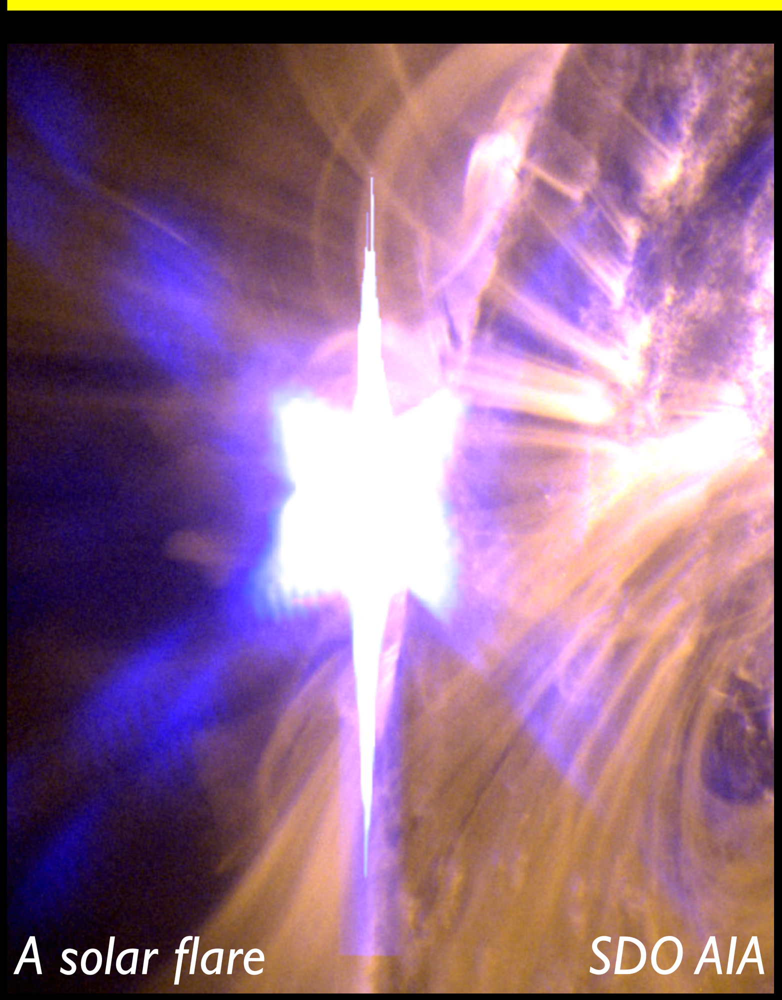
Solar flare plasma diagnostics and determining the properties of solar flare electrons and ions

Natasha L. S. Jeffrey, SUPA School of Physics & Astronomy, University of Glasgow

University of Glasgow | Science & Technology Facilities Council | SUPA

What is a solar flare and why do we study them?

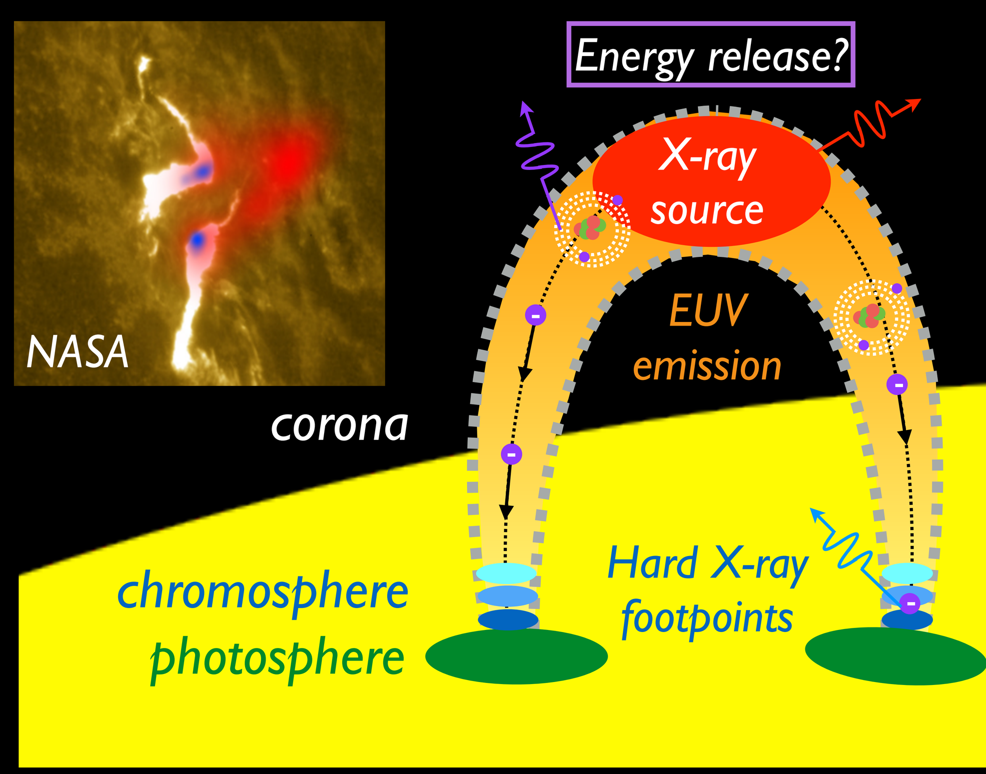


Solar flares are huge releases of energy from the Sun's atmosphere. High energy flare processes such as particle acceleration, transport and plasma heating are studied by observing the Sun in different wavelengths.

We can study high energy processes using X-ray and EUV emissions currently using space-based instrumentation such as *RHESSI*[1] (X-rays) and *Hinode EIS*[2] (EUV).

Flares initiate in the corona but we see emission from all parts of the atmosphere from heating and streaming particles guided by the magnetic field and producing radiation in lower, denser parts of the atmosphere.

Understanding the high energy processes occurring in the Sun allows us to understand the same processes occurring elsewhere in the Universe.

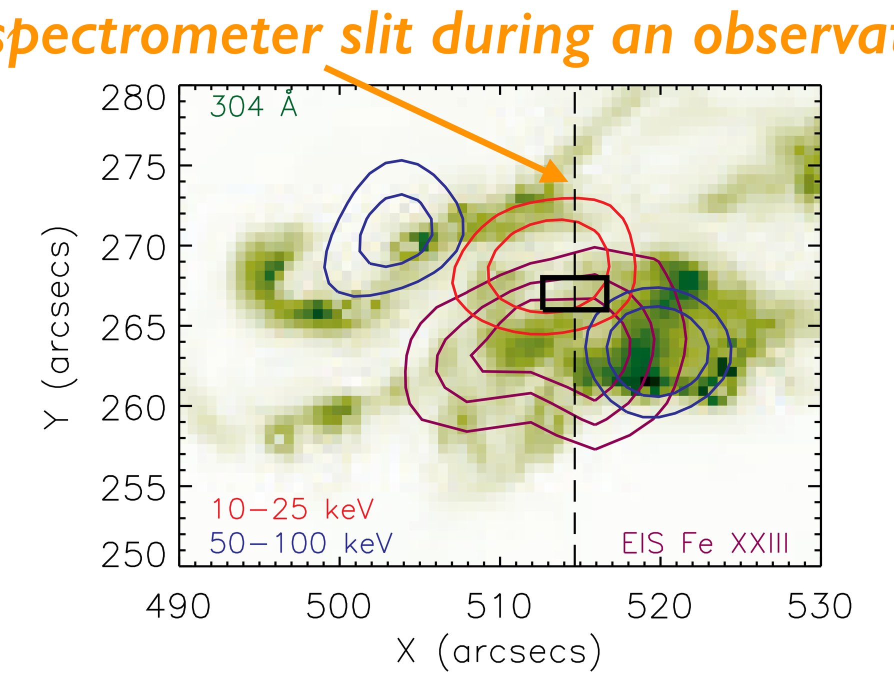


EUV line spectroscopy

EUV line spectroscopy with Hinode EIS allows us to probe flare ion properties.

Figure 1: A multi-wavelength observation of a solar flare occurring on the 29th March 2014.

EIS spectrometer slit during an observation.

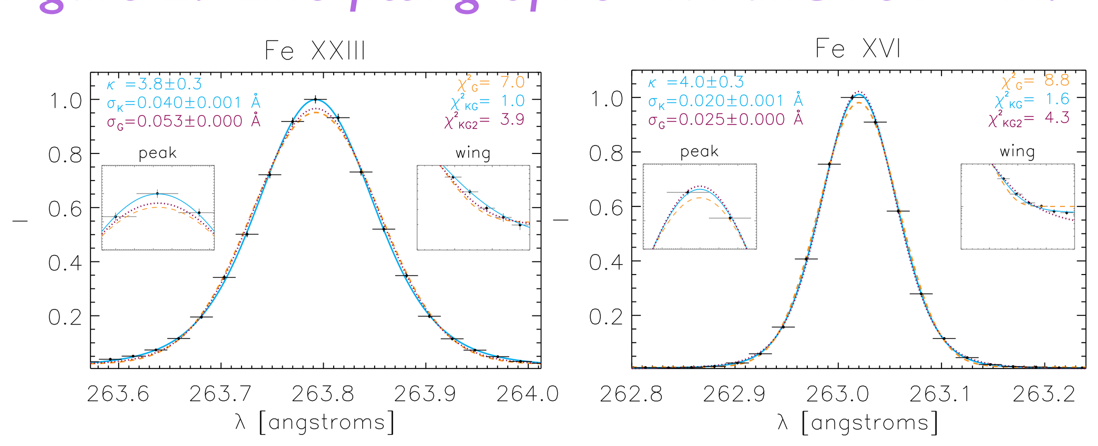


The spectral lines are better fitted using a *kappa* rather than a *Gaussian* line profile.

$$I(\lambda) = A_\lambda \left(1 + \frac{(\lambda - \lambda_0)^2}{\kappa 2\sigma_\kappa}\right)^{-\kappa+1}$$

Gaussian line when $\kappa \longrightarrow \infty$

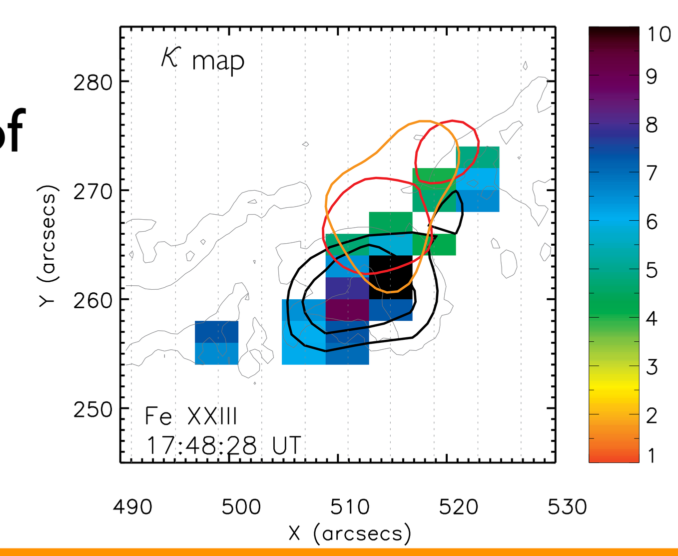
Figure 2: Line fitting of Fe XVI and Fe XXIII.



Kappa lines: peaked with broad wings!

Kappa lines (small κ) are indicative of either:

1. *non-thermal ion velocities*
2. *multi-thermal plasma.*

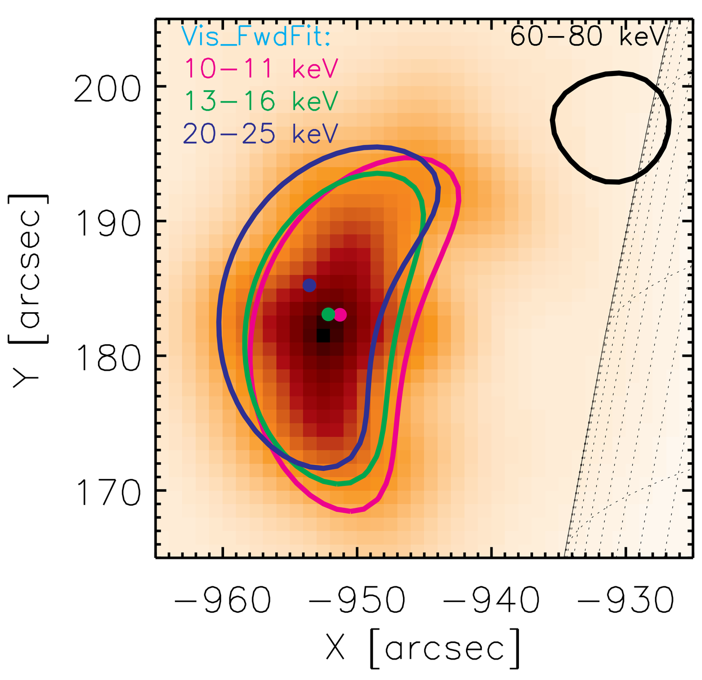


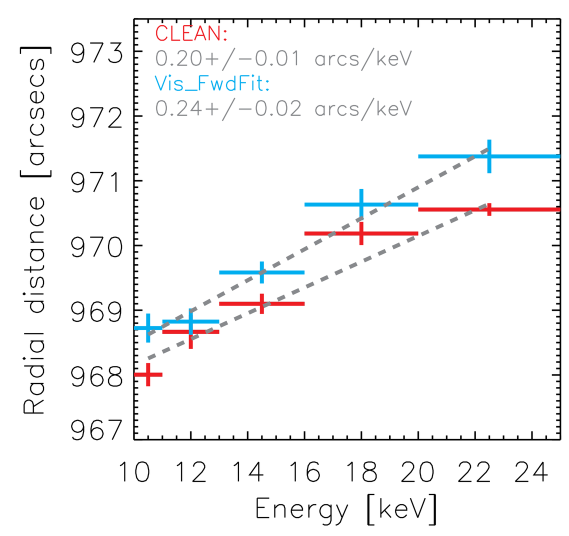
Full work in Jeffrey, Fletcher & Labrosse (2015)

X-ray imaging and spectroscopy

X-ray spectroscopy and imaging are key tools for understanding flare accelerated electrons. We can also use them to understand the properties of megakelvin plasma in the flaring corona such as temperature and electron number density.

Figure 3: A RHESSI X-ray image of solar flare coronal sources at different energies (13-May-13 flare).



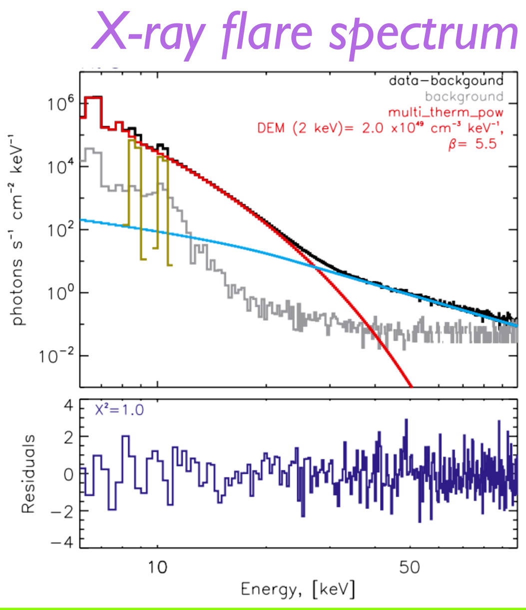


Coronal source height R increases with energy and can be described by

$$R(\epsilon_0) = R_0 + \alpha\,\epsilon_0$$

We combine this RHESSI X-ray imaging observation with RHESSI X-ray spectroscopy, allowing us to better constrain flaring coronal plasma properties.

X-ray flare spectrum



These observations show that the flaring corona *cannot be isothermal* and properties from spectroscopy should not be found using an isothermal model.

Full work in Jeffrey, Kontar & Dennis (2015)

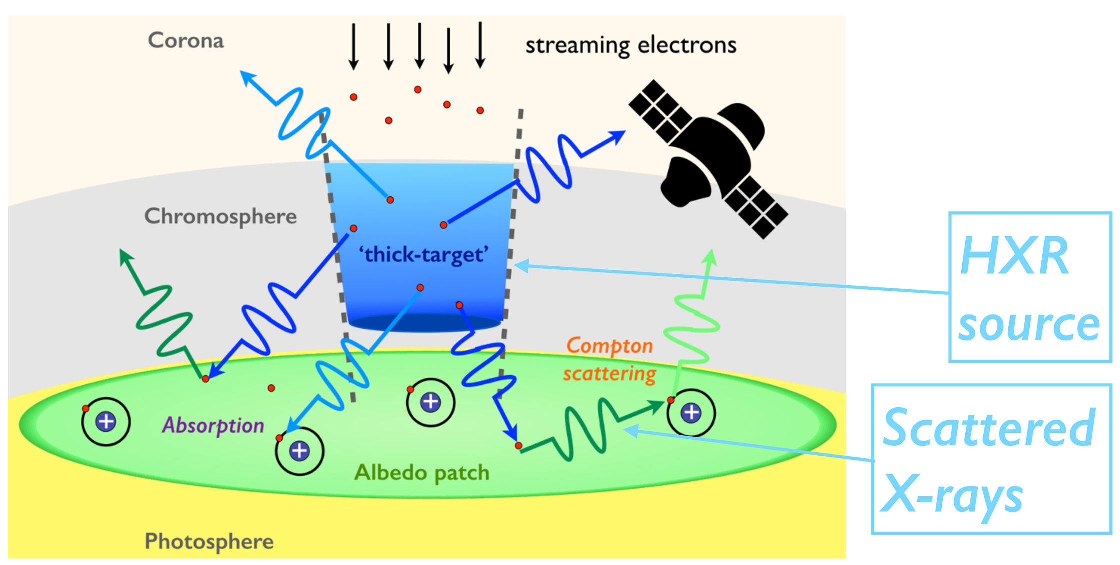
X-ray polarization

Hard X-ray (HXR) polarization is an important tool for determining the electron pitch-angle distribution which is related to the electron acceleration mechanism.

New X-ray polarization measurements!

A new instrument POLAR[3] will be launched in September on-board the Chinese space station.

We used simulations of X-ray transport to understand an effect known as *X-ray albedo* that *changes* all X-ray properties including polarization measured by POLAR.



X-rays can be *Compton scattered* in the Sun's photosphere. This is *X-ray albedo*.

By accounting for albedo, we can make polarization maps and use them in the future as detailed probes of hard X-ray electron properties.

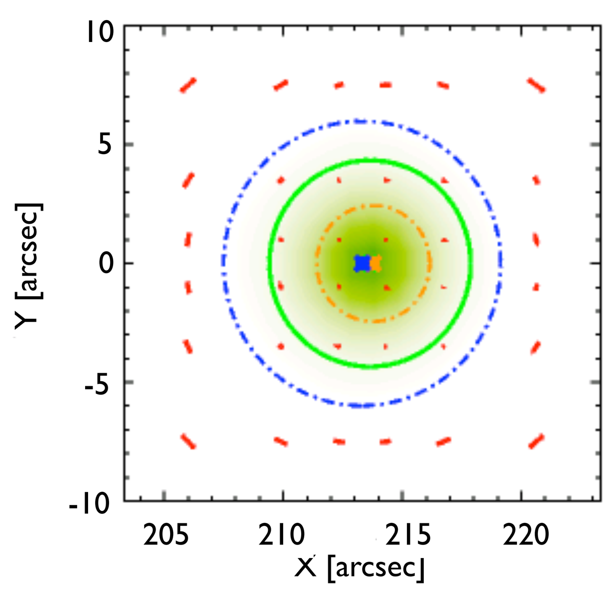


Figure 4: Simulated HXR polarization map.

Full work in Jeffrey & Kontar (2011)

References: 1. Lin, R. P., et al. 2002, Sol Phys., 210, 3 2. Culhane, J. L., et al. 2007, Sol Phys., 243, 19 3. Hajdas, W., et al. 2015, JAMP, 3, 272 4. Jeffrey, N., et al. 2015 A&A, 584, 89 5. Jeffrey, N., et al. 2016, A&A, accepted 6. Jeffrey, N., & Kontar, E., 2011 A&A, 536, 93