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Testing Galactic magnetic field structure model predicted by magnetohydrodynamical numerical simulation using distribution of polarization angle of Galactic synchrotoron emission.

Author & Co-Authors

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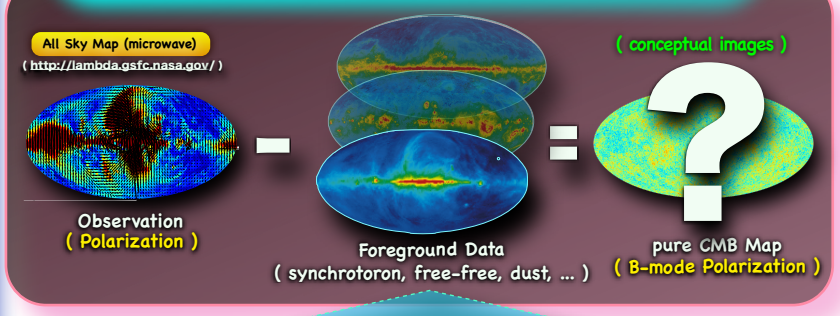
Abstract

We have reemphasized that distribution of polarization angle of Galactic synchrotron emission extracted from the WMAP K-band polarization data is valuable tool to study global topology of Galactic magnetic field. Methods to analyze the distribution of the polarization angle by taking into account a periodicity in 180 degree, are proposed. The global Galactic magnetic field models proposed by global three dimensional magnetohydrodynamical numerical simulations of Galactic gaseous disks are tested by applying these methods. We have shown that currently existing numerical models are incompatible with the observation because pitch angle of spiral pattern found in the magnetic field structures in the numerical results was too small. We have also tested bi-symmetric spiral model as one of bench mark models which take into account concentration of magnetic field in the spiral arms. The model is incompatible with the observation as far as pitch angle of the model is same as that of the spiral arms. Among the currently examined models, pitch angle in any spiral magnetic field model must be as large as two times larger than that of the spiral arms to be compatible with the observed distribution of the polarization angle.

Our group final aim is ....
to extract **pure B-mode polarization component !**



A highly precise foreground subtraction is required !

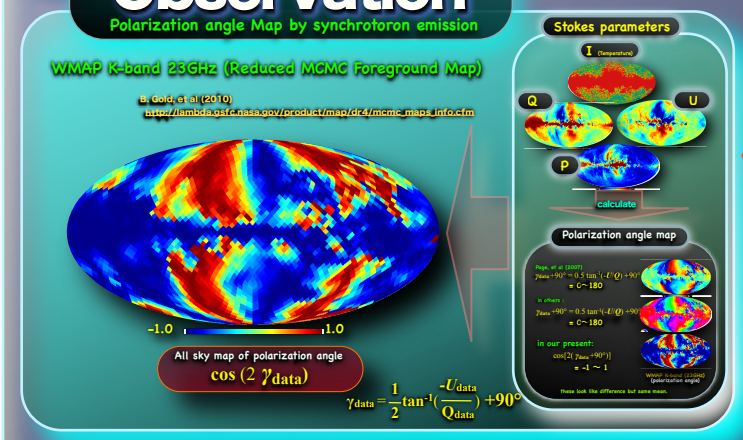
Our means to an end are ...

- All sky dust map with highly precise resolution.
  - New dust map production by AKARI data. On processing, now !
- All sky synchrotoron map with highly precise resolution.
  - ≒ Construction of realistic Galactic magnetic field structures model.
- High advanced computing with MHD simulation (+statistical method)
- etc

Method

Observation

Polarization angle Map by synchrotoron emission



$$\gamma_{data} = \frac{1}{2}\tan^{-1}\left(\frac{-U_{data}}{Q_{data}}\right) + 90^\circ$$

Compare

correlation is **r= ?**

It can be considered Benchmark value to measure agreement with them.

correlation is defined by

$$r = \frac{\sum_{i=1}^{N}(X_i-\bar{X})(Y_i-\bar{Y})}{\sqrt{\sum_{i=1}^{N}(X_i-\bar{X})^2}\sqrt{\sum_{i=1}^{N}(Y_i-\bar{Y})^2}}$$

where $X_i = \gamma_{model}$, $Y_i = \gamma_{data}$

Model

Galactic magnetic field model + Synchrotoron distribution model

the polarization angle is a fundamental parameter to represent Galactic global structure

Galactic magnetic field model: $\mathbf{B}(R,\varphi,z) = \mathbf{B}_0$ [for example, some function of (R,φ,z) ...]

Synchrotoron distribution model: $n_e(R,\varphi,z) = n_0 \exp(-R/h_R)\ \mathrm{sech}^2(z/h_d)$

calculate

definition:

$$Q_{model}(\vec{n}(i)) = \int dx\, n_e(x,\vec{n}(i))\,[B_x(x,\vec{n}(i))^2 - B_t(x,\vec{n}(i))^2],$$
$$U_{model}(\vec{n}(i)) = \int dx\, n_e(x,\vec{n}(i))\,2B_x(x,\vec{n}(i))\,B_t(x,\vec{n}(i)),$$

calculate

definition:

$$\gamma_{model} = \frac{1}{2}\tan^{-1}\left[\frac{U_{model}(\vec{n}(i))}{Q_{model}(\vec{n}(i))}\right] = \frac{1}{2}\tan^{-1}\left[\frac{\int dx\, n_e(x,\vec{n}(i))\,2B_x(x,\vec{n}(i))\,B_t(x,\vec{n}(i))}{\int dx\, n_e(x,\vec{n}(i))\,[B_x(x,\vec{n}(i))^2 - B_t(x,\vec{n}(i))^2]}\right]$$

independent of model parameters B_0, n_0

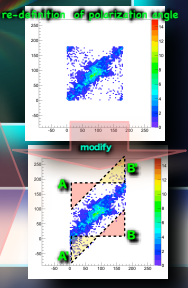
calculate

All sky map of polarization angle
cos (2 γmodel)

re-definition of polarization angle

$\gamma_{data} = \gamma_{data} + 180^\circ$ (if $0 < \gamma_{data} < 90^\circ$ and $90 < \gamma_{model} < 180^\circ$ and $\gamma_{model} - \gamma_{data} > 90^\circ$)
$\gamma_{data} = \gamma_{data} - 180^\circ$ (if $0 < \gamma_{model} < 90^\circ$ and $90 < \gamma_{data} < 180^\circ$ and $\gamma_{data} - \gamma_{model} > 90^\circ$)

the periodicity is 180 degree.
the region A, A' is near that of B, B', respectively



Result

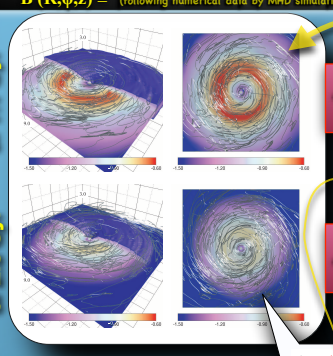
MHD-model

(= Numerical data obtained by 3D MHD simulation) Nishikori, Machida, Matsumoto (2006)

Synchrotoron distribution model: $n_e(R,\varphi,z) = n_0 \exp(-R/h_R)\ \mathrm{sech}^2(z/h_d)$

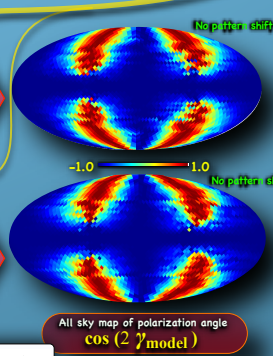
Galactic magnetic field model: $\mathbf{B}(R,\varphi,z) =$ (following numerical data by MHD simulation)

t= 1.1 Gyr / t= 2.3 Gyr



tightly wound / loosely wound

calculate



Npix=3072 (Nside=1f)

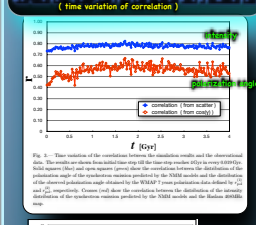
r~0.77
χ²/N~4.9x10

r~0.79
χ²/N~4.4x10

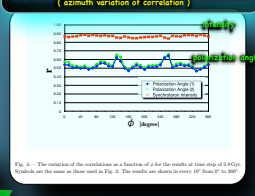
All sky map of polarization angle
cos (2 γmodel)

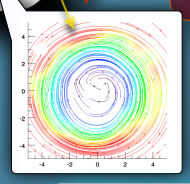
scatter plot of polarization angle
γdata - γmodel

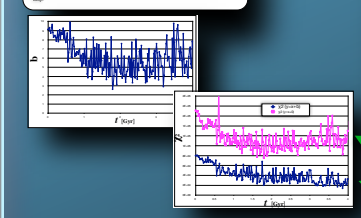
correlations between the simulation and observation
(time variation of correlation)

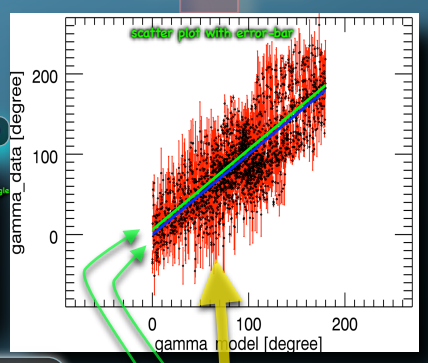


correlations between the simulation and observation
(azimuth variation of correlation)





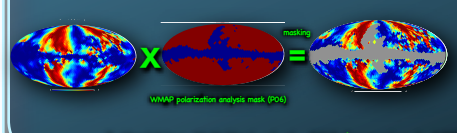




$\gamma_{data} = \gamma_{model} + b$
$\gamma_{data} = \gamma_{model}$
calculate
χ^2/N

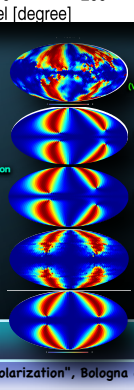
Error-bar is estimated by Monte Carlo simulation

variance map of Q
(by wmap_mcmc_K_synch_stk_q_7yr_v4p1.fits)



T. Morishima, M.Hattori, et al, 2012 (preparing to APJ)

WMAP K-band 23GHz (Reduced MCMC Foreground Map)
http://lambda.gsfc.nasa.gov/product/map/dr4/mcmc_maps_info.cfm



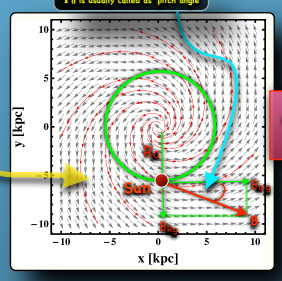
LSA-model

(= Logarithmic Spiral Arm model) L. Page, et al (2007)

Synchrotoron distribution model: $n_e(R,\varphi,z) = n_0 \exp(-R/h_R)\ \mathrm{sech}^2(z/h_d)$

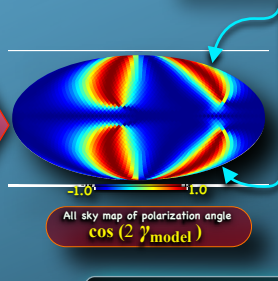
Galactic magnetic field model:
$\mathbf{B}(R,\varphi,z) = B_0\,[\sin\Psi(R)\cos\chi(z)\,e_R + \cos\Psi(R)\cos\chi(z)\,e_\varphi + \sin\chi(z)\,e_z]$
where $\Psi(R) = \Psi_0 + \Psi_1 \log(R/8\mathrm{kpc})$, $\chi(z) = \gamma_1 \tan(z/1\mathrm{kpc})$

Ψ_0 is usually called as "pitch angle"



pattern shift

calculate

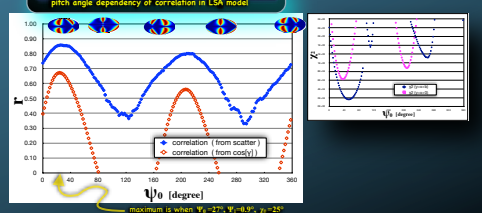


rmax~0.86
χ²/N~3.5x10

All sky map of polarization angle
cos (2 γmodel)

scatter plot of polarization angle
γdata - γmodel

correlations between the simulation and observation
pitch angle dependency of correlation in LSA model



BSS-model

(= Bi-Symmetric Spiral model) X.H.Sun et al, AA, 477, 573 (2008) etc

Synchrotoron distribution model: $n_e(R,\varphi,z) = n_0 \exp(-R/h_R)\ \mathrm{sech}^2(z/h_d)$

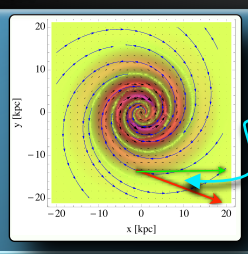
Galactic magnetic field model:
$B_R(R,\varphi,z) = D_1(R,\varphi,z) \cdot D_2(R,\varphi,z)\sin(p)$
$B_\varphi(R,\varphi,z) = -D_1(R,\varphi,z) \cdot D_2(R,\varphi,z)\cos(p)$
$B_z(R,\varphi,z) = 0$

where $D_1(R,\varphi,z) = \begin{cases} E_r \exp[-(R+R_r)/R_r - |z/z_r|] & (3\ \mathrm{kpc} < R) \\ B_r & (0\ \mathrm{kpc} < R < 3\mathrm{kpc}) \end{cases}$

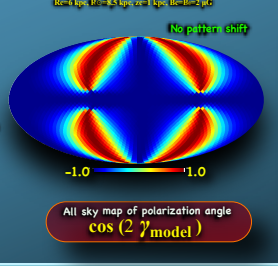
$D_2(R,\varphi,z) = -\cos[\varphi + 1/\tan(p)\log(R/R_r) + \varphi_r]$

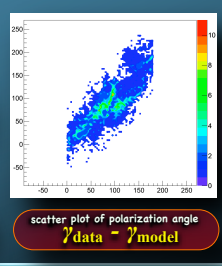
$(p, R_r) = \begin{cases} (18°, 9\ \mathrm{kpc}) & (6\ \mathrm{kpc} < R) \\ (15°, 6\ \mathrm{kpc}) & (0\ \mathrm{kpc} < R < 6\mathrm{kpc}) \end{cases}$

R_r=6 kpc, R_z=8.5 kpc, z_r=1 kpc, B_r=B_z=2 μG



No pattern shift





rmax~0.79
χ²/N~4.4x10

All sky map of polarization angle
cos (2 γmodel)

scatter plot of polarization angle
γdata - γmodel

Planck Conference "Astrophysics from radio to sub-millimeter wavelengths - The Planck view and other experiments: temperature and polarization", Bologna on 13-17 February 2012.