Combined WIND-RHESSI-TRACE studies

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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
energetic electrons escaping from the Sun

EM radiation

Sun

? e-

magnetic field line

REMOTE sensing observations

IN-SITU electron observations
STEREO, WIND, ACE
FLARE accelerated electrons escape

RHESSI X-rays: 01:41:54 UT

6-12 keV (thermal loops)
20-50 keV (HXR footpoints)

magnetic field line

IN-SITU electron observations
STEREO, WIND, ACE
FLARE accelerated electrons escape

IN-SITU electron observations
STEREO, WIND, ACE

6-12 keV (thermal loops)
20-50 keV (HXR footpoints)
Escaping electrons could also be accelerated late in the flare → no correlation with impulsive phase

IN-SITU electron observations
STEREO, WIND, ACE

acc. site of escaping electrons

main flare

HXR footpoints

magnetic field line

e−
Flare accelerated electrons do not escape or escape along field lines not connected to the spacecraft.
Flare or shock acceleration?

1. Different **timing**
2. Depending on **magnetic connection** different components are observed
Timing

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

Controversy: propagation effect or scattering?

![Graph showing timing relationship](image)

- **Slope gives path length**
- **Intersection gives release time**
Timing

From onset times at 1 AU (velocity dispersion) solar release time can be approximated.
Controversy: propagation effect or scattering?

![Graph showing onset time vs. inverse velocity](image)

**December 6, 2000**

**Linear Fit:**
- \( L = 1.28473 \text{ AU} \)
- \( t = 2000-12-06/16:16:43 \)

**WIND/3DP**
Electrostatic analyzers: large error bars

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

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

Controversy: propagation effect or scattering?

STEREO/STE
Solid state detectors down to 2 keV

WIND/3DP observations
Electrostatic analyzers: large error bars

Solid state detectors: SMALL error bars (~few minutes)
What is reported?

- Same timing as flare for some events

  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 $\rightarrow$ shock


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- 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?
Early on, only one spacecraft is connected to the shock
Early on, only one spacecraft is connected to the shock. Later both spacecrafts are connected to shock. ➔ different onset times are expected.
Shock accelerated electrons are seen by STEREO 2

Flare accelerated electrons are seen by STEREO 1

STEREO 1: Earlier on set expected

STEREO 2: Later onset
Timing alone not conclusive. Combination with imaging and modeling needed!
Acceleration site

Electrons lose their energy by collisions → X-ray emission → heating

Escaping electrons produce type III bursts

Acceleration site

$e^{-}$

$e^{-}$
Coronal imaging
EUV/X-ray observations reveal coronal structures.
STEREO: 3d structure, SOLAR B: X-rays, B, flows, RHESSI: HXRs

RHESSI X-rays: 01:41:54 UT

TRACE 195A & RHESSI: 01:41:54 UT

6-12 keV (thermal loops)
20-50 keV (HXR footpoints)

jet
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

Simulated radio positions

1-2 solar radii
<16 MHz: STEREO/WAVES

open field line

type III bursts (electron beams)
Radio tracking (K.-L. Klein):

potential magnetic field extrapolation (Schrijver & Derosa 2003)

May 1, 2000

Only open field lines are plotted.
Type II burst:
RADIO TRACKING gives shock location

Type III burst:
RADIO TRACKING gives path of electron beam

Compare with onset times & 3D observations & modeling
Type II burst: RADIO TRACKING gives shock location

Type III burst: RADIO TRACKING gives path of electron beam

What is possible?

Compare with onset times & 3D observations & modeling
Summary

• Combined observations have great potential
• Timing studies combined with imaging and modeling
Comparing spectra

PHOTON SPECTRA:
Produced by downward moving electron beam

ELECTRON SPECTRA:
spectrum of escaping electrons

→ rough correlation
Comparing spectra

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 \( \gamma \) and \( \delta \)
Flare accelerated electrons are seen by STEREO 1

→ Better estimates of total number of electrons (energy)

STEREO 2 is not connected to flare site

magnetic field line
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