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Slow magneto-acoustic wave propagation in 3D simulations of a unipolar solar plage

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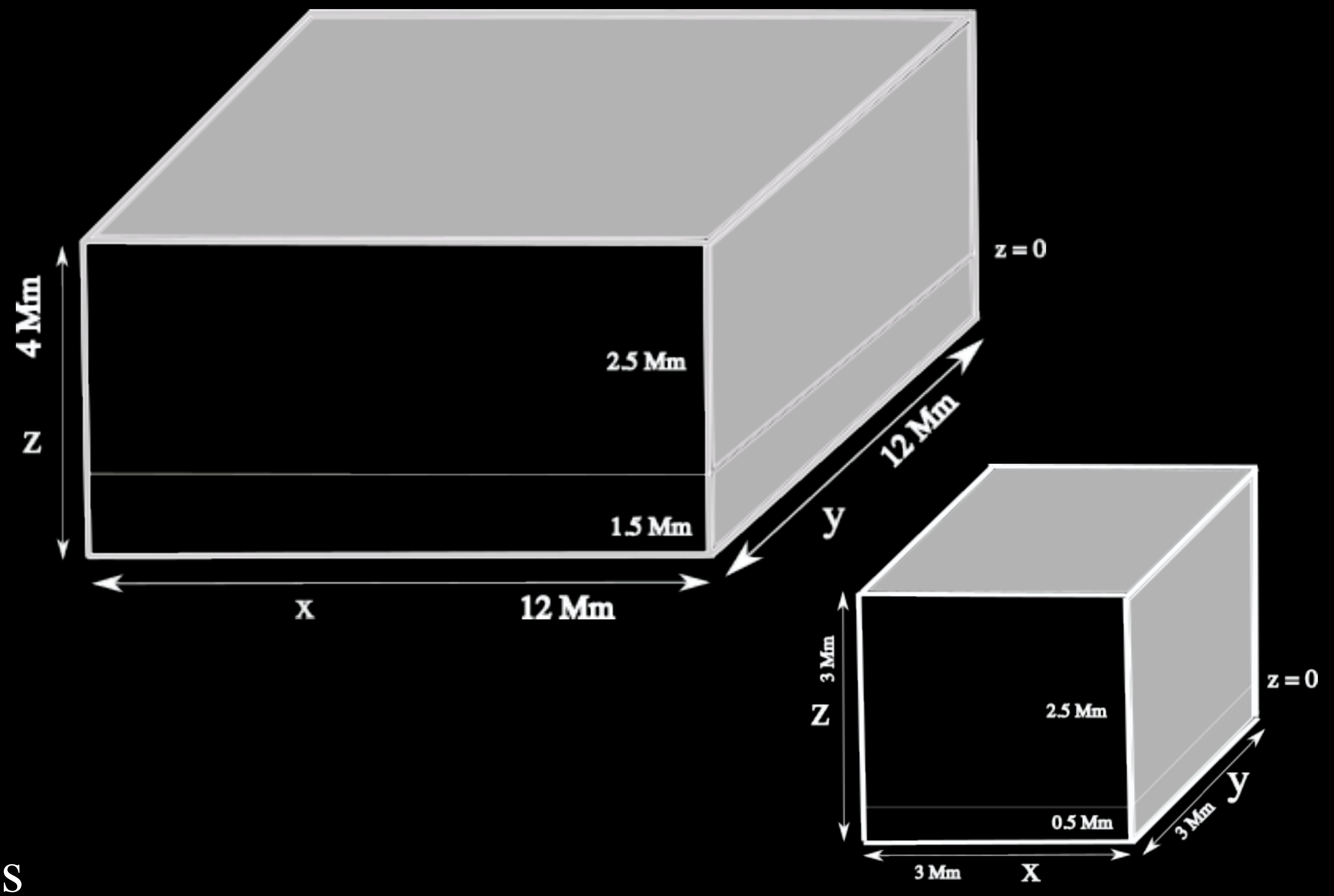
Objective: To investigate slow magneto acoustic waves that are naturally excited in realistic MHD simulations

Simulation Setup: MURaM code

- Dimension: 12Mm x 12Mm x 4 Mm
- Resolution: 1200 x 1200 x 400 (grid points)
- 2 hrs. HD run to reach quasi-stationary state
- Introduced vertical field of 200 Gauss
- Evolved for ~1.2 hour after introducing B
- Used data of a smaller region (3Mm x 3Mm x 3Mm) at 1 s cadence for 25 minutes time-series



Region selection for wave-analysis

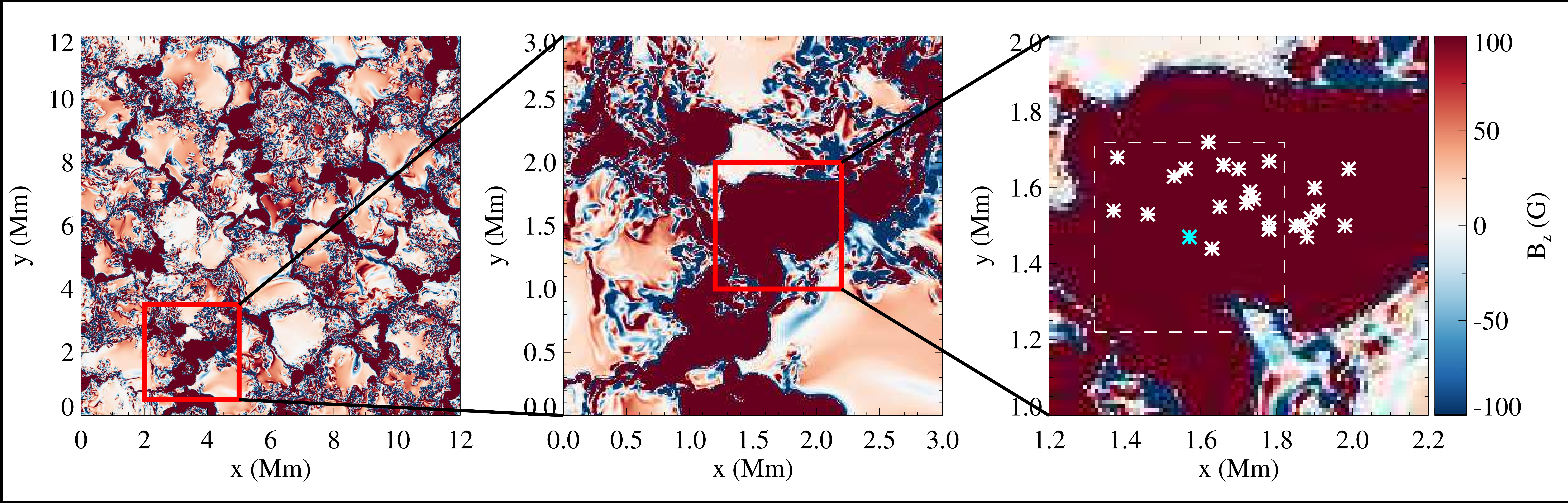
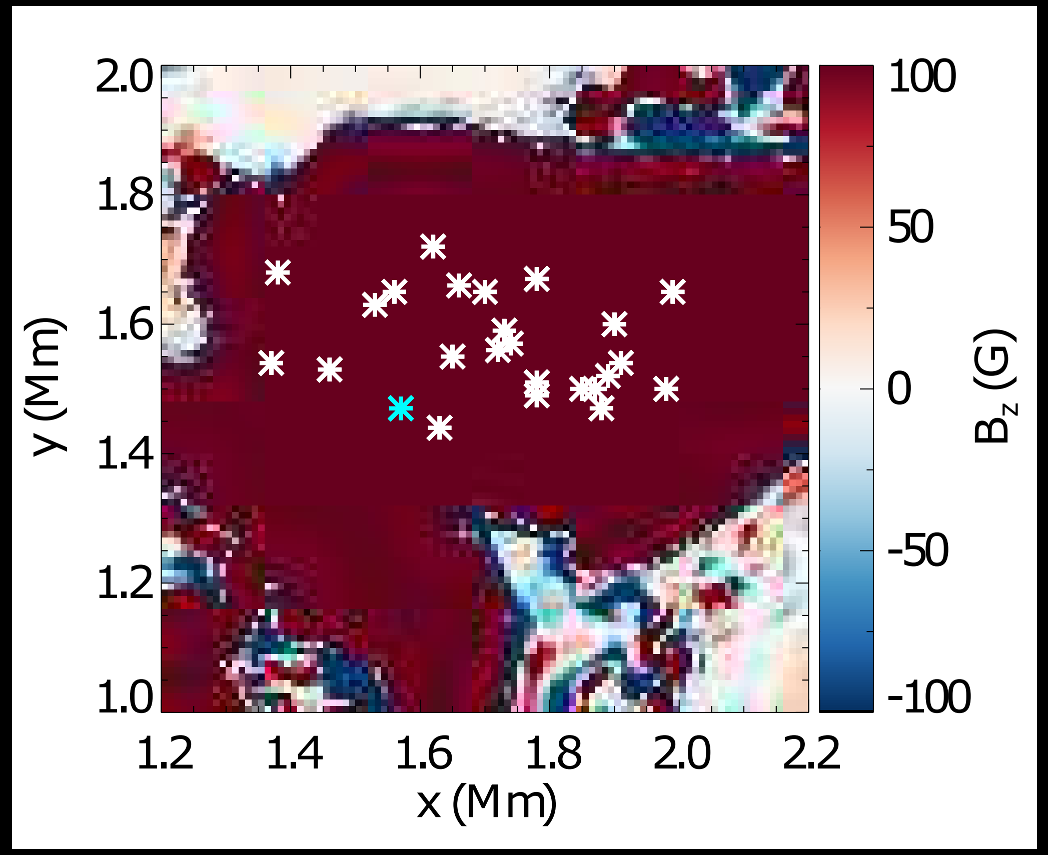


Fig.: Left: 2D map of the vertical component of the magnetic field vector at z=0 layer (corresponding to average $\tau = 1$ layer) covering the whole horizontal extent of the simulation domain (saturated at $\pm$ 100 G), Middle: Blowup displaying the sub-region (red box in the left panel) selected for magneto-acoustic wave analysis. Right: Blowup displaying the seed locations. The dashed square region will be discussed later in the coming slides.

Slow wave propagation



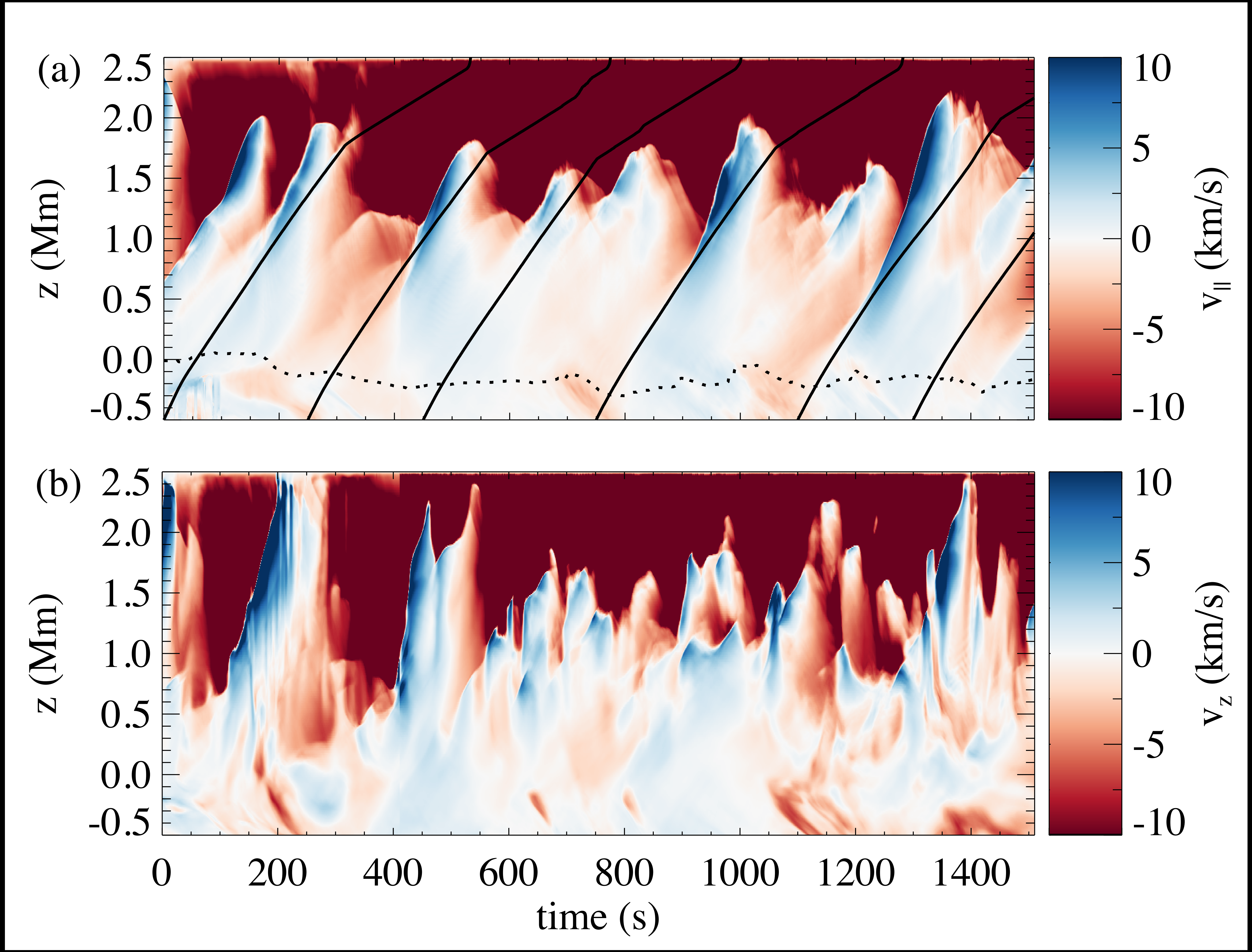
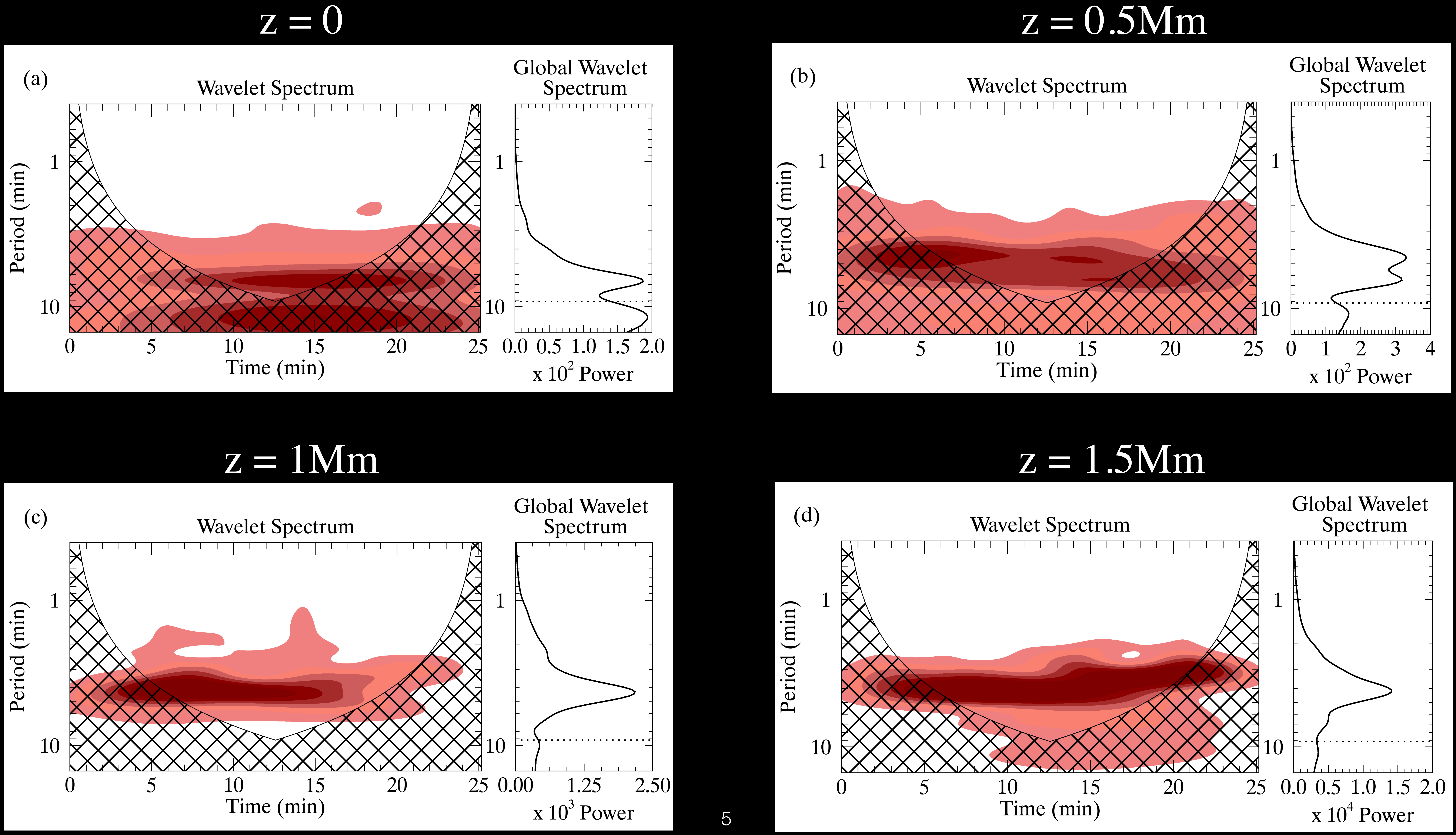


Fig. (a): Height-time map of the component of velocity along a magnetic field line that is tracked in time. The field line initially passing through the seed point identified by the cyan asterisk is considered here.

Local sound speed curves (solid) and a curve showing the height at which $c_s = v_A$ (dotted) are also over-plotted.

(b): Height-time map for a fixed horizontal location i.e. initial seed location without following the magnetic field line for the the seed point shown as cyan asterisk.


z = 0
z = 0.5Mm
z = 1Mm
z = 1.5Mm
(a)
(b)
(c)
(d)
Wavelet Spectrum
Global Wavelet Spectrum
Period (min)
Time (min)
x 10^2 Power
x 10^3 Power
x 10^4 Power

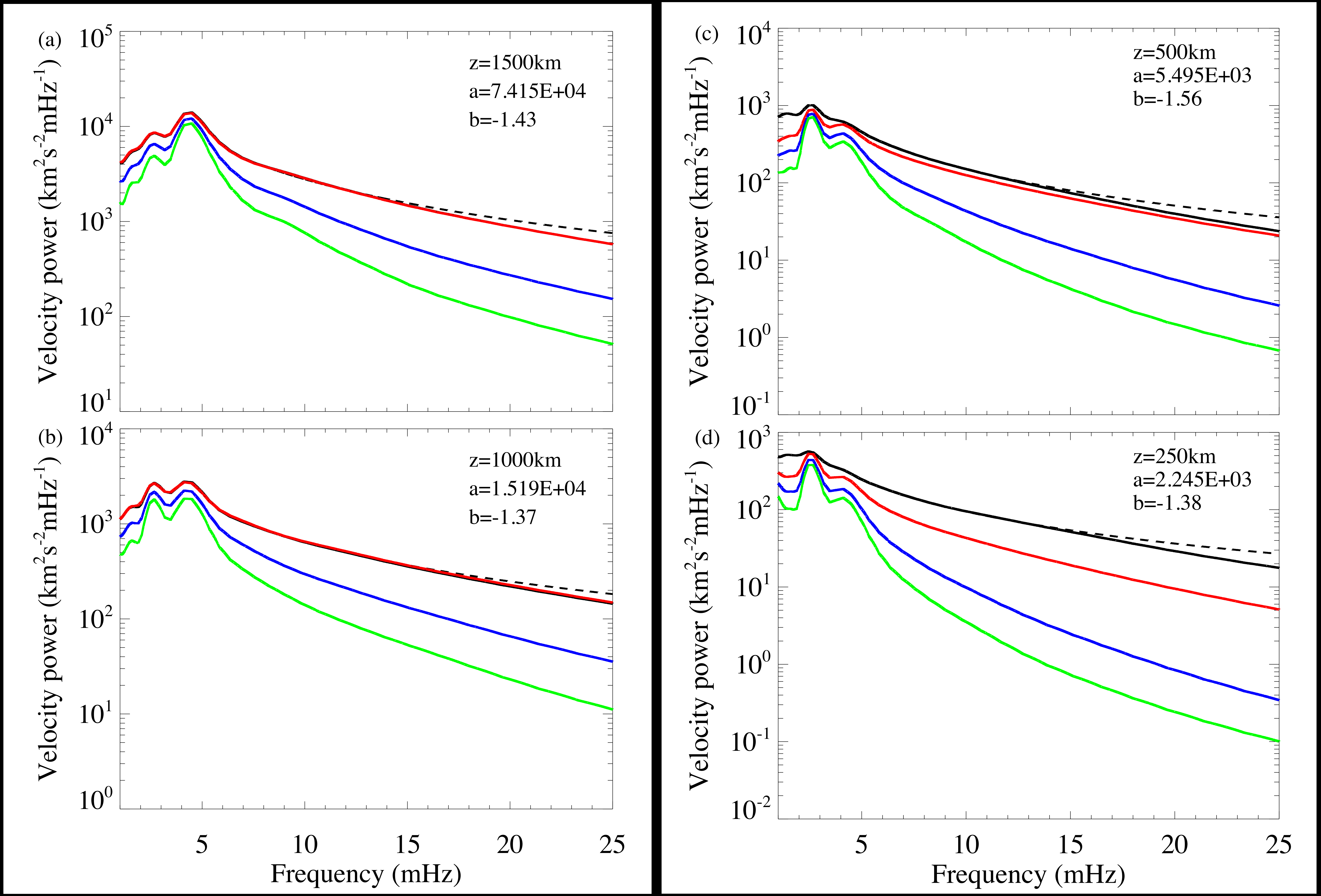


Fig.: Power spectra of longitudinal velocity, i.e. velocity parallel to the field (black) and vertical velocity (red) at the full resolution of simulations. Power spectra of vertical velocity for degraded simulation data with an effective resolution of 100 km (blue) and 200 km (green). Dashed curve displays a power-law fit to the black curve in the frequency range 6-25 mHz in each panel. Different panels correspond to different heights as mentioned in each panel. 'a' and 'b' are the amplitude and the exponent for the power law.

Acoustic wave energy flux

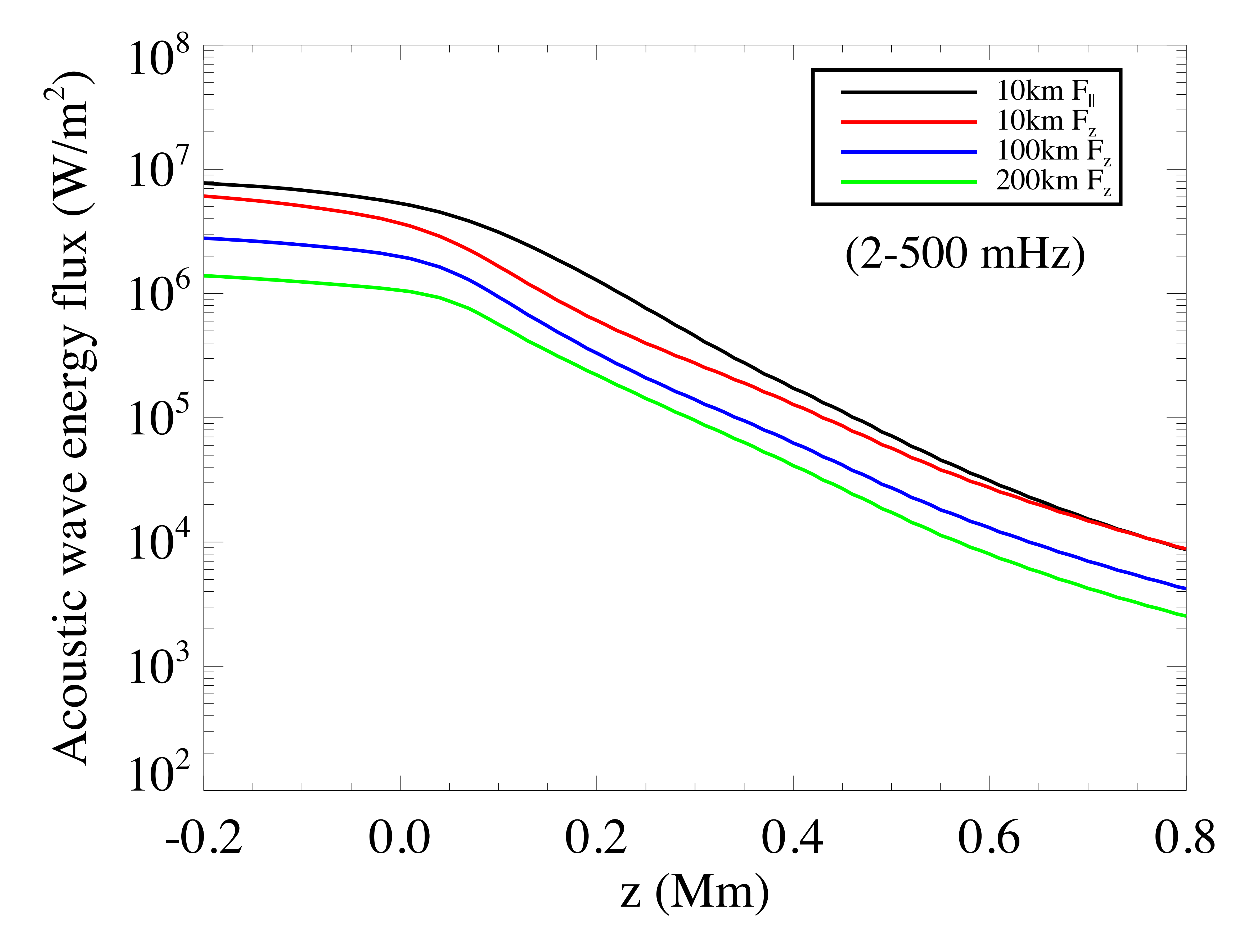


Fig.: Variation of acoustic wave energy flux $(F_{ac}(\nu_i) = \rho P_v(\nu_i) c_s)$ with geometrical height computed using the component of velocity parallel to the magnetic field for full resolution (black), computed using the vertical component of the velocity for full resolution (red), computed using the vertical component of the velocity for degraded data at an effective resolution of 100 km (blue) and 200 km (green).

Conclusions

- Magnetic field lines carrying slow magneto-acoustic waves are continuously advected by the plasma flows in the photosphere
- The power spectra of longitudinal velocity averaged over 25 field lines inside a strong magnetic region reveal that the periodicity of oscillations shifts towards higher frequency in the chromosphere as observed in the core of plages (de Wijn et al., 2009, Rajaguru et al. 2019)
- However, the horizontally averaged (over the whole domain) power spectra show that a significant fraction of low frequency waves leaks through the photosphere and reaches into the higher layers as observed in the periphery of plages (de Wijn et al., 2009, Rajaguru et al. 2019)
- We find that poor spatial resolution (e.g., 100 km) as well as not observing the longitudinal component of the velocity in observations may lead to an underestimated wave energy flux, by up to a factor of four, in the upper photosphere and the lower chromosphere
- The acoustic wave energy flux of slow magneto-acoustic waves is sufficient to account for the radiative losses in a plage (~20kW/m2, Withbroe & Noyes 1977)

For more details: Slow magneto-acoustic waves in simulations of a solar plage region carry enough energy to heat the chromosphere (DOI: 10.1051/0004-6361/202039908)

YouTube

Thank You!