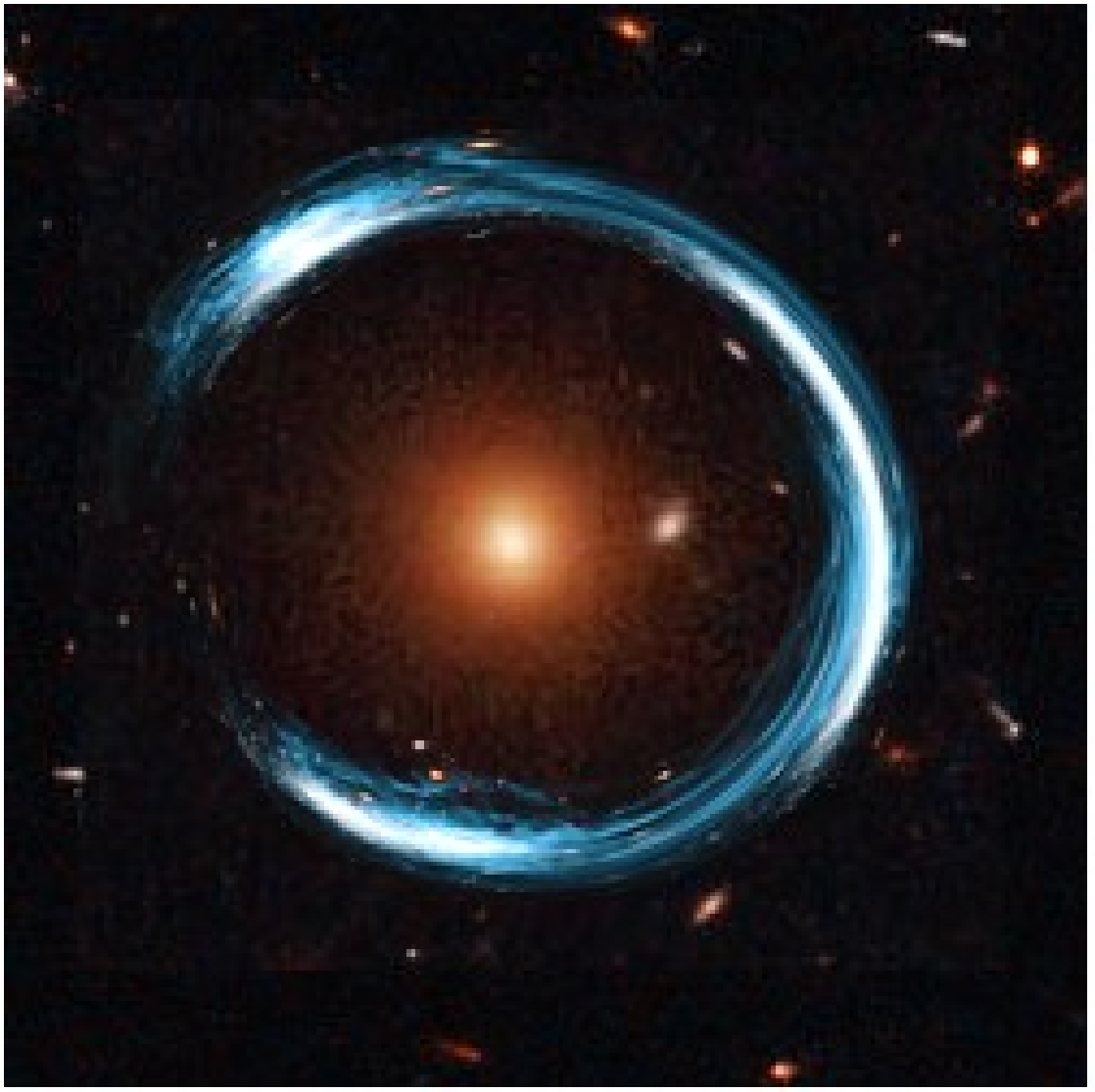
Stellar Halos With Strong Lensing

James Nightingale

Richard Massey

David Harvey

Andrew Cooper



Disclaimers

- **I’m not an expert in Stellar halos.**

  - Stumbled on the topic studying gravitational lensing.

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  - Model parameterizations not optimal.

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- **What we’ve done isn’t perfect.**

  - Model parameterizations not optimal.

  - Analysis doesn’t fully exploit data.

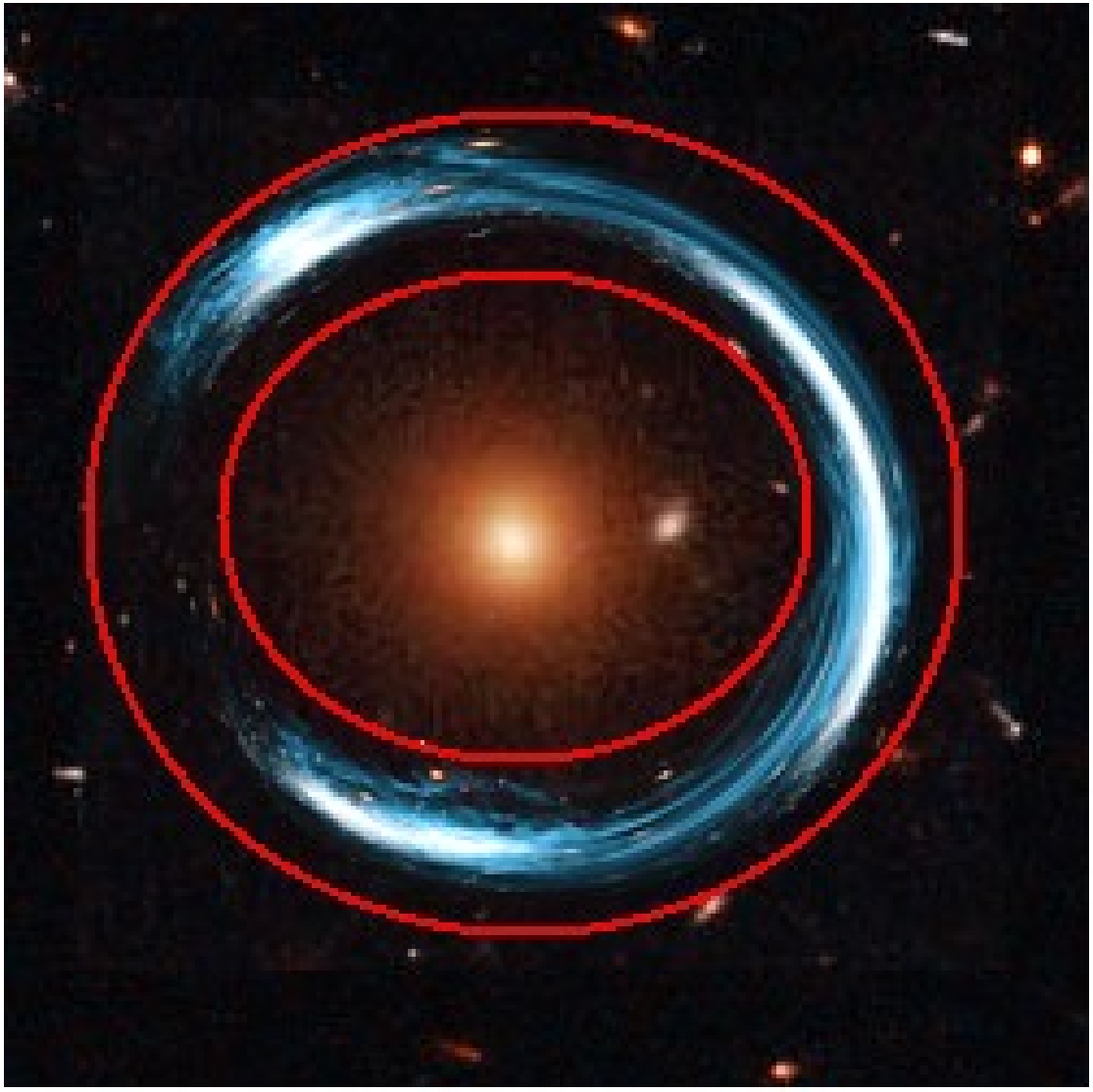
- **However, the idea is solid.**

  - Gravitational lensing can inform us about stellar halos.

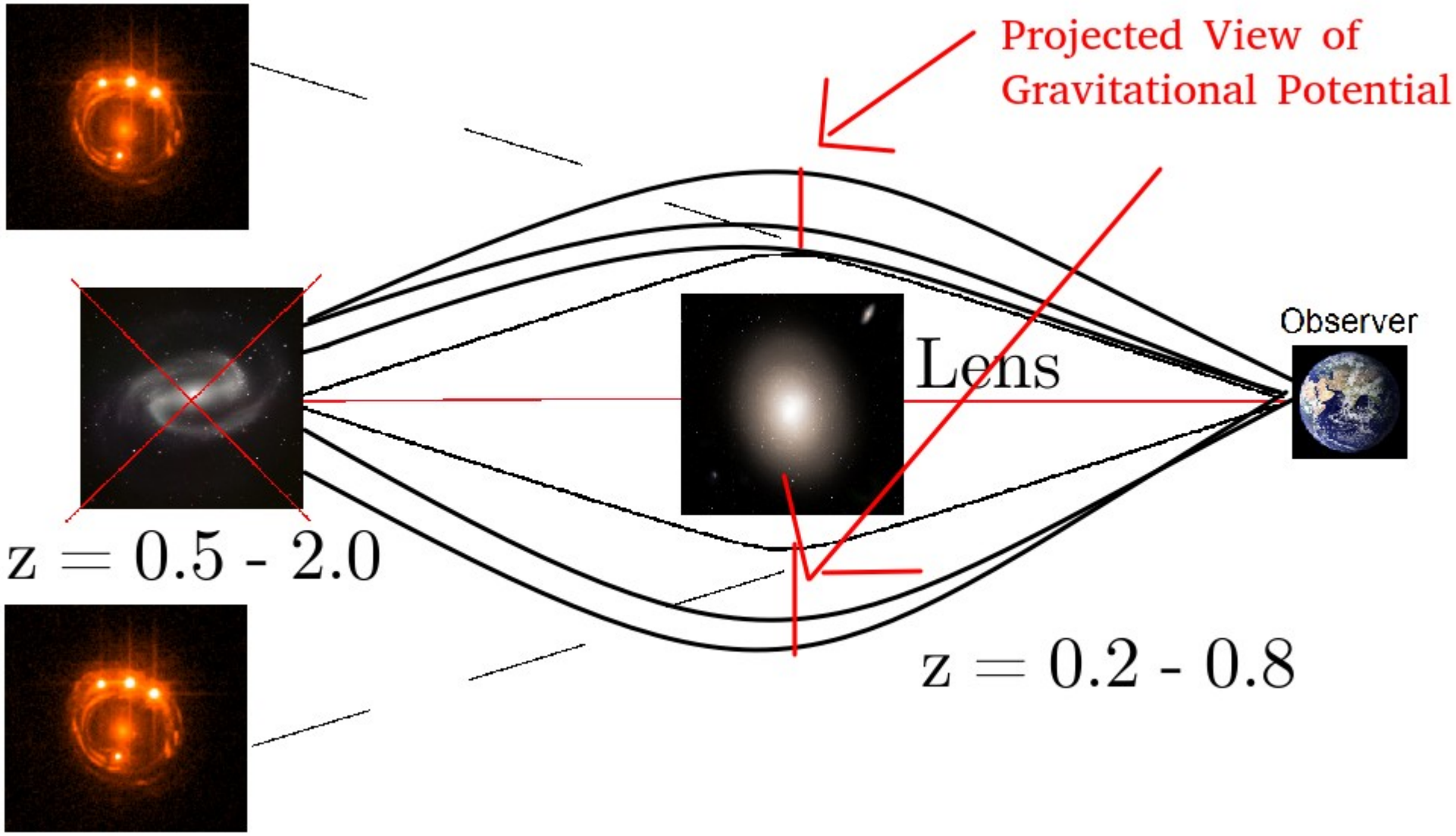
  - Exciting tool once we know how to use it!

‘Advanced’ Strong Lensing

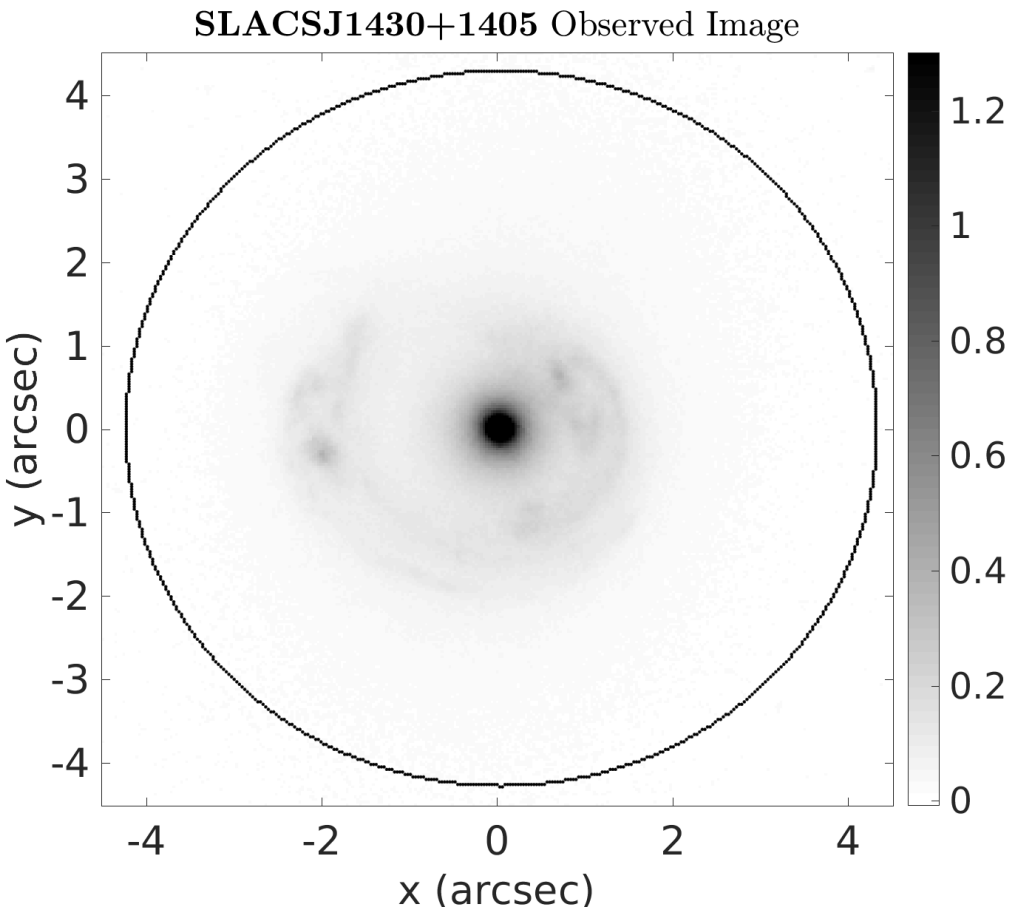
- **The 'Advanced' approach:**
- **Uses -** The extended source light distribution.
- **Measures (direct) –** The lens's mass distribution, at the Einstein Radius, R_{ein}.
- **Measures (indirect) –** The lens's mass distribution within R_{ein}.

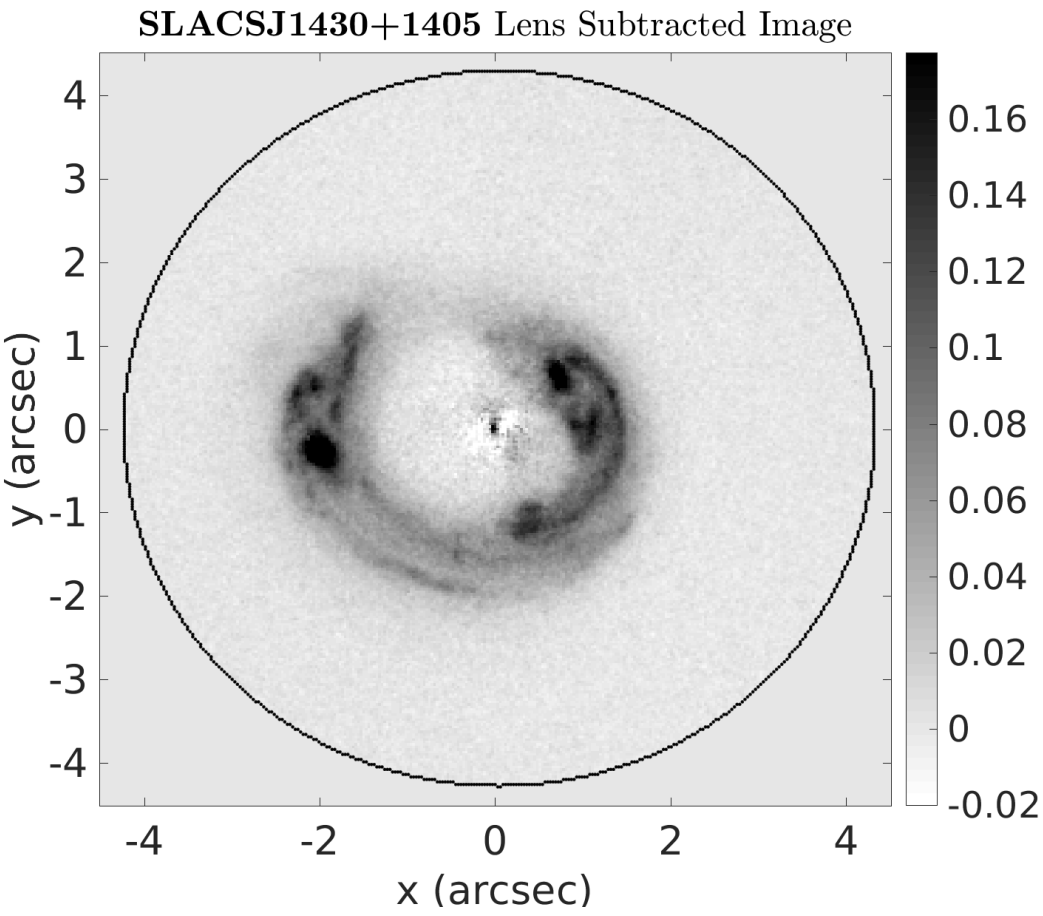


‘Advanced’ Strong Lensing



SLACS3 (SLACSJ1430+4105)





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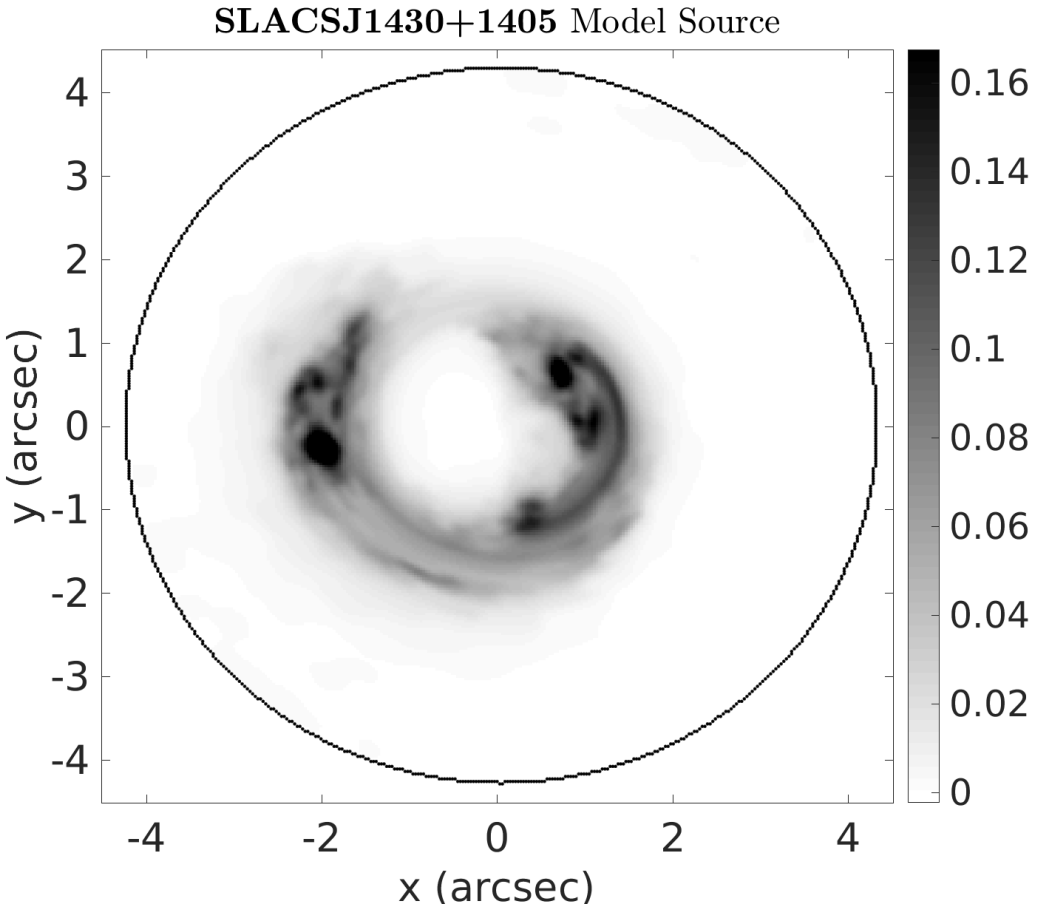
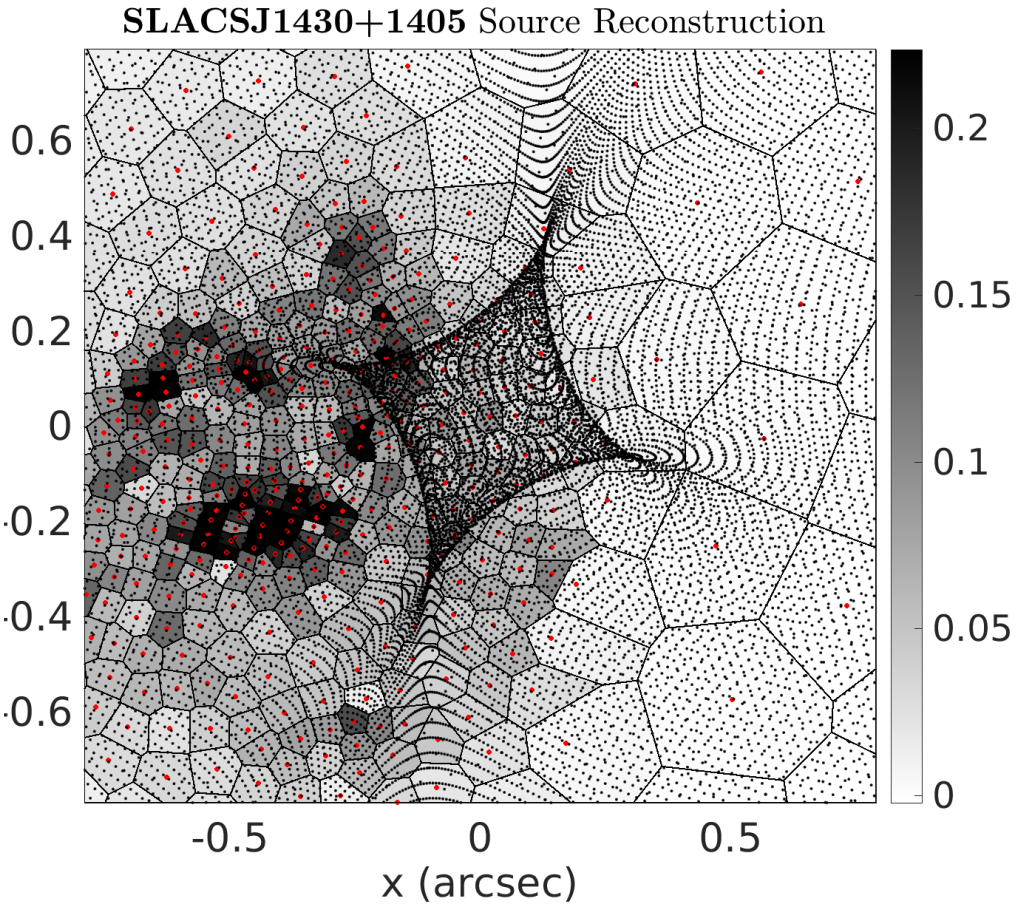
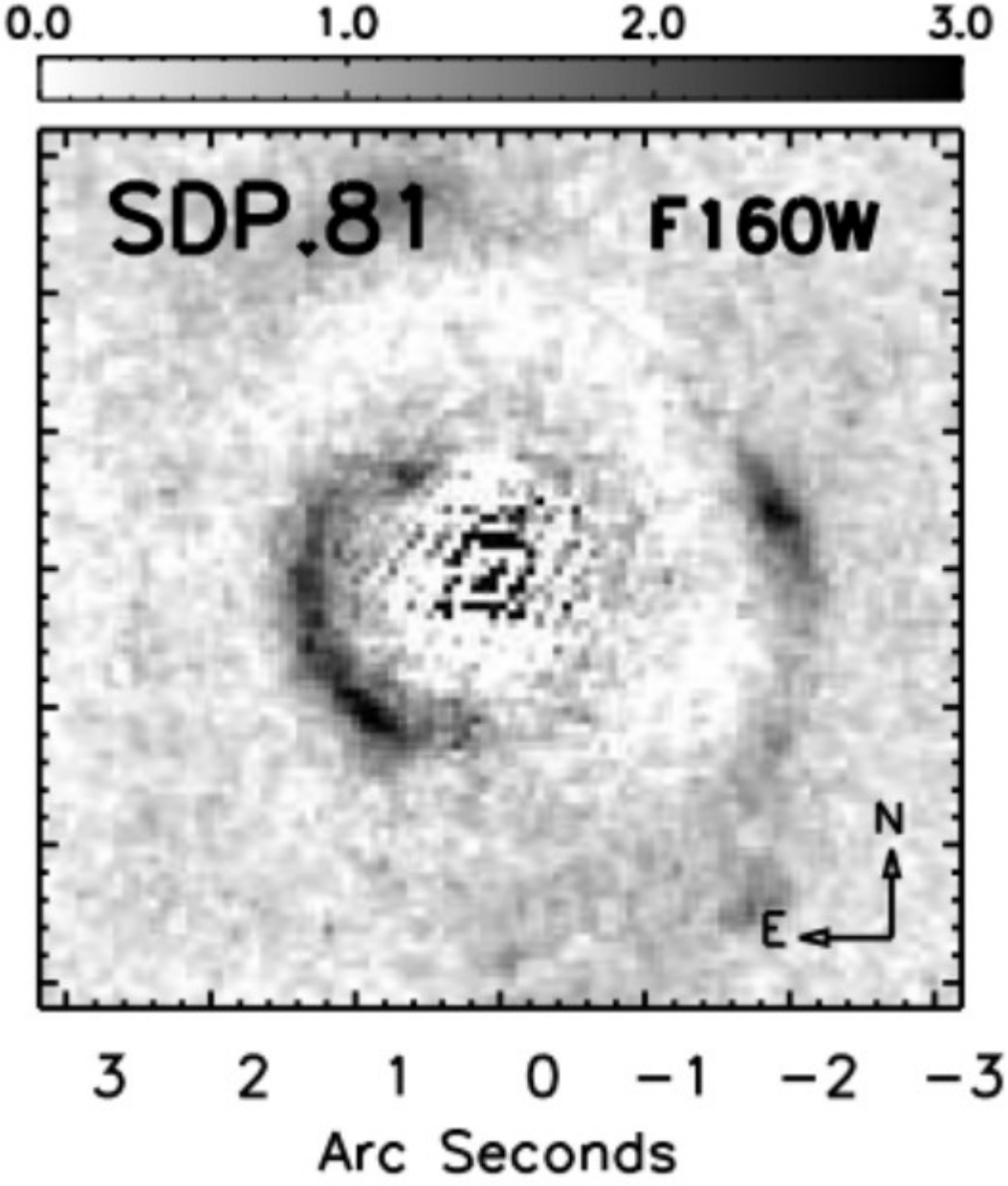




Modeling The Lens's Light

Negrello et al. 2014

Dye et al. 2014



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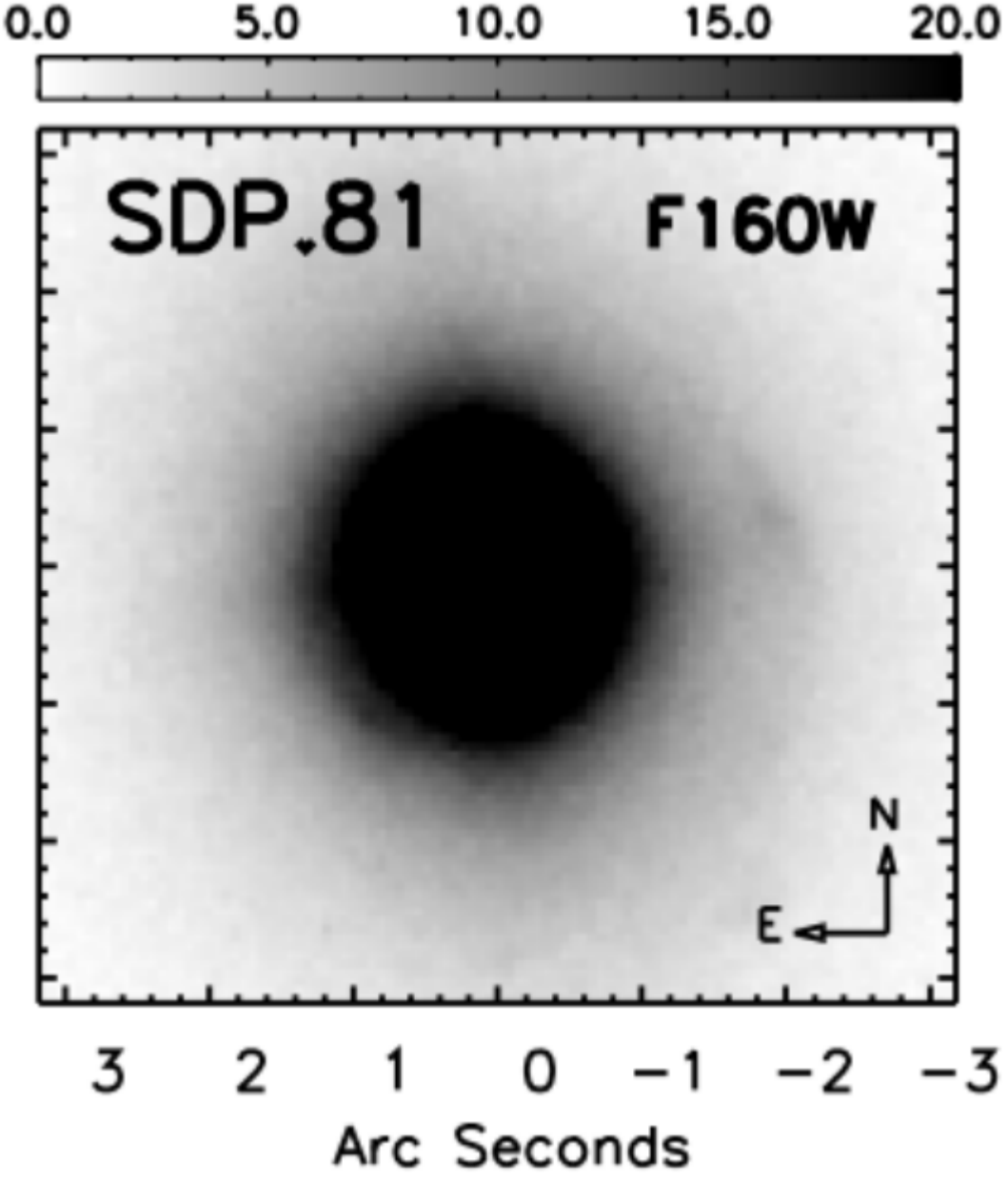

Lens Modeling

- **Simultaneously model:**

  1) The lensed source's intrinsic light distribution.

  - Using an adaptive pixel-grid.

  2) The lens galaxy's light profile.

  - using x2 elliptical Sersic profiles (Sersic + Exponential).

  3) The lens galaxy's mass distribution.

  - Convert Sersic profiles to stellar mass density profiles (using a mass-to-light profile).

  - Spherical NFW profile (ellipticity not necessary).

  - A shear term.

- **These models were informed using Bayesian model comparison.**

PyAutoLens - Open-Source Lens Modeling For The Masses

- **Customizable and fully automated strong lens modeling.**
- **Open-source software in Python.**
- **Check it out!**

https://github.com/Jammy2211/PyAutoLens

Results

Lens Sample

- **3 SLACS lenses:**

  - $z = 0.2 – 0.5$

  - $\sigma = 164, 252, 322$ km/s.

  - $M_{dm} = \sim 10^{13} M_{\Theta}$

  - $M_{*} = \sim 10^{11.5} M_{\Theta}$

- **Abell 2102:**

  - $\sigma = 290$ km/s.

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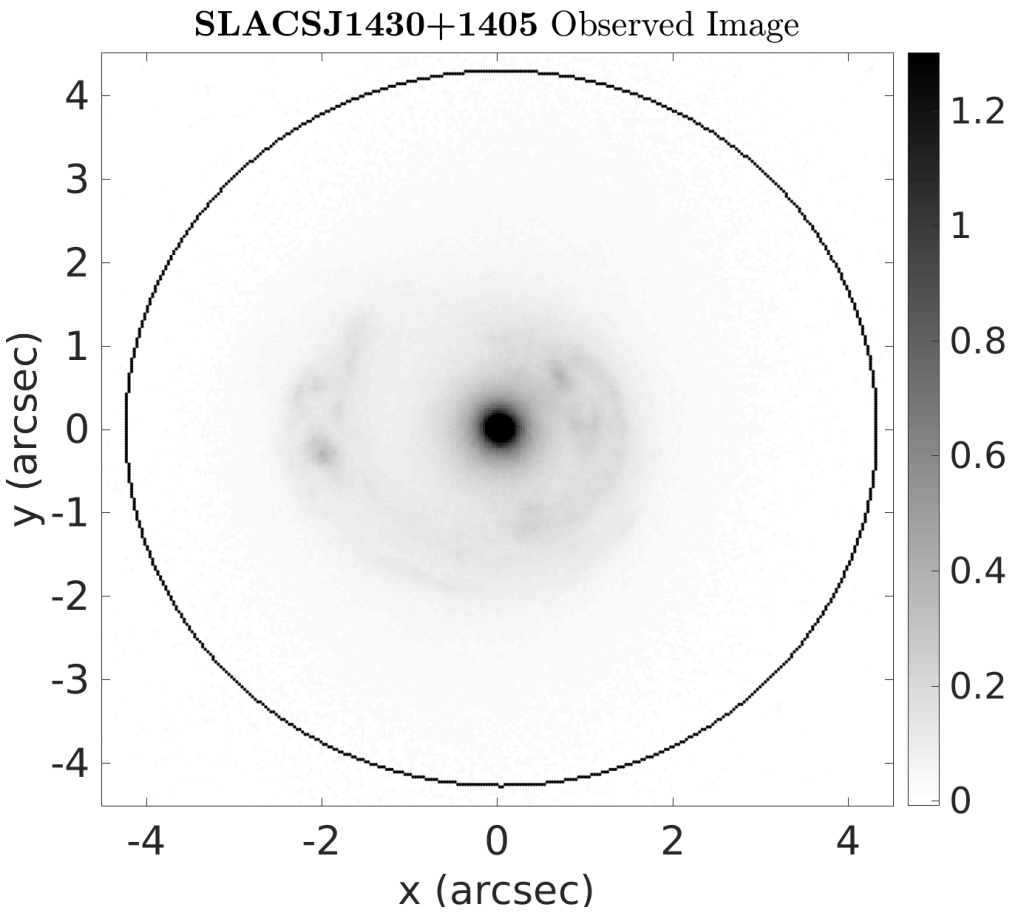
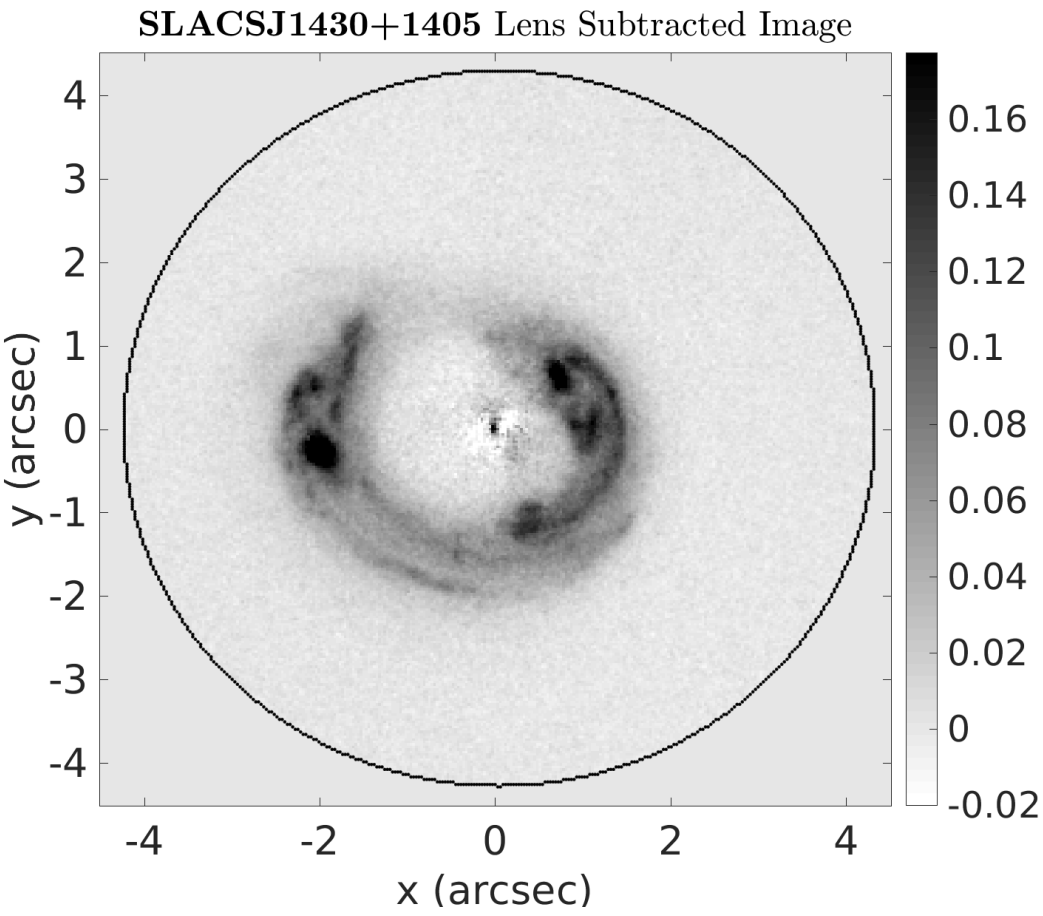
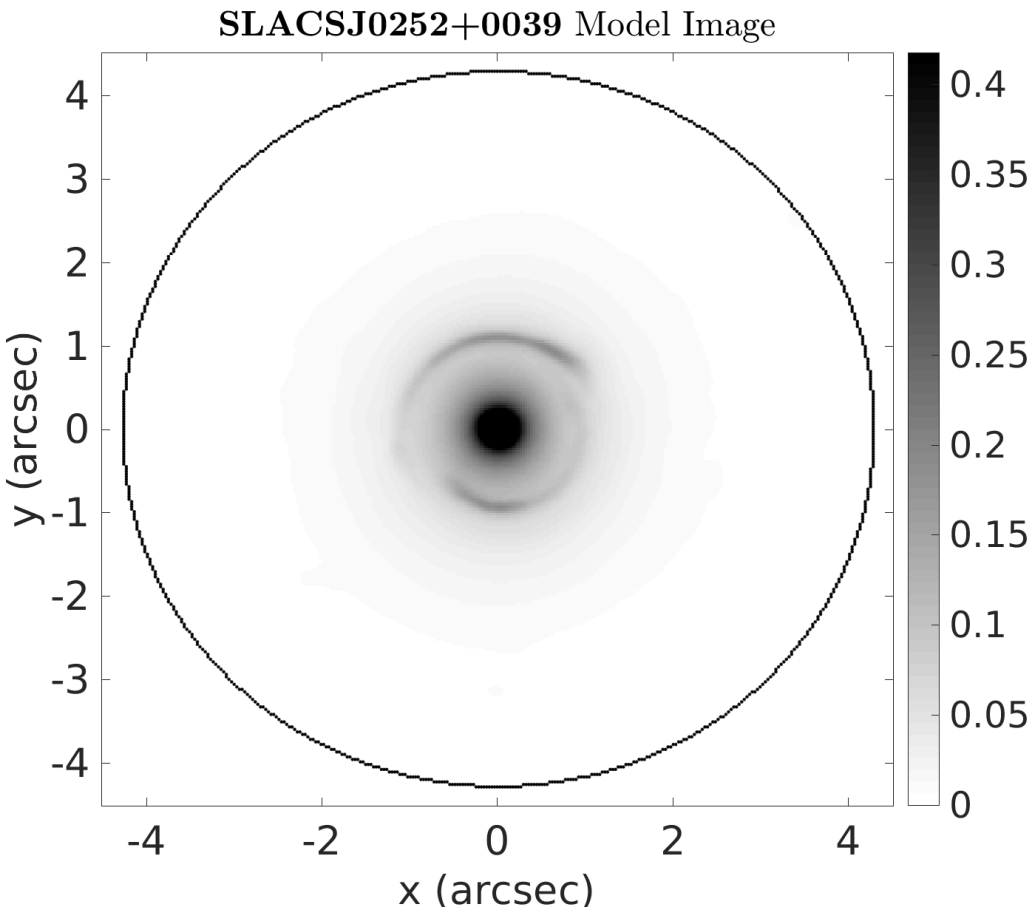
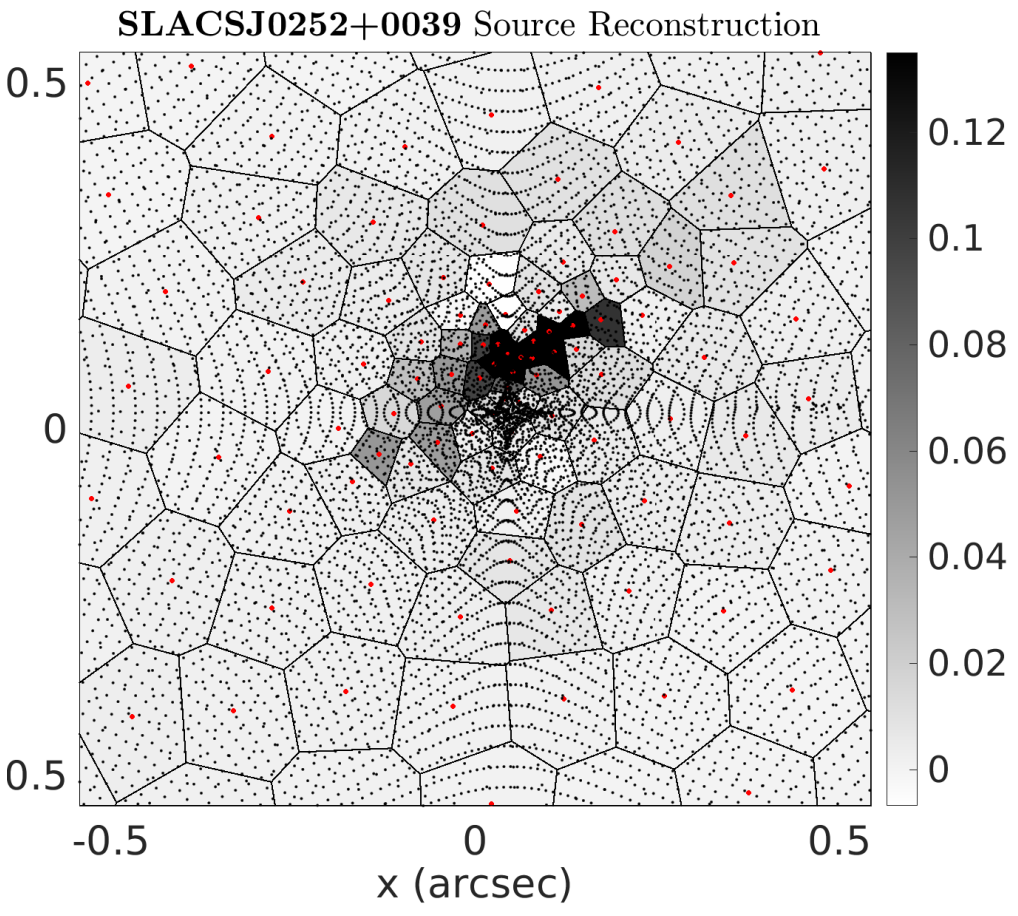


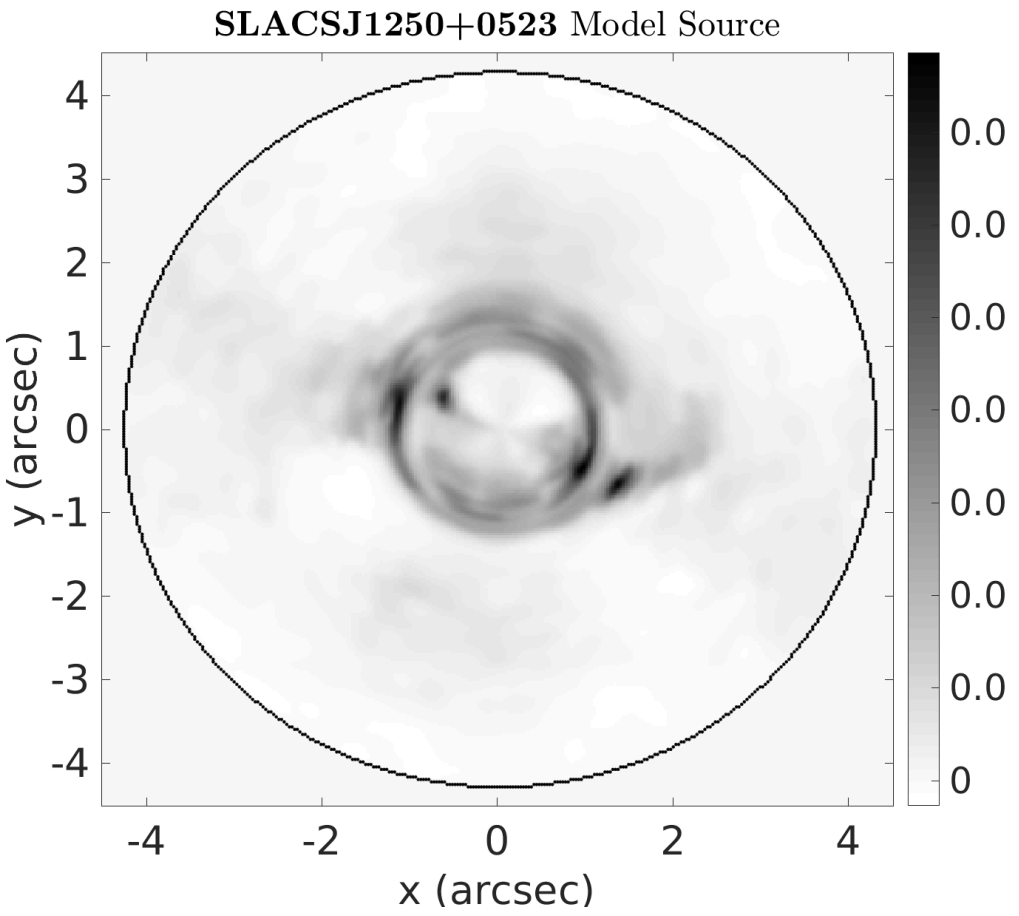


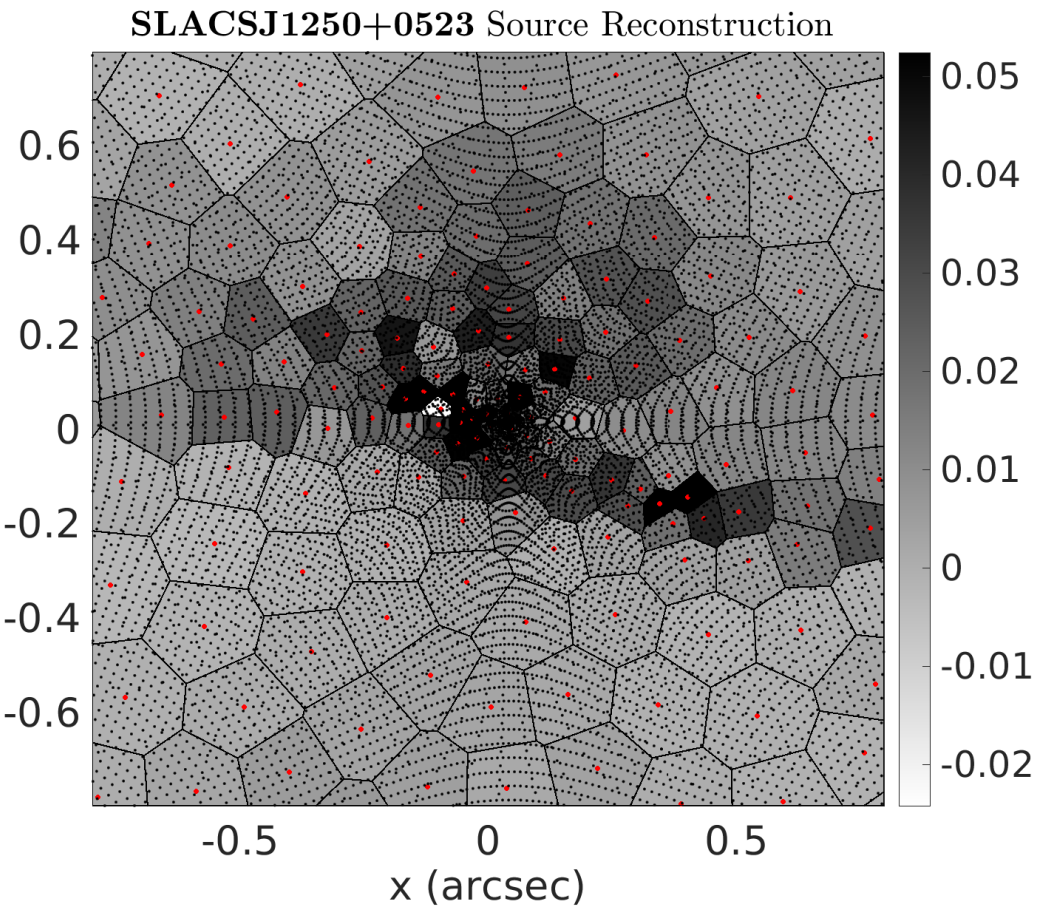
SLACS1 (SLACS0252+0039)





SLACS2 (SLACSJ1250+1319)





Detecting Multiple Components

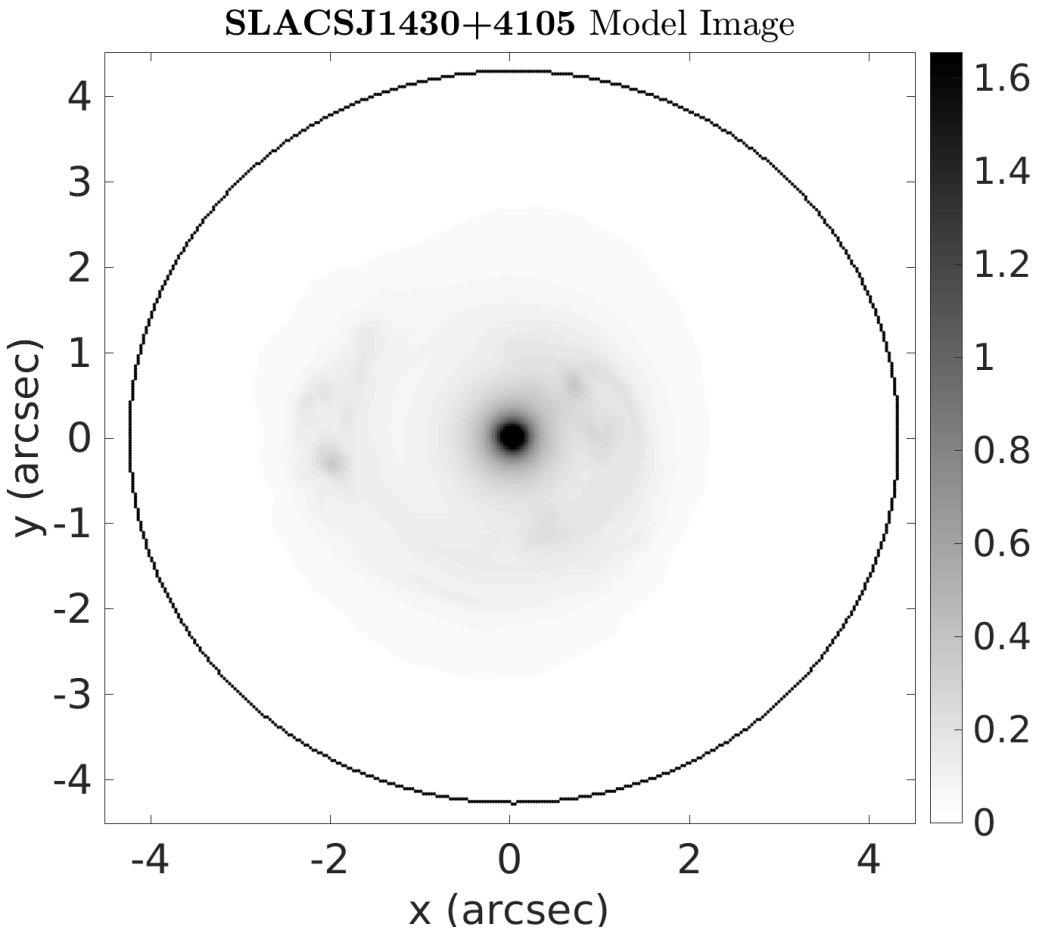
- **Separating different light profile fits to massive ellipticals is hard.**
- **Compare two models:**

  - Model with single Sersic profile **(bulge)**.

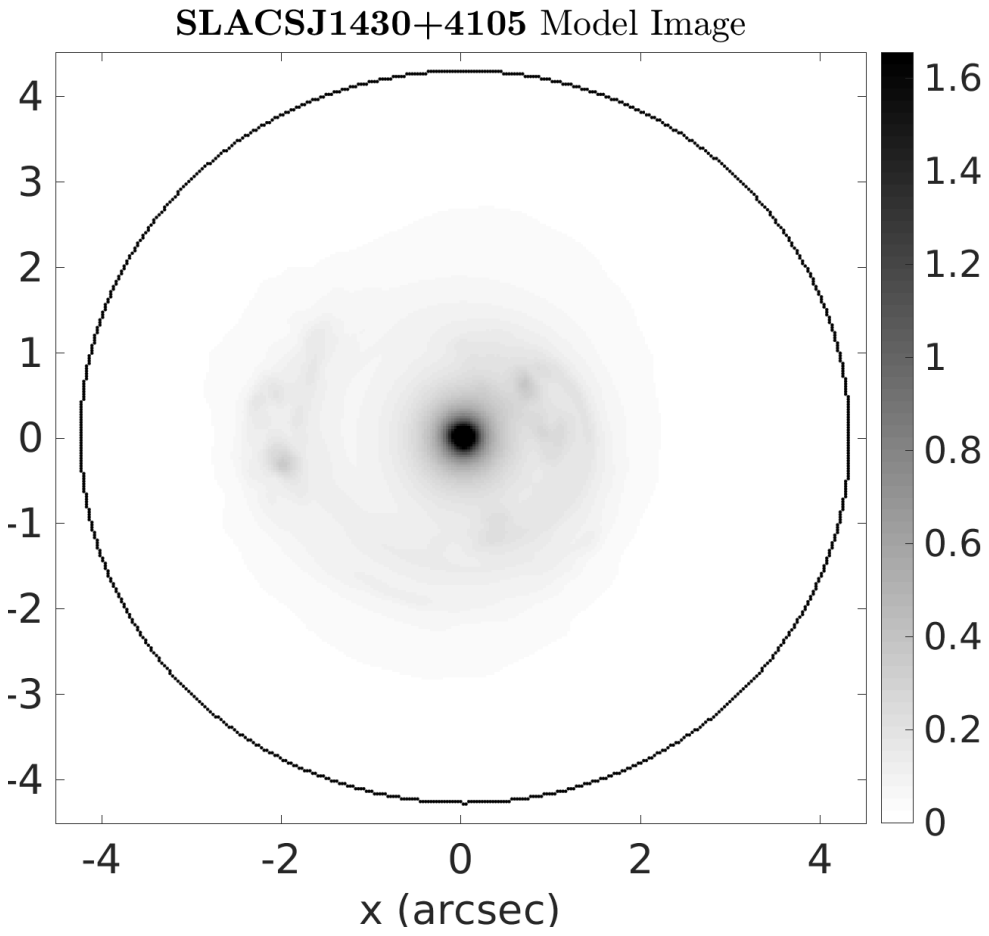
  - Model with a Sersic + Exponential profile **(bulge + halo).**

Light Profiles

Sersic

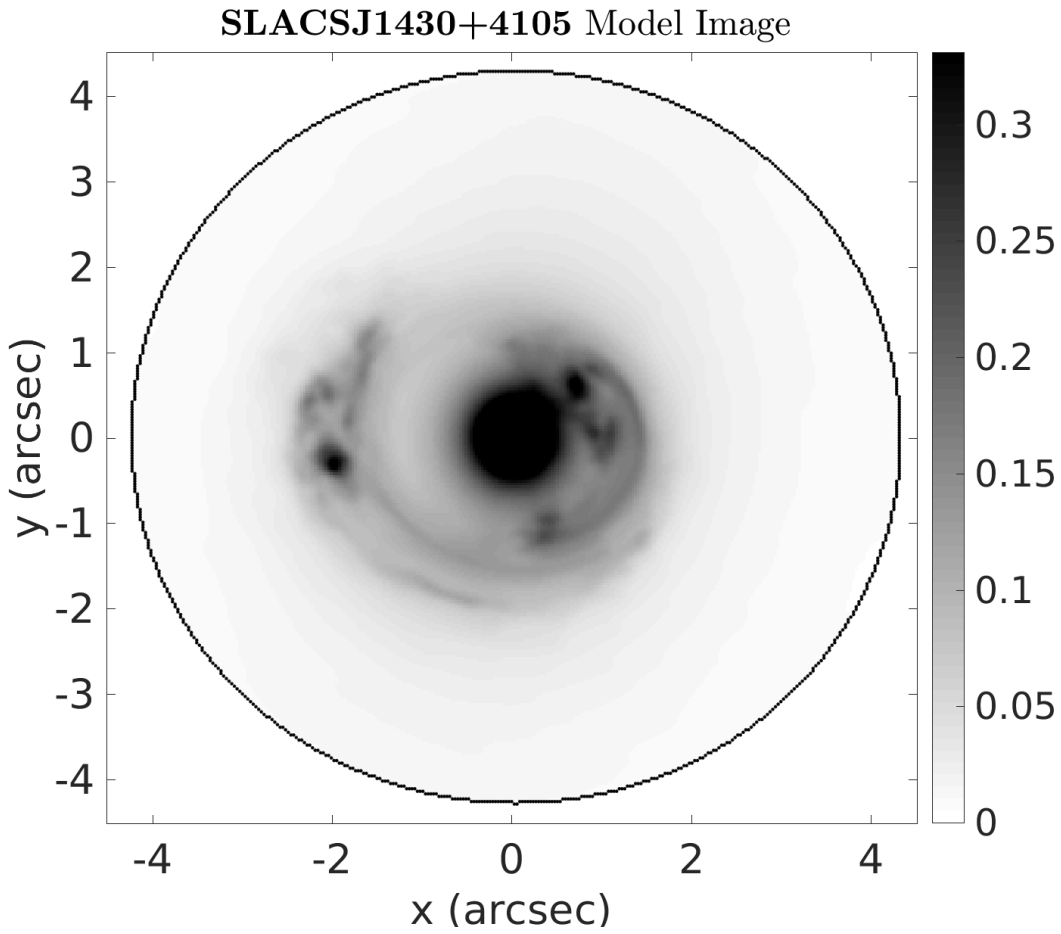


Sersic + Exponential

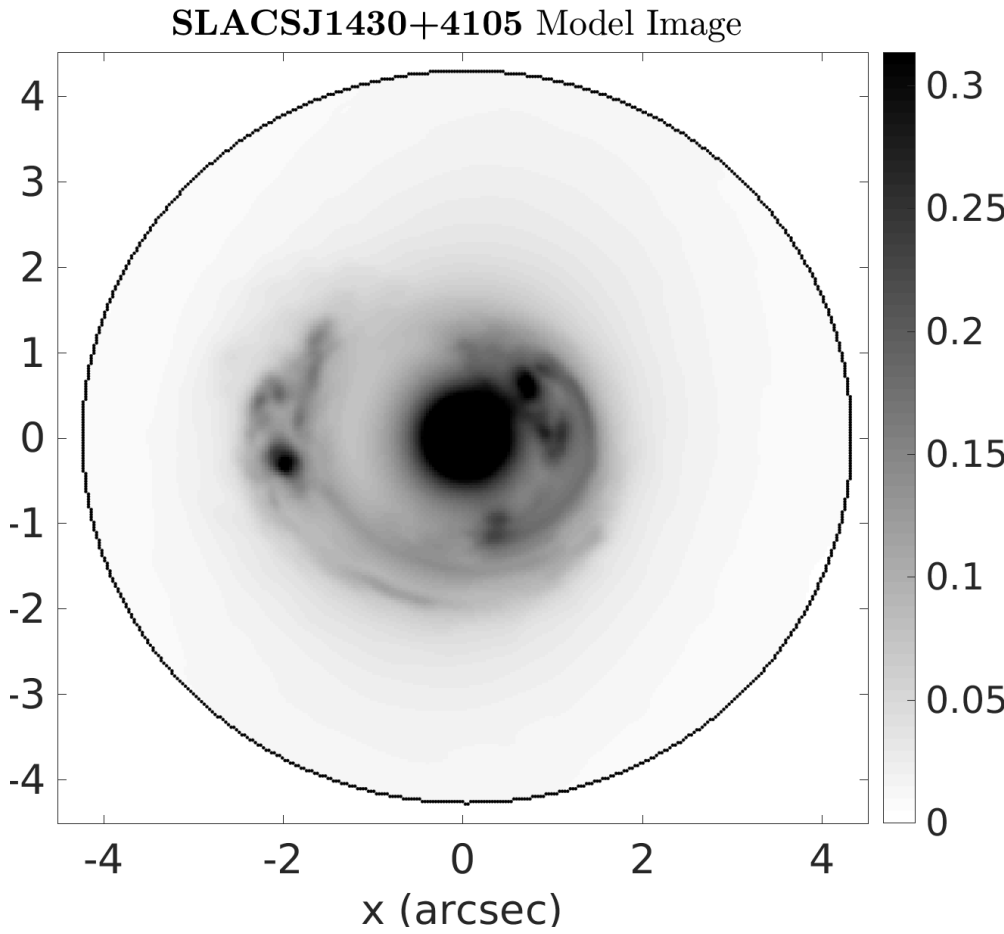


Light Profiles

Sersic

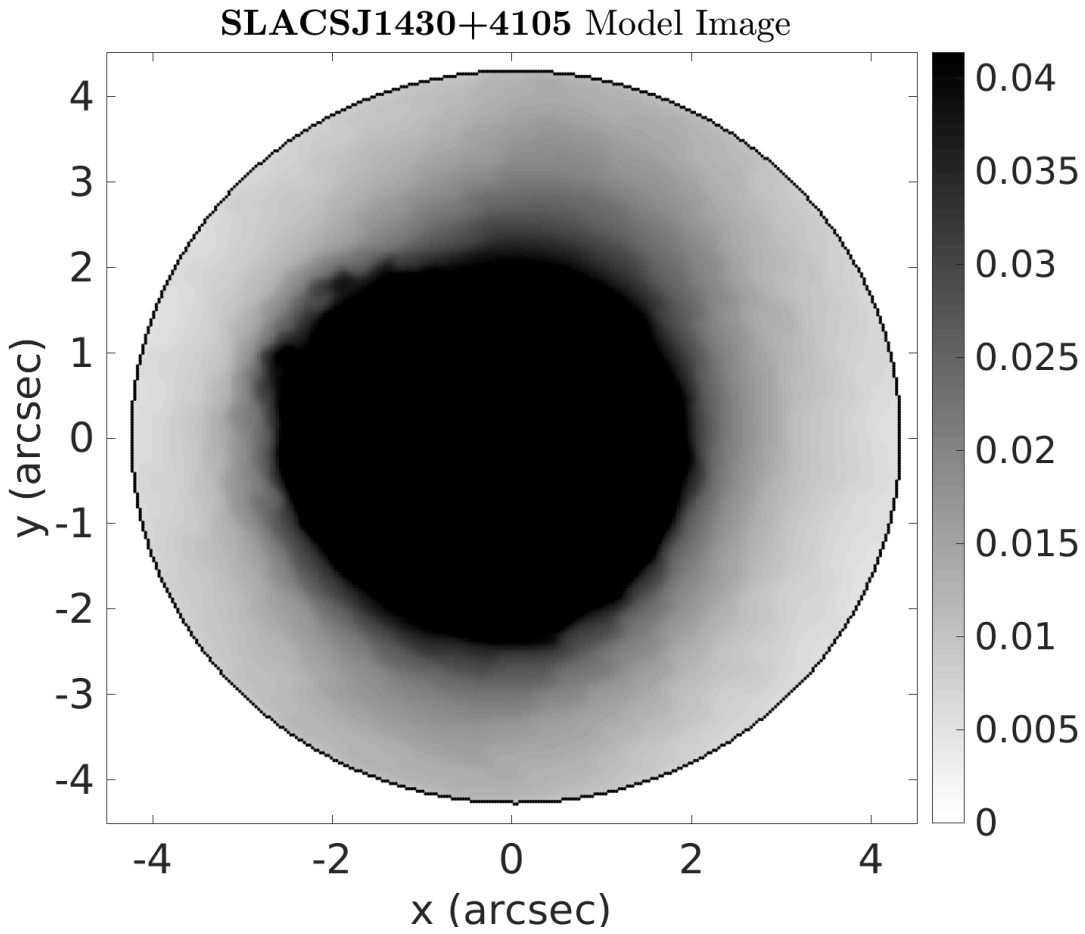


Sersic + Exponential

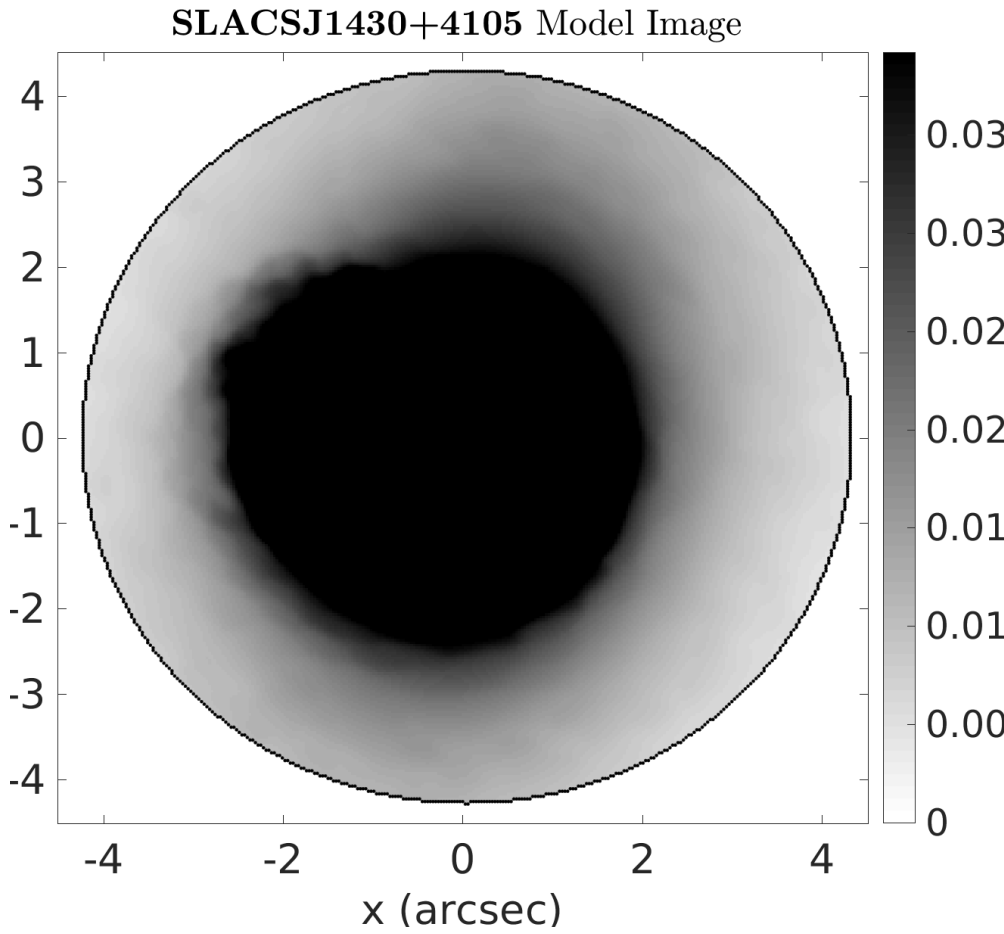


Light Profiles

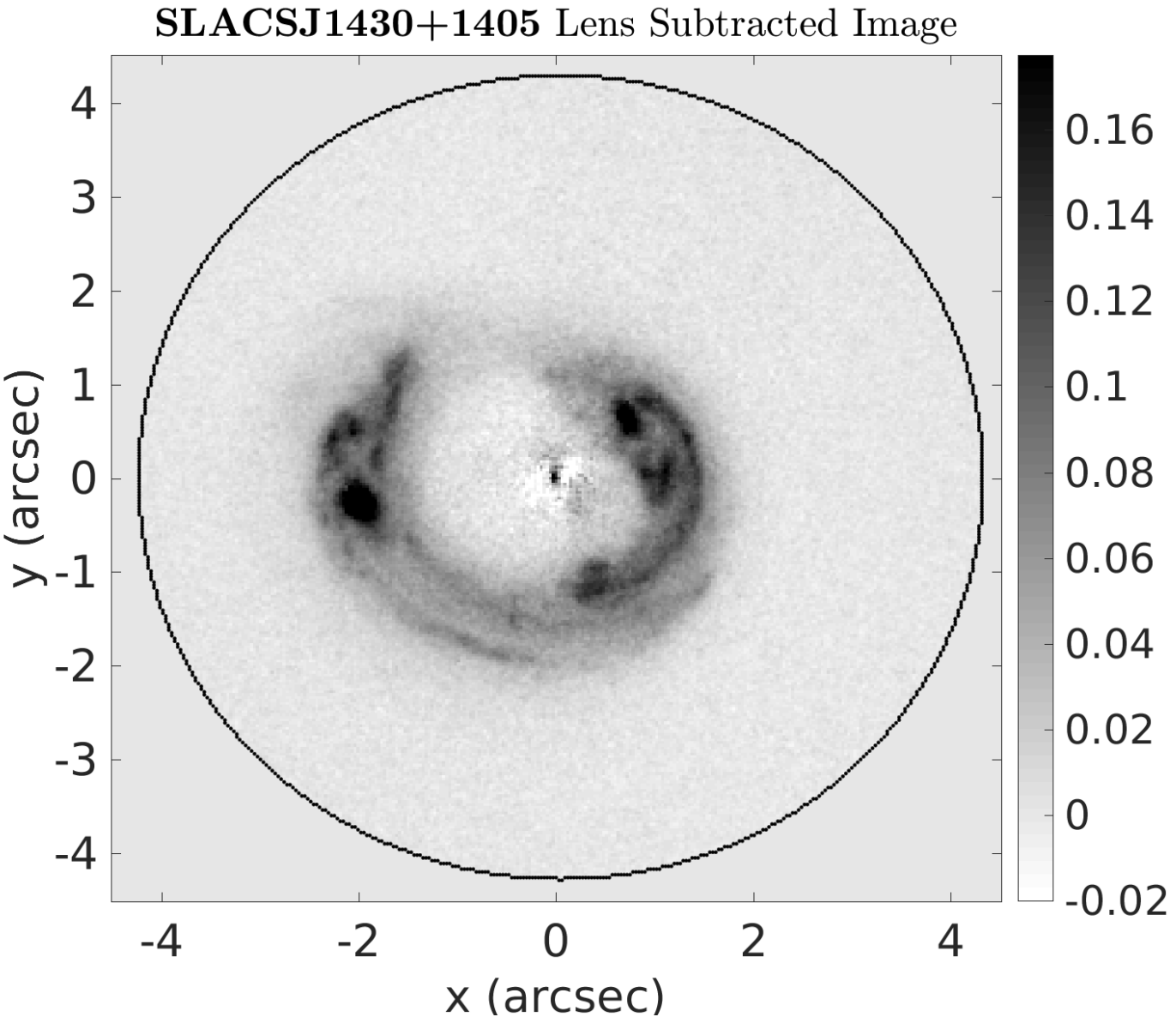
Sersic



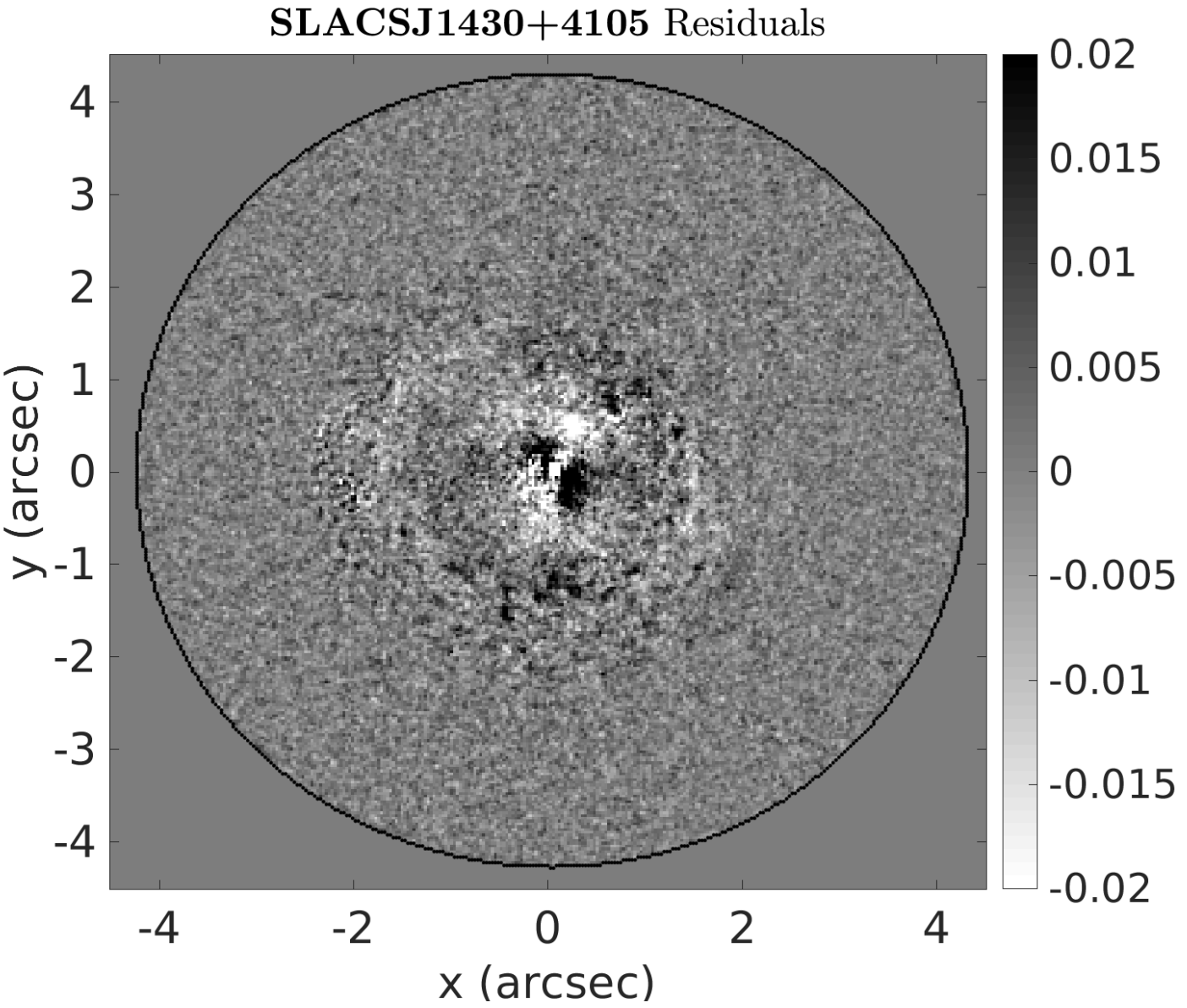
Sersic + Exponential



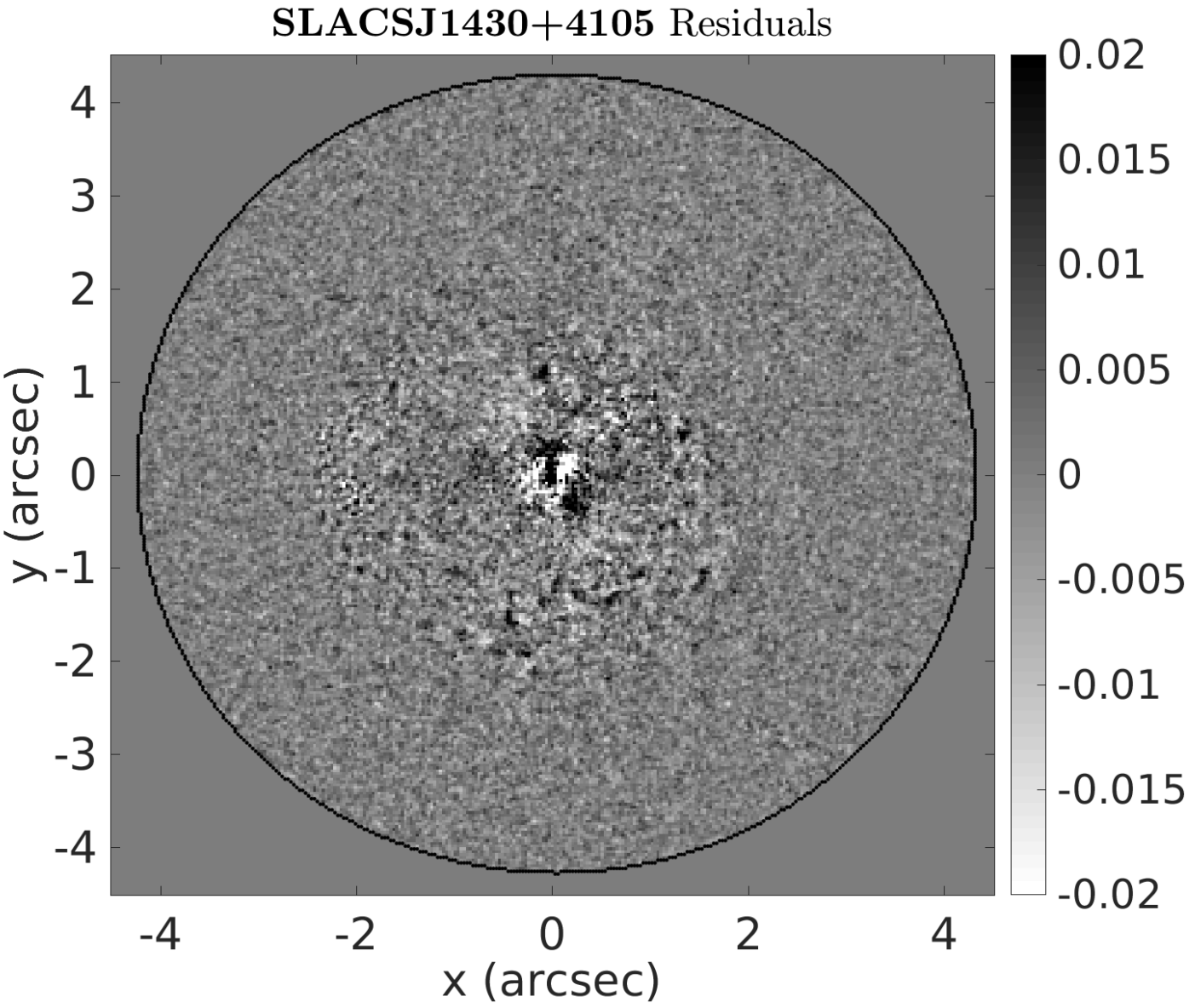
Light Profiles



Sersic


SLACSJ1430+4105 Residuals
y (arcsec)
x (arcsec)
4
3
2
1
0
-1
-2
-3
-4
-4
-2
0
2
4
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02

Sersic + Halo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2
4
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02

Sersic + Exponential

- **Component 1 → Bulge:**

  Smaller: Effective Radius = 0.20”, 0.55”, 0.64”, 0.55”

  Concentrated: Sersic Index = 3.6, 3.8, 3.0, 1.39

  Round: Axis Ratio (b/a) = 0.88, 0.78, 0.92, 0.84

- **Component 2 → Envelope:**

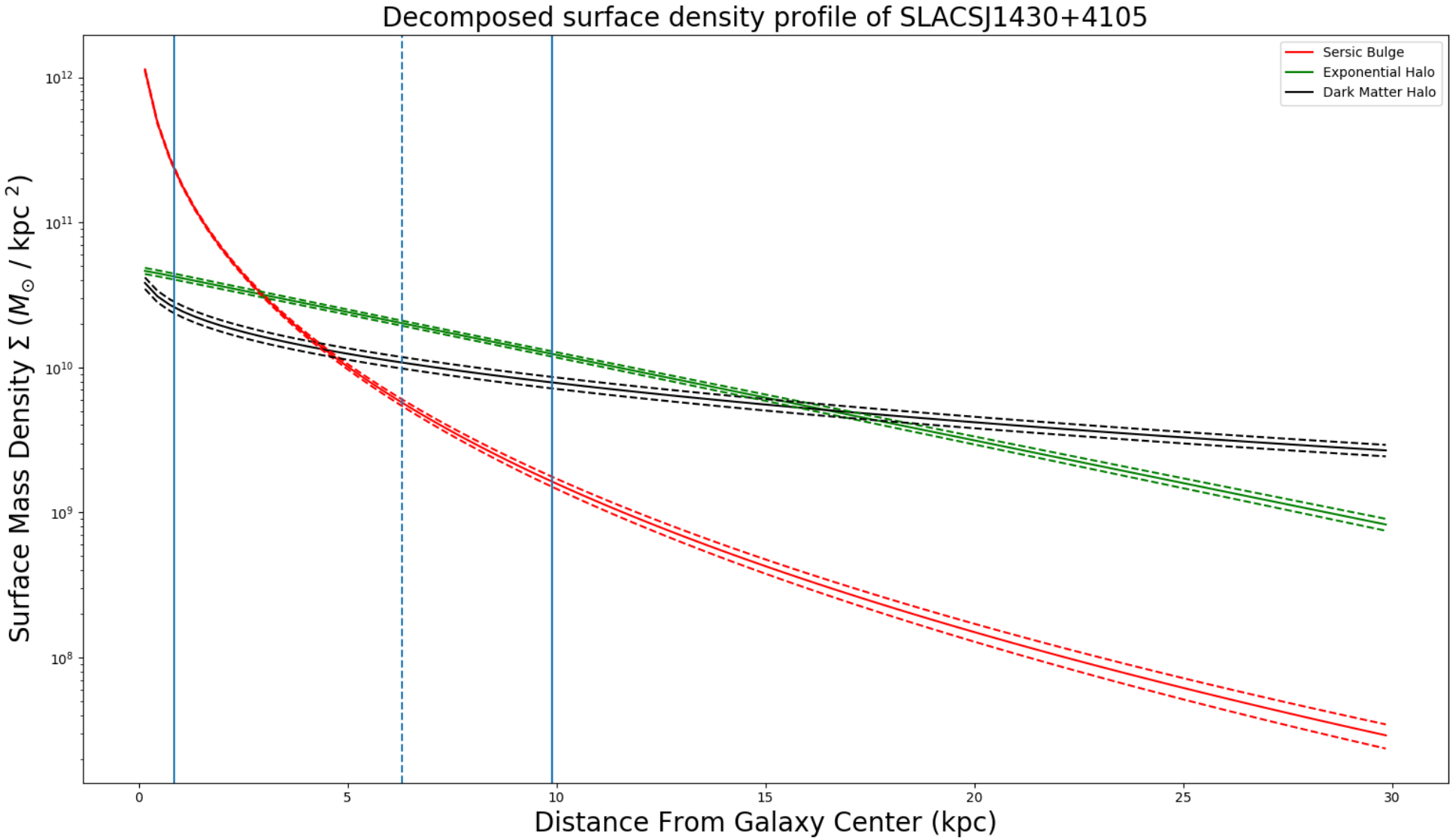
  Extended: Effective Radius = 0.82”, 2.00”, 3.52”, 4.44”

  Smooth: Sersic Index = 1.0, 1.0, 1.0, 1.0

  Flat: Axis Ratio (b/a) = 0.79, 0.77, 0.63, 0.6

What does Lensing Tell Us?

Mass Profiles



Stellar + Dark Mass Profiles

- **Detect different mass-to-light profiles:**

  - Halo lower M/L then bulge in one lens.

  - Higher M/L in another.

  - Gradient in mass-to-light profile of one lens.

- **Direct measurement of the (inner) dark matter halo mass.**

  - Key to understanding stellar halo formation?

Bulge-Halo Geometry

- **Rotational offsets detected in all 4 lenses:**

  70˚

  80˚

  21˚

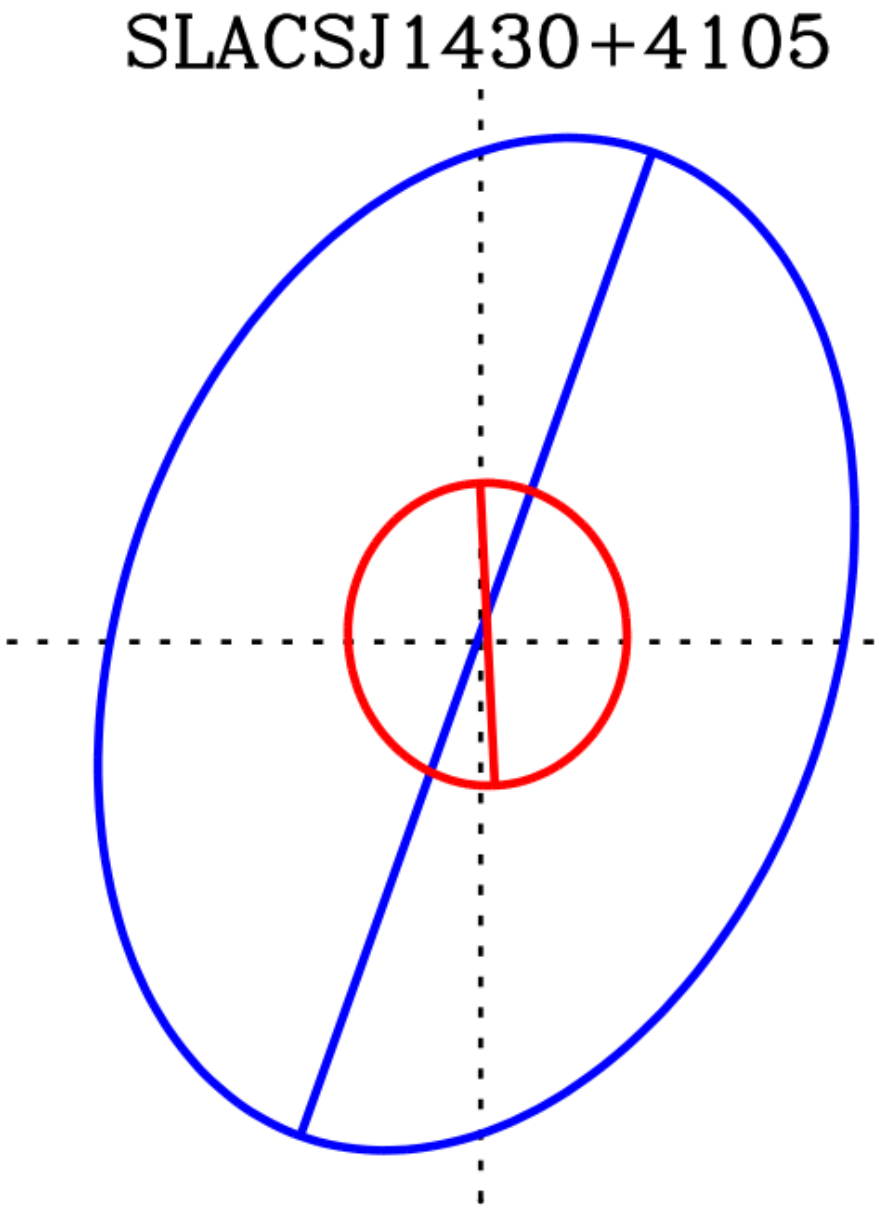
  12˚.

- **Centroid offsets detected in 3 lenses:**

  0.090 kpc

  0.344 kpc

  0.403 kpc.



Everything We Did Wrong

Lens Modeling

- **The lens galaxy's light profile.**

  - using x2 elliptical Sersic profiles (Sersic + Exponential).

- **Should we switch to x3 (or more) Sersic’s?**

  - Probably mixing the halo and ‘thick disk’ / ‘extended envelope.

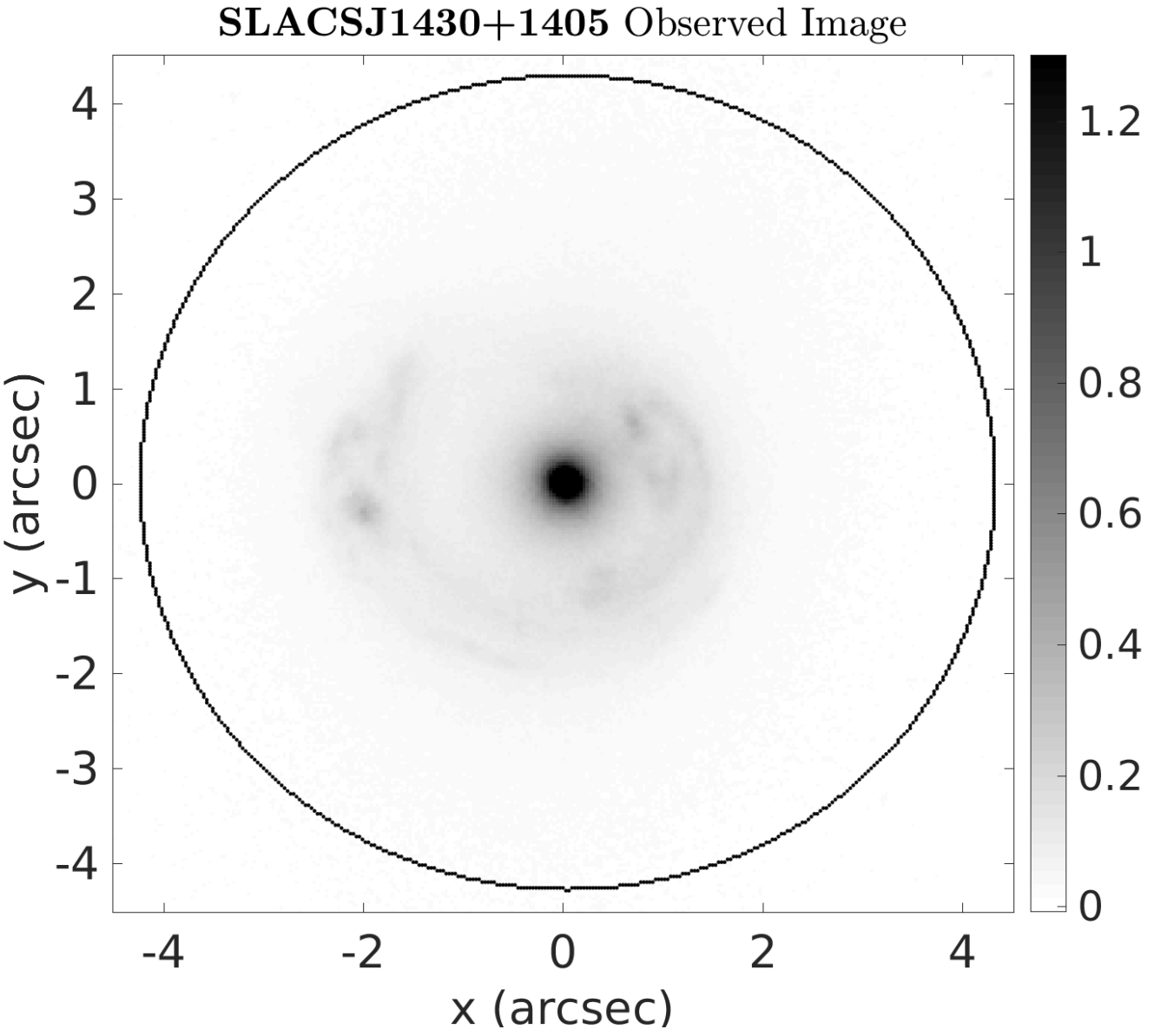
- **Can also target higher mass / lower redshift strong lenses.**

  - More sensitivity to stellar halo.

Masking

- **Our masks are huge for a lensing study!**
- **But embarrassingly small for a stella halos study :(.**

  - We can adjust our approach accordingly.



So Why Should You Care?

Future

- **We’re ready to model 100+ strong lenses:**

  - robust septation of stellar components and dark matter.

  - Does dark matter dictate the stellar halo?

- **Completely different assumptions to other approaches.**

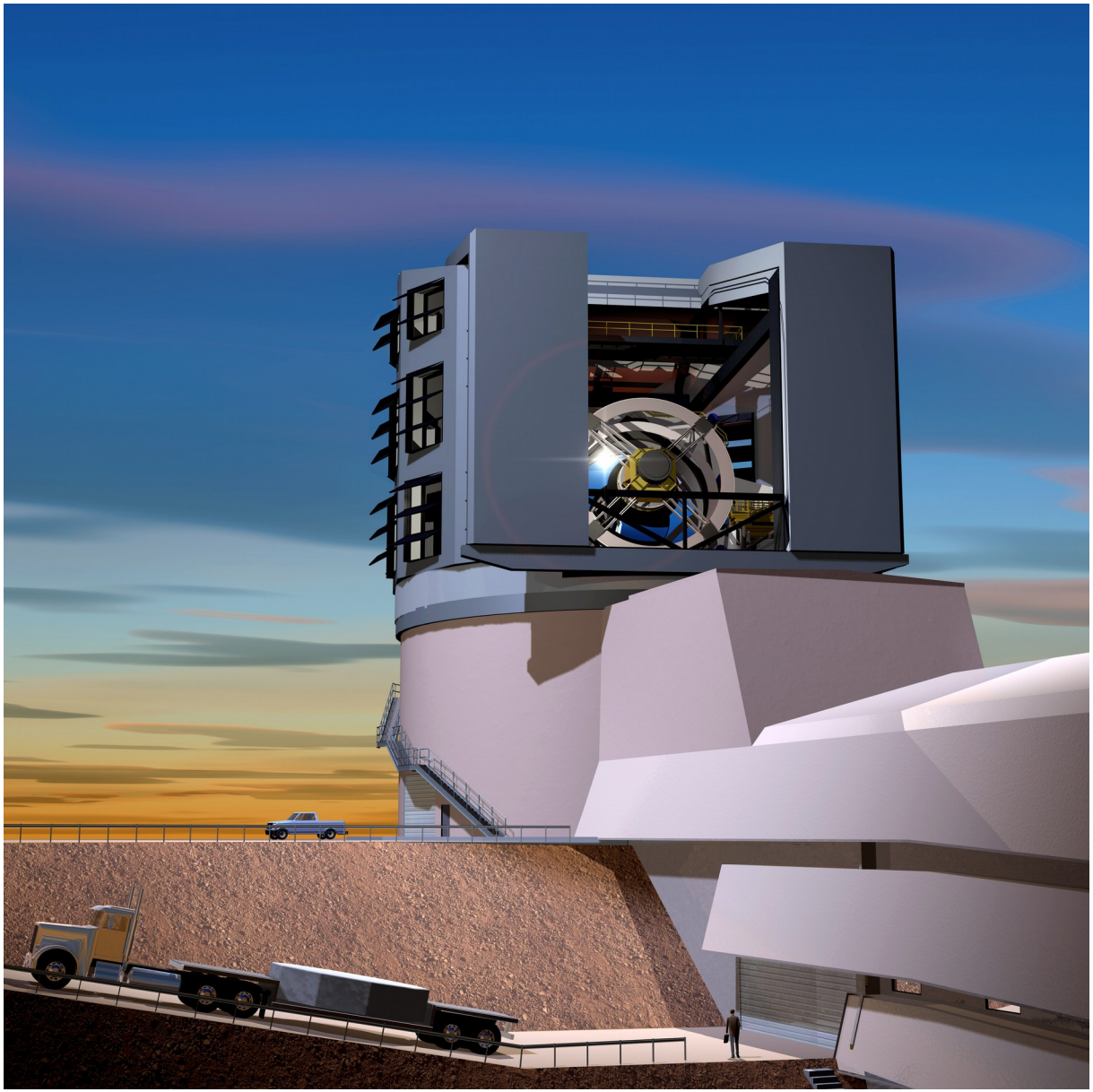
  - No stellar population modeling, metallicities, cosmological dimming, PSF nastiness, background sky ambiguities..

LSST

- **10000 strong lenses:**

  - Deep multi-wavelength data of the stellar halos.

  - Weak lensing data to tie to overall enviroment.



Summary

- **Strong lensing can determine**:

  - The stellar (halo) profile.

  - The dark matter profile.

  - Their geometry.

- **PyAutoLens:**

  https://github.com/Jammy2211/PyAutoLens