The role of turbulence strength on the acceleration of transrelativistic electrons

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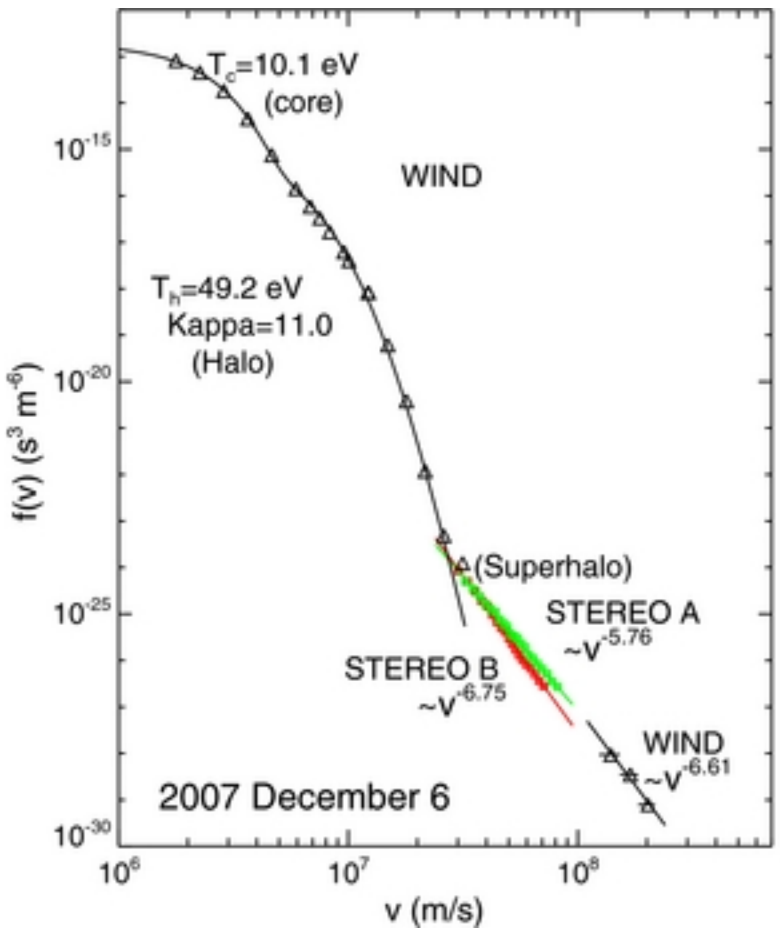
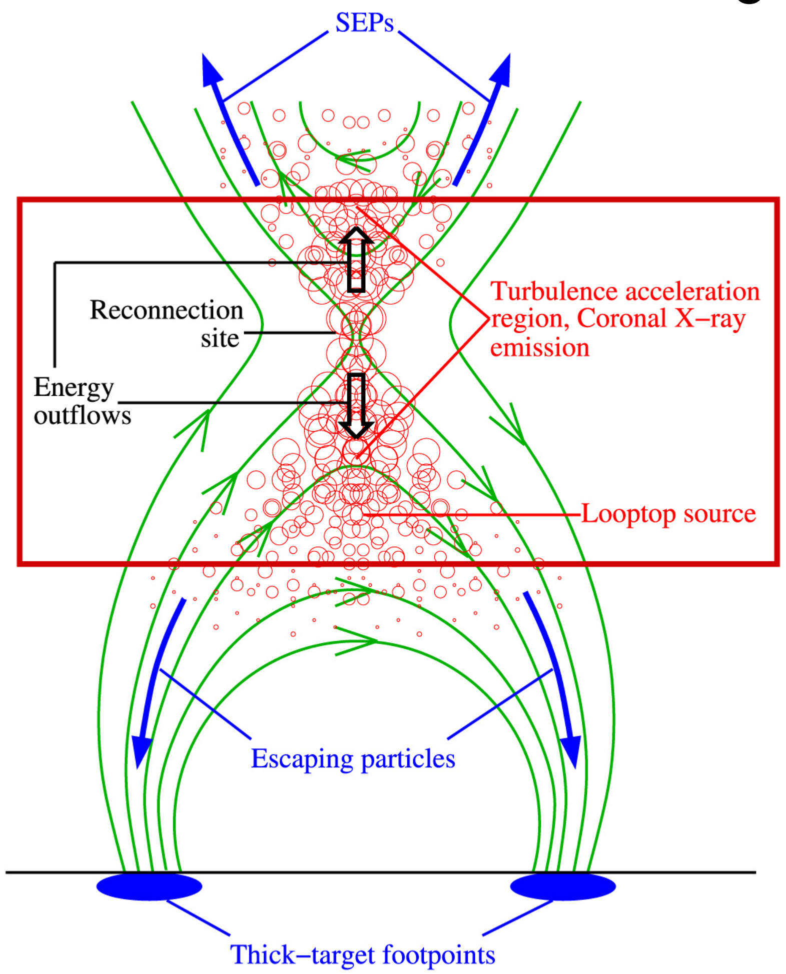
Motivation and highlight

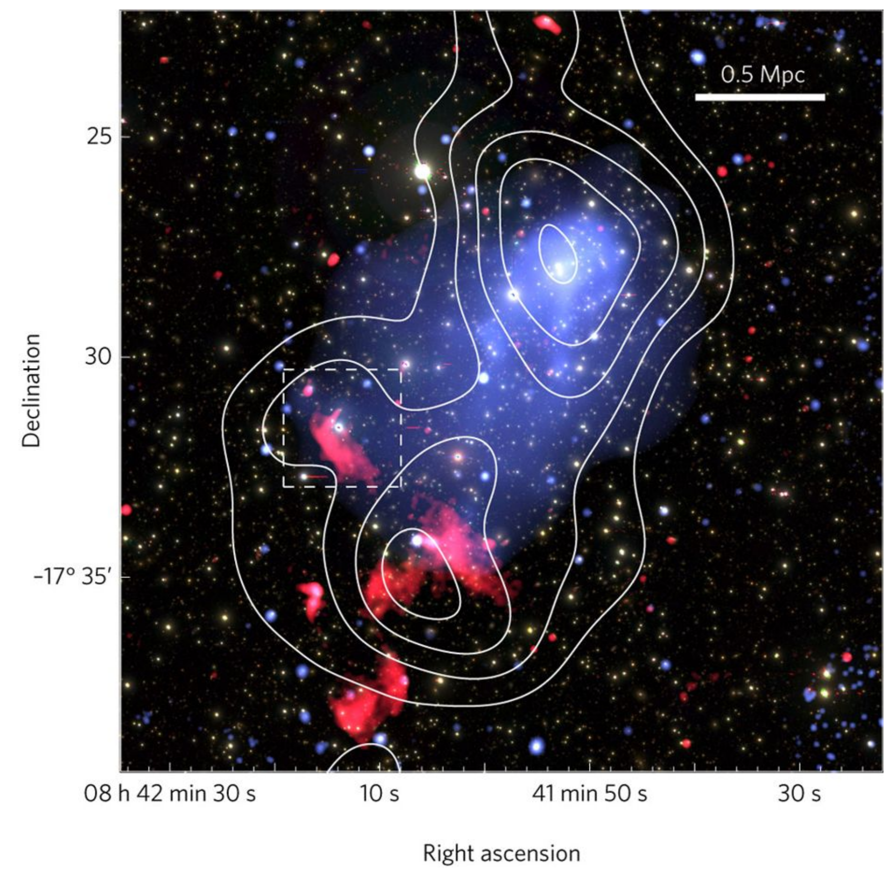
Accelerated electrons are widely observed in our universe, and turbulence is one of the ingredients to accelerate them to high energies



Wang+2012



Petrosian+2016



Van Weeren et al., 2017

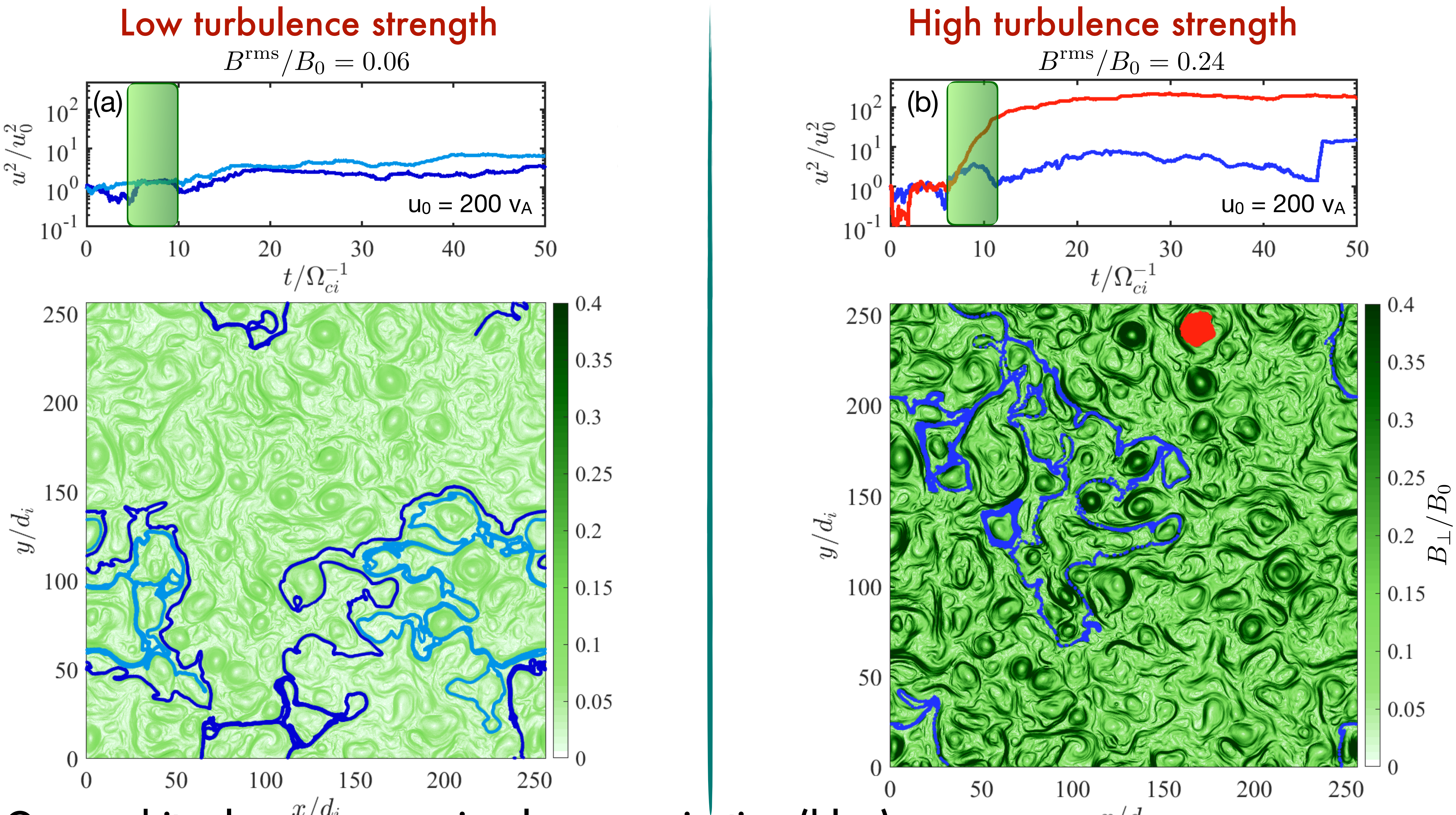
Turbulence is one of the ingredients to accelerate (or re-accelerate) particles to high energies

- We study the energisation of transrelativistic electrons (E_0 ~ 400 eV) in turbulence, identifying the acceleration mechanisms at play

- Depending on electron initial energy and turbulence strength, electrons may undergo a fast and efficient phase of energisation due to magnetic drift during trapping at turbulent structures

Results: Overview of particle trajectories

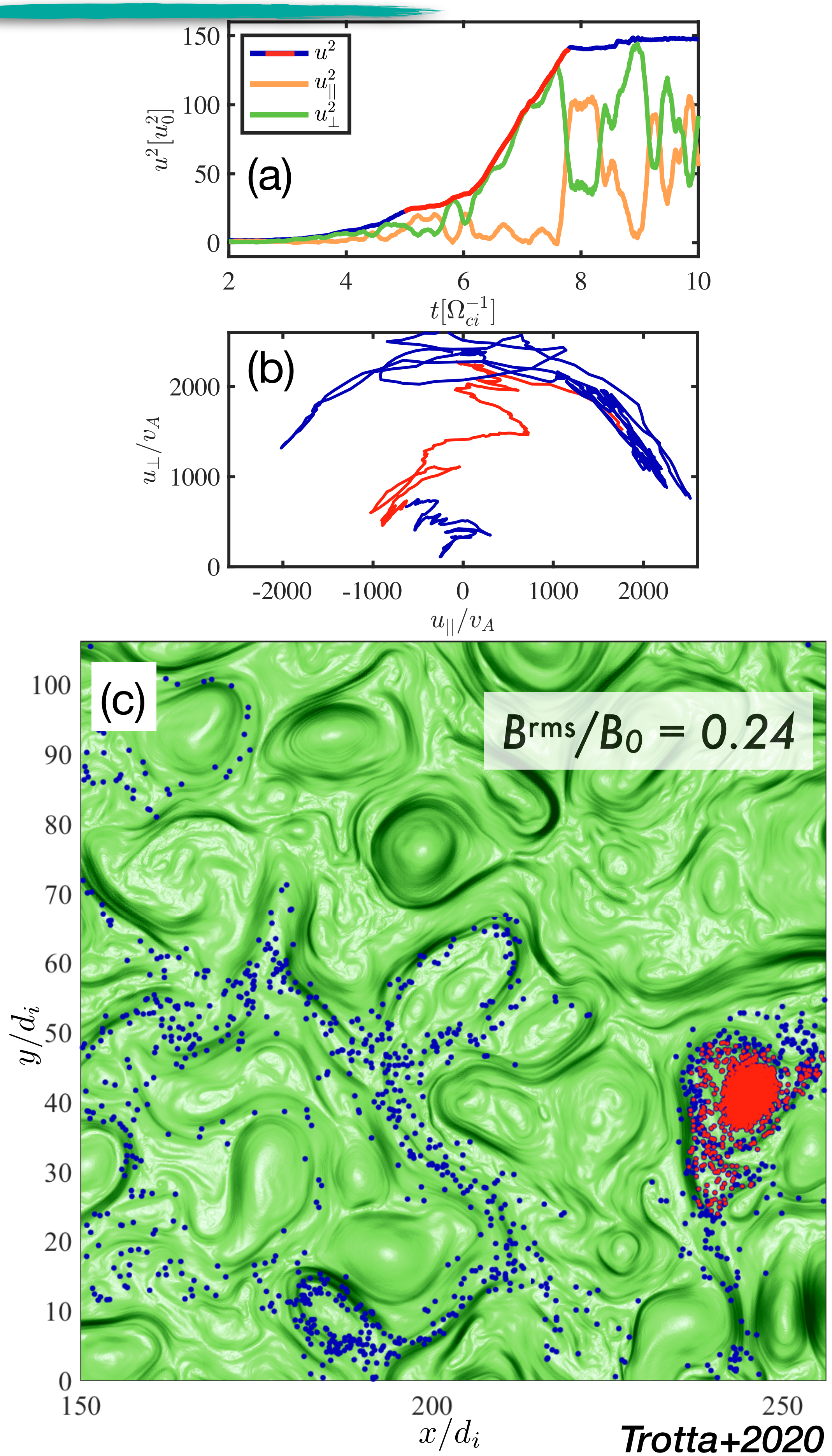
Method: 2.5D hybrid PIC simulations of turbulence + test-particle electrons



▶ Open orbits - low energy gain, slow energisation (blue)

▶ Trapped orbits - high energy gain, fast energisation, active at high turbulence strength (red)

Results: fast acceleration, zoom



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High turbulence strength: presence of trapped trajectories associated with large energy gains

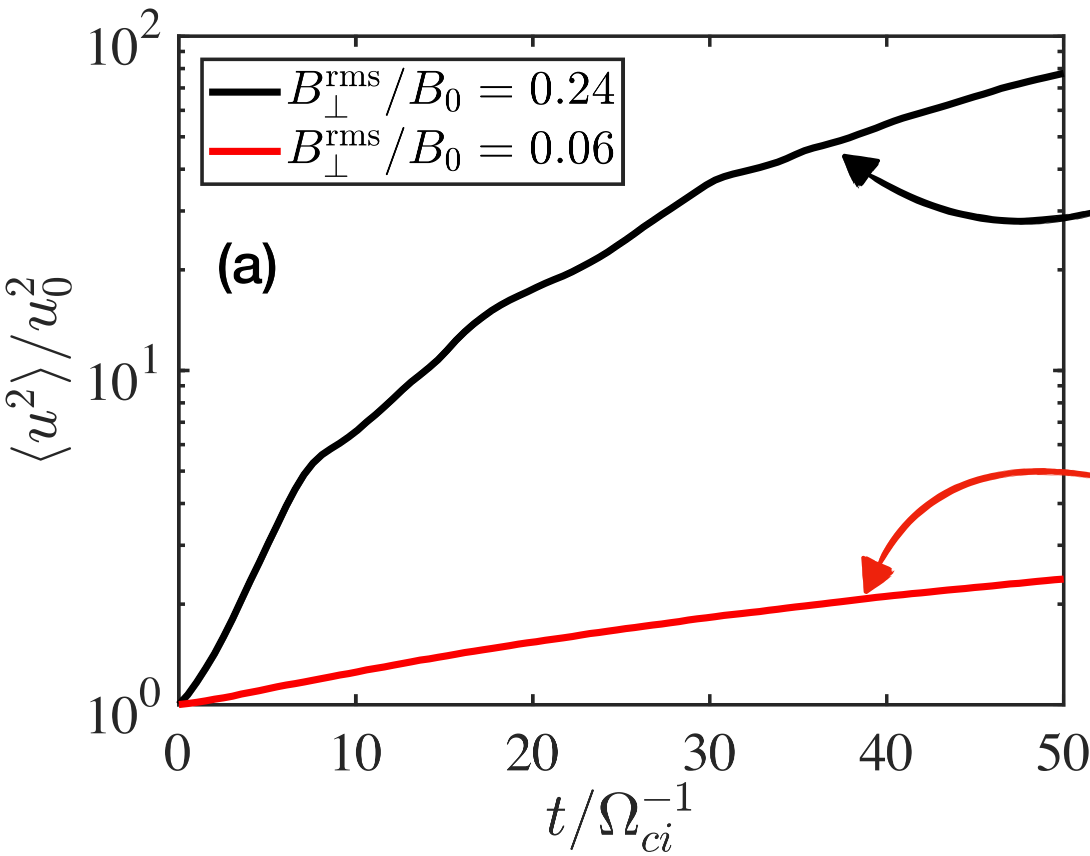
Red: trapped portion of trajectory

Fast energisation is manifested as a strong increase of perpendicular energy due to particle drifts

Fast energisation proceeds once electrons detrap, then pitch-angle scattering dominates (erasing the memory of the process, see (b)).

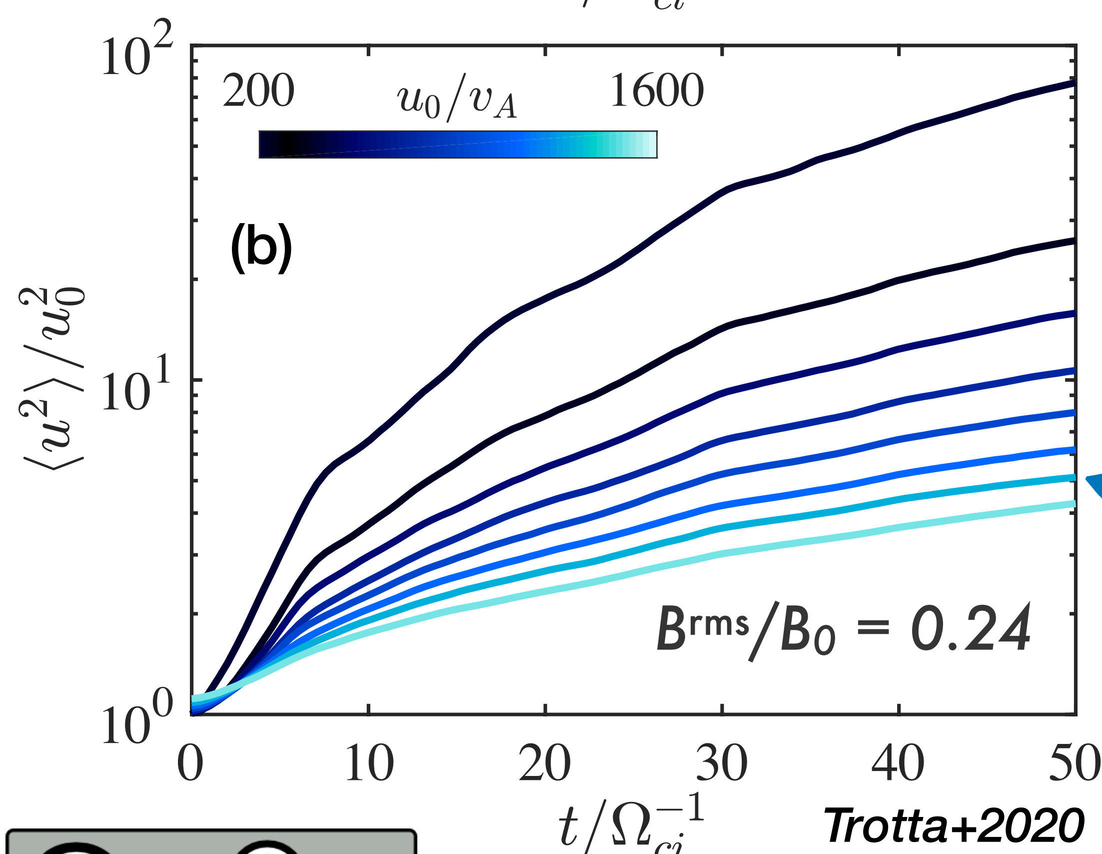
Energisation mechanism resemblant of processes seen in simulations of magnetic reconnection (e.g., Drake+2006, Dahlin+2016, Li+2019)

Results: mean electron energisation



High turbulence strength: energisation proceeds in stages, large energy gains

Low turbulence strength: slow energisation, moderate gain



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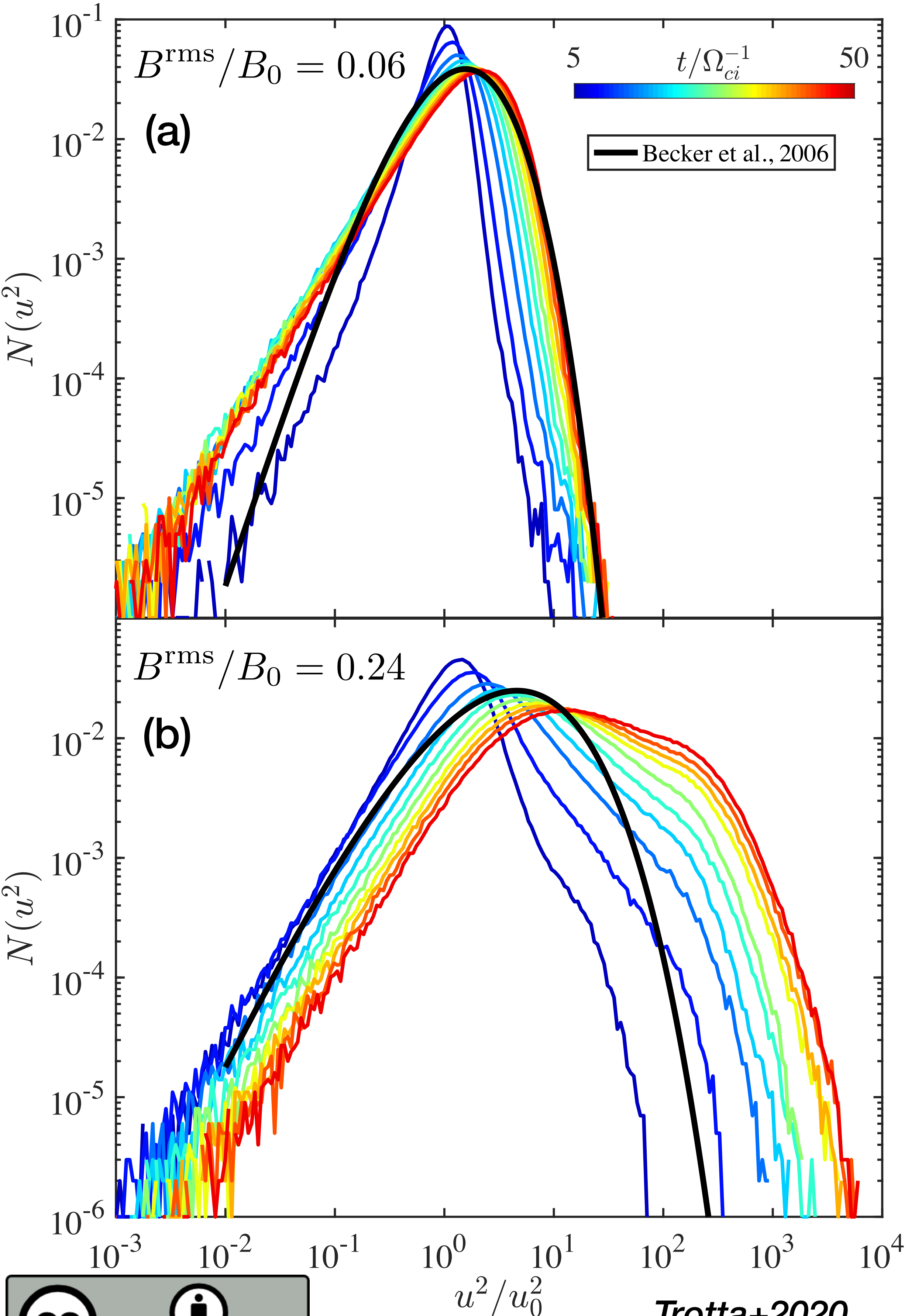
The behaviour observed is dependent on the initial electron energy. If initial electron energy is increased over 800 v_A, the rapid acceleration regime is almost absent

Energisation due to trapping at magnetic structures is efficient only for certain combinations of turbulence strength and electron energy

Results: electron energy spectra



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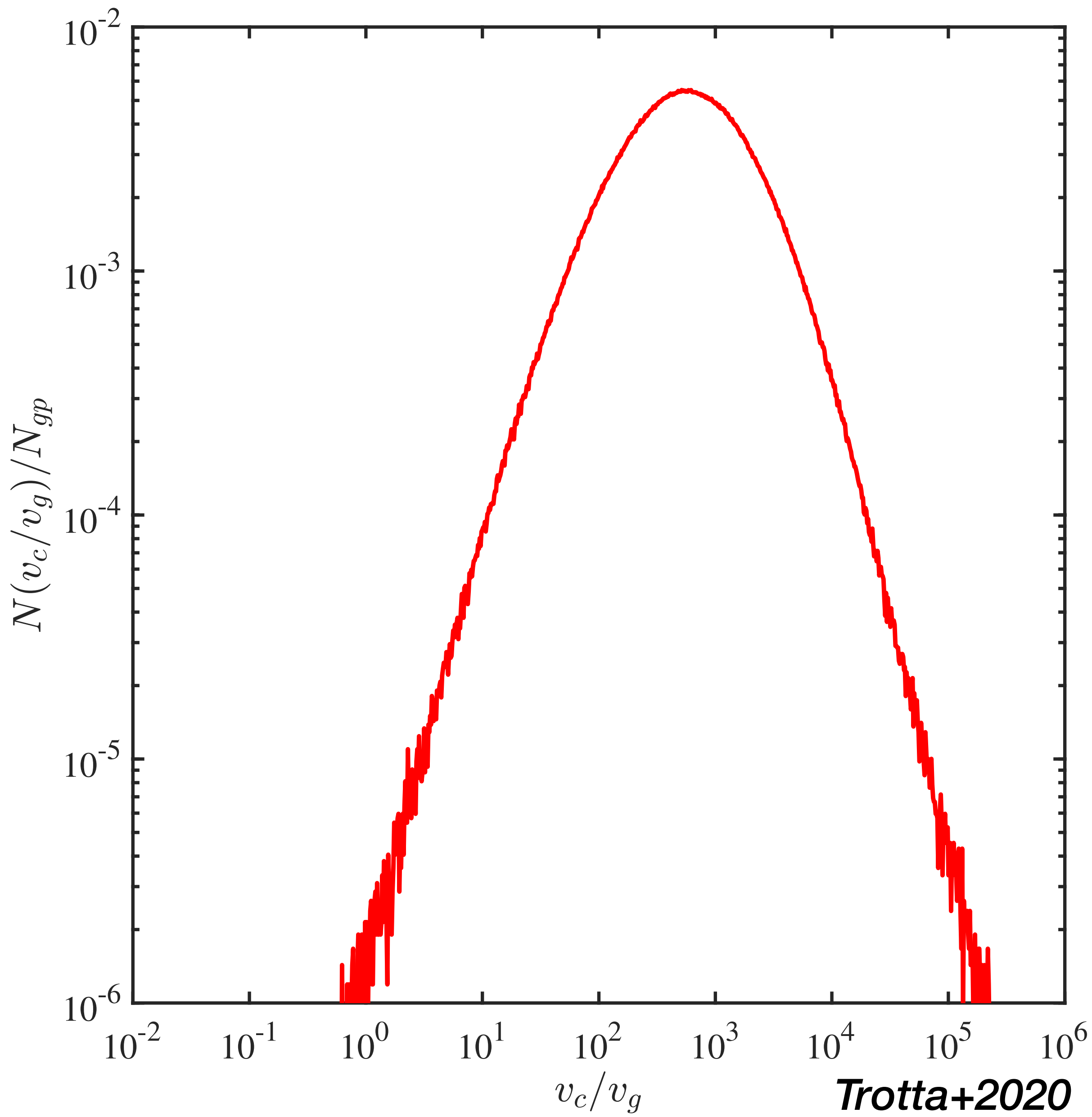
Electron energy spectra from the simulations (colours) are analysed and compared with analytical prediction involving only second-order Fermi acceleration mechanism by Becker+2006 (black)

Low turbulence strength: maximum energy gains small. Spectra compatible with analytical prediction

High turbulence strength: large maximum energy gains. Spectrum flattening at intermediate energies. No qualitative agreement with analytical prediction

No sign of anisotropies in electrons VDFs are found. These results can be put in context of acceleration at contracting islands in the presence of strong scattering (leRoux+2016)

Results: curvature and grad-B drifts



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Definitions of curvature and grad-B drifts:

$$\mathbf{v}_c = \frac{v_{\|}^2}{\Omega_{ce}} \mathbf{b} \times \kappa$$

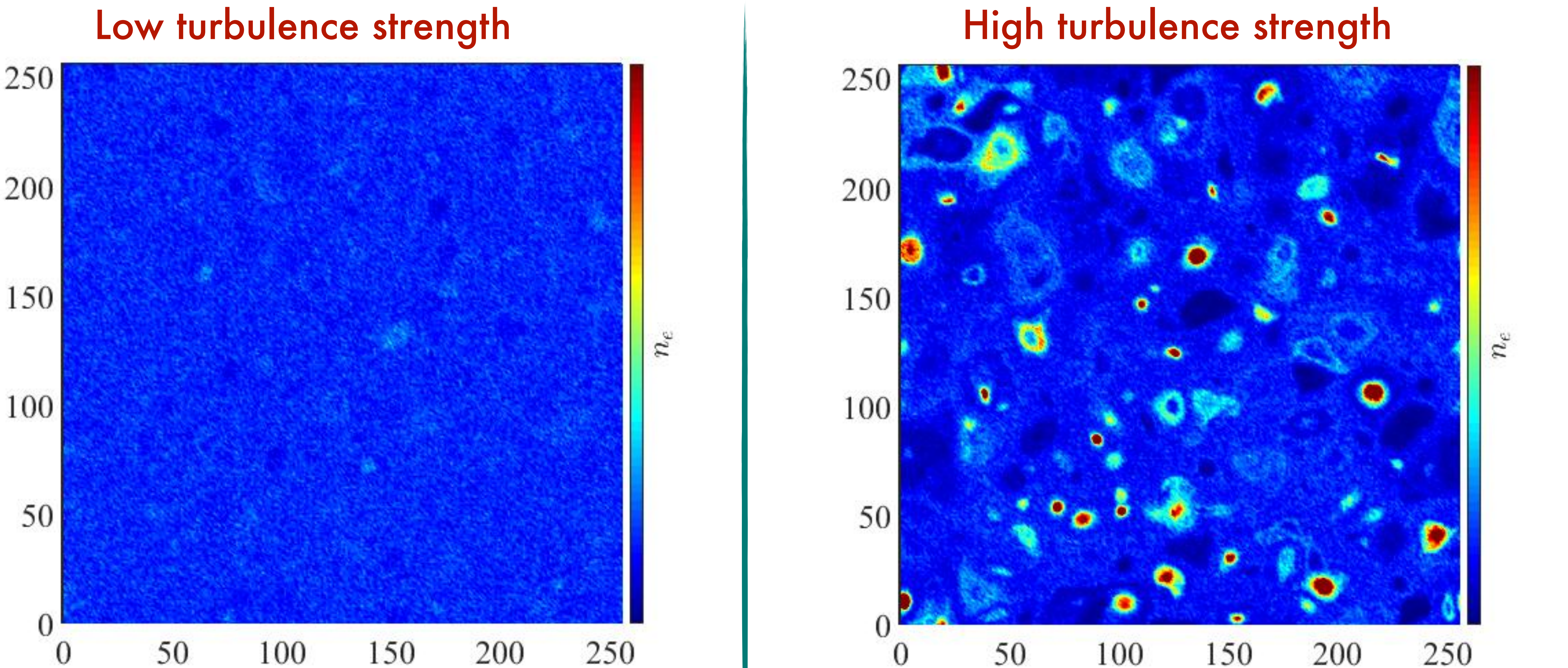
$$\mathbf{v}_g = \frac{v_{\perp}^2}{2\Omega_{ce}} \mathbf{b} \times \frac{\nabla B}{B}$$

The ratio between the magnetic parts of both drifts is computed at every simulation gridpoint in the case of high turbulence strength. A distribution is then obtained.

- The curvature drift term systematically exceeds the grad-B one. In the high turbulence strength case, the rapid energisation is dominated by curvature drift.

Results: possible observational signatures

Spatially intermittent density distributions when trapping is active



$u_0 = 200\ v_A$

Trotta+, in prep.

When trapping is active, energetic electrons show density clumps in correspondence of high-magnetic curvature region. These results can be put in context with other studies such as Yang+2019, Bandyopanday+2019

Conclusions

The combination between turbulence amplitude and electron energy is extremely important when considering electron acceleration in turbulence, as it is found to control the electron energisation mechanisms at play.

With the same initial electron energy, when turbulence strength is low ($B^{rms}/B_0 = 0.06$), electrons are only moderately energised, consistent with the second-order Fermi model (Fermi1949).

On the other hand, when turbulence strength is high ($B^{rms}/B_0 = 0.24$), electrons are energised more efficiently, with a fast, injection phase due to trapping and subsequent acceleration due to curvature drift in turbulent magnetic structures.

References

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For a more exhaustive list, see the following paper upon which this presentation was built:

D. Trotta et al., Fast Acceleration of transrelativistic electrons in astrophysical turbulence, eprint arXiv:1910.11935 (accepted in ApJ)