KIC 8462852—Physical Modelling of its Occulting Objects and the Growing Mystery Surrounding its Cyclic Fluctuations: A New Assessment

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Abstract: KIC 8462862, an F-type main sequence star in the constellation of Cygnus, was found to be experiencing strange light fluctuations during the initial Kepler mission. Recorded data showed that the flux dropped by as much as 16 percent on one occasion in 2011 and 22 percent on another occasion in 2013. Various other major and minor light dimming episodes occurred across the entire Kepler mission, with an eclectic series of theories being offered to account for them. Experimental attempts are made to physically model the occulting objects behind the drops in flux to try and determine their line of sight profile, and through this their nature and appearance. The Kepler data for KIC 8462852 is re-examined to better understand the 0.88-day, 24.2-day and 48.4-day periodicities noted in connection with the star's light dimming events. These reveal cyclic patterns that seem almost mechanical in nature, as well as recurring number sequences that warrant further investigation.

Key words: KIC 8462852, Tabby's Star, Boyajian's Star, Cygnus, Kepler, comets, asteroids, interstellar medium, planetary debris, rings, dust trails, cyclic periodicities, attention-grabbing signals, prime numbers.

Introduction

KIC 8462852, popularly known as Tabby's Star or, more correctly, Boyajian's Star after its discoverer astronomer Tabatha S. Boyajian of Louisiana State University, is an F-type main sequence star, one and a half times larger than the Sun. It lies around 1,280 light years (390 pc) away in the constellation of Cygnus, the swan, at RA.: 20h 06m 15.457s Dec.: +44° 27′ 24.61″ (see fig. 1.1). It has been called the "weirdest star in our galaxy" (Andersen, 2015) due to the strange fluctuations in light it has experienced since it first came to the notice of the astronomical world following the completion of the Kepler space mission's initial phase in 2013.

Various theories have been proposed to explain KIC 8462852's curious light fluctuations. Tabatha Boyajian and her colleagues, following a detailed study of the Kepler data, concluded that a swarm of exo-comets in a highly eccentric orbit following a single previous breakup event might be the cause (Boyajian et al, 2016). A team led by Fernando J. Ballesteros of the University of Valencia considers them the result of a giant ringed planet, five times the size of Jupiter, along with a large cluster of Trojan asteroids in the same or a similar orbit (Ballesteros et al, 2017). Brian Metzger of Columbia University and his colleagues propose that the star is recovering from a collision with an orbiting planet (Metzger et al, 2017), while Valeri V. Makarov of the United States Naval Observatory identifies the culprit as liberated planetary debris in the interstellar medium between here and the star (Makarov, 2016). Jason Wright of Penn State University proposes that the star's dimming episodes could be the result of alien megastructures in orbit around the star (Andersen, 2015; Wright and Sigurdsson, 2016), while Eduard Heindl of Hochschule

Furtwangen University argues that the occulting objects orbiting KIC 8462852 are artificial and involved in a mining or “star lifting” operation to remove the star’s mass (Heindl, 2016).

Figure. 1.1. *The Cygnus constellation showing the location of KIC 8462852 (Credit: Stellarium/Rodney Hale).*

1. Review of the Kepler Data for KIC 8462852

In an attempt to throw further light on the matter, one of the authors, Rodney Hale, examined the Kepler data for KIC 8462852 with the intention of physically modelling the transiting object or objects seen as responsible for the four biggest light dipping episodes. The first of these occurred on Kepler day 792 (henceforth D792), corresponding to March 5, 2011 (see fig. 1.2 for a listing of all the major dipping events recorded by Kepler between 2009-2013 and fig. 1.3 for their photometry). On this occasion the light dipped by a maximum of 16 percent. The second event took place on Kepler day 1519 (D1519), corresponding to February 28, 2013, when the light dipped by as much as 22 percent. The third occurred on Kepler day 1540 (D1540), corresponding to March 21, 2013, when a dip of 3.3 percent was reported. The last major light dipping episode occurred on Kepler day 1568 (D1568), corresponding to April 17, 2013. On this occasion the resulting light curve showed that the star’s flux had dipped by a maximum of 8 percent.

The D792 event would appear to have involved just one main occulting object. This passed in front of the star, causing a slow gradual dip before the flux dropped sharply by a maximum of 16 percent (see fig. 1.4 for the photometry of all four major dipping events). Thereafter it took the star a few days to recover its normal brightness. The other three events would all appear to be linked in some manner. They occurred across a period of approximately 40 days during which time the star’s light fluctuated not only with the three major dips cited above but also with a succession of minor dips, suggesting a more complex series of events involving several occulting objects.

Kepler observations for KIC8462852 (Tabby's star) 2016

	Barycentric Julian Date	Kepler Day No.	Calendar date	Approx dip
Day 0	2454833	0	1 Jan 2009	
First data reading	2454953	120	1 May 2009	
Event 1	2455626	792	5 Mar 2011	16%
Event 2	2456353	1519	28 Feb 2013	22%
Event 3	2456373	1540	21 Mar 2013	3.3%
Event 4	2456401	1568	17 April 2013	8%
Final data reading	2456434	1591	11 May 2013	

Figure. 1.2. *List of the major dimming events recorded in the Kepler data for KIC 8462852 between 2009 and 2013.*

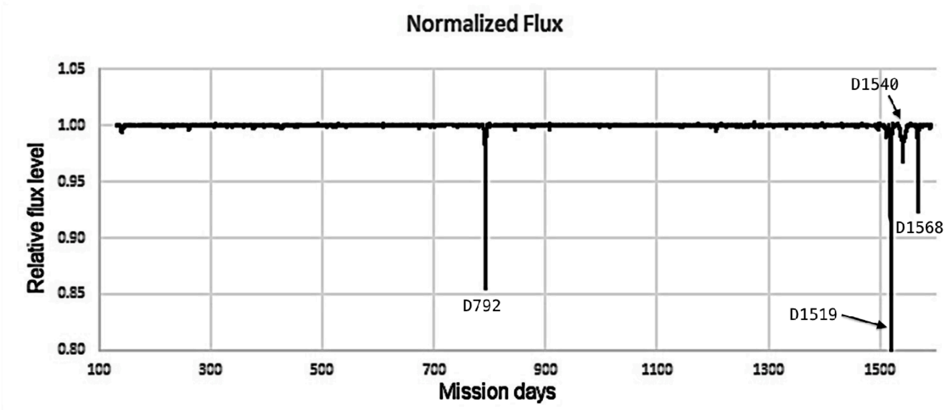

Figure 1.3. *The photometry from the Kepler data for KIC 8462852 from May 1, 2009, through till May 11, 2013. The D792, D1519, D1540 and D1568 dates are all marked.*

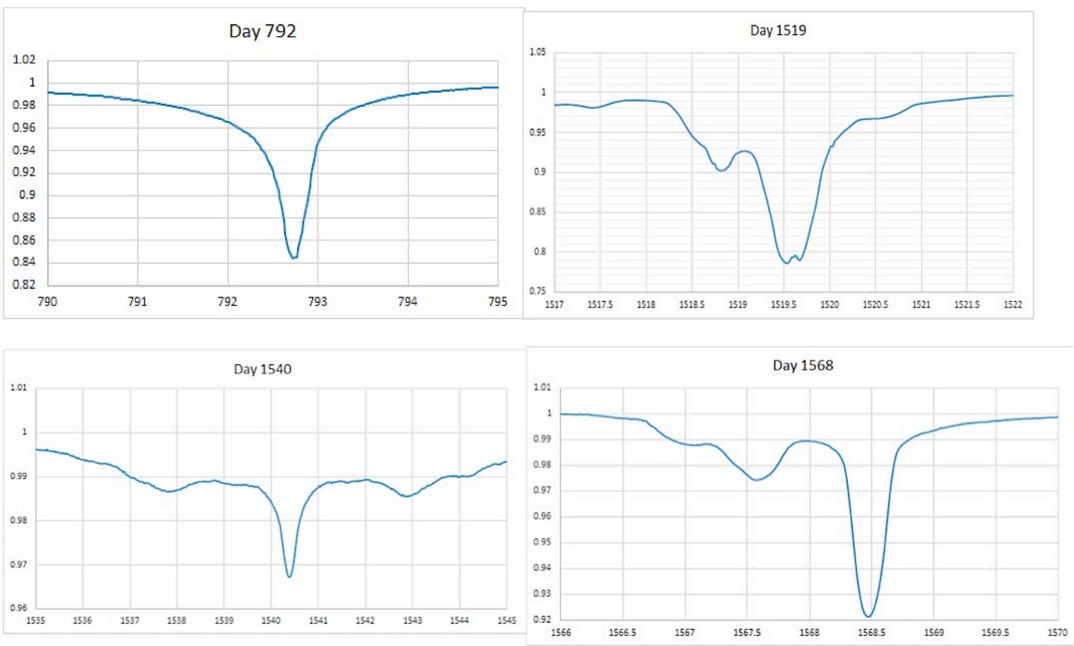

Figure. 1.4. *Photometry of all four major dimming episodes for KIC 8462852 as recorded in the Kepler data.*

2.1. Cyclic Fluctuations

Before any physical modelling of the objects could begin it was essential to establish whether or not the cause of the light dimming events existed independently of the star. For this Hale focused his attentions on the 0.88-day fluctuations first reported in connection with KIC 8462852 by Tabatha Boyajian and her colleagues (Boyajian et al, 2016). A Fourier analysis of the data reveals much the same as their own results with two separate sets of harmonics present (see fig. 2.1). The data was expanded at the low frequency end so that the main peaks with the days per cycle could be shown. This shows that the 0.88-day periodicity is in actuality a clump of frequencies close together (see fig. 2.2). In addition to this, we see that the 0.88-day fluctuations adhere to a larger cyclic pattern of approximately 11 days, a 10.7- and 13-day cycle having previously been recognised.[1]

Although confirmation of the 0.88-day periodicity is easily obtained, Valeri Makarov argues that it could be interference from a nearby star (Makarov et al, 2016), a theory unsubstantiated at this time. More likely is that it defines KIC 8462852's rotational pattern, the conclusion of Boyajian and her colleagues (2016).

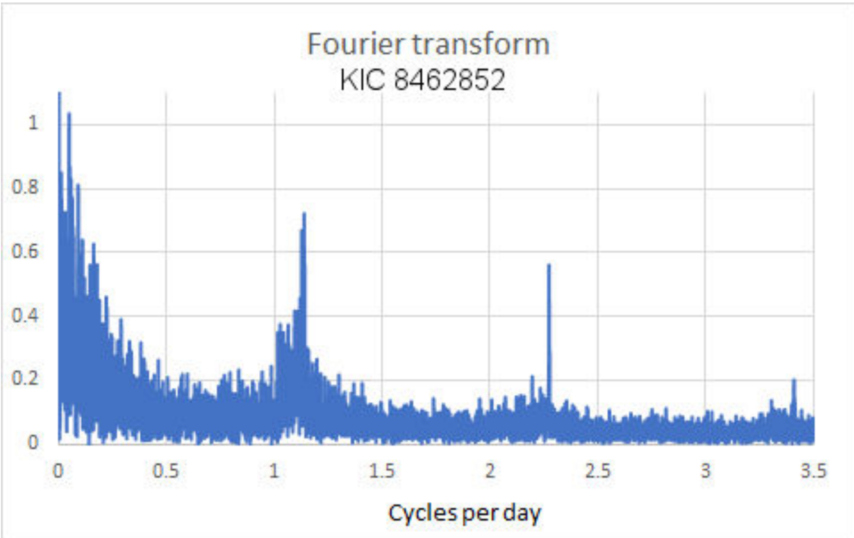

Figure 2.1. *Fourier analysis of KIC 8462852's 0.88-day cycle.*

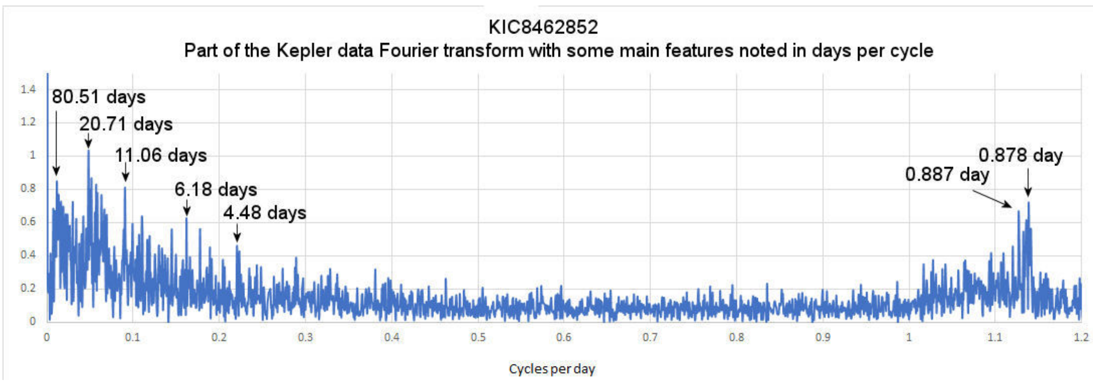

Figure 2.2. *The Fourier analysis expanded to show the clusters of close frequencies at approximately 11-day intervals.*

[1] A 10.7-day cycle in the Kepler data for days 1322 – 1352 and a 13-day cycle for days 1232 – 1254 are noted here: http://imgur.com/gallery/CRRSG, courtesy of gdsacco.

Using the Kepler data[2] Hale was able to demonstrate how regularly occurring changes of light levels across the entire four-year period of observation of the star can be shown as a spectrogram, with its base line covering the entire period of observation of KIC 8462852 and its vertical scale indicating the cyclic frequency of light level changes (see fig. 2.3).

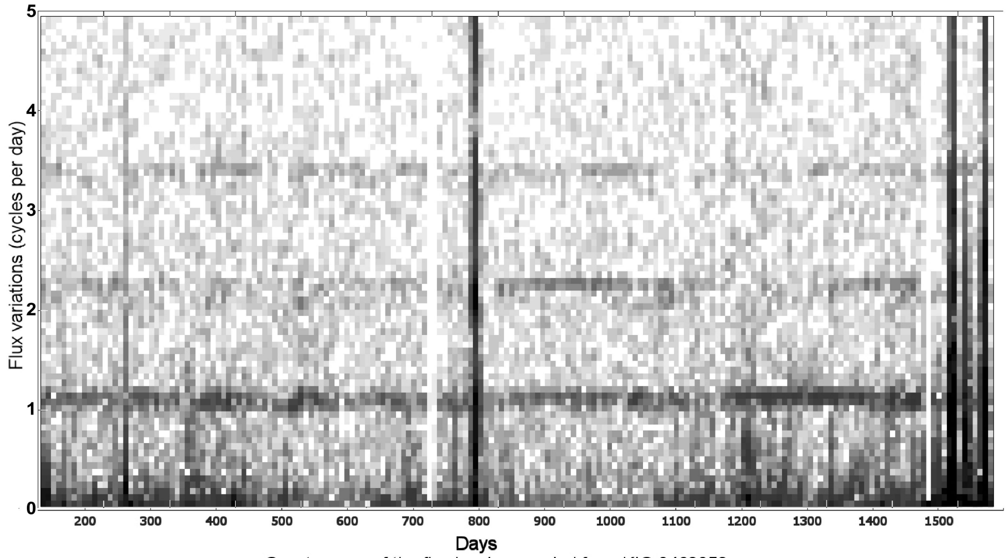

Figure. 2.3. *Spectrogram showing the cyclic fluctuations and dimming events recorded in the Kepler data for KIC 8462852. The random light grey peppering of the area of the plot comes from a general background of noisy signals. Persistent signals with a regular repeating pattern show up as darker horizontal bands, while short-term, larger changes show as narrow vertical bands. Although difficult to reproduce in printed form, the 0.88-day fluctuation represented by the thick horizontal line at the base continues unabated during all the major dimming events represented by the vertical lines.*

The spectrogram's lowest horizontal band indicates KIC 8462852's 0.88-day fluctuation, which is equivalent to a rate of approximately 1.14 cycles per day. The two bands above it are second and third harmonics of this fluctuation. The significant fact gleaned from this exercise is that the lowest band representing the 0.88-day fluctuation continues without interruption throughout the entire duration of Kepler's observation of the star, *even during the major dip events.* This implies two possible scenarios. Either the 0.88-day periodicity is unconnected with KIC 8462852 and is, as Valeri Makarov has concluded, simply interference from a nearby star, or the 0.88-day fluctuation does indeed reflect an orbital periodicity connected with the star. If it represents a rotational cycle, this raises the question of what exactly is causing this 0.88-day fluctuation. It cannot be sunspots as these occur randomly, and not in the same position time after time. The only logical explanation is that the fluctuations signify either a permanent light dimming on the star's surface, or they relate to something in low orbit around the star.

Whatever the cause of the 0.88-day fluctuation seen in connection with KIC 8462852, the fact that it continues unabated during the light dipping episodes means that the

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[2] Flux data from www.wheresmyflux,com/public. Spectrogram using Excel and associated maths software Octave.

occulting objects responsible for the star's major light fluctuations are most likely independent of the star itself for if they *were* a product of the star there is a strong likelihood that the cycle would be interrupted in some way. Thus either the occulting objects causing the light dimming episodes belong to liberated planetary material existing in our line of sight between here and KIC 8462852, the conclusion of Valeri Makarov (2016), or they are in orbit around the star.

2.2. A Further Periodicity

Of these two alternatives, the second can be shown to be more plausible. Tabatha Boyajian and her colleagues noted a second possible periodicity in the Kepler data for KIC 8462852 based on the timing between several major and minor dimming events. They seemed separated by periods of 48.8 days, later refined to 48.4 days, with the presence also of a half cycle of 24.2 days (Boyajian et al, 2016, gdsacco,[3] and see section 4.2). An inter-relationship seems to exist between these various periodicities since 48.4 days is exactly 55 cycles of 0.88 days, while the half cycle of 24.2 days amounts to 27.5 periods of 0.88 days.

3.1. Physical Modelling

So under the assumption that the objects creating KIC 8462852's major light fluctuations are indeed in orbit around the star, what exactly might they look like? Having established that the occulting objects responsible for KIC 8462852's light fluctuations were almost certainly transiting the star, Hale looked at how solid objects of different shapes affect the appearance of resulting light curves. To achieve this he created a computer simulation showing a dark shape transiting a white disk representing the star. The output from a photocell monitoring the light level from the computer screen was recorded and plotted by a second computer, thus comparisons between light curves arising from different shapes were readily made. The transits may be equatorial (as viewed from earth) or at higher latitudes (see Hale, 2016).

What Hale found was that transiting objects with regular shapes of appropriate sizes, including spheres, squares, triangles, etc., produce a characteristic light curve with a flat base (see fig. 3.1). This was completely unlike the sharp dips produced in connection with KIC 8462852. To create a light curve with a pointed tip the object has to have a diameter matching the star's width at the particular latitude of the crossing, as well as a thickness to produce the relevant light drop.

Recognizing the similarity between the four major dips reported in connection with KIC 8462852, Hale superimposed all four together, keeping their scale yet synchronizing them in a manner corresponding to their lowest point. The resemblance in sharpness and form of all four is remarkable and is unlikely to be without meaning (see fig. 3.2). In addition to this, when five minor dipping events found in the Kepler data for KIC 8462852 were synchronised these too displayed a similar width and sharpness (see fig. 3.3). Not one of these dips, whether major or minor, display a characteristic flattened base.

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[3] Gdsacco, "Seeing the forest through the trees," June 10, 2017, https://www.reddit.com/r/KIC8462852/comments/6gim8b/seeing_the_forest_through_the_trees/.

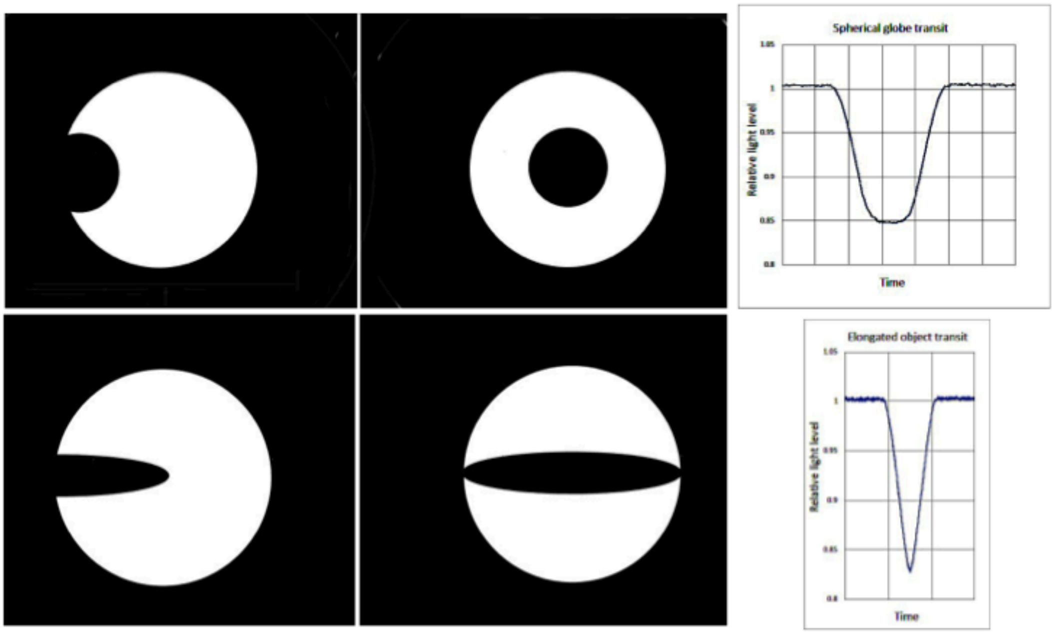

Figure 3.1. *Transiting objects with regular shapes, such as spheres, squares, triangles, etc., produce a characteristic light curve with a flat base when they pass in front of a star (appropriate to the amount of dimming observed), while those with elliptical profiles create light curves with characteristic narrow tips.*

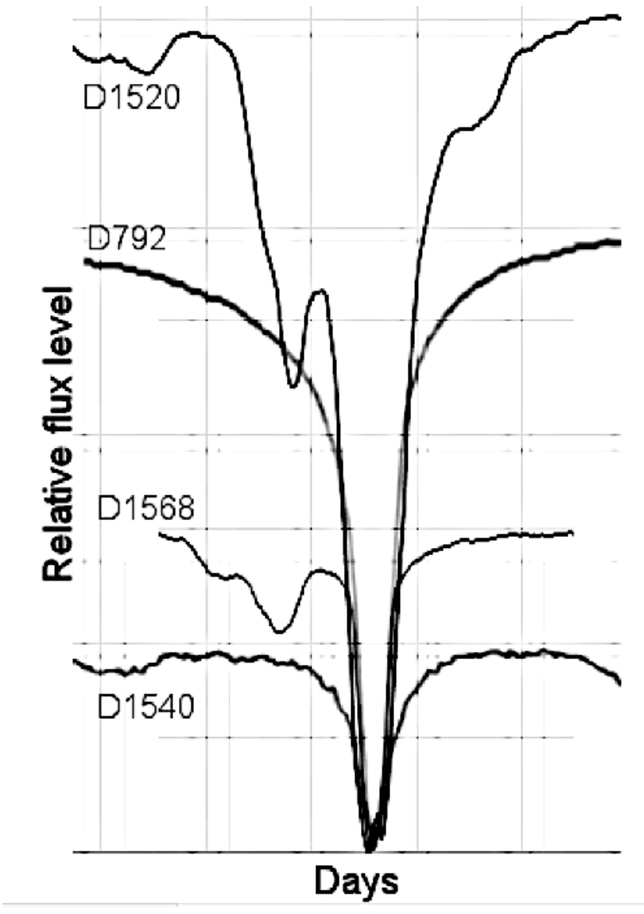

Figure 3.2. *The sharp tips of all four major light dips recorded in the Kepler data for KIC 8462852. Note the similarity in their narrow tips.*

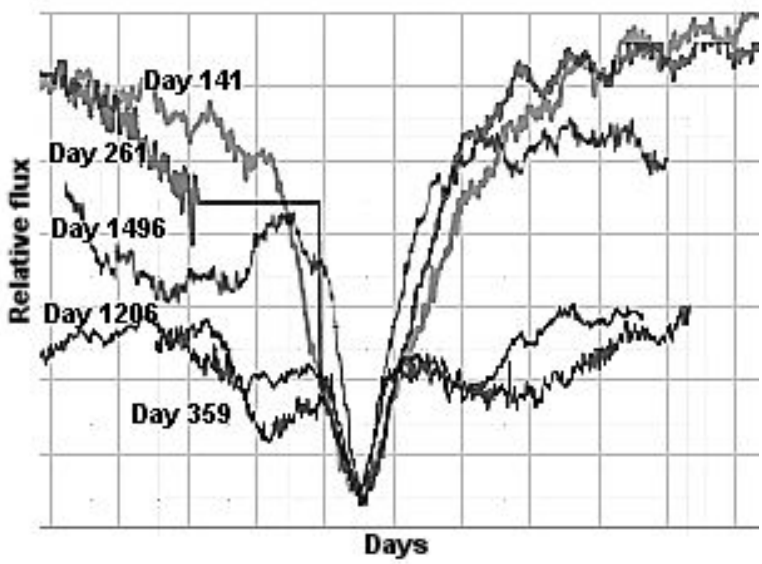

Figure 3.3. *The sharp dips of five minor events as extracted from the Kepler data for KIC 8462852. The day 261 event has some missing data.*

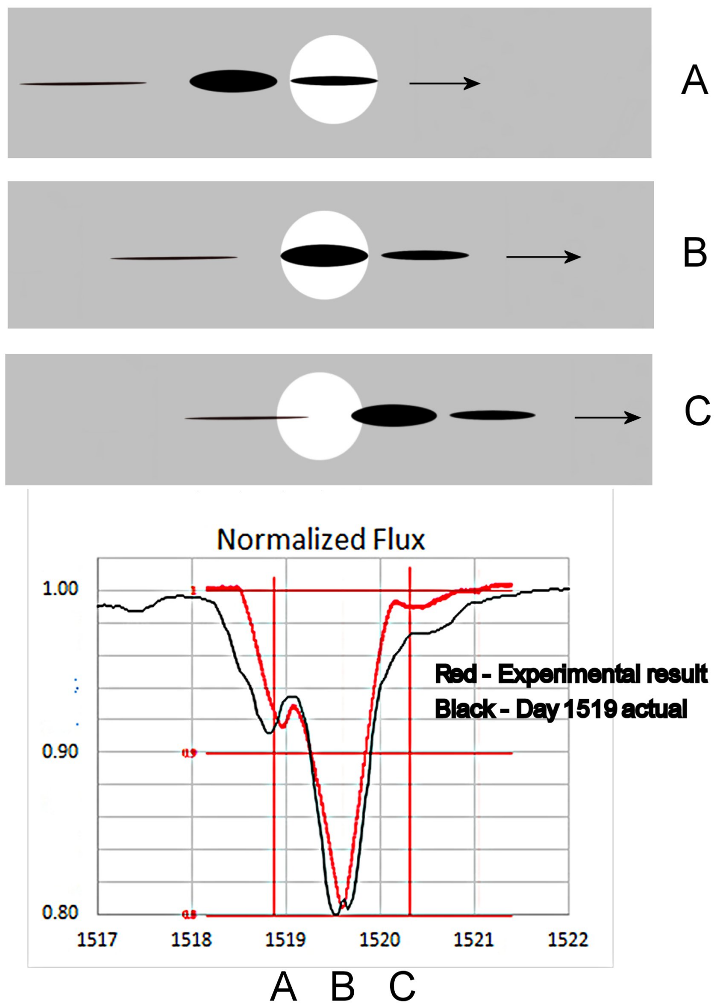

Figure 3.4. *The profiles of the D1519 event as determined from the physical modelling of the Kepler data for KIC 8462852. It shows that at least three occulting objects were responsible for this light curve, all of them ideally either elongated ellipses, disks in profile, or rotating irregular shards.*

Hale determined that one basic shape profile corresponded closely with the resulting light curves seen in the Kepler data for KIC 8462852. This was either an ellipse with a flat base and top or a slim disk seen edge on. A similar profile could also be created by an irregular shard, which if rotating along the line of sight as it transited across the face of the star would average out its profile to create the impression of an ellipse or disk. Hale was able to apply this information to Kepler event D1519 to demonstrate that it could have been caused by three elongated ellipses, disks or rotating shards of irregular shape (see fig. 3.4). Similar objects could be seen to be behind the D1540 and D1568 events (see below for more on the physical modelling of the D1540 event).

3.2. Modelling the D792 Event

Reconstructing the obscuring object that created the D792 light curve was more difficult since this had to include the long, slow gradual dips that occurred before and after the sharp dip of 16 percent. These can only be explained by something extremely long and thin crossing in front of the star's face both before and after the appearance of the main object. Arguably they are dust trails. Whether or not they extend behind and in front of the main occulting object, showing they are in fact rings, is unclear from the data.

Some indication of a ring around an ellipse or disk-like profile is shown in two events, D1540 and another minor dip on Kepler day 1206 (D1206). Rodney Hale overlaid these two events to show their close relationship (see fig. 3.5).

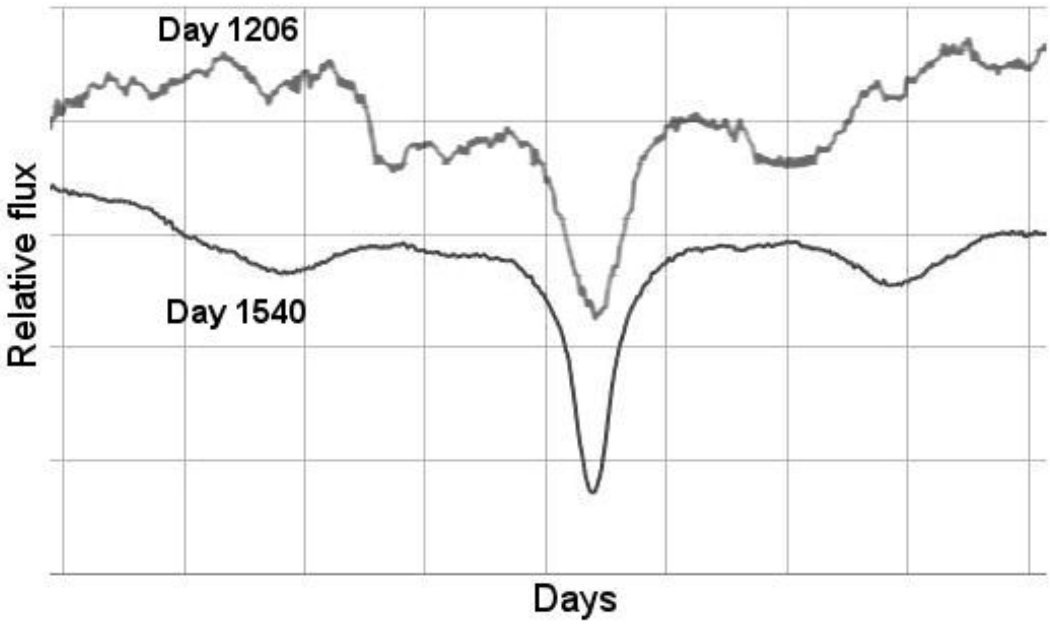

Figure 3.5. *Photometric comparison between two light dipping events in the Kepler data for KIC 8462852, one a major event, D1540, and the other a minor event, D1206. Note that both have shallow depressions on either side of the main dip, suggesting the presence of a ring surrounding an ellipse or disk-like object.*

Each can be seen to have a shallow depression either side of the main object, suggesting the presence of a ring. This tells us that the extremely long trail seen during the D792 object's ingress and egress is either an incredibly large ring seen virtually along the line of sight, or it is some kind of twin trail, one perhaps a dust tail and the other an ion tail. The only argument against the identification of these anomalies as either rings, trails, or tails is that they would most likely re-radiate heat and so should be visible within the IR frequency range, something so far not noted in connection with KIC 8462852 (Boyajian et al, 2016).

The profile of the occulting object behind the D792 episode indicates that, like those of the D1519 event, it too bears a profile consistent with an ellipse showing a flat top and bottom. Equally, it could be a disk viewed edge on, or, once again, an irregular shard rotating along the line of sight. Hale has provided a black and white image showing the profile of the D792 object complete with its "wings" (see fig. 3.6). Accompanying this paper also is an artist's impression of what the D792 object might have looked like as it transited the star during its ingress and egress (see fig. 3.7).

Figure 3.6. *The profiles of the D792 event as determined from the physical modelling of the Kepler data for KIC 8462852. The extending "wings" have been severely shortened to better show the object's profile.*

Very clearly the elliptical or discoid appearance of these objects almost rules out the likelihood that the object involved in the D792 episode is a giant-sized planet. As we have seen, a round object like a planet would create a light curve with a characteristic flat bottom, and that is certainly not what we see in the case of D792. It remains possible that the object is in fact a large planet surrounded by dense rings, which we see at a slightly up-tilted or down-titled angle of anything up to 45° to give the impression that the object has a strong elliptical profile that obscures the presence of the actual planet. However, the idea that three such planets, all with rings tilted at an angle, passed in front of the star one after the other during the D1519 event stretches the imagination indeed. That the occulting objects are either swarms of exo-comets or large clusters of Trojan asteroids does remain possible. Yet accurately modelling such hypothetical swarms or clusters of objects from light curves alone is practically impossible.

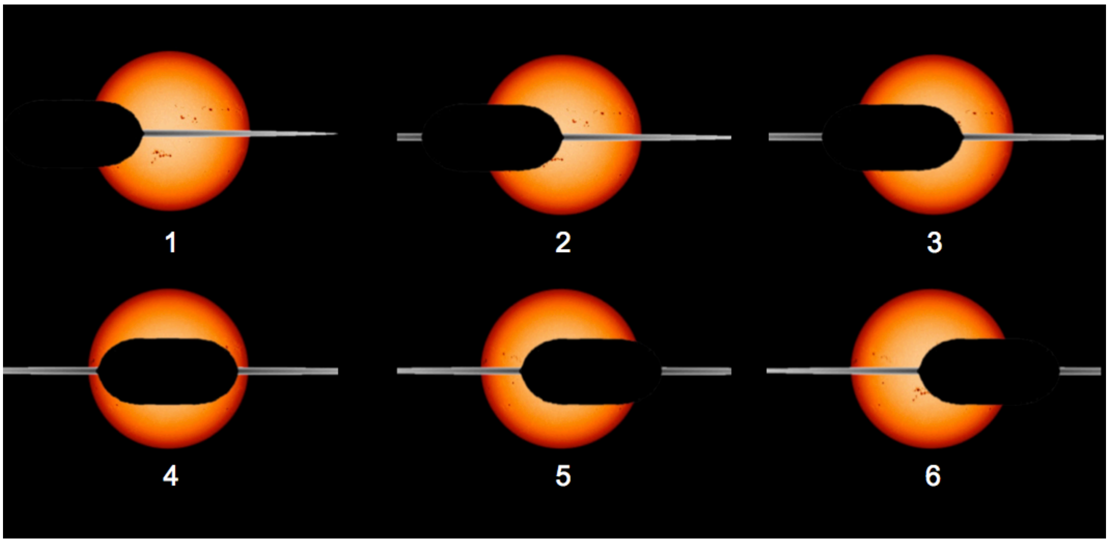

Figure 3.7. *Suggested ingress and egress of the D792 event's occulting object against the background of a star. Not to scale.*

Having said this, the elliptical or perhaps discoid appearance of the occulting objects certainly does not rule out a more exotic explanation. Ellipses or slim disks (although not irregular shards) might well conform to the appearance of alien megastructures.

What is more, a disk would only absorb some of the heat coming from the star. Since we only see part of a disk it might re-radiate its waste heat in a non-isotropic manner. In other words, it could be directed, whether purposely or otherwise, away from our line of sight, a possibility acknowledged by Jason Wright.[4] This could explain why no significant IR excess has been detected in connection with Boyajian's Star's light dimming episodes.

4.1. The Probability of Recurring Cycles

A better understanding of the nature of the occulting objects passing in front of KIC 8462852 might be forthcoming from a deeper examination of the cyclic fluctuations recorded in connection with the star. As previously noted, a full cycle of 48.4 days and a half cycle of 24.2 days[5] have been observed to separate various minor and major light dimming episodes. For example, it was noted that the gap between the D792 and D1519 events was 726 days, the equivalent of 13 x 48.4 day cycles, while the gap between the D1519 episode and the D1568 event was approximately 48.4 days (Boyajian et al, 2016). It is, however, possible to speculate further on this matter.

Jason Wright and Steinn Sigurdsson examined the six deepest dipping events (cited by them as Kepler days 261, 793, 1206, 1496, 1523, and 1568) and observed that they "all fall within a narrow range of phases when folded at a period near 24.2 days, suggesting a close-in orbital period (Wright & Sigurdsson, 2016)." In order to check the statistical probability of these results, 2,000 periods from the Kepler data were evenly sampled in frequency between 10 and 700 days. They then repeated the exercise using 10,000 mock sets of six dips with times randomly drawn from a uniform distribution with the same range as the Kepler time series. Results showed that the apparent periods of 24.2 days between the six deepest dips were without any statistical significance.

4.2. Testing the 24.2-day half cycle

To check these findings, Rodney Hale used the Kepler data to create a graph with a time scale of 24.2 days per unit beginning with the first recorded dipping event on day 140 (D140), a date corresponding to May 21, 2009 (see fig. 4.1). This then became "day" zero. In this manner a significant number of minor and major dips can be seen to line up almost perfectly with complete "Dip Days." More significantly, this trend does not simply apply to the dimming events recorded in the Kepler data. It is extended beyond the two years between 2013 and 2015, where no data was available, to embrace two new dimming events, the data for which coming from Bruce Gary, an astronomer who has been monitoring the star's light fluctuations since October 2015.[6]

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[4] Jason Wright during a presentation for the SETI Institute: Science Colloquium: "Frontiers in Artifact SETI: Waste Heat, Alien Megastructures & Tabbys Star - Jason Wright (ST 2016)", uploaded August 12, 2016. https://www.youtube.com/watch?v=XEDR-G2EDRM

[5] Gdsacco, "Seeing the forest through the trees," June 10, 2017, https://www.reddit.com/r/KIC8462852/comments/6gim8b/seeing_the_forest_through_the_trees/.

[6] See Bruce L. Gary's webpage on KIC 8462852 at http://www.brucegary.net/KIC846/.

The first of these occurred across a course of several days in May 2017, with a maximum drop of two percent recorded on May 19. The second began on June 13 and reached a two percent drop in flux on June 17. Of these, only the June 17 event corresponds to the 24.2-day cycle, falling around one day before Dip Day 122. The May event was askew of Dip Day 121 by approximately 10 days.[7]

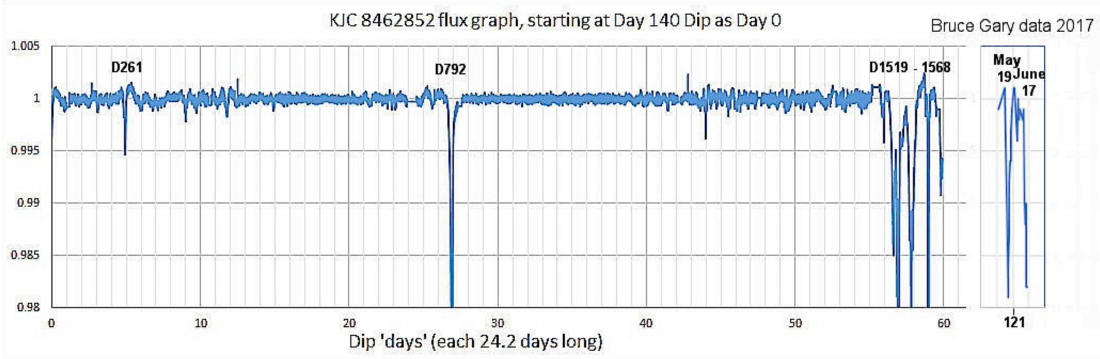

Figure 4.1. *Graph showing the relationship between KIC 8462852's 24.2-day half cycle and all major light dimming events since 2009. The graph starts with the first dip seen in the Kepler data, D140, corresponding to May 21, 2009, which we shall call Dip Day 0. It then counts forward in periods of 24.2 conventional days, i.e., Dip Day 10 would be 242 conventional days later. The graph then continues counting past Kepler's last day, May 11, 2013, to include Bruce Gary's data from May 1, 2017 onwards, which corresponds, sequentially, to Dip Days 121 to 122.*

The fact that so many minor and major dimming events synchronize almost perfectly with the star's 24.2-day calendar is surely now beyond statistical chance, despite the findings of Wright and Sigurdsson. Further analysis of these results will help support this contention. The fact that the June 2017 light dimming episode corresponded pretty well with the 24.2-day gap cycle is important, since it tells us that this cycle is now unlikely to be the consequence of instrumental false data generated by some internal or external mechanism coming to bear on the Kepler data.

The more pressing question is how minor and major light dipping events can synchronize so perfectly with a 24.2-day cycle attached to the star. Naturally occurring astronomical objects such as swarms of comets, clusters of Trojan asteroids, or trails of dust and debris, are extremely unlikely to order themselves into regular groups that appear on cue at the culmination of cyclic periods of 24.2 days. Their appearance would surely display a chaotic randomness that precludes the idea of regular gaps between light dipping episodes. It is unlikely also that we are seeing the same objects coming around and around again on an orbital period of 24.2 days since their size and appearance differ so greatly from one event to the next.

In addition to this, and as noted in Section 2.2, a clear relationship exists between the star's cyclic periodicities of 48.4 and 24.2 days and its 0.88-day fluctuations, the former being exactly 55 cycles of 0.88 days, the latter being 27.5 cycles of 0.88 days.

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[7] Reddit member gdcasso used the existing 24.2-day half cycle to predict a further dimming event after a further dimming episode that peaked at around two percent on May 19, 2017. This did indeed begin on June 13, 2017, with a maximum drop down to two percent occurring on on June 15. Gdsacco, "Seeing the forest through the trees," June 10, 2017, https://www.reddit.com/r/KIC8462852/comments/6gim8b/seeing_the_forest_through_the_trees/.

Not only does this information appear to confirm that the 48.4-day periodicity is the full cycle, while the 24.2-day periods are in fact half cycles, but it also implies that there is a close relationship between all three periodicities, the higher values being speeded up versions of the 0.88-day cycle. Having said this, if the star's 0.88-day light fluctuations are rotational in nature, then it seems unlikely that the occulting objects causing the light-dimming events would time their transits to conform to pre-existing 24.2-day, 48.4-day and even 242-day periodicities.

Yet having discounted the idea that the dimming episodes are occurring on the star itself, this leaves us with a puzzling conundrum. What type of objects can cause such carefully spaced light dimming events? Their clear cyclic behaviour makes them seem almost mechanical in nature, like cogs of different sizes turning inside an old clock.

Such surmises lend weight to the possibility of an artificial solution to the light dimming events connected with KIC 8462852. What is more there appears to be something almost contrived about the manner the four main periodicities associated with the star can be shown to synchronize with the earth's solar cycle.

5.1. Cyclic Number Sequences

KIC 8462852's recorded periodicity of 0.88 days synchronizes with the earth's solar calendar every 22 days. Its 24.2-day cycle coincides with earth days every 121 days, while its 48.4-day cycle synchronizes with the earth every 242 days (see fig. 5.1). The independent importance of this 242-day cycle seems confirmed in the knowledge that the 726-day period between the star's D792 and D1519 light-dimming events is exactly three cycles of 242 days (i.e. 242 x 3 = 726). Almost immediately we can see that each of these synchronizations with earth days are multiples of the number 11 (2 x 11 = 22, 11 x 11 = 121 & 22 x 11 = 242). Remember also that there are 55 cycles of 0.88 days every 48.4 days, with 55 being another multiple of 11 (5 x 11 = 55).

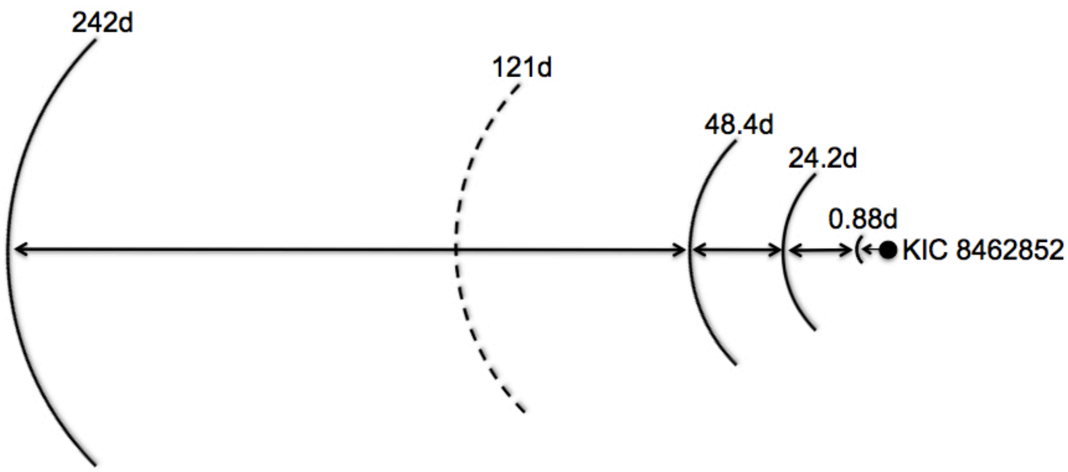

Figure 5.1. *The suspected periodicities of KIC 846852, showing also the 121-day synchronization with the earth of its 24.2-day half cycle and the 242-day synchronization between the star's 48.4-day cycle and earth days, this last amount being a potential Boyajian's Star cycle in its own right.*

A close inter-relationship between KIC 8462852's periodic fluctuations and their relationship to the earth's solar cycle can be expressed in diagrammatic form (see fig. 5.2). Here we see that the star's 0.88-day periodicity becomes the key to determining the proportional relationship between the star's other main cyclic values of 48.4 days and 242 days. For example, 242 days is exactly 275 x 0.88 days, while 48.4 days is 55 x 0.88 days. This means that the star's 48.4-day periodicity is precisely 1/5th of 242 days, making the time between 48.4 days and 242 days exactly four times this amount. In addition to this, the period between 48.4 days and 242 days is not only 4 x 48.4 days, as well as 4/5th of 242 days, but also 220 x 0.88 days, with 220 being 4 x 55 or 20 x 11 cycles of 0.88 days.

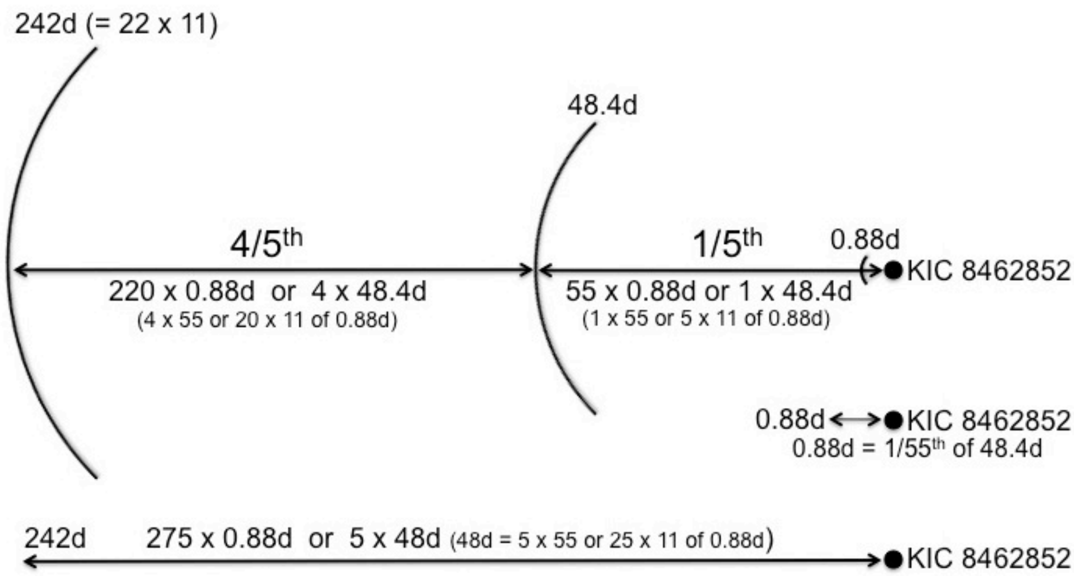

Figure 5.2. *The inter-relationship between the 0.88-day, 48.4-day and 242-day periodicities noted in connection with the Kepler light curve for KIC 8462852 (not to scale).*

Thus there appears to be two basic cycles seen in connection with Tabby's Star. One, lasting a grand total of 242 earth days, can be broken down into either five parts of 48.4 days or ten parts of 24.2 days. The other, based on 0.88 days, coincides with the earth every 22 days, making 11 points of synchronization during a period of 242 earth days. The relationship between the two cycles is 22/25, or 0.88 in decimals.

From this useful exercise we can see the recurrence of a series of inter-related whole numbers generated both individually and collectively by the two separate cycles associated with KIC 8462852. These are 5, 11, 22, 55, 121, 220, 242, and 275. All except five are multiples of 11, a prime number (indeed, it is the fifth prime, coming after 2, 3, 5, and 7). The additional presence of a periodicity of approximately 11 days noted in connection with the star's 0.88-day fluctuation patterns is further evidence that it reflects eleven-fold synchronizations with earth days.

That these two cycles noted in connection with KIC 8462852 should both synchronize with the earth's solar calendar in multiples of the number eleven is difficult to explain. It could, of course, be simply coincidence. On the other hand, it leads perhaps to the vexing question of whether or not the light dimming episodes recorded in connection with KIC 8462852 are being manipulated in some manner to express meaningful mathematical patterns and formula.

5.2. Attention-grabbing Signals

In 2005 French astronomer Luc Arnold proposed that the launch of space telescopes like the future Kepler mission would provide extraterrestrial civilizations with an ideal opportunity to communicate information using what he referred to as "attention-grabbing signals" (Arnold, 2005). In his opinion, this could be achieved by deploying massive solar panels with the express purpose of transiting stars. The resulting light curves could then be used to convey mathematical patterns such as prime number sequences, binary code, and even more complicated formulas. As Jason Wright realised when he first saw the Kepler data for KIC 8462852, this was exactly what Luc Arnold said we should look for in light curves produced by occulting objects transiting stars.[8]

In the knowledge that the star's periodicities synchronize with the earth's solar cycle in a manner that generates multiples of the number 11, a prime number, we really should consider the possibility that these cyclic light fluctuations contain mathematical information of specific interest to life on earth. How exactly will be the subject of a separate study by one of the authors, Andrew Collins.

It is also important to remember that regardless of whether or not the light dipping events of Boyajian's Star are ascribed a natural explanation, the inter-relationship between the different periodicities noted in connection with KIC 8462852 will remain valid.

5.3. Long-term Light Dimming

Understanding the cyclic patterns of KIC 8462852 should also be considered in the knowledge that in addition to the short-term light dips reported in connection with the star a long-term light-dimming trend has been noted. Dr Bradley Schaefer of Louisiana State University has determined from a detailed eyeball examination of photographic plates from the DASCH-Harvard collection that between 1890 and 1989 the star faded by as much as 20 percent (Schaefer, 2016). Even though this finding has been criticised by two separate teams of astronomers, who failed to find the same trend in either the DASCH-Harvard plates or another similar set of plates in Germany (Hippke et al, 2016; Lund et al, 2016), an examination of the Kepler data between 2009 and 2013 by Benjamin Montet and Joshua Simon showed that Boyajian's Star faded by around 3 percent across Kepler's initial four-year mission (Montet and Simon, 2016). A similar "non linear fade" is reported by Bruce Gary who has been observing the star, initially with a clear filter and afterwards with a violet filter, from October 2015 through to the present day. Although the fade rate fluctuates, Gary notes that the star is currently fading at a rate of approximately 1.4 percent per year.[9]

Very clearly, the existence of this long term dimming trend is unlikely to be unconnected with the star's short-term dimming events. Yet finding a mechanism to suitably explain both trends has so far proved difficult, and if the long-term trend can be verified then it could lend weight to an artificial source being behind both trends. If so, then it would strengthen the idea that the mathematical patterns detected in connection with KIC 8462852's light fluctuations really do have meaning and purpose. What is more, if the star's long-term fading continues at its present rate then there is a possibility that it will cease to exist in its present form inside a century. Whether or not Boyajian's Star is an old star about to die, or the long-term fading is being caused, as surmised by Eduard Heindl (2016), by star-lifting operations or by

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[8] Jason Wright during a presentation for the SETI Institute: Science Colloquium: "Frontiers in Artifact SETI: Waste Heat, Alien Megastructures & Tabbys Star - Jason Wright (ST 2016)", uploaded August 12, 2016.
https://www.youtube.com/watch?v=XEDR-G2EDRM

[9] See Bruce L. Gary's webpage: "Kepler Star KIC 8462852 Amateur Photometry Monitoring Project,"
http://www.brucegary.net/KIC846/#Yearly_Timescale_Fade_Observations/

the construction of a Dyson sphere (Wright & Sigurdsson, 2016) is currently impossible to determine. What we can surmise is that the imminent death of a star might well be something of interest to a nearby alien civilization.

6.1. Summary

A number of solutions have been put forward by a host of authors to explain the strange light fluctuations experienced by KIC 8462852. Some of these rely on the assumption that their source comes from the star itself (Metzger et al, 2017). Others rely on the surmise that they are the result of liberated planetary material in the interstellar medium (Makarov, 2016), or that the culprits are occulting objects orbiting the star (e.g. Boyajian et al, 2016; Ballesteros et al, 2017). Of all these possible solutions the physical modelling of the light curves from the Kepler data leans firmly towards the conclusion that the true source of the light dimming events will be found to be extremely large objects, natural or otherwise, either orbiting or transiting the star in some manner.

6.2. Ellipses

The Kepler data suggests also that the occulting objects, which all create light curves with sharp tips, display elliptical profiles with flat bottoms and tops. If correct, this indicates that the objects are themselves either ellipses, slim disks or irregular shards rotating along the line of sight. Indeed, if the obscuring objects can be shown to be slim disks then a disk's non-isotropic manner of distribution of its waste heat could help explain why no IR excess has been noted in connection with the star.

6.3. Physical modelling

Although physical modelling does not tell us what these objects are, the one thing it can do is virtually rule out the idea that the D792 event was caused by a giant-sized planet (Ballesteros et al, 2017). Being round, a planet of any size would provide a distinctive light curve with a characteristic flat-bottomed profile. The possibility that the obscuring objects are in fact the dense rings of planets tilted so that they assume an elliptical profile (and in so doing obscure the true profile of the planet) remains on the table. However, the fact that three slim ellipses in a line appear to have created the D1519 event makes the ringed-planet idea inadequate to explain the sheer number of objects involved. Such a theory cannot also explain the overall shape of the D792 event. This, as we have seen, showed the presence of incredibly long "wings" or trails visible during the ingress and egress of the star, while the main object itself displayed a clear elliptical profile with a flat bottom and top. Together these two quite separate elements do not add up to a giant-sized planet with dense rings tilted so as to create an elliptical profile.

6.4. Cyclic fluctuations

Indeed, the likelihood of the light fluctuations being caused by the transit across the face of the star by random clusters of comets or asteroids, or by giant-sized planets, is greatly lessened by the almost contrived manner in which the occulting objects seem to conform to very specific periodicities, most obviously the 24.2 day half cycle noted above. What is more, the fact that these periodicities reflect multiples of 11, a prime number, and coincide with the earth's own solar cycle in a meaningful manner, only adds to the problem of finding a natural explanation for the star's light dimming events. Indeed, we should not rule out the possibility that encoded within the Kepler data for KIC 8462852 is directed information not only manufactured by an intelligent source, but meant specifically to be understood by life on earth. It is a proposition that if proved correct would vindicate the predictions of Luc Arnold who as long ago as 2005 had one eye on the greater potential of future space missions. This, of course, included the Kepler space telescope, the very source of the data behind Tabby's Star's light dimming episodes.

References

Andersen (2015), Ross, "The Most Mysterious Star in Our Galaxy," The Atlantic, October 13, 2015. https://www.theatlantic.com/science/archive/2015/10/the-most-interesting-star-in-our-galaxy/410023/.

Arnold (2005), Luc, "Transit Lightcurve Signatures of Artificial Objects," *AJ* 627, 534-9, https://arxiv.org/abs/astro-ph/0503580.

Ballesteros (2017), Fernando J., Pablo Arnalte-Mur, Alberto Fernandez-Soto and Vicent J. Martınez, "KIC 8462852: Will the Trojans return in 2021?" *MNRAS* 000, 1–5, https://arxiv.org/pdf/1705.08427.pdf.

Boyajian (2016), T. S., et al. "Planet Hunters IX. KIC 8462852 – where's the flux?" *MNRAS* 457: 4, 3988-4004. https://arxiv.org/abs/1509.03622.

Hale (2016), R. B., "Thoughts on Star KIC8462852," private circulation only, December 21, 2016.

Heindl (2016), Eduard. "A physically inspired model of Dip d792 and d1519 of the Kepler light curve seen at KIC8462852," https://arxiv.org/abs/1611.08368.

Hippke (2016), Michael, Daniel Angerhausen, Michael B. Lund, Joshua Pepper, and Keivan G. Stassun, "A statistical analysis of the accuracy of the digitized magnitudes of photometric plates on the time scale of decades with an application to the century-long light curve of KIC 8462852," https://arxiv.org/abs/1601.07314.

Lund (2016), Michael B., Joshua Pepper, Keivan G. Stassun, Michael Hippke, and Daniel Angerhausen. "The Stability of F-star Brightness on Century Timescales," https://arxiv.org/abs/1605.02760.

Makarov (2016), Valeri V., "Photometric and astrometric vagaries of the enigma star KIC 8462852," https://arxiv.org/abs/1609.04032.

Metzger (2017), Brian D. Ken J. Shen, and Nicholas C. Stone, "Secular Dimming of KIC 8462852 Following its Consumption of a Planet," https://arxiv.org/abs/1612.07332.

Montet (2016), Benjamin T., and Joshua D. Simon, "KIC 8462852 Faded Throughout the Kepler Mission," https://arxiv.org/abs/1608.01316.

Schaefer (2016), Bradley E., "KIC 8462852 Faded at an Average Rate of 0.164+-0.013 Magnitudes Per Century From 1890 To 1989," *AJL* 822: 2, article id. L34, 6 pp. https://arxiv.org/abs/1601.03256.

Wright (2016), Jason T. and Steinn Sigurdsson, "Families of Plausible Solutions to the Puzzle of Boyajian's Star," *AJL* 829: 1, 1-12. http://iopscience.iop.org/article/10.3847/2041-8205/829/1/L3/pdf.

Acknowledgments

The authors wish to thank Greg Little, Richard Ward, and Russell M. Hossain for their help in the preparation of this paper.

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