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INFRARED VARIABILITY OF THE SEYFERT GALAXY NGC 1068

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Abstract

Observations of NGC 1068 at 2.2μ indicate variability with a timescale of a few days, implying that the size of the infrared emitting region is not larger than a few times 10^{15} cm. This limit on size is incompatible with the interpretation of infrared radiation by remission from dust grains, by synchrotron emission in a uniform model, and by synchrotron emission from many compact sources within the same object ("irtrons"). The infrared observations of NGC 1068 could be explained in terms of a nonuniform spherically symmetric synchrotron source with a radial dependence of the flux and of the frequency at which the source becomes optically thick.

Infrared radiation of Seyfert galaxies, detected by Pacholczyk and Wisniewski (1966), was found to be variable (Fitch, Pacholczyk and Weymann 1967, Pacholczyk and Weymann 1968 = Paper I). The observations of NGC 1068, reported in Paper I, suggest variability in the radiation of this object at 2.2μ . Observations by Kleinmann and Low (1970) are not incompatible with possible variations at 5μ .

Fig. 1. Observations of the Seyfert galaxy NGC 1068 at 2.2 microns: a plot for every observing night, b ranges of magnitudes plotted on a continuous time scale. Time is expressed in Julian days and their fractions.

Since 1966 the Seyfert galaxy NGC 1068 was monitored at 2.2μ (in the K photometric system) with the 60-inch telescope at the Catalina observing station of the Lunar and Planetary Laboratory of the University of Arizona. The PbS photometer (Johnson 1965) was equipped with a 15" diaphragm. Because of the particular structure of the photometer the sky readings were made at a distance of 22" from the object measured. The observations are not as numerous as would be desirable to more definitely establish the character of the variations of this object; the amount of telescope time available for this program was rather limited.

Figure 1 summarizes the observations. Each point in Fig. 1a represents an average of twenty values of differences between "star" and "sky" readings, performed with an integration time of 15 seconds. Figure 2 shows standard deviations of a single observation (corresponding to one point in Fig. 1a) from the mean value for NGC 1068 and for several comparison stars of various magnitudes. The scatter of the measured values for comparison stars around the mean value, illustrated by standard deviations plotted in Fig. 2, is indicative of the magnitude of the errors involved.

The scatter for NGC 1068 is significantly higher than if it were solely due to photometric errors. The standard deviation is particularly large if referred to separate short periods of a few days during which a number of observations were made. Before concluding that this is a manifestation of intrinsic variability of NGC 1068, in particular of variability with the time-scale of a few days, the possibility that this large scatter could be due to centering errors within the photometer diaphragm or to differential extinction should be examined.

Fig. 2. Standard deviation from mean value of a single observation consisting of 20 differences between measurements of "star" and of "sky," each measurement employing an integration time of 15 seconds. Squares represent observations of comparison stars of various magnitudes at 2.2μ . Dots refer to measurements of the Seyfert galaxy NGC 1068; the lower dot refers to all 33 observations of NGC 1068, the upper one represents observations on JD 39737, and the middle observations on JD 40487-90.

The photometer used had no provision for a diaphragm of variable size, and therefore investigating the distribution of brightness in NGC 1068 at 2.2μ with this instrument would not be meaningful. Observations at longer wavelengths (Kleinmann and Low, 1970) indicate no effect of beam size when diaphragms ranging from $4.5''$ to $35''$ were used. If the 2.2μ radiation originates in a compact star-like nucleus of NGC 1068, the effect of centering of the object in the diaphragm on measurements of flux is entirely insignificant; this, however, should be confirmed by area scanning at that wavelength.

Differential extinction is the other effect which could contribute to the observed large scatter of points for NGC 1068 in Fig. 1a. The short wavelength side of the K band is more affected by the air mass involved than the long wavelength side (see e.g. Johnson et al. 1968). Therefore the effect of extinction on the measurement of an object with a small value of the color index J-K (like the comparison star 611, J-K = 0.8) will be different than that of an object with a large J-K (like NGC 1068, J-K = 1.5). Measurements indicate that the effect is negligible; the difference in extinction coefficients for a blue star (J-K = -0.05) and for a red star (J-K = 1.02), measured on a photometrically poor night with high extinction is as small as 0.07. This difference cannot be responsible for the observed difference in scatter of measurements between NGC 1068 and the comparison stars; all the observations reported on Fig. 1 were made through air masses smaller than 2.

Infrared observations of the Seyfert galaxy NGC 1068, discussed above, indicate intrinsic variability of flux from this object at 2.2μ with the time scale as short as a few days, thus limiting the physical size of the region emitting the infrared radiation at this wavelength to a few times 10^{15} cm. There are several important consequences of this fact.

1. The observed infrared radiation of NGC 1068 cannot be interpreted as being emitted by dust grains which absorb energy from a central compact optical or ultraviolet source. The dust model, mentioned in Paper I, discussed in detail by Rees et al. (1969) and commented upon by Burbidge and Stein (1970) requires the 2.2μ emitting region to be at a distance of the order of 10^{18} cm from the central ultraviolet source in NGC 1068 and to have a size of the same order of magnitude for any type of dust grains with the absorption efficiency not far below unity at ultraviolet and optical frequencies.
2. A homogeneous synchrotron model of NGC 1068, discussed in Paper I (in Paper I figures 4 and 5 are interchanged), cannot reconcile such a small size of the emitting region with the lack of an observed self-absorption feature up to 100μ without incurring inverse Compton losses substantially exceeding the electron energy losses due to synchrotron radiation. Fig. 3 illustrates the location of such synchrotron models on the radius-magnetic field plane. We can see from Fig. 3 that in the most favourable case of magnetic field being just above 100 gauss the self-absorption should manifest itself in the infrared spectrum of NGC 1068 below 100μ if the radiating region were smaller than 10^{16} cm.

Fig. 3. The location of homogeneous synchrotron models of the infrared source in NGC 1068 on the radius-magnetic field plane.

3. The observed properties of the infrared radiation from NGC 1068 are not compatible with a model consisting of a large number of small synchrotron sources within the same object, like the one suggested by Burbidge and Stein (1970) or Low (1970) ("irtron" model). In fact, one of the reasons Low gave for suggesting such a model was the desire to account for the shape of the infrared spectrum of the galactic center above 100μ through the phenomenon of synchrotron self-absorption, which for a homogeneous source would manifest itself at considerably lower frequencies for any reasonable field strength. A successful synchrotron model of NGC 1068 requires the opposite in the sense that the self-absorption frequencies should be lower than those predicted by a homogeneous model (cf. Fig. 3). For sources located at the same distance, having fluxes F_ν at the same frequencies ν (at which sources are optically thin), and having electron energy distributions characterized by the same exponent $\gamma = 5$, the frequency ν_1 at which the optical depth of the source is equal to unity is proportional to $H^{0.11} F_\nu^{0.22} R^{-0.44}$ (see e.g. Pacholczyk 1970, equation 6.38). Therefore splitting of the synchrotron source into a number of smaller "irtrons" will not lead to a decrease of ν_1 for any reasonable range of parameters involved (the magnetic field H has a lower limit set

by inverse Compton losses). Even if one would assume a radius of a single "irtron" to be as large as 10^{15} cm and the "irtron" to be optically thick at $100\ \mu$, one would need at least $N=10$ "irtrons," located in a volume of much larger radius to account for the full flux of NGC 1068. It would then be necessary to assume that the flux of one "irtron" changes by a factor of 30 (or more if $N > 10$) to account for the variations. If the variable flux is not exclusively emitted at $2.2\ \mu$ (further observations for variability at different infrared wavelength are needed to establish this), the "irtron" would become optically thick at much shorter wavelengths than $100\ \mu$ at its maximum flux, when its contribution to the spectrum of the entire object is dominant.

4. The infrared characteristics of NGC 1068 could be explained in terms of a nonuniform synchrotron model with the field decreasing outwards, somewhat similar to that discussed by Rees and Sciama (1966) for 3C273. The infrared radiation of a given wavelength would originate predominantly in a region at a certain distance from the center of a spherically-symmetric model; at smaller distances the source would be optically thick to radiation of that and longer wavelength; radiation of longer wavelength would be emitted mainly at larger distances. The details of the model are being computed by W.G. Fogarty in his dissertation. The model may, however, be confronted with the difficulty in explaining the steep slope of the spectrum above $100\ \mu$ if further observations around $100\ \mu$ and in the millimeter range confirm the possibility of steeper spectrum than $\nu^{2.5}$. The free-free absorption in a cloud of electrons could account for a steep slope above $100\ \mu$ (Weymann 1970). The requirement that this electron cloud of radius 10^{16} cm is optically thin to Thomson scattering (otherwise it would smear out the variations of intensity at $2.2\ \mu$) sets some constraints on the density and temperature. The constraints do not present a problem if the width of the Balmer lines is not due to electron scattering within the cloud, as seems to be the case for NGC 1068. The explanation of the steep spectrum above $100\ \mu$ through a plasma cut-off would require electron densities as high as $10^{12}\ \text{cm}^{-3}$, which would be completely opaque at all infrared wavelengths.

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