The effect of a magnetic field on the radiative excitation and damping of p-modes

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Abstract

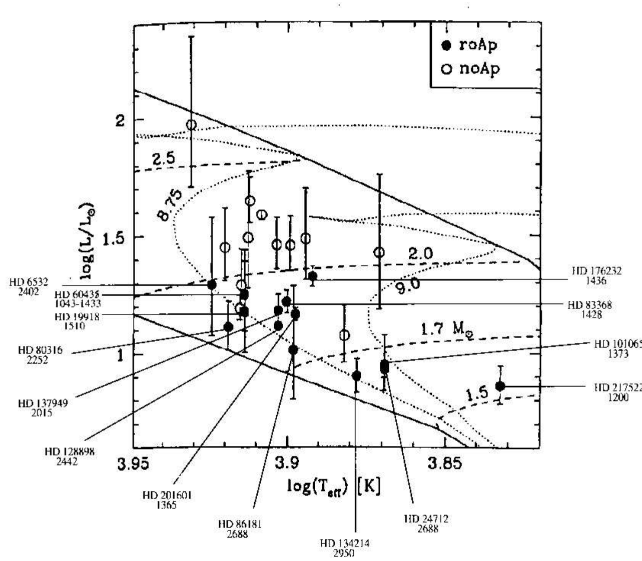
A rapidly oscillating Ap star pulsates in high-oder p-modes under the influence of a strong magnetic field. The strong field distorts spatially the angluar and radial the pulsation amplitude (eigenfunction). To study the effect of the magnetic field on the radiative excitation and damping of p-modes, we performed a fully nonadiabatic analysis including the effect of a dipole magnetic field. A magnetic field always tends to stabilze low oder p-modes. For high-order p-modes, on the other hand, the magnetic field *enhances* kappa-mechanism excitation in some range of the field strength, depending on the pulsation frequency.

Rapidly Oscillating Ap (roAp) stars:

Periods; 6 – 15min
(Freq.; 2.8 – 1.1mHz)

Magnetic fields: a few kG

High-order p-modes under a strong magnetic field



Balmforth et al. (2001)

Unperturbed model: $1.9M_\odot$ main-sequence star
$X = 0.7, Z = 0.02$; Convection is suppressed.
$\log L = 1.164, \quad \log T_{\rm eff} = 3.9125, \quad \log R = 0.281$

Dipole magnetic field:

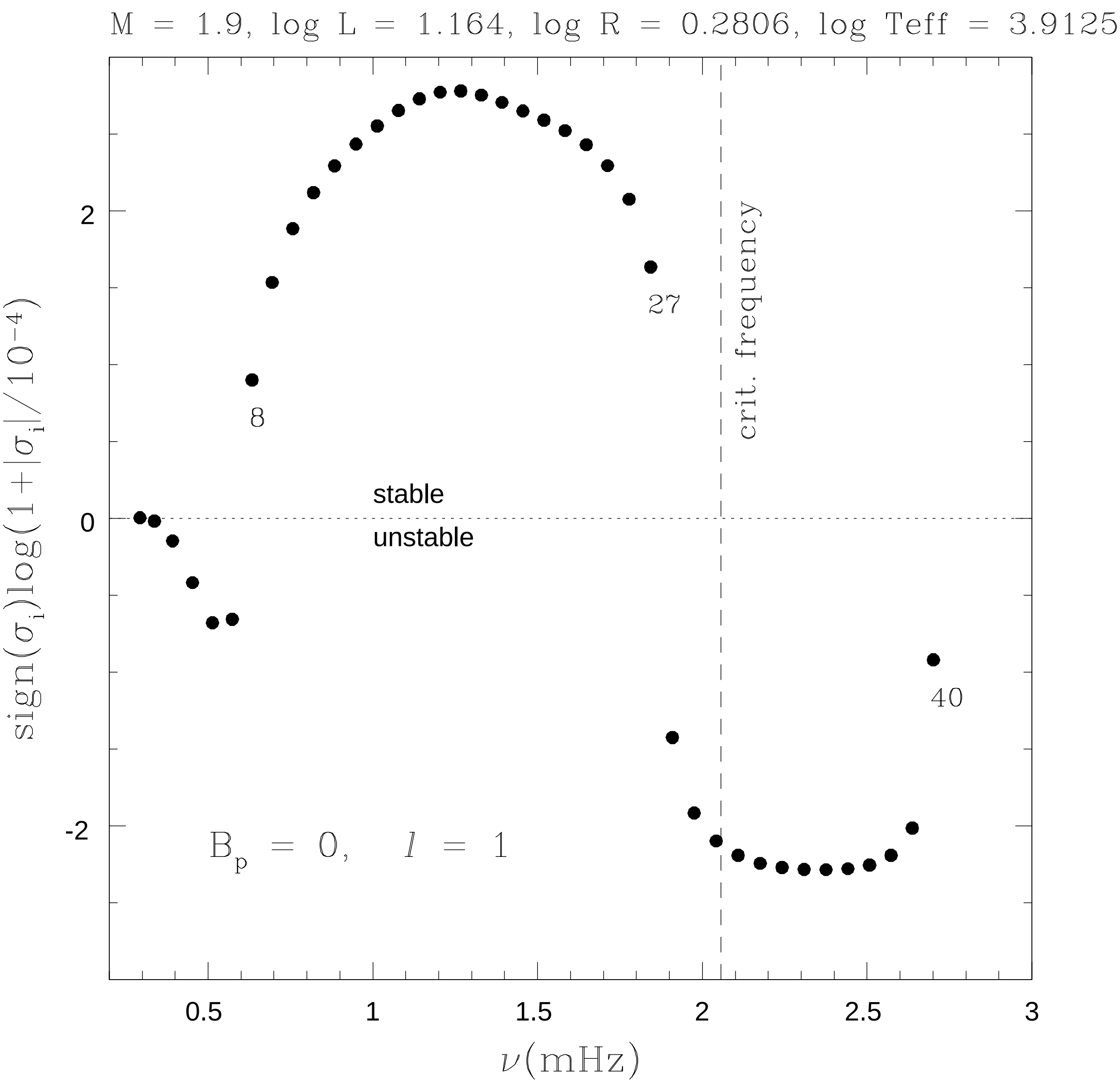
$$\boldsymbol{B}_0 = \frac{B_p}{(r/R)^3}(\boldsymbol{e}_r \cos\theta + \boldsymbol{e}_\theta \frac{1}{2}\sin\theta).$$

Nonadaibatic analysis for axisymmetric ($m = 0$) modes in terms of a series expansion.

$$\boldsymbol{\xi} = e^{i\sigma t}\sum_\ell \left(\xi_r^\ell Y_\ell^0 \boldsymbol{e}_r + \xi_{\rm p}^\ell \frac{dY_\ell^0}{d\theta}\boldsymbol{e}_\theta\right)$$

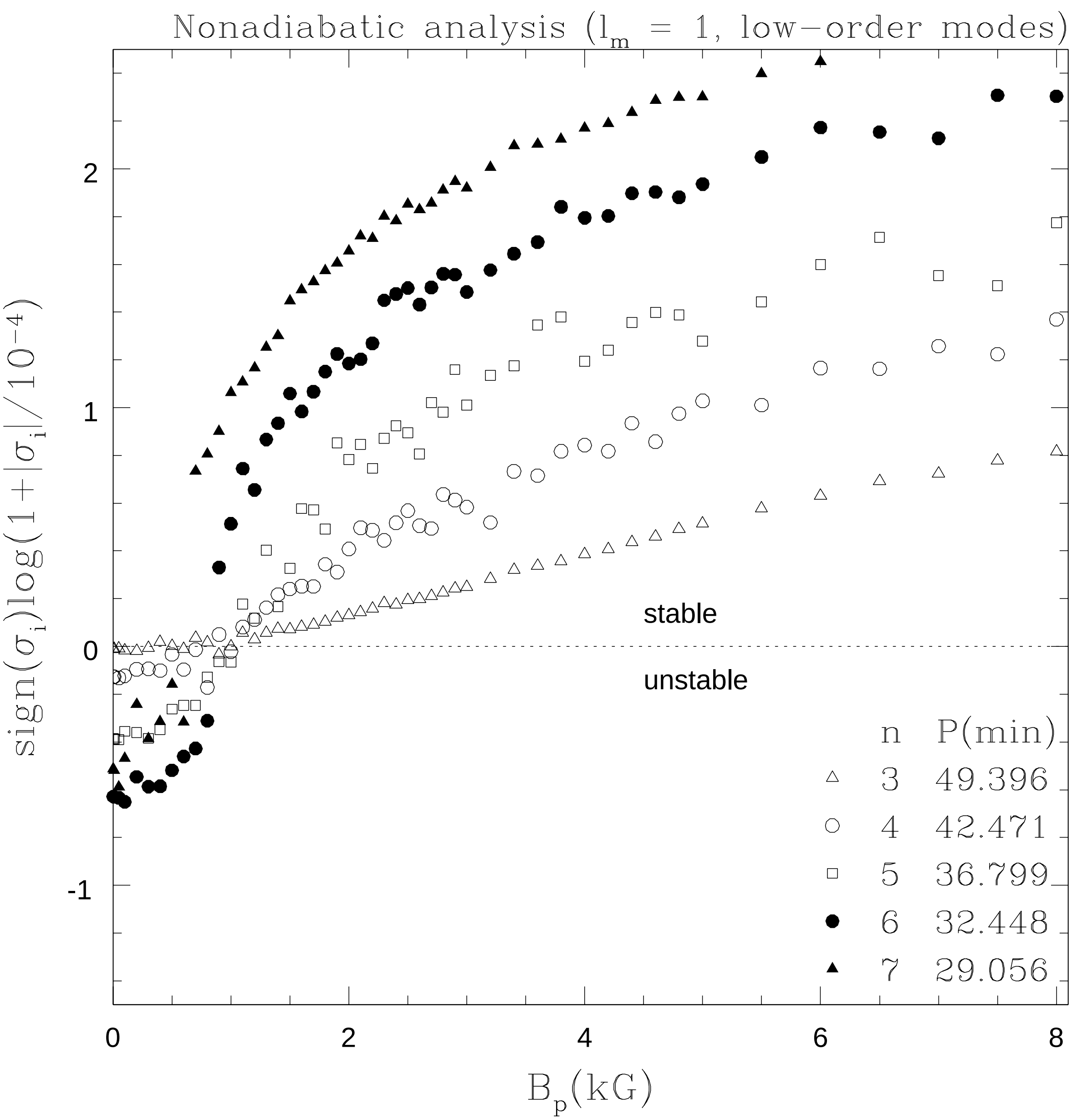
$$\boldsymbol{B}' = e^{i\sigma t}\sum_\ell \left(b_r^\ell Y_\ell^0 \boldsymbol{e}_r + b_{\rm p}^\ell \frac{dY_\ell^0}{d\theta}\boldsymbol{e}_\theta\right)$$

The nonmagnetic situation



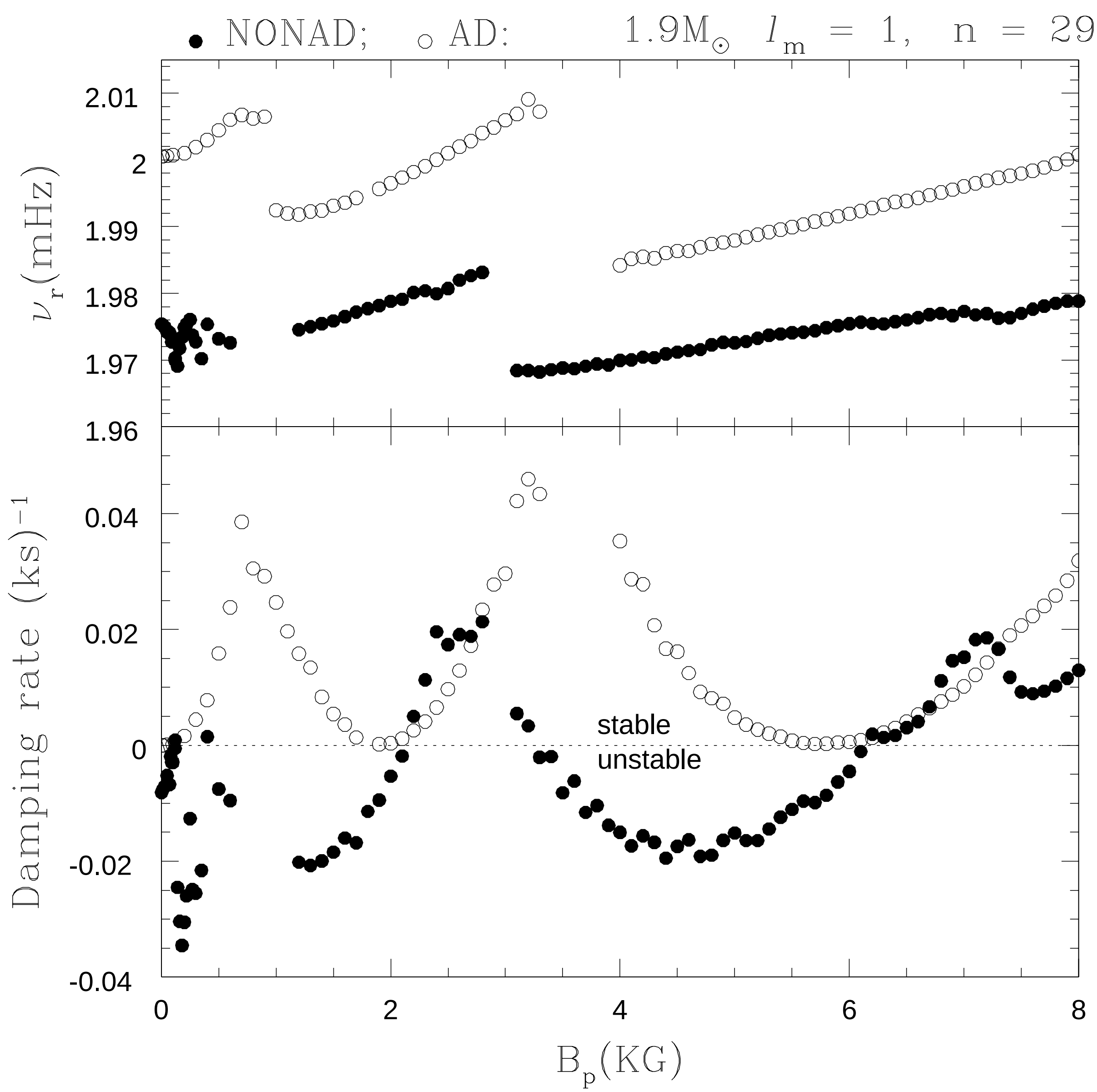
Pulsation frequency versus damping rate for the 2nd to the 40th order $\ell = 1$ p-modes in the absence of magnetic field. The kappa-mechanism in the He^+ ionization zone excites low order (3rd to 7th) p-modes, while the kappa-mechanism in the H-izonization zone excites three (28th–30th) high order-modes below the critical frequency.

Magnetic damping on low-order modes



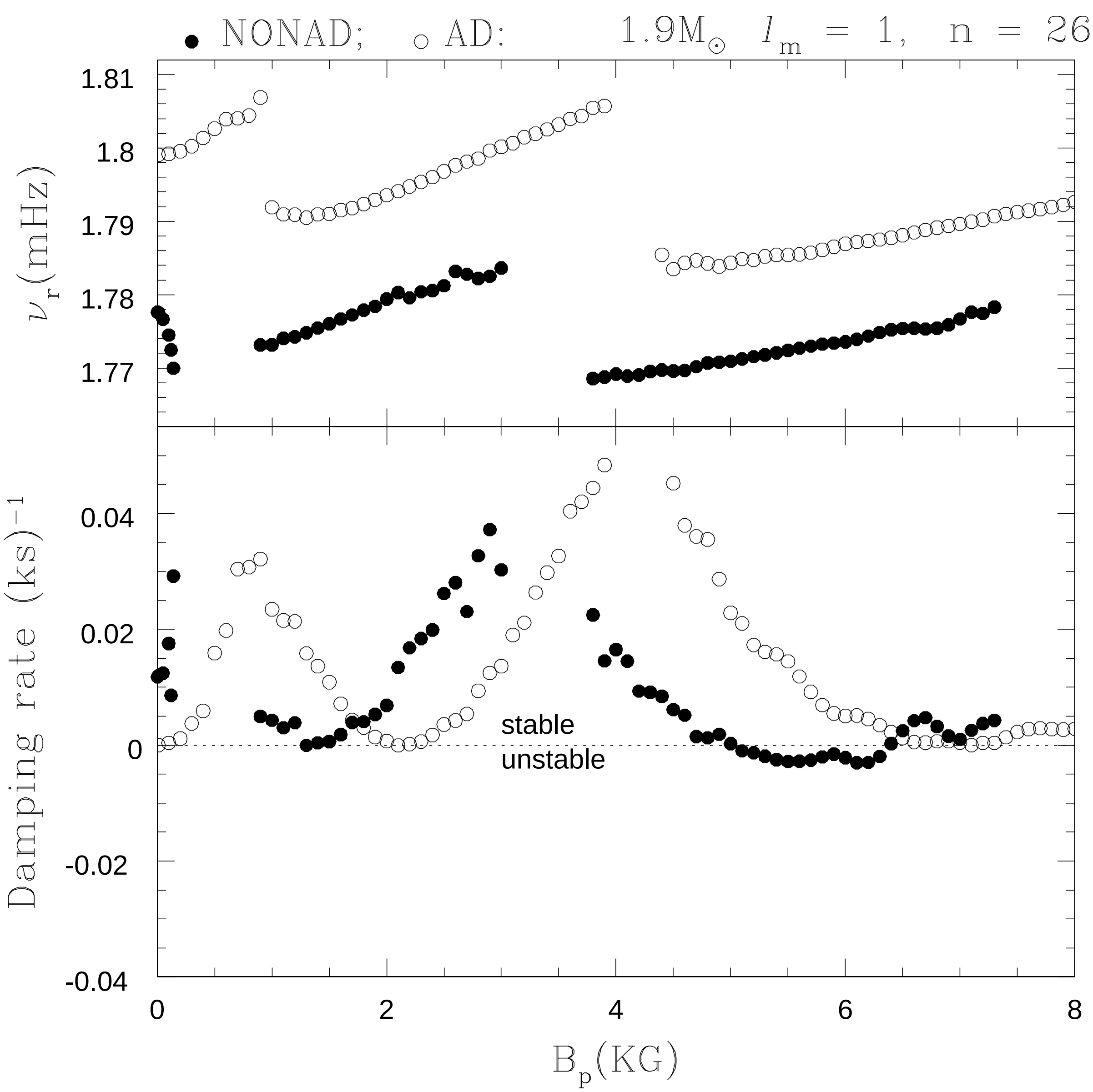
Damping rate versus the strength of magnetic fields for the low-order modes which are excited in the absence of magnetic field. Due to the magnetic damping caused by slow waves, all the δ Scuti type pulsations are suppressed if B_{p} is larger than $\sim$ 1kG.

Comparison adivabatic vs nonadiabatic high-order modes I



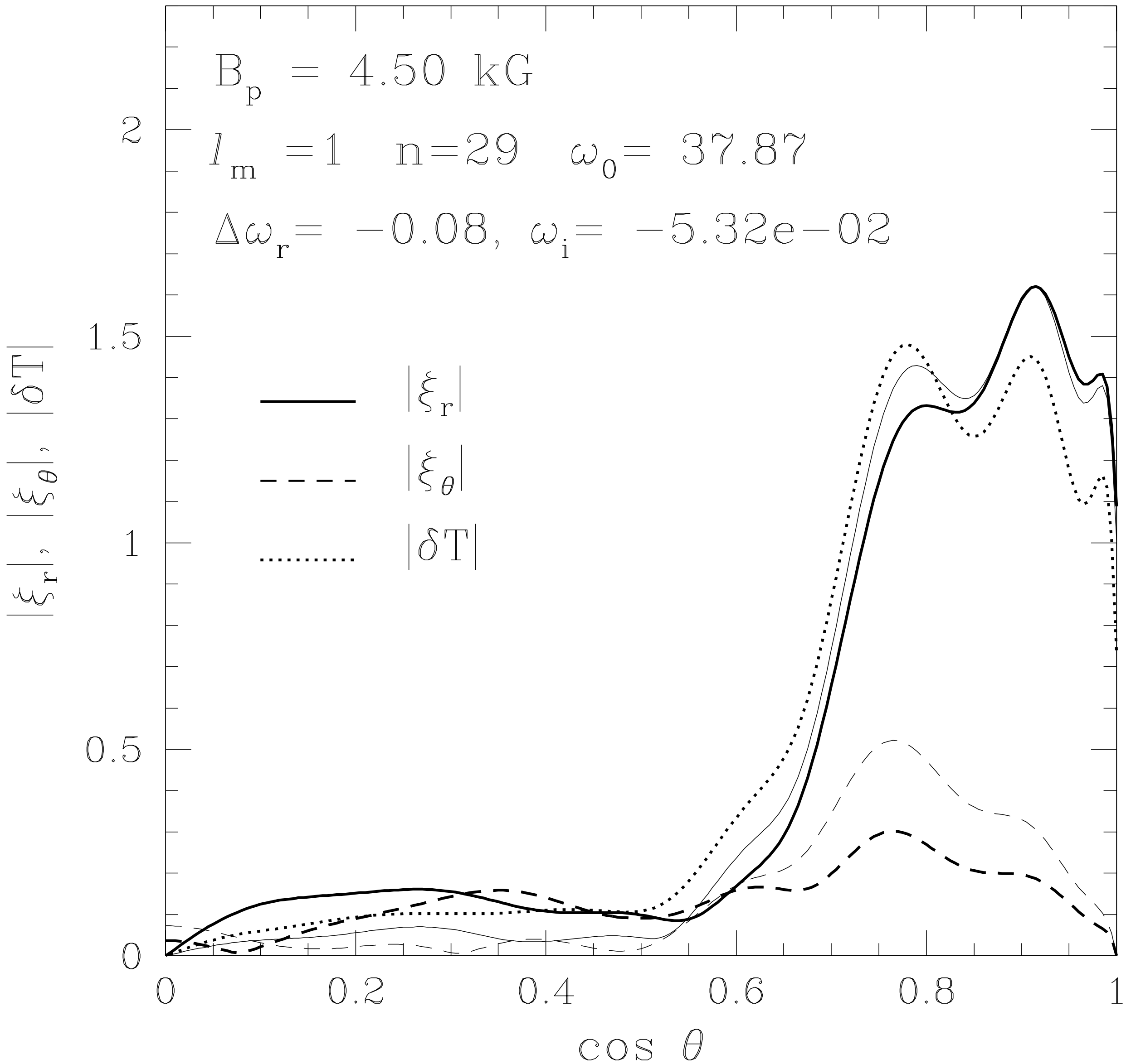
Pulsation frequency (upper panel) and damping rate (lower panel) as functions of B_{p} for the 29th order p-mode of $\ell_m = 1$. Filled and open circles show data from nonadiabatic and adiabatic analyses, respectively. Compared with the adiabatic situation, the frequency jumps (damping-rate peaks) lie at different field strengths in the nonadiabatic case. This mode is unstable for $3.5 < B_{\mathrm{p}}(\mathrm{kG}) < 6$ and $B_{\mathrm{p}}(\mathrm{kG}) < 2$.

Comparison adivabatic vs nonadiabatic high-order modes II



The same as the previous figure but for the 26th p-mode. This mode is stable at $B_p = 0$, but becomes marginally unstable in a range of $5 < B_{\rm p}({\rm kG}) < 6.5$.

Latitudinal amplitude distribution



The modulus of the latitudinal amplitude distribution of the 29th order p-mode of $\ell_m = 1$ at $B_{\rm p} = 4.5$. This mode is excited with a growth rate of $1.7 \times 10^{-5}{\rm s}^{-1}$. Thick and thin lines refer to the photosphere and the outer boundary (at $\tau = 0.002$), respectively. The amplitude is essentially confined in a range of $\theta < 45°$. Compared to the adiabatic case at minimum damping, the confinment to the magnetic axis is less pronounced.