Separation of anomalous and synchrotron emissions using WMAP polarization data

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and

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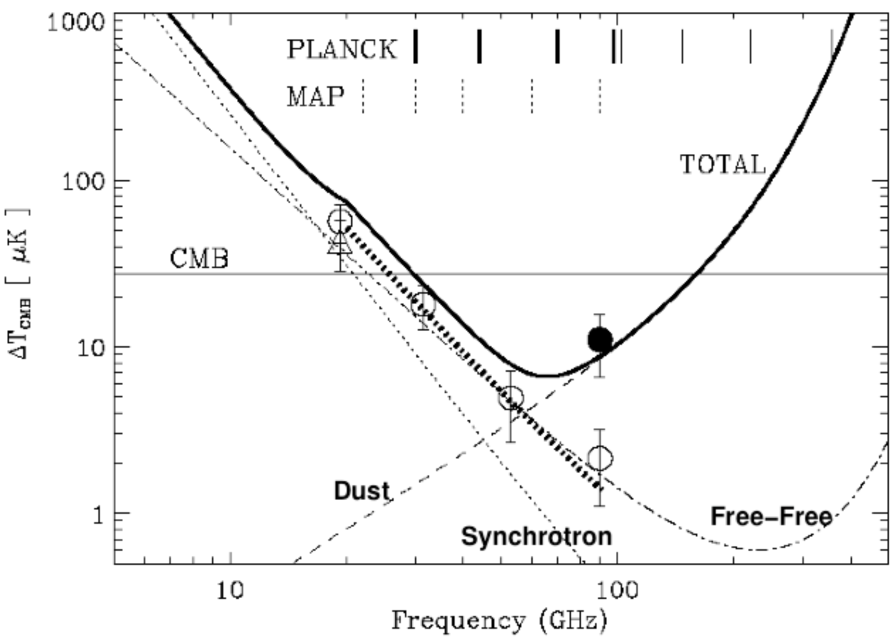
Analysis of Galactic emission in WMAP data

- Galactic emission reaches a minimum in the range 20-200 GHz but there is complicated superposition of emissions : free-free, synchrotron, thermal dust and anomalous emission
- The anomalous emission case
  - Excess in the COBE-DMR data spatially correlated with thermal dust but with a free-free or synchrotron like spectrum
  - Can't be free-free : not well correlated with Halpha and ruled out on energetic arguments
  - Draine & Lazarian (1998) suggested spinning dust : received strong support from several dedicated ground observations and analysis of the WMAP data (e.g. Davies et al., 2006)
  - WMAP team proposed that it is synchrotron emission with a spatially varying spectral index
- So, synchrotron or spinning dust ?
  polarization is the key : synchrotron is highly polarized (75%) but not spinning dust.



Banday et al. 2003

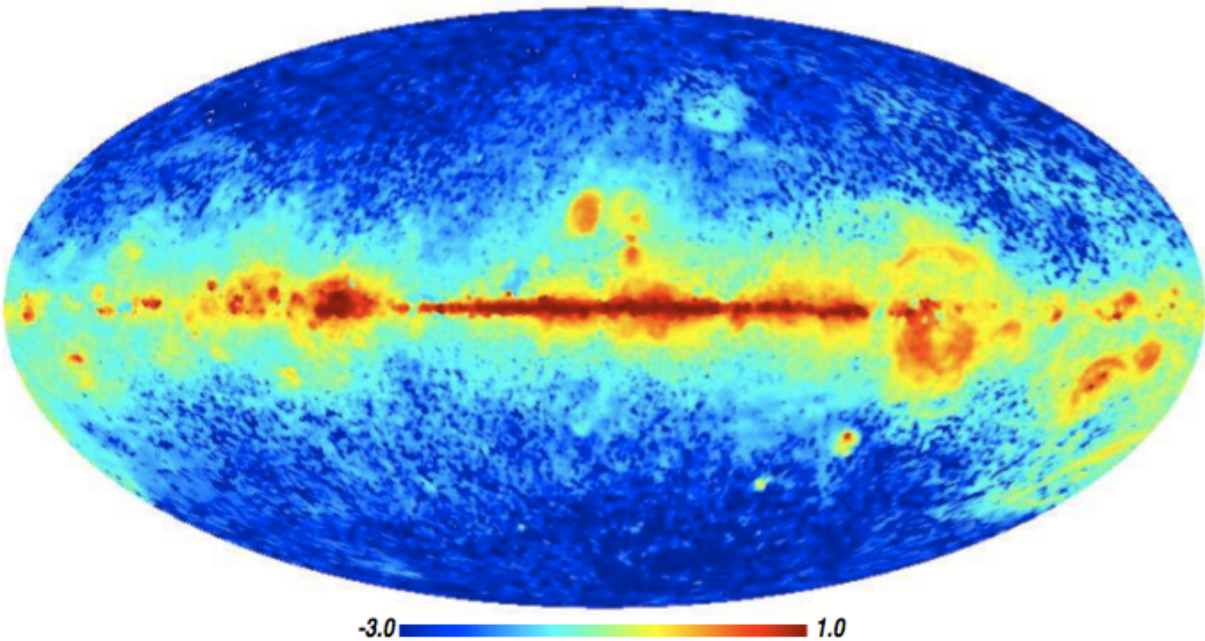
Goal of this study

- Find a model of Galactic emission at 23 GHz that is coherent with
  - Intensity and polarization WMAP data
  - H-alpha measurements
  - Knowledge of Galactic magnetic field and cosmic rays
- Hypothesis
  - Thermal dust is negligible at 23 GHz (intensity and polarization)
  - CMB is assumed to be the ILC map : good enough at 23 GHz
  - No assumption is made on the anomalous component. It is treated as a residual after all other components were estimated.
  - Polarization is only synchrotron at 23 GHz

$$I_{23} = S_{23} + F_{23} + [A_{23}] + CMB$$
$$P_{23} = S_{23}^{P}$$

Free-free

- Estimated from Halpha for Av < 6.
- In denser regions, we use the WMAP free-free template
    - Free-free spectral index is almost constant (based on physical arguments). It is -2.15, which is significantly different than other components : easy to extract with a MEM method
    - Does not depend on an estimate of Te



Free-free emission at 23 GHz ($\log_{10}$(mk))

Synchrotron

$$S(\nu) = \epsilon_s(\nu) \int_z n_e B_\perp^{(1+s)/2}\, dz \qquad B_\perp = \sqrt{B_x^2 + B_y^2}$$

$$Q(\nu) = f_s \epsilon_s(\nu) \int_z n_e B_\perp^{(1+s)/2} \cos 2\phi \sin \alpha \, dz$$

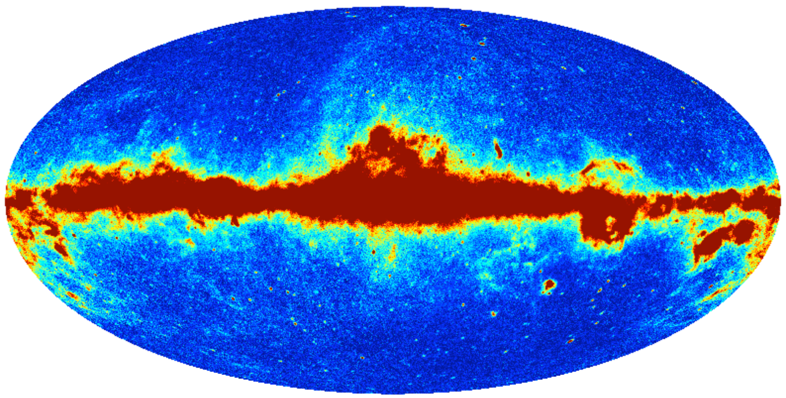
$$U(\nu) = f_s \epsilon_s(\nu) \int_z n_e B_\perp^{(1+s)/2} \sin 2\phi \sin \alpha \, dz$$

$$\cos 2\phi = \frac{B_x^2 - B_y^2}{B_\perp^2} \qquad \sin 2\phi = \frac{-2B_x B_y}{B_\perp^2} \qquad \sin \alpha = \sqrt{1 - B_z^2/B^2}.$$

$$\text{Polar Frac.} = \frac{\sqrt{Q^2 + U^2}}{S} = f_s g$$

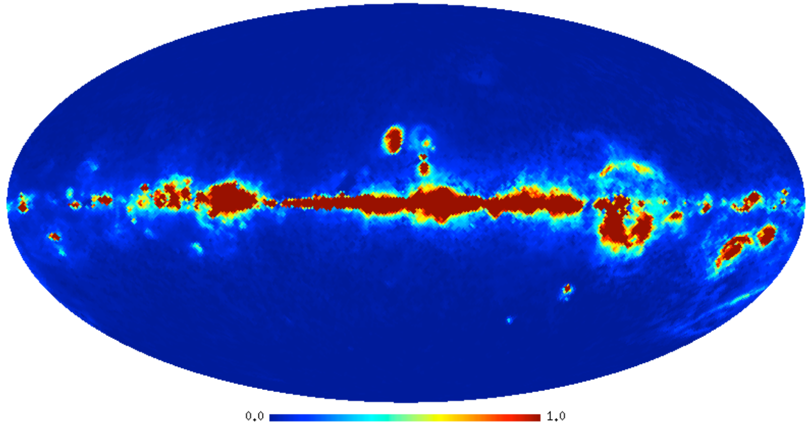
Independant of frequency

Model 1:
The “no anomalous emission” hypothesis

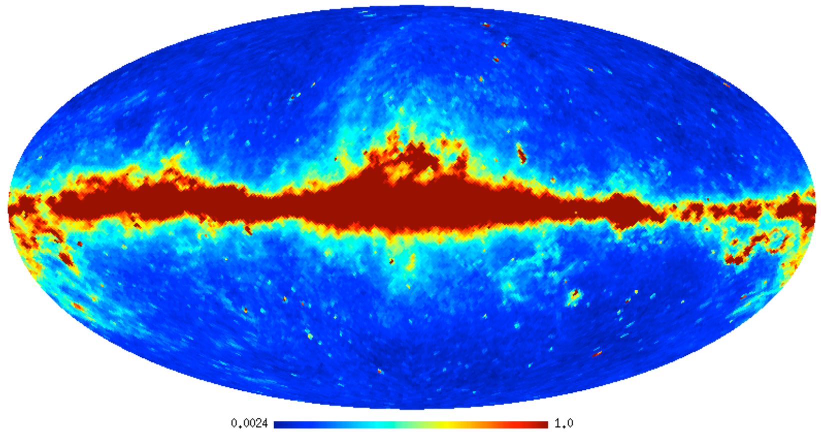


WMAP 23 GHz intensity - CMB

free-free : our model

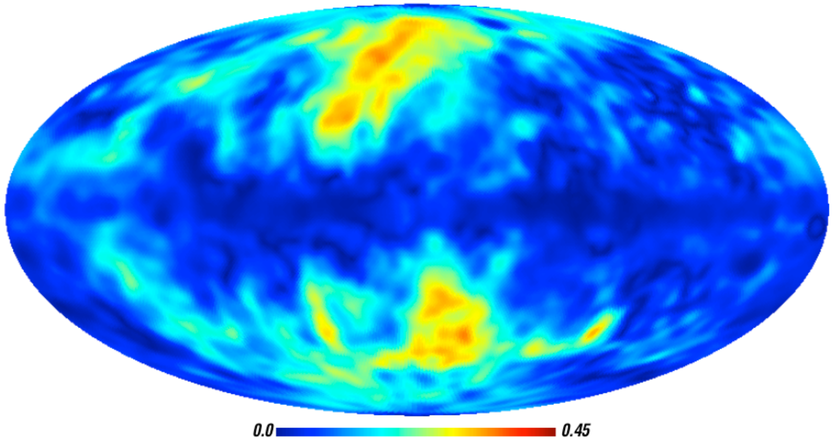


synchrotron : residual

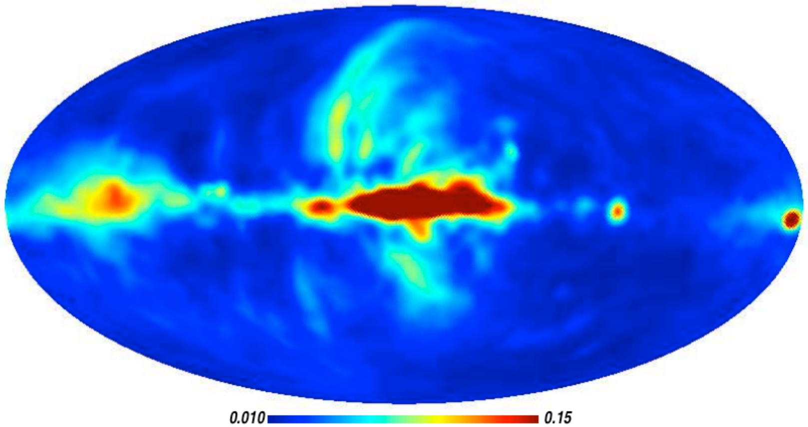


see Bennett et al. (2003); Hinshaw et al. (2007)

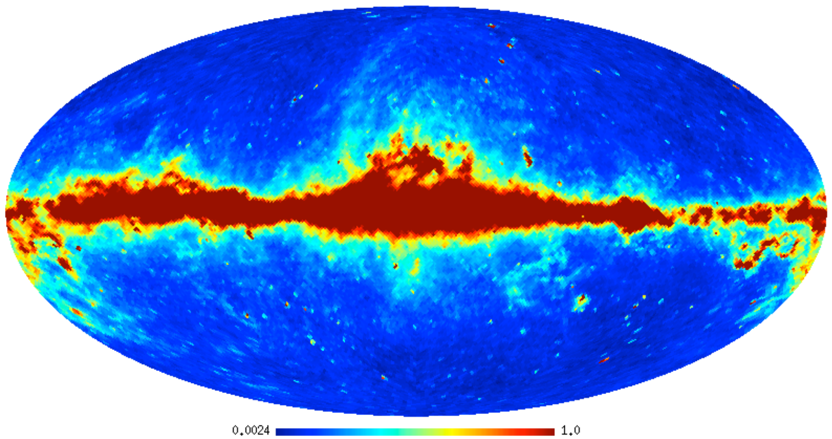
Model 1: polarization



polarization fraction



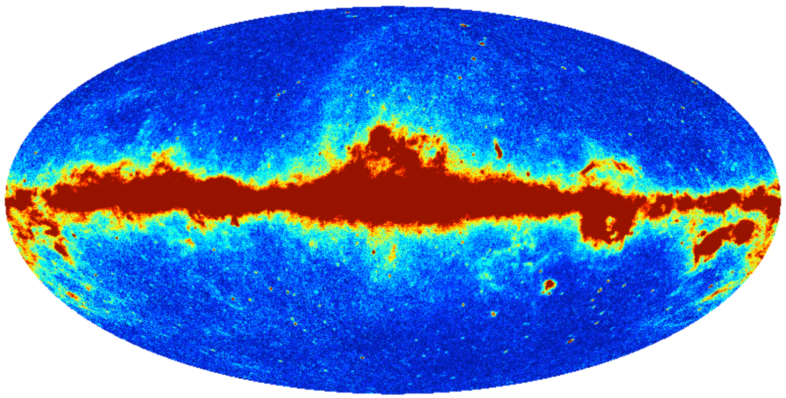
WMAP 23 GHz polarisation



synchrotron intensity

See Kogut et al (2007), Sun et al. (2007)

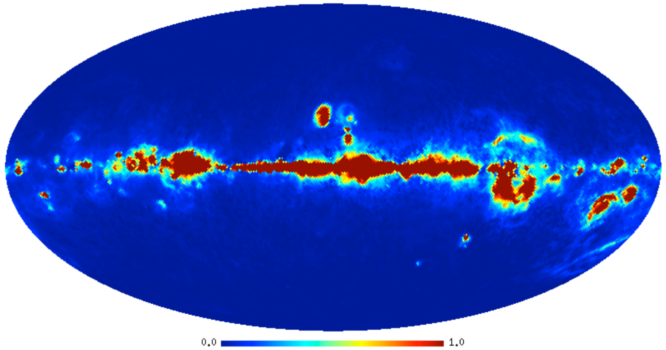
Model 2 :
Beta=-3 synchrotron



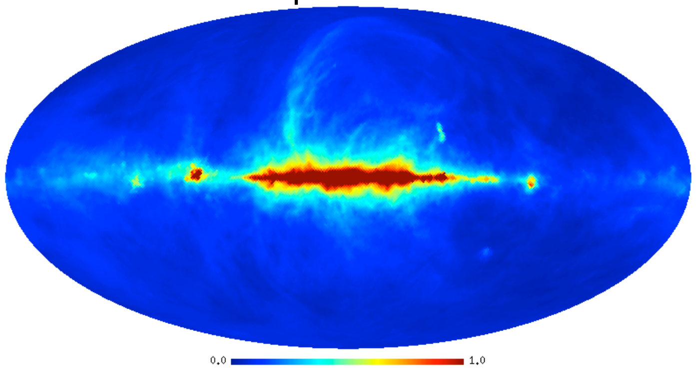
WMAP 23 GHz intensity - CMB

See Davies et al. (2006)

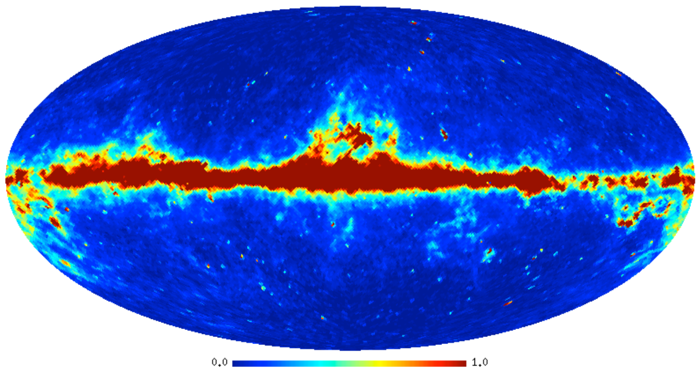
free-free : our model



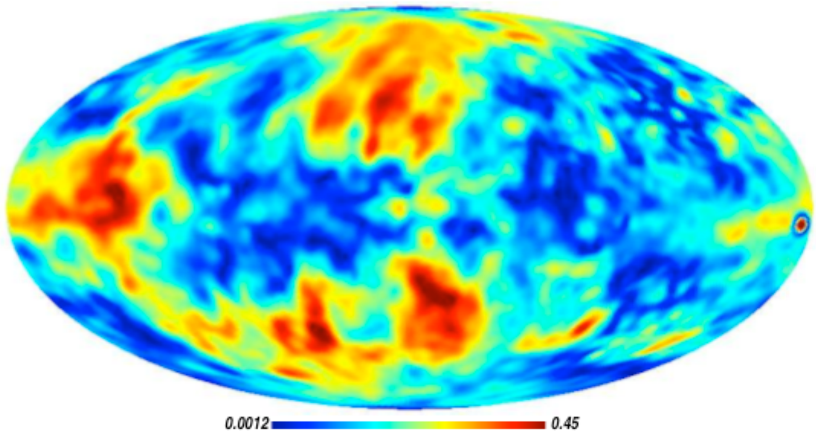
synchrotron : extrapolated from 408 MHz



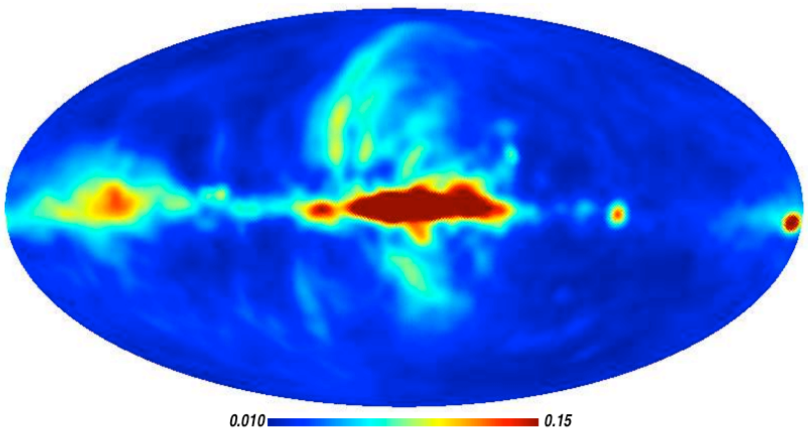
anomalous : residual



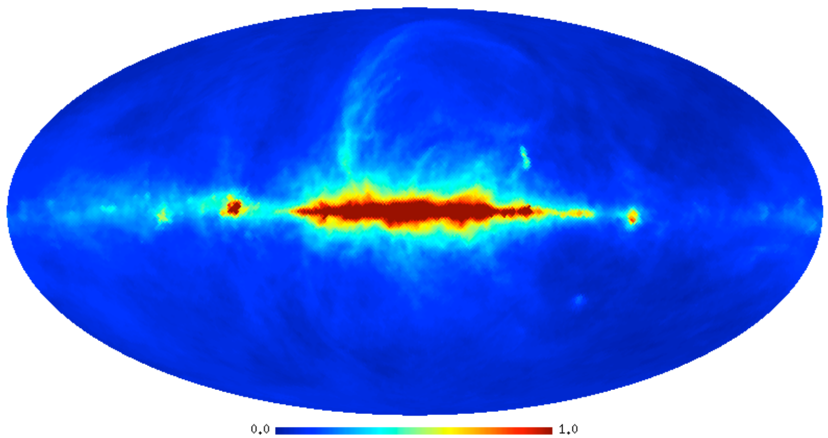
Model 2: polarization



polarization fraction

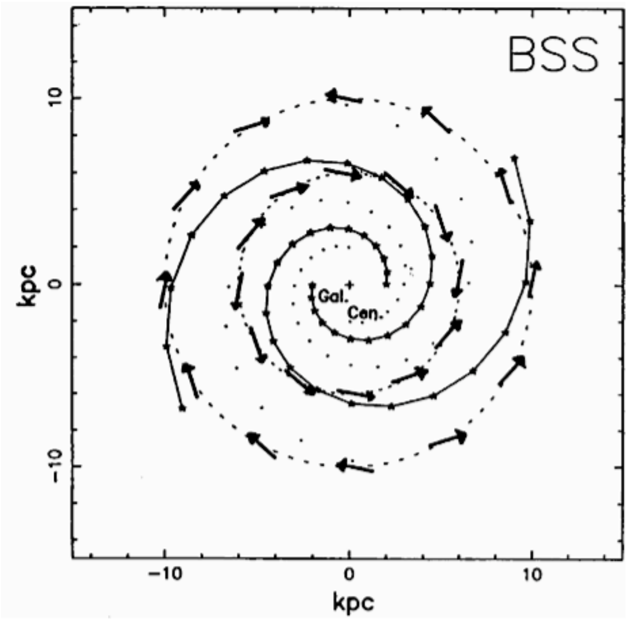


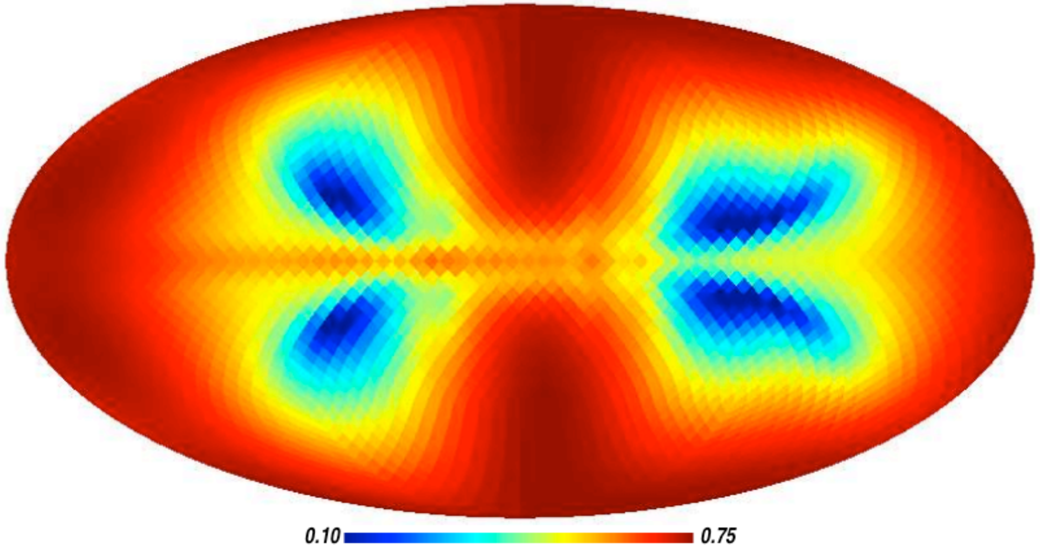
WMAP 23 GHz polarisation



synchrotron intensity

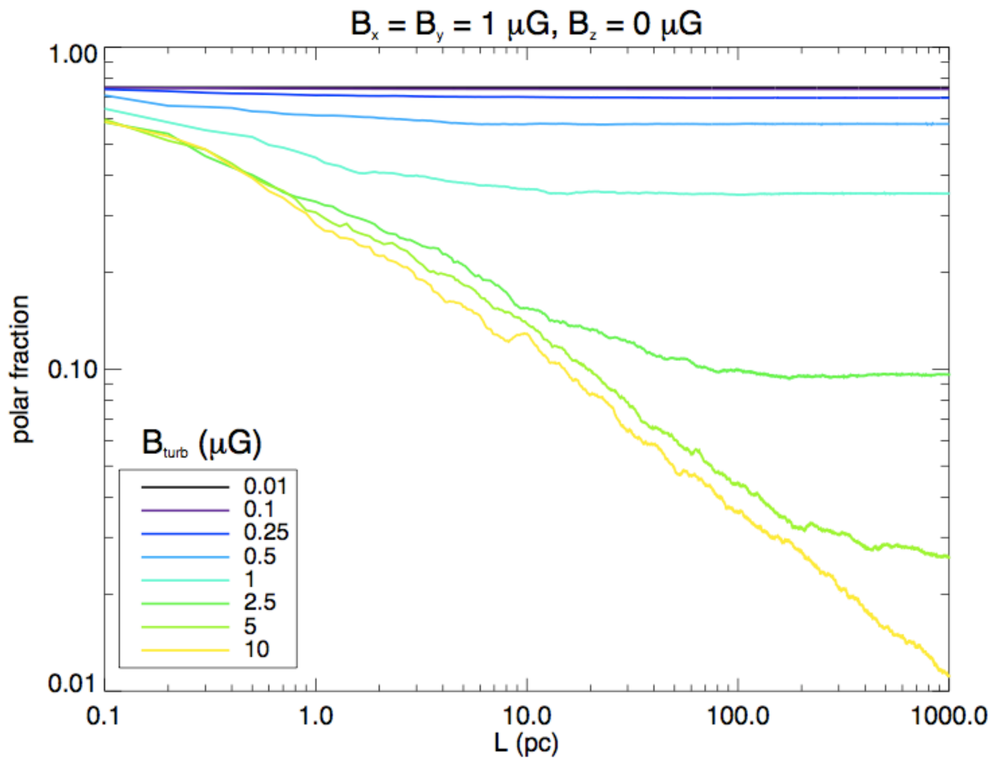
Model of the synchrotron polarization fraction

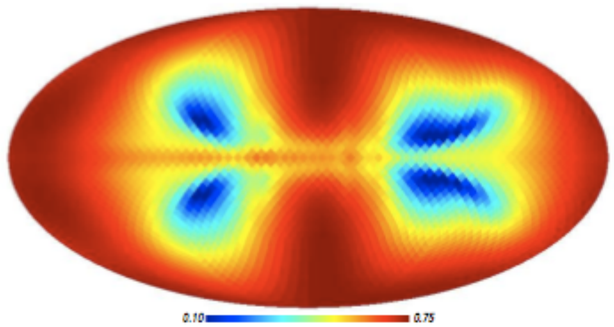


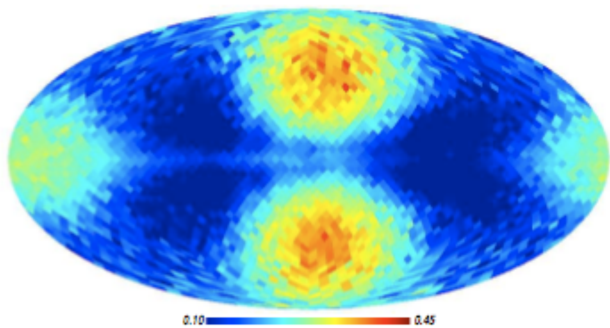


- Pitch angle = -8.5 deg. (constraints by pulsars and NIR extinction)
- CR density : smooth distribution with 1 kpc scale height

Depolarisation by turbulence

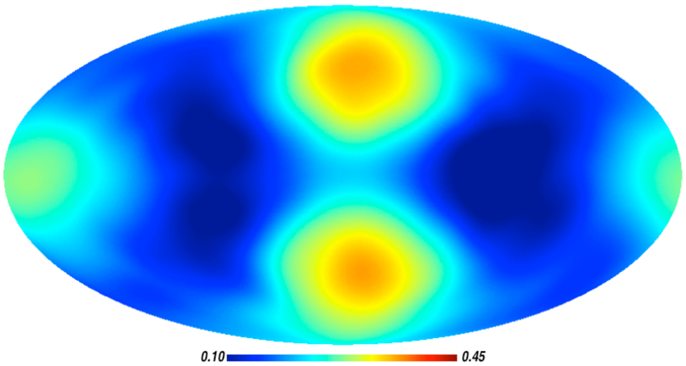




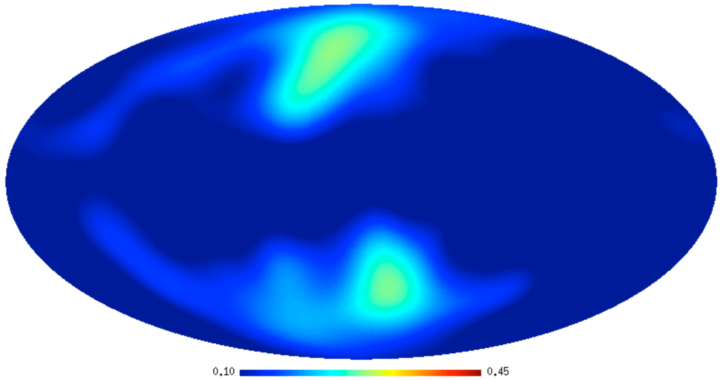


- Power law turbulent field : slope of -5/3 for l < 100 pc
- Turbul/regular = 0.6
- In accordance with radio synchrotron and dust extinction
- Implies equipartition between turbulent and regular parts of the field

Model selection based on magnetic field properties

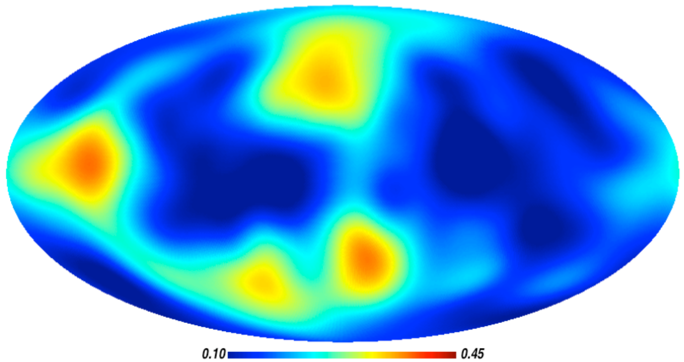


Prediction of polarization fraction



Model 1 : no anomalous emission

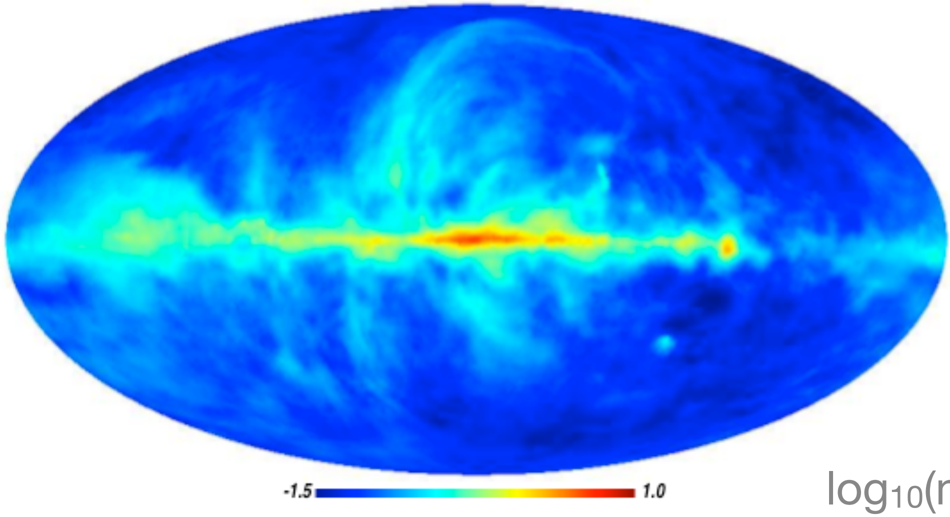
- Polarization fraction maps smoothed to 20 degrees.
- Model 2 reproduces better the overall structure (quadrupole) and absolute value
- Strong argument for the presence of un-polarized anomalous emission



Model 2 : beta = -3

Prediction of synchrotron intensity from polarization

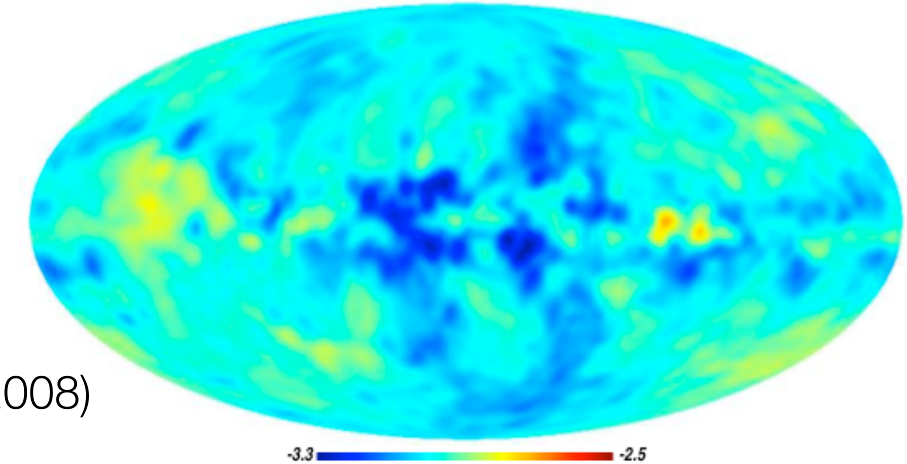
$$S_{23} = \frac{P_{23}}{f_s g_{model}}$$



$\log_{10}(\mathrm{mk})$

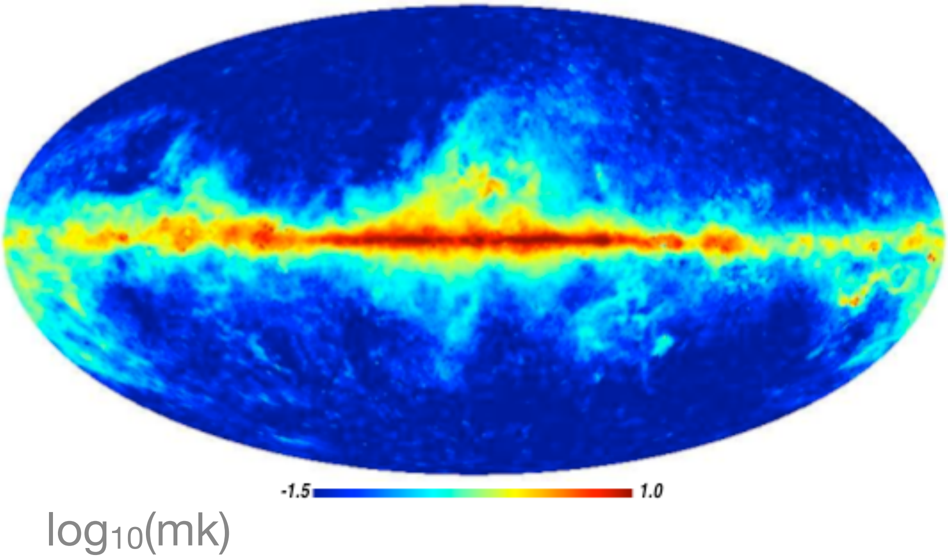
Spectral index map

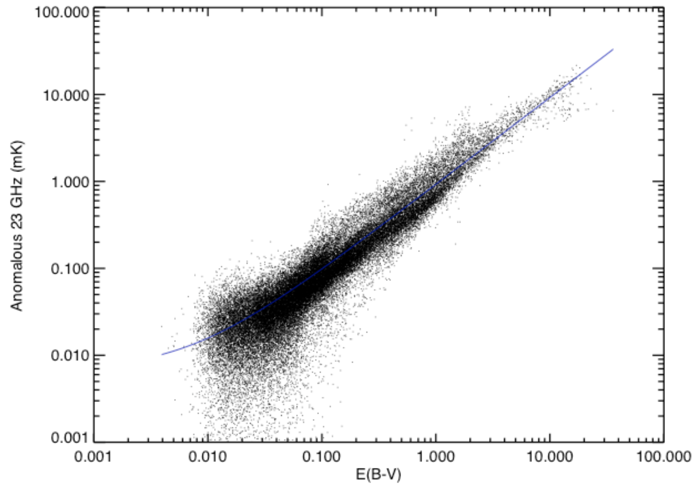
$\beta = -3.00 \pm 0.06$



Compatible with Dunkley et al. (2008) using only WMAP polarization

Anomalous emission at 23 GHz

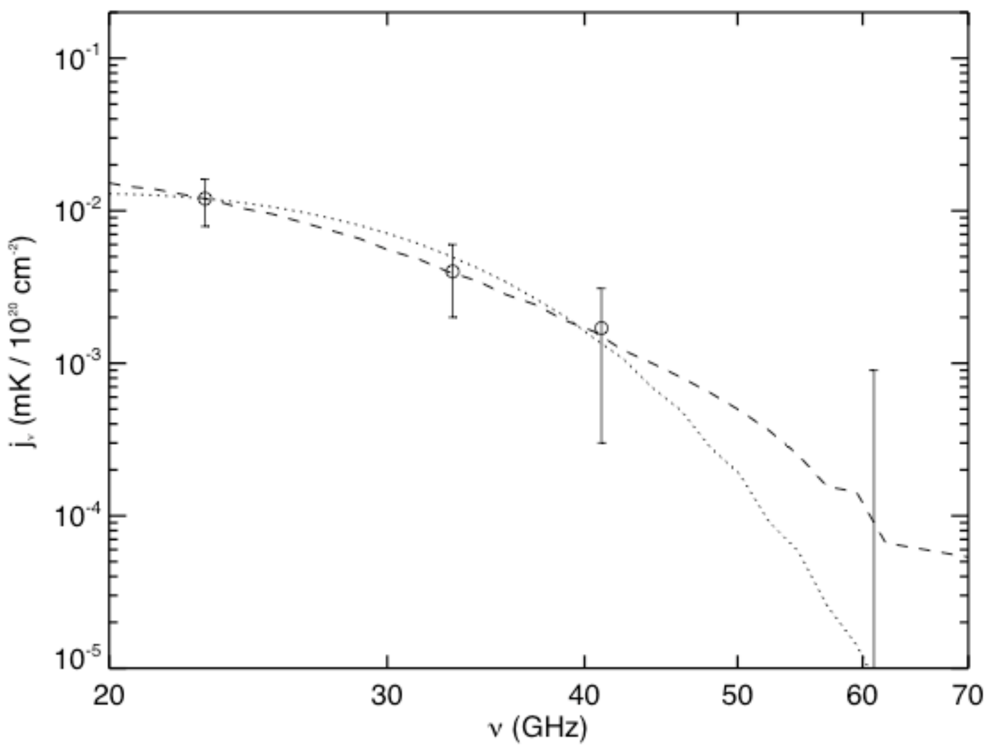




- Residual after removal of free-free and synchrotron (from polarization)
- No assumption on any dust-correlated component in this analysis
- Strong correlation with E(B-V) $\quad A_{23GHz} \propto 0.92 \times E(B-V)$

Anomalous emission spectrum

- Extrapolate free-free and synchrotron at each WMAP frequency
- Remove thermal dust using Finkbeiner et al. (1999) model (scales to match the emission at 94 GHz)
- Correlate residual with E(B-V)
- Matches current spinning dust models
  - dashed : Draine & Lazarian (1998)
  - dotted : Ysard & Verstraete (2008)



Planck sky Model - the Galactic part

- **Free-Free**
  - our composite template (Halpha + WMAP Free-Free MEM)
  - extrapolation in $nu^{-2.15}$
- **Thermal dust** : FDS model
- **Synchrotron**
  - our template based on 23 GHz data (temperature and polarization) + Galactic magnetic field model
  - Beta = $alog(T_{23}/T_{408})/alog(23/0.408)$
- **Spinning dust**
  - our 23 GHz template extrapolated with Draine & Lazarian (1998) spectrum
- **Polarization**
  - Synchrotron : 23 GHz U and Q, extrapolated with same Beta as temp.
  - Thermal dust : Can't use WMAP data (not enough S/N) -> modification of the synchrotron polarization fraction map

PSM v1.6 - the Galactic part

- **Polarization - thermal dust**

$$P_d^\nu = g_s \, \Pi_d \, \phi \, T_d^\nu$$

$$\phi = \frac{g_d^{model}}{g_s^{model}}$$

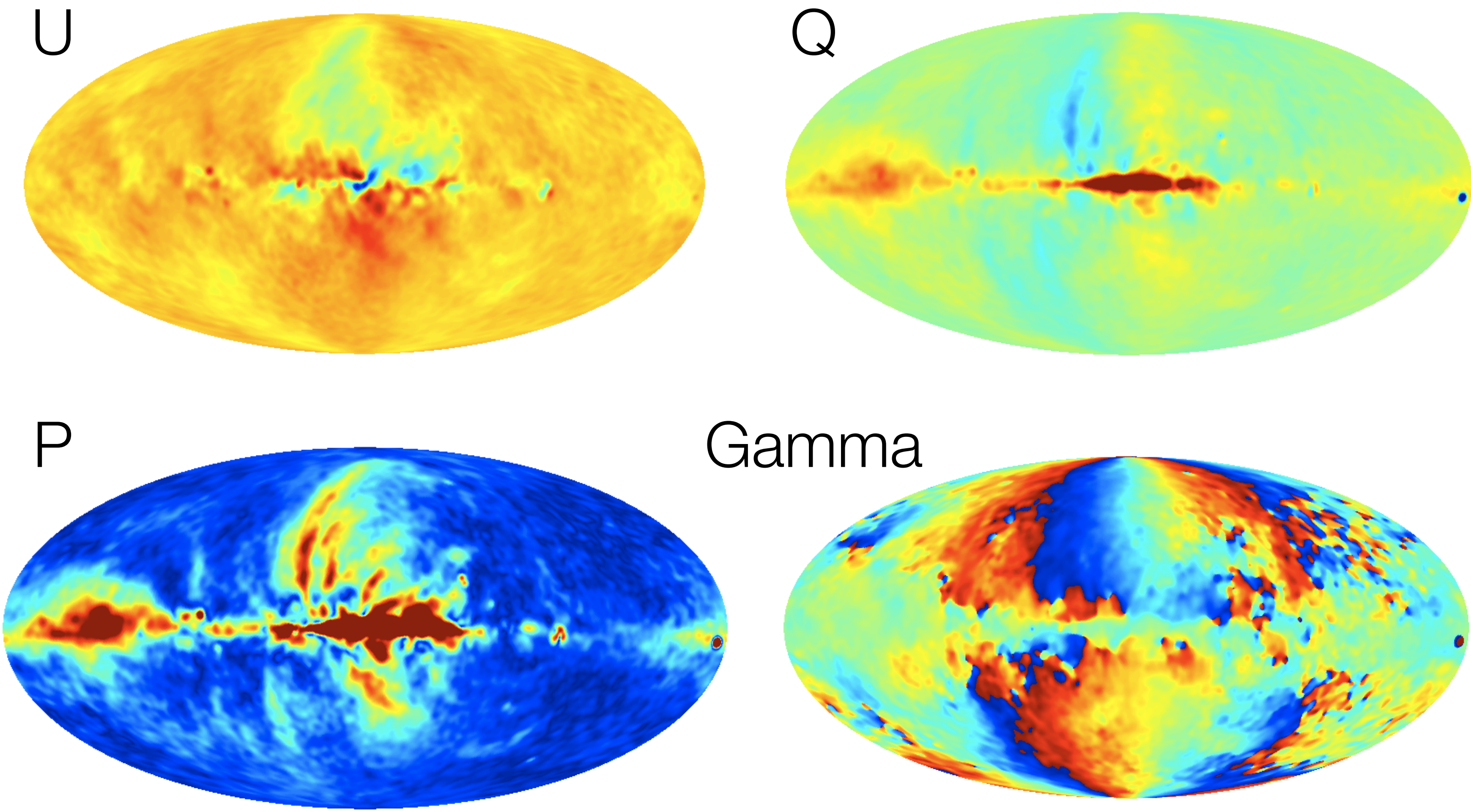
$$g_s = \frac{P^{23}}{\Pi_s T_s^{23}}$$

$$\gamma_d = \gamma_s + \Delta\gamma$$

$$\Delta\gamma = \gamma_d^{model} - \gamma_s^{model}$$

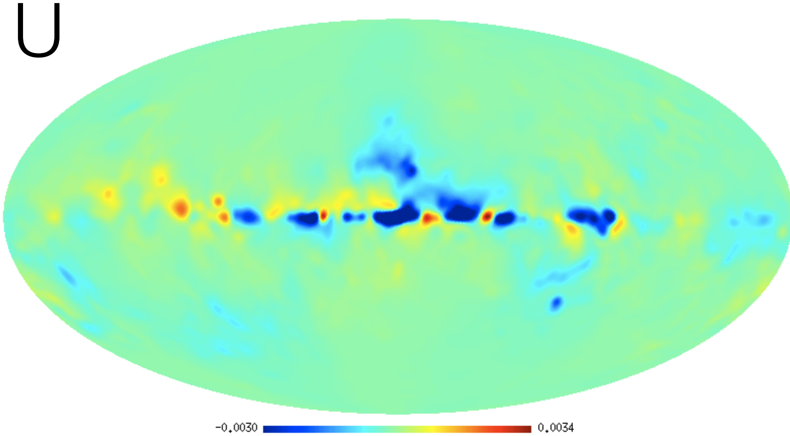
$$\gamma_s = 0.5 \tan^{-1}\left(\frac{U^{23}}{Q^{23}}\right)$$

PSM polarization - synchrotron 23 GHz

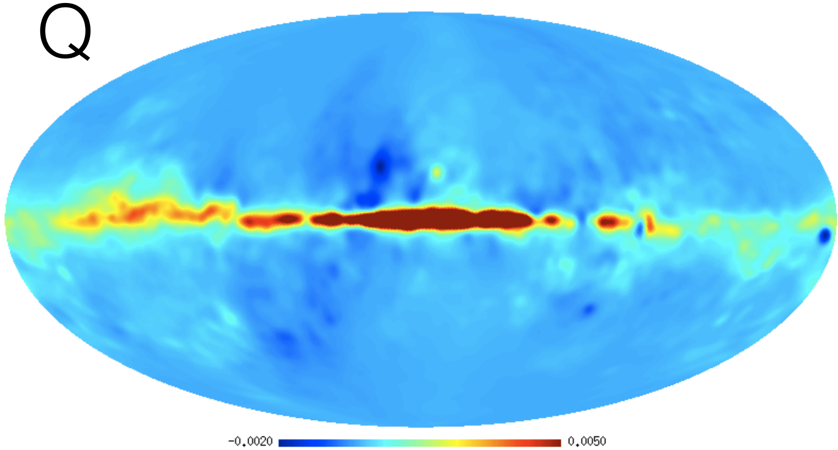


PSM polarization - Thermal dust 94 GHz

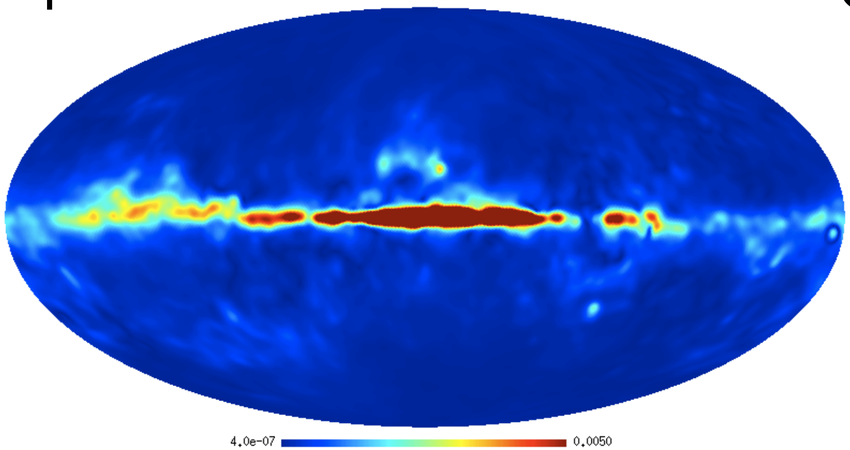
U



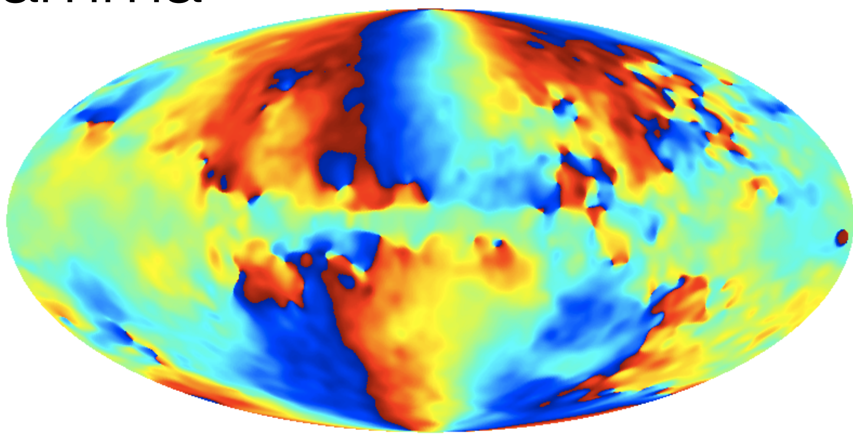
Q



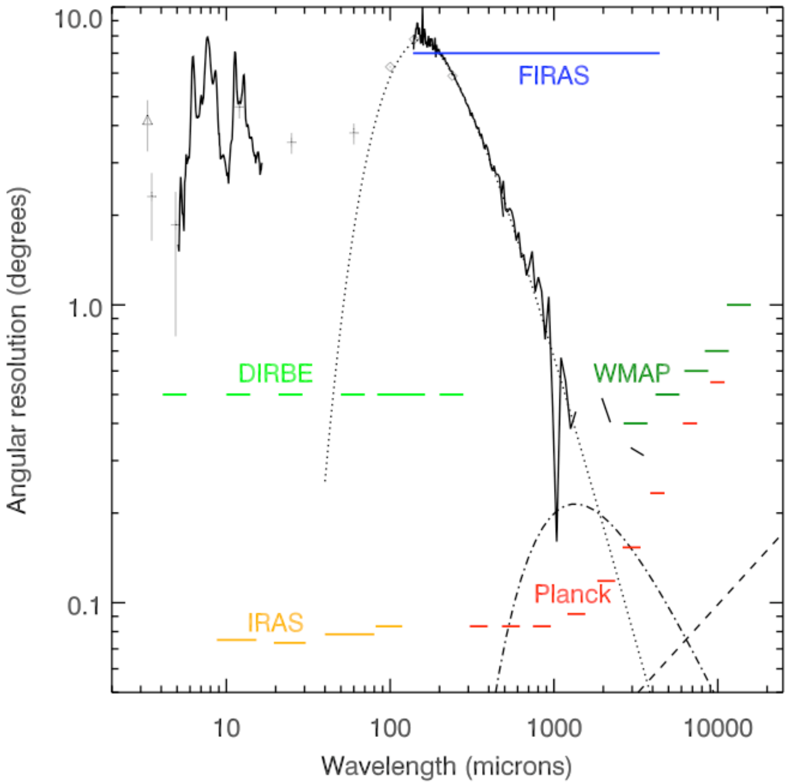
P

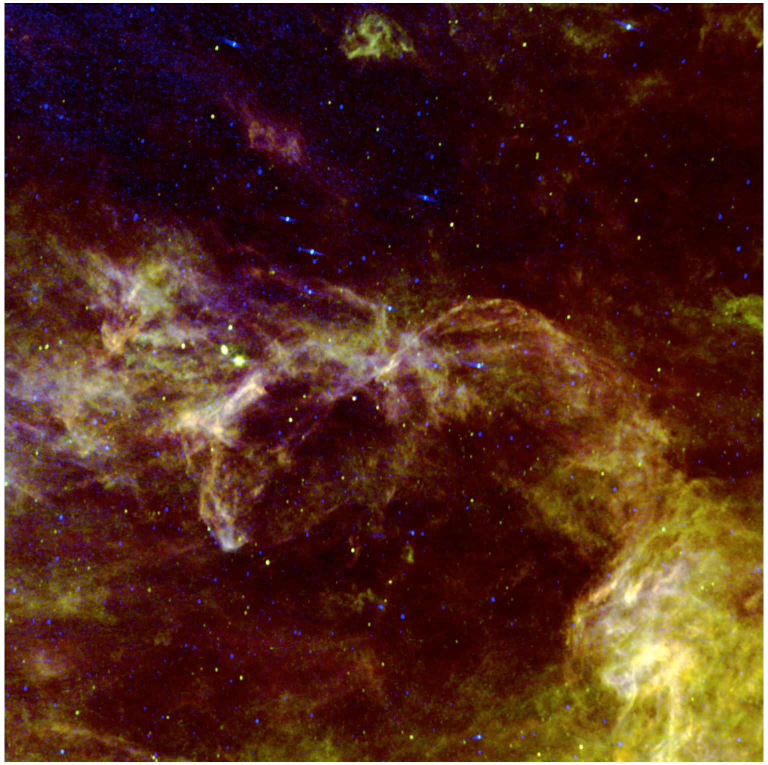


Gamma



Interstellar emission with Planck

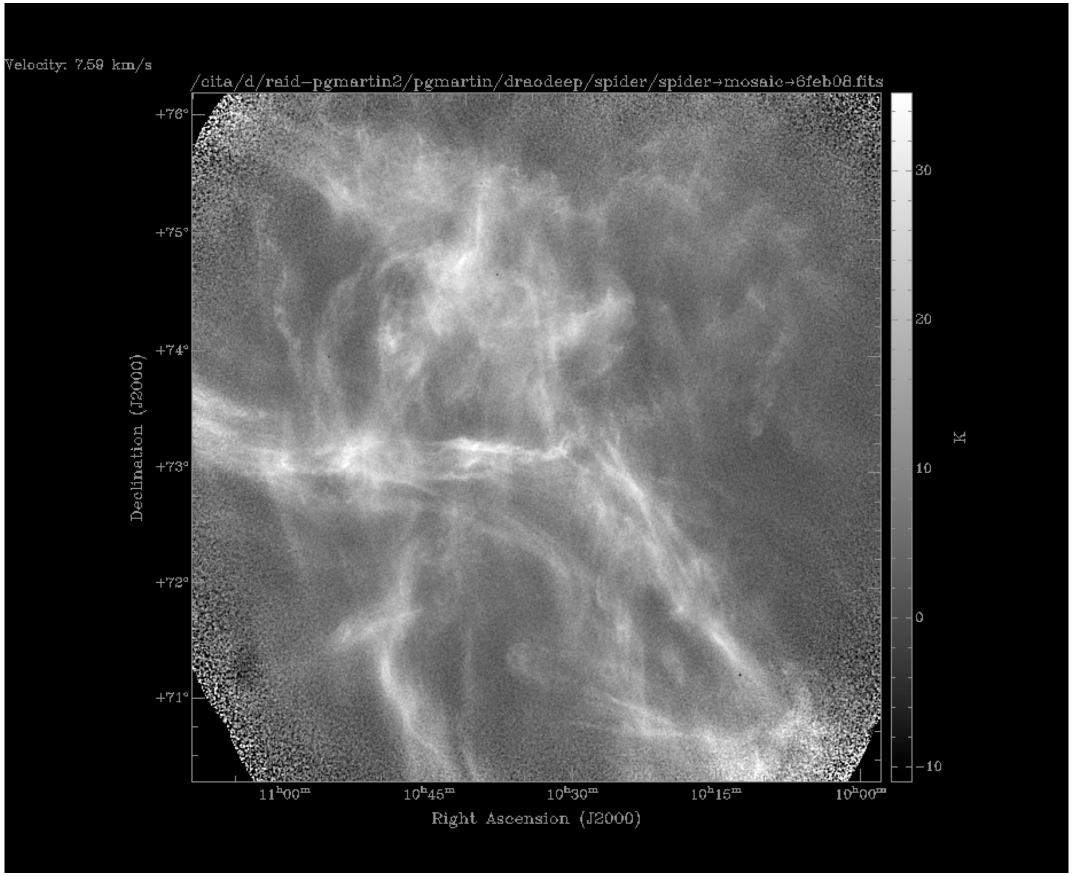




- Need precise model of dust emission down to 5’ to remove it in Temp. and Polarisation
- Planck traces all ISM phases : neutral (dust) and ionized (f-f & sync)

Interstellar emission with Planck

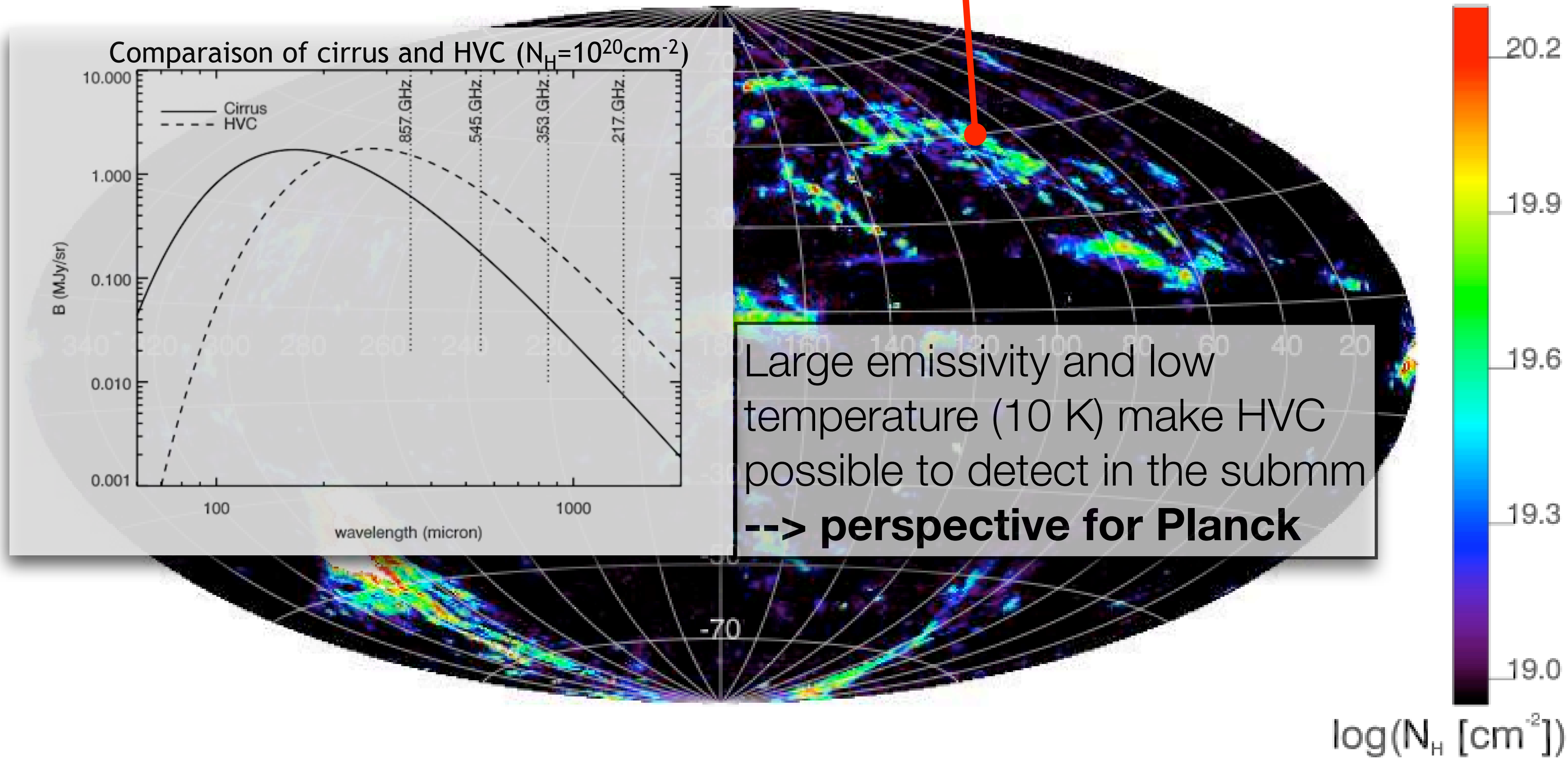
- Studying the Galactic ISM gives a small-scale picture of the physical processes involved in structure formation
- ISM structure formation
  - Formation of cold atomic and molecular gas from warm/hot gas
  - Turbulence
  - Magnetic field
  - Thermal instability
- Planck will provide informations on the density and magnetic field structure
  - Combined with gas lines observations : turbulence
  - Comparison with MDH simulations to have a handle on this non-linear physics



DRAO 21 cm observations of the Planck Deep Field

Dust emission from High-Velocity Clouds (HVC)

First detection in Complex C with Spitzer
Miville-Deschenes et al. 2005



Large emissivity and low temperature (10 K) make HVC possible to detect in the submm

--> perspective for Planck

Conclusion

- New model of synchrotron and anomalous emissions at 23 GHz
- Model is coherent with
  - Intensity and polarization WMAP data
  - Model of the large scale and turbulent part of the Galactic magnetic field
    - pulsar measurements
    - synchrotron radio observations
    - NIR dust extinction
- Synchrotron spectral index has very limited spatial variation
  - In accordance with gamma ray observations
  - Beta = -3.00 +- 0.06
- Anomalous emission is strongly correlated to E(B-V)
  - spectrum in accordance with spinning dust models
- This model is the basis of the Planck Sky Model

- Davies et al. 2006

- Where synchrotron dominates, it has a spectral index (between 408 MHz and 23 GHz) of -3 on average

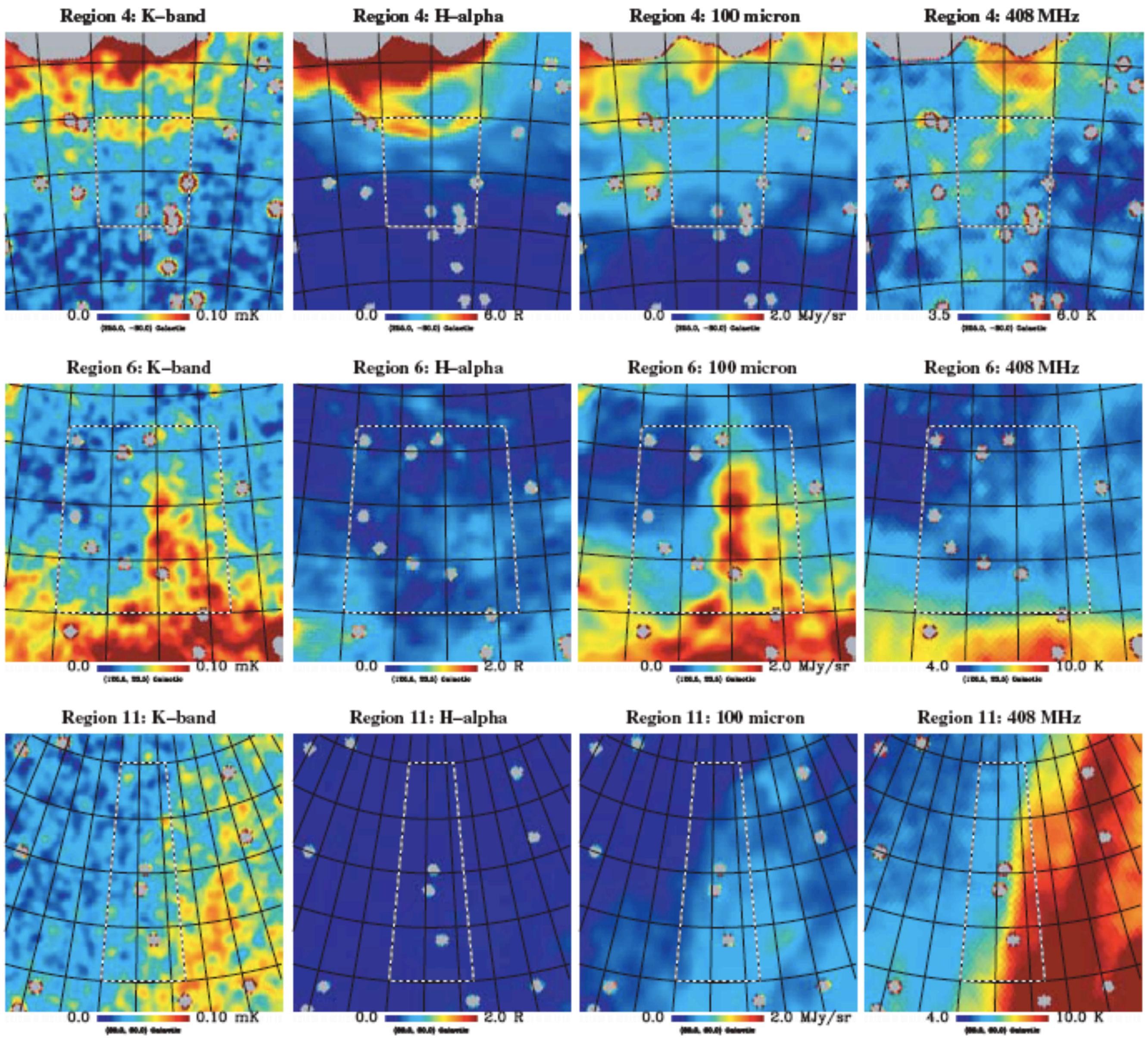
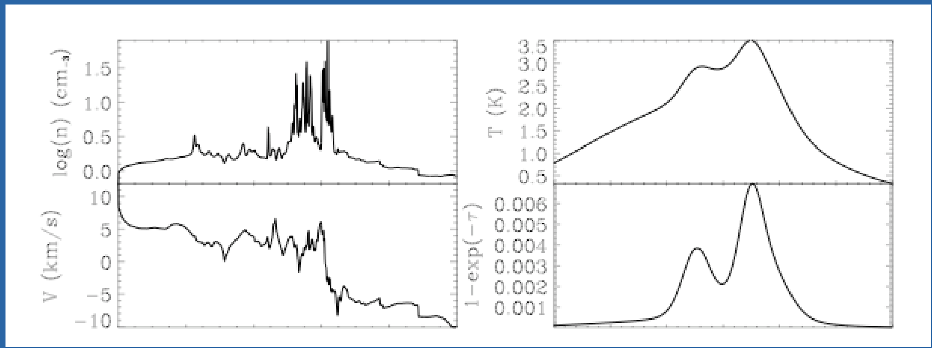
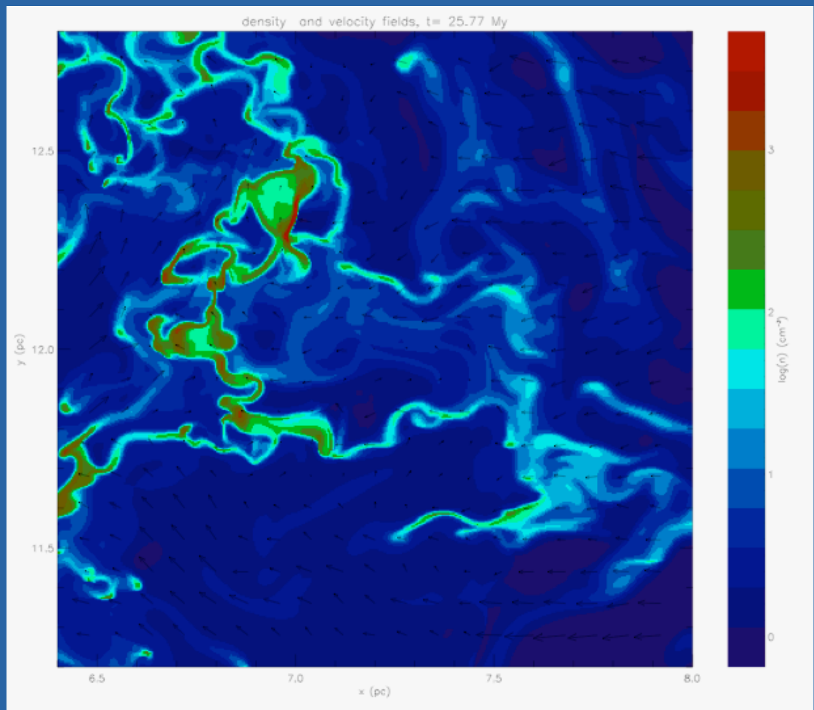


Figure 3. Maps of region 4 [Hα (free–free) dominated; top row], region 6 (dust dominated; middle row), and region 11 (synchrotron dominated; bottom row). From left- to right-hand panel are maps at *WMAP K* band, Hα, SFD98 100-μm dust intensity and 408 MHz. Galactic coordinates are shown. Each map, with a pixel resolution $N_{side} = 256$, covers a 25×25-deg^2 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* Kp2 mask and extragalactic sources mask.

Comparaison observations-simulations numériques





- Simulation d'observations à 21 cm à partir des simulations numériques 2D (n, v et T).
- Première fois que ce type de simulations numériques du HI est comparé directement aux observations
- Spectres réalistes au premier ordre.
  - Proportion CNM / WNM
  - Largeur de raie
- Les simulations 3D permettront de mieux comparer les quantités projetées… à venir.

Hennebelle, Audit & MAMD, A&A 2007