RHESSI Observations of Photospheric Backscattering of Solar Flare X-rays

The diffuse solar X-ray albedo flux, formed from primary-source 10-100 keV X-rays that back-scatter from the solar photosphere, represents a significant component of the observed X-ray flare flux. As such it both distorts the spectral interpretation of X-ray emission and offers a potentially powerful diagnostic of electrons accelerated in solar flares. Our study uses the unique capabilities of the Ramaty High Energy Spectroscopic Imager (RHESSI) to isolate this albedo component, determine its properties such as size, shape and centroid location as a function of energy. We have focused on single-component flares in the 12-30 keV range that appear within 45 degrees of disk center. We have obtained the X-ray visibilities of a number of such flares and applied Forward-Fitting techniques to determine the parameters of the primary component (position, flux, and size) and the albedo-related parameters (primary source height and albedo flux). We will discuss the application of these results to other studies of flare spectra and 3-dimensional models, and their importance for understanding electron acceleration and transport processes.

1. Solar Hard X-ray Albedo from RHESSI Observations

In the early days of solar hard X-ray flare observations, F.F. Tomblin (1972, ApJ *171*, 377) published theoretical arguments that the hard X-ray spectrum of solar flares in the 5-40 keV range must have an albedo component due to Compton back-scattering in the photosphere of those primary bremsstrahlung photons that are emitted downward. In a more complete analysis, Taeil Bai & Reuven Ramaty (1978, ApJ *219*, 705) showed that this albedo component would be polarized and must depend significantly on the height of the primary source.

The "reflected" photons form what is called an albedo patch. For sufficiently high primary source altitudes, the albedo would be much larger in extent than the primary source, with a size scale that increases with source height. (See Fig. 1 below.) Furthermore, the albedo source would be displaced toward disk center by a distance h sin θ.

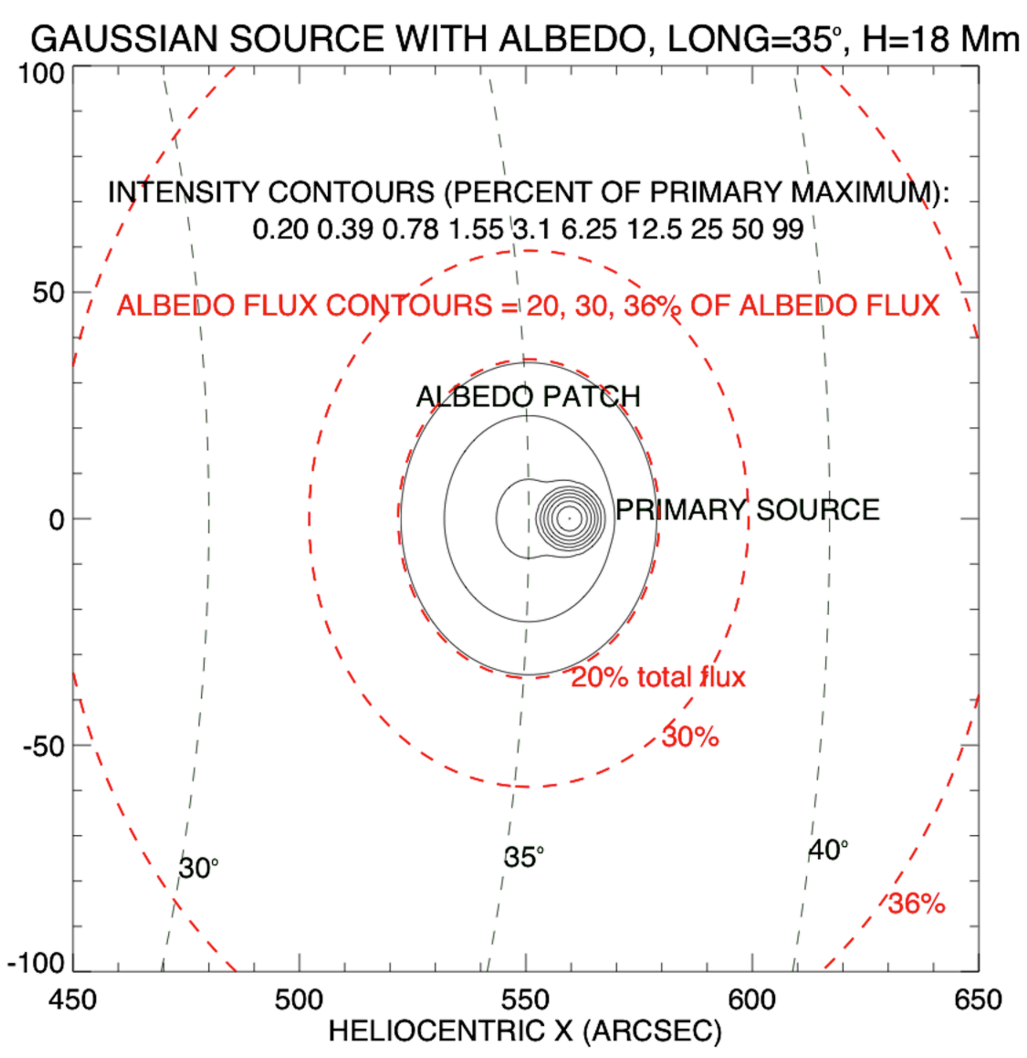

Figure 1.
Model of a circular primary source at 35° longitude and the resultant albedo patch. Solid contours (black) show the intensity of a primary source and its albedo where the albedo patch contains 40% of the total flux. The dashed contours (red) show the boundaries that contain 20, 30 and 36% of the total flux. The primary source is taken to be a 2-D Gaussian, FWHM=5 arcsec, at a height of 18 Mm. Note that the peak brightness of the albedo patch is less than 1% of the primary source, too faint for direct imaging methods, but nevertheless, most of the albedo flux would be modulated by RHESSI's coarsest grids.

2. Methods used for inferring albedo properties

Statistical center-to-limb variations
Kasparova, Kontar & Brown (2007, A&A *466*, 705-712) demonstrated a center-to-limb variation of photon spectral indices in the 15-20 keV energy range and a weaker dependency in the 20-50 keV range, which is consistent with photospheric albedo as the cause.

Spectroscopy of individual flares
Kontar and Brown (2006, ApJ *653*, L149) analyzed the 2002/08/20 and 2005/ 01/17 flares in terms of double-power-law fits. To fit the HXR spectrum with a low-energy cutoff E_c and ignoring albedo requires an unusually high value of $E_c < \sim 30 \pm 2$ keV. This produces a clear gap in the range E = 15 to 30 keV, which is likely to be unphysical and suggests that albedo is important.

Fourier methods
The above statistical and spectral methods give little information about the spatial characteristics of albedo patches. The only hope for getting such spatial information is by using the Fourier amplitudes and phases determined by RHESSI. Schmahl & Hurford (2002, SolPhys, *210*, 273) made a first step towards this by assuming circular symmetry. It is now possible to go beyond this, at least for some flares.

3. Exploitation of Fourier methods

We have found 9 flares with reliable enough amplitudes and phases to compare models of simple sources with albedo patches. The flares all lie within 45° of sun center, where albedo is expected to be strong. These flares form a small subset of RHESSI events for which MEM maps show only single, compact primary components in the range 12 to 30 keV.

3.1 Forward Fitting

Given the RHESSI amplitudes and phases for a flare, one may compare the observed values with those computed from a model. This process is called "Forward Fitting". At the present time, this method is reliable for computing albedo patch parameters only for single elliptical primary sources because the number of parameters (10 in this case) must be much smaller than the number of amplitudes. (For a discussion of Forward Fitting of amplitudes and phases., see RHESSI Nugget #35 (http://sprg.ssl.berkeley.edu/~tohban/nuggets/?page=article&article_id=35)

3.2 Amplitude model of a primary source both with and without albedo.

Modeling the albedo patch in addition to the primary source makes it possible to infer the height of the primary source, and the fraction of the total flux emitted by the reflected photons. Here we show an example of a flare where the primary source amplitudes (blue crosses) are fit by a 2-parameter model (primary height and albedo fraction) of a non-backscattered elliptical source (dashed red and a similar model including both the primary and its associated albedo patch.

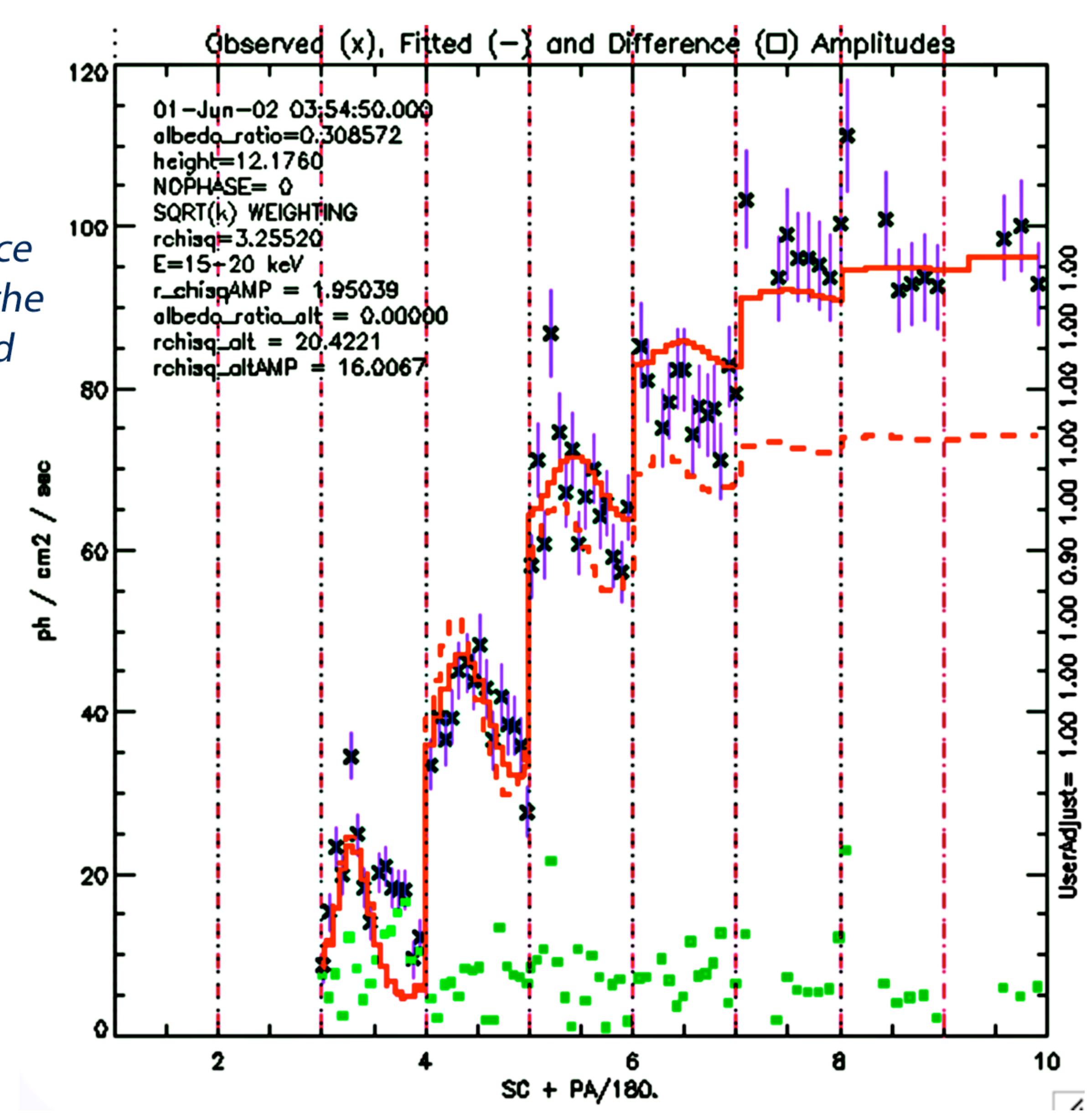

Figure 2.
Comparison of observed and model amplitudes. Primary source amplitudes (blue crosses) are fit by a model of a non-backscattered elliptical source (dashed red curve), and a model including both the primary and its associated albedo patch (solid red curve).
*The abscissa is a combination of subcollimator number (SC) and grid position angle (PA). The integer part of the x coordinate values is SC and the remainder is PA/180. (Thus if x is, say, 3.4, SC=3 and PA = 0.4*180 = 72°.) The coarser subcollimators are to the right (SC=6-9), and these measure the flux coming from larger spatial scales. The excess amplitudes of the solid red curve over the dashed red curve shown for subcollimators 6-9 represent the flux from the larger scales of the albedo patch.*

3.3 Model Albedo Visibility Back-Projection

In those cases where the primary source and albedo patch are both well represented by a model, it is possible to display both sources using back projection. We have done this for a number of flares, with one example "bpmap" here (for the flare and band of Fig. 2.)

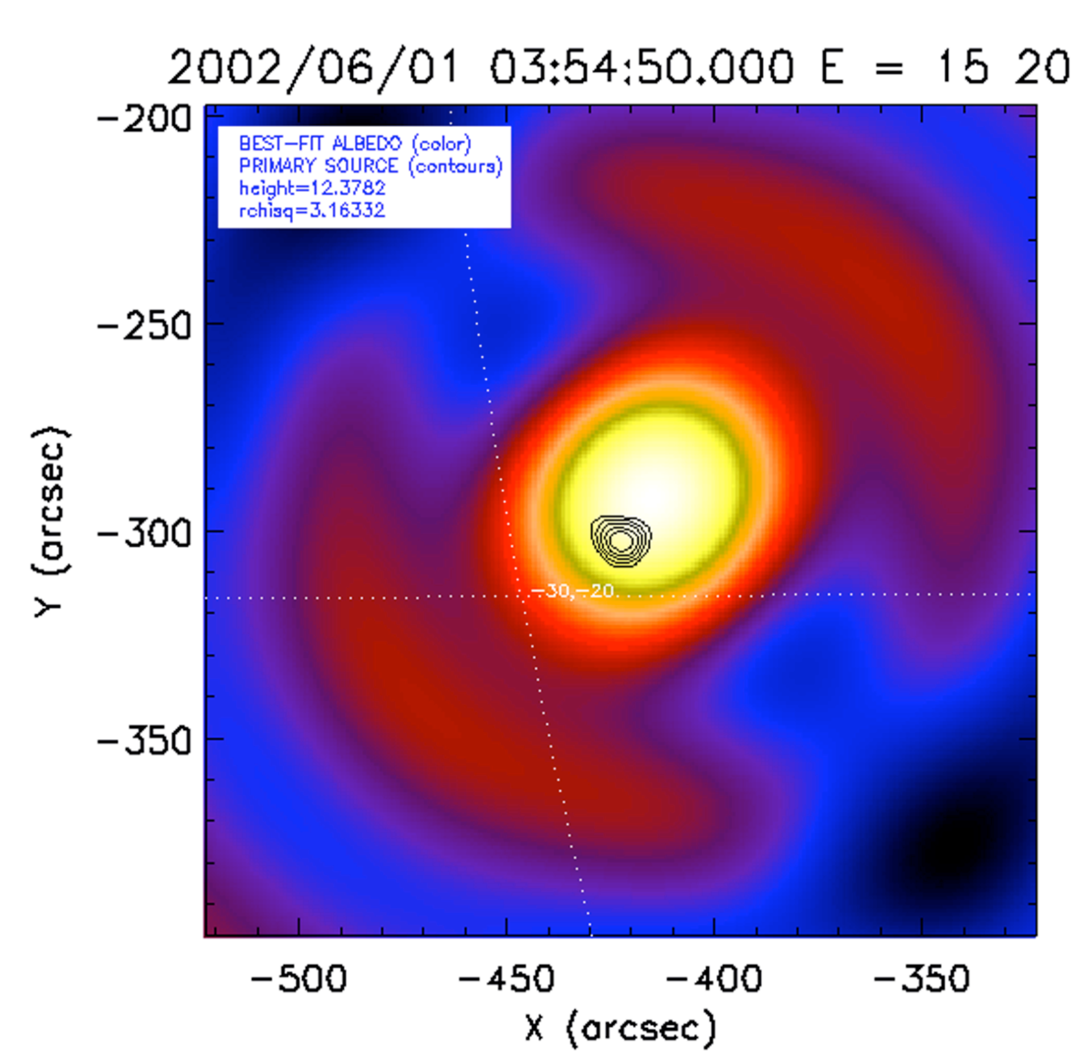

Figure 3.
The black contours show the primary source mapped from the model amplitudes and phases obtained by Forward Fitting, and the colors show a back-projection map made from the best-fit albedo model.

The reddish arcs in the upper right and the lower left are artifacts of the back-projection process, caused by incomplete sampling of spatial scales by RHESSI.