Asteroseismological modeling of PG 1159-035, the prototype of the GW Vir variable stars

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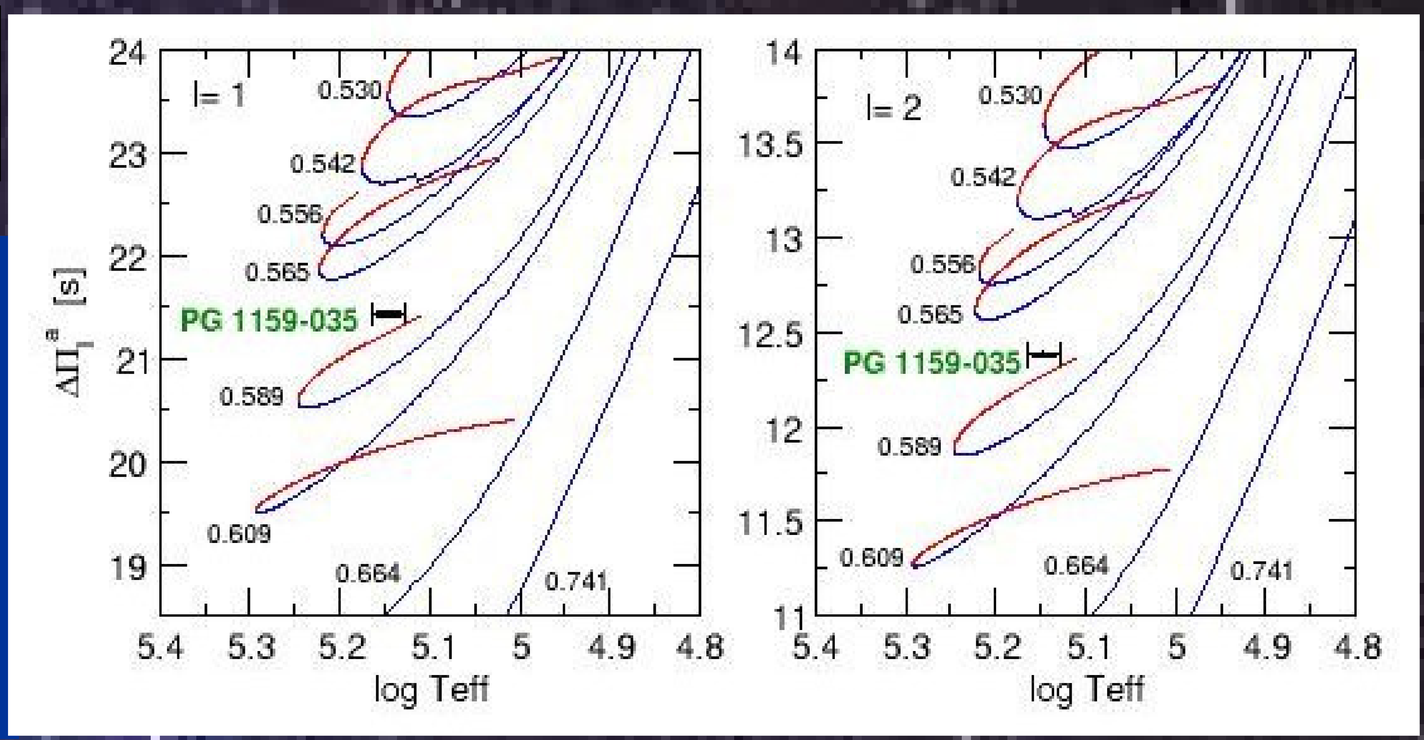
ABSTRACT: we present a comprehensive asteroseismological study on PG 1159-035, the prototype of the GW Vir variable stars, performed on the basis of detailed and full PG1159 evolutionary models recently presented by Miller Bertolami & Althaus (2006). We carried out extensive computations of adiabatic *g*-mode pulsation periods on PG1159 evolutionary models with stellar masses spanning the range 0.530 to 0.741 Mo. We derive the stellar mass from the period spacing data (Methods 1 and 2 below). We also find, on the basis of a period-fit procedure (Method 3 below) that takes full advantage of the new period data of Costa et al. (2007), an asteroseismological model representative of PG1159-035 which reproduces the observed period pattern with an average of the period differences of 0.62-1.02 s. The model has an effective temperature of 128000 K, a stellar mass 0.565 Mo, a surface gravity log g= 7.42, and a He-rich envelope thickness of Menv= 0.017 Mo. For our best-fit model of PG 1159-035 all of the pulsation modes are characterized by positive rates of period changes, at odds with the measurements by Costa & Kepler (2007).

STELLAR MODELING: we employ full evolutionary PG1159 models presented by Miller Bertolami & Althaus (2006) and Córsico et al. (2006) computed with LPCODE evolutionary code (Althaus et al. 2005). The complete evolution of model star sequences with initial masses on the ZAMS in the range 1-3.75 Mo are considered. All of the post-AGB sequences have been followed through the very late thermal pulse (VLTP) and the resulting born-again episode that give rise to the H-deficient, He-, C- and O-rich composition characteristic of PG1159 stars.

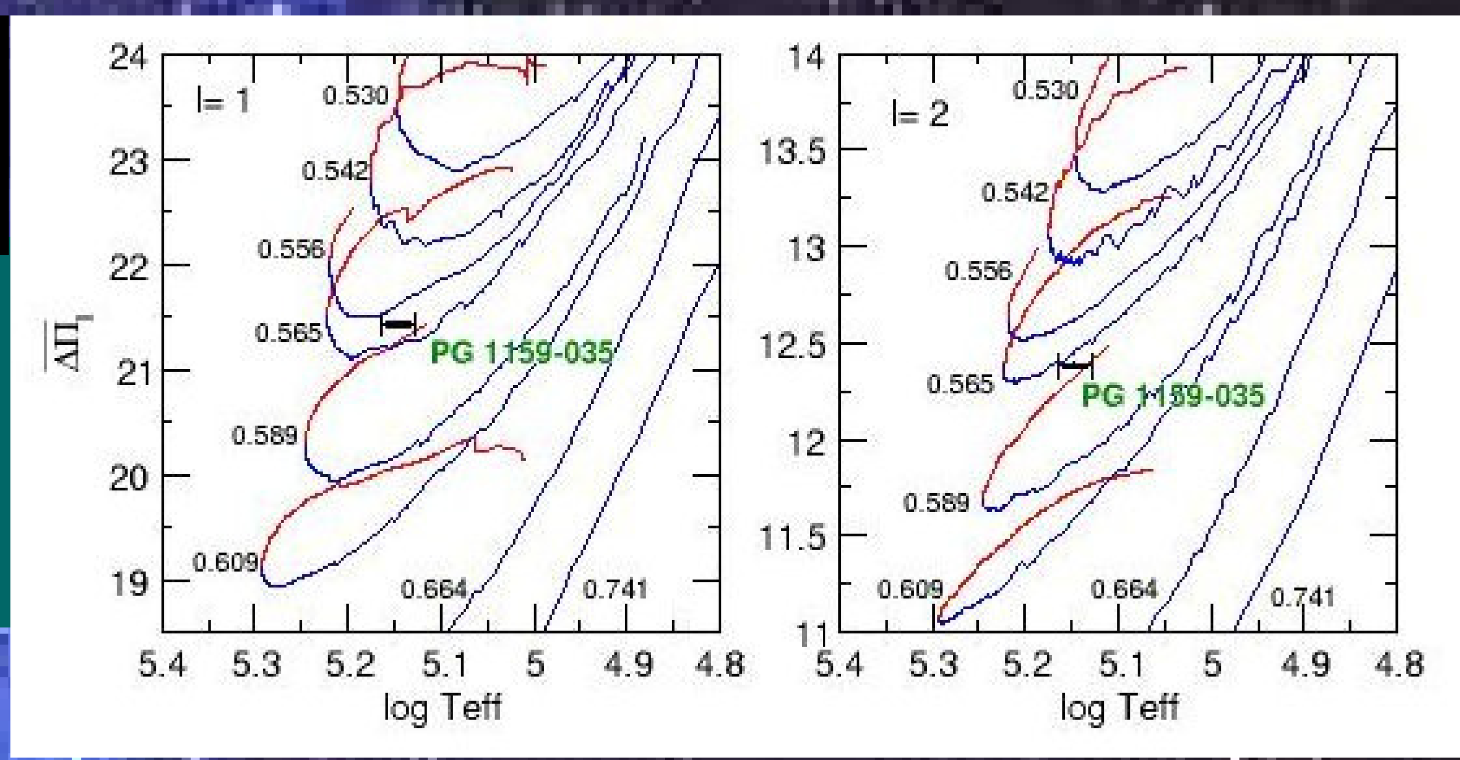
PULSATION MODELING: We compute l= 1 and l= 2 nonradial g-mode adiabatic pulsation periods with the pulsation code described in Córsico & Althaus (2006). We analyze about 3000 PG1159 models covering a wide range of effective temperature, luminosidad and stellar mass.

Dipole (left) and quadrupole (right) asymptotic period spacing in terms of the effective temperature. The stages before (after) the evolutionary ``knee'' are depicted with red (blue) lines. Numbers along each curve denote the stellar masses (in solar units).

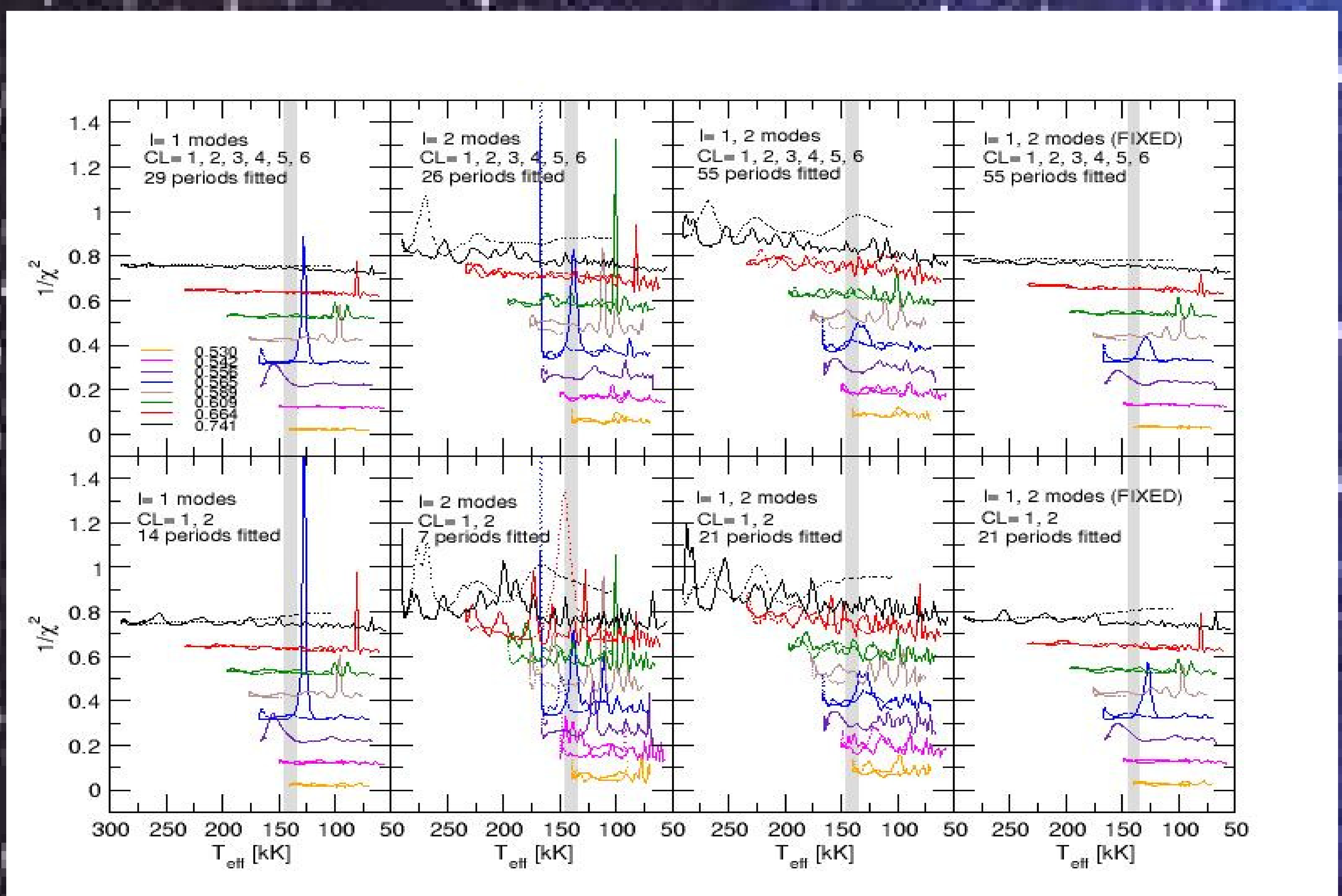


METHOD 1: The comparison between the dipole (l= 1) and quadrupole (l= 2) asymptotic period spacings and the observed mean period spacings is the most simple method to infer the stellar mass of PG1159 stars. For PG 1159-035 we found a stellar mass in the range 0.577-0.585 Mo. However, the asymptotic predictions are strictly valid for chemically homogeneus stars. Since PG1159 stars are thought to be chemically stratified, this method is not completely reliable, and frequently overestimates the stellar mass.

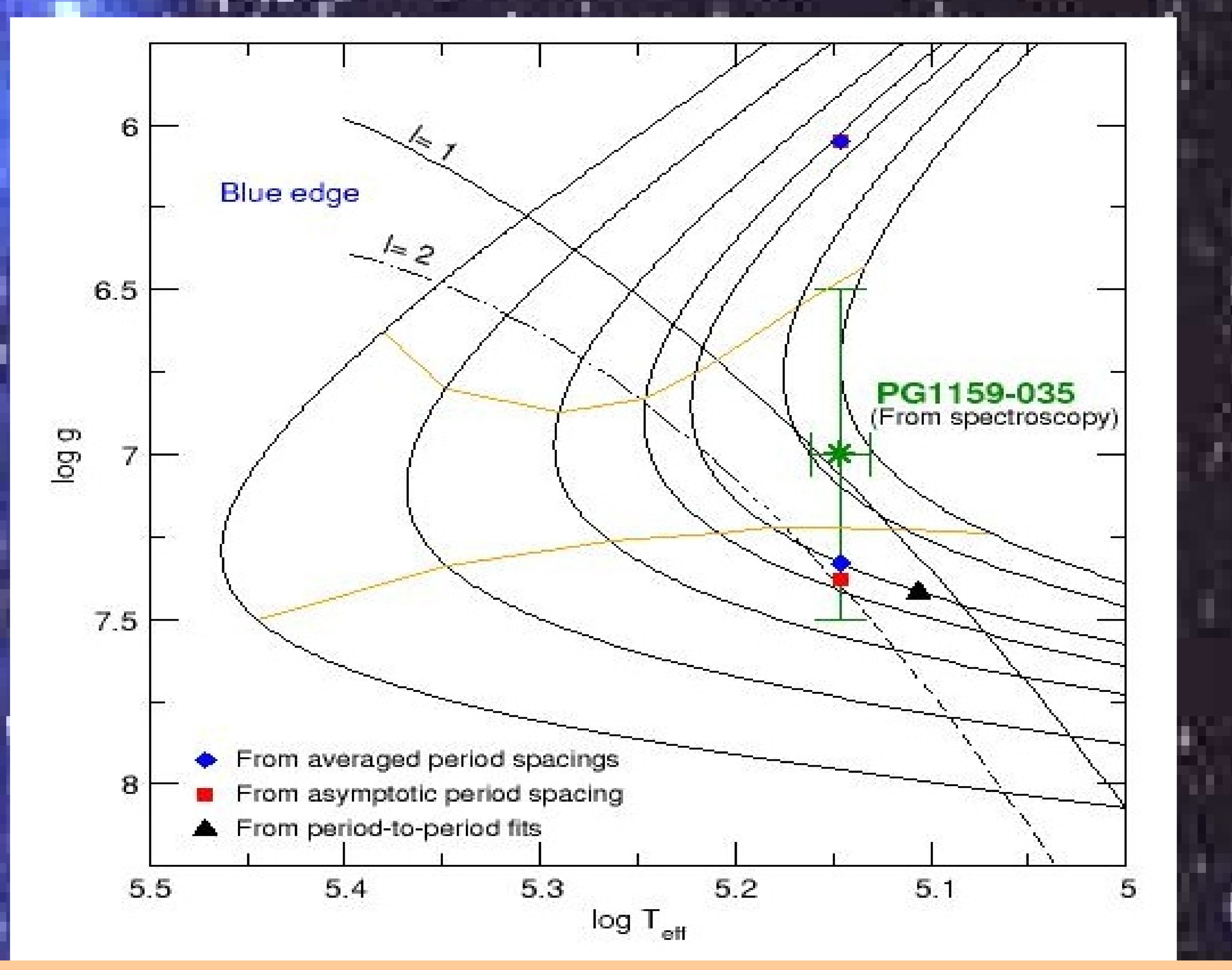
Same as above, but for the average of the computed period spacings



METHOD 2: If we compare the (l= 1 and l= 2) average of the computed period spacings (the output of the stellar pulsation code) with the observed mean period spacing, we obtain a more realistic way to derive the stellar mass of PG 1159-035. For PG 1159-035 we obtain a mass in the range 0.561-0.585 Mo, closer to the spectroscopic mass (0.54 Mo) than the predictions of Method 1.



METHOD 3: In this approach we seek a PG1159 stellar model that best matches the individual observed periods (the "best-fit" model). We perform period-to-period fits with a merit function which is directly related to the standard deviation between observed and computed periods. We use the updated set of pulsation periods measured by Costa et al. (2007). In the figure above, we show the inverse of the merit function in terms of the effective temperature. Each curve corresponds to a value of the stellar mass, from bottom to top: 0.530, 0.542, 0.565, 0.589, 0.609, 0.664 and 0.741 Mo. The curves have been shifted upward (with a step of 0.1) except for the lowermost one (0.530 Mo). Upper panels of the mosaic correspond to period fits considering all of m= 0 periods (those with Confidence Level= CL= 1, 2, 3 ,4, 5 or 6; see Costa et al. 2007), and the lower panels correspond to fits using only the m= 0 high probability periods (those with CL= 1 or 2). For period fits considering only l= 1 modes (left column) we found a clear solution for a model with M= 0.565 Mo (blue curve) and Teff= 128000 K. For l= 2 we are unable to find a solution compatible with the spectroscopic Teff. Period fits to l= 1 and l= 2 modes simultaneously without constraining the l-value of the observed periods do not lead to a unique solution. On the other hand, if we constrain the l-values of the observed (input) periods from the outset we recover the previously solution, as can be seen from the right panel. This model is adopted as our best-fit model. Its location in the log Teff-log g diagram is shown as a filled triangle.



The log Teff- log g diagram. The location of PG 1159-035 according to spectroscopy and the predictions of the asteroseismological methods described in this poster are included. Our best-fit model is able to reproduce the period spectrum of PG 1159-035. However, important observational facts are not explained by our model: (1) the location of the star within the instability domain of GW Vir stars, and (2) the large magnitude (a factor 10 larger than our predictions) of the rates of period change measured by Costa & Kepler (2007), and (3) the mixture of positive and negative signs of the rates of period change (some periods increasing and other decreasing) also reported by Costa & Kepler (2007). We emphasize that our PG1159 models are characterized by ***thick*** He-rich envelopes. We are planning new asteroseismological studies on PG 1159-035 by employing PG1159 models with ***thin*** He-rich envelopes.

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