Strong gravitational lensing and the IMF of early-type galaxies

Talk @ EWASS 2015

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with

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European Research Council

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The pipeline . . .

Knowing the colour of a galaxy means knowing it's stellar mass.

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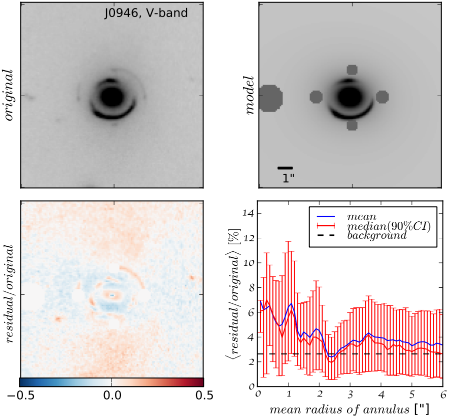
of HST follow-up observation of SLACS lenses
(Galfit v3.0.4, Peng et al. '10)

Quality assessment via residual maps

→ enclosed surface brightness profile
(errors incl. variations along contours & residuals)

Lens mass is reconstructed by free-form method
(PixeLens, see Saha & Williams '01, Coles '08, Leier '09)

→ total mass-to-light ratio Υ_{tot}



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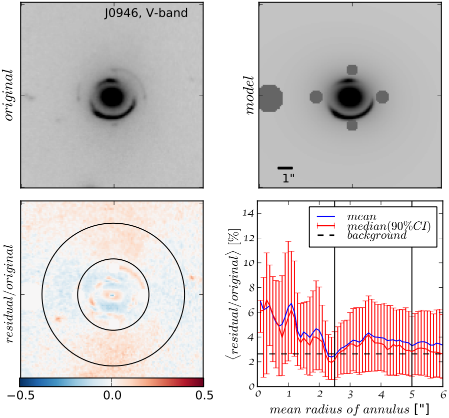

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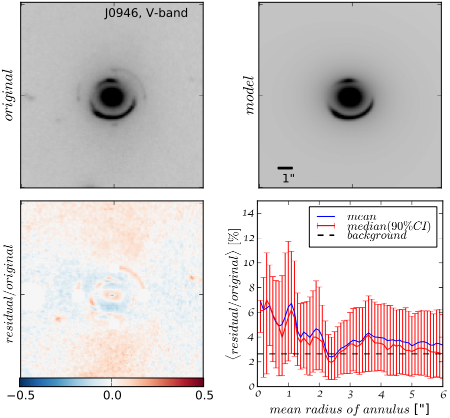

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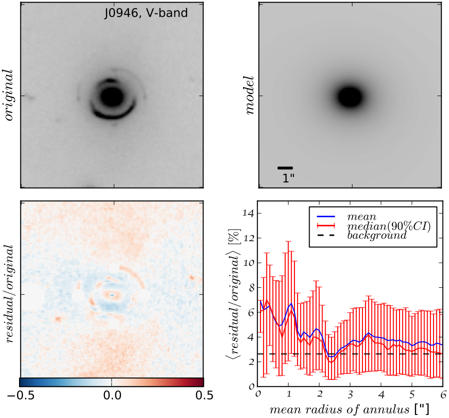

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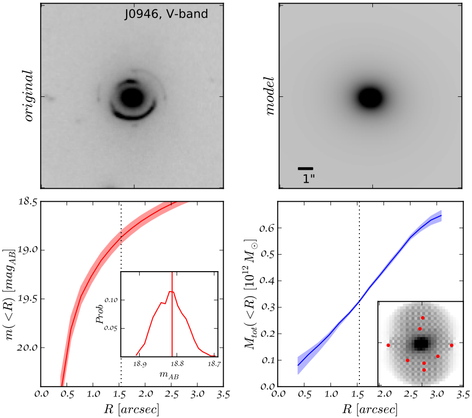

Constraining the stellar IMF by Lensing

The stellar Initial Mass Function (bimodal or two power law)

$$\frac{dN}{d\log M} \propto \begin{cases} 0.4^{-\mu} & M/M_\odot < 0.2 \\ p(m) & 0.2 < M/M_\odot < 0.6 \\ M^{-\mu} & 0.6 < M/M_\odot \end{cases} \quad \wedge \quad \frac{dN}{d\log M} \propto \begin{cases} M^{-\Gamma} & M/M_\odot < 1 \\ M^{-1.35} & 1 < M/M_\odot \end{cases}$$

can be constrained by means of the
total enclosed (lensing) mass-to-light ratio

$$\Upsilon_{tot}(< R) > \Upsilon_*(< R).$$

$M_{tot} \leftarrow$ *pixelated* lens mass-reconstruction
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L $\leftarrow$ HST follow-up on 19 SLACS lenses + photometric modelling (see Ferreras et al. '08, Leier et al. '11).
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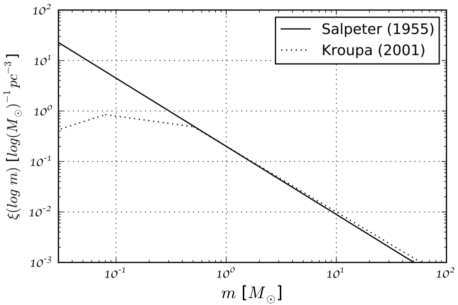
$$F_\lambda = \int S_\lambda(\xi, t, Z) \times e^{-(t-t_0)/\tau} dt.$$



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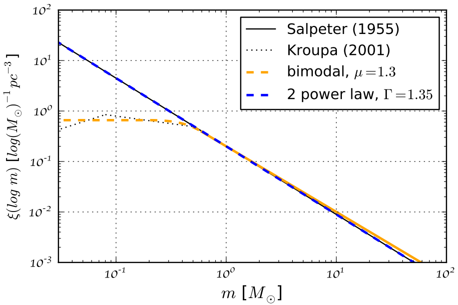

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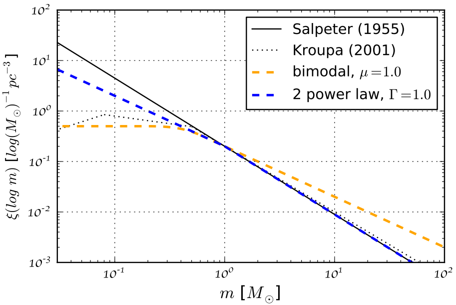

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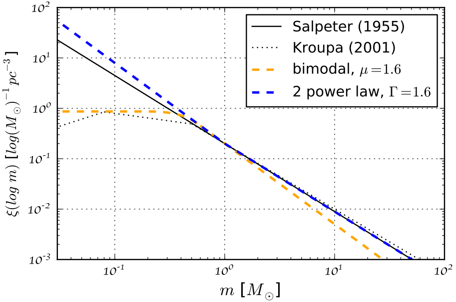
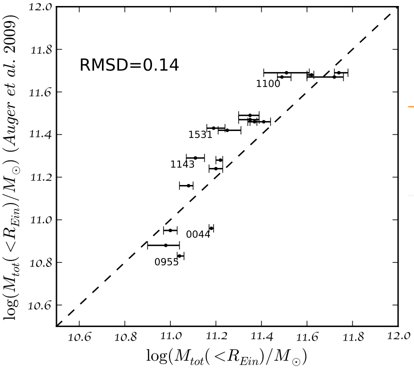


Sanity Checks

Now, how are we doing . . .



→ Total enclosed mass:
Free-form versus analytic modelling
Small non-systematic offset of ~ 0.14 *dex*.
Check-up with analytic modelling tools.

→ Luminosity:
Small non-systematic offset of *RMSD* ~ 0.15.

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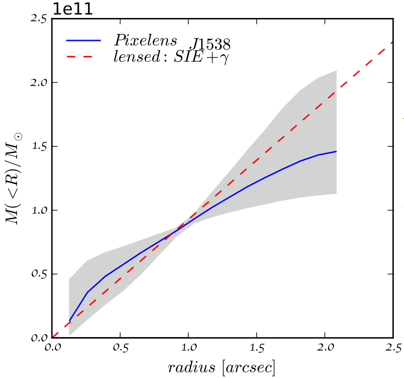

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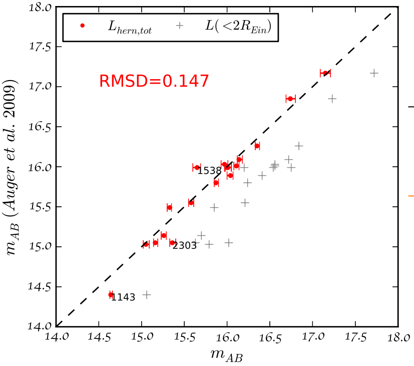

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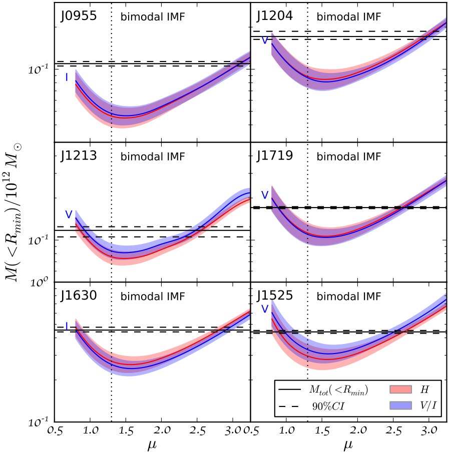
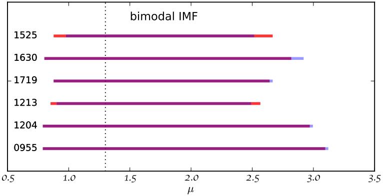
Results: constrained stellar IMF





bimodal $M^*(\mu)$ exhibits u-shape:

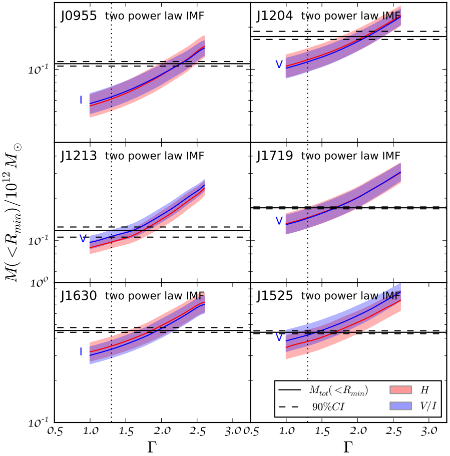
low-μ excess comes from high-mass stars for top-heavy IMF

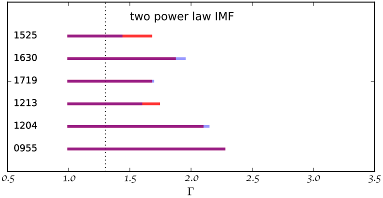
high-μ excess comes from low-mass end of bottom-heavy IMF (stellar remnants)

Pros/Cons

bimodal $M^*(\mu)$ constrains bimodal μ relatively weekly but from both sides

Results: Constrained stellar IMF





2 power law $M^*(\Gamma)$ is increasing:

Note: Γ only regulates the low mass star contribution

low-Γ excess cannot occur: Salpeter slope is enforced for high stellar masses.

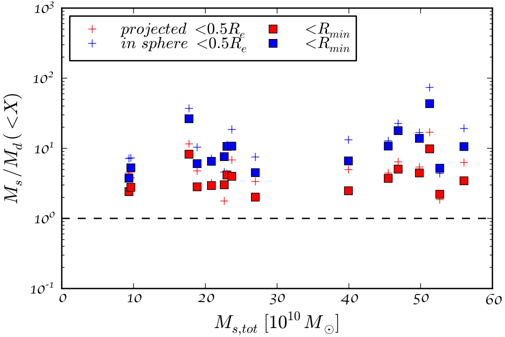
Pros/Cons

2 power law $M^*(\Gamma)$ sets a stronger upper limit to the low mass IMF slope

Results: Baryonic dominance

Question: How much Dark Matter is there?

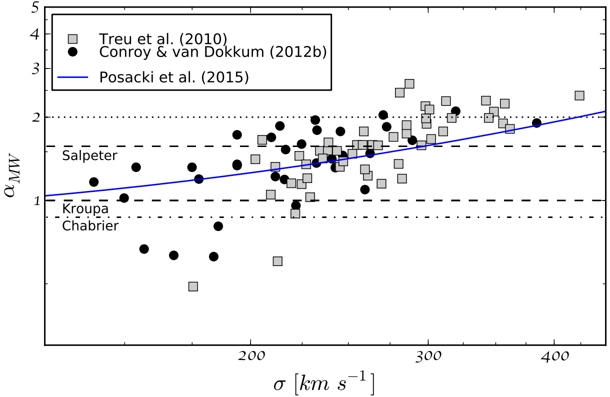
- SLACS lenses: $R_{Ein}/R_e \approx 0.7$ (versus ~ 2.3 for CASTLeS lenses)
  This indicates already that the region of interest is probably dominated by baryonic matter in the form of stars.
- If we knew the DM content exactly, we could constrain the IMF much better! Here's one approach:



Results: Mass excess factor vs velocity dispersion

Definition: $\alpha = (M_*/L)/(M_*/L)_{Kroupa}$

- M_*/L via IMF-sensitive spectral & t/Z-dependent features OR gravity sensitive absorption line features OR $M_{total} - M_{DM}$, inferred from Lensing & DM simulations
- blind to IMF parameterisation (bimodal low & high-μ yield same α)



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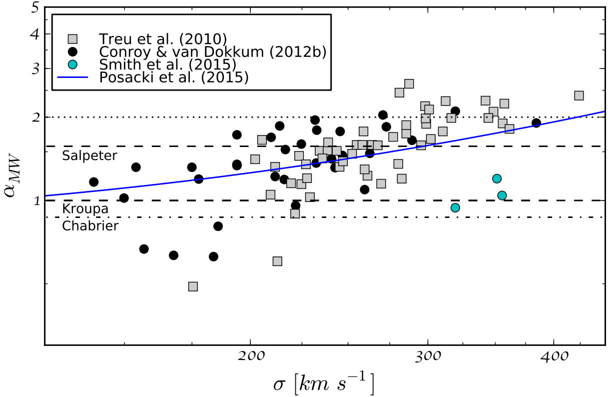

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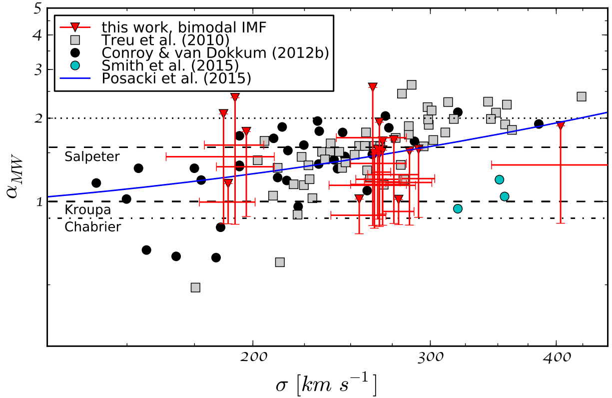

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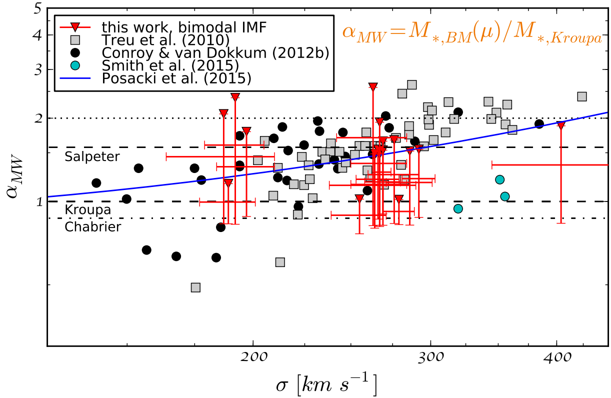

Conclusion

Take away message:

- We constrain the IMF using: Free-form lens models, dedicated SED catalogs, gravity sensitive absorption line features
- 2 Power Law parameterisation is *stronger* constrained by lensing: $\langle \Gamma \rangle \lesssim 1.6$
- Bimodal shape sets *weaker* constraints on the IMF: $1 \lesssim \langle \mu \rangle \lesssim 2.5$
- IMF shape is important and α_{MW} does not necessarily allow to differentiate
- There is in average 3-4 times more stellar mass than dark matter $< R_{Ein}$, given stellar-to-halo-mass relation is applicable.
- Constraints can be set on both the shape and the normalisation: High-σ ETGs are not necessarily heavier than low-σ ETGs!

Thank you!