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# FIRST ground segment and science operations concept

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## ABSTRACT

The Far InfraRed and Submillimetre Telescope (FIRST) is the last of the four Cornerstone Missions in the 'Horizon 2000' long term science plan of the European Space Agency (ESA) and as an observatory type mission it will be open to the international astronomical community. Its launch is presently foreseen for the end of 2005. The nominal mission duration will be 4.5 years and the active archive phase 3 years. Taking into account the experience from other ESA missions and in order to minimize costs, the ground segment for FIRST scientific operations will be structured in a novel 'decentralized' way, creating centres of competence.

**Keywords:** FIRST, FINDAS, ground segment, mission operations

## 1. INTRODUCTION

The Far InfraRed and Submillimetre Telescope (FIRST) is the last of the four Cornerstone Missions in the 'Horizon 2000' long term science plan of the European Space Agency (ESA). Already during the selection process of ESA's Science Programme Committee (SPC) in 1993 it became clear that major steps would be necessary to keep FIRST within the financial allocation of a cornerstone mission. This was not only valid for the spacecraft and the instruments, but also for the ground segment and scientific operations. The FIRST Project set up the FIRST Science Operations Definition Group (FSODG) to study possible scenarios, taking also into account the experience from other ESA missions, and to come up with recommendations for a feasible concept for FIRST.

The FIRST ground segment, as described in the FIRST Science Operations Concept and Ground Segment Document[1], is split into five major elements: the Mission Operations Centre (MOC), the FIRST Science Centre (FSC), and three Instrument Control Centres (ICCs), one for each instrument. Other important elements are the FIRST Project, its responsibility ends after spacecraft commissioning, the Observation Time Allocation Committee (OTAC) during and after the time of the Call(s) for Proposals, and of course the scientific community.

The FIRST Integrated Network and Data Archive System (FINDAS) will be the nervous heart of the whole ground segment. This object oriented distributed database system will contain all the information relevant to the FIRST project, already starting with the development of spacecraft and instruments. It will provide access to documentation, manuals, procedures, software, data (test and flight), calibration files and the whole mission database. In the end it will contain the whole FIRST archive. It will also provide configuration control and check the access rights of the different types of users. FINDAS will be part of the FSC system. Dedicated network connections between FINDAS/FSC and the other four centres link all elements of the ground segment into one coherent system.

The FSC will be responsible for proposal handling, generation of the mission database and mission planning. It will be the single-point interface to the community, will organize a helpdesk and make all science data and scientific processing software, including calibration and auxiliary files, available through FINDAS.

Observers can access FINDAS remotely via public network in order to submit their observing proposals and later, to query their status and to retrieve data and software necessary for the generation of scientific data products.

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MOC tasks are scheduling and the preparation and execution of all real-time operations of the spacecraft, including health and safety monitoring of the scientific instruments.

The three ICCs are responsible for the calibration and successful of their instruments, starting from instrument level. They also provide documentation, software, calibration files and procedures for the scientific processing of the raw data. Their final work will be the consolidation of data, software and documentation for the FIRST legacy archive.

All these activities will finally cover a time-span of more than twenty years. Commonality and continuity between the different mission phases, starting from development and ending with the final archive, was therefore a major requirement. Another aspect was the conservation and propagation of knowledge and expertise, which in the end supported the decision to create these centres of competence.

## 2. SPACECRAFT AND MISSION

FIRST will be a three axis stabilized spacecraft. It comprises a 3.5 m telescope, a sun shield, a superfluid helium cryostat and three scientific instruments: a heterodyne instrument (HIFI), an incoherent photoconductor instrument (PACS) and an incoherent bolometer instrument (SPIRE). The expected mission duration will be 4.5 years. Spacecraft and instruments are described in companion papers of these Proceedings.

FIRST will be launched into a Lissajous orbit around the second Lagrangian Liberation Point (L2). Operations will be carried out with one ground station in Perth, Australia. This requires spacecraft and instrument autonomy for at least 24 hours. Spacecraft and instrument data as well as the time-tagged command queue will be stored in the on-board mass memory. During ground connect times, which will last between two to four hours, the spacecraft will be reoriented towards the earth and the memory content will be sent to the Perth ground station. At the same time the command schedule for the next 24 hours will be uplinked. From Perth the data will be routed to the MOC in Darmstadt, Germany.

FIRST will offer more than 6000 hours of observing time per year which will be divided into 'guaranteed' and 'open time'[2]. The guaranteed time will be shared between the instrument/ICC Principal Investigators, the FSC and the Mission Scientists. The open time will be allocated to the scientific community on the basis of proposals for observing time submitted in response to calls for proposals. Large surveys and key programmes will use up a big part of the available observing time which, in the end, will be divided into a large number of relatively short observations using the different observing modes of the three instruments.

## 3. GROUND SEGMENT AND SCIENCE OPERATIONS

A distributed ground segment needs clean interfaces between the different centres. But, on the other hand close collaboration is necessary to achieve the goals. The FIRST Ground Segment Advisory Group (FGSAG), which consists of representatives of all ground segment elements, will monitor the progress of the development of the ground segment, will provide analysis on system level in view of the overall mission and the science objectives of the ground segment, and provide advice. On working level the geographical distance can be bridged by using modern communication technologies like video and telephone conferences, but also FAX and electronic mail.

### 3.1. FIRST integrated network and data archive system

The FIRST Integrated Network and Data Archive System (FINDAS) will be the heart of the whole ground segment. Dedicated network links will connect it with the other centres. The scientific community will have access via public networks.

FINDAS will be an object oriented database management system based on a 'Three Tier Client-Server' architecture. In such a system the client provides the user interface of the system, the middleware builds the abstract interface between front- and back-ends of the application, e.g. input data validation or bulk data processing, the server finally represents the back-end and is used for data storage and retrieval.

The FINDAS architecture will consist of the following components: the Data Store for the persistent storage of all information, the Object Servers, representing the middleware and defining the set of logical data objects exported by the FINDAS environment, the Real-time Telemetry Distribution Server supporting the distribution of telemetry to the ICCs in near real-time, the Dynamic Web Page Server providing a World Wide Web (WWW) interface to

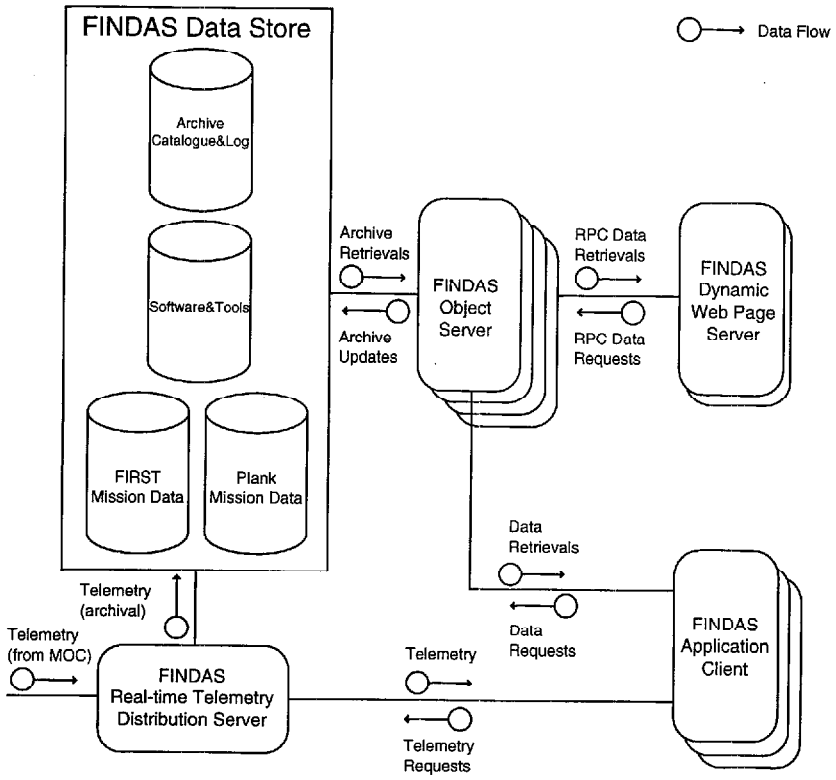


**Figure 1.** Relationship between the architectural components in FINDAS.

FINDAS and the Application Clients for user applications accessing or updating information stored in the archive. Figure 1 shows the relationship between the architectural components of FINDAS.

The distributed infrastructure foresees local servers at the MOC and ICC sites. An automatic messaging system will allow the distributed applications to communicate. This will ensure that objects added to the FSC system will automatically be visible to other users and to external sites independent of the object server or Web server to which they are connected.

FINDAS will also provide configuration track and control. Later on several versions of scientific software and calibration files will reside inside FINDAS and it must be for example possible to identify the versions which have been used to process a certain data set. Another example is the typical development cycle of a software module. A problem has been identified in one of the modules, the software engineer reserves and extracts the module, he fixes the problem and updates the module in the Test Environment, after successful testing the module will be copied to the Operational Environment and is again available for the users.

Another feature is the control of user access rights. FINDAS will have many different types of users: programmers, technical staff, scientists, novice and expert users. For all of them the access criteria will be different. This is especially important for the observers, because the proprietary rights on their data must be guaranteed until the data become public.

FINDAS must be flexible and expandable. The volume of objects will be rather small in the beginning, but at

the end of the post-mission archive phase it will comprise approximately 2.5 Terabytes of documentation, software, telemetry and telecommand sequences, calibration data, observation proposals and catalogues.

In the end FINDAS must allow the efficient query and retrieval of large structures which link objects, relations and methods. The example in Figure 2 shows the history of one observation. The observation description defines the celestial object, the selected instrument, the instrument mode, the observing time necessary for a certain signal-to-noise ratio and other parameters to fill in the Astronomical Observation Template (AOT). The AOT logic translator (CUS) creates a series of Instrument Command Sequences (ICSs). Together with the spacecraft commands they will be uplinked to FIRST and the observation will be executed. The analysis of the downlink telemetry will create different log files which reflect the status and health of satellite and instruments, the executed commands and the quality of the observation data. The scientific software together with the appropriate calibration files will finally create meaningful science data. All this defines one observation.

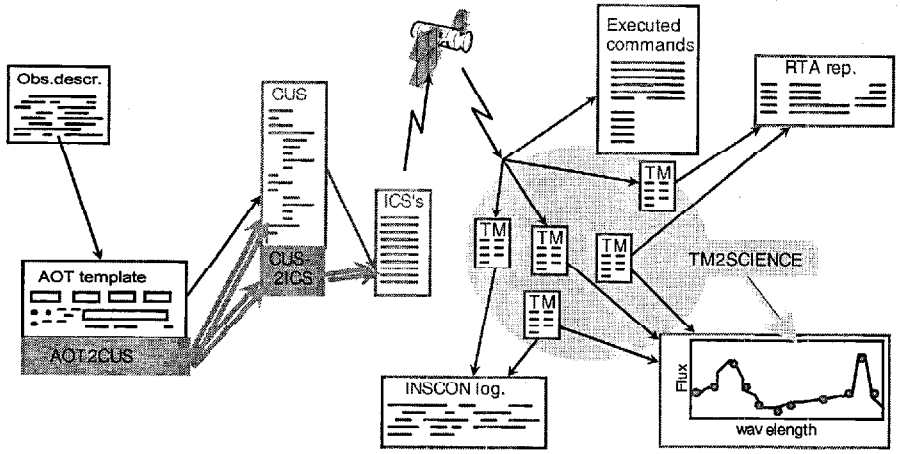


**Figure 2.** Structures in FINDAS: Links between objects, relations and methods

### 3.2. FIRST Project

The FIRST Project is formally responsible for the development of spacecraft, instruments and ground segment until the end of the in-orbit commissioning phase.

One of the fundamental design features introduced by the FIRST Project will be that commonality will be persued, to the maximum extent possible, across all instruments and throughout the different phases of the mission. This will be not only a simplification of the system, but also a cost saving factor.

This commonality covers all the activities carried out during instrument development and testing, system level check-out and mission operations. For the instruments it foresees the use of the same type of on-board micro-processors, the same programming language and development environment, and the same commanding scheme including on-board memory management. It is also valid for required software tools, hardware elements, like EGSE, test sequences and procedures.

Commonality to a certain extent is also foreseen between the Central Check-out Equipment (CCE) used during system level tests and the Spacecraft Monitoring and Control System used during the mission.

Via FINDAS the FIRST Project will provide the documentation and database for the spacecraft, as well as procedures for Acceptance, Integration and Verification (AIV) on system level and for the in-orbit commissioning of spacecraft and instruments.

### 3.3. Mission operations centre

The Mission Operation Centre (MOC) for FIRST will be located at the European Space Operations Centre (ESOC) in Darmstadt, Germany.

The MOC will be responsible for all real-time operations of spacecraft and instruments. It will receive telemetry from the ground station in Perth, check status and health of the satellite and verify the execution of commands and determine orbit and attitude. The incoming telemetry will be delivered to FINDAS in near real-time.

The FSC will provide the MOC with files of time-ordered observations on an orbit by orbit basis for detailed scheduling. The MOC Mission Scheduling System will check this Sequenced Observation List (SOL) for visibility constraints, plan the spacecraft manoeuvres and schedule the observations as agreed with the FSC. The time-tagged command schedule will be uplinked during the ground station visibility period and stored on-board for later execution.

For mission planning and observer support MOC will provide the FSC with star catalogues, the FIRST visibility tool and slew duration predictor and a list of executed observations.

Figure 3 shows the division of tasks between the different centres during operations.

### 3.4. Instrument control centres

There will be one Instrument Control Centre (ICC) for each of the three FIRST instruments located at the institutes of the Principal Investigators.

During the development phase the responsibility of the ICC is to provide all data bases, software packages, procedures and documentation necessary to test and calibrate the different instrument models and to generate scientifically meaningful data products. Members of the ICC will actively participate in all instrument level tests and support the AIV activities on system level, end-to-end testing of the whole FIRST ground segment and mission simulations before launch. The definition of instrument modes (AOTs), AOT logic, which can be used as a time estimator for observations, and an AOT translator, which creates a sequence of instrument commands, will also be developed and are through FINDAS available for the scientific community in support of proposal submission.

During the spacecraft commissioning and performance verification phase of the instruments members of the ICC and of the instrument development team will be collocated at the MOC in order to be able to check status and health of the instrument in real-time and to react quickly in case of problems.

The prime responsibility of the ICC during routine operations is to maintain the scientific performance of the instrument throughout the mission and to update all the tools necessary for the generation of scientifically meaningful data products. It will continuously monitor status and health of the instrument, analyse its engineering and scientific performance, schedule test and calibration observations through the FSC mission planning system, adjust observational and operational procedures, generate calibration data and update existing or develop new data processing software.

The main task during the archive phase is the consolidation of the complete data base, the final calibration of the instrument and the update of the whole documentation.

### 3.5. FIRST science centre

The FIRST Science Centre (FSC) will be located at ESA premises in Villafranca, Spain.

The FSC is the interface between the ICCs, the scientific community and the MOC. It plays a fundamental role in the FIRST science operations concept. Through the Project Scientist it ensures the overall science coordination and the maximum scientific return of the mission. The FSC will be the single-point interface to the scientific community and to the media and it will provide a central helpdesk for the FIRST observers supported by the ICCs. Within the ground segment it ensures that all centres adhere to agreed standards.

The FSC will be responsible for the set-up, management and maintenance of FINDAS, whereas the definition of the data model will be a common task of all centres.

In preparation for the Call(s) for Proposal the FSC will provide the necessary documentation, tools and helpdesk support. It will screen the incoming proposals for duplication and feasibility and submit them to OTAC for scientific evaluation. All accepted proposals will be stored in the Mission Database.

Mission planning will select and sequence sets of observations for periods of 24 hours based on visibility and priority. These Sequenced Observation Lists (SOL) will be send to the MOC via FINDAS for scheduling. The data of successfully executed observations will be made available to the observer. Failed observations will be rescheduled.

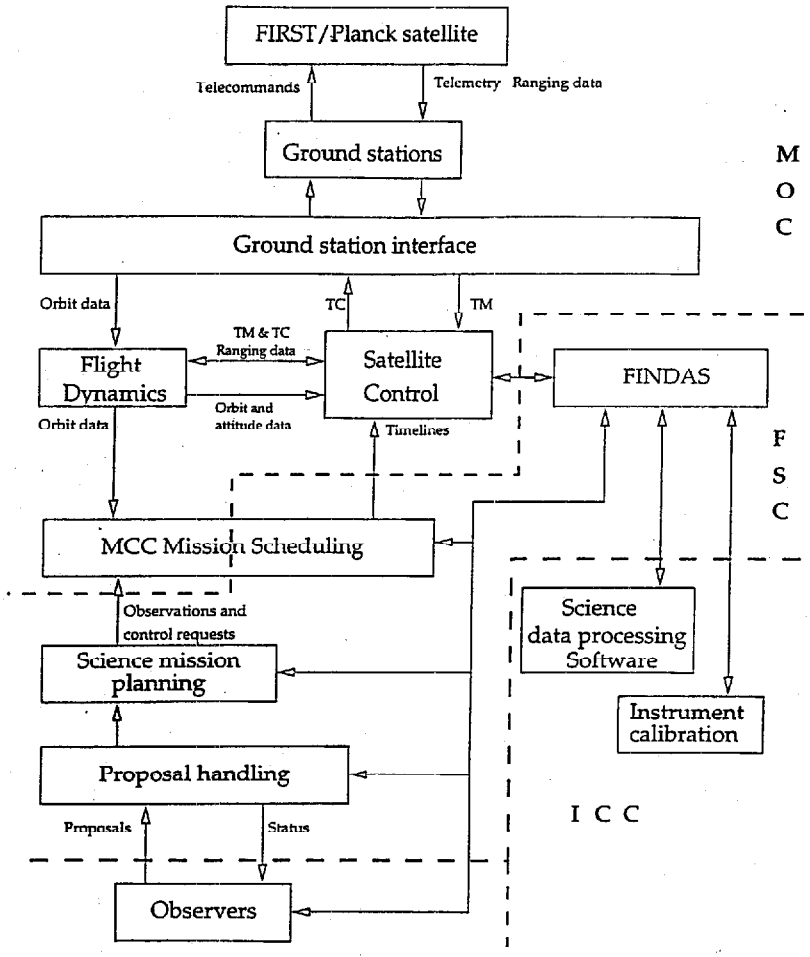


**Figure 3.** The FIRST ground segment during operations. The dashed lines separate the tasks of the different centres.

### 3.6. Observation time allocation committee

Several years before launch the Observation Time Allocation Committee (OTAC) for FIRST will be established by ESA. The OTAC membership will be based on scientific excellence and conflict of interests with proposers will be avoided. All key scientific topics addressed by FIRST should be represented.

OTAC will establish the criteria for 'open time' proposal selection and will review and categorize the proposals on their scientific merits, technical feasibility, and priority in respect of the overall scientific objectives of FIRST. Finally OTAC will recommend to ESA the assignment of observation time. During this selection process OTAC will be supported by the FSC.

### 3.7. Scientific community

The scientific community can access the World Wide Web pages of FINDAS to get information on FIRST. For the preparation of observing proposals observers can retrieve instrument user's manuals, AOT time estimators, visibility tools and other relevant information from FINDAS. In case of problems they can access the FSC helpdesk via electronic mail, FAX or phone. After completion they will submit their proposals to FINDAS and wait for the approval by OTAC and the allocation of observing time. For proposal entry they will use the Web pages of the proposal entry system. The proposals will be validated before they will be stored in the mission database and scheduled according to visibility and priority. The observers can check the status of their proposals via FINDAS. After execution the observer can retrieve his data together with scientific processing software, calibration files and ancillary information. He can analyze his data and repeat this process whenever new software updates and/or calibration files are available. After publication he should send the paper to FINDAS for information of the science community.

## 4. CONCLUSIONS

The decentralized concept of the FIRST ground segment and science operations has many advantages. The most important are the saving of costs and the the creation of centres of competence. Here the expertise of the teams can be used and propagated in an optimum way and the areas of responsibilities and interfaces between the centres are clearly defined. The involvement of the ICCs in instrument development and testing from the very beginning will certainly lead to instruments which are less complex to operate and to a higher quality of the data processing software.

The geographical distance between the centres in times of fast network connections and modern communication techniques is considered to be not important.

FINDAS is the heart of the whole ground segment and certainly belongs to the next generation of space mission archive systems. But being the heart means that it is also the most critical item. Most of its functionalities must be available in two years time, it has to be operational for more than 20 years, and in the end it will hold nearly 2.5 Terabytes of information. The FIRST Project is aware of this criticality and has started the development of a prototype to test the feasibility of FINDAS. This prototype will be available for testing at the end of this year.

## ACKNOWLEDGEMENTS

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## REFERENCES

1. FIRST Science Operations Concept and Ground Segment Document, PT-03056
2. FIRST Science Management Plan, ESA/SPC(97)22