Sun-as-a-star Multi-wavelength Observations: A Milestone for Characterization of Stellar Active Regions

Shin Toriumi[1], Vladimir S. Airapetian[2,3], Hugh S. Hudson[4,5], Carolus J. Schrijver[6], Mark C. M. Cheung[6], and Marc L. DeRosa[6]

1. ISAS/JAXA (toriumi.shin@jaxa.jp), 2. NASA/GSFC, 3. American Univ., 4. Univ. of Glasgow, 5. UC Berkeley, 6. LMSAL

Key factors for super-flaring stellar active regions?

Based on solar observations, we know the following characteristics are critical [Toriumi & Wang 2019].

1. **Size**..amount of accumulated magnetic energy
→ from visible light curves or Zeeman-Doppler imaging
2. **Structural Complexity**......................non-potentiality
→ almost impossible!
3. **Evolution**..energy storage dominates dissipation
→ ...perhaps! [e.g. Namekata et al. 2019]

▷ Starspot monitoring in multiple wavelengths

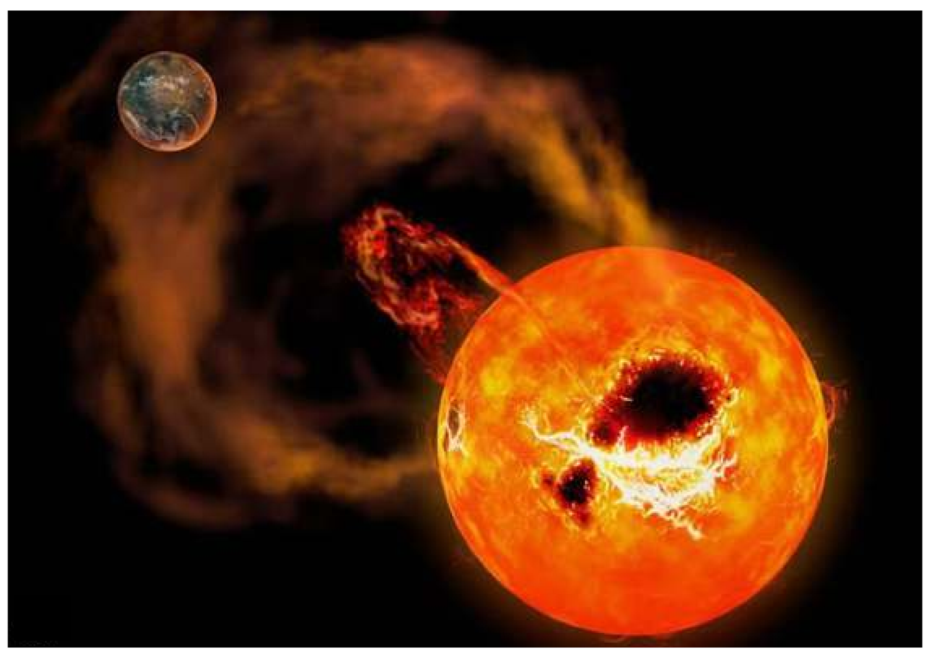


Fig. 1: Artists' impression of superflare (Kyoto Univ.).

Analysis: Sun-as-a-star light curves

Plot full-disk light curves in various wavelengths when only a single sunspot group transits across the disk in prolonged quiet-Sun conditions.
→ Only a few such studies exist [Woods et al. 2004]. Ideal events were found only during the solar minimum between Solar Cycles 24 and 25.
Instruments: SDO/HMI, SDO/AIA, Hinode/XRT, GOES/XRS, and SORCE/TIM

Results

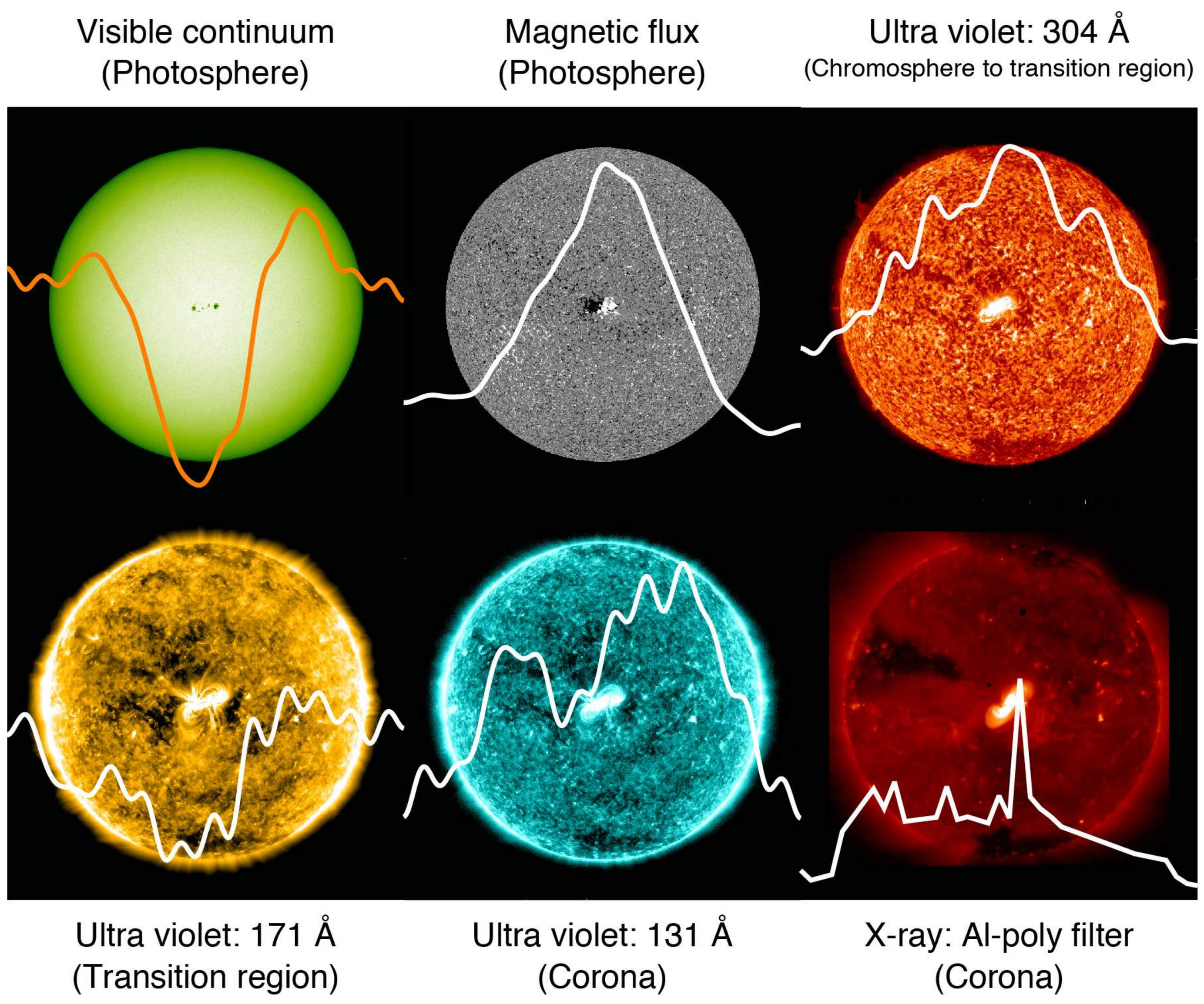
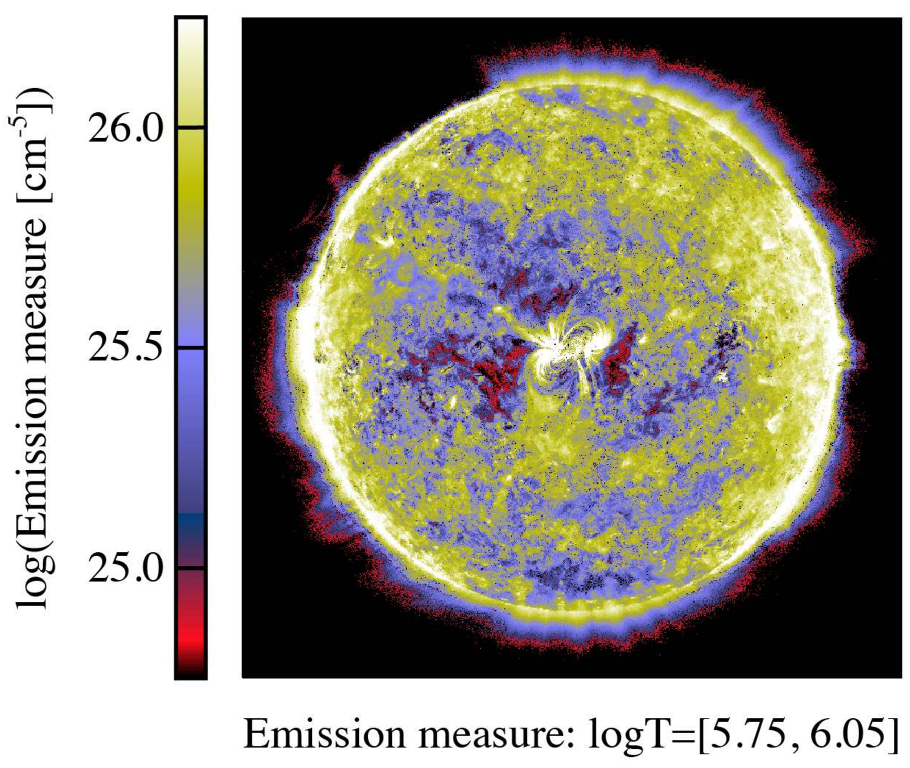
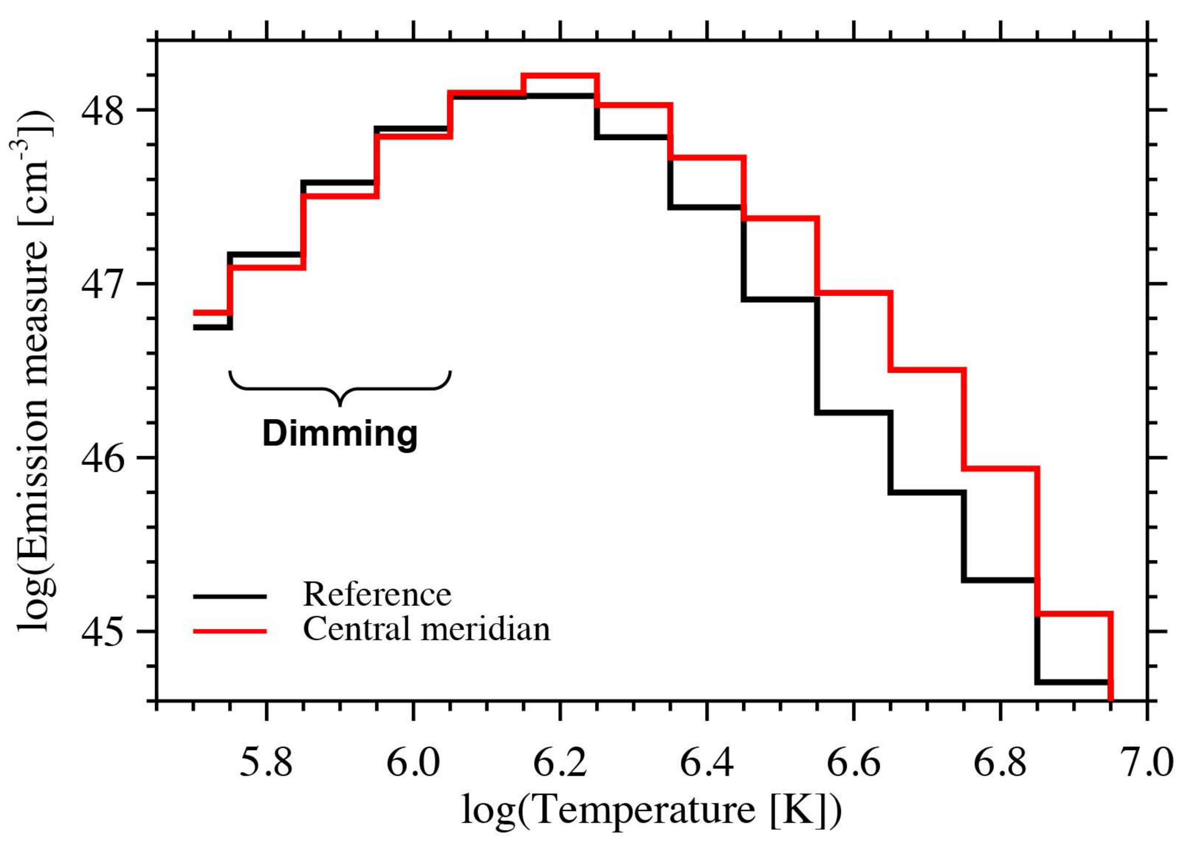


Fig. 2: Light curves in different wavelengths for the case of a sunspot group (active region 12699) transiting across the solar disk [click here for movie].

1. Strong correlations are found between UV irradiance sensitive to the chromosphere (e.g. 1600 Å, 1700 Å, and 304 Å) and photospheric total magnetic flux.
2. EUV and X-ray irradiances show flat-top variations because the coronal plasma is optically thin and thus is less dependent on the viewing angle. In general, the amplitude of light curves are greater for higher characteristic temperatures.
3. Time lags between the coronal and photospheric light curves reflect the extent of coronal magnetic fields above the sunspots.
4. EUV wavelengths that are sensitive to temperatures just below 1 MK (e.g. 171 Å) sometimes show antiphased variations.

Fig. 3: (Left) Emission measure of the transition-region temperature (0.6 to 0.8 MK). While the emission measure is increased above the active region around the disk center (white to yellow), that is reduced in the extended surrounding region (blue to red). (Right) Emission measure integrated over the entire solar disk. The emission measures of transition-region temperatures show reduction (noted "dimming"), whereas those of coronal temperatures are significantly increased.
This indicates a strong plasma heating owing to the active region.





Summary and discussion

Possible "tools" to diagnose magnetic and thermal structures of starspots:
(1) Near-UV radiations as the proxy for the total magnetic flux on the stellar surface (like Ca II monitoring).
(2) Time lags between the coronal and photospheric curves for the extension of coronal magnetic fields.
(3) EUV wavelengths sensitive to temperatures just below 1 MK for diagnosing plasmas around starspots.
The results may applied only to the slowly-rotating G-dwarfs, but nevertheless provide insight into how starspot atmospheres evolve in UV and X-rays. Next, we will explore multi-spot cases and try light curve modeling.

See
Toriumi et al. 2020 (ApJ, 902, 36)
for details