WHT Measures Speed of Surface Vibrations on Stellar Corpses

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Using the William Herschel Telescope, Drs. Simon Jeffery and Don Pollacco have adapted a technique to measure how fast stellar surfaces vibrate, and have applied it to two of the Galaxy's newest class of pulsating stars. The results will appear shortly in the *Monthly Notices of the Royal Astronomical Society* (Jeffery & Pollacco, 2000).

Stellar remnants, the garbage of the Galaxy, include an enormous variety of stars, ranging from very cool supergiants to superhot white dwarfs and neutron stars. Most stars shine because nuclear reactions deep inside release huge amounts of energy as hydrogen is converted to helium. When the hydrogen fuel runs out, the star picks up a one way ticket to oblivion. But first, they attempt a brief nuclear comeback as they convert helium into carbon and other heavy elements.

Extraordinarily common examples of stars having a final nuclear fling are the subdwarf B stars. These are the nearly naked helium cores of low mass stars. They are smaller than hydrogen-burning stars, but larger than white dwarfs — the ultimate stellar corpse. Their surfaces are six times hotter than the Sun. It was a considerable surprise when the light output from some of these stars was discovered to vary with periods between 200 and 500 seconds (Kilkenny et al., 1997, O'Donoghue, 1999). These stars are now known either as subdwarf B variables — sdBV stars for short — or EC 14026 variables, after the first one discovered which had the catalogue number EC 14026−2647.

The sdBV light curves are very complicated, with a few to several tens of simultaneous frequencies. Such 'multiperiodic' oscillations are attributed to non-radial pulsations. These are vibrations of the stellar surface rather like the vibrations of a drum skin or a bell, where many different modes resonate at the same time. As the stellar surface moves up or down it cools down or heats up and hence becomes fainter or brighter. Adding up the effects of all the simultaneous vibrations over the visible hemisphere produces small changes in the light emitted towards the Earth. The same thing happens on the Sun, where thousands of simultaneous vibration occur, but the sdB vibrations have a much larger amplitude.

Light variations only provide an indirect view of the movement of the stellar surface. In many pulsating stars, such as Cepheids, the surface motion can be detected directly by measuring its speed towards or away from an observer. This is much easier when the pulsation amplitude is large and only one period is present, as in classical Cepheids. However, it is very important because it allows the mass of the star to be measured and it helps to explain why these stars pulsate. As soon as their discovery was announced, we wanted to know if the surface motion could also be measured for pulsating subdwarf B stars.

We set out to test this idea in 1997, obtaining our first observations with the William Herschel Telescope in 1998 October. Stellar surface velocities are measured using the Doppler effect. As the surface moves outwards, and hence towards the observer, its light is blue-shifted. These Doppler shifts were measured with a spectrograph called ISIS. A special feature of ISIS allowed us to make a continuous sequence of Doppler measurements with very short exposure times. Using conventional methods to read out the ISIS detector would have taken nearly as long as collecting the starlight, making the observations 50% efficient or less. 'Continuous mode' enabled us to reach efficiencies of over 80%. In just 10 hours of observing over two nights, we obtained 2600 spectra of PB 8783 and KPD 2109+4401, two sdB stars of the 13th magnitude.

We added all the spectra from each star together to make a template (Figure 1), and then measured the Doppler shift of every spectrum relative to its template. This was converted to a velocity. We then looked to see whether the velocity data showed any of the same periods as the light curves measured previously (O'Donoghue et al., 1998, Koen, 1998, Billères et al., 1998). Even with the WHT and our novel techniques, the measured velocities contain a lot of noise. We therefore had to use Fourier analysis to search for periodic variations. Specifically, we were looking for the *amplitude* of any variations with the same frequencies as those seen in the light curve.

Expecting only to find frequencies of the largest amplitude light variations, we were surprised to find some of the smaller light variations also showing up in the velocity data (Figures 2 and 3). Altogether, we identified two pulsation frequencies in KPD 2109+4401 and five in PB 8783, with amplitudes between 1.1 and 2.7 km/s. Some of these are probably a combination of two or more of the frequencies found in the light curve.

Like the light curve, each velocity measurement is an average of the projected velocity over the visible hemisphere. Every point on the surface will have a velocity which is the sum of motion due to several different vibrations which interfere with one another either constructively or destructively. The challenge now is to build a model of the non-radially oscillating surface which can uniquely reproduce the observed velocity and light curves.

Several sdB stars, including some EC 14026 variables, are also binaries. The spectrum of a main-sequence F star can be seen superimposed on that of PB 8783 (Figure 1). An additional surprise was that the average velocity of the sdB stars drifted slowly during our observing run. When we measured the sdB and F star in PB 8783 separately, we found the drifts to be in opposite directions (Figures 3 and 4). This could not be a systematic error; we may have stumbled on the reflex motions of the two stars as they orbit one another with a period of between 0.8 and 3.7 days. It was satisfying to find that pulsations are only seen in the sdB star and *not* the F star! Although KPD 2109+4401 shows no other evidence of having a companion, the drift of 9 km/s over 5 hours in our data may be the first evidence that it, too, is a binary.

High-speed spectroscopy with 4 m-class telescopes has proved to be a very powerful tool for exploring non-radial stellar oscillations. We have already extended the technique by observing with both the William Herschel and Anglo-Australian Telescopes — one after another — in order to improve the frequency resolution. We also intend to explore its application to other non-radially pulsating stars.

References:

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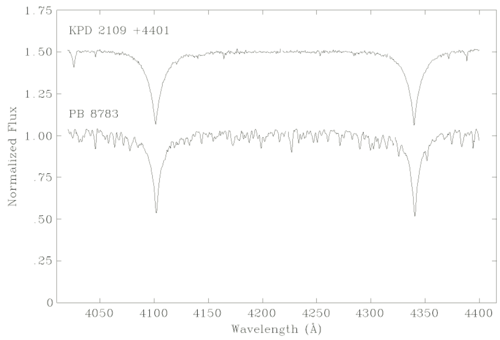

Figure 1. The mean spectra obtained for two pulsating sdB stars KPD 2109+4401 and PB 8783. The latter is a binary star; the faint spectrum of an F star can be seen superimposed on the sdB spectrum, which is completely dominated by broad hydrogen lines.

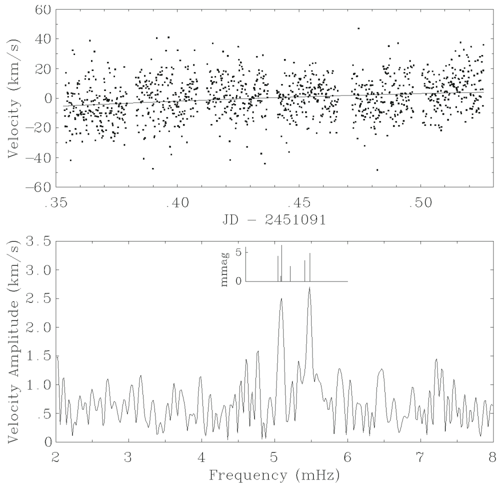

Figure 2. Radial velocities and amplitude spectrum of KPD 2109+4401 from WHT high-speed spectroscopy on 1998 Oct 4. A least squares solution to the slowly varying velocity component is shown in the top panel (solid line). The bottom panel shows part of the velocity amplitude spectrum. The inset light amplitude spectrum is taken from Koen (1998).

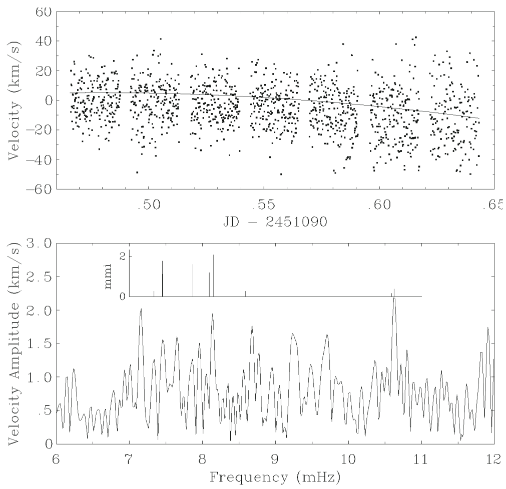

Figure 3. Radial velocities and amplitude spectrum of the sdB star in PB 8783. The least squares solution to the slowly varying velocity component is shown in the top panel (solid line). The inset light amplitude spectrum is taken from O'Donoghue et al. (1998). mmi denotes parts-per-thousand and 1 mmi equals 1.086 mmag.

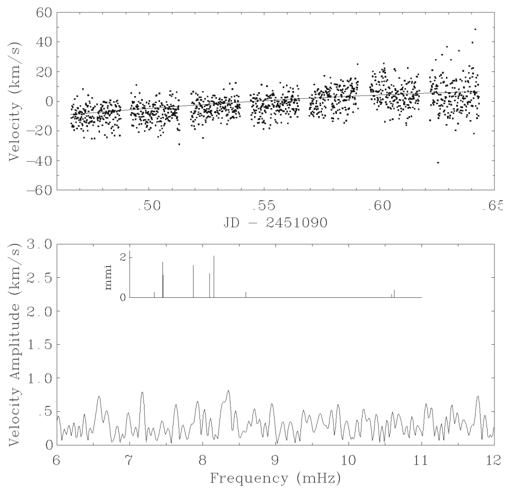

Figure 4. As Figure 3 for the F star in PB 8783.