

# ALMA observations of recombination line and free-free emission from nearby starbursts

**George J. Bendo**

UK ALMA Regional Centre Node  
Jodrell Bank Centre for Astrophysics



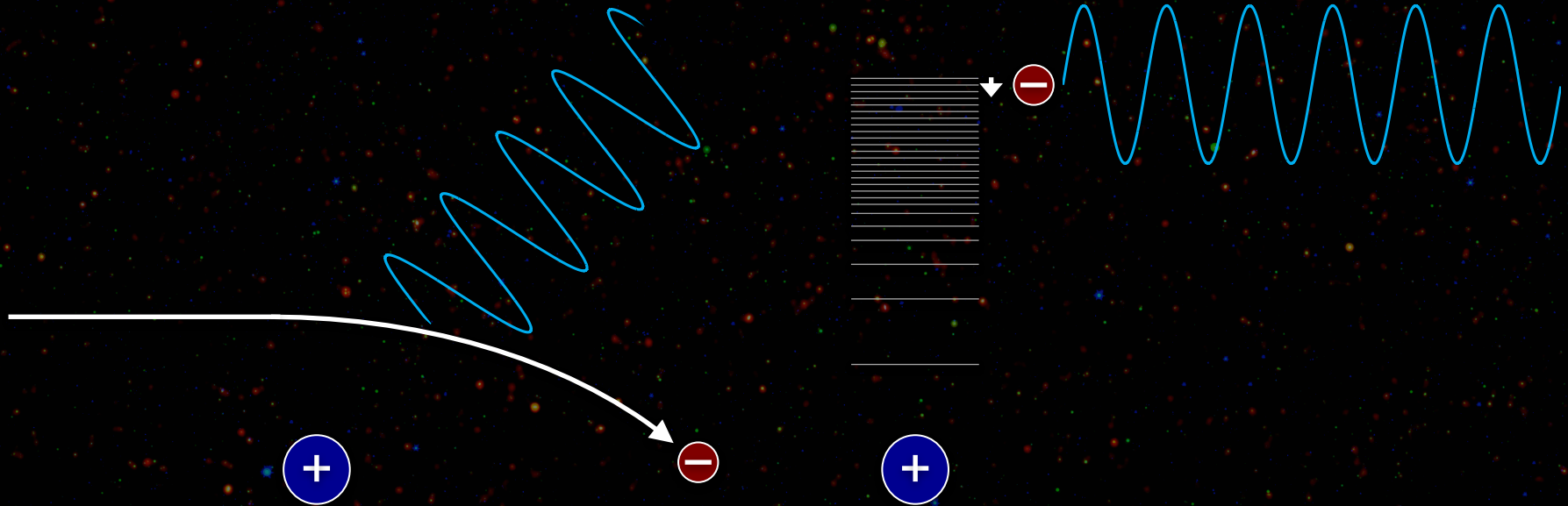
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ALMA can detect emission from photoionized gas in two forms:

- Free-free continuum emission
- Higher order recombination line emission

This emission has two advantages over other commonly-used star formation tracers:

- It directly traces young, photoionizing stars.
- It is unaffected by dust attenuation.

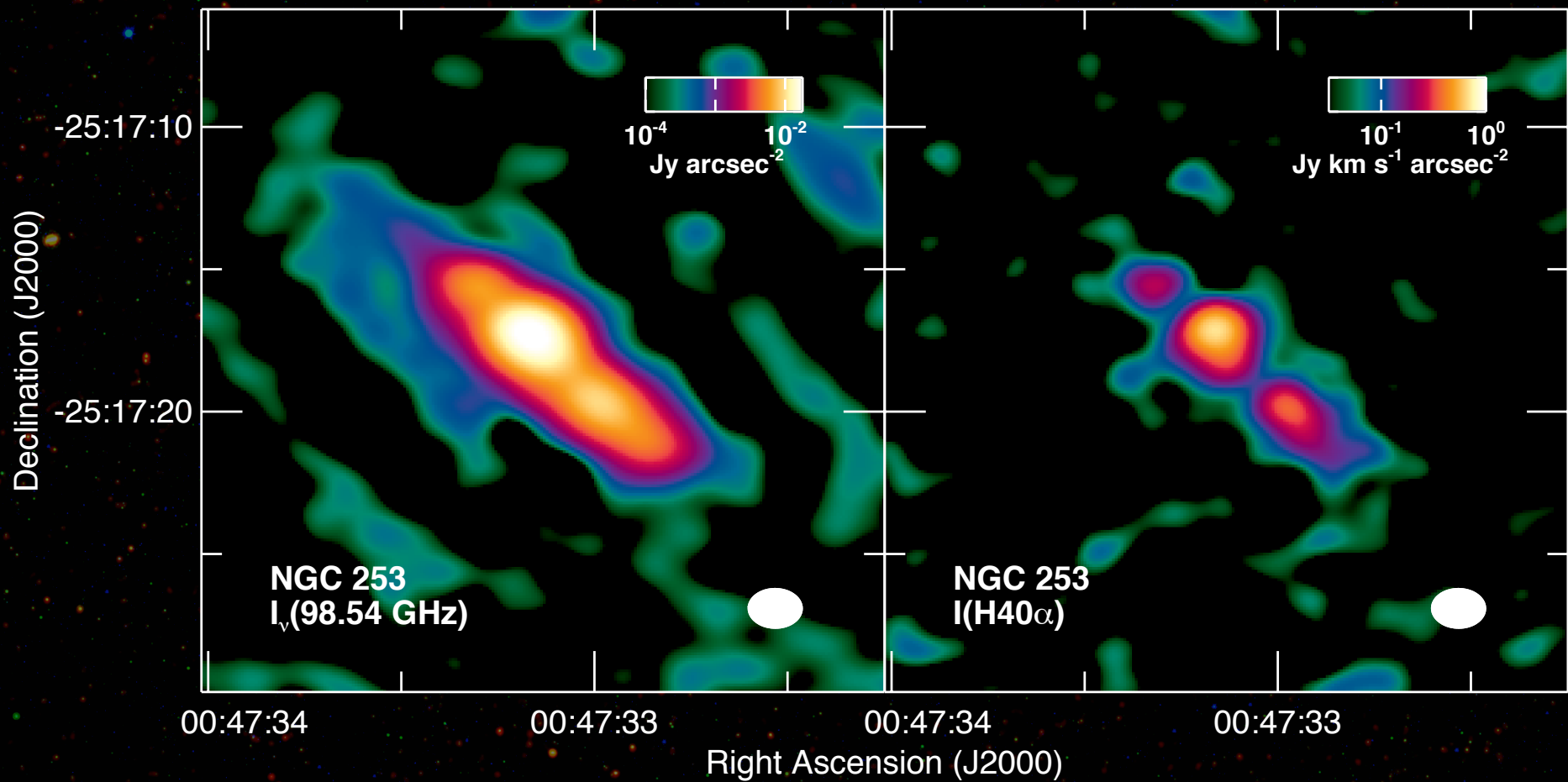


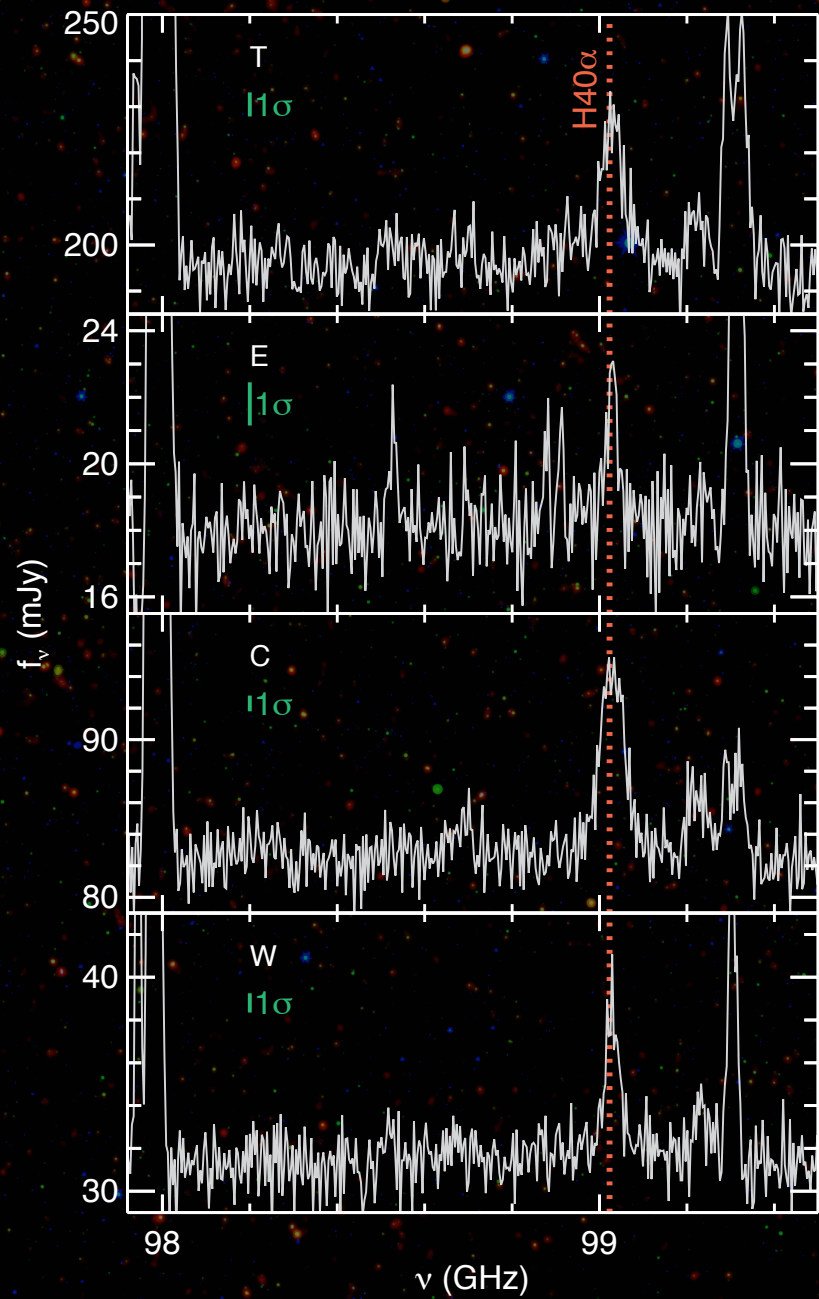
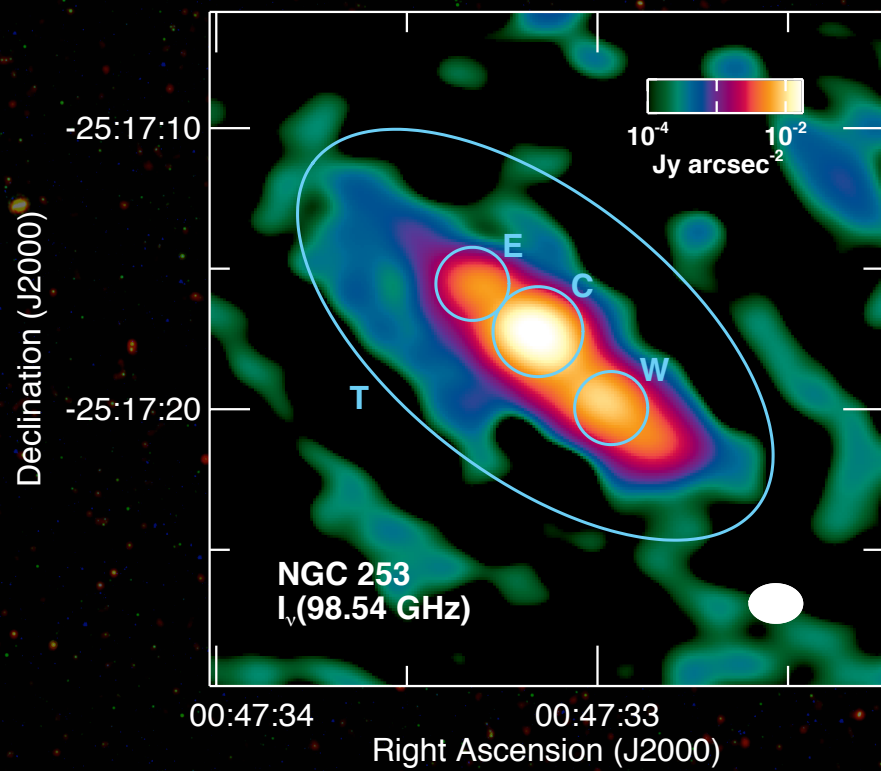
Free-free emission

Recombination line emission

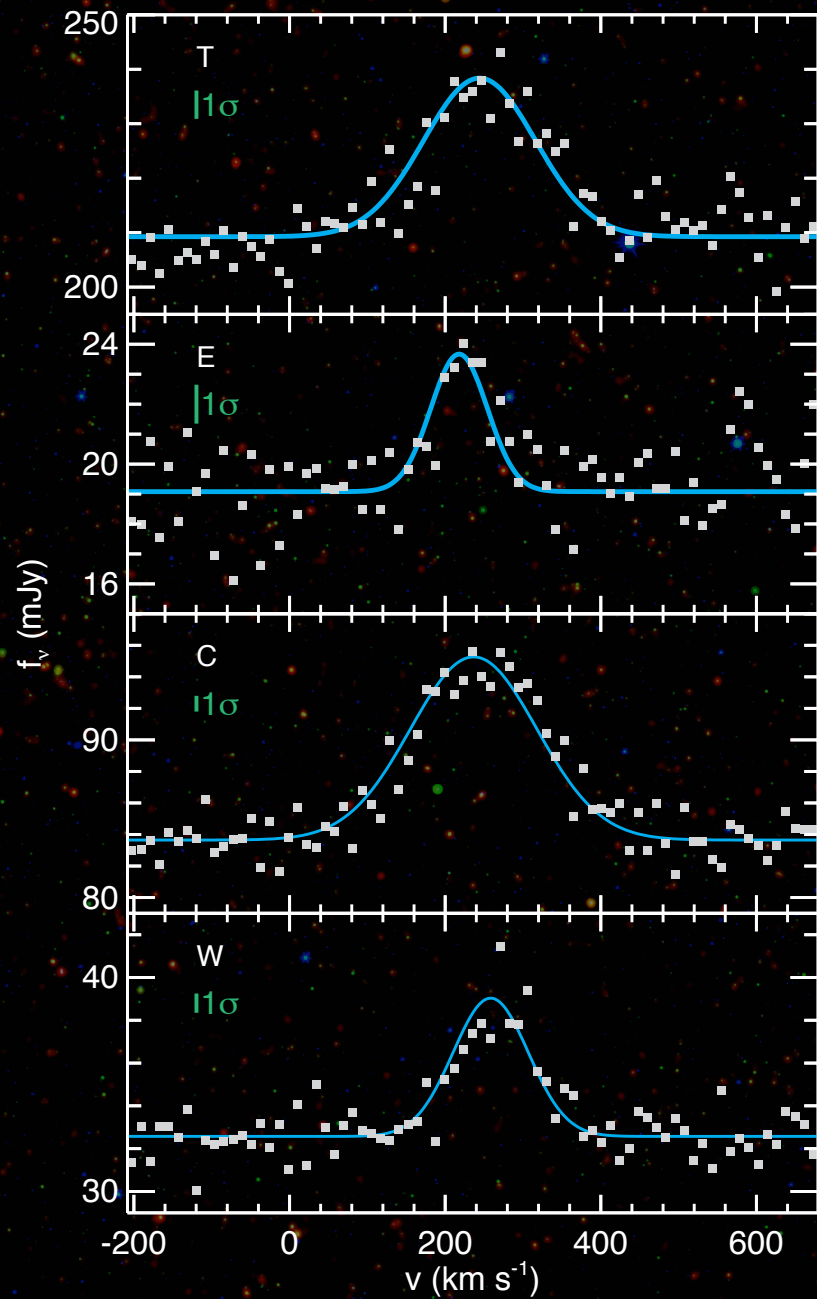
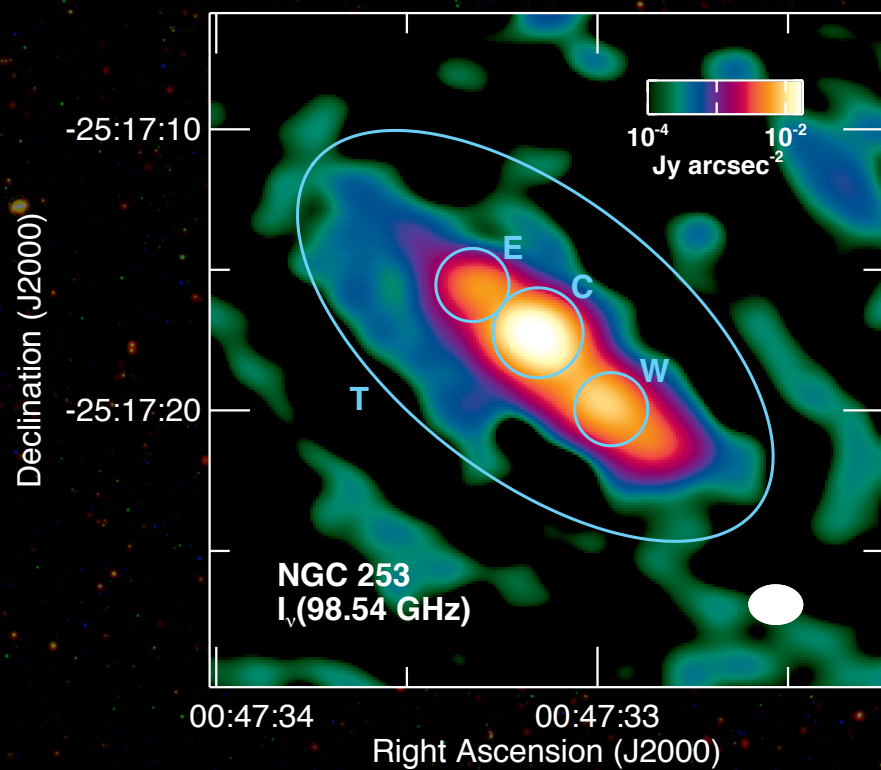
In this talk, I will talk about three galaxies where ALMA has detected recombination line emission:

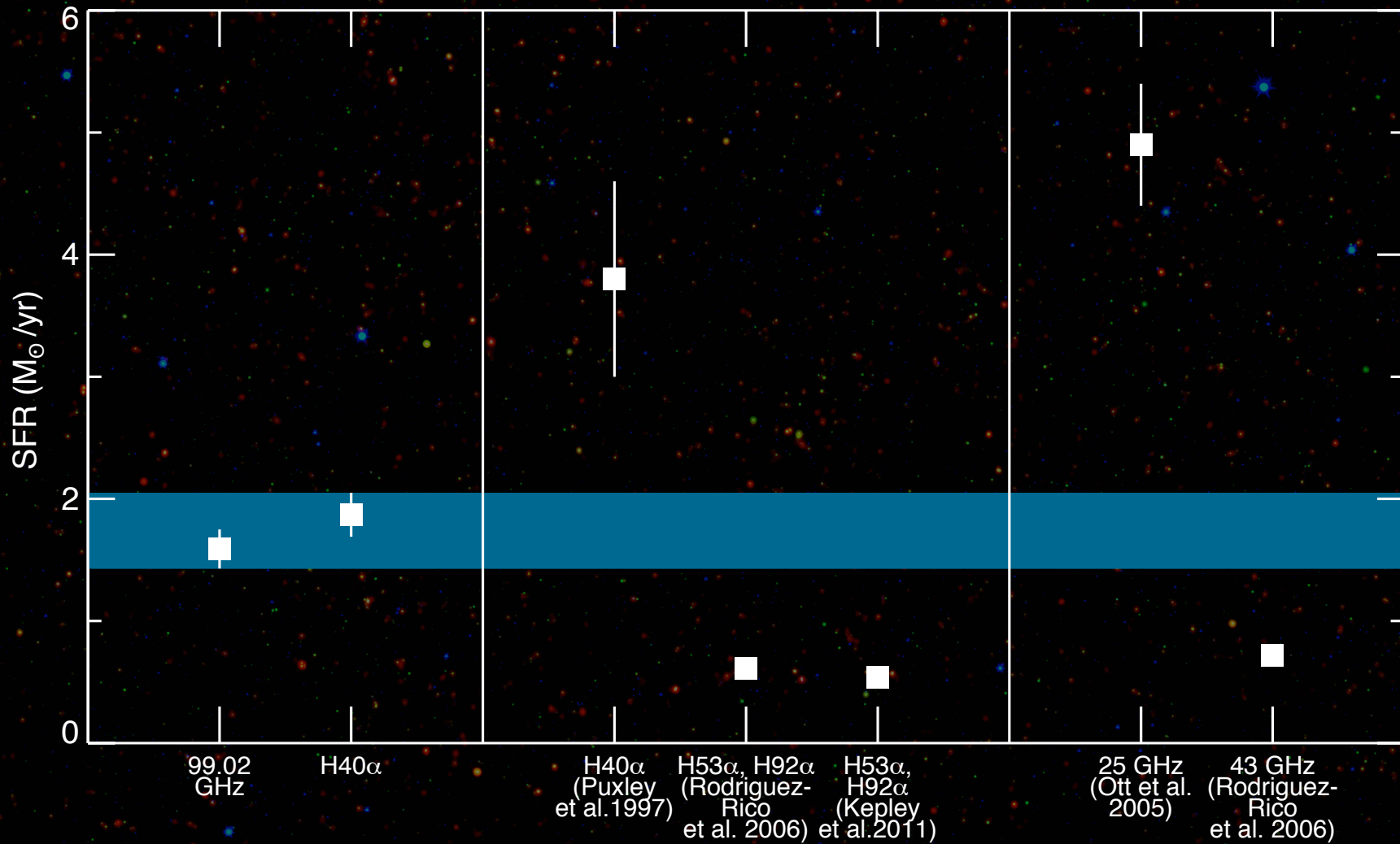
- **NGC 253** (spiral galaxy with nuclear starburst)
  - Bendo et al., 2015, MNRAS, 450, L80
  - Meier et al., 2015, ApJ, 801, 63
  - Ando et al., 2017, ApJ, 849, 81
  - Nakanishi et al., 2017, in preparation
- **NGC 4945** (spiral galaxy with starburst/AGN nucleus)
  - Bendo et al., 2016, MNRAS, 463, 252
  - Hinkel et al., 2017, submitted
- **NGC 5253** (low metallicity blue compact dwarf galaxy)
  - Bendo et al., 2017, arXiv (1707.06184)
  - Miura et al., 2017, submitted







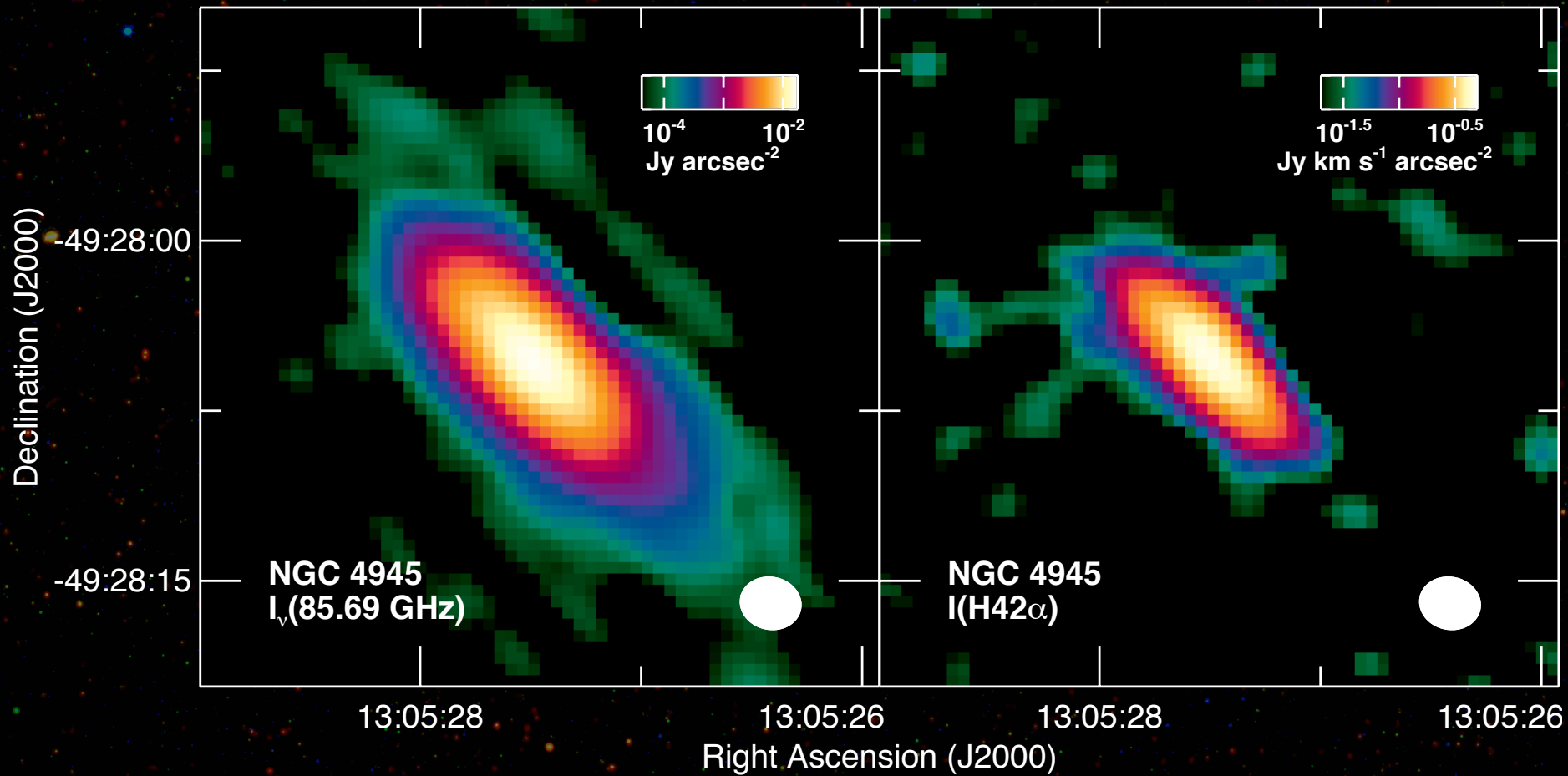


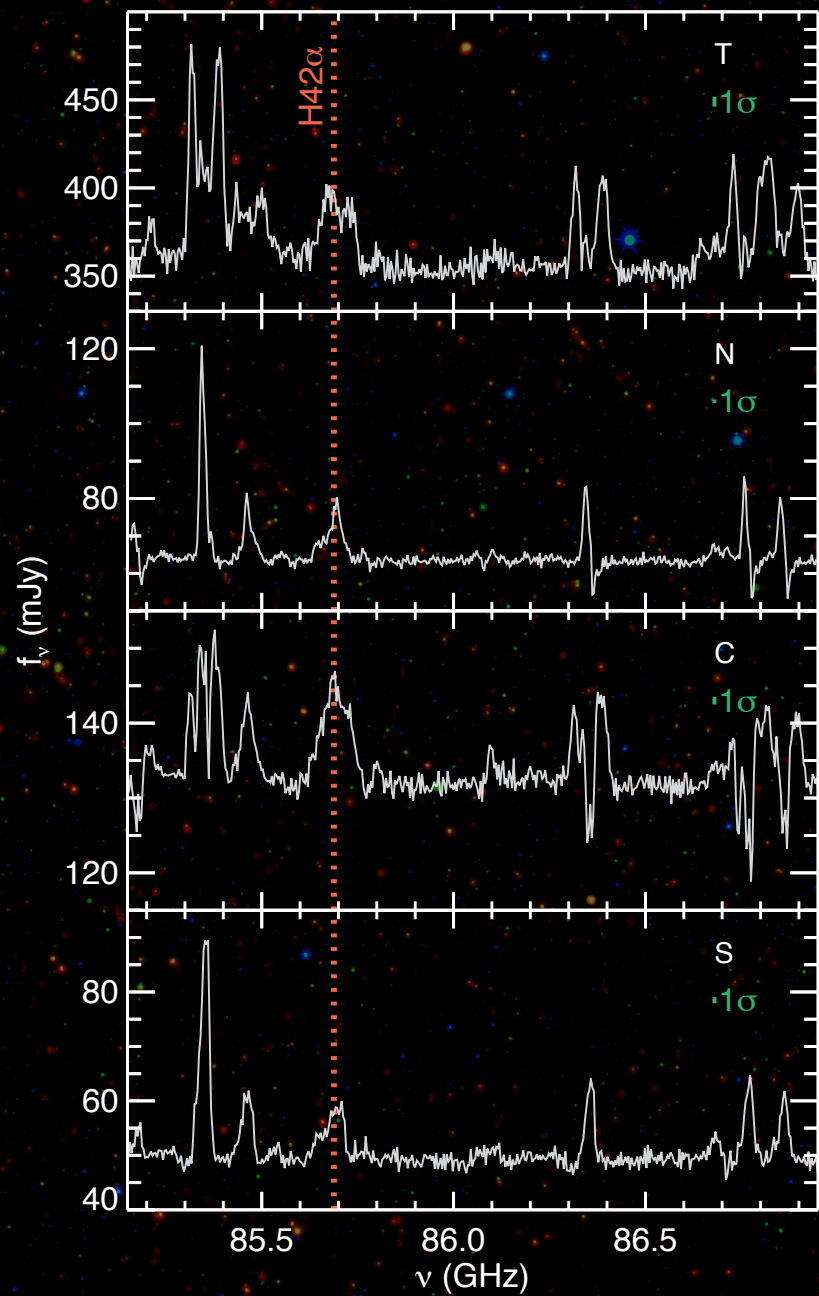
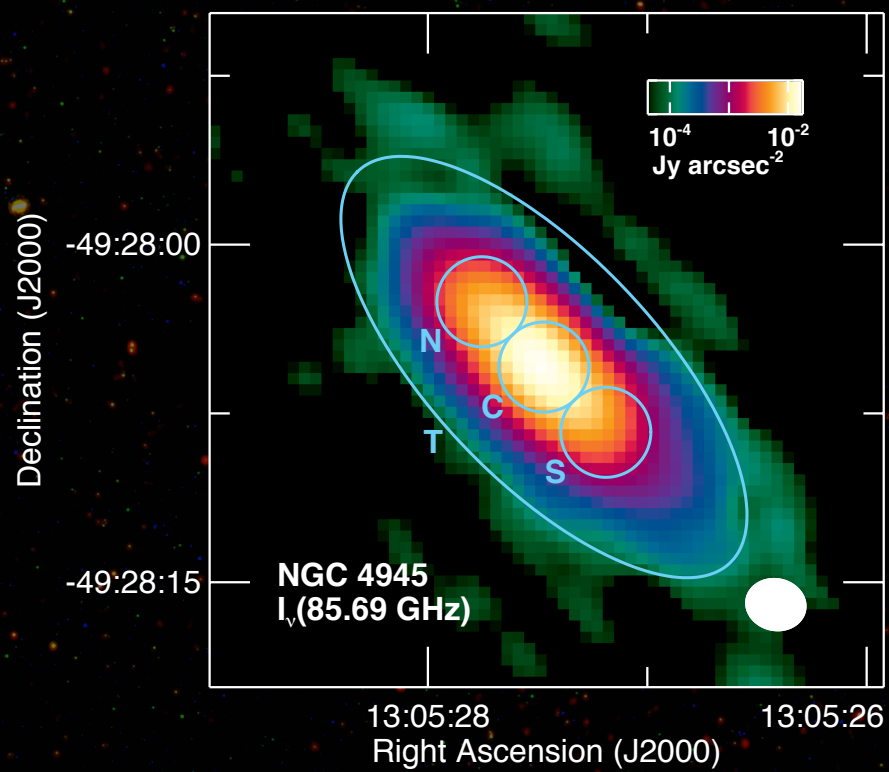


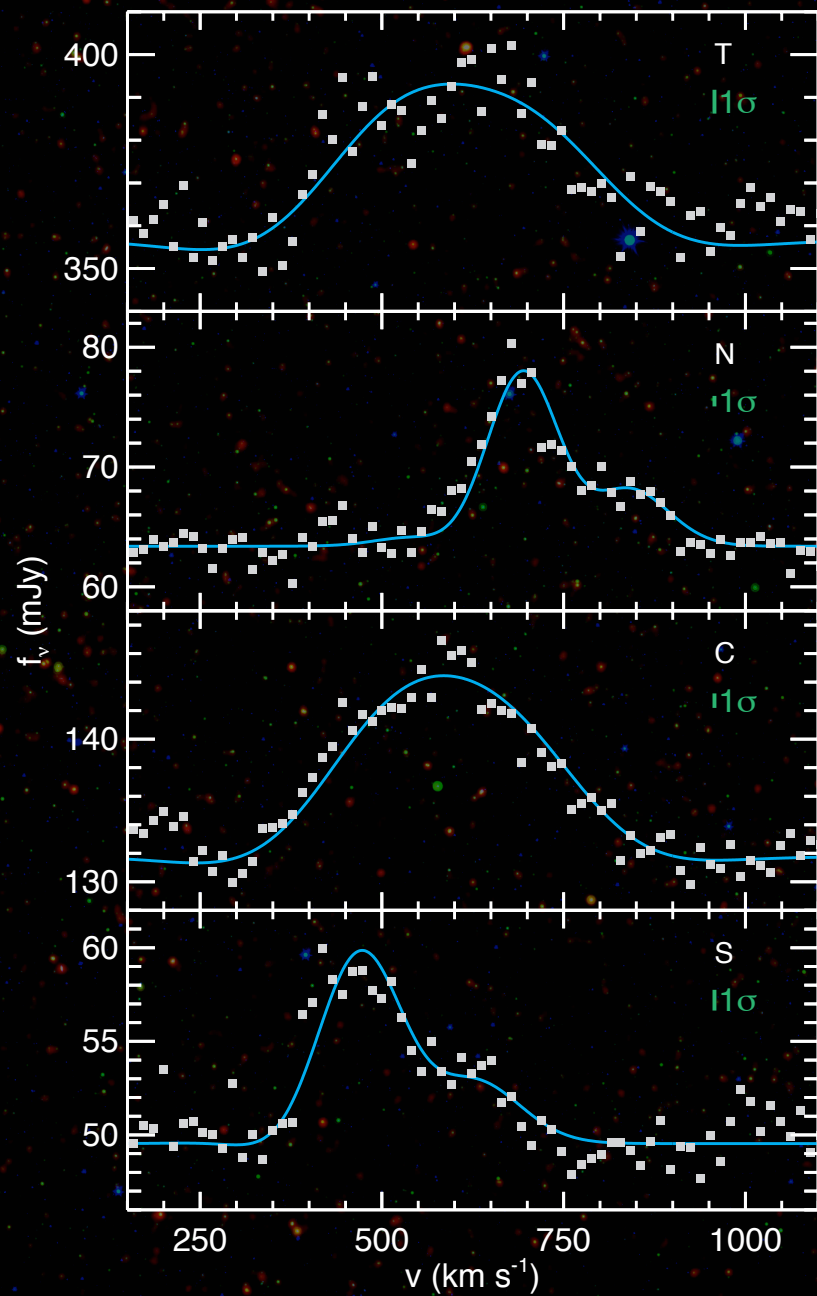
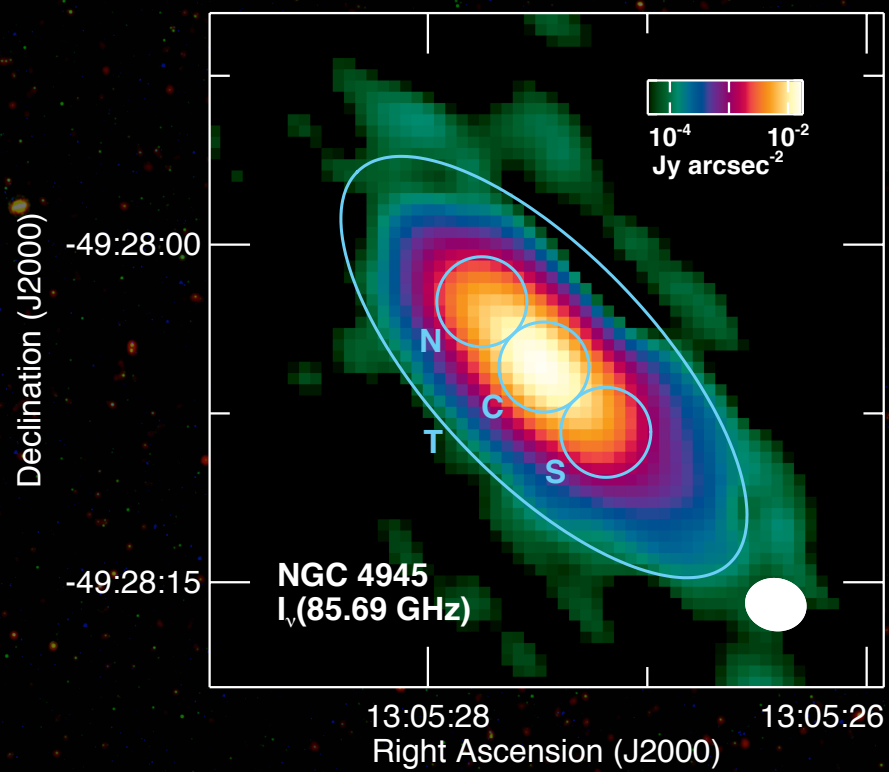
## NGC 253 summary results

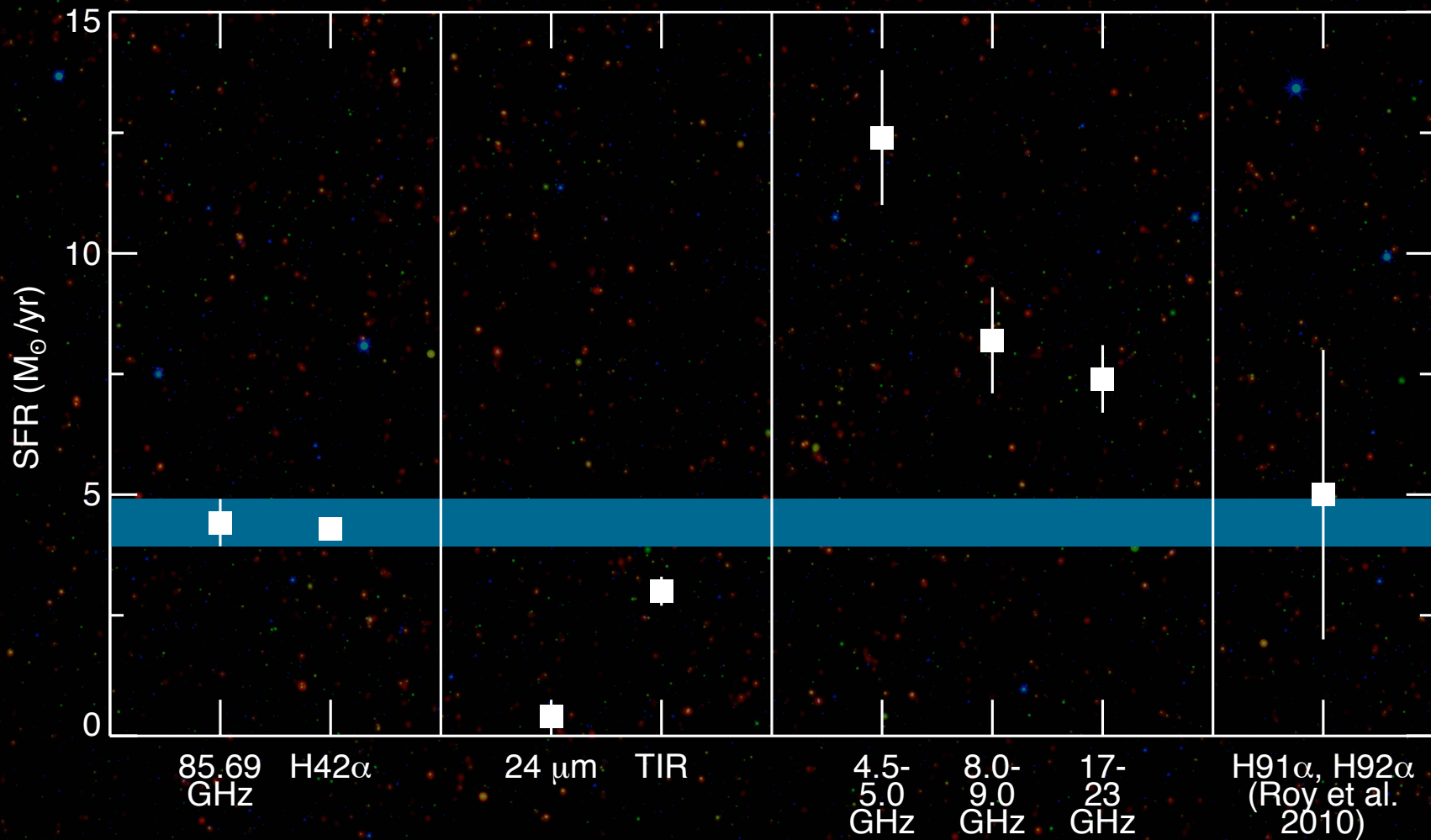
- Electron temperatures (from line/continuum ratio) is 3700-4500 K.
  - Matches measurements from inner regions of Milky Way Galaxy.
- SFR for central 20"x10" is  $1.73 \pm 0.12 M_{\odot} \text{ yr}^{-1}$ .
  - Other published SFRs from mm/radio data show a lot of scatter.
- Near-infrared dust attenuation is measured as  $A_J = 3.4 \pm 0.2$  and  $A_K = 2.1 \pm 0.2$ .
  - ~1.5 magnitudes higher than previously-published measurements based on near-infrared data.







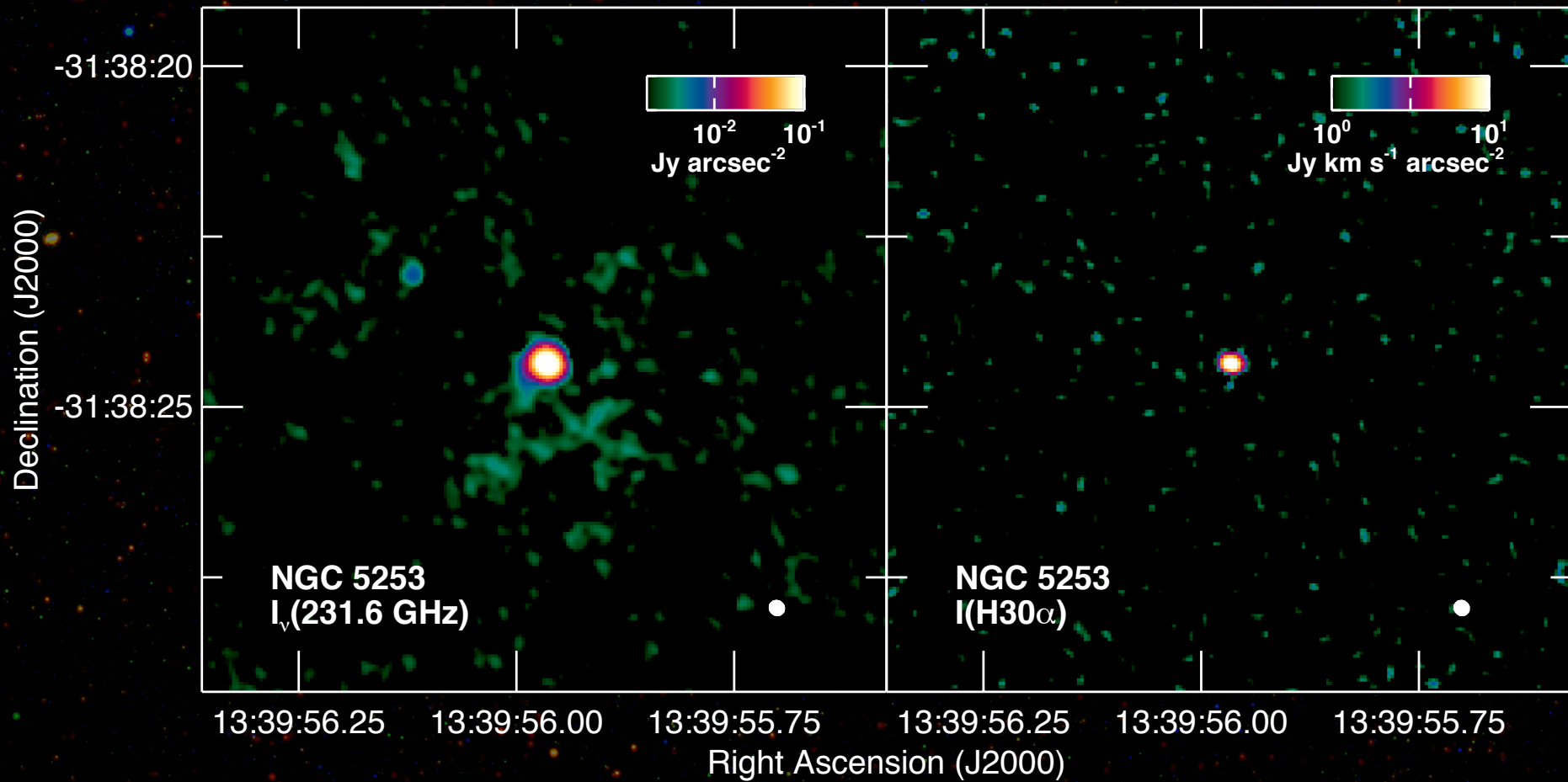


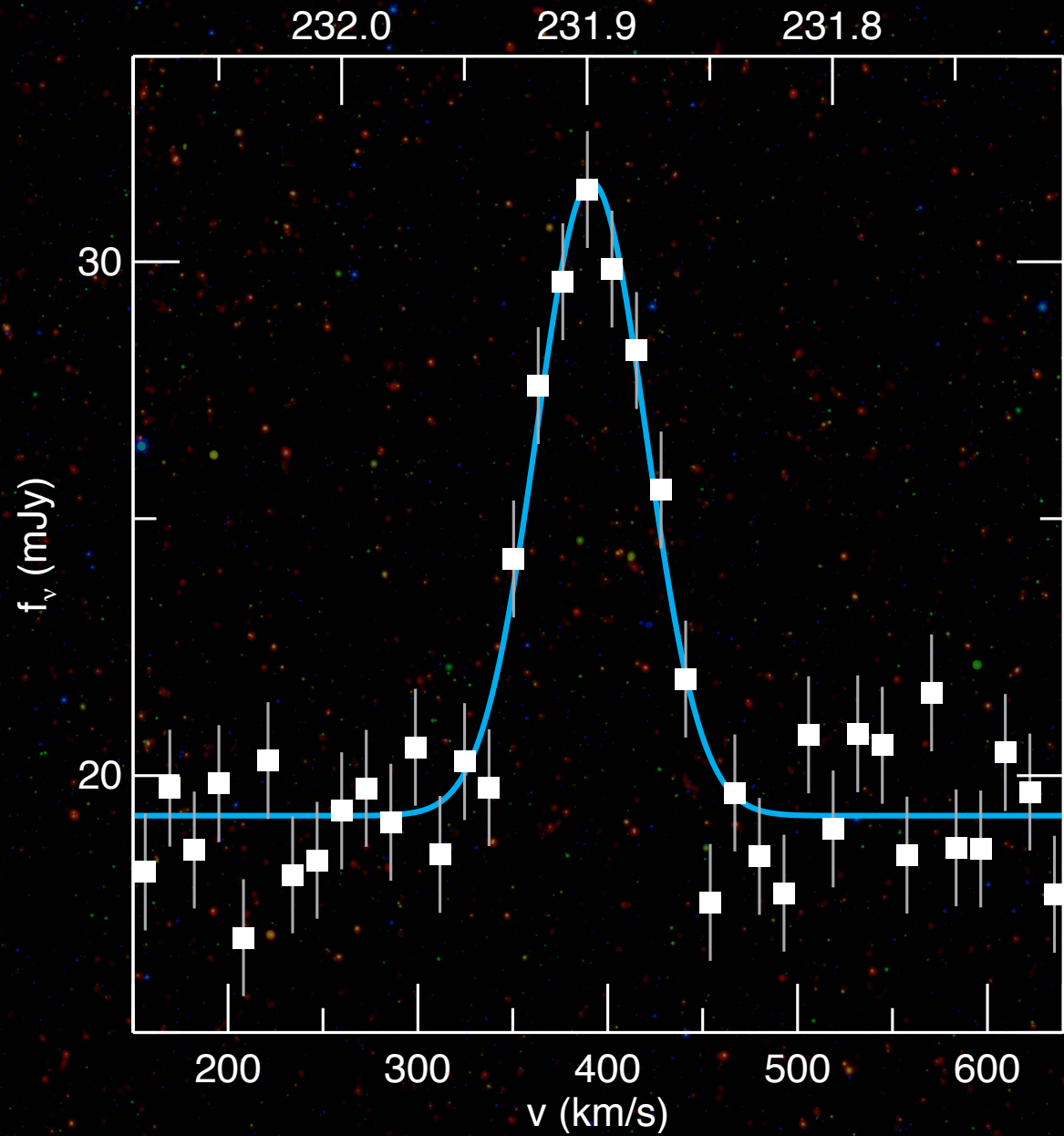


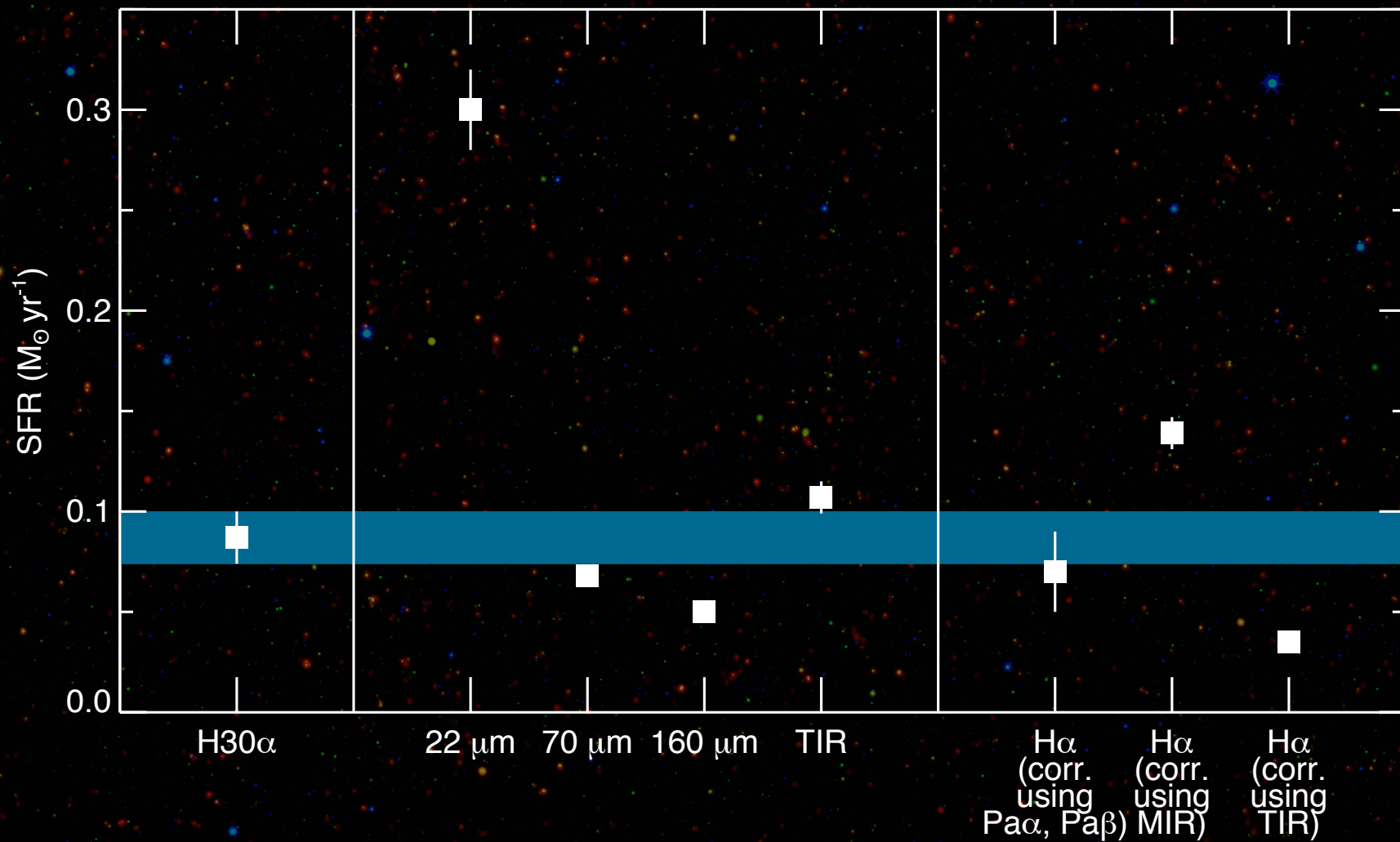
## NGC 4945 results

- Free-free and recombination line emission primarily from exponential disc with scale length of  $\sim 2.1''$  ( $\sim 40$  pc).
  - No evidence of central peak associated with AGN.
- Electron temperatures (from line/continuum ratio) is  $5400$  K.
  - Matches measurements from inner regions of Milky Way Galaxy.
- SFR for central disc is  $4.35 \pm 0.25 M_{\odot} \text{ yr}^{-1}$ .
  - In comparison, mid-infrared flux densities ( $22, 24 \mu\text{m}$ ) appear strongly affected by dust extinction.









## NGC 5253 results

- All detected recombination line emission originates from central 0.6'' diameter region.
- Nuclear star formation rate is  $0.087 \pm 0.013 M_{\odot} \text{ yr}^{-1}$ .
  - Abnormally hot dust temperatures cause SFR from mid-infrared (22  $\mu\text{m}$ ) data to be high and SFRs from far-infrared (70, 160  $\mu\text{m}$ ) data to be low.
  - SFRs from total infrared flux and from H $\alpha$  data corrected with near-infrared lines match H30 $\alpha$  result more closely.

## Summary

- Millimetre free-free and recombination line emission can be detected from many nearby starbursts using ALMA.
- Early analyses with ALMA data have revealed the following:
  - SFRs from lower-frequency radio data lack accuracy and precision.
  - SFRs from individual infrared bands are affected by extreme dust effects.
  - SFRs from total infrared fluxes may be more reliable than other radio or infrared metrics in these types of starbursts.
- Future ALMA observations will allow us to examine the efficacy of other star formation tracers more thoroughly.