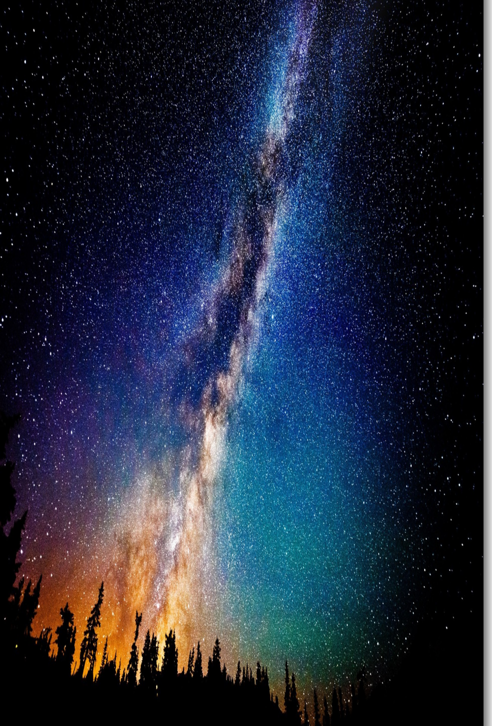


Synchrotron Radiation, magnetic fields and cosmic rays

Giuseppe Di Bernardo [1]

in collaboration with Evoli, C., Gaggero, D., Grasso, D.

[1]Max Planck Institute for Astrophysics

bernardo@MPA-Garching.MPG.DE

Planck Conference

Ferrara, December 05, 2014

e.g., the pre-launch PSM, in Delabrouille, J., et al., A&A (2013)

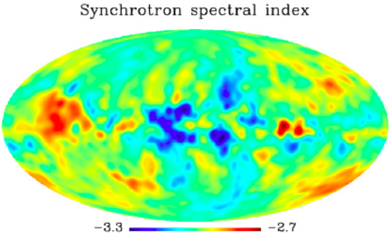
They use the template 408 MHz Haslam, and extrapolate in frequency to the Planck ν-channels, assuming (i) a spectral index $\beta_s = -3.0$ (i.e., $n_e(E) \propto E^{-p}$, $p = 3$), or (ii) using a $\beta_s - map$ derived by combining the 408 MHz and WMAP 23 GHz data (see e.g., Miville-Dechenes et al. 2008)

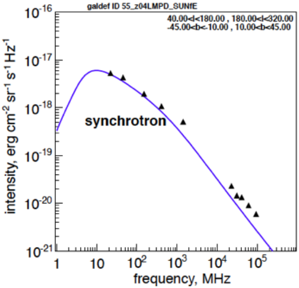
e.g., Fauvet, L., et al., A&A (2012)

analytical spatial distribution $n_e(r, z) \propto \exp(-r/r_{scale})/[\cosh(2z/z_{scale})]$ (Drimmel & Spergel (2001)), with an uniform CRE spectrum and $\beta_s \sim -3.45 (\rightarrow p \sim -4!!)$, and the `HAMMURABI` code (Waelkens et al., 2009) to compute RMs and synchrotron sky maps.

e.g., `GALPROP` results (Strong, A.W., Orlando, E., Jaffe, T.J., A&A (2011)

they based on a physical CRE model, accounting for a double broken power-law source spectrum (w/o extra-component), and uniform diffusion coefficient, and a continuous source distribution (see also Orlando E. contribution in the Poster session)

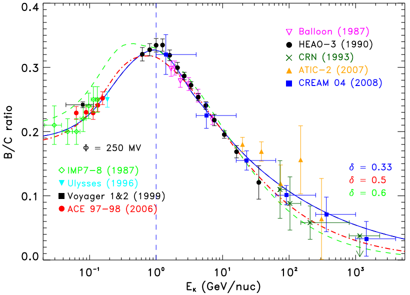


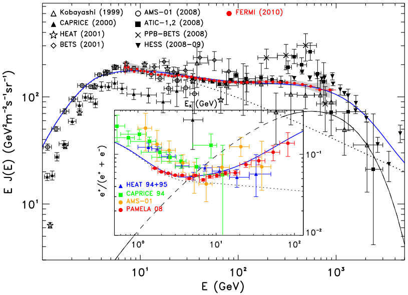


The Synchrotron Emission of the Galaxy

A Multi-Wavelength Analysis using DRAGON

Evoli, C., et al., JCAP (2008); Gaggero, D., et al., PRL (2013) (http://www.dragonproject.org/)





Fixing diffusion models against CR nuclei data

DRAGON is a new numerical code aiming to solve the diffusion equation of CRs in the Galaxy environment. DRAGON features: position dependent, anisotropic diffusion; independent injection spectra for each nuclear species; interfaced with GAMMASKY to calculate diffuse gamma and synchrotron emissions; interfaced with DarkSUSY to calculate DM contribution ... (other major codes, GALPROP, PICARD).

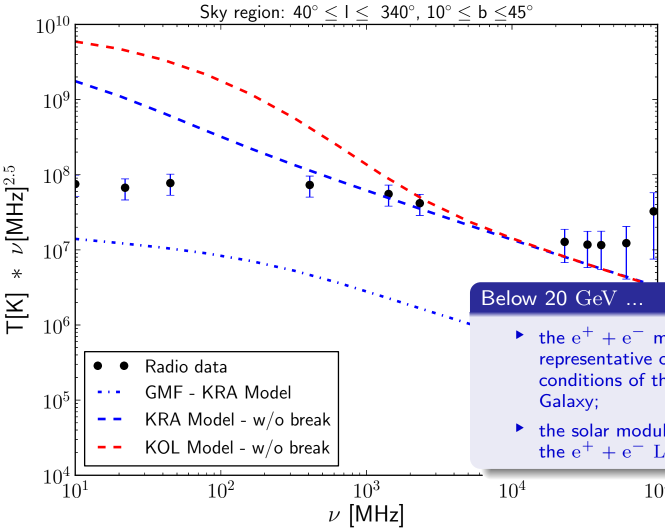
The positron-excess ...

the role of astrophysical galactic extra-component seems more likely than exotic ones (DM annihilation/decay). Plot from Di Bernardo G., et al., 2011. See also e.g., Grasso et al., APP 32 (2009), Serpico, P., PRD, 79 (2009), Hooper, D., et al., JCAP 1 (2009): incomplete list of papers!

THE SYNCHROTRON EMISSION OF THE GALAXY

TO PROBE THE LOW ENERGY LIS OF $e^+ + e^-$ USING DRAGON + GAMMASKY

RESULTS FROM DI BERNARDO G., EVOLI, C., GAGGERO D., GRASSO, D., AND MACCIONE, L., JCAP 3 (2013)

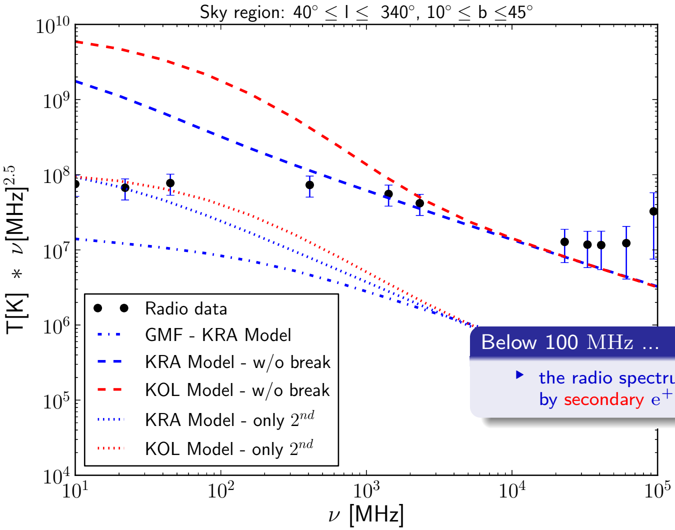


Below 20 GeV ...

- the $e^+ + e^-$ may not be representative of the physical conditions of the rest of the Galaxy;
- the solar modulation reshapes the $e^+ + e^-$ LIS.

The Synchrotron Emission of the Galaxy
To Probe the Low Energy LIS of $e^+ + e^-$ using DRAGON + GAMMASKY

results from Di Bernardo G., et al., JCAP 3 (2013)

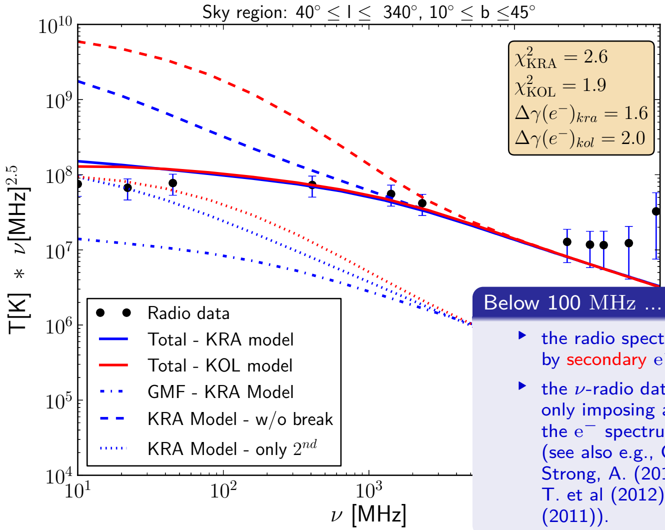


Below 100 MHz ...

- the radio spectrum is dominated by secondary $e^+ + e^-$;

The Synchrotron Emission of the Galaxy
To Probe the Low Energy LIS of $e^{+} + e^{-}$ using DRAGON + GAMMASKY

results from Di Bernardo G., et al., JCAP 3 (2013)

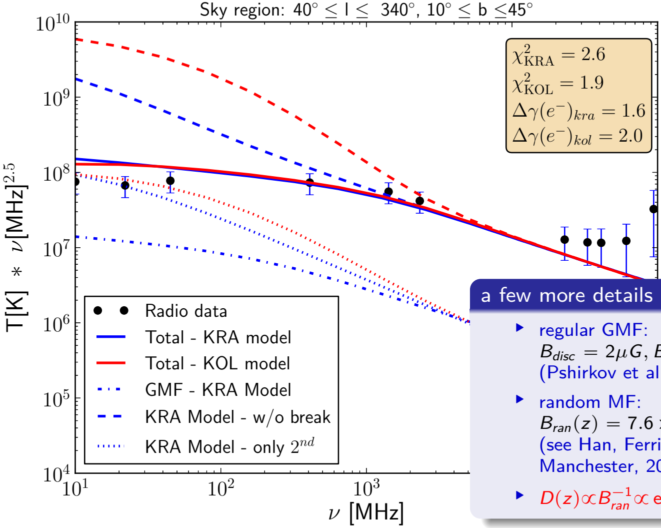


Below 100 MHz ...

- the radio spectrum is dominated by secondary $e^{+} + e^{-}$;
- the ν-radio data are reproduced only imposing a sharp break to the e^{-} spectrum below 4GeV (see also e.g., Orlando E., & Strong, A. (2013); Bringmann, T. et al (2012); Jaffe et al (2011)).

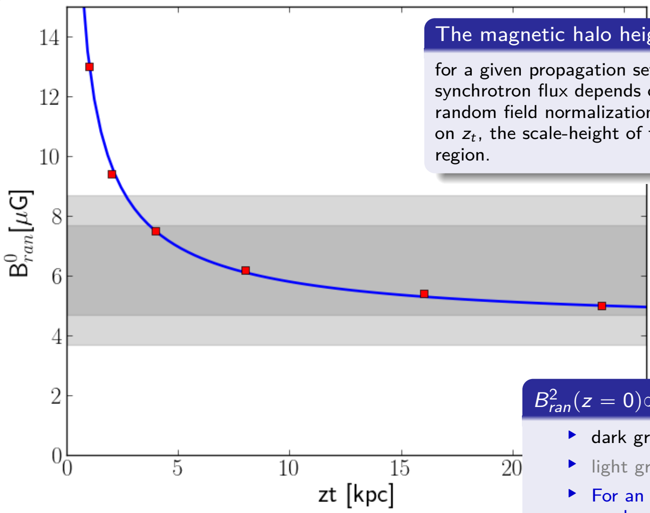
THE SYNCHROTRON EMISSION OF THE GALAXY
TO PROBE THE LOW ENERGY LIS OF $e^+ + e^-$ USING DRAGON + GAMMASKY

RESULTS FROM DI BERNARDO G., ET AL., JCAP 3 (2013)



a few more details ...

- regular GMF: $B_{disc} = 2\mu G$, $B_{halo} = 4\mu G$ (Pshirkov et al. 2012);
- random MF: $B_{ran}(z) = 7.6 \times \exp(-z/z_t)\mu G$, (see Han, Ferriere and Manchester, 2004);
- $D(z) \propto B_{ran}^{-1} \propto \exp(z/z_t)$.



The magnetic halo height ...

for a given propagation set up, the synchrotron flux depends only on the random field normalization $B_{ran}(z=0)$ and on z_t, the scale-height of the diffusion region.

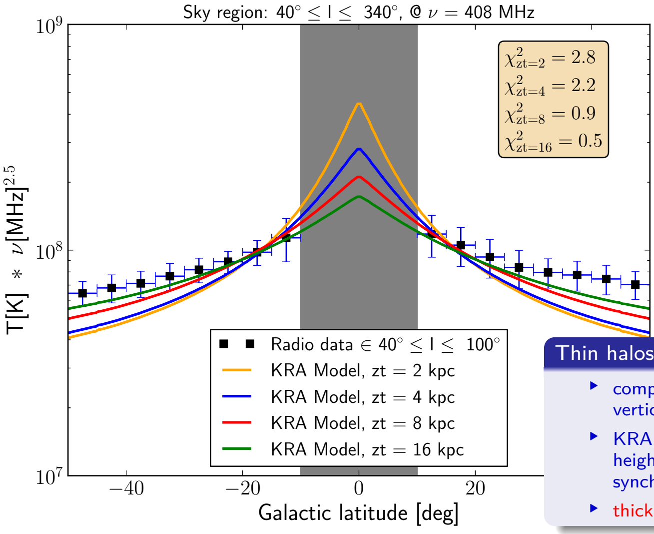
$B^2_{ran}(z=0) \propto z_t^{-1}$... @ 408 MHz

- dark grey $3\sigma \mapsto z_t > 4$ kpc;
- light grey $5\sigma \mapsto z_t > 3$ kpc;
- For an exponential profile of the random MF we constraint the halo height using the RM data

The Synchrotron Emission of the Galaxy

The Latitude Profile: the Global Environment

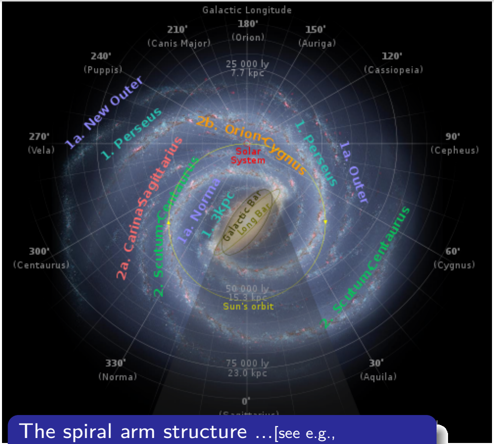
results from Di Bernardo G., et al., JCAP 3 (2013)



Thin halos are excluded at 3 σ...

- complementary probe of the vertical CRE distribution;
- KRA set up at different halo heights reproducing well the synchrotron spectrum;
- thick halos are favoured!

How do the Large Scale Structures Influence the Observables?

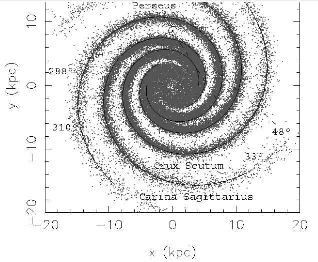


The spiral arm structure ...[see e.g., Faucher-Giguere & Kaspi, 2007]

- birth sites of isolated pulsars $\Longleftrightarrow$ Galactic spiral arms;
- pulsars progenitors traced by four major arm centroids: $\theta(r) \propto ln(r/r_0) + \theta_0$

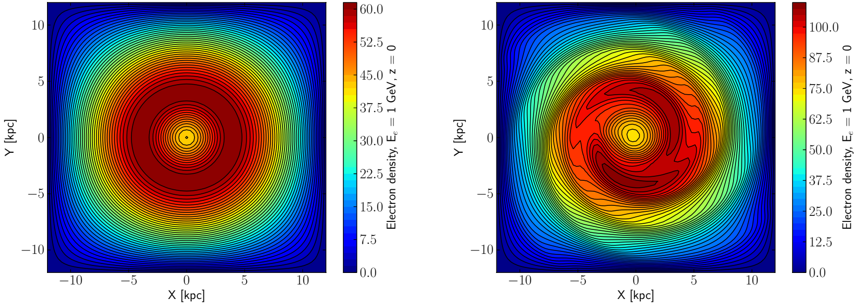
The effects of the spiral arm pattern

- We live in an inter-arm region: most of the CR sources lie in the arms;
- high energy CRE cross through larger distances than what expected in a smooth model, where no spiral arm structure is taken into account;
- more severe energy losses (via *IC & Synchrotron*): steepening;
- no steep injection: compatible with 1^{st} Fermi acceleration mechanism



The effects of the spiral arm pattern
2D vs. 3D

face-on view @ 1 GeV on the Galactic plane

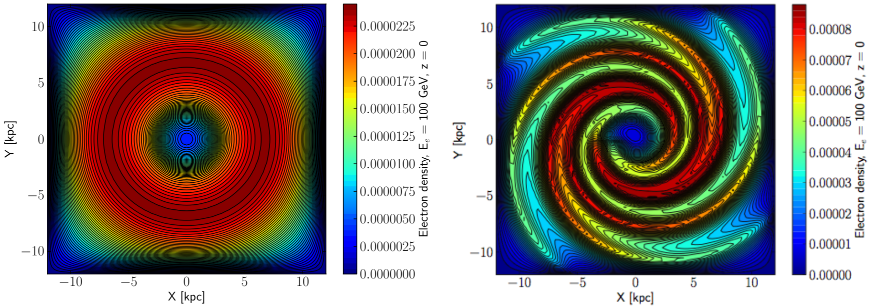


DRAGON 3*D* mode (from Gaggero, D., et al. PRL, 111 (2013))

- sources distributed in the spiral arms [as in e.g., Faucher-Giguere & Kaspi, 2007; see also Blasi & Amato, JCAP I&II (2012)];
- distances between arms $\simeq 1$ kpc: *IC & Synchrotron* radiative losses

The effects of the spiral arm pattern
2D vs. 3D

face-on view @ 100 GeV on the Galactic plane

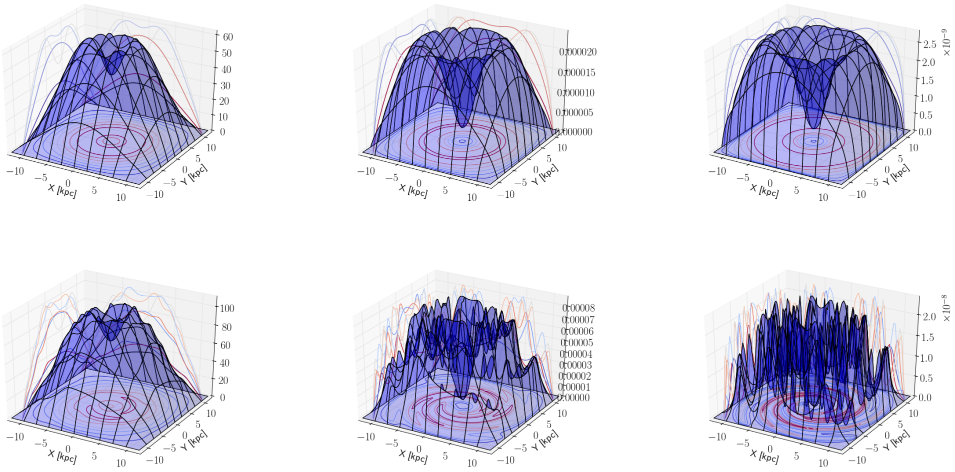


DRAGON 3D mode (from Gaggero, D., et al. PRL, 111 (2013))

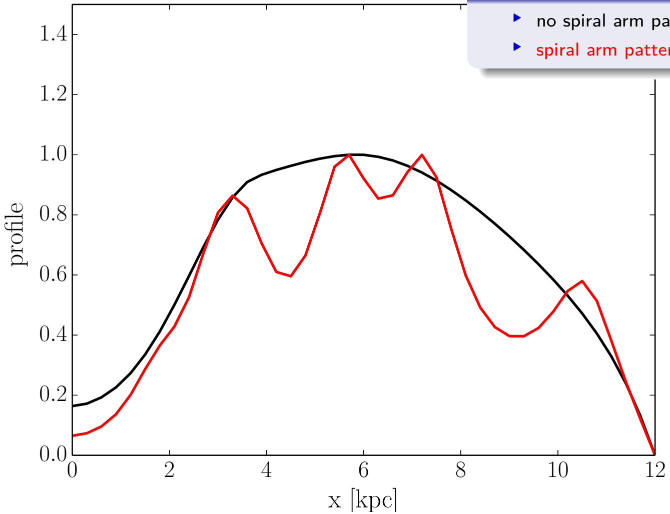
- sources distributed in the spiral arms [as in e.g., Faucher-Giguere & Kaspi, 2007; see also Blasi & Amato, JCAP I&II (2012)];
- distances between arms $\simeq 1$ kpc: *IC & Synchrotron* radiative losses;
- energy losses in the inter-arm region change dramatically the $e^- + e^+$ spectra above ~ 20 GeV

The effects of the spiral arm pattern
2D vs. 3D

radial distribution in the z-plane at different energies (1 GeV, 100 GeV and 1 TeV)



RADIAL DISTRIBUTION AT ENERGY OF 50 GeV

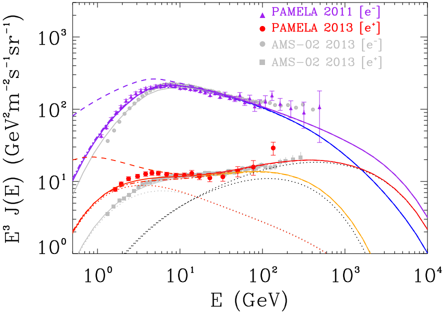


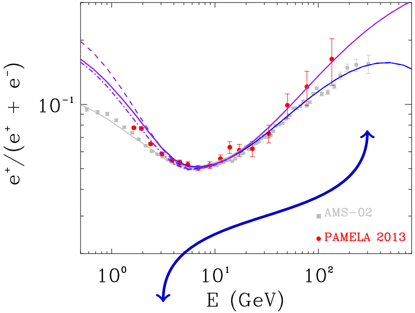
(normalized) electron density ...

- no spiral arm pattern;
- spiral arm pattern.

3D Modelling of PAMELA and AMS-02 data

results from Gaggero, D., et al., PRD 89 (2014)

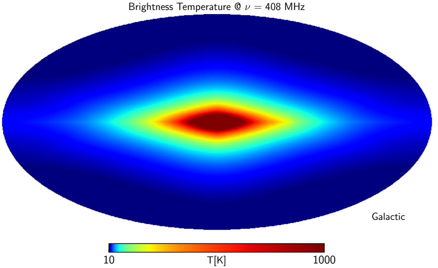


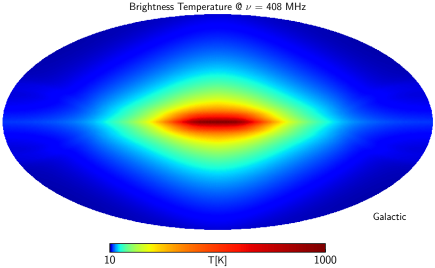


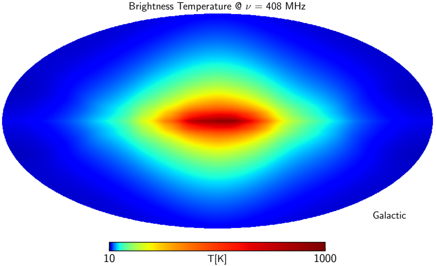
Astrophysical galactic extra-component

- $\Gamma(e^-) = 2.5$, and $\Gamma(e^\pm) = 1.7$;
- $W_{tot}(p) \approx 10^{57}$, $W_{tot}(e^-) \approx 10^{55}$, $W_{tot}(e^\pm) \approx 10^{54}$, $W_{SNR} \approx 10^{58}$[GeV/Myr];
- purple (red): $E_{cut} = 10$ TeV;
- blue (orange): $E_{cut} = 1$ TeV

3D Modelling of Galactic Synchrotron
Ia. 408 MHz Brightness Temperature Maps: Preliminary Results
DRAGON + GAMMASKY





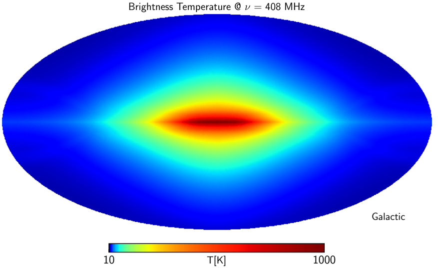


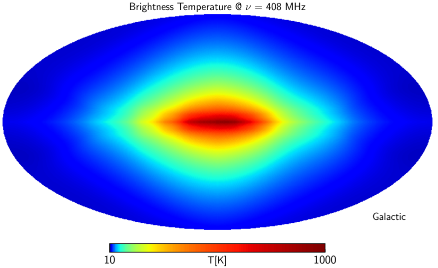
in clockwise order ...

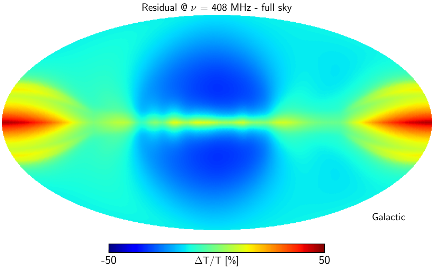
- Drimmel and Spergel (2001);
- GAMMASKY + CRE w/o arms;
- GAMMASKY + CRE w/ arms.

Intensity

$$T = I(\nu)c^2/2\nu^2 k_B$$







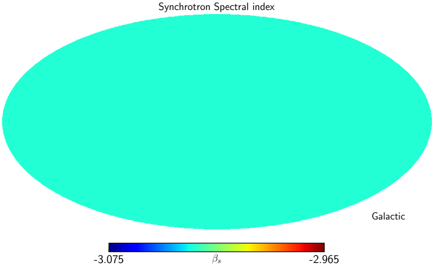
Residuals

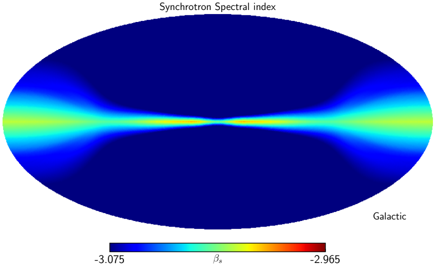
$$\frac{S_{no-arms}(408) - S_{arms}(408)}{S_{arms}(408)}$$

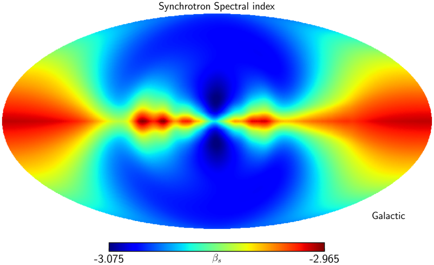
3D Modelling of Galactic Synchrotron

II. Spectral Index Maps from 408 MHz to 23 GHz: Preliminary Results

DRAGON + GAMMASKY







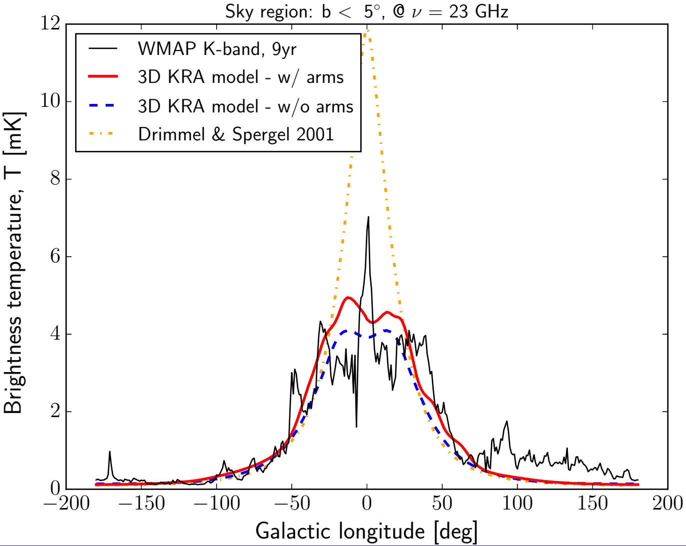
in clockwise order ...

- CRE by Drimmel and Spergel (2001);
- GAMMASKY + GAMMASKY CRE w/o arms;
- GAMMASKY + GAMMASKY CRE w/ arms.

$S(\nu) \propto (\nu/\nu_0)^{\beta_s}$

$\beta_s = 0.248 \log(S_{23}/S_{408})$

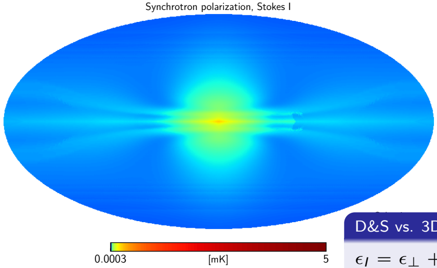
3D Modelling of Galactic Synchrotron
III. The Longitude Profile near the Galactic Plane: Preliminary Results
DRAGON + GAMMASKY

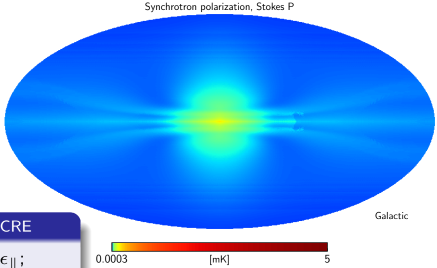


3D Modelling of Galactic Synchrotron

IVa. Polarization Maps at 30 GHz: Preliminary Results

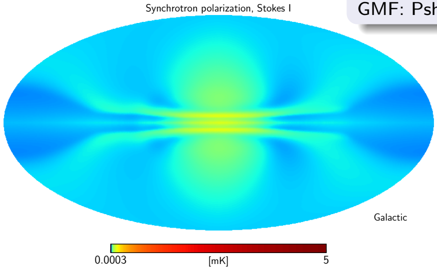
DRAGON + GAMMASKY (following the scheme as in HAMMURABI, Waelkens et al., 2009)

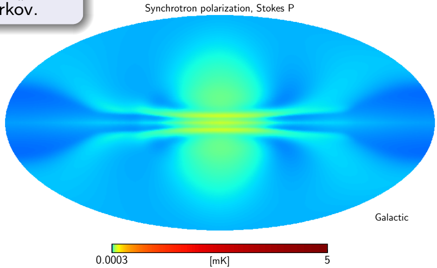




D&S vs. 3D CRE

$\epsilon_I = \epsilon_\perp + \epsilon_\parallel$;
$\epsilon_P = \epsilon_\perp - \epsilon_\parallel$;
GMF: Pshirkov.

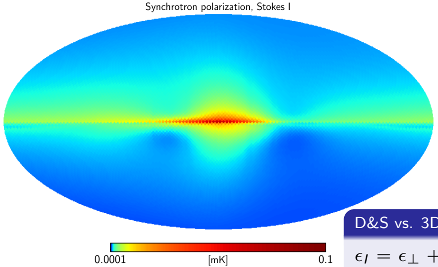


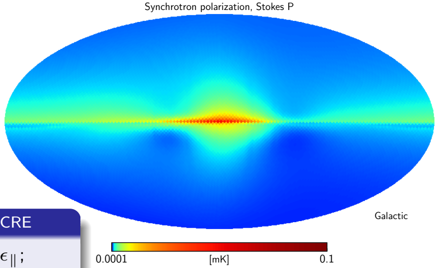


3D Modelling of Galactic Synchrotron

IVb. Polarization Maps at 30 GHz: Preliminary Results

DRAGON + GAMMASKY (following the scheme as in **HAMMURABI**, Waelkens et al., 2009)



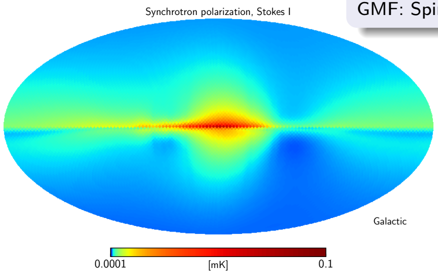


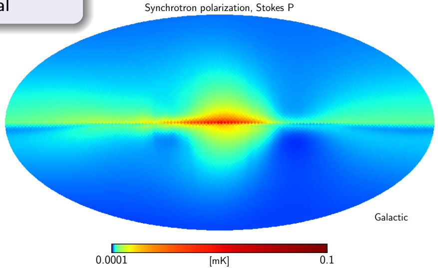
D&S vs. 3D CRE

$\epsilon_I = \epsilon_\perp + \epsilon_\parallel$;

$\epsilon_P = \epsilon_\perp - \epsilon_\parallel$;

GMF: Spiral





- Multichannel analysis!
    - We exploited the galactic diffuse synchrotron emission as a way to measure the low energy LIS spectrum of CRE;
    - The synchrotron emission, conversely to the common $^{10}Be/^{9}Be$ constraint, offers instead a much more direct probe of the magnetic halo height, z_t.
- The spatial and energy distribution of CRE is largely affected by the spiral arm pattern for energy around (and above) $50 GeV$: that reflects drastically on the angular distribution and the spectral index map of the synchrotron emission;
- `DRAGON`: a suitable tool for most CR analysis;
- `GAMMASKY` will be soon complete of all relevant components (free-free emission, all Stokes parameters ... etc)
- γ-Fermi-LAT, CRs and Planck data, simultaneously (see Ensslin's talk).

Backup slides

The legacy of Kolmogorov

- $(\mathbf{u} \cdot \nabla)\mathbf{u}$: distorsions of the velocity field (*eddies*);
- Onset of turbulence: $R_e \gg 1$;
- Energy cascade process: $\dot{\epsilon} \sim (\delta u_L^3/L)$;
- (HD) Kolmogorov's law: $W_K(k) \propto k^{-5/3}$ (Alfvnic eddies elongated along the MF);
- (MHD) Kraichnan's law: $W_{IK}(k) \propto k^{-3/2}$ (fast modes).

In the Quasi Linear Theory ...

- $k_{res} = \Omega/v\mu$;
- $\tau_{sca} \sim \Omega^{-1}(k_{res} W(k_{res})/B_0^2/4\pi)^{-1}$;
- $D = 1/3 v r_L/\mathcal{F}$; $\mathcal{F} = (k_{res} W(k_{res})/B_0^2/4\pi)$;
- $\int dk W(k) = \delta B^2/4\pi$; $W(k)dk \sim k^{-2+\delta} dk$;
- $D(\mathcal{R}) \propto \mathcal{R}^\delta$;
- (HD) Kolmogorov's law: $\delta = 1/3$;
- (MHD) Kraichnan's law: $\delta = 1/2$;

The ISM is turbulent ...

on scales ranging from AUs to kpc, with an embedded magnetic field taht influences almost all of its properties. MHD turbulence is accepted to be of key importance for the propagation and acceleration of Cosmic Rays.