Technische
Universität
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Alfvénic impact on heliospheric plasma turbulence

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in collaboration with

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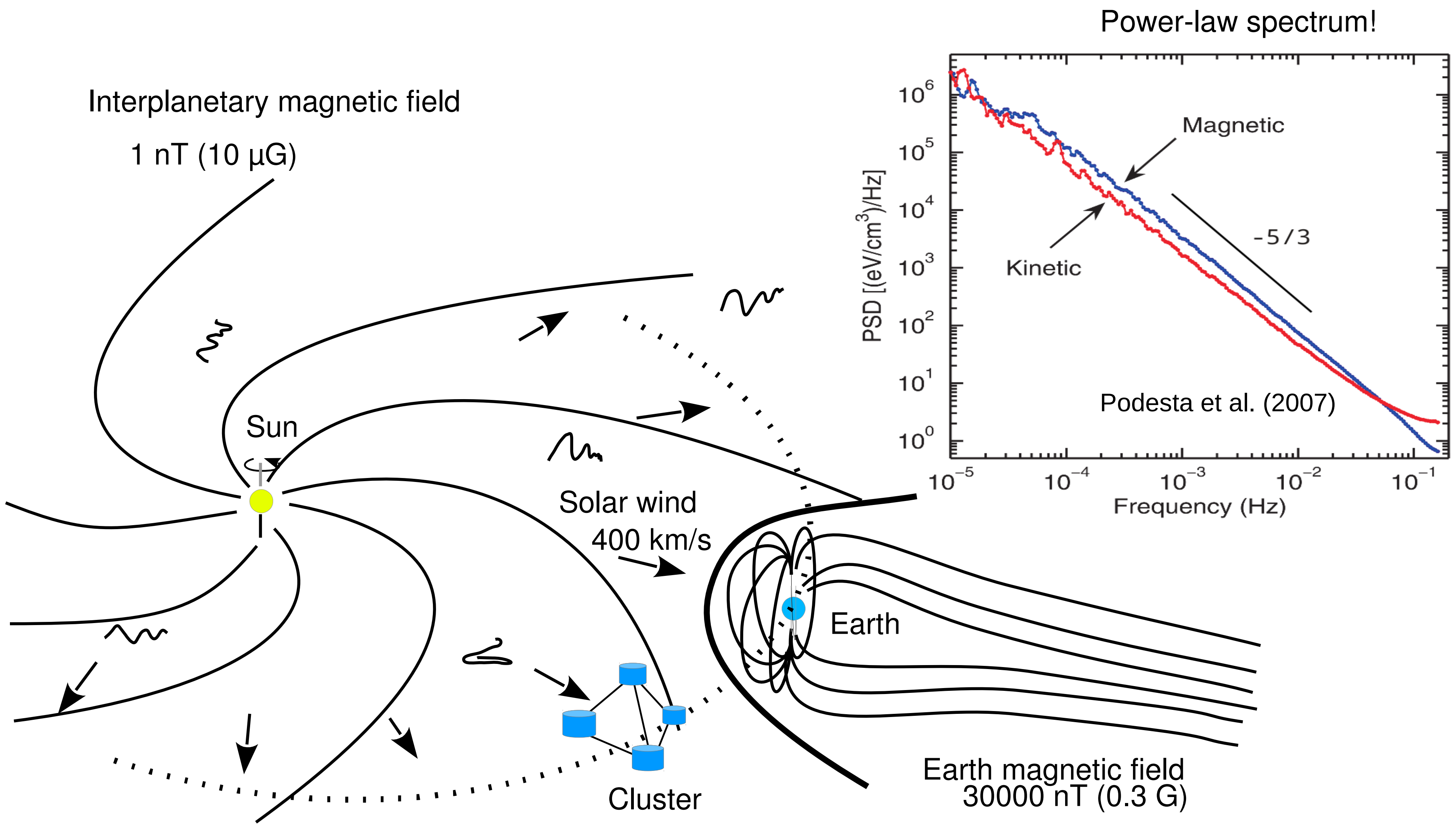
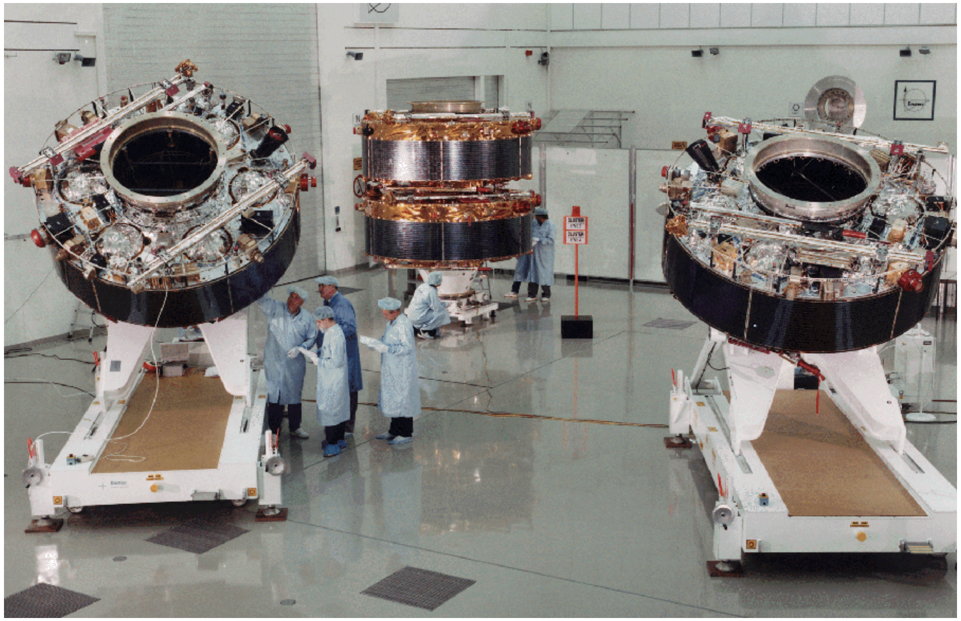
Solar wind turbulence



Solar wind – an expansion of plasma from Sun to interplanetary space; Parker spiral; eddies and Alfven waves;
Earth magnetosphere; Solar wind is in a "turbulent" state – topics today
Cluster; 1-D power-law frequency spectra

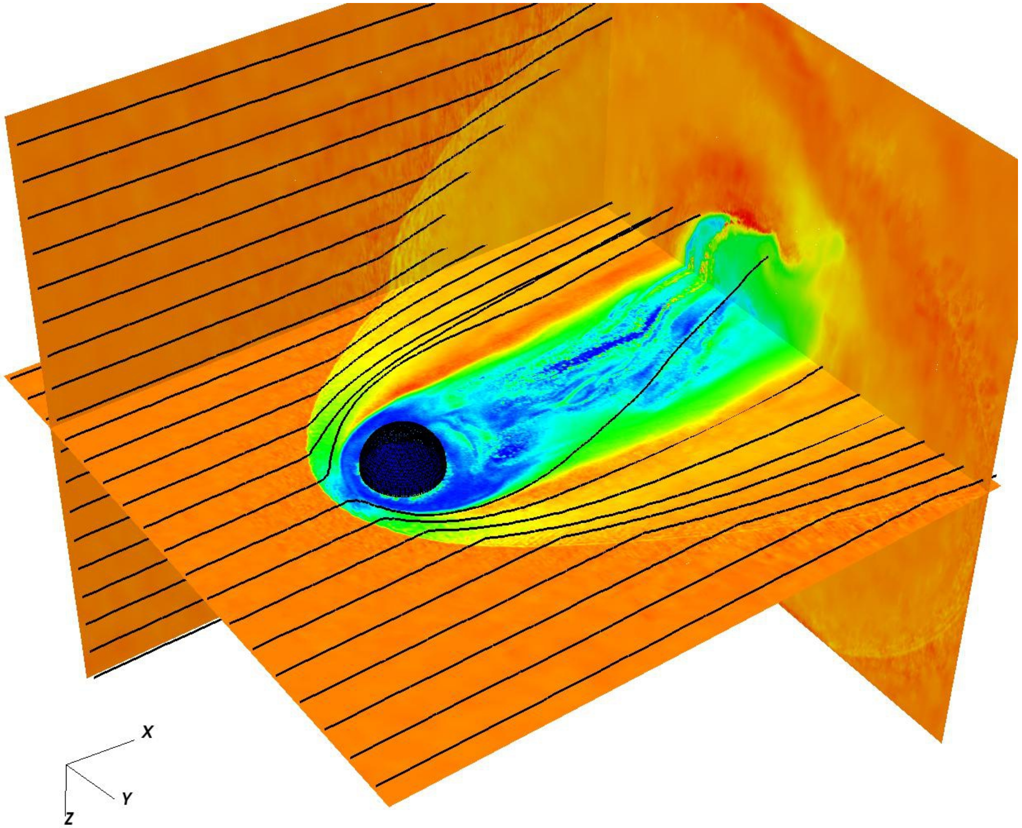
Our methods for understanding turbulence

Four Cluster spacecraft



AIKEF 3-D hybrid plasma simulation

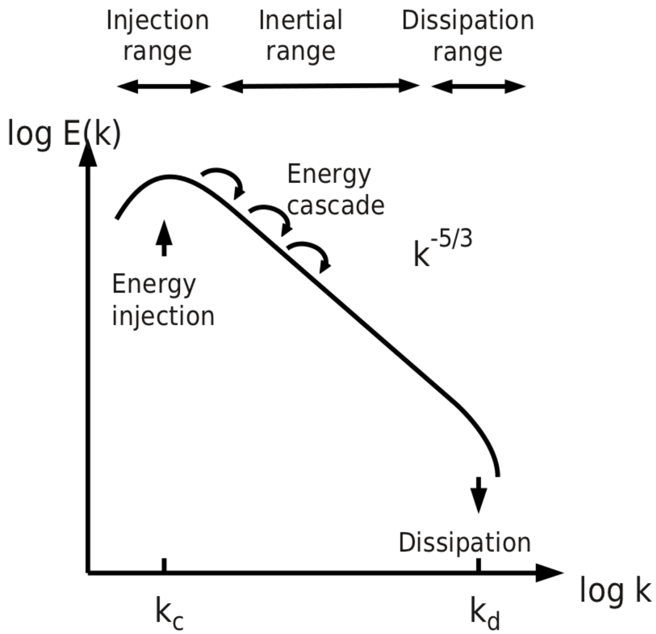
developed by TU Braunschweig team



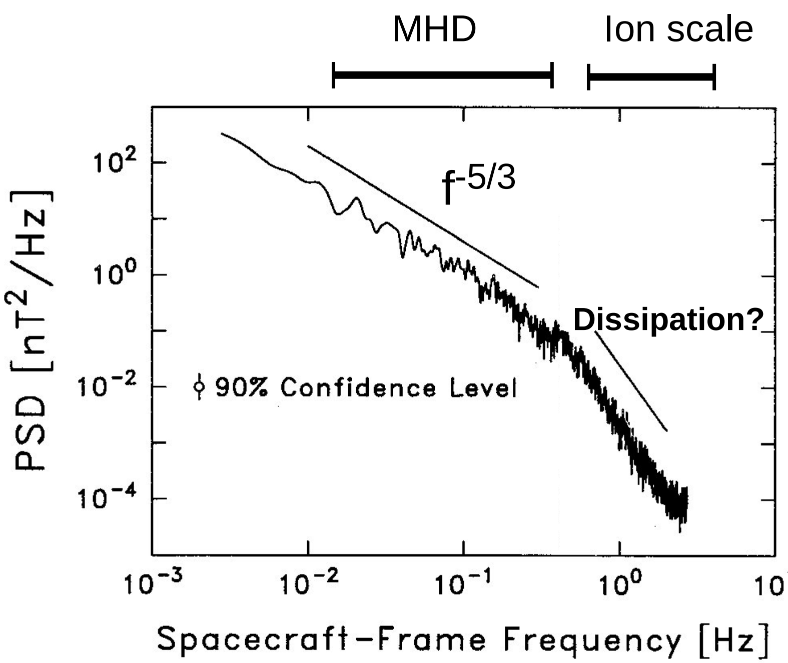
Two independent methods; both 3-D spatial resolution; Cluster still in orbit (until 2016); mag and plasma; AIKEF; 3-D ; Mercury magnetosphere; Rosetta operation planning; para magnetic field; density contour;

Does plasma turbulence really exist?

Fluid turbulence spectrum



Plasma turbulence spectrum
in the solar wind



Leamon et al. (1998)

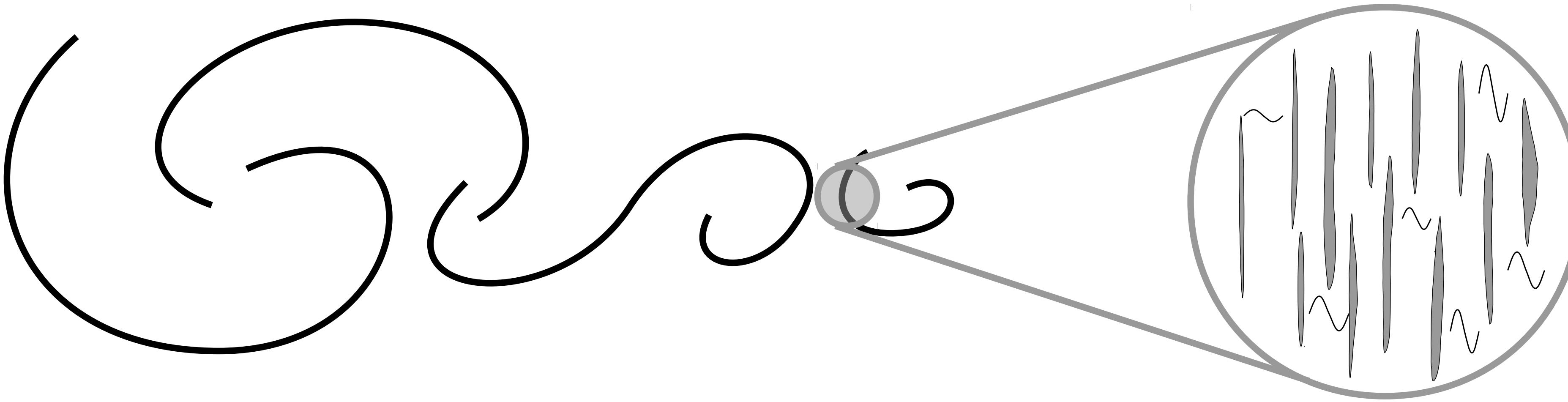
Left x, y axis; three ranges; universality of inertial range; molecular viscosity
Right x, y axis, data source (Wind MAG); FFT; -5/3 power law; spectral break mystery
Taylor hypothesis time = space

Magnetohydrodynamic turbulence

10^3—10^6 km

Ion-scale plasma turbulence

100 km



Eddies and Alfvén waves

Filamentary structure

Perpendicular propagating waves

MHD scale; km; eddies and Alfven waves in competition;
Ion gyroradius; 100 km or below; filaments; waves

Ion Bernstein waves
Kinetic Alfvén waves
Whistler waves etc.

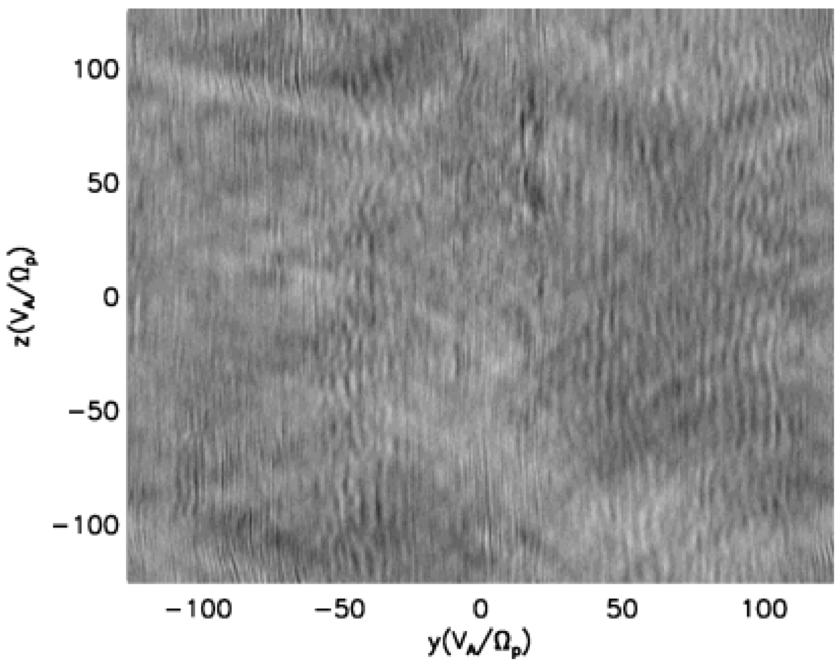
Filamentary structure (AIKEF simulation)

Movie

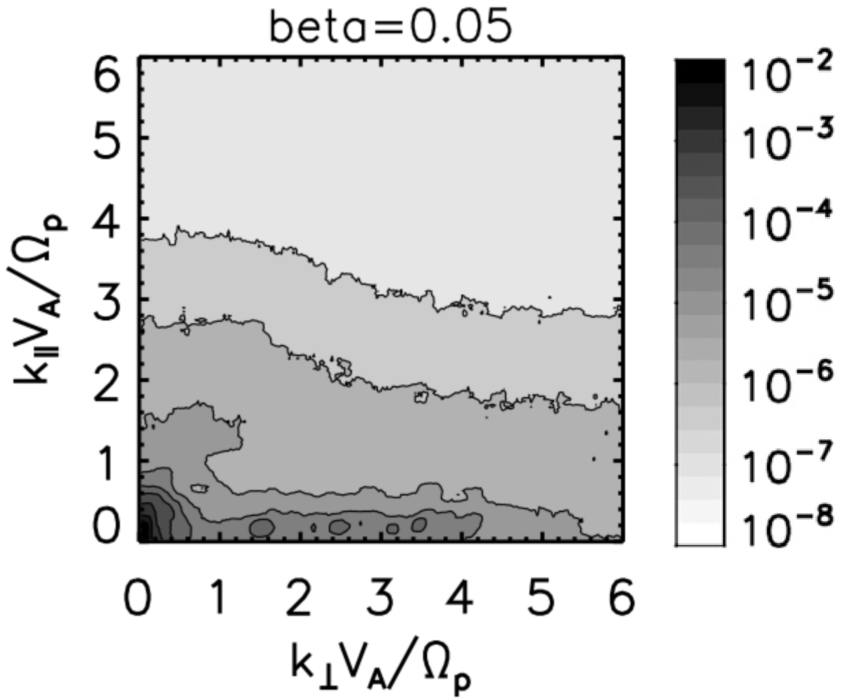
Mag intensity; x, y axis; scales 100 x 100 km; ion beta 0.05 (strong mag);
elongated fine structures; small-scale waves perpendicular forward backward;
Large-scale waves parallel

Filaments seen as spectral anisotropy

Filaments from AIKEF simulation



Energy spectrum
in the k_para – k_perp plane

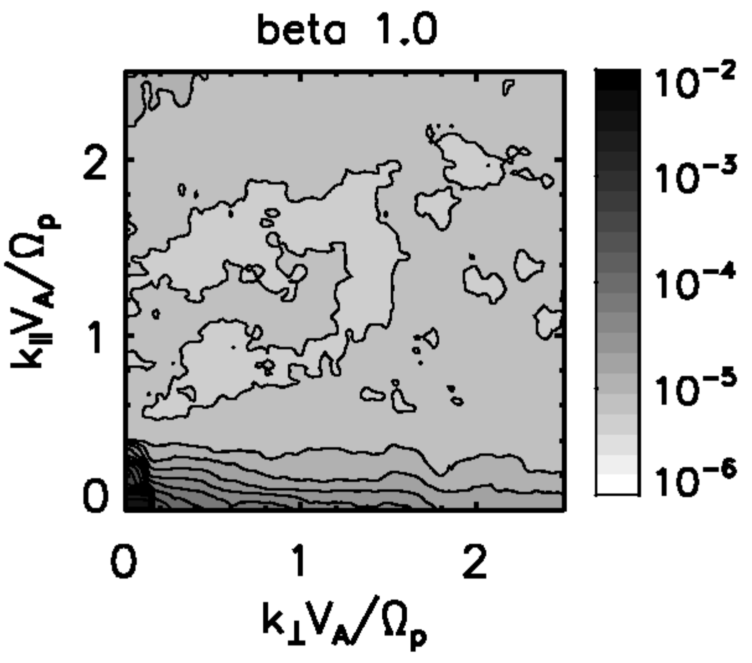


Comisel et al. (Geosci. Lett., 2014)

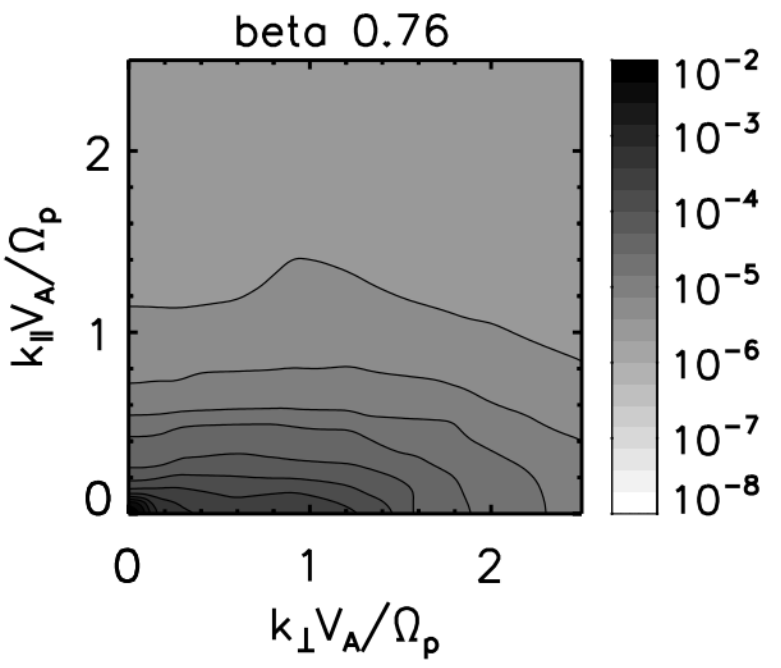
Left mag intensity; x, y axis; 700 gyro; ion beta 0.05;
Right FFT and smoothing; x, y axis; perp wavevec geometry

Spectral anisotropy for filaments
Simulation vs. observation

AIKEF simulation



Cluster observation in the solar wind

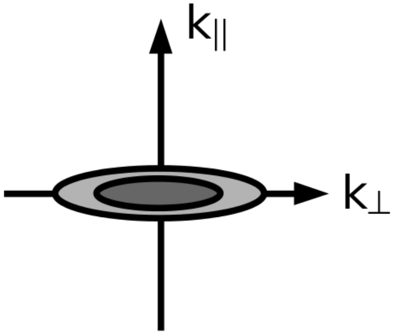


Narita, Comişel, and Motschmann (Front. Phys., 2014)

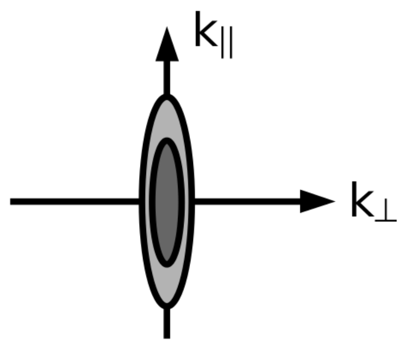
Left mag intensity; x, y axis; 1000 gyro; ion beta 1.0 (hotter plasma);
Right Cluster mag, x, y axis; no Taylor; beta similar; perp wavevec geometry confirmed

Analysis of the filaments

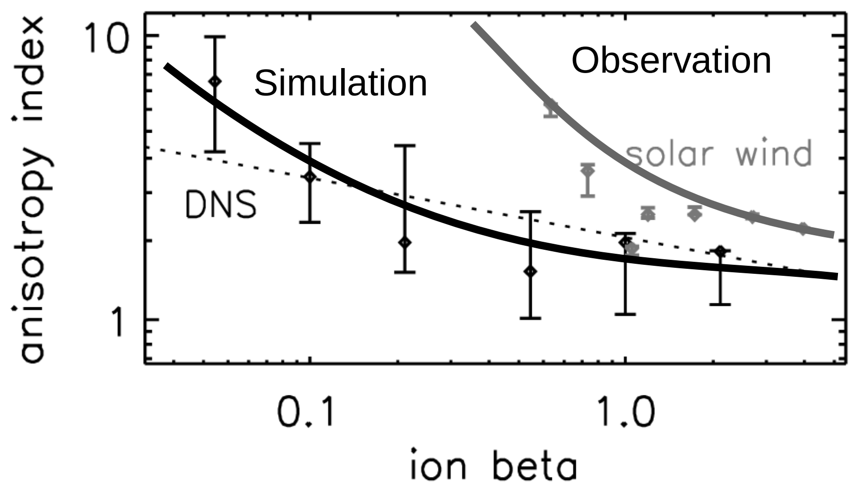
Perpendicular wavevector geometry (filaments)



Parallel wavevector geometry



Strong filamentation



Hotter plasma;
Weaker magnetic field

Anisotropy index

$$A = \frac{\sum_k k_\perp^2 E(k_\perp, k_\parallel)}{\sum_k k_\parallel^2 E(k_\perp, k_\parallel)}$$

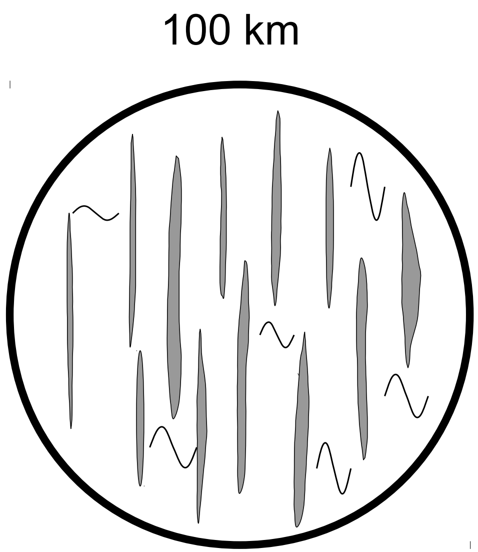
Shebalin et al. (1983)

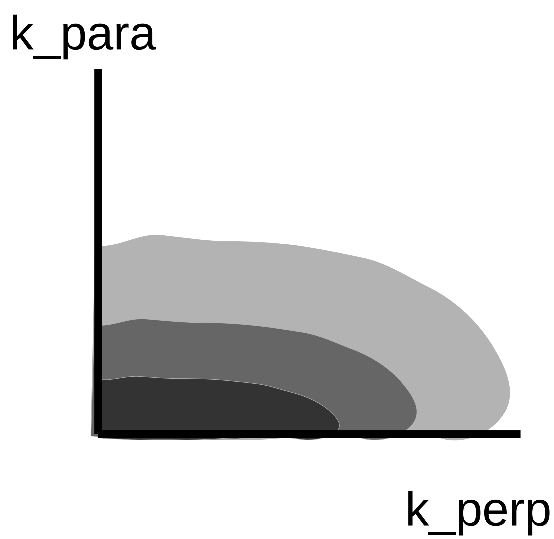
Comisel, Narita, and Motschmann
(Nonlin. Proc. Geophys. 2014)

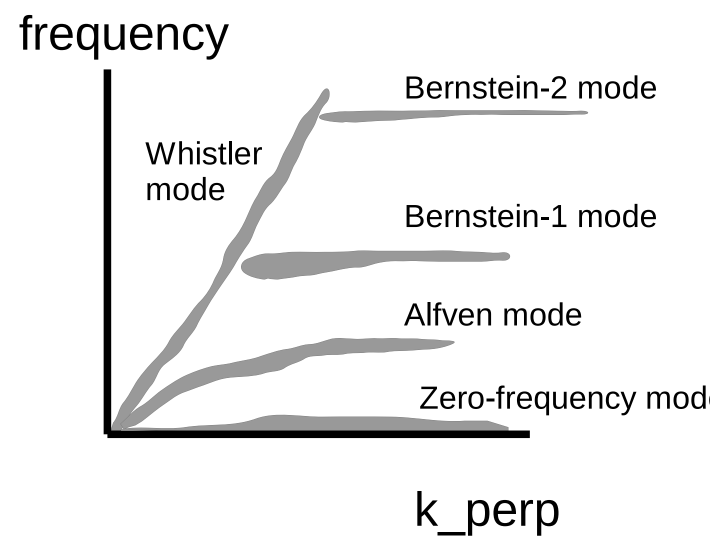
Left top; two competing aniso model; filmaments vs. Alfven wave packets;
Left borrom: Index method; comparison of correlations wavevec – energy;
Right: x, y axis; Cluster and AIKEF; no Taylor; beta dependence; weak filamentation high-beta limit

What makes the filaments ?

Ion-scale plasma turbulence | Filamentary structure | Perpendicular propagating waves!



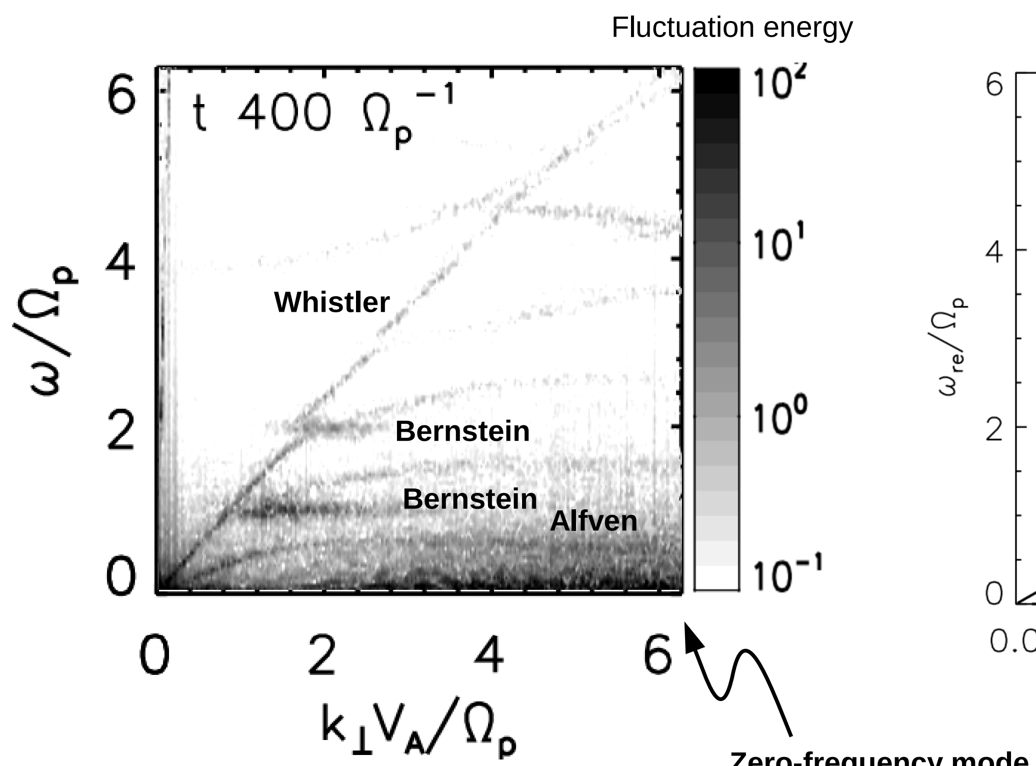




Left: filaments; there must be waves inbetween
Mid: wavevec geometry of energy spectrum
Right: role of waves? K-omega diagram; x, y axis; many modes

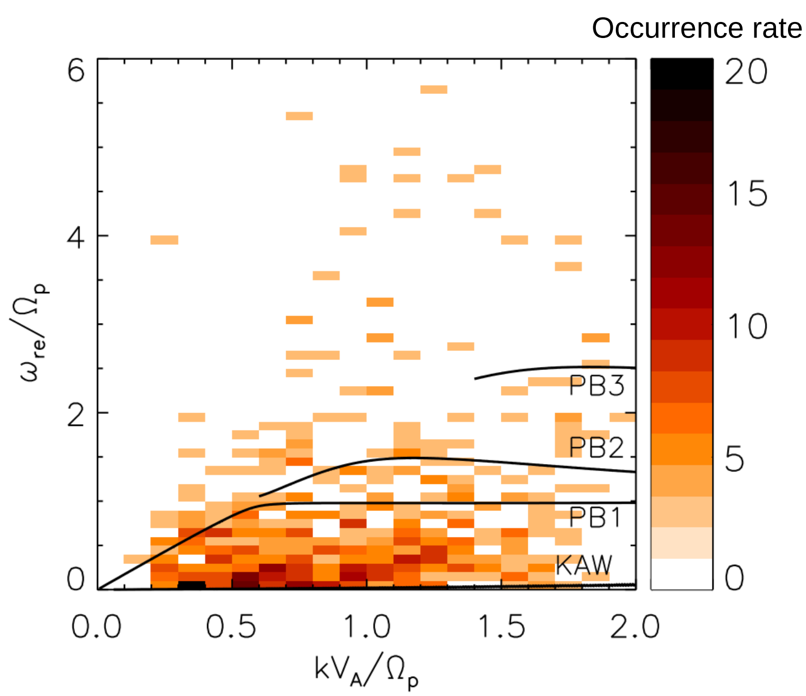
Search for wave modes
Dispersion relation analysis

AIKEF simulation



Comişel et al., (Geosci. Lett. 2014)

Cluster observation in the solar wind

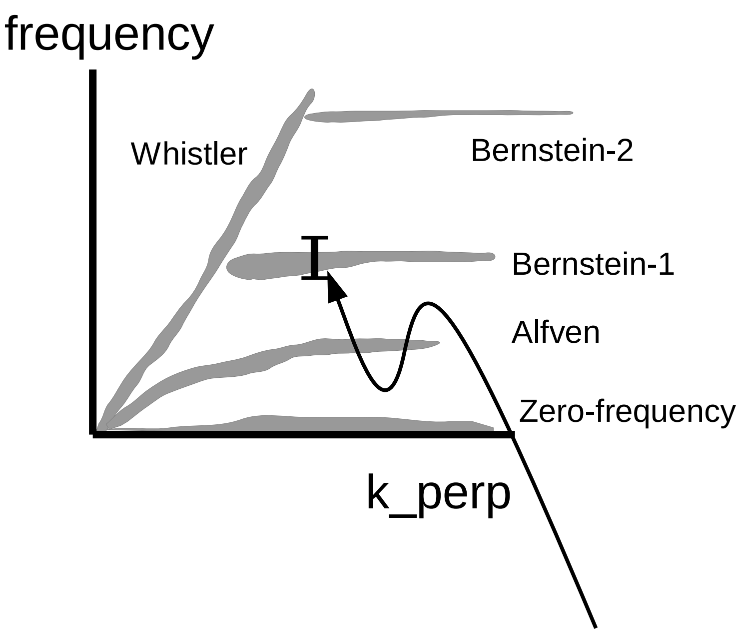


Perschke et al. (ApJ 2014)

Left: mag intensity AIKEF; x, y axis; 400 gyro; Whis; Bern; Alfven; Zerofreq
Right: occurrence frequency or histogram to enhance the contrast;
400 samples solar wind Cluster MAG; freq. range agree; normal modes and sideband waves

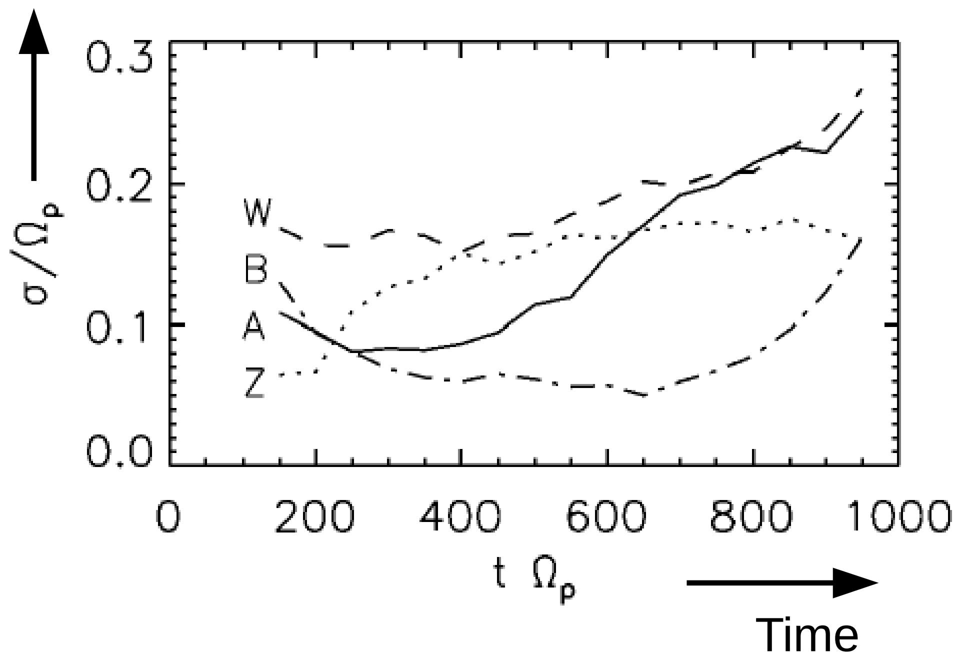
Transition into turbulence

Growth of sideband waves



Frequency broadening
around the dispersion relation

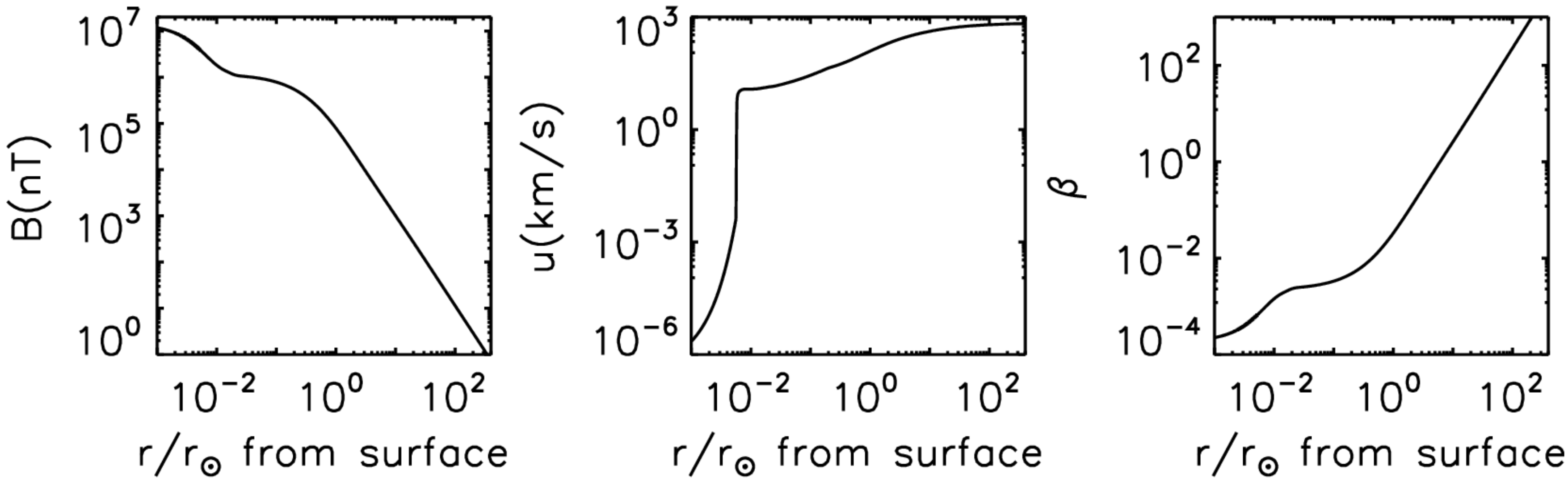
Frequency broadening



Comisel et al. (*Phys. Plasmas* 2013)

Left: theoretical branches revisited: measure of freq broadning as the effect of nonlinearity
Right: x, y axis; four branches in competition; increase of broadening: dispersion diffusive

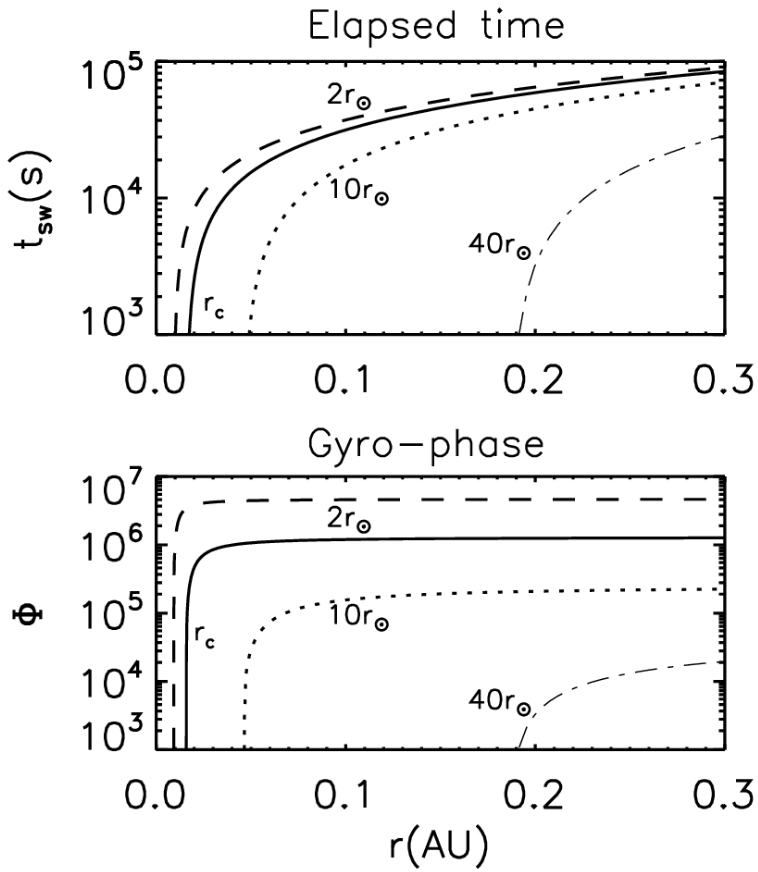
Solar wind model



Woolsey and Cranmer (2014)

Parker momentum equation is extended to including the effect of magnetic field and Alfven waves.

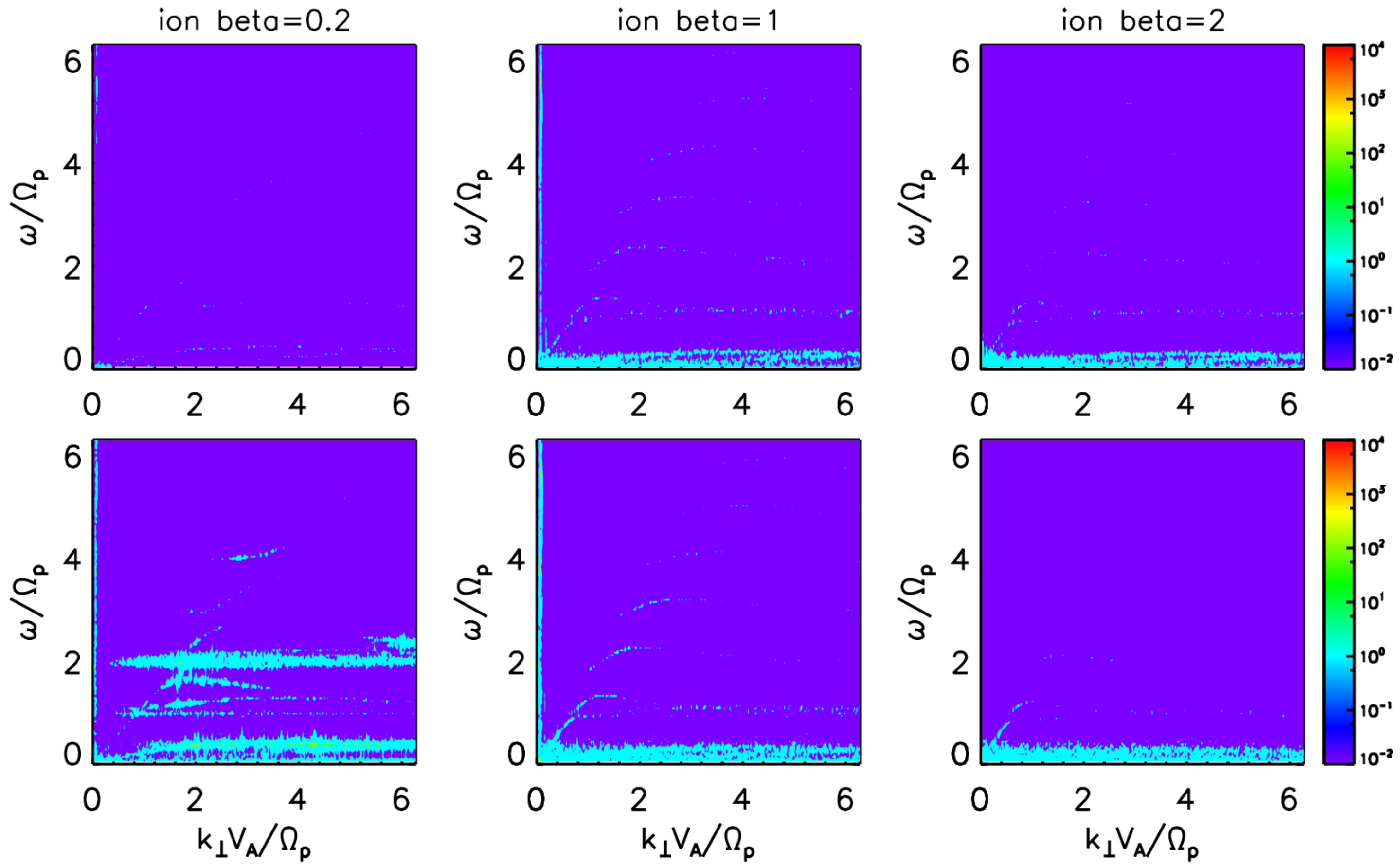
Radial mapping



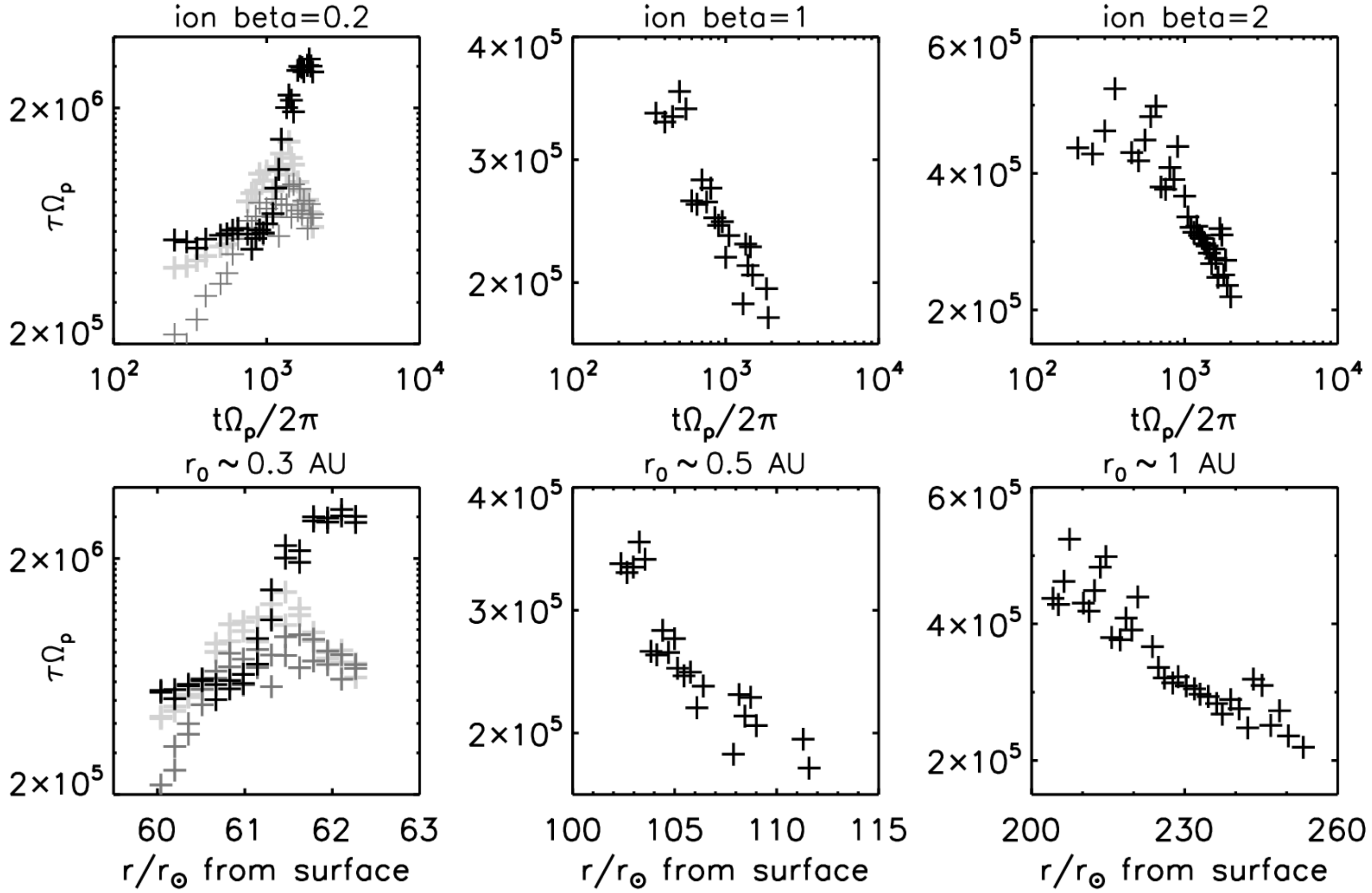
$t_{sw}(r)=\int 1/u(r')dr'$

$\Phi(r)=(2\pi)^{-1}\int \Omega_p(r')/u(r')dr'$

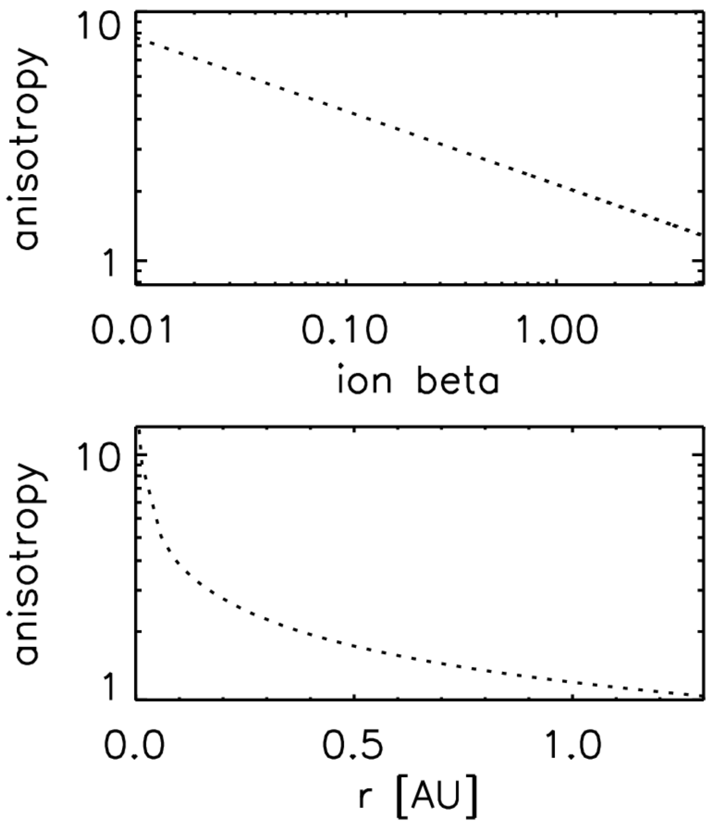
Magnetic energy spectra



Transition time



Wavevector anisotropy



Conclusions

Filamentary structure

- Confirmed by both observations and simulations
- Ion beta as a control parameter (discovery!)

Perpendicular propagating waves

- Ion Bernstein mode
- Kinetic Alfven wave
- Zero-frequency mode
- Whistlers

Implications to astrophysics

- Diagnosis of plasma through studying filaments in interstellar medium (e.g., nebula?)
- We've constructed a reference model for stellar, galactic, and interstellar turbulence!

Ion-scale plasma turbulence