Simulation-guided Galaxy Evolution Inference: A Case Study with Strong Lensing Galaxies

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Agenda

- Galaxy evolution studies
- Simulation-guided galaxy evolution inference
- Application on a strong lensing galaxy

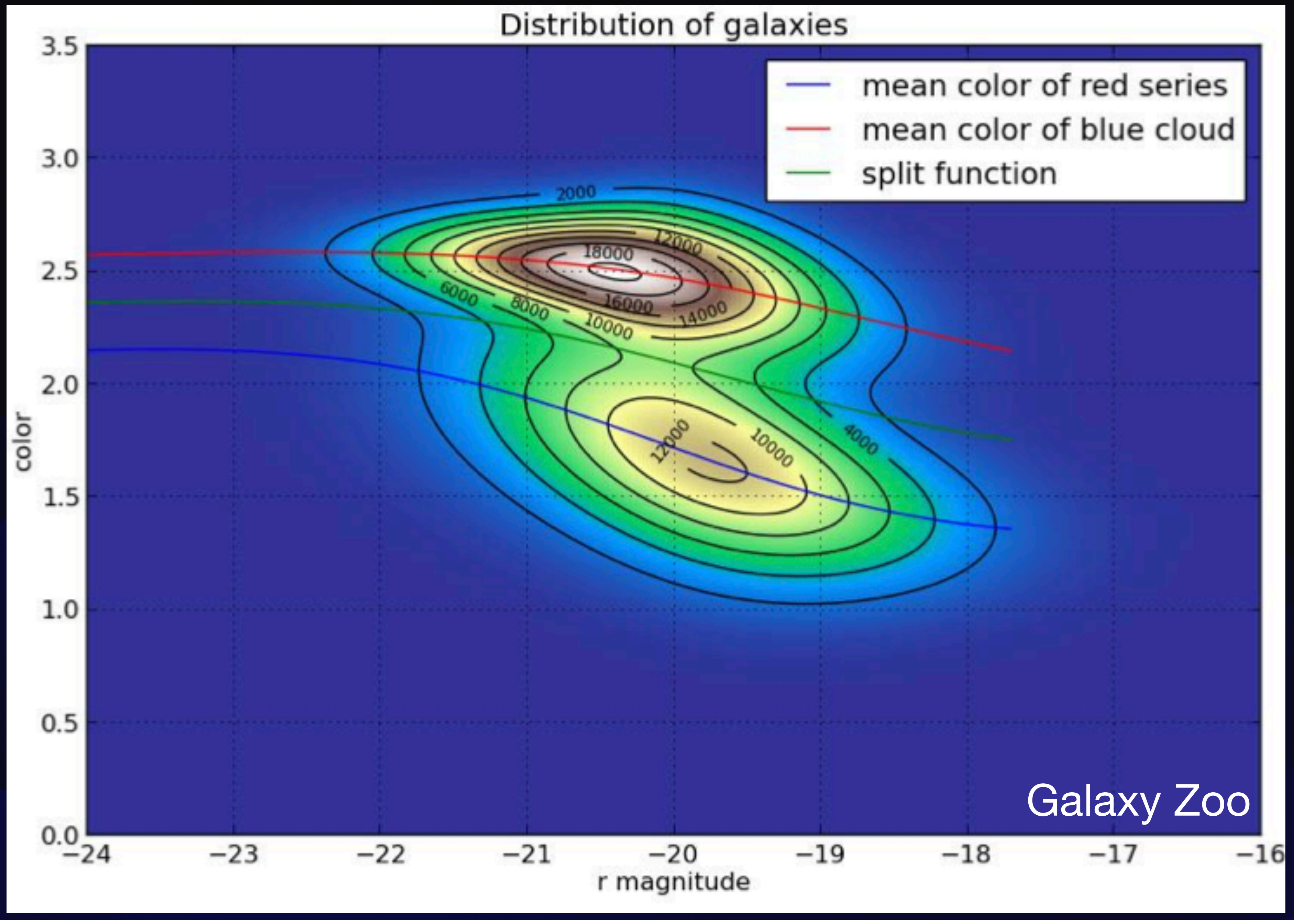
DALL-E

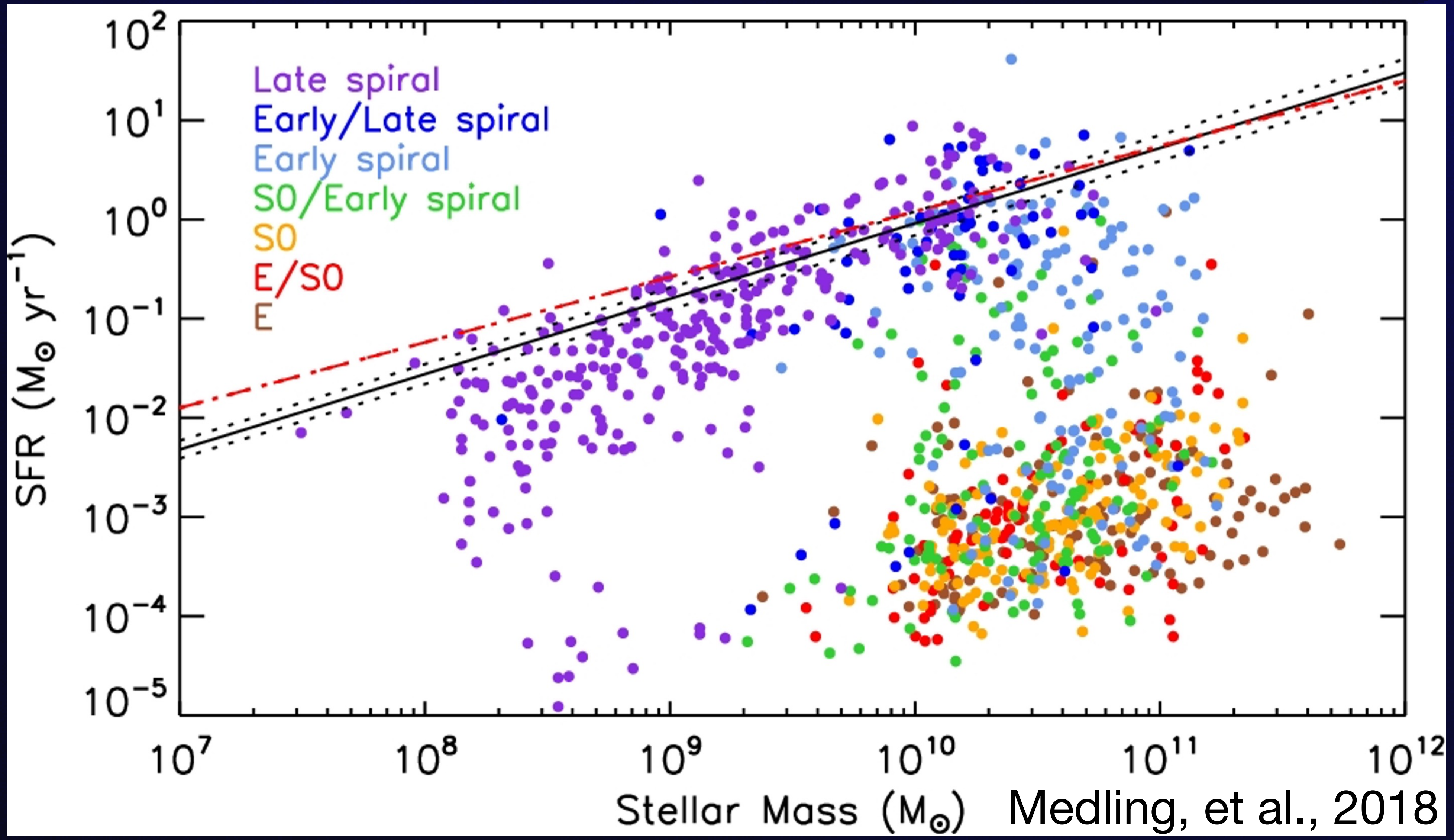
Galaxy Evolution Studies

- Insights in many aspects in astrophysics (e.g. structure formation and growth, nature of Dark and Baryonic Matter…)
- Infeasible to track evolutionary process of individual galaxies
- Studies mostly based on ensembles of galaxies assumed to be from the same population

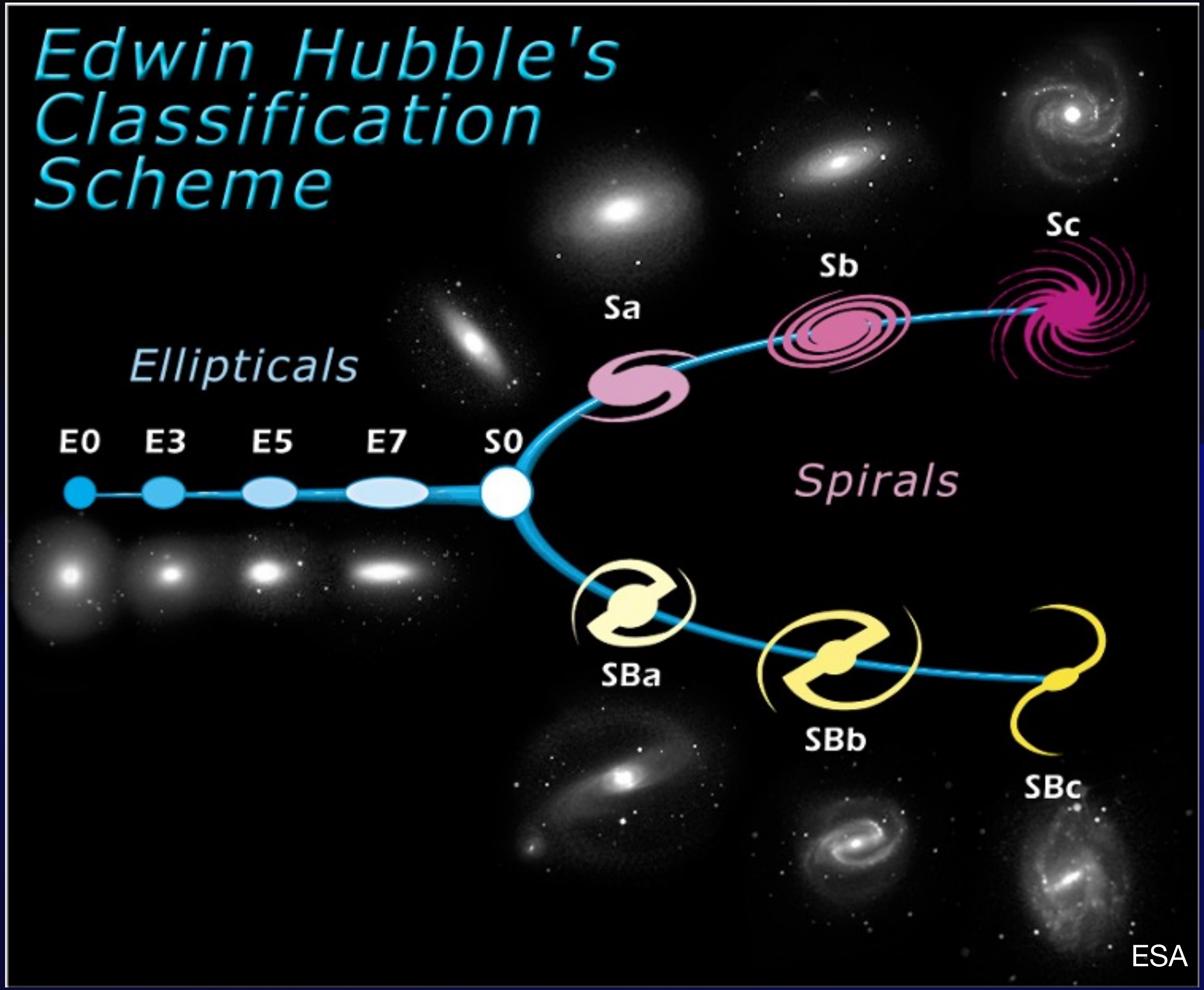

DALL-E

Classification by mass, magnitude, star formation rate





Classification by Morthology

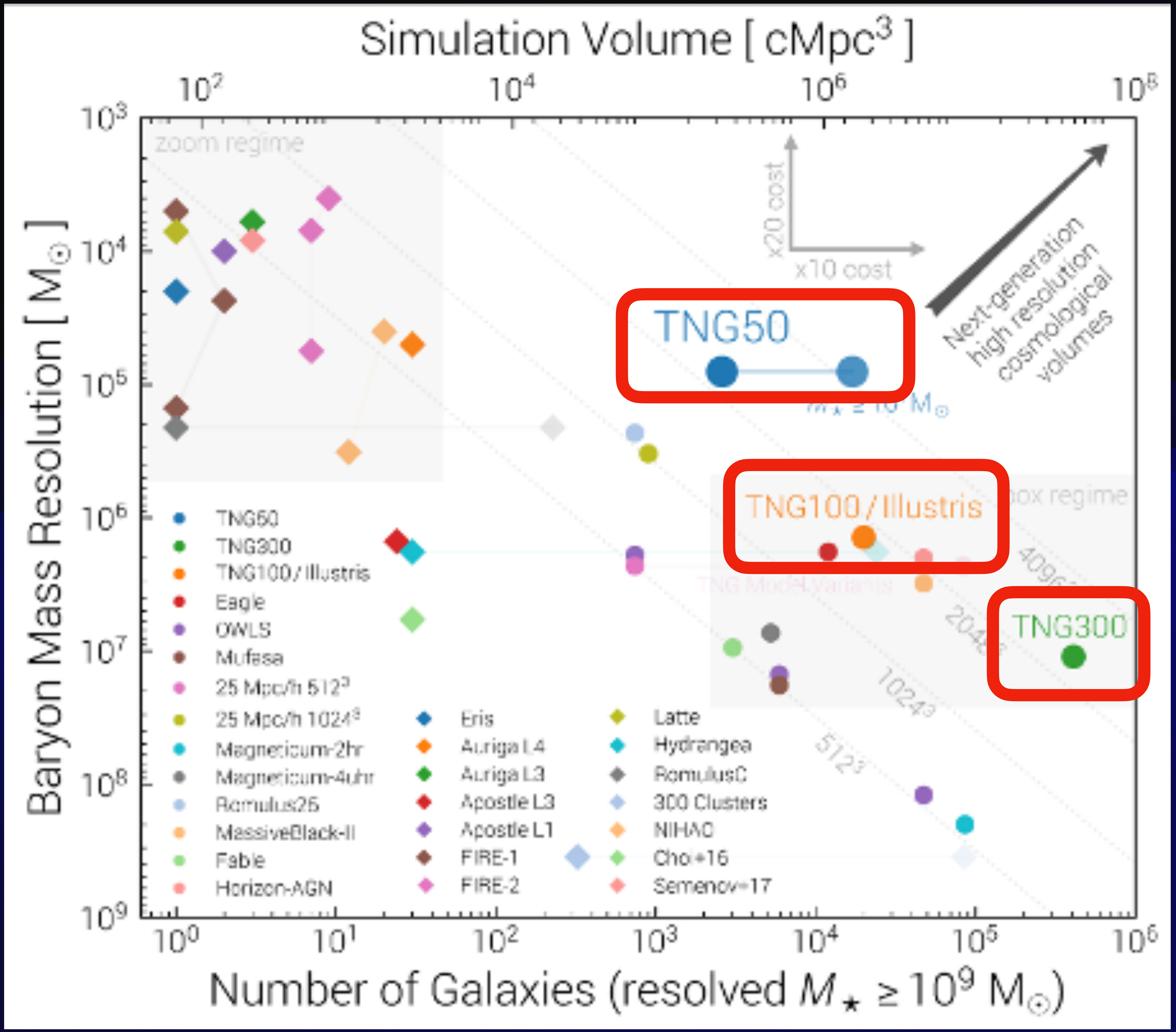


Simulation-guided Galaxy Evolution Inference

- Trace galaxy evolution of individual galaxies:
  - Match one observed high redshift galaxies with simulations
  - Follow matched simulated galaxies to redshift 0
  - Match simulated lower redshift galaxies with observations
  - Compare parameters of interest of simulated and observed galaxies

IllustrisTNG

- Highest mass resolution and simulated volume in IllustrisTNG simulations
- Structure and galaxy properties of IllustrisTNG and observations agree well



TNG Collaboration

Matching between observed and simulated galaxies

- Find size-to-mass relations at different reshifts for early types

	Simulated galaxies	Observed Galaxies
Stellar mass [$\log_{10}(M_\odot)$]	10.9-12.5	10.9-12.5
Star formation rate [$M_\odot$/yr]	<5	<5
	Strict removal of disk dominated galaxies	Ellipticity >0.3
		Error on size <10%

Comparison of Observation and Simulation

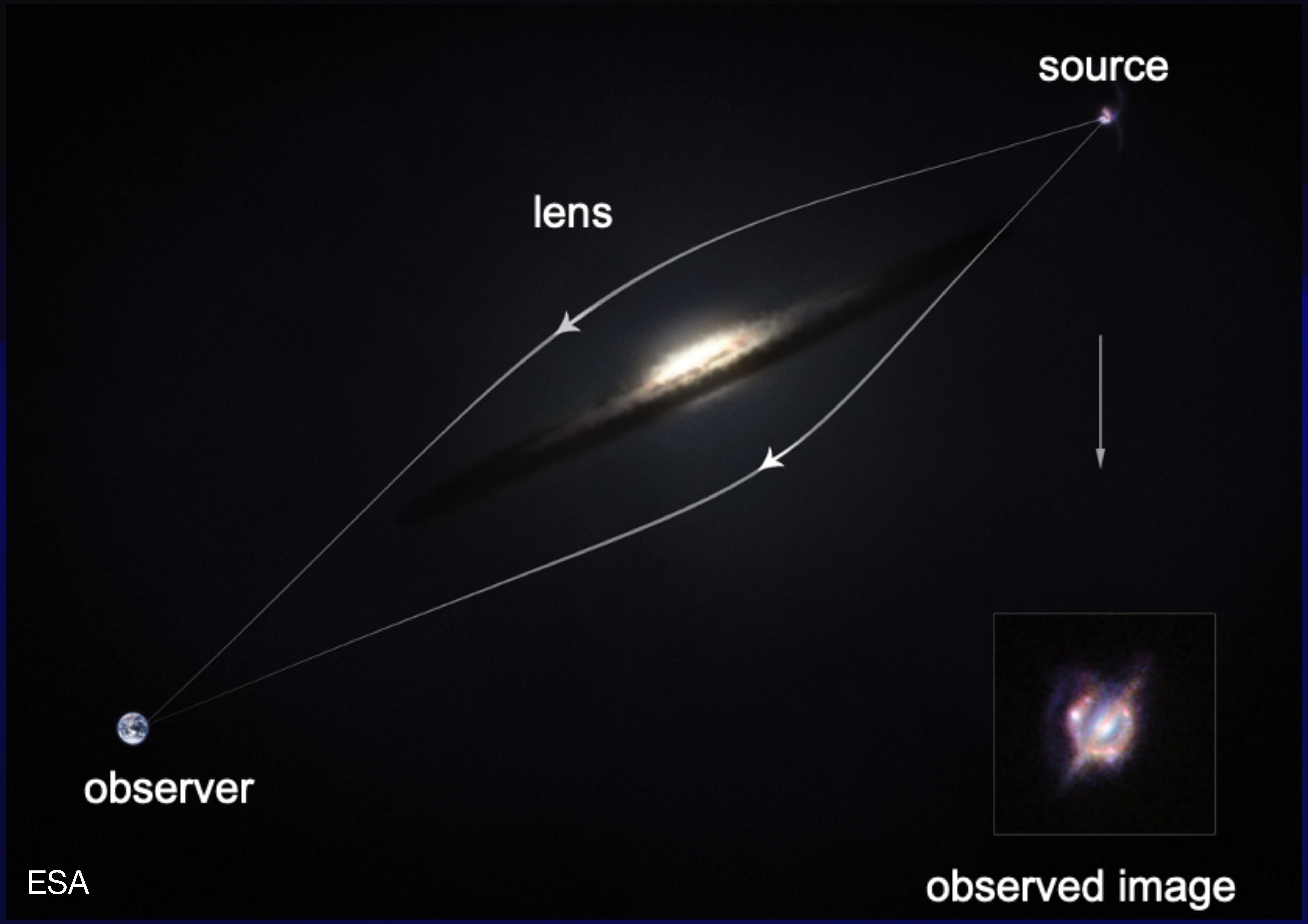
increasing redshift

Matching between observed and simulated galaxies

- Find size-to-mass relations at different reshifts for early types
- Use size-to-mass relations to match observed to simulated galaxies

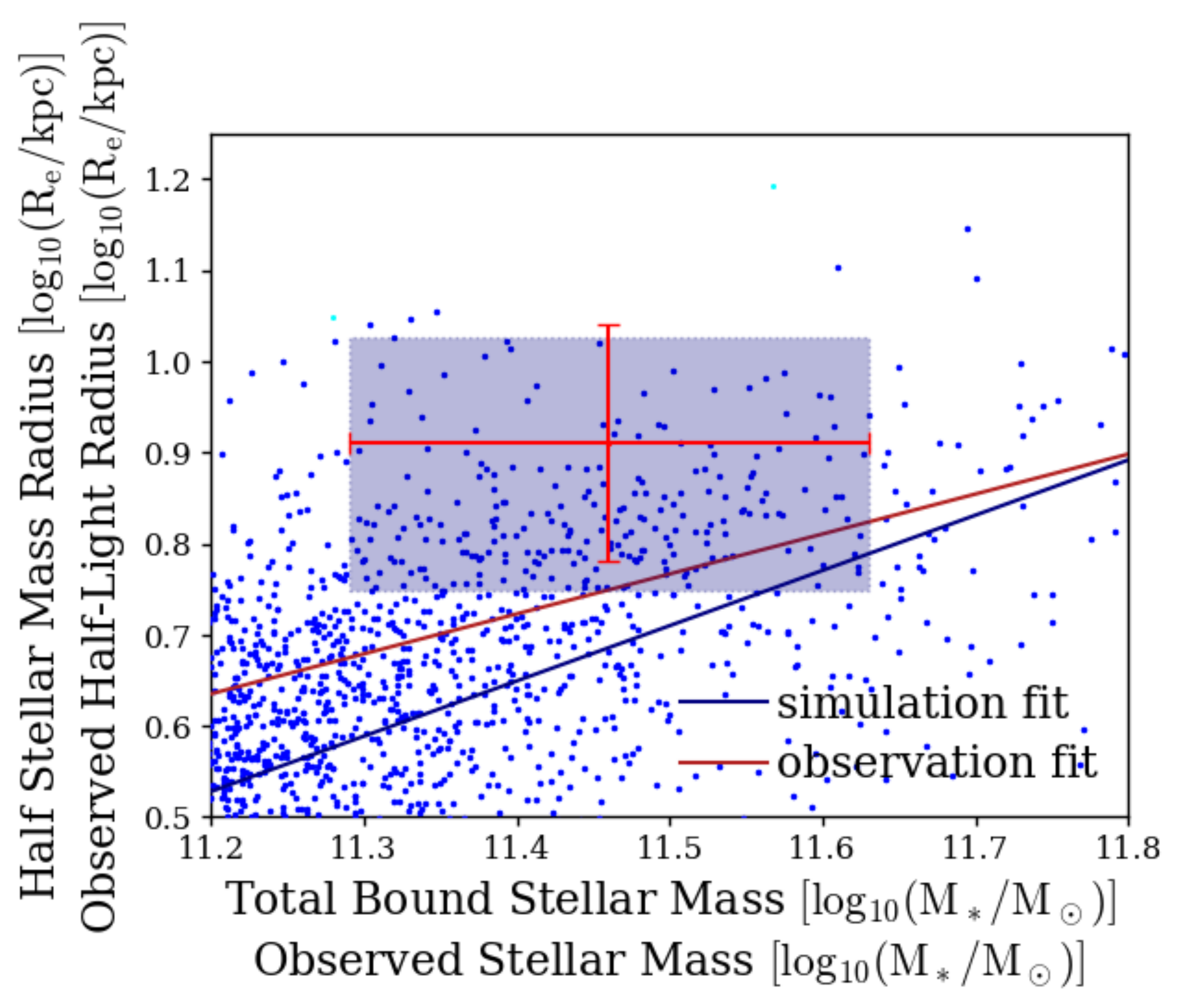
Application on a Strong Lensing Galaxy

- Proof of concept:
  examine evolution of the total mass distribution of a strong lensing galaxy at redshift z=0.884
- Lensing is robust against stellar populations models and assumtions on galaxy properties



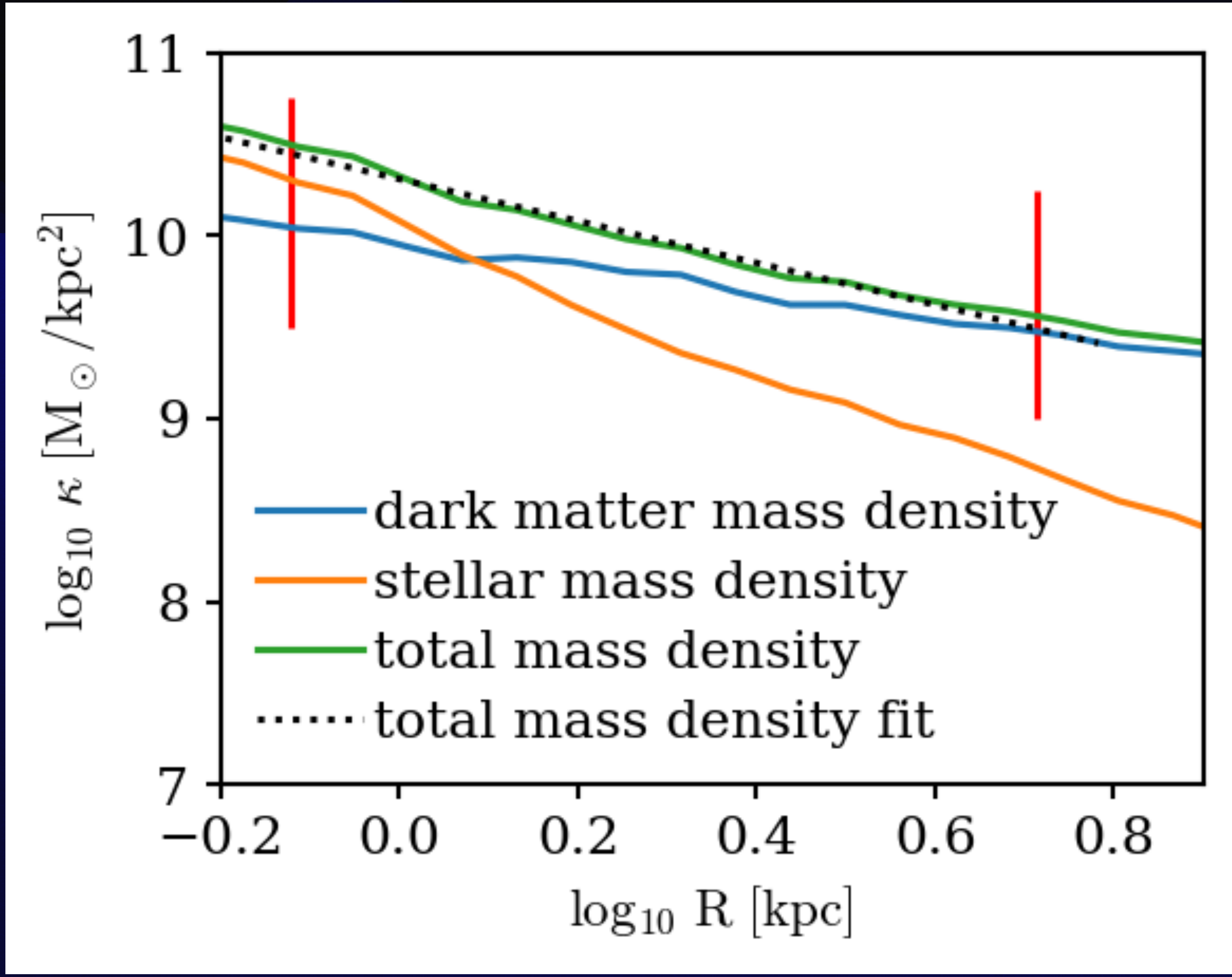
Application on a Strong Lensing Galaxy

- Start with SL2S021801-080247 at redshift 0.884 (red error bar)
- Select corresponding simulated galaxies (within the blue box)
- Follow forward merger tree in simulation to redshift 0 and select analogies to simulated galaxies in observation
- Compare the mass slope of simulated and observed galaxies



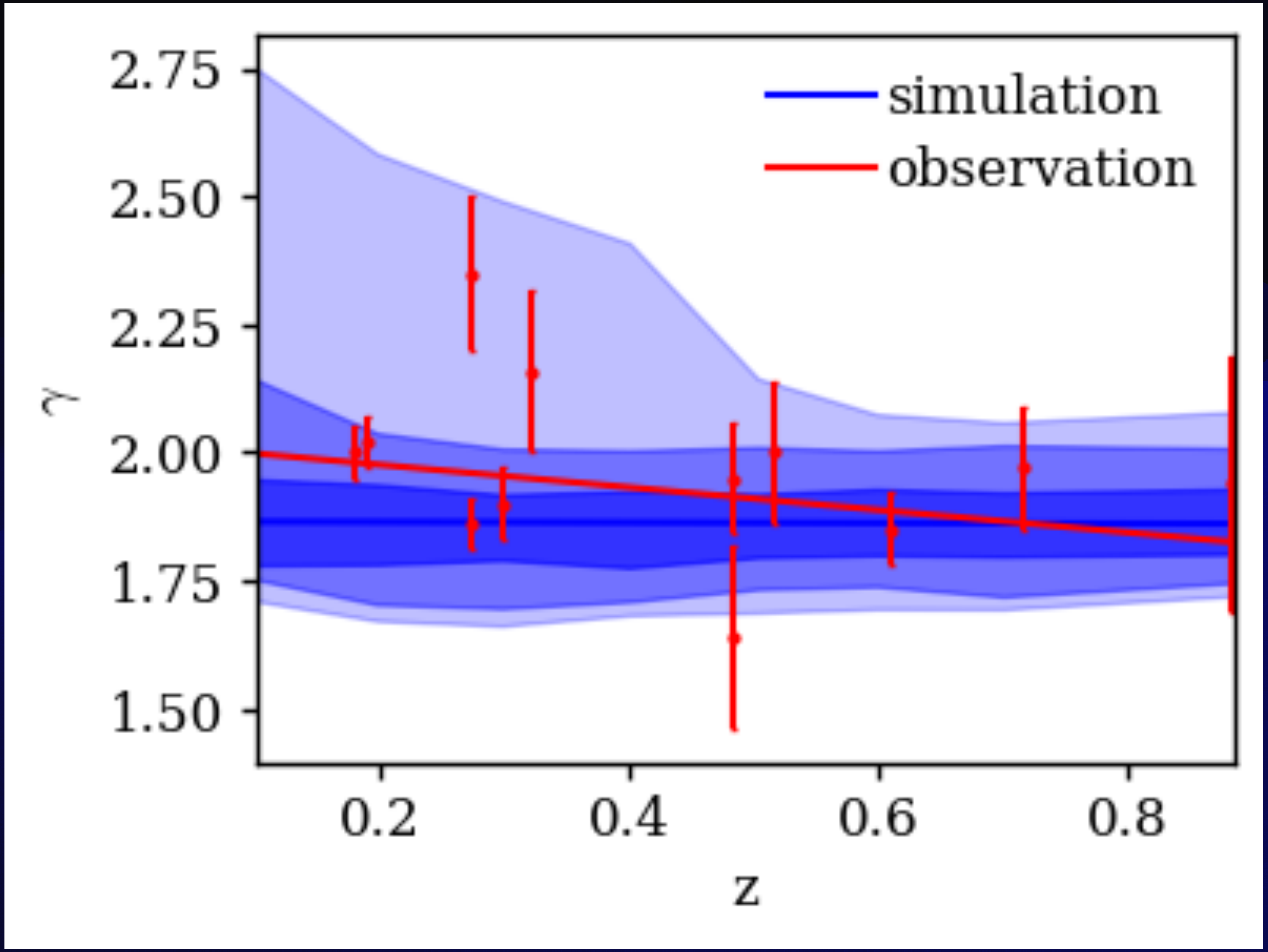
Mass Slope Calculation

- For observation: velocity dispersion measurements and spherical Jeans modelling (e.g. Schwab, et al. 2010; Chen, et al. 2019)
- For simulation:
  fit projected total density profile
  - range: twice softening radius to comparable radius of observed lens
  - profile: power-law



Results

- Best linear fit for observation shows increasing trend from redshift 0.9 to 0.2 with $\delta\gamma/\delta z = -0.22 \pm 0.18$
- Simulated galaxies show close-to-constant trend $\delta\gamma/\delta z = -0.01 \pm 0.01$



Results

- Appear to be in agreement with mass-selected comparisons, e.g. $\delta\gamma/\delta z = -0.60 \pm 0.15$ Bolton, et al. 2012 (80 ETGs)
- For simulated galaxies in IllustrisTNG previous studies also found close-to-constant redshift evolution (e.g. Wang, et al. 2019)
- Results suggest increasing mass-density slopes with time, while simulations suggest close to no evolution
- Our results heavily dominated by Poisson fluctuation
- Results depend on chosen simulation

Conclusion

- Clearly limited by small sample size in observation and simulation
- LSST/Euclid increase lens sample from ~400 confirmed to 1e5 lenses - comparison strategy will play more important role
- Decrease uncertainties on mass slope of observed galaxies by higher quality spectroscopic data (2d stellar kinematics)
- Increase sample on simulation side with MilleniumTNG (public in 2024)

Thank you for your attention