A new component in the radio continua of PNe

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Abstract

A byproduct of experiments designed to map the CMB is the recent detection of a new component of foreground galactic emission. The anomalous foreground at 10-30GHz, unexplained by traditional emission mechanisms, correlates with 100um dust emission, and is thus presumably due to dust.

Is the anomalous foreground ubiquitous in the Galaxy? I will present evidence obtained with the CBI and SIMBA+SEST supporting the existence of the new component in the ISM at large, and in specific objects, in the form of a 31GHz excess over free-free emission in PNe.

Plan

A Introduction: recent results on diffuse galactic emission.

1. Observations of the anomalous foreground.
2. Models for the 10–30 GHz excess.

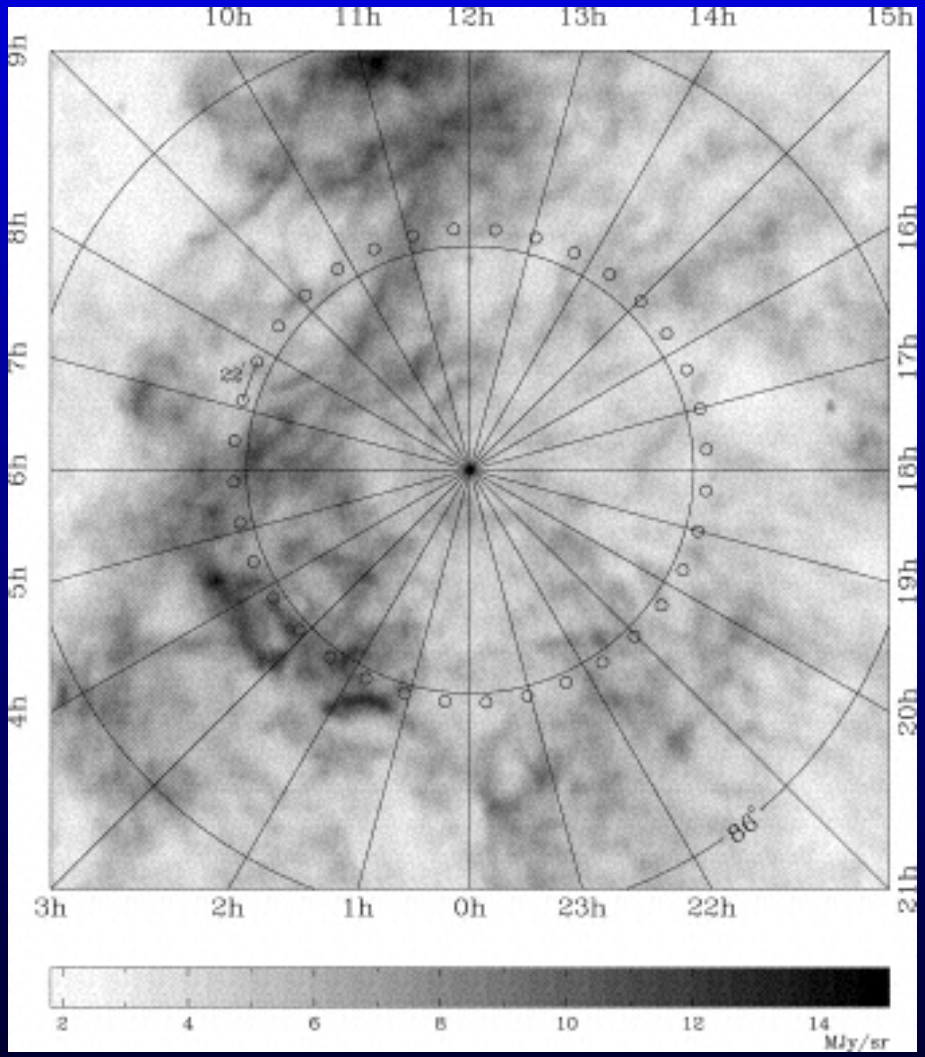
B CBI results.

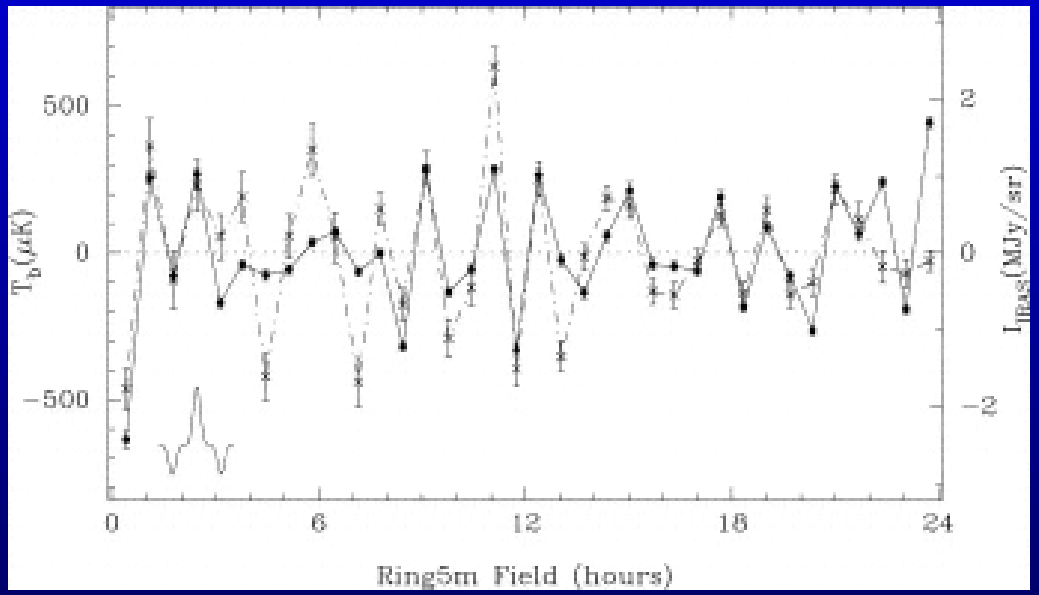
1. LDN 1622.
2. the Helix nebula.
3. compact PNe.

C Other detections.

E Conclusion.

The RING5M experiment (Leitch et al. 1997)





The 14-32GHz and 100 μm intensities correlate, as expected from dust clouds photoionised by the diffuse UV field. But the corresponding Hα emission is absent!

An explanation in terms of a hot plasma at $\sim 10^6$ K, heated by shocks, requires a supernova rate 100 times higher than the estimate of 0.3 $L_\odot$ pc^{-2} (or 1 SN in 100 years, Draine & Lazarian 1998).

Is it spinning-dust[1]?

The spinning dust emission mechanism may be understood in crude terms by assuming equipartition in the rotational degrees of freedom:

$$\frac{1}{2} I \omega^2 = kT.$$

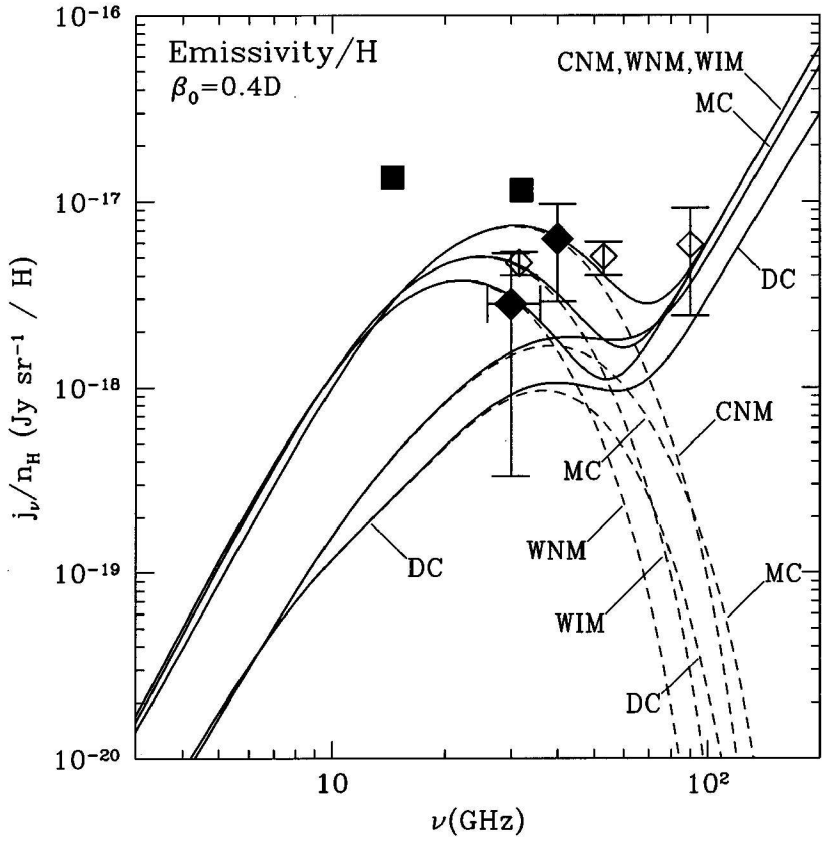
For a spherical and homogeneous grain, with $I = \frac{2}{5} m R^2$, a radius $R = N\ 10^{-10}$ m, and a mass density $\rho = 1$ kg m^{-3}, the rotation frequency is

$$\nu = 2\ 10^3 \sqrt{\frac{T}{N^5}}\ \mathrm{GHz}.$$

A typical dust temperature is $T \sim 25$ K , and a very small grain cannot be much less than 100 atoms in radius (so $N = 10^2$), therefore $\nu \sim 30$ GHz.

[1] Erickson 1957, Hoyle & Wickramasinghe 1970, Draine & Lazarian (1998)

Is it spinning-dust?



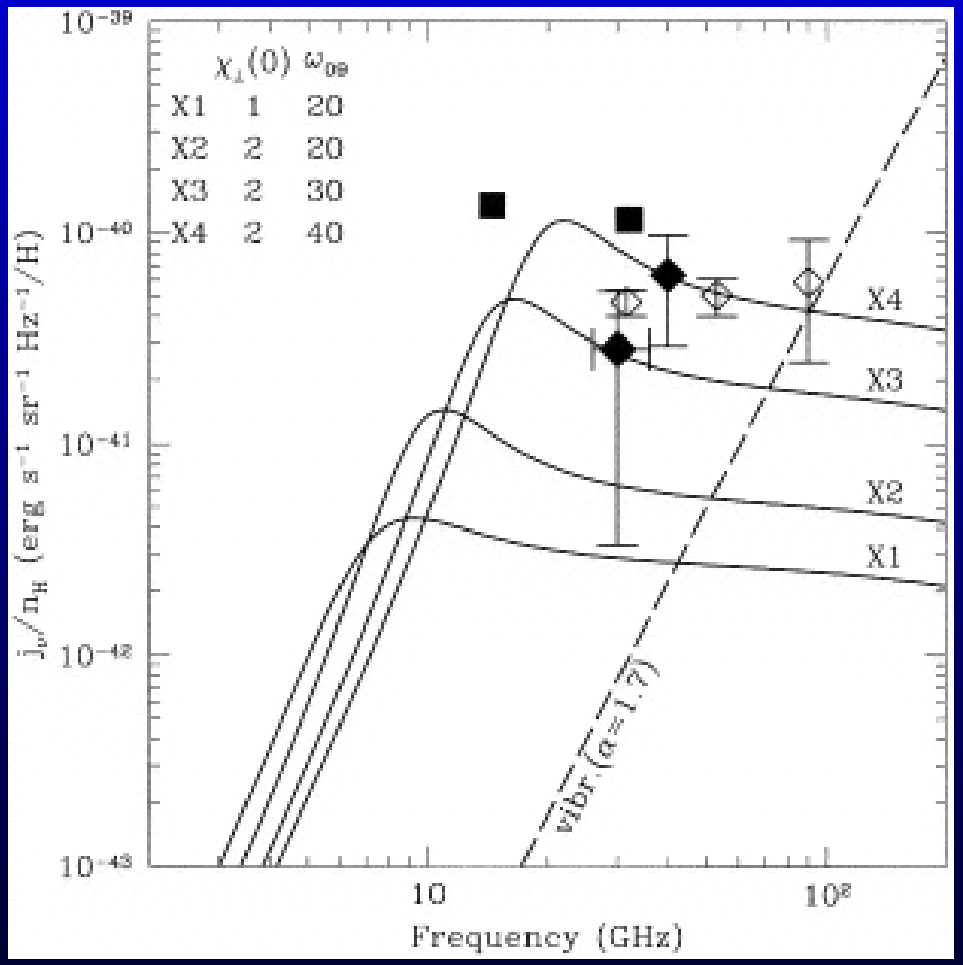
The SED of spinning dust rises steeply with frequency ($\alpha \sim 3$), and then drops-off with a Boltzmann factor. The emissivities predicted by Draine & Lazarian (1999) peak at 30 GHz but fall short of the anomalous foreground.

Or is it magnetic dipole emission?

Draine & Lazarian (1999) show that the inclusion of the grain response to the magnetic field enhances the grain emissivities:

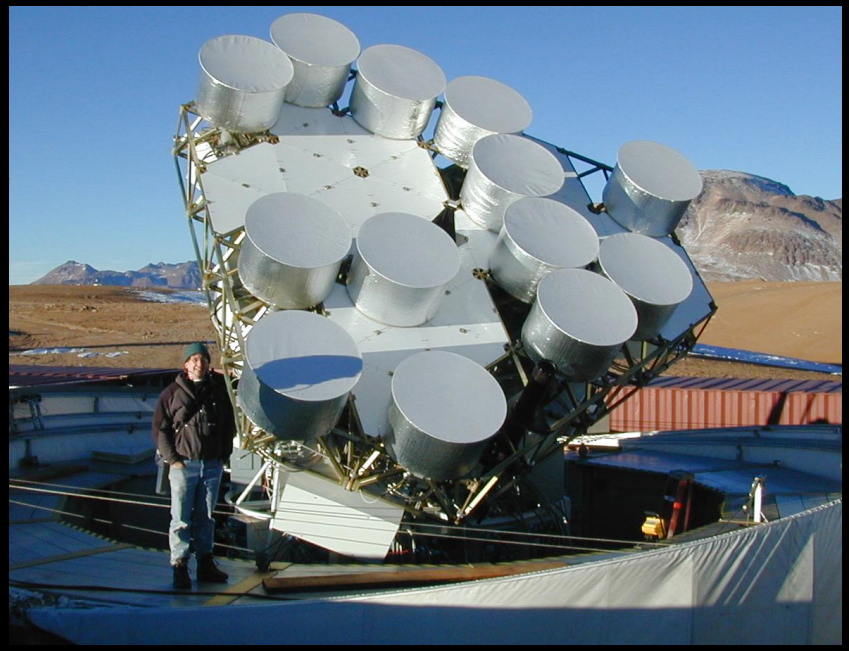
$$j_\nu = n_{\rm grains}(C_e(\nu) + C_m(\nu))B_\nu(T).$$

Unlike spinning dust, magnetic dipole emission at radio-frequencies stems from the **large** grains.



Results on the anomalous foreground from a survey of galactic sources with the CBI

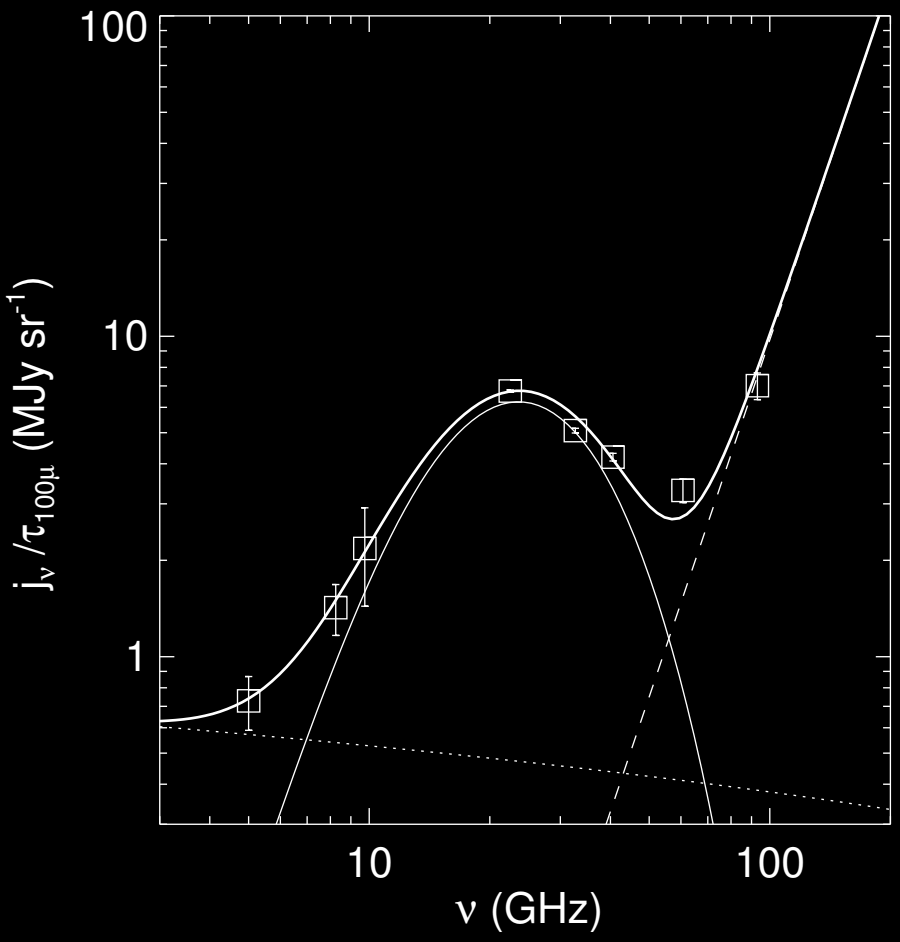
The Cosmic Background Imager is a 13-element radio-interferometer operating in 10 channels over 26–36 GHz.
Its 45 arcmin primary beam (field of view) and 4 arcmin resolution is well suited to map extended sources, such as



- Helix nebula:
candidate for magnetic dipole emission
- dark-cloud LDN 1622:
candidate for spinning dust.

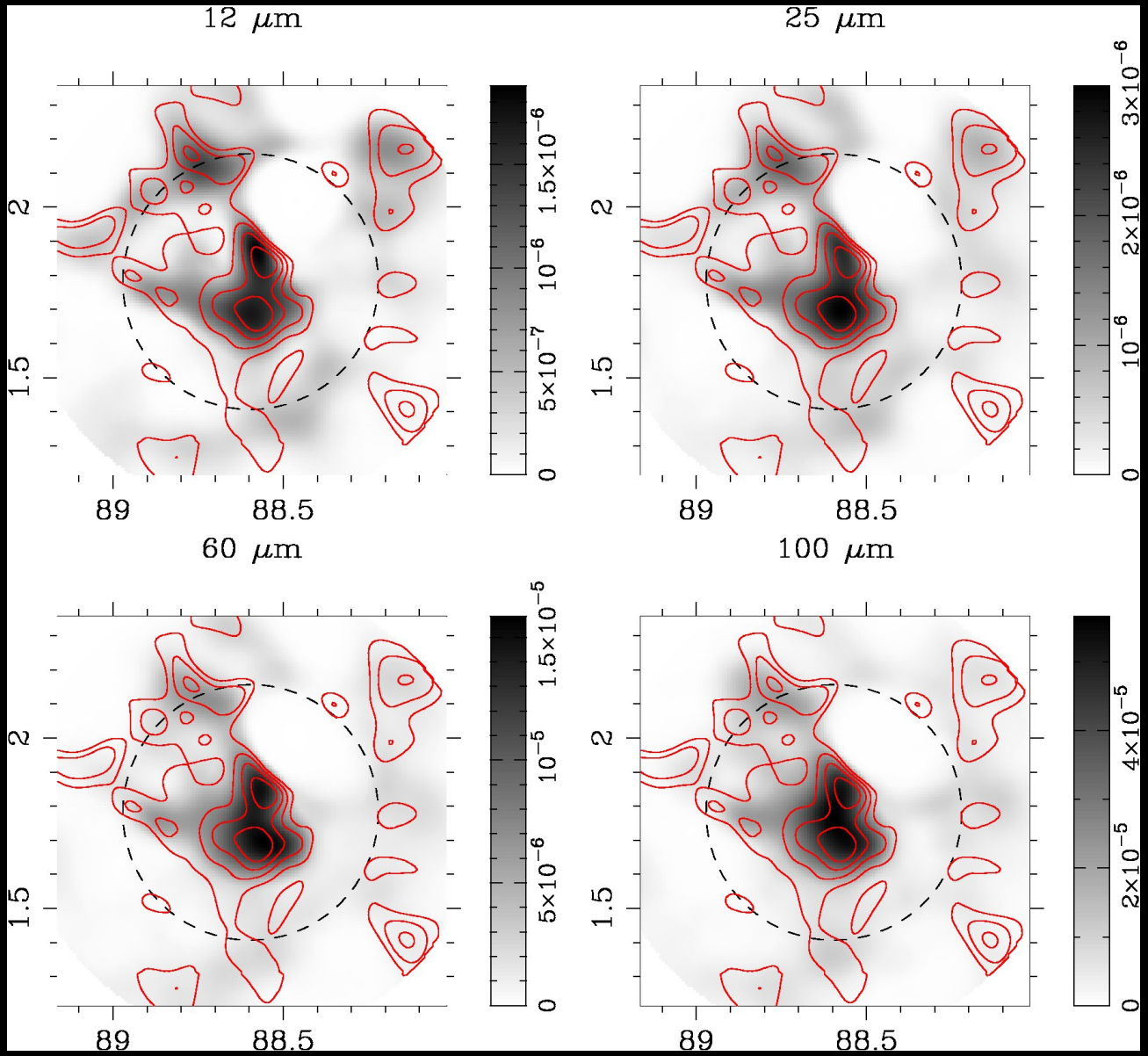
In addition, the CBI's 4 arcmin synthetized beam allows measuring the integrated flux from compact objects, such as young Planetary Nebulae (**PN**e, such as NGC 6302, NGC 7009), which can then be compared with measurements at other frequencies, for instance with SIMBA+SEST at 250 GHz (a programme initiated with the SEST heterodyne receivers by Lars-Åke Nyman).

A radio-bright dark cloud: LDN 1622

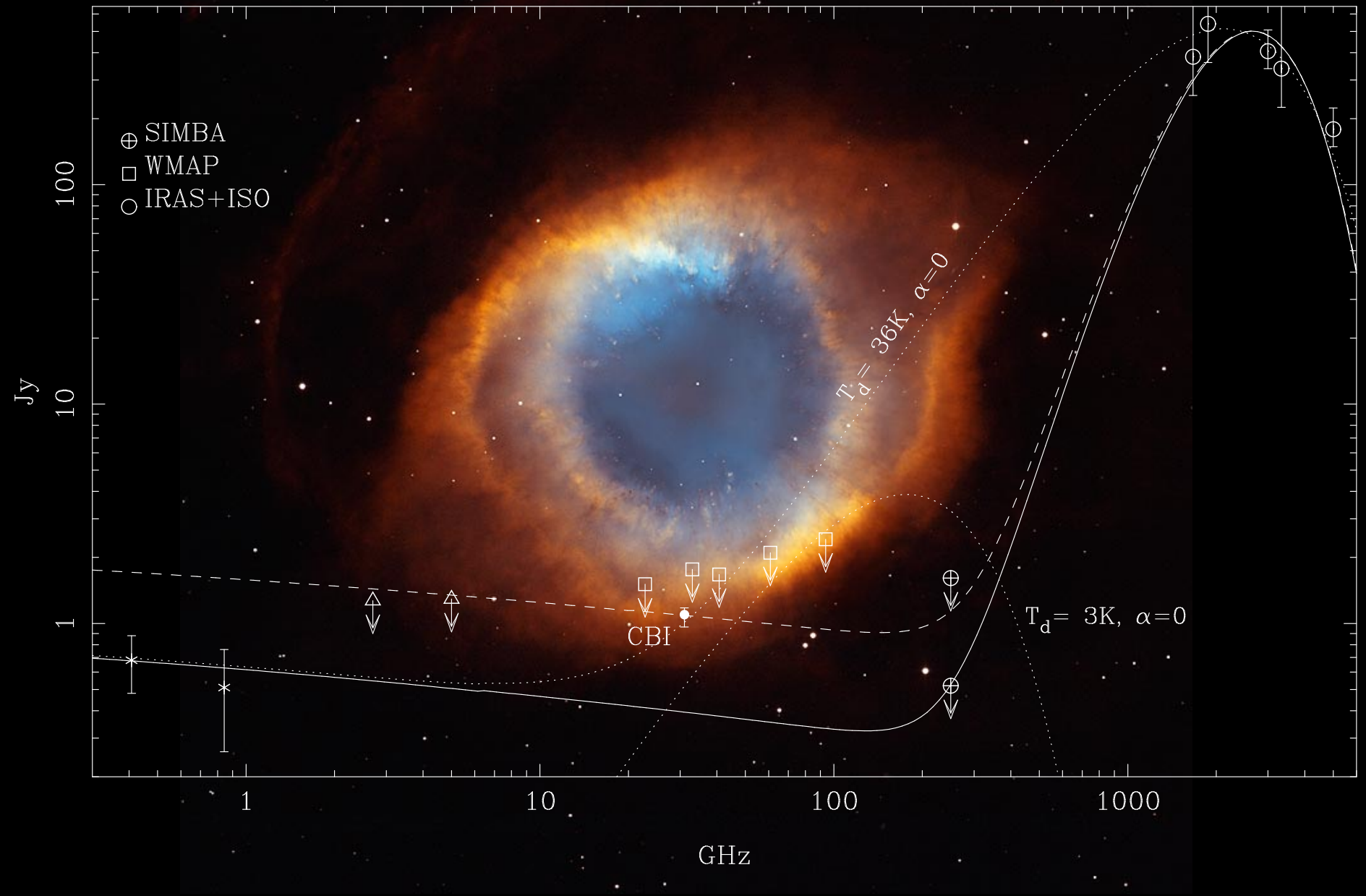


Finkbeiner et al. (2002) reported on a marginally positive 5–10 GHz index, and Finkbeiner (2004) detected a negative index above 30 GHz using the WMAP data.

A radio-bright dark cloud: LDN 1622



The Helix: spectral evidence for an excess at 31 GHz

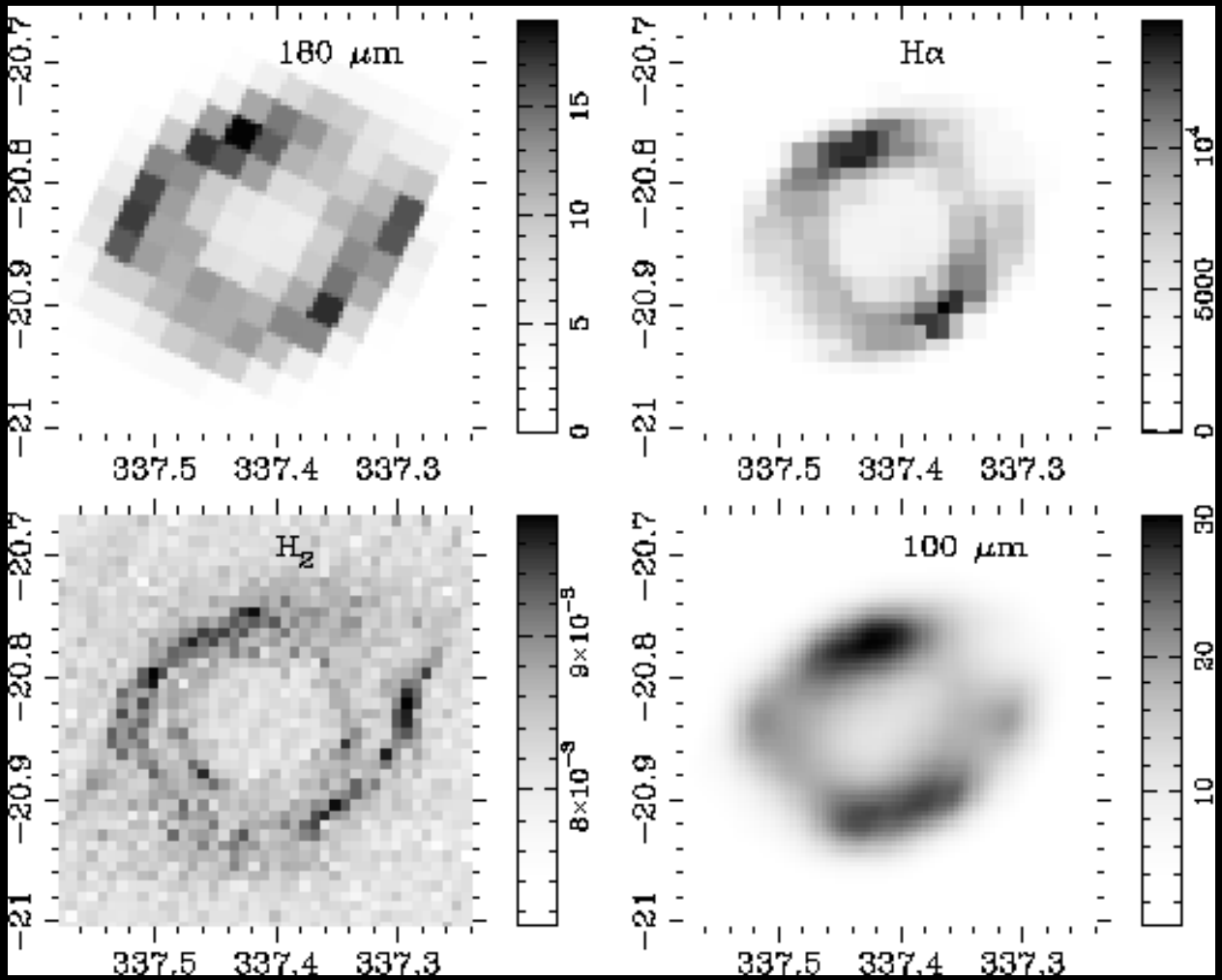


Is the low-frequency rise due to the cometary knots?

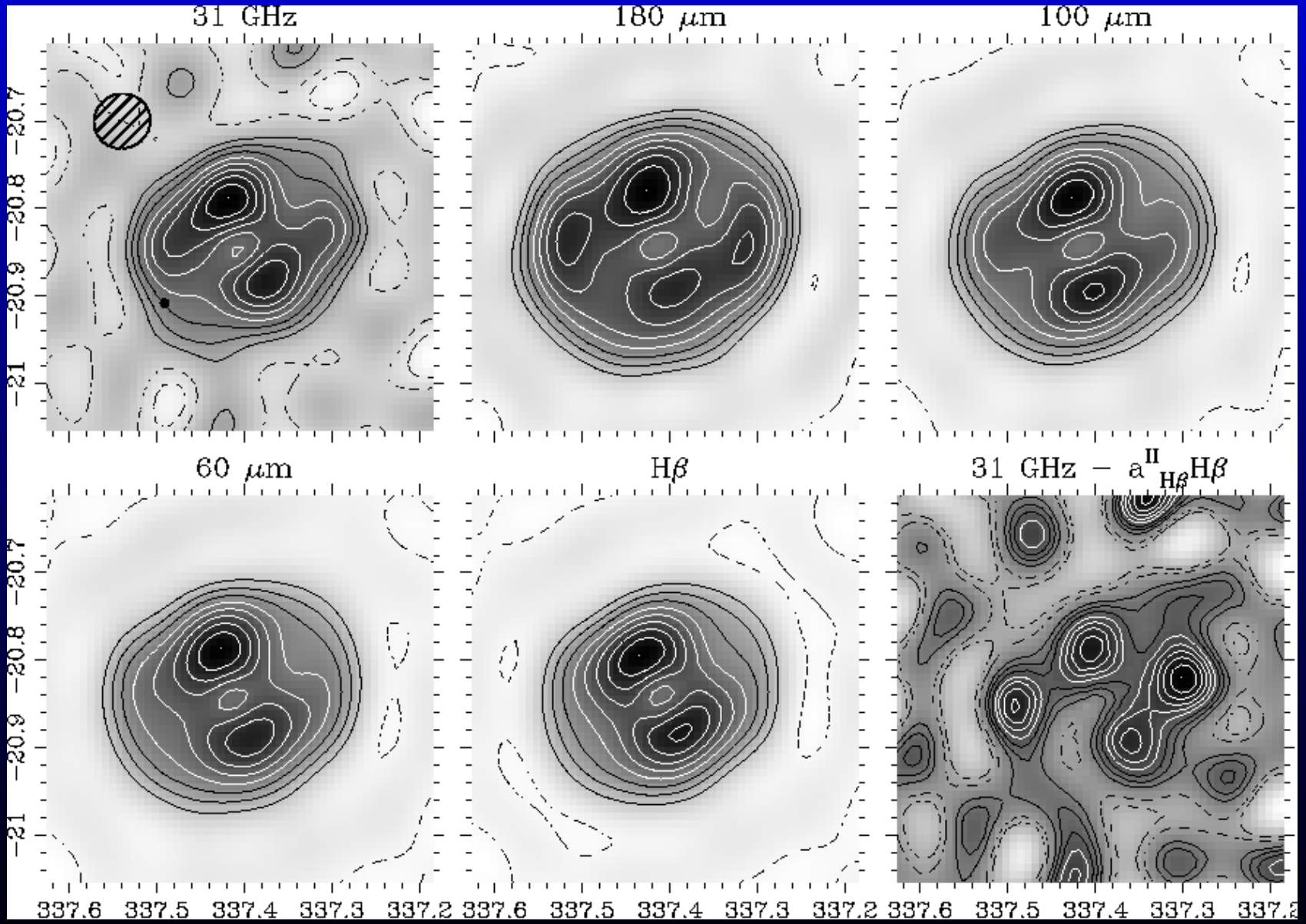
The Helix is renowned for its cometary knot complex. The knots could have optically thick spectra: with a turn-over frequency of $\nu_T \sim 1$ GHz, the knots would be optically thin and stand out at 31 GHz, and yet be optically thick and faint at 0.408 GHz. But the required filling-factor is $\epsilon \sim 1/1000$, while comparing the radio and Hβ fluxes gives $\epsilon \sim 1$ (the Helix is so dilute that bulk extinction is negligible in the visible).

The Helix: Morphological evidence for dust emission at 31 GHz

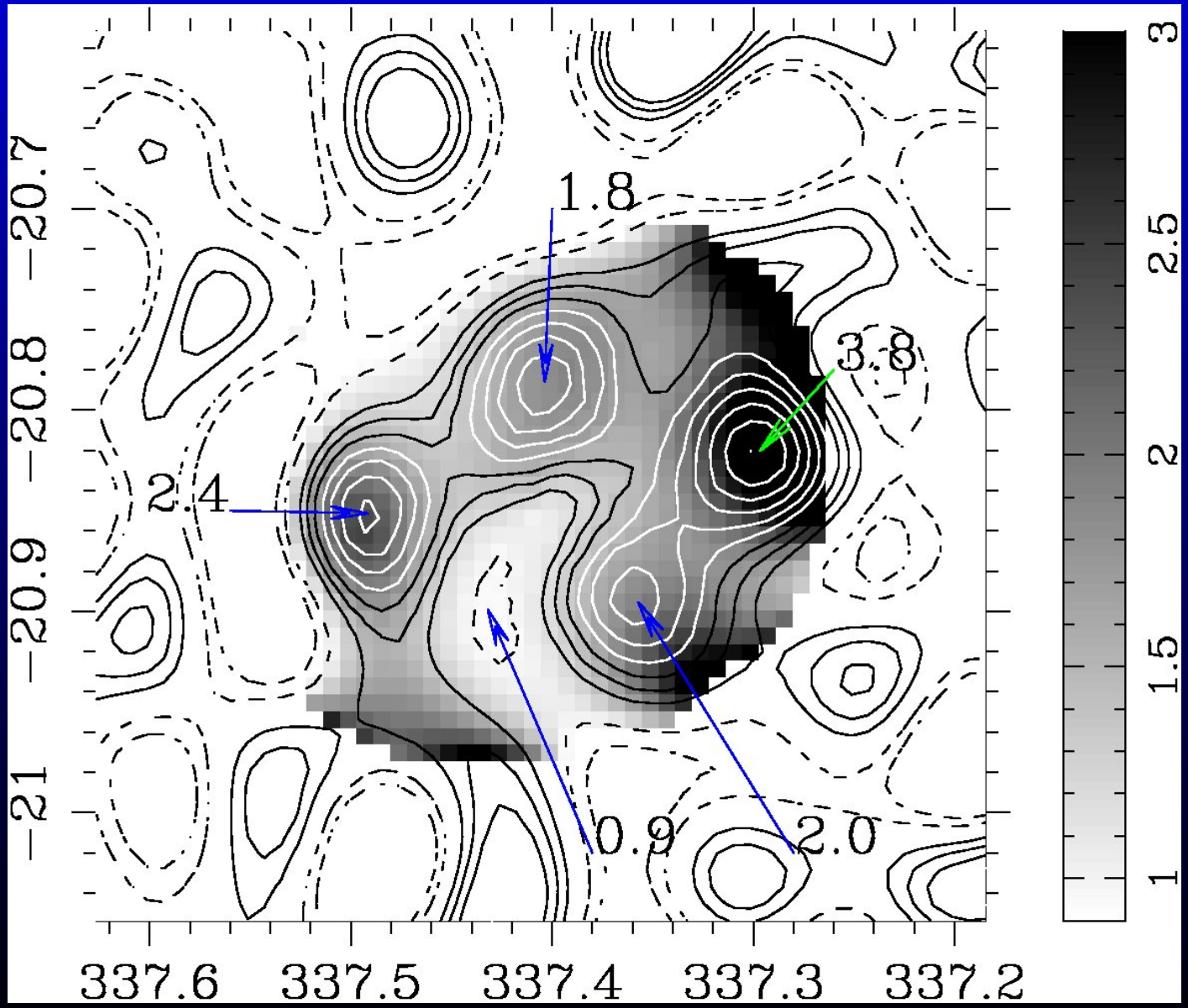
We simulate CBI observations on dust and free-free emission templates, and reconstruct in the same manner as for the CBI data, by fitting a parametrized model to the visibilities.



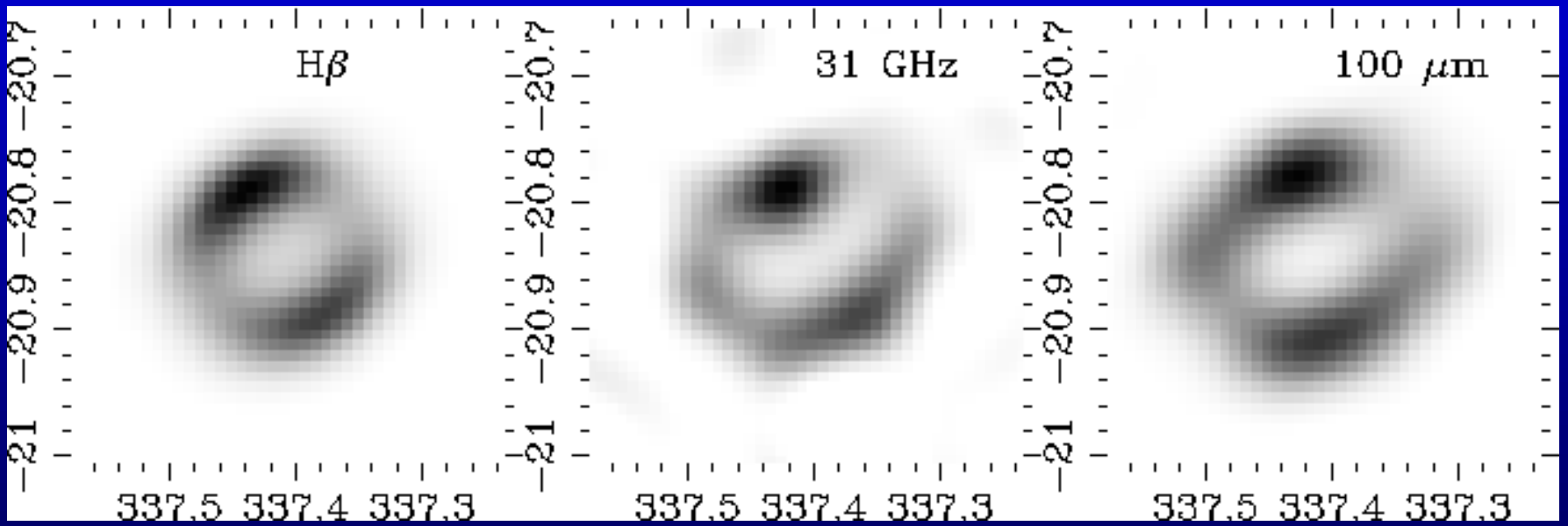
The Helix: Morphological evidence for dust emission at 31 GHz



The Helix: Morphological evidence for dust emission at 31 GHz or T_e variations?



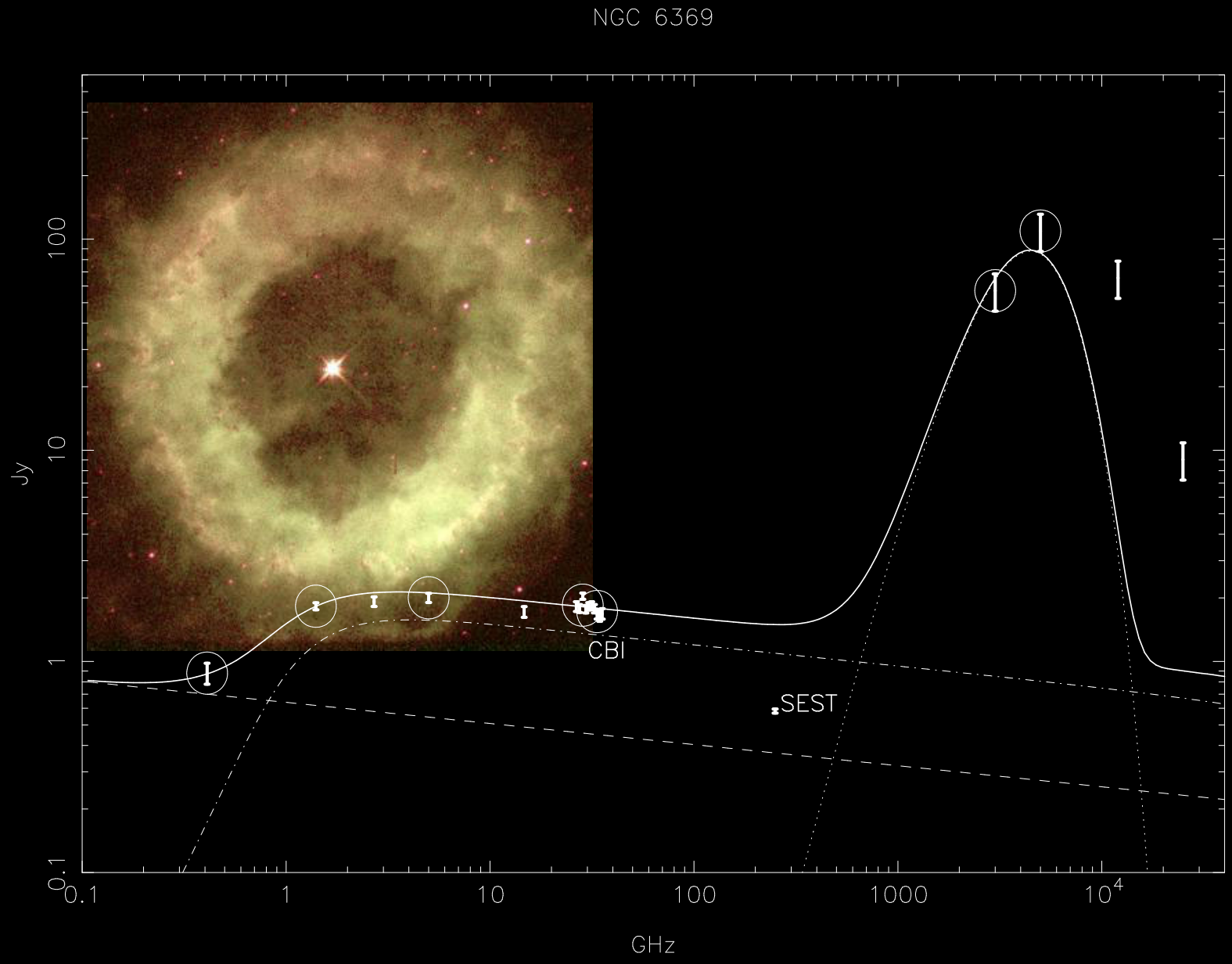
The Helix: Morphological evidence for dust emission at 31 GHz based on MEM models



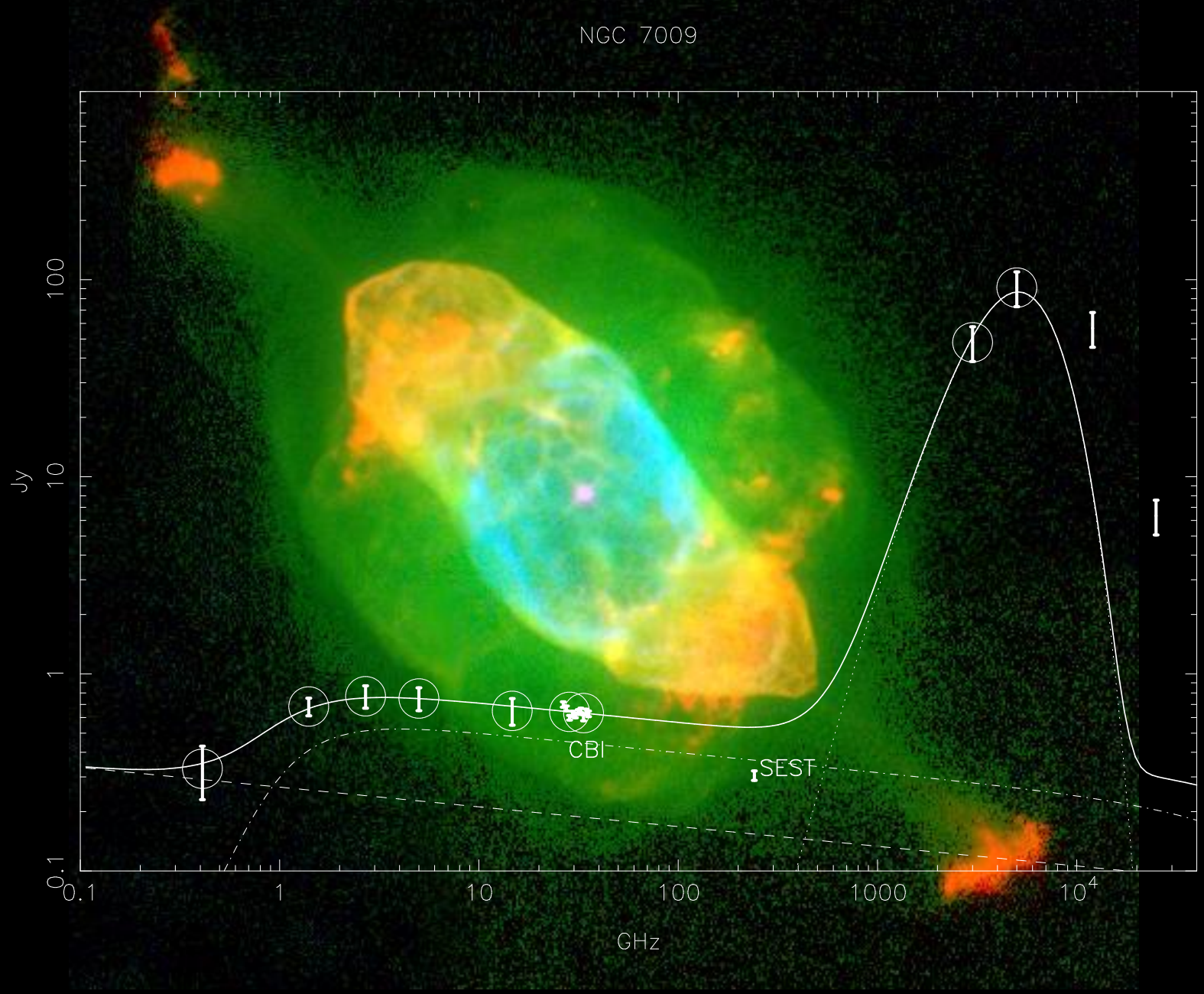
The East-West lobes of the 31 GHz map are reminiscent of the 100 μm map, and the position of the peak of emission at 31 GHz is closer to that at 100 μm than in Hβ.

VSGs are not expected to survive in evolved PNe such as the Helix, which hampers interpreting the 31 GHz–100 μm correlation in terms of spinning dust. Additionally $\sim$90% of the Iron in the ionised phase of the Helix is locked into grains, giving ground for the existence of the ferromagnetic material hypothesised by Draine & Lazarian.

31 GHz excess in compact PNe



31 GHz excess in compact PNe



31 GHz excess in compact PNe

- The SIMBA+SEST data points at 250 GHz:
  - ⋆ were obtained in 3 different observing runs in the case of NGC 7009, and two for NGC 6369 (during 2001 and 2002).
  - ⋆ confirm previous heterodyne data.
  - ⋆ corroborate the fluxes of Hoare et al. (1990) within 20% uncertainties, for the four objects in common (M 2-9, NGC 6572, NGC 6302, and NGC 6537).

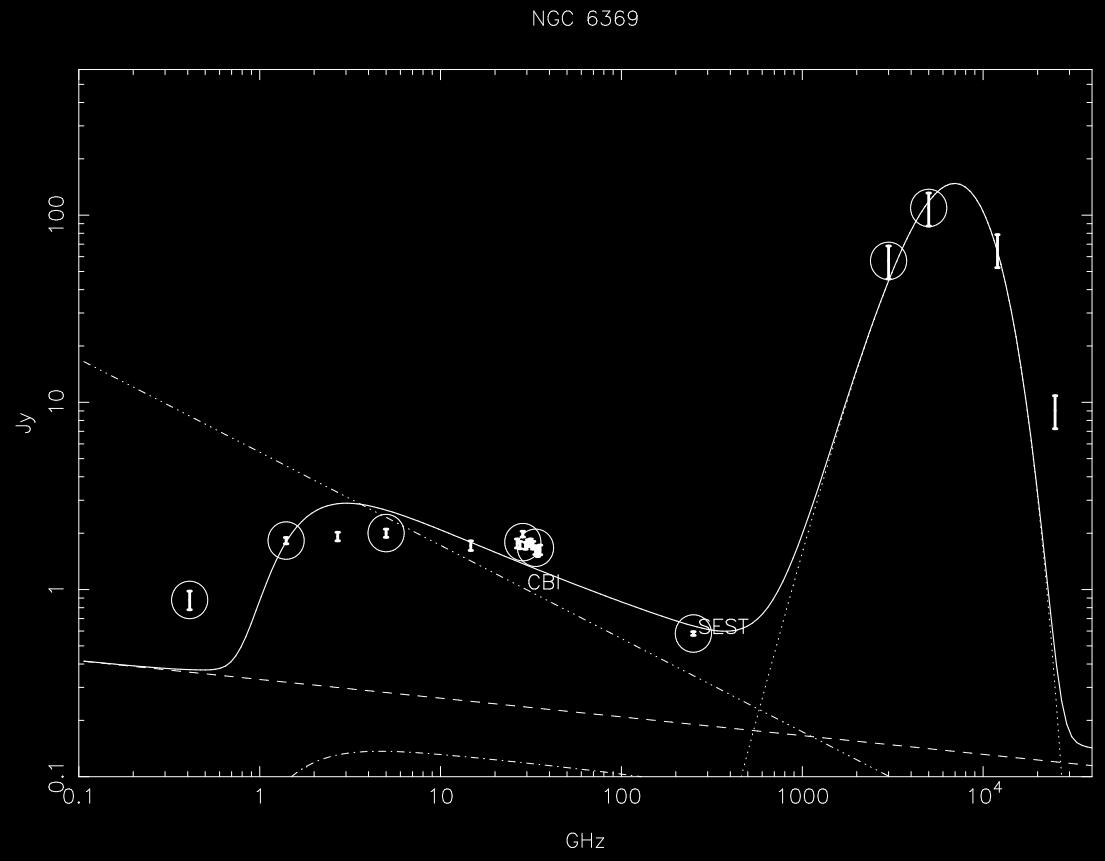
- the 250 GHz fluxes fall well below the expected level of free-free emission in the PNe NGC 3242 (9 σ deviation, where σ is a 20% calibration uncertainty on the SIMBA flux), NGC 6369 (7 σ), NGC 3918 (6 σ), NGC 7009 (5.5 σ), NGC 6572 (3.5 σ).

- the observed SEDs are not reminiscent of spinning dust, as they lack a peak at 30 GHz. Rather, the data follow a free-free-like SED at low frequencies, and then drop-off above 30 GHz. This is also the problem with RING5M, the observed SED rises from 32 GHz to 14 GHz.

- An interpretation of the drop-off above 30 GHz in terms of extinction due to cm or mm-sized grains implies absurd dust-to-gas mass ratios (of order 1).

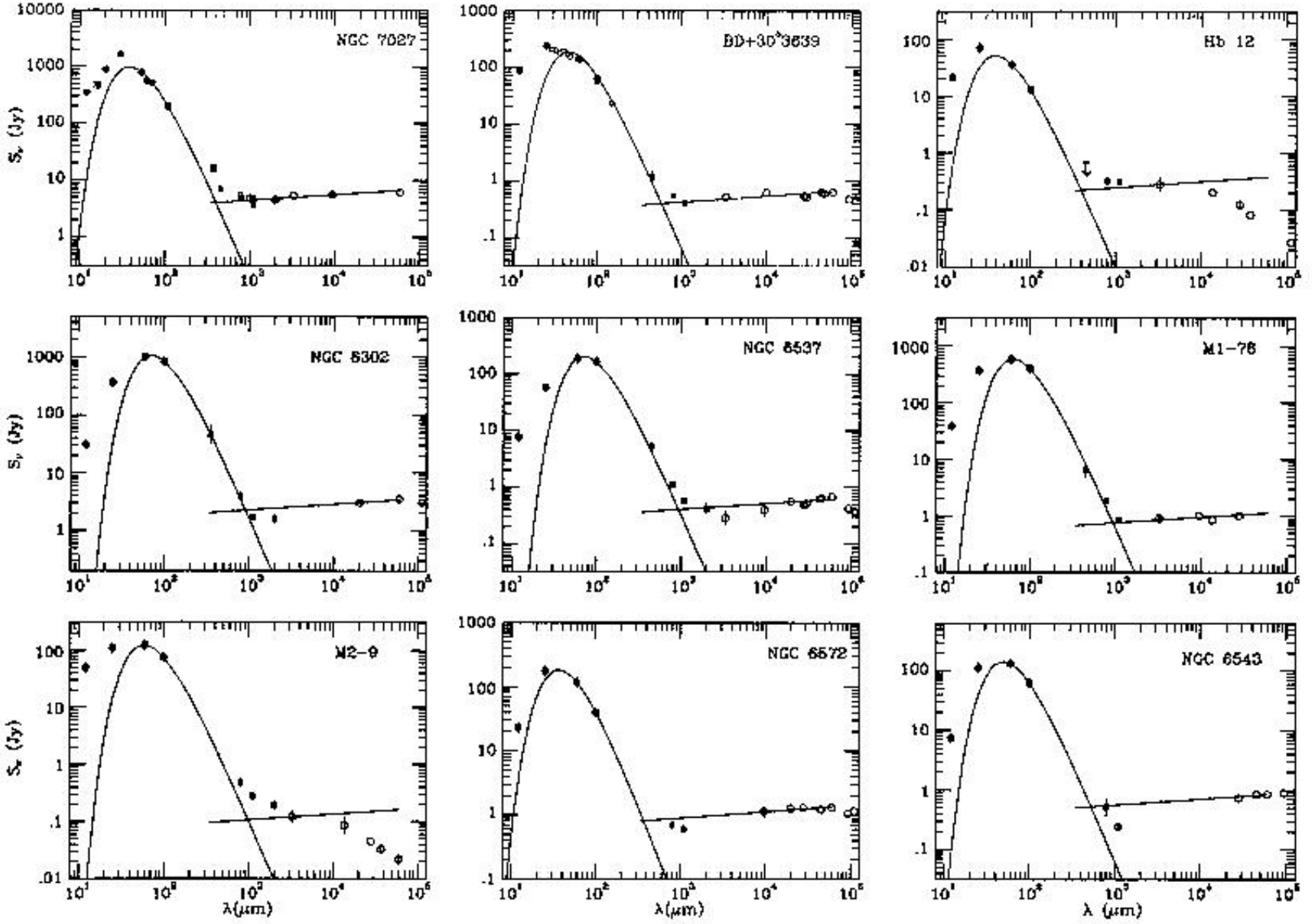
31 GHz excess in compact PNe: A synchrotron component?

Is the negative index above 30 GHz indicative of a synchrotron component? No! Fitting the NGC 6369 SED requires most of the 5-30 GHz emission be synchrotron, modulated by an absurdly cold free-free screen ($\sim$100 K).



$\tau_\nu \propto T_e^{-1.35} \nu^{-2.1} \mathrm{EM}$ + 250 GHz flux sets EM upper limit

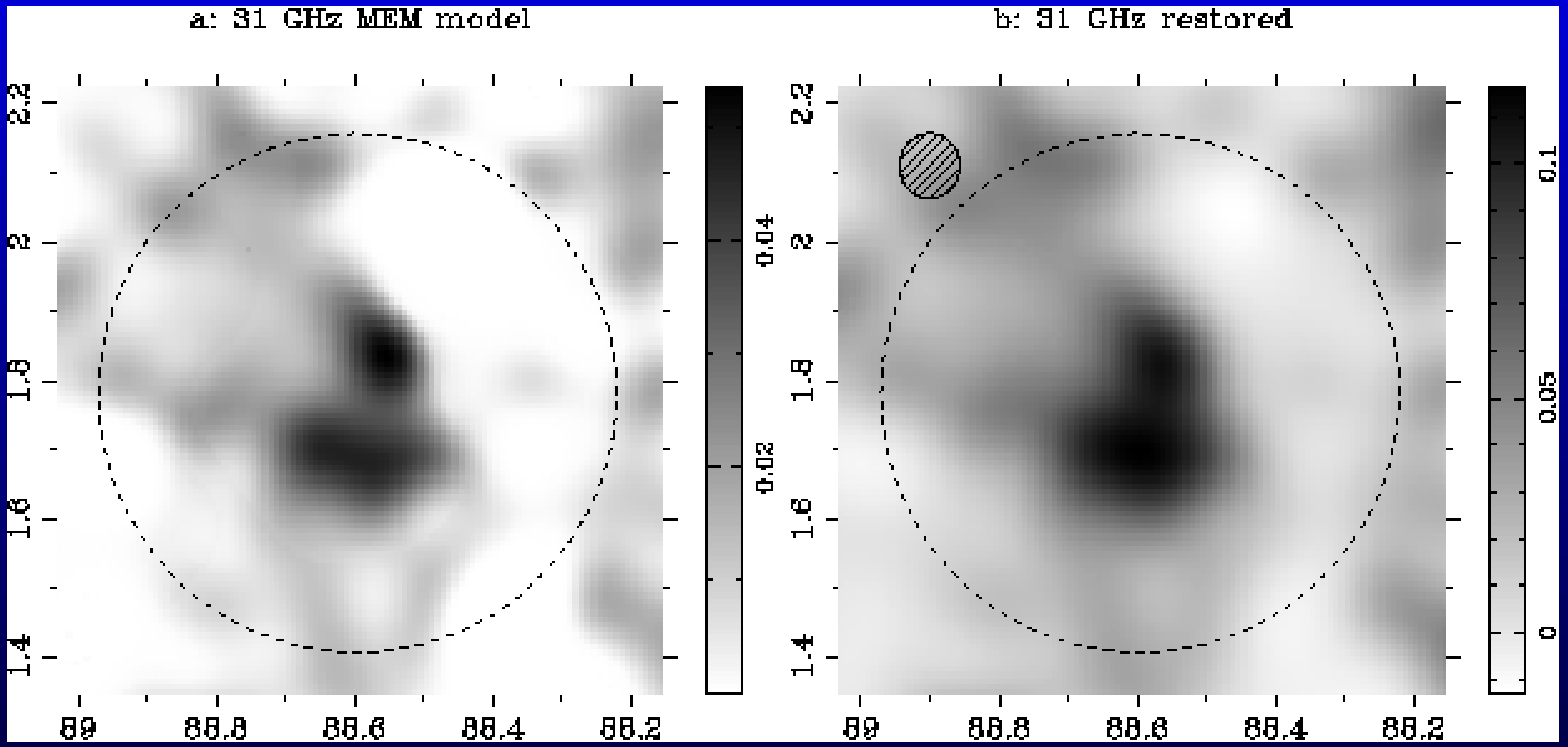
Other detections, Hoare et al. (1992)



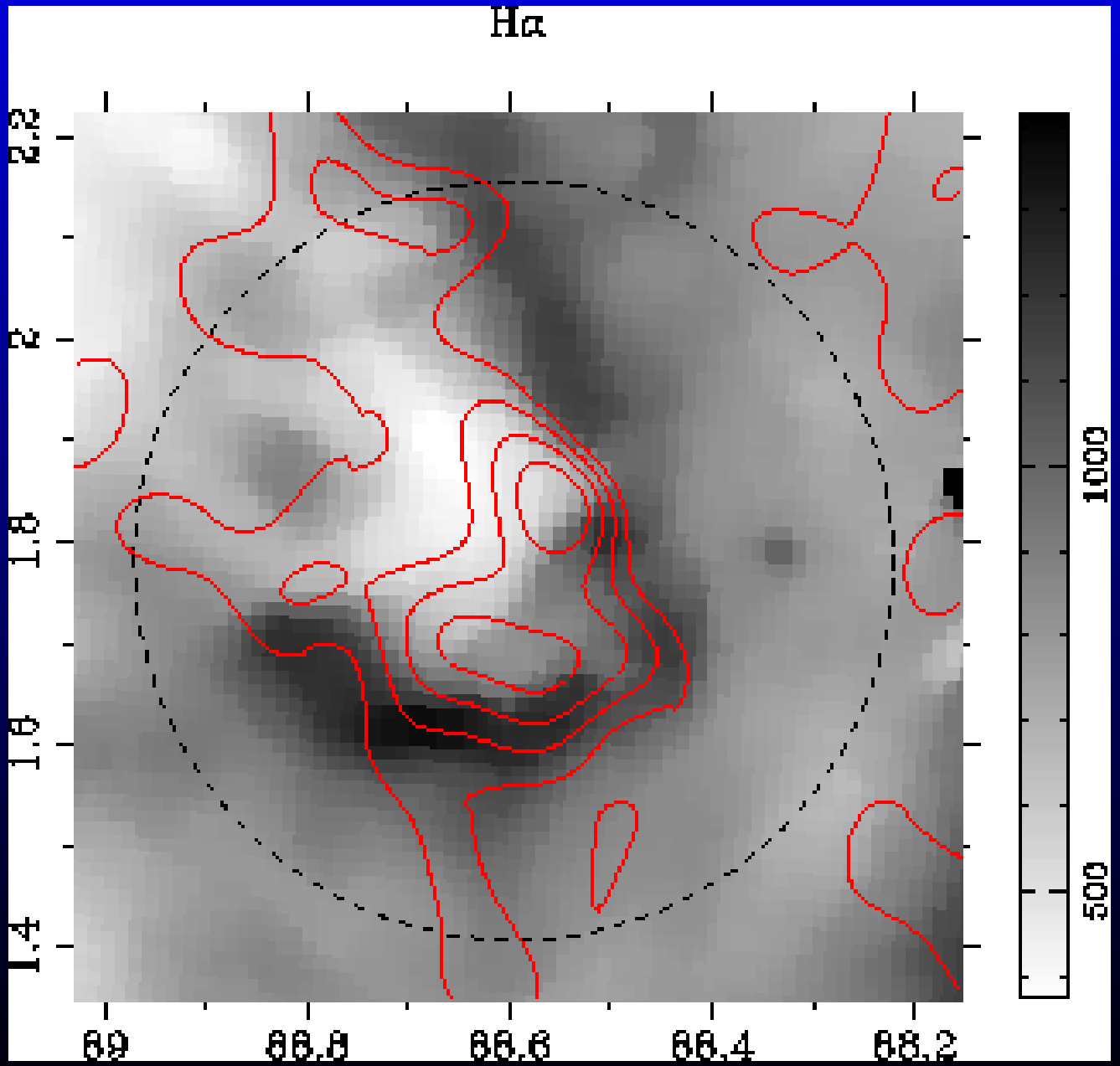
Conclusion

- We obtained the first cm-wave image of the a dark cloud, which is indicative of spinning dust emission.
- The Helix nebula provides morphological evidence for a new emission mechanism at 31 GHz, other than synchrotron or free-free emission.
- The compact PNe provide the strongest spectral evidence for the existence of the new component in the context of photoionised nebulae. Free-free represents 50% of the 30 GHz flux in the extreme case of NGC 6369.

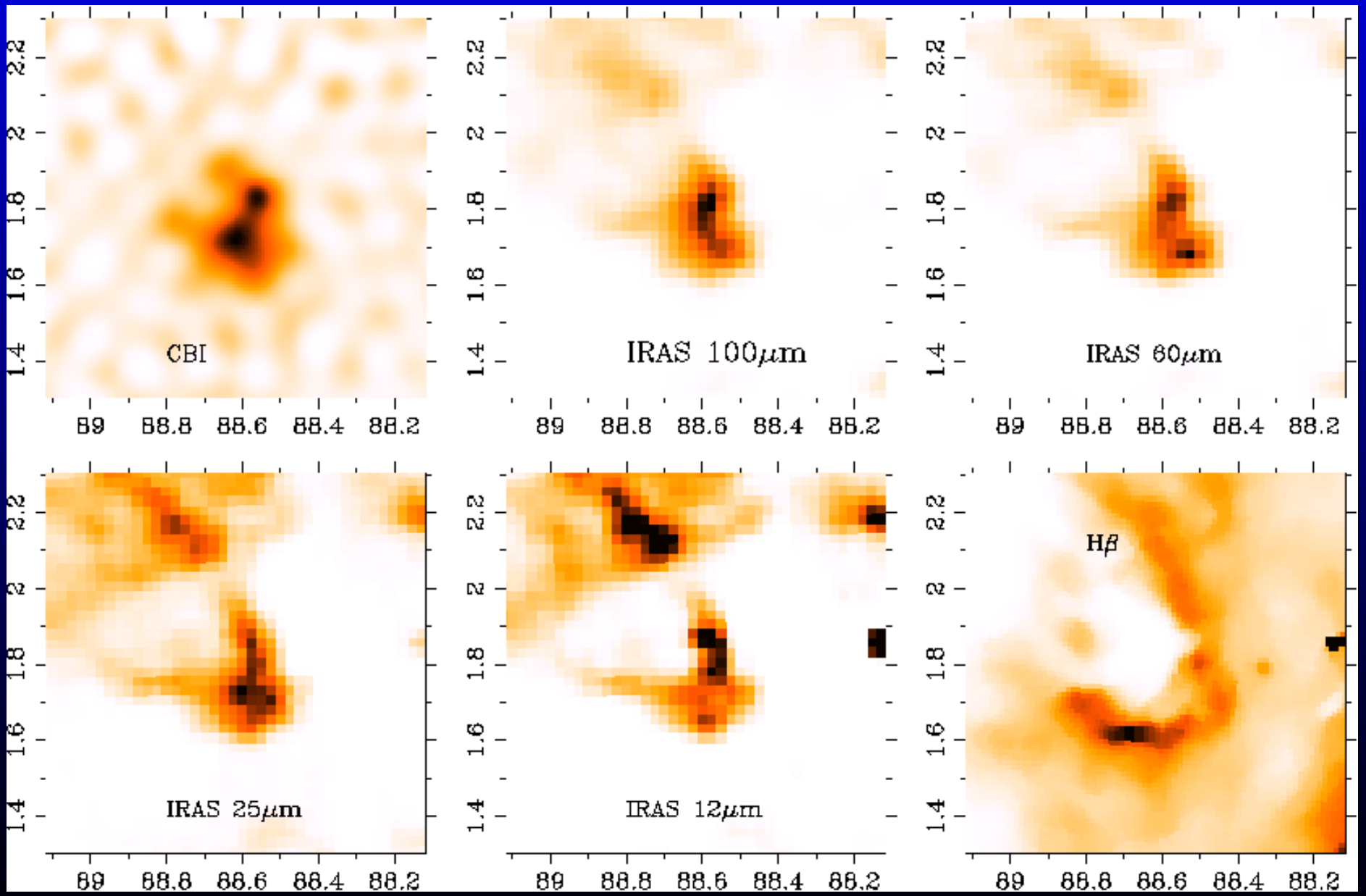
A radio-bright dark cloud: LDN 1622



A radio-bright dark cloud: LDN 1622

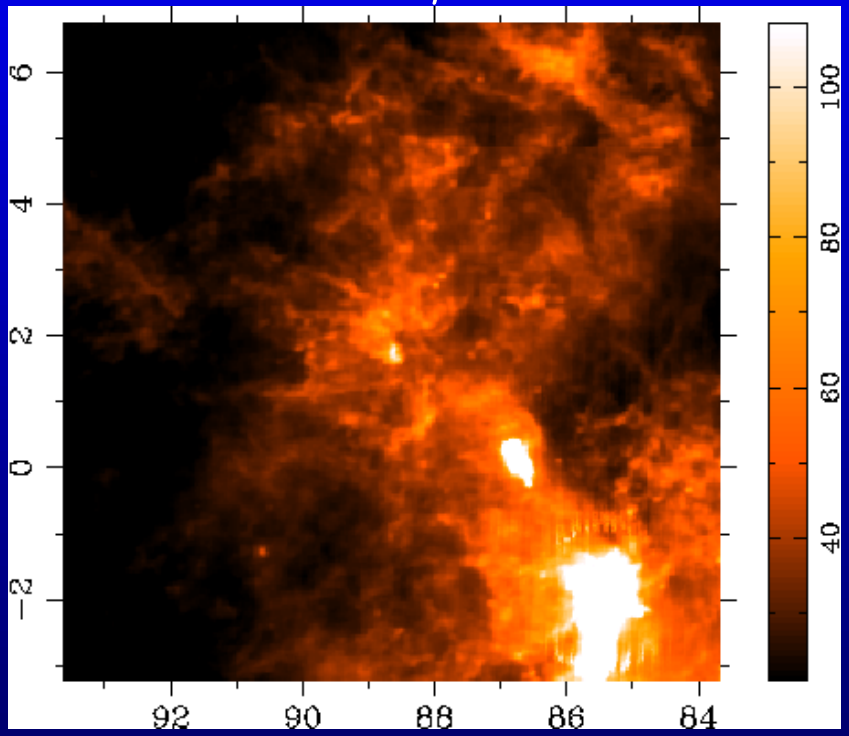


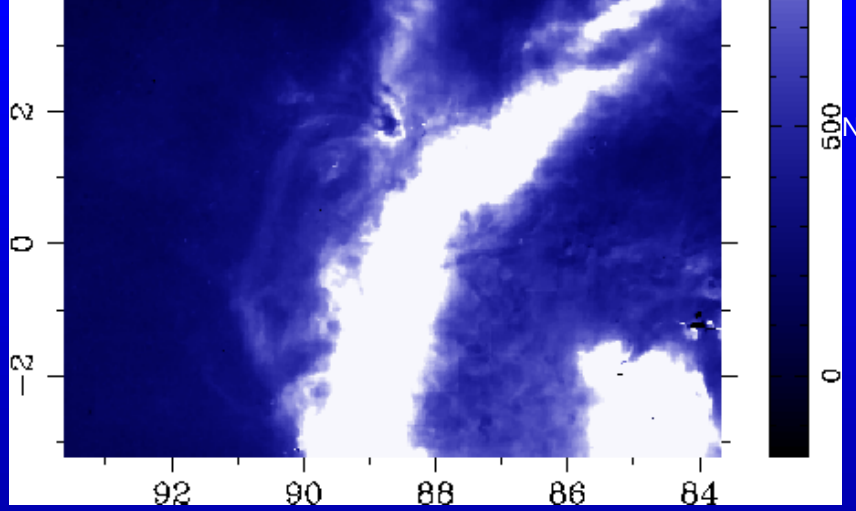
A radio-bright dark cloud: LDN 1622



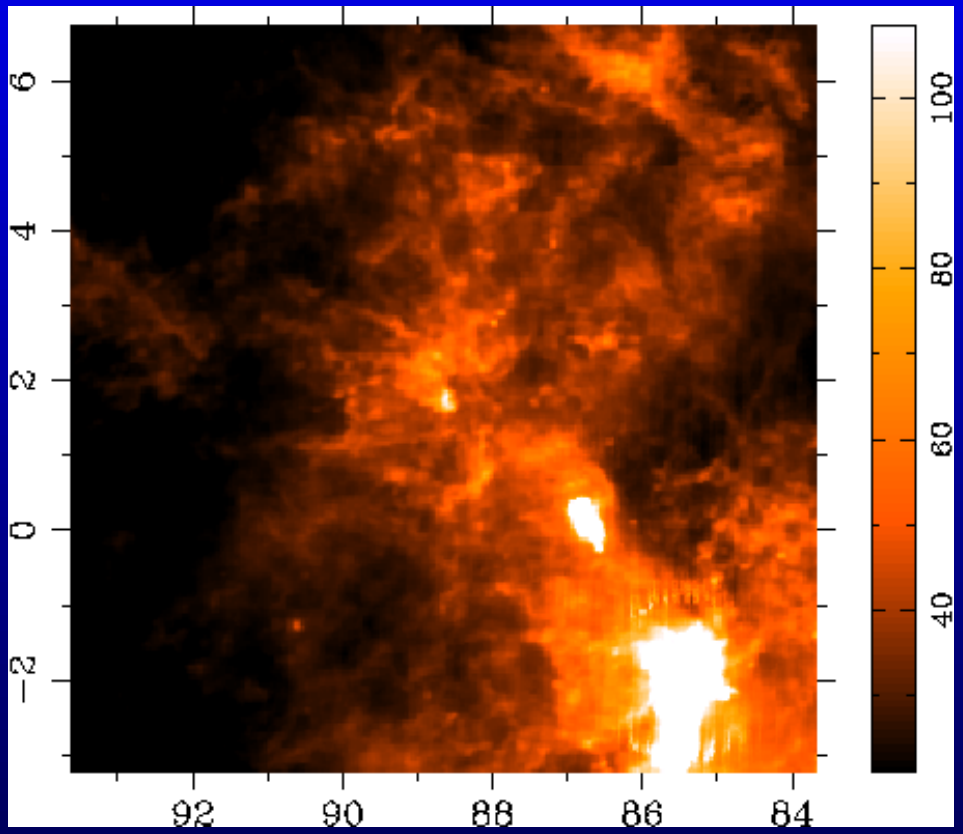
DUST EMISSION AT 31 GHZ

100μm

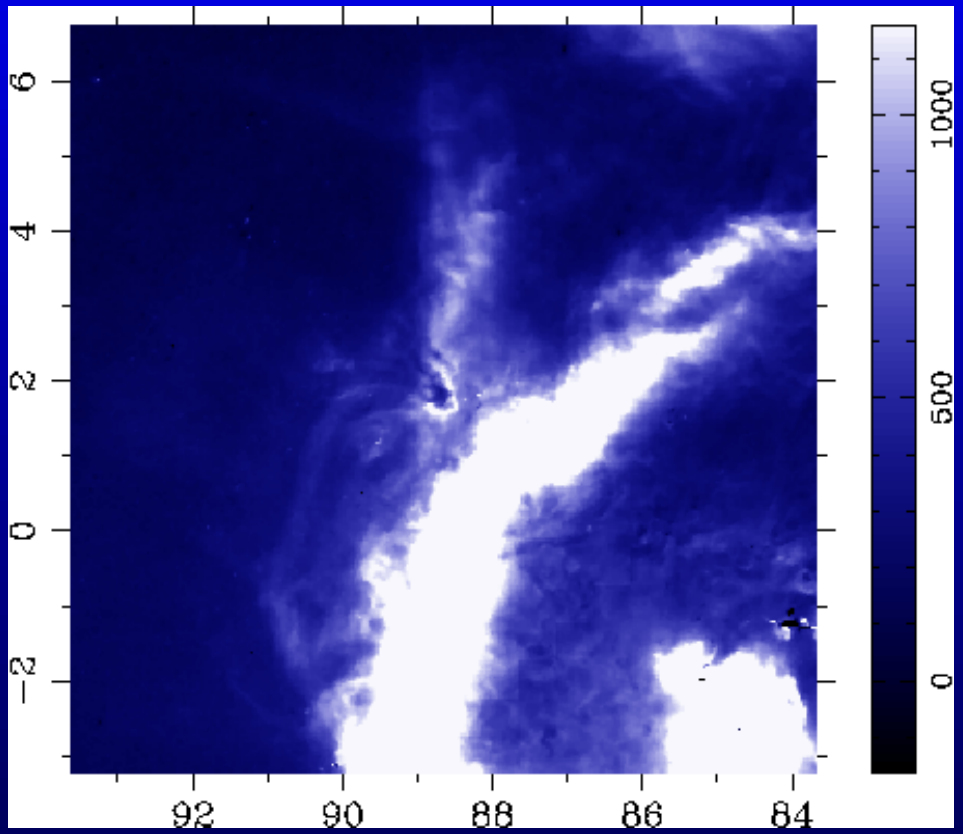


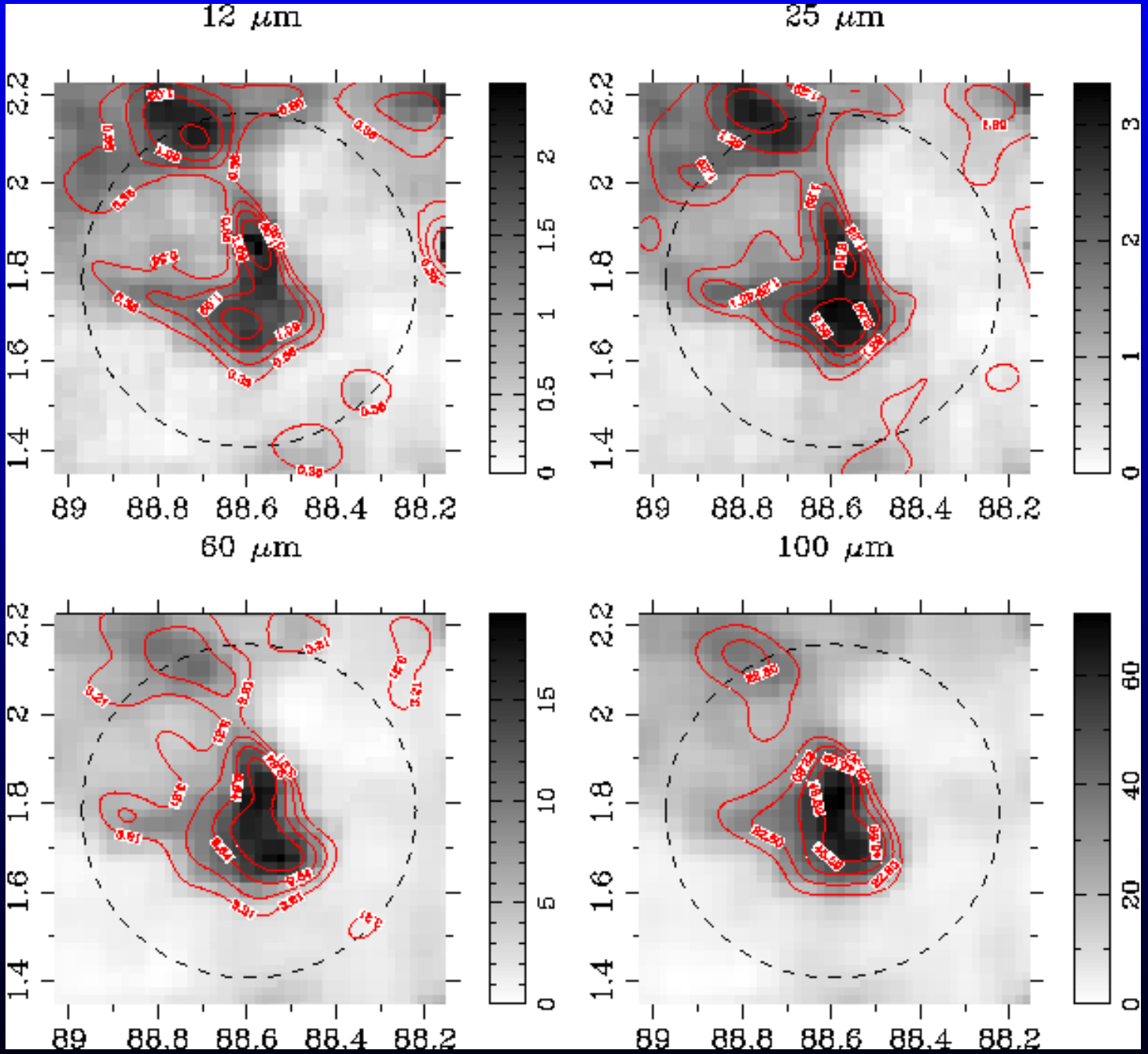


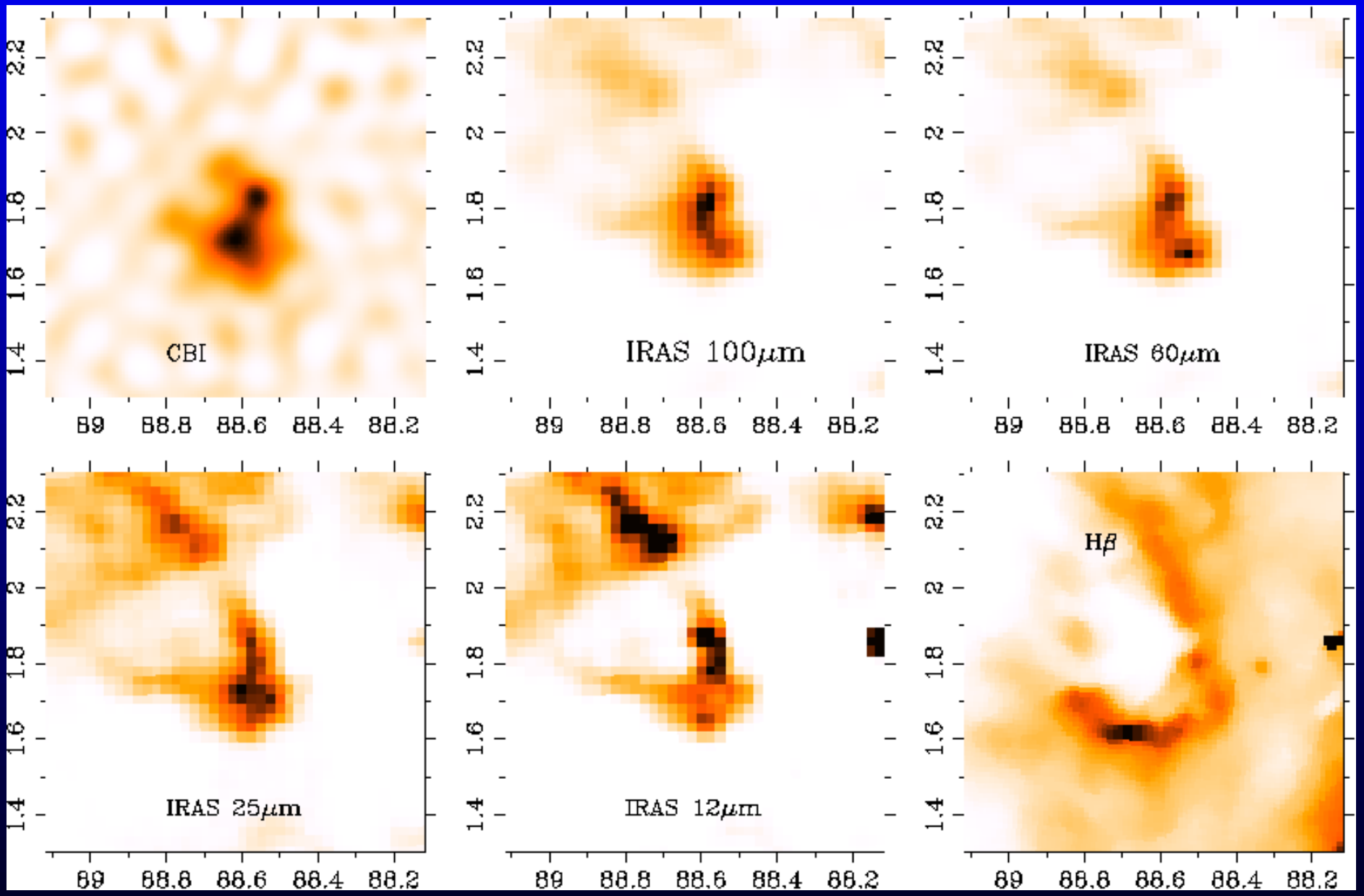
100μm



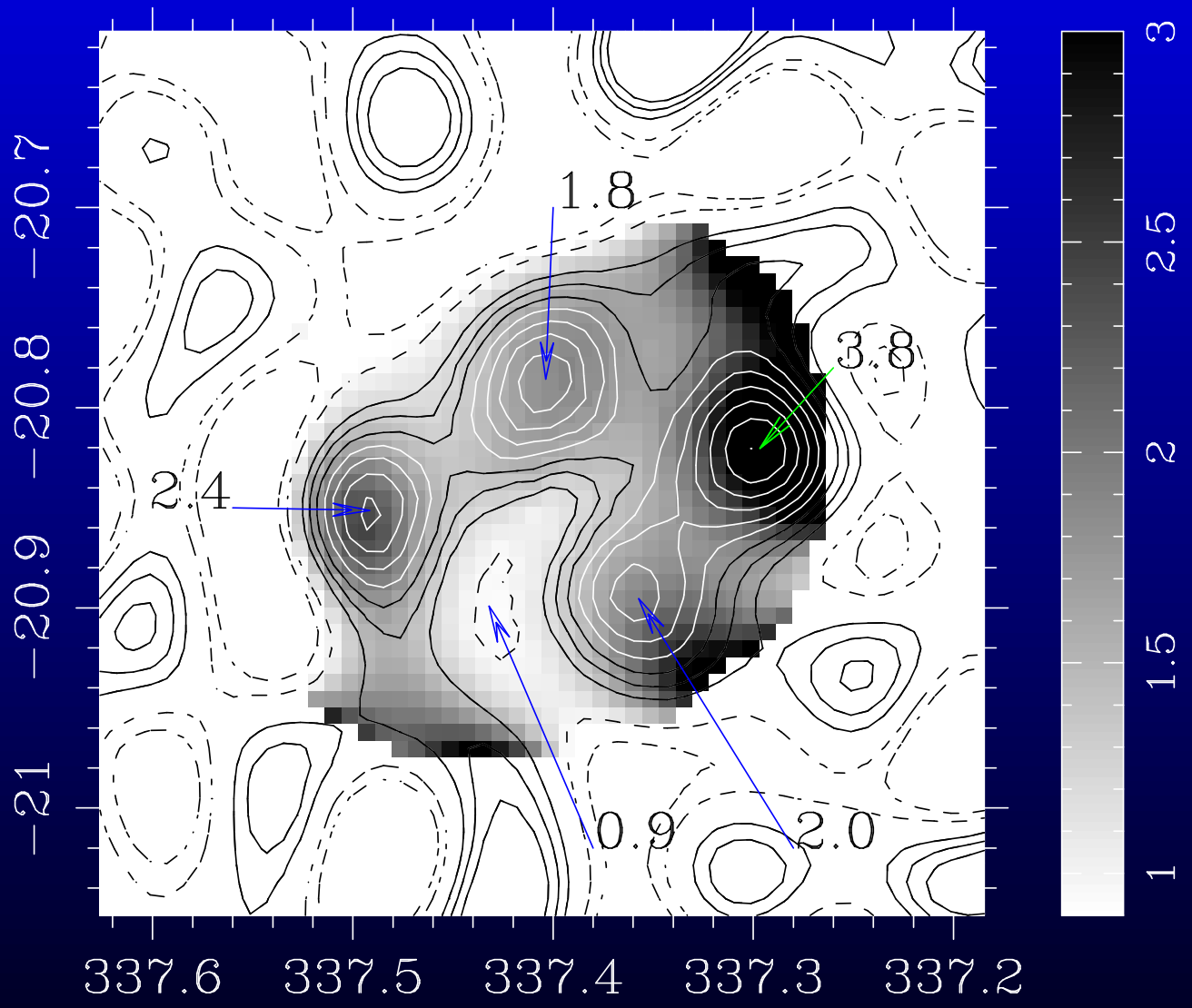
Hα



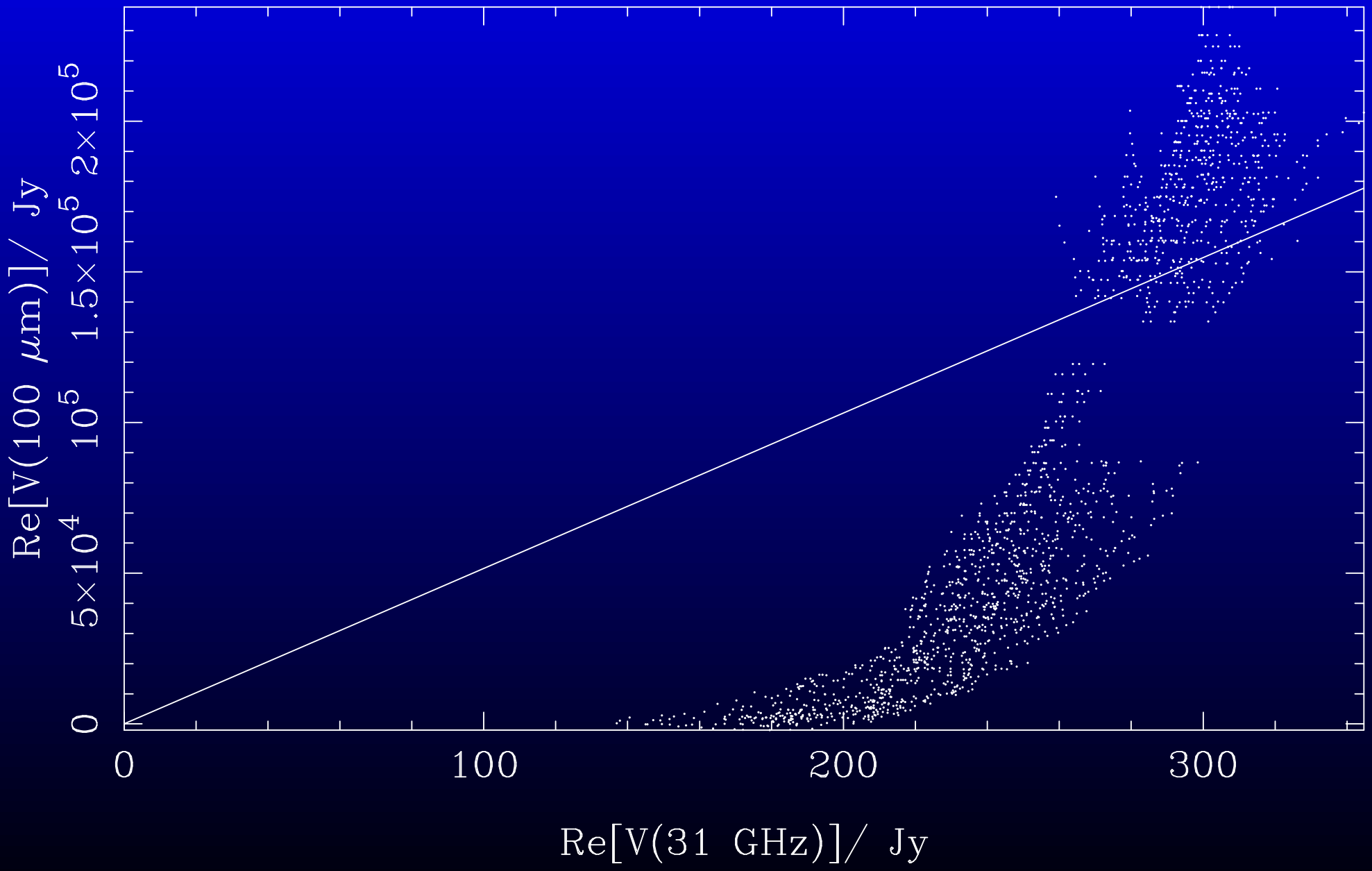

12 μm
25 μm
60 μm
100 μm
2.2
2
1.8
1.6
1.4
89
88.8
88.6
88.4
88.2
0
0.5
1
1.5
2
3
5
10
15
20
40
60


CBI
IRAS 100μm
IRAS 60μm
IRAS 25μm
IRAS 12μm
Hβ
89
88.8
88.6
88.4
88.2
1.4
1.6
1.8
2
2.2

T_e variations in the Helix?

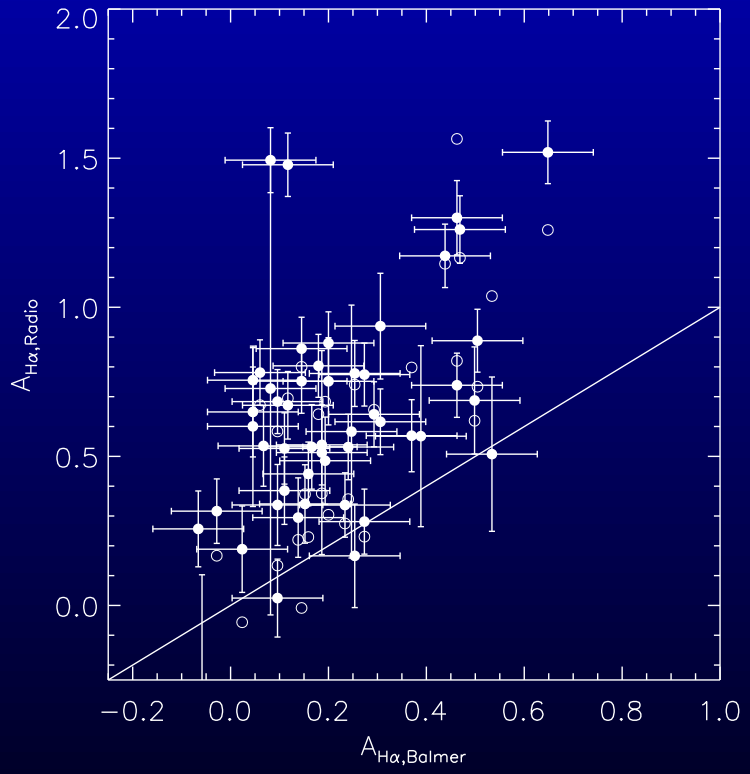


The radio-IR correlation in H II regions: M 42

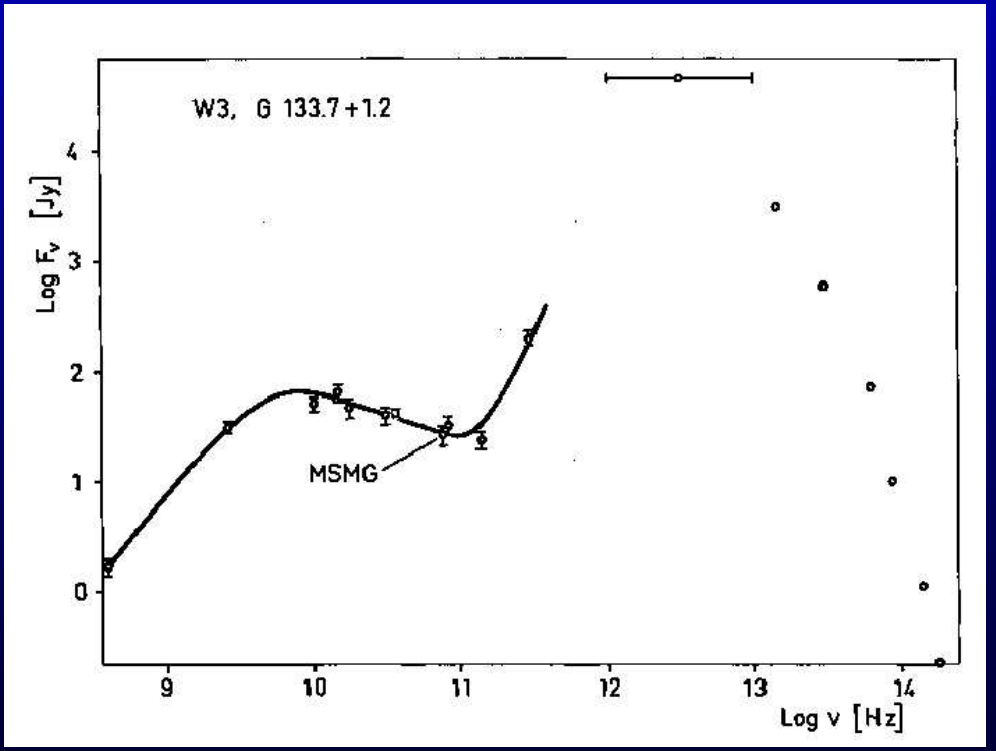


Other detections

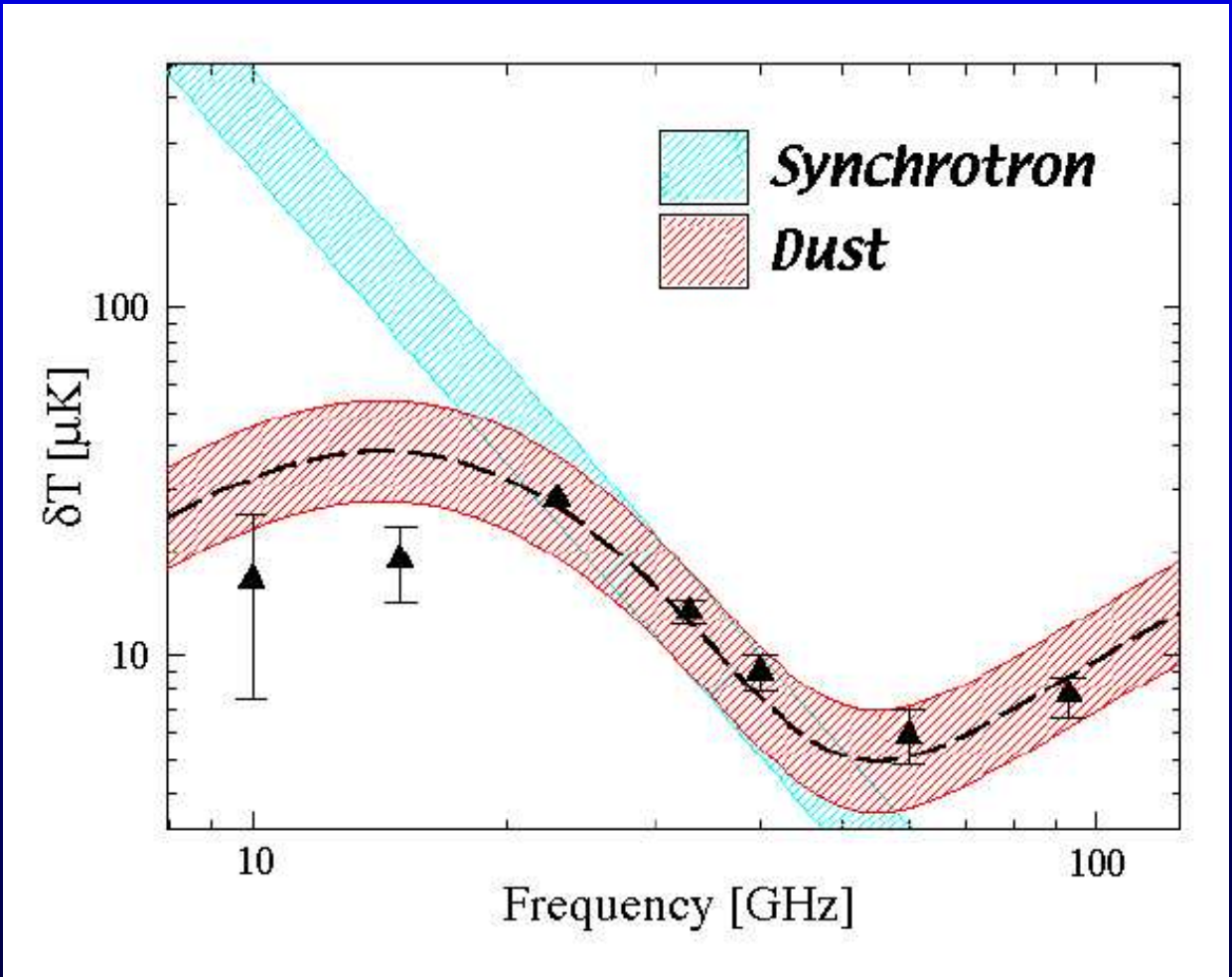
LMC H II regions show a 8.5 GHz excess over free-free emission as inferred from de-reddened Hα fluxes (Bell et al. 2002).



The continuum observations of H II regions reported by Malkamäki et al. (1979, A&A 71, 198) are not suggestive of free-free spectra.



Other detections



de Oliveira-Costa et al. (2004) have recently re-analysed the level of galactic foregrounds in the WMAP data, with the inclusion of 10 GHz and 15 GHz Tenerife data. They disprove the synchrotron interpretation of the radio-IR correlation at 30 GHz.