Characterising suprathermal electrons at interplanetary shocks

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1. Solar wind electrons and interplanetary shocks

Solar wind is stream of particles released from the Sun. It contains suprathermal electrons – electrons with Energy above thermal Energy.

Suprathermal electrons provides information about:

- Origin of solar wind
- Sun magnetic field topology

Solar wind electron distribution function is strongly affected by interplanetary shocks: adiabatic motion across shock, turbulence, particle acceleration.

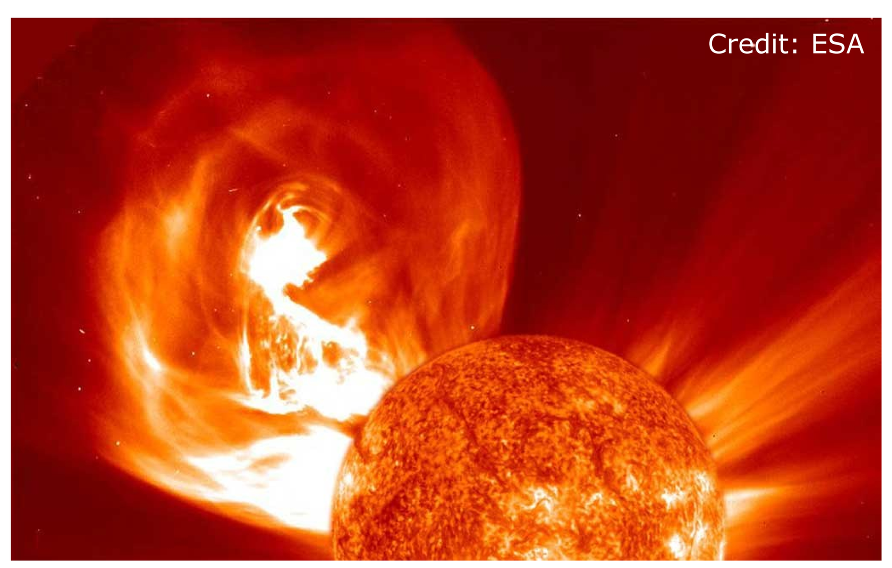

Fig. 1: Coronal mass ejection.

Shock is propagating disturbance that moves faster than the local speed of sound. It separates plsma with different conditions. IP shocks are collisionless – particle Energy is transfered through electromagnetic fields instead of binary particle collissions.

Interplanetary shocks major origins:

- Coronal Mass Ejection (CME) – eplosive release of solar plasma
- Co-rotating interaction region (CIR)- stream of fast solar wind rams into slower stream

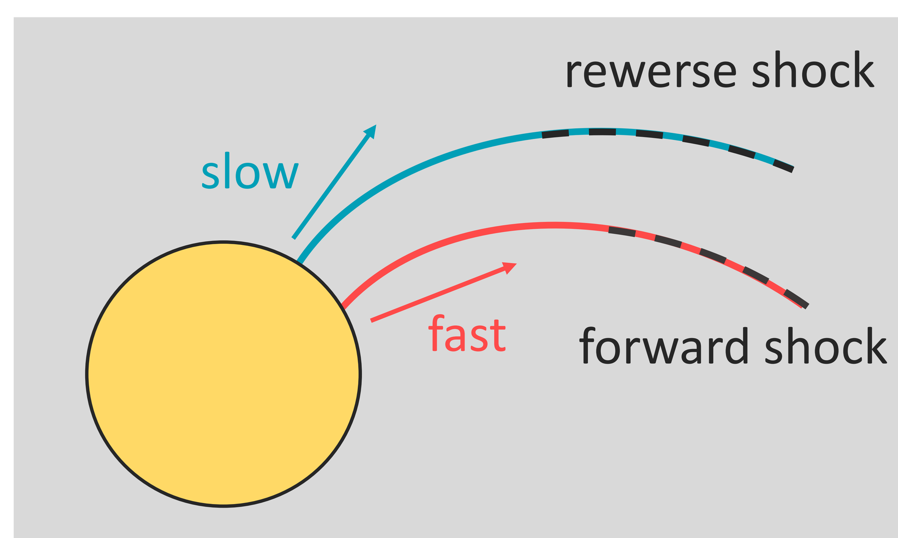

Fig. 2: Co-rotating interaction region.

Project goal: examination and characterisation of the suprathermal solar wind electrons associated with IP shocks using 3D Spherical Harmonics.

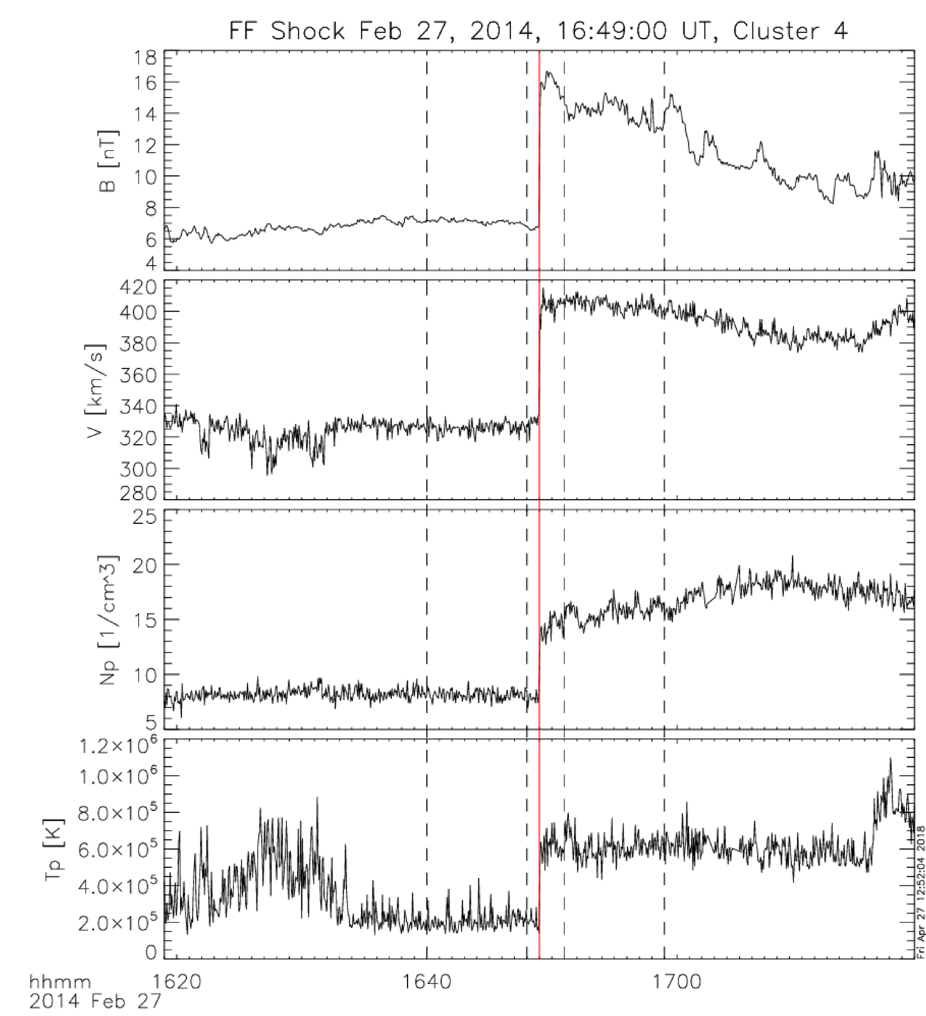

Fig. 3: Example of shock observed by Cluster from IP shock database (University of Helsinki).

2. Source of the electron data

We use data from ESA's Cluster mission, which is currently investigating the Earth's magnetic environment and its interaction with the solar wind in three dimensions. It is constitued of four identical spacecrafts that flight in tetrahedral configuration.

Electron angle-angle distributions are made by PEACE – Plasma Electron and Current Experiment. Instrument contains two Energy sensors: HEAA and LEAA, which cover Energy from 0.6 eV to 26 460 eV (we use 40-400 eV).

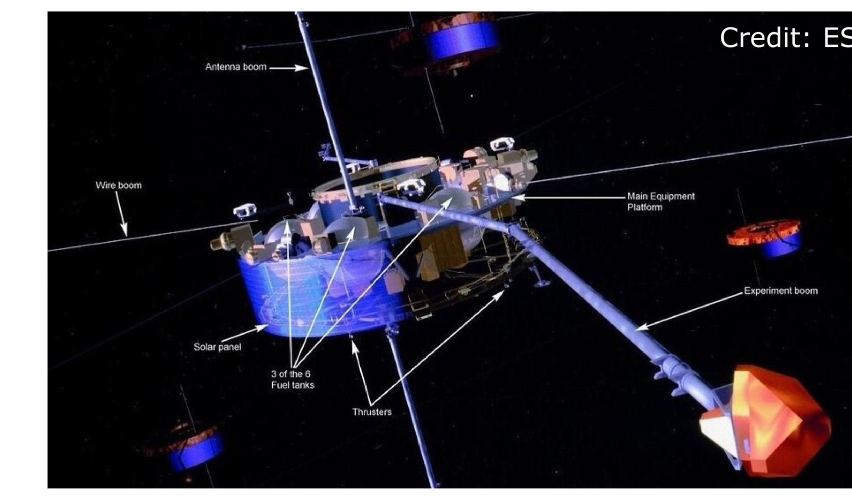

Fig. 4: Cluster spacecraft.

3. Spherical harmonic fitting method

Spherical harmonics are functions with two arguments: polar and azimuthal angle.

$$Y_{lm}(\theta,\phi) = \begin{cases} \bar{P}_{lm}(\cos\theta)\cos m\phi, & m \geq 0 \\ \bar{P}_{l|m|}(\cos\theta)\sin|m|\phi, & m < 0 \end{cases}$$

Any real square-integrable function can be expressed as a series of spherical harmonic functions.

$$f(\theta,\phi) = \sum_{l=0}^{\infty}\sum_{m=-l}^{l} f_{lm}Y_{lm}(\theta,\phi)$$

Power of each l number is described by power spectrum.

$$\frac{1}{4\pi}\int_{\Omega} f^2(\theta,\phi)\,d\Omega = \sum_{l=0}^{\infty} S_{ff}(l)$$

$$S_{ff}(l) = \sum_{m=-l}^{l} f_{lm}^2$$

4. Normal solar wind conditions

Electron populations in the normal solar wind:

- Core – isotropic thermal population
- Halo – isotropic suprathermal population
- Strahl – anisotropic high speed component of SW closely aligned with the magnetic field of the Sun

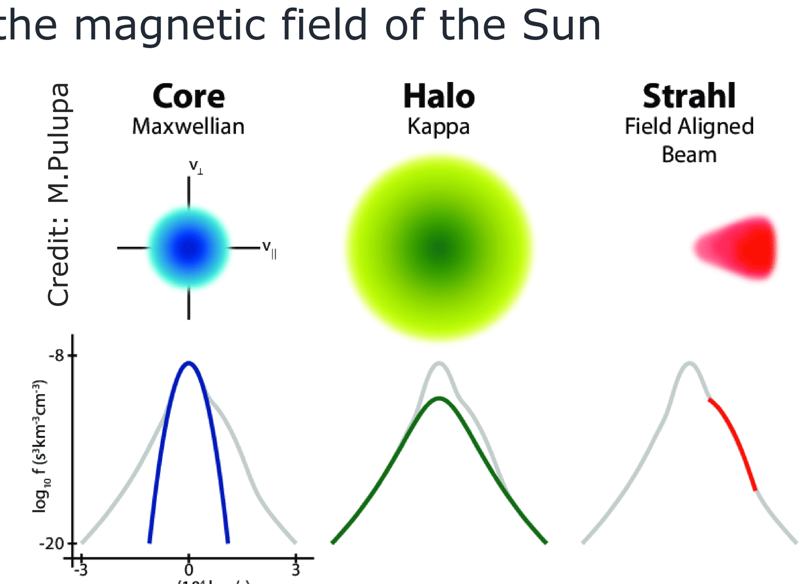

Fig. 5: Main electron populations.

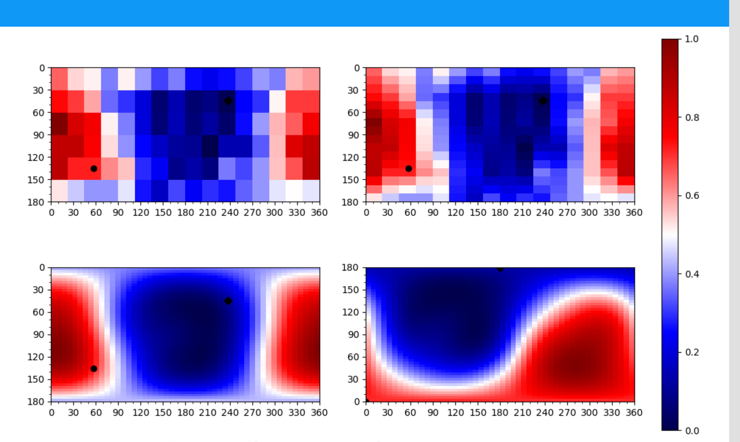

Fig. 6: Halo population: raw data (TR), interpolated data (TR), fitted spherical harmonics (BL), rotated spherical harmonics (BR).

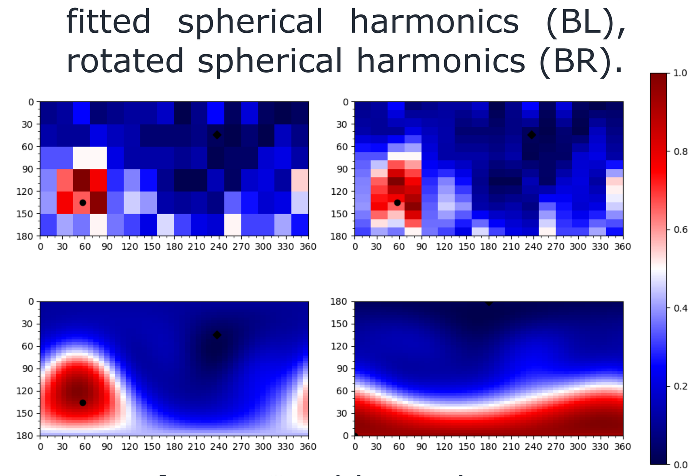

Fig. 7: Strahl population.

5. Electron beams with IP shocks

Electrons affected by IP shocks generate different distribution shapes: biderectional beam, 90º enhancement, loss-cone.

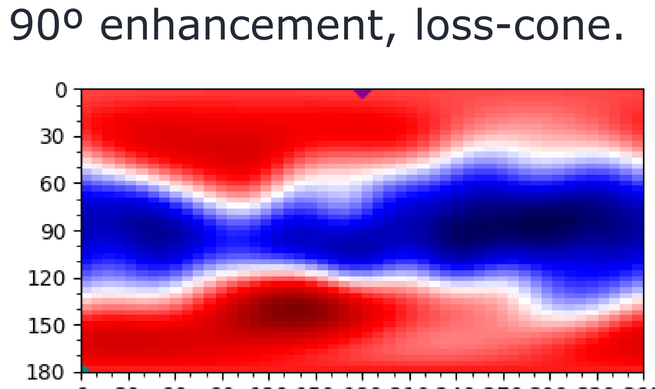

Fig. 8: Bidirectional beam.

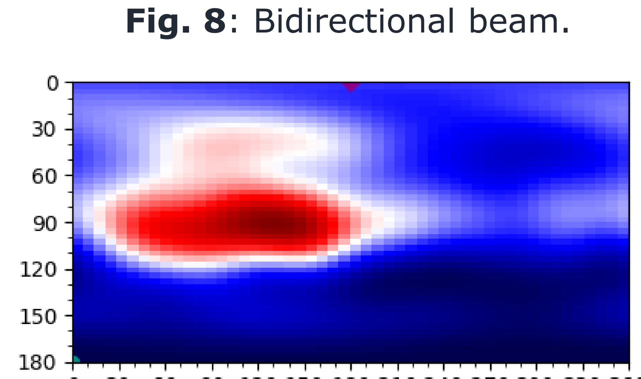

Fig. 9: 90º enhancement.

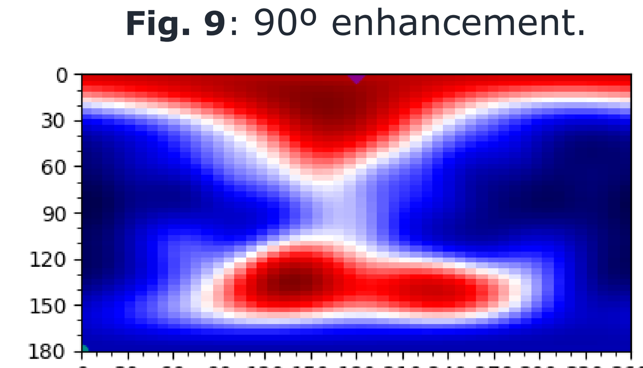

Fig. 10: Loss-cone.

6. Statistical analysis

Comparison of SNRs for normal solar wind conditions and presence of IP shocks – results in agreement with theory and literature. Another goal is comparison of SNRs for different shock conditions: Mach numer, speed, theta angle, etc.

SNR – Signal to Noise ratio $$SNR_{dB} = 10\log_{10}\left(\frac{\mathcal{P}_{signal}}{\mathcal{P}_{noise}}\right)$$

Our SNRs:

- SNR_{l_1/l_0} - strahl/halo
- SNR_{l_2/l_1} - bidirectional indicator
- SNR_{l_3/l_0}, SNR_{l_3/l_1}, SNR_{l_3/l_2} - loss cone
- SNR_{l_4/l_0} , SNR_{l_4/l_3} and SNR_{l_2/l_1} – ninety degree enhancement

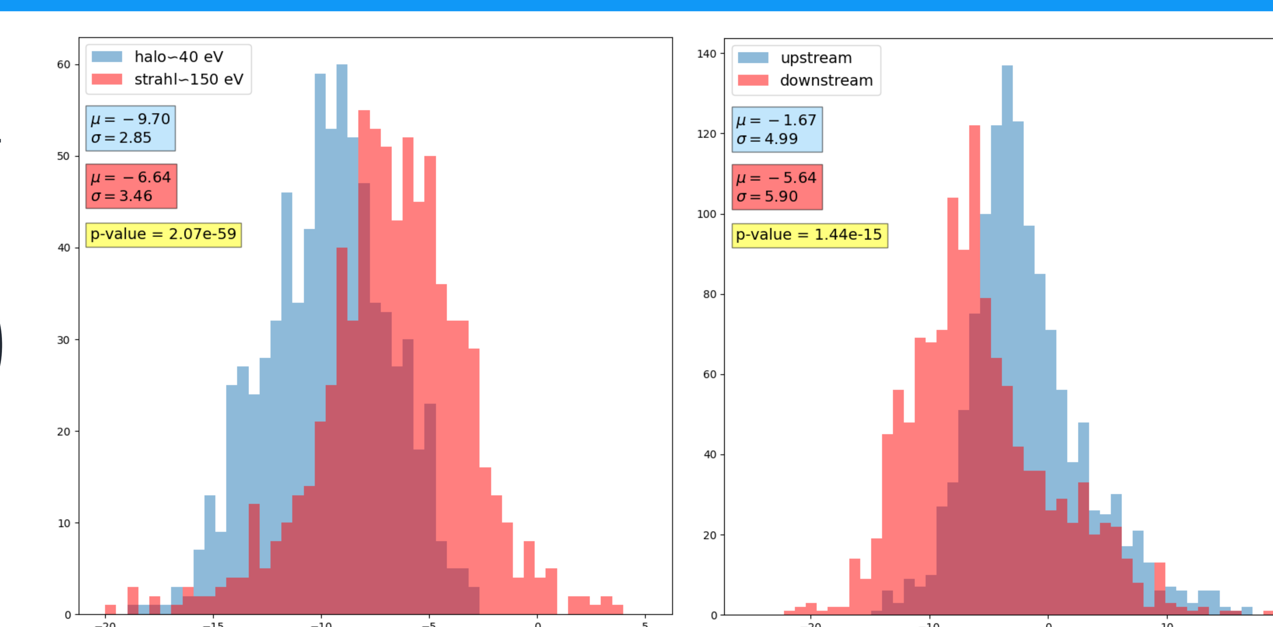

Fig. 11: Example histograms of SNR_{l_1/l_0} for normal solar wind (left) and interplanetary waves (right).

8. Conclusions and future plans

- Spherical harmonics fitting method is useful tool for quick analysis.
- IP shock analysis – test for SH method (results in agreement with theory and literature), qualitative baseline for further research.
- Next steps: quantitative analysis using machine learning and Solar Orbiter data – spacecraft closer to the Sun – evolution of electron distributions at shocks.

Fig. 11: Solar Orbiter spacecraft.

References

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