GLaD

Gravitational Lensing and Dynamics combined analysis to unveil properties of high-redshift galaxies.

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MPA Garching

EXTREMELY BIG EYES ON THE EARLY UNIVERSE

Rome, September 10th, 2019

MAX-PLANCK-GESELLSCHAFT

Early Type Galaxies (ETGs)

Early Type Galaxies can be broadly characterised by:

- old population
- red colours
- small amount of gas and dust
- lack of spiral arms

Fast Rotators

- less massive
- outer disk
- distributed like spiral galaxies
- evolution is gas-accretion driven

Slow Rotators

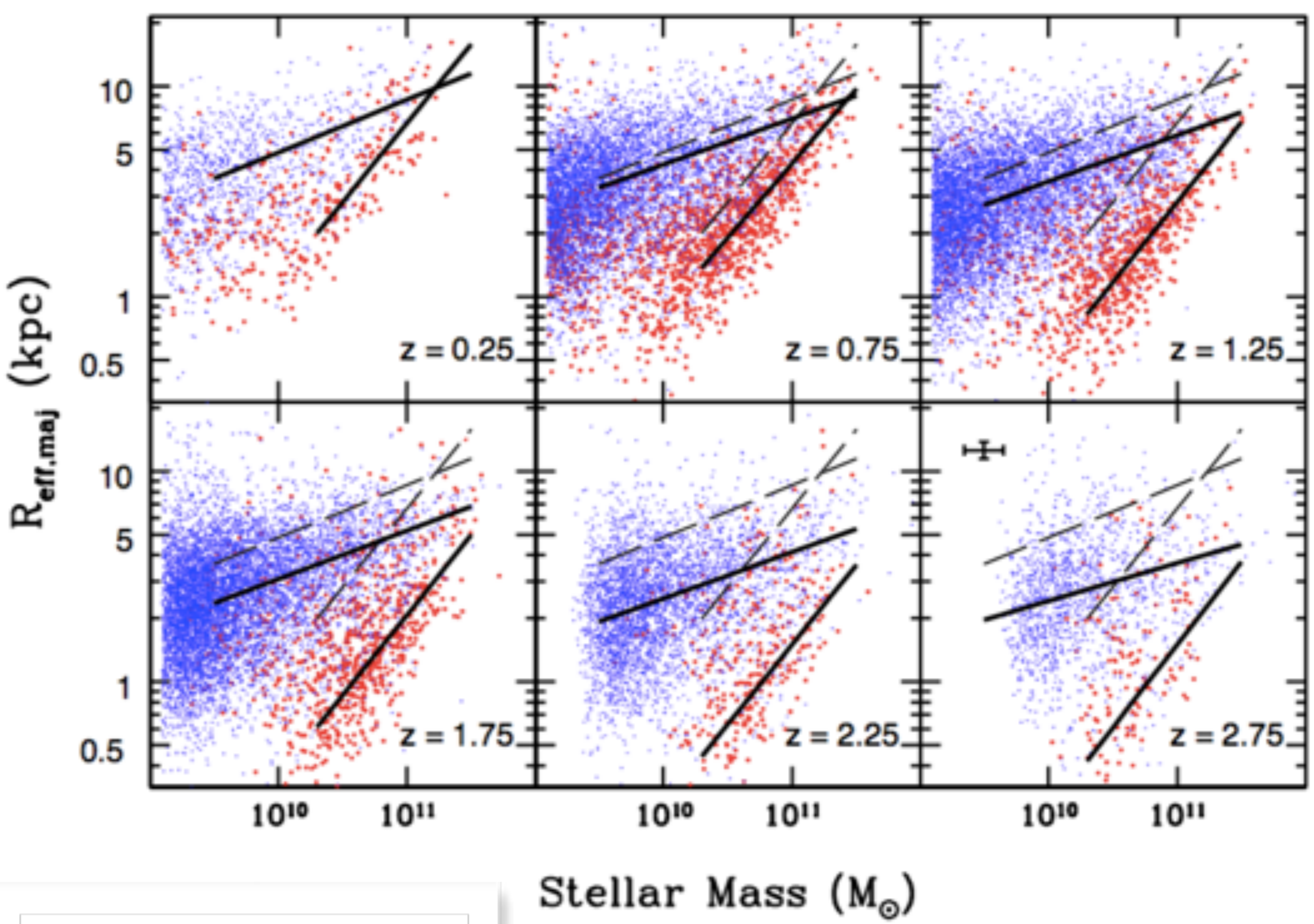
- dominate at high mass end
- weakly triaxial, no disk
- in high density environments
- evolution dry-merger driven

Emsellem et al. 2007, 2011

How did they evolve to be the most massive slow rotators galaxies today?

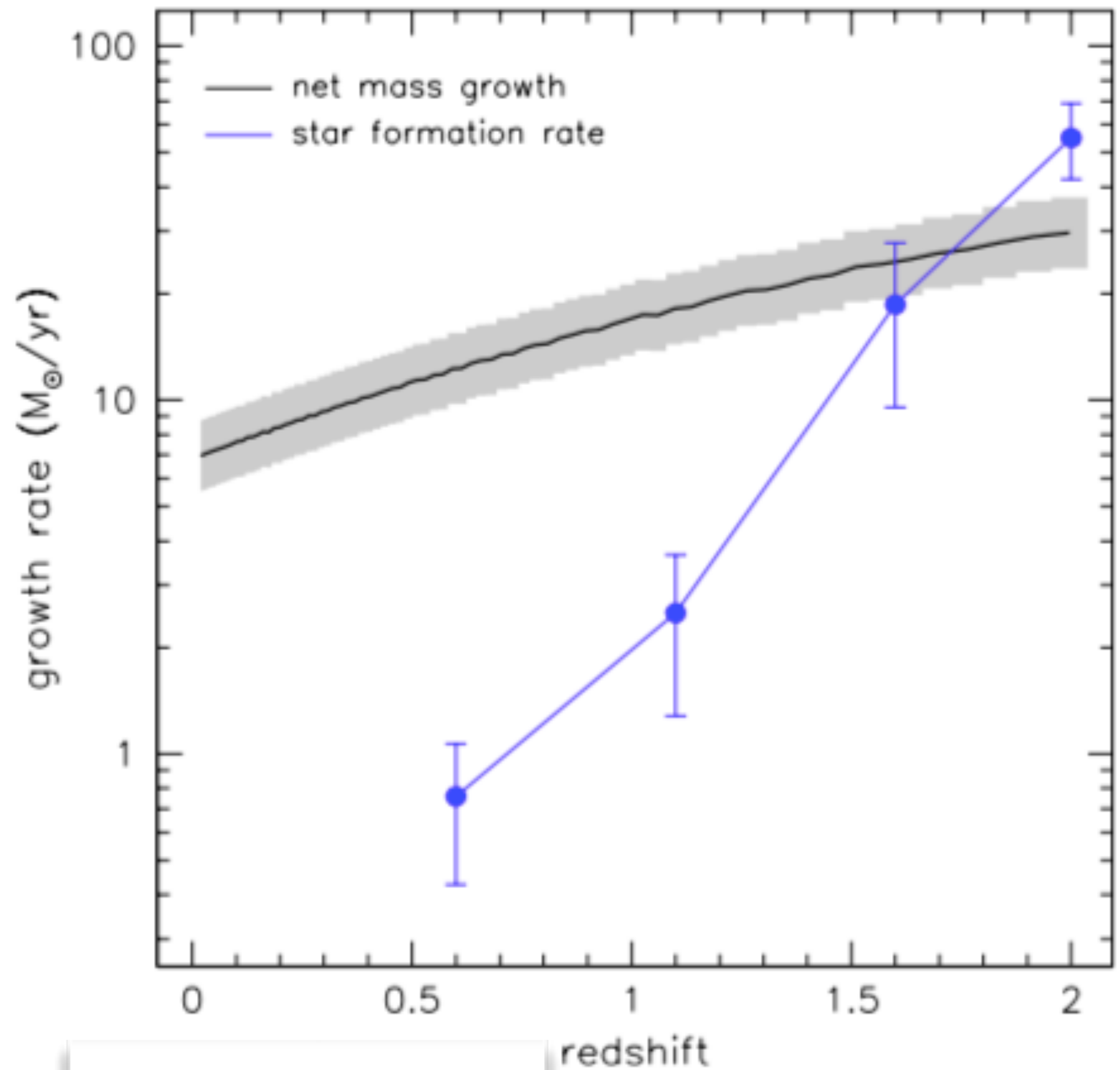
Early Type Galaxies (ETGs)

Evolution of mass-size relation early-type galaxies (red) through cosmic time shows rapid size evolution.



Van der Wel et al. 2014

Star formation cannot account for this growth in the past 10 Gyr.



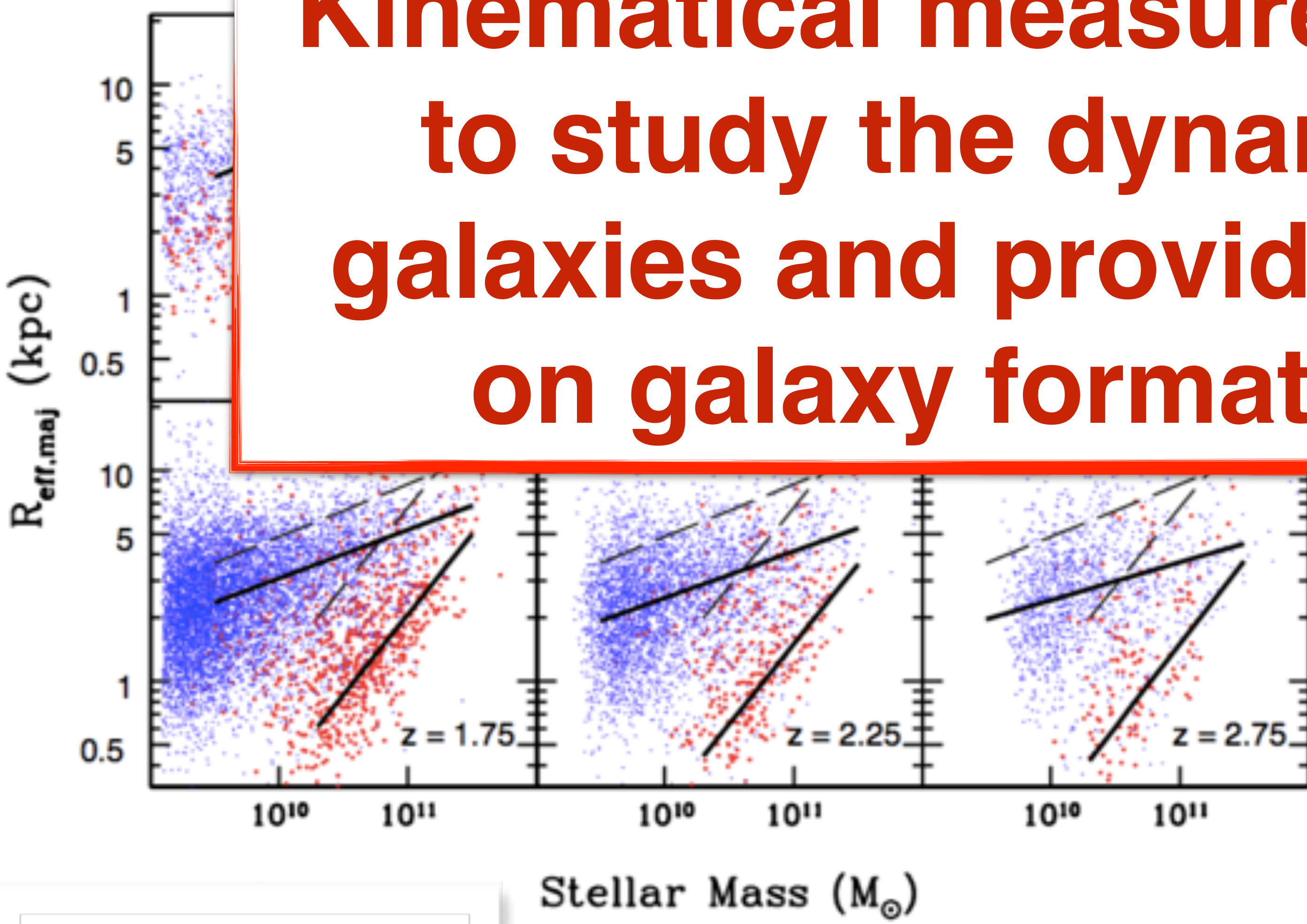
Van Dokkum et al. 2010

Early Type Galaxies (ETGs)

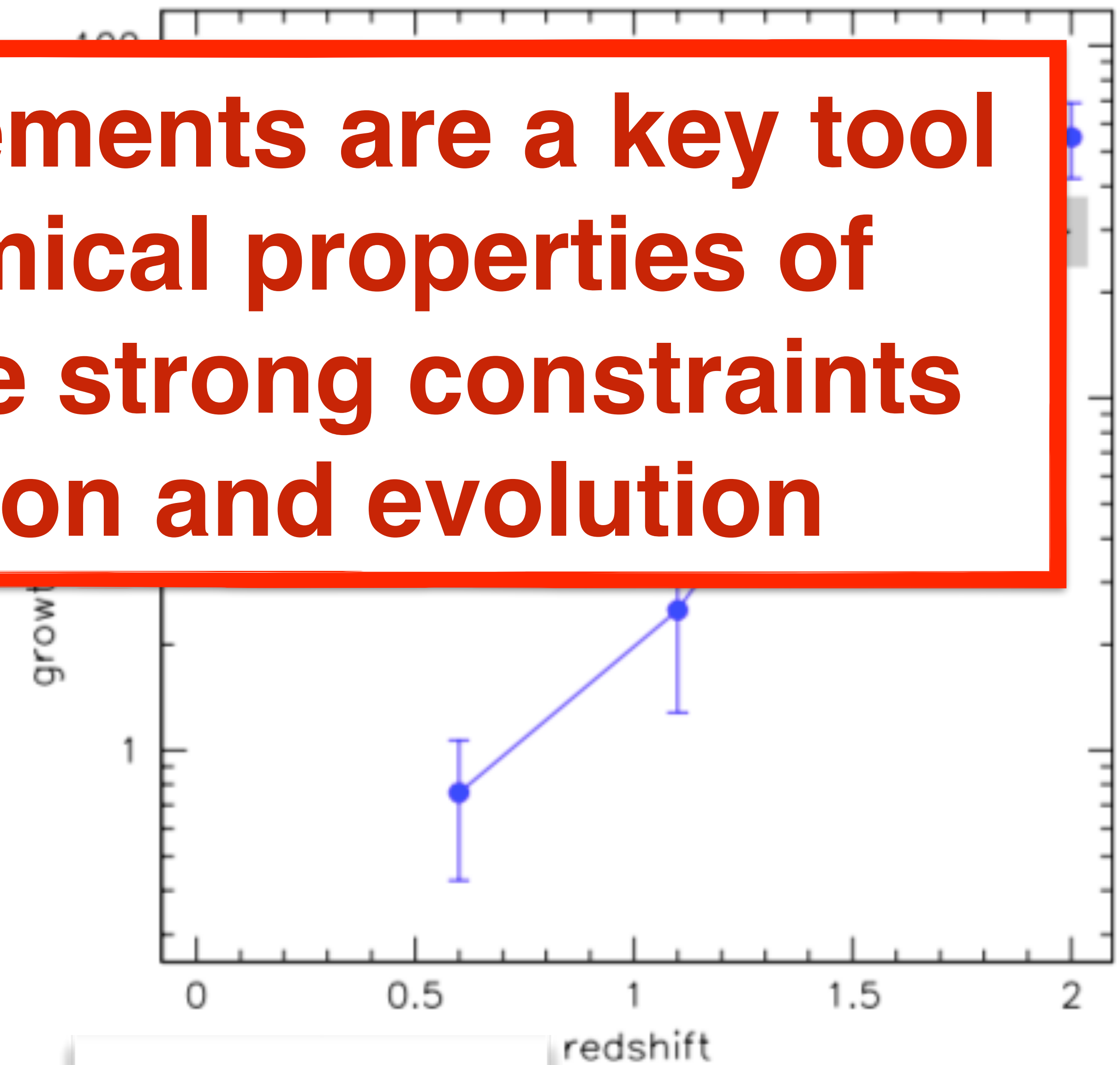
Evolution of mass-size relation early-type galaxies (red) through cosmic time shows rapid size evolution.

Star formation cannot account for this growth in the past 10 Gyr.

Kinematical measurements are a key tool to study the dynamical properties of galaxies and provide strong constraints on galaxy formation and evolution



Van der Wel et al. 2014



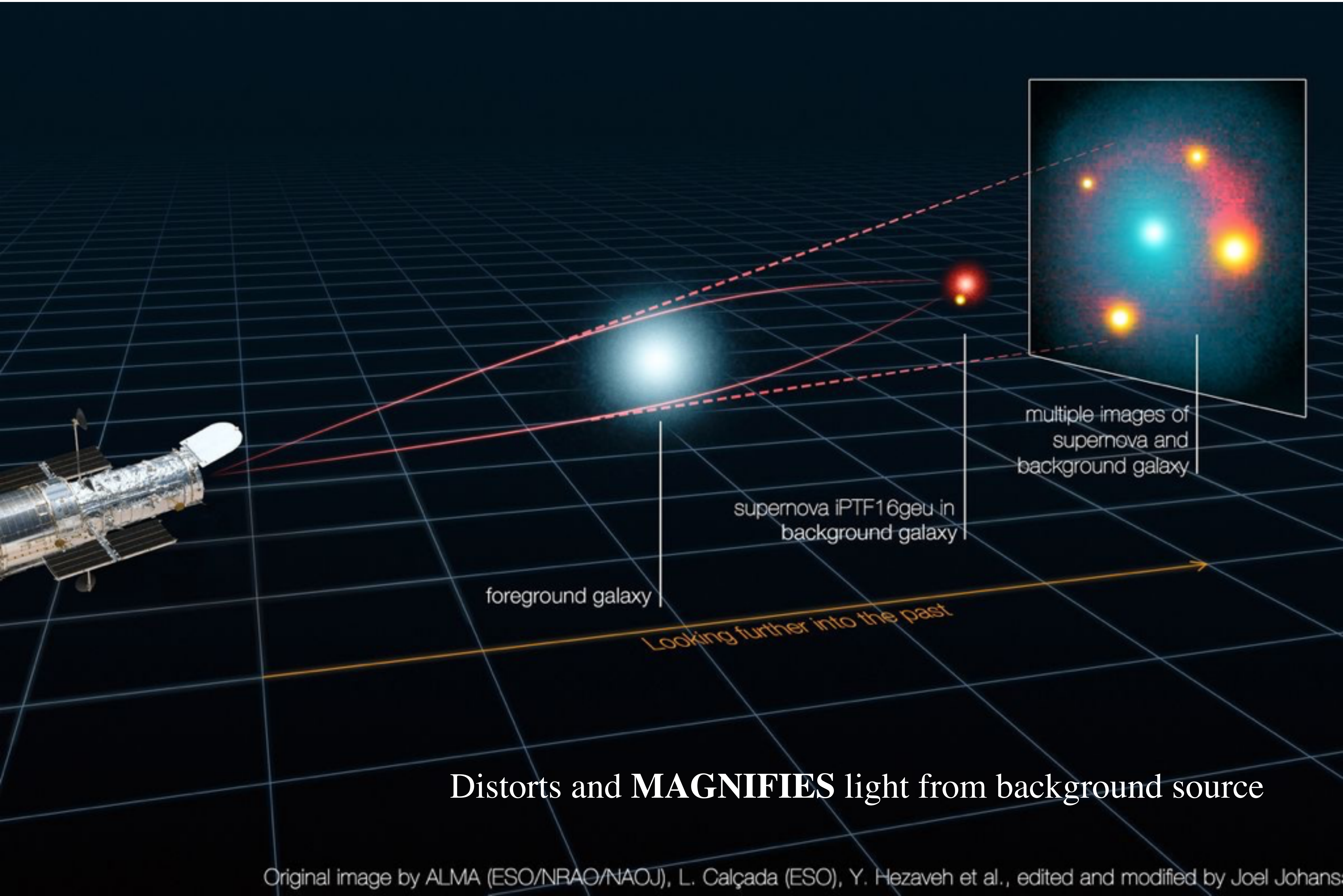
Van Dokkum et al. 2010

Limitations

- **low signal-to-noise** ratios and **low spatial resolution**
- observations are **limited to bright central regions** (bulge).
- only a dozen of quiescent galaxies beyond z=2 are known for being suitable to measure their stellar kinematics (e.g. Kriek et al. 2009, van de Sande 2013, Toft et al 2012, Newman et al. 2015a, Kriek et al. 2016, Hill et al. 2016, Belli et al. 2017, Toft et al. 2017)

How can this be overcome?

Gravitational lensing



Distorts and **MAGNIFIES** light from background source

GLaD Method

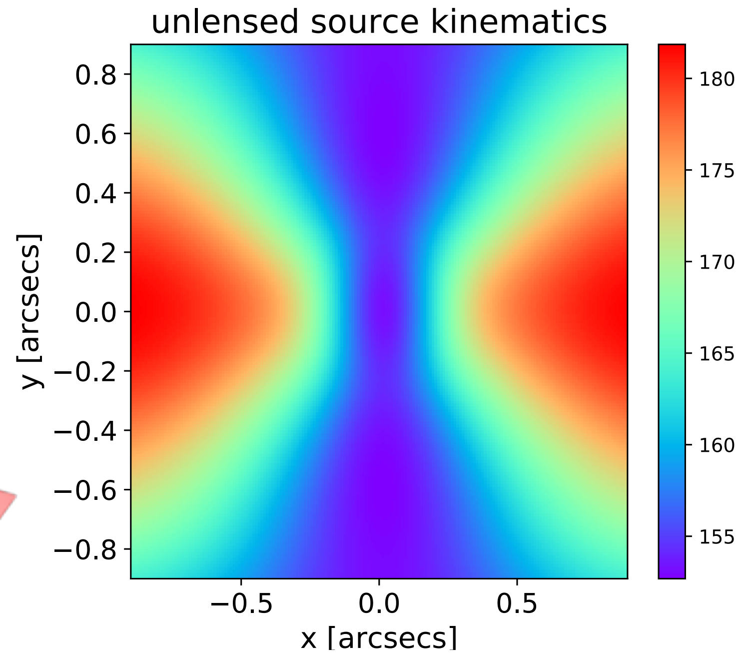
- Lensing and dynamics analysis are performed simultaneously

- We compare the dynamical model of the source kinematics on the image plane

- Use parametrised profiles for both source and lens (do not rely on any source reconstruction)

- Trace gravitational potential using stellar kinematics (no gas)

DYN model

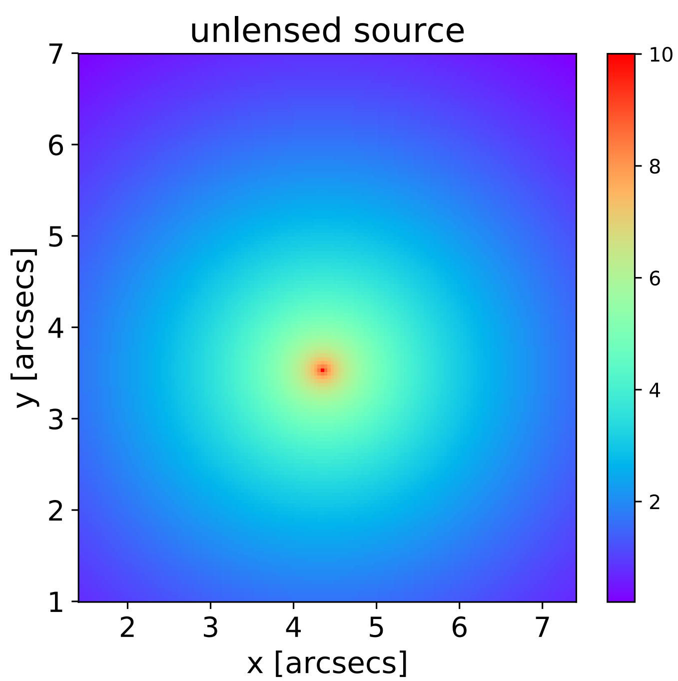


Source

mass model

light model

SB model



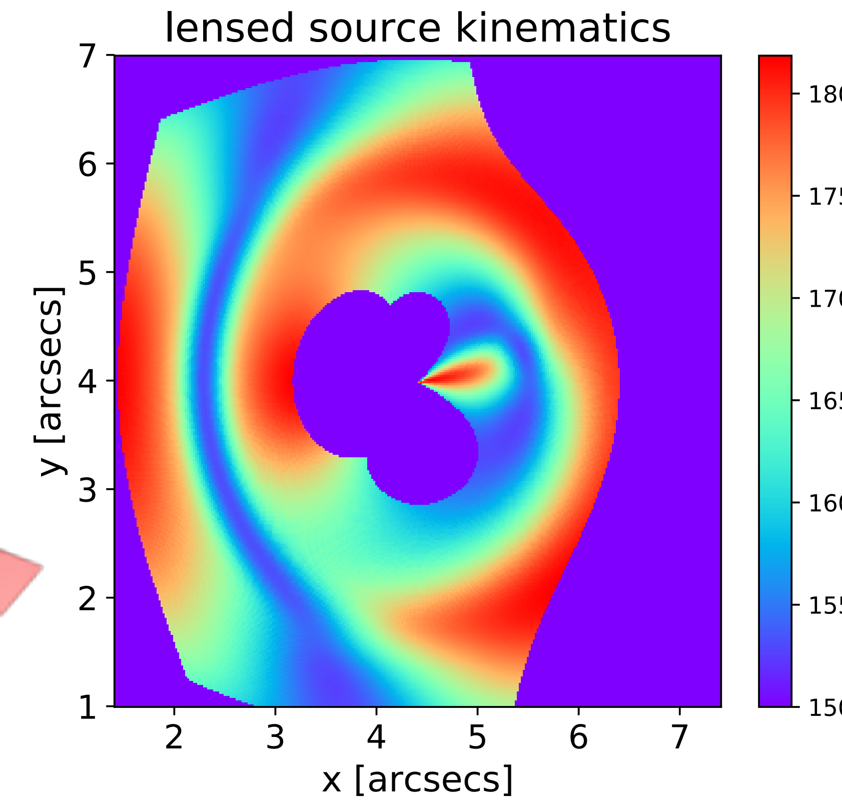
LENSING

Lens

mass model

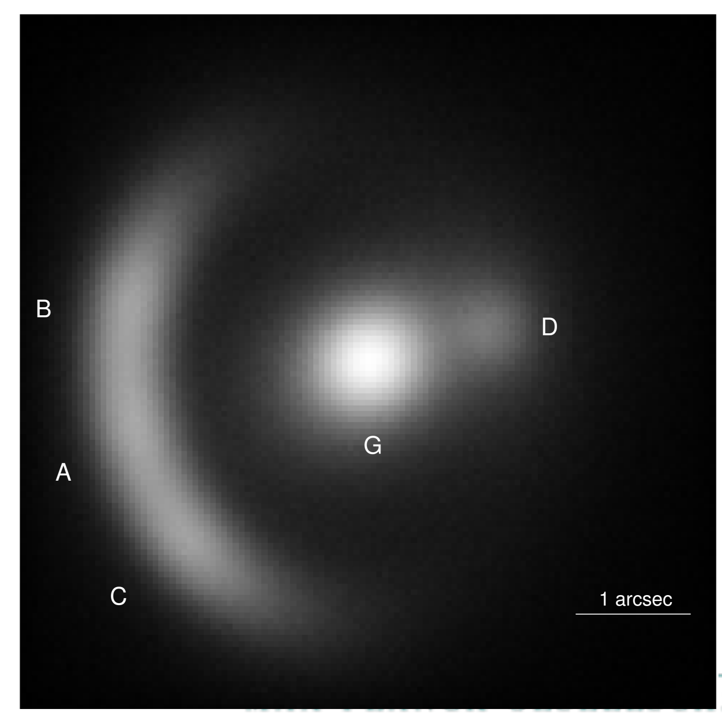
light model

PSF

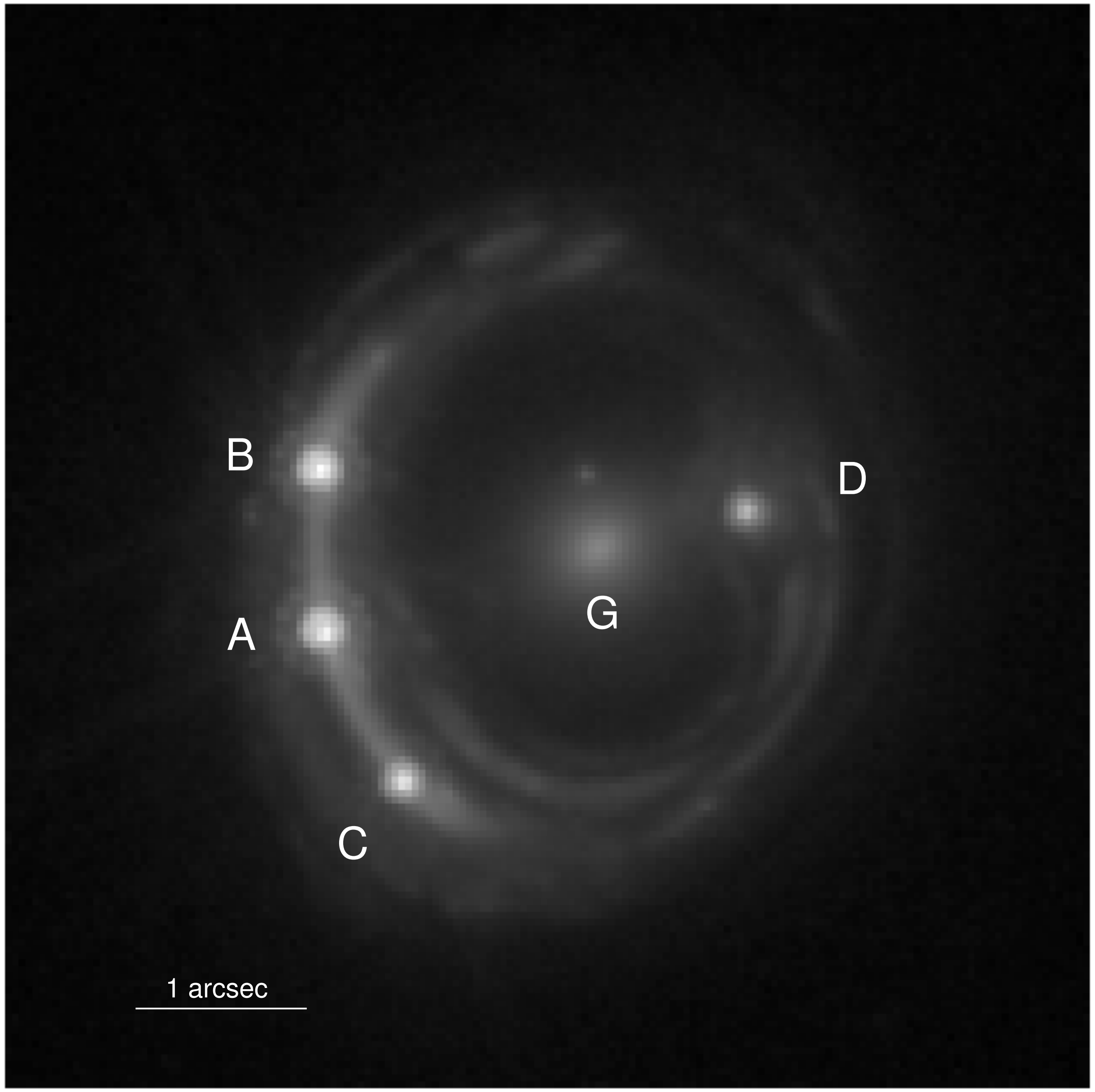


COMPARE to DATA

PSF



RX J1131–1231



HST/ACS F814W filter

$$z_d = 0.295$$
$$z_s = 0.654$$

SLUSE ET AL. 2003

Used for studies on:

- quasars and region around BH
- time delay cosmography
- dark matter substructures
- planet searches with microlensing

Mock Lensing Data: MOCK 1

LENS:

Yildirim et al. 2019

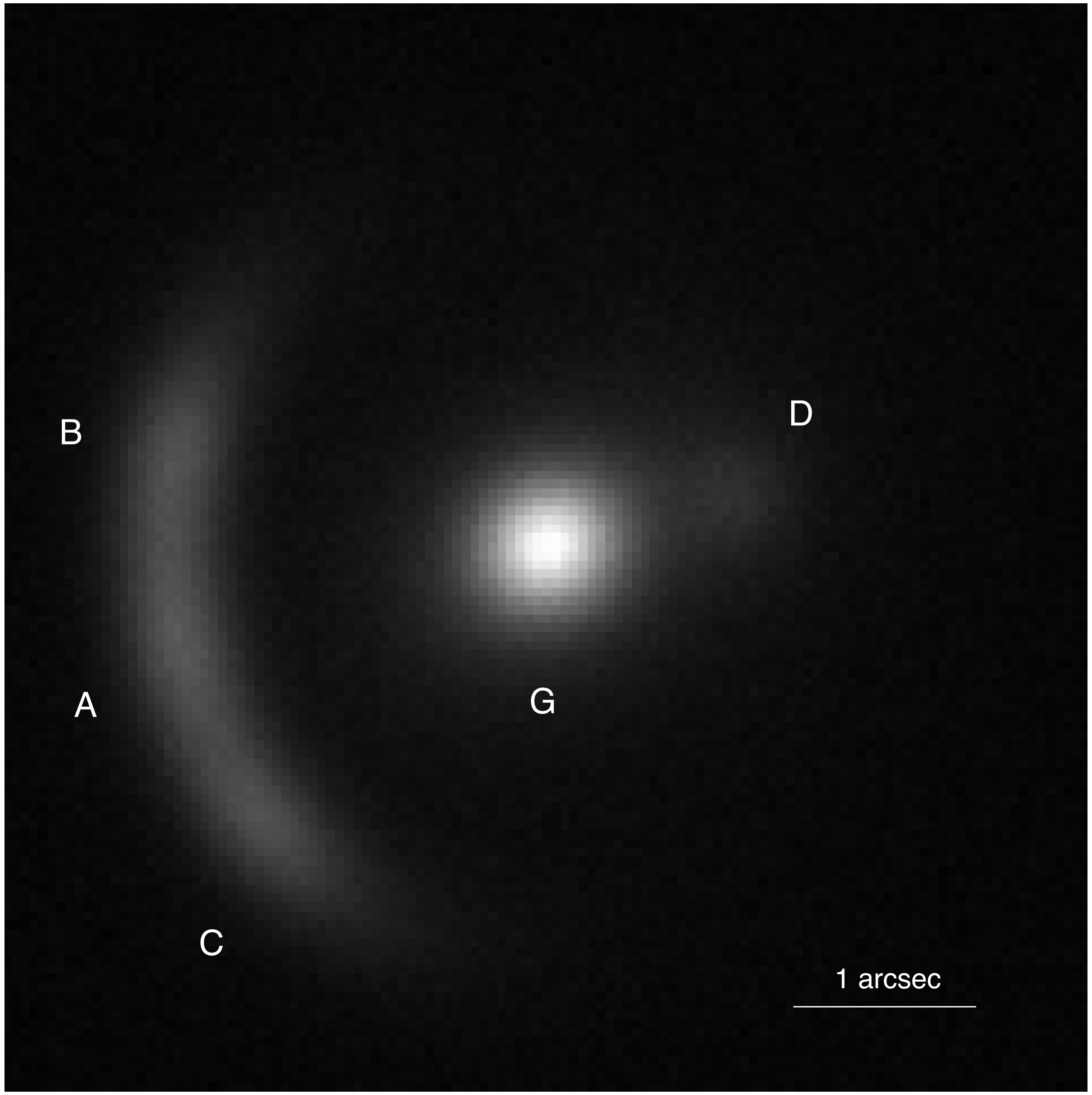
MASS: power law + external shear

LIGHT: Sersic profile

SOURCE:

MASS: isothermal profile

LIGHT: Sersic profile



Adjust amplitudes and effective radii to mimic HST observations of the SB distribution and the S/N.

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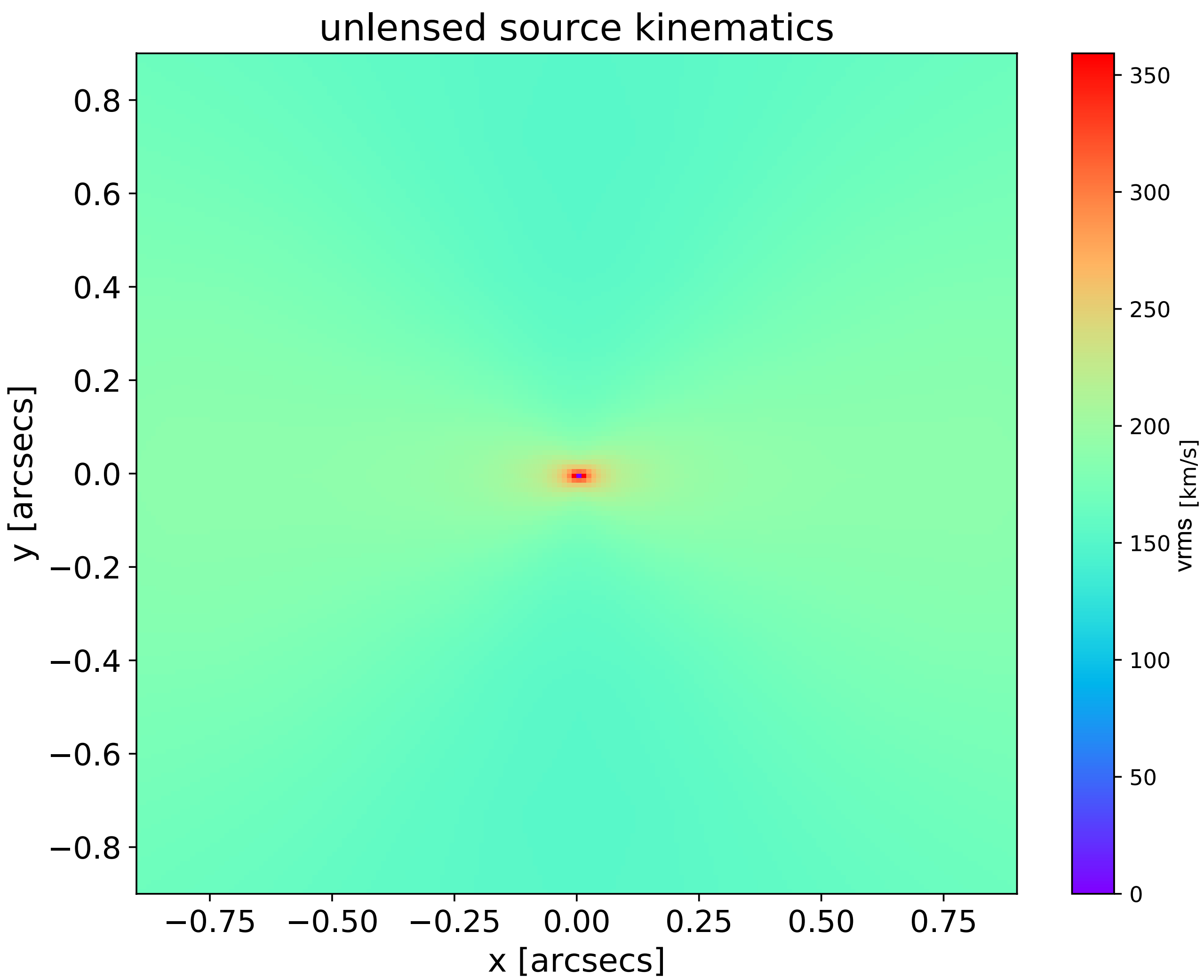
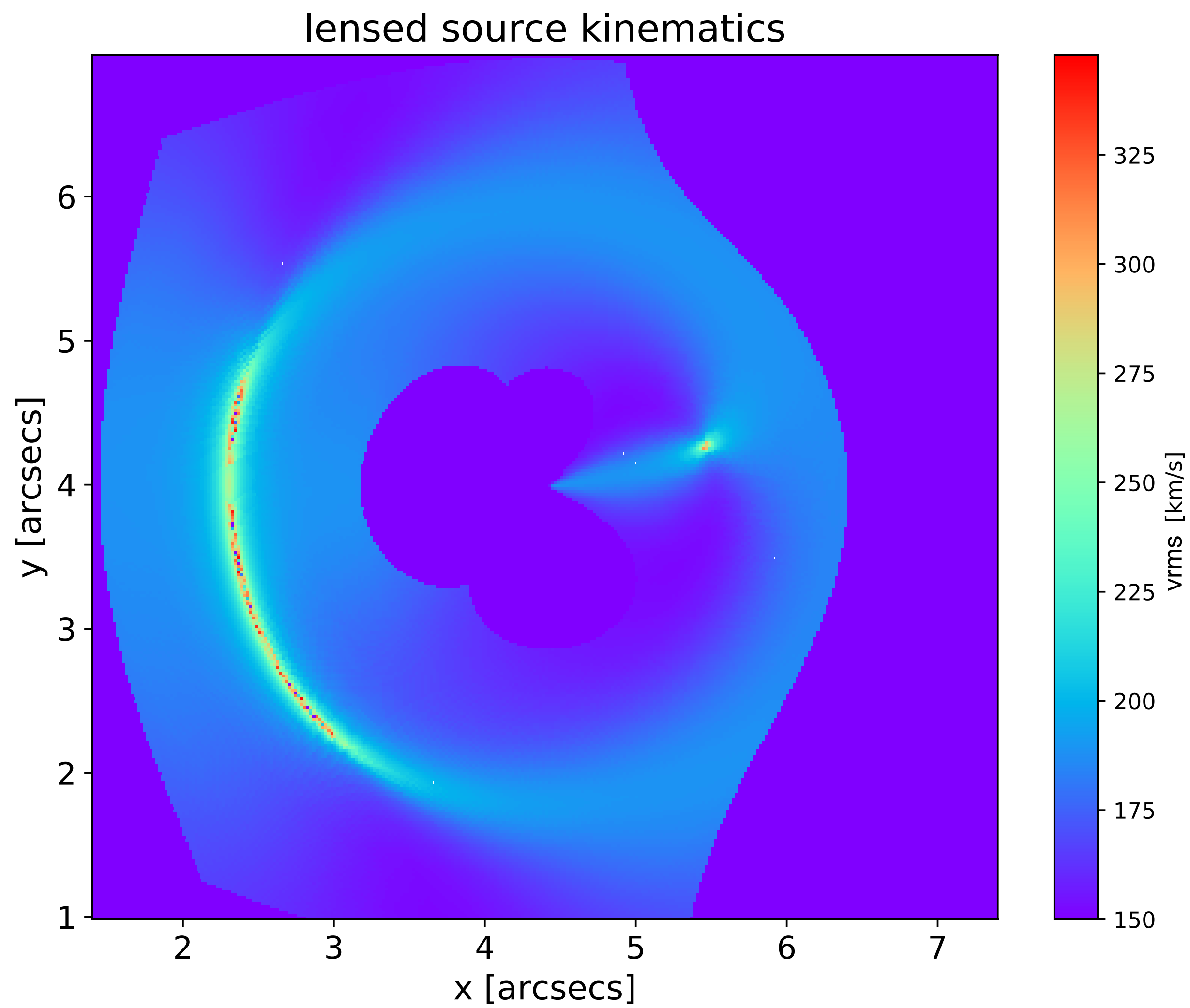
Mock Kinematic Data: MOCK 1

Source Plane



Lens Plane



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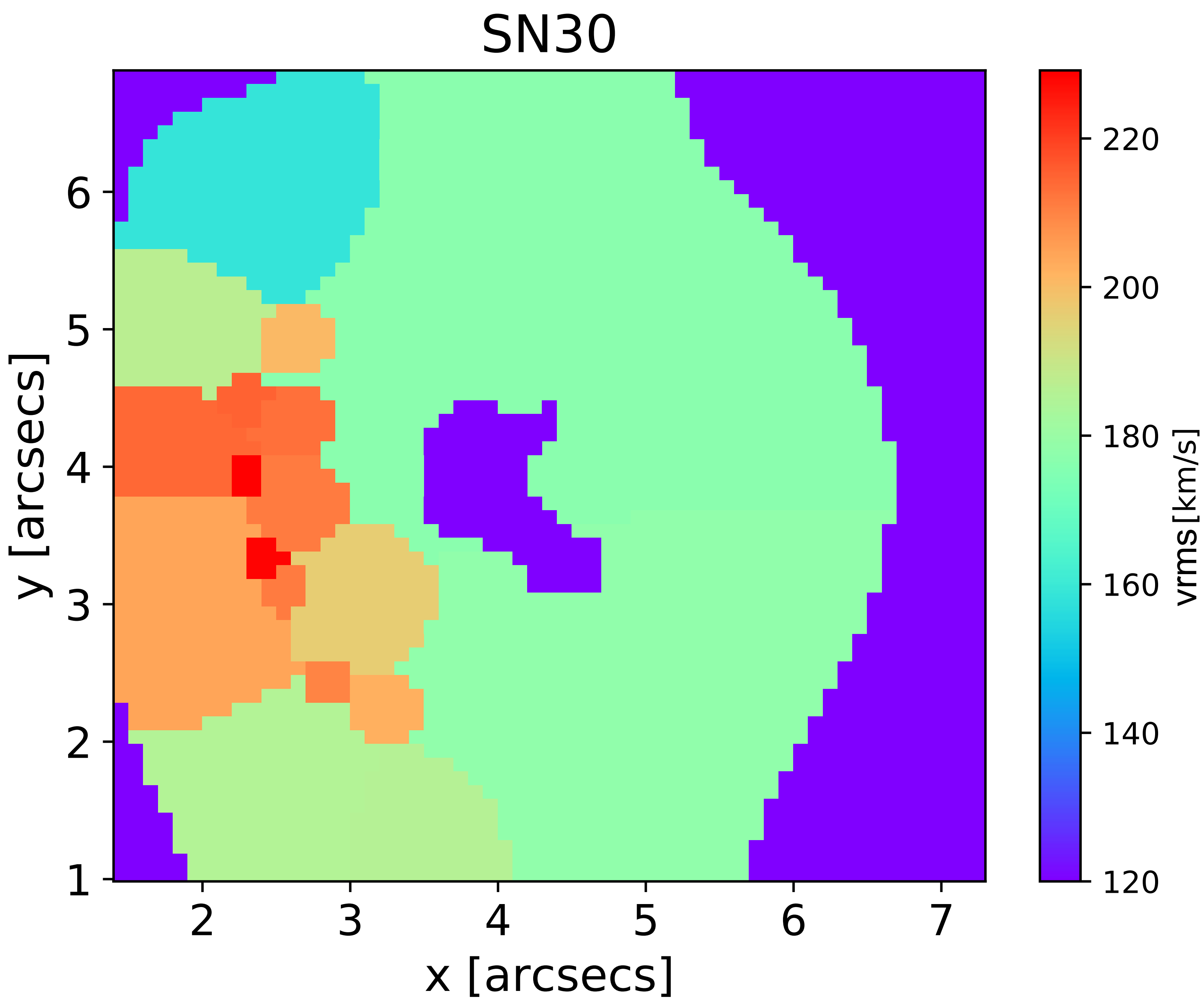
Mock Kinematic Data: MOCK 1

19 bins



This is a very optimistic case, we will probably not be able to measure anything on the right hand side in a realistic scenario.

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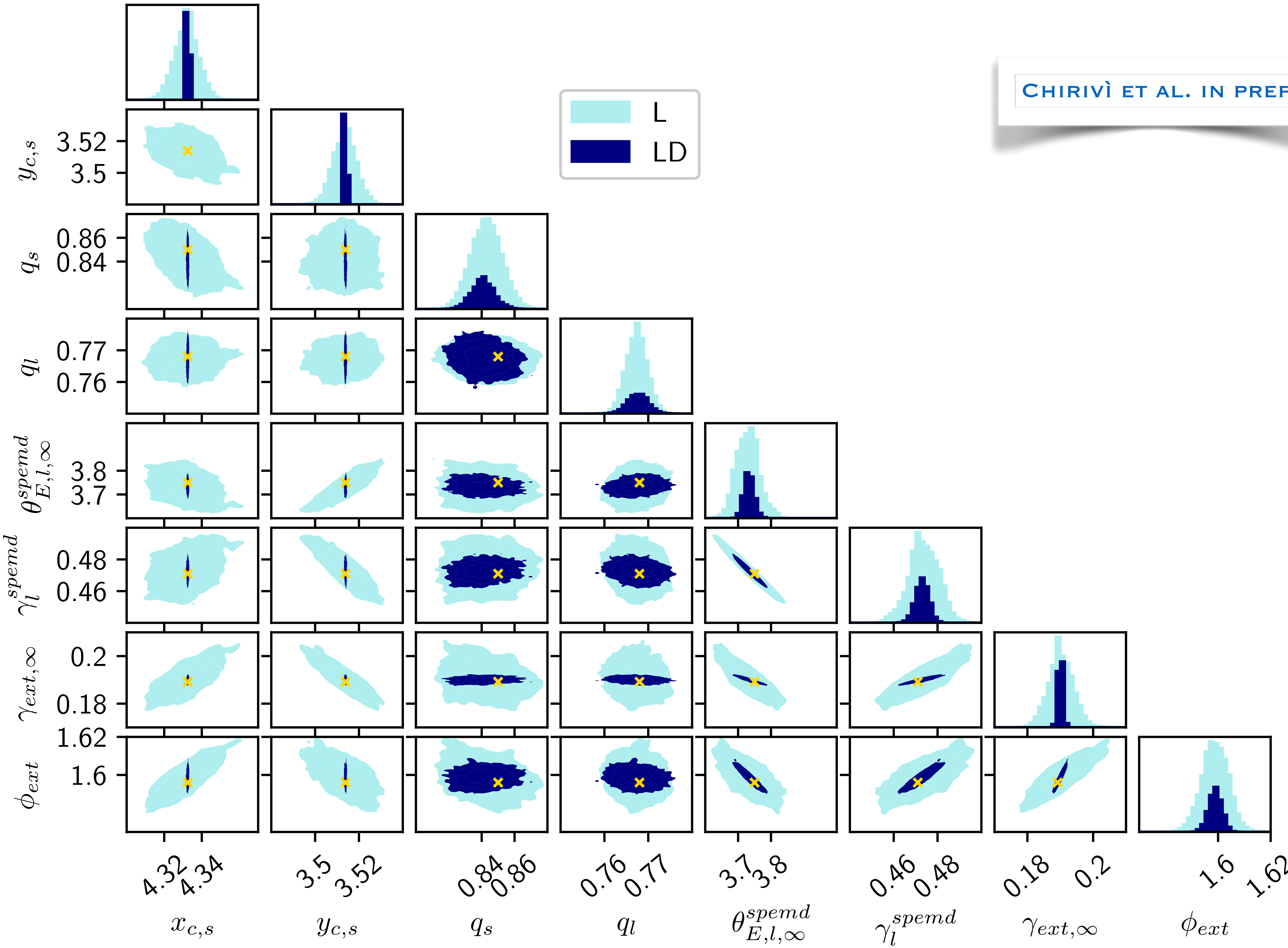
Models

We perform the following tests:

- consistency test
- lensing analysis vs. lensing + dynamics
- systematics for lens and source mass profiles



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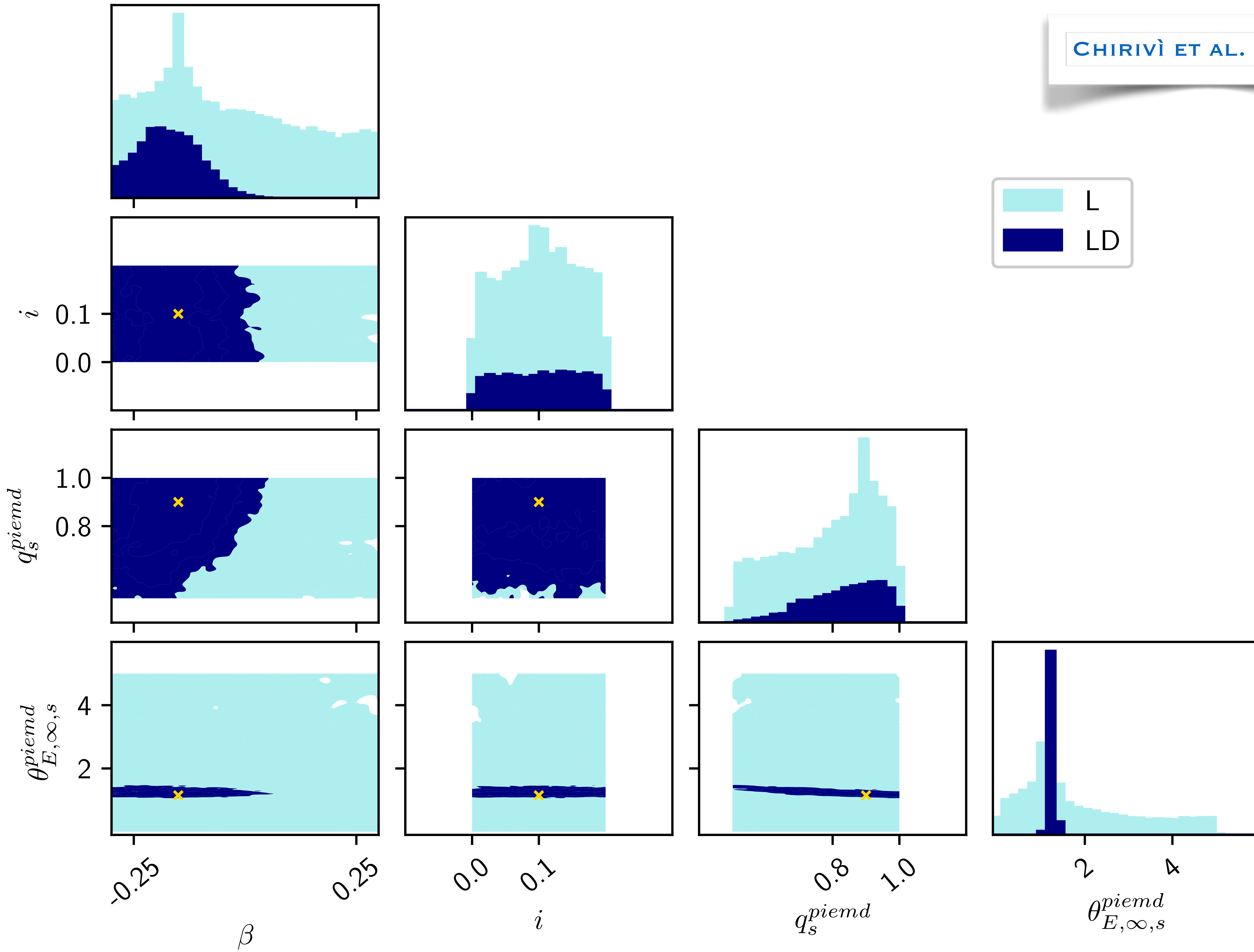

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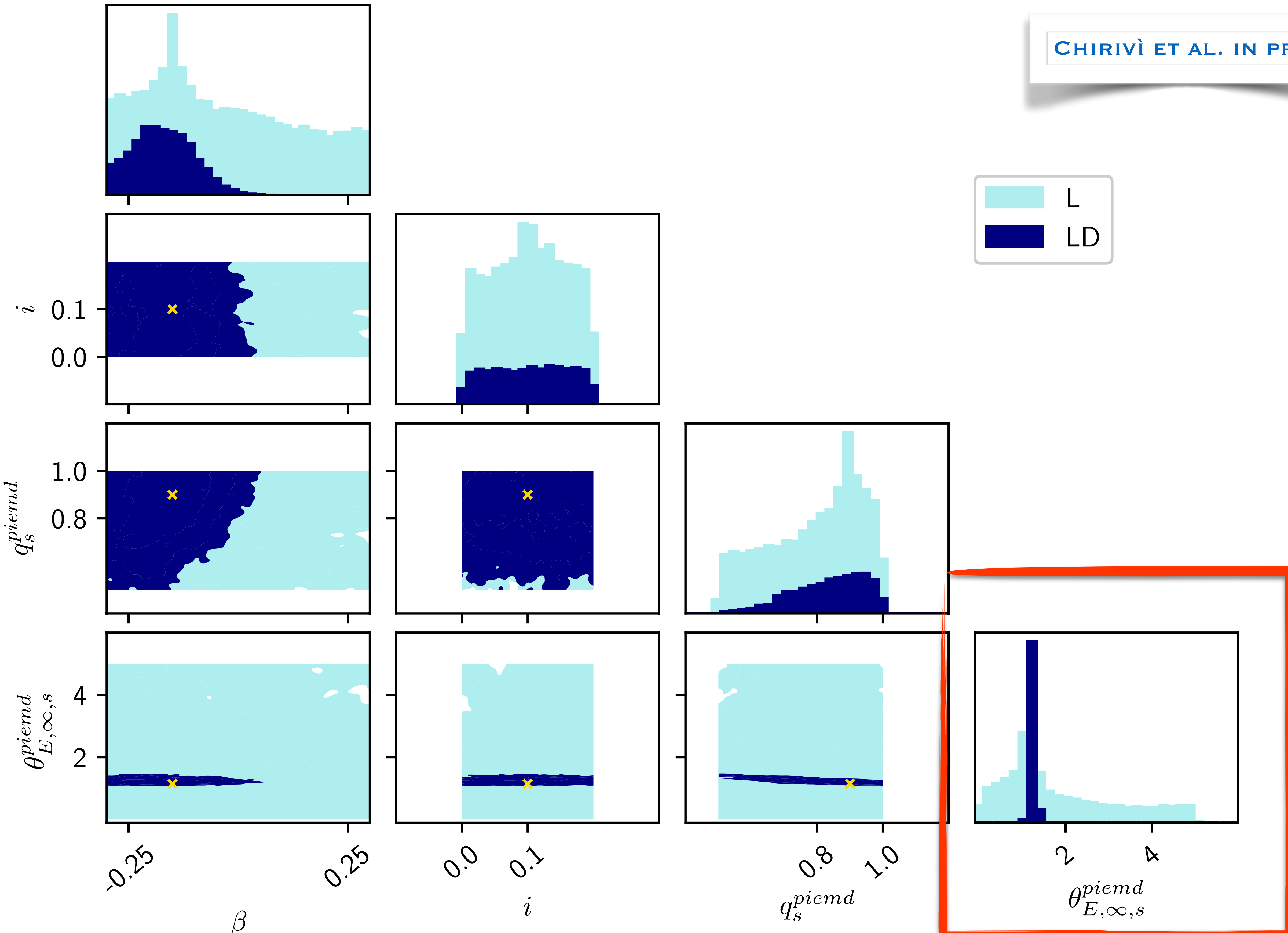
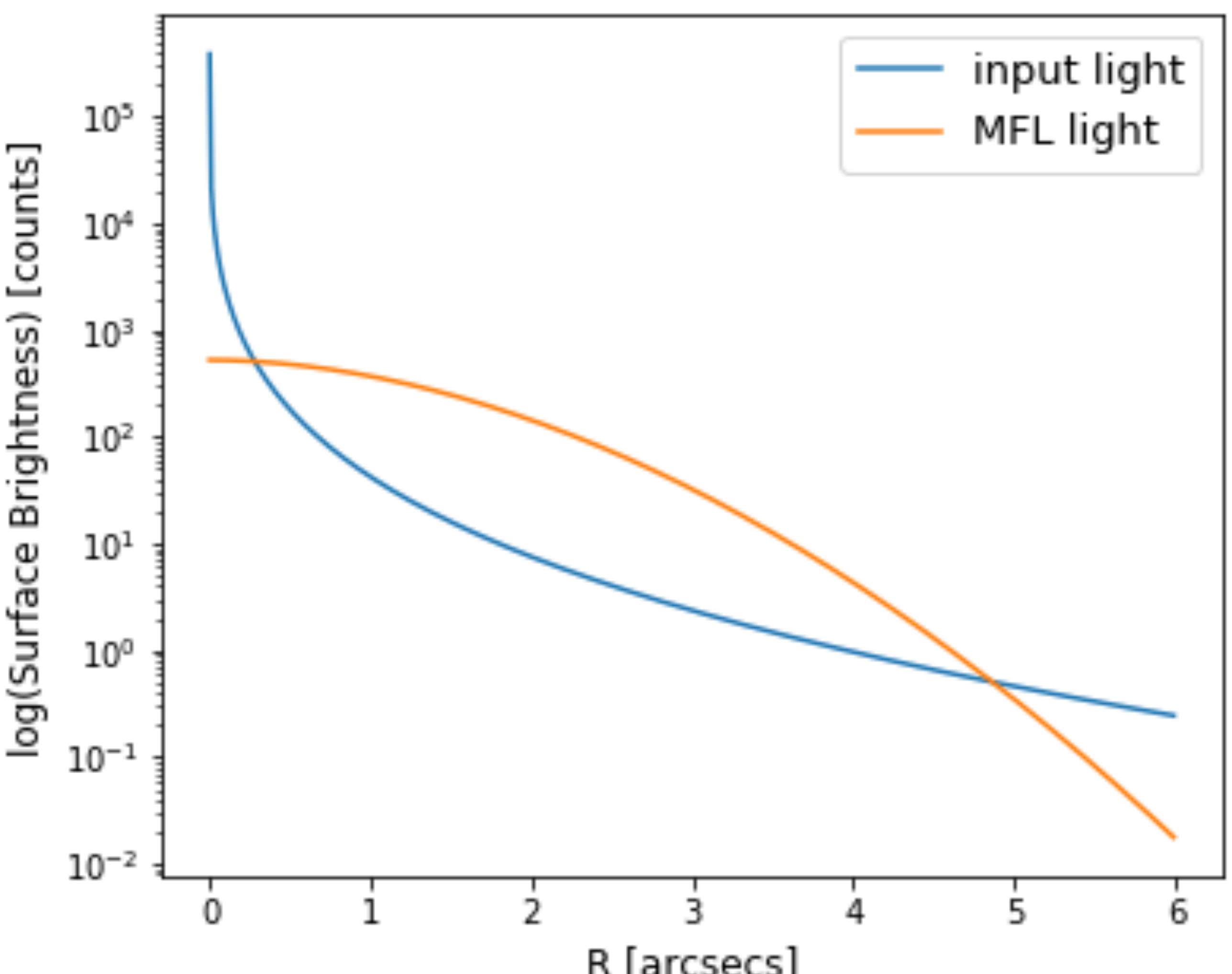
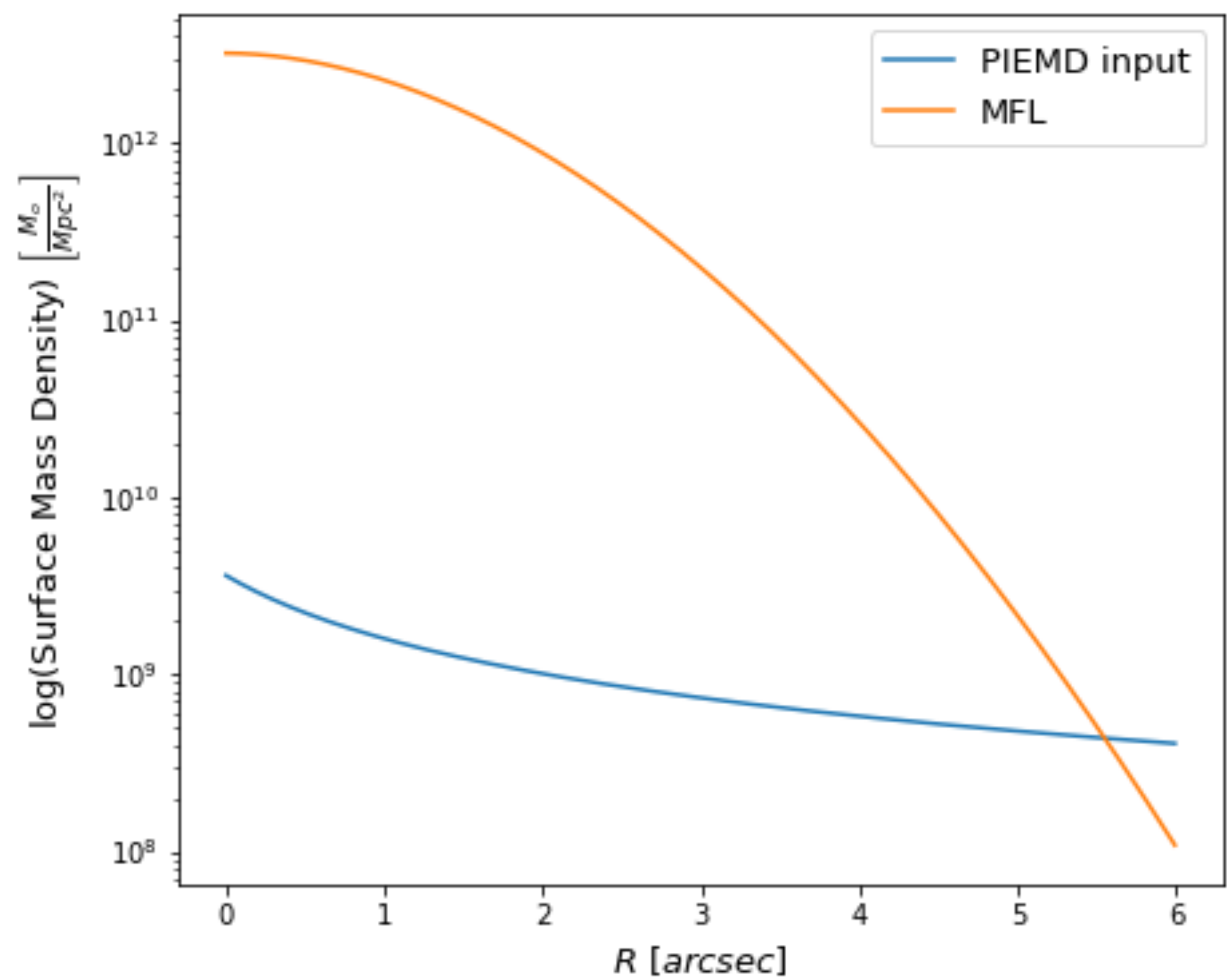


Mass-Follows-Light Profile: model prediction

Test **systematic errors** on **<u>SOURCE MASS</u>**, by modelling it with a mass-follows-light (MFL) profile.





PRELIMINARY

Assuming a **constant** mass-to-light ratio.

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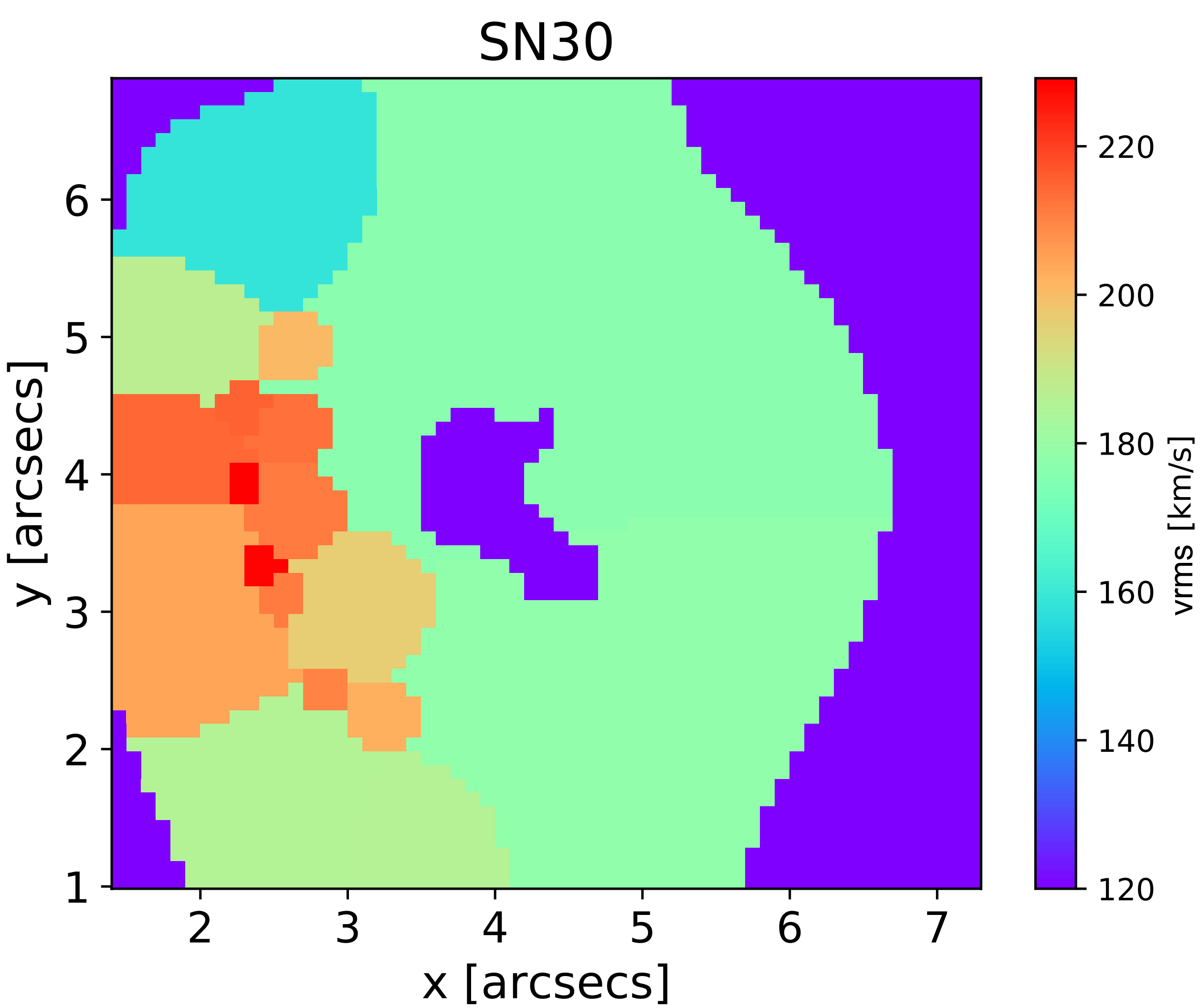
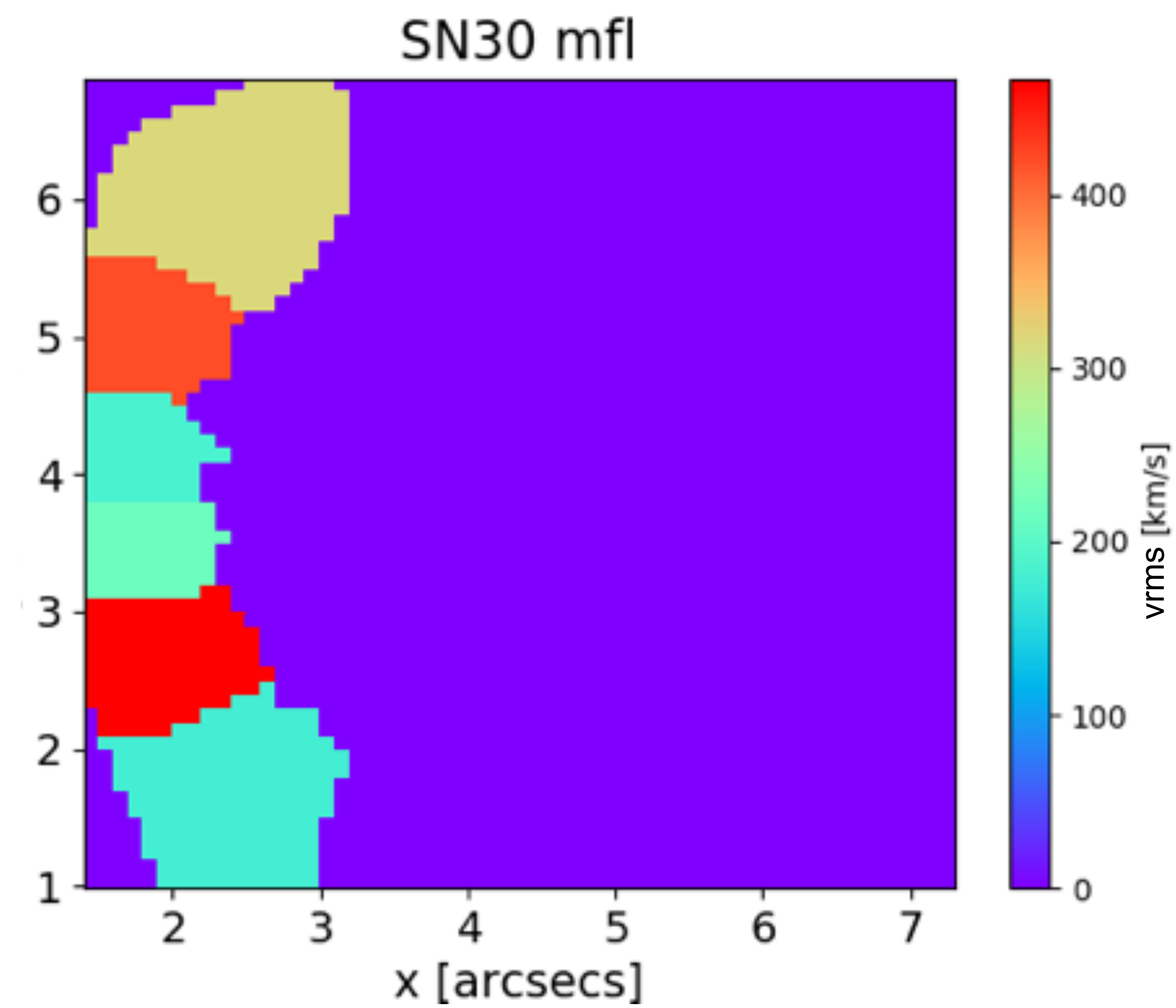
Mass-Follows-Light Profile: model prediction

INPUT ISOTHERMAL PROFILE



MFL PROFILE



PRELIMINARY

$\chi^2_{\rm red} = 42.$

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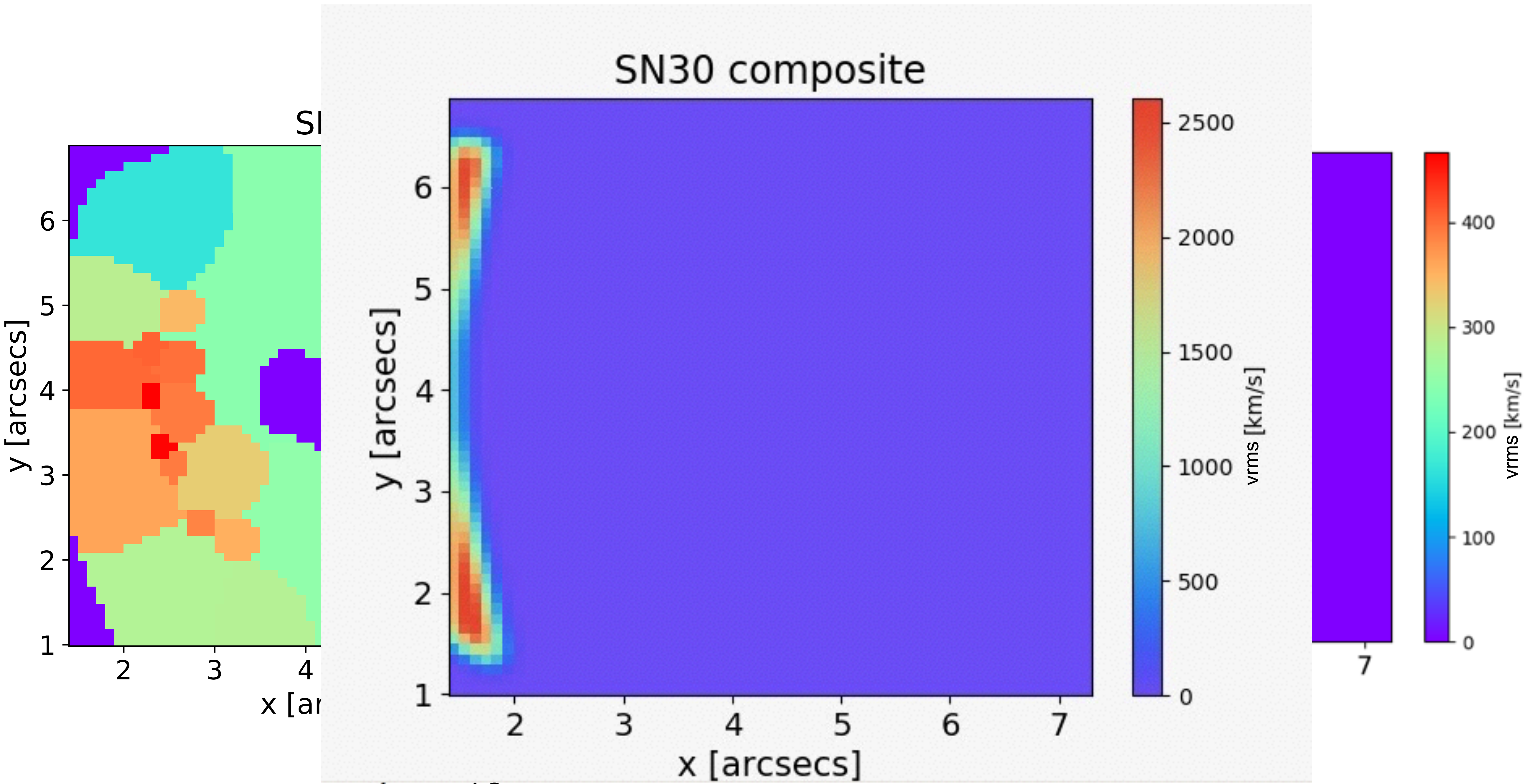
Mass-Follows-Light Profile: model prediction



$\chi^2_{\mathrm{red}} = 42.$

PRELIMINARY

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Mock Lensing Data: COMPOSITE MOCK

LENS:

MASS: NFW+Chameleon x M/L+external shear

LIGHT: Sersic profile

SOURCE:

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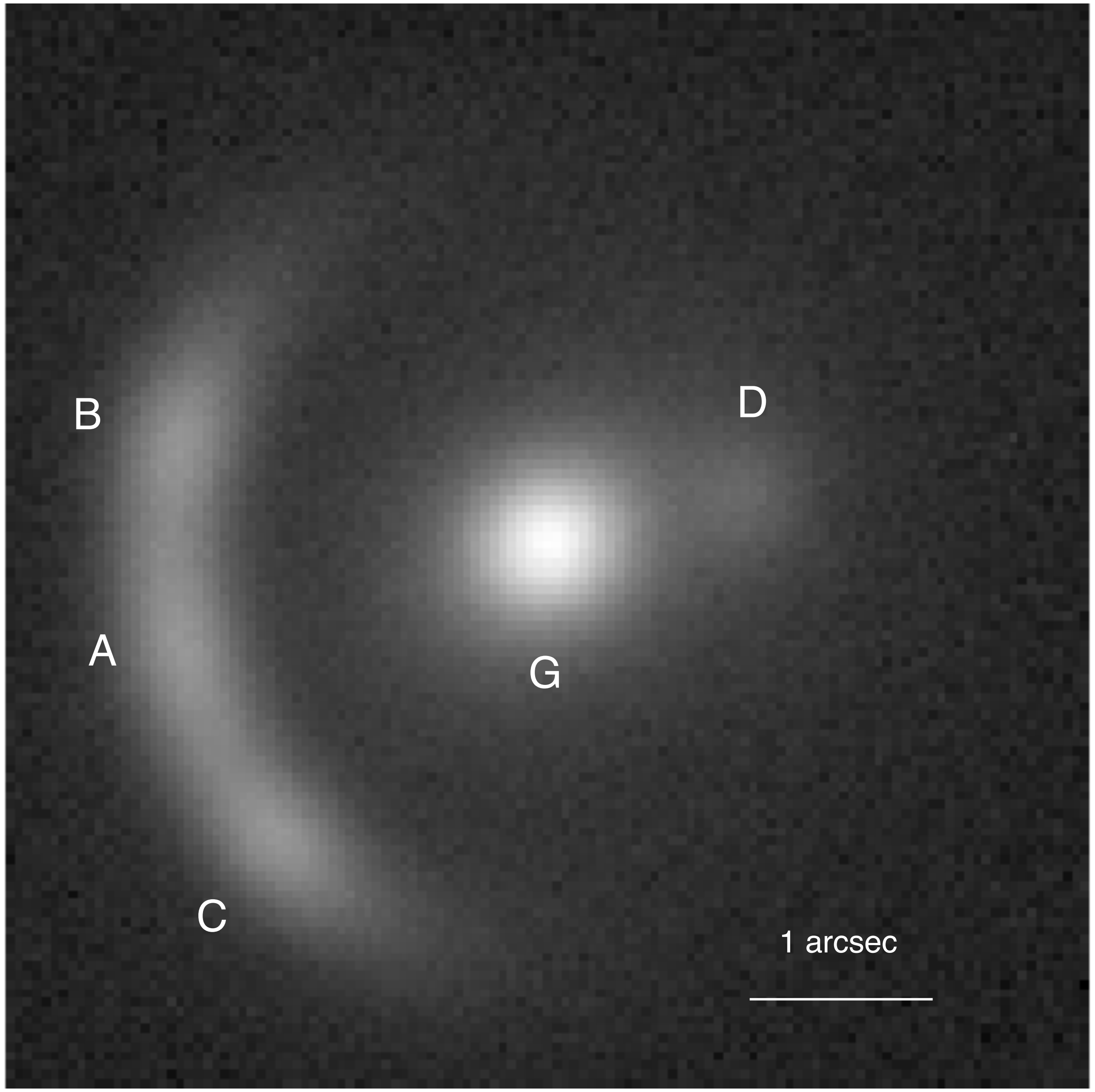

Adjusted amplitudes and effective radii to mimic HST observations of the SB distribution and the S/N

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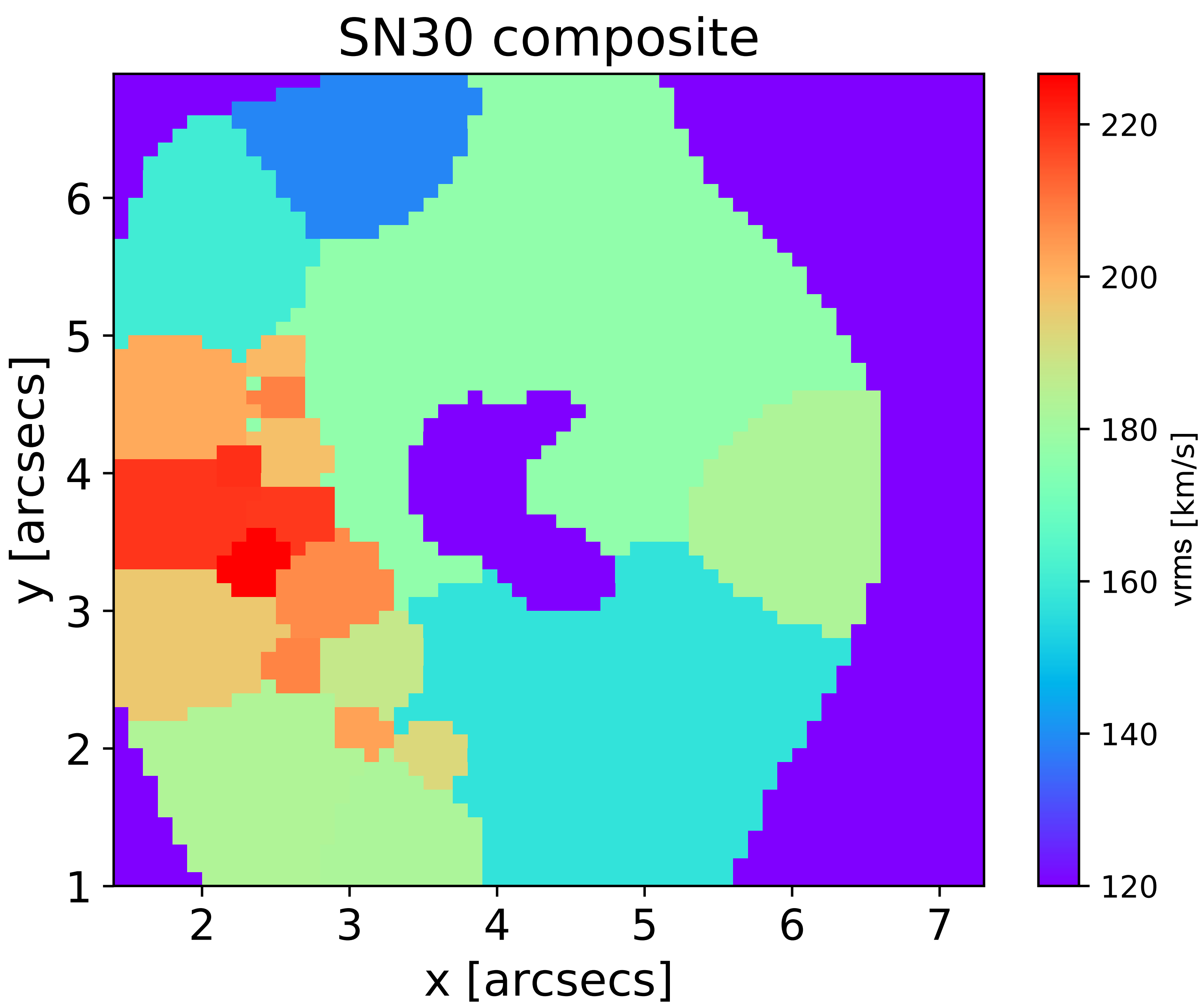
Mock Kinematic Data: COMPOSITE MOCK



22 bins

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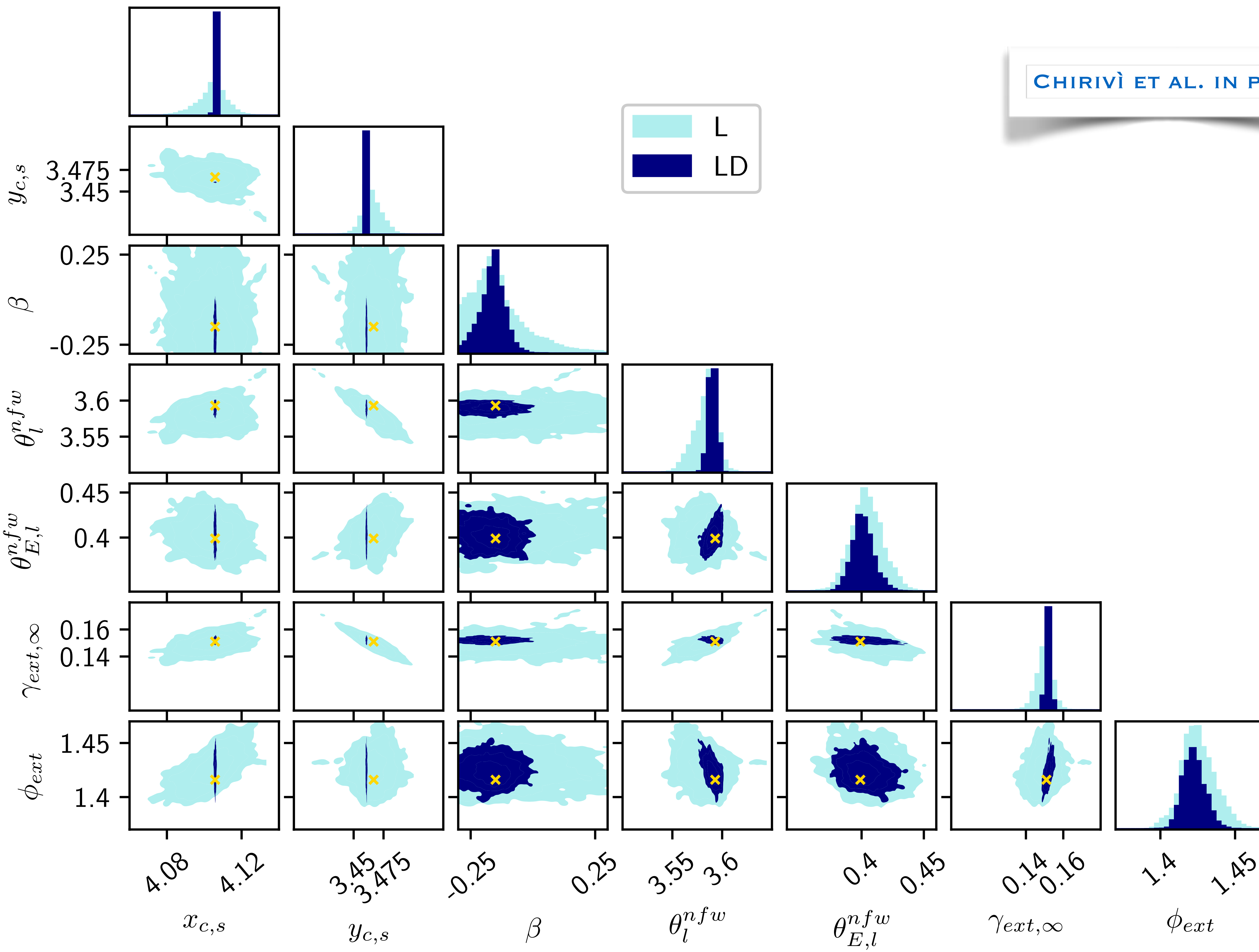

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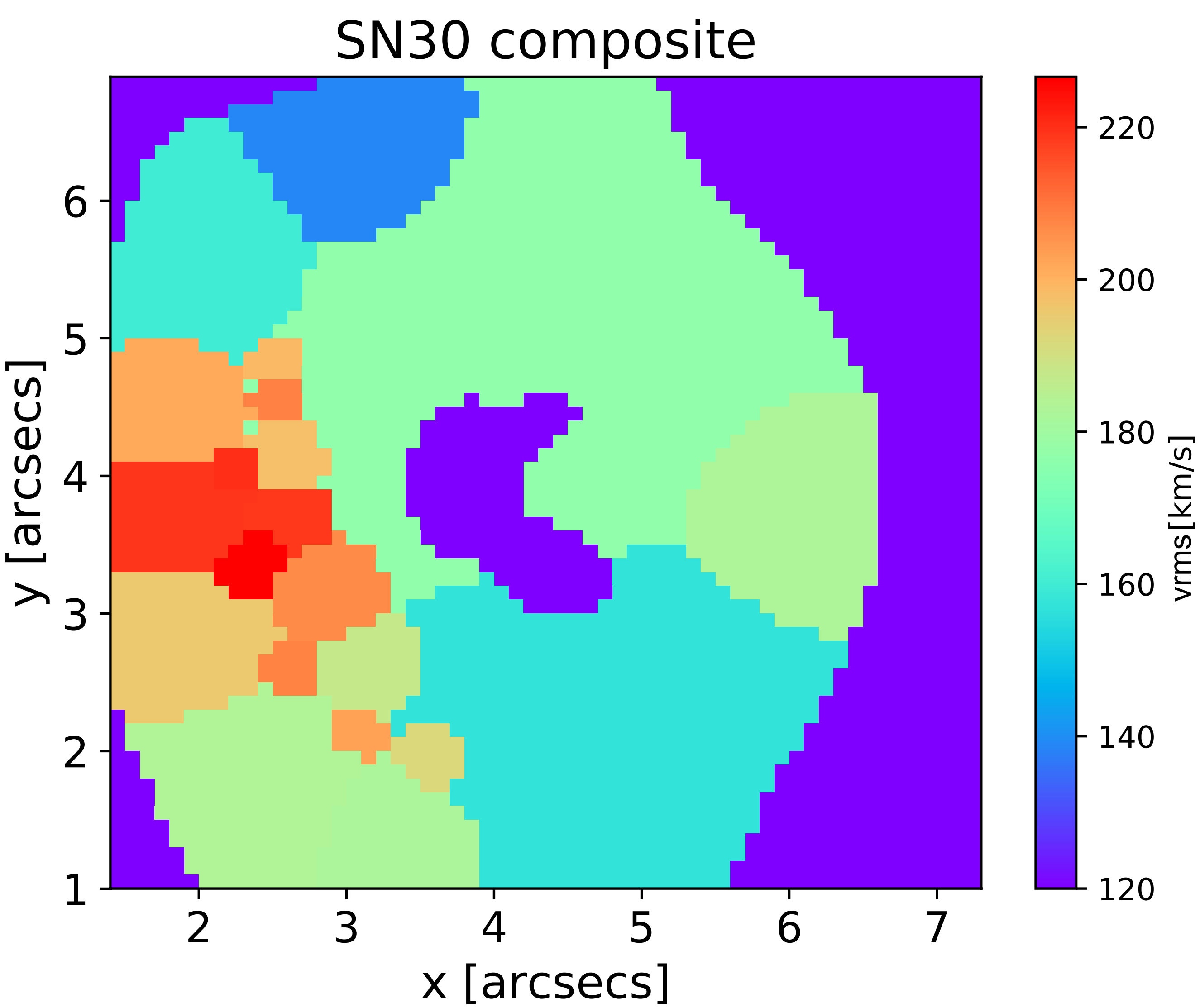
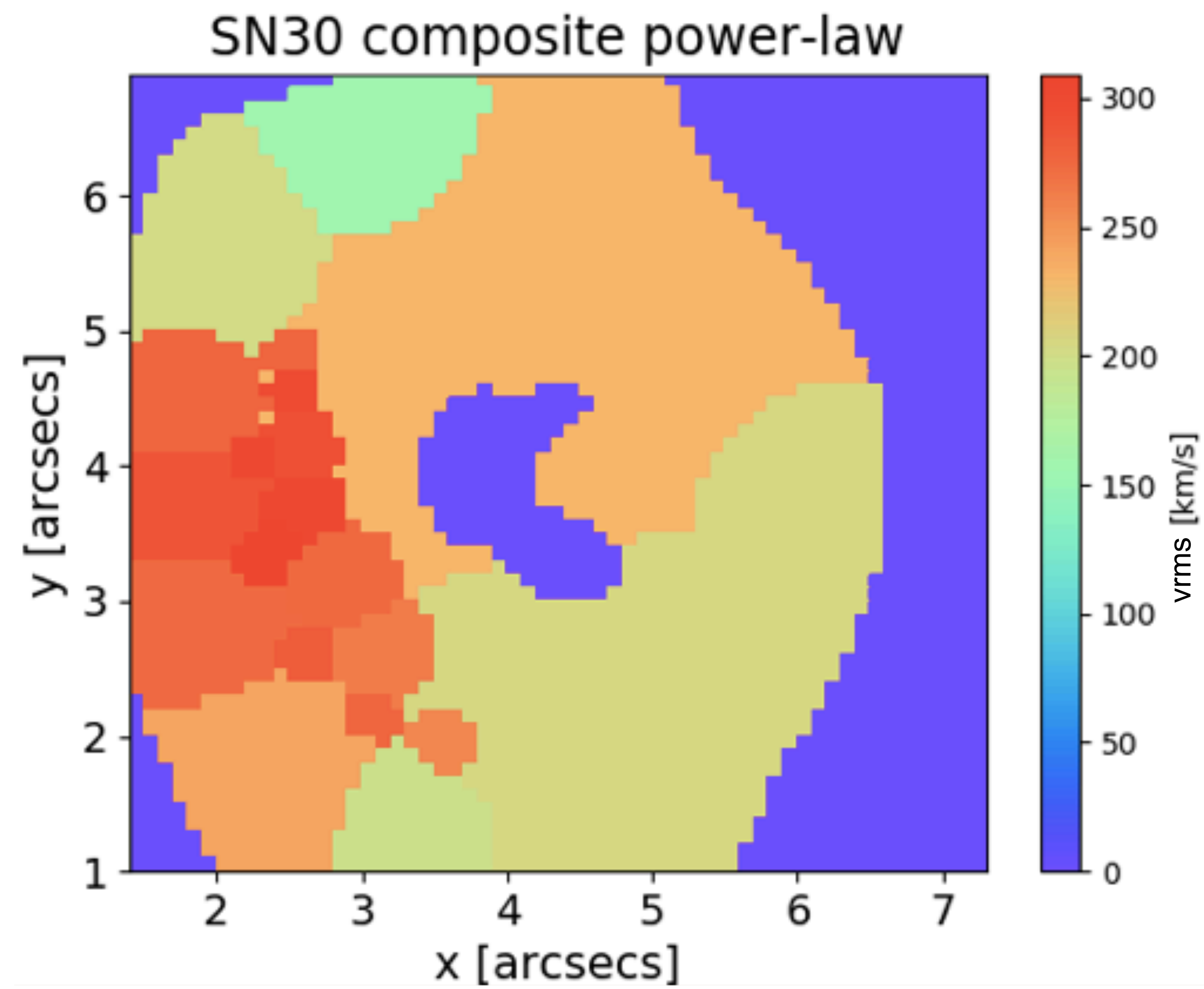
COMPOSITE MODEL: Systematic test on the lens mass

We find that the **lensing analysis gives a good fit, and the dynamics analysis doesn't**. This means that the addition of the dynamics analysis gives a huge contribution to distinguishing between models.





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Results:

- The combined lensing and dynamics analysis:
  - significantly **tightens the constraints** on the source and lens mass parameters (by up to a factor 3-20).
  - allows us to **constrain the source mass parameters**, which are otherwise unconstrained, and reconstruct the **source total mass profile**.
  - allows us to **break degeneracies between lens mass parameters and source kinematic properties**.
  - helps to **better discern between models**.
- Thanks to **instruments** on future telescopes that would provide improved data quality **we would be able to study the source galaxies in even more detail**, and simultaneously tighten the constraints on the lens galaxy mass.

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