Studies of the ISM magnetic field from anisotropies in synthetic PPV cubes

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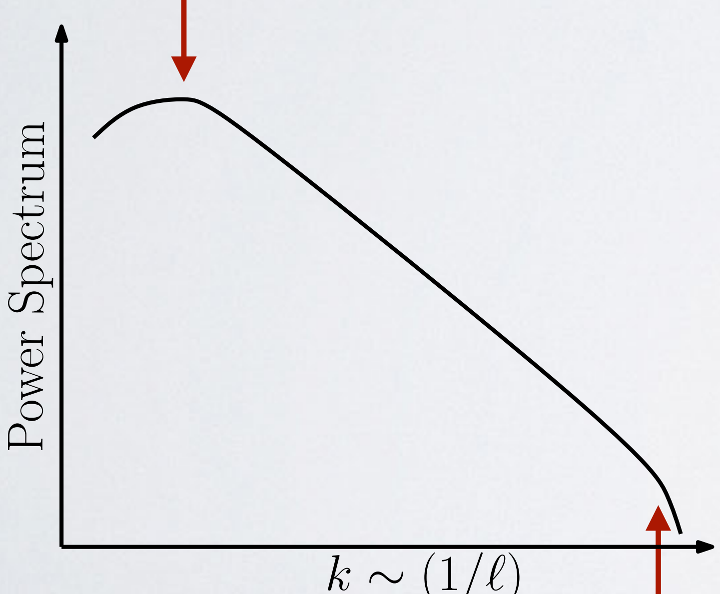
Anisotropic Turbulence

At large scales

$$\ell_{\text{inj}} = \ell_{\perp} = \ell_{\|}$$

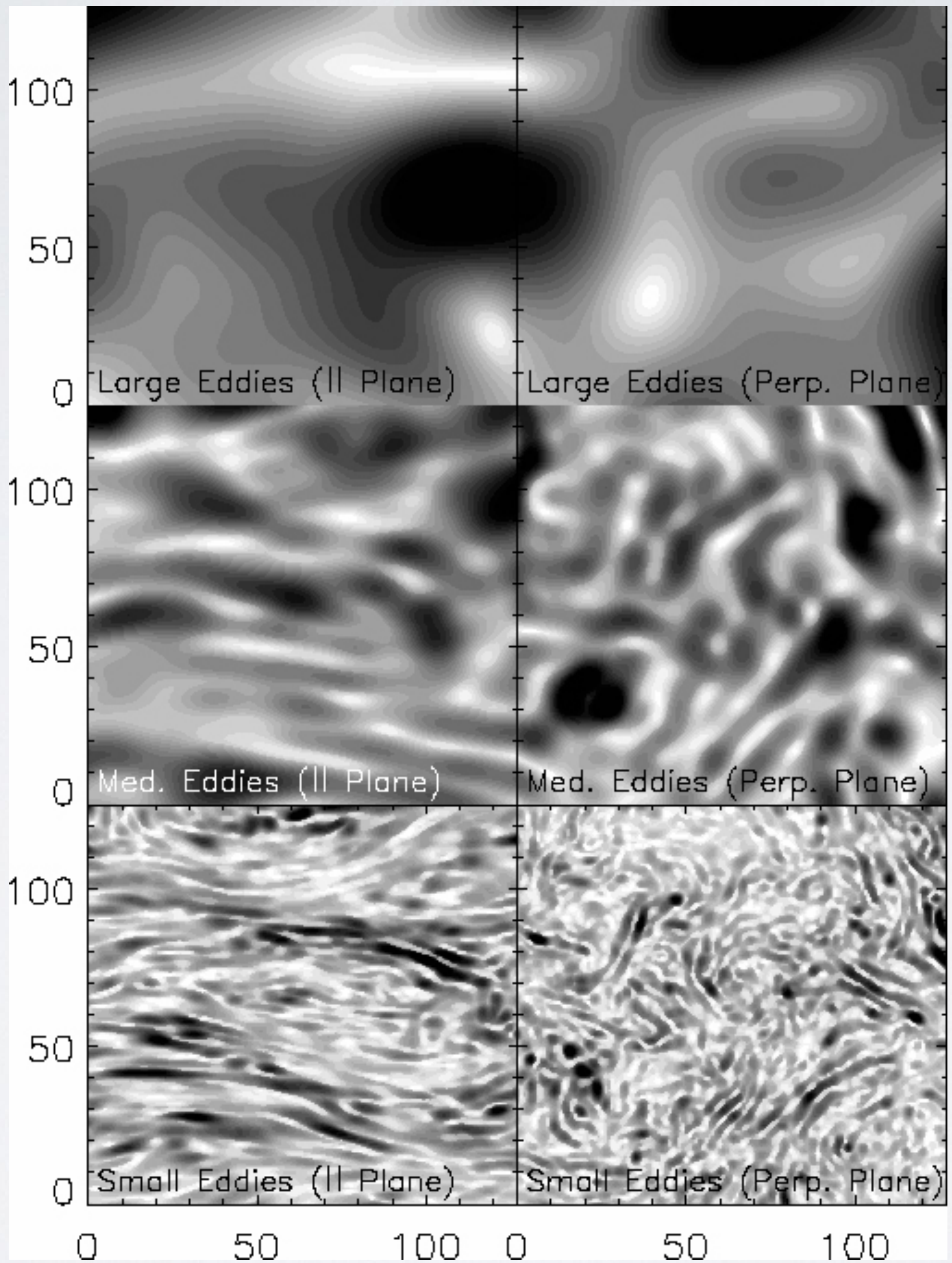
Turbulence becomes anisotropic down the cascade

injection scale(s)

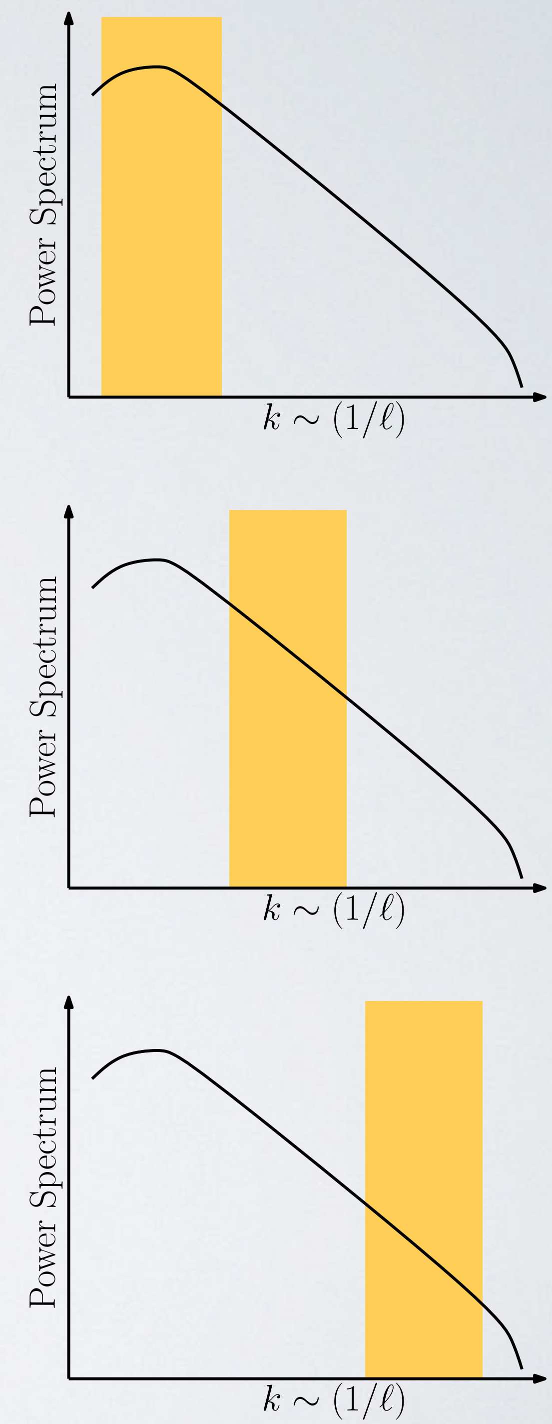


dissipation scale

Magnetic Field Intensity



(Cho, Lazarian & Vishniac, 2002)



Grid of MHD models

- Ideal 3D MHD simulations of fully developed (driven) turbulence
- Isothermal, in a periodic Cartesian grid.
- The parameters that control the simulations are the sonic, and the Alfvén Mach numbers.

$$M_{\rm s} \equiv \frac{v_{\rm L}}{c_{\rm s}}; \quad M_{\rm A} = \frac{v_{\rm L}}{v_{\rm A}}$$

$$c_{\rm s} = \sqrt{\frac{P}{\rho}}; \quad v_{\rm A} = \frac{B}{\sqrt{4\pi\,\rho}}$$

- We take the output of the simulations to create synthetic PPV data cubes, and we measure the anisotropy in velocity channels with different resolutions.
- Similar set of simulations as in Burkhart et al. 2014.
- These results are (will be) in Esquivel, Lazarian & Pogosyan 2015.

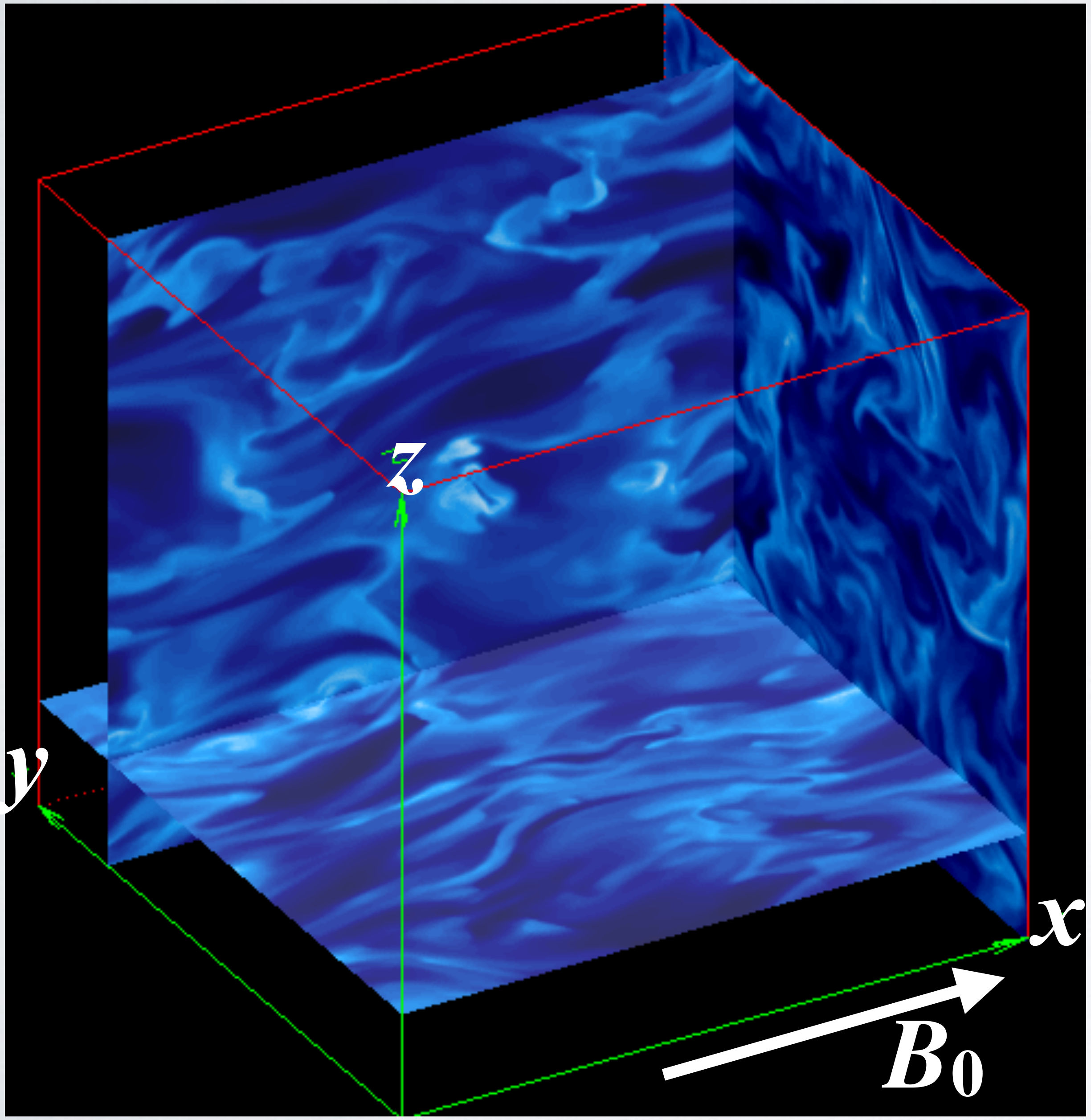
Table 1. Parameters of the MHD simulations.

Model	$v_{\rm A,0}$	$P_{\rm gas,0}$	$\mathcal{M}_{\rm s}$	$\mathcal{M}_{\rm A}$	Resolution
M1	0.1	0.025	~ 4.7	~ 7.4	512^3
M2	0.1	0.050	~ 3.4	~ 7.6	512^3
M3	0.1	0.100	~ 2.6	~ 8.2	512^3
M4	0.1	0.700	~ 0.9	~ 7.6	512^3
M5	0.1	1.000	~ 0.8	~ 7.8	512^3
M6	0.1	2.000	~ 0.5	~ 7.0	512^3
M7	1.0	0.0049	~ 10.8	~ 0.8	512^3
M8	1.0	0.0077	~ 8.6	~ 0.8	512^3
M9	1.0	0.010	~ 7.4	~ 0.7	512^3
M10	1.0	0.025	~ 4.8	~ 0.8	512^3
M11	1.0	0.050	~ 3.4	~ 0.8	512^3
M12	1.0	0.100	~ 2.7	~ 0.8	512^3
M13	1.0	0.700	~ 1.0	~ 0.8	512^3
M14	1.0	1.000	~ 0.7	~ 0.7	512^3
M15	1.0	2.000	~ 0.5	~ 0.7	512^3
M16	2.0	0.010	~ 9.5	~ 0.5	256^3
M17	2.0	0.100	~ 3.2	~ 0.5	256^3
M18	2.0	1.000	~ 1.1	~ 0.5	256^3
M19	3.0	0.010	~ 10.8	~ 0.4	256^3
M20	3.0	0.100	~ 3.4	~ 0.4	256^3
M21	3.0	1.000	~ 1.0	~ 0.3	256^3
M22	5.0	0.010	~ 9.4	~ 0.2	256^3
M23	5.0	0.100	~ 2.9	~ 0.2	256^3
M24	5.0	1.000	~ 0.8	~ 0.2	256^3

Example of one of the simulations

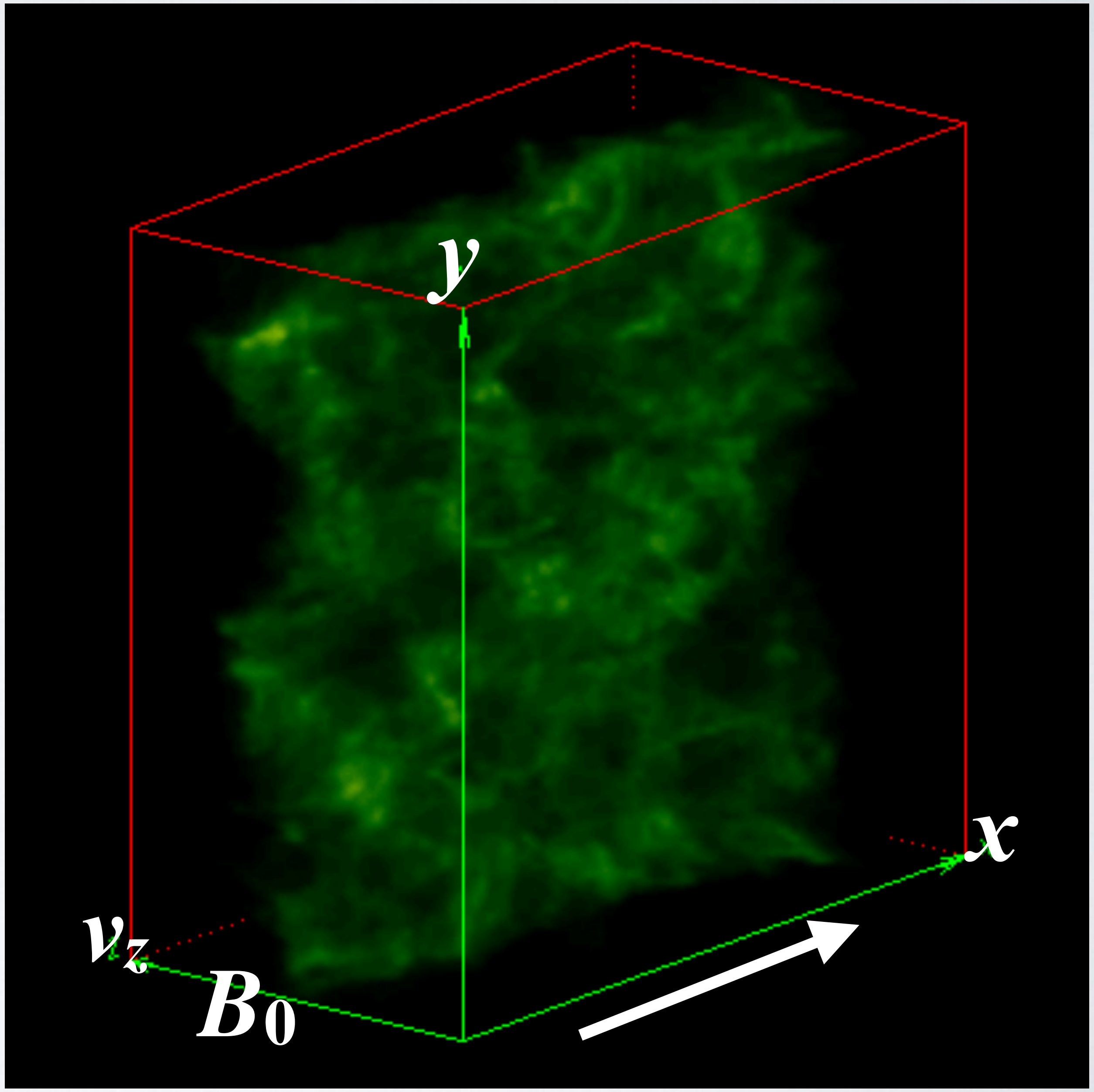
Model M12 (with $M_s=2.7$ and $M_A=0.8$)

Simulation PPP (x,y,z) space



Density cuts

Synthetic Observations
PPV (x,y,v_z) space



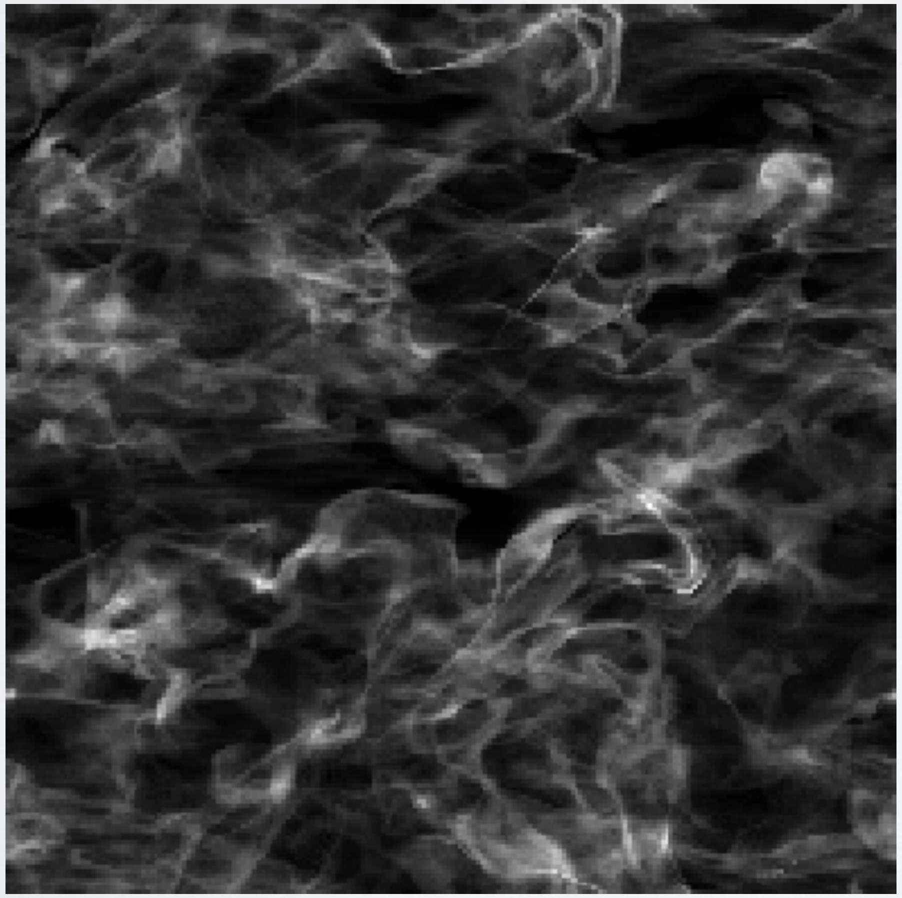
Intensity $\propto \rho$

PPV data: the effect of varying resolution

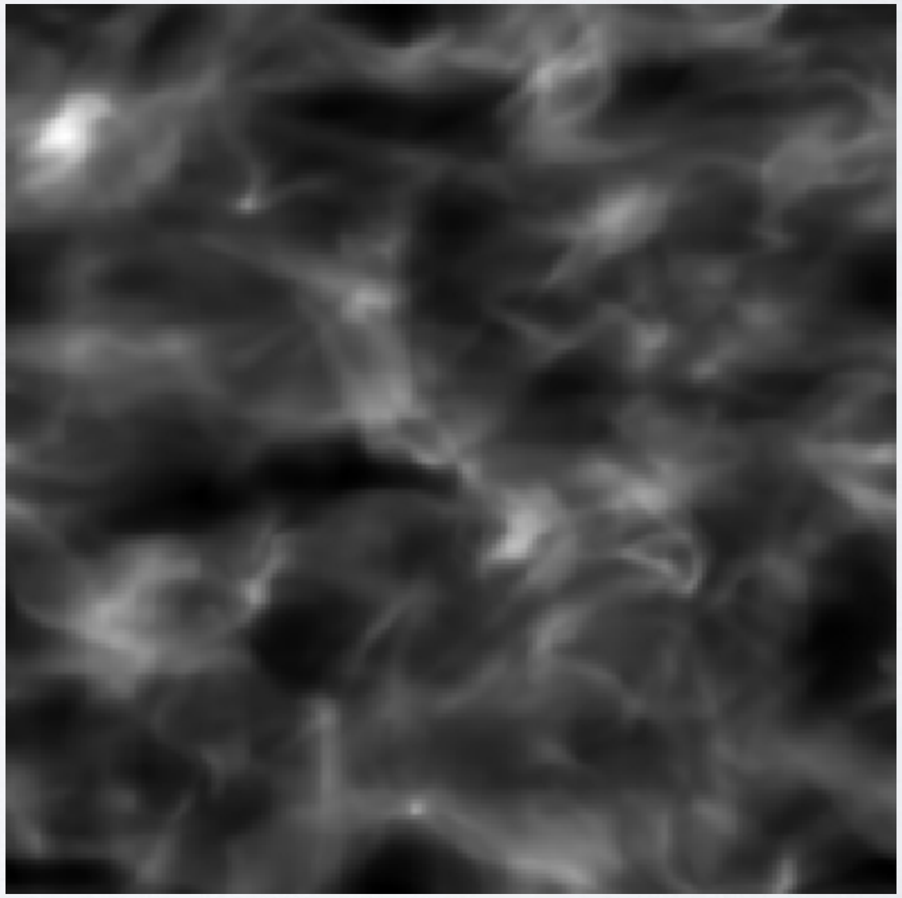
- Emissivity in PPV data depends on density and velocity at the same time.

- Lazarian & Pogosyan (2000) study the effect of varying the thickness in velocity channels (velocity resolution) to obtain the velocity spectral index from observations.

  - As we lower the velocity resolution, the contribution of density becomes more prominent. In thinner velocity channels the velocity can dominate the spectrum.



Velocity slice $\delta v = \Delta v/120$



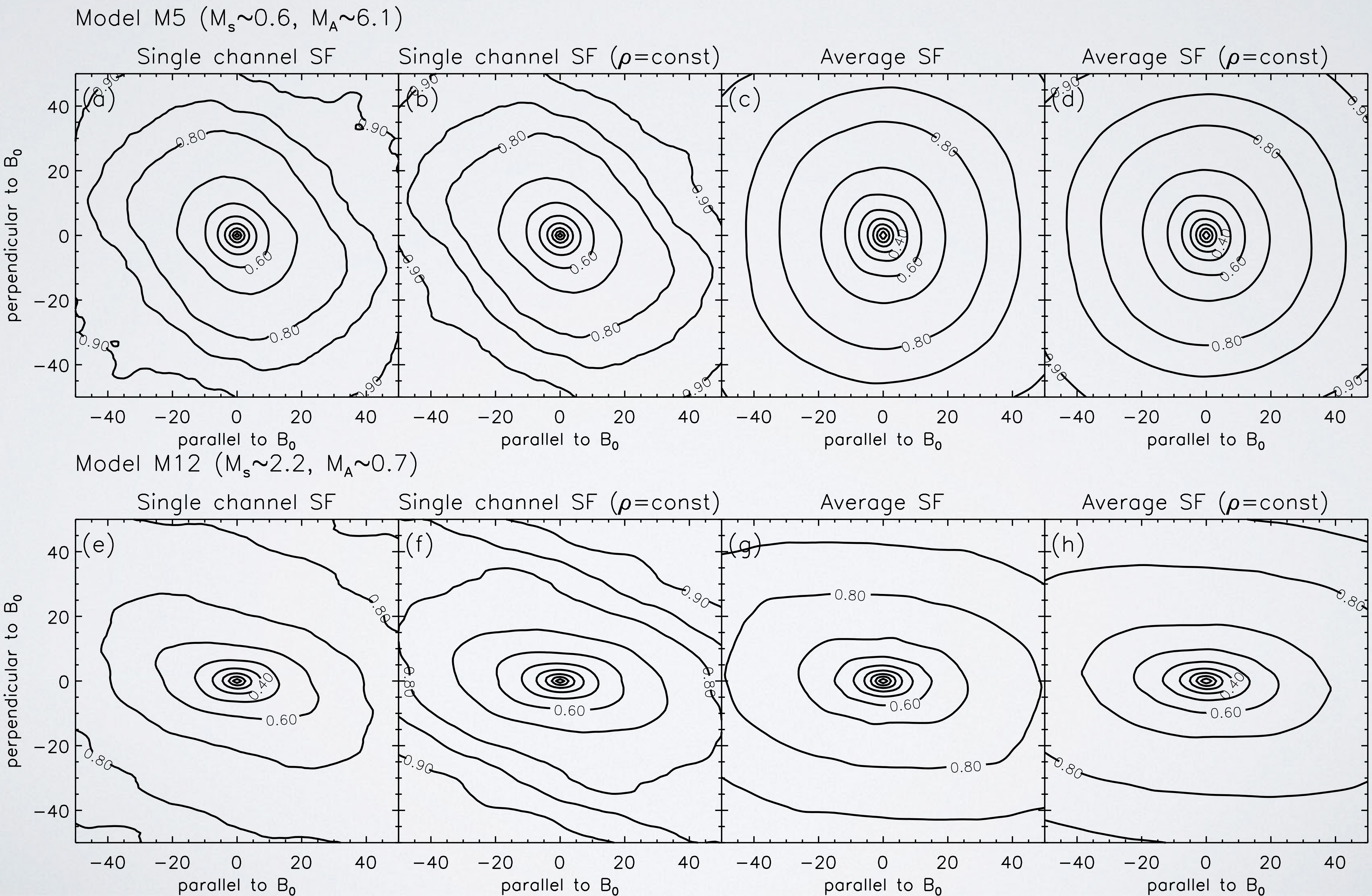
Column density

Anisotropy in the structure function of velocity channels

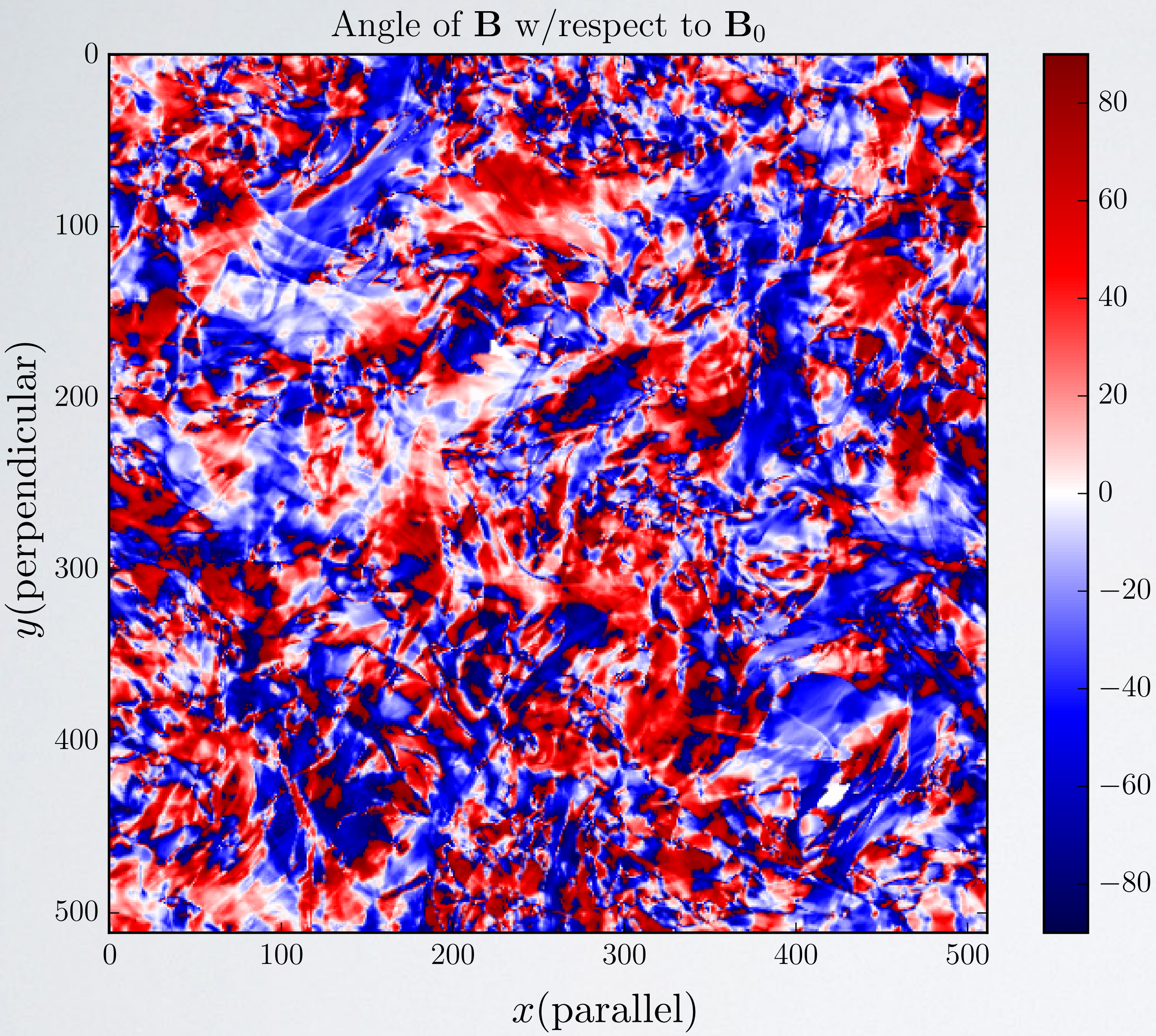
- We take the Structure function in 2D in each ***i-th*** channel

$$SF_i(\mathbf{R}) = \langle [I(\mathbf{X}, v_{z,i}) - I(\mathbf{X}+\mathbf{R}, v_{z,i})]^2 \rangle,$$

- For isotropic (unmagnetized turbulence) the contours are circular, the anisotropy due to the magnetic field can be seen in the elongation in the direction of ***B***. (Lazarian, Pogosyan & Esquivel, '02, Esquivel et al. '03, '05).

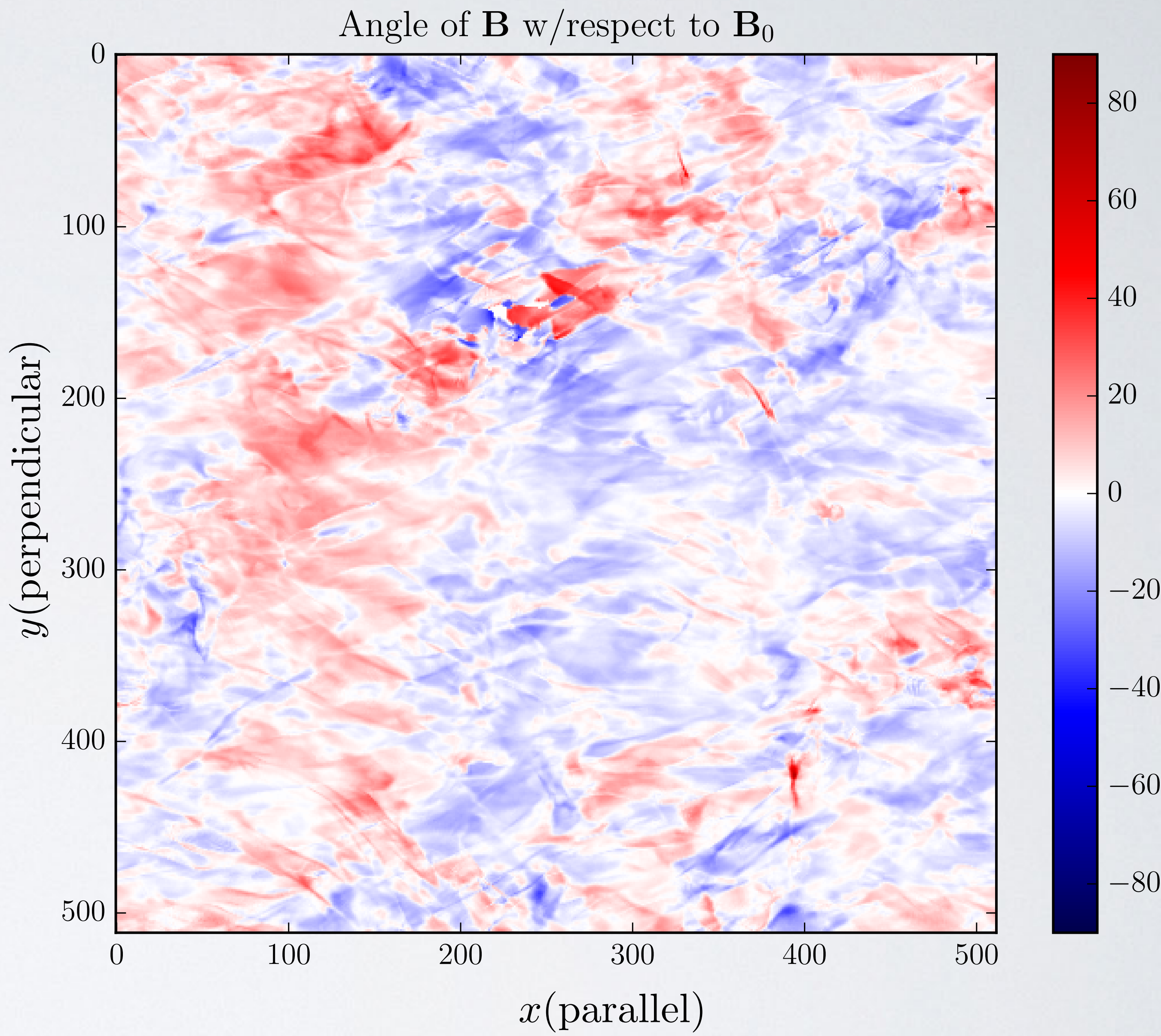


Magnetic Field orientation in one velocity channel



Ms=0.9 and ***M_A=7.6***

$$\langle|\varphi|\rangle \simeq 43^{\rm o}$$



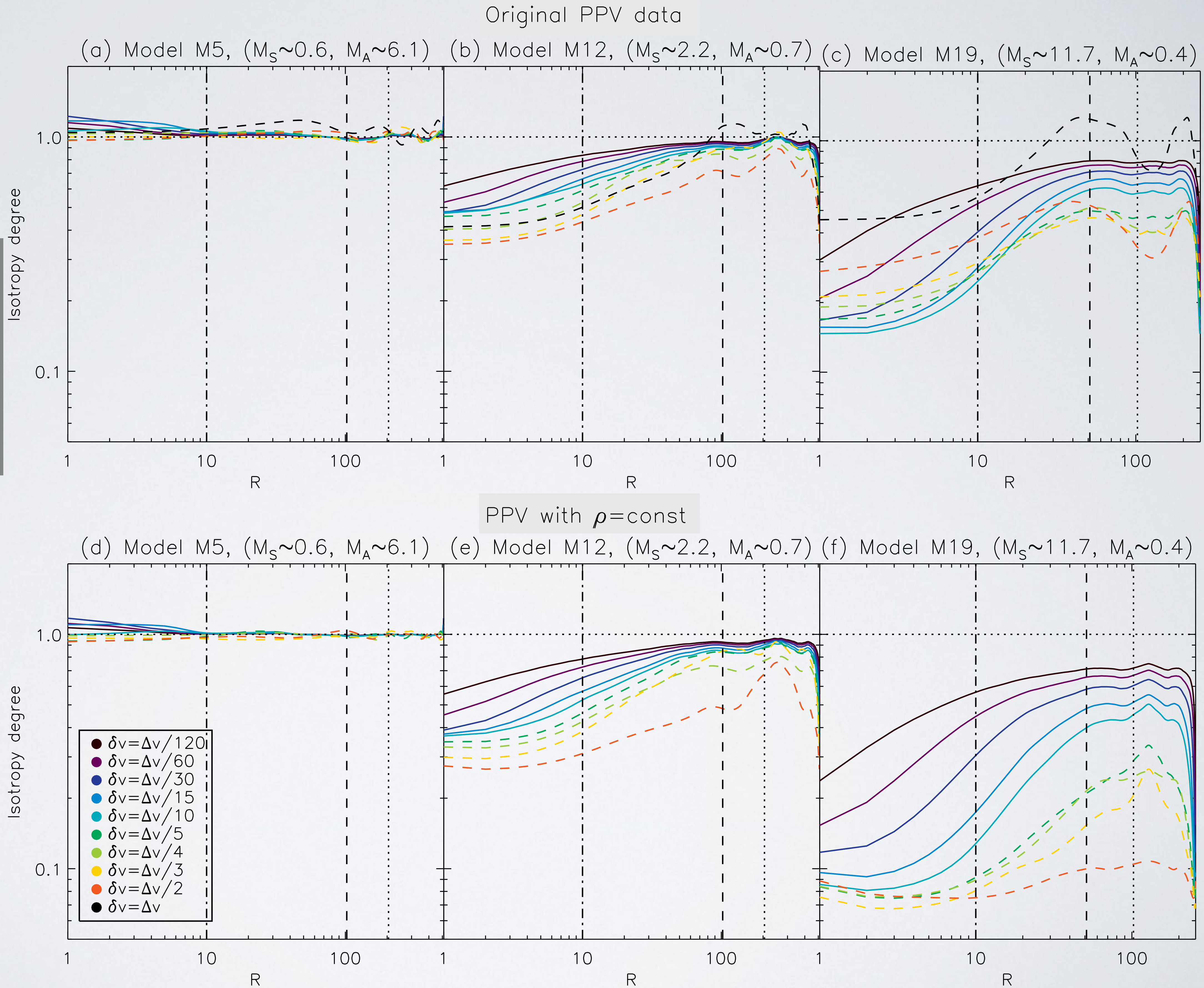
Ms=2.7 and ***M_A=0.8***

$$\langle|\varphi|\rangle \simeq 6^{\rm o}$$

For each averaged structure functions, we measure

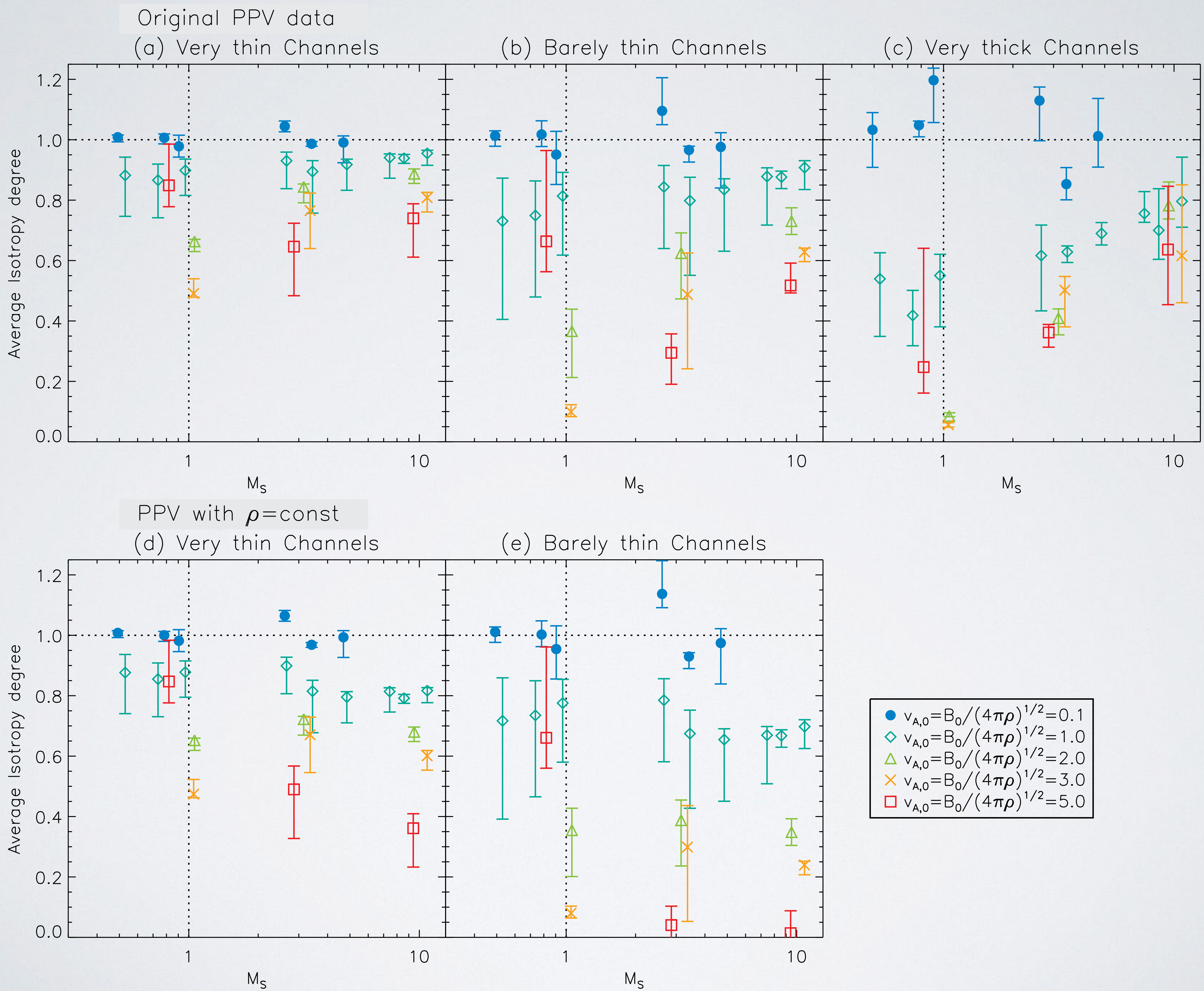
Isotropy degree

$$\text{I.D.} = \frac{SF(R_{\parallel})}{SF(R_{\perp})}$$



Thin channels: solid lines
Thick channels dashed lines

All models, averaging from *10* to *L/5* cells



Summary/conclussions

- Structure functions in velocity channels, as in velocity centroids, and column density maps, are anisotropic.

- Such anisotropy points in the direction of the plane of the sky $\boldsymbol{B}$ field.

- The degree of anisotropy increases with the strength of $\boldsymbol{B}$ (i.e. $\boldsymbol{\sim 1/M_A}$), for a given sonic Mach number ($\boldsymbol{M_S}$).

    - Thus given an estimate of $\boldsymbol{M_S}$ one can infer an upper bound on the Alfvénic Mach number (we miss the information of the $\boldsymbol{B_{LOS}}$)

        - With help of other techniques/measurements (e.g. Zeeman splitting measurements) one could determine $\boldsymbol{M_A}$.

    - These results are consistent with those previously obtained with velocity centroids (Esquivel & Lazarian 2011, Burkhart et al. 2014), but taking thin channels problems with fluctuations for high sonic Mach numbers in density is minimized.