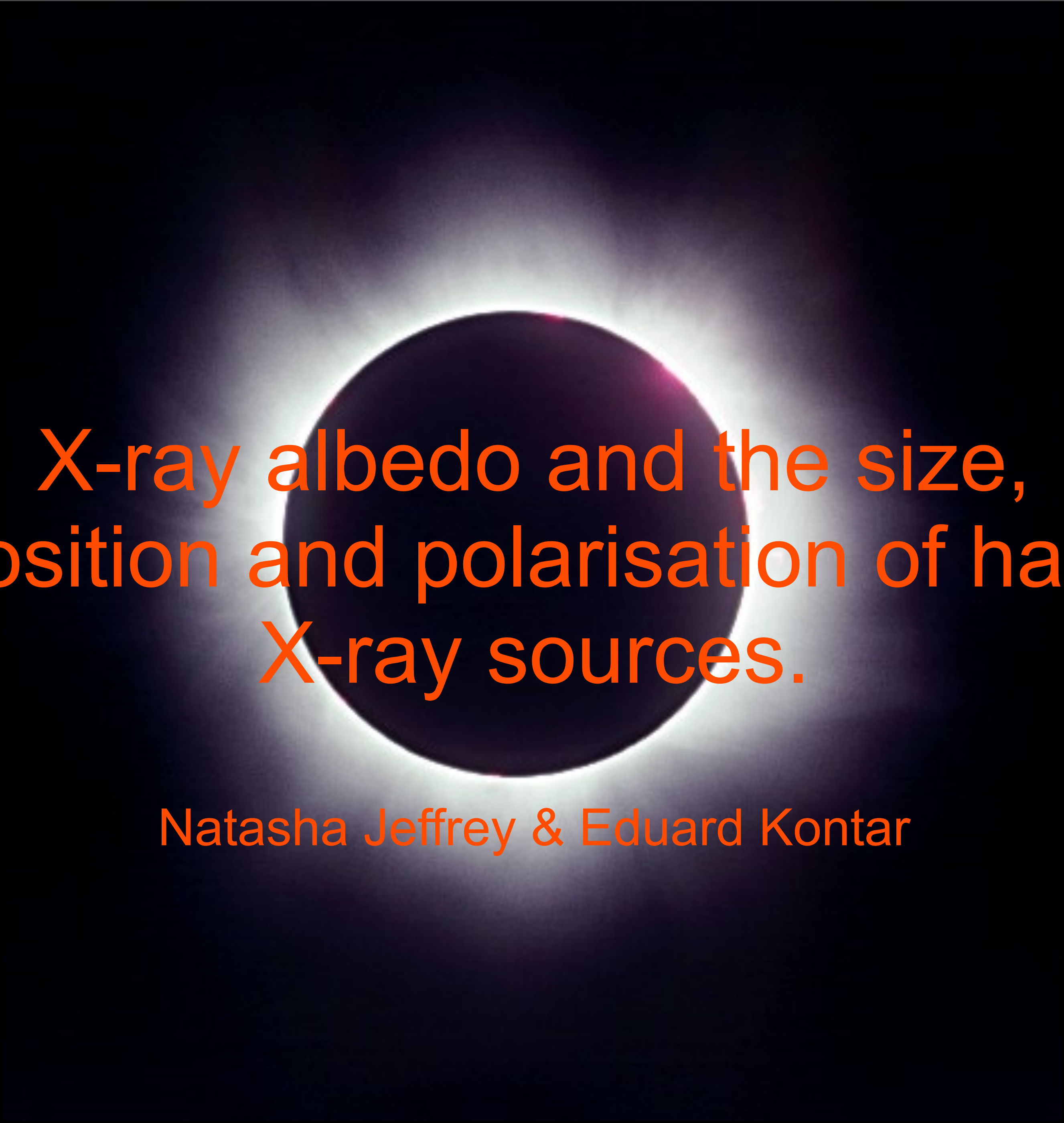
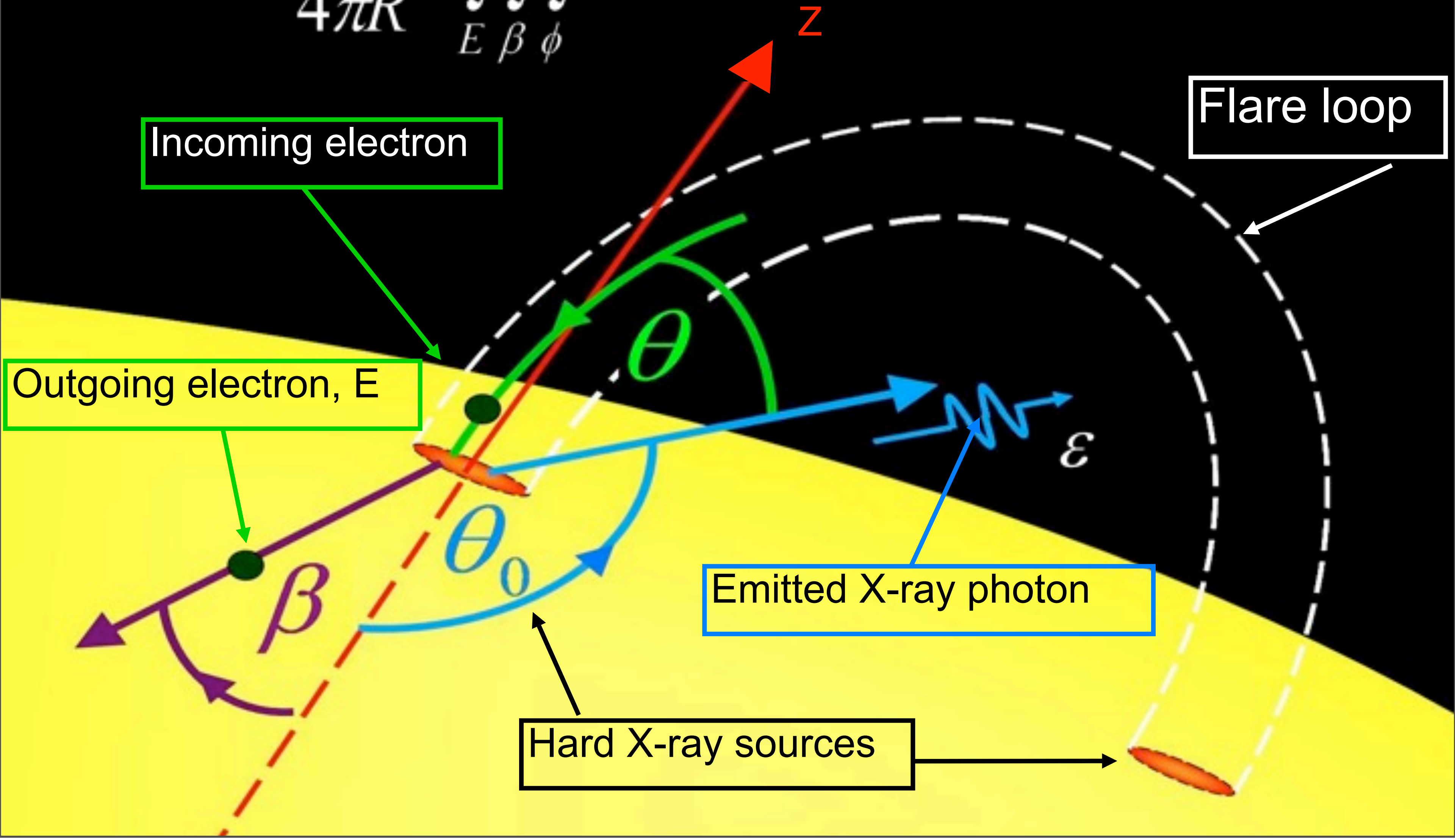


X-ray albedo and the size, position and polarisation of hard X-ray sources.

Natasha Jeffrey & Eduard Kontar

Electron acceleration and photon emission

$$I(\varepsilon,\theta_0)=\frac{nV}{4\pi R^2}\int_E\int_\beta\int_\phi F(E,\beta)Q(E,\varepsilon,\theta)\sin\beta\, d\phi\, d\beta\, dE$$



Flare loop

Incoming electron

Outgoing electron, E

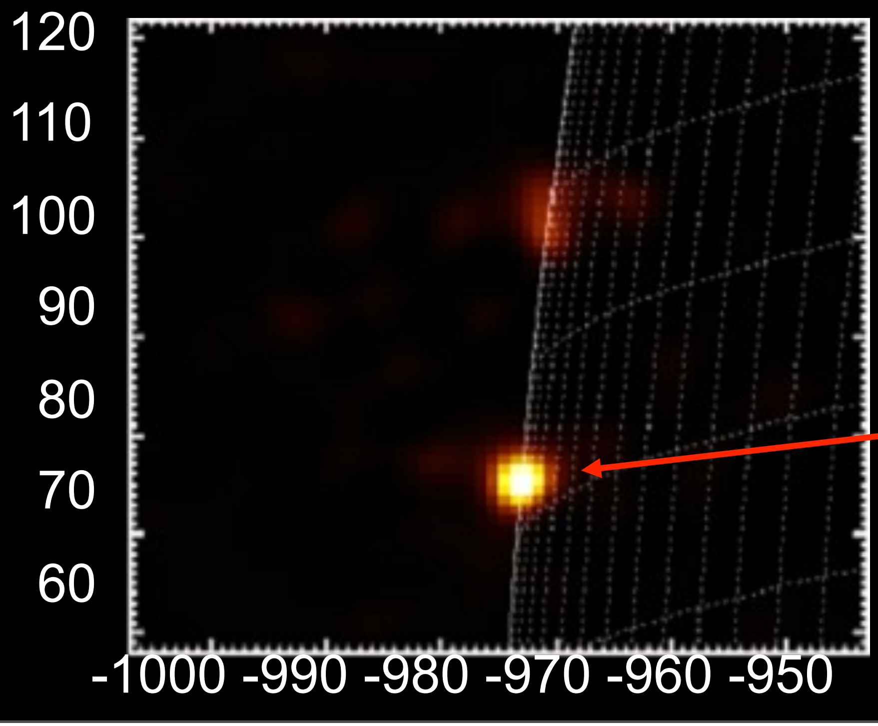
Emitted X-ray photon

Hard X-ray sources

The Viewing of X-rays with RHESSI

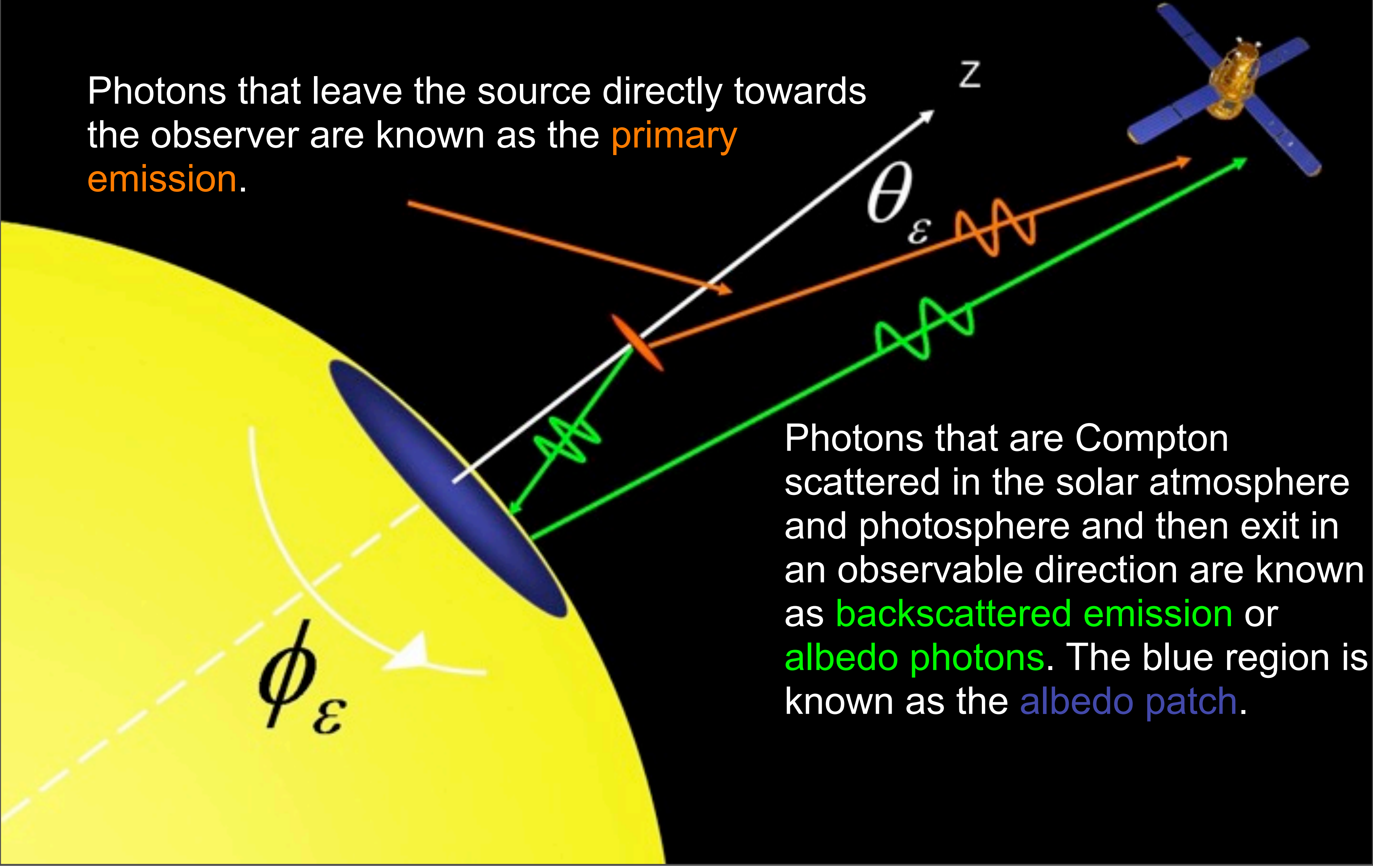
Ramaty High Energy Solar Spectroscopic Imager

- NASA led space based mission
- Views the Sun in X-rays and gamma rays
- RHESSI is helping us to understand particle acceleration and energy release from flares.



Example of a RHESSI viewed limb flare event from 6th January 2004 in the energy range 22-29 keV. The hard X-ray emission appears as a footpoint source.

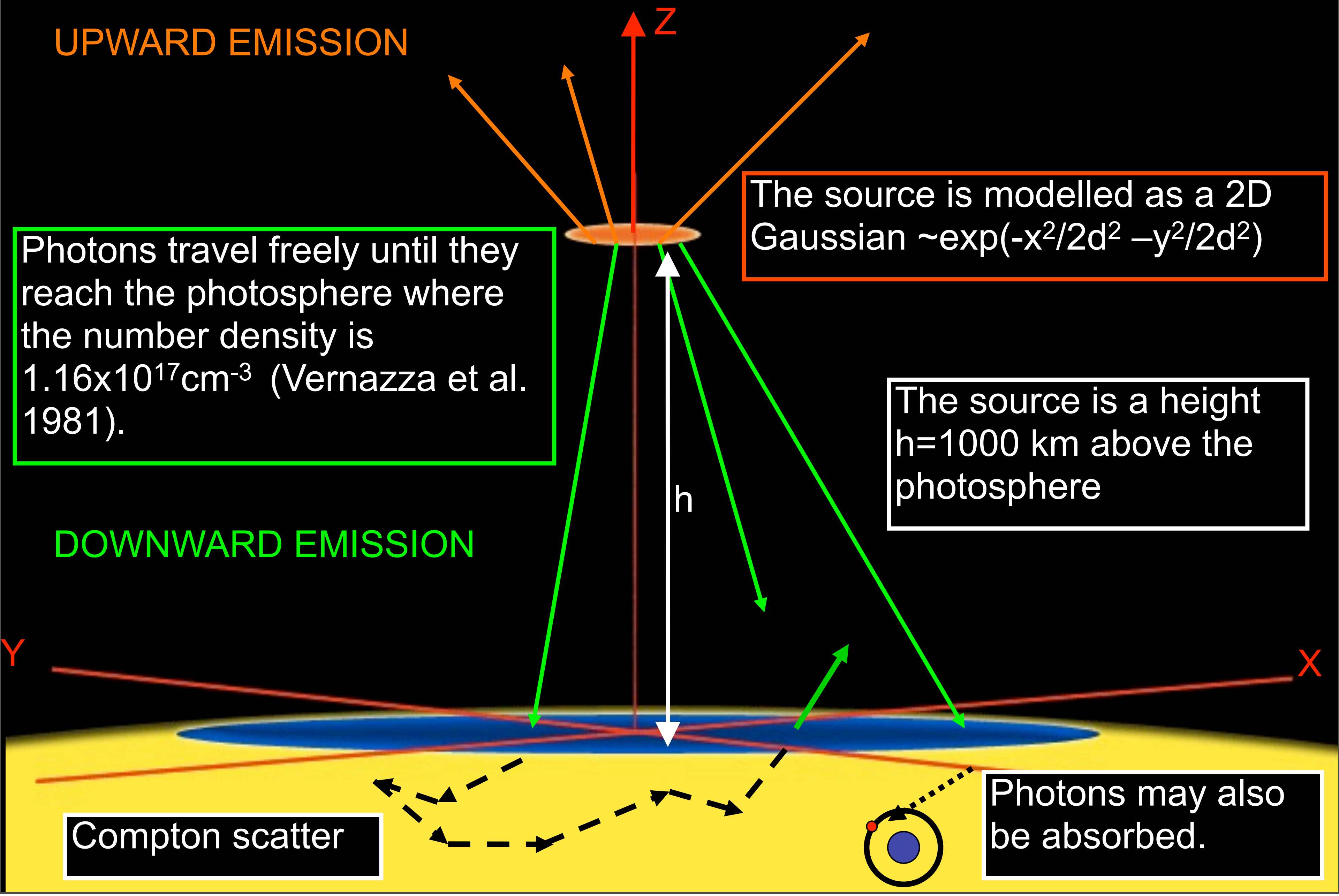
Primary photon emission, Compton backscattering and the albedo effect



Photons that leave the source directly towards the observer are known as the primary emission.

Photons that are Compton scattered in the solar atmosphere and photosphere and then exit in an observable direction are known as backscattered emission or albedo photons. The blue region is known as the albedo patch.

Monte Carlo simulations of photon transport



UPWARD EMISSION

The source is modelled as a 2D Gaussian ~$\exp(-x^2/2d^2 - y^2/2d^2)$

Photons travel freely until they reach the photosphere where the number density is 1.16×10^{17} cm^{-3} (Vernazza et al. 1981).

The source is a height h=1000 km above the photosphere

DOWNWARD EMISSION

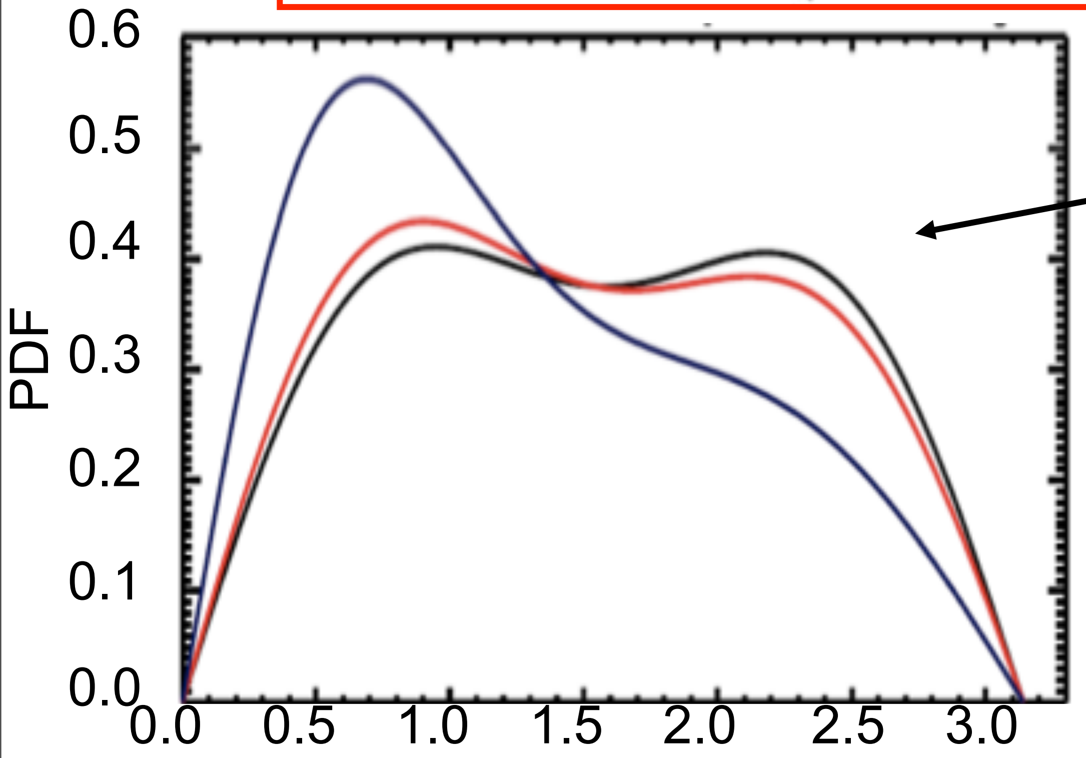
Compton scatter

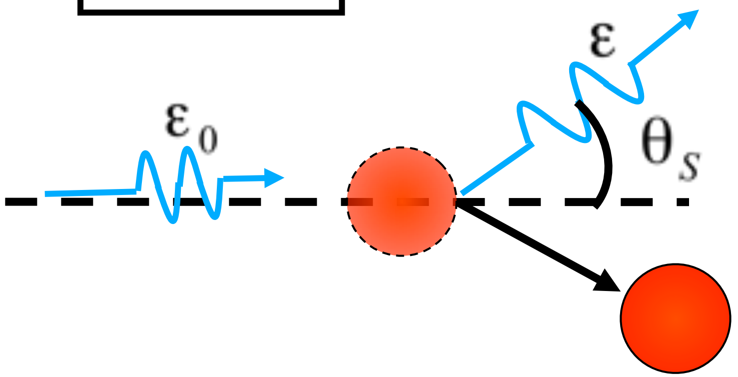
Photons may also be absorbed.

Modelling Compton scattering in the code

Differential Klein-Nishina scattering cross-section for unpolarised radiation:

$$\frac{d\sigma_c}{d\Omega}(\epsilon_0, \theta_s) = \frac{1}{2} r_0{}^2 \left(\left(\frac{\epsilon}{\epsilon_0}\right)^3 + \frac{\epsilon}{\epsilon_0} - \left(\frac{\epsilon}{\epsilon_0}\right)^2 \sin{}^2\theta_s, \right)$$



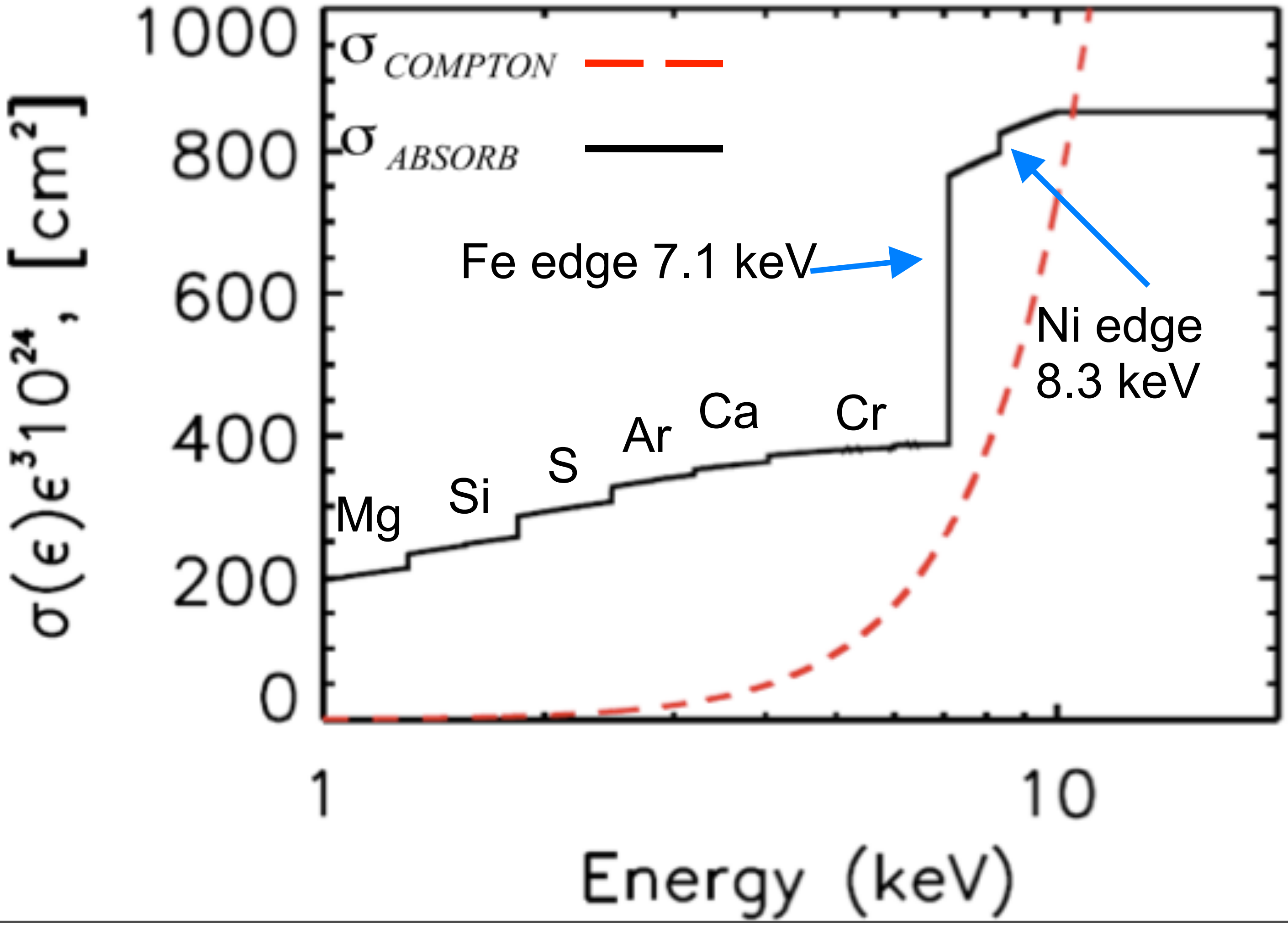


The new photon energy is then just found from the scattering angle.

$$\epsilon = \frac{\epsilon_0}{1 + \frac{\epsilon_0}{mc^2}(1 - \cos\theta_s)}.$$

Modelling absorption in the code

Absorption is modelled using up-to-date solar photospheric abundances (Asplund et al. 2009) and absorption codes for H, He, C, N, O, Ne, Na, Mg, Al, Si, S, Cl, Ar, Ca, Cr, Fe and Ni (Balucinska-Church & McCammon,1992).



Changes in source size and position due to the scattered albedo photons

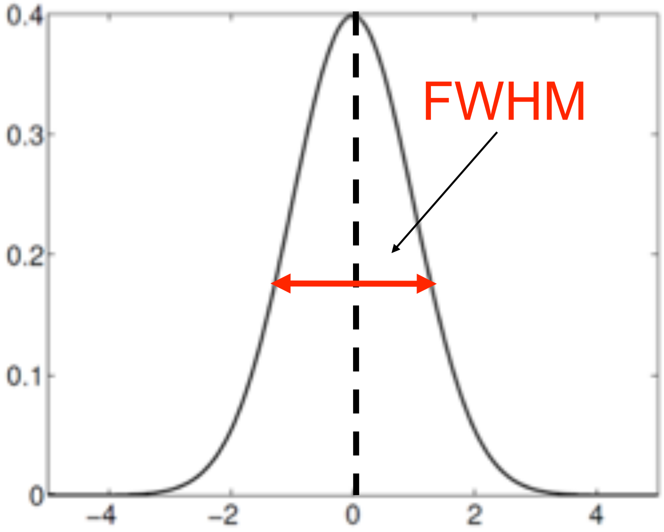
The position and size of the combined (primary and the albedo) source is found using the first and second moments of the intensity distribution I(x,y).

Mean
$$\bar{x} = \frac{\int_{-\infty}^{\infty} xI(x,y)dxdy}{\int_{-\infty}^{\infty} I(x,y)dxdy}$$

Variance
$$\sigma_x^2 = \frac{\int_{-\infty}^{\infty} (x-\bar{x})^2 I(x,y)dxdy}{\int_{-\infty}^{\infty} I(x,y)dxdy}$$

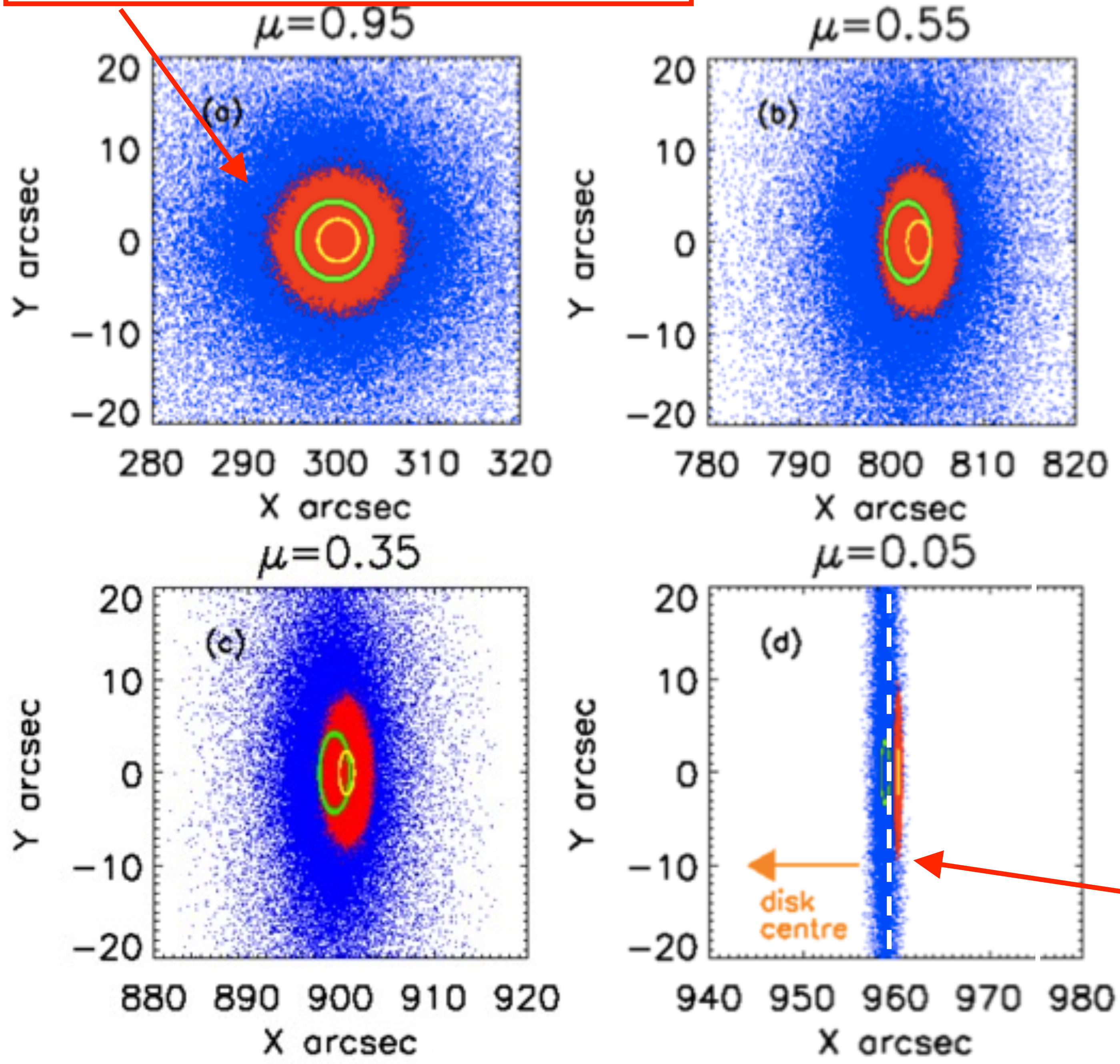
The size of the source can then be measured using the Full Width Half Maximum (FWHM) given by:

$$FWHM = 2\sigma\sqrt{2\ln 2}$$

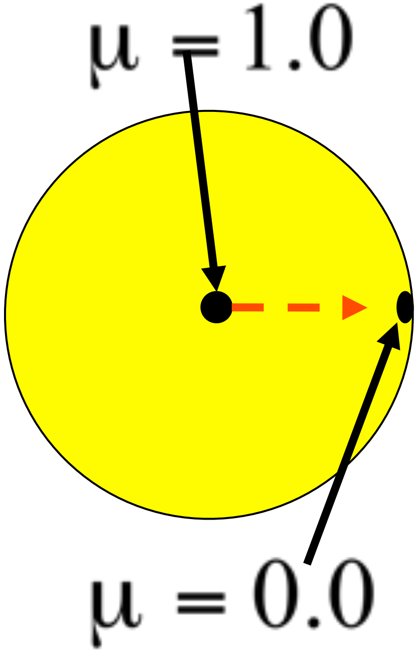


Heading towards the solar centre

Kontar, E., Jeffrey, N., 2010

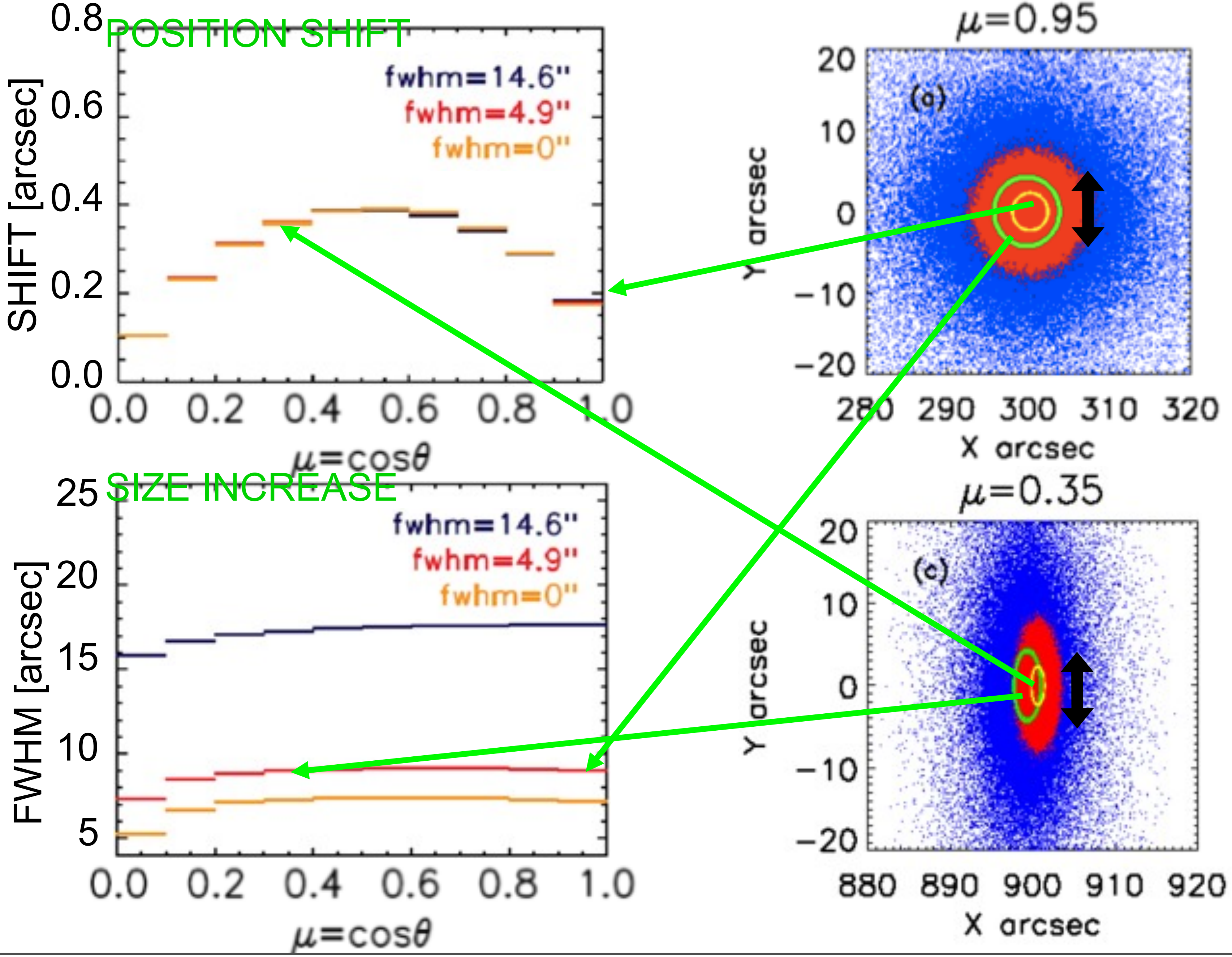


$\mu = \cos\theta$

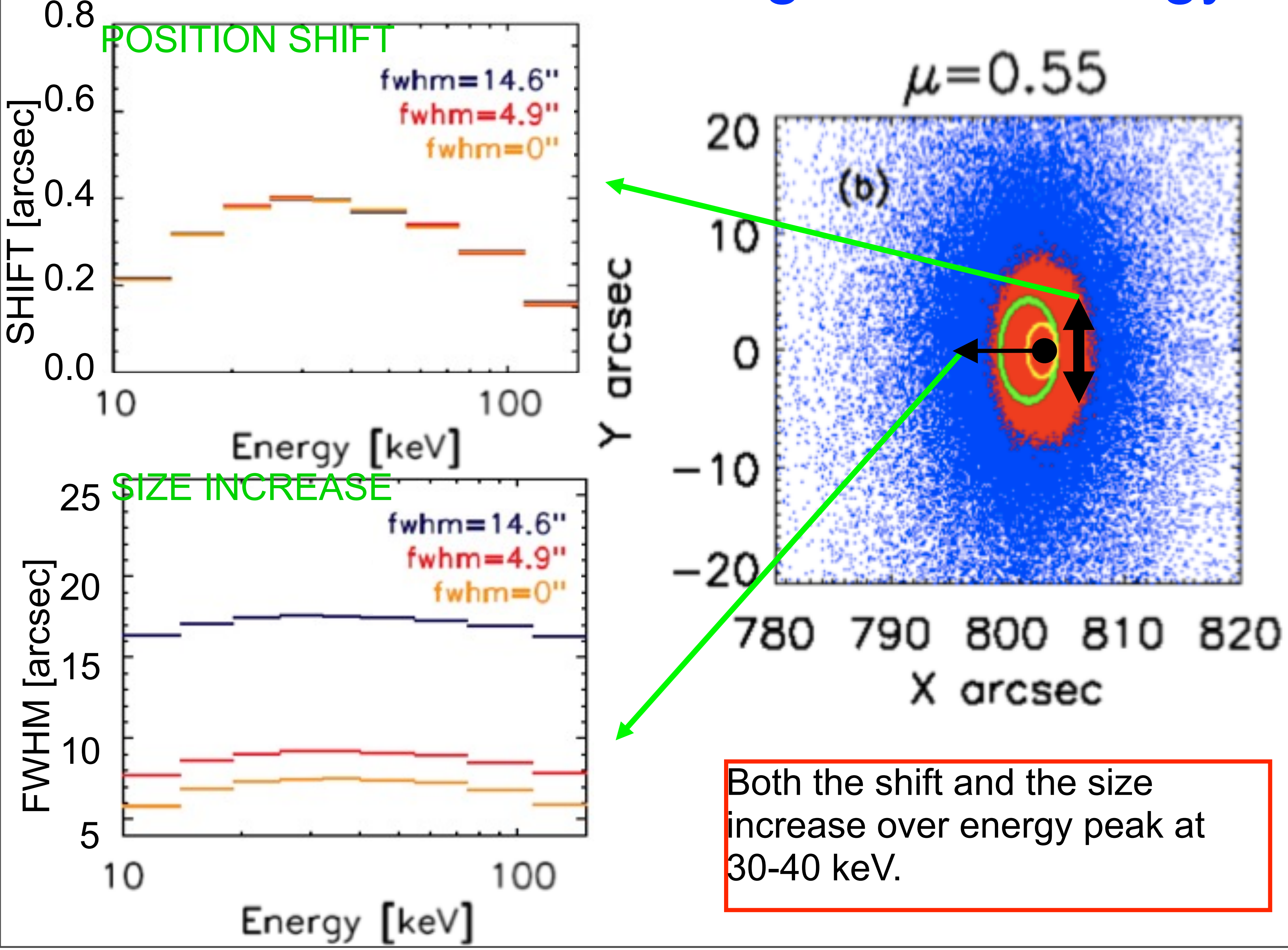


The solar edge (limb)

Position and size changes with location



Position and size changes with energy



Both the shift and the size increase over energy peak at 30-40 keV.

What is the point of this work?

The albedo photons cause the position of the source to be shifted so that the observer does not see the true hard X-ray source position.

The albedo photons cause the source size to be larger than it actually is and even a point hard X-ray source is viewed as an extended source.

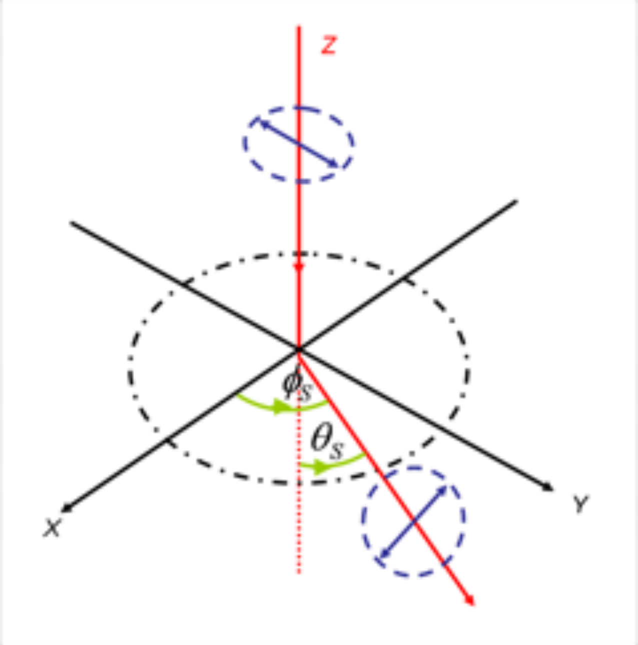
So, hard X-ray sources observed by instruments such as RHESSI do not give the true size and position measurements.

Polarisation and Compton Backscattering

Polarisation is another photon property that can be used to infer information about the parent electron distribution.

The polarisation dependent Compton cross-section:

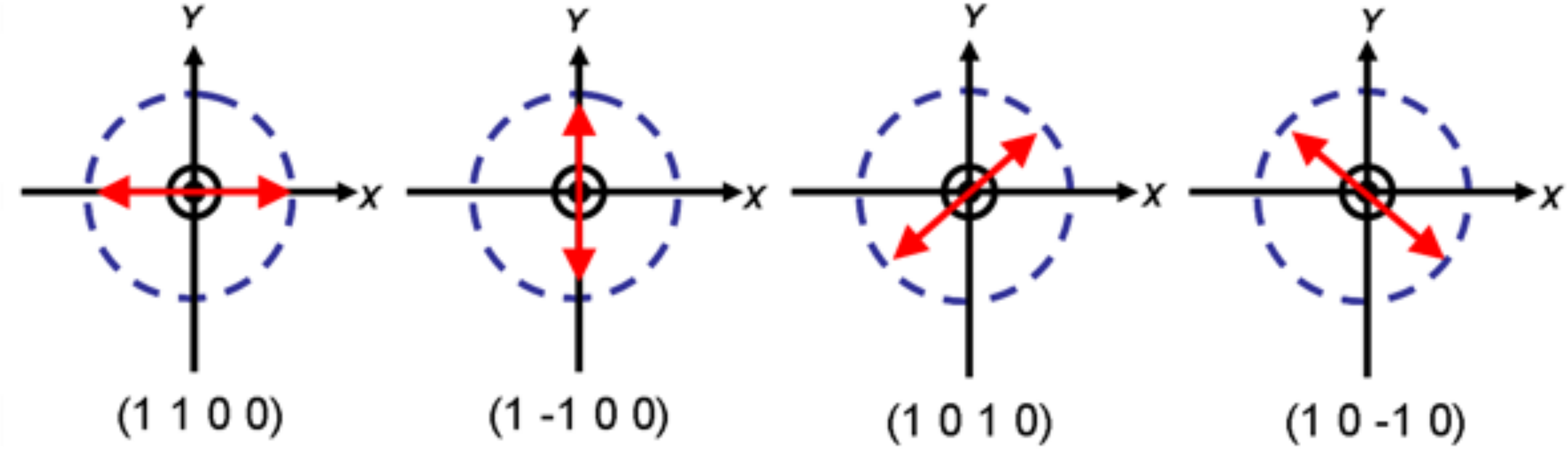
$$\boxed{\frac{d\sigma_C}{d\Omega}(\varepsilon_0,\theta_S)=\frac{1}{2}r_0^2\left(\left(\frac{\varepsilon}{\varepsilon_0}\right)^3+\left(\frac{\varepsilon}{\varepsilon_0}\right)-\left(\frac{\varepsilon}{\varepsilon_0}\right)^2\sin^2\theta_S(1-P_1\cos 2\phi_S-P_2\sin 2\phi_S)\right)}$$



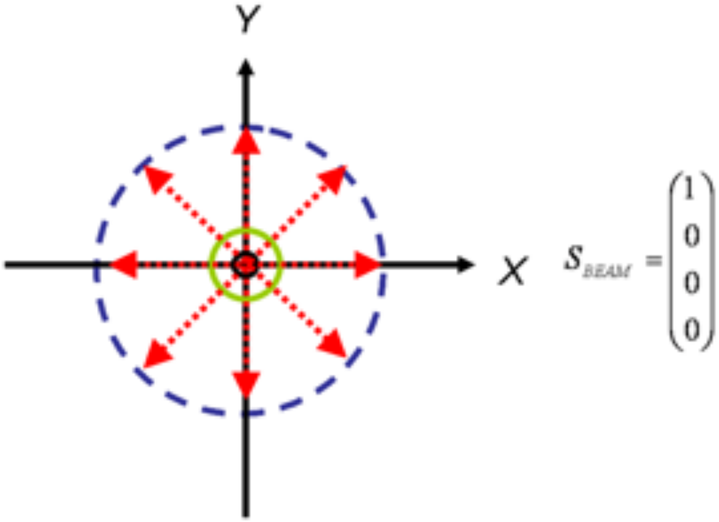
The cross-section is now phi-dependent.

Polarisation and Compton Backscattering

In the simulations polarisation is described using Stokes parameters $S=(I\ P_1\ P_2\ P_3)$:

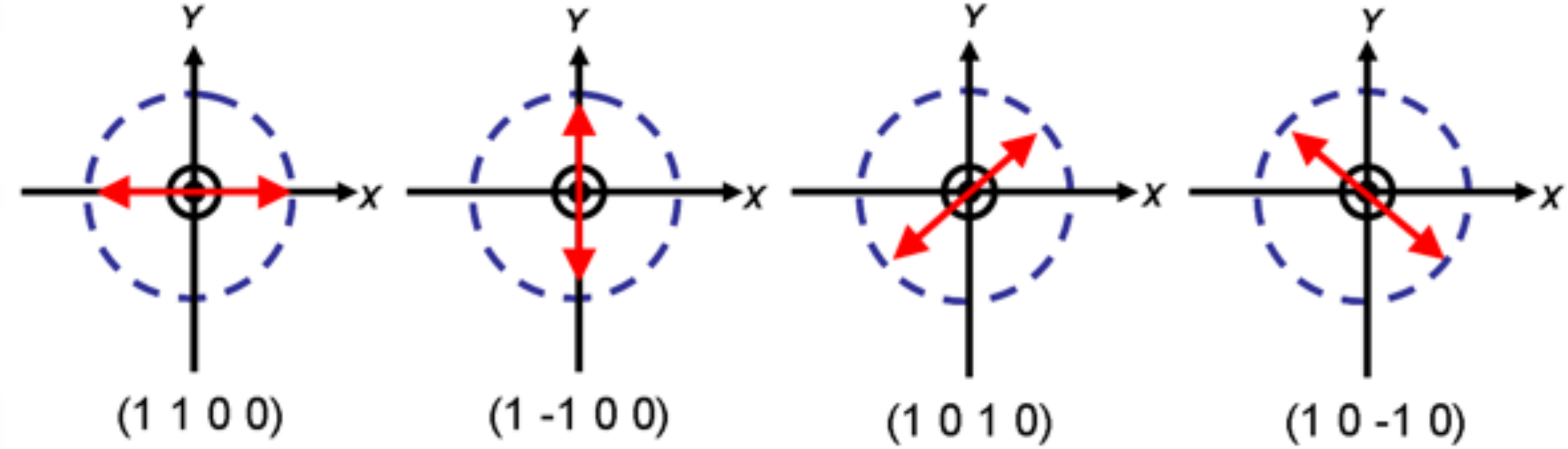


An isotropic, unpolarised beam is simply represented by S=(1 0 0 0)



Polarisation and Compton Backscattering

In the simulations polarisation is described using Stokes parameters $S=(I\ P_1\ P_2\ P_3)$:

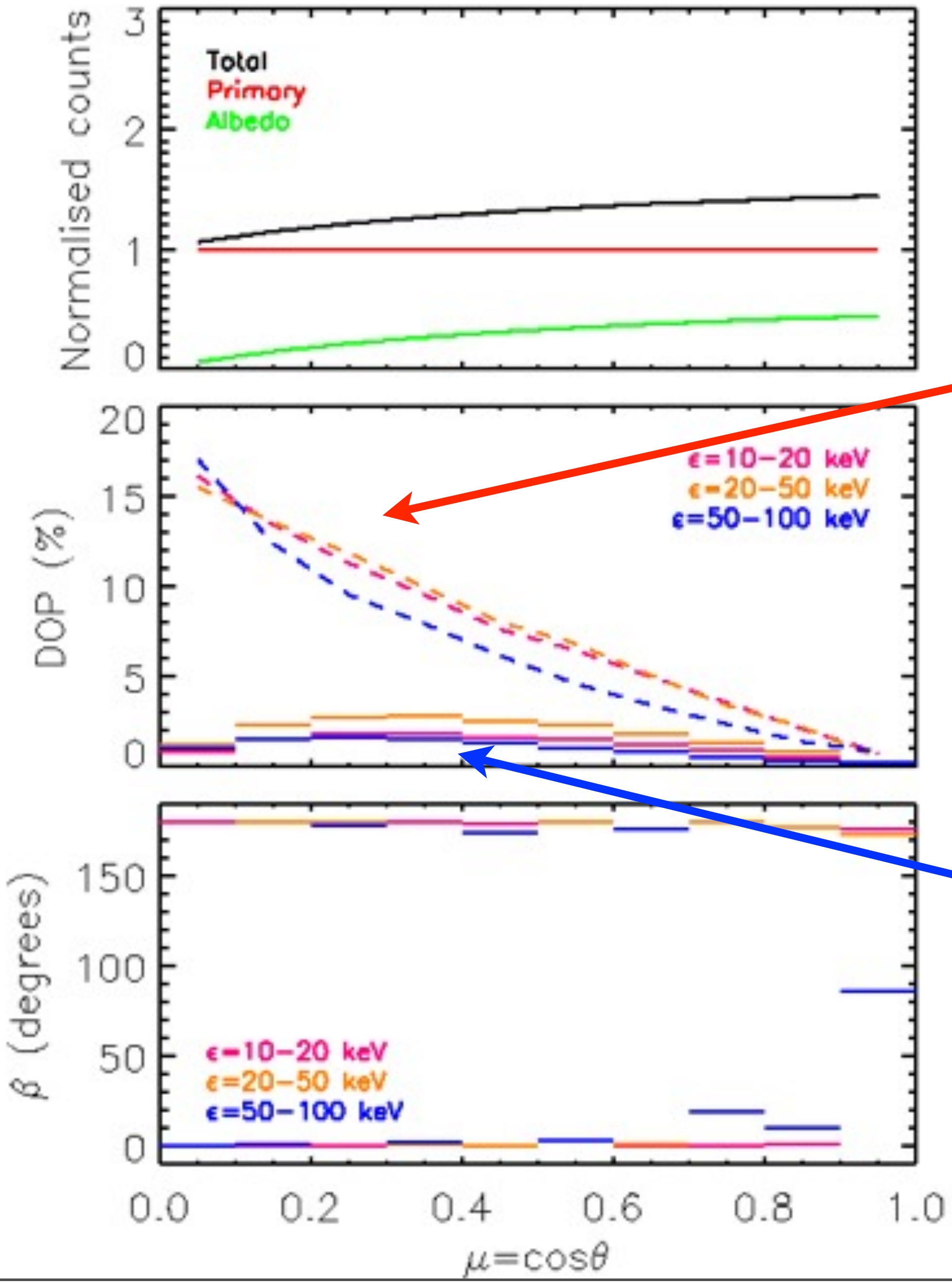


Two properties that describe the polarisation of the photon or the photon beam are the degree of polarisation (DOP) and the polarisation angle:

$$DOP = \frac{\sqrt{P_1^2 + P_2^2}}{I}$$

$$\beta = \frac{1}{2}\tan^{-1}(P_2/P_1)$$

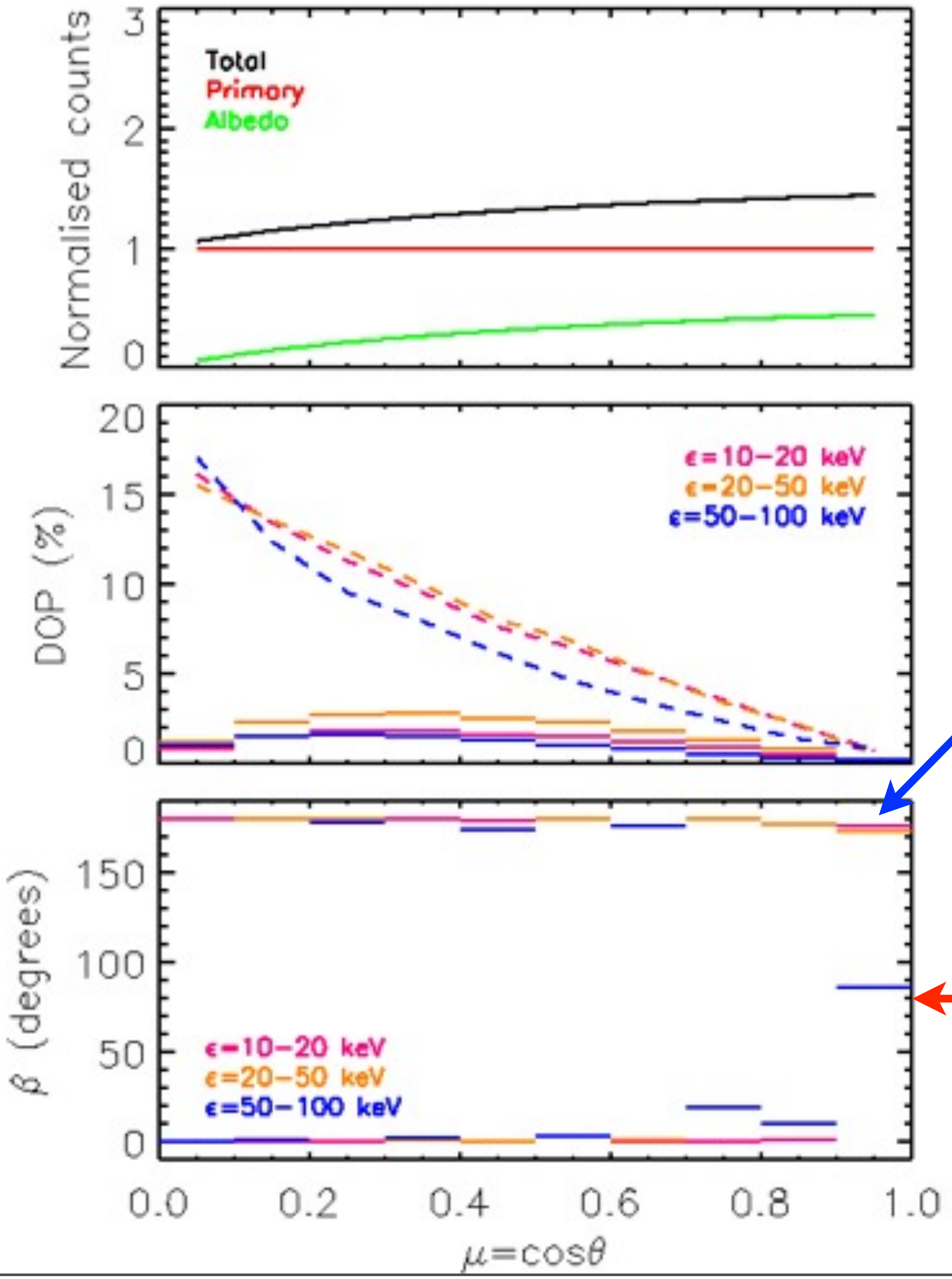
Source polarisation for various locations on the solar disk



The DOP of the albedo component (dashed) increases towards the limb

The DOP of the total source
peaks at around 3-4 % for an initial isotropic, unpolarised source.

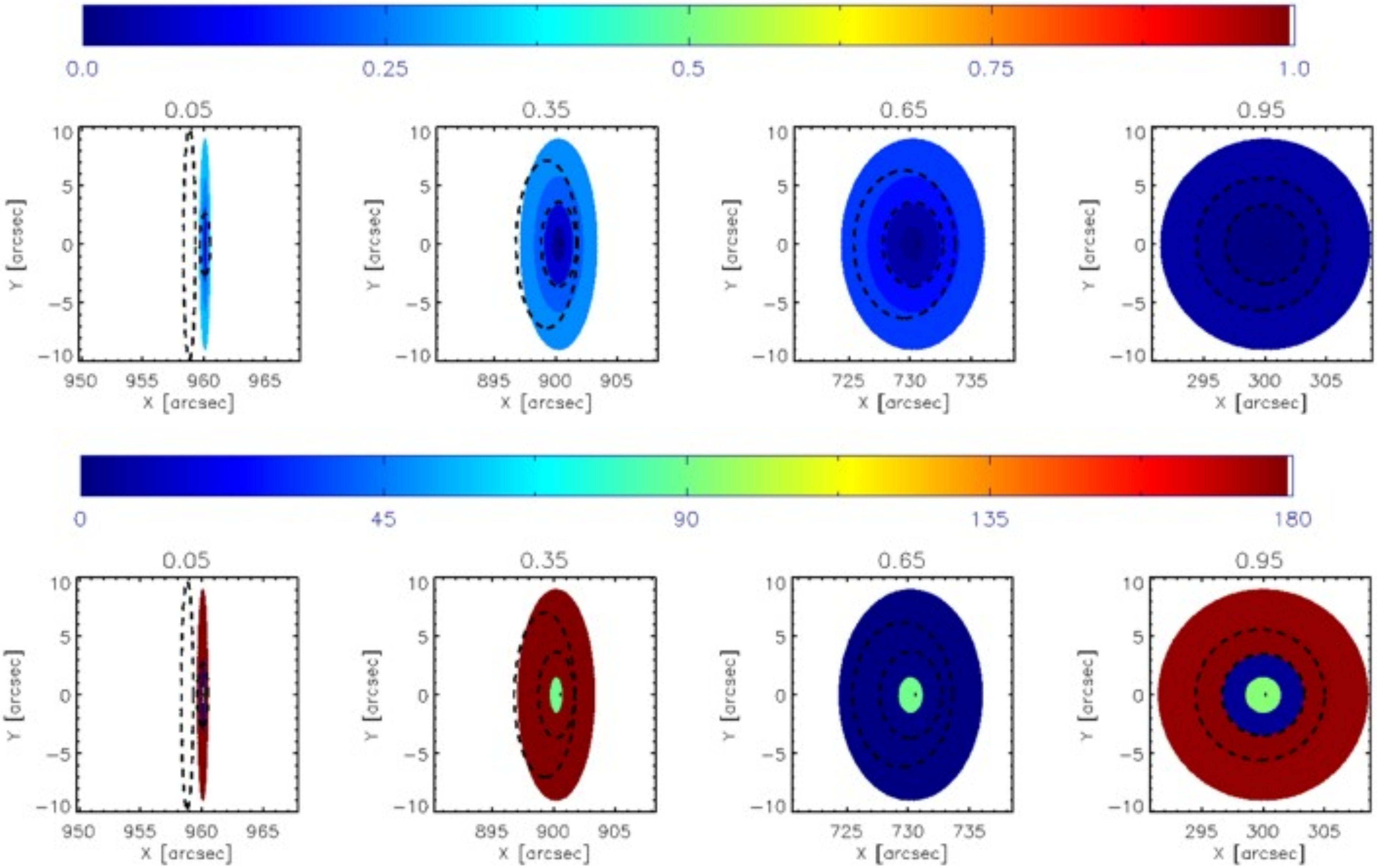
Source polarisation for various locations on the solar disk



The polarisation angle seems to stay at 0=180 degrees!?

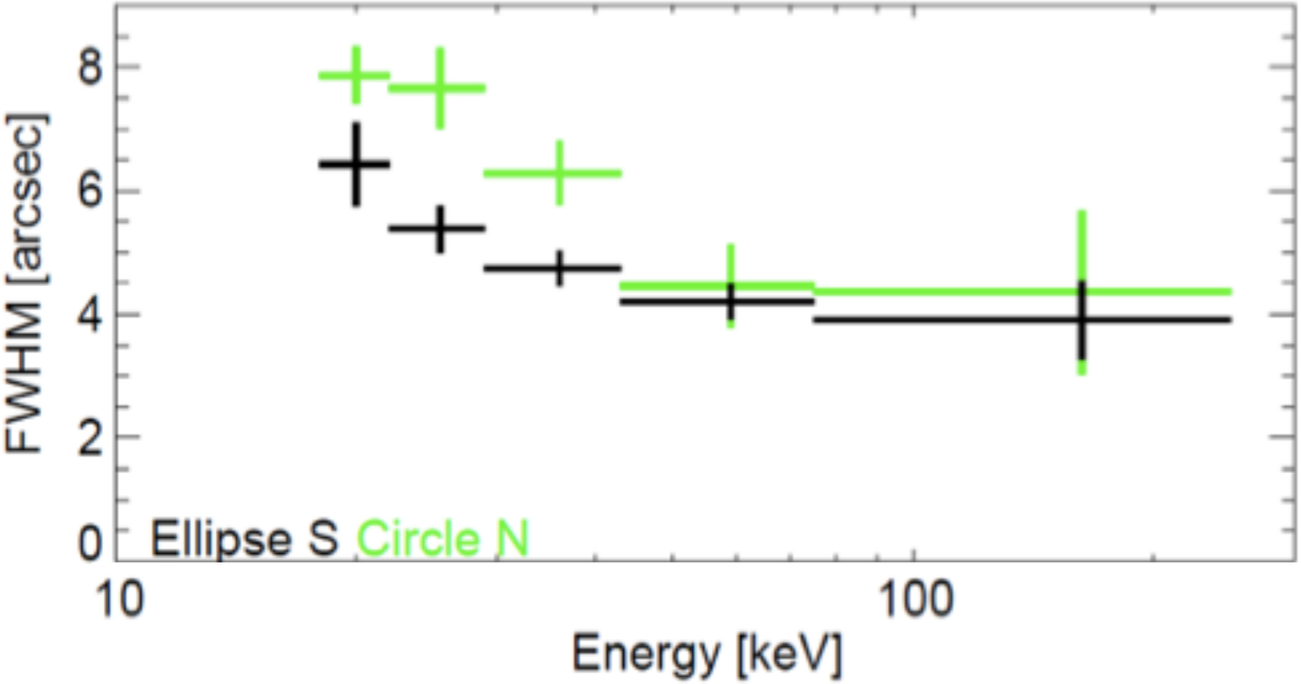
Total source

Polarisation changes across the source



Further work

Model the photons at varying heights in the photosphere – higher energy photons should emerge from lower heights.



Kontar, E., Hannah, I., Jeffrey, N., Battaglia, M. (2010)