Fachhochschule
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X-ray observations of Solar Flares

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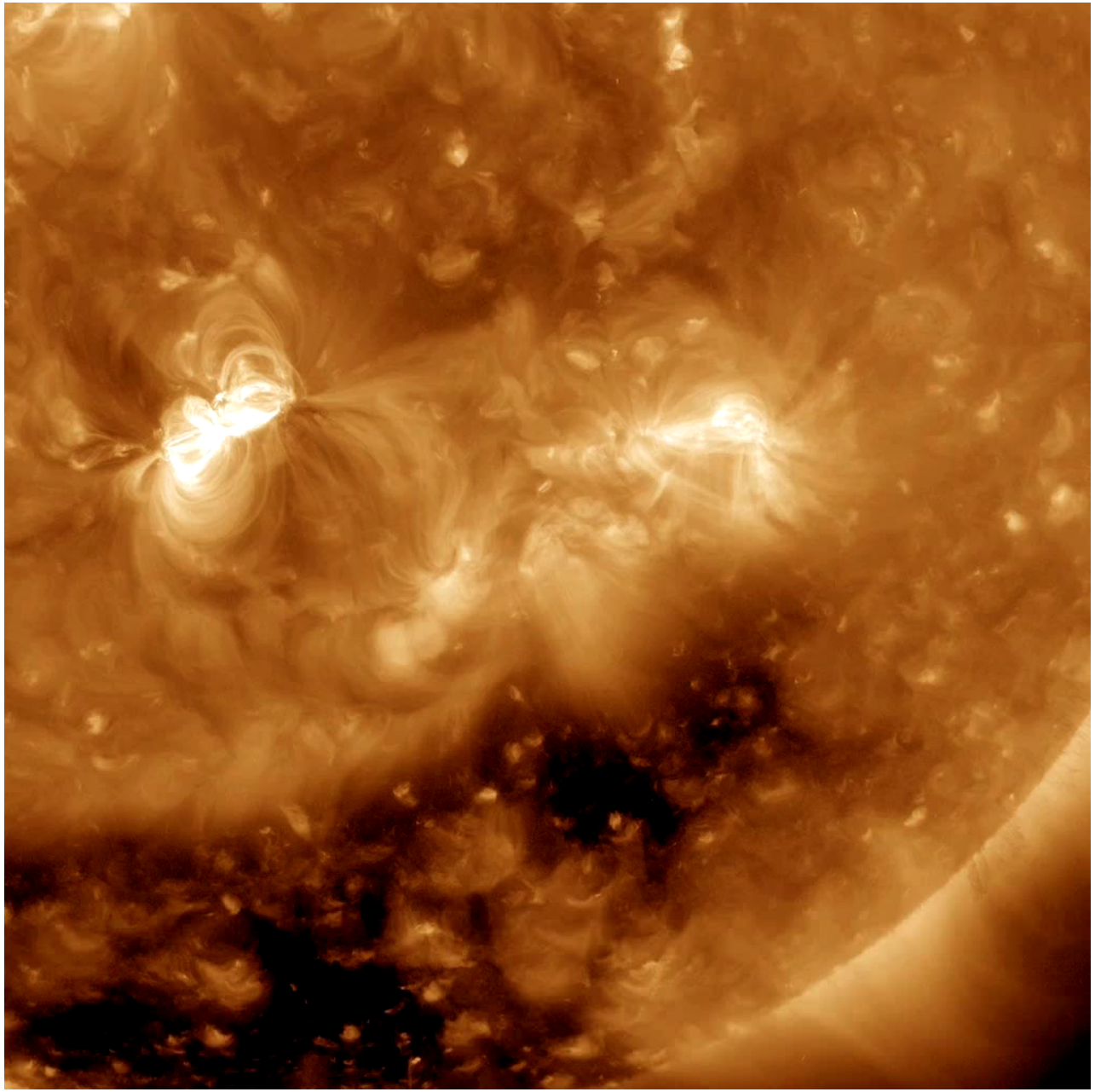
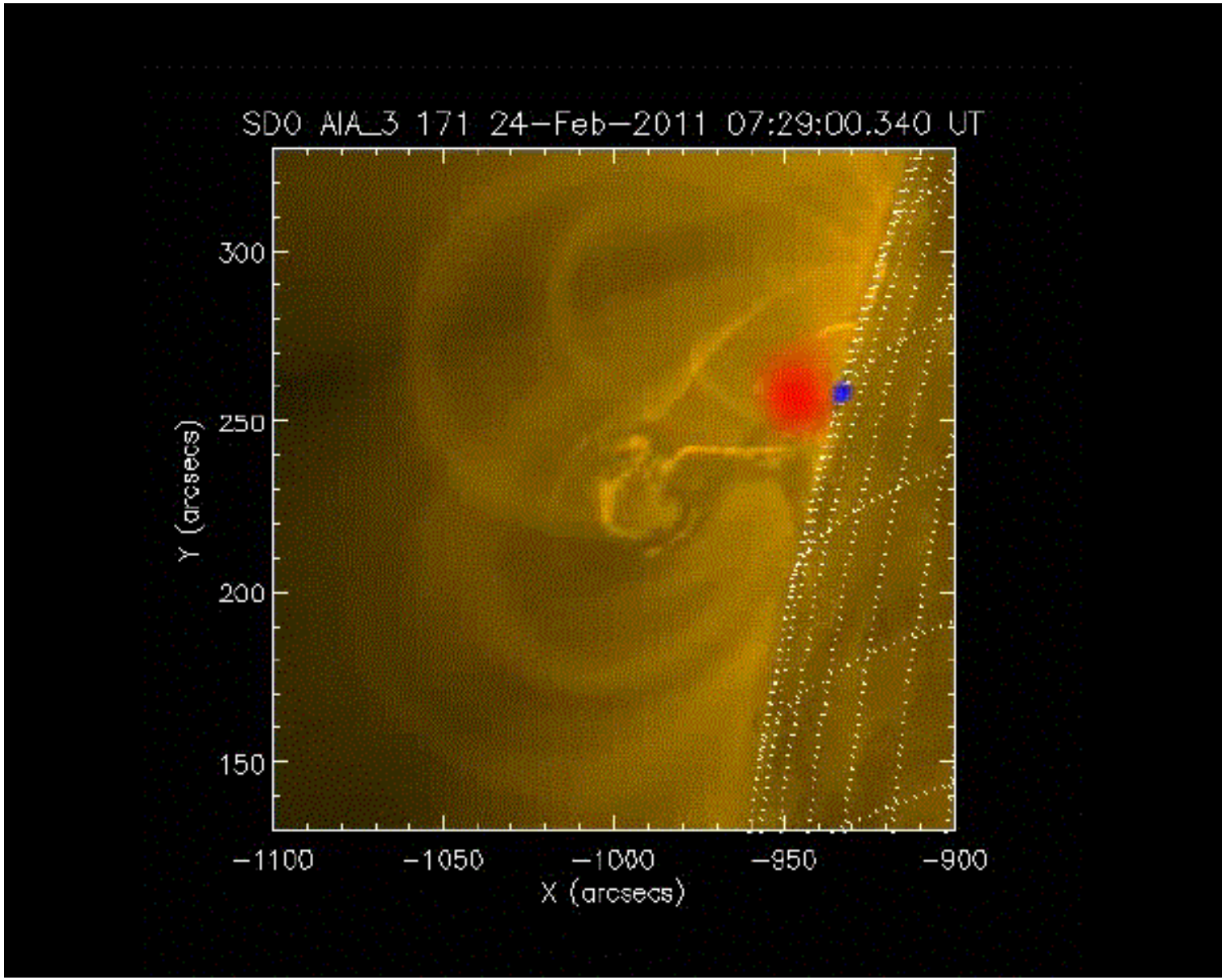



SDO AIA_3 171 24-Feb-2011 07:29:00.340 UT
300
250
200
150
Y (arcsecs)
-1100
-1050
-1000
-950
-900
X (arcsecs)

The solar corona

Close by astrophysical laboratory allows us to study:

- Release of magnetic energy (magnetic reconnection)
- Particle acceleration
- Coronal heating

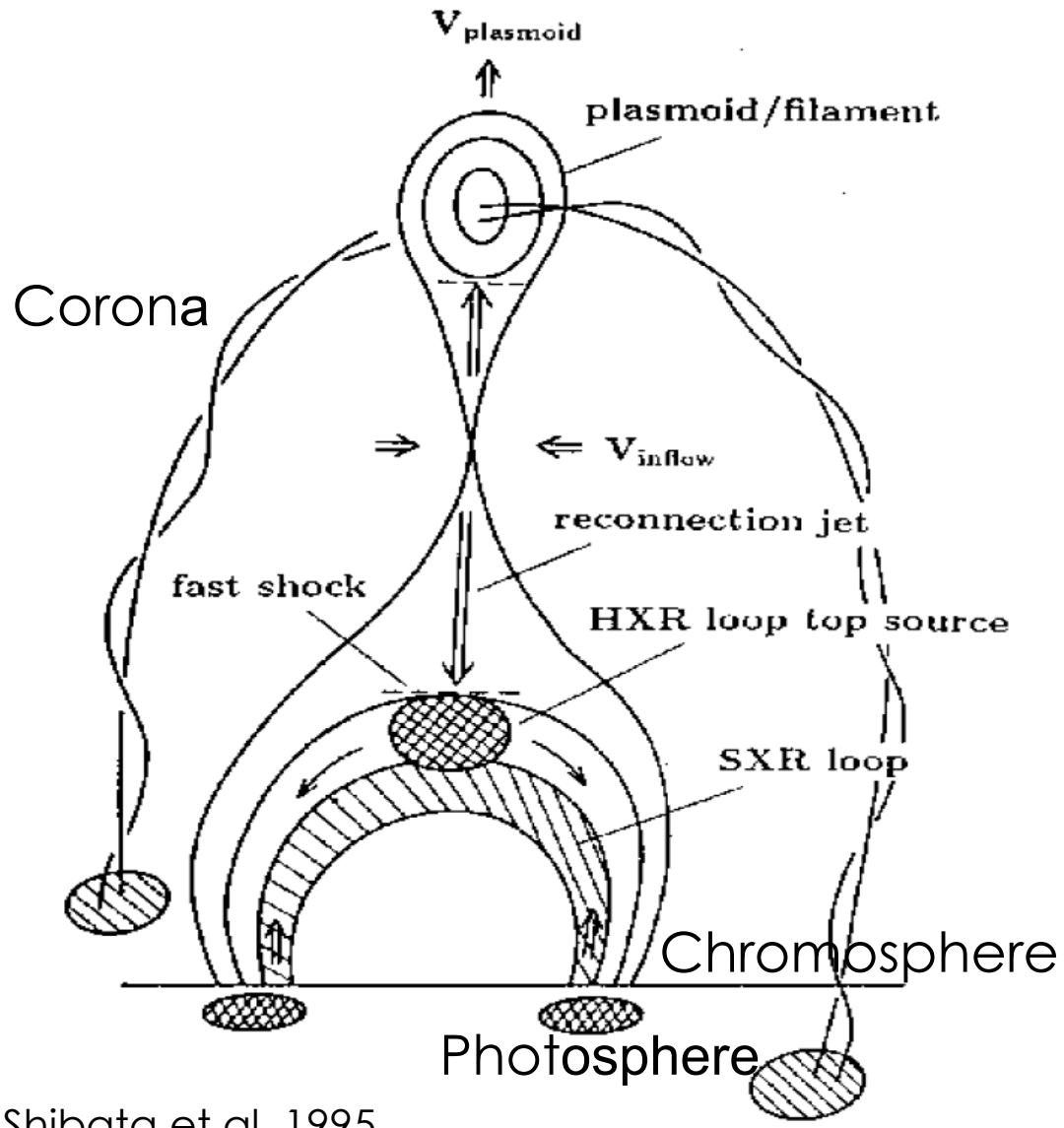
Highly dynamic release of magnetic energy:

- **Solar flares**, coronal mass ejections (CMEs), solar wind
- Creates space weather

Solar flares – open questions

- Where and how is magnetic energy released?
- Where and how are particles accelerated?
- How are particles transported?
  - away from the Sun
  - close to the Sun
- How much energy is contained in flares?
- How do flares affect all layers of the solar atmosphere?

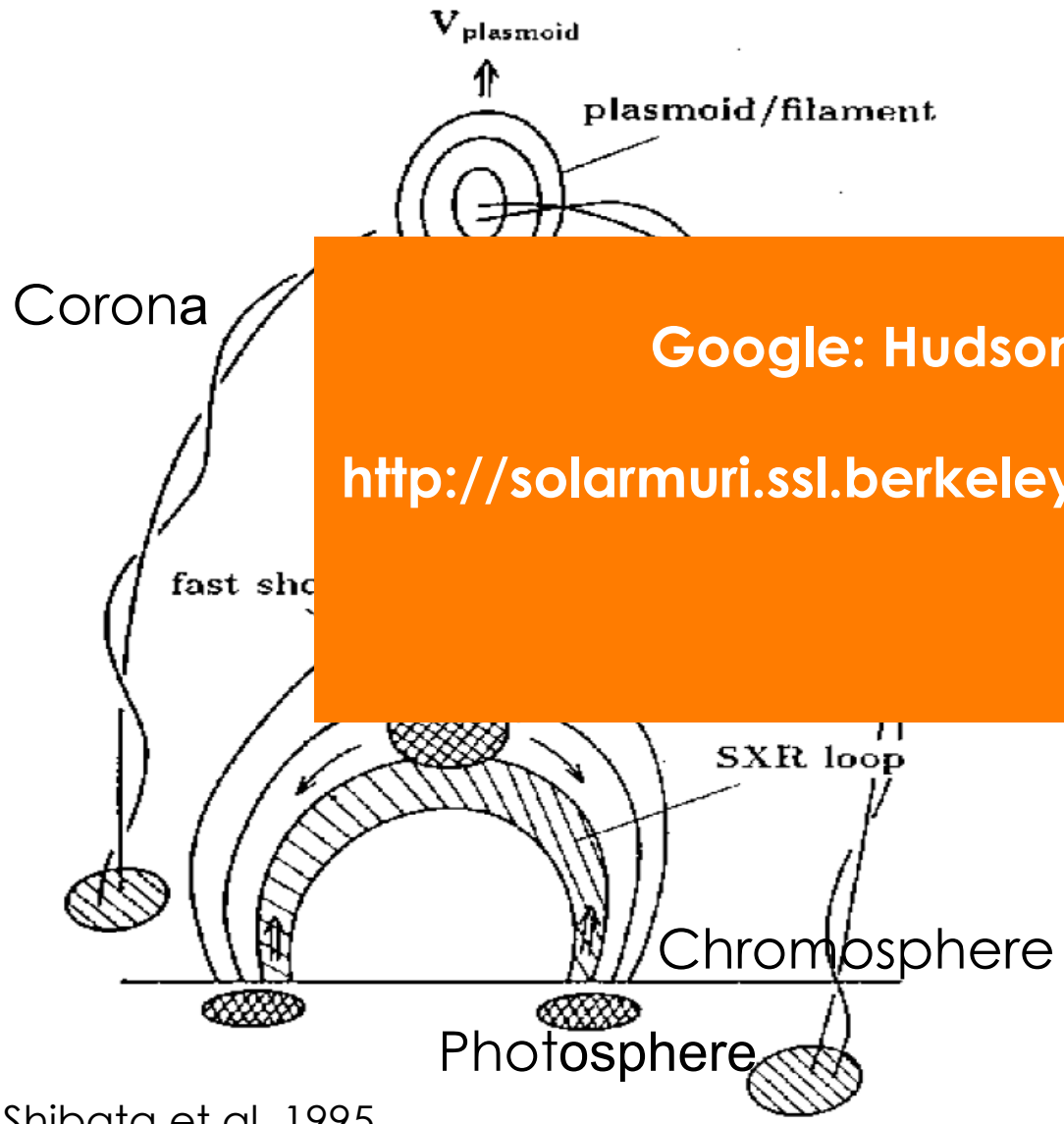
The standard solar flare model



Shibata et al. 1995

1) Release of magnetic energy

The standard solar flare model



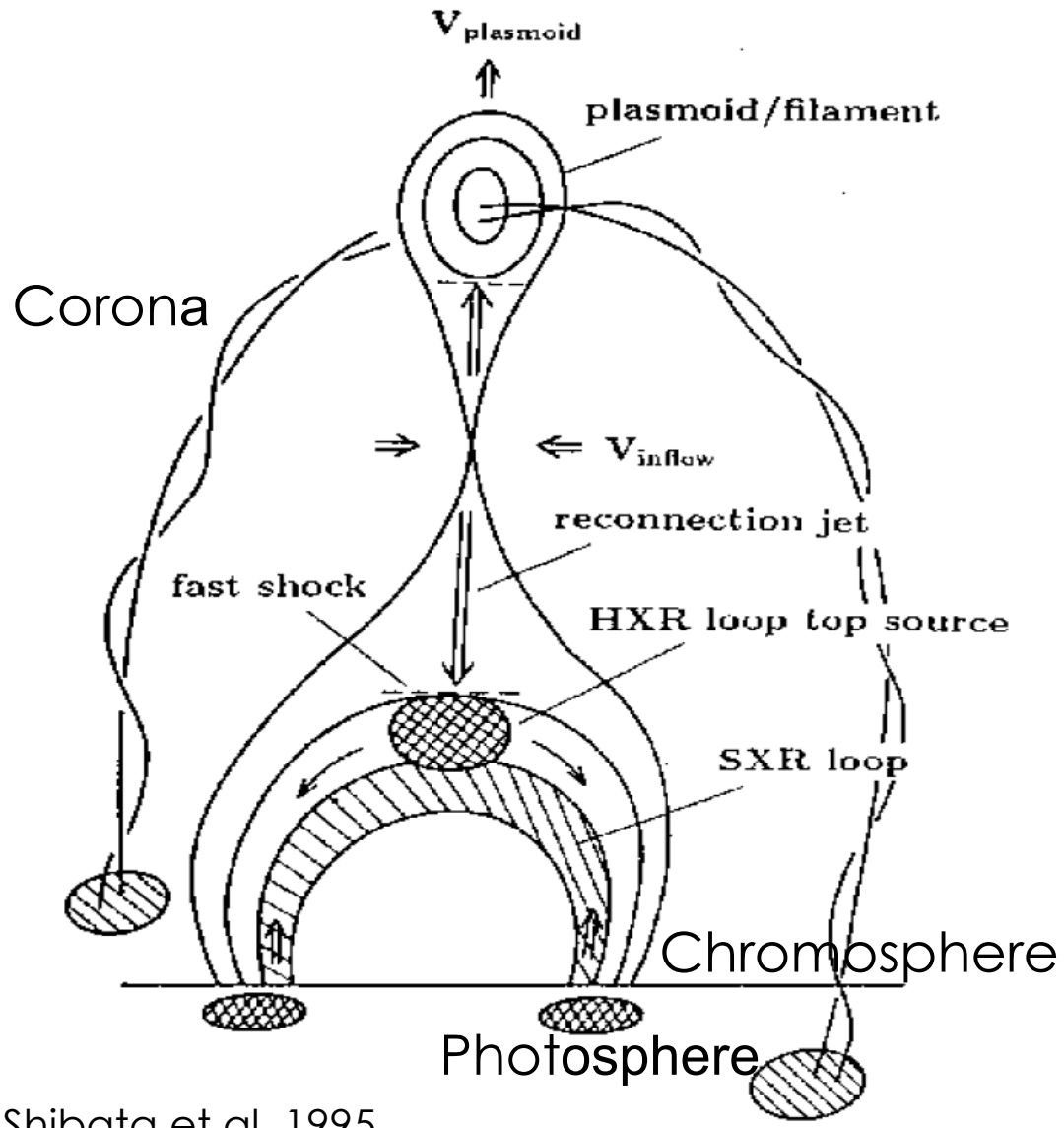
Shibata et al. 1995

1) Release of magnetic energy

Google: Hudson Flare Cartoon

http://solarmuri.ssl.berkeley.edu/~hhudson/cartoons/

The standard solar flare model



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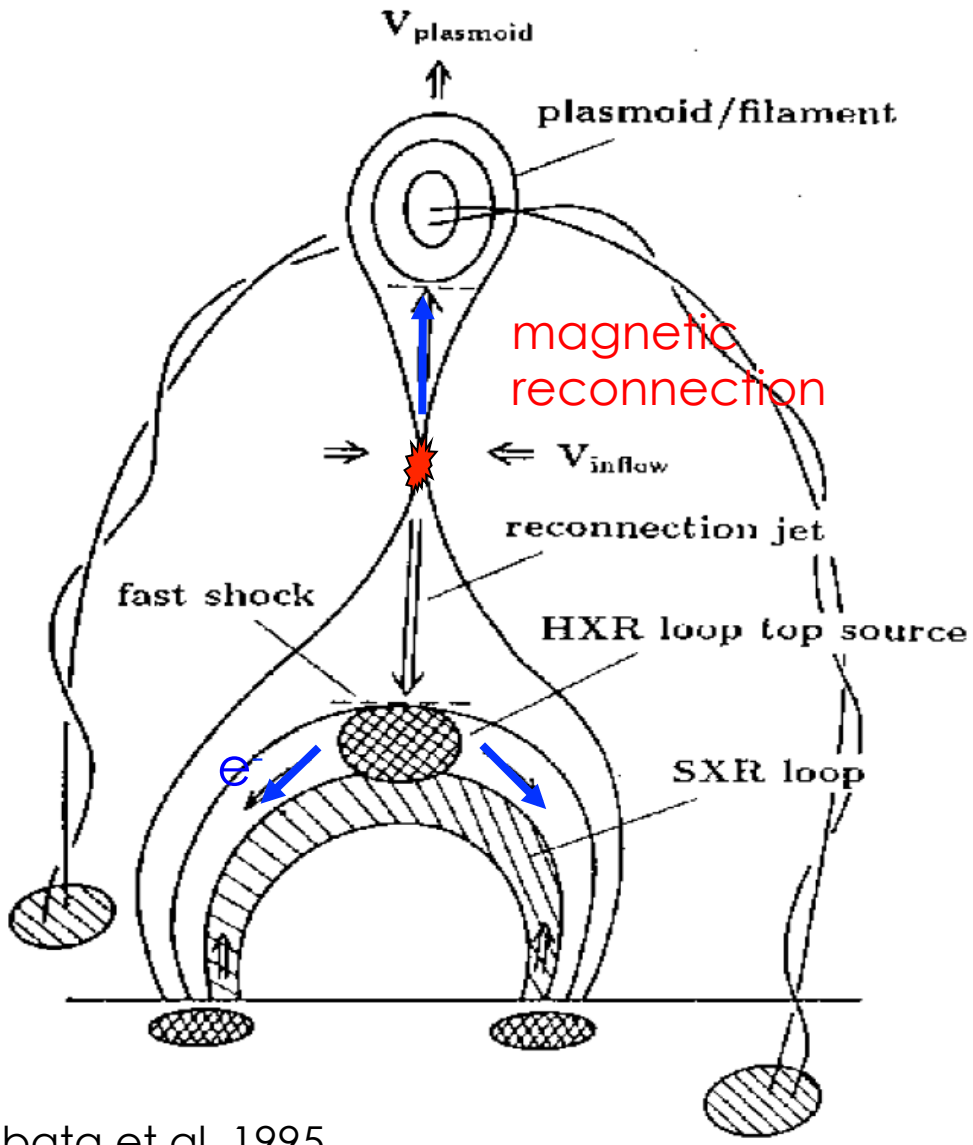
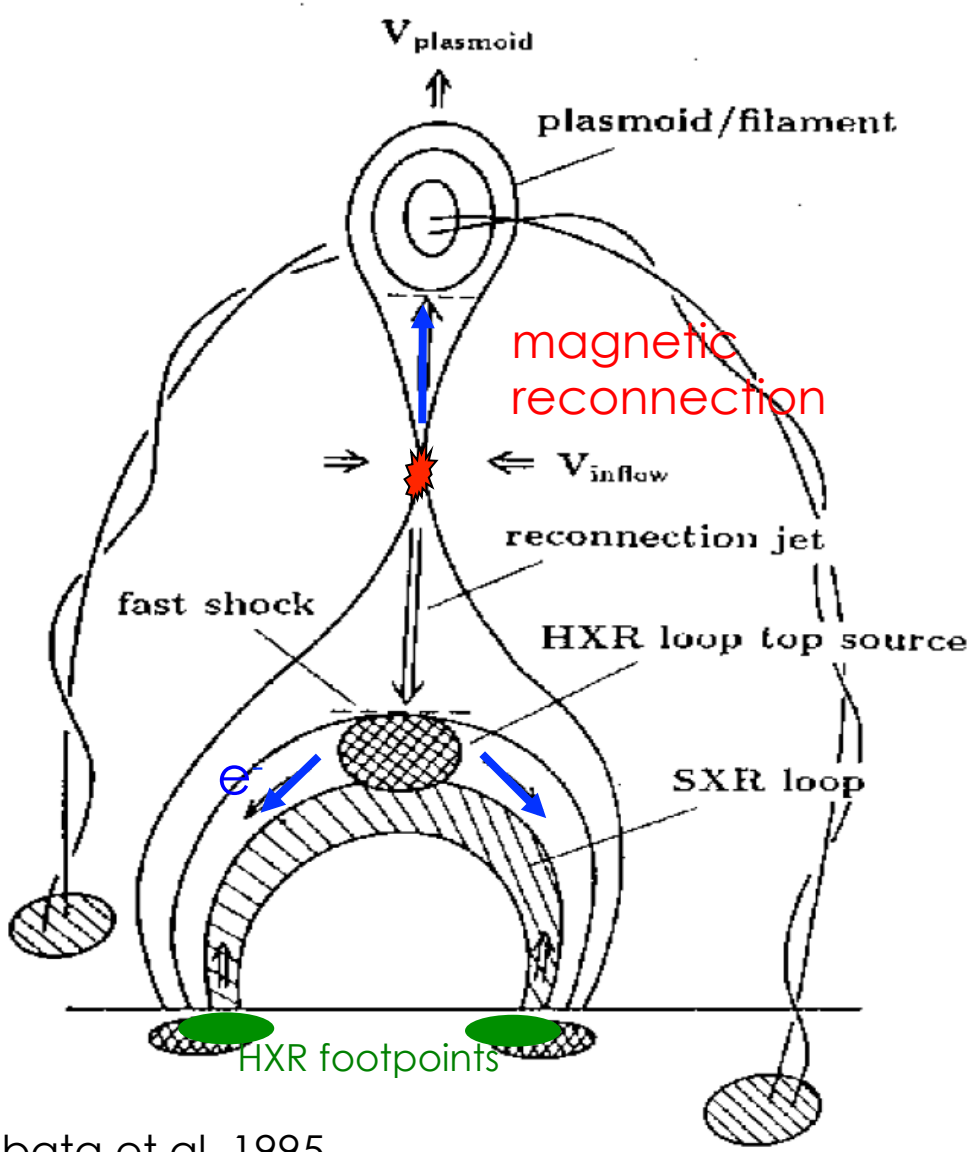


Shibata et al. 1995

1) Release of magnetic energy
2) Particle acceleration and heating

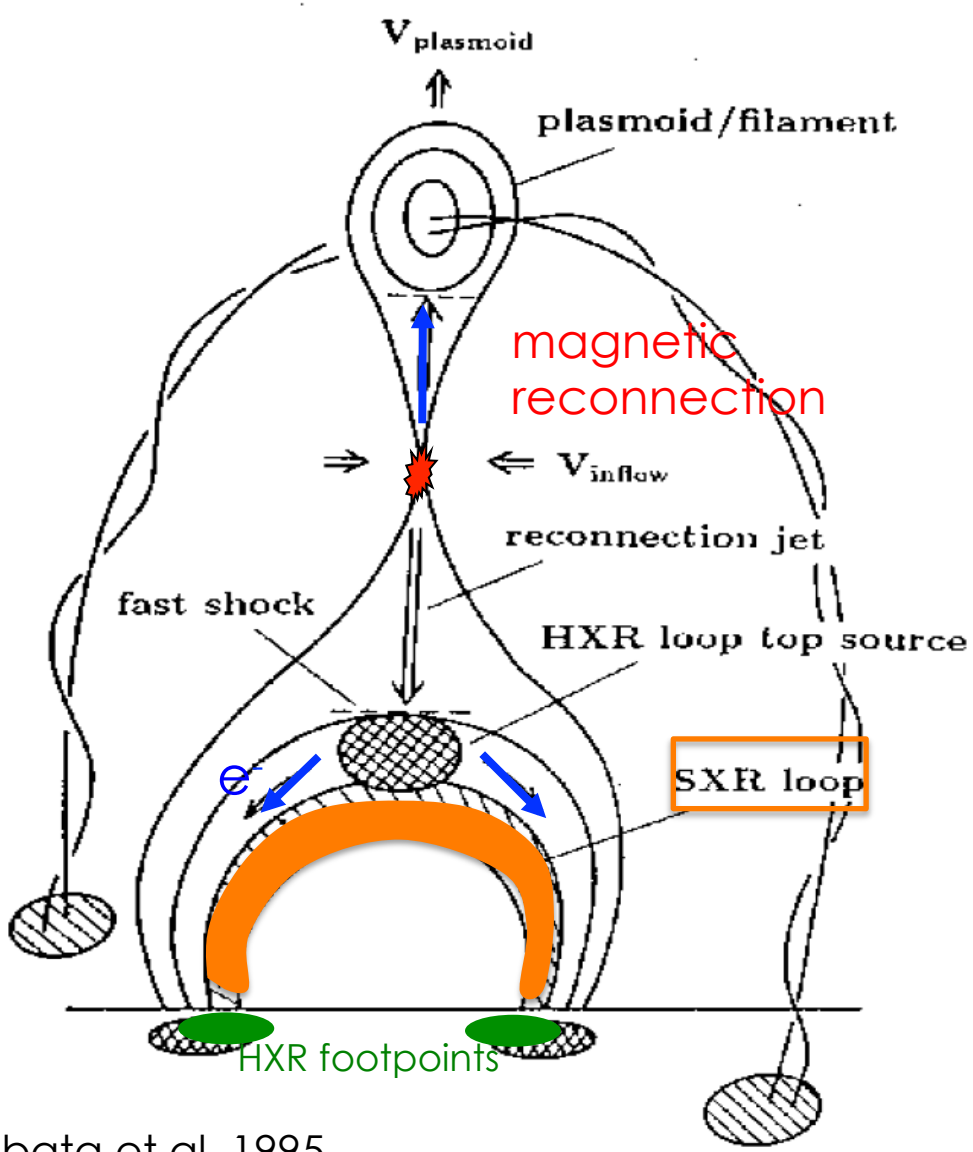
The standard solar flare model



Shibata et al. 1995

1) Release of magnetic energy
2) Particle acceleration and heating
3) Accelerated electrons produce hard X-ray (HXR) emission and heat chromosphere

The standard solar flare model



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4) "Chromospheric evaporation" fills loop

Shibata et al. 1995

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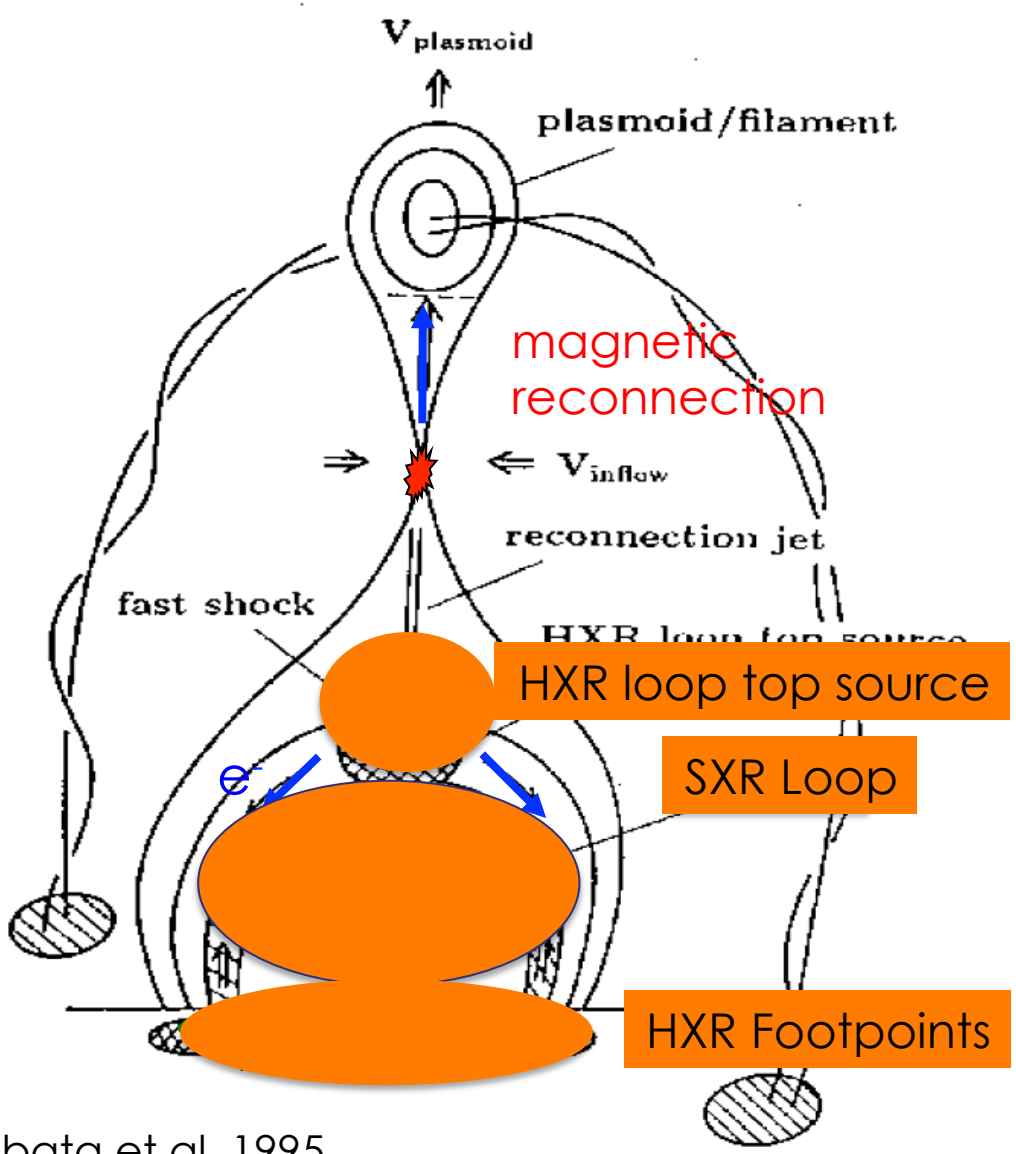

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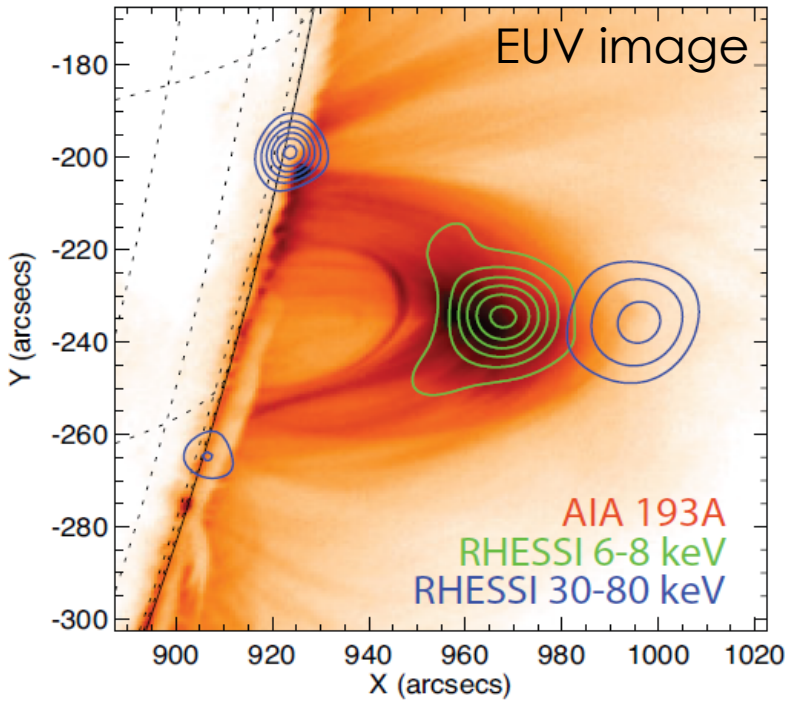
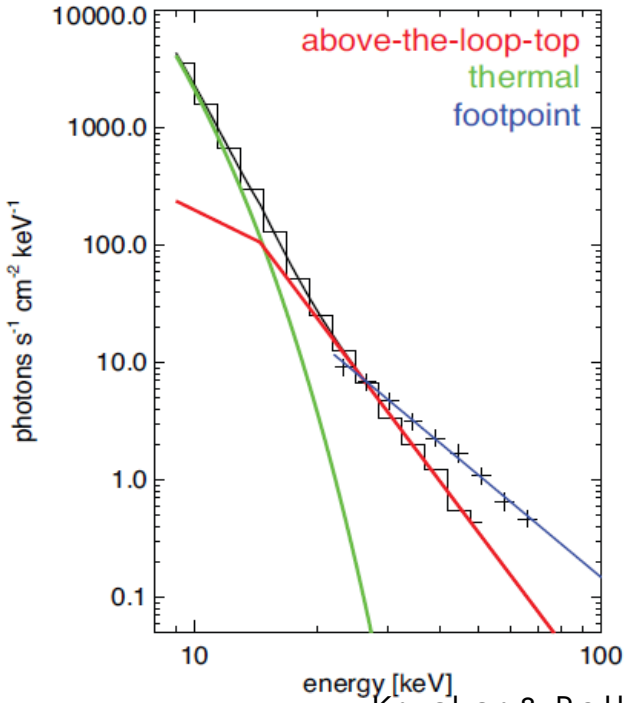
X-ray imaging spectroscopy



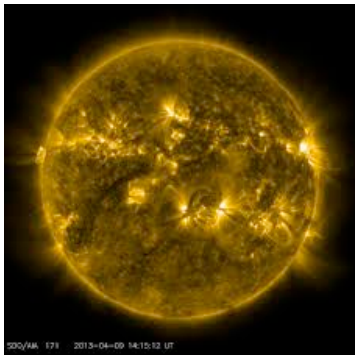


Krucker & Battaglia 2014

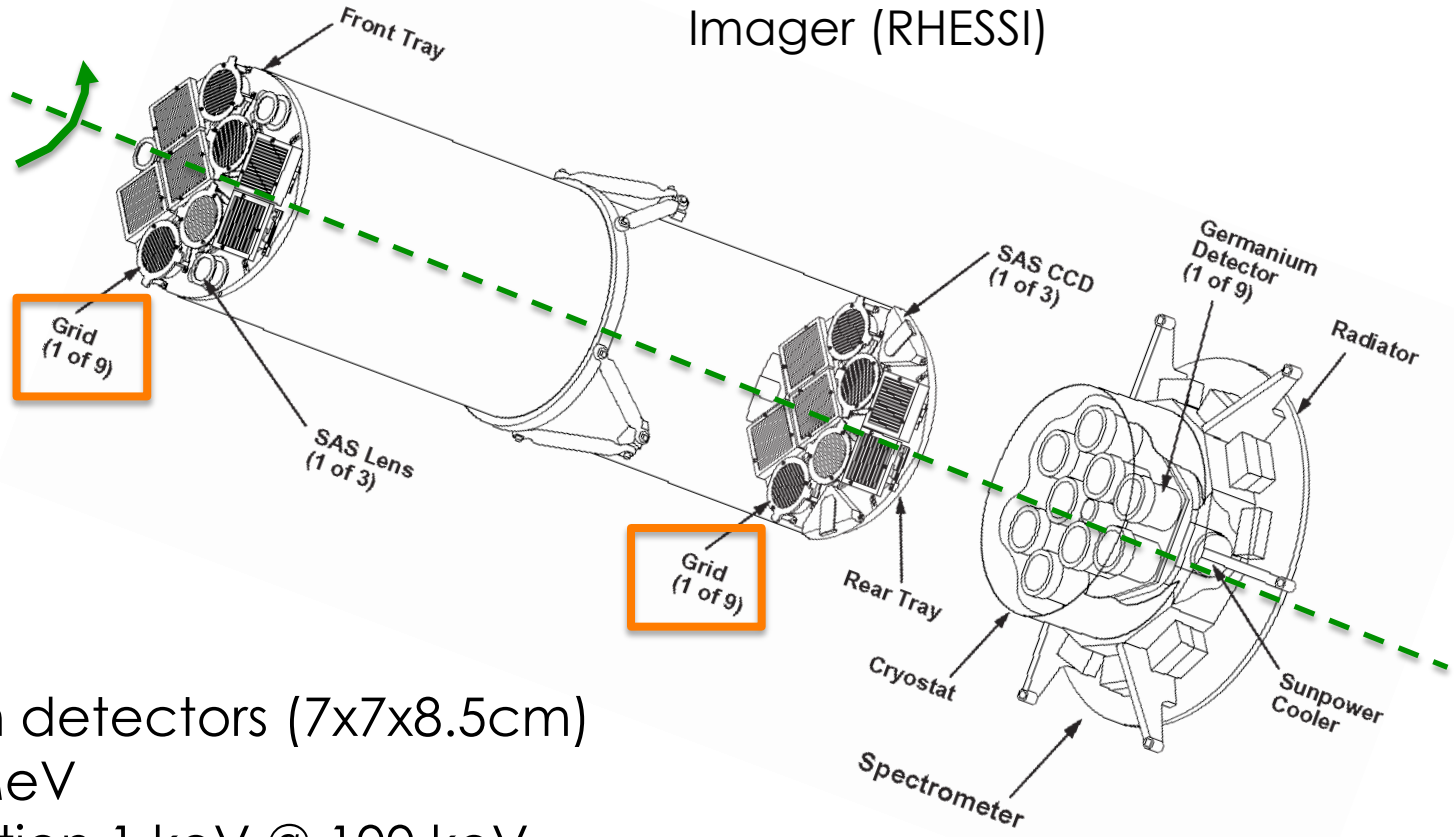
Thermal bremsstrahlung: hot plasma in the flaring loop → temperature and emission measure of heated plasma → total thermal energy involved, flare driven heating, cooling

Non-thermal bremsstrahlung from accelerated electrons → spectrum of accelerated electrons → total energy in accelerated electrons. acceleration mechanism

Solar flare observations with RHESSI



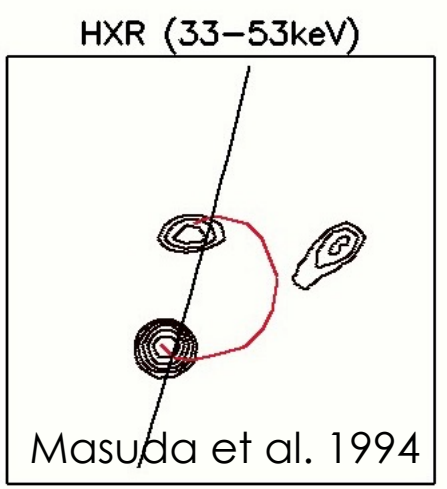
The Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI)



Since 2002
9 Germanium detectors (7x7x8.5cm)
~3 keV – 10 MeV
energy resolution 1 keV @ 100 keV
3 keV @ 2223 keV
spatial resolution 3 arcsec
→ Energy and time of incident photons

Lin et al. 2002

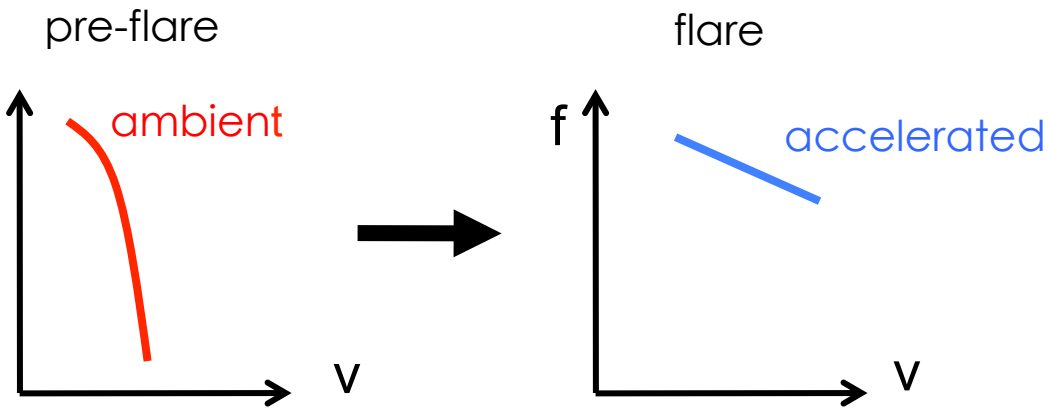
Electron acceleration in above-the-looptop sources

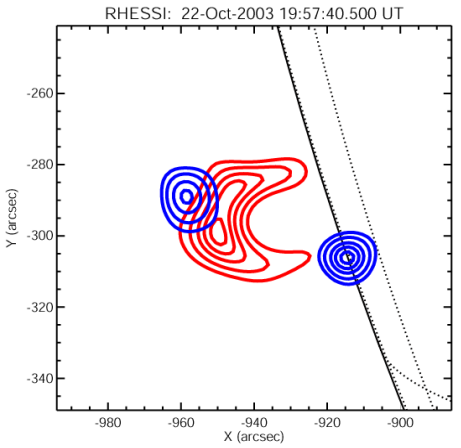


Low ambient density & strong X-ray source → very large number of accelerated electrons

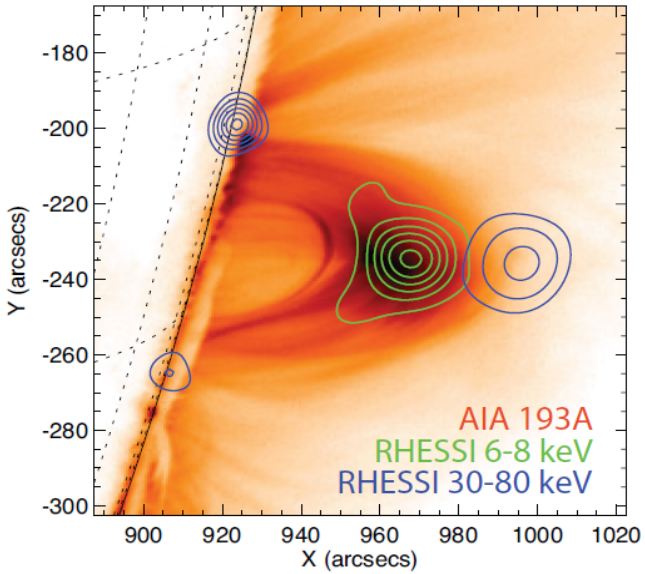
→ Entire plasma is accelerated (non-thermal) in bulk energization process

Above the loop-top-source is acceleration region





Krucker et al. 2010



Krucker & Battaglia 2014

RHESSI imaging spectroscopy in combination with SDO/AIA observations
→ ambient density = accelerated electron density $n_{nt} \sim 10^9$ cm^{-3}

Acceleration and transport of electrons vs ions

Location of

200 – 300 keV emission (signature of accelerated electrons)

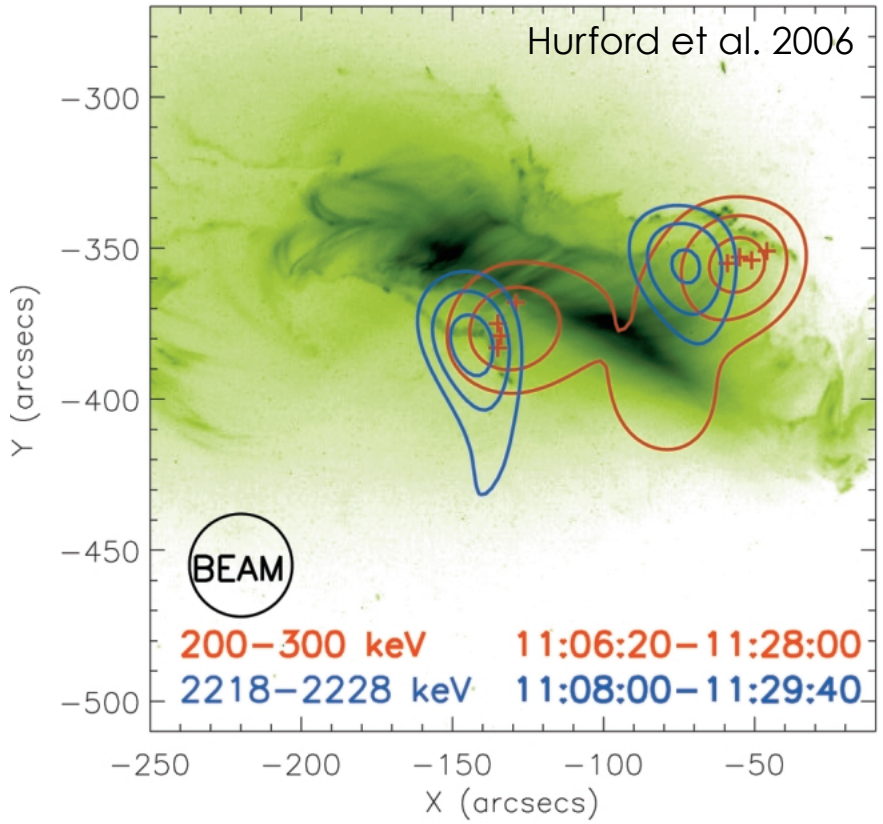
and

2218 – 2228 keV emission (neutron capture line, signature of accelerated ions)

are displaced (Hurford et al. 2003, Hurford et al. 2006) !

Different acceleration of electrons and ions?

Different transport effects?



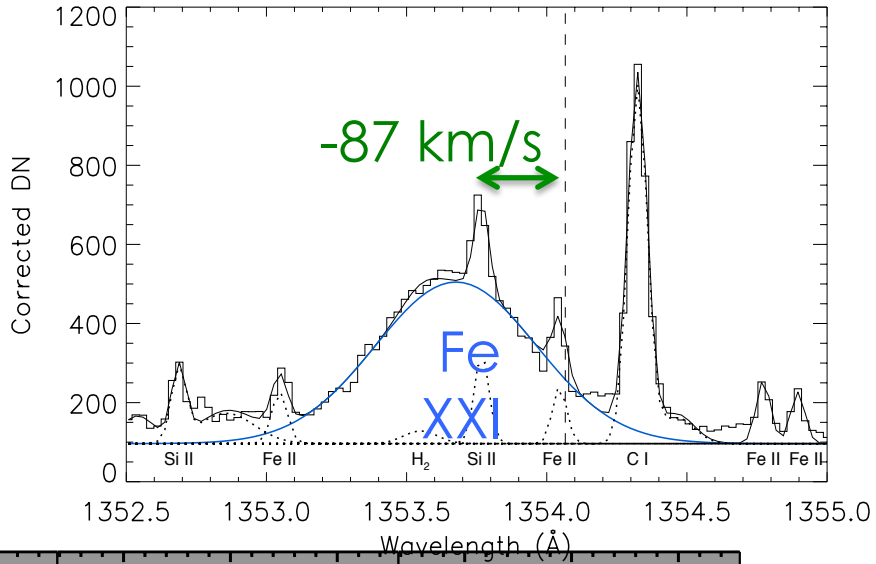
Energy deposition and atmospheric response

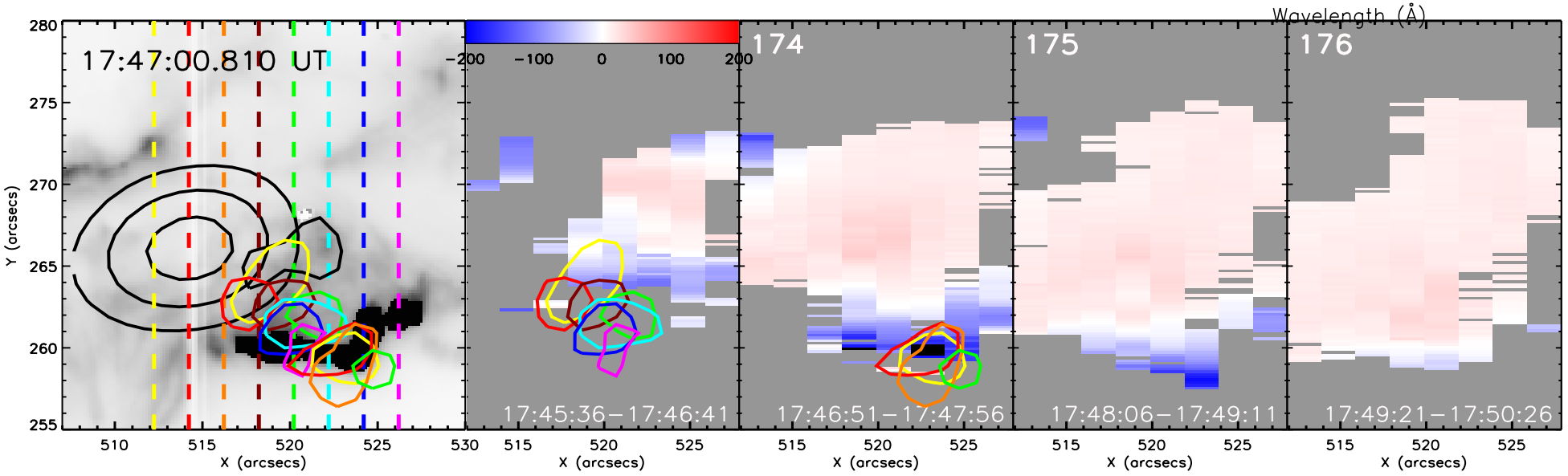
Chromospheric evaporation observed with RHESSI and IRIS

IRIS: Dopplershifts of FeXXI (10 MK) line

→ location and speed of evaporating plasma

RHESSI: location and power of electron beam deposited energy



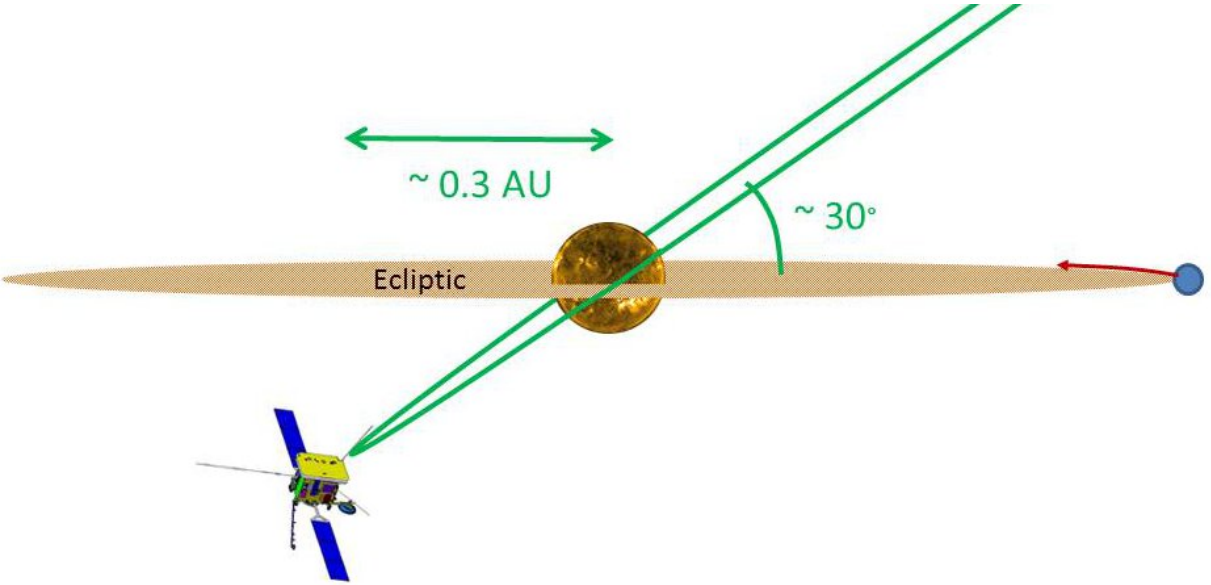


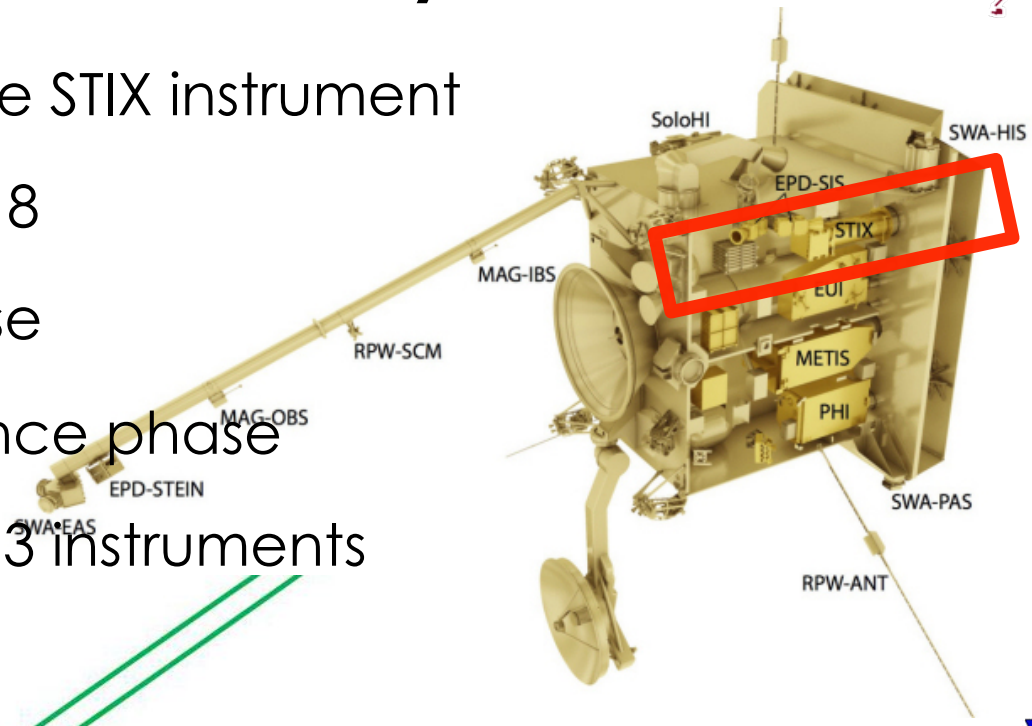
The future of solar flare X-ray observations

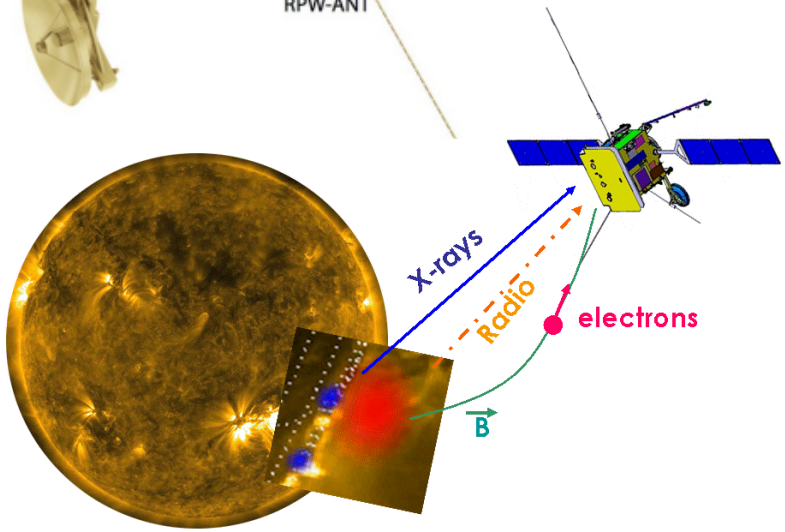
solar orbiter

ESA's Solar Orbiter & the STIX instrument

- Launch October 2018
- 2.5 years cruise phase
- 3 years primary science phase
- Swiss involvement in 3 instruments

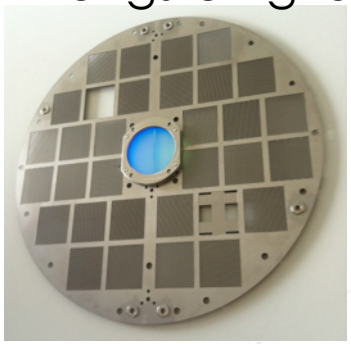




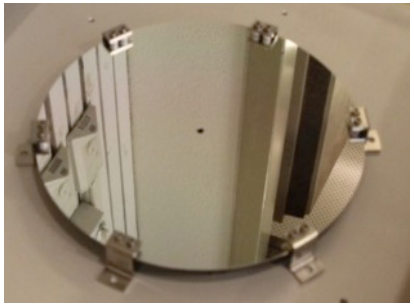


The Spectrometer/Telescope for Imaging X-rays (STIX)

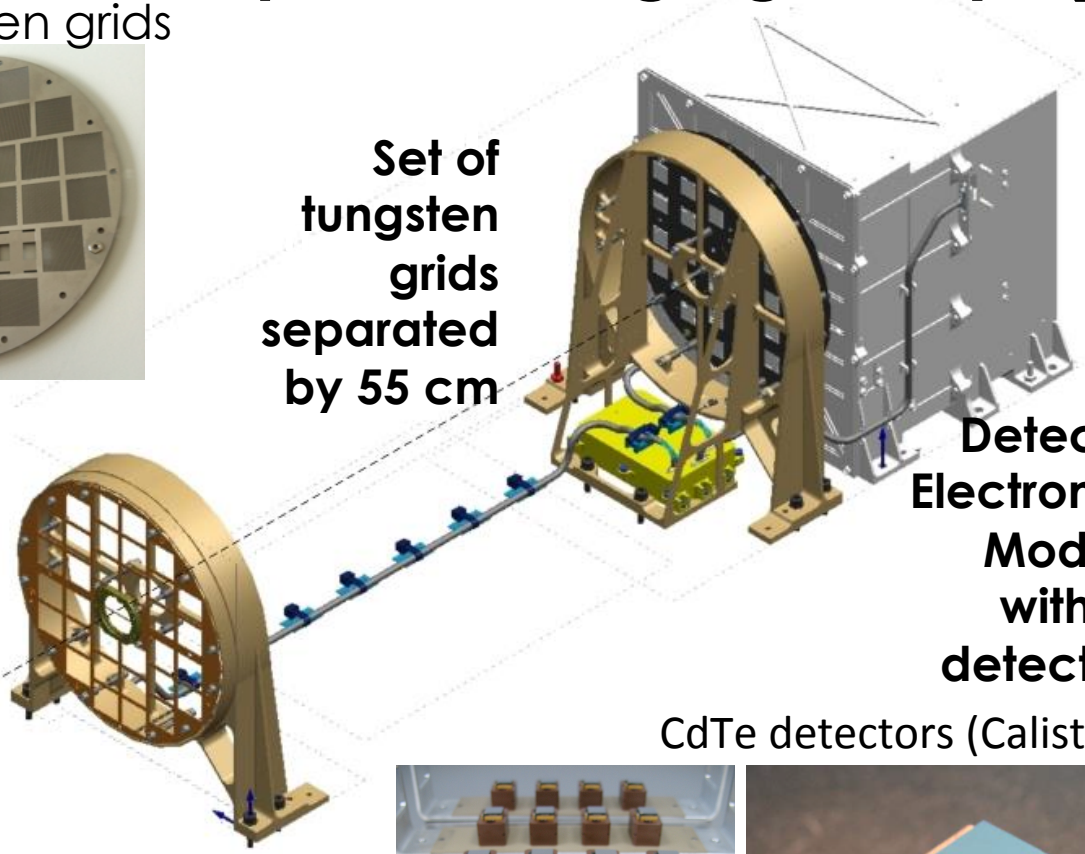
Tungsten grids



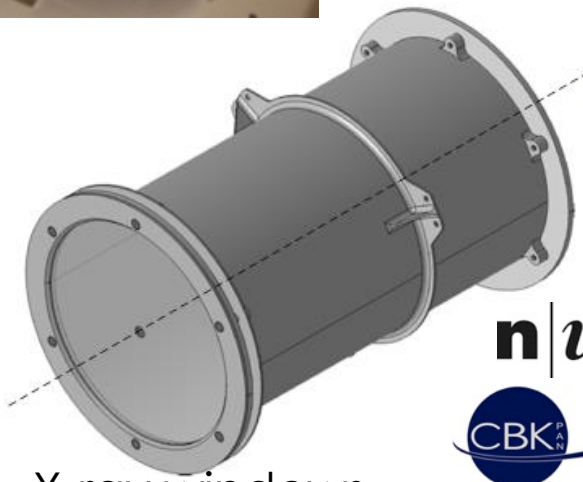
Beryllium window



Set of tungsten grids separated by 55 cm

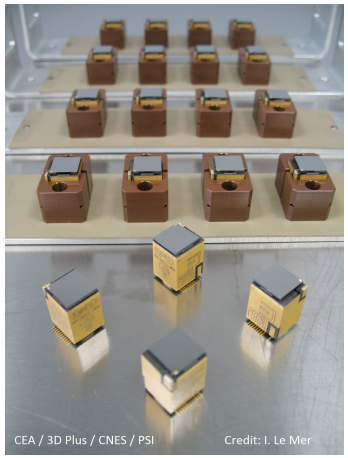


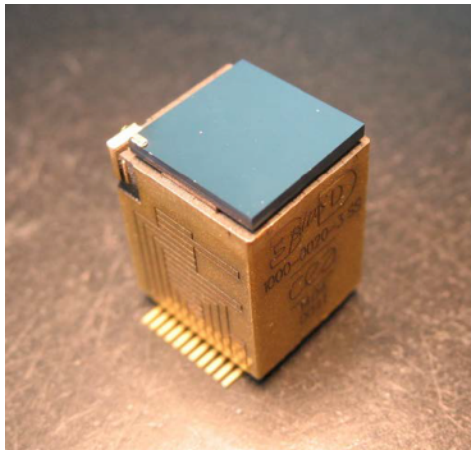
Detector Electronics Module with 32 detectors



X-ray windows and feed-through in heat shield

CdTe detectors (Caliste SO)





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Summary and conclusions

- Solar flares allow us to study fundamental and universal physical processes such as magnetic energy release, particle acceleration, and particle transport in magnetised plasmas
- X-ray observations of solar flares serve as diagnostic of flare accelerated particles and hot plasma
- Need simultaneous observations at many wavelengths for full understanding of solar flares
- Look forward to Solar Orbiter for new view of solar activity and space weather