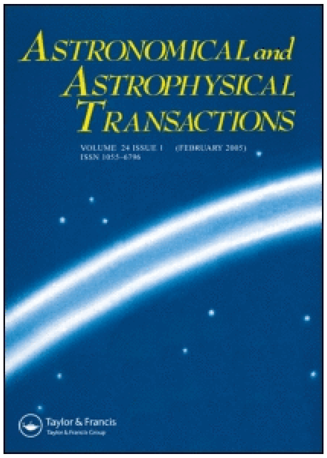

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Infrared variability of the nucleus of the Seyfert galaxy NGC 1068 in 1998–2006

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The results of analysis of *JHKLM* photometry of the Seyfert galaxy NGC 1068 are presented. These observations confirmed its infrared (IR) variability. The magnitudes of the amplitudes of the brightness variations in the J (1.25 μm) and K (2.2 μm) bands are within 0.15 and 0.3, respectively. The nucleus of NGC 1068 is a variable source and can be at different phases of activity. The variable source in NGC 1068 is a complex-structured object. At least two sources radiate in the wavelength range 1.25–5 μm: a hot source whose radiation shows up in the range 1.25–1.65 μm and a cold source radiating at long wavelengths (2.2–5 μm). The total mean luminosity of the two sources did not change between the beginning and the end of our observations. The IR brightness and colour variations observed in 1998–2006 are attributable to the dispersal of the dust envelope that formed around the galactic nucleus some 30 years ago and reached its maximum density in 1994–1995. The optical depth of the dust envelope averaged over the spectrum of the hot source is $\tau \approx 1.5$. In 2004, the state of the dust envelope almost returned to its 1974 level, i.e. the dust envelope formation and dispersal cycle was about 11 000 days (approximately 30 years).

Keywords: Galaxies; Groups and clusters of galaxies; Intergalactic gas; Seyfert galaxies; NGC 1068; Infrared variability

1. Introduction

The bright galaxy NGC 1068 is considered the prototype of Seyfert 2 galaxies. Antonucci and Miller [1] for the first time firmly established that the galaxy contains an invisible nucleus, a Seyfert 1 galaxy; variability over a wide spectral range is common for such galaxies. Based on the galaxy's *JHKL* photometry in 1976–1994, Glass [2] found that its infrared (IR) flux had slowly increased over 18 years and that the variability amplitude increased with increasing wavelength. In the opinion of Glass, the emission from a relatively hot dust envelope (a torus) around the galactic nucleus can be the source of the variable IR radiation. The nuclear variability of the Seyfert galaxy NGC 1068 detected by Glass confirms the similarity between Seyfert 1 and Seyfert 2 galaxies.

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2. Observations

We performed the IR photometry of NGC 1068 using a photometer with a photovoltaic liquid-nitrogen-cooled InSb detector attached to a 1.25 m telescope at the Crimean Station of the Sternberg Astronomical Institute. The photometer was mounted at the Cassegrain focus of the telescope, the aperture was about 12″, and the spatial separation of the beams by modulation was about 30″ in the east–west direction. Star BS 804 from the catalogue by Johnson *et al.* [3] was the photometric standard.

3. Discussion and results

3.1 *The galaxy's brightness and colours in 1998–2006*

The results of our photometry of NGC 1068 in 1998–2006 are presented in figure 1, which shows the JK brightness and $J - H$ and $K - L$ colour variations in the galaxy during our observations. The dotted lines represent the linear fits to the observed variations. The colour temperatures for the corresponding colour indices are plotted on the right-hand vertical axis. The following conclusions can be drawn from figure 1.

The IR photometry presented in figure 1 suggests that the IR variability of NGC 1068 detected by Glass [2] is confirmed by our 1998–2006 observations. Thus, for example, the magnitudes of these variations in the J (1.25 μm) and K (2.2 μm) bands are within 0.15 and 0.3 respectively, and they exceed observational errors by a factor of more than 5. In addition to

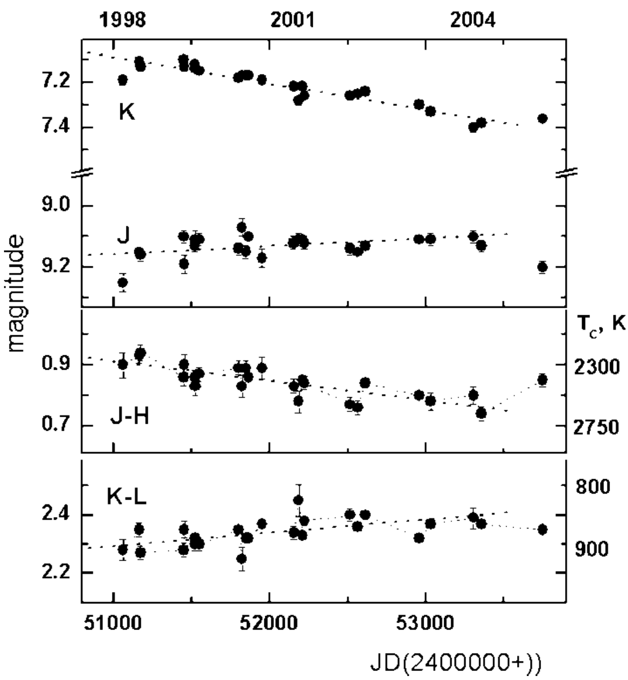

Figure 1. The JK brightness and $J - H$ and $K - L$ colour variations of the Seyfert galaxy NGC 1068 observed in 1998–2004. The vertical bars indicate the observational errors. The dotted lines represent the linear fits. The colour temperatures for some of the $J - H$ and $K - L$ colour indices are plotted on the right-hand vertical axis.

the IR brightness fluctuations, slow brightness variations in the galaxy were observed in 1998–2006; they were accompanied by variations in the colour indices, i.e. an energy redistribution took place in the radiation from the galaxy's variable source in the range 1.25–5 μm. In other words, we may assert that the nucleus of NGC 1068 is a variable source and can be at different phases of activity.

The brightness of the galaxy decreased from 1998 to 2006 in all the bands except J. There was a tendency for the J brightness to increase in this period. The slow colour variations in the galaxy from 1998 to 2006 occurred in such a way that the variable source was hotter in the 1.25–1.65 μm radiation and colder in the 2.2–5 μm radiation. These features of the galaxy's IR brightness and colour variations suggest that the variable source in NGC 1068 is a complex-structured source. The radiation from at least two sources is observed in the range 1.25–5 μm: a hot source whose radiation shows up in the range 1.25–1.65 μm and a cold source radiating at long wavelengths. The colour temperature of the hot source increased from 2300 K (the beginning of our observations) to about 2700 K (the end of our observations). In contrast, the temperature of the cold source decreased by several tens of kelvins. The colour temperature variations of the cold source in the range 800–900 K imply that the most likely source of the galaxy's 2.2–5 μm radiation is the dust component (dust envelope) associated with the galaxy's central source (nucleus). If these two sources are in radiative equilibrium, then the increase in J brightness and the decrease in *KLM* brightness observed in 1998–2006 can be explained by the dispersal of the dust envelope. The increase in colour temperature in the range 1.25–1.65 μm probably implies that the reddening of the central source caused by the dust envelope decreased by 2006 compared with 1998. The cooling of the cold source can be explained by the recession of the dust envelope from the heating source.

3.2 *The infrared spectral energy distributions of the galaxy*

The following conclusions can be drawn from our estimates of the parameters for the variable source in NGC 1068 obtained by analysing the 1.25–5 μm spectral energy distribution for two periods of observations separated by about 2000 days (near JD 2451400 and JD 2453230).

(i) The hot source is relatively compact and is smaller in size than the cold source by a factor of several tens.
(ii) The temperature of the hot source increased approximately by 100 K, while the temperature of the cold source decreased by several tens of kelvins. Concurrently, the hot source slightly decreased in size, while the cold source increased in size.
(iii) The total luminosity of the hot and cold sources remained constant, to within several per cent, over the observed period.
(iv) The mean optical depth of the dust envelope surrounding the galaxy's central hot source is approximately 1.5.

The mean parameters of the two-component variable source in NGC 1068 for the two periods of observations in 1998–2004 are presented in table 1. The rows of table 1 sequentially give estimates of the temperatures T_c, the mean fluxes $F_{obs}(\lambda)$ at 1.25 μm (J) and 3.5 cm (L), the sizes R and the luminosities L. The distance up to the galaxy was accepted as equal to 14.4 Mpc [2].

The 2.2–5 μm radiation originates mainly from the dust component of the variable source in NGC 1068 that is associated with the central source whose radiation shows up in the range 1.25–1.65 μm. On this basis, we can estimate the optical depth of the dust envelope averaged over the spectrum of the hot source, τ (the last row of table 1). For $\tau \approx 1.5$, the magnitude of $E(B - V)$ inside the galaxy is approximately 1.3 for dust grains similar to interstellar grains,

Table 1. Mean parameters of the two-component variable source in NGC 1068 for the two periods of observations in 1998–2004.

	Value for the following Julian dates			
	2451400		2453230	
Parameter	Hot	Cold	Hot	Cold
T_c (K)	3100	760	3200	720
$F_{obs}(J)$ (erg s^{-1} cm^{-2} cm^{-1})	8.16×10^{-6}		8.38×10^{-6}	
$F_{obs}(L)$ (erg s^{-1} cm^{-2} cm^{-1})		8.10×10^{-6}		7.05×10^{-6}
R (cm)	2.39×10^{16}	7.51×10^{17}	2.28×10^{16}	8.17×10^{17}
L (erg s^{-1})	3.75×10^{43}	1.34×10^{44}	3.88×10^{43}	1.28×10^{44}
τ	$\approx$1.50		$\approx$1.45	

provided that the mean optical depth of the envelope corresponds to a wavelength of about 1 μm. In this case the temperature of the hot source should be increased by 500–600 K.

3.3 *The galaxy's variations on a timescale of approximately 30 years*

Glass [4] gave a web reference to the set of infrared (*JHKL*) photometric data for the galaxy from 1970 to 1998 and reduced all the data to a homogeneous photometric system and to observations with a 12″ aperture. Our observations of the galaxy were performed with the same aperture. Figure 2 shows the *K* brightness variations from 1970 to 2006. The full and open circles represent our observations and the data from the work of Glass [5] respectively. As we see from figure 2, although there is a noticeable systematic shift between our data and those of Glass, the maximum magnitude of the *K* brightness with an amplitude of 0.5–0.6 is clearly seen. At 2.2 μm, the dust envelope mainly radiates; its flux is roughly proportional to its optical depth. Hence, the increase in *K* brightness between 1974 and 1994–1995 reflects the increase in the optical depth of the dust envelope, while the decline in *K* brightness after 1995 reflects the decrease in optical depth, i.e. the dispersal of the dust envelope. In 2004, the state of the dust shell almost returned to the 1974 level and the dust envelope formation and dispersal cycle was about 11 000 days. Assuming that the *K* brightness variations are related only to the optical depth of the dust envelope, we find that the variations in the optical depth of the dust component of the variable source in NGC 1068 could reach a factor of 1.5.

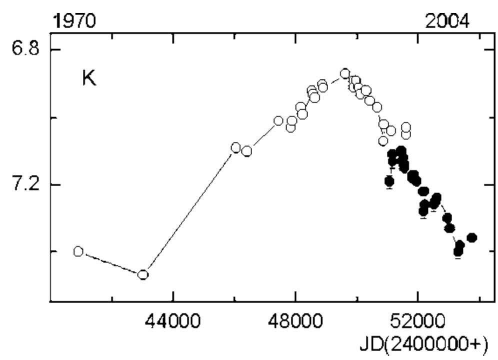

Figure 2. Combined *K*-band light curve of NGC 1068 between 1970 and 2006. The full and open circles represent our observations and the data from the work of Glass [4], respectively.

All the estimates here were obtained without allowing for the contribution of the IR radiation from the surrounding stars of the galaxy, because there are no reliable data available to enable us to make this allowance.

Acknowledgement

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