Stony Brook University

Opportunities and challenges in analyzing 10’000 gravitational lenses to shed light on dark matter and dark energy

Simon Birrer

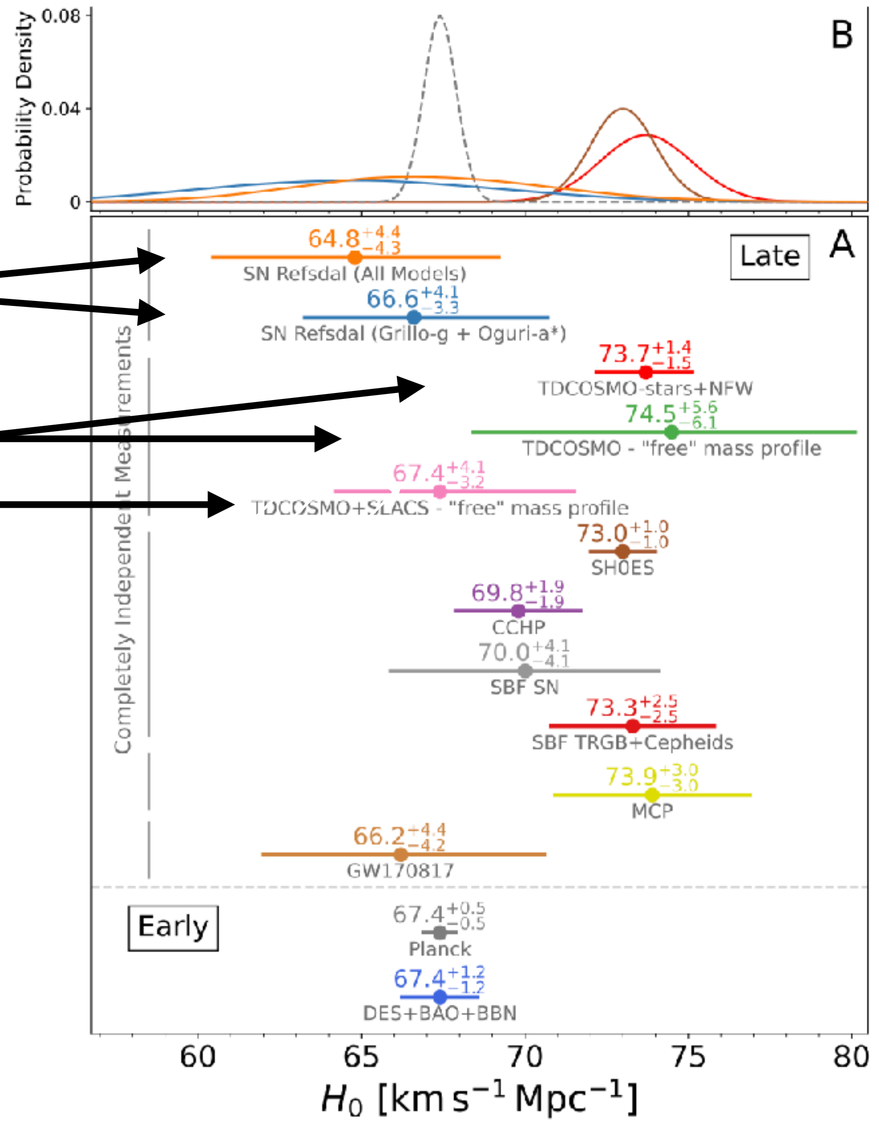
Swiss Cosmology Days, June 5th 2025, ETH Zurich

Hubble constant constraints with strong lenses

1 lensed SN

7 lensed quasars

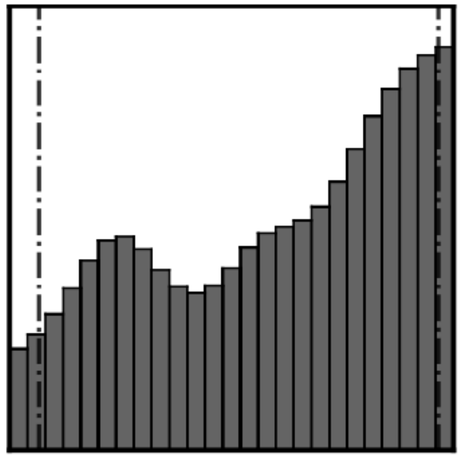
+33 galaxy-galaxy lenses



See Martin's talk of latest TDCOSMO 2025 analysis (**8** lensed quasars + **15** galaxy-galaxy lenses)

Figure: Kelly (incl SB) et al. 2023

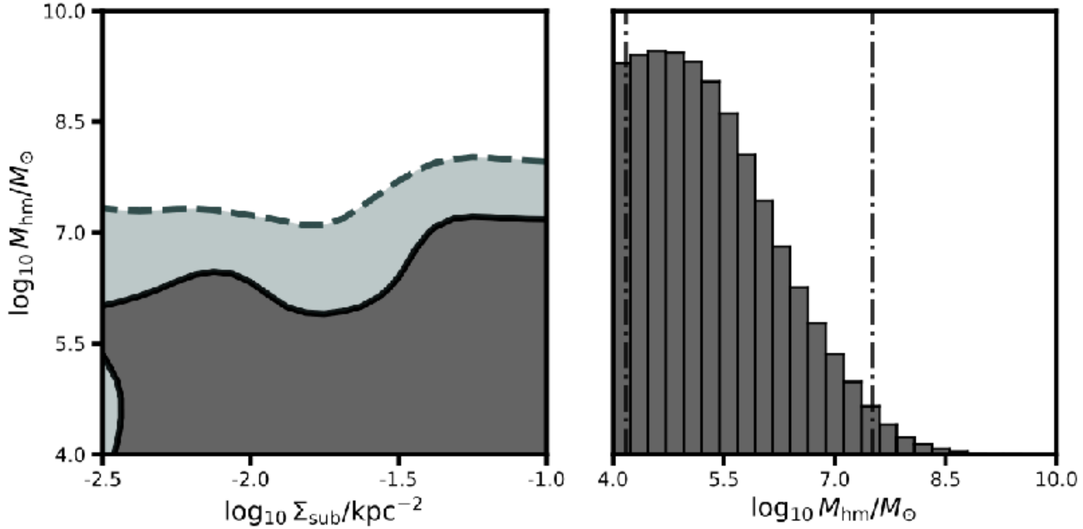
Dark Matter constraints with strong lenses

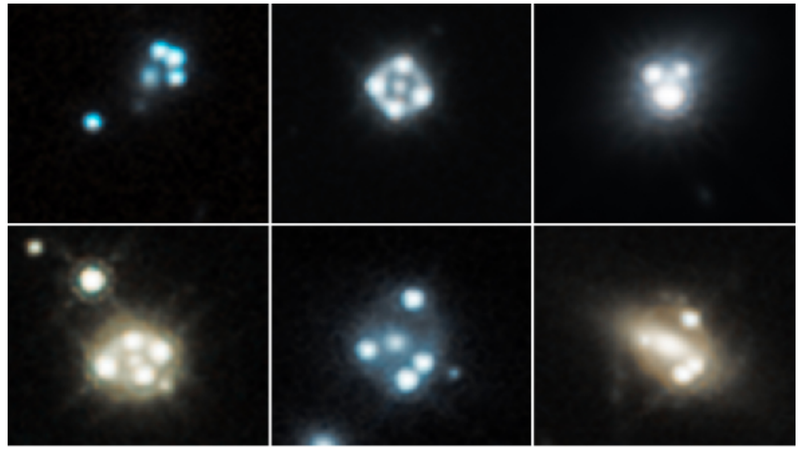


Flux ratio statistics with

9 quadruply lensed quasars

Flux ratios are consistent with CDM predictions!





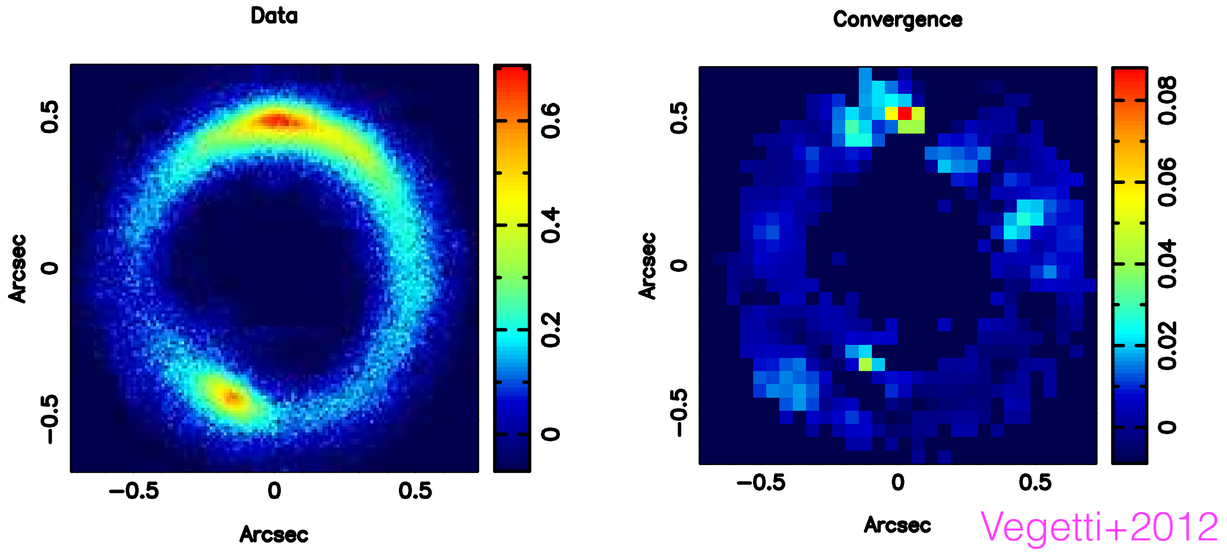
Credit: STSCI, GO-15177, 13732 PI Nierenberg

Keeley (incl SB)+24 Gilman, SB, Nierenberg+2020, see also Hsueh+2020

Dark Matter constraints with strong lenses

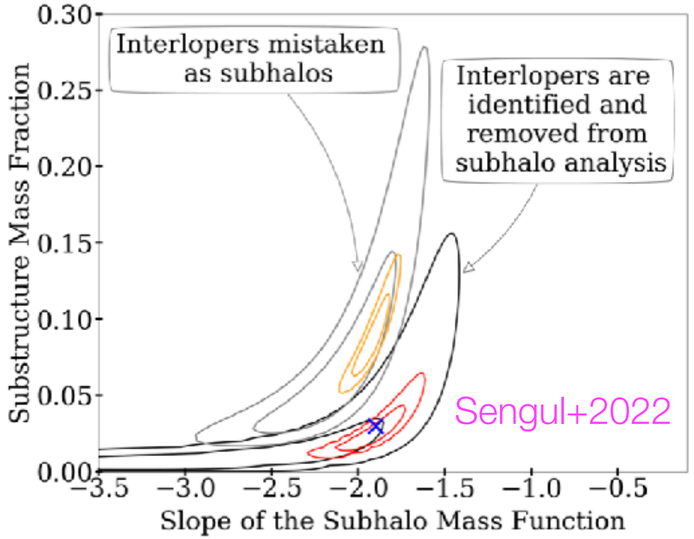
Resolved gravitational imaging

3 subhalo detections

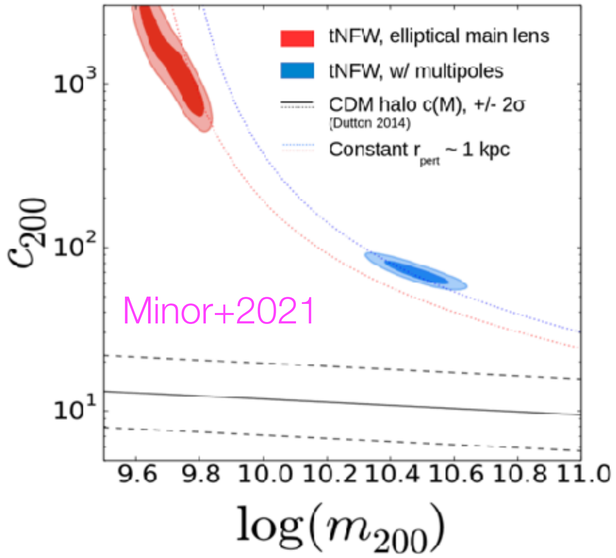


Vegetti+2012

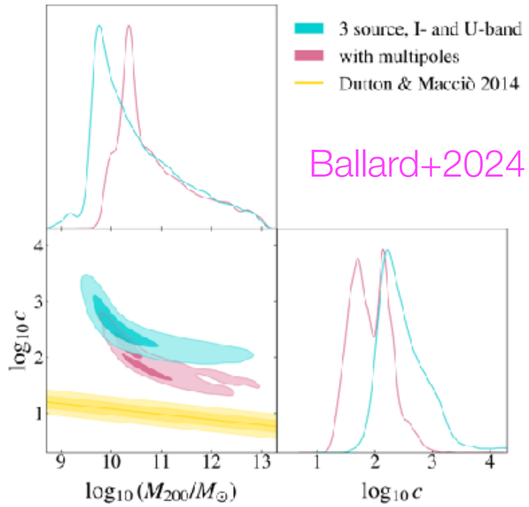
Subhalos seem to have unusually high concentrations!



Sengul+2022



Minor+2021



Ballard+2024

This decade!

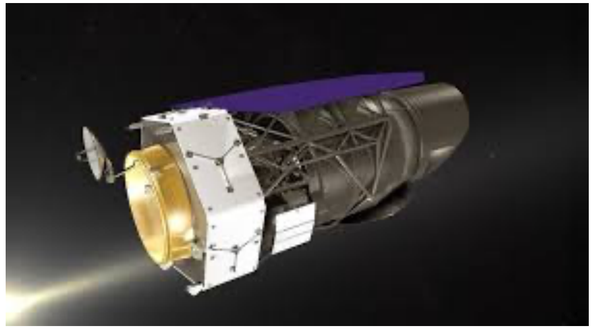
100’000+ strong lenses
200+ quasar lenses
50+ lensed SNe / year

E-ELT, TMT, GMT
(high resolution imaging)

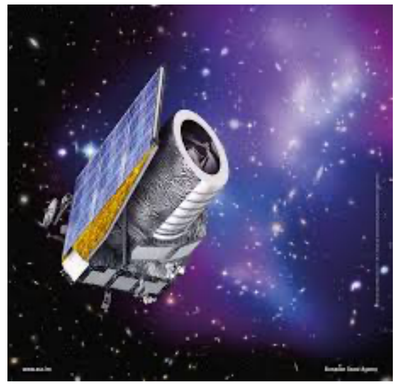
Vera Rubin Observatory
(discovery and time-domain)

Square Kilometer Array, (ng)VLA
(high resolution interferometry)

Nancy Grace Roman telescope
(discovery and imaging)



Euclid
(Discovery and imaging)

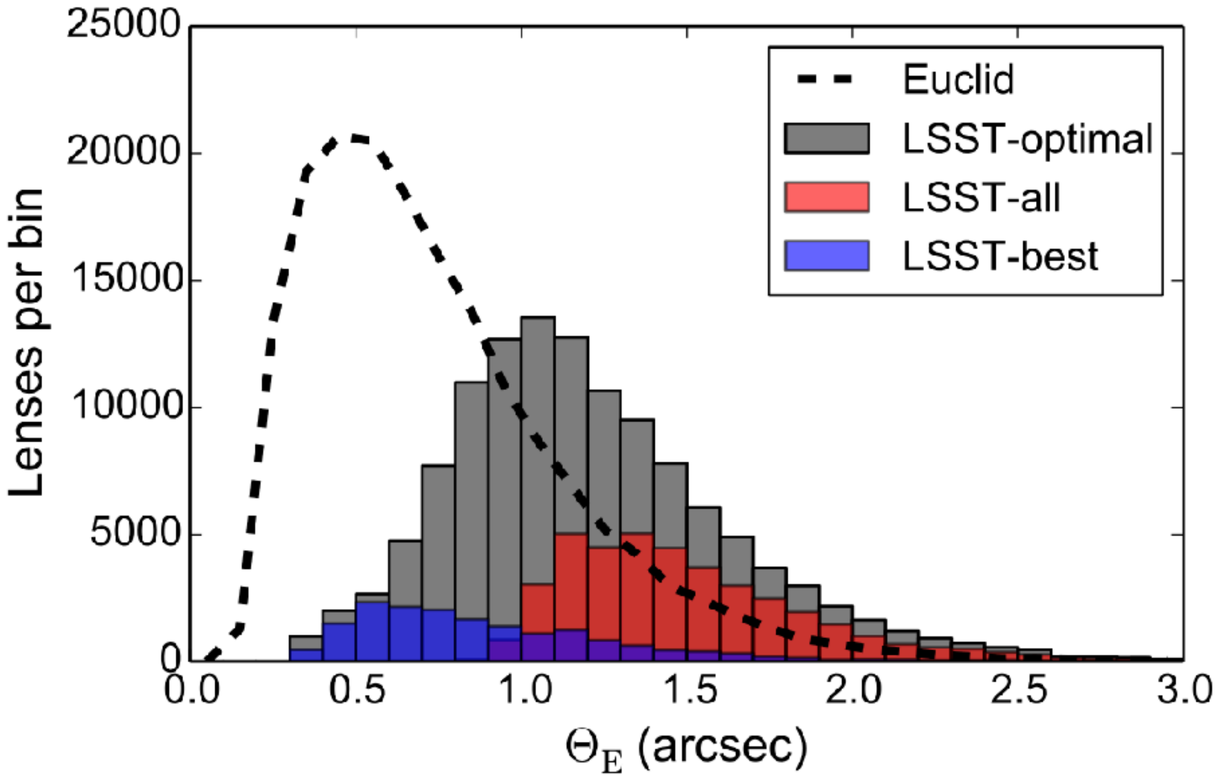


LIGO/VIRGO/KAGRA
(gravitational waves)

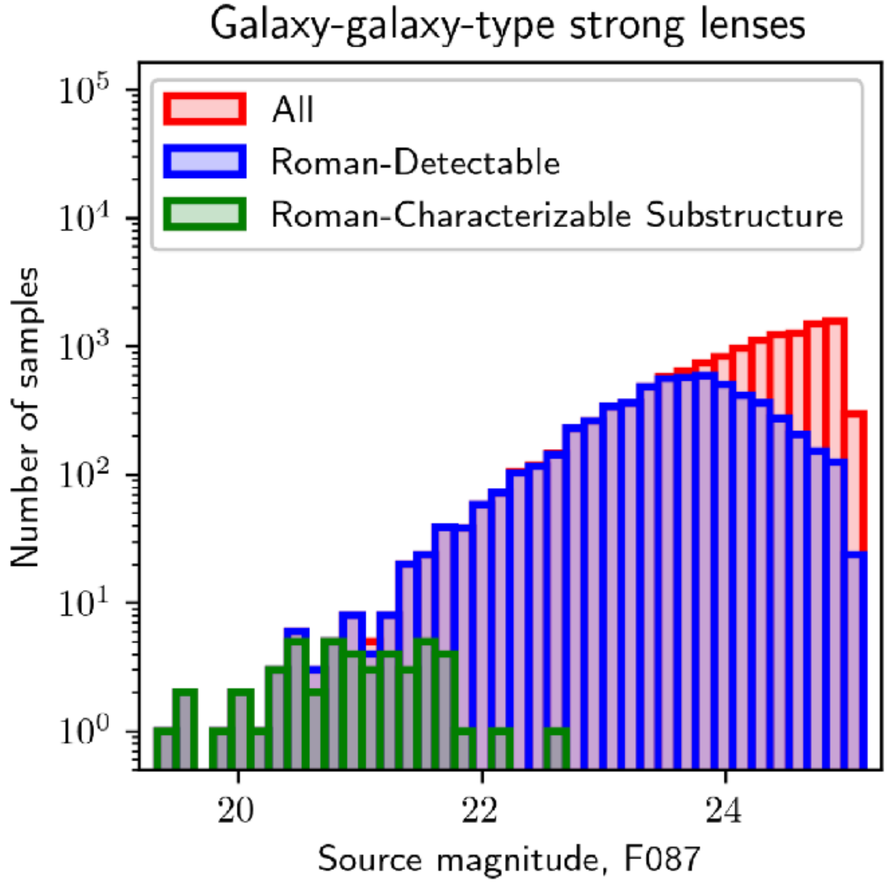
James Webb Space Telescope
(high resolution spectroscopy)

How many lenses are there?

(Soon) the numbers are not the issue anymore…



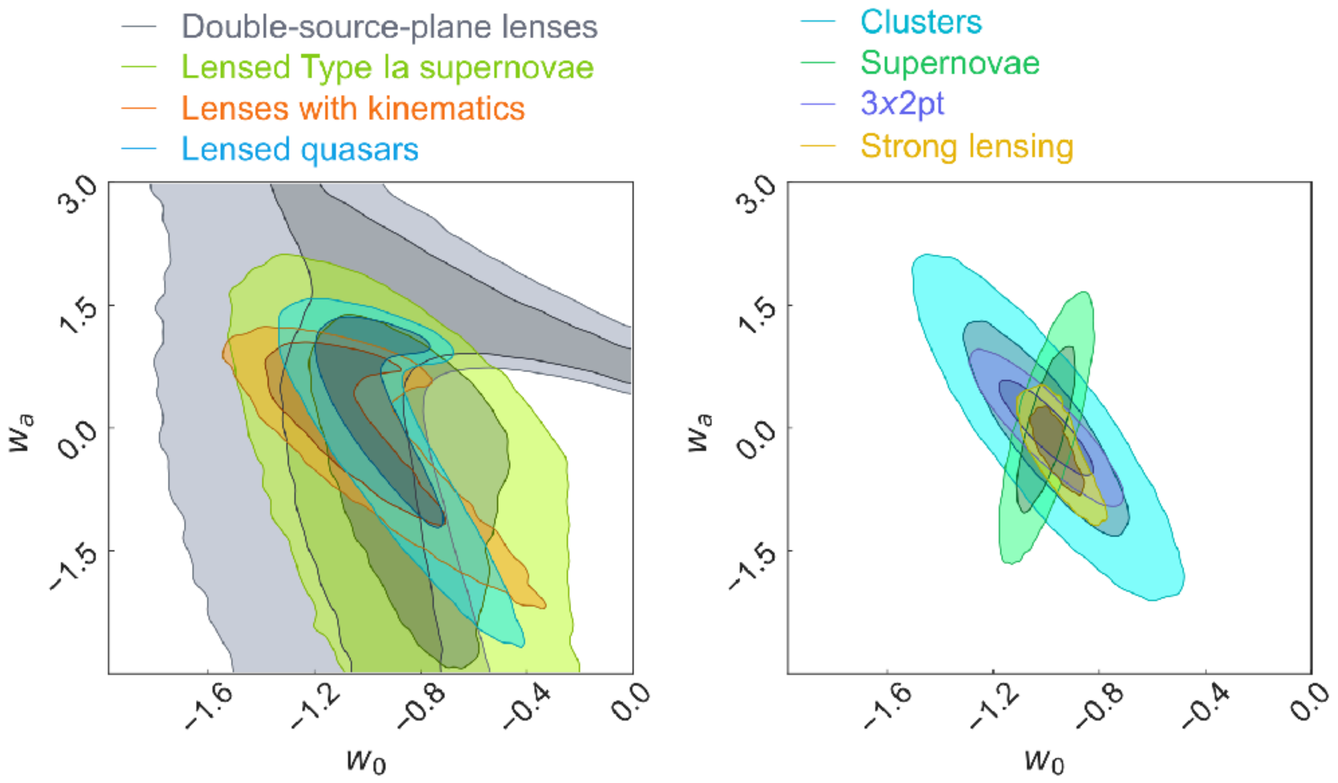
Collett 2015



Daylan & Birrer 2023

The future: Dark Energy constraints

LSST forecast

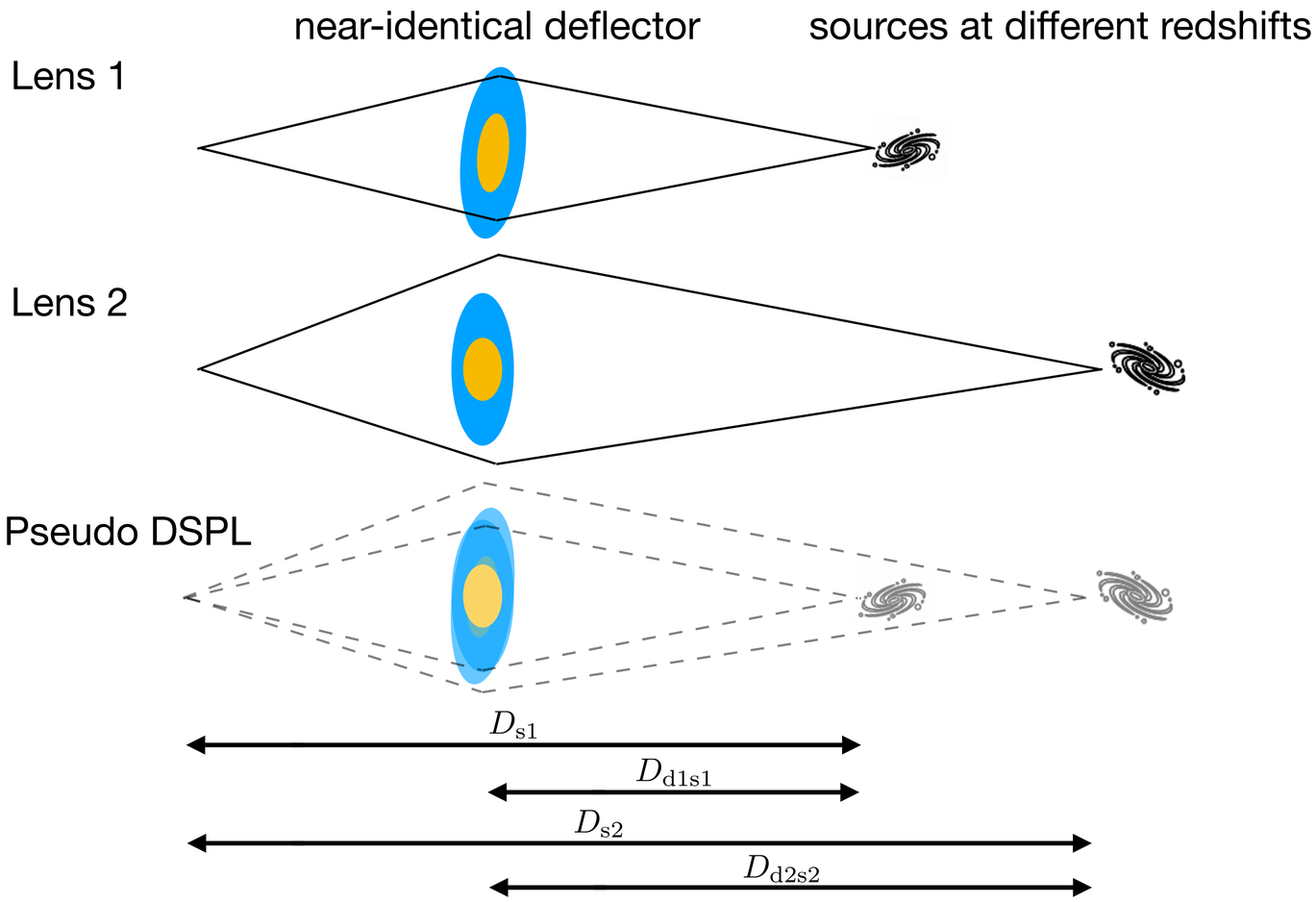


Lensing can constrain distance RATIOS -> sensitive to dark energy!

It is becoming a numbers game.

Shajib+ 2024, based on Collett+2012, Collett 2015, Li+2024, Arendse+2024, Birrer & Treu 2021

Pseudo double source plane tomography



Ratios of Einstein radii -> relative distance measurement.

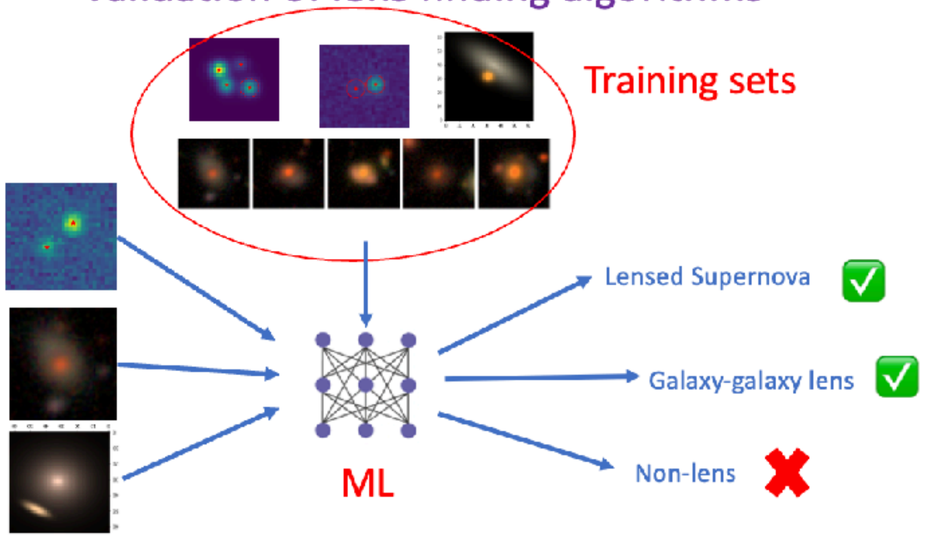
With 10’000s of strong lenses, we can identify near-identical deflector pairs.

Pseudo double source plane lensing analyses contain a lot of information about dark energy!

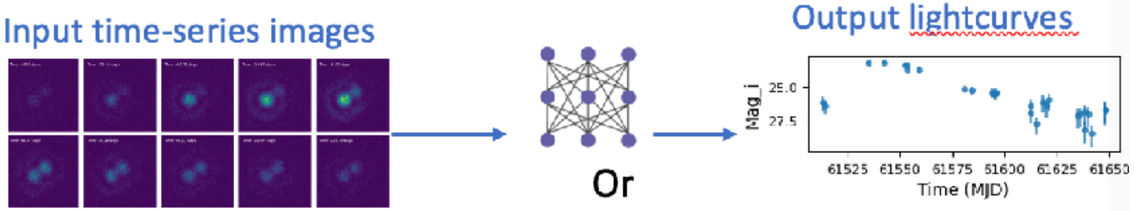
Sharma, SB + in prep.

How do we make sure we maintain accuracy with increased sample sizes? - With a lot of realistic simulations!

- Validation of lens finding algorithms

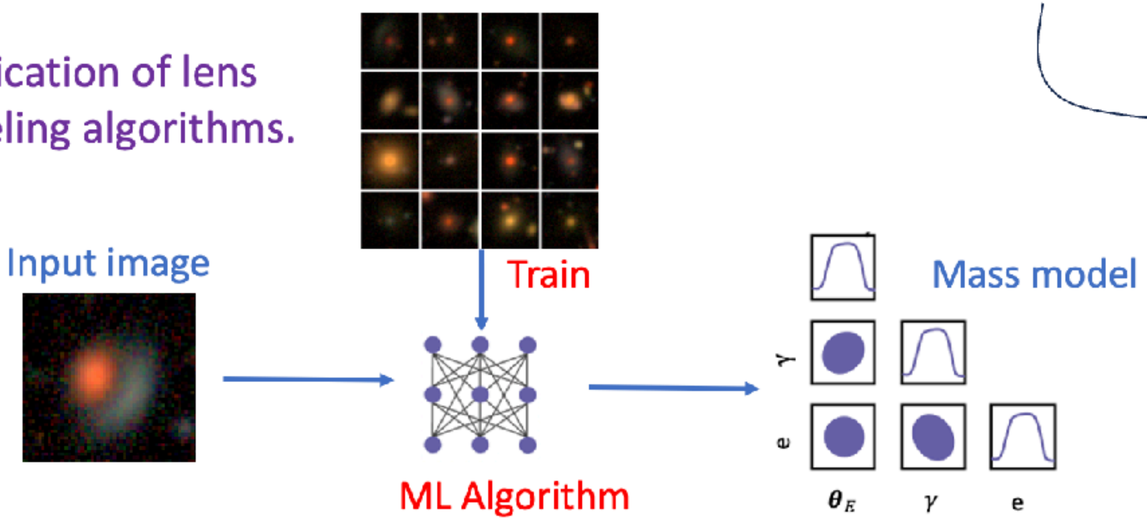


- Validation of lightcurve extraction algorithms.

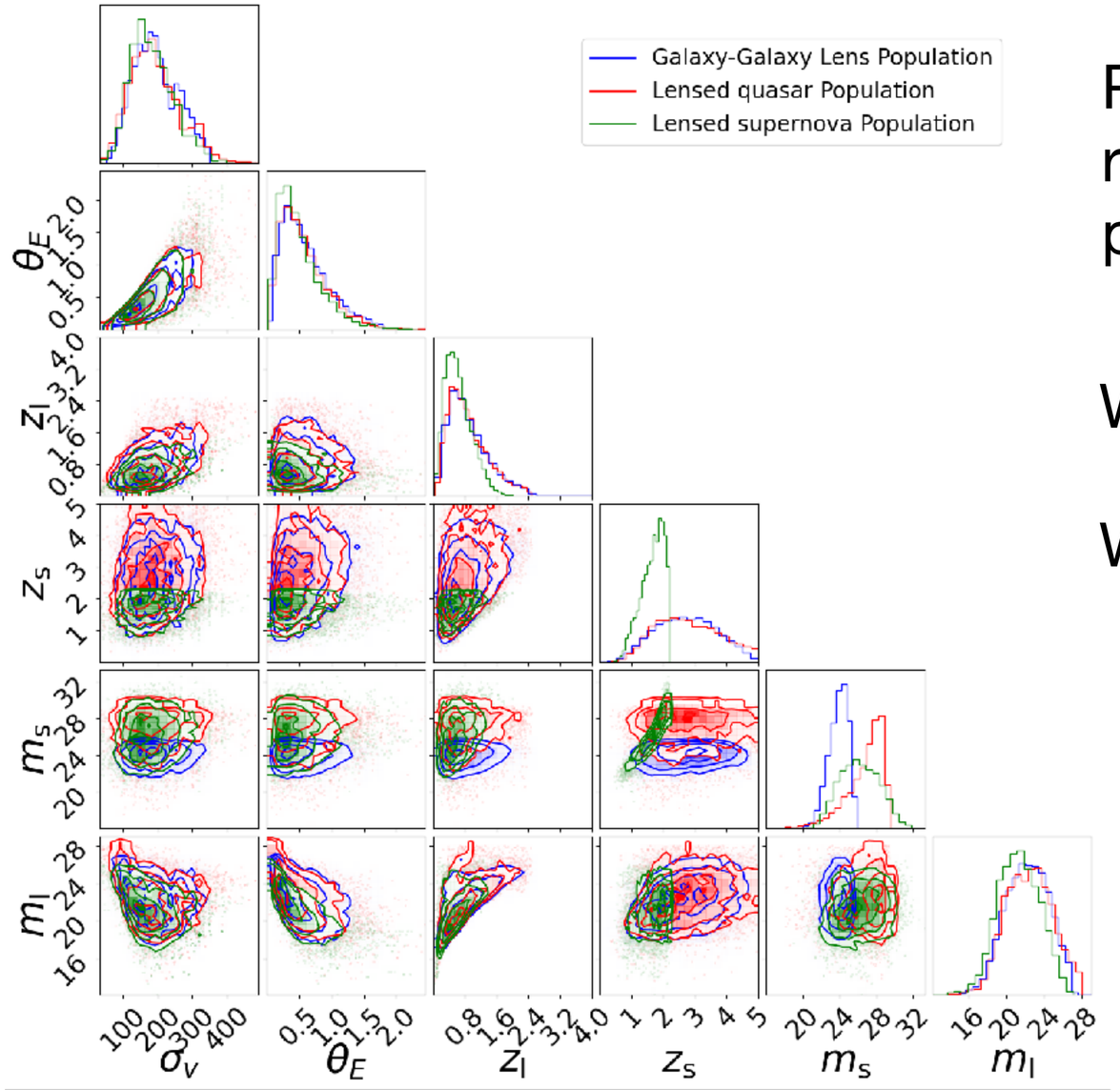


Compare true lightcurves and output lightcurves for the validation

- Verification of lens modeling algorithms.



How do we make sure we maintain accuracy with increased sample sizes? - With a lot of realistic simulations!



Population-level inferences require understanding the population-level selection effects.

Which lenses do we find?

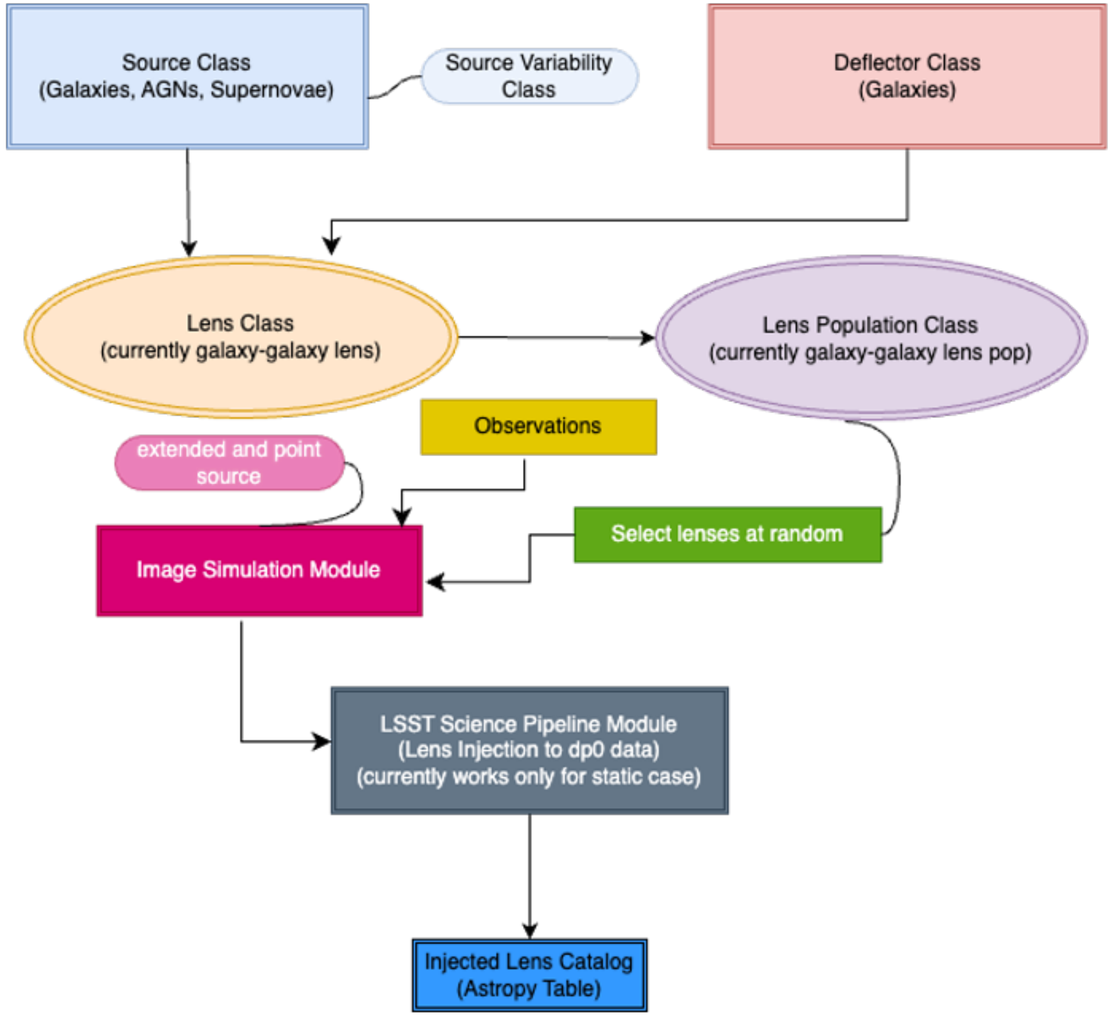
Which lenses do we analyze?

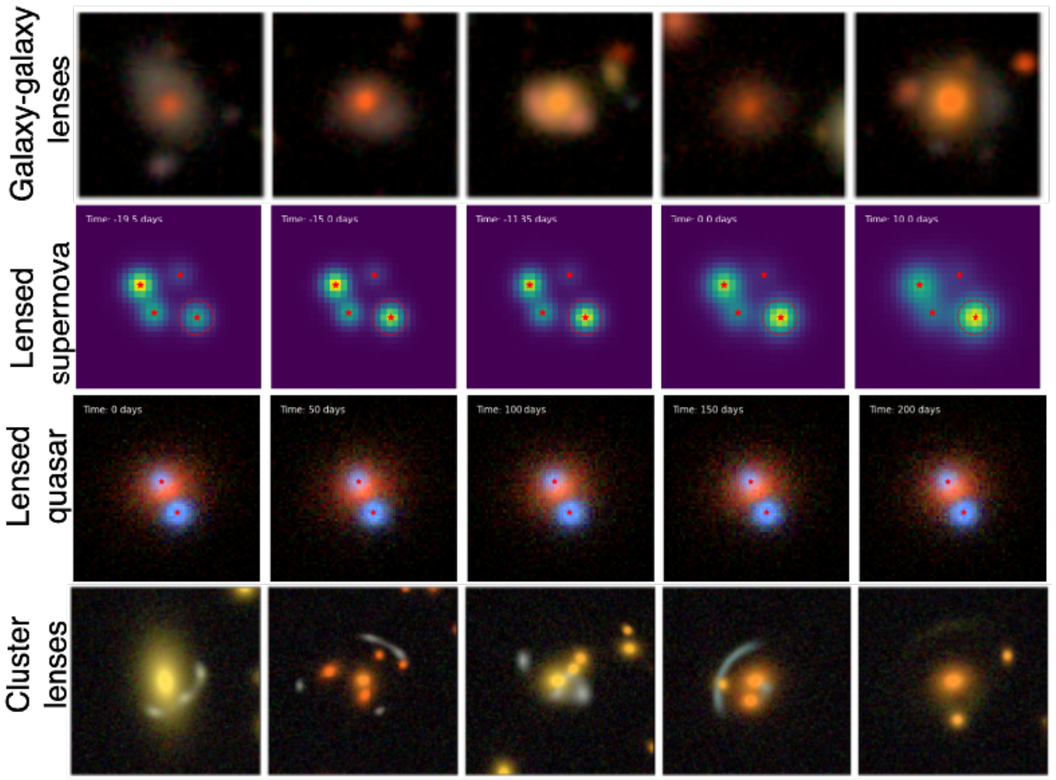
Figure by N. Khadka with SLSim

SLSim (Strong Lensing Simulation) pipeline

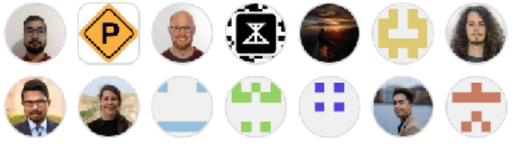
Fork 41 | Starred 26

docs passing | CI passing | codecov 98% | code style black | formatter docformatter | style sphinx





Contributors 22



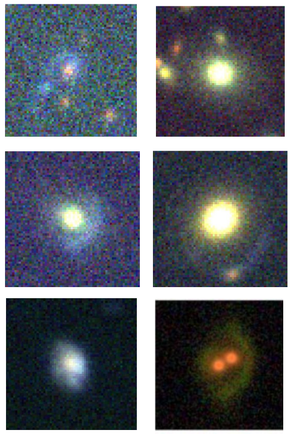
+ 8 contributors

https://github.com/LSST-strong-lensing/slsim

Lens finding challenges with static images and light curves for Rubin

Static Lens Finding Challenge

Co-chairs: Clecio R. Bom, Margherita Grespan, Josh Wilde, Felipe Urcelay, Narayan Khadka, Anupreeta More



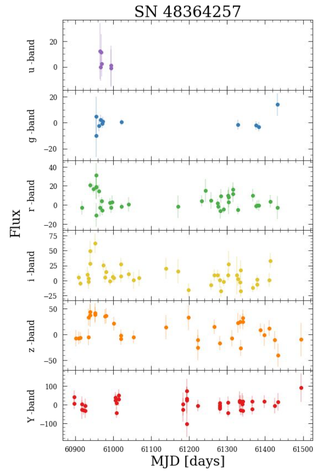
(Some of the images from our mock data)

- Coming soon: Mock galaxy-galaxy lens image data and various false positive images.
- If You are interested in participating in the challenge or helping with its preparation, join our slack channel: sl-desc-static-challenge, and attend the bi-weekly meeting.

First beta-test set out!

JOint Lensed Transient Events Observation Network

Co-chairs: Erin Hayes, Dan Ryczanowski, Ana Sainz de Murieta, Luke Weisenbach



Sample LSST glSN lightcurves
(check out the tutorial on our github!)

- Coming soon: mock LSST transient datasets at lightcurve, alert and image level containing **lensed SNe** and their **main contaminants**.
- If you're interested in running your own finding method, have a science case for including a particular lensed transient, or just want to keep up to date: **join our Slack channel (LSST Members)** or **email eeh55@cam.ac.uk!**

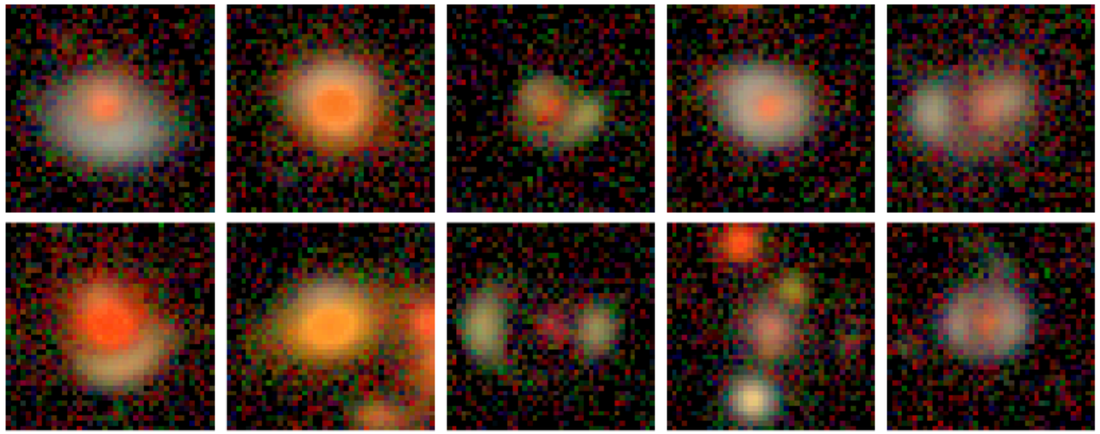
github.com/LSST-strong-lensing/jolteon

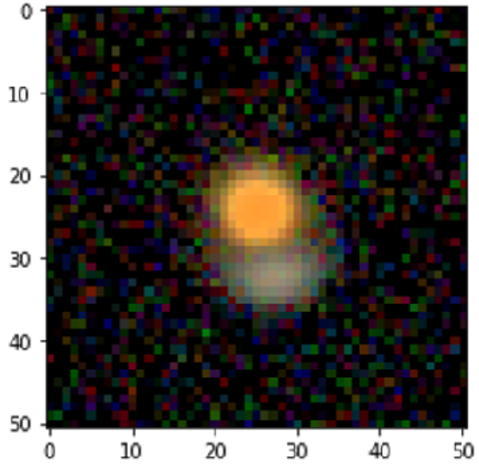
#sl-transient-search-challenge

Started!

Multi-observatory simulations integration

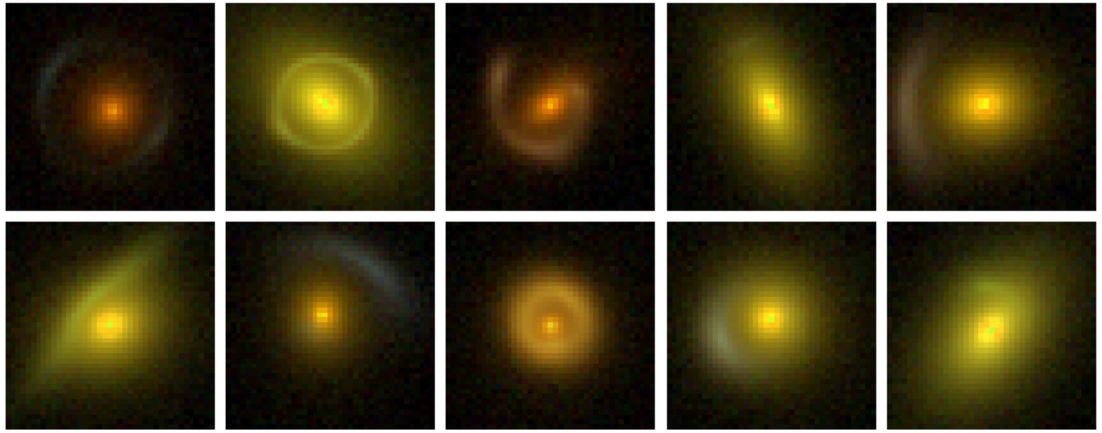
Rubin

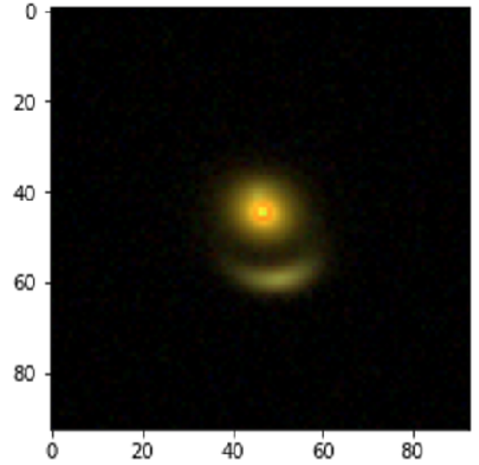




Khadka, SB et al. in prep

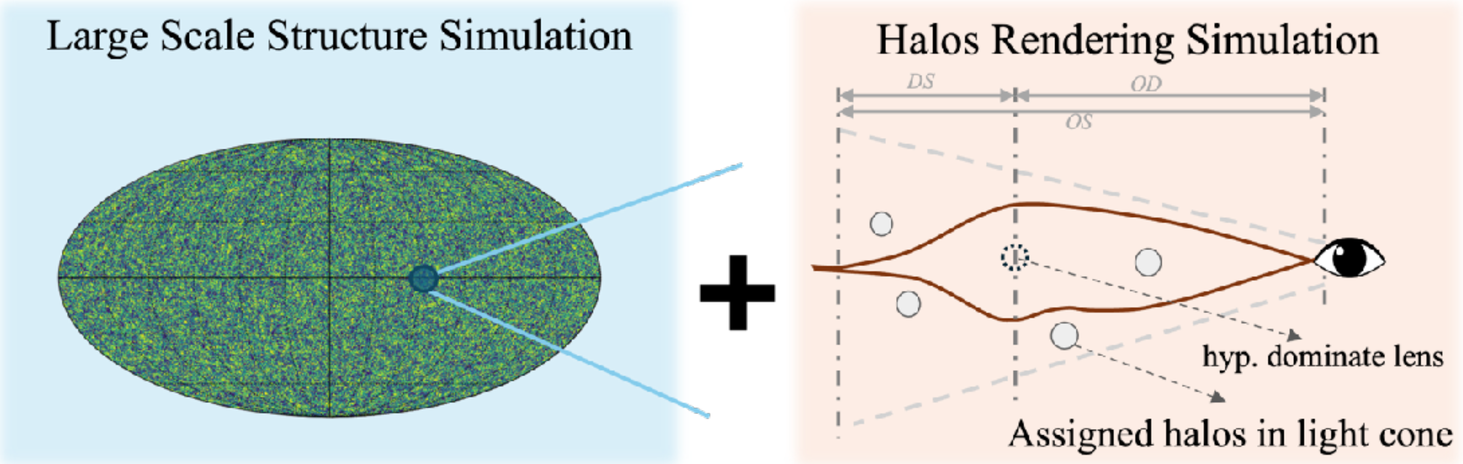
Roman





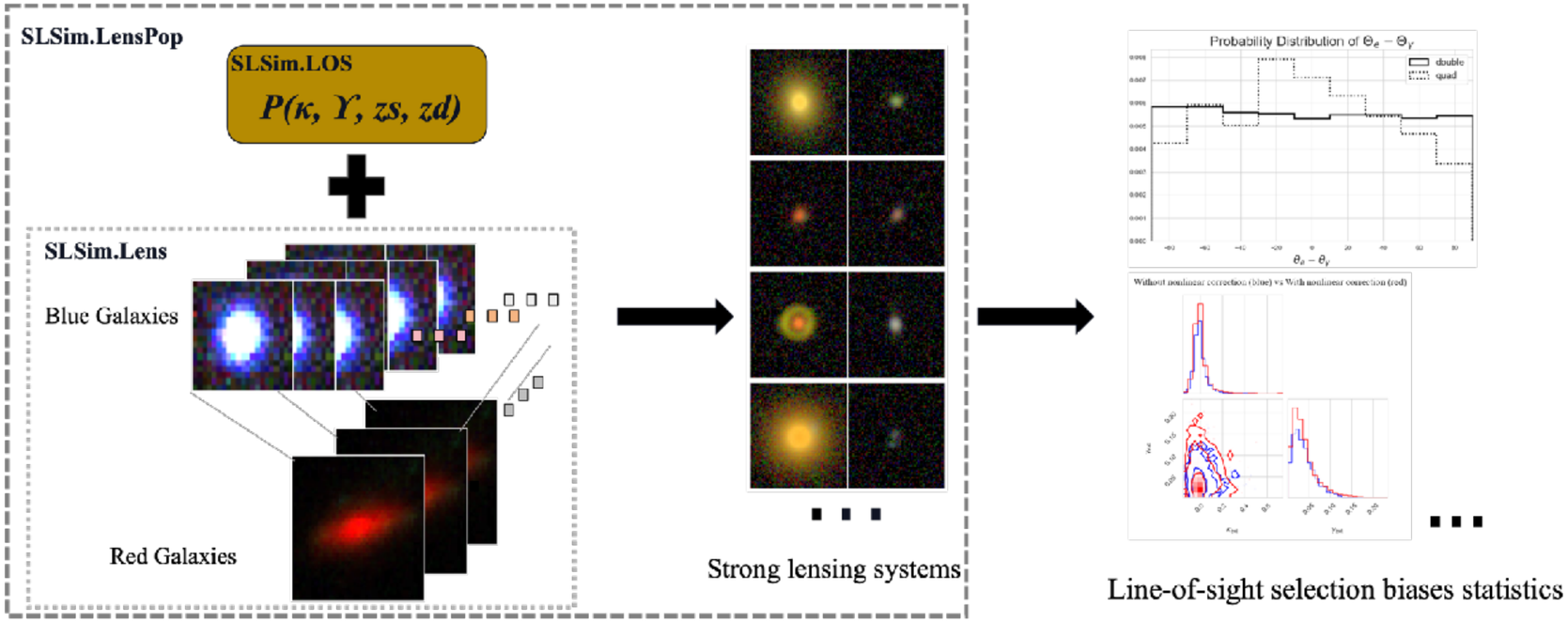
Wedig et al. (incl SB), in press

Population characterization of selection effects



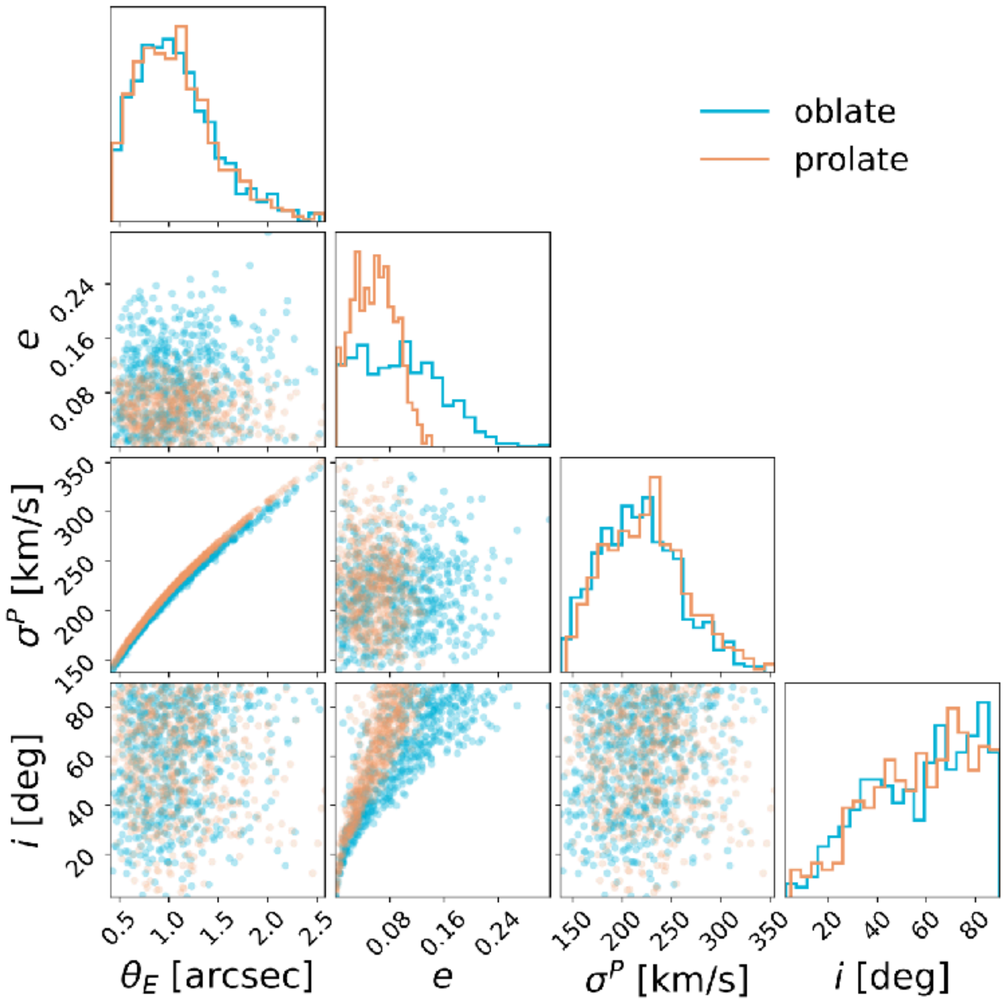
Hybrid LSS + halo model ray-tracing

Strong lenses are biased to over-dens line of sights



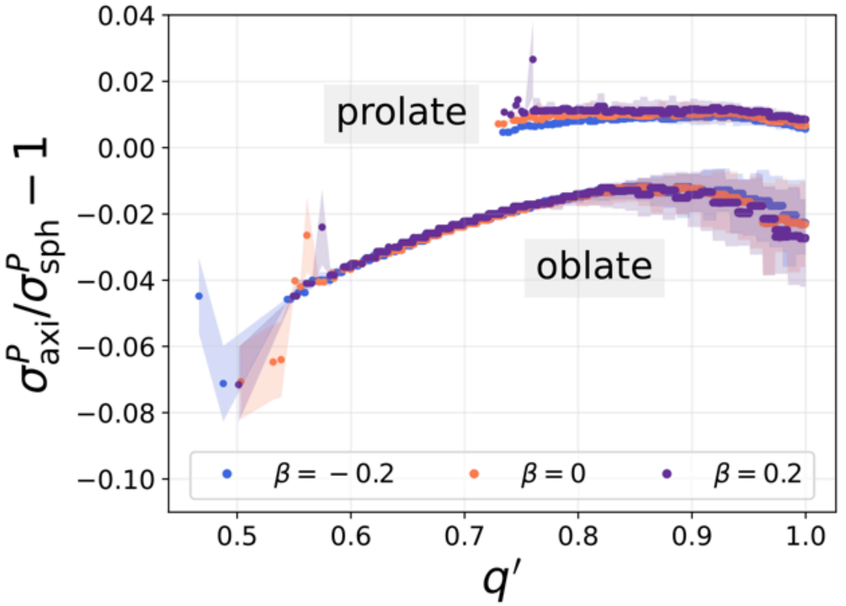
Tang, SB et al. submitted (DESC+SLSC)

Triaxality projection effects



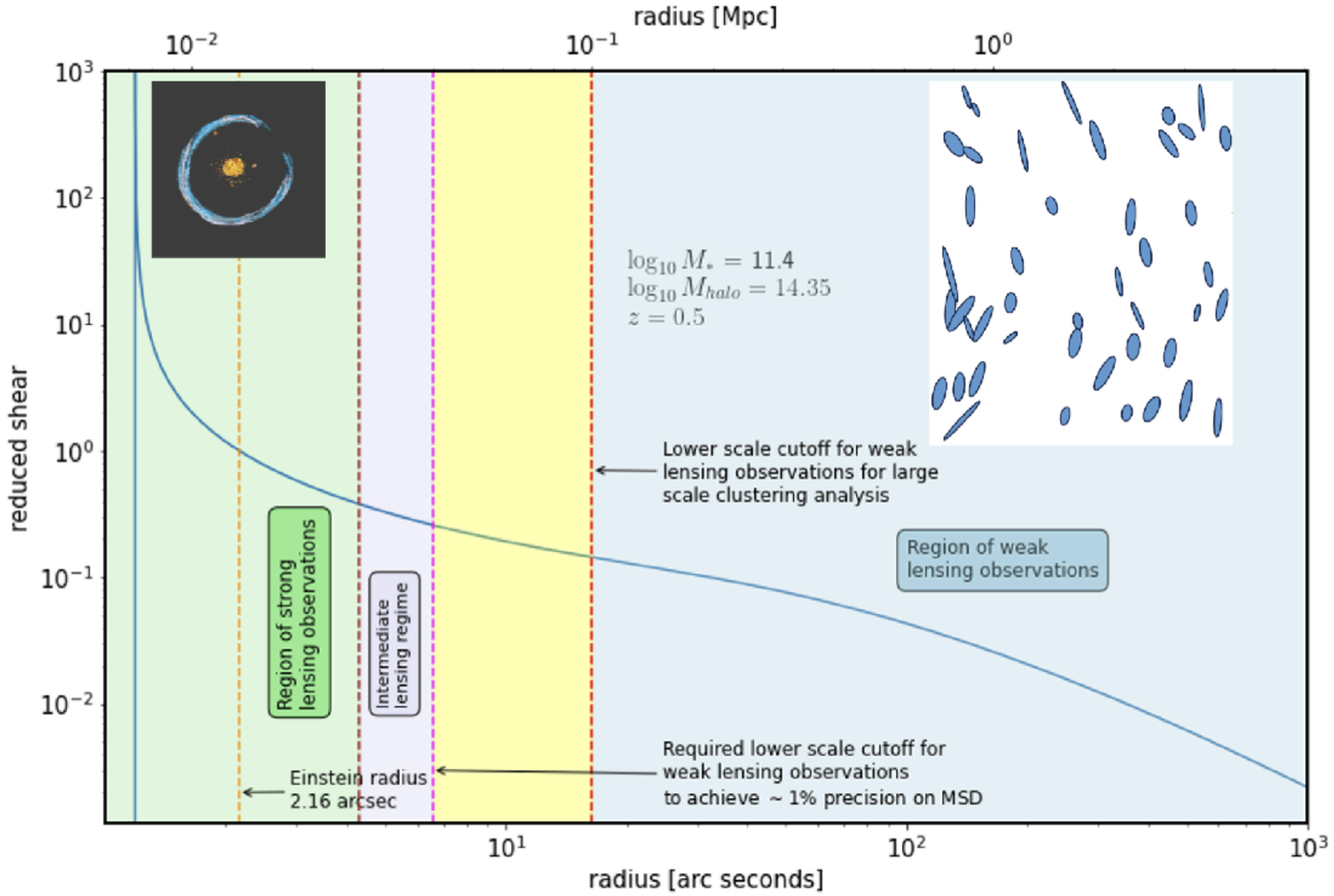
Does strong lensing select preferentially certain inclination?

If so, the kinematics de-projection needs to take this into account.



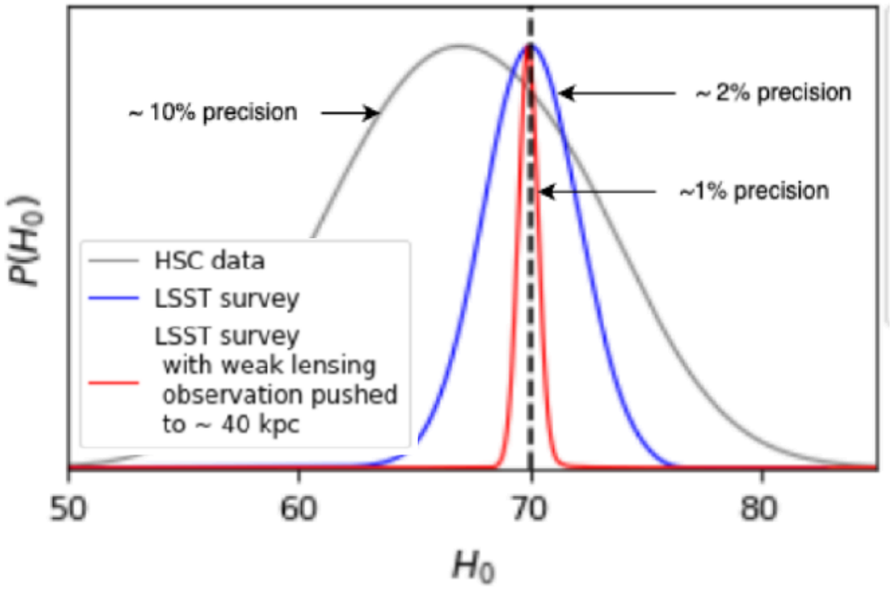
X. Huang, SB, et al. 2025

Weak+Strong lensing



Khadka, SB+ 2024

Tangential shear measurements from stacking selected deflector galaxies can break lensing degeneracies to the percent level!



Challenges and Opportunities with 10’000 strong lenses

This decade will allow us to conduct analyses with 10’000s of strong gravitational lenses, from currently <100 lenses.

Lens search and lens modeling should be considered integrated parts of our astrophysics or cosmology analysis.

This is a great time for Strong Lensing! The work is substantial, the returns potentially transformative.

lenstronomy goes JAX

same lenstronomy API but JAX underneath

JAXtronomy

Tests passing | License BSD 3-Clause | codecov 100% | code style black | formatter docformatter | style sphinx | PyPI v0.0.1rc1

JAX port of lenstronomy, for parallelized, GPU accelerated, and differentiable gravitational lensing and image simulations.

Disclaimer: This project is still in an early development phase and serves as a skeleton for someone taking the lead on it :)

The goal of this library is to reimplement lenstronomy functionalities in pure JAX to allow for automatic differentiation, GPU acceleration, and batched computations.

Contributors 6

credit: **Alan Huang**, Natalie Hogg, Aymeric Galan, et al.

https://github.com/lenstronomy/JAXtronomy