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OBSERVATIONS OF THE CRAB NEBULA AT λ = 5800 Å, 2.2 μ, AND 3.5 μ WITH A 4-MINUTE BEAM

EDWARD P. NEY
University of Minnesota

AND

WAYNE A. STEIN
University of California, San Diego, and University of Minnesota
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NGC 1952, the Crab Nebula, is one of the most interesting and most extensively studied objects in the sky. It has been found to be an X-ray source as well as a source of radio- and optical-wavelength radiation. Therefore, it is one of the objects that must be observed at infrared wavelengths in order to close the great gap in data between λ = 1 μ and λ = 1 mm. A measurement of this object has been made by Moroz (1964) at λ = 1.26, 1.78, and 1.93 μ with an angular beam width of about 2′. However, this measurement suffers from several weaknesses, including correction of the observations with a 2′ beam width to the Crab as a whole and use of atmospheric water vapor as a long-wavelength limit on the spectral range of the observations.

New observations of the Crab Nebula have recently been made with the 30-inch-aperture telescope of the University of Minnesota at Marine on St. Croix, Minnesota. A new photometer has been constructed for the purpose of observing extended astronomical sources in the infrared. This photometer, when used with a large optical throughput infrared detector system, forms two angular beam widths on the sky of 4′ that alternate on and off the object at a frequency of 10 c/s. The two beams are separated by about 8′ center to center. In this system the gallium-doped germanium bolometer constructed at the University of Minnesota is placed at the focus of a 1-cm-diameter f/1 field mirror inside a liquid-helium Dewar vessel and cooled to 2° K by pumping on the liquid helium. The profile of the beam of this system was measured by allowing stars to drift through the beam at sidereal rate. The beam was found to be square over the 4′ beam width. The filters determining the spectral band pass of the system are cooled to the same temperature as the detector.

This system has been used to observe the Crab Nebula with results of high statistical accuracy at wavelengths of λ = 2.2 and 3.5 μ. In addition, the Crab Nebula was observed at λ = 5800 Å using an Amperex 152-AVP photomultiplier (S11 response) and filter with the same 10 c/s scanning photometer that was used in the infrared measurements. The photomultiplier system with a 1-cm-diameter diaphragm in front of a field lens was placed at the same position as the infrared detector system. This was done not only to check the results of O'Dell (1962) by using the 10 c/s chopping technique but also to verify that the optical radiation from the Crab Nebula was entirely within the 4′ beam of the infrared system. The Crab was observed at λ = 5800 Å with a signal-to-noise ratio of 1 in 1 sec with an uncooled photomultiplier using this technique. A longer integration on the object was necessary at the infrared wavelengths because of the inherently noisier infrared detectors and sky noise. However, even with the λ = 3.5 μ system, for example, integration for almost 15 min yielded a signal 6 standard deviations of the mean above zero signal.

Observations of the Crab Nebula were made on various cold nights in December 1967 and January and February 1968. Calibration of the brightness of the extended nebula was done by observing several stars of known optical and infrared brightness (Johnson 1965*a*). These observations were then converted to absolute flux from the nebula by using the absolute flux calibration of the observed stars discussed by Johnson (1965*b*). The results of the observations of flux from NGC 1952 are given in Table 1 along with the probable error (p.e. = 0.675 times standard deviation of the mean).

These results are shown in Figure 1, where the flux per unit frequency interval is

TABLE 1

RESULTS OF OBSERVATIONS OF THE CRAB NEBULA

(4′ Beam)

λ	$F(\nu)$[W m^{-2}(c/s)$^{-1}$]
5800 Å.........	$1.2\times10^{-26}\pm0.1\times10^{-26}$
2.2 μ..........	$6.4\times10^{-26}\pm.5\times10^{-26}$
3.5 μ..........	$1.3\times10^{-25}\pm0.15\times10^{-25}$

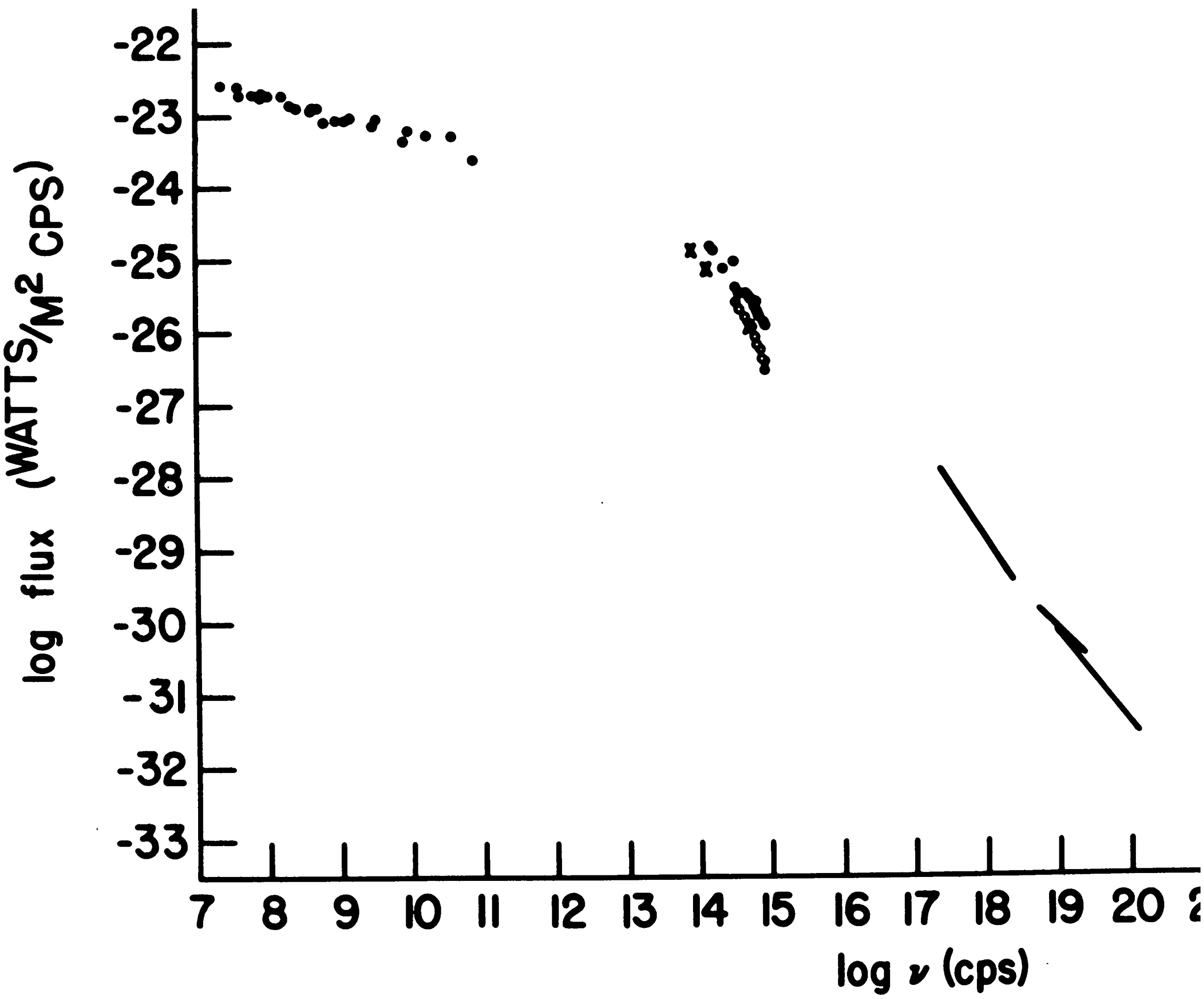

FIG. 1.—Spectrum of the Crab Nebula. *X* denotes the present infrared and optical observations. All other observations plotted are referred to in the text.

plotted as a function of frequency over the entire observed electromagnetic spectrum. It was not necessary to apply any corrections to the data presented here, such as for beam profile. The radio-frequency data were obtained from the summary of Howard and Maran (1965). The point at $\lambda = 3.4$ mm is that of Oliver, Epstein, Schorn, and Soter (1967) and is in striking disagreement with the earlier work of Tolbert (1965). The X-ray spectrum is plotted from the observations of Grader, Hill, Seward, and Toor (1966). Peterson, Jacobson, and Pelling (1966), and Haymes, Ellis, Fishman, Kurfess, and Tucker (1968). The optical-wavelength observations shown in Figure 1 are those of O'Dell (1962). Finally, the optical spectrum of O'Dell (1962) as corrected for interstellar extinction by Moroz (1964) is shown along with the 1.78 and 1.92-μ observations of Moroz (1964). The $\lambda = 2.2$ and 3.5-μ observations reported here are clearly in disagreement with the observations of Moroz. Extrapolation of the spectrum from the optical and infrared points as discussed by Moroz would predict a much larger flux than has actually been observed. However, note that the observation at $\lambda = 5800$ Å, using the same 10 c/s chopping techniques as in the infrared, shows close agreement with the earlier results of O'Dell (1962). No rediscussion of the interstellar-extinction corrections to the optical data will be attempted here, and no corrections for interstellar extinction have been applied to the $\lambda = 2.2$ and 3.5-μ data. It must be emphasized that the infrared measurements reported here are based on the absolute calibration of the flux from stars as derived by Johnson (1965*b*). It is unlikely that the uncertainties in this calibration compare with the errors in these measurements. However, any error in the absolute infrared flux from stars would appear in these observations of absolute flux from the Crab Nebula.

It has been suggested that a change in the slope of a synchrotron radiation source would occur at a frequency where electrons radiating at that frequency have a lifetime in the magnetic field of the source equal to the age of the object (Kardashev 1962). The frequency at which this break would occur is given by

$$\nu_b \simeq \frac{3.4 \times 10^8}{B^3 t^2} \text{ c/s},$$

where the magnetic field B is in gauss and the age t in years. The above result arises from the case of the simplest model in which expansion of the source and continuous acceleration of particles are not taken into account. The data reported here show that the break in the spectrum must occur not at $\nu \simeq 10^{14}$ c/s, as has been discussed recently (Moroz 1964), but rather at lower frequencies. The change in the slope of the spectrum must occur at $\nu \leq 3 \times 10^{13}$ c/s. If the above-discussed simple model is applied, a magnetic field for the Crab Nebula of about 2×10^{-4} gauss results. Finally, it should be noted that, in the case of the Crab Nebula, no unexpected peak of the spectrum has been observed in the infrared at wavelengths as long as $\lambda = 3.5$ μ in contrast to some other sources, such as 3C 273 (Low and Johnson 1964), NGC 1068 (Pacholczyk and Wisniewski 1967), or NGC 7027 (Gillett, Low, and Stein 1967).

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