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With modifications by David W. Hogg and Daniel Foreman-Mackey

THE GALEX VIEW OF “BOYAJIAN’S STAR”

James R. A. Davenport[1,2] Riley W. Clarke[1] Zachery Laycock[1] Kevin R. Covey[1] scott flemming[3] tabby boyajian[4] Bernie Shiao[3] chase million[5] Benjamin T. Montet[6] david wilson[7] Manuel Olmedo[8] eric mamajek[9]

[1]Department of Physics & Astronomy, Western Washington University, 516 High St., Bellingham, WA 98225, USA

[2]NSF Astronomy and Astrophysics Postdoctoral Fellow

ABSTRACT

The enigmatic star KIC 8462852, also known as “Boyajian’s Star”, has puzzled for both its short (days) length dimming events, and a years-long secular dimming observed by the *Kepler* mission. GALEX provides both short timescale sampling from the photon-counting data, and longer baseline data from multiple campaigns that imaged this field/ also providing a wide wavelength baseline to compare with the optical *Kepler* data, and provide important constraint for models of this system. here we investigate both the short and long timescale data. from 4 GALEX visits totaling 1600 seconds of exposure time in 2011, spread over 70 days, we find no coherent NUV variability in the system on 10–100 sec timescales during these time windows. Comparing the integrated flux from these 2011 visits to the 2012 NUV flux published in the GALEX-CAUSE Kepler survey, we find a 3% decrease in brightness of KIC 8462852. This decrease is the first independent validation of the secular fading reported by Montet & Simon (2016). The similar amplitudes between the NUV and optical data rule out typical interstellar dust as the cause of this fading.

1. INTRODUCTION

The *Kepler* mission (Borucki et al. 2010)

found this F3 star with strange dips Boyajian et al. (2015). further mystery, the star slowly fades over the time of the *Kepler* mission Montet & Simon (2016)

debated fading also over a century from photographic plate archive Schaefer (2016) for, Hippke et al. (2016) against.

The GALEX mission (Martin et al. 2005)

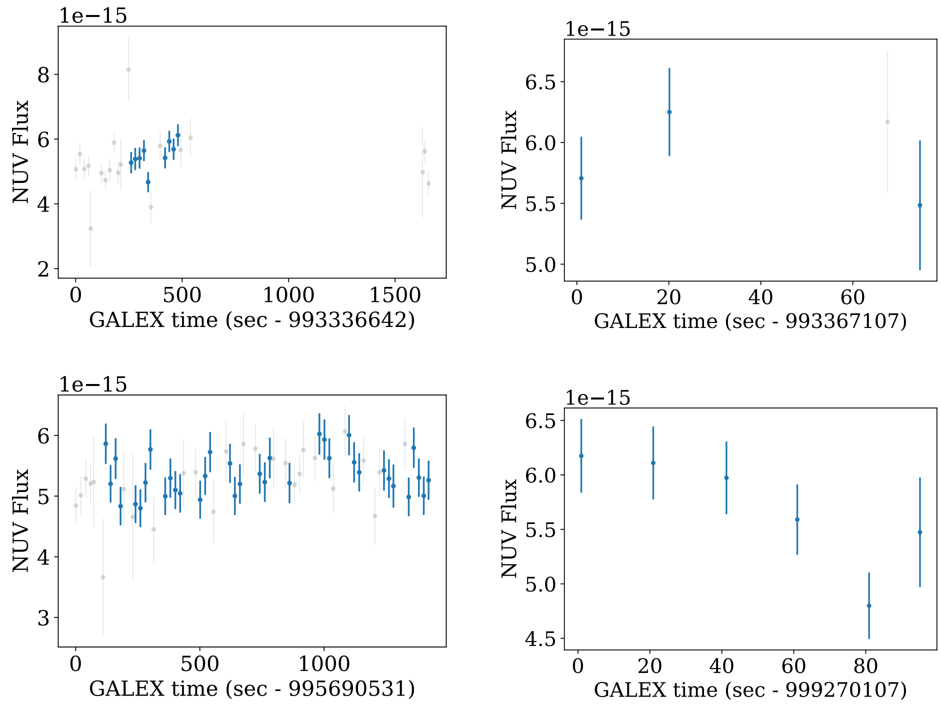

Figure 1. 10-second light curves from gPhoton for the 4 visits in 2012. All epochs shown (grey), and those that have no photometric warning flags set (blue), with the photometric errors for each point computed

time-tagged photon archive data (Million et al. 2016a) is available via the gPhoton Python toolkit (Million et al. 2016b).

GCK catalog (Olmedo et al. 2015) for the 2012 visit, which overlapped Q14 of the *Kepler* mission.

search for infrared flux excess, no strong detection found (Marengo et al. 2015)

2. SHORT TIMESCALE VARIABILITY

gphoton gives us unique ability look for short timescale variations in the NUV. In Figure 1 we show the four GALEX visits covering KIC 8462852, sampled at a 10-second cadence. small variations are seen in some of the visits. we re-sampled the data at 9- and 11-sec cadence, and these are visible in each. computing a Lomb-Scargle periodogram using `gatspy` (VanderPlas & Ivezic 2015) shows moderate power around 80-seconds. They appear to be primarily due to the ∼120 second observing cycle of the GALEX instrument in "Petal Pattern" mode A periodic signal of 0.88 days was found in *Kepler*, which was presumed by Boyajian et al. (2015) to be due to stellar rotation. our data are not able to verify this timescale.

nanosecond optical variability has been searched for this star (Abeysekara et al. 2016), but not much else shorter than was available at 30-min cadence with *Kepler*.

Since the GPhton data for this target is spread over four separate visits, we can also examine the medium-timescale variability over ∼70 days. In Figure 2 we show

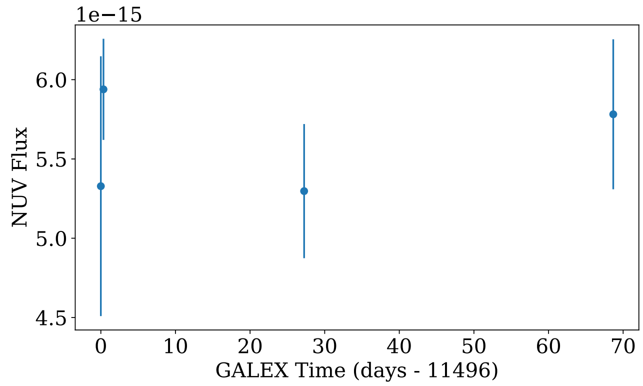

Figure 2. median flux of the 10-sec sampled data over the ∼70 days of 2011 visits by GALEX. Uncertainties shown are the standard deviation in fluxes within each 10-sec sampled visit from Figure 1.

the median flux from within each of the GPhoton visits. No significant variability is seen between these visits.

3. LONG TIMESCALE VARIABILITY

While the standard GALEX survey data available within GPhoton only sampled ∼70 days within 2011, the *Kepler* field was fortunately observed again by the CAUSE/GCK survey. [INSERT DETAILS OF THIS DATA]. A catalog of the integrated fluxes and uncertainties for *Kepler* targets observed in the CAUSE survey was made available by Olmedo et al. (2015)

In Figure 3 we present the GALEX data for this target as observed in 2011 and 2012. The 2011 data is the final GALEX GR6 catalog flux for KIC NNNN of 16.46 ± 0.01 from Bianchi et al. (2014), while the 2012 data is from the GCK data of 16.499 ± 0.006 Olmedo et al. (2015). Both data were converted to fluxes and were normalized to the flux of the 2011 visit. For comparison we also show the FFI decay from Montet & Simon (2016). Note: the fact that the GALEX and *Kepler* FFI data are normalized to a relative flux of 1 around 2011 (MJD∼55700) is a coincidence. However, the GALEX flux decays with the *Kepler* FFI flux over this time baseline

4. IMPLICATIONS FOR THE NATURE OF KIC 8462852

fit with Cardelli et al. (1989) dust model, using Python code from Barbary (2016).

Metzger et al. (2017) argued long-time fading due to stellar atmosphere recovery after a planetary in-spiral. (and possibly short-time dips due to debris)

our added data from GALEX adds important constraint on the nature of the long timescale fading. If its dust, must have $R_V = 5.0 \pm 0.9$ to satisfy the optical and NUV dimming. This is not typical for interstellar extinction material, though is seen for young protostars (e.g. Hecht et al. 1982). based on different prescriptions of the NUV extinction law, which can be very sensitive to the large "bump" near the GALEX

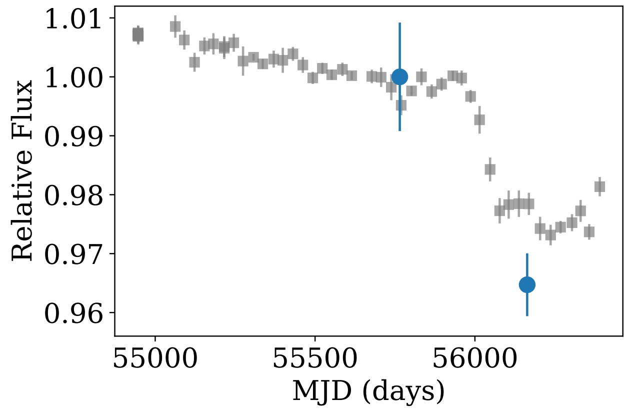

Figure 3. comparison of 2011 and 2012 fluxes (blue circles), with the *Kepler* FFI data shown in Montet & Simon (2016) but reduced with the new "f3" package from Montet et al. (2017) for comparison (grey squares).

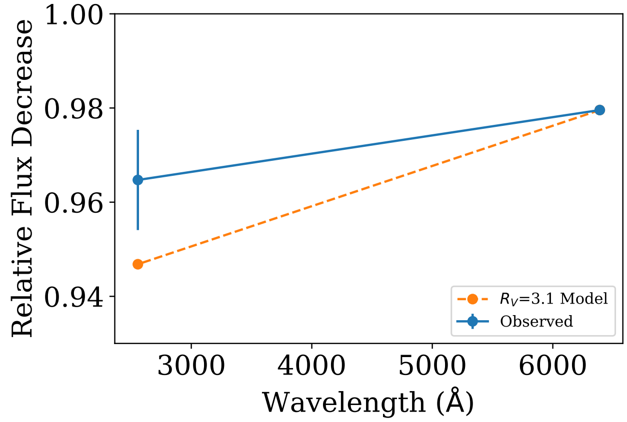

Figure 4. comparison of flux decrease observed at the effective wavelengths of the NUV and *Kepler* bands (blue solid line) and a corresponding $R_V = 3.1$ dust model from Cardelli et al. (1989) tuned to pass through the *Kepler* data (orange dashed line). The standard dust model over-predicts the NUV flux decrease given the observed *Kepler* decrease fromMontet & Simon (2016).

NUV center wavelength. for example, models from Fitzpatrick & Massa (2009)give $R_V = 5.8 \pm 1.6$

If the slow variability is due to dust, we can further put a weak constraint on how much dust should be present. Based on relations from (Güver & Özel 2009), we find that an extinction of $A_V = 0.026$ mag corresponds to a column density of $N_H \sim 5 \times 10^{19}$ cm^{-2} . Similarly, using the relations from Rachford et al. (2002) that have some dependence on dust composition (R_V), we get an estimated $N_H \sim 4.0 \times 10^{19}$ cm^{-2} .

5. SUMMARY

we have provided the first independent verification of slow fading of this target though the long timescale light curve is very sparsely sampled, the combination of NUV and optical wavelengths provides a powerful constrain on the nature of this slow dimming.

In the hunt for other objects of this class, we are able to expand our search criteria beyond the dramatic short timescale events and slow dimming observed with *Kepler*, to now include slow variability in the NUV.

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REFERENCES

Abeysekara, A. U., Archambault, S., Archer, A., et al. 2016, ApJL, 818, L33

Barbary, K. 2016, extinction v0.3.0, , , doi:10.5281/zenodo.804967

Bianchi, L., Conti, A., & Shiao, B. 2014, Advances in Space Research, 53, 900

Borucki, W. J., Koch, D., Basri, G., et al. 2010, Science, 327, 977

Boyajian, T. S., LaCourse, D. M., Rappaport, S. A., et al. 2015, ArXiv e-prints, arXiv:1509.03622

Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ, 345, 245

Fitzpatrick, E. L., & Massa, D. 2009, ApJ, 699, 1209

Güver, T., & Özel, F. 2009, MNRAS, 400, 2050

Hecht, J., Helfer, H. L., Wolf, J., Pipher, J. L., & Donn, B. 1982, ApJL, 263, L39

Hippke, M., Angerhausen, D., Lund, M. B., Pepper, J., & Stassun, K. G. 2016, ApJ, 825, 73

Marengo, M., Hulsebus, A., & Willis, S. 2015, ApJL, 814, L15

Martin, D. C., Fanson, J., Schiminovich, D., et al. 2005, ApJL, 619, L1

Metzger, B. D., Shen, K. J., & Stone, N. 2017, MNRAS, 468, 4399

Million, C., Fleming, S. W., Shiao, B., et al. 2016a, ApJ, 833, 292

Million, C. C., Fleming, S. W., Shiao, B., et al. 2016b, gPhoton: Time-tagged GALEX photon events analysis tools, Astrophysics Source Code Library, , , ascl:1603.004

Montet, B. T., & Simon, J. D. 2016, ArXiv e-prints, arXiv:1608.01316

Montet, B. T., Tovar, G., & Foreman-Mackey, D. 2017, ArXiv e-prints, arXiv:1705.07928

Olmedo, M., Lloyd, J., Mamajek, E. E., et al. 2015, ApJ, 813, 100

Rachford, B. L., Snow, T. P., Tumlinson, J., et al. 2002, ApJ, 577, 221

Schaefer, B. E. 2016, ApJL, 822, L34

VanderPlas, J. T., & Ivezic, Z. 2015, ApJ, 812, 18