# $\delta$ Scuti stars as primary and secondary targets for COROT

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COROT Seismology Working Group

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**Abstract.** This report summarizes the state-of-art in the selection of $\delta$ Sct stars as target for the space mission COROT

## 1. Introduction

In the framework of the preparation of the COROT space mission, the selection of the targets must be made in the due time, both to provide specifics for the spacecraft pointing and to allow a reliable characterization of the objects in the field of view of the Exoplanet CCD. At this stage, a dedicated meeting has been considered the best opportunity to evaluate the bright star content of the COROT scenario (a double cone centered at $\alpha = 6^h 50^m$, $\delta = 0°$ and $\alpha = 18^h 50^m$, $\delta = 0°$ with a semiaperture of 10°). Such a meeting has been held at the Observatoire de Cote d'Azur, in Nice, the 4th and 5th March. The participants were R. Garrido, M.J. Goupil, P. Mathias, E. Michel, E. Poretti and J.C. Suarez. Written, very useful reports have been prepared in advance by C. Aerts, G. Handler and W. Weiss, who could not participate. J.A. Belmonte reported to R. Garrido and E. Michel about STARE facilities.

In the discussion, the primary targets already retained by the Scientific Committee have been considered. As possible other targets, the participants considered mainly $\delta$ Sct, both already known as variables and potential new variables. $\gamma$ Dor stars have been considered at a lesser extent, as a primary target has been already identified (HD 49434, see below). It should be noted that a generic $\delta$ Sct variable is not necessarily a good primary target. First, the star is required to be multiperiodic at the photometric level reachable from ground; second, it should not be evolved, in order to handle a simple frequency spectrum and to fully exploit the COROT resolution (time baseline 150 days; we didn't examine the targets for the Exploratory short runs). It is known that evolved models have a so much dense frequency spectrum that theoretical comparison becames very difficult without any previous mode identification. However, it should be noted that the huge number of excited frequencies is not seen in 4 CVn, at least with amplitudes above the ground–based observational limit of about 0.4 mmag. Breger (1998) concluded "In fact the frequency spectrum resembles those uf unevolved $\delta$ Sct stars, once the frequency shift caused by the lower density is accounted for"; he was also wondering if "exists for evolved $\delta$ Scuti stars a presently unknown mechanism which damps pulsation in the stellar core". Therefore, the rejection of a "evolved" $\delta$ Sct should be made cautiously.

We remind that the field covered by the Seismo CCDs is $1.3° \times 2.7°$. The focal plane is composed of four 2048x2048 CCDs. Two are dedicated to seismology and are highly defocused, to avoid saturation on bright sources.

## 2. Center direction

In the center direction there are three candidates as primary targets. Their fields have been validated by the exoplanet Working Group: HD 184663 (F6 IV, considered to be a solar–like star), HD 174866 (a candidate $\delta$ Sct star) and HD 171834 (a possible $\delta$ Sct star). Moreover, there are some objects which can be considered as interesting targets: HD 172748 ($\delta$ Sct itself), HD 183324 (a $\lambda$ Boo star), HD 167858 (a bona-fide $\gamma$ Dor variable), HD 175337 (a suspected $\gamma$ Dor variable) and NGC 6633 (an open cluster). The characteristics of these stars are listed in Tab. 1; their position is shown in Fig. 2.

### *2.1. HD 174866*

Proposed as possible $\delta$ Sct variable on the basis of some OHP spectra, the star was found to be constant both in photometry (6 hours of $uvby\beta$ photometry at OSN; Garrido et al. 2001) and in spectroscopy (7 ESO/FEROS spectra, S/N=195 each; Mantegazza, private communication). From spectroscopy, we get $v \sin i$=180 km s$^{-1}$. Therefore, it is suggested to drop it as primary target.

### *2.2. HD 171834*

It has been found constant at the 2 mmag level on the basis of 6 hours of $uvby\beta$ photometry at OSN (Garrido et al. 2001). There are 56 spectra taken with OHP/ELODIE; their investigation can be useful to detect possible spectroscopic variations. It is still considered a primary target for COROT.

### 2.3. HD 172748

It is $\delta$ Sct itself, i.e., the prototype of the class! It is not considered a good target for COROT as it is an evolved star. Unpublished results of a multisite campaign (June 1987) show an evident multiperiodic behaviour (more than 10 frequencies, from 4.74 to 10.52 $\mathrm{d}^{-1}$). Templeton et al. (1997) constructed evolution and pulsation models that match the observed spectral type, luminosity and the identified radial mode frequency of $\delta$ Sct. There are 3 radial, 24 $\ell$=1 and 40 $\ell$=2 modes in the observed frequencty range. Accounting for rotational splitting, this model has 275 possible modes. Many $\ell$=2 modes can match the remaining frequencies, making asteroseismological inferences impossible (Guzik et al. 2000).

### 2.4. HD 183324

It is a $\lambda$ Boo variable, showing a multiperiodic behaviour. It is at/beyond the the hot border of the classical instability strip; close to the ZAMS, it has $v\sin i$=90 $\mathrm{km\,s^{-1}}$. W. Weiss identified several objects located close to HD 183324, making the field interesting also for secondary targets: HD 182640 (candidate low amplitude roAp), HD 182835 (a Fm Delta Delphini star) and the possible Hipparcos variables HD 183589, HD 183518 and HD 184279. The stars surrounding HD 183324 and the FOV of the Seismo CCD are shown in Fig. 1.

### 2.5. HD 167858

Recently classified by Handler & Shobbrook (2002) as a bonafide $\gamma$ Dor star. Hipparcos and ground–based observations agree to consider it as a multiperiodic variable; there is no evidence of $\delta$ Sct variability.

### 2.6. HD 175337

Even if the $\gamma$ Dor variability was suspected on the basis of Hipparcos data, this star did not received any further attention.

### 2.7. NGC 6633

This open cluster contains at least two $\gamma$ Dor variables (HD 169577 and star 275); a campaign on these two stars will take place next summer (P.I. Susana Martin). It is not clear if a cluster can be a good target for COROT (crowding, resolution, ...) and if the field of NGC 6633 is acceptable from the point of view of the Exoplanets research. If it is, NGC 6633 is more likely than NGC 2264; the latter is located in the anticenter direction, where the number of candidates is larger than in the center direction. It should be noted that NGC 2264 contains two pre-main sequence pulsating stars (Marconi et al. 2001).

## 3. New targets in the center direction

### 3.1. Primary targets

The candidate for primary targets in the center direction are not very numerous. For this reason, R. Garrido, in collaboration with M.J. Goupil and E. Michel, will prepare a colour-magnitude diagram of all potential $\delta$ Sct stars located in the whole field of view in the center direction. These stars should be close to ZAMS (i.e., not evolved objects) and brighter than $V$=8.0 ($uvby\beta$ photometry available, $v\sin i$ value can be requested from Ground–Based Working Group). As a result, we will get a list of $\delta$ Sct candidates to be photometrically monitored. E. Poretti is charged to coordinate the observational studies on these stars. Spectroscopic observations will be carried out on the best candidates supplied by the photometry.

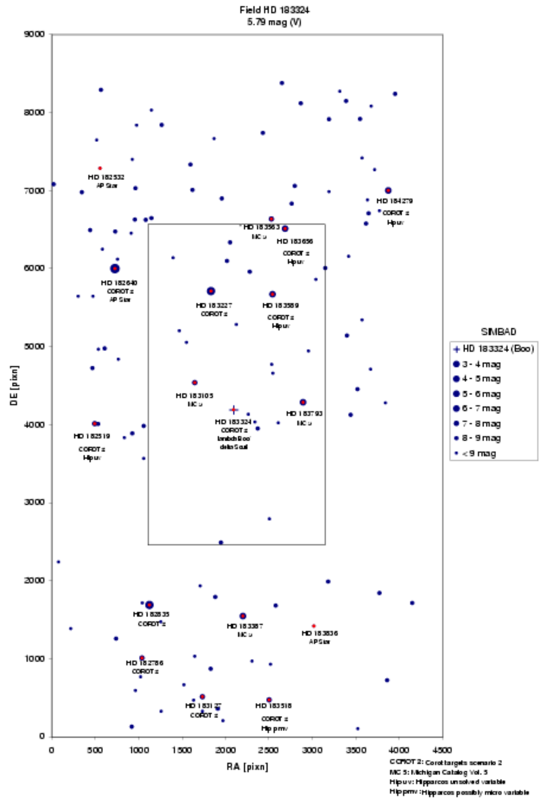


**Fig. 1.** Stars of possible interest around HD 183324. The rectangle at the center is the size of the Seismo CCD.

### 3.2. Secondary targets

G. Handler supplied a list of potential secondary targets, i.e., stars which can belong to a pulsating variable class on the basis of a colour-magnitude diagram. These stars are located $\pm1.2°$ in RA and $\pm3°$ in Dec away from the main targets HD 171834, HD 174866, HD 184663. Table 2 lists all the stars selected in the fields of HD 171834 and HD 184663, as HD 174866 has been not further considered as primary target. The same stars are indicated in Fig. 2. Note from Fig. 2 that the primary targets should be put away from center to include some secondary targets in the FOV. By the way, the primary targets cannot be put exactly in the center also for practical reasons, i.e., to allow a proper reading of the CCDs.

The list includes stars brighter than $V$=9.5; the observation of these stars has a lower priority than the list of candidate primary targets (Tab. 3), as it is not established that HD 171834 and HD 184663 will be actually selected as primary targets. However, the stars brighter than $V$=8.0 are first choices to search for new primary targets ($uvby\beta$ and high–resoluton spectroscopy available) and deserve immediate observations.

**Table 1.** Candidate primary targets in the Center direction. To be completed by an exhaustive list of potential $\delta$ Sct stars brighter than $V$=8.0.

| Star | RA (2000) | Dec (2000) | $V$ | Sp. | Remarks |
|---|---|---|---|---|---|
| HD 184663 | 19 35 25.1 | +02 54 49 | 6.37 | F6 IV | Field validated. Outside IS. |
| HD 174866 | 18 53 01.8 | −09 34 32 | 6.27 | A7 Vn | Field validated. Constant (Photometry and spectroscopy) |
| HD 171834 | 18 36 39.1 | +06 40 18 | 5.43 | F3 V | Field validated. Constant in photometry |
| HD 172748 | 18 42 16.4 | −09 03 09 | 4.70 | F2IIIp | Evolved $\delta$ Sct. Not suitable. |
| HD 183324 | 19 29 01.0 | +01 57 02 | 5.79 | A0V | $\lambda$ Boo star |
| HD 167858 | 18 17 04.8 | +01 00 21 | 6.62 | F2V | Bona–fide $\gamma$ Dor variable |
| HD 175337 | 18 54 54.4 | +01 07 18 | 7.39 | F5 | $\gamma$ Dor candidate |
| NGC 6633 | 18 25 06.2 | +05 59 55 | | | Open cluster |

**Table 2.** Candidate $\delta$ Sct stars around HD 171834 and HD 184663. Among them, HD 172230, HD 182597, HD 171835 and HD 171263 deserve priority as they can be primary targets (brighter than $V$=8.0).

| Star | RA (2000) | Dec (2000) | $V$ | Sp. | Related field |
|---|---|---|---|---|---|
| HD 172230 | 18 38 54.9 | +06 16 14 | 7.1 | A5 | HD 171834 |
| HD 182597 | 19 38 21.6 | +00 20 43 | 7.27 | A2 | HD 184663 |
| HD 172588 | 18 40 46.0 | +08 47 34 | 7.22 | F0 II-III | HD 171834 |
| HD 171126 | 18 32 52.7 | +04 12 47 | 8.25 | F0 | HD 171834 |
| HD 184965 | 19 36 54.7 | +00 07 32 | 8.55 | F0p | HD 184663 |
| HD 172189 | 18 38 37.5 | +05 27 55 | 8.85 | A2 | HD 171834 |
| HD 171262 | 18 33 27.6 | +07 41 19 | 8.92 | A0 | HD 171834 |
| HD 184545 | 19 34 53.9 | +05 10 37 | 8.46 | A3 | HD 184663 |
| HD 171835 | 18 36 41.3 | +06 02 32 | 7.85 | A2 | HD 171834 |
| HD 171263 | 18 33 36.0 | +05 36 24 | 7.75 | A0p | HD 171834 |
| HD 184474 | 19 34 30.6 | +01 28 55 | 8.71 | A0 | HD 184663 |

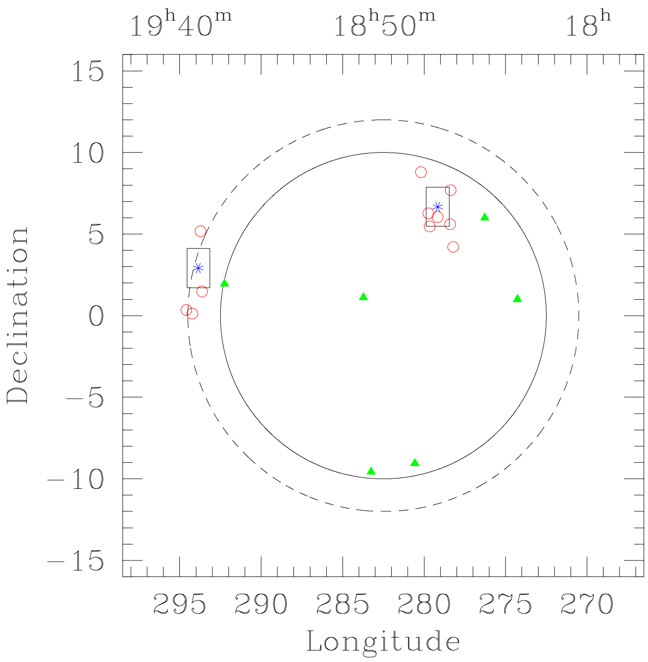


**Fig. 2.** Position of the candidate primary targets in the FOV of COROT in the Center direction. Boxes are the FOV of the seismology CCD around the proposed primary targets HD 171834 and HD 184663; potential $\delta$ Sct stars (i.e., not yet confirmed variables) are indicated around them (open circles). Triangles are other objects of possible interest.

Fainter stars, if confirmed to be suitable $\delta$ Sct variables, can be primary targets as well, but complementary data will be not immediately available.

## 4. Anticenter direction

Here we have a good number of candidate primary targets (Tab. 3). The choice should be made among HD 43587, HD 45067, HD 57006, HD 49434+HD 49933, HD 55057 and HD 43318. The star HD 46304 has been rejected because not satisfying the exoplanet requirements. Therefore, there is no need to search for other candidates in the whole FOV, but just to characterize the secondary targets, in order to give a criterium to select primary ones. Potential secondary targets are listed in Tab. 4. This list has been obtained by E. Michel in two steps. First, he selected all the A0 to F2 objects with $5.5 < V < 9.5$ located around the Principal Targets candidates. Second, he made a rough HR diagram using Hipparcos $B-V, V$ and parallaxes to select the object belonging to the Instability Strip (Fig.4). Even if these positions should be taken with care, Tab. 4 constitutes a good sample of candidates.

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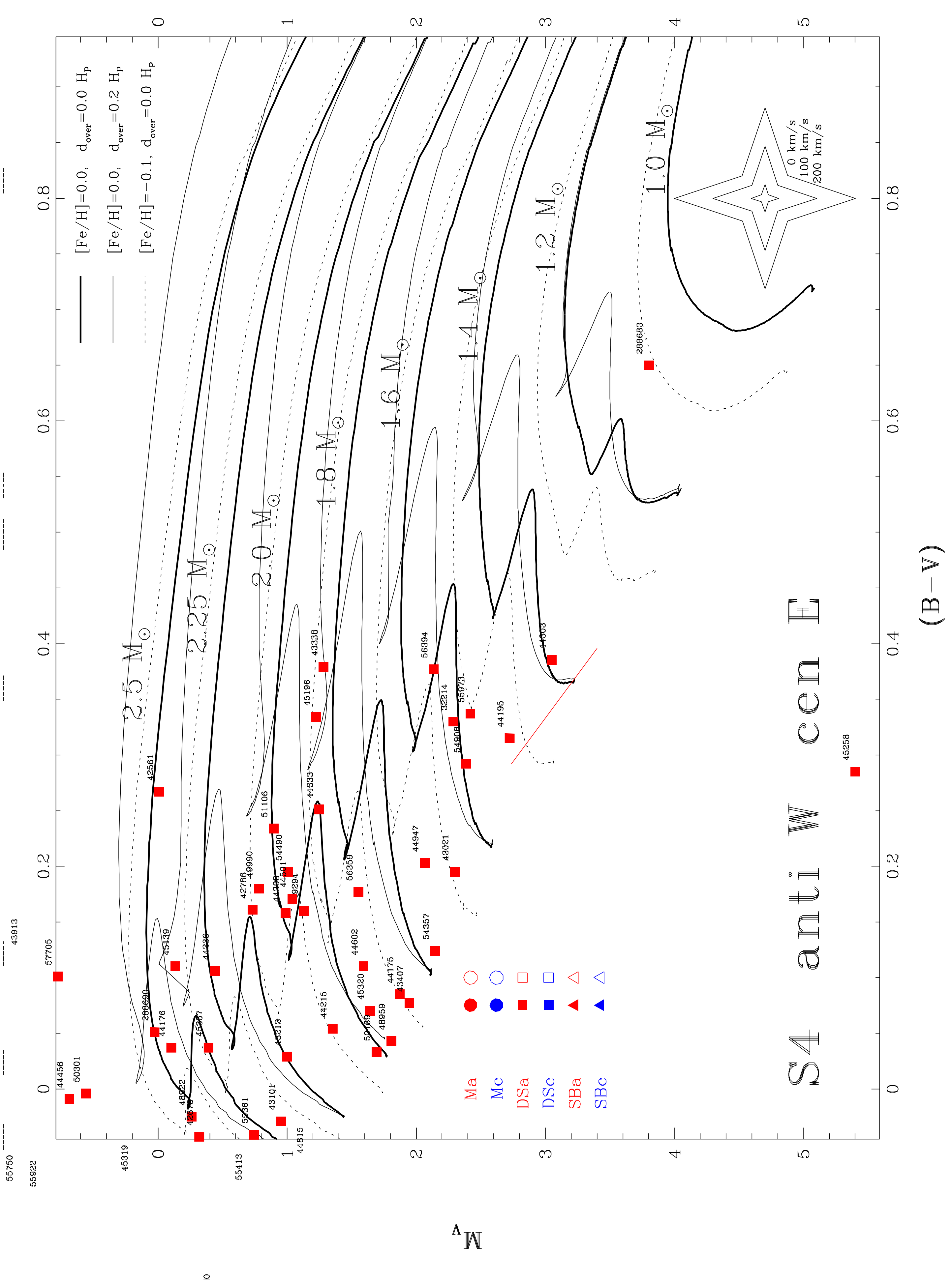


**Fig. 4.** Colour–Magnitude diagram for potential secondary targets in the Center direction. Stars are indicated by their HD number.

**Table 3.** Candidate primary targets in the Anticenter direction. All fields have been validated on the basis of the Exoplanet requirements.

| Star | RA (2000) | Dec (2000) | $V$ | Sp. | Remarks |
|---|---|---|---|---|---|
| HD 43587 | 06 17 16.14 | +05 06 00.4 | 5.70 | F9 V | |
| HD 45067 | 06 25 16.55 | −00 56 45.2 | 5.88 | F8 V | |
| HD 57006 | 07 19 47.65 | +07 08 34.6 | 5.91 | F8 V | |
| HD 49434 | 06 48 19.07 | −01 19 08.1 | 5.75 | F1 V | |
| HD 49933 | 06 50 49.83 | −00 32 27.2 | 5.78 | F2 V | |
| HD 55057 | 07 11 23.62 | −00 18 06.9 | 5.44 | F0 Vn var | |
| HD 43318 | 06 15 34.27 | −00 30 43.9 | 5.62 | F6 V | |

**Table 4.** Stars to be observed to verify if they are $\delta$ Sct or $\gamma$ Dor variables; they are located in the Anticenter direction.

| Star | RA (2000) | Dec (2000) | $V$ | Sp. | Related field |
|---|---|---|---|---|---|
| HD 43338 | 06 16 01.00 | +06 32 09.3 | 7.64 | F0 | HD 43587 |
| HD 44195 | 06 20 42.75 | +05 16 42.4 | 7.56 | F0 | HD 43587 |
| HD 56359 | 07 17 00.17 | +09 27 47.2 | 7.24 | A2 | HD 57006 |
| HD 56394 | 07 16 55.97 | +04 36 35.3 | 8.84 | F2 | HD 57006 |
| HD 45196 | 06 25 58.97 | −01 48 48.7 | 8.36 | F0 | HD 45067 |
| HD 44947 | 06 24 43.07 | +00 54 30.7 | 8.77 | A3 | HD 45067 |
| HD 43021 | 06 14 10.42 | +02 34 28.6 | 7.82 | A0 | HD 43857 |
| HD 54908 | 07 10 38.97 | −01 50 34.4 | 7.98 | A0 | HD 55057 |
| HD 54357 | 07 08 35.28 | +00 27 35.4 | 7.84 | A0 | HD 55057 |
| HIP 32214 | 06 43 32.24 | −03 24 09.5 | 9.47 | A5m | HD 49434 |
| HD 44333 | 06 21 25.77 | +02 16 06.7 | 6.30 | A4.5V | too far from all |

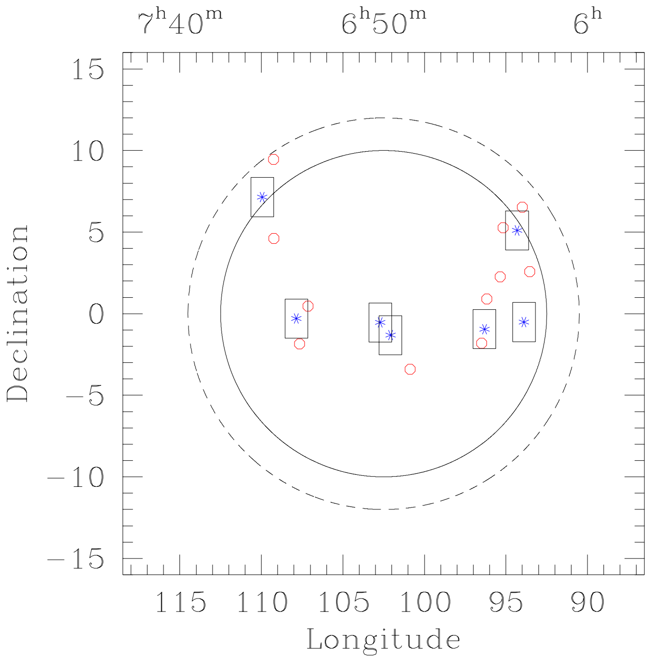


**Fig. 3.** Position of the candidate primary targets in the FOV of COROT in the Anticenter direction. Boxes are the FOV of the seismology CCD around the primary targets listed in Tab. 3. Potential $\delta$ Sct stars (i.e., not yet confirmed variables) are indicate around them (open circles).

should be taken with care, Tab. 4 constitutes a good sample of candidates.

### *4.1. Field of HD 43587*

HD 43857 is a star with 1 M$\odot$. It will be very probably a final choice for COROT. There are two possible $\delta$ Sct variables in the field: HD 43338, preliminarly found to be variable both in photometry (Uytterhoeven & Aerts 2002) and in spectroscopy (Mathias et al. 2002); HD 44195 is a suspected variable in spectroscopy, but no sufficient data on photometry. The two stars can be included simultaneously in the FOV of the Seismo CCD ($\Delta\alpha$=1.17°). If HD 43338 and HD 44195 will be included in the FOV, HD 43021 (suspected to be variable in photometry; Uytterhoeven & Aerts 2002) will be outside ($\Delta\delta$=2.5°). The automatic telescope STARE will supply photometric data on the field in a short time.

### *4.2. Field of HD 45067*

As regards secondary targets, HD 44947 could be a $\gamma$ Dor variable from photometric data (Uytterhoeven & Aerts 2002). No data on HD 45196. HD 44333 seems to have a composited spectrum (Mathias et al. 2002), but it seems too far away the main target ($\Delta\delta$=3.2°). The automatic telescope STARE will supply photometric data on the field in a short time.

### *4.3. Field of HD 57006*

HD 56359 and HD 56394 may be photometrically variable stars (Uytterhoeven & Aerts 2002). However, the two stars cannot be both included in the FOV of the Seismo CCD ($\Delta\delta$=4.8°). Note also that HD 56359 is 2.32°away from the main target and HD 56394 is 2.53°, i.e., both are close to the acceptable distance. The automatic telescope STARE will supply photometric data on the field in a short time.

### *4.4. Field of HD 49434 and HD 49933*

HD 49434 is a $\gamma$ Dor variable (Bruntt et al. 2002), while HD 49933 is a solar–like star. They are both in the same field. As secondary targets, only HIP 32214 has been considered, but no data is currently available. In any case, it seems too far ($\Delta\delta$=2.85°) The automatic telescope STARE will supply photometric data on the field in a short time.

### *4.5. Field of HD 55057*

HD 55057 is a known $\delta$ Sct variable, 21 Mon≡V571 Mon. The star is a fast rotator ($v \sin i = 136$ km s$^{-1}$, F2V). From a photometric point of view, its variability is well established (Stobie et al. 1977). The evolutionary phase and the physical properties of this candidate primary target deserve further studies. As possible secondary targets, we have HD 54357 (maybe variable in photometry; Uytterhoeven & Aerts 2002) and HD 54908 (no data).

### *4.6. Field of HD 43318*

No secondary target, since HD 43021 is too far ($\Delta\delta$=3.1°) and closer to HD 43587.

## 5. Observational strategy

On the basis of the analysis star by star done in the previous sections, two different approaches can be established:

*Center direction* – Search for variability in a list of possible $\delta$ Sct variables located on the whole COROT field of view. Such a list will be prepared as soon as possible. If a star is found to be a $\delta$ Sct variable, it will be examined further to be proposed as primary target.

*Anticenter direction* – Search for variability in a list of stars centered around selected candidates for primary targets (Tab. 4 and Fig. 3). The goal is to drive the primary target selection on the basis of secondary targets.

The following campaigns are expected to give some clarifications on the COROT targets, both primary and secondary:

### *5.1. Center direction*

1. SAAO : $UBV$ photometry of stars in the whole FOV (April 1-14, 2002, 0.5-m telescope; April 1-7, 2002, 0.75-m telescope). Contact person: G. Handler.
2. APT Arizona: $v$ and $y$ photometry of stars in the whole FOV (to be planned in June, July or August, if telescope time is available). Contact person: W. Weiss.
3. S.Pedro Martir : $uvby$ photometry of stars in the whole FOV (May 2-9, 2002, end of night only). Contact person: E. Poretti;
4. Mercator : Geneva photometry of stars in the whole FOV, possibly increasing the number of measurements on each night. Contact person: C. Aerts;
5. STARE Automatic telescope : provide the photometric monitoring of few fields on the basis of the results of the campaigns listed above. Contact person: J.A. Belmonte;
6. OSN: $uvby\beta$ photometry of stars in the whole FOV. Contact person: R. Garrido
7. OHP/AURELIE: include some interesting objects in the May 2002 and August 2002 spectroscopic runs (telescope time already allotted). Contact person: P. Mathias.

### *5.2. Anticenter direction*

1. STARE: 4 fields have been proposed to be observed in March 2002. Contact person: J.A. Belmonte;
2. Mercator: if possible, provide new results on already observed target by means of more intensive time–series. Contact person: C. Aerts;
3. APT Catania: to survey few stars during intensive campaigns in November-December 2002. Contact persons: E. Poretti and G. Cutispoto;
4. S. Pedro Martir: observing time will be requested to observe in November-December 2002. Contact person: E. Poretti;
5. OSN: $uvby\beta$ photometry of selected stars to obtain dense time–series. Contact person: R. Garrido
6. OHP/AURELIE: spectroscopic survey of confirmed new $\delta$ Sct variables. Contact person: P. Mathias.

## 6. List of Actions

The previous section lists the observational efforts to be made to progress in the selection of $\delta$ Sct stars which can be proposed as primary and secondary targets for COROT. The following list of actions is a sort of guideline:

1. To prepare a colour–magnitude diagram for potential targets in the Center direction and to issue a list of potential primary targets (RG, MJG)
2. To verify if an open cluster can be a good primary target for COROT (JCS, EM)
3. To verify the evolutionary status of HD 55057≡21 Mon (MJG)
4. To coordinate the observational campaigns on potential targets (EP)
5. To verify the possibility to use the Arizona APT's for selected targets (WWW)
6. To verify the possibility to use the Catania APT for selected targets (EP)
7. To propose fields to be monitored with STARE (EM)
8. To include selected targets in the spectroscopy monitoring at OHP (PM)
9. To continue the MERCATOR survey, possibly by increasing the number of measurements per night (CA)
10. To detect variability of potential targets by means of already allotted observing time (GH at SAAO, EP at SPM)

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