Solar Variability 101

Peter Foukal
Heliophysics, Inc.
Nahant, Massachusetts, 01908

What we knew about TSI variation before SMM/ACRIM

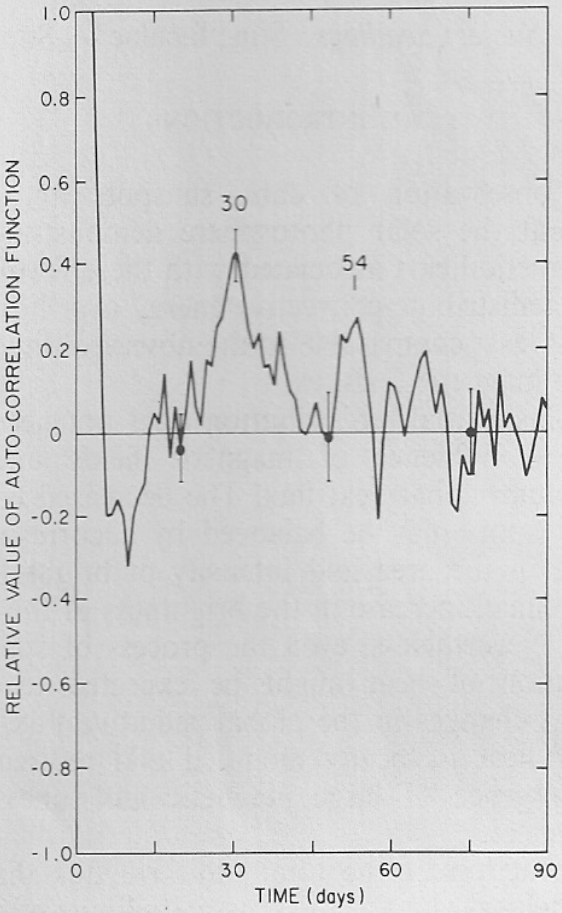


FIG. 1.—Autocorrelation function of APO daily solar flux measurements (residuals) for 1923–1952. The abscissa is time shift in days, the ordinate is the relative value of the auto-correlation function normalized to a value of 10. The first and second significant recurrence peaks are indicated at 30 days and 54 days.

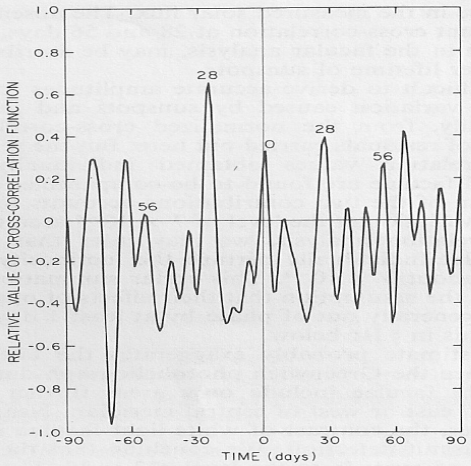


FIG. 2.—Cross-correlation function of APO daily solar flux measurements (residuals) and facular projected areas (residuals) for 1925–1952. The abscissa is time shift in days, the ordinate is the relative cross-correlation value normalized to unity. The approximate recurrence period of faculae at intermediate latitudes is marked as ±28, ±56 days.

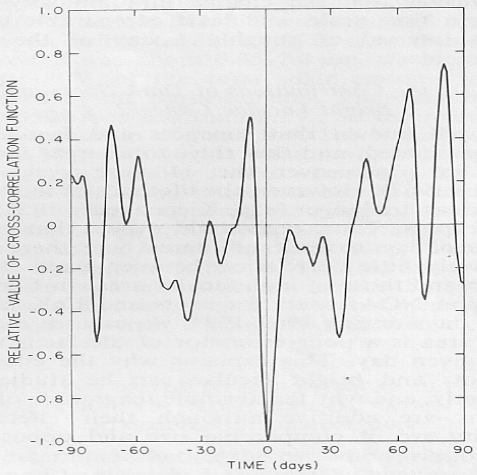
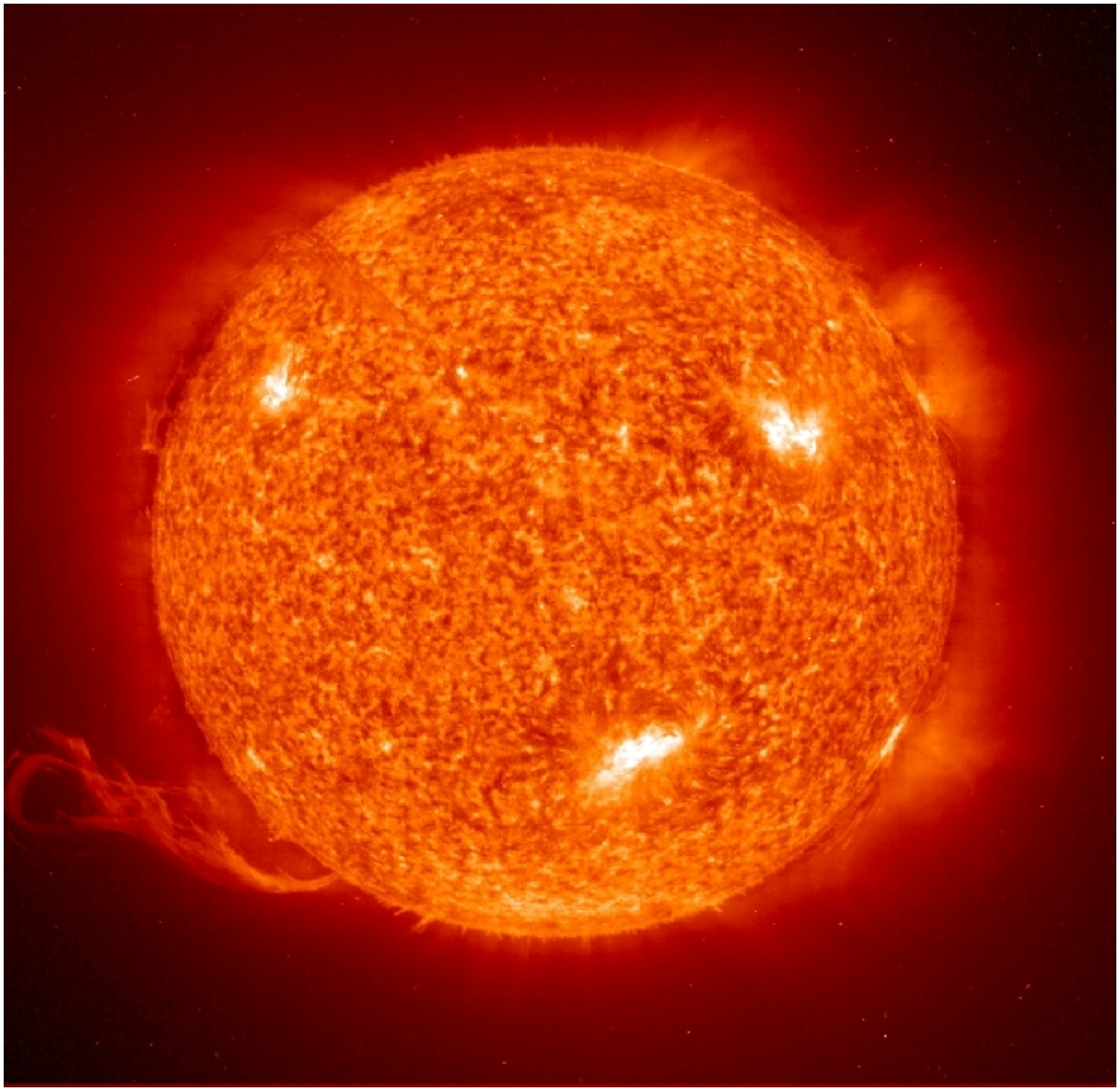


FIG. 3.—Cross-correlation function of APO daily solar flux measurements (residuals) and sunspot projected areas (residuals) for 1925–1952. The abscissa is time shift in days, the ordinate is the relative cross-correlation value normalized to unity.

Two Faces of the Sun: Activity and Also…Inertia



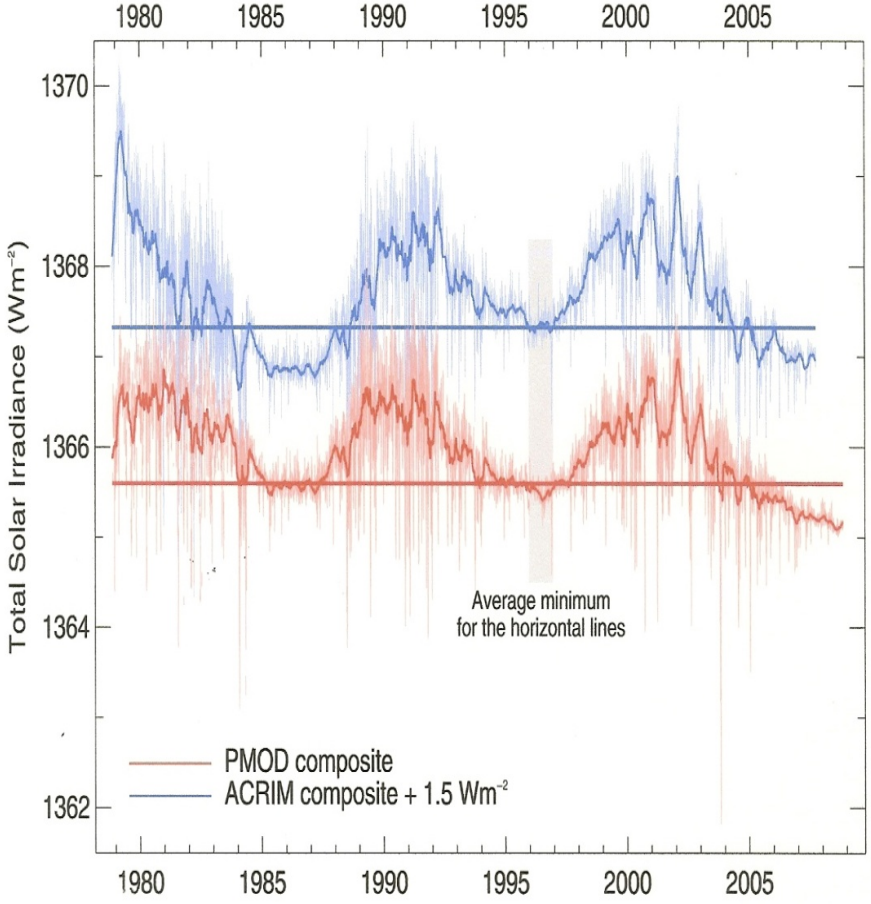
“Climate - Effective”Solar Variability

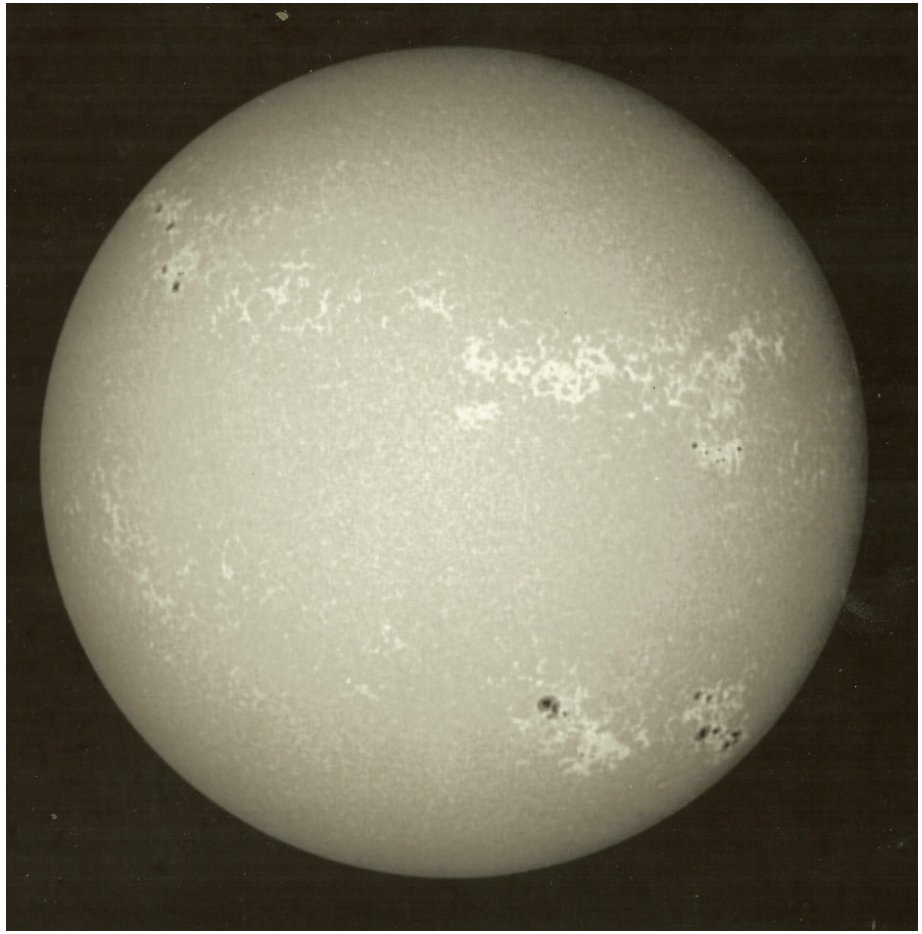
- Total Solar Irradiance (TSI)- i.e. solar luminosity
- Ultraviolet Irradiance (ozone – effective wavelength range: ~ 130- 240 nm)
- Fluxes of Plasmas and Magnetic Fields

Total Solar Irradiance (TSI) Variation …… and What Causes It

- Sun brightens < 0.1% at spot maxima
- 27- day variation(solar rotation) < 0.3%

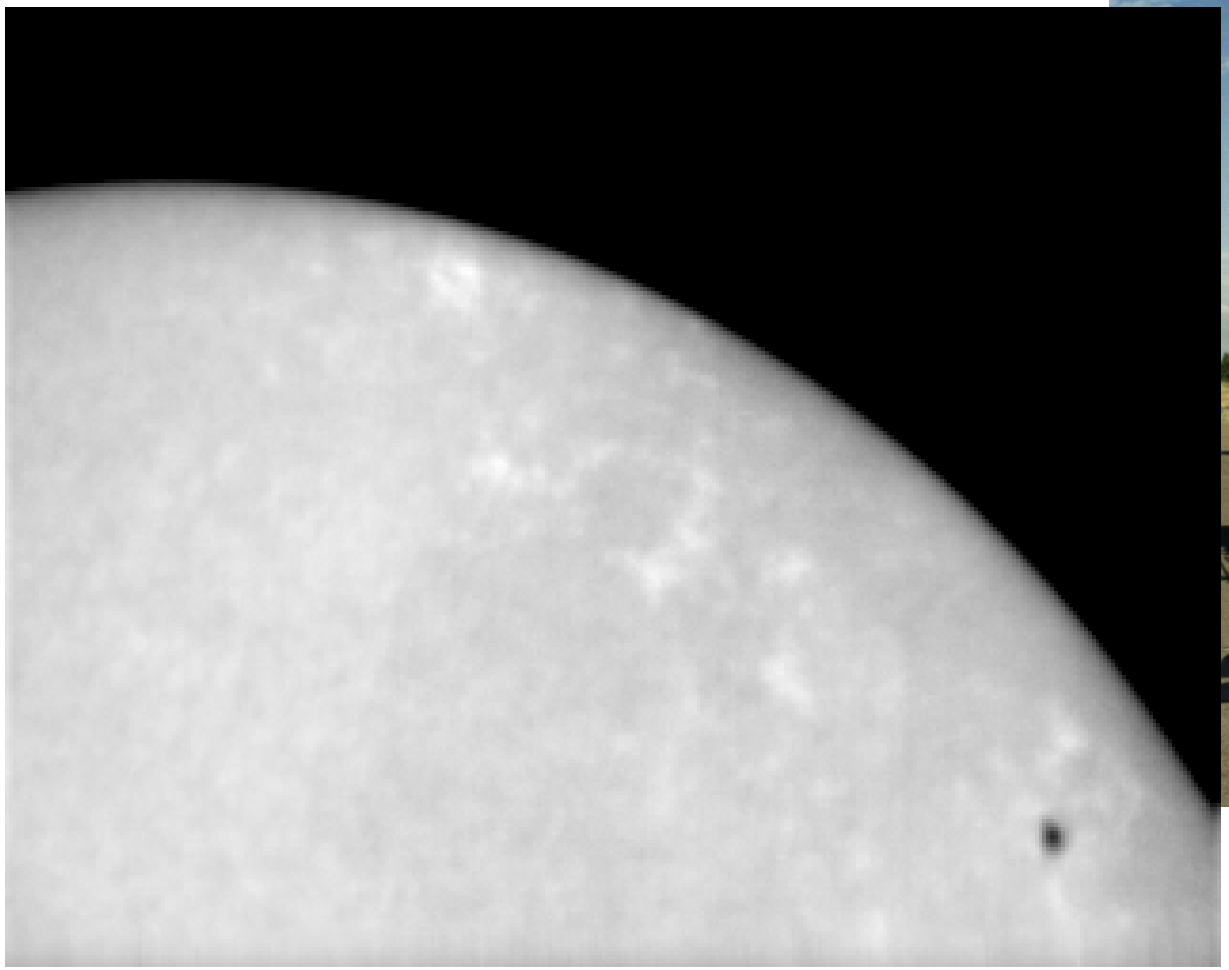
- Dark sunspots decrease TSI
- Bright faculae increase TSI
- Other influences on TSI?





Broad Band Imaging of Spot, Facular Contributions to TSI Variation

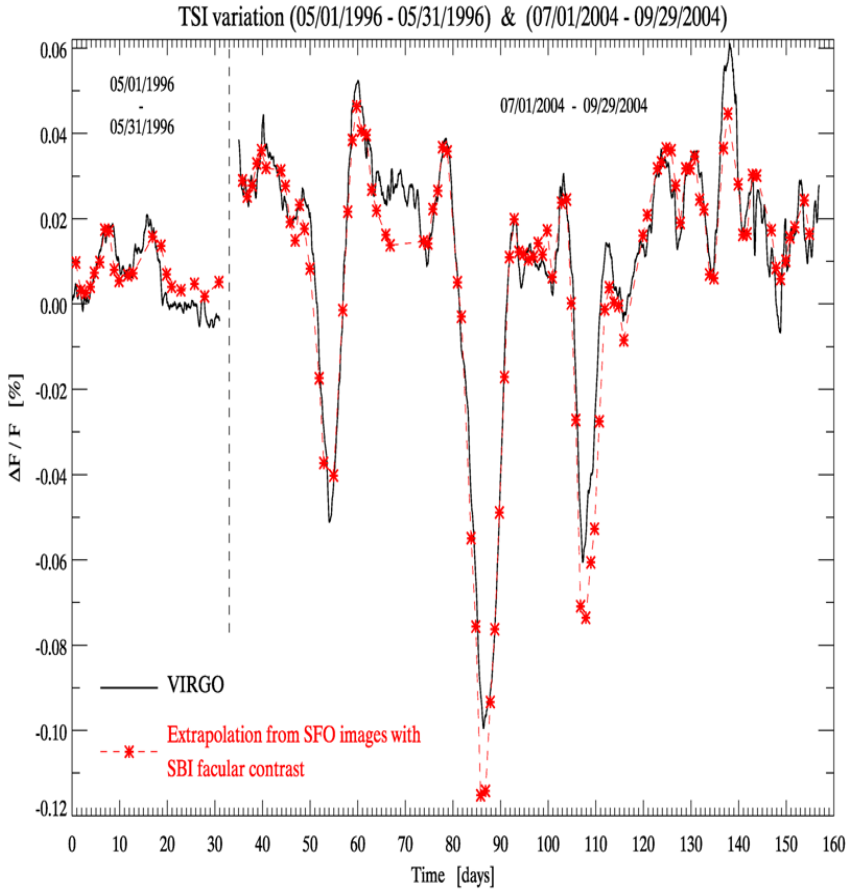
Solar Bolometric Imager (SBI) *images* the solar photosphere with the same spectrally flat (~ 200 – 3000 nm) response, as *non – imaging* radiometers, like ACRIM or TIM.

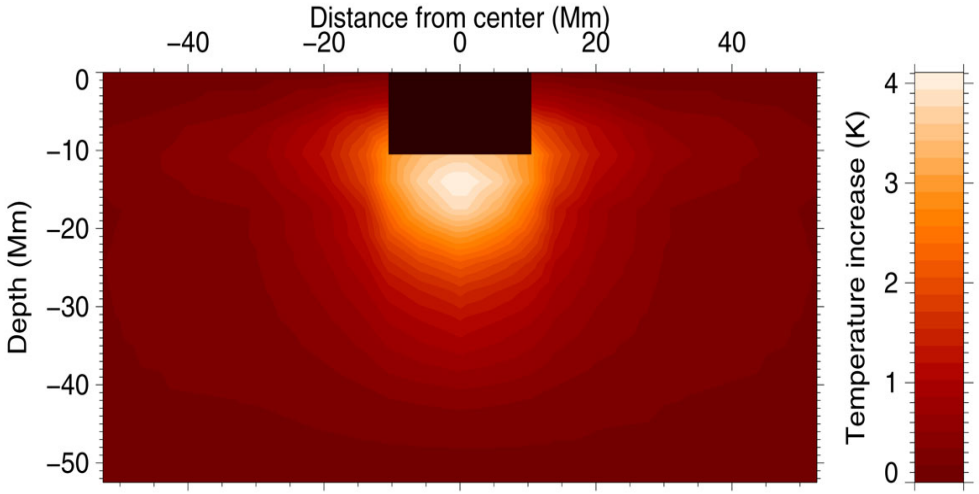


Why do spots cause TSI variation?

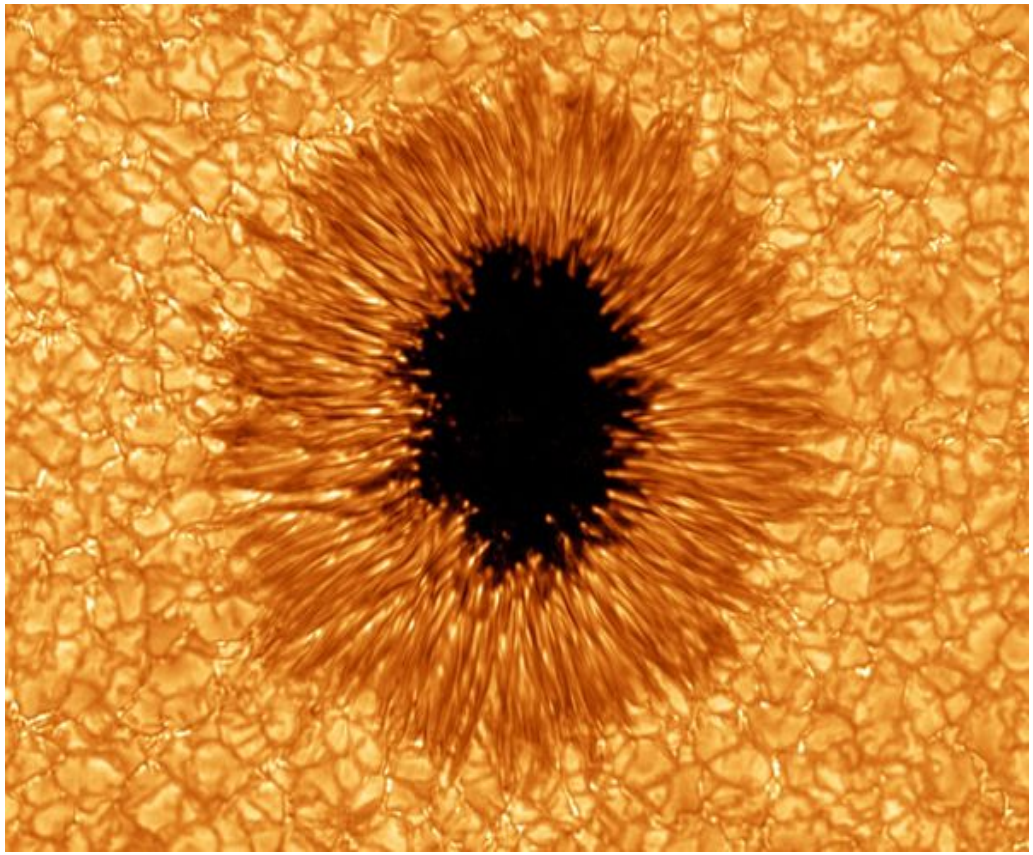
Observations: radiometry and photometry of spot – induced TSI dips match, so blocked heat is *not re- radiated,* must be stored over time > spot lifetime.

Calculation: The blocked heat is stored as a tiny increase of the Sun's internal and potential energy.





Why is a sunspot dark?

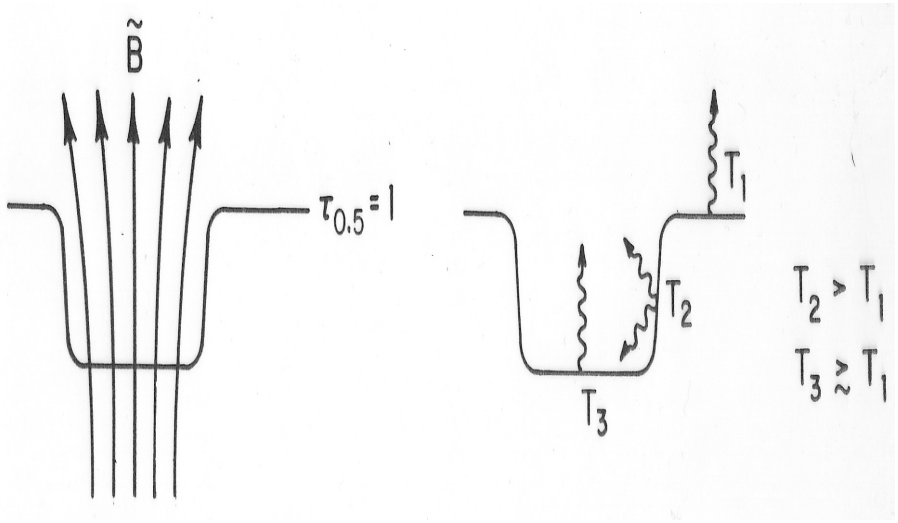


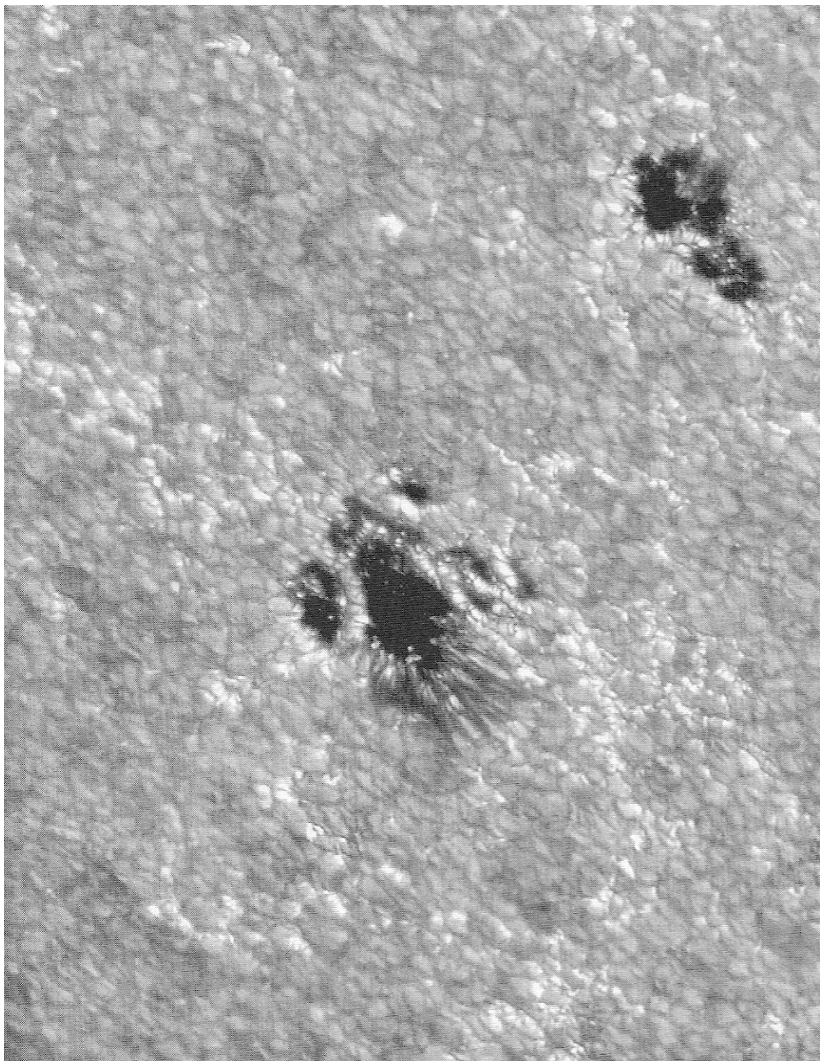
Because its strong vertical magnetic field obstructs convection of heat to the photosphere - it is a "**thermal plug**."

The blocked heat is redistributed and stored efficiently in the solar interior

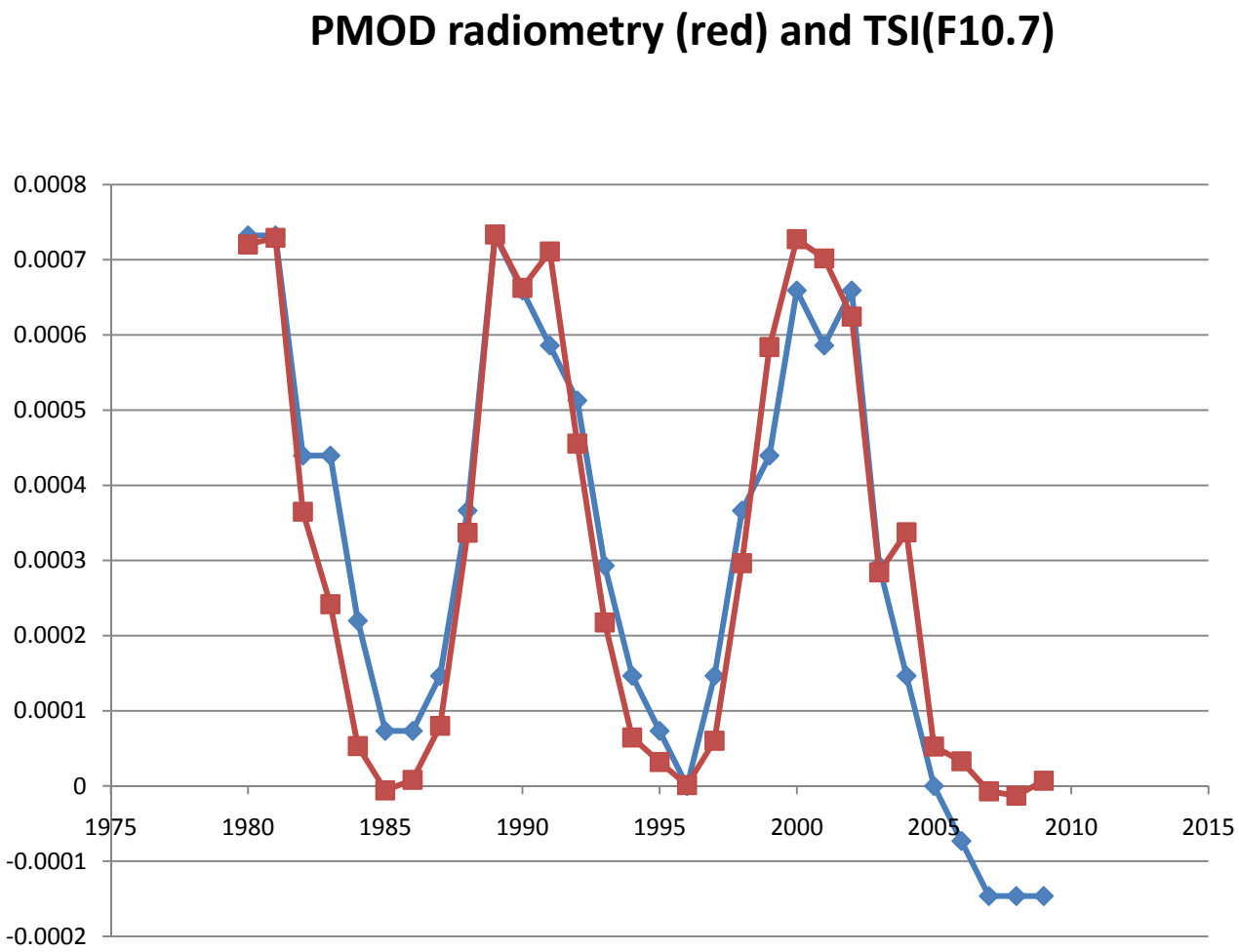
Why are Faculae Bright?

Because the vertical magnetic field reduces density, making a cavity that facilitates radiation from its brighter walls into space – it is a thermal "**short circuit**".



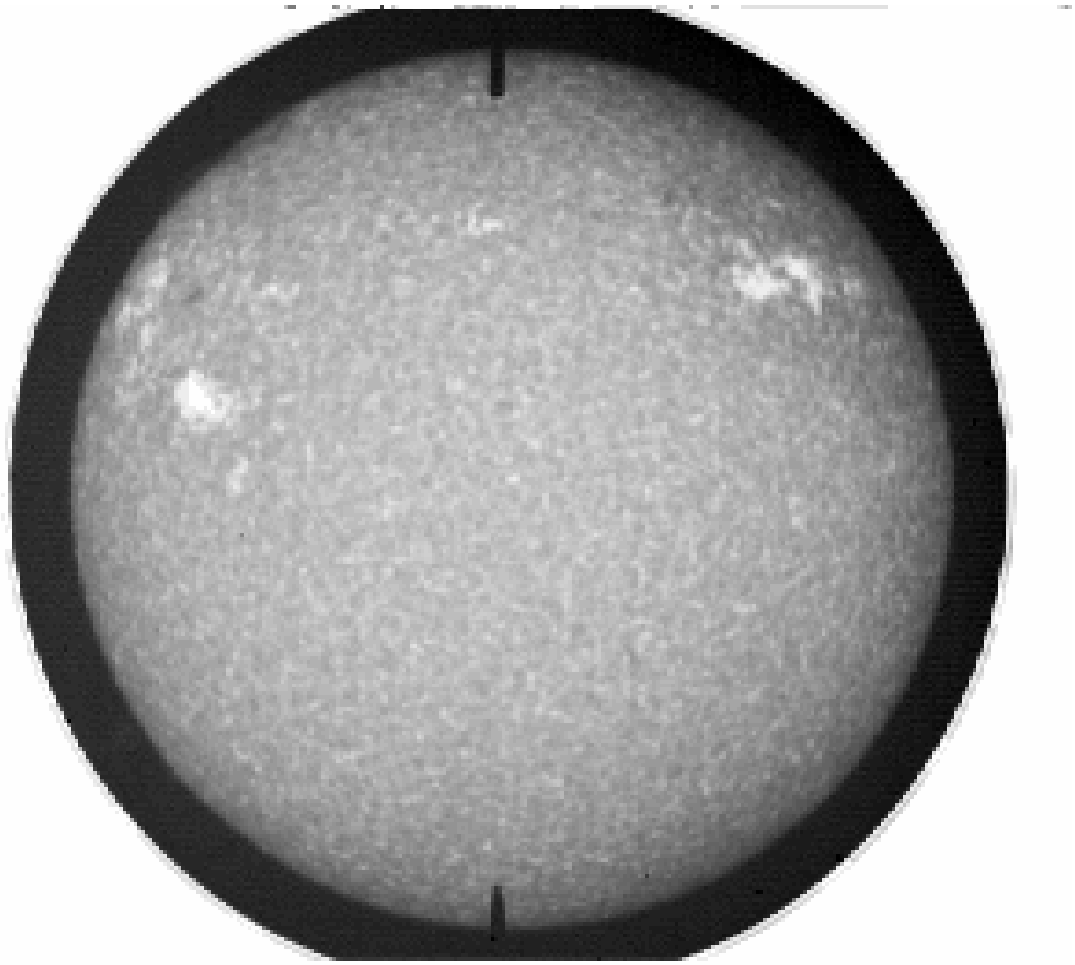


Measured and Reconstructed TSI Variation 1980-present

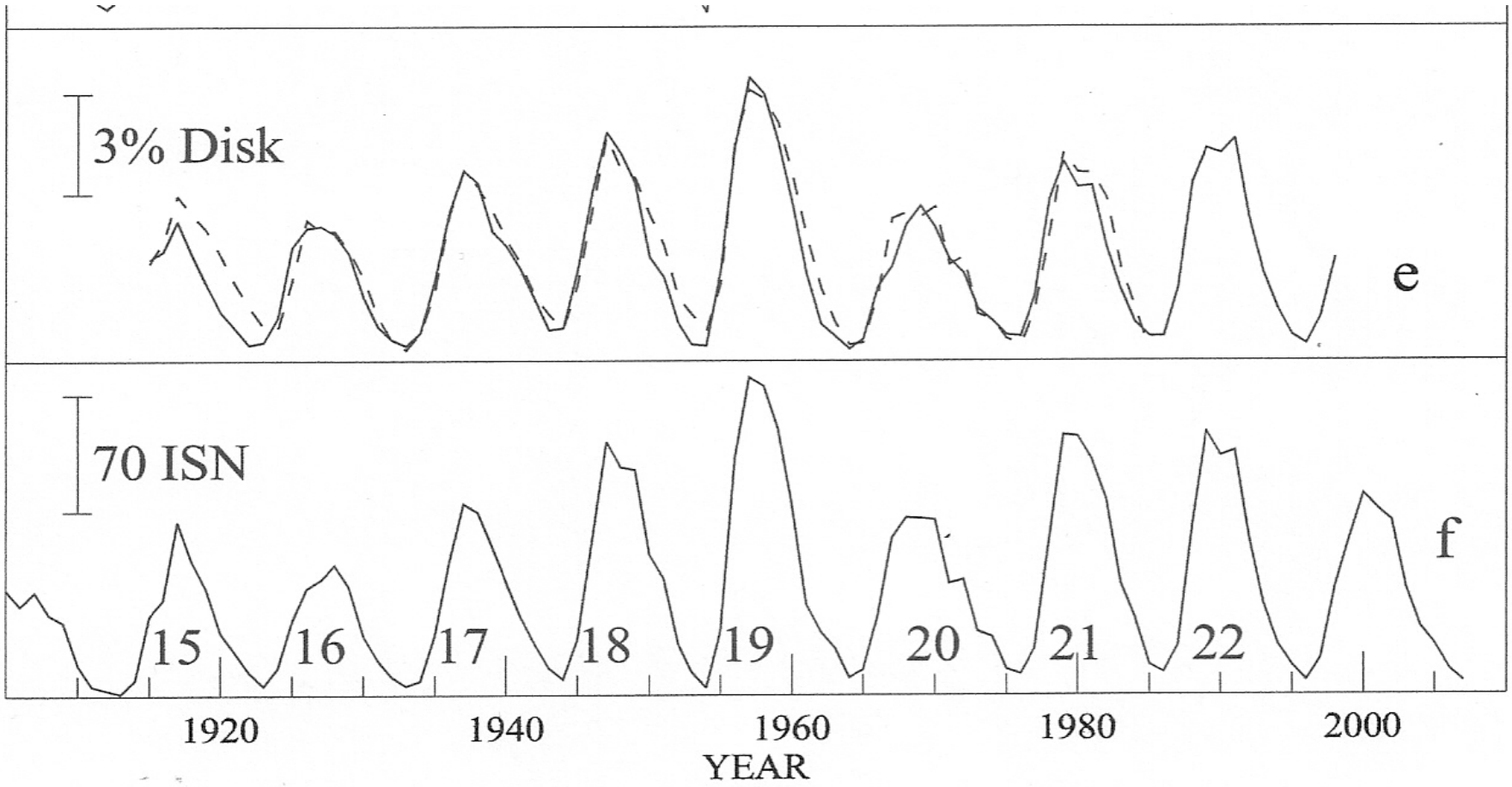


Reconstructing the 20th century facular irradiance contribution

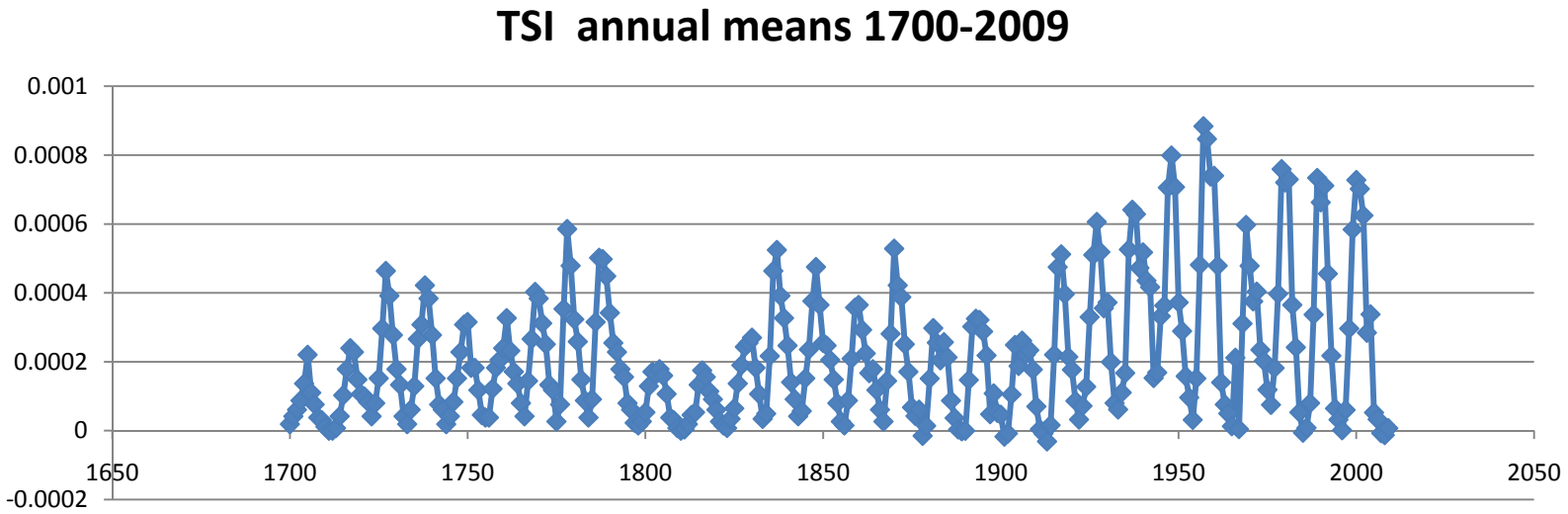
- ~ 20,000 archival daily Ca K spectroheliograms 1915- 1984 (Mt Wilson; also 1907-present at Kodaikanal, Sacramento Peak, Arcetri…)
- Digitized, reduced by CRI, Pulkovo, UCLA, Rome…

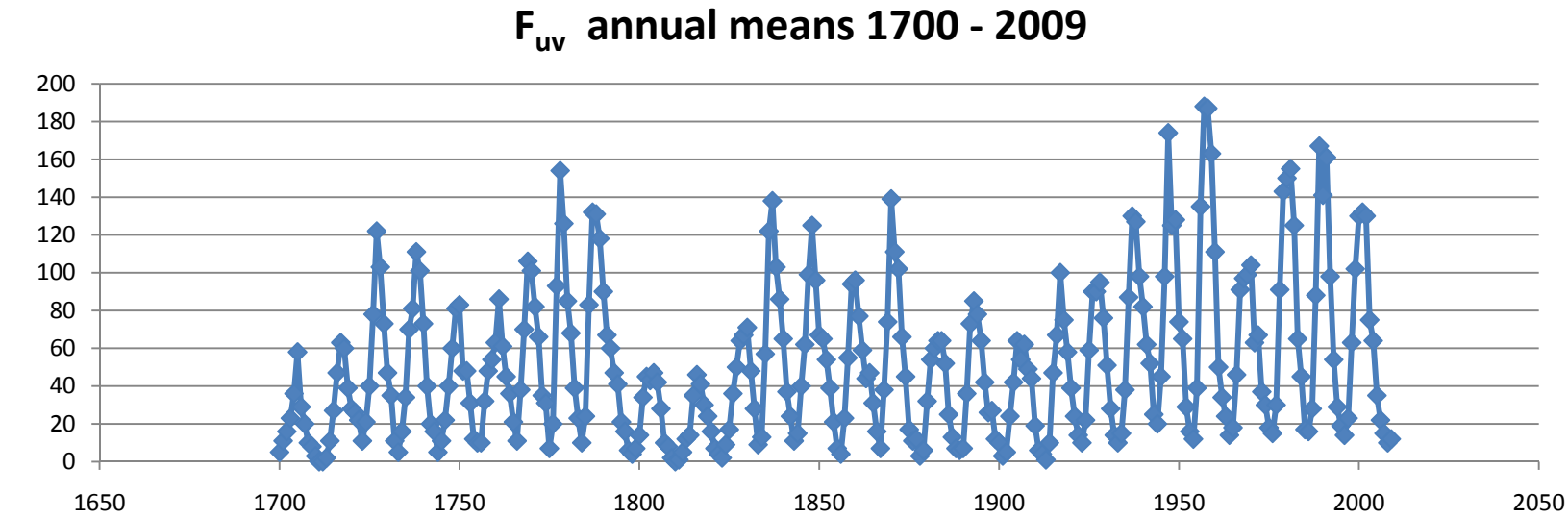


Two independent reductions of Mt Wilson facular areas: CRI(solid) and UCLA (dashed)

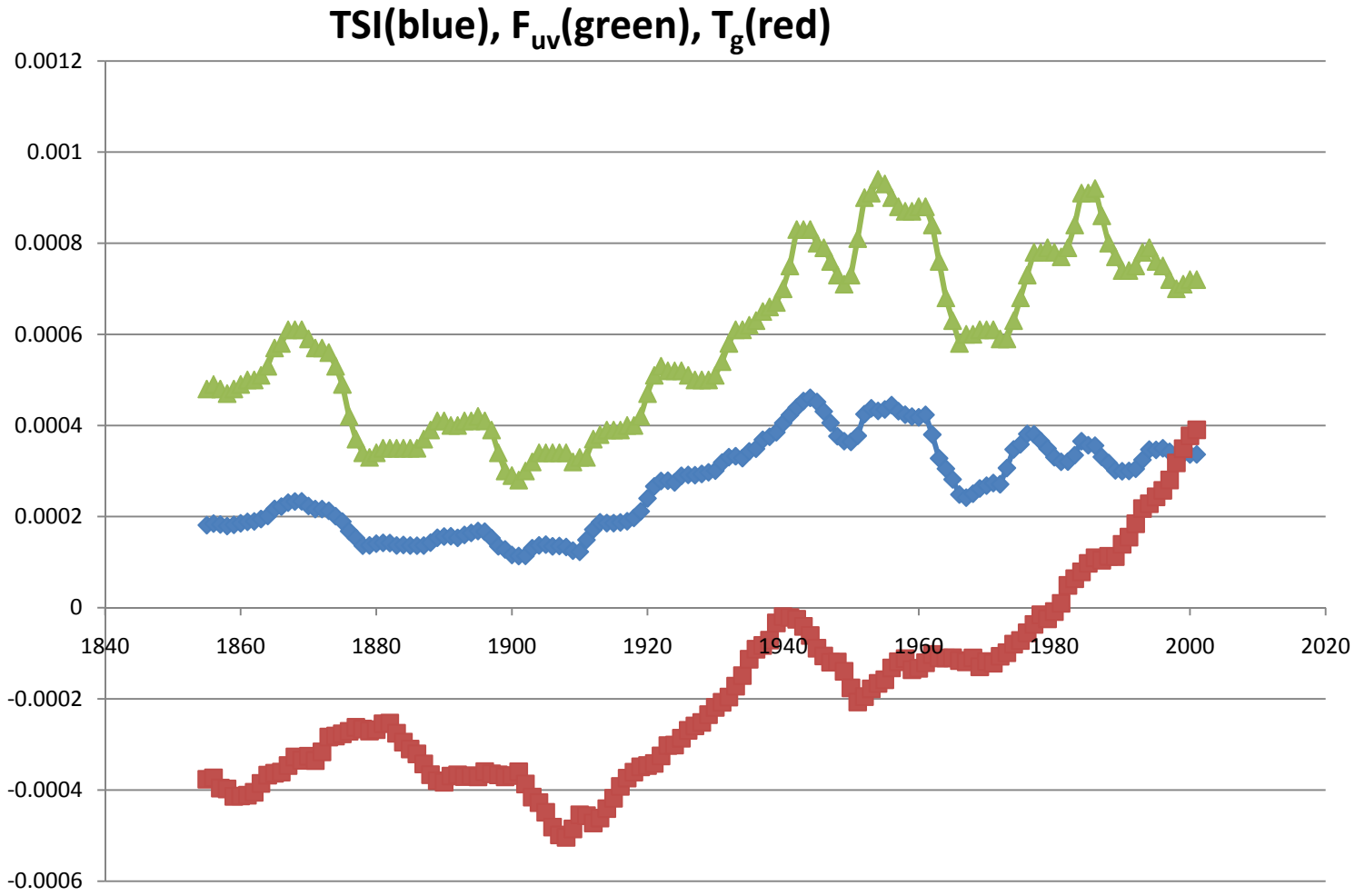


TSI and Fuv to beginning of regular spot record

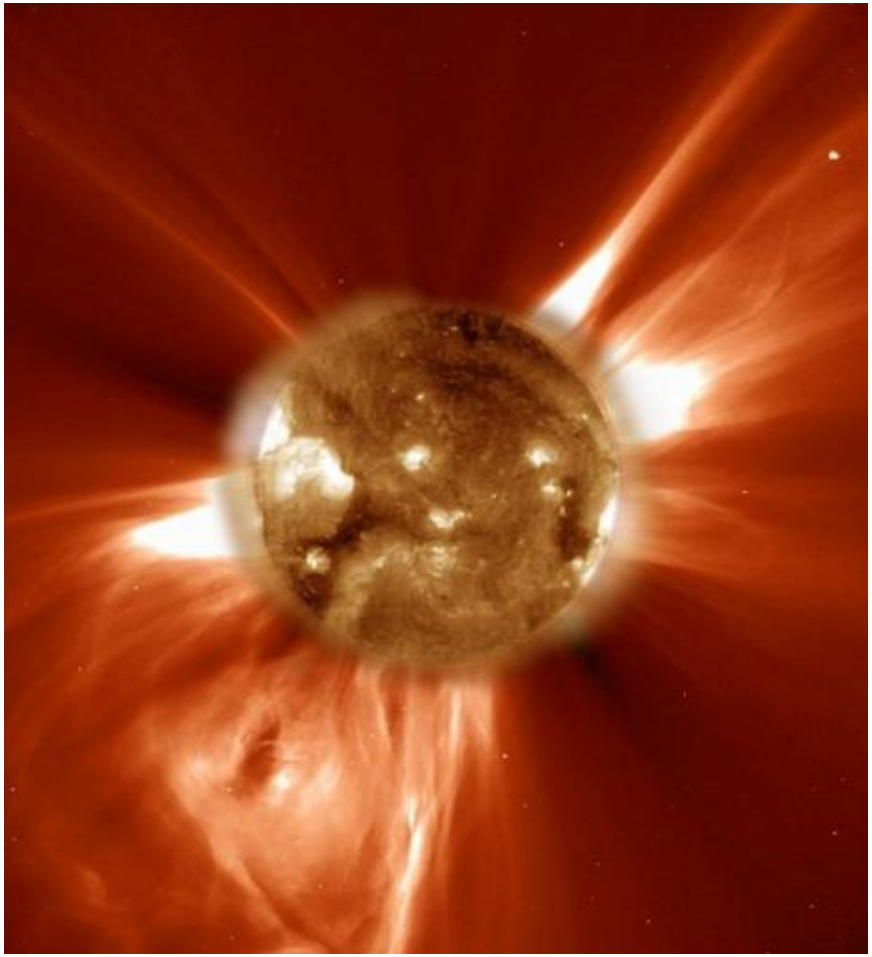


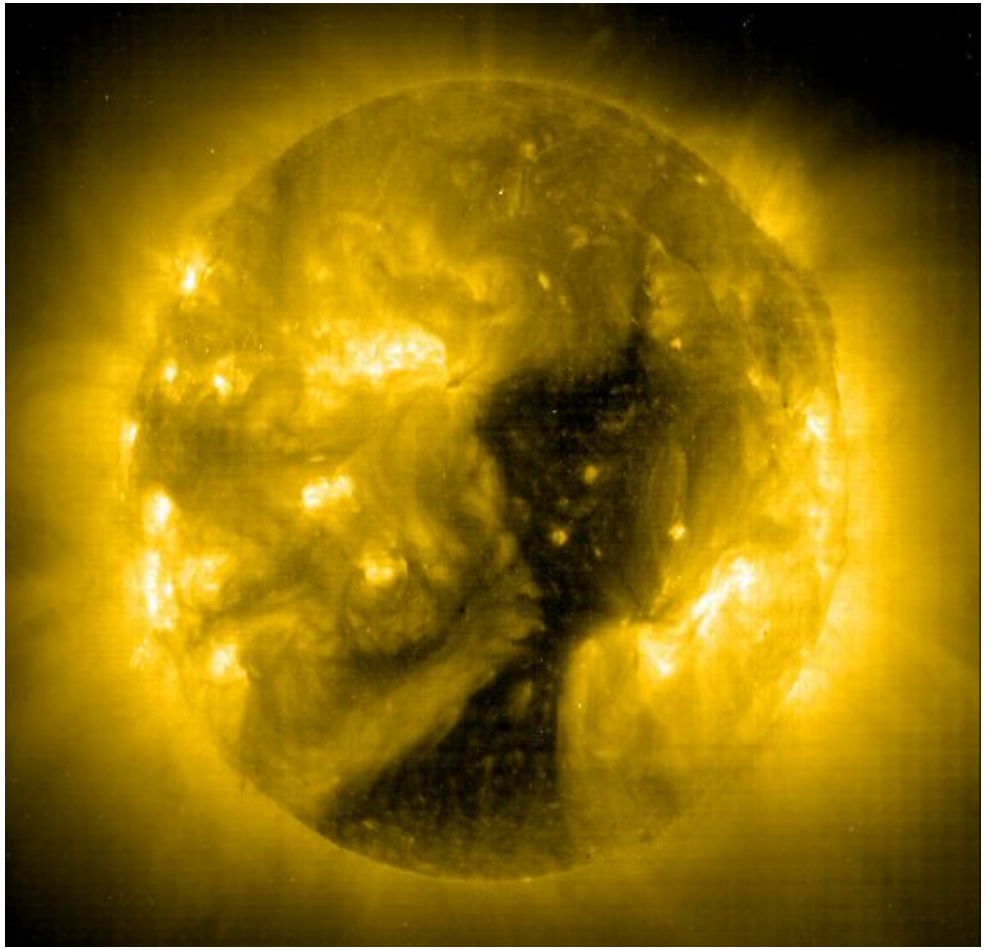


150 yrs of TSI, Fuv, and Global Temperature

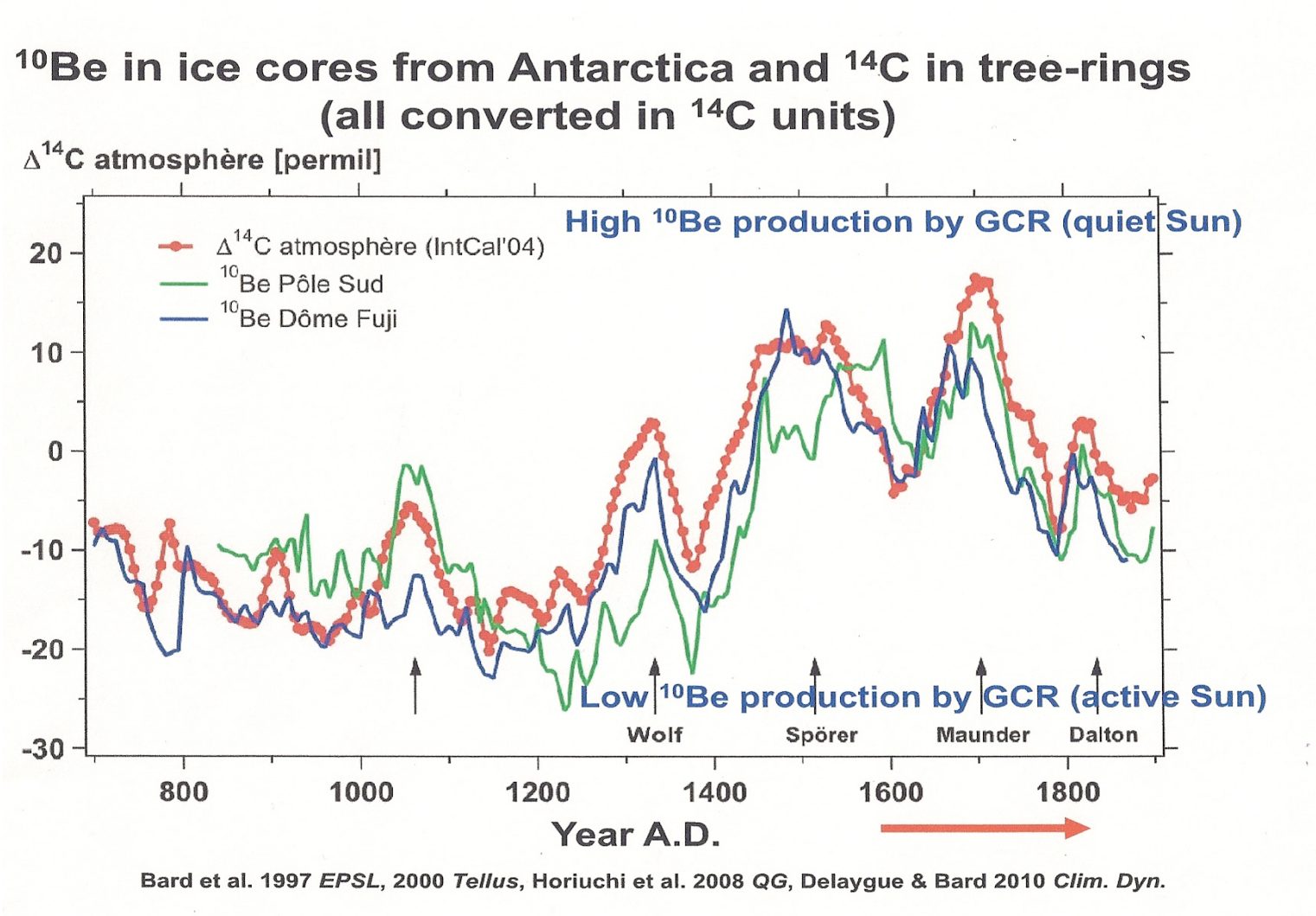


GCR modulation by heliospheric fields supplied by the solar wind and coronal mass ejections



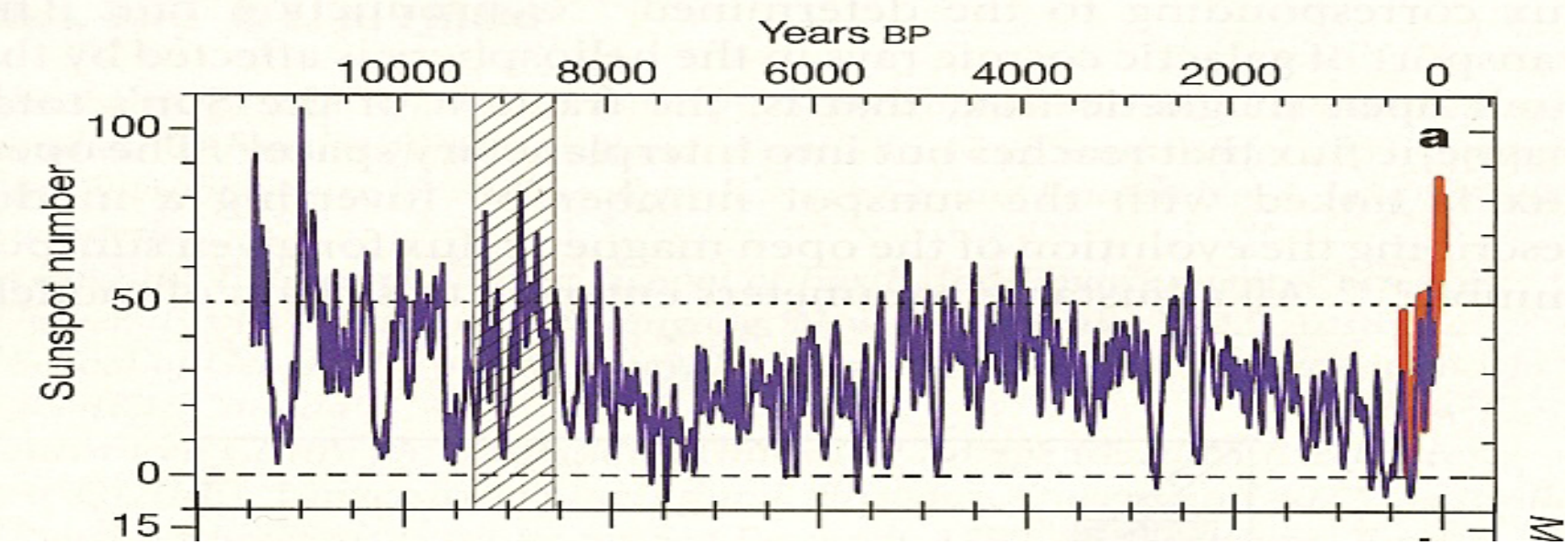


Solar activity from radio-isotopes over the past millennium (N.B.: high activity *decreases* radio-isotope production)



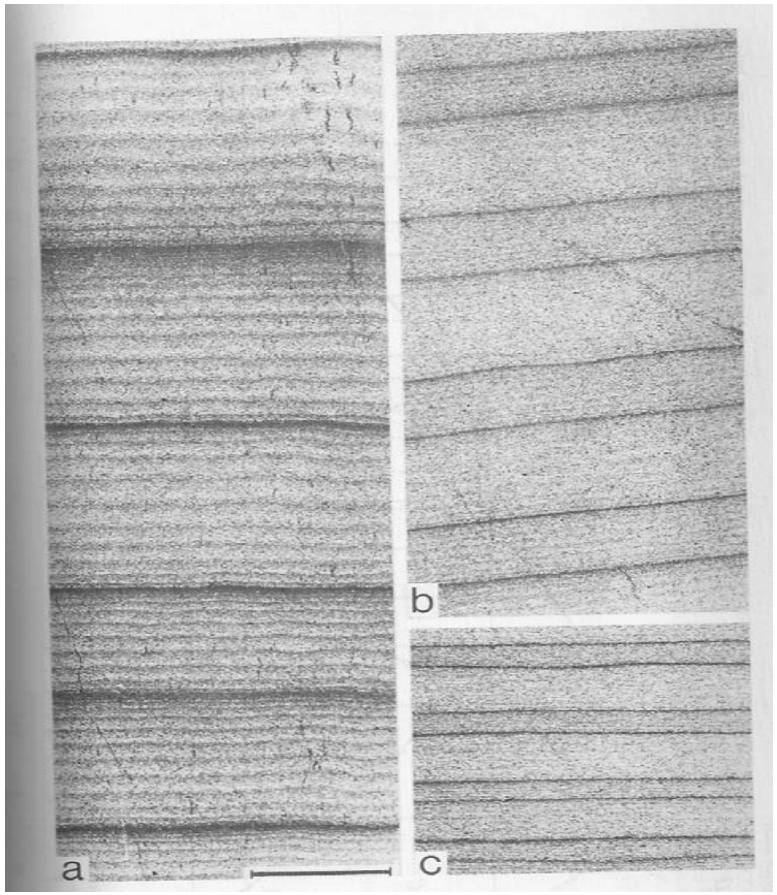
Could Extended Solar "Hyperactivity" have Occurred During the Holocene?

- Unlikely (Solanki et al., 2004)
- But that study does not consider *C14 production by solar energetic particles (SEP's)*
- Total C14 = production by(GCR's + SEP's).SEP's are oppositely correlated with activity level.

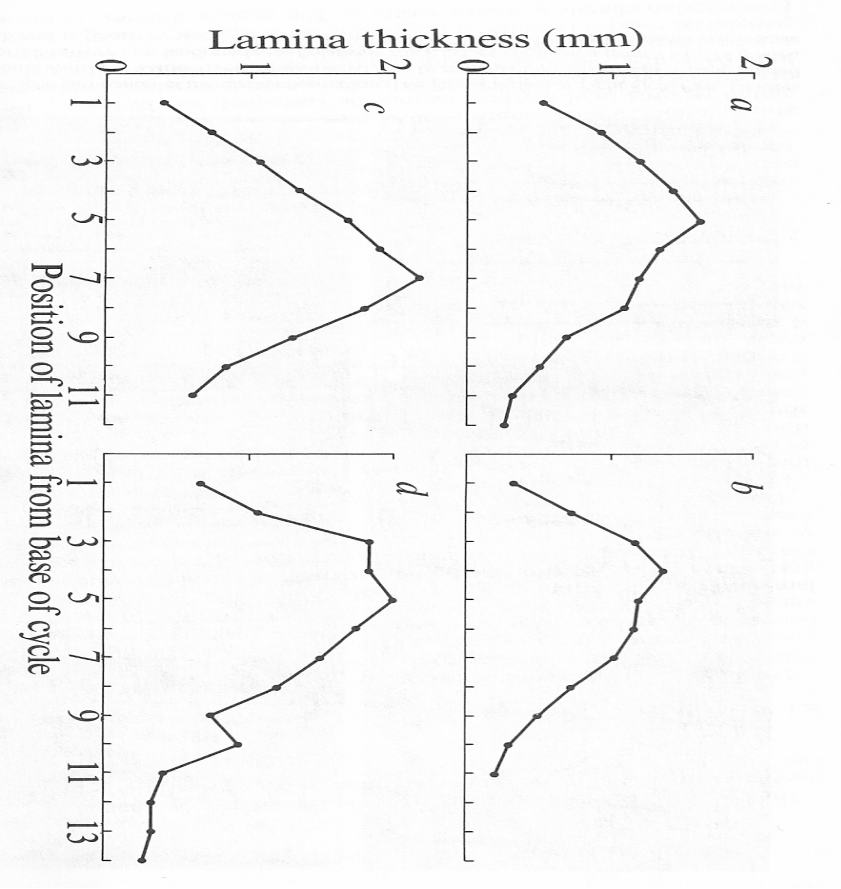


How Did the Solar Cycle Behave When The Sun Was 650 million yrs (15%) Younger?

Elatina varves: sedimentary deposits laid down 650 million yrs ago? (Williams, 1983).



Tracings across 11- 14 year varve cycles: 30,000 (!) yr time span.



CalTech Team Drilling Varve Cores

(photo by courtesy of T. Raub and J. Kirschvink)

Conclusions

- Jack's two basic points - that the Maunder Minimum was real, and that it coincided with the Little Ice Age, have remained robust
- These two findings continue to drive Sun – climate studies 35 years later; to many they are still the most persuasive evidence of a causal relationship between solar activity and climate
- Sun – climate studies remain, after > two centuries, a high- risk, high - stakes field of astronomy and climate physics. Onward and upward!