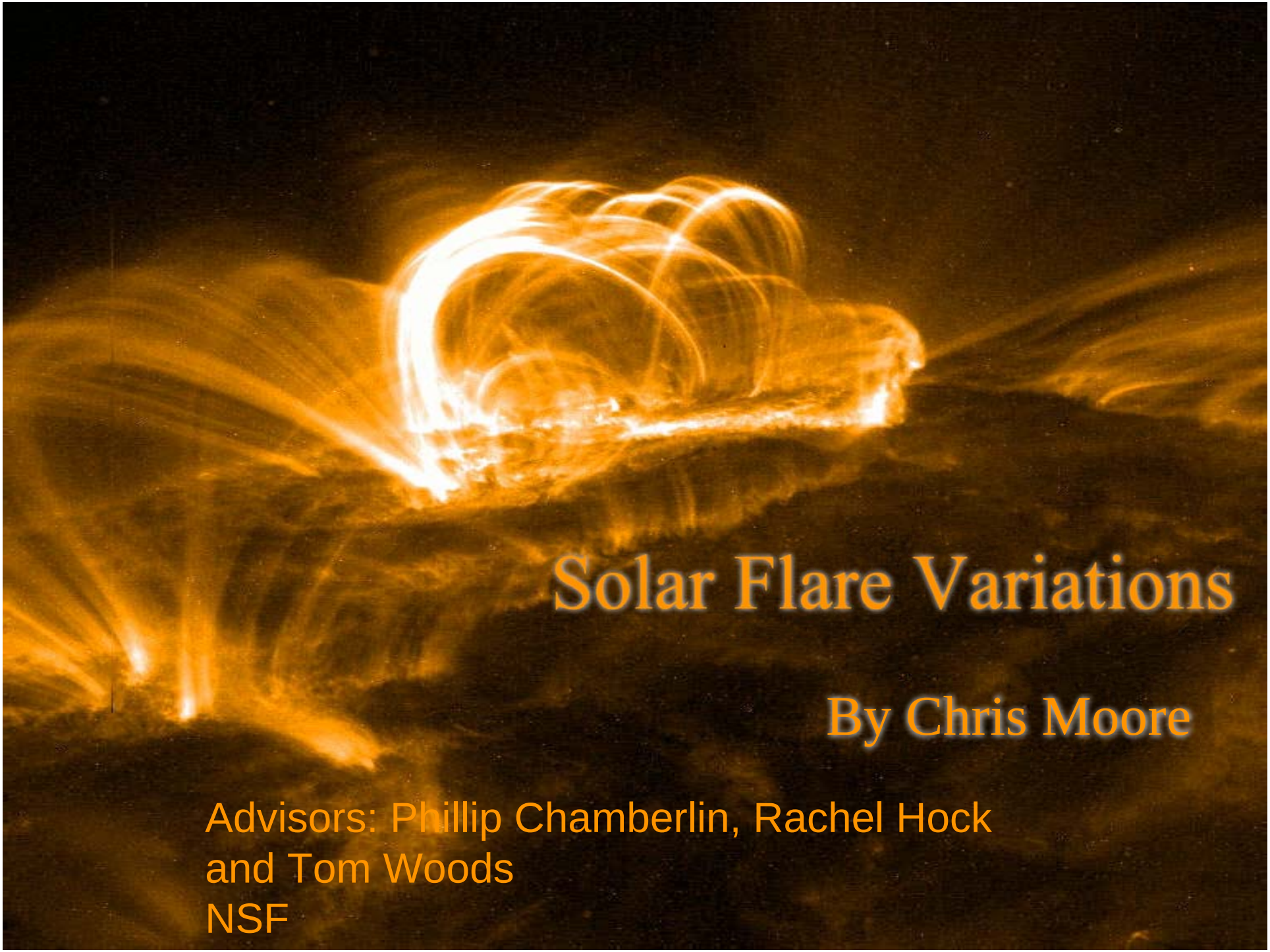


Solar Flare Variations

By Chris Moore

Advisors: Phillip Chamberlin, Rachel Hock and Tom Woods
NSF

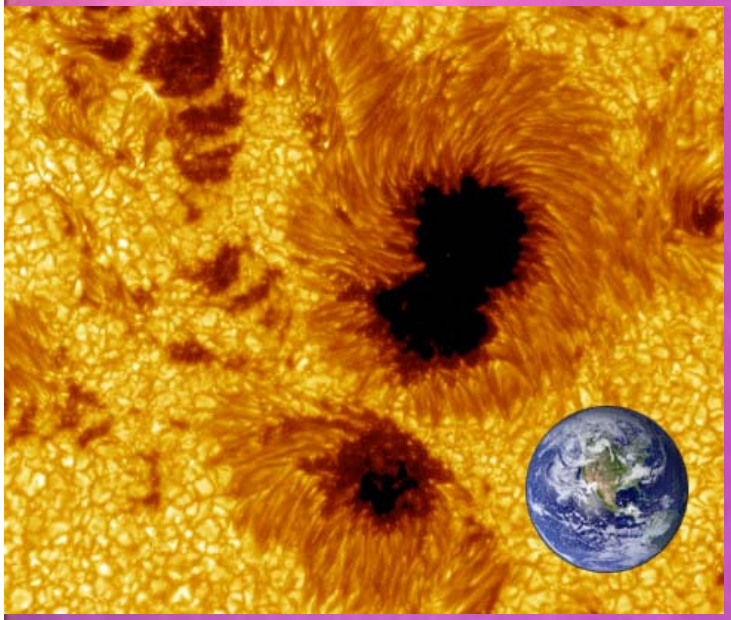

Outline
Overview of solar activity
Relevance
Proxies
Halloween flares
Procedures
Analysis
Conclusion

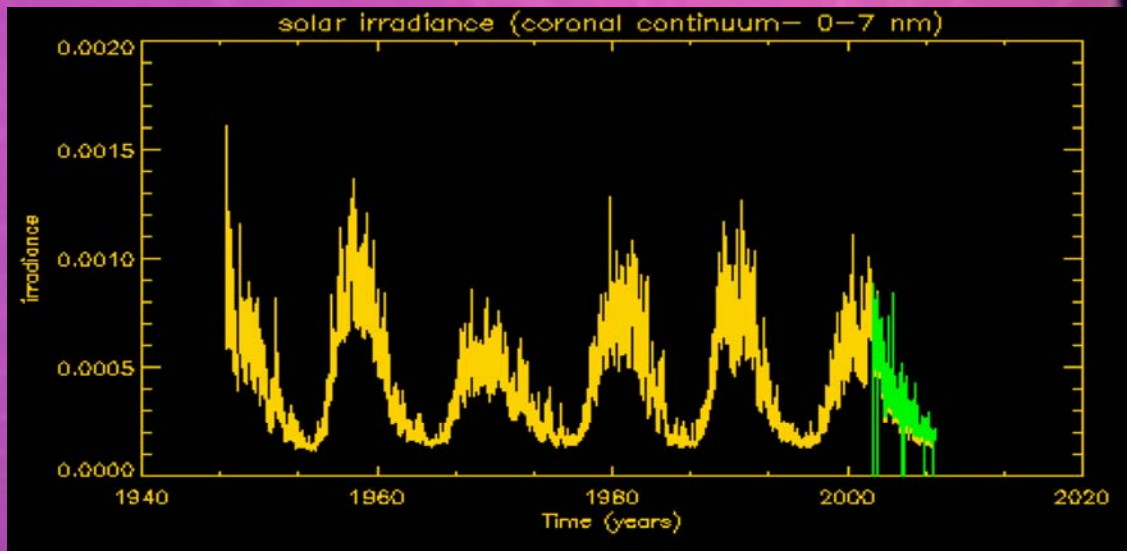
Goals

- 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

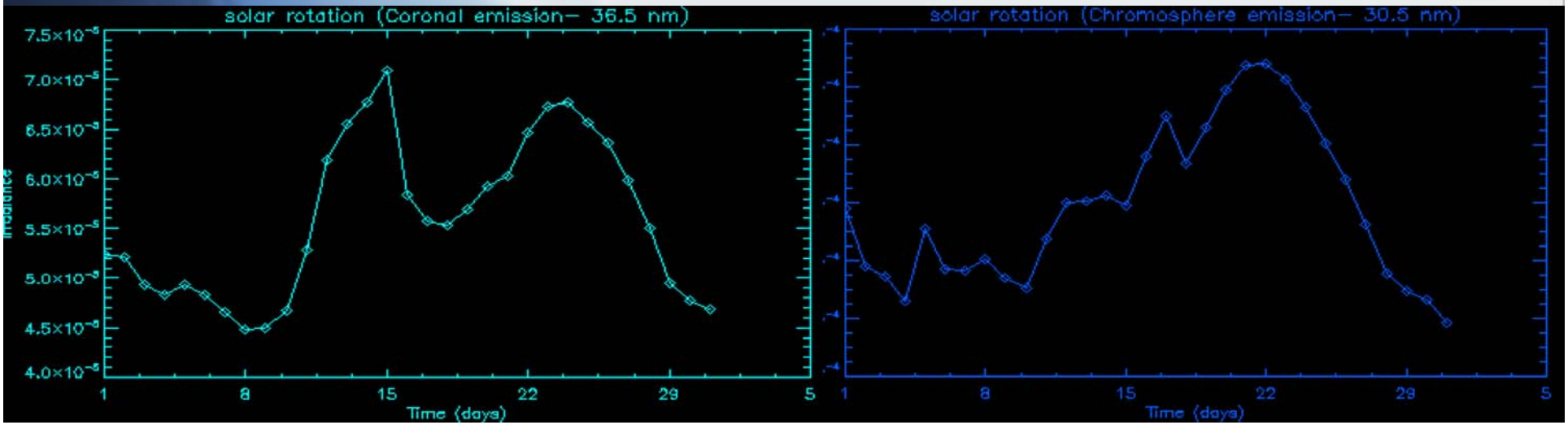
- 22 year magnetic cycle
- 11 min/max sun spot cycle





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

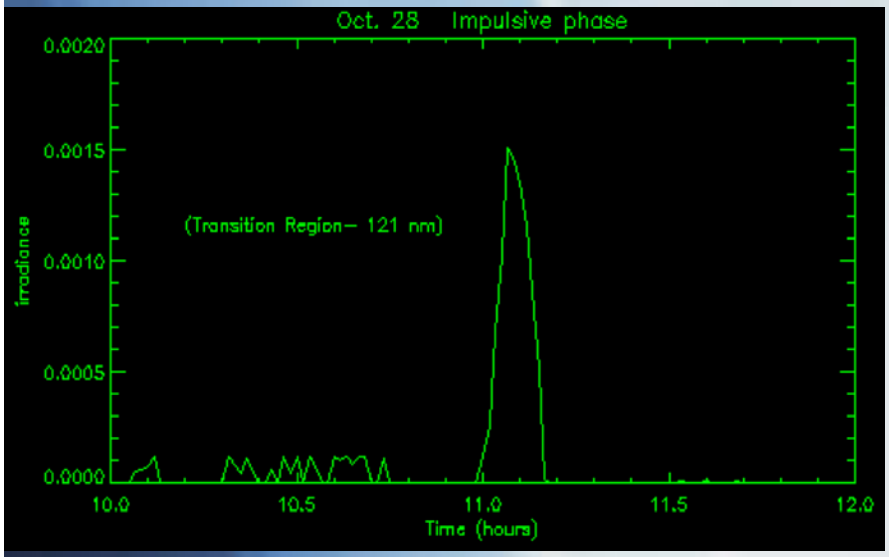
Dynamics of Solar Flares 2

- 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)



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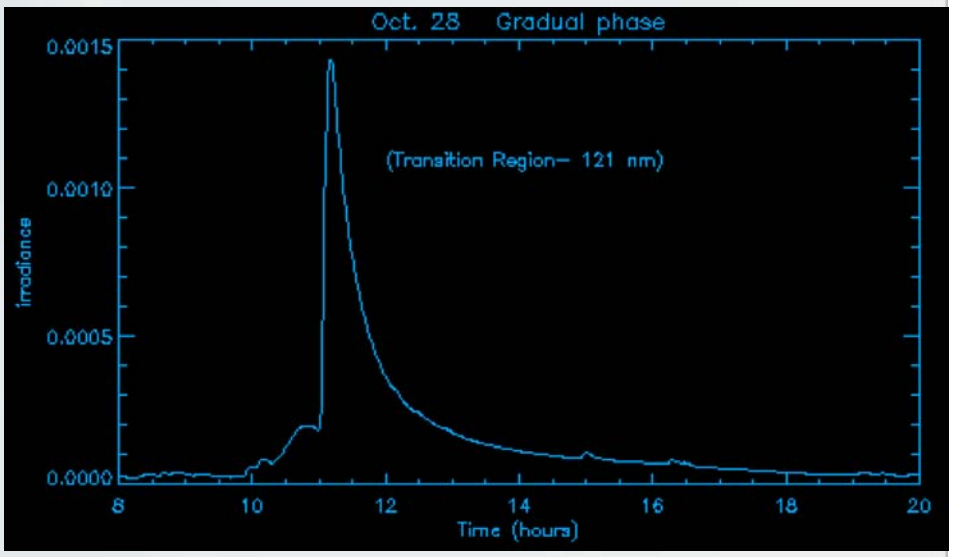

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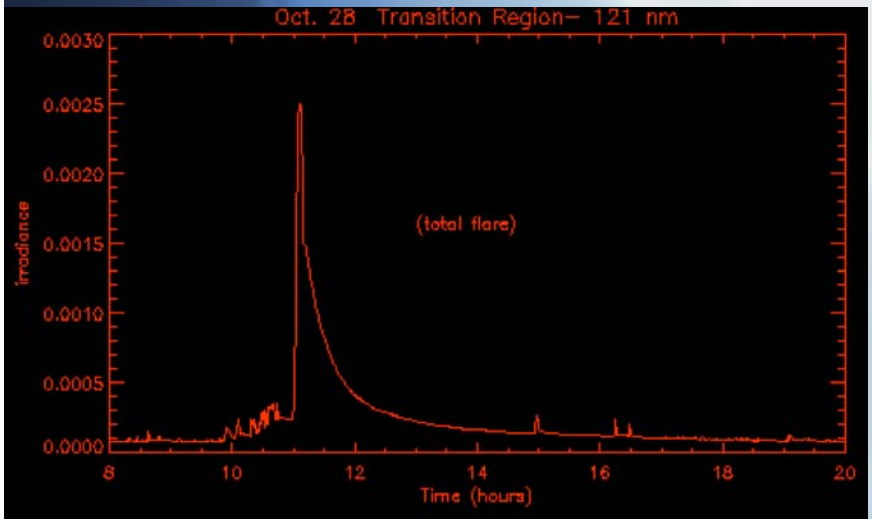

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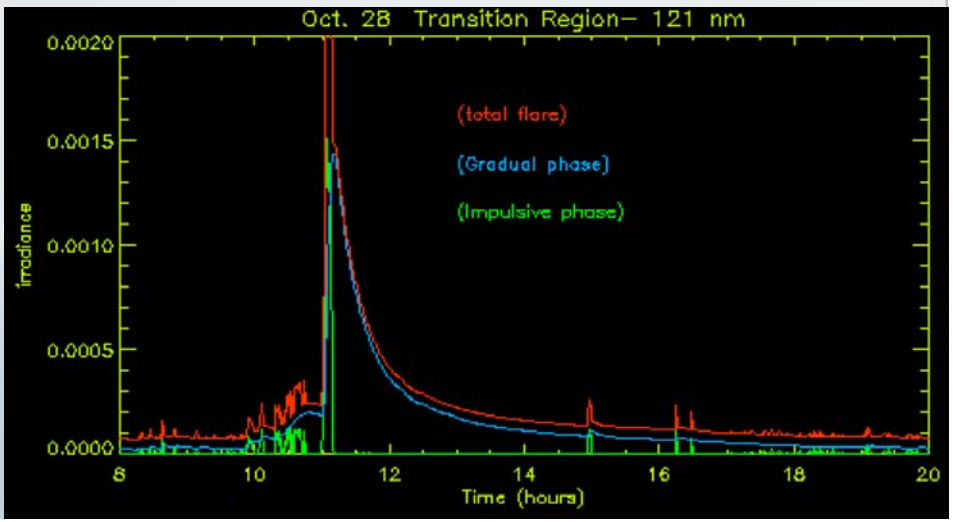
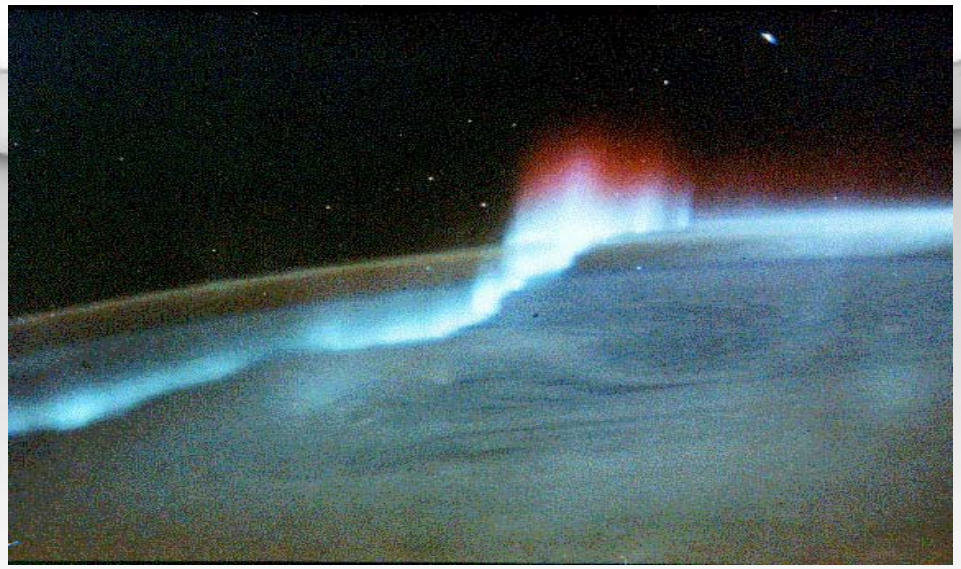


Why are Solar Flares important to the Earth



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

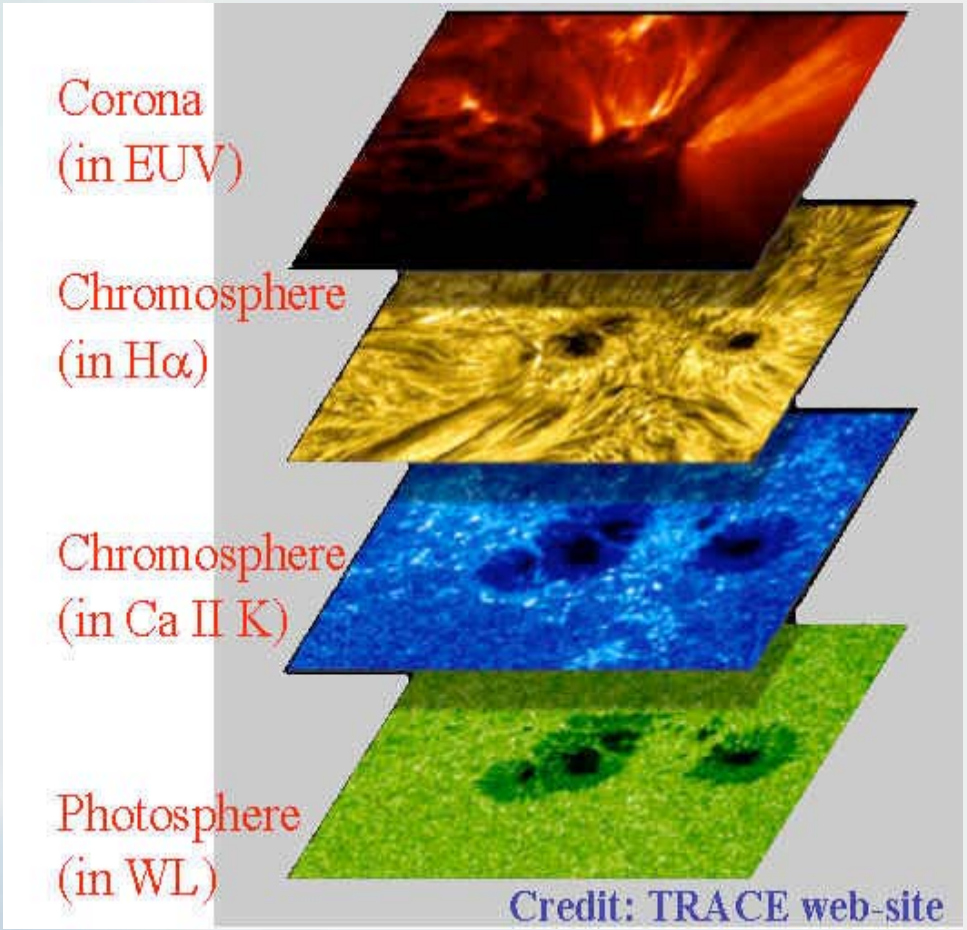
- CMEs
- Geomagnetic storms
  - Airlines (rerouting)
  - Disrupts: GPS, Satellites and communications (radio blackouts)
  - Power grids
- NOAA SEC

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

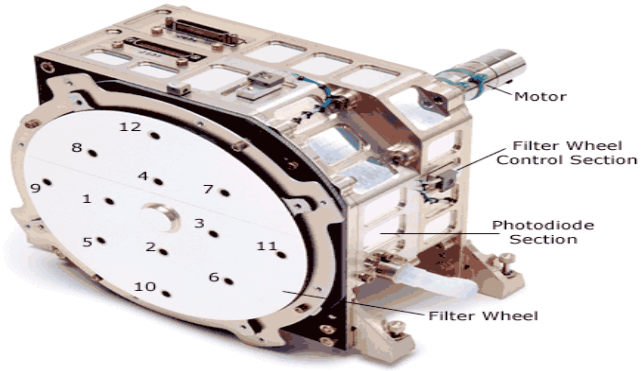
- Coronal emission (36.5 nm) EUV
- Coronal Continuum (0-7 nm) XUV
- Transition Region (121.5 nm) FUV
- Chromosphere emission (30.5 nm) EUV
- Blackbody Continuum (175.5 nm) FUV

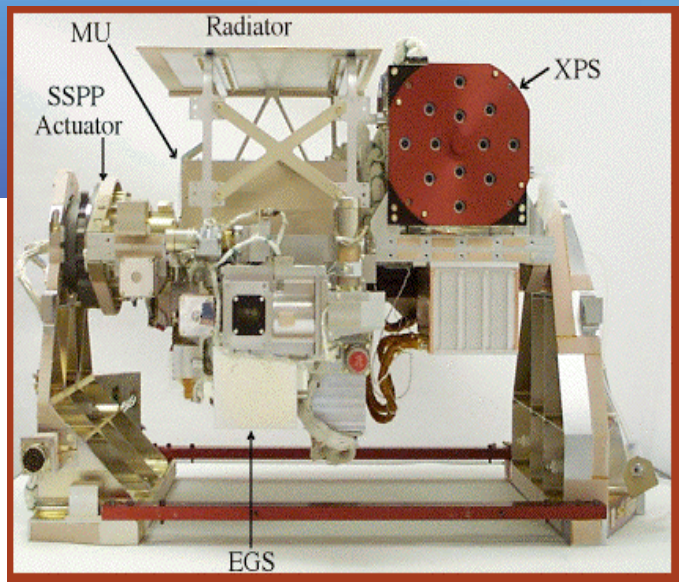


Instruments used for these proxies

- 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



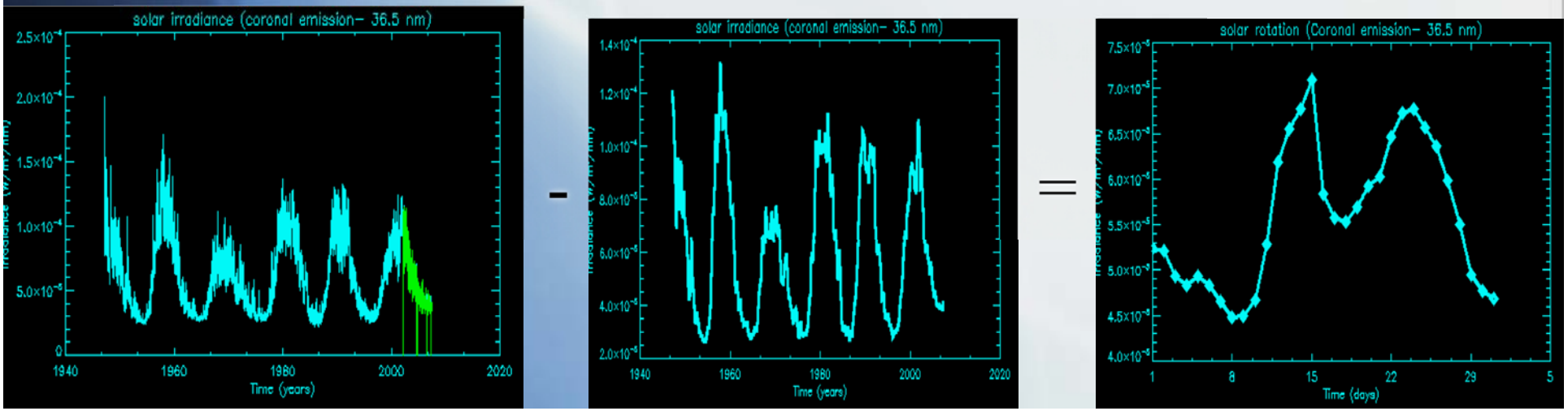


FISM (Chamberlin P.C. 2005)

- 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

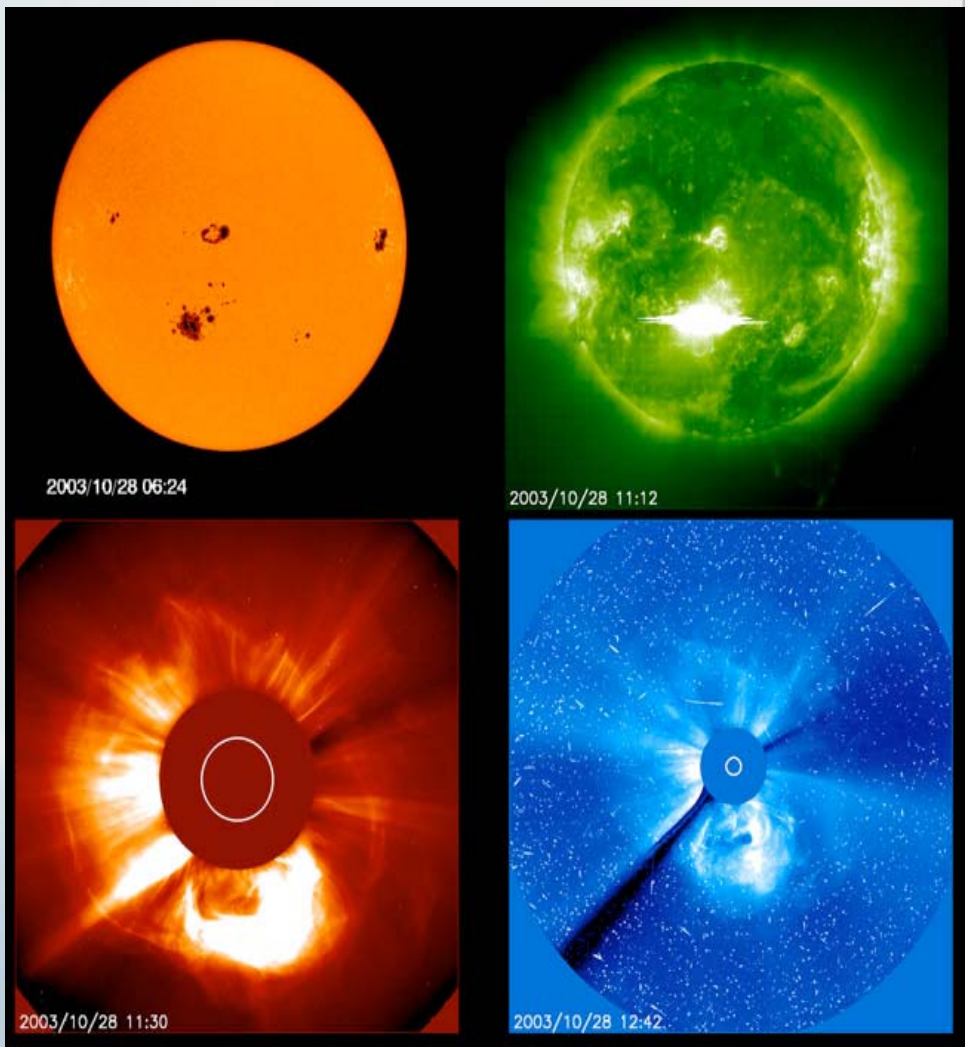


Solar variations

- 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

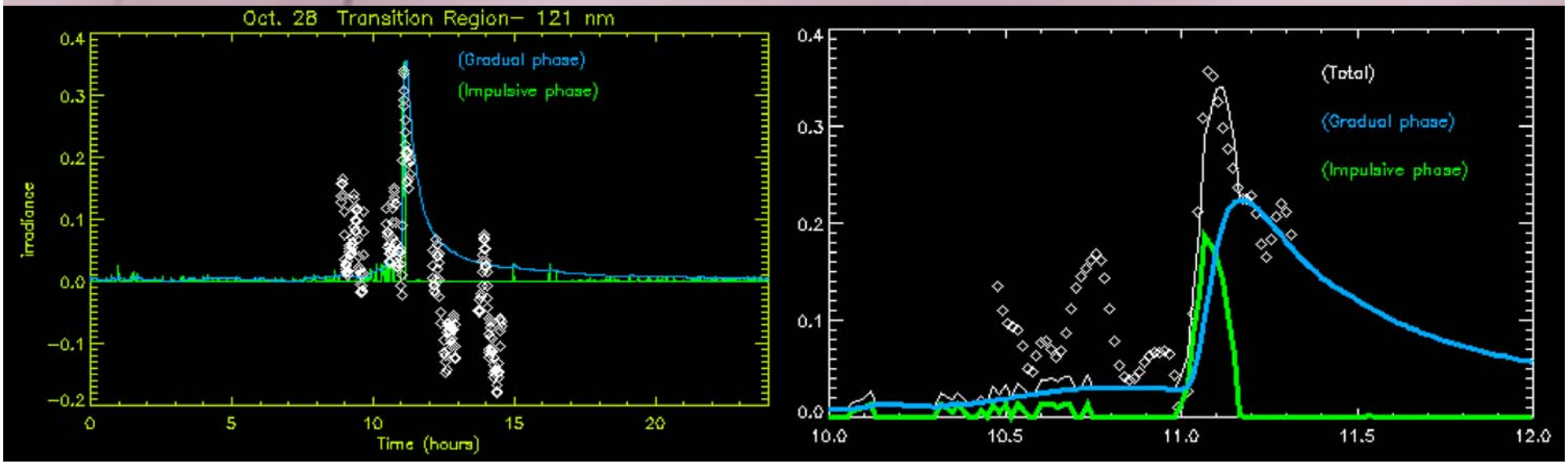


Halloween Imp and Grad phases

- Impulsive phase
  - Transition region
    - Max/min ratio 15%
  - Chromosphere emission
    - Max/min ratio 45%
- Gradual Phase
  - Transition region
    - Max/min ratio 14%
  - Chromosphere emission
    - Max/min ratio 50%
  - Coronal continuum
    - Max/Min ratio 161x

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 x 10^30 (ergs)
- Gradual phase (0-190 nm) VUV
  - 1.2 x 10^32 (ergs)
- Total (Impulsive + Gradual)
  - 1.29 x 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

- FISM, Chamberlin P.C. (2003)
- CSUI, Woods T.N., Kopp G., Chamberlin P.C., Journal of Geophysical Research, Volume 111, Issue A10, CiteID A10S14 (2006)
- FISM, Chamberlin P.C. Woods T.N., Epravier F.G. (2006)
- SORCE, G.J. Rottman, T.N. Woods, V.L. George (2005)
- Neupert W.M., Astrophysical Journal, vol. 153, p.L59 (1968)
- Hudson, 1972
- NOAA
- (GPS) Lean, 1997
- Modern Physics (second Edition) kenneth Krane, 1996