Established requirements on the Telescope and OGSE.
- Alignment model and method for the HFI may need to take careful account of this.
- Not a primary reference document for the proposal.

FIRST

ALIGNMENT PLAN

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0. REFERENCE

R.1 Minutes of meeting from alignment working group
. 1rst meeting dated 7/2/96,
. PT.MM.01765 dated 29/02/96
. PT.MM.02051 dated 2/04/96)

R.2 Fax MMS/FIR/18/96 dated 20/02/96

R.3 Cryostat option study FIRST-GR-B0000.003 dated 27.06.95

1. INTRODUCTION

This document provides the alignment plan for FIRST (Far InfraRed Space Telescope) which has been defined through an Alignment Working Group managed by ESA.

This plan starts from the Scientific Instruments / Telescope alignment needs derived from mission objective which have been shared to give allocations to telescope, instruments, payload module and satellite levels.

It describes the alignment concept covering adjustments and measurements methods for the integration of Scientific instruments and Telescope in the Payload Module (*The internal alignment and associated control of the telescope and Scientific instruments are out of the scope of this document).*

It defines the optical interfaces and associated OGSE necessary to implement this concept.

2.2 DEFINITIONS

a. Telescope axis

Telescope optical axis (in "space image") is defined by the line passing through the centre of the secondary mirror and the telescope focus. The telescope focus is defined as the centre of the unvignetted field of view (this centre is referred to a reference mark on the telescope).

b. Instrument pupil and axis

The exit pupil of the instrument is defined as the image of the instrument internal pupil in telescope space. In the current design for PHOC and BOL instruments, the internal pupil is the mirror M4, while the instrument exit pupil is the image of M4 through M3, and is ideally located at M2 (exit pupil of the telescope) and centred with respect to M2, i.e. the centre of the instrument exit pupil is ideally also the centre of M2.

The instrument axis is here defined by the line passing through the instrument focus (instrument F.O.V. centre) and the exit pupil of the instrument.

c. Alignment parameters:

- the focus location error along the optical axis, "defocus", is the distance between the telescope focal plane and the instrument focal plane measured along X axis.

- the lateral alignment error is the distance between the Instrument focus (F.O.V. centre) and the theoretical centre of the field of view given by the telescope to the instrument, measured in a plane perpendicular to the optical axis.

- the tilt error refers to the lateral alignment error between the exit pupil of the instrument and the telescope pupil M2. Tilt error is the alignment between optical axis of the instrument and line between telescope secondary mirror (exit telescope pupil) and F.O.V centre of instrument.

- Roll error is the rotation of the whole focal plane around the optical axis.

- The telescope must be transversely aligned on the PLM with an accuracy of +/- 1 mm.

	AXIS	LATERAL	TILT (arcmin)
Instruments adjustments in the focal plane w.r.t optical bench I/F	8 arcmin	3 mm	9.11
Optical bench / PLM	1 arcmin	0.5 mm	1.2
Telescope knowledge	NA	1 mm	1.5
PLM/Telescope adjustment	1 arcmin	1 mm	1.8
Telescope stability (equiv. WFE 2 µm)	NA	0.1 mm	0.1
Instruments Stability	**	**	**
PLM Stability (ISO type)	0.4 arcmin	0.3 mm	0.6
TOTAL			**9.5**

** included in "instrument adjustment"

c. Roll

The absolute requirement is roll less than 1 degree.
This requirement is not shared between the telescope, PLM and Instruments

2.4 ANALYSIS

a. Focus alignment

The rational for 11 mm telescope defocus has been already provided in ref. 2: this figure is consistent with the telescope image quality requirement.

Capability for PLM/Telescope interface adjustment along X axis must be kept to take into account the real location of the telescope focus.

3. AIT PHILOSOPHY

Telescope

The mirrors are integrated inside telescope structure and adjusted in order to achieve both the image quality and alignment requirements. Then these performances must be verified together with the environment test, at least:

- Image quality and alignment at ambient and cryo conditions
- Image quality and alignment before and after vibrations

The measurement of secondary mirror and focus lateral locations will be used for the adjustment of the whole three instruments w.r.t the PLM interface and for the lateral adjustment of the PLM telescope interface.

In addition, the knowledge of the telescope defocus can be also taken into account during PLM/Telescope interface adjustment.

Instruments

Prior to delivery to the PLM, each instrument is aligned with respect to its mechanical interface with the PLM. Here also the performances are verified with the environment tests.

PLM

The instruments are located inside the PLM. Before integrating the telescope, the instruments must be aligned w.r.t the PLM/telescope interface and the alignment performances verified with the environment tests.
After this level, it is not possible to re-adjust later the instruments independently inside the PLM.

Satellite

The telescope is finally mounted on the PLM with an adjustment of the PLM/Telescope mechanical interface to take into account (at least) the lateral shift of secondary mirror if this has not been done during the instruments adjustment.

During the environment tests, the alignment of telescope w.r.t. the instrument will be at least verified on optical reference located on PLM and telescope interface.

[redacted]

4.3 SATELLITE LEVEL

When the telescope is mounted on the PLM, this interface is adjusted to take into account telescope behaviour. We can not imagine that the PLM optical bench adjustment can take into account the telescope behaviour for two reasons:

* The adjustment of the PLM/Telescope interface is mandatory to avoid schedule links between the telescope and PLM activities.

* The optical bench adjustment capabilities will be limited.

The figure 4.3 summarises this alignment concept.

5. ALIGNMENT MEASUREMENT METHODS

5.1 ADJUSTMENT CONTROL

5.1.1 Instruments - Optical bench

The instruments are integrated without adjustment on the optical bench.

Instrument optical reference are used to check co-alignment of instruments on the optical bench and to adjust the optical bench with respect to the PLM/telescope mechanical interface:

An alignment cube and optical ball visualise the PLM mechanical I/F. Two linear tables are fixed at PLM I/F and aligned with respect to PLM cube with theodolites.

then the adjustment control of the optical bench can be performed:

- tilt measurement with theodolite and flat mirror (~10 mm diameter) mounted on top of the instruments.

- lateral measurements with same OGSE, the instruments flat mirror must have a reticule.

- Focus along X axis can be measured using Simon collimator.

These measurements can be performed at ambient or cryogenic temperatures (both are mandatory for PLM tests sequence)

5.1.2 Telescope/PLM

The telescope PLM I/F must be laterally adjusted and telescope tilt controlled. This is also achieved with theodolite and measurements on alignment cubes and optical balls mounted on PLM and telescope side.

The table here below summarises the alignment control capabilities versus the alignment components available:

INSTRUMENTS OPTICAL I/F SELECTED	ALIGNMENT CONTROL AT SATELLITE LEVEL
Mirrors on top of instruments	optical bench/ PLM stability
dedicated mirrors on the optical bench	telescope alignment w.r.t optical bench
dedicated mirrors (or marks on M4 mirror) inside one instrument	telescope alignment w.r.t one instruments axis
dedicated mirrors (or mark on M4 mirror) inside instruments	telescope alignment w.r.t instruments axis

ISO experience shows that it is not obvious to implement these components inside the FM instruments.

That is why it is today assumed that:

- marks on the M4 mirror will be available at least on the QM,
- dedicated mirrors simulating M3 and M4 will be placed directly on the optical bench,
- Instruments will have mirrors on the top

6. REQUIREMENTS

6.1 TELESCOPE

The telescope must be delivered with an alignment cube and an optical ball.

With respect to this reference the following parameters must be measured prior to delivery:

- mechanical I/F tilt
- Secondary mirror location
- focus location

6.2 PLM

The PLM/Telescope interface must be also visualised with an alignment cube and optical ball mounted outside in the vicinity of this interface.

For instruments alignment control, an optical window (or FPA access) must be placed above the focal plane size of which must not limit the telescope unvignetted F.O.V.

A pupil simulator must be mounted on the optical bench in the telescope unvignetted.F.O.V. This device must have two mirrors as defined in appendix.

APPENDIX 1: PUPIL OVERSIZING

The question as to whether the instrument exit pupil should oversize M2 or the contrary was not fully answered by the science team. J.M.Lamarre proposed that the instrument exit pupil should undersize M2 for avoiding unwanted modulations of the detected signal during sky shopping due to the sources located in the vicinity of M2. However, it was pointed out that such sources are not imaged through the telescope: the modulation during sky shopping would be due to direct radiation from these sources to the focal plane, which may lead to an acceptable modulation level.

Moreover, undersizing the instrument exit pupil w.r.t M2 diameter by 16 mm for alignment purpose implies a reduction of the collecting area and therefore an energy loss of 13%.

Therefore the Working Group has considered, as a working assumption, that the instrument pupil oversizes M2. The reverse assumption has no impact on the present alignment plan. Whatever will be the final choice of the science team, the following remarks should be made:

- The instrument exit pupil diameter cannot be made exactly equal to M2 diameter for alignment purpose. In any case, the exit pupil oversizing or undersizing will be of several millimetres.

- The tilt error value, that is 12 arcmin or equivalently 16 mm exit pupil oversizing, can be discussed, but it is doubtful that it will be significantly reduced without considerably increasing the alignment procedure complexity. One should keep in mind that all figures refer to cold condition. In addition, the major contributor is the internal alignment of instruments.

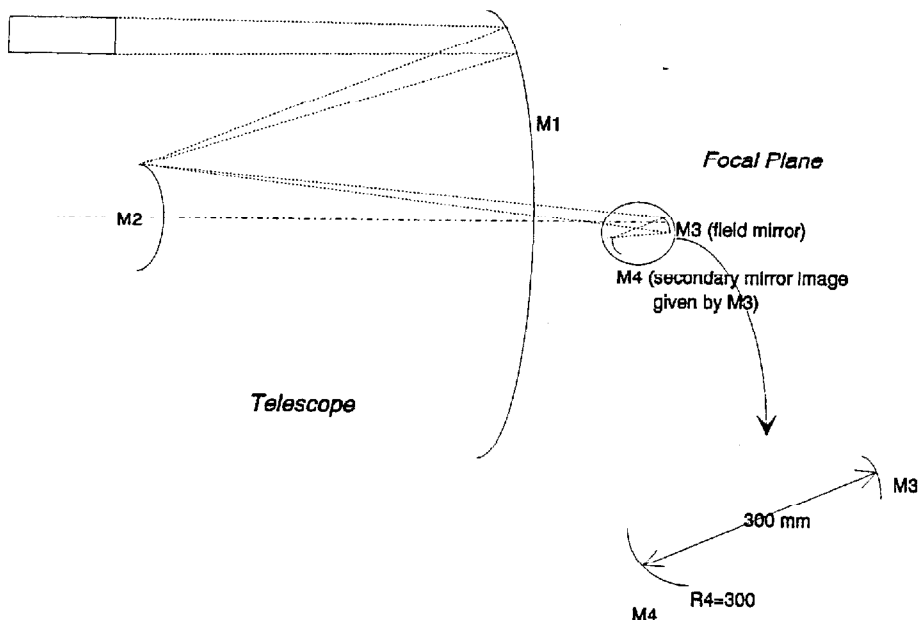
- Should the problem of straylight due to the exit pupil oversizing be really critical, two solutions can be envisaged:

1) undersizing the instrument exit pupil to the detriment of collected energy,

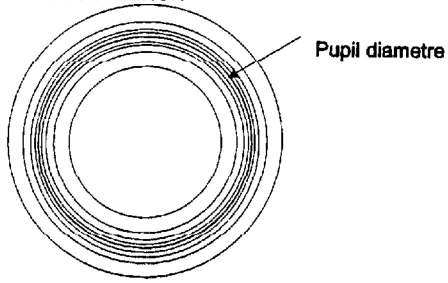
2) use the end to end test not only to verify the pupils co-alignment but also to re-align the instrument exit pupil w.r.t M2 by translating the telescope w.r.t the PLM and/or the instruments on the optical bench. This last solution adds complexity at PLM level.

2. AXIS MEASUREMENT

the figure below gives the measurement configuration: a collimator placed in front of the telescope is focused, through the primary mirror on the edge of the secondary mirror where is also located the image of the instrument pupil given by the field mirror M3.



To measure the co-alignment of the telescope and instrument pupil, concentric circles are put on the M4 mirror:



APPENDIX 3: OGSE DEFINITION

1. TILT ALIGNMENT MEASUREMENT ACCURACY

The global specification is 12 arcmin.

The present budget (cf § 2.3) gives 9.5 arcmin tilt performance, so the measurement accuracy (including OGSE and Optical reference performances) must be below 7 arcmin ($\sqrt{(12^2-9.5^2)}$).

2. OGSE DEFINITION

This analysis is done in the case of ISO configuration (cf figure Appendix 2 §2) to define the parameters of the collimator, but the proposed definition of the alignment mirrors is valid for both configurations.

The telescope entrance pupil location is about 16 meters behind the primary mirror with a magnification factor w.r.t M2 equal to γ=11.8.

1 arcmin tilt of instrument axis w.r.t telescope induces .7 mm pupil misalignment at M2 level and therefore ~ 8mm lateral misalignment on the entrance pupil.

The sighting collimator will be placed in front of the telescope at ~ 2 metres from the primary mirror.
So this lateral shift is seen under 1.5 arcmin angle. Which is seen without difficulty for an observer with x10 magnification factor on the collimator.

Taking into account the ISO alignment dummy design, as shown on the figure here after, the characteristics could be:

M3 diameter: TBD versus collimator F.O.V (10 arcmin?) and vignetting analysis not performed up to now.
M4 -M3 distance: 300 mm
M4 diameter (mini): 31 mm

distance between two circles (equivalent to 3 arcmin): 270 μm
thickness of circles: 50 μm