COSMIC ALIGNMENT TOWARD THE RADIO EINSTEIN RING PKS 1830–211?

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ABSTRACT

Optical and near-IR Hubble Space Telescope and Gemini North adaptive optics images, further improved through deconvolution, are used to explore the gravitationally lensed radio source PKS 1830–211. The line of sight to the quasar at \( z = 2.507 \) appears to be very busy, with the presence, within 0.5 arcsec from the source, of (1) a possible galactic main-sequence star, (2) a faint red lensing galaxy visible only in \( H \) band, and (3) a new object whose colors and morphology match those of an almost face-on spiral. The \( I' \)–\( I \) color and faint \( I \) magnitude of the latter suggest that it is associated with the molecular absorber seen toward PKS 1830–211, at \( z = 0.89 \) rather than with the \( z = 0.19 \) \( H \) \( I \) absorber previously reported in the spectrum of PKS 1830–211. While this discovery might ease the interpretation of the observed absorption lines, it also complicates the modeling of the lensing potential well, hence decreasing the interest in using this system as a means to measure \( H_0 \) through the time delay between the lensed images. This is the first case of a quasar lensed by an almost face-on spiral galaxy.

Subject headings: cosmology: observations — gravitational lensing — quasars: individual (PKS 1830–211)

On-line material: color figures

1. HISTORICAL CONTEXT

This paper presents a new step in the long series of studies trying to unveil the properties of the gravitationally lensed quasar PKS 1830–211. The object has a heavily populated line of sight, crowded by galactic and extragalactic objects. We start this introduction with a few highlights of what has been a particularly slow discovery process.

The radio source PKS 1830–211 was first detected as a single source in the Parkes survey (Shimmins, Manchester, & Harris 1969) and soon recognized as one of the brightest sources at centimeter wavelengths. About 20 years later, high spatial resolution Very Large Array (VLA) observations at 1.5, 5, and 15 GHz unveiled the double structure of this otherwise flat-spectrum source (Pramesh Rao & Subrahmanyan 1988). These authors immediately mentioned gravitational lensing as the best qualitative explanation for the presence of the two components, their separation, their flux ratios, and their almost identical substructures with a point inversion symmetry with respect to each other. Further high-resolution VLA observations at 5, 15, and 22.5 GHz provided enough information to allow theoretical modeling of the lensing effect, in spite of the unknown redshifts of both the source and the lens (Subrahmanyan et al. 1990).

Deeper VLBI, MERLIN, and VLA observations, at 2.3, 1.7, and 8.4 GHz, respectively, showed an unusual elliptical ring–like structure connecting the two brighter components (Jauncey et al. 1991). This further favored the gravitational lens explanation, specifically, an Einstein ring formed by the gravitational imaging of a background radio source by a foreground mass concentration. Extensive theoretical modeling studies that successfully reproduced the ring and the two bright components were soon published (Kochanek & Narayan 1992; Nair, Narasimha, & Rao 1993).

Since the line of sight to PKS 1830–211 passes the Galactic bulge (Galactic longitude \( l = 127^\circ \) and Galactic latitude \( b = -5^\circ 7 \)), earlier attempts to identify the source and the lens failed because of source confusion, faintness, and poor spatial resolution. No visible counterpart was found down to \( B \approx 23 \) mag. A relatively bright object, nearly coincident with the northeast component of the radio source, was identified spectroscopically with the Palomar 200 inch telescope.

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1 Based on observations made with the NASA/ESA Hubble Space Telescope, obtained from the Data Archive at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555. The HST data used here come from the archives related to the programs 7495, 8804, and 9133 (CASTLES). This study is also based on observations made with the NOAO Gemini North Telescope; NOAO is operated by the Association of Universities for Research in Astronomy (AURA), Inc., under cooperative agreement with the National Science Foundation.

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as a foreground M star (Djorgovski et al. 1992). Extensive theoretical modeling studies that reproduced successfully the ring and the two bright components were soon published (Kochanek & Narayan 1992; Nair et al. 1993).

Wiklind & Combes (1996) identified 12 molecular absorption lines in a millimeter spectrum of PKS 1830–211 taken with the 15 m Swedish-ESO Submillimetre Telescope (SEST) and the ESO telescope. They inferred that the lines originate in the lensing galaxy at \( z = 0.89 \) and that the lens is a spiral, since the molecular abundances are compatible with Milky Way values. Lovell et al. (1996) observed H \( \alpha \) absorption at \( z = 0.19 \) in Parkes data, indicating the presence of another galaxy at this redshift and pointing toward a possible compound lens (see also Frye, Welch, & Broadhurst 1997). The \( z = 0.89 \) redshift value was confirmed by Mathur & Nair (1997), who observed strong absorption features in their X-ray spectrum acquired with the *ROSAT* Position Sensitive Proportional Counter. H \( \alpha \) absorption is also seen at \( z = 0.89 \) (Chengalur, de Bruyn, & Narasimha 1999). Further observations made at the 30 m IRAM and 15 m SEST/ESO telescopes confirmed the presence of two absorption lines at \( z = 0.89 \), one corresponding to the southwest lensed image of the background source, and the other, shifted in velocity by \(-147\ km\ s^{-1}\), corresponding to the northeast image. This implied that the background radio source is situated at a redshift of about 3 and consistent with the lensing galaxy being an early-type spiral seen almost face-on (Wiklind & Combes 1998; see also Swift, Welch, & Frye 2001).

At that stage, models predicted time delays on the order of 1 day to several tens of days for a reasonable range of source and lens redshifts (Nair et al. 1993). This expectation and the fact that PKS 1830–211 varies regularly on timescales of months made this object an ideal target, at that time, for determining a time delay between the lensed components. VLA observations at 8.4 and 15 GHz over a period of 13 months provided a first estimate \( \Delta t = 44 \pm 9 \) days (van Ommen et al. 1995). More recently, Australia Telescope Compact Array observations at 8.6 GHz over a period of 18 months provided a second— inconsistent—estimate \( \Delta t = 26 \pm 5 \) days (Lovell et al. 1998). Since the redshift of the source was unknown and the lensing galaxy poorly parameterized, no estimate of \( H_0 \) was obtained. Microlensing, as deduced from *ASCA* X-ray observations (Oshima et al. 2001), may complicate the computation of the time delay.

It was only with the advent of a powerful deconvolution method (Magain, Courbin, & Sohy 1998) that significant progress was made in identifying the optical-infrared counterparts of PKS 1830–211. Near-infrared \( J \) and \( K \) images obtained at the 2.2 m MPl/ESEO telescope and \( I \) and \( K \) images with the Keck I telescope, all with subarcsecond seeing, were deconvolved by Courbin et al. (1998). Both counterparts of the flat-spectrum core of the radio source were searched for. The M star identified by Djorgovski et al. (1992) was clearly separated from the bright northeast component of the quasar, whose radio and optical positions were shown to be identical. The southwest radio component, with similar radio flux, was not unambiguously identified with the optical object, because of mismatches between the positions of the source in the \( I, J, \) and \( K \) bands, and with its radio position as well. This object, much fainter in \( I, J, \) and \( K \) than in the radio, was possibly identified with the lensing galaxy alone or a blend of various objects. The source counterparts are very red with \( I-K \sim 7 \), which suggests strong absorption from the Galaxy, the lensing galaxy, or both.

The brightness of the source at near-infrared wavelengths enabled the redshift of the source \( (z = 2.507 \pm 0.002) \) to be determined with infrared spectroscopy (Lidman et al. 1999).

Using intrinsically high spatial resolution images obtained with the *Hubble Space Telescope* (HST) in the near-infrared \( (I, K_2) \) and \( H, K \) with NIC2/1600W/2050W, Lehar et al. (2000) confirmed and improved the earlier quasar component identifications proposed by Courbin et al. (1998) with their ground-based deconvolved data. In addition, Lehar et al. (2000) identified an object that they associated with the lensing galaxy (lens G in Lehar et al. 2000 and in the following).

In this paper we present new results obtained from the deconvolution of deep imaging archive data obtained with the *Hubble Space Telescope* at visible and near-IR wavelengths, namely, WFC2/F555W/F814W and NICMOS2/F160W/F205W. In addition, we use some new ground-based \( K \)-band adaptive optics images from the Gemini North/Hokupa’a Adaptive Optics (AO) system, further improved with deconvolution. These observations in four broadband filters, viz., \( V, I, H, \) and \( K \), allow us to detect very clearly the arms of a spiral galaxy between the two quasar images. In addition to this new object, two other objects are seen along the line of sight: (1) a red point source that might be either the bulge of the spiral or a galactic star and (2) a very faint and red object seen only in \( H \), at the position of the object G previously reported by Lehar et al. (2000).

2. OBSERVATIONS

2.1. HST Imaging

The HST observations presented in this paper are public and available in the archives. They were obtained as part of the GO programs (PI E. Falco with programs 7495, 8804, and 9133) known as the Center for Astrophysics Arizona Space Telescope Lens Survey (CASTLES), and aimed at imaging with the HST all known gravitationally lensed quasars. The near-IR data, viz., WFC2/F555W/F814W and NIC2/F160W/F205W, collected by CASTLES for PKS 1830–211 were used in their study of 10 two-image gravitational lenses (Lehar et al. 2000), while the observing details can be found.

We reanalyze here these data, using deconvolution techniques for further improvement. We also take advantage of the fact that, since the publication of Lehar et al. (2000), much deeper WFC2/F814W images were obtained (program 8804), corresponding to 4 times 1200 s, in addition to the four 400 s exposures already published. These additional data allow us to discover an almost face-on spiral galaxy acting as a gravitational lens on PKS 1830–211 (see below). We also detect this galaxy in new WFC2/F555W data (three images, for a total of 2000 s; program 9133), however, very close to the detection limit.

2.2. Gemini/Hokupa’a Adaptive Optics Imaging

The preceding HST data are supplemented by ground-based \( K \)-band AO images of PKS 1830–211, obtained during the night of 2000 August 8, with the Hokupa’a instrument mounted on the 8.2 m Gemini North telescope at Mauna Kea, Hawaii. The raw data have excellent sampling
(0.020 pixel\(^{-1}\)) and fairly good image quality (FWHM = 0.15). The reduced data before deconvolution is presented in Figure 1, where the two quasar images are seen, well separated, as well as the \(V \sim 13.5\) mag star used for the wave front correction, about 7\(^\circ\) to the northeast of PKS 1830–211. Owing to the high air mass of the object (between 1.5 and 2.2) and to the relatively faint guide star, the wave front correction was not fully satisfactory, with a final seeing about twice as large as the diffraction limit of an 8.2 m telescope in the K band. These images are rather shallow, with a total exposure time of 30 minutes, but they nevertheless allow the measurement of the positions of the quasar images with an accuracy better than could be done with the HST data alone. No standard star was observed, as the observations were performed through thin cirrus.

These data are the first images of a gravitational lens taken with AO on a 10 m class telescope. The presence of a suitable wave front guide star and many point-spread function (PSF) stars should allow one to improve the present result if the observations can be repeated at a smaller air mass and with much longer exposure time. Given the low declination of PKS 1830–211, the Paranal Observatory is ideally located for such observations.

3. ASTROMETRY–PHOTOMETRY

All the data are deconvolved with the MCS deconvolution algorithm, which results in images with improved resolution and sampling (see Courbin et al. 1998 for more details about the application of this method). The spatial resolution of the final images is 0.046 for the WFPC2/F555W/F814W data, 0.075 for the HST NIC2/F160W/F205W near-IR data, and 0.020 for the Gemini K-band data.

Figures 2, 3, and 4 show the resulting deconvolved images. In all cases but for the F205W filter, the result of the deconvolution process is good, as several PSF stars are available in the immediate vicinity of the deconvolved field.

Since the objects in the vicinity of PKS 1830–211 have very different colors, astrometry is performed in all available...
bands, taking as a reference coordinate system the best and deepest data available, i.e., the HST F814W image. The transformation between the astrometry of the different bands into the coordinate system of the F814W image is done by using stars seen simultaneously in all filters. Tables 1 and 2 gives the photometric and astrometric results for all selected objects (see § 4 for the meaning of the object labeling that we keep as in Lehár et al. 2000).

The photometry and astrometry are always performed on the deconvolved images in order to avoid mutual contamination of the extended and unresolved objects. We used the same zero points as in Lehař et al. (2000). The magnitude of...

Fig. 3.—Left: Part of the HST/NICMOS2 image of PKS 1830–211 obtained in the F160W filter (four individual frames). Right: Simultaneous deconvolution of the four F160W images, with a final resolution of 0″075. Note the object right to the west of star P. Lens G is visible in this frame only. There is no trace of the spiral galaxy SP, which is marked with a circle. [See the electronic edition of the Journal for a color version of this figure.]

Fig. 4.—Left: Gemini + Hokupa’a K-band image of PKS 1830–211. This image shows a close-up of the same data as in Fig. 1. Right: The simultaneous deconvolution of eight stacks of images allows a resolution of 0″020 to be reached, sampled on a grid of pixels of 0″010. The data, too shallow to reveal the lensing galaxies, is useful to measure the positions of the quasar images, with a very high precision. The pointlike object P (not modeled as a point source in the Gemini data) is clearly visible. [See the electronic edition of the Journal for a color version of this figure.]
extended objects are measured in apertures of 0\'5 in diameter. As PKS 1830–211 is situated at low Galactic latitude, we have corrected the photometry for galactic absorption. From the DIRBE/IRAS maps of Schlegel, Finkbeiner, & Davis (1998), Kochanek et al. estimate \( E(B-V) = 0.464 \) toward the PKS 1830–211. We correct our photometry using this value and a mean galactic absorption law with \( R_V = 3.1 \) (Savage & Mathis 1979). The results are indicated in Table 1. Note that while the correction is reasonable for extragalactic objects, it might be an overestimate for galactic objects such as object S1 and P.

### 4. STARS AND GALAXIES TOWARD PKS 1830–211?

With these observations of improved spatial resolution, greater spectral coverage and greater depth, it is easier (but still challenging) to identify the different objects along the line of sight to PKS 1830–211.

#### 4.1. Stars

The two quasar images are seen simultaneously with a decent signal-to-noise ratio (S/N) only in the \( K \) band, i.e., on the \( HST \) F205W images and on the Gemini data. The M star, observed spectroscopically by Djorgovski et al. (1992) and labeled S1 in Lehár et al. (2000), is seen at all wavelengths. The total field contains also numerous galactic stars, given the low Galactic latitude of the quasar, viz., \( b = -5^\circ 7\).

One pointlike object is seen between the two quasar images. It is labeled P in Lehár et al. (2000) and in Figures 2–7, and remains unresolved even in the deep deconvolved F814W image, in spite of the high S/N. The shallow depth of the Gemini images and the complicated PSF in the \( HST \) images do not allow us to constrain the shape of object P. We construct the color-magnitude diagram for 89 objects in the field immediately surrounding PKS 1830–211 (Fig. 7) and find that object P falls in the bulk of faint main-sequence stars. This diagram has to be taken with caution since the stars are spread over a broad range of distances, metallicities and reddening values. Still, it is indicative that object P might be a galactic star seen on the line of sight to PKS 1830–211.

Star S1 was identified as an M dwarf by Djorgovski et al. (1992) from a Palomar 200 inch spectrum. From our photometry in Table 1 (we use here the magnitude not corrected for galactic reddening), we have \( m_V(S1) = 22.18 \) and \( m_K(P) = 26.20 \) with \( (V-K)_{S1} = 5.46 \) and \( (V-K)_P = 5.13 \). Such colors point toward M dwarf stars, in agreement with Djorgovski et al. (1992). A value \( V-K \sim 5.3 \) corresponds to an M4 dwarf, which has an absolute magnitude \( M_V \sim 11 \).

If both S1 and P objects were M4 dwarfs, they would be located, ignoring any reddening, at a distance 1.7 and 11.0 kpc, respectively. If we adopt 10 km s\(^{-1}\) as a typical lower limit for the transverse velocity, these objects would have proper motions of 1 and 0.2 mas yr\(^{-1}\), respectively. In WFPC2 frames, positions of stars have been measured with an accuracy of about 0.02 pixel (Anderson & King 2000),

### TABLE 1

\hspace{1cm} HST photometry of the objects along the line of sight to PKS 1830–211

| Object          | F555W WFPC2 | F814W WFPC2 | F160W NIC2 | F205W NIC2 |
|-----------------|-------------|-------------|------------|------------|
| QSO A           | 25.62 ± 0.10| 22.10 ± 0.03| 17.04 ± 0.03| 15.47 ± 0.01|
| QSO B           | [24.19]     | [21.42]     | [16.82]    | [15.34]    |
| Star S1 (M-type)| [26.50]     | [>25.07]    | [22.60]    | [19.40]    |
| Lens G          | [22.18 ± 0.05]| [19.43 ± 0.02]| [17.20 ± 0.03]| [16.72 ± 0.03]|
| Lens SP         | [24.77]     | [23.04]     | [21.56]    | [20.94]    |
| Low-redshift lens \((z = 0.19?)...\) | [26.64 ± 0.40]| [25.10 ± 0.20] | ... | ... |
| Low-redshift lens \((z = 0.19?)...\) | [23.71 ± 0.05]| [22.10 ± 0.02]| [20.25 ± 0.05]| [19.55 ± 0.05]|

Note.—The magnitudes given for Lens G, Lens SP, and the low-redshift galaxy to the SW of PKS 1830–211 are measured on the deconvolved images, through apertures of 0\'5 in diameter. Only the bulge of Lens SP is considered; the spiral arms are invisible in the F555W image. Magnitudes between brackets are corrected for galactic extinction.

### TABLE 2

\hspace{1cm} Astrometry of the objects along the line of sight to PKS 1830–211

| Object         | \( x \) (arcsec) | \( y \) (arcsec) |
|----------------|------------------|------------------|
| QSO A         | 0.0000           | 0.0000           |
| QSO B         | +0.654 ± 0.002   | −0.725 ± 0.002   |
| Star S1 (M-type)   | −0.091 ± 0.002   | +0.525 ± 0.002   |
| Star P         | +0.327 ± 0.004   | −0.491 ± 0.004   |
| Lens G         | +0.519 ± 0.080   | −0.511 ± 0.080   |
| Lens SP        | +0.285 ± 0.040   | −0.722 ± 0.040   |
| Center SA for spiral lens       | +0.300 ± 0.050   | −0.610 ± 0.050   |
| Low-redshift lens \((z = 0.19?)...\) | −0.245 ± 0.050   | −2.490 ± 0.050   |

Note.—As the different objects have very different colors, the astrometry is obtained from the best available filter and then matched to the coordinate system of the F814W image. In particular, QSO B is measured in the F205W image and in the Gemini \( K \)-band image. Star P, star S1, and the lens SP are measured in the F814W data. Lens G is measured from the F160W data.
which corresponds to 1 mas on the PC of \textit{HST} in the PC frames. The \textit{HST} observations in the F814W filter are split into two epochs separated by 529 days. After carefully comparing these frames, neither S1 nor P show significant proper motions. However, a time baseline of a few more years may allow the detection of some proper motions, which would confirm the stellar character of these two objects.

4.2. Galaxies

Two more objects are visible between the two quasar images. One, labeled G in Lehár et al. (2000), is seen without ambiguity only in the F160W image. It is completely invisible in the F555W and F814W images, and it is heavily contaminated by the PSF of nearby point sources in the F205W image. We are able to measure its F160W magnitude but disagree with the result of Lehár et al. (2000) by more than 1 mag. Since there is no such discrepancy for all the other objects in the field, a plausible explanation is contamination by PSF residuals, acting in different ways in our deconvolved images and the PSF-subtracted images of Lehár et al. (2000). Note that there are PSF residuals visible on the deconvolved F160W image. These are due to differences between the PSF used for the deconvolution and the actual one of the data. They are prominent near the bright point sources S1 and QSO A. For fainter sources such as star P or QSO B, they become negligible, because they are scaled down well below the noise level. Note that they are not visible close to the faint stars to the west of the field, hence even less near the fainter sources such as star P and QSO B. Object G can therefore be considered real. It was identified
by Lehář et al. (2000) as the one responsible for the molecular absorption lines observed at $z = 0.89$ in the quasar spectra.

The F555W and F814W images allow the detection of a second new object, to the south of object P. Only the brightest parts of this object are visible in the shallow F814W data of Lehář et al. (2000). However, with the new, much deeper exposures, two conspicuous spiral arms appear on both sides of a brighter spot (lens SP in Tables 1–2 and in Figures 2–6), which we identify as a possible position for the bulge of an almost face-on spiral. The putative bulge of the spiral is indicated by a circle in the Figures 2–4 and labeled “lens SP”. Note that given the lack of resolution of the data, even after deconvolution, the bulge of galaxy SP is not well defined. Therefore, we consider its center as the barycenter of the area defined by the spiral arms. It is labeled Center SA in Table 2 and in Figure 2. Given the uncertainties, it is one of the three possible centers considered in our modeling.

Using the F205W HST data and the Gemini data, we find that the extremely red image B of the quasar is exactly superposed with one of the spiral arms, which explains its faintness in the optical. This is clearly visible in Figure 2, but it can also be seen in the “true color” images shown in Figures 5 and 6, which help to mentally visualize the redshift information of the data. The first image (Fig. 5) is a composite of three images, through the F814W, F160W, and F205W filters. It shows the two reddened quasar images and the central star P, which has the same color as the field stars. Owing to contamination by the bright quasar images, it is difficult in this image to see clearly the two lensing galaxies. Figure 6 does not use the F205W frame, where the quasars are very bright. This image is composed of the F814W image as the blue channel, the F160W as the red channel and the mean of the F814W and F160W as the green channel. The objects between the quasar images are now easily seen, with the face-on spiral lens in blue (note the blue arm passing in front of quasar image B) and the much redder lens G, in green.

The spiral lens SP is very faint, but detected, in the F555W image. We infer a $V$–$I$ color of $0.8 \pm 0.5$, which is not well enough constrained to set a first redshift estimate. However, the very faint $V$- and $I$-band magnitudes themselves indicate a relatively high redshift, given the morphological type of the object. This, in combination with the fact that the spiral arms are seen right in front of the heavily reddened southwest quasar component, makes it very likely that we have discovered the spiral responsible for the CO, HCO+, HCN, and HNC absorptions at $z = 0.89$. We stress, however, that we cannot completely exclude a much lower redshift, for example, $z = 0.19$, given the photometric error bars.

5. MODELING

In spite of the complexity of the system, one can attempt to model the different components of the lens using the few available constraints (position and flux ratio) and try to infer what might the correct lens configuration be. We have considered here pseudoisothermal elliptical mass distributions, as used for example in Burud et al. (2002) and Kneib et al. (1996). Note, however, that the results quoted here depend only weakly on the exact mass profile chosen. We have considered the flux ratio between the quasar components to be the one observed in the radio, unaffected by dust, i.e., $F_A/F_B = 1$. We chose a “realistic” cosmology with $H_0 = 65 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Lambda = 0.7$, and $\Omega_M = 0.3$.

First we consider a single mass distribution centered at different plausible locations: galaxy G, galaxy SP, and the barycenter of the spiral arms SA. Only for position G and SA could we obtain a good fit using an elliptical mass model with a predicted time delay of about 40 days at position G and 31 days at position SA. Changing the observed flux ratio to $F_A/F_B = 1.5$ as measured by Lovell et al. (1998) does not significantly change the predicted time delay. Centering the mass distribution on star P, assuming it is the bulge of the lensing galaxy, predicts time delays that are much higher than what is observed, for reasonable values of $H_0$.

Next we consider two lens models with the lenses centered on G and SP. For simplicity, we assume G and SP to be at the same redshift, i.e., $z = 0.89$, with only the velocity dispersion of the two galaxies as a free parameter. For circular mass distributions, a good fit could not be found (reduced $\chi^2 = 25$), and the mass of G was found to be 3 times larger than SP. We therefore added ellipticity. We found that if $e < 0.2$ and P.A. = $-50^\circ$ a good fit is achieved with a mass ratio (G over SP) of 3.5. However, the models never predict a time delay much lower than 40 days, highly incompatible with the observed one ($\Delta t = 26 \pm 5$ days). This was already pointed out in Lehár et al. (2000), who find unrealistically high values for the Hubble parameter if the whole lensing potential were to be due to lens G alone. Changing the observed flux ratio to $F_A/F_B = 1.5$ does not improve the situation.

Decreasing the redshifts of the two lenses G and SP to $z = 0.19$ can also be used to fit the data (with an elliptical mass distribution for G) but of course predict very low time delays, on the order of 10 days. We have therefore considered a model composed of only galaxy G (the most massive of the two) and of the large spiral galaxy seen a few arcseconds to the southwest of PKS 1830–211, which will introduce some external shear. As in the model with two lenses (G+SP), no decent fit can be obtained if G is circular. Good fits are found by introducing an ellipticity, with $e > 0.3$, P.A. $\sim -90^\circ$. In this case, the predicted time delay ($\Delta t \sim 32 \pm 4$ days, depending on the exact mass contribution of the lower redshift component) matches the observations. However, we reproduce the same range of time delay with a model that considers only the lens G ($z = 0.89$) but is located 0′08 to the north of its observed position. Such a shift is large but not out of the question given the astrometric error bars.

Constructing a model that matches all the constraints (position, flux ratio, time delay) is possible, especially when including the low-redshift spiral galaxy to the southwest of the quasar. However, in order to use PKS 1830–211 to constrain $H_0$, much better observational information is required in order to characterize the various mass component along the line of sight to PKS 1830–211 and to ascertain the exact nature and reality of all intervening objects.

6. CONCLUSION

The lensing potential in PKS 1830–211 is composed of one face-on spiral galaxy, with a poorly defined center and probably at $z = 0.89$, galaxy G, also with a poorly defined center and unknown redshift, and a third galaxy, possibly at $z = 0.19$. With two and probably three galaxies contribu-
ting to the lensing effect, we conclude that it will be difficult to successfully model the system with an accuracy comparable to that reached for other simpler systems.

Unless more observational constraints become available, in particular, the precise redshifts and positions of the lenses, PKS 1830–211 will remain of little interest in terms of modeling and for the determination of $H_0$, even though the time delay is now measured with good accuracy. Nevertheless, PKS 1830–211 is important for the study of absorption lines, microlensing, and absorption by dust.

PKS 1830–211 illustrates very well the need for high spatial resolution in quasar lensing studies. Modeling of this complicated system will not only require the redshift measurement of the lenses but also the discovery of more lensed sources so that the lensing potential can be probed in more than just the two points given by the quasar images. The host galaxy of the quasar can be used to further improve the models, and arcs or arclets might appear at very high spatial resolution. Such data will only become available with the next generation of space instruments or with AO systems mounted on large telescopes, possibly coupled with integral field spectrographs.

Note added in manuscript.—After the submission of this paper, Winn et al. (2002) analyzed some of the present data independently and concluded that star P is the bulge of one single lensing galaxy. This hypothesis is also plausible, and modeling of the system is given by Winn et al. (2002).

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