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MROI's Automated Alignment System

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ABSTRACT

We present an outline of the automated alignment system for the 350m baseline Magdalena Ridge Observatory Interferometer (MROI) which will manage the simultaneous alignment of its six principal optical subsystems (telescopes, beam relay trains, delay lines, beam reducing telescopes, switchyards, and beam combiners). Many of these components will be held under vacuum, will be subject to varying thermal loads and will use different coatings (optimized for either optical or near-IR wavelengths). We review the proposed architecture of our scheme and discuss the procedures, tools, and optical analyses we have used to design it.

Keywords: Interferometer, alignment system, Magdalena Ridge Observatory

1. INTRODUCTION

Figure 1 is the general optical layout for a single telescope of the interferometer. As can be seen in the figure, upon exiting the unit telescope (UT), a 95 mm beam enters vacuum at the relay lines and exits into the beam combining area (BCA) from the delay line area (DLA). It then gets compressed to 13 mm by a Mersenne telescope before encountering the switchyard and finally the beam combining table. In all, before arriving at the beam combiner, the beam will have will have undergone 13 reflections ranging in distances from 460 to 660 meters, depending upon the location of the UT.

There are a total of four beam combining tables in the BCA that will operate at visible and IR wavelengths. The first table is for visible science, the second is to be used for fringe tracking in H and K bands, the third is the IR science combiner at J, H and K, and the fourth table is to be reserved for visiting instruments. For the first three tables, each has a pair of switchyard optics that are comprised of a dichroic, optimized for the bandpass under investigation for that particular table, and a flat turning mirror to direct the beam into the beam combiner. A dichroic in the switchyard for the visiting instrument table is not necessary since it is located at the end of the beam train. This discussion will exclude the alignment of the visiting instrument and its switchyard.

One major obstacle in designing an automated alignment system for MROI is the planned simultaneous measurements covering the visible through near-IR wavelengths. As was discussed above, there are dichroics located in front of the beam combining tables optimized for the different bandpasses. Therefore, the alignment light source to be used that defines a reference axis from which co-alignment of the different optical axes is achieved, cannot simply be back propagated from the last table in the beam train. This makes necessary the use of a broadband source that can be propagated into the switchyards, while traveling parallel and collinear to another source that is propagating outward toward the UT. Added to this is the fact that a pair of turning mirrors does not exist between the delay line and beam compressor, two independent optical assemblies, and thus tilt and shear between the two cannot be corrected for in an automated fashion.

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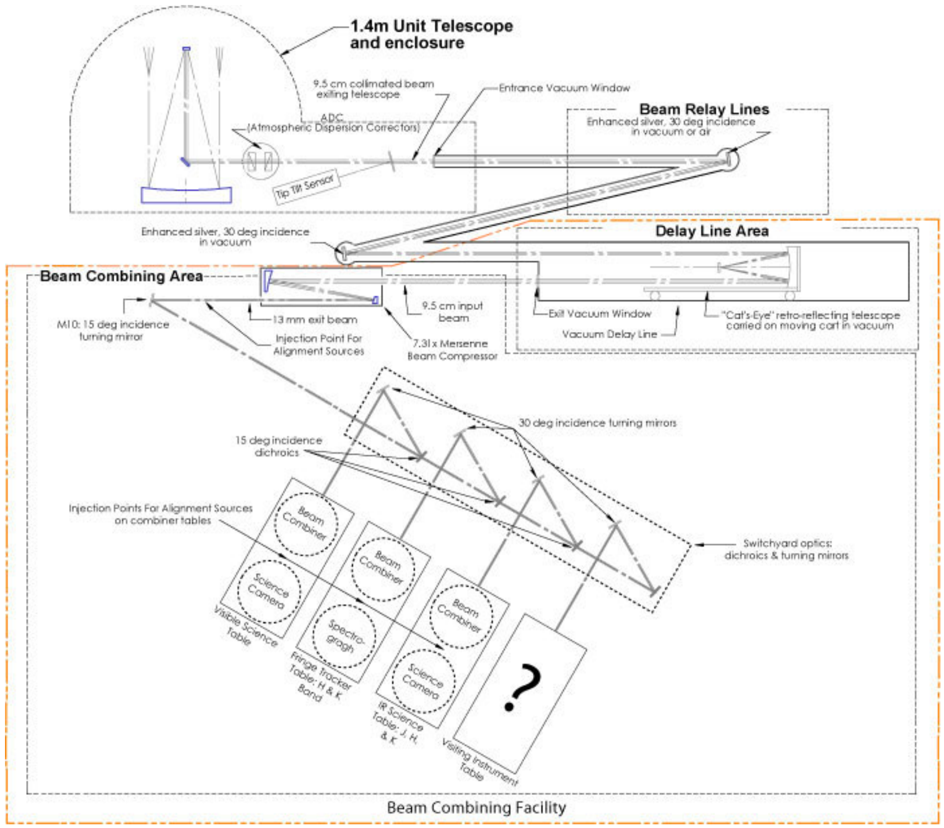

Fig. 1. The general optical layout for one of the telescopes in the interferometer.

A review of the alignment practices of other interferometers[1] shows that many have the difficulties of complicated beam trains (i.e. lots of mirrors). Even though MROI's beam train is less complicated, it certainly has its own difficulties to overcome, as mentioned above. Presented here is the conceptual design for MROI's automated alignment scheme. Laboratory testing has begun on candidate actuators and cameras to be used in the beam train for automated mirror adjustments, and we will begin the development and testing of other components such as pop-up mechanisms and quad cells that will be used for automated alignment checks.

2. THE BEAM TRAIN

In much the same fashion that was done for the VLTI[2], the alignment problem for MROI will first be broken down into three parts: 1) a description of the optical elements involved in the alignment, 2) identification of the sub-systems or optical assemblies of which they are a part, and 3) identification of the optical axes that need to be brought into co-alignment.

2.1 Optical Components in the Beam Train

As was mentioned in the introduction, a beam of certain wavelength range (visible, J, H, or K), traveling from the UT to a camera back in the BCA undergoes thirteen reflections from twelve mirrors. This excludes transmission through ADCs, windows or dichroics, of which there is one ADC, two vacuum windows, and depending upon the bandpass, a maximum of two dichroics to travel through. Table 1 lists the optical components in the beam train from the UT through the switchyard, and each is illustrated in Figure 1 above. The MROI Name follows the convention of labeling mirrors in the order in which light encounters the reflecting surface. The Component Name refers to the subsystem of which it is a part, the Location is a descriptor of its location in the optical train, and Shape is the shape of the reflecting surface. The first mirror in each switchyard is a dichroic, thus the labeling M11VIS (reflects visible), M11FT (fringe tracker will reflect either H or K band), and M11IR (will reflect J,H, or K).

MROI Name	Component Name	Location	Shape
M1	UT Primary	UT Structure	Parabolic
M2	UT Secondary	UT Structure	Parabolic
M3	UT Tertiary	UT Structure	Flat
M4	Beam Relay Flat 1	Beam Relay	Flat
M5	Beam Relay Flat 2	Beam Relay	Flat
M6	Cats-Eye Primary	DL Cart	Parabolic
M7	Cats-Eye Secondary	DL Cart	Flat
M8	Beam Reducer Primary	BCA	Off Axis Parabolic
M9	Beam Reducer Secondary	BCA	Off Axis Parabolic
M10	BC Turning Mirror	BCA	Flat
M11(VIS/FT/IR) thru M12	Switchyard Components	BCA	Dichroics & Flats

Table 1. Names, location, and shape of the optical components in the interferometer optical train.

2.2 Optical Assemblies

From the above table it can be seen that there are six optical assemblies that make up a single beam train of the intereferometer. In order proceeding outward (upstream) through the interferometer, these are (see Fig. 2): 1) beam combiners, 2) switchyard, 3) beam compressor, 4) cats-eye, 5) beam relay, and 6) the UT.

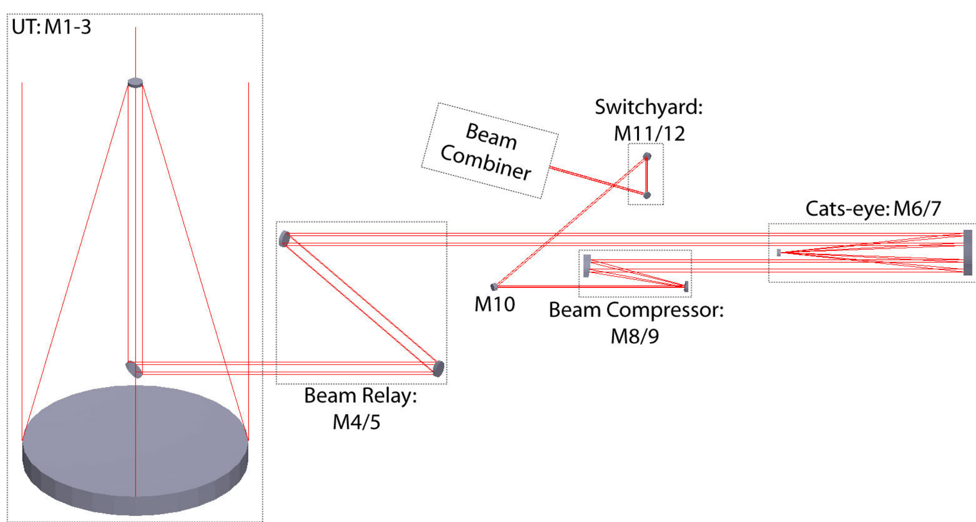

Fig. 2. Abbreviated optical train for a telescope on the west arm through to the first switchyard, illustrating the six optical assemblies.

2.3 Turning Mirrors

Turning mirrors on kinematic mounts are located at four locations within the optical train. Two in the switchyard for the three combiner tables (M11/12, for visible, fringe tracker, and IR tables), one following the beam reducer (M10), and two that make up the beam relay, M4 and M5. Pairs of mirrors are needed to remove beam tilt and shear between different optical axes. A hypothetical situation of a tilted and sheared beam is illustrated in Figure 3 below. In the figure, the red ray represents the path of an alignment laser that has been back propagated, and the black line represents the ideal path that the ray would take if the mirrors, M1 and M2, were properly aligned. Following M1 would be a detector system capable of measuring beam shear and tilt, and it is assumed that the light arriving at M2 travels along the ideal axis. In the diagram on the left, M2 is adjusted to remove the beam shear at M1. In the middle diagram, M1 is adjusted to remove tilt, and the right shows the beam coaligned with the ideal axis.

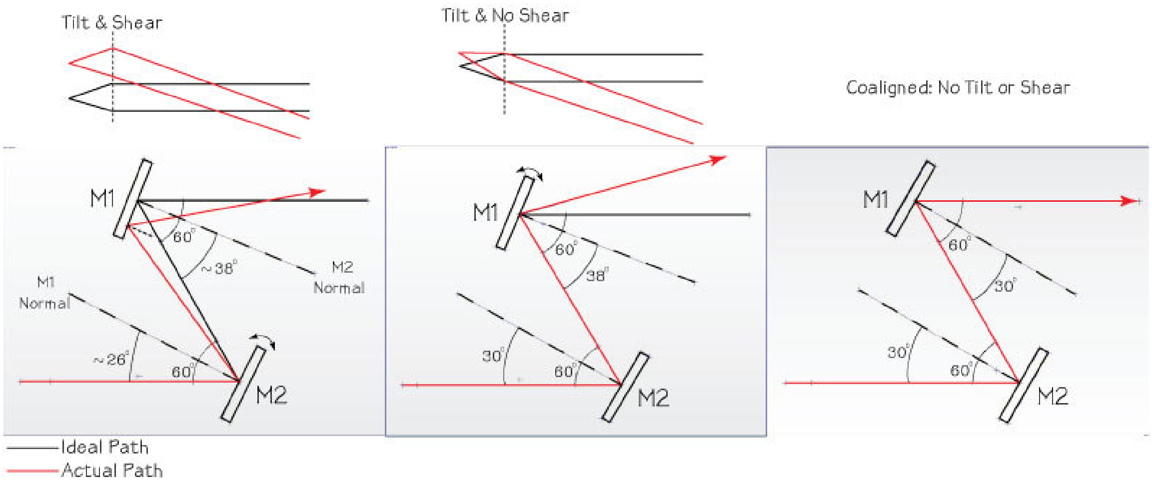

Fig. 3. Removal of beam shear and tilt via a pair of turning mirrors.

There are two locations within the optical train that allow for beam tilt and shear removal via a pair of turning mirrors, in between the delay line and UT (M4/5), and following the beam reducer in between M10 and beam combining optics (switchyard mirrors M11-M12). The goal for MROI is to have a net beam shear less than 1% of the beam diameter, and less than 1% visibility loss due to beam tilt (corresponding to an angular error of less than[3] $[(0.0885*\lambda)/D]$), at the beam combiner. In the beam relay where the beam diameter is 95mm, the maximum allowable shear is 0.95 mm, and that in the BCA (beam diameter 13mm) would then be 0.13 mm. For the tilt, the maximum allowable errors are, for the beam relay 1.58 µrad and 11.57 µrad for the BCA, assuming a wavelength of 1.7 µm.

2.4 Optical Axes

MROI has three optical axes that can be brought into co-alignment with one another using the automated alignment system. An axis defined by the UT, one by the delay line, and the third defined by the beam combiner. These were chosen because, as discussed in the previous section, a pair of turning mirrors for shear and tilt removal exists at their interfaces. Figure 4 is a simplified block diagram illustrating the optical train and the various locations important to the alignment system. Each box represents an optical assembly, and the symbols in between indicate the location of different automated alignment tools.

The primary fiducial is the location of the alignment sources of light to be propagated in both directions through the interferometer, downstream to the beam combination tables and upstream to the UT. This is used to define the delay line optical axis, and, as discussed in the introduction there is a white light source and a laser. Secondary fiducials are pop-up targets spaced throughout the beam train that will be used to identify the location of the beam relative to the ideal axis. There are three locations where tilt and shear measurement takes place. Two of them will actively feed back to the turning mirrors to adjust misalignment, one located on the UT optical bench following M3, and the other on the beam combining table will. The third is more of a pseudo secondary fiducial located at M5, and operates in the same pop-up fashion as the secondary fiducials.

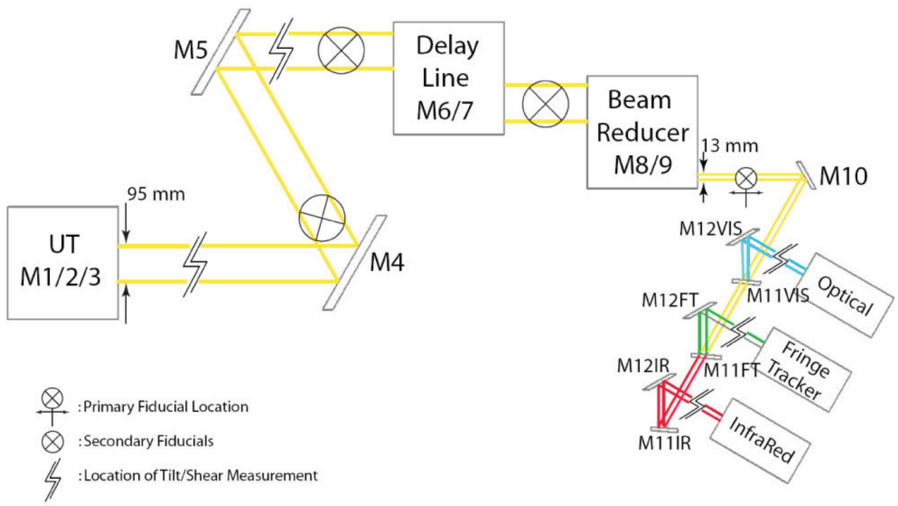

Fig. 4. Block diagram of alignment scheme.

3. AUTOMATED ALIGNMENT TOOLS

3.1 Primary Fiducial

The purpose of the primary fiducial is to establish a reference axis representing that of the delay line, to be brought into co-alignment with the UT and beam combiner axes via M4/M5 and the switchyard mirrors. It will consist of a table in the BCA, upon which sits the white light/laser alignment sources, and beamsplitters on slides to allow individual or multiple beam lines to be selected (see Figure 5). As was mentioned in the introduction, two alignment sources are necessary due to the dichroics in the BCA. They must travel parallel and colinear to one another, but in opposite directions. The laser alignment source is directed from the alignment bench out through the delay lines to the UT, while the white light source is sent toward the beam combiner tables.

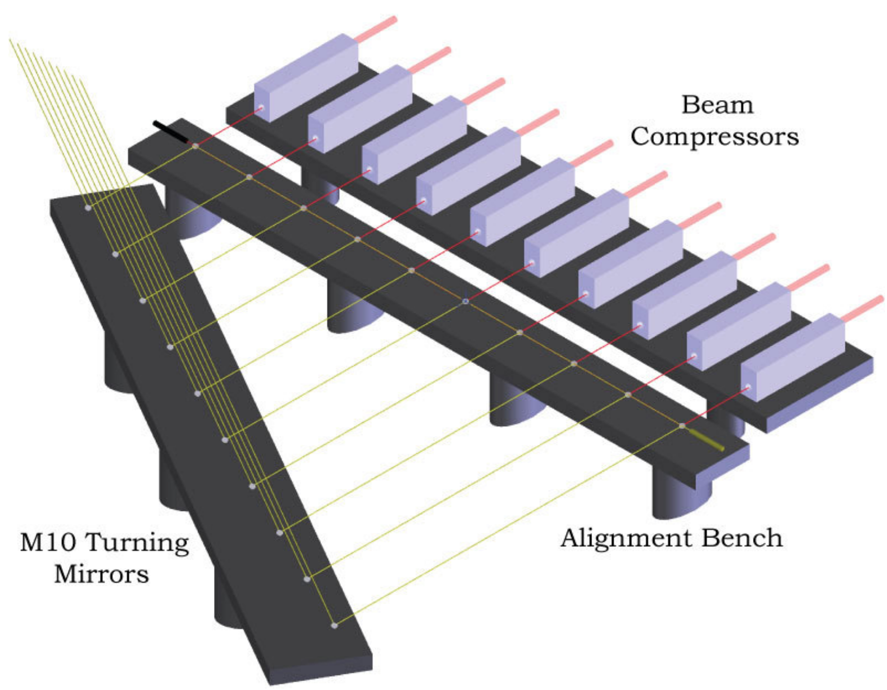

Fig. 5. Primary fiducial bench in the BCA used to define the delay line axis for co-alignment.

It should be noted that the alignment of the primary fiducial is not automated. The delay line carts travel in pipes without rails, and are thus subject to undulations in the pipes that affect their motion (see Buscher et al. this conference 6268-93). As a result, the laser must be aligned to the mean trajectory of the cats-eye vertex of the delay line. Given the benign environment in which it will exist (daily temperature swing < 0.1° C / < 5° C annual swing), its alignment is something that will hopefully only need to be done on a timescale of weeks. Once aligned, the sources are turned on remotely, and the beamsplitters are slid into place, sending the light to the UTs and beam combiner tables. The design allows for automated checks of its alignment in the form of secondary fiducials, which are discussed in the next section.

3.2 Secondary Fiducials

Once the alignment sources have been turned on, secondary fiducials located at various positions thoughout the individual arms of the interferometer can provide an automated remote check of the alignment. One type secondary fiducial will consist of pop-up quad cell targets like those developed for use at NPOI[4]. NPOI custom made quad cells using space-qualified solar cells so that the centroiding errors can be measured on larger diameter beams. These devices are lightweight and card like, and thus easily slipped in and out of the beam path in an automated fashion.

A similar development is under way for installation within MROI. The laser light of the primary fiducial, upon leaving the alignment bench gets expanded 7.31X by the beam compressors, which act as beam expanders since the light traverses the telescope in reverse. As a result, the beam will be on the order of 30 to 40 mm in diameter. The intended location for the quad cells is at the exit of the delay line in the BCA, inside of the vacant vacuum cans at array arm junctions, and in front of M4. Figure 6 depicts three vacuum cans at one of the array junctions. The innermost can houses M5, illustrating that there is a telescope at this location. The vacuum can for M5 will not have a pop-up quad cell, but rather another type of secondary fiducial.

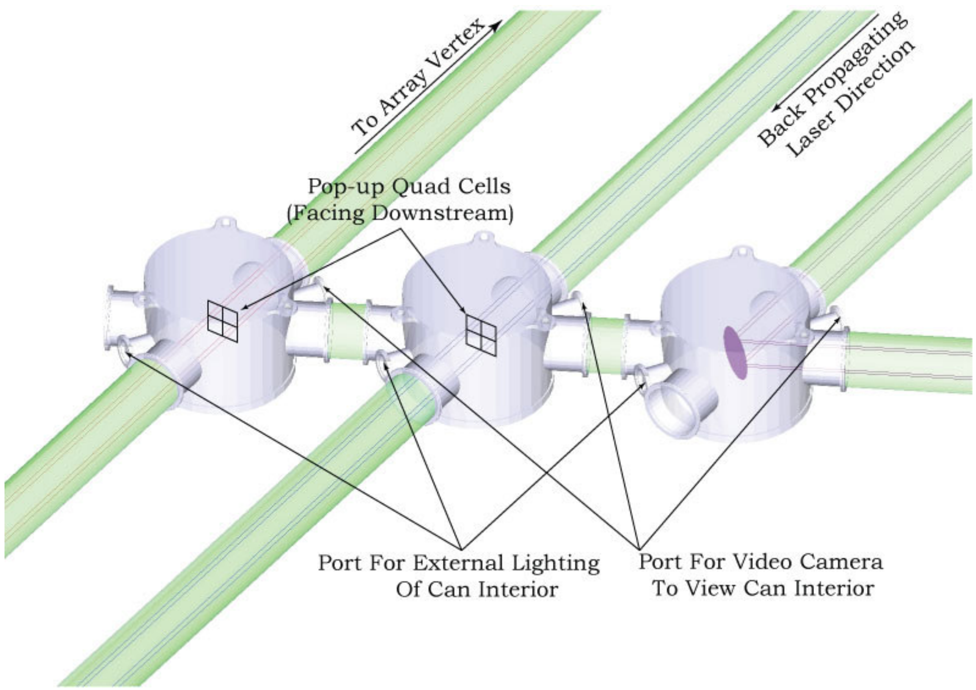

Fig. 6. Array arm junction illustrating location of pop-up quad cell targets used as secondary fiducials.

Figure 7 on the next page is a blow up of the vacuum can that houses M5 at the location of a telescope. This can corresponds to the last telescope station on the west arm of the array. As was just discussed, one type of secondary fiducial to be used are the pop-up quad cell targets in the empty vacuum cans. In the illustrations of the cans, there are ports that would enable remote viewing of the can interior with a CCD camera. Another type of secondary fiducial that will be used here is an obstruction that rotates into the path of the laser, cocked at 15 degrees relative to the mirror so that a camera in this port can view the scatter off of the obstruction. This would allow beam shear to be observed. One technique employed at CHARA[5] is a cap with a small mirror in the center that is placed over the telescope secondary. Beam shear information is extracted from the scatter off the cap, and beam tilt from an image of the laser spot in the mirror. A similar application is being considered for deployment at MROI, in the form of an obstruction with a small mirror at its center that rotates into the alignment beam at M5 to measure shear and tilt through the delay lines.

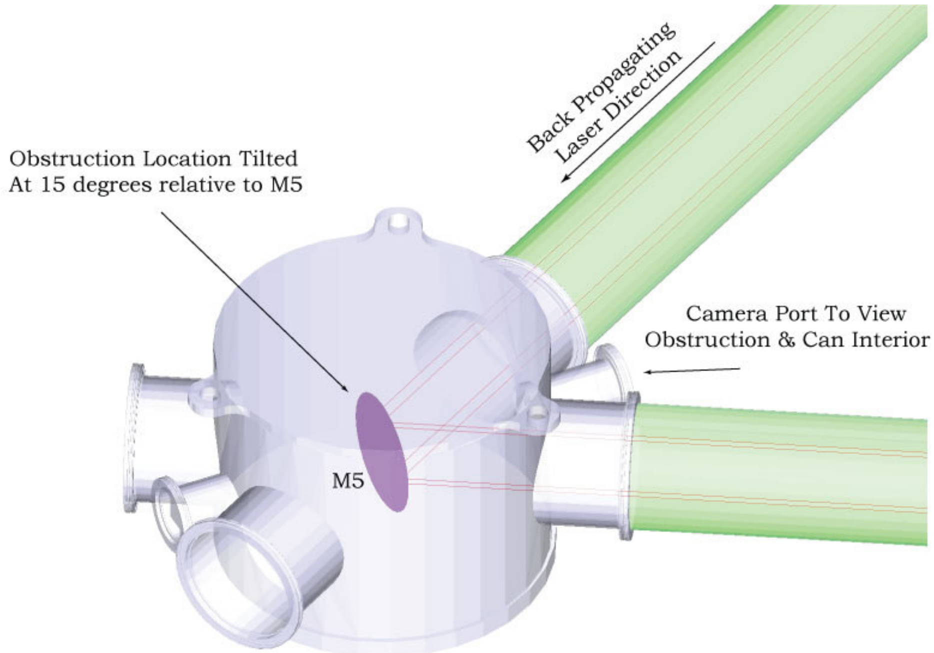

Fig. 7. M5 vacuum can for the last telescope station on the west arm. An obstruction can be rotated into the beam at this location for simultaneous tilt and shear measurement.

3.3 UT/Delay Line/Beam Combiner Co-alignment

Both the UT and beam combiners will each have their own light sources that can be turned on to define their axes with respect to the primary fiducial. Illustrated in figure 8 is the optical schematic to measure the relative tilt and shear between the three axes. Light from the primary fiducial is compared with that from the UT at the UT optical bench (following M3), and with that from the Beam Combiners in the BCA (following the switchyard mirrors). Quad cells will measure the relative position of the two collimated beams to calculate the shear, and a CCD camera will measure the relative tilt from the two focused spots on the detector. These measurements then get fed back to the control program that adjusts the actuators on M4/5, in the case of the UT/delay line co-alignment, and to the actuator control of the switchyard mirrors for co-alignment of the delay line with the beam combiner axes.

In Section 2.3 the amount of net allowable shear and tilt error at the beam combiners was discussed. It was found that the maximum shear between the beams in the beam relay was 0.95 mm, and that in the BCA was 0.13 mm. For the beam relay, the longest path length that the beam will travel is on the order of 660 m, so the amount of optical tilt to meet the shear requirement is 0.95mm/660m ≈ 1.44 μrad. This translates to a mirror tilt resolution of 0.72 μrad on the M4/M5 mirror actuators. In the BCA, the longest path length is on the order of 20 m, so to meet the shear requirement the maximum amount of optical tilt is 0.13mm/20m ≈ 6.5 μrad, which translates to a mirror tilt resolution of 3.25 μrad. Recall that the maximum amount of allowable tilt error was 1.58 μrad for the beam relay, and 11.57 μrad for the BCA.

4. CURRENT STATUS

The alignment system has gone through a conceptual design review, and we are currently in the process of testing candidate actuators, cameras and slides in the laboratory. Initial investigations into the type of solar cell that will be purchased and the pop-up mechanism that will deploy it have begun as well.

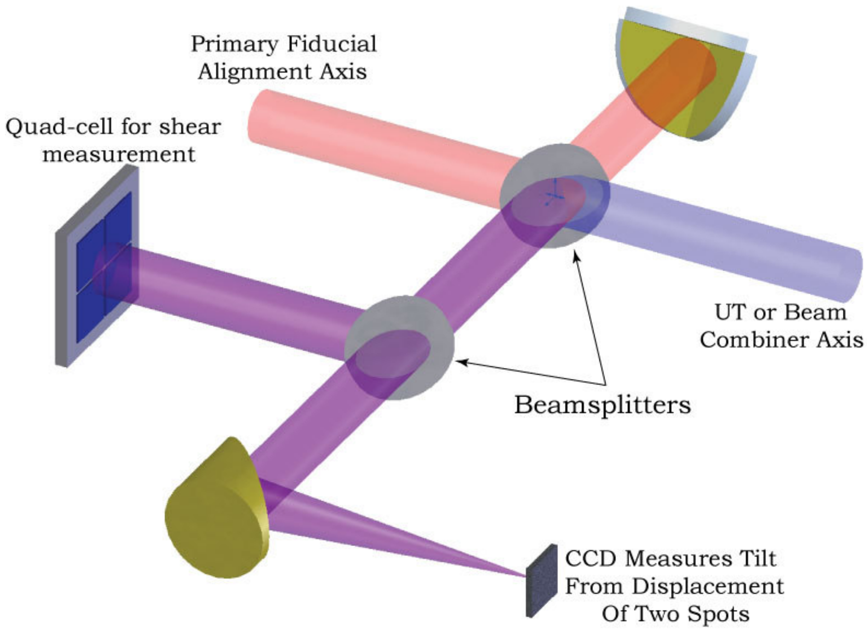

Fig. 8. Tilt and shear measurement between the three optical axes of a single line of the interferometer.

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