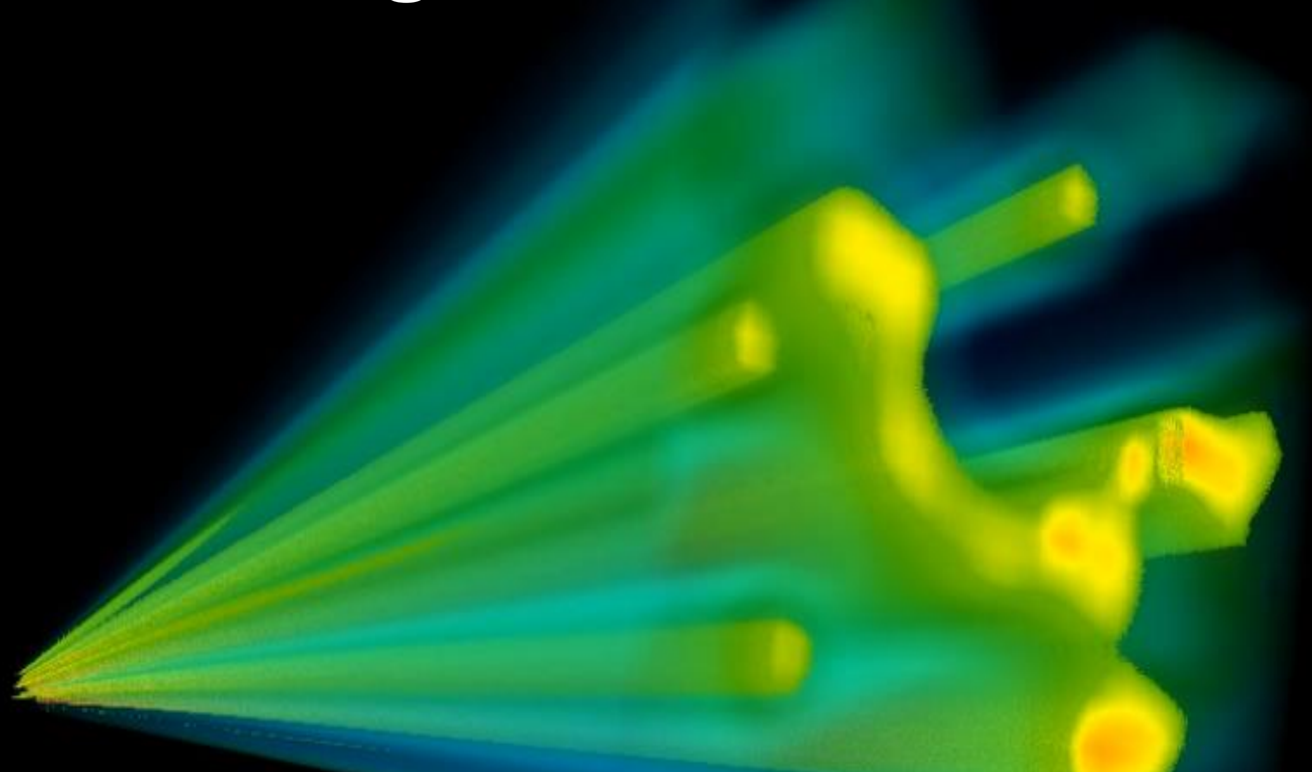
Three-dimensional Simulations of the Inhomogeneous Low Solar Wind



Norbert Magyar

FWO postdoctoral fellow

KU Leuven

Belgium

ESPM-16

9th of Sept. 2021

Past 3D solar wind simulations:

- **Global models**

  - Driven by approximated equations for Alfvén waves and their turbulent dissipation (e.g. AWSOM, Van Der Holst et al. 2014, MAS, J. Linker et al., PSI)

- **Reduced MHD models**

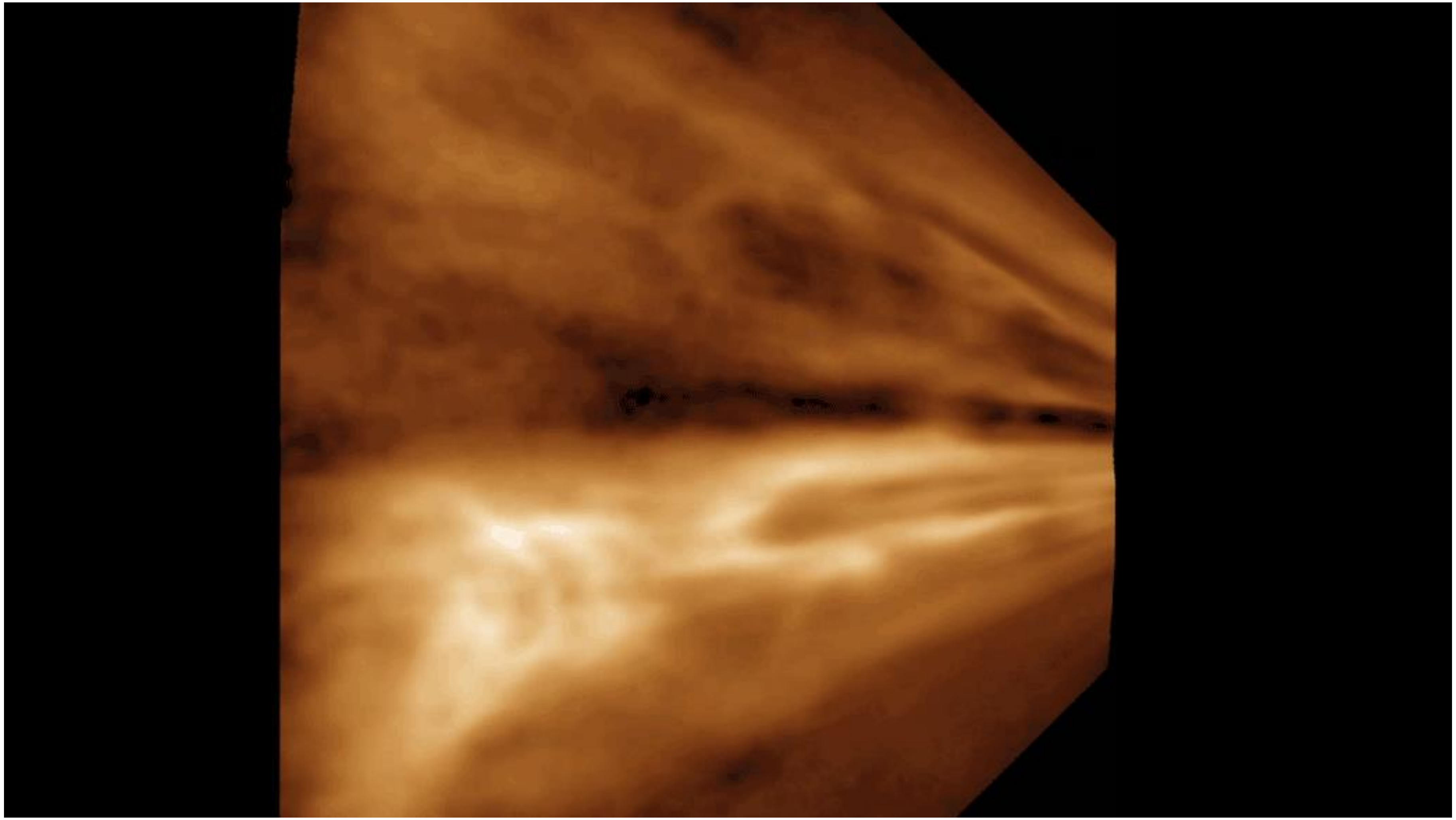
  - No background inhomogeneity across the magnetic field, no velocity perturbation along the field. Basically, Alfvén wave dynamics and turbulence (Van Ballegooijen & Asgari-Targhi 2016, Chandran & Perez 2019, etc.)

- **Compressible MHD**

  - Considering full compressible MHD dynamics, no background inhomogeneity across the field (e.g. Shoda et al. 2019, Matsumoto et al. 2021)

The solar wind is inhomogeneous across **B**

4 to 10
Solar radii



Data credit: (STEREO-A)/COR2, Craig DeForest, SwRI

KU LEUVEN

Inhomogeneous MHD allows for:

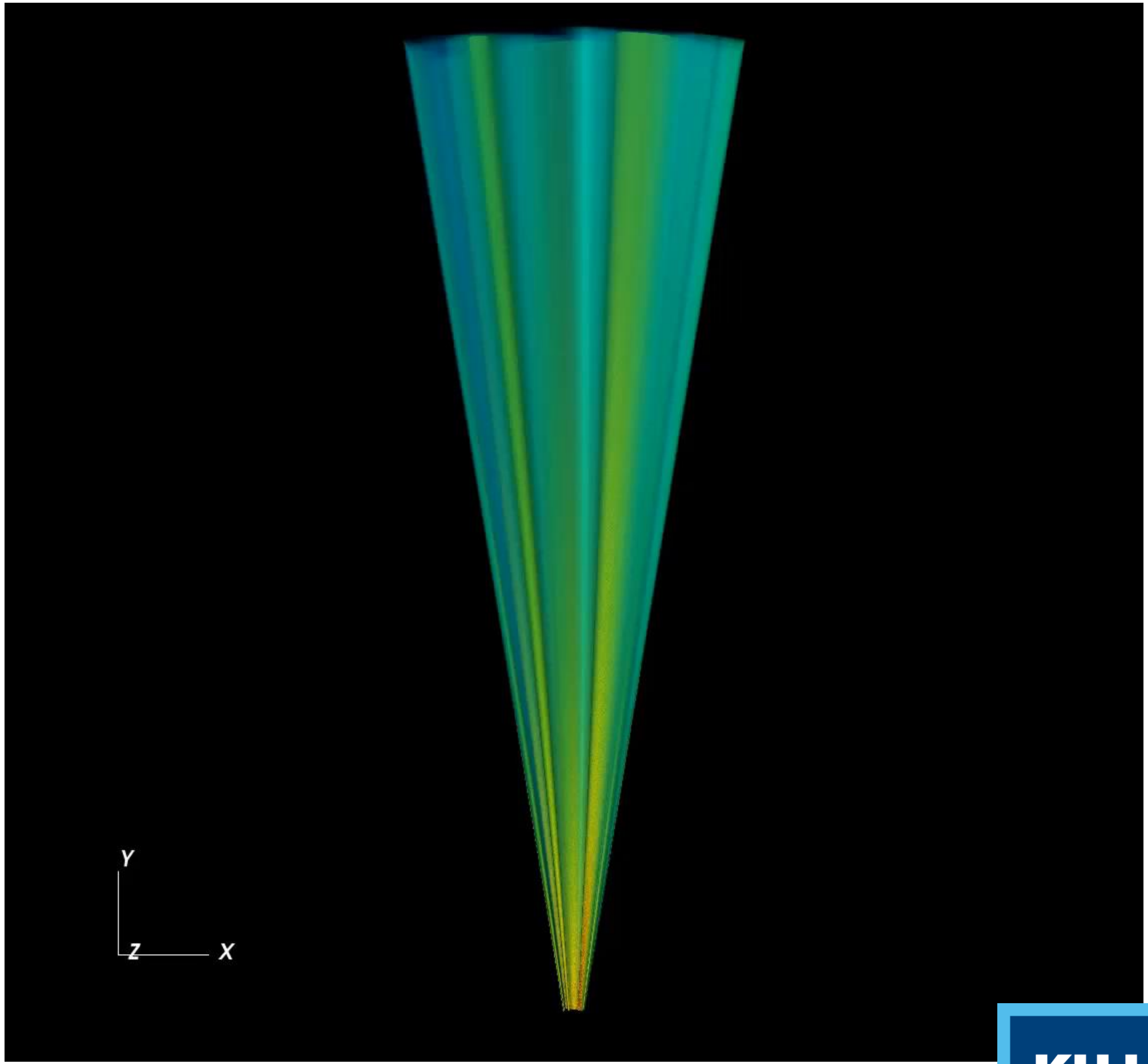
- Surface and body (global) waves (e.g., surface Alfvén, kink)
- Mode coupling (res. absorption) and mixed properties
- Phase mixing
- **Turbulence of unidirectionally propagating waves** (Magyar et al. 2017,2019; Van Doorsselaere et al. 2020)

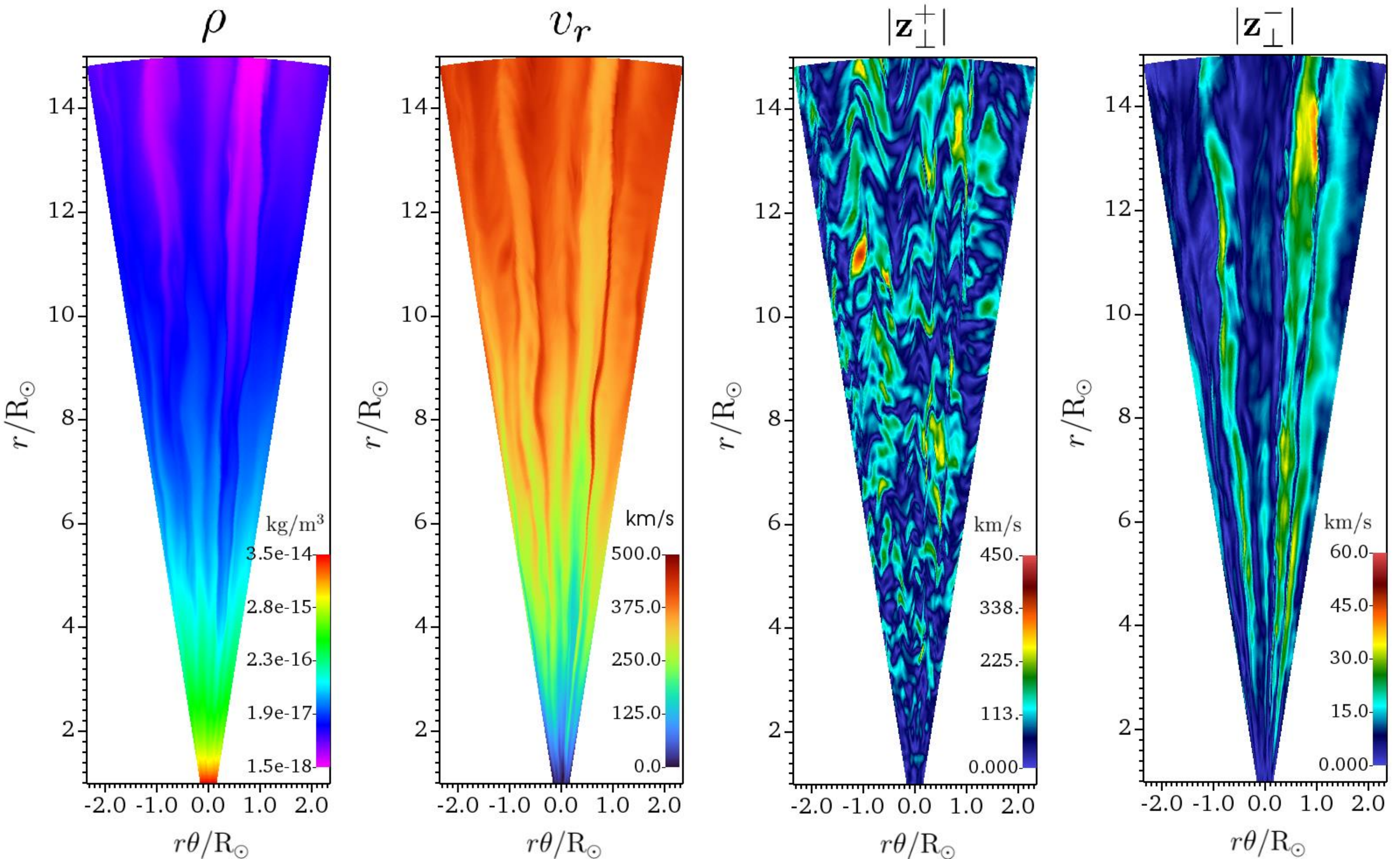
fwo

KU LEUVEN

Inhomogeneous 3D MHD solar wind simulation:

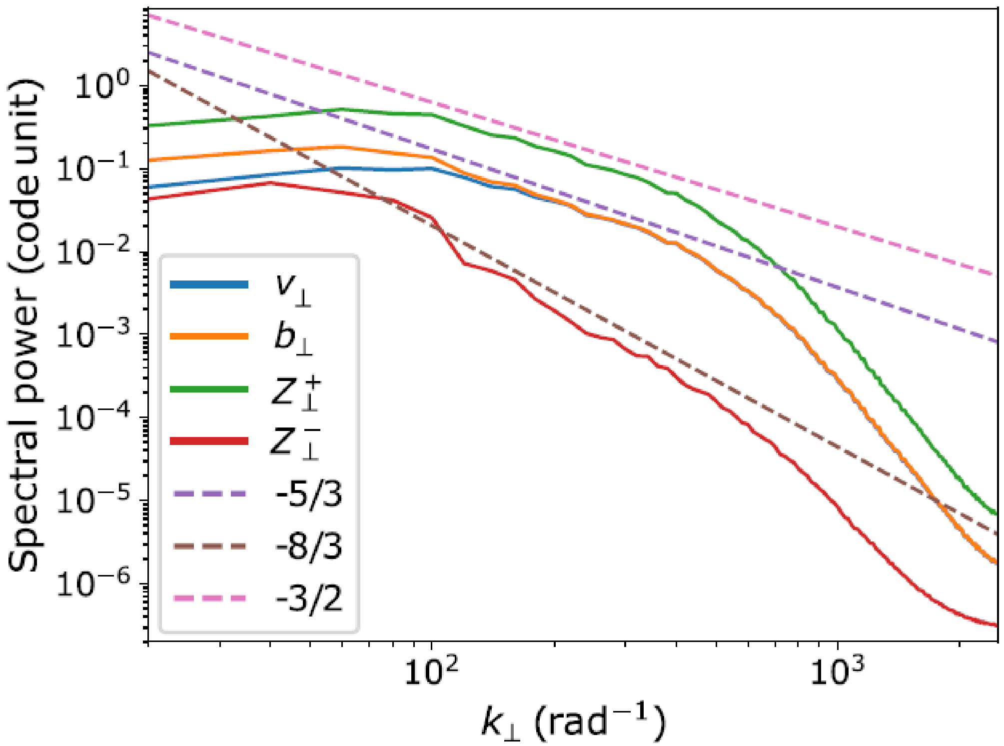
- MPI-AMRVAC
- Full 3D MHD
- 1.07 to 15 R⊙
- 18° wide
- Alfvén point at 12 R⊙
- Relaxed to steady inhomogen. wind
- Driver with k=1-4 at bottom bound.
- Vrms ≈ 15 km/s
- 1024x256^2

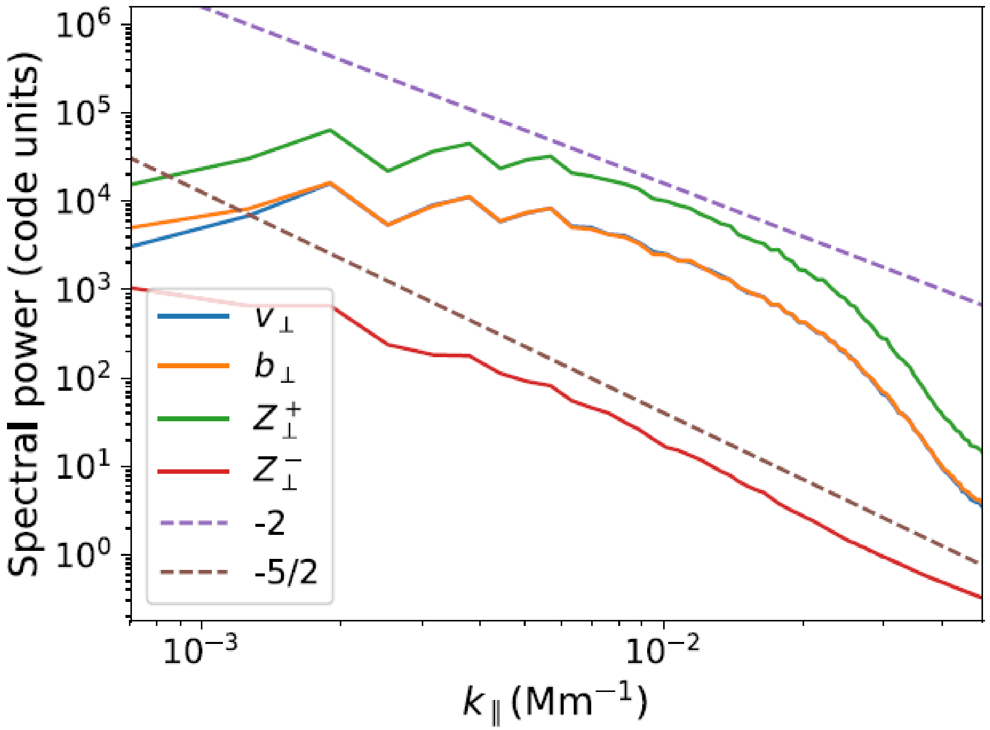




ρ
v_r
$|\mathbf{z}_\perp^+|$
$|\mathbf{z}_\perp^-|$
$r/R_\odot$
$r\theta/R_\odot$
kg/m³
3.5e-14
2.8e-15
2.3e-16
1.9e-17
1.5e-18
km/s
500.0
375.0
250.0
125.0
0.0
450.
338.
225.
113.
0.000
60.0
45.0
30.0
15.0
2
4
6
8
10
12
14
-2.0
-1.0
0.0
1.0
2.0

Energy spectra



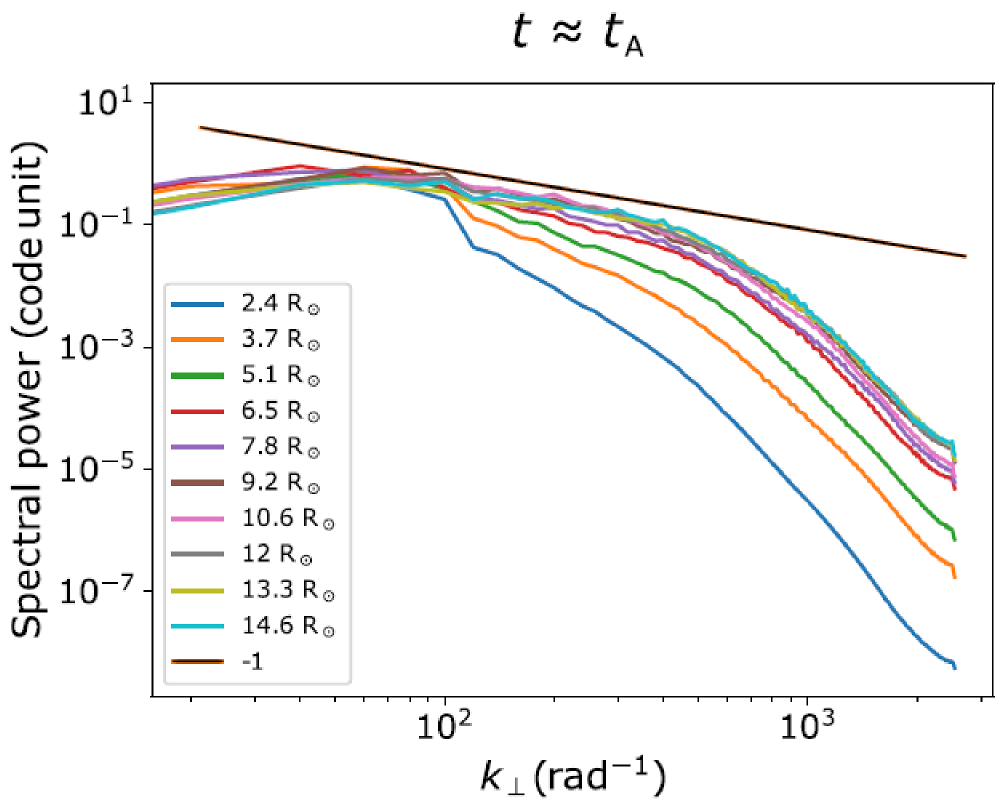


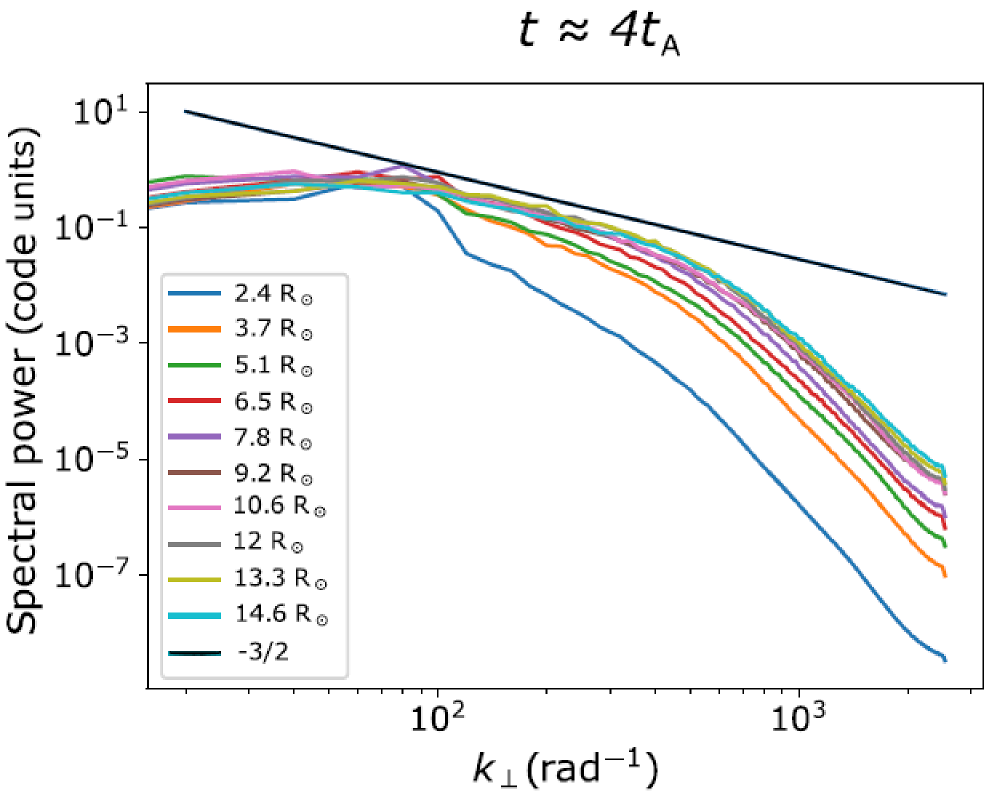
- Perp. Energy spectra -3/2 or -5/3 ✓ Par. energy spectra -2 ✓
- Magnetic field spectra steeper than vel. ✓
- z^-spectra steeper than measured ?

ESPM-16, 9th of September 2021

KU LEUVEN

Energy spectra evolution in time and with r

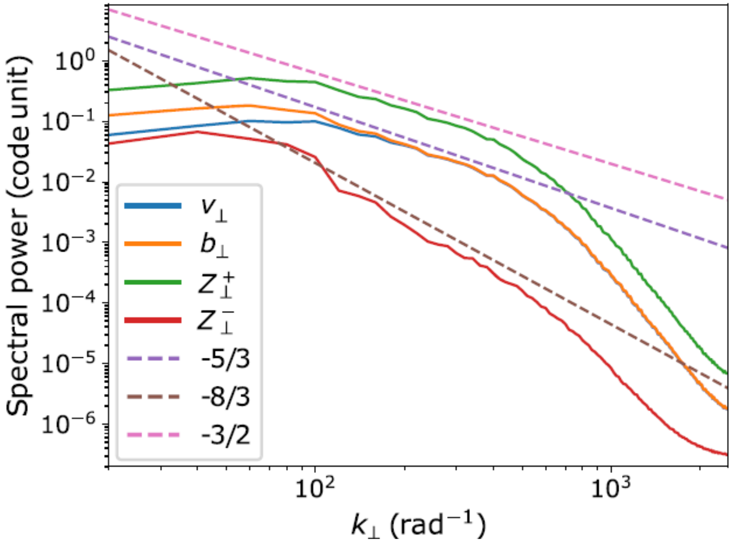




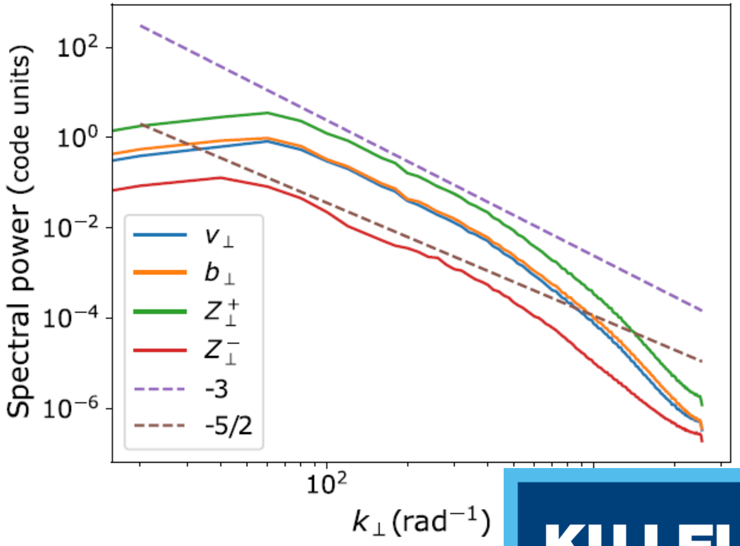
- Initially a 1/f spectrum due to linear phase mixing
- In the statistically steady state, it evolves towards -5/3.

Homogeneous vs. inhomogeneous turbulence

- Same domain, same wave driver, no structuring
- Energy spectra in the homogeneous setup at the end of the simulated time ≈ -3
  - Cascade to smaller scales, both linear and nonlinear, much faster in the inhomogeneous setup → uniturbulence cascade rate higher than AWT.



inhom.



hom.

Conclusions

- Background structuring has a strong effect on the evolution of MHD turbulence in the nascent solar wind, on faster timescales than in the perpendicularly homogeneous case.
- 1/f spectrum may be due to phase mixing of slowly cascading waves.
- Self-cascade of kink waves the dominant nonlinear cascade channel in the pristine solar wind?
- Remaining questions: heating? is the self-cascade identifiable in in-situ data?