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No. 108 POLARIMETRY FROM HIGH-ALTITUDE BALLONS

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ABSTRACT

The ballooning is for an extension of the groundbased polarimetry of planetary atmospheres and interstellar matter to wavelengths shorter than 3000 Å. Some of the largest available balloons are used to carry telescopes to an altitude of 36 km, which is above a sufficient fraction of the terrestrial ozone to allow polarimetry with ±0.03% precision at 2850 and 2250 Å. The development of and operations with two gondolas are described, one gondola has two 7.5 cm telescopes and the other has a 71-cm telescope.

1. Introduction

A new discipline is being developed with precise polarimetry over the widest possible range of wavelengths; the observations are compared with the Rayleigh-Chandrasekhar theory of multiple molecular scattering and with the Mie theory of light scattering by small particles. From such a comparison it is possible in certain cases to derive the optical thickness of a planetary atmosphere and to determine the sizes and refractive indices of aerosols and interstellar grains.

Since 1959 we have made polarimetric observations of a variety of objects, ranging from minor planets to extragalactic nebulae (some results are shown by Gehrels and Teska 1963). Various telescopes were used at Indiana University, the McDonald Observatory, the Kitt Peak National Observatory, and recently the 154-cm telescope in the Santa Catalina Mountains near Tucson (Coyne and Gehrels 1967).

The Polariscopes programs now consist of balloon-borne as well as ground-based photometry and polarimetry in order to extend the wavelength range to 2850 and 2250 Angstroms. The possibility of using balloons above the ozone in the earth's atmo-

sphere has been discussed (Gehrels and Teska 1963; Gehrels 1967). The following sections describe the equipment and flights in the ballooning.

2. Instrumentation

At the start of this new program of photometry and polarimetry at 2250 and 2850 Angstroms, preparations were needed of new materials for analyzers, depolarizers, and filters (Pellicori, Johnson, and King 1966). The required precision in most polarimetry problems is about ±0.03% polarization (±0.0006 astronomical magnitudes), which we obtain with groundbased telescopes and during the balloon flights. Development was needed of special techniques and equipment such as a suitable magnetometer compass and a noise-free telemetry system (Brumbaugh, unpublished), the radio-frequency link (Frecker 1966), the stable platform (Frecker 1968), and optical testing instruments (Pellicori, Roland, and Teska 1965). We have adhered to a rigorous testing schedule, with crane suspension as high as 200 feet, and with many sessions in environmental chambers for individual packages and also for the completed gondola.

The design, construction, and testing is being

done entirely "in house," that is all the work is done by a crew at the University of Arizona. During the balloon flights it is invaluable to have the people that developed the equipment also in charge of the operations. Troubles that occurred during the nights of balloon operations were readily spotted and cured by the operators because of their intimate knowledge of the components, assembly, and performance during the tests. The "in house" principle is to be compared with that of primarily having contracted equipment and services.

There are three distinct polarimetric systems in the Polariscope programs. The first of these is the groundbased equipment (shown in Fig. 1 of Communications No. 106, Coyne and Gehrels 1967). The second is a prototype polarimeter being developed for use on space probes to Mars and Venus (Pellicori and Gray 1967). The third is the polarimeter designed for use with the 71-cm balloon telescope.

Figure 1 shows the optical diagram of the space prototype polarimeter. The Cassegrain telescope of 7.5 cm in aperture is followed by a depolarizer that can alternately be inserted in and removed from the beam, followed by a filter wheel. The light is next split by a Wollaston prism into two beams with orthogonal vibrations. Each of the beams brings the 7.5-cm primary mirror into focus on the face of a photomultiplier tube. The tubes are EMI 9256B, made partially 'solar-blind' with 3mm NiSO<sub>4</sub>·6H<sub>2</sub>O. The outputs of the phototubes are integrated, processed digitally and sent by a radio-frequency telemetry link to a ground station, which belongs to the National Center for Atmospheric Research. The polarimeter consists of two such optical trains fixed at right angles to one another about the optical axis. Thus a pair of observations — one with the depolarizer in the beam and one with it out — offers a simultaneous

solution for the amount and position angle of polarization. With this arrangement, brightness, color, and polarization measurements can be made quickly during a planetary fly-by.

Figure 2 shows this polarimeter mounted on its balloon gondola. In addition to the polarimeter the yoke is seen that allows motion in elevation and in azimuth. At the bottom left is the battery pack; the ballast hopper is under the polarimeter, and the telemetry/command package is at the bottom right.

In Fig. 3 is seen the optical diagram of the 71-cm balloon telescope. On the outside is a finding telescope with a vidicon television system and also a star tracker for pointing the ensemble on the object chosen for observation. At the focus of the star tracker is a beam splitter that consists of a sharp pyramid with four polished sides. Four 1P28 photomultipliers sense the balance of the light on the four pyramid sides and they send correction signals to the gyros.

The main telescope has a diameter of 71 cm, it has an  $f/2$  primary mirror of fused silica. The centering of the image can be checked with another vidicon, and after that check the viewing mirror is removed. The light then goes through a Lyot depolarizer, a filter wheel, a focal-plane diaphragm, a Wollaston prism, and the field mirrors form an image of the primary mirror on the Ascop 541F photomultiplier cathodes. The Wollaston prism and phototubes rotate, and measurements are made at 30° increments of the Wollaston angle.

Figure 4 shows the Polariscope telescope mounted in the gondola. Its major components are the 71-cm telescope, the polarimeter, two television cameras for star acquisition, a radio command receiver, two magnetometer compasses, a television and telemetry transmitter, three-axis servo-stabiliza-

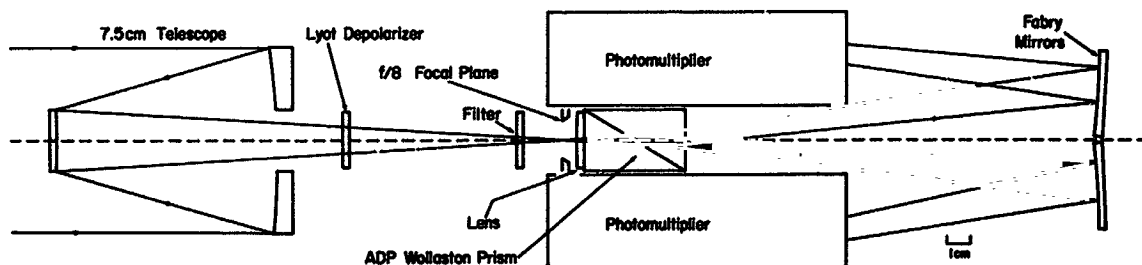


Fig. 1 Optical diagram of space-prototype polarimeter.

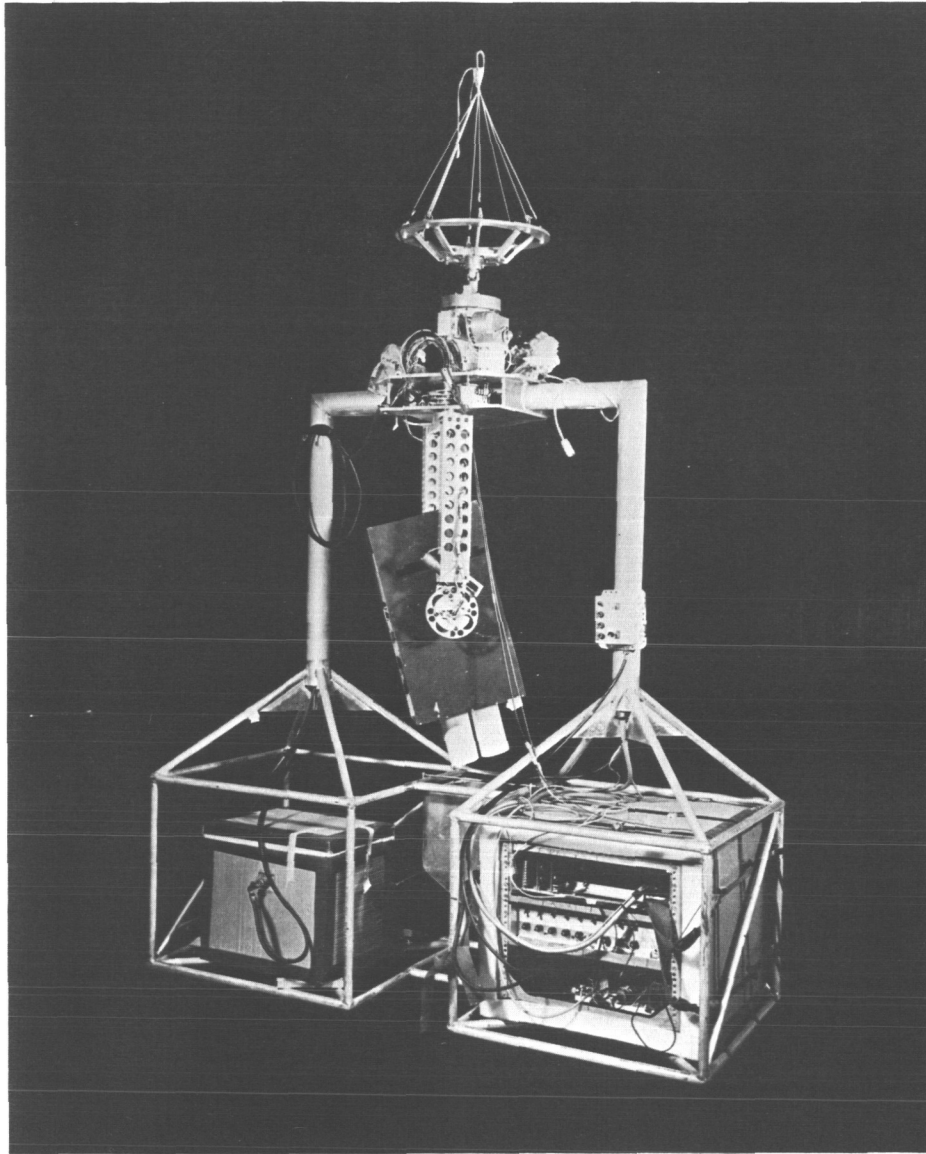


Fig. 2 Space-prototype polarimeter mounted in its balloon gondola.

tion system, and a light-weight gondola of thin aluminum tubing to contain all of these. Power is supplied by 60 kg of silverzinc batteries in order to provide  $\pm 12$  volts and 28 volts for 15 hrs. operating time. There are two ground stations (Fig. 5) to control the gondola/telescope system and to receive and record the telemetry data; one ground station is at the launch site and the other is placed in a van up to 900 km downwind.

The television system is slow scan: 500 lines, one frame per second. Vidicons were selected rather than image orthicons because of their smaller size,

lower operating voltage, and their simplicity of in-flight adjustments. The outboard television has two lenses on a turret giving a  $14^\circ$  and a  $4^\circ$  field. The second television looks through the 71-cm telescope and has a field of 13 minutes of arc.

The gondola, complete with 181 kg ballast but not including the parachute, weighs 730 kg. The telescope weighs 125 kg and it is stabilized to  $\pm 6$  seconds of arc in elevation and cross-elevation.

### 3. Observations

The 71-cm telescope has flown 3 times success-

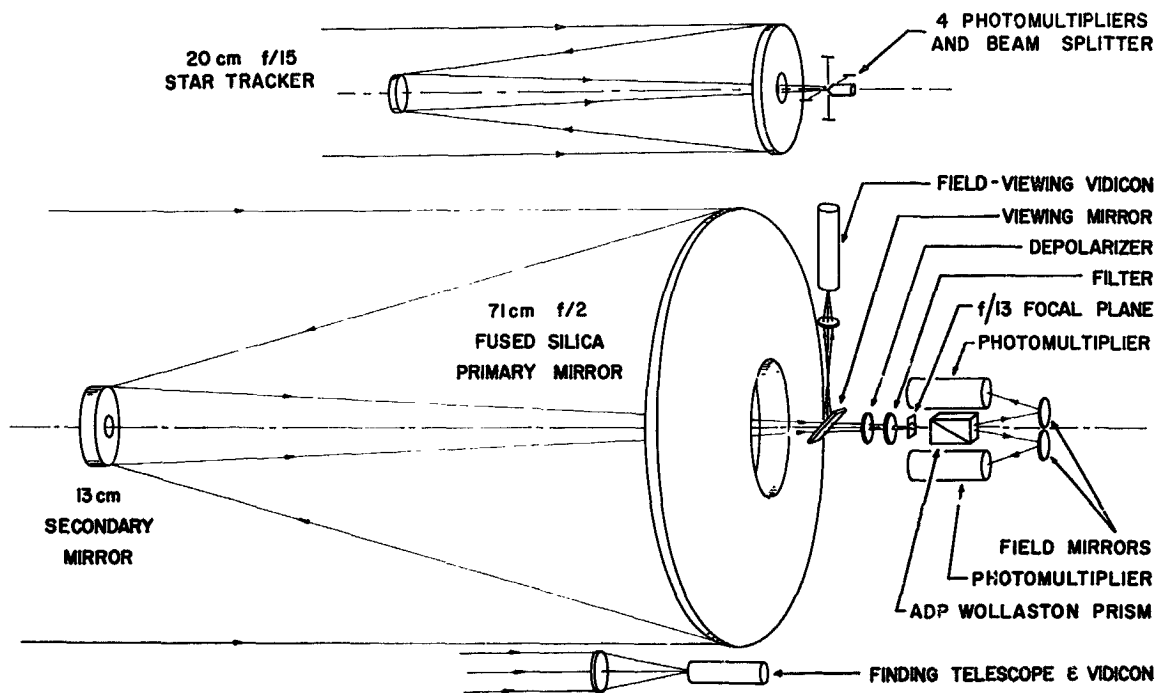


Fig. 3 Optical diagram of 71-cm balloon telescope.

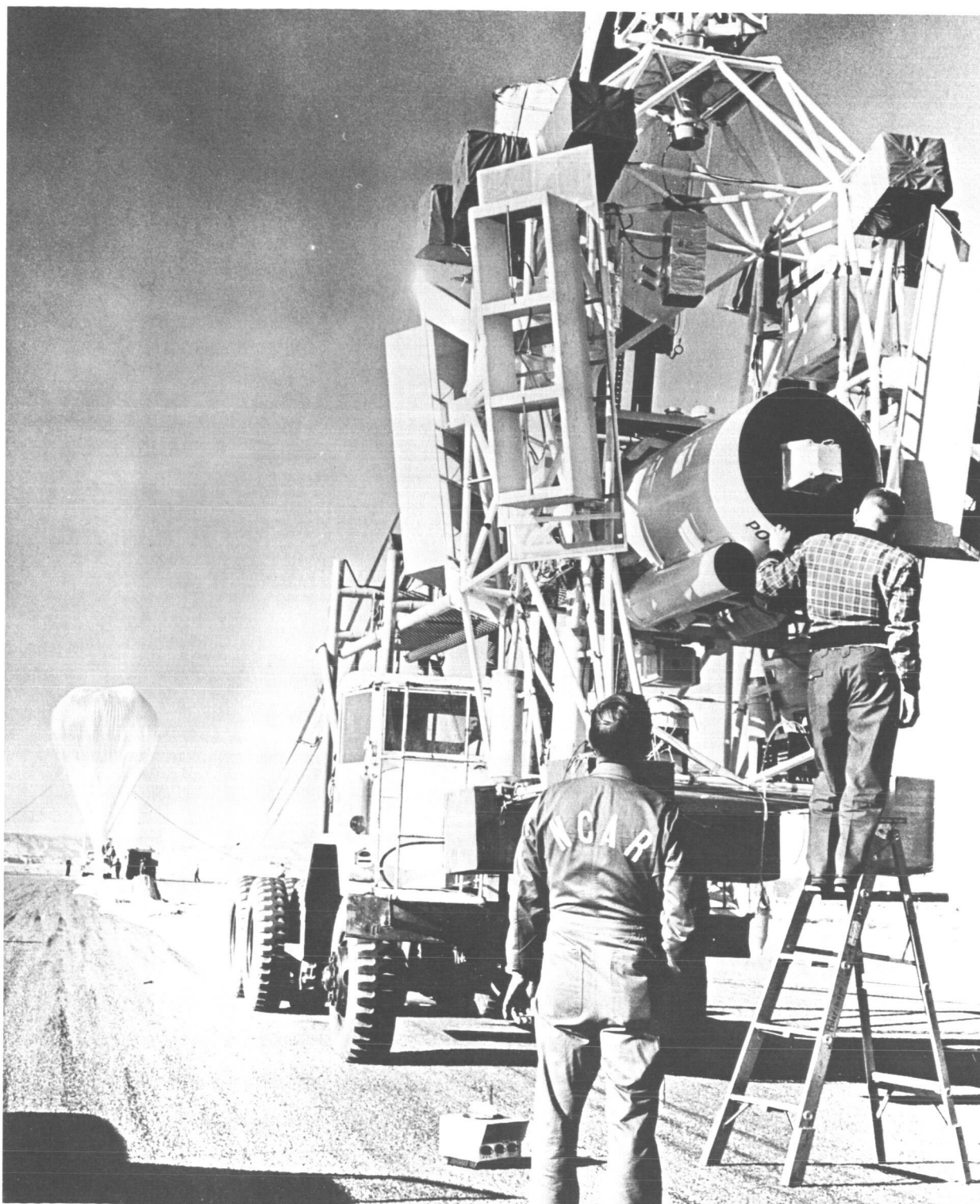
fully, launched from Palestine, Texas, in May, 1966, and from Page, Arizona, in March, 1967, and in January, 1968. The launch, tracking and recovery is done by the National Center for Atmospheric Research. The balloon is made of polyethylene, 0.9 mil thick and  $3 \times 10^5 \text{ m}^3$  in volume. The smaller system has flown 3 times for engineering tests at 36 km altitude with successful operation of the polarimeter but without azimuth stabilization.

We expect to fly the Polariscope 71-cm telescope once or twice per year. So far we have obtained new results on the interstellar polarization with measurements at 2250 and 2850 Angstroms on Zeta Ophiuchi, Kappa Cassiopeia and Gamma Orionis. Such measurements are made on stars in various directions in the galactic plane in order to determine the size and composition of particles in various interstellar clouds. The position angles of the interstellar polarization also are important as indicators of the direction of the galactic magnetic fields. With groundbased telescopes we found a peculiar dependence of the position angle upon wavelength. The effect is as yet unexplained but it is undoubtedly connected with spiral structure and galactic magnetic fields, and it is important to observe the effect over the widest possible range of wavelengths.

During the March 1967 flight, precise measurements were obtained of the polarization of Mars at 2250 and 2850 Angstroms. A preliminary study of the results gives the surface pressure on Mars at 10 mbars. A surface pressure as low as 10 mbars had been found spectroscopically, and also in an occultation experiment, while polarimetric measures made by Dollfus have indicated a much higher pressure. With the wide range of wavelengths, made possible by the ballooning, the polarimetric result appears to be no longer anomalous. And the polarimetric determination is important because the technique and the detection capability differ from those in spectroscopy. We are making a detailed study of the brightness and polarization over the full range of wavelengths of observation (0.2 – 2.6 microns), with an analysis of the aerosols as well as of the molecular component of the Martian atmosphere.

During the balloon flights with both systems, preliminary, but essential, measurements were made of the sky brightness at 2250 and 2850 Angstroms, as well as reconnaissances for future work on Venus, Jupiter, the Moon and various types of stars.

The small polarimeter has also been useful on the ground for observations of the whole Moon; because of its short focal length, the whole lunar



*Fig. 4* Balloon telescope mounted in its gondola and suspended from a launch truck of the National Center for Atmospheric Research (NCAR) at Page, Arizona, March 1967.



Fig. 5 A Polariscope Ground Station. The oscilloscope serves as a television screen, below which are the toggle switches for the command system, and under that is a binary clock-timer. The middle panel has quick-look indicators and recorders, and the panel on the right has special command switches operated by a separate observer. At the top, a papertape punch is shown; a magnetic tape recorder is also used.

image is accepted within the focal-plane diaphragm (Coyne and Pellicori 1968).

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