Star formation in the infrared bubble G10.32-0.13

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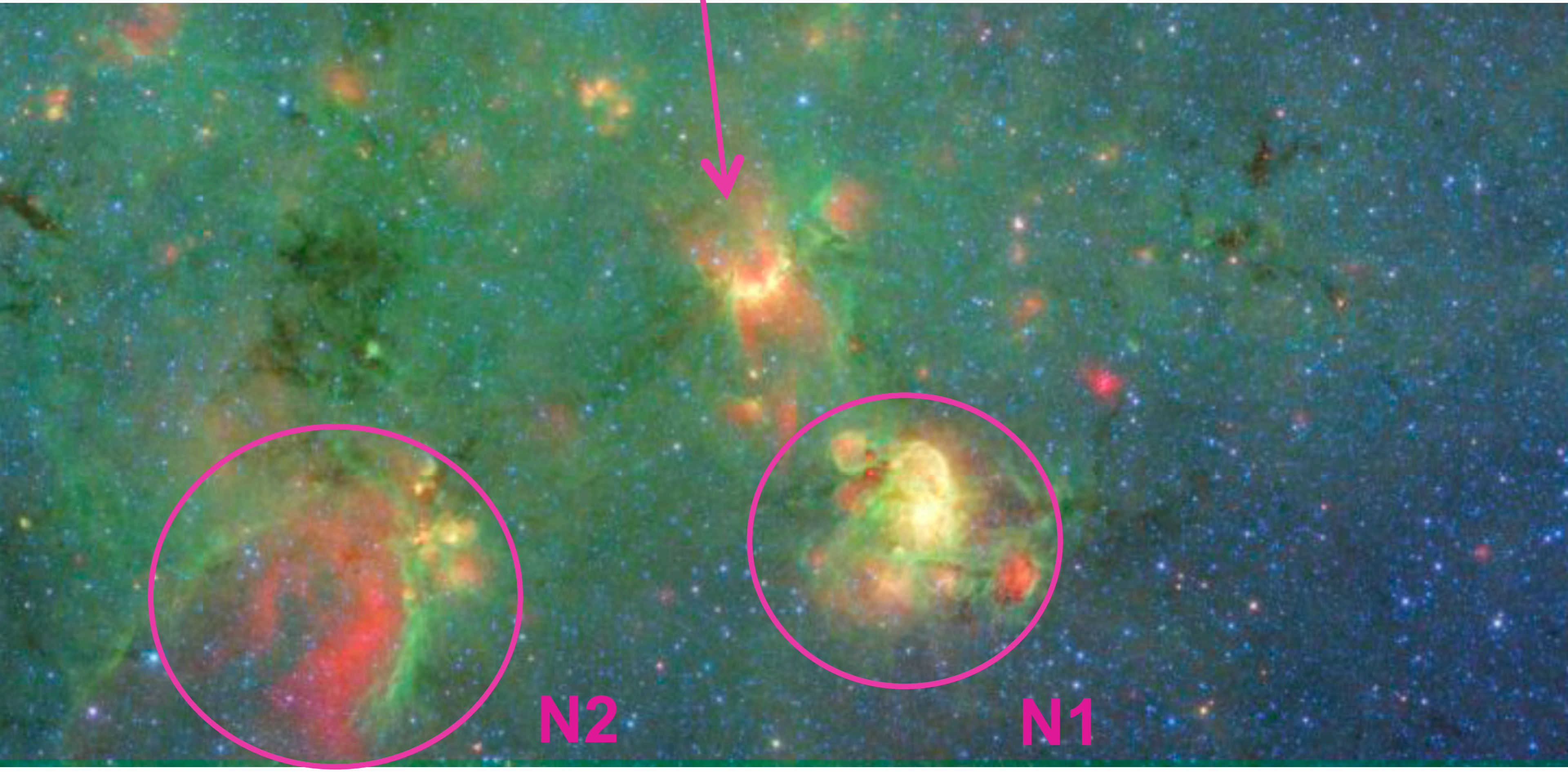
Soul of high-mass star formation

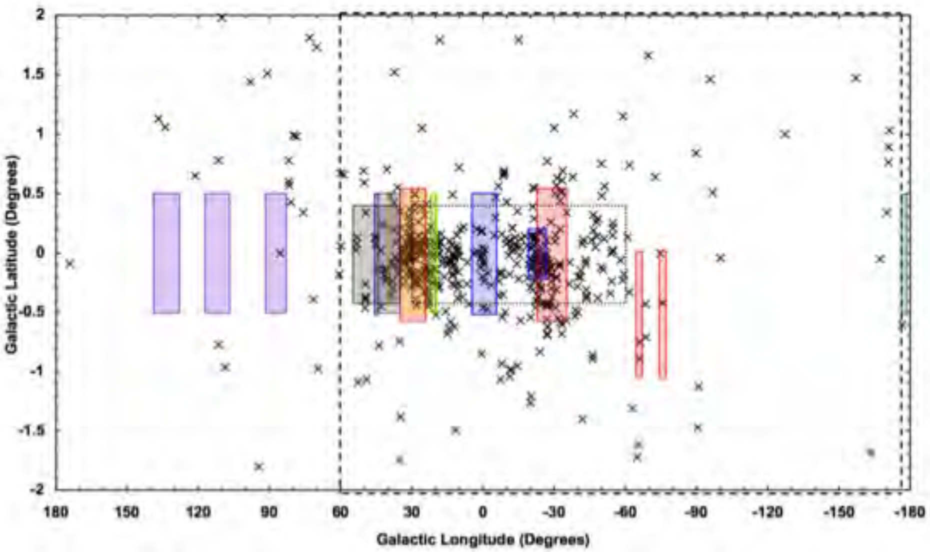
The region: G10.32-0.13 (CN 148; Churchwell et al. 2007)



The Methanol Multibeam Survey (MMB)

Unbiased, systematic search for 6.7 GHz methanol masers within the Galactic plane and the Magellanic clouds

- 6.7 GHz methanol masers exclusively trace sites of high-mass star formation (Minier et al. 2003, Xu et al. 2008, Breen et al. 2013)



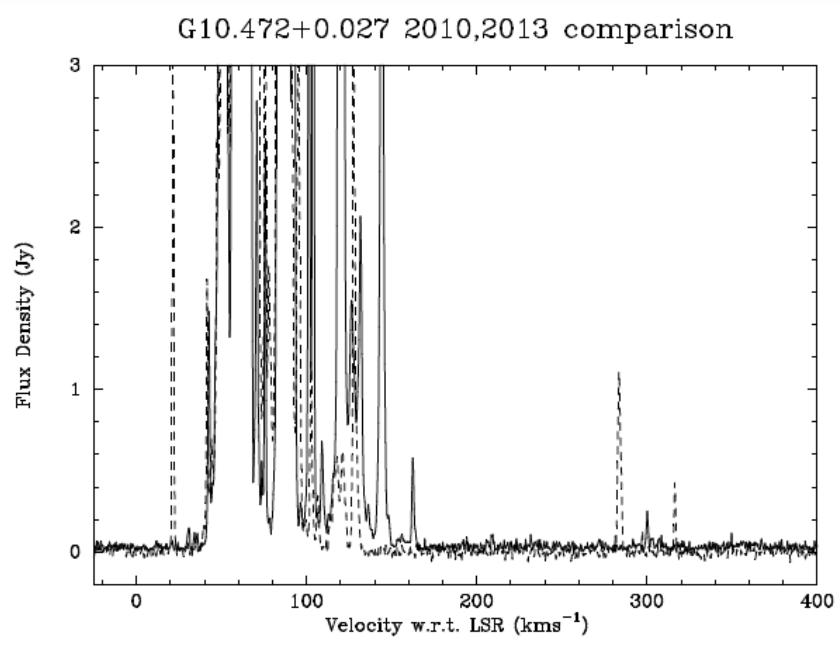
Green et al. (2009)

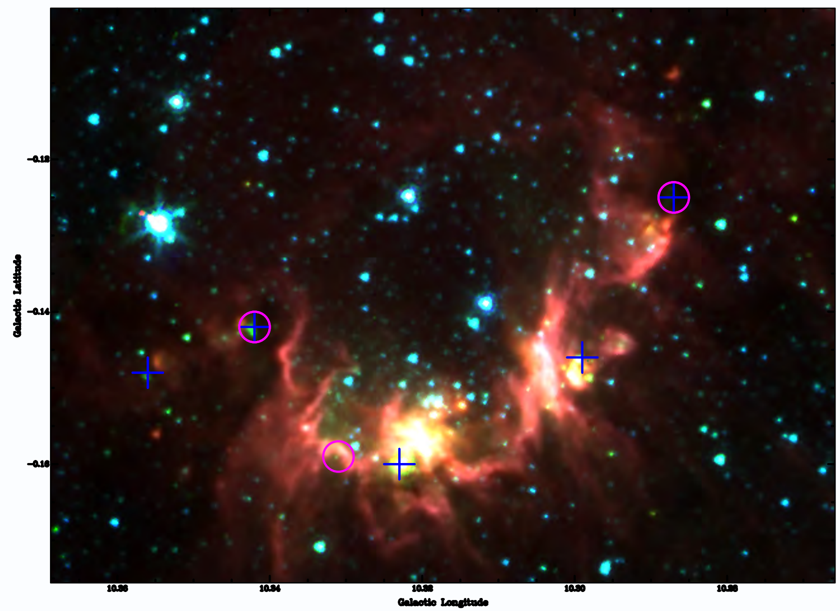
- 3σ survey sensitivity of 0.7 Jy
- ~1000 detections, ~40% new sources
- 20 to 60 longitude about to be submitted!

CSIRO

Water maser follow-up 6 – 20 longitude

Two special regions stood out immediately:



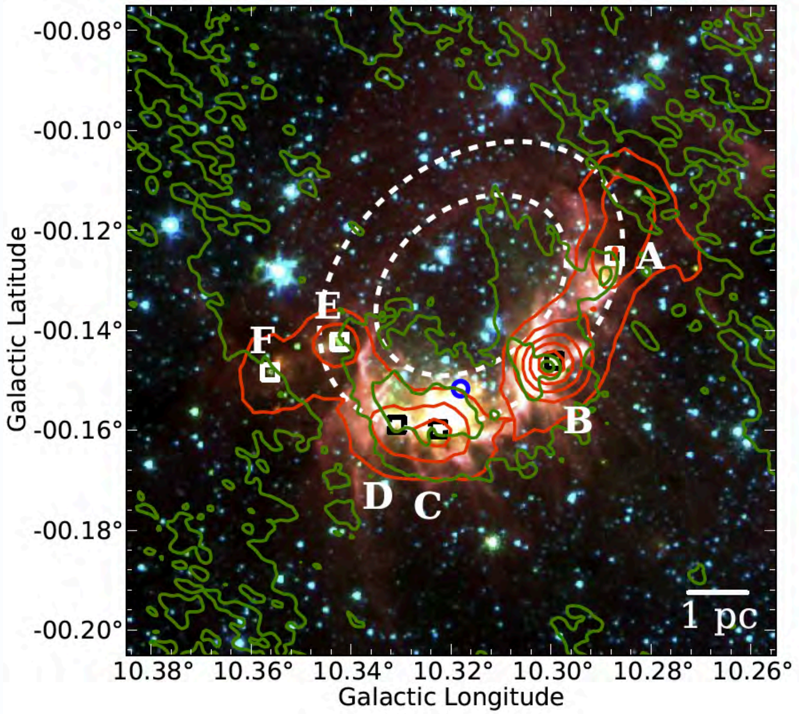


Titmarsh et al. (2013)

Titmarsh et al. (2014)

The G10.32-0.13 infrared bubble

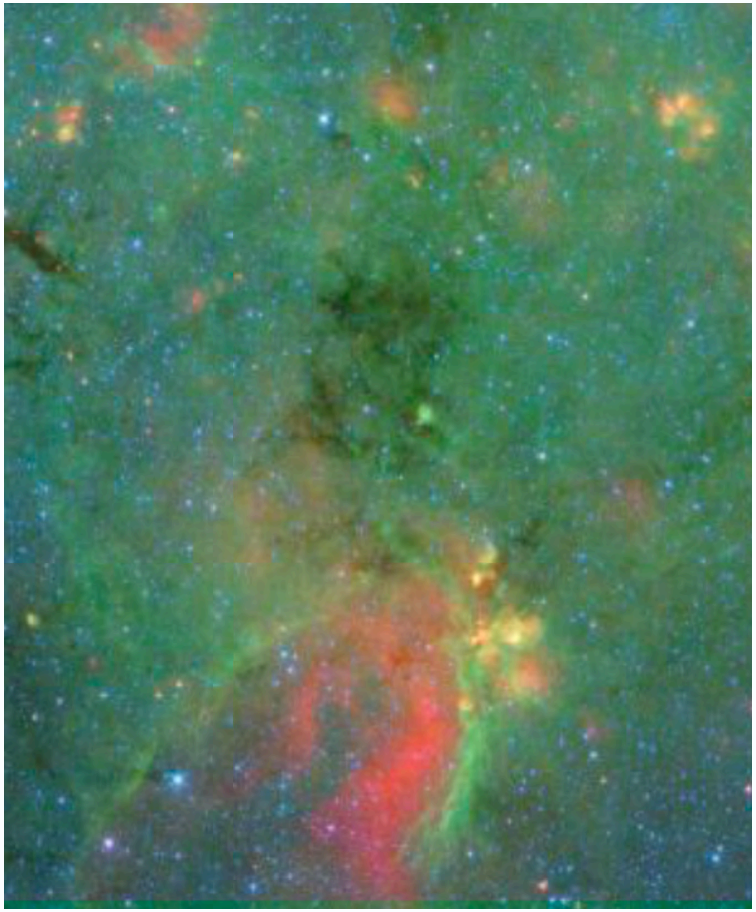
- Located in the W31 complex
- Distance of 4.95 kpc determined by parallax (Sanna et al. 2014)
- Diffuse 21 cm radio continuum fully covers the bubble, extending ~10pc either side of its center due to pressure driven expansion at 10 – 30 km/s
- Dynamical age ~ 3 – 10 x 10^5 years (Kim & Koo 2002)
  - << sound crossing time (1.3 x 10^7 years for a 4 pc structure at a temperature of 20 K) so information on the initial conditions will still be present.



RED: BGPS

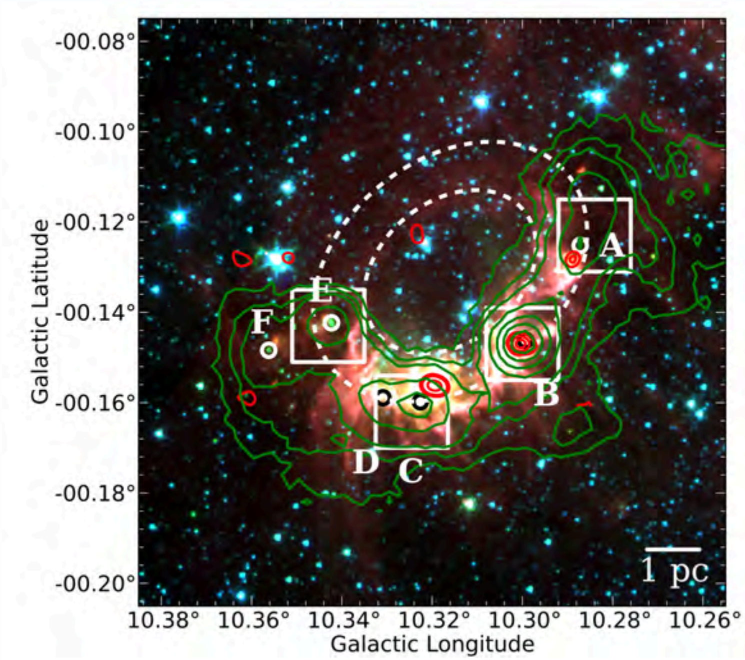
GREEN: 21cm radio continuum

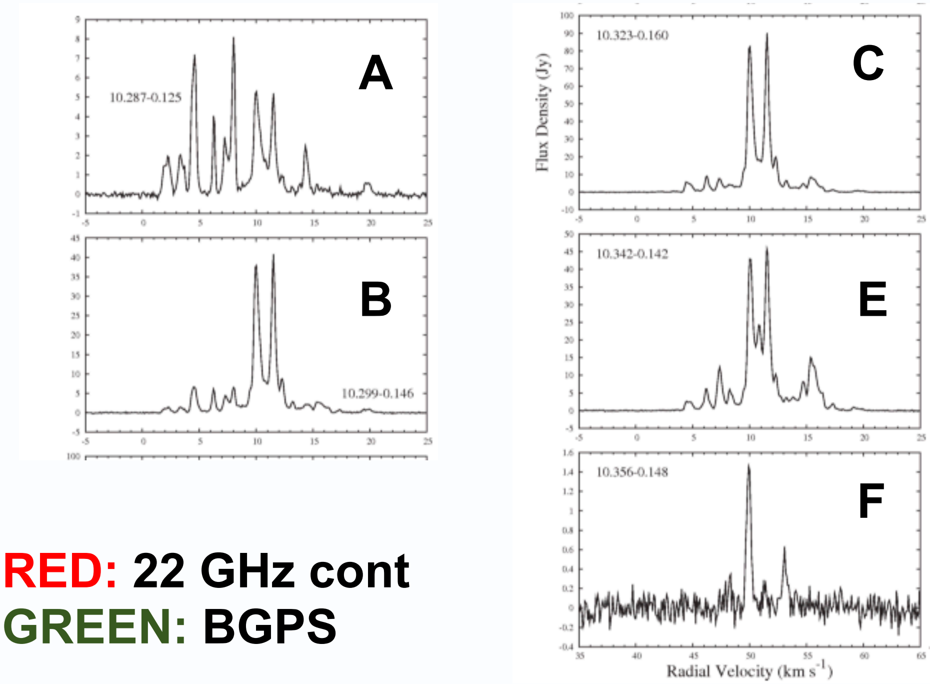
Star formation in bubble rims



- High-mass stars form in clusters and infrared bubbles form from high-mass stars --> more YSOs near bubbles than in the field
- Thompson et al. (2012) shows statistically that there is an overdensity
- Estimated that 20 – 30 % of high-mass star formation is triggered by the expansion of infrared bubbles (Thompson et al. 2012)
- But how exactly does that triggering occur?

MASERS!





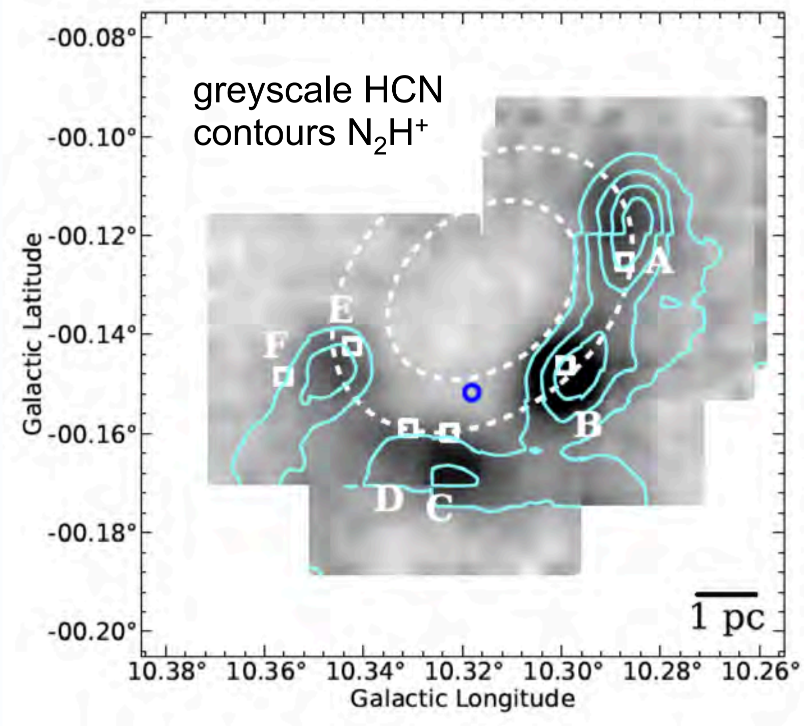
RED: 22 GHz cont
GREEN: BGPS

- 6 separate sites of maser emission (A-E) embedded in ridge of molecular gas
- Maser F is a chance alignment
- Methanol maser lifetime estimated to be 2.5 – 4.5 x 10^4 years (van der Walt 2005), an order of magnitude smaller timeframe than the bubble age → star formation has been triggered by the bubble expansion

Molecular gas and dust in the region

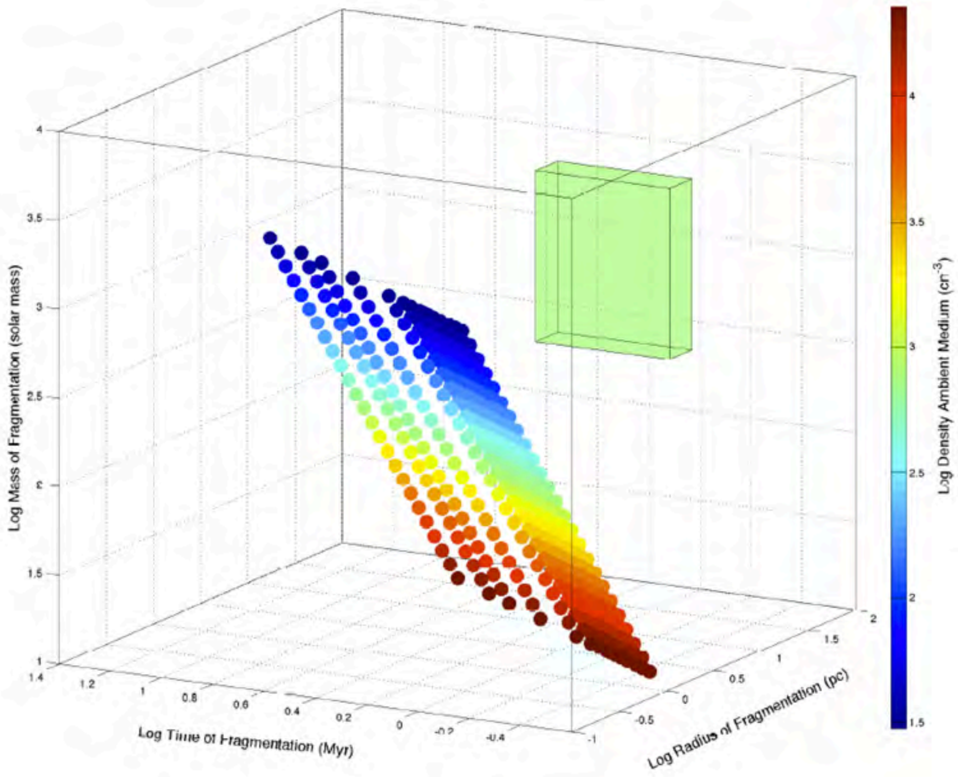
- Enhanced CO and CS towards maser-associated YSOs (esp. B ; Kim & Koo 2012, Beuther et al. 2011)
- N_2H^+, HCN, HNC and HCO^+ (1-0) from MALT90 shows a similar distribution.
  - but N_2H^+ systematically at greater radii, suggesting that the gas is cooler in the other parts of the rim
- 4 of the maser sources are associated with ATLASGAL compact source (Contreras et al. 2013)
  - Conservatively estimate 3 of the 4 to be > 1000 Msol

→ Age and environment of the YSOs in the bubble rim are well constrained by the observational data



Maser source name	ATLASGAL Compact source	Temperature (K)	Radius (pc)	Peak Column Density (cm^{-2})	Dust Mass ($M_\odot$)
G 10.287 − 0.125 (A)	AGAL010.288−00.124	30±8	0.36	4.7–9.8× 10^{22}	620–1300
G 10.299 − 0.146 (B)	AGAL010.299−00.147	32±8	1.60	0.78–1.5× 10^{23}	2900–5700
G 10.323 − 0.160 (C)	AGAL010.323−00.161	55±22	2.00	2.1–5.9× 10^{22}	1400–4000
G 10.342 − 0.142 (E)	AGAL010.342−00.142	28±10	0.79	0.56–1.5× 10^{23}	1000–2800

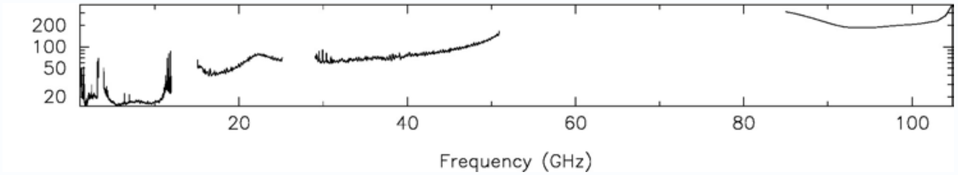
Comparing with collect and collapse expectations



- Radius, time and fragmentation mass using Whitworth et al. (1994)
- Green box shows the parameter space consistent with the sources in the bubble rim
- Colour of the points represents the average density of the ambient gas
- Lines represent a different flux of ionising photons (B3 (left) through O3 (right)

ATCA observations

ATCA observations

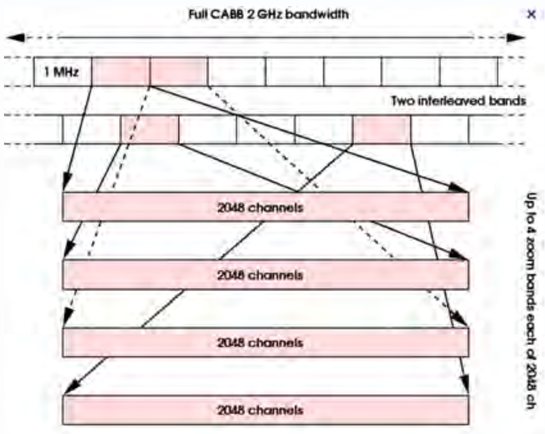


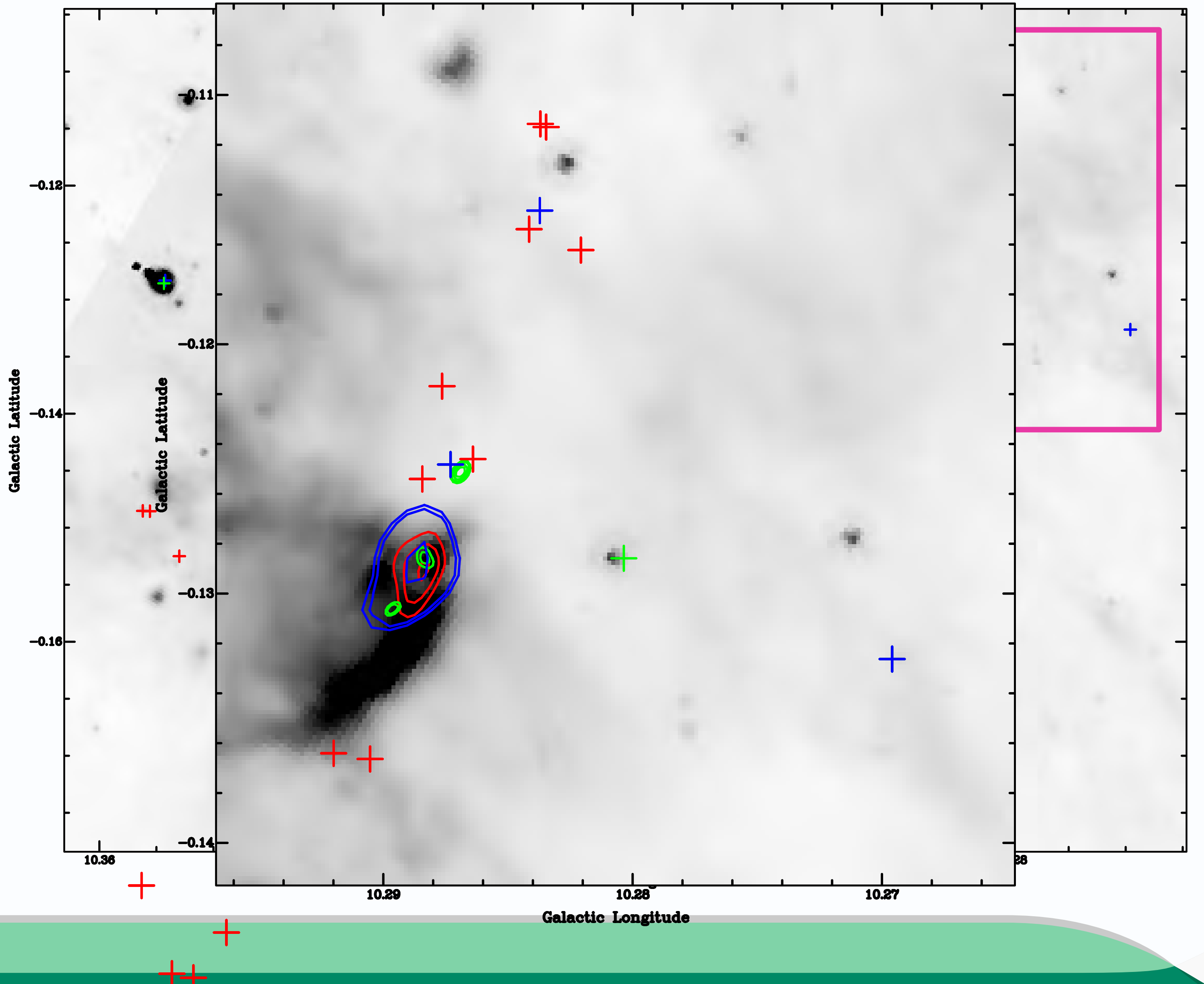
- ATCA located ~600km NW of Sydney
  - CABB allows sensitive continuum and line observations to be made simultaneously
  - Recievers from 1 – 105 GHz

- Made observations at 12, 7 and 3mm of 36 lines and 3 x 4 GHz continuum to:

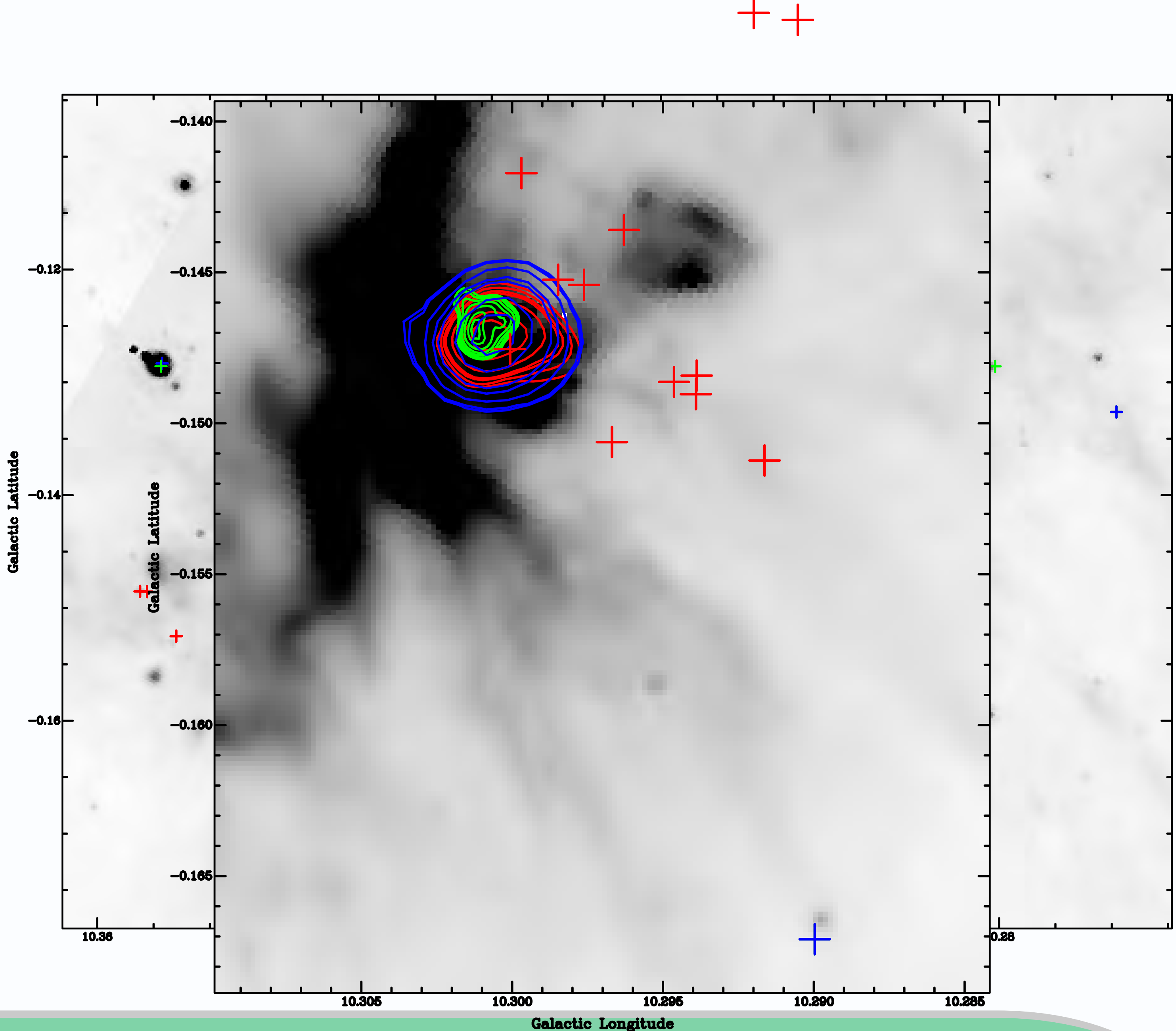
  1) determine the locations of the star forming cores

  2) measure the mass distribution and the dynamics of the molecular gas

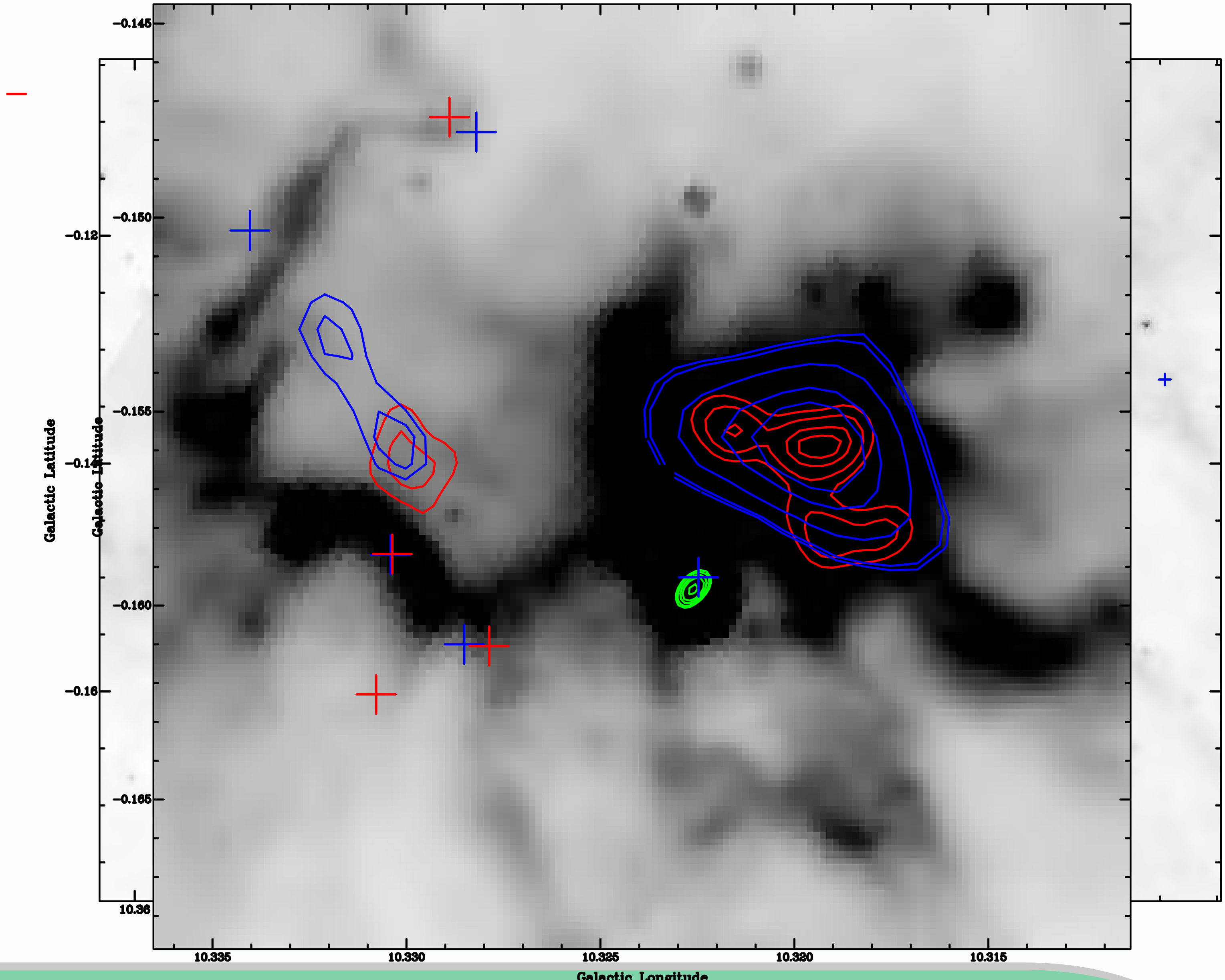




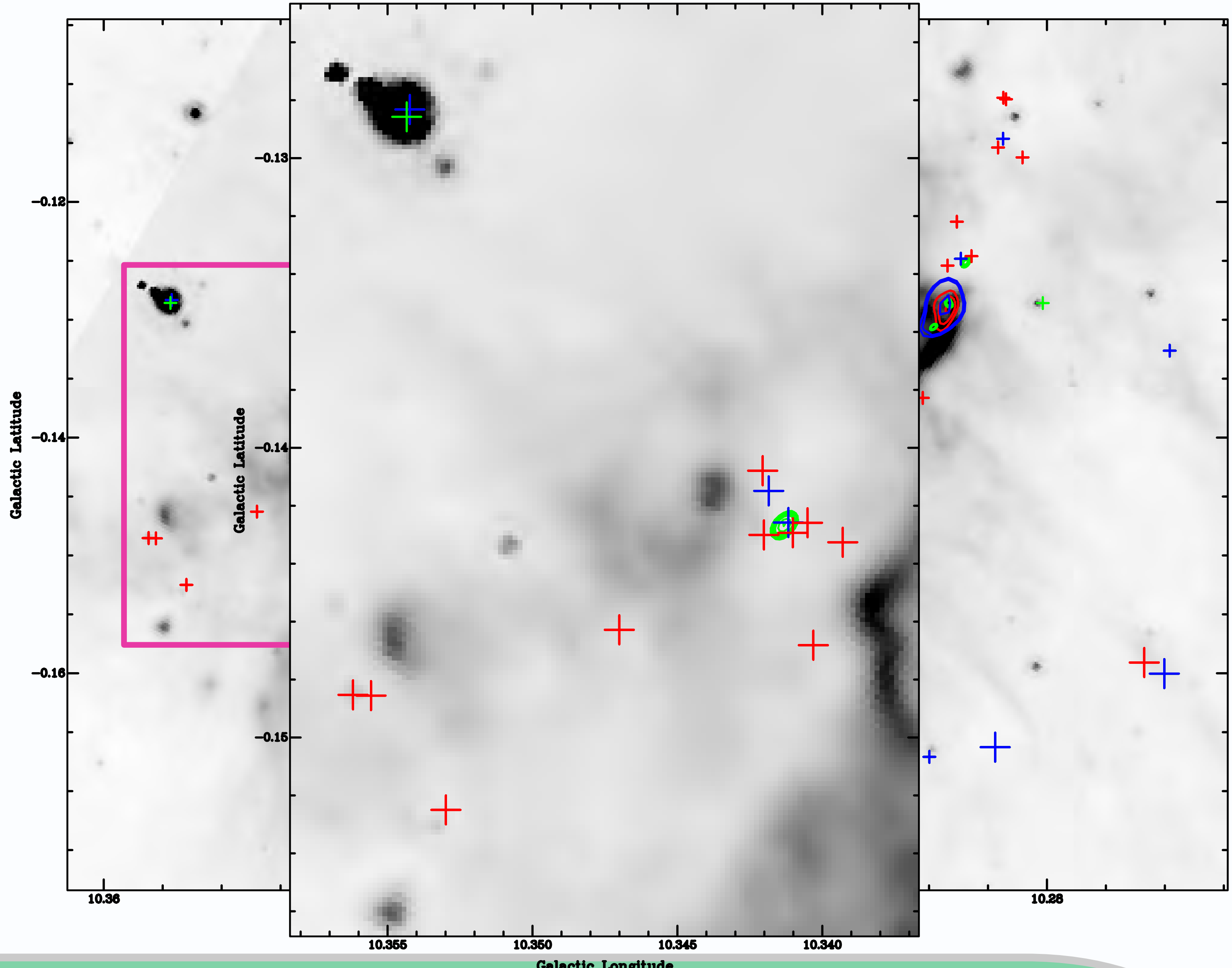
-0.11
-0.12
-0.12
-0.14
-0.13
-0.16
-0.14
10.36
10.29
10.28
10.27
Galactic Latitude
Galactic Latitude
Galactic Longitude



Galactic Latitude
Galactic Latitude
Galactic Longitude
-0.140
-0.145
-0.150
-0.155
-0.160
-0.165
-0.12
-0.14
-0.16
10.305
10.300
10.295
10.290
10.285
10.36
0.28



−0.145
−0.150
−0.12
−0.155
−0.160
−0.16
−0.165
10.36
10.335
10.330
10.325
10.320
10.315
Galactic Latitude
Galactic Latitude
Galactic Longitude

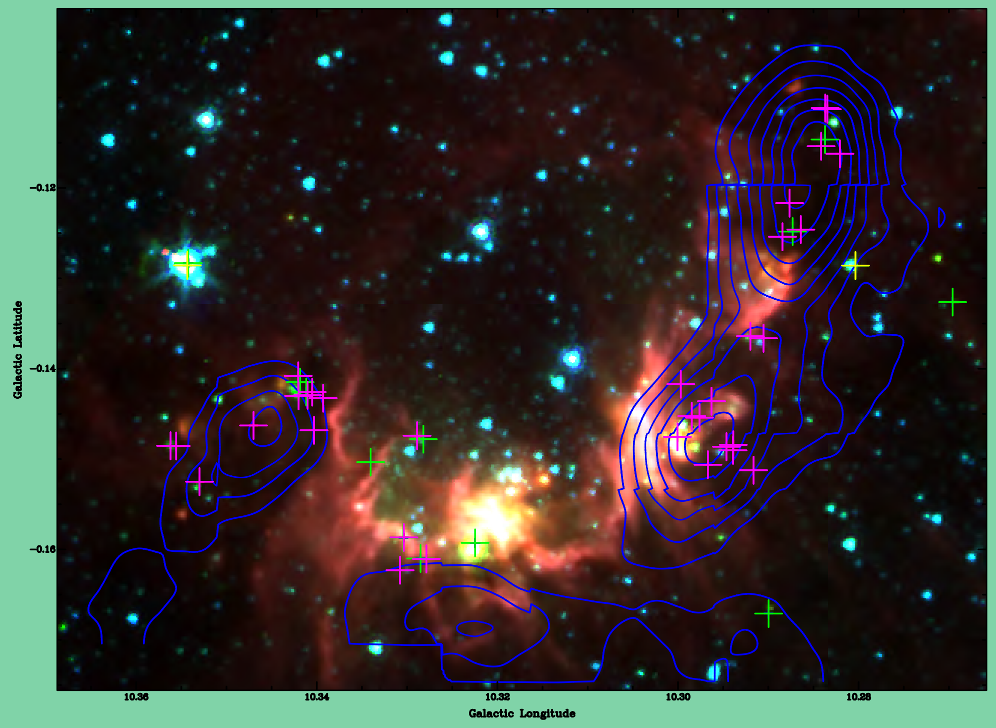

Galactic Latitude
-0.12
-0.14
-0.16
10.36
10.28
-0.13
-0.14
-0.15
10.355
10.350
10.345
10.340
Galactic Longitude

What's next

- Finish reducing the ATCA data…
- VLBA proposal to measure the proper motions of the masers

Summary

- MMB catalogue series nearly complete and is highlighting many interesting regions of high-mass star formation
- G10.32-0.13 has many advantages over other star formation regions and the masers are key to this (parallax, proper motions)
- Current data appears to be inconsistent with expectations of collect and collapse
- New ATCA data covers many lines and continuum at 12, 7 and 3mm and should provide more interesting results



Thank you

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Used the rotational temperature estimated from CH3CN (Purcell et al. 2006) the parallax distance, a gas to dust ratio of 100, dust absorption coefficient of 1.85 cm2 g-1 and a mean molecular mass 2.8 times H.