

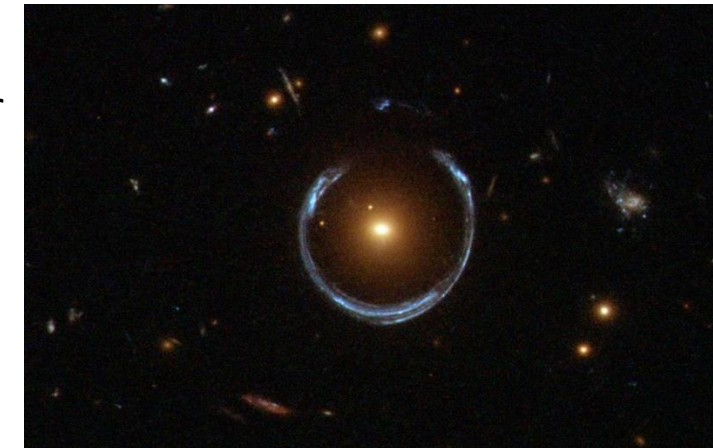
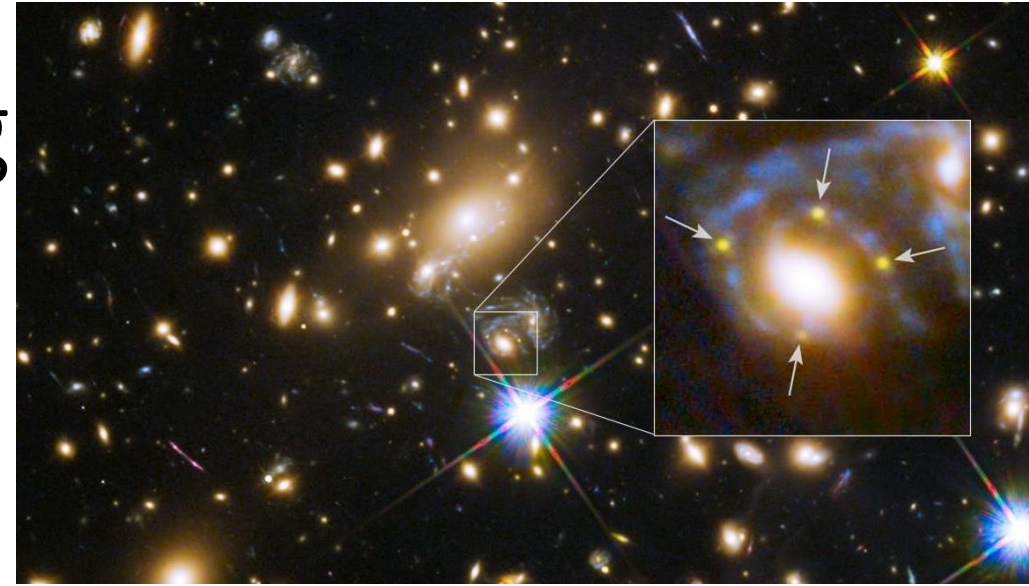
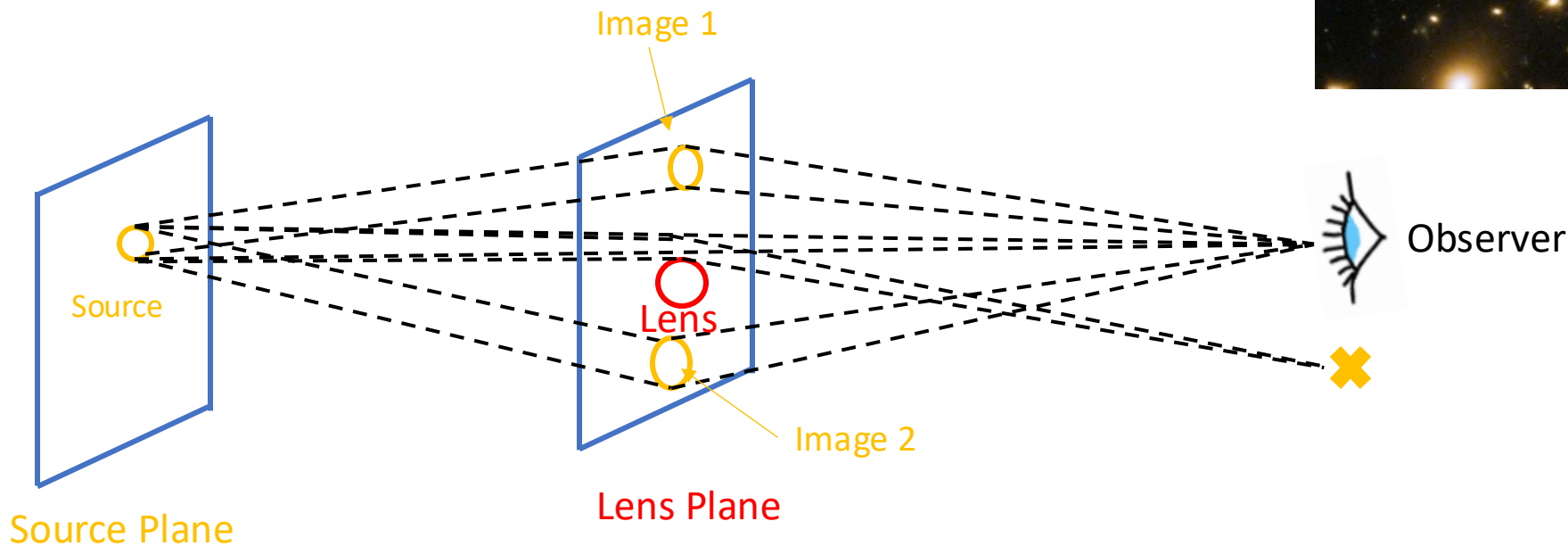


SLSim - Simulating a Strongly Lensed Universe

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Stony Brook University
LSST-DESC

Strong Gravitational Lensing

- Gravitational lensing occurs when a massive foreground object bends the light from a background source.

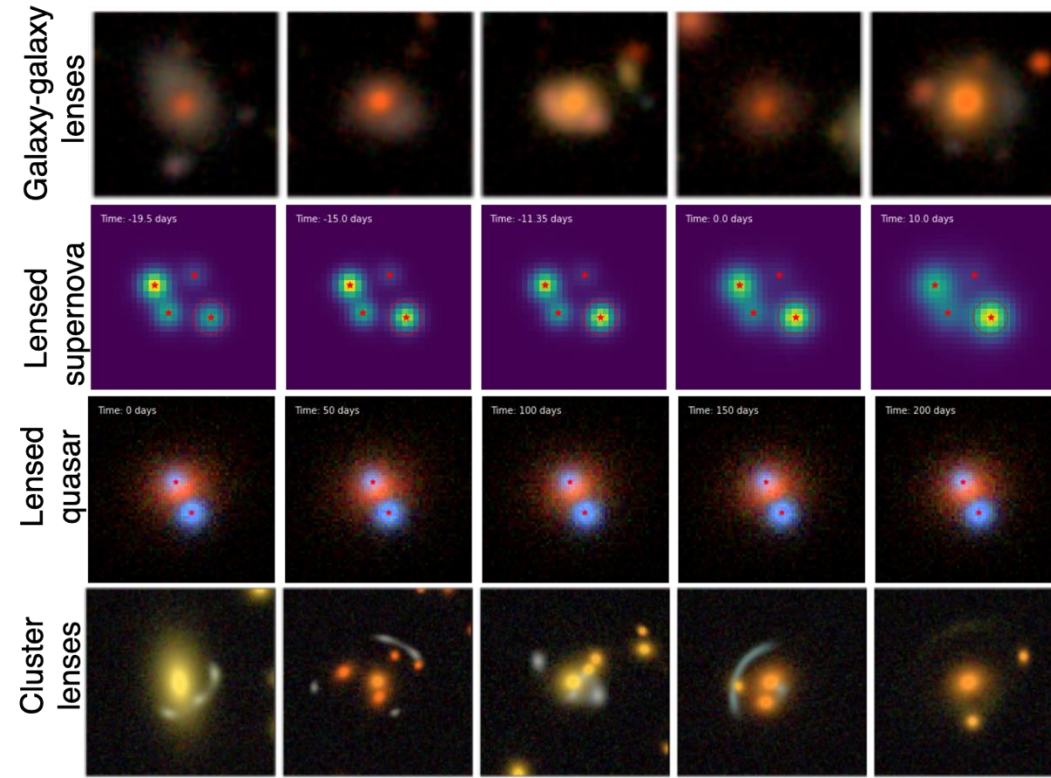


Credit: HST

Science cases: 1) Measuring current expansion rate of the universe 2) Measuring dark energy 3) Distribution of dark matter

Strong Lensing Simulation (SLSim)

- SLSim is a Python-based software that simulates different kinds of strong gravitational lens population.
 - Static Lens (galaxy-galaxy, galaxy-cluster)
 - Variable Lens (lensed supernovae, lensed quasar)
- Simulates realistic images of these lenses by injecting lens image to simulated survey sky or real observational data.



Contributors:

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



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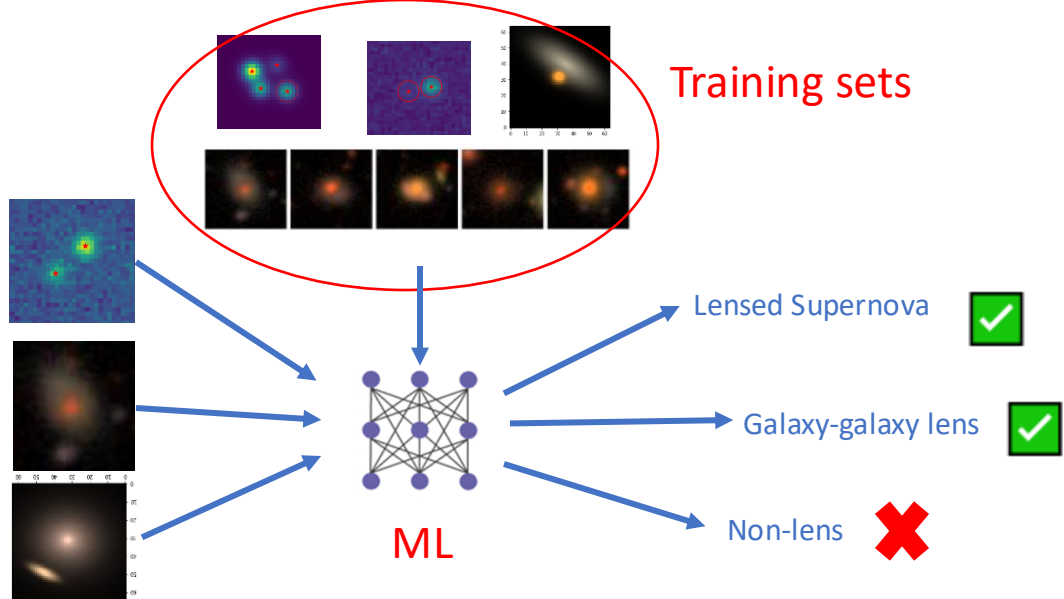


Remy Joseph

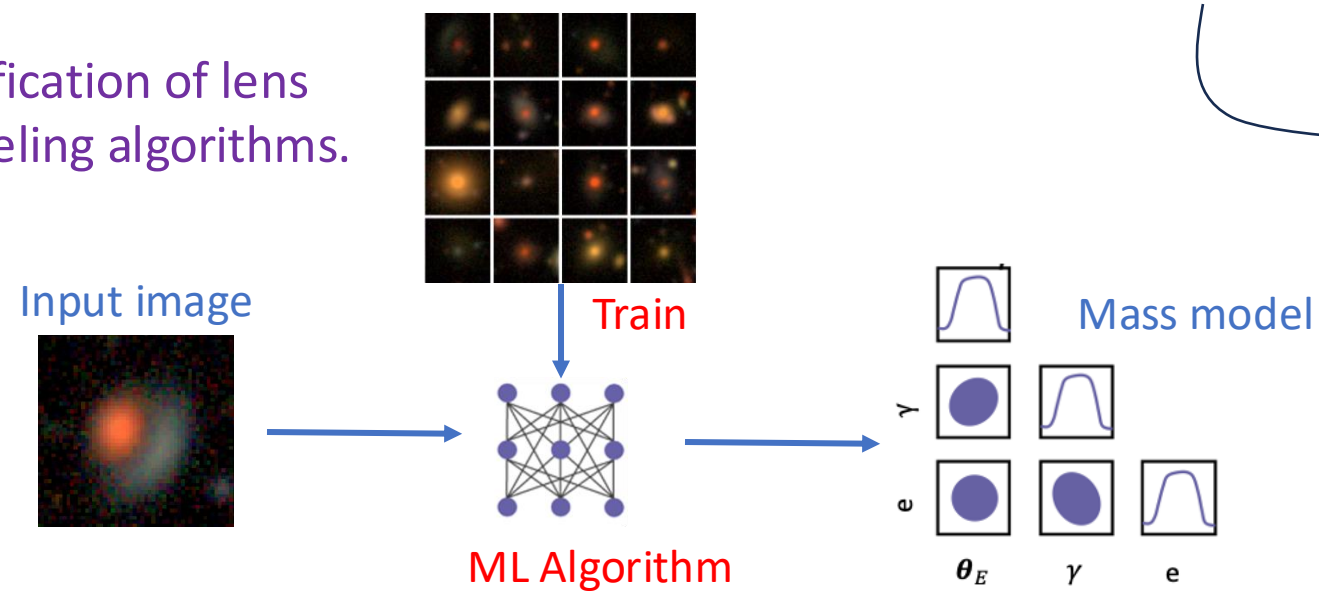


Why do we need lens images?

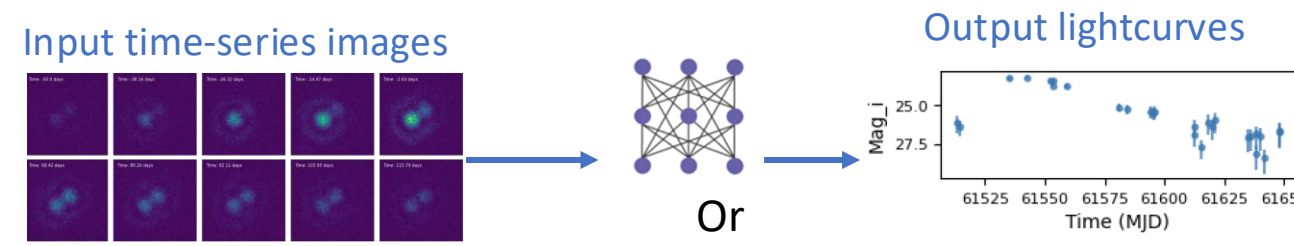
- Validation of lens finding algorithms



- Verification of lens modeling algorithms.



- Validation of lightcurve extraction algorithms.

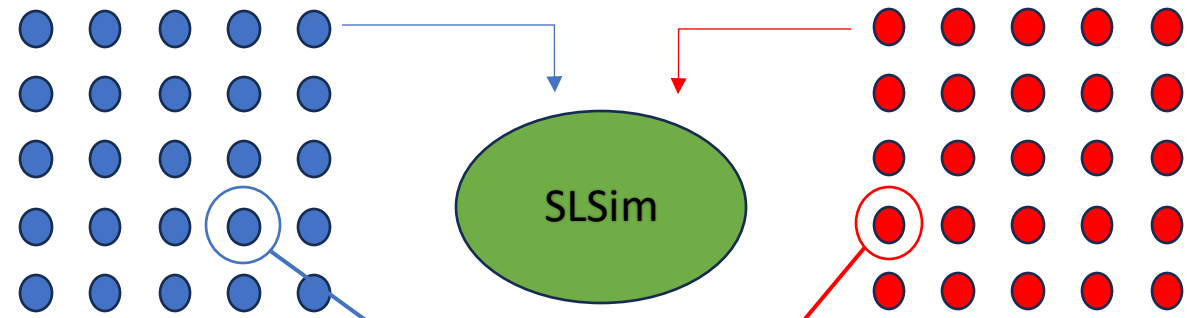


Compare true lightcurves and output lightcurves for the validation

How does SLSim simulate Lenses?

Two Basic ingredients:

1. Source Catalog
2. Deflector Catalog



Source Catalog

Deflector Catalog

Galaxy
Supernova
Quasar

Galaxy
Galaxy Cluster

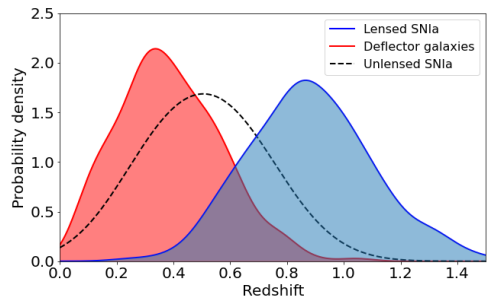
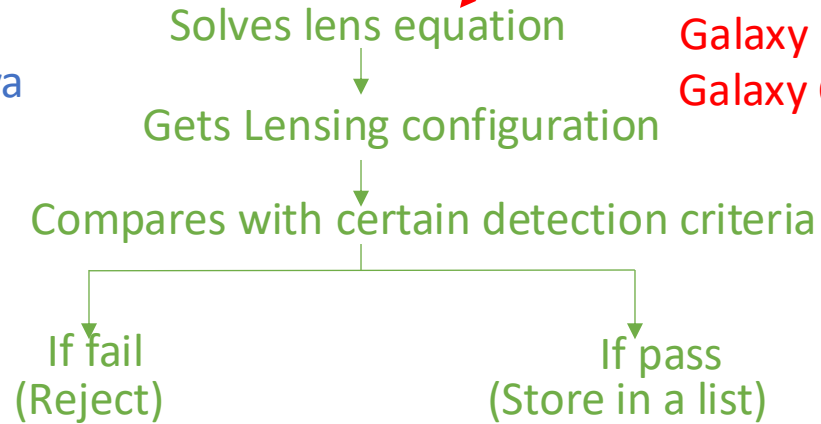


Fig: Lensed supernovae distribution For LSST survey

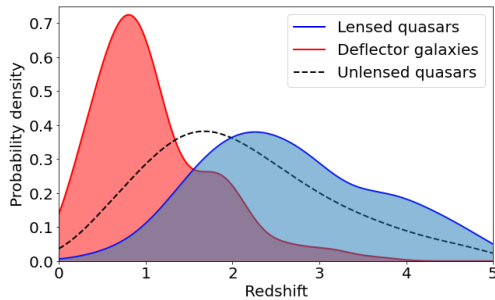


Fig: Lensed quasar distribution for LSST survey

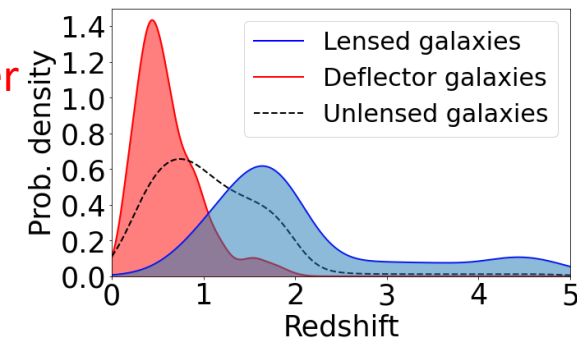
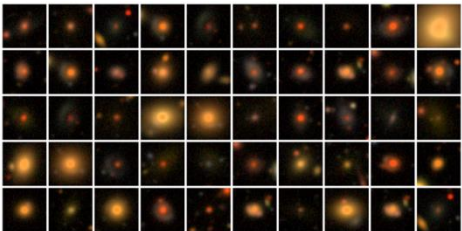


Fig: Galaxy-galaxy lens distribution for LSST survey

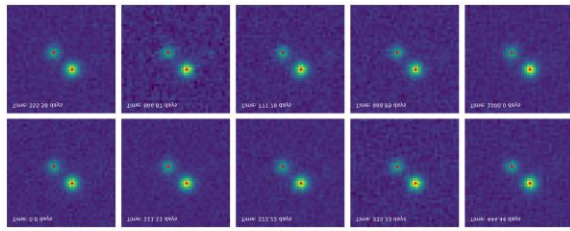
Processing the Lens (Population)

- SLSim has an image simulation module

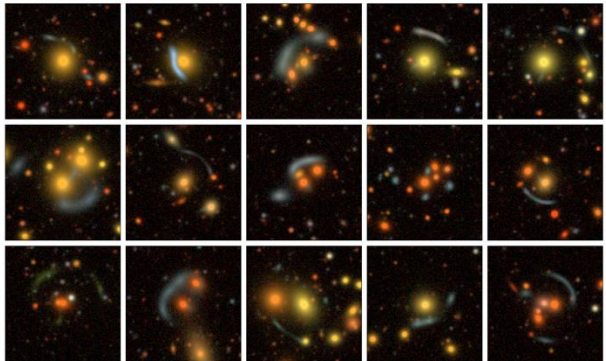
- Transient lightcurves with survey cadence



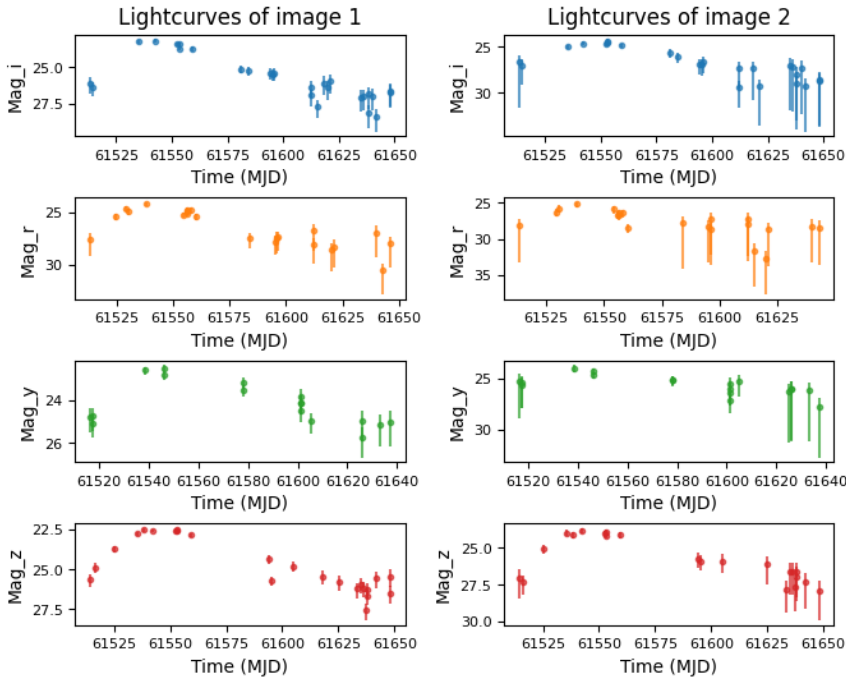
Galaxy-galaxy lens images



i-band time series images of a lensed quasar.



Cluster lenses



An example of lensed supernova in LSST cadence

Does SLSim work for Roman?

- The answer is **yes!**
- All the routines are applicable for Roman.
 - Roman filters have been implemented consistently throughout the code.
 - A separate Roman image simulation module has been implemented.

- Transient lightcurves for Roman can be obtained following a survey cadence.
 - The missing piece is the Roman cadence, so we need to develop a Roman cadence simulator.

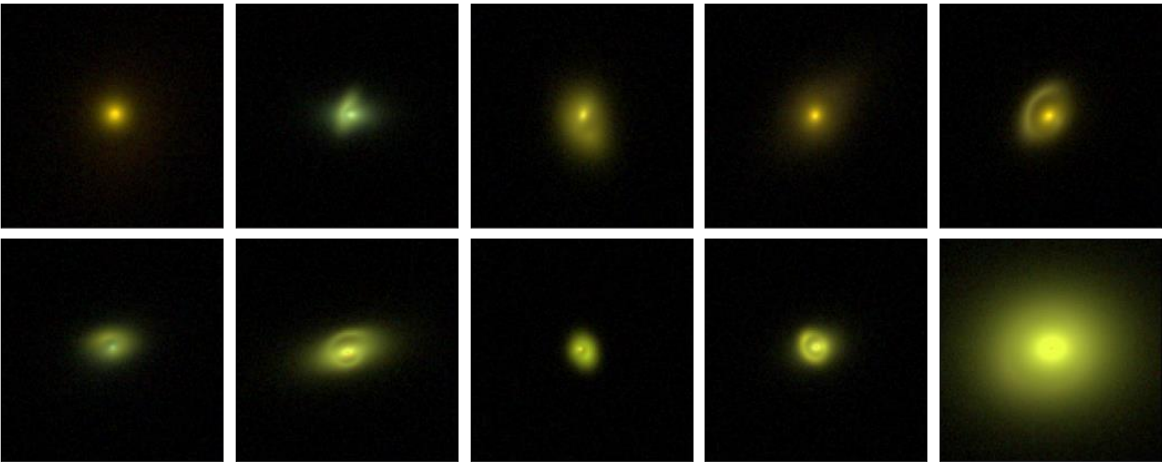


Fig: Galaxy-galaxy lens sample for Roman.

Bryce et al. (2024) used SLSim for Roman galaxy-galaxy lens simulations.

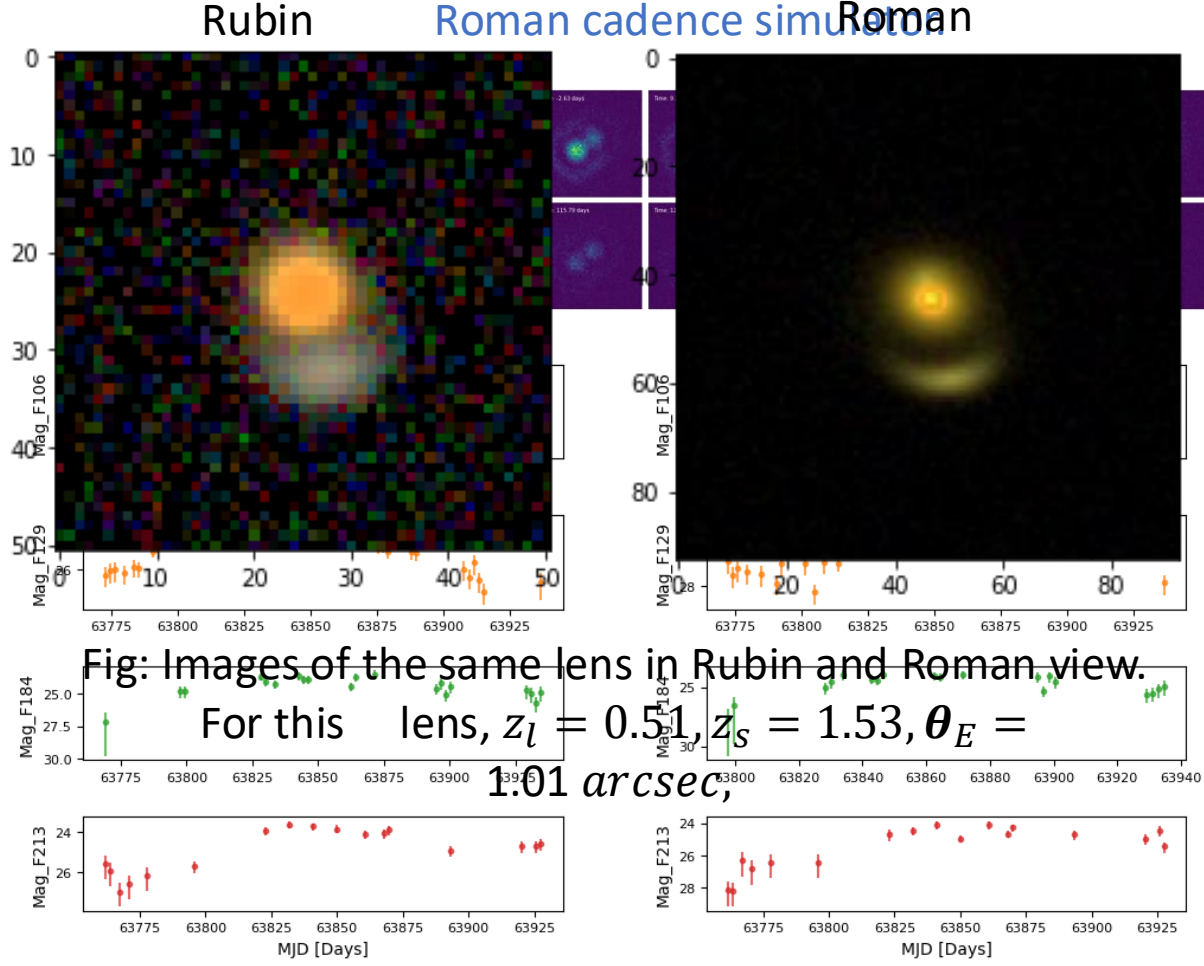


Fig: Images of the same lens in Rubin and Roman view.

For this lens, $z_l = 0.51$, $z_s = 1.53$, $\theta_E = 1.01$ arcsec,

Fig: Images and lightcurves of a lensed supernova.

Other Strong lensing efforts in LSST

1. Lens finding challenges

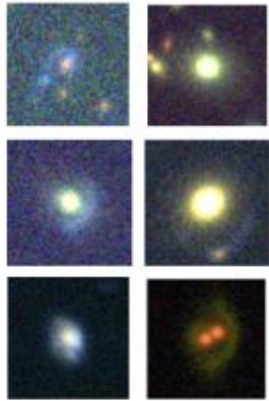
- We are organizing LSST static lens finding

Static Lens Finding Challenge

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



- ❖ 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.



(Some of the images from our mock data)

(Distributing data/collecting algorithms/grading algorithms)

it

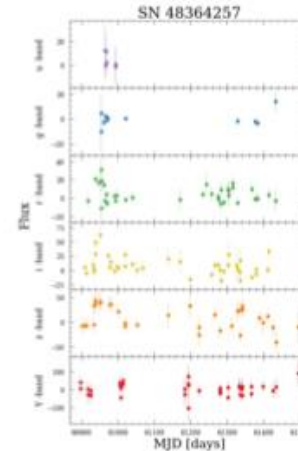
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(identifying best algorithms)



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


JOint Lensed Transient Events Observation Network

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



- 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!](mailto:eeh55@cam.ac.uk)

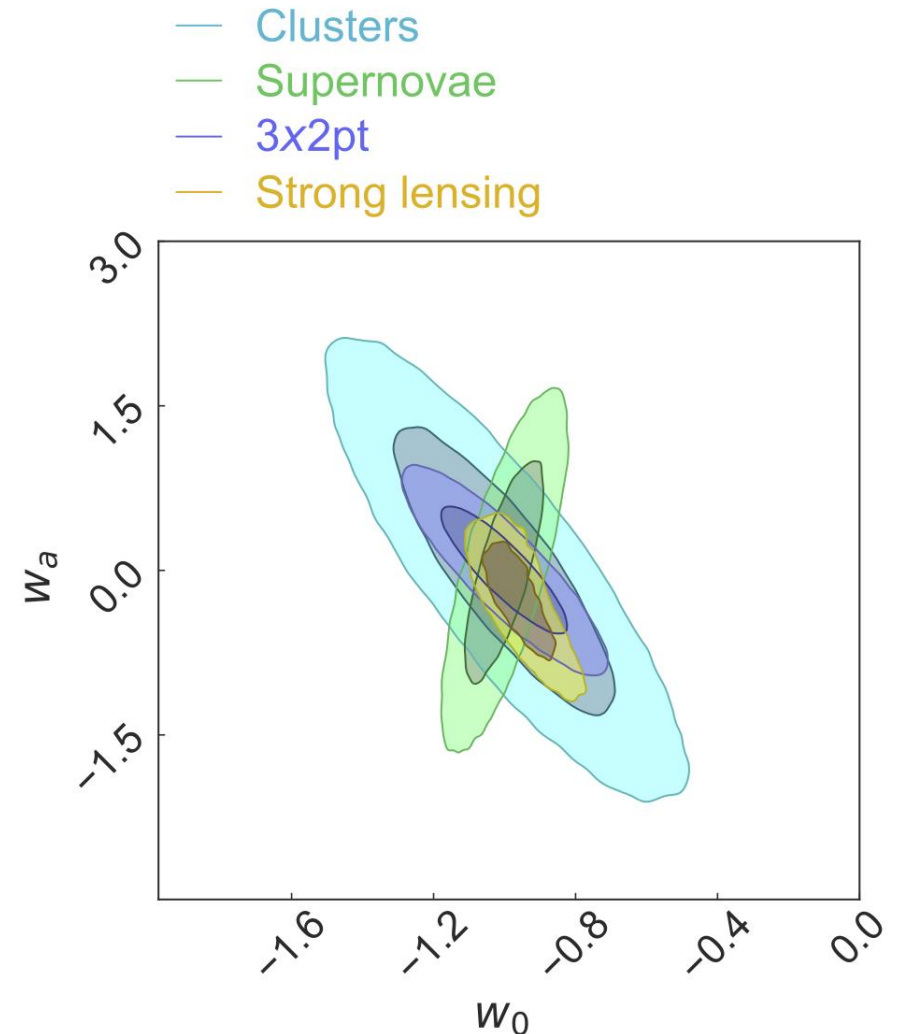
 github.com/LSST-strong-lensing/jolteon

 [#sl-transient-search-challenge](#)

data

2. Cosmology Forecast using Strong Lenses

- Initial assessment suggests LSST SL can be as competitive as the other DE probes from the LSST.
- Constraint in RHS plot are forecasted using following data:
 - Time-delay cosmography with lensed SNIa (144).
 - Time-delay cosmography with lensed quasar (236).
 - Galaxy-galaxy lenses (10,000).
 - Double source plane lenses (87).
- We are working on a strong lensing forecast project for LSST. For this, the SLSim-generated population of strong lenses will be used. Additionally, this project will develop all the necessary analysis pipelines.



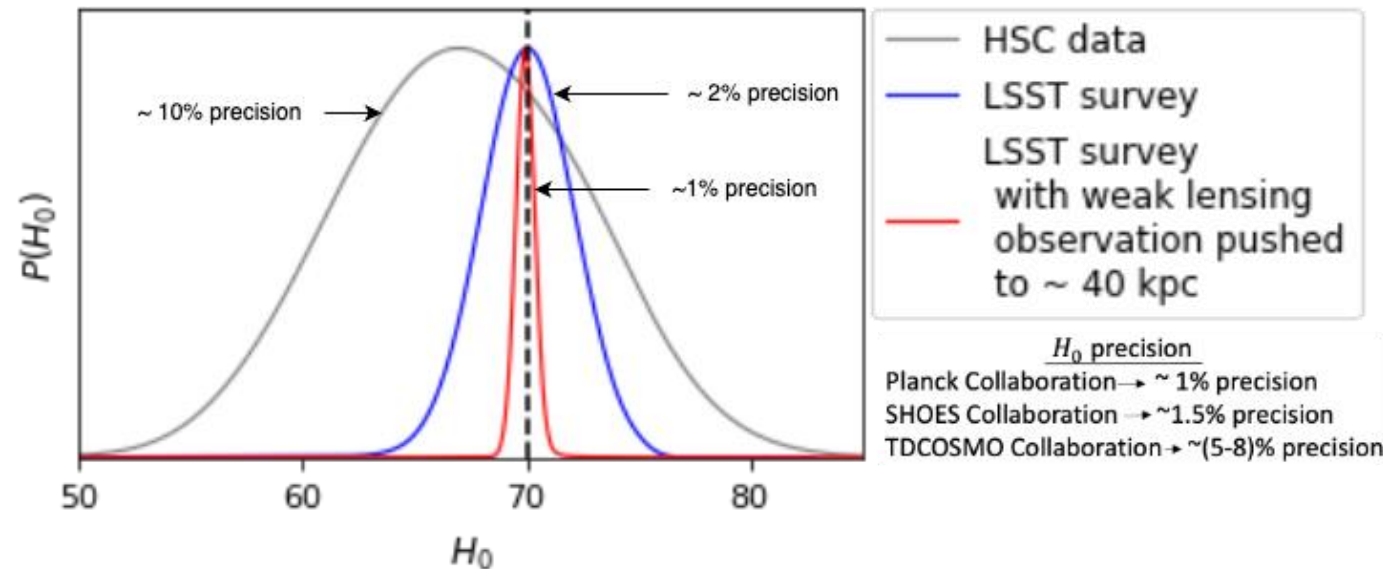
Shajib et al. (2024)

3. Forecast on H_0 constraint for LSST survey

- LSST will observe 200+ lensed quasars. 50+ lensed supernovae per year. These lenses will be sufficient to reduce statistical error on H_0 measurement to sub-percent level.
- By combining these strong lenses and weak lensing data, we can achieve $\sim 1\%$ precision on H_0 measurement.
- For large weak lensing data from LSST and other future surveys, we need to do following study:
 - Need to develop a selection function for weak lensing deflector which will identify self similar galaxies.
 - Need to study the strong lensing selection effect.
 - Feasibility of weak lensing shear measurements at lower scale of 40 kpc.



Rubin/LSST



(Khadka et al. 2024)

Summary

- SLSim can generate realistic strong lensing images and lightcurves. These data can be used for various projects.
- We are preparing for the discovery of strong lenses in Rubin data through various lens finding challenges.
- We are developing Strong Lensing analysis pipeline for Rubin through SL cosmology forecast project.
- We are also preparing to combine strong and weak lensing data to achieve 1-2% precision on the Hubble constant measurement.