OBSERVING REQUEST
University of Arizona Observatories

Year: 2015 **Term:** Jan–Jul **Proposal type:** short-term

CSS 41177: a Rosetta Stone for white dwarf asteroseismology?

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Abstract of Scientific Justification

Asteroseismology of pulsating white dwarfs is a rapidly evolving field. However, in contrast to the situation with subdwarf B stars, no one has yet found a pulsating white dwarf in an eclipsing binary, which would permit the first ever independent test of asteroseismic results under degenerate conditions. The secondary star in the recently discovered WD+WD eclipsing binary, CSS 41177, has an effective temperature and surface gravity that place it within the white dwarf ZZ Ceti instability strip. We propose to obtain light curves for this star with sufficient precision to determine whether or not it is a pulsator, assuming the pulsational amplitudes are similar to those of other known pulsating white dwarfs. (N.B. This proposal has lower priority for spring 2015 than the three other proposals submitted for our group by Green and Fontaine.)

Summary of observing runs requested for this project

Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Scheduling Optimal	Scheduling Acceptable	Sharing Poss.	Sharing Adv.
1	61”	f/13.5	Mont4K			8	dark	Jan–Jan	Jan–Jan	no	no

Scheduling constraints and unusable dates *(up to 4 lines)*: The January nights do not have to be contiguous; gaps of 1 or 2 days would be OK.

no text past this line

A ⋆ appended to the proposal type indicates a continuation proposal; a ⋆ appended to the name of a proposer indicates the proposer is a (graduate) student; a proposer whose name is underlined is certified on the proposed telescope/instrument combination; if a ∗ appears within the PI or AO box in the observations summary table, the instrument is a PI instrument and/or Adaptive Optics are requested – signatures are required on the next page.

Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	CSS 41177	10:05:59.1	+22:49:32	V=17.3

Approval for Instrument Use from PI: ________________________________

(have instrument PI signature appear on, or attach PI e-mail to, ***all*** *copies)*

Graduate students *(provide the following information for* ***each*** *student named as PI or CoI on the cover page. Have the advisor's signature(s) appear on* ***all*** *submitted copies)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis

Scientific Justification

White dwarfs are the endpoint of the evolution of more than 95% of the stars in the Universe. They no longer undergo fusion reactions and are slowly evolving to fainter luminosities along a cooling sequence. Roughly 80%, the DA white dwarfs, have atmospheres of essentially pure hydrogen, with very little contamination from heavier elements. During the cooling process, the ionized hydrogen in the outer envelope eventually reaches a temperature where it recombines (near $T_{\rm eff} \sim$ 12,000 K) to neutral hydrogen. The recombination leads to a huge increase in envelope opacity which, in turn, strangles the flow of radiation, resulting in pulsational instabilities that are observed as g-mode oscillations in the so-called ZZ Ceti white dwarfs. About 200 ZZ Ceti pulsators have been found since the first discovery by Landolt (1968, ApJ, 153, 151).

On the observational side, mapping the ZZ Ceti instability strip to precisely determine its empirical boundaries has been a long-term objective of the Montréal group (Gianninas et al. 2011, ApJ, 743, 138; and references therein). Recently, pulsations have also been found in extremely low-mass DA white dwarfs (Hermes et al. 2012, ApJ, 750, L28; 2013a, ApJ, 765, 102; 2013b, 436, 3573). Van Grootel et al. (2013, ApJ, 762, 57) demonstrated that these pulsators constitute a low-gravity extension of the classical ZZ Ceti instability strip. ZZ Ceti pulsators are thus found ranging from 0.15 to 1.2 $M_\odot$. A remarkable property of the observed ZZ Ceti instability strip is that it is a pure strip, i.e. every DA white dwarf will become a ZZ Ceti pulsator when it passes through the strip along its cooling track.

On the theoretical side, huge progress has recently been made in reproducing the empirical boundaries of the ZZ Ceti instability strip, both for the blue (hot) and red (cold) edge. Van Grootel et al. (2013) showed that including a time-dependent treatment for convection in the envelope and an energy leakage argument through the atmosphere for the oscillations, results in a theoretical ZZ Ceti instability strip which agrees remarkably well for the boundaries of the empirical strip.

The existence of pulsations in DA white dwarfs opens the opportunity to apply asteroseismology in order to provide tight constraints on stellar structure and evolutionary models of these objects. Asteroseismic modeling of ZZ Ceti white dwarfs has already led to spectacular results, such as the determination of the bulk core composition, the envelope layering, and global mass and radius parameters of ZZ Ceti stars (Giammichele et al. 2014, APSC, 481, 187, and references therein).

Another powerful technique for testing stellar models is eclipsing binaries, from which mass and radius can be measured model-independently. Unfortunately, eclipsing white dwarfs are quite rare because of their small diameters. Of the dozen white dwarfs known to be in eclipsing systems (Bours et al. 2014, MNRAS, 438, 3399), none have yet been found to pulsate. A ZZ Ceti pulsator in an eclipsing binary would be a "Rosetta stone" for white dwarf asteroseismology, analogous to the famous sdB pulsator in the PG 1336−018 eclipsing system, but in this case it would provide a stringent test of degenerate stellar models.

Precise atmospheric parameters and accurate measurements of the masses and radii of both components of CSS 41177 have been derived from ULTRACAM photometry and X-Shooter spectroscopy on the VLT (Bours et al. 2014). Most interestingly, the atmospheric parameters of the secondary ($T_2 = 11678 \pm 313$ K, log $g_2 = 7.32 \pm 0.02$) place it in, and potentially well within, the ZZ Ceti instability strip, according to the error bars. Bours et al. (2014) ruled out pulsations down to an amplitude of 0.5%, but this is not an unexpected result given the light dilution due to the WD primary, which is about three times brighter than the secondary, and the proximity of the blue edge, where ZZ Ceti amplitudes are smallest. Much higher sensitivity observations, down to a noise level in the Fourier transform lower than 0.1%, are needed to determine if CSS 41177b could be the Rosetta stone for ZZ Ceti asteroseismology that we are searching for.

The Mont4K on 61$''$ is well suited to this task. We have obtained light curves of other ZZ Ceti stars near the blue edge in the past, and have identified pulsations with amplitudes as small as 0.1% to 0.2% from light curves with total exposure times of 9 to 15 hours.

Experimental Design & Technical Description *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science.* ***(up to one page)***

We have used the Mont4K on the 61″ in the past to observe light curves for two white dwarfs with magnitudes of about 17.2 (WD 1247+310) and 17.4 (WD 1607+205), similar to CSS 41177. In both cases, the light curves were observed through the Schott−8612 "white light" filter during two closely spaced nights when the sky was very dark. Total exposure times of 9.76 and 9.35 hours resulted in the detection of a single significant pulsational mode in each case, with amplitudes of approximately 0.2%, although several other potential modes with less significant amplitudes were also seen. The 4σ noise levels in the Fourier transforms were 0.20% and 0.13%, respectively.

For CSS 41177, $V = 17.3$, we would need four times that exposure, or nearly 40 hours, to reduce the noise level by a factor of two, to less than 0.1%.

If CSS 41177 is indeed located in the instability strip, the expected pulsational periods are likely to be of the order of 800–2500 s. Periods of 650–1930 s have been found for typical 0.6 $M_{\odot}$ white dwarfs near the blue edge of the ZZ Ceti instability strip. The lower mass, 0.32 $M_{\odot}$, derived by Bours et al. (2014) for CSS 41177, implies longer periods. It is therefore necessary to observe CSS 41177 for as long as possible each night, which would be about 8 hours per night above airmass 2. (At higher airmasses, the sky noise is too great for such a faint star to get the required precision.)

We therefore request 8 dark nights during which we will be able to observe CSS 41177 for most of the night. Assuming a typical January weather factor of 65%, we would achieve a total observation time of nearly 42 hours.

If this proposal should be allocated time this year, we could further observe CSS 41177 for 3.0 to 3.5 hours in February at the beginning of Green et al.'s PG 1336−018 nights, whenever the moon is down in the first half. The additional integration time and longer total time baseline would significantly improve our ability to detect pulsational modes.

Summary of Time Requested and Awarded *The TAC needs to understand the scope of this project — (1) tell us how many UAO nights you've already had for this project, how many you request this time, and (a good guess of) how many you need to complete the project; (2) if a substantial amount of observing for this project comes from non-UAO telescopes, tell us about that observing, and how the UAO part fits in; (3) if you are collaborating with people who have telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how UAO time and your participation fit in. (**up to one page**)*

This is a new proposal which is best suited for the 61″/Mont4k. The VATT will not have the required wide-band Schott filter by January 2015, and no one in our group has access to other telescopes where adequate light curve observations could be obtained.

Scope of the project: our objective for the first year of observations is to obtain the 40+ hours of light curves required to reduce the 4σ noise limit in the Fourier transform to 0.1% or less. If we see no evidence for pulsations down to a 3σ level, we will probably not pursue this target further. If we do detect at least some pulsational modes, we would request a larger block of time the following year, perhaps 25–30 nights during January–March, in order to try to identify a sufficient number of pulsations and measure their frequencies precisely enough for an asteroseismic analysis.

However, this proposal has much lower priority than Green's and Fontaine's other proposals (90″ B&C spectroscopy survey, 61″ Mont4k light curves for asteroseismology of an eclipsing sdB, and VATT4k light curves for asteroseismology of a massive white dwarf). We are submitting the CSS 41177 proposal merely on the off chance that 61″ dark time is very undersubscribed for January 2015. If that time would not otherwise be used, we would be happy to conduct the preliminary search for pulsations in CSS 41177 sooner rather than later. Otherwise, we expect to resubmit this proposal next year.

Previous Use of Steward Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through UAO during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark those allocations related to the present proposal (i.e, precede text with* `\related` *command). **(up to one page)***

90″ B&C: **2013:** 01–04 Jan,01–03 Apr, 01–04 May, and 03, 26, 27, 30 Jun, 01 July, 03–06 Sep; **2014:** Apr 3–6, 30, May 1–4, Jun 17, 20–22. 14 papers have been published so far based on our high S/N, 90″ B&C survey results, including most recently:

"*A preliminary look at the empirical mass distribution of hot B subdwarf stars*", Fontaine et al. 2012, A&A, 539, 12
"*Third generation stellar models for asteroseismology of hot B subdwarf stars. A test of accuracy with the pulsating eclipsing binary PG 1336-018*", Van Grootel et al. 2013, A&A, 553, 97
"*Improved Determination of the Atmospheric Parameters of the Pulsating sdB Star Feige 48*", LaTour et al. 2014, ApJ, 788, 65

90″ B&C: **2013:** 20–22 and 28–30 Jan, 19–20 and 28–30 Feb, 01 and 19–20 Mar, 27–28 May, 22–23 Nov, 06–07 Dec, **2014:** Mar 8–10, Apr 19–20, Jun 6, 17, Sep 2–4, 12–15, for exploratory near-UV spectra of field sdO stars to follow up our recent discovery of potential accretion disks. We have discovered unexpected RV variations in a number of sdO stars, but haven't yet acquired sufficient orbital coverage to derive unique periods.

⋆ **61″ Mont4K**: **2013:** 03–07 and 11–12 Jan, 01–02 and 15–16 Feb, 10–14 Mar, 13–18 May, 14–16 Jun, 14 and 16–17 and 20 Sep, 14 and 20 and 23–24 Oct, 12–13 and 16 and 22–23 Nov, 11-14 and 19–21 Dec; **2014:** Jan 1–8, 10–12, 24–28, Feb 2, 4–7, 9–10, 17, 19–20, 23–24, 27, Mar 3, 5, 22-24, 26–27, 30–31, Apr 1–3, 8–9, 15–20, May 5–7, 16–19, 23–28, Jun 5–8, 12–13, 16–17, Sep 2, 12–13, 16–18, 20, 24–25, 28–30, Oct 1–3, 12–15, 31, Nov 1, 10–15, for light curves of sdO stars, the sdB pulsators PB 5450 and PG 1047+003, and a few white dwarf ZZ Ceti candidates:
"*Observational Asteroseismology of Hot Subdwarf Stars with the Mont4K/Kuiper Combination at the Steward Observatory Mount Bigelow Station*", Fontaine, G., Green, E.M. et al. 2013, arXiv1307.6112
"*High-speed photometric observations of ZZ Ceti white dwarf candidates", Green, E.M. et al. 2015, poster presented at "The 19th European Workshop on White Dwarfs" in Montreal, August 11–15, 2014*