Referee Review of Ms. Paulina Sowicka's PhD Thesis
"Excitation of pulsation in hot pre-white dwarf stars from an observational point of view"

I have read Paulina Sowicka's thesis entitled "Excitation of pulsation in hot pre-white dwarf stars from an observational point of view". This thesis was submitted to the Nicolaus Copernicus Astronomical Center of the Polish Academy of Sciences in fulfillment of the requirements for the degree of Doctor of Philosophy in Astronomy.

This doctoral thesis presents new observational data and analysis of the hot pre-white dwarf PG1159 stars. The thesis clearly states the motivation for the study, the methods employed, the results of the current work, and lays a structure for future investigations. The motivation is the importance of PG1159 stars for understanding the structure and evolution of white dwarf stars which then leads to a clearer understanding of stellar evolution. PG1159 stars are perhaps the least studied of the white dwarf pulsators. This thesis lays the groundwork for combining an understanding of the atmospheric composition of these objects with the study of stellar pulsations to produce an in depth understanding of their origins and evolution. The methods employed are photometry and frequency analysis, and are presented in the impressive photometric observations. These new observations are a substantial step towards producing the first statistically significant sample of well studied PG1159 stars. The results of the current work include a search for evidence of the ε mechanism for driving pulsations. New observations presented in this work clearly refute earlier claims for the detection of pulsations attributable to the ε mechanisms in VV 47. The second key result is the examination of two groups of PG1159 stars: those with nitrogen rich atmospheres and those with nitrogen poor atmospheres. This study shows that nitrogen does play some role in whether pulsations are excited in PG1159 stars, but there are some caveats that will be the focus of future work. To my knowledge, this is the first extensive survey of a statistically significant number of PG1159 stars.

The thesis starts with the required introduction of white dwarfs and their roles in stellar evolution. The author introduces theoretical evolutionary tracks that comprise the last stages of stellar evolution. The chapter is well laid out and demonstrates a good grasp of the topic. The introduction then proceeds into a description of the spectral characteristics of PG1159 stars themselves and introduces the idea of a dichotomy between PG1159 stars with "nitrogen rich" atmospheres (about 1% N/He) and PG1159 stars with nitrogen poor atmospheres (~below 0.01 % N/He). This topic will become a central pillar of the thesis. The introduction next introduces stellar pulsations, provides the basic equations for spherical harmonics, discusses the effects that break spherical symmetry, and introduces the known properties of PG1159 pulsators. Pulsational driving mechanisms are introduced. The canonical driving mechanism is the $\kappa - \gamma$ mechanism. The concept of the ε mechanism, which involves residual nuclear burning, is clearly described. The ε mechanism will also become a central pillar of the thesis. The introduction then discusses additional parameters to be considered when studying PG1159 stars. These include binarity and the possible presence of planetary nebulae. The introduction concludes with a brief description of the telescopes and observing programs used to obtain the data presented in the thesis. The introduction clearly demonstrate that the author possesses the theoretical knowledge required to carry out the astrophysical investigations.

The second chapter of this thesis presents the data reduction and analysis plans. The author describes the function of a CCD detector, the calibration of observations, and the difficulties introduced by data obtained from multiple telescopes and observing set ups. The author then presents a detailed discussion of aperture photometry, and presents the software employed in the analysis. The author also discusses Fourier analysis. This chapter is vital to understanding the analysis presented in the following chapters. I am very familiar with these techniques, and this chapter is clear and well presented.

Chapter 3 presents the first set of results, specifically from observations of the PG1159 star VV 47. These results are published in the Monthly Notices of the Royal Astronomical Society. In 2006, Perez et al. claimed detection of pulsations in VV47 that were attributed to the ε driving mechanism. The author of this thesis presents extensive new observations and also a reanalysis of the original data that clearly refutes the initial detection. This is an important result that forms one strong pillar of this thesis.

Chapter 4 presents the second set of results, specifically an analysis of the nitrogen rich PG1159 star PG1144+005. These results have been published in the Astrophysical Journal Letters. The hypothesis presented is the following: Nitrogen is left behind by a very late thermal pulse experienced by a star already on the white dwarf cooling track. Only nitrogen rich PG1159 stars are observed to pulsate. Therefore, all pulsating PG1159 stars would pass through the VLTP stage of evolution, while non pulsating white dwarf without detectable nitrogen would have experienced their last thermal pulse while hydrogen burning was still active. PG1114+005 was the counter to this hypothesis. PG1114+005 is a nitrogen rich pulsator that was not observed to pulsate. The author presents extensive new observations of this object conclusively showing that PG114+005 is indeed a low amplitude pulsator. This is an important result that improves our understanding of the final stages of stellar evolution.

Chapter 5 presents the third set of results, specifically a presentation of new photometric observations of 29 PG1159 stars. To my knowledge, this is the first statistically significant survey of the PG1159 stars. The work also incorporates astrometric measurements from the *GAIA* DR3 catalog. The results has been accepted for publication in the Astrophysical Journal Supplements. The photometric survey was accomplished over 8 years, and employed an impressive array of telescopes and instrumentation. The survey produced 1 new variable star (Abell 72), a candidate variable (RX J0122.9-7521), and numerous objects with various upper limits on pulsations. I agree with the author that the distinction between DOVs and PNNVs is artificial and should be discarded.

Questions and Comments:

I do have a few questions I would like to present for consideration:
1) Chapter 1: what are the expected pulsation periods and amplitudes for pulsations driven by the ε mechanism? Do the expected pulsations periods differ from those driven by the $\kappa - \gamma$ mechanism? If so, why do the expected periods differ?
2) Chapter 1: For DA and DB pulsating white dwarfs, the amplitudes of the pulsations increases as the effective temperature decreases. Is a similar pattern seen for the PG1159 stars?
3) Chapter 5: There are several stars where consecutive nights of data were obtained. Where these data combined to produce a single light curve, and did that improve the detection levels?
4) Chapter 5 Figure 5 (and also fig 6) show evolutionary tracks where the stars evolve to higher temperatures before entering the hot end of the white dwarf cooling track. What is the timescale for this phase of evolution? Why do the stars evolve to higher temperatures?
5) Chapter 5 Figure 6: There is only one evolutionary track for a LTP. Would there be a noticeable difference in the evolutionary tracks followed by higher mass stars that experience a VLTP and those that do not?
6) There are 4 nitrogen poor PG1159 stars that are pulsators, out of a sample of 16 (from Table 2). This seems like a significant fraction of the nitrogen poor stars. How can these stars be explained?
7) The two groups of PG1159 stars (nitrogen rich and nitrogen poor) could represent different evolutionary tracks. Nitrogen is a product of the very late thermal pulse so the nitrogen rich stars followed this path, and probably also have no hydrogen. The nitrogen poor objects probably

experiences a late thermal pulse, so they have no nitrogen, but hydrogen could be diluted below detection limits. It was unclear to me what effects, if any, the hydrogen, even in small amounts, could play on the excitation of pulsations. Another way to phrase the question is "is the nitrogen playing a role in the pulsations or is it the lack of hydrogen that is important?"
6) Chapter 5: In many cases, less than 2 hrs of observations was obtained for these objects. Treating these stars as nonpulsators is too strong. Is there a way to determine the statistical significance of these nondetections? How many can be expected to actually be pulsating, given the typical amplitudes, frequency distributions, and typical noise levels? The fraction of PG1159 pulsators presented in the thesis (36%) is likely a lower limit.
7) Conclusions: The second paragraph says that "If GW Vir pulsators still had He-burning shells, they should show oscillations driven by the ε mechanism, according to theoretical predictions." Does this work clearly show that the ε mechanism is not functioning in PG1159 stars which would then mean that these stars do not possess He-burning shells?

The thesis is very comprehensive. It begins with a detailed outline of the current theoretical understanding of the formation and evolution of PG1159 stars that demonstrates Paulina's broad knowledge of the scientific work. The work presented in this thesis is also a significant step forward in our understanding of white dwarf formation and evolution. Summing up, I consider the doctoral thesis of Ms. Paulina Sowicka to be a valuable contribution and to meet the criteria prescribed by the law for a doctoral dissertation. Therefore, I request that this dissertation be admitted to a public defense."

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