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A GRAVITATIONAL LENS CANDIDATE DISCOVERED WITH THE *HUBBLE SPACE TELESCOPE*[1]

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ABSTRACT

We report evidence for gravitational lensing of the high-redshift ($z = 3.8$) quasar 1208+101, observed as part of the Snapshot Survey with the *Hubble Space Telescope* Planetary Camera. An *HST V* image taken on gyroscopes resolves the quasar into three point-source components, with the two fainter images having separations of 0.″1 and 0.″5 from the central bright component. A radio observation of the quasar with the Very Large Array at 2 cm shows that, like most quasars of this redshift, 1208+101 is radio-quiet. Based on positional information alone, the probability that the observed optical components are chance superpositions of Galactic stars is small, but not negligible. Analysis of a combined ground-based spectrum of all three components, using the relative brightnesses from the *HST* image, supports the lensing hypothesis. If all the components are lensed images of the quasar, the observed configuration cannot be reproduced by simple lens models. Future *HST* observations can test the lensing hypothesis for 1208+101.

Subject headings: gravitational lensing — quasars: individual (1208+101)

1. INTRODUCTION

A number of gravitationally lensed quasars have been discovered during the past 13 years, all having at least one image separation larger than $\approx 1''$. Theoretical models (Turner, Ostriker, & Gott 1984; Kochanek 1991; Fukugita & Turner 1991) predict that about one-half of all gravitationally lensed quasars have subarcsecond image separations, and are therefore difficult to identify in ground-based observations. The *Hubble Space Telescope* (*HST*) is a powerful tool for searching for lensed quasars. Despite the spherical aberration of *HST*'s primary mirror, the sharp core of the point-spread function permits high spatial resolution studies of closely separated bright point sources (Burrows et al. 1991). Based on an *HST* Planetary Camera (PC) image obtained as part of the snapshot survey (Bahcall et al. 1992), we report here evidence for the probable gravitational lensing of the quasar 1208+101.

The *HST* Snapshot Survey is a search for cases of gravitational lensing among 354 bright quasars. Short exposures (260 s) with the PC through the F555W filter are taken during gaps in the scheduled observing program when the telescope would otherwise be idle. Images are typically obtained using only the gyroscopes for pointing and guiding, saving the time needed to acquire guide stars. This results in slightly trailed images. A detailed description of the Snapshot Survey, the quasar sample, and the results for the first 30 quasars that were observed appears in Bahcall et al. (1992). Information on the PC can be found in Griffiths (1990).

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2. OBSERVATIONS AND DISCUSSION

An image of the 1208+101 was obtained on 1991 July 22. The quasar 1208+101 is a luminous, high-redshift ($z = 3.8$) object. At the time of its discovery in 1986 it was the most distant quasar known (Hazard, McMahon, & Sargent 1986; Sargent et al. 1986). Figure 1 shows a section of the PC image centered on the quasar. In this exposure, the gyroscope drift (which here has a rate of 0.9 milli–arcseconds s^{-1}) results in the image being trailed approximately in the column direction; a point source therefore appears as a thin vertical strip. The nonvertical pixel groups in the image are cosmic-ray events in the PC. The quasar is resolved into three separate point sources. The central, brightest component (labeled "A" in Fig. 1) has a visual magnitude of $V = 18.3$. A second component is present at a separation of 0.″5, position-angle 160° (labeled "C"), with $V \approx 19.8$. The third component is at $\approx$0.″1 separation from the central component, position-angle $\approx$40° (touching to the left of, and slightly below the central component in Fig. 1, labeled "B"), with $V \approx 20.0$. The brightness ratio of the central and the faint components is accurate to about 0.2 mag for the "C" component and about 0.3 mag for the "B" component. The total V-magnitude of the three components is 17.9.

Apart from the objects appearing in Figure 1, the PC field of view includes only a faint close pair of stars 19″ northwest of the quasar, an 18.5 mag star 20″ north of the quasar, and two faint galaxies 35″ to the east. In order to test the reality of the quasar components, particularly component "B", we have attempted to subtract out the "A" component using a point-spread function determined from the star 20″ north of the quasar. The subtracted image indicates that components "B" and "C" each have the low-level broad wings characteristic of sources that have been focused by the *HST* optics. However, the results of this process are uncertain because: (1) the reference star is not bright, and the point-spread function is therefore noisy, and (2) the point-spread function of the PC varies across the field of view.

In an attempt to obtain further information about this system, we observed the quasar in the radio band with the Very

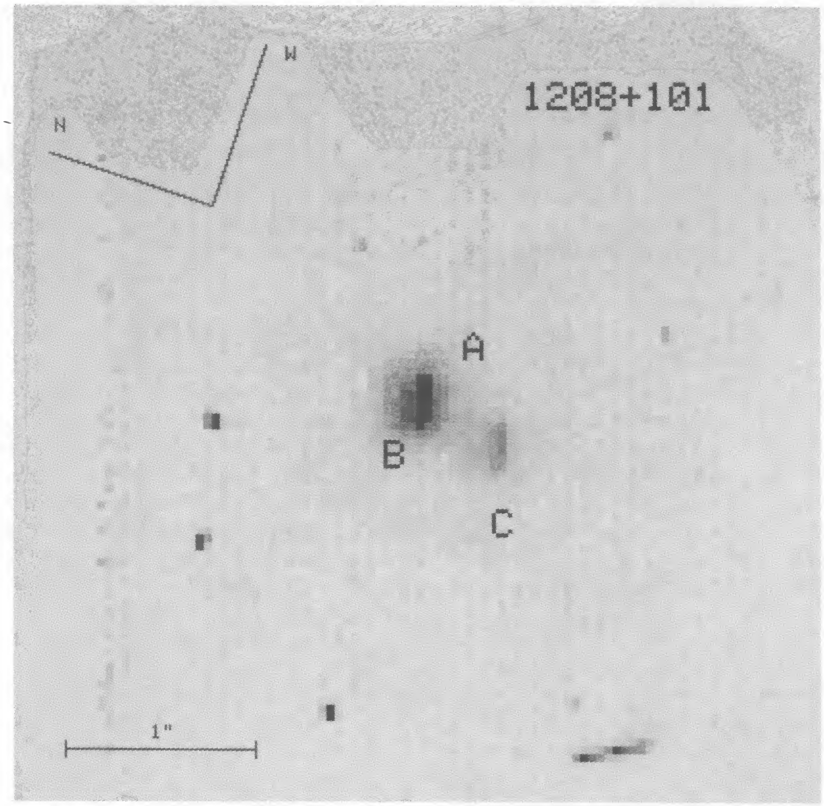

FIG. 1.—Section of the PC image centered on 1208 + 101. The image shown is 4″.3 on a side. The scale is 0″.043 pixel^{-1}. North is 18° above left, West is 18° right of up. The gyroscopic drift results in the image being trailed approximately in the column direction; a point source therefore appears as a thin vertical strip. The nonvertical pixel groups in the figure (e.g., the almost horizontal strip near the lower right-hand corner) are cosmic-ray events in the PC. The quasar is resolved into three separate point sources: the central, main component (labeled "A"), a second component at a separation of 0″.5 (labeled "C", below and to the right of the central component), and a third component at ≈0″.1 separation from the central component (labeled "B", just to the left of, and slightly below the central component).

Large Array (Napier, Thompson, & Ekers 1983) for approximately 1 hr on 1991 October 6. The BnA configuration was used at a wavelength of 2 cm, giving a beam size of 0″.12 × 0″.57. The quasar was undetected. The 3 σ upper limit on the flux is 0.6 mJy. This is not surprising, as only about 5% of optically discovered high-redshift quasars are radio-loud (Schneider et al. 1992).

Could this be a case of gravitational lensing? With its large redshift and apparently high luminosity, 1208 + 101 has a relatively larger probability than most known quasars of being gravitationally lensed into multiple images by an intervening galaxy or other mass concentration. It is unlikely that the secondary images, which have the shape of unresolved point sources typical for *HST*, are foreground galaxies. Examination of a direct UK Schmidt telescope image of this region (Hazard et al. 1986), which for diffuse objects goes deeper than the *HST* image, reveals no galaxies at or near the position of the quasar.

However, there is a nonzero a priori probability that one or two secondary images could appear close to the quasar because of chance superpositions of Galactic stars. The probability that a Galactic star is projected within a circle of radius r_0 in the direction of the primary quasar image (Galactic latitude $b = 70°$) is $P \approx 6 \times 10^{-4}(r_0/1'')^2$, if we suppose that we could have a priori been interested in images within 1″ of the quasar and brighter than our limiting magnitude of $V \approx 23$ mag. This estimate is obtained from the export version of the Bahcall-Soneira Galaxy Model (Bahcall 1986), which gives a reasonably accurate account of the star densities on other deep images. Had we adjusted post facto the parameters of the probability calculation to fit the actual case observed, $r_0 \approx 0''.5$ and $V_{\rm limiting} = 19.8$, we would have obtained a result that is about a factor of 15 smaller. Our calculation is an intentionally conservative overestimate; at small image separations the limiting magnitude is considerably brighter than $V = 23$ (Bahcall et al. 1992) and the probability of a superposition is accordingly smaller. The probability of *two* stars being superposed within 1″ of the quasar is of order $P^2/2 \approx 2 \times 10^{-7}$, assuming the superposition of each star is independent. At the separations of interest here, $\approx 10^{-3}$ to 10^{-2} pc (adopting a typical Galactic star distance of 200 to 2000 pc), the correlation function of stars is apparently large and many stars may have physical companions (Bahcall & Soneira 1981; Retterer & King 1982; Abt 1983; Eggleton, Fitchet, & Tout 1989; Weinberg 1990). We make the conservative assumption that we are seeing only one independent superposition whose probability is $P \approx 6 \times 10^{-4}$. Since we have examined approximately 100 other quasar images in the snapshot data, none of which have shown additional sources within 1″ of the quasar, one may multiply the above probability estimate by a factor of order 170 (calculated with the export Galaxy model) which takes account of the galactic latitude and longitude of the star fields in the directions of the quasar sample. On the basis of these positional considerations alone, we conclude that the probability that the two images near 1208 + 101 are Galactic stars is small, but not completely negligible, perhaps as large as 10%.

An independent test of the nature of the quasar components can be obtained from analysis of the ground-based spectrum of 1208+101, published by Sargent et al. (1986), which combines the light from the three components. Since components "B" and "C" contribute about 30% of the flux in the V band, one may expect stellar features to appear in the quasar spectrum if "B" and "C" were Galactic stars. Even if "B" is an artifact, "C" still contributes about 20% of the total V flux. To examine this possibility, we subtracted from the Sargent et al. (1986) spectrum a variety of main-sequence stellar spectra taken from Jacoby, Hunter, & Christian (1984) and scaled according to the contribution of component "C" in the V band. We find that spectral types K1 and earlier for component "C" can be eliminated, either because they have too much UV flux (for the early-type stars) or because the net quasar spectrum would be negative in the region around 4030 Å (840 Å in the quasar rest-frame), where the flux in the Sargent et al. (1986) spectrum dips down close to zero. Spectral types K8 and later are unlikely because the net quasar spectrum would have to be much bluer than other high-redshift quasars, and because of the absence of molecular bands, mostly TiO, in the red part of the total spectrum. Stars of type K2 to K7 cannot be definitively ruled out but are also unlikely, due to a combination of the previous arguments: the low flux at 4030 Å in the total observed spectrum, and the bluer than average quasar spectrum that would be required if such a star was a significant contributor of the flux in the red part of the total spectrum. This spectral analysis therefore supports the lensing hypothesis.

It is noteworthy that the observed image configuration cannot be caused by any obvious simple lens (see, e.g., Blandford et al. 1989). Both the nonlinear arrangement of the three components (forming an angle of $\approx 120° \pm 20°$) and the existence of a bright image between two similarly faint images constitute a problem. Simple lenses produce a more colinear image arrangement, and either a faint central image, or a bright central image that is comparable to, and slightly fainter than the image closest to it. This problem would be solved if just one of the fainter components is a lensed image (e.g., if "C" is a Galactic star, or if "B" is an artifact). On the other hand, the only other known lensed quasar with a redshift larger than 3, 2016+112 (Lawrence et al. 1984), also has an image geometry that requires two lensing galaxies.

Further observations are needed to establish whether or not the observed configuration is caused by gravitational lensing. We have proposed to obtain multicolor images and spectra of the separate components with *HST*. If verified to be a lens system, 1208+101 will be the most distant lensed quasar and the one with the smallest total component separations found to date. In any event, the demonstration that the Snapshot Survey observations can detect lensing at small angular separations is an important step toward studying the density of matter at early cosmological epochs.

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