Probing Cluster Halos with Caustic-Crossing Stars

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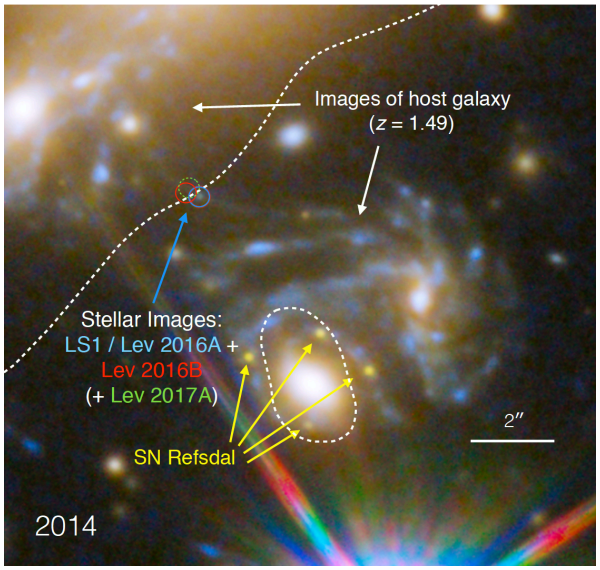
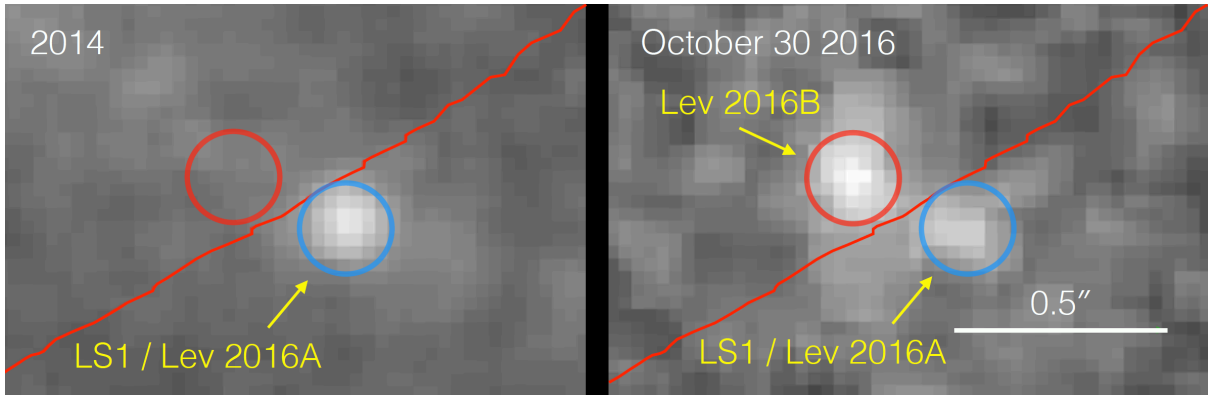
New Lensing Phenomenon: Caustic Crossing Stars with Cluster Lenses





HST detection in MACS 1149
Kelly+ 17

Color resembles a B star with a Balmer break

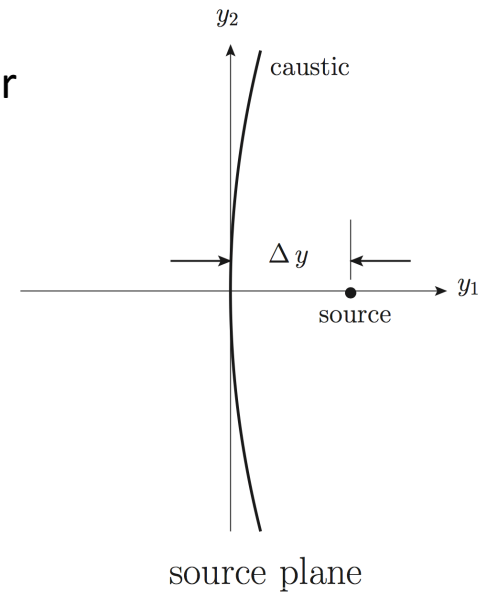
Explained by a caustic-crossing star
Miralda-Escudé 91

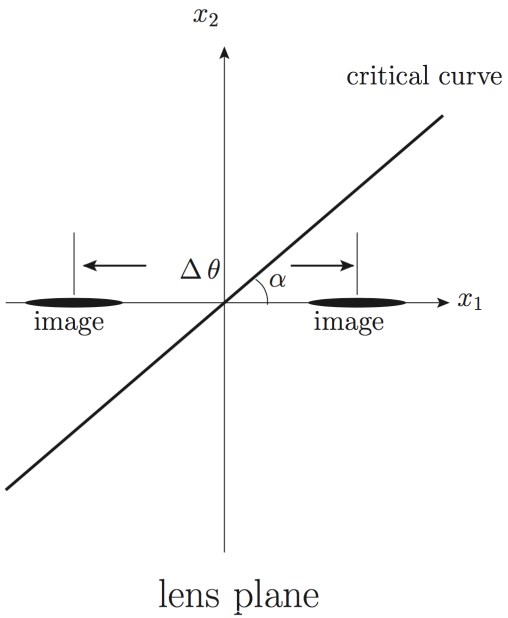
Extreme magnification factor

$$\mu \sim \frac{\theta_C}{\theta} \sim \text{few} \times 10^{2-3}$$

Super-bright stars can be visible

$$L \simeq 10^{4-6}\, L_\odot$$

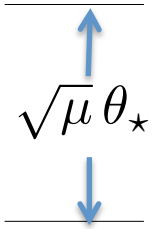


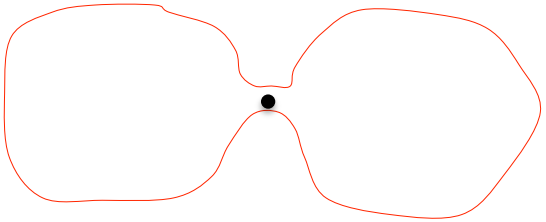


Microlensing by Intracluster Stars

Venumadhav, Dai & Miralda-Escudé 17; Diego+ 17

$$\theta_\star \sim 1\,\mu\mathrm{as} \quad \text{for} \quad 1\,M_\odot \longrightarrow \sqrt{\mu}\,\theta_\star$$



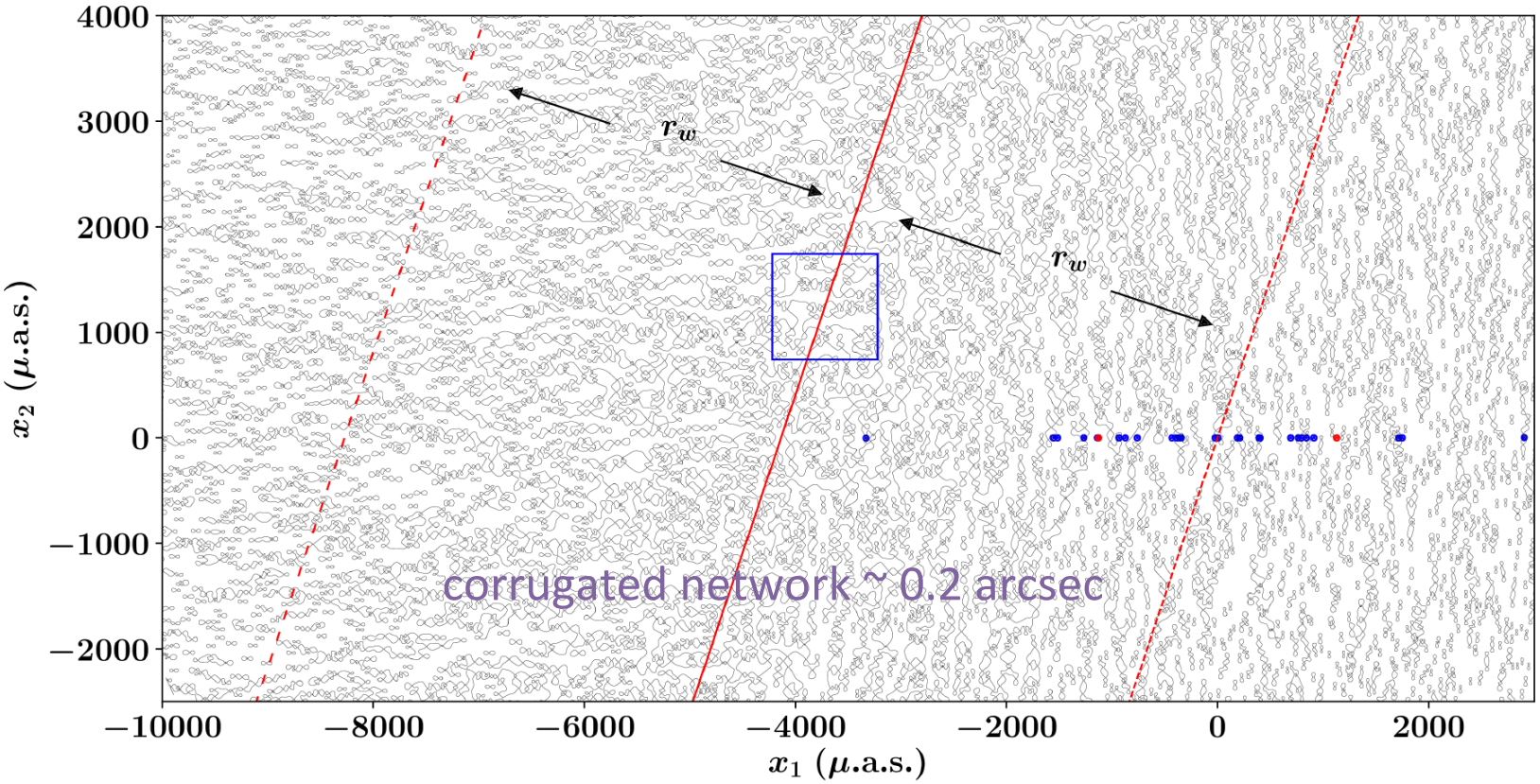


"Dumbbells" join and form a corrugated network of micro-critical curves even for small surface density of intracluster stars

from intracluster light

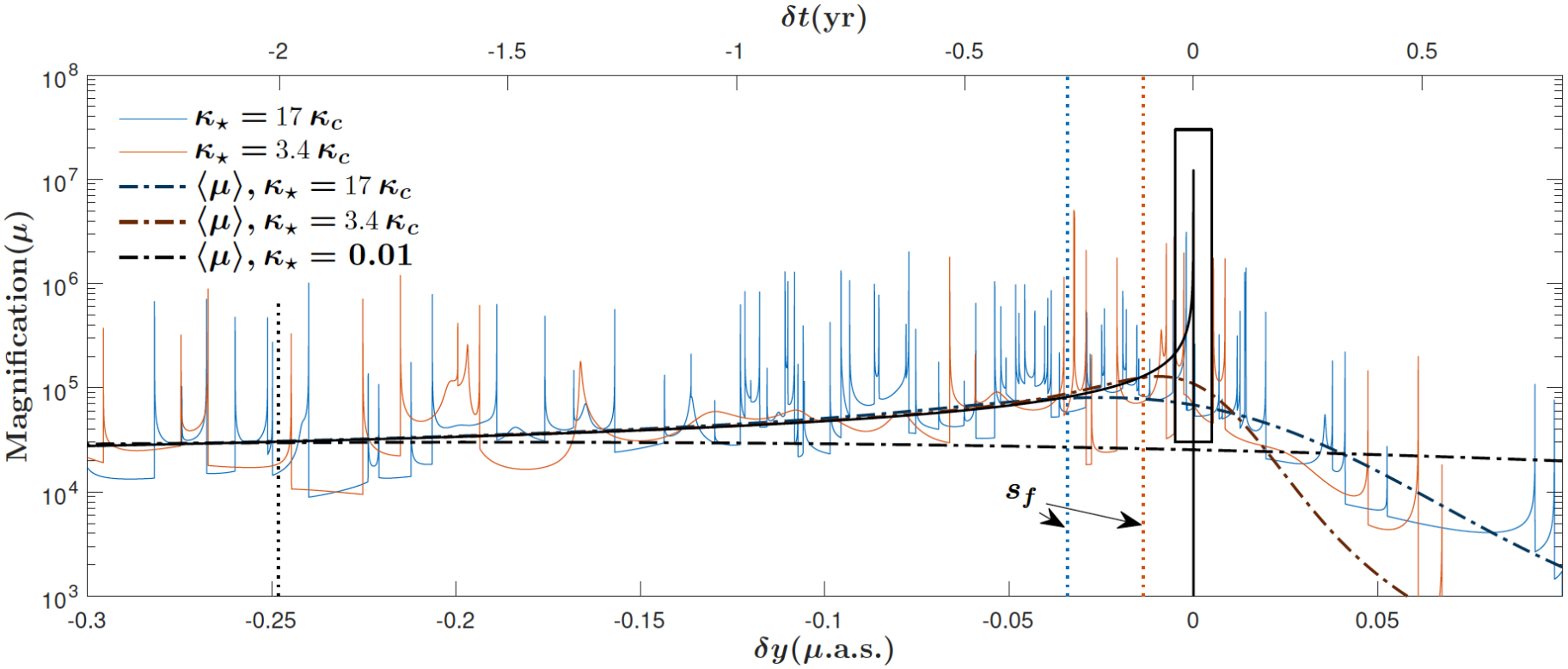
$$\kappa_{\rm crit} \sim (\theta_\star/\theta_C)^{2/3} \sim \text{few} \times 10^{-5}$$

$$\kappa_\star \sim 10^{-3} - 10^{-2} \gg \kappa_{\rm crit}$$



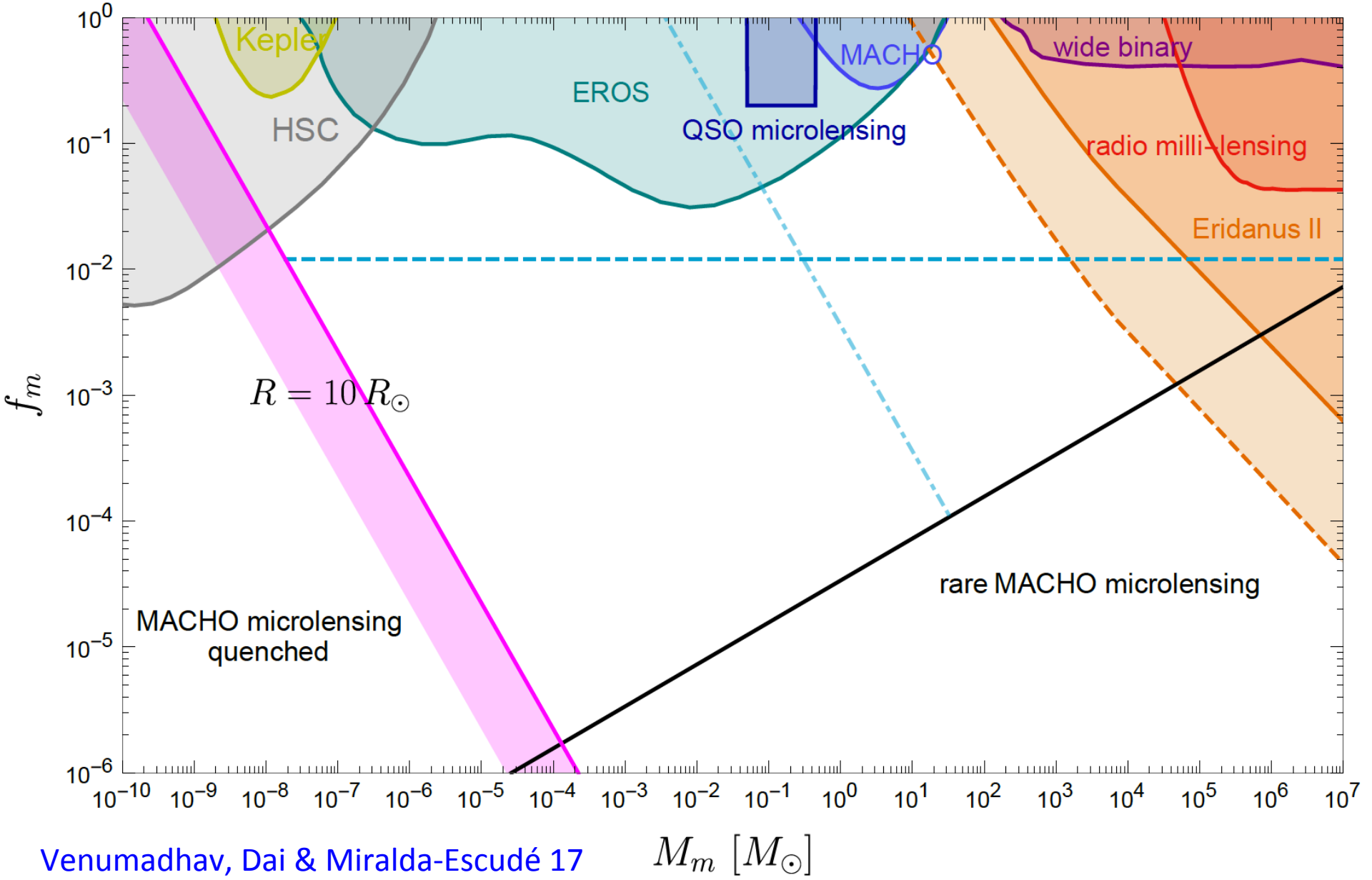
Microlensing Light Curves

Venumadhav, Dai & Miralda-Escudé 17



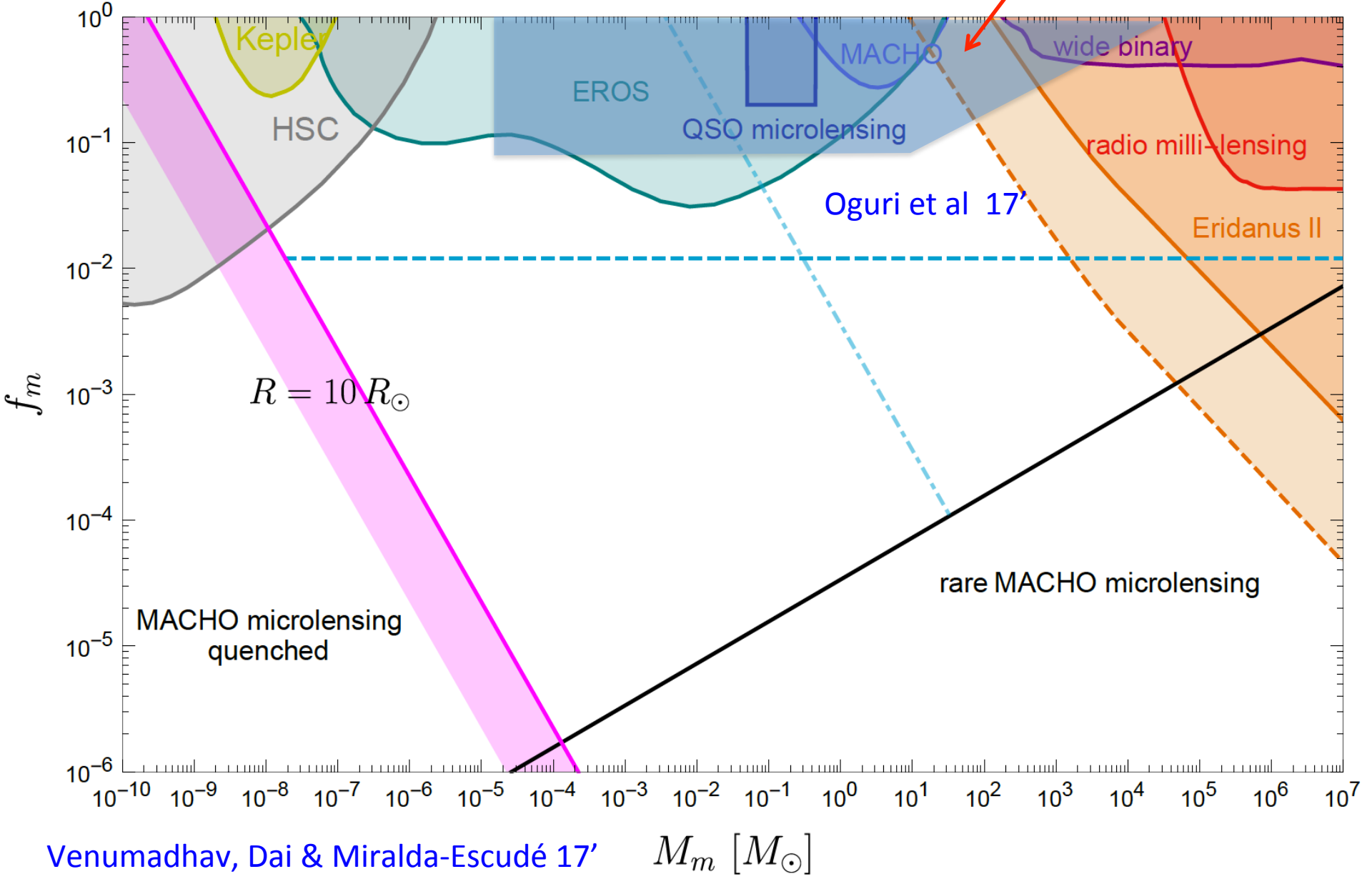
- Maximum peak magnification reduced: $\mu_{\rm peak} \sim 10^4\,(R/10\,R_\odot)^{-1/2}$
- Spending tens of thousands of years crossing the band!!
- Frequent micro-caustic crossings: 1-100 per year ---- **better chance to see individual stars!**
- Culmination of each crossing lasts for $\sim 5\,\mathrm{hr}\,(R/10\,R_\odot)$

Constraints on Compact Dark Matter



Venumadhav, Dai & Miralda-Escudé 17

Constraints on Compact Dark Matter



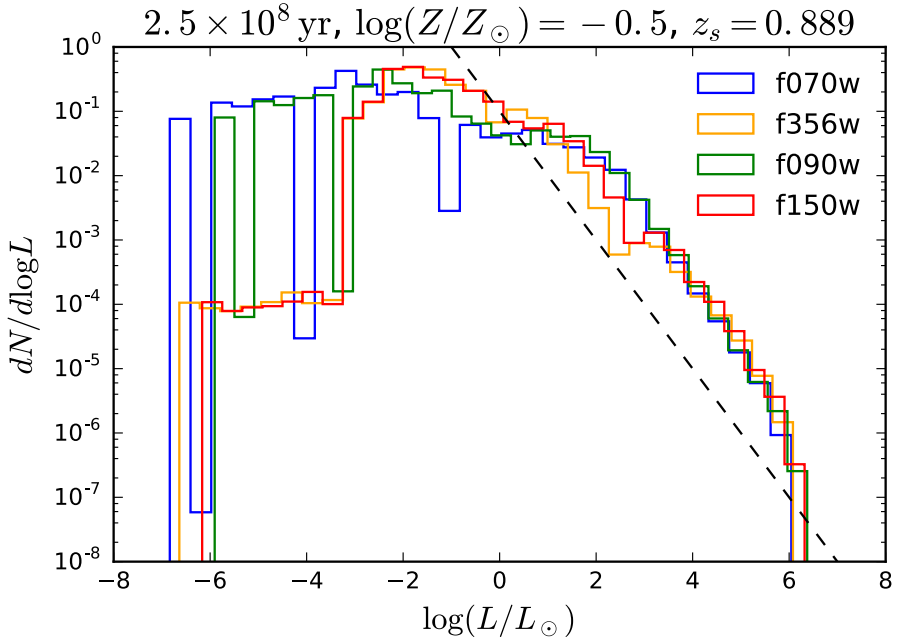
Venumadhav, Dai & Miralda-Escudé 17'

A population of source stars

Relevant region on the source plane: ~ 10 pc by 10 kpc
Contains a total of 10^6 – 10^7 source stars

Dim stars (collectively) unaffected by magnification; bright outliers "stand out" !

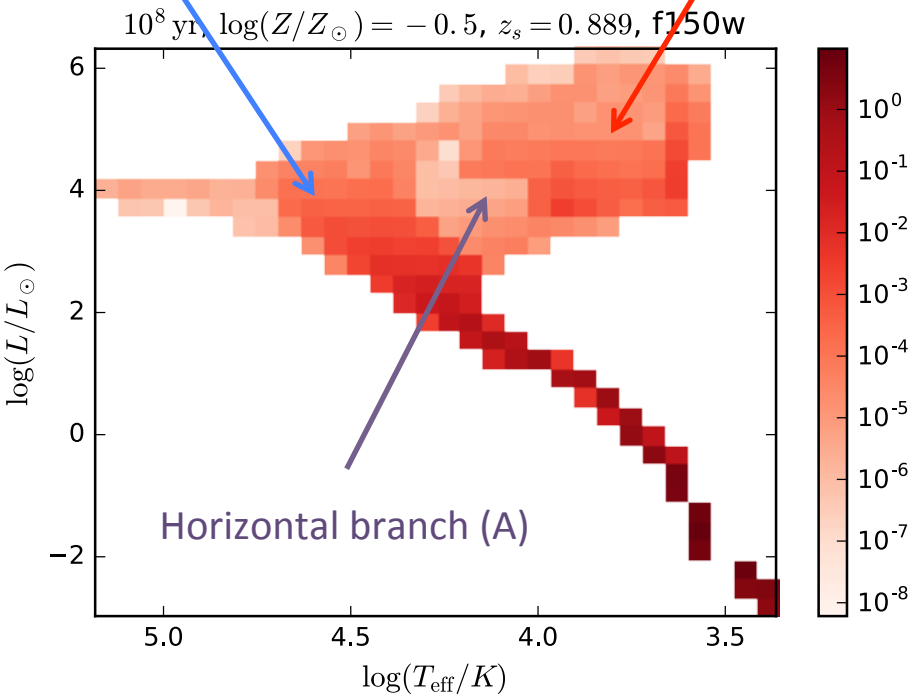
Stellar population synthesis FSPS
Conroy, Gunn, White 09'
Conroy, Gunn 10'



A power-law tail $\dfrac{dN}{d\log L} \propto L^{-1}$

Hot main sequence (B)

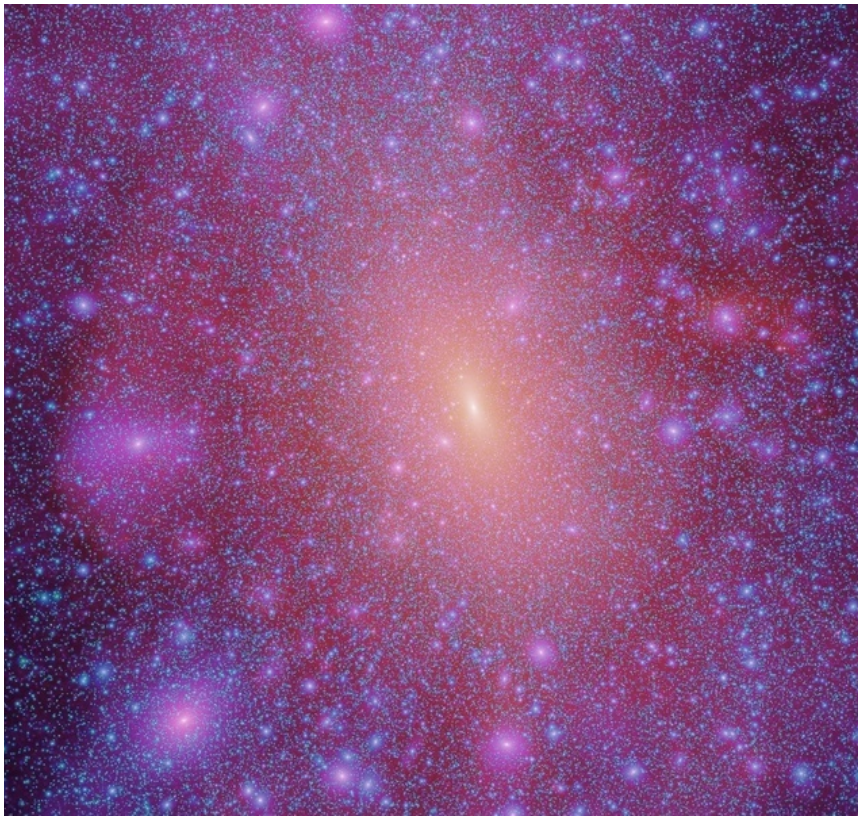
Red supergiant (K)



HST and **JWST** are good for blue and red stars, respectively

CDM Substructure

"Halos in halo" is a generic prediction of hierarchical structure formation within the Cold Dark Matter paradigm



Phoenix simulation, Gao et al 12'

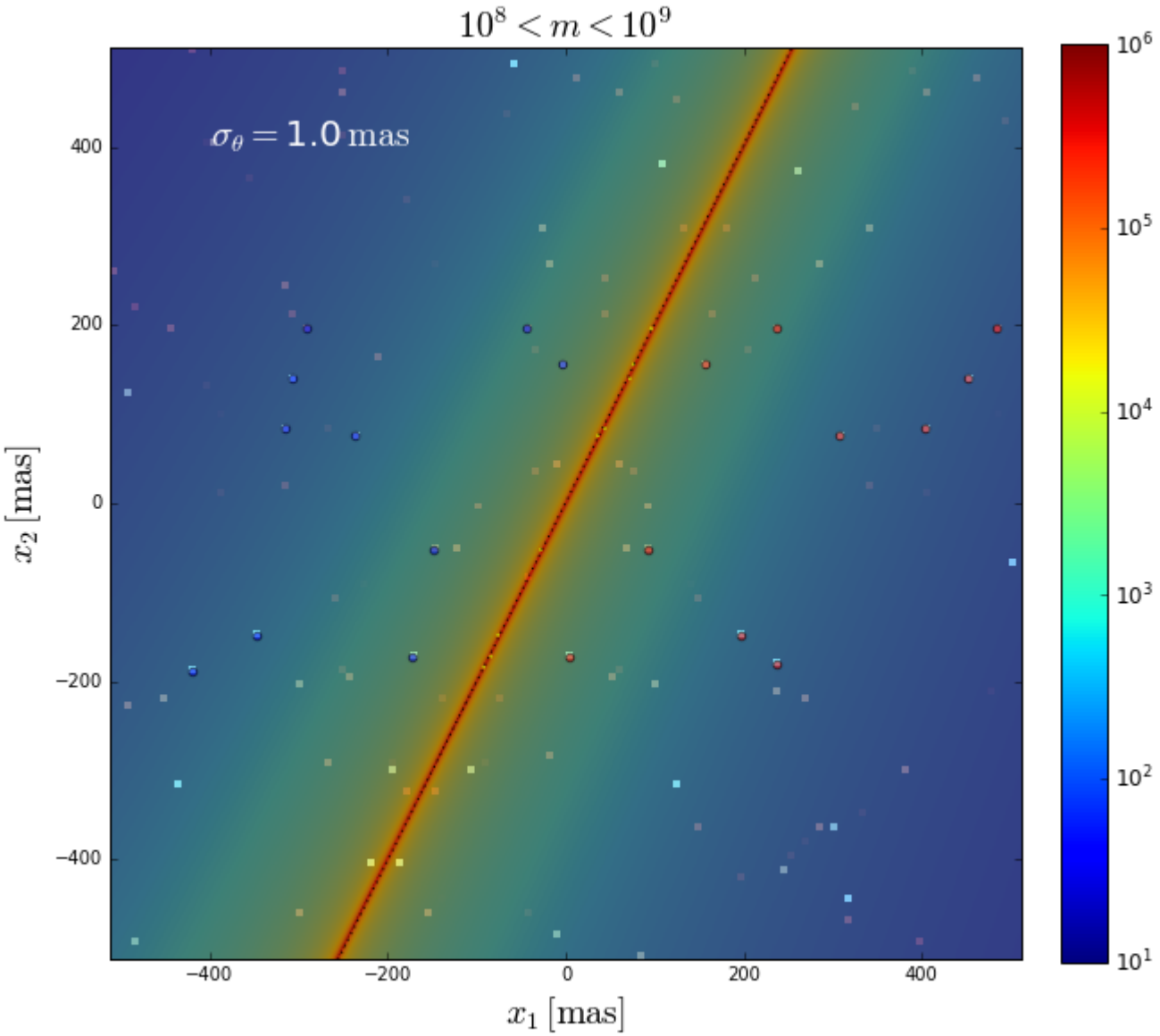
Simulations have revealed:

- Substantial mass fraction ~ few to 10 percent in subhalos
- A power-law substructure mass function

$$dN/d\log m \propto m^{-0.9}$$

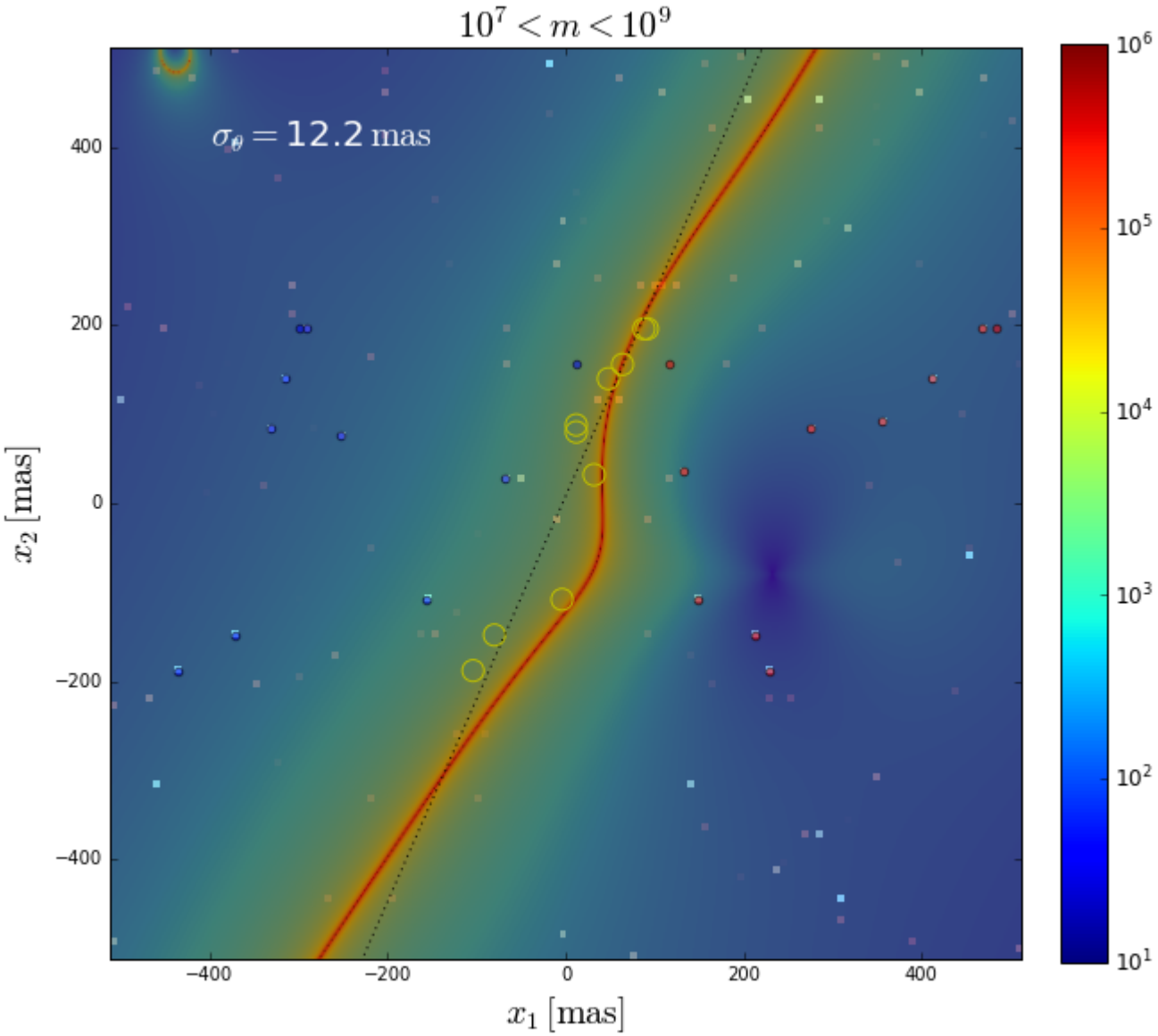
- Shallower spatial distribution within the host's virial radius --- biased accretion;
- Subhalos systematically more concentrated than field halos
- Internal structure roughly described by the NFW profile, but tidally truncated.

Effect of Subhalos on Image Locations



Dai, Venumadhav, Kaurov & Miralda-Escudé, in prep

Effect of Subhalos on Image Locations



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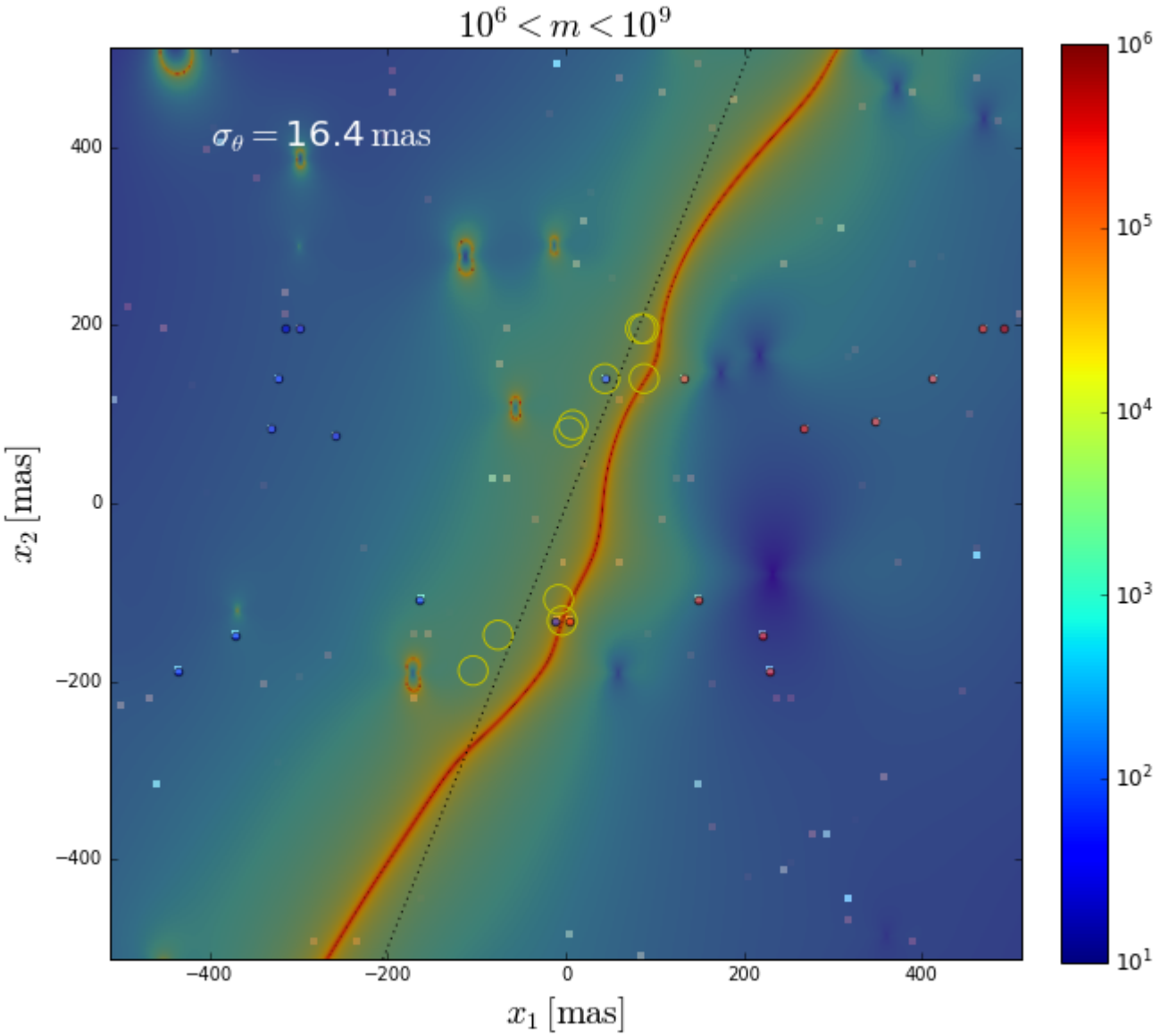

Dai, Venumadhav, Kaurov & Miralda-Escudé, in prep

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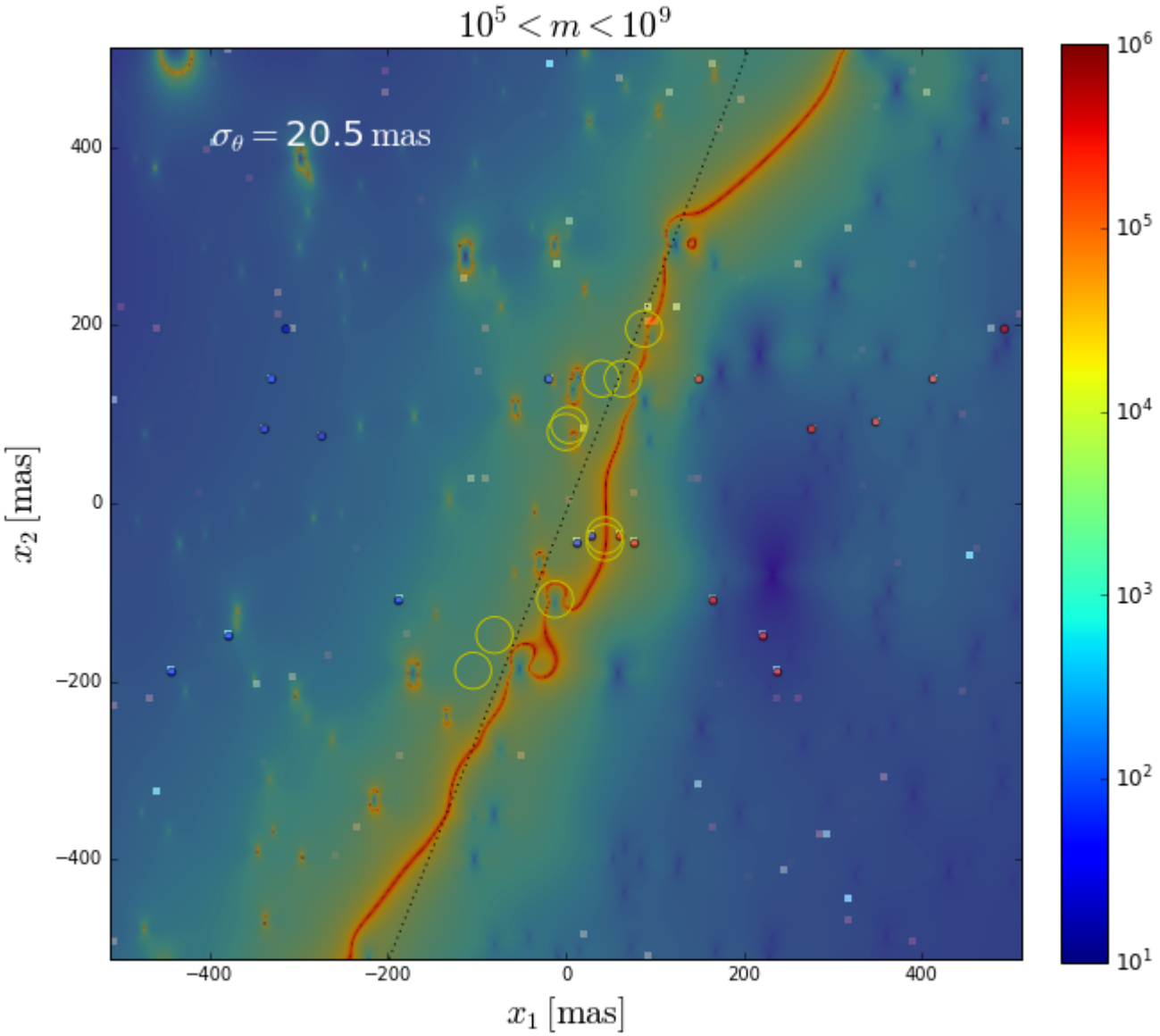

Dai, Venumadhav, Kaurov & Miralda-Escudé, in prep

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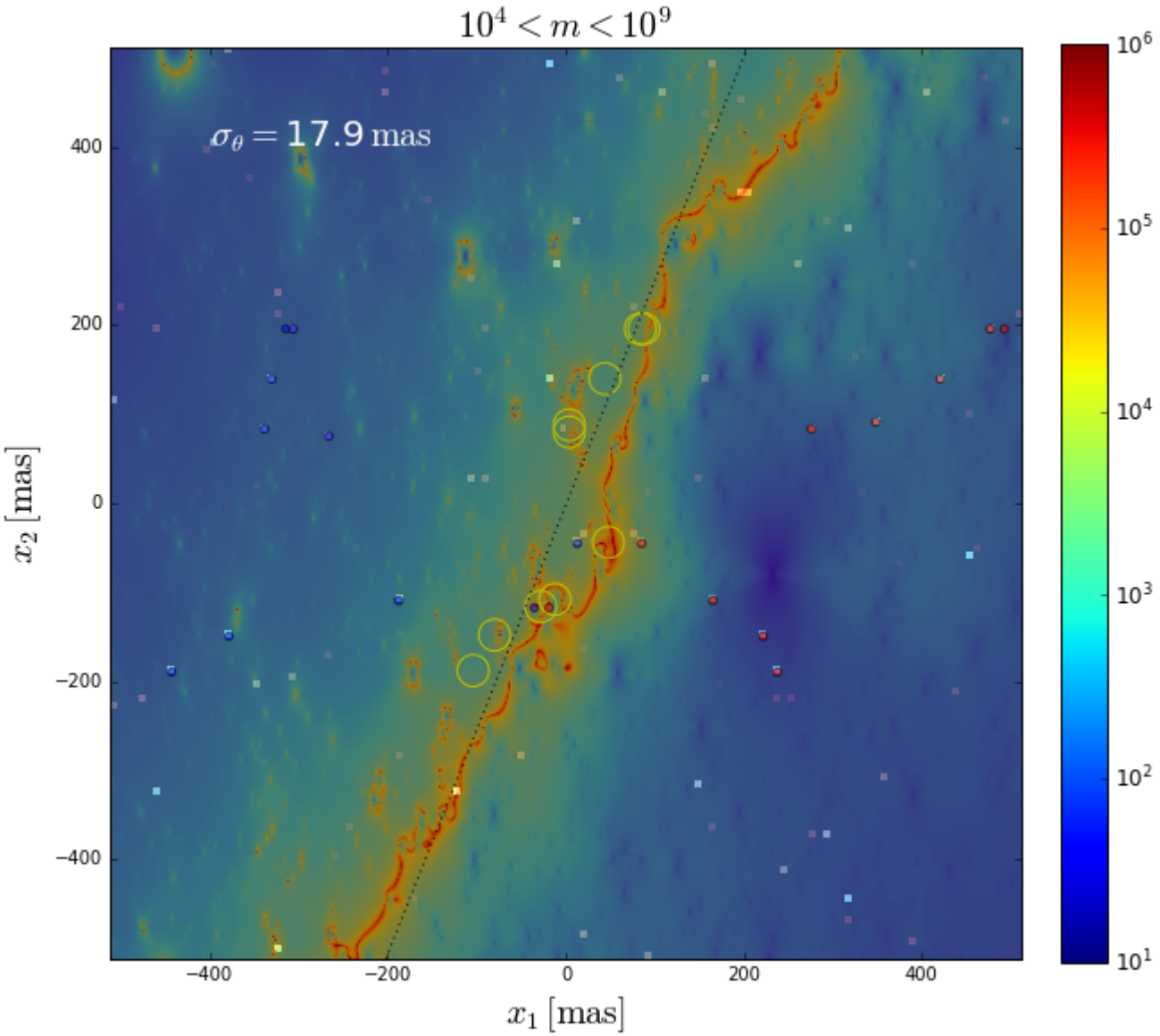
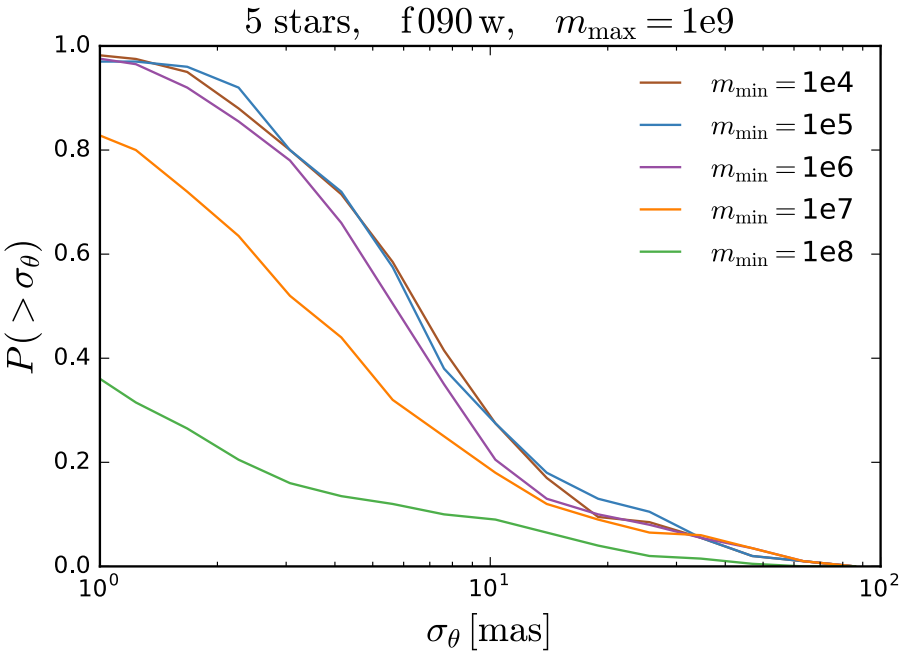


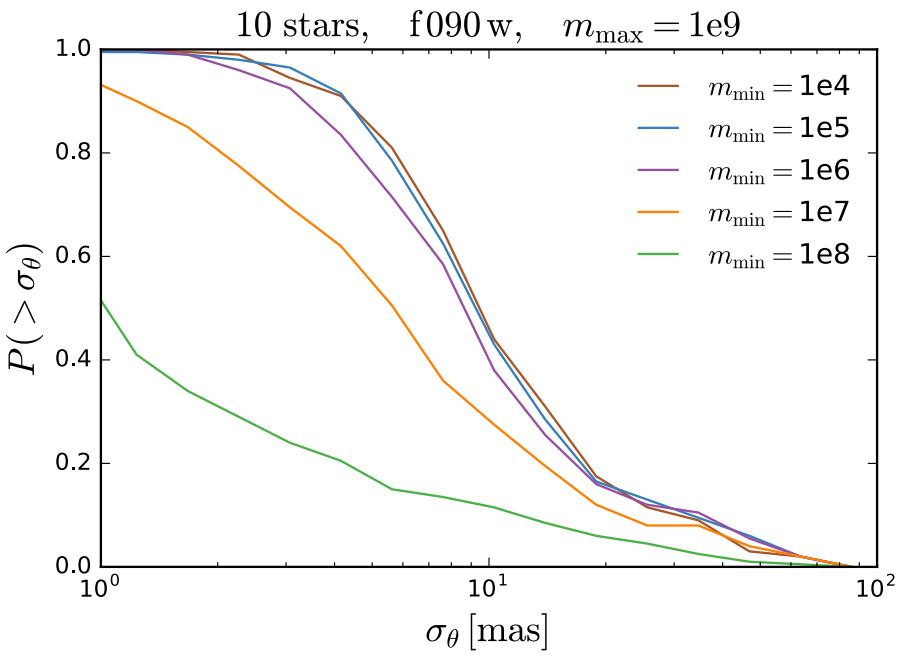
Dai, Venumadhav, Kaurov & Miralda-Escudé, in prep

Astrometric precision required

Dai, Venumadhav, Kaurov & Miralda-Escudé, in prep

for a set of fiducial parameters





- Most likely to see a subhalo at the host's scale radius
- Sensitive to 10^6 – 10^7 Msun subhalos, 7-8 orders of magnitude down the cluster's mass scale; those expected to be non-luminous
- HST and JWST pixel size (short wavelength instrument) ~ 30 mas.

Discussion & Outlook

- Microlensing strongly modifies image magnitudes; multiple visits helpful. But expected to be unimportant for image locations (< few mas).

- Use JWST to image more caustic crossing stars. Better sensitivity and PSF than HST. There might be many red super-giants; faint in HST bands but can be very bright around 3 micron. DD ERS proposal recently submitted.

- Next generation of 30-meter class ground optical/IR telescopes with AO and "lucky image" techniques may do better astrometry ~ a few mas for bright events.

- Intervening field halos along the line of sight (~ Gpc) may be equally or more important than the cluster's subhalos.

- Clumpy structure might also exist in intracluster stars. Wandering globular clusters and their lensing effect?