Pulsating White Dwarfs and Subdwarfs

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Looking for Trends in the Group Properties of Pulsating Subdwarf B Stars

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1. Introduction: Why Study Subdwarf B Stars?

We examine the pulsation properties for 13 members of the pulsating subdwarf B (sdBV, or EC 14026) class of stars. By looking at the pulsation structure of an entire class of stars, it may be possible to determine the various modes of pulsations (O'Brien 1998, Kleinman 1995). Unfortunately, when we examine the ensemble of pulsation periods in EC 14026 stars, we are only able to discern a simple correlation between pulsation period and gravity, and not any structure that might help with mode identification. So we can only report on the lack of structure in the pulsation periods and present some of the work underway, which we hope will identify modes in the future.

1.1. Because There Are a Lot of Them

Forty percent of the objects detected in the PG survey were sdB stars (Green, Schmidt, & Liebert 1986). Subdwarf B stars are the field counterpart of EHB stars which are likely responsible for the UV excess detected in some elliptical galaxies and globular clusters (Dorman, Rood, & O'Connell 1993). This makes them important in the "larger scheme of things" as they need to be accounted for in population synthesis studies.

1.2. They Represent an Important Step in Stellar Evolution

These are horizontal branch stars, which burn helium in their cores. Subdwarf B stars may be key to understanding horizontal branch stars as they have limited envelopes. This means no shell H burning which simplifies their structure and can make them easier to model. They have relatively short lifetimes compared to their main sequence counterparts; thus, they may allow for direct measure of triple alpha reaction rates.

They are likely to evolve directly to white dwarfs. We have a handle on white dwarf models, and so taking this additional step back up the evolutionary ladder brings us one step closer to completing the total stellar evolution picture. We also need to note that sdB evolution is still largely a mystery. We do not have a good handle on the production mechanism, and the evolutionary tracks are model dependent. So we need asteroseismology to further constrain the models.

1.3. Fortunately, Some Pulsate!

Discovered in the EC survey (Kilkenny et al. 1998), the EC 14026 (or sdBV) stars have pulsation periods ranging from 90 to 600 s. Our hope is to probe

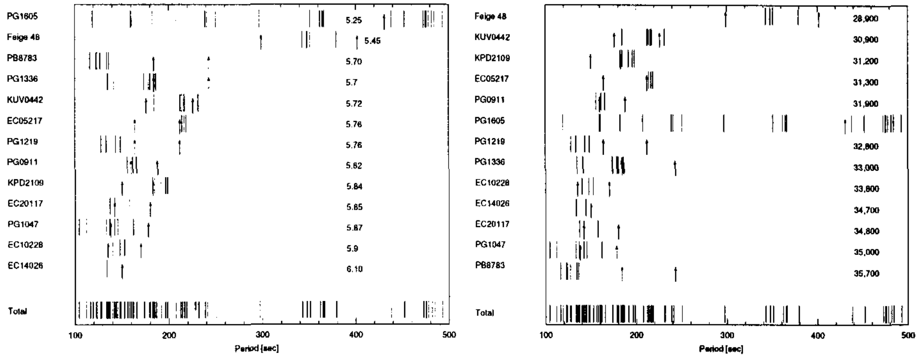

Figure 1. Pulsation periods for 13 EC 14026 stars ordered by $\log g$ and $T_{\rm eff}$. The arrows are the fundamental and first overtone radial modes.

their interiors via their pulsations and then extend our refined models to the larger class of sdB stars. This should also add constraints to horizontal branch stars in general. As previously mentioned, sdB stars evolve in relatively short time scales and the easiest way to detect this evolution is via their pulsations.

2. Pulsation Properties

Since the discovery of pulsators, roughly 4 years ago, there have been 13 individually published pulsation spectra (O'Donoghue et al. 1999 and references therein). What can we say about the spectra to date? Well, they are not simple! 1) They are multi-mode pulsators showing anywhere from 2 to 50-plus pulsation modes. 2) There are too many modes to be strictly radial oscillations. 3) The periods lie in regions that encompass both p and g modes. Thus far, only 3 EC 14026 stars have had multi-site campaigns, all of which have detected additional modes. So for the remaining 10, the pulsation spectra are likely to be incomplete.

Fig. 1 shows the pulsation periods of the EC 14026 stars organized by $\log g$ and $T_{\rm eff}$, including arrows for the fundamental and first overtone radial modes for models of appropriate gravity. Since the radial fundamental pulsation period is inversely proportional to the square root of the density, we expect a general trend towards longer periods with decreased surface gravity; and indeed this is present. Otherwise, there are no obvious groupings or trends which might be used to identify pulsation modes. Some stars have all of their pulsations longward of the fundamental radial mode, while others have all of their pulsations shortward. We also see a weaker trend towards shorter period with higher effective temperature. However, we do not see that trend in the calculated radial modes. Some correlation between period and temperature is expected since higher effective temperature is an indication of larger surface gravity (see Fig. 2b).

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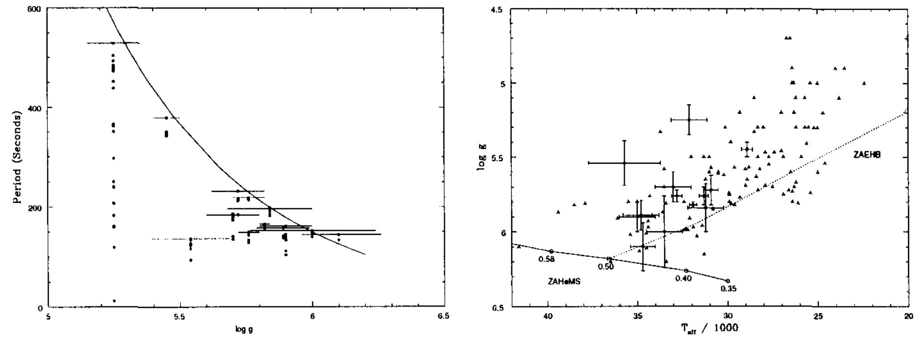

Figure 2. a) Pulsation periods of EC 14026 stars to scale in $\log g$; $\log g$ error bars are placed on the longest period for each star. b) $\log g$ vs $T_{\rm eff}$ for sdB stars. Pulsators are circles with error bars while non-pulsators are triangles.

Additionally, with the exception of 3 stars, all the stars in Fig. 1 are within 0.2 of each other in $\log g$. This is emphasized in Fig. 2a, where the pulsation periods are to scale with $\log g$. The solid line is the fundamental radial mode with error bars in $\log g$ on the longest period of each star. It is plain to see that the error bars for many stars overlap! If there truly is a ($\log g$, period) correlation to be found, the error bars will need to be reduced. Fig. 2b is a plot of surface gravity versus effective temperature showing the pulsators as circles with error bars and non-pulsators as triangles. We note that there is no obvious instability strip in the plot. Pulsators and non-pulsators share the same region, and even the pulsators have outliers that frustrate the definition of an instability strip.

3. Conclusions

So what have these plots shown us? Only that it will be tricky to decipher the pulsation spectra of EC 14026 stars. There are no obvious groups in the pulsation periods and they seem to defy having limits placed on their instability strip. Even the pulsation mechanism, an iron opacity bump proposed by Charpinet et al. (1997), is in question as EC 14026 stars have been detected in a wide range of metallicities.

3.1. So Where Do We Go From Here?

Fortunately there is a silver lining appearing on the clouds. Preliminary pulsation mode identification has been made for two EC 14026 stars.

1) For PG 1605+072: A multi-site campaign yielded a rich pulsation spectrum (Kilkenny et al. 1999) and Kawaler (1999) was able to identify five of the largest amplitude modes; with the provision that it had a large rotational velocity. Recent Keck spectra by Heber, Reid, & Werner (1999) have provided a rotation rate that meets Kawaler's requirements.

2) For PG 1336: This eclipsing binary was the target of a Whole Earth Telescope (WET) run in April of 1999 and preliminary analysis has identified a rotationally split mode (Reed et al. 1999). Additionally, the eclipses allow us to briefly resolve the surface of the star and we hope to use this to separate some of the radial modes from nonradial ones. (During partial eclipse, nonradial modes with $m = 0$ should show the largest amplitude enhancement).

3.2. Work Under Way

Naturally, since this field is so young, there is plenty of work remaining. Here are some of the projects underway:

There has been a preliminary detection of one (or two) EC 14026 star(s) in open cluster(s) by a group at Yale (Yong, Bailyn, & Demarque 1999). By detecting EC 14026 stars in clusters, we can examine the pulsation dependence on metallicity. Not only is a metallicity bump presumably responsible for the pulsation, but it may be a third parameter in the instability strip. The authors, as well as the Yale group are working to detect and obtain pulsation spectra for EC 14026 stars in clusters.

There are ongoing searches for binarity as a means of sdB production. Green & Chaboyer (1999) at Steward Observatory have been looking for radial velocity variations, R. Aznar Cuadrado at Armagh Observatory is working in the infrared to search for binaries, and, as proposed by Darragh O'Donoghue, there is now an effort to monitor stars through several seasons to look for phase changes caused by an unseen companion.

Lastly, we should note that both stars for which mode identification seems likely were the subjects of multi-site campaigns, so use of instruments such as the WET will likely be vital if we are to discern the nature of sdB stars.

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Discussion

Joyce Guzik: Do you need binarity to explain sdB production, or can you explain it by a single star losing lots of mass on the red giant branch?

Mike Reed: It would seem that there are two popular methods for producing sdB stars:
1. As a binary that evolves through a common-envelope phase, and
2. as a single star that somehow loses nearly all of its hydrogen envelope during the helium flash. However, both methods seem to require uncommon conditions to produce relatively common stars.

Joyce Guzik: What fraction of 2- to 8-$M_\odot$ stars go through the sdB phase?

Mike Reed: Since sdB stars are likely to produce low-mass white dwarfs (since the sdBs themselves only have $\approx 0.5\ M_\odot$), assume that some fraction of low-mass white dwarfs were sdB stars and go from there. Also, Liebert, Saffer, & Green (1994, AJ, 107, 1408) estimate that 1.5% of post-RGB objects in NGC 6791 evolve to sdBs.

Tim Bedding: I notice that the prototype of this class (EC 14026), like many prototypes, is extreme in having the largest surface gravity.

Mike Reed: And only 2 pulsation periods, making it the most extreme pulsating sdB star to date.

Tim Bedding: I would also like to know what we should call these stars: pulsating sdB stars, sdBV, or EC 14026 stars.

Mike Reed: The only published name so far is EC 14026 stars, and of course it's common to name the class after the first one discovered. However, just to state my preference, I like sdBV stars, as it's more descriptive and follows the white dwarf example (DOV, DAV, etc.). Of course, the IAU has the final word.