The CoRoT Legacy Book
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I.3
The CoRoT story

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As this book is devoted to the global legacy of CoRoT, this chapter called "the CoRoT story", is essentially historical. It recalls how it was a long process full of unexpected events and surprises, during all the phases of the project.

The major events of the prelaunch phase were developed in the "CoRoT book" (Baglin et al. 2006), and are not repeated here.

The technical details of the in-flight operations are described in Part II, Chap. 1.

1. CoRoT 1: a second generation after EVRIS

The CoRoT story started a very long time ago, as, even before the crash of EVRIS, the seismology community already thought about a more ambitious mission, which would be able to do seismology on a variety of stars with very high precision.

A call for ideas issued by CNES in 1993 for scientific missions of small size, called "petites missions", gave to the French scientists the opportunity to propose and launch rapidly, an instrument called CoRoT, more ambitious than EVRIS, devoted to the study of stellar COnvection and internal ROTation. The project was presented at the GONG'94 meeting at Los Angeles on May 16th (Catala et al. 1995).

The scientific objectives of this second generation mission were intermediate between EVRIS and STARS (see. Chap. I.2), the more ambitious mission studied at ESA.

The goal was to provide very high precision measurements of oscillation mode frequencies, for 5 to 7 bright solar-type and F-type stars, to extract new "seismic" indexes: large and small separation of p-modes to obtain constraints for models of internal structure, second order differences to access the physics of convective transport, mode amplitudes and lifetimes to understand the energetics of the excitation mechanism, rotational splitting to start to measure the internal rotation.

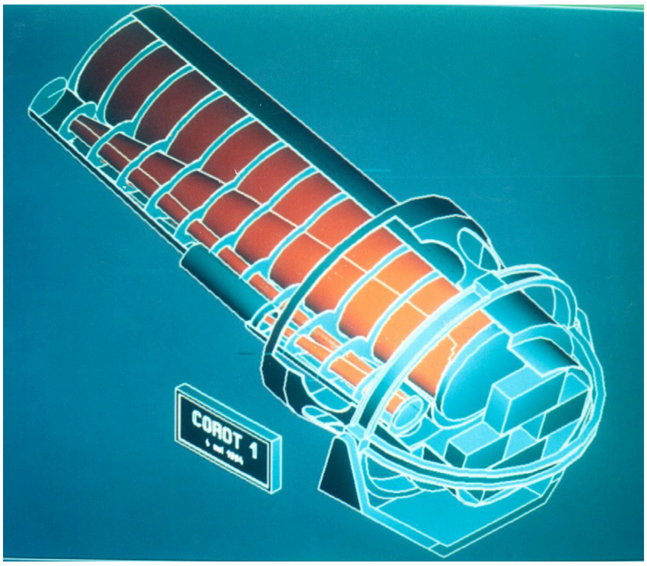

Fig. I.3.1. The design of CoRoT 1, © Laboratoire d'Astronomie Spatiale, Marseille.

These objectives required some technical improvements:

- increase of the photometric accuracy, by increasing the diameter of the telescope (25 cm instead of 9) (Fig. I.3.1);
- increase the duration of the observations leading to more accurate frequency measurements.

Two solutions were proposed for the orbit: either LEO at 800 km, allowing 5 months observations of stars close to the equatorial plane, or a GTO at 36 000 km increasing the number of accessible targets but also the cost!

In addition, the design proposed to test in space conditions, the CCDs detectors, which became available for space uses, in a control camera used essentially as a stellar sensor for the AOCS.

CNES selected the project at the end of 1994 for a launch as early as 1998!

2. The final CoRoT

Two unexpected but major events changed completely the scope of the mission: the failure of EVRIS, CoRoT becoming a first generation mission, and the discovery of the first extrasolar planet in 1995. Indeed, the technical requirements to detect transits of extrasolar planets, even of small sizes, would be quite similar to seismology ones.

This led the project to propose a second version of CoRoT, able to do both seismology and planet search.

Administrative and financial problems have paved the period between the preselection and the final decision from 1995 to 2003.

In 1998, the French Ministry of Research asked for an international blessing and financial contribution. ESA Science Programme as well as Austria, Belgium, Brazil, Germany and Spain decided to contribute to the project, giving to CoRoT an European and even wider impact. This interest of a large scientific community to the project probably helped the final selection, which occurred only in 2000, leading to a 2 years delay.

A second stop of more than one year occurred in 2002, due to a re-evaluation of the different projects in CNES.

This lead to a total of 4 years delay, with a start of the development phase in 2003.

2.1. The development phase

To keep CoRoT its status of a pioneer mission, the launch was foreseen in 2006, which meant that the satellite had to be developed in a very short time (less than 4 years) with a duration of development really out of norms.

Thanks to the efforts of all the engineers, scientists and companies working on the project, a launch at the end of 2006 has been possible.

The total budget was an important matter of concern, as in the framework of the "petite mission" program, it was limited to 70 M€ for the French part. The contribution of the different countries has been helpful in this domain. Difficulties came also from the evolution of the political and technical changes of the launchers landscape (1/3 of the budget in general). The first baseline was to use cheap launchers as the Russian Rockot (Fig. I.3.2.)

A new solution came from the proposal of Arianespace to offer for a non-commercial cost, a maiden flight of the new Soyuz, developed under Starsem leadership, a subsidiary of Arianespace. This version aimed at modernising Soyuz with new third stage engine and digital control, and preparing it for the new Kourou launch pad for the SOYUZ launchers as decided by the European policy (see Lam-Trong 2006).

It was a maiden flight with the additional risk of failure and this risk was an additional factor of pressure for the mission (Fig. I.3.3).

CoRoT has paid its tribute to the promotion of Soyuz in French Guyana!

The results of this very intense development phase are extensively described in *The CoRoT mission, pre-launch status* (Baglin et al. 2006) and will not be repeated here (Fig. I.3.4).

Fig. I.3.2. The Rockot rocket ready to launch the European satellite GOCE on March 4 2004 at the Plesetsk cosmodrome. Credit: EUROCKOT, Khrunichev Space Research & Production Centre.

2.2. The operational phase

The operations started with the launch of the satellite on the 27th of December 2006; CoRoT was injected very accurately by the Soyuz/Fregat launcher on the desired orbit, which saved propulsion capacity for the future. The Launch and Early Orbit Phase (LEOP) lasted 4 days to secure the spacecraft, assess the good health of all the sub-systems and switch to the normal mode. The instrument has been switched on January 2nd, and on January 17th 2007 the cover of the instrument has been opened with the first acquisition of real sky data (Fig. I.3.5)

The CoRoT system, including the satellite and instrument, the CoRoT Control Centre, the CoRoT Mission Centre, the ground station network and the Brazilian and Austrian ground stations of Alcantara and Vienna performed all together successfully.

As we wanted to obtain scientific results as rapidly as possible, it has been decided to use the commissioning phase to both adapt the instrument and point towards stars chosen for their scientific interest. This phase started on February 3rd 2007.

The first in-flight data show that globally the results fulfil the specifications, and even surpass them in many domains (Auvergne et al. 2009; Pinheiro da Silva 2008). This has been confirmed all along the mission.

During the first year, the data (both scientific and housekeeping) were used to obtain a final tuning of the instrument, but also to understand and correct parasitic signals, for instance the role of the crossing of the South Atlantic Anomaly, or the tuning of the faint star field templates.

But most of these perturbations have been corrected as described in Part II, chaps. 2 and 3 of this book.

A number of improvements were introduced at several levels in order to maximize the scientific output of the mission. Let us cite for instance the wish of scientists to visit regions of the sky slightly outside the continuous viewing zone, which lead to a set of orbit manoeuvres to change the

Fig. I.3.3. The launch of CoRoT at the BaÏkonour cosmodrome on december 27th 2006. Credit Arianespace, © Starsem Arianespace.

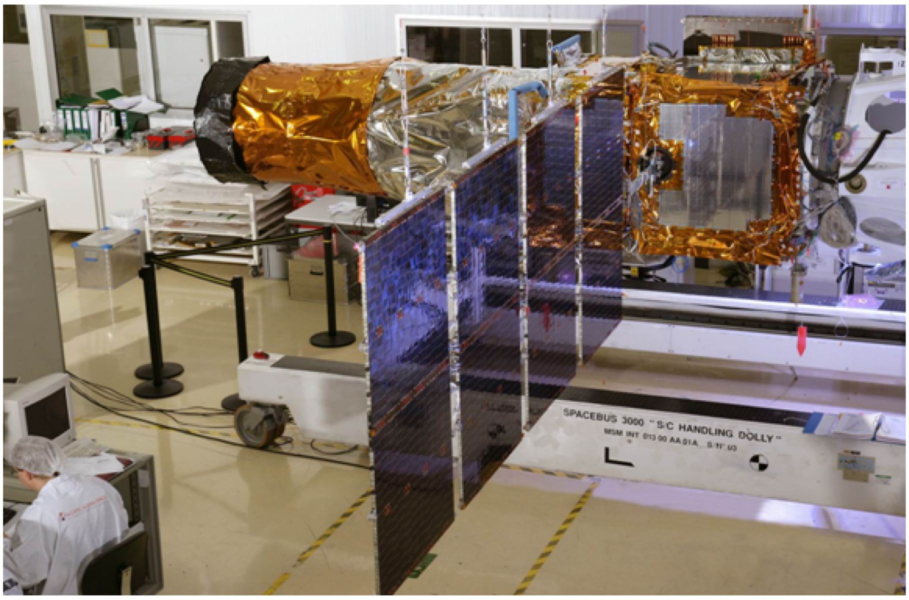

Fig. I.3.4. The CoRoT telescope, during the final tests (opening of the solar panels) at Alcatel (Cannes), © Thales Alenia Space.

inclination of the orbital plane and make it rotate slowly (–3°/year).

To optimise the duration of the scientific observations, the duration of the operations for the positioning of the runs has been constantly decreased, from an average of 11 days per run for the first 4 operations down to 4.1 days in average per run for the last 2 years of operation.

The strategy and monitoring of the downloading of the instrument telemetry has evolved to reduce the telemetry loss that could happen due to ground station anomalies.

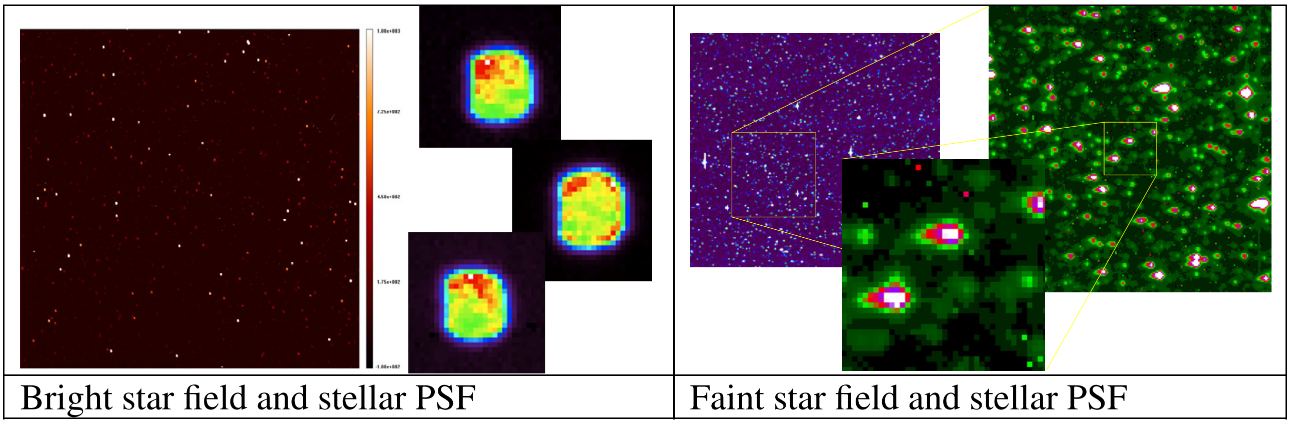

Fig. I.3.5. Point spead functions in the two CoRoT fields, with the very broad stellar images in the bright star field (to improve the accuracy of the photometry) and the smaller faint star images in the faint star field, enlarged by the very low resolution prism to extract color information, © CNES.

As for scientific purposes, any discontinuity is a problem the control of the detectors temperature has been optimised to favour the stability for a long period of time.

A total of 26 runs of observation were performed, representing 1981 days of observation with the bright star channel and 1919 days with the faint star channel out of a period of availability of the instrument to perform the scientific mission of 2113 days.

The 6-year flight has been perturbed only by two anomalies:

– on March 8th 2009, the communication between the platform and the photometric chain N° 1 of the instrument has been lost and never restarted. But both the satellite and chain 2 were working perfectly. So the system has been adapted to this new configuration making compromises with the scientific requirements. For instance, the strategy of observation has been modified by rotating the satellite around the direction of the bright star detector between 2 runs (e.g. LRc05, LRc06, see Chap. II.1.4) to allow still long duration (6 months) of the seismology programme, and increase the number of faint stars while exploring with the exoplanet detector two different directions (called later the DR method, after Daniel Rouan idea);
– on November 2nd 2012, the communication with chain N° 2 stopped suddenly, which lead to the end of the mission.

2.3. The end of the space mission

Following the major anomaly that occurred on November 2nd 2012, a tiger team was gathered to analyse and try to understand the reasons why CoRoT stopped abruptly. The study lasted 6 months and the experts went through theoretical analyses, various testings on test benches on the ground but also a series of tests onboard the satellite itself.

A total of 8 tests with different configurations were performed on the satellite trying to switch back on the instrument processor unit but also allowing to gather more information for the investigation team. The last but not the least test was performed in May 2013 and was supposed to give the maximum chances of success in powering ON the instrument through optimal electronic conditions onboard as well as a payload temperature cooled down to the minimum possible, supposedly favourable to the restart.

Fig. I.3.6. Launch of the last telecommand at CNES Control Center on Tuesday 17th June 2013 at 8:27 TU, © CNES.

Unfortunately, all those trials were unfruitful. They gave more information to the experts, but they succeeded neither in bringing the instrument back to life nor in being a hundred percent sure of the anomaly root cause.

The final decision to end the mission was taken in June 2013. CNES went then through the process of selecting technological experiments to be run on the PROTEUS platform. Indeed, the PROTEUS platform, that was created by CNES around 2000 to propose a low cost solution for medium-size scientific instrument, was still fully operational at that time. Seven experiments were chosen such as new guiding and attitude control methods, thermal effects study on solar arrays or other technological feedbacks that would be useful for next generation satellites.

Parallel to those experiments, end of mission operations have been conducted from the satellite control centre in CNES Toulouse. They started end of December 2013 by lowering the satellite orbit, in order to reduce the duration of the atmospheric re-entry to the minimum (Space Operations Law), while ensuring no more liquid propellant was left onboard.

The operation team finally performed the last step of the end of mission by commanding the final discharge of the battery. The very last telecommand was sent from Toulouse on Tuesday 17th June 2013 at 8:27 TU. The final extinction of the satellite was observed a few hours after the telecommand was sent (Fig. I.3.6).

The long trip of CoRoT will end in roughly 30 years from now when it will be low enough to become a shooting star in the sky.

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