Far infrared astronomy at the South Pole

M.A. POMERANTZ

Bartol Research Foundation of the Franklin Institute
University of Delaware
Newark, Delaware 19716

F. PAJOT, R. GISPERT, *and* J.M. LAMARRE

Laboratoire de Physique Stellaire et Planetaire
Verrieres-le-Buisson, France

J.L. PUGET

E.N.S.
Paris, France

When the potentially overwhelming advantages of carrying out certain astronomical observations at the South Pole were first noted (Committee on Polar Research 1970), it was predicted that the exceedingly low water-vapor content would make this a superb site for infrared astronomy. This was confirmed by later measurements (Smythe and Jackson 1977). The ultimate test was performed during the 1984–1985 austral summer when our U.S.-French collaboration successfully conducted the first submillimeter astronomy experiment there.

The sky noise was a factor of 10 less than at Mauna Kea, heretofore the world's best infrared site. The same equipment used at Mauna Kea was modified to withstand ambient temperatures down to -40°C. For the first time, the sensitivity of the helium-four cooled photometer at the focus of a 45-centimeter primary mirror was limited by the instrumental noise rather than by fluctuations of atmospheric emissions. Furthermore, the precipitable water vapor content was significantly below the 0.5-millimeter lower limit of the earlier measurements (Harvey, Pomerantz, and Duvall 1982).

The observations included:

- Galactic studies—mapping of galactic emission over several target regions, spectrophotometry of galactic emission at three selected longitudes at 460, 720, 850, and 920 micrometers, and observations of a dense core in a molecular cloud.
- Extragalactic studies—dust emission of nearby spiral galaxies, Sunnyaev-Zeldovich effect and fluctuations of cosmological background including scans through two clusters of galaxies.
- Calibrations (photometric and beam profile)—Jupiter, Venus, and the Moon.
- Properties of atmosphere—water-vapor column density.

For illustrative purposes, we show in figure 1 the spectrum of the emission of the galactic center region, including data at 900 micrometers from Hawaii as well as from the South Pole. Similar spectra have been compiled for other regions of the disk: the complex associated with W41 at galactic longitude $\ell_{II} = 24°$ and the average emission between $\ell_{II} = 3°$ and 35°. The processing of the South Pole data will yield additional spectra of, for example, the complex at $\ell_{II} = 352°$ and the Carina region at $\ell_{II} = 285°$.

Interstellar dust is responsible for most of this emission for wavelengths (λ)greater than 4 micrometers. Data points at wavelengths less than 20 micrometers have been corrected for the interstellar absorption (open circles in figure 1), and the stellar component of the emission has been subtracted from the spectra (dashed line in figure 1). Thus, the resulting spectra reflect the dust emission alone. At wavelengths less than 300 micrometers, the spectrum $\lambda I(\lambda)$ is proportional to $\lambda^{-4.5}$. Assuming a Rayleigh-Jeans regime for the interstellar medium (Blackbody emission proportional to λ^{-4}), and using a dust emissivity proportional to λ^{-2} as derived from specific observations, we obtain a spectrum proportional to λ^{-5}. Therefore, the Rayleigh-Jeans regime does not apply, which implies the presence of cold dust (temperature less than 15° Kelvin), in the interstellar medium.

Further information on the dust temperature can be obtained by a numerical inversion of the equation giving the measured flux as an integral over the temperature of the product of the dust emissivity, the Planck function, and the temperature distribution of the dust. The dust emissivity as a function of wavelength is known from specific observations and models. The results in figure 2 show two important characteristics of the temperature distribution in mass column density of the dust:

- The peak of the distribution is between 12° and 14° Kelvin for the three regions studied.
- The distribution is bimodal, with one component at 12° to 14° Kelvin and the other at about 300° Kelvin (6 orders of magnitude smaller in mass).

Only the cold component can be explained by classical dust models (Mezger, Mathis, and Panagia 1982; Rouan 1979). Sellgren, Werner, and Dinerstein (1983) and Puget, Leger, and Boulanger (1985) have proposed transient heating of very small grains by single ultraviolet photons as an explanation of the warm component.

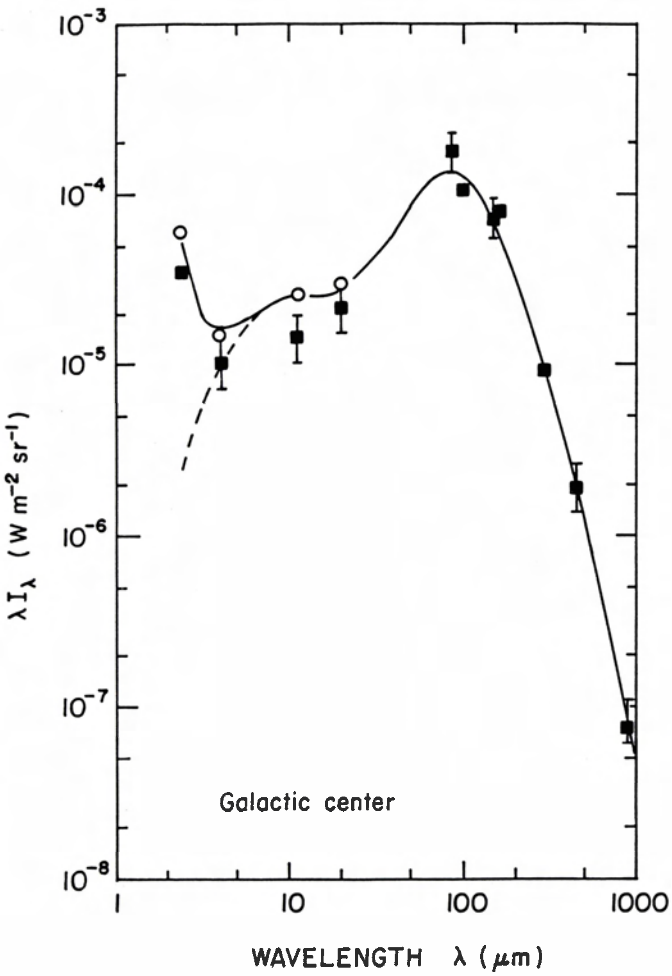

Figure 1. Compiled spectral emission [λI(λ)] of the galactic plane for the galactic center region: galactic latitude (b^{II}) between −1° and +1°, galactic longitude (ℓ^{II}) between −1.5° and +1.5°. ("$Wm^{-2}Sr^{-1}$" denotes "watts per square meter per steradia". "μm" denotes "micrometer.")

The South Pole measurements will enable us to confirm the existence of this bimodal behavior of the temperature distribution of the dust.

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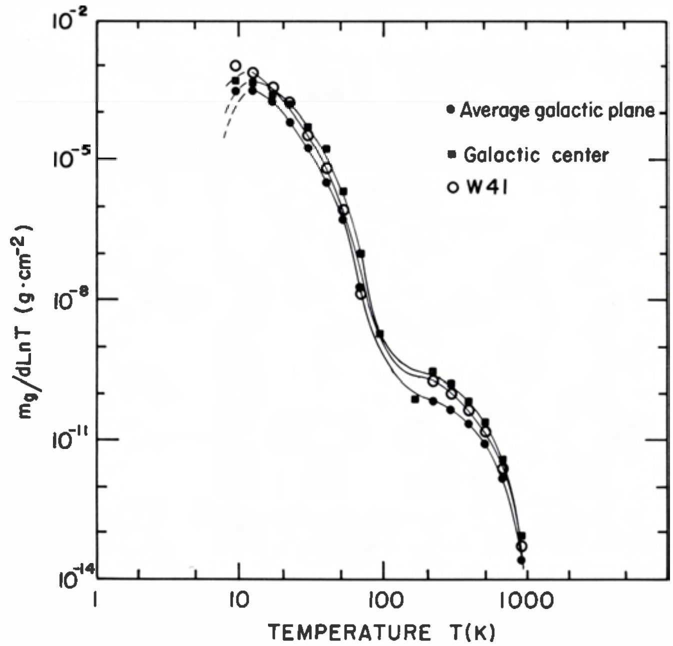

Figure 2. Temperature distribution of the interstellar dust deduced from the compiled spectra of: the average galactic emission, the galactic center region, and the complex associated with W41 (galactic longitude = 24°). The abscissa is the logarithm of the dust temperature and the ordinate is a measure of the mass of dust (m_g) along the line of sight at each temperature.

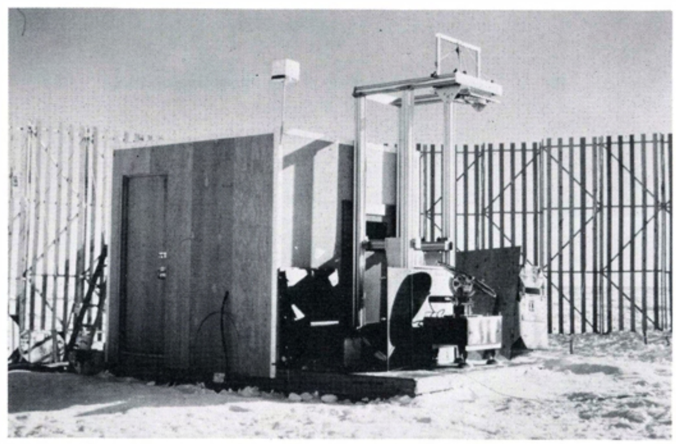

Figure 3. Custom-designed module housing the submillimeter photometer. The bolometers, operated at 1° Kelvin in a double tank helium-four cryostat, covers different bands in the range 300 micrometers to 1 millimeter with an atmospheric transmission of 20 to 90 percent. The lower mirror is the coelostat, and the 45-centimeter fixed primary mirror is at the top of the structure on which the various optical components are mounted.

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