Self-Consistent MHD Simulations of the Local ISM

Synthetic Polarized Dust Emission

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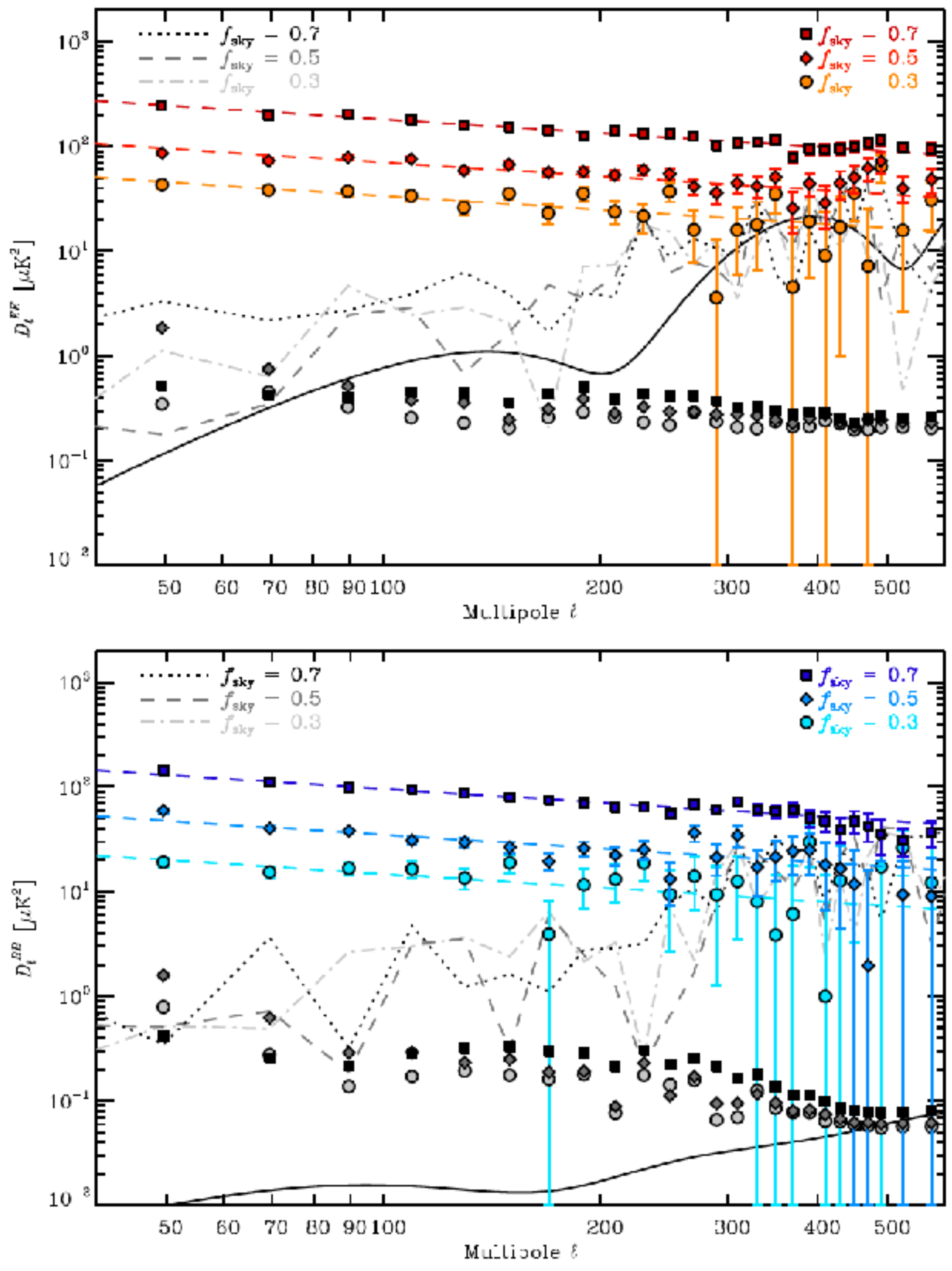
EE/BB ~ 2;TE>0

PIP XXX (2016)



Is this observation consistent with MHD turbulence?

Is this general property of the diffuse ISM?

What physical conditions do we need to model?

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MHD simulations

	Global	Local periodic box
System Size	~10-100kpc	<< H
Spatial Resolution	10-100pc	sub-pc
well-resolved/ self-consistently treated physics	large-scale B-field galactic rotation global geometry spiral arms and bars	turb. cascade (inertial range) turbulent dynamo
marginally resolved physics	turbulence driver dynamo	turbulence dissipation scale multiphase ISM
unresolved physics	turb. cascade/dissipation gas cooling/heating	turbulence injection scale large-scale B-field large-scale variation

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sonic Mach number v_{turb}/c_s
Alfven Mach number v_{turb}/v_A
plasma beta P_{th}/P_{mag}

MHD simulations

	Global	Local stratified box	Local periodic box
System Size	~10-100kpc	<< R	<H
Spatial Resolution	10-100pc	a few pc	sub-pc
well-resolved/ self-consistently treated physics	large-scale B-field galactic rotation global geometry spiral arms and bars	turbulence driver multiphase ISM vertical stratification	turb. cascade (inertial range) turbulent dynamo
marginally resolved physics	turbulence driver dynamo	turbulence cascade (inertial range) galactic differential rotation dynamo	turbulence dissipation scale multiphase ISM
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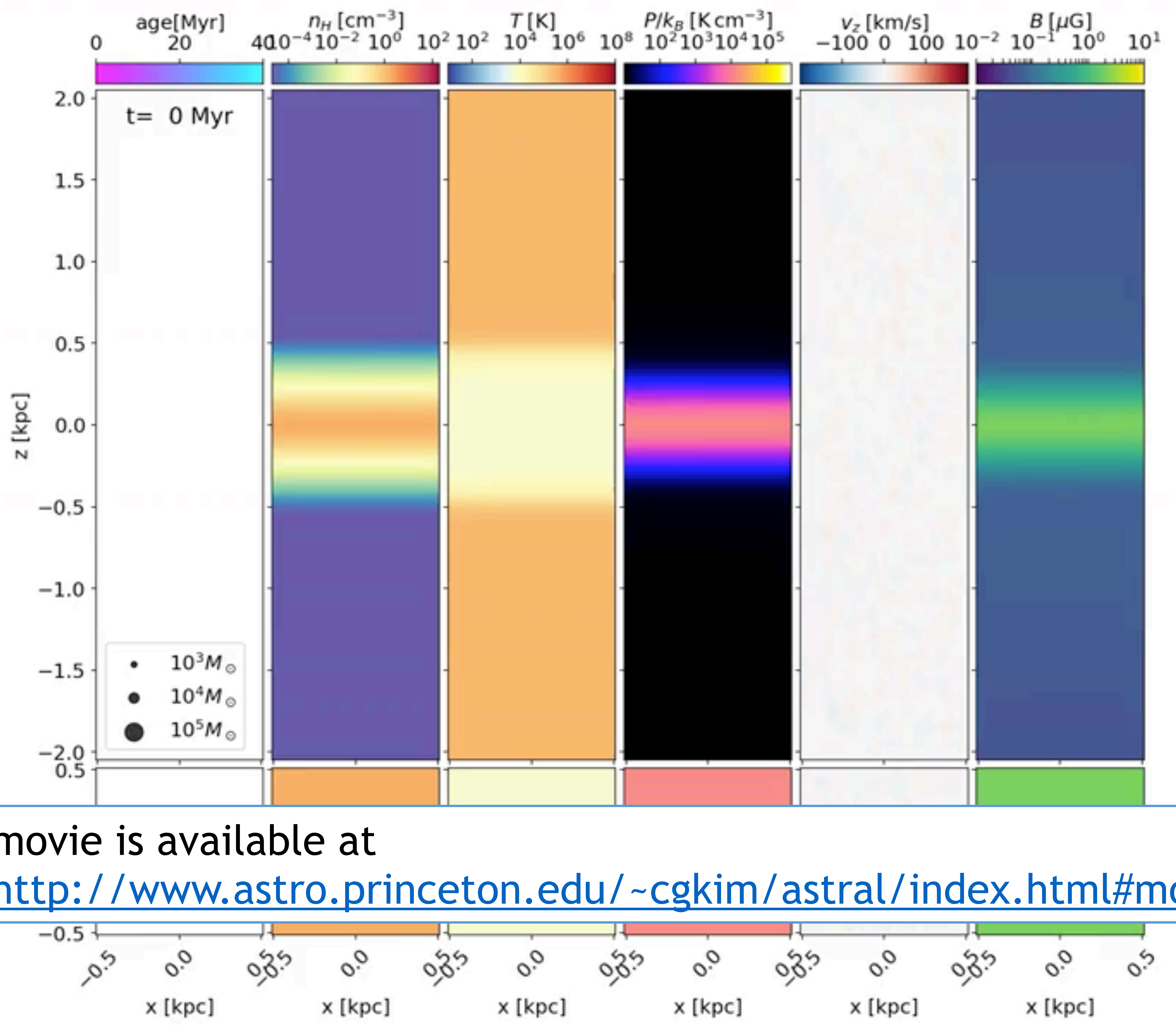
MHD simulations

Kim & Ostriker 2017

	TIGRESS **Three-phase ISM in Galaxies Resolving Evolution with Star formation and Supernova feedback**
System Size	1x1x(2-8) kpc
Spatial Resolution	(2, 4, 8) pc
well-resolved/ self-consistently treated physics	**turbulence driver** **(star formation — SN)** multiphase ISM vertical stratification
marginally resolved physics	turbulence cascade (inertial range) galactic differential rotation **mean-field + turbulent dynamo**
unresolved physics	turbulence dissipation global geometry

Self-Regulation of key physical properties

Kim & Ostriker 2017



movie is available at
http://www.astro.princeton.edu/~cgkim/astral/index.html#movie

TIGRESS

Three-phase ISM in Galaxies Resolving Evolution with Star formation and Supernova feedback

1x1x(2-8) kpc

(2, 4, 8) pc

turbulence driver
(star formation — SN)
multiphase ISM
vertical stratification

turbulence cascade (inertial range)
galactic differential rotation
mean-field + turbulent dynamo

turbulence dissipation
global geometry

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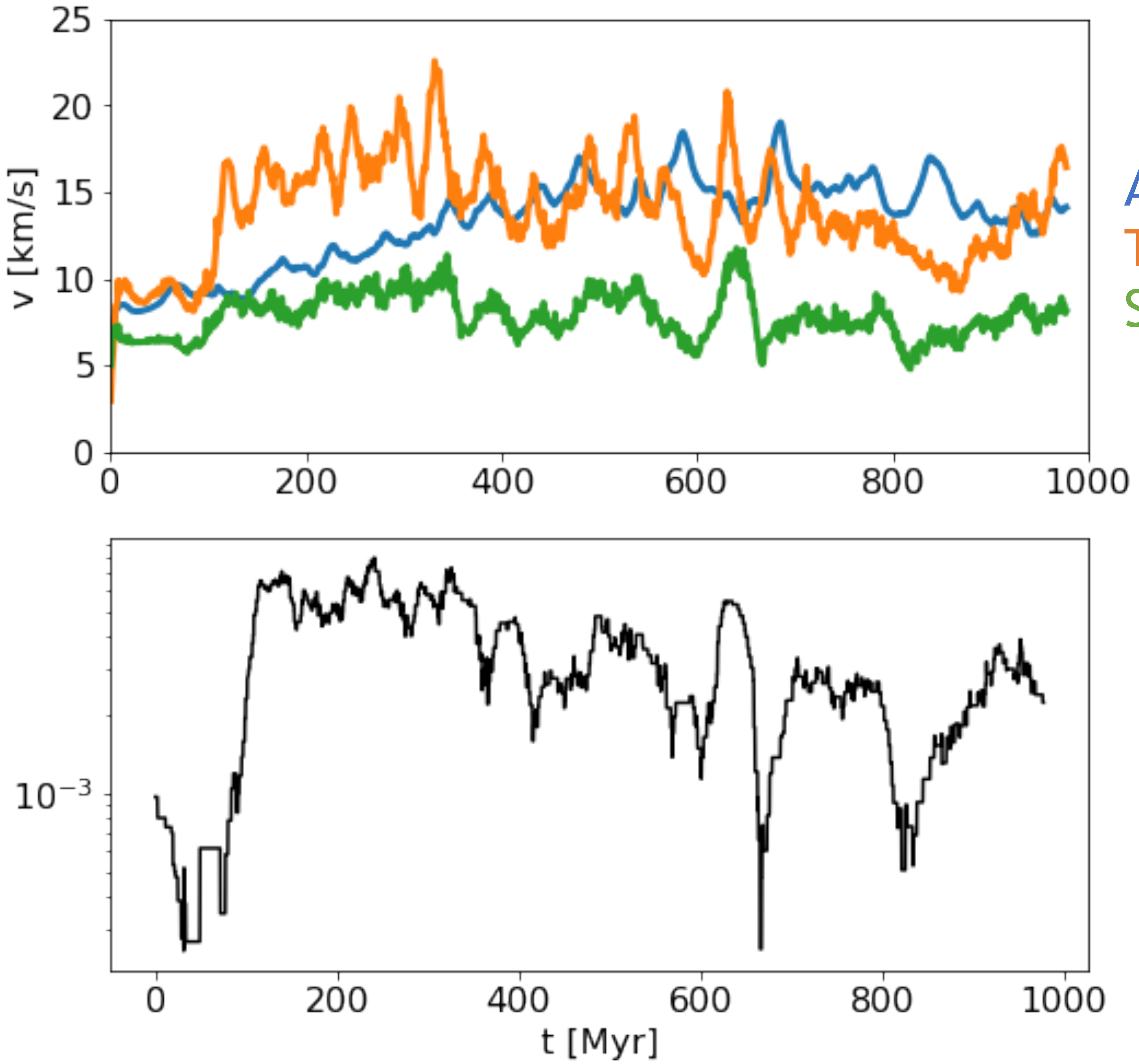
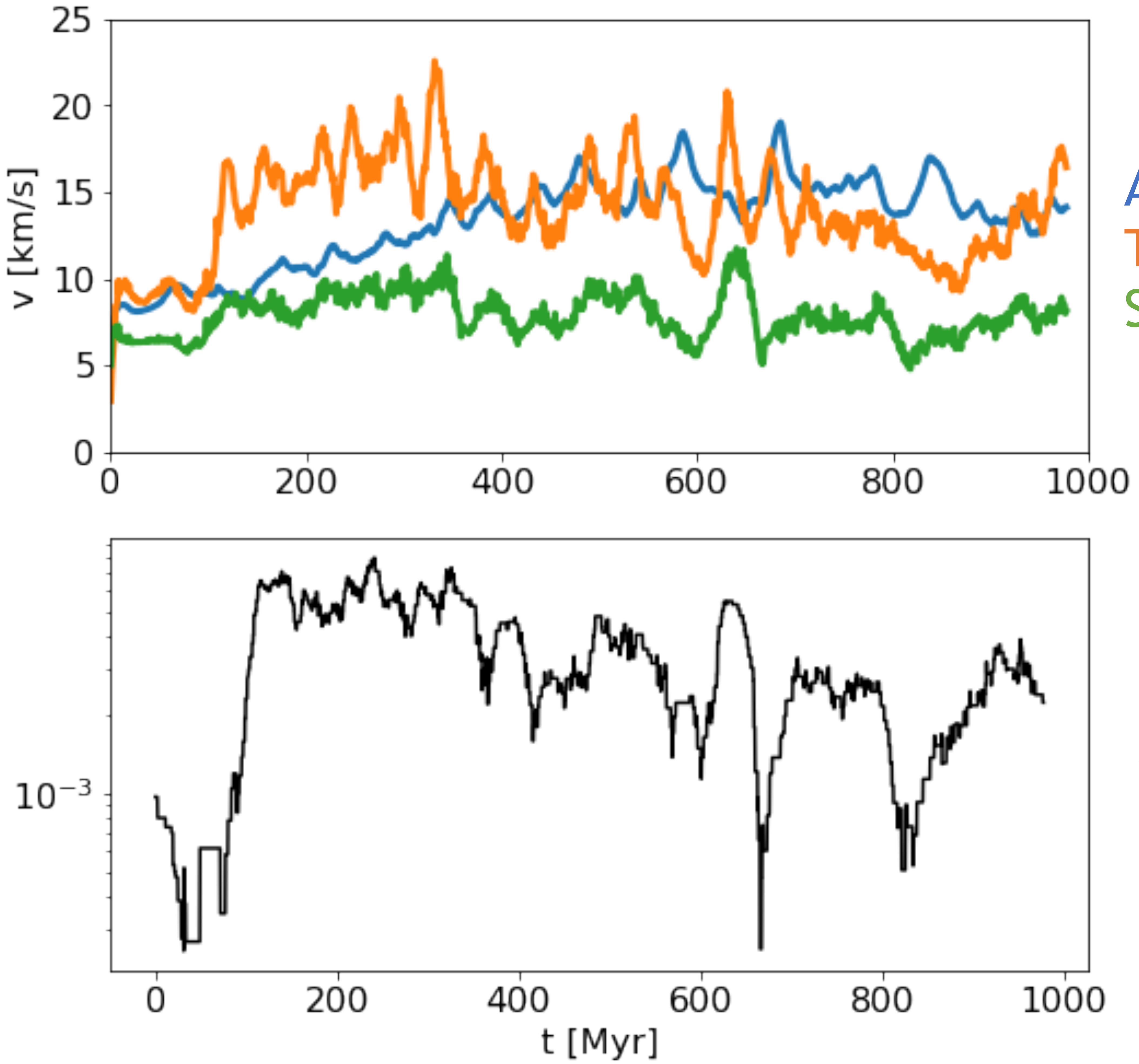
Self-Regulation of key physical properties



Alfven Velocity
Turbulent Velocity
Sound Speed

Σ_{SFR}
$M_{sun}/kpc^2/yr$

Self-Regulation of key physical properties



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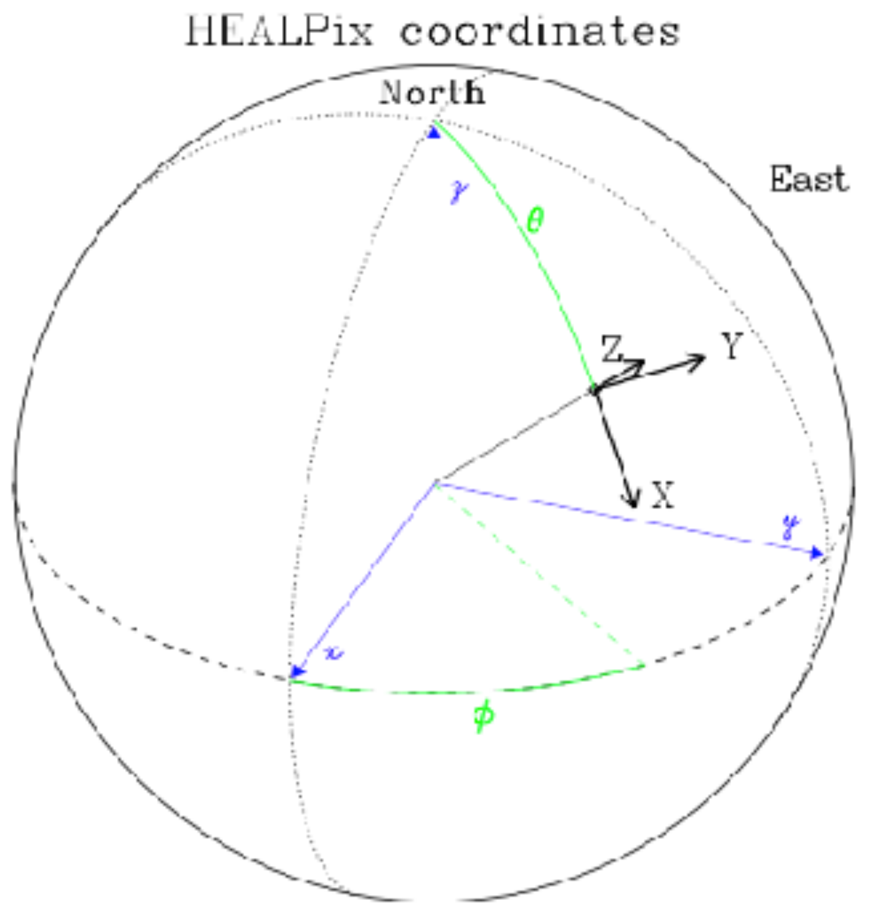
3D data cube (ρ, v, B, P)



LOS data

Projection
Radiative transfer (LOS integration)

Polarized Dust map

all data will be available soon!

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EE/BB ~ 2; TE>0

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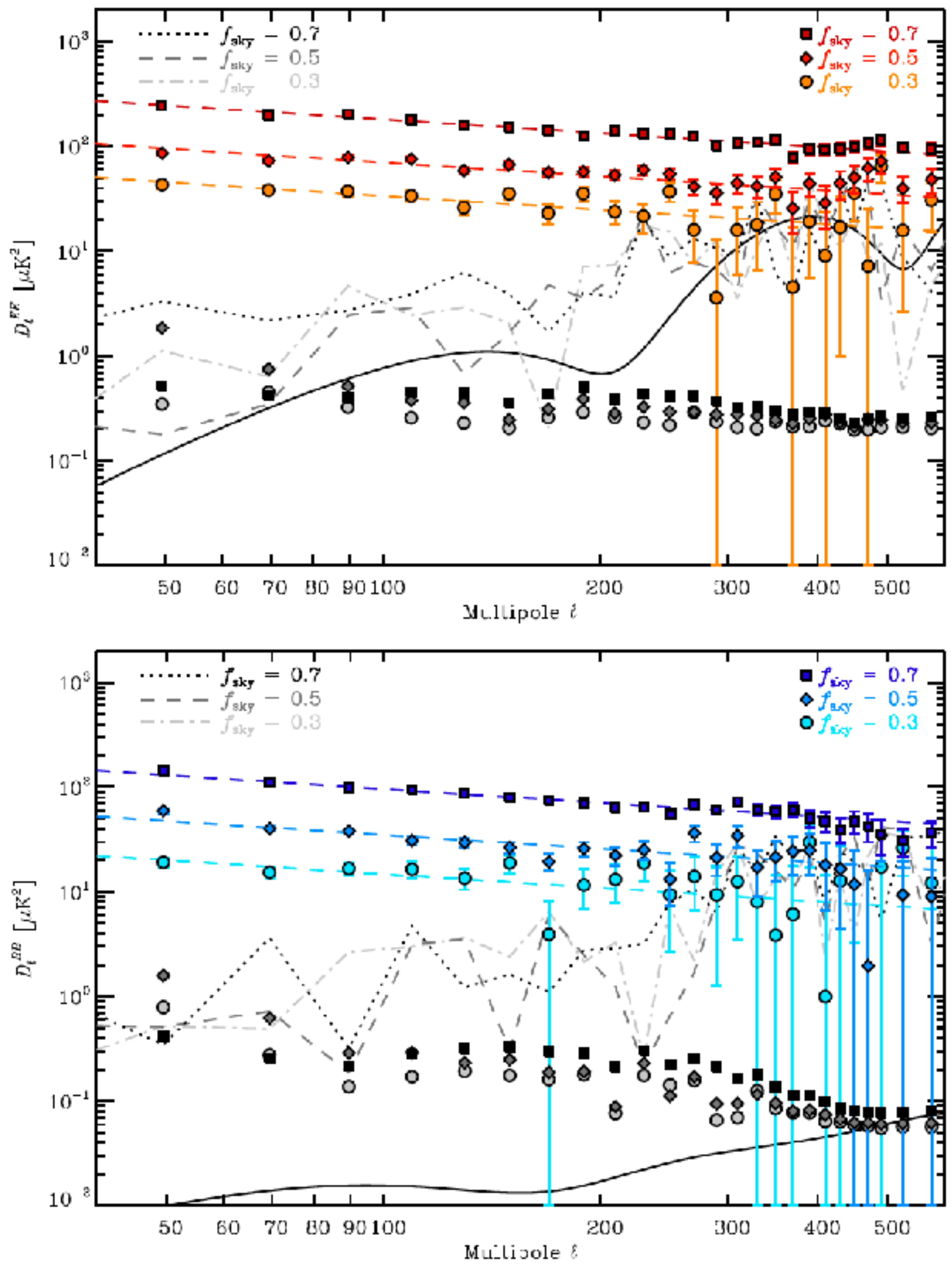
Is your simulation consistent with the observation?

Does your ISM always look like this?

What conditions do you need?



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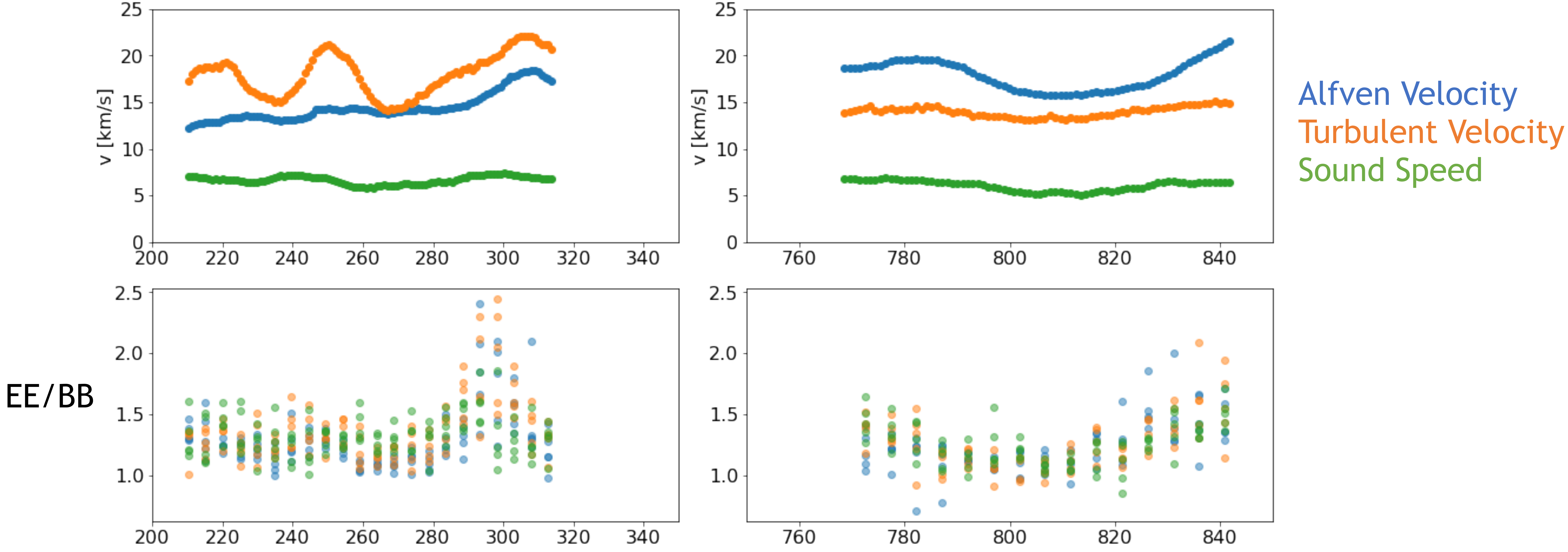
Is your simulation consistent with the observation?

Yes! Not perfect, but consistent.

Does your ISM always look like this? No!



In fact, EE/BB>1 is common, but EE/BB~2 is not common in our simulation. Within the same realization, synthetic polarization maps can be very different (mask, observer's position).

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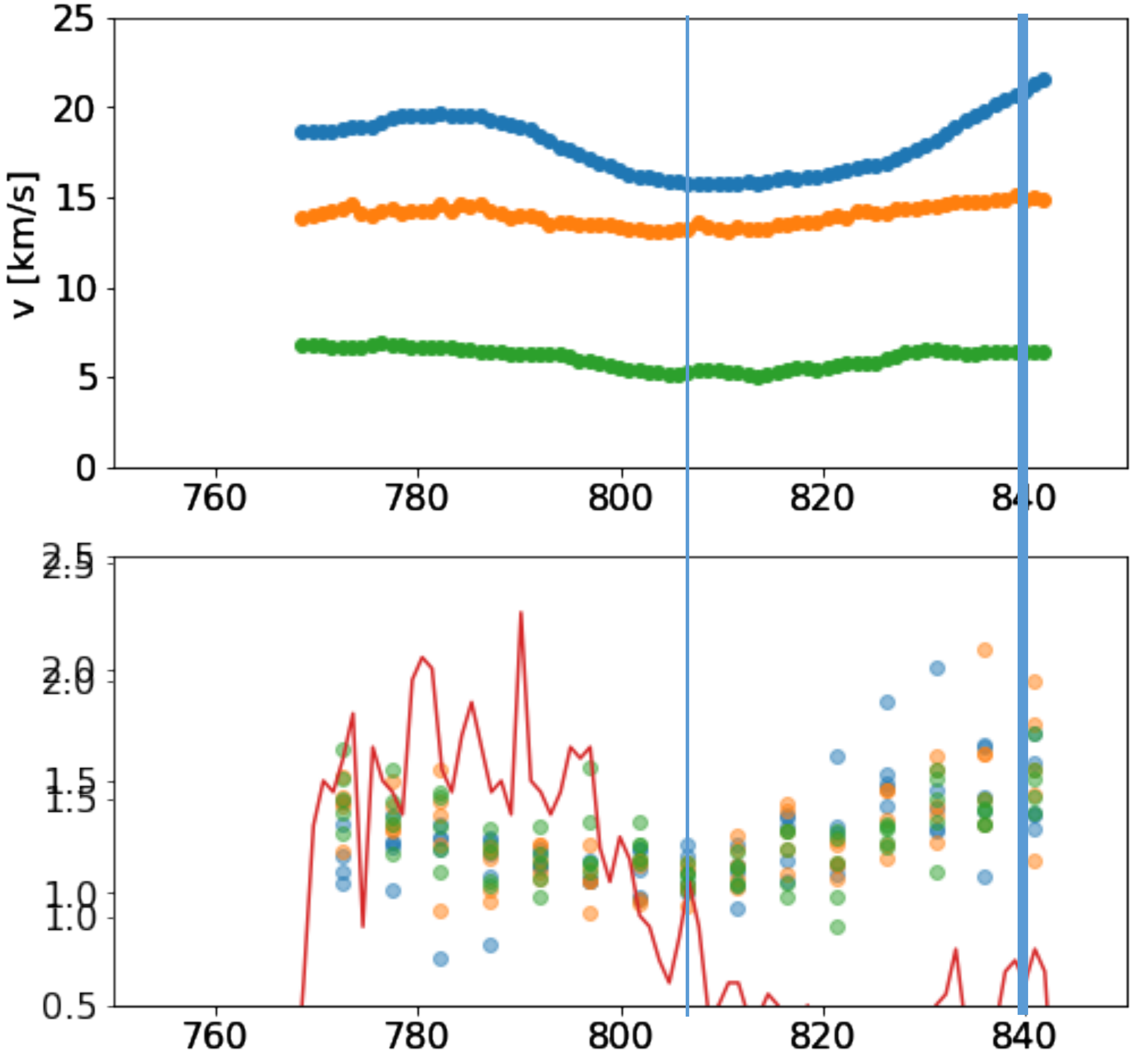
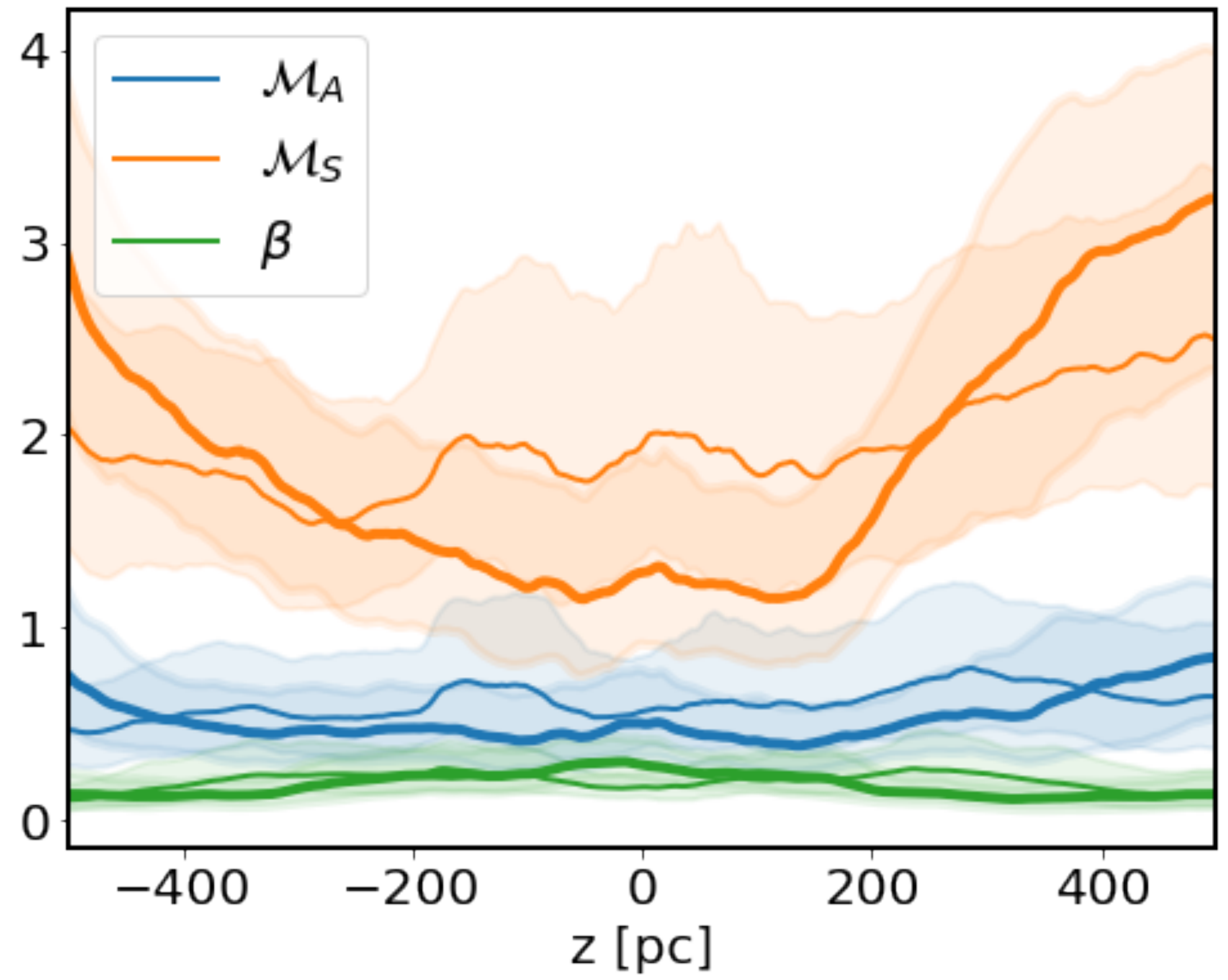
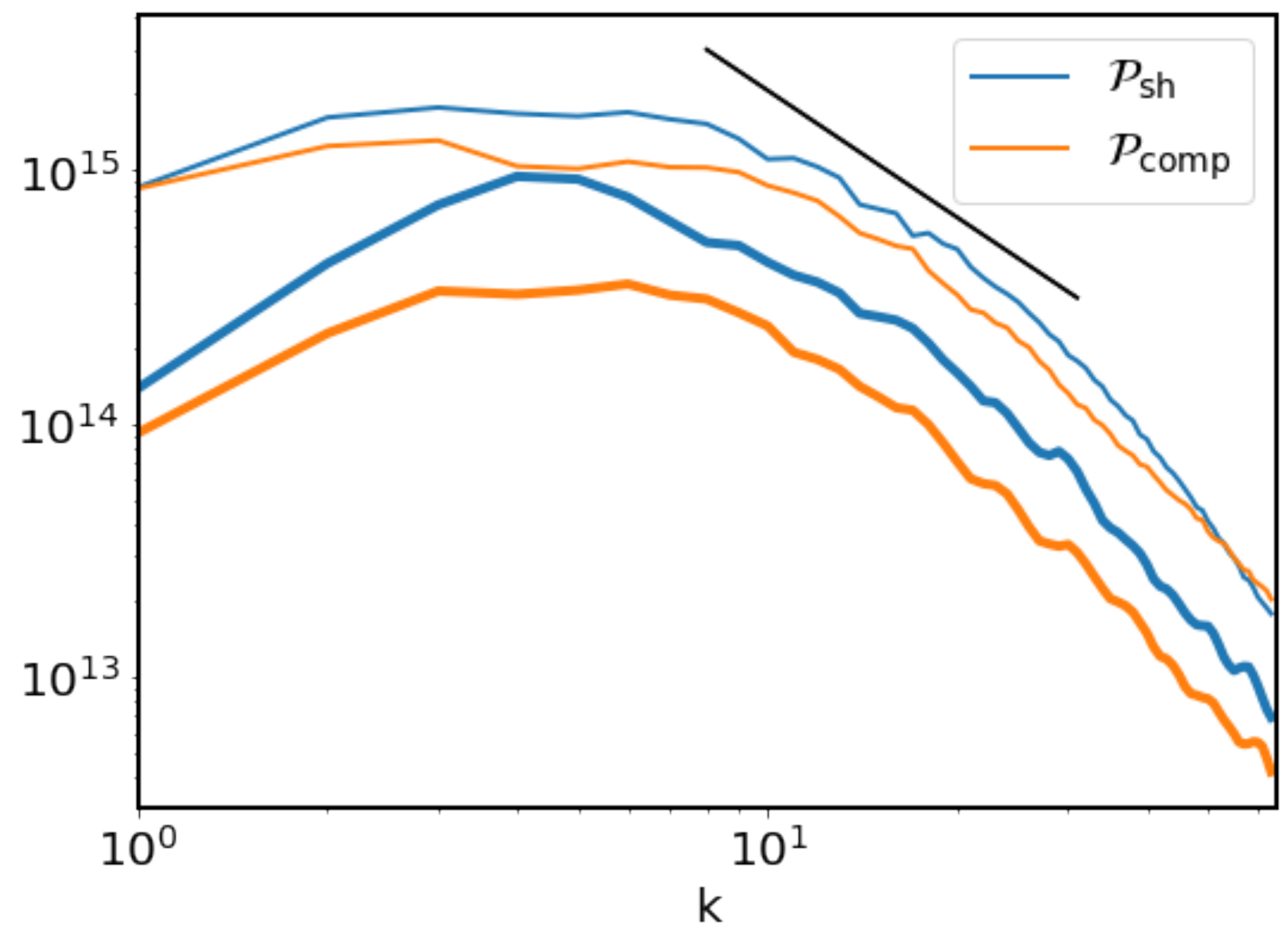
What conditions do you need?

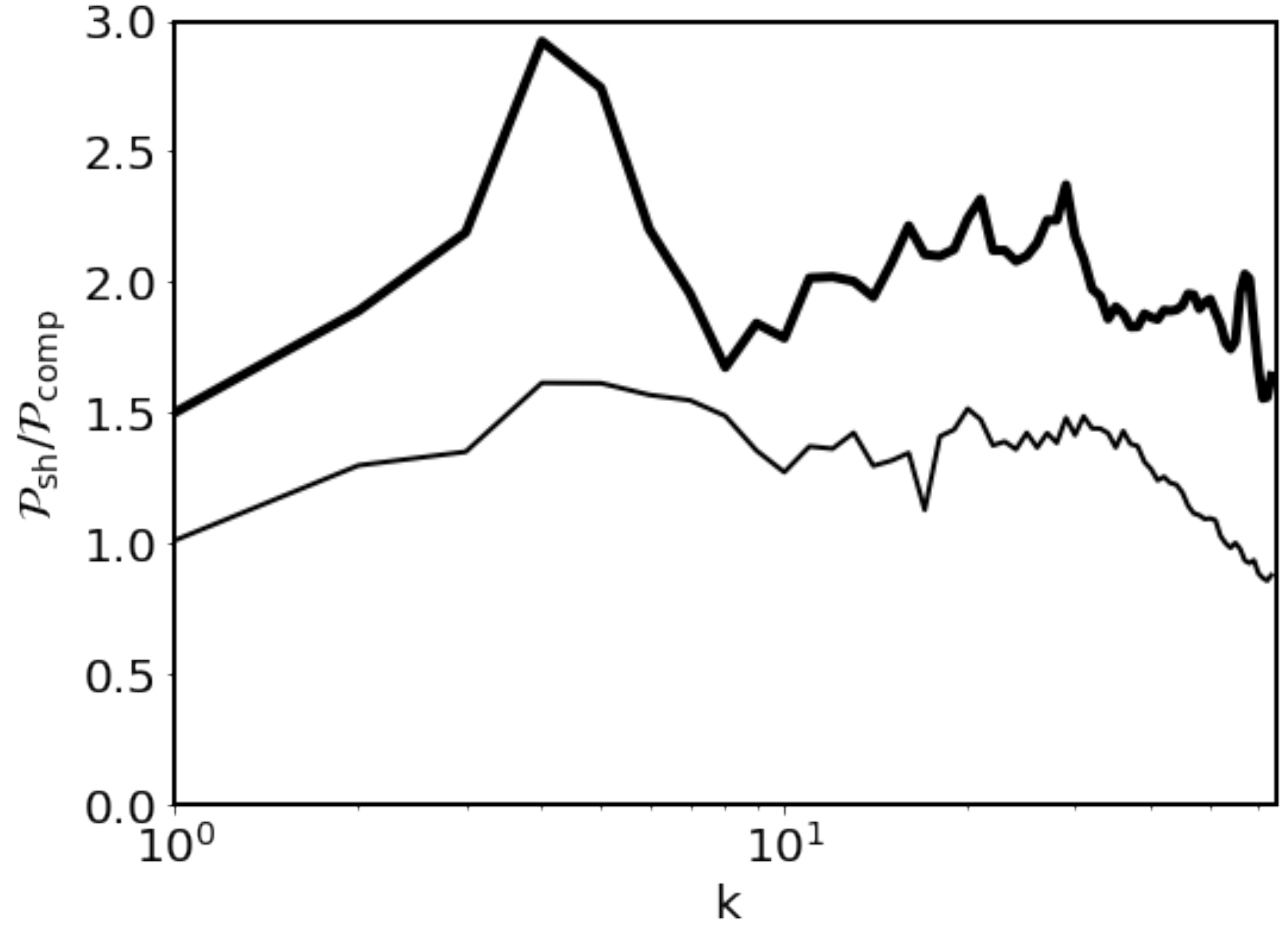
Well, I don't know yet. But, there are some hints!

EE/BB









$$v^2_{\rm shear}(\boldsymbol{k}) = |\hat{k} \times \boldsymbol{v}(\boldsymbol{k})|^2,$$

$$v^2_{\rm comp}(\boldsymbol{k}) = |\hat{k} \cdot \boldsymbol{v}(\boldsymbol{k})|^2.$$

- sub-Alfvenic turbulence does not guarantee high EE/BB-ratio
- Intermittency is important!

SN explosions — turbulence driving (mostly compressive) — generate shear component (colliding shells, background shear)

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EE/BB ~ 2;TE>0

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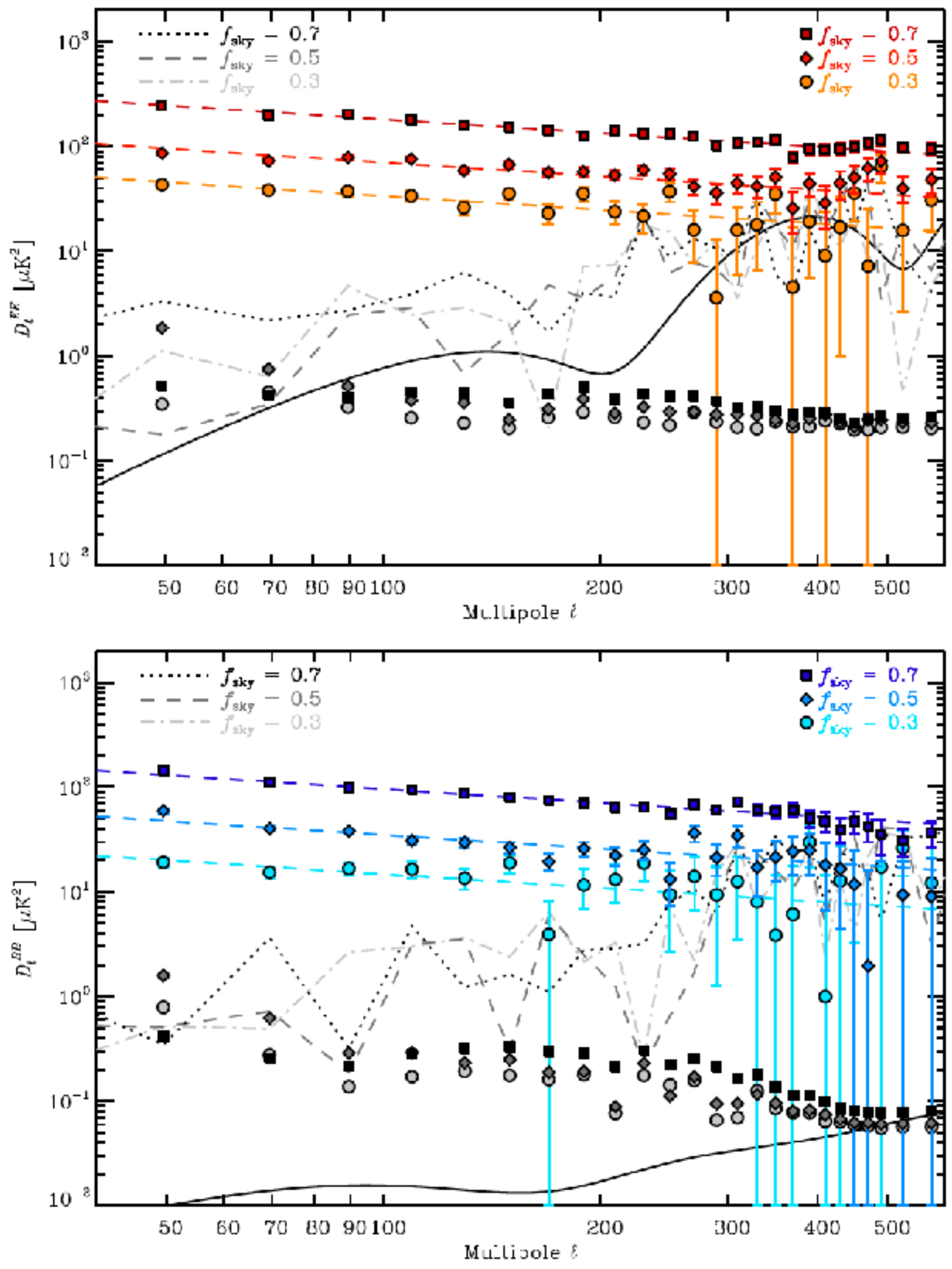
Yes! Not perfect, but consistent.

Does your ISM always look like this?

No! EE/BB>1, but EE/BB~2 is rare. TE is positive.

What conditions do you need?

Well, I don’t know yet. But, there are some hints!



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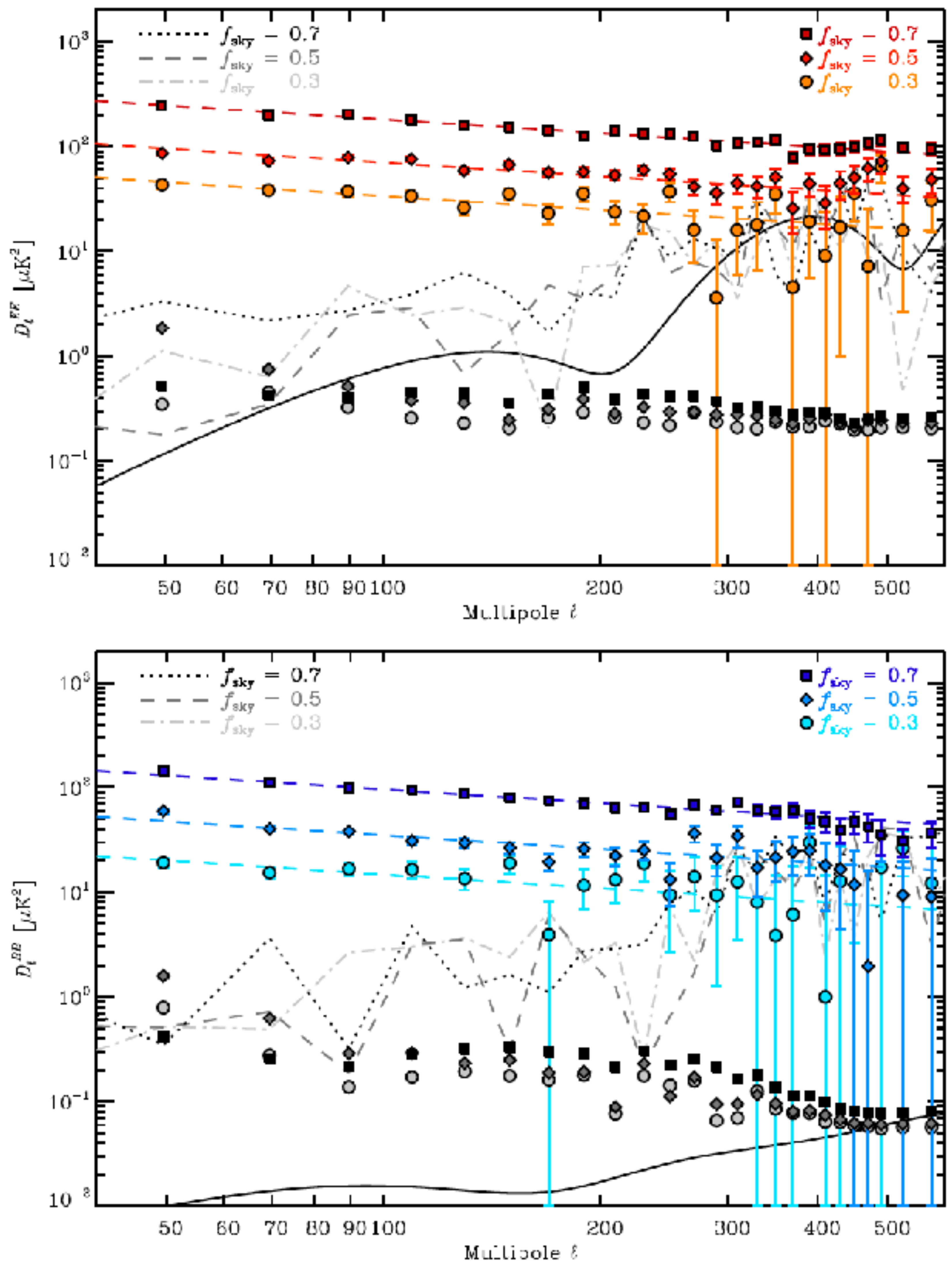
Physical explanation? Implication?

- Further analysis is necessary: sh/comp, fast/slow/Alfven
- Maybe, we are sitting in the local bubble created by recent SN feedback events and looking at the ISM in a somewhat relaxed period.
- Intermittency!



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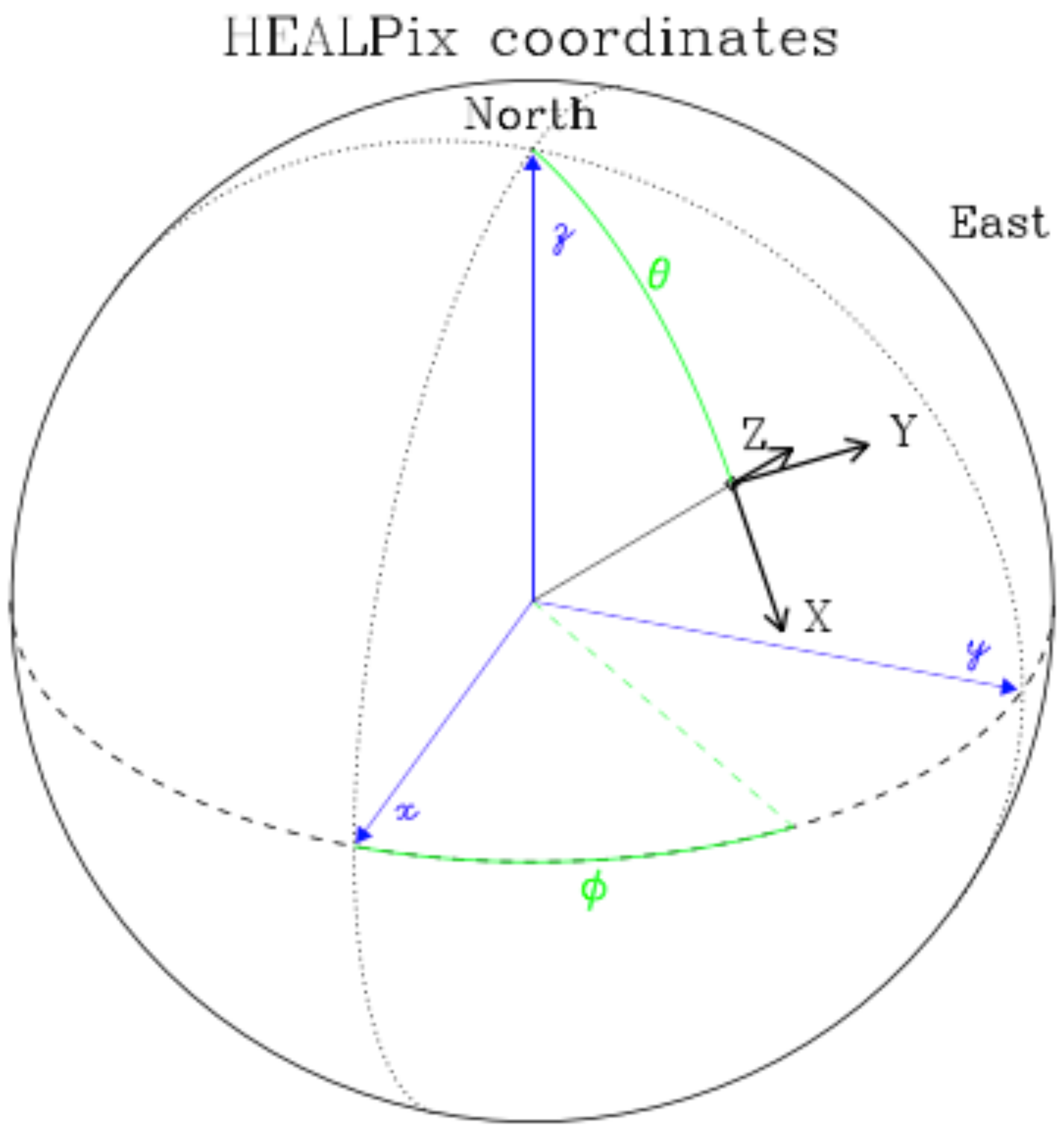
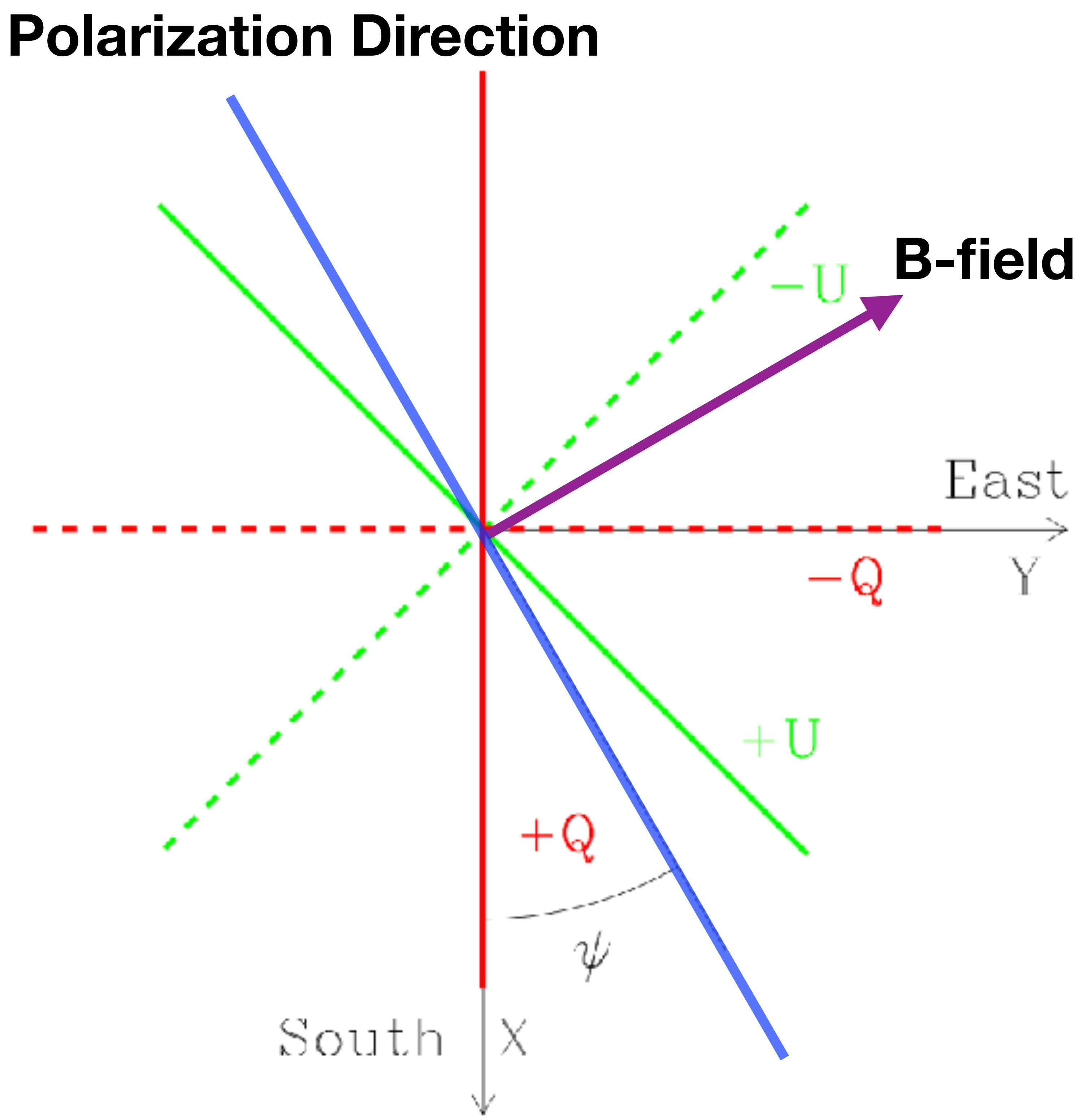


$$Z = \sin\theta\cos\varphi\,\hat{\mathbf{x}} + \sin\theta\sin\varphi\,\hat{\mathbf{y}} + \cos\theta\,\hat{\mathbf{z}}$$

$$X = \cos\theta\cos\varphi\,\hat{\mathbf{x}} + \cos\theta\sin\varphi\,\hat{\mathbf{y}} - \sin\theta\,\hat{\mathbf{z}}$$

$$Y = -\sin\varphi\,\hat{\mathbf{x}} + \cos\varphi\,\hat{\mathbf{y}}$$



$B_{perp}^2 = B_X^2 + B_Y^2$

$B_{los} = B_Z$

$\cos\gamma = B_{perp}/B$

$\cos\phi = B_Y/B_{perp}$

$\cos 2\phi = (B_Y^2 - B_X^2)/B_{perp}^2$

$\sin 2\phi = -2 B_X B_Y / B_{perp}^2$

$\nu = 353\,\mathrm{GHz}$

$S_\nu = B_\nu(T_d)$ and $T_d = 18\,\mathrm{K}$

$p_0 = 0.2$

$d\tau_\nu = \sigma_{353} n_H dr$

$\sigma_{353} = 1.2\times10^{-26}\,\mathrm{cm}^2$

$$I = \int S_\nu e^{-\tau_\nu}\left[1 - p_0\left(\cos^2\gamma - \frac{2}{3}\right)\right] d\tau_\nu;$$

$$Q = \int p_0 S_\nu e^{-\tau_\nu}\cos(2\phi)\cos^2\gamma\, d\tau_\nu;$$

$$U = \int p_0 S_\nu e^{-\tau_\nu}\sin(2\phi)\cos^2\gamma\, d\tau_\nu.$$