

This work was written as part of one of the author's official duties as an Employee of the United States Government and is therefore a work of the United States Government. In accordance with 17 U.S.C. 105, no copyright protection is available for such works under U.S. Law.

Public Domain Mark 1.0

<https://creativecommons.org/publicdomain/mark/1.0/>

Access to this work was provided by the University of Maryland, Baltimore County (UMBC) ScholarWorks@UMBC digital repository on the Maryland Shared Open Access (MD-SOAR) platform.









Please provide feedback

Please support the ScholarWorks@UMBC repository by emailing scholarworks-group@umbc.edu and telling us what having access to this work means to you and why it's important to you. Thank you.

NOTICE: We are aware of an issue affecting the delivery of some of the website content to a small subset of our customers. It appears to only affect those using Avast or AVG antivirus software. We apologise if this causes any inconvenience while we work to resolve this issue.

OPEN ACCESS

A Pilot Survey of an M Dwarf Flare Star with Swift's UV Grism

Shashank Chavali¹ , Allison Youngblood² , Rishi R. Paudel^{2,3,4} , R. O. Parke Loyd⁵ ,
Karan Molaverdikhani^{6,7,8} , J. Sebastian Pineda¹ , Thomas Barclay^{2,3,4} , and
Laura D. Vega^{2,4,9} 

Published September 2022 • © 2022. The Author(s). Published by the American Astronomical Society.

Research Notes of the AAS, Volume 6, Number 9

Citation Shashank Chavali *et al* 2022 *Res. Notes AAS* **6** 201

shashank.chavali@colorado.edu

¹ Laboratory for Atmospheric and Space Physics, University of Colorado, 600 UCB, Boulder, CO 80309, USA; shashank.chavali@colorado.edu

² Exoplanets and Stellar Astrophysics Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA

³ University of Maryland, Baltimore County, Baltimore, MD 21250, USA

⁴ Center for Research and Exploration in Space Science and Technology, NASA/GSFC, Greenbelt, MD 20771, USA


⁵ Eureka Scientific, Oakland, CA 94602, USA


⁶ Universitäts-Sternwarte, Ludwig-Maximilians-Universität München, Scheinerstrasse 1, D-81679 München, Germany


⁷ Exzellenzcluster Origins, Boltzmannstrasse 2, D-85748 Garching, Germany

⁸ Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany


⁹ University of Maryland, College Park, MD 20742, USA


Shashank Chavali  <https://orcid.org/0000-0001-9615-7181>

Allison Youngblood  <https://orcid.org/0000-0002-1176-3391>


Rishi R. Paudel  <https://orcid.org/0000-0002-8090-3570>

R. O. Parke Loyd  <https://orcid.org/0000-0001-5646-6668>

Karan Molaverdikhani  <https://orcid.org/0000-0002-0502-0428>

J. Sebastian Pineda  <https://orcid.org/0000-0002-4489-0135>


Thomas Barclay  <https://orcid.org/0000-0001-7139-2724>

Laura D. Vega  <https://orcid.org/0000-0002-5928-2685>

1. Received September 2022
2. Revised September 2022
3. Accepted September 2022
4. Published September 2022

<https://doi.org/10.3847/2515-5172/ac9591>

Stellar flares; M dwarf stars; Pre-main sequence stars; Pre-biotic astrochemistry; Near ultraviolet astronomy

 Journal RSS

Create or edit your corridor alerts

What are corridors?

Create citation alert

Abstract

The near-ultraviolet (NUV) spectral region is a useful diagnostic for stellar flare physics and assessing the energy environment of young exoplanets, especially as relates to prebiotic chemistry. We conducted a pilot NUV spectroscopic flare survey of the young M dwarf AU Mic with the Neil Gehrels Swift Observatory's UltraViolet and Optical Telescope. We detected four flares and three other epochs of significantly elevated count rates during the 9.6 hr of total exposure time, consistent with a NUV flare rate of $\sim 0.5 \text{ hr}^{-1}$. The largest flare we observed released a minimum energy of $6 \times 10^{33} \text{ erg}$ between 1730 and 5000 Å. All flares had durations longer than the $\sim 14\text{--}17$ minutes duration of each Swift visit, making measuring total flare energy and duration infeasible.

Export citation and abstract

[BibTeX](#)

[RIS](#)

◀ **Previous article in issue**



Original content from this work may be used under the terms of the Creative Commons Attribution 4.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

1. Introduction

The near-ultraviolet (NUV; $\sim 1700\text{--}3200\text{ \AA}$) is a historically under-studied region for stellar flares, but has an enormous potential for diagnosing flare physics. In flare models such as Kowalski et al. (2013), the broad-band visible light from a flare comes from a sunspot-sized patch of hot, $\sim 10,000\text{ K}$ plasma on the stellar photosphere, making NUV measurements potentially more efficient at constraining this flaring mechanism than any other wavelength range. The NUV is also thought to be an essential energy source for triggering abiogenesis, the origin of life, and open questions remain about whether the cool photospheres of M dwarfs could provide enough NUV photons to initiate chemical reactions that ultimately lead to the production of RNA precursors and whether flares could make up for the deficit in NUV energy (Ranjan et al. 2017; Rimmer et al. 2018).

2. Observations and Reductions

We designed a pilot program to determine the viability of NUV spectroscopic monitoring of flare stars with the Neil Gehrels Swift Observatory (Swift) UltraViolet Optical Telescope (UVOT) grism. The UVOT UV grism is optimized for $1700\text{--}2900\text{ \AA}$ first-order spectra at spectral resolving power $R \sim 150$. We targeted AU Mic, a pre-main sequence M0Ve star at 9.7 pc , for its brightness ($V = 8.6\text{ mag}$), high flare rate ($\sim 0.5\text{ hr}^{-1}$ based on archival UVOT UVM2 photometry; E. Gilbert et al. 2022, in preparation), and sky location away from the Galactic center where source confusion and oversubscription of Swift observing time are less of a concern. We observed AU Mic for 52 ks (14.4 hr) over 42 individual spacecraft visits between 2020 April 5 and 2021 April 2 using the UVOT 0x0384 mode, which alternates between the UV grism (UGRISM, clocked mode, 120 s exposures) and UVM2 images (30 s exposures, used for aspect correction, $1997\text{--}2495\text{ \AA}$), resulting in $\sim 14\text{--}18$ minutes elapsed time per visit. After overhead, the total target exposure time was 34.5 ks (9.6 hr). Event mode is generally not used with the grism because of the burden on telemetry.

We reduced the UVOT data using standard procedures from HEASoft (Nasa High Energy Astrophysics Science Archive Research Center (Heasarc), 2014) and uvotpy (Kuin 2014). We corrected for offsets in the uvotpy wavelength solutions by fitting the blended Mg II h&k emission lines with a Gaussian and

shifting the centroid to 2800 Å (Kuin et al. 2015). We corrected for contamination by background stars by visually inspecting every 2D spectrum and using linear interpolation to splice out parts of the spectrum contaminated by background stars. These corrections were different for every spectrum because the roll angle of the telescope varies over the course of a year.

3. Results

We established median flux levels for the ensemble UVM2 (11.4 counts s⁻¹) and grism data and searched for data that lay $>3\sigma$ above the median in order to identify flares. In the total 34.5 ks spent on target, we detected four flares (one shown in Figure 1) and three additional epochs where the count rate was significantly elevated above the median, but the light curve morphology was inconsistent with flaring. Note, however, that the cadence and total duration of our visits do not allow us to rule out flaring for these three elevated-flux epochs. Without event mode, 30–120 s cadence combined with 14–18 minutes visit durations is a challenging setup for fully resolving flare light curves. We could not determine the start and stop times of any of our flares, so we adopt the visit durations (16.6–18.2 minutes) as the minimum flare durations. For the three elevated epochs, the visit durations were only 14.2 minutes.

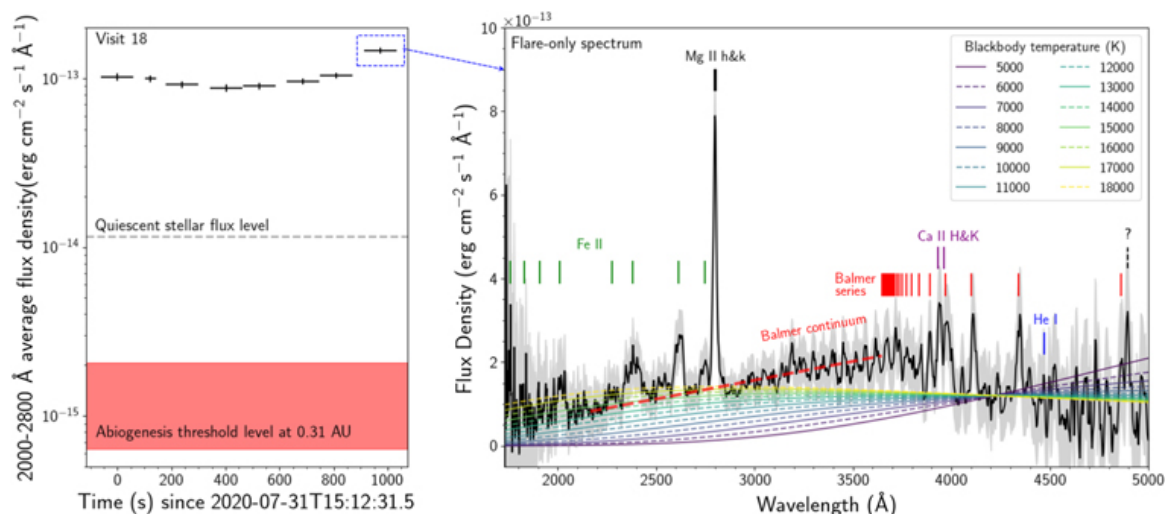


Figure 1. Swift grism data from the brightest flaring epoch show that AU Mic regularly exceeds the abiogenesis threshold and that the flaring emission is comprised of chromospheric emission lines, Balmer continuum, and possibly blackbody continuum. Left: the average stellar flux from 2000 to 2800 Å is shown as a function of time from the start of Visit 18. The red shaded area shows the abiogenesis threshold level from Rimmer et al. (2018) at 0.31 au (AU Mic's conservative inner habitable zone edge), and the dashed gray line shows the quiescent stellar flux level. Right: a flare-only spectrum (i.e., the quiescent stellar spectrum is subtracted from the in-flare spectrum) of the brightest data point from the left panel is shown as a black line with the gray shading representing the 1σ uncertainty. Various emission lines and the Balmer continuum are labeled. The colored lines show blackbody curves with temperatures ranging from 5000 to 18,000 K normalized to match the spectrum at 4200 Å.

The dates corresponding to the four flaring epochs are: 2020 May 10, July 5, 31 (Figure 1), and 2020 October 18. The three periods of elevated flux that could not confidently be identified as flares occurred on 2020 April 26, June 28, and July 26. The observed flare rate of $0.42\text{--}0.73\text{ hr}^{-1}$ is consistent with that expected from archival UVM2 photometry of AU Mic (E. Gilbert et al. 2022, in preparation).

Sufficient NUV photons may be a necessary ingredient for triggering photoreactions that kick off prebiotic chemical pathways. We compared all spectra to the 2000–2800 Å abiogenesis threshold from Rimmer et al. (2018) to determine how flares could impact the ability of M dwarf stars to meet this flux threshold. Unlike older, later type M dwarfs, AU Mic provides $\sim 4\times$ the abiogenesis threshold energy during quiescence to its conservative inner-habitable zone edge (0.31 au; Kane et al. 2022). Our results

indicate that AU Mic spends 98% of the time $>5\times$ above the threshold, 26% $>10\times$ above the threshold, 4% $>25\times$ above the threshold, and 0.3% $>50\times$ above the threshold. Note that AU Mic's two known Neptune-sized exoplanets at 0.06 and 0.11 au are closer to the star than the habitable zone (Cale et al. 2021).

We subtracted the median spectrum from each of the flare spectra in order to analyze the type of emission processes responsible for the flux increases we observe during flaring and/or elevated epochs. We obtained useful flare spectra between ~ 1730 and 5000 \AA for our largest flare (Figure 1), which lasted >18.2 minutes and released a minimum of $6 \times 10^{33} \text{ erg}$ in the $1730\text{--}5000 \text{ \AA}$ bandpass, with roughly equal energy contribution from emission above and below the Balmer series limit at 3646 \AA . We find Balmer emission from $H\beta$ through the Balmer series limit at 3646 \AA , and Ca II H&K emission. Continuum in the $4000\text{--}5000 \text{ \AA}$ region is roughly flat and consistent with a $\sim 6000\text{--}15,000 \text{ K}$ blackbody. Shortward of 3646 \AA , we observe bright Balmer continuum emission that dominates over any hot blackbody component. The emission lines shortward of the Balmer series limit are blended multiplets from Mg II and Fe II. This flare spectral energy distribution is consistent with that found for GJ 1243 (M4Ve) by Kowalski et al. (2019).

4. Conclusion

The goal of this Swift pilot survey of AU Mic was to explore the utility of Swift's UV grism mode for stellar flare monitoring. Aside from the Hubble Space Telescope, which has detector protection restrictions in place against flaring M dwarfs, Swift's grism uniquely provides NUV spectroscopy for studying stellar flares. We have shown that although the 0x0384 mode's lack of event mode and short visit duration make determining flare morphology and total duration challenging, flux-calibrated flare spectra are readily measurable. Future Swift flare surveys should explore the feasibility of consecutive executions of the 0x0384 mode so that individual visits could extend longer.

The authors thank Paul Kuin for advice in setting up this observing program and using uvotpy. This work was supported by NASA's Swift Guest Investigator Program under award 80NSSC20K1112.