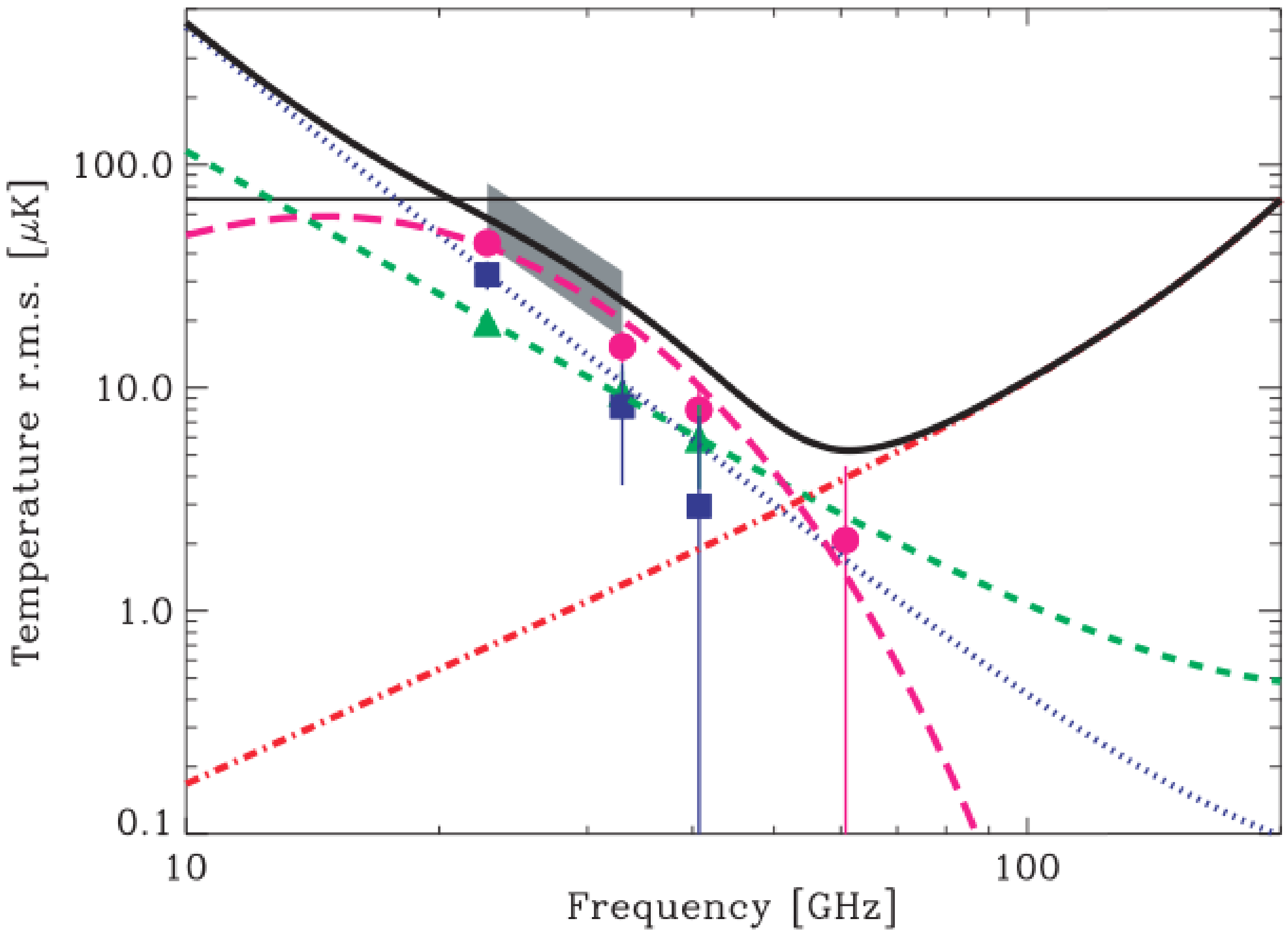
RRLs and low frequency foregrounds

R. J. Davis and many others

Foregrounds



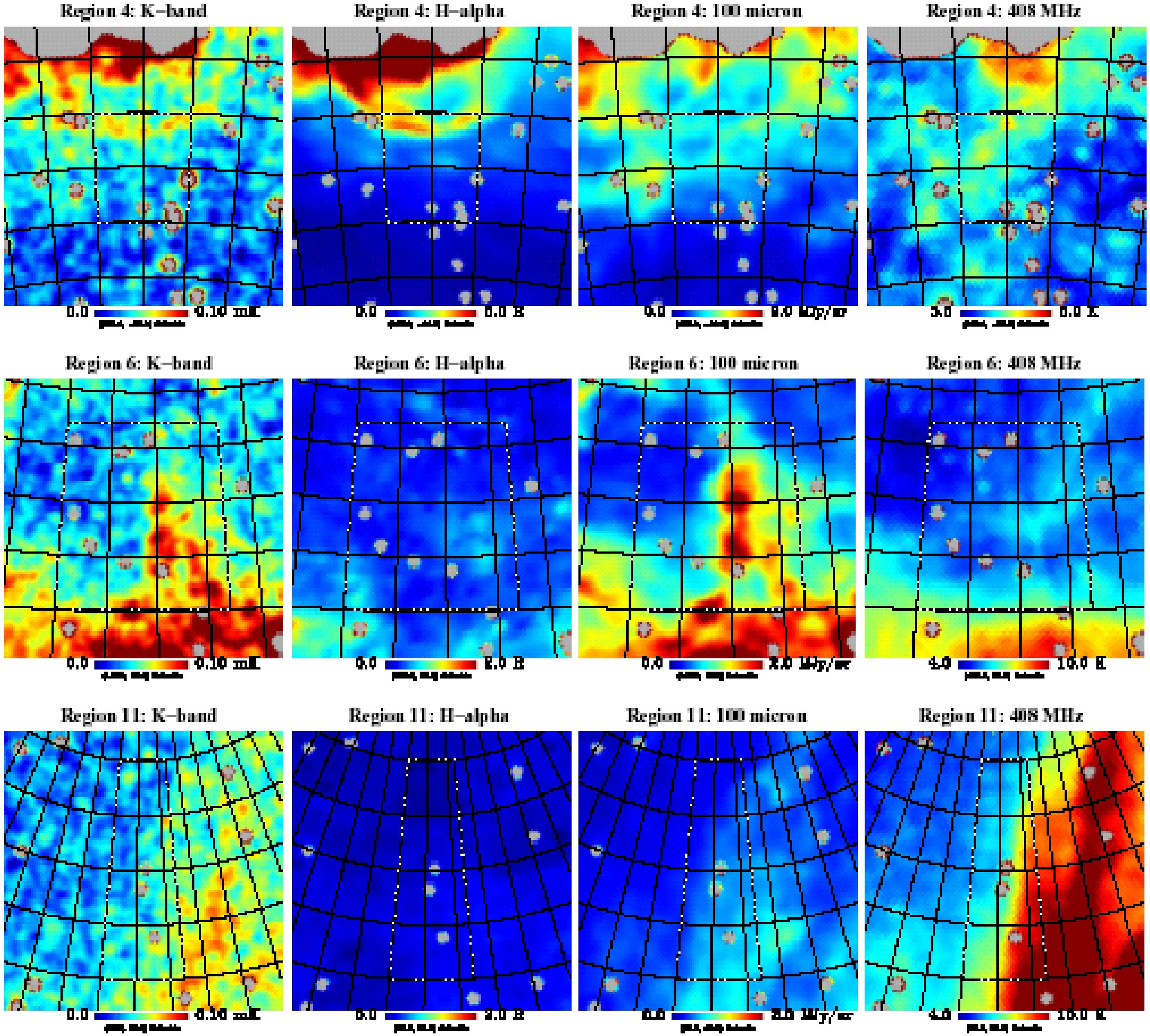
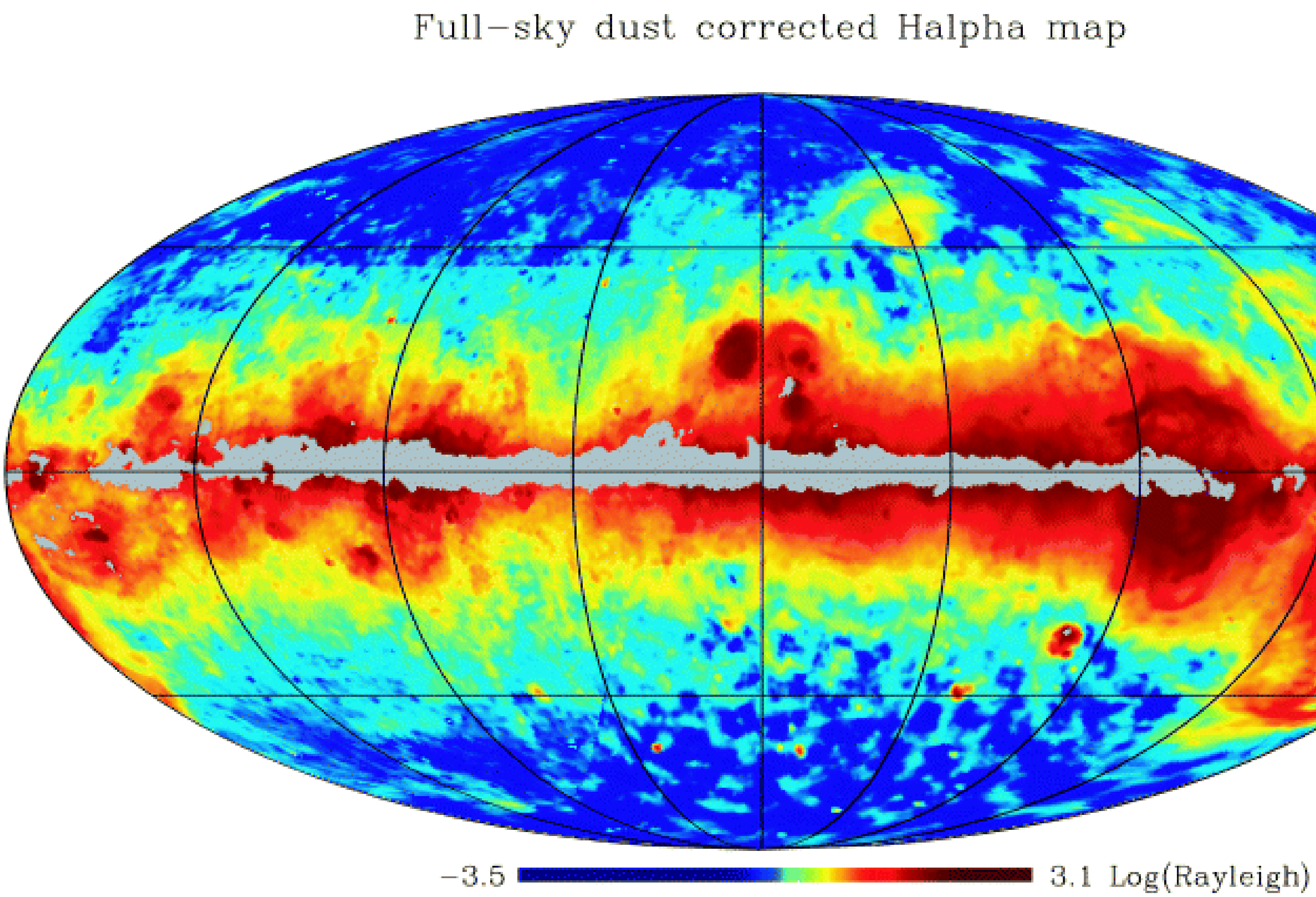


Figure 3. Maps of region 4 (Hα (free-free) dominated; *top* row), region 6 (dust dominated; *middle* row), and region 11 (synchrotron dominated; *bottom* row). From left to right are maps at *WMAP* K-band, Hα, SFD98 100 μm dust intensity and 408 MHz. Galactic coordinates are shown. Each map, with a pixel resolution $N_{side} = 256$, covers a $25° \times 25°$ area with 1° resolution. The dotted black/white line delineates the actual areas used for the T–T plots and cross-correlation analyses. Grey-areas are the standard *WMAP* Kp0 mask and extragalactic sources mask.

Hα maps corrected for dust

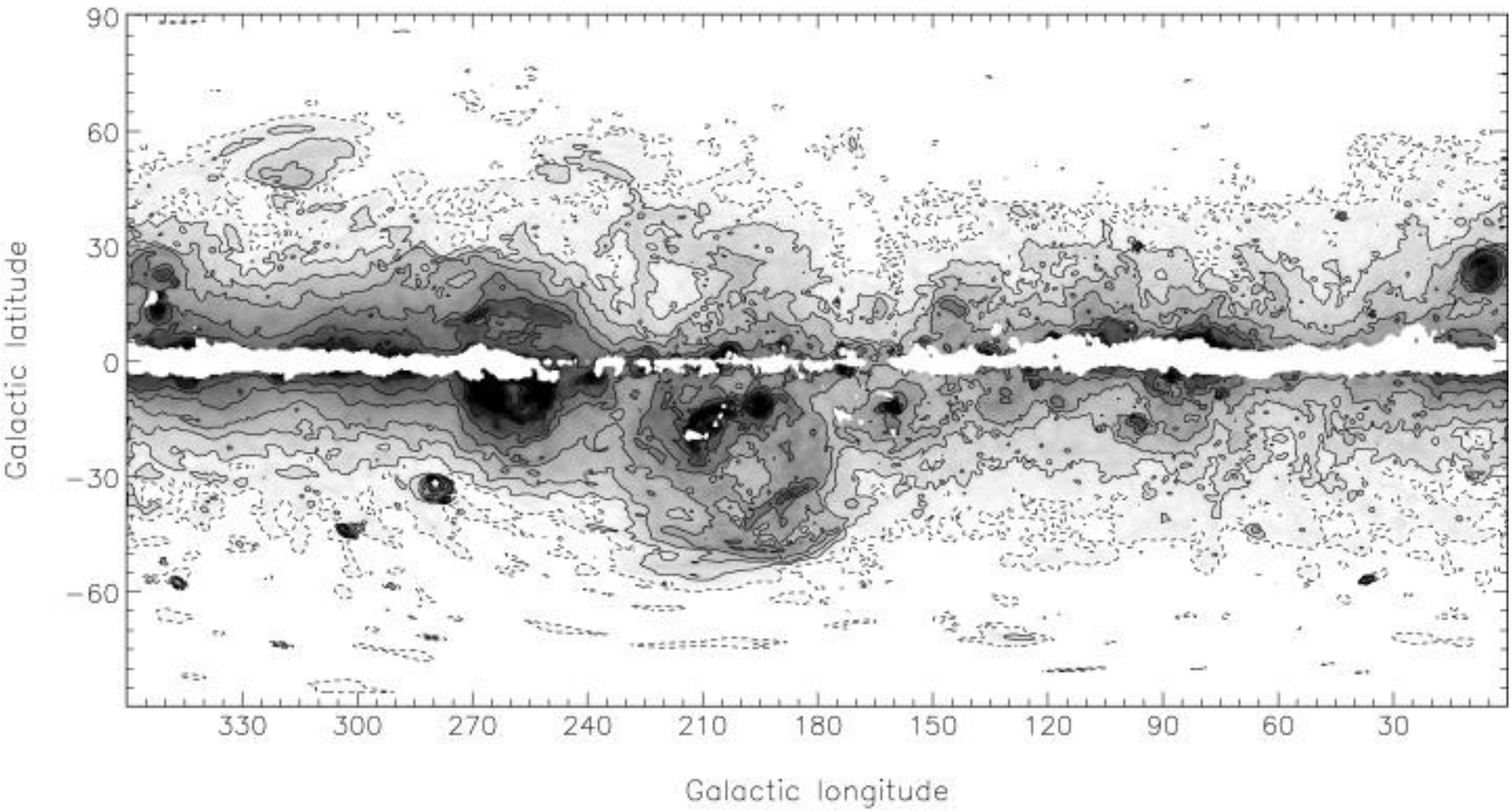
- Towards a free-free template
- Dickinson, Davies & Davis used WHAM and SHASSA Hα surveys for the northern and southern skies
- These were corrected for dust absorption using 100-μm maps of Schlegel Finbeiner & Davis
- Cannot recover 5% of sky along galactic plane


Full-sky dust corrected Halpha map
-3.5
3.1 Log(Rayleigh)

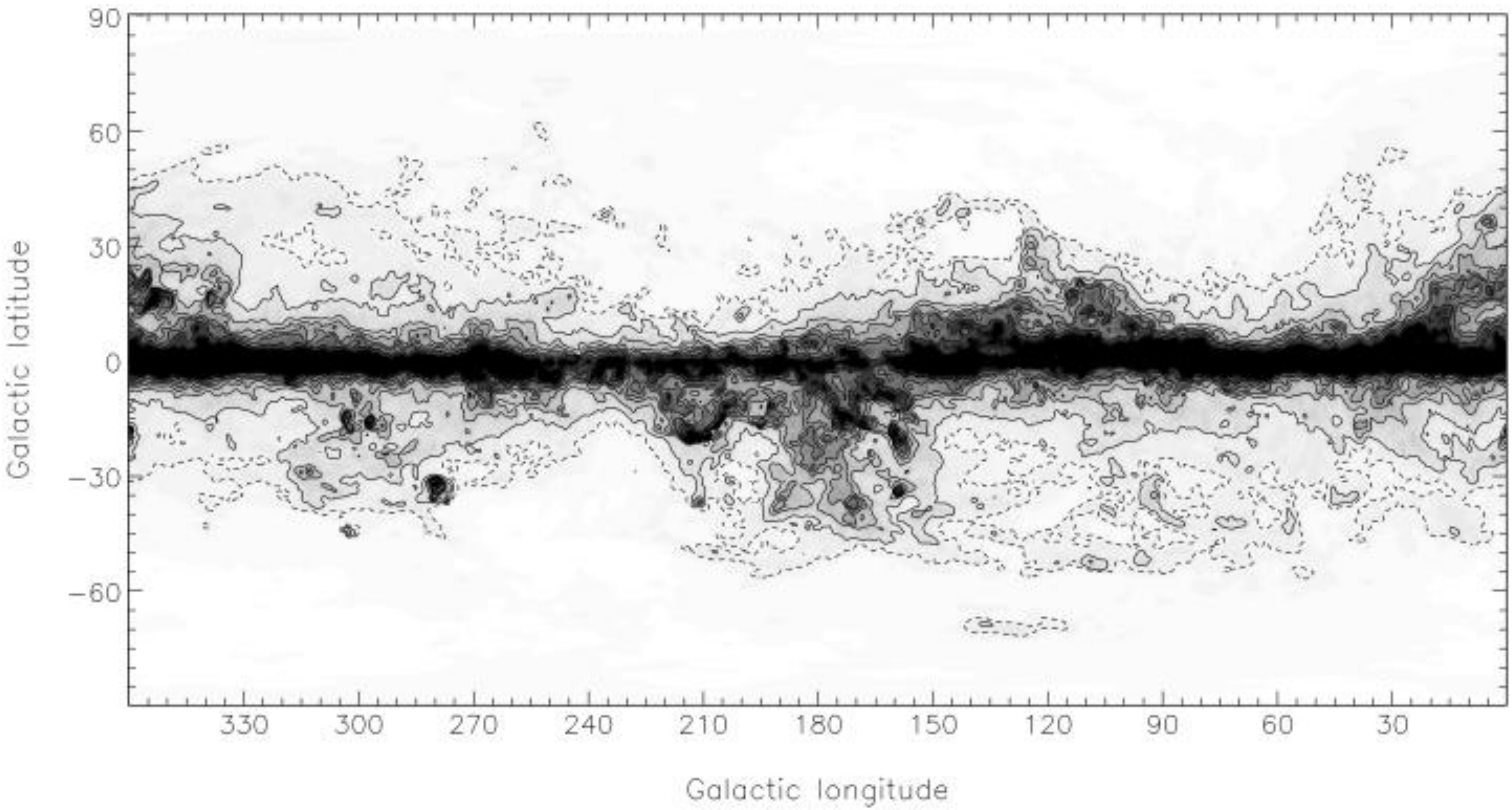
Conversion of dust corrected Hα into predicted radio surface brightness

- The free-free emission formula has been revised to give a 1% accurate formula for 100MHz-100GHz and electron temperature for 3000-20000K
- A full-sky free-free template map is presented at 30GHz.
- The Haslam 408MHz all sky map can be corrected to give a pure synchrotron map

Free-free brightness temperature 5μK – 1mK in powers of 2 at 30 GHz



Dust map shows regions where absorption is too high



Overview

- Radio Astronomy

- The Cosmic Microwave Background (CMB) and its foregrounds

- Determine the Free-free emission on the Galactic plane
  - Hα – heavy absorption on the Galactic plane
  - Radio Recombination Lines (RRLs) – no absorption problem

- RRL data from Parkes Telescope – HIPASS/ZOA survey

- Data analysis – derive spectrum at each pixel of the 3D cube

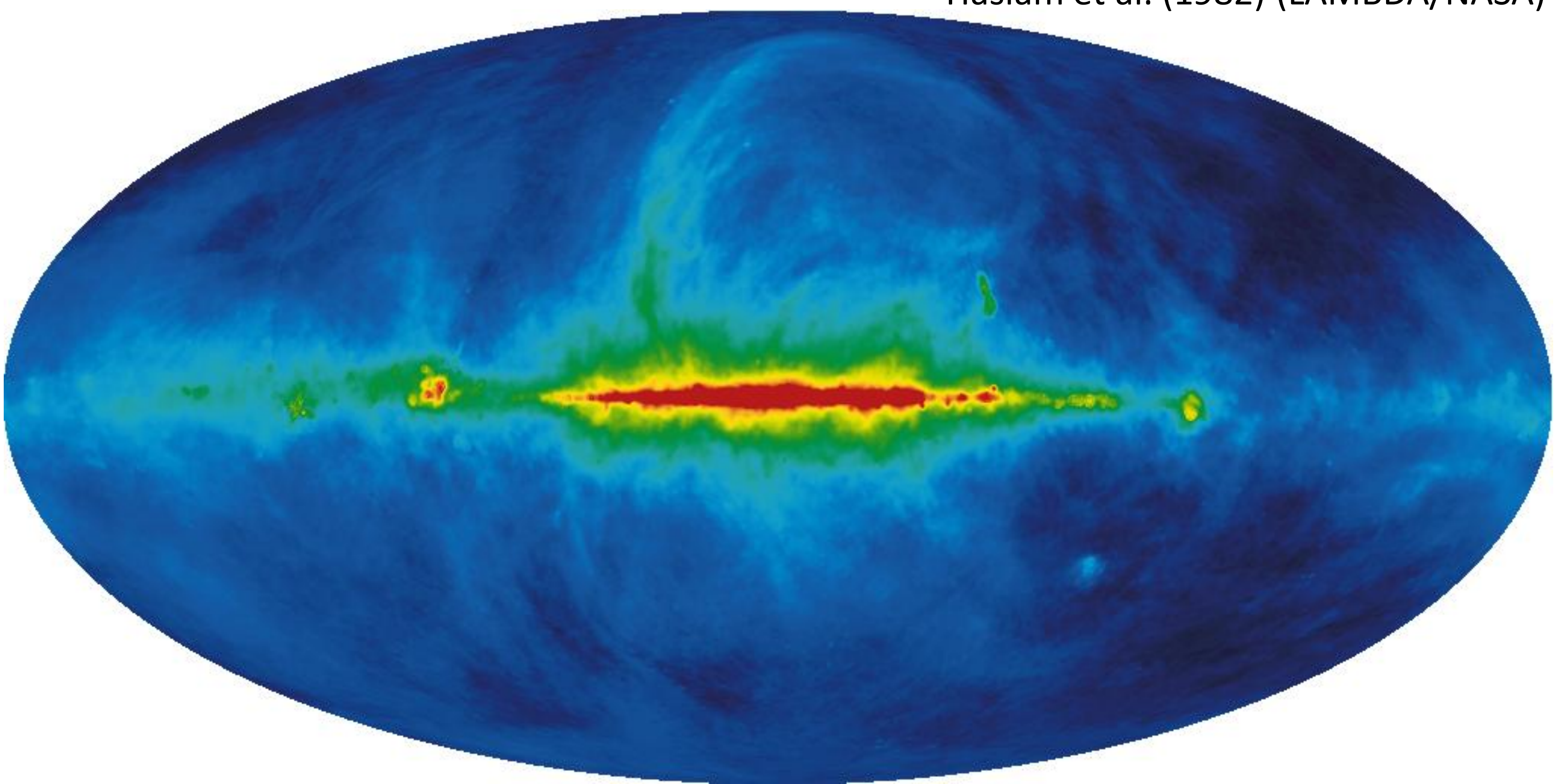
- Results – map of free-free emission between ℓ=36° to 44°, b=-4° to 4° and now l= 20 to 44.

- Conclusions
  - Good method for determining the free-free on the Galactic plane unambiguously
  - Implications for anomalous emission on the Galactic plane

Synchrotron emission

Synchrotron emission is due to relativistic electrons spiraling in the Galactic magnetic field (diffuse synchrotron). It depends on the energy spectrum of the electrons and on the magnetic field intensity (Longair 1994). Dominates at low frequencies, below 1 GHz and has a spectral index β between -2.7 and -3.2 (Davies, Watson & Gutierrez 1996).

Haslam et al. (1982) (LAMBDA/NASA)



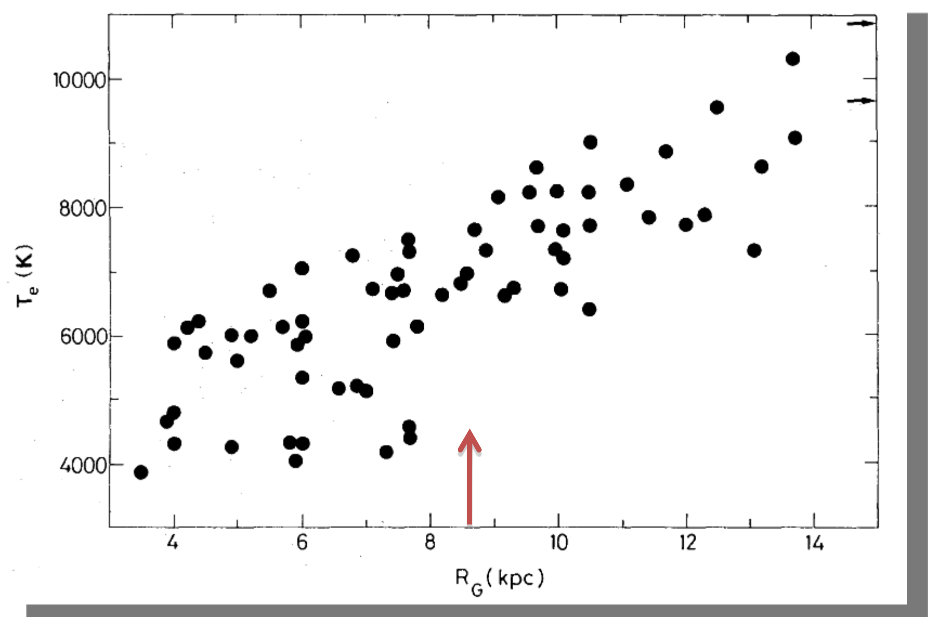
Radio Recombination Lines

Occur when electrons recombine with protons, in a high energy state, and cascade downwards level to level emitting a series of lines.

Transition identified by its principal quantum number, *n* and its respective change, Δ*n*.

To get free-free brightness temperature a value for T_e is needed: Shaver et al. (1983) and Paladini et al. (2004)

→ **~ 7000** K **in the solar neighborhood**



Shaver et al. (2004)

RRL Surveys

Most RRL surveys have concentrated on individual HII regions along the Galactic plane. There is no RRL survey that covers the whole Galaxy at one frequency.

Authors	Longitude	Transition	Frequency (GHz)	Beam width (arcmin)
Gordon & Cato (1972)	9° to 130°	H157α	1.683	33
Hart & Pedlar (1976)	5° to 70°	H166α	1.425	31 x 33
Lockman (1976)	358° to (0°) 85°	H166α	1.425	21
Downes et al. (1980)	0° to 60°	H110α	4.874	2.6
Wink et al. (1982)	Various	H109α	4.9	2.9

ALFA (**A**recibo **L**-Band **F**eed **Array**) RRL survey:

20 cm RRL survey with a longitude range from 32° to 77° and 168° to 214°, |b|<5°. 100 MHz bandwidth (H164α, H165α, H166α, H167α, H209β and He and C lines).

HOPS, The **$H_2$0** southern Galactic **P**lane **S**urvey:

Survey of selected bands in the 12mm window with the MOPRA telescope. From ℓ=300° to (0°) 30° and |b|≤ 0.5°. Includes H62α, H65α and H69α.

HI Parkes All-Sky Survey (HIPASS)

HIPASS (Staveley-Smith et al. 1996) is a deep large area HI survey designed to detect nearby galaxies of low surface brightness in the entire southern sky.

- 64 MHz bandwidth, divided into 1024 channels of 13.2 km/s separation
- 14.4 arcmin FWHM
- Integration time 450 s/beam, 13 beam receiver, 13 mJ/beam/channel rms
- 388 datacubes 8° (RA) x 8° (δ) x 1024 velocity channels

Zone of Avoidance Survey (ZOA)

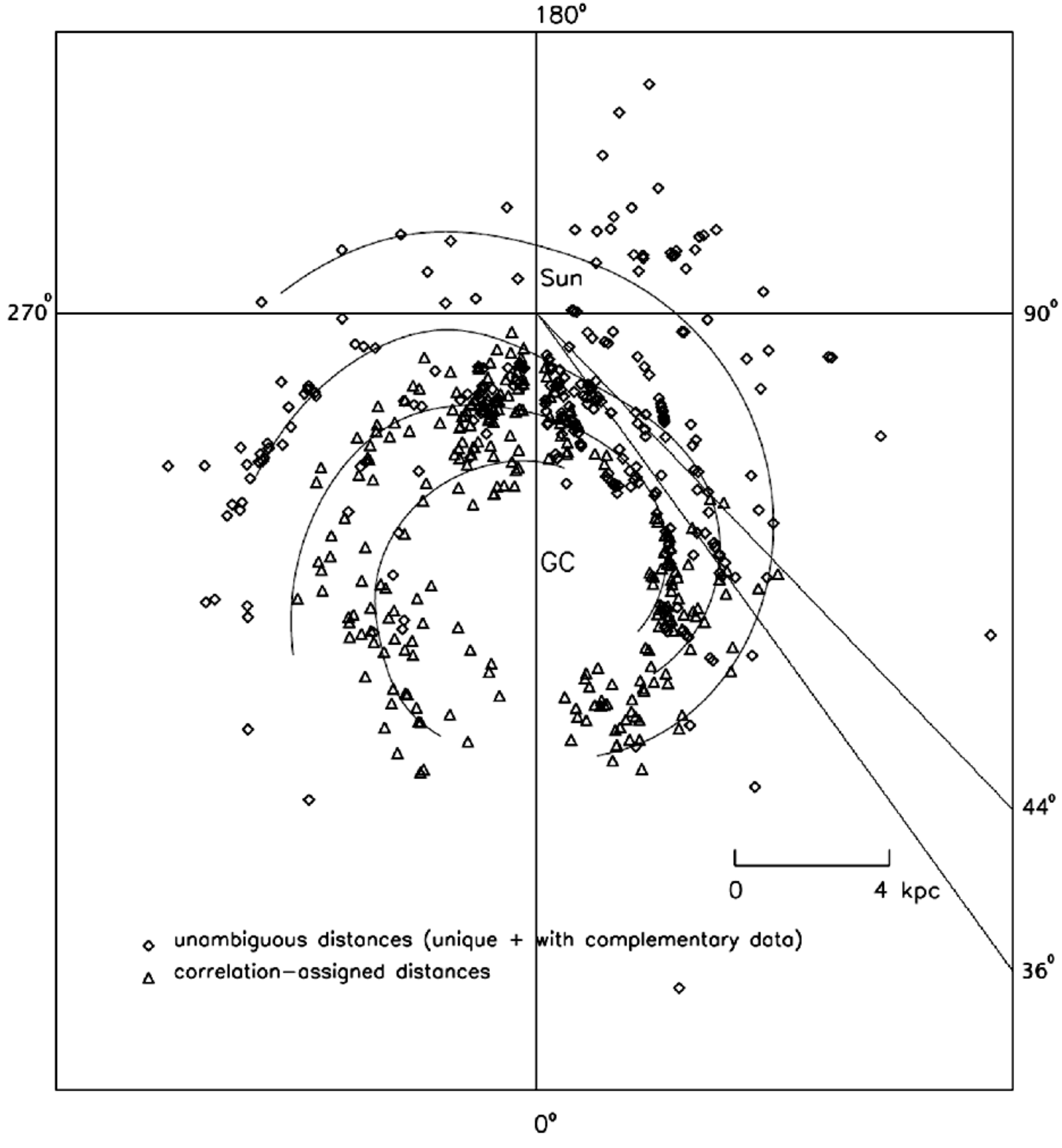
Deeper survey (Staveley-Smith et al. 1998)

- Twice the sensitivity of HIPASS
- rms noise per channel is 6 mJ/beam
- Integration time 2300 s/beam
- 27 datacubes 8° (ℓ) x 8° (b) x 1024 velocity channels

Line	ν (MHz)	v (km/s)
H168α	1374.601	9667.6
H167α	1399.368	4440.2
H166α	1424.734	-913.5

ZOA Cube 040 - 44 ° < ℓ < 36 °, |b| ≤ 4 °

HII regions map



Paladini et al. (2004)

Data reduction and analysis

(Barnes et al. 2001)

1. LIVEDATA - Bandpass correction, data calibration, velocity frame shifting, spectral smoothing (two filters: Tukey and Hanning)

2. GRIDZILLA – Gridding (median of the spectra within 6’ of each pixel)

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3D cube, 8° x 8° x 1024, with spectra for every 4’ x 4’ pixel
27 km/s and 15’.5 spectral and spatial resolution

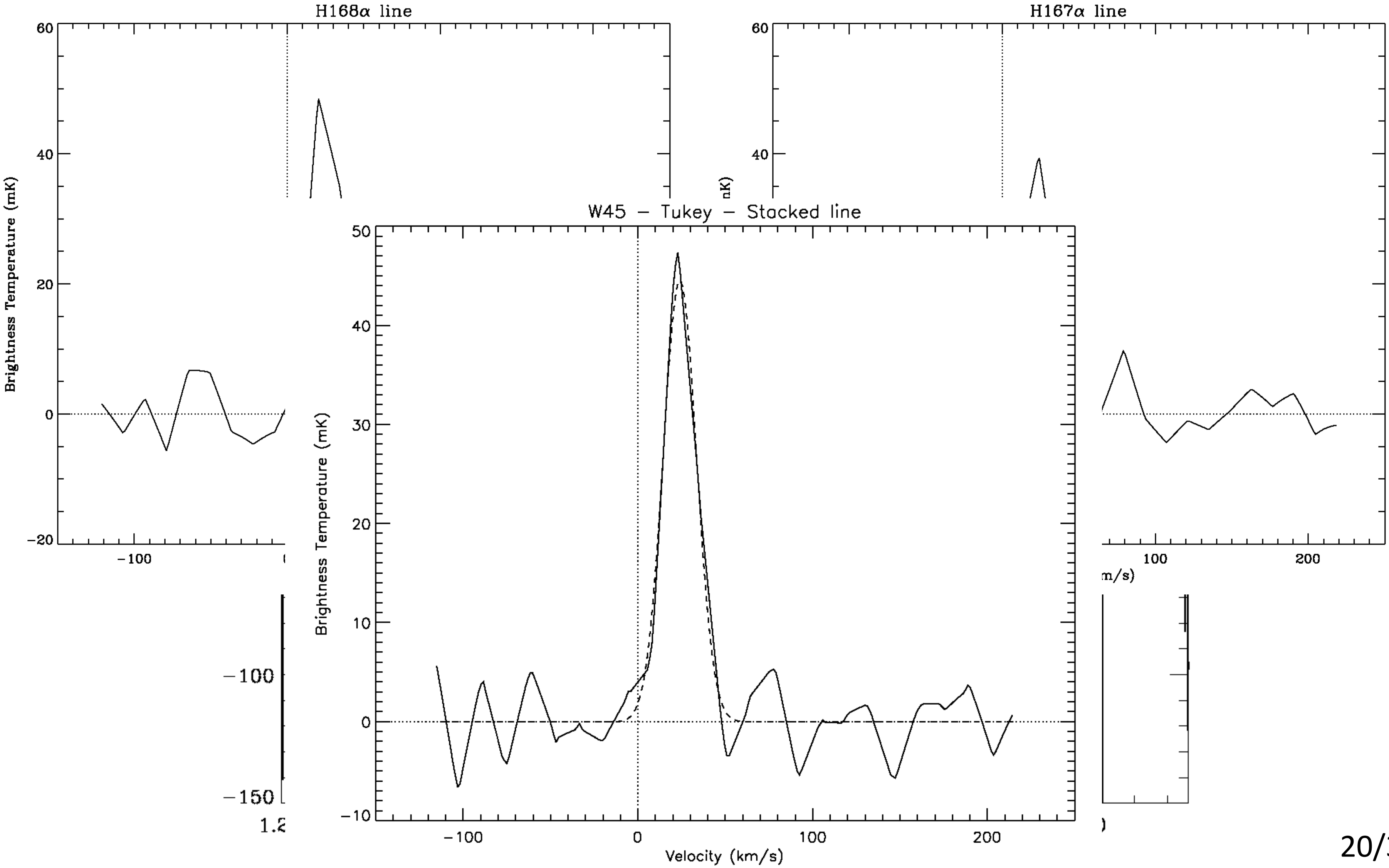
3. IDL – Baseline fitting, Line stacking ➔ Line integral ➔ Free-free emission (T_e)

Results: Line Velocities

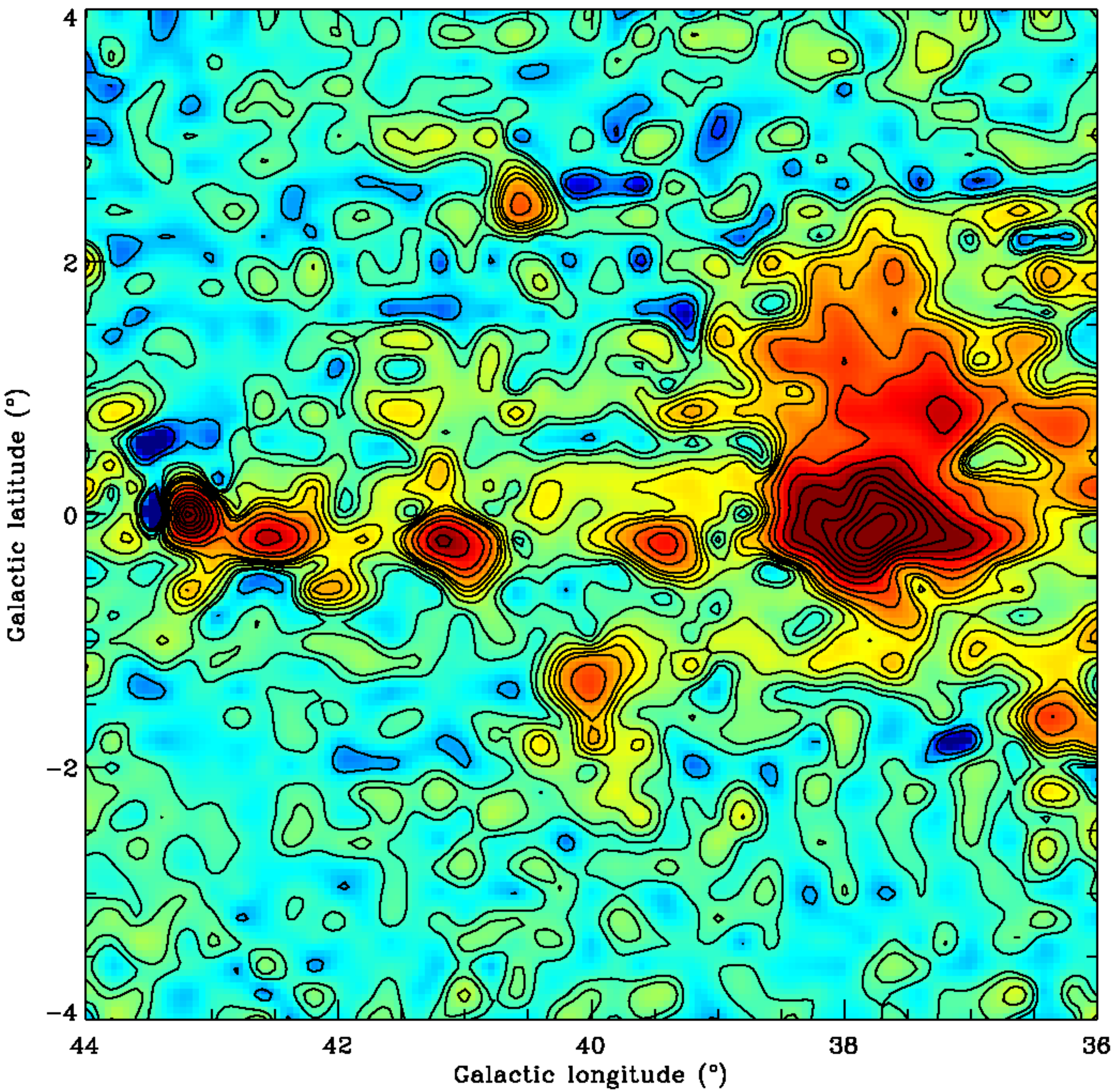
HII region **W45 – G40.5+2.5** (Tukey smoothing)

"Ringing" – associated with the strong HI signal from the Galaxy and narrow band interference

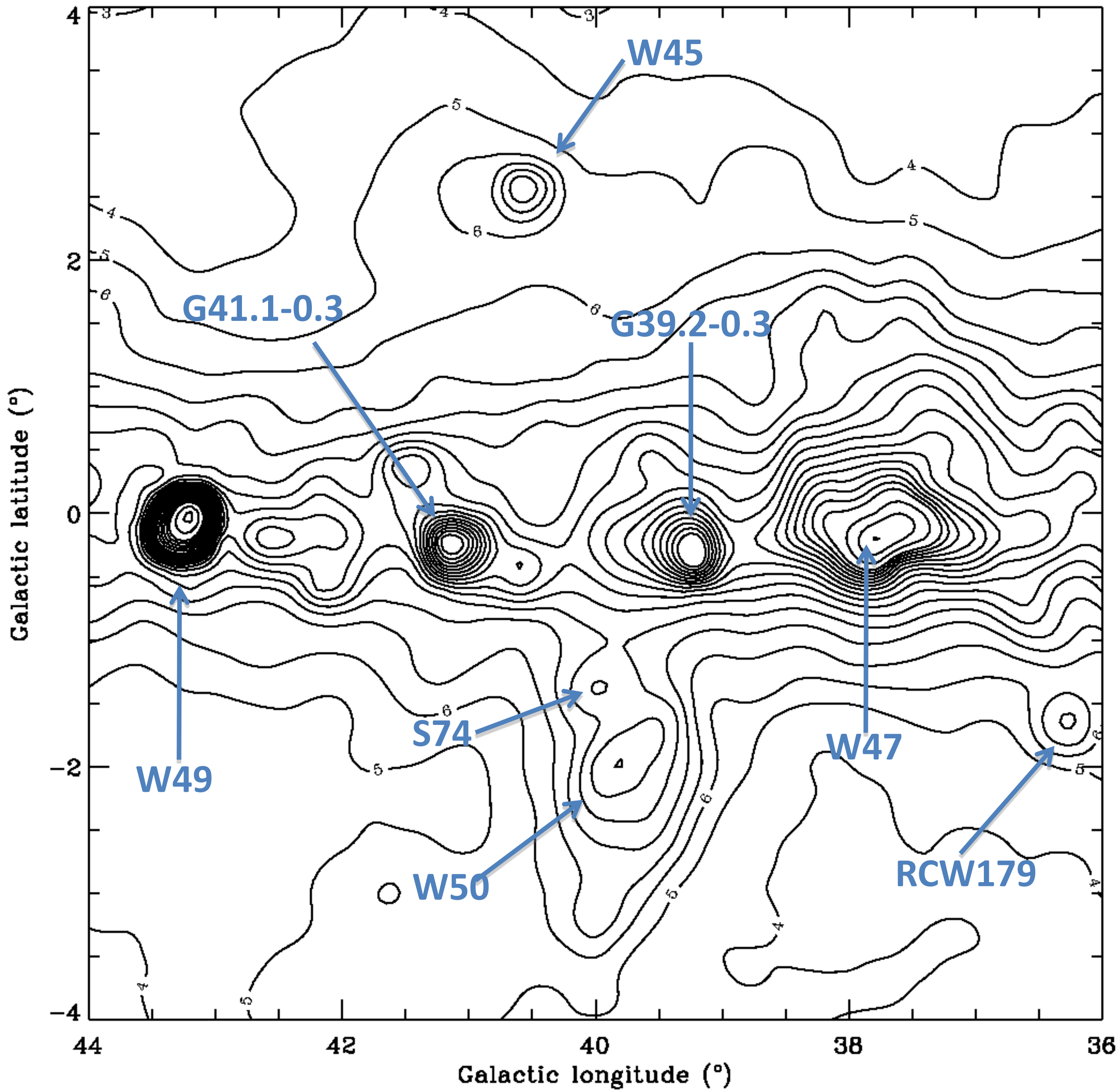
Ripple – caused by standing waves from strong continuum sources (52m – 5.7 MHz period) and by solar emission



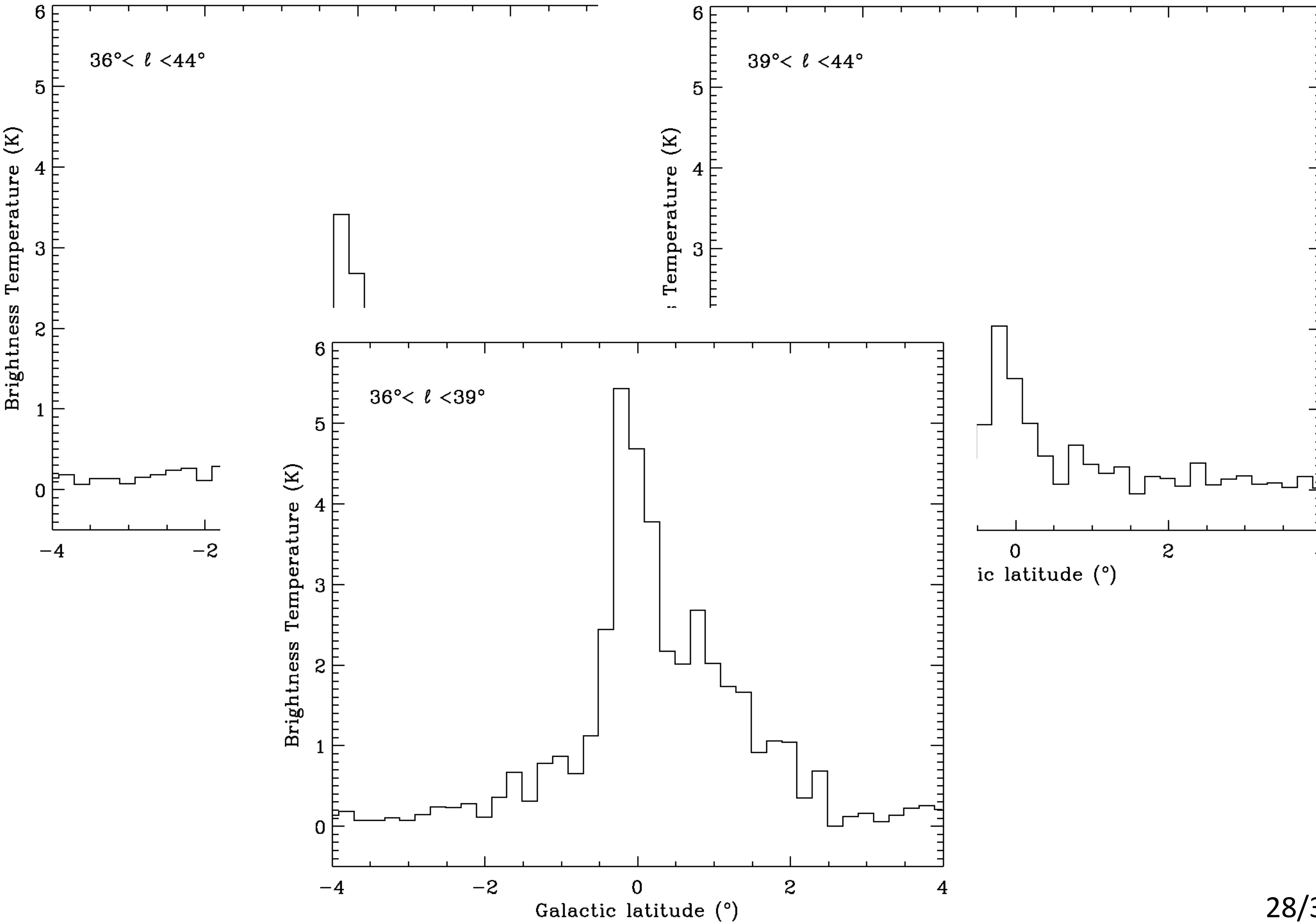
Results: Total RRL emission map



Results: HIPASS+ZOA continuum map at 1.4 GHz



Results: Free-free latitude distribution



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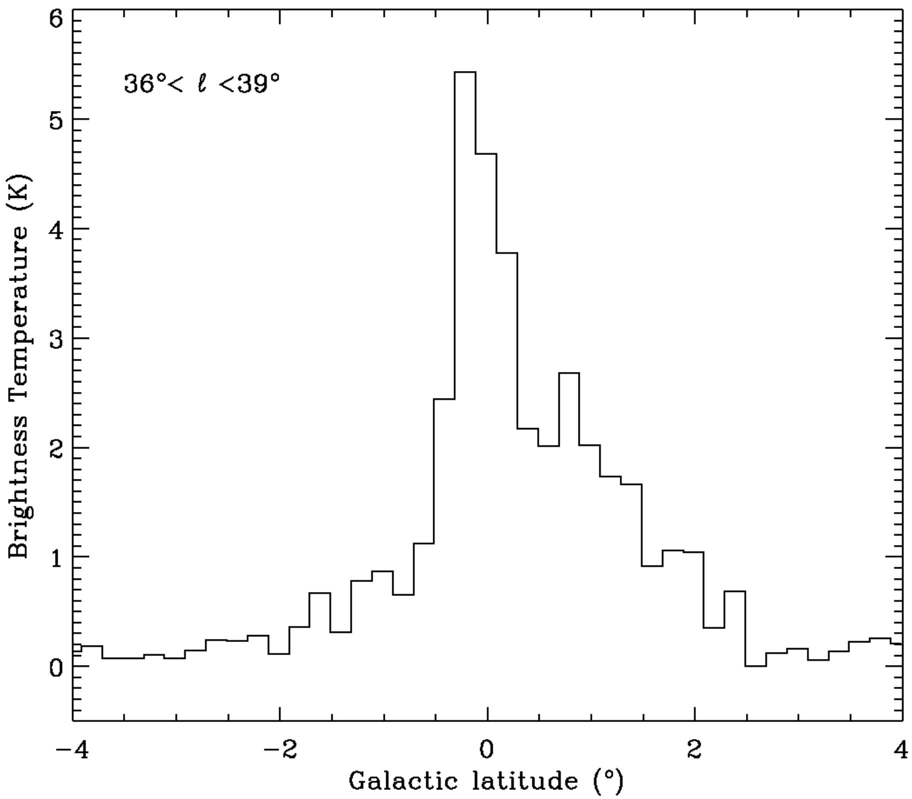
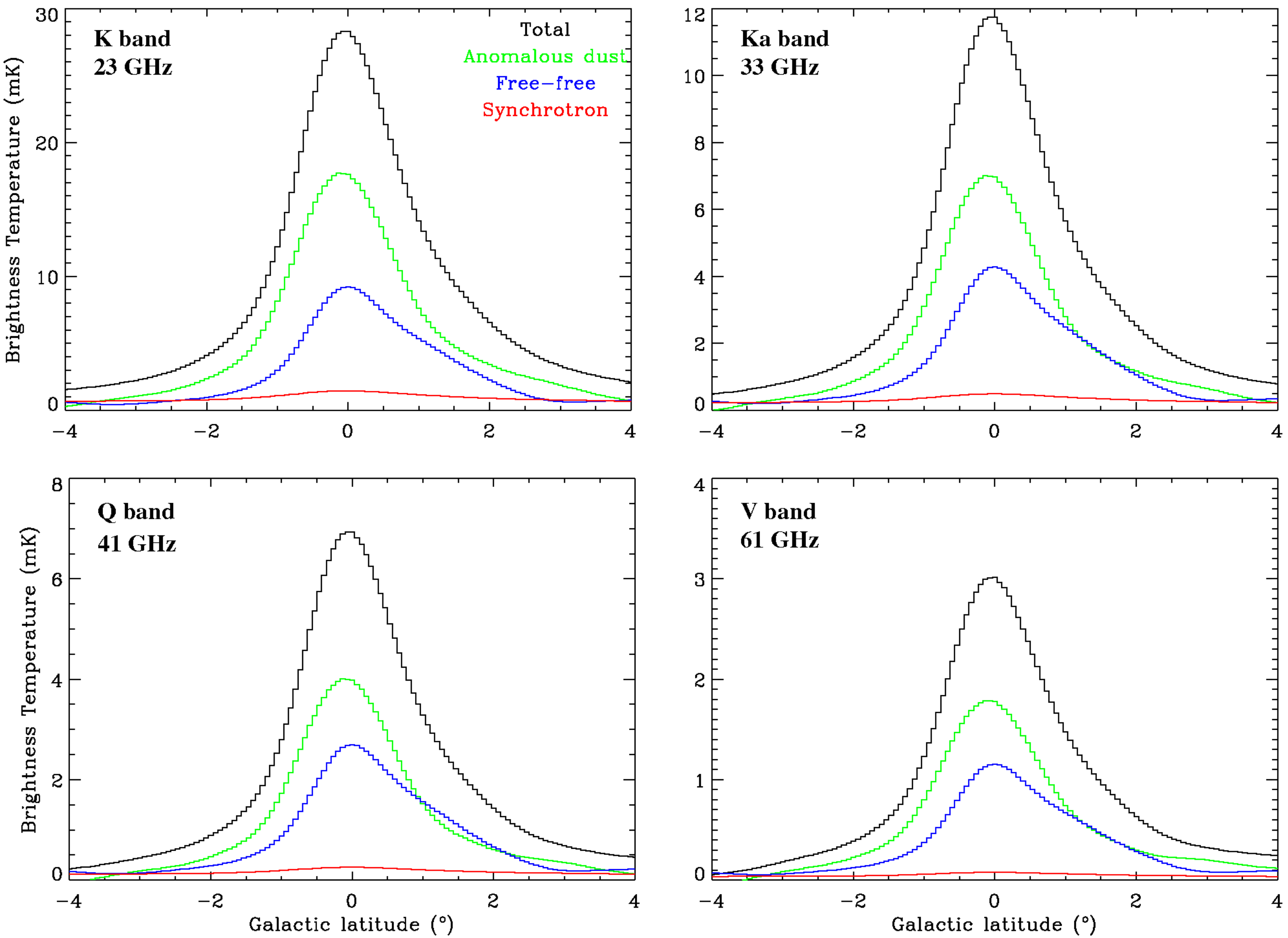


- For the longitude range 36°<ℓ<39° (Sagittarius arm) the FWHM of the distribution is ~ 2°

- Paladini et al. (2005) find a FWHM of ~ 1.4° for the range 20°<ℓ<30° (Scutum arm)

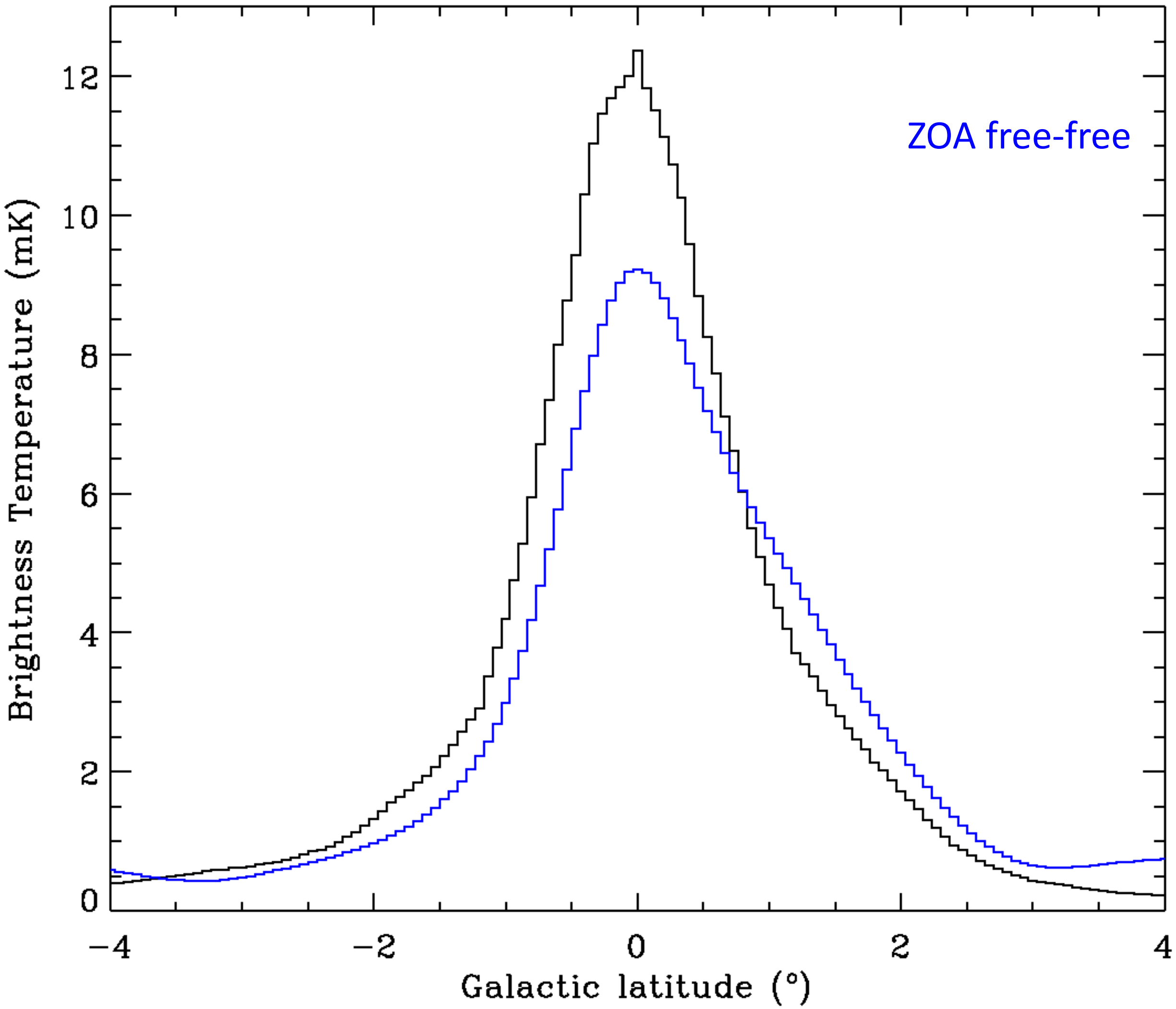
FWHM of HII emission is **z ~ 200 pc**

Results: Comparison with WMAP data



Results: Comparison with WMAP MEM

Maximum Entropy Model (Gold B. et al. 2008)



- T_b dependence on $T_e^{1.15}$

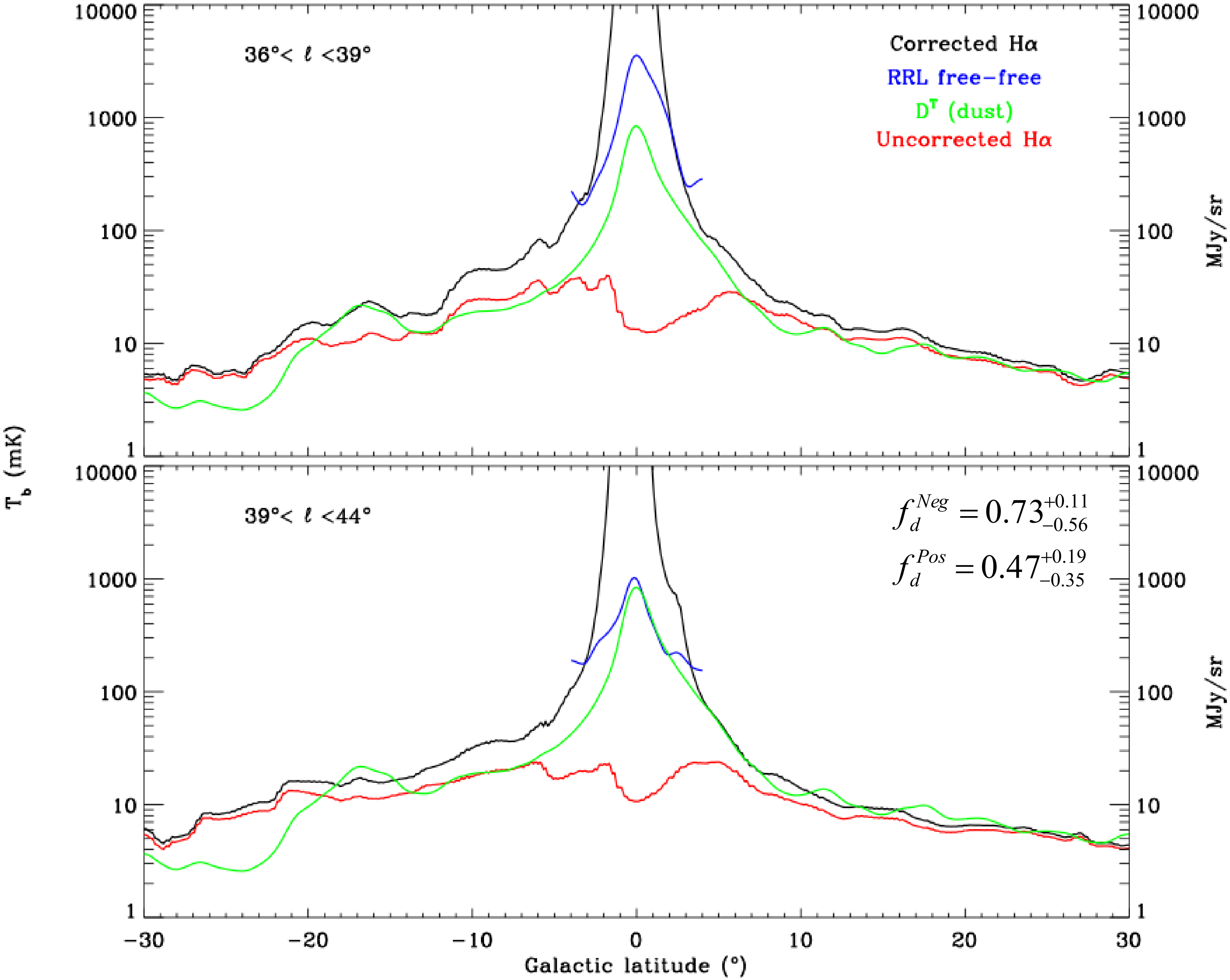
➜

If T_e = 8000 K the ZOA distribution increases by 1.16 and the integral of the two distributions agrees within 10%

- Problems with the model ? – Difficult to estimate the errors!

Results: The Hα latitude distribution

[redacted]



Hα prediction is uncertain on the plane, where the dust properties change from the D^T estimates.

Conclusions

Radio Recombination Lines at 1.4 GHz from the HI Parkes ZOA survey enable us to recover the diffuse free-free emission on the Galactic plane, where other methods fail or are very difficult to apply (component separation).

Comparison of our results with the MEM model give a best fit for T_e of 8000 K. T_e varies from 5500 K (Scutum spiral arm) to 6600 K (Local spiral arm), from HII measurements. But HII regions are only a fraction of the emission at this frequency (20-30 %) so the remaining diffuse emission is likely to have higher T_e (> 8000 K).

Comparison of our determination of the free-free emission with WMAP data clearly show an excess emission between 23 and 61 GHz, likely due to spinning dust.

New data

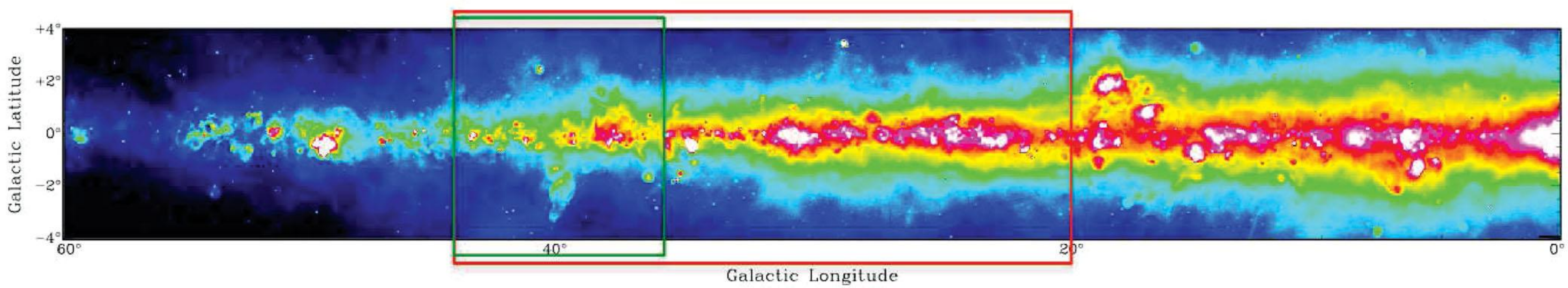


Figure 1. The coverage of the 8◦() × 8◦(*b) region analysed in Paper I (green) and the larger 24◦() × 8◦(b) area under study in the present work (red). The* map is from the 2.7-GHz survey by Reich et al. (1990b).

Improved data processing

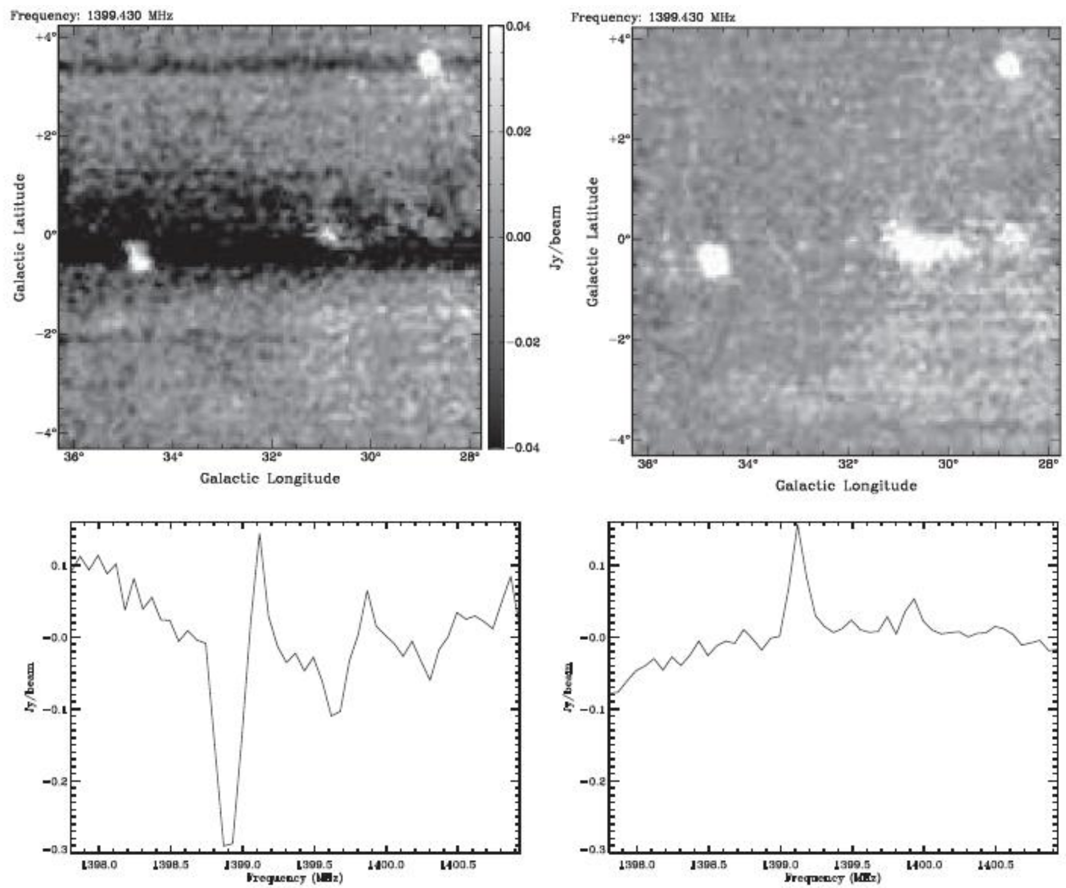


Figure 2. Top: maps of the ZOA-032 data cube at $V = -13.4\ \mathrm{km\,s^{-1}}$ reduced with $minmed_{10}$ (left) and $tsysmin_{10}$ (right). Bottom: the corresponding H167α spectra at $(\ell, b) = (35\overset{\circ}{.}6, 0\overset{\circ}{.}0)$.

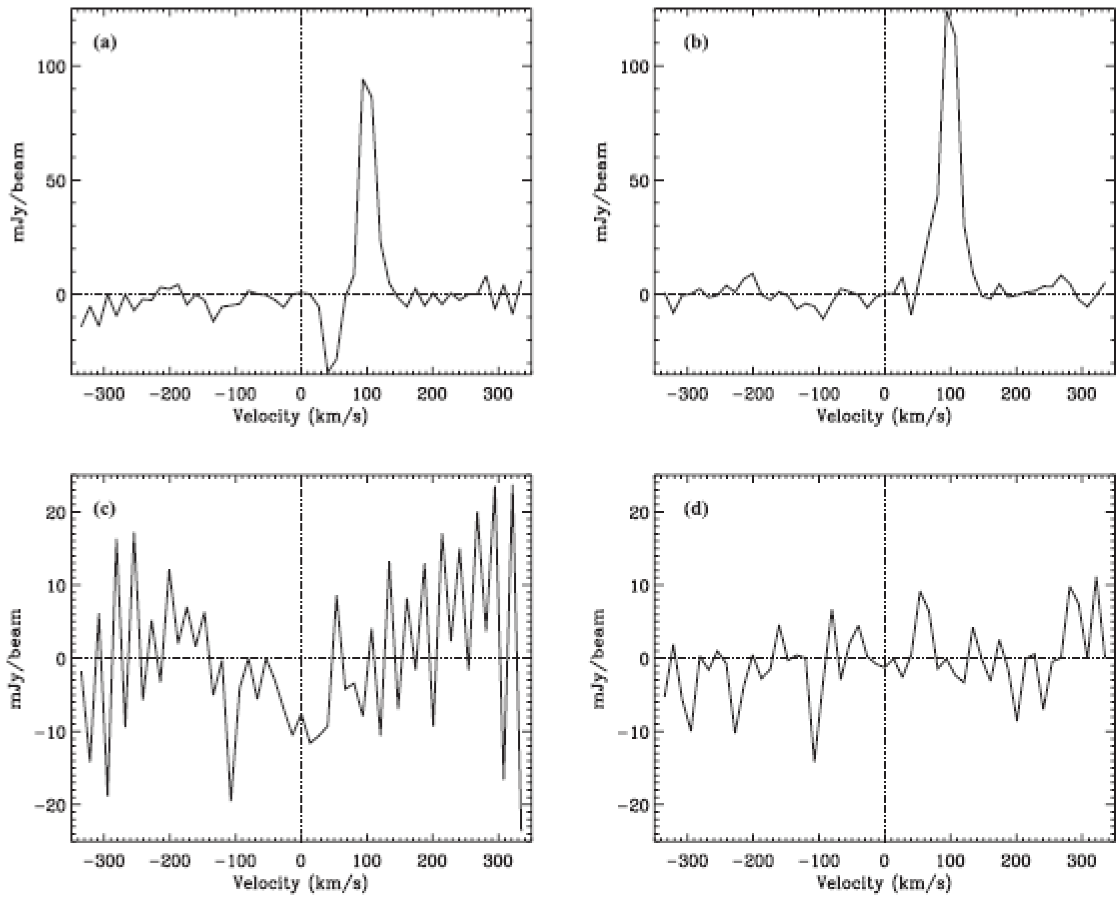


Figure 3. ZOA (left) and ZOA+HIPASS spectra after DC level correction (right) at two positions: (top) G33.1−0.1 and (bottom) G28.6−2.1. The improvement after combining both data sets is visible even for spectra away from the Galactic plane.

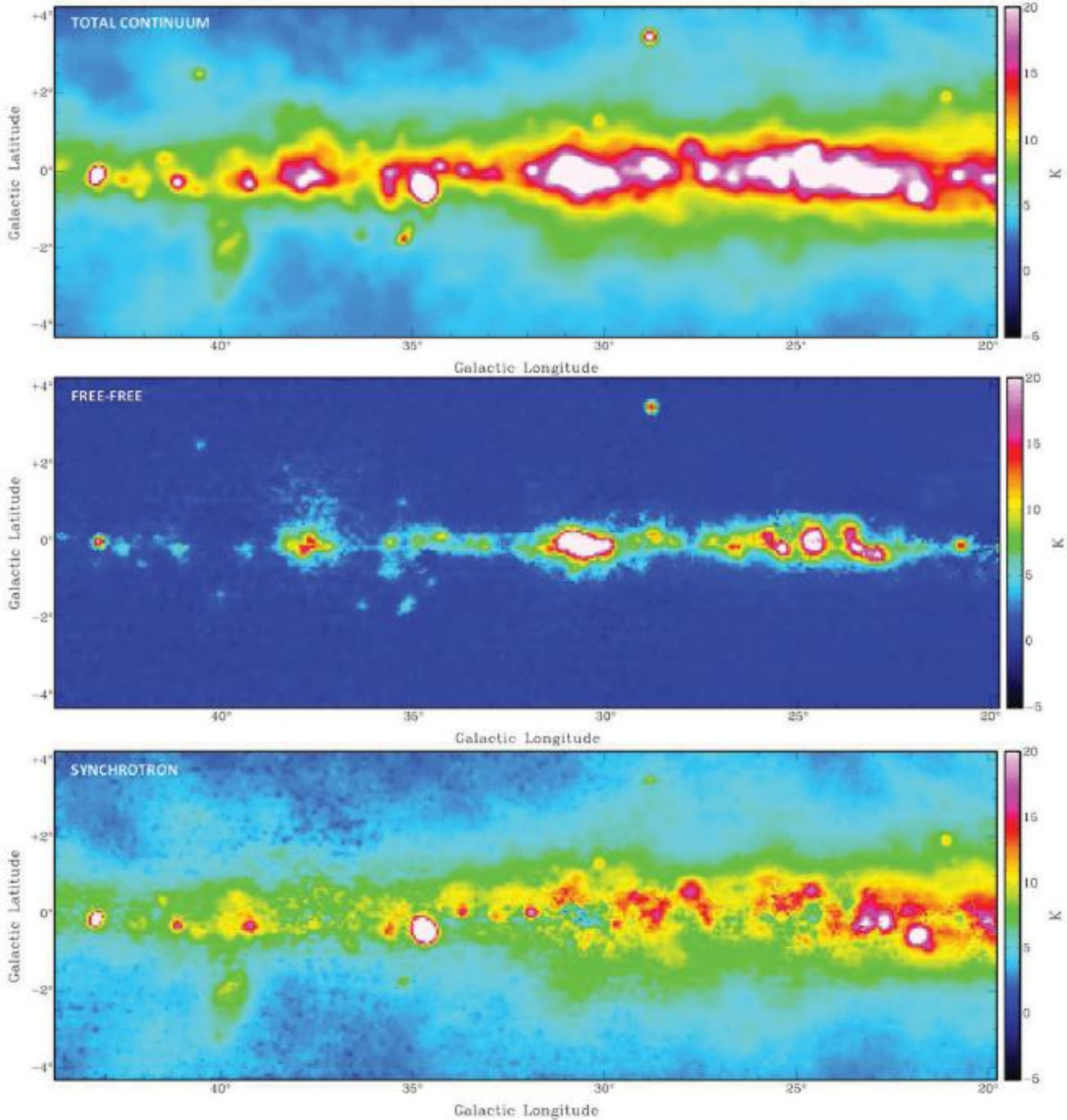


Figure 7. Maps of the total continuum, free–free and synchrotron emission at 1.4 GHz and 14.8-arcmin resolution. The free–free emission is estimated from the RRL integral using the T_e–R_G relationship from equation (5). The synchrotron is the difference between the total continuum and the free–free emission and shows a narrow diffuse emission confined to the plane. The colour scale is linear and in units of brightness temperature (K).

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