Revisiting the Stellar IMF - Dark Matter Halo Degeneracy in Strong Lens Galaxies

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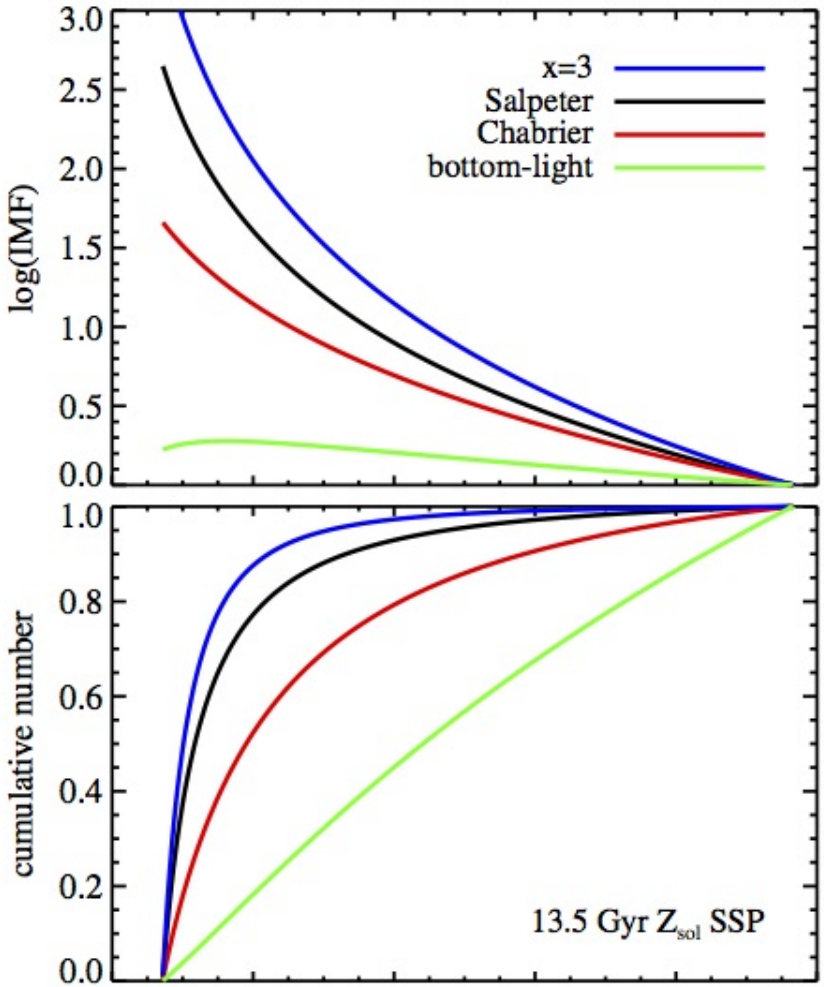
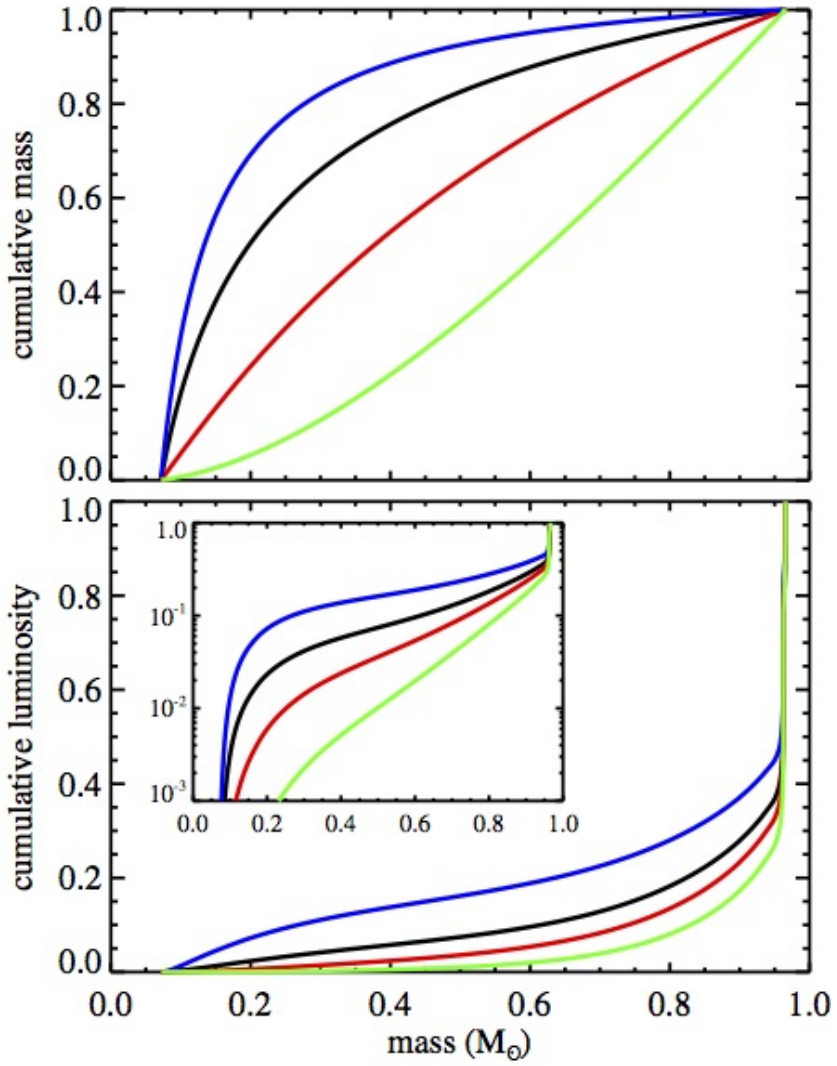
The Stellar Initial Mass Function (IMF)

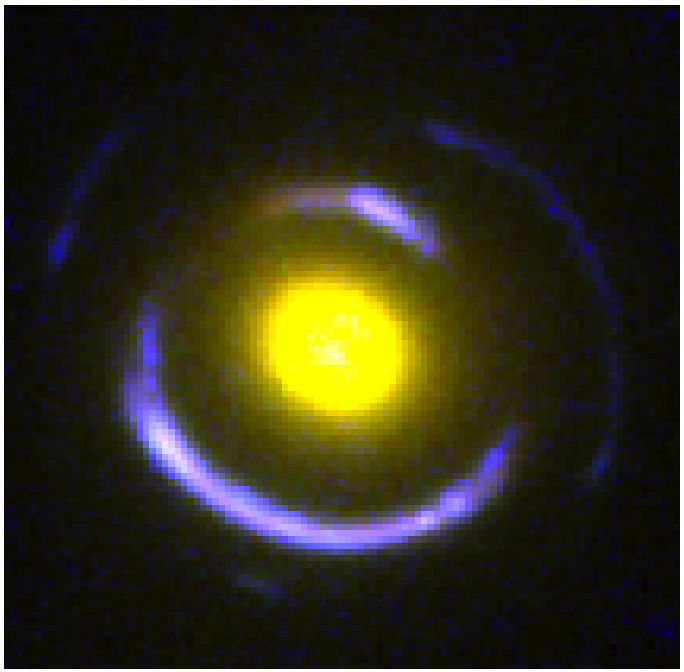


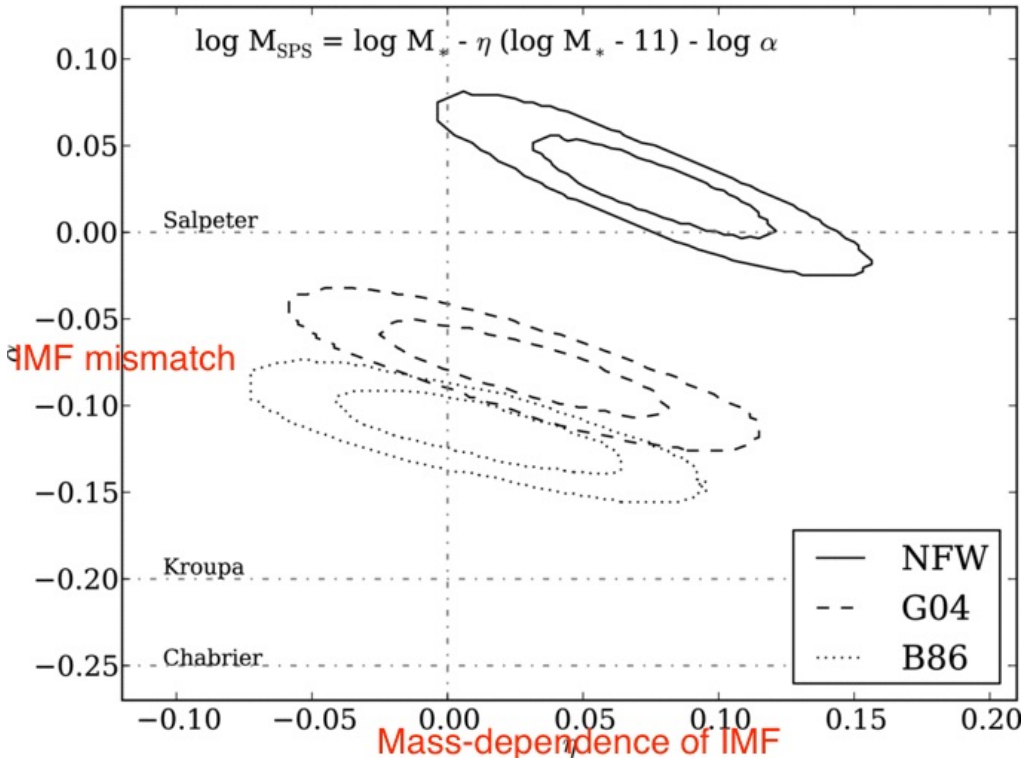


Stellar mass

The stellar IMF - dark matter degeneracy

$$\alpha_{\rm IMF} \equiv \frac{M_*^{\rm (true)}}{M_*^{\rm (SPS)}} \qquad \text{IMF mismatch parameter}$$





Auger et al. 2010

Questions

1. Can we break the degeneracy between dark matter profile and stellar IMF using weak lensing data?

Problem

- The number of strong lenses available for IMF studies is ~ 100
- The weak lensing signal obtained by combining ~ 100 such lenses is very noisy
- Need to work with a much larger sample of twin galaxies

2. How does strong lensing selection affect the distribution in halo mass and stellar initial mass function ($\sim$ stellar mass-to-light ratio), at fixed stellar mass?
3. What is the simplest possible model that can reproduce both strong and weak lensing observations?

The galaxy samples

SLACS strong lenses

- 59 quiescent galaxies from SDSS main spectroscopic sample
- Einstein radius, SPS stellar mass, velocity dispersion for each object
- 33 objects with weak lensing measurements from HST ACS

HSC massive galaxies

- $\sim 2,000$ massive ($\log M_* > 11.0$) quiescent galaxies from SDSS main spectroscopic sample
- SPS stellar mass, velocity dispersion and HSC weak lensing for each object

The Strategy

1. Fit population model to strong lens and HSC sample separately
2. Apply strong lensing selection correction to HSC sample model
3. Compare results from two samples
4. If models do not match, change model
5. Iterate, until the two inferences match

The fit

"Vanilla" model

- NFW dark matter halo, with mass-concentration relation
- de Vaucouleurs stellar profile, constant M_*/L
- Power-law SHMR, with Gaussian scatter in $\log M_h$
- Power-law scaling between stellar mass and stellar IMF, with Gaussian scatter in $\log \alpha_{\rm IMF}$

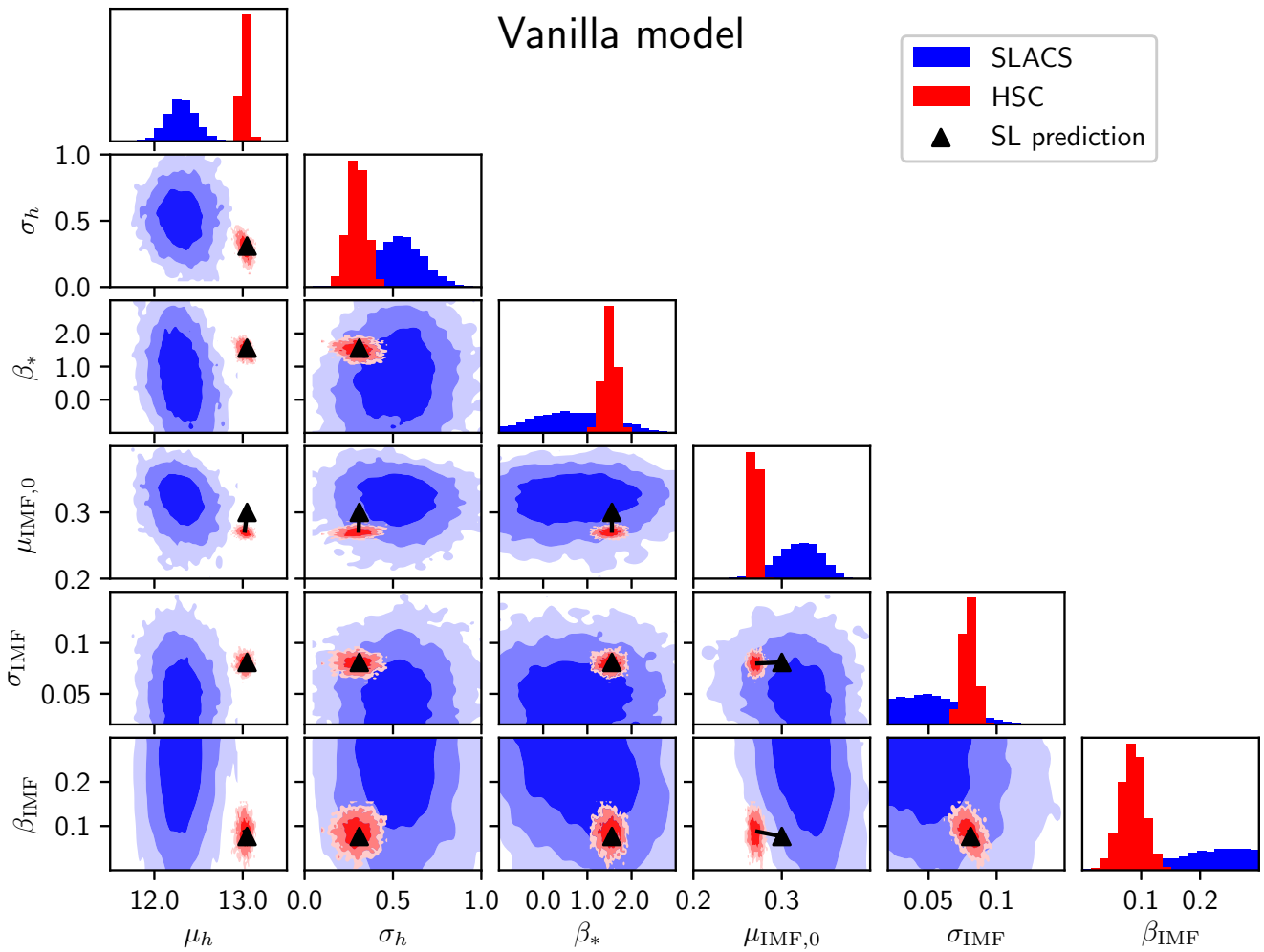
$$\mathrm{P}(\log M_h) \sim \mathcal{N}(\mu_h, \sigma_h); \quad \mu_h = \log M_{h,0} + \beta_h(\log M_* - 11.3)$$

$$\mathrm{P}(\log \alpha_{\rm IMF}) \sim \mathcal{N}(\mu_{\rm IMF}, \sigma_{\rm IMF}); \quad \mu_{\rm IMF} = \log \alpha_{\rm IMF,0} + \beta_{\rm IMF}(\log M_* - 11.3)$$

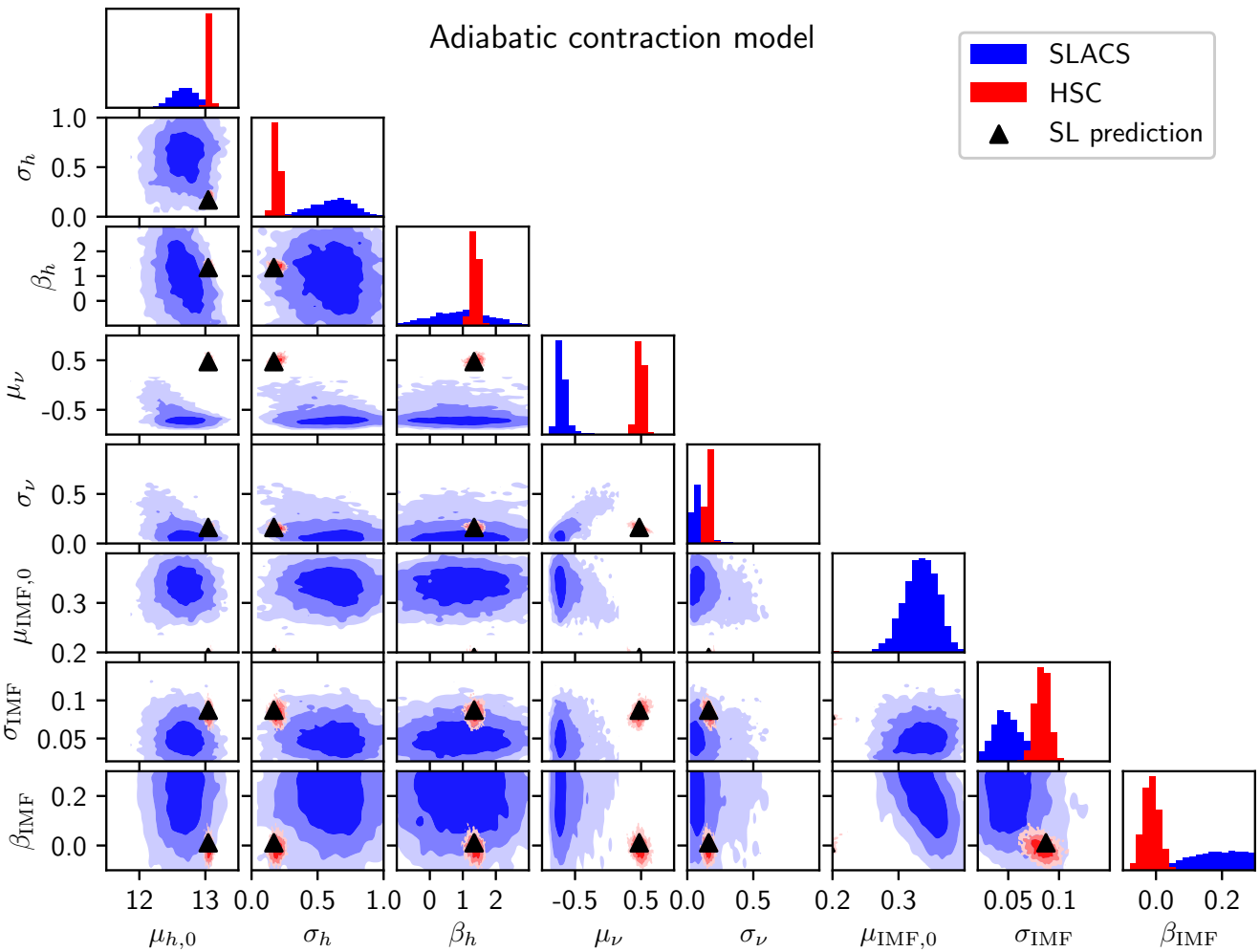
Fitting method

- Bayesian hierarchical inference approach (Sonnenfeld & Leauthaud 2017, arXiv:1710.00007)

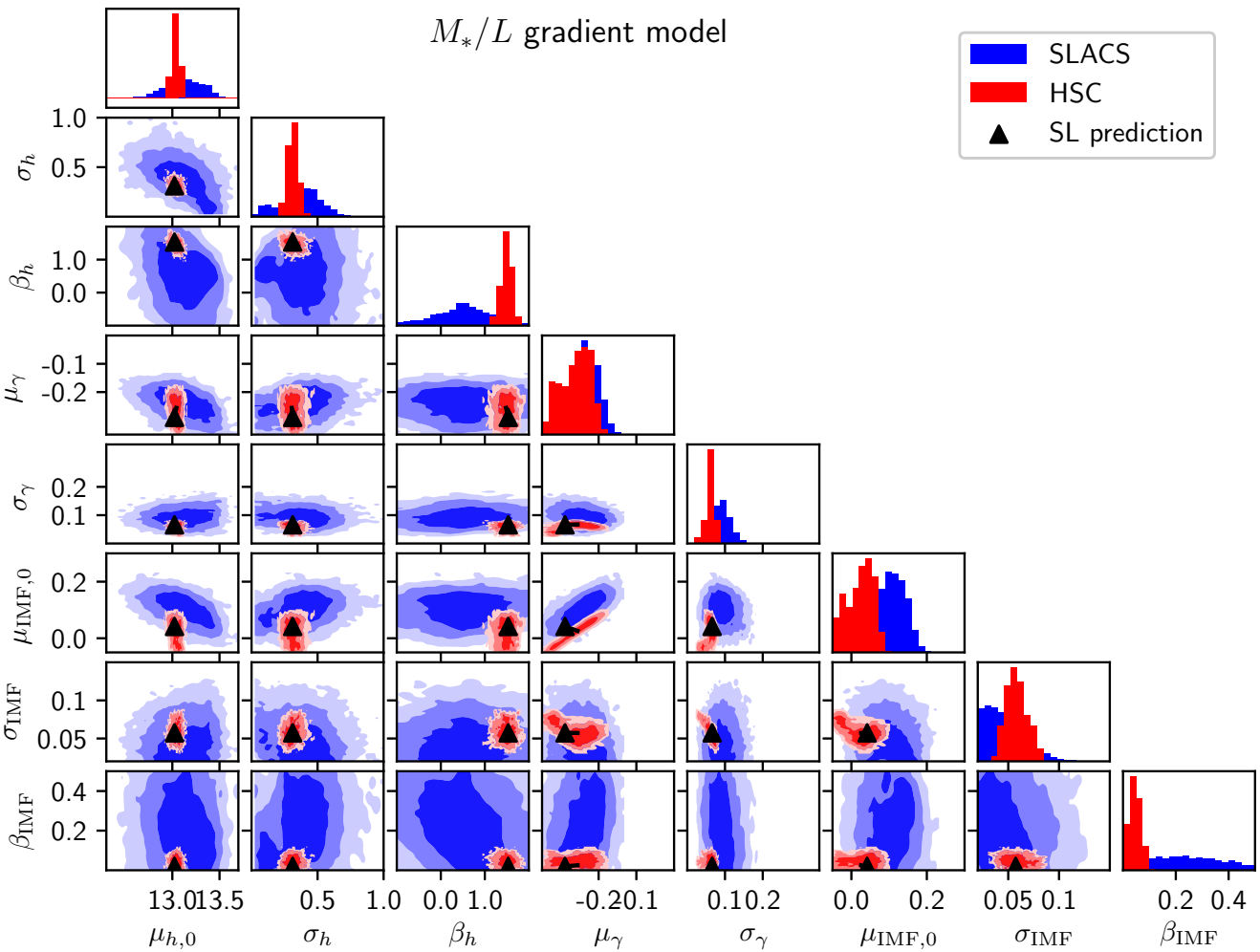
Results (1)


Vanilla model
SLACS
HSC
SL prediction
σ_h
β_*
$\mu_{\rm IMF,0}$
$\sigma_{\rm IMF}$
$\beta_{\rm IMF}$
1.0
0.5
0.0
2.0
1.0
0.0
0.3
0.2
0.1
0.05
0.2
0.1
12.0
13.0
0.0
0.5
1.0
0.0
1.0
2.0
0.2
0.3
0.05
0.1
0.1
0.2
μ_h
σ_h
β_*
$\mu_{\rm IMF,0}$
$\sigma_{\rm IMF}$
$\beta_{\rm IMF}$

Results (2)


Adiabatic contraction model
SLACS
HSC
SL prediction
$\mu_{h,0}$
σ_h
β_h
μ_ν
σ_ν
$\mu_{\rm IMF,0}$
$\sigma_{\rm IMF}$
$\beta_{\rm IMF}$

Results (3)


M_*/L gradient model
SLACS
HSC
SL prediction
$\mu_{h,0}$
σ_h
β_h
μ_γ
σ_γ
$\mu_{\rm IMF,0}$
$\sigma_{\rm IMF}$
$\beta_{\rm IMF}$

Conclusions

- A model in which dark matter halos have an NFW density profile and the stellar mass follows the light distribution does not provide a good description of SLACS lenses: the inferred halo masses are too low.
- Allowing for adiabatic contraction or expansion does not solve the discrepancy between the two samples.
- Allowing for a gradient in stellar mass-to-light ratio, results in a good match between the SLACS sample and non-lens galaxies.
- Such a gradient can be interpreted both in terms of a gradient in stellar population properties at fixed IMF, or in terms of a gradient in IMF itself.
- The main effect of strong lensing selection is to shift the median stellar mass towards higher values.