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A COOLED TELESCOPE FOR INFRARED BALLOON ASTRONOMY

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ABSTRACT

A 16 in. liquid helium cooled Cassegrain telescope with vibrating secondary mirror is being constructed for far infrared astronomical observations. The system will be capable of housing several different detectors for multicolor photometry. This instrument will be flown jointly with Dr. William F. Hoffmann in a gondola that has been used by him in previous flights.

For several years now, the Goddard Institute for Space Studies gondola has been obtaining data on H II regions in the Galaxy. Some of the more recent results are described elsewhere in these proceedings. The system has been flown 6 to 8 times a year. The Gondola consists of a 12" Newtonian telescope with a vibrating secondary chopper. The beam feeds into a liquid helium dewar containing a bolometer and filter system which transmits in the region around 100μ. The gondola is fully steerable and in addition has a programmable scanning mode.

Mechanically, the gondola was built in three separate sections (Figure 1). The middle unit is the structural support, and houses the orientation machinery. The system is magnetometer stabilized to about 5' of arc. An inertial wheel provides the reaction mass against which the gondola stabilizes. In addition, there is an active bearing which transmits excess angular momentum to the balloon. In a sense the middle unit alone should be called "the gondola". The right hand unit, which is simply bolted on to the gondola, is the telescope, detector and preamp section. The left hand unit is a box containing batteries, control electronics, and the telemetry, telecommand system. This unit corotates with the telescope. The 2 boxes hanging below the package are N.C.A.R. transmitters, batteries and ballast hopper. These boxes are cut away (onto a long nylon cable) before landing so that the package may land horizontally on the three crash pads shown. A typical flight lasts about 16 hours. The flight configuration of the system has changed in the course of the program as shown in Figure 2.

The success of the 12" balloon borne telescope has prompted us to build a more sensitive instrument. The 12" telescope has discovered approximately 100 objects along about half of the galactic plane. Two thirds of these have been identified clearly with H II regions or infrared stars. The survey was carried out with an uncooled telescope and helium cooled bolometer with a sensitivity of 10^{-23} w/m^{2}Hz at 100μ. The sensitivity of the telescope is fundamentally limited by the thermal flux falling on the detector due to the telescope and sky emission. They sky emission at 100μ at 100,000 feet is $\sim$ 0.7 percent at the ambient temperature of -65°C. The instrumental emission within the aperture of the telescope is effectively 25 to 50 percent due to mirror emissivity, dewar window emissivity, warm baffles, and diffracted rays reaching the side walls of the telescope tube. At least an order of magnitude improvement in sensitivity can be obtained if the effective telescope emissivity is reduced to a value comparable to or less than the atmospheric emissivity. This can best be obtained by the use of a cryogenically cooled telescope where the emissivity of the mirrors, telescope tube walls, and baffles is reduced by the lower temperature.

One of the principal designers of the gondola (William Hoffmann) is now at the University of Arizona, as is the gondola. The other designer (Carl Frederick) is now at Cornell. The current effort is a collaboration of two groups: William Hoffmann, Murray Campbell and Paul Harvey in Arizona, and Carl Frederick, Martin Harwit, and Mike Jacobson at Cornell. The paper describes principally the Cornell section of the collaboration, i.e. the design and construction of a 16", liquid helium cooled, Cassegrainian telescope for the gondola.

The telescope is outlined in **Figure 3.** It may be described as three distinct units: 1) the dewar, 2) the telescope, 3) the baffle and membrane. In addition, there are two more units not shown in the diagram: 4) the collar and lid, and 5) the external frame and balance mechanism.

We shall briefly describe each unit.

1) The dewar:

The dewar **(Figure 4)** is an 18" aperture, 48" deep, and 52" over all length aluminum and fiberglass double can, made for us by Cryogenic Associates. Within the dewar walls are radiation shields and superinsulation. It is not liquid nitrogen jacketed. There are mounting flanges welded to the inside of the dewar. The only access to the inside of the dewar is through the 18" aperture, i.e. there are no feed throughs or other holes through the dewar. Two aluminum rings are welded to the outside wall of the dewar for mounting to the external frame.

2) The telescope:

The telescope is a 16" diameter Cassegrainian system. The primary is f1.7 and the overall system is f5. The primary and secondary are made of aluminum coated with electroless nickel. The surfaces are polished to within 2 wavelengths (5461Å) to a spherical configuration, and are overcoated with aluminum and silicon monoxide. The circle of confusion is less than 2.4'. The on axis spot size is about 1.3mm. The mirrors were fabricated for us by Muffoletto Optical Company.

Behind the primary mirror is the detector block, which accomodates 4 detector units. The units are interchangeable. Each unit contains a detector and its associated post optics and filters. There are two types of detectors useable in our system: photoconductors and bolometers. The post optics for the photoconductors consists of an off axis segment of a parabola which effectively results in a virtual detector diameter of .34".

The bolometer post optics is a spherical cavity at the focus of which the bolometer is suspended. The four units will be filtered so that 4 overlapping regions in the range anywhere from 10 to 300 microns may be observed. The field of view of each detector is about 1/5°.

In the center of the detector array, there is a fiber optics bundle leading out of the detector block, up the inside wall of the dewar and out. An eyepiece is put on the end so that the telescope may be aligned with the gondola. After alignment, the eyepiece is replaced with a detector for the visual region of the spectrum. Signals from this detector will be the principal method of determination of the positions of the infrared sources with respect to the visual stars.

A 4 arm spider connects the mounting disc to the secondary mirror/chopper assembly. The design of the chopper was motivated by the necessity of minimizing vibration and heat loading in the cool telescope environment.

The chopper is a coil-driven resonant system. The chopping is thus sinusoidal rather than square wave. The calculated chopper efficiency is greater than 80 percent of that of a perfect square wave system. However, the high Q of the resonant system allows the system to run with very little power (less than one tenth watt). To minimize vibration, the drive coils are mounted to a movable plate so that when the secondary mirror rotates in one direction, the coil plate moves in the other, so that to first order, the angular momentum of the system is zero. The chopper resonates at about 16Hz. A sensing coil, magnet combination provides the chopper reference for synchronous detection.

Underneath the telescope proper is mounted the helium can. It is shaped roughly like a bunt cake pan. It is so shaped so that it entirely surrounds the detector block. The can is filled with steel wool to keep the 25 liters of liquid helium from sloshing about. The expected hold time aloft is of the order of a day.

All elements of the telescope, i.e. the primary mirror, the Cassegrain baffle, the spider, the detector block, and the helium can are mounted to an aluminum disc which is itself mounted at its periphery to the dewar.

3) The baffle:

Within the dewar is a thin wall stainless steel baffle with a polyethylene membrane accross it some 10 inches from the front end. The baffle O.D. is 1/4" less than the dewar I.D. The helium gas which is forced up the sides of the dewar efficiently cools the dewar. Above the level of the membrane, vents in the baffle channel the escaping gas over the front surface of the membrane to prevent water vapour frosting. There is a little hole in the membrane above the chopper in order that some of the gas will escape around the chopper, thus providing additional cooling for it. The baffle also contains knife edge rings to prevent grazing light rays from reaching the primary.

4) The collar and lid:

Above the front of the dewar, a 1 1/2" high collar has been mounted **(Figure 4)**. The collar contains the wiring feed through connectors, and it supports the lid mechanism (Figure 5).

The motor-driven lid is made of foam (presently styrofoam, soon to be replaced with thurane) interspaced with foil reflecting layers. A liquid nitrogen compartment will be added to the lid to increase the hold time on the ground. The nitrogen will be blown off before flight.

5) The frame and balance mechanism:

The dewar is mounted within an aluminum and stainless steel protective frame. The frame is bolted to the gondola. On top of the frame, a balancing mechanism is mounted. It is a way of moving a 10 pound weight up and down the telescope length. It is used to compensate for the weight loss during flight of the liquid helium. This compensation is required because the telescope is a scanning instrument which is very sensitive to weight imbalance.

Figure 5 shows the gondola during preliminary integration of the system at Arizona in January, 1974. The overall system has been modified so that the electronics side no longer co-rotates with the telescope.

The first two flights of the system are currently scheduled for June of 1974.

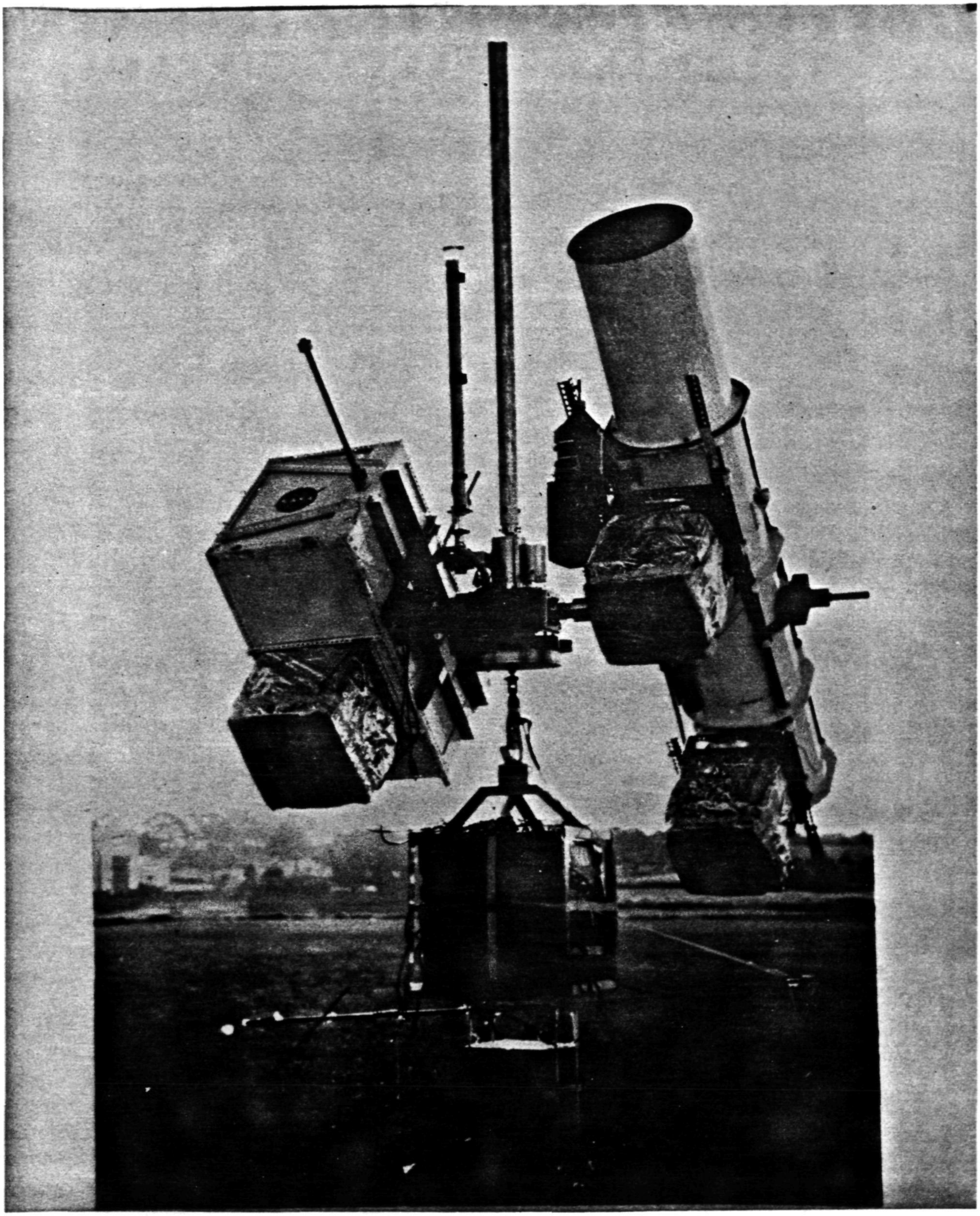

Figure 1.

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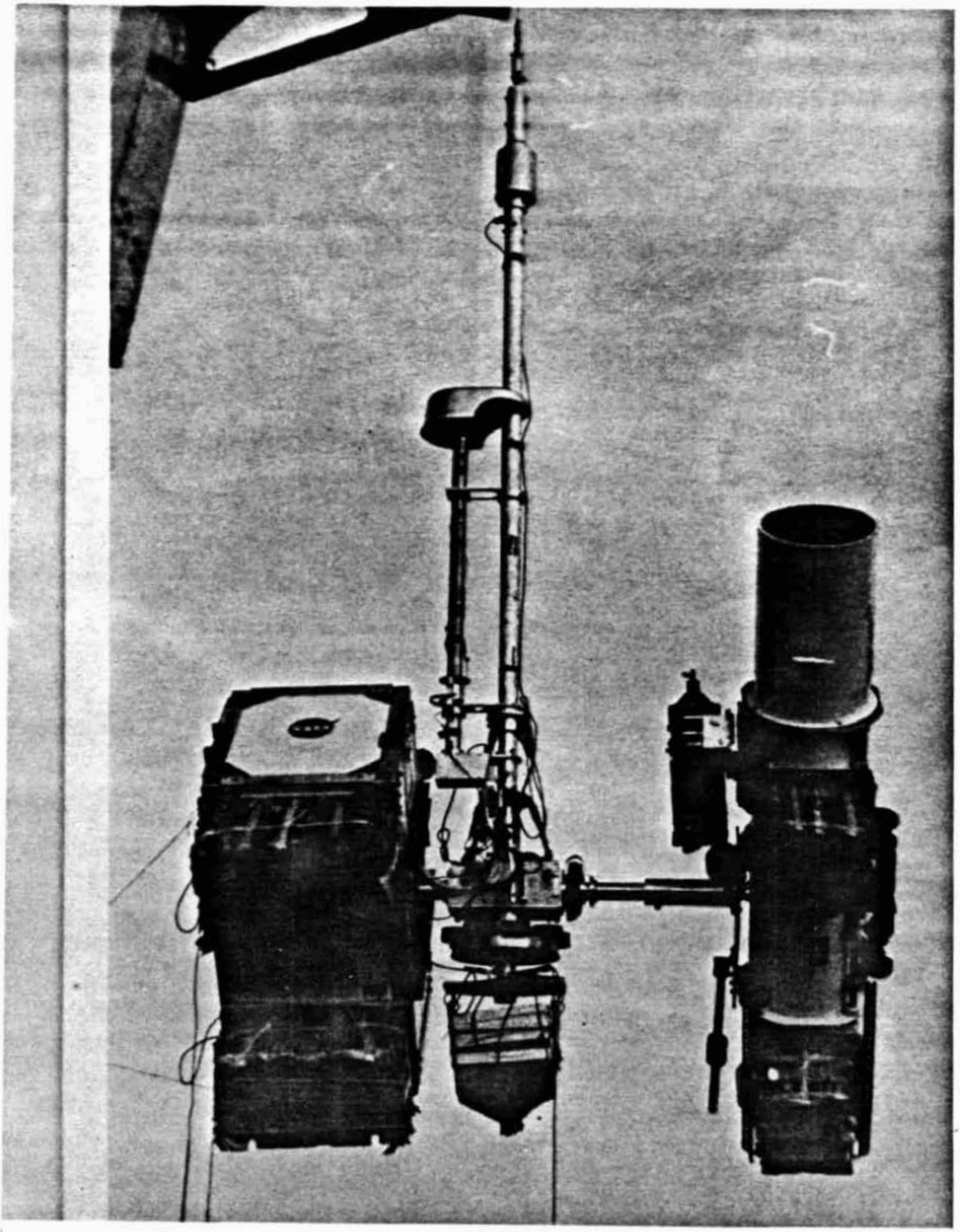

Figure 2.

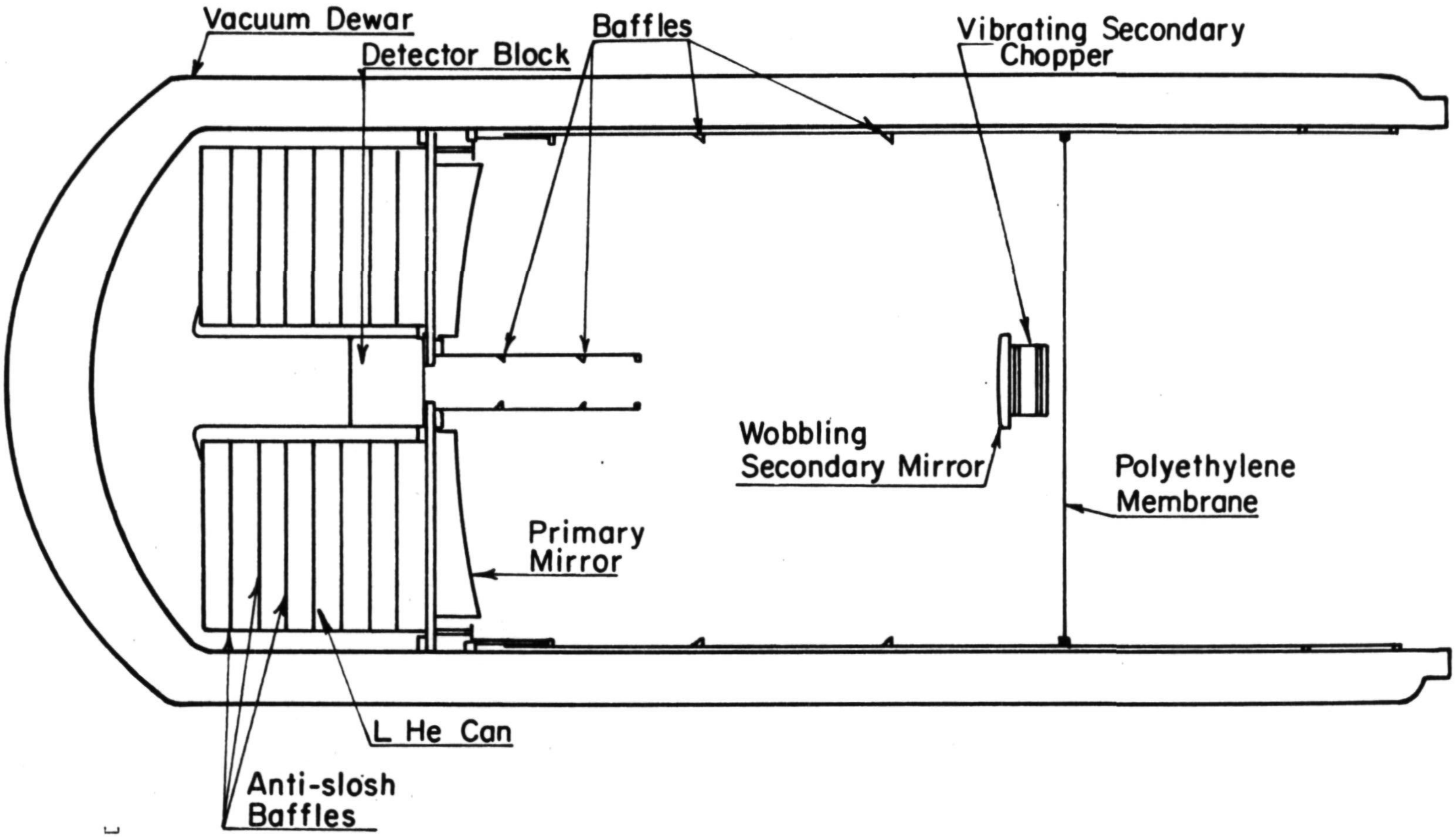
Vacuum Dewar
Detector Block
Baffles
Vibrating Secondary Chopper
Wobbling Secondary Mirror
Polyethylene Membrane
Primary Mirror
L He Can
Anti-slosh Baffles

Figure 3.

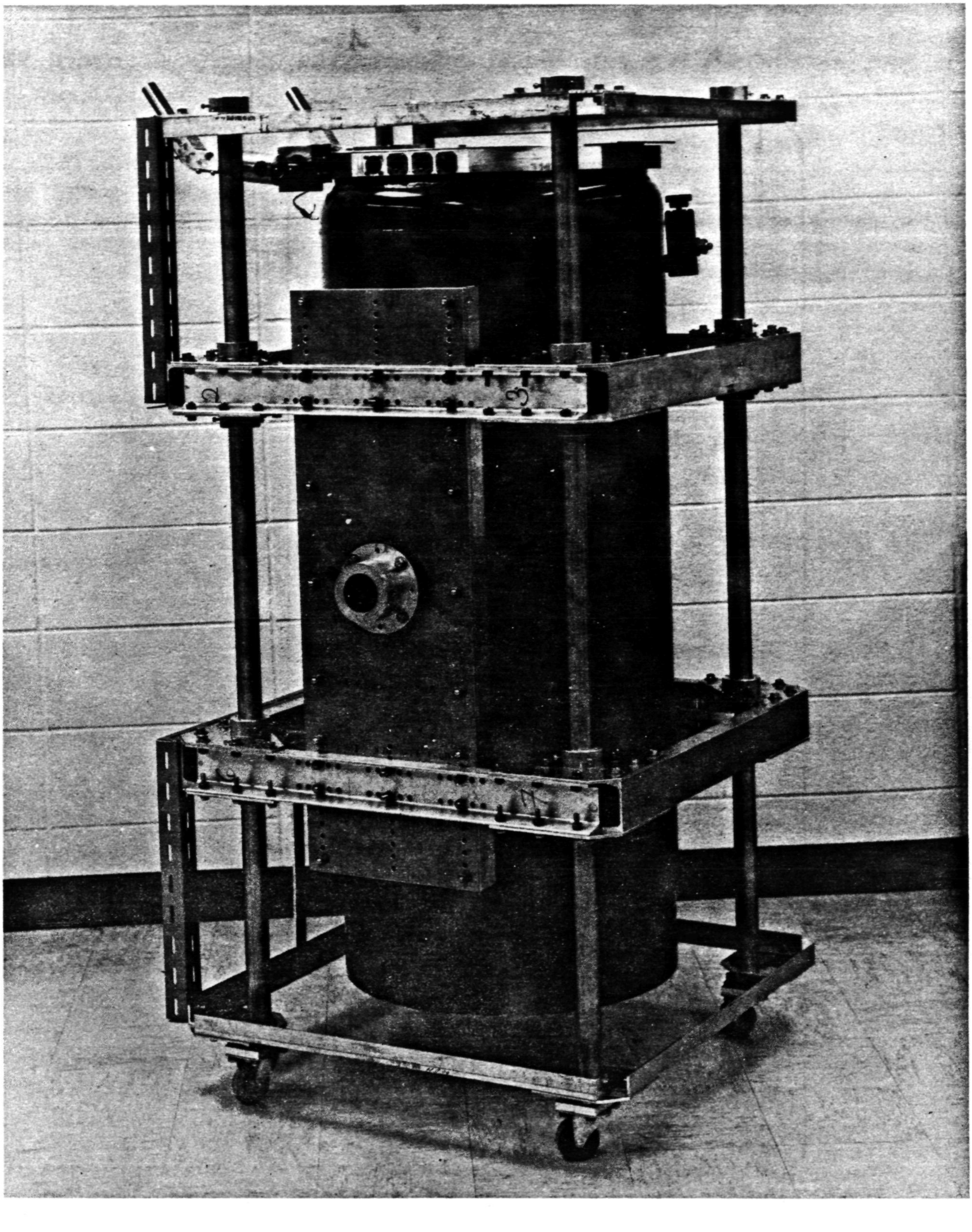

Figure 4.

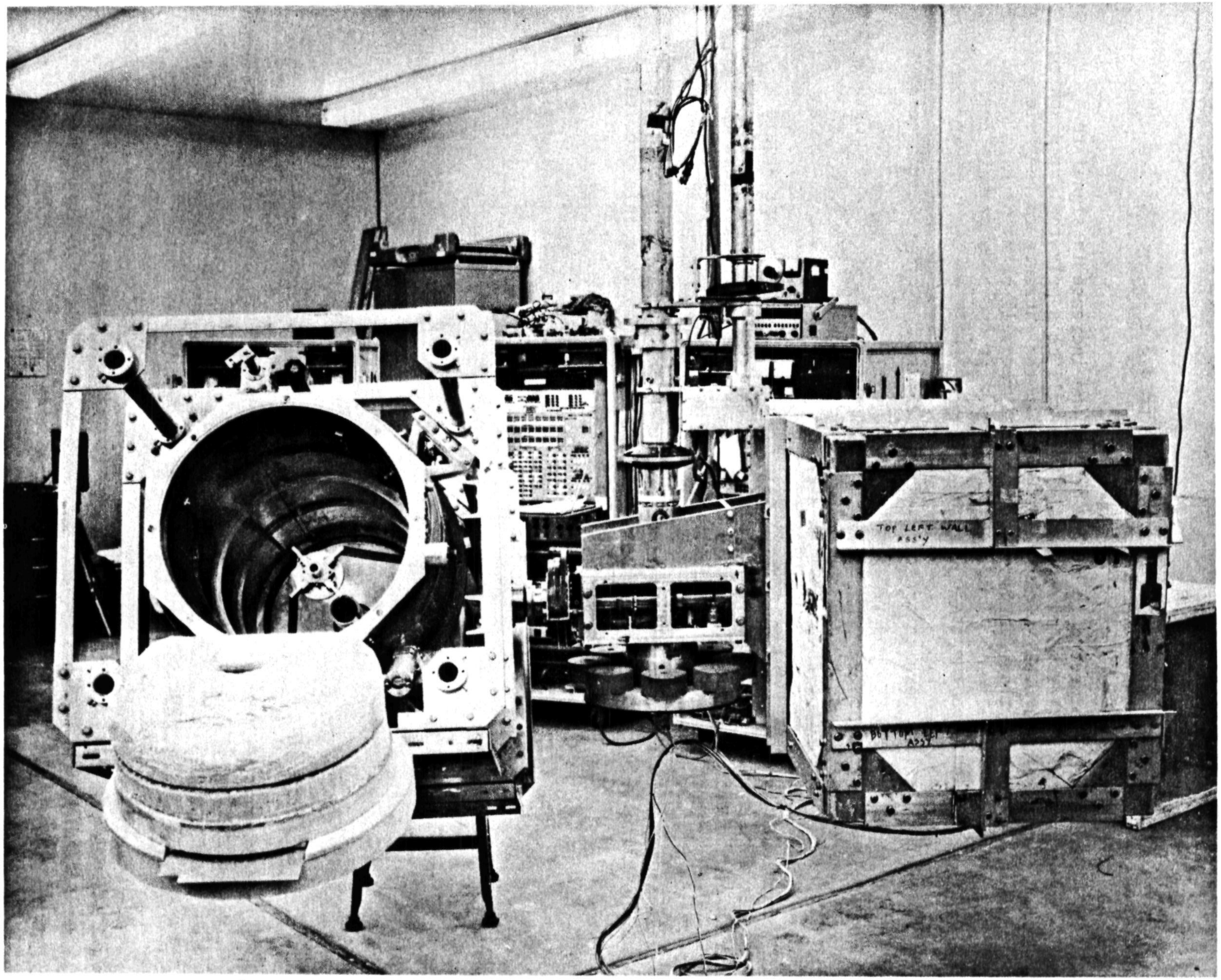

Figure 5.

DISCUSSION SUMMARY — PAPER 2.3

This telescope is expected to have a ten to one increase in signal-to-noise ratio over a similar warm version. There will be a polyethylene diaphram operated at a temperature below the dew point near the entrance to the telescope. It is expected that frosting of this diaphram will be no problem because it will have helium boil off gas blown over it and because this has not been a problem in another telescope of 12-inch diameter.

These expectations were contrasted with the experience of the North American Rockwell group.

The Cornell group expects that the ten inches of baffle height outside the membrane will protect the system from frosting.

Experience by F. Low and W. Potete, using a cryogenic telescope aboard a Lear jet were summarized. One outstanding problem was noise introduced by motion of the thin mylar diaphram used on the airborne telescope. This membrane was three to four microns thick.

It is hoped that the quieter balloon environment in conjunction with the membrane being very cold in the Cornell telescope will minimize this problem.