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VARIABILITY AND THE NATURE OF QSO OPTICAL-INFRARED CONTINUA

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ABSTRACT

We present the preliminary results of a program to study the optical and infrared continuum emission of "quiescent" QSOs using simultaneous *UBVRIJHK* photometry. The amplitude of variability in six of the seven sources discussed is greatest in the blue and ultraviolet and decreases toward longer wavelengths. Only 3C 273 exhibits variability at all wavelengths observed, changing by a similar amount in each spectral band. All of the other QSOs were nonvarying at 2.2 μm, despite variations in the visible and ultraviolet. This variability behavior and the optical-infrared spectral energy distribution in each object except 3C 273 strongly suggest that the infrared and variable optical continuum emission arise from distinct sources within the QSOs. We examine several possible models of the origin of the continua.

Subject headings: quasars — radiation mechanisms

I. INTRODUCTION

Angel and Stockman (1980) have suggested that QSOs may be generally grouped into two classes. The first class, the OVVs and BL Lac objects, consists of those sources which show rapid, correlated variations, large polarizations, and spectra which can be reasonably characterized as power laws over optical and infrared wavelengths. All these properties may be interpreted as evidence that a single nonthermal source produces the optical-infrared continuum emission. In the second broad class of QSOs, those sources which display mild variability, low polarization, and spectra which cannot be described by a single power law, the source of the optical and infrared continuum emission is not at all clear.

Most of the QSOs of this latter type show spectra which fall steeply through the infrared to a rest wavelength of about 1 μm, shortward of which the spectra become relatively flat (see, e.g., Neugebauer *et al.* 1979). These characteristics could be intrinsic to the continuum flux distribution, or they could indicate that the optical and infrared continua arise from distinct source components. The mild variability of these "quiescent" QSOs can be used to test interpretations of this spectral break, in a manner analogous to previous studies of Seyfert galaxies (Penston *et al.* 1974; Cutri *et al.* 1981; Lebofsky and Rieke 1981). To do so, we have performed simultaneous *UBVRIJHK* photometric monitoring of a selection of bright, mildly variable, low-polarization QSOs and have searched for correlations in the optical and infrared variability.

II. THE SAMPLE

The program objects were selected from the Revised Optical Catalog of QSOs (Hewitt and Burbidge 1980) to satisfy several criteria. First, sources were chosen for mild yet detectable variability (0.5 mag $\leq \Delta m_B \leq$ 1.5 mag), over long time scales ($\tau_{\rm var} \sim$ 1 yr). This criterion should exclude obvious OVVs and BL Lac objects. Implicit in this first constraint is relatively low optical polarization ($\lesssim$2%; Stockman 1978). Second, only objects within the declination limits of $-15° \leq \delta \leq +60°$ were considered so that they were accessible to the yoke-mounted telescopes at the UAO Mount Lemmon and Catalina sites. To facilitate accurate measurements, sample members were required to have archival *V* magnitudes brighter than 17.0 mag. Objects at $z \gg 1$ were excluded so that the rest frame 1 μm region would be accessible in *JHK* photometry. Those sources with published infrared magnitudes all had $K \leq 14.0$ mag, but only 10 of the objects in the sample had previously been observed in the infrared.

This sample was not intended to be statistically complete, but rather representative of a homogeneous cross section of the class of "quiescent" QSOs. These sources range in redshift from 0.06 to 1.04, and in apparent visual magnitude from 12.7 to 17.5 mag, thus assuring a fairly wide distribution in luminosity. A more detailed discussion of the sample and the data on all 20 members will be published after additional time coverage has been obtained; this interim report discusses the seven sources with the most complete data sets to date. See Table 1.

III. OBSERVATIONS

All the infrared observations were made with the University of Arizona 1.55 m telescope using a liquid helium–cooled photovoltaic InSb detector system. Broad-band photometry in the *J* (1.25 μm), *H* (1.65 μm), and *K* (2.2 μm) spectral bands was performed through an 11".5 aperture, typically using chopper throws between 12" and 15". Each QSO measurement was calibrated by comparison to the measurements of one of a set of nearby standard stars. As often as possible, the same standard star was used to reduce the observations of each QSO every time it was observed. The observed infrared magnitudes are listed in Table 2 and shown graphically in Figure 1.

TABLE 1

PROGRAM QSOs FOR OPTICAL-INFRARED MONITORING

Coordinate Designation	Alternate Designation	z	Variability Reference	Notes
PKS 0837−120	3C 206	0.200	1	
PKS 1004+130	4C 13.41	0.240	1, 2	
PKS 1217+023	ON 029	0.240	1, 2	
PKS 1226+023	3C 273	0.158	...	RV
1229+204	Ton 1542	0.064	1, 2	
PKS 1354+195	4C 19.44	0.720	1, 2, 3	z(abs) = 0.457, RV
PKS 1545+210	3CR 323.1	0.264	1, 2, 3	NRV

REFERENCES.—(1) Grandi and Tifft 1974. (2) Selmes, Tritton, and Wordsworth 1975. (3) Usher 1978.

NOTES.—RV = radio variable at 2.8 or 4.5 cm (Andrew *et al.* 1978). NRV = non–radio variable (Webber *et al.* 1978).

TABLE 2

Summary of Observed Magnitudes

QSO	Date (UT)	*U*	*B*	*V*	*R*	*I*	*J*	*H*	*K*	Notes
0837−120.........	81 Oct	16.06 ± 0.08	16.83 ± 0.08	16.60	16.09 ± 0.05	15.45 ± 0.06	14.99 ± 0.06	14.13 ± 0.04	12.85	Avg. of Oct 25, 26
	82 Feb 17	15.79	16.53	16.53	16.00	15.49	...	...	...	
	82 Feb	15.69 ± 0.06	16.51 ± 0.06	16.41	15.88	15.20 ± 0.04	...	...	...	17″ aperture, avg. of Feb 17, 20
	82 Apr	15.74	16.48	16.38	15.84	15.40	14.60 ± 0.07	14.11 ± 0.09	12.89 ± 0.10	
	82 Dec 19	15.65	16.34	16.18	15.80	15.21	...	...	...	17″ aperture
	82 Dec	15.54	16.37	16.24	15.85	15.32	14.58 ± 0.04	13.98	12.89 ± 0.08	IR avg. of Dec 19, 20
	83 Mar	15.38	16.23	16.14	15.78	15.19	14.62 ± 0.06	13.86	12.88	
	84 Feb	15.10	15.88	15.83	15.45	14.88	14.48 ± 0.05	13.75 ± 0.04	12.73	
1004+130.........	81 Feb	14.43	15.24	15.07	14.60	14.21	...	...	...	17″ aperture
	81 Apr 1	14.40	15.17	14.97	14.55	14.17	...	...	...	17″ aperture
	81 Apr 7	14.22	15.17	14.83	14.66	14.25	14.05 ± 0.04	13.56	12.73	
	82 Feb	14.32	15.16	14.92	14.58	14.18	14.02 ± 0.05	13.46 ± 0.05	12.67 ± 0.06	
	82 Dec	14.32	15.21	15.02	14.60	14.30	13.98	13.47 ± 0.06	12.71	Opt. 17″ aperture, IR avg. of Dec 19, 20
	83 Feb	14.51	15.33	15.07	14.64	14.28	14.13 ± 0.06	13.46	12.73 ± 0.04	
	83 May	14.58	15.24	15.10	14.76	14.30	14.04 ± 0.05	13.51	12.74 ± 0.04	
	84 Feb	14.53	15.34	15.09	14.70	14.33	14.12 ± 0.04	13.59	12.70	
1217+023.........	81 Apr	15.39 ± 0.05	16.29 ± 0.04	16.69 ± 0.09	15.92 ± 0.06	15.18 ± 0.05	14.82 ± 0.06	14.17	13.11	
	83 Feb	15.17	16.04	16.06	15.54	15.05	14.66 ± 0.05	13.95	13.04	
	83 May	15.52	16.43	16.34	15.84	15.39	14.75 ± 0.05	14.06 ± 0.04	13.10	
	84 Feb	15.47	16.30	16.37	15.87	15.21	14.69	14.02 ± 0.04	13.12	
1226+023.........	82 Jun	11.74	12.71	12.51	12.23	11.86	11.40 ± 0.05	10.66 ± 0.07	9.60 ± 0.06	Avg. of Jun 11, 12
	82 Dec	11.93	12.81	12.64	12.38	11.92	11.68	10.89	9.83	
	83 Feb	11.76	12.75	12.55	12.24	11.79	11.36	10.64	9.57	
	83 May	12.00 ± 0.09	12.93	12.71	12.48	12.02	11.54	10.76 ± 0.08	9.71	
	83 Dec	12.08	12.94	12.70	12.36	11.86	...	...	...	
	84 Feb	12.25	13.13	12.85	12.56	12.05	11.73	10.84	9.71	
	84 Mar	12.24	13.10	12.83	12.54	12.05	...	...	...	
1229+204.........	81 Apr	14.47	15.33	14.97	14.26	13.77	13.44 ± 0.04	12.60	11.70	
	82 Feb	14.55	15.49	15.05	14.38	14.02	13.40	12.56	11.69	
	82 Apr	...	...	...	...	...	13.26	12.43	11.59	
	82 Jun	14.42	15.36	15.00	14.32	13.97	13.26	12.54	11.72	
	82 Jun	14.42	15.28	14.83	14.26	13.90	...	...	...	17″ aperture
	82 Jun	14.38	15.20	14.78	14.11	13.76	...	...	...	26″ aperture
	83 Feb	14.22	15.29	14.92	14.27	13.94	13.24	12.60	11.60	
	83 May	14.38	15.31	14.97	14.26	13.94	13.52	12.67	11.78	
	84 Feb	14.28	15.24	14.96	14.18	13.77	13.46	12.72	11.63	
1354+195.........	81 Apr	15.94	16.54	16.36	16.10	15.70	15.24 ± 0.08	14.96 ± 0.06	14.08 ± 0.04	
	82 Feb	16.18	16.66	16.40	16.16	15.97	...	...	...	
	82 Jun	16.06	16.70	16.38	16.09	15.73	...	...	...	
	83 Feb	16.02	16.64	16.54	16.07	15.66	15.36 ± 0.11	14.94 ± 0.08	14.23 ± 0.07	
	83 May	16.22	16.63	16.41	16.11	15.73	15.55 ± 0.16	14.85 ± 0.04	14.22 ± 0.05	
	84 Feb	16.23	16.65	16.50	16.26	16.00	15.42 ± 0.12	14.84 ± 0.06	14.19 ± 0.06	
1545+210.........	81 Apr	15.82 ± 0.10	16.53 ± 0.13	16.25 ± 0.11	15.51 ± 0.05	15.25 ± 0.07	14.57 ± 0.04	13.82	12.84 ± 0.04	
	82 Jun	14.90	15.74	15.69	15.27	14.86	14.65 ± 0.05	13.85	12.89	
	83 May	15.18	16.08 ± 0.06	16.01	15.50	14.93	14.87 ± 0.08	13.98	13.12 ± 0.04	Avg. of May 3, 5
	84 Feb	15.23	16.09	16.00	15.50	14.88	14.74 ± 0.06	13.94	12.91	

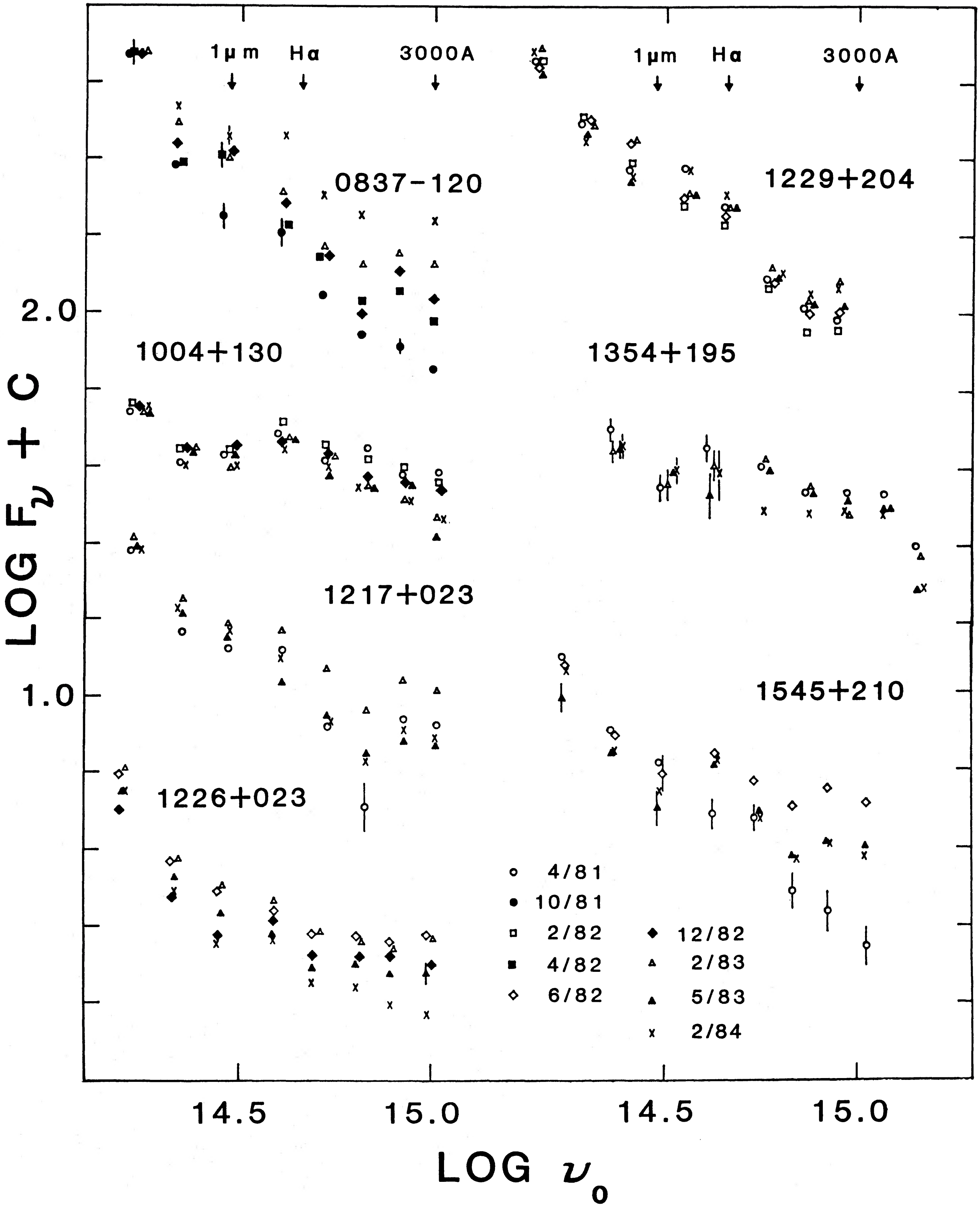

FIG. 1.—The observed spectral energy distributions of the program QSOs with the best temporal coverage are plotted here in the rest frame frequencies of the objects. Spectra have been plotted for only those epochs with simultaneous infrared and optical observations and have been arbitrarily normalized. The error bars shown represent statistical uncertainties in individual measurements when those uncertainties exceed 5%. Fiducial markers at 1 μm, 3000 Å, and the nominal position of Hα are included.

Optical photometry was performed with the NASA 1.5 m telescope on Mount Lemmon. Photoelectric measurements in the Johnson *U*, *B*, *V*, *R*, and *I* spectral bands were made using a dry ice–cooled Varian 159A photomultiplier. Typically, the projected beam diameter was 12″, although some measurements were made with other apertures as noted in Table 2. The optical photometry was calibrated against observations of standard star sequences made throughout each night. The optical magnitudes are also listed in Table 2 and shown in Figure 1.

By using the same observing systems and equipment for the duration of this work we have been able to accumulate consistent temporal spectral information that is free of any effects resulting from comparing data acquired with different photometric systems or beam sizes. Statistical errors in these magnitudes amount to ≤ 0.03 mag unless otherwise noted. The total photometric uncertainties are estimated to be 0.05–0.06 mag. The optical and infrared data for a given QSO were usually obtained within 1 hr of each other, except on those dates so marked in Table 2. There was no evidence for variability on time scales up to a few days. Therefore, in the case where data were obtained from the same object on consecutive nights, the average magnitudes are given in the table. Figure 1 shows the observed broad-band flux densities of the QSOs, plotted at the rest frame frequencies. Only the data from those nights during which both infrared and optical observations were made are included in the figure. As is seen in the spectra, the contribution of the Hα line flux to the broad-band fluxes can be considerable. We have made no attempt to correct for contamination by this or any other emission line for this presentation. The nominal frequencies of the 1 μm "break" and the 3000 Å "bump" seen in many quiescent QSOs are also noted.

Detailed monitoring of 3C 273 at 10 μm was reported by Rieke and Low (1972). Since then, we have continued to measure this source occasionally. To increase the photometric accuracy, observations were made relative to the nearby star ρ Vir. The source appeared to be inactive during this period at a flux level of 0.239 ± 0.014 Jy (Rieke and Lebofsky 1979). In view of the increase in optical activity, we repeated measurements of 3C 273 relative to ρ Vir on 1983 January 10 and 11 with the NASA Infrared Telescope Facility on Mauna Kea. We used the Seward Observatory bolometer system with a defining *N* bandpass filter and aperture (5″.8) that were virtually the same as those used previously. We found a flux of 0.295 ± 0.009 Jy, an increase of 0.056 ± 0.017 Jy over the flux level in 1973–1979.

IV. RESULTS

A summary of the maximum amplitudes of variation at each wavelength is displayed in Figure 2. Given the measurement accuracy of 0.05 mag, we consider statistically significant variations to have occurred if measurements made at two separate epochs differ by more than 0.20 mag. Optical variability is indicated for all seven of the QSOs discussed here, with the largest variations occurring in the *U* band and the amplitude of the changes decreasing toward longer wavelengths. The one possible exception is 1354+195 which may have weak variability in *I* but does not show variations in other bands. No variations were noted to exceed the magnitude or time scale limits specified in the sample definition.

The most striking feature of the variability data in Figures 1 and 2 is the virtual absence of any significant infrared variability. By infrared, we refer to wavelengths longer than 1 μm in the rest frame of the QSO. Particular emphasis is given to the *K* magnitude because it is least likely to be contaminated by stellar emission or any continuum source which might dominate the optical emission. Only 3C 273 shows indisputable change in the infrared flux levels. There is some suggestion of infrared variability in 1545+210, but at a lower significance level than in 3C 273.

Stellar emission from an underlying galaxy peaks near 1.5 μm and would, therefore, contribute a nonvariable component to the QSO light in the near-infrared. Nebulosity has been detected around four of the seven QSOs discussed here, including 0837−120 (Wehinger and Wycoff 1978), 1226+023 (Wycoff *et al.* 1980), 1229+204 (Vanderriest and Lelievre 1977; Hutchings, Crampton, and Campbell 1982), and 1545+210 (Kristian 1973). A number of authors have identified the nebulosity with the host galaxy of the QSO. An upper limit to the contribution of starlight can be made by assuming that each QSO resides in a giant elliptical galaxy; it is usually found that the host galaxies are significantly fainter than giant ellipticals. We estimate the near infrared brightness of such a galactic component by using the *K* magnitudes from the Hubble diagram for giant ellipticals (Lebofsky 1981) corrected to a 12″ aperture, and by extrapolating to shorter wavelengths using standard galaxy colors and *K*-corrections for the appropriate redshifts (Lebofsky and Eisenhardt 1985). The resulting fraction of the light from each QSO that may be contributed by an underlying galaxy is listed in Table 3. In only one QSO, 1229+204, could a significant portion of the near-infrared emission arise from a host galaxy. Hutchings, Crampton, and Campbell (1982), however, have derived an apparent brightness for the host galaxy of this object approximately 1 mag fainter than our upper limit; hence, at least at *K* the galaxy contribution to the total flux is small. It appears that in no case is stellar emission sufficiently strong to account for the reduced infrared variability in our program QSOs.

Infrared photometry obtained by others can be used to expand on the results reported here. In particular, Glass (1981) obtained repeated *JHK* measurements of a number of QSOs, frequently over a period of 1 or 2 yr. In no case is there detectable variation at 2.2 μm for those sources at $z < 1$ which are not optically violently variable. Although photometric systems may differ slightly, particularly on objects with nonstellar spectra, it is also of interest to compare photometry by different groups to extend the time baseline. Reasonably complete coverage over a period of 7 yr is available for 0837−120 and 1004+130 from the work of Neugebauer *et al.* (1979), Glass (1981), Hyland and Allen (1982), Sitko *et al.* (1982), and our work. Neither QSO exhibits any significant variability at *K* over this interval. Our *K* measurements of 1217+023 agree

TABLE 3

UPPER LIMITS TO THE CONTRIBUTION OF GALACTIC LIGHT TO TOTAL QSO LIGHT

	F_{gal}/F_{total}		
QSO	*J*	*H*	*K*
0837−120	0.23–0.33	0.27–0.34	0.21
1004+130	0.14	0.14	0.13
1217+023	0.17	0.22	0.18
1226+023	0.02–0.03	0.03	0.02
1229+204	0.81–0.96	0.89	0.57
1354+195	0.03	0.04	0.07
1545+210	0.12–0.15	0.15–0.18	0.15

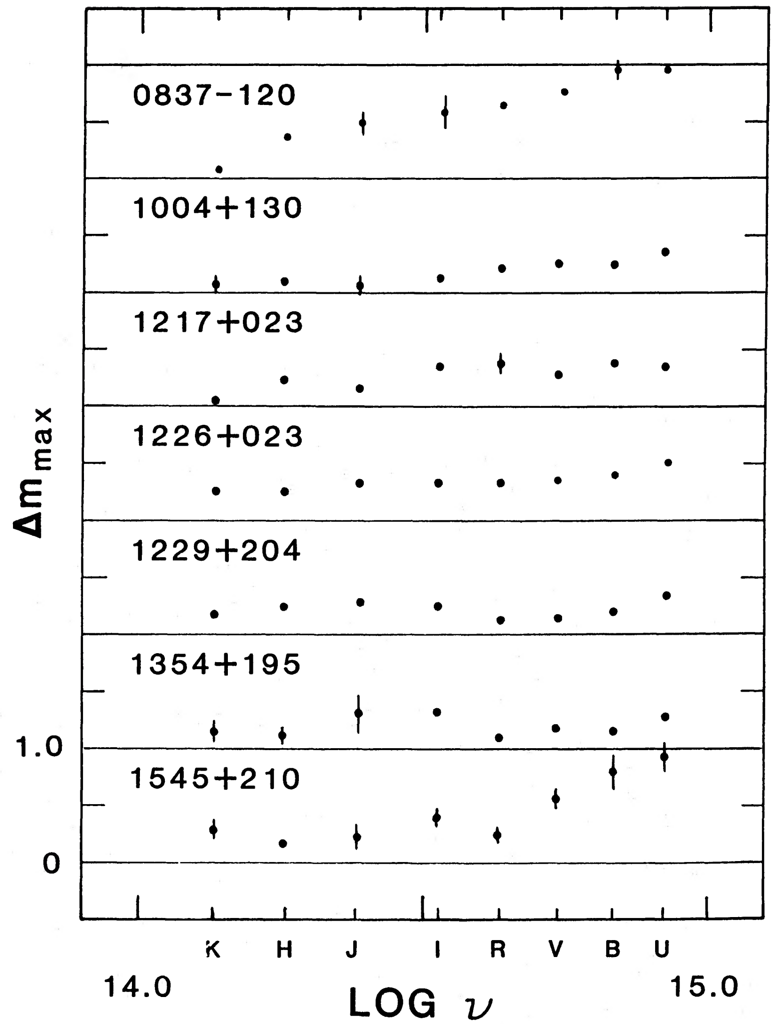

FIG. 2.—The maximum amplitude of variation, in magnitudes, for each observed spectral band. The points represent the difference in observed magnitude between maximum and minimum light. Error bars shown represent the uncertainties in each individual measurement taken in quadrature and are included only when they exceed 0.05 mag.

excellently with that of Hyland and Allen (1982), showing no changes over a total interval of 5 yr. Optical photometry was obtained simultaneously only with our measurements, so over these more extended baselines we cannot be positive that optical variations occurred that were decoupled from the infrared. However, given the typical time scales for optical variability, such a conclusion appears highly likely.

V. DISCUSSION

The only source in our sample in which the infrared flux appears to be closely coupled to variations in the optical is 3C 273; we therefore postpone a description of it and treat the remaining six objects together. We now list some possibilities to explain the optical-infrared continua of these QSOs and compare them with the typical pattern of variability described above.

a) Optical Continuum

While there is a wavelength dependence in the amplitude of the optical variations in most of the QSOs discussed here, the variations are predominantly in phase. That is, the changes observed at all wavelengths are well correlated in time, though they may differ in magnitude. This indicates that the variable optical continuum emission arises from a single region no more than about 1 lt-yr in radius. The decrease in variability toward longer wavelengths would follow naturally if this variable source dominates the emission at or below 3000 Å but contributes a small percentage of the total continuum flux at the longest wavelengths. Alternately, we may be seeing variations in the spectral energy distribution of a single source—arising, for example, from variations in the high-energy electron spectrum responsible for synchrotron emission.

In the first of these possibilities, the intrinsic spectrum of the variable source can be determined by subtracting the spectra observed at different epochs. The spectra are found to be extremely flat (i.e., $F_\nu \approx$ constant), or even, in the extreme case of 1545+210, possibly to rise with increasing frequency. In the second possibility, at least at maximum light the variable source appears to dominate the total output in the blue and ultraviolet. The optical spectra of each of the sources flatten with increasing brightness, and, at maximum, all have slopes less than $\alpha = 0.5$ (where $F_\nu \propto \nu^{-\alpha}$). In particular, those sources which exhibit the most extreme variability, 0837−120 and 1545+210, have optical spectra significantly flatter than this.

In either case, the salient feature of the variable optical continuum is its extremely flat slope. In the presence of electron energy losses, such behavior is difficult to produce at optical frequencies with plausible synchro-Compton source models (e.g., Kardashev 1962). Mechanisms other than pure synchrotron emission need to be considered for production of the variable optical continuum.

Given the relatively slow variability of these QSOs, it is conceivable that significant fluctuations in the line strengths in their broad emisssion-line regions are occurring in response to changes in the ionizing continuum. In principle, the variable continuum source need not be detectable in our photometry; however, the paucity of strong emission lines in QSO spectra longward of 7000 Å in the rest frame would make it difficult to explain the observed variability at these wavelengths. Our data appear to be generally consistent with a model in which the nonthermal continuum is seen directly in the red, with quasi-simultaneous variability by excited gas supplementing the nonthermal continuum at shorter wavelengths. A second possibility is that the continuum source itself has a flat or rising spectrum, possibly corresponding to a hot blackbody or an accretion disk (e.g., Malkan 1983). These possibilities need to be tested more definitively by monitoring these objects with optical spectrophotometry.

b) Infrared Continuum

i) *Single Source with Complex Spectrum*

In light of the possibilities discussed for the optical continuum, the infrared spectrum could simply be an extension of the output of a single complex central source, in which case the observed variability behavior represents a hardening and softening of the output in response to changes in such parameters as source temperature, maximum relativistic electron energy, etc. Although such models cannot be absolutely ruled out by our observations, they fail to explain the very frequent occurrence of spectral breaks just at 1–1.5 μm (e.g., Neugebauer *et al.* 1979; Glass 1981; Hyland and Allen 1982). The similar spectral breaks found in type 1 Seyfert galaxies are presumably analogous and appear to be most easily explained as the output of a distinct source component which dominates in the infrared. Consequently, we consider single-component models to be much less probable than those with a separate source component to account for the nonvarying infrared flux.

ii) *OVV QSO plus Optical-UV Excess*

One possibility would have all QSOs contain a BL Lac– or OVV–type nucleus; the relatively quiescent sources observed by us would have an additional and less variable spectral component dominating the visible flux and accounting for the general spectral flattening shortward of 1 μm. Such models would predict that the variability amplitude would increase longward of 1 μm and farther into the infrared would be typical of OVV sources. This behavior is clearly inconsistent with our observations.

iii) *Central Source plus Thermal Radiation*

Neugebauer *et al.* (1979) and Hyland and Allen (1982) have suggested that hot dust near the broad-line region could account both for the spectral inflection near 1 μm and for a general tendency near 2–3 μm for QSOs to have a weak excess above a power law. The variability observations reported here are an independent test of this suggestion for QSOs.

The steeply rising infrared component seen in these QSOs is consistent with the presence of thermal emission from dust grains which lie within a few parsecs of the central source and is analogous to the thermal spectral components identified in Seyfert 1 galaxies. If there is a contribution to the near-infrared light by hot dust, the consistent location of the spectral inflection near 1 μm in QSOs would then be a natural consequence of the 1500 K upper temperature limit for grains before evaporation.

Variations in the thermal emission due to fluctuation in the heating source might be expected in QSOs which exhibit variable optical-ultraviolet spectra. The high luminosities of the QSO nuclei would be expected to destroy dust close enough to the nucleus to vary on short time scales; roughly, the shortest time scale for variations by thermal reradiation should be proportional to the square root of the nuclear luminosity. The time scale in NGC 4151, with a luminosity of about $10^{10}\ L_\odot$, is of the order of months (Penston *et al.* 1974; Rieke and Lebofsky 1981). The QSOs studied here have luminosities 100–1000 times greater, and therefore the lack of infrared variations over 2–3 yr is consistent with a continuity of properties with type 1 Seyfert galaxies.

The response of thermal reradiation to variations in the heating is likely to depend on both the geometry about the central source of the regions containing the grains and on the optical properties of the grains. Any decline in the mean density of grains with increasing distance from the center will tend to dampen the amplitude of the response of the thermal component to variations in the central source. Extreme optical properties could have the same effect. Although it is an attractive possibility, it is not clear that the grain properties in QSOs will be similar to those in Seyfert 1 galaxies. Hence, additional observations to test for the expected dependence of variability time scale on luminosity would be one way to confirm the thermal radiation model, but the lack of infrared variations on any time scale does not rule it out.

iv) *Central Source plus Excited Gas*

Puetter and Hubbard (1985) have recently suggested that free-free emission from very dense ($n_e > 10^{10}$ cm^{-3}) broad-line clouds could produce a near-infrared excess in QSO spectra that would in some ways mimic an excess due to hot dust. This suggestion would also appear to be consistent with our observations and might be a viable alternative to explain the behavior of type 1 Seyfert galaxies. More detailed monitoring of variations to determine the shape of the high-frequency tail of the excess could distinguish the two cases, since free-free emission can contribute significantly to the flux shortward of 1 μm. One might also search for variations of the infrared excess correlated with changes in the broad emission line components.

c) 3C 273

By far the most extensive observations of any QSO are available for 3C 273. In general, it has shown a remarkable lack of variability in both the infrared and the optical (see, e.g., Neugebauer *et al.* 1979). A brief flare was detected in early 1972 both at 2.2 μm and at 10.6 μm (Rieke and Lebofsky 1979). Recently, 3C 273 has shown increased activity in the optical and infrared (e.g., Robson *et al.* 1983), leading us to add it to this sample.

Unlike the other QSOs, 3C 273 shows detectable variations through 2.2 μm that are at least roughly correlated with its variations in the optical (see Table 1). We also found evidence for a change in flux level at 10.6 μm; as discussed in § III, compared with the average of previous measurements it was 35% $\pm$ 12% brighter relative to ρ Vir.

The spectrum of 3C 273 in a quiescent state can be fitted well by a single power law of slope 0.7 from 10 mm to 1 μm, with a broad excess centered near 3 μm accounting for approximately half the flux at this wavelength (Robson *et al.* 1983; Neugebauer *et al.* 1979). In this case, it appears that the nonthermal source component is a large enough fraction of the total near-infrared flux that its variations are apparent. Hyland and Allen (1982) noted a small number of other QSOs which had exhibited infrared variations; they may be similar to 3C 273 in this regard.

V. CONCLUSION

We have presented data from simultaneous optical and infrared observations of seven mildly variable QSOs. Of these sources, only 3C 273 was observed to vary at all wavelengths, including 2.2 and 10 μm. We conclude that its infrared flux is dominated by nonthermal emission, although the broad excess above a power law near 3 μm may arise through some other means such as reradiation by hot dust. The remaining six sources have generally very similar behavior: the most extreme variability occurs at the shortest wavelengths observed, and the scale of variations decreases steadily toward the longer wavelengths. There are no conspicious time delays between the variations observed at different wavelengths. Most striking is the fact that none of these six QSOs show evidence for variability at 2.2 μm, the longest wavelength surveyed.

The lack of variations at 2.2 μm and a nearly universal spectral inflection at 1–1.5 μm both indicate that most of the near-infrared luminosity in these quiescent QSOs is produced by a source component distinct from that which dominates the optical and ultraviolet spectra. In this regard, the QSOs behave analogously to type I Seyfert galaxies. In both cases, it is plausible that the near-infrared emission arises from hot dust within a few parsecs of the central source.

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