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Balloon-Based Measurements of the Cosmic Background Radiation

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ABSTRACT

We have developed and flown a balloon-borne liquid helium cooled spectrometer to measure the cosmic background radiation in the 3-18 cm^{-1} region. It features a cooled horn antenna, polarizing Michelson interferometer and germanium bolometer. These design features and the performance of the instrument are discussed.

I. INTRODUCTION

Big bang cosmology theory and measurements in the microwave and optical frequency region support the idea that the universe is filled with isotropic blackbody radiation with a characteristic temperature of 2.7K.[1] Accurate spectral measurements of this radiation are not available for frequencies above the peak of the blackbody spectrum (which occurs at $\sim 6\ cm^{-1}$ or $\lambda \approx 1.7$ mm).

II. SPECTROMETER DESIGN AND OPERATION

A far infrared spectrometer has been developed that can be flown by balloon to an altitude of ~ 40 km to measure this radiation over the frequency range from ~ 3 to $\sim 18\ cm^{-1}$. The principle features of the system are shown in Fig. 1. These include a cooled two-section horn antenna, a cooled polarizing Michelson interferometer[2] used for Fourier spectroscopy, and a germanium bolometer detector. The bolometer is illuminated with a germanium focusing cone. This use of immersion optics[3] increases the throughput by a factor of ≈ 3 without degrading the bolometer responsivity and permits the use of an antireflection coating on the front surface of the germanium cone. The broadband radiometer sensitivity is better than .02K for a 1 sec. observation of a Rayleigh Jeans source. The spectral sensitivity for a two-hour observation with $1\ cm^{-1}$ resolution is .05K at $13\ cm^{-1}$. Blackbody sources are used in flight for absolute calibration.

One critical feature of this measurement is the avoidance of signals from extraneous warm objects. Radiation from the apparatus is reduced by cooling to liquid helium temperature all portions of the optical system

which contact the geometrical beam. The warm horn at the top of the antenna (which contacts only diffraction side lobes) has a pro-reflection dielectric coating. In addition, the temperature of both horns is varied in flight to check for residual emission. All windows in front of the antenna are removed for the measurement. The antenna has been designed for minimum diffraction side lobes at large angles to avoid observing signals from the earth or the balloon hardware. The measured antenna pattern is shown in Fig. 2. The measurements at large angles were made using the system shown in Fig. 3. It produces a large solid angle ring-shaped image of a thermal source. The observed antenna pattern agrees with diffraction theory calculations.

The most important remaining sources of extraneous radiation are the line emissions from the residual atmosphere. Even at an altitude of 40 km, atmospheric emission is greater than the cosmic background radiation for frequencies higher than 11 cm^{-1}.[4] The important lines arise from water, ozone, and oxygen. Since the relative line strengths and positions[5] are known, the observed spectra can be accurately fitted to a model of the atmosphere with only a few parameters. Computer programs have been written to generate simulated atmospheric emission spectra, which will be subtracted from the observed spectral data to obtain the residual background radiation. An example of such a simulated atmospheric emission spectrum (plotted as an antenna temperature) is compared with a 2.7K blackbody curve in Fig. 4.

III. FLIGHT PERFORMANCE

The apparatus described here has been constructed and tested in

space environment simulators (cold and vacuum) and interfaced to a balloon gondola developed by Professor K. Anderson's group at the Berkeley Space Sciences Laboratory. The first flight was launched from Palestine, Texas on October 26, 1973. During the flight the payload temperature dropped to -60°C. At this low temperature, the mechanical drive to the interferometer lost power and stopped working. Consequently, although all other electrical and mechanical systems functioned well, very little spectral data were obtained. The payload was recovered undamaged near Anniston, Alabama.

Despite the absence of spectral data, much of value was learned from the flight. Preliminary data analysis indicates that another flight with the same apparatus (with a working interferometer drive) will produce significant new information on the cosmic background radiation. A second flight is planned in the spring of 1974, after minor modifications to the apparatus have been completed.

Another potential application of this apparatus is the study of the composition of the atmosphere. If the apparatus is modified to look horizontally, and to measure spectra out to 100 cm^{-1}, the sensitivity to minor atmospheric constituents will be greatly increased. A rough estimate suggests that a detection limit of $\sim 10^8$ molecules cm^3 can be achieved in a 1 sec. observation for a gas with an electric dipole moment of 1 Debye.

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† Fannie and John Hertz Foundation Fellow. Dr. Mather's present address: Goddard Institute for Space Studies, New York, N.Y. 10025.

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FIGURE CAPTIONS

Fig. 1. Schematic drawing of the radiometer-spectrometer for measurements of the cosmic background radiation. The cryostat is ~ 1.5 m high and maintains the apparatus at minimum temperature for more than 10 hours.

Fig. 2. Response of the radiometer to a point source as a function of the angle of the source from the axis of the antenna.

Fig. 3. System for measuring antenna pattern at large angles.

Fig. 4. The radiation from a 2.7K blackbody and an estimate of the emission from the residual atmosphere above 40 km[4] plotted as an antenna temperature. The principle emission is that of O_3 with a few H_2O lines. Antenna temperature is defined as the temperature of a Rayleigh-Jeans source with unit emissivity which gives the same emitted power as the actual source. The frequency range of the background measurement will be from ~ 3 to ~ 18 cm^{-1} with .25 cm^{-1} resolution.

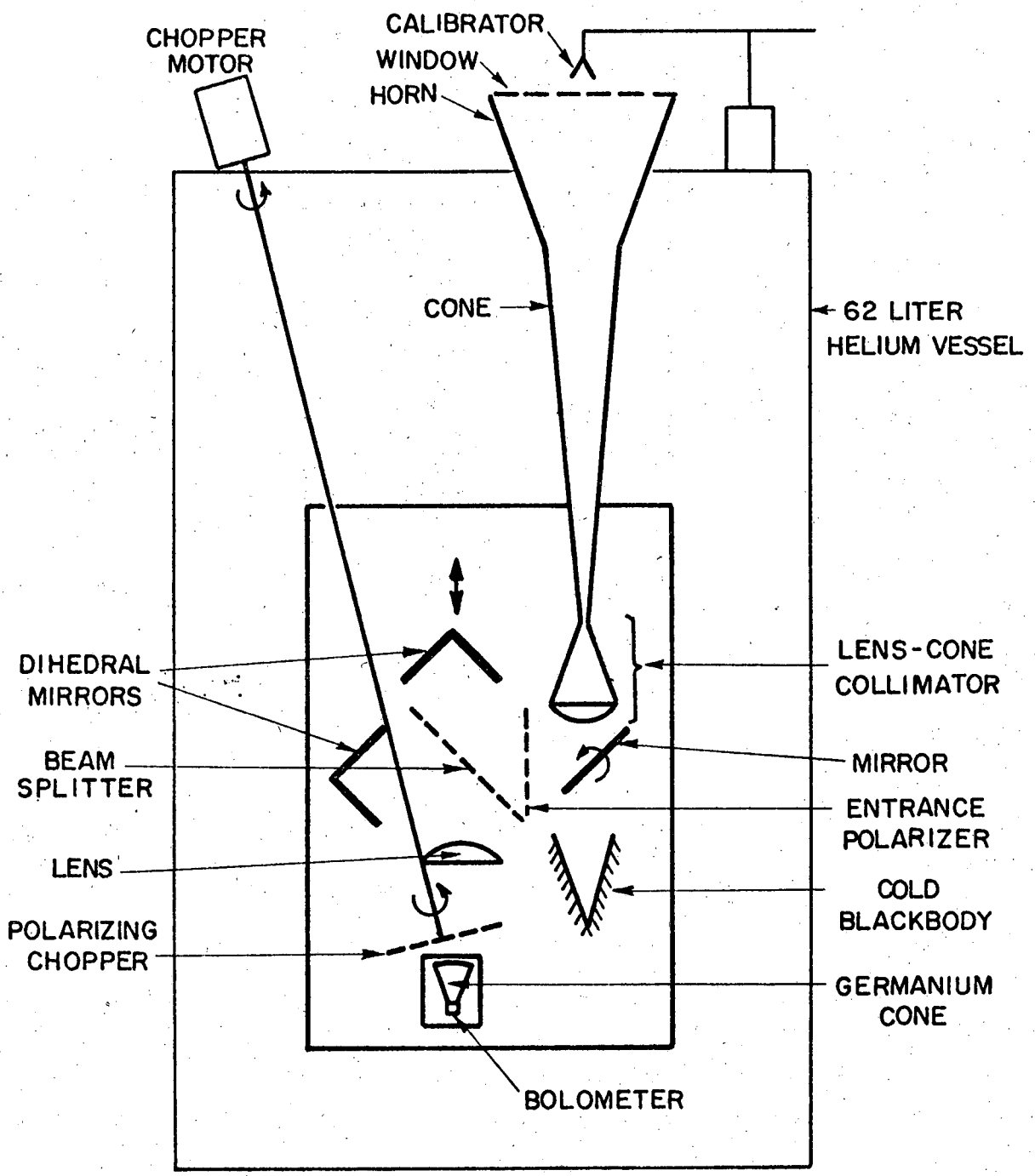

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Fig. 1

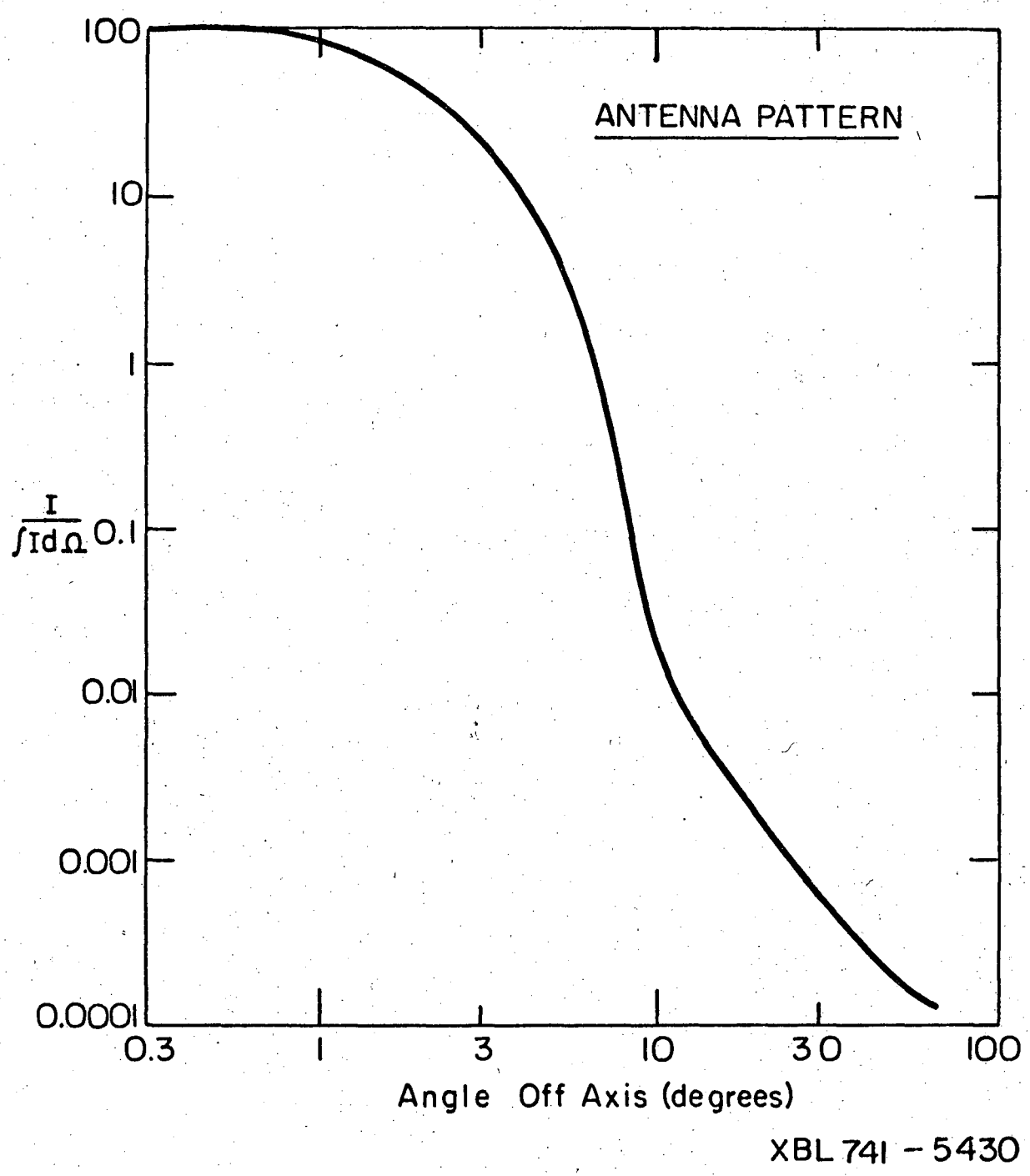
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Fig. 2

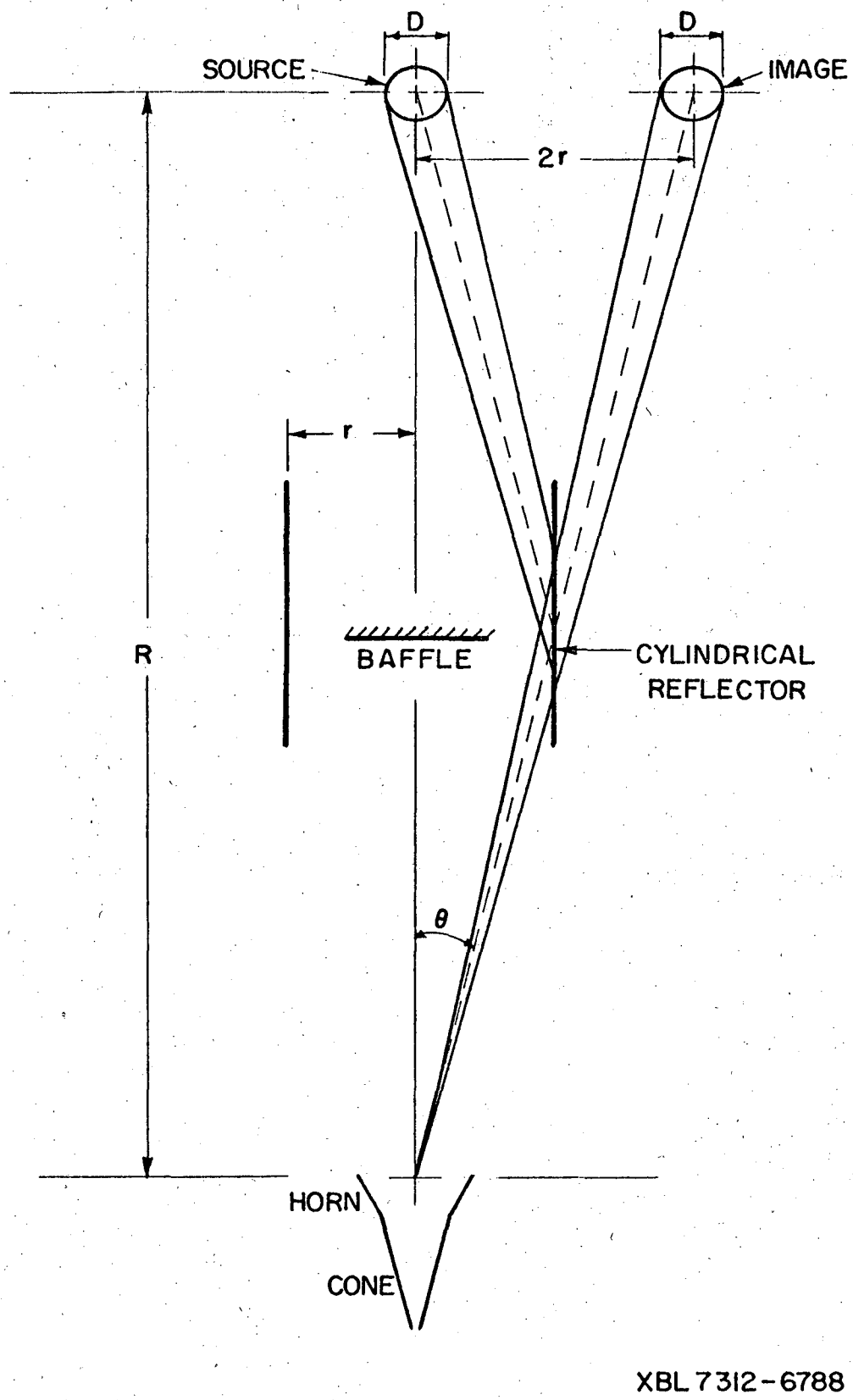
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Fig. 3

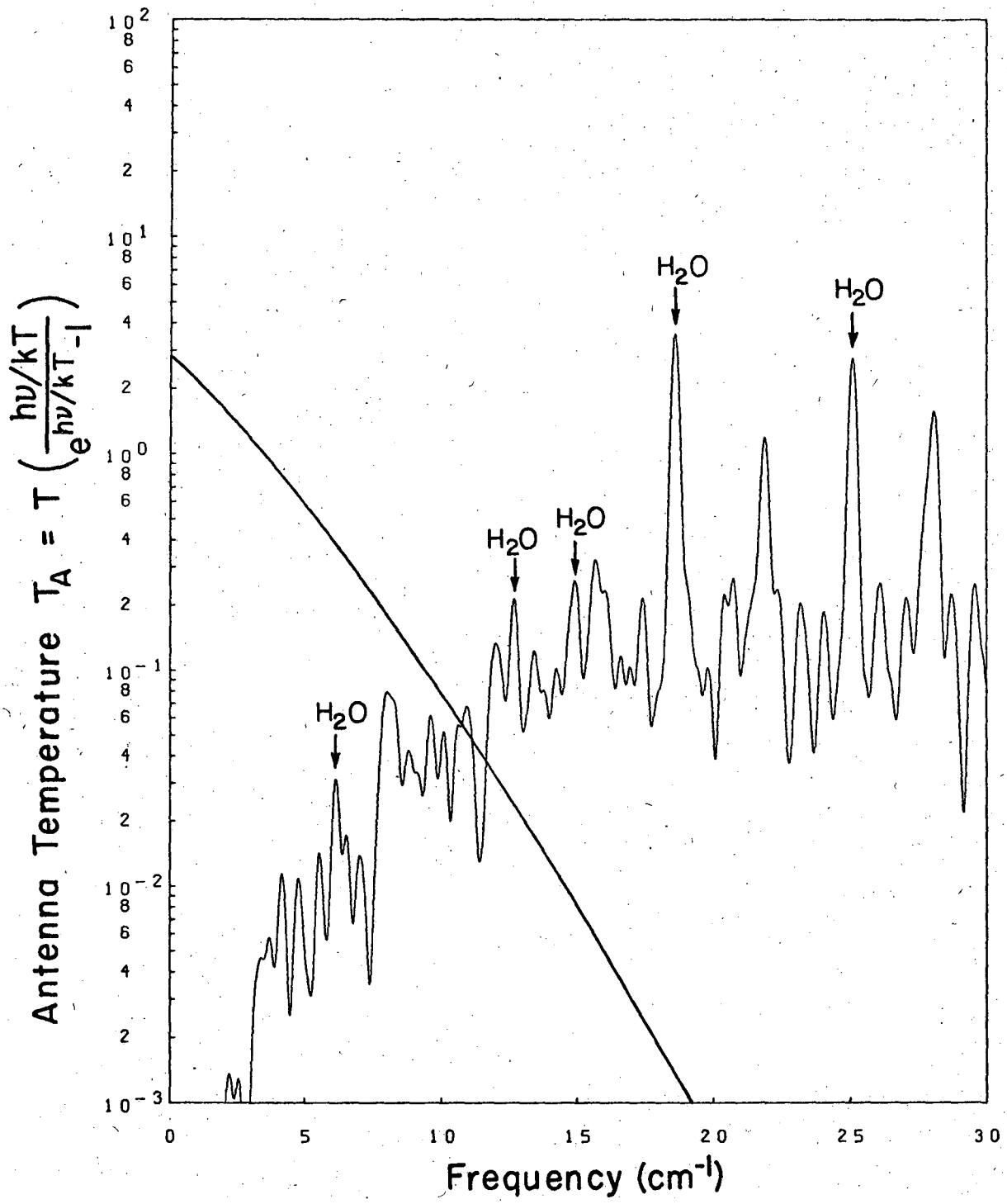

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Fig. 4

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