Solar Flare Variations

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NSF
Outline

- Overview of solar activity
- Relevance
- Proxies
- Halloween flares
- Procedures
- Analysis
- Conclusion
Goals

- Find the total energy released in a solar flare
- Energy composition associated in the impulsive and gradual phases
- Find the contribution of the VUV to the total solar flare energy output in the TSI
- Using wavelengths outside of the VUV to find its contributions to the TSI
Solar Cycle

- 22 year magnetic cycle
- 11 min/max sun spot cycle
Daily variations

- Center-limb variations
- Brighter for coronal emissions (36.5 nm)
- Dimmer for Chromosphere (30.5 nm) and Photosphere (visible) emissions
Dynamics of Solar Flares

- A magnetic flux tube emerges above the solar surface in active regions.
- Magnetic flux tube is more buoyant than the surrounding plasma.
- Eventually a filament of plasma is released after the stretching of the magnetic field lines reached their eruptive limit.
- This gives rise to the two phases of the solar flare.
Energy is forced back into the atmosphere by magnetic reconnection, this is the energy input (Impulsive phase).

It is not visible until the Transition region, the corona is not dense enough.

This influx of energy creates thermal heating in the atmosphere, seen in all regions.

This is the slow phase (Gradual phase) of the solar flare.

- Impulsive phase lasts around 5-10 minutes.
- Gradual phase lasts for several hours.
Impulsive and Gradual phases
Neupert effect (1968)
Why are Solar Flares important to the Earth

- Release energy up to 40 billion Hiroshima sized atomic bombs
- Proton events
  - Auroras

- CMEs

- Geomagnetic storms
  - Airlines (rerouting)
  - Disrupts: GPS, Satellites and communications (radio blackouts)
  - Power grids

- NOAA SEC
How to study the Solar Atmosphere

- F10.7 cm
  - Used since 1947
  - Coronal continuum (Bremsstrahlung emissions) and rest of Atmosphere
  - Free-Free emission
- X-ray and ultraviolet emissions display flare irradiance
- VUV (0.1-200 nm)
  - Is ideal for analyzing the solar atmosphere
Proxies used

- Coronal emission (36.5 nm) EUV
- Coronal Continuum (0-7 nm) XUV
- Transition Region (121.5 nm) FUV
- Chromosphere emission (30.5 nm) EUV
- Blackbody Continuum (175.5 nm) FUV

Credit: TRACE web-site
Instruments used for these proxies

- On board the SORCE satellite
  - Solstice II
    - EUV and FUV (115-180 nm)
  - X-Ray Photometer System (XPS)
    - Wavelength varies by filter photodiode

- On TIMED SEE
  - EUV Grating Spectrograph (EGS)
    - (27-195 nm)
  - XPS
**FISM** (Chamberlin P.C. 2005)

- Model that estimates the solar irradiance in the VUV (0.1-190 nm)
- 1 nm resolution and a time cadence of 60 seconds - allows for modeling of solar flares
- Includes solar cycle and rotation variations

- Phil’s dissertation so he could get out of grad school
Solar Cycle and Rotation

- When modeling the 11 year solar cycle, it was helpful to remove the variations due to the solar rotation
- Subtract the smoothed solar cycle data from the unsmoothed data to get the solar rotation variations
- Makes plot easier to interpret and cleaner
Solar variations

- **Solar cycle**
  - Transition region
    - Max/Min ratio
      - 2.04
  - Chromosphere
    - Max/Min ratio
      - 2.63
  - Blackbody continuum
    - Max/Min ratio
      - 1.15

- **Solar rotations**
  - Transition region
    - Max/Min ratio
      - 1.08
  - Chromosphere
    - Max/Min ratio
      - 1.11
  - Blackbody Continuum
    - Max/Min ratio
      - 1.03
Halloween Flares

- Largest flares recorded in recent history
- On October 28, 2003 X17 flare
- Caused radio blackouts
- GPS disturbances
- November 4, 2003 X28 flare
<table>
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<tr>
<th>Phase</th>
<th>Transition region</th>
<th>Max/min ratio</th>
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<tbody>
<tr>
<td>Impulsive phase</td>
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<tr>
<td>Gradual Phase</td>
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<td>14%</td>
</tr>
<tr>
<td></td>
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<td>50%</td>
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Scaling

• For Transition region (121.5 nm)
  – Impulsive phase scaling factor
    • 123
  – Gradual phase scaling factor
    • 156
Energy associated with flare

- Impulsive phase (0-190 nm) VUV
  - $8.9 \times 10^{30}$ (ergs)
- Gradual phase (0-190 nm) VUV
  - $1.2 \times 10^{32}$ (ergs)
- Total (Impulsive + Gradual)
  - $1.29 \times 10^{32}$ (ergs)

- % of total energy from flare contributed to the TSI from the VUV (0-190 nm)
  - 9.33%
Analysis of one proxy during, solar cycle, rotation and flare

- Coronal Continuum
  - One of the highest magnitudes of increase
  - Transparent
  - Temperature
  - Bremsstrahlung continuum
  - Free-Free emissions
Future plans

- Search for additional spectral contributions to the impulsive and gradual phase to the TSI
  - Ex. Hard x-rays (<0.1 nm) from RHESSI
  - Microwaves
References

- Hudson, 1972
- NOAA
- (GPS) Lean, 1997