BRIGHTNESS AND COLOR VARIATIONS IN THE HOT PULSATING HORIZONTAL BRANCH STAR PG1627+017

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We have measured the variations in brightness of the hot horizontal branch star PG1627+017 in the U and R filters (?= 0.37 µm and 0.66 µm, respectively) caused by low-order g-mode pulsations. Theory predicts that the changes in magnitude will not be achromatic and the U magnitudes will have a larger variance, i.e. the star becomes hotter as it becomes brighter. A preliminary analysis shows a more complicated behavior, with a variety of relative amplitudes in U and R. These are the first extensive observations of a cooler subdwarf B star in more than one wavelength.

1. INTRODUCTION

The Extended or Extreme Horizontal Branch (EHB) is a stage of evolution where stars previously on the Red Giant Branch have lost most of their outer envelopes due to a helium flash, leaving behind only a core of helium and a thin shell of hydrogen covering it. At this stage they move to the EHB as low mass, hot (22,000-40,000 K), pulsating subdwarf B (sdB) stars. These are commonly found in the disk of our Galaxy and in some star clusters. We can use astroseismology, the study of oscillations in a star that pulsates in numerous excited normal modes simultaneously, to learn more about the inner structure of these stars. Depending on the chemical makeup of the layers within the star, the different oscillations will dive to different depths of the interior. Because sdB stars are essentially the same as the cores of Red Giants, astroseismological studies may also help reveal the details of the interior structure of these stars.

Pulsating sdB stars were recently discovered by Kilkenny et al. (1997). Unofficially known as EC14026 stars, these variables vibrate with periods from 80-600s because of pressure-mode (p-mode) pulsations. P-modes are caused by an iron opacity ? mechanism in the thin outer diffusion-dominated envelopes. But recently Green et al. (2002) found another type of sdB stars whose pulsation periods are over a factor of ten too long to be a result of p-mode waves. Instead, a gravitational restoration force (whose mechanism to excite the modes is unknown) must cause the driving of these deeper pulsations. These gravity mode (g-mode) pulsations occur in ~75% of sdB stars cooler than 30,000K or 25%-30% of all sdB stars. (Green et al. 2002)

Theory predicts that stars pulsating by g-modes do so non-achromatically and will have a larger range of magnitudes in the shorter wavelengths (Randall, private communication). We took time-series photometry of PG1627+017, a cooler sdB pulsator, in the U and R filters in effort to verify this prediction. In this paper we show that this star is more complex than expected and the U does not always have a larger range of magnitudes. Further analysis is needed to draw any definitive conclusions, especially since the results depend on the treatment extinction through the earth's atmosphere, now modeled in a simplistic fashion.

2. OBSERVATIONS

Star PG1627+017 pulsates with a period of a few hours. All time-series photometry was gathered on July 1-6, 2003 at the MDM Observatory at Kitt Peak, Arizona. The 2.4m Hiltner Telescope and CCD camera with 9.4 arcminute FOV@ 0.28 arcseconds/pixel were used for all data collecting. The exposure times ranged from 6-15s for the R filter and 30-75s for the U filter. Aperture photometry was done with the local sky estimator. Taking a number of stars with similar magnitudes from within the ccd frame we performed differential photometry with respect to these nonvariables. Correcting for atmospheric extinction with two filters is extremely difficult because UV light is more strongly scattered. By using a nearby slightly redder comparison star PG1432+004 (right ascension 14:35:20.00, declination +0:13:48.00) we found the correction for each night and applied it to our star.

Each night produced a different light curve, but the magnitudes varied on average 0.06 in the U and 0.04 in the R. These approximate ranges for U and R do agree with the theory that U magnitudes vary more.

On Night 1 a very strange curve appears when graphing the Heliocentric Julian Date vs. the differential magnitude of the R filter. In the middle of the night the guider program crashed and a new guide star was established. The coordinates of all of the stars were moved significantly halfway through the night. This affected the definition of the exact locations of the stars while reducing the data.

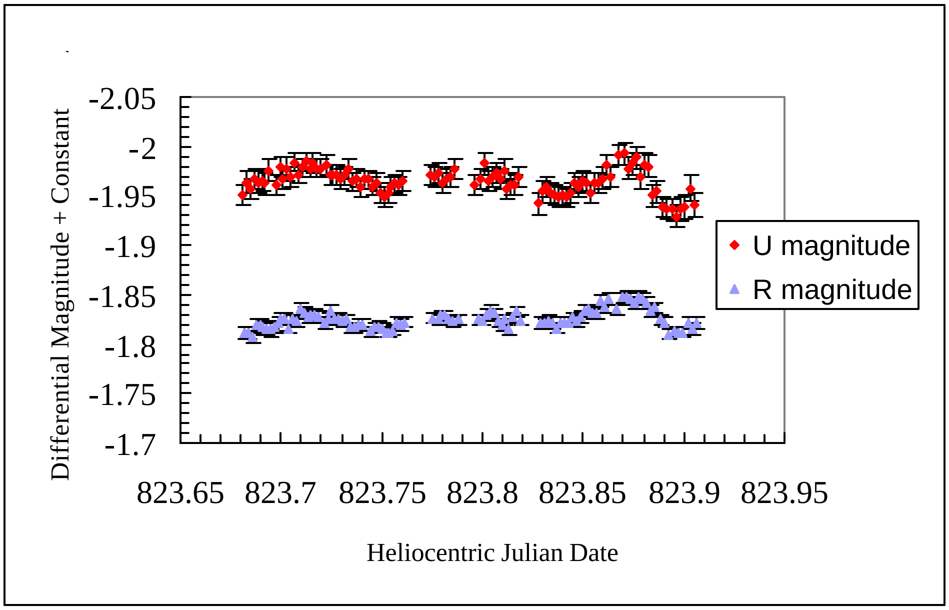

Figure 1. The variations in the U and R pulsations are correlated as suspected. The same behavior is seen on all nights.

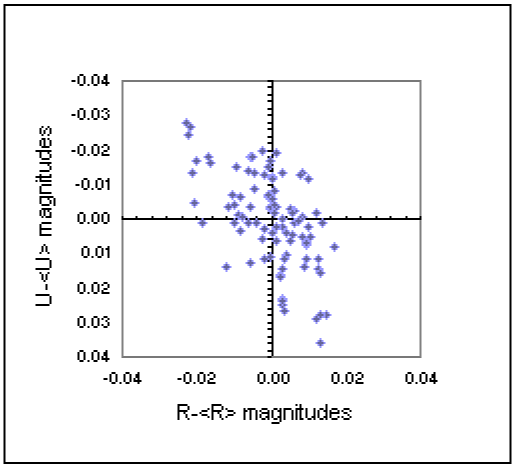

Figure 2. (left) Relative Amplitude for Night 2. The comparison between the U and R magnitudes tells us whether or not the star is pulsating achromatically, i.e. with a slope of one. In night 2, the slope of 0.796 means that R varies more than the U magnitude. This result is preliminary and does not agree with the strong prediction from theory that the U should have a larger variation.

Night	**Slope of Relative Amplitude (all pts)**	**Stdev[U]**	**Stdev[R]**	**<err U>**	**<err R>**	**Slope of Relative Amplitude (#2)**
1	1.497	0.045	0.021	0.009	0.005	0.580
2	0.796	0.013	0.009	0.010	0.006	0.796
3	0.582	0.012	0.008	0.009	0.006	0.975
4	1.460	0.014	0.008	0.005	0.006	1.460
5	0.617	0.014	0.014	0.019	0.008	0.856
6	0.391	0.014	0.012	0.011	0.006	1.044
Average	0.891					0.952
Stdev	0.473					0.296

Table 1. The slopes of the R-<R> vs U-<U> graphs for all nights are shown above. The standard deviation in both U and R are high, but only in the R are these numbers large enough to pass as an actual variance in magnitude instead of error. The slope of relative amplitude #2 comes from the corrections mentioned below.

Nights 2 and 4 went very smoothly with almost photometric skies and relatively good seeing. An example of the light curves collected for night 2 is seen in Figure 1 above. Nights 3, 5, and 6 had sections of poor seeing that surface in the slope of the R-<R> vs U-<U> graphs. From this point on when the slope is mentioned, it refers to the R-<R> vs U-<U> graph on the respective nights. Figure 2 shows an example of these graphs for night 2. It is obvious that the period here is not constant, but the two magnitudes are correlated. Slopes for all points for all nights can be seen in Table 1 above. The second set of amplitudes results from the changes below.

The end of night 3 does not have a clear light curve. This effect may be caused by the star ceasing its pulsation during that time. If only the first 56 exposures are used, the slope is greatly increased from the original 0.582 to 0.975. This striking difference could also be caused by the correction for atmospheric extinction being inaccurate or the general decay of good seeing towards the end of the night.

Cloud coverage became a problem on Night 5. If all of the data is used, the slope is 0.617, with a dramatically larger variance in the R. However, if only the second half of the night's data is used (after the clouds had passed), the slope becomes 0.856.

A horseshoe shape appears in the R-<R> vs U-<U> graph for night 6. Each half of the night makes a slope close to one separately. However, the R magnitudes are brighter the second half of the night so the data appears shifted to the left.

3. SUMMARY AND CONCLUSIONS

G-mode pulsations appear to be much more complicated than theorists predicted. It is unclear whether or not the star's pulsations are achromatic because the U magnitudes do not immediately show a larger variance than the R. The large variations in these slopes, if real, may be caused by the changes in the projected oscillations as the star rotates.

PG1627+017 is the first star observed in detail in more than one wavelength simultaneously. It would be beneficial to repeat this process with several stars for longer time periods. Plans have been discussed of a worldwide observing run that would allow for continuous observations of these periods. This would help to determine why the slopes of the relative amplitudes for all nights are different than we expected. Further analysis is needed and will reveal the true variations of this sdB star and its angular modes of pulsation.

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REFERENCES

Green, E.M., et al. 2003, ApJ L31
Kilkenny, D., Koen, C., O'Donoghue, D., & Stobie, R.S. 1997, MNRAS, 285, 640