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VISUAL-INFRARED VARIATIONS IN THE BROAD-LINE RADIO GALAXY 3C 382

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ABSTRACT

A very large-amplitude change in the visual wavelength flux from the radio galaxy 3C 382 occurred on a time scale of about a month during mid-1977. The infrared flux was constant during the onset of the outburst, but showed an increase at 2.28 μm about a year later. Such activity strongly suggests that the observed infrared radiation does not originate in the same component as the visual wavelength radiation. Extension of the spectral-flux distribution to 10 μm shows a flattening between 2.20 and 10 μm. A plausible origin for the infrared flux longward of 2.20 μm is thermal reradiation by hot dust.

3C 382 has nonstellar visual and infrared continuum emission (O'Dell *et al.* 1978), like many other active galaxies. An interesting characteristic of the object is that a compact flat-spectrum radio source is coincident with the visual-infrared nucleus (Riley and Branson 1973). Yet, as in most radio galaxies, the radio emission originates predominantly in extended, steep-spectrum components. The optical spectrum shows very broad (FWOI $\sim$ 25 000 km s^{-1}) Balmer lines with much narrower cores at the same redshift (z = 0.0578) as narrow forbidden lines and at least two components in the continuum—a steeply falling power law from 0.4 to 0.7 μm ($F_\nu \propto \nu^{-2}$, not corrected for Galactic reddening) and a relatively flat component showing up as an ultraviolet excess (Osterbrock, Koski, and Phillips 1976).

Visual and infrared photometry of 3C 382 is summarized in Table I. Data have been included from the University of Minnesota 1.5-m telescope on Mt. Lemmon, Arizona (previously summarized by O'Dell *et al.* 1978 and Puschell 1979); the University of Minnesota 0.76-m telescope at Marine-on-St. Croix, Minnesota; and the NASA 3-m Infrared Telescope Facility (IRTF) on Mauna Kea. The correction for Galactic extinction (A_V = 0.29) was determined using the method of Burstein and Heiles (1978). In order to concentrate on the continuum spectral fluxes, emission lines were subtracted from the broadband visual measurements by convolving the filter response curves with the line fluxes measured by Osterbrock, Koski, and Phillips (1976).

An outburst in the visual-wavelength fluxes began in mid-1977 with a time scale of about a month. Photographic photometry reported by Aksenov and Kurochkin (1978) suggests that this outburst was preceded by a gradual increase in the photographic passband between September 1976 and May 1977. As shown in Table I and Fig. 1, a high visual flux level was measured as late as September 1978. Whether or not the increased flux level persisted throughout the entire period from June 1977 to September 1978 is not known from this work because the data are so scattered in time. A flux substantially smaller than the outburst level was measured in May 1980. Figure 1 illustrates that no measurable change in the 2.28-μm flux occurred during the onset of the outburst in 1977, but that a substantial increase at 2.28 μm was observed about a year later ($t_{\rm var} \sim$ 3.5 yr). The 2.20- and 3.50-μm fluxes continued to be relatively high in August 1980, even though the level of visual activity was lower in May 1980. This behavior argues strongly in favor of separate components for the visual and infrared fluxes longward of 2.20 μm. The strong aperture dependence of the 1.25- and 1.65-μm fluxes and the fact that the outburst was not a major event in this region imply the emission at J and H is dominated by starlight.

The time scale of the onset of the outburst at visual wavelengths implies the emission originated in a compact volume ($R \sim 10^{17}$ cm). The data in Table I show that the largest fractional increase in flux due to the outburst occurred in the bluest visual bands. Considering the size of the increase at 0.69 μm, it is surprising that the outburst did not show up clearly at 1.25 and 1.65 μm. This suggests that the spectral flux distribution of the outbursting component was flat or rising with frequency, leading to the possibility of a long-wavelength cutoff to the outburst and the very speculative notion that the observed increase in the visual bands was actually the long-wavelength counterpart of an event at higher energies. IUE observations by Longair and Perryman (1980) scattered from 13 May 1978 through 13 June 1980 do show evidence for variability in the continuum flux at 1450 Å. However, the ultraviolet measurements and the results presented here do not correspond very closely in time, so it is not possible to show that the optical brightening observed in 1977 was related to activity in the ultraviolet. Nevertheless, HEAO-1 observations

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TABLE I. Visual-infrared spectral fluxes (in milliJanskys) for 3C 382.

Date (UT)	Ap. (arcsec)	0.36 μm	0.43 μm	0.55 μm	0.69 μm	1.25 μm	1.65 μm	2.28 μm	3.5 μm	10.6 μm
76.05.30	18	2.3 ± 0.3	3.5 ± 0.2	5.2 ± 0.4	6.5 ± 0.4					
76.06.27	9						15 ± 1	19 ± 1	20 ± 5	
76.10.30	9						14.4 ± 0.8	18.1 ± 0.7	23 ± 3	
76.10.30	18						20 ± 1	19.3 ± 0.7	25 ± 3	
77.05.21 + 22	18					18 ± 3	20 ± 1	21.9 ± 0.8	29 ± 9	
77.05.23	18	2.5 ± 0.2	1.9 ± 0.1	3.0 ± 0.2	3.5 ± 0.2					
77.06.15 + 16	18	4.2 ± 0.2	4.8 ± 0.2	6.2 ± 0.2	8.5 ± 0.4					
77.06.21	18					19 ± 2	23 ± 1	23 ± 2		
78.07.01 + 05	18	5.0 ± 0.3	5.1 ± 0.3	6.7 ± 0.4	10.9 ± 0.6					
78.07.02 + 04	18					16 ± 2	20 ± 1	31 ± 1		
78.09.12	18	6.3 ± 0.4	6.3 ± 0.4	7.3 ± 0.4	11.7 ± 0.6					
80.05.13	6									41 ± 14
80.05.15	27			4.8 ± 0.3	6.6 ± 0.4					
80.08.13	8					15.4 ± 0.6	21.0 ± 0.6	26.2 ± 0.8[a]	36 ± 3	
line contamination		0.02	0.07	0.39	1.51					

[a] $\lambda_0 = 2.20\ \mu$m for this measurement.

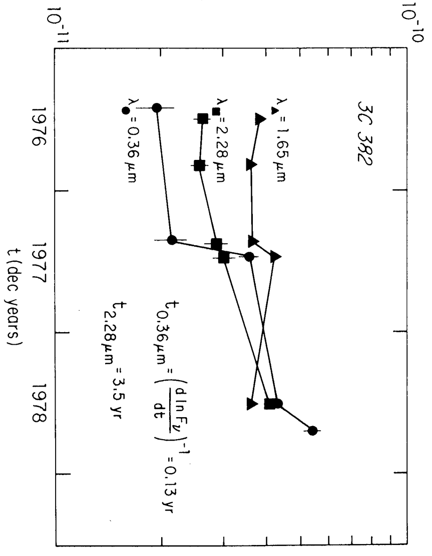

FIG. 1. $\nu_0 F_{\nu_0}$ vs time for the 1977–1978 outburst of 3C 382. The squares represent data at $\lambda_0 = 2.28\ \mu$m ($\nu_0 = 131$ THz), the triangles represent data at $\lambda_0 = 1.65\ \mu$m ($\nu_0 = 182$ THz), and the circles represent data at $\lambda_0 = 0.36\ \mu$m ($\nu_0 = 845$ THz).

by Dower *et al.* (1980) showed that 3C 382 was brighter by a factor of 2 to 3 in the x-ray region (2–10 keV) during October 1978 than in the mid-1970s Ariel V measurement reported by Elvis *et al.* (1978).

The apparently gradual increase in the 2.28-μm flux following the onset of the outburst implies that the 2.28-μm emission originated in a relatively extended emission region near the compact visual-wavelength source, such as a thermally reradiating dust cloud. Thermally reradiating dust accounts very well for the infrared emission from the Seyfert galaxy NGC 1068 (Jones *et al.* 1977) and may be present in other active galaxies as well (e.g., Lebofsky and Rieke 1980 and Puschell 1980). The time scale for a substantial change in flux from a hot dust cloud is roughly the light travel time across the dust cloud, since the heating and cooling times for the dust grains are insignificant. From the simple equilibrium condition for an optically thin dust cloud (see Jones *et al.* 1977 for a more general treatment),

$$\epsilon_a \frac{L}{4\pi R^2} \pi r^2 = \epsilon_r \sigma T^4 \, 4\pi r^2, \qquad (1)$$

where ϵ_a is the absorption efficiency, ϵ_r is the reradiation efficiency, L is the luminosity of the source of heating photons, R is the size of the dust cloud, and r is the size of the dust grains, it follows that

$$T = 20(L/R^2)^{1/5} \qquad (2)$$

for $\epsilon \propto \lambda^{-1}$ and $\lambda_a \sim 0.3\ \mu$m. For 3C 382, $R \sim ct_{\rm var}^{2.28\ \mu m} \lesssim 3 \times 10^{18}$ cm, and $L_{\rm UV} \gtrsim 3 \times 10^{44}$ erg s^{-1}, so that $T \gtrsim 700$ K. Thus, the idea that hot dust is responsible for most of the near-IR radiation from 3C 382 is self-consistent in the sense that the observed UV luminosity of the source and the time scale for 2.28-μm variations predict a temperature for dust causing it to reradiate in the near-IR.

For dust reemitting at 10 μm, Eq. (2) and the above

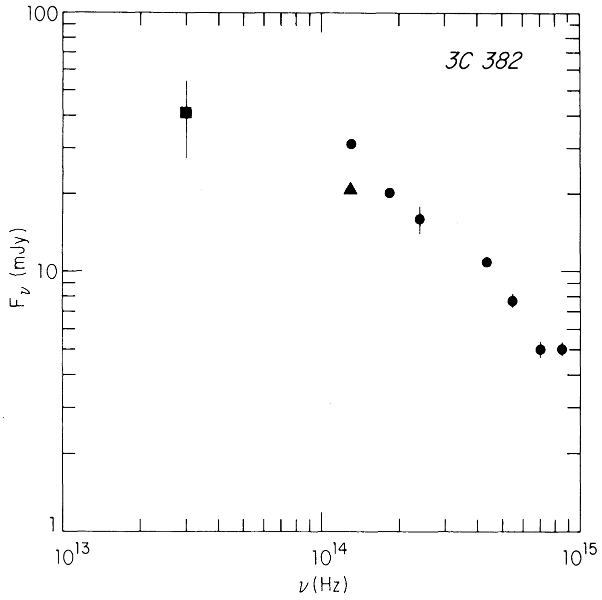

FIG. 2. The visual-infrared spectral flux distribution at 3C 382. The circles refer to measurements obtained through an 18″ aperture at the Mt. Lemmon Observing Facility during July 1978. The triangle refers to the 2.28-μm flux level before the outburst appeared at that wavelength. The square represents a 10-μm measurement made at the NASA 3-m IRTF.

parameters predict a variability time scale of ~20 yr. Thus, if the 10-μm flux is from somewhat cooler dust around the nucleus, Fig. 2, showing the 0.36–2.3-μm spectral fluxes for July 1978 and the 10-μm spectral flux for May 1980, may be reasonably thought of as representing the visual-infrared spectral flux distribution during mid-1978.* The flattening of the spectral flux distribution between 2.3 and 10 μm may be due to 3C 382 entering an active phase at short wavelengths only recently, resulting in the 10-μm emission not yet having had time to "catch up" to the 2.3-μm emission. This conjecture is supported by the general increase in visual-wavelength fluxes through the 1970s as inferred from the results of Sandage (1972), Aksenov and Kurochkin (1978), and this work. Studies of archival plate collections could determine whether or not 3C 382 has recently entered a relatively active phase at optical wavelengths. Another possible explanation for the turnover is that the dust is strongly concentrated toward the central heating source, so that most of the energy reradiated in the IR is from very hot dust.

In summary, a large increase in the visual-wavelength flux from 3C 382 occurred with a time scale of about a month during mid-1977. The infrared fluxes remained constant during the onset of the outburst, but showed an increase at 2.28 μm about a year later. Furthermore, the 2.20- and 3.50-μm fluxes remained relatively high in August 1980, even though the level of visual activity was lower in May 1980. The extension of the spectral flux distribution to 10 μm shows a flattening between 2.20 and 10 μm, suggesting that 3C 382 may have recently entered an active phase, or the putative dust is strongly concentrated toward the heating source. Such behavior constitutes strong evidence for the presence of thermally reradiating dust in the nuclear regions of the broad-line radio galaxy 3C 382.

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* The difference in aperture size is probably unimportant, because the 6″ aperture used at 10 μm includes the inner 7 kpc of 3C 382 and thus practically all of the 10-μm emission, considering the infrared emission from active galaxies is always concentrated toward the nucleus (e.g., Rieke and Lebofsky 1979 and references therein).

REFERENCES

Aksenov, E. P., and Kurochkin, N. E. (1978). IAU Circ. No. 3197.
Burstein, D., and Heiles, C. (1978). Astrophys. J. **225**, 40.
Dower, R. G., *et al.* (1980). Astrophys. J. **235**, 355.
Elvis, M., *et al.* (1978). Mon. Not. R. Astron. Soc. **183**, 129.
Jones, T. W., Leung, C. M., Gould, R. J., and Stein, W. A. (1977). Astrophys. J. **212**, 52.
Lebofsky, M. J., and Rieke, G. H. (1980). Nature **284**, 410.
Longair, M. S., and Perryman, M. (1980). In preparation.
O'Dell, S. L., Puschell, J. J., Stein, W. A., Warner, J. W., and Ulrich, M. H. (1978). Astrophys. J. **219**, 818.
Osterbrock, D. E., Koski, A. T., and Phillips, M. M. (1976). Astrophys. J. **206**, 898.
Puschell, J. J. (1979). Ph.D. dissertation, University of Minnesota.
Puschell, J. J. (1980). Submitted to Astrophys. J. Lett.
Rieke, G. H., and Lebofsky, M. J. (1979). Annu. Rev. Astron. Astrophys. **17**, 477.
Riley, J. M., and Branson, N. J. B. A. (1973). Mon. Not. R. Astron. Soc. **164**, 271.
Sandage, A. (1972). Astrophys. J. **178**, 25.