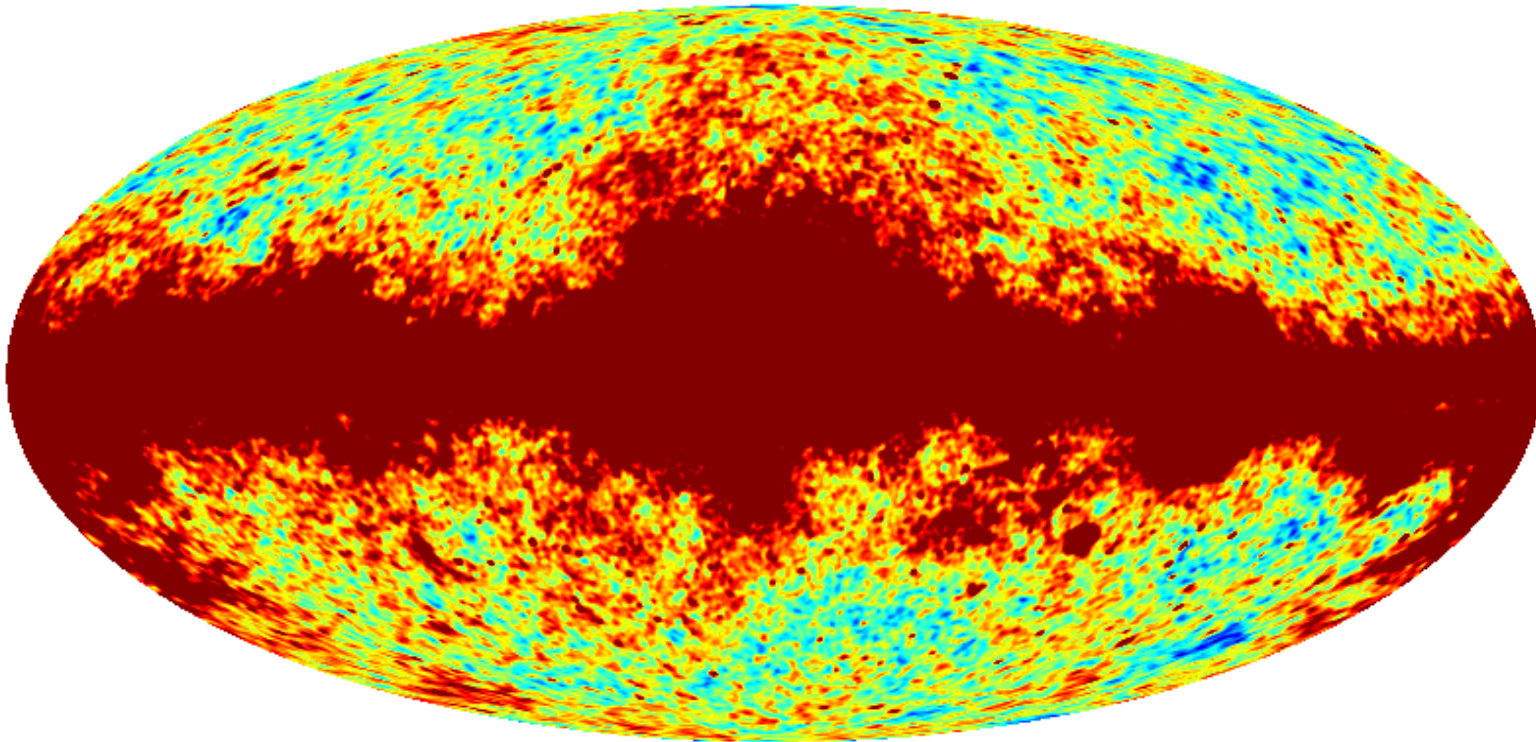


Characterisation of CMB foregrounds

23 GHz



Tuhin Ghosh (IUCAA)

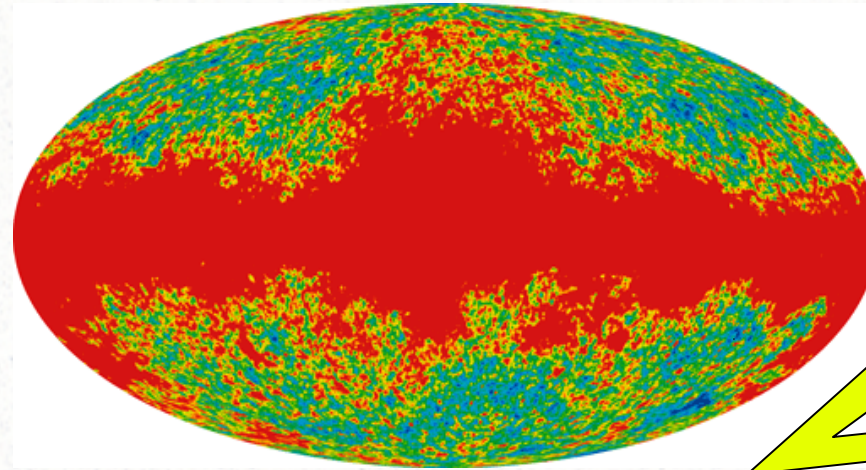
Tarun Souradeep (IUCAA), A.J. Banday (IRAP, Toulouse), T. Jaffe (IRAP, Toulouse), C. Dickinson (Manchester), R. Davis (Manchester), R.J. Davies (Manchester), K.M. Gorski (Caltech, USA)

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Importance of CMB Foregrounds

- ✓ Foregrounds are everything after redshift of 1000 ($z \sim 6!$).
- ✓ For precision cosmology, one needs to understand foregrounds completely specially its **spectral characteristics, morphological distribution** and its **statistical distribution**.
- ✓ Any uncertainties of spectral properties of foregrounds might leave non-Gaussian residual in the map (detected by f_{NL} parameter).
- ✓ Foregrounds are important in their own rights and encode lots of information regarding the physical processes behind its origin.

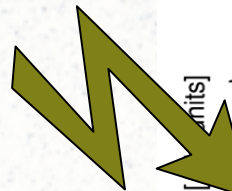
Spectral Characterization of Foregrounds



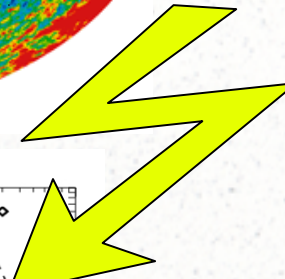
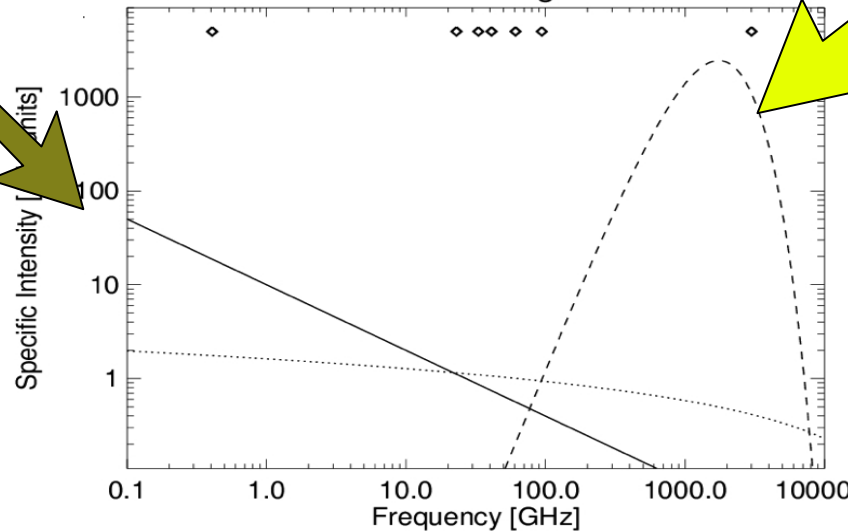
IRAS maps

Radio Observations:

408 MHz Haslam map



Microwave Foregrounds



Halpna map

WMAP observations: 20-100 GHz

Planck Collaboration Early Results

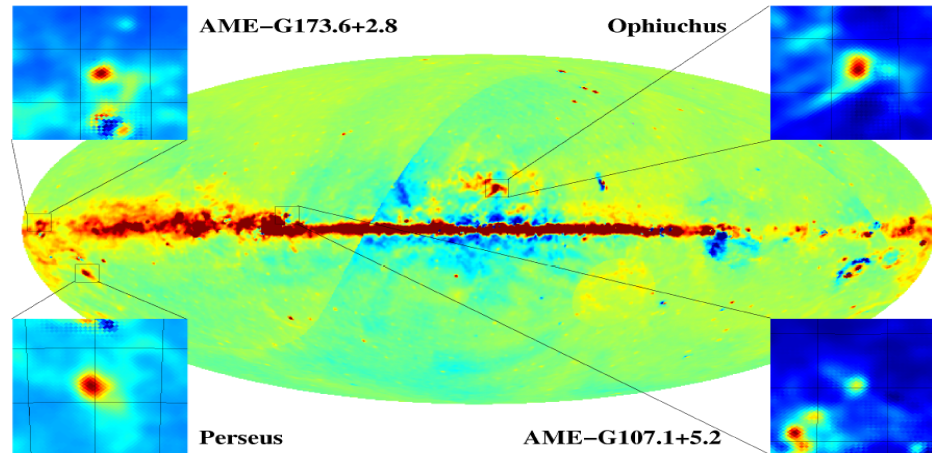


Fig. 10. Residuals in the full sky *Planck* LFI 28.5 GHz 1° smoothed map after subtraction of synchrotron, free-free and thermal dust emission (see text). 12.5×12.5 cut out maps are shown for the Perseus and ρ Ophiuchi molecular clouds, and the two new regions of AME, AME-G107.1+5.2 and AME-G173.6+2.8. The graticule spacing is 5° in Galactic coordinates.

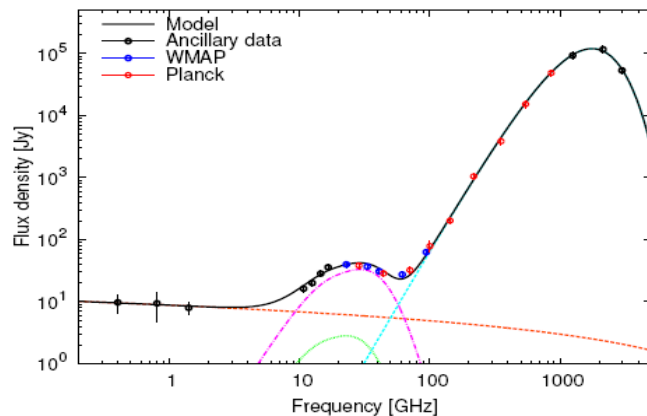


Fig. 4. Spectrum of AME-G160.26–18.62 in the Perseus molecular cloud. The best-fitting model consisting of free-free (orange dashed line), spinning dust, and thermal dust (light blue dashed line) is shown. The two-component spinning dust model consists of high density molecular gas (magenta dot-dashed line) and low density atomic gas (green dotted line).

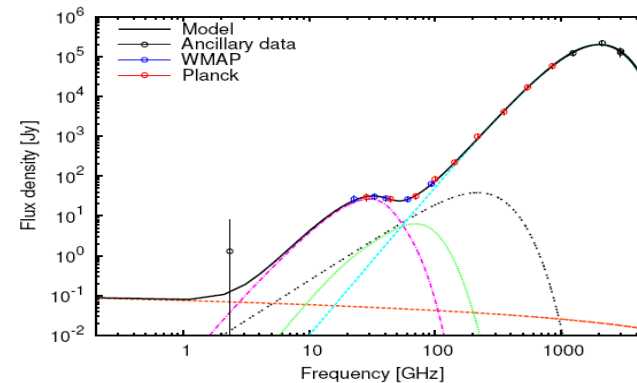
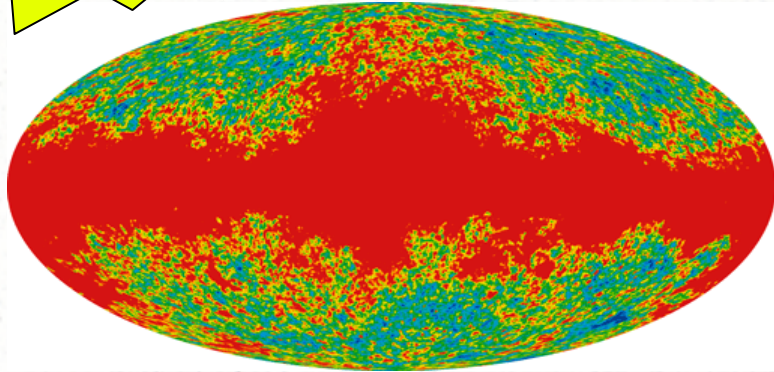


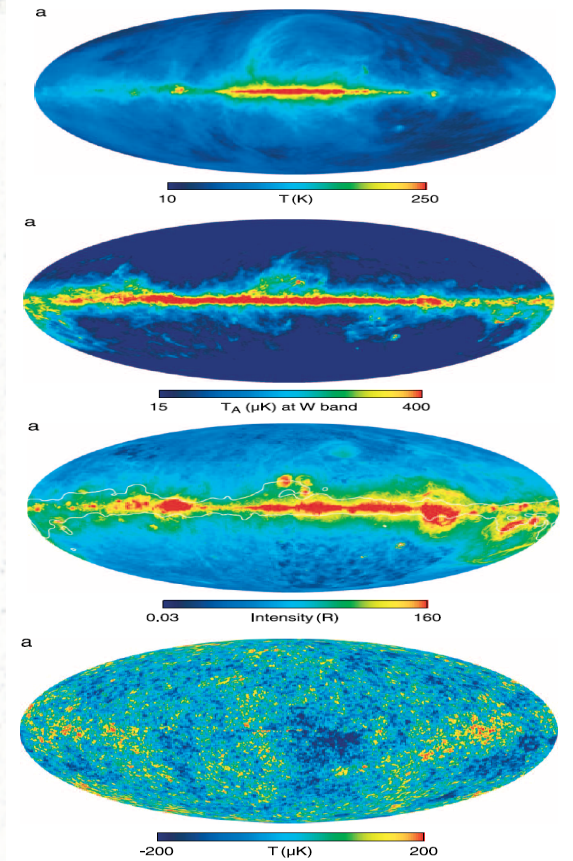
Fig. 8. Spectrum of AME-G353.05+16.90 in the ρ Ophiuchi West molecular cloud. The best-fitting model consisting of free-free (orange dashed line), spinning dust, CMB (black double/triple-dotted line), and thermal dust (light blue dashed line), is shown. The spinning dust model consists of two components: high density molecular gas (magenta dot-dashed line); and low density atomic gas (green dotted line). The 100/217 GHz data are contaminated by CO line emission and are not included in the fit.

Assumptions

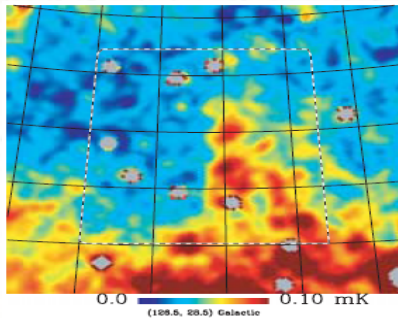


23 GHz Map

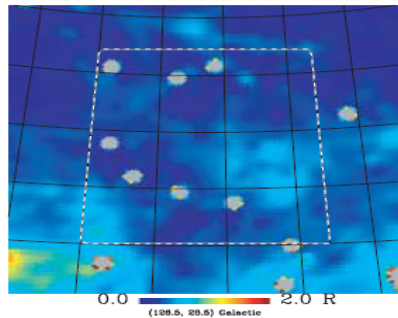
The given WMAP frequency map is a linear superposition of different foreground emissions in addition with CMB and instrumental noise.



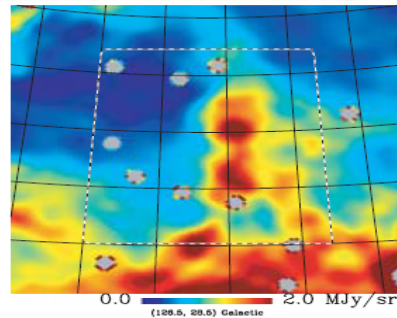
WMAP K band



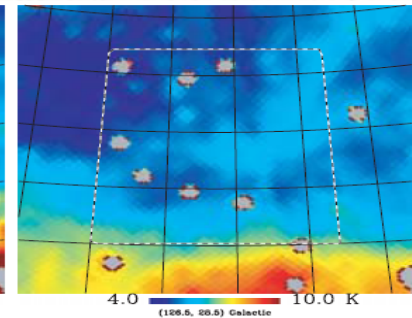
Free-free



Dust



Synchrotron



Cross-Correlation Analysis

$$T^i(p) = T_c(p) + \sum_j S_{ij} T_j^f(p) + T_N^i(p)$$

The cross-correlation measure, α , between a data vector, \mathbf{d} and a template vector \mathbf{t} can be measured by minimizing,

$$\chi^2 = (\mathbf{d} - \alpha \mathbf{t})^T \mathbf{M}_{SN}^{-1} (\mathbf{d} - \alpha \mathbf{t})$$

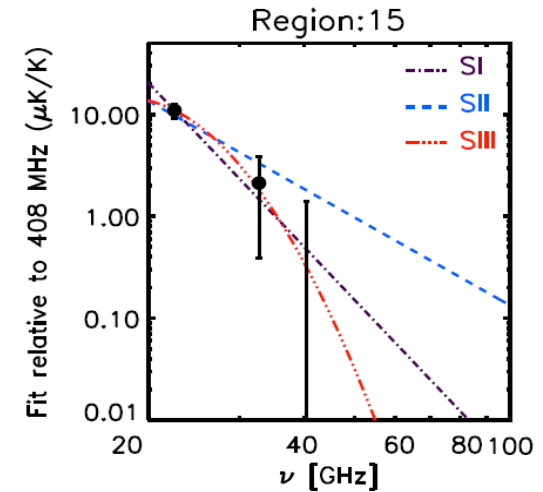
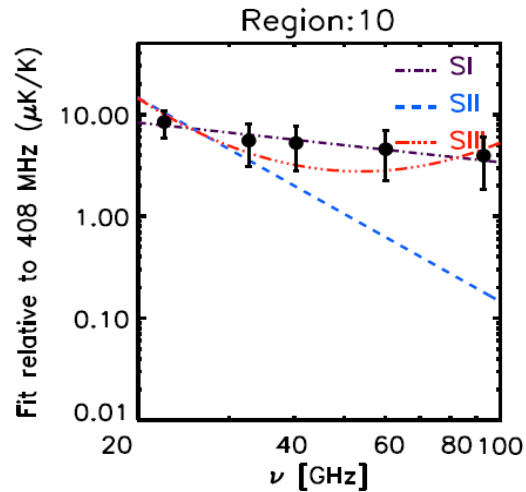
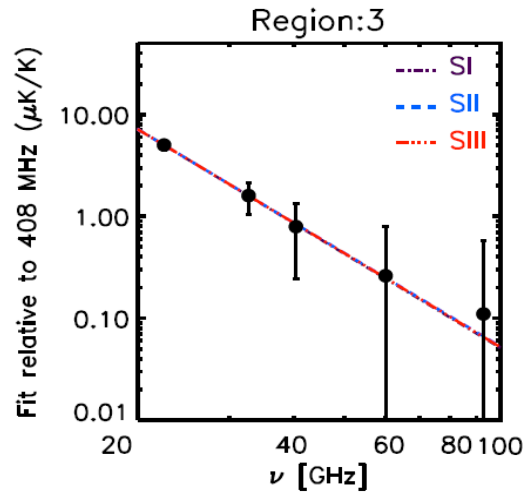
where \mathbf{M}_{SN} is the covariance matrix including both signal and noise for the template-corrected data vector.

Solving for α then becomes,

$$\alpha = \frac{\mathbf{t}^T \cdot \mathbf{M}_{SN}^{-1} \cdot \mathbf{d}}{\mathbf{t}^T \cdot \mathbf{M}_{SN}^{-1} \cdot \mathbf{t}}$$

Noise covariance matrix is directly extracted from the dataset.

Synchrotron Emission



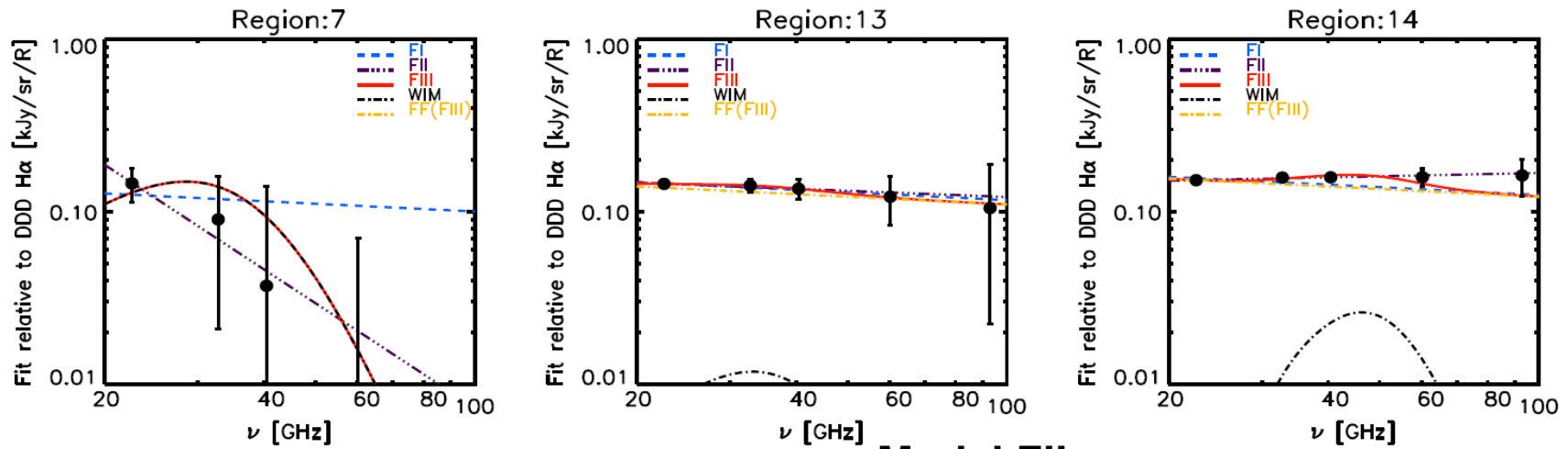
Model SI: $F(\nu) = A_s \times \left(\frac{\nu}{23.}\right)^{\beta_s}$

Model SII: $F(\nu) = 10^6 \times \left(\frac{\nu}{0.408}\right)^{\beta_s}$

Model SIII:
$$F(\nu) = \begin{cases} A_s \times \left(\frac{\nu}{23.}\right)^{\beta_s} & \nu < \nu_K \\ A_s \times \left(\frac{\nu}{23.}\right)^{\beta_s + c_s \ln(\frac{\nu}{\nu_K})} & \nu > \nu_K \end{cases}$$

Synchrotron spectral index gives us the information about the energy spectrum of cosmic ray electrons.

Free-free Emission



Model FI:

$$F(\nu) = A_f \times \left(\frac{\nu}{23.}\right)^{-0.15}$$

Model FII:

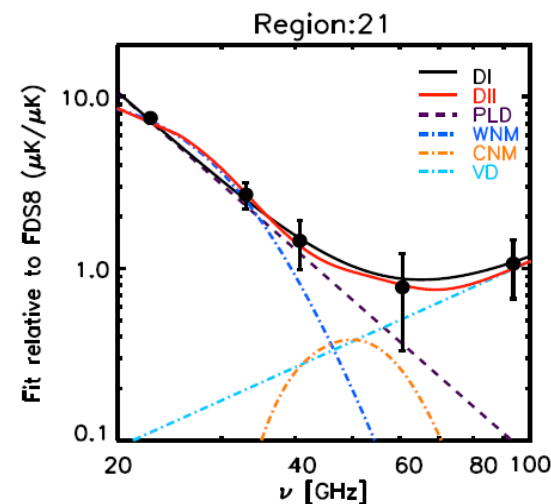
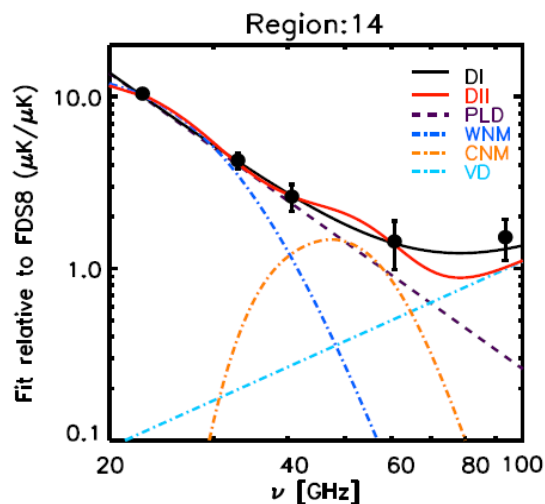
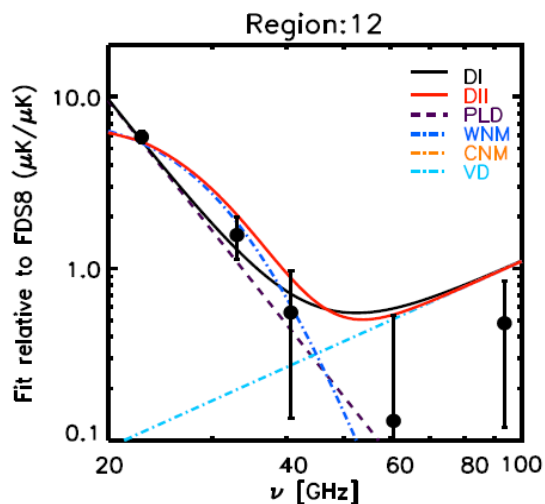
$$F(\nu) = A_f \times \left(\frac{\nu}{23.}\right)^{\beta_f}$$

Model FIII:

$$F(\nu) = A_f \times \left(\frac{\nu}{23.}\right)^{-0.15} + (\text{shifted WIM spectrum})$$

The fit coefficient relative to Halpha template encodes the information about free-free electron temperature which we found to be around 6000-7000K.

Dust Emission



Model DI:

$$F(\nu) = A_{vd} \times \left(\frac{\nu}{94.}\right)^{1.55} + A_{sd} \times \left(\frac{\nu}{23.}\right)^{\beta_{sd}}$$

Model DII:

$$F(\nu) = \left(\frac{\nu}{94.}\right)^{1.55} + A_{CNM} \times (\text{shifted CNM spectrum}) \\ + A_{WNM} \times (\text{WNM spectrum})$$

The spinning dust template (WNM+CNM) templates can be used to constraint parameters of the spinning dust models (such as grain size distribution, number density,.....)

Conclusions

- Cross correlation analysis method is used to extract foreground information by cross-correlating the WMAP frequency maps with available external templates.
- The cross-correlation method is unbiased and is checked with simulations.
- Evidence of curvature term in synchrotron spectral index from our selected regions. Evidence of H α correlated WIM spinning dust spectra which peaks between 40-50 GHz. Spinning dust can be well represented by linear superposition of WNM and shifted CNM spectra which peaks between 50-60 GHz.
- CMB needs to be subtracted from original WMAP maps to reduce the errorbars on foreground parameters.
- Monte Carlo Markov chains needs to be implemented to get the distribution of foreground parameters.