THE ASTROPHYSICAL JOURNAL, 288:718–724, 1985 January 15

THE BURSTING BEHAVIOR OF THE BL LACERTAE OBJECT B2 1308+326

S. L. MUFSON[1]
Indiana University

W. A. STEIN
University of Minnesota

W. Z. WIŚNIEWSKI
Lunar and Planetary Laboratory

J. T. POLLOCK
Appalachian State University

AND

H. D. ALLER AND M. F. ALLER
University of Michigan

Received 1984 March 19; accepted 1984 August 1

ABSTRACT

Visual and radio observations of the BL Lac object B2 1308+326 have been accumulated for a period of several years. In this source, repetitive optical–near-infrared outbursts are observed which can have luminosities exceeding 10^{48} ergs s^{-1}. Based on light travel time arguments, the size of the region powering these bursts is less than 10^{17} cm. In the radio, bursting behavior is also observed. However, the radio bursts are less energetic and come from larger regions. We argue that the photometric properties of B2 1308+326 are the result of nonthermal emission by an object or objects with $M > 10^8\ M_\odot$ confined to a region of dimension $R \lesssim 10^{17}$ cm.

Subject headings: BL Lacertae objects — infrared: sources — radiation mechanisms — radio sources: variable

I. INTRODUCTION

The powerful BL Lac object B2 1308+326 is a strongly variable, highly polarized source of nonthermal radiation. At optical and near-infrared wavelengths, this source is seen to brighten by 1.5–2.5 mag and then dim on a time scale of weeks to months (Moore *et al.* 1980; Pollock 1982). If we assume that B2 1308+326 is an isotropic emitter and that its weak Mg II emission-line redshift of $z = 0.996$ (Miller, French, and Hawley 1978*a*) is cosmological, then the optical–near-infrared luminosity of this source during its peak emission periods can exceed 10^{48} ergs s^{-1} (Pollock 1982). This makes B2 1308+326 one of the most powerful quasars known.

In the radio regime, B2 1308+326 is also strongly variable and polarized. But in the radio, the time scale on which the source brightens and then dims is a year or more. There appears to be little correlation between the optical and radio variability.

In 1977, the spectral flux distribution of B2 1308+326 was measured in a coordinated multifrequency program of radio-visual observations (O'Dell *et al.* 1978). It was found there that the flux density remains roughly constant as the frequency varies between 15 and 90 GHz, and then falls as the frequency decreases below 15 GHz. This behavior is characteristic of an inhomogeneous synchrotron emitter which is showing the effects of synchrotron self-absorption (Condon and Dressel 1973). The flux density distributions in the optical and near-infrared both have power-law shapes ($S \propto \nu^\alpha$), with the optical spectral index being somewhat steeper than the infrared. The flux density distribution in the optical-infrared is most likely due to optically thin synchrotron emission. In a spectrum like that observed in B2 1308+326, most of the luminosity is radiated in the infrared.

We present here optical and radio light curves of B2 1308+326 made over a period of several years. These data have been assembled from published sources and private monitoring programs. One interesting result we have found is that the optical bursts seem to recur on a time scale of approximately 1 year; however, the sporadic nature of the observations makes it impossible to demonstrate this conclusion reliably. Our analysis shows that the bursts observed in B2 1308+326 are probably powered by an object or objects with $M > 10^8\ M_\odot$ confined to a region of dimension $R \lesssim 10^{17}$ cm.

II. PHOTOMETRIC HISTORY OF B2 1308+326

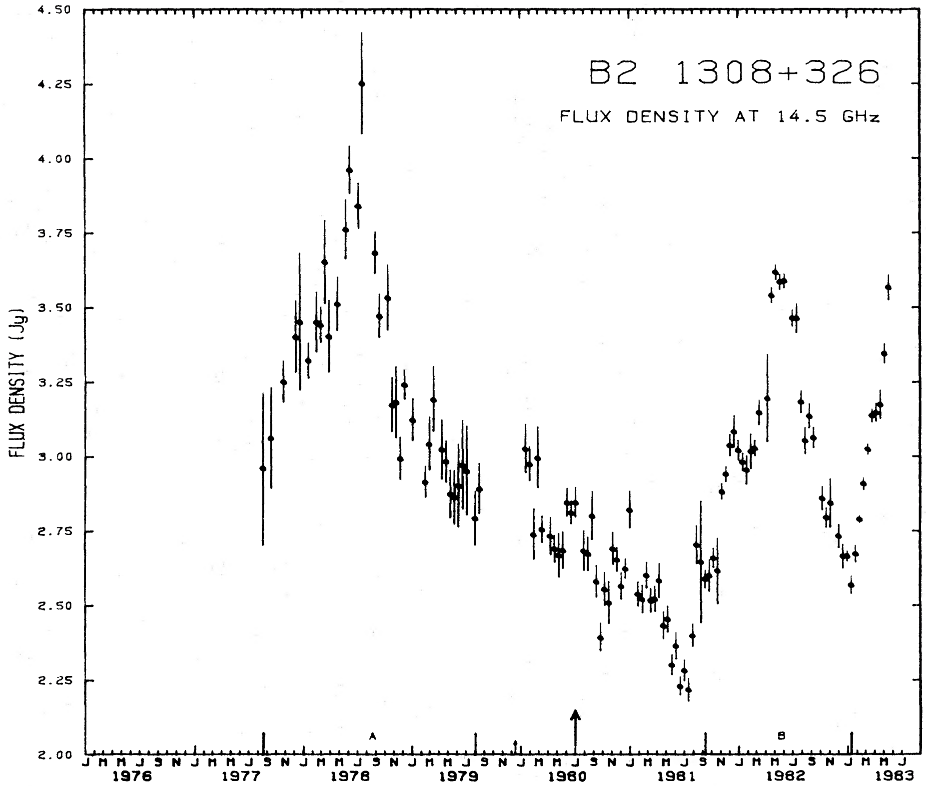
a) Optical Regime

In Figure 1 we show the flux density of B2 1308+326 in the *B* bandpass from late-1976 to 1983. The data in this figure were obtained from the many different sources described below. Once collected, the data were converted to a flux density scale using the factor 4.64×10^3 Jy for a 0 magnitude star (Johnson *et al.* 1966). The flux densities were then averaged over 2 week intervals, with each measurement weighted by its photometric error. The weighted mean of the flux density for each 2 week period is plotted in Figure 1. The errors on the data points are errors of the mean computed from the photometric errors.

The data shown in Figure 1 have been obtained both from individual monitoring programs and from the literature. Rather than enumerate each data point separately, we will simply list where the data have been obtained.

Many data points were obtained from the photoelectric monitoring program of W. Z. W. This ground-based photoelectric photometry consists of broad-band *UBVRI* measure-

[1] Guest Observer with the *HEAO 2* satellite.



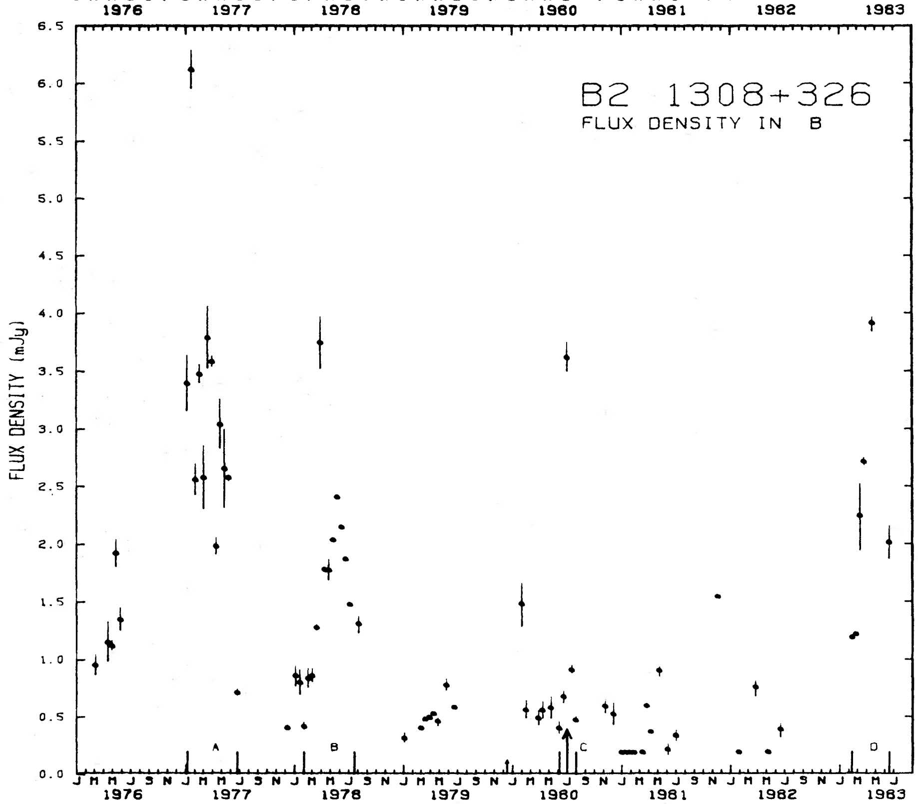


FIG. 1 (*top*).—Optical light curve of B2 1308 + 326 from 1976 to 1983. The sources for the data are given in the text. Parameters for the four marked bursts are given in Table 1. The *Einstein* X-ray measurements are marked by arrows, with the height of the arrow proportional to the X-ray count rate. The coverage is not good enough to determine whether event A includes the small, earlier burst, nor do we have measurements which would determine the base level of burst D.

FIG. 2 (*bottom*).—Radio light curve of B2 1308 + 326 from 1977 to 1983. The data shown here were obtained at the University of Michigan Radio Observatory. Two prominent bursts are marked. Parameters for these bursts are given in Table 2. The X-ray measurements are marked by arrows, as in Fig. 1. There is no apparent correlation between the radio and X-ray bursts.

ments made using the University of Arizona's 1 m and 1.5 m telescopes on Mount Lemmon and the 1.5 m telescope on Mount Hopkins. Extinction and transformation coefficients were determined from observations of the primary *UBVRI* standards (Johnson *et al.* 1966). Many additional data points come from Pollock (1982). The majority of these data points were obtained photographically as part of the University of Florida quasar monitoring program. The plates used employ a plate-filter-instrument combination which yields magnitudes reasonably close to the standard Johnson *B* magnitudes. The 1983 data points from the Florida program shown on Figure 1 were kindly supplied to us by Mr. J. Webb and Dr. A. Smith of the University of Florida. The plate reduction technique used for these data has been carefully discussed by Pollock (1982). Other unpublished photoelectric measurements in Figure 1 include measurements for 1977–1978 by H. D. Miller; measurements for 1983 by Sitko, Stein, and Smith; Balonek and Smith; and Landau.

The published data in Figure 1 have been obtained from Stein *et al.* (1978), O'Dell *et al.* (1978), Puschell *et al.* (1979), Mufson *et al.* (1980), Puschell and Stein (1980), and Moore *et al.* (1980).

Examination of the optical light curve in Figure 1 shows clearly that B2 1308+326 undergoes frequent periods of bursting activity. Tick marks which show the four most prominent of these bursts have been placed along the horizontal axis. Although they are not labeled, smaller bursts occur between the four large bursts. But since their scale of activity is an order of magnitude smaller, the weaker bursts have not been analyzed below. An active period (from base level to base level) can last from a few weeks to a few months, during which time B2 1308+326 can increase its brightness by up to a factor of 10. During most bursts, however, it only brightens by a factor of 3–5. When it is most active, B2 1308+326 can flare or fade by more than a magnitude in only a few weeks.

Figure 1 also shows some evidence that active periods recur quasi-periodically on a time scale of about 1 year. The observational coverage, however, is not good enough, nor is the timeline long enough to demonstrate this hypothesis reliably. This source needs to be monitored in a dedicated, photometric program to determine whether or not periodic behavior is present.

b) *Radio Regime*

Radio data were obtained at 14.5 GHz, 8.0 GHz, and 4.5 GHz by H. D. A. and M. F. A. using the University of Michigan computer-controled 26 m radio dish. The flux densities plotted in Figure 2 are 2 week means of the observations at 14.5 GHz, weighted by their photometric errors. The errors plotted are 1 σ errors of the mean.

As was the case for the optical light curve, the radio light curve of B2 1308+326 is composed of a sequence of bursts. The bursts in the radio, however, last a year or more, during which time the radio brightness of the source only increases by a maximum of 40%. The two strongest bursts in Figure 2 have been labeled by tick marks. (Although more than two bursts are required to explain the radio light curve, the uncertainty in the number and characteristics of these extra bursts is too great to make a further decomposition worthwhile.) There appears to be little correlation between the radio and the optical bursts.

c) *X-Ray Regime*

The X-ray data were obtained by the Imaging Proportional Counter (IPC) aboard the *HEAO 2* satellite (Giacconi *et al.* 1979). The data reported here have been reprocessed by the *HEAO 2* staff (phase 2 processing), and the total count rates given are free of most calibration problems. Two measurements were made. On 1979 December 12–13, the source had a count rate ([source-background]/effective exposure time) of $(3.5 \pm 0.4) \times 10^{-2}$ counts s^{-1}. Between 1980 June 30 and July 8, B2 1308+326 had a higher average count rate of $(1.23 \pm 0.08) \times 10^{-1}$ counts s^{-1}. On neither date, however, were enough counts observed to compute spectra or flux densities. On Figures 1 and 2, an arrow has been drawn on the horizontal axis proportional to the X-ray count rate. It is quite evident from Figure 1 that the soft X-ray emission was high during an optical flare, as was reported in Wiśniewski, Mufson, and Pollock (1980). Unfortunately, there are no optical data during the first X-ray measurement when the source was weak.

III. DISCUSSION OF THE LIGHT CURVES

a) *Optical Light Curve*

Table 1 gives the characteristics of the large bursts marked on Figure 1. After the designation of the event in column (1), we give in column (2) the size of the source as calculated from its variability time scale

$$d \lesssim \frac{4c}{\pi(1+z)} \frac{\delta T}{\delta L} \bar{L} \qquad (1)$$

(Terrell 1967). This formula assumes that no beaming is present. For each active period, we chose a value of $(\delta T/\delta L)\bar{L}$ corresponding to the largest variation which occurred in less than a month. In column (3) we have calculated the luminosity per unit frequency interval from the relation

$$\Delta L_\nu = 4\pi \Delta S_\nu \frac{c^2\{q_0 z + (q_0 - 1)[(1 + 2q_0 z)^{1/2} - 1]\}^2}{H_0{}^2 q_0{}^4} \qquad (2)$$

(Sandage 1975), where $\Delta S_\nu = S_\nu^{\text{peak}} - S_\nu^{\text{base}}$, S_ν^{peak} is the peak

TABLE 1

OPTICAL BURSTS

Event (1)	d (cm) (2)	$(\Delta L)_B^{\text{peak}}$ (ergs s^{-1} Hz^{-1}) (3)	α[a] (4)	S_0[a] (Jy) (5)	Optical/IR Luminosity[b] (ergs s^{-1}) (6)	E (ergs) (7)
A	2×10^{16}	1.2×10^{33}	−1.35	2.46	4.6×10^{48}	1.9×10^{55}
B	5×10^{16}	5.5×10^{32}	−1.40	1.68	2.1×10^{48}	7.9×10^{54}
C	3×10^{16}	5.0×10^{32}	−1.30	1.48	1.9×10^{48}	2.0×10^{54}
D	6×10^{16}	4.4×10^{32}	−1.25	1.98	1.7×10^{48}	9.0×10^{54}

[a] From spectral fits of the form $S_\nu = S_0(\nu/6.82 \times 10^{14})^\alpha$ Jy.

[b] $\int_{\nu_1}^{\nu_2} (\Delta L)_B^{\text{peak}}(\nu/6.82 \times 10^{14})^\alpha d\nu$, where $\nu_1 = 8.8 \times 10^{13}$ Hz and $\nu_2 = 8.3 \times 10^{14}$ Hz.

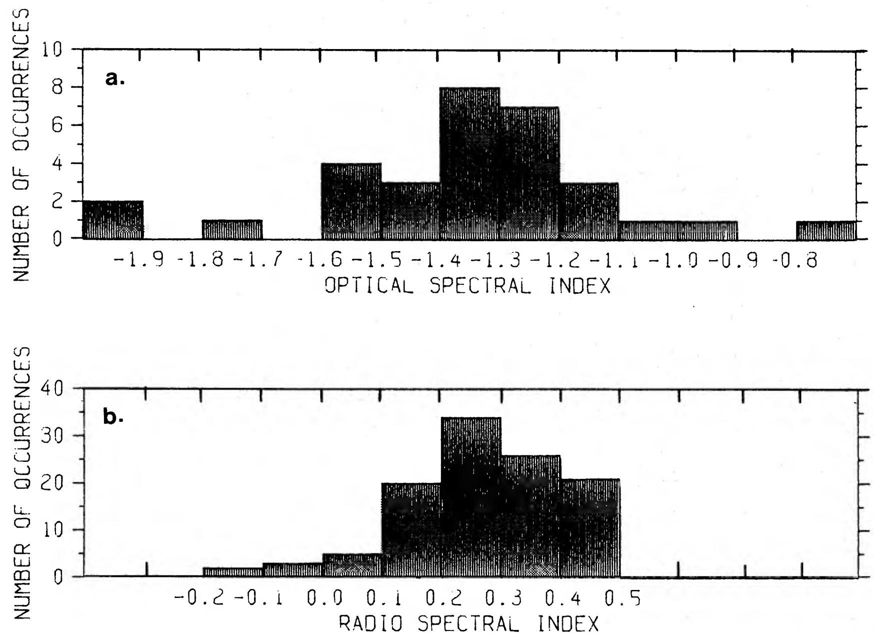


FIG. 3—(*a*) Histogram of the optical (*BVR*) spectral indices derived from our data. (*b*) Histogram of the radio (8–14.5 GHz) spectral indices derived from our data. Evidence for a partially opaque synchrotron spectrum is apparent.

flux density in the event, and $S_\nu^{\rm base}$ is the base-level flux density. In general, we chose as the base level the lowest measured flux density before or after the peak. In our calculations we have used $H_0 = 55$ km s^{-1} Mpc^{-1} and $q_0 = 0.5$, and we have assumed that the source emits isotropically. Clearly ΔL_ν would be reduced if the source were beaming radiation.

In column (6) we give the optical–near-infrared luminosity of each burst in the interval 0.36–3.45 μm (*U* band–*L* band). For this computation we have approximated the continuous spectrum of each burst as a single power law characterized by the mean *BVR* spectral index and the mean *B* flux density observed during the burst. These spectral parameters are listed in columns (4) and (5) of Table 1. In Figure 3*a* we have plotted a histogram of all the *BVR* spectral indices for our data set. As is easily seen, the spectral indices we used are near the mean. From Table 1 we find that a very small region within B2 1308+326 can flare to an optical–near-infrared luminosity in excess of 10^{48} ergs s^{-1}, making this quasar one of the most luminous objects in the universe.

Examination of the historical photometry of B2 1308+326 suggests that the optical spectral index is steeper than the near-infrared spectral index. However, the optical and infrared data were usually taken at different epochs, making it difficult to be certain whether the continuous spectrum of this rapidly variable source really has curvature. But if it does, then our computation of the peak luminosity in a burst (and the total energy in a burst computed below) is suspect. We have tested the accuracy of our approximation by fitting the simultaneous 1977 March optical–near-infrared data (O'Dell *et al.* 1978) with both a single power law and a second-order polynomial, and then integrated both spectra from 0.36–3.45 μm. We found that the results of the two computations differ by less than 10%. This leads us to believe that the assumption of a single power law is acceptable.

Finally we give in column (7) the total energy released in each burst. This calculation was made by converting the flux density at each point in the burst into a luminosity as outlined above, and then numerically integrating over the burst duration. (In our integration we have corrected the burst duration back to the source frame.) As seen from the table, prodigious amounts of energy are released during a burst, unless the source is beaming its radiation toward us.

b) *Radio Light Curve*

In Table 2 we list the characteristics of the two radio events marked in Figure 2. The calculations made for Table 2 are similar to the ones described for Table 1. In computing the radio luminosity, the continuous spectrum from 1 to 20 GHz was assumed to be a single power law. The radio spectrum in O'Dell *et al.* (1978) is in satisfactory agreement with this approximation. The mean spectral parameters we used in our calculations are listed in Table 2. As seen in Figure 3*b*, the

TABLE 2

RADIO BURSTS

Event	*d* (cm)	(ΔL) (ergs s^{-1} Hz^{-1})	α[a]	S_0[a] (Jy)	Radio Luminosity[b] (ergs s^{-1})	*E* (ergs)
A	9×10^{17}	2.3×10^{32}	0.10	0.60	3.1×10^{42}	4.5×10^{49}
B	6×10^{17}	1.6×10^{32}	0.35	0.40	2.2×10^{42}	2.4×10^{49}

[a] From spectral fits of the form $S_\nu = S_0(\nu/1.45 \times 10^{10})^\alpha$ Jy.
[b] $\int_{\nu_1}^{\nu_2} (\Delta L)^{\rm peak}_{14.5} (\nu/1.45 \times 10^{10})^\alpha d\nu$, where $\nu_1 = 10^9$ Hz and $\nu_2 = 2 \times 10^{10}$ Hz.

8–14.5 GHz spectral indices we used are near the mean for all the radio data. The inverted spectral indices seen in the radio continuum demonstrate clearly that B2 1308+326 is partially opaque below 15 GHz.

Comparison of Tables 1 and 2 shows that the optical–near-infrared luminosity of B2 1308+326 far exceeds what is seen in the radio. Not surprisingly, the source also has a larger variability size in the radio than it has in the optical–near-infrared.

IV. INTERPRETATION

It is beyond the scope of the present paper to develop a detailed model for the bursting behavior of B2 1308+326. However, we believe it is reasonable, in light of the data we have collected, to discuss here observational constraints which limit possible source models. We begin by supposing that the power-law emission and strong polarization observed in B2 1308+326 are best interpreted as incoherent synchrotron radiation. This enables us to estimate the physical parameters associated with the emitting volume. Assuming the optical bursts decay due to synchrotron radiation losses in approximately 1 week (Fig. 1), we find typical electron energies of $\gamma_e \sim 5 \times 10^4$ ($E = \gamma_e m_e c^2$) and magnetic field strengths of order $B \approx 0.1$ gauss. In the radio, assuming a decay time for a burst of approximately 1 year (Fig. 2), we again find $\gamma_e \approx 5 \times 10^4$. We calculate field strengths, however, which are an order of magnitude smaller, $B \approx 0.02$ gauss. We note that when the optical–near-infrared luminosity peaks at better than 10^{48} ergs s^{-1}, the ratio of the energy density in photons to the energy density in the magnetic field is large, $u_{\rm phot}/u_m \gg 1$, a result which implies a large self-Compton X-ray flux when the source is optically bright. In fact, we observed bright X-ray emission when the source was optically bright.

In Figure 4 we summarize the physical arguments that constrain the mass and size of the object responsible for the outbursts seen in B2 1308+326. The variability sizes given in Table 1 imply a source region of less than 10^{17} cm, unless relativistic beaming effects are present. This upper limit is indicated in Figure 4 as the "Variability size." (We discuss the effects of beaming below.) Angel *et al.* (1978) and Moore *et al.* (1980) argue for smaller emission regions, of order 10^{15} cm, on the basis of rapid fluctuations in the angle of polarization. But variations in the angle of polarization may involve only a small fraction of the emitting volume, so we do not base our light travel time arguments on them.

Next we place limits on the mass and size of the emitting region by considering what the central engine might be. In the case of many lower luminosity BL Lac objects, the nonthermal source lies in the nucleus of an elliptical galaxy (Ulrich *et al.* 1975; Miller, French, and Hawley 1978*b*). Continuity arguments with lower luminosity BL Lac objects therefore support the notion that B2 1308+326 is at the core of a distant galaxy. The presumption that BL Lac objects lie in the nucleus of a galaxy is a point of view most recently stressed by Begelman, Blandford, and Rees (1984). We thus associate the mass of a galactic nucleus with the emitting object, and adopt a conservative lower limit of $10^8 M_\odot$ for it. This limit is labeled "Galactic Nuclei" in Figure 4, and probably represents a true lower limiting mass. A lower limit to the size of the emission region can now be obtained by using the Schwarzschild radius $R_S = 2GM/c^2$ for masses in excess of $10^8 M_\odot$. This limit is also shown in Figure 4.

The mass within the nuclear region of B2 1308+326 could be either a single supermassive compact object (supermassive star, magnetized spinar, or black hole) or a dense cluster of lower mass compact objects. But no matter what powers the observed bursts, the luminosity generated should be constrained by the Eddington luminosity, $L_E = 1.3 \times 10^{46} M_8$ ergs s^{-1}, where M_8 is the mass in units of $10^8 M_\odot$. Several theoretical calculations have demonstrated this result. Models of spherical, supercritical ($\dot{M} > \dot{M}_E = L_E/c^2$) accretion onto

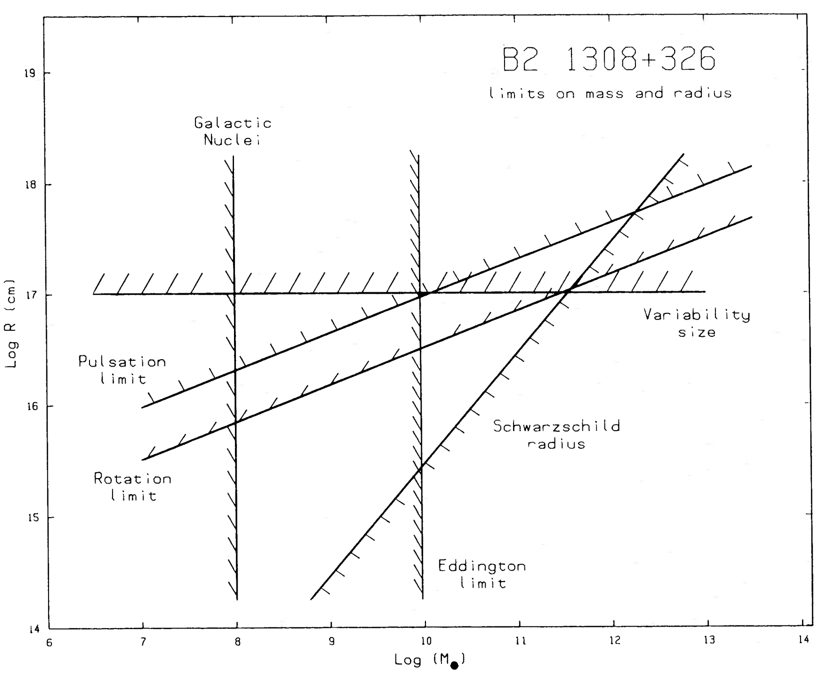


FIG. 4.—The theoretical mass-radius relation for B2 1308+326 in the absence of relativistic beaming. This figure demonstrates how constraints on the mass and radius are consistent with the bursts being powered by a supermassive compact object.

black holes (Gilden and Wheeler 1980; Flammang 1983) show that distant observers always see $L \lesssim L_E$. Radiation generated in excess of L_E is trapped and dragged into the hole. In addition, time-dependent, supercritical accretion onto neutron stars (Klein, Stockman, and Chevalier 1980; Burger and Katz 1983) generates $L \lesssim L_E$, except for an initial large pulse of radiation $\sim 1.25 L_E$ which rapidly decays to $L < L_E$ (Burger and Katz 1983). We have therefore used the Eddington limiting luminosity to estimate a minimum mass for the emitting volume associated with B2 1308+326. In this calculation we have used the average optical–near-infrared luminosity for all our observations, $\bar{L}(0.36\text{–}3.45\ \mu\text{m}) = 1.2 \times 10^{48}$ ergs s^{-1}, since the peak luminosity may represent a transient super-Eddington luminosity. Our result shows that $M \gtrsim 10^{10}\ M_\odot$, and has been labeled the "Eddington limit" in Figure 4.

Our data allow us to place further constraints on models for the emitting object in B2 1308+326. Since the maximum luminosity allowed for a stable supermassive star is 10^{47} ergs s^{-1} (Fowler 1966), at least a factor of 10 below what we observe in a burst, it seems unlikely that such an object could power B2 1308+326. However, a magnetized spinar or a black hole could be responsible for the luminosity we observe. If the emitting object is a magnetized spinar, then its nonthermal magnetic-dipole luminosity is (Bisnovatyi-Kogan and Blinnikov 1972)

$$L_{\text{em}} = B^2 R^6 \omega^4 / 8c^3 , \tag{3}$$

where B is the surface magnetic field of the spinar, R is its radius, and ω is its angular speed. Assuming a magnetic field strength of 0.1 gauss and a periodicity of 1 year (§ II*a*), we find that $R = 3 \times 10^{17}$ cm, a limit that agrees well with the size of the emission region determined from variability arguments. However, such a supermassive aspinar is thought to be unstable to collapse into a black hole (Begelman, Blandford, and Rees 1984). A cluster of stars or stellar remnants could also power the bursts (Weedman 1983), since large numbers of small compact objects of the same total mass as a single large object would produce the same luminosity. But this multiple source model is still constrained by the limits we have just discussed. The radius and mass of the object responsible for the outbursts observed in B2 1308+326 are confined to a region in Figure 4 which implies it is compact and supermassive.

We also show in Figure 4 the mass-radius relations for a single object rotating and for a single object pulsating with a period of 1 year, the typical time scale for the recurrence of the optical bursts. For an object rotating at its critical angular speed, where the equitorial centrifugal force equals the gravitational attraction at the equator, the rotation period is (Wagoner 1969)

$$P_r = \left(\frac{4\pi^2 R^3}{GM}\right)^{1/2} . \tag{4}$$

For the pulsation period we have

$$P_p = \left(\frac{\pi R^3}{2GM}\right)^{1/2} . \tag{5}$$

As is easily seen, these limits are consistent with our previous discussion.

Finally we must consider how the above arguments are modified by the presence of bulk relativistic motion or beaming. If bulk relativistic motion is present, the characteristics of the emitting volume change (e.g., Königl 1981). In particular, the emitting volume would be increased by a factor D and the optically thin luminosity would be decreased by a factor $D^{2+\alpha}$, where D is the relativistic Doppler factor and α is the optically thin spectral index (Begelman, Blandford, and Rees 1984). Nevertheless, the conclusion that the region from which the emission originates is very small in comparison with galactic dimensions still remains valid, since a massive compact object is required to collimate and power the relativistic flow (Begelman, Blandford, and Rees 1984). Further, all VLBI observations of powerful extragalactic jets find compact cores associated with them. We believe there is strong evidence that a compact supermassive object or objects are present in B2 1308+326, whether or not the source is beamed.

V. CONCLUSIONS

The remarkable light output of B2 1308+326 in the form of strongly polarized nonthermal radiation, observed over many years, implies the existence of a supermassive compact object or objects as its power source. This conclusion follows whether or not the observed emission is beamed nonthermal radiation. In addition, the light curve we have presented shows evidence that bursting activity may recur on a time scale of 1 year. More comprehensive observations of this source and others like it are clearly needed in order to obtain complete and accurate light curves. With these light curves we can gain a wealth of information about the processes and conditions in this active high-energy source.

We would like to thank Jim Webb of the University of Florida for contributing data in advance of publication. Research in extragalactic astrophysics at the University of Minnesota is supported by a grant from NSF.

REFERENCES

Angel, J. R. P., *et al.* 1978, in *Pittsburgh Conference on BL Lac Objects*, ed. A. M. Wolfe (Pittsburgh: University of Pittsburgh), p. 117.
Begelman, M. C., Blandford, R. D., and Rees, M. J. 1984, *Rev. Mod. Phys.*, **56**, 255.
Bisnovatyi-Kogan, G. S., and Blinnikov, S. I. 1972, *Ap. Space Sci.*, **19**, 119.
Burger, H. L., and Katz, J. I. 1983, *Ap. J.*, **265**, 393.
Condon, J. J., and Dressel, L. L. 1973, *Ap. Letters*, **15**, 203.
Flammang, R. A. 1982, *M.N.R.A.S.*, **199**, 833.
Fowler, W. A. 1966, *Ap. J.*, **144**, 180.
Giacconi, R., *et al.* 1979, *Ap. J.*, **230**, 540.
Gilden, D. L., and Wheeler, J. C. 1980, *Ap. J.*, **239**, 705.
Johnson, H. L. 1966, *Ann. Rev. Astr. Ap.*, **4**, 193.
Klein, R. I., Stockman, H. S., and Chevalier, R. A. 1980, *Ap. J.*, **237**, 912.
Königl, A. 1981, *Ap. J.*, **243**, 700.
Miller, J. S., French, H. B., and Hawley, S. A. 1978*a*, in *Pittsburgh Conference on BL Lac Objects*, ed. A. M. Wolfe (Pittsburgh: University of Pittsburgh), p. 176.
———. 1978*b*, *Ap. J. (Letters)*, **219**, L85.
Moore, R. L., *et al.* 1980, *Ap. J.*, **235**, 717.
Mufson, S. L., Hutter, D. J., Kaitchuck, R. H., Wiśniewski, W. Z., and Vrba, F. J. 1980, in *HEAO Space Science Symposium*, ed. C. Dailey and W. Johnson (NASA CP-2113), p. 214.
O'Dell, S. L., Puschell, J. J., Stein, W. A., Owen, F., Porcas, R. W., Mufson, S. L., Moffett, T. J., and Ulrich, M. H. 1978, *Ap. J.*, **224**, 22.
Pollock, J. T. 1982, Ph. D. Thesis, University of Florida.
Puschell, J. J., and Stein, W. A. 1980, *Ap. J.*, **237**, 331.
Puschell, J. J., Stein, W. A., Jones, T. J., Warner, J. W., Owen, F., Rudnick, L., Aller, H., and Hodge, P. 1979, *Ap. J. (Letters)*, **227**, L11.

Sandage, A. 1975, in *Stars and Stellar Systems,* Vol. **9**, *Galaxies and the Universe*, ed. A. Sandage, M. Sandage, and J. Kristian (Chicago: University of Chicago Press), p. 761.
Stein, W. A., *et al.* 1978, *Ap. J.*, **224**, 22.
Terrell, J., 1967, *Ap. J.*, **147**, 827.
Ulrich, M. H., Kinman, T. D., Lynds, C. R., Rieke, G. H., and Ekers, R. D. 1975, *Ap. J.*, **198**, 261.
Wagoner, R. V. 1969, *Ann. Rev. Astr. Ap.*, **7**, 553.
Weedman, D. W. 1983, *Ap. J.*, **266**, 479.
Wiśniewski, W. Z., Mufson, S. L., and Pollock, J. T. 1980, *IAU Circ.*, 3500.

H. D. Aller and M. F. Aller: Department of Astronomy, University of Michigan, 953 Physics-Astronomy Building, Ann Arbor, MI 48109

S. L. Mufson: Department of Astronomy, Indiana University, 319 Swain West, Bloomington, IN 47405

J. T. Pollock: Department of Physics and Astronomy, Appalachian State University, Boone, NC 28608

W. A. Stein: School of Physics and Astronomy, University of Minnesota, Minneapolis, MN 55455

W. Z. Wiśniewski: Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721