Kavli Institute for Theoretical Physics, Santa Barbara, Mar. 8, 2011

Spatio-temporal structures of solar wind turbulence

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Magnetohydrodynamic turbulence

Navier-Stokes eq.

$$\left(\partial_t - \underbrace{\nu\nabla^2}\right)\vec{v} = -\underbrace{\vec{v}\cdot\nabla}\vec{v} + \vec{b}\underbrace{\cdot\nabla}\vec{b} - \underbrace{\nabla p}$$

Viscosity — Advection — Magnetic tension — Total pressure grad. (thermal and magnetic)

Induction eq. with Ampère's law

$$\left(\partial_t - \underbrace{\eta\nabla^2}\right)\vec{b} = \underbrace{-\vec{v}\cdot\nabla\vec{b} + \vec{b}\cdot\nabla\vec{v}}$$

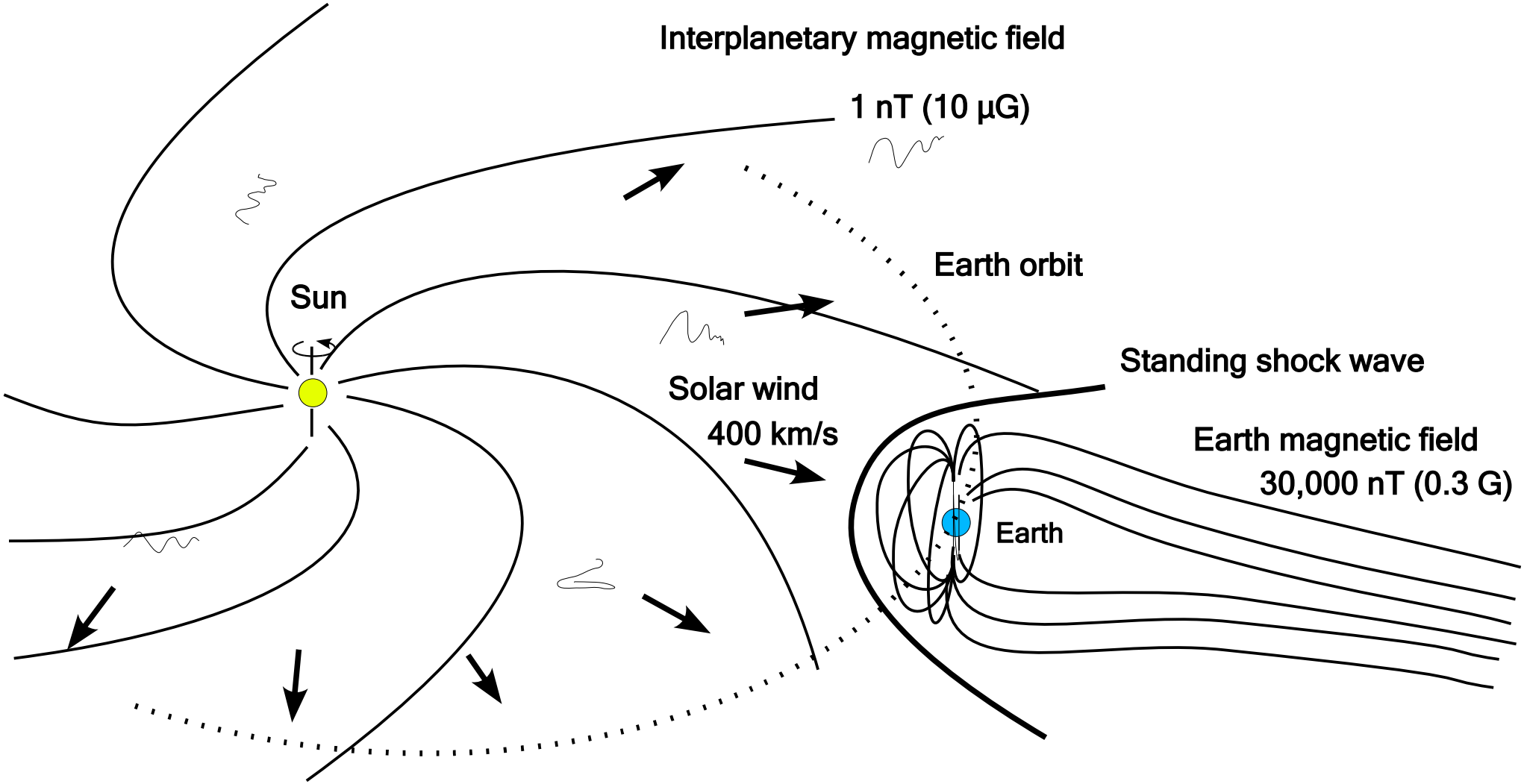
Resistivity — Frozen-in magnetic field

Under conditions:

$$\nabla\underbrace{\cdot\vec{v} = 0} \quad , \quad \nabla\underbrace{\cdot\vec{b} = 0}$$

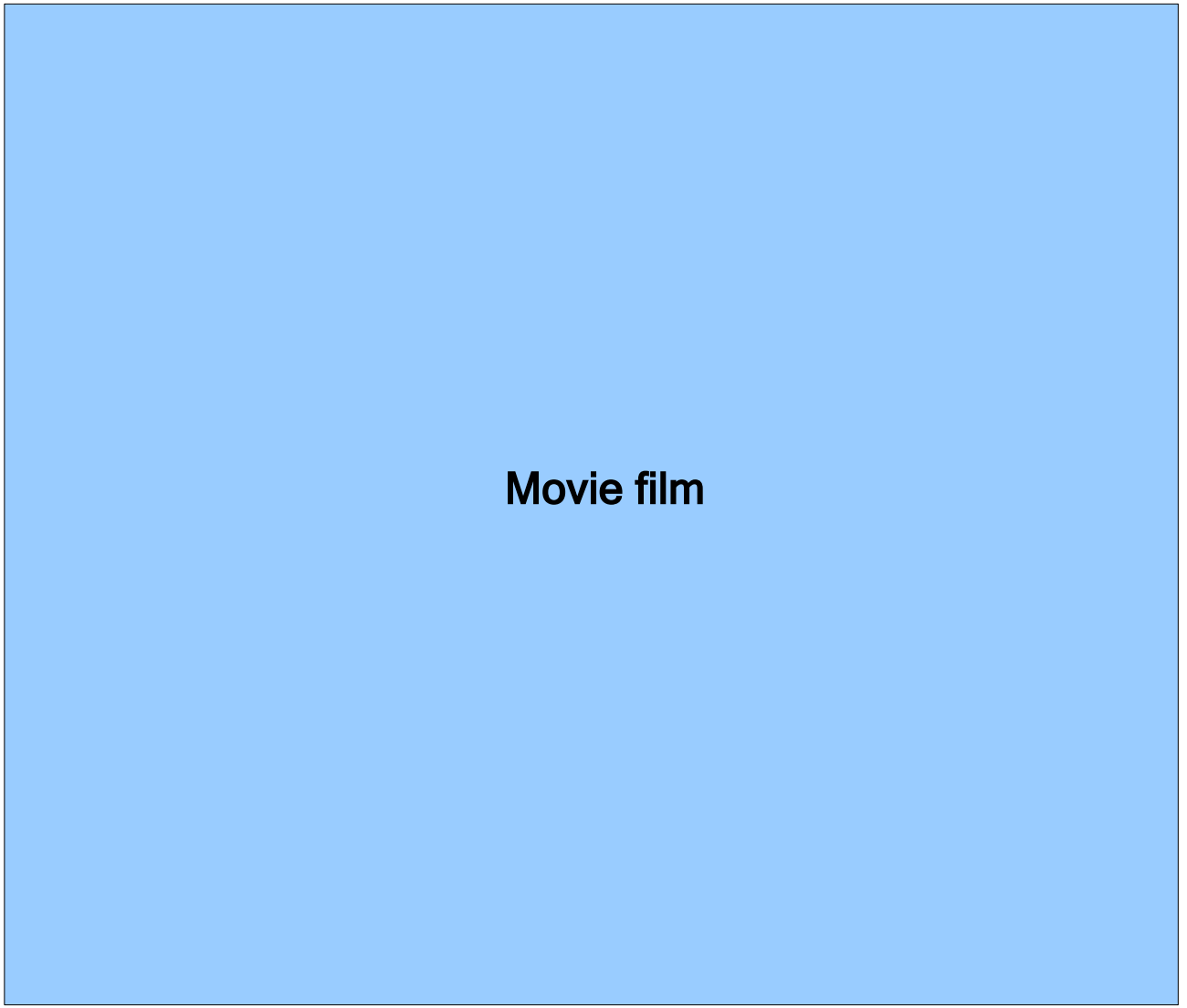
Incompressibility — No magnetic monopole

Near-Earth interplanetary space

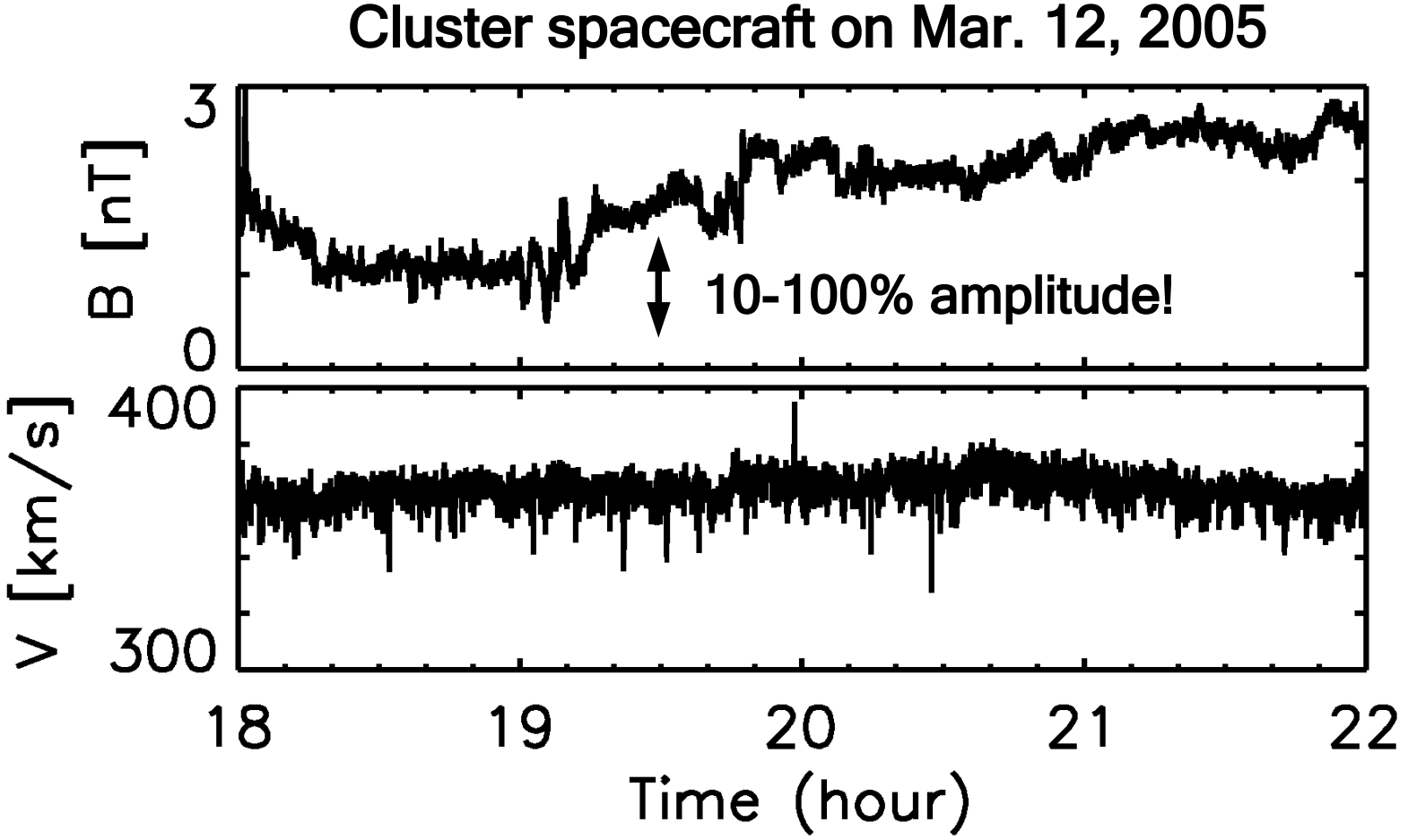


Solar wind is the only accessible natural laboratory of astrophysical plasma turbulence.

Solar corona observed by SOHO spacecraft



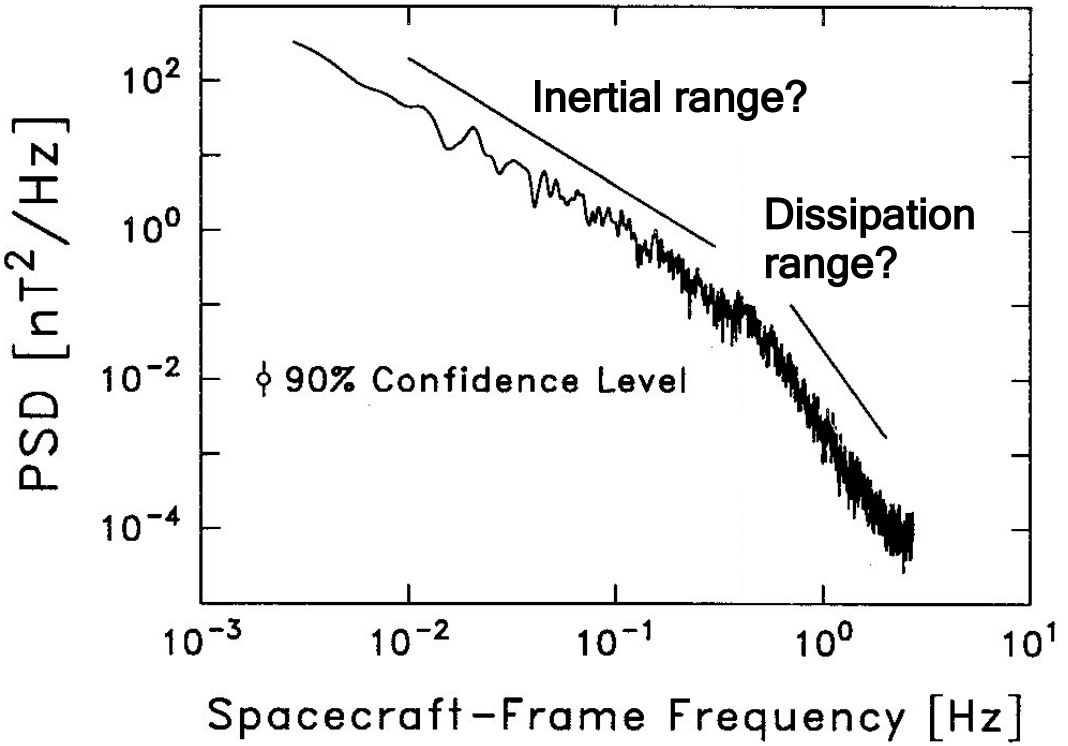
Large-amplitude fluctuations in the solar wind



Are the fluctuations temporal variations or spatial structures swept by the flow?

Turbulence in the solar wind?

Frequency spectrum of magnetic field fluctuations



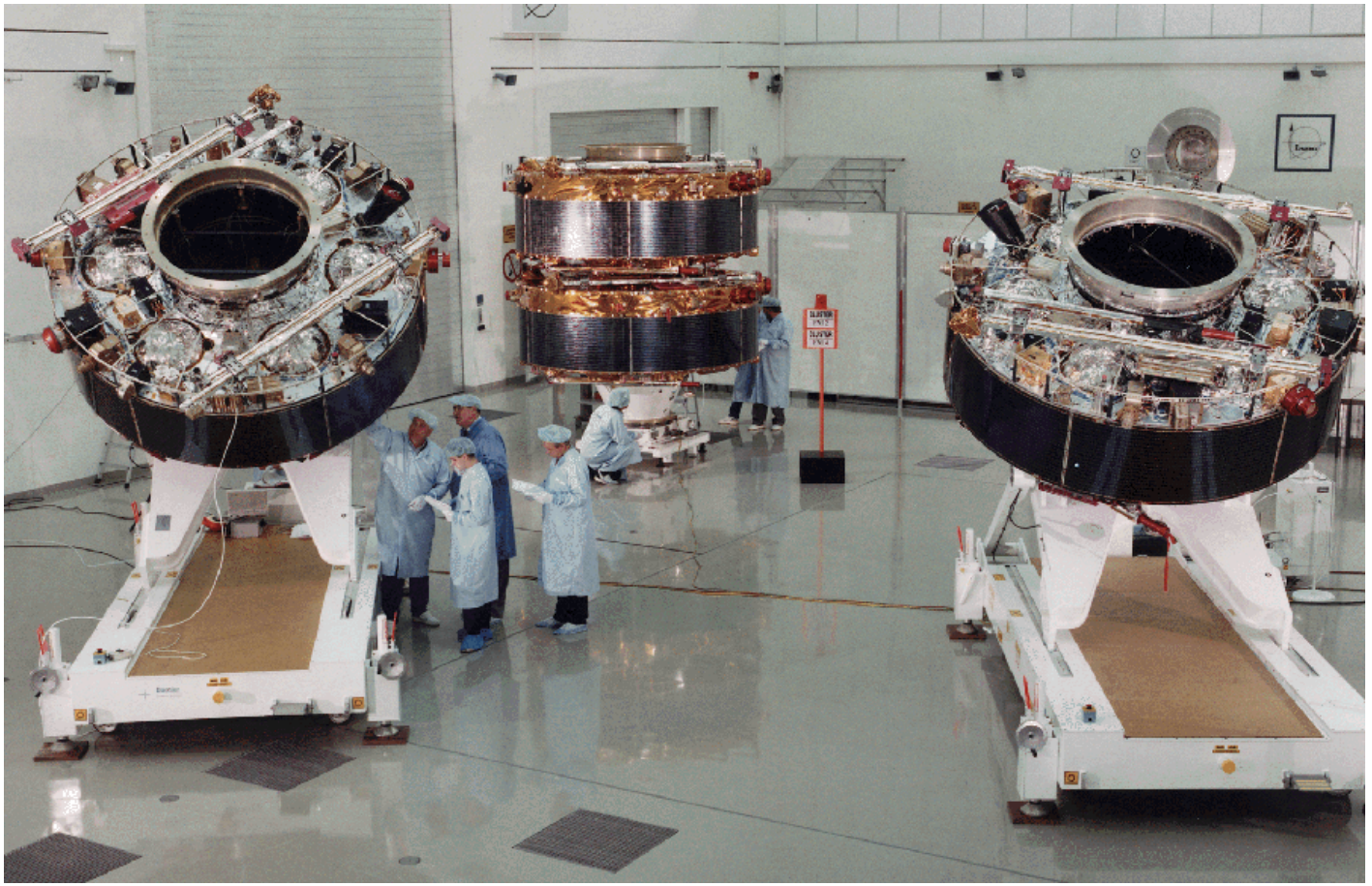
Leamon et al. (1998)

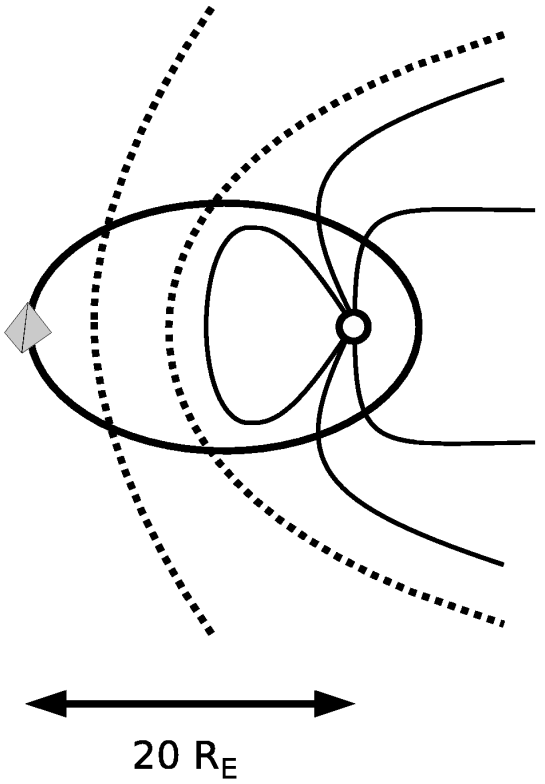
Motivations:

1. Is there any dispersion relation in solar wind turbulence?
2. What does the 3D spatial structure look like?

We can answer these questions using multi-spacecraft measurements!

The Cluster mission



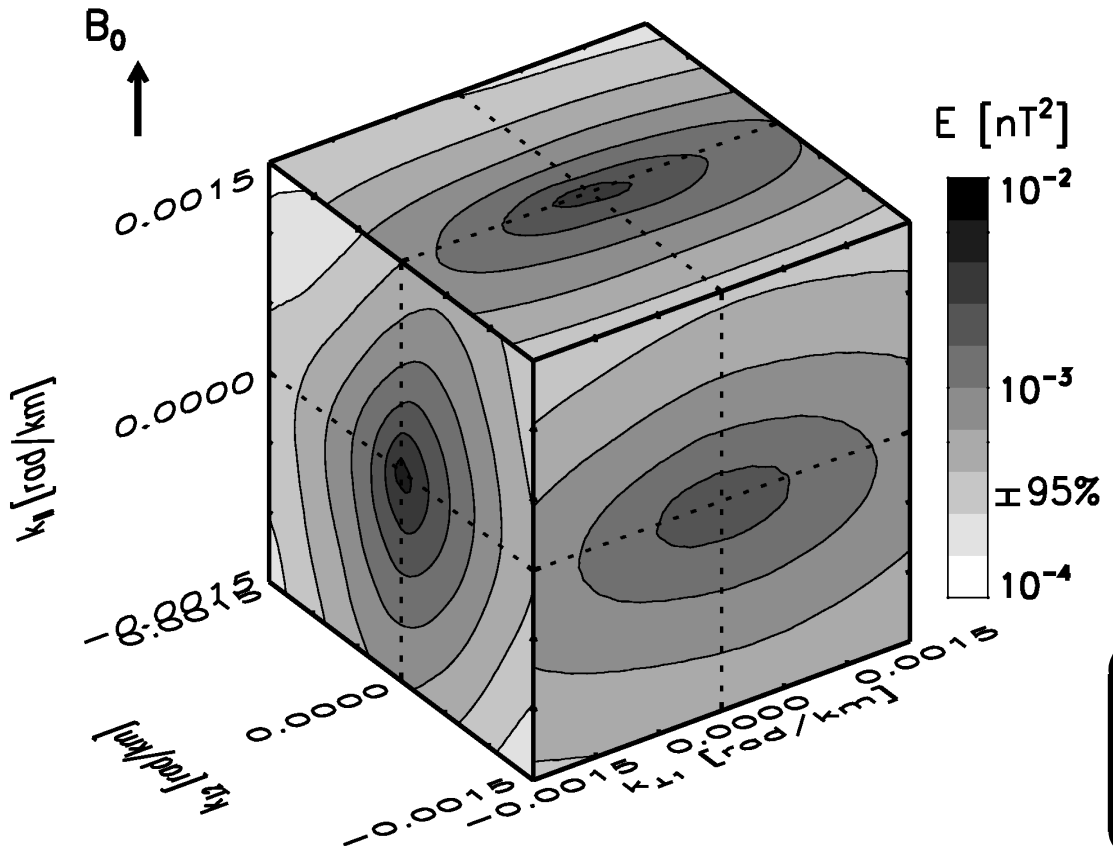


Wavelengths, propagation speeds and directions can be determined (interferometric method).

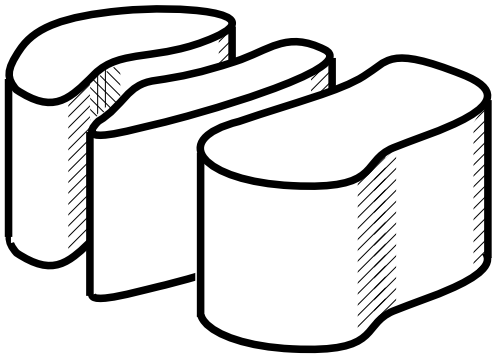
Taylor's hypothesis is no more necessary.

Energy distribution in the wave vector domain

1000 km separation



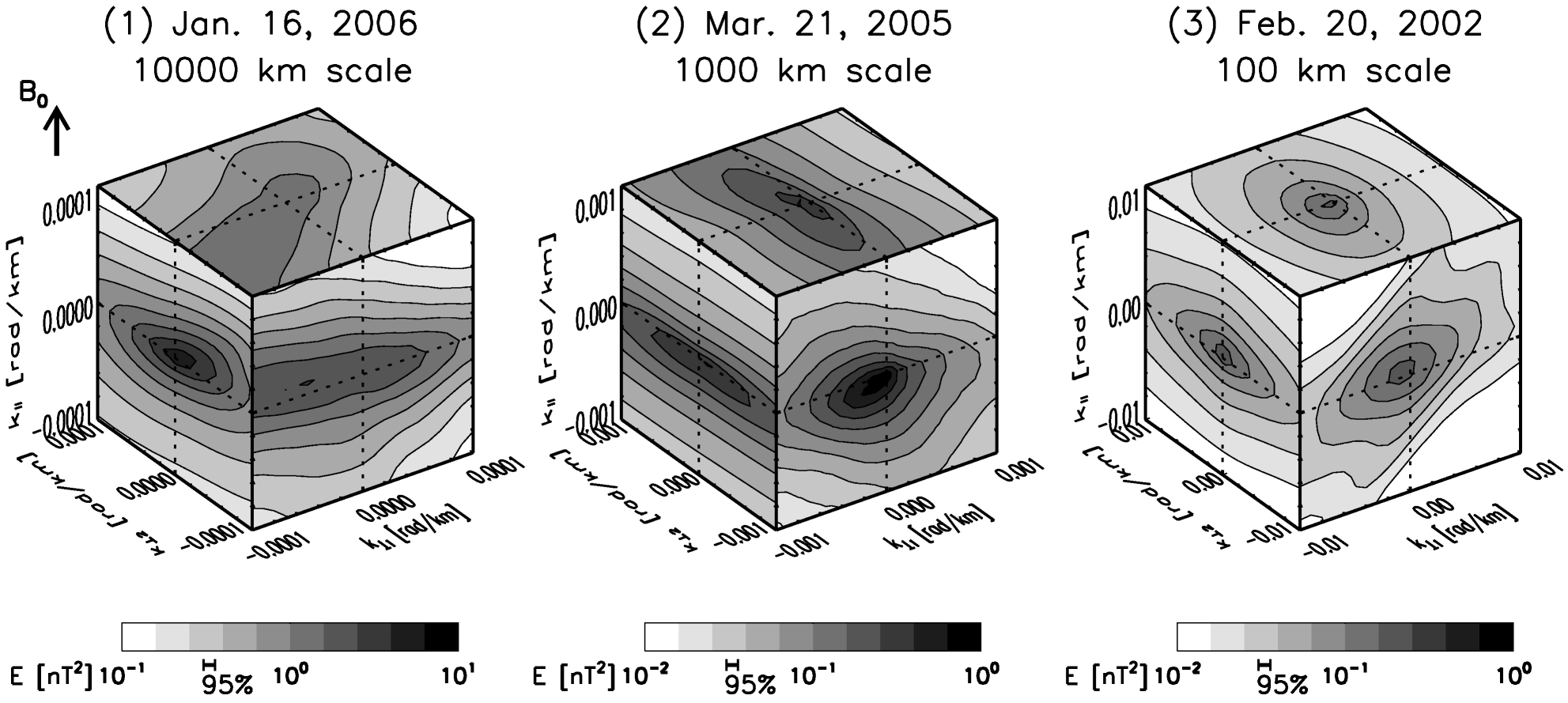
Narita et al. (PRL,2010)



Two discoveries:

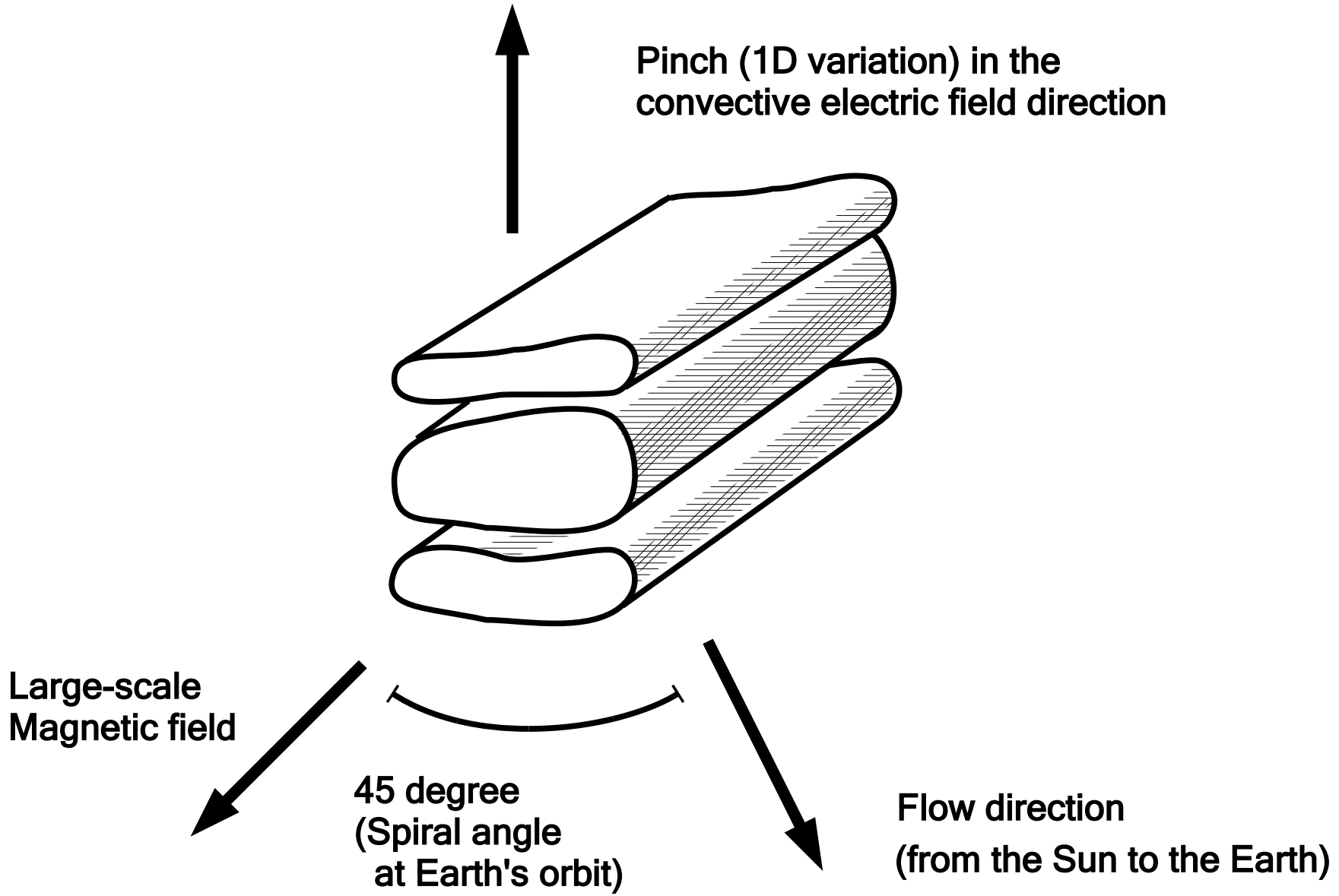
1. Asymmetry around the large-scale magnetic field
2. Anisotropy between parallel and perpendicular directions

More examples of 3D energy distributions

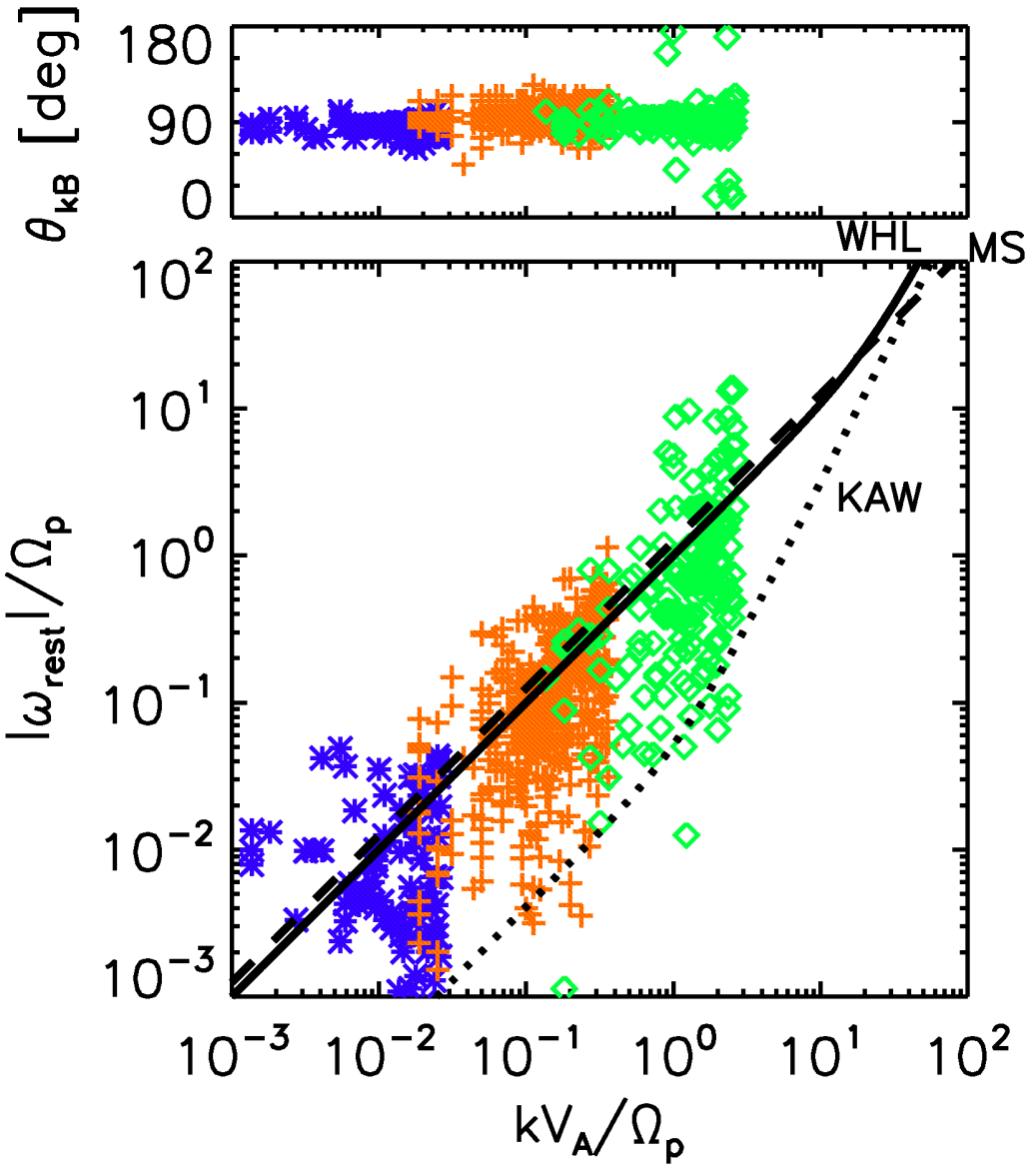


Axial asymmetry exists on various spatial scales.
Anisotropy prefers the direction perpendicular to the large-scale magnetic field.

Fluctuation geometry in the coordinate space



Is there any dispersion relation?



Narita et al. (GRL, 2011)

Summary

ω - *k* dependence of MHD turbulent fluctuations was determined for the first time using Cluster data.

Origin of anisotropy: Perpendicular cascade to the magnetic field?

Origin of axial asymmetry: - Nature of MHD turbulence?
- Radial expansion of solar wind?
- Field structure in the solar corona?

My question to you:

"What does the energy distribution for fluid turbulence look like in the ω - *k* domain?"