The electron injection puzzle in astrophysical shocks

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Motivation

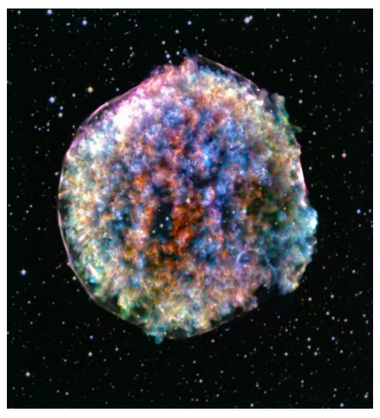
Supernova are among the most powerful cosmic ray accelerators in the universe.

Our goal is to study two important open questions in shock physics:

1) How are magnetic fields amplified at the shock?

2) How are electrons efficiently injected into shock acceleration?

a)



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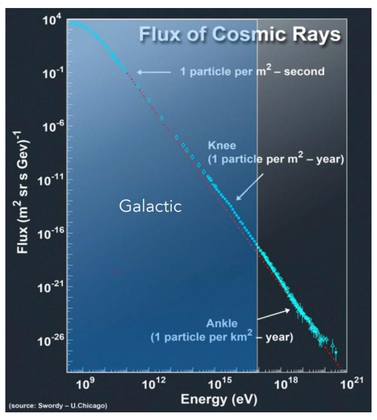
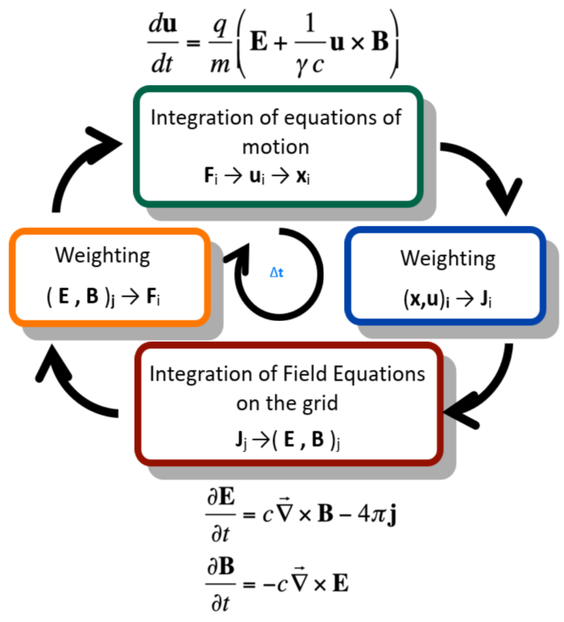


Figure 1: a) Tycho Supernova Remnant **b**) Flux of cosmic rays as a function of their energy. SNR might be at the origin of the very energetic ones

PIC simulations as a tool to study astrophysical plasmas

Astrophysical shock studies rely on state-of-the-art PIC code OSIRIS, which allow a first-principles description of collisionless plasmas.

a)



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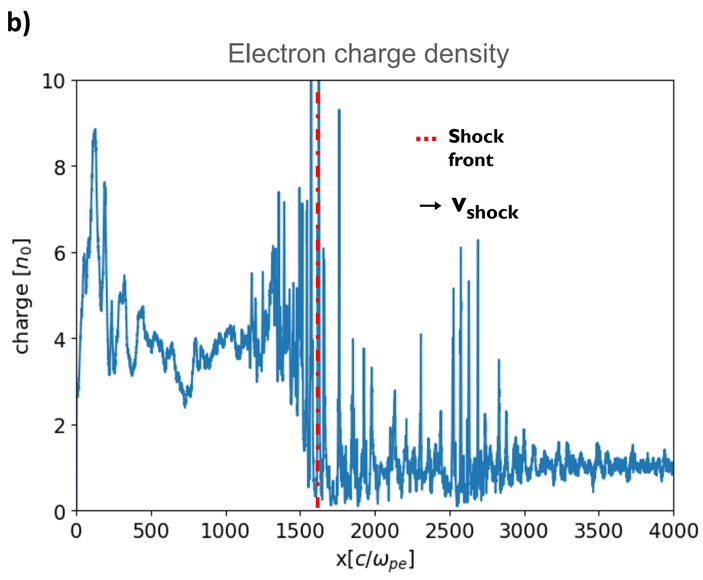
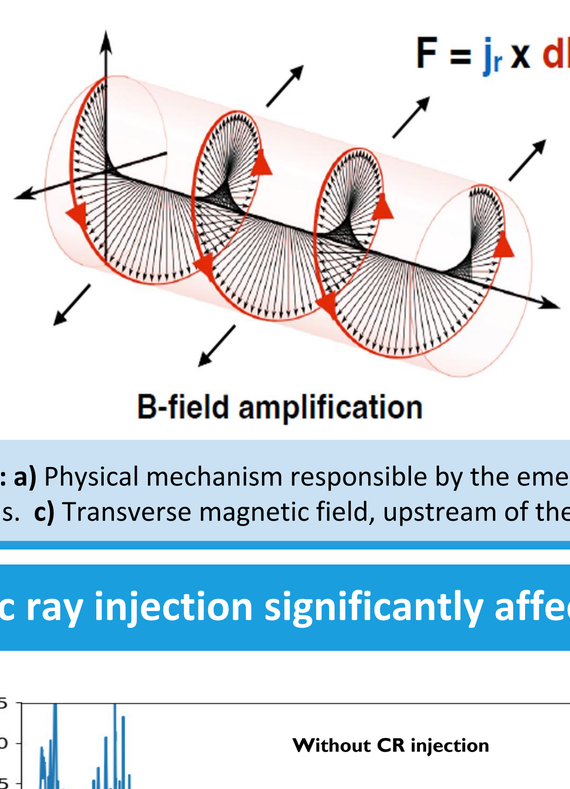


Figure 2: a) Visual representation of PIC code working mechanisms. **b)** Electron charge density in a shock simulated using the PIC code OSIRIS, with different properties highlighted.

Bell's instability in astrophysical shocks

Bell instability: cosmic rays can drive (non-resonant) magnetic field amplification of **right-handed, circularly polarized waves.**

a)



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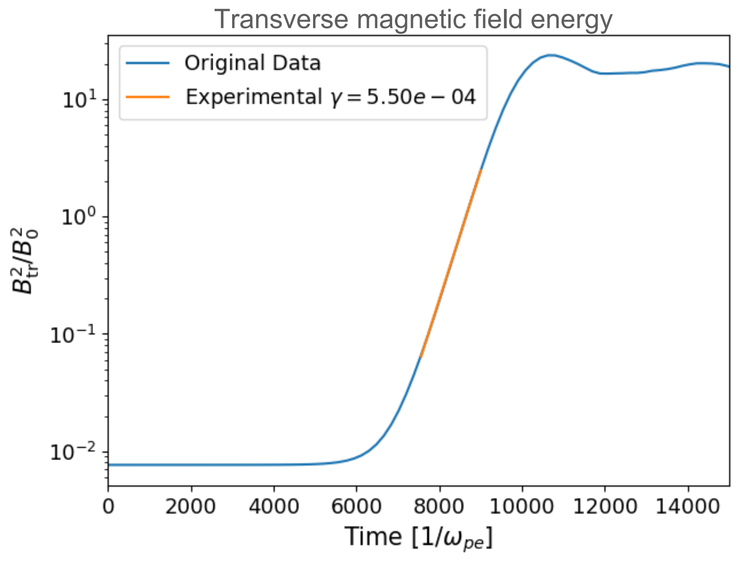

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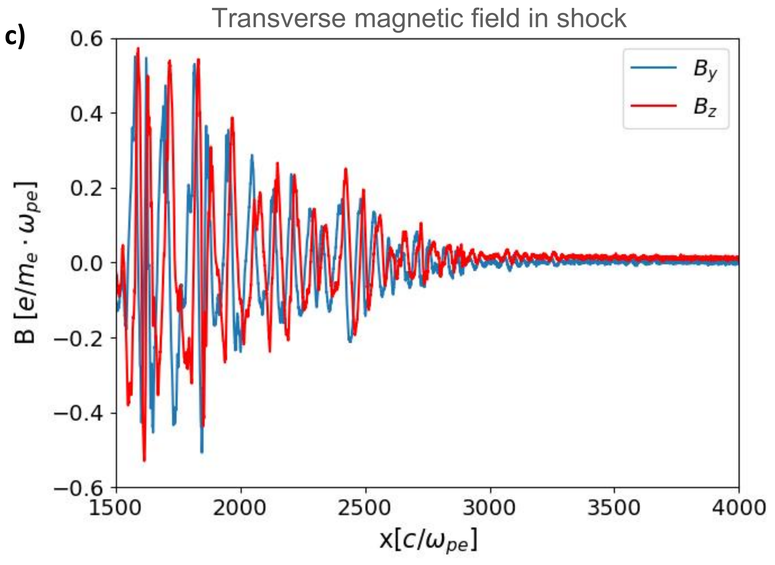
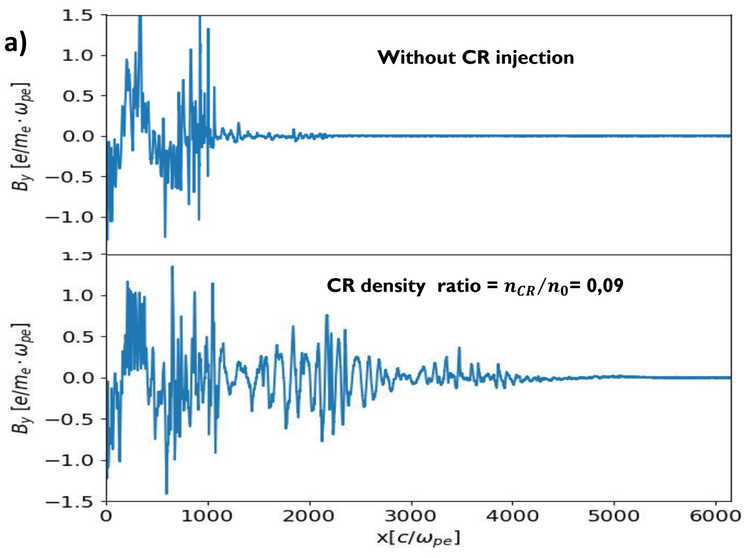


Figure 3: a) Physical mechanism responsible by the emergence of the Bell instability. **b**) Transverse field energy over time. The qualitative behavior and growth rate is in good agreement with the expectations. **c)** Transverse magnetic field, upstream of the shock front, with clear amplification of right-handed modes, corresponding to the Bell instability.

Cosmic ray injection significantly affects particle acceleration in shocks

a)



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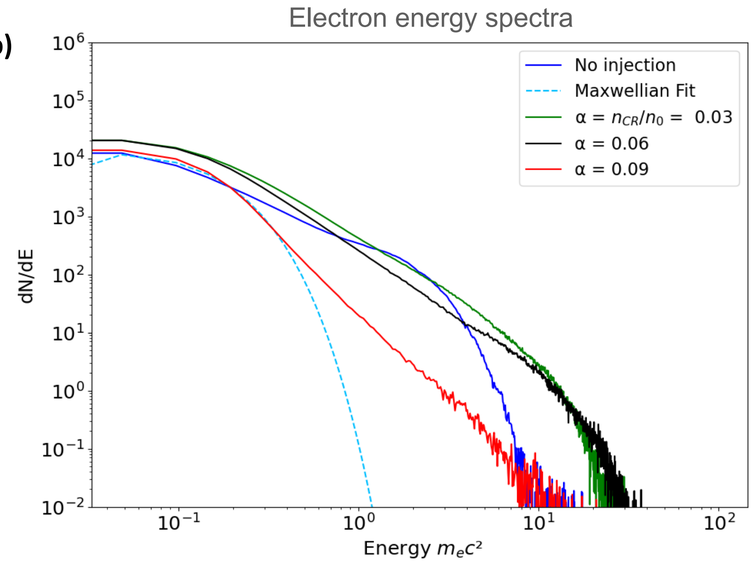

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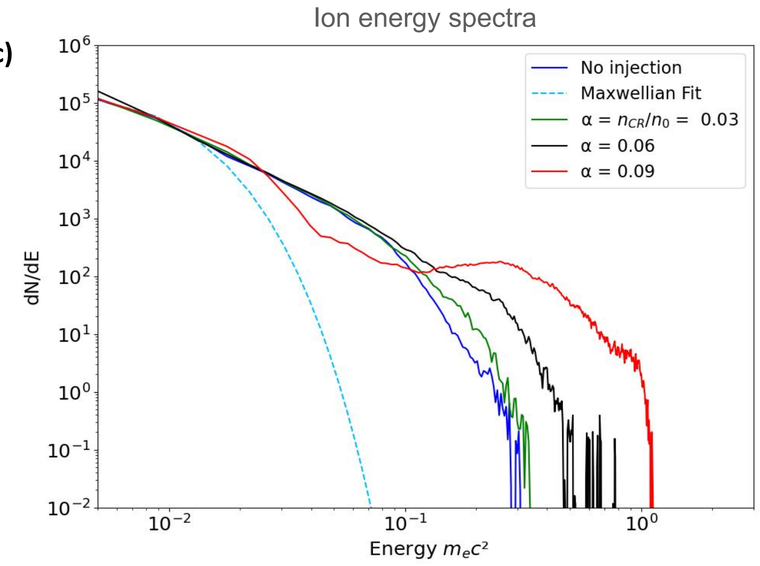

Figure 4: a) Transverse magnetic field in shocks without and with cosmic ray injection. **b**) Electron energy distribution and Maxwellian fit for different simulation. The increase in CR density hinders electron acceleration. **c**) Ion energy distribution, and a Maxwellian fit. The behavior is opposite to that of the electrons.

Conclusions & Future work

- Supernova remnant shocks are efficient cosmic ray accelerators, but how magnetic fields are amplified and control particle acceleration is not yet well understood;
- PIC simulations indicate that fraction of injected cosmic rays significantly affects magnetic field amplification and the relative efficiency of electron and ion acceleration;
- Shocks that are powerful cosmic ray accelerators may not be very visible.

References & Acknowledgements

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