The Energetic Particle Detector of Solar Orbiter

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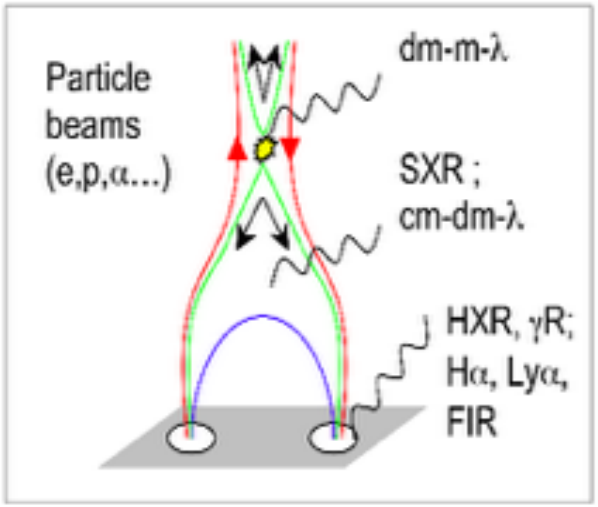
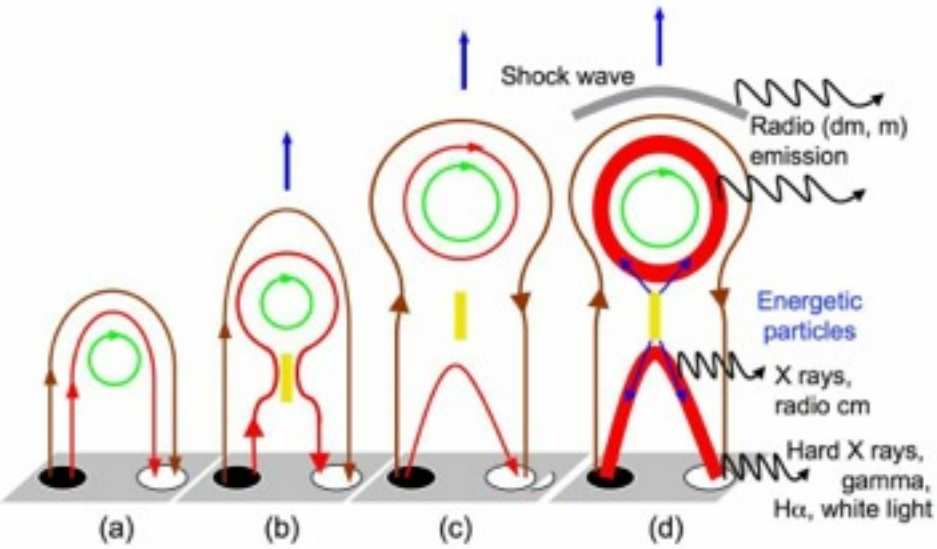
Solar energetic particle events
Scenarios of particle acceleration

- "Flare acceleration" :
  - reconnecting current sheet, induced E, waves, possibly reconnection shock
  - active region, mainly low corona
  - particles revealed by radiative signatures (gamma, HXR, radio), evidence for e(>10 MeV), p(>300 MeV)



After K.-L. Klein., *Solar Orbiter* Workshop, Athens, ESA-SP



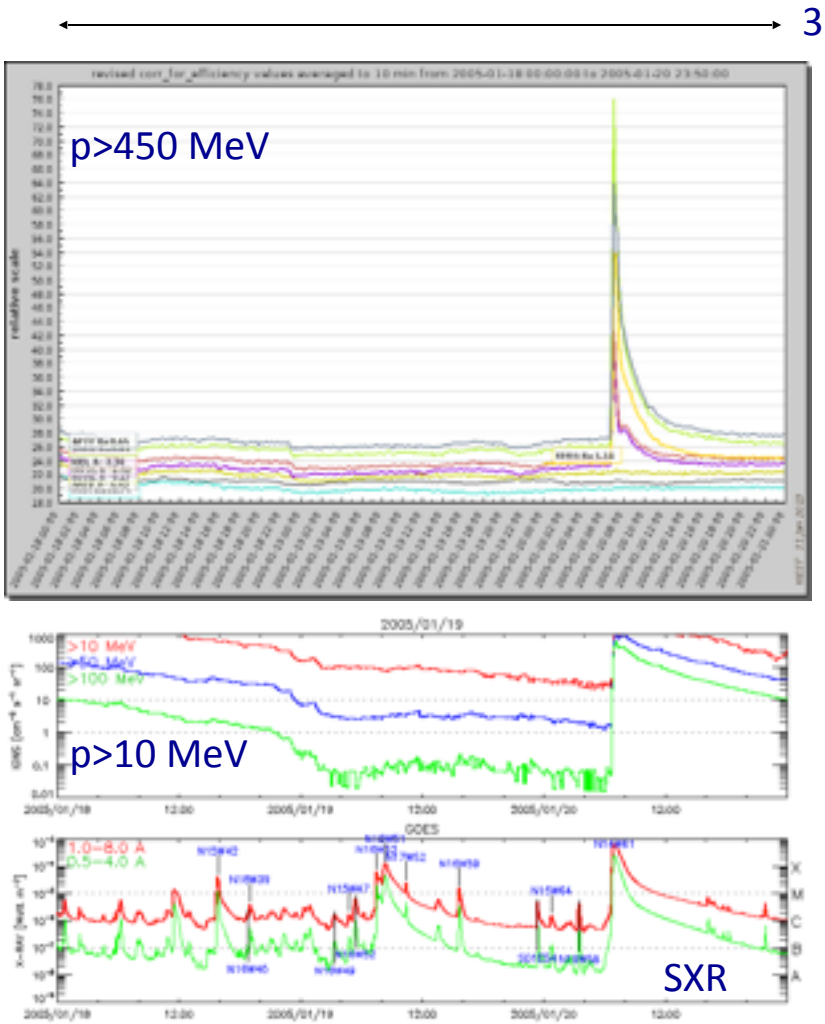
'CME acceleration" :

- fast CME drives shock wave
- particles scattered between shock and upstream turbulence ("diffusive shock acceleration")
- evidence in situ (IP space, planetary bow shocks; up to which energy ?)
- also: reconnection in the aftermath of the CME

Solar energetic particle events

Difficulties – the interest for a mission closer to the Sun

- Large SEP event on 2005 Jan 20 observed at 1 AU: GOES (bottom), neutron monitors (top)
- SEP time profiles near 1 AU have been smeared out by IP propagation (especially at some MeV – 100 MeV): difficult / impossible to trace the time profile back to acceleration processes near the Sun
- Solar Orbiter (Solar Probe +): SEP measurements close to the Sun



www.nmdb.eu

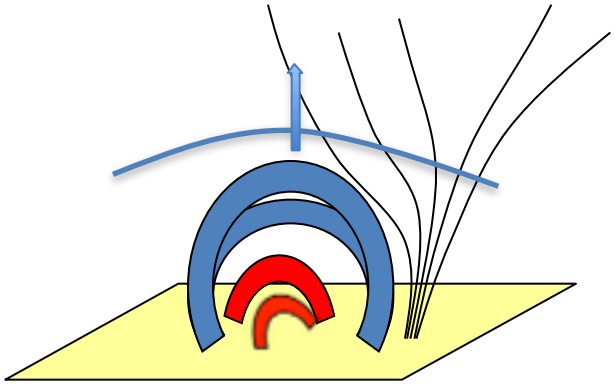
cdaw.gsfc.nasa.gov/CME_list/

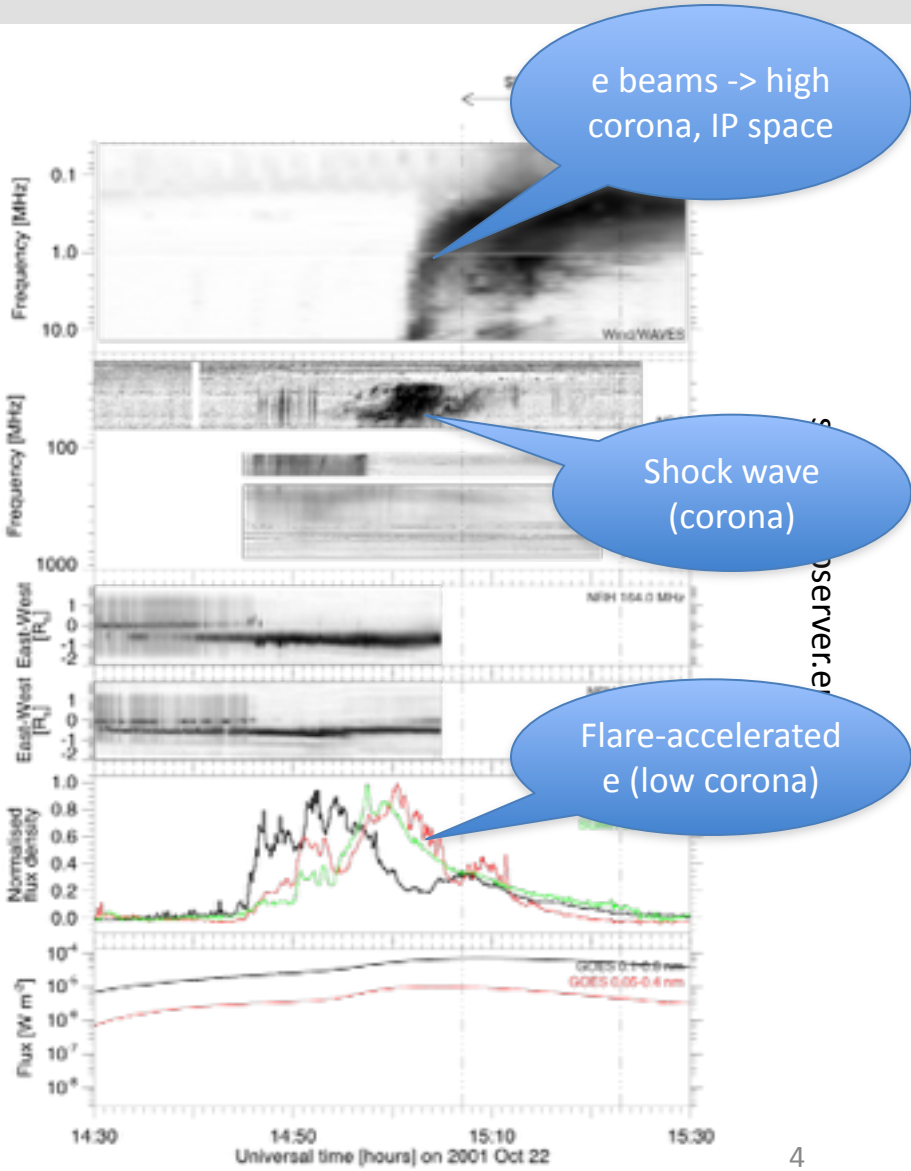
SEP acceleration 1

Timing of SEPs as a key to distinguish different accelerators

- Can we distinguish flare-related from shock-related SEP acceleration from the SEP timing ?

- Case study (radio evidence):
  - flare-accelereated electrons confined in the low corona
  - SEPs accelerated at a coronal shock wave (consistent with onset @ SoHO/ERNE)

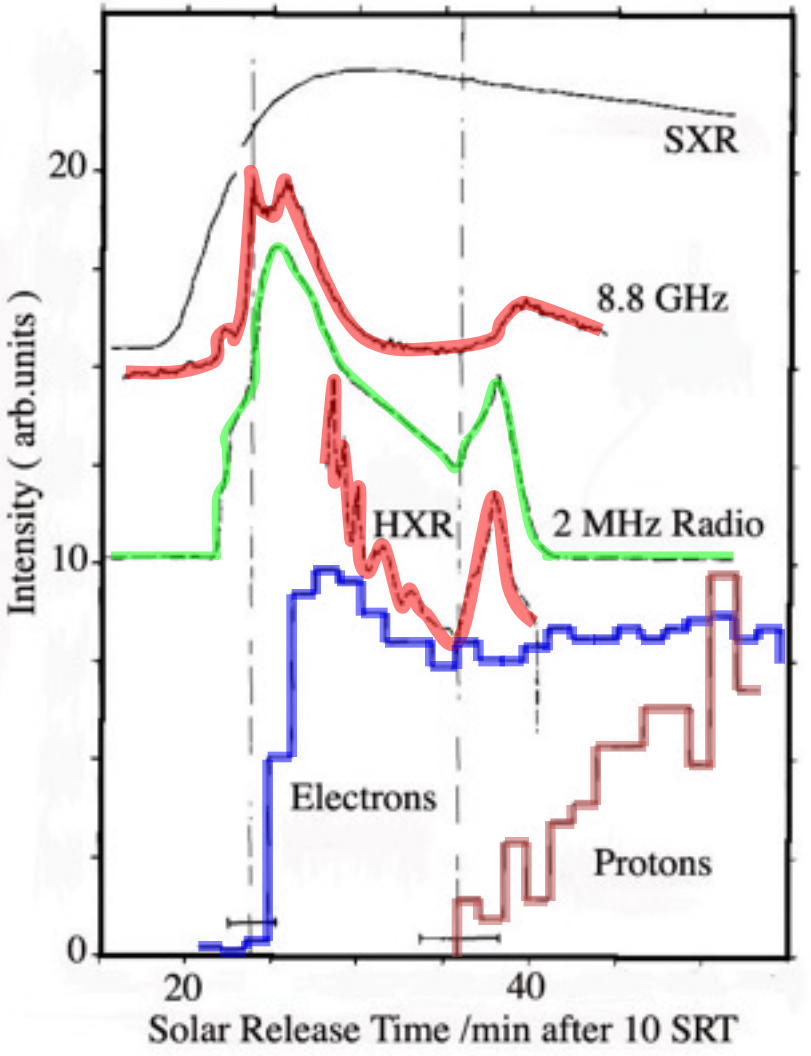




SEP acceleration 1

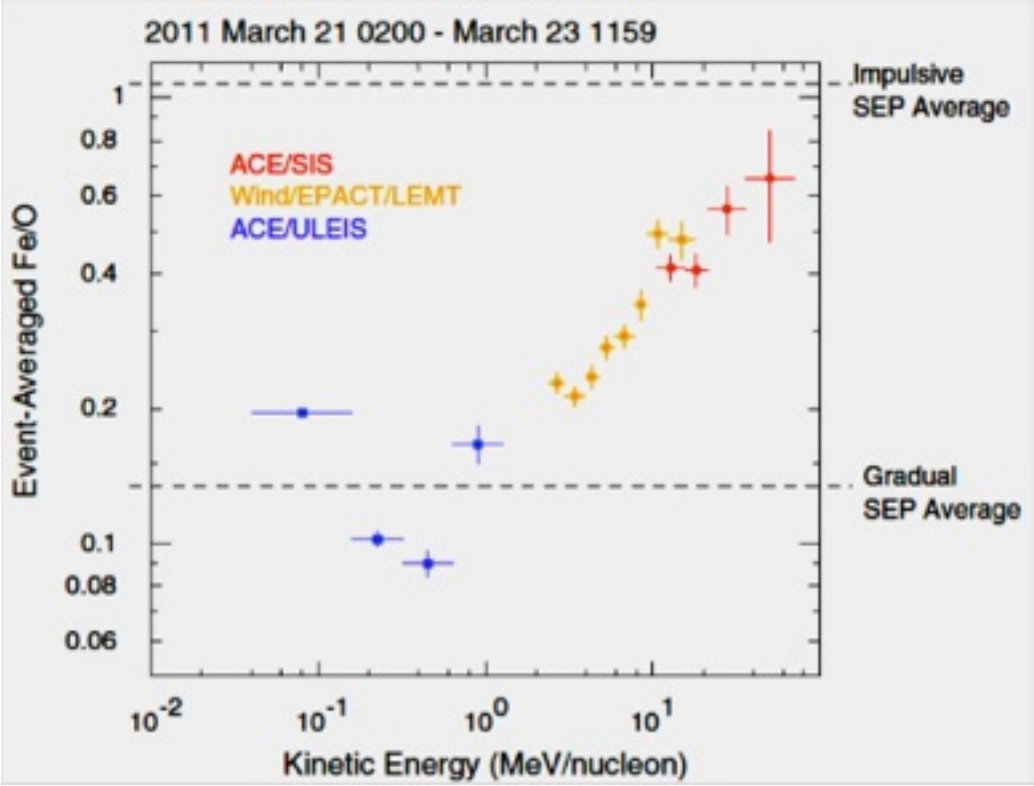
Timing of SEPs as a key to distinguish different accelerators

- A key to use this tool: ability to distinguish features in SEP time profiles
- Problem at 1 AU: time profiles smeared out by IP propagation (scattering of SEPs by waves)
- An example from HELIOS at *r*=0.38 AU :
  - Protons delayed wrt electrons (~10-15 min)
  - Type III (2 MHz): two episodes of e release to IP space
  - HXR/microwaves: two episodes of electron (particle) acceleration in the corona



Kallenrode & Wibberenz 1991 ApJ 376, 787

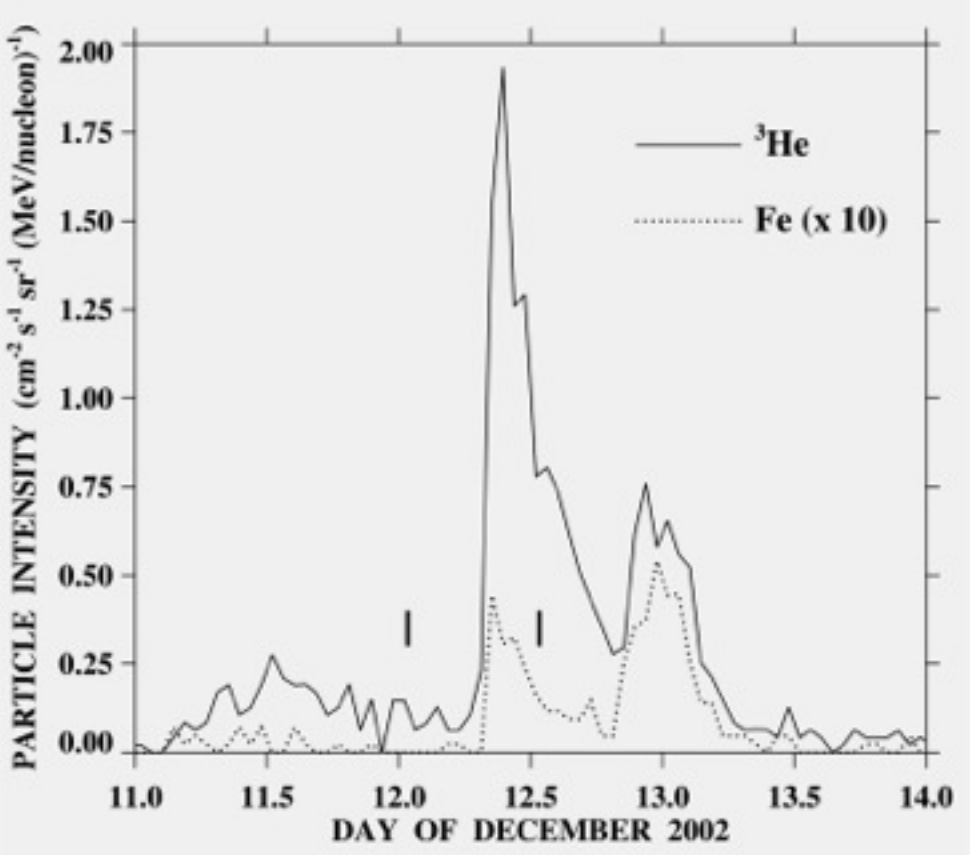
SEP acceleration 2
Shock acceleration scenarios



Rouillard et al. 2012 ApJ 752, 44

- Why are elemental abundances and charge states increasingly different from the quiet corona or solar wind with increasing energy ?
- The role of the seed population:
  - Standard corona and solar wind ?
  - Suprathermal populations from previous events ?

SEP acceleration 2
Shock acceleration scenarios



Wang et al. 2006 ApJ 639, 495

- Why are elemental abundances and charge states increasingly different from the quiet corona or solar wind with increasing energy ?
- The role of the seed population:
  - Standard corona and solar wind ?
  - Suprathermal populations from previous events ?
- Sol O near the Sun:
  - measure seed populations
  - Particles and waves in shock acceleration regions

SEP acceleration
Key questions for Solar Orbiter

From the Solar Orbiter Red Book:

How do solar eruptions produce energetic particle radiation that fills the heliosphere?

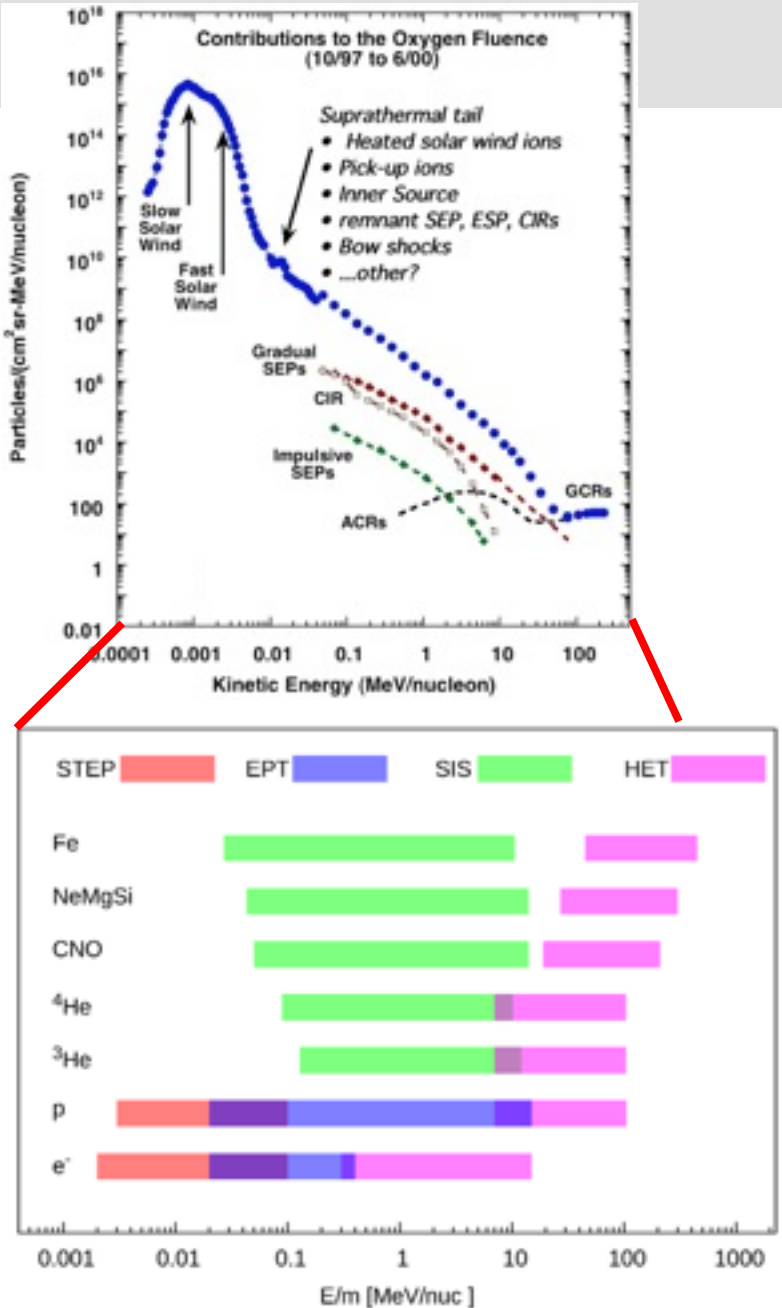
1) How and where are energetic particles accelerated at the Sun?

2) How are energetic particles released from their sources and distributed in space and time?

3) What are the seed populations for energetic particles?

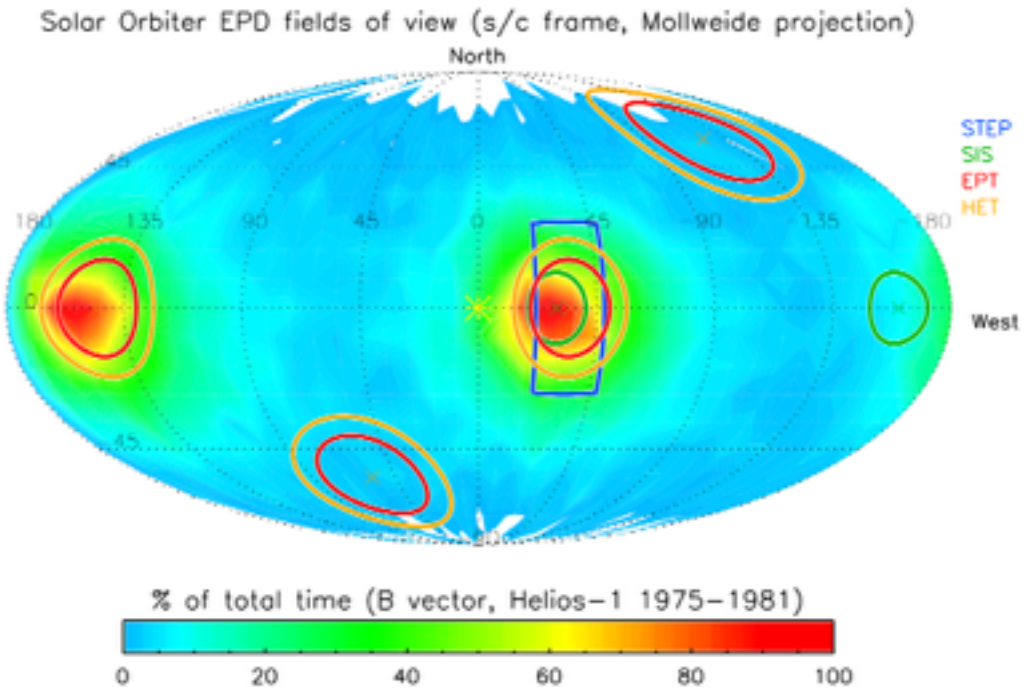
SEP observations with Solar Orbiter

The Energetic Particle Detector (EPD)



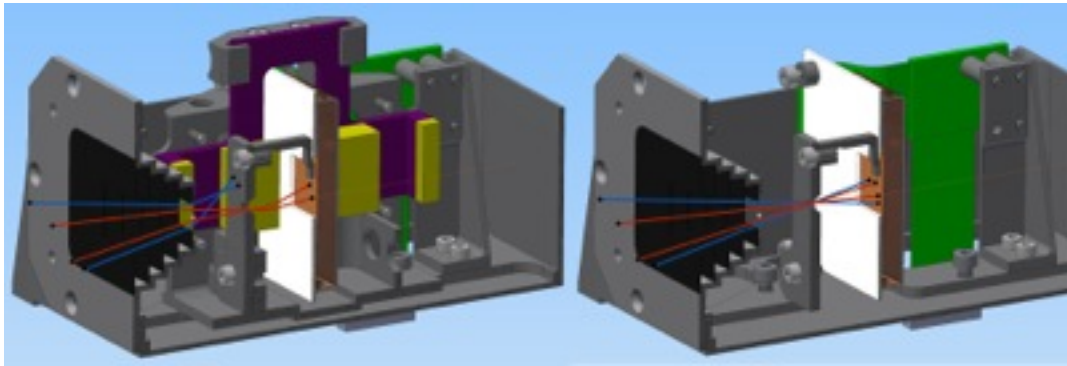
How do energetic particles behave close to the Sun?

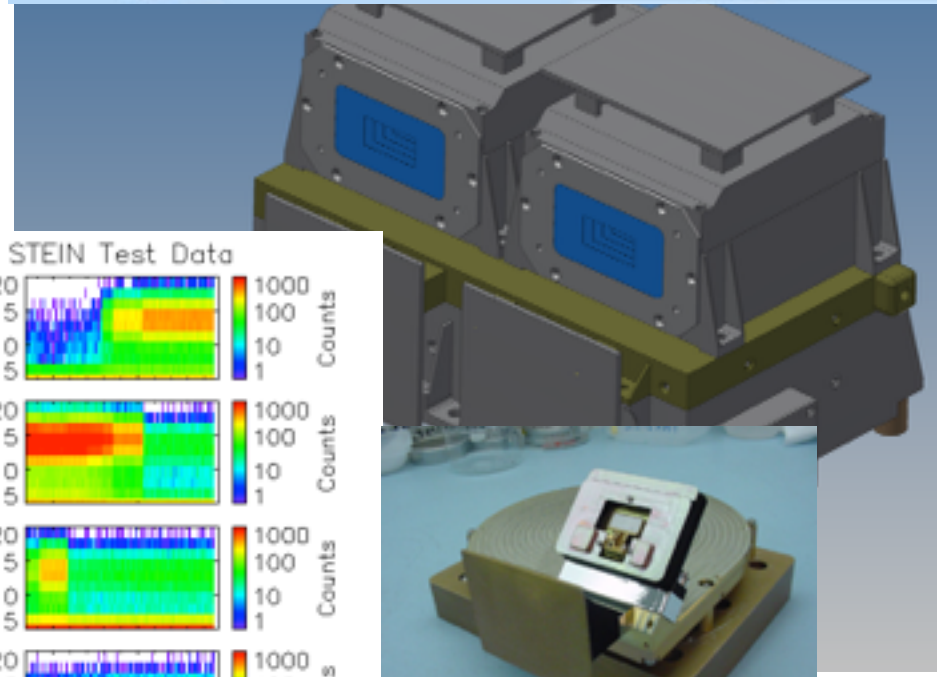
- Which populations are injected into the acceleration process ?
- How are they accelerated?
- What influences their transport?

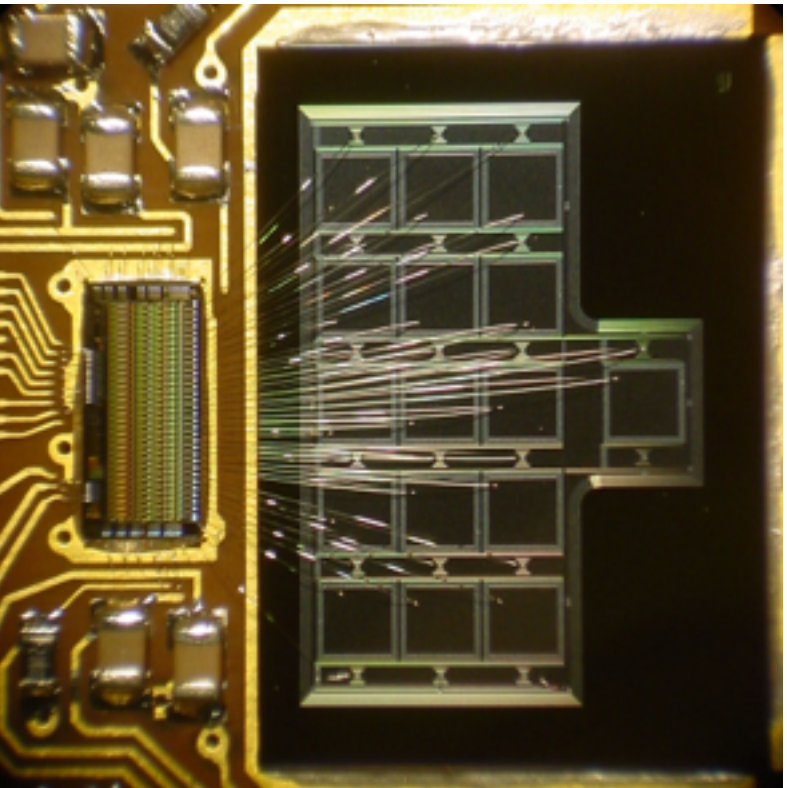


Solar Orbiter - EPD
Supra Thermal Electrons and Protons (STEP)

- Spacecraft mounted
  - STEP will measure e^- [2 - 100 keV], p^+ [3 - 100 keV]
- Instrument Heritage:
  - STEP has direct heritage from STEREO/STE and SEPT



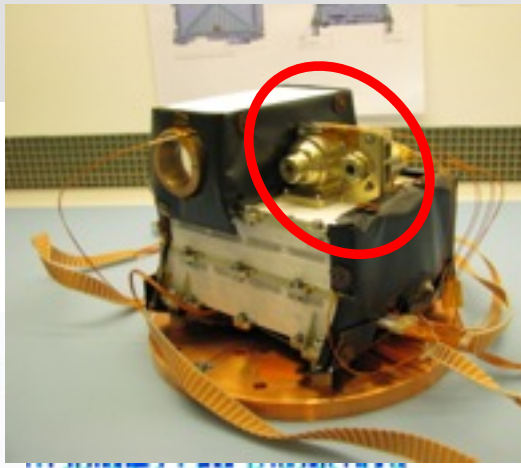


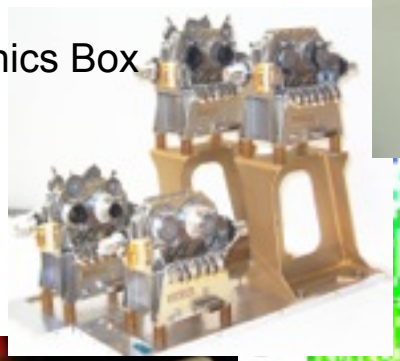


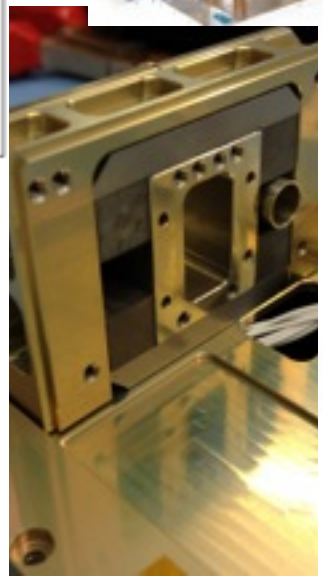
Solar Orbiter - EPD

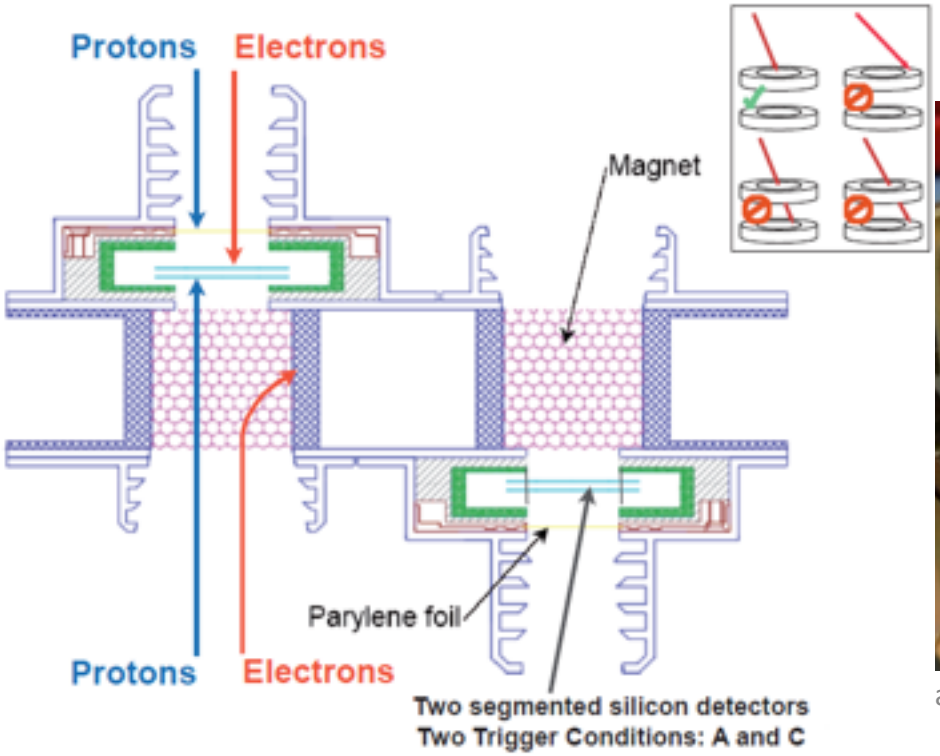
Electron-Proton telescope (EPT)

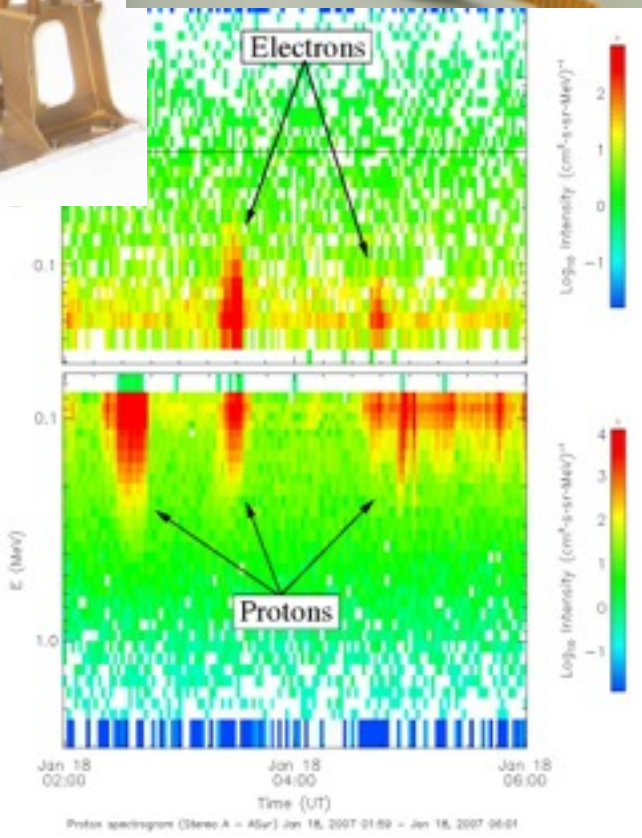
- Measures electrons and protons
  - EPT will measure e^- [0.02-0.7MeV], p^+ [0.02-7MeV]
  - Four view directions (in and out of orbital plane) with two units
  - EPT and HET sensors share the same Electronics Box
- Instrument Heritage:
  - EPT has direct heritage from STEREO/SEPT







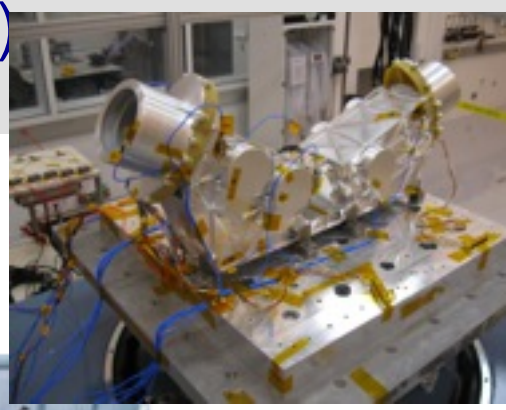




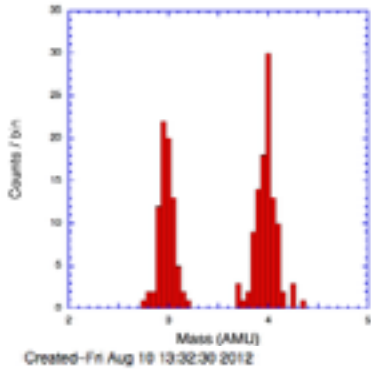
ap, cau

Solar Orbiter - EPD

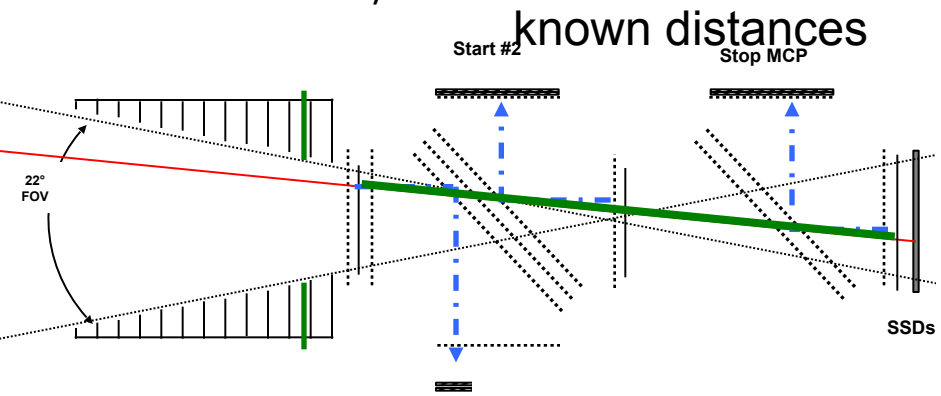
Supra Thermal Ion Spectrograph (SIS)

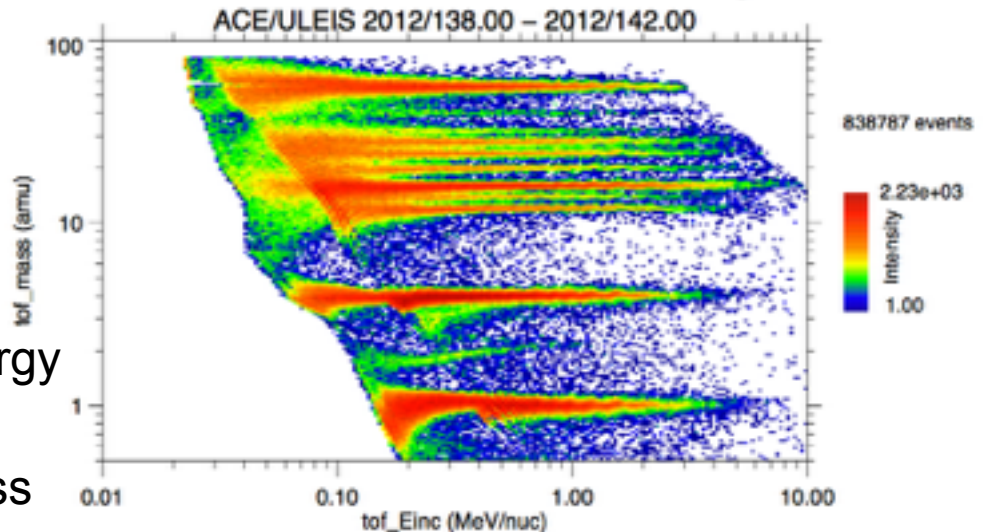


- Measures all elements from helium to iron and samples trans-iron elements
  - Energy range: 8 keV/nuc – 10 MeV/n (oxygen)
  - Two telescopes view forward and aft directions; single electronics box



- Instrument Heritage
  - SIS has heritage from ACE/ULEIS and STEREO/SIS





ToF ⟶ speed

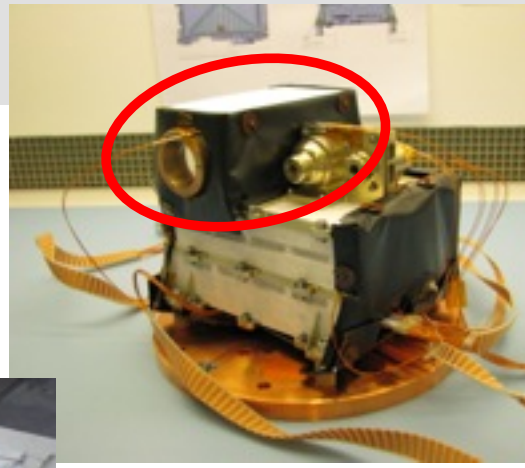
Energy

$E = \frac{1}{2} m v^2$

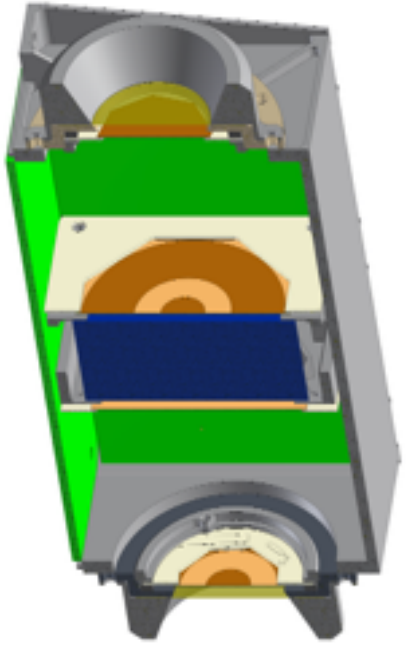
mass

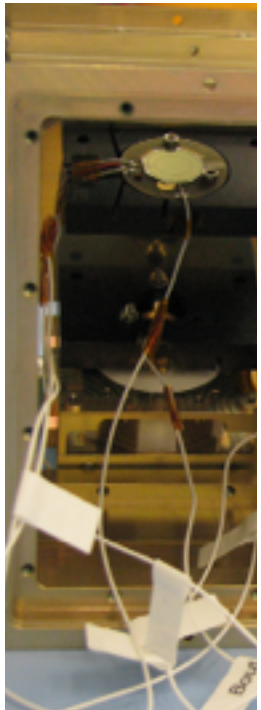
Solar Orbiter - EPD

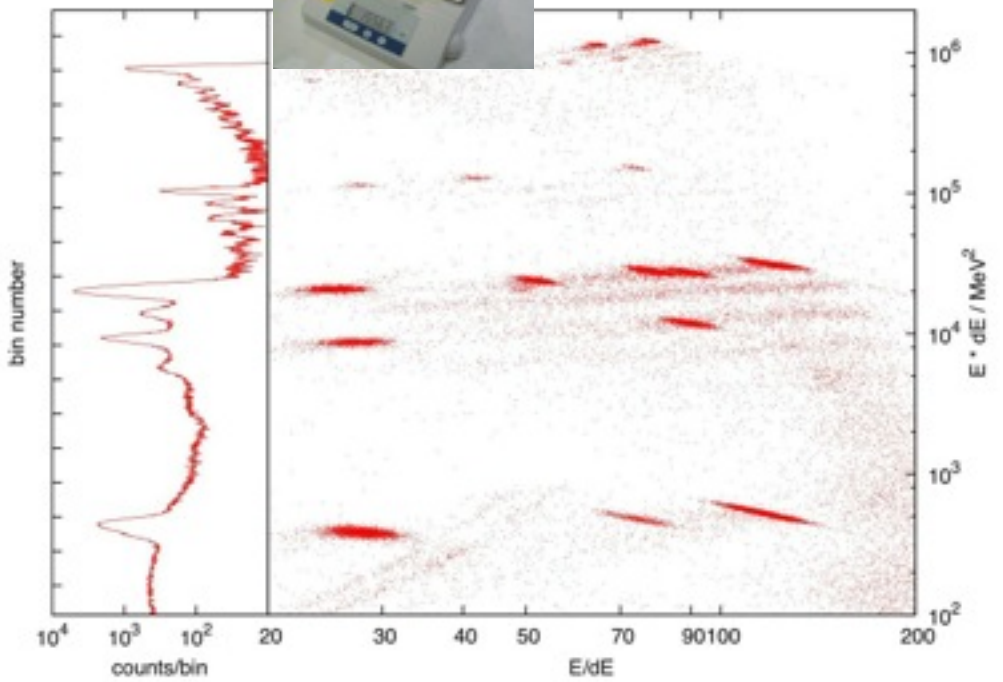
High-Energy Telescope (HET)



- Measures e- [0.3-20MeV], p+ [10-100MeV] and ions [10s-200MeV/nuc species-dependent]
  - •Four view directions (in and out of orbital plane) with two units
  - •EPT and HET sensors share the same Electronics Box
- Instrument Heritage:
  - –HET has heritage from the MSL/RAD instrument

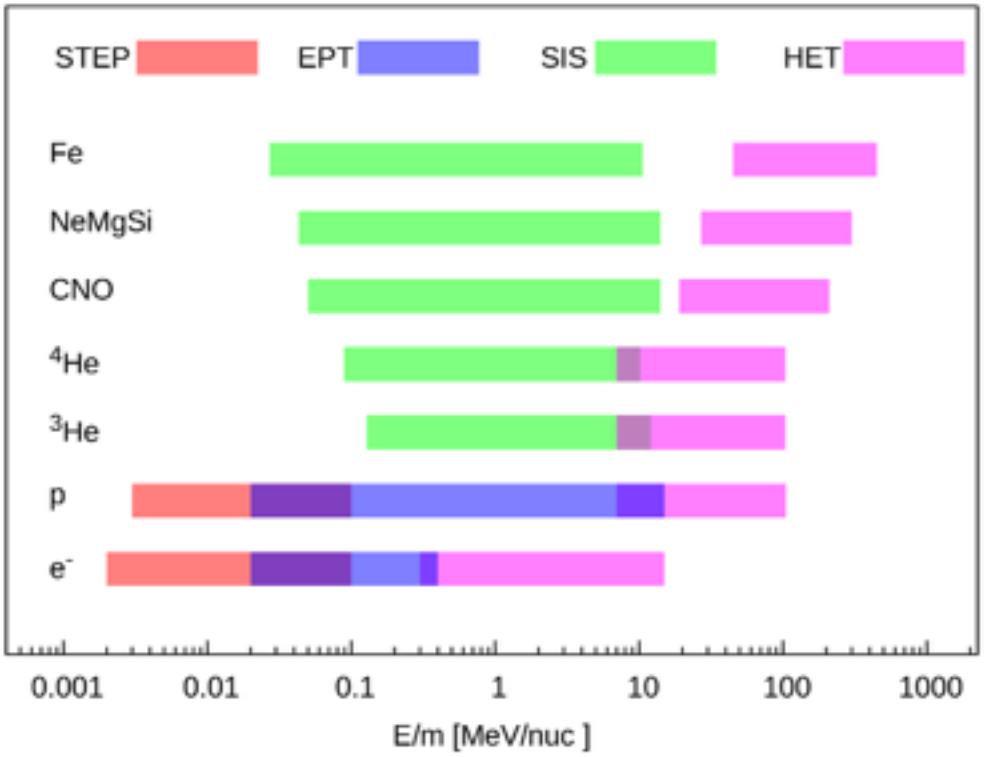


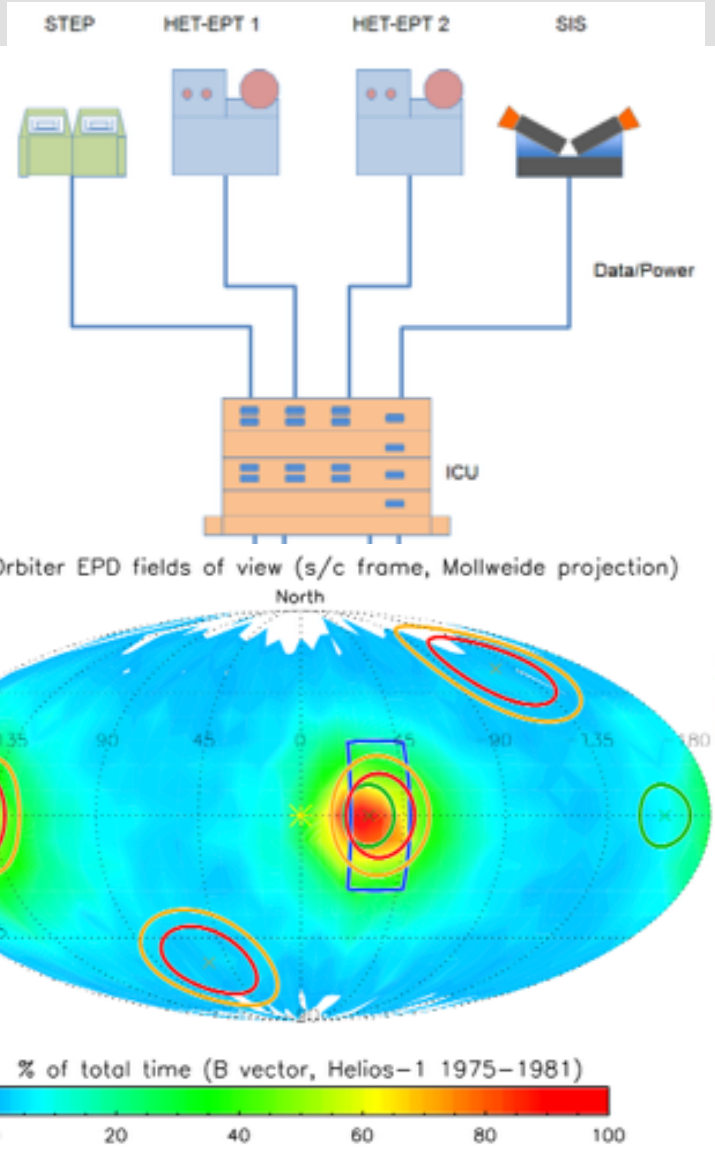




Solar Orbiter - EPD
Summary

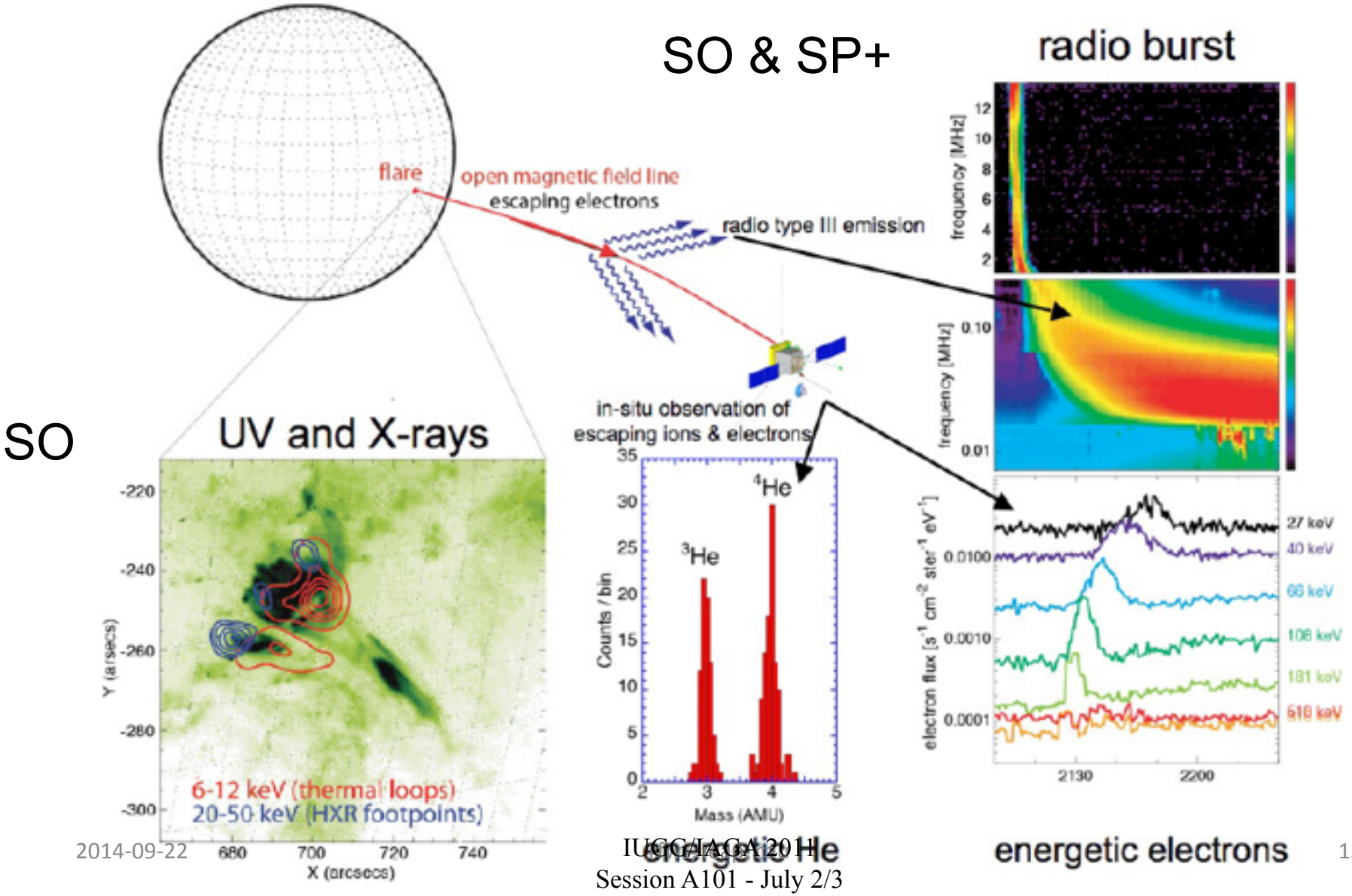
EPD will measure
- electrons from 2keV – 20 MeV,
- protons from 3keV – 100 MeV,
- ions from 8 keV – 200 MeV/nuc
- at high cadence
- In up to 4 view directions (STEP: 15)





Solar Orbiter - EPD

To connect the Sun to the Heliosphere



Solar Orbiter - EPD

To connect the Sun to the Heliosphere