RHESSI Gamma-Ray Line Spectroscopy of the X-Class Flare of July 23, 2002

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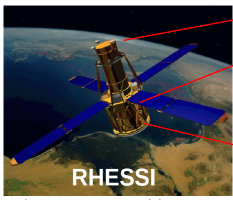
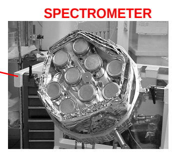
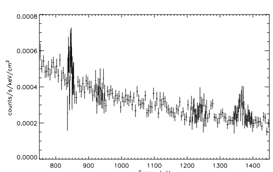




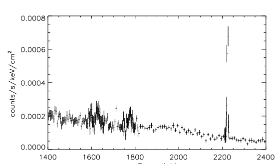
The Reuven Ramaty High-Energy Solar Spectroscopic Imager (RHESSI) is designed to make high-angular-resolution images and high-energy-resolution spectra of solar flares from 3 keV to 17 MeV. Imaging at resolutions of 2.3" to 3' is done by the Rotating Modulation Collimator (RMC) technique, using pairs of grids above each detector. The different grid spacings give different resolutions, therefore different Fourier components of the image. The detectors are cryogenically cooled Ge crystals with energy resolution of 1 keV FWHM below 200 keV and about 4 keV at 2 MeV. RHESSI is in a 600 km orbit and views the Sun about 50% of the time, factoring in eclipses and transits of the South Atlantic Anomaly, during which detectors are turned off. Every photon is recorded and telemetered to the ground station at Berkeley and other stations.

On July 23, 2002, at X4.8 flare, the largest since RHESSI's launch on February 5, was recorded from its initial rise through most of its decay. We report results from gamma-ray spectroscopy of this flare. Gamma-ray spectroscopy can reveal the spectrum, composition, and angular distribution of ions accelerated in a flare and the composition (location) of the medium where they interact. Dr. Ramaty was the foremost pioneer in this field of study and a leading member of the RHESSI team until his death in 2001.

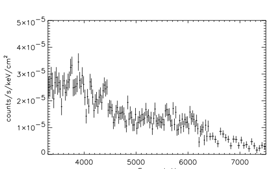


Closeups show the individual lines in the overall spectrum.

56Fe (847 keV) and 24Mg (1369 keV)

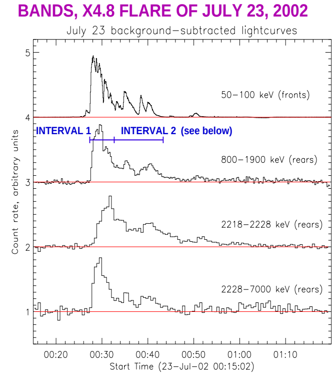


20Ne (1635 keV), 28Si (1779 keV), neutron capture (2223 keV) and the escape peak of the neutron capture line (single high point at 1712 keV).

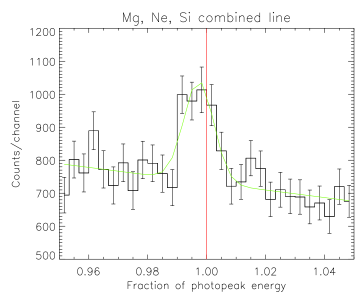


12C (4.4 MeV), its escape peak (3.9 MeV), with 16O (6.1 MeV) and its escape peaks barely visible.

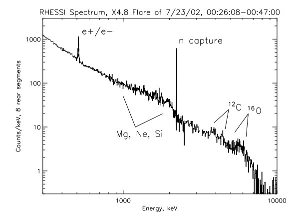
RHESSI RAW LIGHTCURVES IN DIFFERENT ENERGY BANDS, X4.8 FLARE OF JULY 23, 2002



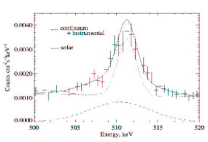
This has been the largest X-class flare so far observed by RHESSI, and the only one to have significant emission in gamma-ray lines from accelerated ions inducing excited states ambient nuclei. The top panel is the history of bremsstrahlung emission from energetic electrons accelerated in the flare. The second and fourth panels are energy ranges where > 50% of the emission is in the form of broad and narrow lines from excited nuclei (the rest is bremsstrahlung). The third panel is almost entirely emission in the narrow line from neutron capture on protons; the onset is delayed because the neutrons must thermalize before capture.



Although the individual gamma-ray lines shown above do not have a very high statistical significance, we can get a better idea for the redshifts and broadenings by scaling several lines to their photopeak energies and adding them. This is the result. We chose to add ^{24}Mg, ^{20}Ne, and ^{28}Si because they have comparable masses and a comparable amount of recoil when struck by an energetic proton; it is this recoil that determines both the redshift and broadening, since the excited nuclear state decays before the nucleus can re-thermalize. The combined line has a redshift of 0.27% +/- 0.08% and a FWHM of 1.2% +/- 0.2%. This flare was at a heliocentric angle of about 74°. Share et al. (ApJ 573:464, 2002) used an ensemble of flares observed by the Solar Maximum Mission Gamma-Ray Spectrometer to constrain the redshift and width of the average ^{20}Ne line vs. heliocentric angle. They found a width slightly more than twice this value and no detectable redshift, but in both cases the uncertainties were large enough to allow our values, which are better constrained due to RHESSI's far better energy resolution.

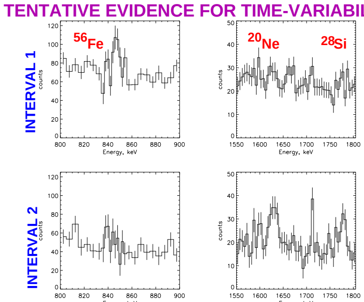


The overall spectrum in the gamma-ray range shows two very narrow, delayed lines: positron annihilation at 511 keV and the line from neutron capture on protons at 2.223 MeV. The lines from Mg, Ne, and Si are about 8-20 keV broad (completely resolved) and the lines of C and O are a factor of 2-3 broader. All are too weak to be seen clearly on this plot (see the next panel). The C and O lines are actually quite strong, but the detectors are very inefficient at stopping gamma-rays of those energies.



The positron annihilation line has a component from interaction of higher-energy photons in the instrument as well as the solar flux. When the instrumental component is removed, the solar line is shown to be broad (6-8 keV FWHM). A line of this width can imply either Doppler broadening from annihilation in a hot, fully ionized plasma or else annihilation in a cold, neutral medium where the Doppler broadening is caused by the electron's motion in its orbital.

TENTATIVE EVIDENCE FOR TIME-VARIABILITY:



These spectra are taken during the two intervals marked in the second panel of the lightcurve figure shown above. There appears to be a sharp drop in the flux of the 847 keV line of Fe while the Ne line increases and the Si line increases slightly (it is roughly constant in units of counts/second). If this effect survives further statistical tests, it is difficult to explain. Fe and Si both have a low first ionization potential and should change together if the change is due motion from a region with photospheric composition to one with coronal composition (Murphy et al. ApJ 490:833, 1997). Fe has a slightly higher excitation energy threshold (~4 MeV) than Ne and Si (~2.5 and 3 MeV) (Kozlovsky et al. ApJS 141:523, 2002) so variation in the proton spectrum might be partially responsible; however, there seems to be no major variation in the ratio of the 2.2 MeV line, which is caused by much higher-energy protons, to the other lines (see the lightcurve figure).

SUMMARY

- **This is the first fully-resolved spectrum of multiple solar-flare nuclear lines**
- **It is the best determination to date of lineshape and redshift in deexcitation lines, which will constrain the ion angular distribution**
- **There is preliminary evidence of variation in line ratios, implying changes in the accelerated ion spectrum or composition or in the ambient abundances.**