Lyman-alpha Variability During Solar Flares

Ryan O. Milligan
(Queen's University Belfast)

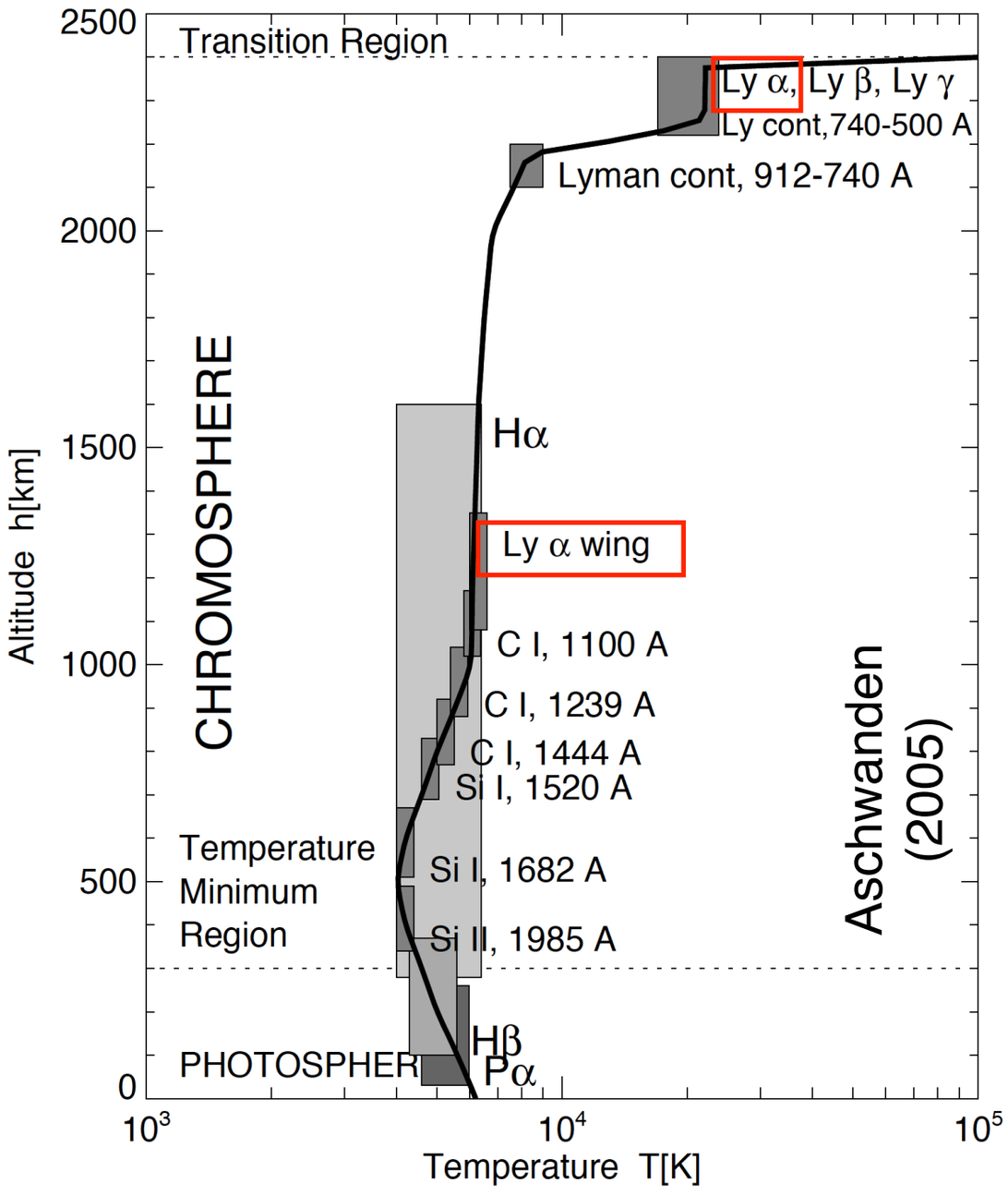
Co-authors: Hugh S. Hudson, Phillip C. Chamberlin, Laura A. Hayes

Queen's University Belfast

Science & Technology Facilities Council

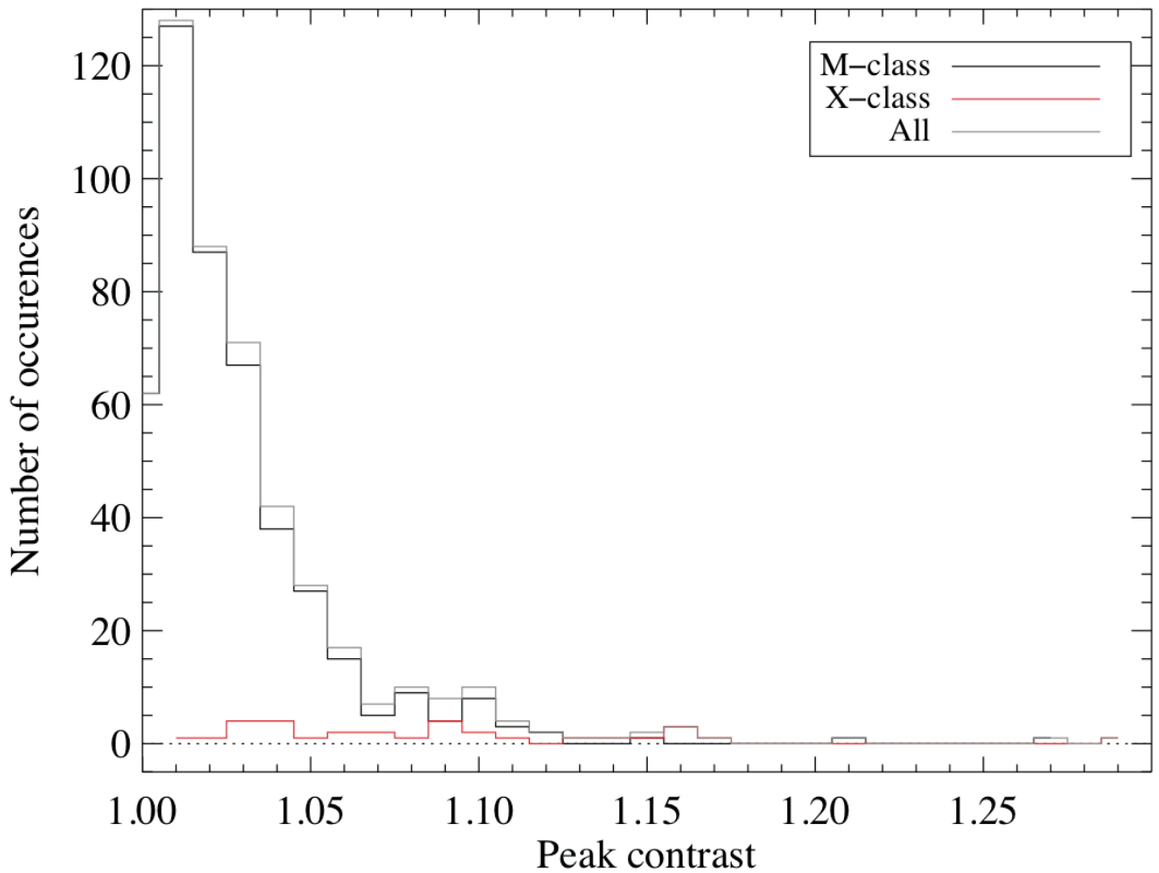
@ryanomilligan

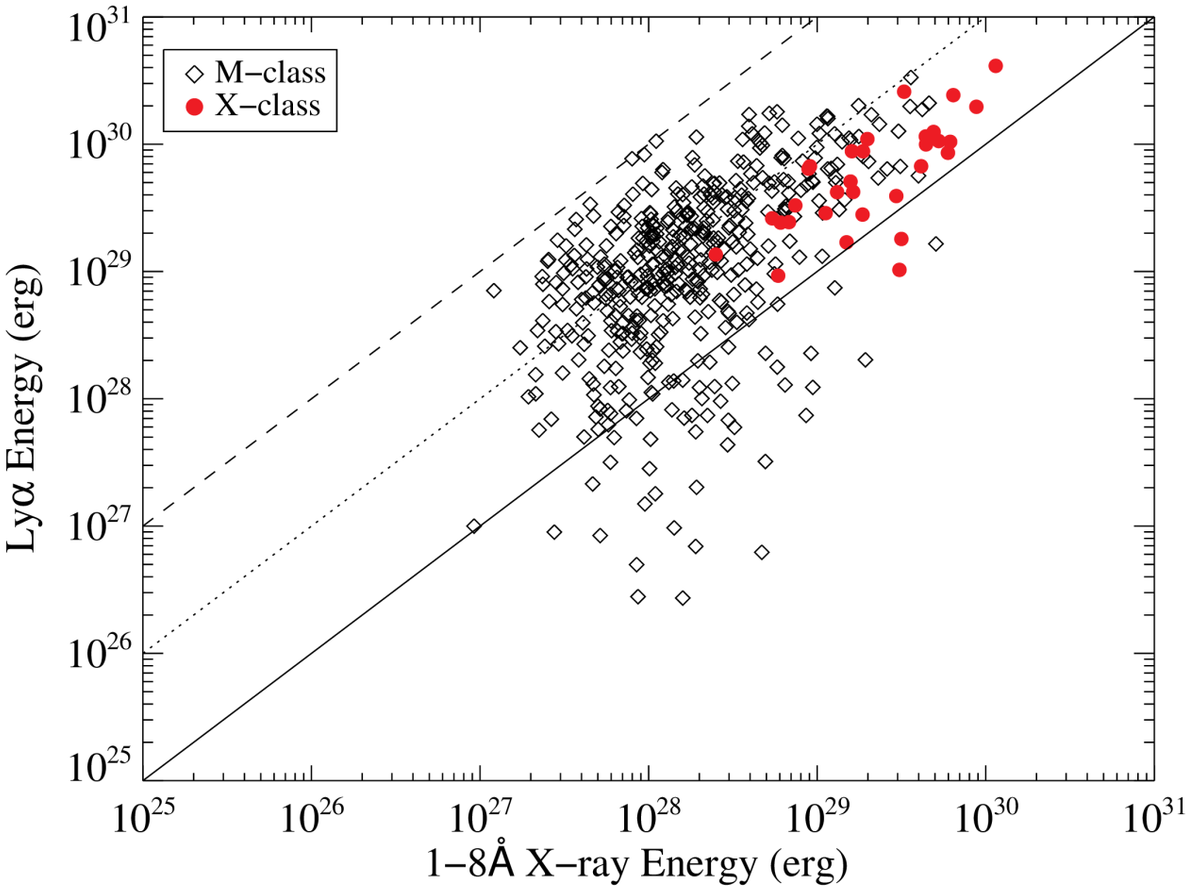
Lyman-alpha



- Lyman-alpha (Lyα; 1216Å) is the strongest emission line in the solar spectrum (H I: 2p→1s, T=8-40x10^{3}K)
- Line core is formed in the lower TR, wings are formed mid-chromosphere (quiet Sun), and is optically thick
- During solar flares, Lyα comes predominantly from the ribbons/ footpoints
- Important for ionospheric effects, flare energetics, and exoplanet habitability

Energetics

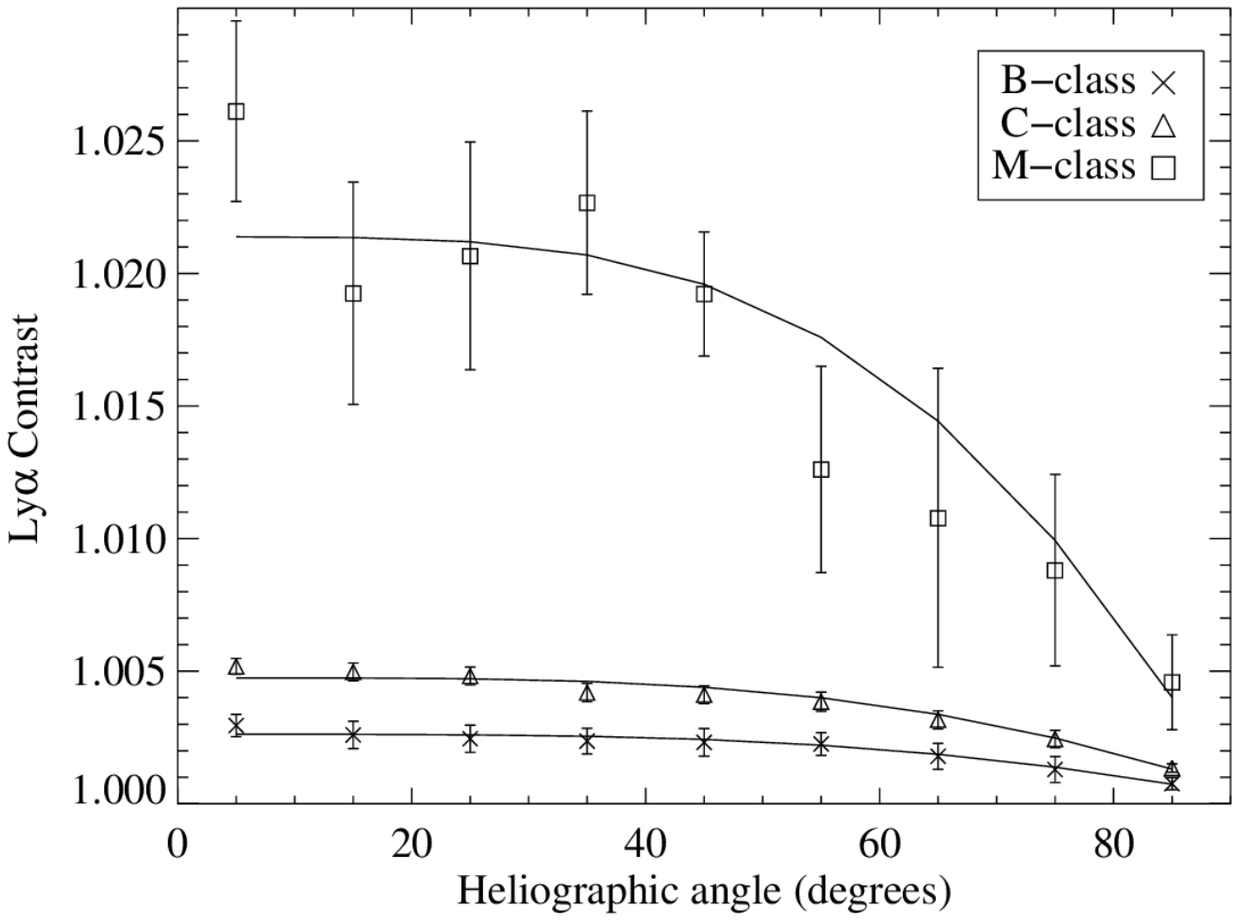


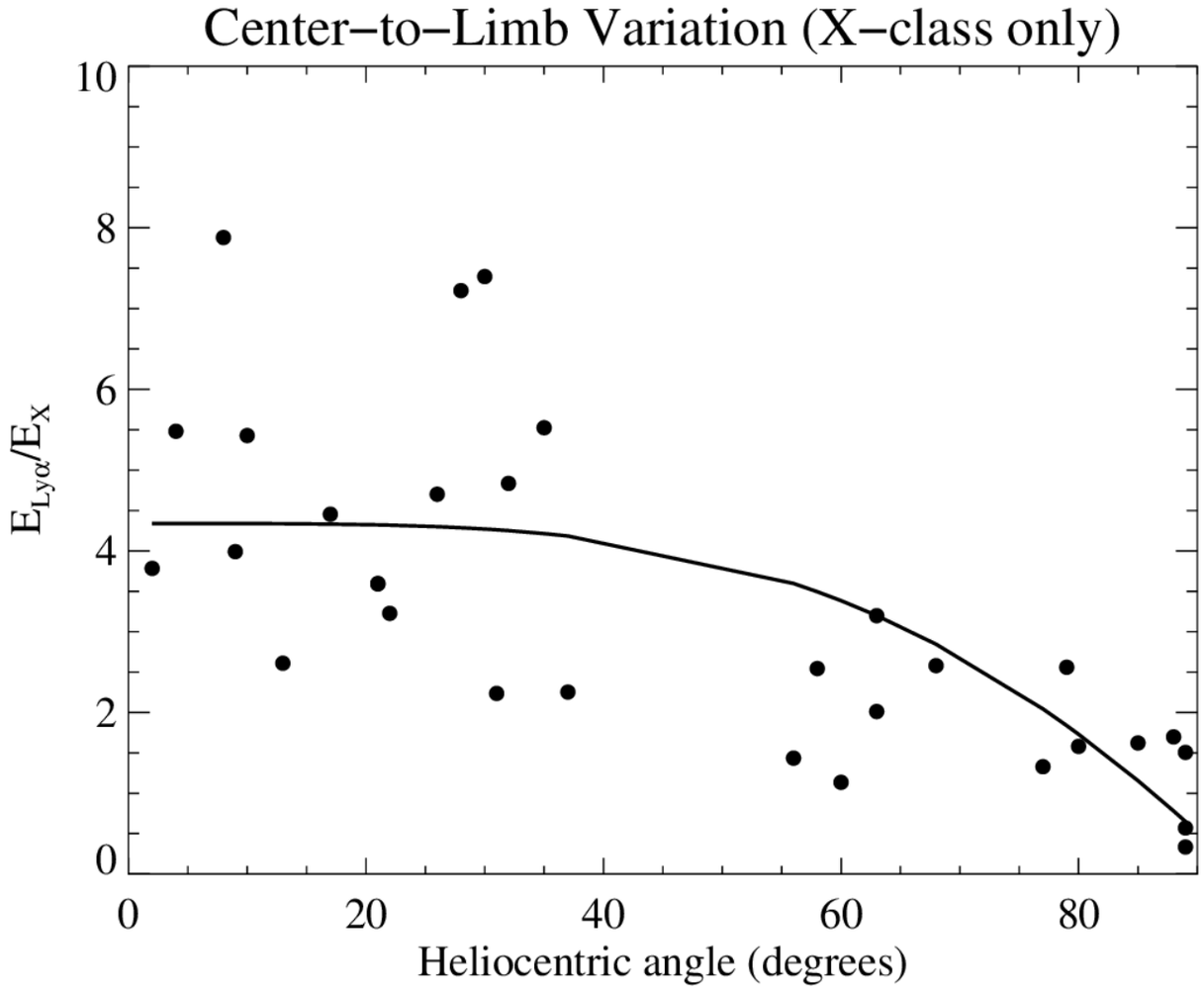


- Enhancements of Lyα emission above background did not exceed 30% for ~500 M and X flares (2010-2016)
- Typical increases of <10%
- Comparable to variability due to AR rotation, albeit on much shorter timescales
- Peak M-class Lyα flux/energy ≈ 1-100x peak X-rays
- Peak X-class Lyα flux/energy ≈ 1-10x peak X-rays
- (1 W/m^2 @1AU = 1.40x10^{30} erg s^{-1})

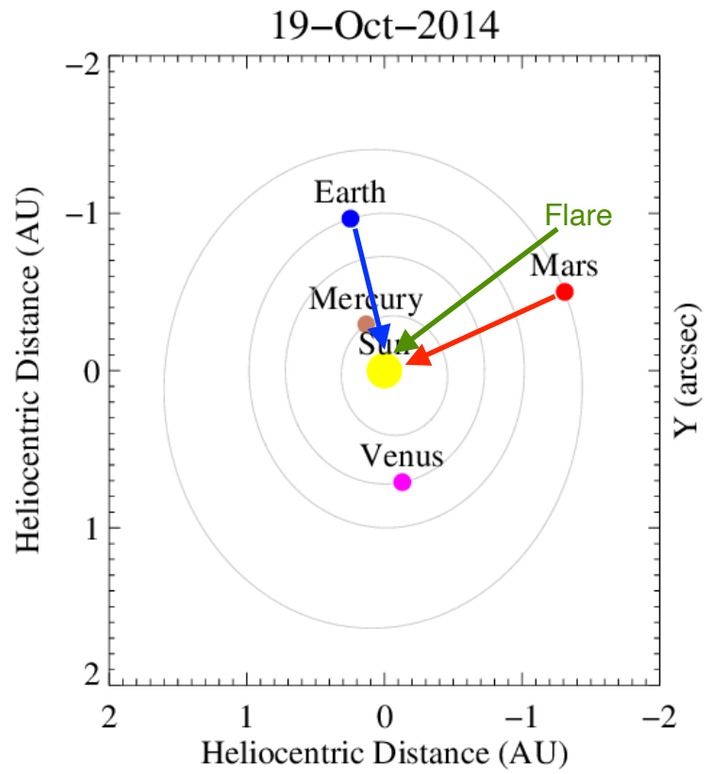
Milligan+ (2020)

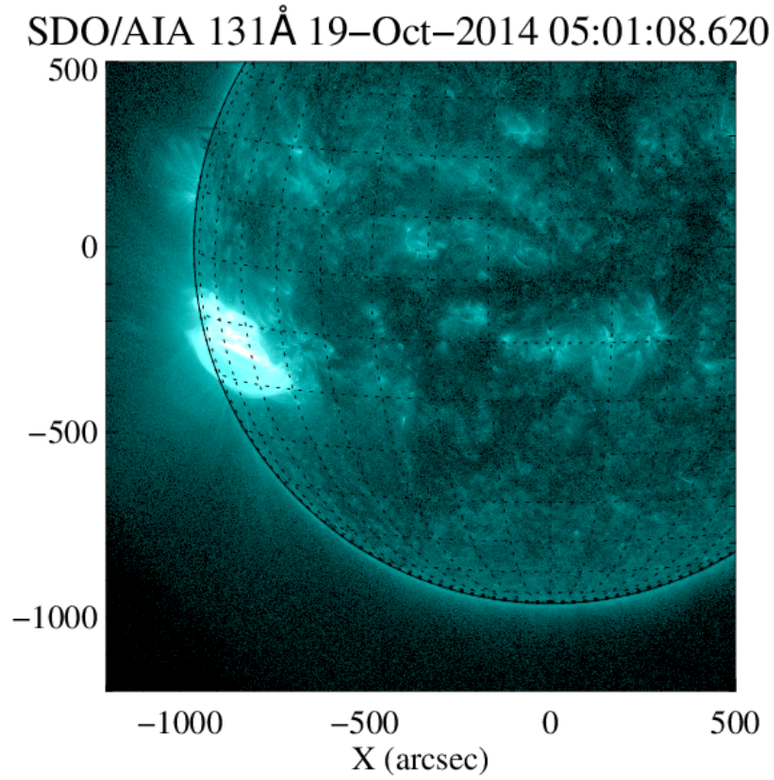
Center-to-Limb Variation

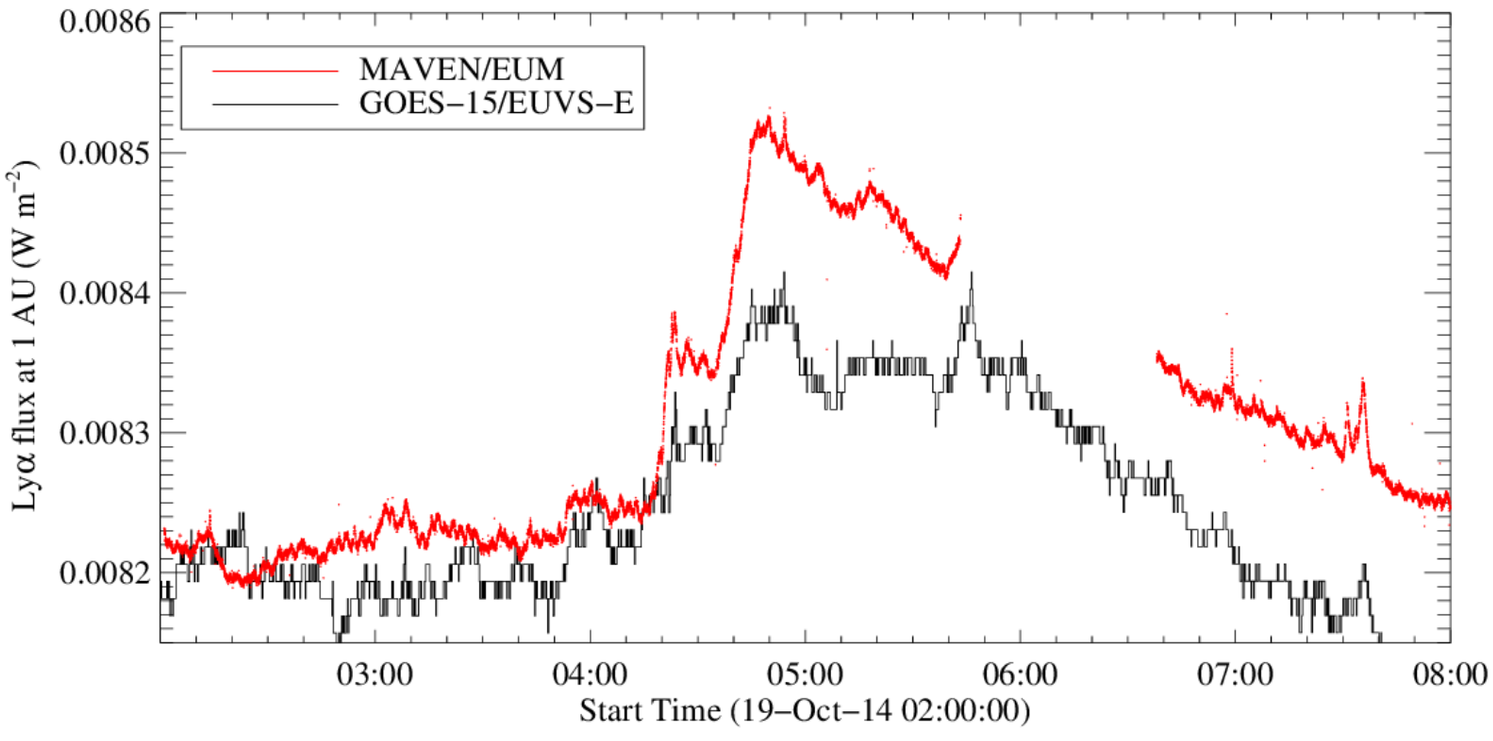




- The CLV can be expressed by (Woods+ 2006): $R = R_C\left[k + 2(1-k)\left(\mu - \frac{\mu^2}{2}\right)\right]$
- CLV has been found for flares of all classifications, although the nature remains an open question (opacity and/or foreshortening?)

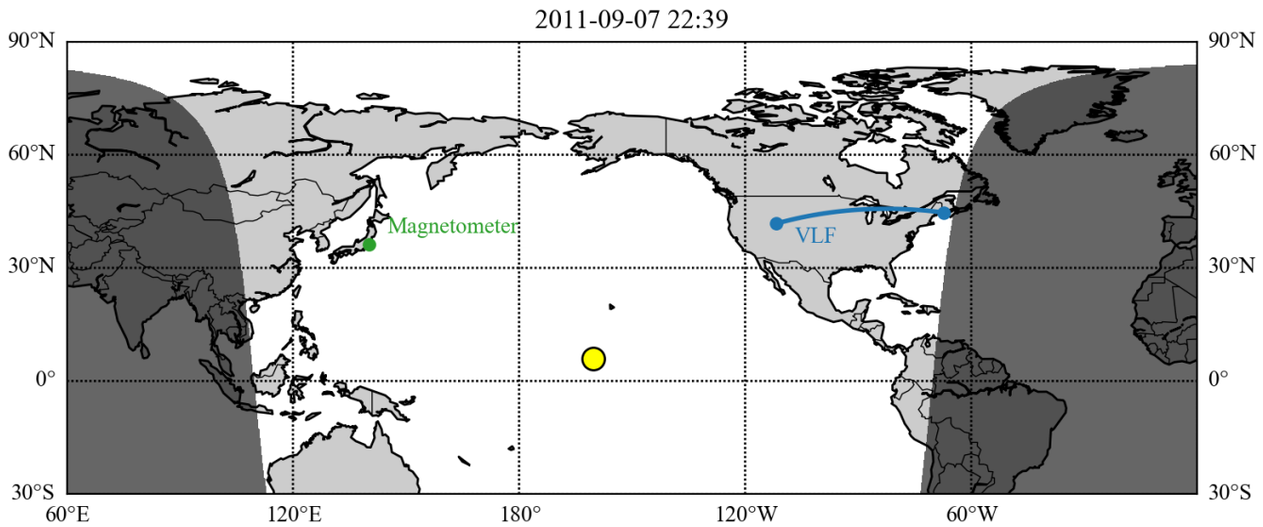


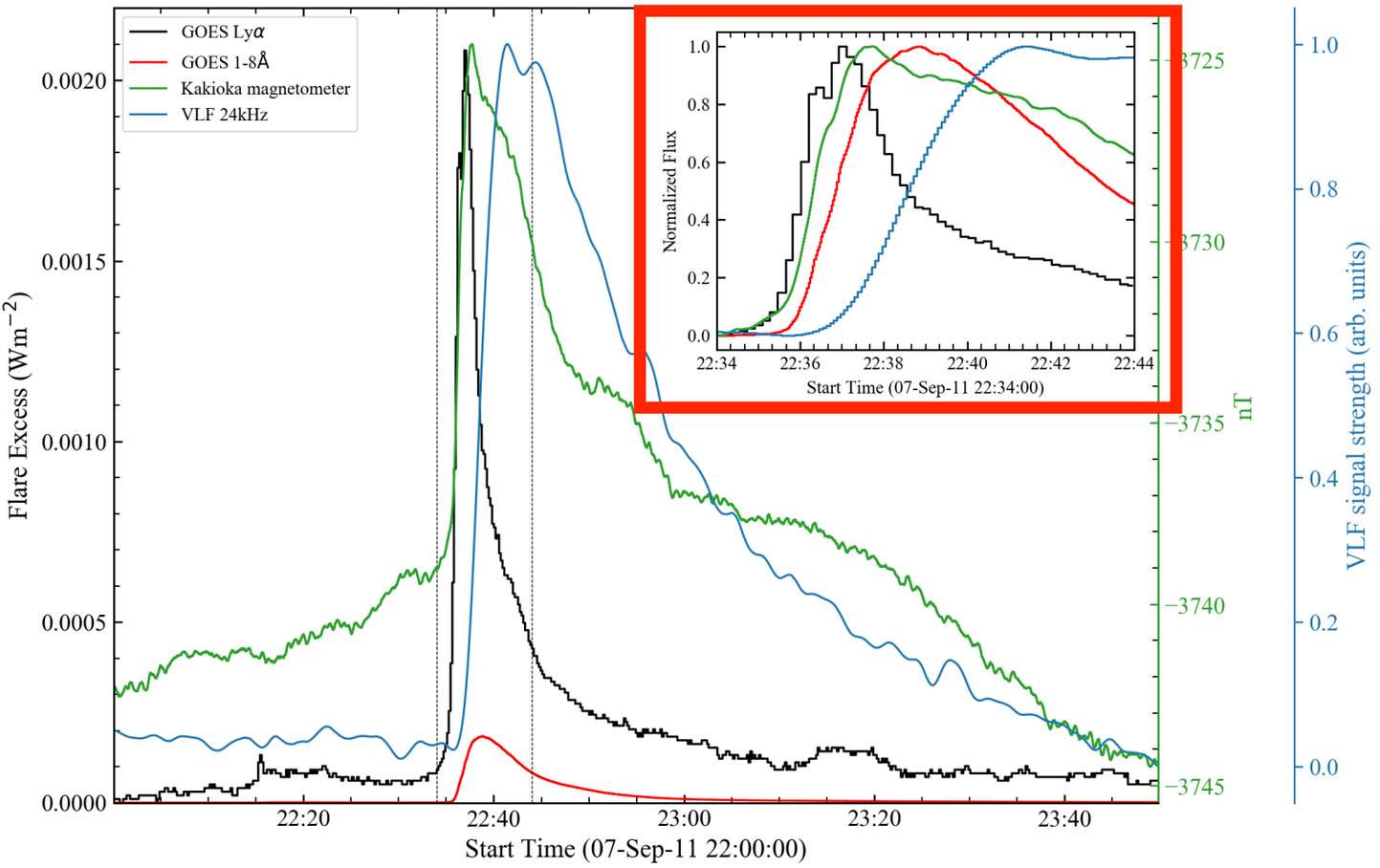




- In October 2014, an X-class flare was observed by GOES (on the limb) and MAVEN (at disk centre)
- After correcting for distance and light travel time, MAVEN flux was ~45% higher relative to that from GOES

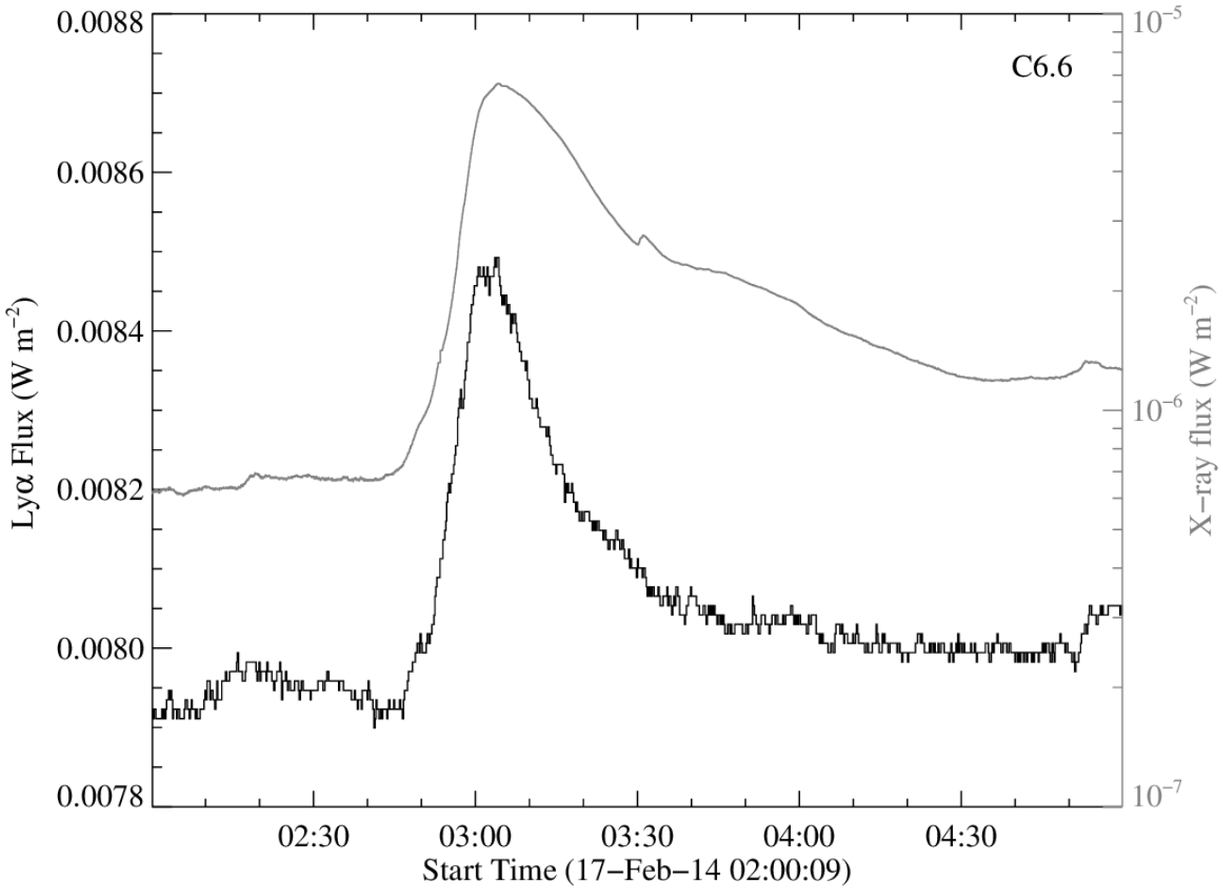
Ionospheric Effects of Lyα





- During the 7-Sep-2011 X-class flare, enhanced E-layer conductivity closely followed the increased **Lyα emission**
- Due to increased ionisation of nitric oxide (“Solar Flare Effect/Magnetic Crochet”)
- Corresponding X-rays lagged the E-layer response, implying that they could not have been the driver (Raulin+ 2013)
- The X-ray profile resembled the D-layer response from VLF observations with the known ~3-minute delay (“sluggishness”)

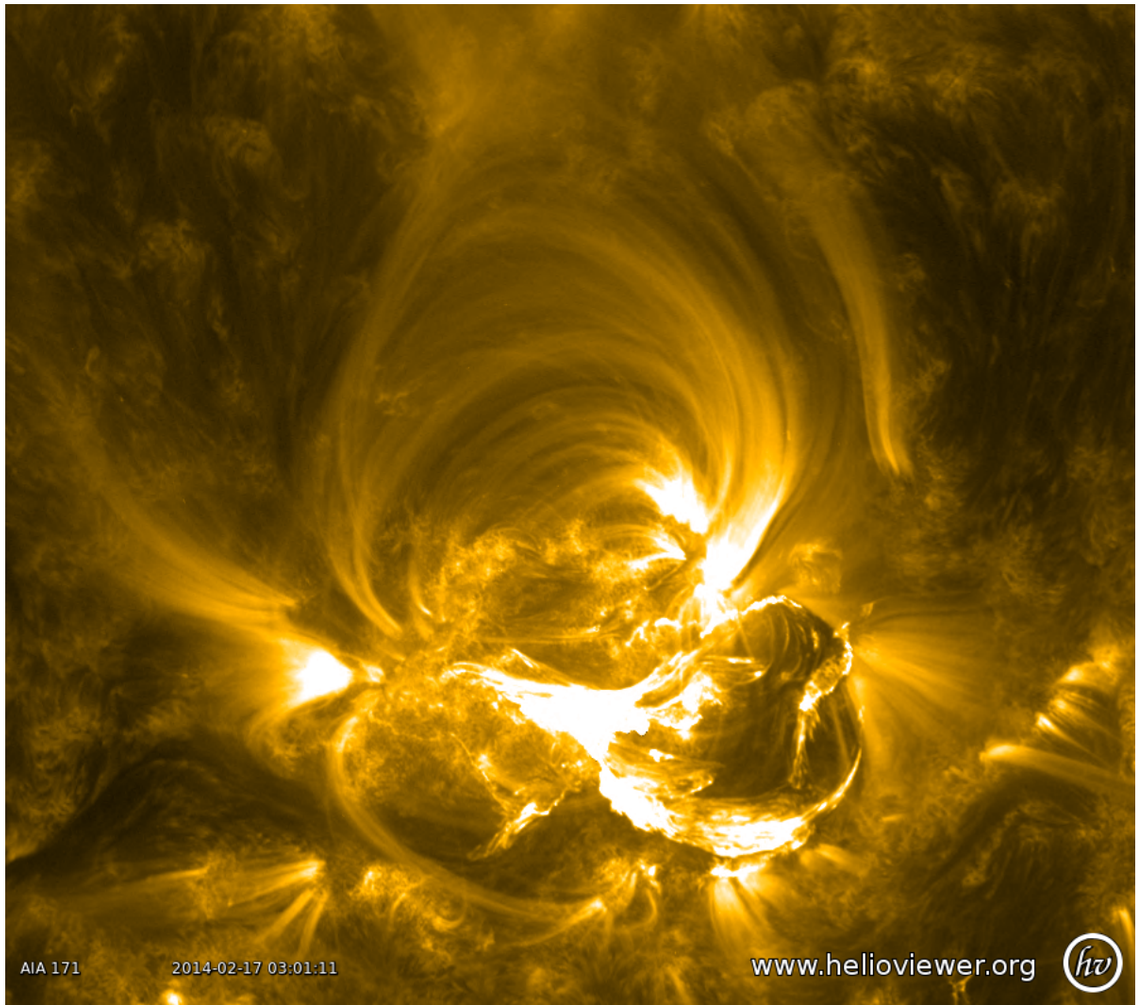
Milligan+ (2020)



An Unusual C-class Flare

- One event in the study - a C6.6 flare - produced a remarkable 7% increase in Lyα!

- This equates to 10^{30} erg of energy



- Such enhancements were believed to be associated with X-class flares

- Appears to be due to a failed filament eruption

- Evidence for Lyα emission from the corona…?

Milligan, Solar Physics, (2021)

Summary

(questions/comments/preprints: r.milligan@qub.ac.uk)

- Increases of <30% are observed in Lyα during flares (typically <10%) for M- and X-flares. B- and C-flares <0.5%.

- Energy radiated in Lyα equates to 1-100x that of X-rays.

- Center-to-limb variation is significant for all GOES classes; due to either opacity effects and/or foreshortening of the flare ribbons.

- Impulsive Lyα emission can induce currents in the E-layer of the ionosphere (previously attributed to X-rays, which affect the D-layer).

- These studies pave the way for Lyα datasets being released from current (GOES-N, SDO, MAVEN, SORCE, PROBA2, Solar Orbiter) and future (GOES-R, ASOS, Solar-C, SNIFS) missions, and modeling.