Redefining the Neupert Effect in M Dwarfs through Multi-Wavelength Timing Analysis of AU Mic's Flares

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Research Reflections

When observing stars,
looking through different lenses
can make secrets flare.

The Neupert Effect Helps Us Understand Flare Physics

The Neupert effect (NE) is a phenomenon in solar/stellar flares where the X-ray flux derivative peak and the Near-UV (NUV) peak flux occur simultaneously [1]. The Neupert effect is valuable in assessing habitability around stars: NUV radiation photo-dissociates ozone and X-rays evaporate planetary atmospheres [2]. The physical processes underlying the empirical NE are the following:

1. Electron beams propagate through magnetized parts of the corona, producing radio/microwave emission
2. The beams deposit energy into the chromosphere, releasing hard X-ray (HXR) and NUV/optical emissions
3. The pressure generated by the beam heating ablates chromospheric material into the corona, releasing soft X-ray emissions

However, the NE has not been investigated for a large sample of M dwarf flares at high-time resolution. **With a detailed study of high-time resolution X-ray and NUV M dwarf flare data, we can characterize the extent to which the Neupert effect holds up and constrain the role of powerful electron beams in producing multi-wavelength responses.**

We Used Multi-Wavelength AU Mic Observations to Study M Dwarf Flares

Our team collected simultaneous multi-wavelength data of the dM1e star AU Mic over a period of 7 days using a variety of telescopes (Swift, XMM, LCOGT, SMARTS, APO, ATCA, VLA) for full wavelength coverage.

In this poster, we present the results from the analysis of the following datasets:

- 10 sec resolution - XMM X-ray & UVW2 (sub for NUV)
- 25 sec resolution - LCO V
- 45 sec resolution - LCO U & SMARTS V

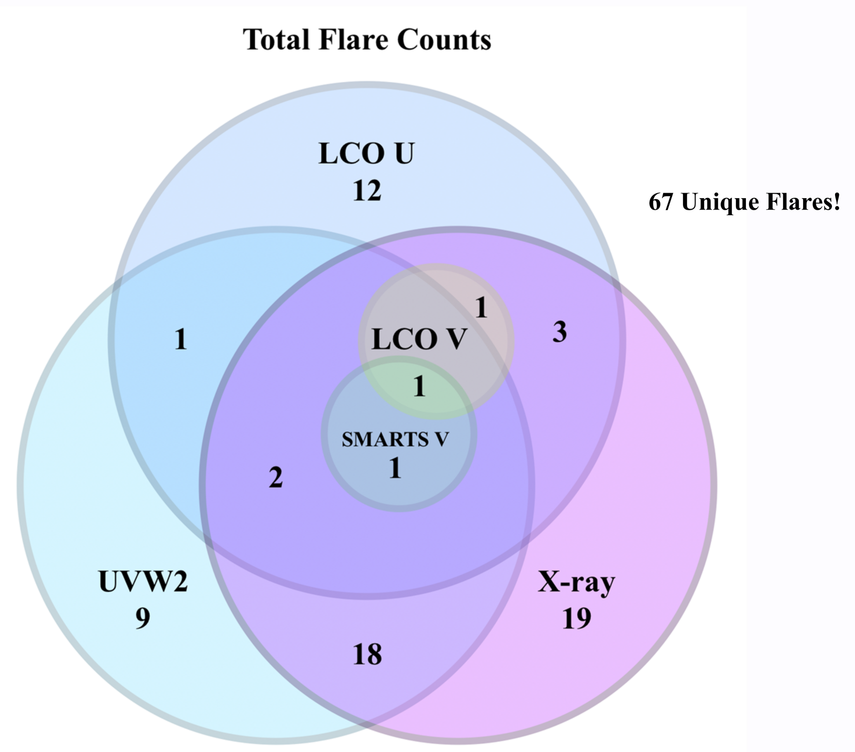


Figure 1. This Venn diagram shows the number of flares common to each dataset. Note that complex flares were treated as a single event for this studt.

The Neupert Effect Must be Adapted to Account for All Response Types

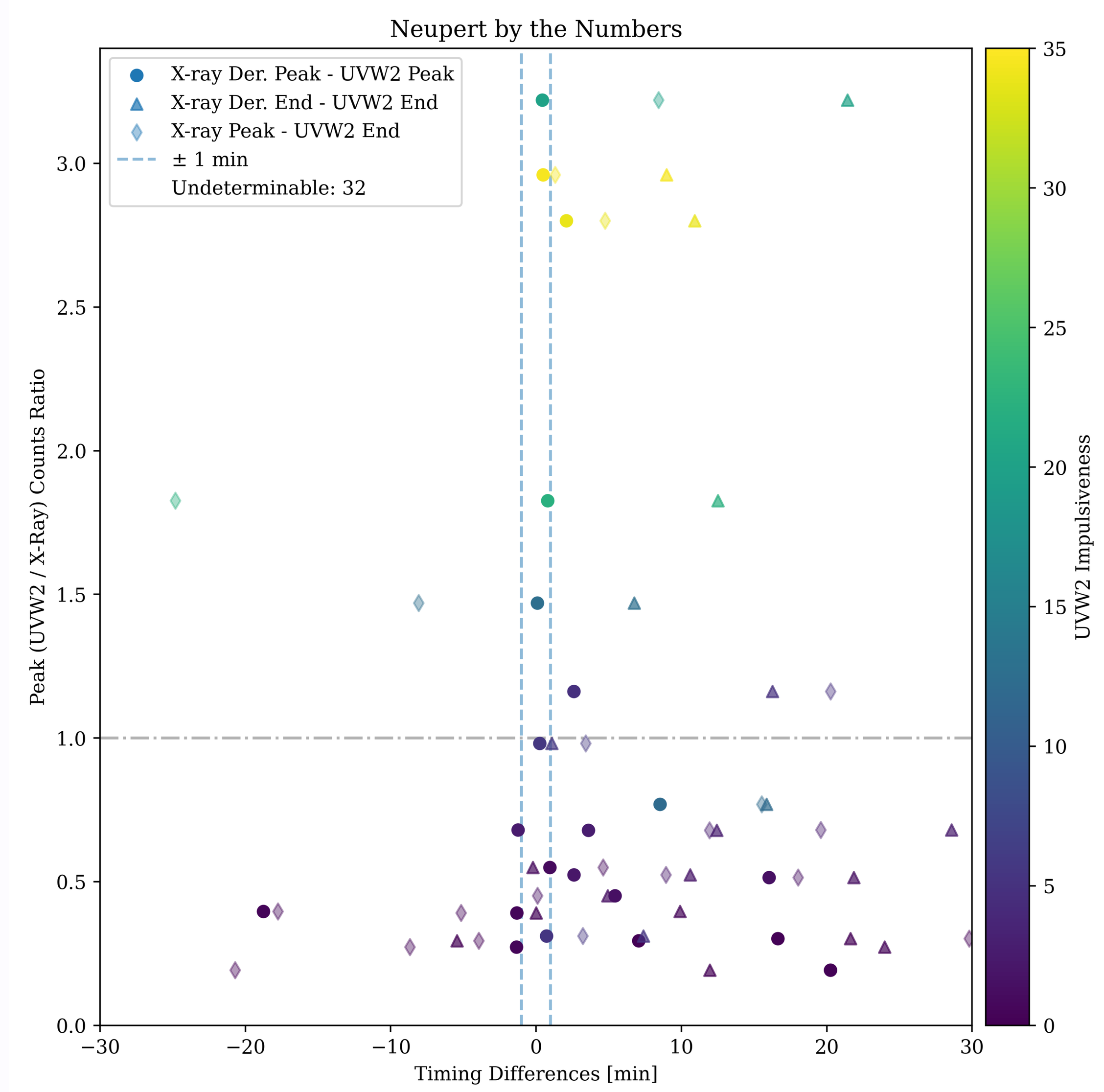
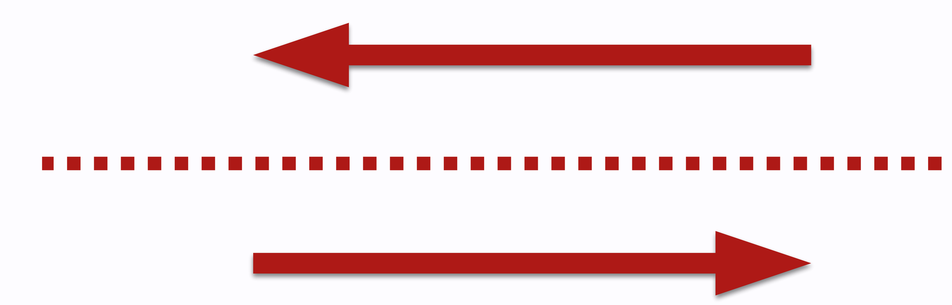


Figure 2. The most common NE metric is having no difference in timing between the X-ray derivative peak and the UVW2 (NUV) peak. Only 7 of 22 flares show this within a one minute buffer. More impulsive (normalized peak divided by FWHM [11]) flares tend to follow the NE more consistently.

The basis of the Neupert effect is that there is a causal relationship between the NUV and soft X-ray emissions during a flaring event that can be constrained by the differences in timing between the two responses [5]. Figure 2 compares several NE timing metrics used to categorize flares, using the 22 flares with simultaneous coverage in both X-ray and UVW2 filters.



The different flare responses in Figure 1 and timing differences in Figure 2 suggest a variety of multi-wavelength relationships, which we classify according to the following:

1. Neupert - Responses in both; SXR-derivative and NUV peak timings match
2. Quasi-Neupert - Responses in both; SXR-derivative and NUV peak timings do not match
3. Non-Neupert Type I - Only SXR response
4. Non-Neupert Type II - Only NUV response

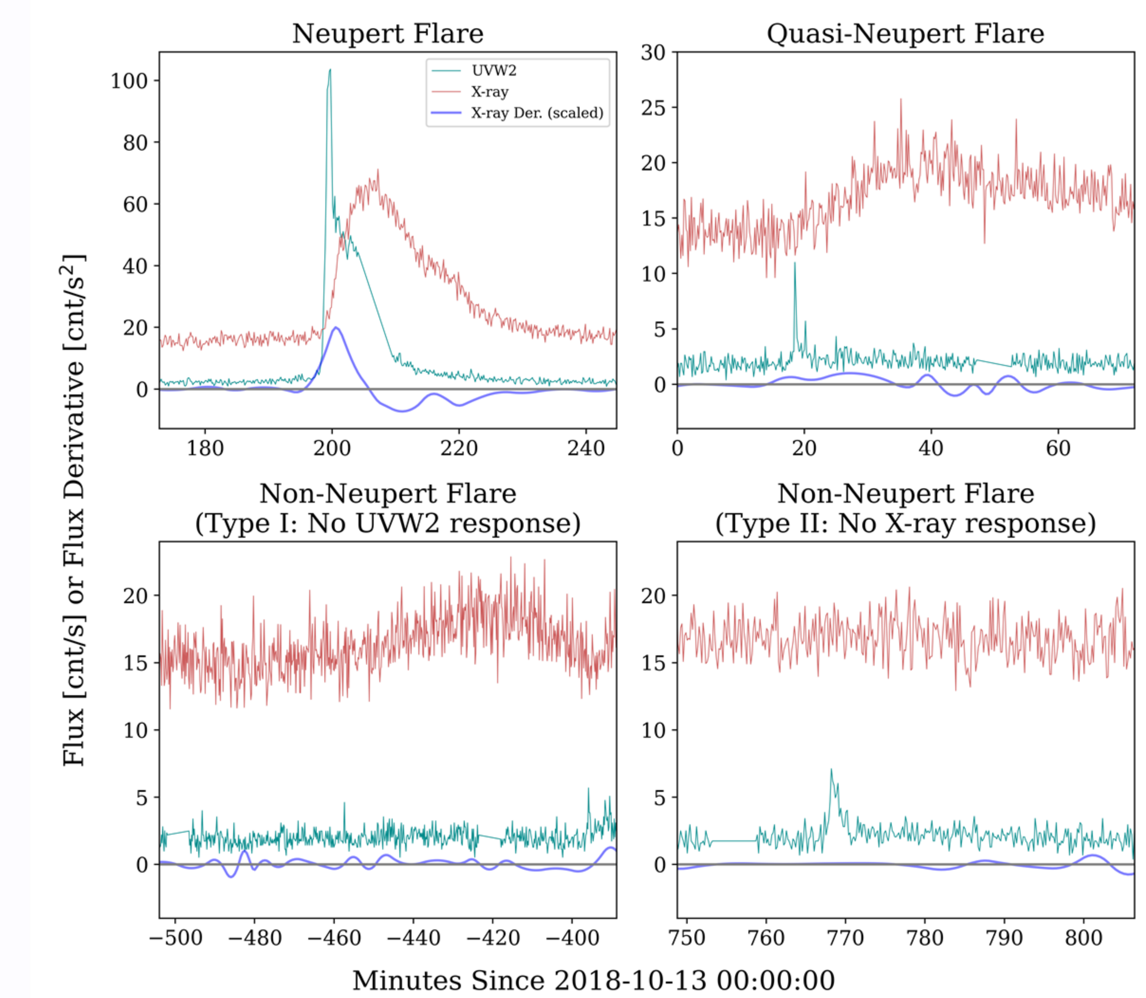


Figure 3. Visualizations of our classification. The existence of both Non-Neupert Type I & II flares shows that there is not always a definitive relationship between UVW2 and X-ray responses. This implies that each of these cases could have different physical processes generating the flare , as in solar flares where heat conduction is thought to contribute to the total heating in lower energy events [10].

Flare Energy Analysis

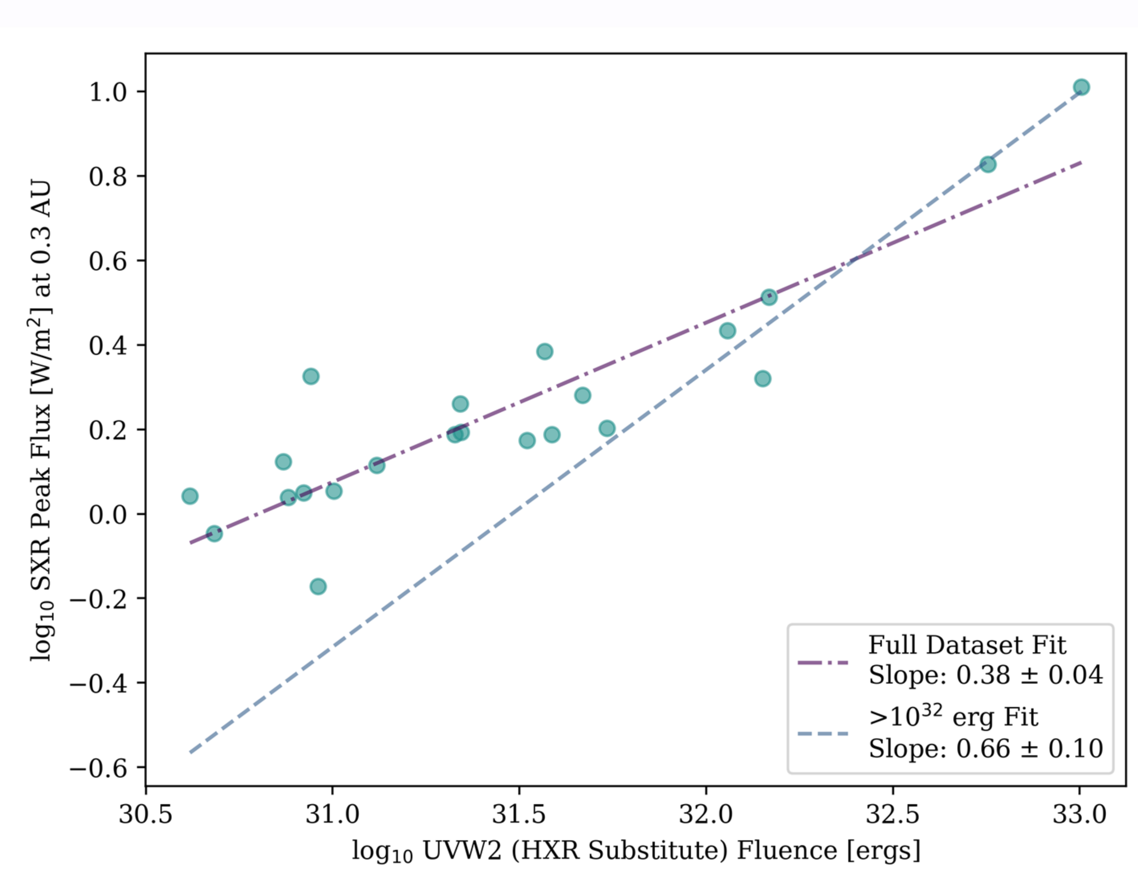


Figure 4. In general, it is expected that the Neupert effect may lead to a linear relationship between the soft X-ray peak flux and hard X-ray (or in his case, UVW2) fluence [6]. If this were the case, the slope of a linear-fit in log-log space would be 1, but our data departs from this expectation.

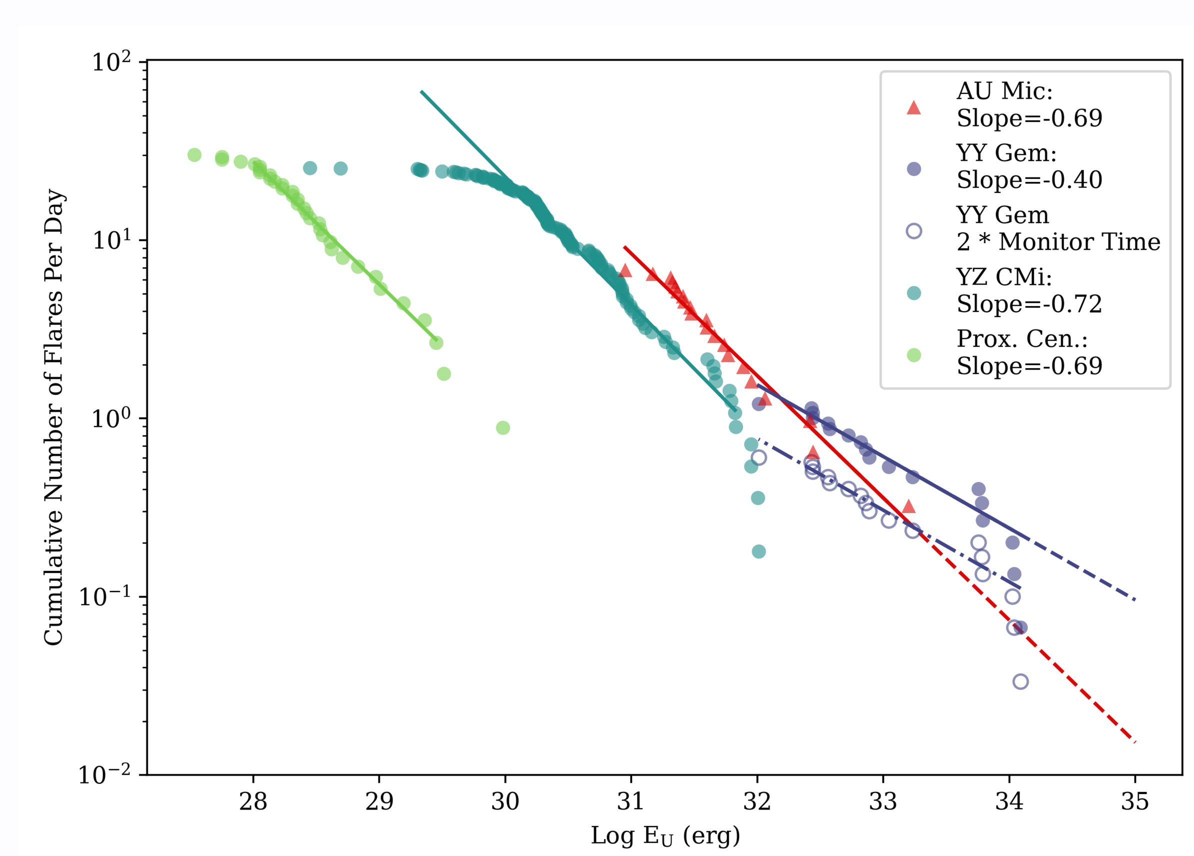


Figure 5. A cumulative flare frequency diagram (FFD) was created using U band flares. To our knowledge, this is the first modern U band survey of AU Mic's flare properties. We determined flare energies using the equivalent duration method [9]. Compared to YY Gem's flares from [4], AU Mic's flares are generally less energetic and more frequent. The opposite is true when comparing to YZ Cmi's and Proxima Centauri's flares from [4] and [3].

Summary and Future Work

- We used simultaneous high-time resolution multi-wavelength AU Mic observations to study the Neupert effect in M dwarfs
- We found that many flares did not adhere to the traditional NE and proposed a new classification to fit all responses

The next step of our AU Mic flare project is to add the existing radio and H-alpha data to our analysis. These will help us place tighter constraints on the non-thermal and thermal heating mechanisms and corresponding energies in M dwarf flares.

We then plan to use the RADYN flare modeling code [7,8] to place constraints on the heating processes needed to produce the flares in our data. We will explore the roles of proton beams and magnetic mirroring of electrons in producing the variety of panchromatic responses in Neupert, Quasi-Neupert, and non-Neupert (I and II) type M dwarf flares.

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