

STATUS OF THE CRYOGENIC TELESCOPE AND GUIDE STAR FOR GRAVITY PROBE B

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ABSTRACT

We describe the status of the development and testing of the star tracking telescope for Gravity Probe B. The fused quartz telescope with an aperture of 14 cm and 3.8 m effective focal length is attached to the gyroscope housing and continuously points to a guide star. A star image divider assembly in conjunction with cryogenic photo detectors is used to provide quadrant pointing information which is used to maintain the attitude of the spacecraft. Development and testing of the flight telescope has been completed. The optical test results will be discussed.

INTRODUCTION

The Gravity Probe B experiment consists of measuring the precession of gyroscopes in earth orbit relative to inertial space. The reference frame is established by observing a distant star with known proper motion using a specially designed telescope capable of splitting the diffraction-limited image to about a part in 10^4 . The goal of the experiment is to measure the precession to an accuracy of about 10^{-4} arc-sec per year. To achieve the desired level of stability in the reference direction, the telescope is attached to the gyro support assembly using an all-quartz system. This approach places a number of constraints on the star tracker design, primarily because of the operating temperature of the gyros, close to 2 K. However, this constraint also has significant advantages because of the enhanced stability and low thermal expansion coefficient of materials at such temperatures.

The star tracking telescope is a nominal Cassegrainian-Schmidt design with an additional tertiary mirror. The spherical aberration of the three reflectors is corrected by hand-figuring the primary mirror to an elliptic shape. The effective focal length is 3.8 m and the aperture is 14 cm. An image divider assembly is used to provide the pointing information. When the star image is centered within the field of view, it is split by a beam splitter and focused on the apexes of a pair of roof prism mirrors, providing pointing angle information in two orthogonal directions. Each bisected beam passes through a set of relay optics and a beam splitter before it reaches a primary and a redundant photodiode detector. The signal from the photodiodes is preamplified by a set of Si JFETs. To accommodate the high operating temperature of the Si JFETs of about 70 K while maintain the temperature of the telescope near 2 K, the JFETs and photodiode assembly is heated to its operating temperature and thermally isolated by polyimide films from the rest of the telescope.

IM Peg (HR 8703) has been selected as the current baseline guide star, with visual magnitude of 5.64. For this star, the worst case scenario estimate yields about 10 fA of photo current in each photo detector when the star image is centered on the optical axis. With the Si JFETs developed at NASA Goddard Space Center, photon noise limit performance has been achieved ¹.

TESTING OF THE TELESCOPE

The telescope is tested with an optical facility called artificial star. A schematic of the facility is shown in figure 1. The light source of the star consists of a laser diode of wavelength 685 nm pigtailed with a single mode fiber with its end located at the focal point of the spherical mirror. The collimated beam is directed by a diagonal mirror to enter the telescope located inside a low temperature dewar. The incident angle of the beam can be changed by either tilting the dewar-probe assembly in increments of 0.2 arc sec in the range of ± 30 arc min or by rotating a tipping plate in increments of 1 milli arc sec in the range of ± 5 arc sec. The optical components are placed in an invar structure inside a vacuum chamber to minimize the thermal variations from the room temperature environment and the entire system is anchored in 4 buckets of sand and suspended with inflated tires to reduce the vibration coupling from the floor. A second reference beam is reflected from a mirror on top of the telescope to provide an error signal for tilt control of the main beam. A servo control system steers the diagonal mirror dynamically to remove any residual disturbances of the incident angle of the star beam.

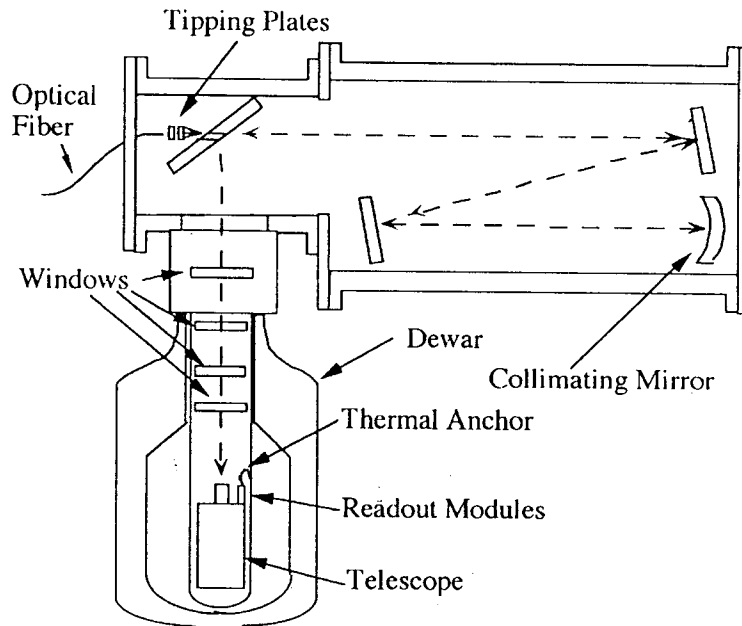


Figure 1: Artificial Star Facility.

Figure 2 shows the output from one axis of the telescope readout as a function of the beam incident angle for the flight telescope. Here the solid line is the calculated telescope response for a Strehl ratio of 93% and the crosses and circles are test data points at room temperature and 4 K respectively. It is obvious from the data that the cryogenic focus shift we observed in the prototype telescope ² has been eliminated in the flight telescope. The current telescope is fabricated from a single boule of Herasil 1-top fused quartz to minimize the mismatch of thermal expansion coefficients of the various elements. The data confirms our analysis ³ that the cryogenic focal shift was caused by mismatch of thermal expansion coefficients between adjacent fused silica components.

So far, a monochromatic light source is used for all the tests. On the other hand, a typical spectrum

of the guide star approximates black body radiation. An analysis has been performed to incorporate the effect of the star spectrum as well as the spectra response of the Si photodiodes. The result showed that the difference in scale factor is less than 20% within 5 arc sec of the optical axis. This is within the prelaunch requirement specification.

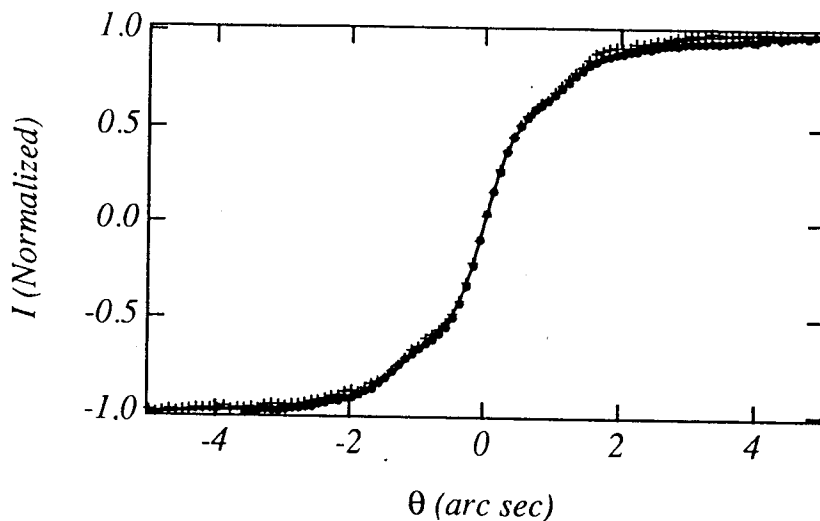


Figure 2: Telescope Readout.

The telescope has been extensively tested both at room temperature and at 4.2 K. The test configuration is such that the telescope is in a similar thermal environment to that expected during the mission. The major differences are the temperature of the outer window and the actual operating temperature of the telescope. The outer window during flight will be at 220 K while it is at room temperature in the test facility. The operating temperature of the telescope is around 3 K and in the test it is kept at 4.2 K. Both of these differences are not expected to have much impact of the test results. Table 1 shows a list of requirements for the flight telescope as well as the current test status. All specifications for which data has been obtained have been met.

Table 1. Telescope Requirements

| Parameter | Requirements | Flight Telescope at 4.2 K |
|-------------------------------------|---------------------------------|--------------------------------|
| Mechanical & Readout Null Stability | < 0.1marcs over roll period | |
| Linear Range | ± 60 marcs | |
| Linearity | < 3 marcs peak to valley | |
| End to End Readout Noise | < 10 marcs / $\sqrt{\text{Hz}}$ | < 4 marcs / $\sqrt{\text{Hz}}$ |
| Orthogonality of Readout Axes | < 1 degree | 0.4 degree \pm 0.2 degree |
| Field of View | > 1 arc min | 75 arc sec \pm 1.5 arc sec |
| Saturation Range | > 1 arc sec | > 1 arc sec |
| Strehl Ratio | > 72% | 93% \pm 1% |
| Transmission | > 20% | 27% \pm 2% |

SUMMARY

The flight telescope for GP-B Relativity Mission is in the final testing phase. So far, it has met or exceeded all the optical test requirements. Upon completion of all the tests of the telescope at the

subsystem level, it will be bonded with the quartz block which houses the gyroscopes. Final testing will be conducted at the payload verification level before going through the final payload test.

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