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PHOTOMETRY OF TWO POORLY STUDIED PLANETARY NEBULAE WITH BINARY CENTRAL STARS

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ABSTRACT

We have observed the central stars of two planetary nebulae, Abell 65 and Hubble 12, both of which are claimed to be close binary systems. We looked at the differential photometry from these systems in hopes of confirming previous reports of variability caused by close binaries. Binary interaction in a planetary nebula is a possible source of the structure of bi-polar or butterfly PN. We determined that one of the two systems, Abell 65, most likely exhibits variability due to irradiation of a cool companion or deformation of one companion caused by it filing a significant fraction of its Roche Lobe. We cannot confirm the binary classification until a complete light curve is obtained. With Hubble 12, which was claimed to be an eclipsing binary system with an irradiation effect, we found no clear variability indicative of a binary system and recommend that it be removed from the list of known binary central stars.

Subject headings: Planetary Nebulae: individual (Hubble 12 and Abell 65), Binaries: close

1. INTRODUCTION

The central star in any planetary nebula (PN) is believed to play an important role in how the structure of a PN is formed. The structures of PNs can range from a spherical structure to what some call a bipolar or butterfly shape (Balick, B. 1987, e.g.). There have been many different views on how these structures have come to be. One belief is that the presence of a binary companion will create an environment such that the observed shapes can be formed.

Recent work has shown that stars on the asymptotic giant branch (AGB) can exhibit strong magnetic fields (García-Segura 2005, e.g.). However, as the star loses material via a strong wind, that material carries angular momentum away from the star and the rotation is reduced, resulting in a loss of magnetic field strength. If an AGB star happened to have some type of binary companion, the binary orbit could provide angular momentum and thus allow for the star to maintain its magnetic field (De Marco, Hillwig, & Smith 2008). The resulting magnetic field may then be able to create the observed shapes in planetary nebula by confining the ejected material.

In the 1970s a survey was begun to determine the percentage of PNs with close binary central stars. The survey was looking for evidence of close binary effects on the photometry of approximately 100 different planetary nebulae (De Marco et al. 2008). This survey concluded that 10-15 % of PNs have binary central stars (Bond & Livio 1990). Currently, there are 17 catalogued PNs with close binary central stars (De Marco et al. 2008). However, some of these show little evidence of actual binary nature or doubts have been raised that the published evidence does support binarity. Some of these doubts have been in regards to the type of binary interaction occurring, while others suggest that the observed variation was not from binary interactions at all, but from some other source of photometric variability.

Many of the PNs with close binary central stars have been discovered because of some type of photometric variability with orbital phase. The variations can differ depending on the type of binary system we are seeing. In some cases, an eclipse may be present in the photometry. An eclipse occurs when one star passes in front of the other, causing a decrease in the observed brightness. For an eclipse to be seen, the binary system must be at an inclination angle where the two stars will block each other for some portion of their orbit.

Another form of variation happens when one star is much hotter than the other and heats the facing hemisphere of the cooler star; this effect is called irradiation and will produce a sinusoidal pattern in the photometry. Lastly, if one or both of the stars fill a significant fraction of their Roche Lobes, the system will have a similar sinusoidal pattern as with the irradiation effect. However it will now have two maxima and minima per orbital period (De Marco et al. 2008). This is known as ellipsoidal variability. A binary system can have variations due to more than one of these effects at a time, but it can also have variation due to winds, pulsations, or even dust. Since non-binary variations can produce similar photometric variability as binary systems, only very precise and constant periodicity is evidence of true binary interactions (Zijlstra 2007).

From the current list of binary central stars of PNs, we have observed two that we believe needed more data to accurately determine the nature of the variations.

2. BACKGROUND

2.1. *Hubble 12*

The central star of PN Hubble 12 (Hb 12), NSV 26083, has recently been reported as an eclipsing binary system with a period of 3.4 days (Hsia et al. 2006). Hsia et al.

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(2006) observed the central star of Hb 12 in the R and I filter and from the photometry found what they claim to be an eclipse lasting approximately 40 minutes. The eclipse had a depth of 0.08 mag in I and it was not seen in the R filter. However, doubts have been raised regarding the true binary nature of Hb 12. The eclipses that are believed to be seen every night do not appear the same on multiple nights of observation. Also, the irradiation effect that they claimed to have measured does not align with what would be expected from an eclipsing binary system. De Marco et al. (2008) notes that in the Hsia et al. (2006) folded period plot the scatter is larger than that of a single night, this is unlikely in a binary system because well-behaved, consistent periodicity is a key characteristic of a binary system (Zijlstra 2007). Doubts have been raised about the true binary nature of Hb 12, so by obtaining more observations on it we hope to be able to discover more about the variability associated with Hb 12 and possibly determine a source.

2.2. *Abell 65*

PN Abell 65 (A65) was listed as having a close binary central star in Bond & Livio (1990) with a period of one day. This claim was based on observations showing a 0.5 mag decreases over six hours on four consecutive nights. However, no light curve was published on ESO 526-3, the central star of A65, even though it was claimed to have variations due to binary interactions in Bond & Livio (1990). Walsh & Walton (1996) later stated that A65 is an eclipsing binary system based solely on the Bond & Livio (1990) statement. No data or light curves have been published to support the photometric variation that was seen by Bond & Livio (1990), and therefore we cannot tell if the detected variability is due to an eclipse instead of ellipsoidal variation or irradiation (De Marco et al. 2008). Until data can be published on the system, the cause of the variability in A65 is a mystery.

3. OBSERVATIONS AND DATA REDUCTION

All of the data on A65 and much of the data taken on Hb 12 were obtained at Kitt Peak National Observatory (KPNO) in Arizona using an Apogee U42 CCD on the SARA 0.9m telescope. The remainder of the Hb 12 data was taken using an SBIG STL6303E CCD on the 16" DFM telescope at the Valparaiso University Observatory (VUO) in Valparaiso, IN. All of the A65 data were taken using an R filter and the Hb 12 data was taken using the V and R filters and the R and I filters at KPNO and VUO, respectively. In the early part of the project B, V and R filters were used at KPNO, but to improve our time resolutions the B filter observations were discontinued.

All of the data taken with the SARA telescope had bias and dark current removed from the images as well as flat field corrections. All of this was done using the Image Reduction and Analysis Facility[2] (IRAF) IMRED software package. The VUO data went through a similar process without the dark corrections due to low dark current present in exposures, but bias removal and flat field corrections were again done using the IRAF IMRED package.

For both objects photometry was performed using the IRAF DAOPHOT package. One comparison star and two check comparison stars were selected in each field. The Hb 12 data taken with the SARA telescope and the VUO data used the same first comparison star, but the other, brighter comparison stars were used because of the wider field produced by the camera at VUO. In the data taken with the SARA telescope, we noticed that the original chosen comparison stars were changing values from night to night; comparison stars were chosen that seemed to minimize this effect.

4. ANALYSIS AND CONCLUSIONS

4.1. *Hubble 12 Analysis and Conclusions*

The data that was taken with the SARA telescope was collected to look for the variations within a night and see if the eclipse with a period of 3.4 hours as claimed by Hsia et al. (2006) is present. Our photometry from three of the nights with the longest durations has been compiled and can be seen in Figure 1. The first night of the set shows what could be an eclipse. However, this eclipse lasts approximately 70 minutes, unlike the eclipse reported by Hsia et al. (2006) which lasted approximately 40 minutes. The depth of the dip we saw in our photometry has amplitudes 0.02 and 0.015 in R and V filters, respectively. On the next night, a similar dip is seen in the R and V filters. However, the observed brightness in the R filter is almost double the amplitude of that in the V filter and the light curve does not return to the original level afterwards. The R amplitude only recovers about half of the amplitude and seems to remain constant afterward, with some slight additional variations occurring.

Similarly, in the V filter the amplitude of the observed brightness is again almost double that of the dip seen in the first night. Also, the data are not constant before or after the possible eclipse or dip. In the whole night,

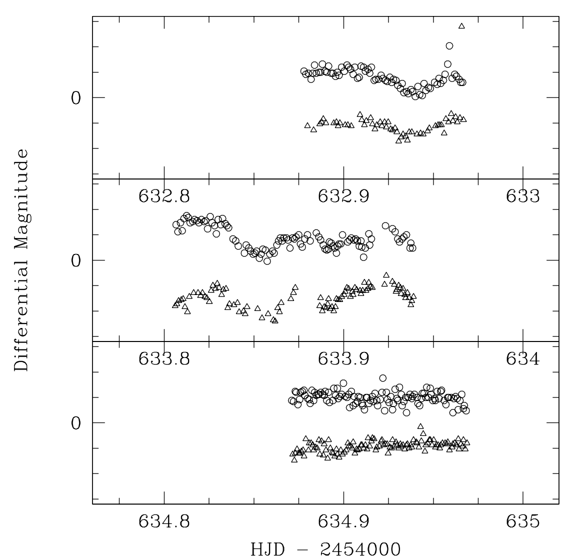

Fig. 1.— R and V filter differential photometry for Hb 12 showing nightly variations in three consecutive nights. The R band data has been represented by the circles and the V band by triangles.

[2] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

some type of variation is occurring that was not evident in the data from the night before. In the last night of this data set, we did not see any sign of a dip or possible eclipse. Throughout this whole set, mainly on the last two nights, there are clear differences between the observed brightnesses in the R and the V filters. Although the time resolution that we had was not as good as that of Hsia et al. (2006), based on the length of their claimed eclipse, we should have been able to see around 32 points of data that would be able to capture the eclipse. Therefore we can conclude that no eclipse with a period of 3.4 hours was seen in our photometry

To continue to search for intra-night variability and to observe possible longer term irradiation effects that may be present we began observing Hb 12 in the R and I filters from VUO, the same filters used by Hsia et al. (2006). The time resolution was much lower than that of Hsia et al. (2006) and the SARA telescope data, but a minimum of 5 points of data would have spanned the reported eclipse duration. By observing in the I filter we hoped to see the eclipse reported by Hsia et al. (2006) since the eclipse was completely absent in their published R data. In our VUO observations we saw no signs of an eclipse occurring at the reported period (see Figure 2). Neither did we see the longer term irradiation effects that were reported by Hsia et al. (2006).

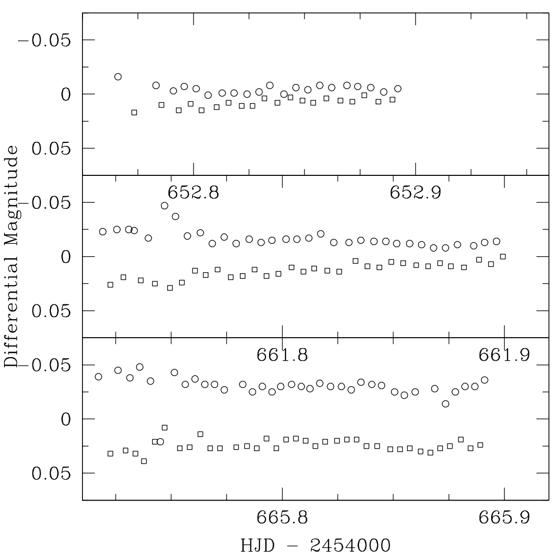

Fig. 2.— Differential Photometry of Hb 12 from VUO in the R and I filters for three separate nights. The I band data has been represented by the squares and the R band data is represented by the circles.

On the first two of the three nights that Hb 12 was observed the system brightness appeared to be increasing in the I filter data, possibly due to some longer term variability trend in the star. However on the third night the photometry appears to be constant and the differential magnitude was at a similar level as the start of the other two nights. Significant differences also appear between the brightness in the R and I bands. While the brightness observed in the I filter appears to be increasing, the brightness observed in the R filter appears to be decreasing. Also, the long term trend across the three nights of data seems to show an increase in the observed brightness in the R filter, whereas the long-term I filter observed brightness appears to be decreasing (see Figure 2).

Based on our observations of Hb 12 it appears that there is no evidence of binary variability. Long term observations of Hb 12 will continue at VUO to determine if any trends may be present in the central star. There are other causes of variability in the star and some of these should be investigated in case the variability is from another source. Until the photometric variations that are seen in Hb 12 can be explained, it should be removed from the current listing of PN with binary central stars.

4.2. *Abell 65 Analysis and Conclusion*

The photometry for A65 showed well behaved night-to-night trends. The data were taken in the fall of 2007, then again in the summer of 2008. All of the data are graphed in Figure 3 to show the range of the measured differential magnitudes. The range of the data shows that the amplitude of the system is at least one magnitude. In a single night, the trends seen were consistent with what we would expect to see in a system with a 24 hour period. As shown in Figure 4, the differential magnitude appears to be increasing of the course of each night during the time span over which the data were collected. Since the period is so close to 24 hours, the trends seen should be similar from night to night, and this is what we see. We conclude that Bond & Livio (1990) were correct in identifying the period as very close to 24 hours.

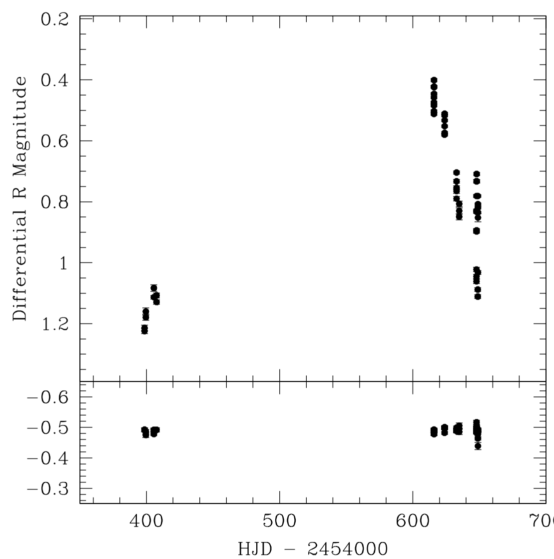

Fig. 3.— *Upper panel:* All of the differential photometry for A65 central star in R filter collected for this paper. *Lower panel:* The differential photometry of the comparison star related to the first check comparison star.

Each night of data appears to show similar trends that are increasing and decreasing depending on where the target would be in its orbit if it is a binary system. That along with the Bond & Livio (1990) claim that the magnitude dropped 0.5 magnitudes in 6 hours leads us to believe that what we are seeing is not evidence of an eclipse but of irradiation or ellipsoidal effects. If the nightly

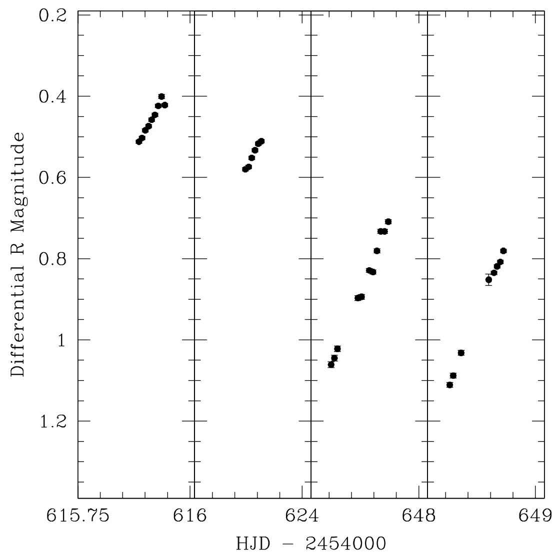

FIG. 4.— Sampling of the nightly differential photometry of A65 showing four nights scattered between late May and early July.

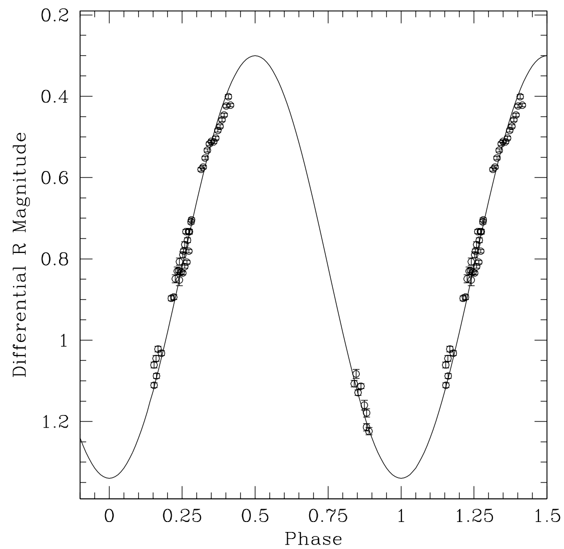

FIG. 5.— The phase diagram in the R band of the current most likely period of 1.00388d compared to a sine curve.

trends that we are seeing were from an eclipse then the eclipse would have to last approximately 12 hours (half of the period). In order to have an eclipsing system with a sinusoidal light curve, *both* stars must fill or nearly fill their Roche Lobes. Given that the PN is old (Frew 2008, $\sim 27 \times 10^3$ yrs), the CS itself should be very close to the WD track, if it has not yet reached it. It is therefore unphysical to expect that this star would fill a significant fraction of its Roche Lobe. Based on our observations, it is most likely that the trends that we are seeing in our data are caused by irradiation or ellipsoidal variability; however, we will not be able to be certain until we can obtain a more complete light curve.

With the data that we have collected so far on A65, preliminary period fitting has been done using IRAF's Phase Dispersion Method software. From the tentative fittings we believe that the period of A65 is slightly over 24 hours, with period ranging from 1.003 to 1.008 days. From these the period that we believe to be most likely, based on the folded phase data and the sinusoid nature of the fit, is a period of 1.00388 days. When the phase-folded data is compared to a sine curve, it shows similar behaviors and shows some evidence of a possible sinusoidal nature in the light curve, which can be seen in Figure 5. If the variation is caused by irradiation, the orbital period should be close to our tentative period fit. If the variability that we are seeing is caused by ellipsoidal variations, then the orbital period would be double that of our tentative period fit. The period fit that we made only takes into account one maximum and one minimum, so in the case of an ellipsoidal effect the fitted period would only represent half of the orbital period.

More observations are needed on A65 in order to get a complete light curve. When a full light curve is found for A65 we will be able to gain a better understanding of the binary interactions happening. We are in the process of observing A65 with telescopes at Cerro Tololo Inter-american Observatory (CTIO) and Perth Observatory. Observations will also continue with the SARA telescope at KPNO.

5. SUMMARY

In our photometry for Hb 12, no evidence of the reported binary variability was seen. Neither the variability from irradiation with a period of 3.4 hours nor the eclipse lasting 40 minutes were present. Although there was variability present in the data, none of it appears to be due to binarity. Further research on the variability will need to be done in order to determine what is causing it, but since it currently does not appear to be due to a binary nature, Hb 12 should be removed from the current list of PN with binary central stars.

With no previously published data (Bond & Livio 1990, identified the photometric variability of the CS in a table but did the photometry has never been published), the nature of A65 was unclear. Through our research we were able to demonstrate that there is strong variability present in the central star. The claim that the variability is due to an eclipsing binary seems to be unlikely based on the physical characteristics of the system. Because of the very consistent, nearly sinusoidal behavior of the light curve, it appears to be more likely that the variability is due to irradiation or an ellipsoidal effect . With the phase-folded plot, it appears that the period is likely in the range of 1.003 to 1.008 days if it is due to irradiation, and twice that if it is due to an ellipsoidal effect. The folded phase data also appear to be nearly sinusoidal, as would be expected with variability due to irradiation. When more observations are taken on A65 we will be able to determine more of the light curve and therefore have more evidence of what is happening in the system.

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