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# Community Outlook for mmATCA Projects

**Kate Brooks**  
**ATCA Science Day**  
**11 June 2008**

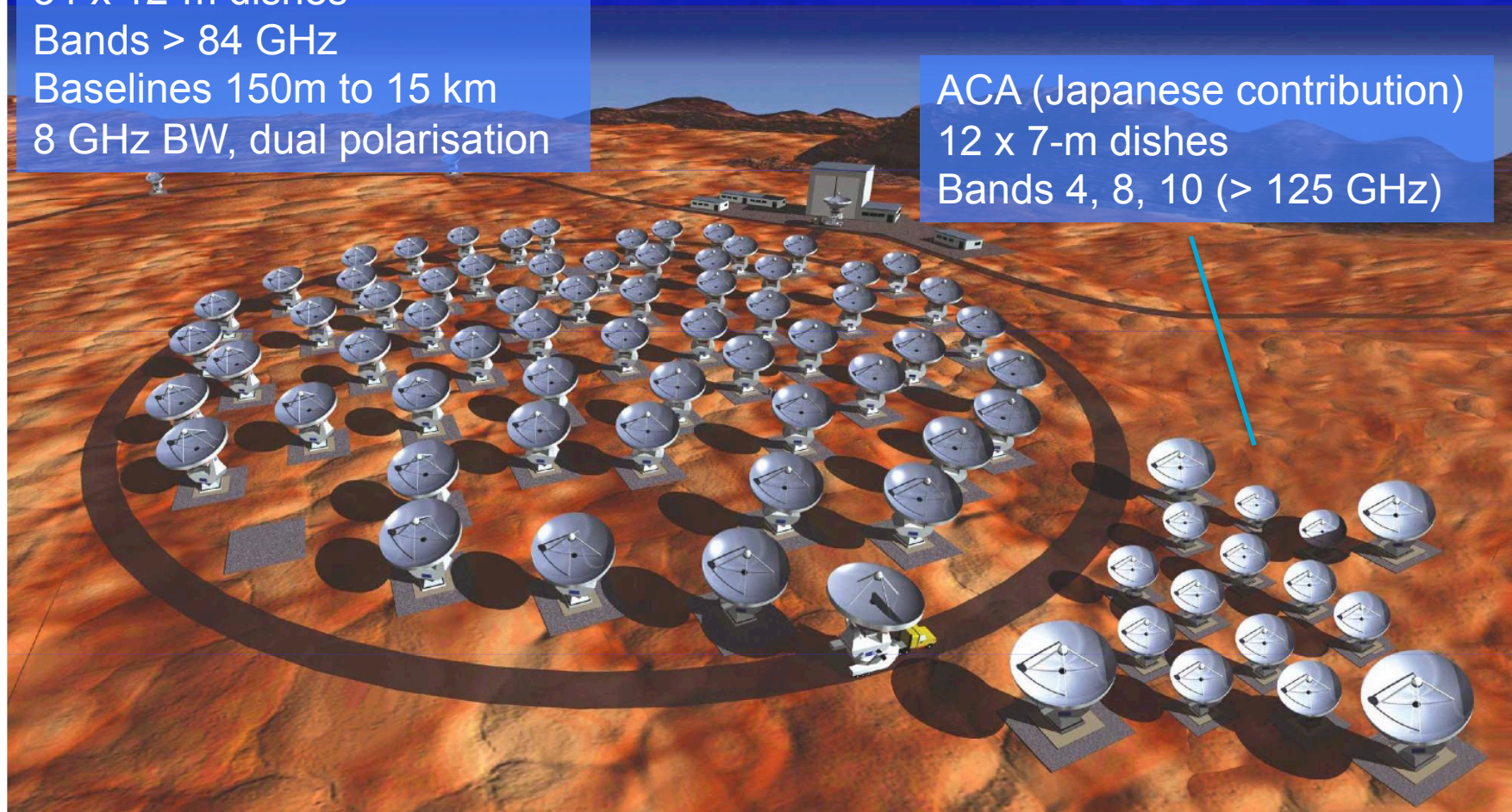




# ALMA + ACA → Atacama Large Millimeter/submillimeter Array

54 x 12-m dishes  
Bands > 84 GHz  
Baselines 150m to 15 km  
8 GHz BW, dual polarisation

ACA (Japanese contribution)  
12 x 7-m dishes  
Bands 4, 8, 10 (> 125 GHz)



# ALMA facts

with Tony Beasley, former ALMA Project Manager

- ALMA will spend ~20% time observing in the 3-mm band.
  - According to the ALMA Design Reference Science Plan ( v1.0) the foreseen use of the receiver bands is: Band 3(100 GHz) / 6 (230 GHz) / 7 (345 GHz) / 9 (690 GHz) = 20% / 30% / 37% / 13%. This is roughly consistent with expected weather conditions. Dynamic scheduling may send more observation to lower frequencies.
- When will be the first science?
  - There'll be a few antennas doing early science late 09/early 10.
- ALMA is a wide-field mapping instrument.
  - ALMA will have mosaicing capabilities. Early ALMA (6 antennas) will be 100 times more sensitive than ATCA at 90 GHz. The ALMA FOV is also a factor of 4 larger than ATCA. So compared with ATCA at 90 GHz, even early ALMA is going to be a mapping machine. You cannot beat ALMA on wide field.

# ALMA Facts *continued*

with Tony Beasley, former ALMA Project Manager

- ALMA is not completely closed access.
  - The US part is open access (37%).
- There will be no 12mm at ALMA.
  - Band 1 (the lowest ALMA band) is slightly higher (bottoms out at ~30 GHz). Therefore 12mm unlikely.
- University of Chile is planning to build a 7-mm (Band 1) ALMA band. (30 to 45 GHz).
  - They're building a prototype, planning a production run, who knows what will really happen.
- It is not too late for Australia to contribute to the ALMA project.

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*Vamos Australia!*



# ATCA's Key Science for mm wavebands

3 mm Band (90 GHz)

7 mm Band

12 mm Band

SED Measurements (1 GHz to 100 GHz)

Wide-field / Surveys

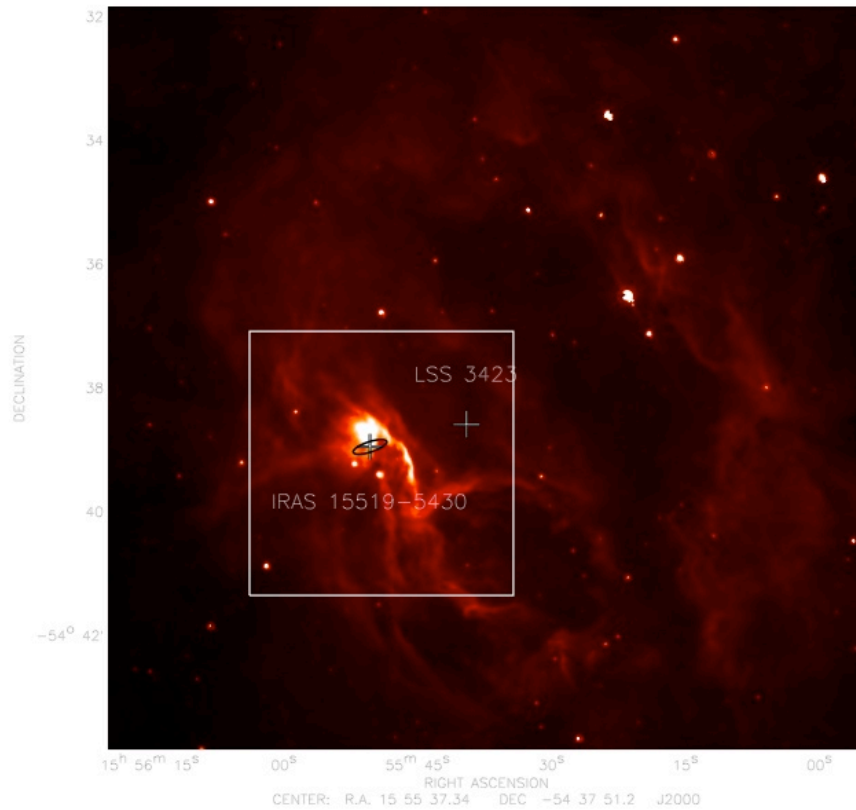
# 12mm & Wide Field Key Science

- Contribution from J. Urqhart and M. Thompson

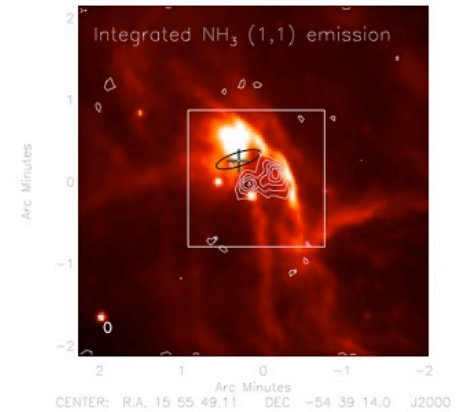
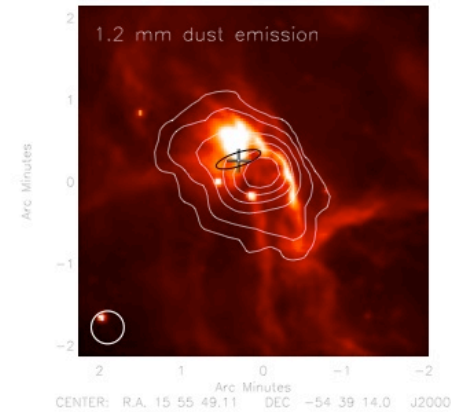
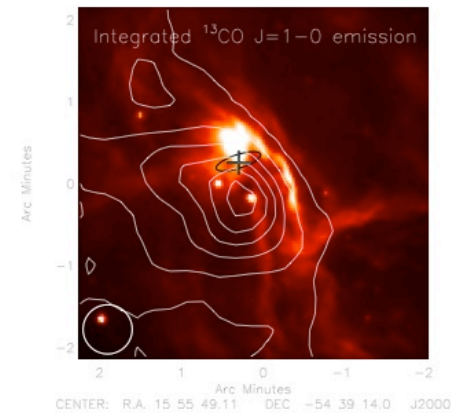
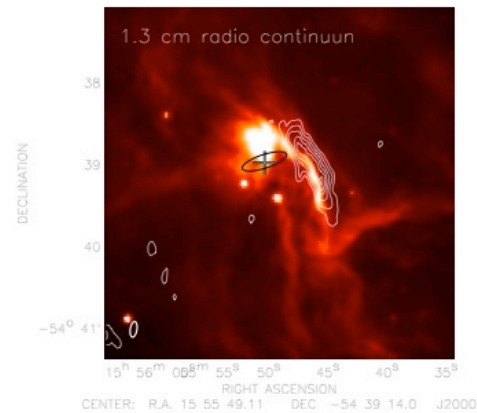
Future Projects:

- 12-mm ATCA and Mopra molecular study to identified sites of triggered star formation.
  - Southern Galactic Plane line surveys (e.g. CO, NH<sub>3</sub>) long overdue.
- 
- A multiwavelength approach is needed to study the birth place of massive stars.
  - NH<sub>3</sub> emission is an excellent probe of the physical and kinematic properties of massive cores.

# ATCA and Mopra molecular images of triggered star formation

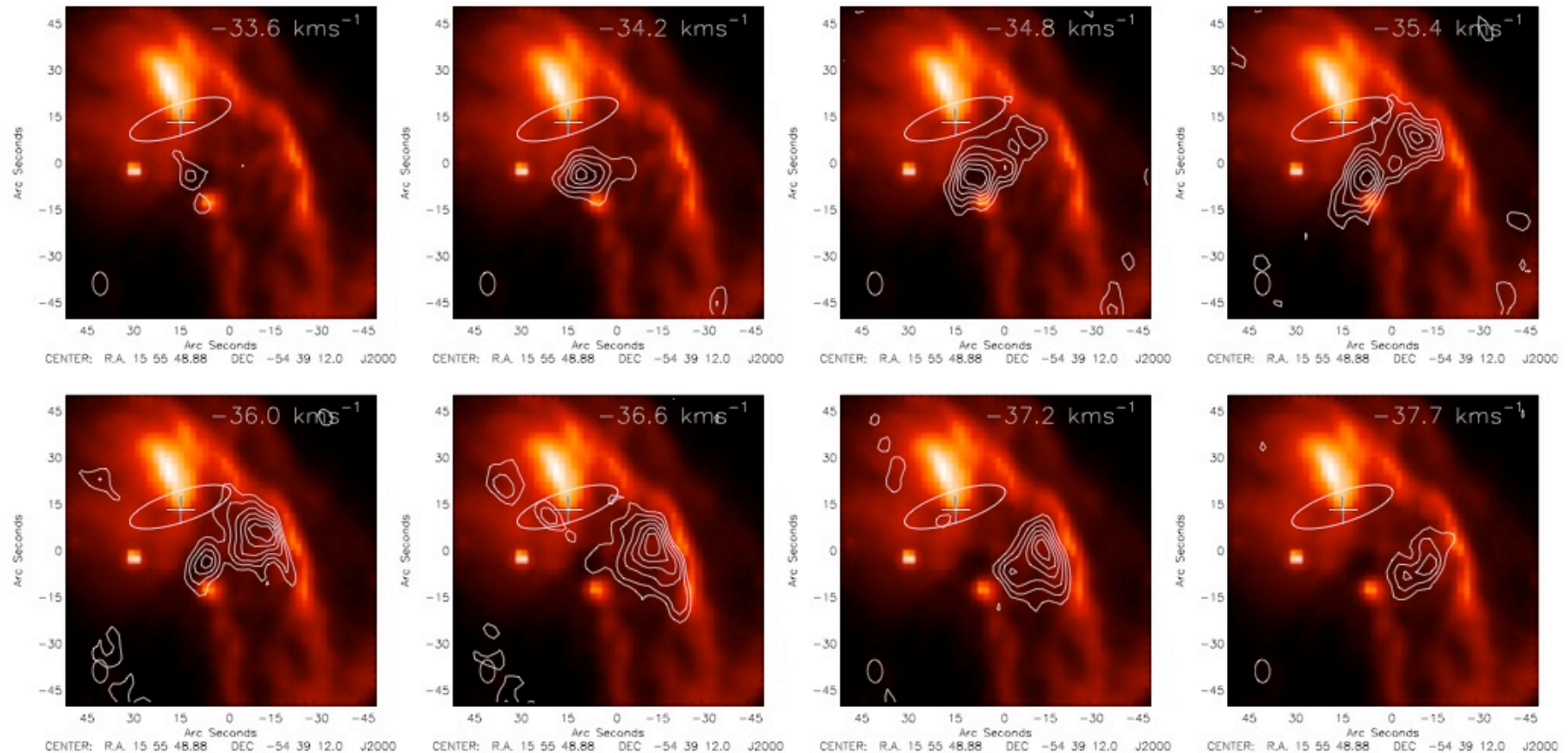


8μm GLIMPSE image of the  
bright-rimmed cloud SFO75



ATCA 13mm continuum, Mopra  $^{13}\text{CO}$ ,  
SIMBA 1.2 mm & ATCA  $\text{NH}_3$  (1,1)  
(Urquhart et al 2007, A&A 467, 1125)

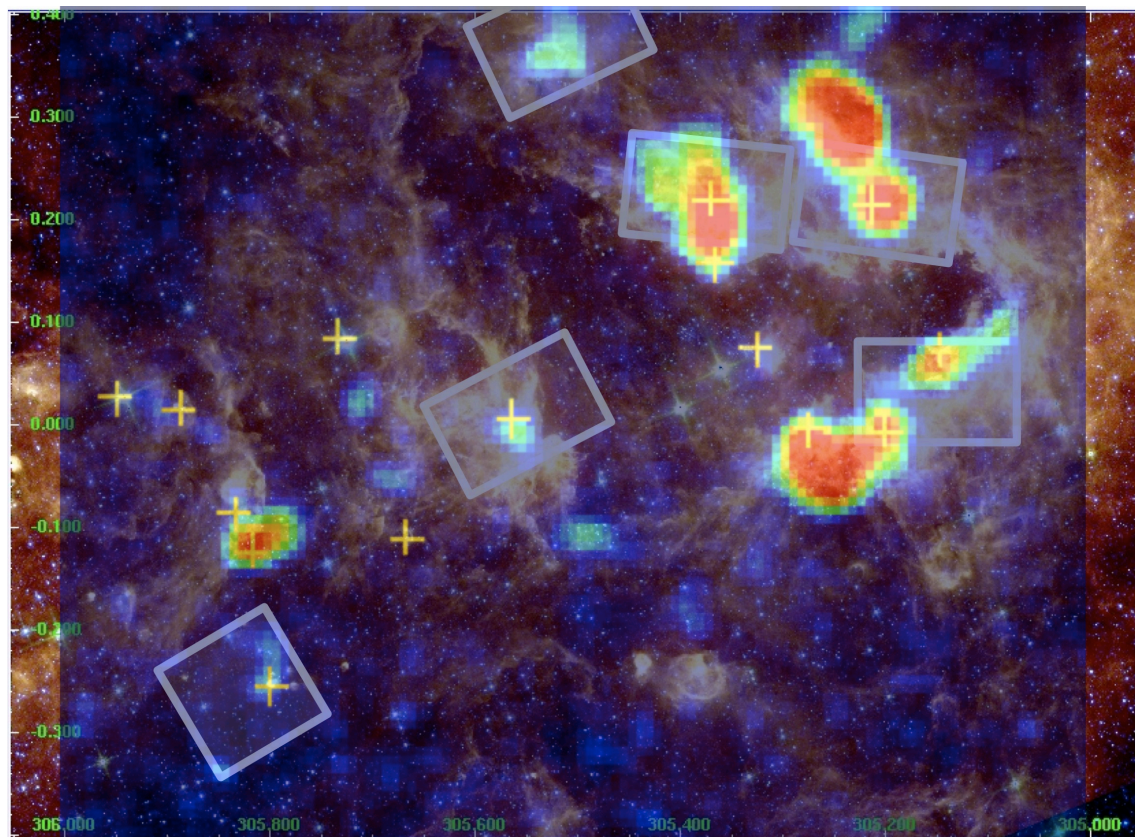




$\text{NH}_3$  channel maps show two cores, one compressed by the ionisation front of the cloud and one quiescent uncompressed core.

The compressed core is forming a massive stellar cluster (inc  $\text{CH}_3\text{OH}$  maser) but the uncompressed core is starless.

Triggered star formation in action?



But one cloud doesn't give the whole picture.

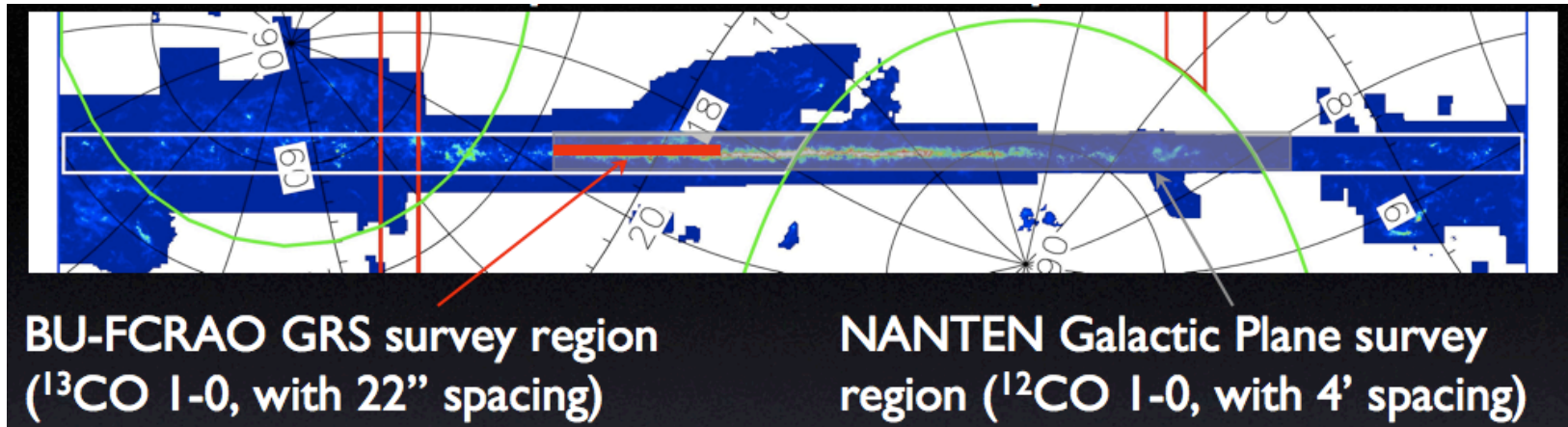
Need to examine whole HII regions to understand how star formation is triggered.

Wide-field degree-scale imaging is not ALMA's forte (at least not until OTF/focal plane array interferometry...)

G305 Giant HII region: GLIMPSE + HOPS  $\text{NH}_3$  (courtesy Andrew Walsh), plus mapped regions in Simba (courtesy Tracey Hill).

Mopra gives the wide-field view of dense molecular gas which can then be followed up at arcsec resolution with ATCA. A unique combination in the South until/if CCAT comes into play with ALMA.

# Southern kinematic distance surveys?



- Galactic Plane surveys are like buses - a number have turned up at once...
- FIR/sub-mm surveys particularly need mm-wave spectroscopic followup to determine kinematic distances
- But as yet, no high resolution Southern equivalent (NANTEN is best with only 4' resolution)
- Kinematic survey + FIR/sub-mm = "Luminosity Engine"
- Strong roles for ATCA & Mopra ( $\text{CO}$ ,  $\text{NH}_3$ , HOPS...)

# 7mm Key Science

- Contribution from S. Longmore

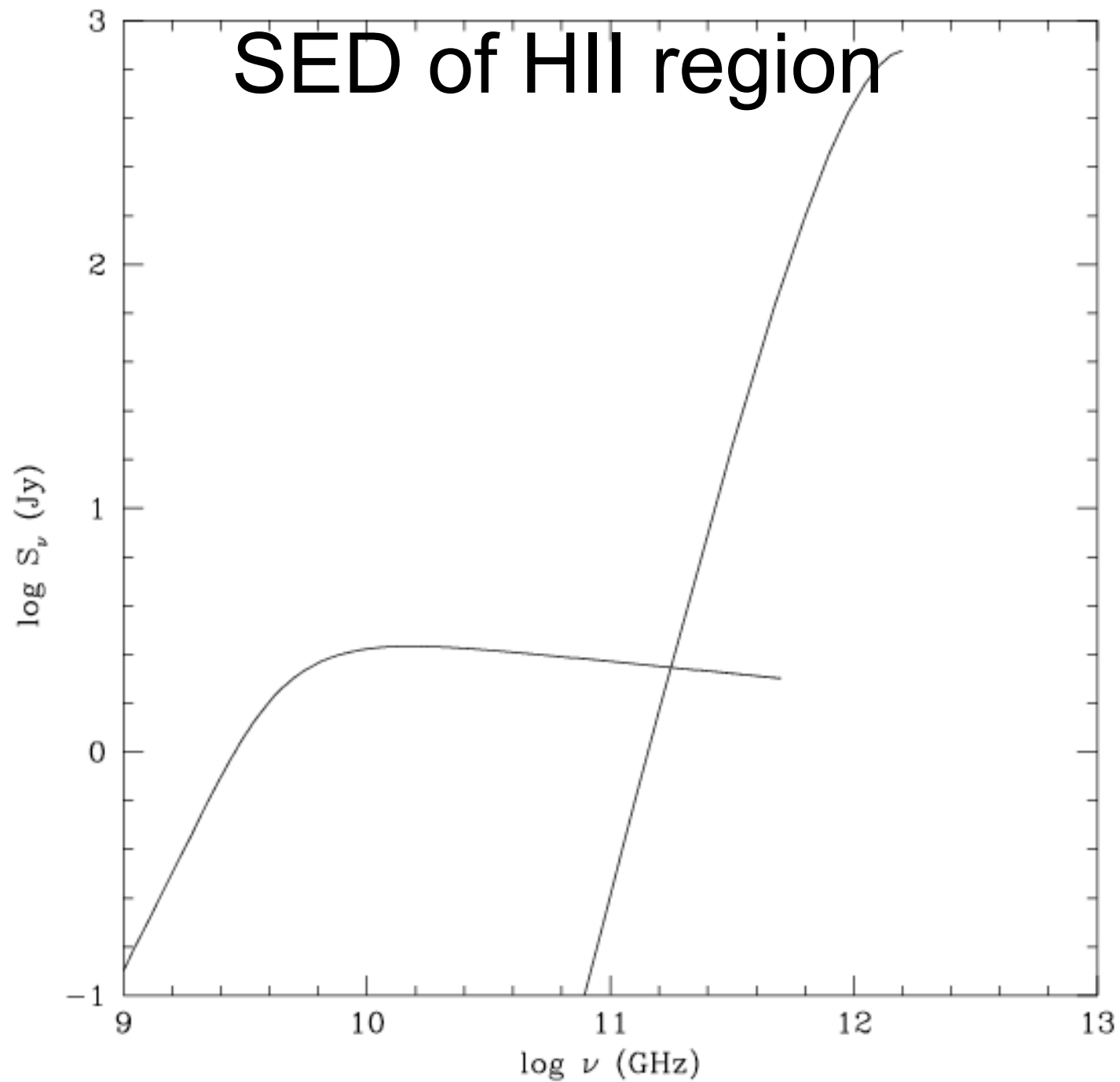
Future Project:

Finding and understanding Hyper-compact HII regions using ATCA

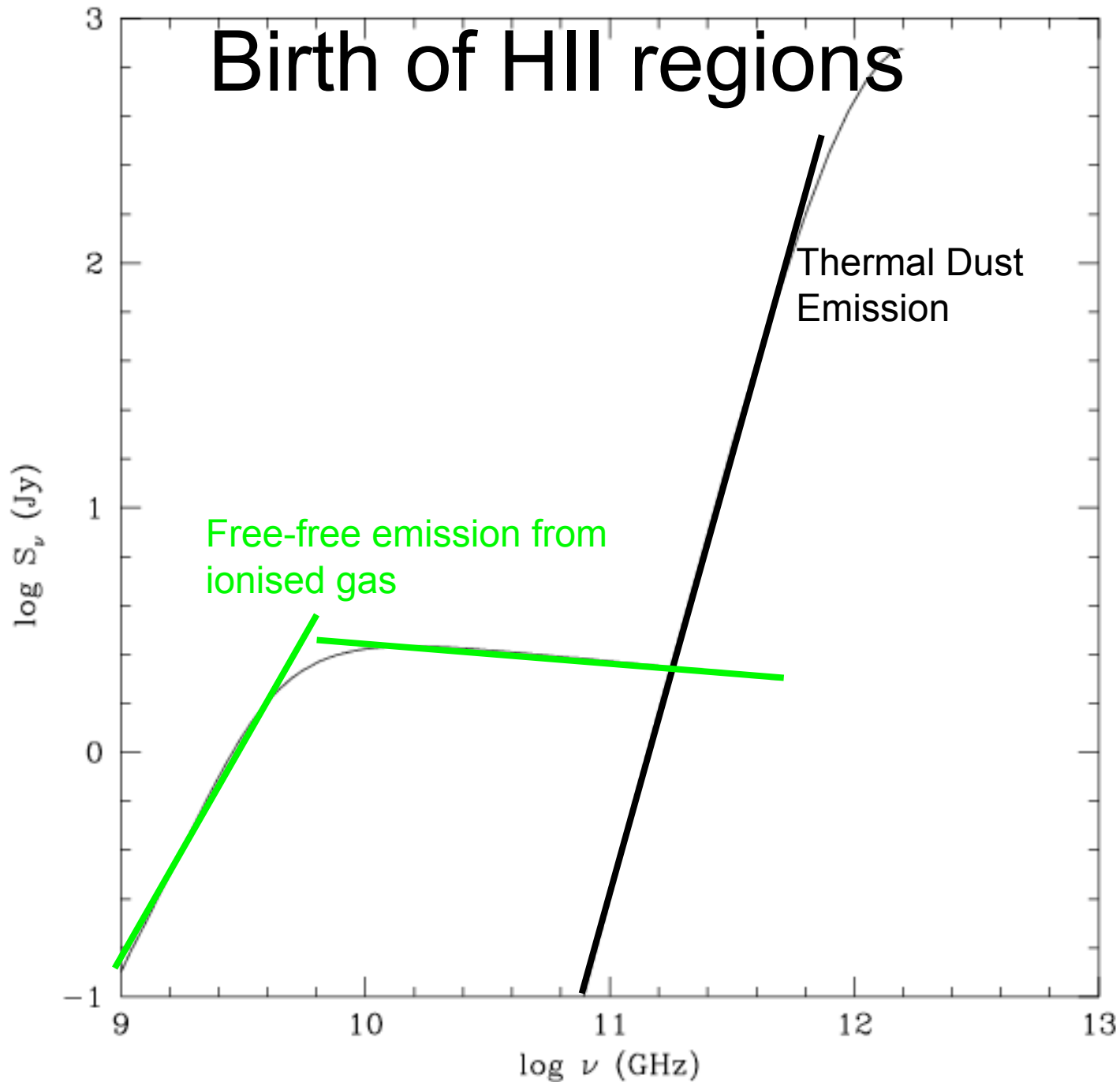
- The point at which a young massive star begins ionising its surrounding natal material - the birth of an HII region – is a key stage in its evolutionary process.
- While there are many well studied examples of the more evolved stages, these so-called “Hyper-compact” HII regions have proven elusive.



# SED of HII region

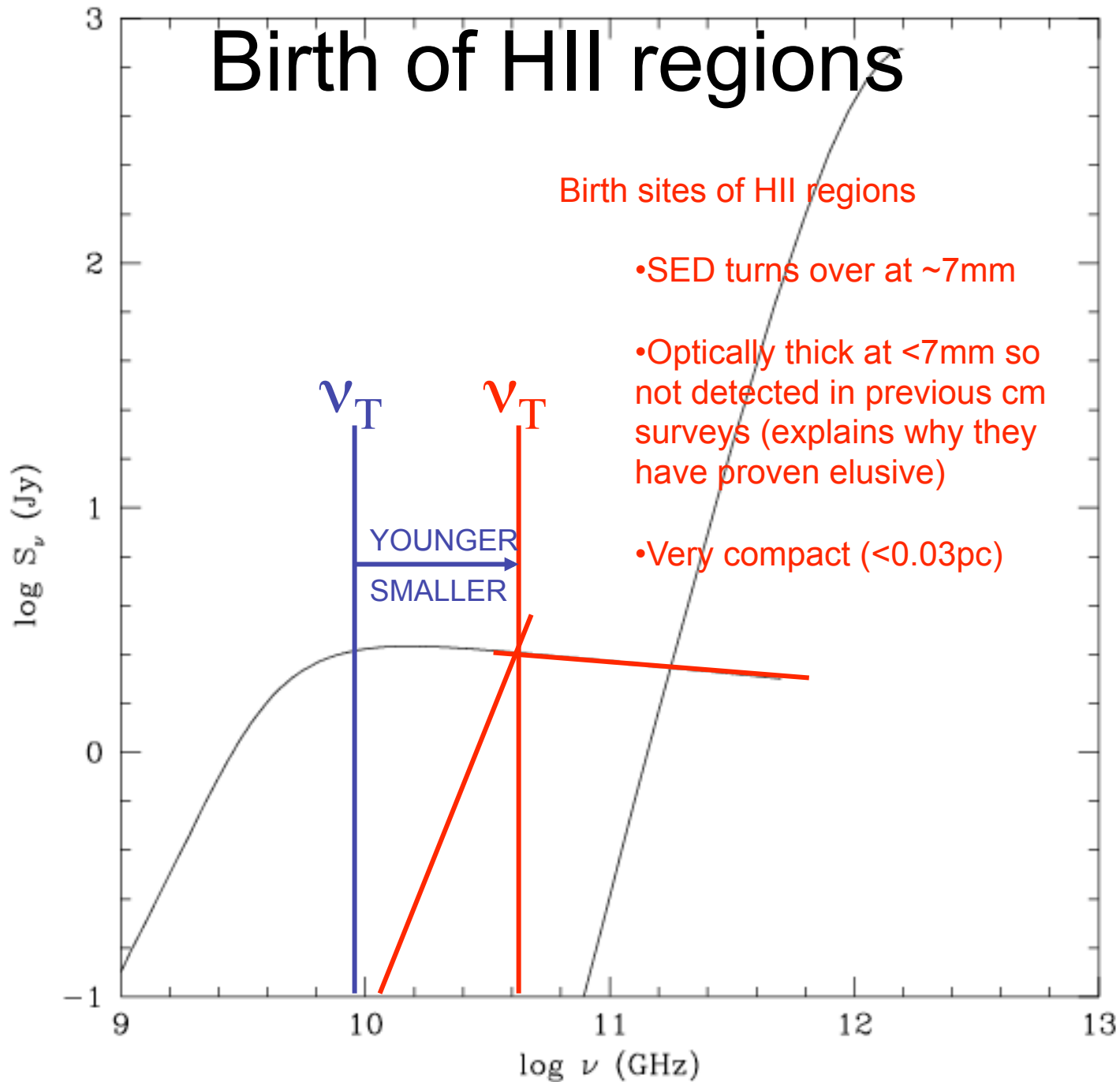


# Birth of HII regions





# Birth of HII regions

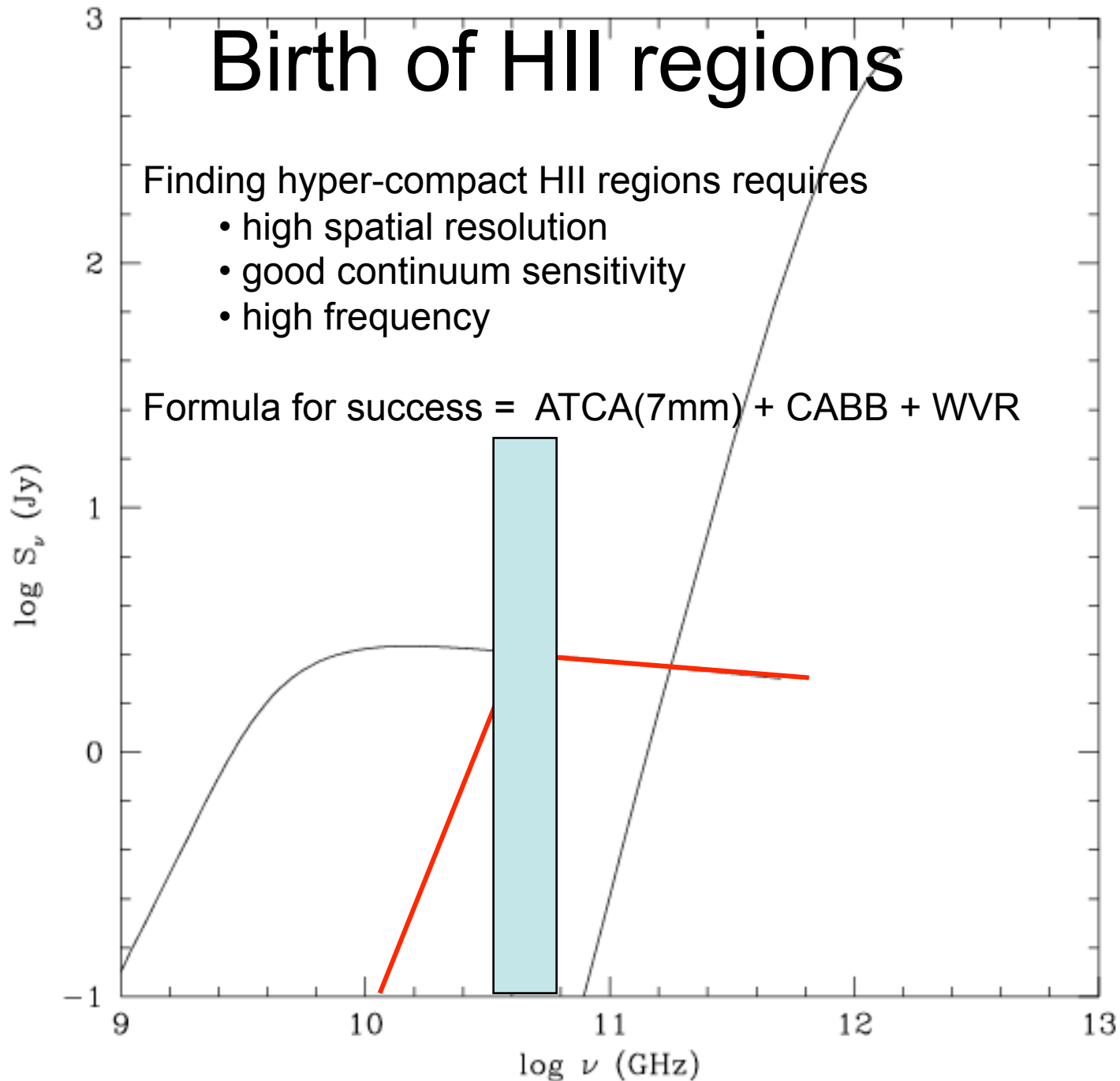


# Birth of HII regions

Finding hyper-compact HII regions requires

- high spatial resolution
- good continuum sensitivity
- high frequency

Formula for success = ATCA(7mm) + CABB + WVR



# 3mm Key Science

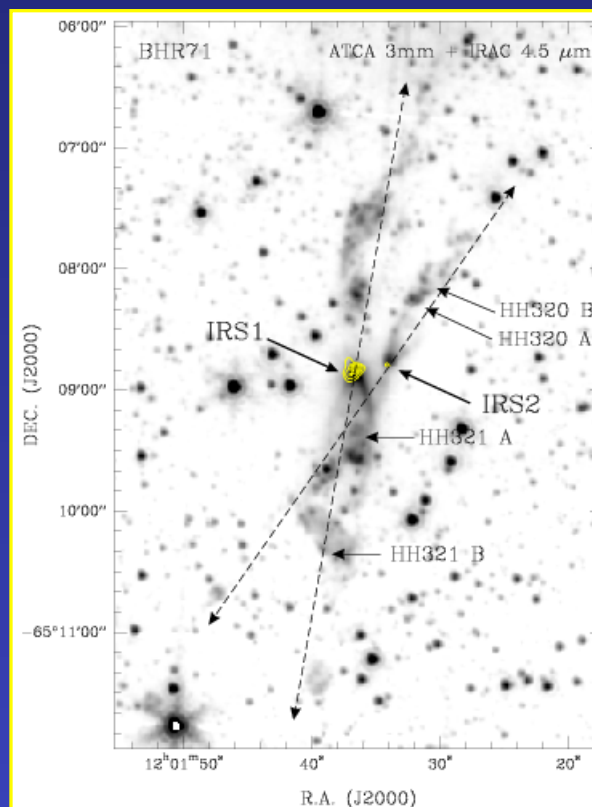
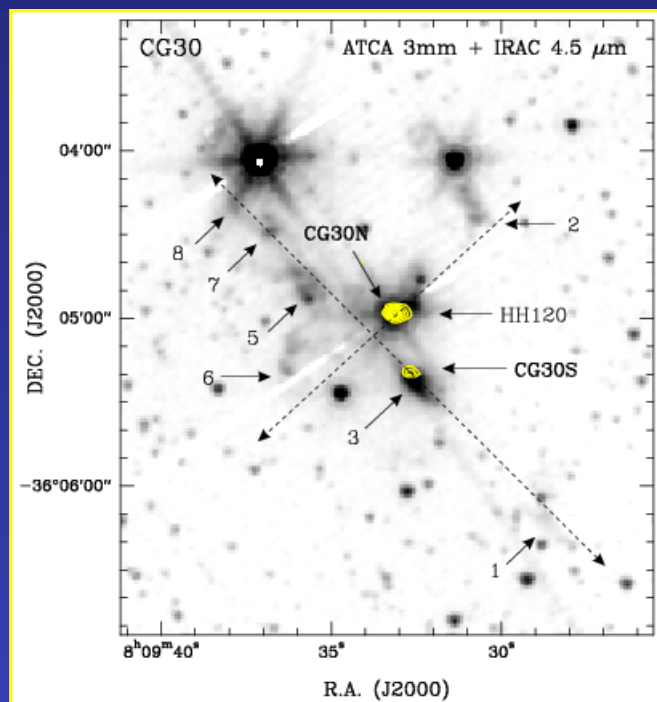
Contribution from T. Bourke et al.

Future Project:

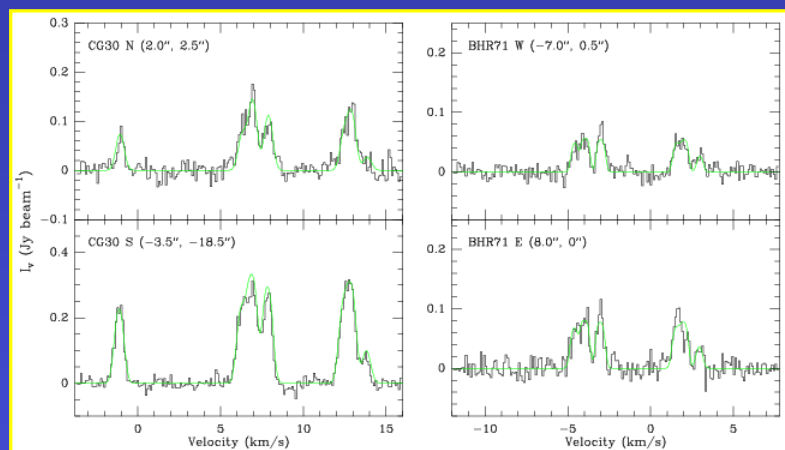
Systematic search for binary protostars & to derive their kinematic properties using ATCA and PdBI.

- At the typical temperatures and densities of low-mass cores, lines in the 3-mm window are easily excited, and the structure and gas motions are best studied in this window.
- At the higher densities, traced by molecular rotational lines at  $< 1.3$  mm, only the very centre of such cores are probed, and only those that are very close to star formation. But at these densities almost all molecules are frozen out onto dust grains.
- Essentially one is left with  $\text{H}_2\text{D}^+$  and other H and D only molecules. Some  $\text{N}_2\text{H}^+/\text{N}_2\text{D}^+$  will be present, but not easily excited in their lines at  $< 1.3$  mm.
- Therefore the  $\text{H}_2\text{D}^+(1-0)$  transition at 93.17 GHz is an excellent probe of low-mass cores.

# ATCA results I: CG30 & BHR71



Spitzer IRAC 2 (4.5  $\mu\text{m}$ ) images (grey scale) of CG30 (left) and BHR71 (right), overlaid with the ATCA 3mm dust continuum contours (yellow). Contours start at  $3\sigma$  with steps of  $2\sigma$  ( $1\sigma$  noise is  $\sim 0.5\text{mJy}$  for CG30 and  $\sim 2\text{mJy}$  for BHR71). Dashed arrows show the directions of protostellar jets.



ATCA  $\text{N}_2\text{H}^+(1-0)$  spectra at the peak positions of the two cores in CG30 (left) and BHR71 (right). Green dotted curves show the results of hyperfine structure line fitting.

# SED Key Science

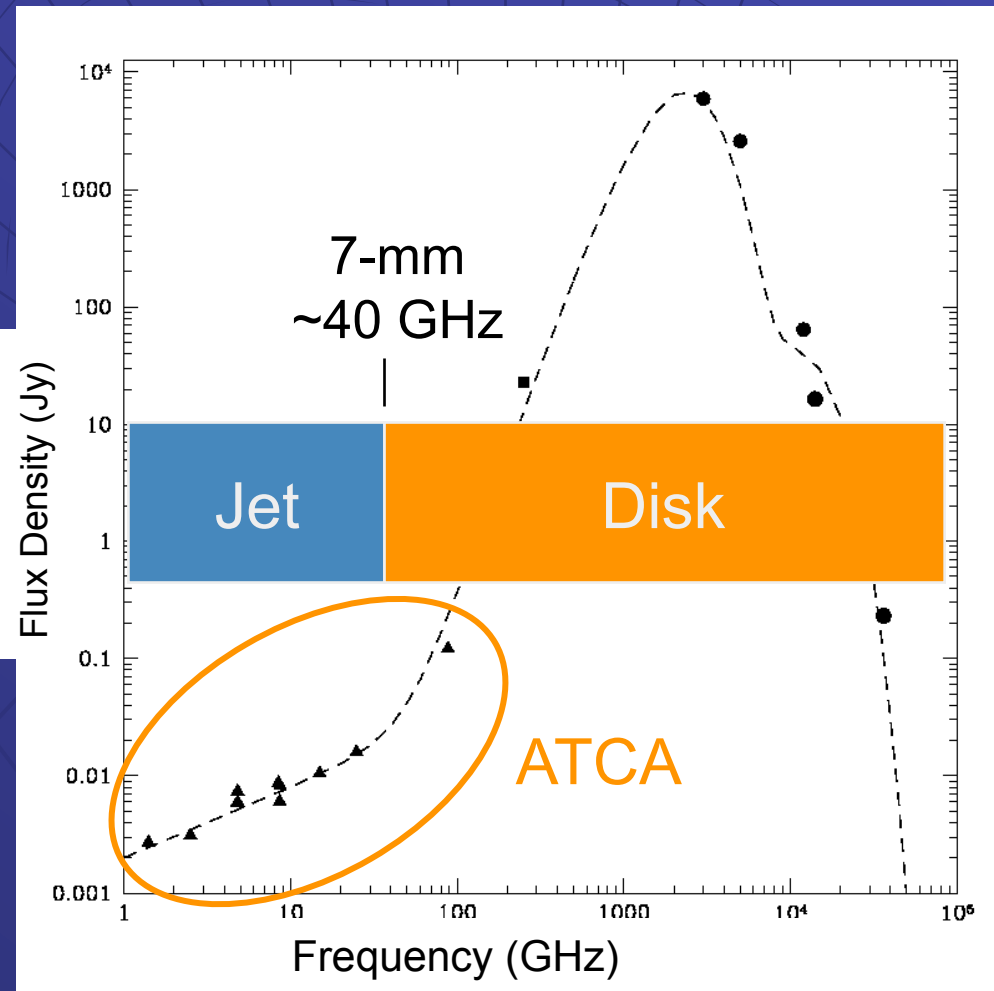
- Contribution from K. Brooks, G. Garay, A. Guzman

Future Project:

Systematic search via ATCA SED studies for jets associated with young massive stars.

- The evidence for jets associated with young massive stars is scarce.
- If massive stars form in a similar way to low-mass stars (e.g. disk/jet accretion mechanism) then we expect more massive star-forming jets to exist.
- We will search for jet signatures in the SED emission (from 1 to 90 GHz) towards a sample of young massive stars. The positive detections will be then followed-up using other southern hemisphere facilities such as APEX, VLT, GEMINI & ALMA.

# Ionized Jet Signatures



$$S_\nu \propto \nu^{0.6}$$
$$\Theta_\nu \propto \nu^{-0.7}$$

IRAS 16547-4247

-> 7-mm probes brightest jet emission

-> 7-mm probes closest to the star

Brooks, Garay, Voronkov, Rodriguez 2007 ApJ



# SED Key Science

- Contributions from D. Lommen, C. Wright & T. Bourke

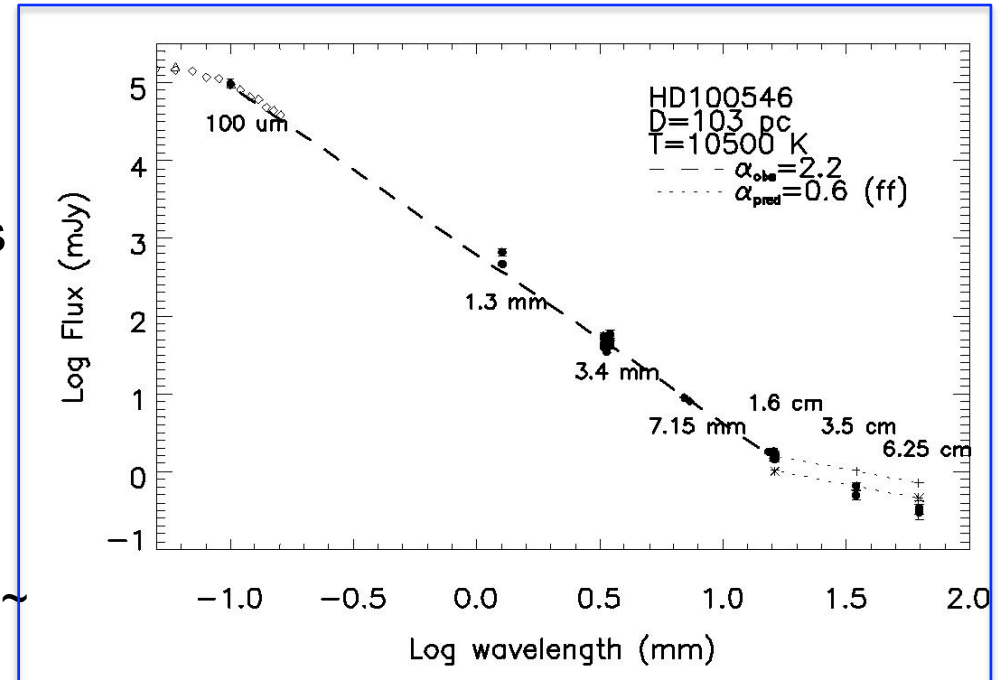
Future Project:

Millimetre and centimetre ATCA observations in the search and studies of proto-planetary disks

- In the study of disks around T-Tauri stars the synergy of ATCA observations at 12, 7 and 3-mm (and even longer wavelengths) are important. Only with such observations can you really search for grain growth through changes in the spectral index of the dust.
- For ALMA to image gaps and proto-planets directly the largest baselines at the highest frequencies are needed. Such observations will be challenging.
- ATCA offers a unique way to study proto-planetary disks.

# HD100546: Results

- Spectral index of SED from 100  $\mu\text{m}$  up to 16 mm is  $\sim 2.2$
- 7 measurements at 16 mm show that the flux is **stable** on time-scales of days to months to years
  - Likely rules out stellar magnetic activity as emission mechanism
- Emission is **resolved** at both 3 mm and 16 mm
  - FWHM of Gaussian fitted source is  $\sim 100$  AU at 3 mm and  $\sim 50$  AU at 16 mm
- Emission is **unresolved** at 3 cm in 6C configuration
  - The 16 mm and 3 cm emissions originate from **different spatial scales**, and so have **different dominant emission mechanisms**
- Argues for **thermal dust emission** up to at least 16 mm



# Conclusions

- **HD100546**

- **Large, mm- to cm-sized, grains** detected in the disk around HD100546 through multi-frequency ATCA observations
  - But are these a result of growth from small sizes, or collisional grinding from larger sizes?
- Smaller spatial extent at 16 mm compared to 3 mm suggests that the **bigger grains are concentrated closer to the star**
  - Consistent with planet formation scenarios
- Detection of rotating molecular gas with ATCA and NANTEN2 suggests that the **disk may not be as evolved** as might otherwise be concluded from the IR spectrum
  - Could planet building be an ongoing process?
  - Or is what we see a result of collisions between large bodies?
- To do
  - **i)** Write some papers, **ii)** fill in the ‘gap’ in disk size at 7 mm, **iii)** observe more molecules and do some chemistry, **iv)** try some new targets

- **ATCA**

- **Is brilliant**
- Is **unique** in allowing observations of circumstellar (planetary) disks and their host stars all the way from 3 mm up to 6 cm
- This capability is absolutely **crucial both** pre- and post-ALMA arrival
  - ATCA will be nicely complemented by ALMA (yes, I meant it this way!)
    - The idea of a “limited window of opportunity” for ATCA is self-defeating
      - » Though we should of course exploit this period (and we are!)
- Several Australian university groups are now at the **forefront** of an exciting research area, and **rely** on ATCA’s continued operation at **all** mm bands for their ‘survival’

# SED Key Science

- Contribution from I. Prandoni

Future Project:

ATESP-DEEP1: Higher Frequency Follow-up

To study AGN activity and faint radio source population

- ATESP (Australia Telescope ESO Slice Project radio survey)
  - initially at 1.4 GHz, followed by 5, 8 and 20 GHz.
  - Over the region of the ESO Slice Project (ESP) galaxy redshift survey.
- A way to distinguish various accretion models is by studying spectral index ( $\alpha$ ,  $S \sim \nu^\alpha$ ) over as wide a range of frequencies as possible, since different models exhibit different spectral behaviour.
- Important are frequencies beyond 10 GHz (20 GHz up to the mm and sub-mm domain, where ADAF spectra peak).

## ATESP-DEEP1: High frequency follow-up

→ ATCA: Multi-freq simultaneous obs. [5, 8, 20 GHz]

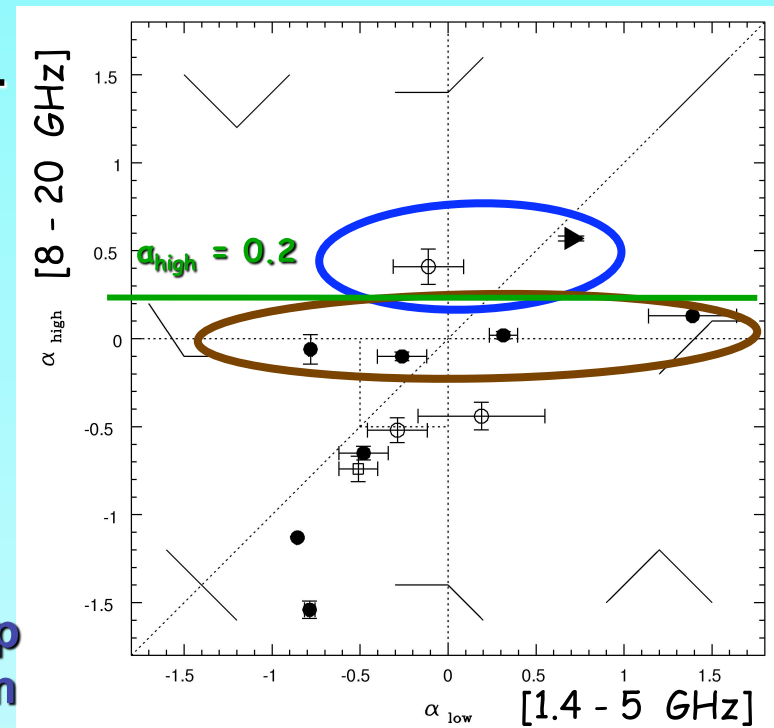
**Jet-dominated sources:**  $-0.7 < \alpha < 0.2$  depending on relative contr. of extended (opt-thin) and base (self-abs.) jet components

**ADAF:**  $0.2 < \alpha < 1.1$  up to mm- $\lambda$  (Nagar+ 01) with  $\alpha$  varying with accr. rate ( $\alpha \sim 0.4$  if  $L \sim 10^{-4} L_{\text{Edd}}$ ;  $\alpha \sim 1$  if  $L \sim 10^{-7} L_{\text{Edd}}$ )

Flux-limited sub-set of 15 ATESP-DEEP1 Early-type radio galaxies with  $S > 0.6$  mJy

- most consistent w. jet-dominated systems ( $\alpha < 0.2$ )
- Base jet components or Jet+ADAF ( $\alpha \geq 0$ ) systems
- 2 radio sources still consistent with pure ADAF systems ( $\alpha > 0.2$ )

Important to obtain ATCA 7 and 3 mm follow-up to better assess accretion regimes and confirm ADAF candidates



## **Future: Combining radio and mm wavelengths [combining ATCA and ALMA]**

- ✓ **A combination of ATCA and ALMA will permit us to determine the SED of the radio source over a wide range of radio frequencies, and thus to discriminate between the different accretion models.**
- ✓ **ALMA observations will provide high-quality and high-resolution imaging in the (sub)-mm range (and can match HST, and AO-assisted ground-based telescopes)**
- ✓ **ALMA will resolve structure and dynamics of molecular gas around nearby AGN: direct information on accretion scenario.**



# Summary for mmATCA Key Science

3 mm Band (90 GHz)	Star Formation <i>low-mass cores</i>
7 mm Band	Star Formation <i>HCHII regions</i>
12 mm Band	Star Formation & ISM <i>NH3 emission</i>
SED Measurements (1 GHz to 100 GHz)	Star Formation <i>Jets, Disks, Grain Growth</i> Galaxies AGN
Wide-field studies (with future FPA)	Star Formation & ISM <i>NH3 &amp; CO</i>

# Comments from around the globe

- Check out the notice board for comments from leading mm astronomers.

*“At lower freq, the ATCA could play a crucial supporting role for ALMA, doing many of the cm-related support work, like NH<sub>3</sub> or H<sub>2</sub>O mapping in star forming regions. ”*

*Chris Carilli*

*“In the North, the EVLA will more than complement ALMA at longer wavelengths, but in the South the ATCA would need serious upgrades. As a minimum I would consider RXs similarly wideband to the EVLAs (+ the necessary correlator).”*

*Karl Menten*

*“I think it is very unlikely that ALMA will not have an open-sky policy.”*

*Leonardo Testi*

*“You cannot beat ALMA on wide field.”*

*Tony Beasley*