - chemical follow-up

Molecular survey of Massive Young Stellar Objects

- Red MSX source survey selection criteria
  - Red colours – embedded dusty objects



Red MSX Source survey - chemical follow-up

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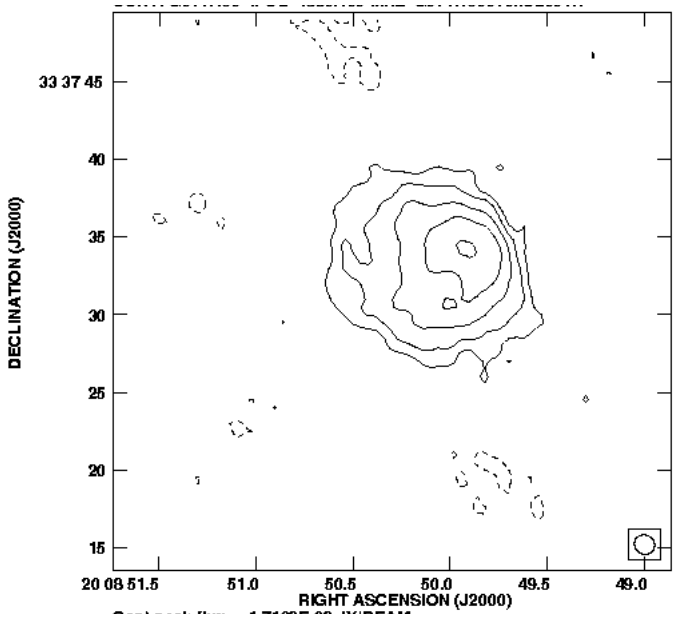
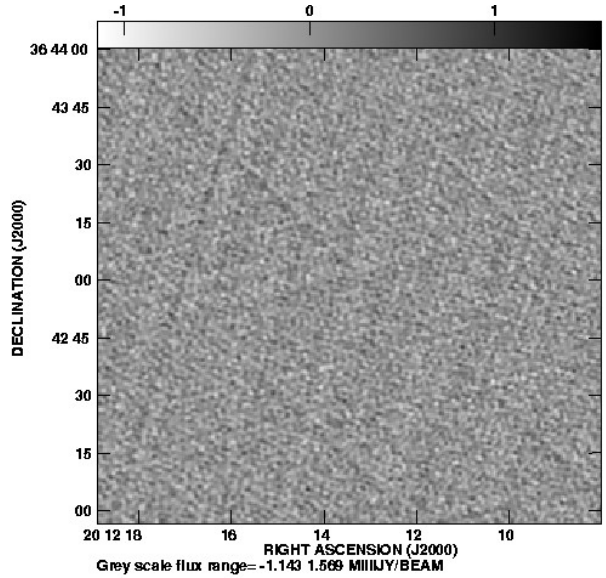
  - Luminous enough to host massive SF
  - No detectable radio-emission at cm wavelengths



UCHII region



Candidate MYSO

Red MSX Source survey - chemical follow-up

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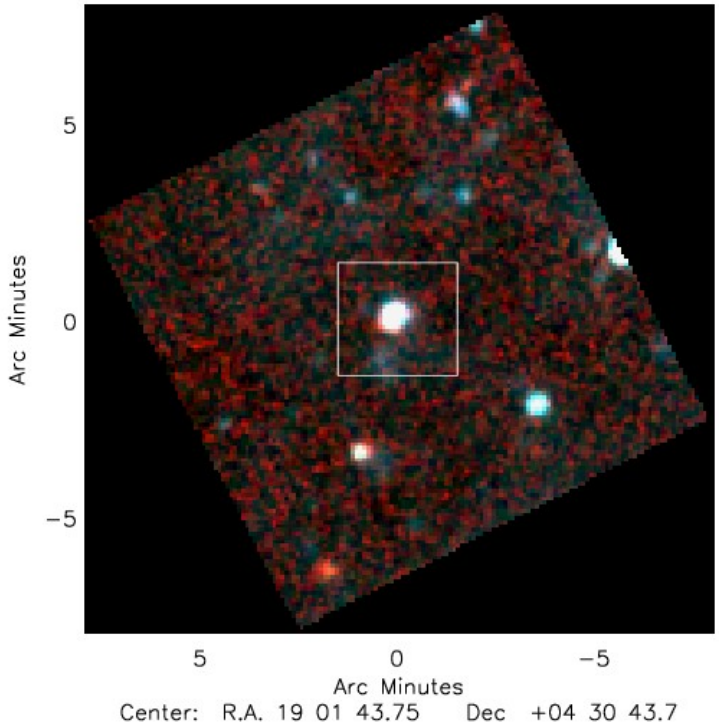
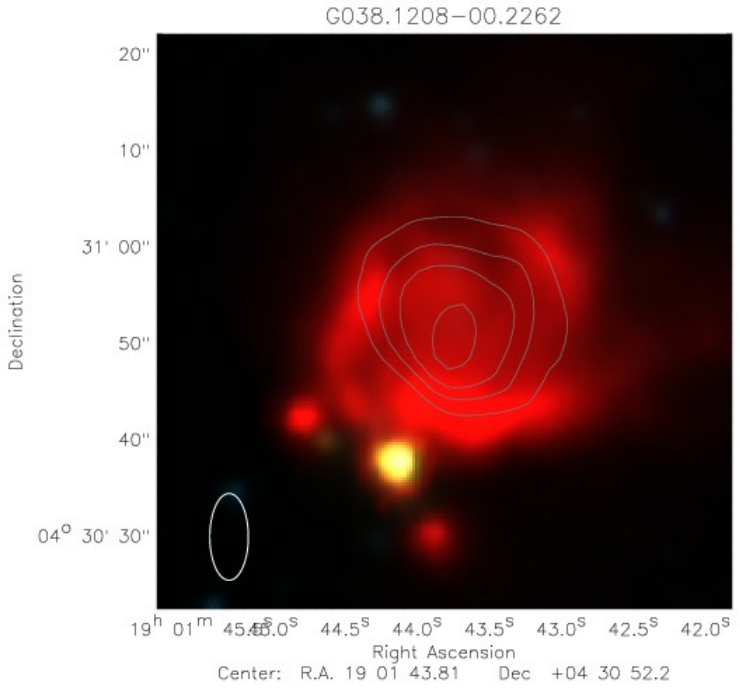




Red MSX Source survey - chemical follow-up

Molecular survey of Massive Young Stellar Objects

- Do RMS MYSOs exhibit complex chemistry?
- Investigate with Mopra in the MOPS era:
  - Selec 35 MYSOs with strong CS and N_2H+
  - Pointed observations with 60min on-source time
  - 8 GHz wideband mode

Red MSX Source survey - chemical follow-up

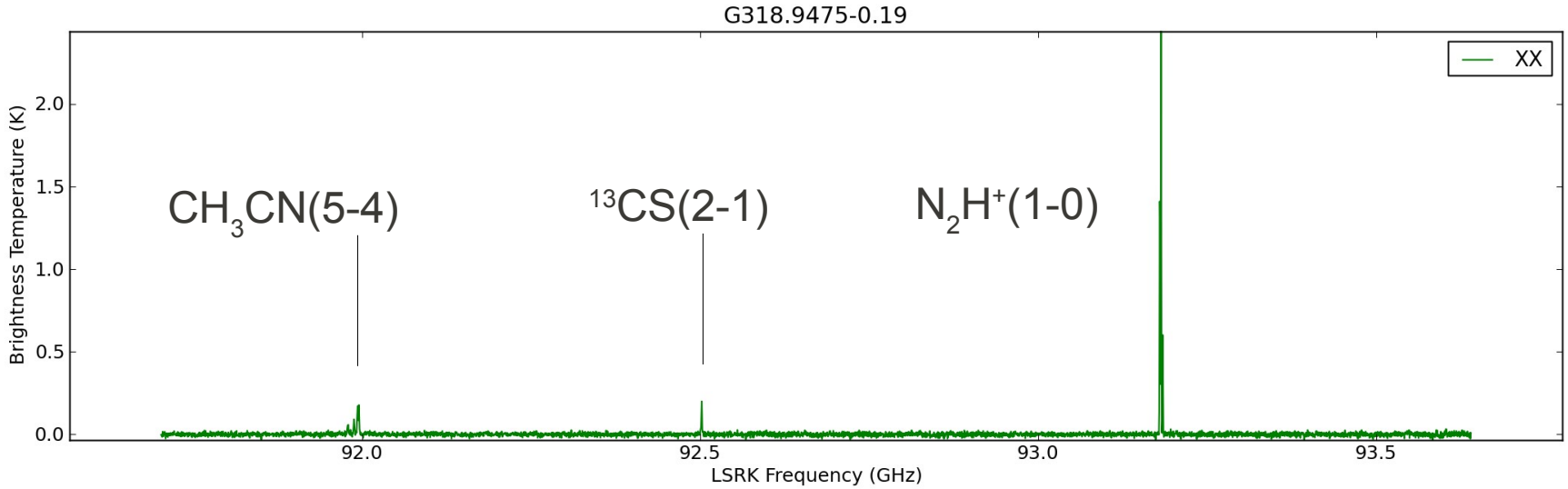
Molecular survey of Massive Young Stellar Objects

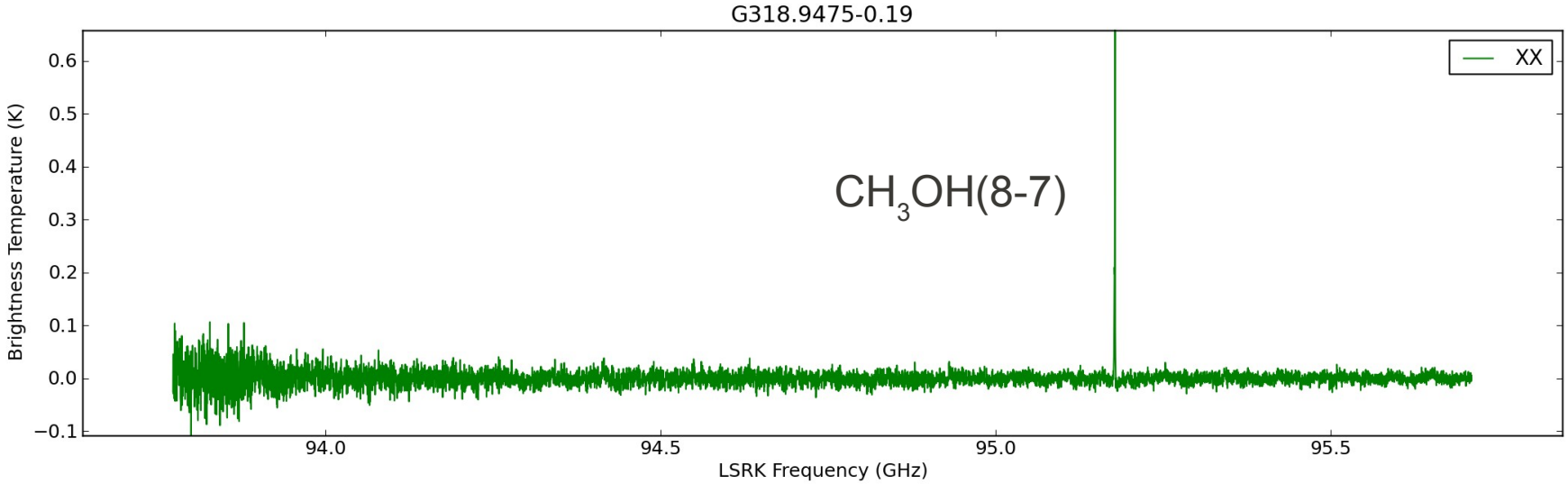
- Are some of these objects hot cores?
- Investigate with Mopra in the MOPS era:

Species	Transition	Frequency (GHz)
CH_3CN	5 – 4 K-Ladder	91.99
^{13}CS	2 – 1	92.49
N_2H^+	1 – 0 hyperfines	93.17
CH_3CHO	5 – 4	93.50
CH_3OCHO	37 transitions	93 – 99
$13CH_3OH$	2 – 1	94.4
CCS	8,7 – 7,6	93.9
CH_3OCH_3	21 transitions	93 – 99
$C^{34}S$	2 – 1	96.4
CH_3OH	2 – 1 K-ladder	97.0
$O^{13}CS$	8 – 7	97.3
OCS	8 – 7	97.3
CS	2 – 1	98.0
CH_3CH_2CN	11 – 10	98.7
SO	3 – 2	99.3

Red MSX Source survey - chemical follow-up

Molecular survey of Massive Young Stellar Objects





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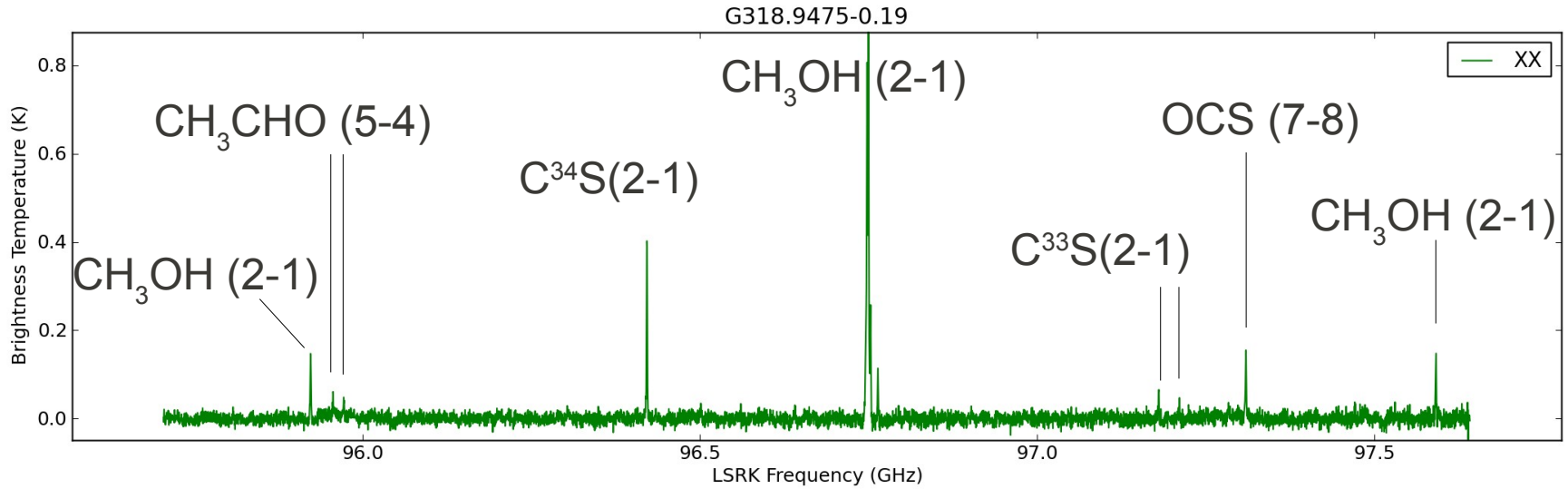

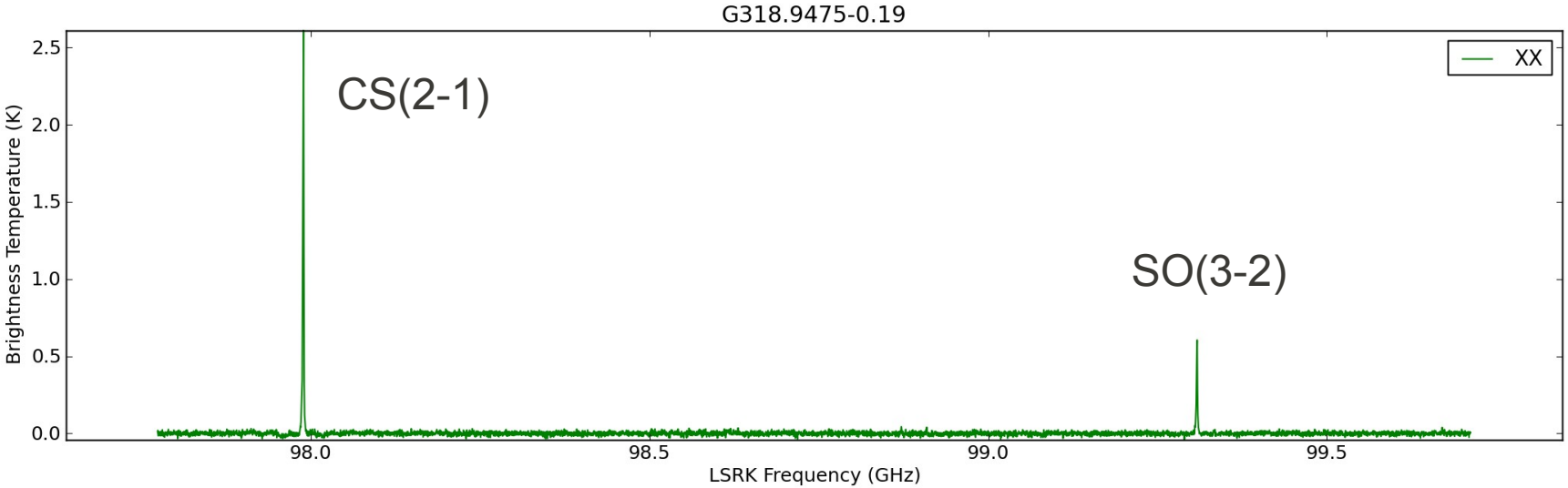

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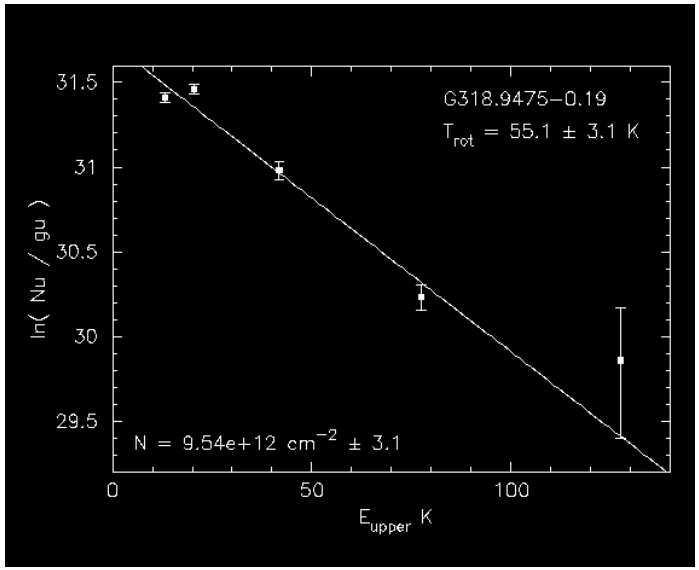
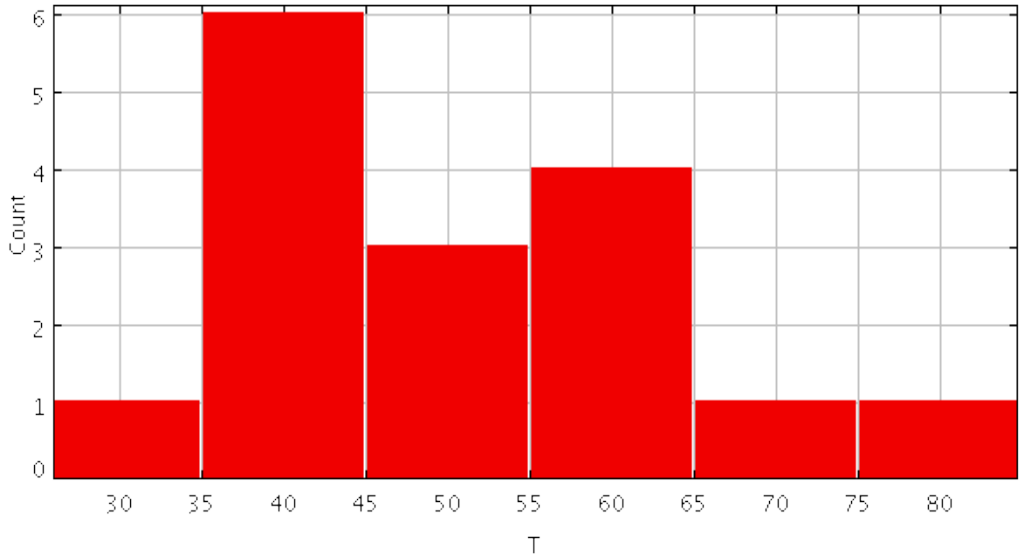
- Detect CH_3CN in 32/25 MYSOs – 62%
  - Comparable to maser-selected detections (71%)
- Rotational temperatures:





- Median ~ 55 K, similar to methanol maser sample
  - Tracing cooler outer layers of gas

Summary

- Take away message:
  - Hot-core style chemistry seems to exists in a variety of evolutionary phases
- Intrinsically associated with 6.7 GHz methanol masers
- Environment of UCHII regions may contain externally heated clumps
- Further progress requires high resolution observations – roll on ALMA.

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