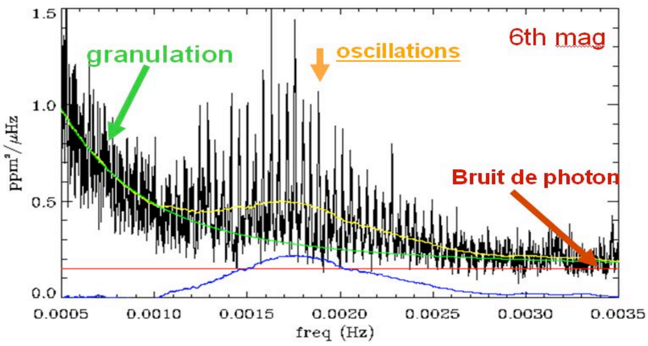
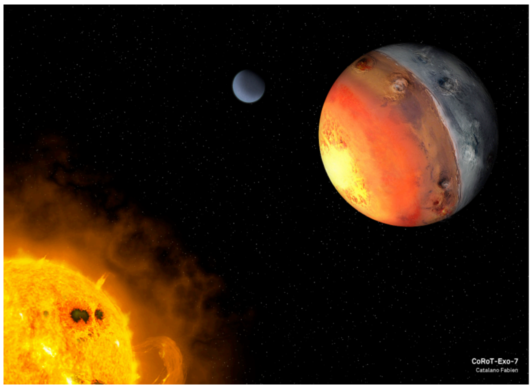
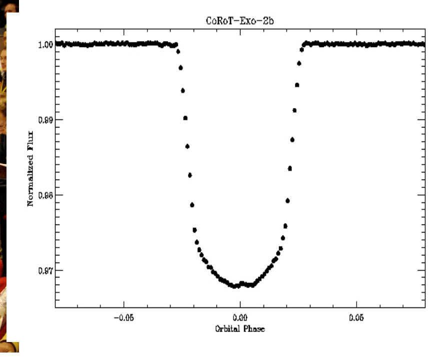
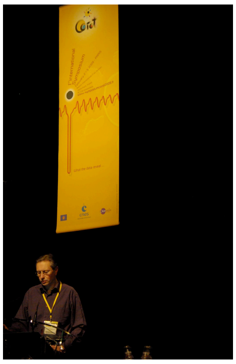
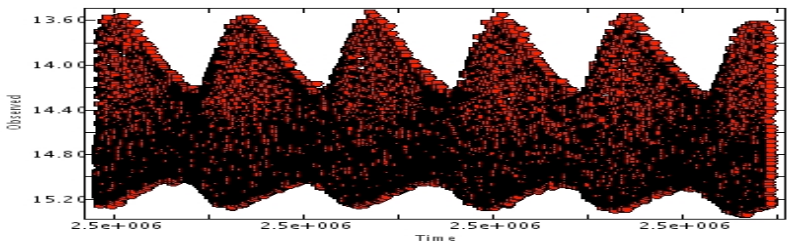
Mission extension 2010-2012











Proposition for an extension 2010-2012
Executive summary

CoRoT has been working perfectly during more than 800 days. It has generated 1.5 Terabytes of scientific data, in 9 periods of almost uninterrupted observation. The photometric accuracy is only a few percent above the photon noise in the seismology channel and twice the photon noise in the exoplanet channel over periods of up to 150 days, with a 95% duty cycle. This corresponds to specifications and is a qualitative jump both in term of sensitivity and duration of the observations compared to what had been achieved thus far. As a result, CoRoT has discovered new planets, oscillations in solar-like stars, oscillations in red giants, a transiting brown dwarf, it has for the first time been able to detect reflected light from giant exoplanets, it allowed studying in detail stellar spots, stellar activity and rotation…etc. Most of these results are published and already widely cited in the scientific literature.

The recent discovery of the hitherto smallest transiting planet CoRoT-7b, with a corresponding photometric variation of only 0.03%, an order of magnitude better than any detection so far, has demonstrated the capability of the spacecraft to discover and characterize planets of with sizes close to that of the Earth. With an orbital period of 0.854 days, this is probably a member of a new class of planets: super-Earths orbiting extremely close to their parent star. Thanks the satellite stability and also to a dedicated follow-up of transit candidates using the world's most sensitive telescopes, CoRoT has also led to the detection and characterization of giant planets with an unprecedented accuracy. An example is the recent discovery of reflected light from planet CoRoT-2b, a photometric variation of only 0.0066%!

The challenge in asteroseismology, of detecting in photometry Solar Like Oscillations in solar like stars, has been achieved for the first time in a convincing way beyond any doubts. In this domain, CoRoT is really unique and will continue to be as it is, the only satellite in orbit to study the interior of many stars of all types (including bright ones).

After one year of proprietary period, CoRoT data are released to the public. The first public released occurred on December 2008 and has proceeded nominally since then. The CoRoT public site has been visited more than 1500 times, from all over the world.

A fraction of the CoRoT results are already published in the scientific literature, and a dedicated issue of Astronomy and Astrophysics is presently being edited for a publication towards the end of 2009. Because CoRoT has allowed probing effects that were not detectable so far, many surprises have been met –from very complex oscillation spectra to the discovery of a super-Earth that close to its star-. This will allow new work based on further analyses of the CoRoT data but will also require new theoretical tool.

Unfortunately, in early March 2009, at the end of the 9th Run, one of the photometric chains has stopped working, and up to now it has not yet been possible to repair it. The satellite is presently operating with only one chain, but **without any degradation of the quality of the observations**. Only the field of view and hence the number of targets in each programme is reduced by a factor two.

On the basis of CoRoT's performances and of the new questions that have been raised by the CoRoT discoveries, the CoRoT team asks for an extension of the mission for three years (2010-2012). The extension will be devoted to studying new types of stars that were not observed for seismology during the nominal mission, observing stellar types for which particularly intriguing behaviours were observed, and increasing the number of exoplanets detected. In particular, special emphasis will be put to the discovery of close-in super-Earths similar to CoRoT-7b. The extended mission will also allow the re-observation of stellar fields, detecting smaller planets, probing for the presence of additional planets and studying long-term evolution of stellar activity

The observing programme for the next years will combine a few long sessions and as many sessions of intermediate duration as possible, in order to maximize the possibility to detect super-Earths. As before, we will try to optimise pointing in the two fields, to address major questions on both the seismology field and the exoplanet field. But in some cases priority will be given to either one or the other Core Programme.

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1 Introduction

The mission has been working perfectly during more than 800 days, producing 1.5 Terabytes of scientific data, in 9 periods of almost uninterrupted observation (Runs).

The recent discovery of the hitherto smallest planet CoRoT-7b has demonstrated the capability of the spacecraft to discover and characterise Small Planets -- almost in the same size as the Earth and thus completely fulfills the CoRoT design criteria up to expectation.
The CoRoT planet family contains a larger diversity of objects than known before.

The challenge, in asteroseismology of detecting with photometry Solar Like Oscillations in solar like stars, has been achieved for the first time in a convincing way beyond any doubts.
In this domain, CoRoT is really unique and will continue to be as it is, the only satellite in orbit to study the interior of many stars of all types (including bright ones).

We already have, thanks to CoRoT, a lot of results as presented in the special volume of Astronomy and Astrophysics presently being edited. A few of them are in agreement with the predictions, but many of them reveal serious conflicts with current theoretical concepts of how these stars are working and these investigations are just starting.
More observations and sophisticated data treatment on the existing and future data will certainly reveal new ones…..

Unfortunately, in early March 2009, at the end of the 9th Run, one of the photometric chains has stopped working, and up to now it has not yet been possible to repair it. The satellite is presently operating with only one chain, but **without any degradation of the quality of the observations**. Only the field of view and hence the number of targets in each programme is reduced by a factor two.
The same scientific objectives, valid at the beginning of the mission, can still be achieved but in an extended mission.

For each of its primary science goals, the scientific results, already obtained, are described briefly, highligtening a few remarkable discoveries.
Then the major questions which need and can be addressed by an extended mission after this first period, are described.

The large number of scientifically promissing subjects need more than two or three years of observations, and hence requires an extension of the misssion..

A global strategy for the next three years is proposed at the end.

2 The performances achieved in flight

As described in details in the paper Auvergne et al. of the special volume of A and A, all the scientific specifications are fulfilled. Let's summarise them rapidly.

2.1 The photometric accuracy

After corrections, the photometric accuracy is very close to the photon noise (down to a few percents) at high frequency (between 1 and 10mHz) for the seismology channel. The measured noise is twice the photon noise in the exoplanet channel (in the interval 2.5 10**(-5) ,1.5 10***(-4)), as foreseen before launch.

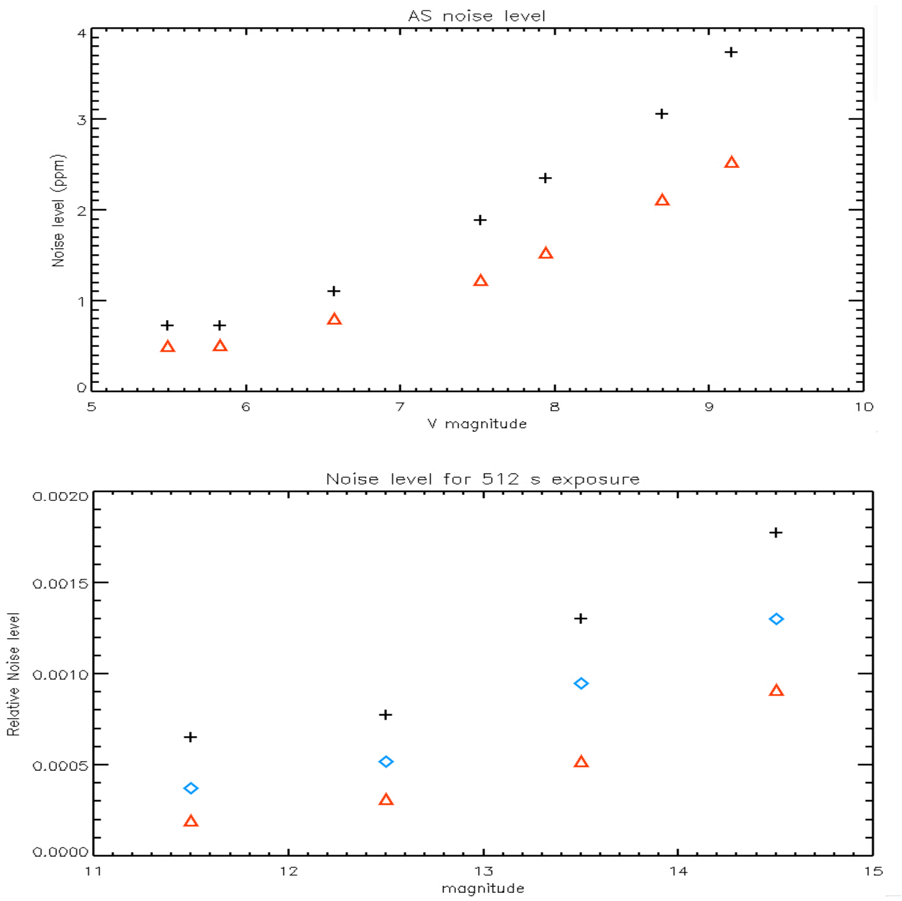


Figure 1 : Variation of the photometric noise as a function of magnitude in both channels.

2.2 The duration of the runs and the duty cycle

The duration of the observing runs, as well as the dutycycle are also in complete agreement with the proposed programme.

We have been able to reach a total duration of more than 150 days.
The foreseen problems of the Earth straylight turned out to be completely negligeable, thanks to the overperforming baffle, thus allowing the longest possible runs to be performed.
The duty cycle is extremely good (on average 95%) and never achieved before by any space mission for such long time scales.
Due to the importance of avoiding interrruption in the data stream for both programmes, this is a point which still needs to be treated with enormous care. Curiously, the interruptions that have occured, were essentially due to technical problems on ground antennas that have

slightly reduced the volume of data downloaded.

Run				Data			Distribution		
Code	Num	Begins	Ends	Begins	Ends	Duration	Date	Type	V
IRa01	3	07/01/18	07/03/04	07/01/31	07/04/02	62 days	07/12/10	astero	1.0
								exo	1.1
SRc01	4	07/04/03	07/05/09	07/04/11	07/05/09	29 days	08/04/01	astero	1.1
								exo	1.2
LRc01	5	07/05/09	07/10/15	07/05/11	07/10/15	158 days	08/02/15	astero	1.2
								exo	1.3
LRa01	6	07/10/15	08/03/03	07/10/18	08/03/03	138days	08/07/24	astero	1.3
							08/10/29	exo	1.4
SRa01	7	08/03/03	08/03/31	08/03/04	08/03/31	28 days	08/11/06	astero	1.3
							08/09/04	exo	1.4
LRc02	8	08/03/31	08/09/08	08/04/11	08/09/07	150 days			
SRc02	9	08/09/08	08/10/06	08/09/09	08/10/06	28 days			
SRa02	10	08/10/06	08/11/12	08/10/08	08/11/12	36 days	seismo	09/01/31	
							exo	09/04/30	
LRa02	11	08/11/12		08/11/13	09/03/08	115days	09/07/31		

Table 1 : Duration of the runs already completed.

2.3 The March 8th 2009 accident.

After the loss of chain 1 the instrument was restarted on March 30th.
The analysis of the recent data show that the photometric quality of the data is not affected.
The only performance which is significantly degraded is the number of targets observable in one pointing.
It can easily be overcome by an increase of the length of the mission.

2.4 Prevision on aging.

The major sources of degradation of the performances with time are the density of hot pixels, the decrease of the total gain of the electronic chain, the optics and the AOCS accuracy.

*** Hot pixels**

Along with transient events, proton impacts produce permanent hot pixels due mainly to atomic displacements in the silicon lattice. The intensity of a bright pixel is not stable in time. On short time scales (few minutes to few hours), rearrangement phase induces abrupt or exponential decreases in the intensity. A long term annealing often follows, and a bright pixel can disappear after several days to a few years.

At the beginning of each run, the bright pixels are detected on the exoplanet CCDs images as a function of their intensity. The evolution of the number of hot pixels appears to be linear in time and can be extrapolated to the satellite's end of life.

The extrapolation to six years gives a proportion of 0.3 % of hot pixels stronger than 3000^{e} e- (corresponding to 3 times the average photon noise), which will affect one third of the targets.

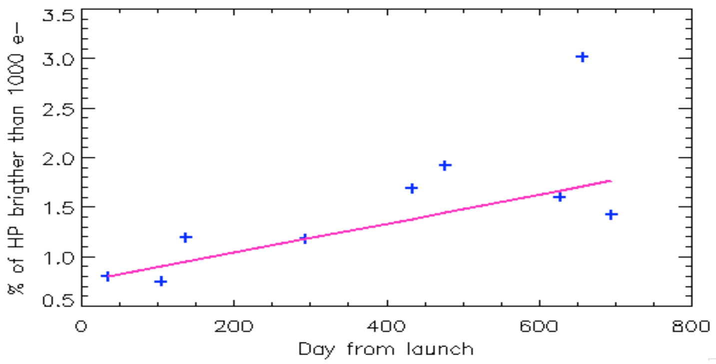


Figure 2 : Number of bright pixels of intensity smaller than 1000e-- measured on full frame CCD images at the beginning of each run.

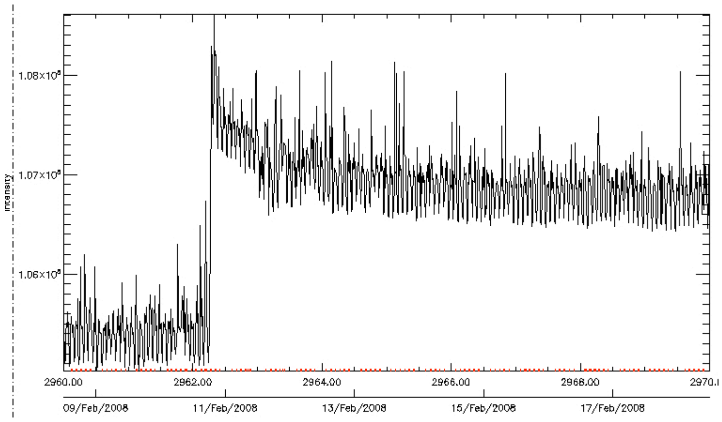


Figure 3 : Example of a background raw-data light curve (LC) perturbed by a new hot pixel appearing during the crossing of the SAA. In this example the hot pixel intensity decreases exponentially on a 1 day time scale and reaches a stable but higher mean value.

*** Decrease of the total gain of the chain**

All stars show a long term decrease in the flux that is roughly linear in time. The slope, measured on several long runs for theseismology and exoplanet targets, varies linearly with the absolute flux value. Attributing the flux decrease to a gain decrease, the relative flux variation is close to 5.3 10^{-5} day $^{-1}$. The efficiency of the photons to electrons conversion will be reduced by 10% after six years in flight. This flux reduction is acceptable.

As the conversion efficiency is slightly better than the specification at the beginning of the satellite life, the loss with respect to the original specification will be smaller than 10%, after 6 years in orbit.

* Optics

No significative long term PSF variation have been detected.

*AOCS

Du to the loss of one photometric chain, and in order to keep a good AOCS performance, some constraints must be taken into account in the choice of seismology stars on CCD A2. Now we need to have two stars brighter than V = 7.5 at a distance greater than 1000 pixels on the same CCD.

3 The exoplanet hunting programme

3.1 The present CoRoT family

3.1.1 The striking discoveries

For more than two years, CoRoT has demonstrated that it is the most sensitive instrument in the world to discover and characterize transiting exoplanets at visible wavelengths. As a result, it has discovered planets that would have been missed by any existing ground based survey, and it has brought back data that enable an extremely accurate characterization of the planets, at least an order of magnitude better than what had been possible so far. It has shown its ability to probe for a population of planets that extends from brown dwarfs down to Earth-size planets with a high efficiency.

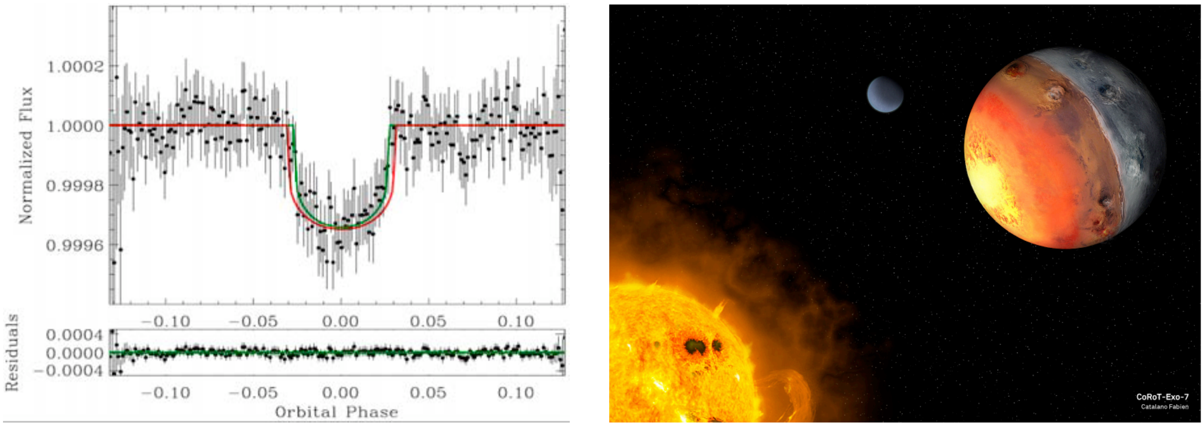


Figure 4 : Left : Transit lightcurve of CoRoT-7b as measured by CoRoT. Notice that the transits are extremely shallow : only 3 part per 10,000, hence the planet's small radius of 1.7 times that of the Earth. Right : Artist view of the system. The planet is so close to its star that it may have lava on its day side. A second planet (Saturn like, non transiting) has been discovered by HARPS during the radial velocity follow-up with a period of 3.7 days.

The best proof of CoRoT's extremely high sensitivity is its discovery of CoRoT-7b, the first transiting super-Earth ever discovered. The photometric dip that was detected is only of order 3/10,000, compared to 1/100 for the vast majority of planets discovered so far, and at least an order of magnitude smaller than the smallest transit to have been discovered previously. The planet has a size of 1.7 times that of the Earth. It orbits extremely close to its star: its orbital period is shorter than a day! (0.854 days, precisely). It was not expected to detect a planet in such a short orbit, and this case opens new possibilities for the future. Radial velocity measurements from the ground tell us that small-size planets may be frequent. The discovery of this new class of planets is within CoRoT's reach.

Another beautiful example of CoRoT's efficiency is its discovery of the star+planet system CoRoT-2. As shown in fig. 2, the 143-days lightcurve is characteristic of a very active star with many star-spots. Because of the large intrinsic variability, any discontinuous observation (as done from the ground) would have missed the planetary events. To the contrary, CoRoT has been able to discover the giant planet orbiting around the star. The system is extremely interesting because it may be a key to understand how stellar tides are modifying the orbital and physical characteristics of exoplanets: this planet is so large for its mass that it cannot be explained by conventional models.

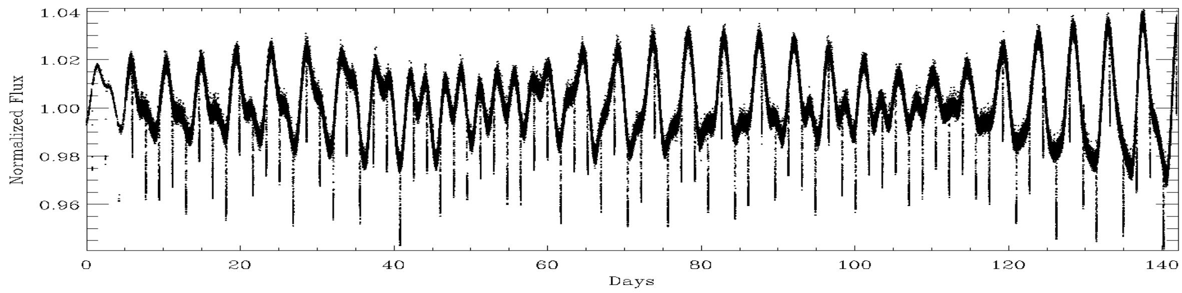


Figure 5: Lightcurve of CoRoT-2, an active star with spots and its planet. The planet reveals itself by a 2% dip in the lightcurve every 1.73 days. This is the youngest and by far the most active star with a transiting planet discovered so far. It highlights the capability of CoRoT in detecting planets even around active stars

CoRoT has also enabled a new science: the discovery of secondary transits at visible wavelengths. For the first time, we can see in the optical the disappearance of the planet behind the star (Fig. 6). It allows for the measurement of a very important property of the planet's atmosphere: its albedo, i.e. the amount of light that is reflected by the planet. This is found to be small, only of order 10% (compared to about 40% for the Earth), meaning that giant exoplanets are very dark. Again, CoRoT's extreme stability and precision is essential for this measurement, where the signal is only of order 2/10,000 .

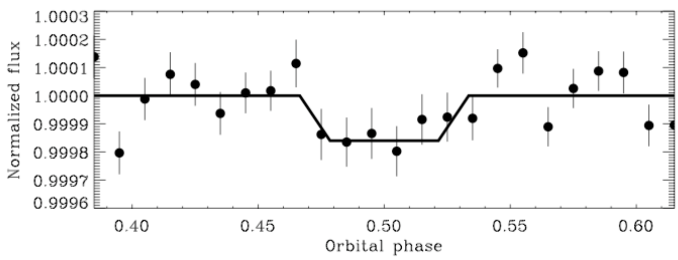


Figure 6: Secondary transit of CoRoT-1b, measured from the CoRoT lightcurve

Table 1 gives the parameters of the first CoRoT planets and some of their main characterisics. Most of the CoRoT planets are in the domain of giant gaseous planets, with radii ranging from 0.97 to 1.49 R_{Jup}. The two most inflated ones (CoRoT-1b and CoRoT-2b) also correspond to very short periods (1.51 and 1.74 days respectively), confirming the role of irradiation in the radius evolution. CoRoT-4b and CoRoT-6b are among the rare transiting planets with orbital period significantly greater than 4 days. Thanks to the analysis of their CoRoT light curves the stellar rotation periods have been measured and show that both systems are synchronized. Among other interesting pecularities, while the radial velocity surveys have proposed that planetary frequency is rising as a function of the metallicity of the host star, 3 out of the five CoRoT hot-Jupiter are surprisingly metal poor.

CoRoT has also started to widen the domain of planet mass : from the very massive CoRoT-3b (21.6 M_{Jup}) at the frontier between planets and brown dwarfs, to CoRoT-7b, first planet in the telluric size domain for which radius and mass have been measured.

Name	Period (day)	Mass (M_{Jup})	Radius (R_{Jup})	Density (g/cm^3)	Star type	Main features

CoRoT-1b	1.51	1.03	1.49	0.38	G0V	planet radius Metal poor host star
CoRoT-2b	1.74	3.31	1.46	1.31	G7V	Active star – planet radius
CoRoT-3b	4.26	21.6	1.0	26.4	F3V	Brown dwarf or Super planet
CoRoT-4b	9.202	0.72	1.19	0.525	F9V	long orbital period Synchronized system
CoRoT-5b	4.03	0.46	1.39	0.217	F9V	Very low density
CoRoT-6b	8.89	2.96	1.15	1.94	F9V	Low metal content
CoRoT-7b	0.85	1.4 – 1.9 10^{-2}	0.157	4.23	G9V	First transiting super-Earth

Table1 : The confirmed CoRoT planets

At the time of writing, there are more than 1500 transiting events detected by CoRoT (see Fig 4).
Many of them can be immediately attributed to eclipsing binaries, on the basis of the light curve itself.
More than 300 have been followed up with complementary techniques, and 7 planets are fully confirmed and characterized. A number of unsolved cases (among which a number of almost certainly planets) remain, either due to a difficult spectroscopic follow-up (faint stars, fast rotators, active stars) or to observing material not sufficient for a robust conclusion.

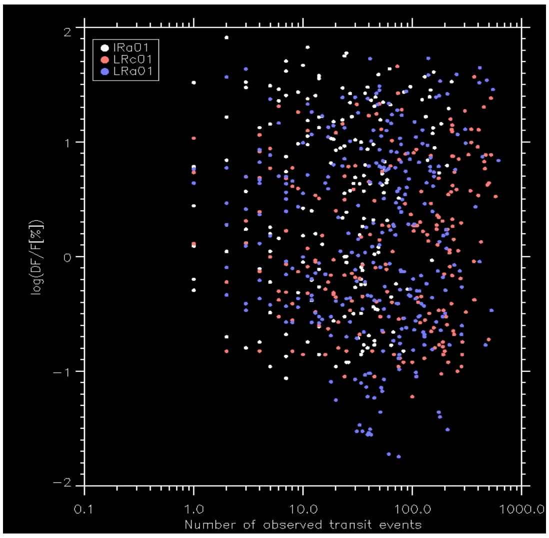


Figure 7 : Depth of all the transit signals detected in the three first field of view observed by CoRoT as a function of the number of observed transit events.

3.1.2 A demanding confirmation process

The CoRoT Exoplanet science team has decided to publish, during the proprietary period, confirmed and fully characterized planets only and not simple planet candidate lists. To achieve such a goal, a complex strategy of tests has been set up, well beyond the simple detection of transits in the CoRoT light curves. As several configurations due to stellar eclipsing systems indeed result in events mimicking true planetary transits, a number of verifications are mandatory to rule out transiting stellar companions.
The regular temporal coverage over a long period of time and the good photometric precision

that CoRoT provides is very favorable compared to the situation for ground-based surveys. It allows the best possible information to be extracted from the light curve, mainly with search for secondary transits and out-of-eclipse ellipsoidal variations that are observed when the two companions are stars (Fig. 9). The detailed analyses of the CoRoT light curves give opportunity to rule out about ¾ of the candidates.

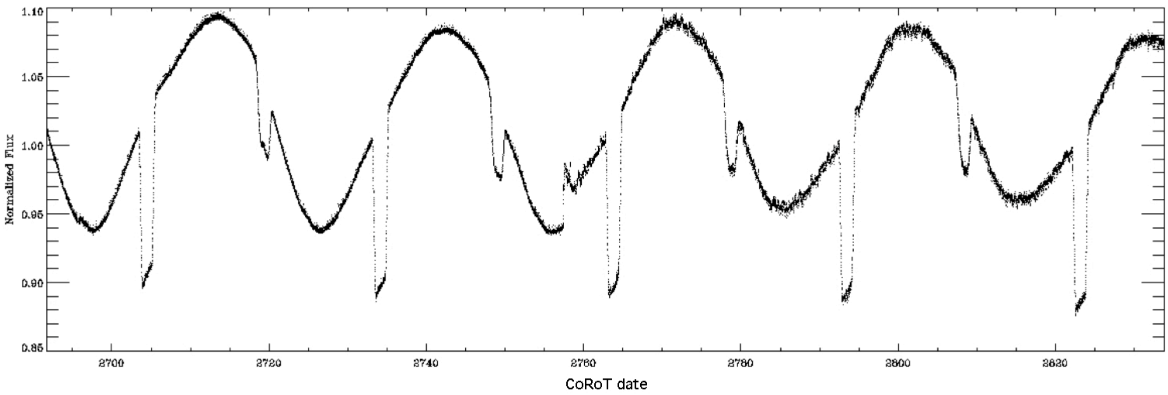


Figure 8: Light curve of an eclipsing binary observed by CoRoT. The mutual ecclipses of the two stars with different radii result in transits with different depth and duration, easily identified in the long duration light curve.

For the remaining candidates, complementary ground-based observations are essential. They help to identify and discard the remaining stellar eclipsing systems.

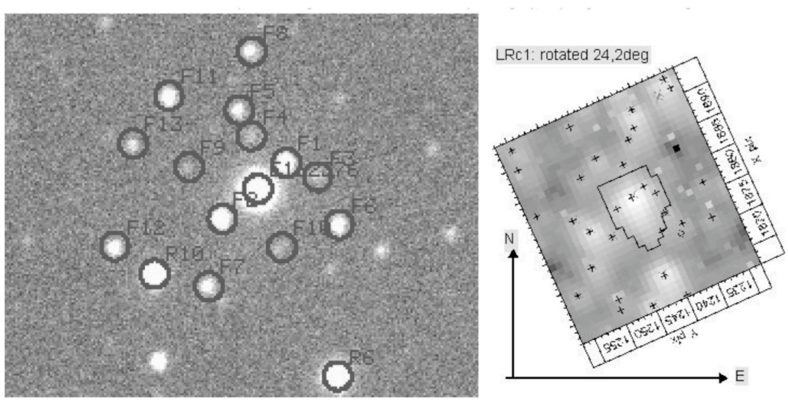


Figure 9 : Left: high spatial resolution image of one CoRoT target and its neighbor stars encircled. Right: same region as seen by CoRoT with the contour of the photometric aperture overplotted. The fainter nearby stars encompassed by the mask are not readily visible on this image.

Different kinds of complementary observations must be carried out in order to help identifying impostors among the selected candidates:

- Ground-based photometry performed on high spatial resolution images at epochs derived from the ephemeris of CoRoT transits, provides the needed verification to rule out a possible contamination by a diluted eclipsing binary in close vicinity of the target (Fig. 9.).
- Radial velocity measurements allow for the identification of binaries at short orbital period or even triple systems. Given enough observations, radial velocity measurements also provide a definitive establishment of the planetary nature of a transiting body and provide the mass of

the planet. The *a priori* knowledge of the orbital period and phase from the CoRoT transits optimizes the sequence of Doppler measurements to be performed. This technique is, on the other hand, limited to slow rotating solar-like stars and quiet stars and cannot be used to remove all ambiguities.
- Spectroscopic observations at high spectral resolution for secured planets are performed. This final detailed spectroscopic analysis is mandatory to get precise fundamental parameters of planet host stars such as stellar radius and mass and further derive those of the planet.

The publication reporting the discovery of CoRoT-7b is a very good illustration of the complexity of the sequence of tests needed to assess a robust level of confidence in the identification of the nature of the transiting object. It has been possible to rule out with a very high probability all the impostors without the radial velocity measurements. This verification however required to use a number of telescopes, from the 80cm telescope at Canaries to the 8m ones at ESO and instruments such as FORS and UVES on the VLT or MEGACAM at the CFHT. This was fortunate as for such a system of very small mass, the signal is very small and embedded in the variability due to the star activity.

Radial velocity measurements are also mandatory in order to get a complete characterization of a planet, if possible. The planet mass could be indeed measured only by radial velocity observations. Combined with the planet radius, it provides the planetary mean density, giving access to fundamental insights into their interiors.
In the case of CoRoT-7b, HARPS has succeeded to confirm the planet and measure its mass but it required 108 individual observations with this 3.6 meter telescope equipped with a presently unique spectrograph. This data has also permitted the detection of a second (larger) planet that does not transit its star in this system.

At last, complementary observations permit deeper studies of the planet properties, such as for example, the measure of the spin-orbit angle, which provides insights into the planetary system formation history.

Though quite lengthy, the adopted strategy clearly increases the scientific return of the CoRoT mission. It is not to much to say that the set of published CoRoT discoveries constitute some of the best exoplanetary studies that have been carried out so far.

Further, the list of confirmed planets will increase (most immediately with 4 new planets which are currently being processed through the follow-up) as there are still many candidates awaiting a confirmation by ground based complementary observations.

3.1.3 New questions raised by CoRoT

CoRoT's discoveries has allowed the study of exoplanets in new and different ways and led to several key questions :

- How can small planets like CoRoT-7b migrate so close to their parent star ? Where do they form ?
- Did such planets form by gradual accumulation of planetesimals or is it the remnant core of a gaseous planet stripped from its gaseous layers?
- How frequent are they ?
- How can a massive planet like CoRoT-2b be so much larger than theoretical models predict ? Is it due to its youth ? Are tides a solution ?
- How did CoRoT-1b and 6b, transiting planet with very low metallicity parent star, form ?

- What is the link between the existence of a close-in planet and the activity of its parent star ? How do star and planet interact ?

3.2 The challenge of the Small Planets

CoRoT is ideally suited to address this major question of extrasolar planetary science*: Does a family of very small (rocky) planets on very short periods exist ("hot terrestrial)"?* Such objects would form an equivalent to the family of the meanwhile well known close-in gas giant planets ("hot Jupiters").
The existence of such type of planet family would put important constraints on the models of planet formation and open a new branch in comparative planetology towards hot terrestrial planets in extreme environments (strong stellar heating, stellar wind and radiation environment).
The distribution of planet masses versus orbital period (Fig 10) does not show a uniform distribution and an apparent lack of small close-in planets (lower left). Only a few planets are found in this range with CoRoT-7b being the smallest and closest to its central star (demonstrating the difficulty of detecting such objects before CoRoT). Migration of planets during the planet system formation process provides a possible explanation for this apparent lack of close-in small planets. However, at present it is unclear to which extent observational detection limits bias the distribution in the small planet mass range. To continue the search more small, close-in terrestrial planets is urgently needed.

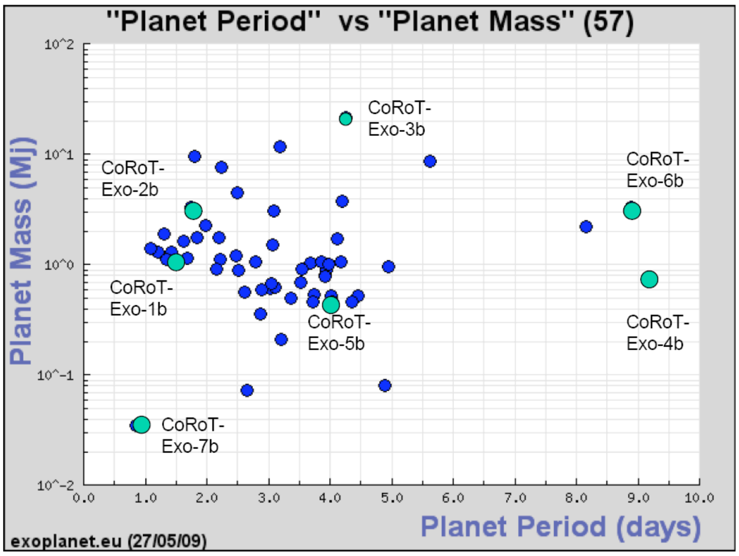


Figure 10: The transiting planets at periods less than 10 days (known by the end of May 2009). The number of planets is very small in the low mass range.

Characterizing the physical nature of small extrasolar terrestrial planets will be a major scientific goal in exoplanet science in the future. Terrestrial planets detected by CoRoT already provide input for such scientific activities by measuring the planet size (from transits) and mass (from radial velocity follow-up). These parameters provide input for mass-radius models giving a first indication of the interior nature of the planets (metals, rock, ice). Extended exospheres/tails of large close-in terrestrial planets found around the bright end of its magnitude range will even be potential targets for further future follow-up observations.

Systems with small planets show other unexpected pecularities. For example, whereas giant planets are preferentially formed around stars with high metallicity, this seems not to be the case for small planets. Unfortunately, the number of planetary systems with small planets is still extremely sparse. CoRoT is just timely to address this still open question by increasing the number of small planets.

Detecting small planets on longer periods (the link to planets as we know them in our own Solar System) complements these observations.
The comparison of terrestrial planets in different system configurations (associated with outer gas giants, different mass functions, etc.) will provide significant constraints on our understanding of planet formation and evolution.

In summary, the CoRoT extended mission is timely and ideally suited to expand the range of known extrasolar planets towards small, terrestrial, close-in planets, thereby significantly enhancing the information provided to a number of scientific areas studying planet formation and evolution.

3.2.1 Detecting small planets very close to their star

CoRoT detected the smallest planet ever found by the transit method (CoRoT-7b) to date. Therefore, we can now confirm our pre-launch expectations: CoRoT is able to detect small planets around solar type stars, measure their radius and, thanks to the mass measured with complementary radial velocity measurements, infer their density. Furthermore, CoRoT-7b turned out to be part of a planetary system, since a companion planet with a Neptune mass was subsequently discovered by HARPS. An additional planet is still debated. This first example of a small, terrestrial planet detected by CoRoT and its subsequent follow-up observations from ground convincingly demonstrates the strength of the mission concept and its team, leading to scientifically new and interesting results which stimulated exciting discussions among the scientists as well as the general public with a high impact factor.

Finding close-in planet systems is not a complete surprise since others have been previously discovered by the radial velocity method. Most of these planets are, however, giants or Neptune-sized planets. Only very recently Mayor et al. (2009) reports the discovery of another close-in system containing a small planet, however orbiting around an M star. Since the diameter of this object have not been measured (its signature could only be determined from space wven if it was transiting), we do not know its composition. Today, we can reasonably expect that other similar systems, composed of rocky terrestrial planets, possibly associated to a giant planet, should exist. Such close-in systems are well within the grasp of CoRoT for three reasons :

(i) the high transit number (high duty-cycle, long duration),
(ii) the high geometrical probability of detection (> 30% in the case of CoRoT-7b),
(iii) the higher transit probability for a system than for a single planet.

Since close-in planet systems seem to be the rule, CoRoT could have (before KEPLER) the unique opportunity to bring relevant statistical results on these systems covering the planet size spectrum from giants to super-Earths and a range of periods from approximately 1 to 20 days.

3.2.2 Detecting small planets at long period

Presently no long-period transiting planet was found in the low mass range of the mass spectrum (Fig 5). This part of the mass-period range is therefore not well sampled with planets for which their primary parameters, radius and mass, are known. The discovery of one (or some) small long period planet(s) is a challenge that will be an important step for the future mission. Fortunately, the depth of the transit signal is independent of the orbital period of the planets, in contrast to the radial velocity method. Thus, for planetary systems with appropriate alignment of the orbital plane, CoRoT will be able to detect such long-period small planets due to its unprecedented photometric precision and high duty cycle. Good characterization of the transit signal, however, requires long observing periods to cover a sufficient number of events.

Improving the detection of these planets is possible by increasing the length of the observation. Today, the longest period transiting planet is HD80606b with a period of 111 days. This planet, as well as the other only known transiting planet with P>20 days (HD17156b, P=21 days), was detected first by radial velocity measurements. The longest period transiting planet detection was made by CoRoT (CoRoT-4b, P=9 days). Furthermore, planet candidates found by CoRoT include objects up to 100 days in the present data sets and are being followed up. Re-observing the fields will confirm or reject known objects.

3.3 The discovery and fine characterization of gaseous planets with CoRoT

An extension of CoRoT would of course enable extending the population of known transiting gaseous planets, yielding in particular detections that would otherwise be missed by ground-based surveys. CoRoT's high yield implies that detailed statistical studies can be performed to discover links between parameters of the problem and constrain models of the formation of planets. The spacecraft stability and high sensitivity also allow to answer such question, that is not possible from the ground.

3.3.1 Increasing the sample

The number of known transiting planets is increasing thanks to CoRoT and to intensive observational effort carried out from the ground for years. The resulting population displays an unexpected and puzzling diversity. Clearly, the large number of parameters (planet mass, radius, orbital distance, eccentricity, inclination, stellar age, mass, radius, effective temperature, metallicity) imply that the sample of ~60 transiting planets is still too sparse for a precise understanding of the role and links of the different parameters. Importantly, there are biases that prevent or limit the detection of certain planets by ground-based surveys.
CoRoT has demonstrated that it is able to detect very small planets, planets on long-period orbits and around very active stars. The fact that the whole CoRoT database is being made publicly accessible and not only the detections will be a key for future statistical studies.

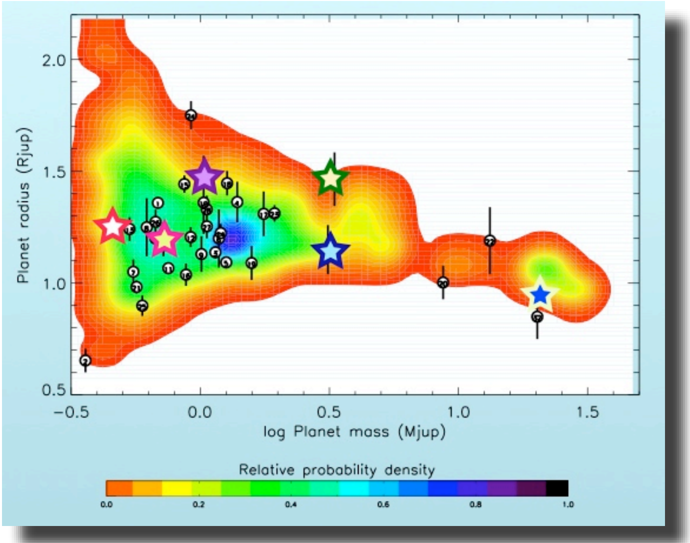


Figure 11 : Predicted probability density function for giant planets (colored region) as calculated by CoRoTlux (Fressin, Guillot & Nesta 2009) compared to transiting giant planets discovered by ground-based surveys (circles) and by CoRoT (stars). Note that the calculation is valid for giant (gaseous) planets only, so that CoRoT-7b is not on this diagram.

In an extended mission, we will seek especially the discovery of long-period planets (Out of 5 transiting planets with period larger than 6 days, radial velocity surveys have found 2 of them, ground-based surveys 1 and CoRoT so far 2), planets around young active stars (CoRoT has discovered the only one known so far) and Uranus-Neptune size planets. Two of these are now known to transit their star, but CoRoT hasn't discovered any. The fact that it has discovered a super-Earth proves that it would have found ice-giants as well if they had been in the sample. But we know that these planets exist, they are also extremely interesting because we would like to know whether they always contain both ice and hydrogen, or if they show large varieties in their compositions like the gaseous planets. Only two are known so far. CoRoT is able to detect them, if it is given time to do so.

3.3.2 Secondary eclipses and planetary atmospheres

The transiting planets are presently the only ones for which the nature, internal structure, and atmospheric properties can be probed. This has a strong impact not only on our understanding of their interiors and their formation mechanisms but also on the physics of their atmospheres. This could be achieved by deeper complementary analyses carried out on the CoRoT light curves themselves, but also thanks to ground-based complementary observations.

Depending on the composition of their atmosphere, the highly irradiated close-in giant planets are valuable targets to probe their atmospheric properties. Fortney et al. proposed the existence of 2 classes of hot Jupiters, each being expected to have very different emitted spectra and day to nightside circulation. As a consequence, the depth of the secondary eclipse which corresponds to the occultation of the planet by its host star, is expected to be significantly different from the one class to the other. The detection and measure of the secondary eclipses is thus a critical observational test and provides precious information about their atmospheric properties.

Studies carried out thanks to Spitzer Space Telescope, in the near infrared spectral domain where the planet thermal emission is more important, have produced a number of detections in good agreement with the model predictions. However, in the optical domain, the expected signal from the secondary eclipses is expected to be around some hundredths of a percent and remain impossible to detect from the ground. Despite several attempts, no positive detection

from the ground has been reported so far. However, such measurements in the optical domain would nicely complement the Spitzer measurements. They would allow for an independent test of the theory of Fortney et al. and would made possible a detailed modeling of the highly irradiated hot Jupiter.
Very recently CoRoT has demonstrated its unique capability with the detection by two independent studies of the secondary eclipses of CoRoT-1b (Fig 6). These first results and the improving quality of the data reduction pipeline with better correction show that such studies could be carried out over an increasing sample of planet in the post –cryogenic Spitzer area.
CoRoT will then have a significant contribution for the study of exoplanetary atmospheres.

3.3.3 Transit time variations and multiple planetary systems

The high quality of the CoRoT photometric measurements can be used to investigate the presence of other planets in the same system, thanks to the analysis of the transit timing variations which need long term monitoring and a high time sampling. Depending on its mass and orbit, the presence of an additional companion could indeed perturb the orbit of the transiting planet and cause deviation from strict periodicity of the observed transits with sensitivity to very small masses (Earth masses or below).

In general, Transit Timing Variations (TTV) caused by a companion planet have, for reasonable values of the planet parameters, amplitudes of the order seconds. But there are two exceptions: resonant planets where the TTV can be of the order of minutes and Trojan planets where it can be of the order of tens of minutes. TTVs are larger in long period planets because they are proportional to the star-planet distance if due to a second planet. TTVs due to a second planet also increase with time if they are due to a distant planet. Reobserving the same field after a couple of years thus increases the likelihood of TTVs. Finally, TTVs due to an exo-moon are more likely at large distances (moon around hot Jupiters are not very likely).
Moreover, the lack of detected transit time variations allows to place limits on the mass and orbital properties of an hypothetical additional planet.
Two recent independent studies carried out on CoRoT-1b detected no periodic period variation at a shorter period than the duration of the CoRoT observational window (55 days). They also demonstrated that **CoRoT has the sensitivity to detect or rule out planets with masses greater than that of Mars in the 2 :1 outer mean motion resonance, providing insights into the planetary system structures and further their formation and evolution**.

3.3.4 Systems of transiting planets

New evidence suggests that planetary systems are the rule at low mass:

- the bimodal theoretical planetary initial mass function points to an abundant population of Hot Neptunes with the two peaks being even narrower for radii and near Jupiter and Neptune-values.
- new dynamical stability investigations demonstrate the physical possibility of ultra-dense close in planet systems (10 or more planets in the period range of 1 to 10 days in the same system);
- radial velocity discoveries published in spring 2008 indicate a 30% presence of planets with Msini of 5 to 30 earth masses around solar like stars, all in multiple systems.
- Systems with two transiting planets would be an extremely interesting configuration to characterize.

3.4 Improvement of the preliminary results from the previous run

In the field of view already observed by CoRoT a number of candidates have received less attention due to the small transit number in their light curve. For many others, follow-up has become very difficult due to the imprecision in their ephemeris (which makes the predictions for their transit times increasingly unreliable). These cases can be solved by reobserving some previous fields or at least part of them.

3.4.1 Increasing the significance and the parameters of the transit signals

At a given photometric accuracy it is possible to increase the significance of successive transits, by increasing the length of the light curve. For example, if the data set is two times longer, the signal-to-noise ratio (SNR) would be approximately increased by a factor 1.4. Transits marginally detected with a SNR of 3 would become more secure candidates with a SNR of 4.2.

A number of undetected transit signals could become marginally detected candidates (and thus allow precise follow-up), thus increasing the possibilities of new interesting discoveries. This would be highly valuable in the case of small long period planets.

3.4.2 Revisiting candidates with two detected transits

These targets are extremely interesting because they correspond to long period planets. Long periods imply cool planets with a different physics and mass-radius relation.

Presently for the runs LRc01 and LRa01 there are 4 long period candidates with transits each with depth ~1% and periods from 50 to 80 days corresponding to a ~ 0.3 AU. Were they planets, this number would be consistent in order of magnitude with the statistical prevalence of ~ 1% for planets in the a = 0.15 – 0.5 region, as discerned from RV surveys.

The reobservation of the same targets preferably in another long run should give transits with a probability of 100% and would confirm the period.

3.4.3 Recovering lost ephemeris

For many of the candidates identified in the CoRoT light curves the follow-up turned out to be very difficult (particularly in the short runs); this is due to the imprecision in their ephemeris which makes the predictions for their transit times increasingly unreliable.

This was the case for candidates from the first short runs SRa01 and SRc01 (four priority 1 candidates + six priority 2 candidates). Considering that Short-runs are nearly as effective as longer runs in detecting Hot Giant planets, one may estimate that we are loosing some 2-4 real planets among these priority 1 and 2 candidates, unless something is done about it.

To recover these candidates' ephemeris from ground-based observations is very uncertain and could only be done under special very rare circumstances for each candidate. The only efficient solution would be a re-observation with CoRoT of the short-run fields.

3.5 The strategy for the exoplanet hunting programme

The different objectives presented before point towards two different observing programmes:

- one oriented towards an increase of the number of runs with the increase of the number of bright stars. The main outcome would be the detection of low mass planet systems, i.e. super-Earths and Neptune like planets, that should be present in the very close vicinity of their parent star and a significant increase in the statistics of Hot Jupiters and Neptunes.

- the second one would be a reobservation of previously observed fields in order to increase the significance of promising candidates by lengthening the duration of the observation (and increasing the number of detected transits).

As the duration of the mission is certainly limited, we tried to estimate the minimum duration of an observation for an efficient detection.
Using all the detections made during the long run, LRc01, the change in the performance as a function of the run duration is given in Figures 12 and 13. It is found that the number of detections is reduced by only 10% when the duration of the run is divided by 2.

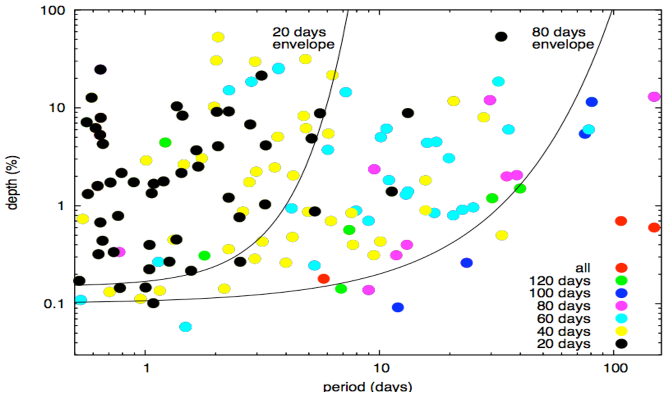


Figure 12: Depth of the transit candidates detected by the CoRoT detection teams in the run LRc01, as a function of the period of the signals. The various colors indicate the length of the light curves on which the candidates were detected. A run with a duration of 80 days do not change significantly the detection capacity at the various periods.

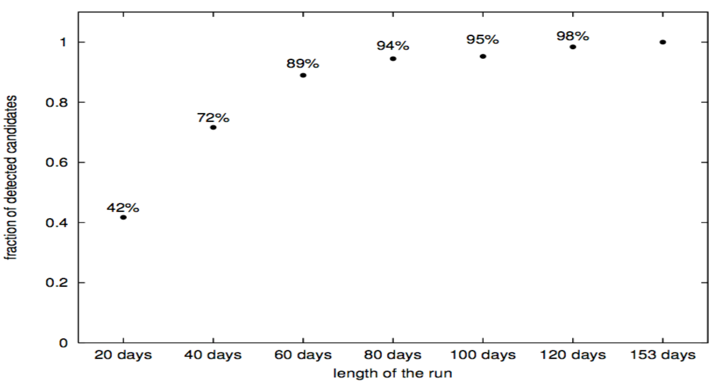


Figure 13 : Total fraction of the detected candidates as a function of the length of the run LRc01. The various dots correspond to the different durations of the run. For a mid run of 80 days the loss fraction is only ~ 6% of the number of candidates detected after 153 days.

4 The Seismology programme

A few highlights illustrate the ability of CoRoT to perform seismology measurements sufficiently accurate to allow detailed interpretations.
Then propositions for the extension are presented based on two main orientations, exploration of new types of stars and more detailed studies of some pulsators.

4.1 A few highlights

With the observations already achieved, we have proven that CoRoT has the capability to provide a completely new vision at the stars, by revealing their microvariability.
CoRoT is able to measure and characterize oscillations at the ppm level in other stars than the Sun, thus opening the way to extend helioseismology beyond the solar case. CoRoT is the first instrument to achieve it.

90 “bright” ($5.4<mV<9.5$) stars have been observed so far in the Seismo Field, during 4 long runs (~150d), 1 intermediate run (60d) and 4 short runs (~30d).
In seismology, all the presentations at the CoRoT Symposium (Paris February 2009) revealed an unprecedented step forward. CoRoT revealed low amplitude oscillations in stars looking constant so far, hundreds of oscillation frequencies where a few were detected from the ground. The characteristics of these oscillations can be followed continuously on time scales of 5 months inaccessible from the ground.

Among the results already achieved by CoRoT, a few striking ones are presented here.

4.1.1 Solar-like pulsation, granulation and convective core:

CoRoT measured solar-like oscillations and granulation in stars hotter than the Sun. This result made the cover of Science Magazine where it was published in October 2008. Science Magazine, with Observatoire de Paris, CNES and CNRS also organized a press conference for this event at Paris Observatory (22/10/08). The amplitudes measured have been found to be in agreement to within 25% of the theoretical values thus providing a first confirmation of these estimates at first order and a valuable guideline to refine them further. The characteristics of the granulation signature suggest time scales by 30% larger than in the Sun for convection near the surface and granule size about 4 times larger than in the Sun. The modes widths (inversely proportional to the lifetime of the modes) have been found to be noticeably larger than those in the Sun, and larger than expected. This tells us that the interaction between convection and oscillation in the outer part of the stars are more efficient than expected in damping the oscillations. This also makes the data analysis more challenging and induced the development of specific techniques. In terms of stellar structure, the first seismic interpretations of the measured eigenfrequencies are addressing the crucial question of the extension of the mixing beyond the stellar convective core. This key process is responsible for the present large uncertainty on stellar age determination. These interpretations still need to be consolidated, but several studies already suggest the need for a noticeable extension of the mixed central region, of the order of the maximum expected values or even larger.

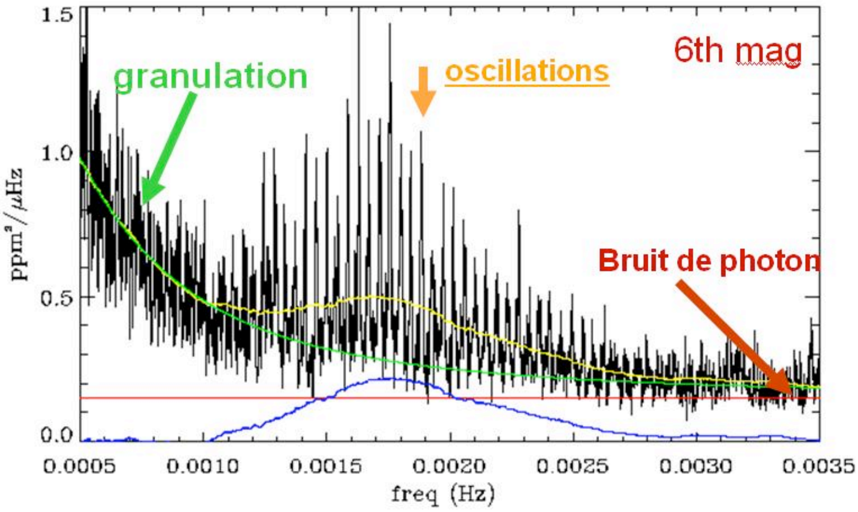
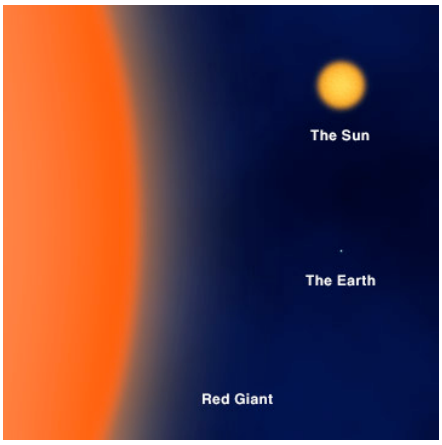


Figure 14: The very rich Fourier spectrum of solar like stars

4.1.2 Red Giants and the future of our Sun

Toward the end of their lives, stars like the Sun expand and become red giant stars. Because of the turbulent convection in their outer layers, red giants stars are expected to exhibit solar-like oscillations, but in a much lower range of frequencies (10 to 100microHz). Though some spectroscopic observations from the ground on a few bright objects, this behavior has been detected. The small sample available, plus the limitation in duration and duty cycle have made it impossible to get a clear idea of how these objects pulsate.

Thanks to CoRoT data it has been possible, for the first time to measure clearly such oscillations in a large sample of red giants, both on bright objects in the seismo field and on faint ones in the exofield.



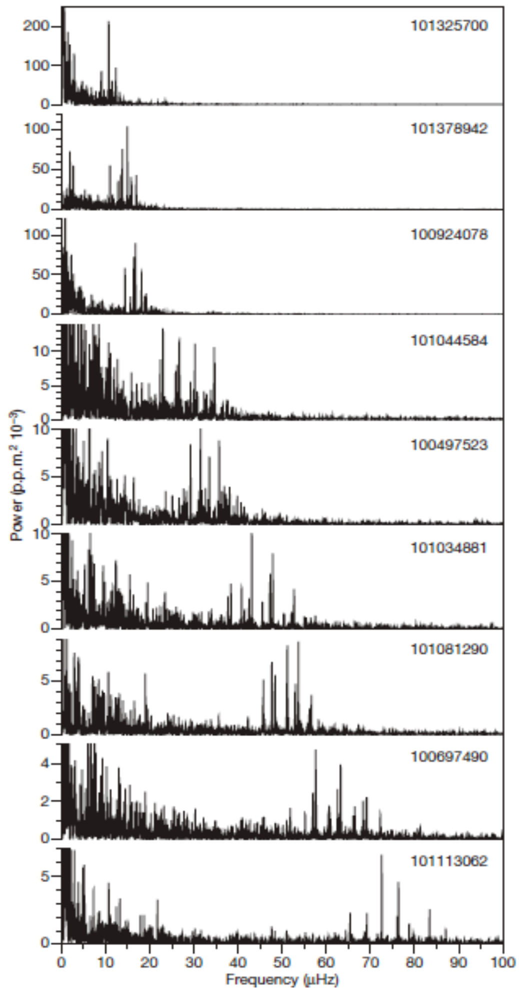


Figure 15: A set of Fourier spectra of giant stars

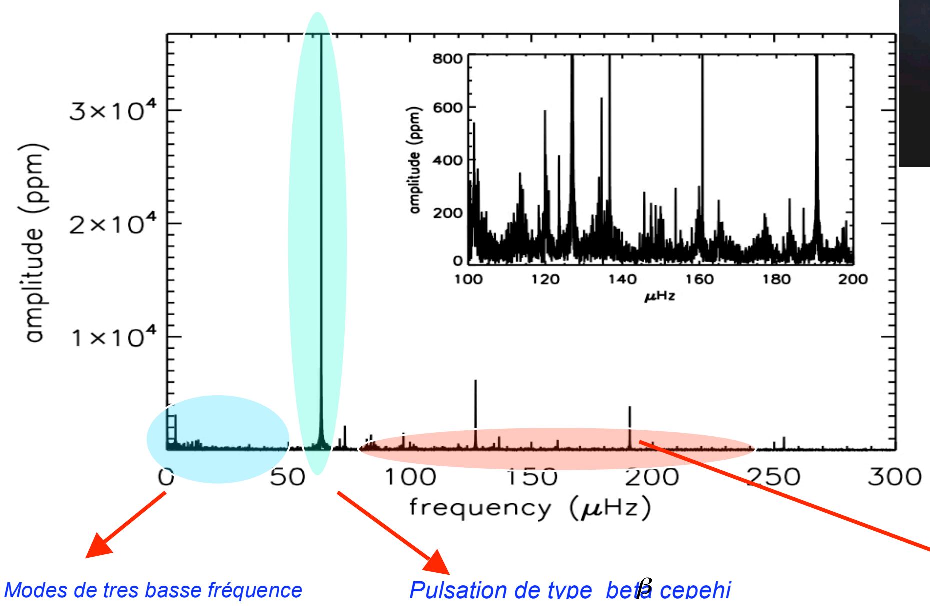
, with their oscillations ordered by frequency domain

Beyond this, the quality of the CoRoT data has provided unambiguous evidence that both radial and nonradial modes are excited, an open question so far. It also confirmed the existence of modes with lifetimes of the order of a month. These results have been published in the review Nature (May 2009).
This observational breakthrough has initiated a strong effort in theoretical modelling of this stellar evolution stage. The first results suggest that it would be possible to explain the observed oscillation spectra and their variety for different stages of the structure of stars, along their expansion in the red giant phase.
It seems that the distribution of frequencies at maximum power, among all the observed red giants, presents a rather narrow peak which has to bear the print of the evolution of our galaxy. Indeed these red giants of different masses and ages are representative of all the successive generations of stars in the galaxy. The exact shape of this distribution could indeed reveal secondary peaks, indicative of different stellar populations or different stellar formation episodes, if the number of observed red giants increases. This requires long periods of observations, in the seismo field for detailed analysis of a few bright stars and in the exofield for a statistical complement.

4.1.3 Chimera, new types of pulsators:

Thanks to the noticeable gain in sensitivity, duration and duty cycle, CoRoT data were expected to lead to the discovery of new types of pulsating stars. HD180872 is one of them. This star was known to belong to the Beta Cephei class of pulsators, young massive stars progenitors of SN-II type supernovae and thus main responsible for the enrichment of the Universe in carbon and oxygen. These stars classically show oscillation periods of the order of a few hours. In the lightcurve of HD180872, CoRoT data revealed, at very low amplitude, the existence of higher frequency modes, due to stochastic oscillation, very comparable to the ones observed in the Sun. This confirms the existence of a powerful convective zone and will allow the scaling of its energetics. This discovery opens new perspective in the study of these objects where low frequency oscillations and high frequency ones could be used in a complementary way to probe the centre and the outer layers of the star. These results are being published in a June issue of Science.

monstre femelle
qui crachait des flammes ;
elle avait la tête d'un lion, le
corps d'une chèvre
et la queue d'un dragon.



Figurel 6: The star HD 180642 showing three types of pulsations. Two of them have been discovered by CoRoT: the very low frequencies ‹hich were expected, and the high frequencies solar like modes which were totally unexpected.

4.2 Proposition for the extension

4.2.1 Cooler solar-like stars

Solar-like pulsators are the most demanding targets of the CoRoT programme, due to their very low amplitude and low coherence time. On the other hand, they are closer to the Sun in structure and thus an important link in the extension of helioseismology to other stars. They are also a niche for CoRoT which is the first mission to be capable to measure and characterize those oscillations.

So far, 4 such stars have been observed with CoRoT: Two 'hot' (6700K) ones and two intermediate temperature (6100K) ones. The hotter ones revealed power spectra very different from the known solar case, apparently because of mode lifetimes shorter than expected. This fact is interesting for studying the energy exchange between oscillations and convection, but this also makes the recognition and analysis of the oscillation spectra more challenging. The two intermediate temperature ones have been observed only recently. Their oscillation spectra look more like the solar one, but still some ambiguous features remain. In fact, it seems difficult to interpret completely this set of 4 spectra in the framework of what we know, or believe to know from the solar case, in terms of relative energy of the modes and main characteristics of the oscillation spectra. This could be due to several factors like metallicity, rotation profile, magnetic activity, etc. It is thus important to extend further this sample of solar-like pulsators in order to disentangle the effect of the various potential parameters and have a clearer view of what is common and what is specific to these different stars. An extention by two years of the CoRoT mission constitute a unique possibility to increase significantly this sample and make it richer, especially at low temperatures, close to solar one.

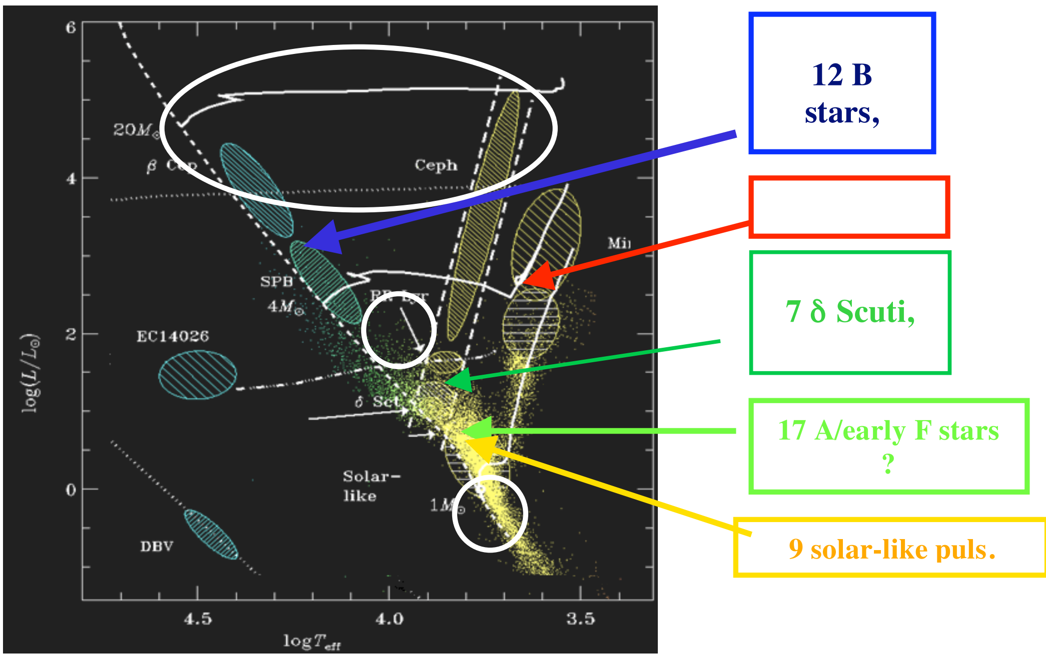


Figure 7 HR diagram showing the regions were CoRoT observations have been performed and those (in white) where they are badly neede.d.

This objective is among the less affected by the perspective of a reduced field of view, since bright enough solar-like targets are difficult to find targets and always principal targets (high priority targets) around which the field selection is organized. The only constraint is that for these objects, data obtained till now suggest that the length of the observations has a crucial impact on the precision of the oscillation parameters. These objects should be observed in long runs.

Duration of the runs and identification of the modes in solar like pusators
We have now several cases evidencing the long duration of an observation for these types of pulsators.

* The first one is HD 49933, which has been observed in the Initial run for 60 days and in a long run for 132 days.
The echelle diagram with the confidence box, done for the inital run only and for the two runs, illustrate the increase on the accuray on the frequencies, and then increases the confidence level of the mode identification

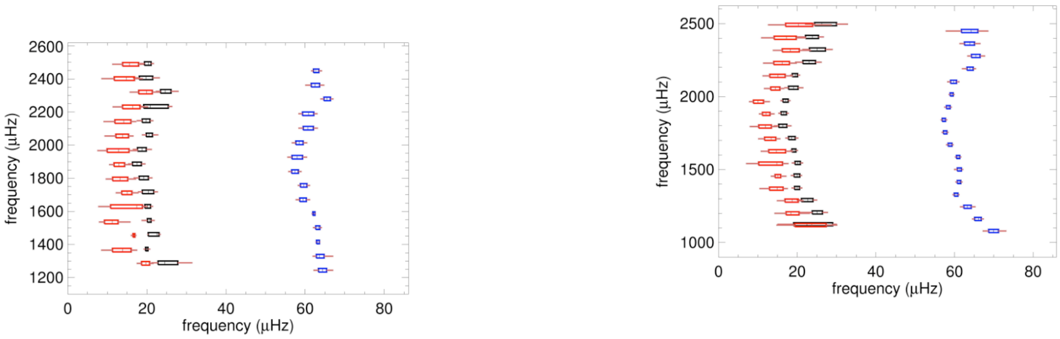


Figure 8 :Echelle diagram of HD 49933, as observed for 62 days in IRa01 and combined with the second observation of LRa01 for 138 days.

* Another example is given by HD 43589, a pulsator with higher amplitudes, in which using the total length of the data (150d), one can distinguish l=3 modes, whereas with only 80 days it is not so

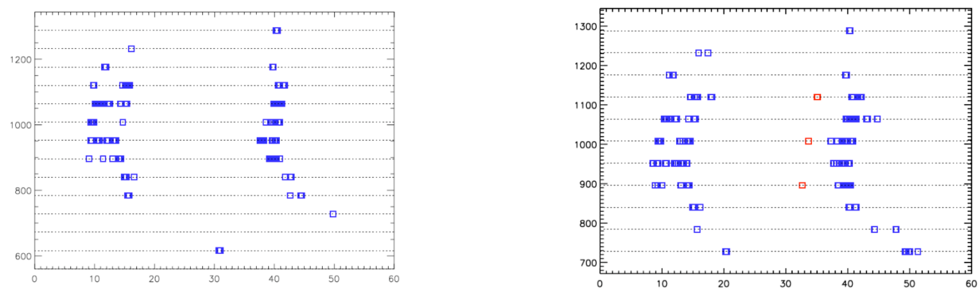


Figure 9 Echelle diagram for 80 days and for 150 days in red

* The comparison of HD 175726, which was observed for only 27 days, with other Corot targets, proves that the short observation duration is prejudicial for retrieving precise eigenfrequencies in the oscillation spectrum. We have computed the Fourier spectra of HD 49933, HD 181420 (Barban2009) and HD 181906 (Garcia2009) for a reduced 27.2-day time span. The spectra of the short time series of HD 49933 and HD 181420 exhibit the seismic signature, whereas the spectrum of HD 181906 shows no clear signal when the time series is reduced to 27 days, contrary to the full time series spectrum. As HD175726 and HD 181906 have very similar signal-to-noise ratios, we can expect that HD175726 will exhibit a spectrum as clear as the one of HD 181906, if observed during a Corot long run.
As compared to other CoRoT targets, HD175726 is cooler, with an estimated G0 type. Reobserving it will permit to extend the CoRoT seismic analysis to G dwarfs.

Table 3. Contributions to the power density at the frequency where the seismic signal is maximum, and mean seismic signal-to-noise ratio for HD 175726, compared to other CoRoT targets. *Indication of the maximum height-to-background ratios for HD 175726, in the spectrum respectively rebinned to 1 or 2μHz.*

star	$f_{\max}$ (mHz)	mean power density at maximum total	granulation	noise	p modes	⟨SNR⟩	$HBR_{1\mu Hz}$	$HBR_{2\mu Hz}$
		.... ($ppm^2\,\mu Hz^{-1}$)						
HD 49933	1.8	0.44	0.11	0.14	0.19	1.18		
HD 181420	1.6	0.65	0.20	0.28	0.17	0.79		
HD 181906	1.8	1.01	0.10	0.79	0.12	0.39		
HD 176725	2.0	0.41	0.05	0.31	0.05	0.37	4	3

Other candidates exist in the CoRoT eyes, and the next Long run in the anticenter direction, as already programmed will focus on such a star – HD 43587.

4.2.2 B supergiants

The internal structure of B supergiants is closely related to their past history of core hydrogen burning. For such massive stars (M > 10 Ms), the convective core in which hydrogen burns, is surrounded by a semiconvective region whose structure is not understood at present. If a partial mixing takes place, the adiabatic and the radiative gradients are so close during the whole main sequence phase that the ignition of the hydrogen shell burning at the onset of the supergiant phase gives rise to a fully convective zone (ICZ). The existence of an ICZ is very important because it is the necessary condition to allow excited g-modes in the spectrum of a B supergiant. The presence and the extent of the ICZ closely depend on the treatment of semiconvection but also on the amount of rotation and mass loss. The conclusion is that the observation of g-modes (even only one g-mode!) in the spectrum of a B supergiant is a signature of the physical processes which have been at work in shaping the layers surrounding the convective core during the main sequence phase. These layers play a significant role in the location in the HR diagram and the duration of the more advanced phases of evolution which in turn affects the ratio of blue/red supergiants. No B supergiants have been selected as main asterosismology targets during the first three years of the CoRoT mission which means that a large zone of the HR diagram is still fully uncovered by CoRoT (see figure 7)

This programme can be achieved through the observation of a few candidate targets in the anticenter direction, of several months duration

4.2.3 A variety of young Clusters

Members of Open Clusters were born at about the same time, from the same molecular cloud and therefore have similar chemical composition, if the cloud was homogeneous, and members usually have similar ages. Equally important, the distance of a member can be estimated from cluster properties without knowing a parallax. Open clusters allow therefore to test models of stellar structure and evolution in a much more stringent way than is possible with an isolated star.

Within its field of view of ~1.3 square degrees, COROT is most suitable for observing also nearby clusters, which allows for complementary measurements (e.g., spectroscopy) without the need of heavily oversubscribed 8m-plus telescopes. In the foreseeable future COROT will be the only space telescope capable to observe young clusters. Although the open field of the MOST satellite is of comparable size, the limiting magnitude for MOST is around V = 12mag, which constrains the list of observable clusters significantly. Furthermore, COROT features a more than 7-times larger aperture, considerably reduced background and hence provides much better photometric accuracy. The KEPLER field-of-view on the other hand is located high above the galactic plane where no young clusters can be found. Hence, the KEPLER mission is not suited for such objects.

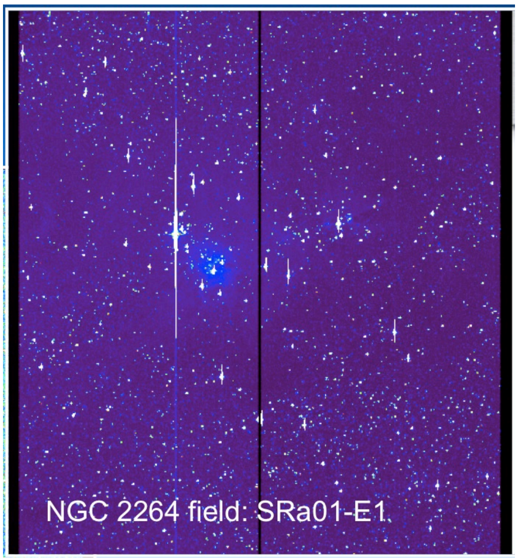


Figure 8 The young NGC 2264 observd by CoRoT in the exoplanet field. 900 stars member of the cluster have been followed

Several open clusters are visible in the current eyes of COROT: 14+/-3 in the center direction and 41+/-4 in the anticenter direction. The actual number depends on the requested level of population in the color-magnitude diagram and how much stray light can be tolerated close to the borders of the "eyes". Five of the clusters in the anticenter direction are younger than 10 million years allowing thus to observe stars that were recently born, still contract towards the main sequence and have not yet started hydrogen burning. Among those are the two clusters that were already observed by COROT with much success: Dolidze 25, which was observed as additional target during one of the long runs, and NGC 2264, which was driving the selection of a short run (SRa01).
This later run also illustrates the breadth of science which can be addressed with open clusters. The "NGC 2264 team" consists of ~70 scientists from the COROT community which study the interaction of young stellar objects with their circumstellar matter, investigate the rotation and activity properties of cluster members, probe the interiors of pre-main sequence stars using asteroseismology and search for planetary and stellar eclipses around young stars.

4.2.4 A/F stars:

The observations of A/F stars in and around the instability strip of delta Scuti stars has been an intense activity from the ground for decades. This domain of masses just above the solar-like pulsators is dominated in terms of energy production by the CNO cycle and not the PP chain as in the Sun. Consequently, this is also the domain where the outer convective zone becomes very shallow and the convective core becomes the dominant feature in the stellar structure. This domain is characterized by the very rich variety of stars classes showing specific surface chemical composition, specific pulsational behaviours, specific rotation rates (delta Scuti stars, Gamma Dor CP stars, HgMn stars, Am stars…). This rich variety is the indication of how transport of chemical species and transport of angular momentum develop and interact in intermediate mass stars on Main Sequence, one of the present high priority open question in stellar physics. In this domain, CoRoT has brought in two years a wealth of data of unprecedented quality, revealing hundreds of oscillation modes where only a few tens could be found from the ground. It thus becomes possible, for the first time, to address the long-standing problem of the amplitude distribution between modes, that is to say the energetic aspect of the oscillations and the processes ruling it.

CoRoT also revealed stars showing no oscillation at the ppm level. The occurrence in the instability strip of such stars, in which helium responsible for triggering the oscillations would have sunk and the link between this and rotation is also a long standing question and CoRoT by lowering the detection level by a few hundreds shed a new light on it. After two years of the CoRoT programme, we have observed about 40 of those objects, half of them in long runs. Even if this number is high, it has to be increased again, as the number of processes at stake is also large, as attested by the variety of behaviours of the variability in this domain.

The extention of the CoRoT mission by two years would allow to increase this sample and help to investigate further which differences in structure exist between these different types of objects and distentangle the effects of the global parameters (rotation, metallicity,...) responsible for it.

This objective is of course sensitive to the perspective of a reduced field of view, since the number of targets stars observed simultaneously will be divided by 2. However, the data already obtained have confirmed that CoRoT is doing well on such targets up to mV=9.5. They have also shown that for such targets, valuable data can be obtained also in intermediate or short runs, down to a few weeks. They also showed that, at this magnitude, A/F type stars are generally easy to find as secondary targets in selected fields, thus adding only light constraint on the field selection. For these stars, the reduction of the field of view can thus be compensated by the prolongation of the observations.

4.2.5 O stars

The evolution of massive O stars is very important since they are the progenitors of supernovae. They suffer a rather large amount of mass loss during core hydrogen burning and an even greater one once they leave the main sequence. This transforms O stars into Wolf-Rayet stars. The origin of this drastic increase of mass loss is still unknown. A possible explanation could be that they are subject to high amplitude pulsations coming from the excitation of “strange modes”.

The trapping of such modes requires a particular internal structure with a cavity where the density *increases* towards the surface. This can only happen if the radiation pressure is very large, i.e. in stars with a very high mass/luminosity ratio. Asteroseismology will in this respect be an invaluable tool to constrain this mass loss which in turn will precise the WR/O stars ratios and eventually the type II/type Ia supernova ratio. Some ground-based observations suggest that such modes could indeed exist in at least one O star. It would be extremely interesting to select O stars in the sismo field to help understanding the mechanism leading from O stars to Wolf-Rayet stars and then to supernovae. **O stars have been observed by CoRoT in one short run only, which means that there is an urgent need to go further in this exciting domain.**

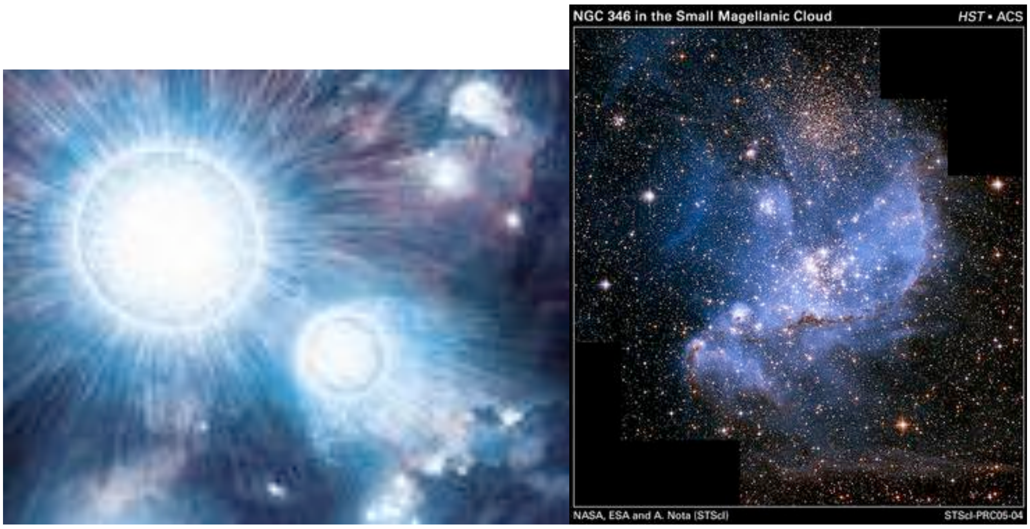


Figure 11 LFTE: An astrisitc view of the complexity of the star/cloud interaction for O stars. A very young cluster showing O stars surrounded by gas clouds.

4.2.6 Reobservation of Be stars

Be Stars are rapid rotators showing an equatorially-concentrated ionized envelope responsible for the observed Balmer emission and infrared excess (the so-called “Be phenomenon”). This envelope is fed by discrete mass ejections from the star. However, the origin of these outbursts is yet to be explained. One hypothesis is that a beating of non-radial pulsation modes added to the rapid stellar rotation could be responsible for the mass ejection episodes.
Some CoRoT fields contain very active Be stars. In particular, the LRa1 field contains HD 49330 in the seismo field. The Corot light curve for this Be star shows a clear outburst and has allowed us to discover many pulsation frequencies with associated amplitudes varying along the observing run; dominant frequencies detected during the (relatively weak) observed outburst are different from the ones detected before and after the outburst. This is the first time a direct correlation between a light outburst and non-radial pulsations has been observed. However, whether the beating of pulsations is at the origin of the outburst or whether the outburst modified the pulsations still has to be investigated. A wider temporal coverage and the observation of a second outburst in the same star would teach us about the stability of the main frequencies and their role in the triggering of outbursts. New, important insights to explain the Be phenomenon could thus be achieved.
Some fields contain very active Be stars, particularly LRa1 with HD 49330 in the sismo field. The Corot light curve for this Be star has allowed us to discover many frequencies with associated amplitudes varying along the run; dominant frequencies detected during the outburst are different from the ones detected before and after the outburst. A wider temporal

coverage will teach us about the stability of main frequencies and their role in the triggering of outbursts, which are known to be recurrent.

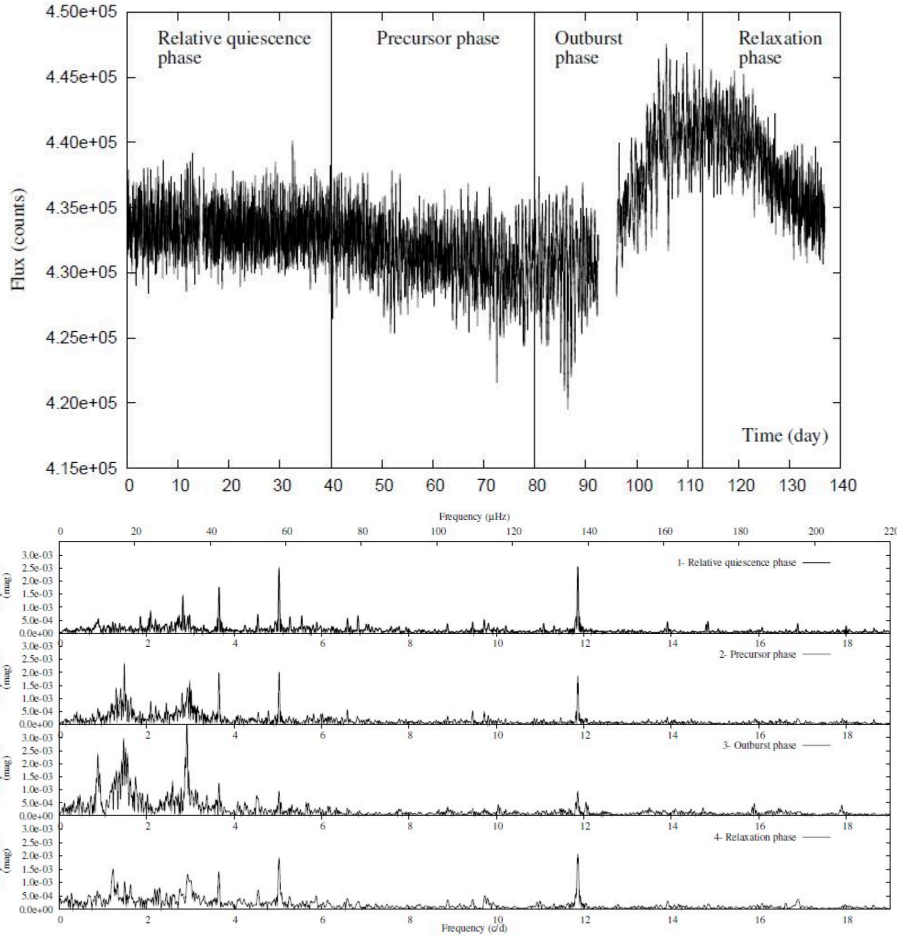


Figure 12: The Fourier spectrum of HD 49330 before, during and after an outburst as seen above

5 The Additionnal Programmes

In addition to the two major programmes described above, CoRoT has given the possibility to address other scientific questions in the framework of Additional programmes.
They are open to the world wide community. Announcements of opportunity are regularly issued when the pointings are known.
This programme has been already very succesful, in particular in the field of ecclipsing binaries, classification of variability, specila dn rare types of variables and stellar activity, rotation and convection

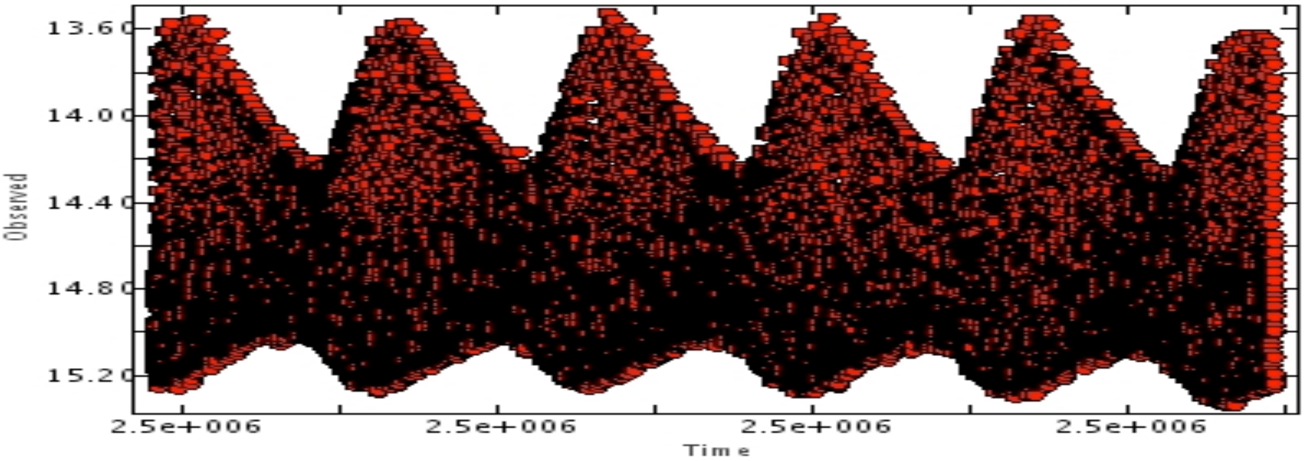


Figure 11 : The Blasko effect (modulation of the amplitude of the 0.5 days oscillation) perfectly measured on RR Lyrae stars thanks to the extreme accuracy and the length of the observations (156 days).

The long and continuous light curves are very appropriate to measure the rotation period, through the periodic modulation due to activity.
The evolution of the rotation rate with the stellar age has been followed on solar analogs, chosen to represent the evolution and characterised from the ground.

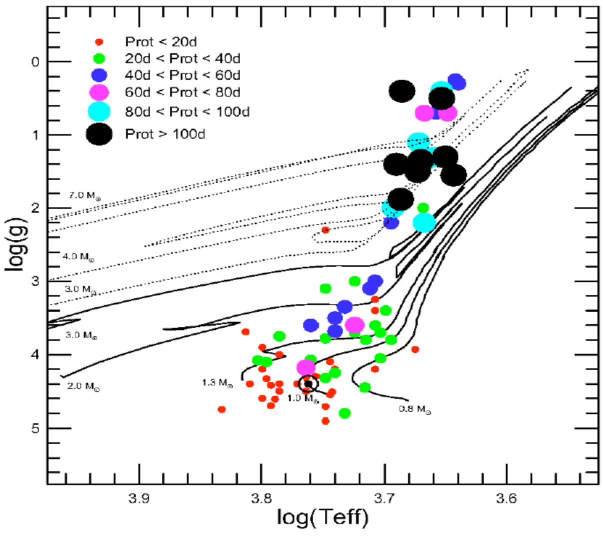


Figure 23 : The rotation/age relation for the solar analogs

The fluctuations of luminosity are also interpreted with spot modeling. In already several stars, it came out that the spotted area (several percents) is generally larger than for the Sun. Differentail rotation is even found in these long data sets.

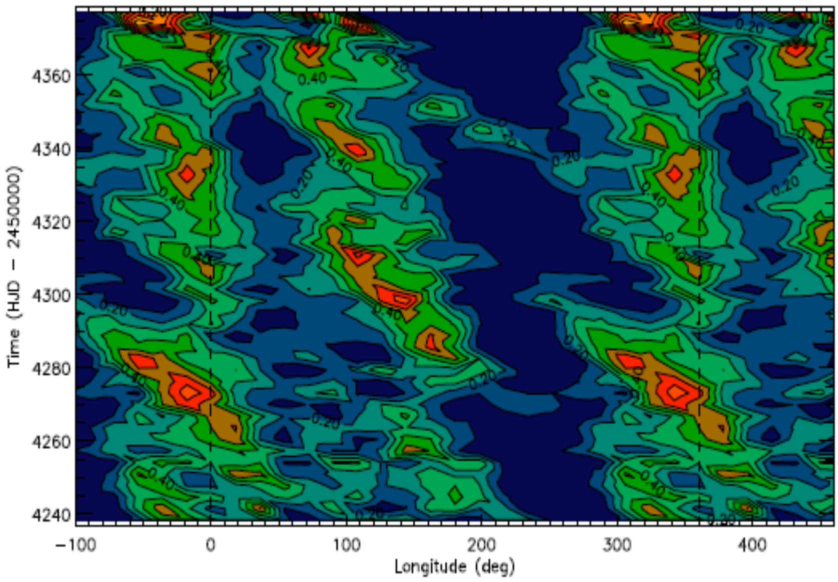


Figure 24 Differential rotation of CoRoT-2a

These programmes rely essentially on statistics and so need to collect data on as many objects as possible.
They will strongly benefit from the extension.

6 Towards a global strategy for three years

The present document has given a rapid survey of the work done by the CoRoT scientific community in two years.

Based on the knowledge of the instrument and its capacity, as well as some of the results obtained up to now, we are strongly willing to extend the duration of the mission.

We have shown that many subjects can be adressed, some completely new, some needing more statistics, in the different topics that CoRoT can document.
We need both to study new types of targets in seismology, and increase the statistics of the exoplanet hunting. Some runs could also be devoted to a reobservation in specific cases.

A global vision of the observing programme for the next years will combine a few long sessions and sessions of intermediate duration.
As before, we will try to optimise pointing in the two fields, to address major questions on both the seismology field and the exoplanet field. But in some cases priority will be given to either one or the other Core Programme.

The Scientific Committe is in charge of defining precisely the pointings, after a detailed analysis of the stellar content of the possible fields.

7 CoRoT and Kepler

Kepler has been succesfully launched on 6 march of this year, an dis starting to produce secintific data.
Kepler, a bigger and much more expensive mission is a kind of second generation with respect to CoRoT.
In the exoplanet domain, it is focussed on the discovery of earth like habitable planets.
It observes in a unique direction for at least 4 years.
In principle, it will also be able to detect planets in the domain of parmeteres where CoRoT is adapted to, complementing the CoRoT statistics in his field of view.
CoRoT cannot reach such long durations, but observes in different directions of the sky.

The confirmation of earth-ike habitable planets will be a very long process.
We know from CoRoT that the detection of variability in the photometric signal is only a fraction of the work. The follow-up process is so extensive that it will be a long time as long or longer than for CoRoT) before one starts producing scientific results. The real important thing is small planets. We now know that something like CoRoT-7b requires ~ 100 HARPS observations or more in order to confirm its nature.
Keplers goals are similar planets with very much fewer detected eclipses (and ideally smaller). This requires an even larger FU effort.
Apart form the 'Marcy-machine' HARPS-north will go on line in 2010 will produce results around late 2010/11. There is also a long period to learn how to use the available ressources (after 757 days in orbit! For CoRoT) efficiently plus pipelines, plus manpower.
This means that CoRoT has several years when we will be increasingly more and more competitive before Kepler slowly takes over.

Kepler will of course do some asteroseismology via the KASC, but the KASC (of which several of us are members) knows very well that the data will be very hard to analyse for this matter and only very few and faint stars will be observed (for up to 4 years though).
Comparison of the S/N shows that CoRoT nad Kepler are complementary
The photon noise in Kepler is 24 ppm in 6.5 h., e.g. 3.6 ppm / sqrt(microHz) ou 13 ppm^2/microHz for a V=12 star
For V=9 , it is 0.9 ppm / sqrt(mircroHz) e.g. 0.81 ppm^2 / microHz **5 times higher than on the bright targets** V=6 (=0.15 ppm^2/microHz) of CoRoT.
But Kepler will observe 100 stars during 3 years, which will give probably a similar accuracy on the frequencies.

Then the major differences between the two missions is
- CoRoT is a pionner small mission, and Kepler a second generation project
- CoRoT being first has developped methodologies, and understood the major difficulties
- CoRoT observes in different regions of the sky, populated by differrent steallr popultions
- CoRoT is doing seismology on bright stars that Kepler will not do
- Kepler may detect Earth-like habitable planets and other long period objetcs that CoRoT cannot reach.

8 The CoRoT task Force

Figure 25: The foor during the First International symposium in Paris on February 2009

The exploitation of the 5 first runs has provided the material for the First CoRoT Symposium, held in Paris, Cité Internationale, February 2009, under the hospice of CNES, …
More than 250 participants from 20 countries, 70 oral presentations, 130 posters.
Most of the results presented there are now being edited in a Special volume of Astronomy & Astrophysics.

In addition to CoRoT data direct treatment and analysis, the European (+Brazilian) astronomical community has really put *huge* efforts to be able to follow-up CoRoT targets.
This has taken time but is just beginning to bear fruit.
The community is prepared and expecting CoRoT's extension most eagerly.

As detailed below the number of people directly involved in the present exploitation phase of the mission **counts more than 100 EFT Scientists and 15 EFT engineers plus the CNES Operation Team.**
More than 250 scientists are working on CoRoT data presently, and as seen in the next Chapter**, their number is rapidly increasing as data become world wide spread. ….**

8.1 In French laboratories

8.1.1 Laboratoire d'Astrophysique de Marseille : 9 FTE (5 engineers and 4 scientists)

Nom, prénom	% temps	CNAP (AA ,A)	CNRS (IT , CR, DR)	Université (MdC, Pr, BIATOSS)	Autres	Rôle dans le service
Meunier J-C.	100		CNRS-ITA-IE2			Resp. tech. EXODAT (SO5)
Agneray F.	100				CDD CNES - IE	Developpeur EXODAT (SO5)
Granet Y.	30				CDD CNES - IE	Accessibilite VO (SO5)
Surace C.	30		CNRS-ITA-IR1			Coordination EXODAT (SO5)
Fenouillet T.	40		CNRS-IT-IE2			Architecture EXODAT (SO5)
Barbieri M.	80				CDD ANR - Sci	Analyse Sci. EXODAT (SO5)
Moutou C.	30		CNRS - CR1			Analyse Sci. EXODAT (SO5)
Deleuil M.	50			Univ. - MdC		Resp. Sci EXODAT (SO5
Chabaud P-Y.	100				CDD CNES - IE	Resp. Tech. ALERTES (SO
Alonso R.	100				CDD CNES - Sci	Analyse Transit ALERTES (SO4)
Barge P.	40	A2				Resp. Sci. ALERTES (SO4)
Jorda L.	30	AA1				Resp. Sci. EXOPIPE (SO4)
Cautain R.	100		CNRS - ITA-E1			Developpeur - EXOPIPE (SO4
Guterman P.	100				CDD CNES - IR	Developpeur - EXOPIPE (SO4
Llebaria A.	20		CNRS - ITA -IR			Analyse & DevEXOPIPE (SO4
Bouchy	50		CNRS CR			Obs VR, analyse scient

8.1.2 Laboratoire d'Etudes Spatiales et d'Instrumentation pour l'Astrophysique, Paris : 12 EFT (6.6 engineers and 8.4 scientists)

Chaintreuil S..	85		IR1			Chef de projet
Grolleau E..	100			ITRF		Intégration, gestion de configuration, qualité
Gueguen L.	15					Maintenance logiciel vol et ban
Romagnan R.	50		AI			Gestion BD, génération des données corrigées
Essasbou Hamza	50				CDD CNRS	Génération des données corrigées
Gillard Frédéric	100				CDD CNRS	Developpement interfaces E/S
Naudet Damien	100				CDD CNRS	Integration des algorithmes pip line de traitement
Heuripeau Frédéric	100				CDD CNRS	Integration des algorithmes pip line de traitement
Mertens F.	100				CDD CNRS	Maintenance de la BD gestion des échanges de données
Lefevre L.	100				CDD CNRS	Recontruction Courbes de lumière avec fit de PSF
Auvergne M.	100		DR2			Project scientist
Baglin A.	100		DR1 Emerite			Resp Centre de données
Michel E.	70	AA				Pipe-line sismo
Samadi R.	60	AA				Coorections Nà-N1
Catala C.	20		DR1			Preparation sol
Tiphène D.	30	A				Suivi instrument Operations
Barban C.	50			MdC		Groupe Geantes

Goupil MJ	50	A				Modélisation
PhD	300					

8.1.3 Institut d'Astrophysique Spatiale. University Paris Sud Orsay : 7.3 FTE (1.8 engineers and 5.5 scientists)

Baudin F.,	60	AA				Responable archive mission, corrections sismo N1-N2
Appourchau x T.	40		DR2			Analyse des données sismo
Ollivier M.	60	AA				Mise en place archive mission Operations satellite
Léger A.	60		DR1			Analyse de données et modèle exo
Ballans H.	50		IE2			Realisation archive mission
Adam C.	95				CDD CNRS	Realisation archive mission
Boumier P.	30		CR			Participation pipe-line sismo
PhD	200					

8.1.4 Observatoire de Midi-Pyrénées : 6 FTE (1,5 engineers and 4.5 scientists)

Platzer	20		IR			BD Corotsky
Cuvilo J.	100		AI			BD Corotsky, interface CNES
Vauclair G.	50		DR1			sismologie
Charpinet S.	30		CR			Receuil données sol
	50				CDD CNRS	
Vauclair S.	50			professeur		sismologie
Theado S.	100				CDD CNES	sismologie
Toublanc D .	20			professeur		Recherche de planetes
PhD	200					

8.1.5 Other french laboratories : Observatoire de la cote d'Azue, LUTH and GEPI, Observatoire de Paris, Sevice d'Astrophysique du CEA : 9.1 FTE, all scientists

T. Guillot	70		DR2 ?			Aanlyse de données, modelisation
P. Mathias	70	A ?				Resp. groupe gan dor
JC Valtier	30	A				Analyse de données
Daniele Lecontel	50		IE			Analyse de données
E. Chapellier	50		CR			Analyse de données
S. TurckChièze	50		Ing CEA			Aanlyse de données, modelisation
R. Garcia	70		Ing CEA			Solar like scillations
L. Piau	70		Post-doc			Modélisation stellaire
G. Alecian	50		DR			Etoiles chimiquement particlière
J. Schneider	50		DR			Exoplanetes
C. Neiner	70		CR			REsp. Groupe Be
AM Hubert	50		DR			Groupe Be
M. Floquet	50	A				Groupe Be
J. Guttirriez	70				Post-doc	Groupe Be
J. Schneider	50		DR2			Plnetes et satellites

G. Alecian	60		DR2			Suimologie d'étoiles particulière

8.2 In the participating countries

8.2.1 Belgium : 17 FTE

** K.U.Leuven: 6 FTE*
Conny Aerts, Maryline Briquet, Fabien Carrier, Jonas Debosscher, Pieter Degroote, Joris De Ridder, Maarten Desmet
** Royal Observatory of Belgium: 4 FTE*
Ronny Blomme, Jan Cuypers, Peter De Cat, Yves Fremat, Patricia Lampens
** Université de Liège: 7 FTE*
Kevin Belkacem, Marc-Antoine Dupret, Michael Gillon, Mélanie Godart, Andrea Miglio, Josefina Montalban, Arlette Noels, Anne Thoul

8.2.2 RSSD/ESA : 6 FTE (scientists)

S. Carpano , M. Fridlund, F. Favata, B. Foing, P.Gondoin.

8.2.3 ESA Science Programme : 13 FTE (sc ientists)

** University of Exeter :2 FTE*
S. Aigrain ,+
** University of Aarhus : 2 FTE*
H. Kjeldsen, +
** Observatoire de Genève : 4 FTE*
D. Queloz, +
** Institut d'Astrophysique Porto : 2 FTE*
M. Monteiro +
** Queen Mary College :3 FTE*
I. Roxburgh +

8.2.4 Germany : 9.5 FTE (1 engineer + 8.5 scientists

** Institut fuer Planetenforschung, DLR, Berlin: total: 4,5 FTE*
Heike Rauer (Co-I), Anders Erikson (Co-I), Ruth Titz--Weider, Juan Cabrera, Szilard Csizmadia, Thomas Fruth
** DLR : Maintenance of the onboard software : 1 FTE*
Gisbert Peter, Fritz Rollenhagen, Rainer Berlin, Bernd Ulmer, Natasha Russ
** Univ. Koeln: total 2 FTE*
Martin Paetzold (Co-I) , Ludmilla Carone ; 1 Student
** Thueringer Landessternwarte Tautenburg: 2 FTE*
Artie Hatzes (Co-I), Guenther Wuchterl (Co-I), Eike Guenther, Holger Lehmann, Philipp Eigmueller, Bringfried Stecklum, Jochen Eisloeffel

8.2.5 Austria : 7 FTE (0.5 engineer + 6.5 scientists)

** Institut füfr Astronomy Vienna : 4.5 FTE*
Rudolf Dvorak, Werner Weiss, Konstanze Zwintz, Theresa Luftinger, Thomas Kallinger, Nicole Nescvacil, Denis Shulyak, Luca Fossati, Michael Gruberbauer, Markus Hareter, Alexander Kaiser + students
** Institut für Weltraumforschung Graz : FTE 2.5*

Helmut Lammer+ Manfred Students

8.2.6 Spain : 19,5 FTE (1 engineer and 18.5 scientists)

* *Granada (IAA) 9 FTE*
Antonio Hernandez, Javier Pascual, Juan Carlos Suarez, Andres Moya, Pedro Amado, Susana Martin, Rafael Garrido, Juan Gutierrez, Pilar Lopez de Coca, Angel Rolland, Eloy Rodriguez, Cristina Rodriguez
* *Canaries (IAC) 4 FTE*
Hans Deeg , one student, Teo Roca Cortes, Clara Regulo , Juan Belmonte, Orlagh Creevy
* *Valencia 3 FTE*
Juan Fabregat, Julia Suso , Pascual
* *Barcelone 1 FTE*
Ignasi Ribas, etudiant
* *Madrid 1,5 FTE*
Enrique Solano , Luis Sarro , Rodrigo
* GMV : Contriution to the software of the ground segment 1 FTE

8.2.7 Brazil : 9.5 FTE (1 engineer and 8.5 scientists)

* *IAG, Sao Paulo University: 2 FTE*
Eduardo Janot Pacheco, Sylvio Ferraz Mello, Roberto Costa , Marcos Dias , Laerte Andrade
* *Mackenzie University:*
Adriana Silva 0.4 FTE
* *Federal University of Rio Grande do Norte: 4,5 FTE*
José Renan de Medeiros, José Dias, C. Melo (30%), Izan de C. Leão, Y.F.M. Osório, D.B. de Freitas, C. Cortés, B.L. de Canto Martins, L.P. de Souza Neto, S.C. Maciel
* *Federal University of Minas Gerais: 0.5 FTE*
Silvia Alencar
° *Laboratório Nacional de Astrofísica: 0.4 FTE*
Carlos Alberto Torres, Germano Quast
* *Federal University of Rio de Janeiro: 0.3 FTE*
Gustavo Porto Mello
* *Observatório Nacional: 0.9 FTE*
Ramiro De la Reza, Carolina Chavero
* *State University of Ponta Grossa:0.5 FTE*
Marcelo Emilio
* *Mauá School of Engineering 1 FTE*
Vanderlei Cunha Parro, Fabio Fialho.

9 Data deliveries and archives

9.1 Data delivery

The data policy, presently accepted by all the partners states that all the data are delivered to all the Co_Is, and that there have a private access for one year.
Gentlemen agreements among them, as proposed by the Scientific Committee, manage the sharing of the different scientific questions without too much conflicts.
We propose to continue the same policy, which has been very long to install, after many discussions.

9.2 The archives

The private archives are restricted to the Co_Is and Gis during their proprietary period.
There has been many requests, phased with the succesive releases, as presented in figure 26.

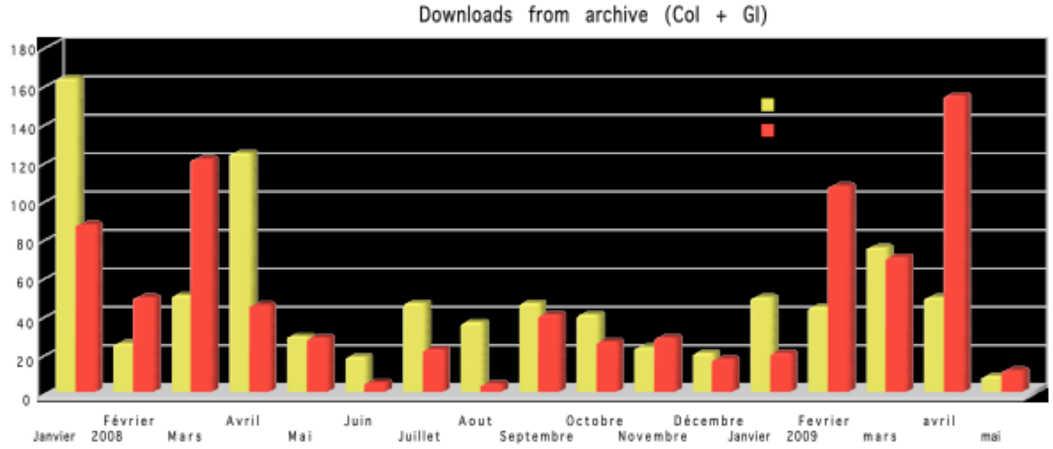


Figure 26: Requests form the CO_Is

The public archive is open since 19 December 2008, and implemented with data which have been delivered one year before to the CO_is and Gis.
In 5 months, it has received 1500 visits from 738 different IP addresses

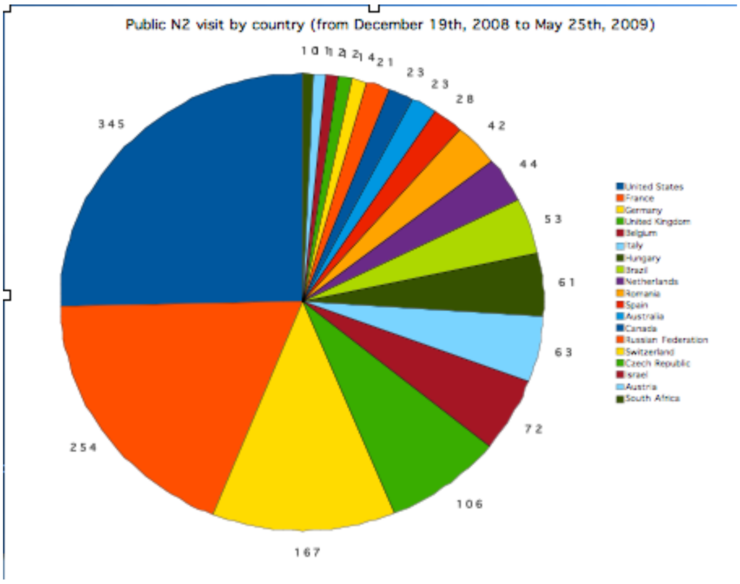


Figure 27 : Geographic repartition of the requests of the public archive.

The volume of data retreived up to now reaches 6 terabytes. Figure 27 shows the international interest, specially from the United States, of these data.