1. The life cycle of an ESA science mission and how to get involved

By ALVARO GIMÉNEZ

Research and Scientific Support Department, ESA–ESTEC, The Netherlands

When I gave this talk in the Canary Islands Winter School of 2003, it was obvious that the interest of the audience was about how to make a successful proposal rather than finding out about the developing phases of a space mission. Unfortunately, I do not know how to make a 100% successful proposal. Success depends on a combination of bright ideas, creativity, timely response to the needs of a large scientific community, adequate system knowledge and, certainly, a bit of good luck. This presentation aims to make young scientists acquainted with the phases and challenges encountered in new space science missions. For that purpose these notes are organized in two sections. The first one establishes the phases of a mission, that is the process of carrying through a generic science project, while the second deals with the actual role of scientists in the whole process. Other talks in the Winter School focused in the science and the experiments that might be done, on how we can increase our knowledge of the Universe by means of space technologies. Here, we try to help making these, as well as other new ideas, real space science experiments.

1.1. The phases of a space mission

In this section, I want to bring to your attention the different phases of the process, starting with a bright scientific idea and finishing with the delivery of science data. This is, in other words, the life cycle of a European Space Agency (ESA) mission.

1.1.1. *The call for ideas*

The initial step of a space mission is normally a call for ideas periodically issued by the ESA science programme. These ideas are needed to allow for long-term planning in the agency and also to identify specific mission objectives and the technologies that may be required to actually carry them out. Through the call for ideas, ESA tries to identify possible flagship missions requiring concerted efforts as well as an advanced knowledge of smaller missions that may compete for selection following an eventual *Call for Proposals*. In this latter case, the response to the call for ideas allows ESA to evaluate the best rate and size of call for proposals and whether these will be completely open in scope or tailored to a specific budget envelope or even the use of a given spacecraft.

This process has been put in place by ESA several times, basically every decade. The one that took place in 1984–5 crystallized in the Horizon 2000 long-term programme that brought cornerstone missions (as flagship projects), and medium and small missions to be selected through dedicated calls for proposals and open competition. That plan consolidated a European-level approach to space science and led to a steady enhancement of the programme funding. Around 1994–5, a second call for ideas was issued that helped the definition of the Horizon 2000 programme extension by introducing additional cornerstone missions as well as new opportunities for calls for proposals with the scope of the then called flexible and Small Missions for Advanced Research and Technology (SMART) missions. The projects that are being launched now, within the period of time between 2004 and 2014, were actually identified after the latter *call for ideas*. The selection of the order in which the approved cornerstone missions would be implemented as well as the identification of the next flexi missions took place in 2000. A full revision was made in 2002, following the continuing degradation of the *level of resources* of the programme, and an imposed de-scope in 2003 was needed due to unforeseen financial problems. Nevertheless, in all discussions the programming of launches was kept open within a 10-year cycle, that is with launches up to 2014, and the long-term programme, already well beyond 2000, was renamed Cosmic Vision. In 2004, the period of 10 years finalizes again, just before an ESA Council meeting at Ministerial level in 2005. Consequently, the process of defining the missions leading to launches in the period between 2015 and 2025 has to be started, and the new programme receives the name Cosmic Vision 2020.

The call for ideas process starts again, but this time ESA has decided to begin with a *call for themes*. This was a result of a preliminary discussion with the scientific community that took place under the structure of a cross-disciplinary working group (XPG) and the difference is obvious: rather than looking for specific missions immediately, with a name attached to them, ESA is looking for priorities in scientific research within open areas of space sciences. It is, of course, difficult to forecast the best science to come, but after a number of years of proposing and even developing space science missions, it is worrying that the community could lose its sense of prioritization in scientific objectives and merely focus on trying to recover old ideas or even reuse more or less available payloads. The analysis of the responses to the call for themes will allow ESA, through the advisory structure of the scientific programme, to identify the possible new flagship missions as well as the need for a call for proposals restricted to smaller projects. In this process, the analysis of possible mission scenarios to answer the questions put forward within the call for themes, as well as the identification of technology developments, will be performed. Eventually, the missions to be launched after 2014 will be selected in steps; thus completing the Cosmic Vision 2020 science programme. This call for themes has already been issued with a deadline to receive the inputs by the 1 June 2004. The advisory structure of ESA is involved in prioritizing the themes and the community at large will be consulted through specific workshops.

Once the call for ideas or themes is issued and the proposals from the scientific community are received, the following steps are taken. With internal resources, ESA evaluates the broad technical feasibility of the proposed ideas, rejects those technically unfeasible or clearly unrealistic, and brings the rest to a survey committee or the advisory structure for:

(*a*) evaluation of the scientific merits,
(*b*) assessment of timeliness and scope of mission,
(*c*) identification of scale of the mission and overall feasibility,
(*d*) identification of possible international cooperation.

In the case of call for ideas the proponents already draw a mission scenario to ESA. In the case of the call for themes, several mission scenarios are provided with internal resources, to analyse the feasibility of properly addressing the questions raised, without compromising the final selection of a specific mission. In other words, the thematic approach provides the necessary flexibility to optimize the scientific output of the programme and the use of international cooperation efficiently and science driven.

1.1.2. *The advisory structure of the science programme*

The importance of involving the scientific community in these early phases of the life cycle of an ESA science mission has been mentioned. This can be done through an "*ad hoc*" survey committee that scrutinizes the proposals received from the scientific community and then makes recommendation to the advisory structure of the programme, or directly by the latter with the necessary inputs from the corresponding ESA groups (Figure 1.1).

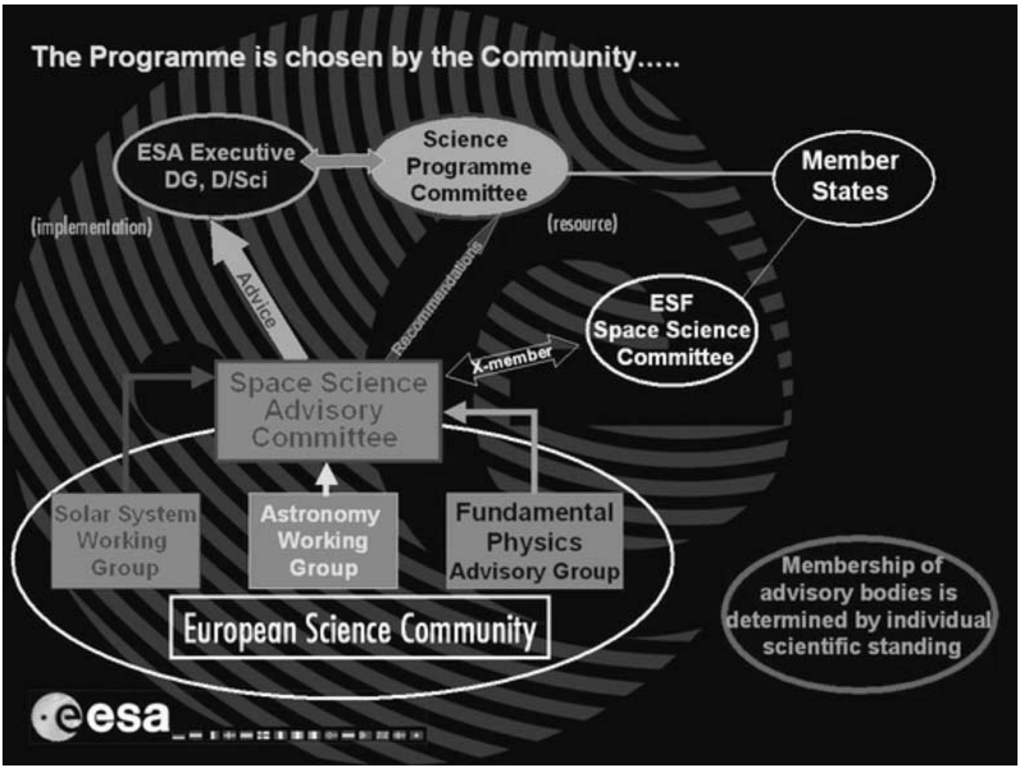

FIGURE 1.1. The components of the advisory structure of ESA science programme.

The advisory structure is composed of two Working Groups, devoted to Astronomy (AWG) and Solar System (SSWG) missions, an Advisory Group focused on Fundamental Physics missions (FPAG) and a senior body, the Space Science Advisory Committee (SSAC), that embraces the inputs from the three previous groups, and makes final recommendations to the science programme and its governing body, the Science Programme Committee (SPC). The AWG and the SSWG are formed by European scientists actively working in space sciences and selected partly by cooptation and partly by the Executive for a period of 3 years. The working groups each include 15 members and a chairman while the FPAG is composed of nine members and the chairman. Each of these groups convenes to make recommendations in their expert fields. These recommendations are then passed to the SSAC, which is composed of six experts from all three fields appointed by the ESA Director General and the Chairmen of the SSWG, AWG and FPAG. In addition there are four *ex officio* members: the Chairman of the SPC, the Chairman of the European Science Foundation – European Space Science Committee (ESF–ESSC) and two representatives of advisory bodies of other ESA programmes. Finally, the SPC is composed of delegates from each Member State of ESA. The SPC has the power to decide on the activities of the programme and recommends the yearly budget to the Council, which approves it.

One of the results of the process initiated by the call for themes is the selection of important scientific topics, or long-term goals, requiring the definition of flagship missions. The following step for these potential types of missions is a detailed assessment study (see Section 1.1.5). The other output is to identify the scope, scientifically and programmatically, to set up a call for proposals in the science programme, out of which the missions to be assessed will be selected (see Section 1.1.4).

1.1.3. *Other options*

If a good scientific idea is available, ESA is of course not the only option. The possible mission scenario may not fit the way ESA works or the idea possibly cannot afford to wait for the call to be issued. Scientists normally proceed following all possible routes. One of them is to propose a national mission, within the scope of a given Member State programme or a bilateral cooperation with other, or even non-European, agencies. Nowadays this does not seem to be a very promising route, given the budgets of national agencies, but the support of ESA can be requested once the mission has been secured as a nationally led proposal to the science programme with certain conditions: among others, that ESA will always only play a junior role in these proposals, as it will not be the driving force.

Ideas can also be presented for evaluation as unsolicited proposals. They may not get into the science programme of ESA, but a scientific and technical evaluation is performed allowing the proposal to be presented to other agencies, or other directorates within ESA, with an adequate independent assessment of feasibility. For example, this is the case of some experiments proposed to fly on board the International Space Station.

Internally, the ESA science programme also works on what are now called Technology Reference Studies to ensure innovative ideas within the community, so that scientists are not self-censored by what they think is available technology, rather they think openly about new possibilities for missions. In this case, without any previous call or competition, "wild" or "blue-sky" ideas proposed by scientists who are either inside or outside ESA are studied. The output information is of course given back to the scientific community for their evaluation of usefulness in future calls for proposals.

A final possibility is to present scientific ideas to ESA or national agencies involving a contribution to a mission driven by other agencies (generally the National Administration for Space and Aeronautics (NASA), but also Russia, Japan, China and India). In all cases a scientific evaluation is possible, an assessment of technical feasibility may be done and, eventually, ESA may get involved.

1.1.4. *The call for proposals*

What used to be called the pre-phase A of a mission starts with the formal call for proposals to the wide scientific community. These are issued asking the community for new mission proposals within a given budgetary envelope and, sometimes, with specific scientific objectives or technical requirements.

Letters of intent (LoI) may be requested to scope the expected response before the actual deadline. This is important so that ESA can set up the evaluation panels with no conflict of interest as well as identify the levels of competition and needs for technical support. As a result of the peer-review process, a number of proposals (typically four per slot) are selected and the SSAC recommends them for the assessment study phase. Proposals not selected for assessment may be proposed again in modified form to a later call, and they can also seek other opportunities within ESA (outside the science programme) or elsewhere as pointed out in Section 1.1.3.

1.1.5. *The assessment phase*

The objective of this important phase of a mission life cycle is to look for a definition of the project to a level showing scientific value, technical feasibility as well as to be programmatically realistic.

Assessment studies normally require some limited industrial support and usually make use of the Concurrent Design Facility (CDF) at ESTEC. From the point of view of the science directorate organization, assessment studies are led by Science Payload and Advance Concepts Office (SCI-A), with the coordination of Science Coordination Office (SCI-C). A study manager is appointed in SCI-A and a study science team is formed with external scientists, including the mission proposers, to monitor all the activities. The Research and Scientific Support Department (RSSD) provides a study scientist to chair the study science team and to make sure that the ultimate scientific goals of the proposal are well respected and supported by the scientific community.

The competitive assessment phase generally takes less than 9 months. Larger, long-term goal missions (cornerstones) may stay in this phase for significantly longer time since specific technology developments are generally needed before going on and no competitive phase is required. During this phase, only a model or "strawman" payload is considered.

For each proposed mission, ESA produces a final assessment report. This includes confirmed science objectives and top-level science performance together with a model payload as defined in a Payload Definition Document (PDD). Of course, an overall mission profile (launch vehicle, orbit, bus, model payload, technology map and preliminary operations profile) is also provided as well as a technical feasibility assessment and an implementation scenario, including the evaluation of possible international cooperation. Another point to be addressed is the potential reuse of technology/hardware from previous missions. As a final result of all these considerations, a schedule outline is produced and preliminary cost estimates to ESA and to Member States (payload) are drawn.

Out of this competitive phase, the advisory structure, and eventually the SPC, recommend one, or may be two missions (one being kept for further assessment and as a backup), to go into definition phase. Technology readiness and programmatics drives the handover of cornerstone missions from assessment into definition phase after the SPC decision (Figure 1.2).

1.1.6. *The definition phase*

This includes the old phase A, pre-phase B and phase B1. It is characterized by the startup of real industrial studies. In fact, two parallel industrial studies are initiated through an Invitation To Tender (ITT) for mission definition. Deviations from the parallel competitive baseline can only be done in special cases (e.g. spacecraft reuses or specific international cooperation). Industrial studies are first done with the model payload and with the real one only after selection. On the other hand, industry also incorporates technology developments into the system design as a result of studies underway and planned within long-term technology programmes of ESA. Towards the end of this phase, once the payload is selected, industry comes to an agreement about payload interfaces with the principal investigators (PIs) and makes binding proposals for the implementation phase in response to a (restricted) ITT.

The selection of the payload to achieve the science goals of the mission is the other main objective of the definition phase. The first step is the preparation of a Science Management Plan (SMP), which has to be approved by the SPC, framing the responsibilities of the respondents to the announcement of opportunity (AO) for the provision of the payload, including the Science Requirements Document (SRD). The Science Directorate of ESA then issues the AO and the different components of the payload, submitted as proposals, are peer reviewed. Selection is based on three criteria: the science case, technical feasibility and maturity, and management and financial plans. The results of the selection process are then to be endorsed by the advisory structure and confirmed by the corresponding funding agencies. Eventually, the SPC makes the final payload decision with specific PIs. Soon after, the PI teams come to an agreement with ESA and industry on an instrument delivery programme. The understanding of the interfaces is generally done through a very important document for PIs, the experiment interfaces document (EID), containing the mission characteristics and constraints (e.g. in terms of spacecraft power, observing restrictions or radiation environment), the instruments design and requirements (e.g. telemetry, thermal control or data handling), the schedule for deliveries (including model philosophy) and the management structures (including reporting procedures and decisions on changes). Since changes are in fact unavoidable during the different phases of the mission, the EID is a living document serving as the reference to ensure that the spacecraft and the payload are suitable to achieve the approved scientific goals. Therefore, it is very important to keep the EID updated to reflect reality rather than design goals.

In order to make sure that the science of the mission covers the required range of objectives, and is not just driven by the specific scientific interests of the selected PIs, ESA also issues a parallel AO to involve mission scientists, or multidisciplinary scientists, in the project. These are scientists from the community who are not providing hardware but rather their scientific expertise. In this way, they contribute significantly to the excellence of the mission performance by ensuring that the science not covered by the PIs is taken into account and by providing cross-disciplinary thinking.

During definition phase, a study science team is kept to monitor the initially approved science goals and, after payload selection, a Science Working Team (SWT) is formed including the PIs and mission scientists. A study scientist provided by the RSSD, who evolves into a project scientist after payload selection, again chairs these teams. Within the science directorate, the overall responsibility shifts from SCI-A (assessment) to the Science Projects Department, SCI-P (definition). This phase lasts some 2–3 years.

When definition phase is nearing completion, the mission reaches a critical point. The SPC should now decide on starting the implementation phase or not, having the payload selected and committed, and a cost at completion (CaC) properly evaluated. At this point a decision about issuing an ITT for the spacecraft main contractor has to be made. Possible problems shown by the definition phase are that science might not be properly scoped, the payload not properly funded or the required CaC may be larger than initially foreseen. Any of these may introduce delays in the decision to go full speed into implementation since, once started, this is a clear budget-consuming phase and delays have dramatic effects (Figure 1.3).

1.1.7. *Comments on payload procurement*

Before going on with the different phases of missions, I considered it important to make some comments on payload procurement due to the relevance of these aspects in the scientific performance of the project as a whole and the interfaces with the scientific community in particular. Things are generally not black and white in this area. The continuous erosion of national funding for payloads as well as the increasing complexity of space instruments are leading to large consortia being formed to procure payloads that exclude real science competition. In practice, we are finding that some payloads have to be directly procured by ESA with industry and others may require ESA involvement at a later phase due to technical or financial problems not properly addressed by the PI. As a partial solution, a non-competitive consortium may have to be formed to ensure the proper payload delivery. Nevertheless, in these cases peer review is still needed to verify that payload packages meet science requirements and are going to be technically and managerially feasible.

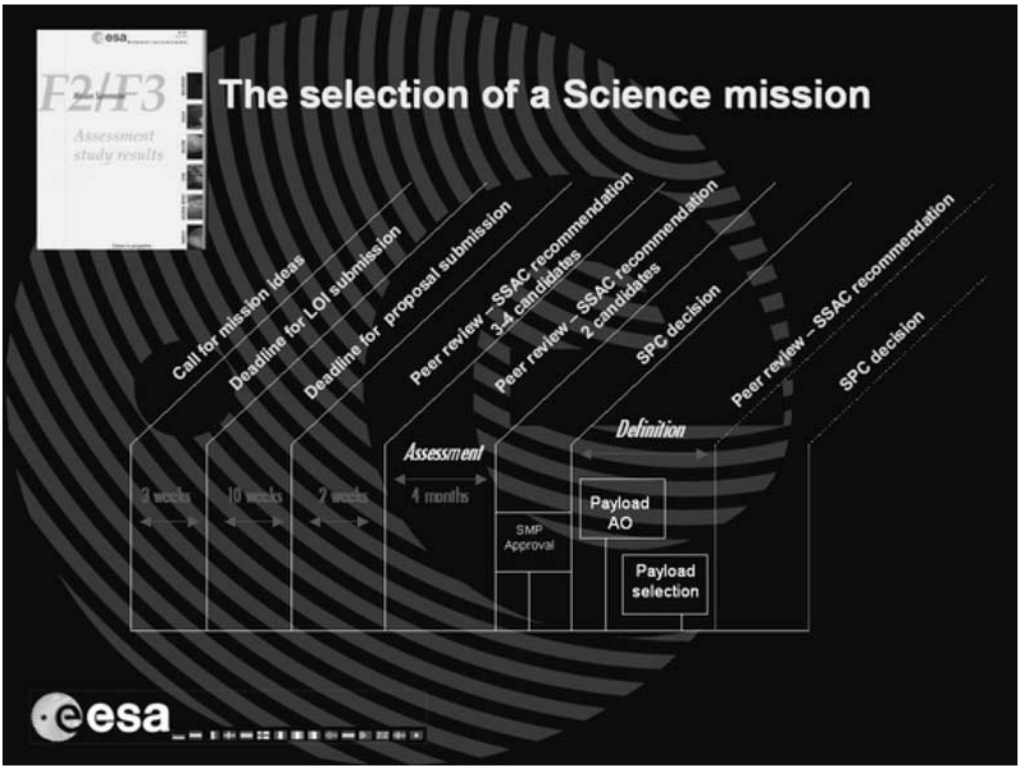

FIGURE 1.2. The selection process of a science mission.

The traditional approach to payload procurement through open AO and national funding has many advantages. Among them, the full control of payload development by the scientific community and keeping a "user-driven" programme may be cited. Moreover, this approach compensates for the lack of expertise in industry to provide control of the scientific performances while ensuring close cooperation between spacecraft developers and the instrument building community. Finally, mission cost sharing between ESA and Member States (typically 30%) is always welcome.

However, this traditional approach also presents clear disadvantages. Some of these are that it becomes easy to arrive at the payload AO with low maturity levels, the spacecraft and mission design may be based on a poorly defined payload, or even that the availability of funding, rather than scientific and technical merits, may drive payload consortia to be formed. Moreover, shortfalls in Member States are picked up by ESA during implementation under cost and schedule pressure, and such ESA funding lacks visibility and effective management control during critical payload development phases. Within this context, smaller instruments may be welcomed, but in fact, isolated instrument development may well lead to unbalanced maturity and duplication of efforts, resulting in problems during implementation and further complications during final assembly, integration and verification (AIV) activities. The lack of technology funding in some Member States adds to the potential difficulties, while ESA's control, or oversight, on payload activities is very limited due to lack of binding agreements.

During the past few years new approaches have been discussed to circumvent the problems mentioned. The basic idea has been to promote iterations between ESA, science teams and funding agencies, leading to a high-level formal agreement. This agreement is signed by ESA and the funding agencies responsible for the payload delivery. The process starts with the approval by the SPC of a baseline mission and payload procurement approach. Then a peer-review team is put in place with the support of the SSAC. This team reviews the adequacy of a reference payload (based on the previously prepared science requirements and PDD) leading to the specification of a definitive payload. After the approval by the SPC of the SMP, a Request For Proposals (RFP) is issued for the payload procurement. Then, instrument consortia involving PIs, institutes and funding agencies are formed, and the proposals reviewed by the advisory structure. These proposals should in principle reflect the initially defined payload complement but new ideas can be accommodated if found scientifically interesting and technically/managerially feasible. Finally, the SPC is asked to endorse the instrument consortia and the level of ESA involvement through ESA-provided elements. This is done through the signature of multilateral formal agreements for each consortium.

Examples can now be found for payloads developed following all kinds of approaches. For instance, ESA procured some astronomy payloads, as for HST (FOC), EXOSAT, Hipparcos, GAIA or JWST (NIRSPEC), whereas some others were supported at different levels by ESA, as in the case of Integral, Mars Express and Rosetta. Finally, certain payloads have been selected for different reasons via non-competitive processes as in the cases of the JWST (MIRI), LISAPF and Venus Express.

1.1.8. *Implementation phase*

This phase includes the old phases B2 (design), C/D (development, integration and verification) and E1 (launch and in-orbit spacecraft commissioning). At the end of the definition phase, the confirmation of the CaC envelope leads to a ratification of the mission by SPC and a decision to go into implementation. Starting this phase implies "no return" since cancellation may involve higher costs to the programme than the delivery of the mission. That is why commitments on schedule and delivery of all components of the project (payload, spacecraft, launcher and ground segment) have to be well evaluated and ensured before starting.

At the beginning of implementation phase the prime contractor is selected among those involved during definition. Following the selection of the prime contractor and its core team, industry executes all the spacecraft development activities, integration, test and delivery of the flight spacecraft, launch preparation, launch and in-orbit commissioning. Within ESA, the overall responsibility remains in SCI-P where a project manager is appointed together with a project team. The duration of this phase is around 4–5 years. Meanwhile, RSSD maintains its support to the project through a project scientist and starts preparation activities for the exploitation phase. In fact, science operations are defined through a Science Implementation Requirements Document (SIRD) and the subsequent Science Implementation Plan (SIP). For interfaces with the scientific community, the SWT continues with its activities, chaired by the project scientist, and including the payload PIs and mission scientists. During this phase, the PIs are generally extremely busy developing their contribution to the payload (and worried about how real the assumed national funding was), but it is important for them to keep the scientific research active to ensure the optimal exploitation of the final data. Again, I would like to emphasize the importance of keeping an updated EID alive.

1.1.9. *Exploitation phase*

This phase includes the old phase E2 (operations and archiving). After the successful integration and verification, the launch, and the commissioning in orbit of the payload and spacecraft, ensuring that all performances are within the scientific requirements, the real

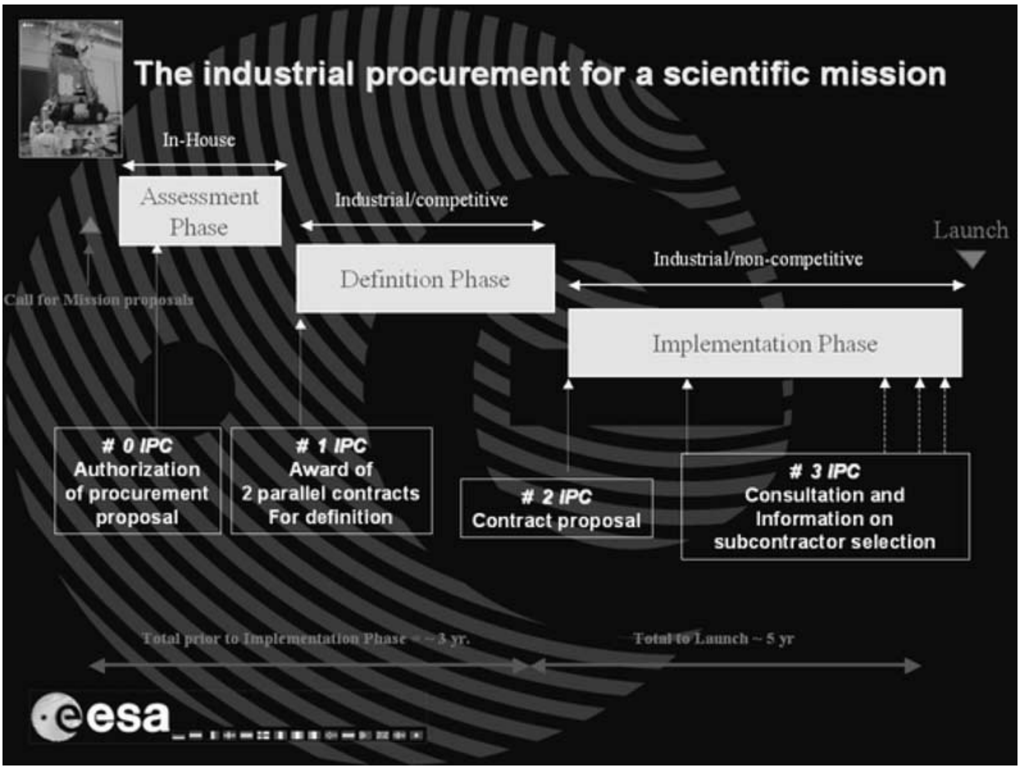

FIGURE 1.3. The development of a project and its industrial milestones.

science starts. As a matter of fact, this is the time for which scientists have been working all the previous years. Data are being delivered and have to be properly processed and calibrated to be useful. In this phase it is very important, for the benefit of the scientific community at large, that the full set of science data is put into useful format, with physical units, and recorded in an archiving system that can be accessed by all those interested in carrying out scientific research with them. In the case of observatory-type missions, calls are issued regularly to select the best-observing proposals through competition and peer review. In all kinds of missions, a detailed science operations planning is needed to ensure the best possible science-driven use of the available resources in orbit.

Within ESA, after commissioning, the overall responsibility of the mission falls on the RSSD. A mission manager is appointed in charge of the mission performance and the CaC while the project scientist remains responsible for the science delivery (e.g. users group, science working group or the issuing of AO for observing time allocation).

1.2. How *you* may be part of it

Since the reader of these notes is most probably a young scientist keen to get involved in space sciences, I found it pertinent to add some comments about science and engineering. A science mission can obviously not be carried out without the scientists, but it is important to understand that it can also not be implemented without the involvement of space engineers. We have to work together, and of course talk to each other, which is something the scientist aiming to get involved in a mission has to be prepared to do. One of the problems in this working relationship is the different ways of setting priorities, and another problem is the use of quite different languages. The latter is generally solved through extensive documentation; the former requires an effort to quantify the scientific objectives through a set of scientific requirements and priorities. This is not a one-off task and involves the continuous monitoring of the scientific performances throughout the life cycle of the mission. Engineers often see lack of communication as poor knowledge of the scientists about what they really want to achieve. Scientists, on the other hand, accuse the engineers of incompetence: they believe the engineers jump too easily to the conclusion that they have to reduce the scientific performance of the mission in order to solve technical problems. It is very important to break the "us versus them" syndrome.

Let us see how to face the most critical phases of the scientific definition of a potential mission.

1.2.1. *The first questions*

Before you even propose an idea, it is necessary to be sure about what you want to do. What is the *science*? What are the questions to be answered? For example, do you want to know what is the radial velocity of a given quasar? Do you possibly want to analyse the chemical profile of the atmosphere of a given planet? Perhaps, the objective is to have a final answer to the origin of the Universe? Then, you have to evaluate whether answering the identified primary questions can really be considered first-rate science or merely useful to know. The other basic point is whether or not it could be done from the ground and if use of space is fully justified.

Once all these questions are correctly answered, you have to evaluate your particular level of involvement and how far you are willing to go. There are many ways of using space sciences to answer interesting questions and they may require very different levels of involvement. You have to assess the investment you are ready to make for the sake of the science return. First, you may consider making a proposal for observing time with a space observatory (e.g. Newton or Integral). In this case, though you should have a good understanding of the performance of the instrument you intend to use, no hardware development is needed. Of course, using a mission in orbit with an existing payload puts constraints on the scientific wishes you may have but the preparation of a response to an AO for observing time could satisfy your needs and the required effort is not very different from that of requesting observing time for ground-based facilities.

Another option you may like to consider is to apply for a mission or multidisciplinary scientist position on an approved mission. If successful, you will be able to influence the development of the mission by making sure that it can achieve the best possible scientific results. In this case, you will have to deal with PIs for guaranteed time and gain a better knowledge of the performance of the instrumentation before launch, thus placing yourself in an optimum situation to apply for observing time in response to AOs. In addition, you gain exclusive access to science data from the mission in orbit.

A third level of involvement in a mission is to make a proposal for a contribution to the payload. In this case, you have to make sure that the proposed science is within the objectives of an approved mission and, therefore, understand well the core science goals of the mission and reference payload. Then, you have to respond to the AO (or RFP) writing a LoI and presenting a *proposal*. Perhaps, this is the highest level of involvement possible from the point of view of engineering, financial and managerial responsibilities, though the level can be somewhat tuned to your capabilities by playing either the role of PI or the co-investigator (Co-I). What you gain by submitting a proposal and being selected is access to influence the science of the mission, large amounts of science data and possibilities of developing state-of-the-art hardware.