Review and Observations of Tabitha Boyajian's Star – KIC 8462852

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Abstract

KIC 8462852 was observed by the Kepler Space Telescope from 2009-2013 and brought to the attention of scientists for its unique light curve with magnitude decreases up to ~20%. Thus far, no solid evidence exists to explain the light curve. We conducted a literary review of observations for this star, and made new observations at BSU. For 13 nights from 05/31/2016 - 12/042016, this star was imaged at the BSU Observatory in B, V, R and luminance filters. During Spring 2017, we processed these images in MaxIm DL 6 to produce light curves for each filter. KIC 8462852's magnitude did not change significantly during this observation period, however, it is likely a transit occurred from dates 11/17/16 - 11/28/16. On 10/26/16 an anomaly occurred that was highly visible in the Blue filter, less so in the Green, nearly invisible in the Red, and unobservable in luminance. Continued observations need to be made. Observations will be submitted to the American Association of Variable Star Observers (AAVSO).

Introduction

Dr. Boyajian's team's observations were categorized into 2 properties: intrinsic or extrinsic. Intrinsic properties included flux/period, spectroscopy, and blackbody radiation (characteristic to the star), while extrinsic properties included a nearby companion star, dust and gas, and orbiting material (characteristics external to the star). The flux/period of KIC 8462852 is 0.88 Earth days while the spectrographic profile designated this as a young F3 V-type star. For blackbody radiation, there was found to be no excessive infrared radiation emanating from the system and the star was in normal constraints for its designation. Refer to **Figure 1** for details regarding when and in what magnitude unusual dimming events occurred.

If the companion star is in orbit around KIC 8462852, then it is ~885 AU out. The companion is an M-type brown dwarf star and based on its mass and distance, is unlikely to be affecting Boyajian's star significantly. Inter-stellar dust and gas at the early stages of solar system formation would release excessive infrared radiation, so the system is considered to be past this stage of development.

Regarding solid bodies creating the transits like planets, asteroids, or potential comets, the range of radii was determined to be between ~3-10AU for a circular orbit. For an elliptical orbit, the range would become more eccentric, between ~1-26AU. Due to the lack of infrared radiation excess, it can be concluded that no solid-body collisions, planetesimal formation, or planetary deconstruction is occurring. A regular orbiting interval has yet to be determined.

It was suggested that comets might be the culprit, but there is no current way to confirm this. The orbital period for a comet exceeds the length of the Kepler mission, and 3 regular transits are required for designation. Lastly, the transits were proposed to be due to extraterrestrial behavior from a Dyson Sphere – a megastructure which engulfs a star for its energy. The spatial geometry and irregularity of period, plus the lack of excess heat given off as a waste by-product does not support this theory.

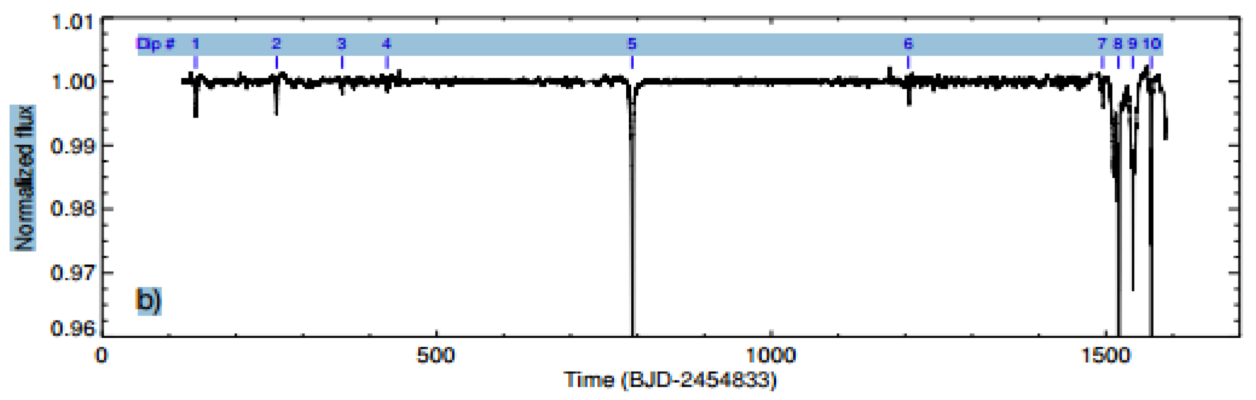

Figure 1: Kepler Space Mission (2009-2013) light curve pinpointing specific dimming events. The y-axis represents Normalized Flux - a smooth line generated from averaged data, while the x-axis represents the Barycentric Julian Date (BJD) - utilizing the common center of mass between the Sun and Earth as a constant point of distance.

Data Acquisition and Processing

Instrumentation and Software:

- 14" Celestron EdgeHD on Paramount ME Robotic Mount controlled by TheSky6 and TPoint
- Apogee Alta U47 CCD (D2 Body) Camera and FW50 Filter Wheel
- Astrodon Standard UBVRI Color Filters
- MaxIm DL 6
- AAVSO Variable Star Plotter

Observations:

- Observations were taken over a total of 13 nights in the year of 2016 with the BVR and luminance filters.
- Biases were taken at 50 images per filter over 3 days: 05/27, 10/24, and 12/04, to accommodate changing seasonal temperatures.
- Flat images were taken at twilight at an average of 12 images per filter. Exposure times varied with sky brightness.
- Dark images were taken at exposure times to match the night's flats and 30s for data images (12 images each).
- Data images had 30s exposure times and typically 12 images were taken per filter.

Processing:

- Images were calibrated using MaxIm DL 6. Calibrated images were stacked via the median combine method to produce an overall image per night per filter. -Images displaying streaking, 'ghosting,' or heavy pixelation were not used.
- The photometry feature in MaxIm DL 6 was used to find the magnitudes of KIC 8462852, a reference star: 000-BLS-549, and 3 check stars in the stacked images (**Figure 2**). Aperture, gap width, and annulus sizes were chosen to include maximum counts from measured stars and background while excluding counts from neighboring stars. We utilized the AAVSO Variable Star Plotter to identify the reference star.
- The lightcurves of the object and check stars were compared to the reference star in MaxIm DL 6 (**Figure 3**). The Reference star remained at a consistent magnitude retrieved from either AAVSO or USNOB databases: Red – 12.445 (USNOB), Green – 12.427 (AAVSO), and Blue – 12.230 (AAVSO). The luminance filter magnitude had to be derived as there wasn't one designated in any database.

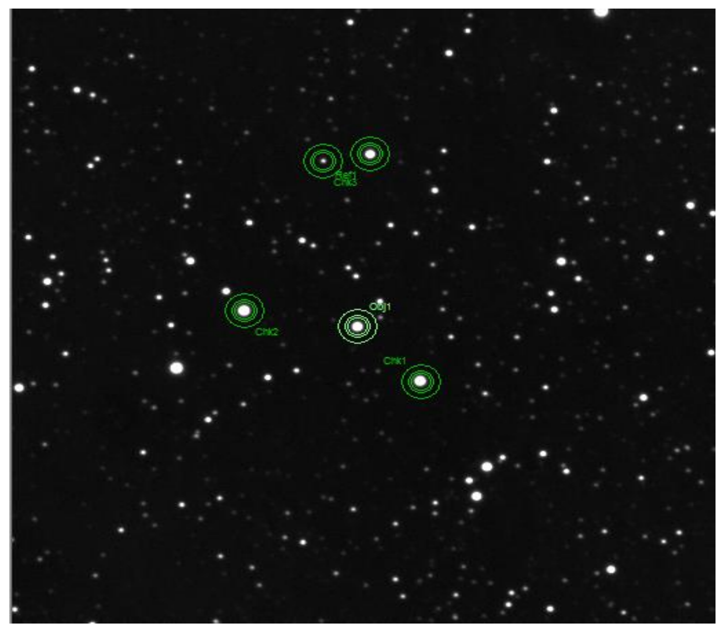

Figure 2: Aperture and Annulus configuration around Object Star (KIC 84602852).

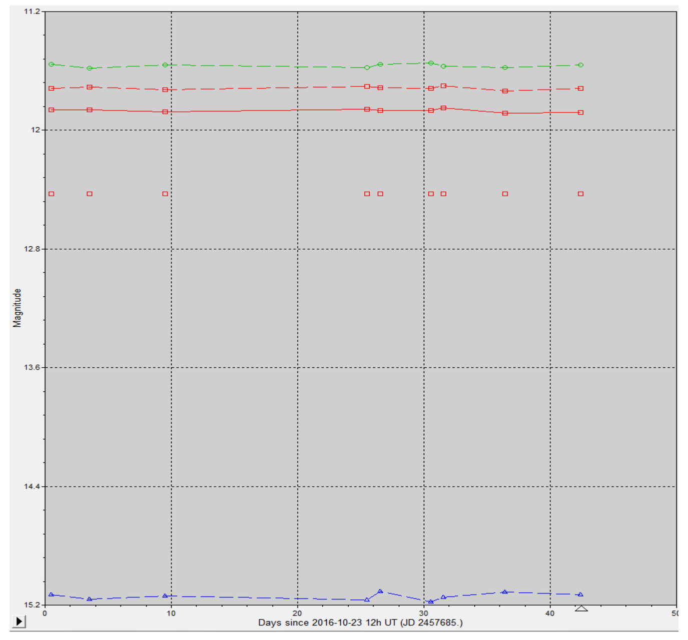

Figure 3: Calibrated magnitudes for Object, Reference, and Check stars for stacked images in the Green filter.

Data

Data from the stacked calibrated magnitudes was transferred into an Excel file. The error was derived utilizing the signal to noise ratio (SNR) generated by MaxIm DL. In Fig. 5-8, the y-axis represents star magnitude and the x-axis is the Julian Date. ***Note***: Lower magnitudes denote brighter stars; the graphs show a magnitude difference that is much less than the 20% dip observed in the Kepler light curve (less than a 0.05 mag difference).

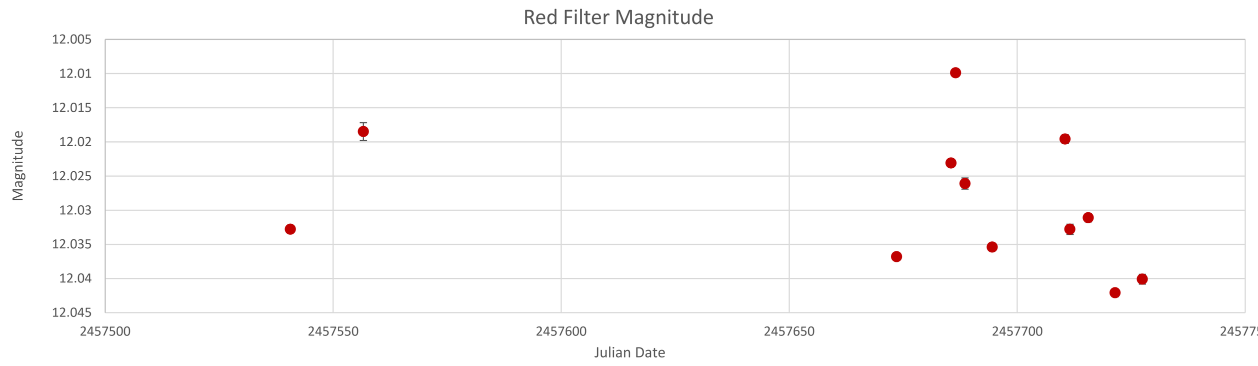

Figure 5: Light curve magnitudes for the Red filter. Annulus-11 pixels, Gap Width-4 pixels, Aperture-12 pixels. Ultimate difference in maximum peak brightness vs depth is 0.0322 mag.

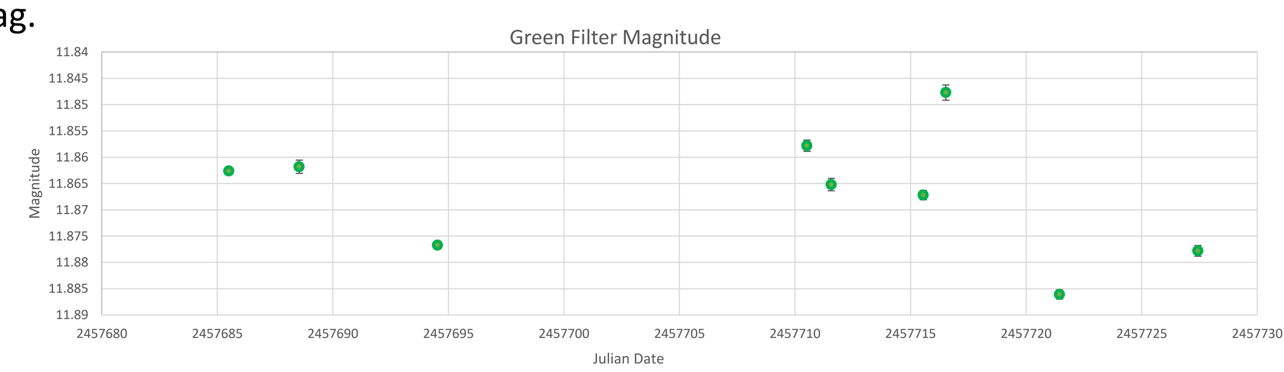

Figure 6: Light curve magnitudes for the Green(V) filter. Annulus-5 pixels, Gap Width-5 pixels, Aperture-15 pixels. Ultimate difference in peak brightness vs depth is 0.0384 mag.

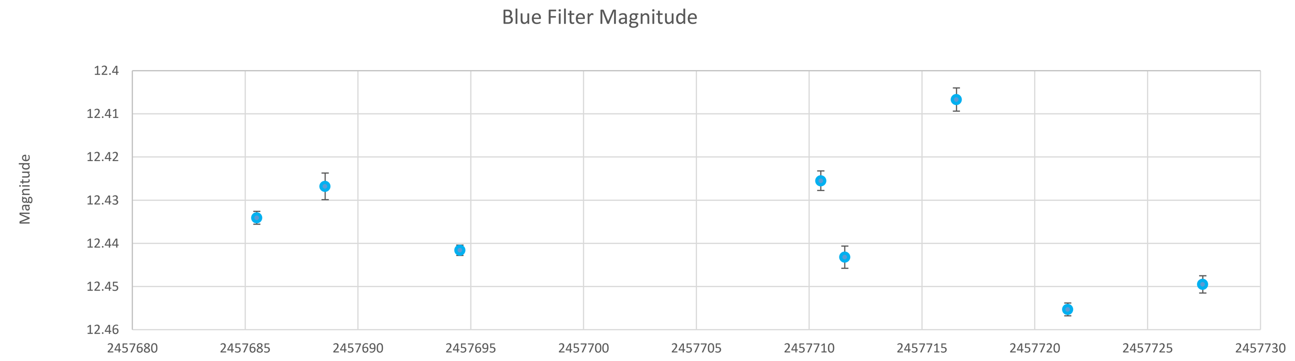

Figure 7: Light curve magnitudes for the Blue filter. Annulus-5 pixels, Gap Width-5 pixels, Aperture-15 pixels. Ultimate difference in peak brightness vs depth is 0.0486 mag. ***Note***: several nights in the blue filter were omitted due to high pixelation and reflective streaking issues.

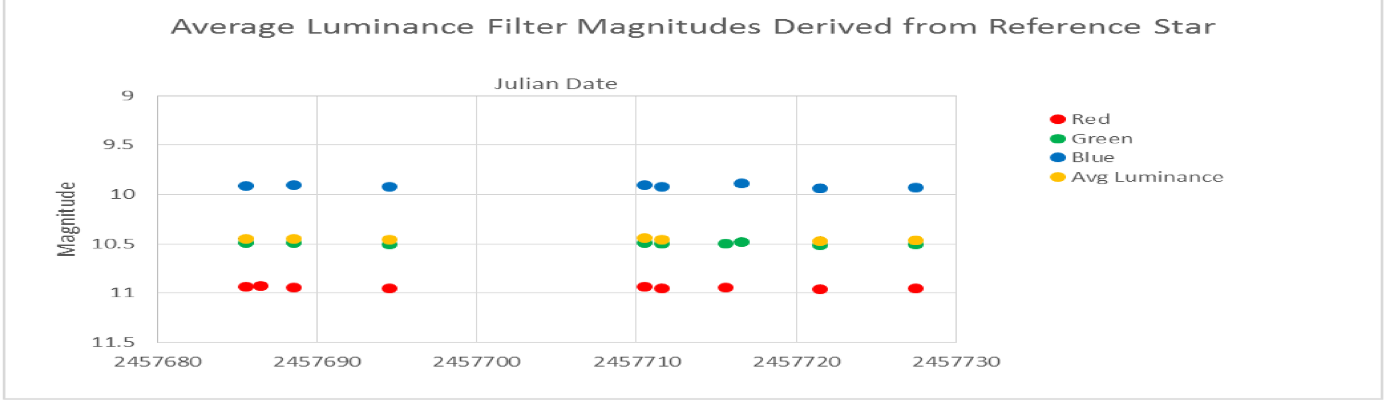

Figure 8: Derived magnitudes of KIC 8462852 in luminance based on comparison to the Red, Green, Blue, and luminance filters of Reference star 000-BLS-549. For these values, instrumental magnitudes were used for derivation point by point. Not all nights that had luminance images had correlating color-filter images – these were not used in calculating the average luminance magnitudes. Annulus-10 pixels, Gap Width-5 pixels, Aperture-14 pixels. Ultimate difference in peak brightness is 0.0268667 mag.

Luminance magnitude from colored filters:

$$\left[\frac{\Sigma(L_{Inst.\,mag} - Color_{Inst.\,mag})}{Total\ nights\ shared\ between\ filters(\#)}\right] + Color(Real)_n = L(Real)_n$$

Average luminance magnitude per night:

$$\frac{[L(Real)_{Red} + L(Real)_{Green} + L(Real)_{Blue}]}{3} = Avg.\, luminance\ magnitude\ per\ night$$

Error calculation for luminance magnitude compared to a single color filter:

$$\sqrt{(Error\ propagation\ (color))^2 + \left(\frac{1}{SNR(Obj:color)}\right)^2 + \left(\frac{1}{SNR(Obj:luminance)}\right)^2} = \text{Color Error}$$

Error calculation for overall luminance magnitude on a date:

$$\sqrt{(Red\ Error\ Point)^2 + (Green\ Error\ Point)^2 + (Blue\ Error\ Point)^2} = \text{Luminance Avg}$$

Anomaly

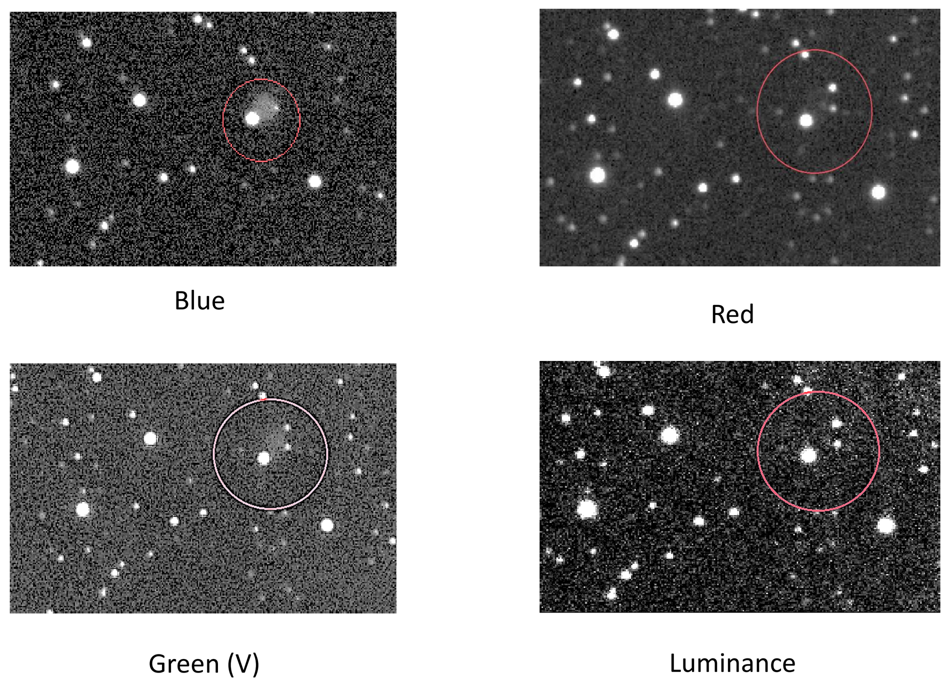

Figure 10: Anomaly images in Red, Green, Blue and luminance filters for October 26, 2016.

On 10/26/2016, an anomaly was seen in the BVR filters north-east of the Object Star. It was most prominent in B, growing dimmer in V, and almost undetectable in R. The luminance filter showed no trace of the anomaly. Images were taken near zenith. One possible explanation is reflection from campus lighting. Some images on other nights in the B filter had to be discarded as their data were obscured by some reflective streaking, all pointing in the same NW/SE direction. This effect could have occurred from the telescope following the constellation as the semester progressed as it dipped down to the W/NW until it was beyond a measurable angle after 12/04/2016.

Conclusions

Overall, there was no extreme alteration in KIC 8462852's magnitude save for the night of the anomaly on 10/26/2016. Changes in magnitude were significant, however, they did not reflect a magnitude change greater than 0.0322 in the Red filter, 0.0384 in the Green(V) filter, 0.0486 in the Blue filter, and 0.0226 in luminance. These values are much smaller than major dimming events from the Kepler mission 4-year light curve. The greatest magnitude change occurred between 11/17-11/28, possibly indicating an ordinary transit.

Future Work

Continued observation of KIC 8462852 is recommended. However, based on the continuous dimming in magnitude and the irregular transiting period, there may be material passing between Earth and KIC 846 2852 and not material orbiting it. The reason for the tremendous dips could be due to large objects passing at a closer distance through our line of sight to the star. This material is not massive enough to generate heat via frictional compression, but is able to block up to 20% of KIC 8462852's light at a closer distance. This would explain the irregularity of transits along with the lack of excess radiation.

To test this hypothesis, the star should be monitored spectroscopically, with control spectra gathered out-of-transit, then compared to spectra during a transit. Changes in chemical composition could determine the nature of the object(s) transiting. Also, continued observations could confirm or refute periodicity.

To obtain an improved standard luminance magnitude for KIC 8462852 on each night, a standard luminance magnitude for the reference star should be determined by comparing instrumental magnitudes in luminance to instrumental magnitudes in B, V, and R for the reference star. The reference star's variations in instrumental magnitude can then be incorporated to smooth out changes in KIC 8462852's magnitude due to varying sky conditions.

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References

[1] AAVSO -- Light Curve Generator (LCG). Dec 5, 2016, from *https://www.aavso.org/lcg*
[2] AAVSO -- Variable Star Plotter. Nov 29, 2016, from https://www.aavso.org/apps/vsp/
[3] Boyajian, T. S., et. al., (2016). Planet hunters IX. KIC 8462852 – Where's The Flux? Monthly Notices of the Royal Astronomical Society, 457(4), 3988–4004.
[4] Comins, N. F. (2006). Discovering the Essential Universe (3rd ed.). New York, NY: Freeman, W. H. & Company.
[5] Crow, C. (October 25, 2009). The Main Asteroid Belt. April 12, 2017, http://dawn.jpl.nasa.gov/science/pdfs/asterbelt.pdf
[6] Eastman, J. Barycentric Julian Date. Nov 29, 2016, from *http://astroutils.astronomy.ohio-state.edu/time/bjd_explanation.html*
[7] Hippke, M., Angerhausen, et. al., (2016). A Statistical Analysis of the Accuracy of the Digitized Magnitudes of Photometric Plates on the Timescale of Decades with an Application to the Century-Long Light Curve of KIC 8462852. *The Astrophysical Journal*, *825*(1), 73.
[8] Kepler: Home page. Nov 29, 2016, from *https://kepler.nasa.gov/index.cfm*
[9] McClure, B. October 21, 2016. What is an astronomical unit? (n.d.). Retrieved April 11, 2017, from http://earthsky.org/space/what-is-the-astronomical-unit
[10] Montet, B. T., & Simon, J. D. (2016). *KIC 8462852* Faded Throughout The Kepler Mission. *The Astrophysical Journal*, *830*(2), L39.
[11] Planet Hunters. Nov 29, 2016, from *https://www.planethunters.org/*
[12] Schaefer, B. E. (2016). *KIC 8462852* Faded at an average Rate of 0.164 ± 0.013 Magnitudes Per Century From 1890 to 1989. *The Astrophysical Journal*, 822(2), L34.
[13] USNOB http://www.nofs.navy.mil/data/fchpix/ Last updated: 07dec2009 by sel
[14] (2010, January 12). WISE: Wide-Field Infrared Survey Explorer. *WISE - Mission.* Dec 16, 2016, from http://wise.ssl.berkeley.edu/mission.html
[15] Wright, J. T., Cartier, K. M. S., Zhao, M., Jontof-Hutter, D., & Ford, E. B. (2015). The Ĝ Search for Extraterrestrial Civilizations with Large Energy Supplies. IV. The Signatures and Information Content of Transiting Megastructures. *The Astrophysical Journal*, 816(1), 17.