The High Energy Sun & NASA’s award winning Mission

WHITE LIGHT CORONAGRAPH
The Sun is NOT boring like this
Ramaty
High Energy Spectroscopic Solar Imager
Sunspots & Wilson Effect

Alexander Wilson
Glasgow Chair 1760
Flare – Magnetic Reconnection Theory
Sweet (Glasgow)-Parker (Chicago) 1957
Earth Impact of Flares & CMEs
High Energy Imaging Technology

SOFT X-RAYS (< ~ 10 keV)
FROM HOT (> 10 MK) PLASMA

HARD X-RAYS (~ 10 - 2000 keV)
FROM ACCELERATED ELECTRONS

GAMMA-RAYS (> ~ 0.5 MeV)
FROM ACCELERATED IONS (& POSITRONS)
PARABOLIC REFLECTION
SOFT X-RAY IMAGING … GRAZING INCIDENCE REFLECTION

Mirror elements are 0.8 m long and from 0.6 m to 1.2 m diameter

NuSTAR

Deployable Mast

Focal Plane/Detectors

Optics
RHESSI on shake table
HESSI vibration test ‘anomaly’
Crack in spectrometer mountings

Broken solar panels
Mating with Rocket
Following a delay of 17 months, the RHESSI launch on Feb 5 2002 was flawless.
Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) Launch Feb 5, 2002

Energy: 2-2000 keV

Resolns down to 1 keV & 2"

Launch Video

LV: Orbital Pegasus XL

Time: 0:20
A lot of happy RHESSI people!

Professor Bob Lin æRHESSI Principal Investigator
RHESSI WORKSHOPS
-Berkeley, Zuerich, Taos, Meudon, Sonoma, Locarno…

GLASGOW WorkShops
2003
2004
2005
2008
2011
SOME RHESSI DISCOVERIES
RHESSI
Non-flare
Hard XR
microevents

May be relevant
to the problem of
what heats the solar
corona to 2 MK
HXR bremsss versus gamma-ray line spatial structure

RHESSI HXR and 2.2 MeV Gamma-ray Images Hurford et al 2003 23/7/03

Stochastic Acceleration interpretation Emslie Miller and Brown 2003
‘Classic’ 2 footpoint HXR flare
RHESSI High Res Spectral Image
Foot-point structure and radiation

Brown Aschwanden et al, 2002

Higher energy sources appear lower in the chromosphere (consistent with simple collisional transport)
Veronig & Brown discovery of thick target coronal loop HXRs

Color Image: 6 - 12 keV
Contour lines: 25 - 50 keV
Integration time / image: 21 s
Time range: 00:01 - 00:16 UT
FoV: 64 x 64 arcsec
HIGH RESOLUTION
HXR Bremsstrahlung SPECTROMETRY
AND ELECTRON SPECTRUM RECONSTRUCTION
Early Low Resoln HXR Bremss. Spectrum
Ge Detector High Resoln HXR Spectrum

RHESSI 23/7/03
Deconvolved Bremsstrahlung Source
Electron Spectrum with ‘Dip’

Piana, Brown et al 2003

Electron Spectrum Reconstruction

x100

$\log_{10} \bar{n} \bar{F} \text{ (electrons cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1})$

$E$ (keV)
Effect of Albedo on Gap

![Graph showing the effect of albedo on gap with three different lines representing original, corrected for $\gamma=2$, and corrected for $\gamma=3$. The x-axis represents energy in keV, and the y-axis represents $F_{bar}(E)$ on a logarithmic scale.](image)
Are energetic particles in flares central to magnetic reconnection and energy transport?

- Dubov ~ 1950
- Giovanelli ~ 1950
- Hoyle and Ellison ~ 1950
- Elliot “Proton Store” ~ 1968
- Brown, Hudson and others 1970-76
  “Thick Target Model”
Extensively used since then to model flare data
Blind Inversion Photon Spectrum

Tiny deviation from power-law
Recovered source e-spectrum

CASE NUMBER 2

Massone x 10
Kontar
Johns-Krull x0.1

x 3 Dip in electron spectrum
Problems with Thick Target

- Assumes no HXR Radn from acceleratn regions, all from collisional ‘target’ =>
- High beam density
- Ne >> radio and IP values
- Lack of Halpha polarisation
- HXR versus IP spectral index
- HXR spectrum from beamed electrons + albedo
Does Albedo kill the Thick Target Model?

TOTAL OBSERVED SPECTRA

Primary Spectrum

Isotropic Source

Albedo Spectrum

Beamed Source
Compton scattering in pictures

Primary

Reflected flux

Direct

Scattered

Observed flux

Reflected flux

Direct flux

Observed
X-ray spectrum from typical flares

Soft X-ray coronal source
HXR chromospheric footpoints

Coronal Source
Footpoints
The Future?
European Space Agency
SOLAR ORBITER AT 0.2 AU
Conclusions

Remote observations in combination with in-situ will be a powerful tool to diagnose solar flares.

Spatially resolved electron spectra help to understand the physics of electron transport/acceleration.

Combination of various instruments greatly improves our understanding of solar flare physics.

Sunspots sketched by Richard Carrington on Sept. 1, 1859.