# ADDITIONAL SCIENCE POTENTIAL FOR COROT

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## Abstract

Space experiments which are aiming towards asteroseismology and the detection of exoplanets, like COROT or MOST, EDDINGTON and KEPLER, are designed to deliver high precision photometric data. Obviously, the they can be used also for other purposes than the primary science goals and in addition many other targets can or will be automatically observed simultaneously with the primary targets. As a consequence, fascinating possibilities for additional (parallel, secondary) science projects emerge. For COROT a dedicated working group was thus established with the goal to contribute any useful information which may optimize the scientific output of the mission.

Key words: COROT – Stars: variable, pulsating – Asteroseismology – Exoplanets

## 1. Introduction

COROT (COnvection, ROtation and planetary Transits) is based on ultra high precision, wide field, relative stellar photometry for very long continuous observing runs in the same field of view.

It has two main scientific programs working simultaneously on adjacent regions of the sky: ASTEROSEISMOLOGY & EXTRASOLAR PLANET SEARCH.

The COROT instrument is a white-light wide-field photometer with an entrance pupil of 27 cm and a set of 4 frame-transfer CCDs as detectors. Two CCDs are devoted to asteroseismology (defocussed, unfiltered light), respectively to exoplanet search (focussed, color information). COROT will be launched in mid of 2006 on a low-earth polar inertial orbit, allowing it to monitor continuously stellar fields near the pole of the orbit for about 5 months. The mission lifetime will be nominally 3 years.

## 2. The Additional Program (AP) concept

The Additional Program (AP) section of COROT will be available to the community after an Announcement of Opportunity (AO) and has the goal to maximize the scientific return of the mission. This will be achieved by using

- archival data. Successful proposals will have to address science outside the primary goals and will get access to specific archival data for proprietary use, but exclusively in the context of the science addressed in the proposal.
- short runs ($\approx$ 5 to 20 days) devoted to specific target fields.
- long runs (up to 130 days). About 100 windows of the exoplanet fields will be available for additional science.
- windows. During short runs of the core program, it will also be possible to apply for specific windows in the exoplanet fields.

Asteroseismological programs using the exoplanetary CCDs are considered to be part of the AP, as are exoplanetary programs using the seismology CCDs.

In order to prepare the AO mentioned above and to help defining the COROT science, an Additional Program Working Group (APWG) was established.

All response to the AO will be evaluated by the COROT Scientific Committee, which will be in charge for the selection, taking into account the quality of the proposed science. A successful proposer will obtain status of a Guest Investigator and will have exclusive data rights for the science described in his proposal. The COROT Scientific Committee, however, will have the rights to use the same data for any other science.

One year after the first release of data to the Co-and/or Guest-Investigators the data will be available for the public.

## 3. The additional science

In the context of the Additional Program various aspects of variability were discussed. In the following subsections we describe with some *arbitrarily chosen examples* the COROT additional science potential. For some of the presented target groups no members are yet known within the visibility region of COROT, but dedicated surveys may change this situation.

Many of the ideas outlined in the following, are elaborated in more detail by members of the COROT Additional Program Working Group in the poster section of these proceedings and the reader is encouraged to browse the table of content for authors name and/or topic. Further information can be found at

Proc. 2nd *Eddington* workshop *"Stellar Structure and Habitable Planet Finding"*, Palermo, 9–11 April 2003 (ESA SP-538, July 2003, F. Favata, S. Aigrain eds.)

http://www.astrsp-mrs.fr/projets/corot/

selecting the link "meetings" and further the contributions to the various COROT Science Weeks. All science addressed in the following will benefit from or be made possible by the high photometric quality of the data obtained during long and uninterrupted observing sequences provided by COROT.

### 3.1. Variability not caused by pulsation

#### 3.1.1. Kuiper belt objects, Exo-comets transits

The discovery of hundreds of transneptunian objects has confirmed the hypothesis of a residual protoplanetary disk beyond Neptune. The knowledge of the structure of this residual disk is a key element to reconstruct the history of the Solar System, but the large distance (up to 100 AU and even beyond) excludes the direct detection of objects smaller than some tens of kilometers. Moreover, the objects already detected show a steep size distribution with the consequence that most of the disk mass is in the small, hitherto undetectable objects.

Roques & Moncuquet (2000) demonstrated that serendipitous stellar occultations could be a powerful tool to detect these small objects orbiting beyond Neptune if they are dense enough in the sky plane. A dedicated program with COROT will allow the detection of very small objects and will constrain their size distribution.

A by-product of the exoplanet search program could be the detection of exo-comets. In the $\beta$ Pictoris system, comet-like objects falling onto the star have been detected by their signature in the stellar spectrum. Such objects could also be discovered by the comet tail transit in front of the star.

#### 3.1.2. Pre-main-sequence stars

The photometric study of T Tauri stars, a subgroup of PMS stars, provides valuable information on periodic phenomena, such as the rotational modulation due to hot/cold spots on the stellar surface, or non-periodic, like accretion events and flares. The characterisation of such photometric variabilities will help to determine the conditions which may cause pulsation in solar-type PMS stars.

#### 3.1.3. Stellar activity and flares

The activity level and the characteristic time scales of the luminosity variations of magnetic active late-type stars will be monitored by COROT better than ever before what will improve significantly our knowledge of stellar intrinsic variability on all time scales (Fig. 1). Studying the brightness variations on time scales of days to weeks will allow us to detect small solar-like spots, derive the lifetimes of surface features, hence to estimate the turbulent magnetic diffusivity in the upper layers of the convection zones

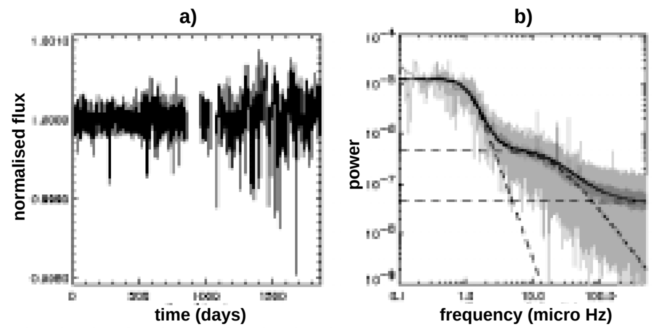


*Figure 1. a): Total solar irradiance light curve from PMO6 data, covering the period 1996-2001. b): Power spectrum of the light curve, with a multiple powerlaw fit with three components (active regions, meso-granulation and granulation) overlaid.*

(Rodonò et al. 1995, Lanza et al. 1998), and to measure rotation and stellar differential rotation. This information is fundamental to test the available hydromagnetic dynamo models.

Variability on time scales of hours to days is thought to be due to distributed networks of smaller structures, rather than a few active regions or spots. This is the range of time scales that is most critical for planetary transit detection, as it corresponds to the duration of a typical transit. The identification and characterisation of the surface structures involved is underway for the Sun using SOHO data (Fligge et al. 2000). COROT data will allow this to be done for the entire range of stars observed, yielding the relative coverage, contrast, rotation of the various types of structures. These will be included in irradiance models currently applicable to the Sun only (Unruh et al 1999, Krivova et al. 2003).

COROT data and the improved knowledge of intrinsic stellar variability we will gain from it will be used to test and refine filtering tools designed to minimise the effect of stellar activity on transit detections ahead of missions such as EDDINGTON and KEPLER (Carpano et al. 2003).

Finally, the monitoring of a few dMe flare stars in the seismology channel could help in shedding some light on the mechanisms of coronal heating by investigating the statistics of white-light stellar micro/nano-flares and related precursor phenomena and assessing the power law distribution of very low energy events.

#### 3.1.4. Stellar rotation

It is now observationally well established that stars with masses similar to or below that of the Sun initiate their lives at the main sequence as relatively fast rotators, with associated strong high-energy chromospheric and coronal emissions resulting from magnetic processes. In addition, observations suggest that young stars exhibit high rates of powerful flare events and have dense stellar winds. Then, the magnetic activity of the stars decreases with time as

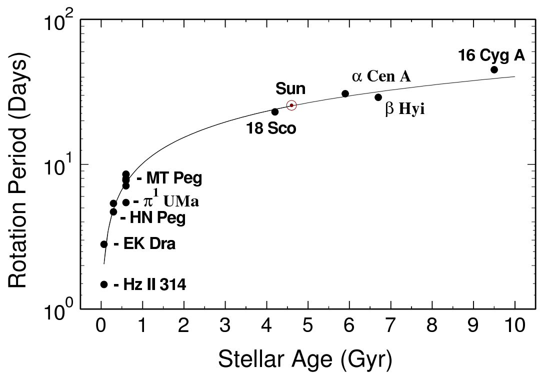


*Figure 2. Plot of the rotation period vs. stellar age for a sample of solar-type stars. The solid line corresponds to a power law fit and indicates a spindown of solar-type stars with increasing age.*

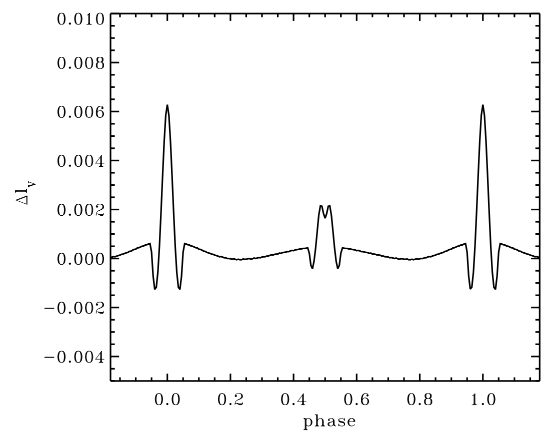


*Figure 3. The difference between two synthetic light curves (V) obtained by changing the linear limb darkening coefficient from 0.57 to 0.67. The corresponding system is a model of V805 Aql, according to Popper (1981), i.e. a detached binary with relatively short period and MS components ($P = 2^d.41$, effective temperatures $T_p = 8164\,K$, $T_s = 7178\,K$). The other parameters are: mass ratio $q = m_s/m_p = 0.81$, inclination $i = 86^\circ$, fractional radii $r_p = 0.18$, $r_s = 0.15$, and fractional luminosity $L_s/L_p = 0.362$. The synthetic light curves were computed with the 1995 version of the Wilson and Devinney code.*

they evolve across the main sequence and the rotation slows down from the loss of angular momentum via stellar winds. Besides providing important tests to stellar dynamo models, the enhanced XUV (0.1 to 100 nm) radiation and particle environments could have a major impact on the atmospheres and on the eventual development of life in possible orbiting planets around young, active stars. As an example, the results obtained from solar proxies in the narrow G0 to G5 spectral type range (Guinan & Ribas 2002) indicate that the solar XUV flux 2.5 Gyr and 3.5 Gyr ago was about 3 and 6 times higher than today, respectively, and that the high-energy flux of the zero-age main sequence Sun was stronger by up to a hundred-fold. The extension of this study to other spectral types of relevance to exoplanetary research (G-K-M stars) hinges on the establishment of calibrated rotation period-age relationships (see Fig. 2). COROT data will permit the definition of such relationships (from rotational modulation) and provide detailed information on flare statistics for an extended sample of late-type stars.

### 3.1.5. Binaries

COROT photometry has the potential of distinguishing between various models of limb darkening of detached binaries as is illustrated in Fig. 3 for synthetic light curves with different limb darkening coefficients.

### 3.1.6. Cataclysmic variables

The cataclysmic variables (CVs) are binary systems consisting of an accreting white dwarf (WD) and a late type secondary star filling its Roche lobe. The periodic light variations are related to the binary system, while non-periodic variations are due to mass accretion changes or instabilities in the accretion disc or accretion flow. Depending on the strength of the magnetic field, matter accretes onto the WD via a disk or directly channelled towards the magnetic poles. Hence CVs represent close–by test objects of accretion processes in different physical environments.

The dwarf-nova CW Mon is observable in the exoplanet field of COROT contemporaneously with the primary seismology target HD 45067. These observations would allow to precisely measure the amplitude of the orbital variability in low state and to provide a constraint on the hot spot component. Photometry in high state will give information on the evolution of an outburst (Flickering, Quasi Periodic Oscillations, Dwarf Novae Oscillations and their relation) with unprecedented details. The results will pose a unique challenge to theory of accretion processes in galactic binaries.

### 3.1.7. Outbursts in Mira variables

Short brightness outbursts have been observed on top of the periodic light change of several Mira variables (e.g. de Laverny et al. 1998). One explanation is the interaction between the stellar pulsation and hypothetical giant planets orbiting in the outskirts of a Mira atmosphere, developing an accretion disk during the stellar expansion phase. In the cycle of contraction the accretion disk rotating around the planet and the orbital motion leads to a collapse of accreted matter causing outbursts observed hitherto only at light minimum (Struck et al. 2002), probably due to the low amplitude which contrasts to the noise sufficiently only at minimum. But outbursts are expected to happen also at other phases of their light curve, depending on the different orbits of large planets. COROT

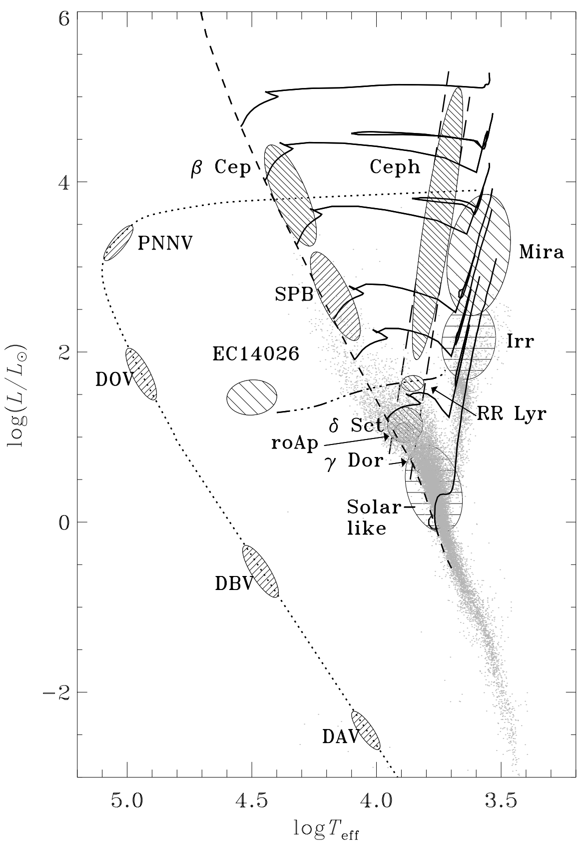


*Figure 4. Prominent groups of variable stars in the HR-diagram, based on Hipparcos data. The EC14026 group is now better known as sdB stars (see Sect. 3.2.13).*

observations have the potential to follow such periodic phenomena continuously in the exofield for a sufficiently large sample of Miras over full light cycles.

### 3.1.8. QSOs

Our knowledge of photometric variations of QSOs over short time scales (i.e. less than a day) is not only hampered by a lack of data but also by the fact that high frequency variations have so small amplitudes that they are often lost in the observational noise. COROT observations in the exoplanet search fields ought to provide time series of several well sampled ($\Delta t \approx 15\,min$, S/N $\simeq 40-100$) QSO photometric lightcurves which will lead to the identification of special or fundamental time scales for QSO variability or at least a measure of the variability power at short periods. This pseudo-imaging has the potential to provide information on the QSO inner core structure on scales (typically, less than one light day) much smaller than those currently accessible with modern VLBI techniques (typically, of the order of several tens of parsec). Information on time evolution and stability of the accretion disk should also become accessible. It would be ideal to observe an X-ray/radio loud quasar simultaneously with COROT, XMM and a ground-based radio telescope.

## 3.2. Variability caused by pulsation

One of the crucial by-products of the COROT exoplanet searches will be the discovery of new periodically variable stars, starting from an unbiased sample. The most interesting of these new variables will then be used to perform asteroseismology. Figure 4 illustrates nicely the existence of pulsating variables nearly everywhere in the HR-diagram. The observation strategy adopted by the planet hunters is ideally suited for asteroseismology of many classes of pulsators, i.e. the variables with periods longer than an hour such as $\beta$ Cep, $\delta$ Scuti, slowly pulsating B and $\gamma$ Dor stars. Besides EDDINGTON and KEPLER, COROT is a very suitable mission to study the gravity modes in the latter two groups of stars, as they have beat periods of several months and some even of years. Asteroseismology of gravity-mode oscillators is therefore a unique by-product of the search for exoplanets (Aerts 2001).

### 3.2.1. Pre-main-sequence stars

PMS stars with masses $\geq 1.5\,M_\odot$, called Herbig Ae/Be stars, cross the instability region during their evolution to the main sequence. Although the crossing times are very short (e.g. only 80 000 years for a $4\,M_\odot$ star), several Herbig Ae/Be stars are located in the classical instability strip. PMS stars differ from MS stars of same mass and temperature mostly in their inner structure, whereas their envelopes are quite similar to those of their more evolved counterparts, the classical $\delta$ Scuti stars (Marconi & Palla, 1998).

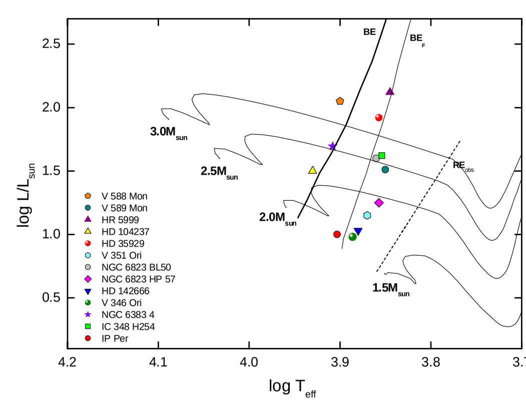


*Figure 5. HR diagram including the 13 known PMS pulsators and the PMS evolutionary tracks for 1.5, 2.0, 2.5 and 3.0 $M_\odot$ (D'Antona & Mazzitelli, 1994)*

Recent investigations (Montalban et al. 2003) indicate a strong dependence of the PMS evolutionary tracks on the treatment of convection. In addition to the known $\kappa$ driven pulsation, solar type oscillation could be also excited due to the presence of a strong convective envelope in low mass PMS. From the seismological analysis of these oscillations, one can constrain stellar evolutionary models for those stars, in a similar manner as is presently done for PMS stars with $\delta$ Scuti type pulsation (Pinheiro et al. 2003, and references therein).

#### 3.2.2. Central stars of planetary systems

Central stars of planetary systems are claimed to be overabundant in metals (e.g. Santos et al. 2001) with presently two explanations. First, the protostellar gas is metal-rich and so is the star. The high density of heavy elements, compared to stars without planets, increase the probability of planetisimal formation, and thus of planet formation. The second explanation assumes that the system is formed from gas with solar metallicity, but planets accrete onto the stars, enhancing thus the metallicity of the latter.

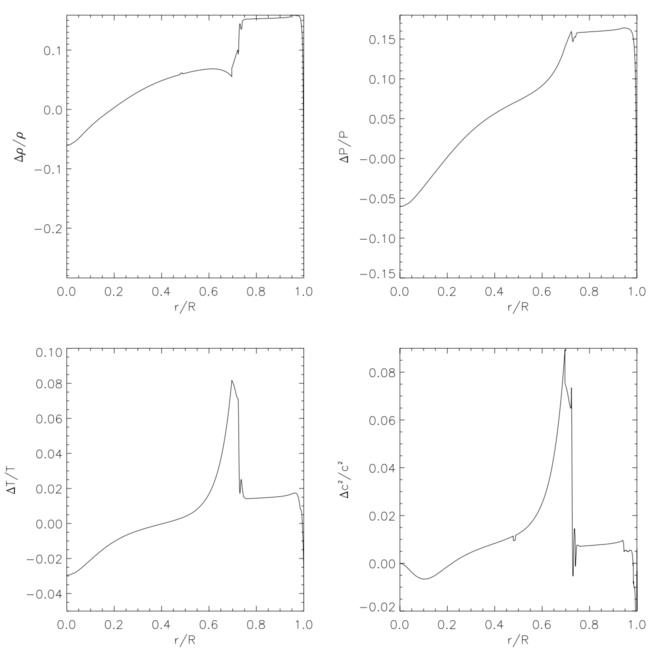


*Figure 6. Relative density, pressure, temperature and square sound speed differences for two 1.1* $M_\odot$ *stellar models. One is homogeneous with an initial* $\left[\frac{Fe}{H}\right] = 0.18$, *the other has an initial* $\left[\frac{Fe}{H}\right] = 0.00$ *and an accreted mass of* $0.5 M_{Jup}$ *of solar like material assuming microscopic diffusion. The* $\Delta$*'s are defined in analogy to, e.g.,* $\Delta T$ *which is for* $\frac{T_{(accr+diff)} - T_{hom}}{T_{hom}}$.

These two scenarios can be tested by comparing oscillation frequencies of stellar models with the same external parameters but with different histories: with and without accretion and/or diffusion. Preliminary investigations indicate an internal structure of a homogeneous supermetallic star which is different to that of stars experiencing accretion of planets, but with an initial solar like metallicity. For example, the differences of the squared sound speed for both stars can be as high as 6.5 % (Fig. 6). The first results concerning the diagnostic potential of oscillation frequencies in these stars are encouraging.

#### 3.2.3. Eclipsing binaries

Various types of pulsating stars are known to be components of eclipsing binaries e.g. $\beta$ Cep, RR Lyr or Cepheids (Szatmary K., 1990). Other very interesting objects are detached or semi-detached systems, like AI Her, MM Cas, AB and RZ Cas, and more (Lampens & Boffin 2000, Mkrtichian et al. 2002). The virtue of such binaries is the possibility to determine precisely their mass, radius and effective temperature and the potential of mode identification during the primary eclipse, using the transiting companion as a spatial filter (see Fig. 7). Furthermore, a precise estimate for the accretion rate and mass transfer could be obtained.

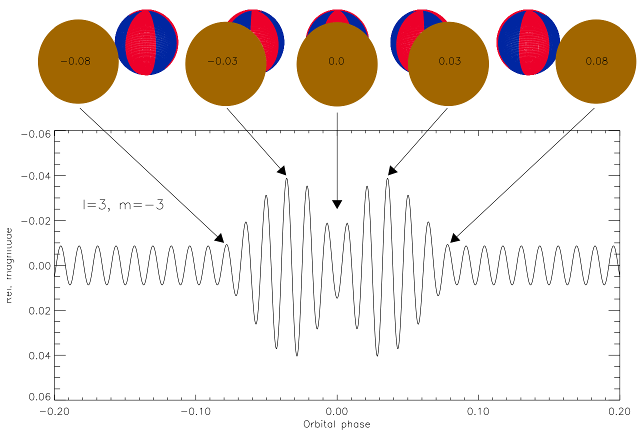


*Figure 7. Pulsation amplitude modulation during primary eclipse*

#### 3.2.4. $\beta$ Cepheids

The opacity-driven main sequence pulsators for which asteroseismology has very recently implied considerable progress in understanding of stellar structure are the $\beta$ Cephei stars (Aerts et al. 2003). These objects can be used to tackle many open problems in astrophysics, such as angular momentum transport, convective core overshooting and even the chemical evolution of galaxies. Due to the sparse eigenmode spectra of $\beta$ Cephei stars it is important to detect as many pulsational signals in their light curves as possible, a task for which COROT is perfectly suited.

### 3.2.5. Be–stars

Be stars are main-sequence or slightly evolved, usually rapidly rotating stars, surrounded by an equatorially concentrated envelope (disk) fed by discrete mass-loss events caused by yet unkown mechanisms. In the H-R diagram, early Be stars are located at the lower border of the instability domain of the $\beta$ Cephei stars, while mid and late Be stars are mixed with SPB stars. Short periods have been commonly detected in light curves and spectral line profile variations are generally attributed to nonradial pulsation. A combination of high rotation and beating of pulsation modes having closely spaced frequencies are considered as a possible explanation for discontinuous mass loss events; stellar activity of magnetic origin could be also involved. COROT will offer the opportunity to detect new pulsation periods, especially beating periods, and to better understand how the disk is beeing generated.

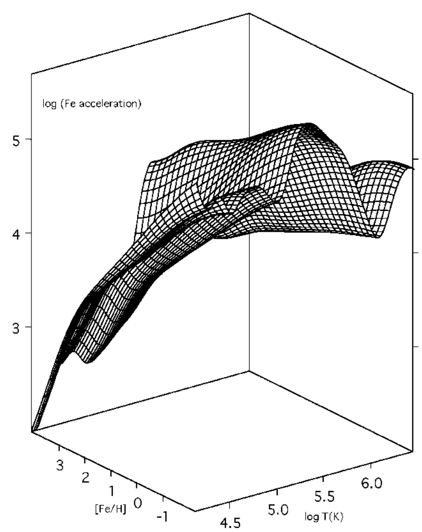


*Figure 8. Radiation accelleration and gravitational settling results in stratification of elements (iron, in the given case, from Alecian & LeBlanc 2000)*

### 3.2.6. Cepheids

Strange pulsation modes were predicted for Cepheids and other supergiant stars near the instability strip (Buchler et al. 2001). The modes are high order radial overtones and have a very small amplitude. They could appear in different ways: a) as single mode pulsations with periods typically 1/4 to 1/5 that of the fundamental mode (this would occur outside the instability strip, on both sides); b) as double mode pulsations with incommensurate frequencies (most likely near the edges of the instability strip); c) as phase locked pulsation similar to that of bump cepheids (with resonance 4:1 or 5:1). The detection of this type of pulsation would be very important because it would add very strong additional constraints on the Cepheid modeling. These modes have not yet been detected, since the ground based observations are probably affected by spurious variations related to the instrumentation and observing conditions. COROT will be able to detect also very small variations due to, e.g., possible nonradial modes, which have been probably detected in first overtone mode Cepheids from line profile variations (Kovtyukh et al. 2003). Several known Cepheids and yellow supergiant stars fall in the sky areas of interest for COROT.

### 3.2.7. HgMn stars

HgMn stars are known to be not variable, at least at the current level of detection. However, according to recent calculations, pulsation could exist in these stars due to iron accumulation in the outer envelope (Fig. 8) where this element is the main contributor to the Rosseland opacity. HgMn stars are among the best laboratories to study diffusion processes and COROT offers an exceptional opportunity to check some of the theoretical models concerning particle transport in stars.

### 3.2.8. High–Amplitude $\delta$ Scuti stars

In the $\delta$ Scuti domain, there is a rough subdivision between radial, mostly monoperiodic high–amplitude objects (HADS) and mostly nonradial, multiperiodic low-amplitude objects. However, Walraven et al. (1992) found the

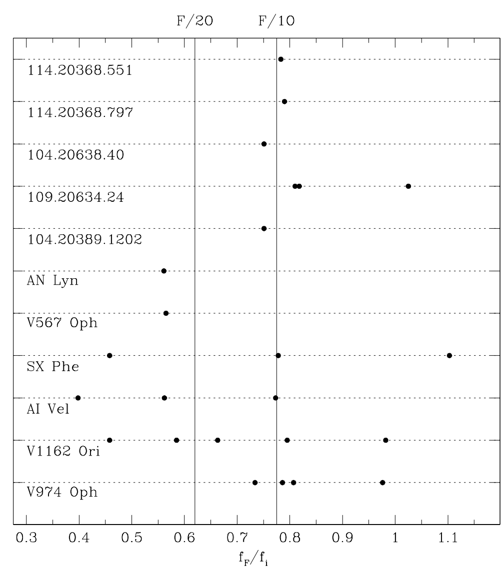


*Figure 9. Observed (filled dots) frequency ratios among HADS stars. Numbers indicate stars in the MACHO catalogue. Vertical lines indicate the theoretical ratio between fundamental (F) and overtone (1O, first; 2O, second) radial modes.*

HADS star AI Vel to be multiperiodic (fundamental and first three radial overtones) and they also suspect a nonradial mode. Later, Garrido & Rodríguez (1996) analyzed some time–series of HADS stars and detected indications for other radial and nonradial modes in SX Phe and DY Peg. Arentoft et al. (2001) found evidence for amplitude variation and nonradial modes for V1162 Ori. Therefore, the phenomenology of HADS stars becomes similar to low–amplitude $\delta$ Scuti stars. The case of V974 Oph (Poretti 2003) corroborates this trend, as this star shows a dominant mode with a very large amplitude and a number of nonradial modes.

HADS provide an immediate identification of the high–amplitude modes with the radial ones, providing thus the density of the star as an important physical parameter. As shown in Fig. 9, the frequency ratios among HADS stars have different values (suggesting a nonradial nature) and are quite different from the canonical F/O1=0.77 and F/O2=0.62 values for radial modes. The results obtained by large–scale projects (see Poretti 2001) demonstrate that HADS variables are commonly found and hence are promising targets for the additional program using the Exoplanet CCDs of COROT.

### 3.2.9. $\lambda$ Bootis stars

In general, chemical peculiarity inhibits $\delta$ Scuti type pulsation but for the group of $\lambda$ Bootis stars it is just the opposite. That small group comprises late B- to early F-type, Population I stars which are metal weak (particularly the iron group elements), but with the clear exception of C, N, O and S (Paunzen et al. 2003). Only a maximum of about 2% of all objects in the relevant spectral domain are believed to be $\lambda$ Bootis type stars. This is a small fraction, but with thousands of stars observed by COROT and up to 100 000 and more stars by EDDINGTON and KEPLER, we can expect a substantial improvement of the statistics for $\lambda$ Bootis stars.

Diffusion in interaction with accretion probably is the main source of the $\lambda$ Bootis phenomenon (e.g. Kamp & Paunzen 2002). Turcotte et al. (2000) found little direct pulsational excitation from Fe-peak elements (see Sec. 3.2.7), but effects due to settling of helium along with the enhancement of hydrogen are important. Paunzen et al. (2002) analyzed the pulsational characteristics of the group of $\lambda$ Bootis stars (Fig. 10) and found that a) at least 70% of all $\lambda$ Bootis types stars inside the classical instability strip pulsate; b) only a maximum of two stars may pulsate in the fundamental mode but there is a high percentage with $Q < 0.020$ d (high overtone modes); and c) the instability strip of the $\lambda$ Bootis stars at the ZAMS is 25 mmag more blue in $(b-y)_0$ than that of the $\delta$ Scuti stars.

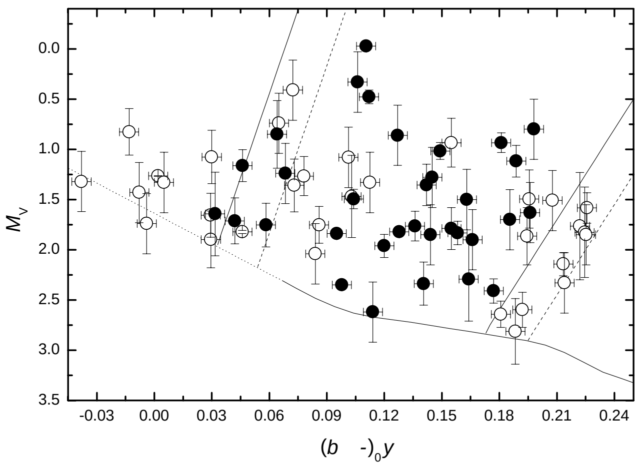


*Figure 10. $M_V$ versus $(b-y)_0$ diagram for the non-variable (open circles) and pulsating (filled circles) $\lambda$ Bootis stars from Paunzen et al. (2002). The borders of the classical instability strip (dotted lines) are taken from Breger (1995). The observed borders for the $\lambda$ Bootis stars are indicated as filled lines.*

### 3.2.10. Rapidly oscillating Ap stars

Rapidly oscillating Ap (roAp) stars are chemically peculiar hydrogen core burning stars of about two solar masses with a global magnetic field and which pulsate with few minutes up to about 25 minutes in radial and nonradial p–modes. roAp stars have contributed much to the advances of asteroseismology and have been subject of many international conferences during the last 15 years. A fascinating aspect of roAp star asteroseismology is the potential to derive information on the global stellar magnetic field geometry what was shown, e.g., for 10 Aql (Bigot & Weiss, 2000), a roAp COROT target candidate.

About 3% of A0 to A5–type stars are chemically peculiar, and even less of the cooler A–type stars (Vogt et al. 1998). Within this group of cool CP2 stars (in the more precise terminology of Preston, 1974), the fraction of roAp stars is high. Hence, we estimate that about 1% of the cool A to early F – type stars may be rapidly oscillating, which opens another rich source for asteroseimology in the COROT exoplanetary field. Unfortunately, due to the short pulsation period which is comparable to the standard integration time for windows in the exofield, candidate roAp stars have to be identified in advance and selected for one of the few tens windows in the exofield which allow for a 32 sec integration time.

### 3.2.11. Am – stars

Some Am stars have been observed to oscillate with frequencies ranging from 0.1 mHz to 0.21 mHz and with oscillation constants, Q, ranging from 0.028 to 0.034, which are typical for $\delta$ Scuti stars cohabitating the same parameter space in the HR-diagram (Kurtz, 1989; Martinez et al., 1999; Zhiping, 2000; Joshi et al., 2002). But according to standard theory microscopic diffusion of helium should inhibit oscillations induced by the $\kappa$ mechanism what is corroborated by the slow rotation of Am stars (less than $50\,\mathrm{km\,s^{-1}}$) whereas the $\delta$ Scuti stars rotate faster. The different behavior is interpreted in terms of rotational induced mixing.

Turcotte et al. (2000) found that low radial modes of pulsation can become stable for evolved stars. A new model of the internal structure of Am stars, where diffusion occurs in a partially mixed zone, will be developed and shall be constrained with asteroseismic measurements from COROT.

### 3.2.12. K – Giants

Precise radial velocity studies have established that K giant stars are a new class of pulsating stars with periods of 2–10 days (Hatzes & Cochran 1994). Figure 11 shows such variations for Arcturus with at least 4 different periods which later were extended to 10 pulsation modes with periods of 2–10 days equally spaced in frequency (Merline 1997). Photometry of $\alpha$ UMa (Buzasi et al. 2000) also showed that many modes can exist in K giants.

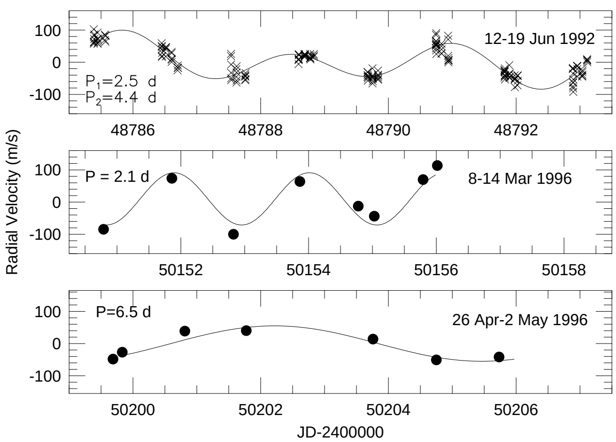


*Figure 11. RV measurements for the K Giant star Arcturus obtained at McDonald Observatory.*

The first firm discovery of solar-like oscillations in a giant star were reported by Frandsen et al. (2002) for the G 7 III star $\xi$ Hya. At least nine acoustic modes were detected in accurate radial-velocity measurements. These modes have periods in the range of 2–6 hours and amplitudes below 2 m/s. The potential of space photometry is illustrated with data obtained for a K 4 III star with the Fine Guidance Sensor of the Hubble Space Telescope (Zwintz et al. 2000, VGS 18 in their Fig. 4).

There are several basic questions regarding G/K giant oscillations that remain unanswered: What is the full oscillation spectrum? What is the lifetime of an individual mode? How do the characteristics of the oscillations change up to the giant branch?

With many modes having periods of several hours to days and low amplitudes it is very difficult to answer these questions with ground-based observations. The relative high photometric amplitude (100–400 $\mu$mag) of some of these modes and the long periods make G/K Giants ideal targets for the exoplanet field of COROT.

### 3.2.13. Subluminous dwarf B-type stars

Pulsating subdwarf B (sdB) stars (sometimes also called EC 14026 – stars, see Fig. 4) have been discovered in 1996 and identified as extended horizontal branch stars which are He-core burning with an extremely thin H-rich envelope. Their life time is about 100 Myr, they remain hot (22 000 to 40 000 K, Fig. 12) during all the evolution and presumably reach the white dwarf (WD) track without experiencing the AGB phase. sdB's should form WD's with lower than average masses ($\approx$ 0.5 solar masses) and it seems that about 1% of the WD's are formed in this way. Because of their role in the UV excess seen in giant elliptical galaxies and the possibility to use this excess as an age indicator there is a rising cosmological interest in these stars. However, their structure and evolution are still poorly understood: the formation process, physics of the He burning convective core, and there are controversies concerning their evolutionary paths. Currently about 30 multiperiodic, radial and nonradial p-mode pulsators

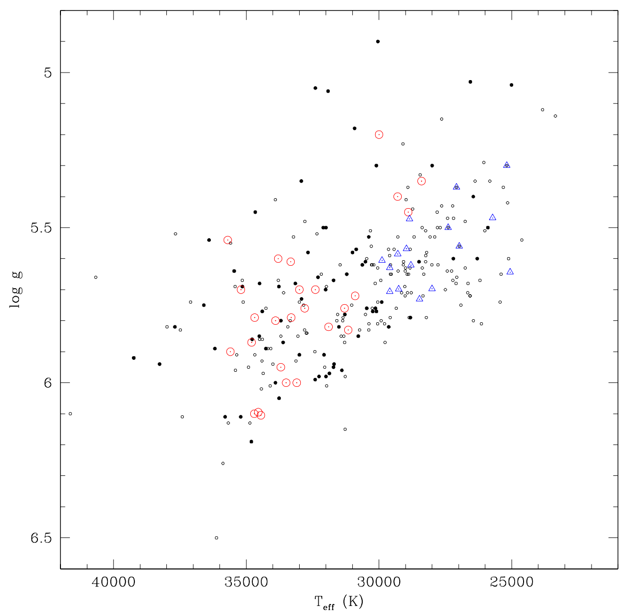


*Figure 12. Pulsating subdwarf B stars with p-modes (short period, red circles) and g-modes (long period, blue triangles), detected in a sample of 205 sdB stars.*

are known. With the discovery in 2001 of another type of sdB's which are pulsating with longer periods in g-modes, the significance of this part of the HR–diagram for asteroseismology increased considerably.

### 3.2.14. White Dwarfs

About 97% of the stars in our galaxy end their evolution as white dwarfs. WD's do keep the memory of all the physical processes which occurred during the prior evolution, explaining the interest in their internal structure and the cooling sequence, which is another promising age indicator. However, its current use for the determination of the age of the galactic disk or stellar clusters has to wait until the internal structure of the white dwarfs is better understood.

There are presently two main uncertainties in the age determined from models of cooling white dwarfs: one comes from the description of the C/O core crystallisation phase and the other from the determination of the hydrogen mass fraction in the DA white dwarfs. This latter quantity could be, in principle, deduced from the asteroseismological analysis of their multimode nonradial $g$-mode oscillations. A number of low amplitude oscillation modes can be expected to be detectable by COROT adding significantly to the potential of asteroseismology.

While it is well established that most variable white dwarfs exhibit long term amplitude variations, nothing is known about the relevant time scales. Such amplitude variations may be due to the natural lifetime of the oscillation modes linked to the excitation mechanisms, or to nonlinear mode interactions, or to pulsation-convection interaction.

### 3.2.15. Borders of instability strips

The hot and cool border of the instability strip are determined for classical pulsators by several important astrophysical parameters, like Y, Z, excitation and convection. These borders are not yet well defined for classical pulsators, like $\delta$ Scuti and $\lambda$ Bootis stars (Fig. 10), and even more so for rapidly oscillating Ap stars, for which, in addition, a global magnetic field is important. The situation is even worse for the $\gamma$ Dor stars (Fig. 13, from Handler & Shobbrook 2002).

The exoplanet CCDs will provide a large sample of such pulsating stars covering the entire temperature and luminosity range and thus allow to improve significantly the theoretical background for modelling pulsation. The expected improvement in the detection of small amplitude variations will also improve considerably on the separation of otherwise similar stars which are pulsating, respectively non–variable. This will allow to determine the various instability areas in the HR–diagram and provide further information on yet poorly understood or modelled physical processes, like convection and excitation.

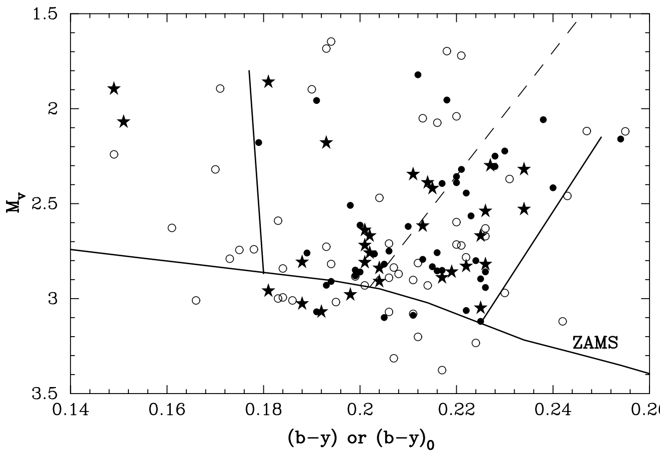


*Figure 13. Attempt to determine the instability strip of $\gamma$ Dor stars (full vertical lines). The cool border of the $\delta$ Scuti instability strip determined from observations is marked by a dashed line. Circles: candidate $\gamma$ Dor stars; asterisks: definitely pulsating $\gamma$ Dor stars; dots: multiperiodically pulsating stars which probably are $\gamma$ Dor stars, but have to be confirmed as members of this group. The two asterisks left of the proposed $\gamma$ Dor instability strip indicate two binaries (HD 209295 and HD 221866) with colors possibly influenced by the companion which might be even the pulsating component.*

## 4. And EDDINGTON?

Thanks to the larger aperture of the 4 parallel telescopes, which also will provide color information for each of the targets, EDDINGTON will push the magnitude limits well beyond those of COROT. As the EDDINGTON instrumentation is the same for asteroseismology and exoplanet search the definition of an additional program is different to that for COROT. However, all what has been discussed as additional science potential for COROT is also relevant for the science goals of EDDINGTON (Favata et al. 2000).

More (some tens) fainter QSO's will come into reach of the instrument, but also long-integration imaging, possible for the first time with EDDINGTON, in combination with a very stable point spread function will allow to investigate the surface brightness of the very outer parts of galaxies with unprecedented accuracy. About once every 30 days of operation complete fully-sampled light curves of supernovae will be obtained, starting from the pre-nova phase, which also would be a novum in astrophysics! The low brightness limit of EDDINGTON will allow to detect the brighter slowly moving Kuiper belt objects and also asteroids. All of these goodies – and some more – are described in the Assessment Study Report (Favata et al. 2000) and in these proceedings.

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