

A description of the High Resolution Dynamics Limb Sounder (HIRDLS) instrument

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ABSTRACT

We describe the top level design of the High Resolution Dynamics Limb Sounder (HIRDLS) instrument including the optical and scanning subsystems which have been developed to meet 0.7 arcsec pointing and the 1% radiometric accuracy requirements. The HIRDLS instrument is an infrared limb-sounding radiometer designed to sound the upper troposphere, stratosphere, and mesosphere. The instrument performs high resolution limb scans at multiple azimuth angles, measuring infrared emissions in 21 spectral channels¹ ranging from 6 to 18 microns. The instrument design includes an off-axis Gregorian telescope with high resolution optical shaft encoders, a silicon carbide scanning mirror, and a vibration isolation system incorporating accelerometers in a feed-forward scanning control system. The detector subsystem includes 21 HgCdTe detector elements cooled by a mechanical Stirling cycle cooler.

Key Words: HIRDLS, Radiometer, Limb Sounding

1. INTRODUCTION

The High Resolution Dynamics Limb Sounder (HIRDLS) is an infrared limb-scanning radiometer designed to sound the upper troposphere, stratosphere, and mesosphere to determine: temperature and horizontal pressure gradients; the concentration of O₃, H₂O, CH₄, N₂O, HNO₃, N₂O₅, CFC11, CFC12, ClONO₂, and aerosols; and the locations of polar stratospheric clouds and cloud tops. HIRDLS will perform limb scans in the vertical at multiple azimuth angles, measuring infrared emissions in 21 channels ranging from 6.12 to 17.76 μm^2 . The goals are to provide global sounding observations with horizontal and vertical resolution superior to that previously obtained³.

HIRDLS is part of the Earth Observing System (EOS) Chemistry observatory (see Figure 1). The observatory will be launched into a 705 kilometer, 98.2 degree inclination, polar sun synchronous orbit with an ascending node equatorial crossing time of 1:45 PM.

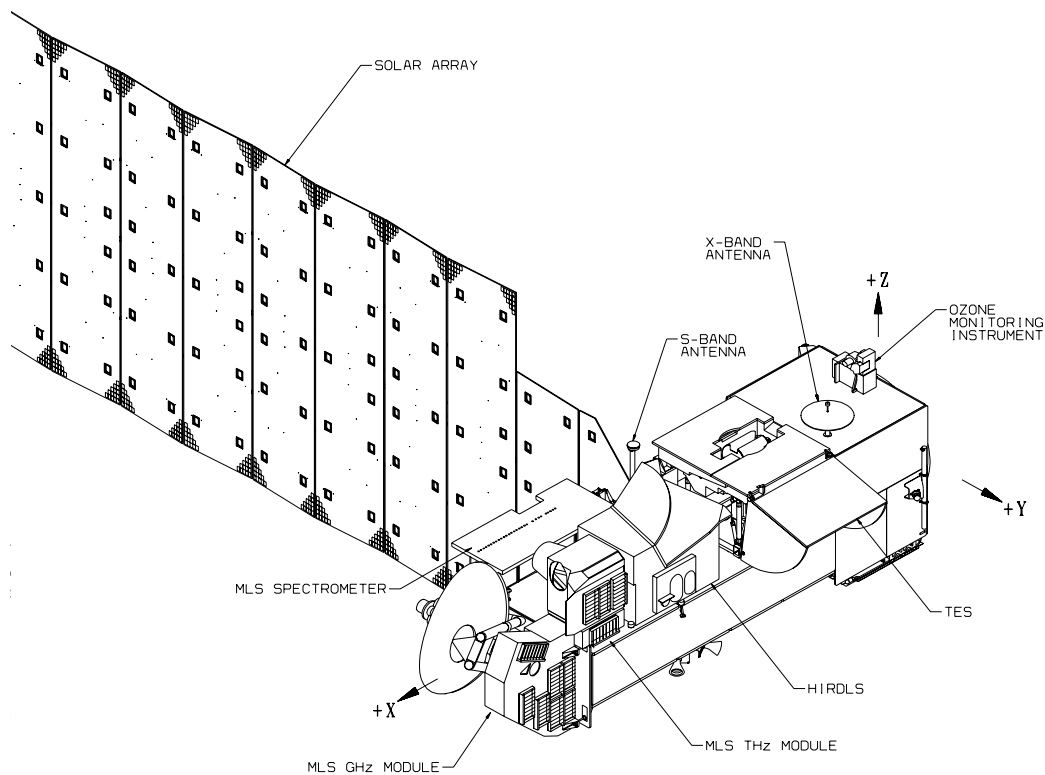


Figure 1 – EOS Chemistry Satellite

2. GENERAL DESCRIPTION

The HIRDLS instrument is designed to examine the role of the upper troposphere, stratosphere, and mesosphere in global atmospheric change. This requires measurements of the temperature and a large number of trace species, with global coverage, day and night (including the polar night). Consequently, the instrument must measure atmospheric emission, rather than absorption. Furthermore, since the atmospheric quantities must be determined with high vertical resolution, the atmosphere must be observed at the limb, with a narrow vertical field-of-view (FOV). High vertical resolution also dictates the use of limb scanning, rather than limb staring, because the high spatial frequency features in the atmosphere can be measured by oversampling. Low noise and precise FOV knowledge are critical requirements for high vertical resolution since this requires some degree of deconvolution in the retrieval process which implies noise amplification⁴.

The dimensions of the HIRDLS instrument (see Figure 2) are approximately 1330 mm high by 1500 mm wide by 1185 mm deep. The outer structure is constructed of aluminum honeycomb with carbon composite face sheets. Within the outer structure is an optical bench assembly carrying a telescope and 2-axis scanning mirror, a detector dewar assembly, a precision internal blackbody calibrator, and a gyroscope package. Incoming radiation is chopped by a rotating chopper⁵ at 500 Hz. When the chopper is closed the detectors are presented with a cold space image through a space view port. A Stirling cycle cooler, mounted on the side of the instrument with its own integral radiator, maintains the detectors at their 65 K operating temperature.

Since the main instrument aperture view is in the general direction of the anti-flight vector, and beta angles can be as low as 15 degrees, it is necessary to ensure that direct sunlight does not enter the radiometer. This is achieved by means of a moveable aperture door which is partially closed for 10-15 minutes per orbit, prior to sunset. The exact time profile and angular range are continuously adjusted to allow for seasonal variations and to maximize geographical coverage.

The nominal operating sequence consists of a vertical scan of approximately 3 degrees (LOS) over 9 seconds, then an azimuth step of ~12 degrees followed by another vertical scan. This process is repeated until 6 vertical scans are completed, then the scanner moves to view the internal precision blackbody reference. The in-flight radiometric accuracy will be

established by using the space view at the top of an altitude scan and by viewing the known-temperature blackbody through the entire optical system. Although it is expected that the instrument will follow this sequence the majority of time, the azimuth and elevation scan rates and sequences are completely programmable from the ground.

The most critical requirements that affect the optical bench and telescope are the radiometric accuracy and the line-of-sight (LOS) stability. Radiometric accuracy drives the performance of the internal blackbody subsystem as well as the requirements on the emitted radiation from the scanning and primary mirrors and scattered light from out-of-field sources. These affect the optical design form, baffle design, BRDF of the mirrors and contamination control of the assembly.

Some key instrument requirements are listed below:

- Relative elevation knowledge within a scan: 0.7 arcsec
- Radiometric Accuracy: 1%
- Out-of-Band Response < 1% of the in-band radiance
- Mass < 200 kg
- Power < 220 W

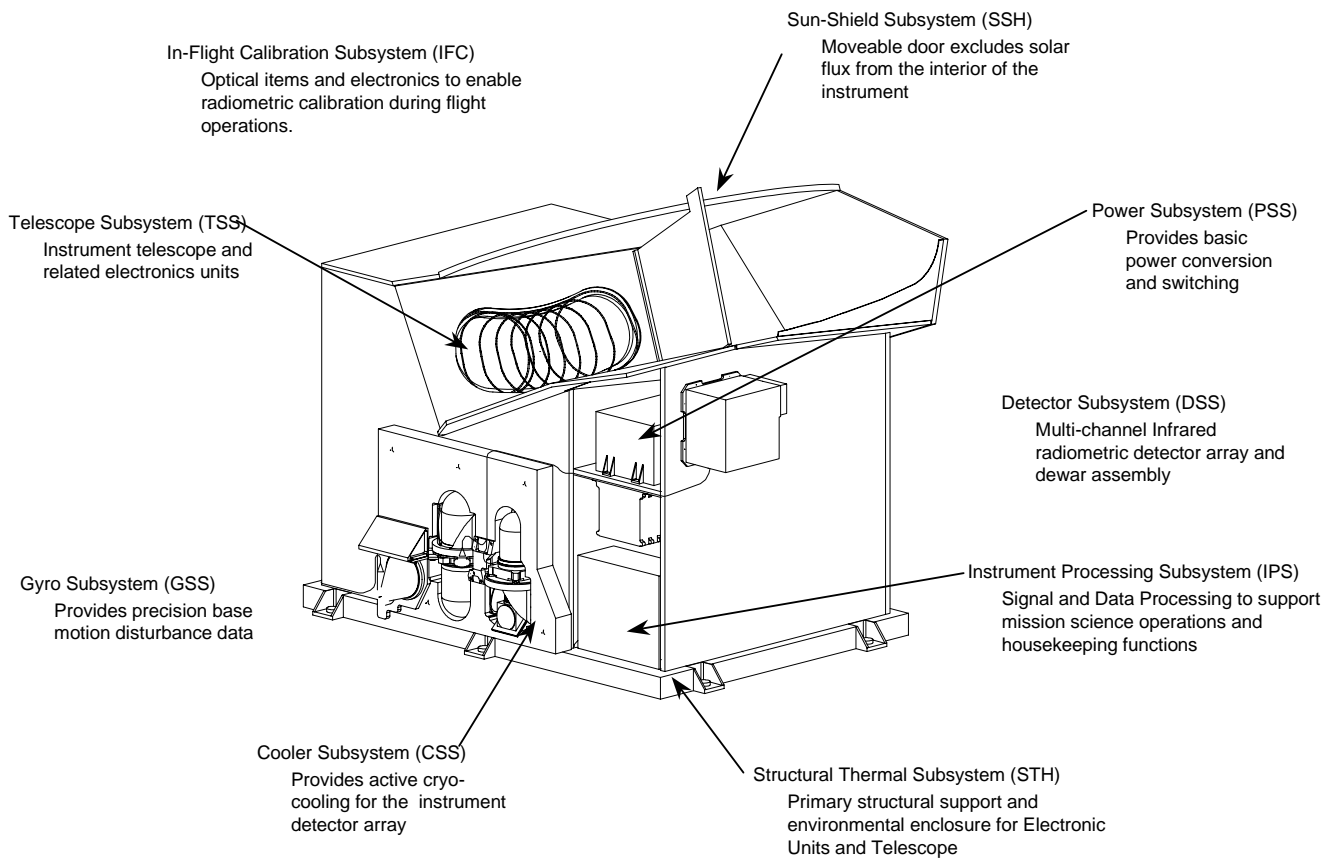


Figure 2 – HIRDLS Instrument

3. OPTICAL CONFIGURATION

Figure 3 shows the optical schematic for the instrument. The basic form is that of an off-axis Gregorian telescope⁶ with a lens relay after the second image plane to give the correct image scale and aberration control. The system was optimized for good image quality and controlled Intermediate Lyot Stop (ILS) to the System Aperture Stop (SAS) pupil aberrations. The telescope has an entrance pupil diameter of ~160 mm on-axis. The geometrical image scale is such that a 1 km object height, at 3000 km object distance, subtends 0.0818 mm at the focal plane.

There are two sets of spectral filters^{7,8}. The set at the second image plane (the warm filters) define the spectral shape of each channel. The spectrally broader filters adjacent to the final image plane (the cold filters) reduce the out-of-field signal reaching the detectors, and greatly reduce both the warm background photon flux noise and the out-of-band spectral leakage. The dewar window is made of ZnSe and therefore provides additional long wave blocking.

The In-Flight-Calibrator (IFC) optical path provides the detectors with a clear view of the blackbody radiometric source through the entire imaging system. The scan mirror rotates to 59 degrees (LOS) in azimuth to view the off-axis parabolic calibrator mirror, at the focus of which is location the blackbody aperture. The blackbody, whose emissivity exceeds 0.9995 and whose temperature is known to 70 mK absolute, is at the same temperature as the calibrator mirror so that the radiance produced is independent of calibrator mirror reflectivity. The scanner elevation angle is set to view the blackbody at approximately the zero torque position of the scanner elevation axis flex pivots, and therefore minimizes the heat load of the scanner actuators.

The space view optical path provides the detector with a clear view of cold space, after reflection off the chopper surface, through an aperture in the instrument radiator wall. This provides a cold reference to the instrument when the chopper is closed. The axial ray exiting the space view port is depressed 1 degree toward the orbit normal. This geometry minimizes the outages due to lunar incursion into the space reference field-of-view.

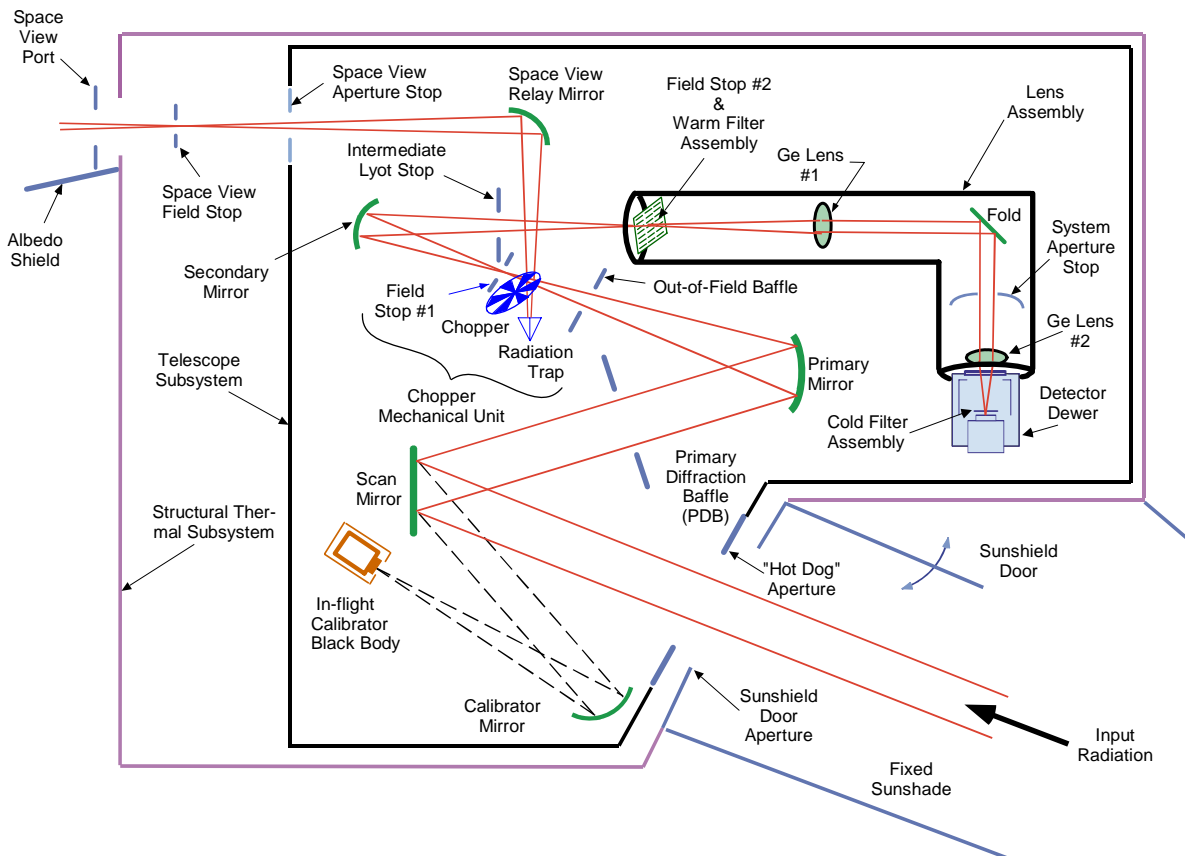


Figure 3 – Optical Schematic

4. OPTICAL BENCH ASSEMBLY

The original instrument conceptual design used relatively simple designs of aluminum and aluminum honeycomb for the outer structure and the optical bench. However as the preliminary design progressed it became clear that something was going to have to be done to reduce the instrument mass. The fundamental trade was to either reduce the input aperture, and therefore the telescope volume and resultant mass, or to redesign using more exotic materials. Since reduction in aperture would have reduced the signal-to-noise ratio and compromised some of the science objectives, the redesign approach was chosen.

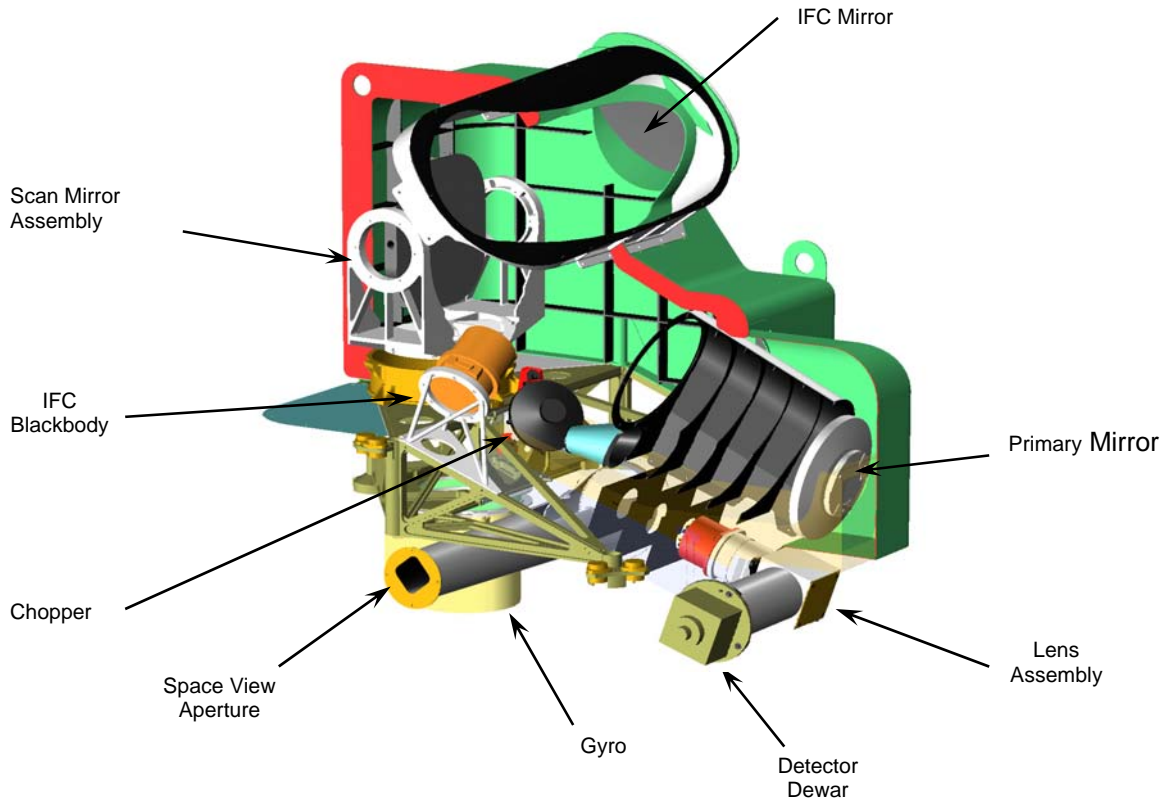


Figure 4 – Optical Bench Assembly

The outer structure was redesigned using aluminum honeycomb with carbon composite face sheets. The optical bench now uses a brazed beryllium truss type construction. The two-axis scanner uses a 230 mm x 230 mm ribbed SiC mirror housed in a beryllium/aluminum alloy yoke. These design changes were primarily responsible for reducing the mass to within the 200 kg allocation for the instrument.

Tight line-of-sight knowledge requirements in the presence of induced angular jitter, both from within the instrument and jitter from the spacecraft and other instruments, drive the design in several areas. First the optical bench is mounted to the structure base plate with kinematic low-Q isolators tuned to ~ 50 Hz. In addition, the scanner servo incorporates a feed-forward system to attenuate angular jitter induced into the optical bench. The feed-forward system uses accelerometers and attenuates the jitter by approximately a factor of 5 for frequencies from 10 Hz to 100 Hz. A 4-axis gyroscope is mounted to the optical bench in order to precisely determine bench angular rotation of the LOS with respect to inertial space. Three of the gyroscopes are needed for operation and the fourth is included for redundancy. The gyroscopes are GEC-Marconi Electro-Optics (GMEO, formerly Ferranti) TYPE 125 floated rate-integrating gyroscopes. In conjunction with spacecraft orbital position knowledge, scanner angular position knowledge and optical bench structural stability requirements, the gyroscope provides knowledge of the motion of the LOS, and hence the tangent point with respect to the atmosphere, for frequencies up to 40 Hz. Another key feature of the design is relatively small, 70 mm diameter, optical shaft encoders which have a resolution of 0.019 μ rad in elevation.

The detector dewar assembly consists of 21 HgCdTe detectors⁹, which are operated in the photo-conductive mode. A quadrant detector, which operates at the same wavelength as channel 20 (6.49 – 7.03 μm), is used for LOS measurements during instrument integration, test, and calibration. (See Figure 5.) Each of the 21 detectors subtends 1 km elevation by 10 km azimuth at the limb (approximately 3000 km slant range).

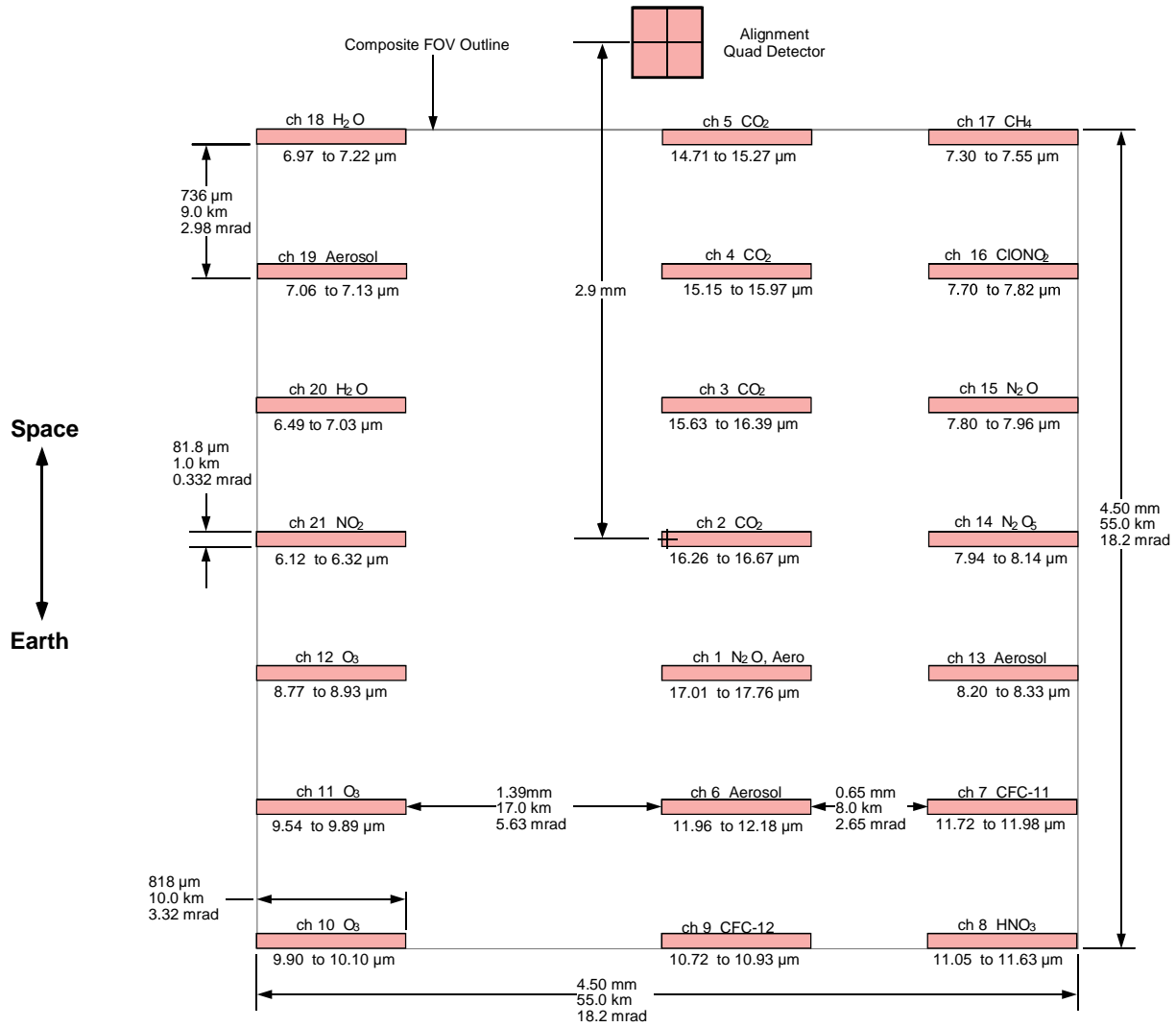


Figure 5 – Focal Plane Layout

5. STIRLING CYCLE COOLER

A single-stage Stirling cycle cooler¹⁰ maintains the detectors at their 65 K operating temperature (See Figure 6). The compressor is a balanced piston-cylinder pair operated in a coaxial, head-to-head configuration. The cooler uses a novel fixed regenerator and a non-contacting compressor that is designed to meet the 6 year on-orbit operating life. In order to reduce induced vibrations into the telescope, the cooler control electronics includes an active vibration cancellation system. This system uses force transducers within a servo loop to significantly reduce compressor and displacer axial mode exported forces. Radial forces are held to within 0.36 N by careful alignment of the compressor assembly. A very compliant “S” link is used as the cold link interface to the detector dewar in order to reduce undesirable forces applied to the focal plane.

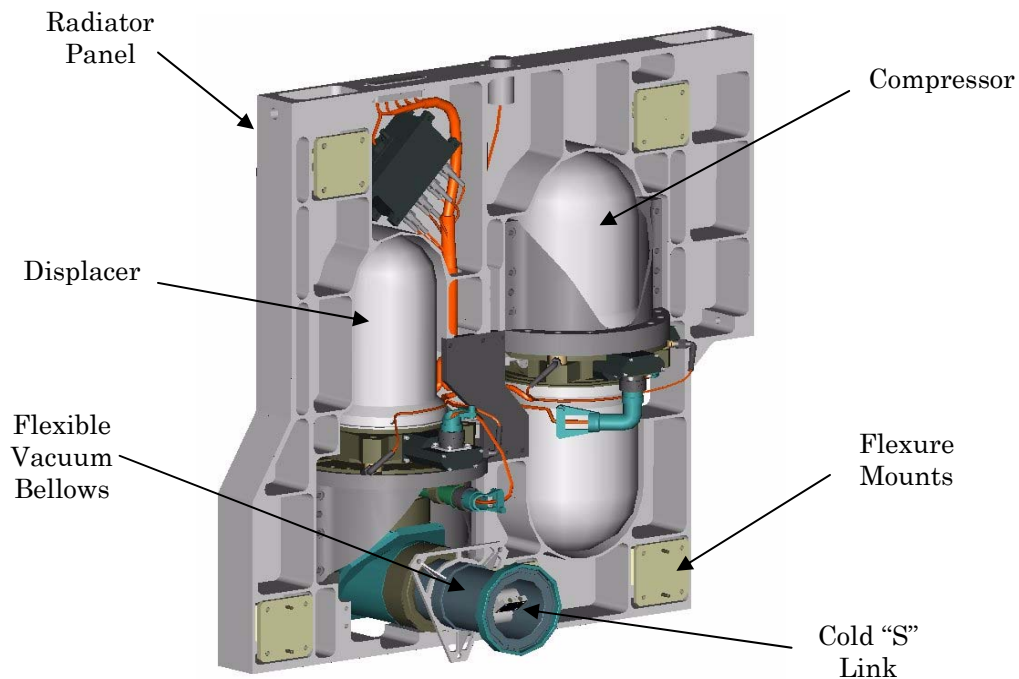


Figure 6 – Cooler Mechanical Unit

6. ACKNOWLEDGEMENTS

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