Astrometric Microlensing by Local Dark Matter Subhalos

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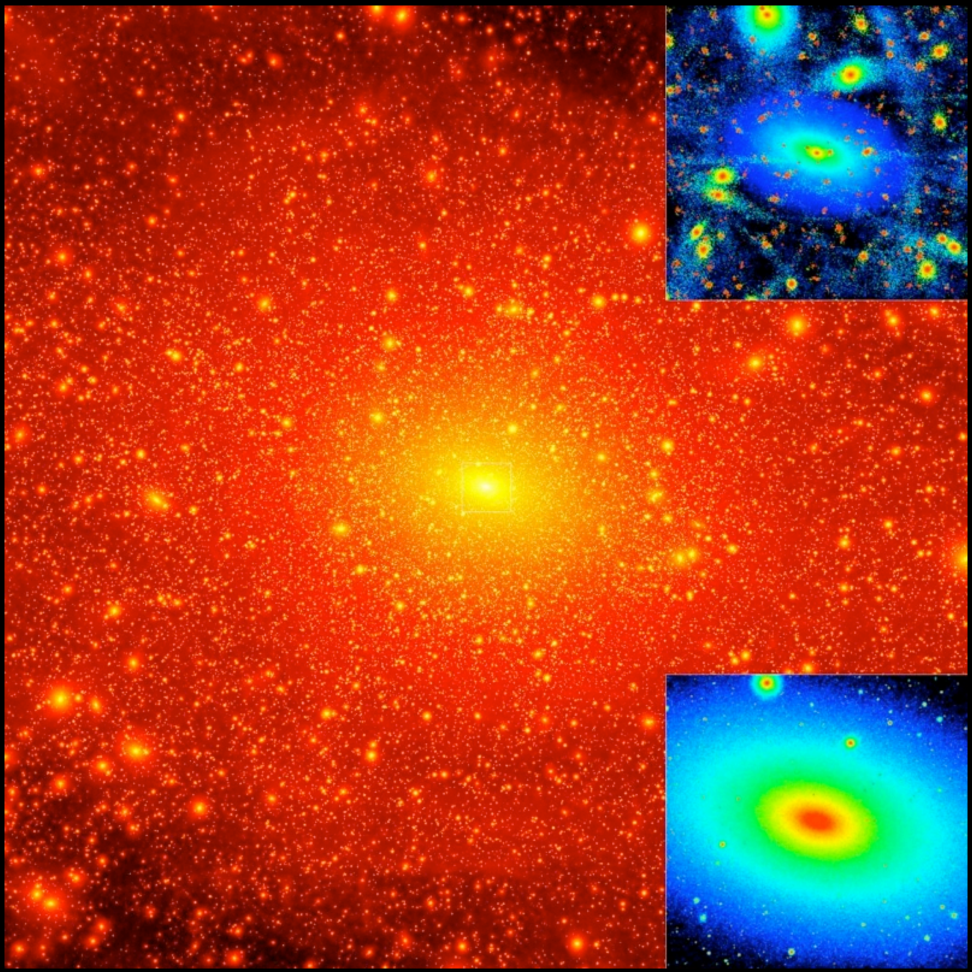
arXiv: 1007.4228
ApJ in press

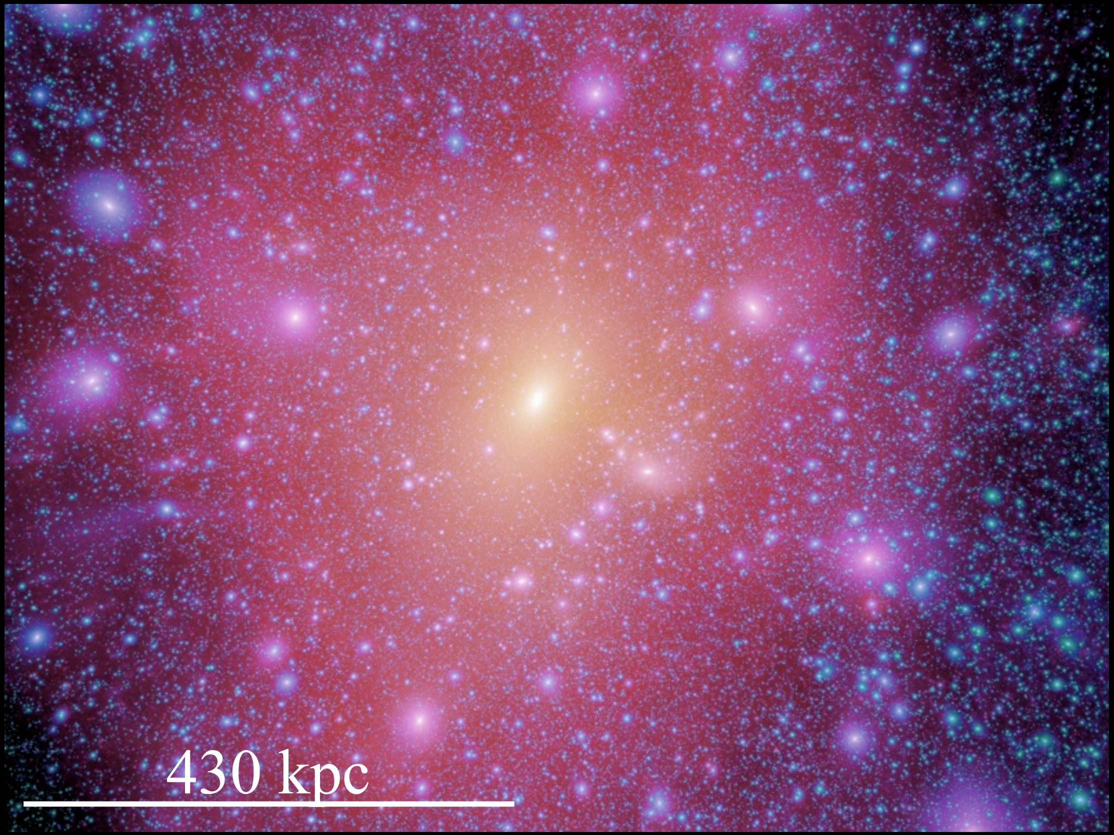
Dark Matter Halos are Clumpy!

Via Lactea II



Diemand et al. 2008

Aquarius

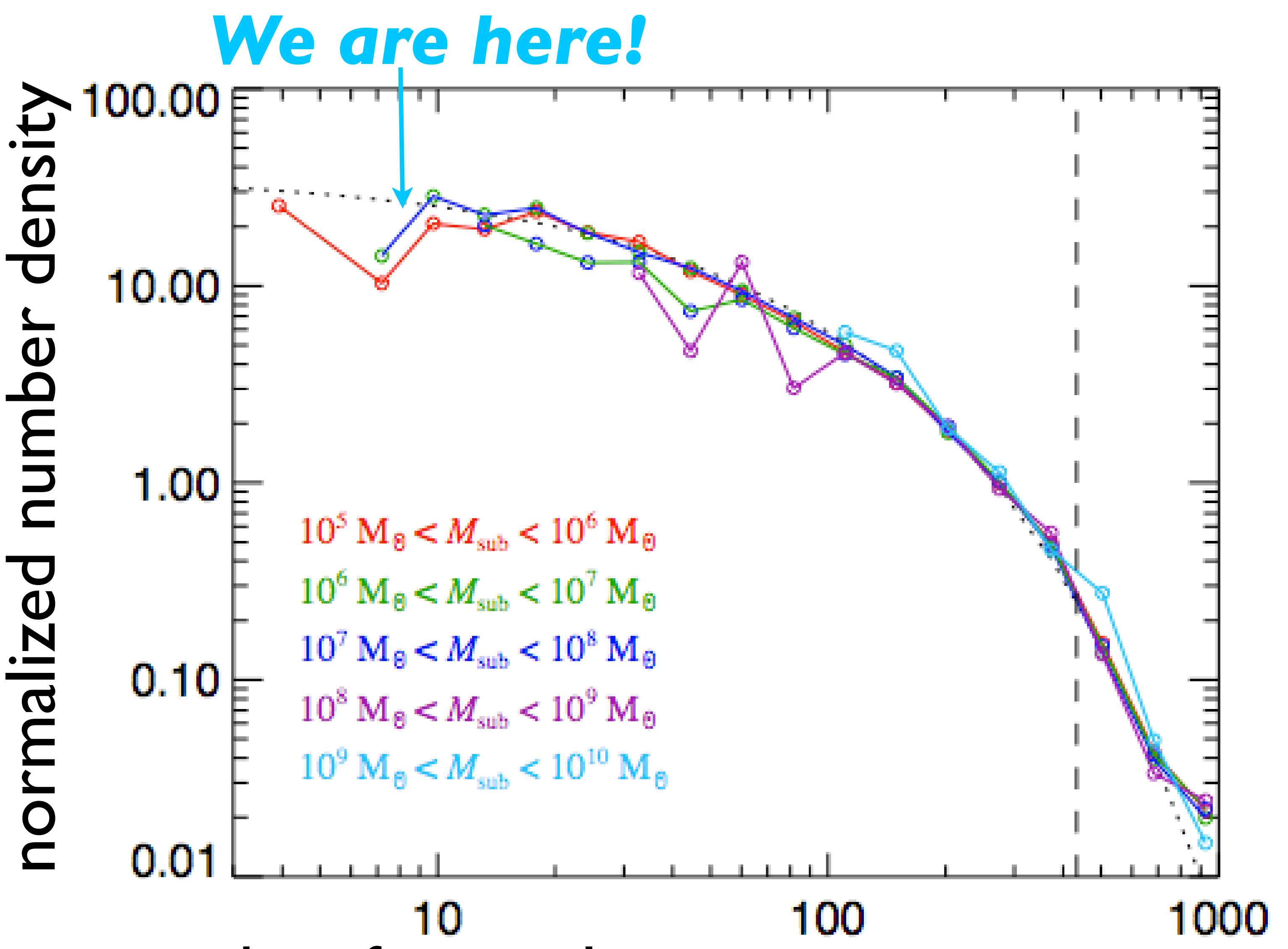


Springel et al. 2008

- High-resolution simulations of Galaxy-sized halos with billions of particles
- Aquarius halo has >200,000 resolved subhalos with $M_{\rm sub} \gtrsim 4 \times 10^4 M_\odot$

Subhalos in our Neighborhood

Locations of Subhalos in Aquarius Simulation



Springel et al. 2008

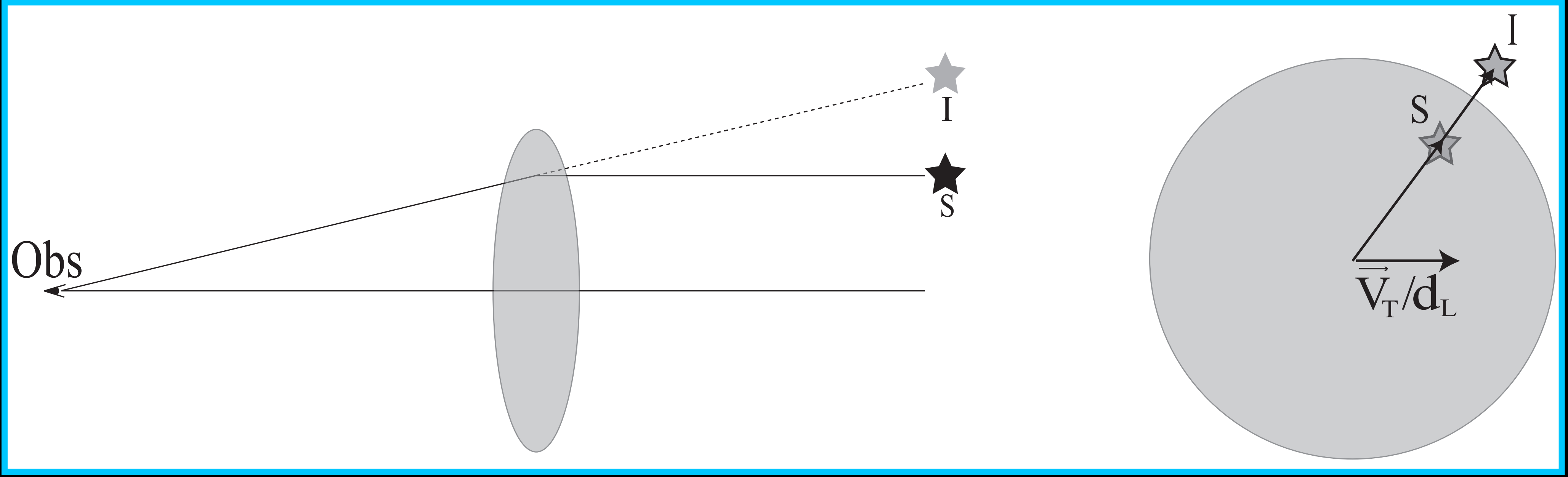
Subhalos are Gravitational Lenses

When galaxies produce multiple images of a quasar; subhalos can modify the properties of these images.

Mao & Schneider 1998; Metcalf & Madau 2001; Chiba 2002; Dalal & Kochanek 2002
Keeton& Moustakas 2009; Congdon et al. 2010
Koopmans et al. 2002; Chen et al. 2007; Williams et al. 2008; More et al. 2009
Yonehara et al. 2003; Inoue & Chiba 2005; Zackrisson et al. 2008; Riehm et al. 2009

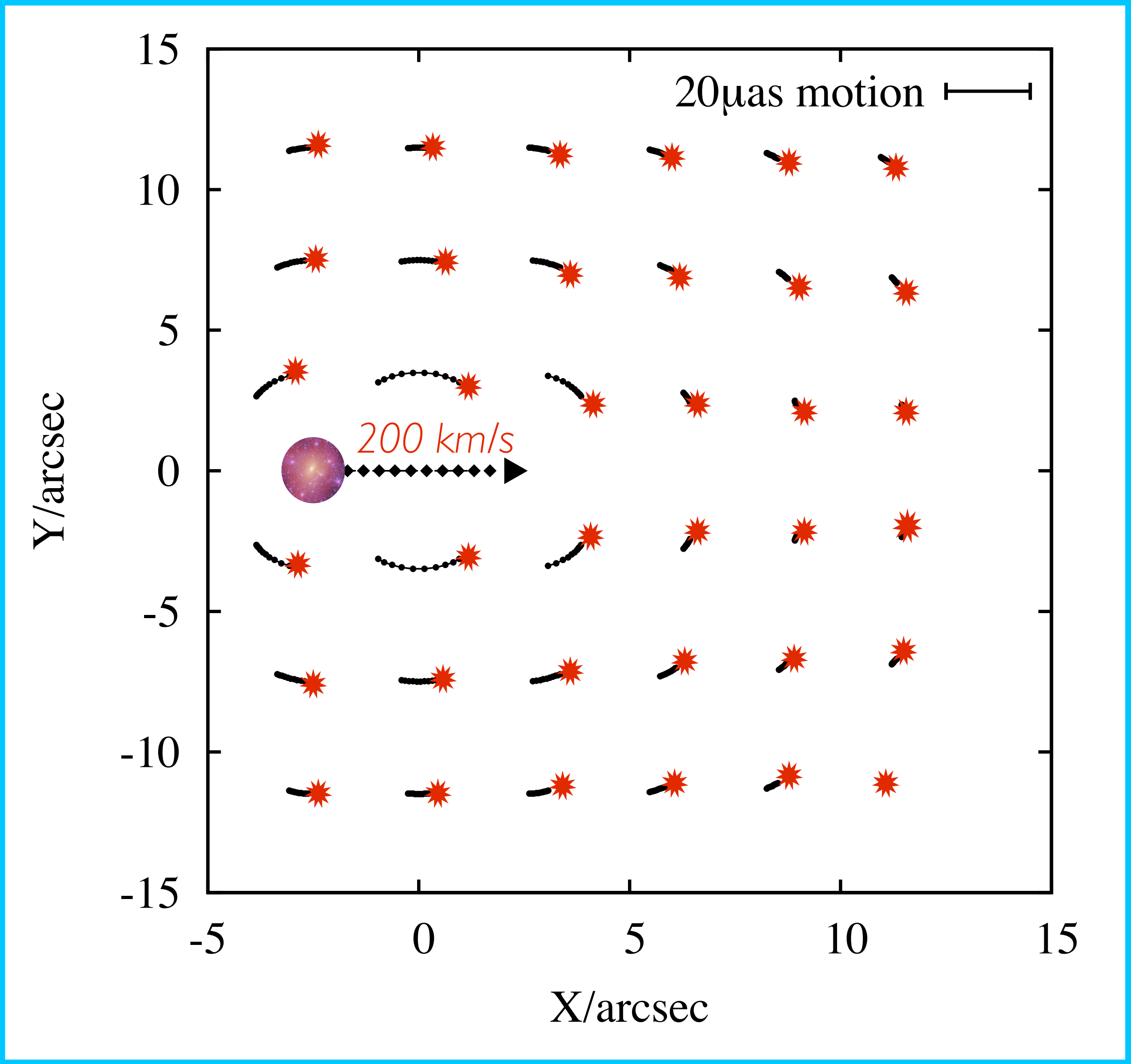
What about astrometric deflections of stars within the Galaxy?

- we're looking for a dynamical signature from a local subhalo
- subhalos are diffuse, so we need high-precision astrometry



Astrometric Microlensing

Star field over 4 years

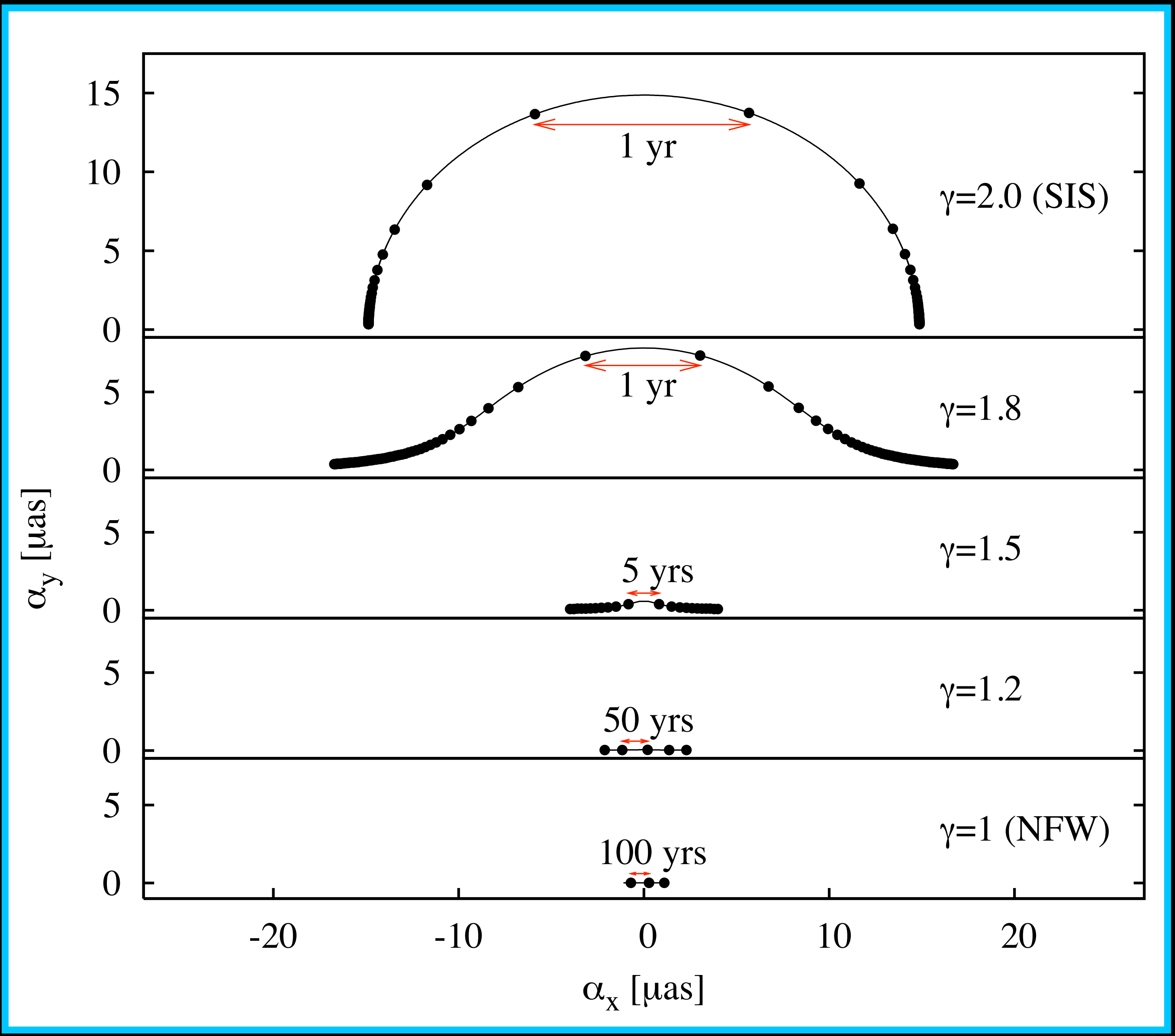


We need a subhalo center to pass by a star with an impact parameter of ~10 arcseconds.

Lens virial mass: $5 \times 10^5 M_\odot$

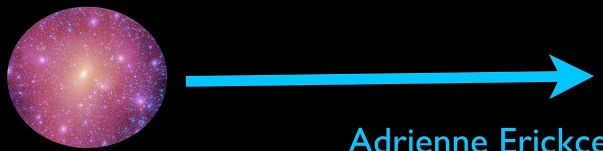
Lens distance: 50 pc

Lensing with a General Profile



$$\rho(r) \propto r^{-\gamma}$$

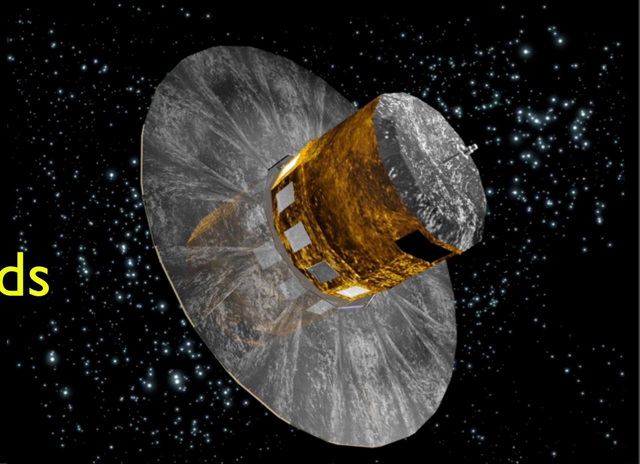
The steepness of the density profile determines the shape of the image's path across the sky and the rate of its motion.



High Precision Astrometry

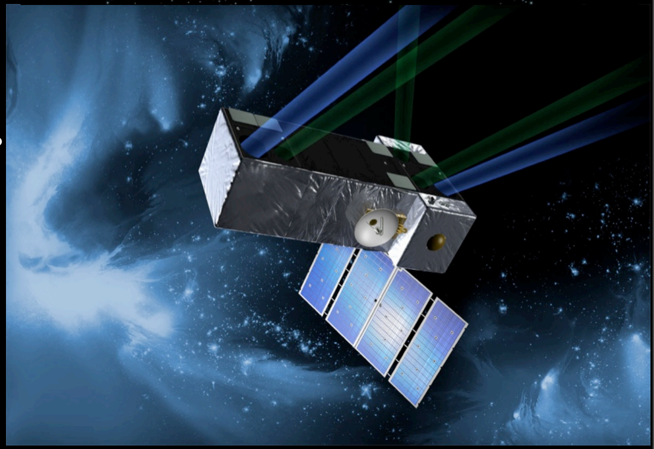
Gaia is an ESO satellite scheduled to launch in late 2012.

- astrometric precision per epoch: ~35 ***micro***arcseconds for its brightest targets (~5 million stars)



SIM PlanetQuest was the top space mission recommended by NASA's Exoplanet Task Force.

- astrometric precision per epoch: 1 ***micro***arcsecond for planet-finding, 4 ***micro***arcseconds for general high-efficiency astrometry (~10,000 stars)



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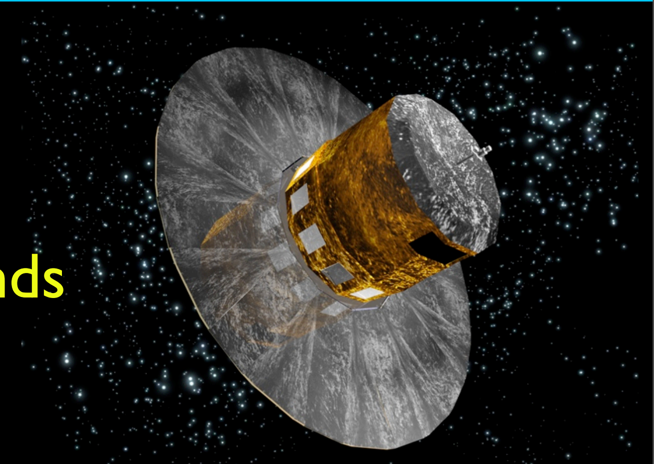

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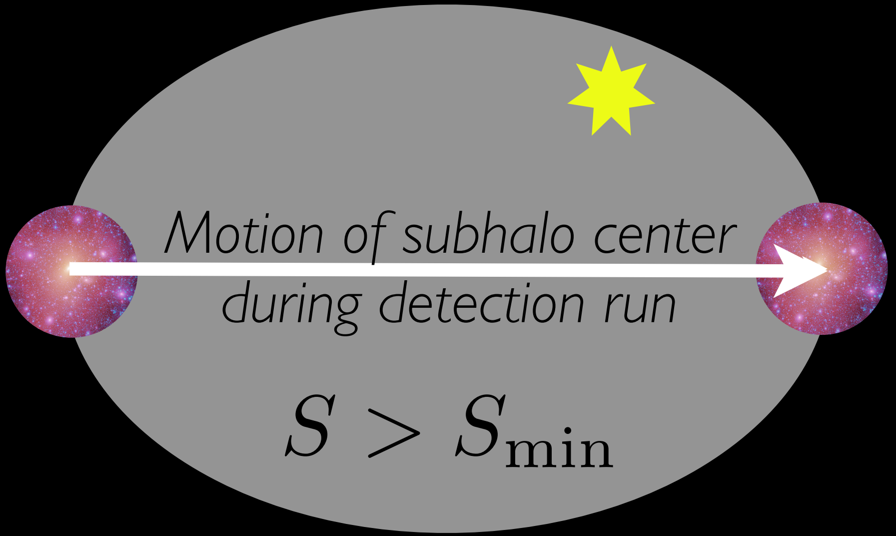
Ground-based telescopes have great potential.

- Keck can reach ~100 ***micro***arcsecond precision
- TMT is designed for 50 ***micro***arcsecond precision and could reach much higher precision (Cameron *et al.* 2009)

Lensing Cross Sections

We define a lensing cross-section based on a minimum value for the lensing signal; all stars within this area will produce $S > S_{\rm min}$.

$$S_{\rm min} \simeq {\rm SNR} \times 1.5\sigma_{\rm inst}$$



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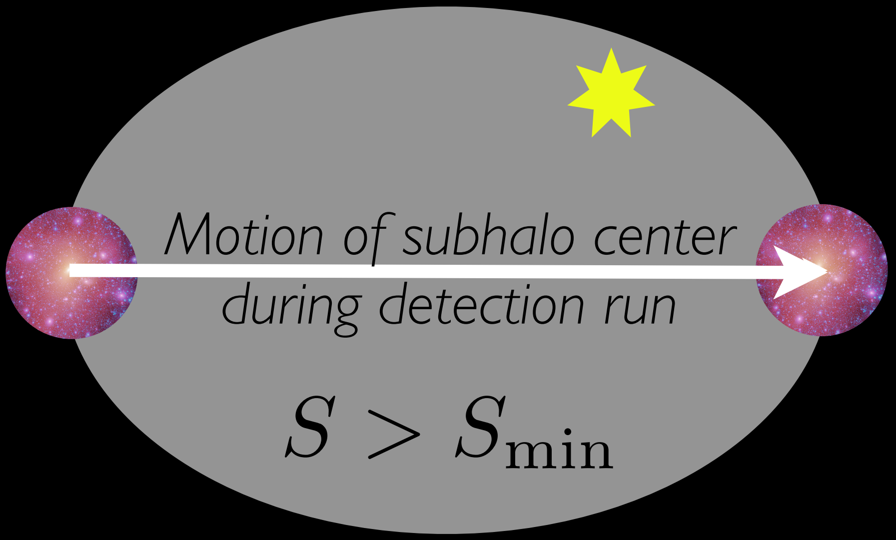
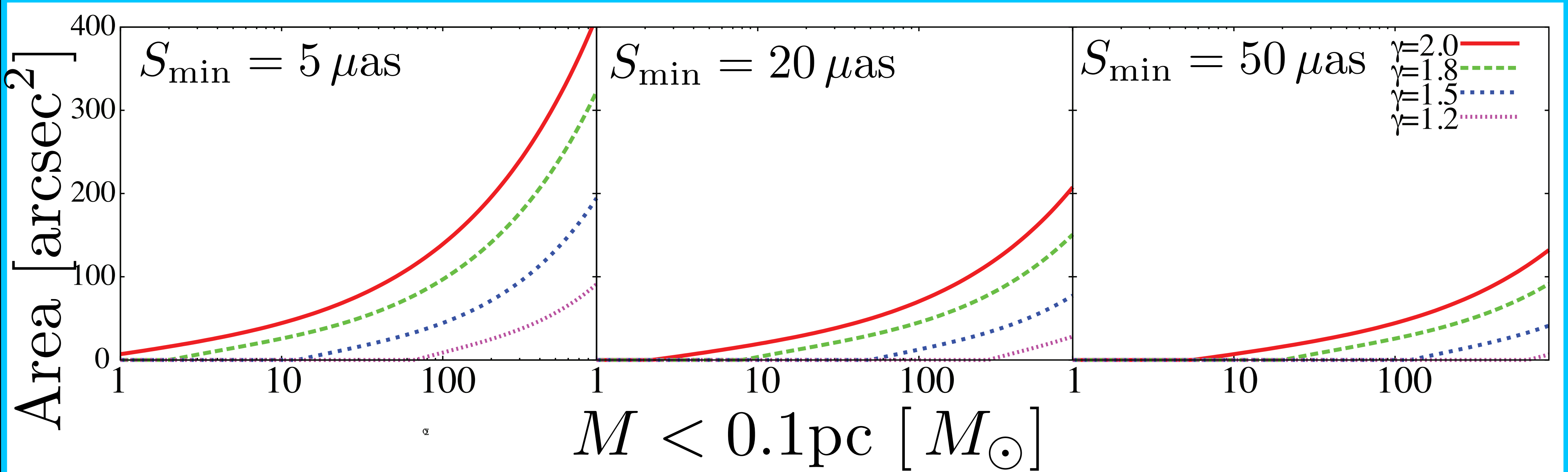
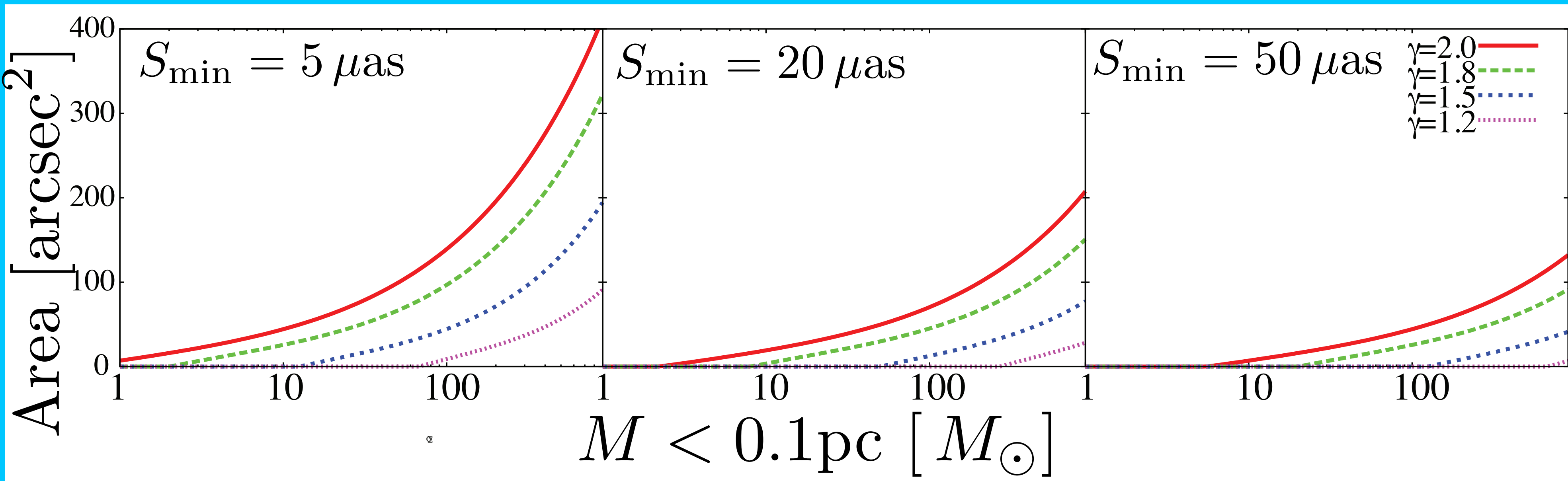
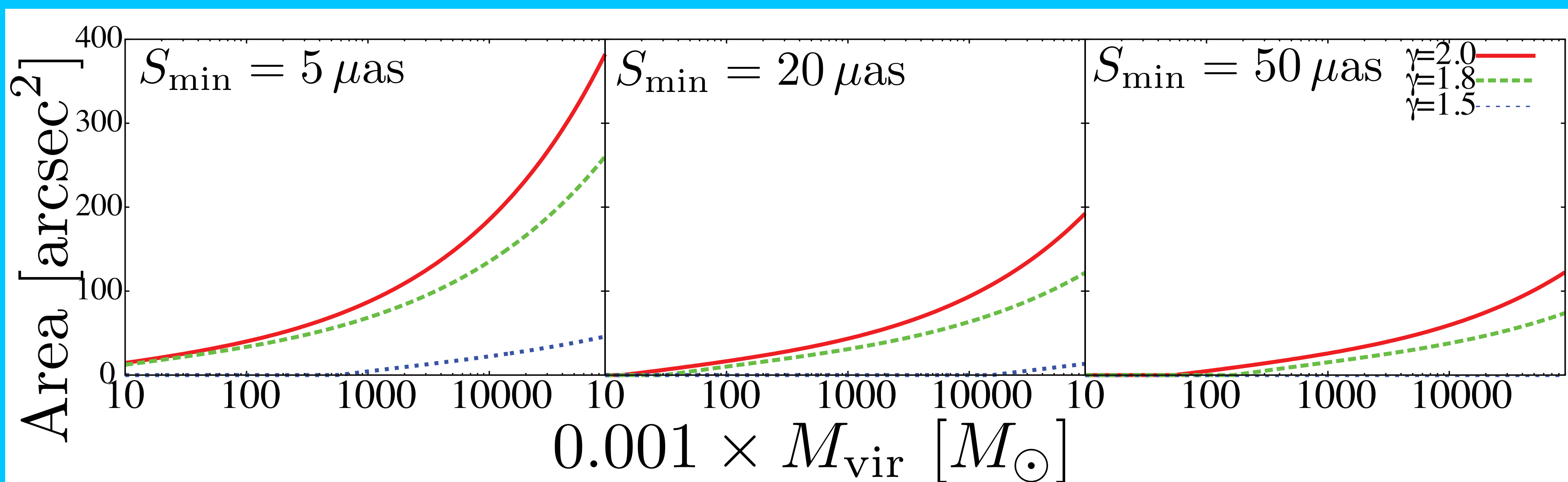




Lens distance: 50 pc; Lens velocity: 200 km/s; Source Distance: 5 kpc

Lensing Cross Sections





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Lensing Event Rates

We can combine the lensing cross sections with a subhalo mass function to calculate the fraction of the sky that is detectably lensed ($S > S_{\rm min}$) by a subhalo.

We derived a local subhalo mass function from the results of the Aquarius simulations.

$$\begin{array}{c}\text{Fraction of Sky}\\ \text{Lensed by a Subhalo}\\ (1.8 \lesssim \gamma \lesssim 2.0)\end{array} \simeq 10^{-11}\left(\frac{S_{\rm min}}{5\,\mu{\rm as}}\right)^{-1.6}$$

But what if dark matter is clumpier?

Lensing Event Rates

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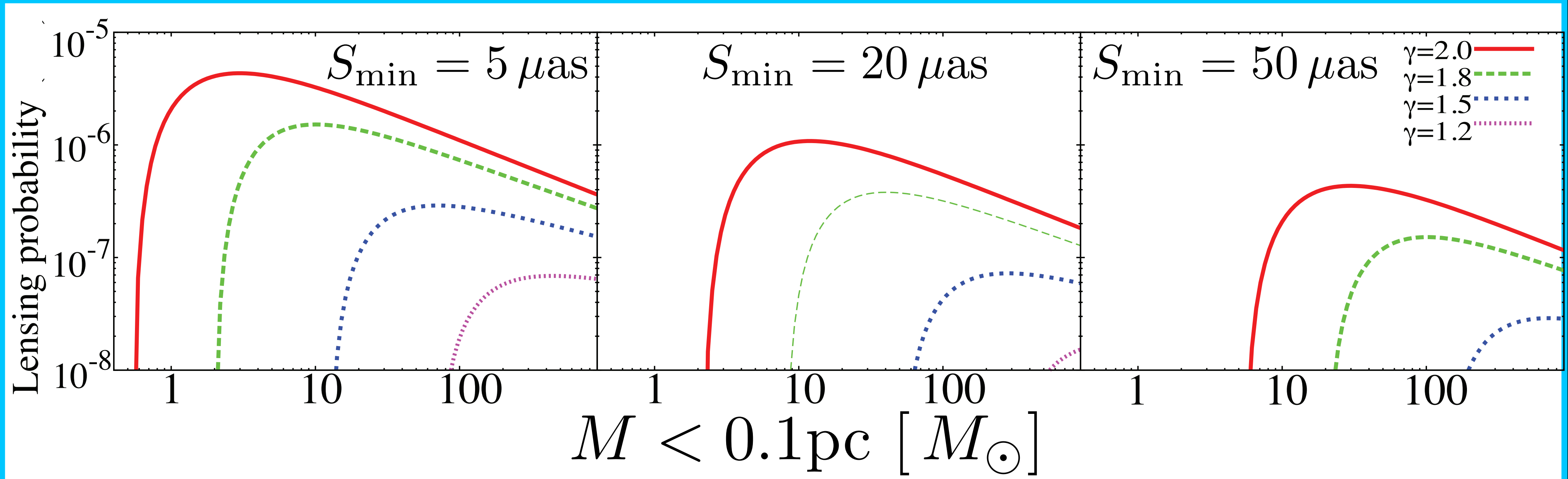
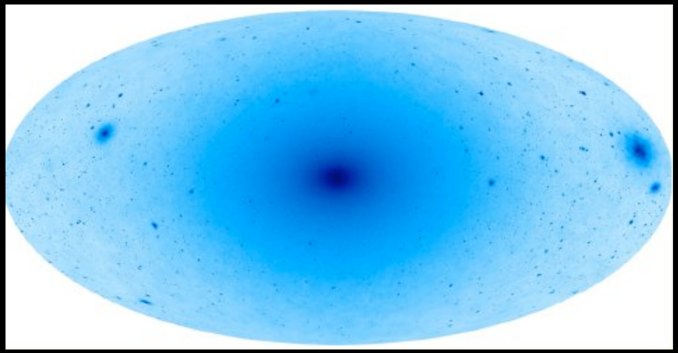
All the halo mass is contained within 0.1 pc of a subhalo center



Lens velocity: 200 km/s; Source Distance: 2 kpc

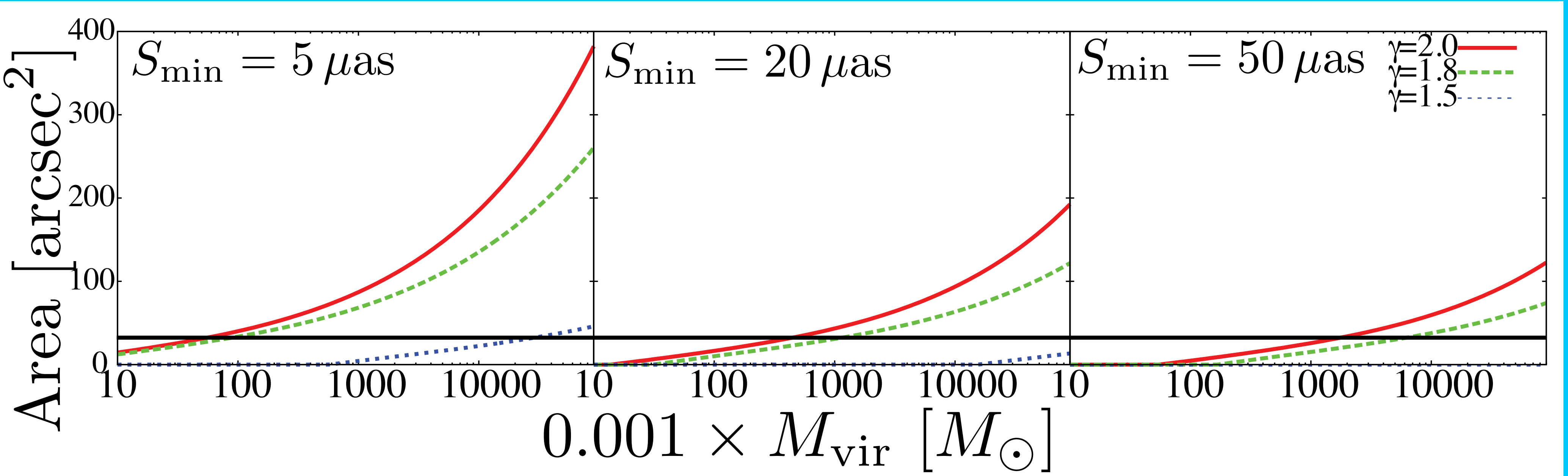
Detection with Targeted Observations

Finding a subhalo through astrometric microlensing is unlikely, but what if you know where to look?



Kuhlen et al. 2009

Fermi may detect emission from dark matter annihilation in subhalos and could localize the center of emission down to a few sq. arcminutes.



Lens distance: 50 pc; Lens velocity: 200 km/s; Source Distance: 5 kpc

Summary

Local subhalos deflect the light from background stars, producing a unique astrometric microlensing signature.

- only the innermost 0.1 pc of the subhalo can produce a signal
- the star's apparent motion depends on the subhalo density profile
- the image deflection is measured in microarcseconds -- we can do that!

To see a subhalo lensing event, we'd have to get lucky!

- nearly impossible to find a subhalo through lensing, unless subhalos are more numerous and/or more concentrated than expected
- if Fermi points the way, high-precision astrometry can follow; we can detect subhalos within 100 pc of us with (stripped) masses $\gtrsim 1000\, M_\odot$.

For more details see

Erickcek & Law 2011 (arXiv:1007.4228)

EXTRA SLIDES

Subhalo Density Profiles

Unfortunately, even the best simulations can only probe the density profiles of the largest subhalos ($M_{\rm sub} \gtrsim 10^8 M_\odot$), and the inner 350 pc are unresolved.

- Via Lactea II: $\rho(r) \propto r^{-(\gamma \simeq 1.24)}$ for large subhalos. *Diemand et al. 2008*
- Aquarius: $\rho(r) \propto r^{-(\gamma < 1.7)}$ for large subhalos. *Springel et al. 2008*
- Simulations of first halos: Earth-mass halos at a redshift of 26 have $\rho(r) \propto r^{-(1.5<\gamma<2.0)}$ extending to within 20 AU of the center. *Diemand et al. 2005; Ishiyama et al. 2010*

We'll assume a "generalized NFW profile:"

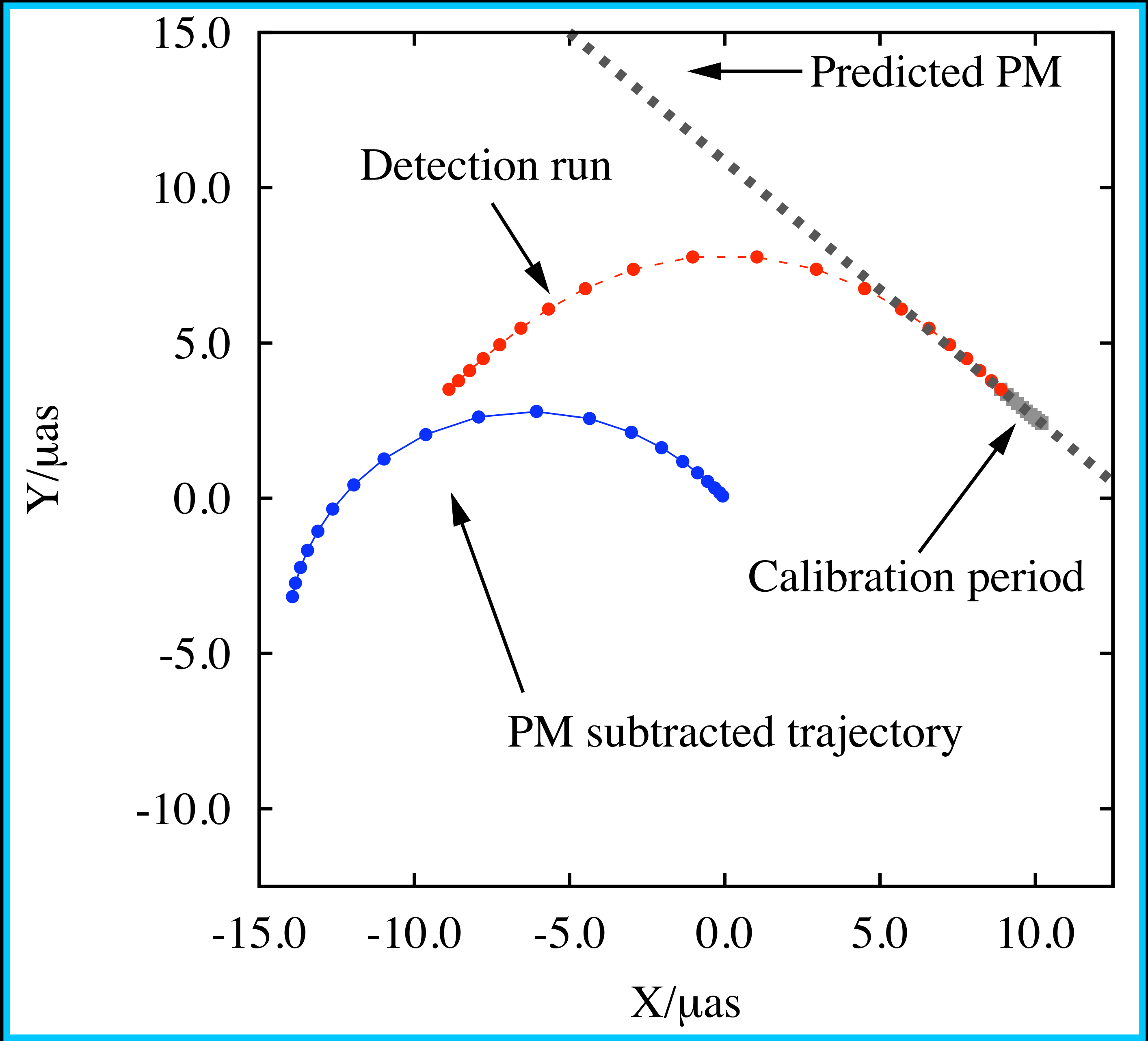
$$\rho(r) = \frac{\rho_0}{\left(\frac{r}{r_0}\right)^\gamma \left(1+\frac{r}{r_0}\right)^{3-\gamma}}$$

r_0 is set by the concentration

ρ_0 is set by the virial mass

$r \ll r_0$	$r \gg r_0$
$\rho(r) \propto r^{-\gamma}$	$\rho(r) \propto r^{-3}$
$\alpha \propto r^{2-\gamma}$	$\alpha \propto r^{-1}$
deflection angle	*deflection angle*

The Signal We're Looking For



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