Mass makeup of galaxies

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Abstract

Lensing galaxies, unlike other samples of galaxies, are selected based on their masses and mass profile, rather than their colors or surface brightnesses. Therefore, gravitational lensing allows us to select galaxies based on their mass rather than their light, even at high redshift, without the need for medium resolution spectroscopy. Unfortunately, lensing by galaxy mass objects produces lensed sources with image separation of the order of 1" and a large fraction of the lensed sources by galaxies are unresolved using typical seeing-limited ground based observations. In this white paper we outline the need for a homogeneous lensed quasar study and we argue that this can be achieved using a new observational paradigm - namely the use of relatively low-cost Adaptive Optics (AO) systems mounted on 2 m class telescopes. We note that such instruments will have impact also ob galaxy-galaxy lensing studies.

Introduction

Galaxy mass objects deflect the light of background sources, and in some cases can produce multiple images of a source, with a typical image separation of order $1''$. Unfortunately, the angular separation of most lensed quasars is somewhat smaller than the typical seeing at ground based telescopes.

Usually the observed properties of lensed objects depends on many factors, like the mass profile of the lens, and on distances to the lens and source and therefore on the cosmological parameters. In practice, separating between the cosmology and the properties of the galaxies proves to be a barrier for the use of strong lensing for deriving the cosmological parameters. However, one can invert the problem and use the values of the cosmological parameters as measured by other methods to study galaxies.

Why do we need to study lensed quasars

Although lensed quasars are not as abundant as lensed galaxies, for some studies they have advantages over lensed galaxies. For example, they can be found at very large redshifts, and due to quasar variability they also provide the possibility to measure the time delay by the gravitational potential of the lens. In addition, some statistical methods require lensed systems to be selected based on the source rather then the lens, and finally, they allow us to study quasars.

Observations of lensed quasars can probe the mass content of galaxies and the detailed structure of quasars and their host galaxies. Below we list some science highlights which are strongly driven by lensed quasars observations.

Mass profile of galaxies and the isothermality of galaxy potential

Lensed quasars and lensed galaxies are being used to probe the mass profile of galaxies (mainly elliptical). These measurements are indicating that elliptical galaxies are isothermal up to distances of at least 10 kpc (e.g., Koopmans et al. 2006). We note that the fact that galaxies are isothermal is not well understood. Specifically, this fact suggest that there is some unexpected fine tuning between the dark matter and baryon components in galaxies.

We note, that current observations do not rule out the possibility that there are some non-isothermal galaxies, which have not been found so far due to selection biases. The selection bias may be overcome by searching for additional fainter images (due to lensing) of quasars which are spatially associated with galaxies with known velocity dispersions (e.g., the SDSS sample). Such images will be spatially closer to the galaxy, sometimes below the resolution of ground based telescope. For each such quasar, one can calculate the probability that the quasar will be lensed by a galaxy with an isothermal density profile, and compare the result with the observations.

Evolution of galaxies total mass with cosmic time

Given large enough samples, lensed quasars allow us to probe the mass evolution and number density evolution of massive galaxies (e.g., Ofek et al. 2003; Fig. 1). This can be used to test models of hierarchical formation of galaxies.

Existing measurements of galaxy mass and number density evolution are shown in Fig. 1. This plot is based on a relatively small sample (14 lenses) and we suggest that given large enough samples this will be a promising method to follow galaxy mass evolution.

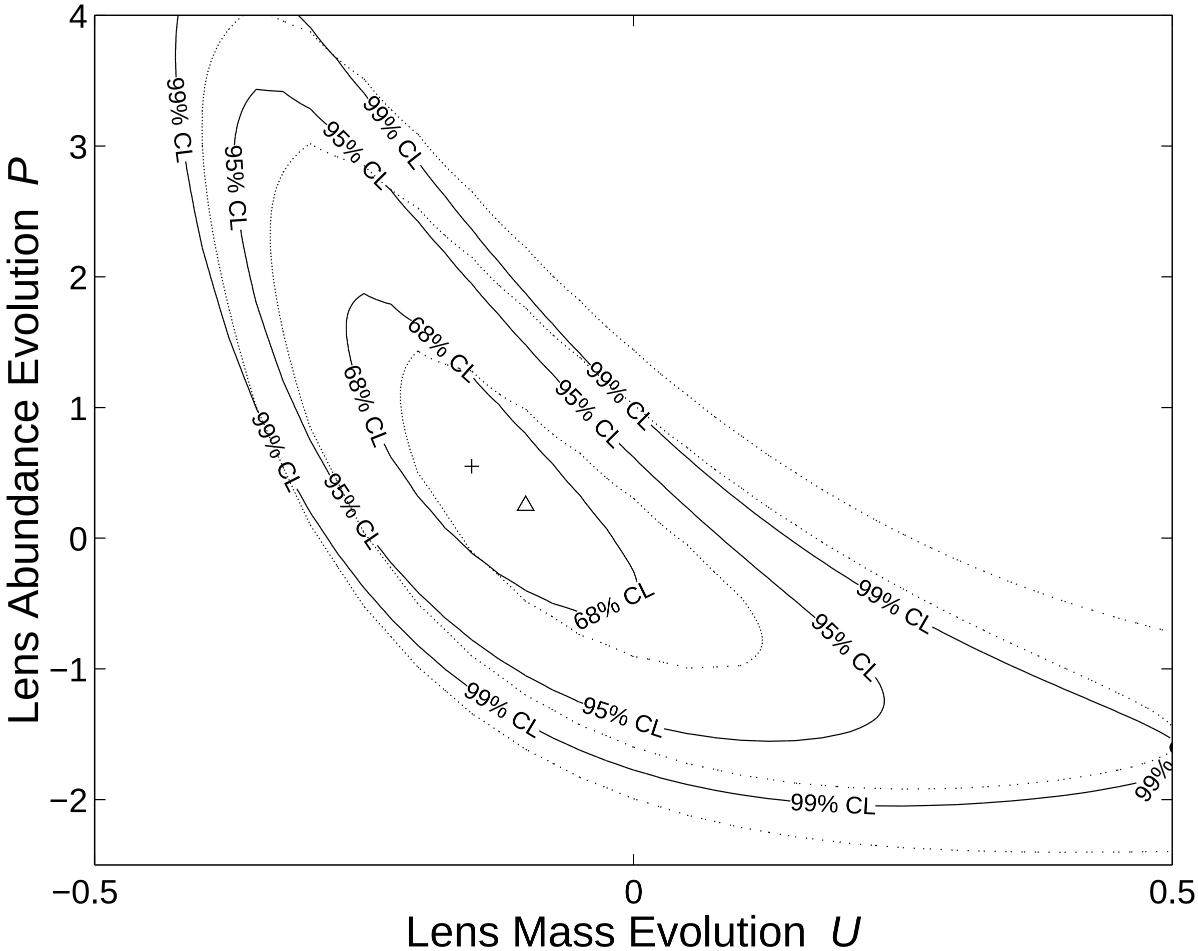

Figure 1: Fig. 1. - Likelihood contours on the mass evolution and number-density evolution of galaxies, as obtained from a sample of 14 lensed quasars (Ofek, Rix, & Maoz 2003). The mass (i.e., velocity dispersion) evolution is parametrized as $\sigma(z) = 10^{Uz}$, and the number evolution is parametrized as $n(z) = 10^{Pz}$. The solid curves are the, 1σ, 2σ and 99% CL lines for the main sample of 14 lensed quasars presented in Ofek et al. (2003), where the plus sign marks the position of maximum likelihood. The dotted curves are the same, for a smaller test sample, for which the triangle marks the position of the maximum.

Evolution of galaxies Mass to Light ratio with redshift

Gravitational lenses, unlike other samples of galaxies, are selected based on their masses, rather than their colors or surface brightnesses. By combining the masses of the lenses, as determined by lensing, with the photometry of the lens galaxies as obtained from HST or AO images, one can directly measure the mass-to-light ratio of the lens population as a function of redshift (e.g., Rusin et al. 2003).

The surface density of galaxies and their dark matter content

By measuring time delays and monitoring for microlensing by stars in the lensing galaxy we can determine the surface density of dark matter and stars near the lensed images (e.g., Kochanek et al. 2002). Moreover, as was shown by Schechter & Wambsganss (2002) it may be possible to use microlensing to measure the fraction of dark matter relative to stars.

Resolving quasars emission region

Microlensing measurements can be used to resolve the emitting region (i.e., accretion disk) of lensed quasars and to measure its size and light profile. In fact, the best estimates of quasars emission region size comes from such measurements (e.g., Kochanek 2004; Poindexter et al. 2007).

Other uses of lensed quasars include studying: The structure of broad absorption lines quasars (Chelouche 2005); measurement of cosmological parameters (e.g. Chae et al. 2002); and the morphology of quasar host galaxies (Peng et al. 2006). Finally, we suggest that using new generation large aperture telescopes, along with the magnification provided by lensing, it will be possible to measure the mass-sigma relation of a large sample of high redshift quasars, based on direct measurements of the velocity dispersion in the bulge surrounding the quasar.

An instrument for lensed quasars

The science case presented above, can be addressed using a very small investment. In fact a single ground base 2-m class telescope equipped with adaptive optics (AO), can revolutionize the way we currently study lensed quasars.

A single 2-m class telescope with AO, can observe about 22,000 targets[1] yearly. Splitting the time between a survey for new lensed quasars and monitoring for time delays – Within 5 years such a telescope can image 85,000 quasars and look for lensed quasars. In addition such a system can monitor about 100 lensed quasars on weekly basis and measure their time delays and microlensing signals accurately.

Observing such a large sample will yield between 200 and 500 new lensed quasars. Most importantly, these lensed quasars will be selected by an homogeneous survey down to very small image separations ($\sim 0.2''$). For comparison, the largest comparable homogeneous surveys existing to date are the two HST snapshot programs among ~ 1000 quasars in which about 10 lenses were found and the CLASS/JVAS radio survey among 15,000 quasars in which about 20 lenses were found. However, due to the magnification bias visible-light surveys are about twice or more as efficient as radio surveys.

Since AO requires a bright (17th magnitude for 2-m class telescope) tip/tilt star, only 50% (Fig. 2) of the quasars can be observed with an AO system on 2-m class telescope. Due to the reduced background, the sensitivity of a 2-m class telescope equipped with AO will allow it to get high-S/N images of 20 mag quasars easily. To this limit there are $\sim 10^5$ quasars with appropriate tip/tilt star visible from each celestial hemisphere.

Finally, we note that the variability of quasars is wavelength dependent. Quasars are more variable in visible light then in infra-red. AO system on small telescopes can obtain relatively high Strehl ratio images at visible-light (e.g., r-band) in which most of the "action" takes place.

Such a survey will increase the number of measured time delays by a factor of 10, and the number of known lensed quasars that are found in a homogeneous survey (which has well known selection biases) by a factor of 10-20.

Comparison with other methods

Other approaches to look and monitor for lensed quasars exist. However, we argue that these methods are expensive and less efficient. Hubble Space

[1] assuming 3 min integration and 2 min overhead time per image, and taking weather and engineering time into account

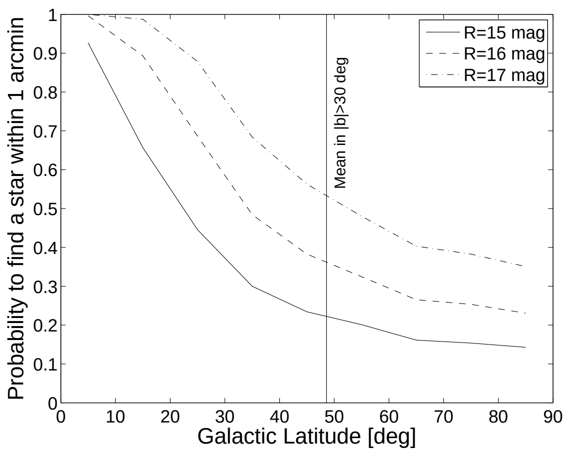

Figure 2: Fig. 2. - The probability to find a star brighter than R-band magnitude 15, 16, and 17 (solid, dashed, ad dash-dotted lines, respectively), within one arcmin from a random point, as function of Galactic latitude.

Telescope for example observed a sample of 1000 quasars, which produced a clean sample (but small) of lensed quasars for which the selection biases are known. Other optical searches like the SDSS are most probably missing a large fraction of the lensed quasars because of the seeing-limited imaging. Small separation systems probes lenses with smaller mass or different mass profile. Therefore, current studies are mostly biased towards massive galaxies.

A completely different approach is to use VLBA radio surveys to look for multiple image compact radio sources. However, the sky density of radio quasars is much lower than those detected in visible-light and existing radio surveys like CLASS and JVAS already exhausted almost all the sources that can be observed with current instrumentation (e.g., VLA).

Measuring the time delays of lensed quasars usually requires telescopes at excellent seeing sites. Even then, one is limited to systems with image separation above $\sim 1''$.

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