Properties of Super Active Region 13664 in Context of the 2024 May 10-11 Severe Geomagnetic Storm

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Abstract

The impact of solar-stellar activity on planetary environments is a topic of great interest within the Sun-Earth system as well as exoplanetary systems. In particular, extreme events such as flares and coronal mass ejections have a profound effect on planetary atmospheres. In May this year, a magnetic active region (AR) on the Sun (AR 13664) – with a size exceeding hundred times that of Earth – unleashed 23 high energy X-class flares and associated mass ejections over its lifespan [Fig. 1]. The resulting Earth impact (geomagnetic storm) on May 10-11 was the strongest in the last two decades. We perform the first comprehensive analysis of the magnetic properties of the AR that spawned these flares and identify this to be a super active region with very rare physical characteristics. We also demonstrate how the rate of energization in the magnetic properties of this AR is related to its flaring activity. Our work illuminates how flare productive super active regions on the Sun and stars can be identified and what are their salient physical properties.

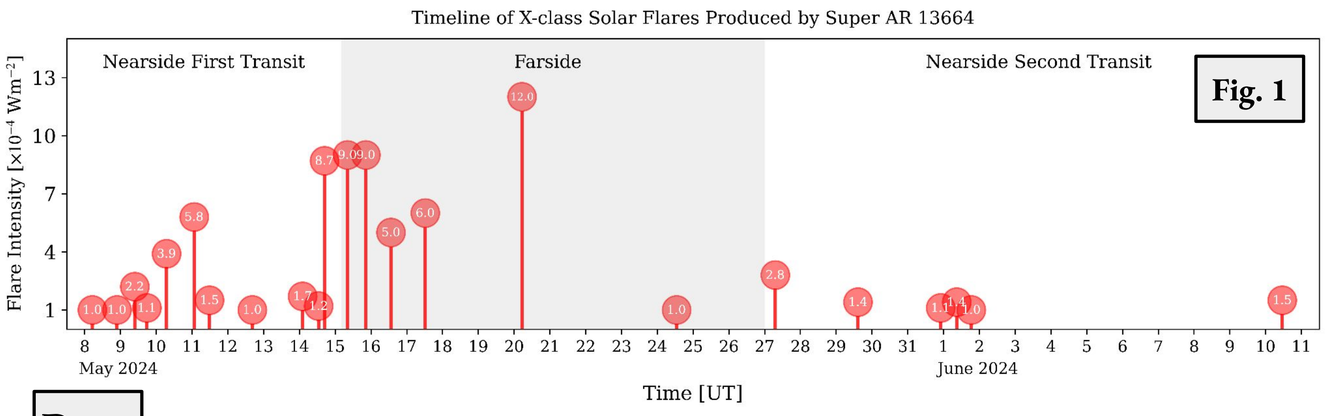
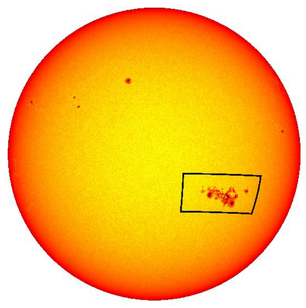


Fig. 1



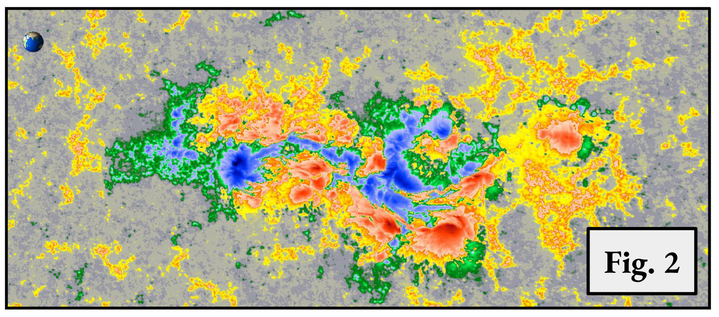


Fig. 2

Data

We use sunspot group area data recorded by the Royal Greenwich Observatory (RGO) and National Oceanic and Atmospheric Administration (NOAA) over the period May 1874 - June 2024. [Fig. 3]

Line of sight flux values are taken from Michelson Doppler Imager (MDI) onboard the ESA's Solar and Heliospheric Observatory (SOHO) and Helioseismic and Magnetic Imager (HMI) onboard the NASA's Solar Dynamic Observatory (SDO) over the cumulative period of April 1996 - June 2024. [Fig. 3]

Physical properties of active regions are curated from the Space weather HMI Active Region Patch (SHARP) data series – hmi.sharp_cea_720s. [Fig.4]

Spectrometer/Telescope for Imaging X-rays (STIX) data center is used to figure out the X class flares spawned from AR 13664 on the farside of the Sun. [Fig. 1]

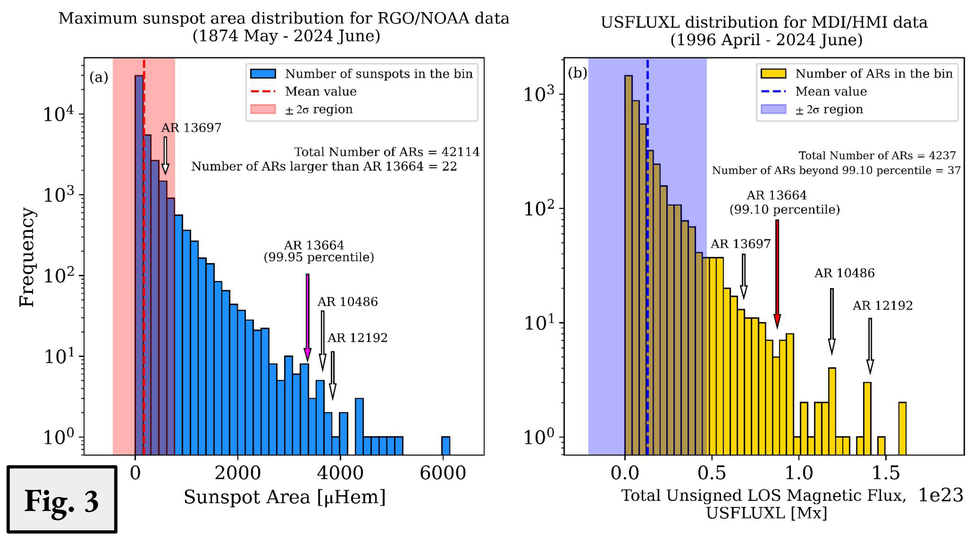


Fig. 3

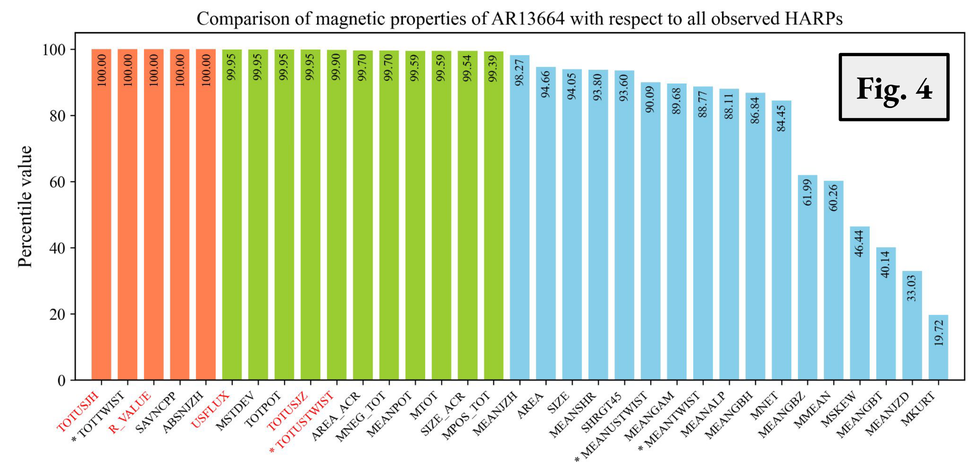


Fig. 4

How rare was AR 13664?

The maximum area of active pixels of AR 13664 during its lifetime was ~4395 μHem and as per the RGO data its maximum area was 3360 μHem during its lifetime on the solar disk [Fig. 2]. This puts AR 13664 at 99.95 percentile in area distribution of all the sunspot groups recorded in the RGO/NOAA database from May 1874 till June 2024. In simpler terms, in the past ~150 years, only 22 out of 42114 ARs were larger than AR 13664.

In terms of unsigned line-of-sight flux, AR 13664 ranks at 99.10 percentile with only 37 out of 4237 ARs exceeding its flux value over the cumulative period of April 1996 - June 2024.

Five of the physical properties of AR 13664 ranked the highest at 100.00 percentile among all the ARs in the SDO era (May 2010 - June 2024).

Results & Discussions

We find that AR 13664 is characterized by extremely large values of area and total unsigned line-of-sight flux. Given its large area, AR 13664 meets and far exceeds the area criterion of being a super active region (SAR).

Flaring activity occurred around the peak values of physical properties (including non-potentiality markers) of AR 13664, indicating that extreme activity levels require extreme energization of AR flux systems.

Taken together, our analysis establishes the extreme nature of AR 13664, firmly putting it at the high end of solar super active regions and demonstrating its uniqueness in terms of flare relevant properties.

Progression of X-class flares in AR 13664

Most of the X-class flares are observed to occur during the rapid rise in the flare relevant physical properties of the AR, clustered around the peak, which indicates that sufficient energization of flux system is required for flaring activity to commence and be sustained. [Fig. 5]

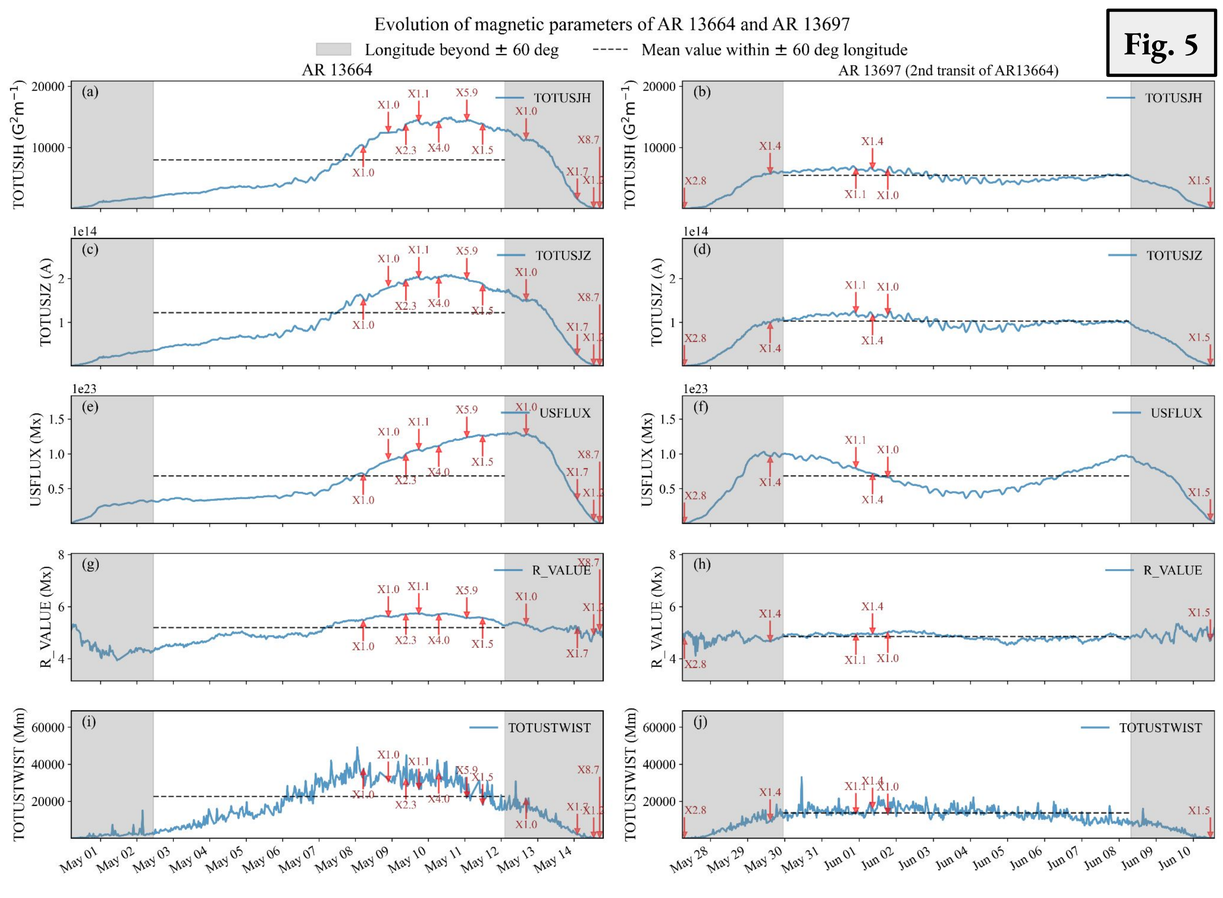


Fig. 5

References

"Deconstructing the Properties of Solar Super Active Region 13664 in the Context of the Historic Geomagnetic Storm of 2024 May 10-11", Jaswal P., Sinha, S., and Nandy, D., 2025, The Astrophysical Journal, 979, 31.

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