A Far Infrared Sky Survey

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A far infrared sky survey

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[Plate 11]

A balloon-borne instrument for making far infrared sky surveys with 2° angular resolution is described. In two initial flights at a wavelength of 320 μm approximately half of the celestial sphere including most of the northern milky way was surveyed. The thermal emission of the moon was alone detected. The upper limit to the flux from other sources was 3×10^{-12} W cm^{-2} in the 300 to 360 μm band, or approximately 2×10^{-23} W cm^{-2} Hz^{-1}. A blackbody (optically thick) source 2° or greater in diameter yielding this flux would have a temperature of 10 °K. A warmer, small or optically thin source providing this much radiation in the Rayleigh–Jeans tail of the Plank distribution would have a temperature averaged over the 2° beam of 0·6 °K. These observations can be used to set upper limits to the opacity and temperature of interstellar grains.

1. Introduction

This paper describes the first two balloon flights of a series† intended to search the sky for extended emission regions and bright point sources in the far infrared (25 μm to 1 mm). This region cannot be studied from sea level because of strong water-vapour absorption. Farmer & Key (1965), studying the solar spectrum from a 17 000 ft. mountain top, found no trace of solar emission between 40 and 300 μm, while the narrow peak found at 350 μm corresponded to about 5 % transmission.

This spectral region of five octaves is almost entirely unexplored, yet it is of interest for a variety of reasons. The unknown emission process giving rise to the continuum of the brightest quasar, 3 C 273 appears to peak here (Low & Johnson 1965); in fact, most of the energy from 3 C 273 seems to be radiated in the infrared. At slightly shorter wavelengths, other processes appear to give variable emission from regions surrounding red giant stars (Low 1965). It has been predicted (Stein 1966) that the thermal radiation of interstellar grains may be observable in this region and probably cannot be observed outside it.

Already existing measurements can be used to provide an upper limit for the flux from

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† Further flights have observed the Sun and Moon at 100 μm and also detected radiation from the region of the galactic centre.

possible objects radiating in this spectral region. Upper limits on the cosmic background flux at 340 and 560 μm have been derived by Thaddeus (1967) from a study of interstellar molecular lines. These limits are 2.5×10^{-20} and 2.5×10^{-21} W cm^{-2} Hz^{-1} sr^{-1}. Similar, perhaps slightly tighter but less convincing limits on the energy density in the galaxy at infrared wavelengths might be derived from the cut-off in the cosmic ray electron spectrum. Since these limits are not very restrictive for the possible existence of localized bright sources in the far infrared, a balloon-borne telescope and radiometer was designed and built to search for such objects.

It was not known *a priori* how far fluctuating atmospheric emission might hinder observations from the stratosphere. Therefore, initial observations were planned for a wavelength of 350 μm where there is a minimum in the water-vapour opacity. Angular resolution was chosen to be 2° to give reasonable sensitivity both for extended objects like the Milky Way and Zodiacal light and for small angular diameter sources.

2. EQUIPMENT

The balloon gondola is constructed of aluminium slotted angle as shown in figure 1, plate 11. The helium dewar vessel, preamplifier, modulation mirror and calibrator are mounted on the front. A compartment insulated with 3 in. thick styrofoam covered with aluminium foil contains the electronics, recorder and batteries. The dimensions of the gondola are 22 in. × 29 in. × 36 in. high. The weight not including the radio tracking beacon and balloon equipment is 115 lb.

The radiometer is a liquid helium-cooled germanium bolometer (Low 1961) with an rms noise equivalent power of 7×10^{-14} W s$^{-\frac{1}{2}}$ at a temperature of 1·8 °K. A liquid helium-cooled bolometer works very satisfactorily in a balloon experiment. The ascent reduces the temperature of the liquid by evaporation at a rate similar to that employed in the laboratory. The helium passes the λ-point transition near 70000 ft. At altitude the pressure varies sufficiently slowly that no additional source of detector noise due to bath temperature variation arises. The cap of the dewar is provided with a safety valve and a long inner neck so that if the main neck of the dewar becomes plugged with frozen air during decent, there will be no explosion. On the two flights to date, however, the landing shock proved too great for the stainless steel dewar neck, and it snapped. The bolometer element was not damaged. There has been no problem encountered with the shock of a dynamic balloon launch. The dewar capacity is 1 l. of liquid helium. It is filled 70 min before launch and helium was still present at the termination of a flight 15½ h later.

The detector amplifier is a modified Texas Instruments RA-3 parametric amplifier, immediately adjacent to the detector, enclosed in 1½ in. thick urethane foam with a 5 W heating element to maintain the temperature. This enclosure also contains no. 523 Eveready alkaline dry batteries for powering the amplifier and providing a bolometer bias current. All leads from this enclosure are provided with r.f. filters to avoid interference from the balloon radio beacon.

The detector is at the focus of a 1 in. aperture $f/1.2$ crystal quartz lens that is inside the dewar. The filters are fused quartz, black polyethelene, no. 80 wire mesh used in transmission (Mitsuishi *et al.* 1963) and thallium bromide at liquid helium temperature (Hadni

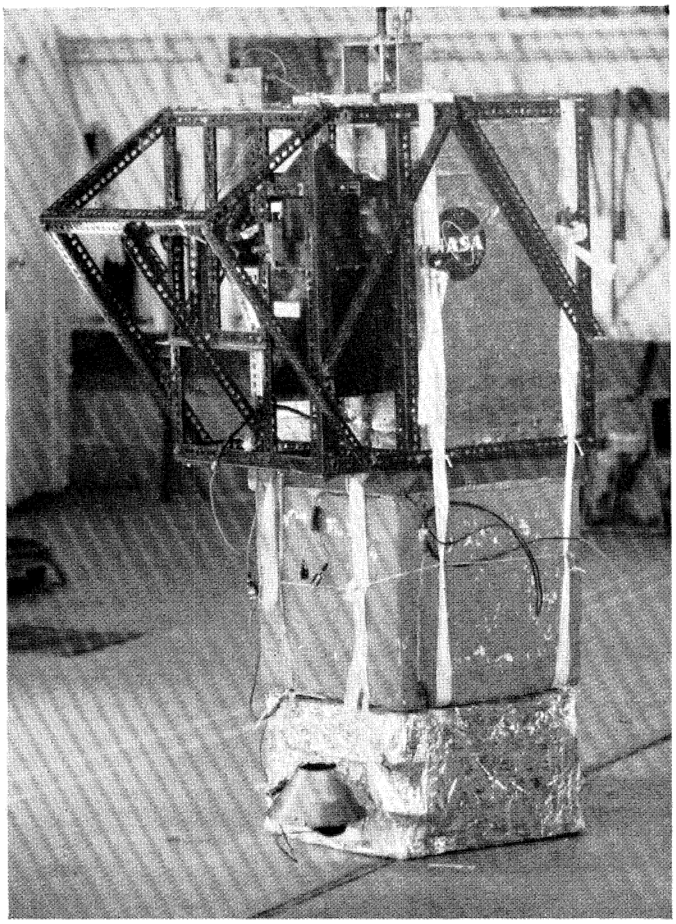

FIGURE 1. The balloon Gondola with radio beacon and crash pad attached.

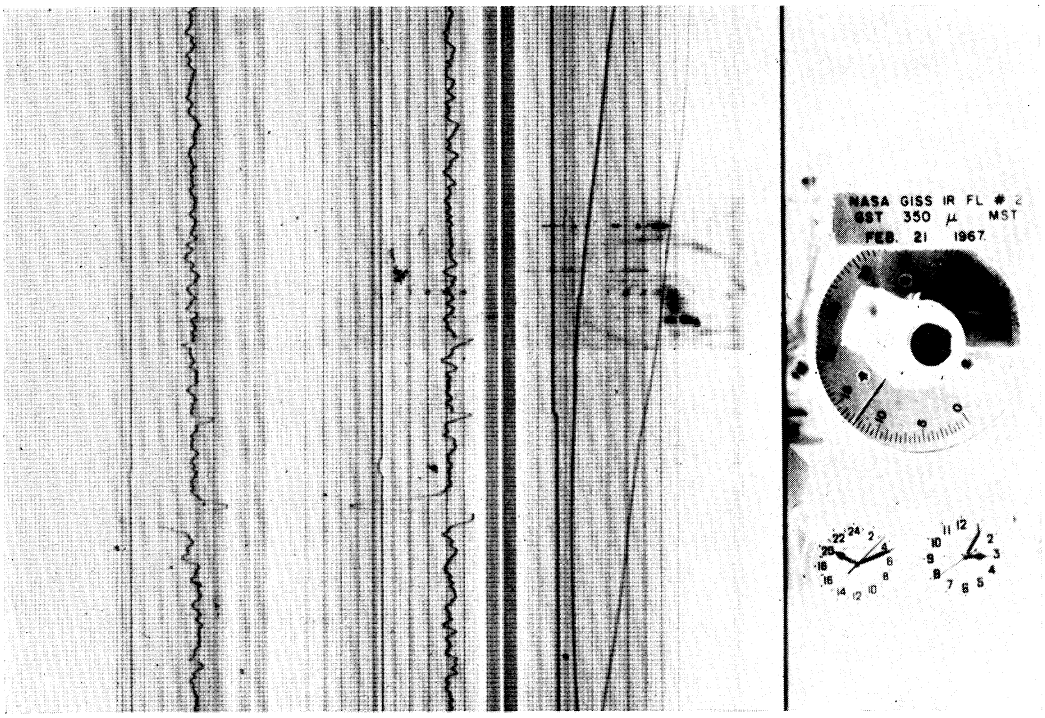

FIGURE 3. An on-board record of the observations of the Moon at a wavelength of 320 μm. The traces are: channel 1 (farthest to left) detector output phase 1; channel 2 (centre) detector output phase 2; channel 3 (right) the magnetometer outputs and an engineering data record. On the far right are a barometer and two clocks.

et al. 1965). The spectral response of the system was checked with a laboratory thermal source and a variety of dielectric and wire mesh filters.

The response to the thermal source appears to be entirely in the band from 300 to 450 μm, with a peak at 320 μm. The high transmission found when the source was observed through additional mesh filters (69 % with no. 100; 47 % with no. 80) shows that the energy was mainly concentrated between 300 μm, the short wavelength cut-off of thallium bromide and 360 μm, the wavelength where the mesh filters have equal transmission. This band is distinctly narrower than predicted from published data on the behaviour of filter materials.

Modulation of the incident beam is accomplished by an aluminium mirror, outside the dewar, rotating at 8 Hz. The mirror normal is set $\frac{1}{2}$° off from the axis of the motor so that its motion causes a wobble of the telescope beam around a circle of 2° diameter. Two optical pickups at the mirror give signals for phase-sensitive detection in two phases separated by 90°. This system then determines flux gradients in the sky in two directions at right angles. The beam mirror reflexion is so arranged that the radiometer looks up at the sky 60° from the Zenith. Once every 20 min a thermal calibrator giving a crude calibration corresponding to about 35 °K is inserted in the beam.

The package is rotated in azimuth with respect to the balloon at $\frac{1}{8}$ rev/min. Combined with the Earth's diurnal motion this sweeps a large part of the celestial sphere during one 12 h flight. The magnetic azimuth of the balloon is read by flux gate magnetometers.

The observational and engineering data are stored by an on-board photographic recorder. The method allows low weight and power consumption combined with the ability to store a large amount of analog data. The 35 mm camera employs continuously moving film with the rate adjustable between 0·5 and 1·5 in./min. It holds 150 ft. of Estar-based Kodak RAR 2496 film. The lens is a 25 mm *f*/3·5 lens normally used at *f*/5·6.

The data panel contains ten edgewise meters, $\frac{1}{2}$ in. thick with 2·3 in. scale length. Pointer tips and scale markings are white on a matt black background. Also there are a 0–50 mm aneroid barometer, and two clocks giving Greenwich Sidereal Time and Mountain Standard Time. Channel 1 contains three centre zero meters presenting signal phase 1 at relative sensitivities of 1, 20 and 400. Channel 2 presents the same data for phase 2. Channel 3, with four meters, displays the output of three orthogonally placed magnetometers, and a sampled output which is switched each 90 s to successively sample 12 intrumental voltages and temperatures. The edgwise meters are continuously illuminated, while the barometer and clocks are flashed by discharging a capacitor through two incandescent bulbs (Edgerton & Andrus 1960).

Power for motors, relays, parametric amplifier heater and lights is provided by a 36 V alkaline battery consisting of 24 'G' cells in series, delivering 0·5 A at a regulated 22 V. The electronics are largely built up from commercial operational amplifiers. They are powered by two 15 V alkaline batteries consisting of 'D' cells, delivering 0·065 and 0·12 A respectively. The power dissipated in the insulated packages maintained the temperature above 0 °C, while the outside ambient temperature was −55 °C.

3. Results

Two flights have been made for the 350 μm survey, both of them conducted by the National Center for Atmospheric Research. In the first flight from Palestine, Texas, on 2 November 1966 sensitivity was severely reduced by interference with the balloon radio beacon that developed aloft. The second flight made from Page, Arizona on 21 February 1967 was fully satisfactory. The balloon reached an altitude of 98000 ft. at 17.25 MST, and slowly descended to 89000 ft. during the night. The package was parachuted to Earth at 07.45 the following morning landing near Kingman, Arizona. The area of sky surveyed is shown in figure 2. It covers over 50 % of the celestial sphere and most of the northern milky way.

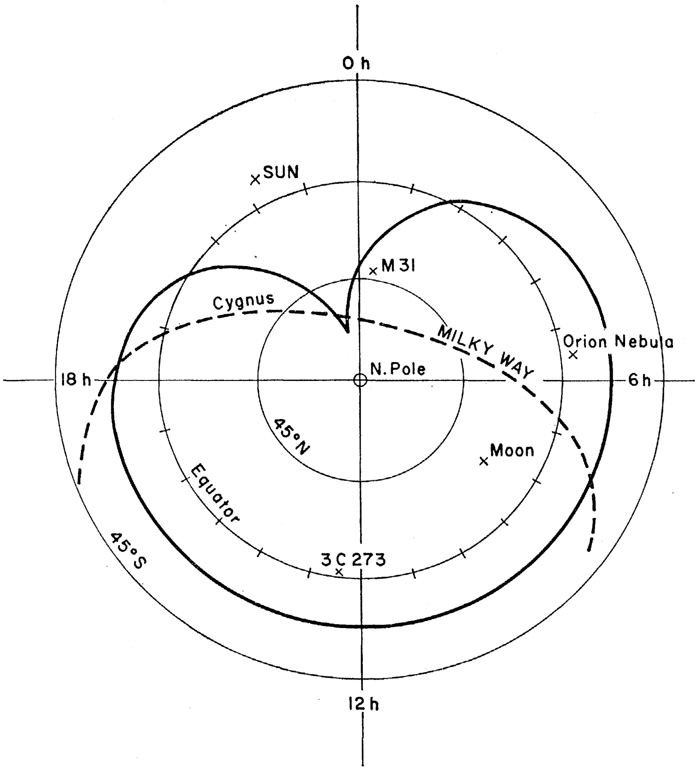

Figure 2. The region of sky surveyed in the flight of 21 February 1967. The position of interesting features are indicated. The Moon alone was detected.

During the flight the thermal radiation of the Moon, which was almost at full phase, was detected. The observed flux and angular resolution of the instrument are compatible with the expected effective temperature of 300 °K of the moon at this wavelength and phase. This observation of the moon is believed to be the first in this wavelength band. The flight record corresponding to one of three observed lunar transits is shown in figure 3, plate 11. Since the Moon only fills $\frac{1}{16}$ of the telescope beam, the signal corresponds to about a 20 °K grey body 'antenna' temperature. The rms noise is about 0·6 °K for a 1 s integration time.

No source was detected other than the Moon. This result places an upper limit on the flux from the interstellar grains and other sources. The record corresponding to the directions of the brightest stars of various types, radio sources of different kinds, and of the lane of dark interstellar matter in Cygnus, the Andromeda galaxy M 31, and the Orion Nebula were all examined. The maximum possible flux in a 10^{-3} sr solid angle in the 300 to 360 μm band is 3×10^{-12} W cm^{-2}. This corresponds to an average of approximately 2×10^{-23} W cm^{-2} Hz^{-1}. A blackbody (optically thick) source 2° or greater in diameter yielding this flux would have a temperature of 10·0 °K. For a warmer small or optically thin source providing this much radiation flux in the Rayleigh–Jeans tail of the Plank distribution, the apparent temperature averaged over the 2° beam width would be 0·6 °K.

It should be noted that the galactic centre, the Sun, the inner zodiacal light and most of the planets were not observed in these first flights. However, no observational problems appeared after sunrise, and thus all of these observations seem possible. Indeed it was encouraging that no effects attributable to variable atmospheric emission could be seen at any time during flight. Further flights will be made at shorter wavelengths, and with increased sensitivity through reduced sky coverage.

The radiometer was constructed by one of us (F. J. L.), while the other three constructed the remaining equipment, flew it and analysed the data.

We are indebted to the staff at N.C.A.R. who flew the balloons, to Dr G. Clark who gave much useful advice on balloon-borne instrumentation and to Dr R. Jastrow, Director of the Goddard Institute for Space Studies, for his encouragement of the venture. These studies were in part supported by a N.A.S.A. grant to Columbia University.

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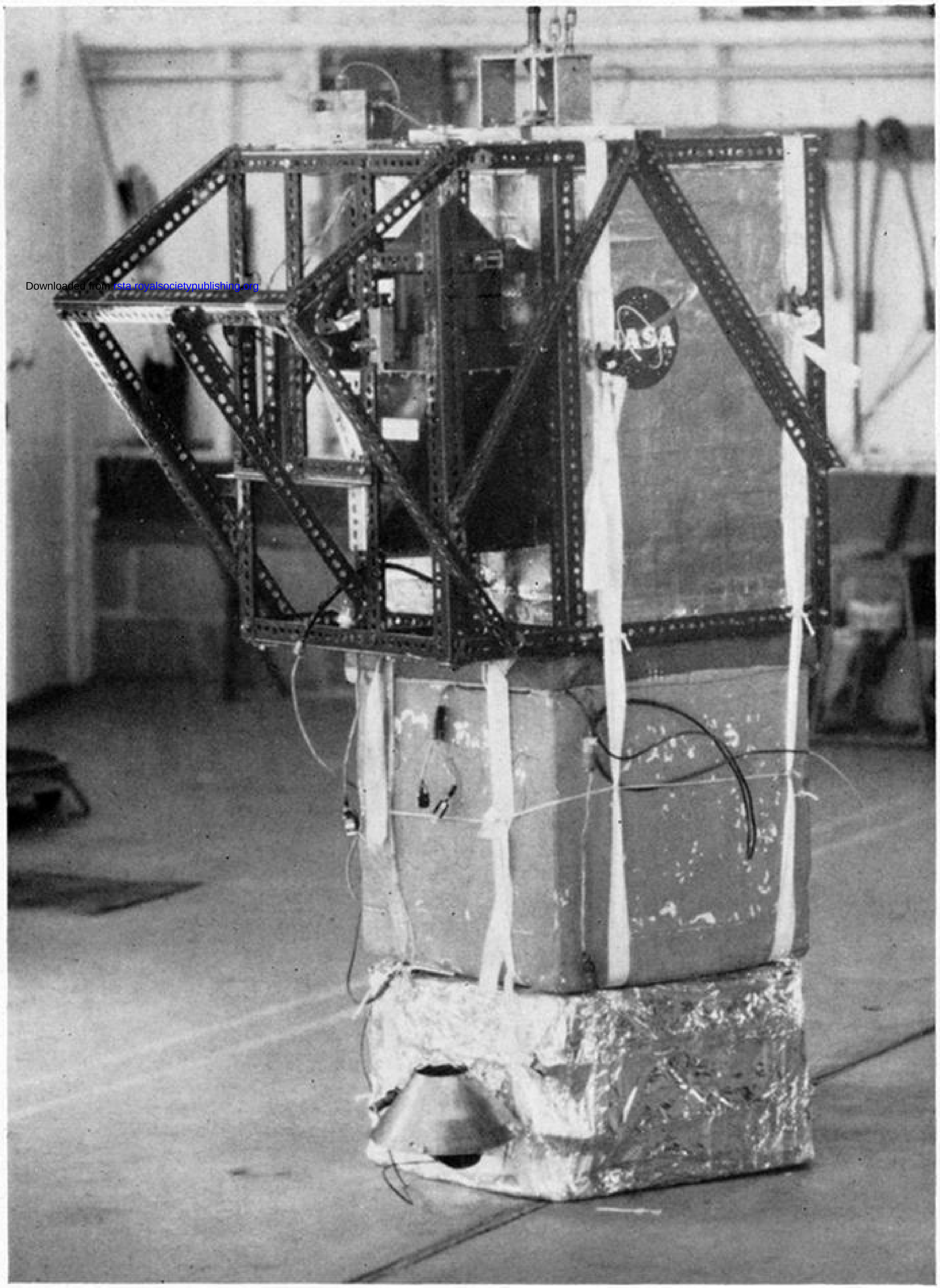

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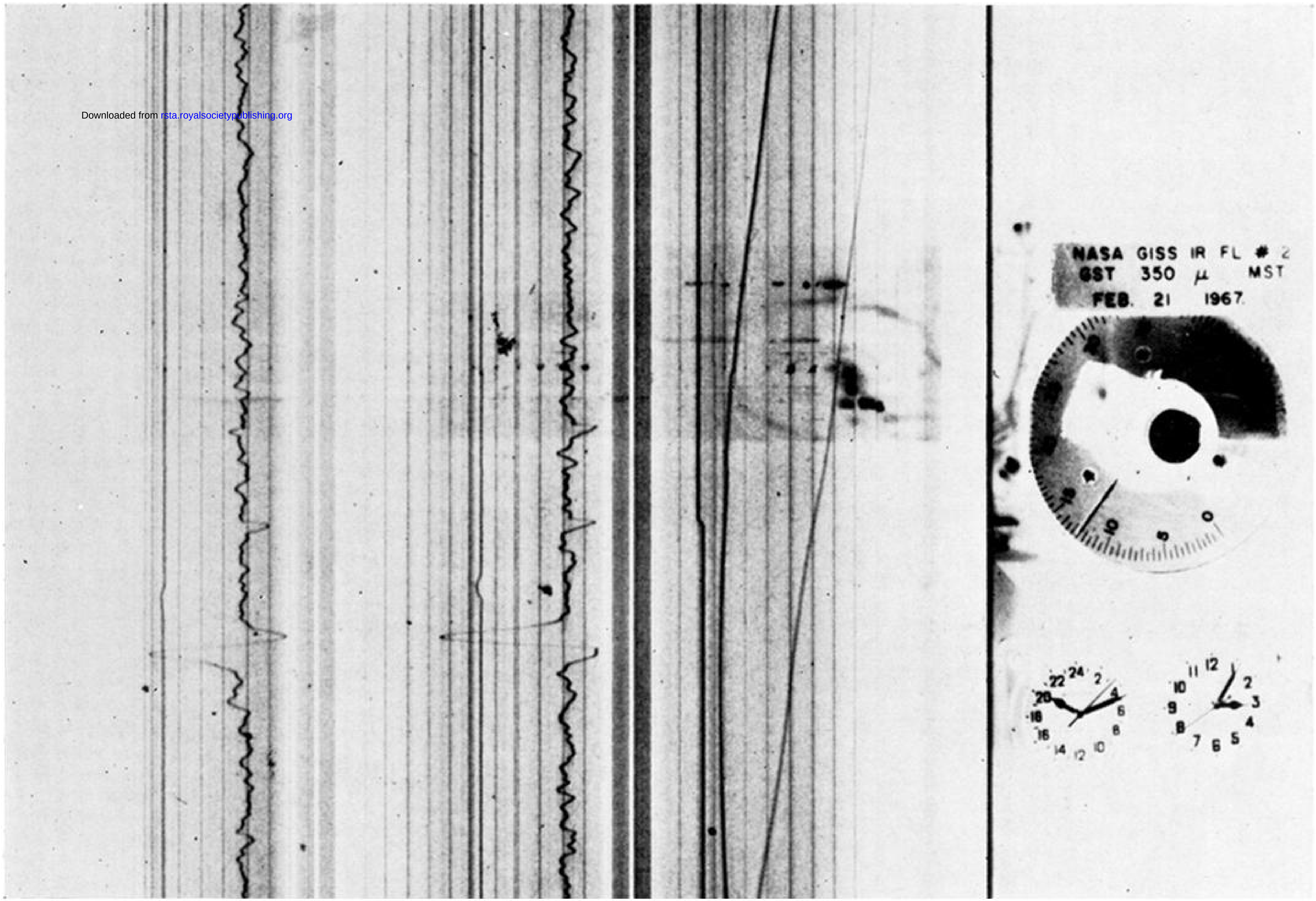

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