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10 Aql, a new target for COROT

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Abstract

The satellite COROT (e.g., Baglin & Foing 1999) will be devoted to the seismic investigation of stars. It will provide new insights into our knowledge of stellar structure. Among the variable stars, the group of roAp stars is unique. Indeed, the oscillations of these stars are dominated by the effects of magnetic fields, which are typically three orders of a magnitude higher than in the Sun. The study of the oscillations in roAp stars provides a chance to test and to improve our knowledge of the structure of these extremely peculiar stars. The spirit of this article is to argue in favor of 10 Aql (HD 176232, HR 7167) as an interesting target for COROT. We then present basic aspects of roAp stars and in particular recent theoretical developments concerning the magnetic field and rotation effects on the mode properties. We also propose an interpretation of the frequencies already observed for this star.

The Ap and roAp stars

The group of Ap stars is one of the most studied. They are Main Sequence stars of about 2 $M_\odot$ but with spectra showing abnormal lines of some elements. These peculiarities were first discovered more than a century ago and were the first application of spectroscopy to stellar astrophysics. During the twentieth century these stars indeed revealed strongly abnormal chemical composition, with spectral lines of some rare elements enhanced by several order of magnitude (Morgan 1933, Adelman 1973, Preston 1974). The most abnormal lines concern the rare elements like Europium, Chromium, Strontium ($7000 < T_{eff} < 10000$) and Lithium (10000-14000 K). The elements of the iron peak are in turn of solar abundances. These elements are concentrated in some spots (and even rings) at the surface of the star. This has been observed by Doppler imaging techniques (e.g. Piskunov & Rice 1993). All these features were unexplained during the first part of the 20th century.

Babcock (1947) made a crucial discovery to explain the physical processes that occur in Ap stars. Indeed, he was the first to underline a Zeeman splitting of spectral lines, proof for the presence of a strong magnetic field. The typical strengths of the fields present in Ap stars are of the order of kilogauss, say at least 2 or 3 orders of magnitudes higher than the value of the global field of the Sun. These magnetic fields first appeared to be dipolar. The variability of the observed field was explained by the model of the oblique rotator (Babcock 1949, Stibbs 1950) which claimed that the axis of symmetry of the field is inclined to the rotation axis, so that as the star rotates the observer sees different aspects of the same field. The inclination, β, between the magnetic and rotation axes is discussed in Landstreet & Mathys (2000). They show that slowly rotating Ap stars are characterized by small values of β. There is now clear evidence for non-dipolar components of fields in Ap stars (e.g. Landstreet 1980, Mathys 1987, Landstreet 1992, Mathys & Hubrig 1997, Landolfi et al. 1998).

Recently, Hubrig et al. (2000a) showed that the magnetic field in Ap stars becomes detectable after some time spent on the Main Sequence, roughly after 30%, which indicates that this abnormal intense magnetic field may be related to a special stage in the life of the star.

The chemical peculiarities in Ap stars were explained by the presence of these huge fields. Indeed, the intense field is supposed to stabilize the external layers of the star against turbulent mixing. In the stable upper layers, the chemical elements are then subject to the balance between the gravitational settling and the radiative pressure (Michaud 1970). The elements which are concentrated in their line forming regions appear then overabundant.

Kurtz (1978) made an important and unexpected discovery in the late seventies. In studying the effective temperature of Przybylski's star, he was the first to detect a rapid light variation of about 12 min in an Ap star. This was clear evidence for the presence of acoustic oscillations. This discovery was unexpected because it was wrongly thought before that the huge magnetic field would suppress any type of oscillations. These Ap stars are the only stars of the Main Sequence to show the same short periods as the Solar-like stars, i.e. from about 5 to 15 min. Kurtz (1982) named them the *rapidly oscillating Ap* (roAp) stars. However, with typical amplitudes from 0.3 to about 8 mmag (Johnson B filter), the oscillations in the roAp stars are three orders of magnitudes higher than those in the Sun. Their number has grown to 32 (Martinez et al. 2001).

From the time of their discovery these stars showed multiplets with peaks exactly separated by the rotation frequency, Ω, of the star. Kurtz (1982) then proposed the model of the *oblique pulsator* which states that the axis of sym-

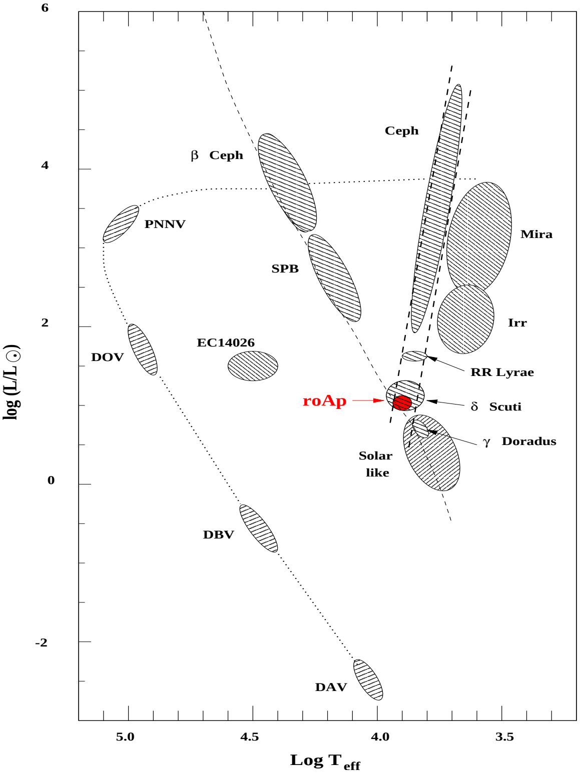

Figure 1: Representation of the Hertzsprung-Russell diagram for variable stars. The roAp stars are located on the Main Sequence at the intersection with the δ Scuti instability strip. From Christensen-Dalsgaard & Dziembowski (2000).

metry of the mode is aligned with the magnetic axis of the star, i.e. is inclined from the rotation axis. Then, exactly as in the model of the oblique rotator, the observer sees different aspects of the same mode during the rotation of the star. There is a double light variation, one with a short time scale due to the oscillations (few minutes) and one longer due to the rotation of the star (few days). In the frequency domain, the modulation by rotation makes each mode of degree ℓ to appear as a multiplet with $(2\ell + 1)$ components separated by exactly the rotation frequency. This fact has been confirmed for several roAp stars by comparison with the rotation periods obtained from mean light variations due the spots (e.g. Kurtz & Marang 1988, Kurtz et al. 1990, 1996) and is the best evidence in favor of the model of the oblique pulsator. Another property of these oscillations is a phase jump by π radians exactly at the amplitude minima. This aspect is evidence for dipole ($\ell = 1$) modes. This variation indeed corresponds to the fact that the observer sees alternatively the two hemispheres of the mode with opposite phases (one in contraction, one in expansion).

The source of these oscillations is still not clearly established. The short periods of the pulsations could lead us toward the stochastic excitation due to the turbulence in the outer layers of the stars, as for the Sun. However, the large amplitudes ($\sim$ mmag) cannot be explain by this process. Dziembowski & Goode (1996) show that for large number of nodes, the oscillations are driven by the κ-mechanism of the hydrogen ionization zone, and not by the He II zone as in the δ Scuti stars. The frontier between the roAp stars and the Ap stars which do not show rapid light variations, the *non oscillating Ap* (noAp) stars, is not clear. Indeed, the two classes of stars have similar magnetic field strengths, similar color indexes, etc. However, Hubrig et al. (2000b) point out a significant difference in their masses, which are somewhat larger in the noAp stars. This may have important consequences in the excitation mechanism. Balmforth et al. (2000) proposed a kappa-mechanism depending on the latitude, as a consequence of the suppression of convective turbulence at the magnetic poles. They show that the excited modes can be in some cases aligned with the magnetic field.

Reviews on roAp stars are available in Weiss (1986), Unno et al. (1989), Matthews (1991) and Kurtz (1990, 2000).

A model for roAp star pulsation

The model generally accepted to interpret pulsations in roAp stars is the model of the *oblique pulsator* (Kurtz 1982, Dziembowski & Goode 1985, Kurtz & Shibahashi 1986, Bigot & Dziembowski 2002). We are now going to describe the basic aspects of this model and its consequences on the interpretation of the seismic data. We consider only the main component of the magnetic field, say the dipole one. The non-perturbative treatment of the effects of a dipole magnetic field on acoustic modes has been done by Dziembowski & Goode (1996), Bigot et al. (2000) and Cunha & Gough (2000). These studies show shifts of frequencies of the order of several μHz for fields of about 1 kG. There is also a significant damping of the oscillations by dissipation of Alfvénic waves. We will ignore here this effect. In roAp stars the axis of symmetry of the magnetic field generally differs from the axis of rotation. Therefore, their combined effects on acoustic modes lead to a coupling of spherical harmonics, see Fig. 2 represented for dipole modes. In the context of roAp stars, only the coupling in the azimuthal order m matters. We may then write the general displacement

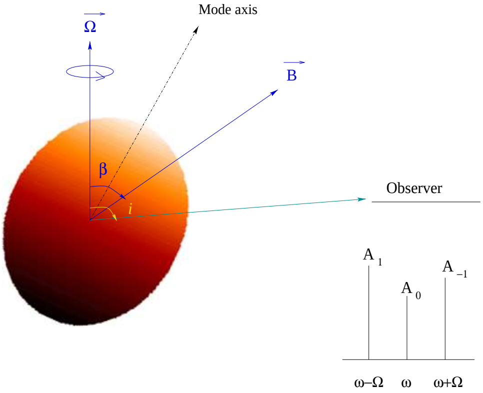

Figure 2: Representation of the model of the oblique pulsator in the special case of a dipole mode. This axis of symmetry of this mode generally differs from both rotation and magnetic axes. Then the inertial observer sees a variation of the aspect of this mode as the star rotates. This leads to the presence of a triplet in the spectrum.

vector as a linear combination of the $(2\ell + 1)$ unperturbed eigenvectors

$$\vec{\xi} = \sum_{m=-\ell}^{\ell} \alpha_m \vec{\xi}_m, \tag{1}$$

with α_m coefficients to be determined. This degenerate perturbation formalism was first applied by Dziembowski & Goode (1985) in this context of roAp stars. It can be shown then that the equation of oscillation leads to the following eigenvalue problem

$$\sum_{m=-\ell}^{\ell} \alpha_m \left\{ O_{jm} - \omega^2 \delta_{jm} \right\} = 0 \qquad j = -\ell, ..., \ell, \tag{2}$$

where O_{jm} is the projection of the sum of the rotational, Lorentz and the usual adiabatic operators on unperturbed eigenvectors. The system (2) has $(2\ell + 1)$ eigenvalues ω and $(2\ell + 1)$ eigenvectors $\{\alpha_m\}$ which are orthogonal. For the rotational operator we take into account both Coriolis and centrifugal forces. The latter is the dominant effect of the rotational shift of frequency and is typically two orders of magnitude higher than the Coriolis force. This is mainly due to the presence of large radial orders for which the modes are more sensitive to the centrifugal force. However, the effects of the Coriolis force are essential to keep an asymmetry in the problem and cannot be neglected. This asymmetry leads to unequal coefficients for the coupling, i.e. $|\alpha_m| \neq |\alpha_{-m}|$, see Bigot & Dziembowski (2002) for more details.

Once the solutions of equation (2) are found, one has to express them in the reference frame of the observer in order to compare with observations. This reference frame is defined with the polar axis along the line-of-sight. It is well known (e.g. Kurtz 1982) that the fluctuations of luminosity of *each eigenmode* expressed in the observer's system writes as the multiplet

$$\frac{\delta L}{L} \propto \sum_{m=-\ell}^{\ell} A_\ell^m \cos(\omega - m\Omega)t, \tag{3}$$

with consecutive peaks separated exactly by the rotation rate Ω. The amplitudes of the multiplet are given by

$$A_\ell^m = d_{m0}^{(\ell)}(i) \sum_{j=-\ell}^{\ell} \alpha_m d_{m0}^{(\ell)}(\beta), \tag{4}$$

where $d_{jm}^{(\ell)}$ are expressed in term of the Jacobi polynomials (e.g. Edmonds 1960), and i is the angle between the line of sight and the axis of rotation. It can be shown that the inequality of side peaks $A_m \neq A_{-m}$, often observed in roAp stars, is only due to the asymmetry introduced by the Coriolis force. The Lorentz and the centrifugal forces have a mirror symmetry that cannot lead to this inequality.

The case of dipole modes

The case of dipole modes ($\ell = 1$) is of special importance to interpret pulsations in roAp stars, since these modes are the most observed ones. In that case, recently Bigot & Dziembowski (2002) have shown that the effects of rotation, mainly due to centrifugal force, are sufficient to tilt the axis of symmetry of this mode from the magnetic axis. The geometrical picture of the dipole mode is that during the pulsation cycle its axis of symmetry moves in a plane inclined from both the rotation and magnetic axes. In general, the maximum of the displacement vector describes an ellipse in that plane. In Fig. (3) we represent the fundamental parameters of the dipole mode, say the angle δ between the normal of the mode plane and the rotation axis, the ellipticity ψ defined as the arctan of the ratio between the major and semi axes of the ellipse and the dimensionless frequency of the mode $\sigma = (\omega - \omega_1^{mag})/D\Omega^2 + 1/3$, where $D\Omega^2$ is the shift due to centrifugal force and ω_1^{mag} is the magnetic shift without rotation for $m = 1$. These parameters are plotted as functions of the obliquity angle β and for different values of the quantity $\mu = (\omega_0^{mag} - \omega_1^{mag})/D\Omega^2$, which measures the strength of the magnetic field; $|\mu|$ increases with B. We show clearly on this figure that the dipole modes are very dependent on the

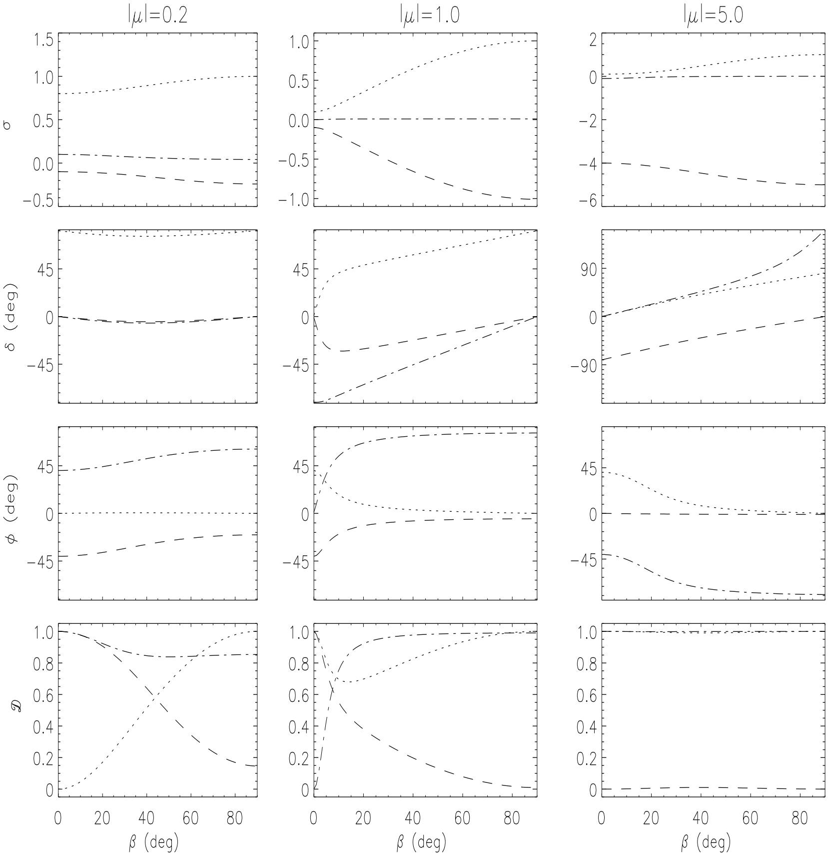

Figure 3: The fundamental parameters of the dipole modes σ, δ and ψ as function of the obliquity angle β and for different values of μ (see text). The three types of lines correspond to the three solutions of the system (2). The magnetic effects dominate over the rotational effects on the mode if $|\mu| > 1$. The last quantity $\mathcal{D}$ measures the alignment of the mode axis with the magnetic axis: $\mathcal{D} = 0$ means alignment and $\mathcal{D} = 1$ means orthogonality with the magnetic axis. From Bigot & Dziembowski (2002).

value of β and on the magnetic strength (through μ). We see that in general there is no preference for alignment of the dipole axis with the magnetic axis. The reason is that in roAp stars the centrifugal effects are in general comparable to the magnetic effects of the m components of the mode, and therefore are sufficient to affect the inclination of the mode.

Amplitudes of the side lobes ($\ell = 1$)

For the moment, no rotational side lobes have been detected in 10 Aql. This might be due to the probable small rotational frequency $\Omega/2\pi$. From $v \sin i <$ 5 km s^{-1} (Hoffleit 1982), $R = 2.42\,\mathrm{R}_{\odot}$, and an arbitrary assumption $i = 70\,\mathrm{deg}$ we get $\Omega/2\pi = 0.5$ μHz, which is very small. That is probably the reason why we have not yet detected the rotational multiplets in 10 Aql.

We hope that with the improved accuracy of COROT, we will resolve the rotational side lobes of the modes and get important constraints on this star. With this idea, we now illustrate the effects of the magnetic field on the amplitudes of the dipole modes. We plot in Fig. (4) the amplitudes of the triplet as functions of the parameter μ. The magnetic effects are larger than the rotational effects on the mode, when $|\mu| \gg 1$. We also consider two different values of β, the angle between the axes of the magnetic field and rotation. Fig. (4) shows that the magnetic field has a strong influence on the amplitudes of the triplet. For 10 Aql, we are certainly in the regime $|\mu| > 1$. There is also an important dependence on β. Therefore, we see that a comparison between the observed values of the triplet and these calculations can lead to an estimate of B and β for this star.

Analysis of the frequencies in 10 Aql

The roAp stars are excellent candidates for asteroseismology. From their pulsations we can potentially estimate their radii, luminosities, mean densities, ages, magnetic fields, rotation rates, inclinations i and β. These variable stars can then be used as tests for stellar structure models and for dynamo theories.

One of the most important criteria to select a target for an asteroseismic space mission is the number of modes that we can expect for this star. The short periods of oscillations in roAp stars allow us to use the formalism of the asymptotic theory for p-modes (e.g. Tassoul 1980) to interpret their spectra. The non-magnetic and non-rotational frequencies are then given by

$$\nu = \Delta_0 \left(n + \frac{\ell}{2} + \epsilon \right), \tag{5}$$

with ϵ a small constant depending on the stellar structure. The fundamental spacing Δ_0 between two consecutive radial orders n and $n+1$ is defined by

$$\Delta_0 = \left\{ 2 \int_0^R \frac{dr}{c_S} \right\}^{-1} \sim < \rho > \sim M^{1/2} R^{-3/2}, \tag{6}$$

with c_S the sound speed. This quantity has been calculated for several stellar models by Saio & Shibahashi (1985). They found that these values are between

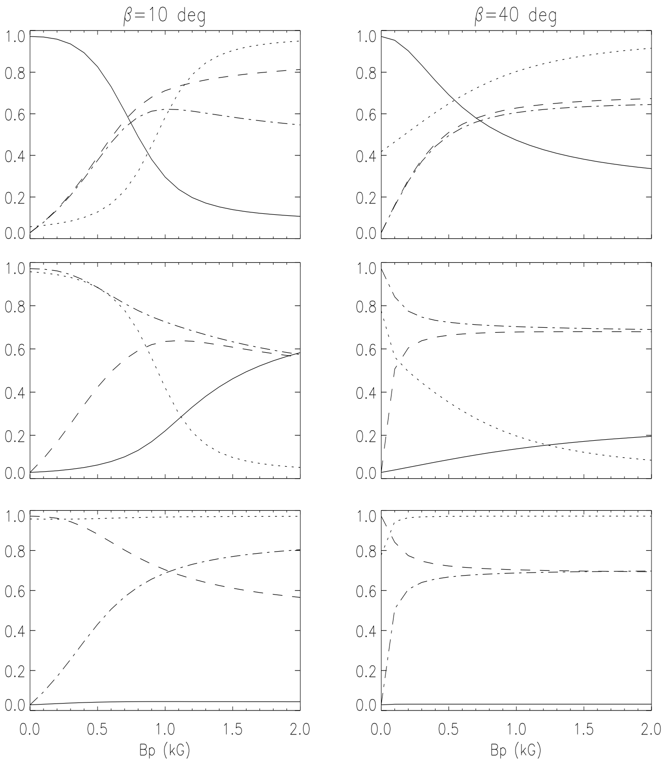

Figure 4: Amplitudes of the triplet (A_0, A_1, A_{-1}) normalized to the unity as function of the magnetic field and for two different values of $\beta = 10\,\mathrm{deg}$ (left) and $40\,\mathrm{deg}$ (right). The meaning of lines is A_0 (full line) , A_1 (dashed), A_{-1} (dot-dashed) and $\mathcal{D}$ (dotted).

20 and 100 μHz. From its value we can get an estimate on the mean density of the star, which is then a constraint on the stellar model. About half of the roAp stars are multiperiodic. One of them is in the field of COROT in the northern hemisphere. This star is 10 Aql (HD 176232, HR 7167). It is a F0 SrEu star whose recent spectroscopic investigation is available in Ryabchikova et al. (2000). The variability of this star has been discovered by Heller & Kramer (1990) who showed three distinct eigenmodes whose frequencies are $\nu_1 = 1435.99$, $\nu_2 = 1385.37$ and $\nu_3 = 1239.26$ μHz. Their amplitudes are less than 0.5 mmag (Johnson B filter). These amplitudes are much larger than the solar amplitudes but they are quite small for roAp stars which have generally $\Delta B > 1$ mmag. These three modes are very close to the noise detection ~ 0.2

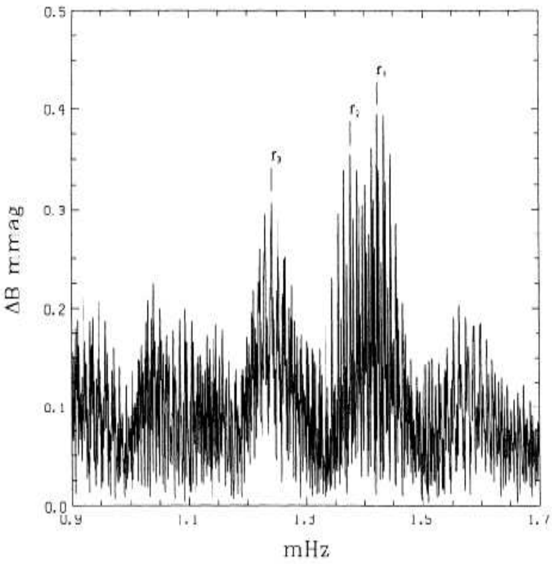

Figure 5: The three detected frequencies in 10 Aql, $\nu_1 = 1435.9$, $\nu_2 = 1385.4$ and $\nu_3 = 1239.2$ μHz. Note also the low amplitudes ($\Delta B <$ 0.5 mmag) of the eigenmodes. From Heller & Kramer (1990).

mmag. The main source of this noise is the scintillation of the sky. Therefore it is a great advantage to observe these stars from space. There are others roAp stars which show small amplitudes like HR 1217 (Kurtz et al. 1989) or γ Equ (Martinez et al. 1996), and in these cases they exhibit more than one mode. In turn, the roAp stars which show large amplitudes, like HR 3831 (Kurtz et al. 1997) or α Cir (Kurtz et al. 1994) have only one single mode. Therefore since 10 Aql has similar amplitudes to HR 1217 and γ Equ we expect that there are many modes hidden in the noise of detection. The satellite COROT will considerably decrease this noise and will be able then to discover a large number of eigenmodes.

The geometrical nature of the modes already detected in 10 Aql is not yet clearly established. In most roAp stars (e.g. Kurtz 1990, 1998) the modes responsible of the oscillations are dipole ($\ell = 1$) modes. We can expect the same nature of pulsation in 10 Aql.

In order to interpret oscillations and to prepare the space mission, we have to choose a stellar evolutionary model for this star. The metallicity Z is certainly one of the most undetermined parameters regarding the extreme chemical complexity of the outer layers. There is no reason to choose solar metallicity for an Ap star, since the Sun is known to be metal deficient compared with its neighborhood. Therefore, following Saio & Shibahashi (1985), we consider $Z = 0.03$. The effective temperature and luminosity are given by Matthews et al. (1999). The latter is obtained from Hipparcos measurements. They are: $T_{eff} = 8000 \pm 100$ K and $L = 21.4 \pm 0.6$ $\mathrm{L}_{\odot}$. The model is also constrained by the large frequency separation observed in 10 Aql, i.e. $\Delta_{12} = \nu_1 - \nu_2 = 50.6$ μHz. The overshooting is supposed to be $0.2H_p$, with H_p the pressure scale height. The stellar model is calculated with the CESAM evolutionary code developed at the Observatoire de la Côte d'Azur (Morel 1997). The model which reproduces well all these constraints is: $M = 2.11\,\mathrm{M}_{\odot}$, $R = 2.42\,\mathrm{R}_{\odot}$, $X = 0.70$, $Z = 0.03$ and a central fraction of hydrogen $X_c = 0.4$. We found a spacing of $\Delta_0 = 50.15$ μHz and a cut-off frequency equal to 1510 μHz (see Audard et al. 1998 for a discussion of the limit of frequencies for trapped acoustic modes in roAp stars). These results that we obtain are comparable with the observations of Heller & Kramer (1990). We note that the largest observed frequency is close to the cut-off frequency. In Figs (6), (7) and (8) we represent the three frequencies which are closest to the observed ones, assuming that they correspond to a same degree $\ell = 1$. They have respectively the radial orders $n = 24$, 27, and 28. We note that the calculated non magnetic frequencies (full lines) differ from the observed ones (dot-dashed lines) by several μHz, up to about 8 μHz. However, it is now well known (Dziembowski & Goode 1996, Bigot et al. 2000, Cunha & Gough 2000) that the magnetic field is responsible for an important shift of frequency in roAp stars. It also breaks the degeneracy of frequencies which depend on $|m|$. In Fig. (6), (7) and (8) we place the frequencies corresponding to the radial orders $n = 24, 27$ and 28 affected by two different values of the magnetic field $B = 0.5$ and 0.8 kG. The best value of B that reproduces the data is 0.8 kG. We then get an agreement with the three observed frequencies within ~ 0.3 μHz. This value of B agrees with the estimate given in Ryabchikova et al. (2000) from spectroscopy. The frequencies ν_1 and ν_2 correspond to the modes $(n = 27, \ell = 1, m = 0)$ and $(n = 28, \ell = 1, m = 0)$ and ν_3 correspond to $(n = 24, \ell = 1, |m| = 1)$. We note that the shifts introduced by the field are quite large. This is due to the fact that these frequencies are close to the cut-off frequency.

We emphasize here that the non-obvious observed inequality $\Delta_{23}^{obs} = \nu_2^{obs} - \nu_3^{obs} \neq k\Delta_{12}^{obs} = k(\nu_1^{obs} - \nu_2^{obs})$, with k integer, is well explain by the effect of the magnetic field and the shift that it produces. The magnetic spacings that we obtain for $B = 0.8$ kG are $\Delta_{12}^{mag} = \nu_1^{mag} - \nu_2^{mag} = 50.4$ μHz and $\Delta_{23}^{mag} = \nu_2^{mag} - \nu_3^{mag} = 146.8$ μHz which are close to the values observed by Heller & Kramer (1990).

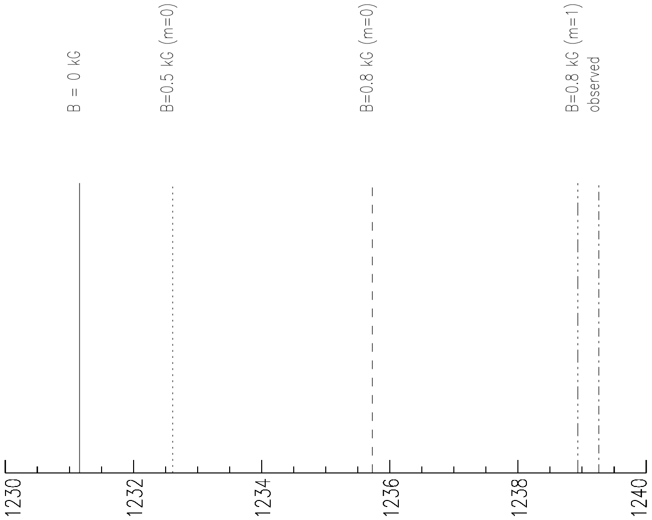

Figure 6: Positions of the frequency ν_3 without a magnetic field (full line) and for $B = 0.5$ kG with $m = 0$ (dotted line) and for $B = 0.8$ kG with $m = 0$ (dashed line) and $|m| = 1$ (dot(×3)dashed line). The observed value is plotted with a dot-dashed line.

Conclusion

The roAp star 10 Aql is a very interesting target for the asteroseismic space mission COROT. The observations from the ground already lead to three eigenmodes with large radial orders. We have shown that the positions and amplitudes of the eigenmodes in the spectrum of oscillations are strongly influenced by the magnetic field, which by our estimation is close to 0.8 kG. The lack of accurate measurements leads to an absence of rotational sidelobes. The interest in COROT is to improve the resolution of observations, to resolve the multiplets and to discover a large number of modes hidden in the noise. As we have shown, the amplitudes will lead to a determination of the magnetic field

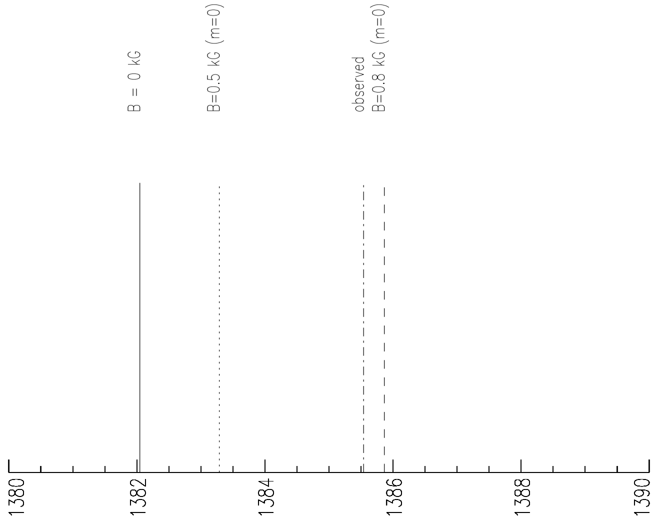

Figure 7: Same as Fig. (6) for the frequency ν_2.

and the obliquity angle between the rotation and magnetic axes, which then would be a constraint for dynamo theories for Ap stars.

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References

Adelman, S. J. 1973, ApJ 183, 95
Audard N., Kupka F., Morel P., Provost J., Weiss W. W., 1998, A&A 335, 954
Babcock, H. W. 1947, ApJ 105, 105
Babcock, H. W. 1949, *Obs* 69, 191
Baglin, A., Foing, B. H. 1999, AdSpR 24, 145
Bagnulo, S., Landolfi, M., Landi Degl'Innocenti, M. 1999, A&A 343, 865

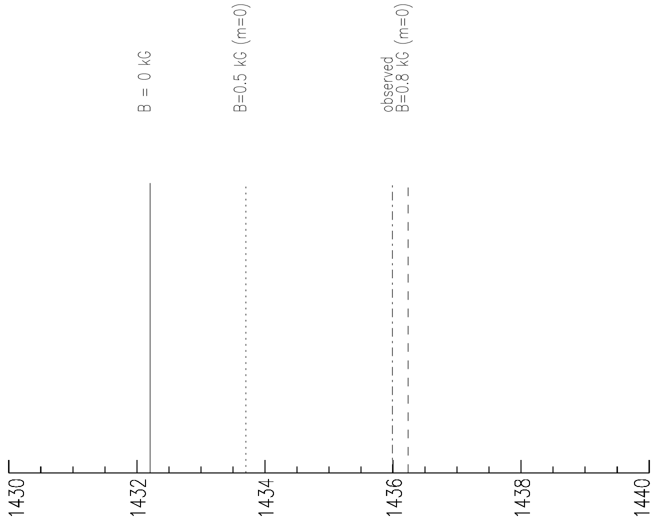

Figure 8: Same as Fig. (6) for the frequency ν_1.

Balmforth, N. J., Cunha, M. S., Dolez, N., Gough, D. O., Vauclair, S. 2001, MNRAS 323, 362

Bigot, L., Provost, J., Berthomieu, G., Dziembowski, W. A., Goode, P. R. 1999, RoAJS 9, 129

Bigot, L., Provost, J., Berthomieu, G., Dziembowski, W. A., Goode, P. R. 2000, A&A 356, 218

Bigot, L., Dziembowski, W. A. 2002, A&A, *accepted*

Christensen-Dalsgaard, J., Dziembowski, W. A. 2000, in *Variable stars as essential astrophysical tools*, ed. Cafer Ibanoglu, Kluwer Academic Publishers, Dordrecht, Boston, NATO science series. Series C, Mathematical and physical sciences; vol. 544, p. 1

Cunha, M. S., Gough, D. 2000, MNRAS 319, 1020

Dziembowski, W. A., Goode, P. R. 1985, ApJ 296, L27

Dziembowski, W. A., Goode, P. R. 1996, ApJ 458, 338

Edmonds, A. R. 1960, *Angular Momentum in Quantum Mechanics*, second edition, Princeton Univ. Press

Heller, C. H., Kramer, K. S. 1990, MNRAS 246, 699

Hoffleit, D., 1982, *Bright Star Catalogue*, 4th edn, Yale University Observatory

Hubrig, S., North, P., Mathys, G. 2000a, ApJ 539, 352

Hubrig, S., Kharchenko, N., Mathys, G., North, P. 2000b, A&A 355, 1031

Kurtz, D. W. 1982, MNRAS 200, 807

Kurtz, D. W., Shibahashi, H. 1986, MNRAS 223, 557

Kurtz, D. W., Marang, F. 1988, MNRAS 231, 565

Kurtz, D. W., Matthews, J. M., Martinez, P., Seeman, J., Cropper, M., Clemens, J. C., Kreidl, T. J., Sterken, C., Schneider, H., Weiss, W. W., Kawaler, S. D., Kepler, S. O. 1989, MNRAS 240, 881

Kurtz, D. W. 1990, ARA&A 28, 607

Kurtz, D. W., van Wyk, F., Marang, F. 1990, MNRAS 243, 289

Kurtz, D. W., Sullivan, D. J., Martinez, P., Tripe, P. 1994, MNRAS 270, 674

Kurtz, D. W., van Wyk, F., Roberts, G., Marang, F., Handler, G., Medupe, R. 1997, MNRAS 287, 69

Kurtz, D. W., Marang, F., van Wyk, F., Roberts, G. 1996, MNRAS 280, 1

Kurtz, D. W. 2000, in in *Variable stars as essential astrophysical tools*, ed. Cafer Ibanoglu, Kluwer Academic Publishers, Dordrecht, Boston, NATO science series. Series C, Mathematical and physical sciences, vol. 544, p.313

Landolfi, M., Bagnulo, S., Landi degl'Innocenti, M. 1998, A&A 338, 111

Landstreet, J. D. 1980, AJ 85, 611

Landstreet, J. D. 1992, A&ARv 4, 35

Landstreet, J. D., Mathys, G. 2000, A&A 359, 213

Martinez, P., Weiss, W. W., Nelson, M. J., Kreidl, T. J., Roberts, G. R., Mkrtichian, D. E., Dorokhov, N. I., Dorokhova, T. N., Birch, P. V., MNRAS 282, 243

Martinez, P., Kurtz, D. W., Ashoka, B. N., Chaubey, U. S. Girish, V., Gupta, S. K., Joshi, S., Kasturirangan, K., Sagar, R., Seetha, S. 2001, A&A 371, 1048

Mathys, G. 1989, *The Observation of Magnetic Fields in Nondegenerate stars*, *Fundamentals of Cosmic Physics* (Gordon and Breach Science Publishers, Inc.), vol. 13, 143

Mathys, G., Hubrig, S. 1997, A&AS 124, 475

Matthews, J. M. 1991, PASP 103, 5

Matthews, J. M., Kurtz, D. W., Martinez, P. 1999, ApJ 511, 422

Michaud, G. 1970, ApJ 160, 641

Morel, P. 1997, A&AS 124, 597

Morgan, W. W. 1933, ApJ 77, 330

Piskunov, N. E., Rice, J. B. 1993, PASP 105, 1415

Preston, G. W. 1974, ARA&A 12, 257

Ryabchikova, T. A., Savanov, I. S., Hatzes, A. P., Weiss, W. W., Handler, G. 2000, A&A 357, 981

Stibbs, D. W. N. 1950, MNRAS 110, 395

Tassoul, M. 1980, ApJS 43, 469

Unno W., Osaki Y., Ando H. & Shibahashi H. 1989 *Non-radial oscillations of stars*, second edition University of Tokyo Press

Weiss, W. W. 1986, *Upper Main Sequence star with Anomalous Abundances*, Ed C. R. Cowley, M. M. Dworetsky et C. Mégessier, IAU coll. 90, D. Reidel Publ. Co., Dordrecht, Holland, p. 219