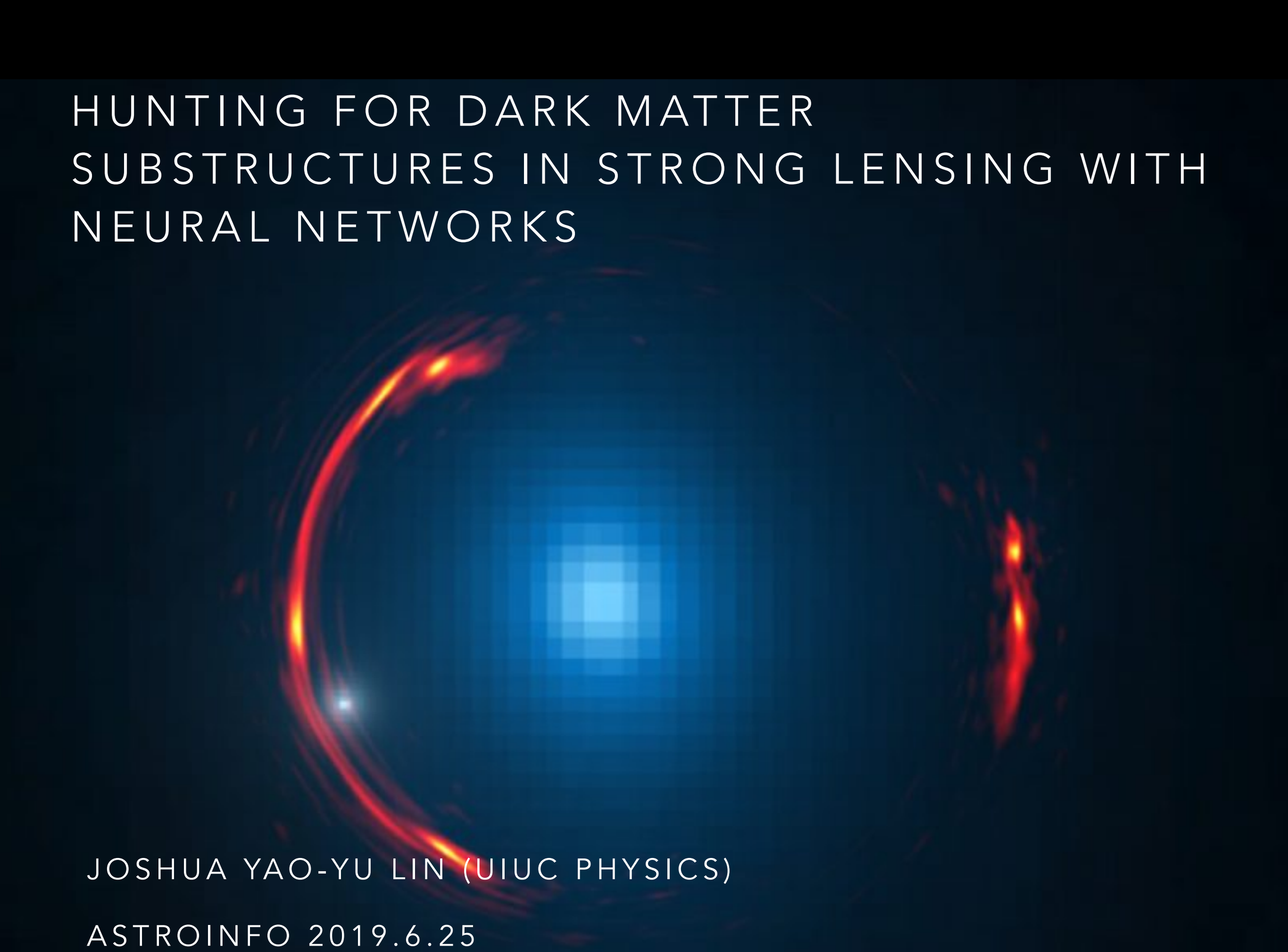
HUNTING FOR DARK MATTER SUBSTRUCTURES IN STRONG LENSING WITH NEURAL NETWORKS



JOSHUA YAO-YU LIN (UIUC PHYSICS)

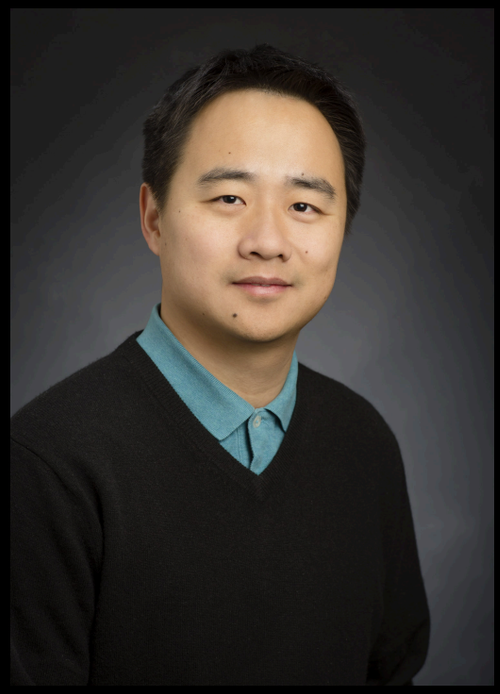
ASTROINFO 2019.6.25

PEOPLE I WORK WITH

LOCAL GROUP

Hang Yu
[UIUC]

Warren
Morningstar
[Stanford]

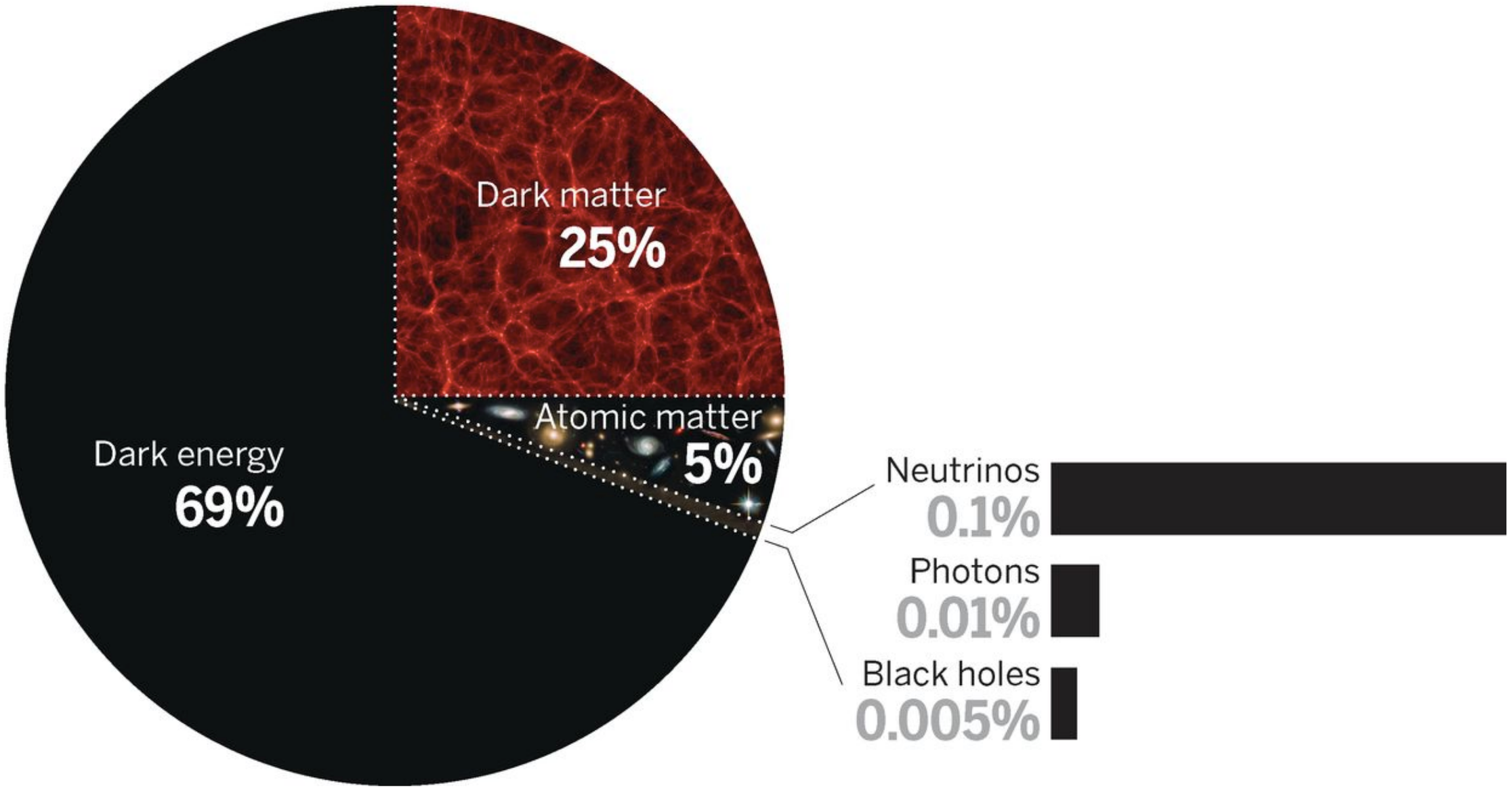


Jian Peng
[CS@UIUC]

Gil Holder
[UIUC]

The multiple components that compose our universe

Current composition (as the fractions evolve with time)



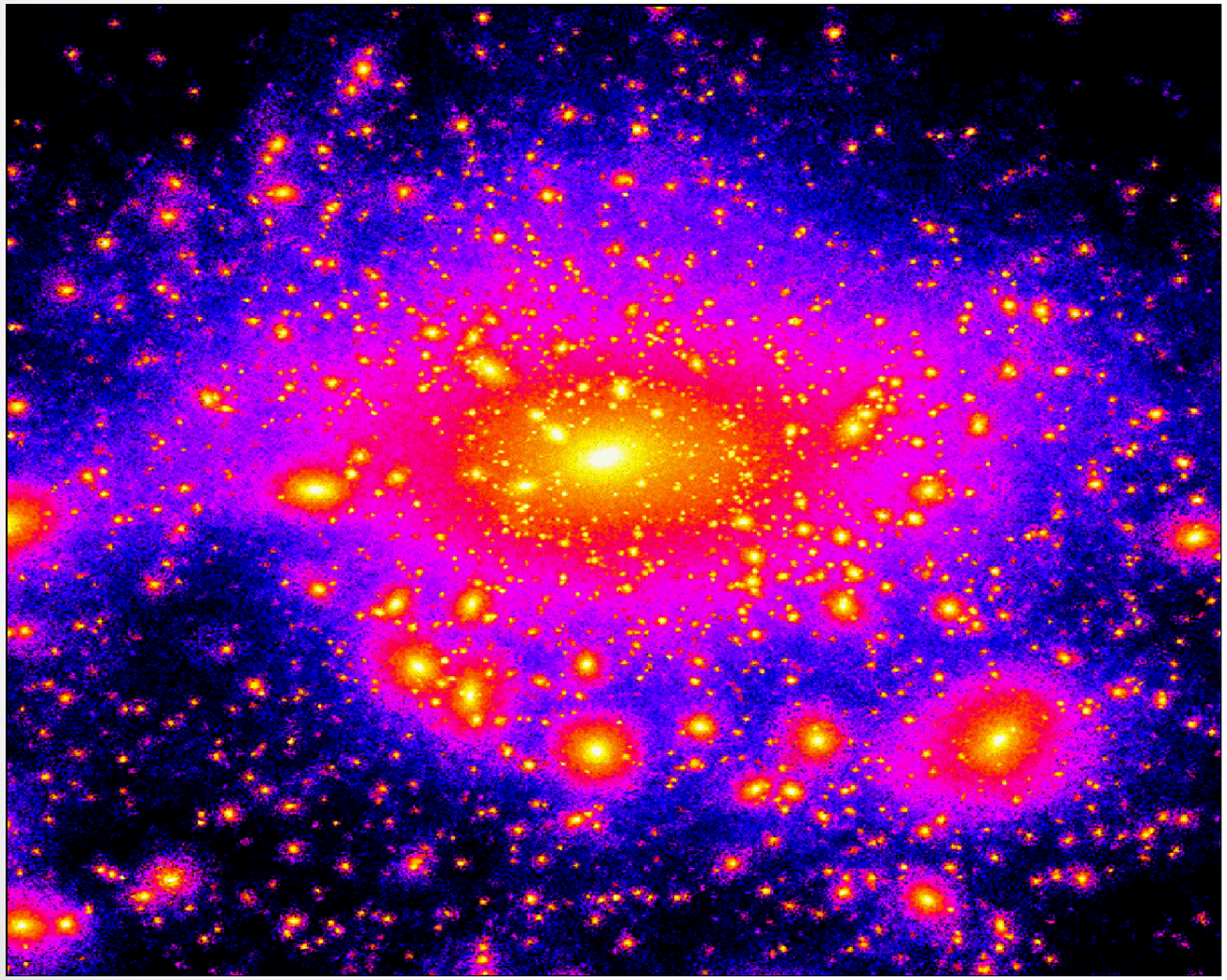
Three different types of neutrinos comprise at least 0.1%, the cosmic background radiation makes up 0.01%, and black holes comprise at least 0.005%.

David Spergel (Science, 2015)

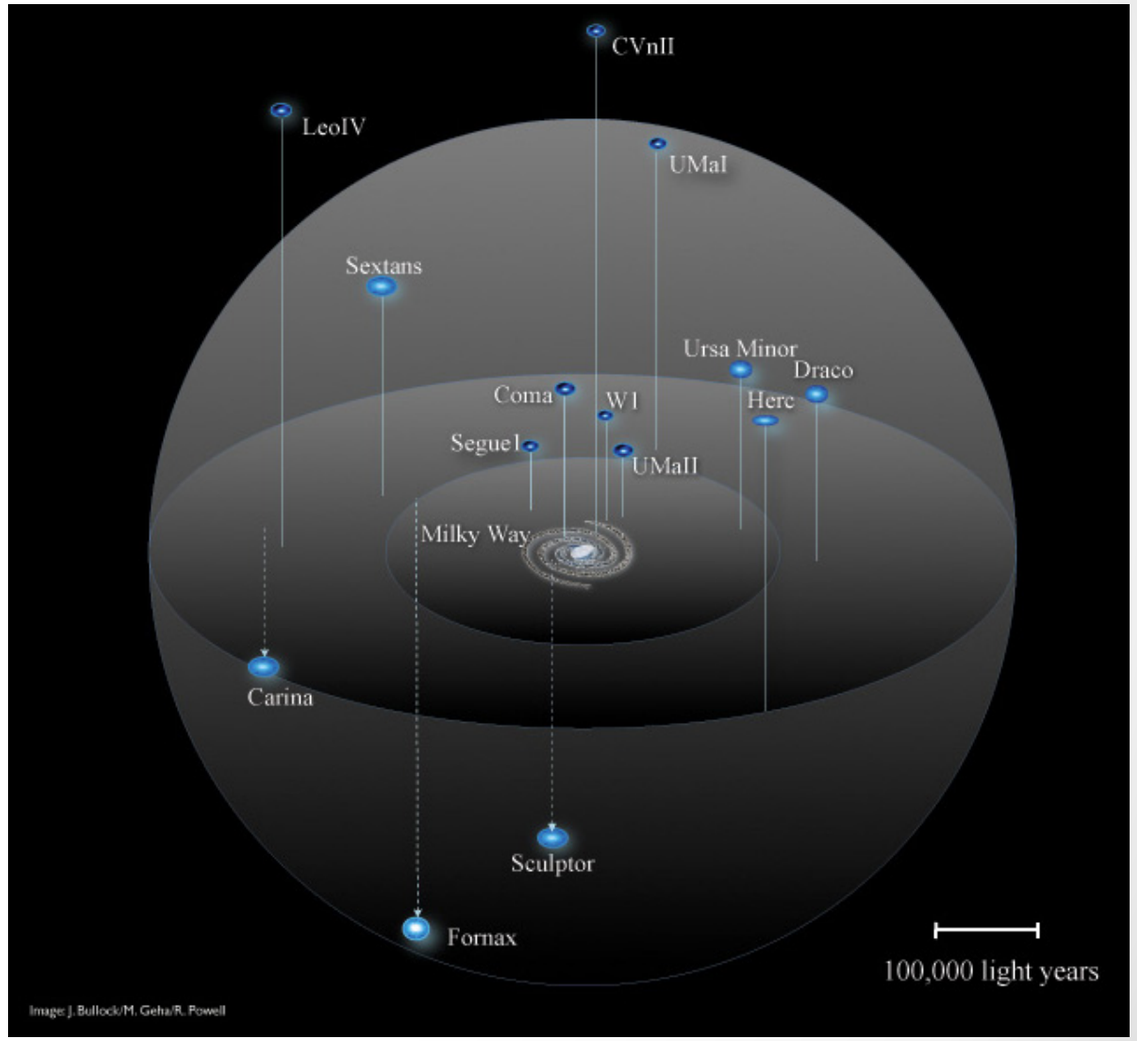
Dark Matter

- 84% of the matter is Dark(DM)
- DM interacts through gravity.
- Further DM interactions unobserved so far. Such couplings must be very weak, much weaker than weak interactions.

Missing Satellites Problem



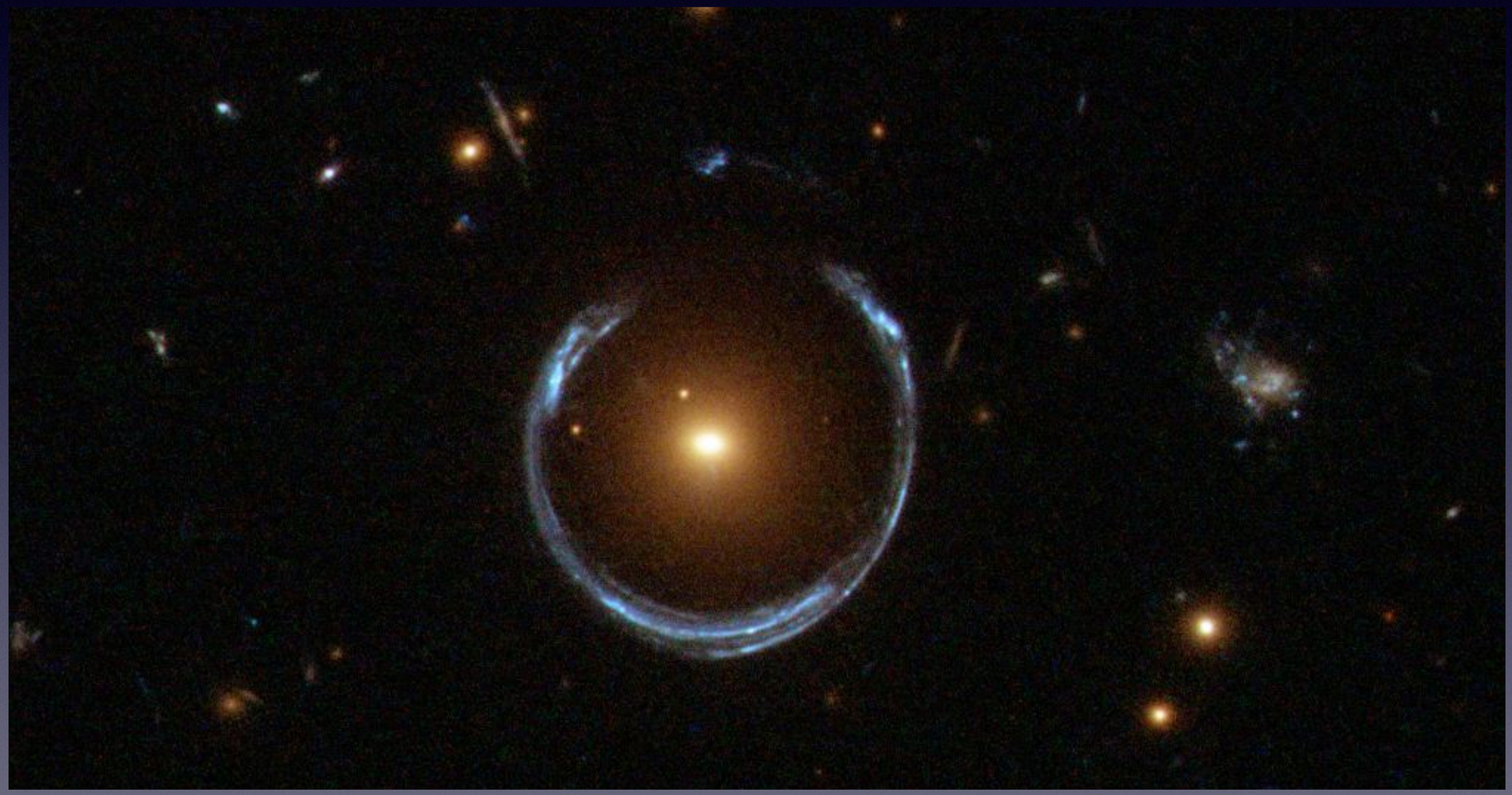
CDM Simulation (Mayer and Kazantzidis)



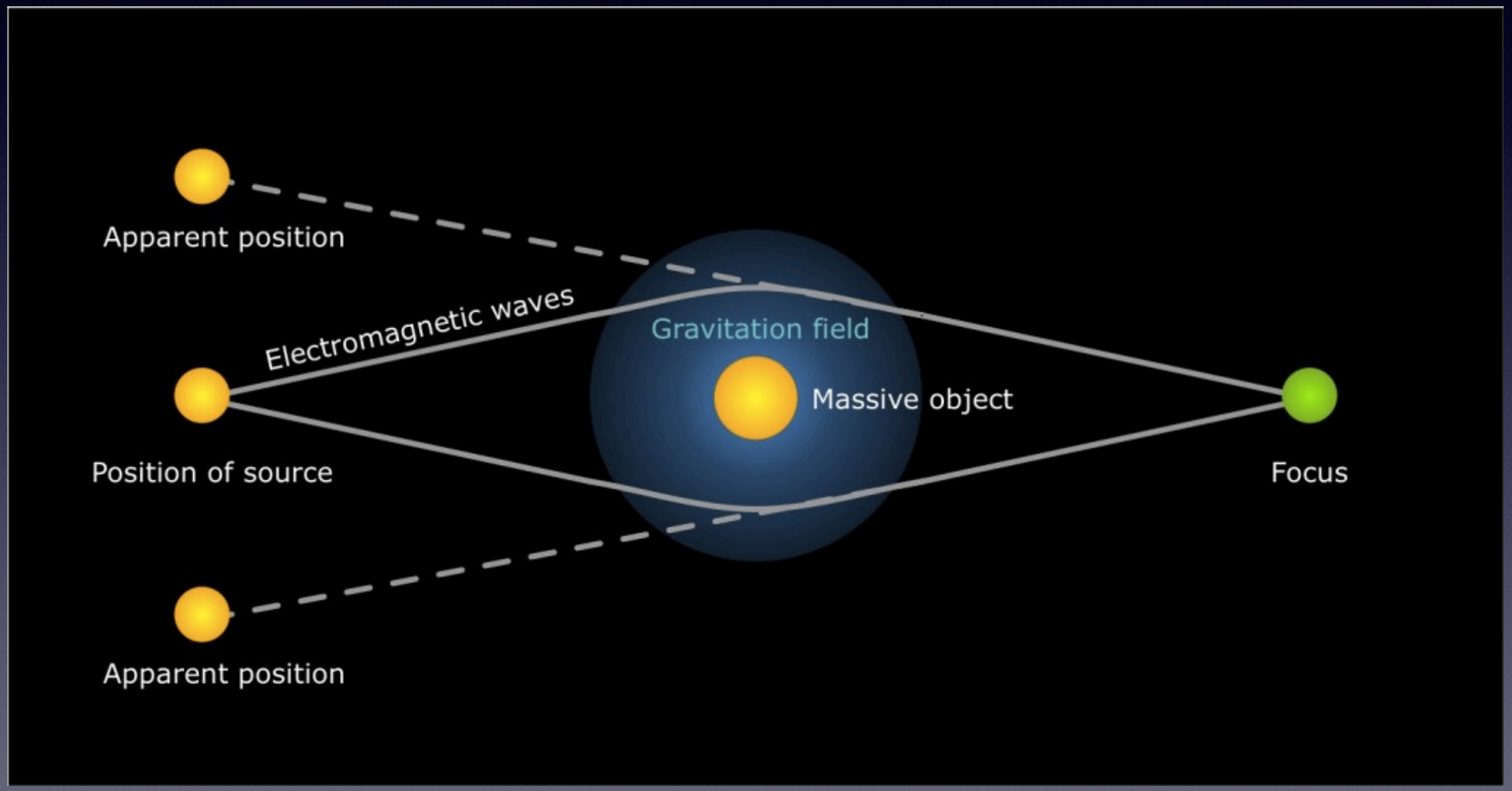
Satellite galaxies of the Milky Way (Observation)

Credit: J. Bullock, M. Geha, R. Powell

Strong lensing: Natural place to probe dark matter substructures



Strong lensing



Lensing basic: caustic & critical curve

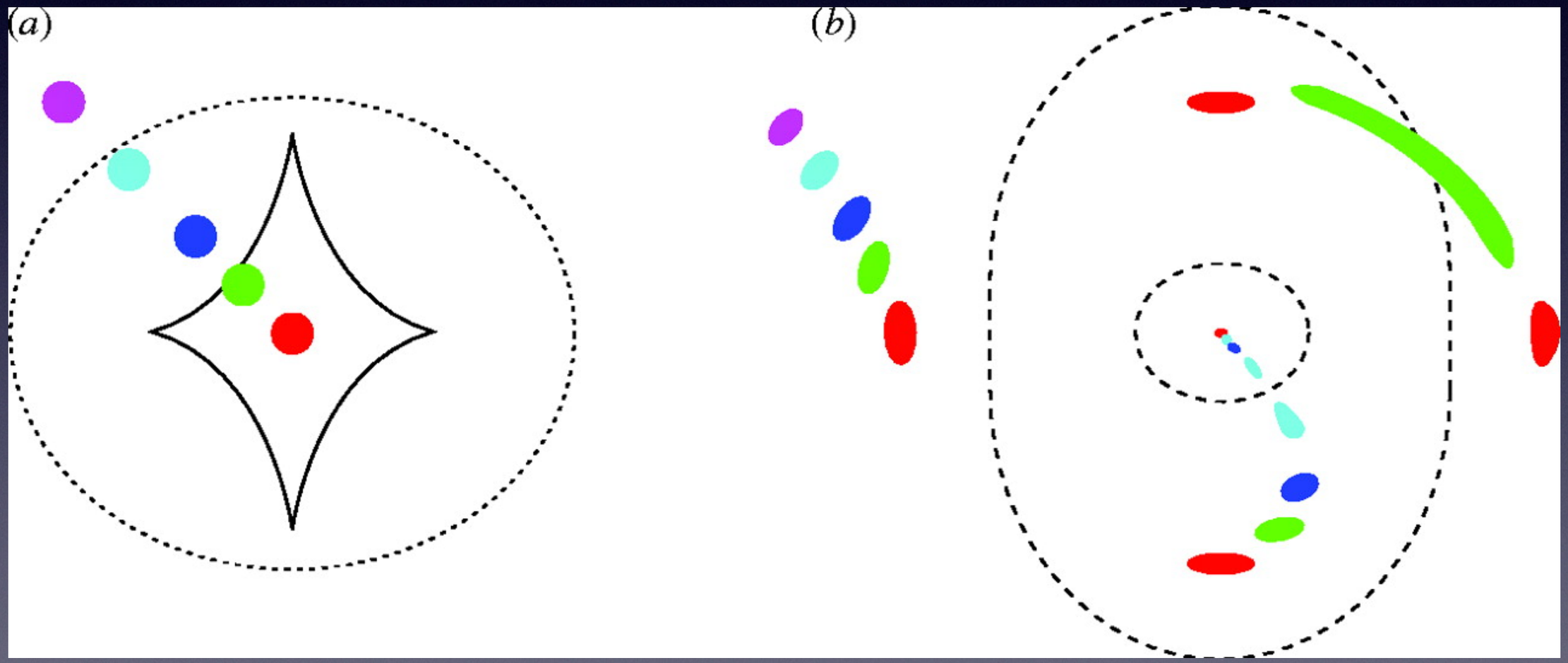


Figure from Narayan & Bartelmann (1995)

Subhalo detection

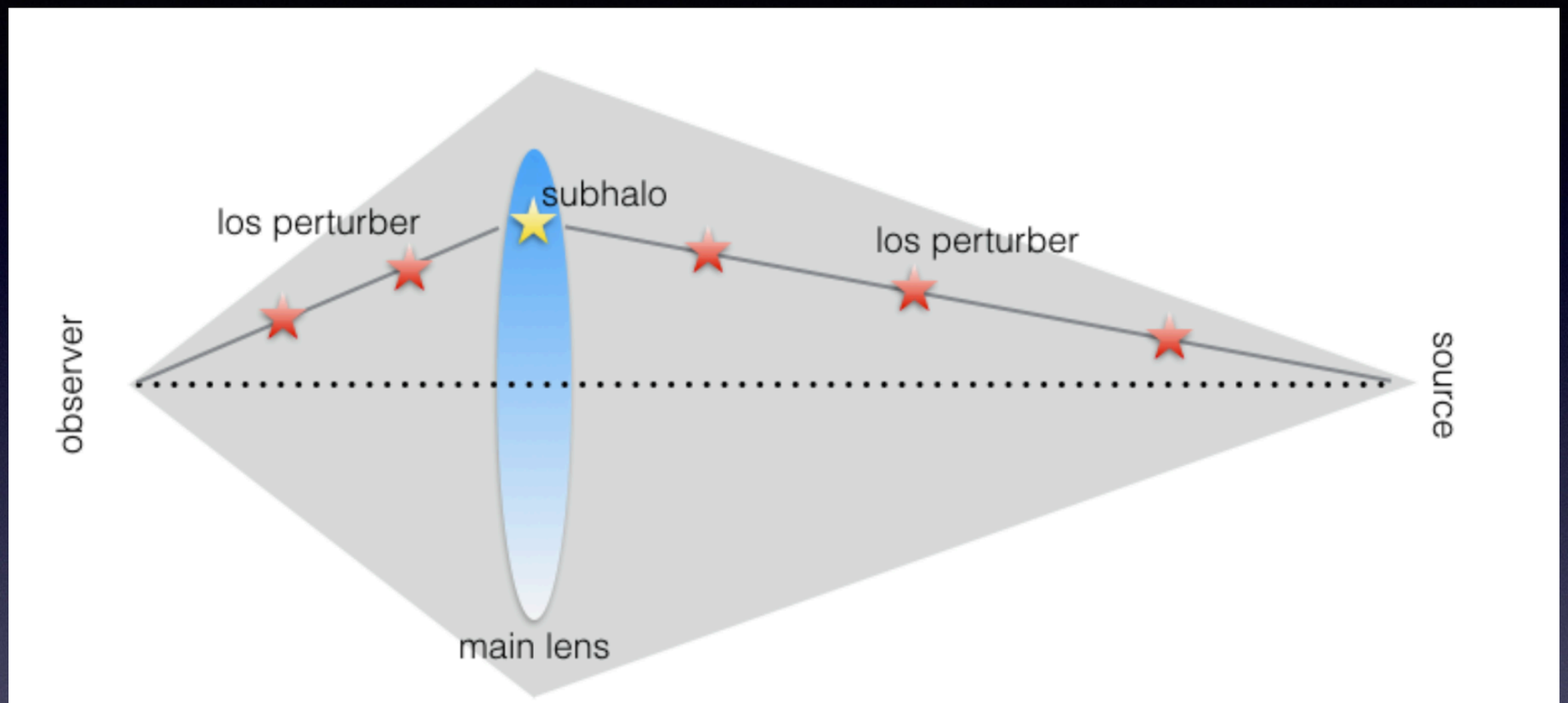
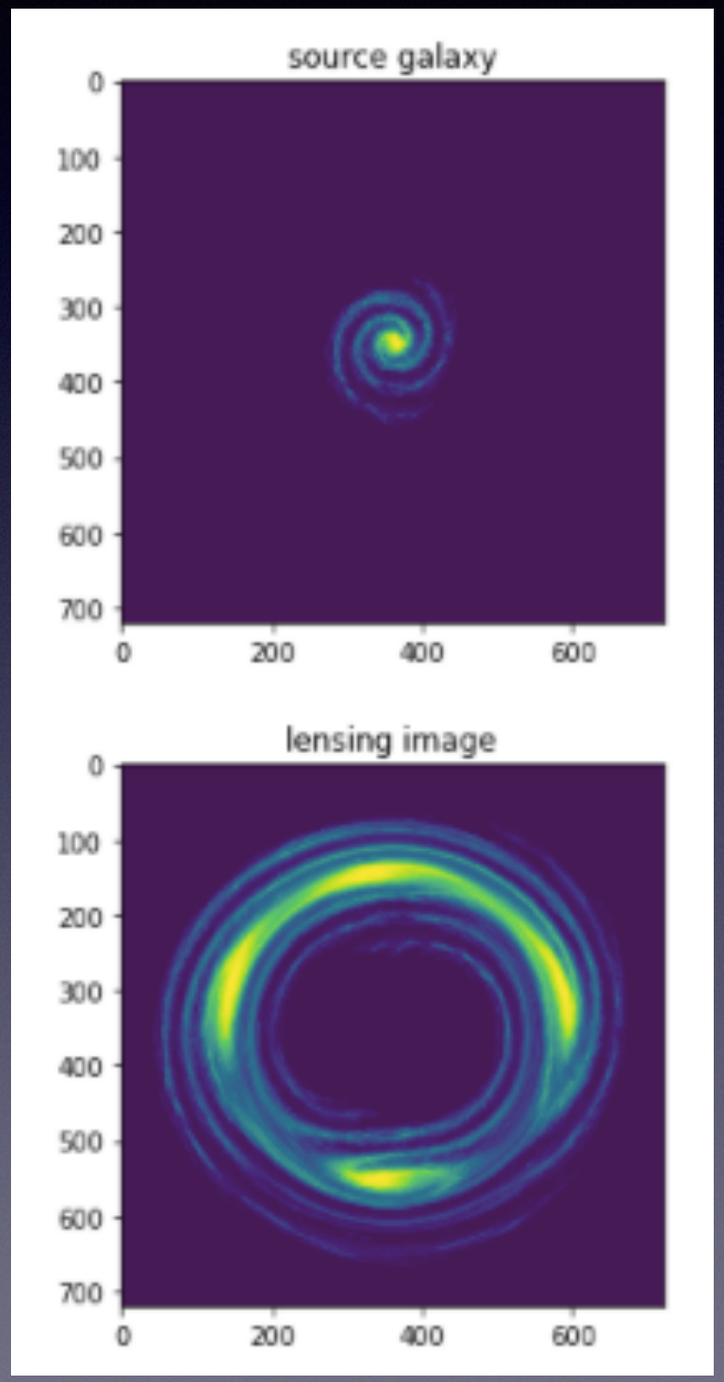
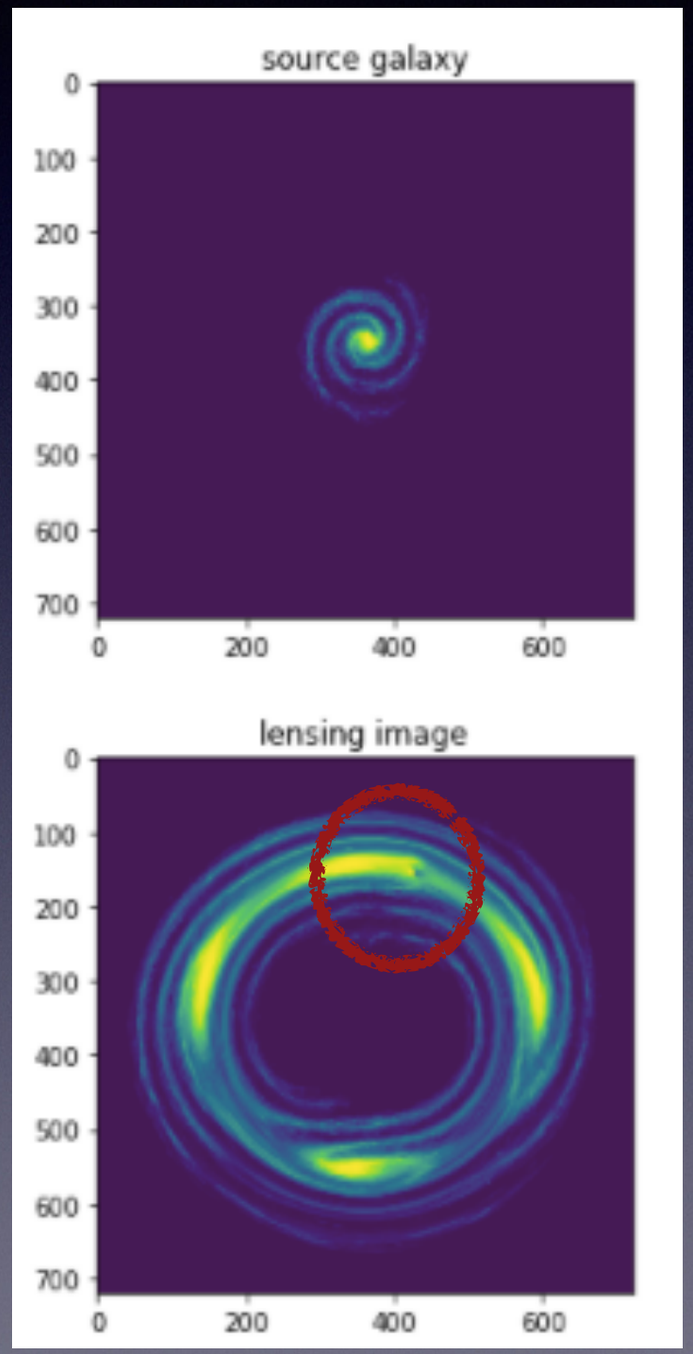


Figure 2. A simple sketch of the method we used to create our mock data; subhaloes and line-of-sight haloes are placed so that their lensing effect lies in the same projected position on the plane of the main lens; the grey region gives an example of the line-of-sight volume that is taken into account.

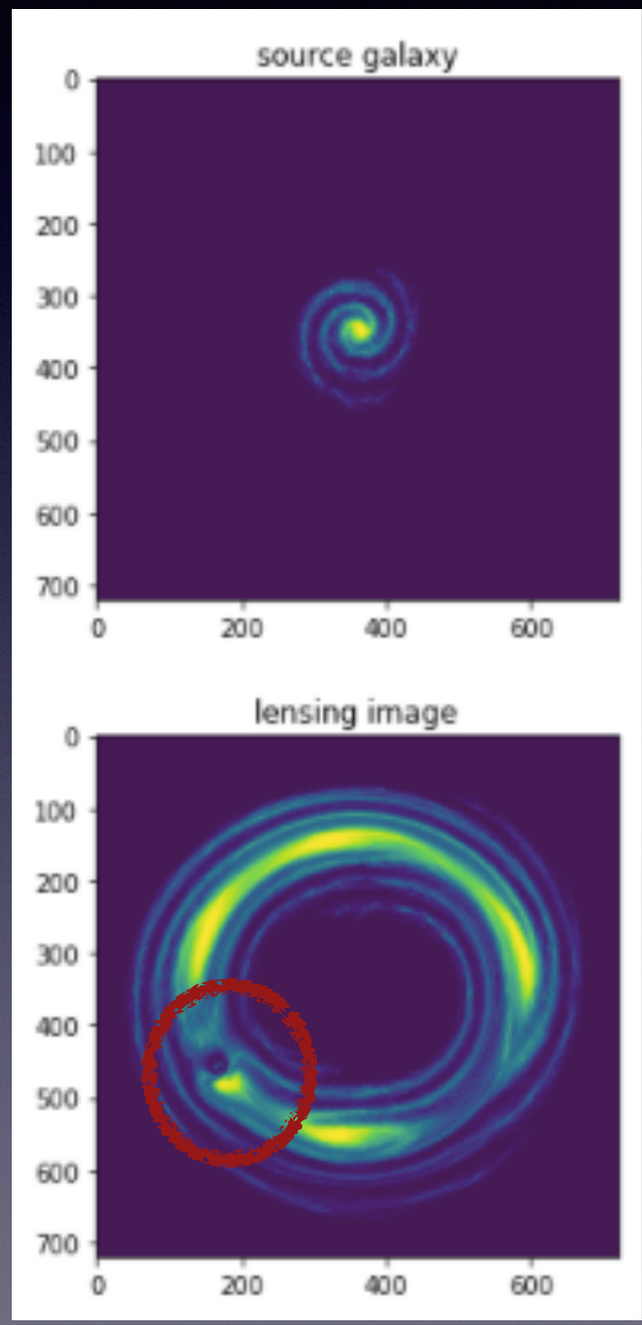
Despali et al. (1710.05029)

Strong lensing with substructure as perturber



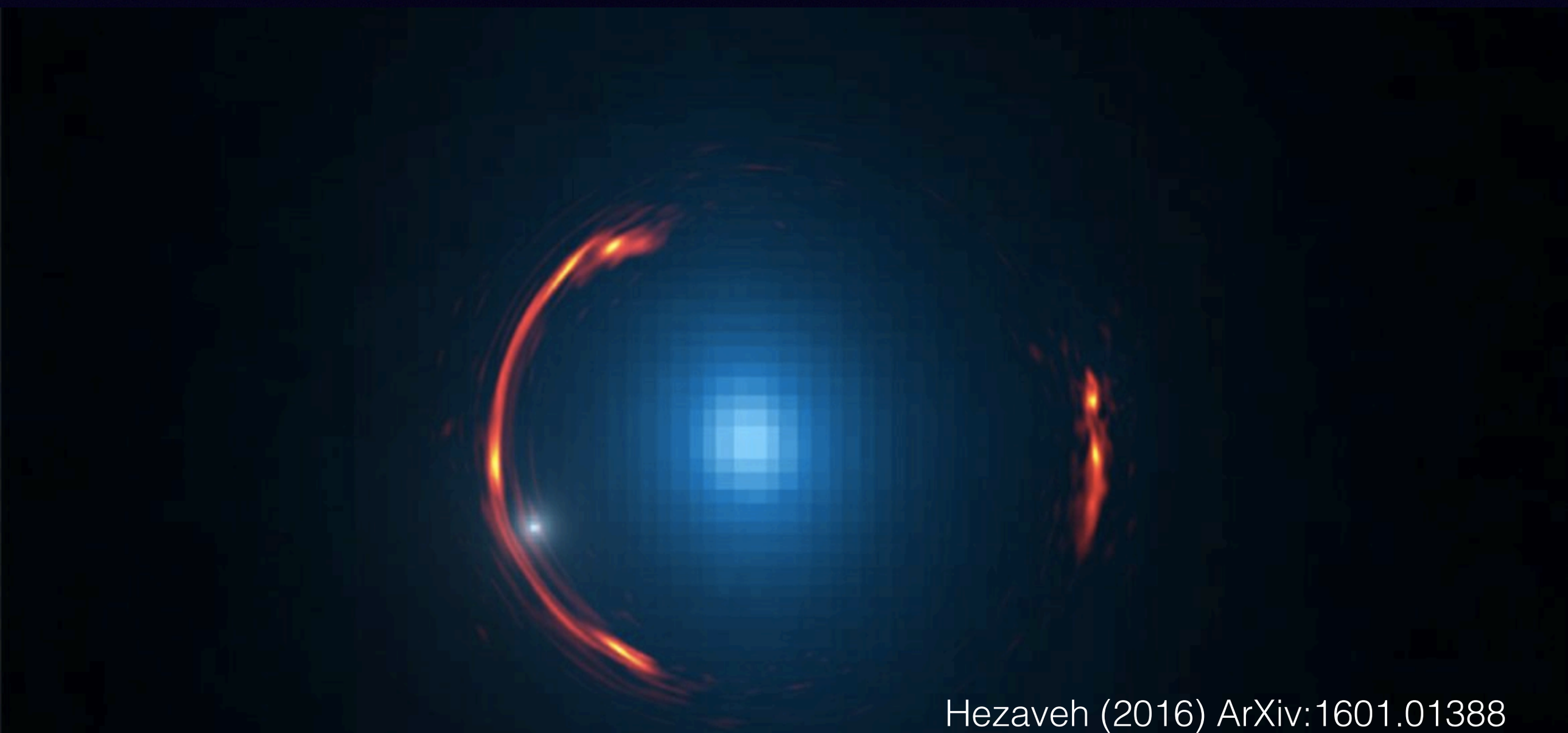


Lensing with perturber



Lensing with (large) massive perturber

Subhalo Hidden in ALMA Gravitational Lens Image



Hezaveh (2016) ArXiv:1601.01388

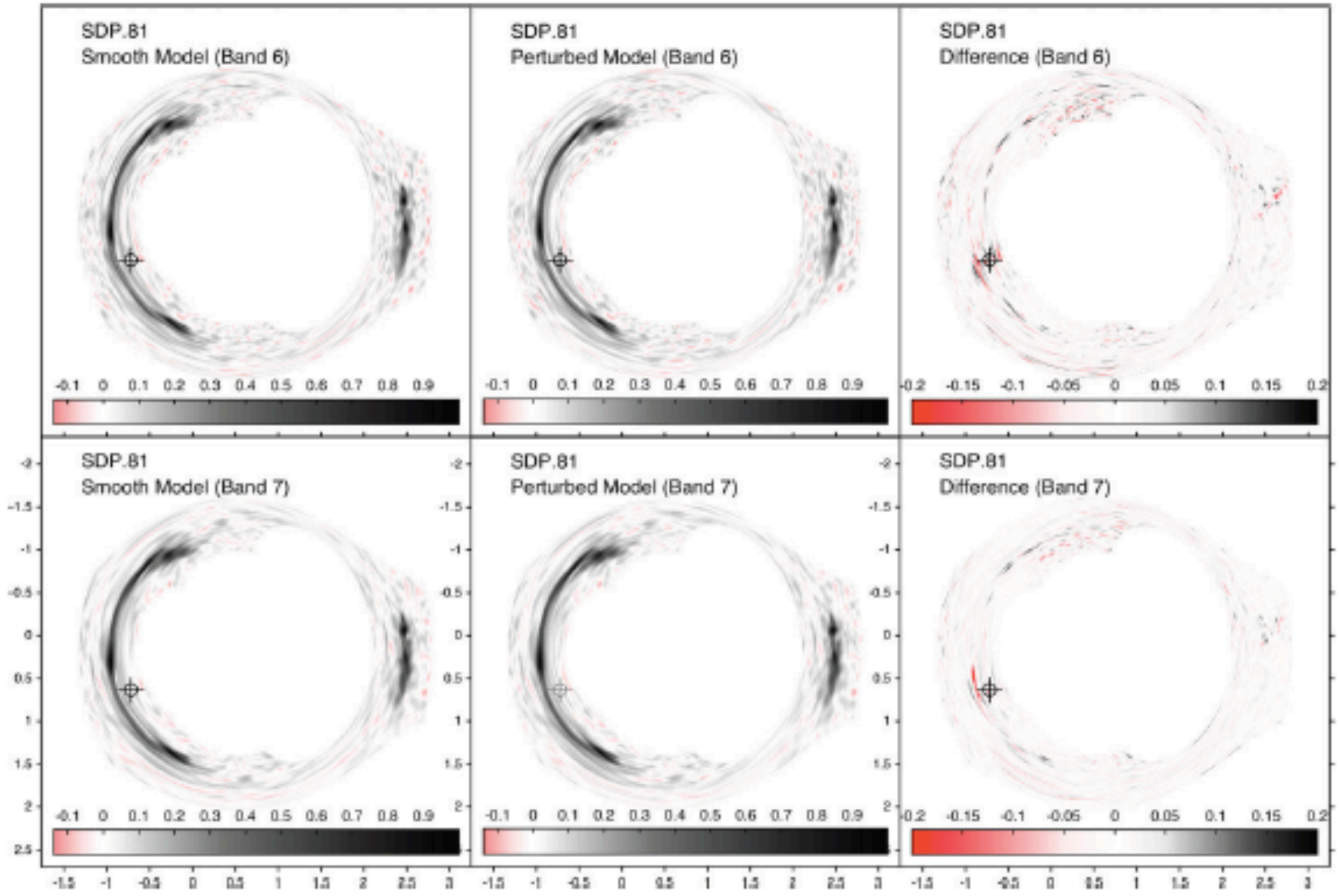


Figure 6. Top left: the sky emission model in band 6 for the best-fit smooth lens parameters for the SDP.81 data. Top middle: the same for the perturbed model. Top right: the difference between the two models. The bottom panels show the same for band 7. The bright feature in the difference plots is mainly caused by the astrometric anomaly of the arc. In each row, the images have been scaled to the peak flux of the smooth model.

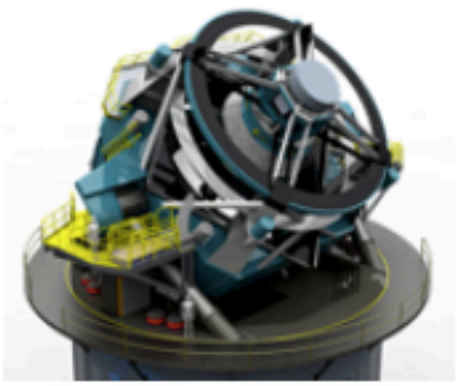
Hezaveh et al., (2016)

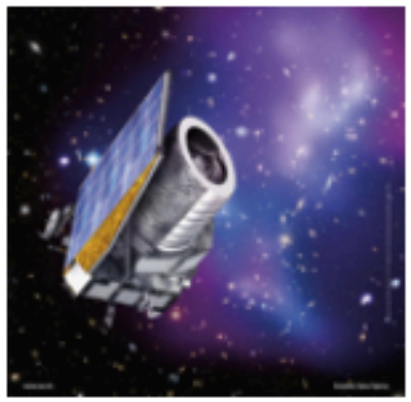
LOOKING INTO THE FUTURE:

New Lenses

For future surveys we find that, assuming Poisson limited lens galaxy subtraction, searches of the DES, LSST, and Euclid data sets should discover **2400**, **120000**, and **170000** galaxy–galaxy strong lenses, respectively

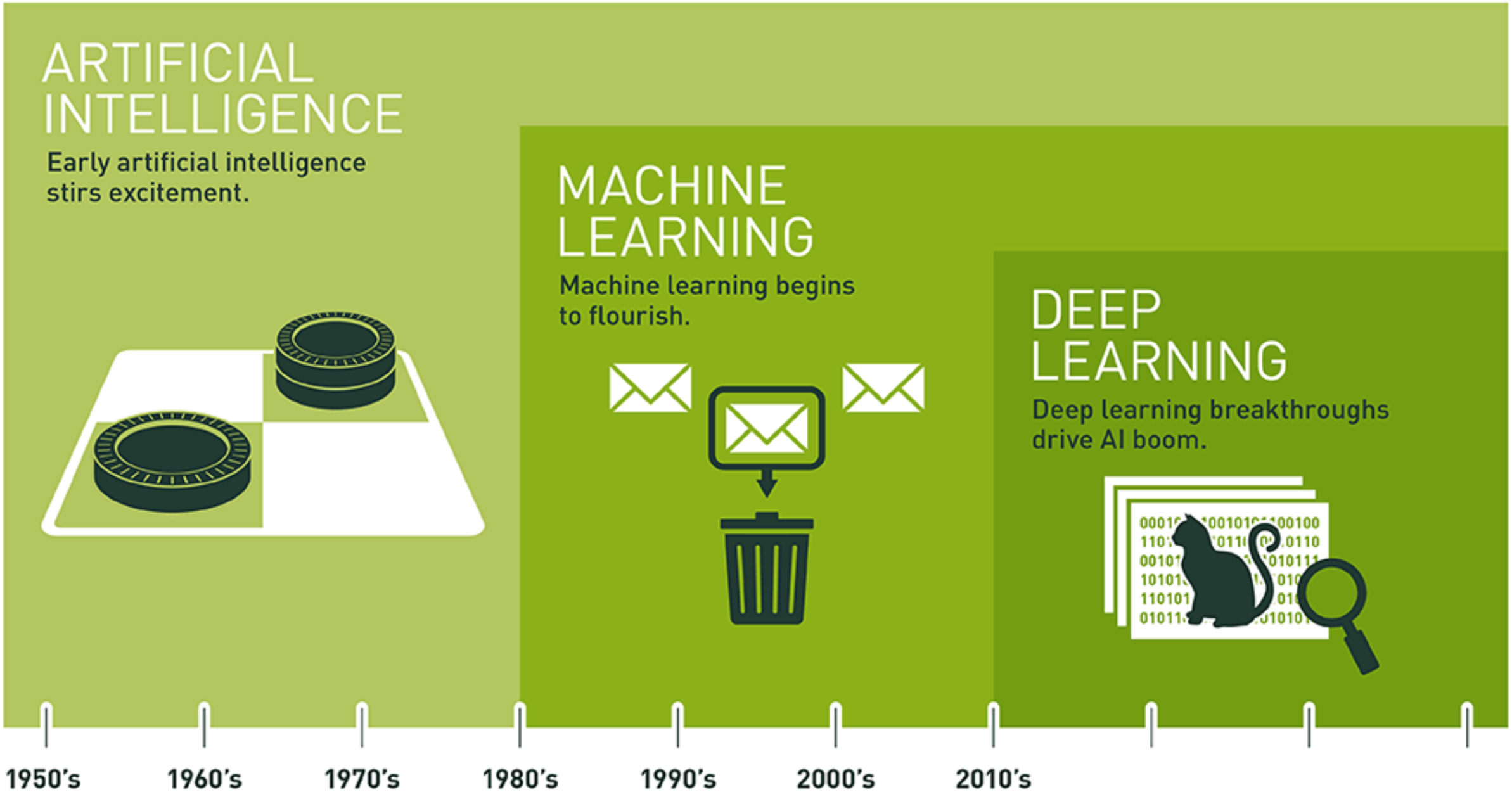
Collett, ApJ. 2015





Slides from Laurence Perreault Levasseur

Can AI (deep learning) helps?

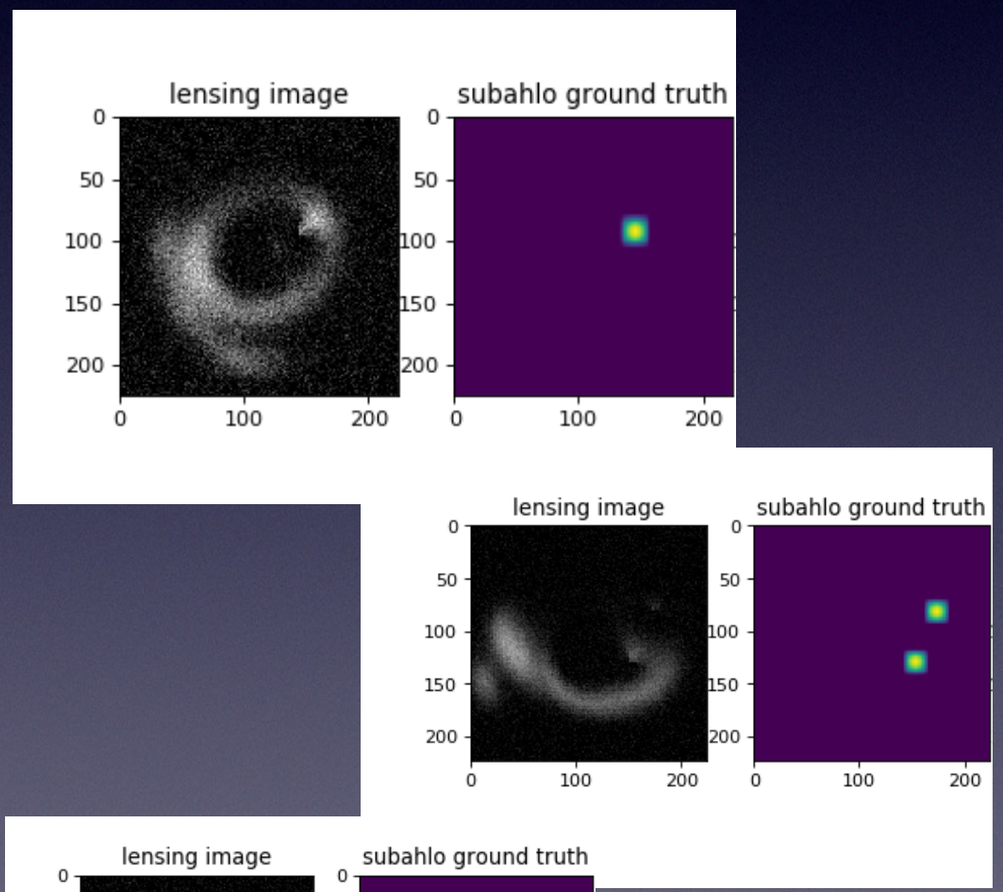


Since an early flush of optimism in the 1950s, smaller subsets of artificial intelligence – first machine learning, then deep learning, a subset of machine learning – have created ever larger disruptions.

Image credit: Nvidia

Deep learning setup

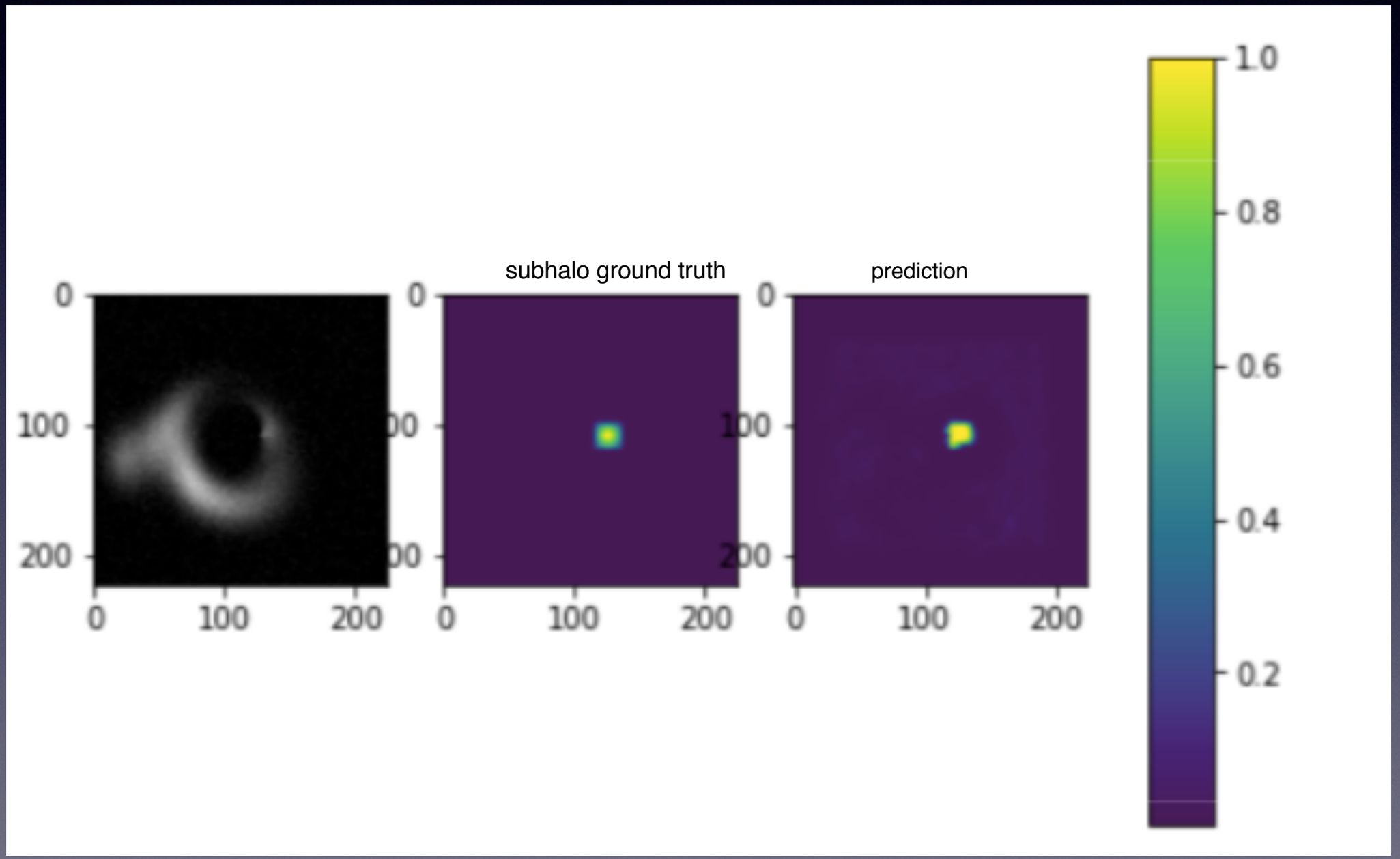
20000 simulated data as training set



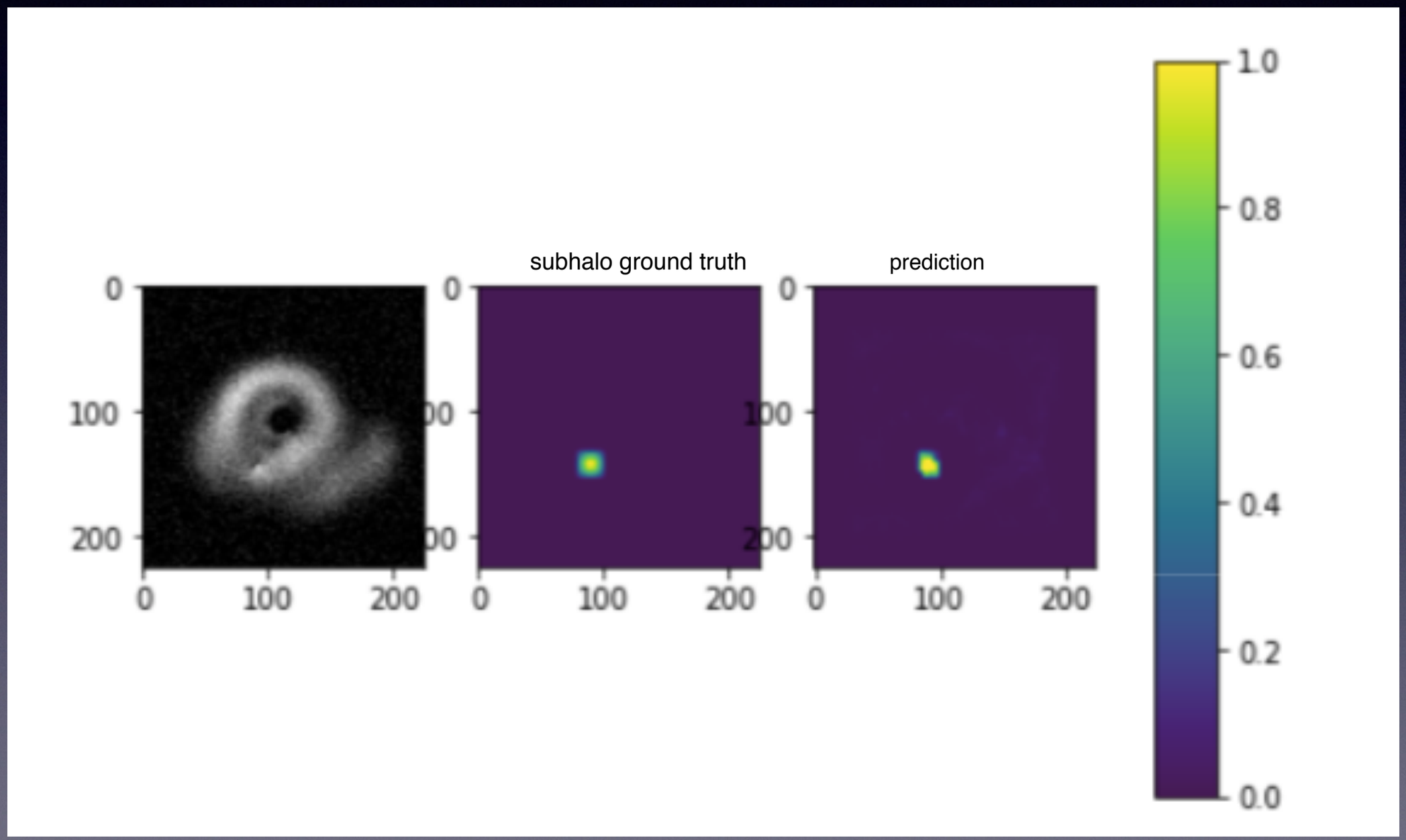
- 20000 simulated data [images and subhalo ground truth]as training set
- 2000 “DIFFERENT” data [images] as test set
- Simulation with SIE (marco lens) contains 0-5 subhalos(perturbers)
- Loss function: Mean Square Loss (of subhalo probability map)
- Adam Optimizer, learning rate = 1e-4
- NN model: DenseNet 121
- Nvidia GPU: 1080Ti

PYTORCH

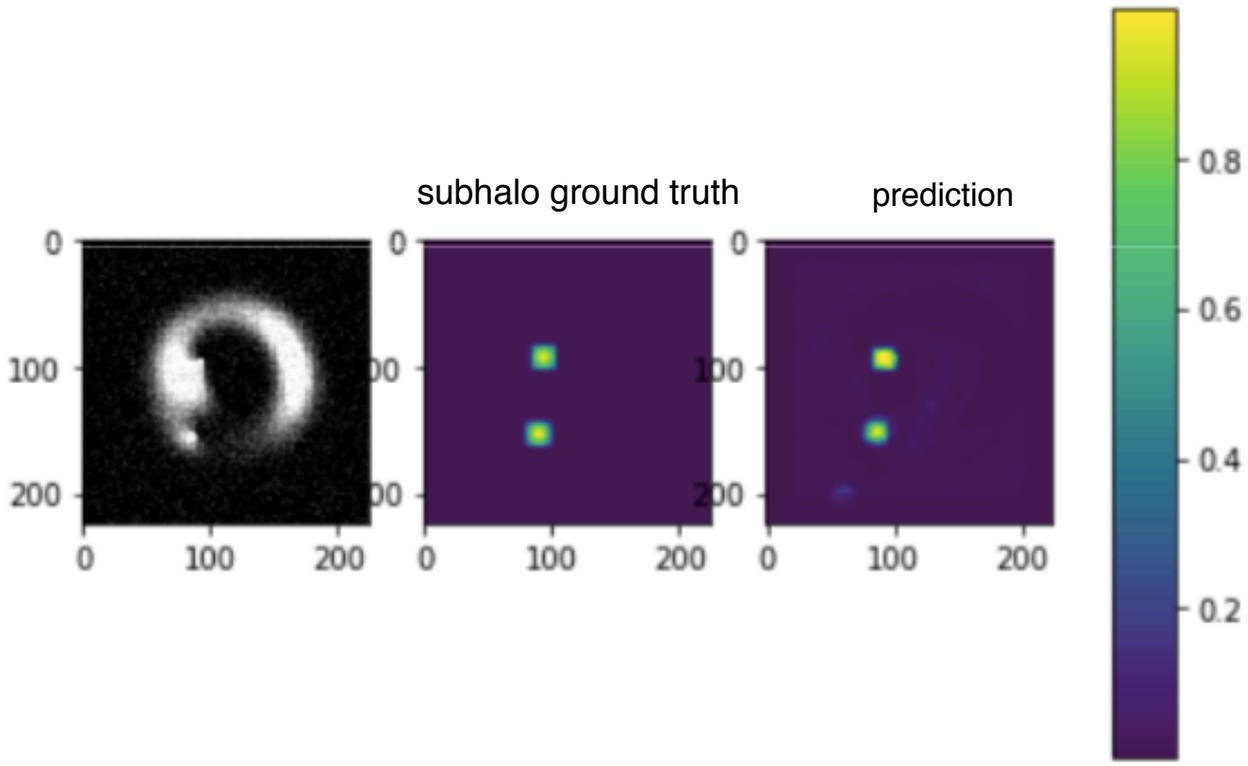
Prediction: subhalo detected!



Prediction: subhalo detected!

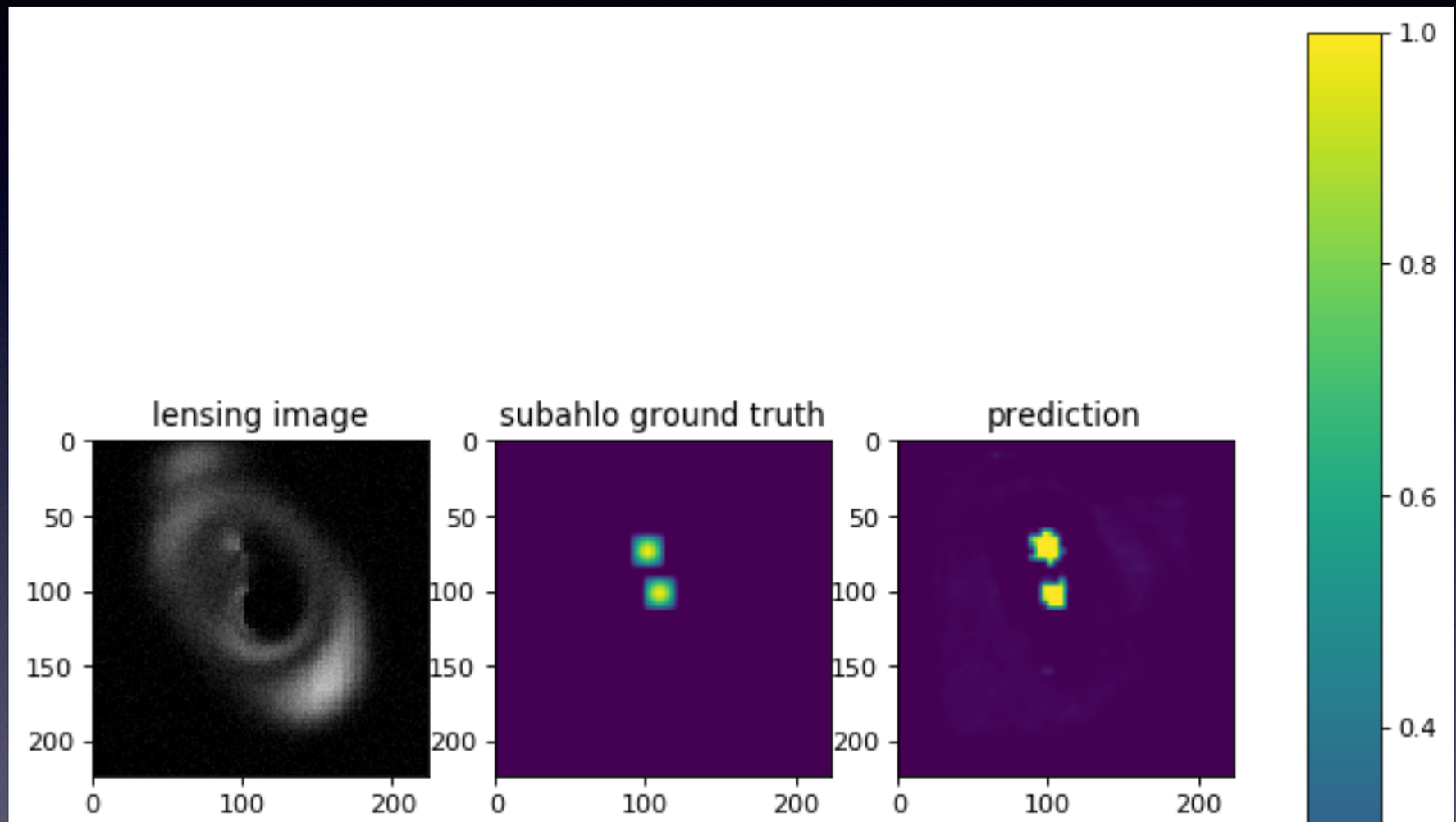


Prediction: multiple subhalos!

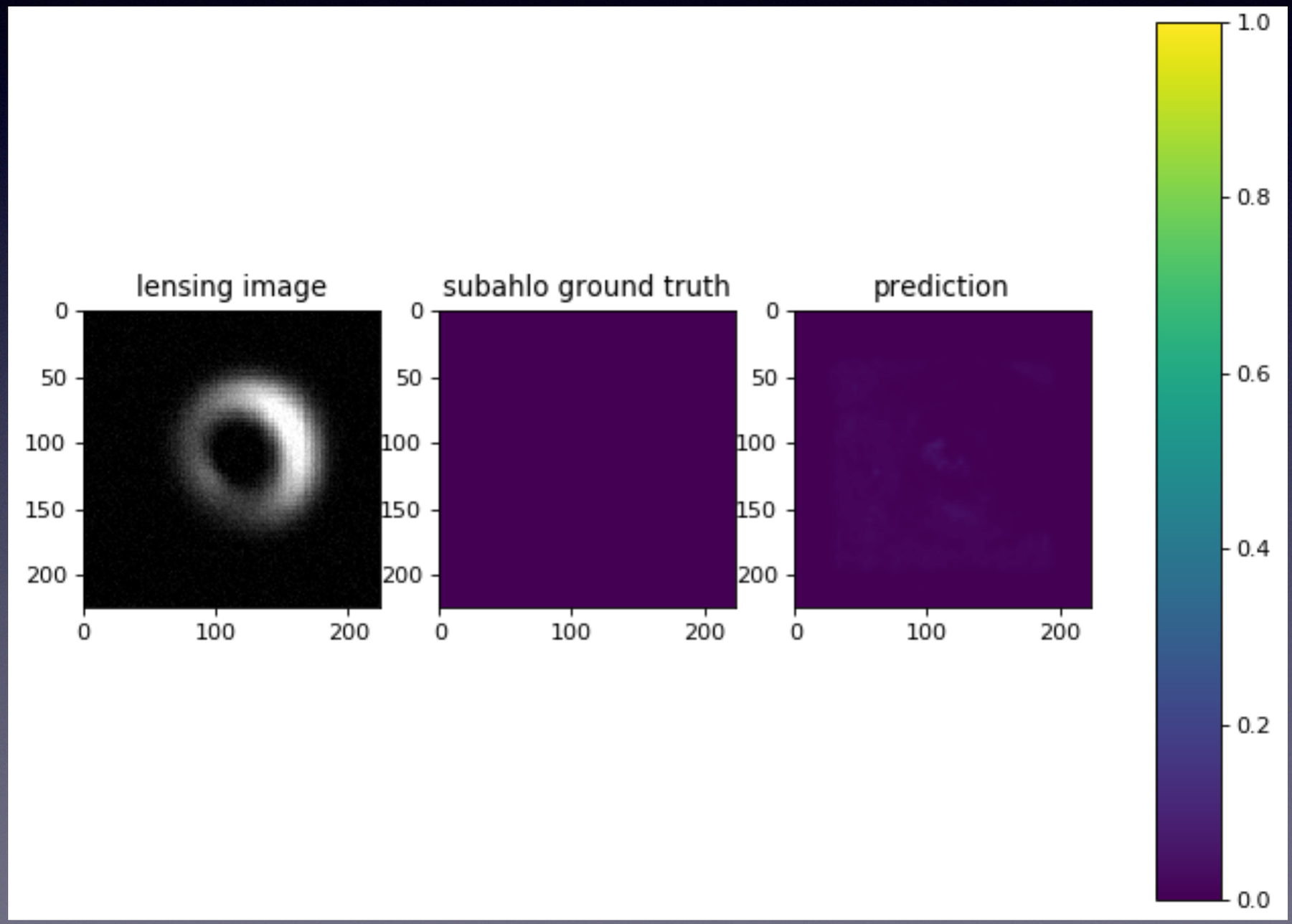



```
Macro:
pred [0.2658, 0.0345, 0.0166, 0.1423, 0.9035, 0.0023, -0.0046, 1.0]
target [ 0.2831 -0.0776  0.1189  0.0781  0.7854  0.      0.      1.    ]
#-------------------------------------------------------------------------
```

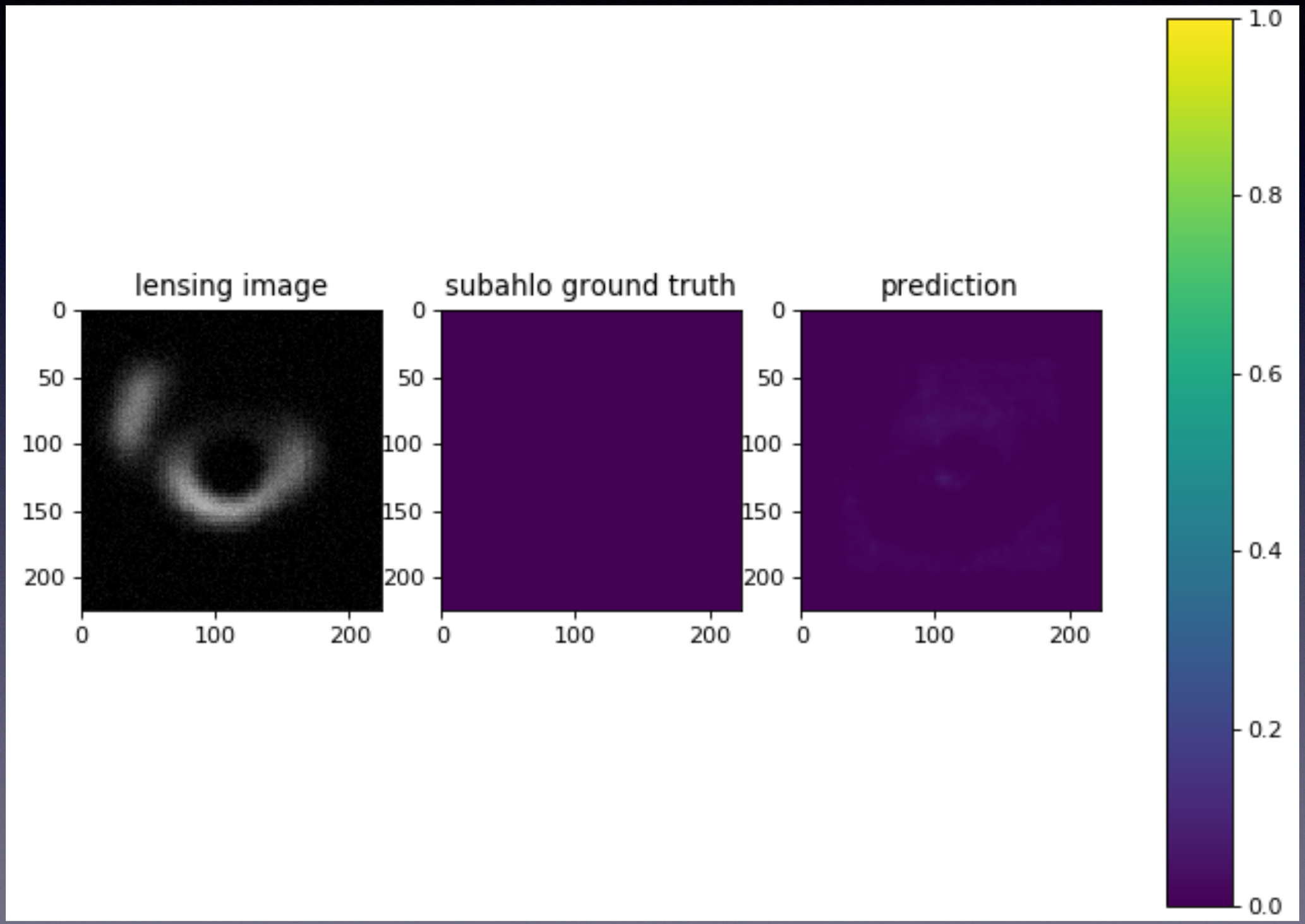
Prediction: multiple subhalos!



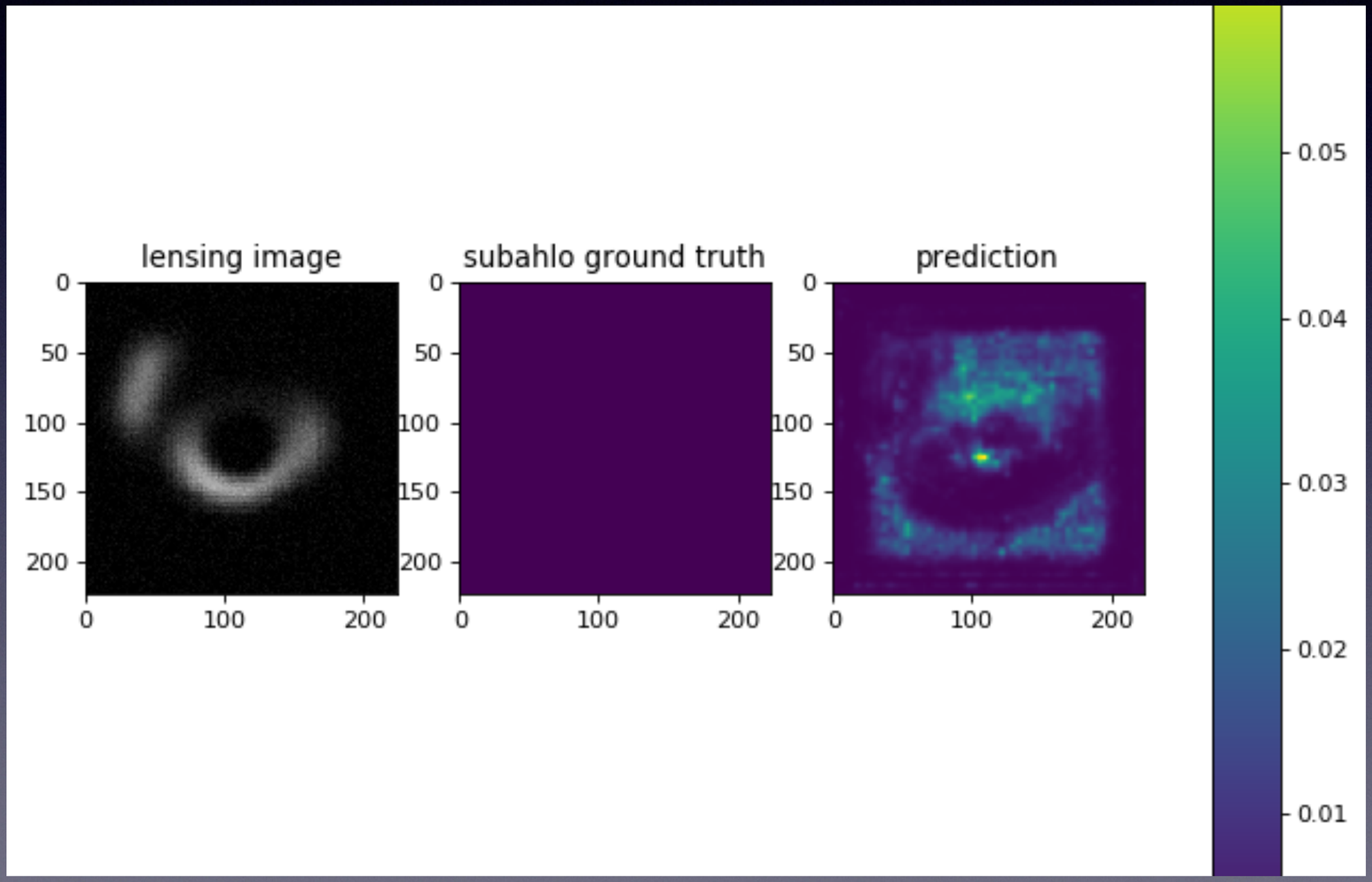
Prediction: No subhalo



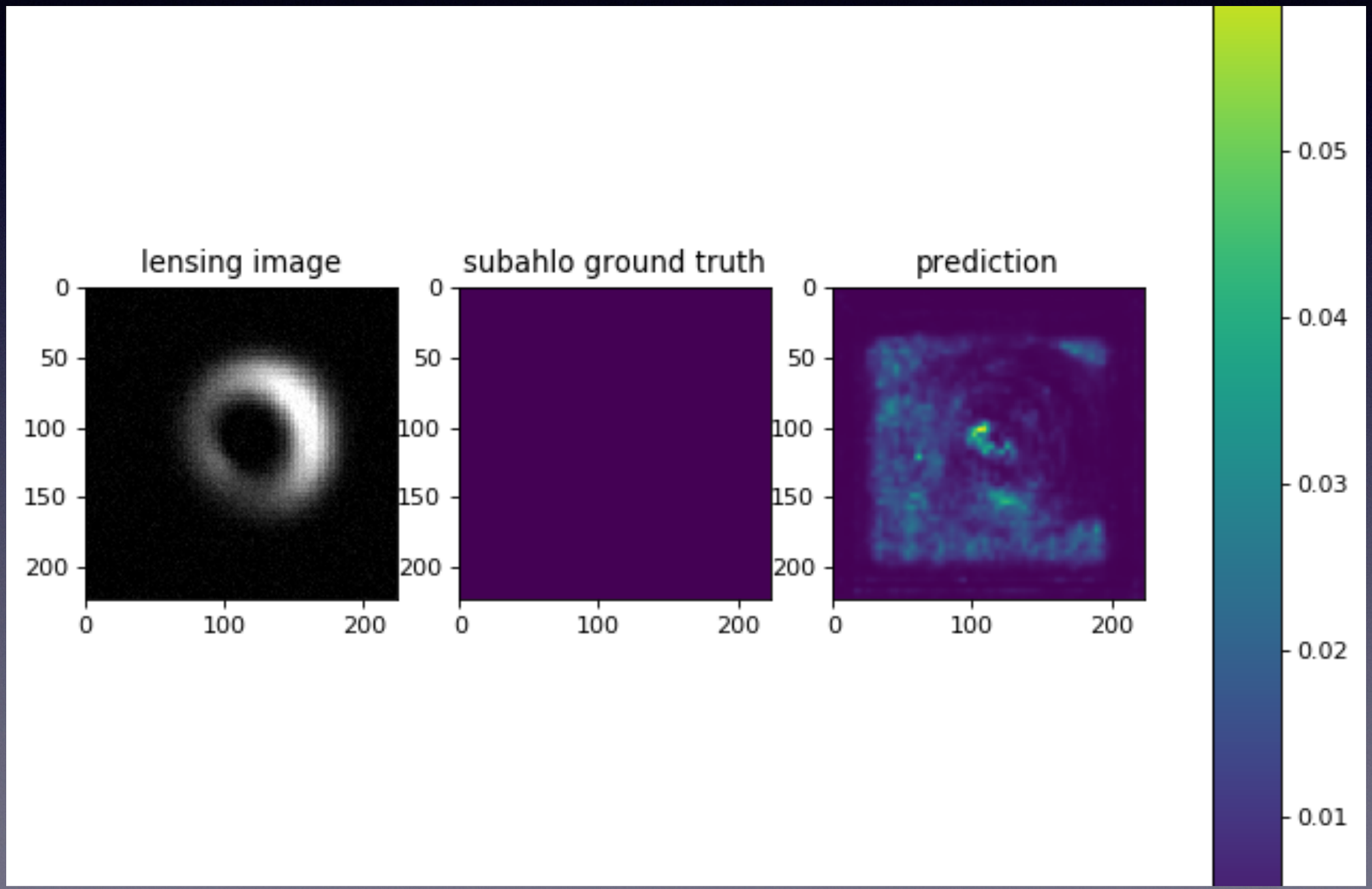
Prediction: No subhalo



“Rejection” of subhalo(s) around the arc



“Rejection” of subhalo(s) around the arc



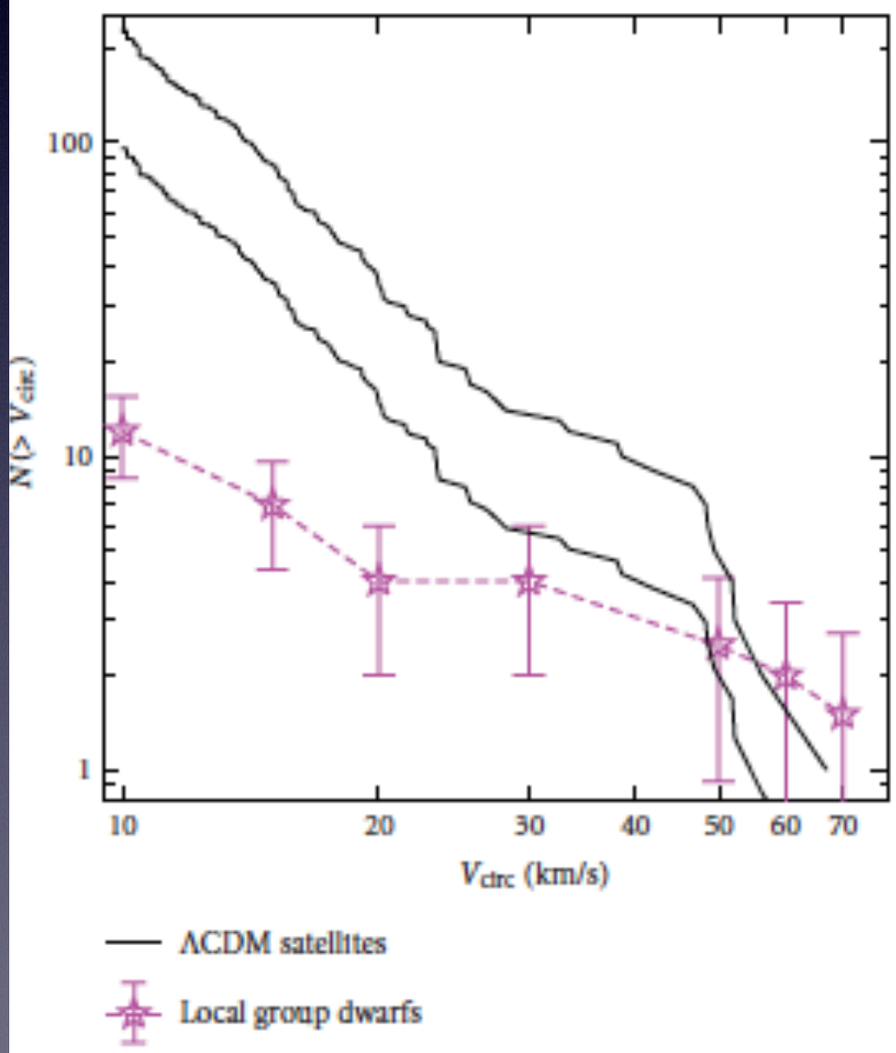
Summary for this project

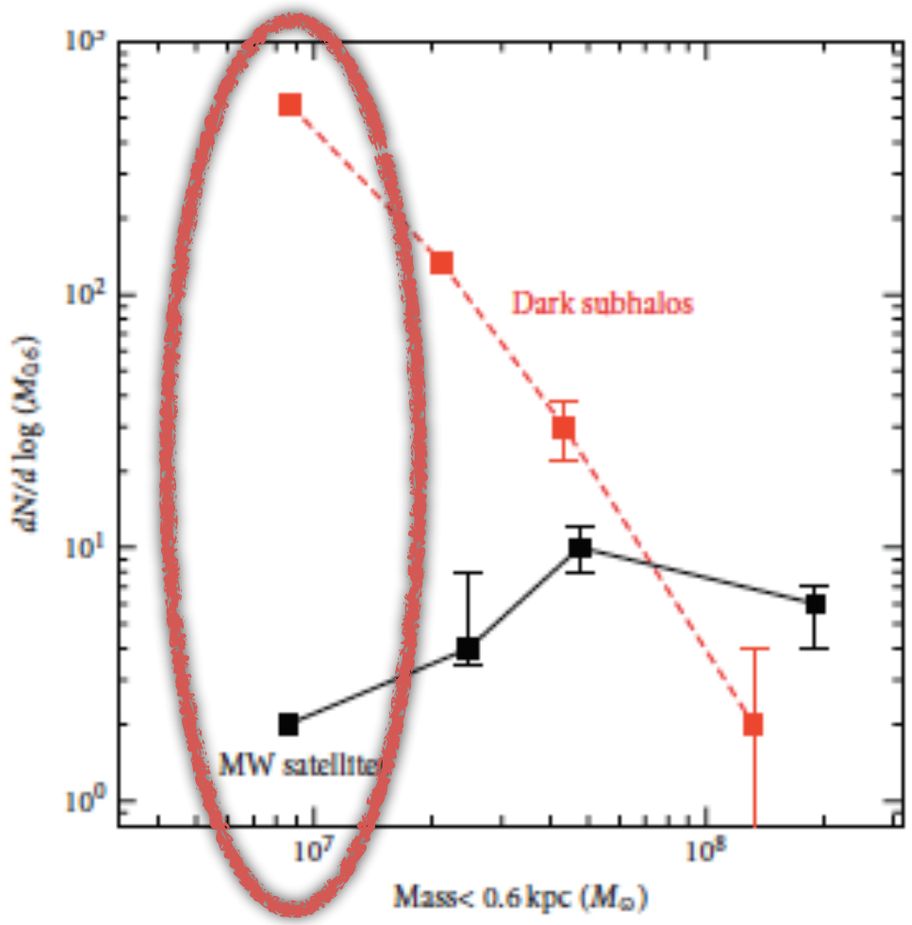
- Deep learning shows some promising result in dark matter substructures detection in lensing.
- “rejections” for no subhalos around the strong lensing arc.
- “detections” and “regression” for subhalos around the strong lensing arc.
- Learning from the NN output might also be interesting (intuitive physics), should be investigate more.
- Generating more realistic simulated data and analyzing real data would be coming soon!

Thank you!

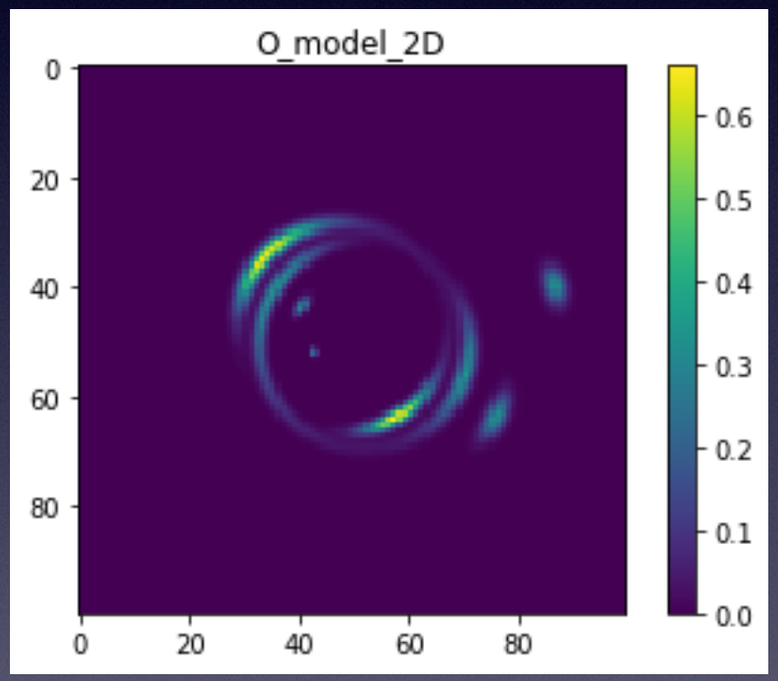
UNIVERSITY OF ILLINOIS
ASTRONOMY BUILDING
1002 W Green Street

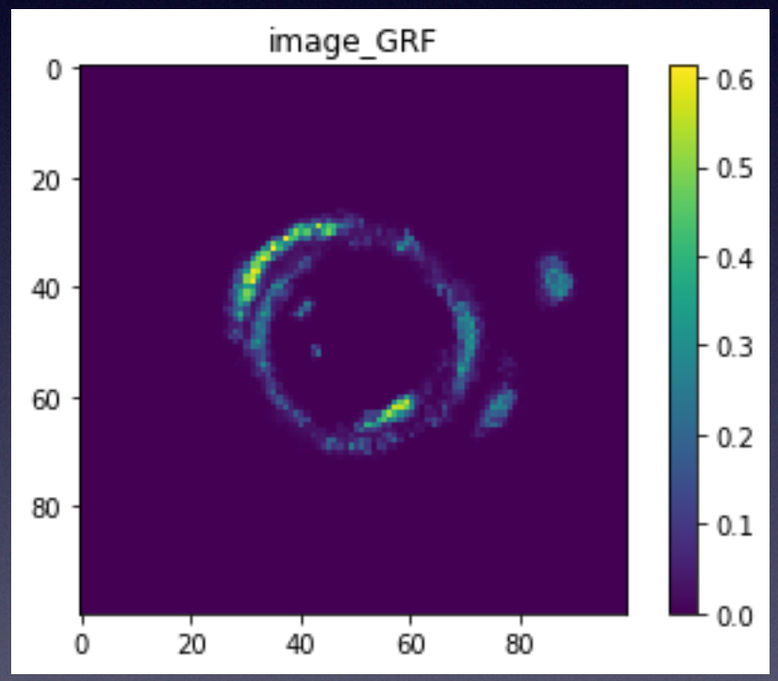
Lots of low mass (< 10^8 M_sun) subhalos contributes!

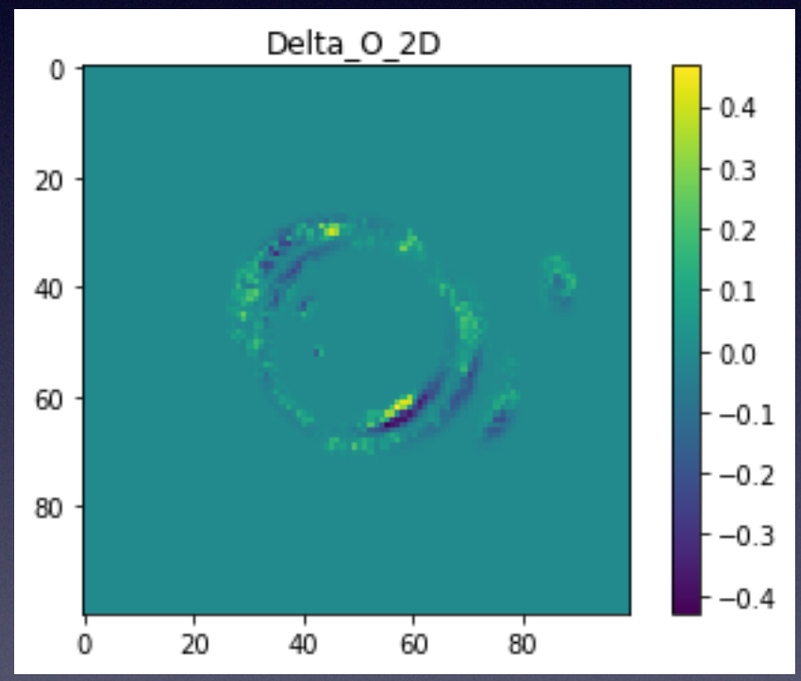




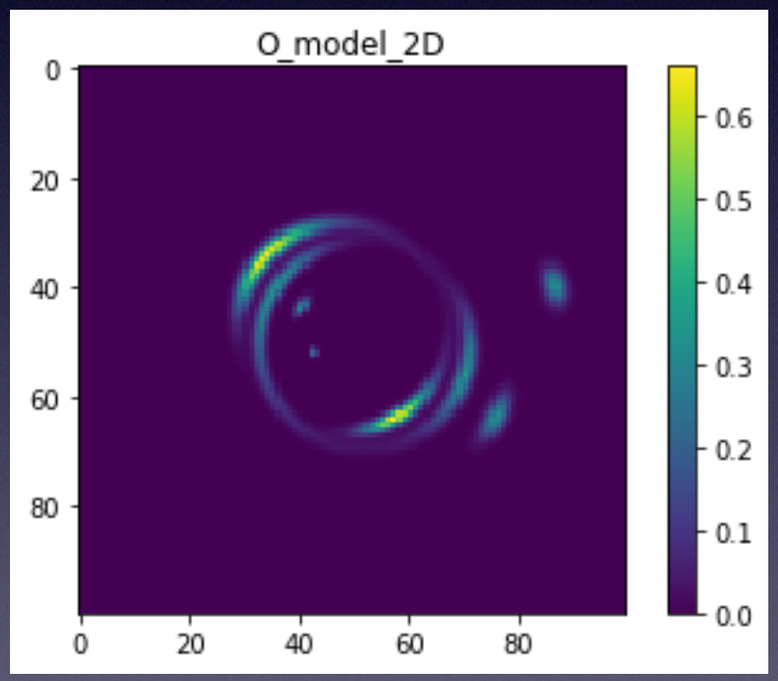
Statistical detection of dark matter power spectrum

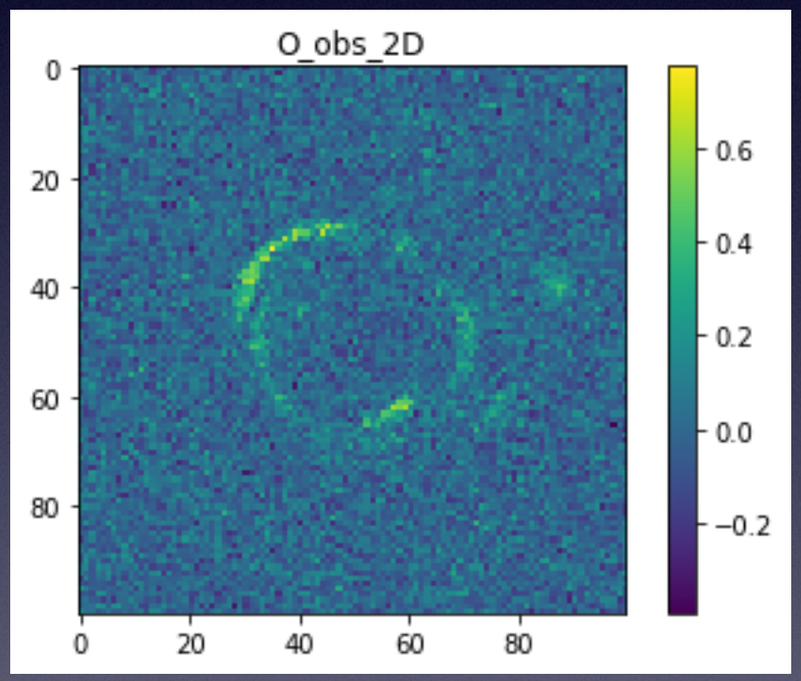


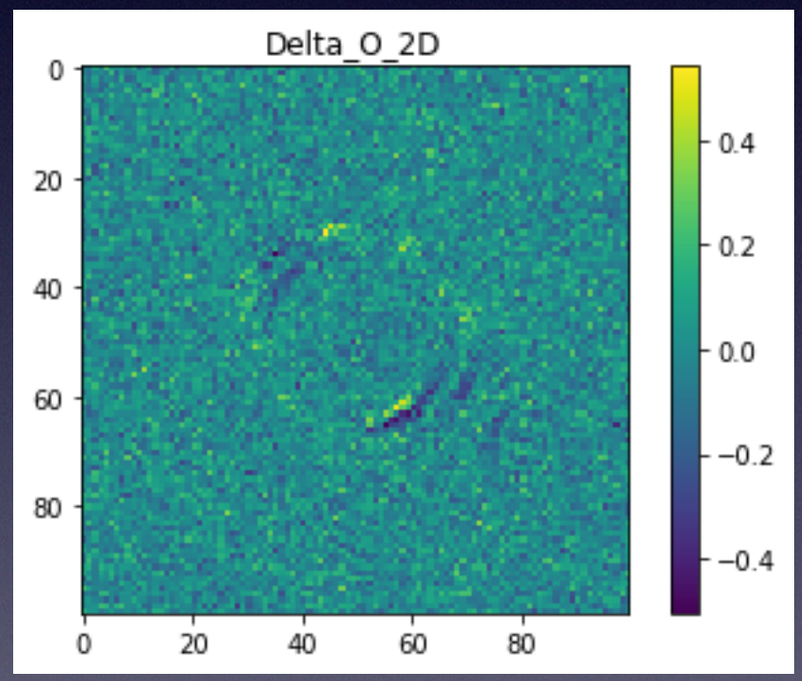




Noise


O_model_2D
0
20
40
60
80
0
20
40
60
80
0.6
0.5
0.4
0.3
0.2
0.1
0.0


O_obs_2D
0
20
40
60
80
0
20
40
60
80
0.6
0.4
0.2
0.0
−0.2


Delta_O_2D
0
20
40
60
80
0
20
40
60
80
0.4
0.2
0.0
−0.2
−0.4

Likelihood function

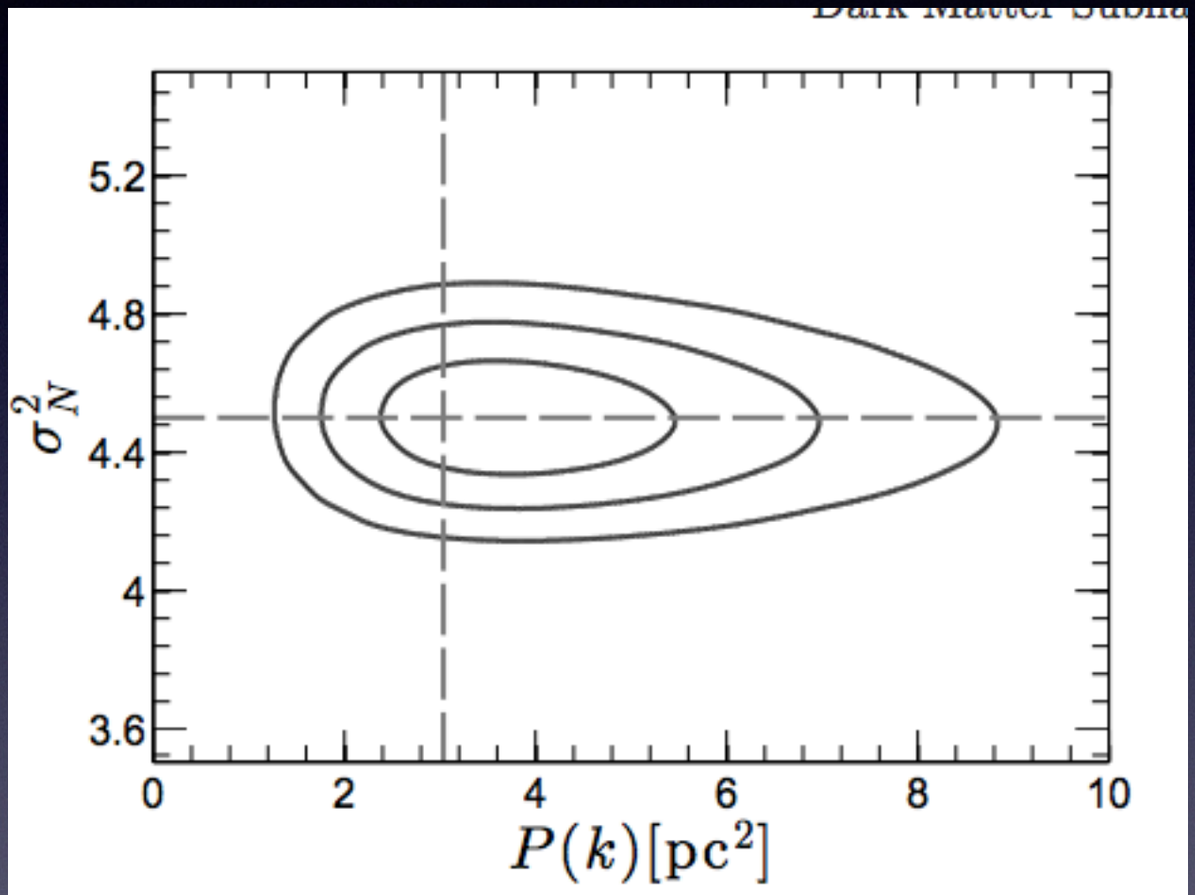


FIG. 2.— Joint-likelihood of noise and the amplitude of the power spectrum, mapped by evaluating Equation (9) using mock observations described in §4, lensed by a density field which includes substructure with a flat power spectrum. The dashed lines show the true values which were used in the mock observation. The input amplitude of the power spectrum is successfully recovered, with little if any degeneracy between instrumental noise and substructure fluctuations.

Hezaveh et al. (2016)