中国科学院上海天文台
Shanghai Astronomical Observatory, Chinese Academy of Sciences

ClUsteR strong Lens modelIng for the Next-Generation observations (CURLING)

The Bias from Point-like Multiple Image Approximation

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OUTLINE

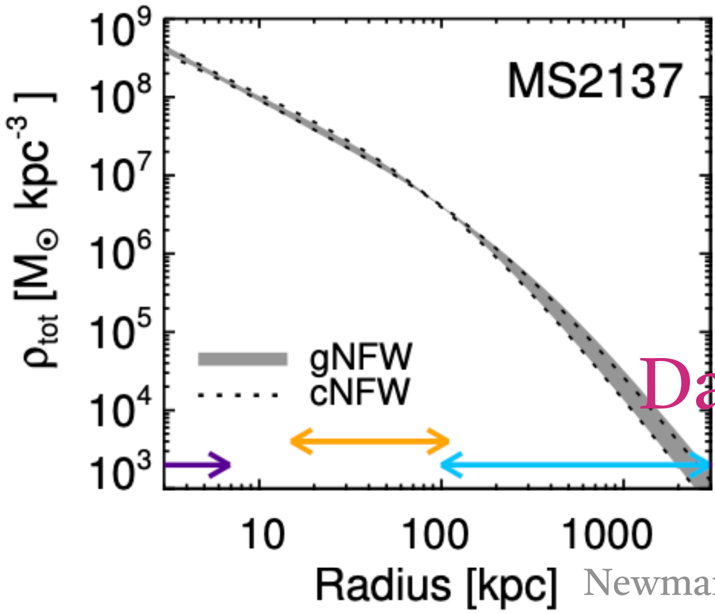
I. Basics

II. The bias from point-like multiple image approximation

III. Solution: A pixelated method

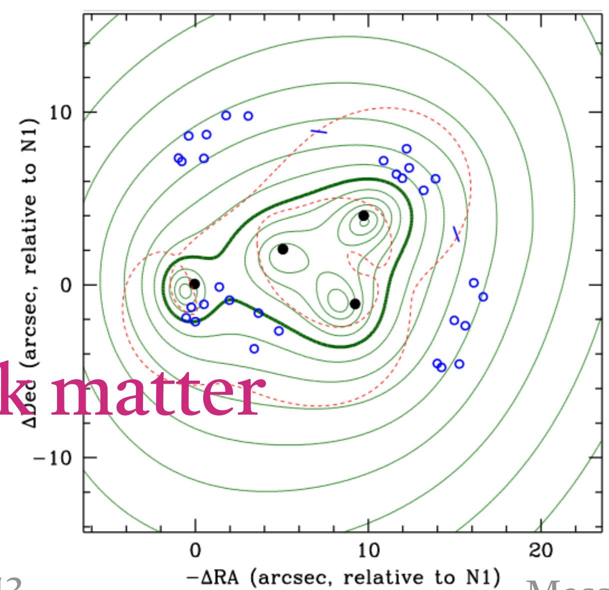
IV. Next steps

I. Basics: cluster strong lensing



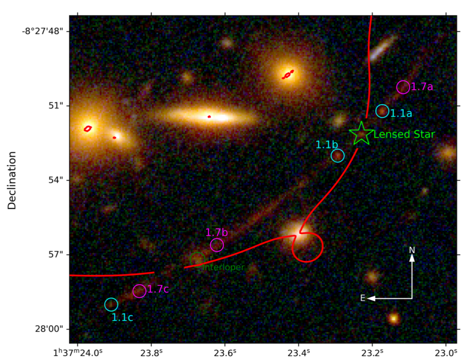
Newman+13

Dark matter

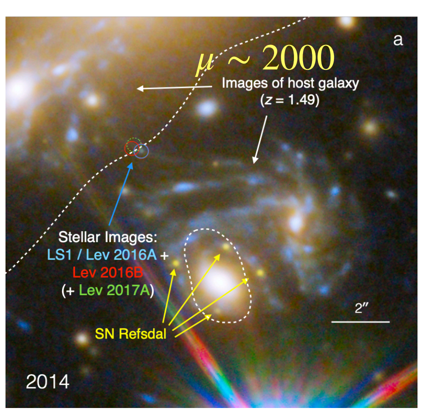


Massey+15

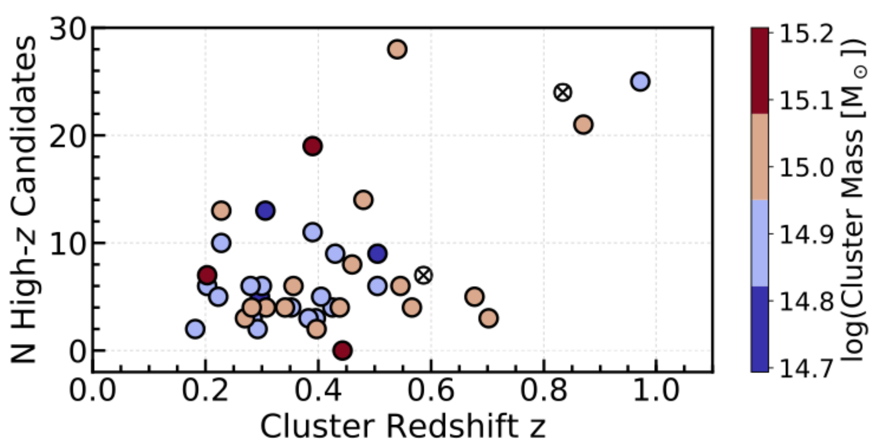
- ~ 1 SL cluster-lens per ~ 10 sq. deg: potentially ~ 2000 to study, only ~ 200 identified today, nearly ~20 with a good mass model (taken from Jean-Paul's talk, 2011)



Welch+22

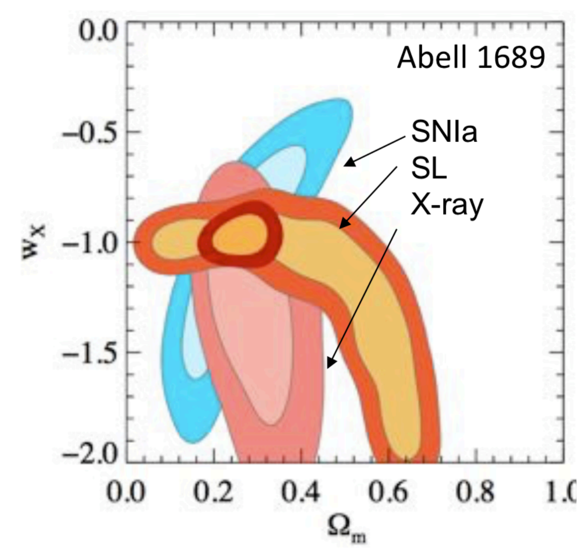


Kelly+18

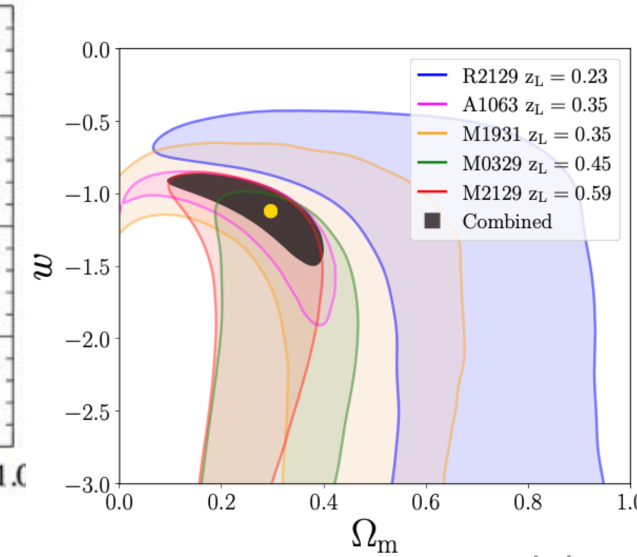


Salmon+20, RELICS

High-z Universe



Jullo+10



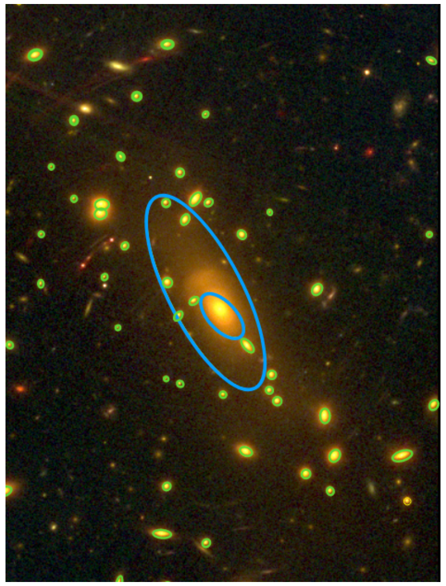
Caminha+21

Cosmography

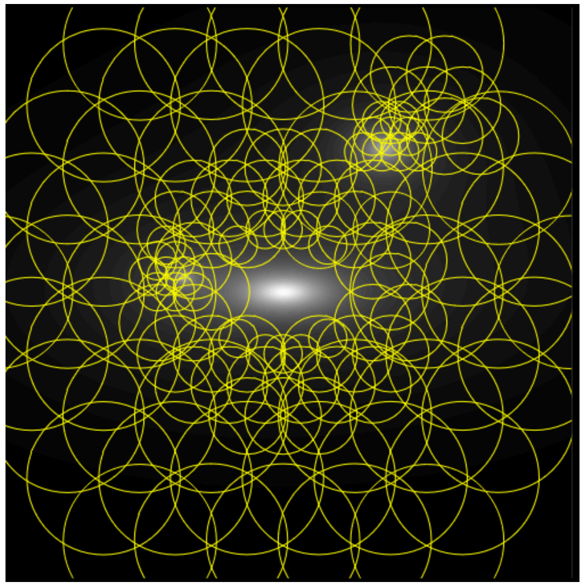
I. Basics: cluster strong lensing

Parametric

$$\phi_{\rm tot} = \sum_i \phi_{c_i} + \sum_j \phi_{p_j}$$



Non-parametric

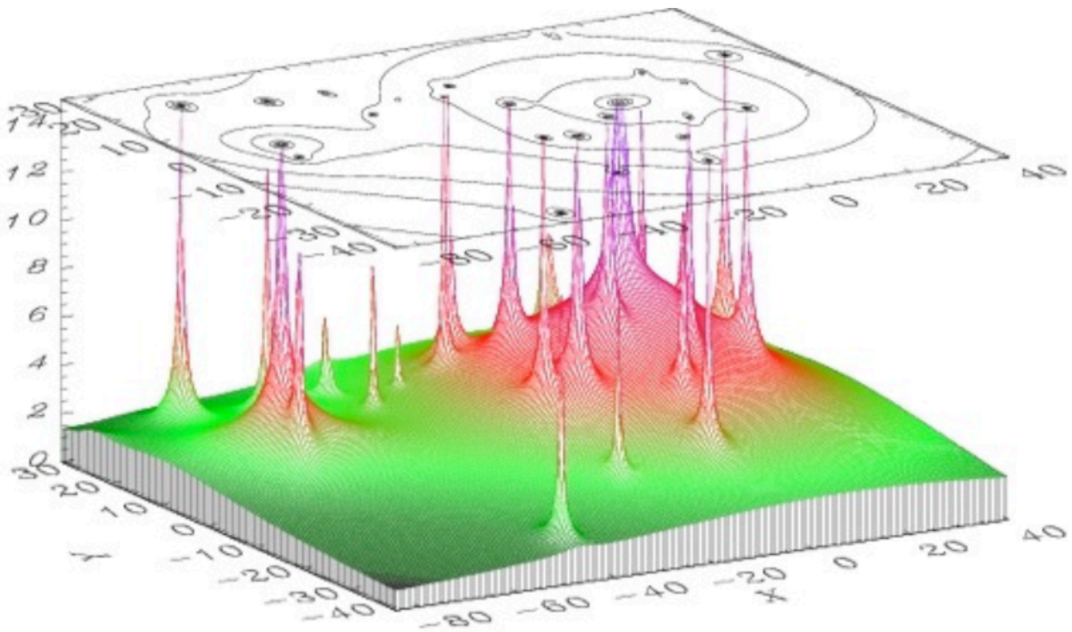


Strong lens modeling: algorithms

Package	Model
gravlens / lensmodel	Para
Lenstool	Para/Non-Para
LensPerfect	Non-Para
glafic	Para
PixeLens	Non-Para
SimpLens	Non-Para
Lensview	Non-para
GRALE	Non-Para
GravLensHD	Para
G-Lens	Para
Gravitational Lensing	Para
lens	Para/Non-para
MOWGLI	-

Lefor+13

II. The bias from point-like multiple image approximation



Kneib+1996

Parametric lens modeling

- Constraints (position, redshift, shape, flux)
- Model parameterization
  - Large scale clumps: dark matter halo, gas
  - Small scale substructures: galaxy subhaloes
- Model optimization

Too complex!

Systematics from observational side:

- scaling relation,

- line-of-sight halos,

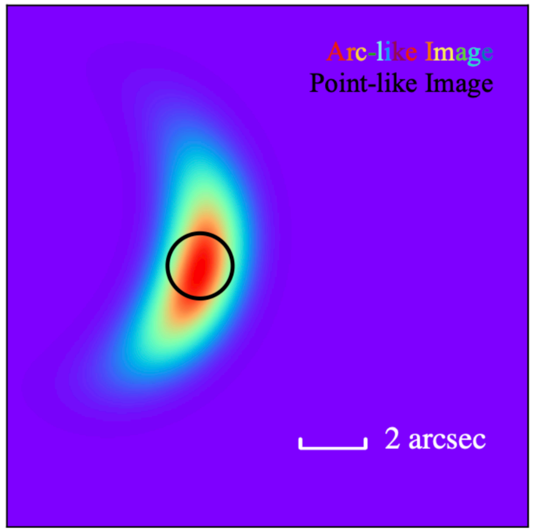
- model assumption,

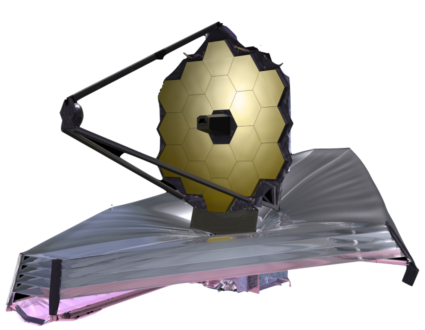
- astrometric errors

- ...

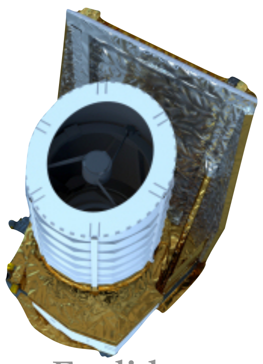
The bias

$$\chi_i^2 = \sum_{j=1}^{n_i} \frac{[\theta^j_{\rm obs} - \theta^j(\mathbf{p})]^2}{\sigma_{ij}^2}$$





JWST



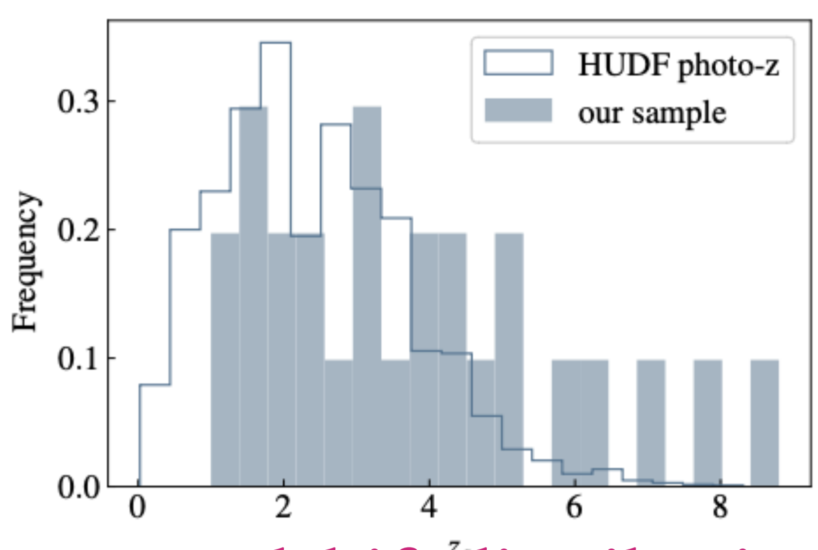
Euclid

CSST

II. The bias from point-like multiple image approximation

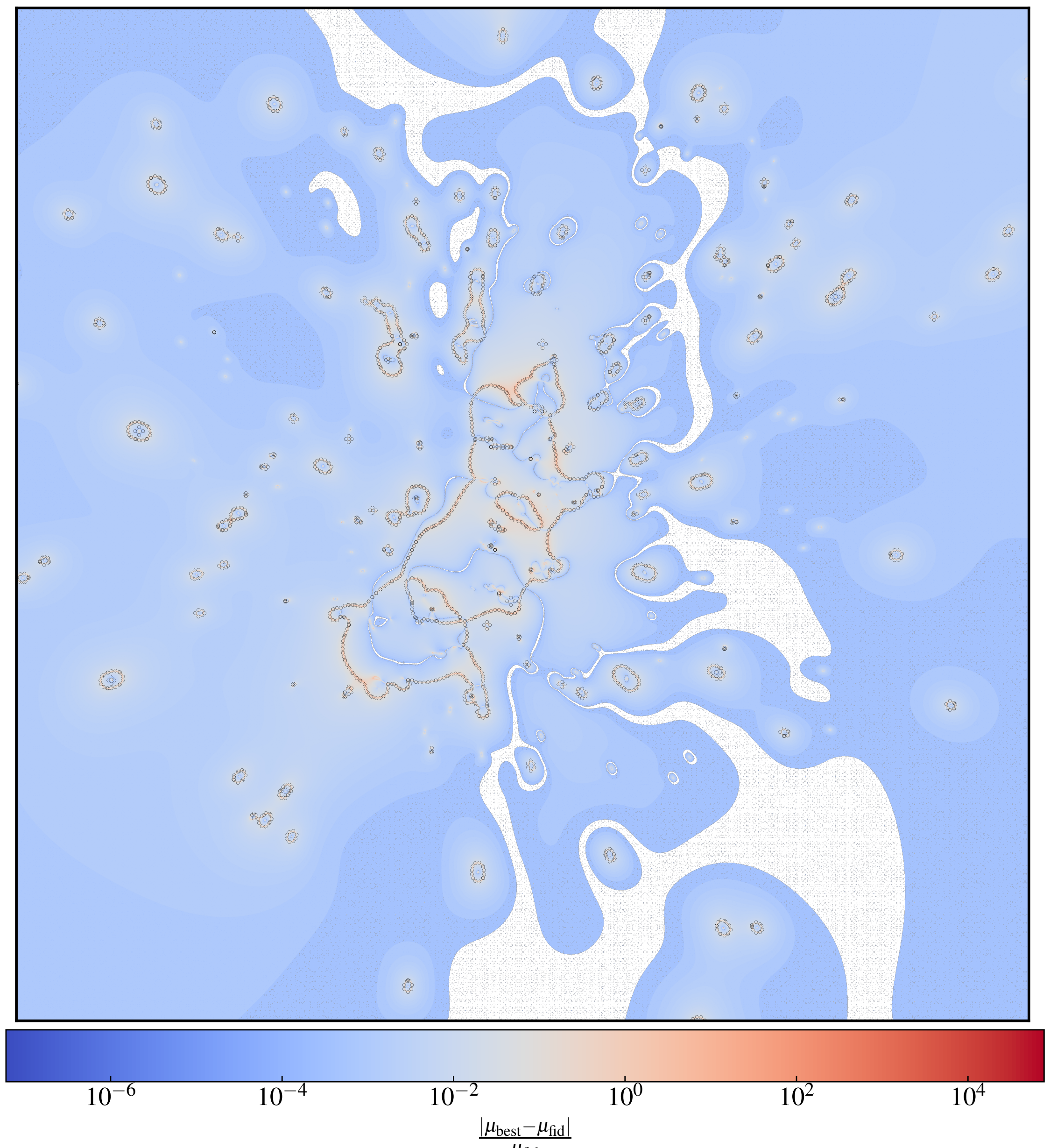
Test on simulated strong lensing clusters: extracted from Hubble Frontier Fields

Component	$\Delta\alpha$ [″]	$\Delta\delta$ [″]	e	θ [deg]	r_{core} [kpc]	r_{cut} [kpc]	σ [km/s]
MACS0416-like, $z = 0.35$; $N_s = 26$, $z_{s,toy} = \{1.6,\ 3.5,\ 6.1\}$							
Cluster Halo 1	-0.22	0.06	0.81	143.14	37.39	987.95	615.06
Cluster Halo 2	22.67	-34.27	0.89	136.49	26.26	987.95	466.55
Cluster Halo 3	-32.45	8.80	0.00	0.00	34.23	987.95	308.96
Cluster Halo 4	22.80	-48.15	0.76	122.43	66.73	987.95	707.09
Perturber 1	31.96	-65.55	0.00	0.00	4.94	274.19	76.82
Perturber 2	13.34	2.62	0.60	-45.59	4.94	65.12	106.11
scaling relations	N(gal) = 212	$m^{ref} = 17.02$	$r^{ref}_{core} = 0.15$	$r^{ref}_{cut} = 15.00$	$\sigma^{ref} = 210.00$		
A2744-like, $z = 0.4$; $N_s = 22$, $z_{s,toy} = \{1.5,\ 2.4,\ 3.8\}$							
Cluster Halo 1	-1.42	0.55	0.59	91.39	28.65	1500.0	515.54
Cluster Halo 2	-17.85	-15.22	0.40	53.89	34.12	1600.0	632.73
Ext. Clump 1	99.49	85.97	0.00	0.00	1.3	800.0	111.28
Ext. Clump 2	138.28	99.87	0.00	0.00	1.4	800.0	372.13
Ext. Clump 3	24.23	155.84	0.00	0.00	1.4	800.0	294.63
BCG-N	0.0	0.0	0.28	133.03	1.3	800.0	208.77
BCG-S	-17.95	-20.05	0.74	26.29	0.17	178.47	308.02
scaling relations	N(gal) = 223	$m^{ref} = 17.34$	$r^{ref}_{core} = 0.15$	$r^{ref}_{cut} = 19.52$	$\sigma^{ref} = 252.66$		
MACS1206-like, $z = 0.45$; $N_s = 25$, $z_{s,toy} = \{1.9,\ 4.2,\ 5.7\}$							
Cluster Halo 1	-1.40	0.14	0.72	19.76	35.22	1151.89	748.96
Cluster Halo 2	9.20	3.63	0.46	116.69	77.60	1151.89	662.94
Ext. Clump 1	-28.87	-6.83	0.33	-25.16	70.94	1151.89	501.28
scaling relations	N(gal) = 258	$m^{ref} = 17.19$	$r^{ref}_{core} = 0.15$	$r^{ref}_{cut} = 15.0$	$\sigma^{ref} = 210.0$		
AS1063-like, $z = 0.5$; $N_s = 23$, $z_{s,toy} = \{2.4,\ 3.3,\ 4.3\}$							
Cluster Halo 1	1.44	-0.73	0.63	-38.91	111.26	1220.84	1165.26
Cluster Halo 2	-48.60	26.26	0.01	0.00	30.52	1220.84	213.01
Ext. Clump 1	18.90	-73.36	0.80	-162.05	8.55	1155.16	355.93
BCG	-18.05	13.47	0.13	-27.80	221.73	2070.29	442.57
Perturber	0.20	-1.24	0.34	-15.49	88.11	610.42	249.68
scaling relations	N(gal) = 222	$m^{ref} = 16.18$	$r^{ref}_{core} = 0.15$	$r^{ref}_{cut} = 15.0$	$\sigma^{ref} = 210.0$		

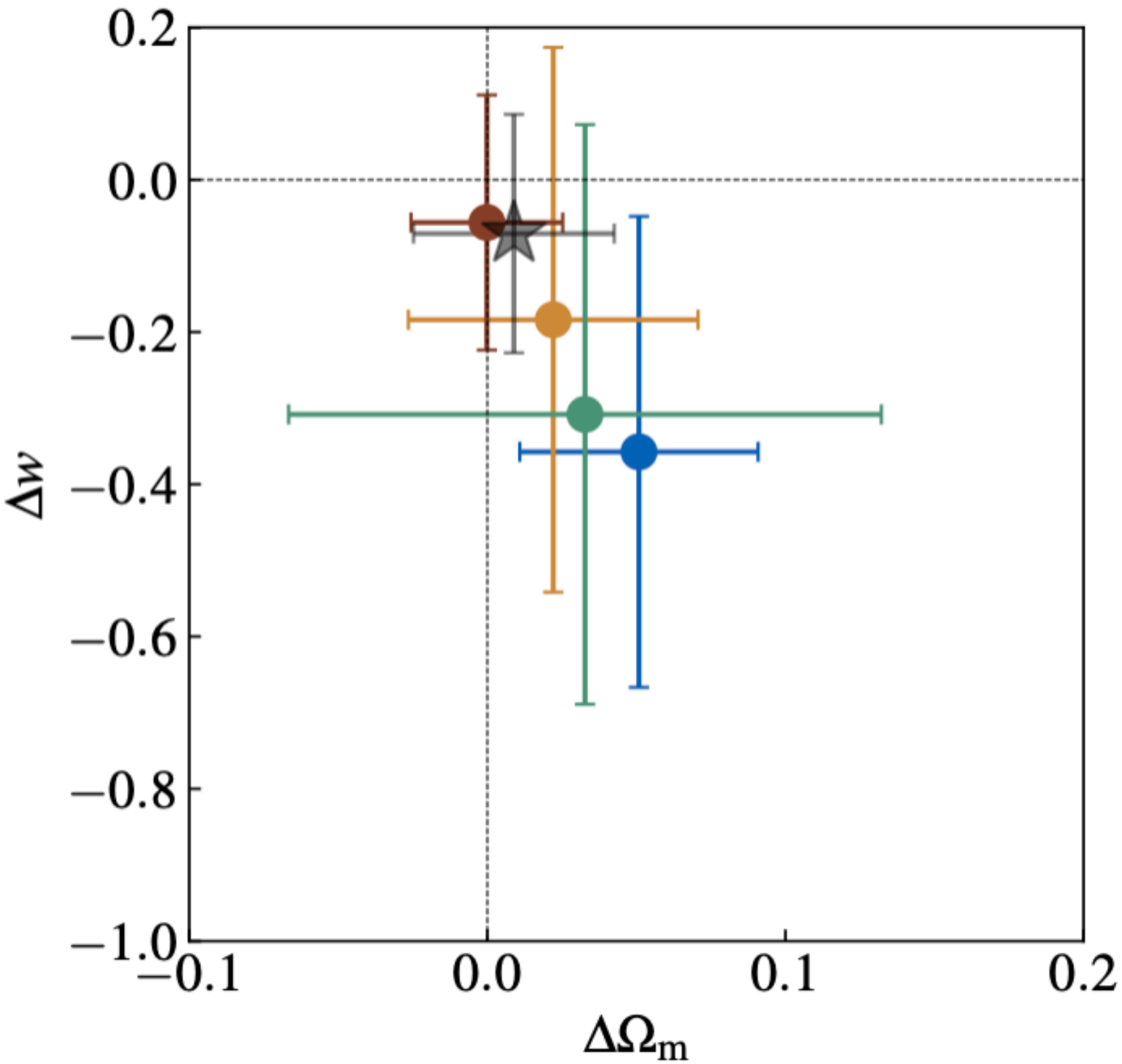


Source redshift distribution

II. The bias from point-like multiple image approximation

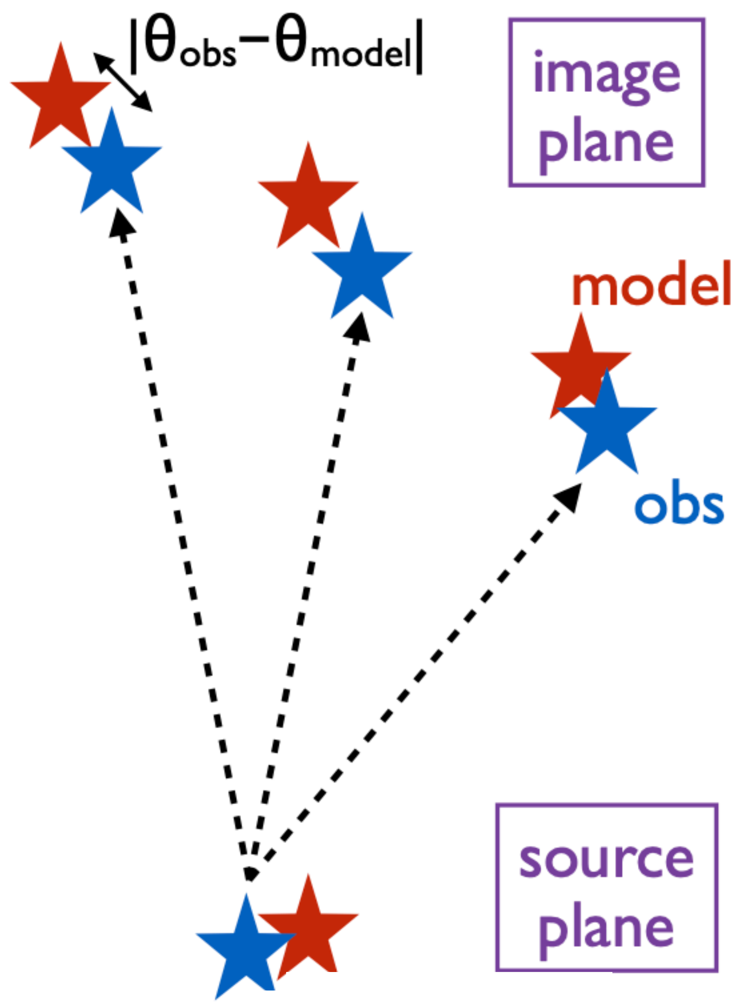


on magnification



on cosmography

III. Solution: A pixelated method



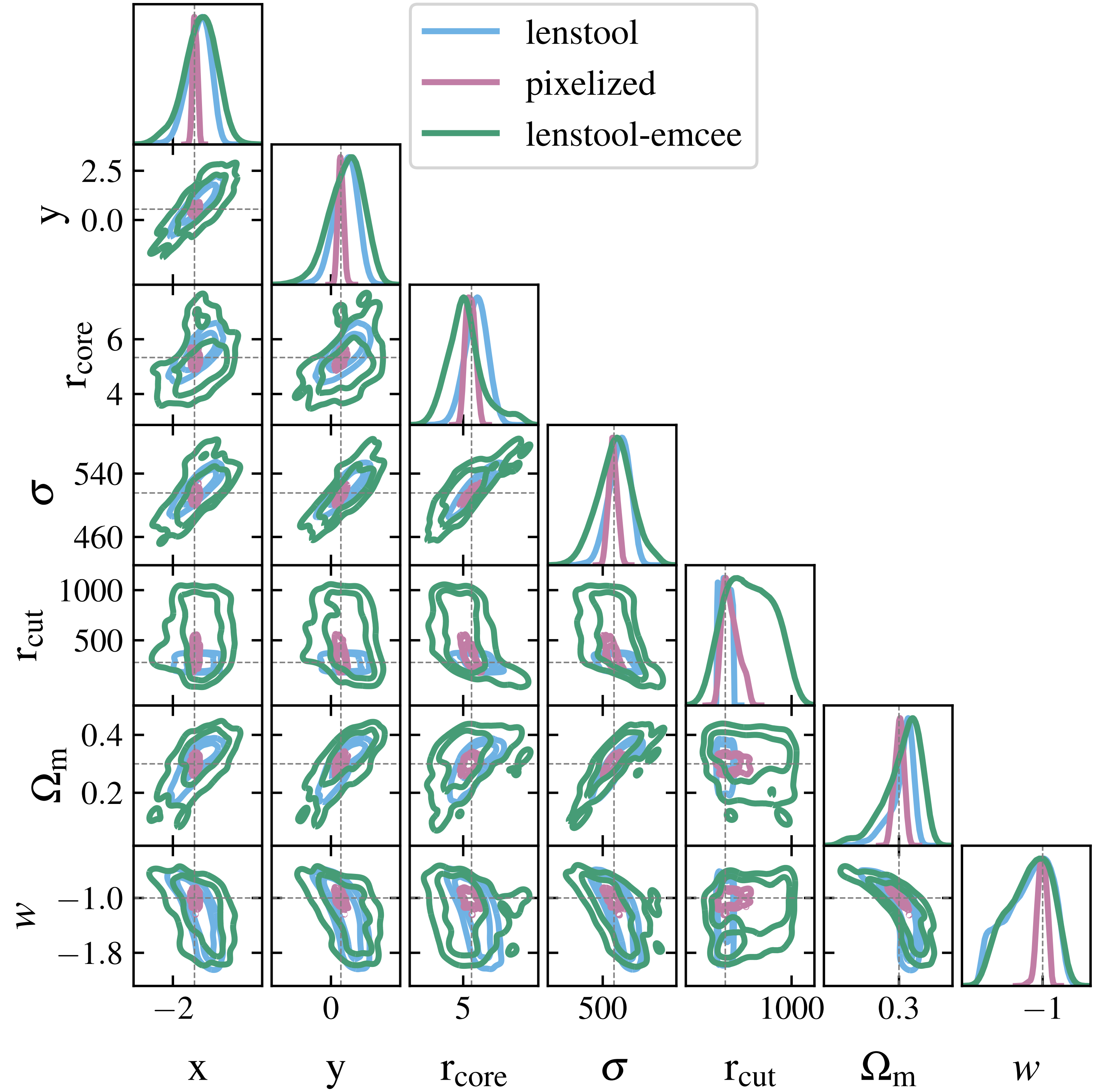
based on the extended surface brightness

$$\chi^2_{\mathrm{SL}} = \Sigma_{j=1}^{n_i} \frac{[x^j_{obs} - x^j]^2}{\sigma^2_{ij}}$$

$$\chi^2_{\mathrm{SL}} = \Sigma_{i=1}^{n_{\mathrm{pix}}} \frac{[s^i_{obs} - s^i]^2}{\sigma^2_i}$$

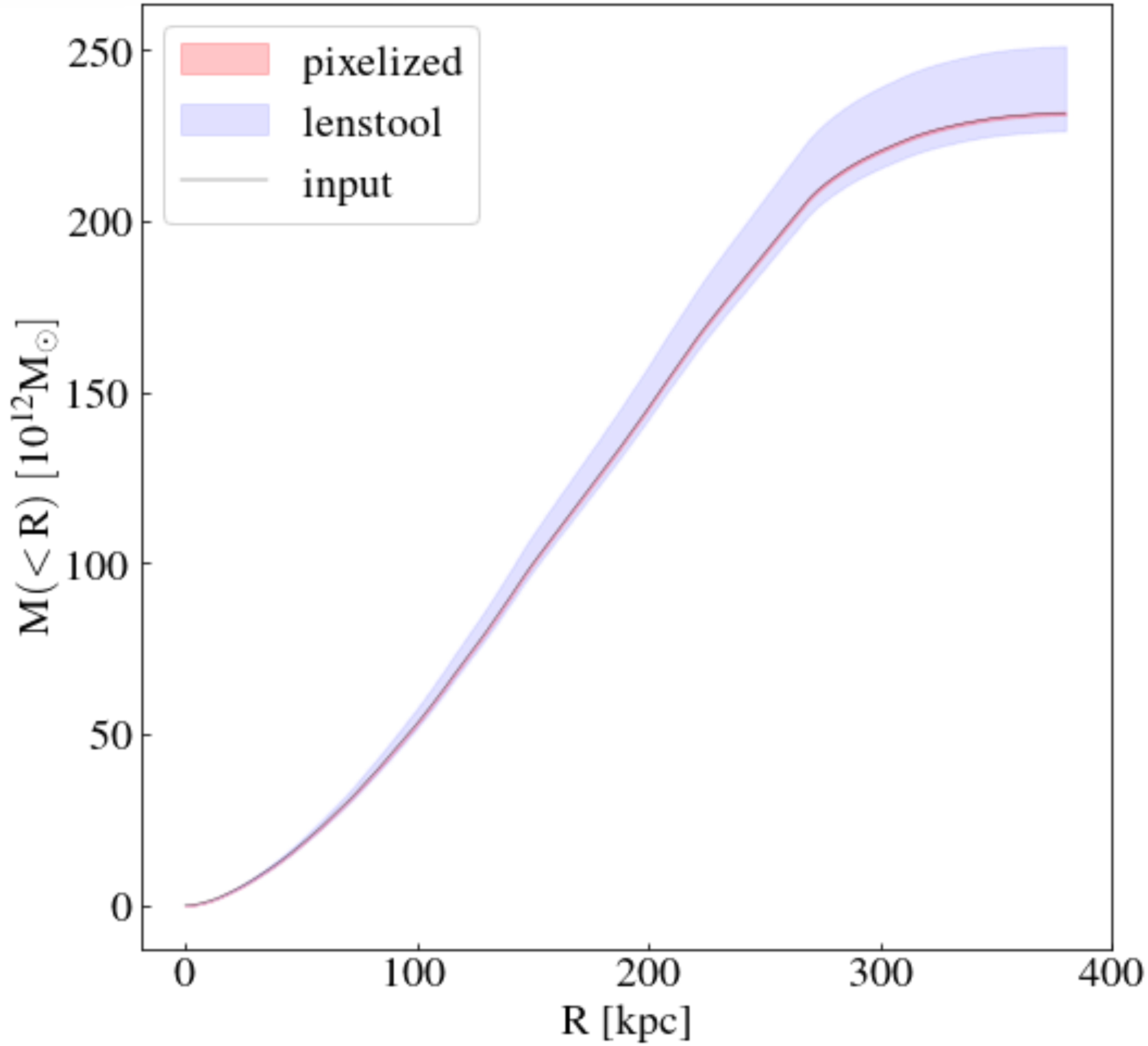
III. Solution: A pixelated method

Posterior

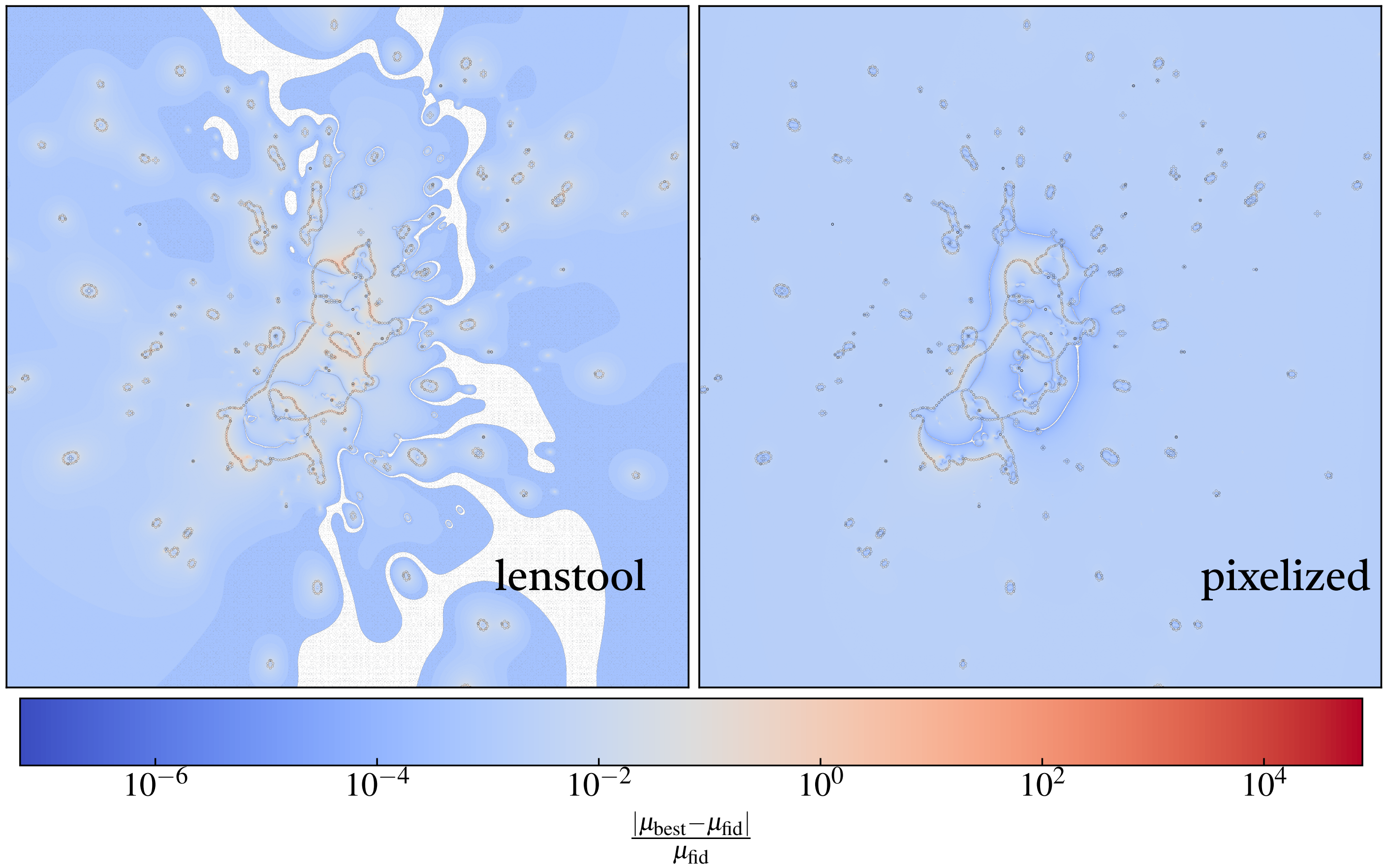


III. Solution: A pixelated method

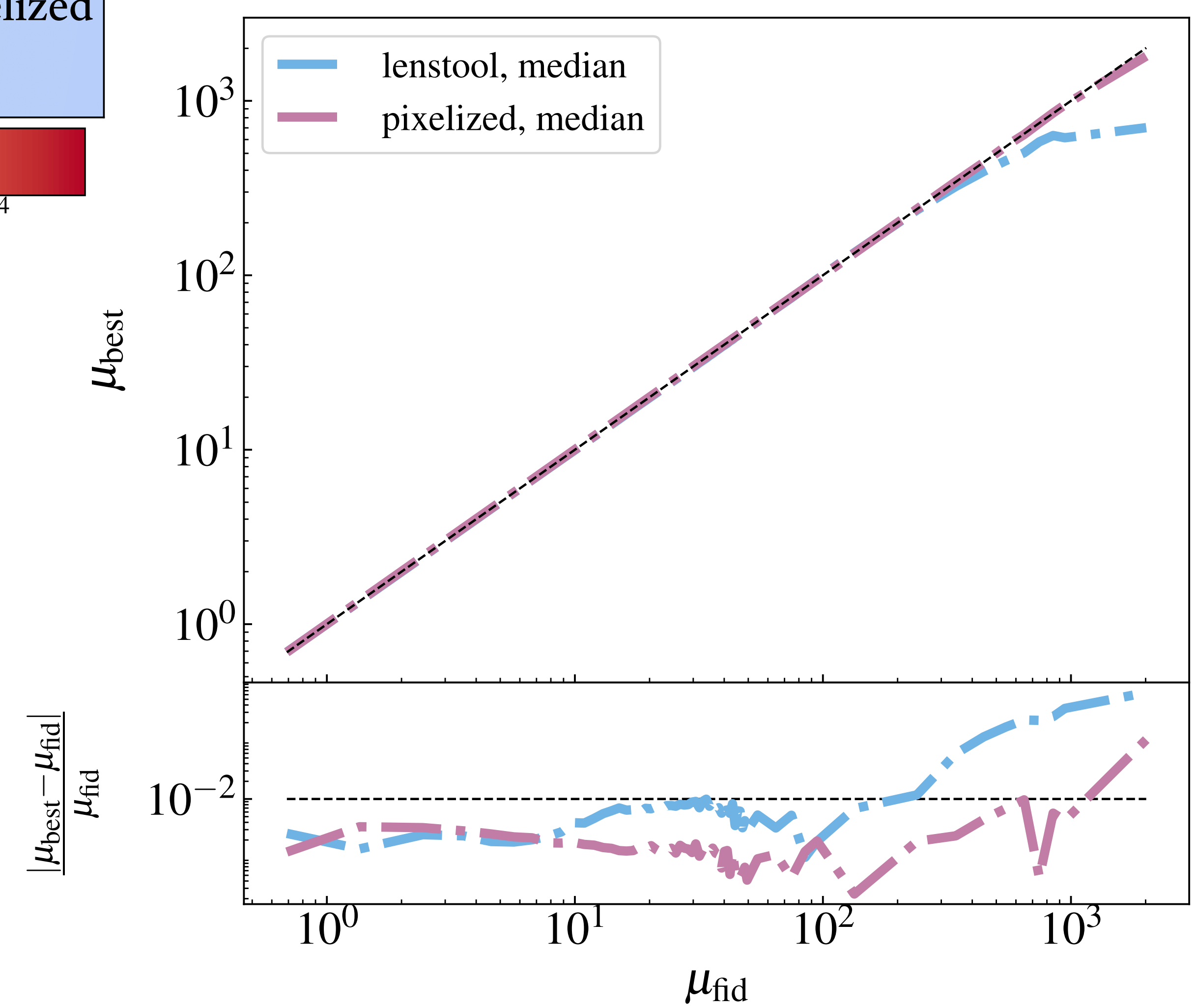
Cluster mass profile



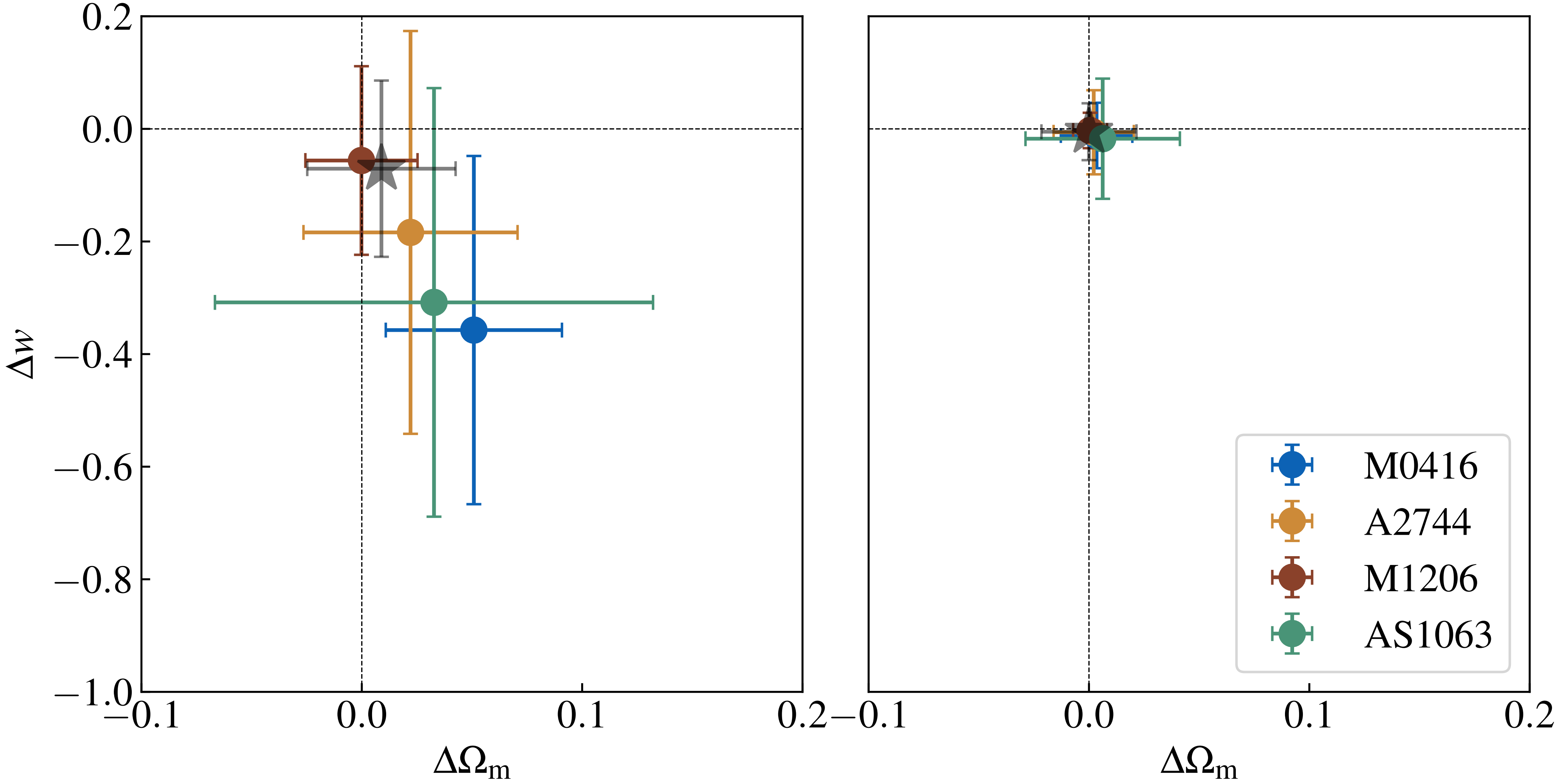
III. Solution: A pixelated method



Magnification maps



III. Solution: A pixelated method



Cosmological parameters

IV. Next step

"TOY": analytical cluster mass

+ free parameters of only the main halo & cosmology

+ 3 image families as constraints

$\simeq$ 1 day

Modeling:

deflection angle map α → de-lensing → re-lensing → sampling

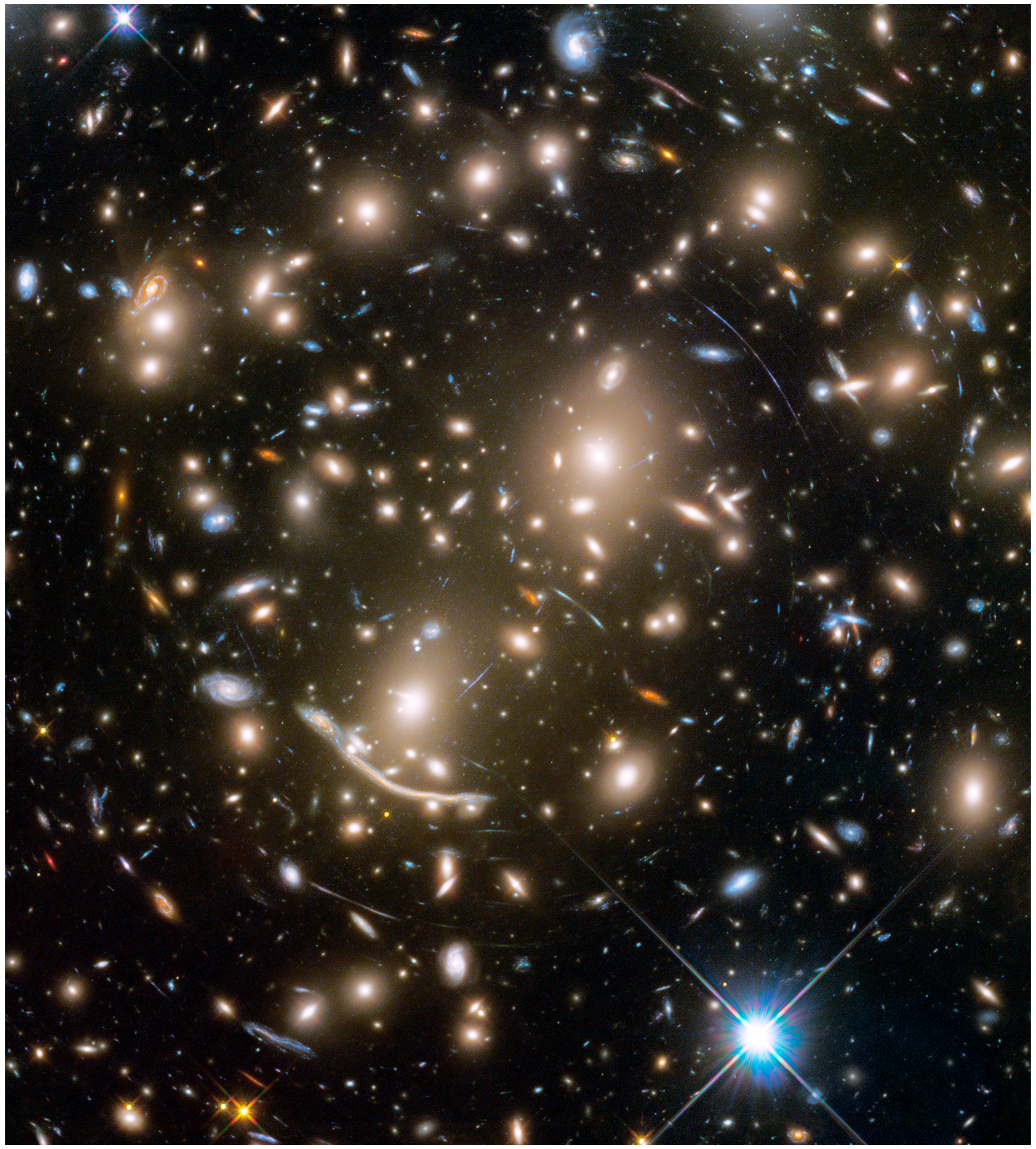
JAX NumPyro

free the following 3 strong lensing parameters, and fix the other lensing parameters, as well as all the source parameters:

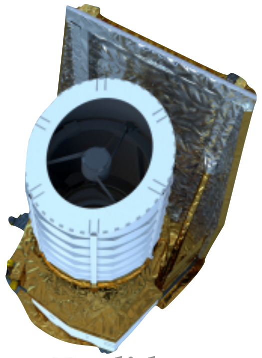
ELLIP:
PHIE:
VELDISP:

lib.	emcee	numpyro (0.12.1)	pymc
Device			
cpu ,4 cores (Jasm.)	> 1 h	14 min 01 s	1 min 51 s
Tesla T4 (google colab.)	/	10 min 08 s	
A100 (Jasm.)	/	1 min 03 s	

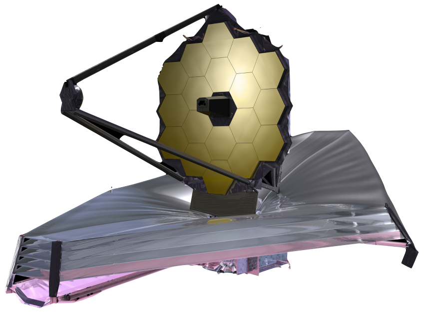
IV. Next step



CSST



Euclid



JWST

Apply on real SL clusters from the next-generation surveys

THANK YOU FOR LISTENING!