A TWO-YEAR TIME DELAY FOR THE LENSED QUASAR SDSS J1029+2623

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Received 2012 July 20; accepted 2013 January 7; published 2013 February 6

ABSTRACT

We present 279 epochs of optical monitoring data spanning 5.4 years from 2007 January to 2012 June for the largest image separation (22:6) gravitationally lensed quasar, SDSS J1029+2623. We find that image A leads the images B and C by $\Delta t_{AB} = (744 \pm 10)$ days (90% confidence); the uncertainty includes both statistical uncertainties and systematic differences due to the choice of models. With only a ~1% fractional error, the interpretation of the delay is limited primarily by cosmic variance due to fluctuations in the mean line-of-sight density. We cannot separate the fainter image C from image B, but since image C trails image B by only 2–3 days in all models, the estimate of the time delay between images A and B is little affected by combining the fluxes of images B and C. There is weak evidence for a low level of microlensing, perhaps created by the small galaxy responsible for the flux ratio anomaly in this system. Interpreting the delay depends on better constraining the shape of the gravitational potential using the lensed host galaxy, other lensed arcs, and the structure of the X-ray emission.

Key words: galaxies: clusters: general – gravitational lensing: strong – quasars: individual (SDSS J102913.94+262317.9)

Online-only material: color figures

1. INTRODUCTION

SDSS J1029+2623 (Inada et al. 2006) is the largest image separation lensed quasar, with a maximum separation of 22:6 that significantly exceeds that of the next largest system (14:6 for SDSS J1004+4112; Inada et al. 2003). Although it was first identified with only two images A and B, it actually consists of three images of $z_1 = 2.197$ quasar produced by a $z_l = 0.58$ galaxy cluster in a rare “naked cusp” configuration (Oguri et al. 2008). The fainter image C lies close to image B (1:8), which would usually mean that B and C should be significantly brighter than A. Instead, the optical flux ratios of the images, A:B:C = 0.95:1.00:0.24, show a large anomaly that cannot be reproduced by ellipsoidal models centered near the bright cluster galaxies (Oguri et al. 2008). The quasar is radio loud, and the flux ratio anomaly persists in the radio, albeit with different flux ratios than in the optical (Kratzer et al. 2011). Recent Chandra X-ray observations (Ota et al. 2012) find a cluster mass consistent with lens models and that there is soft X-ray absorption in the spectrum of image C consistent with explaining the optical color differences between the images A, B, and C as extinction. After correction for this absorption/extinction, the X-ray, optical, and radio flux ratios are broadly consistent and the flux anomalies are due to a small galaxy near image C (Oguri et al. 2013).

As part of a program to better understand this system, including deep Hubble Space Telescope (HST; Oguri et al. 2013), X-ray (Ota et al. 2012), radio (Kratzer et al. 2011), and weak-lensing (Oguri et al. 2012) observations, we have been monitoring the lens in the optical since 2007 to measure the time delay. Time delays generally measure a combination of cosmological distances (the Hubble constant to lowest order) and the surface density of the lens at the radius of the images (Kochanek 2002). Since the mass distribution of the lens can be independently constrained by the X-ray emission profile (Ota et al. 2012) and additional multiply imaged background galaxies of differing redshifts from the quasar (Oguri et al. 2008, 2013), cluster lenses have the potential of being excellent cosmological probes if it can be demonstrated that the effects of substructure are controllable. Here we present a light curve for the brighter A and B images of SDSS J1029+2623 spanning six 8-month observing seasons and measure their time delay. Because image C is faint and very close to B, we cannot independently determine its delay given the quality of our images. Section 2 summarizes the available data, Section 3 derives the time delay, and Section 4 discusses the results.

2. OBSERVATIONS

We have monitored SDSS J1029+2623 using KeplerCam at the Fred Lawrence Whipple Observatory (FLWO) 1.2 m telescope over a period of 1960 days from 2007 January to 2012 June with an average sampling rate of three times a week when the source was visible. KeplerCam has 0:672 pixels, and the 1.2 m telescope presently delivers very poor quality images due to problems with its primary mirror. While the data are adequate for monitoring the widely separated A and B images, our light curve of image B is that of B and C combined. Since image C is relatively faint ($R \sim 20.3$) and expected to have a very short delay relative to image B (2–3 days, see Section 4), merging its flux with that of image B will have no significant consequences for our present results. Each epoch consisted of three 5 minute exposures in the $r$ filter. The data were reduced using standard methods.

Although we analyzed the data following the methods used previously for the quintuple quasar SDSS J1004+4112,
(Fohlmeister et al. 2007; Fohlmeister et al. 2008) and found consistent results, here we use the ISIS difference imaging package (Alard & Lupton 1998). The reference image shown in Figure 1 was constructed from 26 of the best quality sub-images, corresponding to a total integration time of 130 minutes. The quasar images are labeled A and B following the notation of Inada et al. (2006). The third quasar image C lies roughly 1.8'' south of B (Oguri et al. 2008). While it is marginal resolved in the reference image, we cannot obtain a reliable, independent light curve for it. The differential light curves of A and B+C were extracted following the standard procedures for ISIS.

To calibrate the reference image, we matched 39 sources in the field to stars with 15 < r < 21 in the Sloan Digital Sky Survey (SDSS) DR8 (Aihara et al. 2011) catalogs. We defined the zero points using the SDSS magnitudes and SExtractor (Bertin & Arnouts 1996) 5.4 (8 pixel) diameter aperture magnitudes for sources on the reference image. After dropping objects more than 0.1 mag from the median of the initial individual zero-point estimates, the nominal uncertainties in the calibration are negligible (2 mmag). ISIS tends to modestly underestimate photometric errors. Using a combination of the light curves of stars of magnitudes comparable to those of the quasars and the statistics of points in the quasar light curves with small temporal separations, we estimate that we must rescale the ISIS errors by a factor of 1.24. Combining the reference image photometry with the difference imaging light curves, we obtain the calibrated light curves presented in Table 1, where we report and use the rescaled error bars. Figure 2 shows the light curves. Here we have added as a first epoch the original SDSS observations of the system (Inada et al. 2006).

3. TIME DELAY

The challenge in measuring time delays is that the final uncertainties in essence depend on the nature of the interpolation of the light curves used for the comparison (Kundic et al. 1997). Experience demonstrates that it is worth considering multiple methods and that the formal uncertainties are typically smaller

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7 We take three points separated by less than seven days, predict the value of the middle point by linearly interpolating the outer points, and compare the difference between the observed and predicted values of the middle point to the estimated photometric errors.
### Table 1 (Continued)

| HID—2450000 | A  | B+(C) |
|--------------|----|-------|
|              | (mag) | (mag) |
| 4510.952    | 18.524 ± 0.024 | 18.574 ± 0.029 |
| 4518.867    | 18.482 ± 0.066 | 18.482 ± 0.076 |
| 4524.882    | 18.534 ± 0.023 | 18.536 ± 0.026 |
| 4531.700    | 18.566 ± 0.026 | 18.584 ± 0.027 |
| 4534.946    | 18.518 ± 0.023 | 18.574 ± 0.028 |
| 4535.786    | 18.552 ± 0.023 | 18.592 ± 0.035 |
| 4537.630    | 18.591 ± 0.050 | 18.591 ± 0.059 |
| 4548.789    | 18.518 ± 0.020 | 18.531 ± 0.023 |
| 4551.717    | 18.544 ± 0.023 | 18.540 ± 0.027 |
| 4553.846    | 18.526 ± 0.020 | 18.550 ± 0.024 |
| 4554.645    | 18.559 ± 0.021 | 18.510 ± 0.023 |
| 4556.642    | 18.503 ± 0.021 | 18.539 ± 0.024 |
| 4558.726    | 18.502 ± 0.020 | 18.539 ± 0.023 |
| 4560.751    | 18.532 ± 0.020 | 18.542 ± 0.023 |
| 4565.831    | 18.502 ± 0.022 | 18.508 ± 0.025 |
| 4567.789    | 18.469 ± 0.025 | 18.573 ± 0.046 |
| 4569.707    | 18.535 ± 0.036 | 18.513 ± 0.042 |
| 4575.724    | 18.519 ± 0.044 | 18.527 ± 0.050 |
| 4576.730    | 18.635 ± 0.060 | 18.625 ± 0.070 |
| 4577.711    | 18.511 ± 0.040 | 18.526 ± 0.045 |
| 4578.768    | 18.547 ± 0.032 | 18.473 ± 0.036 |
| 4579.698    | 18.541 ± 0.022 | 18.505 ± 0.024 |
| 4583.680    | 18.563 ± 0.027 | 18.507 ± 0.027 |
| 4584.703    | 18.524 ± 0.029 | 18.507 ± 0.029 |
| 4585.747    | 18.586 ± 0.025 | 18.586 ± 0.025 |
| 4586.699    | 18.551 ± 0.025 | 18.551 ± 0.025 |
| 4587.683    | 18.541 ± 0.024 | 18.573 ± 0.035 |
| 4589.648    | 18.491 ± 0.050 | 18.573 ± 0.050 |
| 4596.739    | 18.504 ± 0.029 | 18.504 ± 0.029 |
| 4597.703    | 18.470 ± 0.044 | 18.470 ± 0.044 |
| 4605.654    | 18.505 ± 0.036 | 18.557 ± 0.043 |
| 4607.679    | 18.525 ± 0.039 | 18.563 ± 0.046 |
| 4611.712    | 18.492 ± 0.022 | 18.604 ± 0.028 |
| 4616.671    | 18.524 ± 0.025 | 18.504 ± 0.025 |
| 4628.648    | 18.556 ± 0.043 | 18.571 ± 0.049 |
| 4632.651    | 18.534 ± 0.035 | 18.531 ± 0.047 |
| 4633.655    | 18.634 ± 0.055 | 18.634 ± 0.055 |
| 4769.958    | 18.266 ± 0.028 | 18.266 ± 0.028 |
| 4776.021    | 18.228 ± 0.031 | 18.228 ± 0.031 |
| 4793.023    | 18.279 ± 0.028 | 18.279 ± 0.028 |
| 4801.948    | 18.289 ± 0.023 | 18.289 ± 0.023 |
| 4804.847    | 18.305 ± 0.025 | 18.305 ± 0.025 |
| 4807.942    | 18.335 ± 0.024 | 18.335 ± 0.024 |
| 4829.042    | 18.322 ± 0.026 | 18.322 ± 0.026 |
| 4838.864    | 18.295 ± 0.034 | 18.295 ± 0.034 |
| 4840.957    | 18.327 ± 0.039 | 18.327 ± 0.039 |
| 4842.930    | 18.179 ± 0.061 | 18.179 ± 0.061 |
| 4847.995    | 18.277 ± 0.032 | 18.277 ± 0.032 |
| 4851.991    | 18.437 ± 0.027 | 18.437 ± 0.027 |
| 4859.020    | 18.368 ± 0.026 | 18.368 ± 0.026 |
| 4859.999    | 18.362 ± 0.026 | 18.362 ± 0.026 |
| 4861.001    | 18.347 ± 0.023 | 18.347 ± 0.023 |
| 4863.932    | 18.363 ± 0.021 | 18.363 ± 0.021 |
| 4864.895    | 18.359 ± 0.022 | 18.359 ± 0.022 |
| 4866.841    | 18.307 ± 0.028 | 18.307 ± 0.028 |
| 4867.868    | 18.349 ± 0.029 | 18.349 ± 0.029 |
| 4868.854    | 18.289 ± 0.052 | 18.289 ± 0.052 |
| 4879.646    | 18.348 ± 0.025 | 18.348 ± 0.025 |
| 4882.028    | 18.327 ± 0.027 | 18.327 ± 0.027 |
| 4886.886    | 18.322 ± 0.023 | 18.322 ± 0.023 |
| 4889.620    | 18.351 ± 0.026 | 18.351 ± 0.026 |
| 4891.858    | 18.331 ± 0.020 | 18.331 ± 0.020 |
| 4893.874    | 18.328 ± 0.018 | 18.328 ± 0.018 |
than the actual uncertainties (when tested by improved light curves; e.g., Kochanek et al. 2006 and Courbin et al. 2011 in the case of HE 0435−1223). These issues will be most problematic for short delays of the order of a few days both because the delay is not that different from the sampling cadence and because quasars show less and less variability power on shorter timescales (e.g., MacLeod et al. 2010). There is also a cosmic variance of several percent in time delays produced by fluctuations in the mean density along the line of sight (e.g., Bar-Kana 1996; Wambsganss et al. 2005), although one can attempt to use the visible galaxies in the field to estimate its amplitude (e.g., Suyu et al. 2010). Delay ratios do benefit from higher accuracy measurements because they are little affected by this cosmic variance. Because cluster lenses like SDSS J1029+2623 have relatively long delays (∼years), it is easier to measure cosmic-variance-limited delays than for single galaxy lenses.

Here we determine the time delays between images A and the combined B+C image pair, where we know from simply shifting the light curves by hand that the delay is on the order of two years. We first consider two methods that do not directly test for microlensing or model its effects. If we first consider the simple $\chi^2$-minimization method described in Fohlmeister et al. (2007), we measure a delay of $\Delta t_{AB} = (746 \pm 6)$ days (all delays are in the sense of A leading B). The dispersion method of Pelt et al. (1994, 1996) gives a delay of $\Delta t_{AB} = (745 \pm 10)$ days. The Kochanek et al. (2006) polynomial method, where the source light curve and microlensing magnifications are described by polynomials, lets us examine the effects of microlensing. We modeled each season with polynomials of all orders from $N_p = 3$ to 25 and with constant, linear or quadratic ($N_p = 0$ to 2) polynomials for the microlensing variability in each season.

Models allowing for no microlensing parameters were strongly ruled out by the data. We evaluate the models using Bayesian information criteria to weight the changes in the
numbers of parameters between models, where the probability of a delay with a goodness of fit $\chi^2$ is $\exp(-\chi^2/2 - kN_p)$ where $N_p = 4(N_s + N_\mu)$ is the number of parameters in the model. We consider both the more liberal Akaike information criterion (AIC) with $k = 1$ and the more conservative Bayesian information criterion (BIC) with $k = \ln N_{\text{data}}$ (see Poindexter et al. 2007), where $N_{\text{data}} = 355$ is the number of data points in the seasons that overlap. The AIC favors $N_s \sim 1$ and $N_\mu = 1$ (formally, the relative probabilities for $N_\mu = 0, 1,$ and 2 are 0:1:0.011), while the BIC favors $N_s \simeq 5$ and $N_\mu = 0$ (1.0:0.0:0.11). The combined result for the AIC is a median time delay of $\Delta t_{AB} = 740.0$ with a 90% confidence range of 739.0 $< \Delta t_{AB} < 744.9$, while that for the BIC is a median of $\Delta t_{AB} = 748.6$ with a 90% confidence range of 742.6 $< \Delta t_{AB} < 753.8$. As Figure 3 shows, it is difficult to evaluate the relative merits of these solutions by eye, although the low-order polynomials favored by the BIC seem to overly smooth the light curves independent of their statistical merits. If we apply no information criterion at all, the median is $t_{AB} = 739.3$ with a 90% confidence range of 730.8 $< t_{AB} < 740.5$.

If we consider the two most probable models, $N_s = 7$ and $N_\mu = 1$ for the AIC and $N_s = 5$ and $N_\mu = 0$ for the BIC, we find that the effects of microlensing are small but statistically significant. In the best BIC model, the flux ratios in the four seasons are $\Delta m_{AB} = -0.373 \pm 0.006, -0.413 \pm 0.006, -0.424 \pm 0.005,$ and $-0.384 \pm 0.006$ mag for the four overlapping seasons. The small fluctuations suggest the presence of microlensing, with the middle two seasons showing a significant shift of about 0.05 mag relative to the first and last seasons. The AIC model shifts are very similar but have marginally detected gradients of $-0.04 \pm 0.06, -0.03 \pm 0.03, 0.08 \pm 0.03,$ and $-0.07 \pm 0.04$ mag yr$^{-1}$. Given the quality of the data, these effects are not obvious, and it is not inconceivable that they are partly due to systematics from matching data taken at very different epochs even though ISIS excels at properly cross-calibrating data and correcting for point-spread function differences. In fact, when we fit the light curves of stars with similar magnitudes, there were also shifts of this amplitude. Thus, while the addition of microlensing parameters leads to statistically significant improvements in the fits, they could be modeling effects other than microlensing. Given the low

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**Figure 2.** Optical $r$-band light curves for image A (filled blue circles) and images B+C (black squares). The first data point for both light curves is from the original SDSS observations. (A color version of this figure is available in the online journal.)

**Figure 3.** Polynomial method probability distributions for the time delay based on either the AIC (solid) or BIC (dashed) information criteria for combining the models. Both the differential and integral probability distributions are shown, with the differential probability normalized to its maximum.
amplitudes and the quality of the data we regard the evidence for the detection of microlensing (as a physical process rather than as parameters in a fitting function) to be marginal. In the following we adopt a time delay of $\Delta t_{\text{AB}} = (744\pm10)$ days that conservatively combines the AIC and BIC results from the polynomial method. Note, however, that this estimate is also in agreement with the $\chi^2$-minimization and the Pelt et al. (1994, 1996) dispersion method results that do not take possible microlensing variations into account. Figure 4 shows the light curves of the A and B+C images shifted by the determined time delay of $\Delta t_{\text{AB}} = (744\pm10)$ days and $-0.40$ mag. The shifted photometry for image A from the original SDSS observations in 2004 closely matches the start of our light curves although it is not quite overlapping. The later R-band observations by Oguri et al. (2008) are contemporaneous with the start of our observations, so we lack any additional data in the gap between 2004 and 2007.

The measured time delay allows to assemble a densely sampled light curve spanning more than 1000 days in rest frame. Unfortunately, the merged light curves do not fill in the seasonal gaps due to the delay of almost exactly two years (see Figure 4). We computed the structure function, which represents the intrinsic variability from the merged A/B+C light curves of this distant individual quasar shows a power-law slope of $0.32\pm0.02$ and a variability amplitude at 100 days of $0.15\pm0.03$ mag.

4. SUMMARY AND DISCUSSION

We presented 5.4 years of optical monitoring for the two bright lensed quasar images of the largest image separation gravitationally lensed quasar SDSS J1029+2623. We find that image A leads images B and C by $\Delta t_{\text{AB}} = (744\pm10)$ days (90% confidence). The formal error bar on the time delay, which includes statistical uncertainties and systematic differences, is $\sim1.3\%$ and is in the regime where cosmic variance caused by fluctuations in the mean line-of-sight density is more important than the measurement errors. We find that the effect of microlensing in this system is small. Formally, the detection is statistically significant, but we view the overall evidence for microlensing rather than low-level systematic uncertainties as weak. This is the second longest measured time delay after the 822 day delay between images C and A in SDSS J1004+4112 (Fohlmeister et al. 2008).

A detailed interpretation of the measured delay is deferred pending the completion of our analysis of the HST images (Oguri et al. 2013) and additional spectroscopy of the lensed arcs in this system. However, as an experiment, we fit the lens using a Navarro–Frenk–White model centered near galaxy G2 with a break radius of 78′′ based on the X-ray data (Ota et al. 2012). We adopt the component positions ($\pm0.05$) from Oguri et al. (2008) and a time delay of $\Delta t_{\text{AB}} = (744\pm10)$ days that tries to conservatively combine the AIC and BIC results. We used priors of $\pm1.0$ on the position of the model relative to galaxy G2, $\epsilon = 0.46\pm0.05$ for the ellipticity of the cluster density, and $\gamma = 0.05\pm0.05$ for any additional external shear. The value of $\epsilon$ was determined by the best-fit model with $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$. We then fit models as a function of the Hubble constant $H_0$ assuming a flat, $\Omega_0 = 0.3$ and $\Lambda_0 = 0.7$ cosmological model. We did not include the flux ratios in the fits because of the known flux ratio anomaly. The anomaly appears to be due to a small galaxy near image C (Oguri et al. 2013) which should have little effect on the overall geometry and the AB time delay. In a normal four-image lens, the constraint on the radial mass profile from the X-ray data would largely eliminate any degeneracies because they are created by uncertainties in the surface mass density at the radius of the images (Kochanek 2002).

Figure 5 shows the resulting goodness of fit as a function of $H_0$ for these simple models. Low values of $H_0$ are disfavored.
In our present data, measuring the B–C time delay is impossible given the data quality. It does shift steadily over the model sequence, decreasing with increasing $H_0$ from 3.4 to 2.1 days. This fully justifies our making the measurements using the combined B/C light curve. It is well worth measuring the BC delay because it is very sensitive to the perturbing galaxy that causes the flux ratio anomaly (see Oguri 2007; Keeton & Moustakas 2009) and hence probes the structure of galaxy halos in cluster environments. Such short delays are extremely difficult to measure accurately in ground-based observations because quasars have so little variability power on such short timescales (see Mushotzky et al. 2011) and might require a space-based lens monitoring satellite like the proposed OMEGA (Moustakas et al. 2008).

We thank all the participating observers at the Harvard-Smithsonian Center for Astrophysics for their support of these observations. Our observations were obtained with the F. L. Whipple 1.2 m telescope, with support from the Smithsonian Astrophysical Observatory. C.S.K. is supported by NSF grant AST-1009756. This work was supported in part by the FIRST program “Subaru Measurements of Images and Redshifts (SuMIRe),” World Premier International Research Center Initiative (WPI Initiative), MEXT, Japan, and Grant-in-Aid for Scientific Research from the JSPS (23740161). Funding for SDSS-III has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, and the U.S. Department of Energy Office of Science. The SDSS-III Web site is http://www.sdss3.org/. SDSS-III is managed by the Astrophysical Research Consortium for the Participating Institutions of the SDSS-III Collaboration including the University of Arizona, the Brazilian Participation Group, Brookhaven National Laboratory, University of Cambridge, Carnegie Mellon University, University of Florida, the French Participation Group, the German Participation Group, Harvard University, the Instituto de Astrofisica de Canarias, the Michigan State/Notre Dame/JINA Participation Group, Johns Hopkins University, Lawrence Berkeley National Laboratory, Max Planck Institute for Astrophysics, New Mexico State University, New York University, Ohio State University, Pennsylvania State University, University of Portsmouth, Princeton University, the Spanish Participation Group, University of Tokyo, University of Utah, Vanderbilt University, University of Virginia, University of Washington, and Yale University.

REFERENCES

Althara, H., Allende Prieto, C., An, D., et al. 2011, ApJS, 193, 29
Aldar, C., & Lupton, R. H. 1998, ApJ, 503, 325
Bar-Kana, R. 1996, ApJ, 468, 17
Bertin, E., & Arnouts, S. 1996, A&AS, 117, 393
Courbin, F., Chantry, V., Revaz, Y., et al. 2011, A&A, 536, A53
Fohlmeister, J., Kochanek, C. S., Falco, E. E., et al. 2007, ApJ, 662, 62
Fohlmeister, J., Kochanek, C. S., Falco, E. E., Morgan, C. W., & Wambsganss, J. 2008, ApJ, 676, 761
Inada, N., Oguri, M., Morokuma, T., et al. 2006, ApJL, 653, L97
Inada, N., Oguri, M., Fiedler, B., et al. 2003, Natur, 426, 810
Keeton, C. R., & Moustakas, L. A. 2009, ApJ, 699, 1720
Kochanek, C. S., 2002, ApJL, 578, 25
Kochanek, C. S., Morgan, N. D., Falco, E. E., et al. 2006, ApJ, 640, 47
Kratter, R. M., Richards, G. T., Goldberg, D. M., et al. 2011, ApJL, 728, L18
Kundic, T., Turner, E. L., Colley, W. N., et al. 1997, ApJ, 482, 75
MacLeod, C. L., Inađi, Ž., Kochanek, C. S., et al. 2010, ApJ, 721, 1014
Moustakas, L. A., Bolton, A. J., Booth, J. T., et al. 2008, Proc. SPIE, 7010, 70101B
Mushotzky, R. F., Edelson, R., Baumgartner, W., & Gandhi, P. 2011, ApJL, 743, L12
Oguri, M. 2007, ApJ, 660, 1
Oguri, M., Bayliss, M. B., Dahle, H., et al. 2012, MNRAS, 420, 3213
Oguri, M., Ofek, E. O., Inada, N., et al. 2008, ApJL, 676, L1
Oguri, M., Schrabback, T., Jullo, E., et al. 2013, MNRAS, 429, 482
Ota, N., Oguri, M., Dai, X., et al. 2012, ApJ, 758, 26

Pelt, J., Hoff, W., Kayser, R., Refsdal, S., & Schramm, T. 1994, A&A, 286, 775
Pelt, J., Kayser, R., Refsdal, S., & Schramm, T. 1996, A&A, 305, 97
Poindexter, S., Morgan, N., Kochanek, C. S., & Falco, E. E. 2007, ApJ, 660, 146
Suyu, S. H., Marshall, P. J., Auger, M. W., et al. 2010, ApJ, 711, 201
Wambsganss, J., Bode, P., & Ostriker, J. P. 2005, ApJ, 635, 1