Pushing the Limits of Detectability: MixDM

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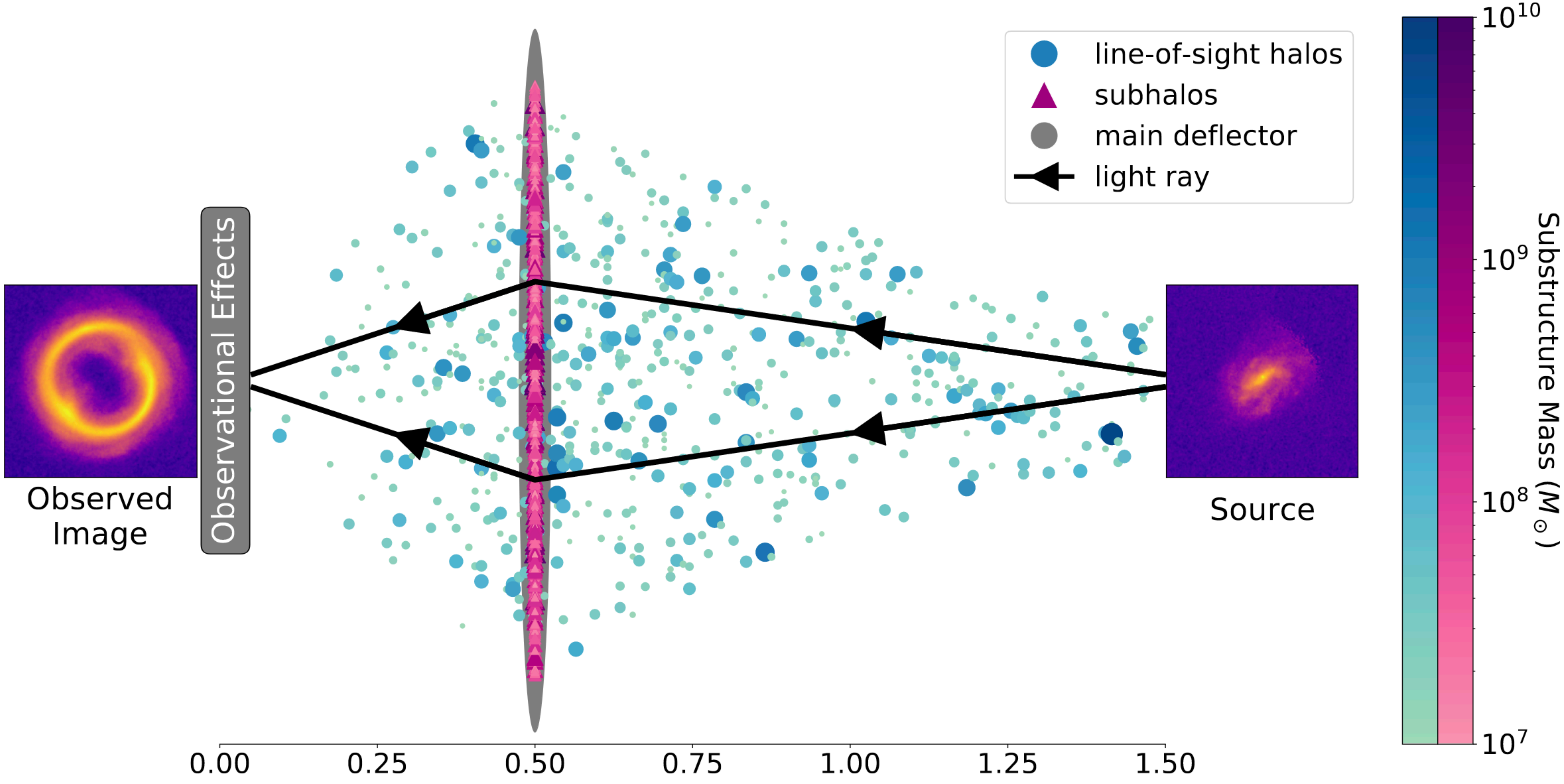
DM in astrophysical environments

- Probes:
  - Rotation curves / velocity dispersion
  - Cold stellar streams
  - Dwarf galaxies / satellite galaxies
  - Lensing
  - Wide binaries



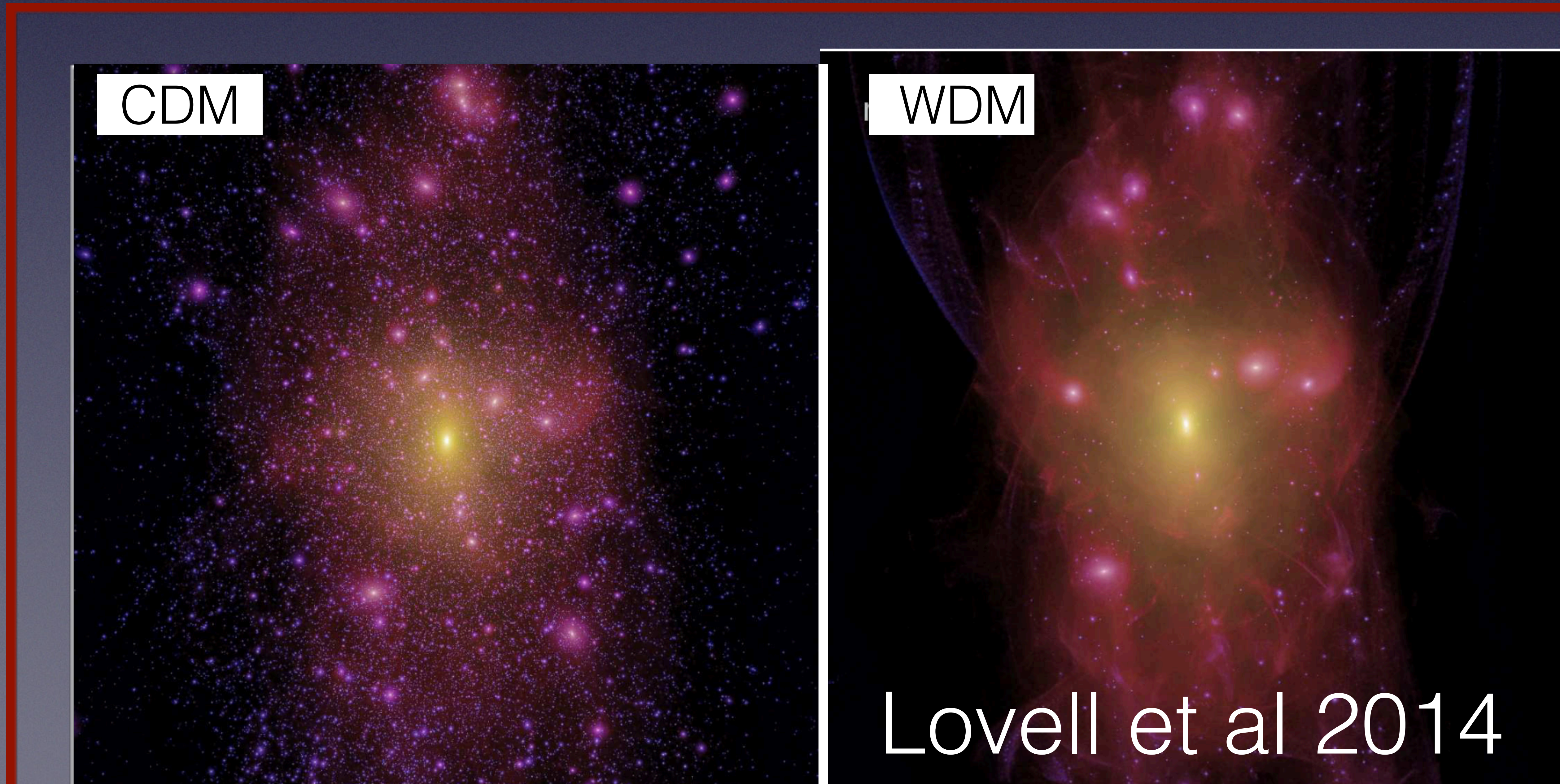
Wagner-Carena et al arXiv:2203.00690

- Gravitational potential: $\psi(\vec{\theta}) = \frac{D_{DS}}{D_D D_s} \frac{2}{c^2} \int^{z} dz \Phi(D_D, \vec{\theta}, z)$

- Deflection: $\vec{\alpha}(\vec{\theta}) = \vec{\nabla}\psi$, magnification: $M^{-1} = \delta_{i,j} - \frac{d\psi}{d\theta_i d\theta_j}$

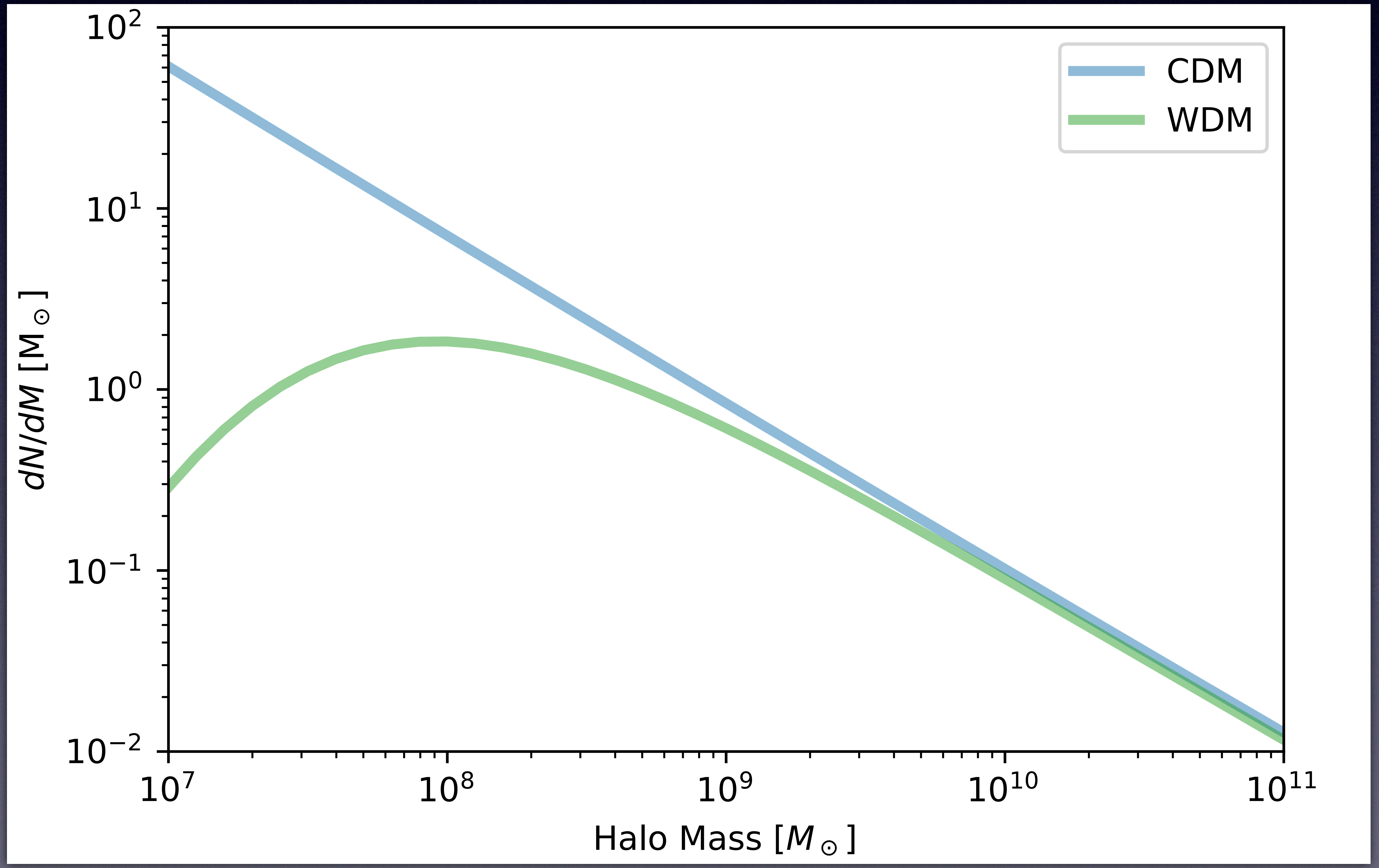
Warm Dark Matter

- Masses on the order of keV
- e.g. sterile neutrinos
- Constrained by observing the smallest gravitationally bound halos
- Half-mode mass, where suppression is half compared to CDM
- $$M_{\rm hm} = 5.5 \times 10^{10} \left(\frac{m_{\rm WDM}}{1\ \rm keV} \right)^{3.33}$$



Halo Mass Function

- Cold DM predicts an abundance of DM halos at small masses
- Warm DM predicts few - structure suppressed at small scales
- Where suppression starts determined by the mass of DM particle



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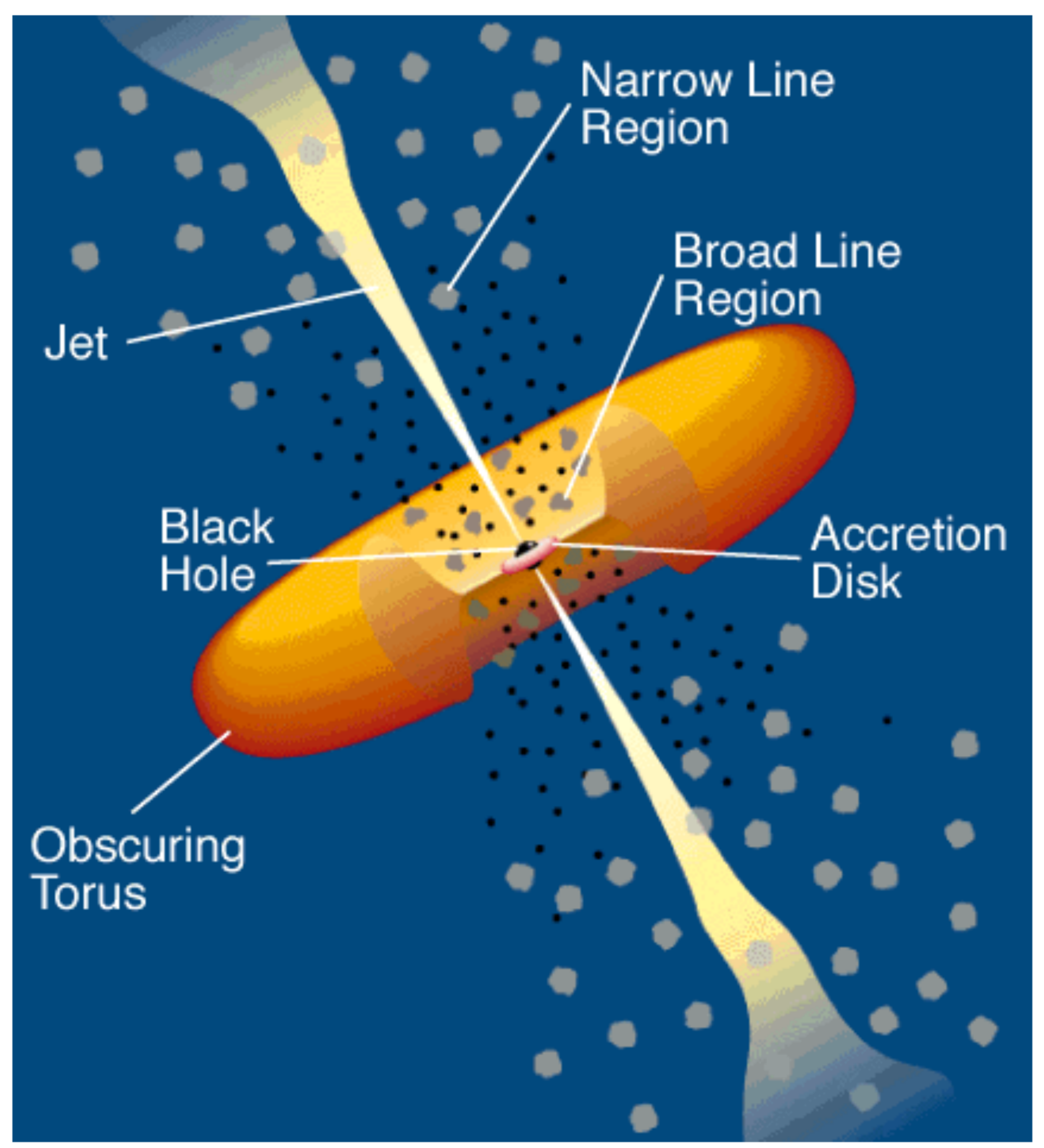
Strong Lensing of Quasars

- For lensing, different regions are of different physical sizes and emit in different wavelengths -> separate tracers

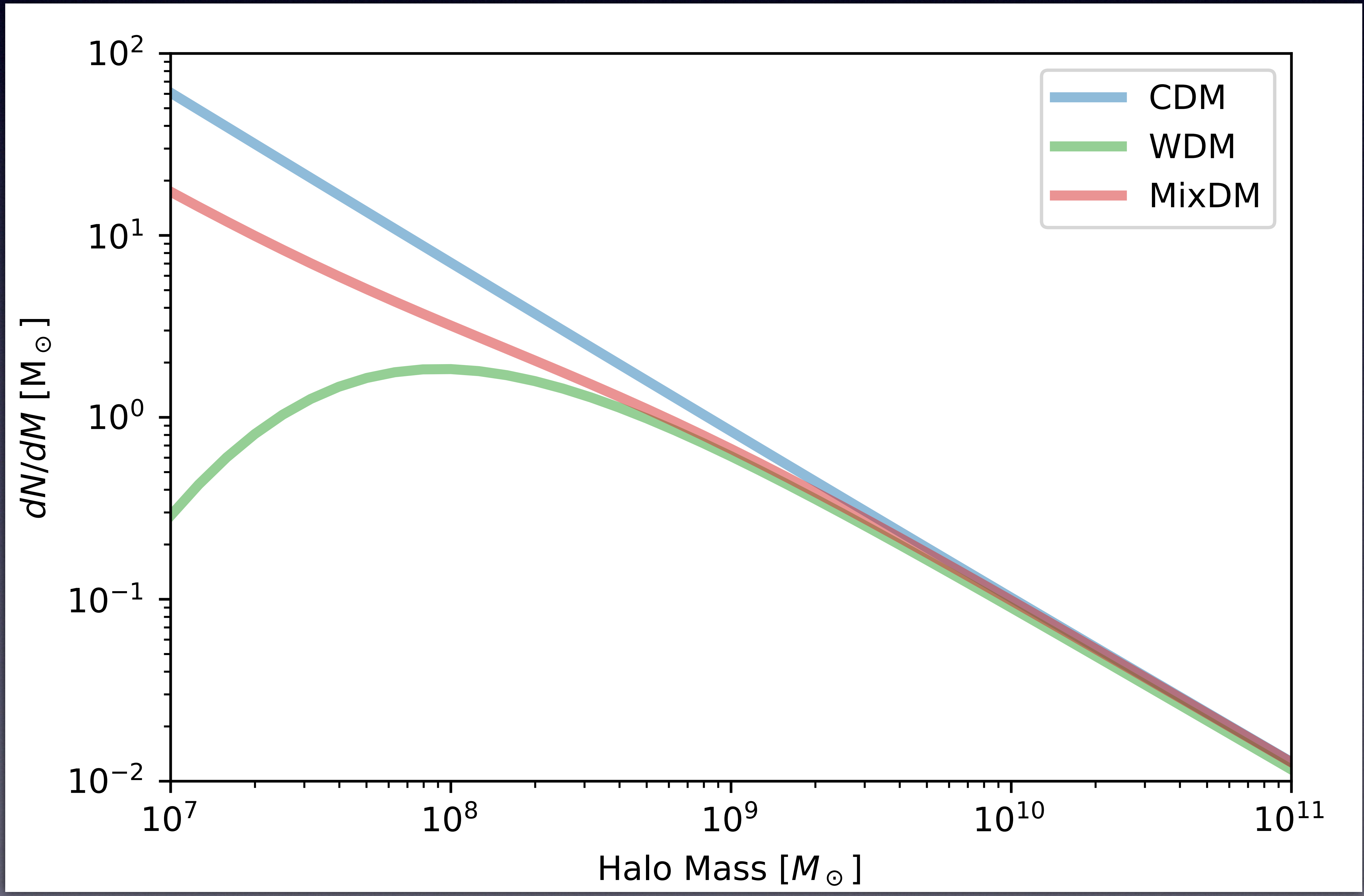
- Smaller source sizes are more sensitive to lower mass DM halos

- Observe narrow line region with HST/Keck and cold torus with JWST



Mixed DM

- Test an intermediate case - 1/2 cold DM and 1/2 warm DM
- Cold DM component still forms low-mass DM halos
- Warm DM component suppresses structure growth
- E.g. WIMP + sterile neutrino; Primordial black hole + axion-like particle
- $$\frac{dN/dM_{MixDM}}{dN/dM_{CDM}} = (f + (1-f)(1 + a(M_{hm}/M)^b)^c)^2$$



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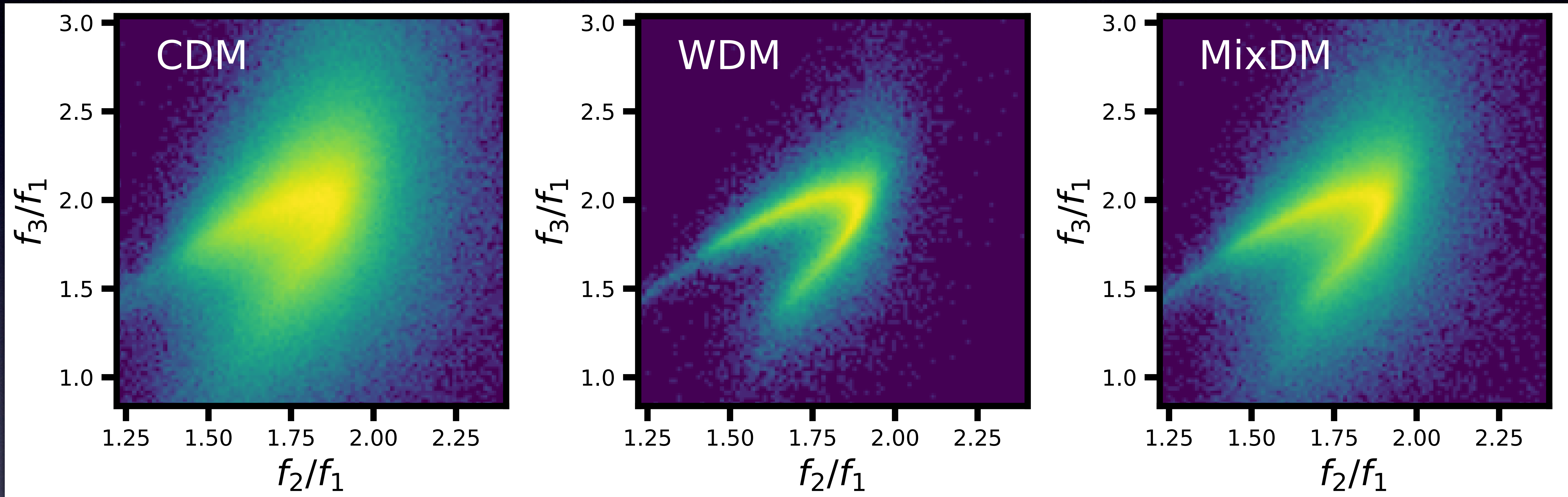
Anomalous Fluxes

- Model predicts *distribution* of fluxes, not a single value
- Need machine learning, simulation-based (likelihood-free) statistical inference
- Summary statistic:

$$Z(f_i) = \sum_i (f_i - f_{\mathrm{ref,i}})^2$$



- Ratios of fluxes from quadruply lensed images
- Ratio to divide out unknown flux of source

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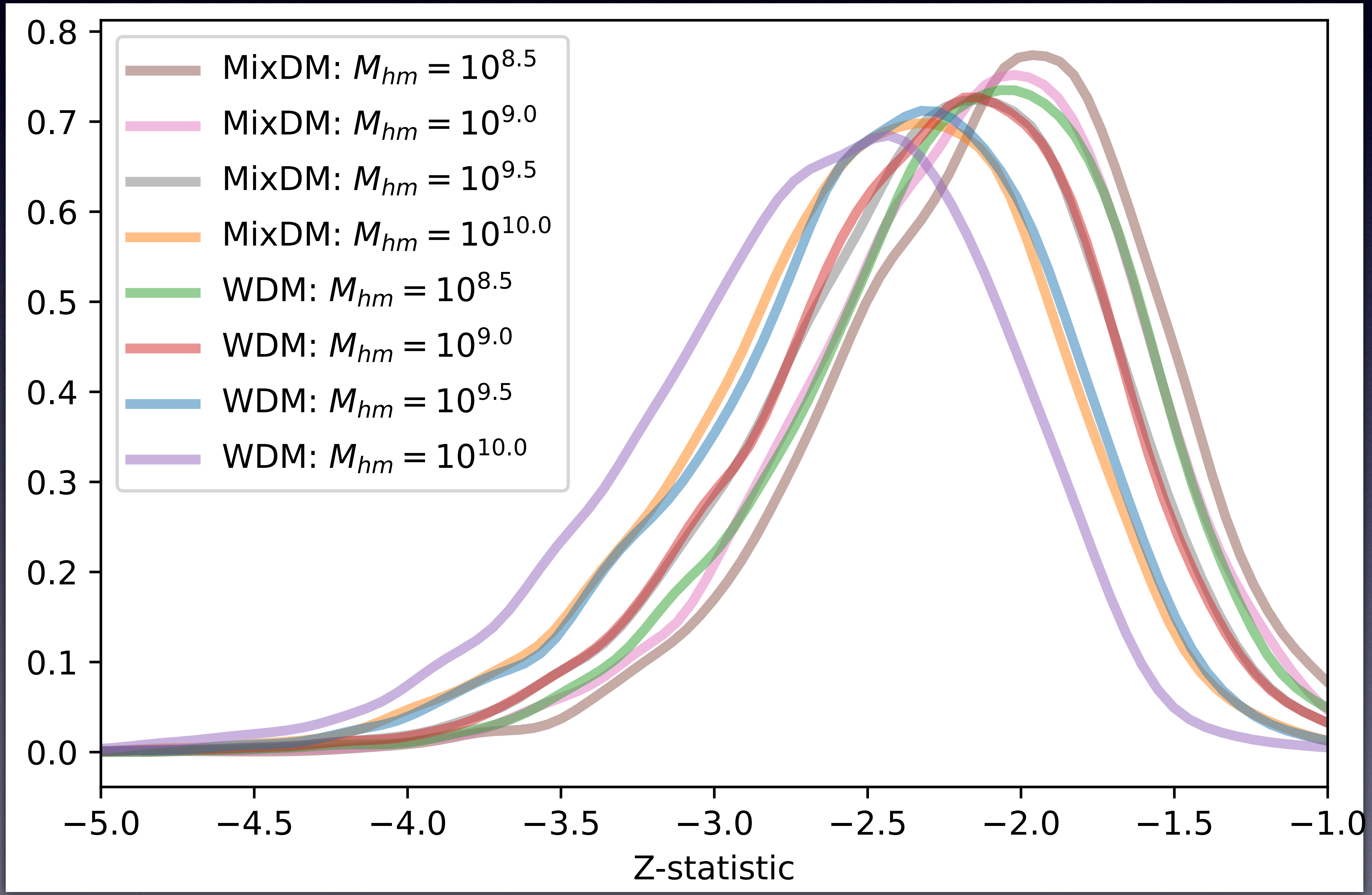
Degeneracies

- $$Z(f_i) = \log\left(\sum_i (f_i - f_{\mathrm{ref,i}})^2\right)$$
- Distributions of the same lens
- Model predicts distribution of fluxes
- If distributions are same, then cannot distinguish
- For any WDM model, there exists a MixDM model with different parameters that predicts the same distributions



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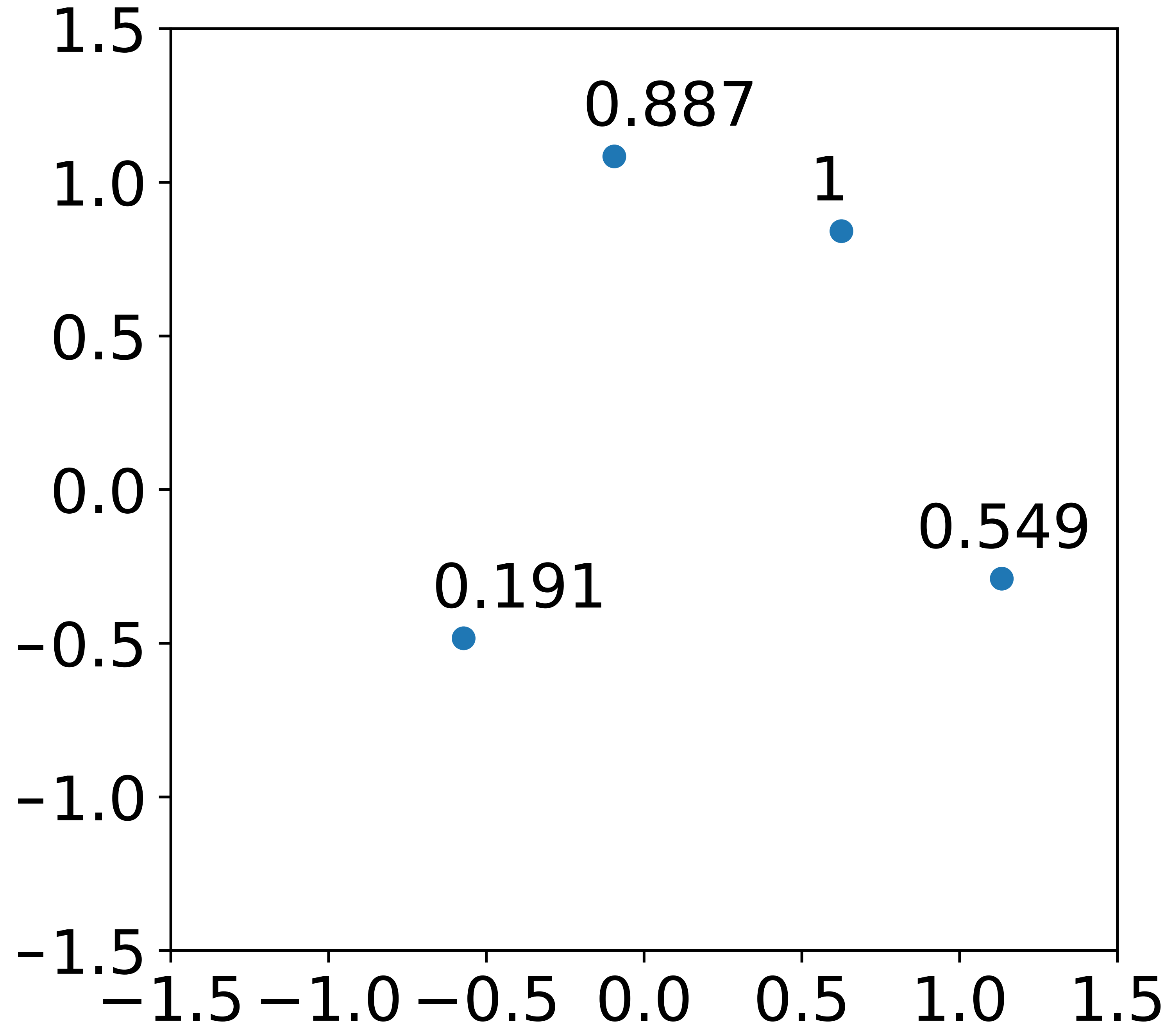
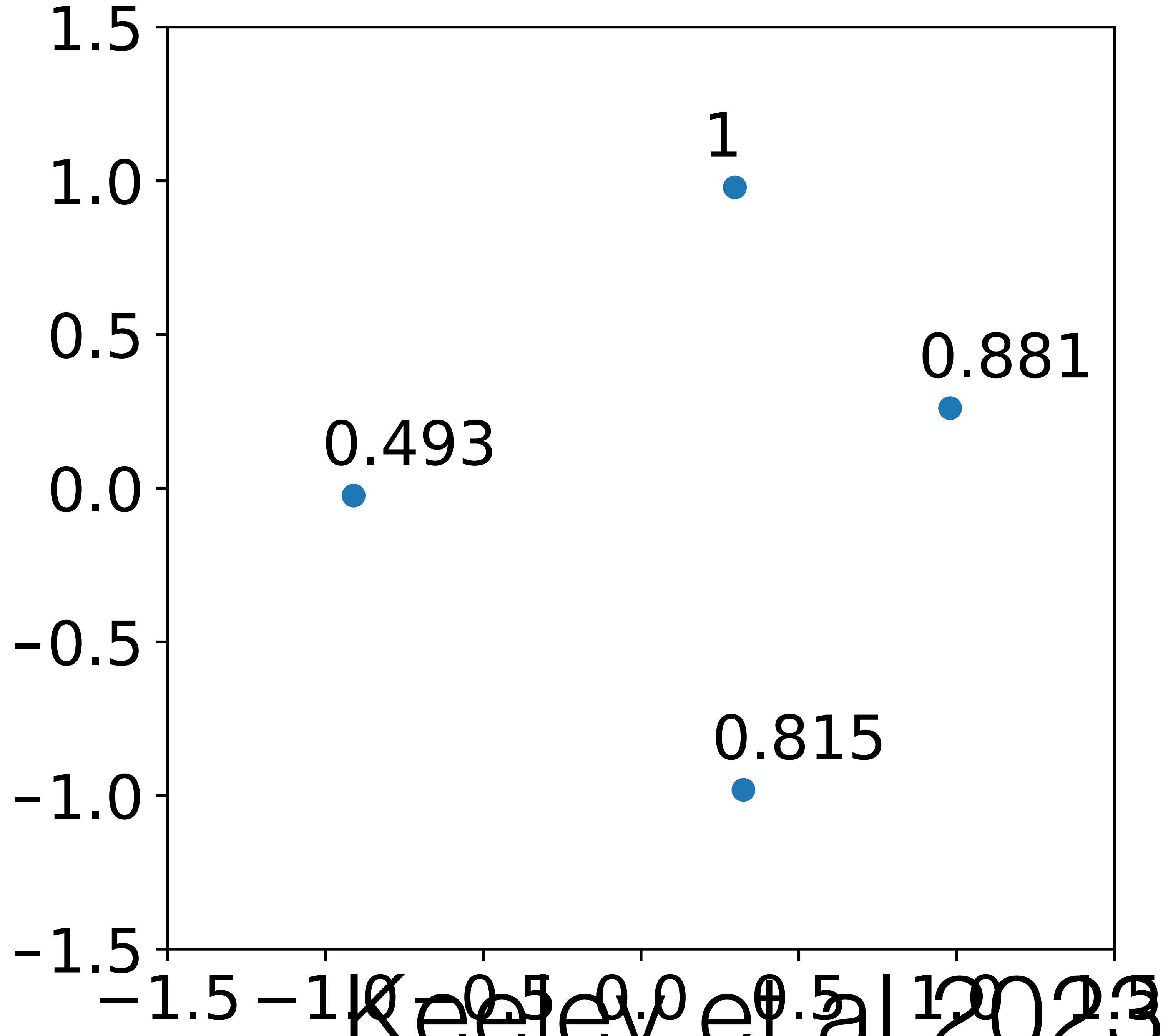
Breaking Degeneracies

- Flux ratios of four images for two different gravitational lenses
- Test whether / to what extent different configurations of a gravitational lens will probe different parts of the halo mass function and hence break degeneracies between models





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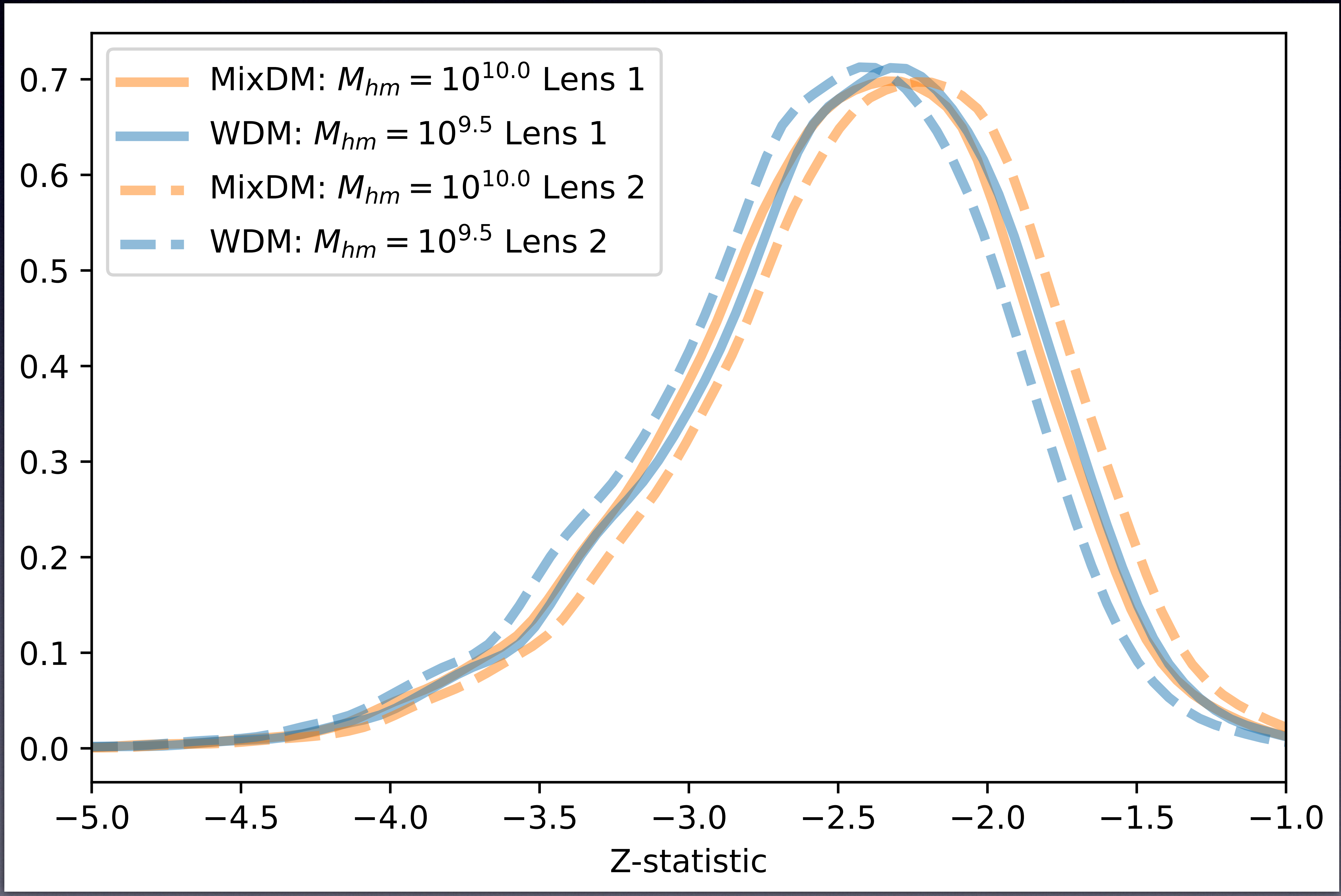
Breaking degeneracies

- Distributions from different lenses
- Predicted distributions depend on configuration of lens
- So correspondence between WDM and MixDM parameters depend on lens
- Different configurations can break degeneracies



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Forecast constraints

- Mock data generated from a MixDM model
- Posterior of parameters $\Sigma_{\rm sub}, M_{\rm hm}, f$
- $f = 0,\ M_{\rm hm} = 10^{10},\ \Sigma_{\rm sub} = 0$ corner with least structure (warmest)
- Easier to differentiate between MixDM and CDM than MixDM and WDM

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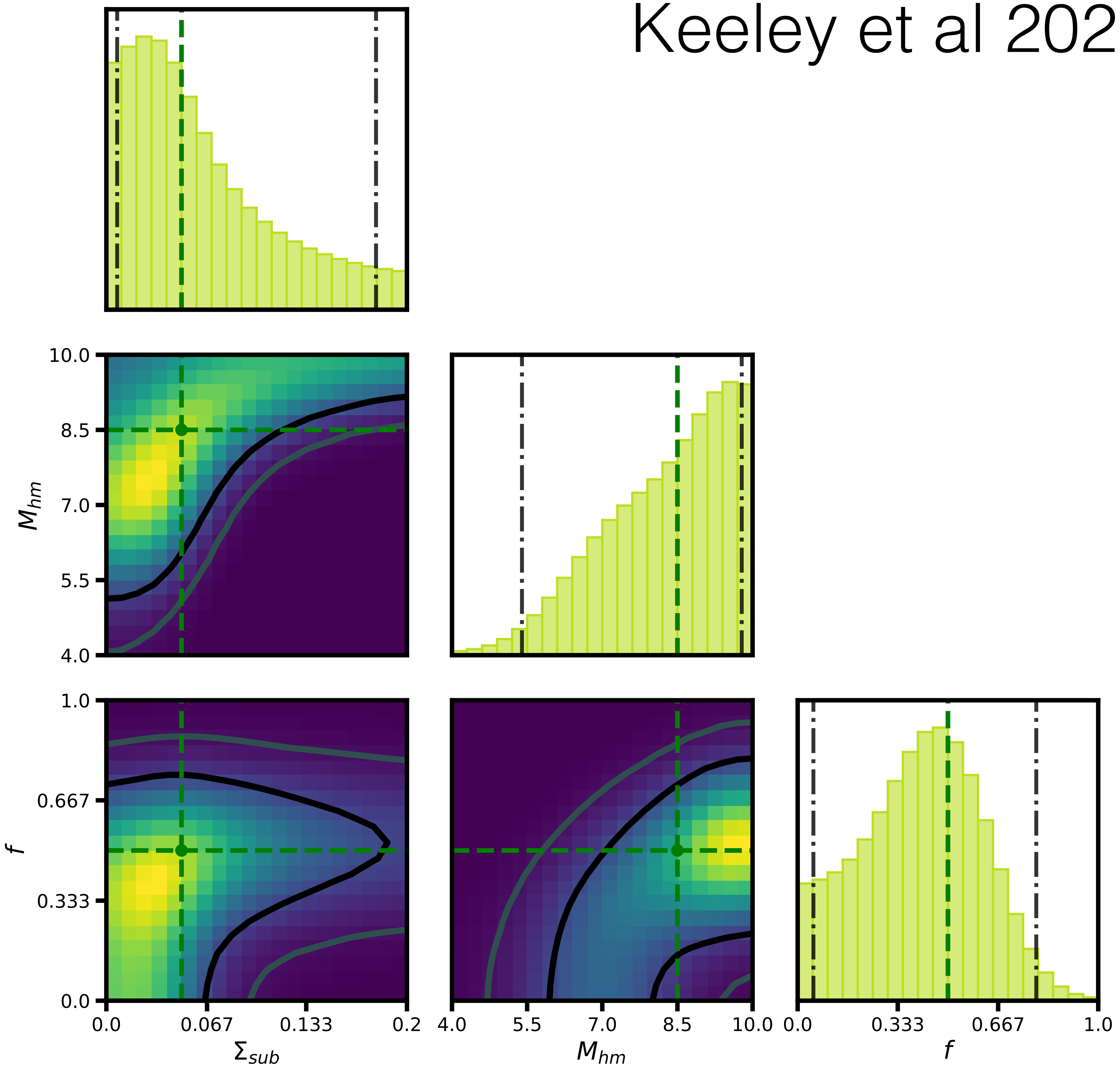
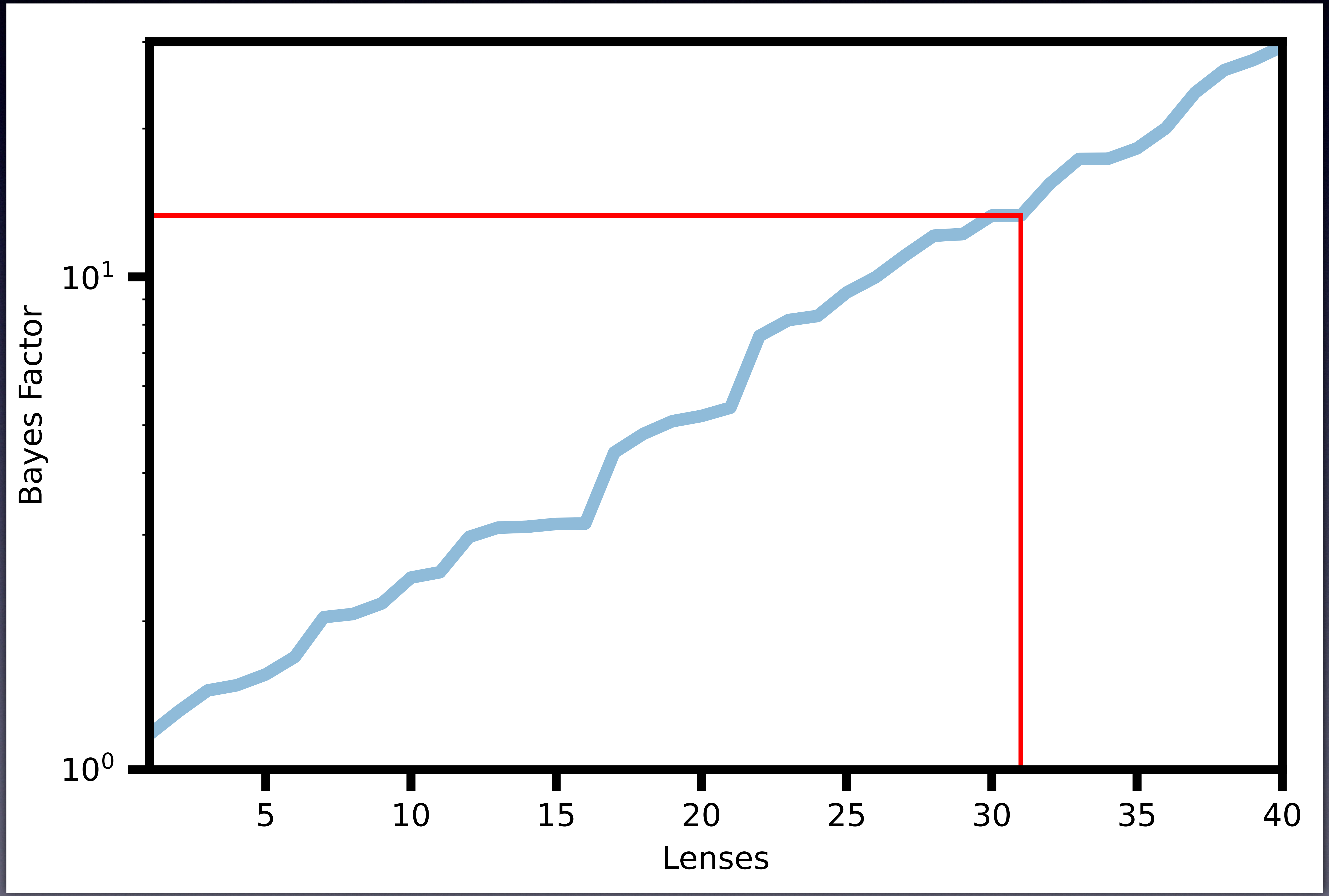


Forecast constraints

- Bayes factor for increasing number of lenses
- $BF = P(M_{\mathrm{MixDM}}|D)/P(M_{\mathrm{WDM}}|D)$
- JWST program will observe 31 lenses (red line)



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Conclusions

- Arbitrary mass functions can be constrained with the right kinds of strong lenses
- DM models beyond CDM and WDM can be constrained this way
- Large parameter degeneracies make this inference problem hard
- Refine predictions for the subhalo distributions
- Use information from other probes (source sizes, extended arcs)