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DISCOVERY OF A REDSHIFT $z = 1.2$ QUASAR WITH A FLAT RADIO SPECTRUM IN THE FIELD OF THE GAMMA-RAY SOURCE CG 195+04

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ABSTRACT

Several radio sources are located within the 90% confidence limit of the strong, unresolved γ-ray source CG 195+04. For the best radio candidate 0630+180, we have optically identified a quasar at $z = 1.2$, the third such object found to lie within a *COS B* error circle. If the QSO 0630+180 really were associated with CG 195+04, it would be the most luminous source of high-energy photons known. If its luminosity is due to proton enhancement, this may be the first step toward identifying a potential source of the nucleonic component of cosmic rays.

Subject headings: gamma rays: general — quasars — radio sources: galaxies

I. INTRODUCTION

CG 195+04 is the second strongest unresolved source of high-energy ($h\nu > 70$ MeV) γ-rays known in the sky (Thompson *et al.* 1977; Swanenburg *et al.* 1981). It is located toward the anticenter direction of the Galaxy where it stands out clearly from the surrounding γ-ray background. Its position is given as $l = 195.^\circ1$, $b = 4.^\circ2$ by Masnou *et al.* (1981), corresponding to $\alpha(1950.0) = 06^h30^m40.^s5$, $\delta(1950.0) = 17°48'30''$, with a 90% confidence error radius of $0.^\circ4$.

Due to its unique character as a source which strongly dominates in γ-rays and which is not connected with an obvious pulsar, CG 195+04 has attracted considerable attention in the past. Recently, two of us (Sieber and Schlickeiser 1982) have therefore searched this field for radio counterparts and detected a number of weak continuum radio sources. Here we report the optical identification of the best candidate radio counterpart, source 7 (0630+180) of Sieber and Schlickeiser (1982), as a quasar of 19th magnitude with redshift of 1.2. This source is noteworthy in having the flattest radio spectrum of any radio source falling in or near the error circle and is the only radio source with an unambiguous optical counterpart on the Palomar Observatory Sky Survey (POSS) charts.

II. RADIO AND OPTICAL MEASUREMENTS

After its discovery with the 100 m Effelsberg radio telescope, 0630+180 was observed with the Cambridge 5 km synthesis array at 5 GHz on 1982 May 1. The half-power beamwidth of the synthesized beam was $2.''0$ $(\alpha) \times 6.''4$ (δ). The source 0630+180 appears unresolved at position $\alpha(1950.0) = 06^h30^m43.^s581 \pm 0.^s005$, $\delta(1950.0) = 18°01'52.''90 \pm 0.''2$ with a peak flux of 52 ± 2 mJy. At $\alpha(1950.0) = 06^h30^m43.^s58 \pm 0.^s03$, $\delta(1950.0) = 18°01'52.''80 \pm 0.''35$, and thus coincident with the radio position, we found on POSS plate no. 1470 a weak, moderately blue ($m_R = 18.7$, $m_B = 19.1$), optical pointlike object. This object is identified on a deeper plate at higher resolution in Figure 1, where it still appears starlike.

On 1982 November 20, spectroscopic observations of this optical candidate were performed with the new, blue-sensitive, intensified Reticon double array at the SAO/UAO Multiple Mirror Telescope. Successive 3 minute integrations were performed with the source and the sky alternately placed in one of the two entrance slots of $2''$ diameter, separated by $30''$. The total exposure time was 36 minutes, the wavelength range was from 3400 Å to 7600 Å, and the wavelength resolution FWHM ~ 8 Å. The data were reduced to flux and wavelength in the usual way, using the flux standard EG 63, a He-Ne-Ar comparison source, and a flat-field lamp.

The optical spectrum is shown in Figure 2; it exhibits relatively weak emission lines superposed on a relatively flat ($d\log S_\nu/d\log\nu \lesssim -1$) optical continuum with $S_\nu = 10^{-4.0}$ Jy at 5500 Å. The flat optical continuum with

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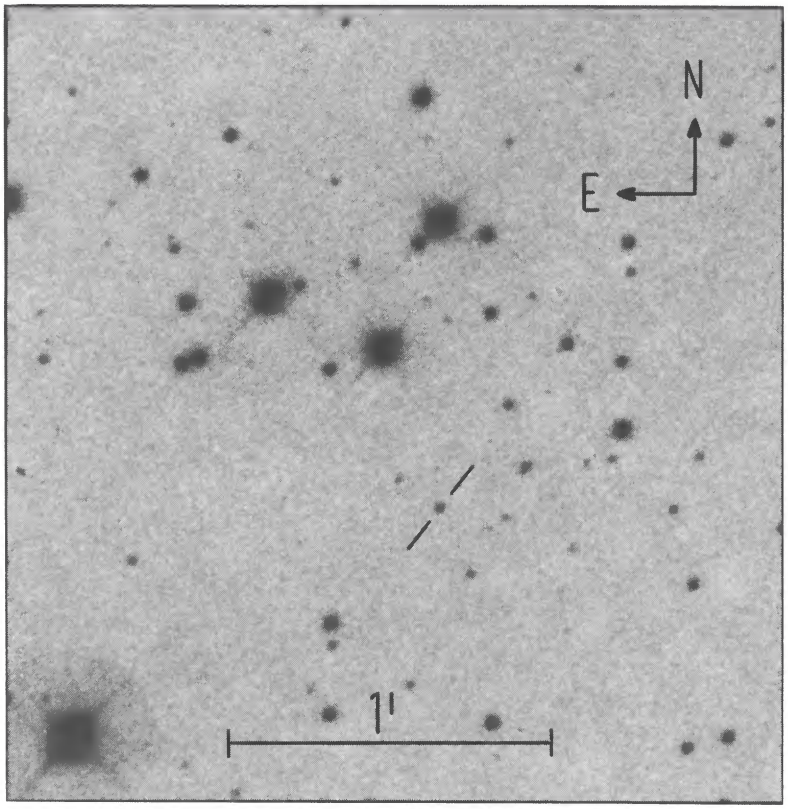

FIG. 1.—Enlargement of the central field of a IIIaJ plate taken with the one-stage magnetically focused ITT image tube at the prime focus of the Canada-France-Hawaii 3.6 m telescope. The exposure time was 5 minutes at 8 : 52 UT, 1983 January 16 in 1″ seeing. With an S-20 cathode on the image tube and an RG 630 filter, magnitudes correspond to the broad *R* band. The position of the optical counterpart of the radio source 0630+180 is indicated.

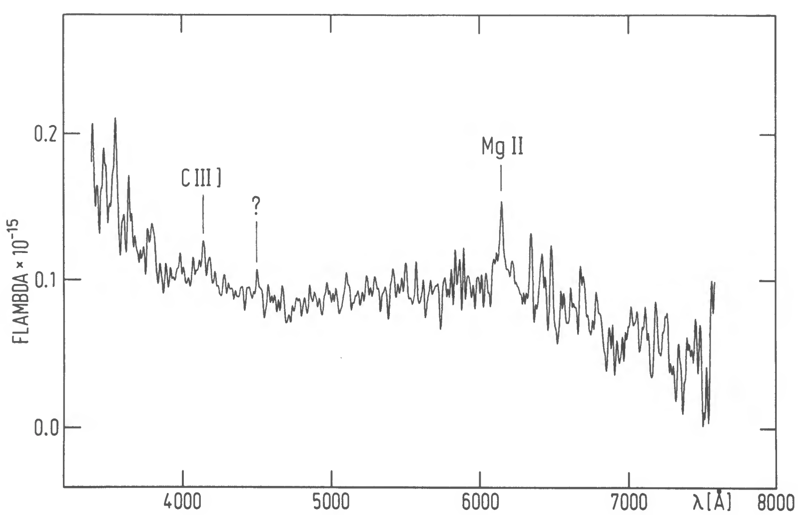

FIG. 2.—Spectrum of the optical candidate for the radio source 0630+180. Flux is given in ergs cm^{-2} s^{-1} Å^{-1}. The spectrum has been convolved with a Gaussian filter of FWHM ≈ 10 Å. At either end, the reliability of the spectrum becomes progressively degraded due to a falloff in instrumental sensitivity. The strongest emission features are indicated; these and many other weaker features match well the spectrum of the QSO 1107+036 with z = 0.963 as given by Murdoch *et al.* (1983).

apparent UV-excess and emission lines is typical for quasars. The features at 6164 Å and 4148 Å are identified as due to Mg II (λ_0 = 2800 Å, thus z = 1.201) and C III] (λ_0 = 1909 Å, z = 1.173), respectively, indicating a mean redshift of $z = 1.187 \pm 0.014$. Other features match well the spectrum of the low-z quasar 3C 273 (cf. Ulrich *et al.* 1980) and the moderate-z quasar 1107+036 (Murdoch *et al.* 1983). In a standard Friedmann cosmological model with $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0$, a redshift of $z = 1.2$ corresponds to a luminosity distance of $D = 1.1 \times 10^4$ Mpc (Sandage 1961). There is no doubt that this is the optical counterpart of the radio source 0630+180. This object is not listed in the Asiago Catalog of quasars (Barbieri *et al.* 1982).

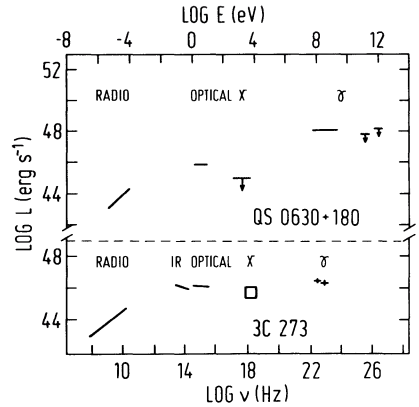

FIG. 3.—Luminosity spectrum from radio to gamma frequencies of QSO 0630+180, z = 1.187 tentatively identified with CG 195+04, compared to 3C 273 (cf. Ulrich 1981), z = 0.158.

III. DISCUSSION

Quasars have been established as possible γ-ray sources since the detection of 3C 273 inside the *COS B* error box CG 289+64 (Bignami *et al.* 1981). Furthermore, the quasar 0241+622 remains a candidate for CG 135+01 (Apparao *et al.* 1978), although an alternate association is with the variable radio star LSI 61°303 (cf. Gregory *et al.* 1979). Our detection would then mark the third case of a quasar inside the field of a γ-ray source.

We estimate the probability of finding a 50 mJy radio-bright quasar to be ~ 20% in a 0°.4 radius error circle. The corresponding expected number of optical quasars with $18 \leq B$ (mag) ≤ 19 and $1.0 \leq z \leq 1.5$ is ~ 0.4, or 1.3 for $B \leq 19$ and $z \leq 3.5$ (Schmidt and Green 1983). The question whether QSO 0630+180 is a chance coincidence in the γ-ray error box, not associated with the actual γ-ray source, can only be definitively answered if a future γ-ray telescope with much improved angular resolution and smaller error boxes is able to exclude QSO 0630+180. Until then, we regard QSO 0630+180 as a strong candidate for CG 195+04. Another strong candidate which lies equally well within the *COS B* error circle is the *Einstein* X-ray source 1E 0631+178 with $F_x \approx 3 \times 10^{-12}$ ergs cm^{-2} s^{-1} noted by Caraveo (1983). This object falls in an empty POSS field, and subsequent deep optical exposures have failed to detect any candidate down to 23rd magnitude (Bignami and Caraveo 1982).

Now let us tentatively assume that the QSO 0630+180 can in fact be identified with the γ-ray source CG 195+04. Several interesting consequences follow. Using the redshift-distance estimate, we obtain, in the case of isotropic emission, a radio luminosity for QSO 0630+180 = CG 195+04 of $L_R \approx 10^{44}$ ergs s^{-1}, a total optical luminosity $L_0 \approx 10^{46}$ ergs s^{-1} and a γ-ray luminosity L_γ ($h\nu$ > 70 MeV) $\approx 10^{48}$ ergs s^{-1}. Since QSO 0630+180 was not seen by the *Einstein* X-ray satellite, the sensitivity limit of ~ 10^{-2} Uhuru counts (Bignami and Caraveo 1982) leads to an upper limit of L_x ($h\nu$ = 0.5–4 keV) < 10^{45} ergs s^{-1}. Whereas radio, optical, and X-ray luminosities are normal for this kind of object, the γ-ray luminosity is spectacular, being ~ 10^2 times greater, compared with other frequencies, than the well-studied QSO 3C 273 (cf. Fig. 3). If true, this would indicate QSO 0630+180 to be intrinsically the most luminous source of high-energy photons yet discovered.

Particularly dramatic is the large ratio of γ-ray luminosity to low-frequency luminosities: $L_\gamma/L_R \approx 10^4$, $L_\gamma/L_0 \approx 10^2$, $L_\gamma/L_x > 10^3$. It should be pointed out that this is true not only for QSO 0630+180 but for almost any potential candidate in the field of CG 195+04 being associated with the γ-ray emission. If such a source were to radiate the same order of luminosity in other spectral regions as in γ-rays, it should emit $S_R = (\nu_\gamma/\nu_R)S_\gamma \approx 10^4$ Jy in radio waves, $S_0 \approx 10^{-1}$ Jy in visible light (which corresponds to an object of magnitude $V \approx 11$ mag), and $S_x \approx 10^{-4}$ Jy in X-rays (which corresponds to ~ 10^{-9} ergs cm^{-2} s^{-1} of 0.5–4 keV photons). *No* source of such strength is found in radio and X-ray observations of this field.[9] Optically, there are about a dozen SAO stars of m_v = 7.2–9.1 in the field, all later than spectral type B9 and none known to show peculiarities. There are also no luminous, hot stars down to m_{pg} = 12.6 in this field (Stephenson and Sanduleak 1971). It would be particularly interesting to observe this field in infrared and ultraviolet wavelengths. In the case of equal luminosity per frequency bin we would expect $S_{IR} \approx (\nu_\gamma/\nu_{IR})S_\gamma \approx 10^2$ Jy and $S_{UV} \approx 10^{-3}$ Jy.

[9] The assumption of isotropic emission of γ-radiation may be incorrect. By analogy to 3C 273 (Swanenburg 1978; McBreen 1979), one might argue that a strong hard X-ray photon field may affect the γ-rays by pair production processes. A jetlike geometry of the γ-ray emission may lower the luminosity requirements to ~ 10^{47} ergs s^{-1} which still is approximately one order of magnitude larger than radio, optical, and soft X-ray luminosities.

The orders of magnitude dominance of the γ-ray emission in luminosity makes it very difficult to understand the physics of this γ-ray source in terms of so-called Compton-emission models or synchrotron-Compton models (for details, see Sieber and Schlickeiser 1982), since these models suggest luminosity ratios of the order of 1. Likewise, the scenario of an inverse Compton, optically thick object (Schlickeiser 1982) is difficult to reconcile if no low-frequency radiation comparable to the γ-ray luminosity is present.

However, at least one not inconsistent scenario can be constructed which we would like to baptize "proton quasar." In compact sources like quasars, the energy density of relativistic electrons is at least *10 orders of magnitude* larger than in the solar neighborhood of the Galaxy. We suggest that a similar enhancement factor for relativistic protons between 1 and 30 GeV occurs in γ-ray bright quasars like QSO 0630+180. A possible scenario for such enhancements has been recently proposed by Protheroe and Kazanas (1983). If these protons interact with gas clouds of mass M, like emission-line regions in active galactic nuclei surrounding the central engine, this would lead to γ-ray emission by π^0-decay and secondary electron bremsstrahlung of $L_\gamma \approx 10^{39} M/M_\odot$ ergs s^{-1}. Values of M of the order of $10^9\ M_\odot$ are necessary to explain the observations. In a subsequent paper the implications of such a model will be considered, in particular the nonthermal radiation of the secondary electrons at low frequencies. Our proposed identification of the γ-ray source CG 195+04 may represent the first hint toward discovering sources of the nucleonic cosmic-ray component.

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