The CoRoT Legacy Book

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# V.1

# Lessons learned from CoRoT

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## 1. General

The CoRoT mission had the ambition to perform high precision stellar photometry on stars for long and continuous periods, to detect both exoplanets and stellar oscillations. This leads to quite unusual and demanding specifications.

Because of very limited available resources, it was clearly a design-to-cost mission. But it was not a "faster, better, cheaper" approach in which there are plenty of management and technical dead-ends. We have taken risks but without any sacrifice in terms of final validation.

Another factor even more driving than the cost was the planning. Only 3 and a half years from the final mission adoption (mid-2003) to the launch decision (end-2006).

So both planning and cost have pushed the project towards unusual and original ways of management and technical approaches.

## 2. Technical approach

### 2.1. The basic low-cost choices

The basic low-cost choices are:

- the choice of the class of satellite: "small" satellite (600 kg, 500 W);
- the use of a standard bus (PROTEUS);
- the choice of the orbit: a low Earth orbit (LEO), imposed by the using of a small bus with limited quantity of propellant:
  - 900 km pure polar orbit ($i = 90°$, no rotation of the orbit plane),
  - because of the Sun, each observation duration (run) is limited to 150 days. Consequently, it is not possible to detect planets with a period >50 days.

### 2.2. The development logics

The technical approach that we have developed is, first of all, based on the compliance to the needs rather than the seeking for absolute performances in terms of solutions. So, we did a permanent hunting of what is nice to have beyond what is mandatory.

The development logic is characterized by a high level of risk taking which has been carefully analyzed, assumed and publicly displayed. It consists essentially in:

- planning activities in parallel;
- postponing some tests at the higher level (of integration);
- limiting the qualification of the ground segment. This position has been fully validated a posteriori. Indeed, the flight data turned out to be significantly different from simulated data and their use in qualification of the ground segment would have been misleading;
- reducing the duration of the operational qualification, relying on the gained experience with the previous missions, which used the same platform (PROTEUS).

### 2.3. The technical challenges

We have met some difficult technical challenges, for instance:

- *The pointing stability*
  Because of the non-uniformity of the pixel-to-pixel response, the pointing jitter produces noise in the frequency domain. In order to keep this noise much lower than the photon noise, a stability of 0.25 pixel is required. That means a stability of 0.5″ (2.4 microrad), which is equivalent to continuously aiming at a football 100 km away. This level of accuracy, never reached before, is achieved by using the instrument in the control loop.
  In order to achieve such a performance, we have developed an innovative solution by using the instrument as a star sensor with much higher accuracy compared to standard star sensors.
  The principle (See Fig. V.1.1) is to measure the gap between the current line of sight and the required one by measuring the barycenter of the light spot of 2 preselected stars among those selected for the asteroseismology mission. The gap between this barycenter and the target is sent (in the form of 3 angles) to the closed-loop attitude controller of the satellite (combined Kalman filtering with data coming from the gyrometers).

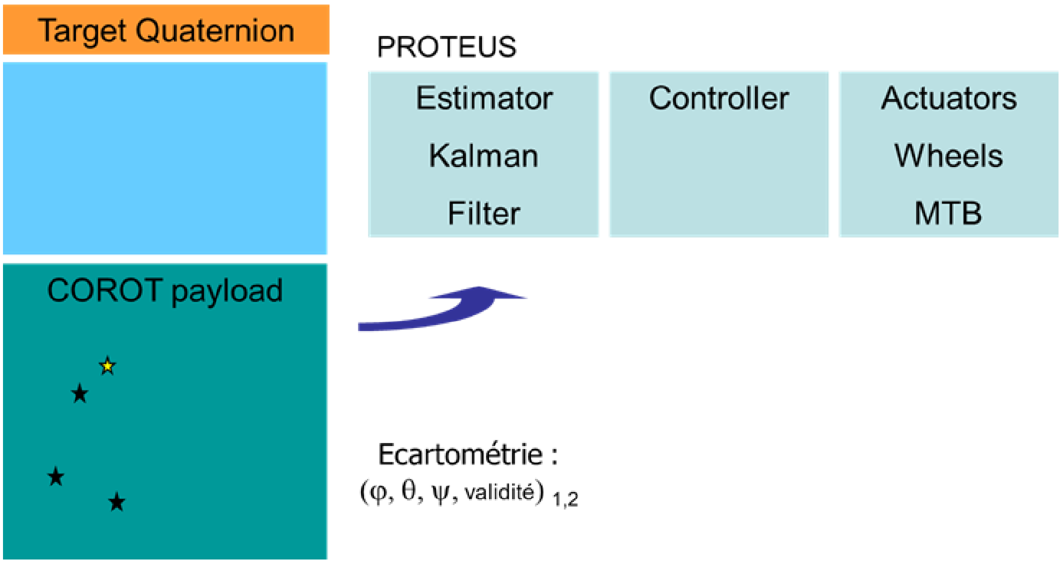



**Fig. V.1.1.** Block Diagram of the Corot attitude control. © CNES

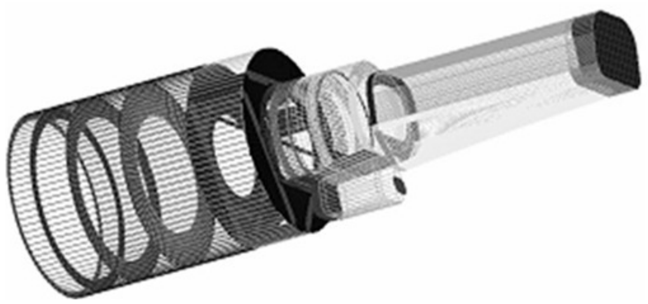


**Fig. V.1.2.** COROT Baffle. © CNES

We have never tested this function on ground in a representative way (only in open-loop). To mitigate the risk, we have developed and used extensively digital simulations. A posteriori, these simulations did fit perfectly the real behavior in orbit.

- *The protection against the stray light*
  One important source of stray light is the light reflected by the Earth. It varies during the orbit. The first estimates of this pollution led to pay attention to it.
  That led to design a telescope with an off-axis unfocused parabolic (2 mirrors) system completed with a baffle (see Fig. V.1.2), which has a rejection factor never achieved before ($10^{-13}$ at 20 degrees).
  Once again, the baffle has never been tested on ground in a representative light environment.
  Then we did rely on simulations made by two independent teams (CSL and CNES).
  The following diagram (Fig. V.1.3) shows the rejection ratio vs. the angle of attack (with respect to the line of sight).
- *The thermal stability*
  The quantum efficiency and the dark current are function of temperature. In order to fight against the periodic noise (orbital period) induced by fluctuations of temperature, the CCD must be at –40 °C with a stability better than 0.05 °C over 1 hour.
  In order to reach this performance, a modular concept has been used, with separate and isolated "cells". The performance realized in flight is better than 15 mK.

The thermal control has the following approach:

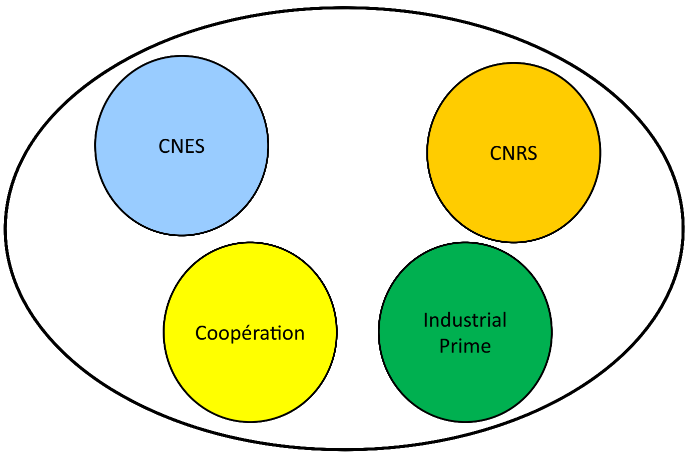
– the instrument is split into independent cells which have each dedicated requirements (average temperature, stability, etc.) and dedicated control (mainly passive).
The design drivers which have been applied are:
– homogenization of each cell by using internal conductive and radiative coupling;
– accommodation of external radiators in front of thermal sinks, as stable as possible;
– drainage of heat towards radiative surfaces;
– since the mass was not an issue for CoRoT, use of the thermal inertia to improve the temperature stability.

The following diagram (Fig. V.1.4) shows the different thermal cells of the instrument.

# 3. The management approach

## 3.1. Learn to work together

The CoRoT organization is complex and hybrid, mixing classical contractual relationship (customer vs. provider) and partnerships based on the principle of the "best effort".



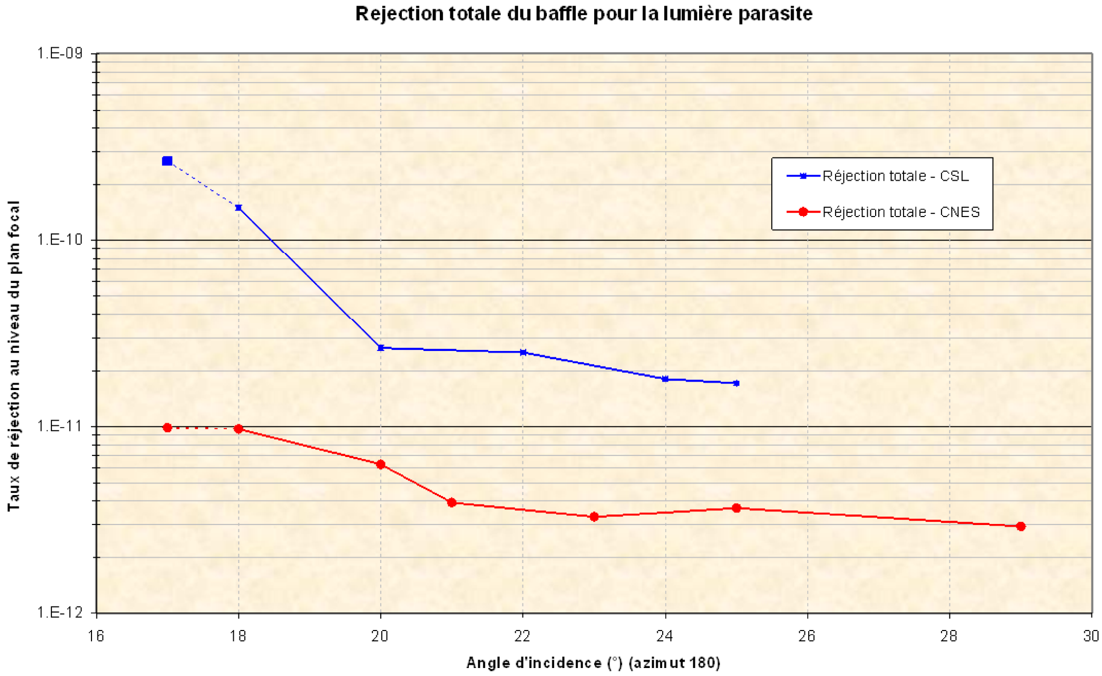



Fig. V.1.3. Straylight rejection simulation. © CNES

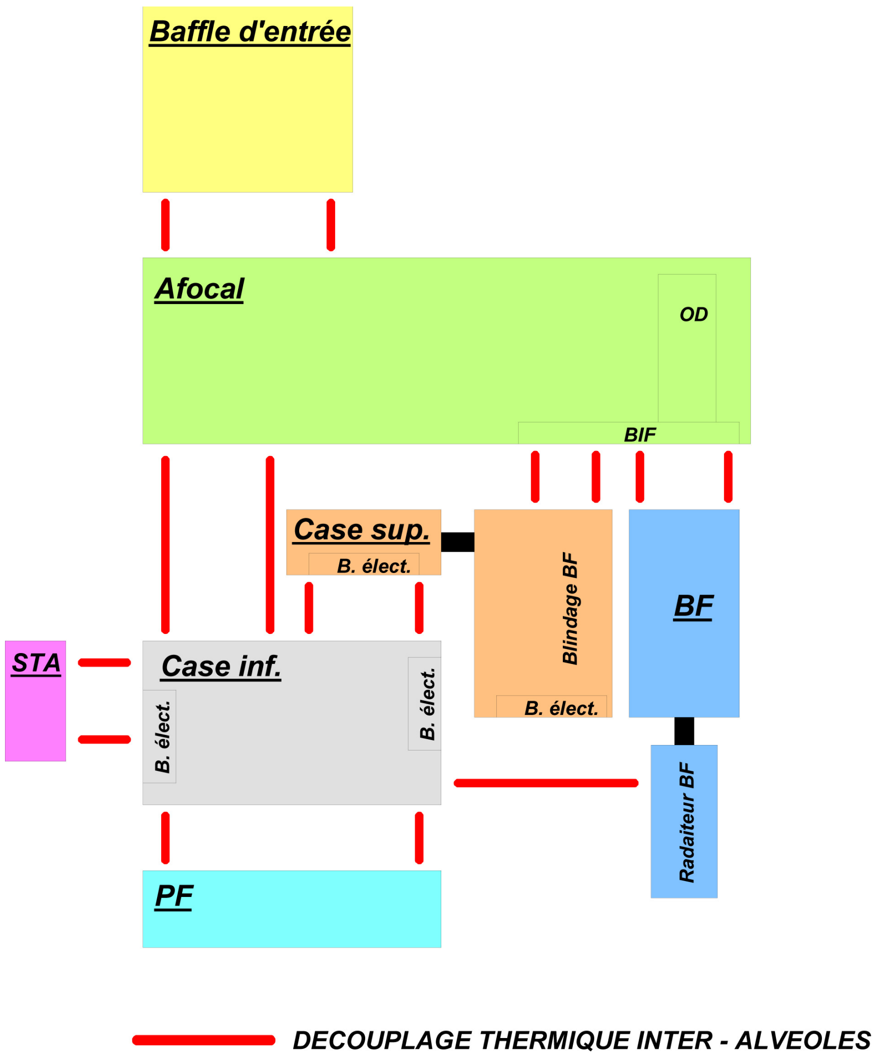



Fig. V.1.4. COROT Thermal Control Architecture. © CNES

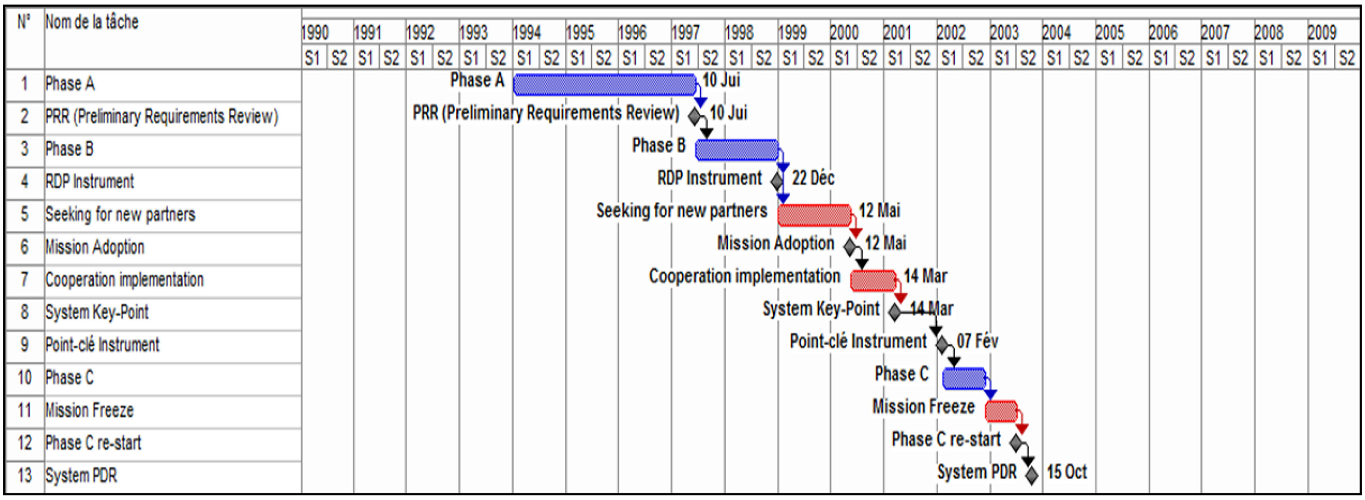



**Fig. V.1.5.** COROT Schedule Overview. © CNES

The lesson learned from the CoRoT project is that, in such an organization, relationships based on power do not work and the consensus should be privileged.

We have learned to work together with different cultures and vocabularies, between Europeans, with Brazilians, between scientists and engineers.

## 3.2. The challenges for the management

The counterpart of international cooperation is a complex management of the project with a high number of interfaces. There are plenty of complexity factors:

- the responsibility of CNES at all levels, from the procurement of parts up to the whole system integration and going through equipment, subsystems, the instrument and the ground and space segments;
- the different nature of relationship between actors: agreement with international partners, convention with the French laboratories (CNRS) and the contract with manufacturers. The project has to manage 6 international agreements, 3 conventions and more than 100 contracts;
- the difference of cultures and experience which leads to always privilege the content to the form.

## 3.3. The management of the planning

### 3.3.1. The CoRoT history

The maturation phase has been very long, roughly 10 yr!

That is a major paradox of this mission, 10 yr to decide and only 3 yr to make it a reality. The main lesson learned is that there is a big progression margin in the process of decision, all the risks being put unreasonably in the development phase. That is not rational (see Fig. V.1.5).

### 3.3.2. The CoRoT final development

#### The "out-of-norms" short duration

In order to be the first hunter in space of exoplanets and to keep at least a 2-year advance with respect to the large

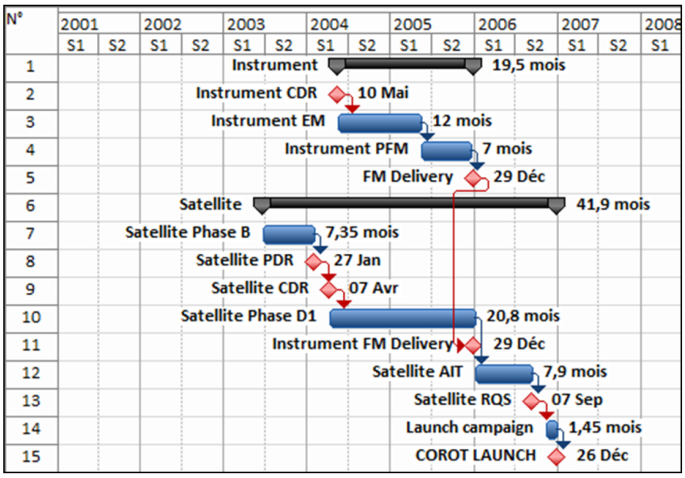



**Fig. V.1.6.** COROT master planning. © CNES

Kepler mission of NASA, it was mandatory for it to be launched by the end of 2006.

The final green light to make CoRoT has been given in mid-2003, that meant 3,5 years to finish the design and the manufacturing of the instrument, the satellite and the ground segment.

The only way to be able to do that was to build a reverse master planning from December 2006 back to 2003 and then to define deadlines for each activity.

The duration of the development of CoRoT (see Fig. V.1.6)is outside the norms in which it should have been, at least twice longer. the following show how fast the activities ran:

- the instrument flight model was integrated and qualified within 7 months;
- the satellite was integrated and qualified within 8 months.

#### The exceptional convergence of the planning

A good indication of the performance is given by the so-called "trend curve" (see Fig. V.1.7).

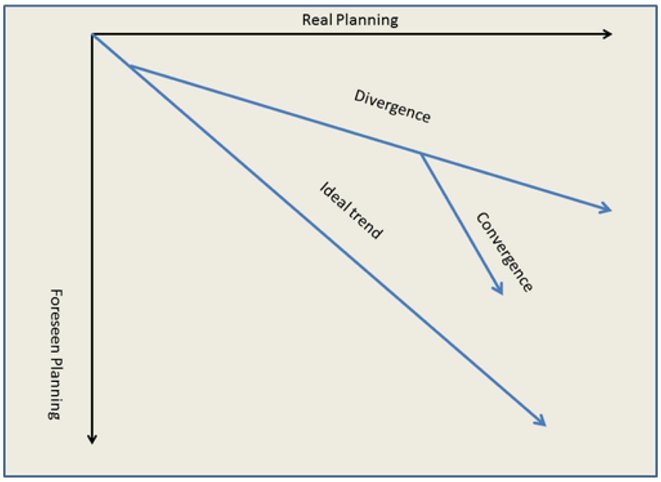



**Fig. V.1.7.** General Development Trend Curve. © CNES

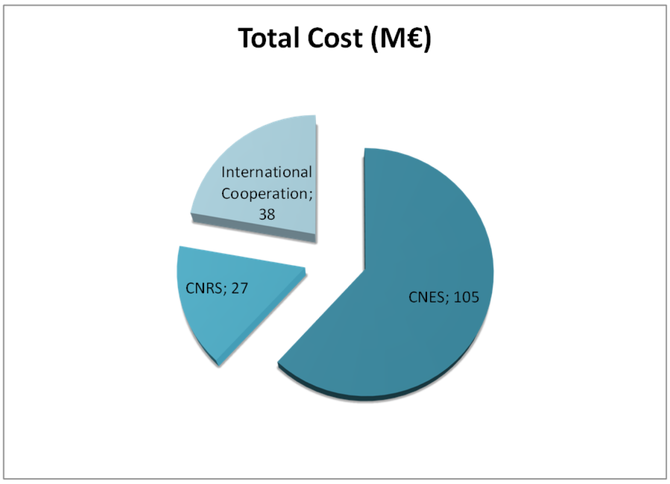



**Fig. V.1.9.** COROT Total Cost Distribution. © CNES

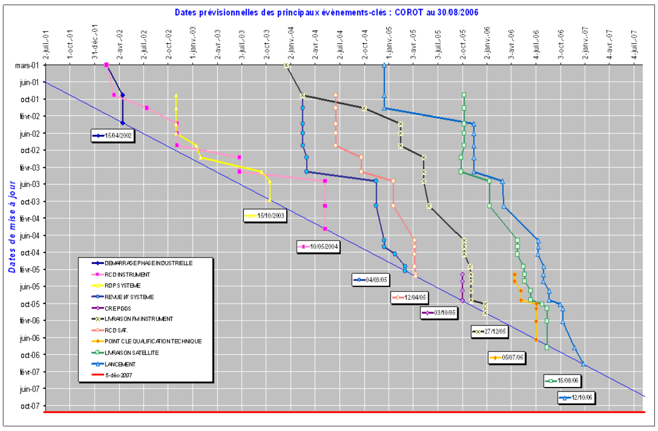



**Fig. V.1.8.** COROT Development Trend Curve. © CNES

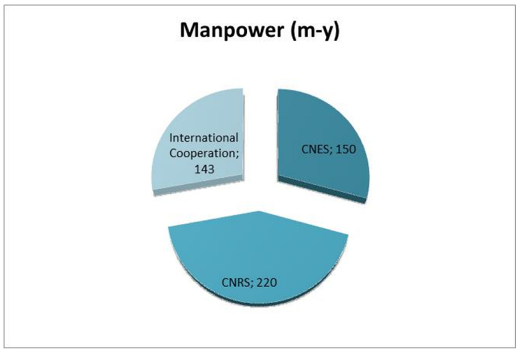



**Fig. V.1.10.** COROT Manpower Distribution. © CNES

The following diagram (Fig. V.1.8) is interesting as it shows the rapid convergence of the planning.

## 3.4. The management of resources

With the passing of time, it appears clearly today that the success of the CoRoT mission is the result of the exceptional quality of the available manpower. This quality has led to a permanent production by everyone of added value, driven by a spirit based on confidence, consensus and best efforts.

The totality of human resources spent in the project is around 500 men-year. The following diagram (Fig. V.1.9) shows the distribution of the manpower between the cooperation partners, the French laboratories and CNES.

The total cost of the development is around 170 M€ (110 M€ of external costs and 60 M€ of manpower).

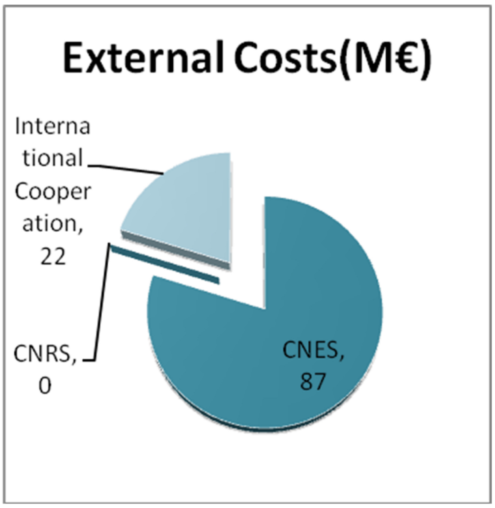



**Fig. V.1.11.** COROT External Cost Distribution. © CNES

## 3.5. The management of risks

In such a design-to-cost project with a very tight schedule, the risk taking is a permanent part of the daily management.

Some examples of risk taking are: the parallel implementation of a lot of tasks, the validation by analyses and simulation then by test, the late validation of major components at the instrument level only, after the final integration.

Yes, we have taken a lot of risks but always with a full knowledge of them by using a rigorous process of risk analysis and mitigation. All the in-flight technical performances have been better than the requirements and the life duration has been twice the required one.

The success of this development is the demonstration that the risk-taking process applied in the CoRoT mission was pertinent.

## 4. Conclusion

The CoRoT project has been a very complex project, with difficulties which are out of the normal range of any space project. The root cause is the process of decision which has been too long (more than a decade) and having as a consequence a very tight schedule after the final decision in mid-2003 for a launch at the end of 2006.

So, we have been obliged to develop a new approach and logic for the development. We have refused to apply a “faster, cheaper” approach but we have found the good compromise between the three poles which are the technical performances, the schedule and the cost.

The price we have paid is quite expensive in terms of pressure and personal investment for all the CoRoT team but that was largely balanced by the success of this project and, what is most important, by the extraordinary and exciting human adventure lived by all the actors of CoRoT.

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