Precision Asteroseismology
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Asteroseismology with the new opacity bump at $\log T \approx 5.06$

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Abstract. Although the κ mechanism of pulsations is known for early-type stars, opacities and the equation of state are still uncertain. Stellar models calculated for the OP data implemented with the new Kurucz opacities at $\log T < 5.2$ were investigated for different chemical compositions of elements. The additional metallic opacity bump at $\log T \approx 5.06$ that occurs in the Kurucz data changes markedly the oscillation spectra of unstable modes. Basic properties of the new opacity bump and examples of seismic models are shown. B-type stars observed in the Galaxy, LMC and SMC were considered. The problem was studied using Dziembowski's computing codes for linear, non-adiabatic and non-radial oscillations.

Keywords. stars, stellar evolution, asteroseismology, radiative opacity

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The opacity and equation of state are necessary ingredients for modelling internal structure, evolution and pulsation of stars. The well known OP and OPAL Rosseland-mean opacities agree reasonably well, but recent critical remarks concerning the atomic physics and accuracy of the OP (and OPAL) data are motivated by unsolved problems in helio- and astero-seismology, cf. e.g., Pradhan & Nahar (2009) and Dziembowski (2009). Recently, we show (cf. Cugier 2012) that the present-day Kurucz (2011) opacity project to include all spectral lines leads to the new opacity bump at $\log T \approx 5.06$, which has only a minor counterpart in the OP (and OPAL) data, cf. Seaton *et al.* (1994). This opacity bump is caused by metals and much more complete atom models than used by the OP and OPAL projects are essential for this effect, cf. Fig. 1a and b.

The H-R diagrams for stellar models $M > 30\,M_{\odot}$ calculated with the opacity bump at $\log T \approx 5.06$ (K-OP models; case No. 2 in Fig. 1b) differ markedly from those corresponding to the OP (case No. 1 in Fig. 1b) and OPAL data, cf. Fig. 1c. Evolutionary tracks for $M < 30\,M_{\odot}$ remain almost the same as in the OP and OPAL cases. The K-OP models mean that hybrid CK/OP opacity data were used, viz. the Castelli & Kurucz (2003) data at outer layers (up to $\log T = 5.2$) and the OP data at $\log T > 5.2$. No mass loss, no rotation and no core overshooting were assumed. For $M > 30\,M_{\odot}$, the effect is caused by the gradient of radiation pressure near $\log T = 5.06$. The OP models for $Z = 0.0054$ are also shown in Fig. 1c.

The new opacity bump at $\log T \approx 5.06$ has important consequences for asteroseismology for all models studied in this paper ($M \geqslant 9\,M_{\odot}$). The proper behaviour of the Rosseland-mean opacities, eigenfunctions and thermal timescale of the driving zone are necessary for the κ mechanism to work, cf. e.g. Dziembowski (2009) and Pamyatnykh (1999). Figure 1d shows frequencies of unstable modes for stellar models calculated for $M = 10\,M_{\odot}$ at the moment when the central hydrogen content was decreased to $X_c = 0.24$. The low-degree modes ($l = 0, 1$ and 2) are marked individually, while unstable modes with $l \geqslant 3$ are shown by small (black) points. The number of a model describes the opacity data used, cf. Fig. 1b. We found no unstable p modes for the K-OP models

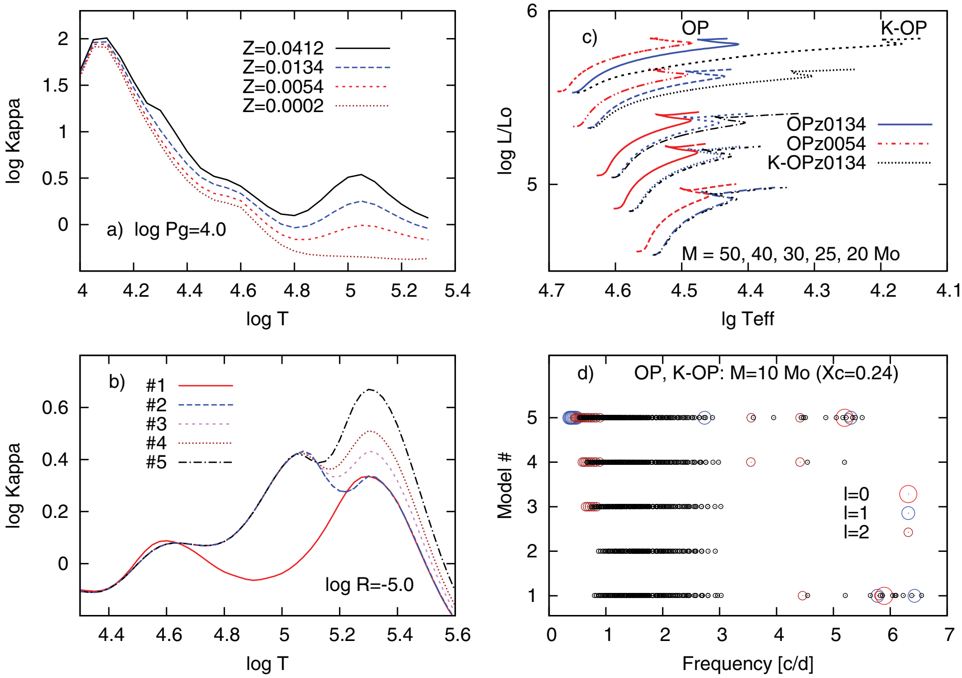

Figure 1. *a*) Examples of the Rosseland-mean opacity calculated by Castelli & Kurucz (2003) for different metallicity parameters $Z = 0.0412, 0.0134, 0.0054$ and 0.0002. (P_g means the gas pressure). *b*) The CK/OP opacities for $Z = 0.0134$ (case No. 2) are compared with the OP data (case No. 1) for $\log R = \log\rho - 3\log T + 18 = -5$. The CK/OP data with increased OP bump at $\log T \approx 5.3$ are shown as cases 3 – 5. *c*) The OP and K-OP models of stars are plotted in the H-R diagram for $Z = 0.0134$ and the OP models for $Z = 0.0054$. *d*) Seismic models of $M = 10\,M_\odot$ for different opacity data shown in panel *b*). 'Lo' means the solar luminosity and 'Mo' the solar mass.

with masses $10 \leqslant M \leqslant 20\,M_\odot$, including those calculated for $Z \geqslant 0.0264$, cf. model No. 2 in Fig. 1d. Using the Castelli & Kurucz (2003) opacity data at $\log T \leqslant 5.2$, an increase of the OP opacity bump at $\log T = 5.3$ by a factor of about 1.7 is necessary to obtain unstable p-modes for the Galactic early-B stars, cf. models No. 4 – 5 in Fig. 1d. The same factor, about 1.7, is sufficient to drive pulsations for $Z = 0.0054$ (p- and g-modes) and for $Z = 0.003$ (g-modes). These values of Z are in a good agreement with those of derived spectroscopically for the Magellanic Clouds.

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