Rapid automated detection and modeling of strong lenses for time delay cosmography and supernova studies with LSST transients

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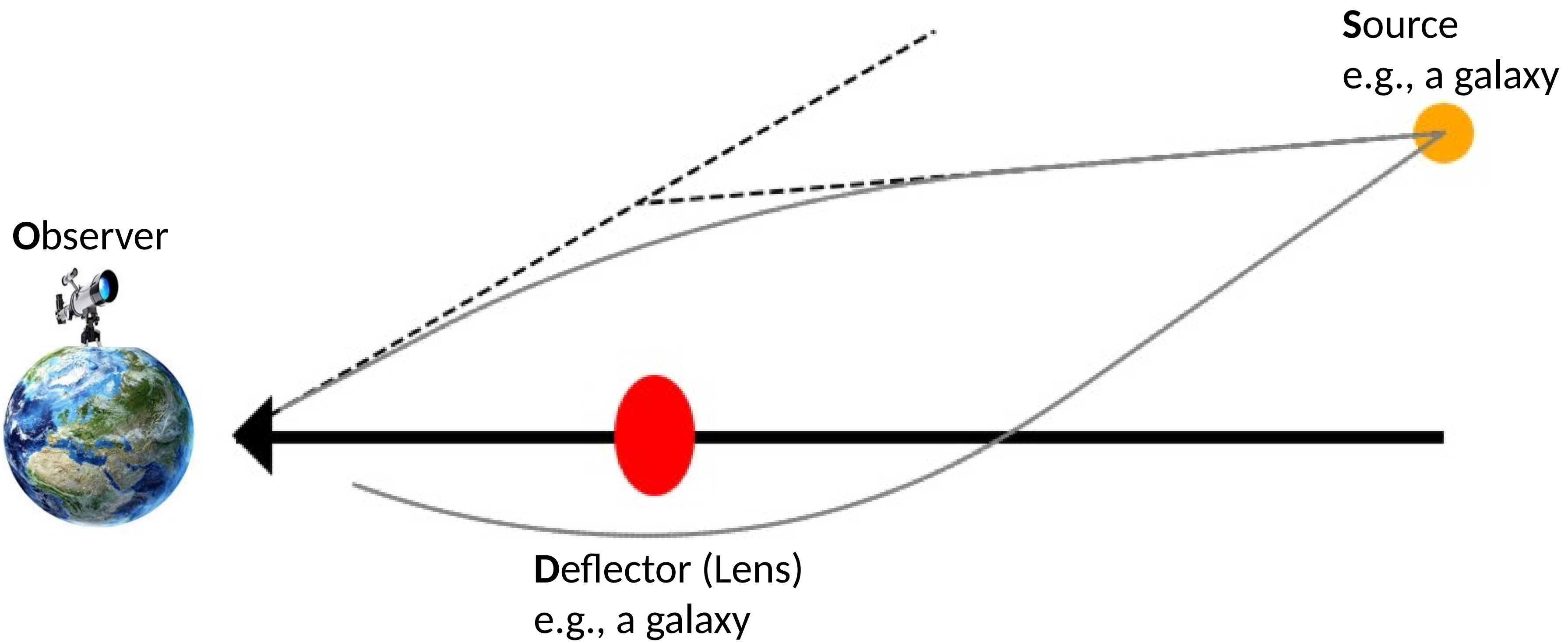
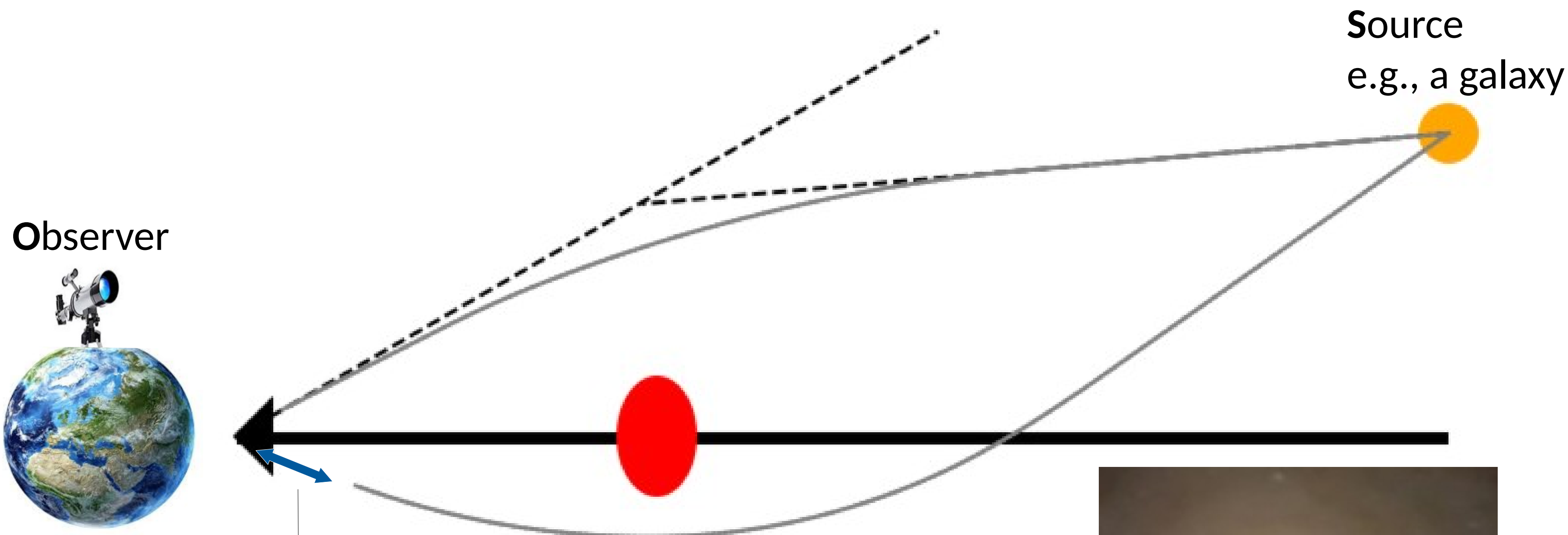
Rio de Janeiro - May 06, 2024

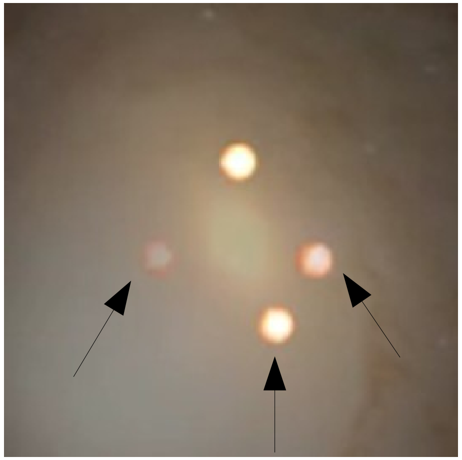
Strong gravitational lensing



Strong gravitational lensing



- Time delay → Hubble constant H_0
- lensed supernova → early spectra → progenitor system



Wide field imaging surveys

- Ongoing:
  - Hyper Suprime Cam (HSC)
  - PanSTARRS

- Upcoming: Rubin Observatory

  Legacy Survey of Space and Time (LSST)

First light planned for 2025

Image southern sky every few days

→ expect ~**100,000 new galaxy-scale lenses**

within billion of galaxies

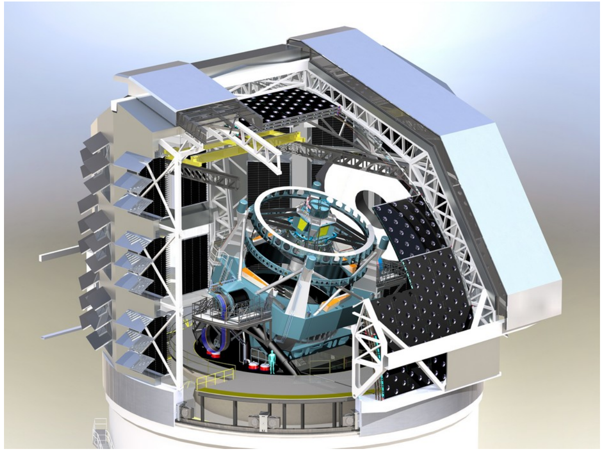


Image Credit: Rubin Obs./NSF/AURA.

HOLISMOKES!

***H**ighly **O**ptimized **L**ensing **I**nvestigations of **S**upernovae, **M**icrolensing **O**bjects, and **K**inematics of **E**llipticals and **S**pirals* (Suyu et al. 2020)

Raoul Cañameras

Alejandra Melo

Sherry Suyu

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Stefan Taubenberger

And many more...

We are more working **supernova** physics and **cosmology**
→ lens finding (Canameras+20, 21, 24, Shu+22, Schuldt et al., in prep)
→ microlensing and cadence strategy (Suyu+20, Huber+21a, b, Huber & Suyu 24, Bayer+21)
→ rapid modeling (Schuldt+22, 23a, 23b)

https://shsuyu.github.io/HOLISMOKES/site/

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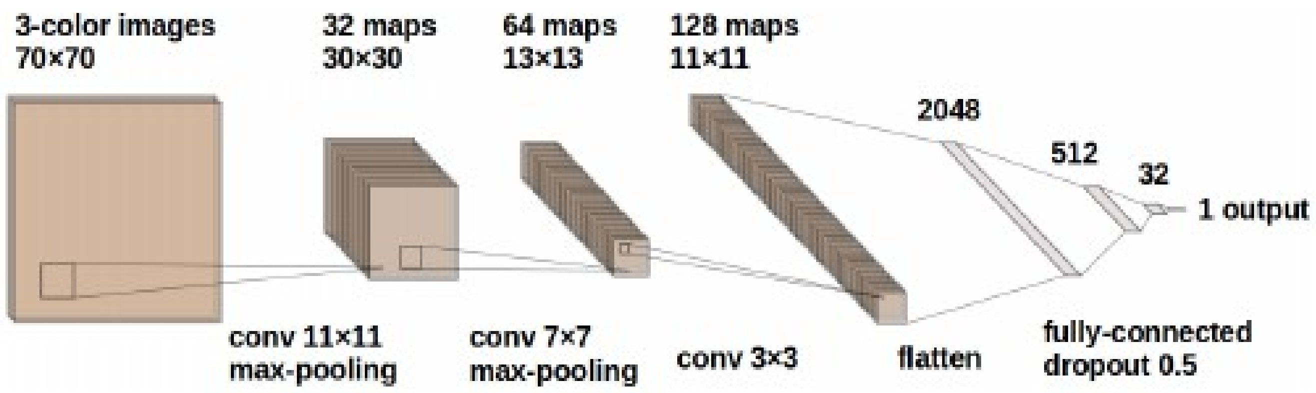
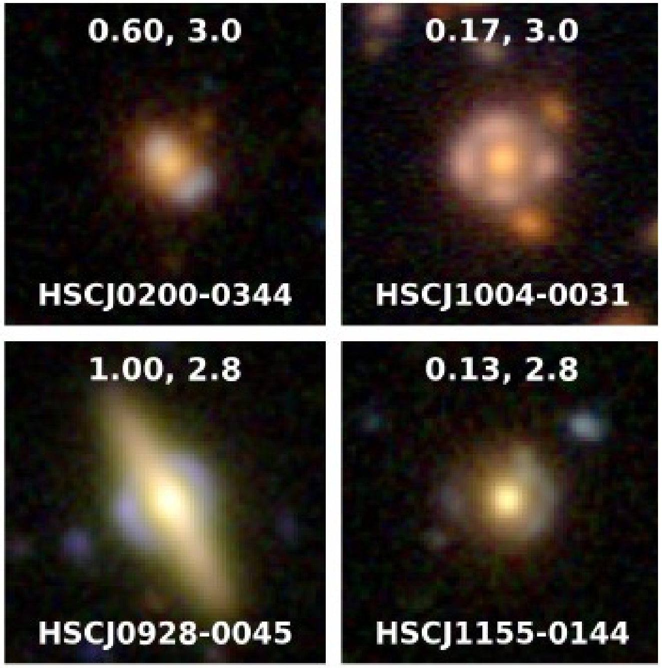
→ **rapid modeling** (Schuldt+22, 23a, 23b)

Various lens search projects



→ ResNet: FPR <0.01% on real COSMOS galaxies and ~60-70% completeness on SuGOHI lenses
(Cañameras et al. 2020, 2021, 2024)



gri-color images of
newly identified lenses
→ thousands more!

Euclid
(1 band,
high resolution)

LSST
(multi band,
low resolution)

CNN

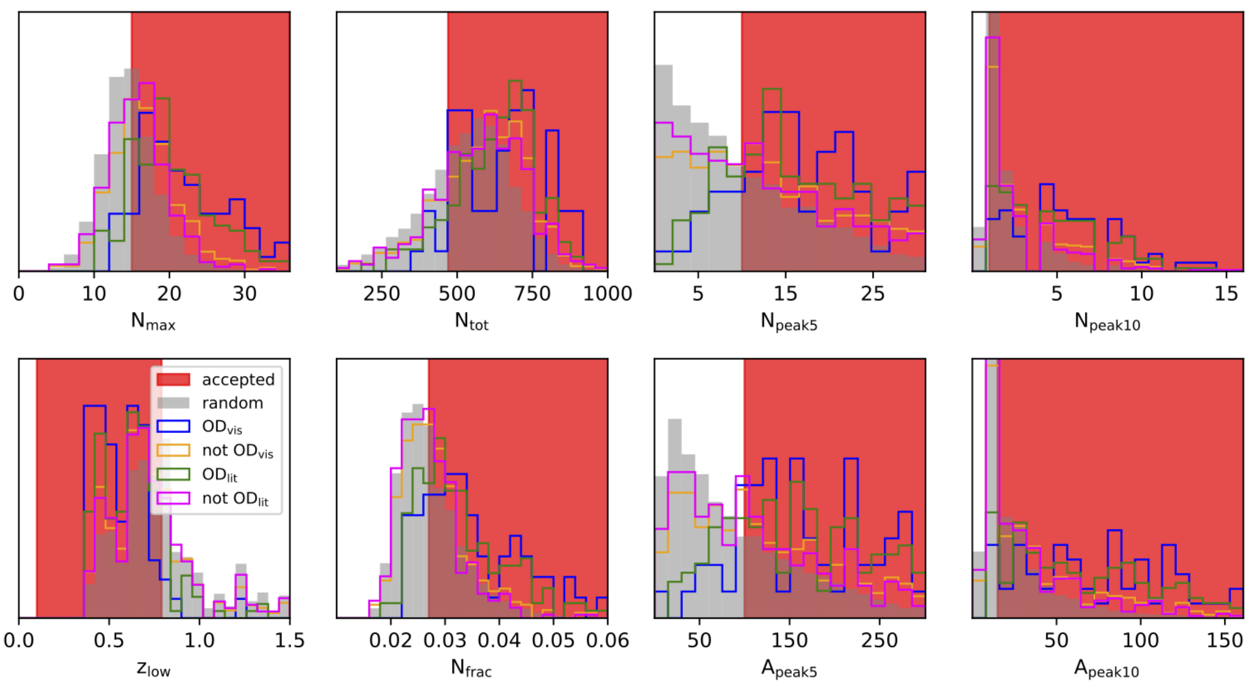
1 output

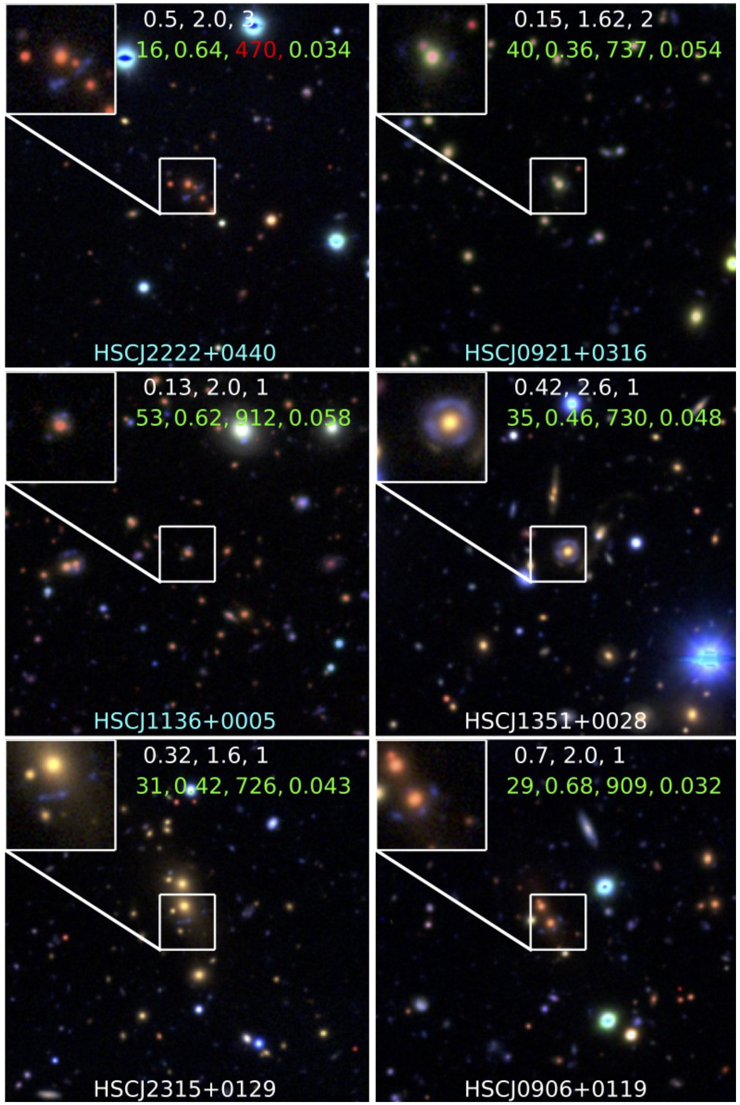
(Melo et al. in prep.)

Also on cluster-scale

→ find 546 grade A or B galaxy-scale lens candidates with ResNet in HSC
→ identify **overdensities** through
- visual inspection
- galaxy cluster catalogs
- photo-z distribution

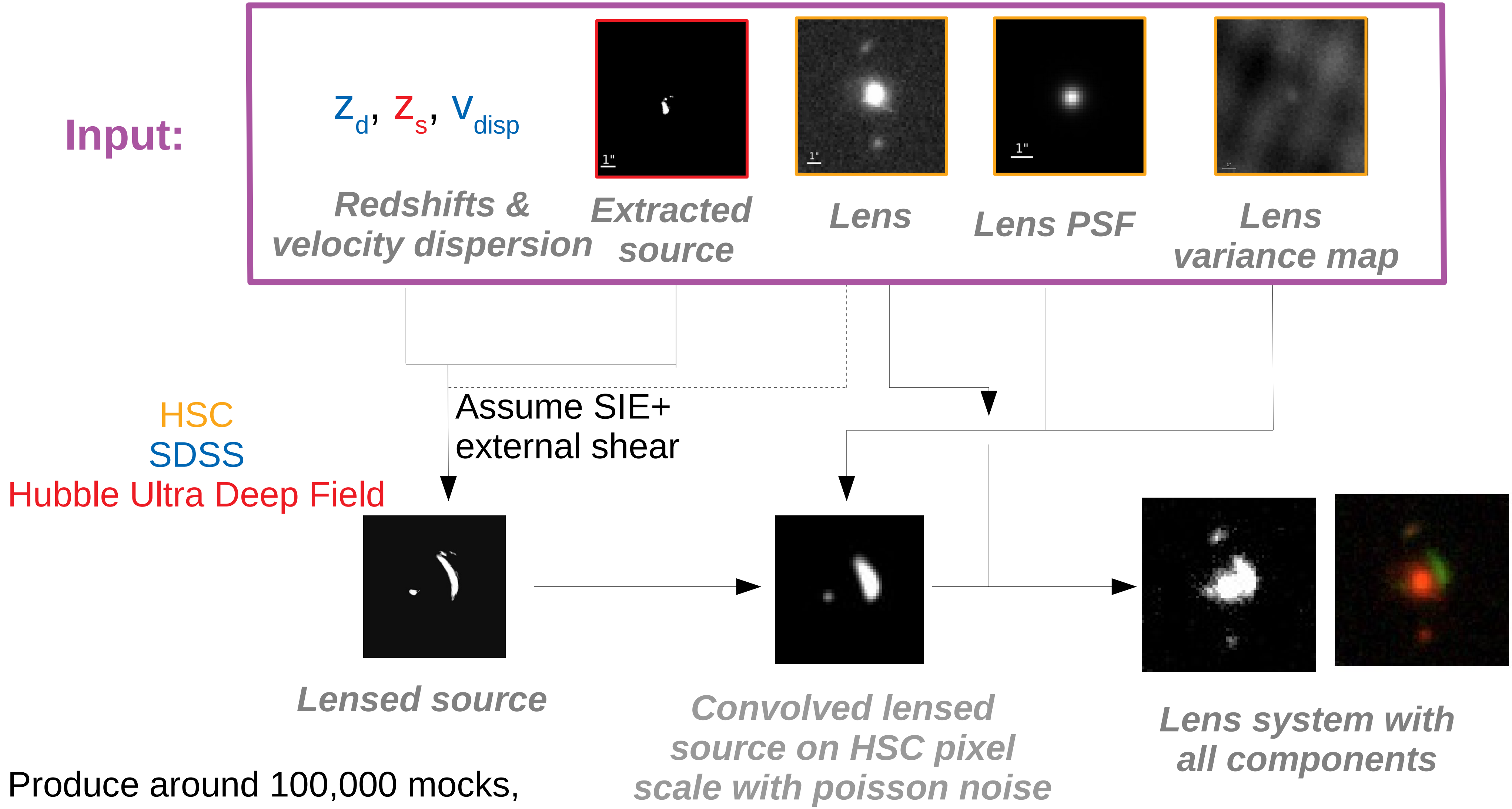
→ define **8 criteria:**





(Schuldt et al. in prep.)

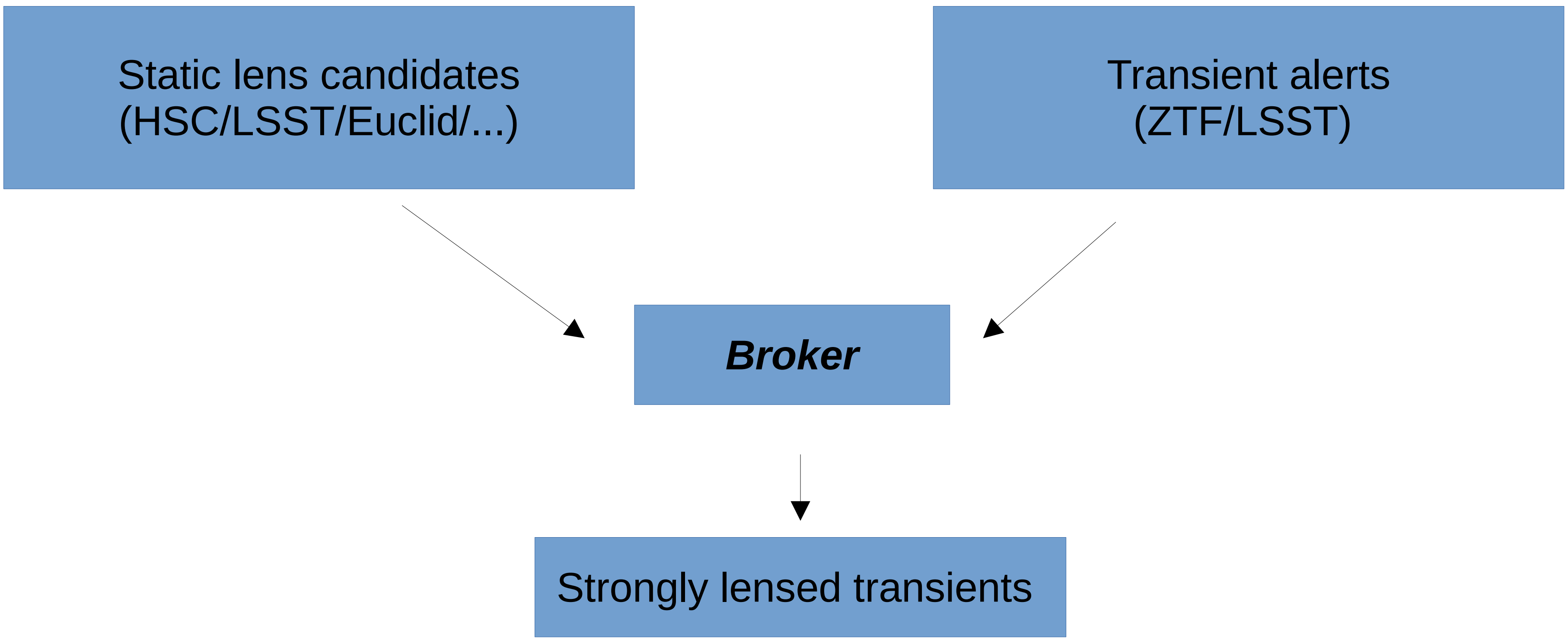
Training data simulations



Produce around 100,000 mocks, each in four filters: *griz*

Schuldt et al. (2022, 2023)

Cross matching



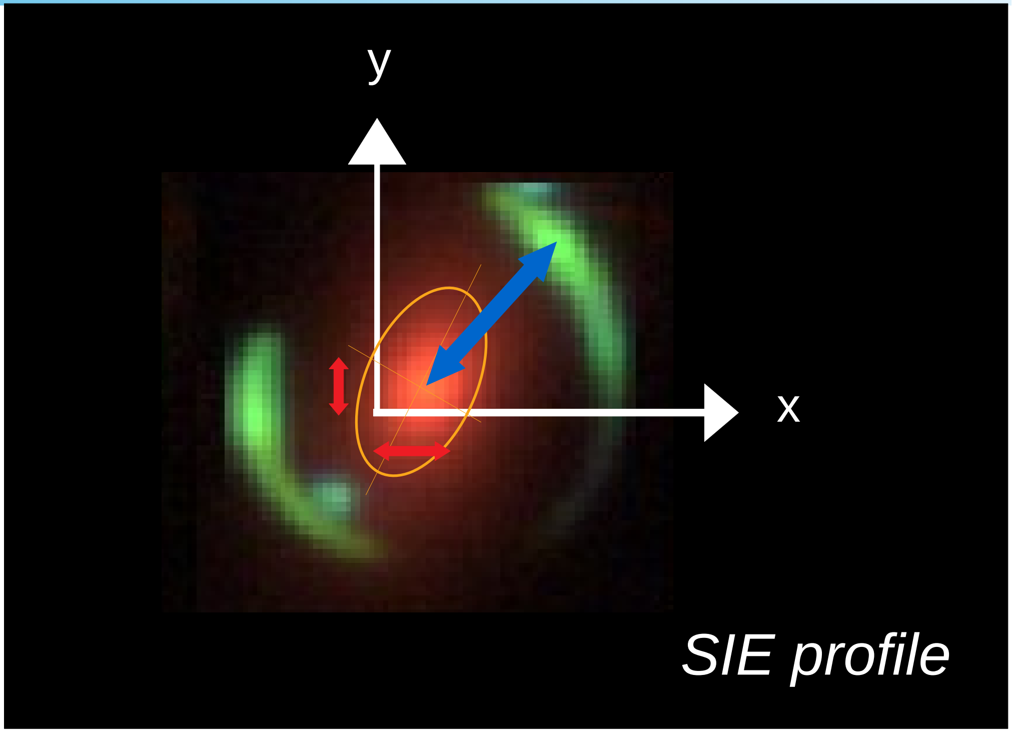
Time delays (galaxy scale): **days to weeks**

→ <u>immediate follow-up planning needed</u>

→ need **lens mass model** to predict when and where next image appears

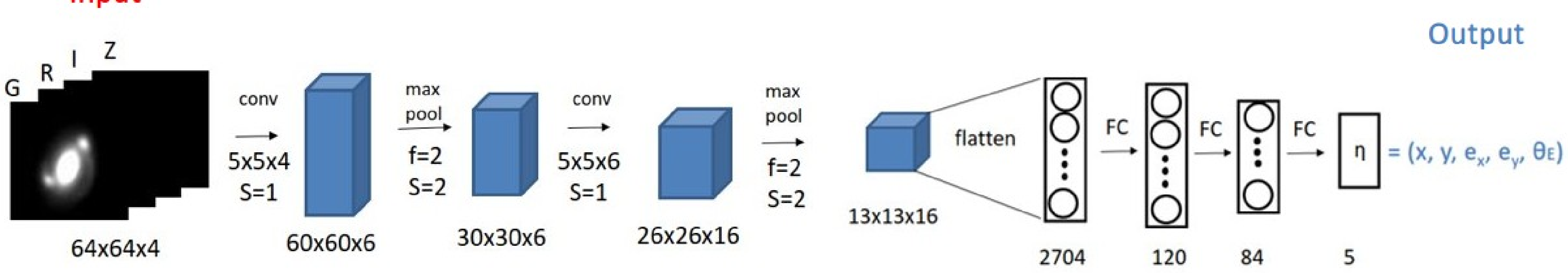
Convolutional neural network

- Lens mass distribution described by:
  - Lens center (x,y)
  - Ellipticity (e_x, e_y)
  - Einstein radius θ_E
- Speed-up with machine learning



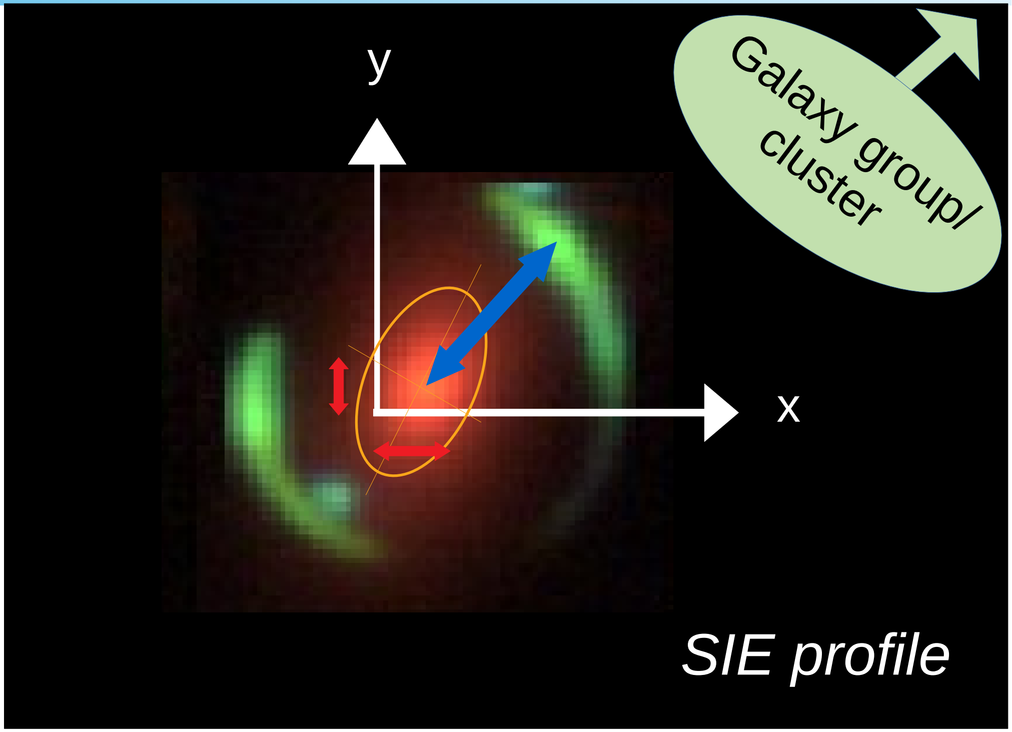
Inspired by Hezaveh, Perreault Levasseur and Marshall (2017)

Weeks → fractions of a second



Convolutional neural network

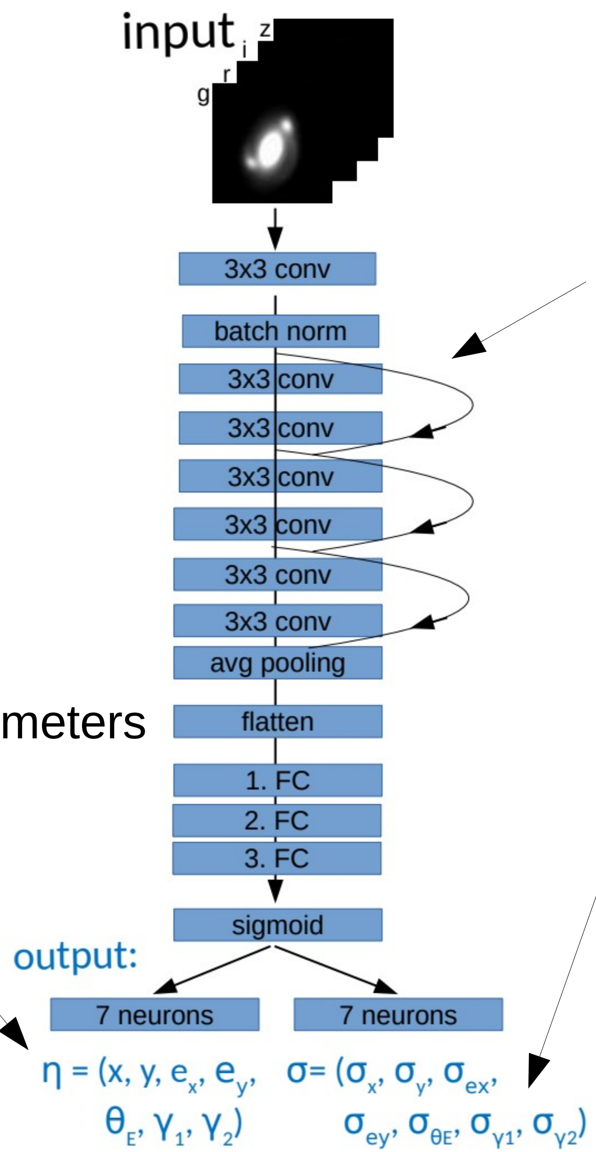
- Lens mass distribution described by:
  - Lens center (x,y)
  - Ellipticity (e_x, e_y)
  - Einstein radius θ_E
- External shear:
  - γ_1 and γ_2



Inspired by Hezaveh, Perreault Levasseur and Marshall (2017)

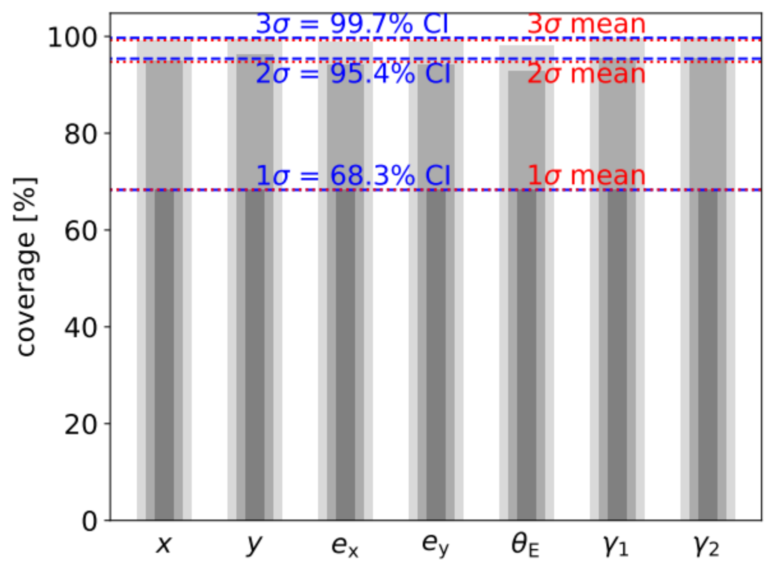
Residual neural network

Residual neural network (ResNet) with skip connections
→ deeper networks trainable



Predict 7 parameters as median

plus 7 uncertainties
→ scale to match 1σ, 2σ, 3σ for correct interpretation

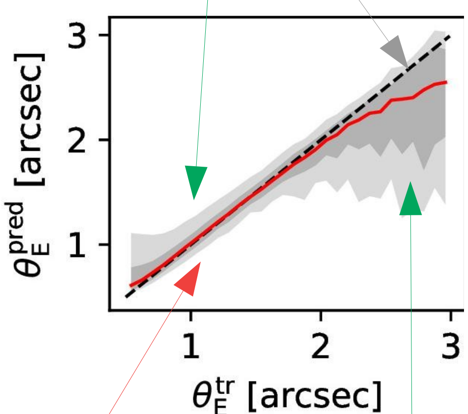


Network performance

Einstein radius

Θ_E ≤~1” very blended

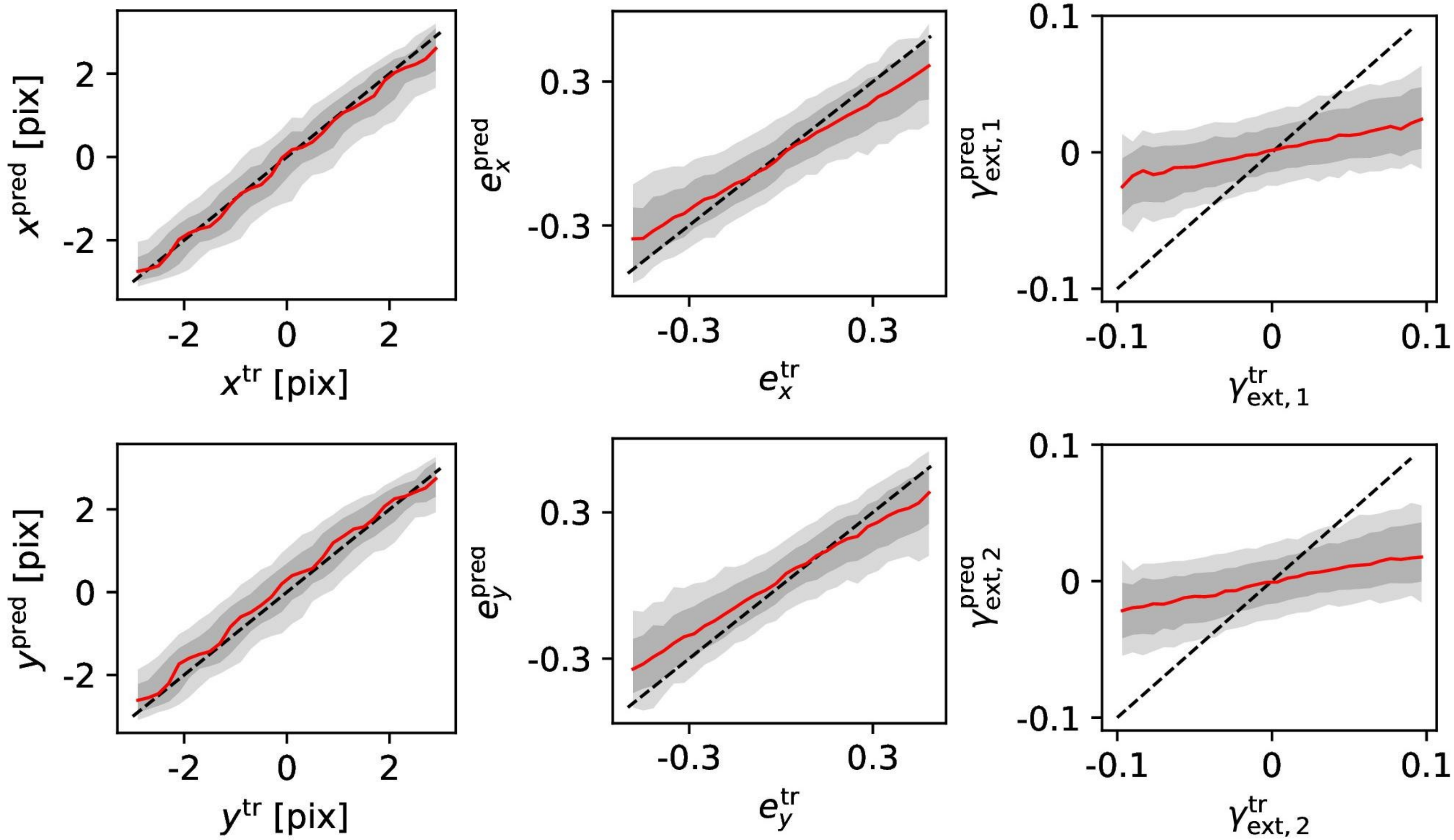
1 & 2 σ



median

Θ_E ≥~2” very selc
the training data

Lens center **Ellipticity** **External shear**



Scatter since mass does not follow perfectly light in our mocks (and reality)

Too hard for the network with given image resolution?

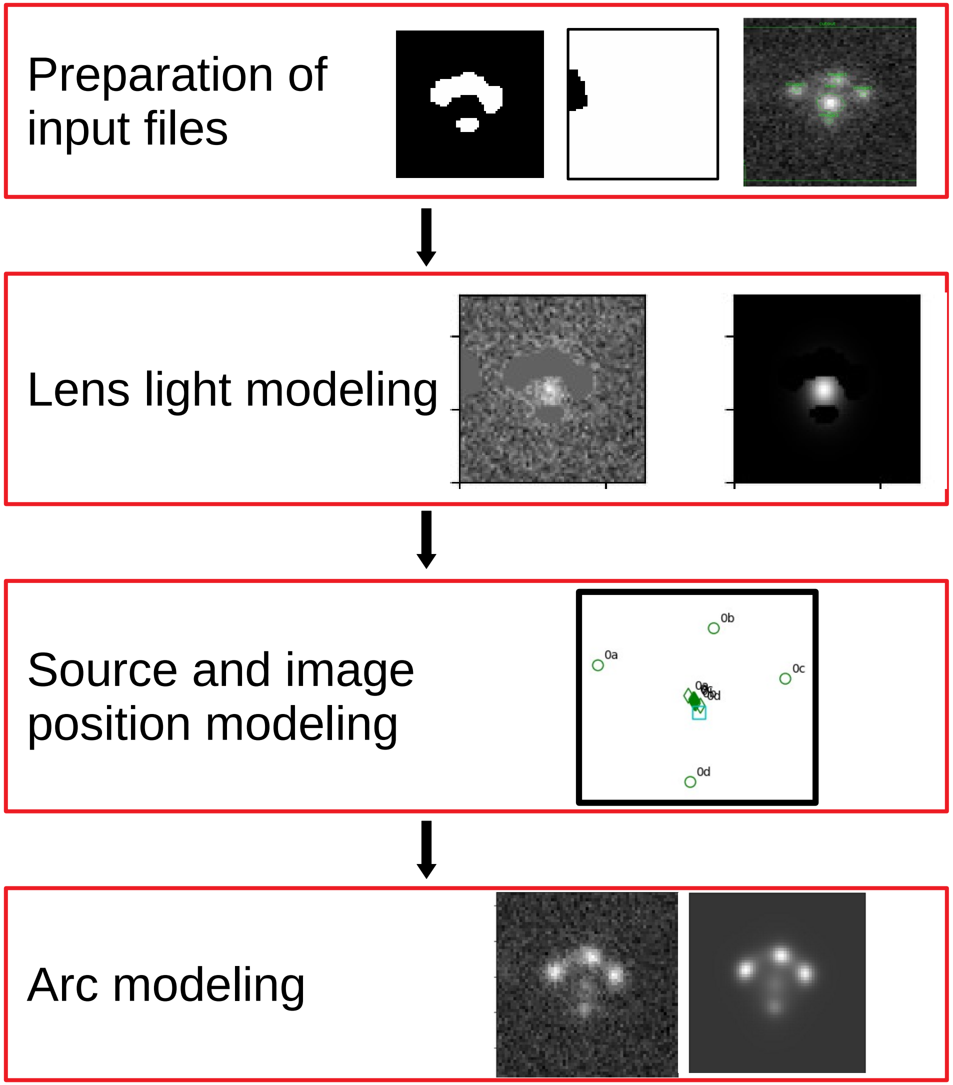
Schuldt et al. (2023)

Direct comparison

31 grade A galaxy-galaxy lenses

- model them with traditional MCMC sampling method

→ develop *glee_auto.py and glee_tools.py* to reduce user input time



Schuldt et al. (2023a)

Direct comparison

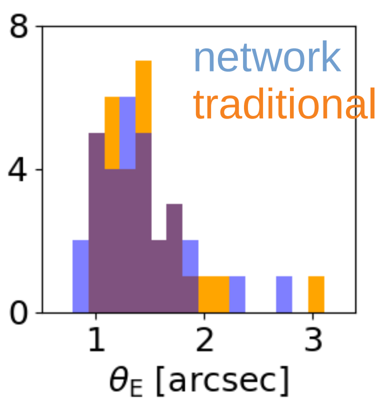
31 grade A galaxy-galaxy lenses

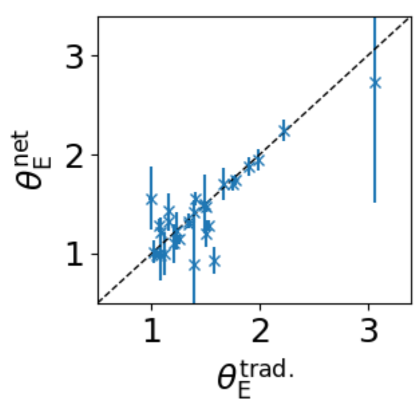
- model them with traditional MCMC sampling method

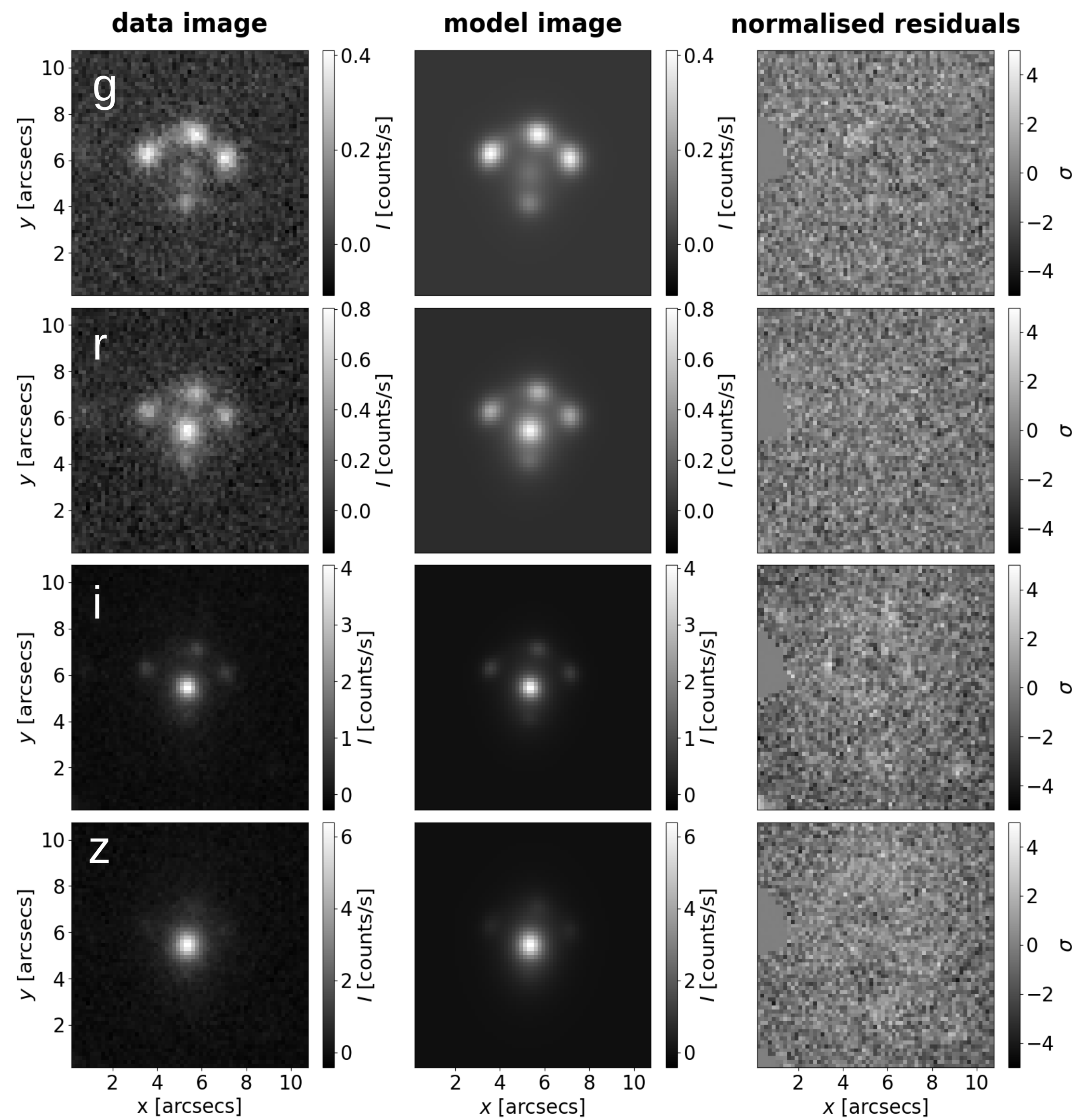
→ develop *glee_auto.py and glee_tools.py* to reduce user input time → days

- model with presented network

→ milliseconds without light modeling

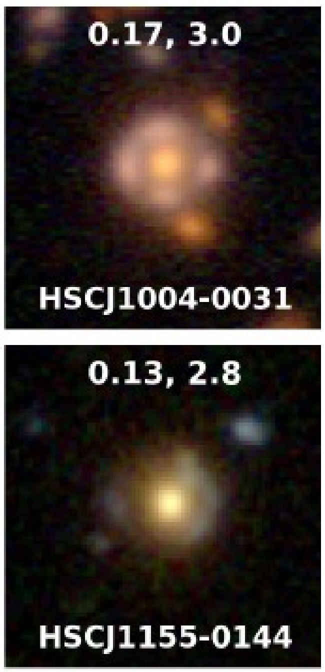






Summary

Galaxy-scale lens search



Cluster-scale lens search

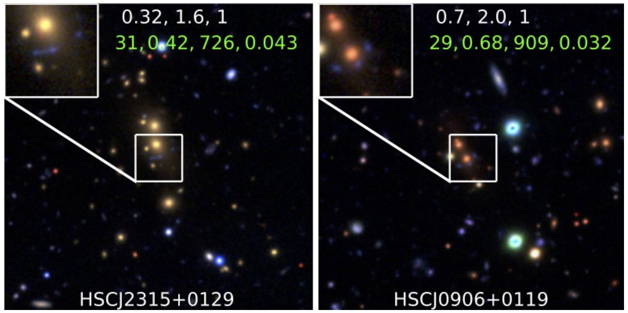
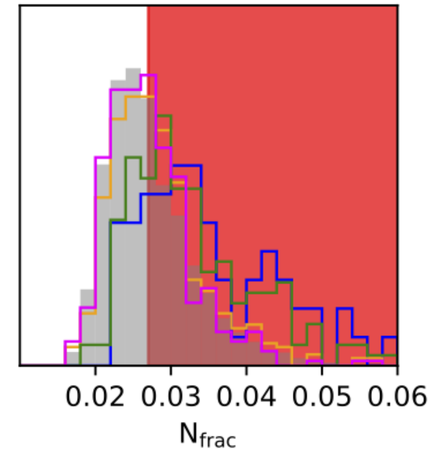
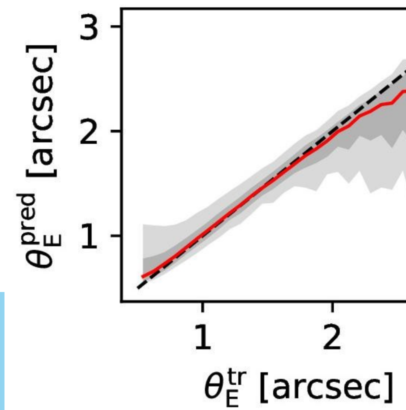


Photo-z analysis



Modeling through deep learning



Automated traditional lens modeling