Exploring dark matter substructures with gravitational lensing

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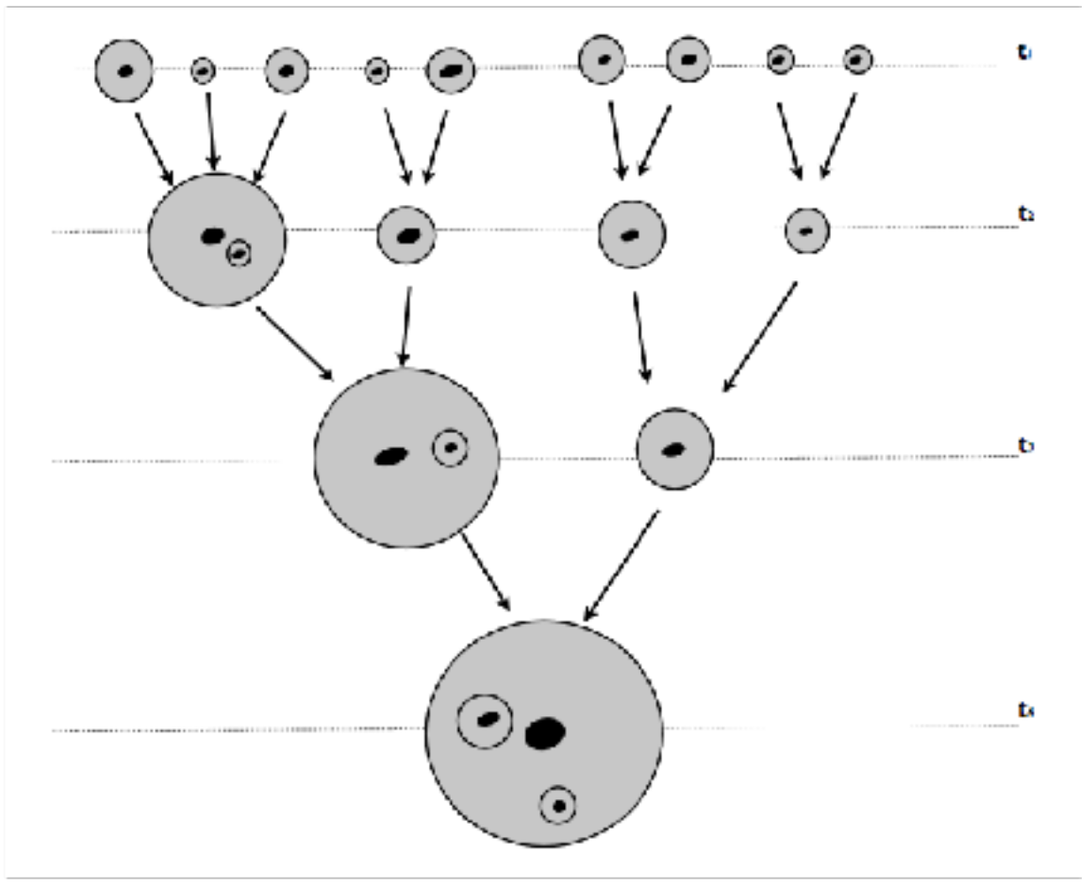
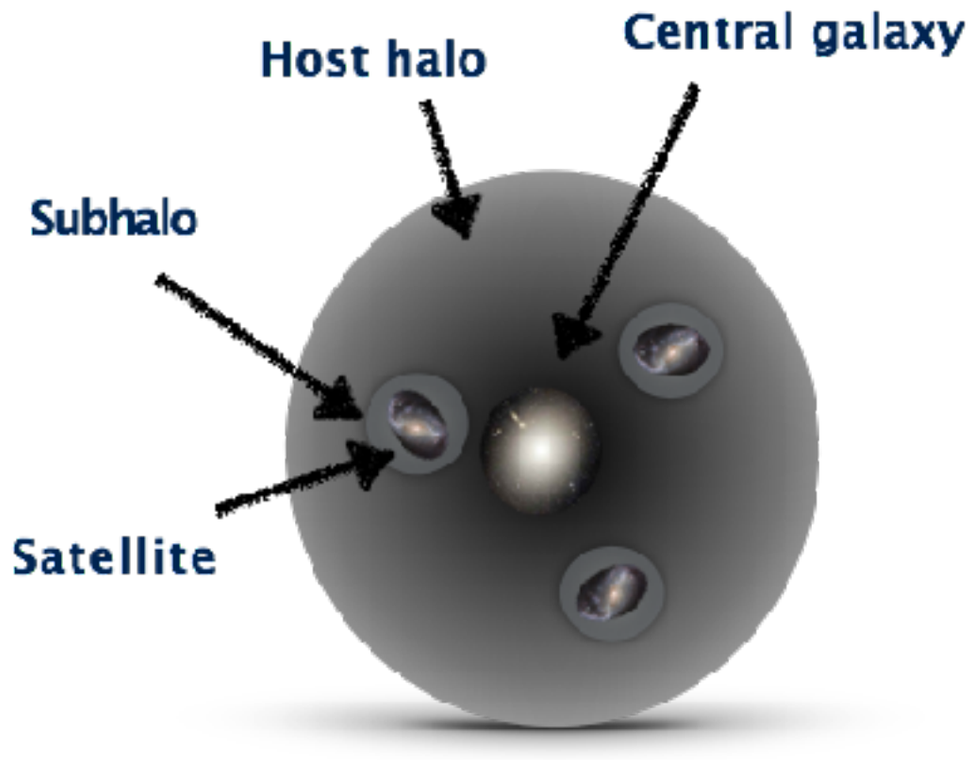
French-Chinese Days on Weak Lensing 5 Oct 2018

Structure formation in CDM universe

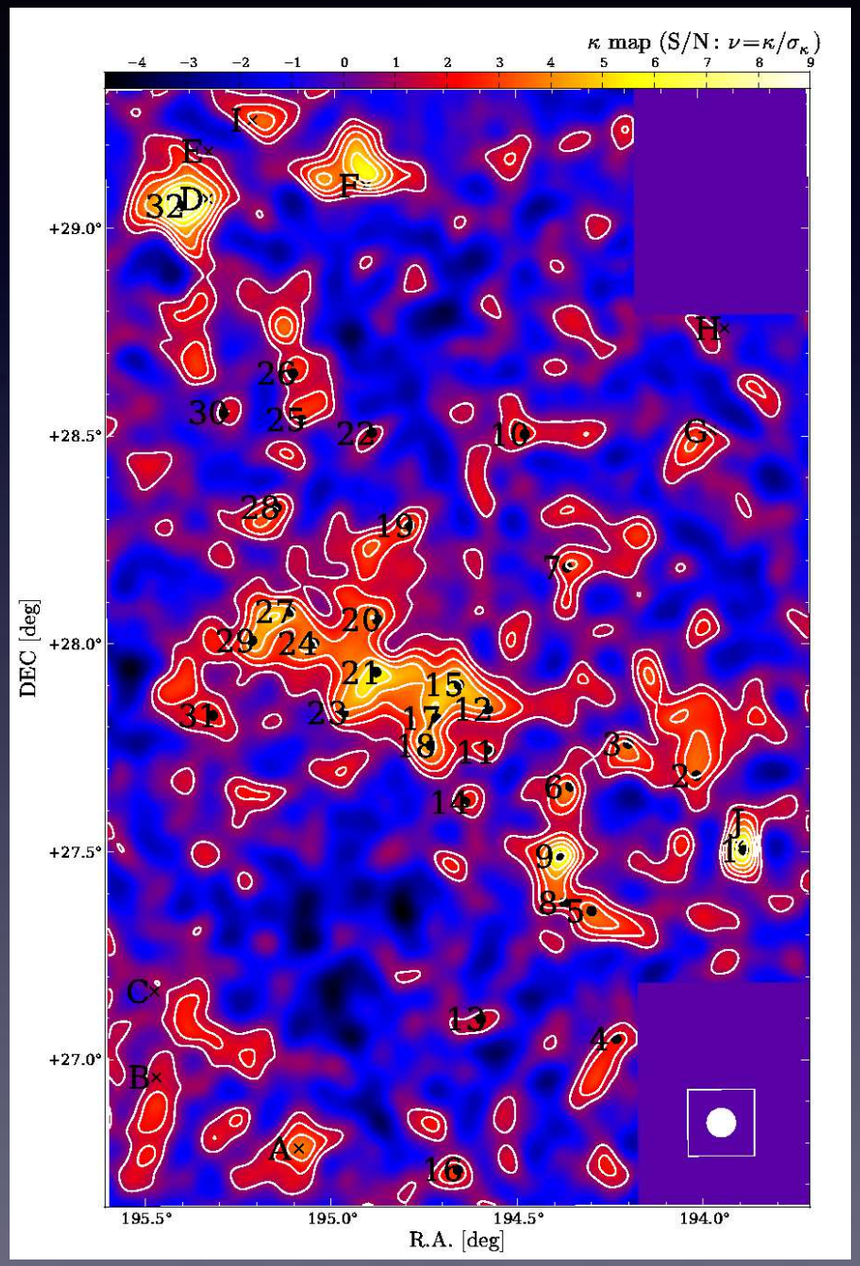
Merger Tree

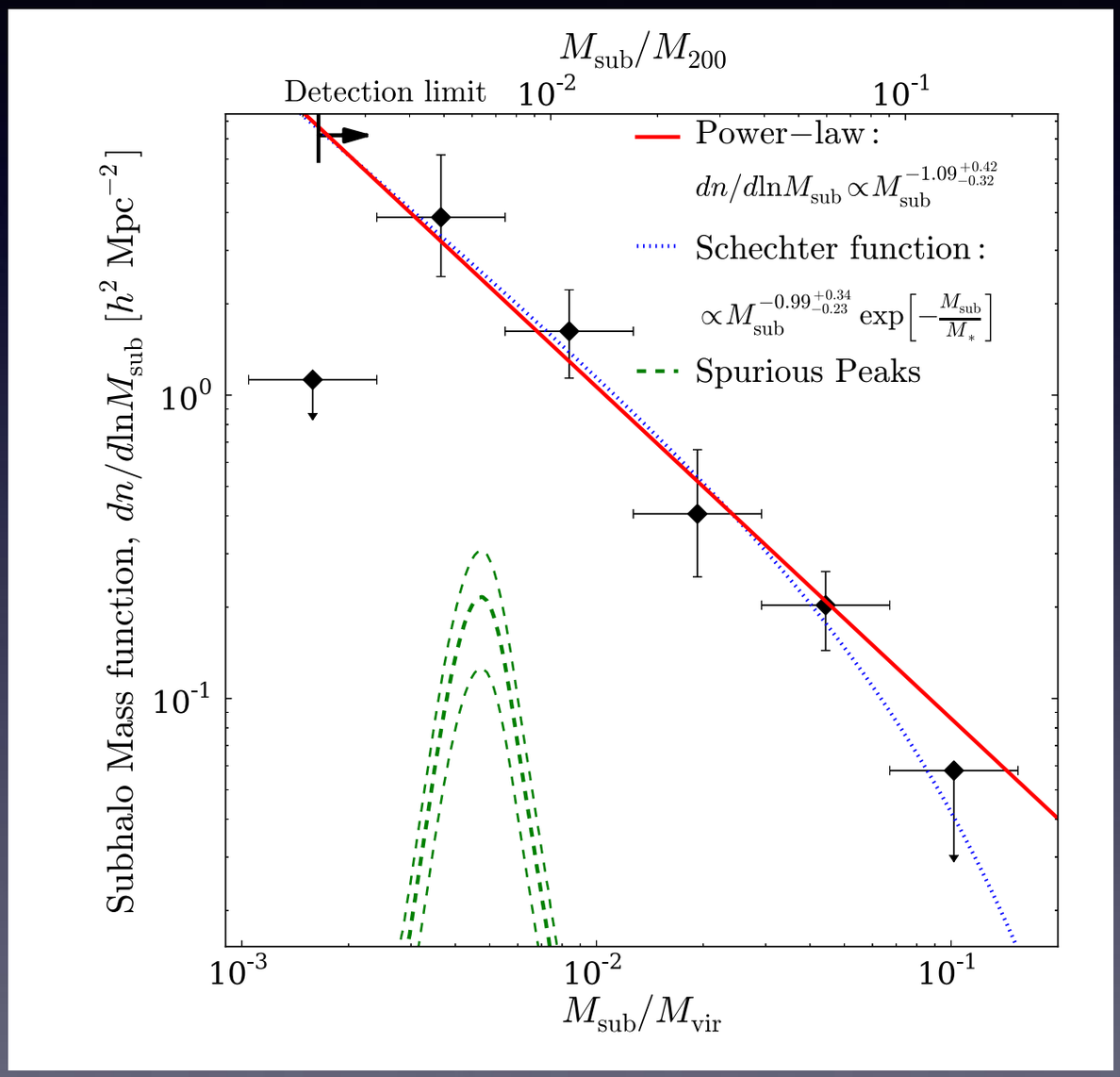


Dark matter halo



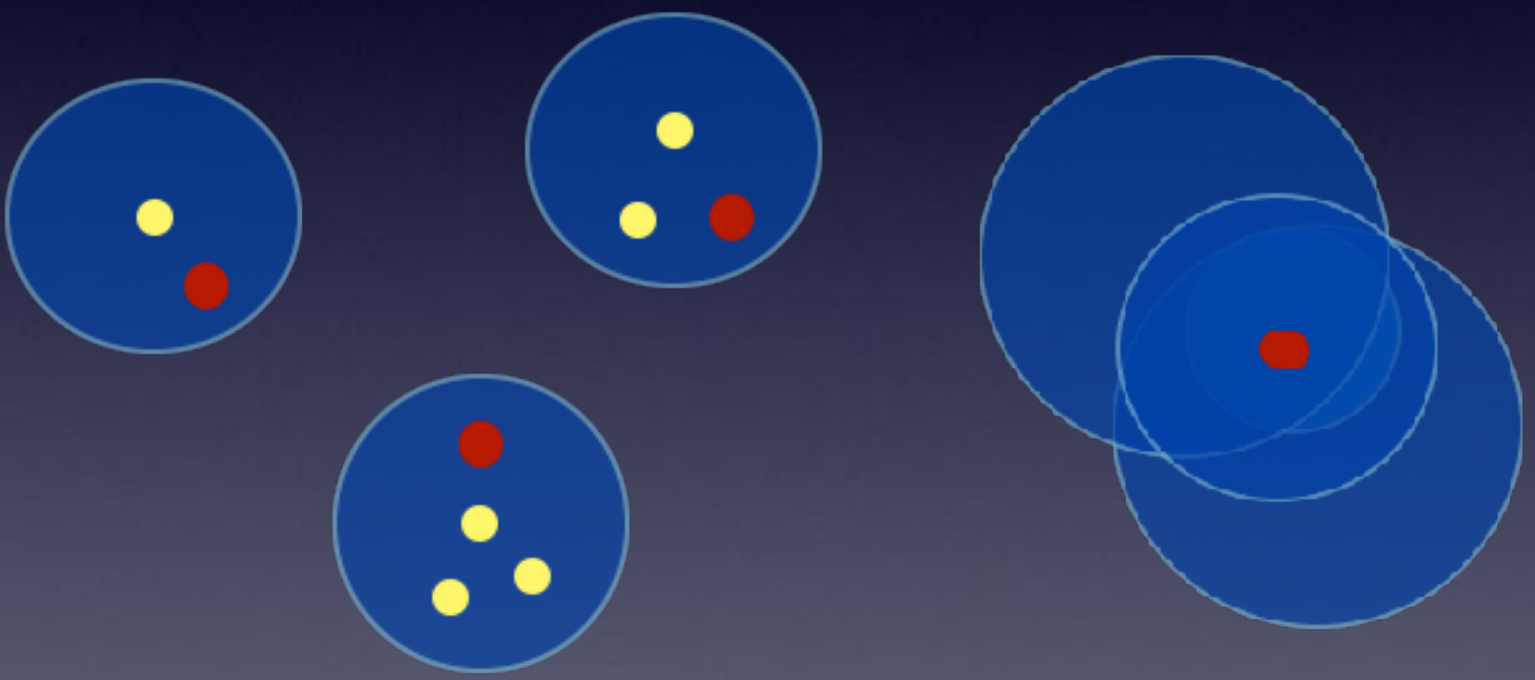
Weak lensing of nearby clusters

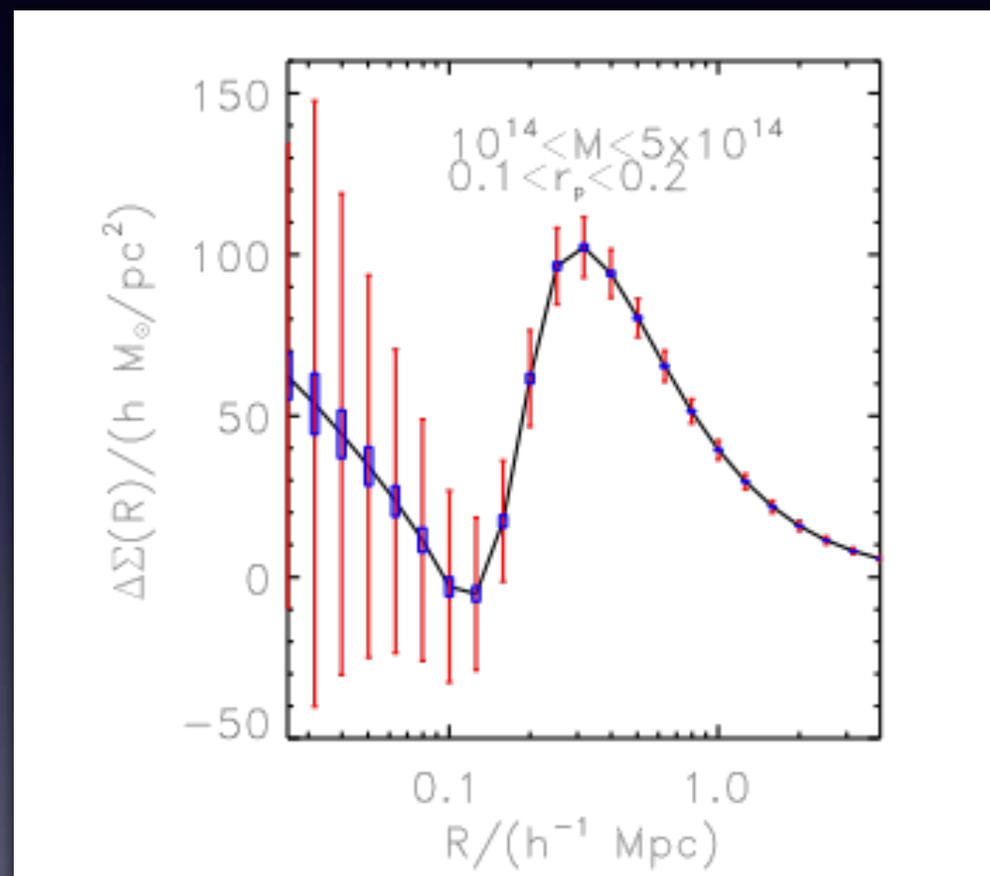




- Okabe et al. 2014

Stacking





Li et al. 2013

Measuring subhalo mass of stacked satellite galaxies

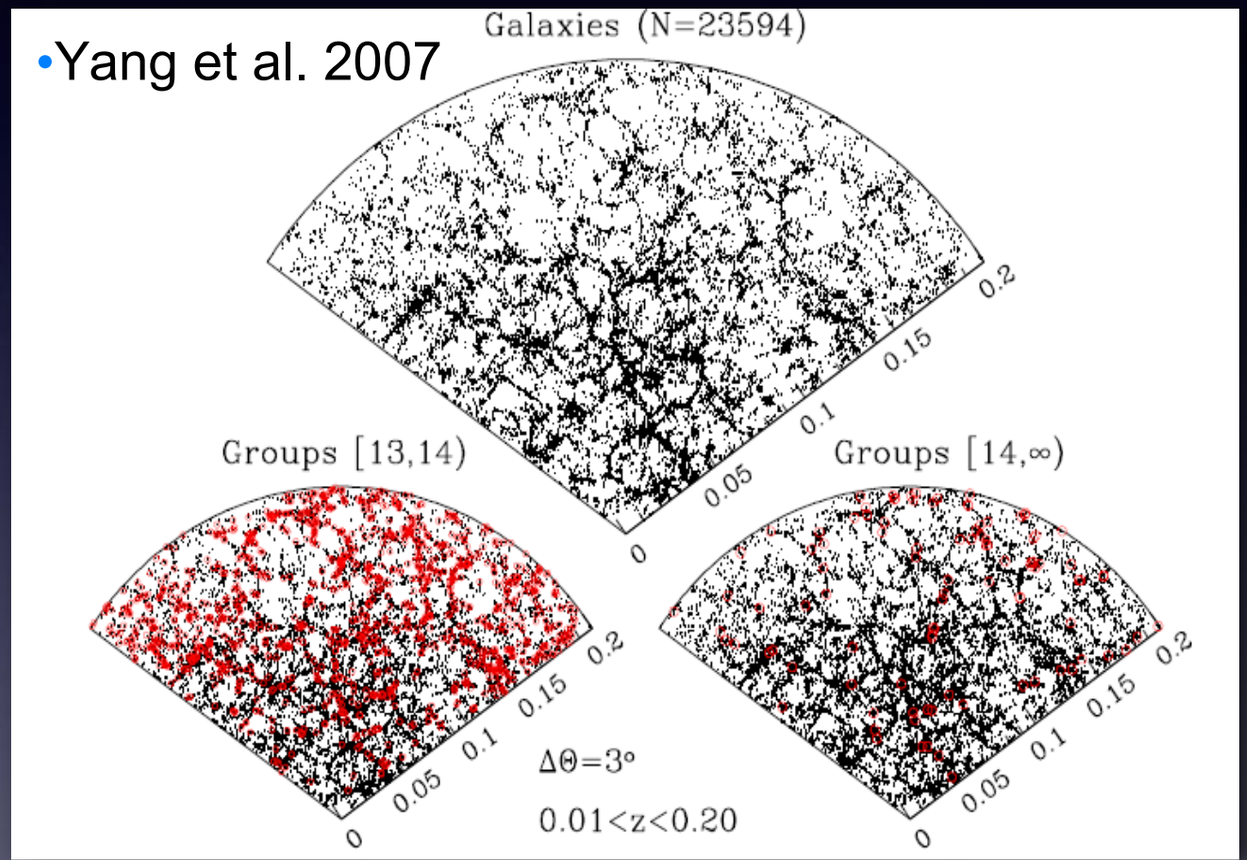
Select satellites directly : Group finder

Yang, Mo and vdBosch 2007, using SDSS spectroscopic sample

1.A self-calibrated FOF method.

2.Assign all galaxies to groups.

2.Estimate group mass by abundance matching.

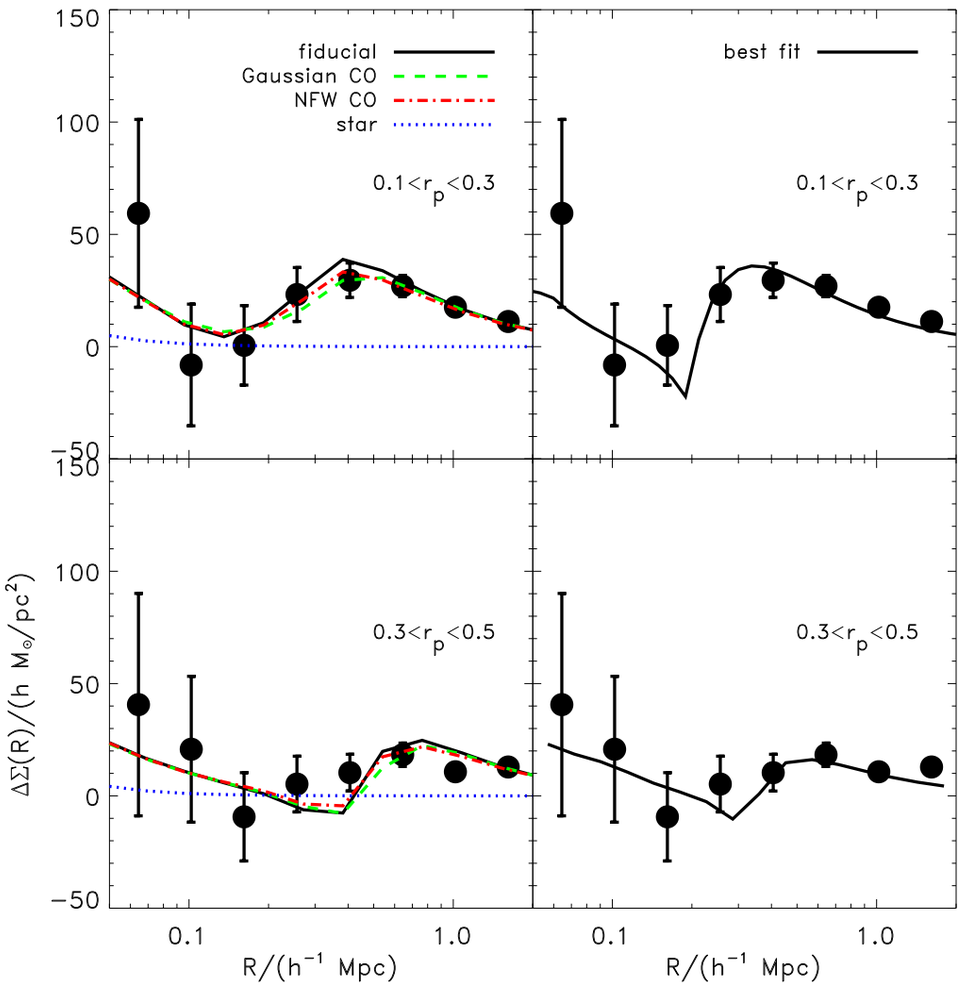


- Yang et al. 2007

Catalogue	sky cov	redshift	galaxies	groups	groups(N=1)	groups(N=2)	groups(N=3)	groups(N>3)
Sample I	4514	0.01-0.20	362356	295992	266763	19522	4511	5196
Sample II	4514	0.01-0.20	369447	301237	271420	19868	4619	5330
Sample III	4514	0.01-0.20	408119	300049	250492	33537	7848	8172

Satellite lensing in CFHT/Stripe82 data

First measurement of subhalo lensing signal in groups.

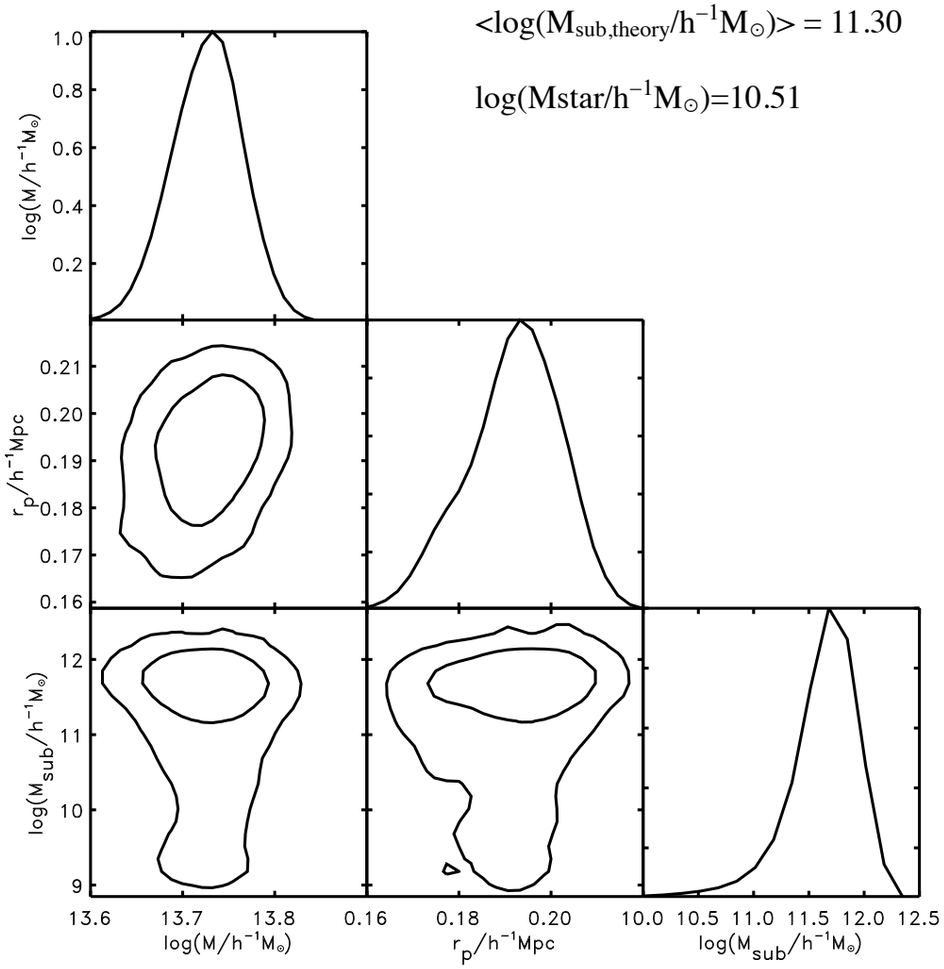


Lensing around satellites in groups with mass>5x10^13 solar mass

$\log(M_{sub}/h^{-1}M_\odot) = 11.68 \pm 0.67$

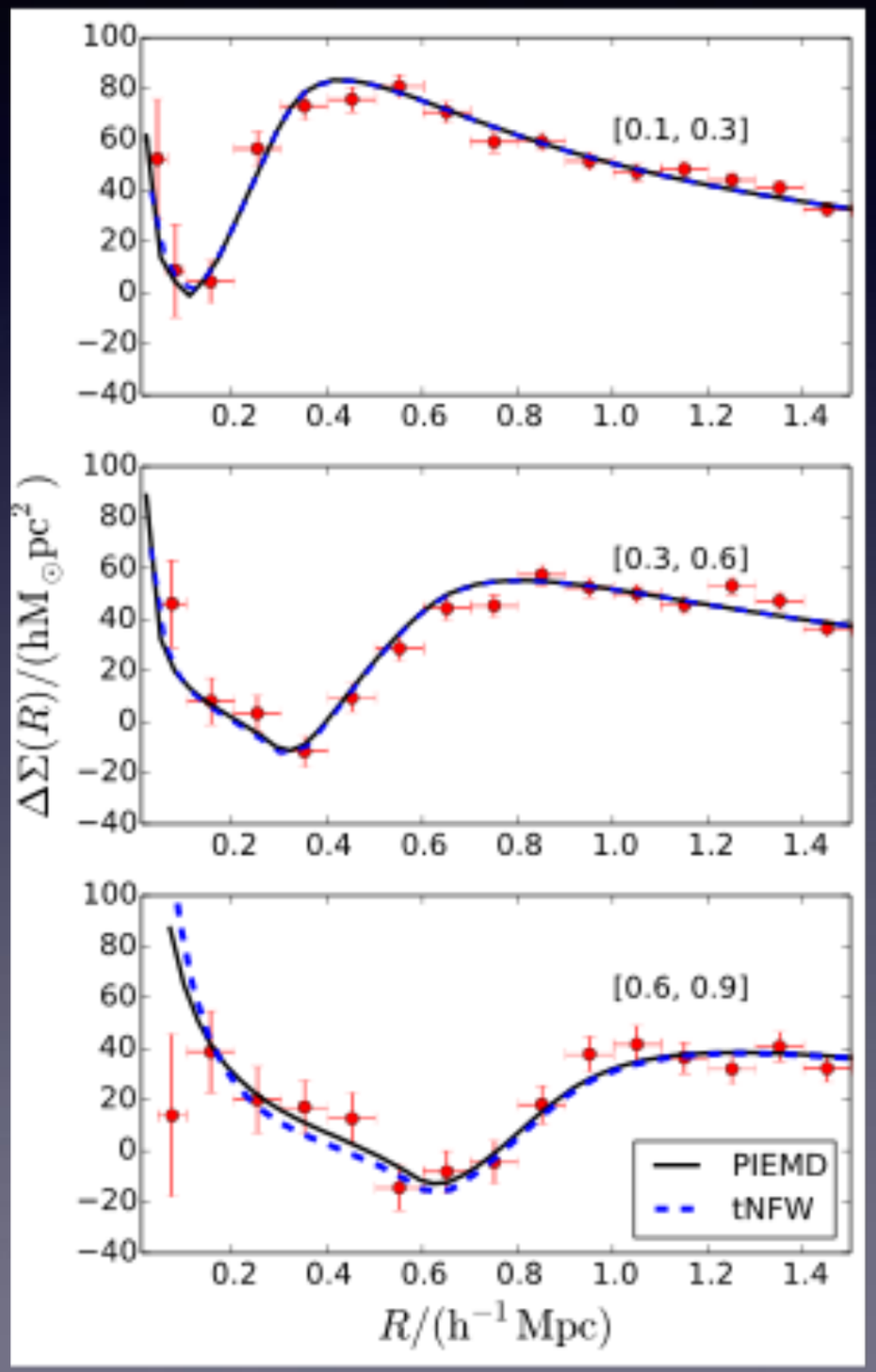
$\langle\log(M_{sub,theory}/h^{-1}M_\odot)\rangle = 11.30$

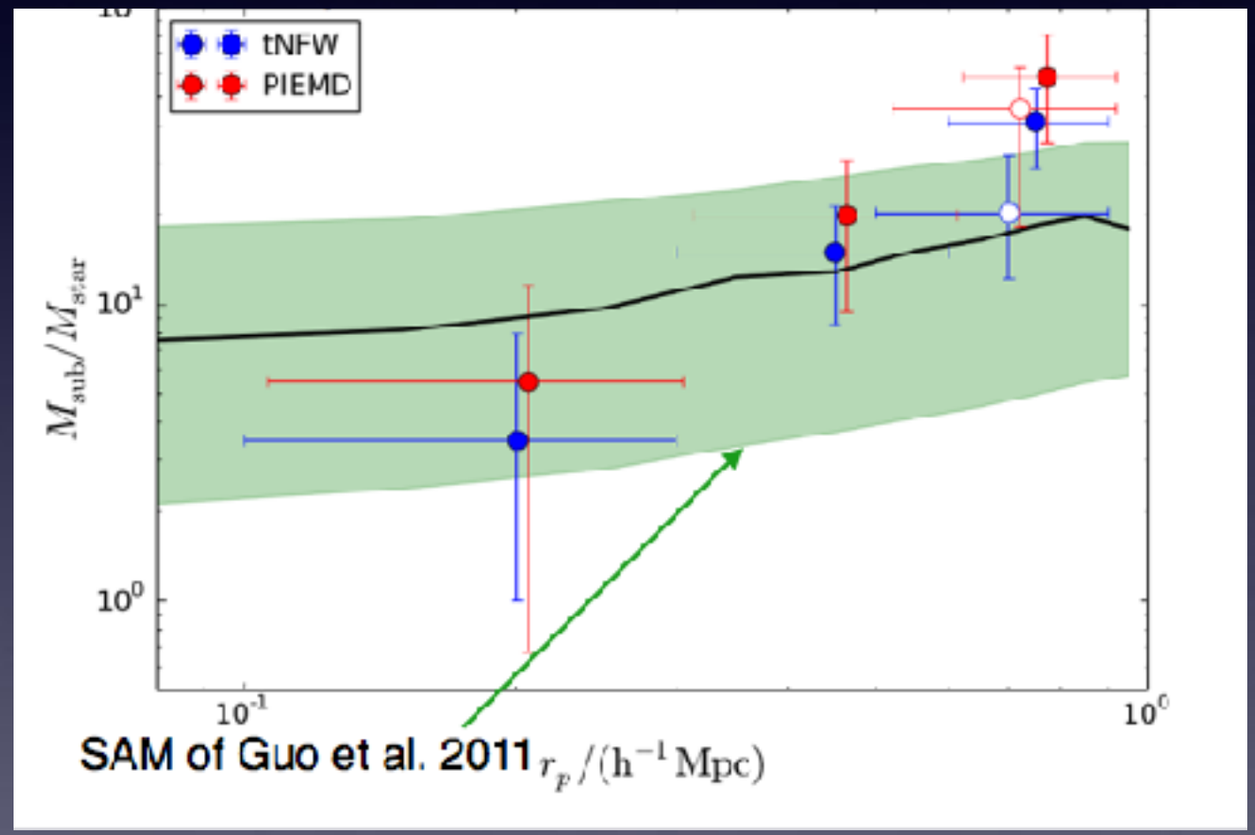
$\log(Mstar/h^{-1}M_\odot)=10.51$



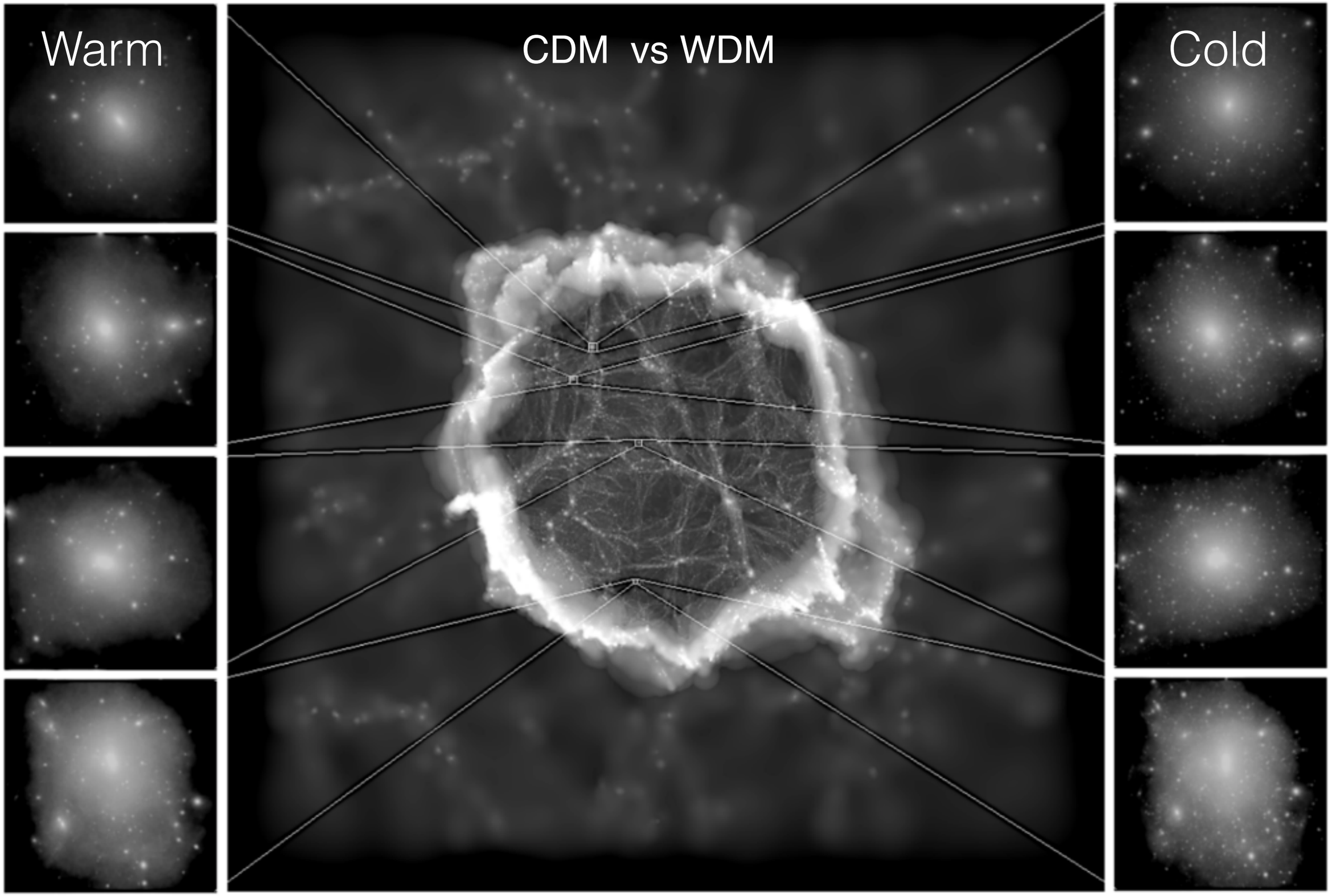
Li et al. 2014, MNRAS, 438, 2864

CFHT/CS82 data + Cluster satellite





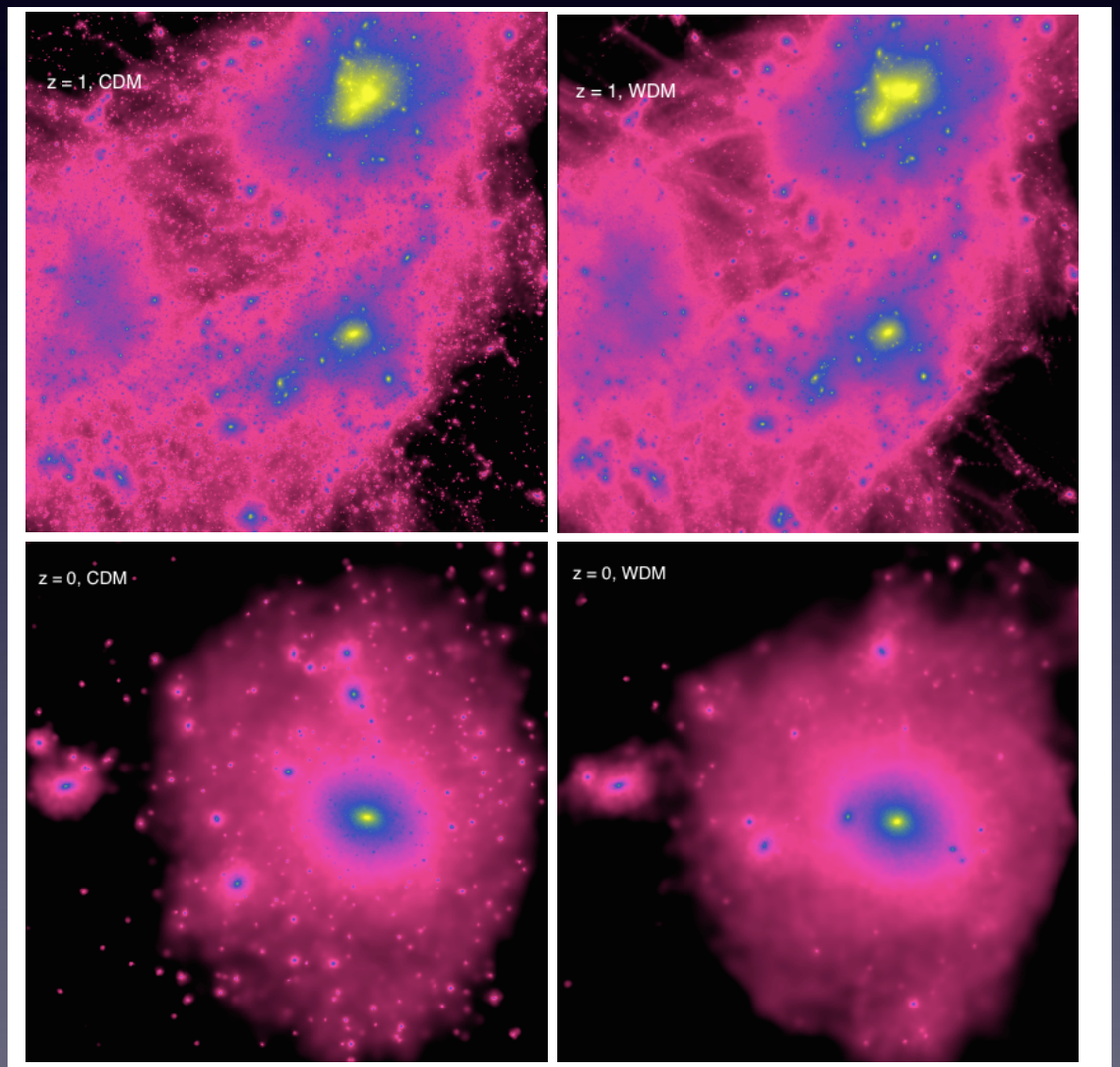
Li et al. 2016, 458, 2573



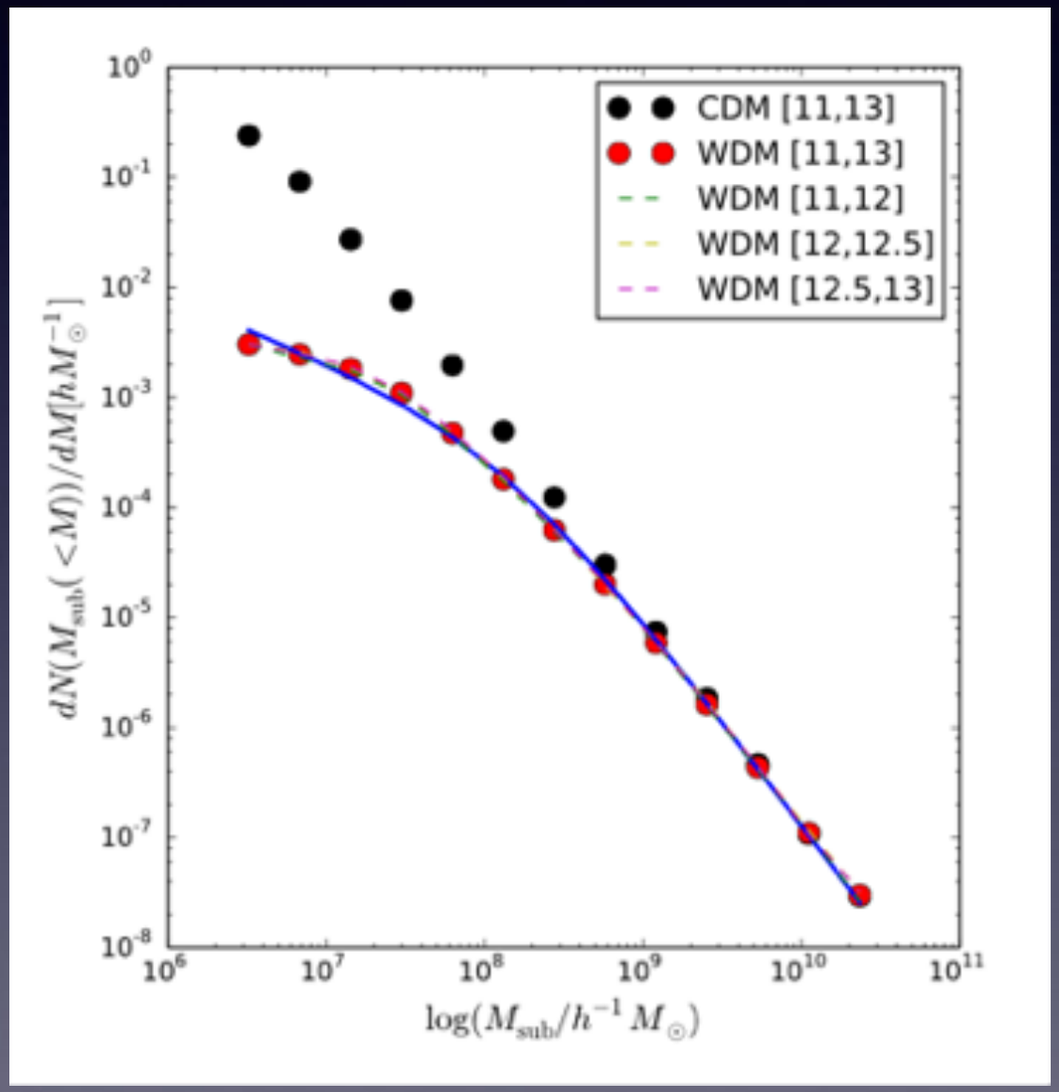
3.3 keV WDM, COCO simulations Bose et al. 2017
The power spectrum of this WDM model is also
very similar to the “coldest” 7 kev sterile neutrino

Identity of Dark matter

COCO simulations Bose+ 2016

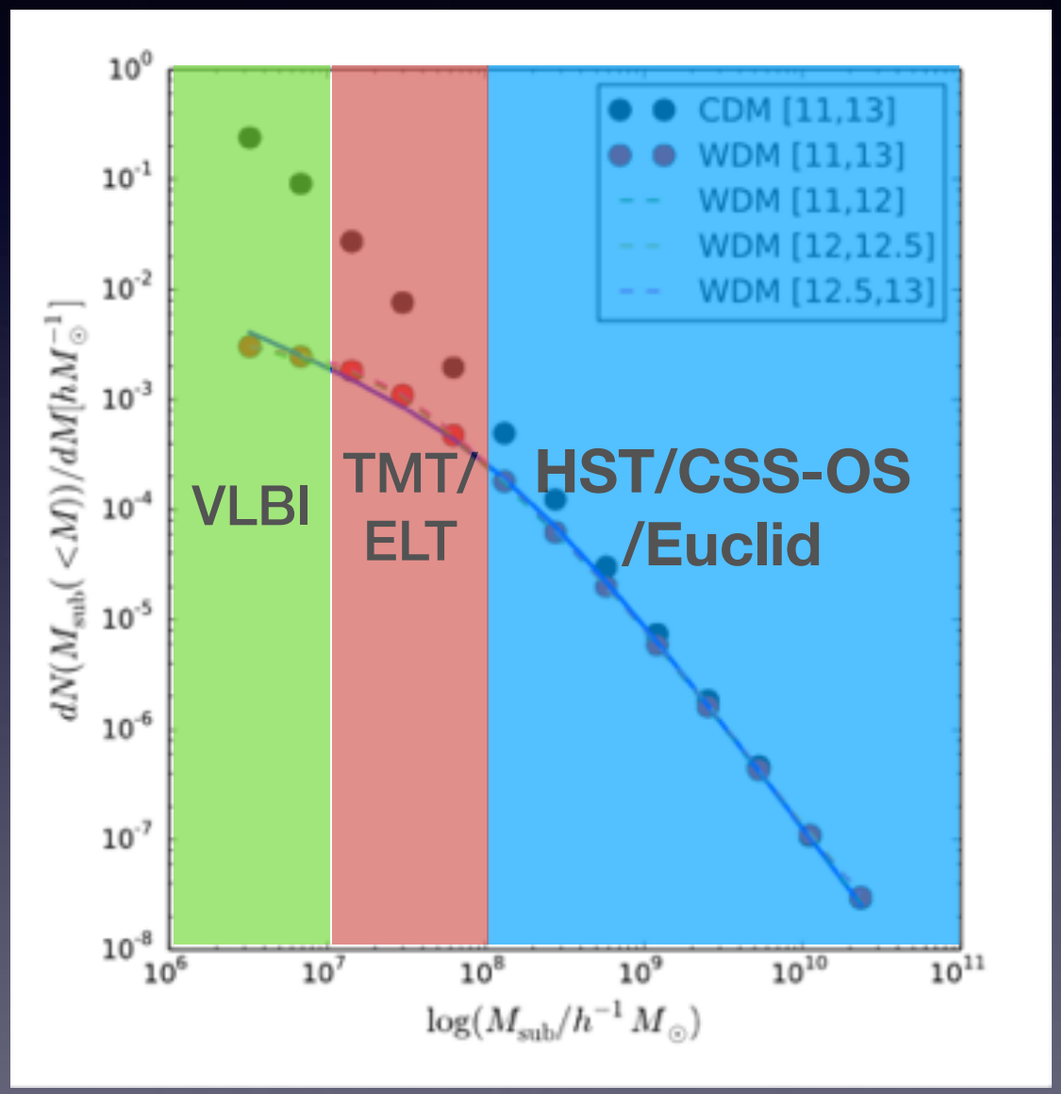


Li et al. 2016 arxiv 1512.06507

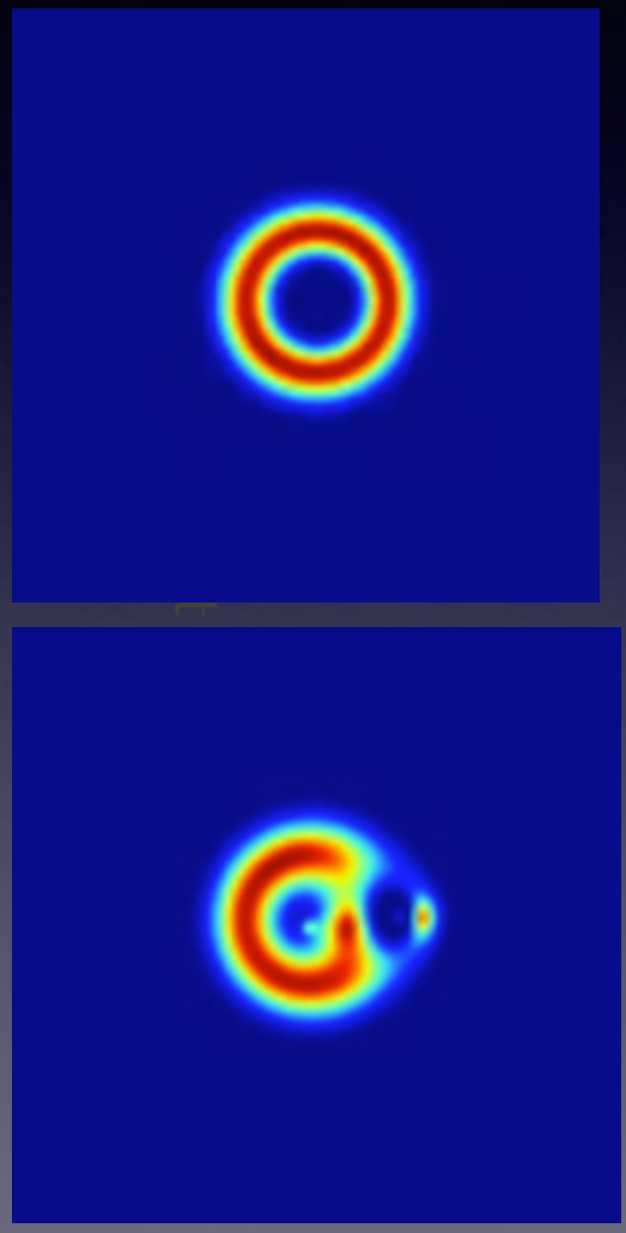


How to find small haloes?
Most very small haloes don't form galaxy

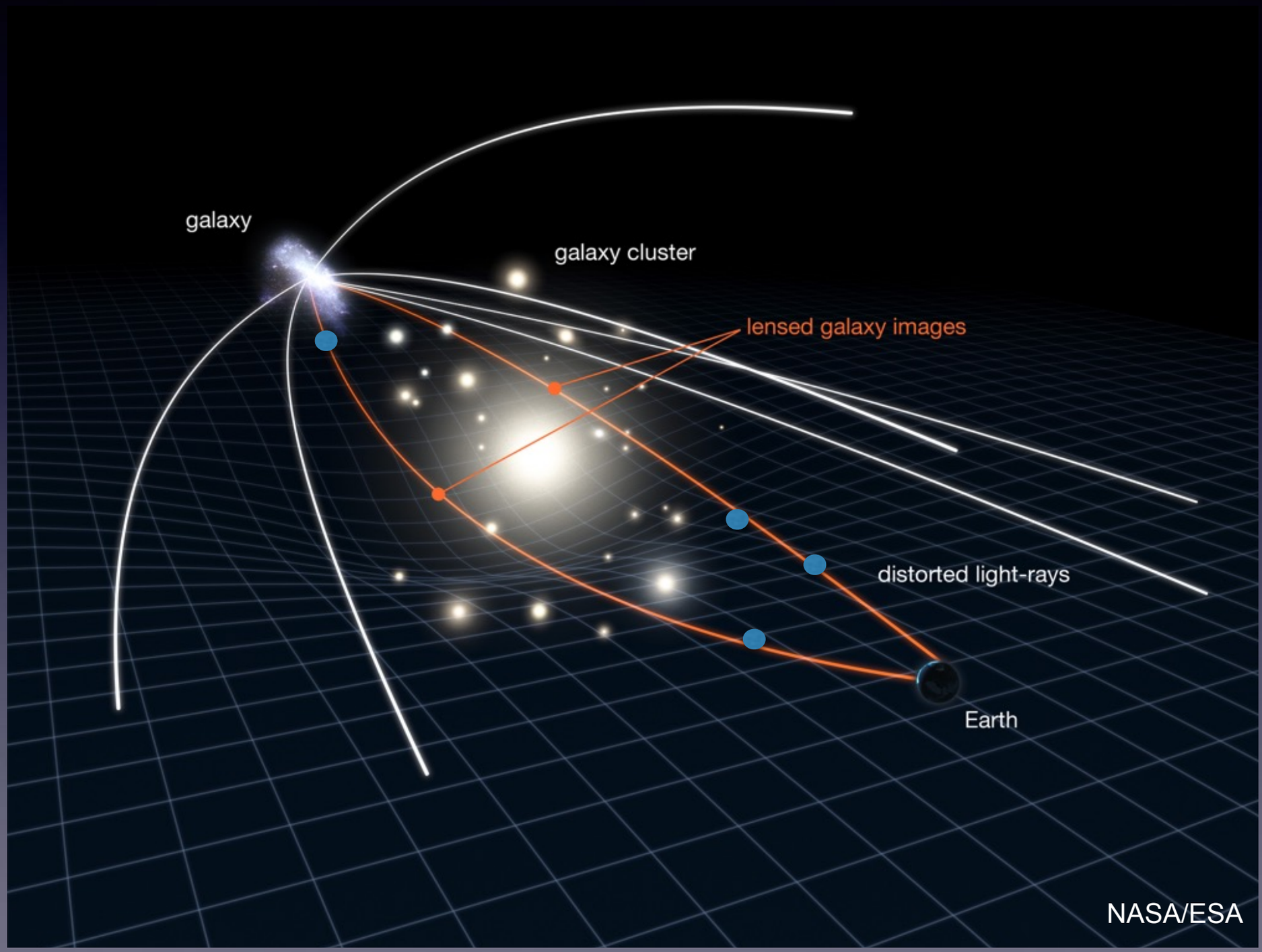
Substructure detection in strong lenses



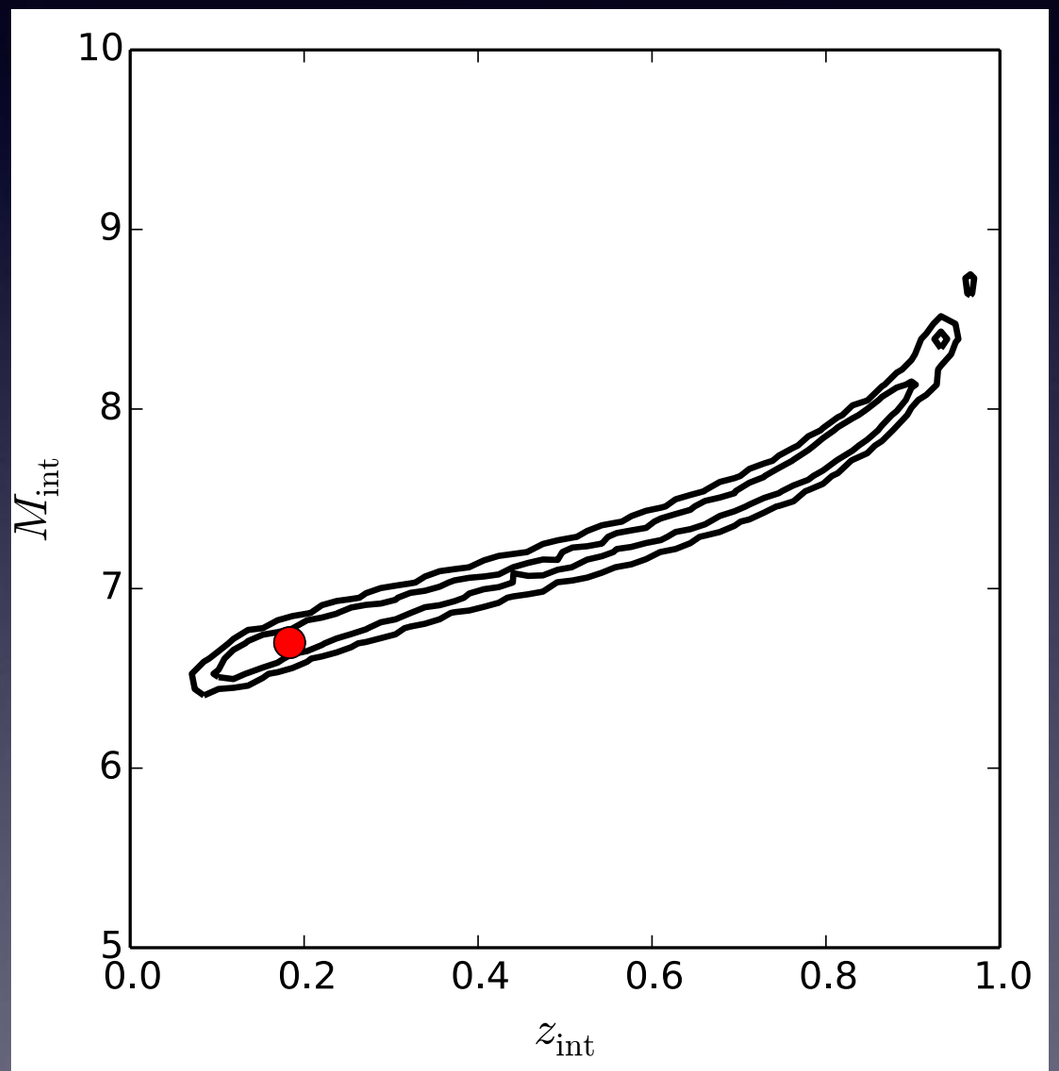
Li et al. 2016 arxiv 1512.06507

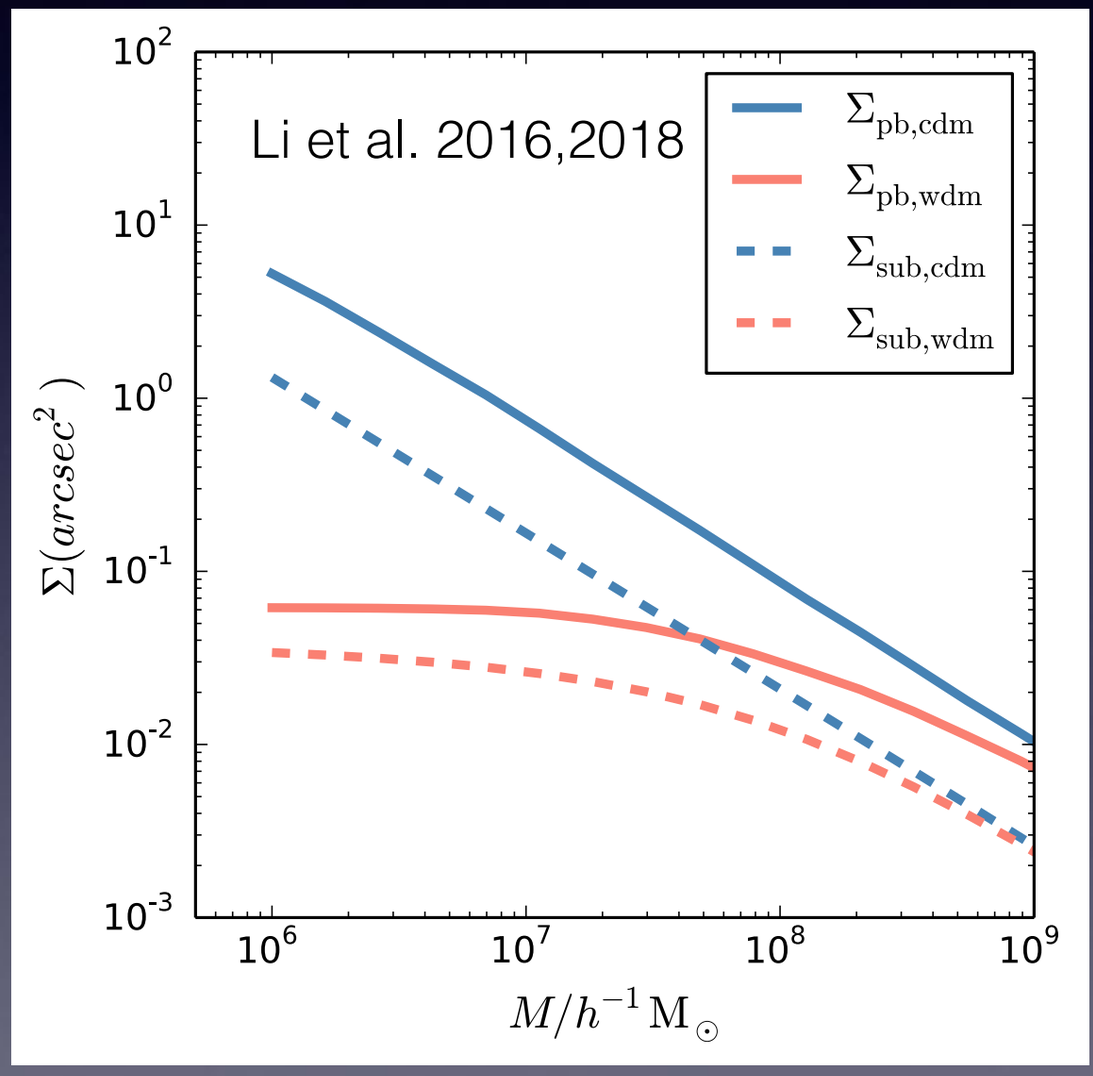


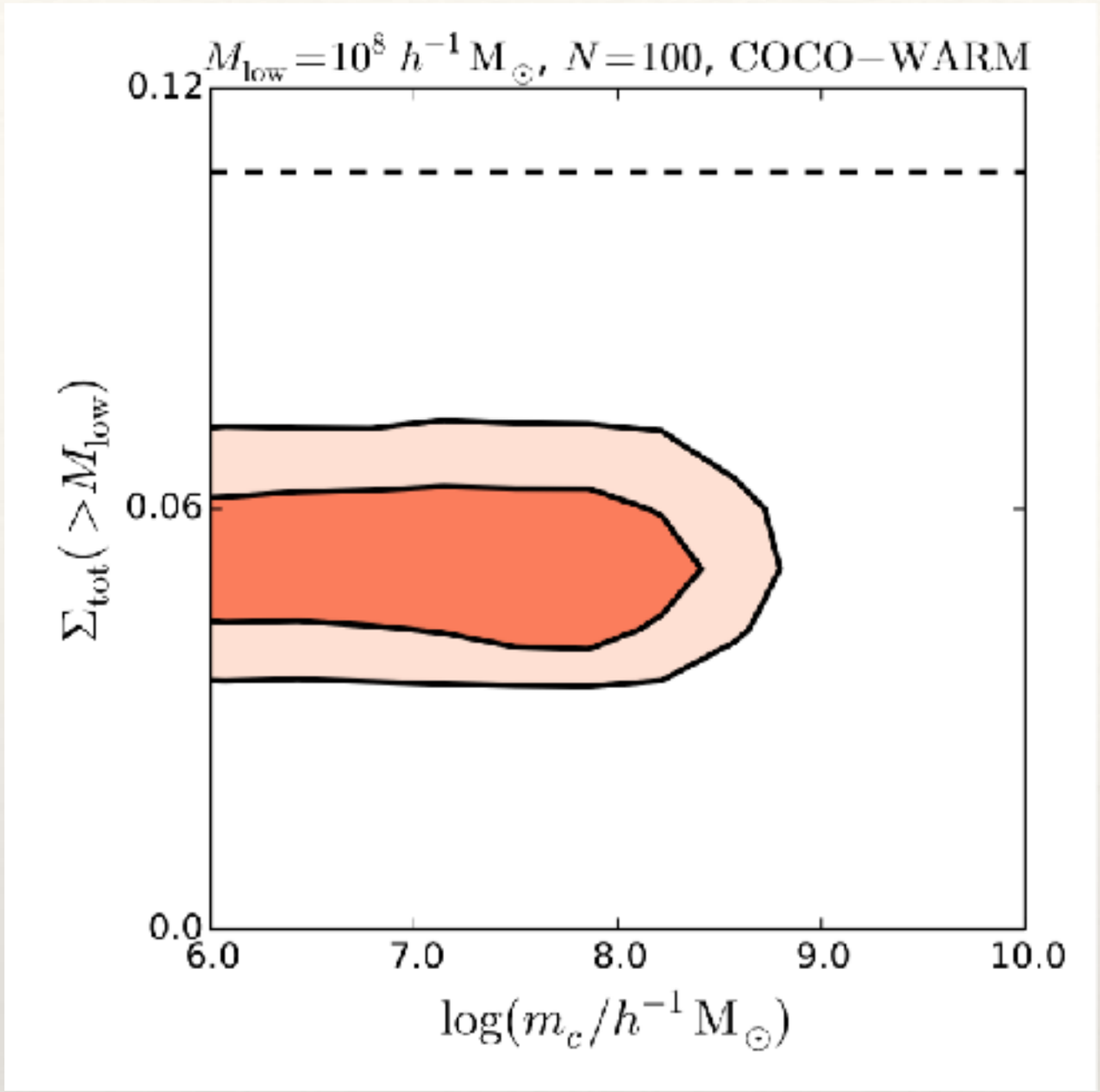
Perturbing Einstein ring

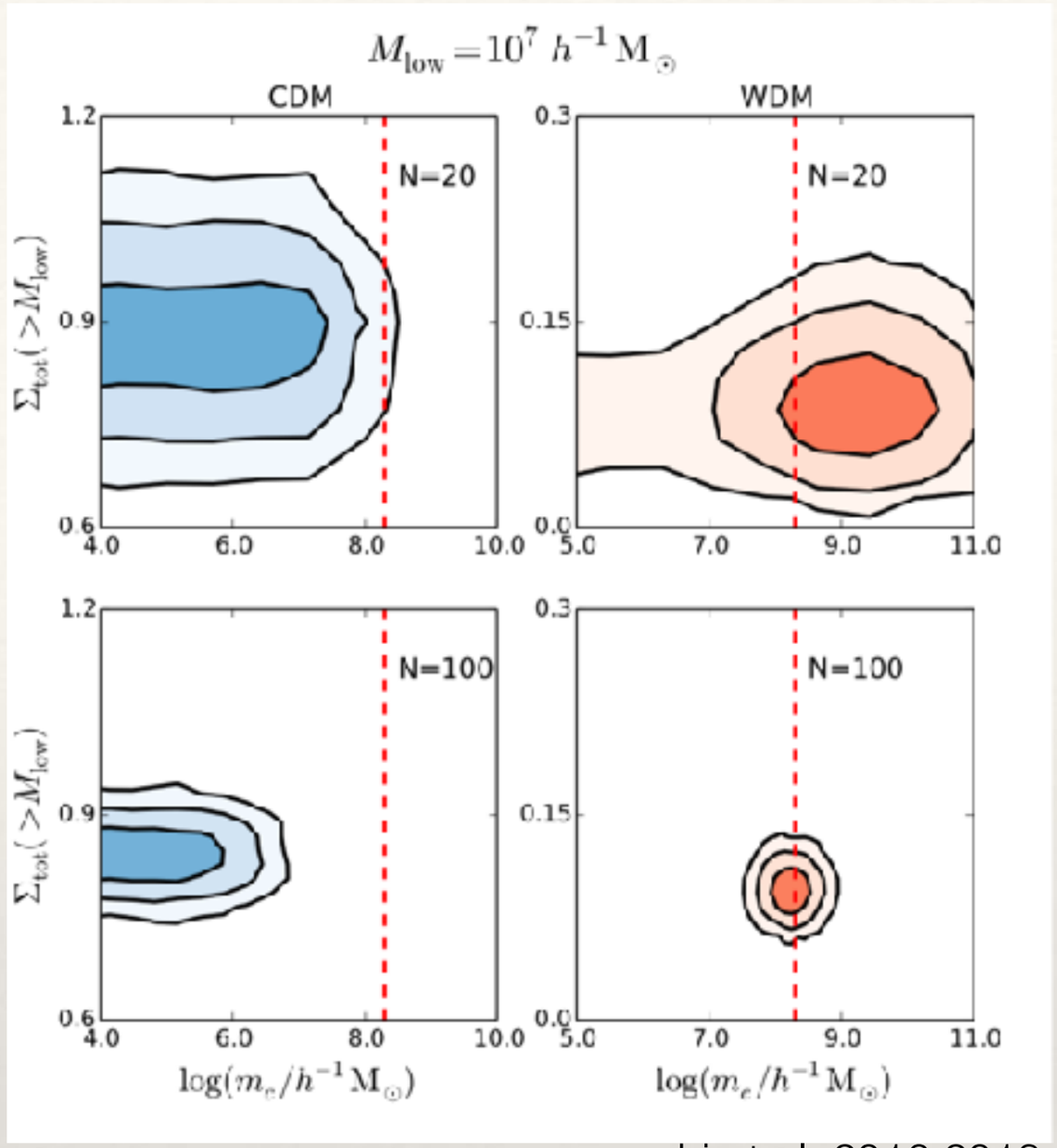


Perturber mass function







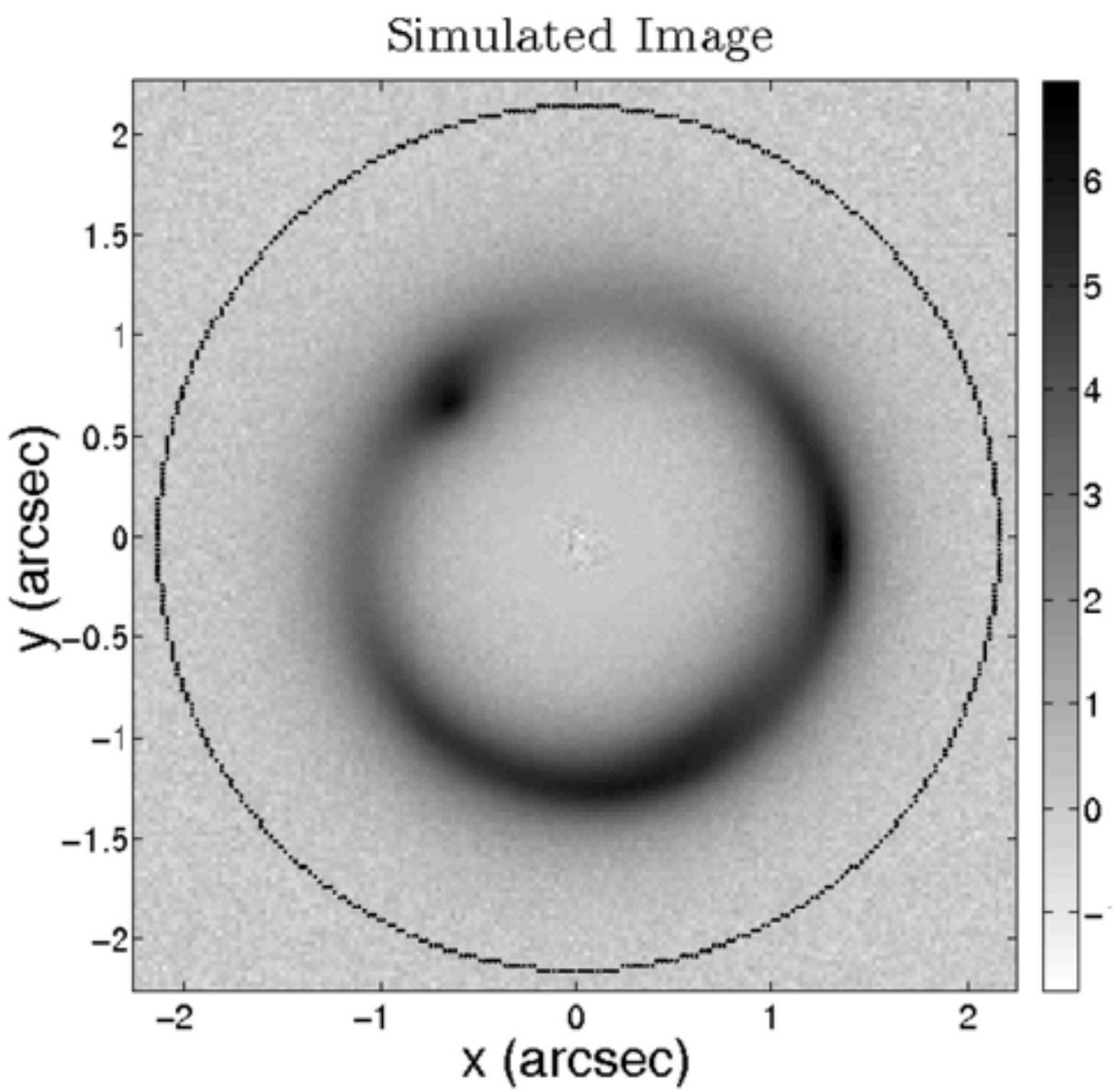


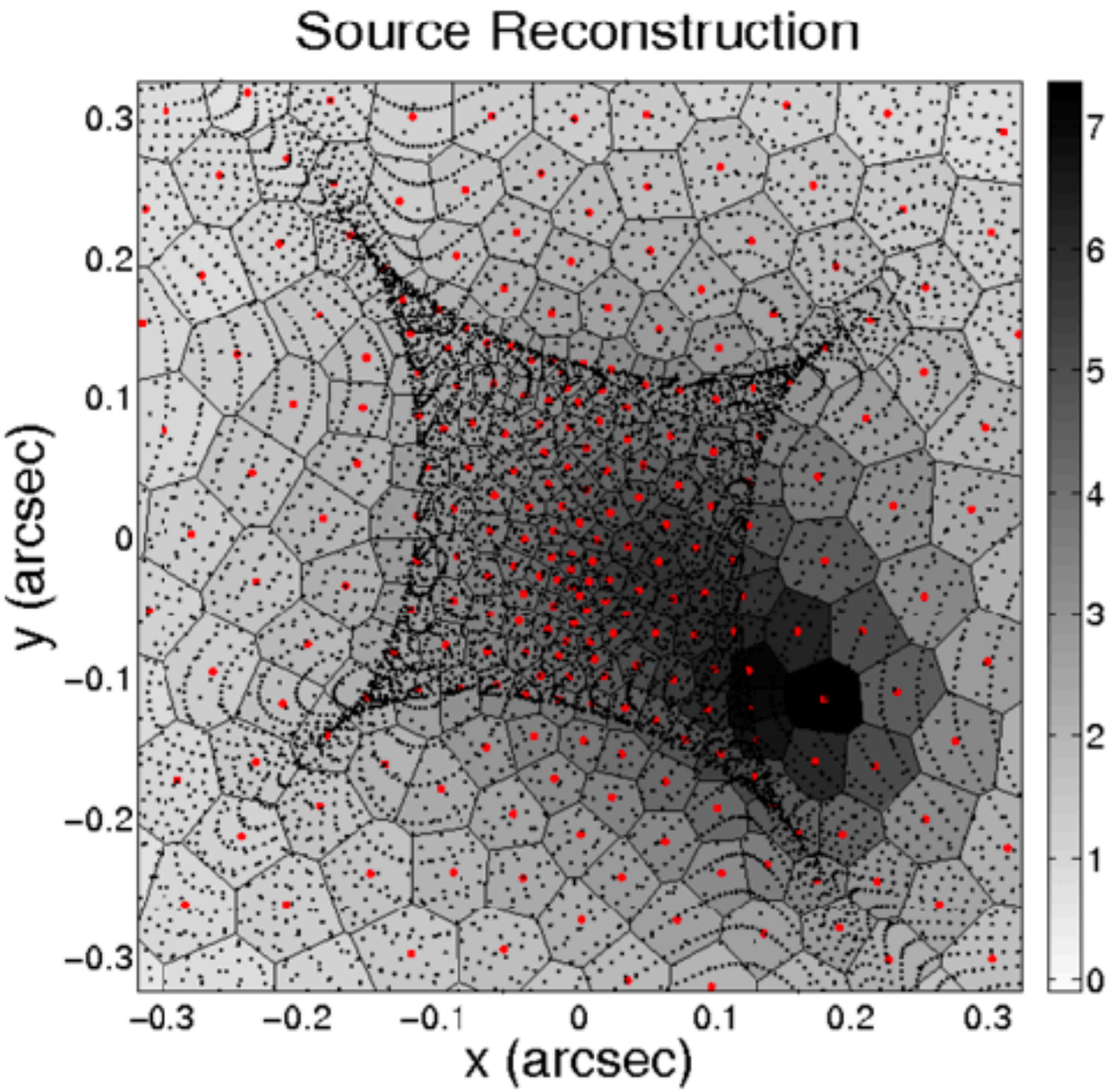
Li et al. 2016,2018

Forecast

M_low=10^7 Msun
Upper: N_lens=20
Lower: N_Lens=100

Voronoi Source Reconstruction

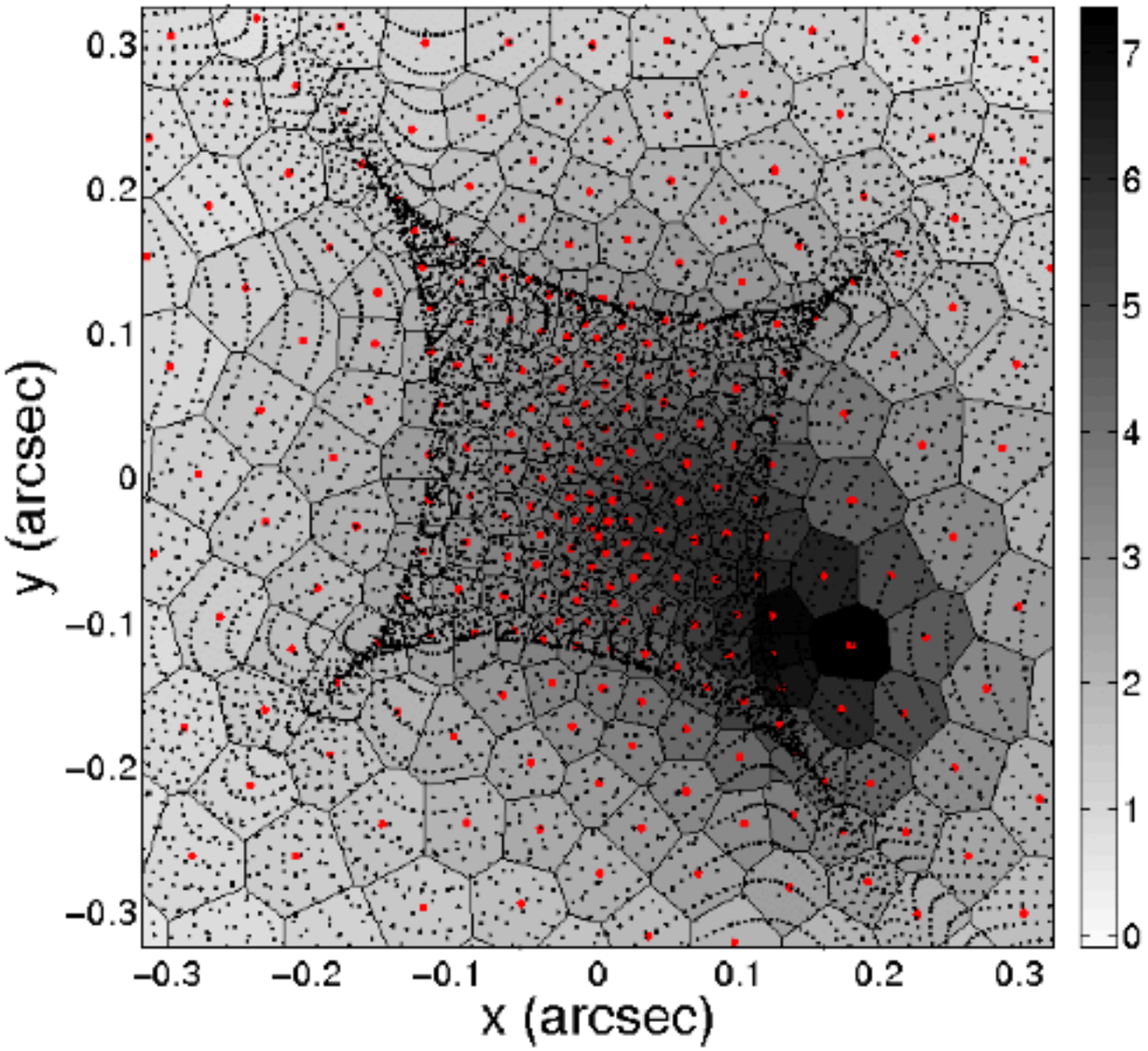




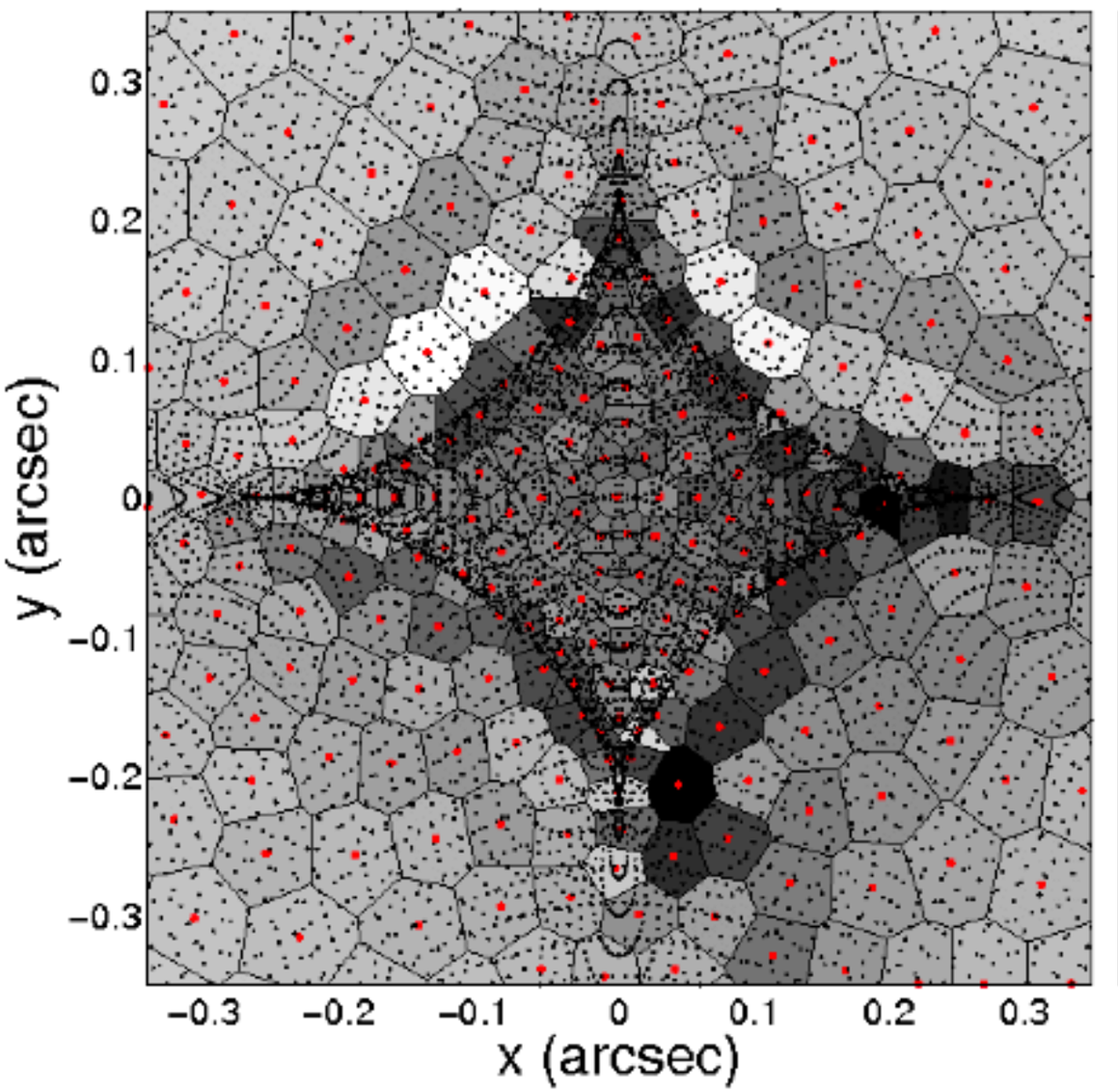
PyAutoLens By Nightingale James

Complexity

Simple

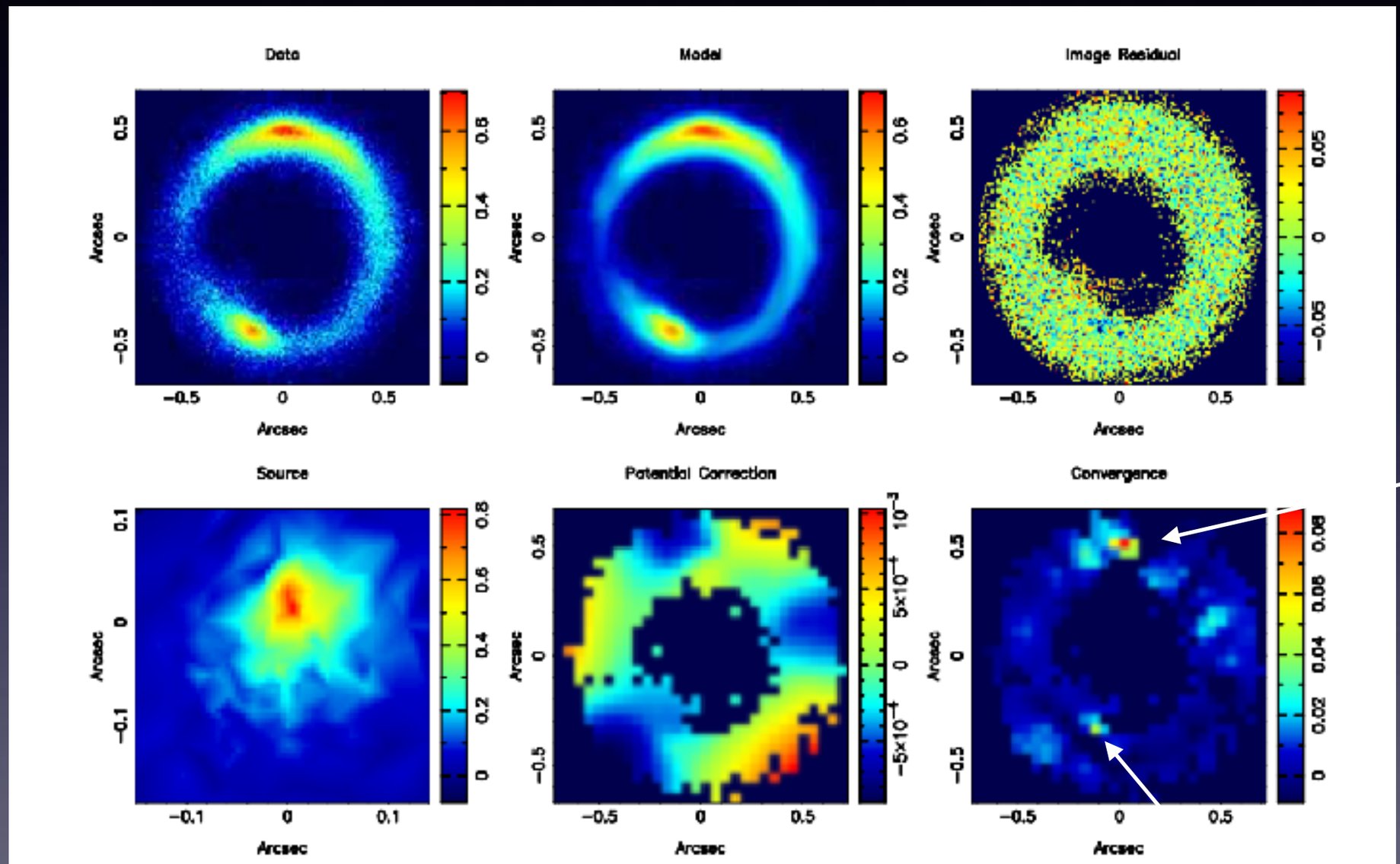


Complex



PyAutoLens By Nightingale James

Subhalo on Einstein ring

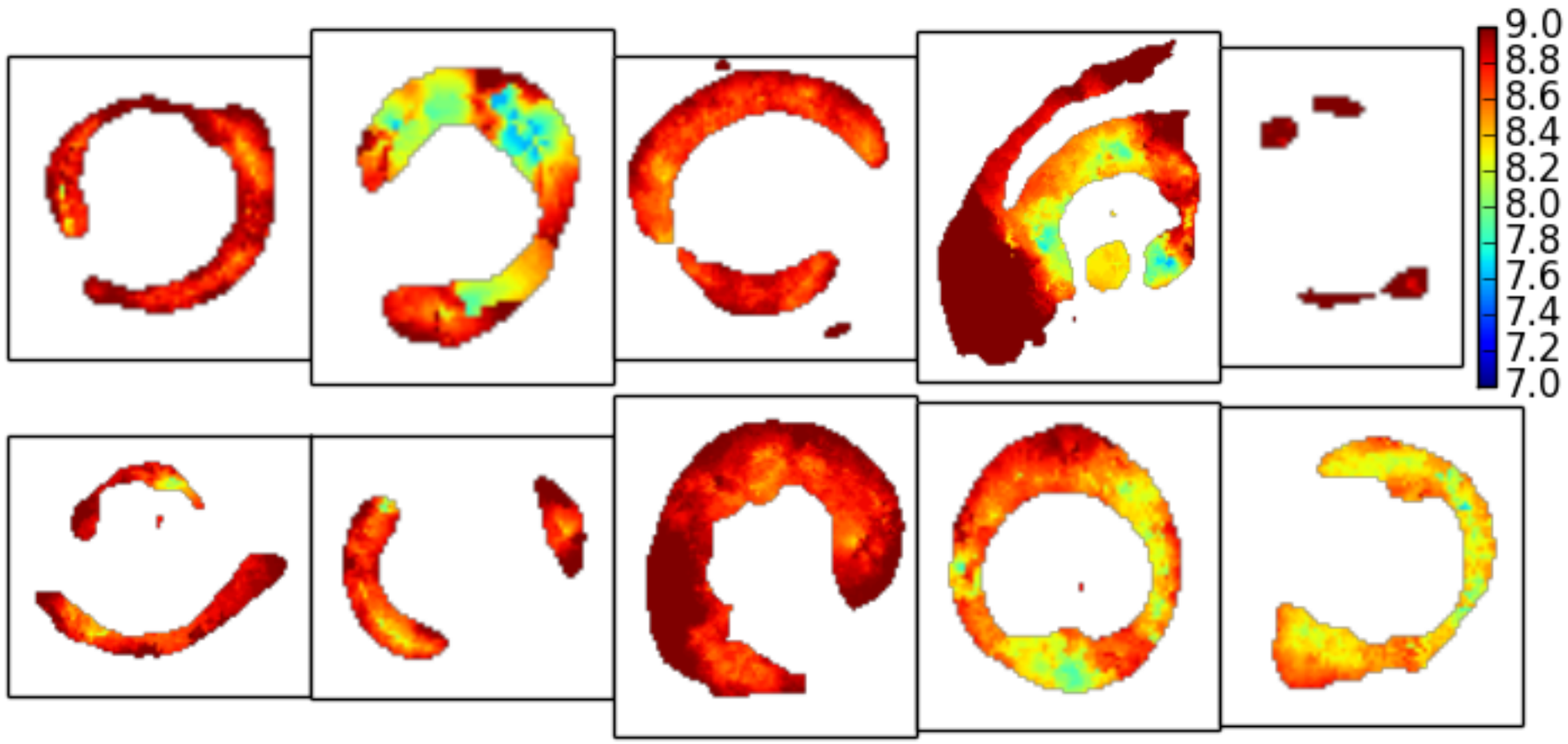


10^8Msun

Vegetti et al. 2012

Not significant enough

Sensitivity function

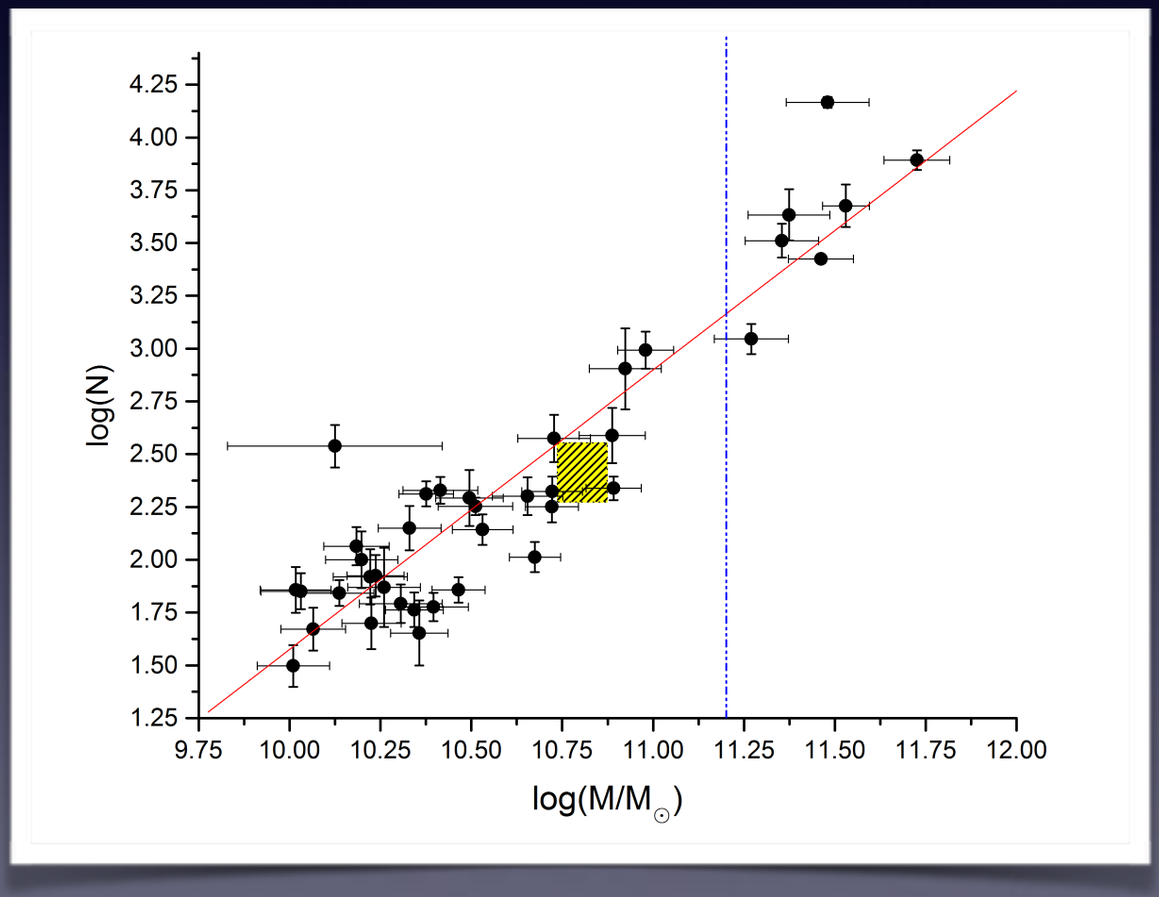


Lenses in Vegetti et al. 2014

Globular clusters

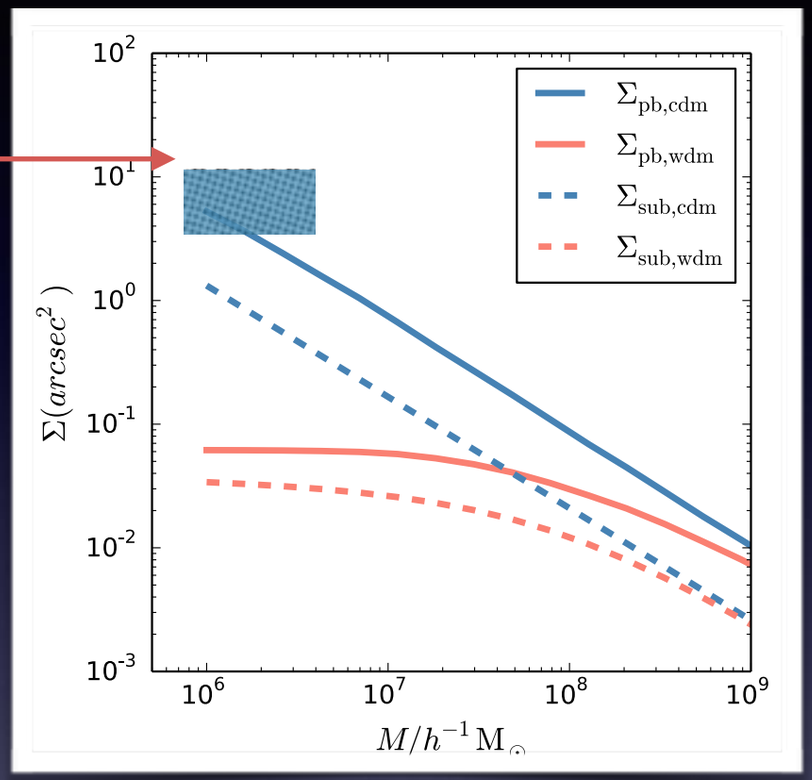
- There are ~1000 of globular clusters in massive early galaxies.
- The GCs can dominate the subhaloes around the Einstein radius.

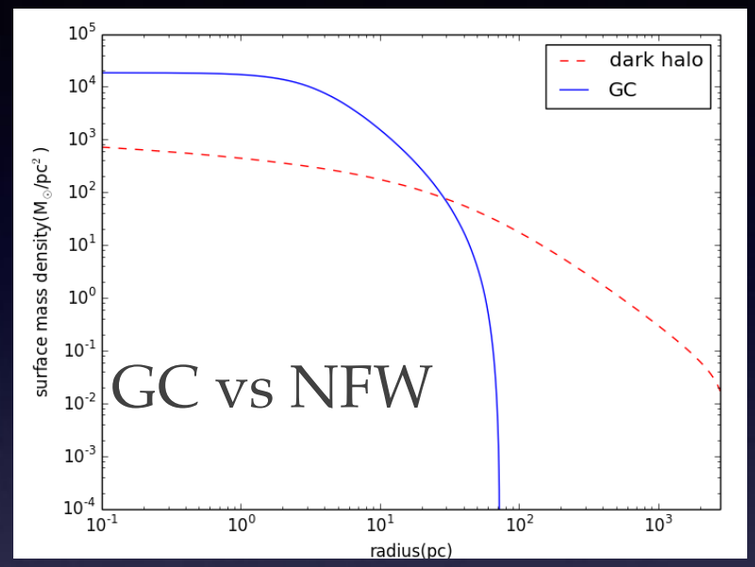
QHH, RL et al. 2018



Effects of Globular Clusters

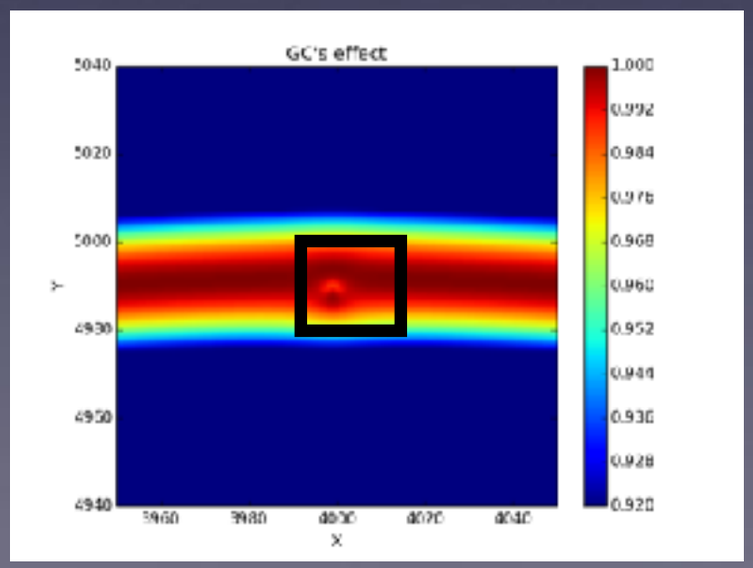
Number density of GCs



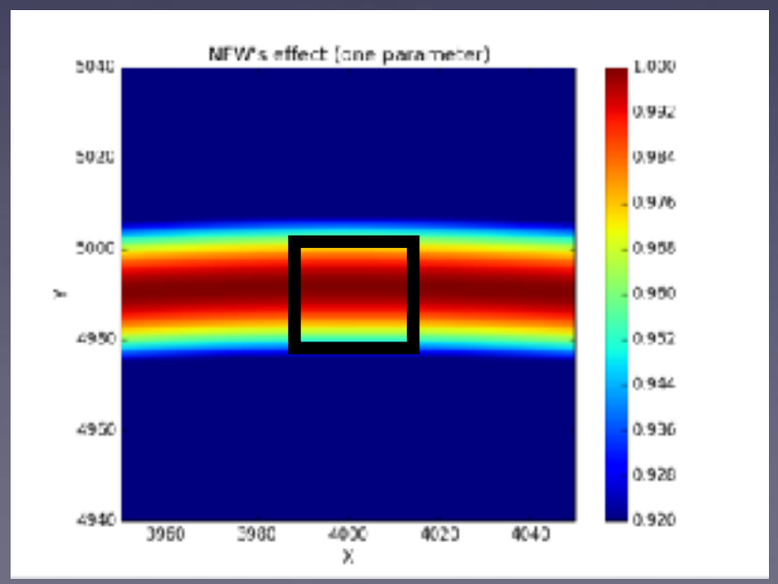


QHH, RL et al 2018

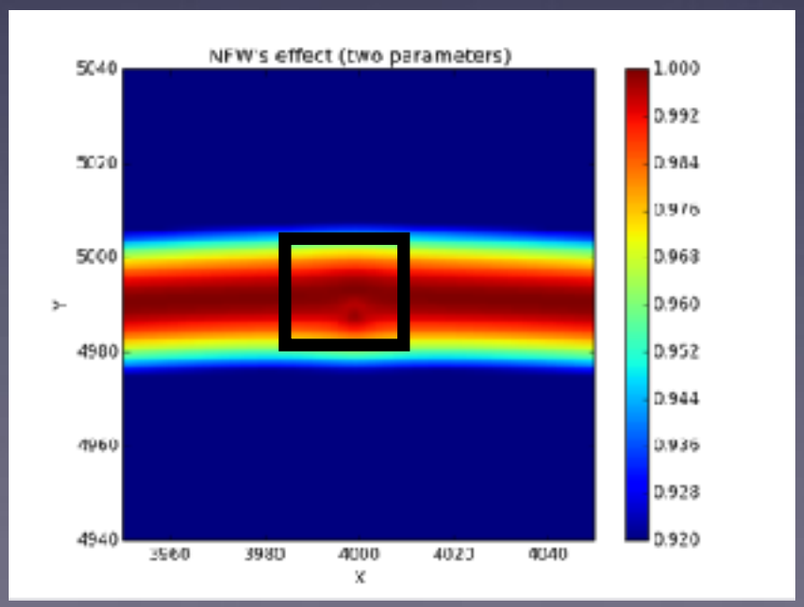
GC



NFW



NFW fit GC



Strong lensing working group

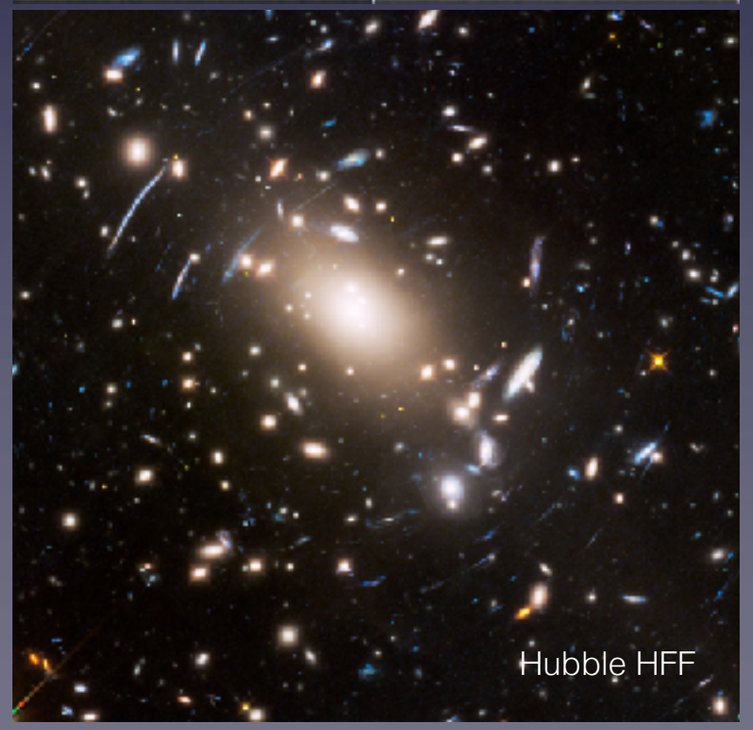
- Member: Ran Li (NAOC), Nan Li (Nottingham) , Dezi Liu (YNU), Guoliang Li (PMO), Xiaoyue Cao (NAOC), Ye Cao (NAOC), Yun Chen (NAOC), Yiping Shu (NAOC), Xin Wang (UCLA), Xiaolei Meng (Tsinghua), Dandan Xu (Tsinghua)….
- Email list CSST_SLWG@googlegroups.com
- Collaboration tool: https://tiangongslwg.slack.com/
- http://linan7788626.github.io/TiangongSurveyStrongLensingWorkingGroup/
- Currently, aim to construct a set of strong lensing simulations and produce some forecast papers.

Expectation for CSS-OS

- ~150000 galaxy scale strong lens systems (currently ~400), Including ~1000 double lens system

- Hundreds of massive clusters with many multiple images

- Accurate photo-z for both lens and source.



Strong lensing science cases of CSS-OS

- Abundance of dark matter substructure and identity of dark matter
- Testing GR
- Inner density structure of galaxy clusters
- Galaxy mass and structure
- Dark matter fraction within galaxies and clusters
- Shape of dark matter haloes
- Evolution of Early type galaxies
- ……

Strong lensing science cases of CSS-OS

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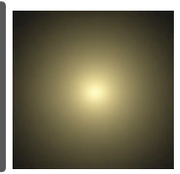
MOCK data for CSS-OS



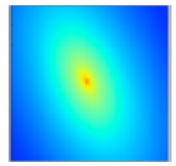
Model/Real Galaxies

Source Light-Cone

Ray Tracing

Deflection Fields

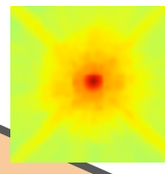
Poisson Solver



Lens Models Analytic/Simulated

Light model

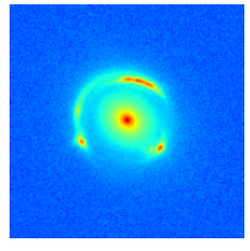
Images of Lenses



Mock Observing (noise, psf…)

Lensed Images

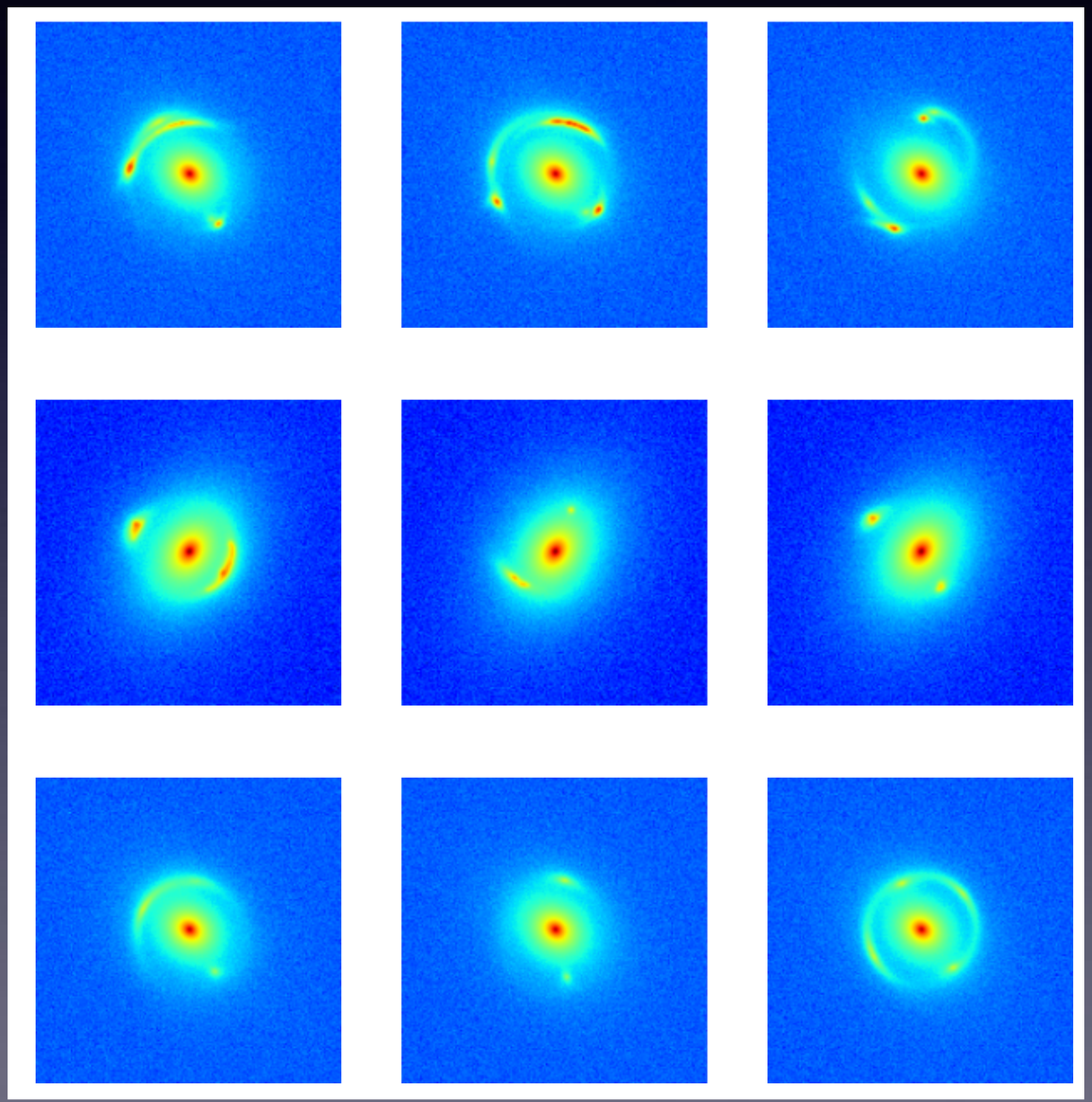
Final Mock Images

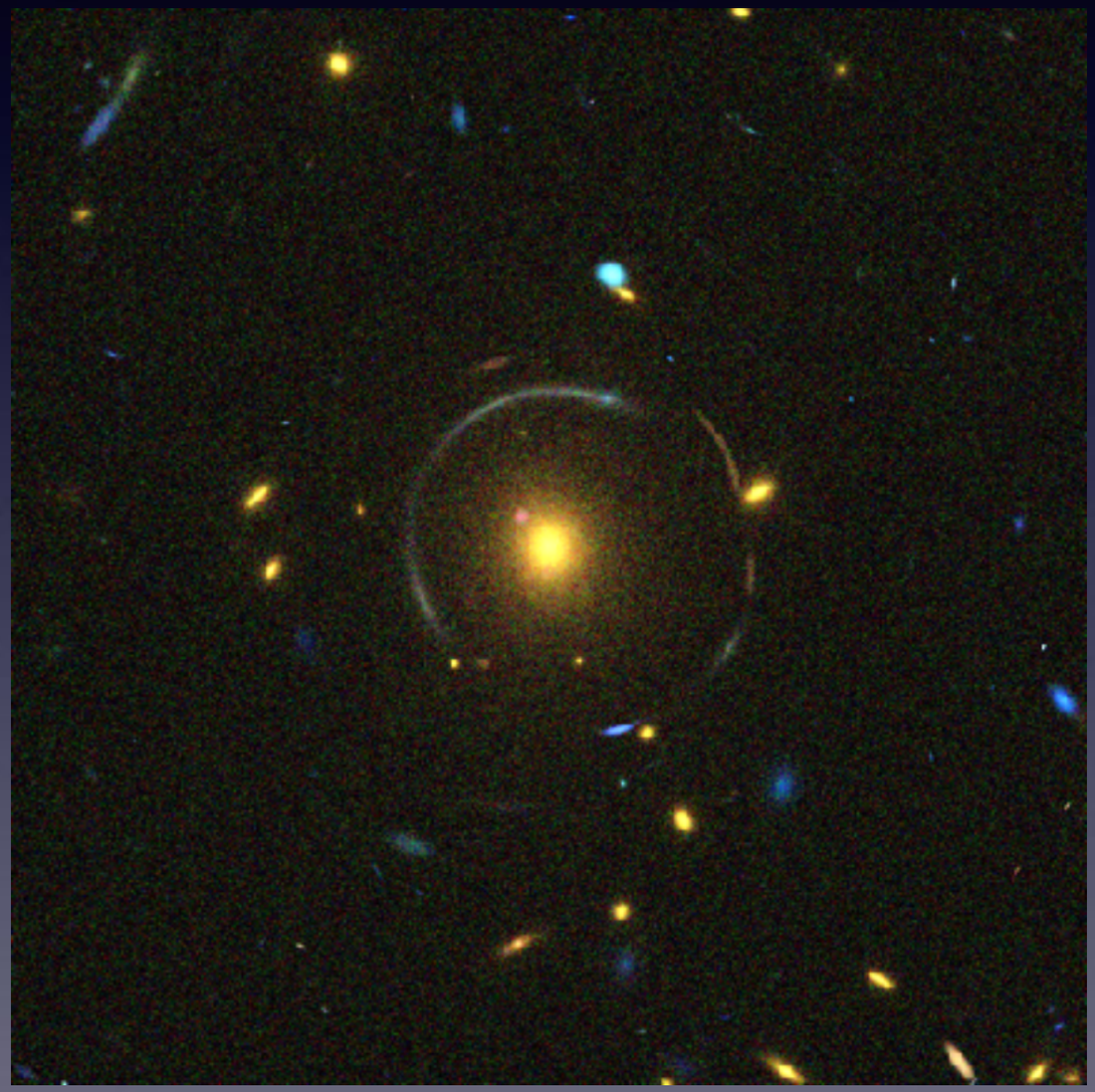


Inputs

Outputs

Some mock data





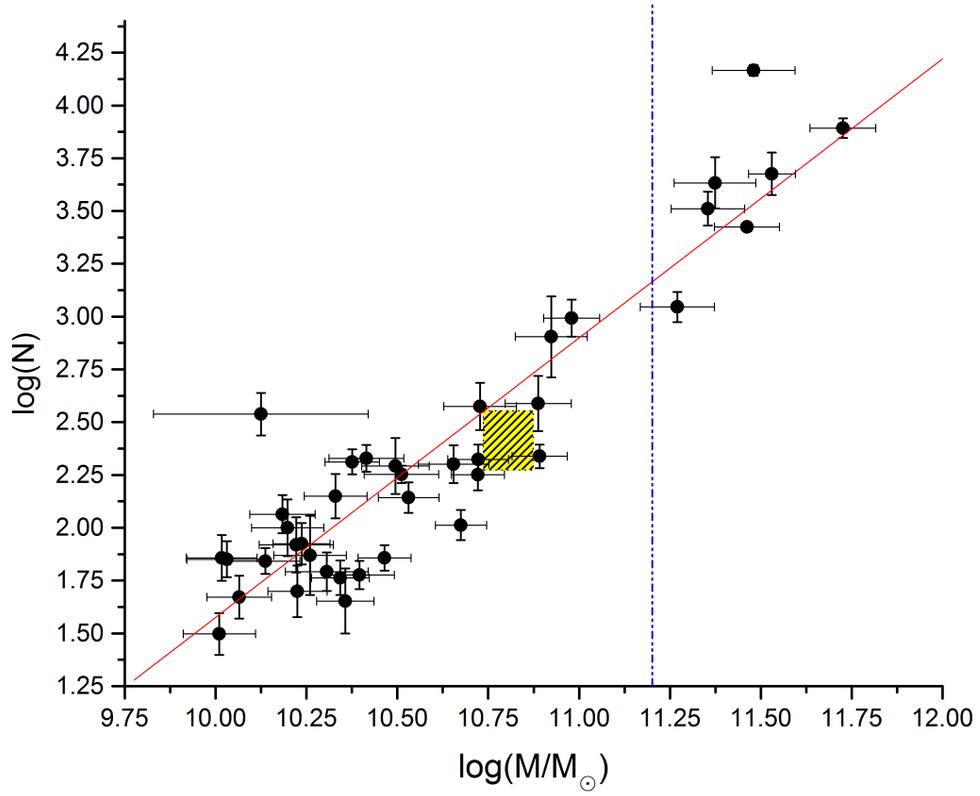
Summary

- Galaxy-galaxy lensing can be a powerful tool to measure subhalo mass for satellite galaxies in groups and clusters.
- Subhaloes detected from Einstein ring systems provide a promising way to distinguish WDM and CDM model.
- 20 lenses with M_low=1e7 Msun, or 100 lenses with M_low=1e8 Msun can put strong constraints on WDM
- LOS haloes dominate the total number of perturbers.
- Understanding the sensitivity function is very important for constraining the SHMF.

Globular clusters

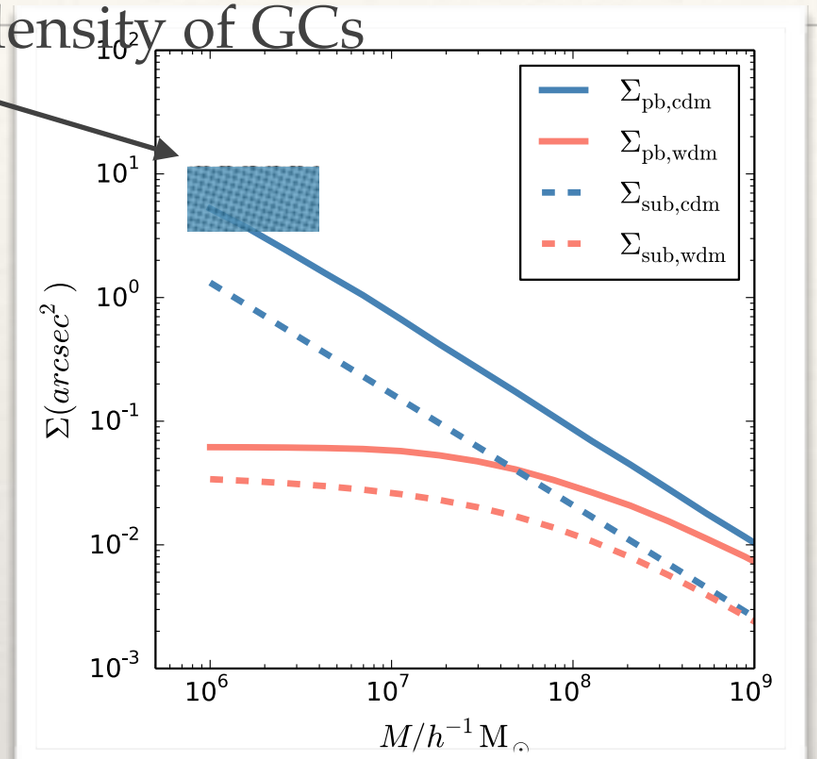
- There are ~1000 of globular clusters in massive early galaxies.
- The GCs can dominate the subhaloes around the Einstein radius.

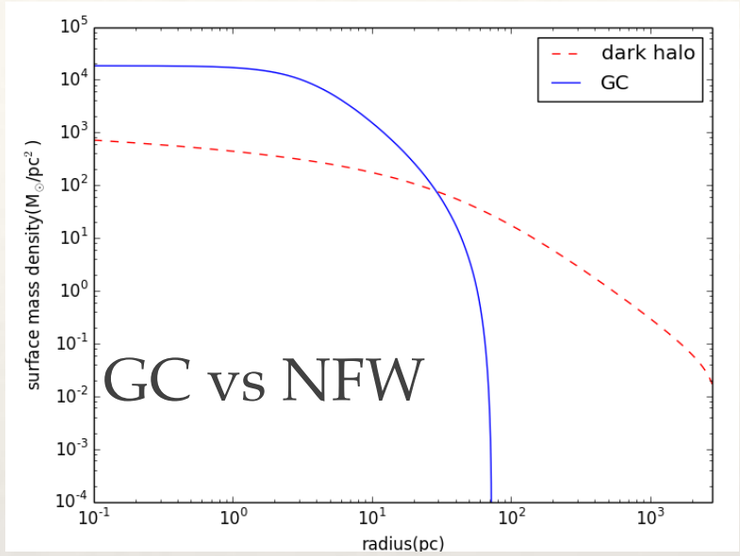
HQ, RL et al. in prep



Effects of Globular Clusters

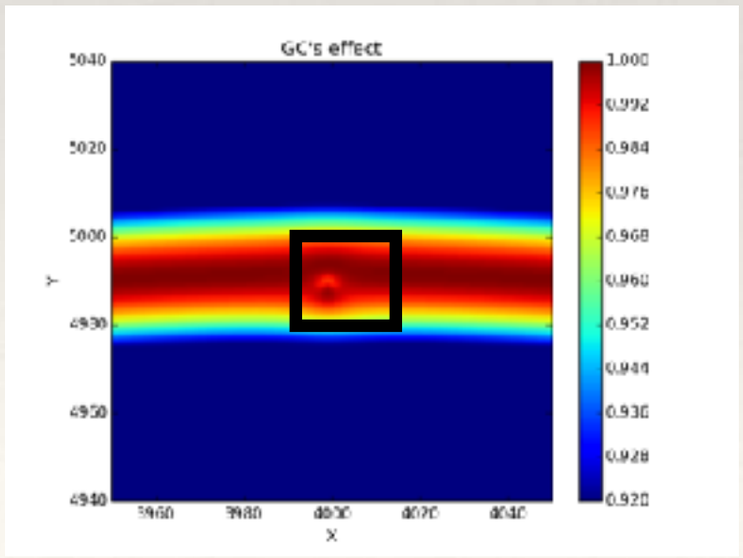
Number density of GCs



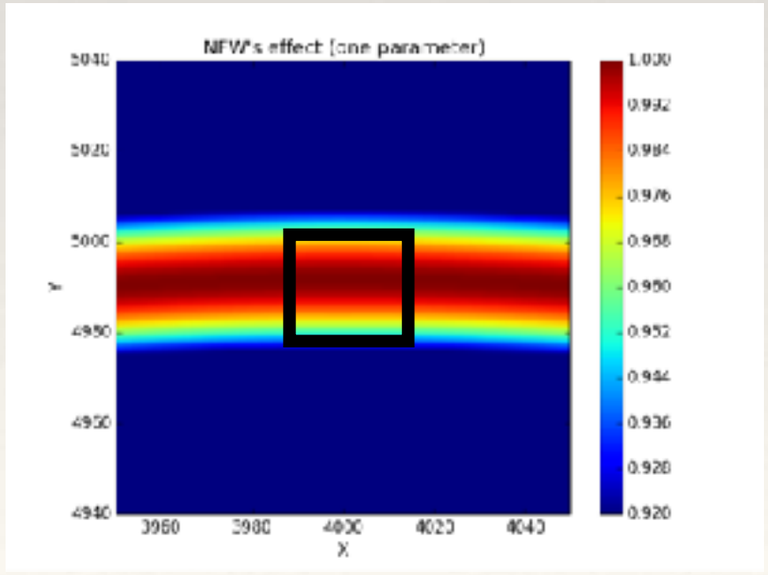


QHH, RL et al 2018

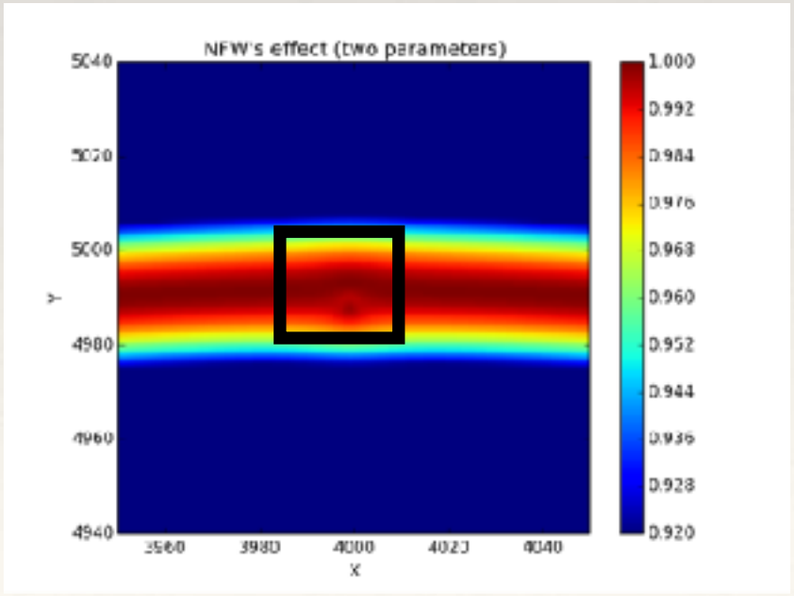
GC



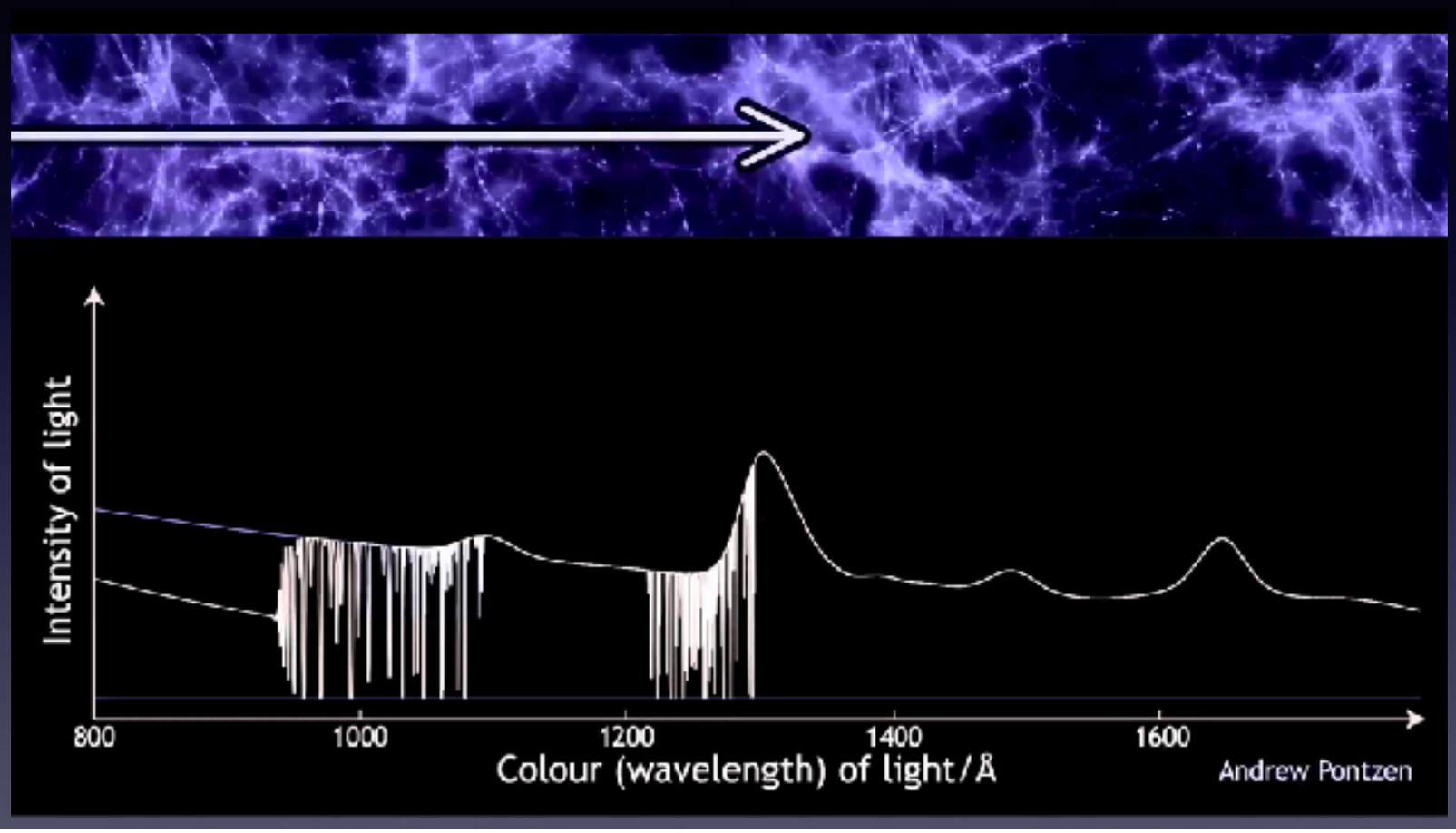
NFW

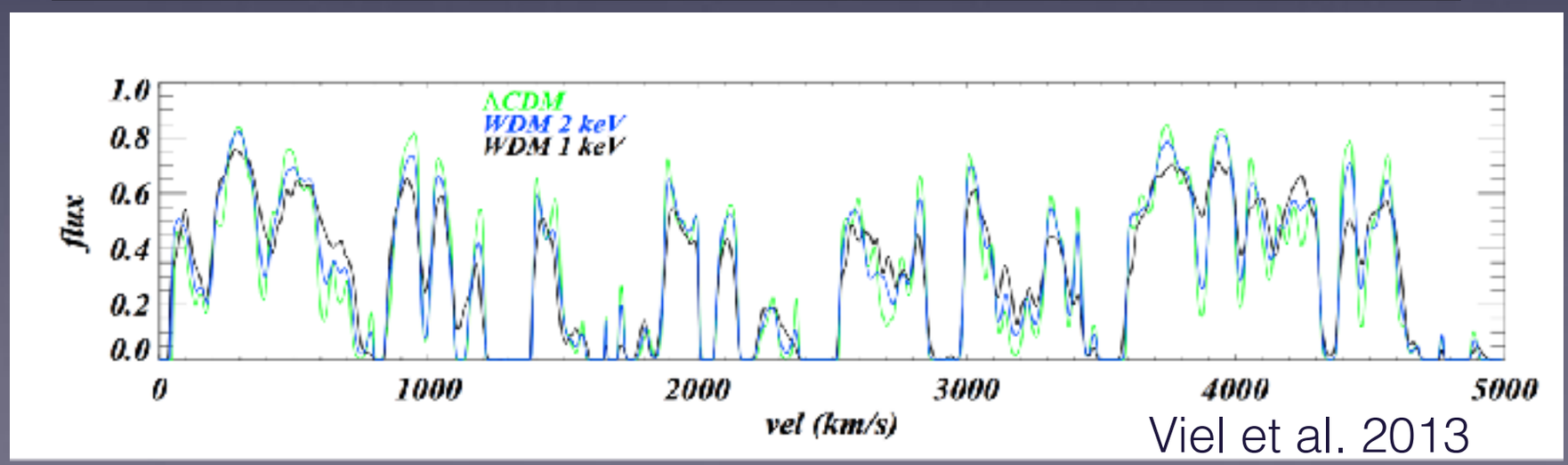


NFW fit GC



Lyman-alpha forest





Viel et al. 2013