Time Delay Lens Modeling Challenge (TDLMC)

Design and Result

https://tdlmc.github.io/

arXiv: 2006.08619

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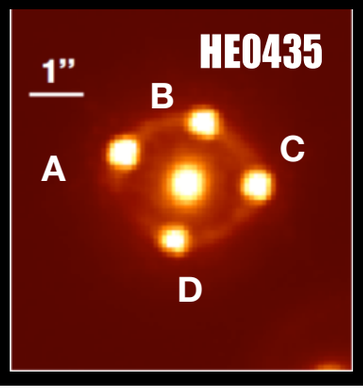
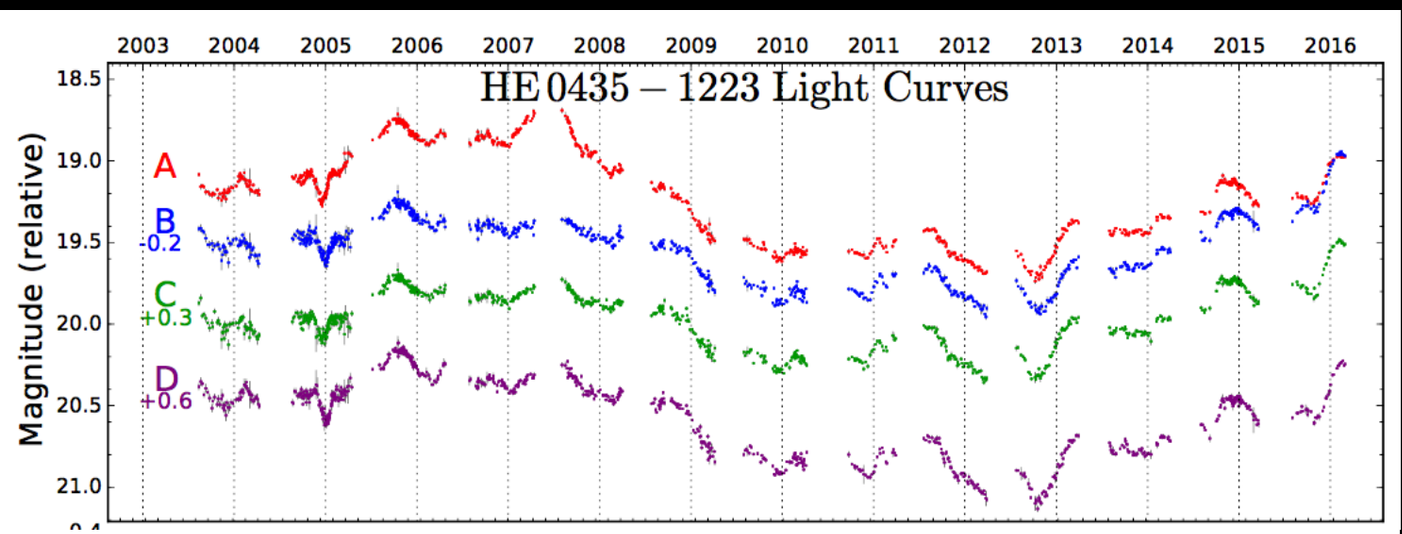
@Time-Domain Cosmology with Strong Gravitational Lensing

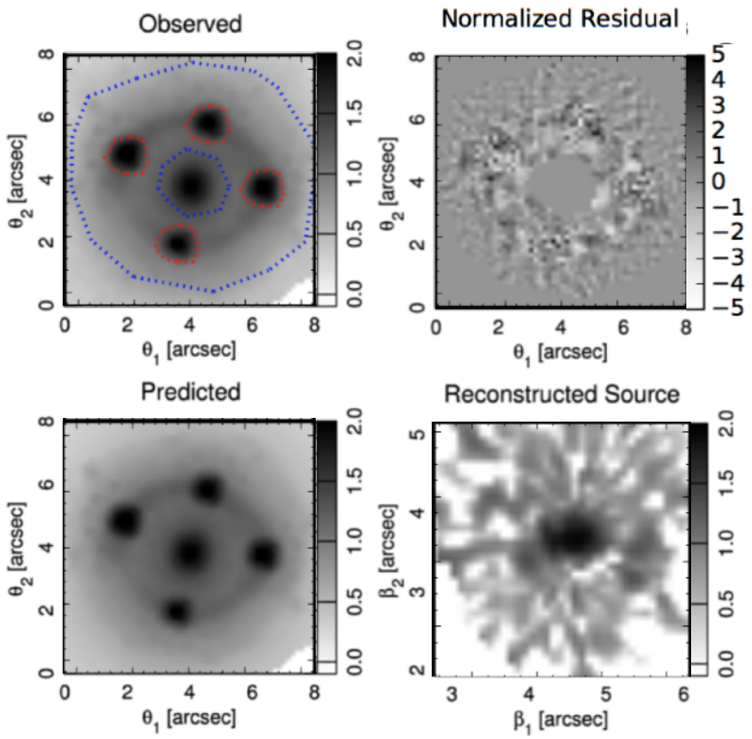
Strong lensing time-delay cosmography





$$t(\boldsymbol{\theta},\boldsymbol{\beta}) = \frac{D_{\Delta t}}{c}\left[\frac{(\boldsymbol{\theta}-\boldsymbol{\beta})^2}{2} - \psi(\boldsymbol{\theta})\right]$$

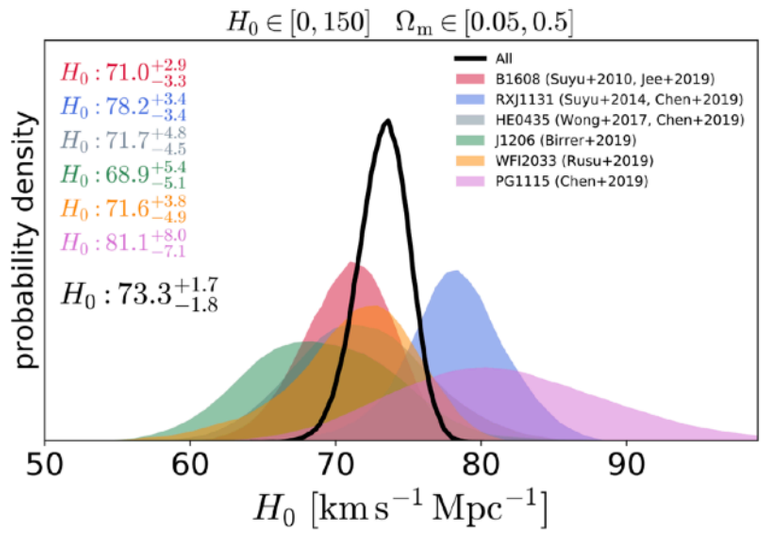
Lens modeling to infer Fermat potential



$$\left[\frac{(\boldsymbol{\theta}-\boldsymbol{\beta})^2}{2} - \psi(\boldsymbol{\theta})\right]$$

Deriving time delay distance to infer H_0

$$D_{\Delta t} \equiv (1+z_{\rm d})\frac{D_{\rm d}D_{\rm s}}{D_{\rm ds}},$$



H0LiCOW combine six AGN systems and determine H0 to 2.4%.

Wong K. C., et al., 2017, MNRAS, 465, 4895

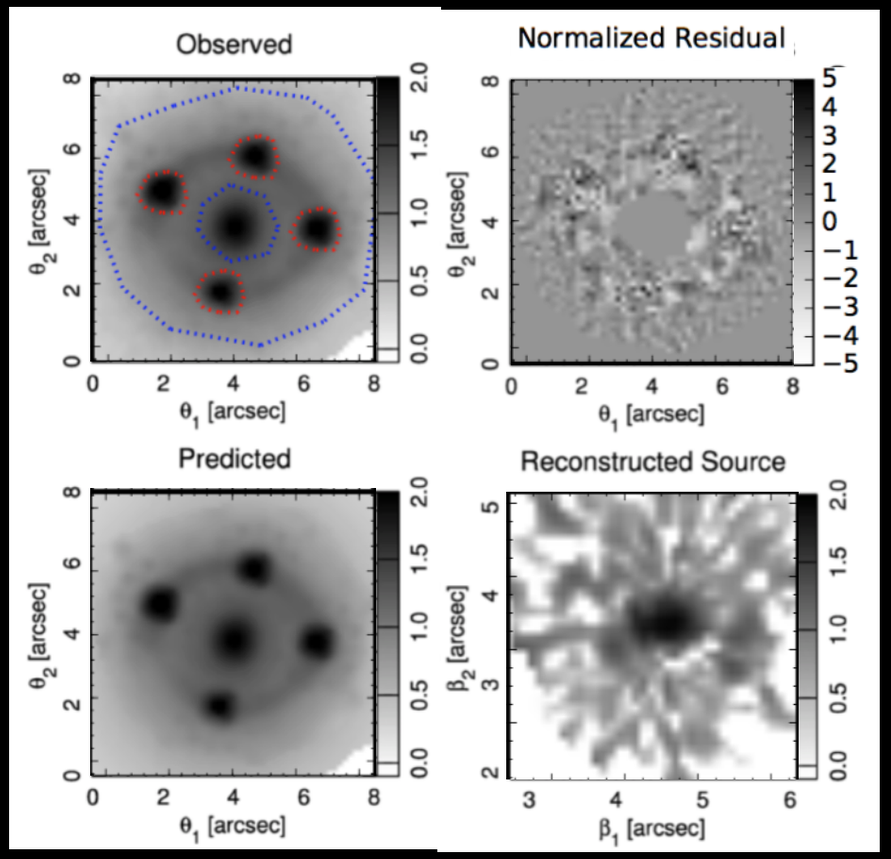
Wong K. C…, Ding X…, 2020, MNRAS, 498, 1420

Uncertainties in the lens mass model

Question:

Can we infer the Fermat potential accurately?

$$\left[\frac{(\boldsymbol{\theta}-\boldsymbol{\beta})^2}{2}-\psi(\boldsymbol{\theta})\right]$$



Time Delay Lens Modelling Challenge (TDLMC)

TDLMC design

- Simulation (“Evil”) team provides mock lenses to modelling (“Good”) team to analyze.

  Mock datasets including:

  i) *HST*-like lensed AGN images,
  ii) lens time delay,
  iii) line-of-sight velocity dispersion.

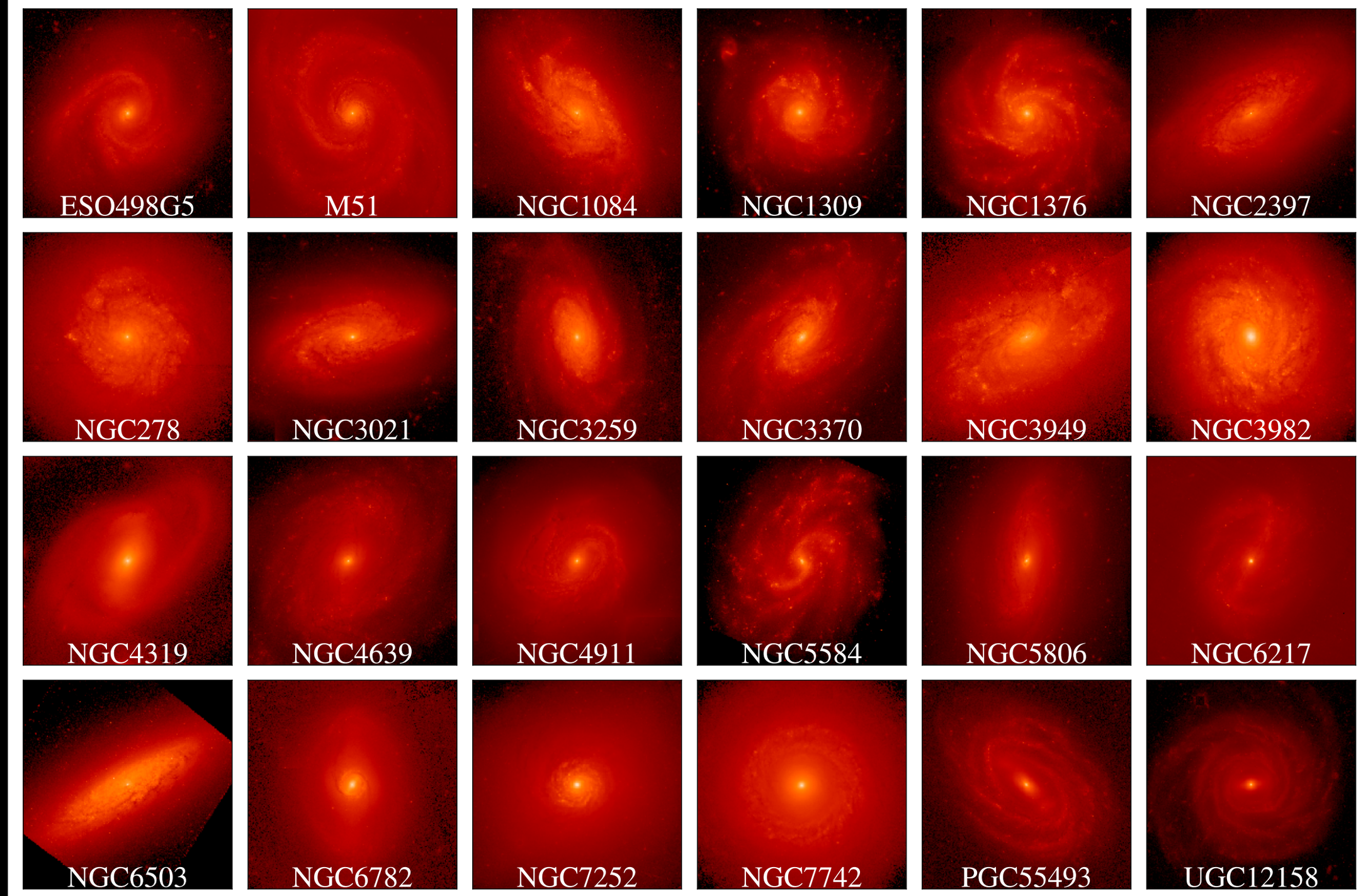
- “Good” teams constrain the H_0 – Blindly
- Compare the result and assess the precision and accuracy

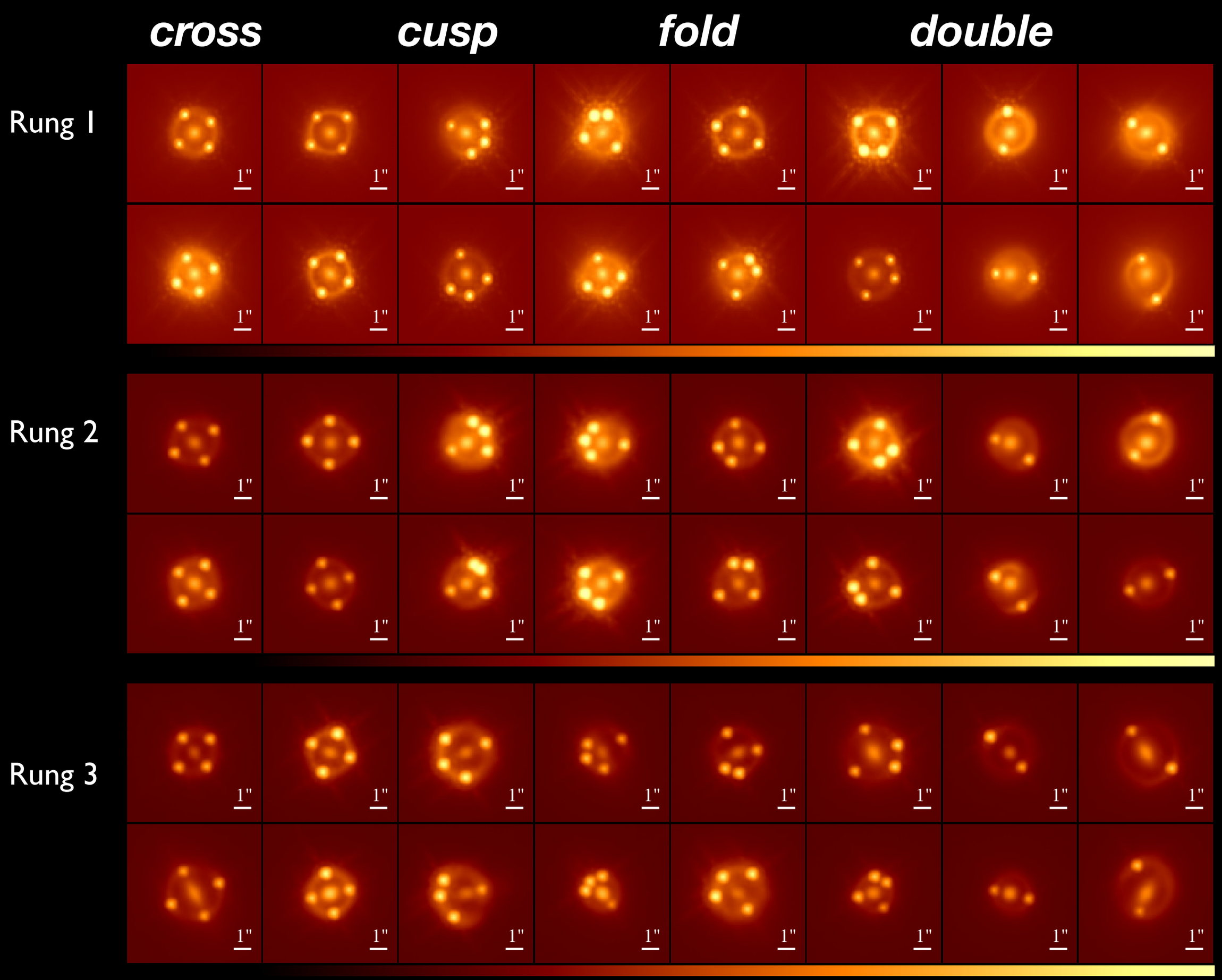
Challenge structure

- Three testing rungs:
  1. Each rung contains 16 systems (***cross, cusp, fold*** and ***double*** configurations)
  2. Increasing complexity and realism during the 3 rungs.

- Details:
  - Rung1: *Realistic galaxy image as the lensed AGN host galaxy.*
  - Rung2: + *True PSF information does not provide.*
  - Rung3: + *Realistic lens mass profile as deflector.*

Realistic galaxy images are adopted as lensed AGN host galaxy.




cross
cusp
fold
double
Rung 1
Rung 2
Rung 3
1"

Mock dataset

i) *HST*-like lensed AGN images,

ii) lens time delay,

$$t(\boldsymbol{\theta}, \boldsymbol{\beta}) = \frac{D_{\Delta t}}{c} \left[\frac{(\boldsymbol{\theta} - \boldsymbol{\beta})^2}{2} - \psi(\boldsymbol{\theta}) \right]$$

iii) line-of-sight velocity dispersion

For Rung 1, 2

$$\frac{1}{l(r)} \frac{\mathrm{d}(l\sigma_r^2)}{\mathrm{d}r} + 2\beta_{\mathrm{ani}}(r) \frac{\sigma_r^2}{r} = -\frac{GM(\leq r)}{r^2}$$

For Rung 3, calculated from the simulated 2D velocity dispersion map

Submissions

- There are five teams participates the TDLMC.

  Student-T; EPFL; Freeform; Rathnakumar; H0rton

- We receive in total 18, 17, 24 submissions in Rung1, Rung2 and Rung3, respectively.
- The approaches:
  - Lenstronomy was adopted by Student-T and EPFL team.
  - Freeform team adopts the PixeLens and GLASS (pixellate the lens' mass distribution).
  - Rathnakumar team uses Glafic (only constrain simple SIE using lensed QSO image).
  - H0rton team uses machine learning approach (they join late submit only Rung3).

Table 3. Summary table of input data.

Team	point sources	extended source	kinematics
Student-T	Yes	Yes	No
EPFL	Yes	Yes	Yes
Freeform	Yes	No	No
Ratherkuma	Yes	No	Yes
H0rton	Yes	Yes	Yes

Note: – Table summarizes the input data as used by the "Good" team. In addition, all teams use time delays and redshifts, and simulated *HST* images to constrain the deflector.

Metrics for each rung

- Success rate:

$$f = \frac{N}{N_{\text{total}}} \quad (N_{\text{total}} = 16)$$

- Goodness:

$$\chi^2 = \frac{1}{N} \sum_i \left(\frac{\tilde{H}_{0\,i} - H_0}{\delta_i} \right)^2$$

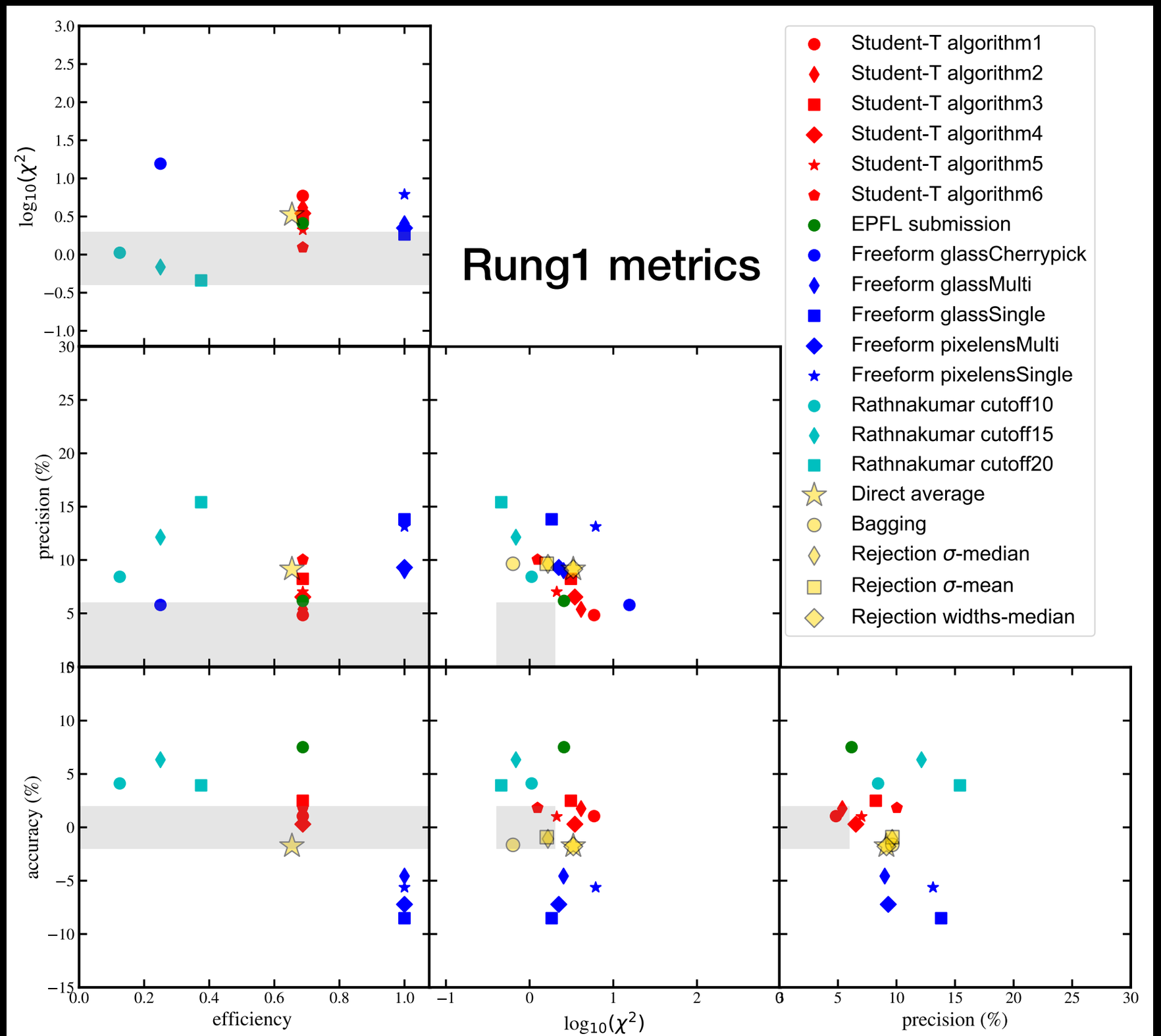
- Precision:

$$P = \frac{1}{fN} \sum_i \frac{\delta_i}{H_0}$$

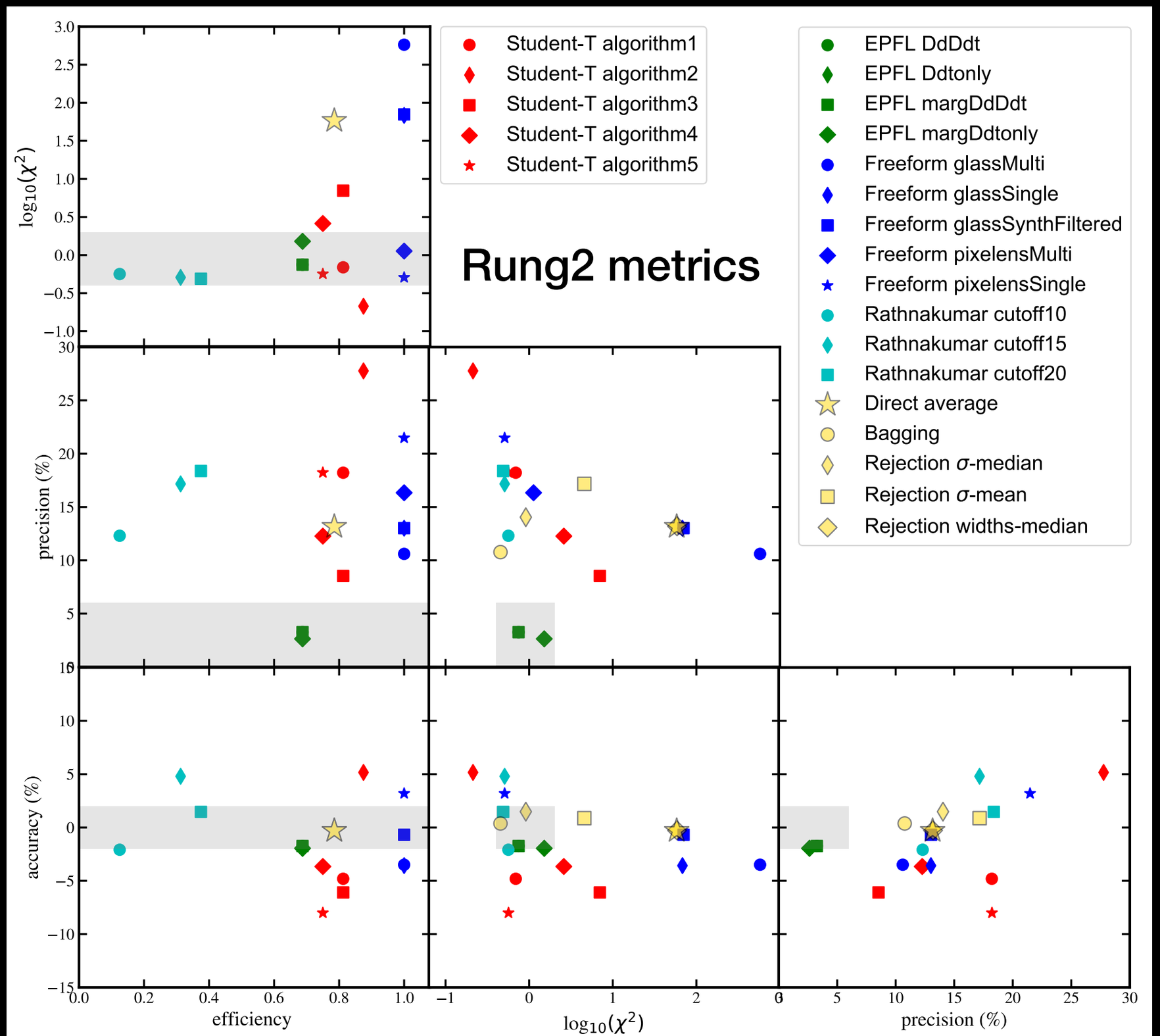
- Accuracy

$$A = \frac{1}{fN} \sum_i \frac{\tilde{H}_{0\,i} - H_0}{H_0}$$

Results of Rung1 and Rung2



Results of Rung1 and Rung2



Summary for Rung1, 2

- Most methods seem to have a realistic assessment of their uncertainties, landing on or close to the χ^2 target.

- Unexpectedly, the accuracy are improved from Rung 1 to Rung 2, likely due to the fact that the “Good” teams learned from Rung 1’s results to improve their algorithms, and identify bugs in the codes.

- The methods constrained only using point source tend to produce significantly larger uncertainties. Only the method using the full extent of the surface brightness of the host galaxy and the ancillary data hits the precision target, with sufficient accuracy.

Combined metrics for Rung2:

Combined fitting algorithm	Precision (%)	Accuracy (%)
Everything	2.9	-1.8 ± 0.4
Extended Source	11.4	-2.7 ± 1.0
Point Sources	15.2	2.5 ± 1.4

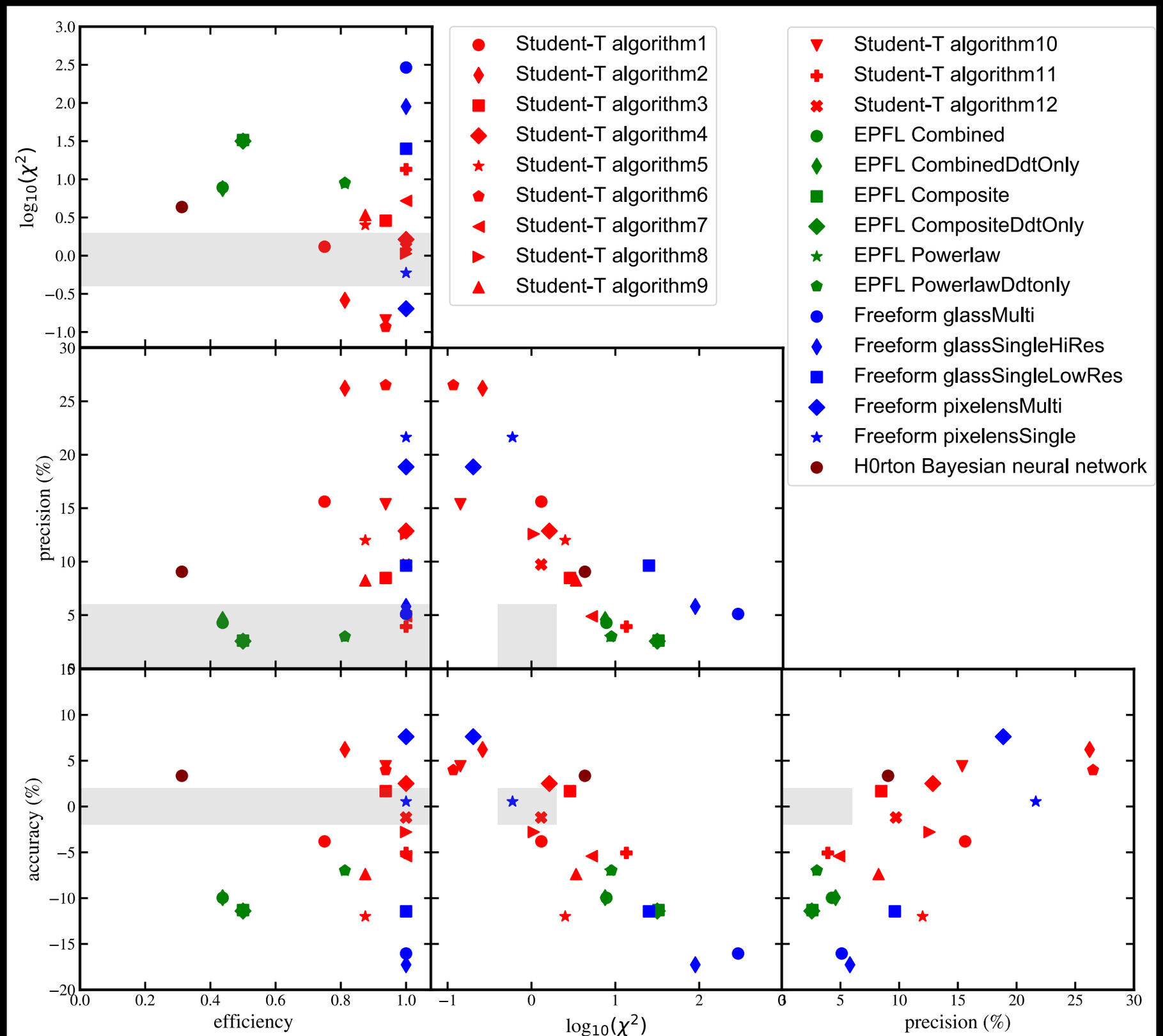
Limitation of Rung3

The Rung3 deflectors are based on hydrodynamical simulations with limitations, making the Rung3 inconclusive.

- The resolution of the simulations we used is insufficient to describe the inner regions of early-type galaxies, generate an artificial core in the central deflector.
- In some simulated deflector fields, some satellite halos were identified and removed before producing the lensing quantities.
- Truncation of the kappa map.
- Unrealistic magnification of the central image.

The result of Rung3 should be taken with cautions.

Rung3 metrics



Thanks!