There and Back Again?: THE DISAPPEARING PULSATIONS OF CS 1246

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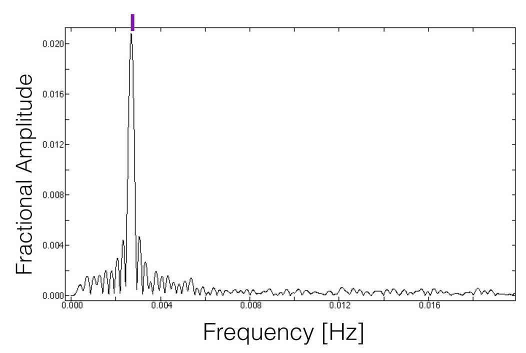
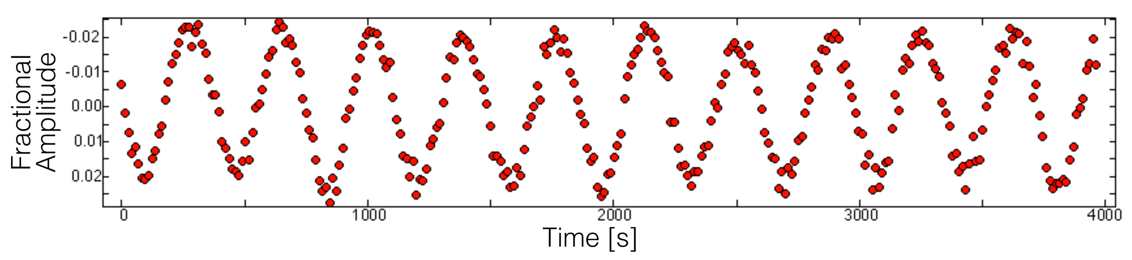
Disappearing Pulsations

2009

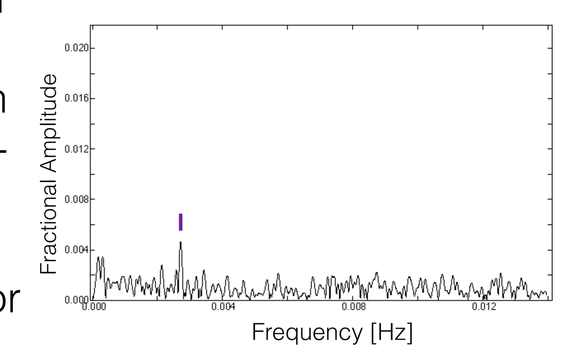
In 2009, CS 1246 was discovered to be a rapidly-pulsating hot subdwarf B star exhibiting a single, radial oscillation (Barlow et al. 2010). One of the largest-amplitude sdBV stars found at the time, it pulses with a period of 371 s and had a photometric amplitude of >2%. A representative light curve and its DFT are shown below and at right.

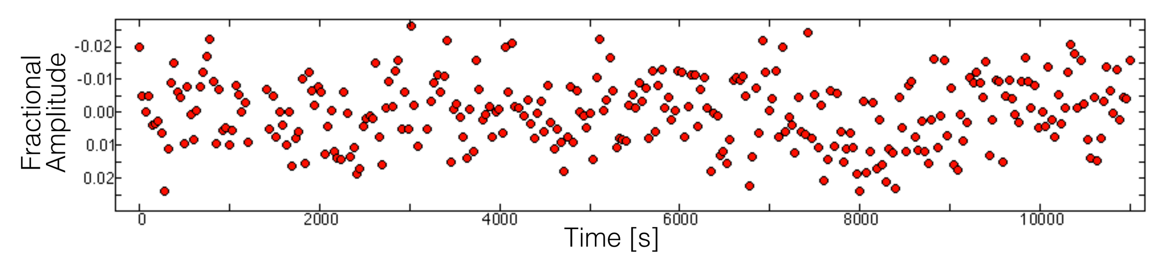




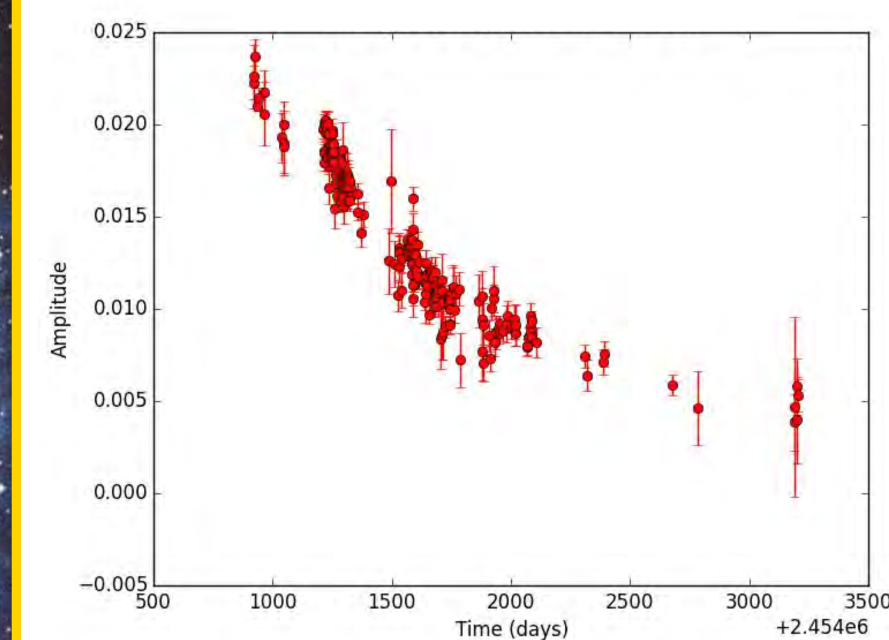
2015

Six years later, the pulsations have decayed to an amplitude of around 0.4%. Our most recent light curve and its Fourier transform are shown below and at right. Given its single-mode The rapid decrease in pulsational amplitude makes CS1246 an interesting candidate for further follow up observations.



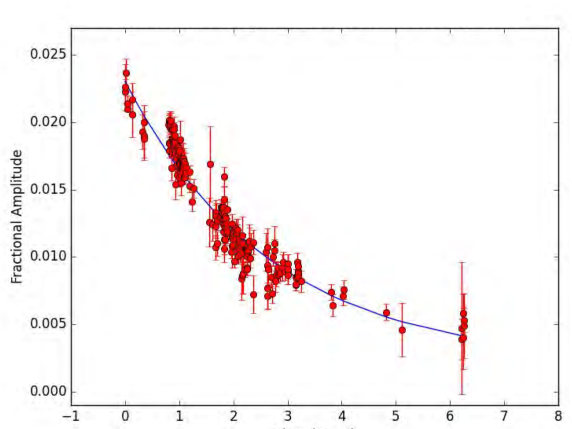


Pulsation Amplitude vs Time



SdBV pulsations are driven by opacity variations in Fe located in the partial ionization zone in the star (Heber 2009). When the conditions are right, this valve-like mechanism can drive *rigorous* pulsations, as seen in CS 1246 in 2009. We have obtained more than 100,000 images of CS 1246 over the past six years with the robotic SKYNET telescopes in Chile (Reichart et al. 2005) in order to monitor its pulsation amplitude. The decrease in strength, shown at left, is unique amongst sdBV stars. While other sdBVs show amplitude variations (Kilkenny 2010), nearly all of these pulsators exhibit *multiple* pulsation modes which can exchange energy. The extreme decay in pulsation amplitude implies **the abundance of iron in the partial ionization zone has changed dramatically**.

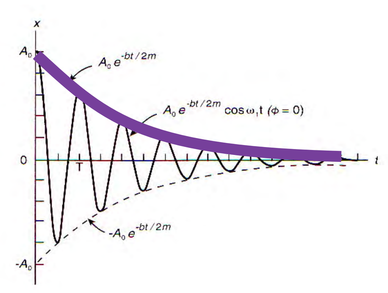
Will the pulsations stop?

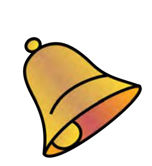


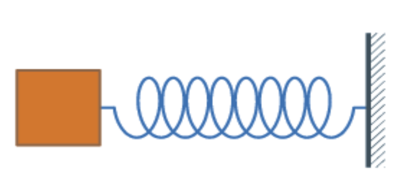
Our data are consistent with a decaying exponential. A range of time constants around 3 yr fit the data equally well with asymptotes ranging from 0 ppt (pulsations have ceased) to 3 ppt. Only the best-fitting model is shown here.

$$A(t) = 0.0215\, e^{-\frac{t}{3.2\ \mathrm{yr}}} + 0.002$$

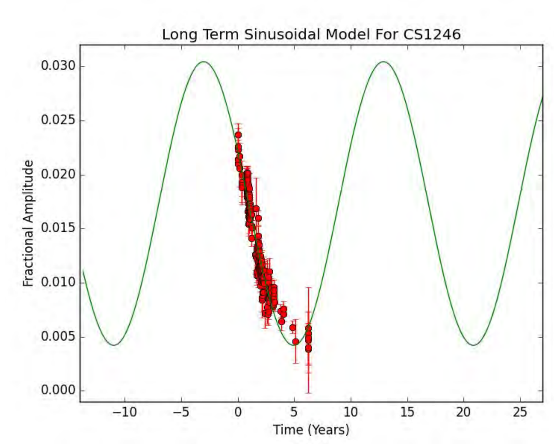
Speculation:
The inspiration for fitting a decaying exponential was a classic damped harmonic oscillator. According to this model, the pulsations of CS1246 will continue to decay until they approach some minuscule value in fractional amplitude close to zero; strong pulsations will never return. Physically, this decay would follow a decrease in the Fe abundance in the partial ionization zone of the star. Whether this is due to a physical movement (e.g., gravitational settling) of the Fe, or instead a change in the temperature profile of the sdB (as it evolves away from the EHB) is unclear.







Will strong pulsations return?



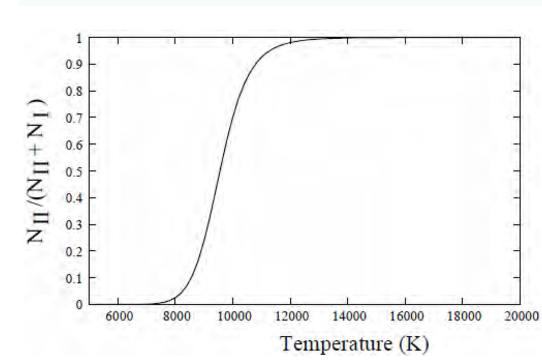
Our data are consistent with a sinusoidal variation. A range of periods and amplitudes fit the data equally well. Only one example model in this family of solutions is shown below and at left. In this model, the pulsation amplitude cycles between 0.4% and 3.0% with a period of 15-20 years.

$$A(t) = 0.0127\,\sin\left(\frac{2\pi t}{16.5\ \mathrm{yr}}\right) + 0.017$$

Speculation:
Large-amplitude radial pulsations like that of CS 1246 in 2009 could disrupt the internal structure of the star, pushing Fe out of the partial ionization zone, and out of diffusive equilibrium between radiative levitation and gravitational settling. As the Fe abundance in the partial ionization decreases in time, the pulsations become squelched. With the violent pulsations having ceased, the Fe might find its way back to its original diffusive equilibrium state over time, after which strong pulsations would return.

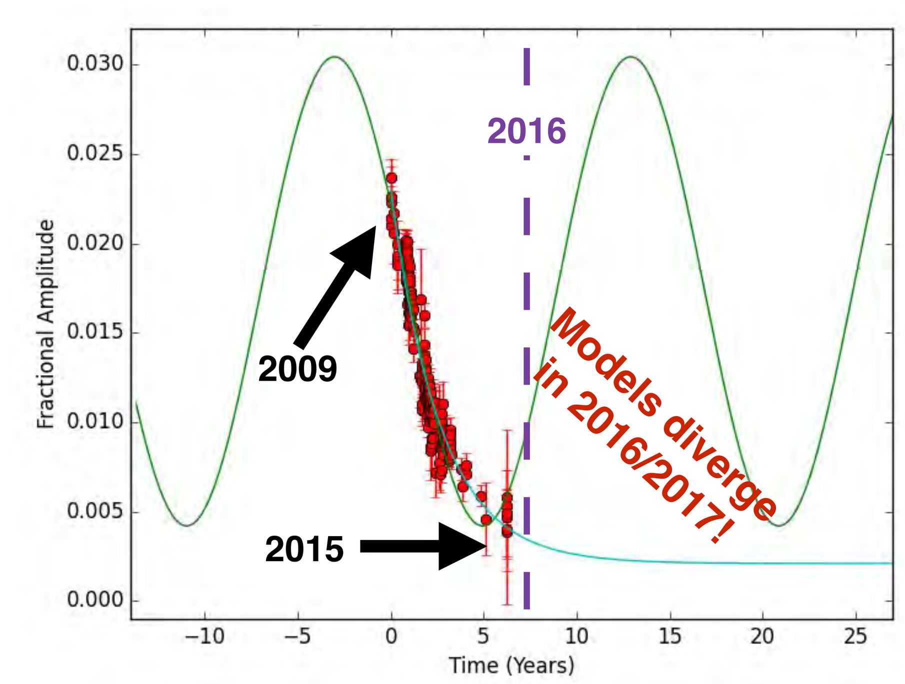
Partial Ionization Zones

$$\frac{N_{II}}{N_I} = \frac{2Z_{II}}{n_e Z_I}\left(\frac{2\pi m_e kT}{h^2}\right)^{3/2} e^{-\chi/kT}$$



Summary & Future Work

After monitoring the sdBV star CS 1246 for six years, we find a remarkable decrease in the pulsation amplitude of its single-radial oscillation mode. We can rule out a linear trend in the amplitude decay and fit two (mathematical) models to the data: a decaying exponential, and a sinusoidal oscillation. We have no statistical reason (currently) to prefer one model over the other, and thus it is not clear whether strong pulsations will return. Physical explanations for the models both include changes in the abundance of Fe in the partial ionization zone of the star. If strong pulsations return, which would imply a return of Fe to its diffusive equilibrium location, our data will constrain the timescales through which radiative levitation and gravitational settling act. Currently, only 10% of sdBs falling in the instability strip pulsate, for reasons unknown. If CS 1246 were a target in a pulsation search today, it would likely be overlooked and marked as a NOV (not observed to vary). If other sdBVs exhibit extreme and relatively rapid amplitude changes like CS 1246, it would help explain why so few are observed to pulsate that should.



We will continue obtaining photometry of CS 1246 with the robotic SKYNET telescopes. By late 2016, the sinusoidal and exponential model predictions should diverge enough that new amplitude measurements will allow us to falsify one of the models. We will also obtain spectroscopy to look for Fe abundance changes.

References

Heber U., 2009, *ARAA*, **47**, 211

Barlow B. N., Dunlap B. H., Clemens J. C., Lynas-Gray A. E., et al., 2010, *MNRAS*, **403**, 324

Reichart D., et al., 2005, *Nuovo Cimento C Geophysics Space Physics C*, **28**, 767

Kilkenny, D., 2010, *ApSS*, **329**, 175

Acknowledgements

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