| | Projet FIRST | REF: **LOOM.KD.SPIRE.2000.001-2**<br>Author **: Alain Origne, Kjetil Dohlen** | PAGE : **1 / 17**<br>Date : **16 May 2000** |
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# FIRST SPIRE: Optical alignment verification plan

**SPIRE-LAM-PRJ-000445**

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# Updates

| Date | Indice | Remarks |
|---|---|---|
| 3 Jan 2000 | 1 | Creation of the document |
| 16 May 2000 | 2 | Update, including spectrometer |
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# Reference documents

| # | Title | Author(s) | Reference | Date |
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| Host system | Windows NT |
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# 1. Scope

# 2. Introduction

## *2.1. General principles*

The alignment of the photometer will be performed according to a philosophy largely based on the experience with aligning the GERB and ISO-LWS instruments. The discussion during the meeting at LAS of 27 August 1999 has allowed us to draw up the principles of this philosophy as applied to FIRST-SPIRE.

Alignment sensitivity and error budget studies show that alignment precisions of 1 arcminute and 0.1 mm at the mirror level are sufficient. This makes possible an alignment philosophy based on the direct assembly of the mirrors onto the structure. It is clear, however, that an extensive verification program is required to make sure that the alignment requirements are met, and that "emergency exits" exist if defaults are discovered.

To answer this need, the alignment verification plan provides a series of actions based on visible light metrology. First, the definition of the instrument gut ray with respect to external references. The instrument is mounted on a panel representing the FIRST optical bench (FOB). The telescope optical axis is materialized by an optical reference cube (FOR) mounted on the FOB. The SPIRE optical bench (SOB) is equipped with an optical reference cube (SOR) allowing optical alignment of the instrument on the FOB after integration of filters etc, opaque to visible radiation.

The SPIRE gut ray, i.e. the line joining the centre of the telescope secondary and the centre of the instrument FOV (one for each channel), is materialized with respect to the FOR and the SOR by the aid of an alignment telescope.

During assembly, it is verified that each mirror reflects the gut ray in the correct direction. This is achieved by mounting the mirrors one by one in the order of light propagation, and by mounting a special tool in place of the following mirror.

After integration of all mirrors, external alignment is verification, assuring that the instrument's object, pupil, and image planes are aligned with the gut ray.

Pupil and image quality are then verified, assuring that the required imaging capabilities of the instrument are met.

Finally, an internal alignment stability and reproducibility test allows to verify that the instrument's object and image planes are aligned with each other, even during cold tests and before and after vibrations, mounting/dismounting of filters, detectors, etc.

The order of these tests may be redefined in view of the overall AIV plan, and may not necessarily be the same for CQM and PFM models.

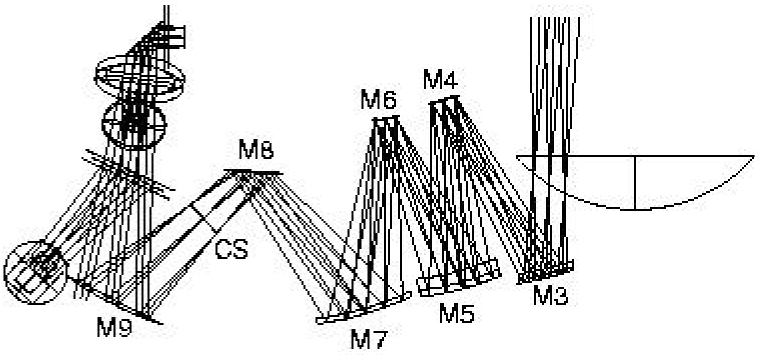
In the case of an observed misalignment exceeding the total budget, two mirrors per channel (M6/M9, TBC, for photometer and M6/Coll, TBC, for spectrometer) are foreseen to be adjustable by remachining of the interface structure/mount, allowing fine adjustment if necessary.

This philosophy assumes that the optical surfaces are good enough in the visible to allow the use of classical apparatus like alignment telescope and theodolites. The optical quality obtained by diamond machining of aluminum allowed to conduct with success a similar alignment scheme for the LWS instrument.

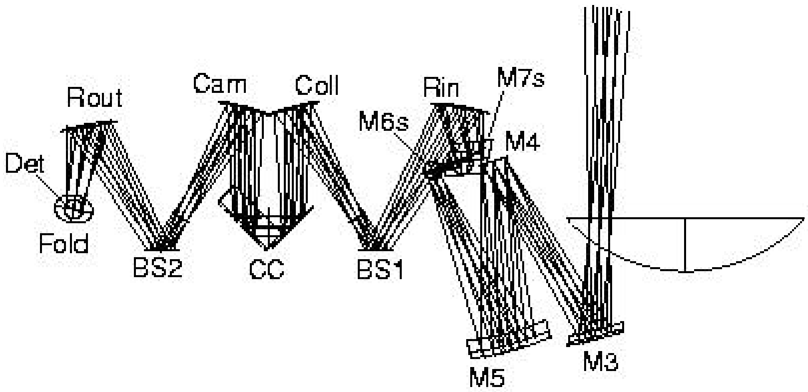
The present document describes the alignment procedure for each channel (Sec. 3 and 4) and provides a detailed description of the required tools (Sec. 5).

### *2.2. Baseline designs*

Current baselines are BOLPHT153 for the photometer channel and BOLSP501 for the spectrometer channel. The systems are shown in Figure 1.




(a)




(b)

Figure 1. Ray diagram of the photometer channel (a) and spectrometer channel (b) of the SPIRE instrument showing the ray paths for three points in the tangential plane, centre and extremes of the FOV. The symmetrical lower half of the spectrometer channel is generated by reflection about the plane containing the two beam splitters.

# 3. Photometer alignment

## *3.1. Outline of the alignment procedure*

The steps of the alignment procedure are listed below and illustrated in the following flow charts. Section 3.2 gives a detailed description of the procedures. Please refer to Sec. 5 for a description of the tools to be used.

1) A preliminary visual inspection of all the interfaces is required. Great care will be taken to detect any surface defects which could compromise the mirror support.

2) A 3-D space metrology to be performed on the mirror mount interfaces on the structure before assembly of the mirrors to allow verification of the coordinates and the orientation of the interface planes with respect to the optical design. Any error detected will be analyze to find its cause and corrected if necessary. A specific, "3 D tool" will be used in place of the mirrors in order to ease the 3-D measurement and to avoid damage of the mirror surface.

3) Integration of the mirrors in sequence with control of the last mirror mounted with respect to the vertex of the following mirror, represented by an "Apex tool".

4) External alignment control: verify that object, image, and CS pupil are centred on the externally defined gut ray.

5) Pupil quality verification

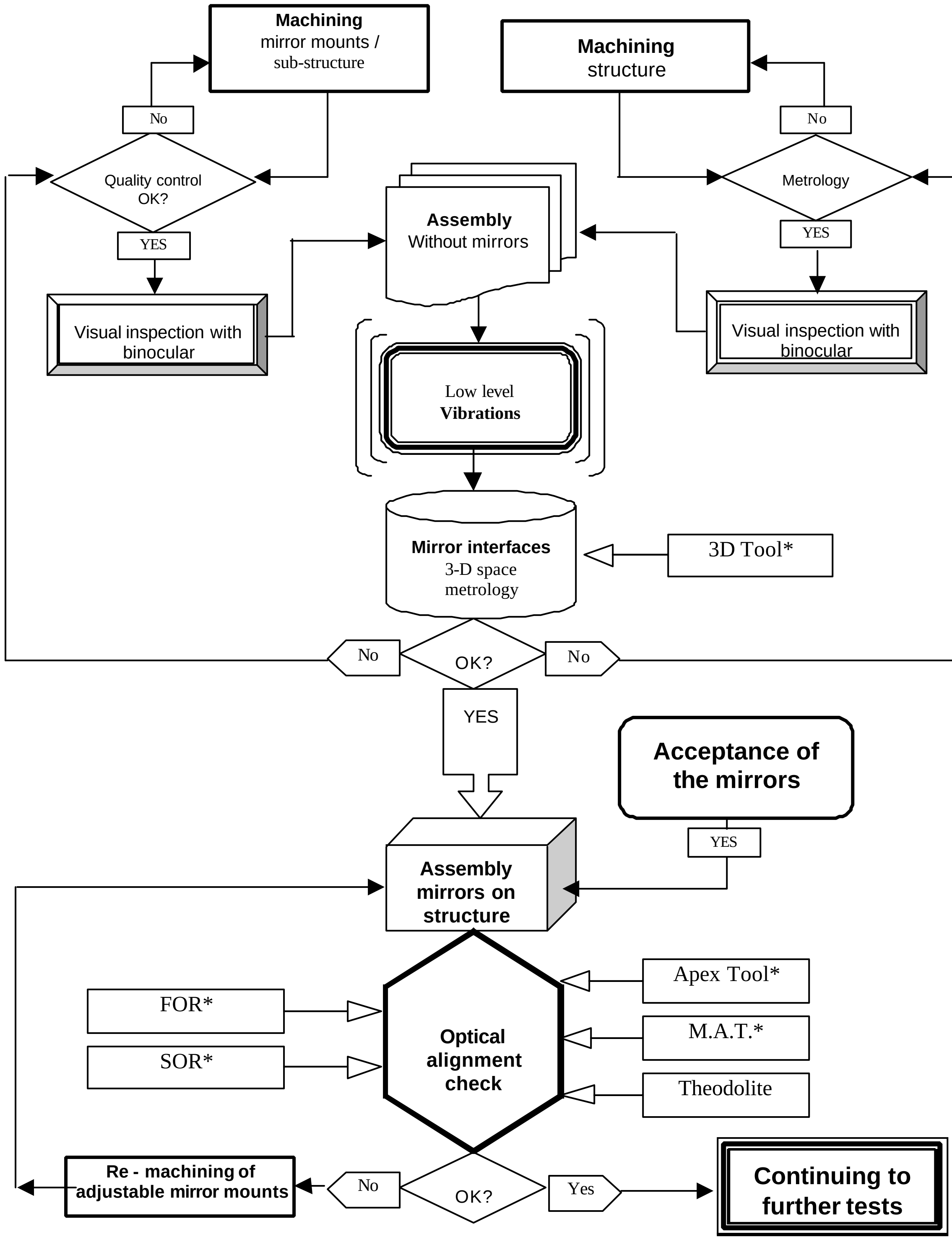
6) Image quality verification

7) Internal alignment stability and reproducibility control: verification of image position after dismounting and remounting of tools, during thermal test, and after vibration test

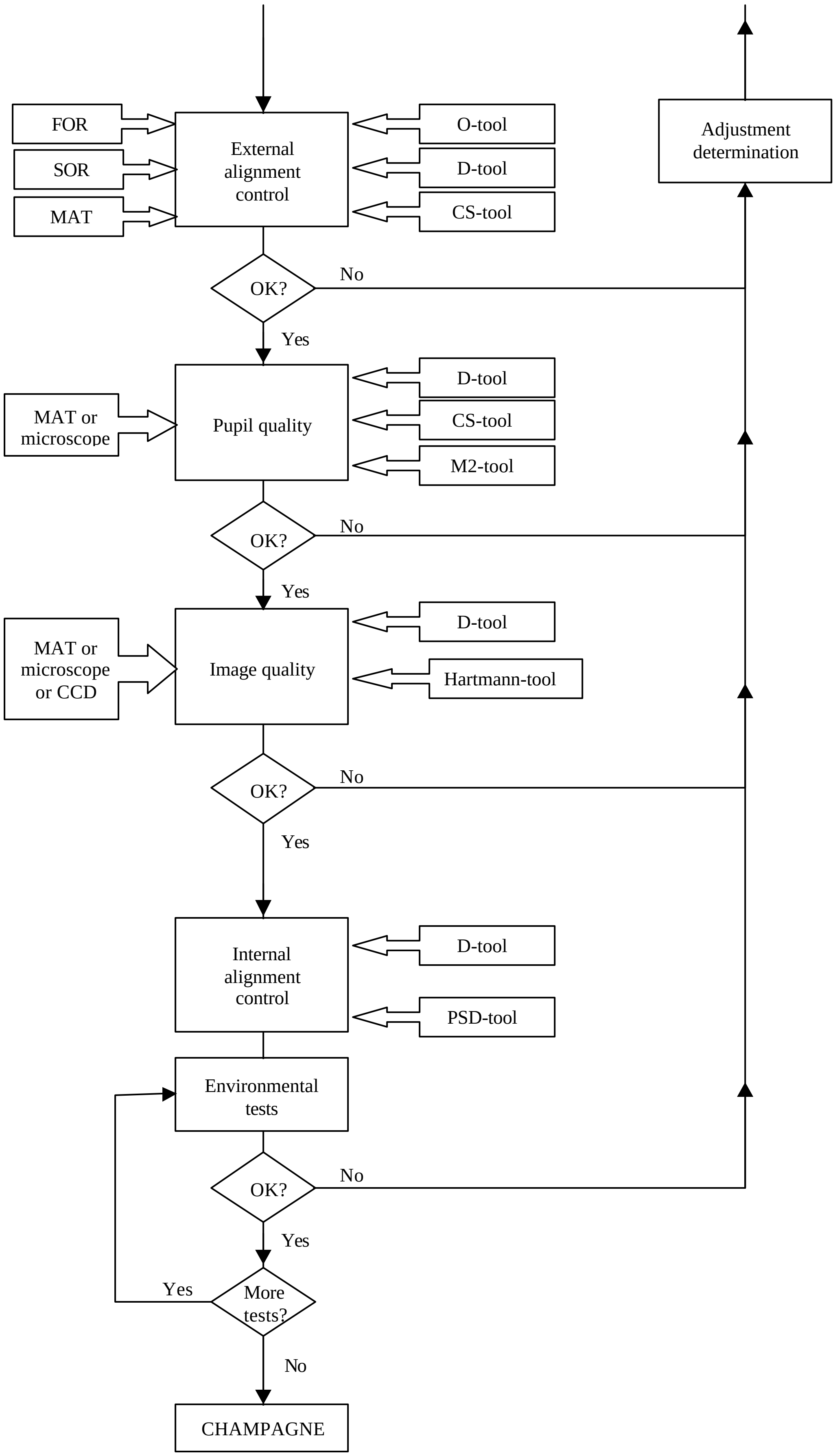
This ends the visible alignment procedure. Integration of IR components (filters, dichroics, detectors, etc), and further environmental tests proceeds without visible alignment checks.

Detector co-alignment is not part of the visible alignment procedure because it is strongly affected by the mounting of filters and far IR dichroics, opaque to visible light. This was discussed at the Systems meeting in Feb. 2000 and a method based on the use of a FIR source was suggested.

# Synopsis of the alignment sequence, steps 1 to 3 :




| | |
|---|---|
| * *3D Tool* | = Specific tool for interfaces measurement |
| * *Apex Tool* | = Tool which gives the direction and the lateral position of each mirror |
| * *FOR, SOR* | = FIRST optical reference and SPIRE optical reference |
| * *M.A.T.* | = Micro Alignment Telescope |



FOR
SOR
MAT
External alignment control
O-tool
D-tool
CS-tool
Adjustment determination
OK?
No
Yes
MAT or microscope
Pupil quality
D-tool
CS-tool
M2-tool
OK?
No
Yes
MAT or microscope or CCD
Image quality
D-tool
Hartmann-tool
OK?
No
Yes
Internal alignment control
D-tool
PSD-tool
Environmental tests
OK?
No
Yes
Yes
More tests?
No
CHAMPAGNE

### *3.2. Alignment procedure*

Probably the most convenient orientation of the instrument during integration and alignment verification is such as to have the telescope optical axis horizontal. The SPIRE optical bench (SOB) may be horizontal and vertical.

#### 3.2.1. Visual inspection

The first activity before starting the assembly is to do a visual inspection of all interfaces, between sub-structure, mounts, and mirrors. Great care must be taken during the inspection, especially of the mirror mounts, to avoid burrs, streaks or cuttings of metal. The use of a binocular is strongly advised.

#### 3.2.2. 3D-metrology

A 3-D space metrology will be performed on the mirror mount interfaces on the structure before the assembly of the mirrors to verify the coordinates and the orientation of the interface planes with respect to the optical design. The eventual differences will first be analyzed to know the basic cause and then corrected if the measured values are out of margins.

A specific "3D tool" will be used at the place of the mirror to ease the 3-D measurement and to avoid damage of the mirror surface. It allows to know the mechanical reference of the mirror interface which is the intersection of the bore and the supporting surface, and the orientation in 3D-space of the normal to this surface.

The 3D-space metrology will be performed at the end of the machining of the sub-structures and the mirror mounts. A check report will follow each part, with the “as-designd” and the “as-built” dimensions.

#### 3.2.3. Alignment verification during integration

After the 3D-space verification of all the interfaces the optical alignment will be performed step by step during integration with the “Apex Tool” in place of each following mirror. This will allow to verify that the mirrors are properly mounted . Any poor contact between interface surfaces will be detected at this point. The following sequence is proposed:

**1) The MAT (Micro Alignment Telescope) is aligned with respect to the First telescope axis by means of the FOR and coalignment of FOR and SOR is verified:.**

1.1) SOB mounted on FOB dummy, SOB is equipped with SOR, FOB is equipped with FOR. We assume FOR is a mirror perpendicular to the FIRST optical axis with a reticule engraved at the intersection with the axis. Similarly, SOR is assumed to be parallel with FOR with a reticule at a known distance from the axis.

1.2) MAT telescope is mounted on a stage permitting transverse movement (~200 mm TBC) and tilt (~3 deg TBC)

1.3) Autocollimation of MAT on FOR

1.4) Focus MAT on FOR to localize reticule

1.5) Translate MAT to check position of SOR reticule and orientation of SOR

**2) The MAT is tilted and positioned so that its axis coincides with theoretical instrument gut ray**

2.1) Placing the “Apex Tool” in the M3 position allows verification of the lateral position of the M3 interface. *(AO thinks this is not necessary since it just verifies the results of 3D inspection. KD thinks it sounds like a good thing to do though.)*

2.2) M3 is mounted and the Apex tool mounted in the M4 position. This allows verification of M3 tilt with respect to the M4 lateral position. The error is determined by comparing the position of the MAT reticule and the Apex tool reticule.

2.3) This principle is reproduced for each mirror up to the detector level.

In some cases the apex tool image will be projected behind the MAT, offering a virtual object. As the MAT is constructed only for real objects, a supplementary lens must then be mounted onto the MAT. The additive lens must be made with high tolerances to conserve the alignment of the MAT axis. This does not appear to be a major problem, the alignment is easily checked by rotation of the lens around its mechanical axis (cylindrical body of the MAT) : the image must not be deviated during the rotation.

The following figures show the concept of this procedure as implemented for an earlier design of the photometer.

### 3.2.4. External alignment control: Object, image and pupil positions

This test verifies that object, image and cold-stop are all aligned with the externally defined gut ray.

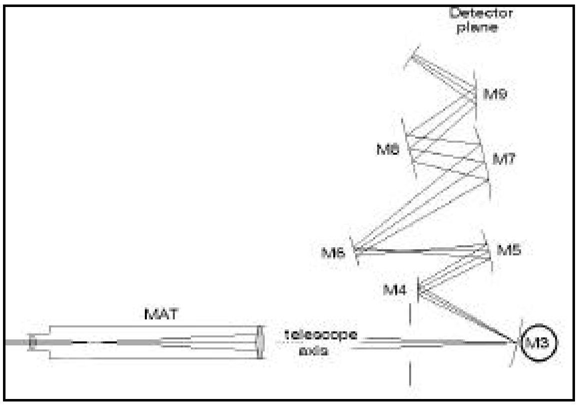
Preparation:

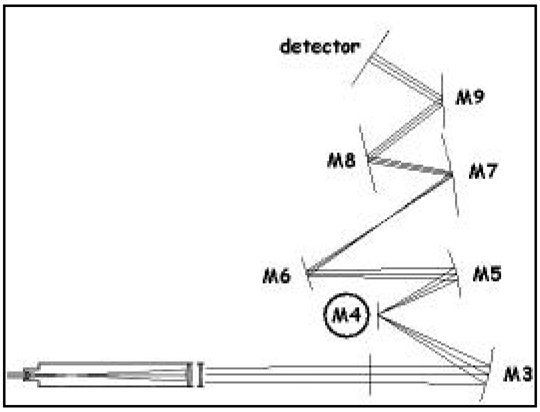
- All optical components (except filters and dichroics) are mounted on the SOB
- Alignment tools D, CS, and O are in place
- SOB mounted on FOB dummy
- MAT telescope is aligned with the theoretical instrument gut ray as explained above

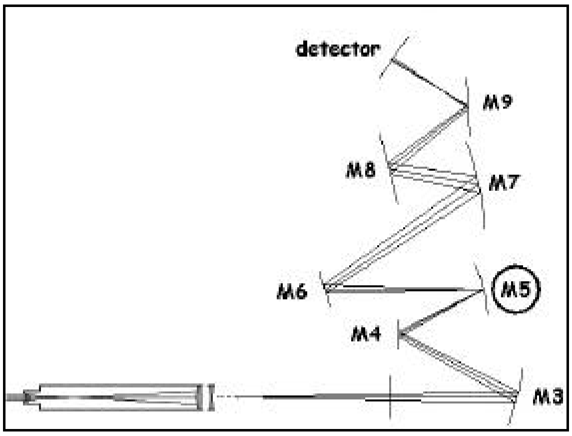
Procedure:

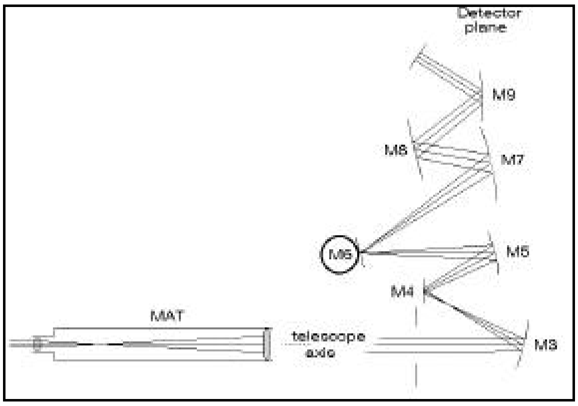
- Focus on O-tool and observe position of central reticule
- Observe position of central source of D-tool as projected onto the O-tool
- Focus on CS-tool and observe position of its reticule

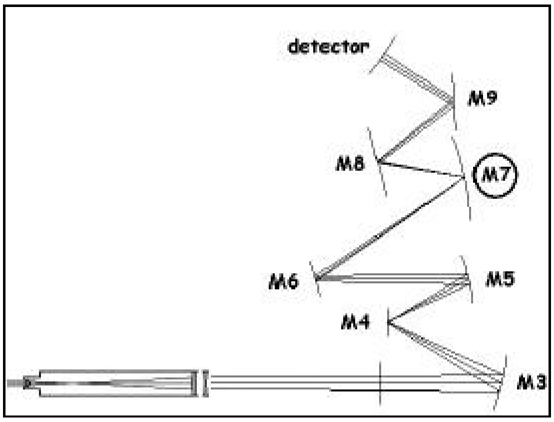
O-tool, D-tool and CS-tool should all be centred on the MAT reticule. Deviations are measured and used to deduce the required adjustments.

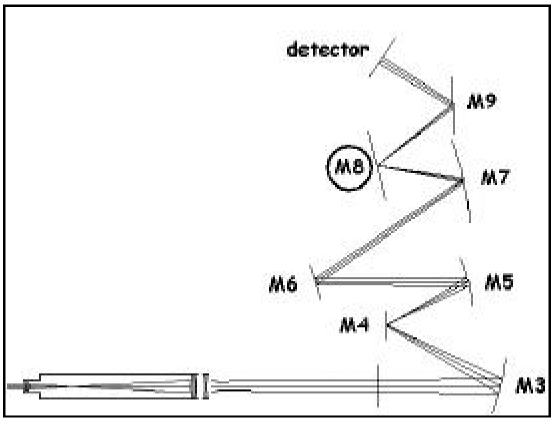

Detector plane
M9
M8
M7
M6
M5
M4
MAT
telescope axis
M3

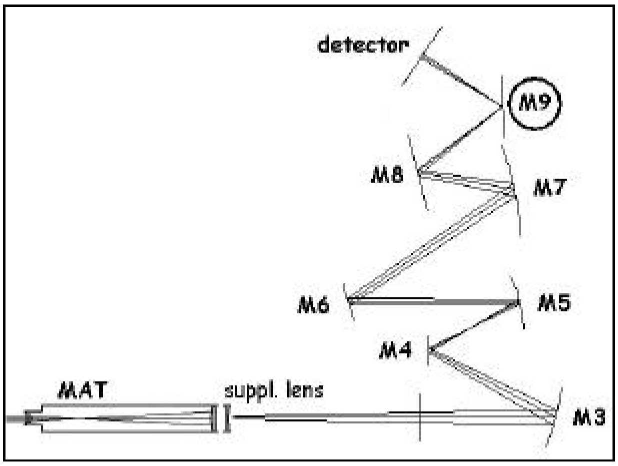

detector
M9
M8
M7
M6
M5
M4
M3

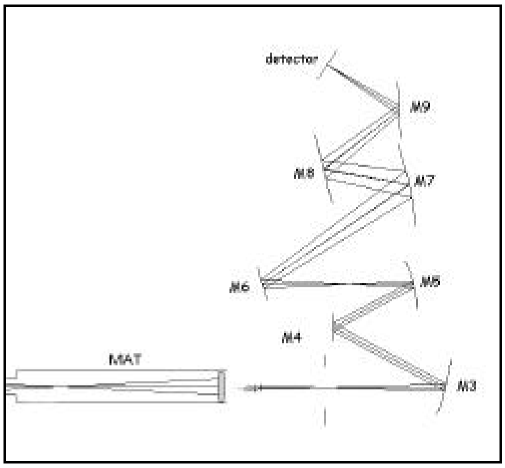

detector
M9
M8
M7
M6
M5
M4
M3


Detector plane
M9
M8
M7
M6
M5
M4
MAT
telescope axis
M3


detector
M9
M8
M7
M6
M5
M4
M3


detector
M9
M8
M7
M6
M5
M4
M3


detector
M9
M8
M7
M6
M5
M4
MAT
suppl. lens
M3


detector
M9
M8
M7
M6
M5
M4
MAT
M3

### 3.2.5. Pupil quality verification

Verification of pupil aberrations, ie the pupil position for different points in the FOV, and absence of vignetting. The test could theoretically be done by imaging entire pupil on a CCD, but etendue of the optical beam is too large for this to be practical. Best method is to observe the image if the CS as projected onto the plane of M2, ie 2.5m outside the instrument. In the location of M2 is placed the M2-tool.

Preparation:

- All optical components except filters and dichroics and the 2K box mounted on the SOB
- Alignment tools (D, CS) in place
- M2-tool appropriately located
- Eye, possibly aided with a loupe, is probably most appropriate observation tool

Procedure:

- With central source of D-tool lit, observe image of central reticule of CS-tool on M2-tool. Adjust M2-tool to make CS reticule coincide with M2 reticule.
- Light sequentially other D-tool sources, measure deviation of reticules for each source.
- Move to edge of M2-tool, measure deviation of CS edge with M2-tool edge reticule, again sequentially for each source
- Repeat for the selected positions along M2 edge.

Compare with theoretically expected results. Large deviations indicate TBD action

### 3.2.6. Image quality verification

We consider two options for verification of image quality: star test or Hartmann test. The star test, ie direct recording of point source images, is preferable due to its simplicity, but it may be impractical due to scattering of visible light in the system. The Hartmann test is more elaborate but should be insensitive to reasonable amounts of scattering. Image quality should ideally be studied at several points in the FOV (centre and edges), but study of the centre point may be sufficient.

**Star test:** Verification of image quality at different points in the FOV could theoretically be done by imaging entire FOV on a CCD, but the etendue of SPIRE renders this impractical. Consider instead field points one by one, observed using travelling microscope or MAT (NB requires Fnumber < 8.68 or numerical apture > 0.06). Recording the observed images using a CCD camera is an advantage for analysis and documentation. Recording directly on naked CCD may also be appropriate.

Preparation:

- All optical components (except filters and dichroics) and the 2K box mounted on the SOB
- Alignment tools D and O in place. CS-tool better left out.

Procedure:

- Focalize on O-tool
- Localize D-tool source under study
- Observe (photograph) image of D-tool source

Analysis: Comparison with spot diagrams. Large deviations indicate TBD action

**Hartmann test:** A plate with a rectangular grid of holes (Hartmann-tool) is mounted in the cold stop. When lit by one of the sources in the D-tool (typically the central source), the projection of the holes through the system materializes geometrical ray paths. Detection of the grid in two planes above and below the SPIRE object plane, allows reconstruction of the geometrical spot diagram. Comparison with theoretical spot diagram provides a measure of the instrument image quality.

Preparation:

- All optical components (except filters and dichroics) and the 2K box mounted on the SOB
- Alignment tools D and Hartmann in place.
- CCD camera, naked or with macro lens, monted on xyz stage near SPIRE object plane.

Procedure:

- With central D-tool source lit, localize its image on the CCD
- Move CCD 20mm (TBC) towards M3, record image
- Move CCD 20+20mm (TBC) towards M2, record image
- Numerical treatment (localize Hartmann spots in both images, calculate ray slopes) allows creating spot diagram for SPIRE as built

Analysis: Comparison with theoretical spot diagrams. Large deviations indicate TBD action

3.2.7. Image position stability and reproducibility

This test verifies alignment of image and object planes. Required for verification of internal alignment after dismounting and remounting of tools etc, and after vibration testing and during cold testing.

Preparation:

- All optical components (except filters and dichroics) and the 2K box mounted on the SOB
- D-tool and PSD-tool in place. CS-tool may or may not be in place.

Procedure:

- Central source of D-tool lit
- Observation of image coordinate provided by PSD.

Analysis: Variation in image coordinate indicates a change in alignment. TBD action to be taken.

*NOTE: AO afraid sources in focal plane bad during cold testing. DP not worried about this as long as 4K source exists. AO prefers fibres in D-tool (NB provide appropriate holes in structure) or external source projected into instrument through cryo window, as he did for LWS.*

*AO also concerned about stability of O-tool. BW looks into what interface is available at the instrument entrance.*

# 4. Spectrometer alignment

## *4.1. Procedure outline*

Spectrometer alignment follows the same general philosophy as that described for the photometer. Main differences are due to the position of the ColdStop and the nature of the interferometer.

Consider spectrometer optics in three parts, separated by the Beam splitters: Input optics, Interferometer, Output optics.

It is assumed that spectrometer integration follows photometer alignment verification procedure. (Probably rechecking after spectrometer integration is necessary).

Spectrometer ColdStop (CSs) follows directly after pick-off mirror (M6s). It is therefore appropriate to do external alignment verification before integration of the spectrometer optics.

Introduction of a few extra steps is required to align the corner cube mechanism within the interferometer optics.

Beam splitters are assumed to act as beam splitters in visible as well. If this is not the case, then they must be replaced with pellicle-type visible beam splitters.

1) A preliminary visual inspection of all the interfaces is required. Great care will be taken to detect any surface defects which could compromise the mirror support.

2) A 3-D space metrology to be performed on the mirror mount interfaces on the structure before assembly of the mirrors to allow verification of the coordinates and the orientation of the interface planes with respect to the optical design. Any error detected will be analyze to find its cause and corrected if necessary. A specific, "3 D tool" will be used in place of the mirrors in order to ease the 3-D measurement and to avoid damage of the mirror surface.

3) External alignment control: verify that M6s and CSs pupil are centered on the externally defined gut ray.

4.a) Integration of the Input optics mirrors in sequence with control of the last mirror mounted with respect to the vertex of the following mirror, represented by the "Apex tool".

4.b) Special procedure for the Interferometer Optics.

4.c) Integration of Output optics similar to Input optics , upper and lower halves treated separately

5) Pupil quality verification

6) Image quality verification

7) Internal alignment stability and reproducibility control: verification of image position after dismounting and remounting of tools, during thermal test, and after vibration test

This ends the visible alignment procedure. Integration of IR components (filters, dichroics, detectors, etc), and further environmental tests proceeds without visible alignment checks.

## *4.2. Alignment procedure*

### 4.2.1. Visual inspection

See 3.2.1.

### 4.2.2. 3D-metrology

See 3.2.2.

### 4.2.3. External alignment control: Object and pupil positions

This test verifies that M6s and CSs pupil are all aligned with the externally defined gut ray.

Preparation:

- Common fore-optics (M3, M4, M5) is mounted as part of the photometer.

- M6s is mounted

- Alignment tools Os and CSs are in place

- MAT telescope is aligned with the theoretical spectrometer gut ray as explained above

Procedure:

- Focus on Os-tool and observe position of central reticule

- Focus on CS-tool and observe position of its reticule

Os-tool and CSs-tool should be centred on the MAT reticule. Deviations are measured and used to deduce the required adjustments.

#### 4.2.4. Alignment verification during integration

<u>a) Input optics</u>

Apex tool in M7s (folding flat) position, MAT aligned as in 4.2.3, provides redundant verification of alignnment up to M7s.

Mount M7s, Apex tool in Rin (input relay) position, verifies alignment of M7s.

Mount Rin and BSin. Mount Apex tool in lower Coll (seen in transmission) position: verifies alignment of Rin.

<u>b) Interferometer optics</u>

Mount Apex tool in upper Coll (seen in reflection) position: verifies alignment of BSin.

Mount both Collimator mirrors. Focus MAT on central reticule of Os tool. Twin images returned by autocollimation should coincide with object. Deviations indicate misalignment of Collimators.

Mount corner cube assembly (CCA, probably a dummy tool replacing the real CCA in its mechanism) and Apex tool in upper Camera position. (Alignment of CC facets and coalignment of the two CCs should be verified separately by TBD procedure.) MAT focussed on Apex tool verifies lateral movement of CCA. Tilt of CCA is of no incidence due to geometry of corner cubes. Apex tool placed in lower Camera position: deviation indicates lateral displacement of CC apexes.

Mount both Camera mirrors and BSout. Mount Apex tool in upper output relay (Rout) position. MAT focussed on Apex tool sees two images, one through each interferometer arm. Identify image from lower arm (transmitted through BSout) to verify alignment of lower Camera mirror.

Mount Apex tool in lower relay mirror. Identify image from upper arm to verify alignment of upper Camera mirror. Identify image from lower arm to verify alignment of BSout.

<u>c) Output optics</u>

Mount Rout, upper and lower, verify alignments with Apex tool in position of fold mirrors.

Mount Fold mirrors, verify alignments with Ds tools.

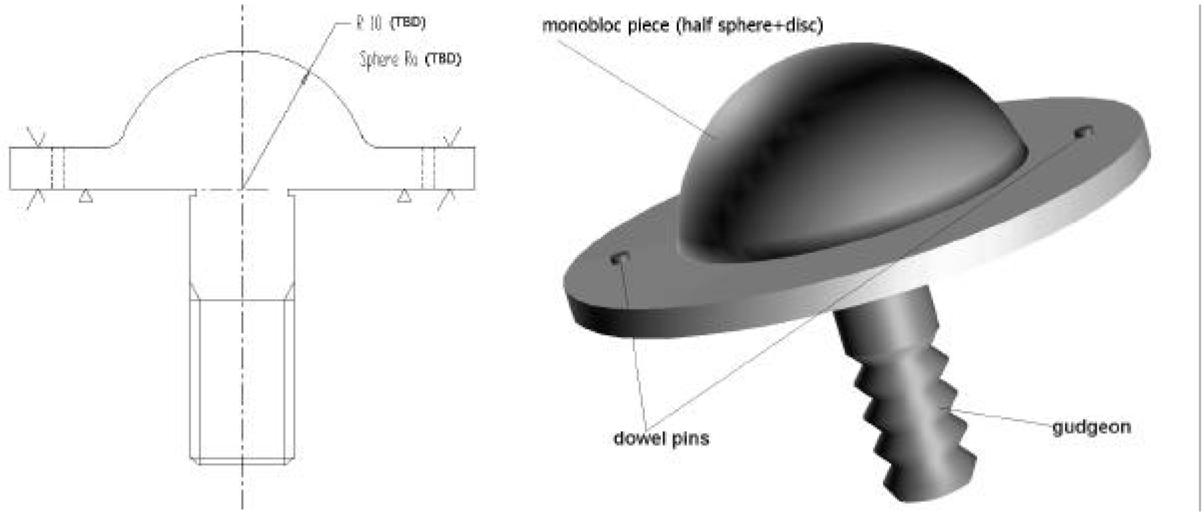
#### 4.2.5. Pupil quality verification: See 3.2.5.

#### 4.2.6. Image quality verification: See 3.2.6.

#### *4.2.7.* Image position stability and reproducibility: See 3.2.7.

## 5. Description of the alignment tools

### *5.1. The “3D Tool”*



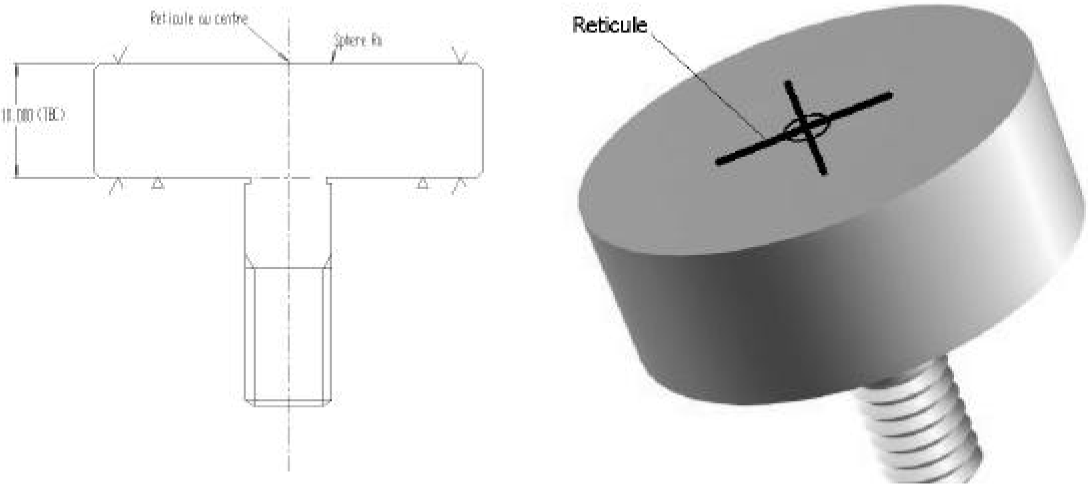

3D Tool for metrology

This tool will be used during step 2, 3D metrology of the structure, to facilitate the measurements in 3D-space of the coordinates of the mirror mount interfaces. It will be mounted and tightend on the interface in the place of the mirror.

The interface is defined in 3D-space by the normal to the support plane and a reference point located at the intersection between the support plane and the axis of the bore that receive the mirror tail.

The tool is a monobloc piece with a shape which associates a disc and a sphere. It will be machined with a great accuracy (TBD). The upper surface of the disc provides the orientation of the interface plane and the half sphere provides the position of the reference point.

### *5.2. The “Apex tool”*




Apex tool

This tool will be used for alignment control during assembly. It has a standard mirror interface. The purpose of this tool is to materialize the apex of the optical surface. The thickness of the tool corresponds to the distance between the interface plane and the apex of the mirror. As far as possible this distance is the same for all mirrors. If some mirrors have a different thickness, several apex tools may be required.

The reticule drawn in its center allows to aim each mirror apex using the MAT (Micro Alignment Telescope). When mirror N has been mounted, the tool is mounted in the place of mirror N+1, allowing verification of the alignment of mirror N.

### *5.3. FOR and SOR, telescope and instrument optical references*

External alignment of the instrument requires knowledge of  the telescope reference frame: optical axis and focal point. These are assumed to be materialized by the FIRST optical reference, FOR, mounted on the FIRST optical bench (FOB). The FOR defines the optical interface between instrument and telescope. It must be positioned accurately with respect to the mechanical interfaces. An FOB simulator containing the same interfaces as the actual FOB is used during integration of the instrument. This allows control of the external optical alignment of the instrument.

We assume FOR is a mirror perpendicular to the FIRST optical axis with a reticule engraved et the intersection with the axis.

The back-bone of the SPIRE instrument is the SPIRE optical bench (SOB). It carries the SPIRE optical reference (SOR), assumed to be a mirror parallel with FOR with a reticule at a known distance from the telescope axis. During optical alignment control we verify the alignment of SOR and FOR, allowing control of the alignment of the instrument on the FOB without access to the internal SPIRE optics. This is necessary since the SPIRE instrument is opaque to visible light.

### *5.4. D-tool*

The Detector tool (D-tool) takes the form of a plate containing small sources (LEDs, fibers, …) in strategic points in the FOV. It is mounted in one of the detector planes, probably the last to which visible transmission is assured when dichroics are dismounted. It has a mechanical interface identical to the detector units. Sources can be lit one by one in order to investigate different ray paths through the instrument.

### *5.5. O-tool*

The Object tool (O-tool) is mounted in the SPIRE object plane (ie the SPIRE FOV of the FIRST focal surface). It should take the form of a glass plate with reticules materializing the same strategic points in the FOV (centre, edges, …) as the D-tool. The plate should coincide with the FIRST focal surface, ie not perpendicular to the gut ray. Mechanical interface is TBD.

### *5.6. PSD-tool*

Tool carrying a position sensitive detector (PSD) located in the centre of the SPIRE object plane. The PSD has a simple electrical interface and works well under hard environmental conditions. It permits tracking of the image of the central source of the D-tool.

### *5.7. CS-tool*

The Cold-stop tool (CS-tool) is mounted in the location of the cold stop (entrance to the 2K box). It should take the form of a glass plate or an open spider structure with a central reticule for control of gut ray position and TBD markings towards the edges allowing localization of the edge of the cold stop and detection of vignetting.

### *5.8. M2-tool*

This tool materializes the telescope pupil (M2) for control of instrument pupil imaging. Its absolute position with respect to the instrument is not important, as the absolute pupil alignment is controlled using the FOR.

The tool has a diameter of about 300mm, located approximately 2.5m outside the instrument. It could be a glass plate with reticules at centre and along the edge, or metal plate with holes and reticules at centre and along the edge.

### *5.9. Hartmann tool*

As an option for image quality measurement (see 3.2.6), it may be pertinent to consider a Hartmann test. A plate with a rectangular grid of holes is mounted in the cold stop. When lit by one of the sources in the D-tool (typically the central source), the projection of the holes through the system materializes geometrical ray paths. Detection of the grid in two planes above and below the SPIRE object plane, allows reconstruction of the geometrical spot diagram. Comparison with theoretical spot diagram gives an excellent measure of the instrument image quality.

## 6. Verification experiments

A series of bench experiments are foreseen to make sure the proposed plan is viable. These experiments are outlined in the table below.

| Bench | Used to… | Note |
|---|---|---|
| **Diffusion Bench** | … characterize the diffusion of Aluminium mirrors | This test prepares the ITT. |
| **PSD Control Bench** | … verify check the PSD | Some parts are used when testing the PSD Tool at cryogenic temperature. |
| **MAT Control Bench** | … control the supplementary lens and its mounting on the MAT | The optical mounting consists in a set of lenses which projects the image of a reticule behind the position of the MAT. |
| **Tools Bench** | … to specify in details the caracteristics of the DTool, the CSTool, the Otool and the M2Tool<br>… to prepare the detailed alignment procedures | |