SK/Tibet空気シャワーアレイによる 10 TeV宇宙線強度の恒星時日周変動の観測

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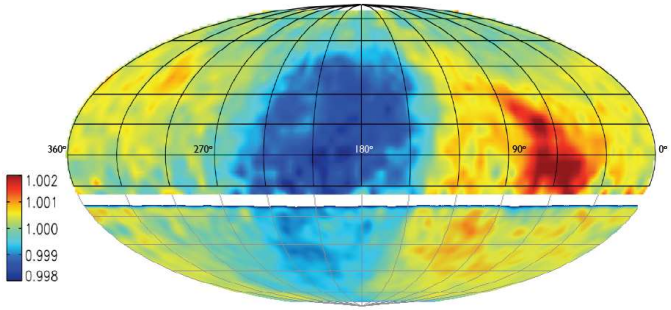
旅費（松本⇔柏）：50千円（SK）/ 150千円（Tibet）

- Anisotropy models (brief review)
- ~100 TeV CR anisotropy



Tibet ASγ (7 TeV)
(Amenomori et al., Science, 314, 2006)

Ice Cube (20 TeV)
(Abbasi et al., arXiv:1005.2960v1, 2010)

Expanding LIC (Mizoguchi+, proc. 31st ICRC, 2009)

Best-fit parameters (Amenomori+, ASTRA, 2010)

Uni-directional

$a_{1\perp}$ =0.166%, $a_{1//}$ =0.038%

$\alpha_{1\perp}$ =34.3°, $\delta_{1\perp}$ =39.3°

Bi-directional

$a_{2//}$ =0.134%

$\alpha_{2//}$ =99.3°, $\delta_{2//}$ =-27.7° (LIMF orientation)

For 5 TeV CRs…

Larmor radius : R_L ~ 0.002 pc in 3μG field

Scattering m.f.p. : $\lambda_{//}$ ~ 3 pc

(e.g. Moskalenko et al., 2002)

Bohm factor $\lambda_{//}/R_L$ ~ 1500 >> 1 (~10 in the helic

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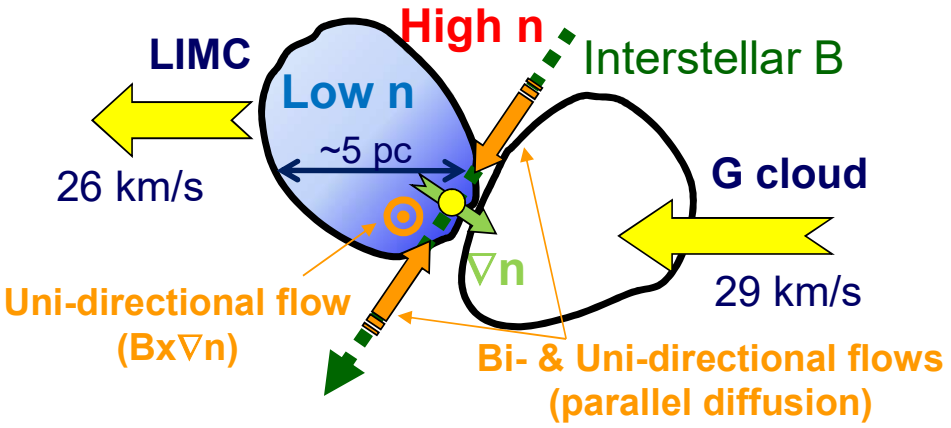
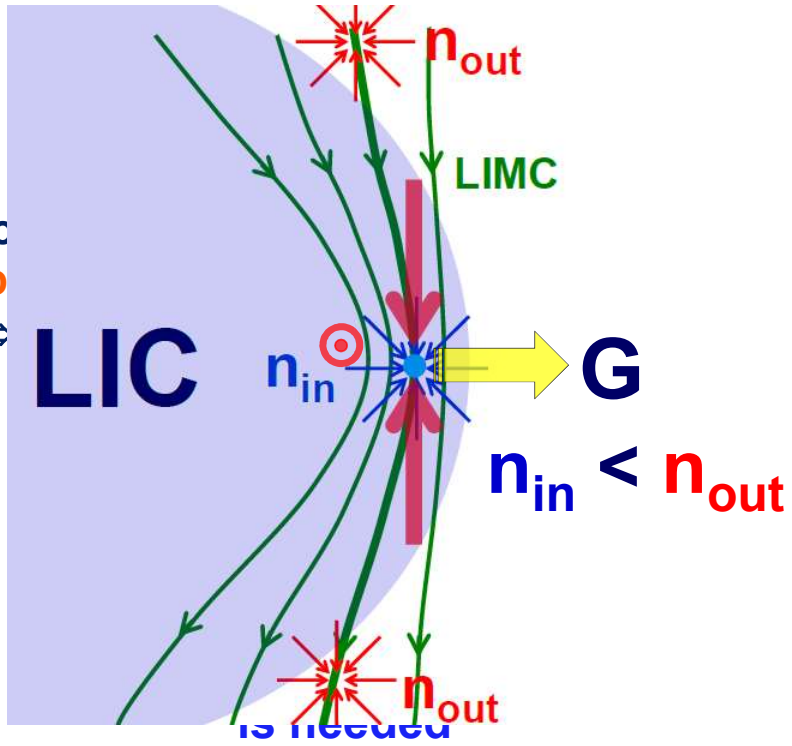
Origin of Uni- & Bi-directional flows

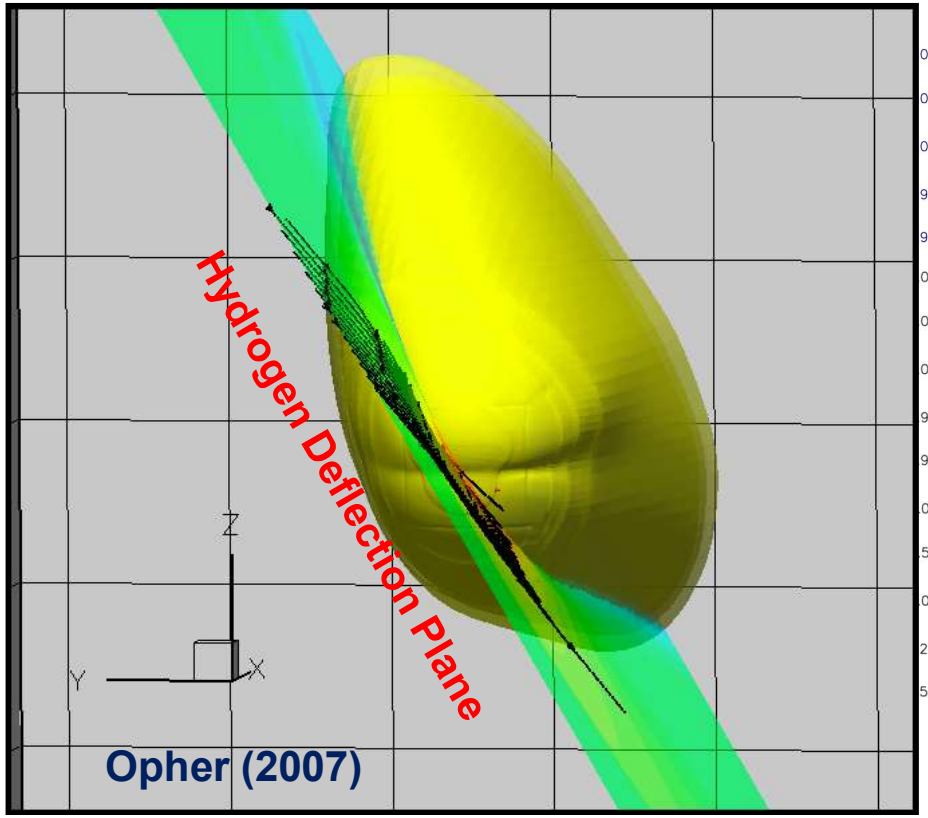




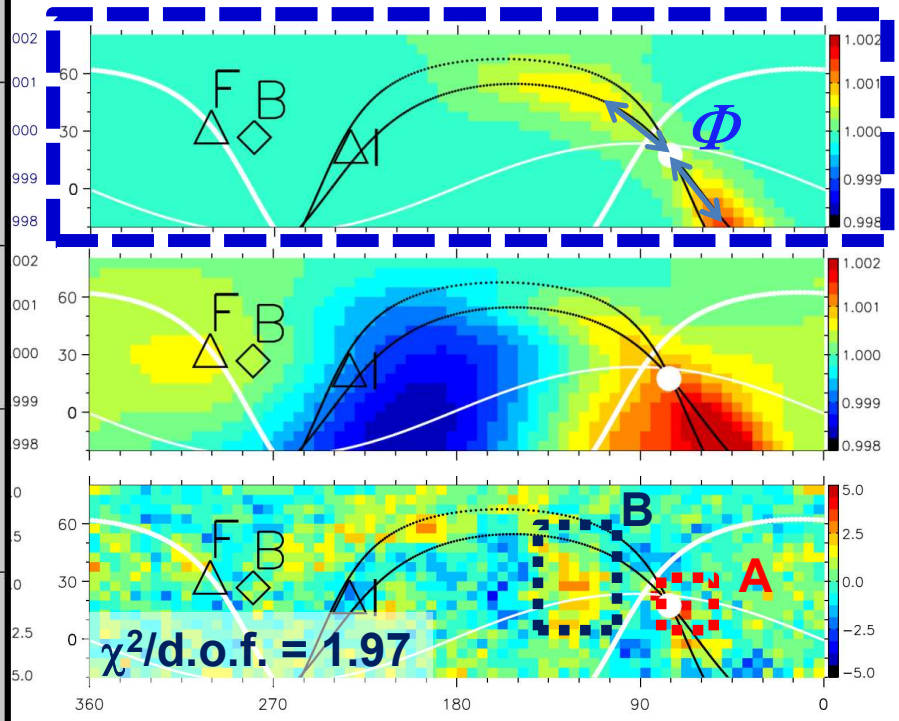
Additional Excess model (heliotail-in anisotropy)

$$\left[b_1 \exp\left\{ -\frac{(\phi_{n,m} - \Phi)^2}{2\sigma_\phi^2} \right\} + b_2 \exp\left\{ -\frac{(\phi_{n,m} + \Phi)^2}{2\sigma_\phi^2} \right\} \right] \exp\left(-\frac{\theta_{n,m}^2}{2\sigma_\theta^2} \right)$$

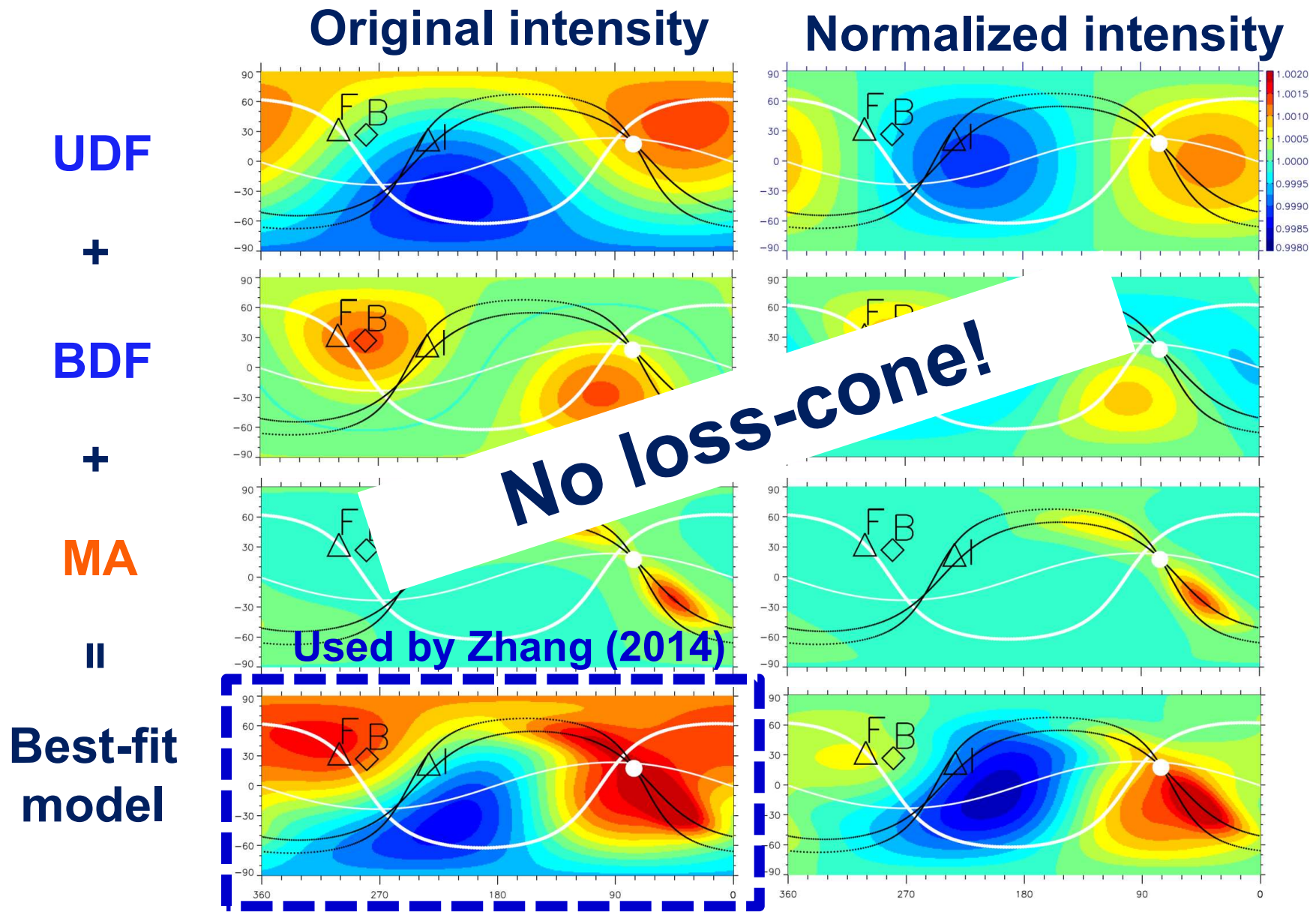
Heliotail-in anisotropy (Nagashima+ 1994) was confirmed for the first time by the best-fit AE aligning the HDP.



Opher (2007)



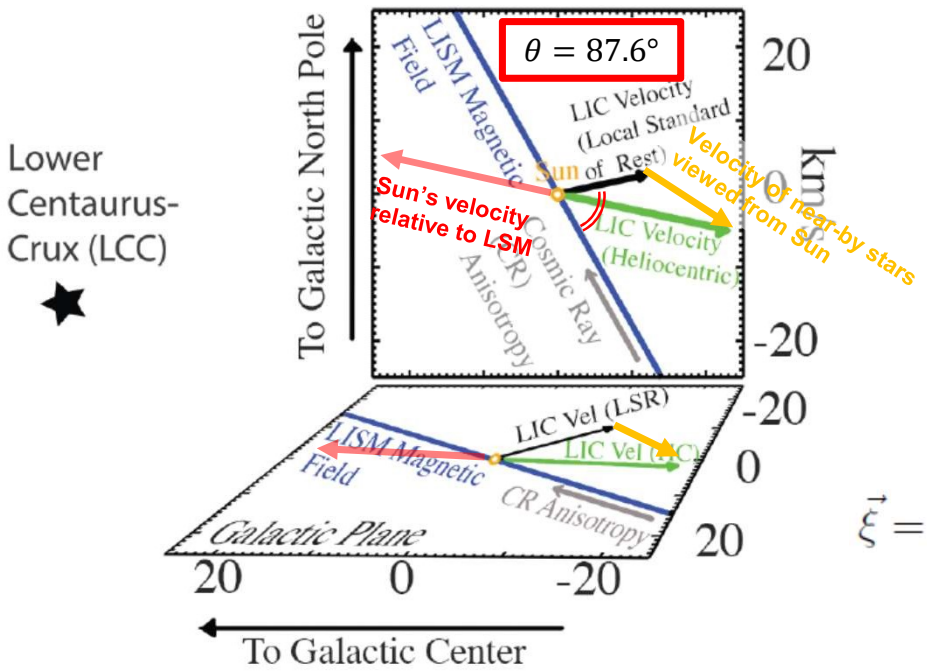
Miraglo "hot" regions A & B
(Abdo et al., PRL, 101, 2008)


Original intensity
Normalized intensity
UDF
+
BDF
+
MA
=
Best-fit model
No loss-cone!
Used by Zhang (2014)
F
B
I
90
60
30
0
-30
-60
-90
360
270
180
90
0
1.0020
1.0015
1.0010
1.0005
1.0000
0.9995
0.9990
0.9985
0.9980

CR diffusion & convection in Loop I superbubble

(Schwadron+, Science 343, 2014)

Local Standard of Rest (LSR)



Diffusion-convection in LSR:

$$\frac{\partial}{\partial x}\left[u_{\rm LSR} f_0 - \kappa \frac{\partial f_0}{\partial x}\right] = 0$$

Force-field solution

$$\rightarrow \quad f_0 \propto \exp\left(\frac{u_{\rm LSR}}{\kappa_{xx}} x\right)$$

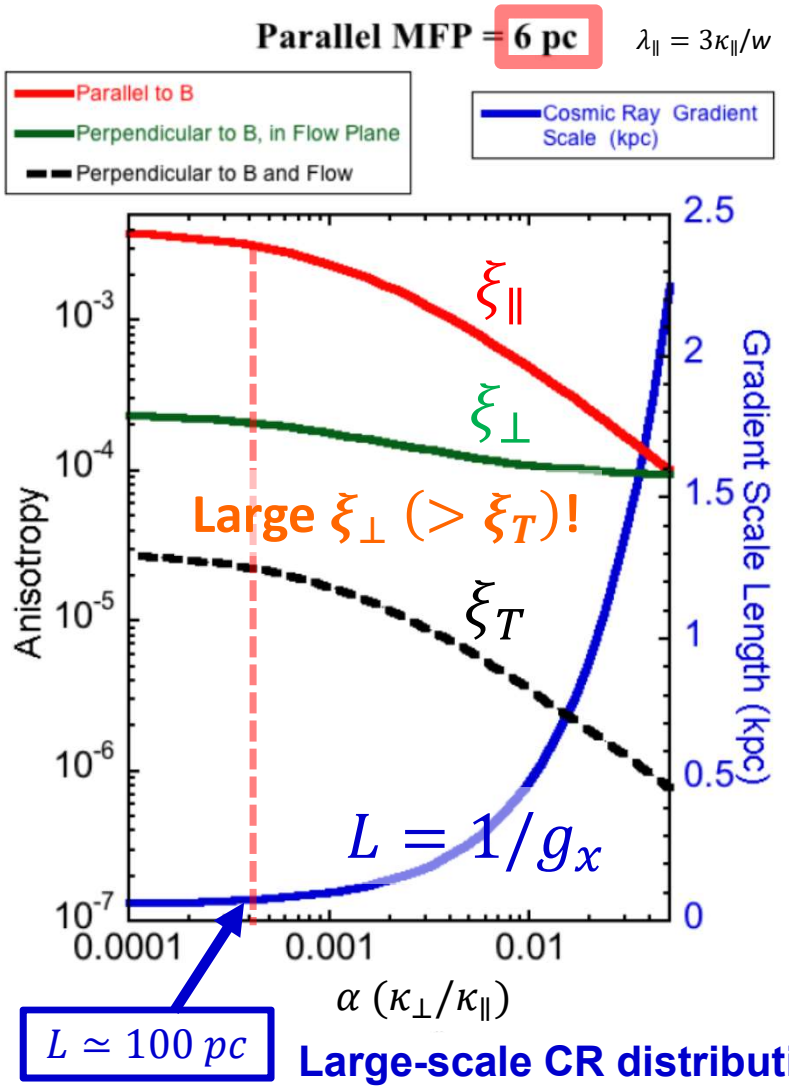
$$: \kappa = \kappa_{xx} = \kappa_{\parallel}\cos^2\theta + \kappa_{\perp}\sin^2\theta, \qquad \boxed{u_{\rm LSR} = 18\ \mathrm{km/s}, \quad \theta = 87.6^\circ}$$

→ **Density gradient:** $g_x = \frac{1}{f_0}\frac{\partial f_0}{\partial x} = \frac{u_{\rm LSR}}{\kappa_{xx}}$

Anisotropy in LSR :

$$\vec{\xi} = \frac{3}{w}\left[C\mathbf{u}_{\rm LSR} - \underbrace{\frac{\kappa_{\parallel}}{\kappa_{xx}} u_{\rm LSR}\cos\theta \hat{b}}_{\kappa_{\parallel} g_x \cos\theta} - \underbrace{\frac{\kappa_{\perp}}{\kappa_{xx}} u_{\rm LSR}\sin\theta \hat{e}_{\perp 1}}_{\kappa_{\perp} g_x \sin\theta} - \underbrace{\frac{\kappa_T}{\kappa_{xx}} u_{\rm LSR}\sin\theta \hat{e}_{\perp 2}}_{\kappa_T g_x \sin\theta}\right]$$

Only uni-directional flow (no bi-directional flow)



Large-scale CR distribution

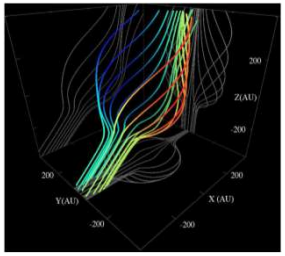
Downfield excess is expected
(2.4° = 90°- 87.6°)

$$\xi_\parallel = -\frac{3}{w}\left[C - \frac{\kappa_\parallel}{\kappa_{xx}}\right] u_{\rm LSR}\cos\theta \qquad \frac{\kappa_\parallel}{\kappa_{xx}} = \frac{1}{\cos^2\theta + \alpha\sin^2\theta}$$

$$\xi_\perp = -\frac{3}{w}\left[C - \frac{\kappa_\perp}{\kappa_{xx}}\right] u_{\rm LSR}\sin\theta \qquad \frac{\kappa_\perp}{\kappa_{xx}} = \frac{\alpha}{\cos^2\theta + \alpha\sin^2\theta}$$

$$\xi_T = -\frac{3}{w}\left[-\frac{\kappa_T}{\kappa_{xx}}\right] u_{\rm LSR}\sin\theta \qquad \frac{\kappa_T}{\kappa_{xx}} = \frac{\frac{1}{3}R_L w/\kappa_\parallel}{\cos^2\theta + \alpha\sin^2\theta} \qquad : \alpha = \kappa_\perp/\kappa_\parallel$$

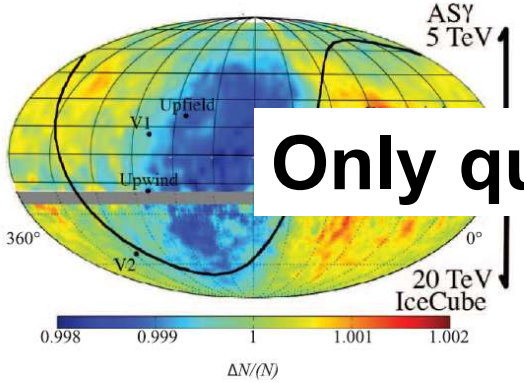
Model local interstellar B_{ISM}



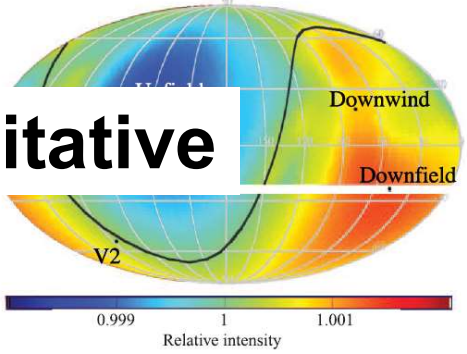
Trace CR orbits in model B_{ISM}

Heliospheric modulation

Observed



Interstellar Conditions from IBEX



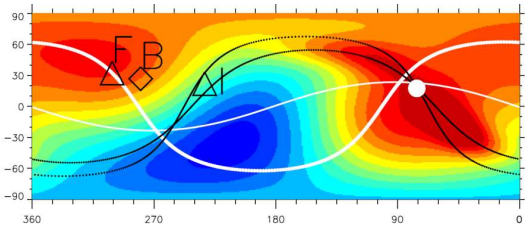
Only qualitative

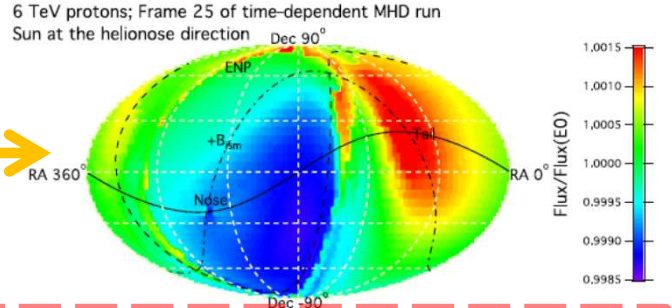
CR modulation in a MHD heliosphere

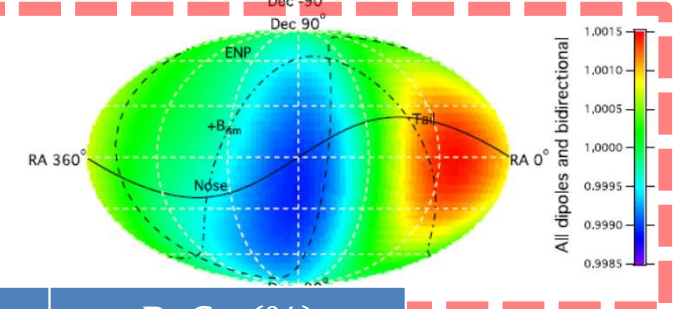
(Zhang+, ApJ 790, 2014)

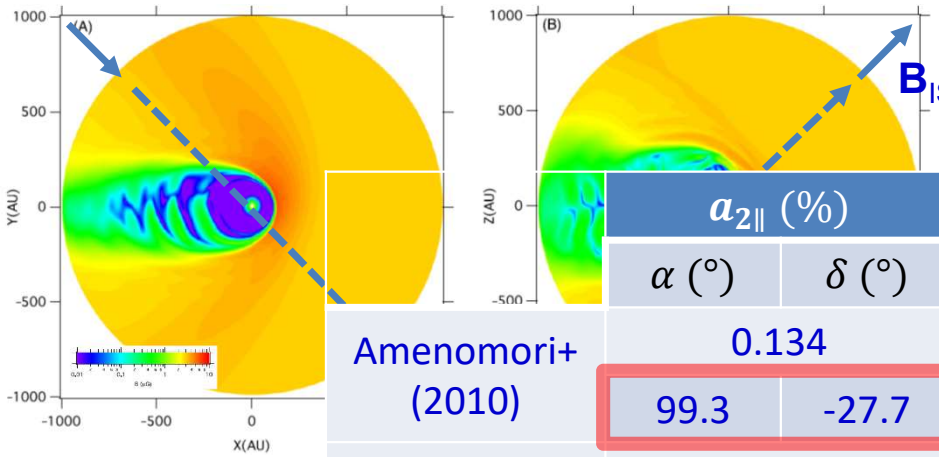
- Apply Liouiville's theorem.
- Trace CR-orbit from Earth to boundary set at 1000 AU.
- Obtain uni- & bi-directional anisotropies outside boundary best reproducing Tibet's GA+AE model 2D map.
- No model/interpretation given for the obtained uni- & bi-directional anisotropies.

Tibet's GA+AE model 2D map





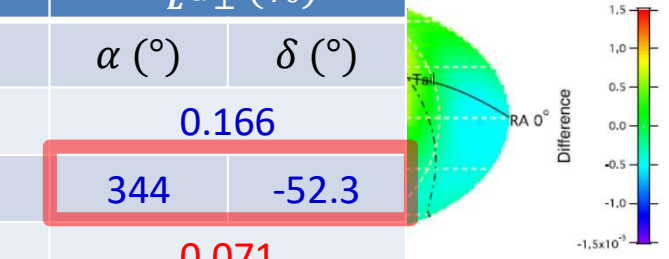




B_{ISM}

Quantitative best-fitting with uni- and bi-directional anisotropies outside the heliosphere

	$a_{2\parallel}$ (%)		$a_{1\parallel}$ (%)		$a_{1\perp}$ (%)		$R_L G_\perp$ (%)	
	α (°)	δ (°)	—	—	α (°)	δ (°)	α (°)	δ (°)
Amenomori+ (2010)	0.134		0.038		0.166		0.166	
	99.3	-27.7	—	—	34.3	39.3	344	-52.3
Zhang+ (2014)	0.051		0.121		0.071		0.071	
	245	9	fixed	—	343	43	144	46



Time-de
(with

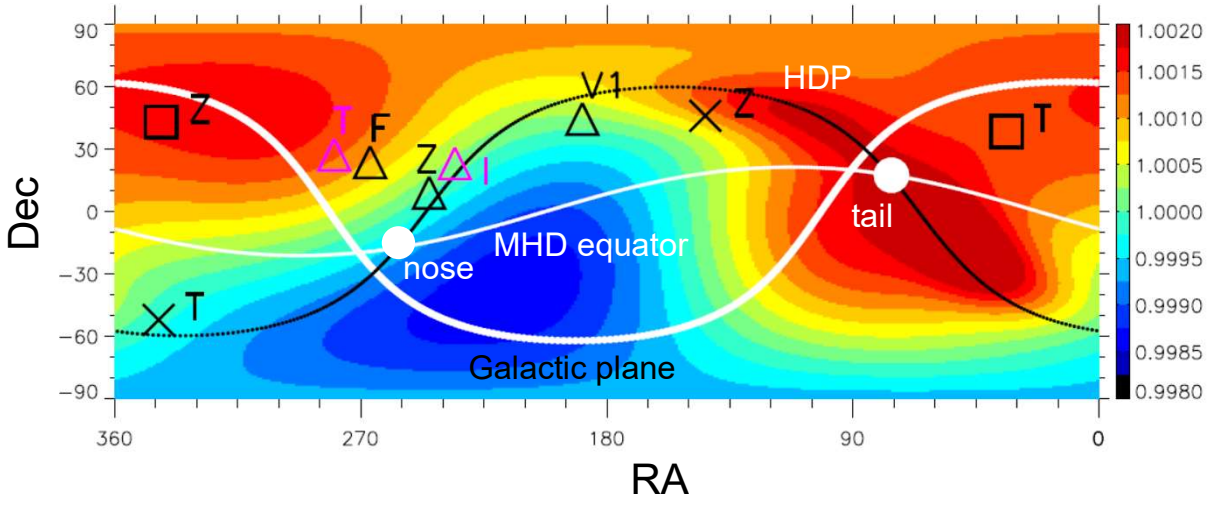
from Equation (14) with best superposition of dipoles and ıt heliospheric influence, and ldle maps.

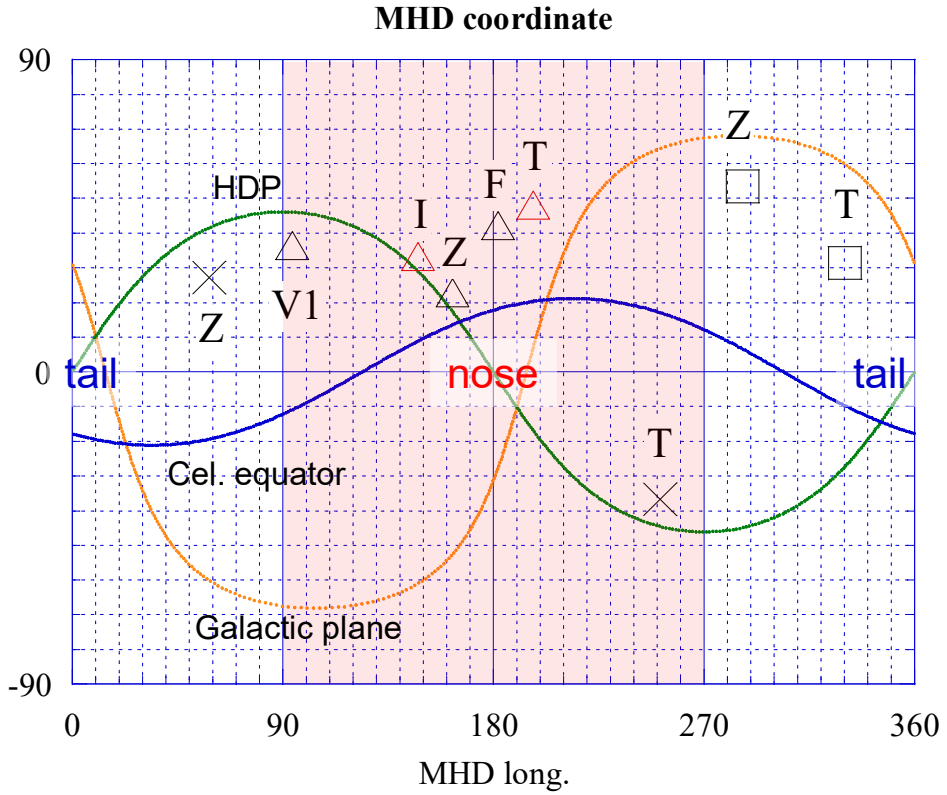
Summary of orientations

△ : **B** toward
△ : **B** from
□ : $\xi_\perp$
╳ : $g_\perp$

T: Tibet
Z: Zhang+

I: IBEX
F: Frisch+
V1: Voyager 1





E-dependence (1st harmonics in 1D plot)

Amenomori+ 2015