Strong Lensing by Supermassive Black Holes

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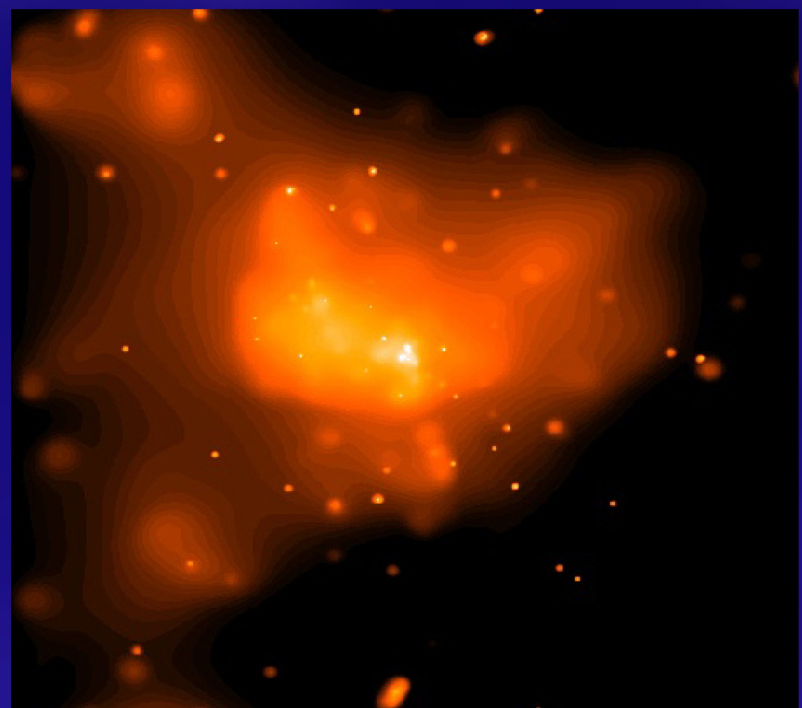
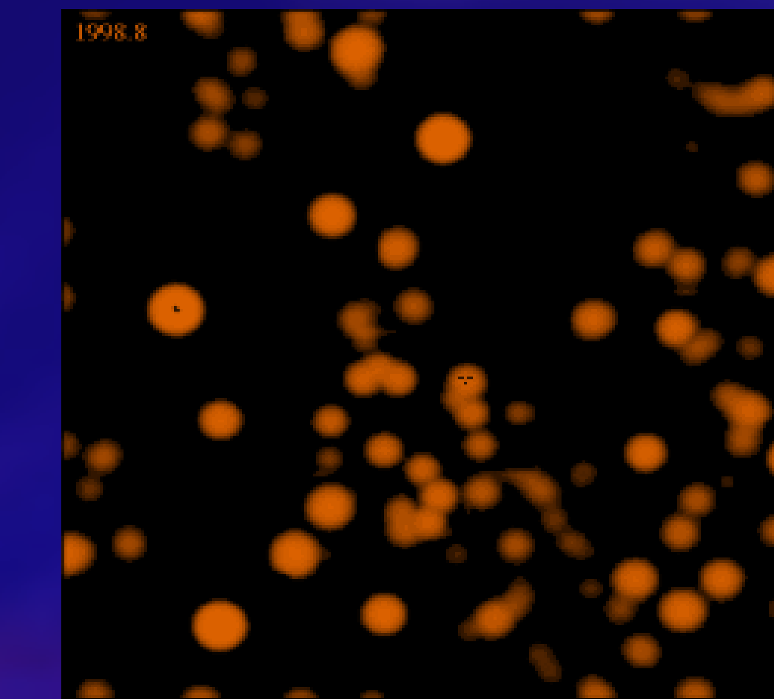


Chandra X-Ray Image of Sgr A* (nasa.gov)

We consider prospects for observing strong gravitational lensing by the supermassive black hole at the Galactic center (Sgr A*). We compute the expected number of strongly lensed stars in the central cusp, bulge and disk behind Sgr A*. We explicitly include density profiles, luminosity functions, and a varying detection threshold in our analysis. We also consider how strong lensing could be used to constrain theories of gravity. Finally, we apply our results to intermediate-mass black holes that have been proposed to inhabit globular clusters, and to supermassive black holes lying at the centers of external galaxies.



IR Image of Stars Near Sgr A*
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Background

A point mass produces two images of a background source.

The image positions and magnifications constrain the mass of the lens.

Lensing of stars beyond the galactic center could provide an additional probe of the putative SMBH, Sgr A*.

Lensing of stars directly behind Sgr A* may provide a test of general relativity in the strong-field limit.

Modeling

We include density profiles (Fig. 1) of the stellar cusp (Schödel et al. 2003), bulge and disk (Kent 1992), and the K-band luminosity function $\phi(L) \propto L^{-1.875}$ (Alexander & Sternberg, 1999).

We require that *both* lensed images of a background star are brighter than the detection threshold and spatially resolved.

We define n_* as the total number density of strong lenses. We integrate over the "Einstein volume" behind Sgr A* to find the total number of lenses :

$$N_{lens} = \int n_* dV$$

Our fiducial model has detection threshold K_0 = 17 mag and extinction A_K = 3.4 mag.

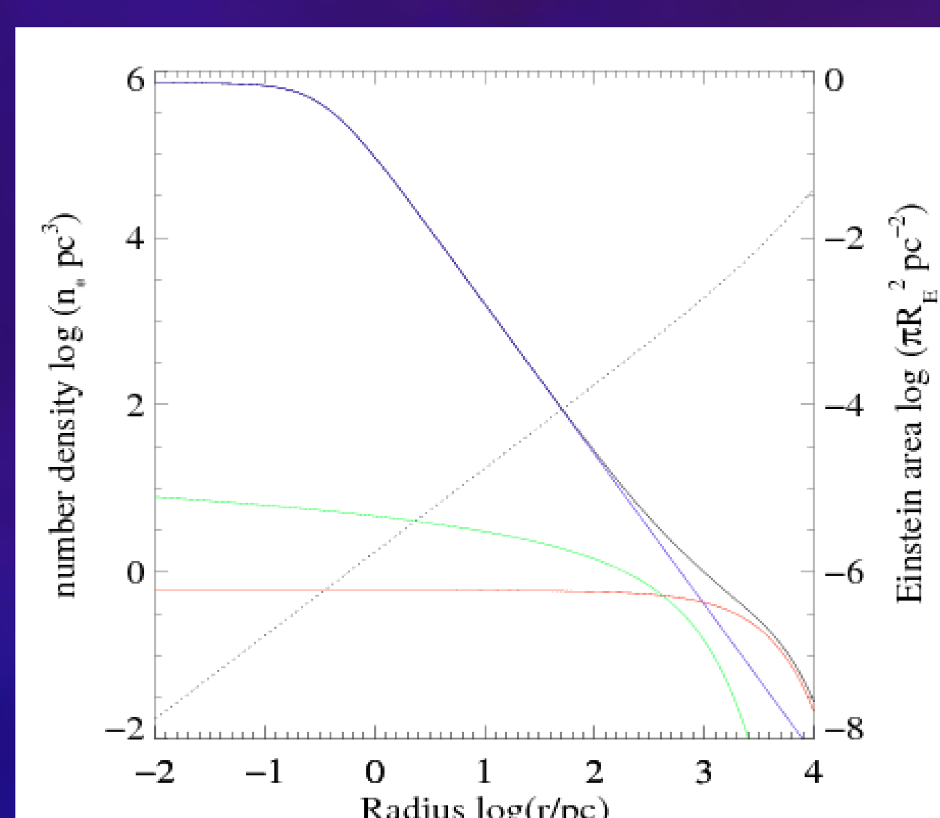

Fig. 1: Stellar number density profiles of the cusp (blue), bulge (green), disk (red) and the sum of all three components (black solid line). The Einstein area (dotted) provides a heuristic measure of the effective cross-section for lensing.

Results

For the cusp, bulge and disk, our fiducial model gives

$$N^c_{lens} = 0.044, \quad N^b_{lens} = 0.017 \quad \text{and} \quad N^d_{lens} = 0.231$$

Increasing K_0 by 5 mag increases N_{lens} by a factor ~60 (Table 1)!

If there is additional extinction beyond Sgr A* that increases linearly with distance, the expected number of lenses is

$$N^c_{lens} = 0.044, \quad N^b_{lens} = 0.012 \quad \text{and} \quad N^d_{lens} = 0.066$$

Using a simplified model, we find that globular clusters likely contain no observable lenses. However, elliptical galaxies may contain hundreds of lensed stars!

Measuring image positions with a precision of 10 micro-arcsec or better would make it possible to test general relativity.

K_0	$N^c_{\rm lens}$	$N^b_{\rm lens}$	$N^d_{\rm lens}$	$N^{\rm tot}_{\rm lens}$
16.5	0.03	0.01	0.15	0.19
17.5	0.07	0.03	0.35	0.45
18.5	0.15	0.06	0.77	0.98
19.5	0.33	0.13	1.73	2.19
20.5	0.75	0.28	3.88	4.91
21.5	1.67	0.63	8.68	10.98

Table 1: Number of strong lenses for a range of limiting magnitudes. The middle three columns give the number of lenses for the cusp, bulge and disk respectively, while the last column gives the total number of lenses. (Congdon et al. 2007)

Previous Work

Alexander & Sternberg (1999) computed microlensing rates for stars behind Sgr A*

Alexander & Loeb (2001) showed that the central stellar cusp enhances mircolensing of background disk stars.

Keeton & Petters (2005, 2006) developed a formalism for constraining gravity with lensing by compact objects.

Previous work has not considered strong lensing by Sgr A* where images can be resolved.

Congdon A. B., Keeton C. R., Nordgren C. E., 2007, submitted to Phys. Rev. D

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