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In-situ measurements of energetic particles with the SupraThermal Electrons, Ions and Neutrals sensor aboard Solar Orbiter

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Abstract:

The SupraThermal Electrons, Ions and Neutrals (STEIN) sensor is part of the Energetic Particle Detector (EPD) instrument suite onboard the upcoming Solar Orbiter mission. Solar Orbiter will be launched in 2017 and reach a perihelion of up to 0.3 AU. This will provide unprecedented opportunities for remote and in-situ studies of the solar corona and the heliosphere.

The STEIN sensor will provide low energy measurements for electrons, ions and neutral particles from a few keV up to 100 keV. Its two telescopes will enable detection of sunward and anti-sunward particle fluxes. Each telescope features several solid state detector (SSD) pixels and an electrostatic deflection system. This combination additionally allows to determine pitch-angle distributions of incident charged particles.

We present the design of the sensor along with studies of the energetic and angular detector response. We will assess the predicted performance in comparison with previous in-situ energetic particle measurements in the given energy range.

The Solar Orbiter Mission

The scientific objectives of Solar Orbiter are:

- to determine in-situ the properties and dynamics of plasma, fields and particles in the near-Sun heliosphere
- to survey the fine detail of the Sun's magnetised atmosphere
- to identify the links between activity on the Sun's surface
- to observe and characterise the Sun's polar regions and equatorial corona from high latitudes

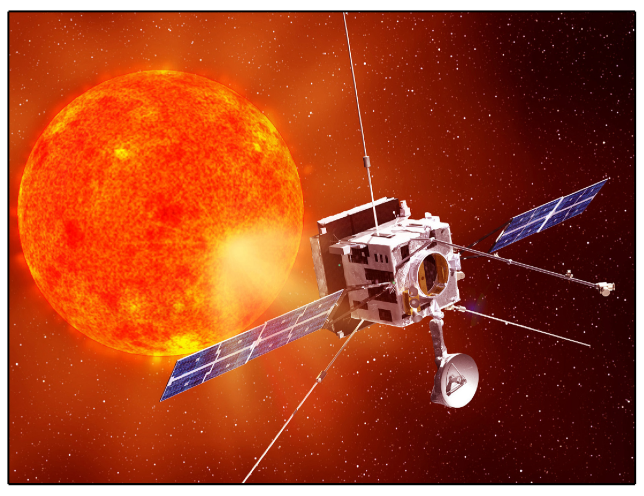

Fig. 1 : Artistic rendition of Solar Orbiter approaching the Sun.

Solar Orbiter is planned to launch in early 2017, featuring a multitude of remote-sensing and in-situ instruments to achieve the above mentioned objectives. The spacecraft will orbit the Sun with a perihelion of up to 0.28 AU. Later in the mission it will leave the ecliptic plane to allow in-depth investigations of the solar polar regions.

Energetic Particle Detector (EPD)

The Energetic Particle Detector (EPD) is a suite of in-situ particle detectors, built in collaboration by multiple international institutions. It is equipped with instruments to measure electrons, protons and neutrals, as well as heavy ions, in a wide energy range from a few keV up to several MeV for electrons and 100 MeV for protons and 200 MeV/nuc for heavy ions, respectively (see Fig. 2)

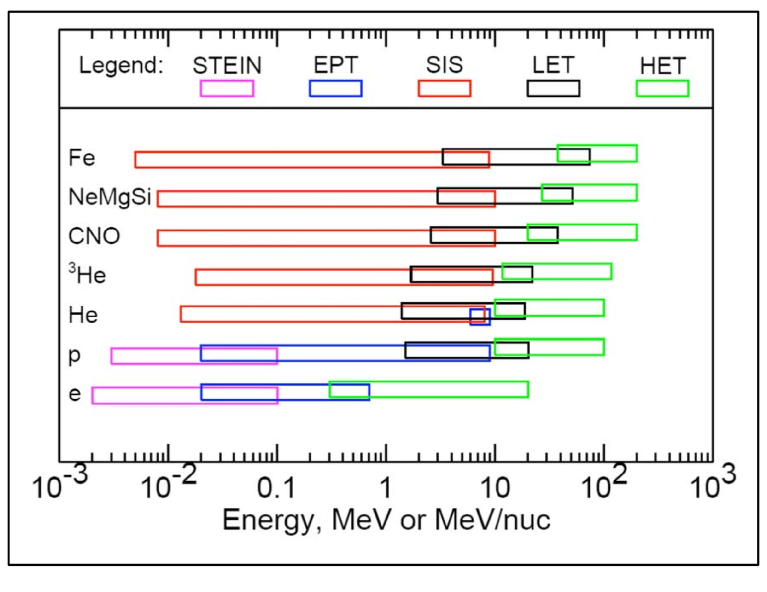

Fig. 2 : Energy coverage of EPD for different particle species.

The SupraThermal Electrons, Ions and Neutrals (STEIN) sensor

STEIN covers the lowest energy part of the EPD suite, ranging from suprathermal energies of a few keV up to 100 keV for electrons, protons and neutral atoms. It features two anti-parallel aligned telescope heads, of which one covers parts of the orbit-averaged Parker spiral direction. Particle identification is performed by using a sweeping electrostatic deflection system, with voltages up to 4000V. Depending on the incident particle's energy, charge and the applied voltage, it gets deflected onto one of three distinct rows of solid state pixels. This allows for the identification of the particle, along with the measurement of its energy (Fig. 3). The three rows of pixels are further separated into five columns, resulting in a 5x3 solid state pixel grid. The solid state detectors will be built by the Lawrence Berkeley National Laboratory, and are able to measure energetic particles energies down to a few keV.

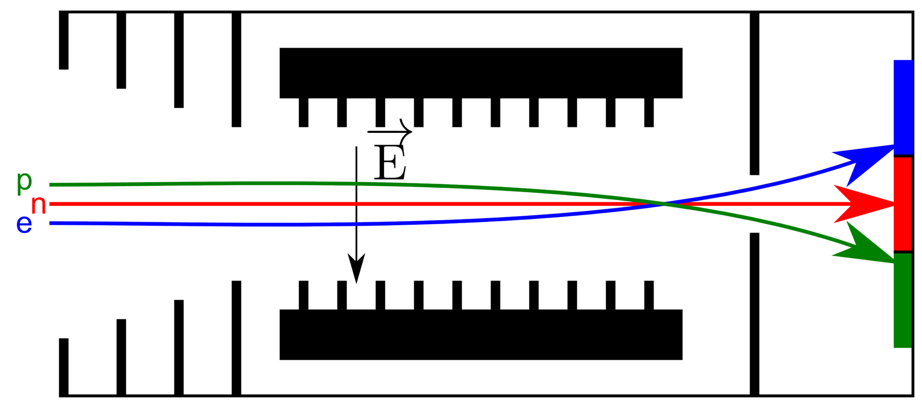

Fig. 3: Schematic picture showing the particle identification principle of STEIN. Incident particles get seperated according to their energy and the applied voltage.

Specifications

Energy range:

- Electrons: 2 keV to 100 keV
- Protons: 3keV to 100 keV
- Neutral Atoms: 4 keV up to 20 keV

Cadence: Up to 10 kHz

Geometry factor (prelim.): adaptive, between 1x10^{-3} cm² sr and 1x10^{-6} cm² sr, depending on deflection voltage and active pixels (Fig. 4)

Dynamic Range (prelim.): up to 10^{10} / (cm² sr sec) for all species

Field of View: 66° x 26° sunwards and anti-sunwards.

Angular resolution (prelim.): due to two telescope heads, 2x5x5 bins for charged particles, and 2x5 bins for neutral atoms.

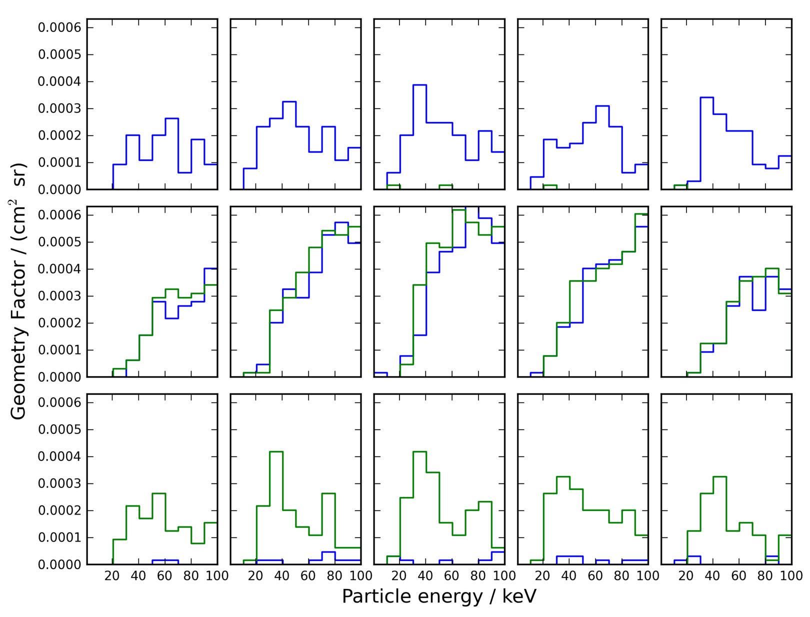

Fig. 4: Simulated per-pixel geometry factor of electrons (blue) and protons (green) at a deflection voltage of 2000V. It can be clearly seen that the particles get separated to the upper and lower row, respectively.

Scientific Performance

It has been shown in the past that impulsive electron events can form in the outer corona with very steep spectra (Fig. 5a) These events show electron flux count rates likely exceeding 10^8 / (cm² sr sec) at 1 keV at 1AU. Assuming quadratic scaling up to 0.3A, similar events will shows fluxes exceeding 10^9 / (cm² sr sec) at Solar Orbiter perihelion. With the current design, we are equipped to resolve this kind of events.

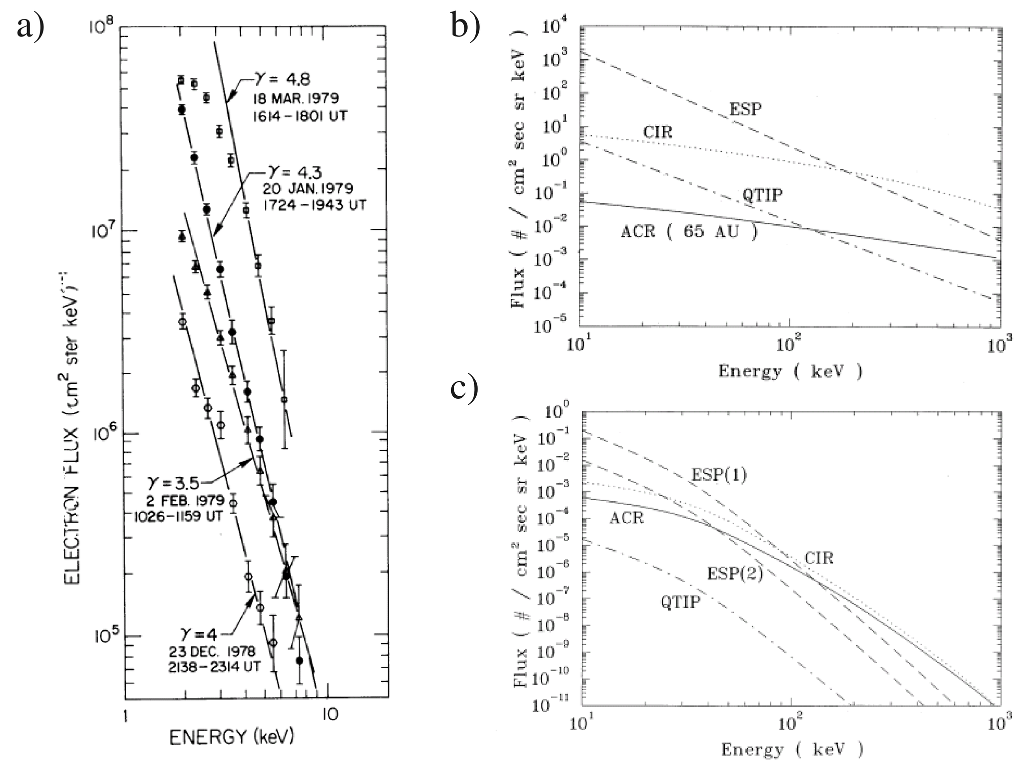

Fig. 5a) Impulsive electron events measured by ISEE 3 at L1. The electron fluxes reach up to 5x10^7 / (cm² sr sec) at 2 keV. [1]
Fig. 5b) Calculated, representative spectra of protons at 1AU, for different particle origins. [2]
Fig. 5c) Calculated EHA spectra at 1AU. The proton spectra in Fig. 5b) serve as „parent“ spectra. [2]

STEIN will also be able to measure protons originating from Energetic Solar Particle events, which are expected to show fluxes around 10³ / (cm² sr sec) at 10 keV at 1AU, leading to fluxes which might exceed 10^7 / (cm² sr sec) at 1 keV at 0.3AU (Fig. 5b). This is within the dynamic range of the sensor as well.

While STEIN will be able to distinguish Energetic Neutral Atoms (ENAs), a clean measurement might prove to be problematic. As can be seen on Fig. 5c), the Energetic Hydrogen Atom (EHA) flux is orders of magnitude lower than the „parent“ proton flux at 1AU. Due to the relatively small geometry factor of STEIN, detection of EHAs or other ENAs might be inhibited by low counting statistics, and detector noise or background fluxes might dominate ENA measurements.

Conclusion

STEIN on Solar Orbiter will provide a low energy in-situ energetic particle detector with capablities to measure electrons and protons originating from solar events. It will be able to resolve even very high flux impulsive solar electron events, due to the small and adaptive geometry factor.
The detection of ENAs is technically possible, but the small geometry factor might pose a challenge for acquiring sufficient statistics. Further studies of the final performance of the telescope with regard to noise and particle identification have to be performed to assess the possibility to clearly detect ENAs.
We will further study the directional response and resolution to determine the possibility of clearly identifying pitch angle distributions of incident charged particles.
To calibrate and test the sensor, we plan to use beam line facilities at the University of Kiel, providing us with charged and neutral ions from an ECR source, and an electron beam, all within the desired energy range.

References:

[1] Potter D, Lin R, Anderson K. Impulsive 2-10 keV solar electron events not associated with flares. The Astrophysical Journal. 1980;236:L97–L100.

[2] Hsieh K, Shih K, Jokipii J. Probing the heliosphere with energetic hydrogen atoms. The Astrophysical. 1992.

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