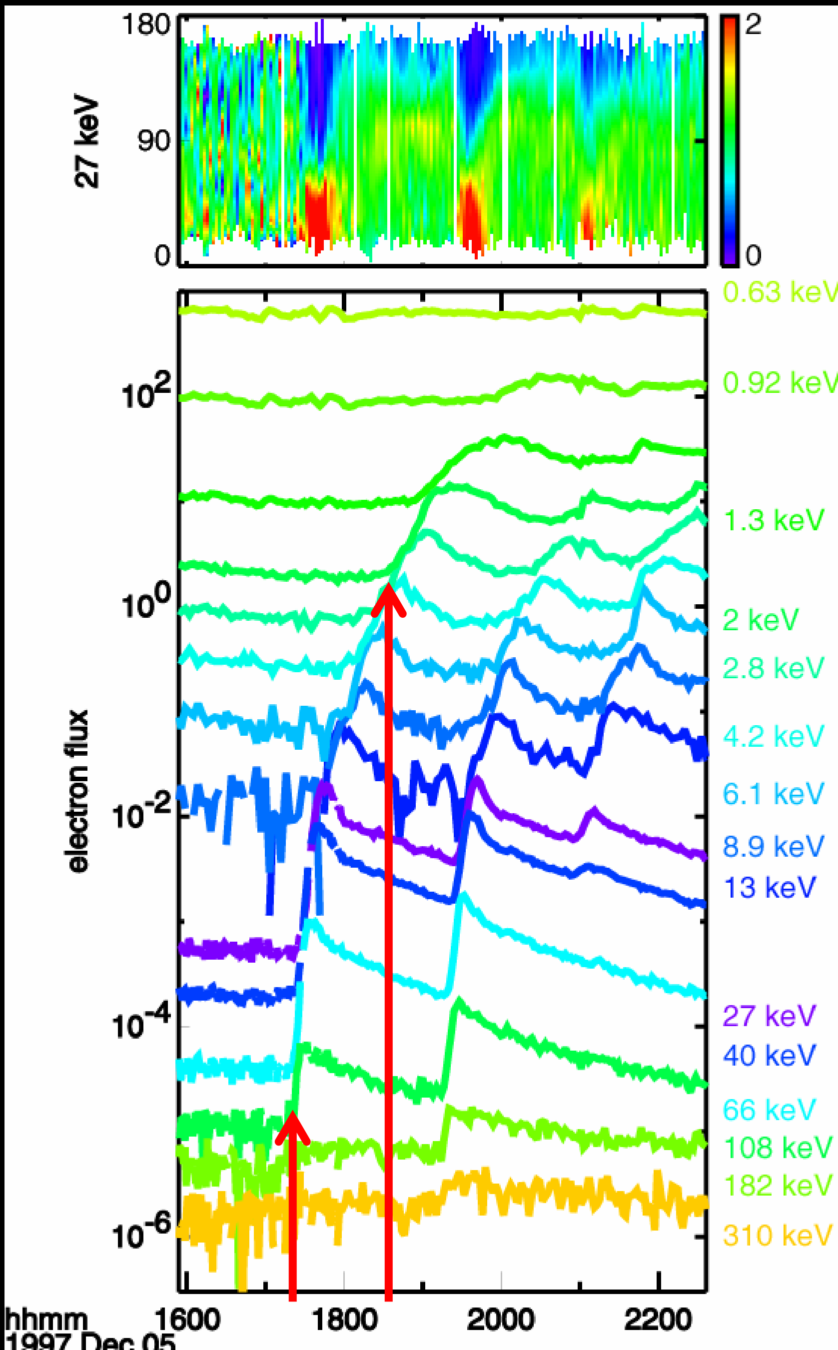
Combined WIND-RHESSI-TRACE studies

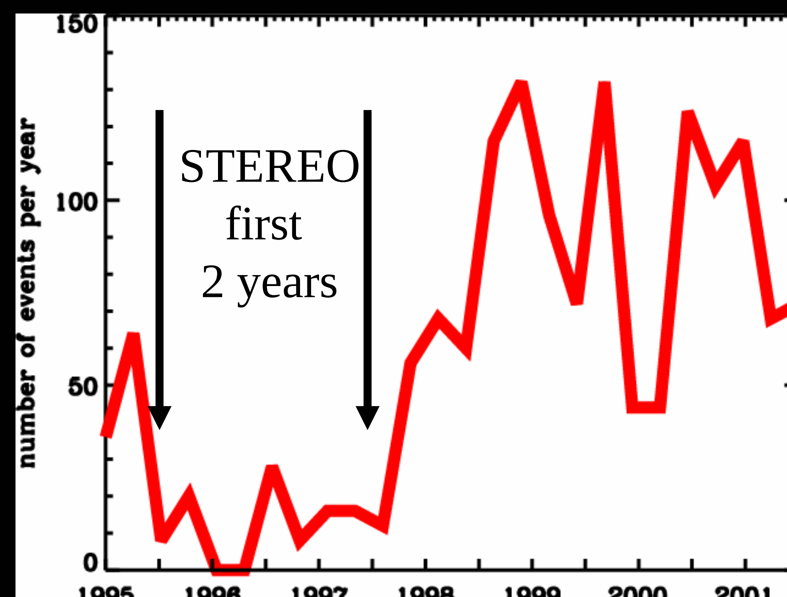
Säm Krucker
Space Sciences Lab, UC Berkeley

The origin of solar impulsive energetic electrons: combined observations

Impulsive electron events observed at 1 AU

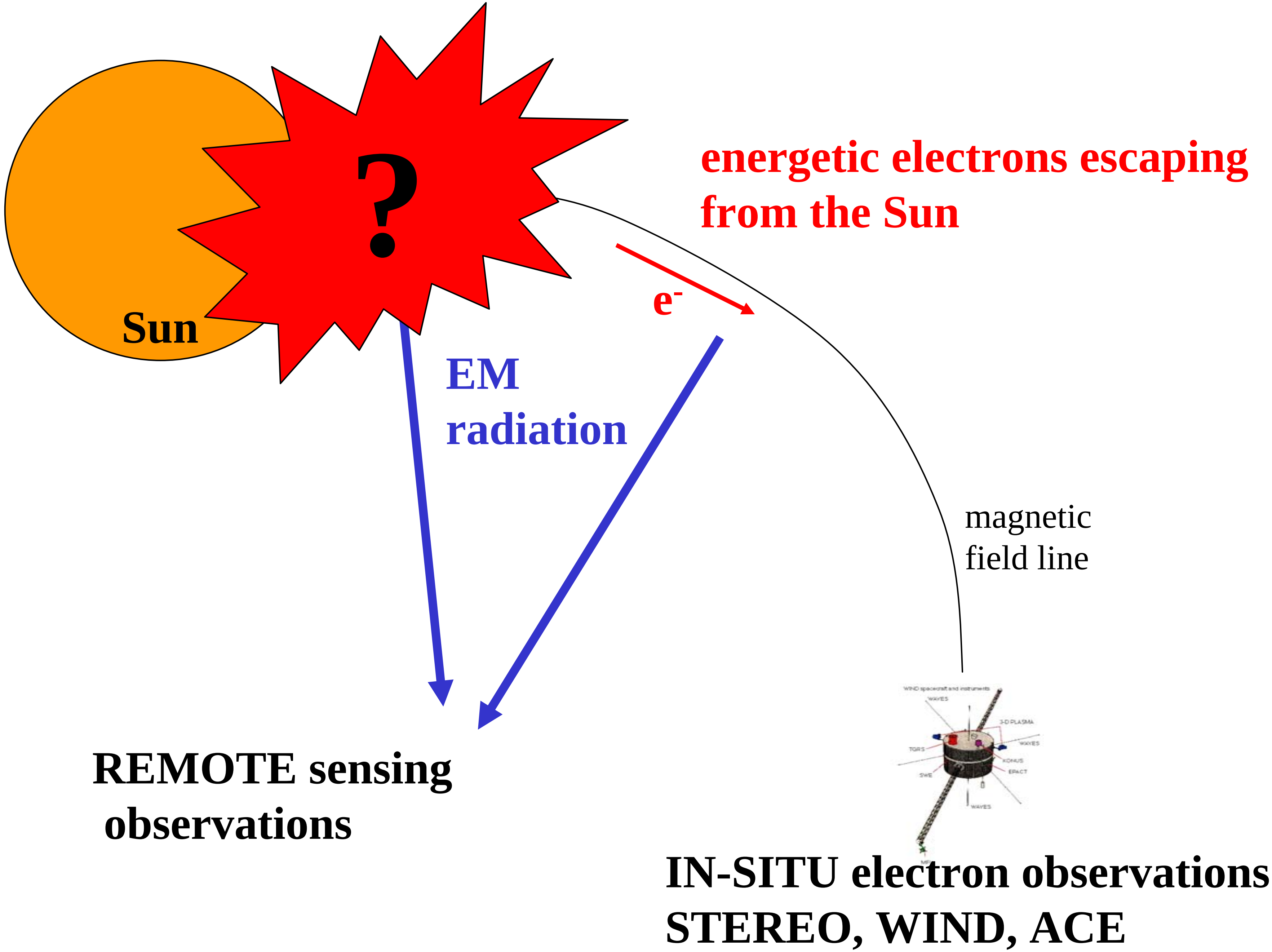


WIND/3DP:
~15 event/year during solar min.
STEREO/STE:
50 times more sensitive
below 30 keV → more events

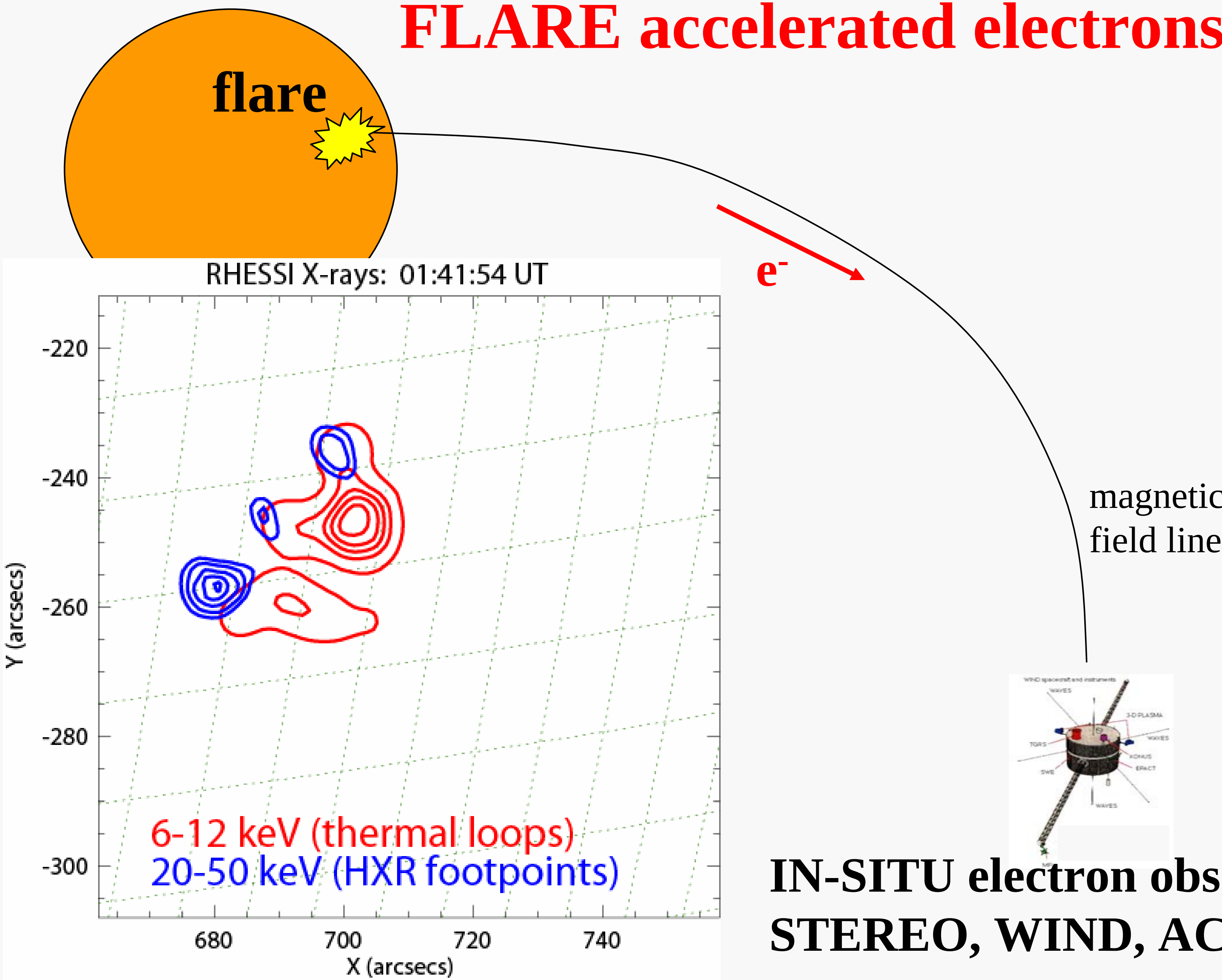


STEREO/STE observations

- Solid state detectors down to 2 keV (wind/3dp: 30 keV)
- 50 times more sensitive
  → 5 times more events
- Accurate onset times down to 2 keV
- 2 point measurements + WIND

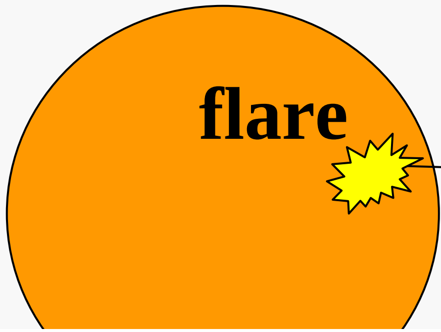

?
Sun
energetic electrons escaping from the Sun
e^-
EM radiation
magnetic field line
REMOTE sensing observations
IN-SITU electron observations
STEREO, WIND, ACE

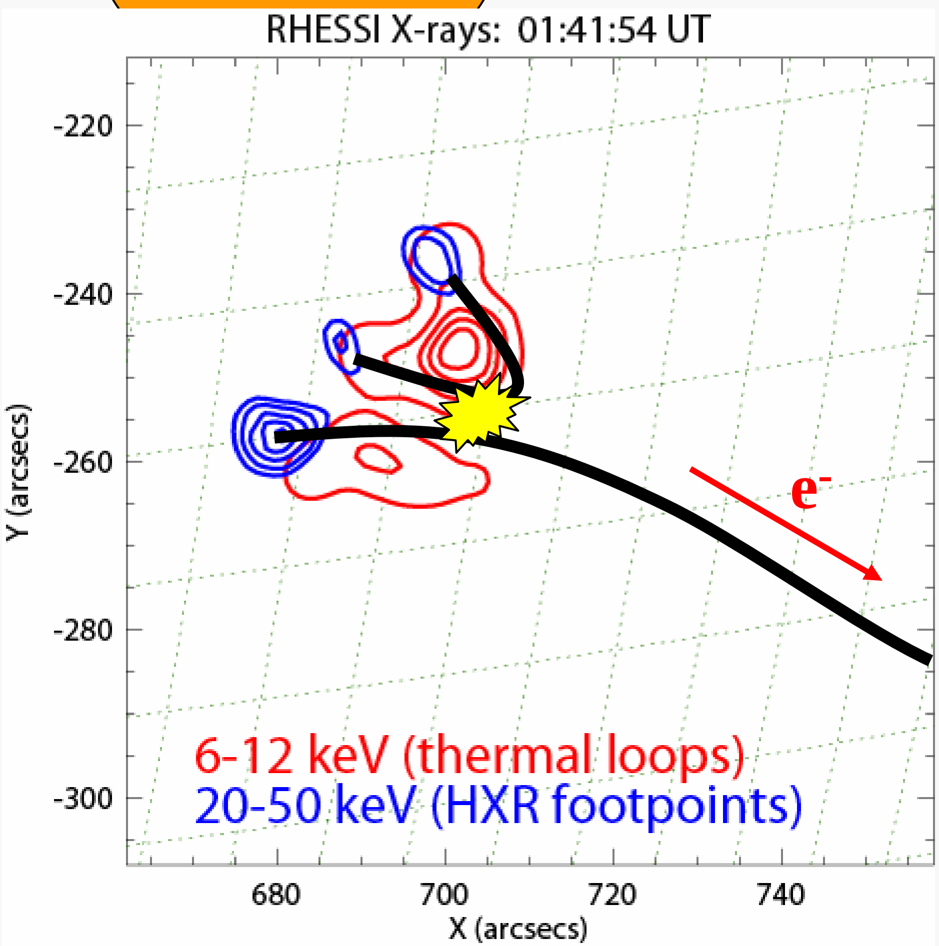
FLARE accelerated electrons escape

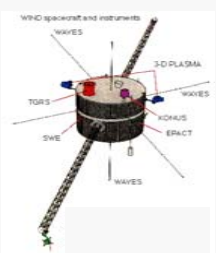


IN-SITU electron observations
STEREO, WIND, ACE

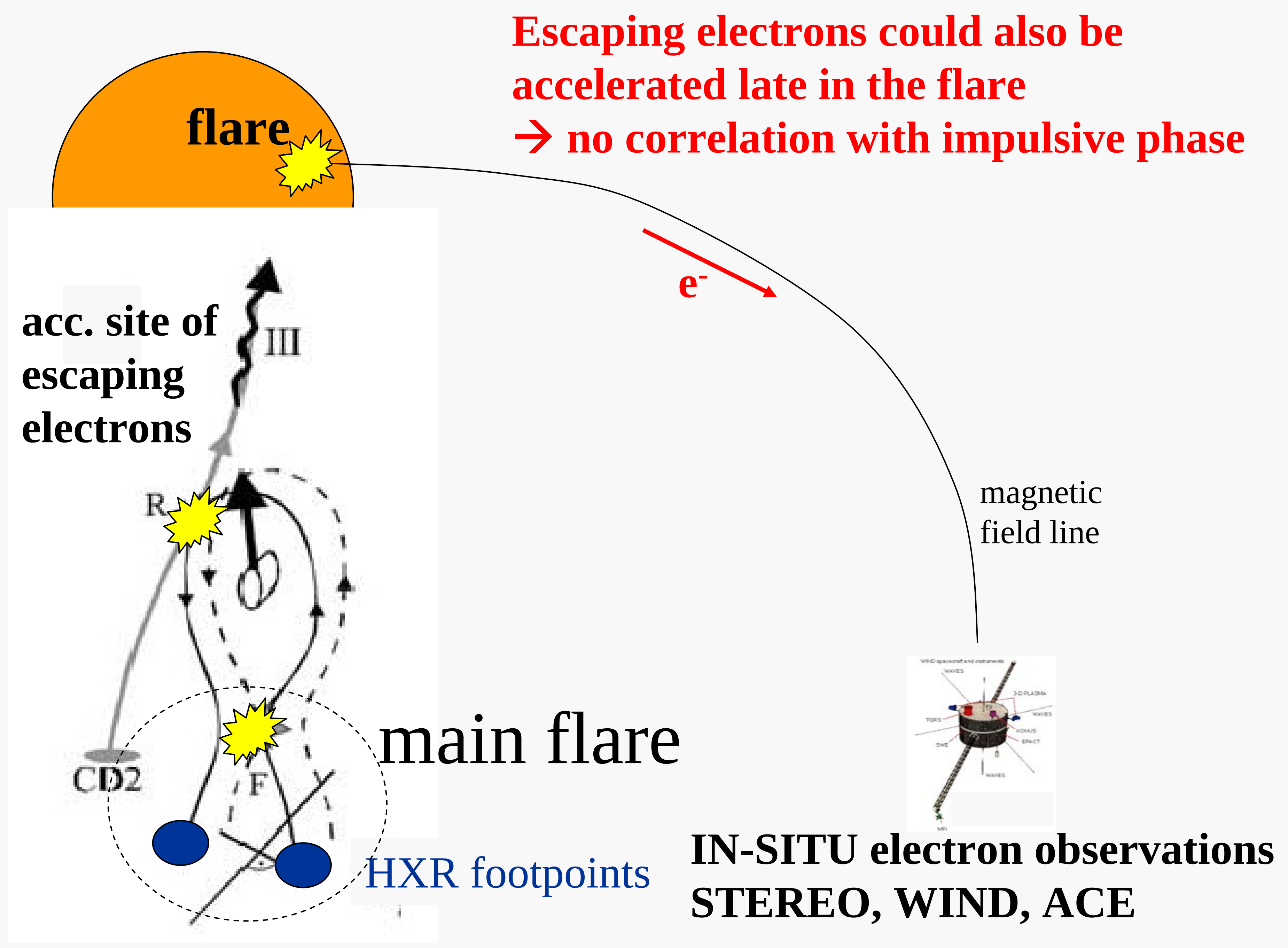
FLARE accelerated electrons escape



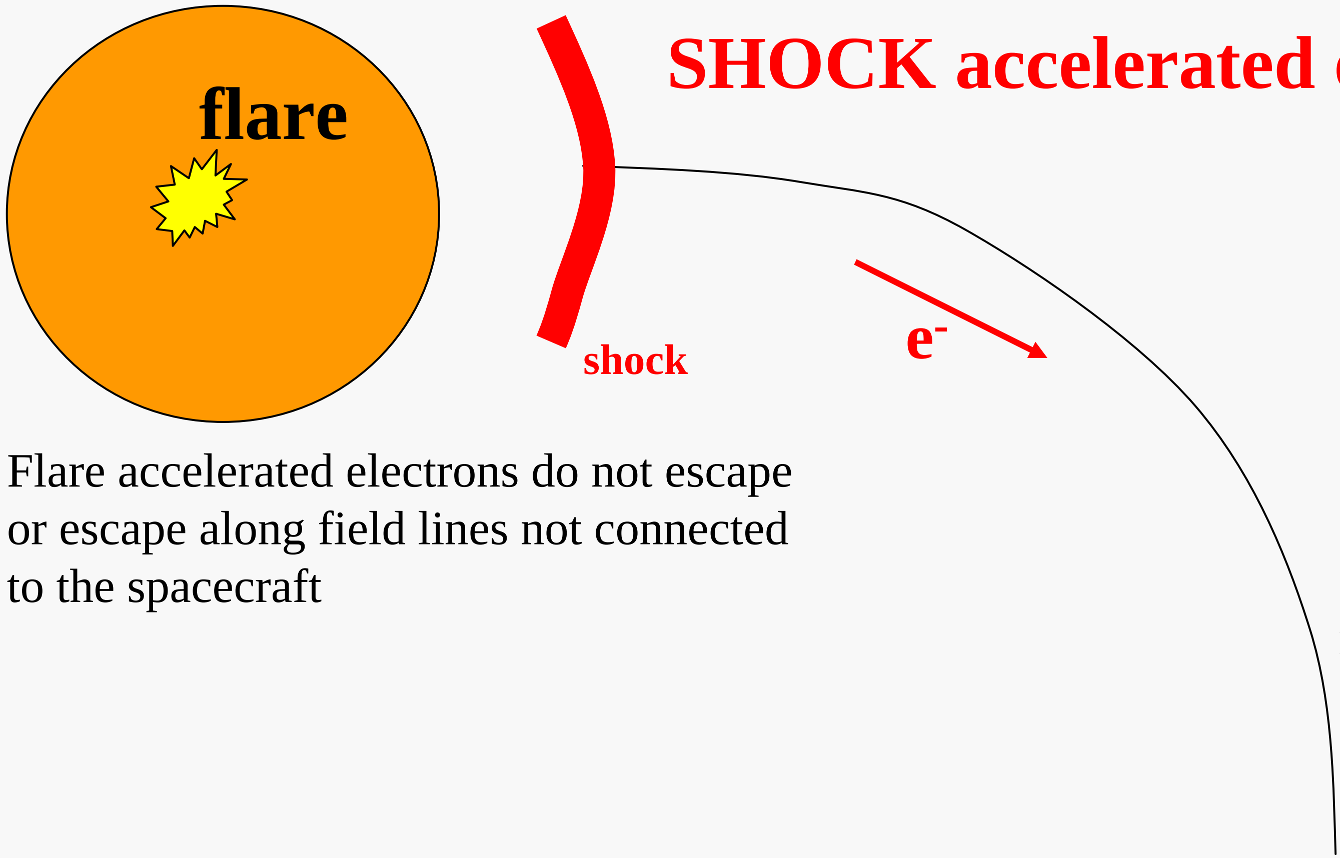




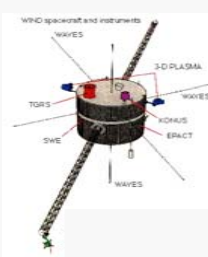
IN-SITU electron observations
STEREO, WIND, ACE


Escaping electrons could also be accelerated late in the flare
→ no correlation with impulsive phase
flare
e-
acc. site of escaping electrons
III
R
CD2
F
main flare
HXR footpoints
magnetic field line
IN-SITU electron observations
STEREO, WIND, ACE

SHOCK accelerated electrons



Flare accelerated electrons do not escape
or escape along field lines not connected
to the spacecraft



IN-SITU electron observations
STEREO, WIND, ACE

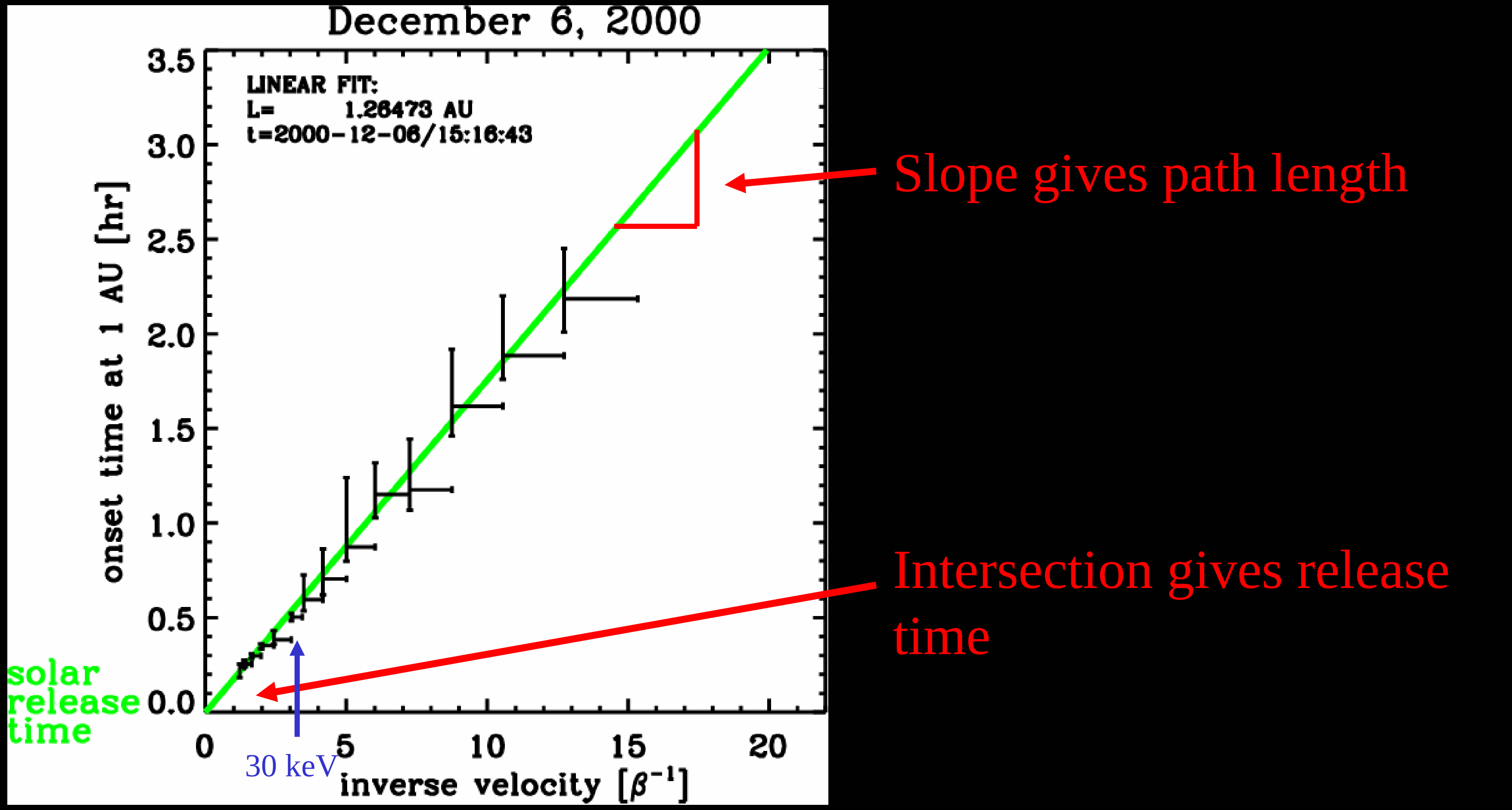
Flare or shock acceleration?

1. Different **timing**
2. Depending of **magnetic connection** different component are observed

Timing

From onset times at 1 AU (velocity dispersion) solar release time can be approximated.

Controversy: propagation effect or scattering?



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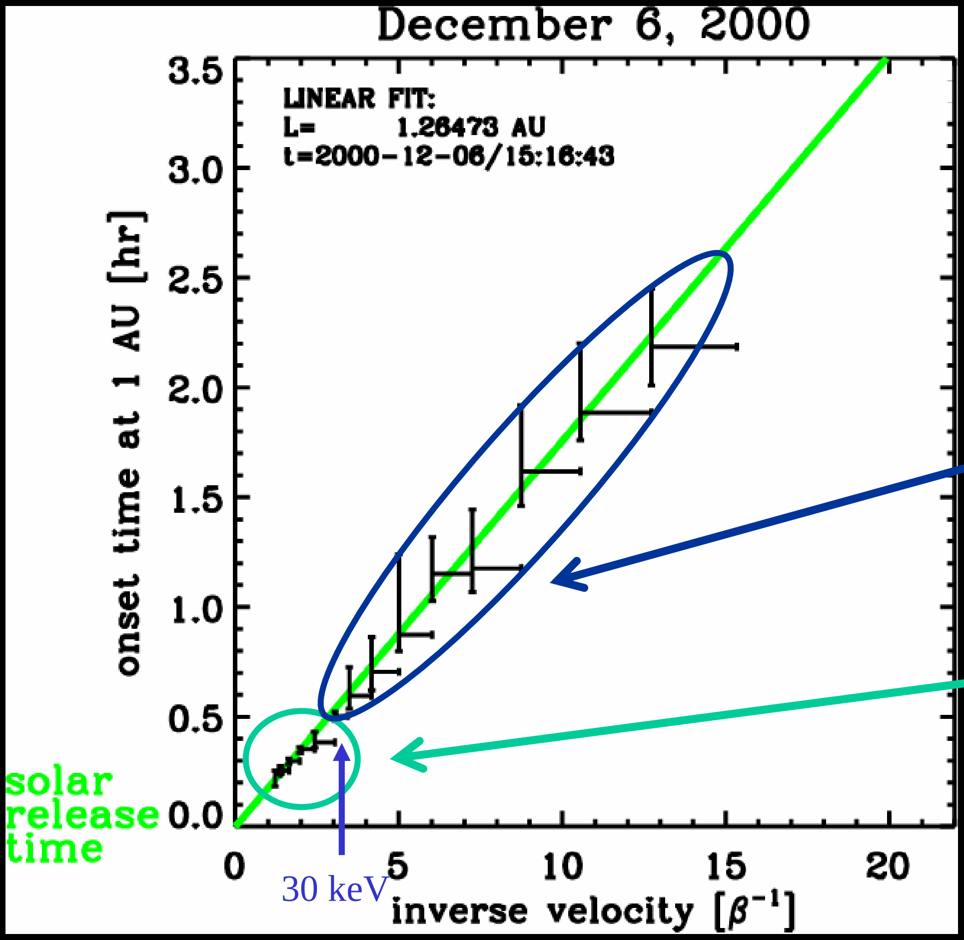

WIND/3DP
Electrostatic analyzers:
large error bars

Solid state detectors:
SMALL error bars
(~few minutes)

Timing

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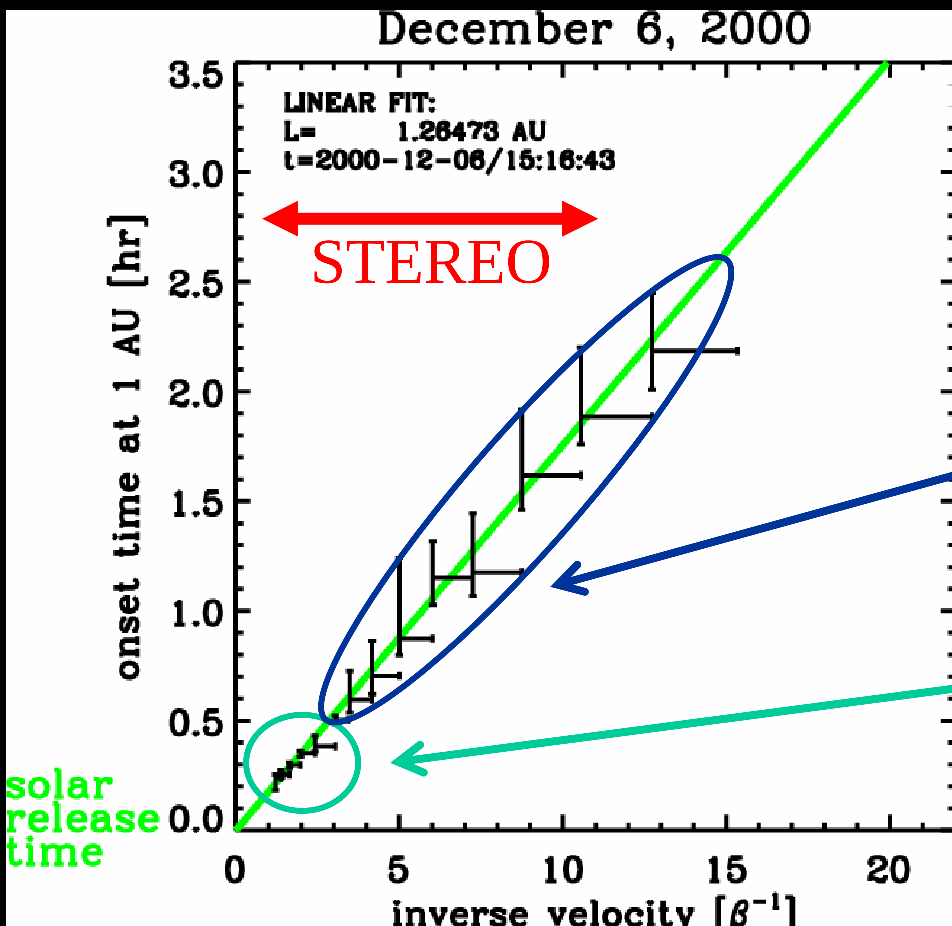
Controversy: propagation effect or scattering?

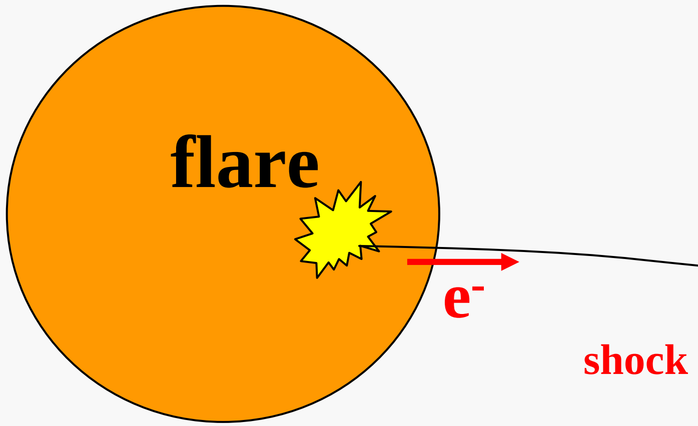


STEREO/STE
Solid state detectors down to 2 keV

WIND/3DP observerations
Electrostatic analyzers: large error bars

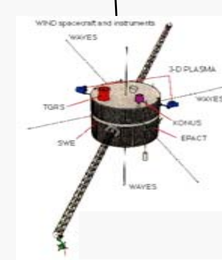
Solid state detectors: SMALL error bars (~few minutes)

What is reported?



• **Same timing as flare for some events**

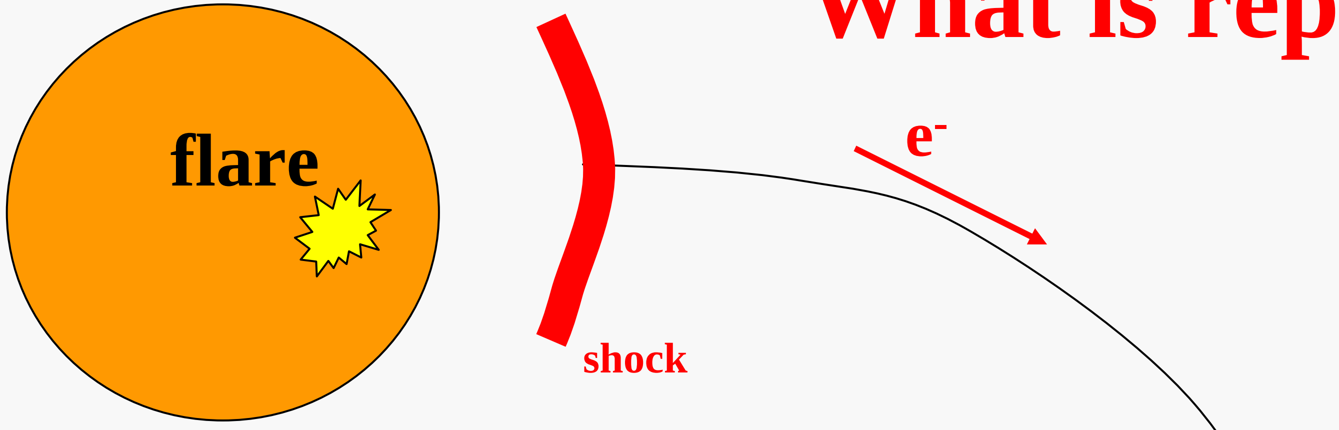
magnetic
field line



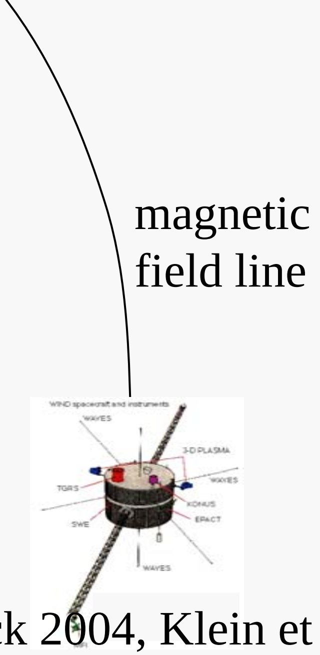
e.g. Krucker et al. 1999, Maia & Pick 2004, Klein et al. 2005

What can be done with multi-point measurements?

What is reported?



- **Same timing as flare for some events**
- **>30 keV electron often delayed → shock**



e.g. Krucker et al. 1999, Haggerty & Roelof 2002, Maia & Pick 2004, Klein et al. 2005

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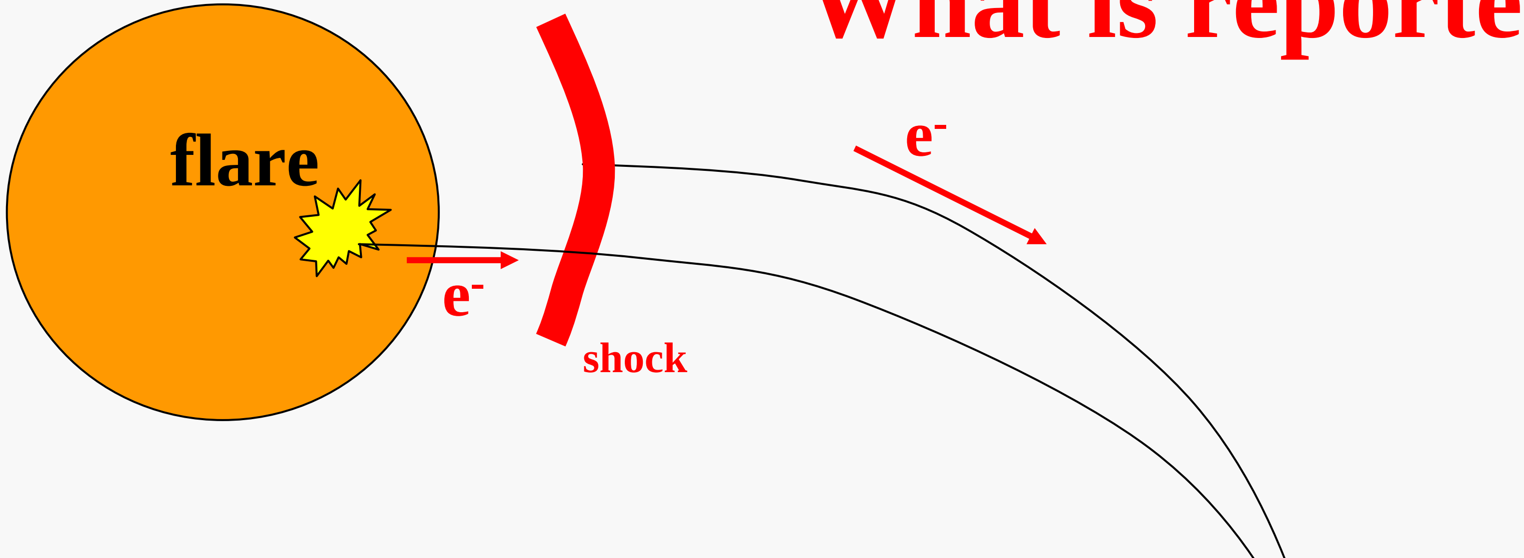
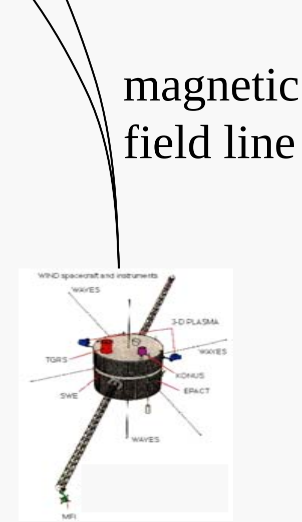
What is reported?



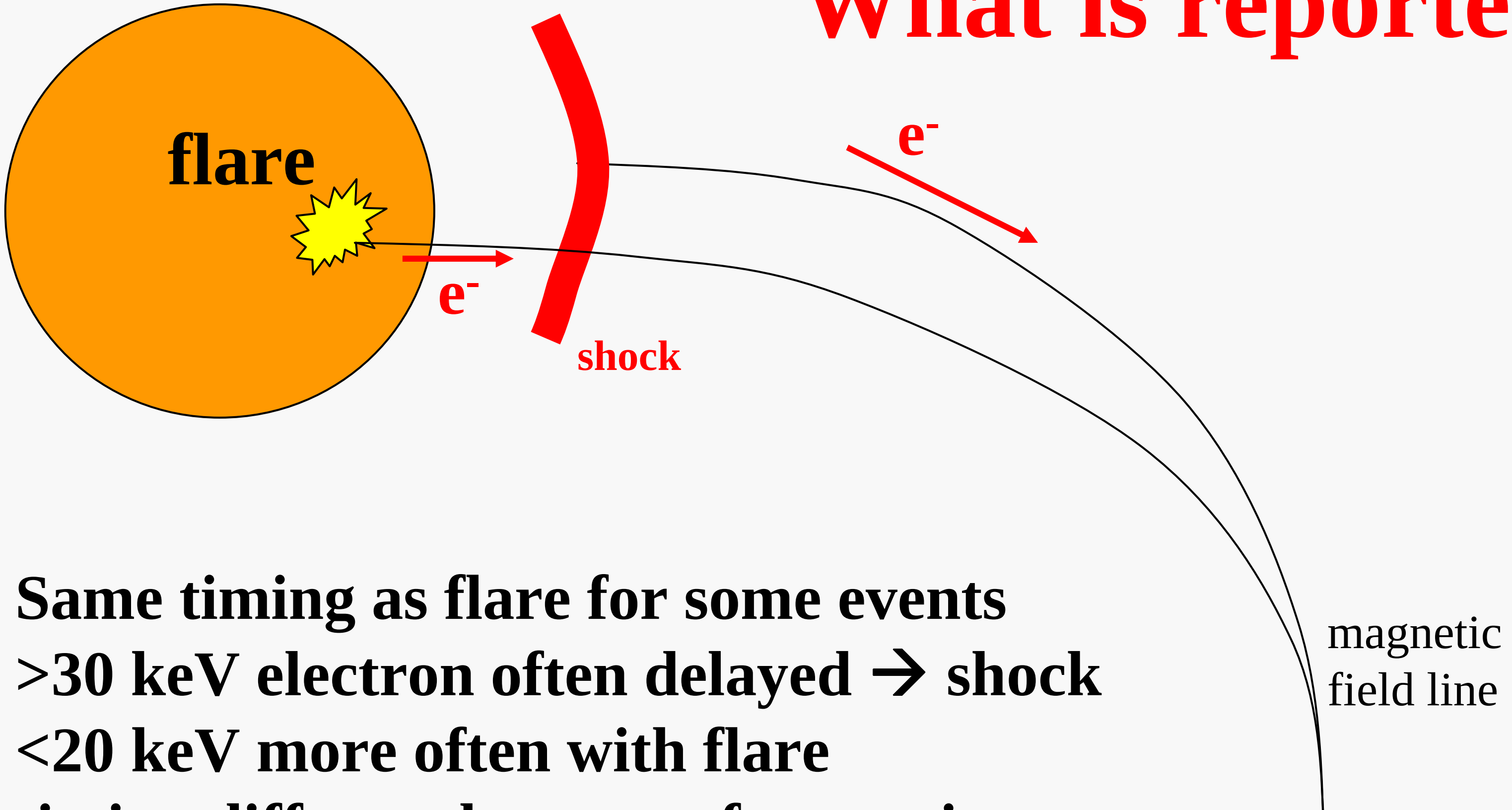


- Same timing as flare for some events
- >30 keV electron often delayed → shock
- <20 keV more often with flare

Wang et al. 2006

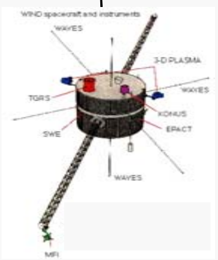
What can be done with multi-point measurements?

What is reported?



- Same timing as flare for some events
- >30 keV electron often delayed → shock
- <20 keV more often with flare
- timing different because of scattering

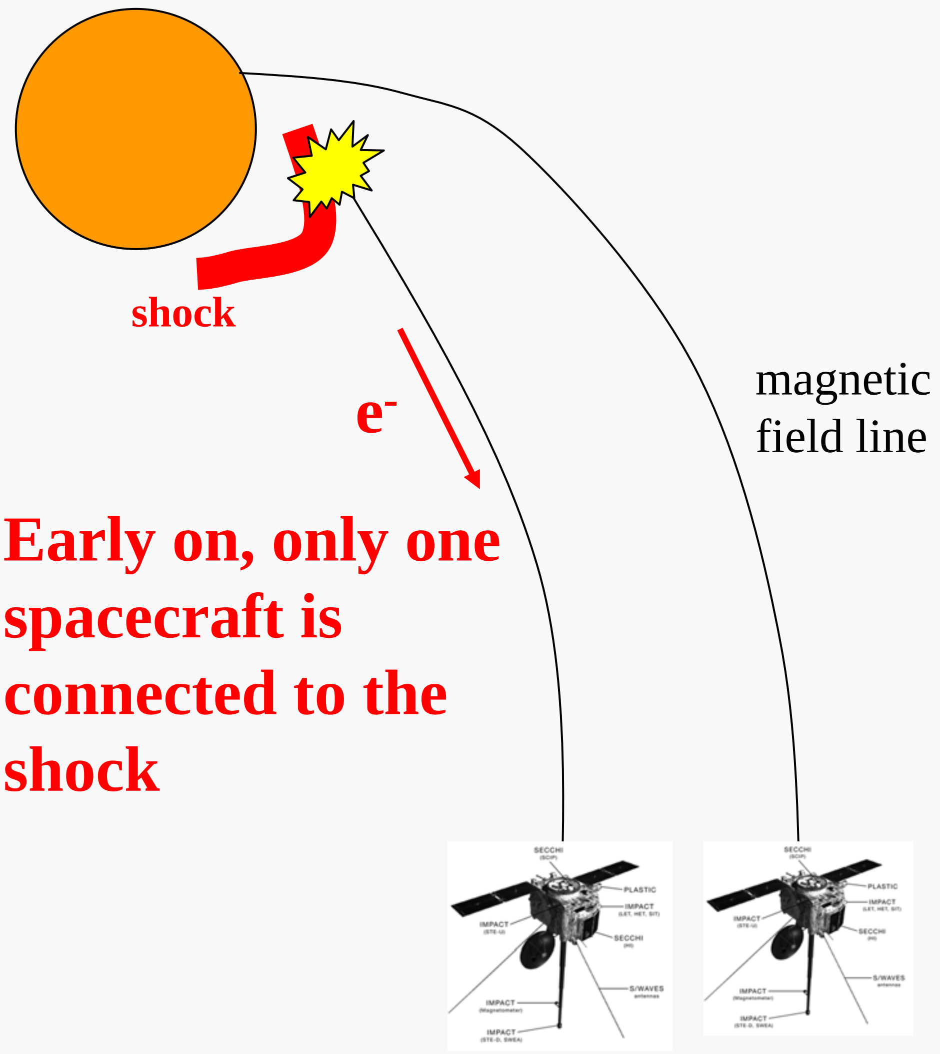
→ all events are flare related



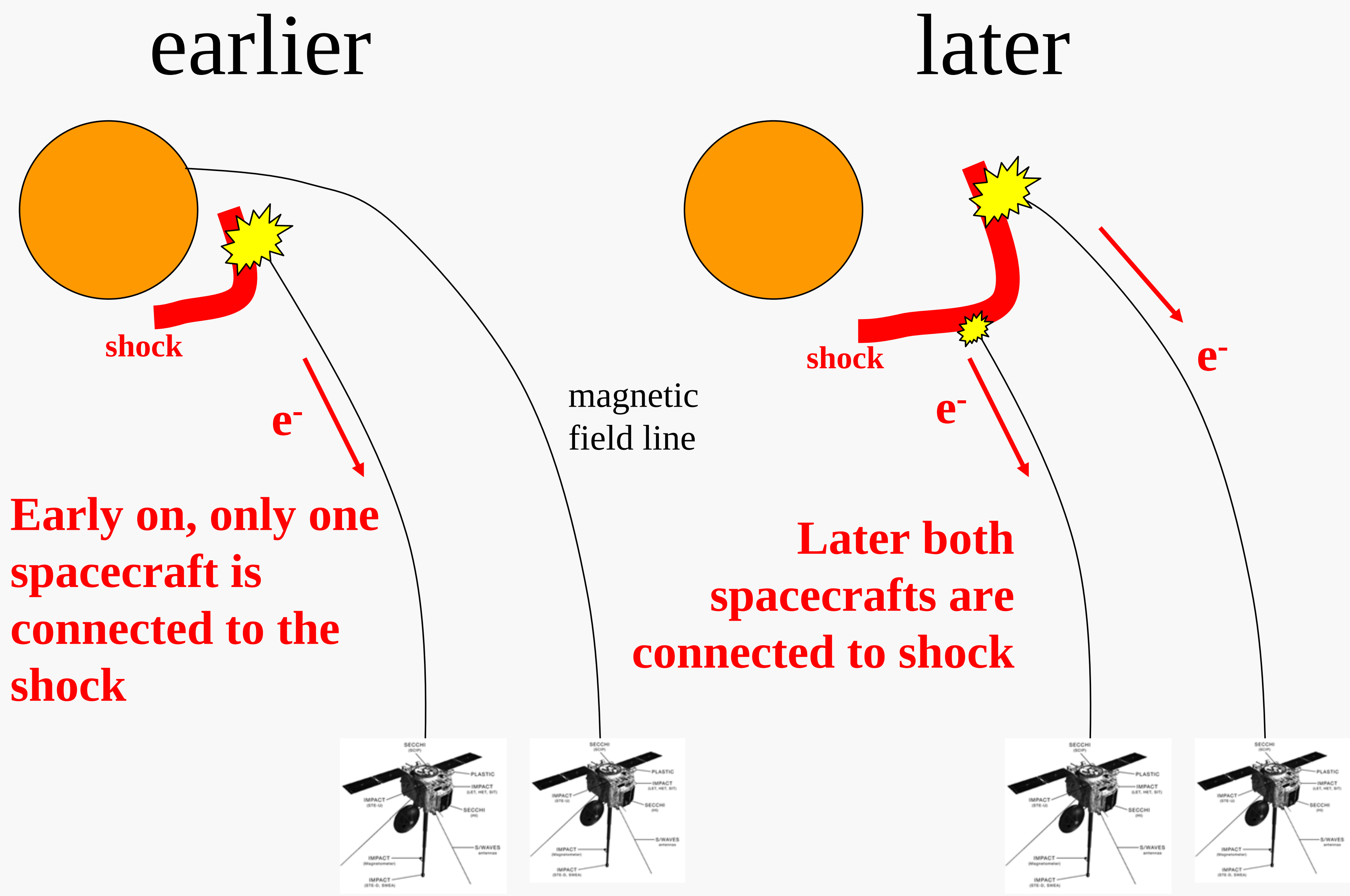
Cane 2004

What can be done with multi-point measurements?

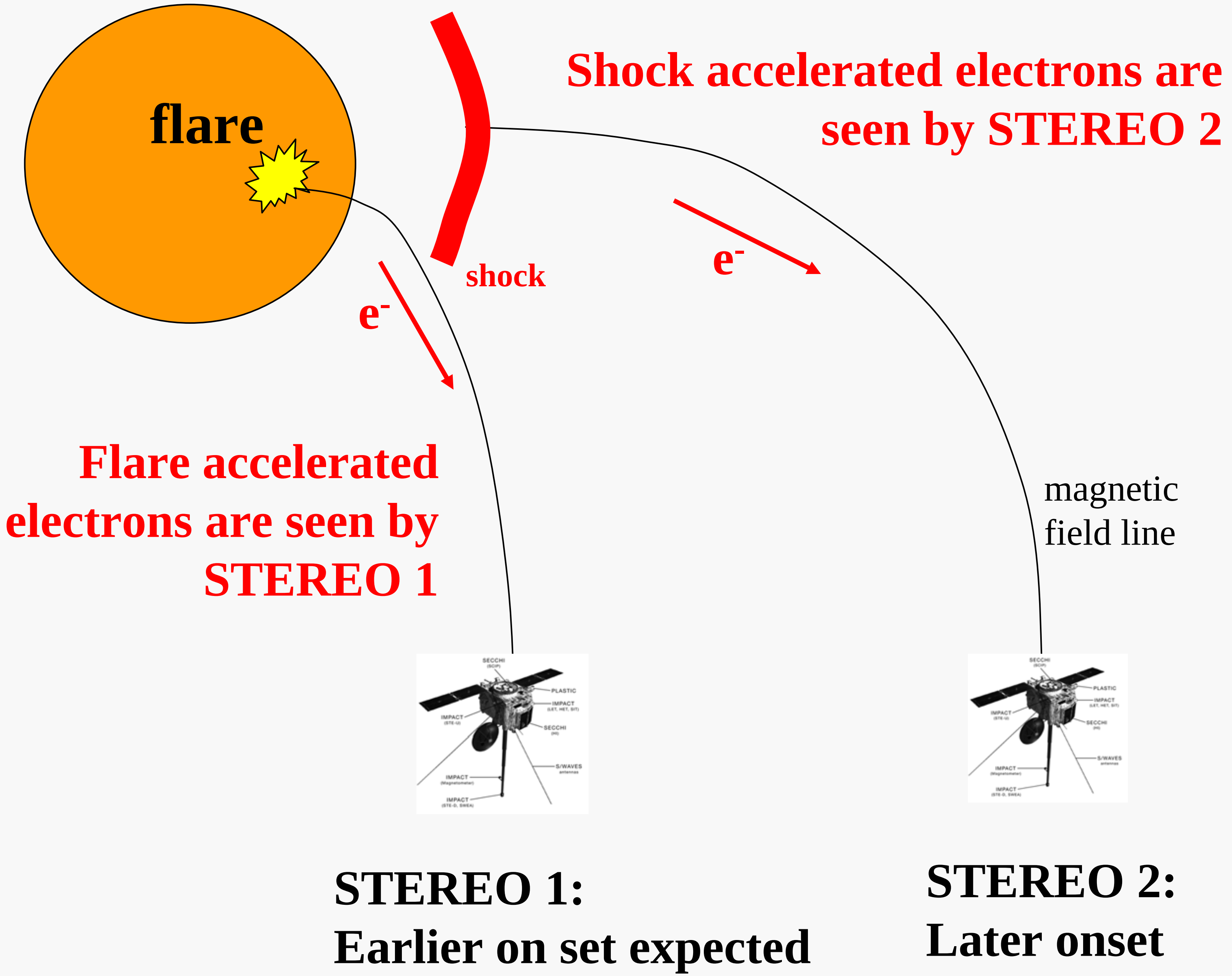
earlier



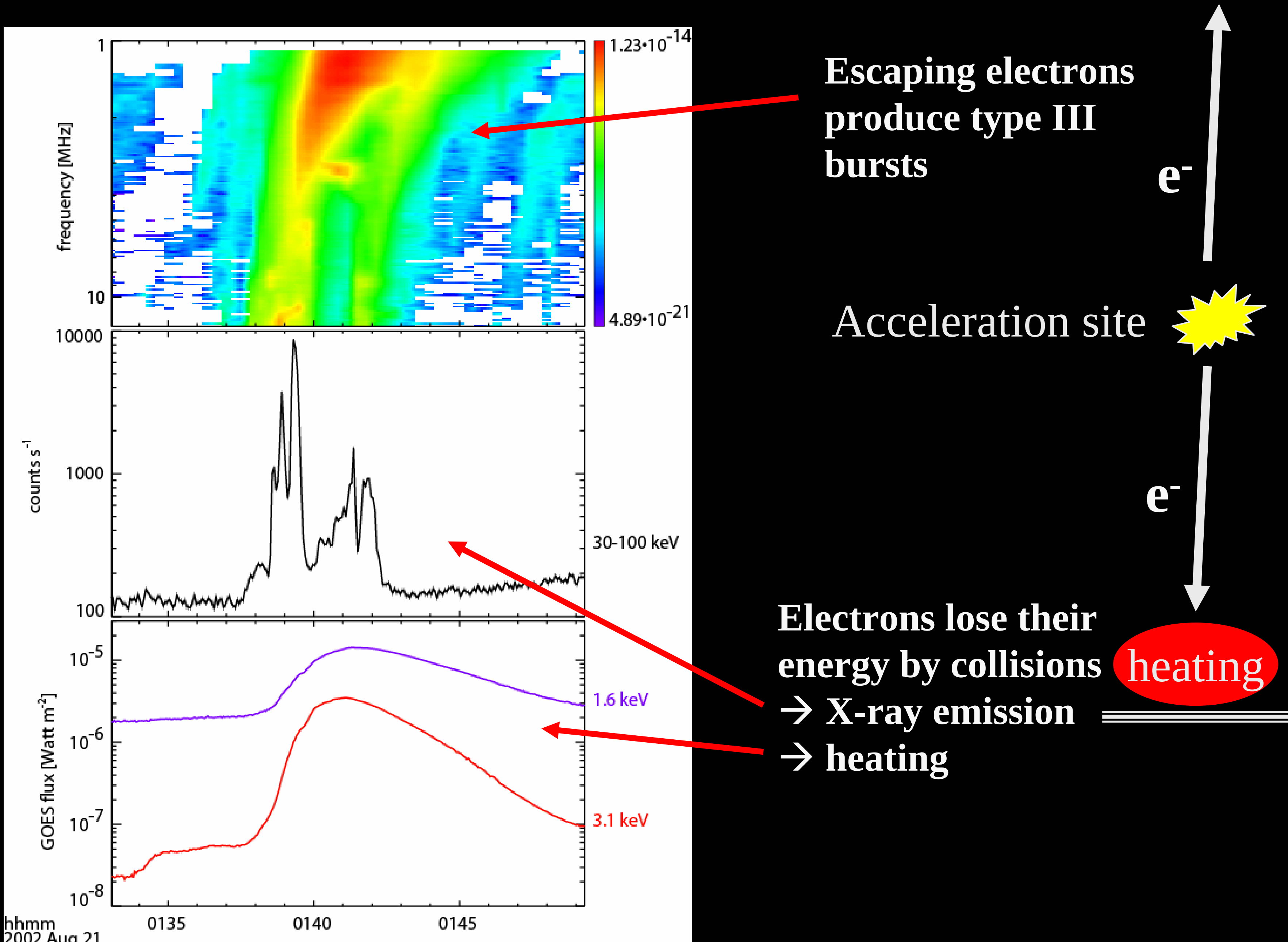
Early on, only one spacecraft is connected to the shock



→ **different onset times are expected**


flare
Shock accelerated electrons are seen by STEREO 2
shock
e-
e-
Flare accelerated electrons are seen by STEREO 1
magnetic field line
STEREO 1:
Earlier on set expected
STEREO 2:
Later onset

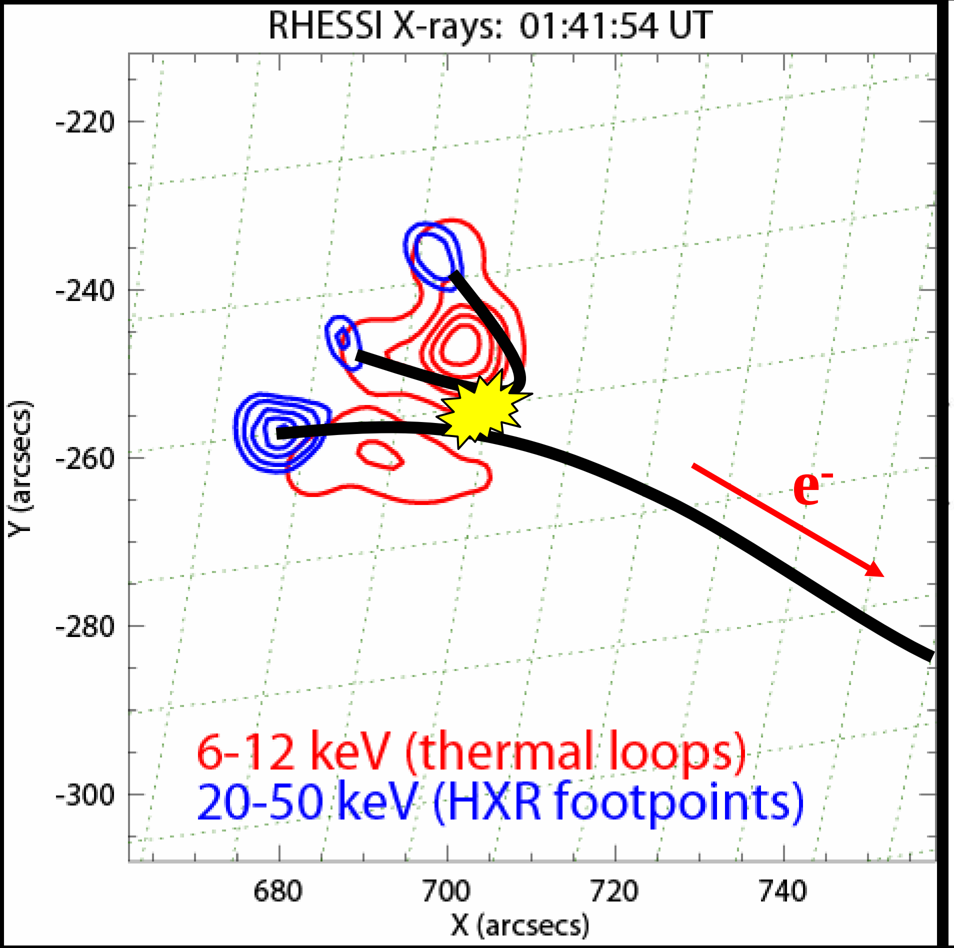
Timing alone not conclusive. Combination with imaging and modeling needed!

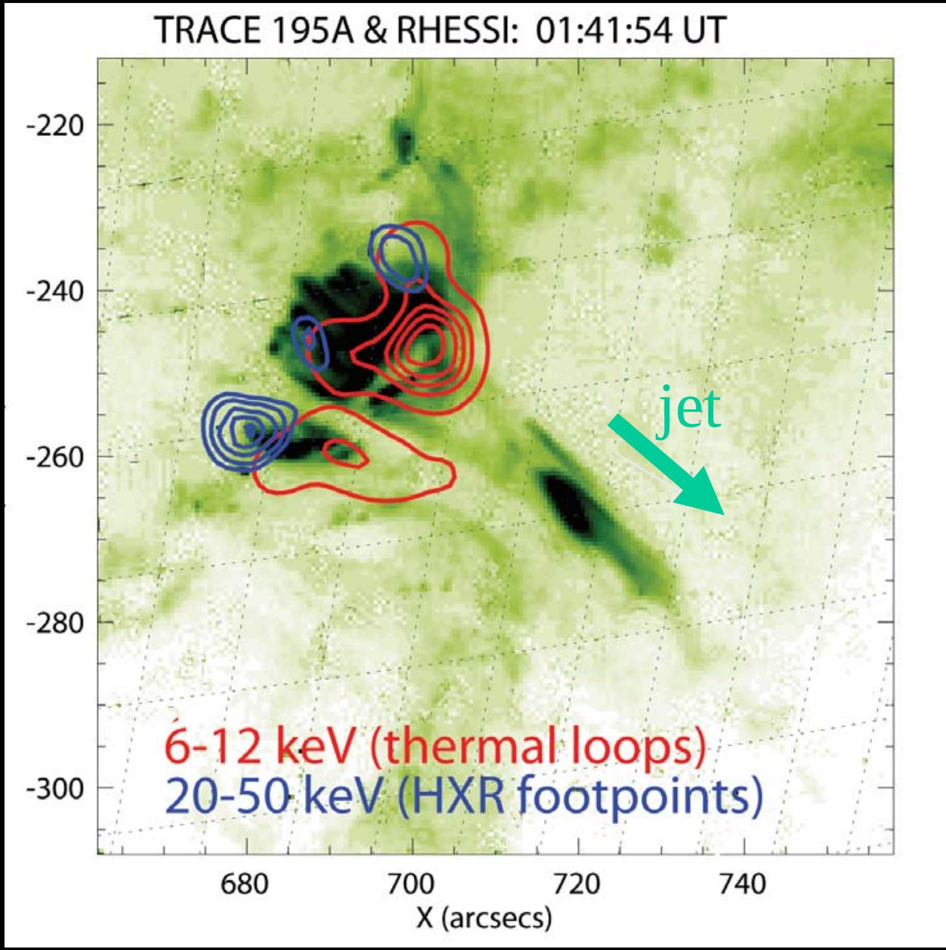


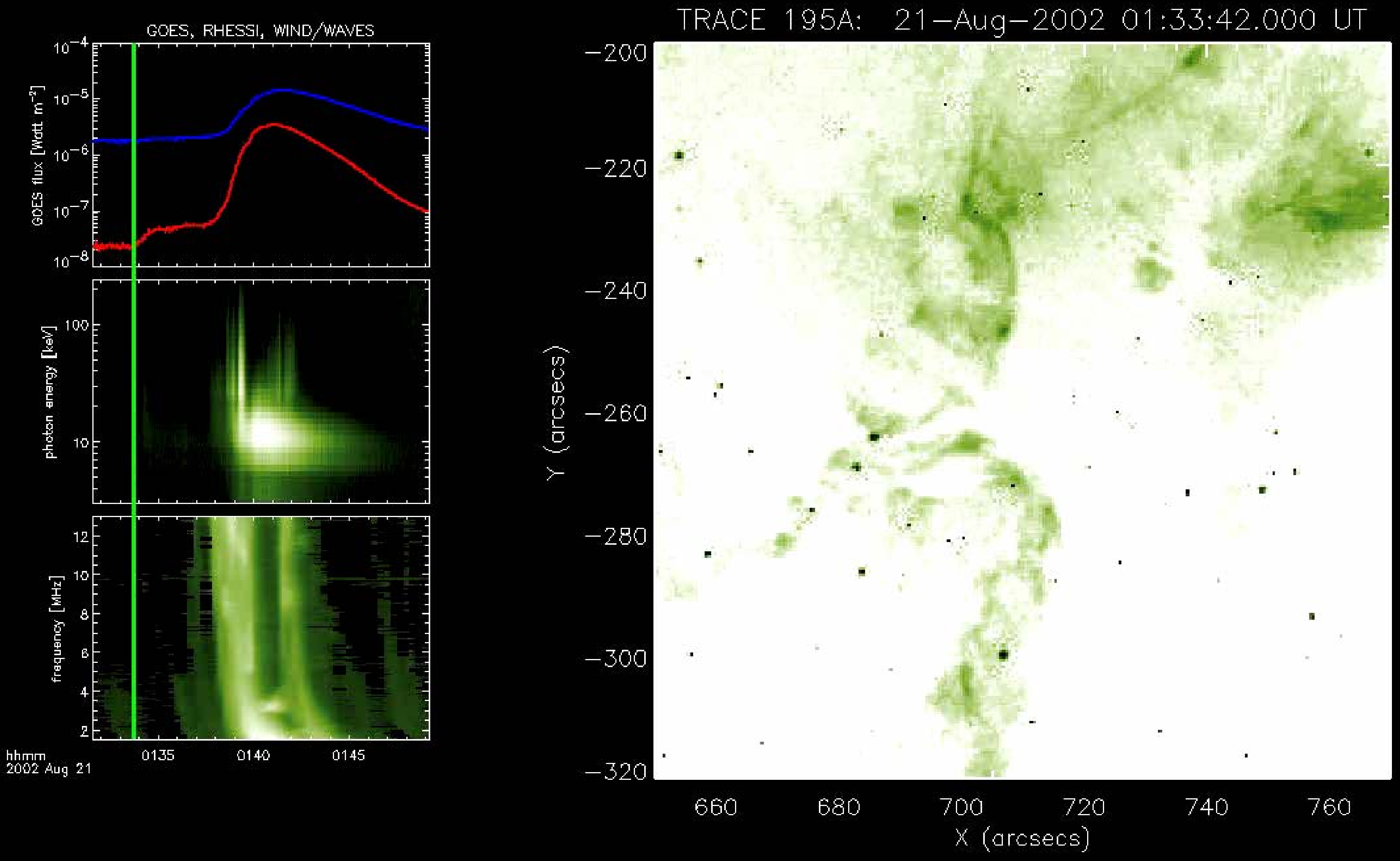
1.23•10^-14
4.89•10^-21
frequency [MHz]
1
10
10000
1000
100
counts s^-1
30-100 keV
GOES flux [Watt m^-2]
10^-5
10^-6
10^-7
10^-8
1.6 keV
3.1 keV
hhmm
2002 Aug 21
0135
0140
0145
Escaping electrons produce type III bursts
e-
Acceleration site
e-
Electrons lose their energy by collisions
→ X-ray emission
→ heating
heating

Coronal imaging

EUV/X-ray observations reveal coronal structures.
STEREO: 3d structure, SOLAR B: X-rays, B, flows, RHESSI: HXRs

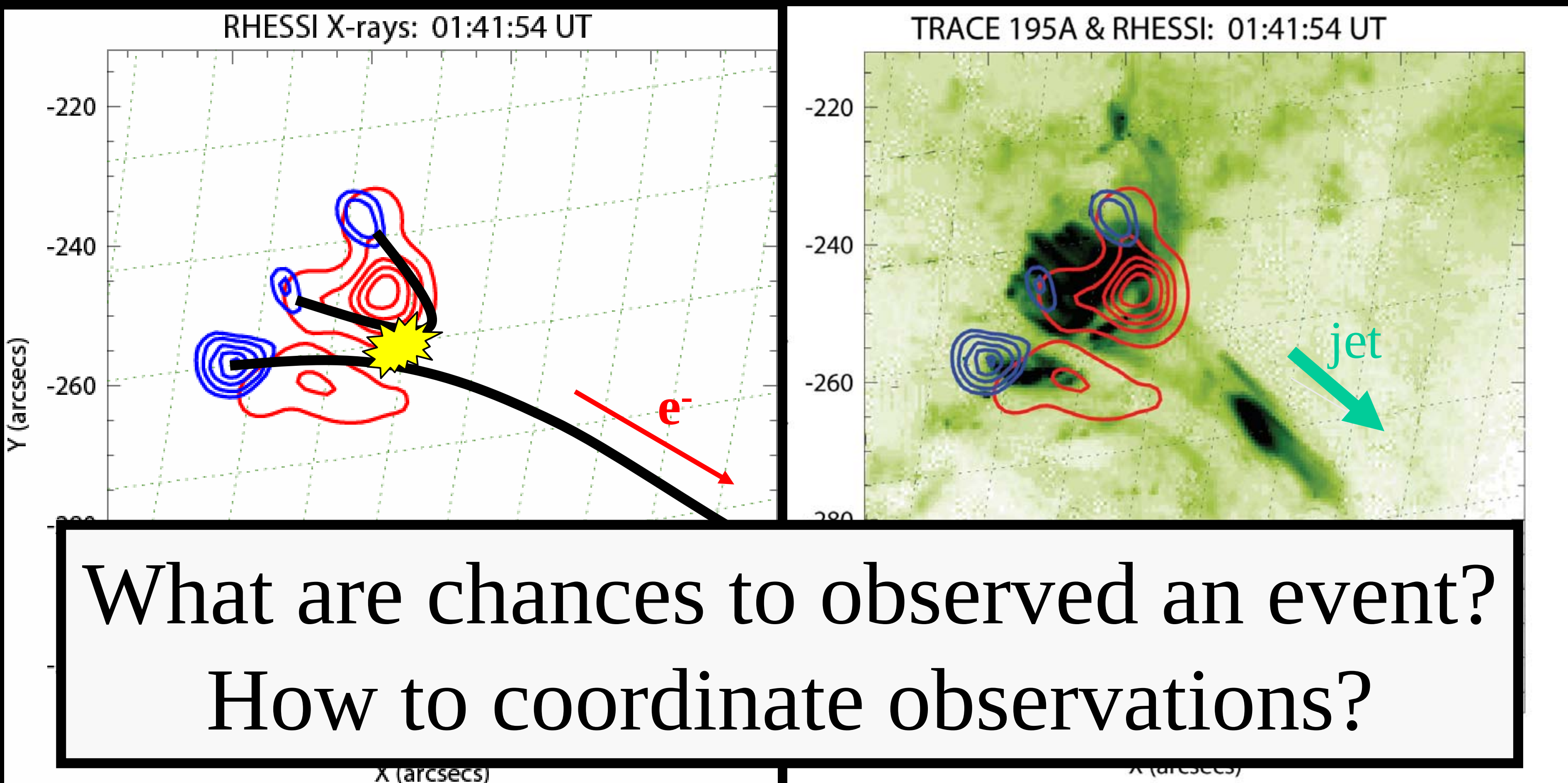





GOES, RHESSI, WIND/WAVES
GOES flux [Watt m^{-2}]
photon energy [keV]
frequency [MHz]
hhmm
2002 Aug 21
0135
0140
0145
TRACE 195A: 21-Aug-2002 01:33:42.000 UT
Y (arcsecs)
X (arcsecs)

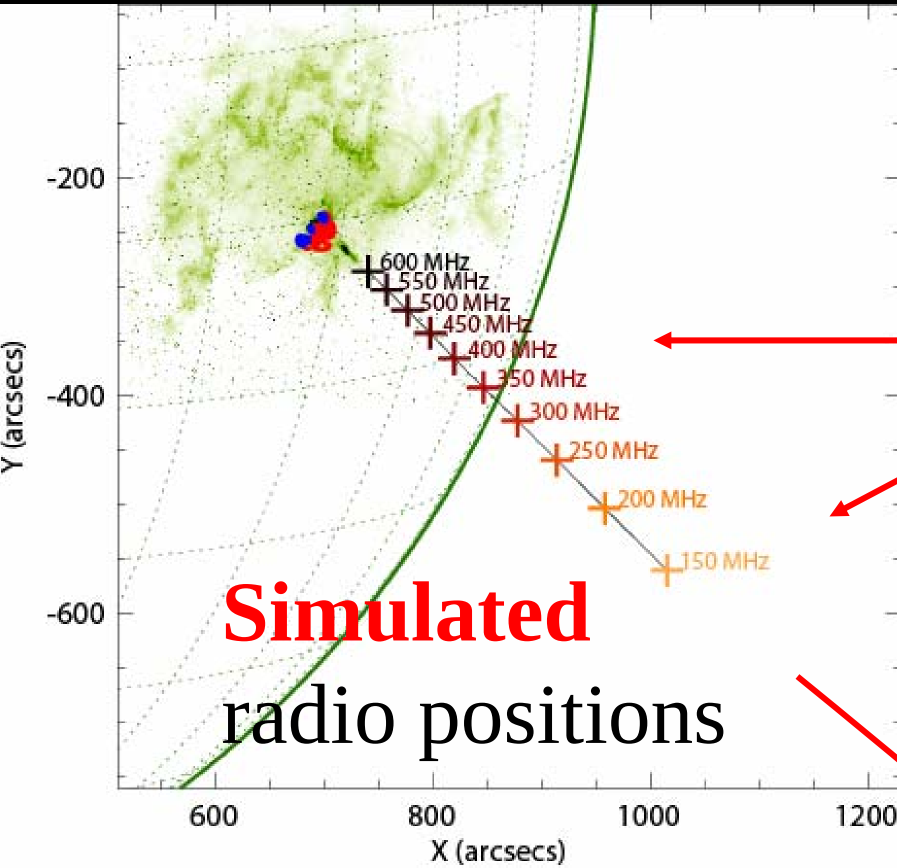
Coronal imaging

EUV/X-ray observations reveal coronal structures.
STEREO: 3d structure, SOLAR B: X-rays, B, flows, RHESSI: HXRs



What are chances to observed an event?
How to coordinate observations?

Radio tracking



400-150 MHz: NRH
In the future: FASR

1-2 solar radii

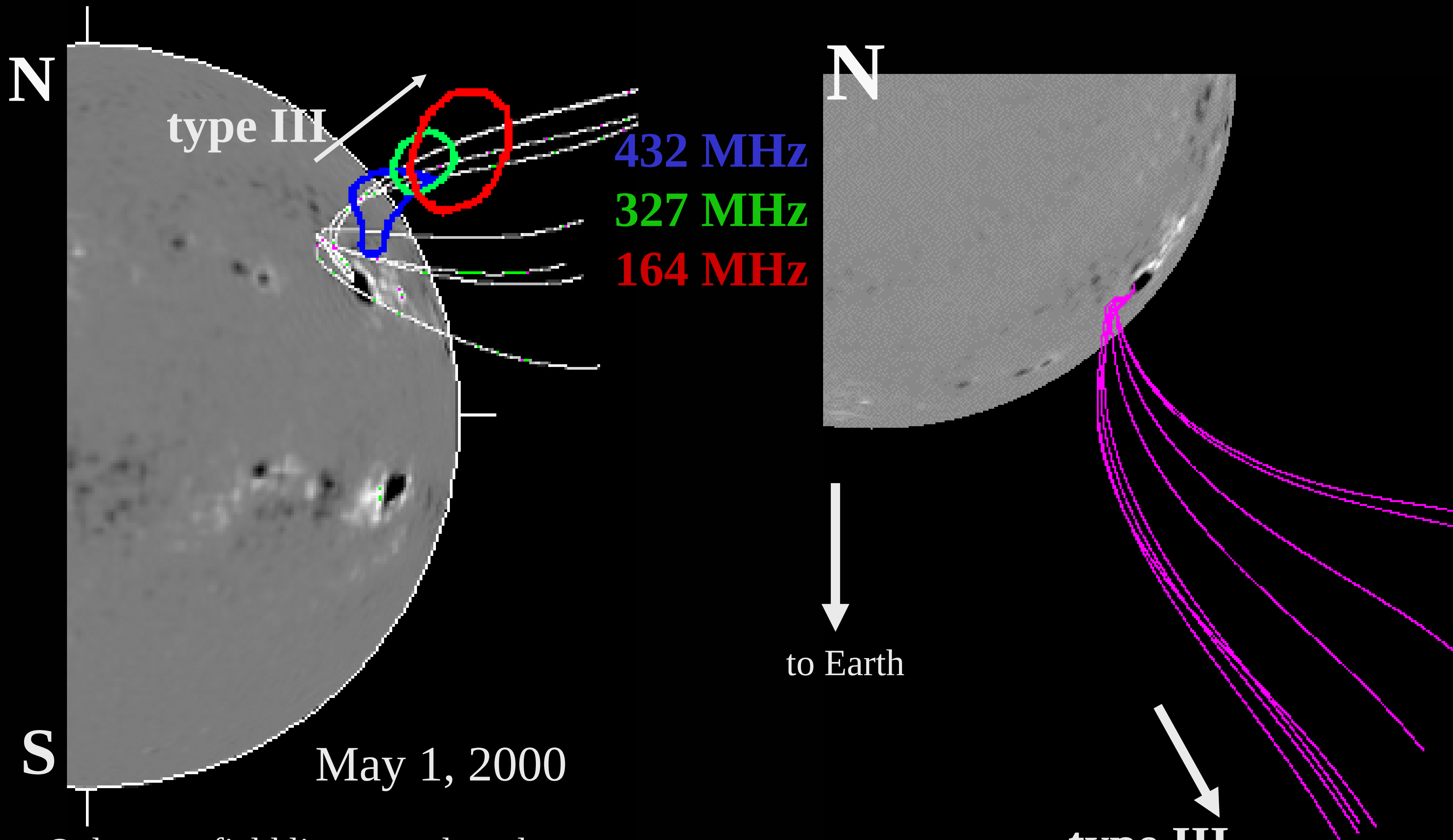
<16 MHz: STEREO/WAVES

type III bursts
(electron beams)

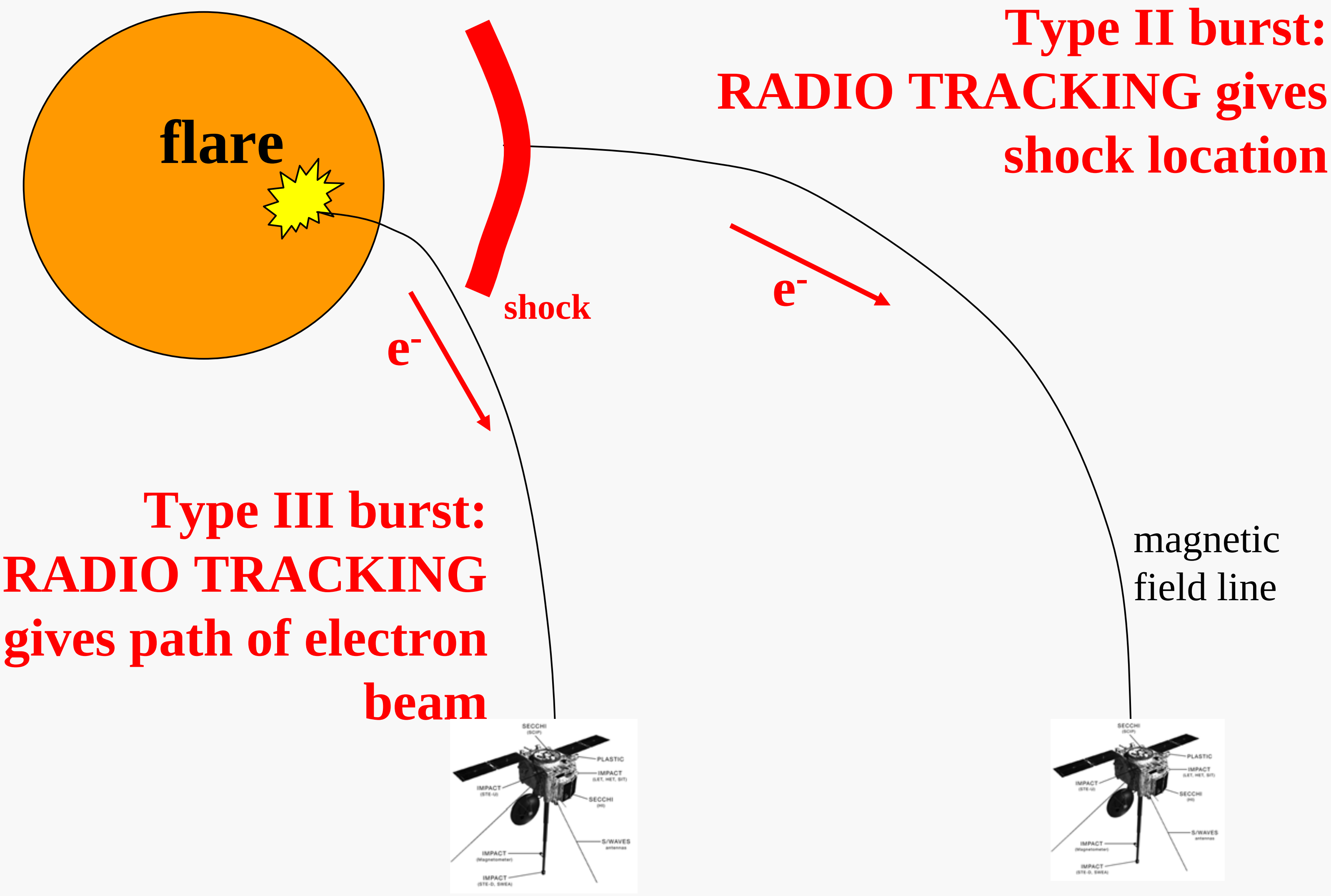
open field line

Radio tracking (K.-L. Klein):

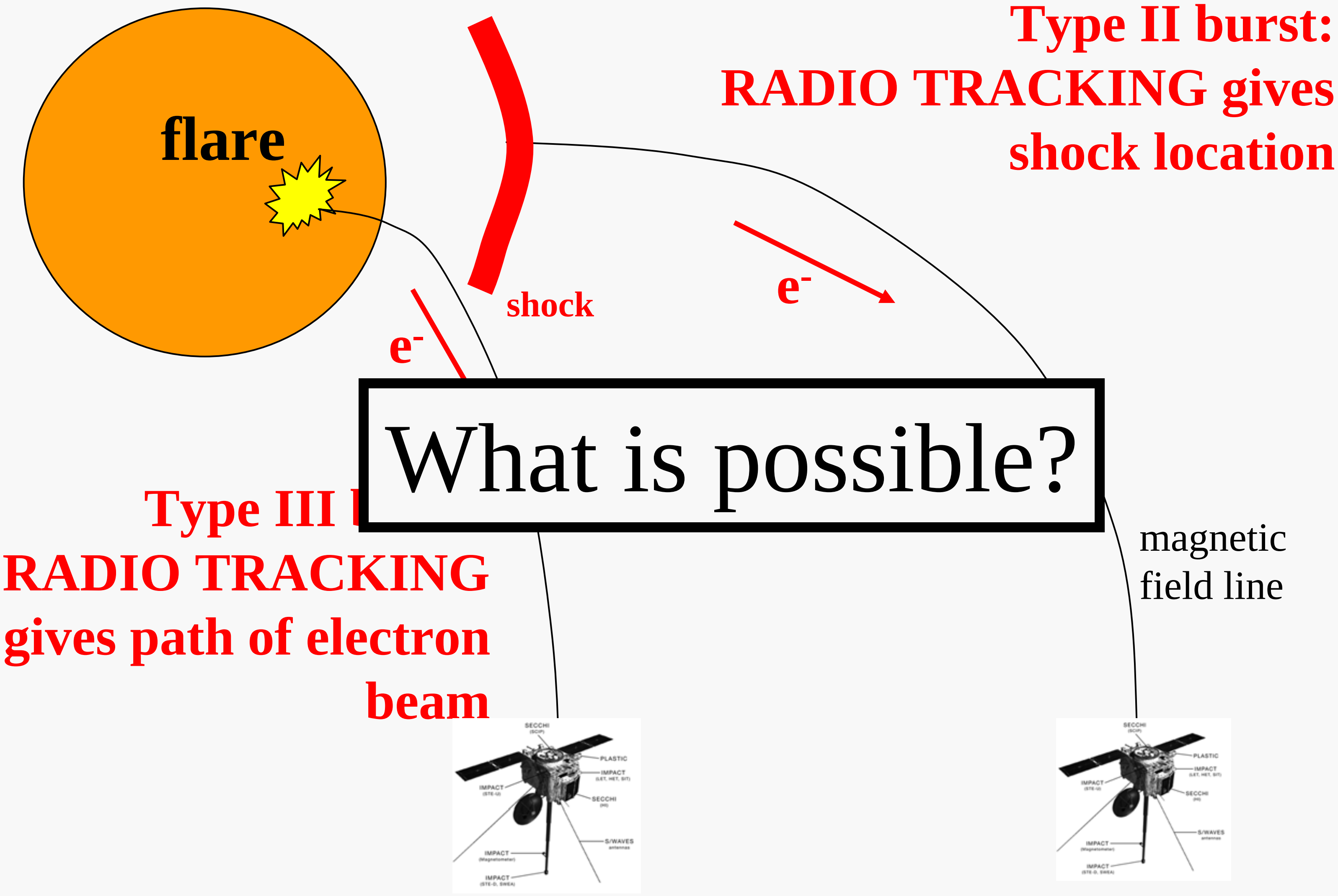
potential magnetic field extrapolation (Schrijver & Derosa 2003)



Only open field lines are plotted.



Compare with onset times & 3D observations & modeling

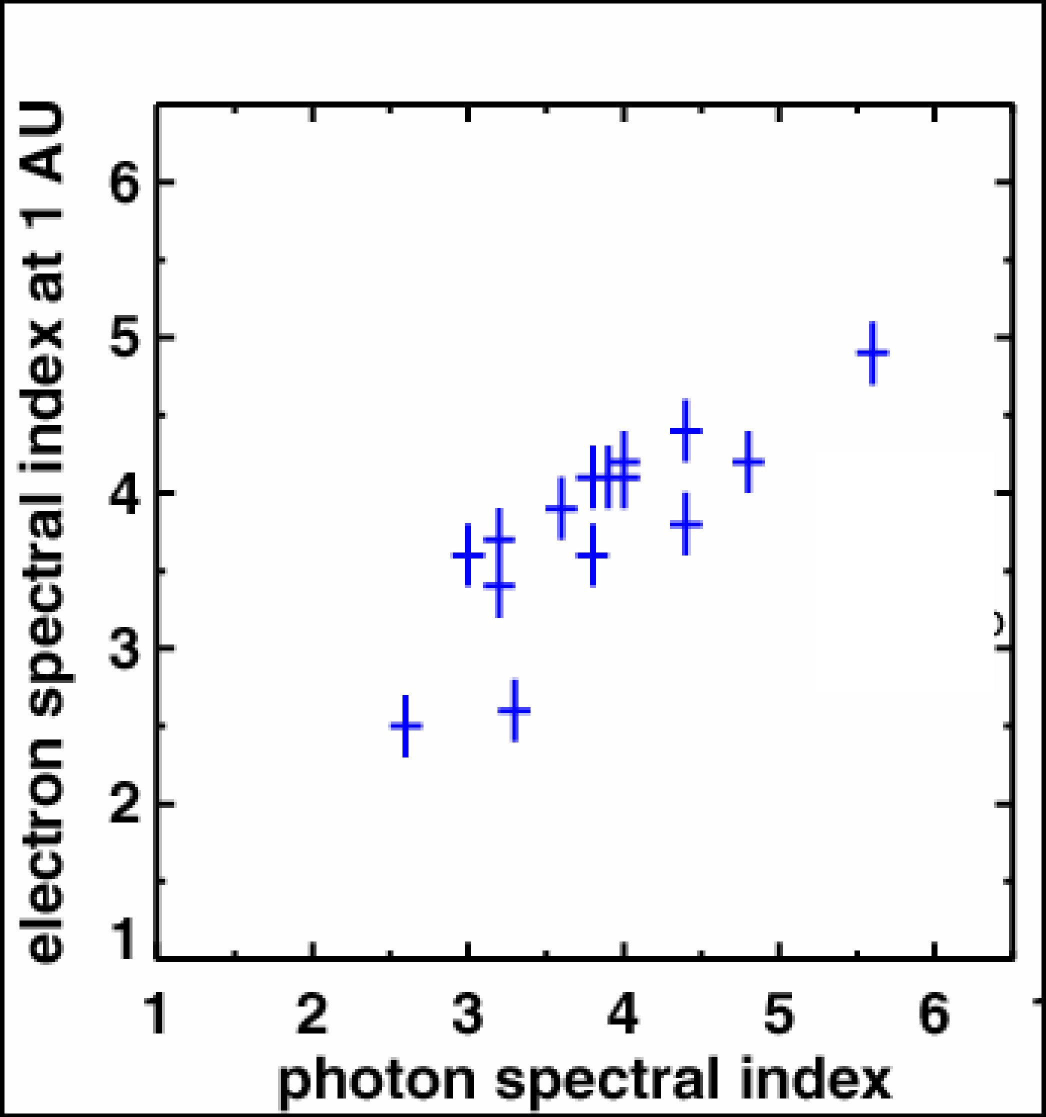


Compare with onset times & 3D observations & modeling

Summary

- Combined observations have great potential
- Timing studies combined with imaging and modeling

Comparing spectra



δ

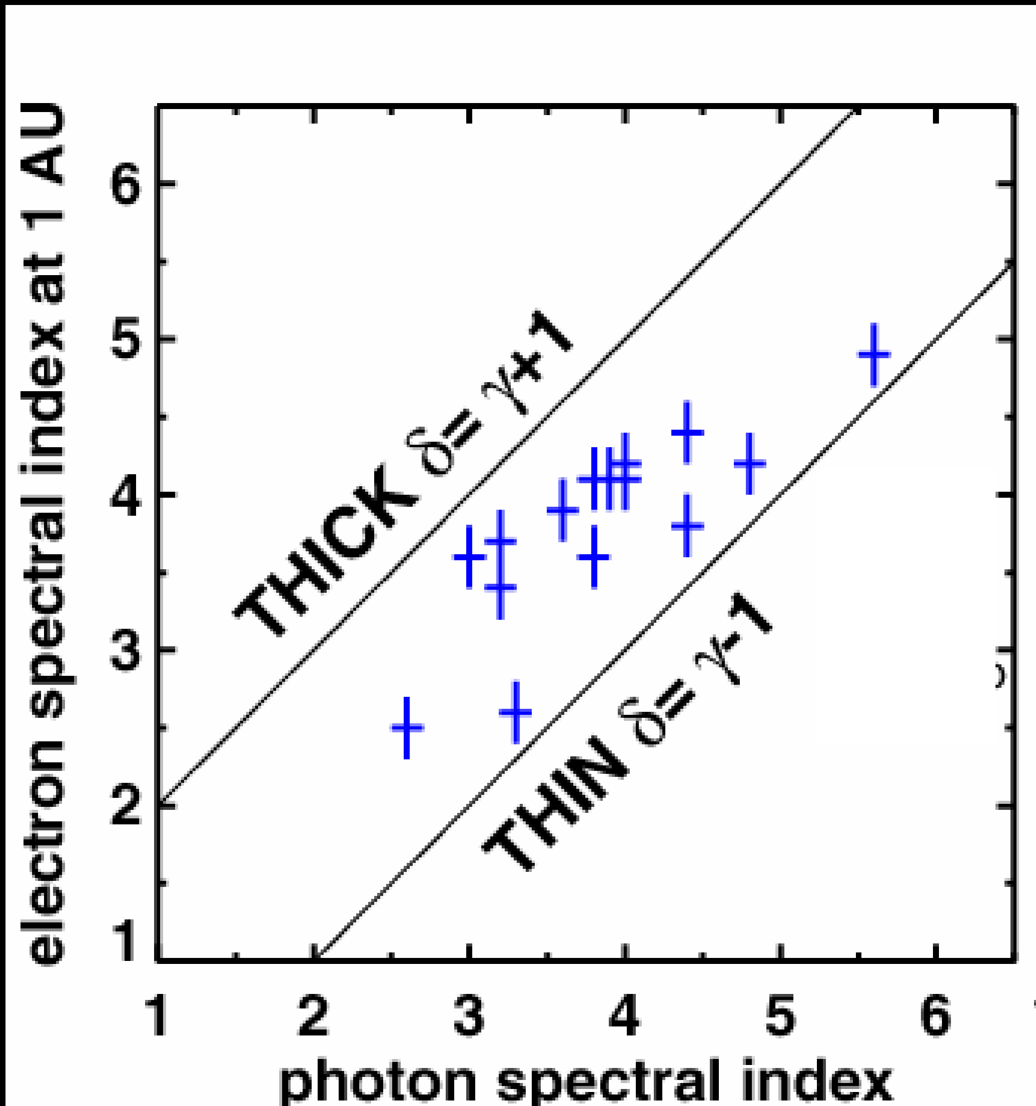
γ

PHOTON SPECTRA: Produced by downward moving electron beam

ELECTRON SPECTRA: spectrum of escaping electrons

→ rough correlation

Comparing spectra



δ

γ

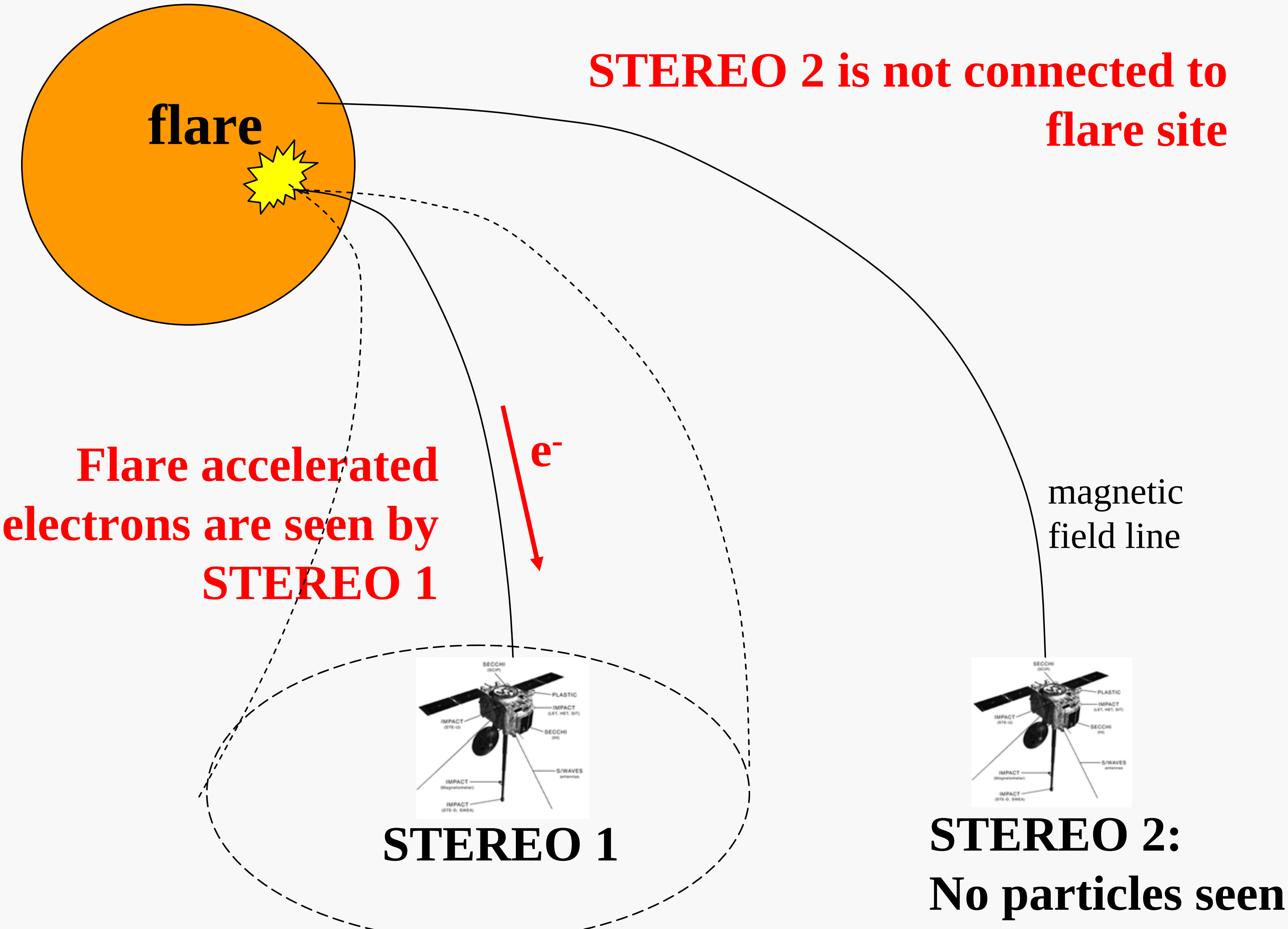
PHOTON SPECTRA:
Power law fit to HXR spectra averaged over peak

ELECTRON SPECTRA:
Power law fit to peak flux

Assuming power spectra:

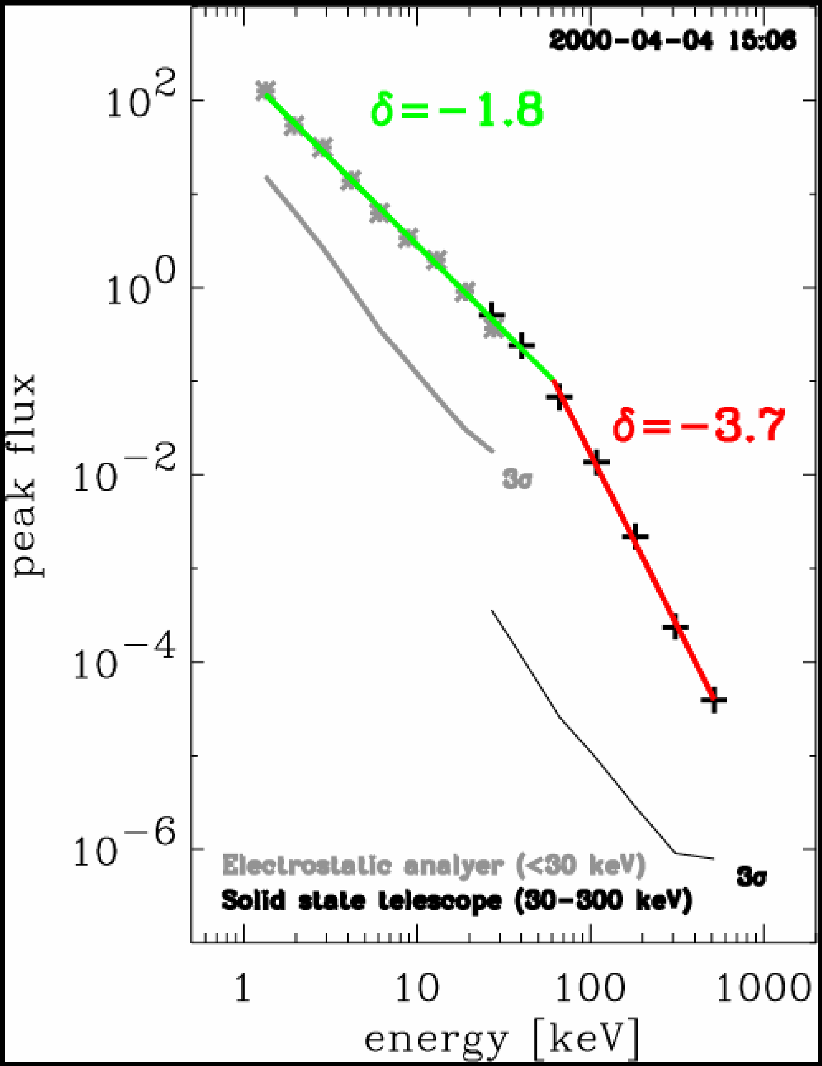
THIN: $\delta = \gamma - 1$
THICK: $\delta = \gamma + 1$

RESULTS:
1) correlation seen
2) values are between



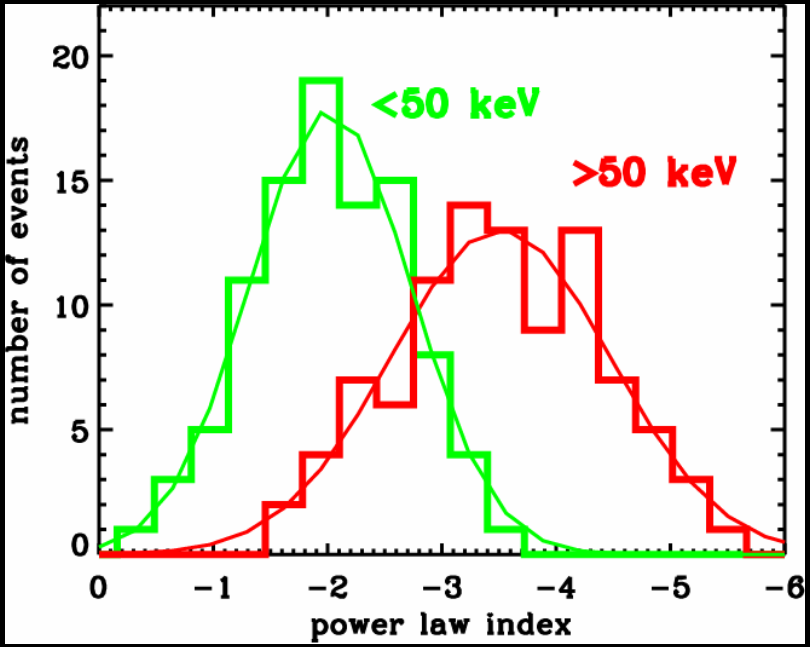
→ Better estimates of total number of electrons (energy)

Electron spectrum at 1AU



Typical electron spectrum can be fitted with broken power law:

Break around: 30-100 keV
Steeper at higher energies



Oakley, Krucker, & Lin 2006