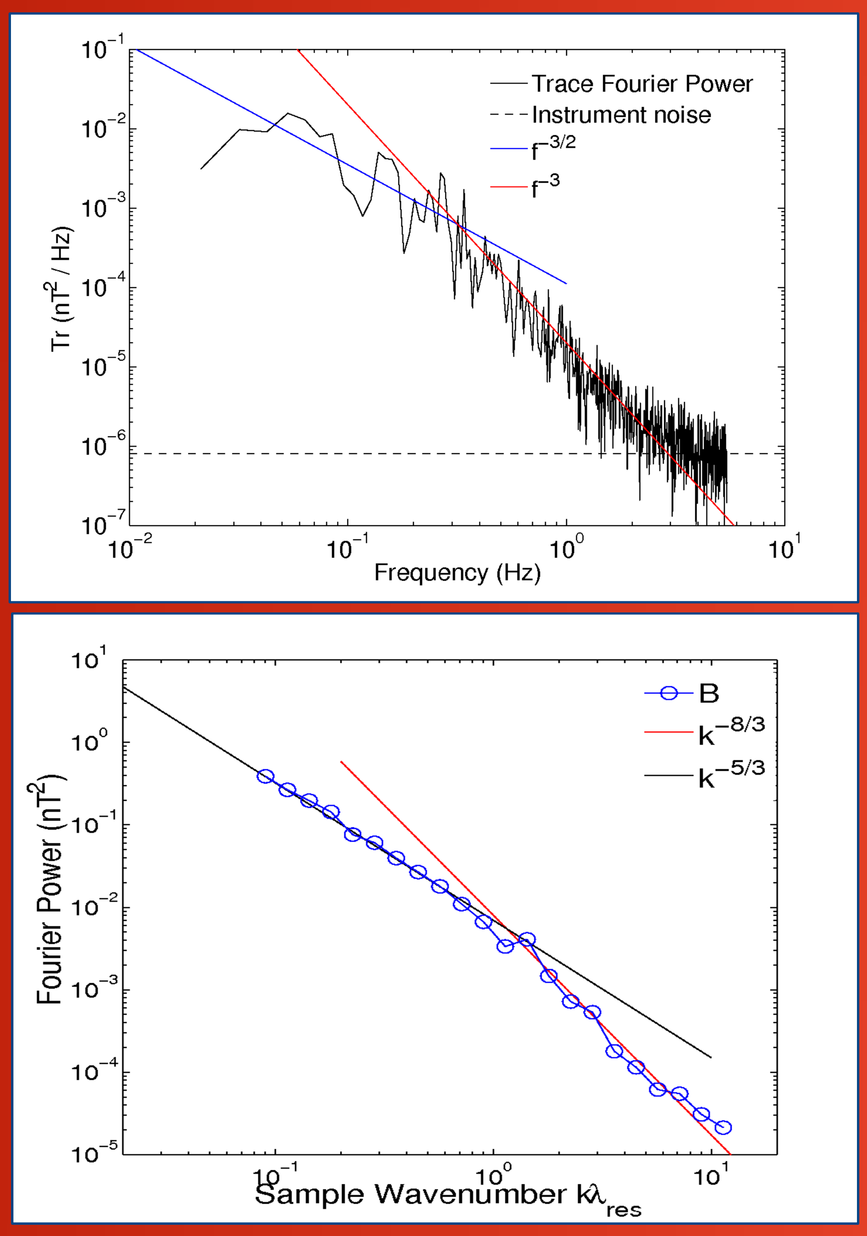
Anisotropic cascade and heating of solar wind He^{++} ions by oblique waves

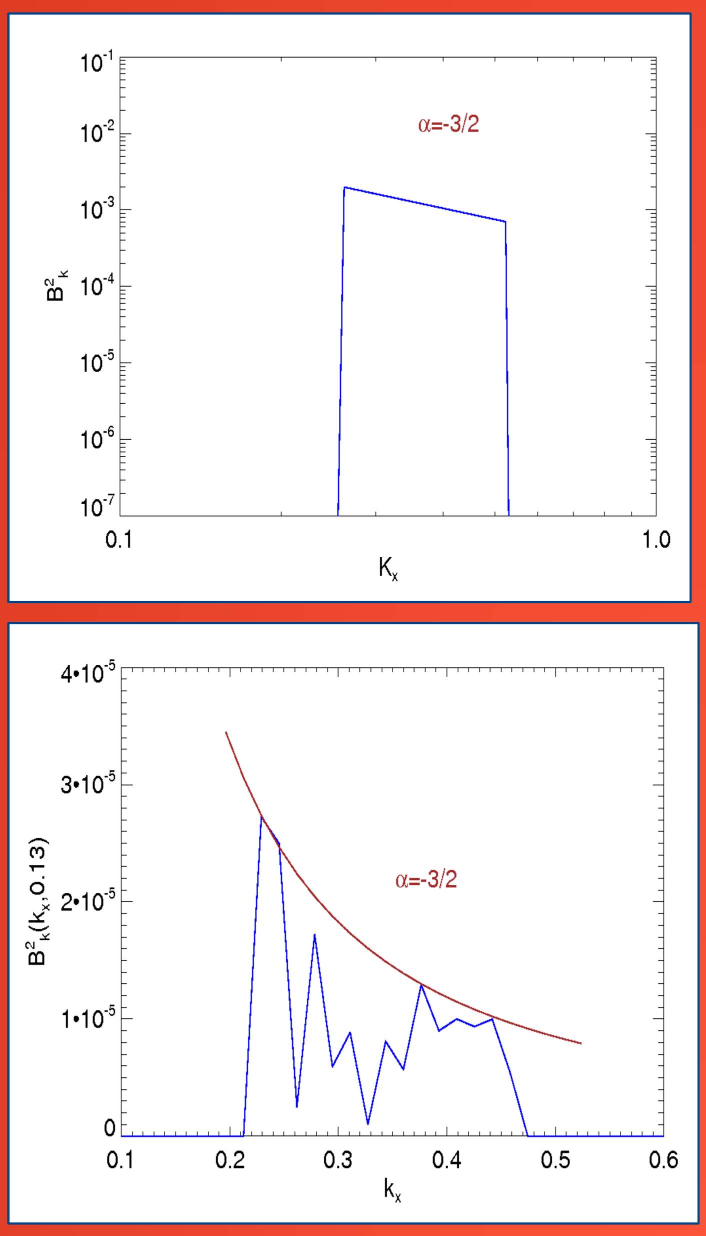
Y. Maneva[1], A. Viñas[2], P. Moya[2], R. Wicks[2] and S. Poedts[1]
[1]CmPA, Department of Mathematics, KU Leuven, Heverlee, BE
[2]Heliospheric Physics Division, Goddard Space Flight Centre, MD, USA
yana.maneva@wis.kuleuven.be; stefaan.poedts@wis.kuleuven.be

Abstract: We perform 2.5D hybrid simulations to study the importance of obliquely propagating Alfven-cyclotron waves for the heating of minor ions in the solar wind. To demonstrate the preferential heating for the minor ions and the onset of temperature anisotropies for both ion species we start with initially isotropic plasma with equal temperatures for the protons and the He++ ions. Next we construct initial broad-band wave spectra to resemble observations of solar wind turbulence at 1 AU. We initialize the simulations with observed ion densities, temperatures and relative drifts, and study the different heating rates resulting from pitch angle scattering and wave-particle interactions between drifting ion populations and parallel or oblique Alfven-cyclotron waves, which propagate along or at an angle with respect to the ambient interplanetary magnetic field. Within the chosen parameter study typical for high beta fast solar wind, the parallel waves appear more efficient in heating the minor ions than the oblique waves. In the course of nonlinear evolution of the system when initial parallel wave spectra is assumed we observe substaintial anisotropic cascade of the magnetic field power spectra towards perpendicular wave numbers. The nature of the anisotropic turbulent cascade depends on the differential streaming between the different ion populations and is affected by the solar wind expansion.

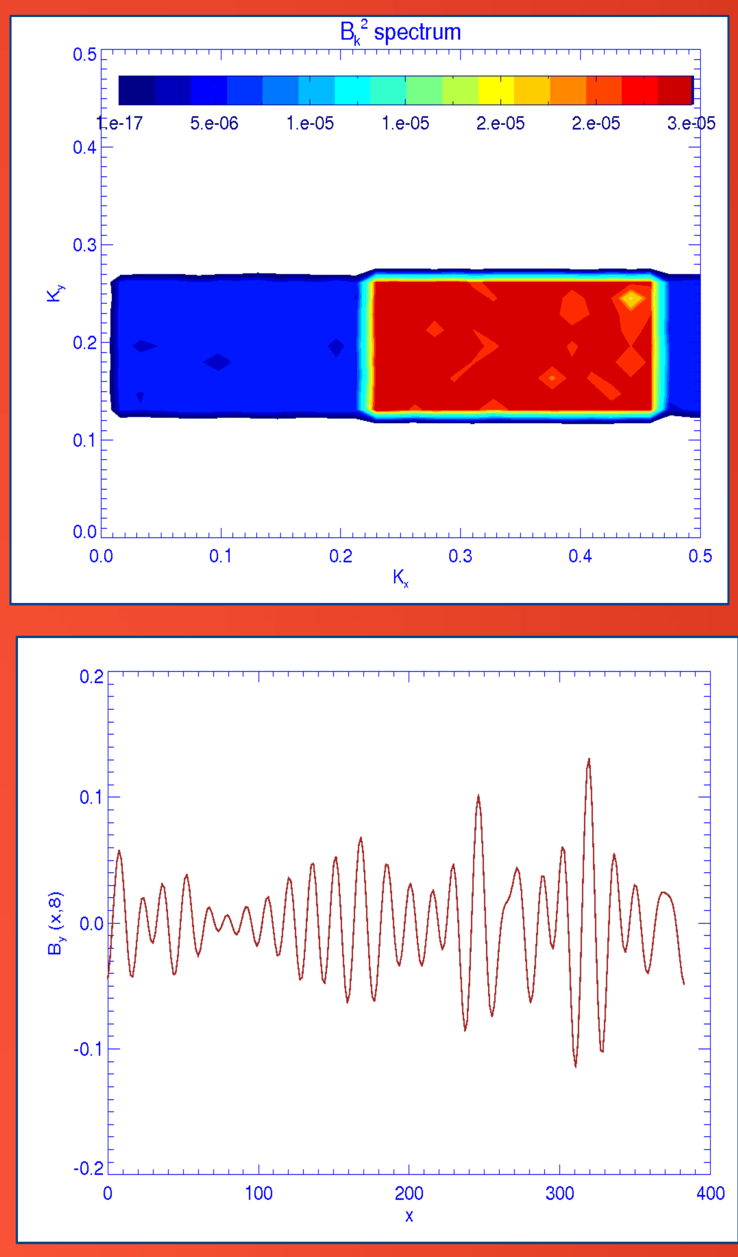
Initial state – *Wind* observations:



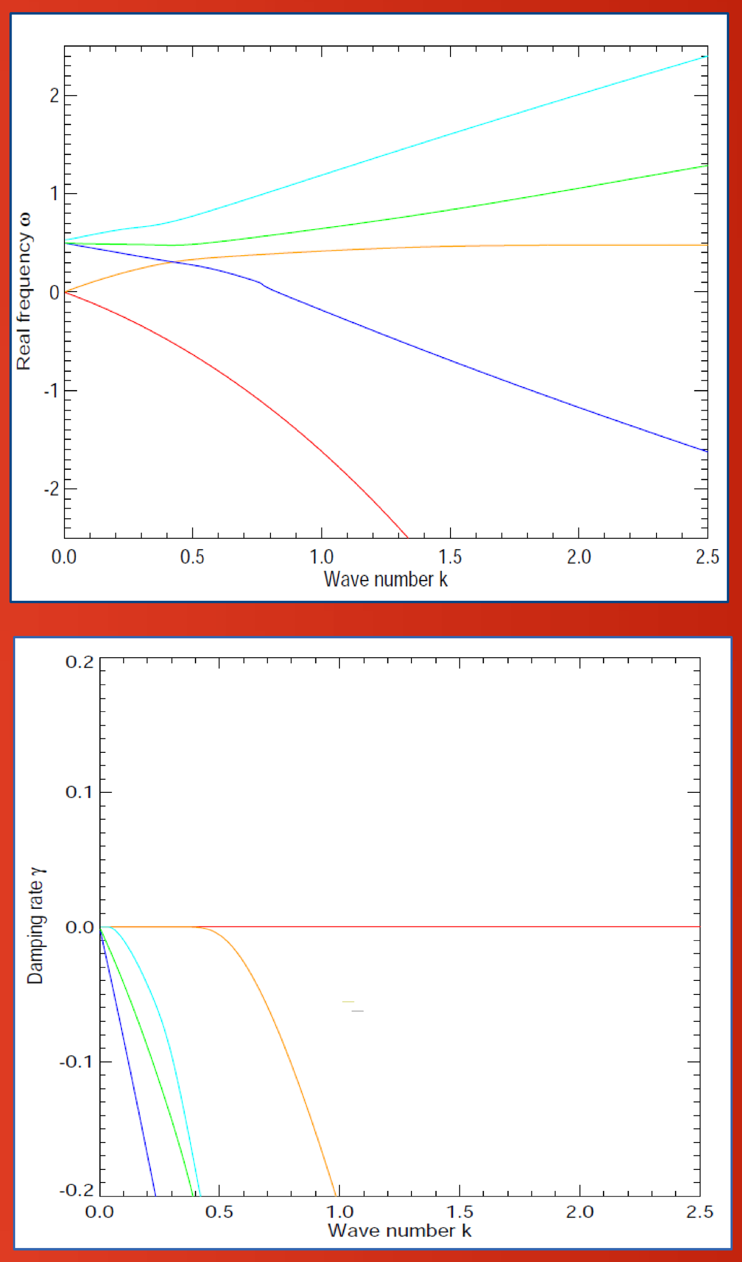
Model reconstruction:



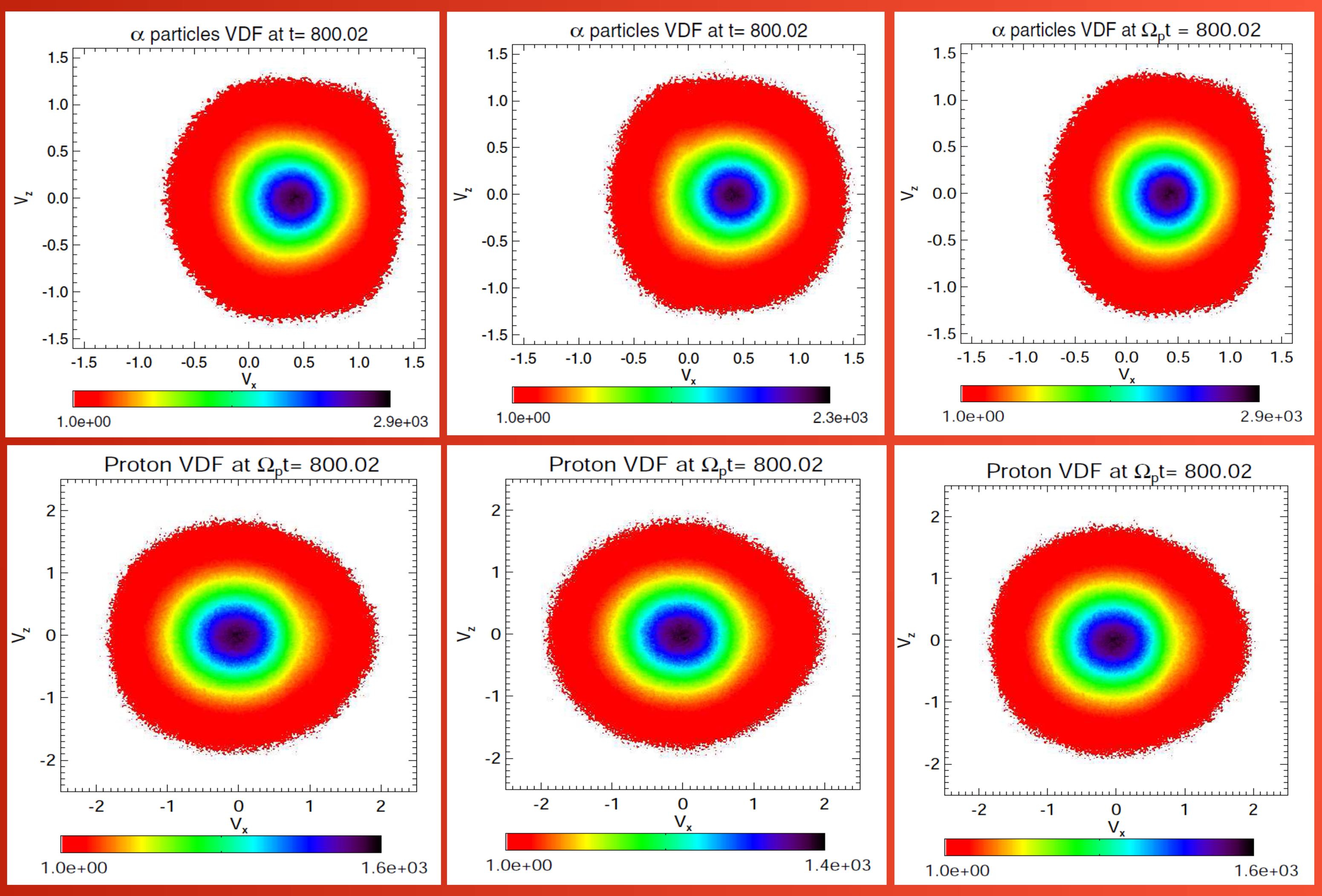
Magnetic field fluctuations:



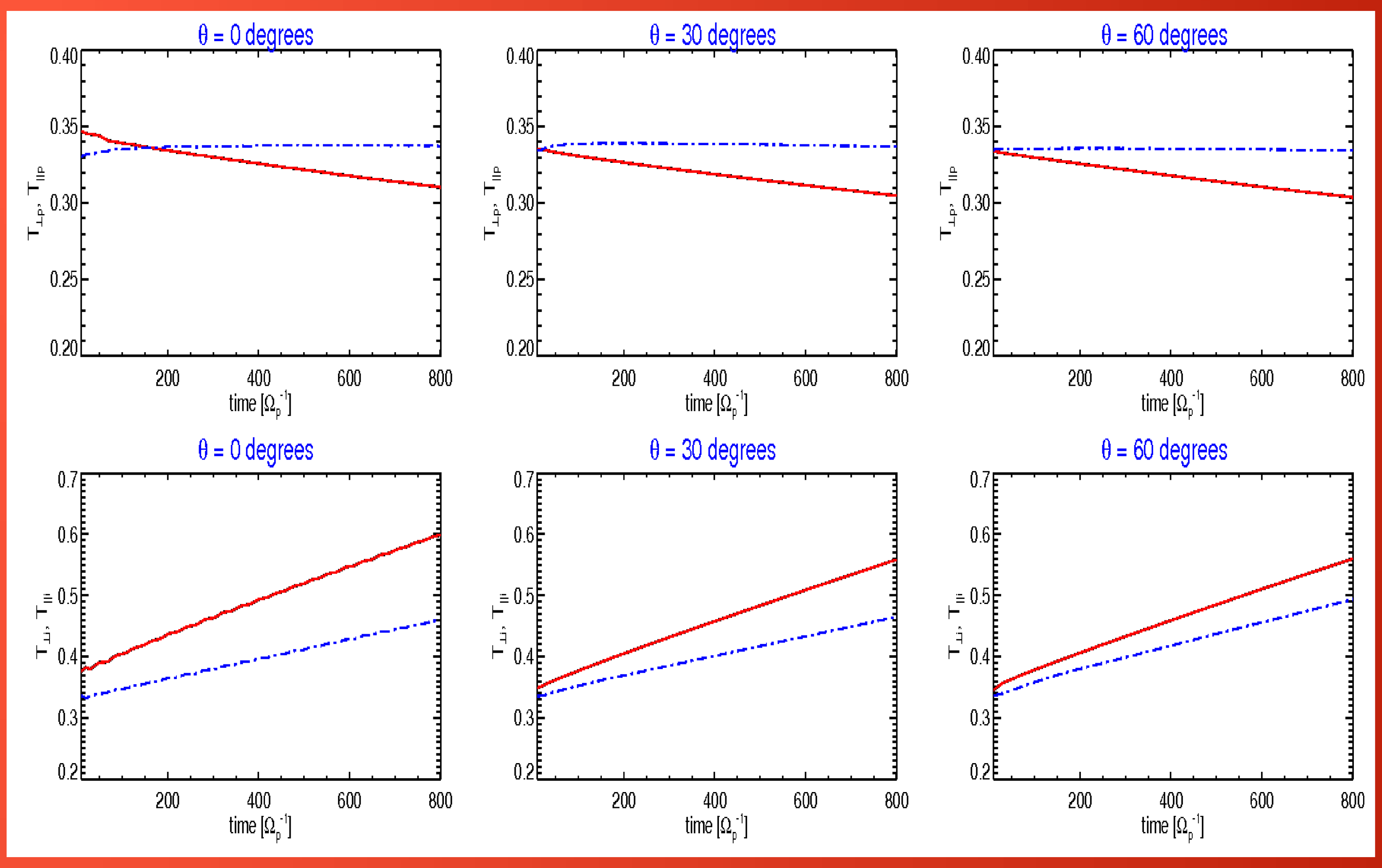
Vlasov solutions:



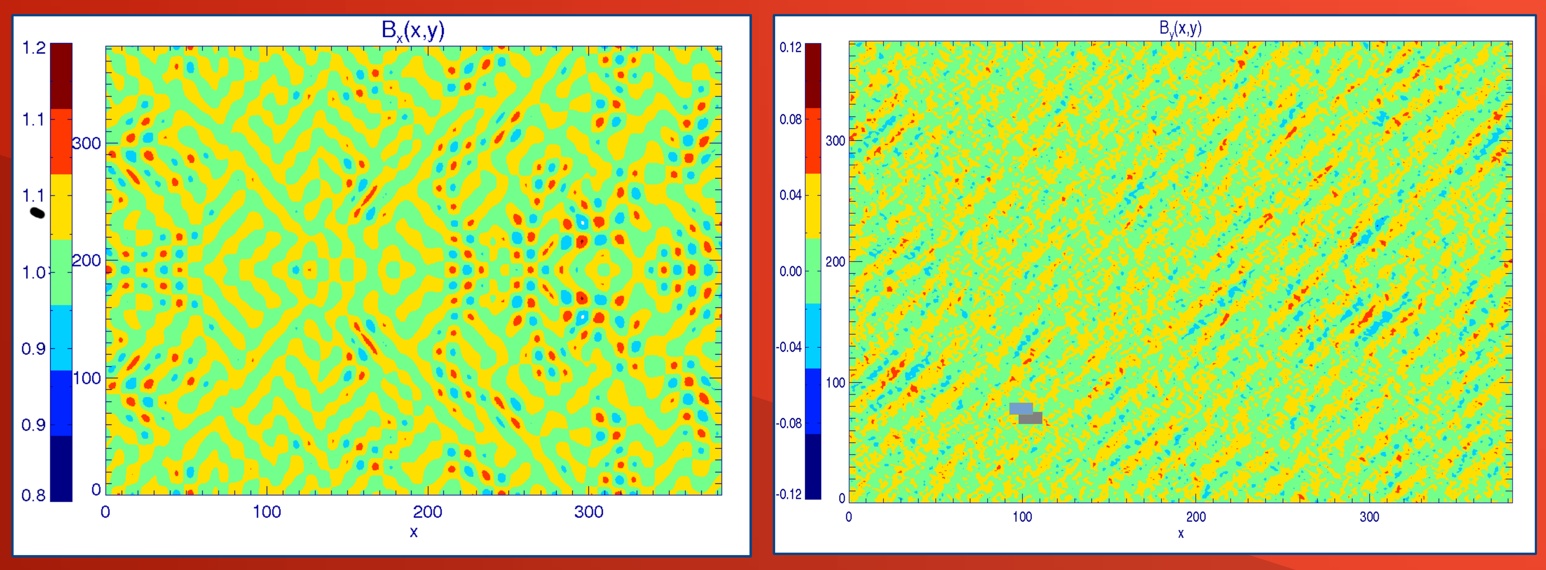
Simulation results – velocity distribution functions:



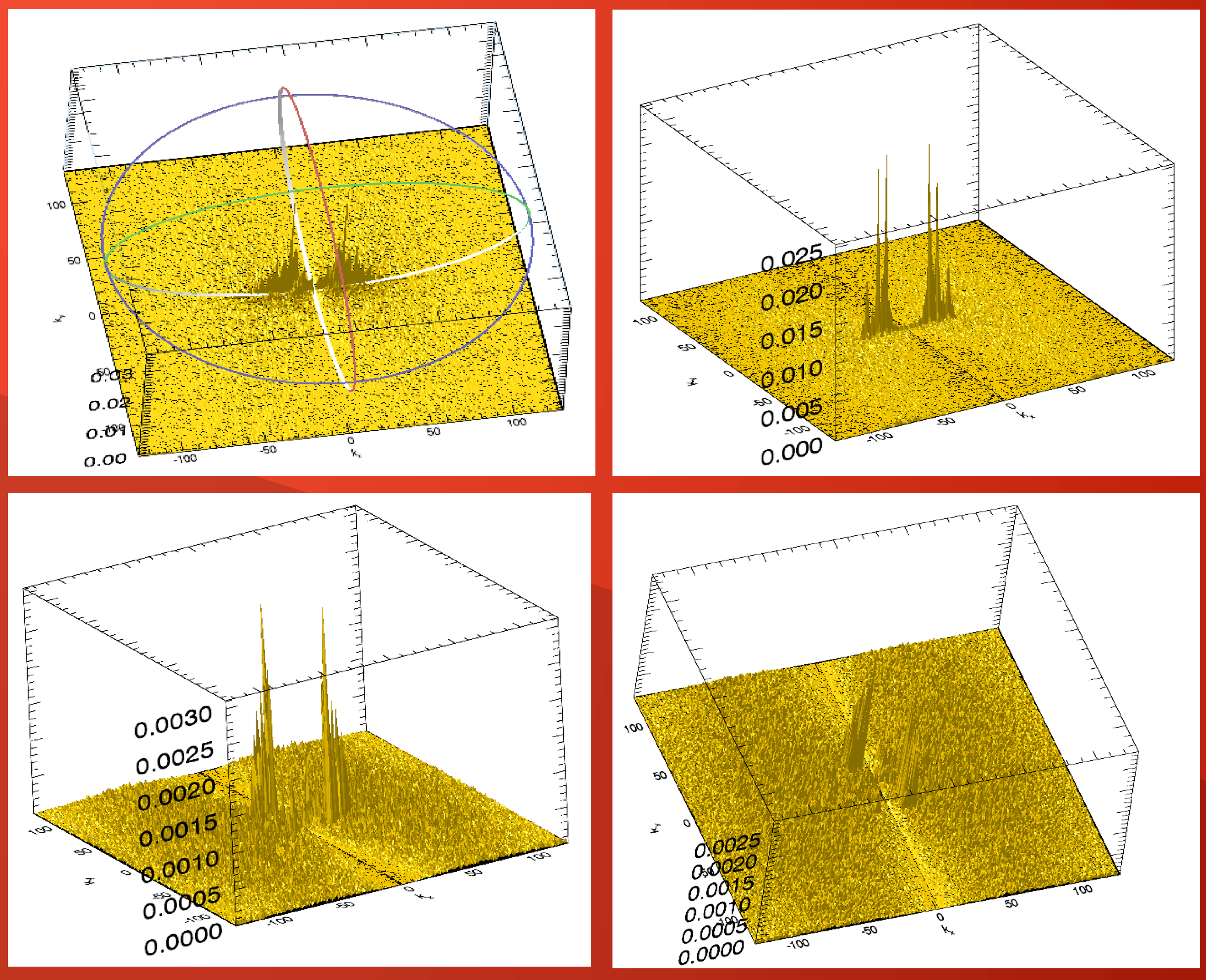
Temperature anisotropies:



Magnetic Field Fluctuations – initial vs. final state:



Magnetic Field Power Spectra:



Conclusions:

We have investigated the ion heating and differential acceleration by broad-band spectra of parallel and oblique Alfven-cyclotron waves in 2.5D hybrid simulations. We have compared the ion heating and acceleration rates corresponding to different angles of propagation (0°, 30°, 60°) and found prominent perpendicular heating for the minor ions, which is strongest in the case of parallel waves. For all cases considered the initially isotropic protons experience strong perpendicular cooling and acquire related parallel temperature anisotropies. Next, we investigate the power spectra of the magnetic fluctuations and find limited turbulent cascade in the perpendicular direction for the parallel case and further oblique mode generation in the oblique case. We further study a gradual solar wind expansion which leads to perpendicular cooling, but overall has insignificant effect on the ion distributions. The velocity distribution functions show signatures of wave scattering, although no prominent beams are formed. We have investigated the evolution of a stable region within the velocity distribution functions of proton and alpha particles in anisotropy- β space. The initial isotropic distributions of the minor ion species interact with the wave spectra and acquire slightly higher perpendicular temperatures. In contrast the protons cool down, as there is no wave energy at the proton scales.

References:

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