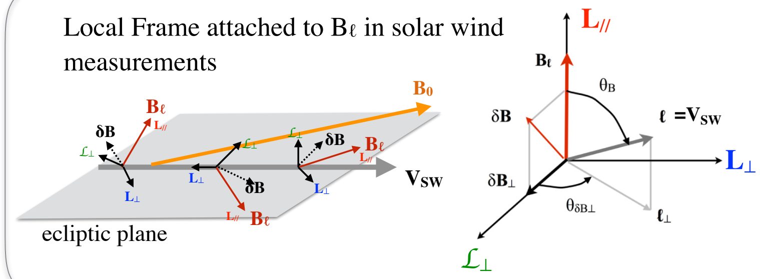
4.11 Solar wind turbulence anisotropy, from large to small scales

A. Verdini (1,2), R. Grappin (1), O. Alexandrova (2)
(1) Laboratoire de Physique des Plasmas LPP, Palaiseau
(2) LESIA (Observatoire de Paris, CNRS)

Method

The 3D anisotropy of turbulence can be measured by computing structure functions $SF=\delta B^2=|\mathbf{B}(t)-\mathbf{B}(t+\tau)|^2$ in a frame attached to the local magnetic field $\mathbf{B}_\ell=1/2[\mathbf{B}(t)+\mathbf{B}(t+\tau)]$

Local Frame



- $L_{//}$ is along B_ℓ
- $L_\perp$ is perpendicular to δB and B_ℓ
- $\mathcal{L}_\perp$ is in the plane defined by δB & B_ℓ, (perpendicular to $L_{//}$ & $L_\perp$)

Observations

Chen et al 2012

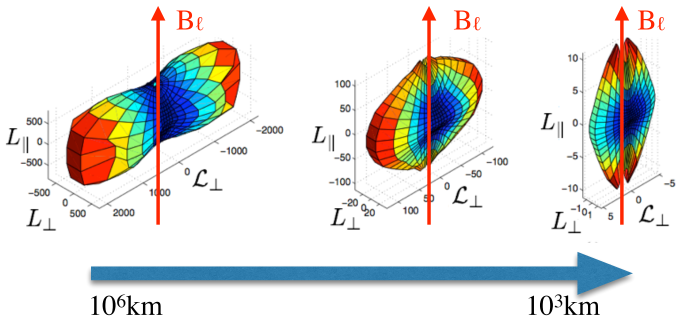
Chen (et al. 2012) analysed Ulysses data at $1.4AU<R<2.5AU$, with $\sigma_c\sim0.6$ (moderate v-b correlation) and $\delta b/B_0\sim1$. They found that **turbulence is not axissymmetric** and the **anisotropy changes with scales**

At large scales : $SF(L_{//}) \sim SF(L_\perp) > SF(\mathcal{L}_\perp)$

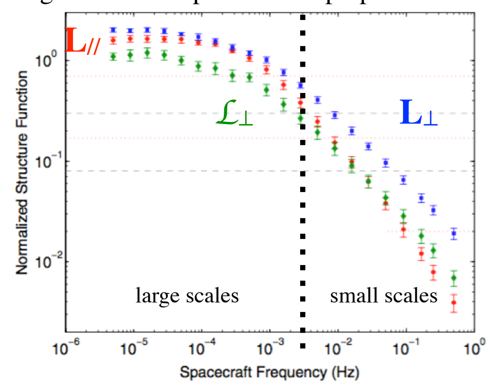
At small scales: $SF(L_\perp) > SF(\mathcal{L}_\perp) > SF(L_{//})$

$SF(L_{//})\sim k^{-1}$, $SF(L_\perp), SF(\mathcal{L}_\perp)\sim k^{-1/2}$ $(k=1/\ell)$

Isosurfaces of constant SF in the local reference frame



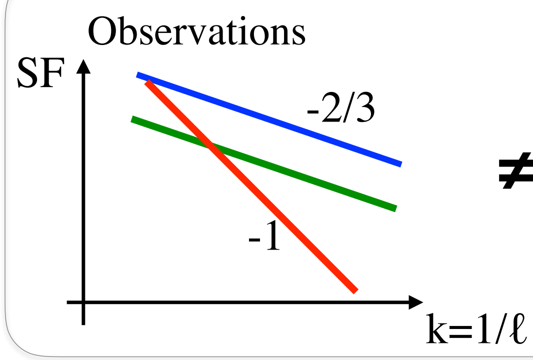
Scaling of SF in the parallel and perpendicular directions



Questions

Solar wind anisotropy is different from any known theory/phenomenology

1) large scales: **why SF// is so energetic?**
2) small scales: **why properties of homogenous turbulence are not recovered?**



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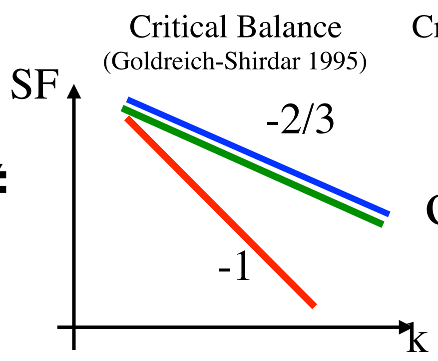
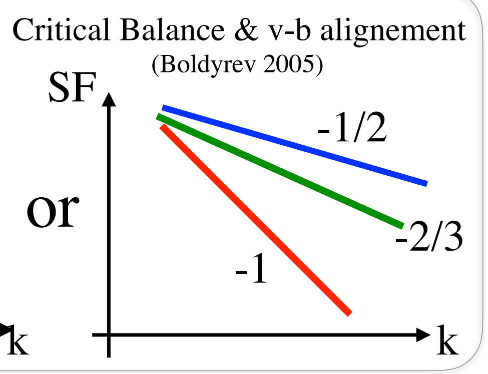


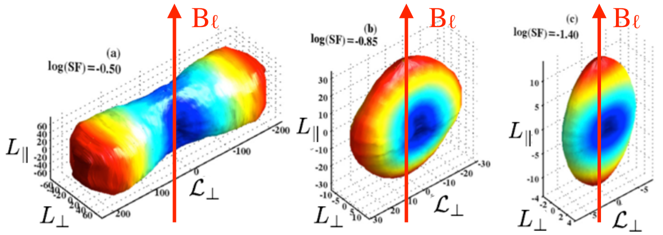
or



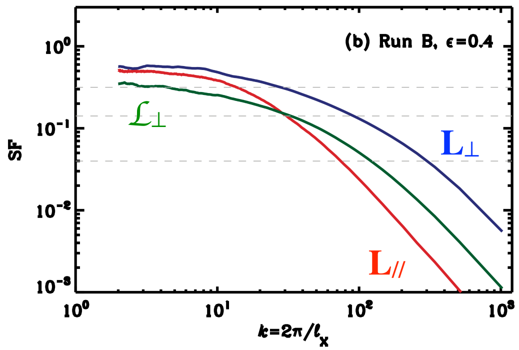
Simulations (EBM)
Verdini & Grappin 2015

By running MHD simulations
- without expansion we obtain the anisotropy of critical balance & v-b alignement (Boldyrev 2005)
- **with expansion we obtain the anisotropy observed in the solar wind**

Isosurfaces of constant SF in the local reference frame



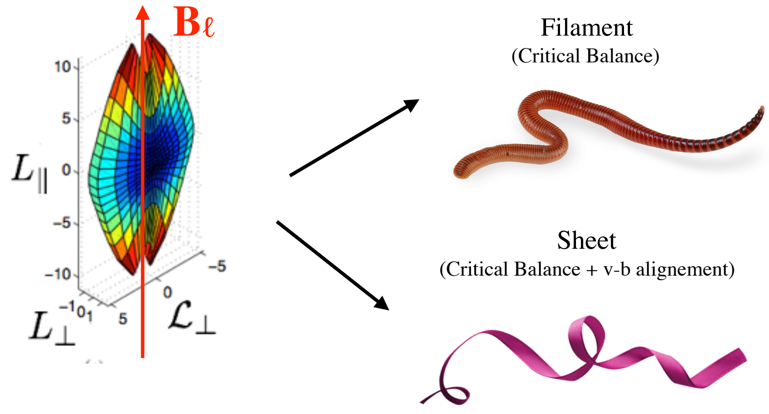
Scaling of SF in the parallel and perpendicular directions



We also showed that :
- **expansion** causes the enhancement of power in **SF$_{//}$** at large scales
- The **sampling directions** affect the power and scaling of SF($L_{//}$, $L_\perp$, $\mathcal{L}_\perp$). i.e. anisotropy changes for scans along the R,T,N directions

Remaining Open Question

What is the asymptotic small-scale regime of solar wind turbulence?



The Project

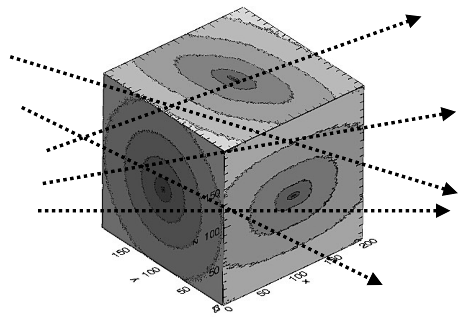
Verdini, Grappin, Alexandrova

The differences of the observed anisotropy at small scales with homogenous turbulence is still not understood. Possible causes are:

a) Bias from the sampling direction (along R in the solar wind) due to
- expansion (Verdini & Grappin 2015)
- wavevector anisotropy (Turner et al. 2012)

<u>use Simulations</u>

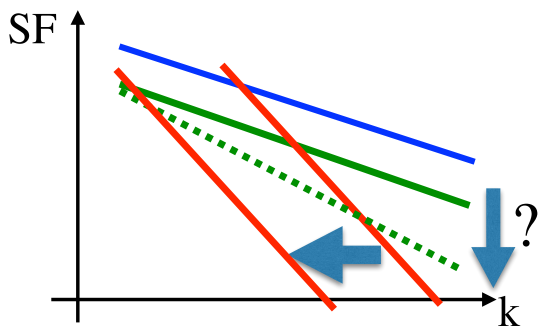
to explore the anisotropy resulting from **different/all sampling directions**



b) A limited Reynolds (in solar wind and simulations) that prevents us from attaining an asymptotic regime at small scales

<u>use Observations</u>

to select intervals with minimal effect of expansion (maximize inertial range)



Simulations (EBM)

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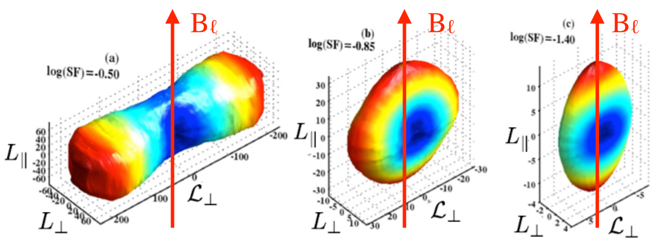
By running MHD simulations in the Expanding Box Model (EBM) we can reproduce the observed anisotropy and showed that:

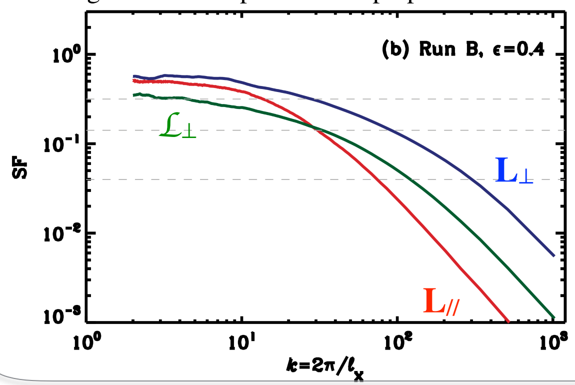
a) Expansion confines B_ℓ in the plane $\perp$ to R and enhances the power of SF// at large scales when the sampling is along R (as in observations).

b) The scaling and ordering of SF along $L_{//}$, $\mathcal{L}_\perp$, $L_\perp$ depend on the sampling direction (e.g. scans along the R,T,N directions yield different anisotropies)

Isosurfaces of constant SF in the local reference frame



Scaling of SF in the parallel and perpendicular directions



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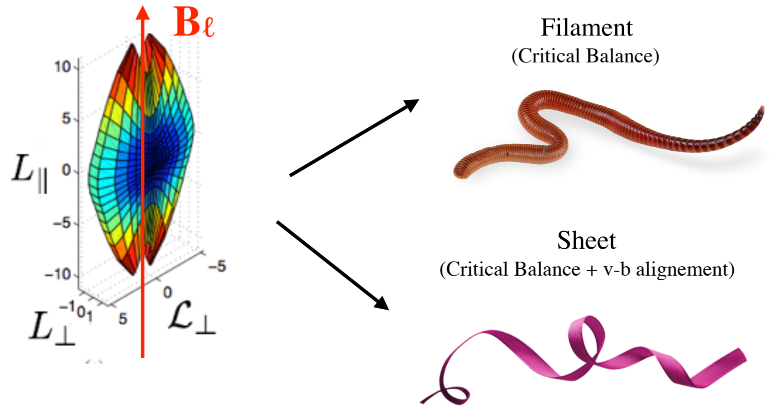

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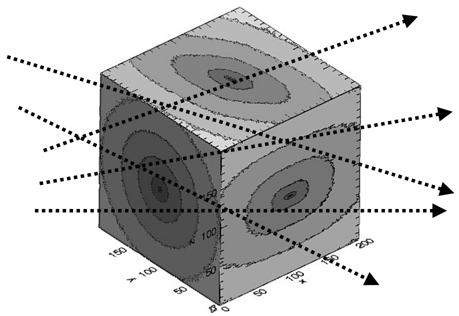
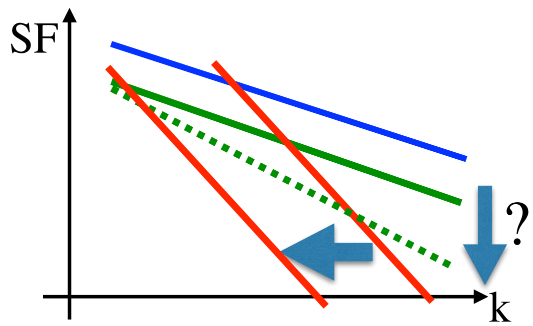


b) A limited Reynolds (in SW and DNS) that prevents us from attaining an asymptotic regime at small scales

<u>use Observations</u>

to select intervals with HIGH $\delta B/B$, σ_C, $\delta U/V_{SW}$ **to increase the Reynolds**



4.12 Solar wind turbulence anisotropy, from large to small scales

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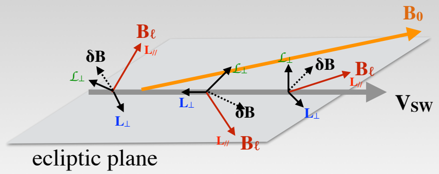
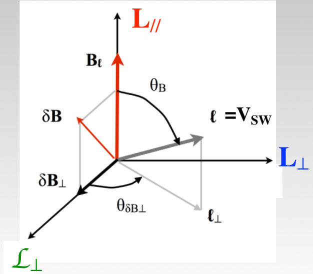
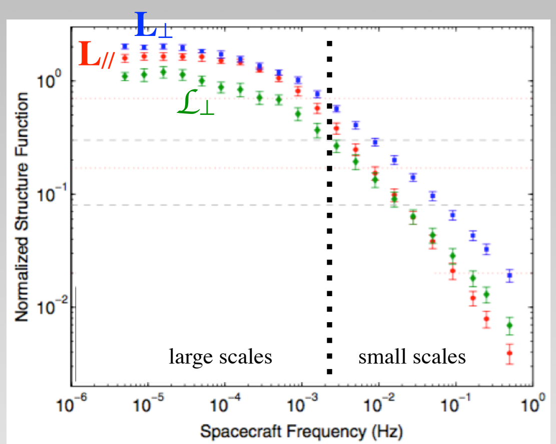
Local Frame attached to B_ℓ in solar wind measurements

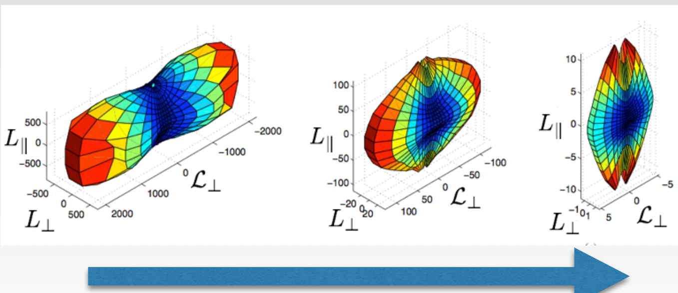




Observations

Chen et al 2012

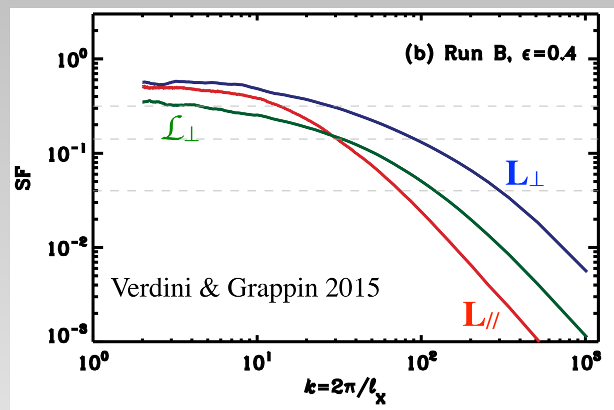


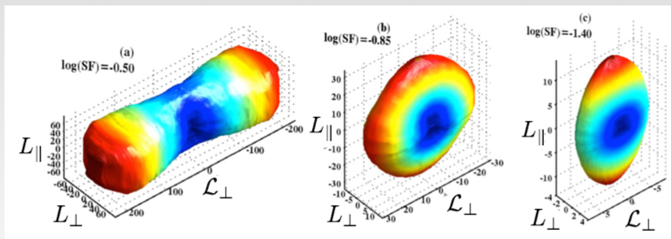


Turbulence is not axis-symmetric

- At large scales the // SF is as energetic as the ⊥ SF
- At small scales the two ⊥ SF dominate over the // SF
- At small scales the two ⊥ SF have the same slope

Simulations (EBM)





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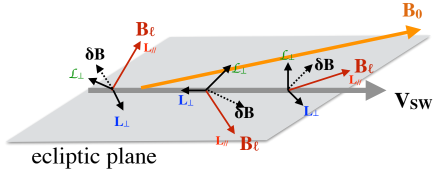
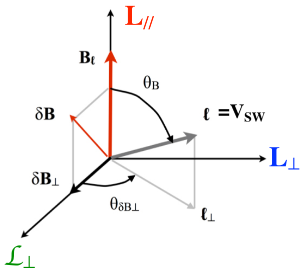


Local Frame



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Observations

Chen et al 2012

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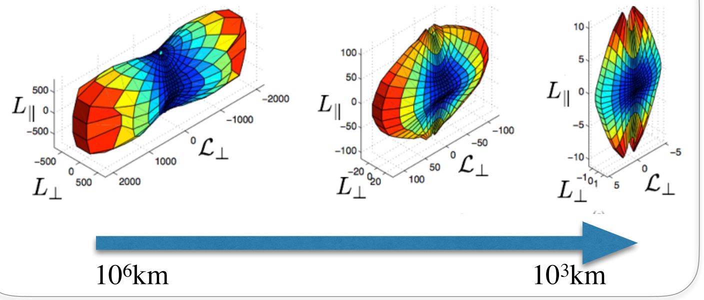

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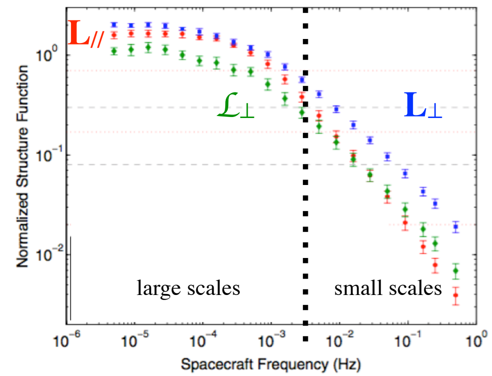
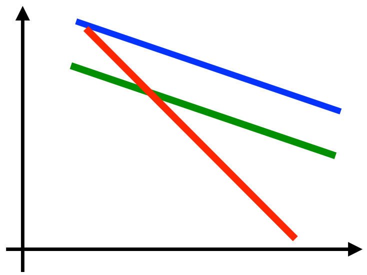
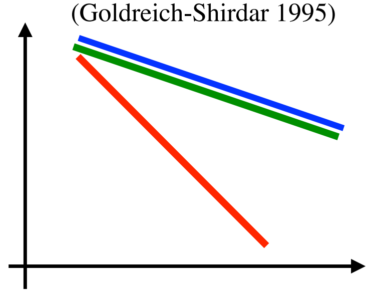


Solar wind anisotropy is different from any known theory/phenomenology

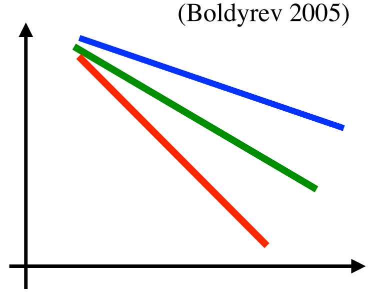
Observations



Critical Balance
(Goldreich-Shirdar 1995)



Critical Balance + v-b alignement
(Boldyrev 2005)



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Expanding Box Simulations

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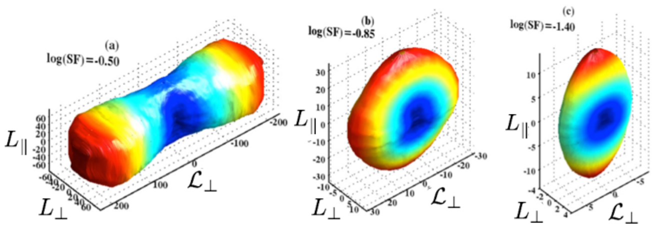

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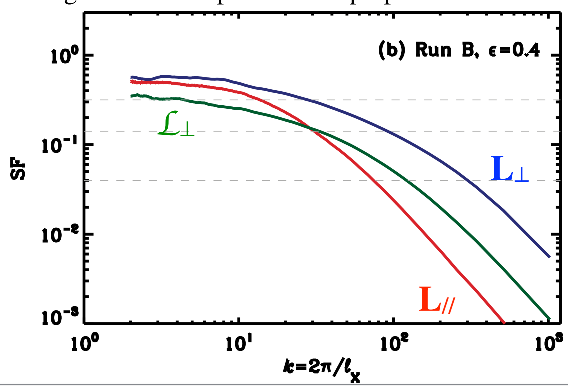

Remaining Open Question

What is the asymptotic small-scale regime of solar wind turbulence?

Filament
(Critical Balance)

Sheet
(Critical Balance + v-b alignement)

The Project

Verdini, Grappin, Alexandrova

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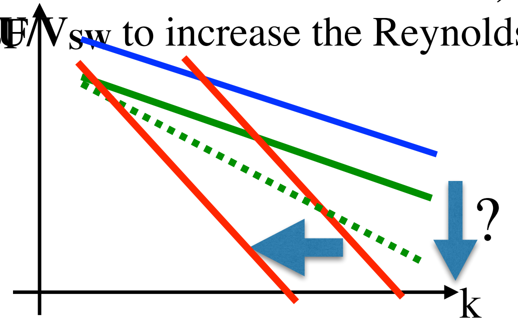

Stronger δb/B0