A First Look at the Nonadiabatic Properties of Pulsating Accreting White Dwarfs of the GW Lib Type

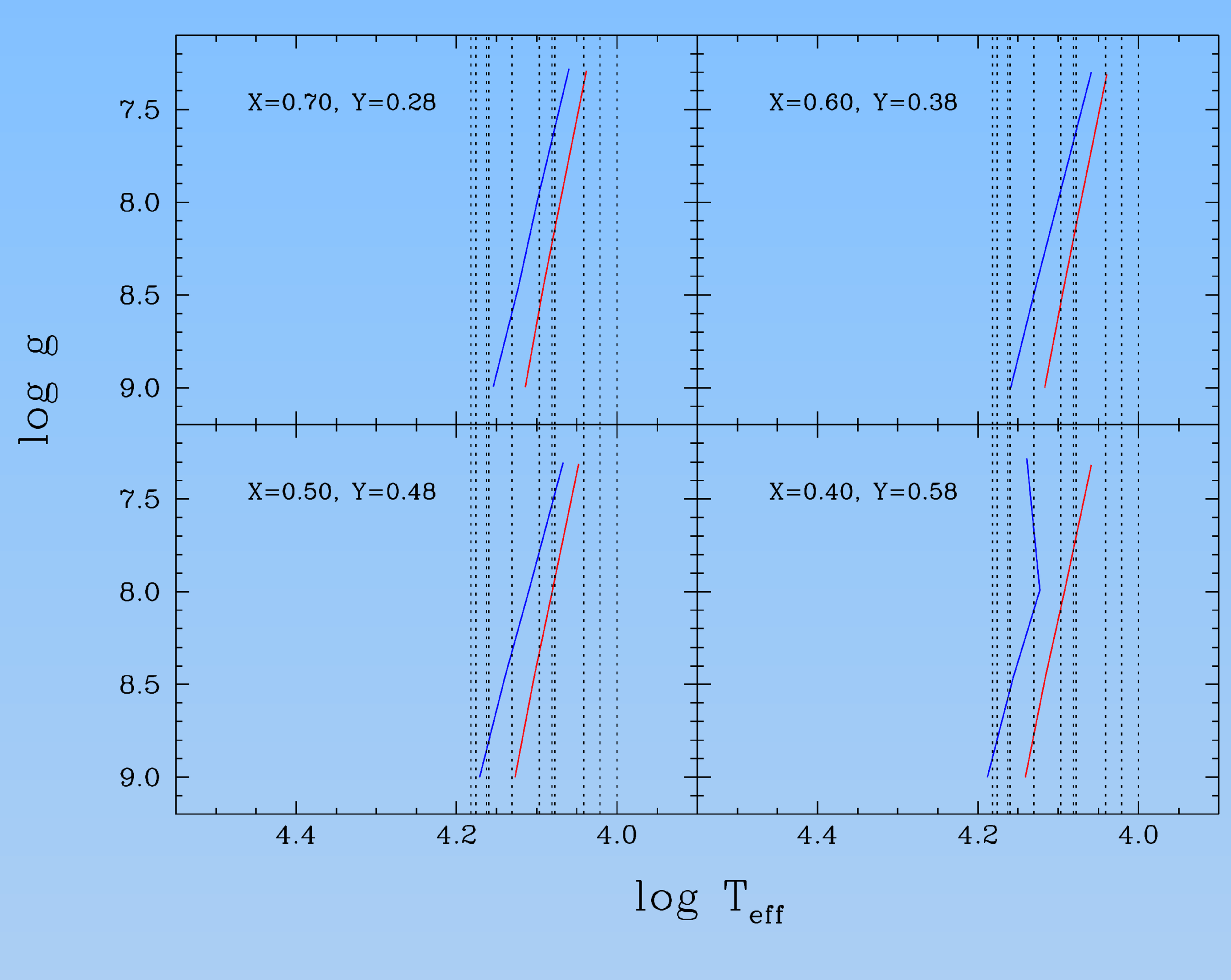
V. Van Grootel[1], G. Fontaine[2], P. Brassard[2], and M.-A. Dupret[1]

[1]Institut d'Astrophysique et de Géophysique, Université de Liège
[2]Département de Physique, Université de Montréal

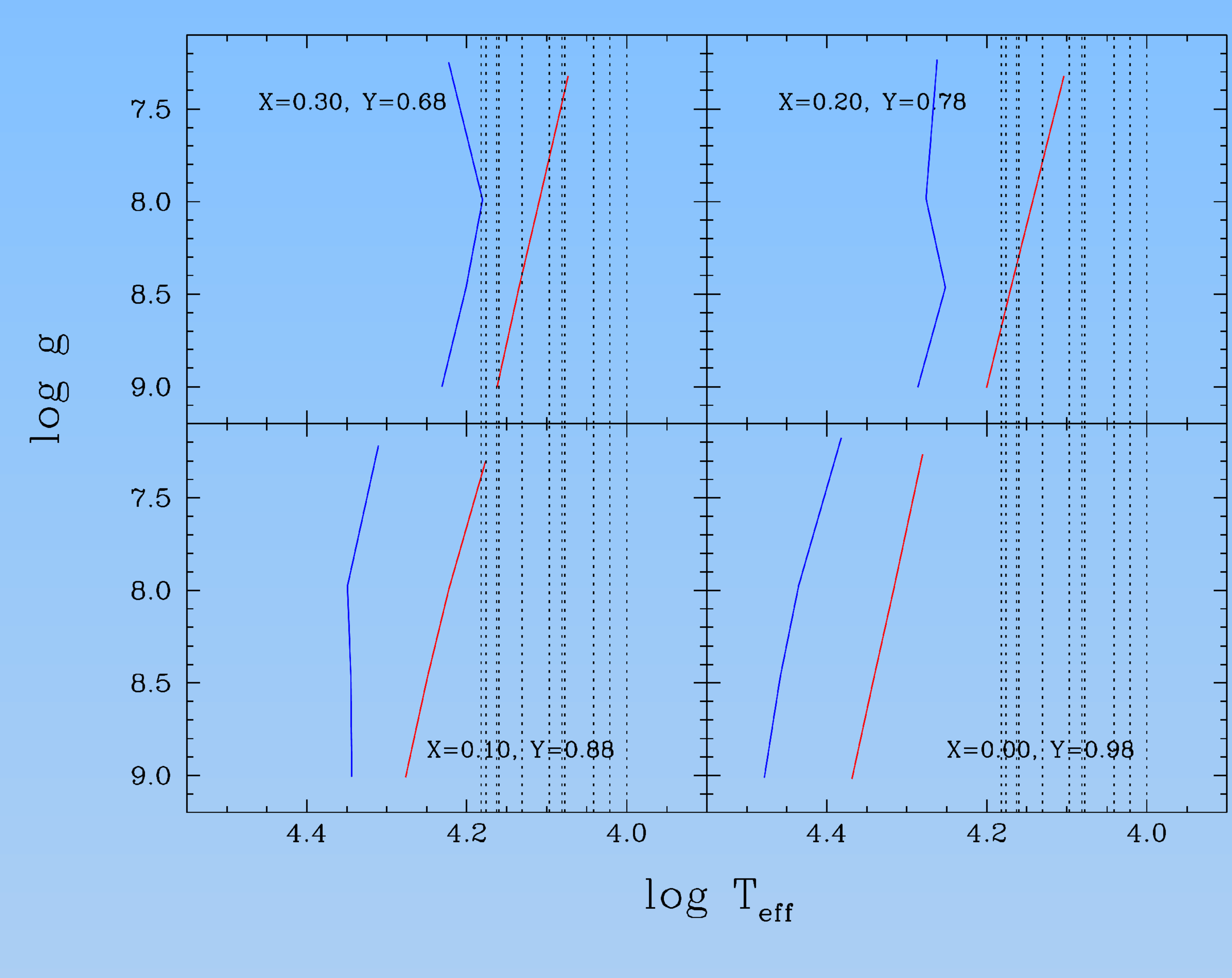
Astrophysical context: Nonradial gravity-mode oscillations similar to those found in pulsating DA (ZZ Ceti) and DB (V777 Her) white dwarfs have been discovered in the white dwarf component of the cataclysmic binary system GW Lib as first reported by Warner & van Zyl (1998, in IAU Symp. 185, New Eyes to See Inside the Sun and Stars, eds. F.-L. Deubner, J. Christensen-Dalsgaard, & D.W. Kurtz, Dordretch, 321). Since then, a dozen more systems of this type have been uncovered and intensively studied (see, e.g., the particularly informative article by Szkody et al. [2010, ApJ, 710, 64] and references therein). Given the close binary nature of these systems, it has remained difficult to characterize the individual pulsating white dwarfs through standard spectroscopy. In particular, no direct information is available from spectroscopy on the surface gravity and on the atmospheric chemical composition, although, in the latter case, it should reflect that of the donor component, i.e., anywhere from a solar mixture to a highly enriched He composition if the donor is well evolved. On the other hand, reliable estimates of the effective temperature have been derived, indicating that GW Lib pulsators occupy a significantly wider domain in effective temperature than the ZZ Ceti stars do, while overlapping the latter.

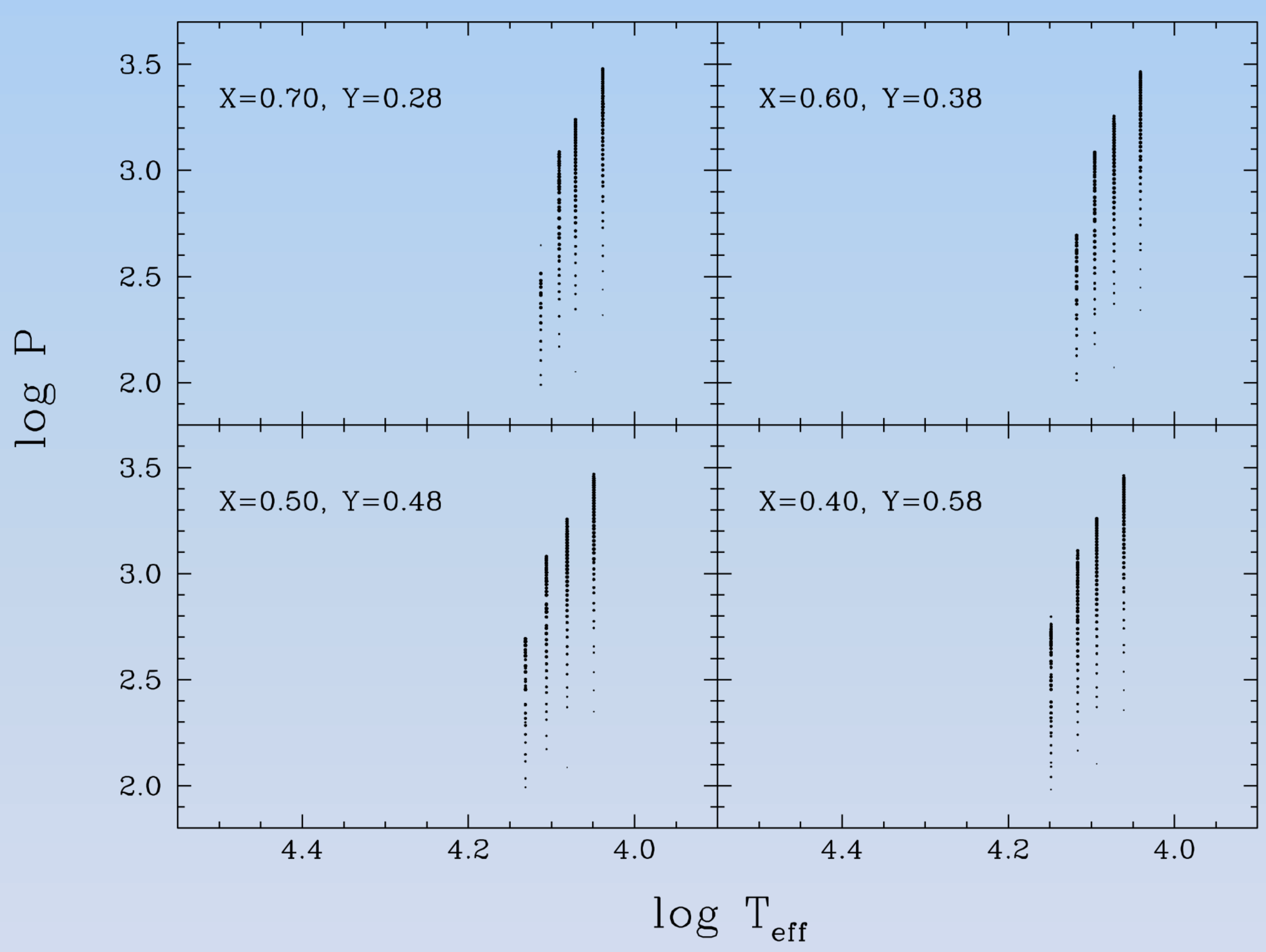
To our surprise, as we learned during the EuroWD12 meeting held in Krakow, no detailed nonadiabatic studies have ever been carried out for these interesting pulsators. To our knowledge, only the paper of Arras, Townsley, & Bildsten (2006, ApJL, 643, L119) actually addressed the question of pulsational instabilities in GW Lib white dwarfs, but this was done using a semi-analytic argument that boils down to a necessary condition for mode driving in white dwarfs. However, it is important to realize that this so-called "thermal timescale argument", according to which pulsation modes may be driven if their periods are comparable to the local thermal timescale at the base of the convection zone, is not a sufficient condition. It allows for rough estimates of the location of the blue edge of a *potential* instability strip, but can say nothing about the reality of such a strip and about the range of periods and actual modes being excited in a stellar model. In short, the approach needs to be validated through lengthy detailed nonadiabatic studies, which cannot be avoided if one wants to fully exploit the potential of stellar pulsation theory. We note that Arras et al. (2006) made excellent use of the thermal timescale approach, emphasizing, in particular, how the blue edge could depend on the chemical composition and the surface gravity for GW Lib instability strips. At the same time, and quite correctly, they warned in their conclusion section that their approach needed to be validated through full nonadiabatic pulsation calculations. We followed that path in the present work.

The tools that we used are the same as the ones we employed recently to map successfully the ZZ Ceti instability strip, including both the theoretical blue and red edges in relation to observational data. Indeed, Figure 2 of Van Grootel et al. (2013, ApJ, 762, 57) offers the first ever coherent picture of that strip and its extension into the ELM domain (the ELM pulsators are simply low-mass ZZ Ceti stars from an nonadiabatic pulsation point of view). That figure also represents the culmination of some 35 years of efforts by several members of the Montréal White Dwarf Group. In brief, we examined the nonadiabatic pulsation properties of a large number of stellar models culled from several evolutionary sequences with the Liège code MAD which incorporates a detailed treatment of time-dependent convection. We present some of our results below.

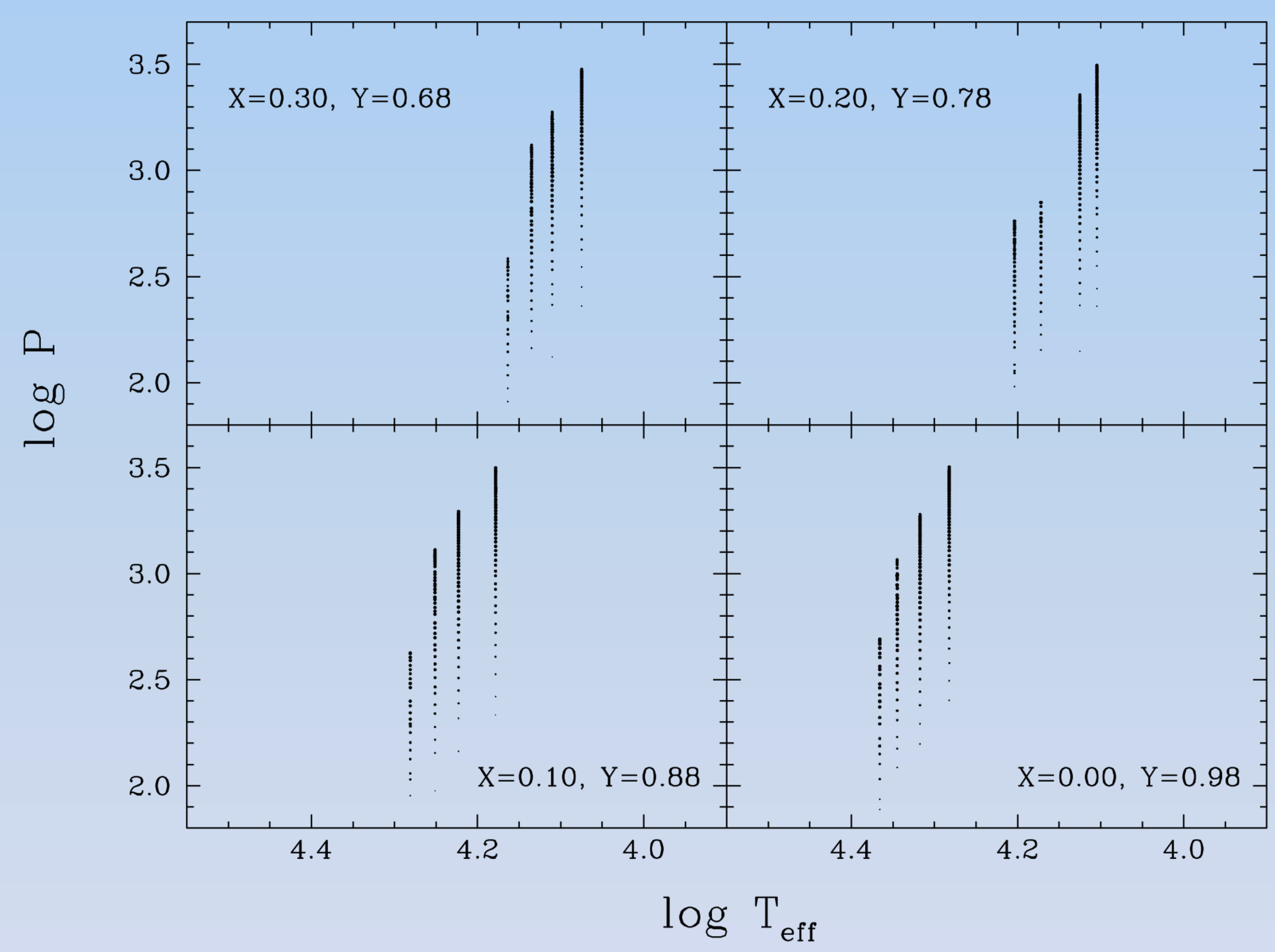


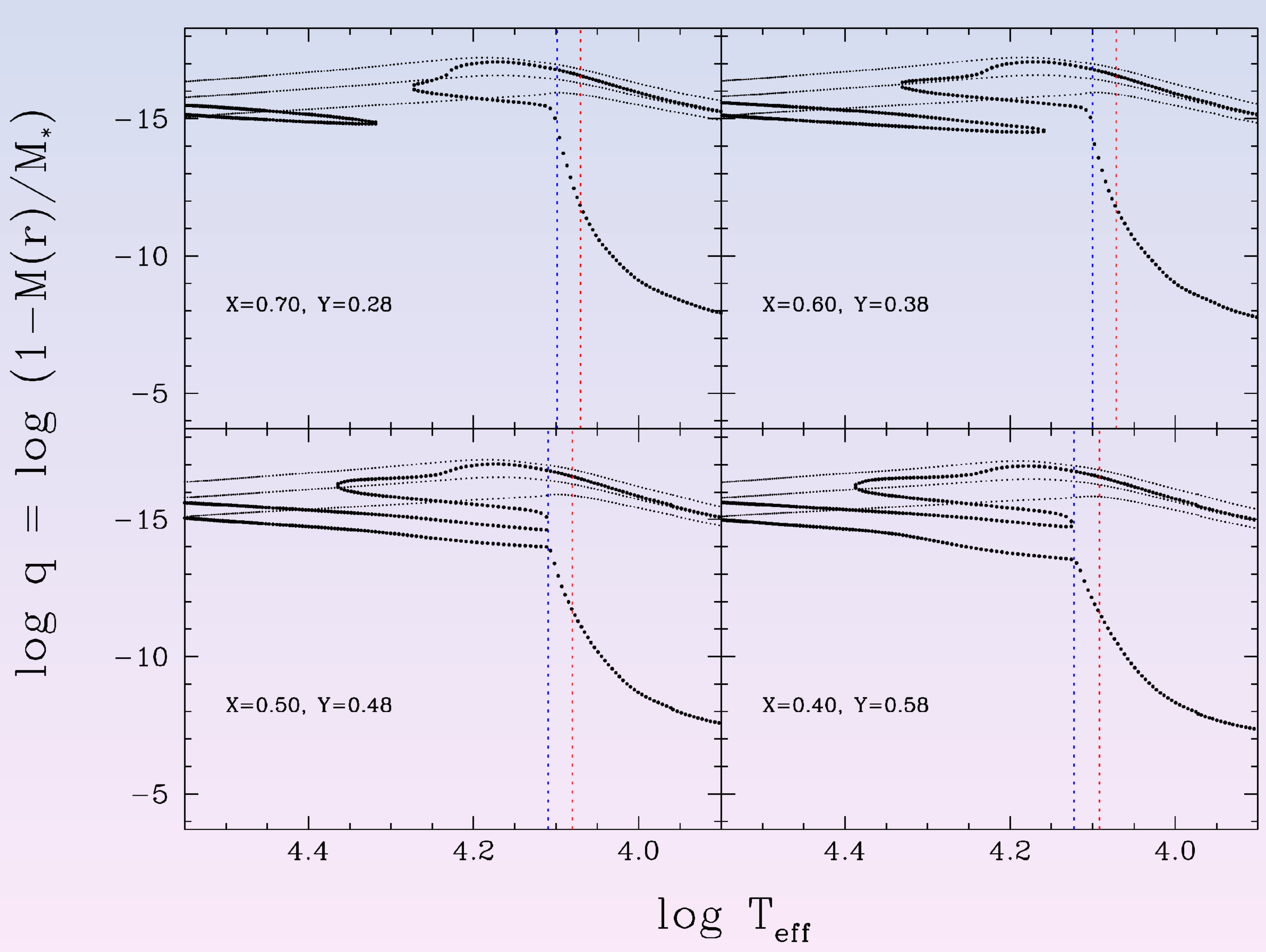
Figs. 1: Predicted GW Lib instability strips for models with envelope compositions ranging from solar (upper left figure of left panel) to a H-less mixture (lower right figure of right panel). For each of the 8 envelope compositions considered, we computed 4 distinct evolutionary sequences characterized by a total mass of 0.3, 0.6, 0.9, and 1.2 $M_{\odot}$.This leads to a somewhat coarse covering in the log g direction as can be seen in the plots (each blue or red edge is defined in terms of 4 points corresponding to these 4 different masses), but this was deemed sufficient in the present context. For comparison purposes, we also plotted the values of the effective temperature for each of the 11 pulsating white dwarfs of the GW Lib type listed in Table 6 of Szkody et al. (2010, ApJ, 710, 64) in the form of vertical dotted lines. Taking into account the uncertainties on these estimates (provided in that table), and allowing for variations in the envelope composition from one star to another, we can qualitatively account for all of the known cases with the suggestion that the coolest GW Lib pulsators are likely low-mass objects.





Figs. 2: Predicted ranges of excited dipole (l = 1) g-modes for representative models inside each of the instability strips, but near the red edge. For each envelope composition illustrated (same format as for Figs. 1), we display the range of excited periods for a massive 1.2 $M_{\odot}$ model near the red edge (lower left and shorter periods on average) as well as for the other masses considered in our evolutionary calculations, including a less massive 0.3 $M_{\odot}$ model near the red edge (upper right and larger periods than average). Each dot represent an excited dipole mode, and the size of the dot is a logarithmic measure of the imaginary part of the complex frequency. The bigger the dot, the more unstable the mode. As an example, if we adopt a value of 15,200 K for the effective temperature of the pulsating white dwarf component in GW Lib itself (Szkody et al. 2010, ApJ, 710, 64), a mass of about 0.84 $M_{\odot}$ according to van Spaandonk et al. (2010, ApJL, 715, L109), the dominant modes with periods of 230, 370, and 650 s (van Zyl et al. 2004, MNRAS, 350, 307) can easily be accounted for at the qualitative level if the donor is rather He-rich.





Figs. 3: Details of the outer envelopes of 8 evolving models of the same total mass of 0.6 $M_{\odot}$ but with 8 different envelope chemical compositions (same format as for Figs. 1). The atmospheric layers are mapped through the use of the 3 dotted curves in each plot, corresponding to a Rosseland optical depth of 0.1, 1.0, and 10.0, from top to bottom. The boundaries of the outer convection zone(s) are indicated by heavy dots. Note the complex double structure associated with HeII and HI-HeI ionization zones. With cooling these distinct convection zones merge together through pressure effects in white dwarfs. The boundaries of the instability strip for each case considered are indicated by colored vertical dotted lines. Pulsational driving is associated mostly with regions at the deeper base of the convection zone complex.