The IR/WL/UV/VUV/EUV energy distribution

Hugh Hudson

Relevant Quotations

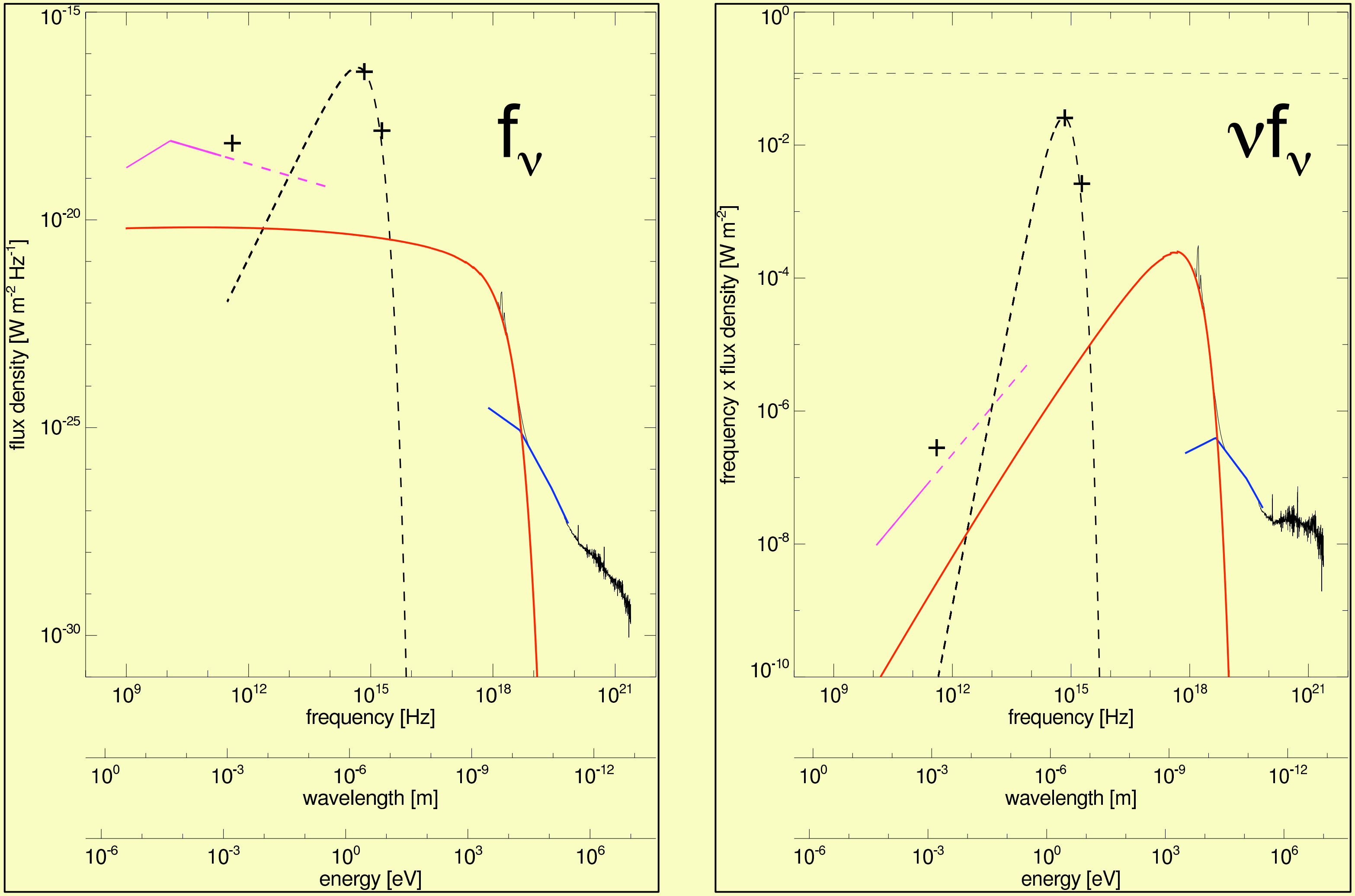
"Follow the **money**" (= "Follow the energy"?)

Deep Throat, 1976

"I would like to emphasize that the 'old fashioned' Hα observations of flares **should** not be underestimated by space scientists, as is often the case."

Z. Svestka, 1976

Flare Spectral Energy Distribution



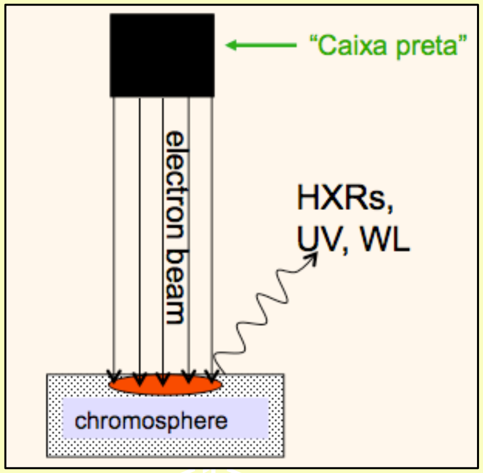
S. Krucker

What is the IR/V/UV/VUV/ EUV spectrum like?

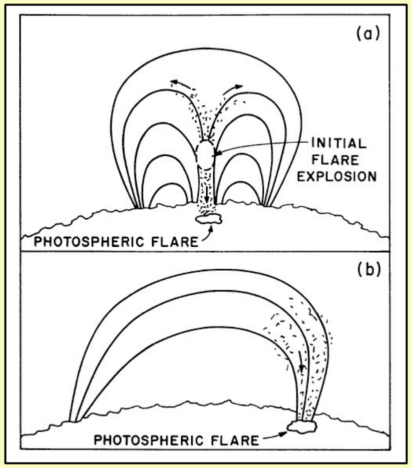
- Fraunhofer lines going into emission
- New lines
- A broad continuum
  - optically thick, ie the photosphere?
  - optically thin, ie new opacity at higher altitudes and higher temperatures

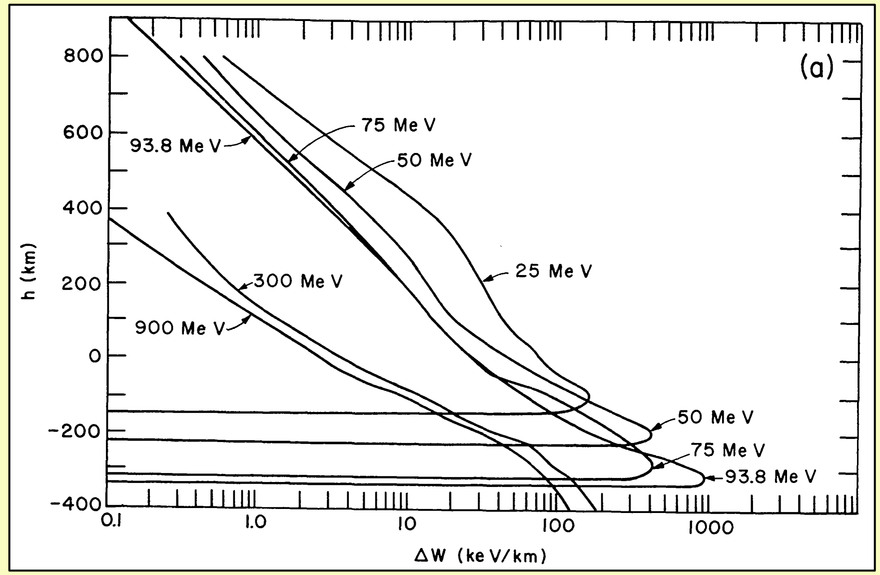
How do we get so much energy into the lower atmosphere?

- Start it there (Ambartsumian idea of eruption from the solar interior)
- Bring it from the corona
    - Najita & Orrall (1970) relativistic particles
    - Svestka (1970), particles, probably protons
    - Hudson (1972), deka-keV electrons + ionization
    - Emslie-Sturrock (1982) waves
    - Fletcher-Hudson (2008) waves

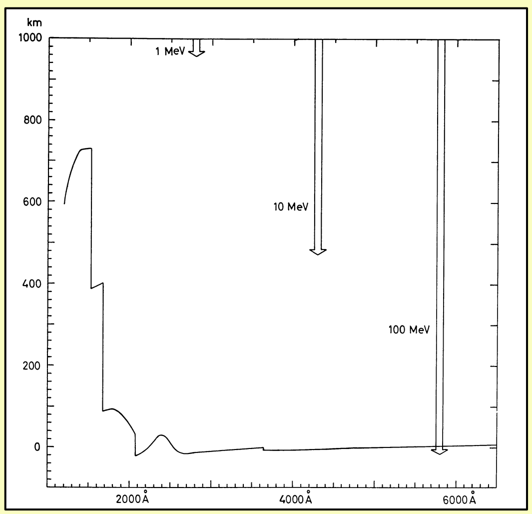


Najita & Orrall

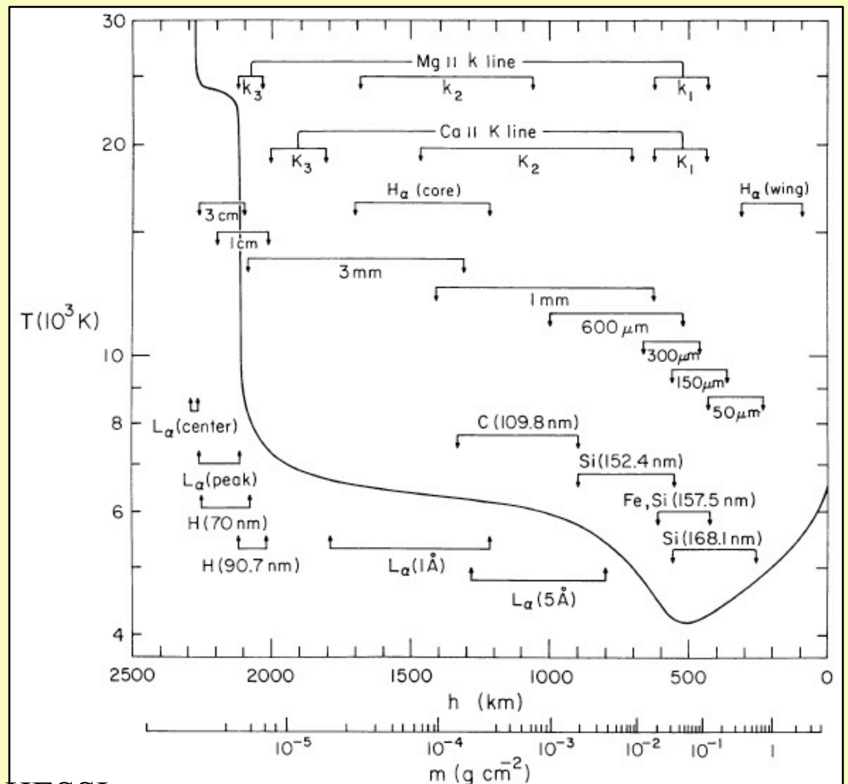




Svestka



VAL-C



Xu

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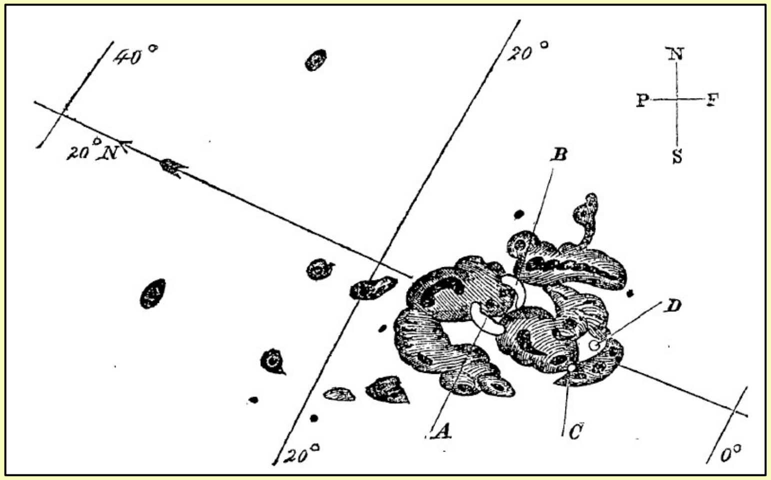
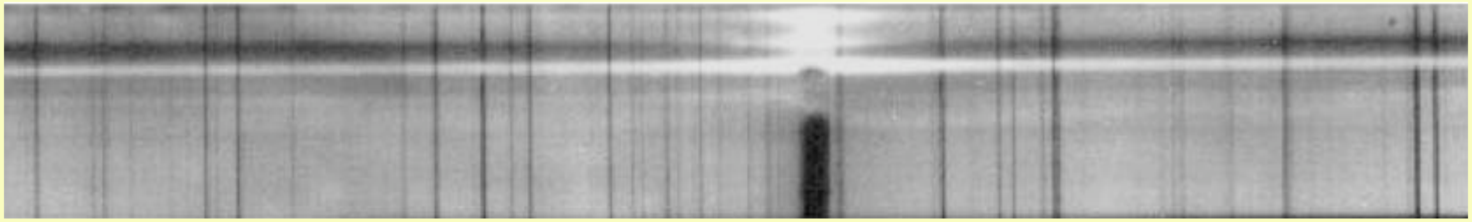
Optical imaging and spectroscopy



Carrington 1859 original flare

- Flare emission is intermittent
- Flare emission is energetic

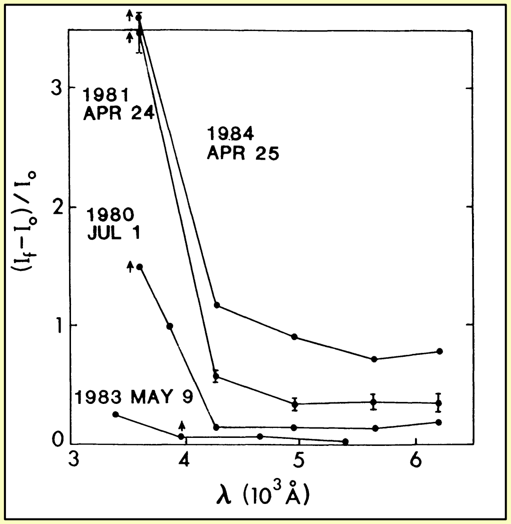


Babin & Koval 2007

- It has been difficult to put the slit on the flare at the right time and place
- Much early observational work was on film
- There is little modern CCD-based flare imaging spectroscopy

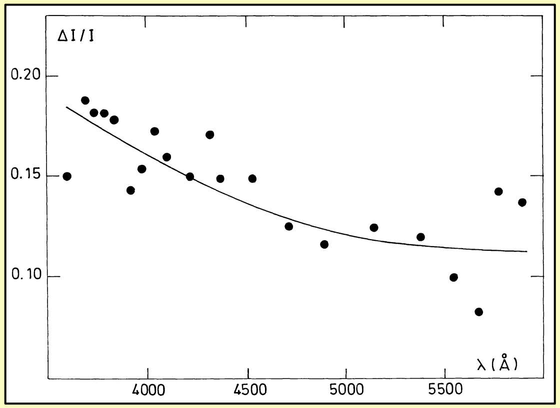
Spectral energy distributions

Neidig, 1989: Balmer jump



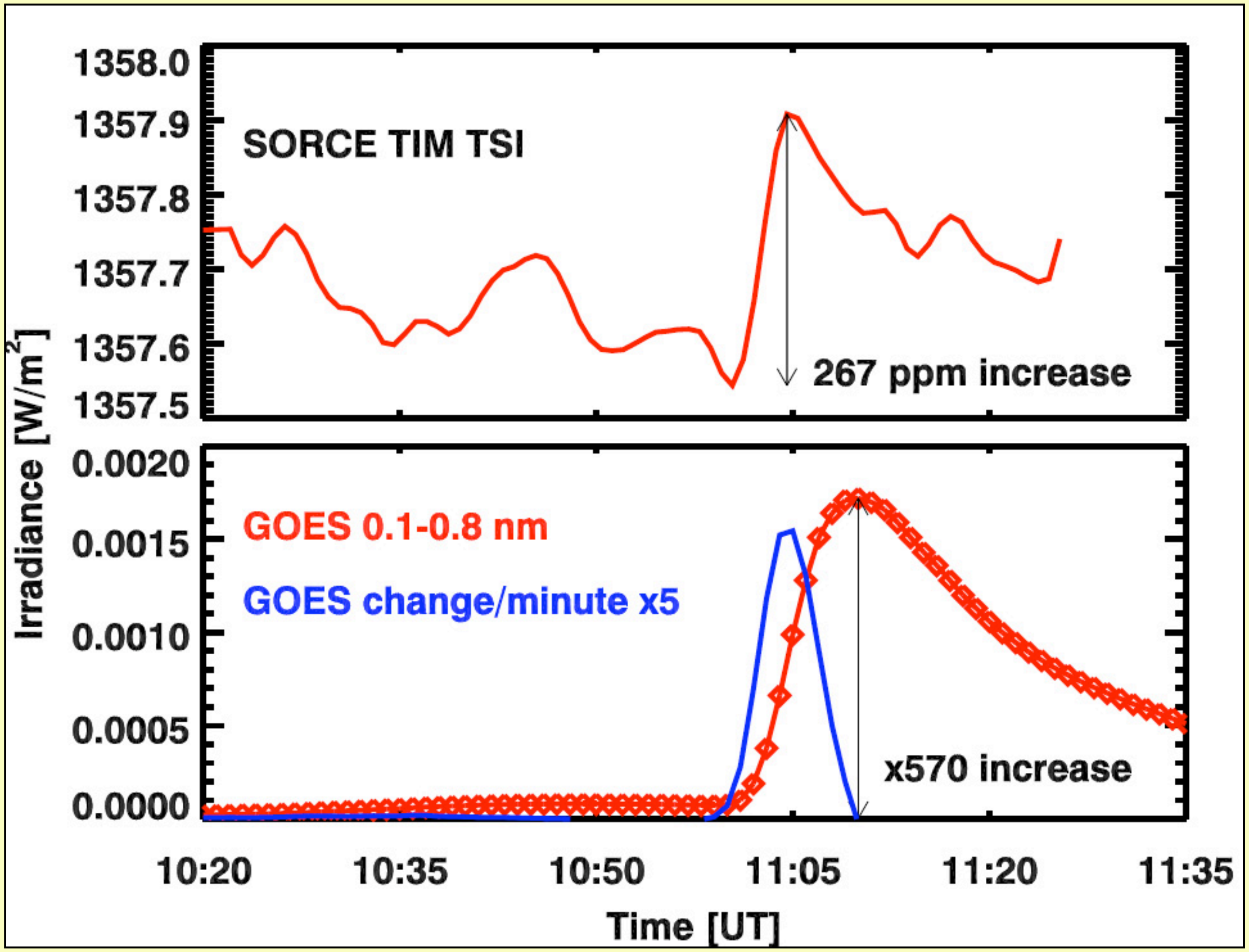
The impulsive-phase spectra exhibit a Balmer jump: a hot optically-thin layer has formed

The gradual-phase spectra tend to be continuous, implicating optically-thick H^- opacity

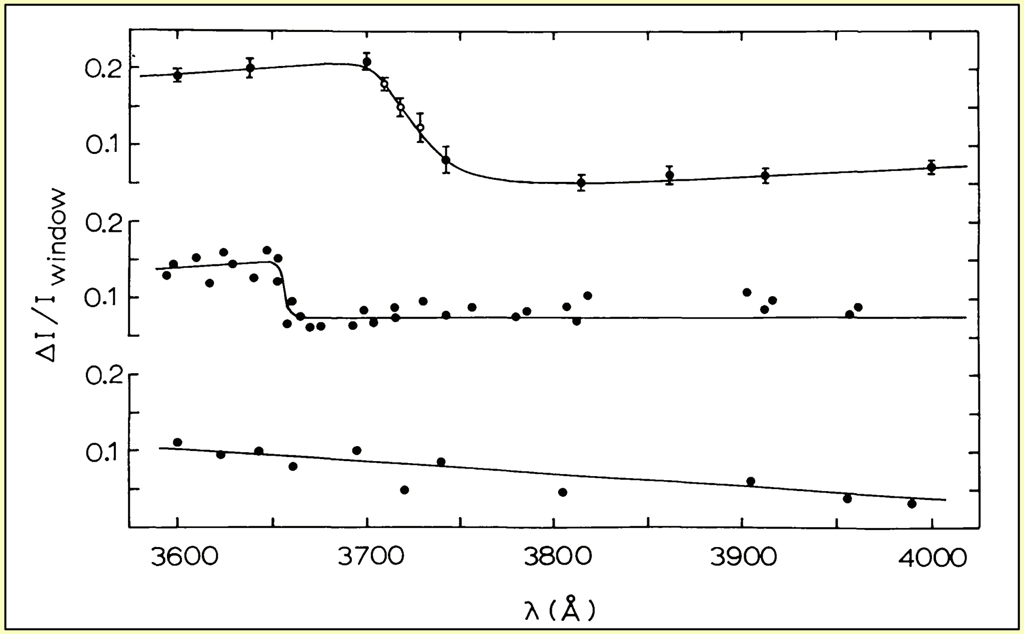


Boyer et al. 1985

First bolometric observation of a solar flare

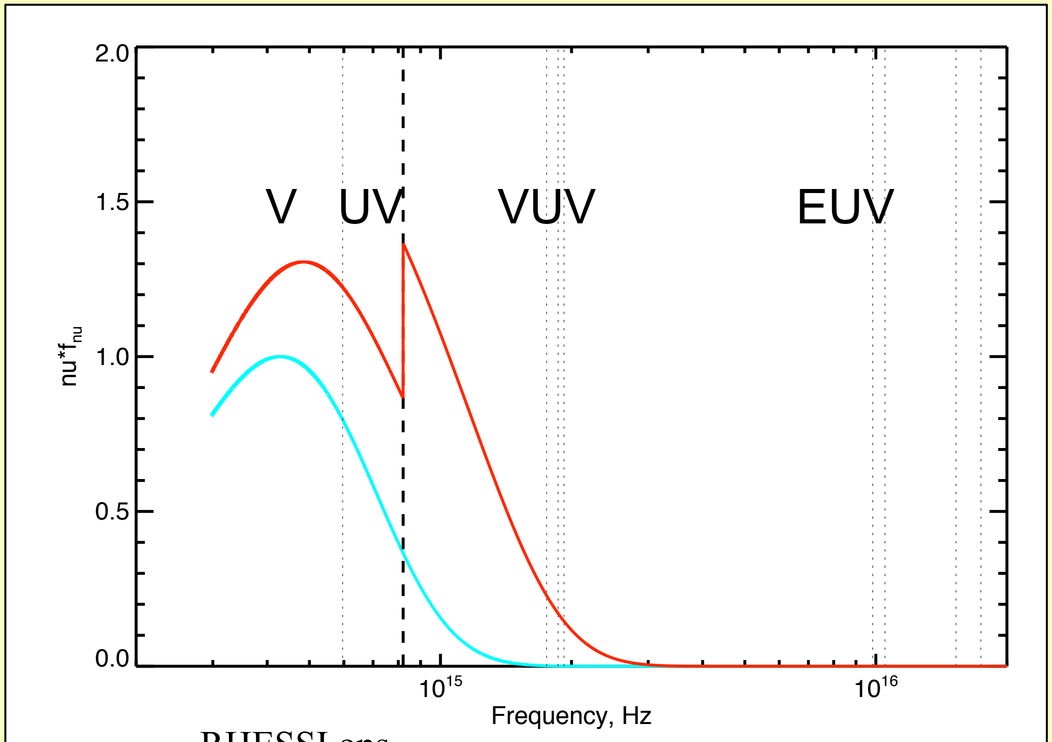


Woods et al. 2004



Neidig (1983): three flare spectra showing differing degrees of Balmer cont.

Balmer continuum



Conclusions

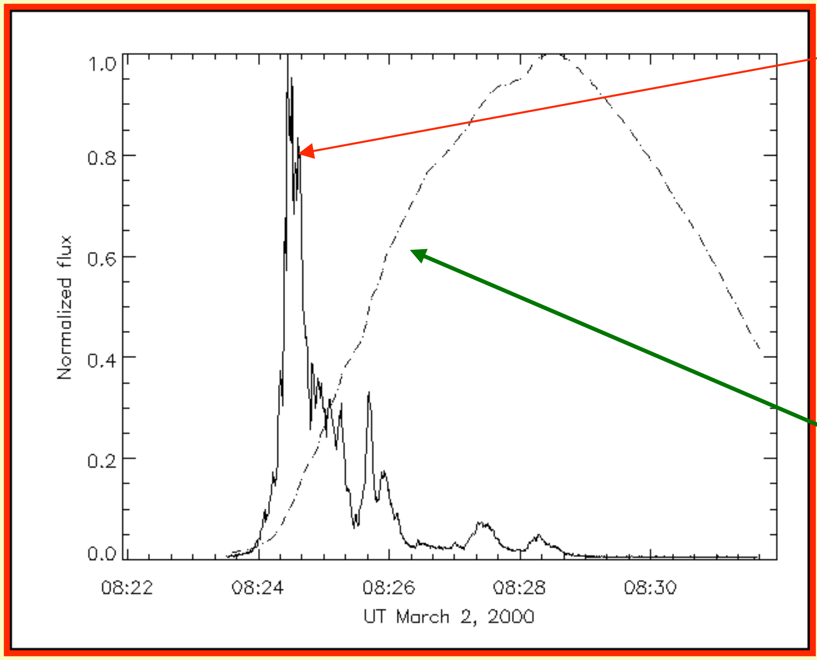
- The WLF spectra with Balmer continuum should be associated with the impulsive phase
- This emission forms well above the photosphere in a hydrogen-ionizing layer
- Energy transport there may be by particles, but could also be by waves (Fletcher & Hudson 2008)

Confusions

- Doppler effect
- Stark effect
- Non-equilibrium ionization
- Radiative transfer, ie non-LTE departure coeffs

OTHER SLIDES

Impulsive phase and gradual phase: The Neupert effect



Impulsive phase – primary energy release

- hard X-rays (10s of keV)
- white light, UV, µwaves - broad spectrum
- duration < few minutes
- intermittent and bursty time profile, 100 ms
- energy injection
- soft-hard-soft spectral evolution

Gradual phase - response to input

- thermal emission (kT ~0.1-1 keV)
- rise time ~ minutes
- coronal reservoir

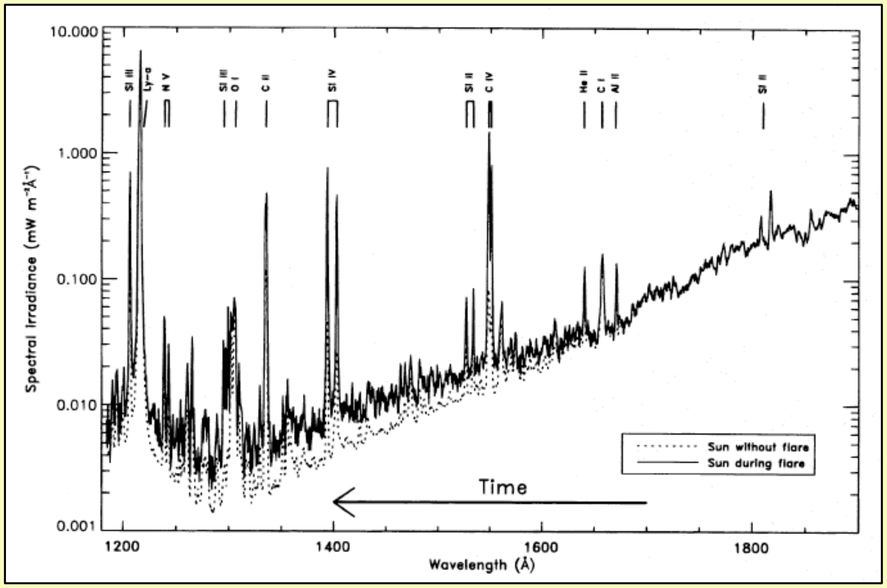
Impulsive phase:

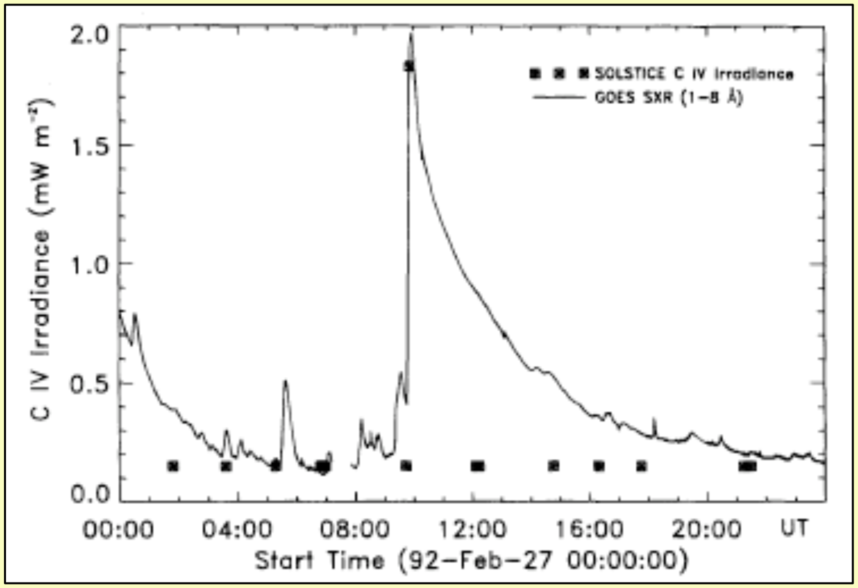
- > few tenths of the total flare energy released (up to 10^{32} ergs)
- Significant role for non-thermal electrons
- CME acceleration

Basic constraints on impulsive-phase energetics

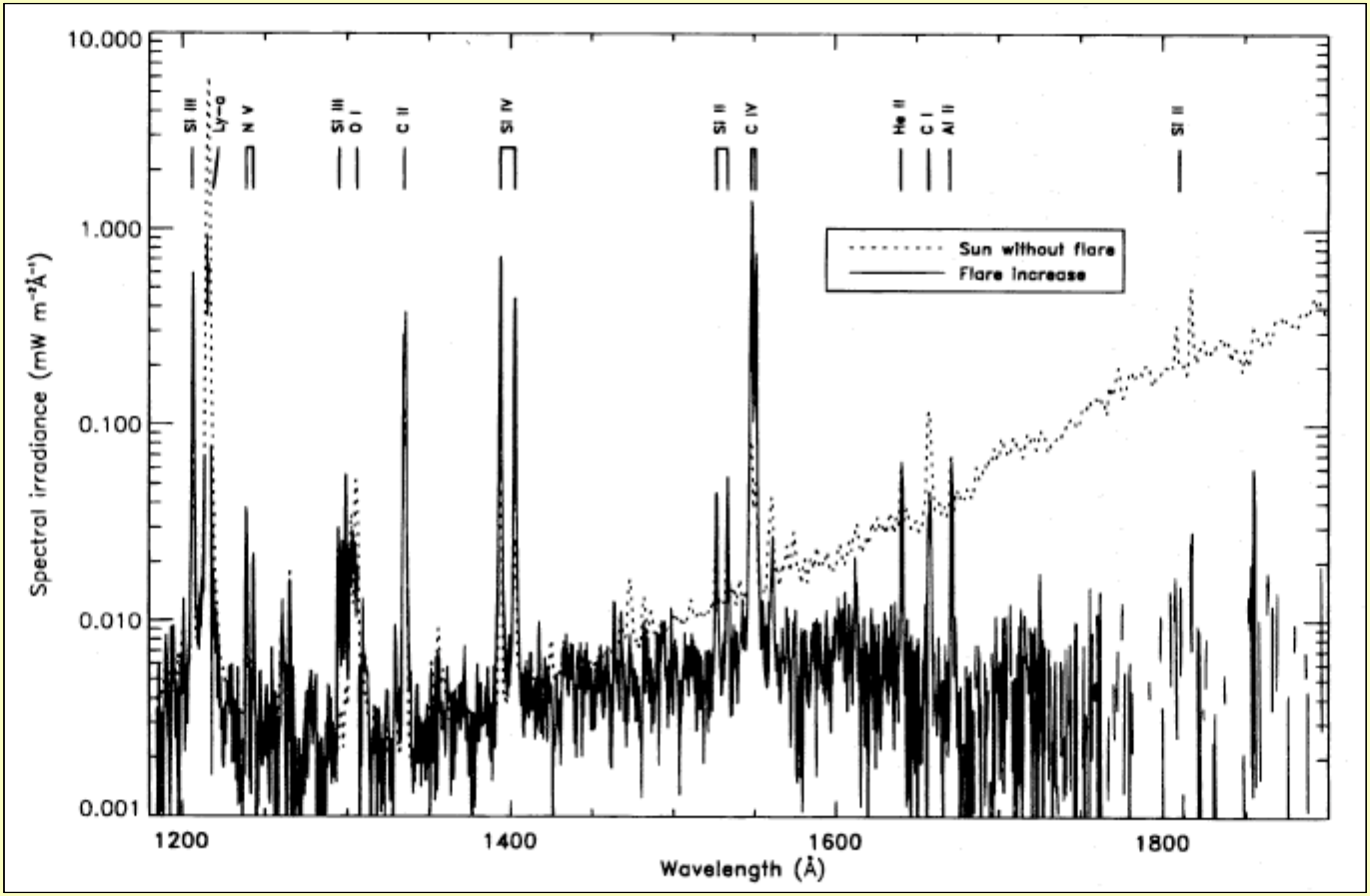
- Fast electrons need to be energized
- The UV/VUV continuum probably contains the bulk of the flare luminosity
- The luminosity is highly localized in space and time

Brekke et al. 1995: a unique VUV spectrum from UARS





• *We expect soon to be able to see many more detailed spectra from SDO/AIA, at 10 s time resolution*



time

RHESSI ops

Absence of UV spectrophotometric information in the impulsive phase

- We know there is Balmer continuum from Neidig's broad-band observations

- There is almost no useful UV/VUV spectroscopy of solar flares, and even less Ly-α

- Stellar spectrophotometry is also weak, and may not be easily applicable

Other guides to the physics of the UV/VUV continuum

- Hard X-ray and γ-ray emission
- Wave formation
- Radiation hydrodynamics modeling