THE CASTLES PROJECT

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Abstract. We describe the goals of the CASTLES (CfA-Arizona-Space Telescope-LEns-Survey)\textsuperscript{1} project including a sample of NICMOS images of gravitational lenses and a brief list of the preliminary findings.

1. Introduction

Gravitational lenses are powerful astrophysical tools to investigate cosmology, the Hubble constant, galactic structure and evolution, dust extinction, and AGN host galaxies. There are now 47 known galaxy lens systems, and their broad astrophysical utility relies on accurate photometry, astrometry and redshifts for as many systems as possible. These lenses consist of 2-4 source images (AGNs, quasars, hosts), superposed on a foreground lens galaxy within a diameter of $\sim 1\"$. Thus, precise and quantitative studies in the optical and IR require Hubble Space Telescope (HST) observations.

2. CASTLES Goals and Preliminary Results

CASTLES is an ongoing HST survey of all the known lensed systems and lens candidates. We are obtaining images with NICMOS and WFPC2 in the H, I and V bands. Some of its goals are: to create a complete, uniform high-resolution photometric sample of the known galaxy-mass lenses; to obtain redshift estimates for all lens galaxies which lack spectroscopic redshifts;

\textsuperscript{1}see http://cfa-www.harvard.edu/castles
to find any source or lens components that have escaped detection and determine their photometric properties; to obtain precise astrometric data for all source components to improve lens models and estimates of $H_0$; and to investigate the wide field environments of the lens galaxies and their role in lensing.

In this contribution we present examples of CASTLES images (see Fig. 1) and a brief list of the preliminary findings:

**Missing Lenses:** As expected, the deeper CASTLES optical and IR observations are detecting most “missing” lens galaxies, even in cases where bright quasar images and small separations make this difficult. Among the 10 doubles in Lehár et al. (1999), we detected 9 lens galaxies (4 of which are discoveries). We failed only in the case of Q1208+1011, due to contrast problems. We never detect lenses in the wider quasar pairs (UM425, Q1429–008, Q1634+267, MGC2214+3550, and Q2345+007) whose extreme limits on the lens $M/L$ make lensing improbable and point to the binary quasar interpretation (see Kochanek, Falco & Muñoz, 1999).

**Host Galaxies:** CASTLES has detected the lensed AGN host galaxies for 7 quasars (MG0414+0534, Q0957+561, PG1115+080, H1413+117, CTQ414, BR0952–0115, HE1104–1805), and 4 radio galaxies (MG0751+2716, MG1131+0456, B1600+434, B1608+656). Lensing provides a unique opportunity to study $z > 1$ host galaxies, because the hosts are magnified to detectable angular sizes. A preliminary analysis (i.e. demagnification) finds that $L_{\text{host}} \lesssim L_*$ and indicates that even the most luminous quasars (e.g. PG1115+080) need not reside in particularly luminous hosts. For 2 of the QSO pairs (MGC2214+3550 and Q2345+007), the host morphology proves the systems are quasar binaries and not “dark” lenses.

**Photometric Lens Redshifts:** We have found that we can accurately estimate photometric lens redshifts by mapping the lenses onto the local “fundamental plane” using passive evolution models for E- and K-corrections. These Bayesian estimates simultaneously use the available color, luminosity, mass, and structural information. Tests on ten double-image systems (Lehár et al. 1999) demonstrate agreement within $\Delta z \lesssim 0.1$ with spectroscopic redshifts.

**Galaxy Structure:** The CASTLES observations provide detailed constraints on lens galaxy structure, through shape and profile fitting. We continue to find that most lens galaxies have De Vaucouleurs profiles, as well as shapes, and colors consistent with passively evolving early-type galaxies; e.g. Q0142–100, BR1095–0115, Q1017–207, B1030+071, HE1104–1805 (Lehár et al. 1999); MG1131+0456 (Kochanek et al. 1999) and PG1115+080 (Impey et al. 1998). B0218+357 and PKS1830–211 (Lehár et al. 1999) are spirals but present a more complex photometric picture due to the high molecular gas column densities and implied dust extinction.
Figure 1. NICMOS images of CASTLES targets, showing the H-band images after deconvolving the HST H-band point-spread function. The target name and field size are displayed for each panel.
**Dark Matter:** We constrain and study the dark matter distribution of lenses by comparing their luminosity distribution to our improved lens mass models (Lehár et al. 1999). While most of the 2-image lenses can be fitted by a single ellipsoidal lens, some require substantial external shear, and most require such shear to explain misalignments between the lens mass and its light. Our observations reveal neighboring galaxies that produce the required shear (e.g. MG1131+0456, Kochanek et al. 1999). In some cases we can study the mass profile. We can use the mass determinations to estimate $M/L$ and explore its value and evolution with redshift.

**Lens Galaxy Extinction:** We use lensed image flux ratios as a function of wavelength to measure the differential extinction in the lens galaxies. Of the 10 doubles in Lehár et al. (1999), 2 are spirals (B0218+357 and PKS1830−211) and are heavily attenuated. The rest are ellipticals; 4 contain modest but measurable amounts of dust (SBS0909+523, Q1009−0252, HE1104−1805, and Q1208+101), and 4 show little or no differential extinction. PG1115−080 (Impey et al. 1998) and MG1131+0456 (Kochanek et al. 1999) are virtually transparent. The transparency of MG1131+0456 rules out the “dusty lens hypothesis” for the very red lenses.

$H_0$: The CASTLES astrometric precision of better than 3 mas is providing stringent new constraints for lensed systems with time delays. Our PG1115+080 data (Impey et al. 1998) show a round, $R^{1/4}$-law lens galaxy, which is part of a small group. With the measured time delay our models robustly limit $H_0 \lesssim 65 \pm 5 \text{ km s}^{-1} \text{ Mpc}^{-1}$. In B0218+357 (Lehár et al. 1999), we found that the lens was best fit by an exponential profile, consistent with its blue colors and small image separation. B0218+357 is one of the most isolated lenses, with an estimated tidal shear of less than 1%. With the observed time delay of $\sim 12$ days, the value of $H_0$ depends very strongly on the precise lens position, which we hope to improve with new observations. Our new image of Q0957+561 shows 2 images of the quasar host galaxy; their geometry rules out the existing lens models for the system.

**References**

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