*Baltic Astronomy, vol. 7, 203–209, 1998.*

# HST OBSERVATION OF GD 358

A. Nitta[1], S. O. Kepler[2], D. E. Winget[1], D. Koester[3], J. Krzesiński[4], G. Pajdosz[4], Xiaojun Jiang[6] and S. Zoła[5]

[1] *McDonald Observatory and Department of Astronomy, University of Texas, Austin, TX 78712, U.S.A.*

[2] *Institutio de Fisica, Universidade Federal do Rio Grande do Sul, 91501-900 Porto Alegre, RS, Brazil*

[3] *Institute für Astronomie und Astrophysik, Universität Kiel, D-24098 Kiel, Germany*

[4] *Mt. Suhora Observatory, Cracow Pedagogical University, Poland*

[5] *Mt. Suhora Observatory, Cracow Pedagogical University, Poland and Astronomical Observatory of Jagiellonian University, Cracow, Poland*

[6] *Beijing Astronomical Observatory, China*

Received October 1, 1997.

**Abstract.** The success of asteroseismology lies in the correct identification of the star's normal modes of oscillation. Winget et al. (1994) identified the normal modes of a helium white dwarf pulsator, GD 358, through the frequency distribution of the pulsation. Robinson et al. (1995) described a new mode identification method by comparing the pulsation amplitudes in the ultraviolet and optical ranges. In order to cross-calibrate the two mode identification methods, we decided to apply the method used by Robinson et al. to GD 358. In August 1996, the Hubble Space Telescope took time-series spectroscopic data of GD 358 using the Faint Object Spectrograph. We also obtained nearly simultaneous ground-based optical data necessary to apply the method of Robinson et al. At this stage, we can only rule out the possibility of $\ell = 3$ for the three modes we analyzed, but cannot determine to which $\ell$ value the modes correspond.

**Key words:** stars: white dwarfs, oscillations, individual: GD 358

## 1. INTRODUCTION

We study the pulsating white dwarfs (hereafter WDs) because they are one of the very few types of stars from which we can learn their internal structure by asteroseismology. Their investigation gives a possibility to learn about physics under the extreme pressure, temperature and density values and to understand evolution both prior to and during the WD stage (mainly the cooling process), so that we can use white dwarfs as reliable chronometers of the Galaxy.

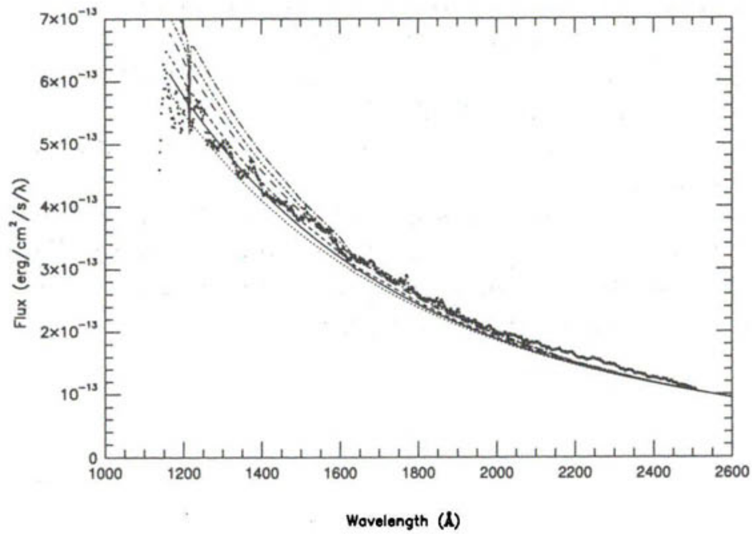


**Fig. 1.** A comparison of the observed ultraviolet spectrum and the model spectra by Koester. All spectra are normalized at the reddest wavelength bin. All models have log $g = 8.0$ and the effective temperatures of 24 500 K (dotted line), 25 500 K (solid line), 26 500 K (short dash line), 27 500 K (long dash line), 27 500 K (dot and short dash line), 28 500 K (dot and long dash line), 29 500 K (short dash and long dash line).

The success of asteroseismology hinges on the correct identification of the normal modes of oscillation which can be represented by three integers: radial overtone number $k$, spherical harmonics index $\ell$ and the azimuthal quantum number $m$. Winget et al. (1994) identified GD 358's normal modes through their period distribution (hereafter referred to as the period spacing method). Recently, Robinson et al. (1995) have demonstrated another way to identify the $\ell$-value

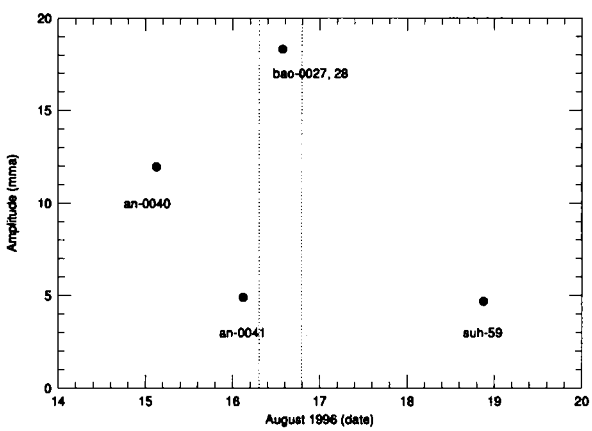


**Fig. 2.** The 423 s mode optical amplitude change in August. The HST observations took place between the dotted lines, an-0040 and an-0041 are obtained from observations at McDonald, bao-0027 and bao-0028 are from observations at Beijing and suh-59 are from obsertvations at Mt. Suhora.

of pulsation mode by comparing the pulsation amplitudes at different wavelengths: UV and optical (hereafter, the relative amplitude method). Due to limb-darkening effects combined with geometric cancellation of the spherical harmonics, the pulsation amplitude has strong $\ell$ dependence in UV compared to the optical wavelength (see the top panel of Fig. 4). The relative amplitude method will be very useful for the pulsating WDs which do not show as many modes as GD 358 or PG 1159-035 since the success of the period structure method used for these stars replied upon the abundance of detected normal modes (Winget et al. 1991, 1994). Robinson et al. (1995) have applied the relative amplitude method to a pulsating WD with the hydrogen atmosphere (DAV) G 117-B15A and concluded that its 215 s pulsation is a $\ell = 1$ mode. So far, nobody has tested if the mode identification made by these two methods is the same or not.

The goal of this project is to cross-calibrate the two mode identification methods. We use GD 358 since the period spacing method has already been successfully applied to it, and since it is the brightest helium variable (DBV) we know. Winget and Kepler have applied for time to observe GD 358 with the HST for obtaining the

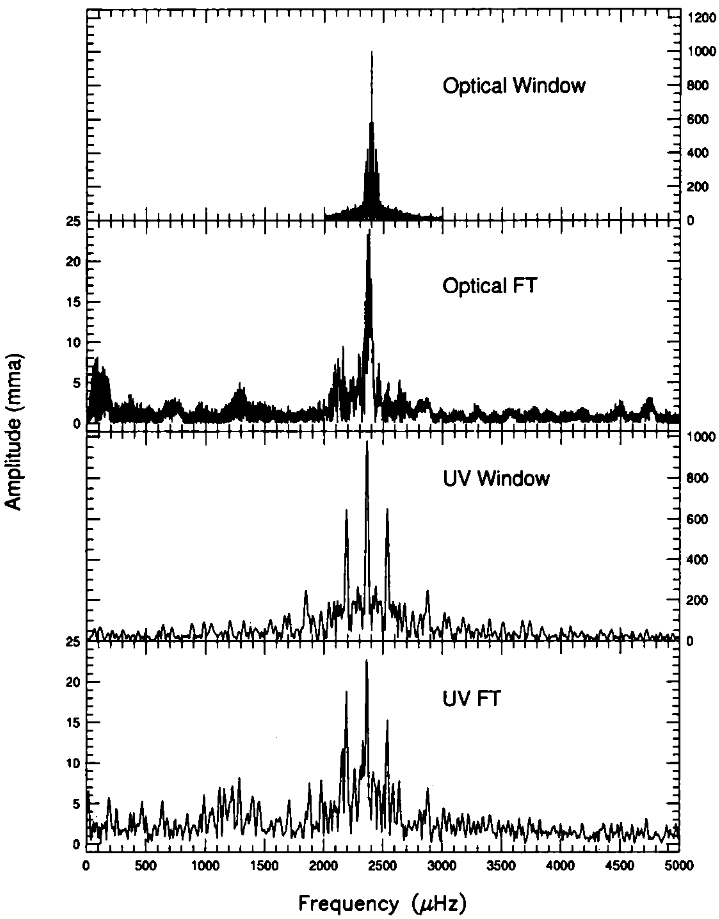


**Fig. 3.** Fourier Transform of the optical data obtained in August 1996 and the ultraviolet data obtained by HST.

ultraviolet data, necessary for the relative amplitude method, and have been granted eight orbits in August 1996. The Faint Object Spectrograph (FOS) was used for obtaining the time series spectra of GD 358. Fig. 1 shows the average UV spectrum along with the model spectra provided by Koester.

In order to apply the relative amplitude method, we must have both ultraviolet and optical amplitudes of the pulsation modes. With the help of our Polish and Chinese colleagues, we obtained the optical data but due to poor weather during the runs, the data are not of sufficient quality. This is a serious problem since we found that

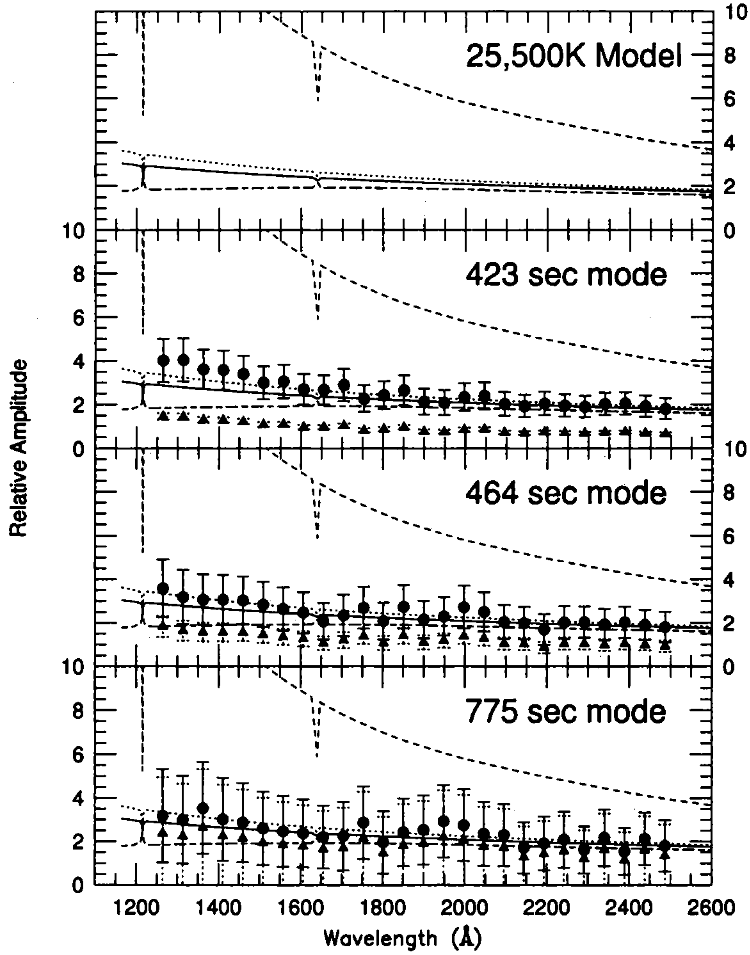


**Fig. 4.** The top panel shows the relative amplitude calculated for the $T_{\rm eff} = 25\,500$ K, $\log g = 8.0$ DB model. The $\ell = 1, 2, 3, 4$ modes are shown by solid, dotted, short dash and long dash lines, respectively. The amplitude is normalized to 1.0 at 5500Å. The second, third and forth panels show relative amplitudes of 423 s, 464 s and 775 s modes in the UV, respectively. Dots are the relative amplitudes normalized to the reddest UV bin, and triangles are the relative amplitudes normalized using the optical amplitude determined for the whole August 1996 optical data set. The amplitude modulation during the HST observations has not been accounted for in these figures; likely we have overestimated the amplitude of the modes when using the whole August 1996 data. The lines shown in these panels are identical to the top panel.

GD 358 showed very large amplitude variations during the HST observations. We can easily see this in Fig. 2 which shows the optical amplitude of the 423 s mode around the time of the HST observations. The 423 s and 464 s modes were the most dominant during the observations in August 1996. Fig. 3 shows the Fourier Transform of the data taken both from the ground and from the HST. Comparison with the previously published data on GD 358 (Winget et al. 1982, 1994, Nather 1995, Hill 1985, 1987) shows how different are the amplitudes in August 1996. Until now, the most dominant was the 770 s mode, and there were many modes with amplitudes larger than those of the 423 s and 464 s modes.

Fig. 4 shows the relative amplitudes vs. wavelength calculated for the Koester model with $T_{\rm eff} = 25\,500$ K and $\log g = 8.0$ and for $\ell = 1, 2, 3, 4$ modes. Dots show the relative amplitudes normalized to the amplitude at the longest wavelength bin in the ultraviolet and then scaled to the corresponding relative amplitude expected for Koester's model. Triangles show the relative amplitude normalized using all the optical data. They seem to show that the optical amplitude is overestimated. Even in such case, we can conclude that none of the modes presented are $\ell = 3$ modes.

## 2. DISCUSSION

Although the results presented here are preliminary, we can conclude that the three modes we studied here are *not* $\ell = 3$. In order to determine the $\ell$-value definitely, we are currently working on the following problems.

(1) Interpolation of the optical amplitude to estimate its value at the time of the HST observation. Reliable optical amplitude estimates are essential for the relative amplitude method.

(2) Application of the $\chi^2$ fitting technique to estimate the $\ell$, $T_{\rm eff}$ and $\log g$ values for each mode using the relative amplitude method. We will then have a quantitative estimate of the physical parameters and evaluation how well the relative amplitude method works.

(3) Application of the $\chi^2$ fitting technique to estimate the $T_{\rm eff}$ and $\log g$ from the ultraviolet continuum. This will be an estimate independent from asteroseismology.

ACKNOWLEDGMENTS. A support for this work was provided by NASA through a grant GO-06727.01-95A from the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555. Also, this work was supported in part by National Science Foundation Grant No. AST-9315461. Observations at Mt. Suhora Observatory were supported in part by KBN Grant 2-P03D-015-08.

## REFERENCES

Hill J. A. 1985, M. Thesis, University of Texas

Hill J. A. 1987, in The Second Conference on Faint Blue Stars (IAU Colloq. No. 95), eds. A. G. D. Philip, D. S. Hayes & J. Liebert, p. 681

Nather R. E. 1995, Baltic Astronomy, 4, 321

Robinson E. L., Mailloux T. M., Zhang E. et al. 1995, ApJ, 438, 908

Winget D. E., Robinson E. L., Nather R. E., Fontaine G. 1982, ApJ, 262, L11

Winget D. E., Nather R. E., Clemens J. C. et al. 1991, ApJ, 378, 326

Winget D. E., Nather R. E., Clemens J. C. et al. 1994, ApJ, 430, 839