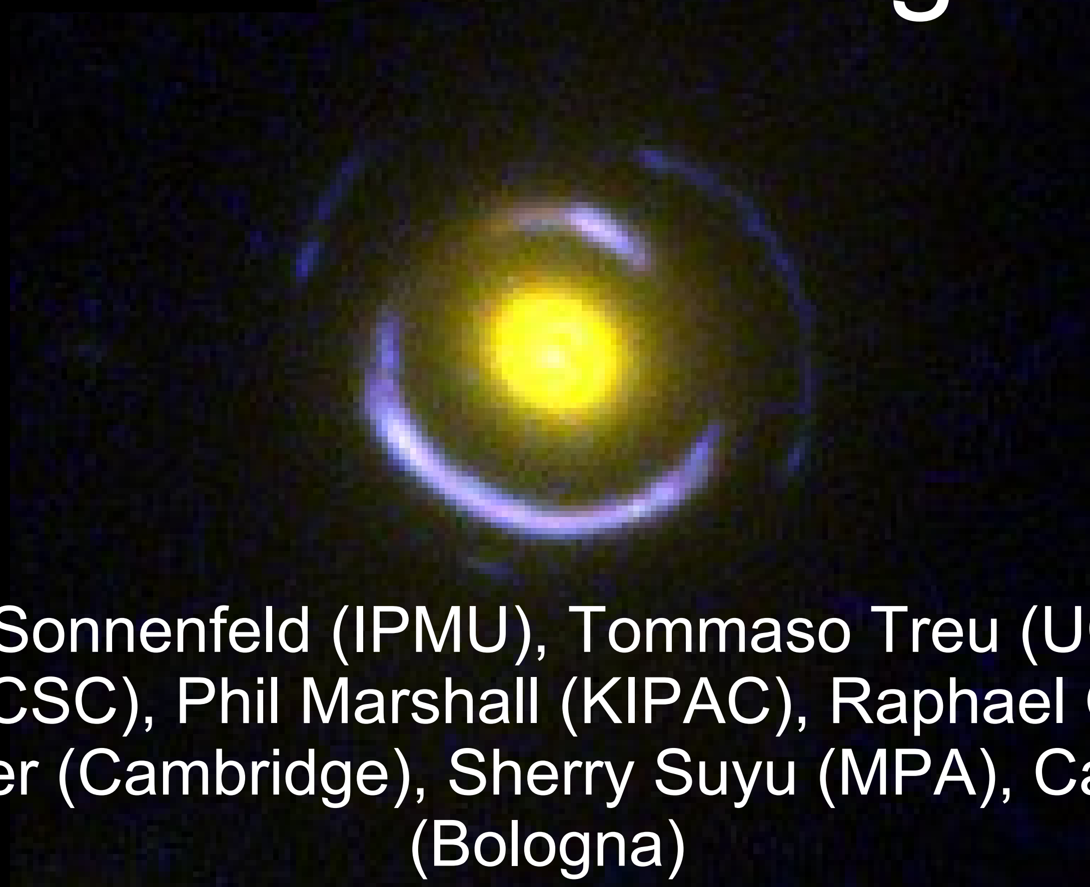
Dark matter in massive galaxies: constraints from strong lensing



Alessandro Sonnenfeld (IPMU), Tommaso Treu (UCLA), Alexie Leauthaud (UCSC), Phil Marshall (KIPAC), Raphael Gavazzi (IAP), Matt Auger (Cambridge), Sherry Suyu (MPA), Carlo Nipoti (Bologna)

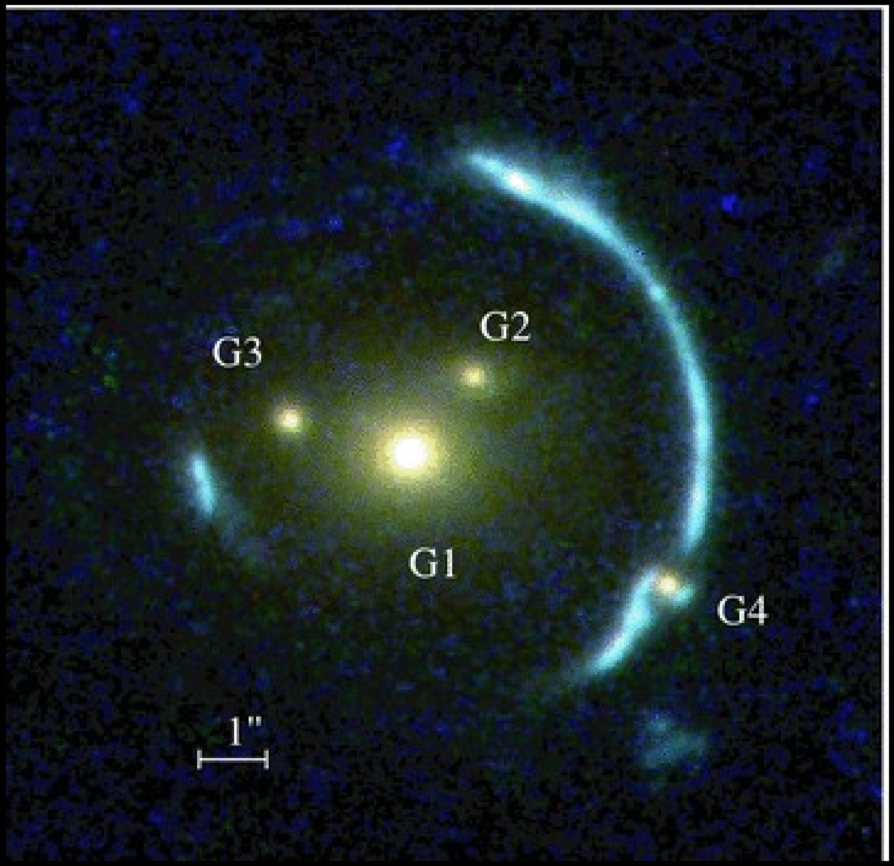
Strong lensing

$$R_{Ein} = \sqrt{\frac{4GM}{c^2}\frac{D_d D_{ds}}{D_s}}$$

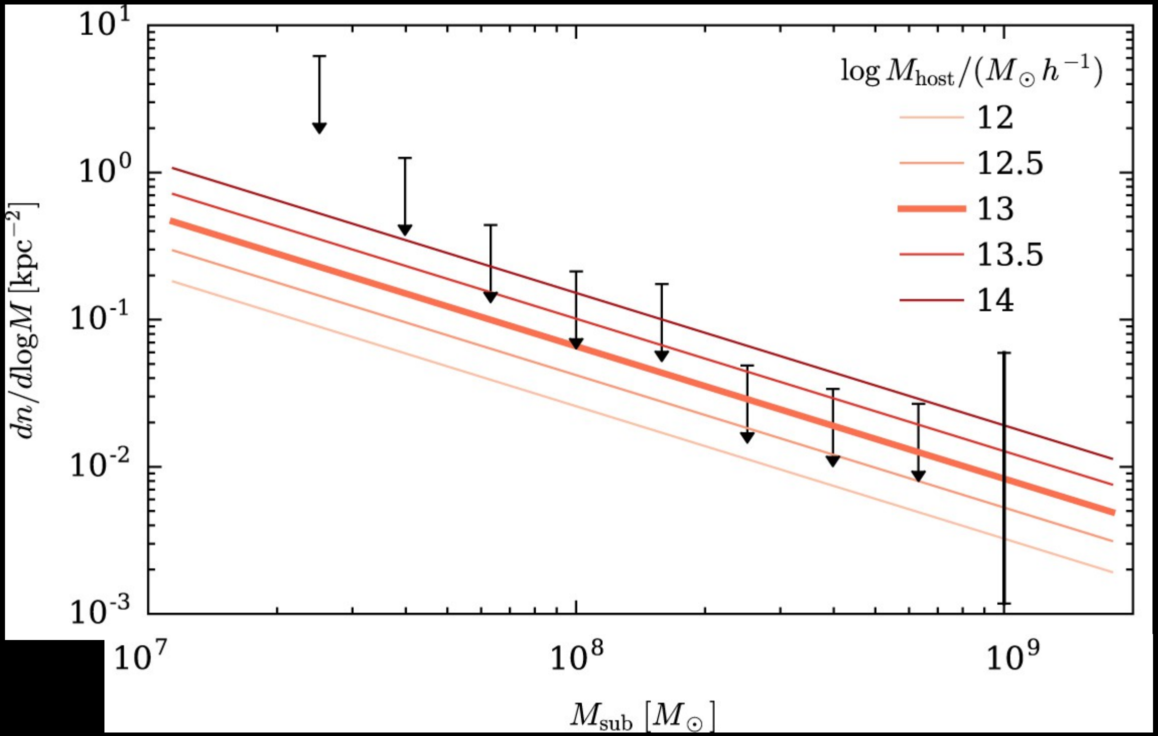
Strong lensing

- Probes dark matter on scales of a few kpc
- In principle, strong lensing can be used to put constraints on dark matter models (e.g. Self-interaction)
- However, inner regions of galaxies are dominated by baryonic physics: challenge for both measurement and interpretation

Substructure lensing



Vegetti et al. (2010)



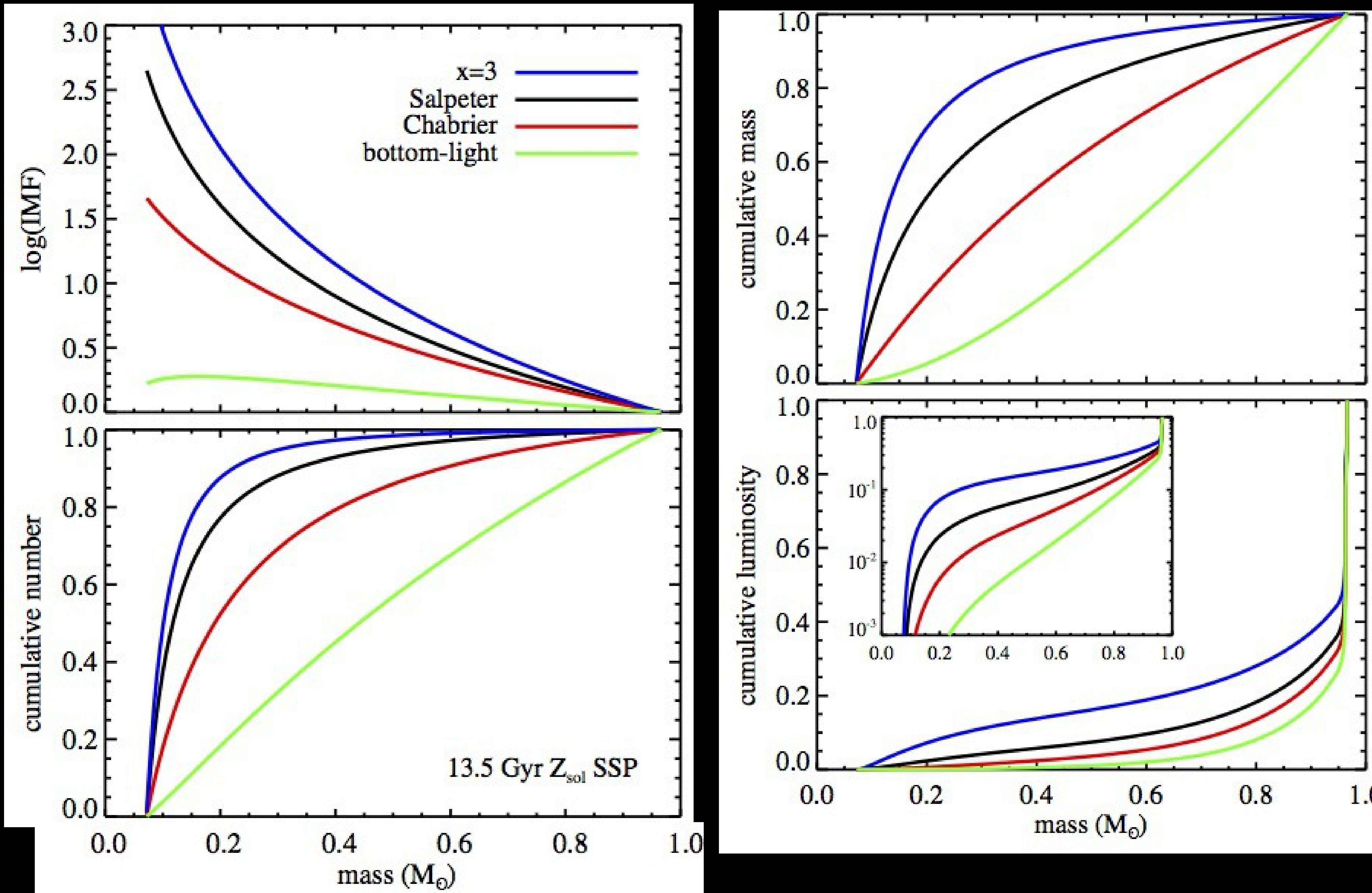
Hezaveh et al. (2016)

Interpretation of subhalo detection depends on density of smooth DM component

Measuring DM density profiles

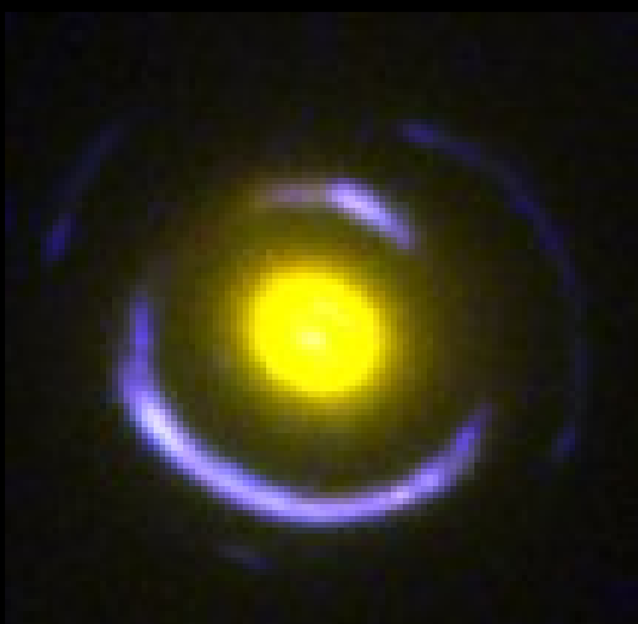
- From an observational point of view, dark matter is whatever mass component that does not follow the light distribution
- Strong lensing gives the total mass within the Einstein radius
- Using only photometry, stellar masses can only be measured up to a constant (!)

The stellar initial mass function

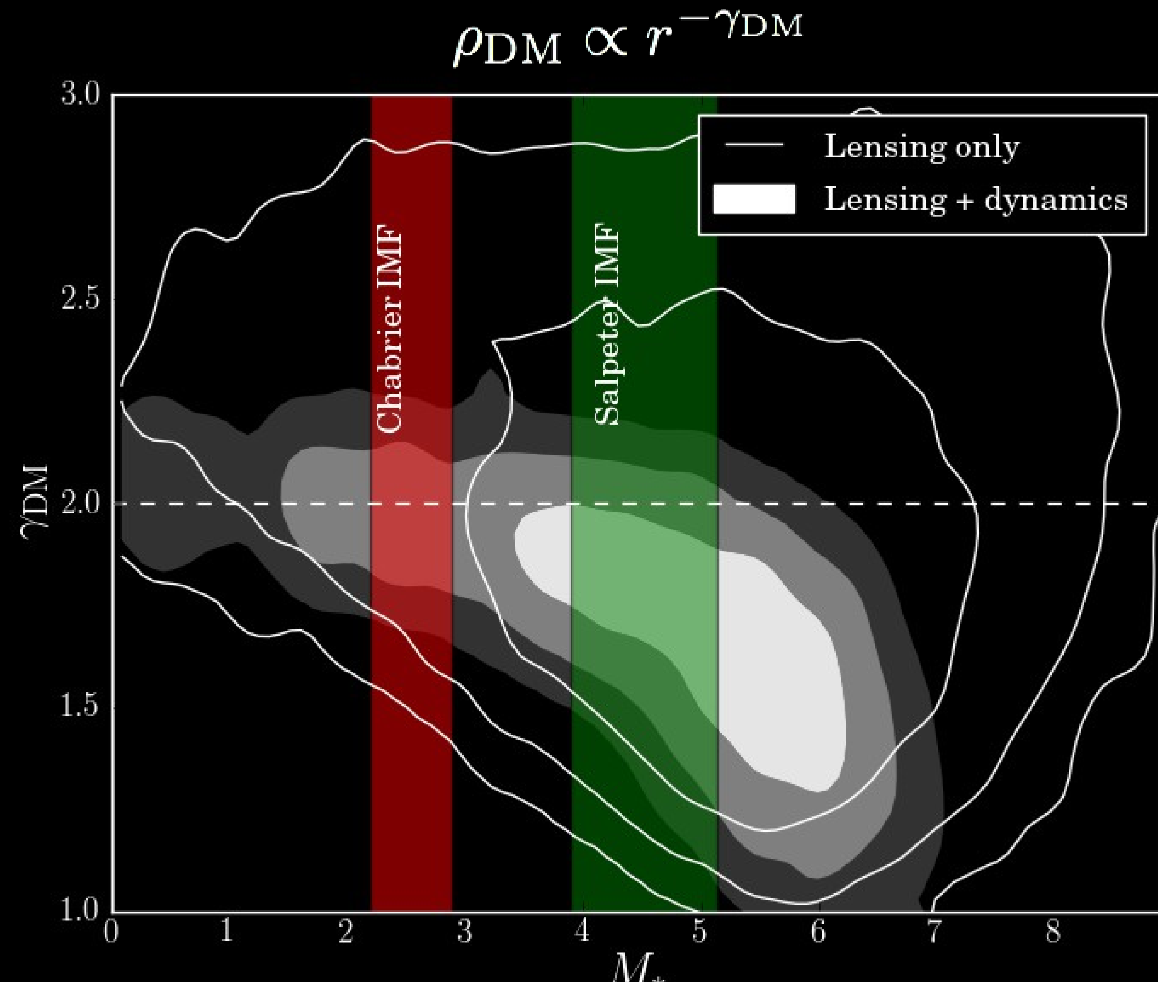


Strong lensing and stellar dynamics

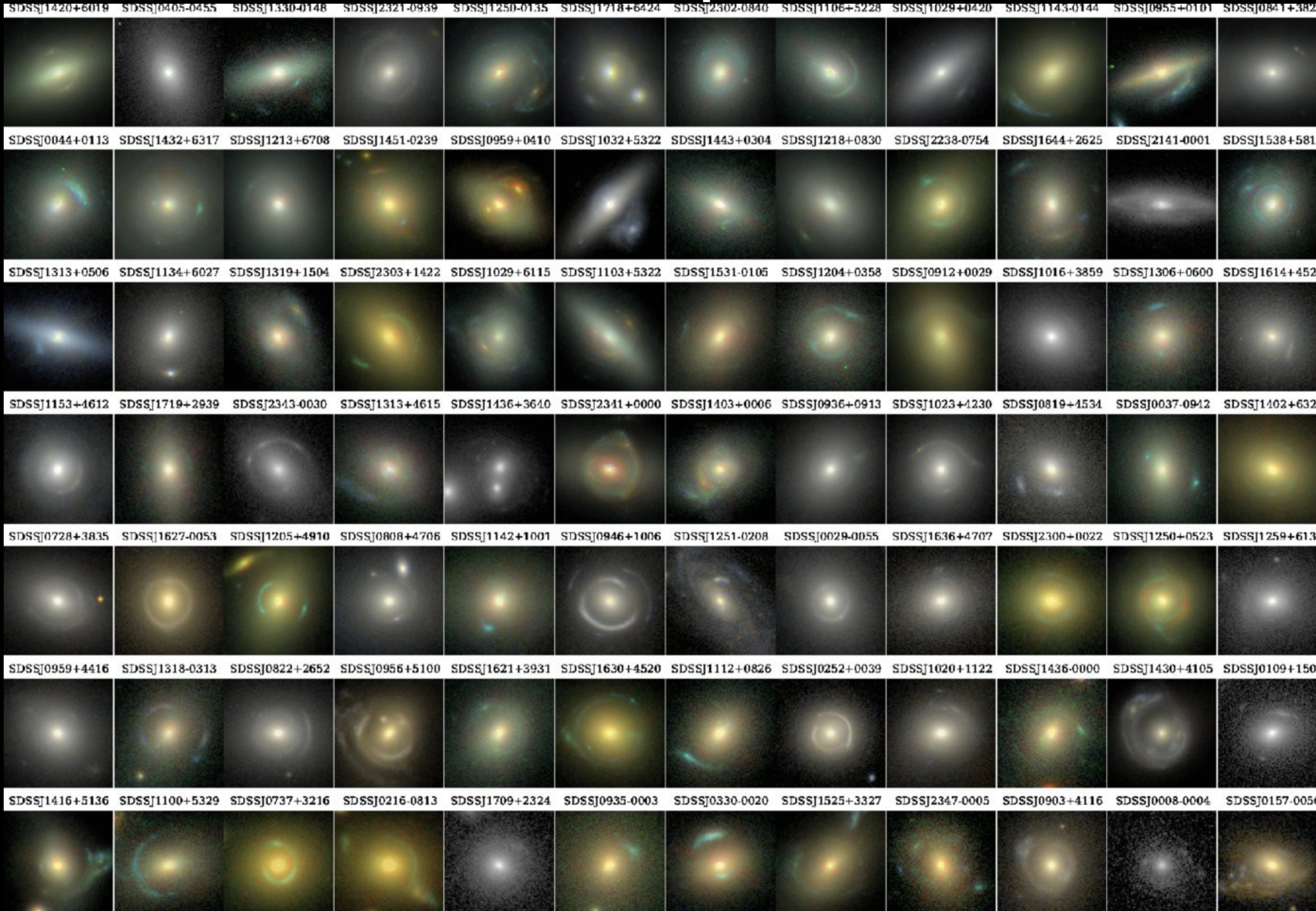
- Stellar kinematics (velocity dispersion) provides an additional constraint on the total gravitational potential



Sonnenfeld et al. (2012)



Statistical sample of lenses

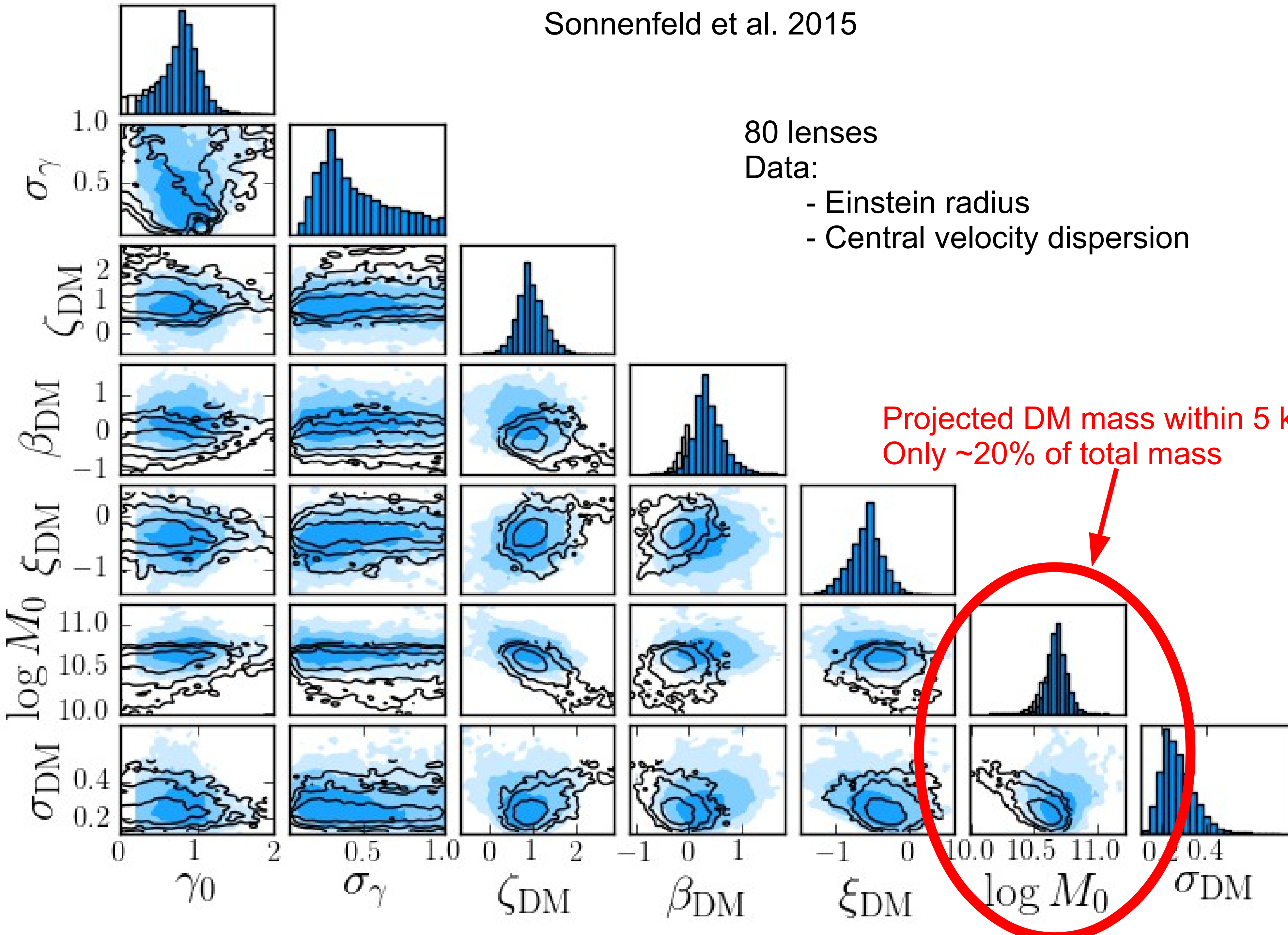


Auger et al. 2009

$$\gamma_{DM} = \gamma_0 + N(0, \sigma_\gamma) \quad ; \quad \log M_{DM} = \zeta_{DM}(z - 0.3) + \beta_{DM}(\log M_* - 11.5) + \xi_{DM} \log \Sigma_*/\Sigma_0 + \log M_0 + N(0, \sigma_{M_{DM}})$$

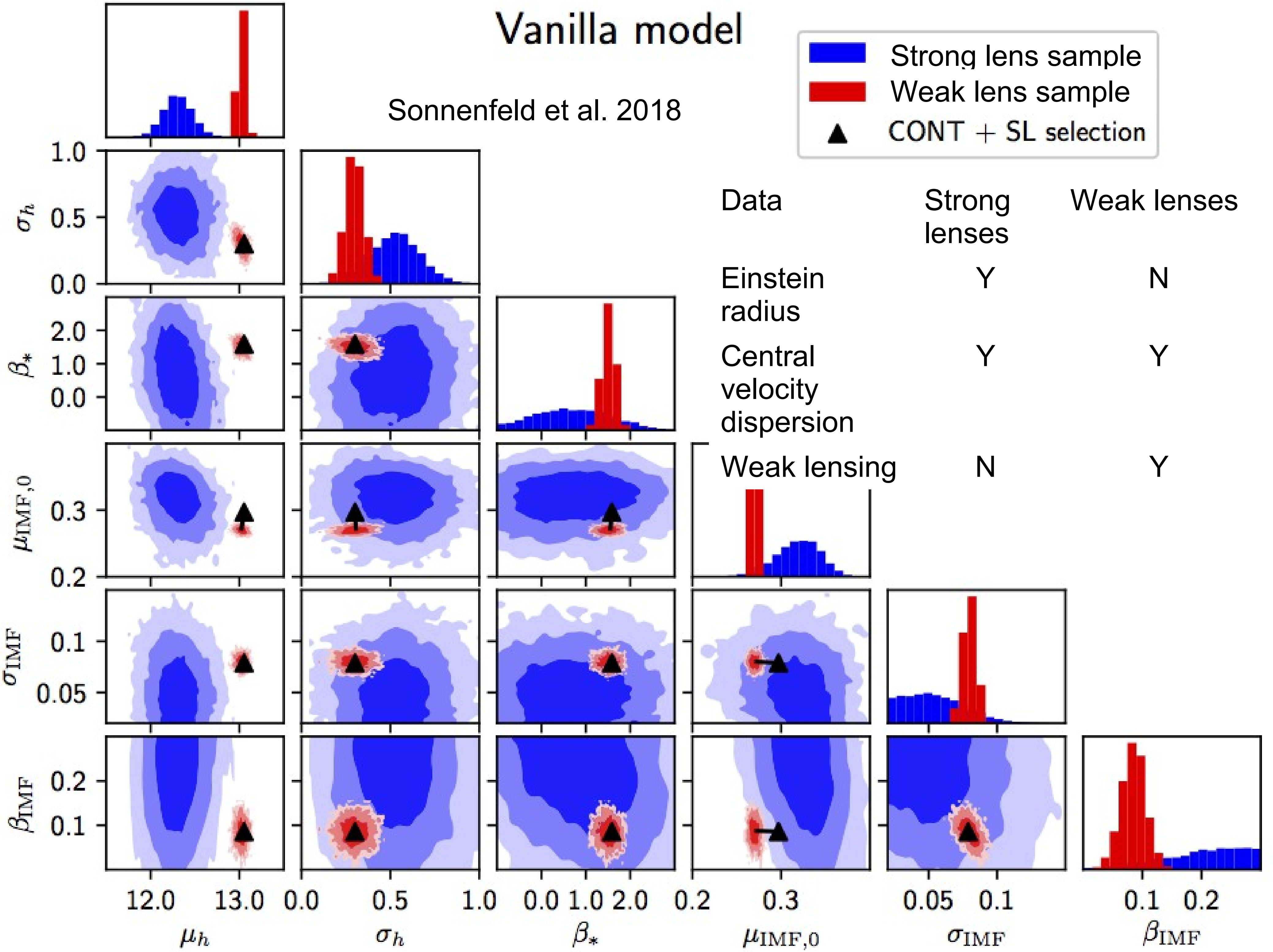
Sonnenfeld et al. 2015

80 lenses
Data:
- Einstein radius
- Central velocity dispersion

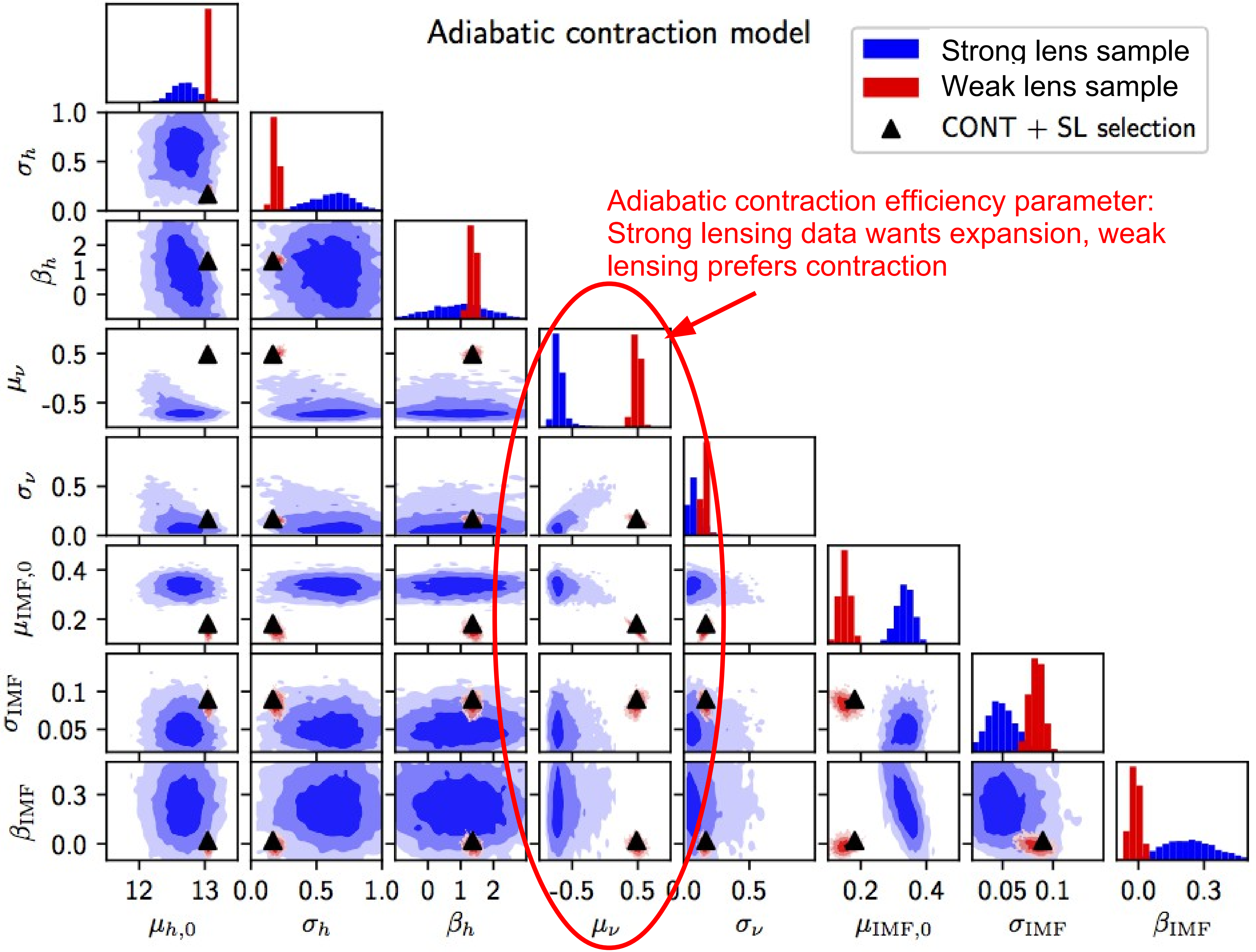


- Key ingredient missing: halo mass.
- We can measure halo masses with weak lensing
- The current number of strong lenses is too small for a meaningful weak lensing measurement of halo mass
- Strategy: obtain weak lensing measurements on a “twin” sample of galaxies, selected in a similar way as the strong lens sample
- Fit same model to the two samples: if model is right, strong lensing and weak lensing data should give the same answer
- Start from simplest possible model, increase complexity until can fit both datasets

Vanilla model



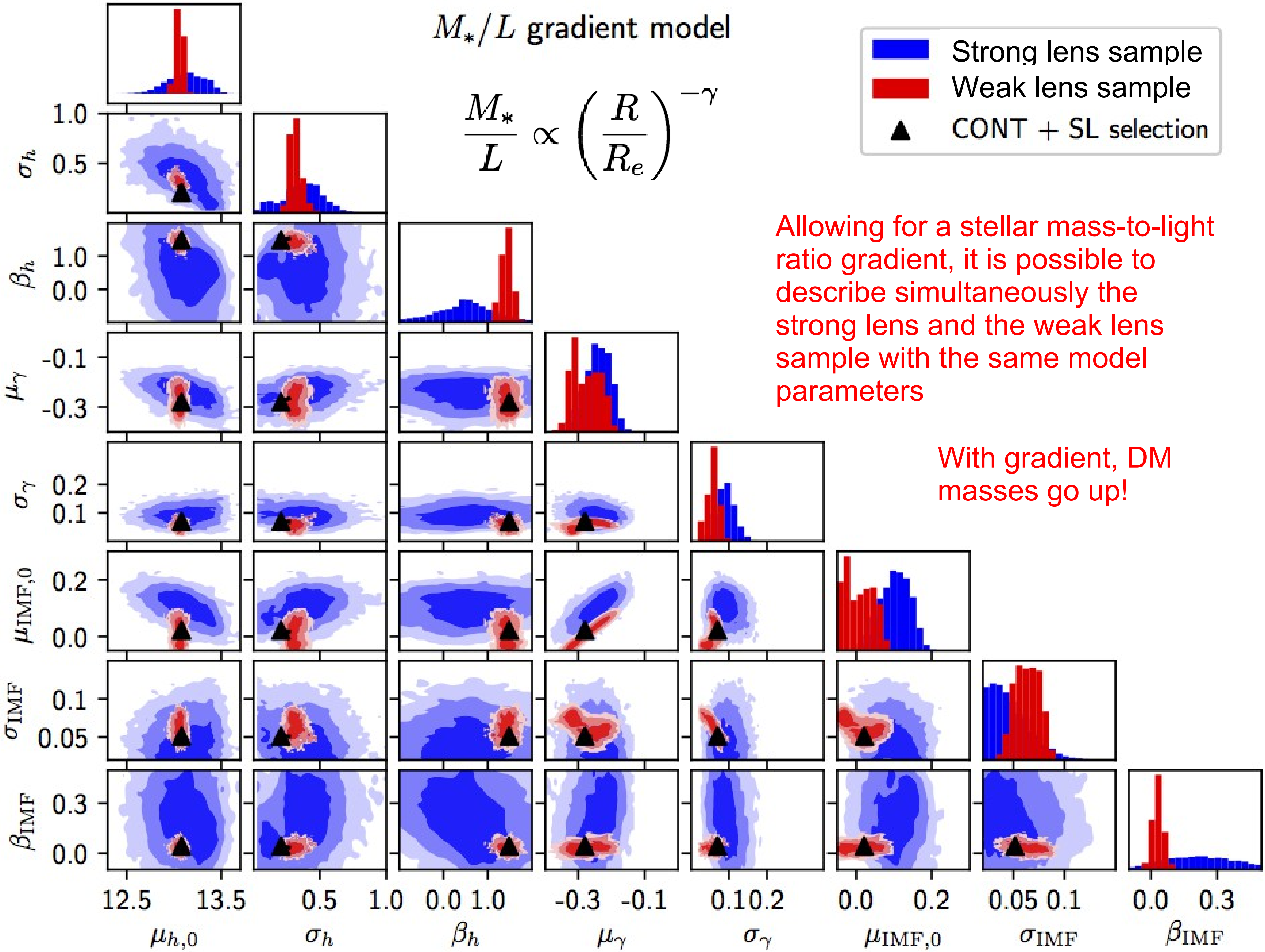
Data	Strong lenses	Weak lenses
Einstein radius	Y	N
Central velocity dispersion	Y	Y
Weak lensing	N	Y



Adiabatic contraction model
Strong lens sample
Weak lens sample
CONT + SL selection
Adiabatic contraction efficiency parameter:
Strong lensing data wants expansion, weak
lensing prefers contraction
$\mu_{h,0}$
σ_h
β_h
μ_ν
σ_ν
$\mu_{\rm IMF,0}$
$\sigma_{\rm IMF}$
$\beta_{\rm IMF}$

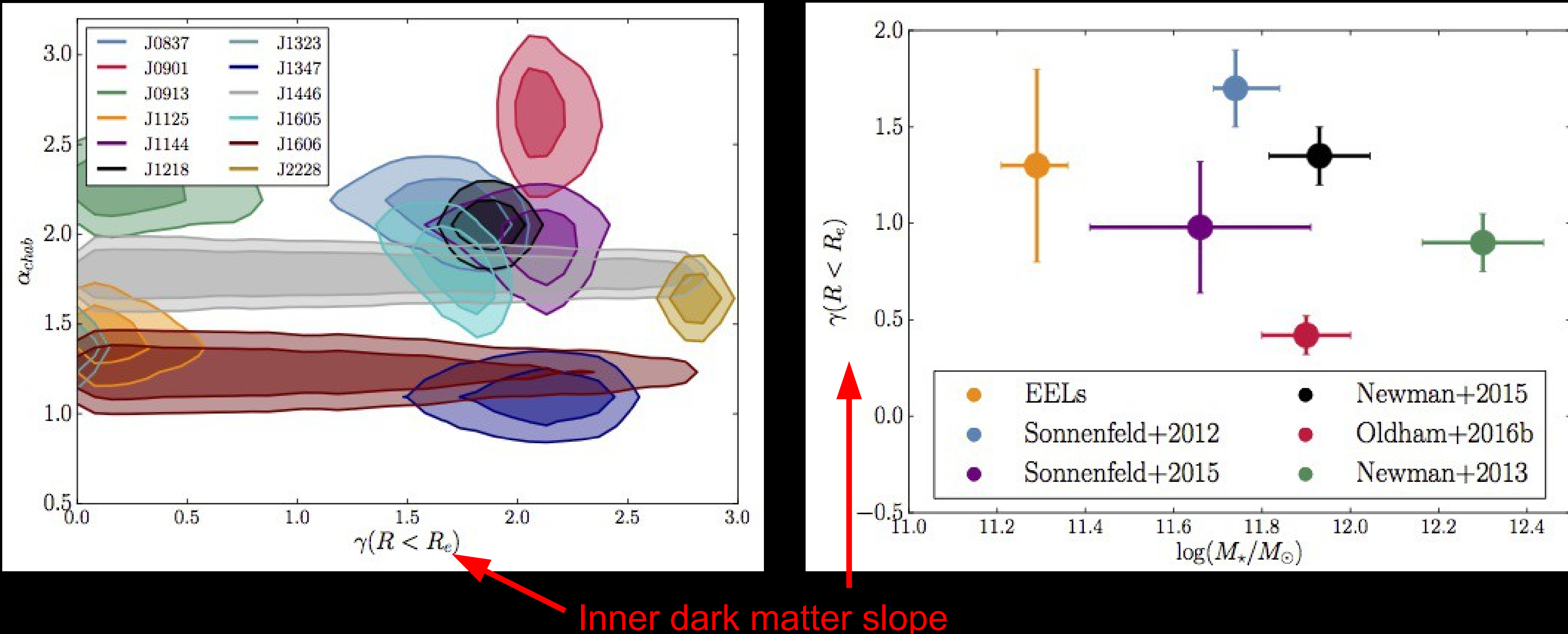
M_*/L gradient model

$$\frac{M_*}{L} \propto \left(\frac{R}{R_e}\right)^{-\gamma}$$



Allowing for a stellar mass-to-light ratio gradient, it is possible to describe simultaneously the strong lens and the weak lens sample with the same model parameters

With gradient, DM masses go up!



Oldham & Auger (2018)

- Detailed strong lens modeling provides more information than just the Einstein radius: differential magnification constraints density profile directly
- Analysis of 12 strong lenses: full surface brightness distribution modeling + stellar dynamics
- Inferred dark matter slopes steeper than NFW, even allowing for M*/L gradients

Summary

- Accuracy of strong lensing constraints on dark matter depends critically on our ability to subtract baryonic contribution from total mass
- “Naive” strong lensing and stellar kinematics analysis reveals small dark matter fractions (~20% within half-light radius), at odds with weak lensing constraints
- Allowing for a gradient in stellar mass-to-light ratio changes dramatically the inferred dark matter masses
- The existence of gradients in stellar population properties (including IMF) complicates greatly our efforts to measure dark matter masses
- However, there's great interest in constraining the stellar IMF from the astronomical community, and many possible probes: spectroscopy, microlensing, stellar kinematics