HST Discovery of a z=3.9 Multiply Lensed Galaxy behind the Massive X-ray Luminous Cluster WARPS J1415.1+36 at z =1.026

X. Huang, T. Morokuma, H. K. Fakhouri, G. Aldering, R. Amanullah, K. Barbary, M. Brodwin, N. V. Connolly, K. S. Dawson, M. Doi, L. Faccioli, V. Fadeyev, A. S. Fruchter, G. Goldhaber, M. D. Gladders, J. F. Hennawi, Y. Ihara, M. J. Jee, M. Kowalski, K. Konishi, C. Lidman, J. Meyers, L. A. Moustakas, S. Perlmutter, D. Rubin, D. J. Schlegel, A. L. Spadafora, N. Suzuki, N. Takanashi, and N. Yasuda

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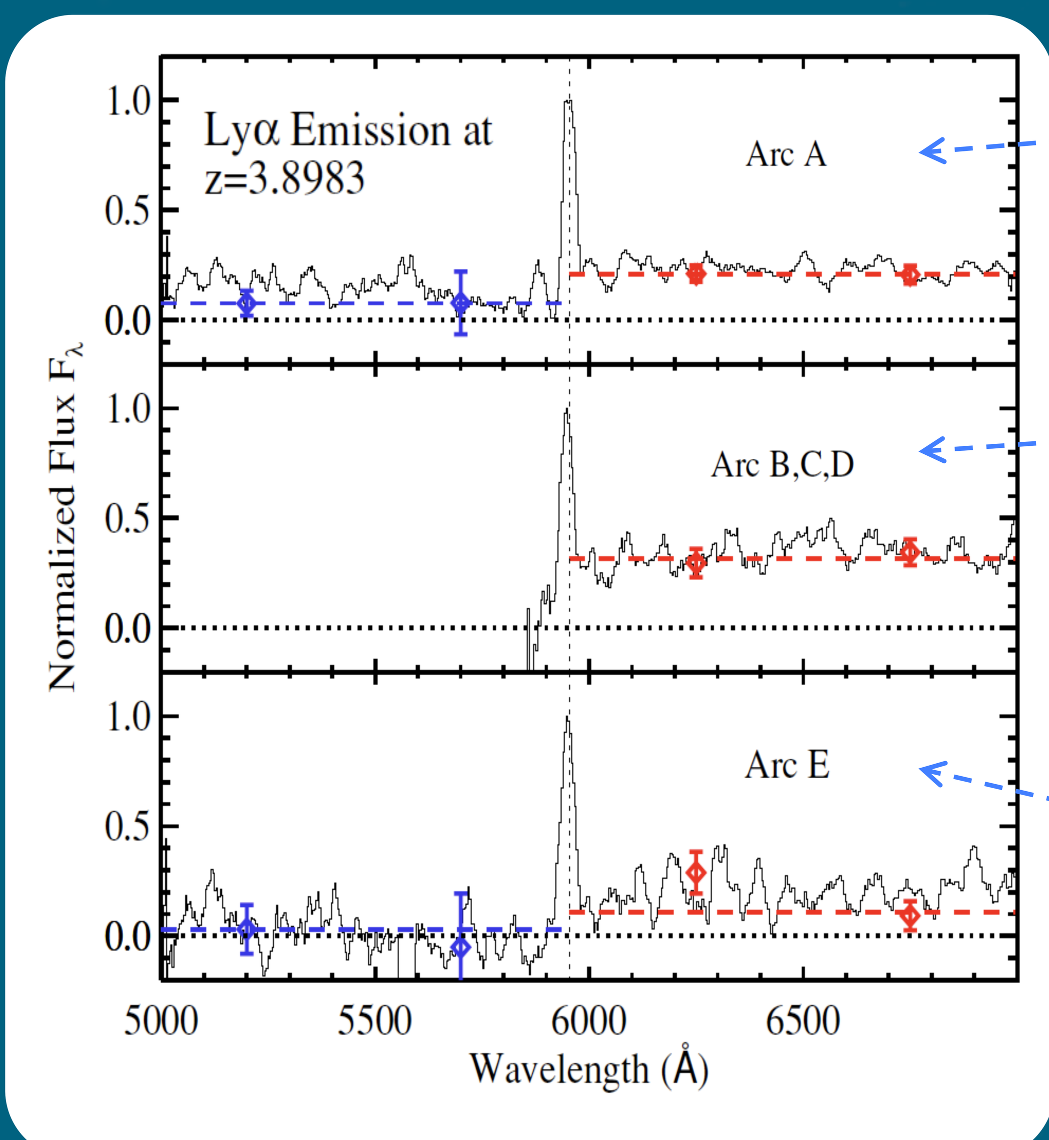
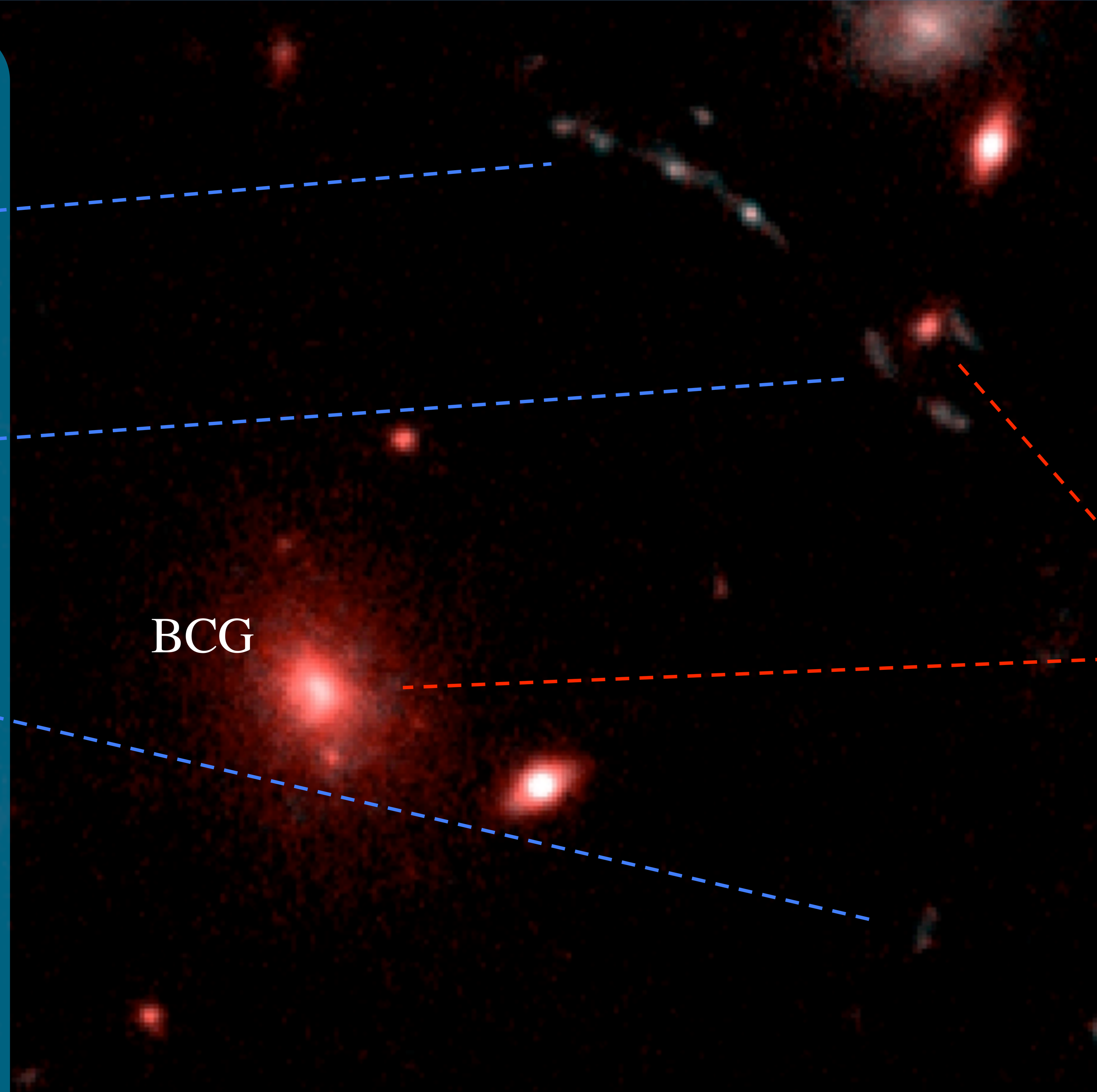
We report the discovery of a multiply lensed Lyα emitter at z = 3.90 behind the massive cluster WARPS J1415.1+3612 at z = 1.026. ACS images taken by the HST Cluster SN Survey (PI: Perlmutter) reveal a complex lensing system that produces a prominent, highly magnified arc and a triplet of smaller arcs grouped tightly around a spectroscopically confirmed cluster member. Spectroscopic observations using Subaru confirm strong Lyα emission in the source galaxy and provide the redshifts for more than 21 cluster members with a velocity dispersion of 807 ± 185 km/s. Assuming a singular isothermal sphere profile, the mass within the Einstein ring (7.13"± 0.38") corresponds to a central velocity dispersion of 686^{+15}_{-9} km/s for the cluster, consistent with the value estimated from cluster member redshifts. Our mass profile estimate from combining strong lensing and dynamical analyses is in good agreement with both X-ray and weak lensing results.

I. Strong Gravitational Lensing





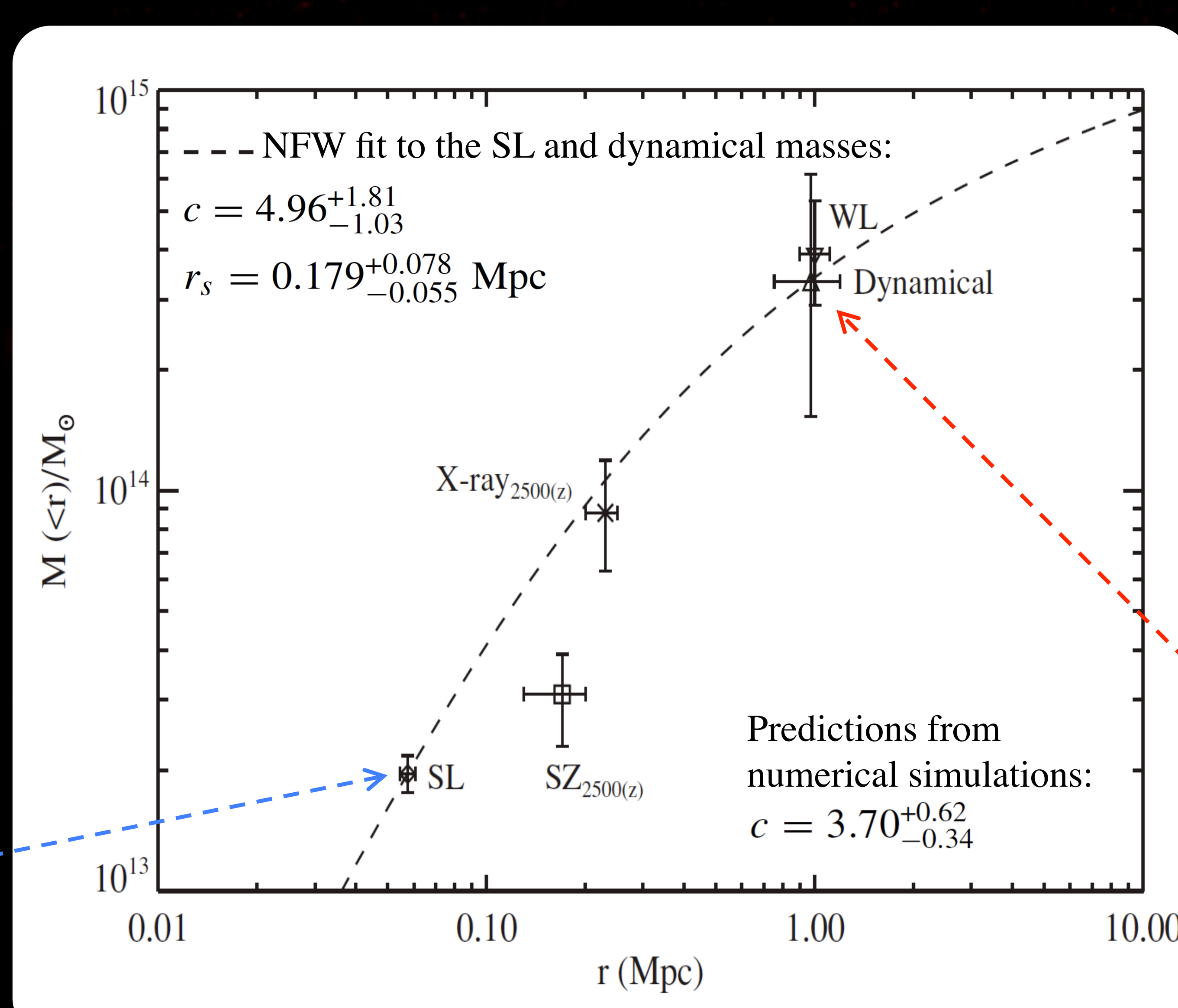
Strong-Lensing Mass:

The five arcs lie very close to an imaginary circle centered on the brightest cluster galaxy (BCG). They subtend slightly more than 90°. We take this circle to be the Einstein ring and measure the strong-lensing mass (SL) within this circle using (e.g., Narayan & Bartelmann 1996),

$$M(<\theta_E) = \frac{c^2}{4G}\frac{D_L D_S}{D_{LS}}\theta_E^2$$

Given θ_E=7.13±0.38"=57.5±3.1kpc

→ $M(<\theta_E) = 1.96^{+0.22}_{-0.20} \times 10^{13}\, M_\odot$



II. Cluster Member Redshifts

Spectroscopic Redshifts

Object ID	R.A. (J2000)	Decl. (J2000)	z
1	14:15:13.08	+36:12:25.4	1.0262 ± 0.0003
2	14:15:12.68	+36:12:59.6	1.0331 ± 0.0003
3	14:15:11.27	+36:14:35.7	1.033 ± 0.001
4	14:15:11.64	+36:11:37.8	1.028 ± 0.002
5	14:15:07.08	+36:14:15.6	1.0255 ± 0.0003
6	14:15:07.68	+36:13:06.3	1.025 ± 0.001
7	14:15:13.95	+36:12:37.8	1.017 ± 0.001
8	14:15:10.36	+36:11:31.2	1.0256 ± 0.0003
9	14:15:15.91	+36:12:58.9	1.0187 ± 0.0003
10	14:15:10.66	+36:11:39.8	1.028 ± 0.001
11	14:15:08.08	+36:12:21.0	1.0234 ± 0.0003
12	14:15:10.54	+36:12:09.9	1.0264 ± 0.0003
13	14:15:10.59	+36:12:07.9	1.023 ± 0.002
14	14:15:10.19	+36:11:49.6	1.0313 ± 0.0003
15	14:15:11.12	+36:12:04.0	1.0252 ± 0.0003
16	14:15:11.47	+36:12:22.8	1.018 ± 0.001
17	14:15:06.61	+36:12:18.0	1.033 ± 0.001
18	14:15:09.12	+36:13:09.1	1.0260 ± 0.0003
19	14:15:13.45	+36:12:56.9	1.035 ± 0.002
20	14:15:12.60	+36:11:09.7	1.023 ± 0.001
21	14:15:00.02	+36:13:02.8	1.011 ± 0.001
22	14:15:05.89	+36:13:03.1	1.025 ± 0.001
23	14:15:13.00	+36:13:07.0	1.0301 ± 0.0003
24	14:15:08.41	+36:13:04.6	1.035 ± 0.002
25	14:15:10.82	+36:10:33.0	1.023 ± 0.001
A	14:15:10.80	+36:12:09.1	3.8983 ± 0.0005
B-D	14:15:10.57	+36:12:06.9	3.891 ± 0.002
E	14:15:10.58	+36:12:00.8	3.897 ± 0.001

Dynamical Mass:

The galaxy velocity dispersion is measured to be

$$\sigma_v = 686^{+15}_{-19}\ \text{km/s}$$

Assuming no velocity bias and using the scaling relation from Evrard et al. (2008), we derive the dynamical mass within r_{200},

$$M_{200} = 3.33^{+2.83}_{-1.80} \times 10^{14}\, M_\odot$$

Conclusions:

◆ The cluster WARPS J1415.1+36 at z_{lens} = 1.026 is one of the most distant strong-lensing clusters reported.

◆ For this z > 1 cluster, consistent estimates of the mass can be obtained from strong lensing (SL), galaxy dynamics, weak lensing (WL), and X-ray (Maughan et al. 2006) measurements. Although the mass estimate from Sunyaev Zel'dovich effect (SZ) appears to differ, this particular measurement was obtained with a single frequency, not the multifrequency approach used by most modern surveys to reduce systematic errors.

◆ Current surveys (e.g., SPT) are discovering new more massive high-redshift clusters. If these clusters are followed up with deep multiwavelength HST observations, many of them are expected to reveal strong lensing arcs. With more precise mass estimates of these high-redshift clusters, galaxy clusters will soon become an even more effective probe of cosmology.

References: Evrard, A. E., et al. 2008, ApJ, 672, 122; Maughan, B. J., et al. 2006, MNRAS, 365, 509; Narayan, R., & Bartelmann, M. 1996, arXiv:astro-ph/9606001. This work was supported by NASA through program GO-10496 from the Space Telescope Science Institute and by the Director, Office of Science, Office of High Energy and Nuclear Physics, of the U.S. Department of Energy under contract no. AC02-05CH11231. For more information about this survey see: http://supernova.lbl.gov/2009ClusterSurvey/.