3. Instrument Description

GNIRS is a cryogenic 1-5 μm spectrograph with an on-instrument wavefront sensor (OIWFS) guider. The spectrograph can be operated in a variety of different observing modes, including a choice of 2 pixel scales, 3 spectral resolutions, different cross-dispersion options, and an integral field mode. The two pixel scales are provided by cameras with different focal lengths. The description presented here is intended to help understand the instrument configuration for service purposes. A more complete description is provided in section 2.1 of the User's Manual.

The instrument optical bench is shown in Figure 3.1.

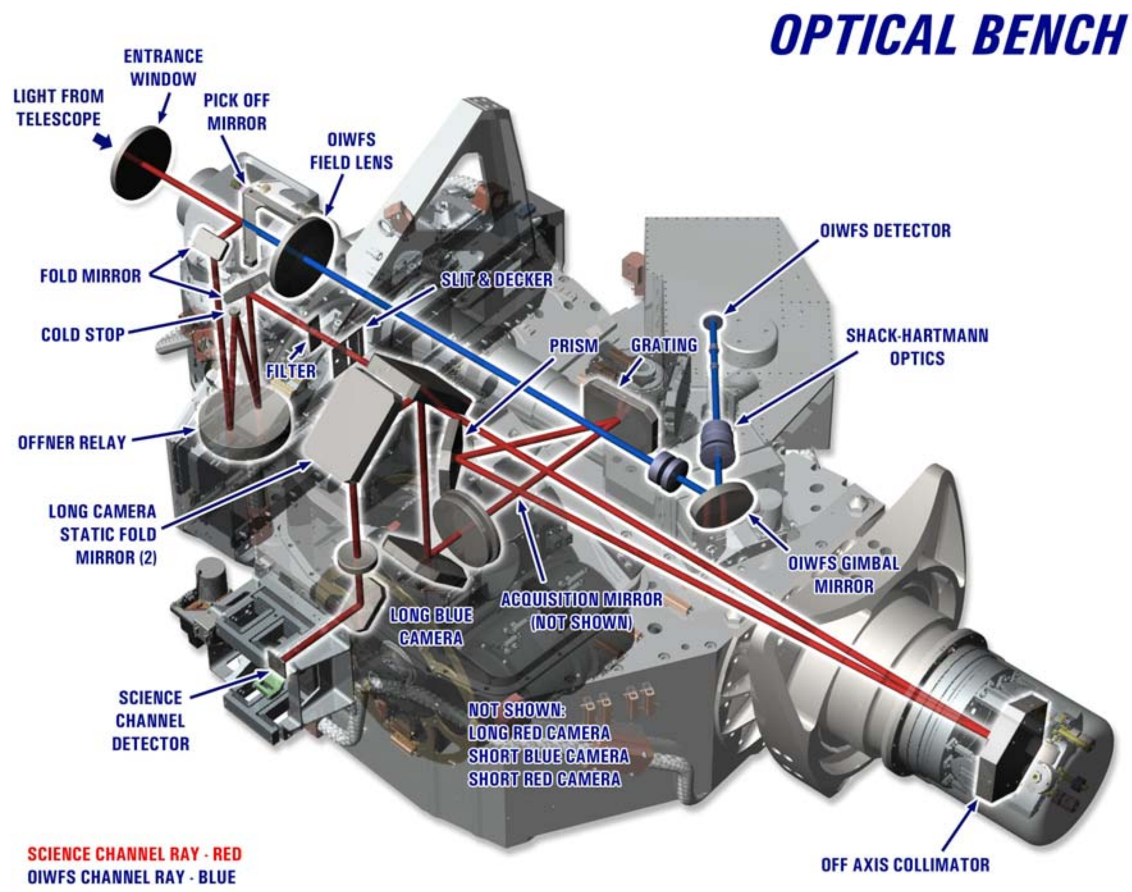

Figure 3.1. Schematic of instrument internal structure, showing light paths. The light path in red is the path through the spectrograph, starting at the entrance window. The light path in blue is the path through the OIWFS, starting at the pick-off mirror.

A functional "flow chart" through the instrument's science channel is shown in Figure 3.2.

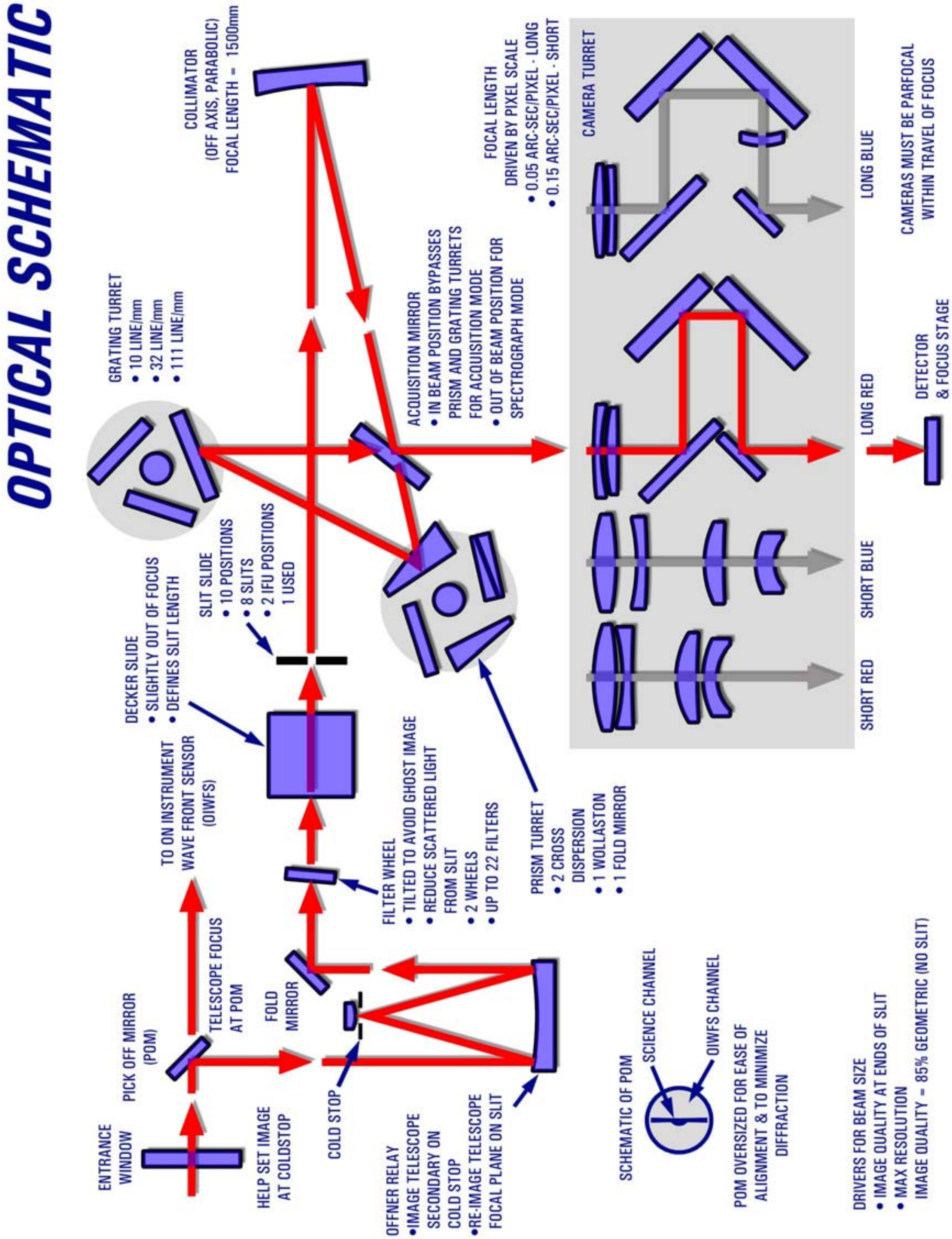

Figure 3.2. "Optical Schematic" for GNIRS, showing functional flow of light through the science channel.

Both the science channel and the on-instrument wavefront sensor are mounted within a cold structure contained within a vacuum vessel. The instrument electronics are mounted externally. The cold structure is operated at a temperature of ~65K in order to minimize excess background on the detector.

3.1 Spectrograph Description

The spectrograph design is a fairly conventional one for infrared spectrographs. There are two main sections: a fore-optics section, which provides field and pupil stops to limit excess background, and a spectrograph section, which disperses light from the object of interest.

3.1.1 Fore-Optics

The fore-optics comprise the following elements:

- Entrance window
- Pick-off mirror
- Entrance fold mirror
- Offner relay (primary and secondary mirrors)
- Exit fold mirror
- Filter wheels

The entrance window also acts as a weak lens, in order to ensure that the telescope secondary is imaged on the Offner secondary mirror, which is where the cold stop is placed.

The pick-off mirror acts as a crude field stop, defining the field accessible to the spectrograph. Light from the rest of the instrument field (roughly 3 arcminutes diameter) is available in principle to the OIWFS (see 3.3). The unvignetted field defined by the pick-off mirror is basically a 10 x 100 arcsecond strip with a superposed half circular field 15 arcseconds in radius centered on the optical axis, as shown schematically in Figure 3.3.

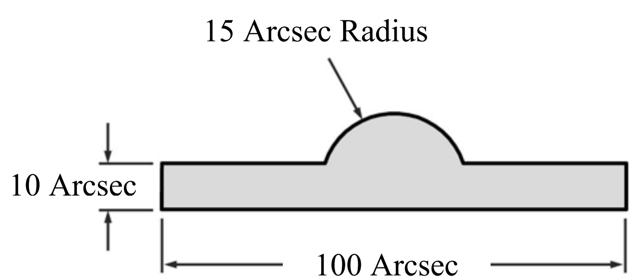

Figure 3.3. GNIRS spectrograph field of view. The long dimension is 100 arcsec; the width is 10 arcsec except for the additional 15-arcsec radius semi-circle.

The Offner relay serves two functions: it produces an image of the telescope secondary on the Offner secondary, where a cold stop is located, and it re-images the telescope focal plane onto the spectrograph slit. The scale at the slit is the same as at the telescope focal plane.

The spectrograph contains two filter wheels. Each wheel can accommodate 9 filters, in addition to an "open" position. The first wheel uses several of the positions for focus masks, a dark position, and a lens used to view the telescope pupil during alignment (see below). These can be used in series with filters in the second wheel. The remaining positions in the first wheel can be used for back-up filters.

The filters are slightly tilted (2.7 degrees) to reduce ghost images; this is also why the filters precede the slit.

Because the filters are located in a converging beam, they all have the same optical thickness in order to avoid refocusing the telescope each time a filter is changed. Any user-supplied filters must have the same thickness (equivalent to 3 mm of BK7) in order to operate properly.

3.1.2 Spectrograph

The spectrograph section consists of the following elements:

- Slit/Decker/IFU
- Collimator
- Acquisition mirror
- Prism turret
- Grating turret
- Camera turret
- Focus stage/detector mount

The spectrograph entrance slit is defined by two mechanisms. The width of the slit is defined by one of several slits in a photo-etched mask located in the slit slide, while the length of the slit is defined by one of several openings in the decker slide. The integral field unit (IFU) is also mounted in the slit slide; there is a location for a second IFU unit, currently occupied by a dummy module of similar mass.

The slit mask is located at the re-imaged focal plane, while the decker apertures are slightly ahead of it, and therefore somewhat out of focus (by a few pixels). The decker sizes are matched to the full width of the array in long slit mode, or to the minimum spacing between adjacent spectra when the prisms are used. The slit mask in the instrument can be changed (see 5.2.2.3).

In addition, the slit slide can be positioned to use the integral field unit or to use the pupil viewer; for the latter a second lens is placed in the beam (used in series with a lens in filter wheel 1).

The next element after the slit and decker is the collimator, an off-axis paraboloid of 1500 mm focal length. The collimator mount includes a system of adjustable weights which provide partial compensation for internal flexure in the instrument. This is a passive system, where gravity acts on a set of weights and levers to tilt the mirror slightly with varying orientation of the instrument. The largest corrective tilt of the mirror is less than 4 arcseconds.

After the collimator, a mirror can be inserted in the beam to direct the light into the spectrograph cameras, without being dispersed. This acquisition mirror allows the observer to identify, acquire, or recenter objects via broadband imaging, without the need to alter grating and prism tilts. This facilitates prolonged observing sequences on faint objects, since the dispersive settings remain stable even while target positions are checked.

The acquisition mirror is shown retracted in Figure 3.1, just below the position where the return beam from the collimator crosses the beam into the camera. When inserted, it diverts the light at the point where the two beams cross.

If the acquisition mirror is out of the beam, light goes from the collimator to the prism turret. The prism turret has four possible positions:

- Mirror
- Long camera cross-dispersion
- Short camera cross-dispersion
- Wollaston prism

The mirror is used for work beyond 3 μm, or when one wants to work with a long slit at shorter wavelengths. The two cross-dispersion prisms provide a cross-dispersed low-resolution spectrum over the approximate range 0.9-2.4 μm, where the two prisms are matched to the two pixel scales produced by the cameras. A complete spectrum is produced at a resolution of ~1800; use of higher spectral resolution results in more or less parallel portions of multiple orders but not a complete spectrum.

From the prism turret, light goes to the grating turret. The grating turret contains three gratings:

- 10.44 l/mm grating
- 31.7 l/mm grating
- 110.5 l/mm grating

All three gratings are blazed for 6.8 μm (first order Littrow), which provides an effective first order blaze wavelength of 6.6 μm in the configuration actually used (scattering angle of 27 degrees).

The different orders of the gratings then correspond fairly well to the atmospheric windows at 5, 3.5, 2.2, 1.6 and 1.2 μm for orders 1 through 5 respectively; the sorting filters specified in Table 2.1 cover the free spectral range of the individual orders, with some allowance for filter roll-off. A filter for order 6 is also supplied; the orders above 5 don't match the atmosphere particularly well.

From the grating turret, light then passes to the camera turret. The camera turret contains four cameras:

- Long blue camera
- Long red camera
- Short blue camera
- Short red camera

The "blue" cameras are optimized for the wavelength range 0.9-2.5 μm, while the "red" cameras are optimized for the wavelength range 2.9-5.5 μm. The blue cameras will not work at longer wavelengths; the red cameras can be used at shorter wavelengths, but with somewhat degraded image quality and transmission. The main short wavelength use of the red cameras below 3 μm is for acquisition of targets in the K band (sorter 3).

The "long" cameras have a focal length of 1305 mm, providing a scale at the detector of 0.05 arcsec/pixel. The "short" cameras have a focal length of 435 mm, providing a scale of 0.15 arcsec/pixel. All four cameras are close to parfocal; the longer focal lengths are achieved by folding the beam with a combination of mirrors in the camera barrel and external to the turret. The light path shown in Figure 2.1 is for one of the long cameras, so one can see the folded light path.

The detector is mounted at the output of the cameras, on a focus stage. The focus stage provides correction for the small focus differences between the different cameras (and potentially other small focus changes produced by other changes in configuration). The detector is a 1K x 1K ALADDIN III InSb array, which is operated at a temperature of approximately 31K.

The detector and its controller can be operated at frame rates in excess of 1/sec, allowing operation at 5 μm with either camera at any spectral resolution (imaging at 5 μm for acquisition purposes is usually not possible). Individual frames can be co-added and then sent to the Gemini Data Handling System (DHS) to ensure a more manageable data flow.

For these high background observations, the main concern is minimization of overhead, since the principal noise source is photon noise from the background. At shorter wavelengths, especially at higher spectral or spatial resolution, detector read noise can be

significant, even for relatively long exposures. In these situations, the detector can be read out non-destructively, so the read noise is reduced by multiple sampling (Fowler sampling). For long exposures and low background, the improved noise performance more than compensates for the increase in overhead involved.

Further details on this subject are found in the User's Manual (section 2.2).

3.1.3 Integral Field Unit

The integral field unit (IFU) is an additional optical system, provided for GNIRS by the University of Durham (UK). The IFU takes a rectangular input field, of approximate dimensions 3.3 x 4.8 arcsec, and divides it into 22 slices 0.15 arcsec in width. The IFU optics map the slices of the rectangular field onto the input plane of the spectrograph, aligning the slices more or less along the regular input slit position (the slices are offset from each other by roughly 2 pixels/slice).

The optics also change the input scale to 0.12 arcsec/pixel along the slit, and 0.075 arcsec/pixel in the dispersion direction. The IFU is intended to feed the long cameras, and therefore can be operated at a maximum resolution of ~5900.

3.2 Spectrograph Configurations

With multiple filters, slits, prisms, gratings, and cameras, there are in principle a very large number of possible configurations. Although the instrument can be configured to any of these, in practice only a much smaller number are of interest. These are tabulated in section 2.1 of the User's Manual (Tables 2.5-2.7)

3.3 On-Instrument Wavefront Sensor

The OIWFS was built for GNIRS by the Institute for Astronomy (Hawaii). The light path is also shown in Figure 3.1. Light from the guide field - anything in a 3 arcminute diameter field that misses the pick-off mirror - enters the OIWFS field lens and then passes to a collimator doublet and then a 2-axis gimbal mirror.

The gimbal mirror can be tilted precisely to direct light from any part of the guide field to the rest of the OIWFS optics. The usable field is roughly 10 arcsec diameter, which is sufficient to acquire individual guide stars.

Light from the selected patch of sky is reflected off the gimbal mirror, through a second doublet, and the guide star is re-imaged on the filter wheel, which contains JHK filters and apertures.

From the filter wheel, light enters the Shack-Hartmann optics, which are mounted on a "snout" on the detector mount. The Shack-Hartmann optics form a pupil image at a shallow four-facet prism, then reimage the star on the detector. Because the light has passed through the S-H prism, four images of the star are actually formed, corresponding

to 1/4 of the pupil each. Only a small portion of the array is read out, allowing rapid data rates, which permit the OIWFS to provide high-speed tip-tilt and focus correction in addition to slower flexure and tracking correction. For fainter guide stars, fast correction is limited to tip-tilt and does not include focus.

The OIWFS filter wheel contains standard JHK filters. In principle, users should select the filter that provides the best signal to noise ratio on the guide star (normally H), since the telescope's acquisition and guide (A&G) system adjusts the OIWFS gimbal mirror position to compensate for differential refraction between the guide wavelength and the observing wavelength.

3.4 Cryostat

The cold structure shown in Figure 3.1 is contained within a larger cryostat, shown in view below (Figure 3.4). The internal structure is maintained at a temperature of approximately 65K using 4 Leybold RG 5/100 cryocoolers. The initial cool-down of the instrument can be done either with the cryocoolers alone, which takes over a week, or with the assistance of a liquid nitrogen pre-cool system, which allows the instrument to reach operating temperature in 3-4 days.

The cryostat is a large vacuum vessel, which contains two aluminum passive shields and a third shield that is connected to the cryocoolers. These act to minimize heat radiated and conducted into the cold structure, which would otherwise produce unacceptable temperature gradients and gradient variations under varying ambient conditions. In addition, a temperature control system adds a varying amount of heat to the cooling system to ensure that the structure is maintained at a constant temperature (±1K or better).

The window at the front of the cryostat has a motor-operated cover that is closed to protect the window when the instrument is not in use. As it is an external warm device, it cannot be used as a "dark slide". There is a manual override on the cover so that the window can be protected even in the event of a power failure.

The window can cool below the dew point in conditions of high humidity, so the window mount provides a slow flow of dry air across the window to avoid condensation. This also helps to keep dust off the window.

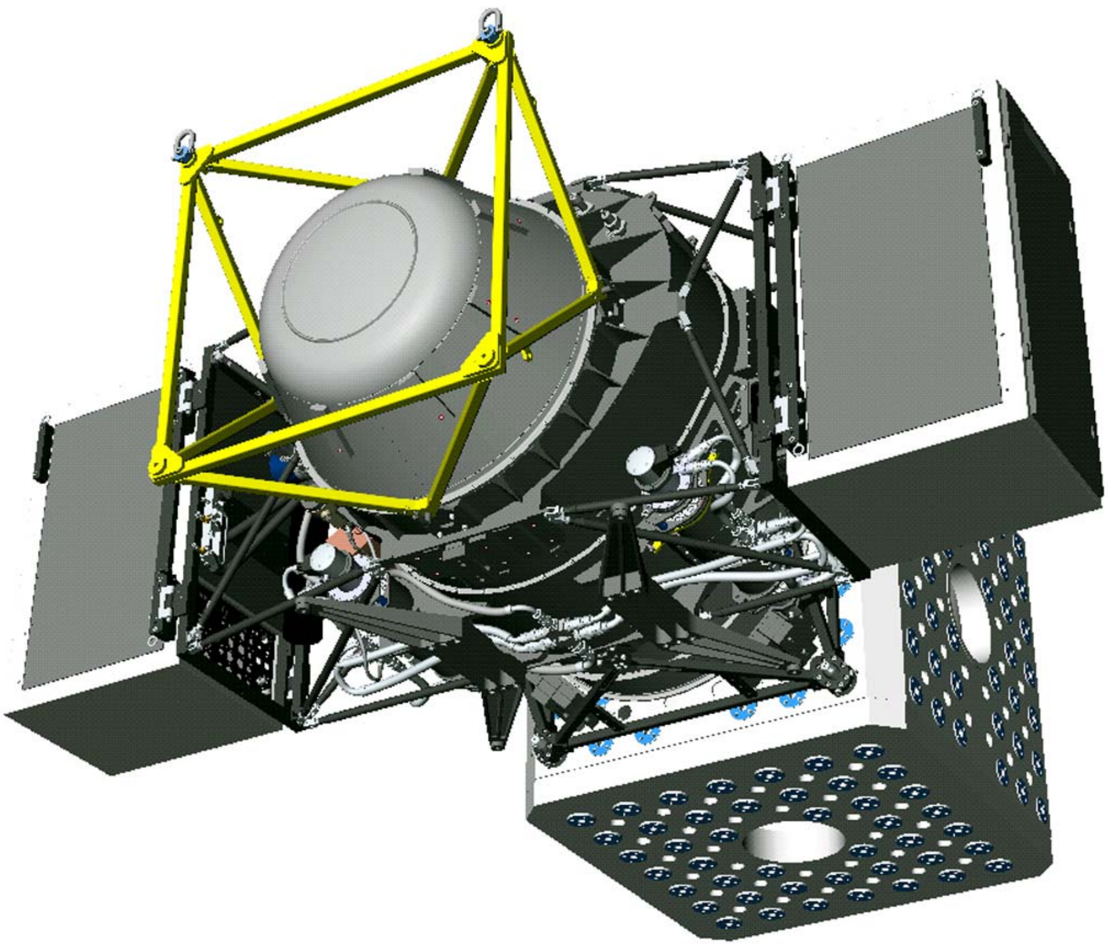

Figure 3.4. View of instrument showing cryostat, electronics boxes, and trusses. The instrument is shown mounted on a side looking port of the Gemini ISS; the yellow truss at the aft end is a temporary installation fixture, which is removed after installation onto telescope.

3.5 Electronics Enclosures

As with all Gemini instruments, the GNIRS electronics are mounted on the instrument to facilitate instrument changes and minimize the complexity of the connections between the instrument and telescope. The electronics are mounted in two thermal enclosures, which are insulated, glycol-cooled boxes that minimize heat dissipation from the electronics into the telescope environment.

One of the enclosures (right in Fig. 3.4) contains the science array controller, which handles operations of the ALADDIN array, including initial processing steps such as non-destructive reads and co-addition.

The second enclosure (left in Fig. 3.4) contains all the other instrument electronics, including the OIWFS electronics, instrument motor and temperature controls, and the instrument's VME crate.

The instrument fits closely within Gemini's allowed instrument envelope and is approximately 2.2m long x 2.5 m wide x 1.3 m high (side-looking orientation). The instrument weight is just under 2 metric tons; ballast is added to bring its weight up to 2000 kg to balance it against other instruments on the Gemini instrument rotator.

3.6 Coordinate System

The instrument coordinate system is defined as follows: The x-y plane of the instrument coordinate system lies in the plane of the telescope ISS. The z axis is orthogonal to the x-y plane and points into the instrument. It is parallel to and coincident with the optical axis. The origin is located at the intersection of the ISS plane and the mechanical axis of the cylindrical opening in the center of the ISS. See Figures 3.5 and 3.6.

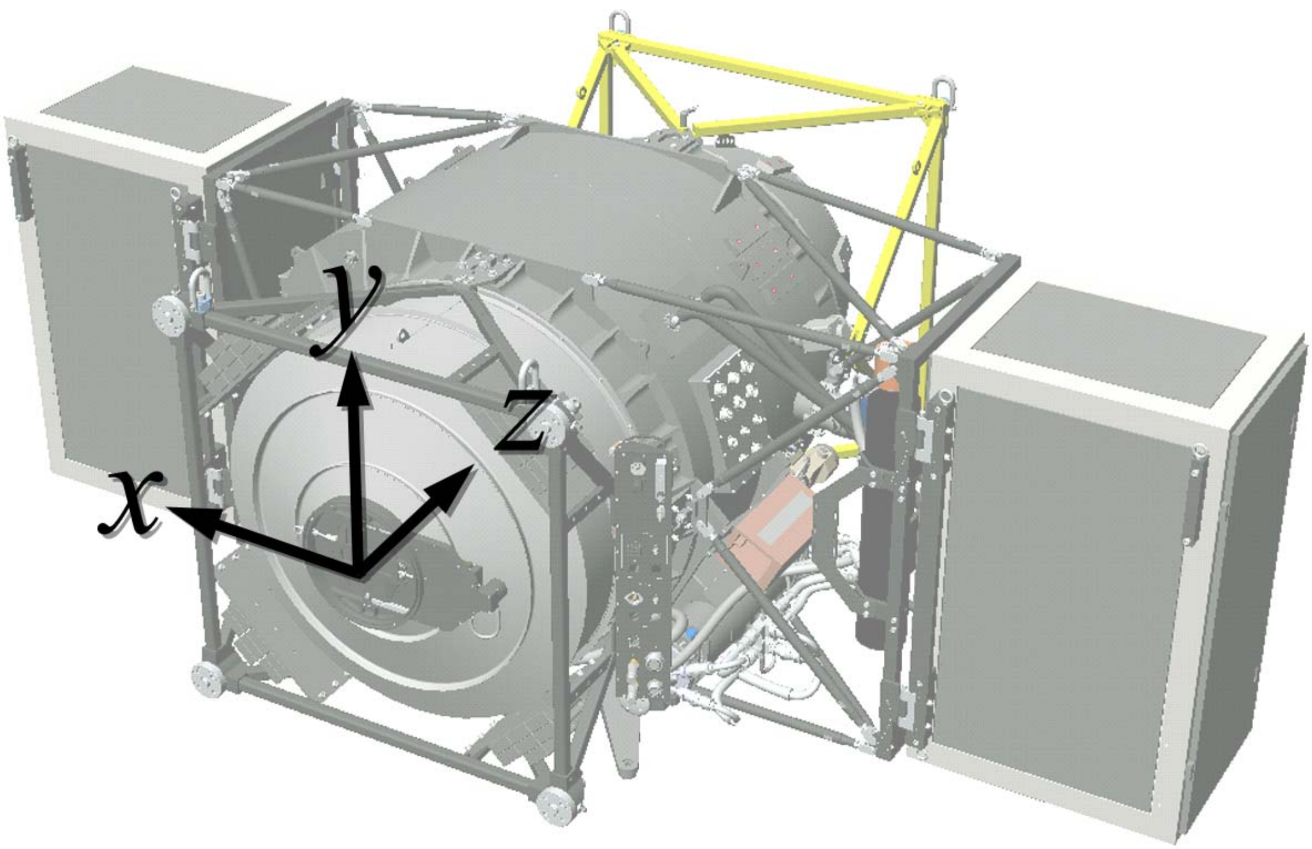

Figure 3.5. Front view of instrument showing Instrument Coordinate System

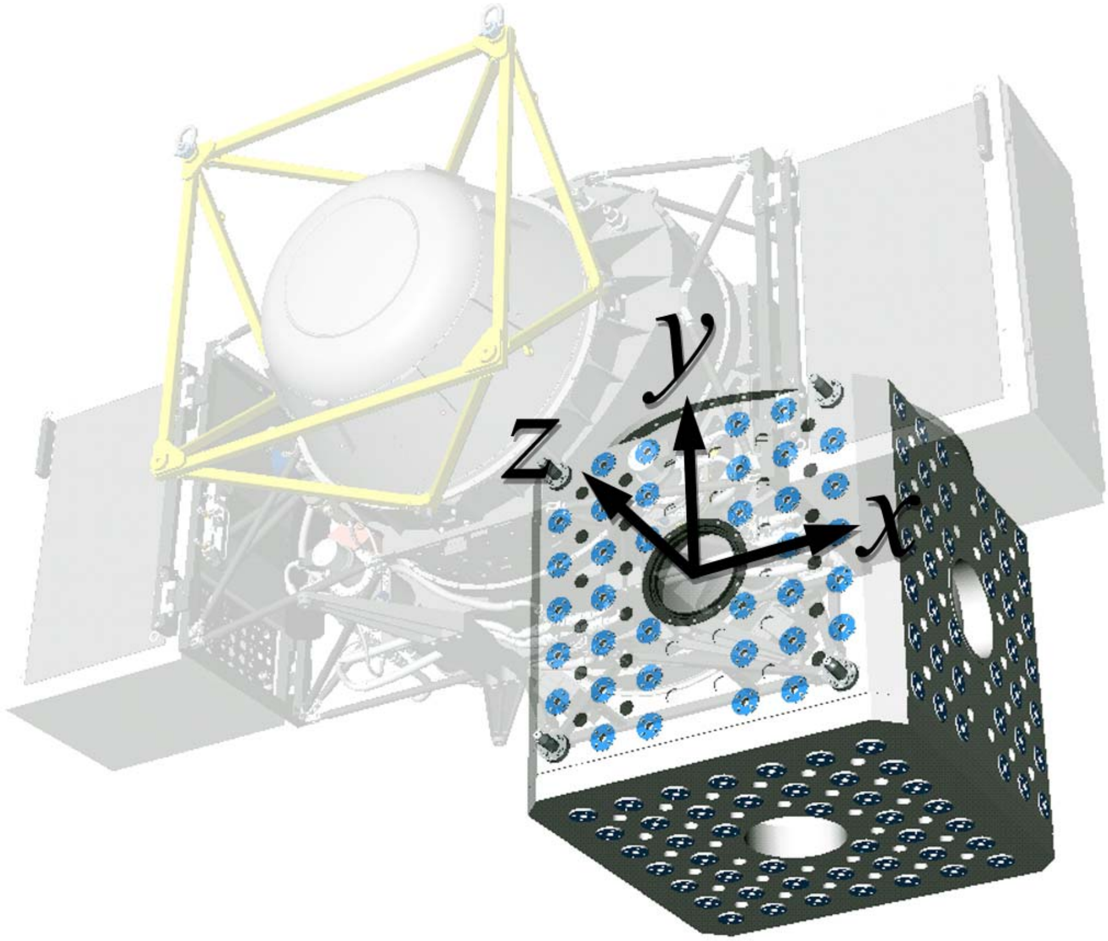

Figure 3.6. View of ISS showing Instrument Coordinate System