Mechanical design of SAM: overview

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Applicable documents

SAM functional and performance requirements (October 25, 2005)
SAM-AD-02-3201, Mechanical Design (January 20, 2004)
SAM-SOAR ICD (June 9, 2005)
SAM-VI ICD (June 9, 2005)
SAM-AD-02-3301, Support Cage Trade Analysis (March 4, 2004)
SAM-AD-02-1109, SAM error budget (May 26, 2005)
SAM-AD-02-3202, Specifications of SAM mechanical design (November 10, 2005)
SAM-AD-02-1110, SAM Optical bench: table-type or box-type (August 21, 2005)
SAM-AD-02-2201, SAM Optical Design (November 10, 2005)

1 Introduction

The mechanical concept of the SAM instrument has evolved along with the design. The bases of the current concept have already been presented at the incremental concept Review (January 26, 2004): the optics are mounted inside a rigid structure called bench which, itself, is related to the telescope through a frame. The frame also supports the visitor instrument and the built-in imager, SAMI. Some flexure of the frame may be tolerated as it is not transmitted to the bench. This separation into bench/frame sub-structures had been dropped briefly in favor of the common shell-type design (as presented in the 2004 SPIE paper), but came back again.

In the fall 2004, the optical layout was simplified by removing the first fold mirror, as we realized that an essentially similar space envelope could be reached without it. Further optimization of the layout was performed in June-July 2005, when the angles were carefully selected to put as many elements as possible in a common plane. This plane can be conveniently realized by an optical table, hence it was called the “table design”, remaining nevertheless fully 3-dimensional. An optimized optical layout permitted conceiving a “table-type” optical bench, with right angles whenever possible. It turned out that using a commercial optical table as a structural reference for all optical elements was not a good solution for several reasons, so the SAM bench remains a custom-built part of the instrument. It does contain a reinforced plane at its base, however.

The mechanical design of SAM would have been much easier if it were not constrained by the small available space envelope and by the need to accommodate the truss surrounding the SOAR ISB[1]. It was decided early in the project that two truss members should be modified to accommodate SAM, and this decision remains valid today. A structural analysis has been done to show that a modification would not affect adversely the rigidity of the cage. Meanwhile, experience shows that the rigidity of the cage is not essential for the Goodman spectrograph mounted inside it.

[1]ISB = Instrument Selector Box

2 Presentation of the mechanical concept

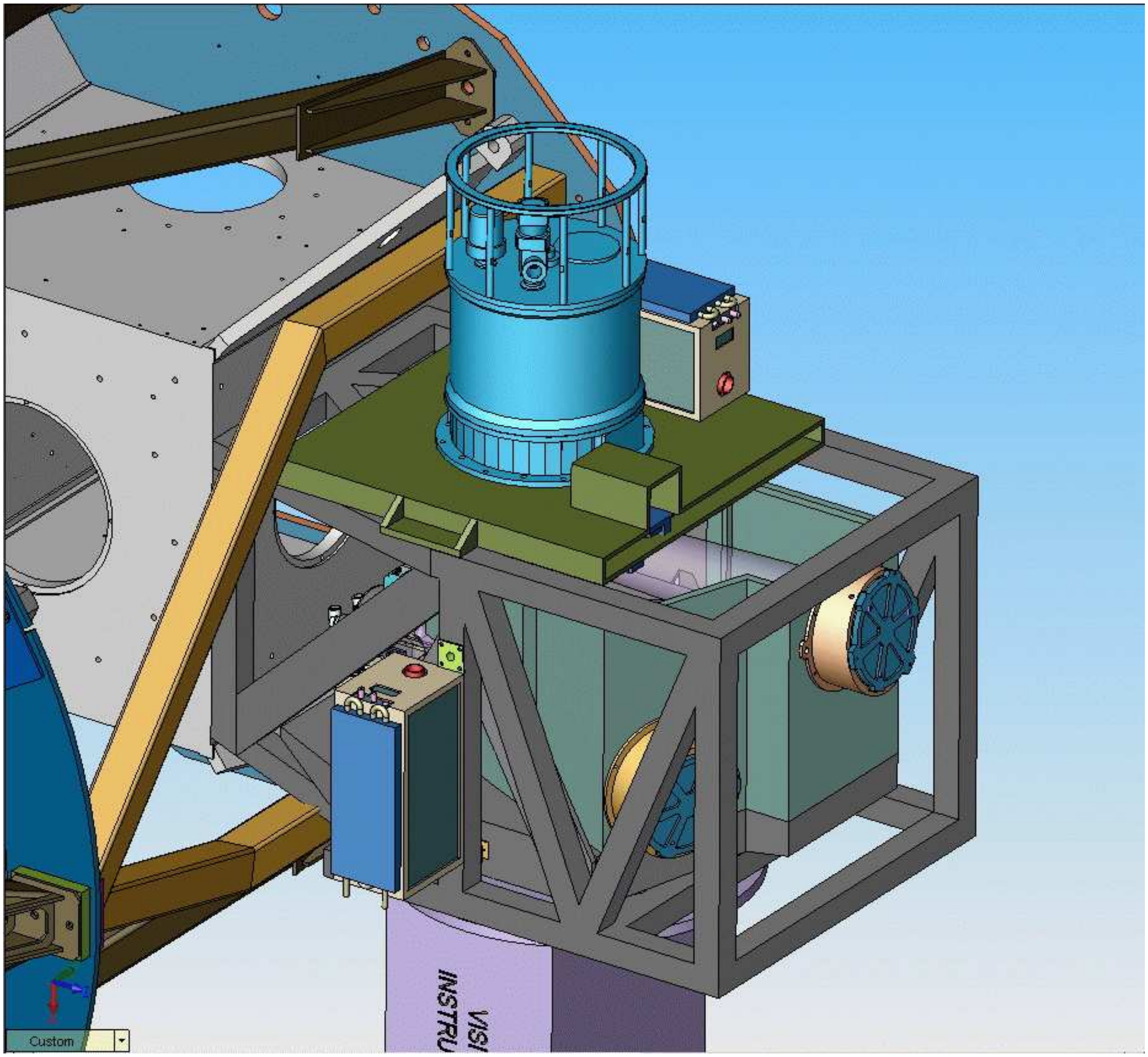


Figure 1: SAM in its support frame, with VI (pointing down) and SAMI dewar (pointing up). The frame is mounted to the SOAR ISB (to the left), and goes through the modified member of the ISB truss (yellow).

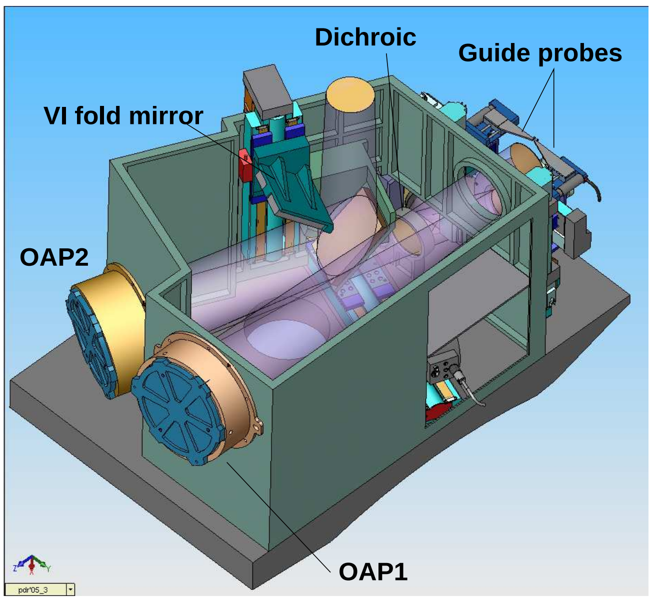
All optical elements of SAM are mounted on a rigid structure, called *bench*. The bench is mounted inside a frame that connects it to the SOAR ISB (Fig. 1). The visitor instrument (VI) is attached to one side of the frame, and SAMI to the opposite side. Such design permits de-coupling the bench from frame mechanically, so that flexure and thermal deformations of the steel frame do not distort the bench. At the same time, the differential motion between frame and bench must be small enough to assure that image in the focal plane of VI and SAMI is not displaced as SAM rotates together with

Nasmyth bearing.

A common coordinate system is adopted in the mechanical and optical designs. The z-axis is directed along the input beam, away from the ISB, the x=axis – down to the VI, and y-axis points to the telescope, parallel to the axis of the SOAR Nasmyth bearing. The coordinate origin is at the entrance focus of SAM – at a distance of 217.5 mm from the ISB mounting surface and displaced by 67.5 mm towards Nasmyth bearing. The displacement results from the optimization of the SAM optical layout, permitting a better match to the available space constraints. It calls for a special, non-standard location of the M4 mirror inside the ISB.

The design of SAM is compatible with the allocated space envelope and the truss surrounding the ISB, provided that the truss members on the SAM side are modified. Figure 1 shows this modified truss member and the ISB.

SAM rotates together with the ISB and Nasmyth bearing, compensating for the parallactic angle changes during observations on the alt-azimuth SOAR telescope. This, in turn, causes the projection of the SOAR optics (e.g. the spider supporting M2) into SAM to rotate. The gravity vector changes as well, but remains in the xz plane.



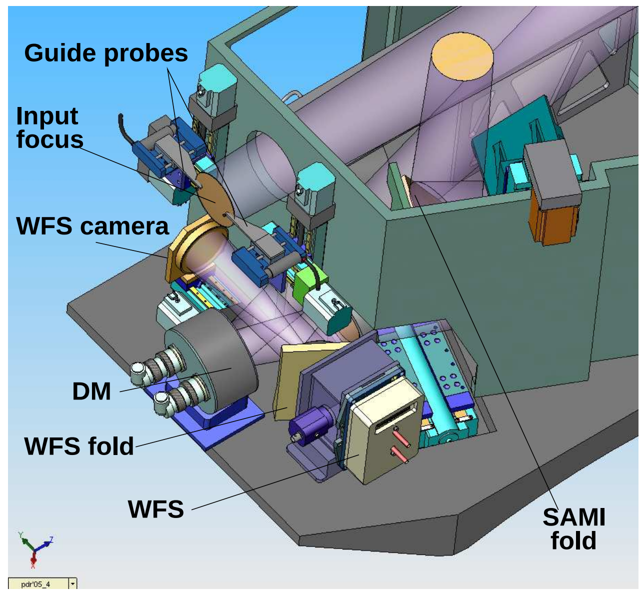


Figure 2: SAM optical bench. Left – view from the OAP side, right – view from the front side.

The design of the optical bench (Figs. 2,3) is based on a custom-made rigid aluminum-alloy table. A box-type structure connects the table to the optical cells and increases the overall rigidity of the bench. The front wall is parallel to the input focal plane (xy-plane) and holds the two guide probes with their translation stages. Then the beam strikes the OAP1 and is reflected back and down to the DM. After the DM, the dichroic (which is parallel to the front wall) transmits the science-channel light further to the OAP2, to be deflected by the fixed fold upwards, into SAMI. When the VI is used, a second fold moves down (on a linear stage), intercepts the beam and reflects it through a hole in the table.

The WFS channel consists of a flat WFS fold mirror with a hole, a WFS camera mirror on a translation stage and the NGS-WFS module with small optics and CCD-39 camera. The NGS-WFS module will be replaced as a whole with the LGS-WFS module when the laser system becomes

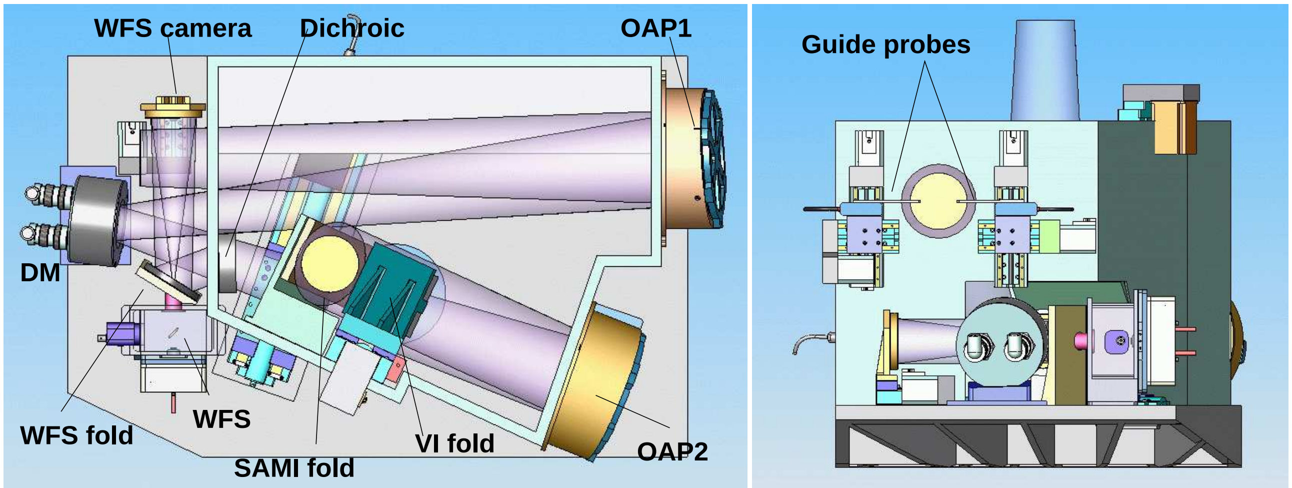


Figure 3: Projections of the bench on the table plane zy (left, view from the top) and on the plane perpendicular to the input beam xy (right, view from the front).

operational.

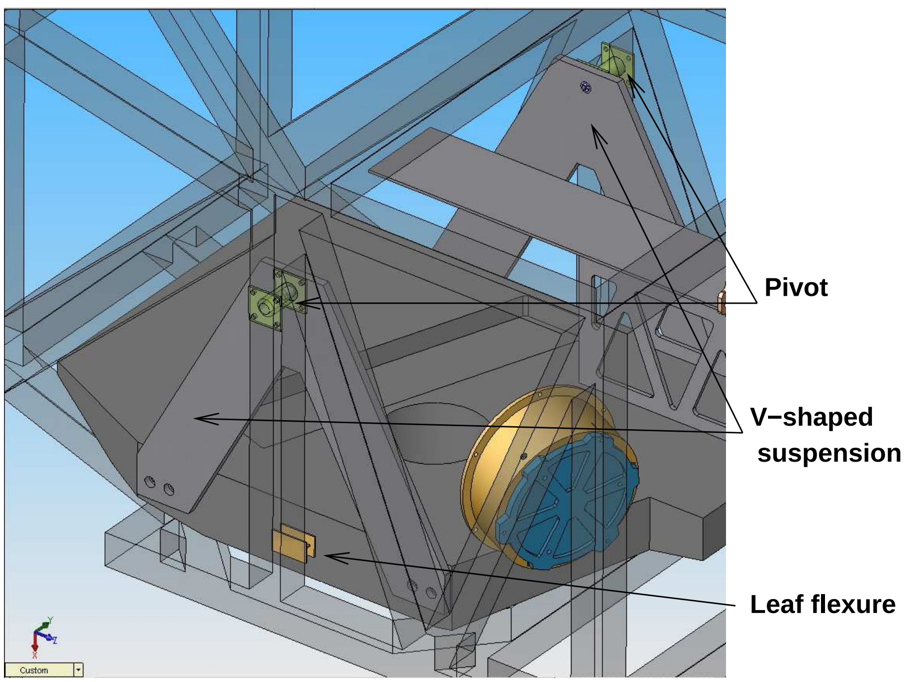


Figure 4: Concept of the interface between the SAM bench and the frame.

The bench is related to the frame by means of flexures, semi-kinematically. Such interface is required in order not to transmit the frame flexure to the bench. The frame is deformed by the weight of the VI and SAMI and, possibly, by temperature gradients inside the dome. The materials of the frame and bench are distinct – steel and aluminum, respectively – and this also calls for an "intelligent" interface. The concept of the interface is shown in Fig. 4. The weight of the bench in the vertical direction is transmitted to the frame through two V-shaped members, attached on flexure pivots to the central section of the frame. These members support the bench in such way that the flexure in the "weak" direction (perpendicular to the table) is minimized. The position of the table in the horizontal direction is defined by the flexure plate (leaf) that connects the table with the lower part of the frame. These same plates transmit the horizontal component of the table weight.

The bench-frame interface as depicted in Fig. 4 is still over-constrained, because it will transmit the torsion of the frame's central section into the bench and will not allow for the differential thermal expansion between the frame and the table, leading to potential distortion. We are going to further optimize this interface to eliminate these problems. The analysis of the thermal behavior of the SAM structure is still ahead.

The frame has been optimized in order to transmit the load to the ISB with a minimum flexure. The central section of the frame is referenced both to the bench and to the science instruments. Thus, the residual flexure of the frame as a whole has only a minor influence on the relative shifts between these critical elements.

3 Flexure analysis

Analysis of the flexure is critical for any astronomical instrument. The SAM FPR[2] calls for an image displacement at the detector of less than 24 μm for any 10° rotation of the Nasmyth bearing, assuming that the tip-tilt correction with guide probes sets the reference position at the SAM entrance focal plane. The flexure is a sum of 3 contributions: i) flexure of the guide probes, ii) internal image shifts due to bench flexure and iii) shifts of the bench relative to the frame.

The flexure analysis has been performed with the finite-element code Algor on a simplified mechanical model of SAM, deemed to be representative of the true instrument. The bench is modeled by a box with light-weighted walls, 4-mm thick with 16-mm structural members, with holes as needed. The walls are connected to the table, and the box has a 2-mm thick top-cover plate. The VI load corresponds to the real SIFS input module (55 kg), and the mounting surface (ISB) is assumed to be rigid.

Figure 5 shows exaggerated displacements of the whole SAM structure, in the 0° orientation (gravity along the x-axis). The frame "sags" down. However, its central section which is related to science instruments and the bench moves mostly as a solid body, ensuring small relative displacements of critical elements. The bench itself (Fig. 6) also tilts mostly as a solid.

The calculated displacements of different parts of the bench have been interpreted in terms of the resulting image displacement in the following way. We associate each critical element (entrance focal plane, OAP1, DM, OAP2, fold, output focal plane) with 3 representative nodes of the FEA model – a fiducial triangle. Average displacement of the 3 nodes defines the displacement of the element as a whole. The tilts of the plane passing through the nodes define corresponding tilts of the optical elements caused by flexure.

A rough scheme of the optical effect of the internal bench flexure is given in Fig. 7, where only 3 critical elements (OAP1, DM and OAP2) are shown. Each of these elements is essentially a mirror. If the bench is supported near its center and sags under gravity as shown in the Figure, the OAP is displaced down (x-positive) from the optical axis (z-axis) and tilts (negative in x, clockwise), partially compensating for this sag. The DM x-tilt adds to the image displacement, and so does the OAP2 tilt.

[2]FPR = Functional and Performance Requirements

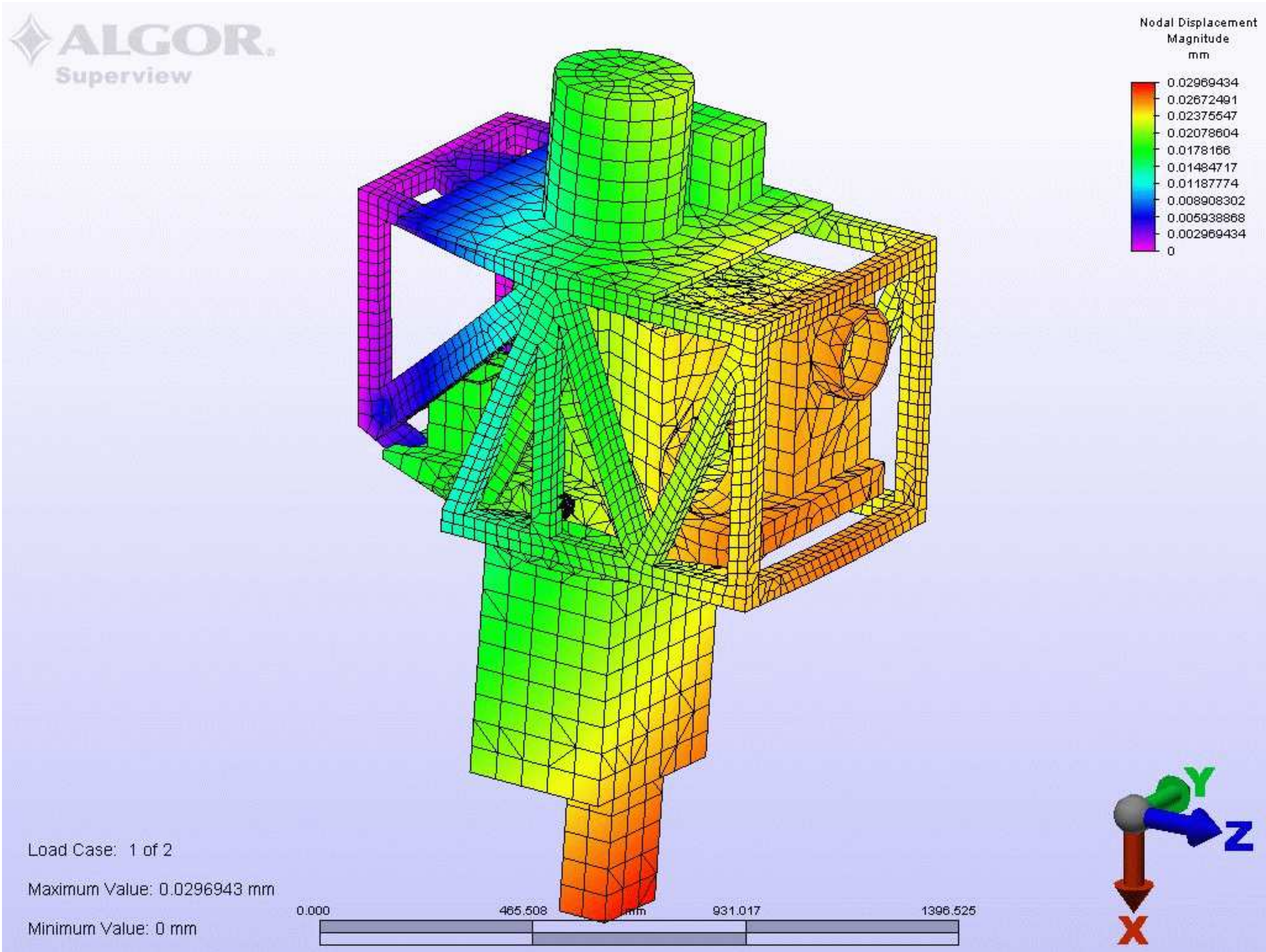


Figure 5: Results of the finite-element analysis of the whole SAM structure. The shape shows exaggerated displacements.

The displacement of the flat DM is not important. Considering this geometry, we evaluate the total image shift Δ_x caused by the bench flexure as

$$\Delta_x = a_x + b_x + c_x \tag{1}$$

$$a_x = 2F(\theta_{x,OAP1} + \theta_{x,DM} + \theta_{x,OAP2}) \tag{2}$$

$$b_x = d_{x,OAP1} + d_{x,OAP2} - 2d_{x,focus} \tag{3}$$

$$c_x = d_{z,bench} - d_{z,SAMI} \tag{4}$$

where θ_x are the angular deflections of the fiducial triangles, d_x are x-displacements of these triangles, $F = 810$ mm is the focal length of OAPs, and factor 2 accounts for angle doubling at reflection. The first term a_x describes the shift caused by tilts, the second term b_x – shifts caused by OAP sags, and the third term c_x – shift of the bench as a whole relative to the SAMI (in the z-direction, as appropriate after reflection by the fold mirror). The shift Δ_y is computed in the same way. The shifts caused by the last reflection at the fold mirror are neglected.

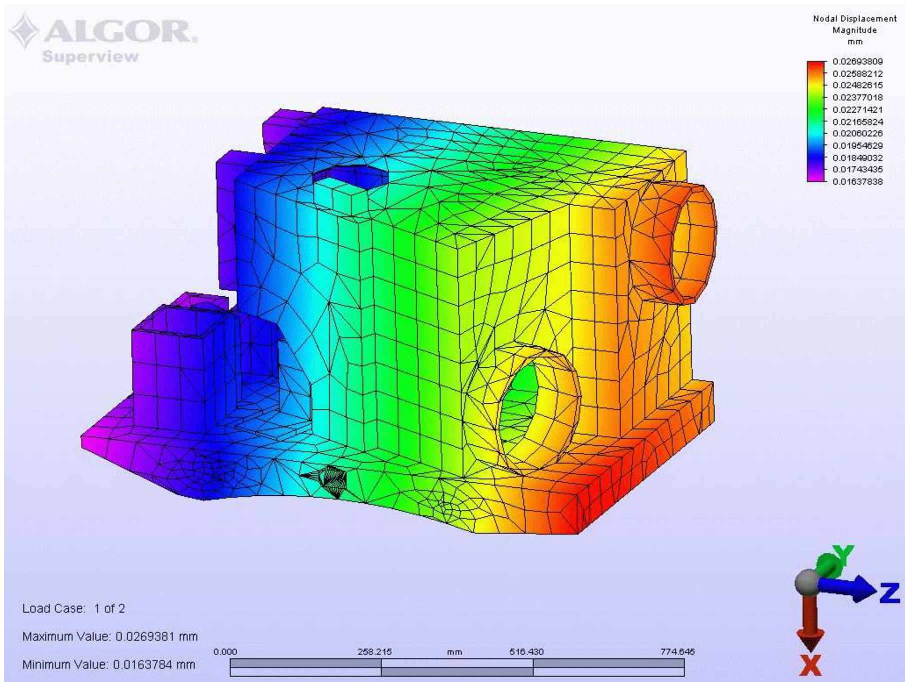


Figure 6: Results of the finite-element analysis of the bench SAM structure. The displacements mostly correspond to the bench tilt as a solid body.

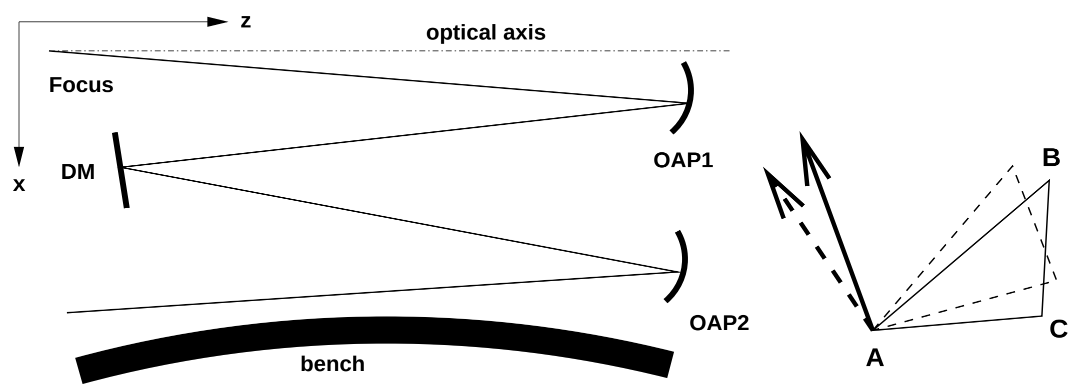


Figure 7: Schematic representation of the bench flexure and of the method used to estimate the tilts of the elements

This method is only approximate because all reflections are assumed to be in the same plane. However, it gives a decent representation of the overall flexure effect. More accurate calculation will be done by incorporating the displacements into the Zemax model.

The coordinates and displacements of fiducial triangles computed by Algor for 10 orientations of SAM (from 0° to 90°) were first exported into an Access database and then transferred into an Excel spreadsheet. The tilts are computed using the formula for the vector product between vectors along two sides of the fiducial triangle and assuming that the deformations are small If ABC is such a fiducial triangle (Fig. 7, right), the normal vector is ABxAC, and its rotation caused by the displacement is a measure of the tilt.

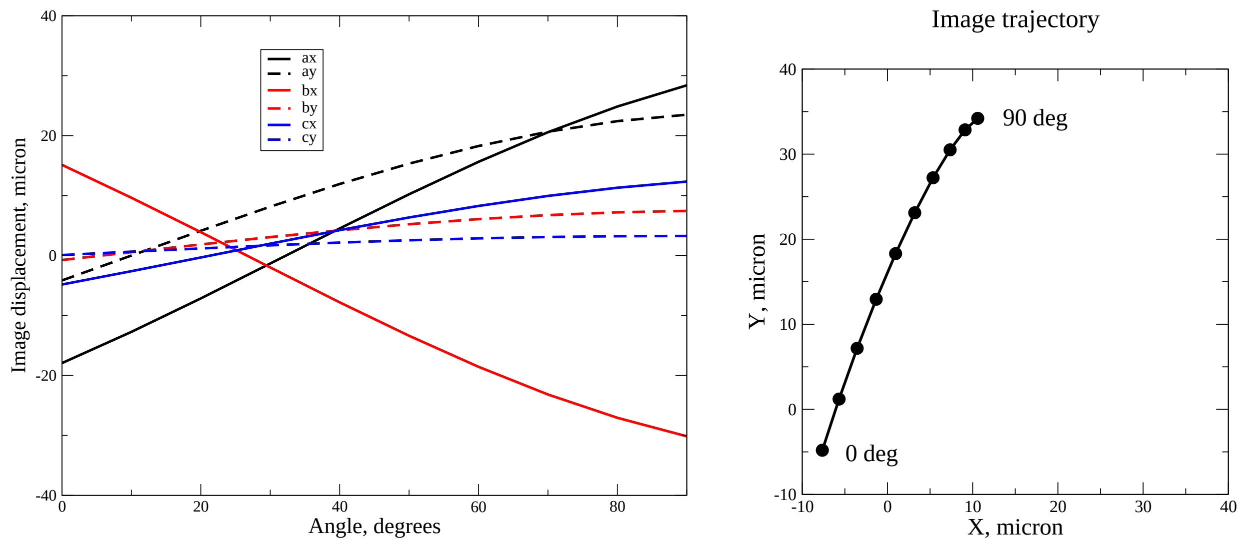


Figure 8: Image displacement in the SAMI focal plane caused by the flexure as the instrument rotates from 0° to 90°. Left: individual terms of Eq. 4, right: image trajectory in the focal plane.

The results of this analysis are plotted in Fig. 8. We see that the terms a_x and b_x partially compensate each other, in agreement with the qualitative behavior depicted in Fig. 7. The displacements of the bench relative to the frame are only few microns. As SAM rotates by 90°, the image in the focal plane of the instrument moves mostly in the y-direction (perpendicular to the optical axis). The total displacement is quite modest, only $\sim$40 μm. For an instrument rotation of 10°, the displacement does not exceed 6 μm. This is 4 times smaller than allowable flexure, 24 μm. Thus, the current design has a large rigidity margin with respect to the specifications. Given this margin, the approximate nature of our flexure analysis is justified.

4 Optical mounts

We show the design of the OAP cell (Fig. 9) as representative of other optical cells.

The position of the OAP blank in its cell is defined kinematically: 3 hard points on the back surface define xy-tilts and axial (focus) position, two hard points on the lateral surface define the lateral position. The radii of the hard point tips will be no less than 10 mm. No flexure will be transmitted from the cell to the optical element.

Each hard point has a matching spring element that acts on the OAP blank from the opposite side and ensures that OAP is pressed against the corresponding hard point with a force of no less than 0.5 n, the force vector passing within 5 mm from the hard point. The force will act in all orientations and despite possible friction. Any loss of contact with the hard point will be restored by the spring.

5 Motion control

Moving elements of SAM are mounted on translation stages coupled to intelligent motors (e.g. SilverMax Nema-17) with internal encoders. The encoders can have up to 8000 counts per revolution, corresponding to a 0.125 μm resolution for a driving screw with a 1-mm pitch.

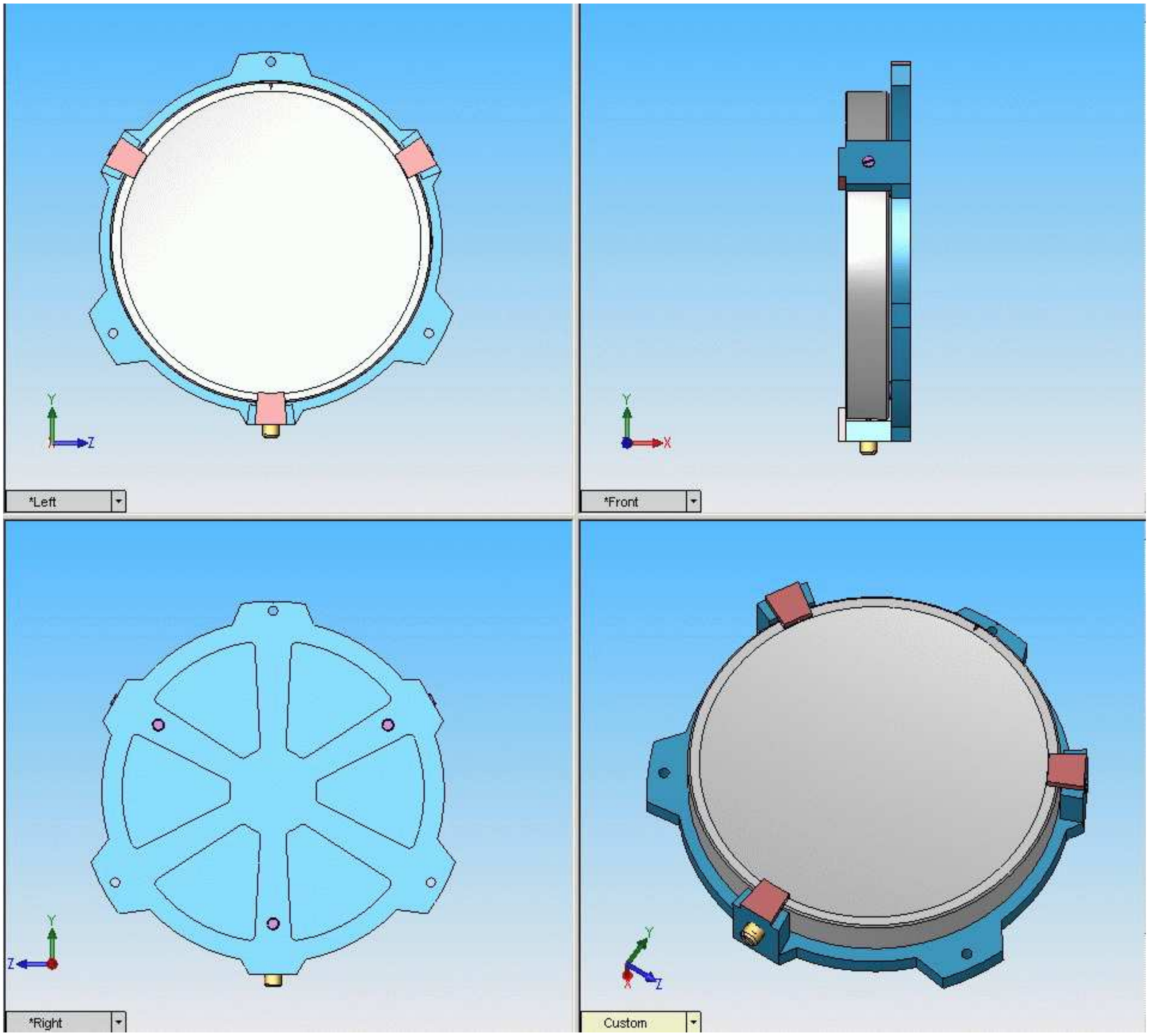


Figure 9: The cell of OAP1, viewed at different angles.

A typical linear stage, 404XR from Parker, is rigid enough and has small angular errors. Considering, for example, the VI fold mirror (mass 1.3 kg, 55 mm from the stage), we calculated the moment and the maximum deflections of the stage: $0.36''$ in pitch, $0.95''$ in yaw and $1.66''$ in roll. The largest tilt of $1.66''$, doubled by reflection, will shift the image in the VI focal plane (at a distance of 479.57 mm) by 7.7 μm, half of a pixel.

6 Science instruments and filters

The design of the SAM imager (SAMI) will be copied from the successful SOAR imager. The filter wheel can be detached, permitting an easy change of filters and a compatibility with the SOAR imager.

Filters and shutters are combined in a single filter/shutter block which attaches to the frame and holds the CCD dewar.

The VI is connected to the frame by a flange with mounting threaded holes identical to those of the ISB. Both VI and SAMI must have focal planes in the nominal position to within 1-2 mm, because the range of the focus adjustment inside SAM is very small.

The HR camera will be the first visiting instrument. It will be assembled from commercial elements inside a very simple cylinder-like structure with a standard SOAR flange.

The user filter or Fabry-Perot etalon will be installed inside the SAM bench on a stage permitting its remotely controlled insertion or retraction from the beam. That same place in the collimated beam will be occupied, alternatively, by the atmospheric dispersion corrector (ADC), which will be fabricated later. This element should be accessible without dismounting SAM from the telescope. However, the space inside SAM is crowded (Fig. 2) and the external access is restricted by the SAM frame and the proximity of the telescope elements (see below). Our default solution will be to access the filter from the top, after lifting the SAMI assembly with a crane. We will try to explore other, more convenient options as well.

7 Auxiliary elements, access and maintenance

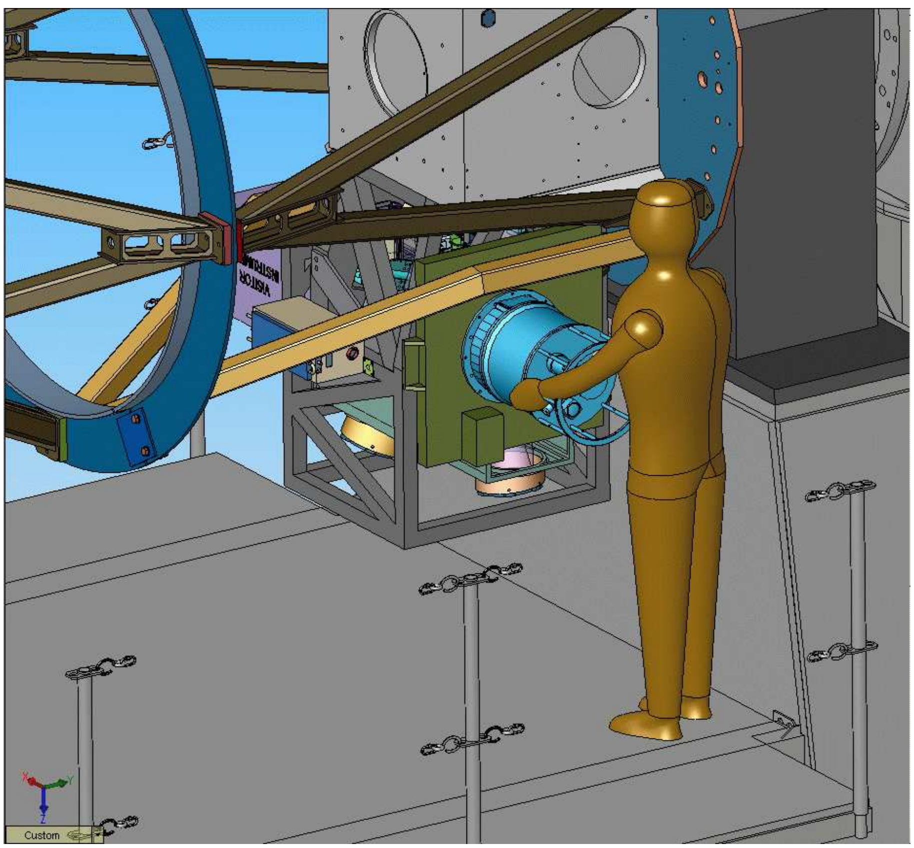


Figure 10: Access to the SAM from the SOAR platform.

Once SAM is installed at the telescope, it can be accessed from the Nasmyth platform (Fig. 10).

The angle of the Nasmyth bearing can be chosen to facilitate the access – either with SAM looking down, as in the Figure, or looking sideways (horizontal).

The frame will be covered to protect SAM from dust and light. The entrance to the instrument will be closed with a protective shutter, actuated remotely. A counter-weight will be fabricated to balance the moment of SAM around the Nasmyth axis. If the SAM electronics cabinets are mounted on the ISB truss, their location will be chosen to counter-balance the SAM moment. However, SAM will work with VIs of different masses, hence some means for re-adjusting the balance will still be needed.

When SAM is dismounted from the telescope for storage or transport, it will be attached to a handling cart.

8 Weight and moment

The mass of the individual SAM sub-systems is listed in Table 1. It fits into the provisional allocation of 340 kg.

Table 1: Mass of the SAM instrument

Assembly	Mass, kg
Frame	88.1
Bench	82.5
Dewar	13.5
Leach controller (x2)	7.3
Filter-shutter box 19 Filter/shutter box	19
Visitor Instrument (SIFS)	55
Electronic cabinet + electronics	70
Total	343

The center of mass of the module (without electronics cabinet) is 273 kg at 550 mm from the ISB surface, de-centered by -85 and -209 mm in horizontal and vertical directions, respectively. So, a possible counterweight of 125 kg could be located at 1.6 m de-centered at coordinates (170,418) mm on the opposite ISB side to balance the system around the axis of the Nasmyth bearing. The balance weight is excluded from the SOAR's allocation for SAM.

We note that the mass of SAM together with the VI is only 11% of the maximum total ISB load, 3000 kg. The major part of the ISB mass budget is consumed by the combined mass of the truss and Goodman spectrograph – 2317 kg. Compared to this, SAM is indeed a *very* small instrument!

9 List of sub-assemblies

Table 2: List of SAM sub-assemblies (phase 1).

Bench (table, walls, cover)
Frame (incl. flexures, light cover and front cover)
Tip-tilt guide probes (stages in x, y, z and arm)
OAP1 and OAP2 cells
DM mount
Dichroic cell (provides for swapping dichroics)
WFS fold cell
WFS camera cell and stage
TurSim with insertion mechanism
NGS-WFS module
Filter (Fabry-Perot) mount, motion and change
Flat mirror 1 (fixed) cell
Flat mirror 2 cell and stage
SAMI filter/shutter box
SAMI dewar
HR camera
Alignment tools
Handling cart
Balance counter-weights
Electronics enclosure
Truss modification
M4 cell and stage (in ISB, part of SOAR)