# CONSTRAINING DARK MATTER MODELS WITH STRONG GRAVITATIONAL LENSING


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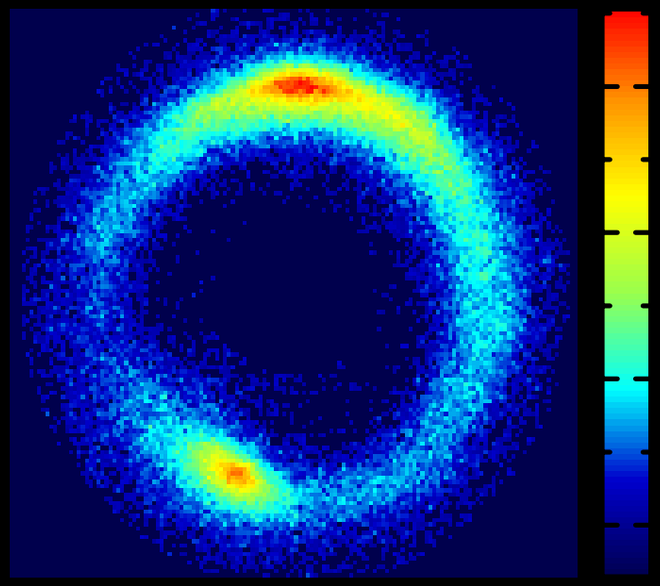
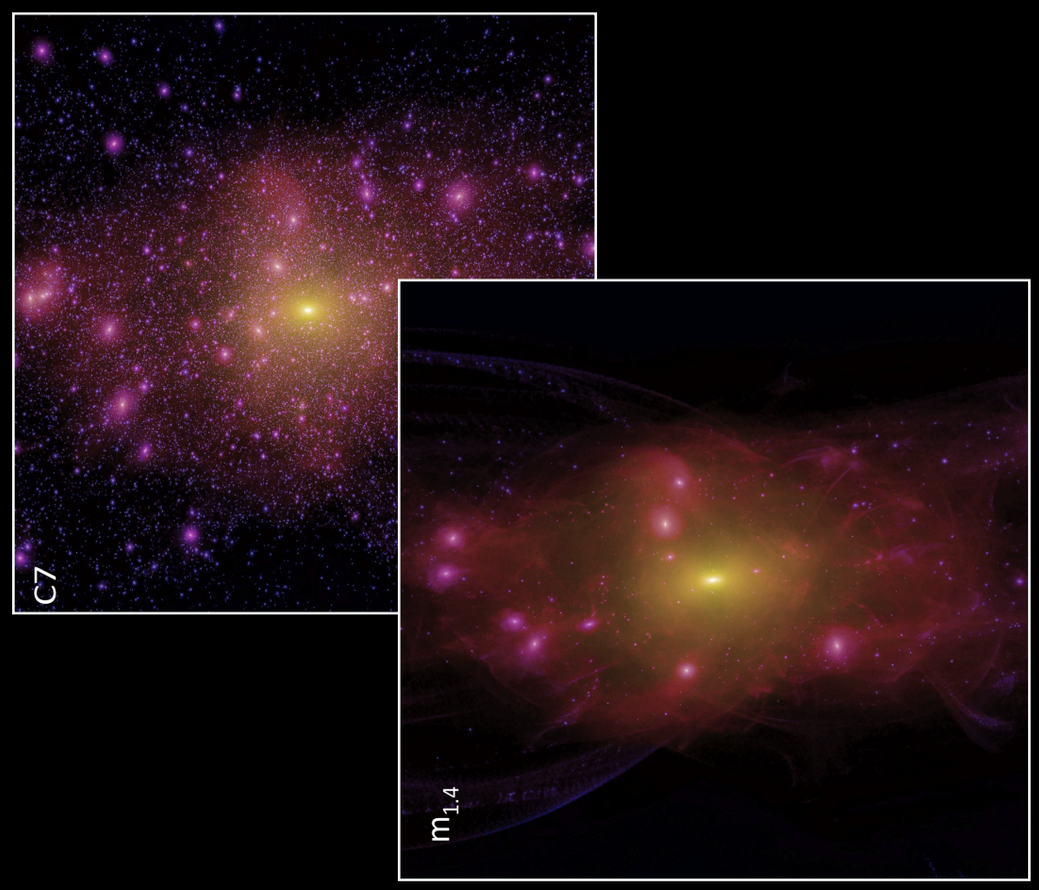




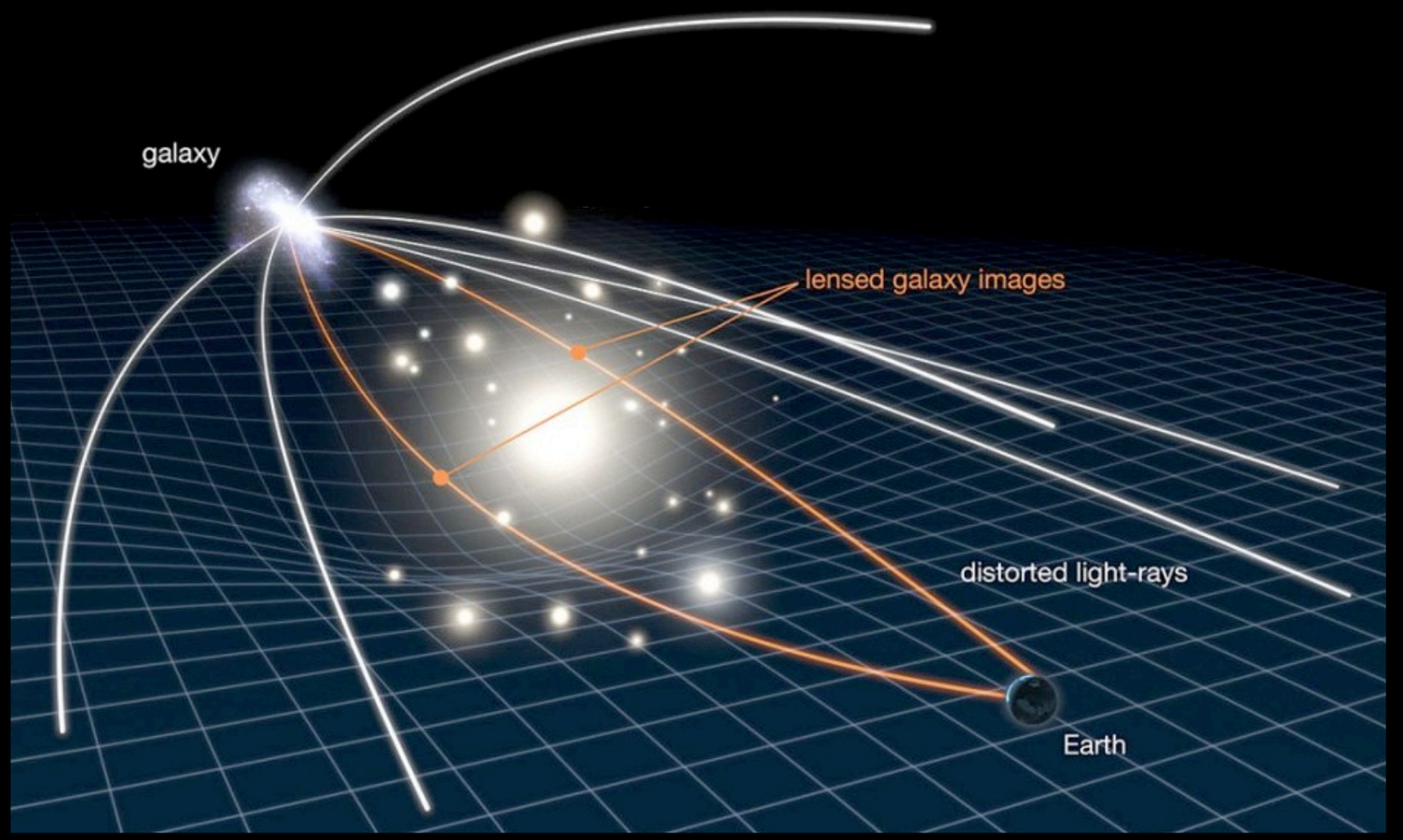

Cambridge, 17.09.2019

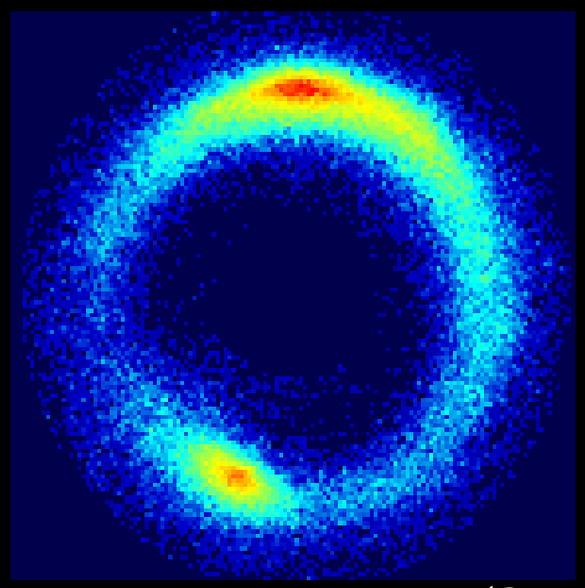
MAX-PLANCK-GESELLSCHAFT

# STRONG LENSING

- the shape of the image is heavily affected by the lensing
- small angular separation between the source and the lens position, i.e. almost aligned

1. extended sources may be heavily distorted in **gravitational arcs**
2. **multiple images** of background sources, such as bright QSO

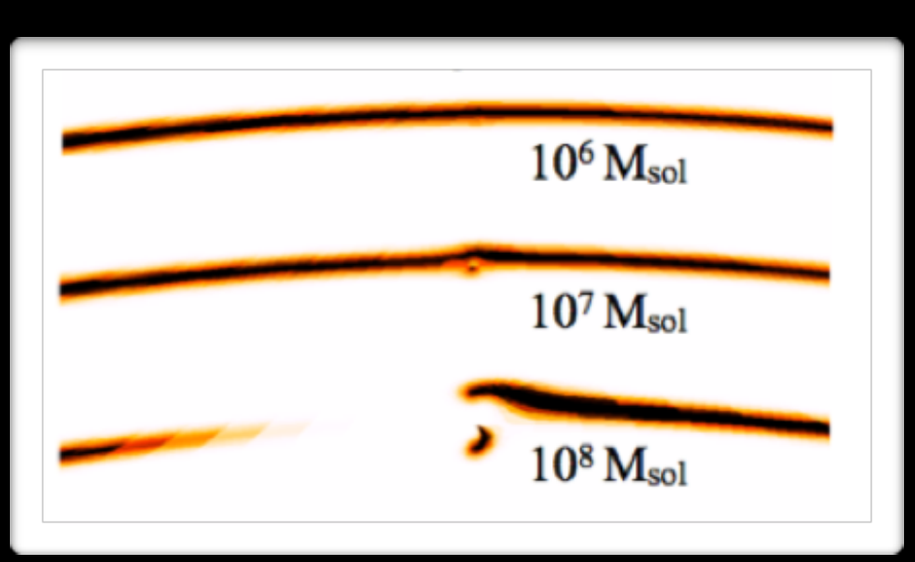


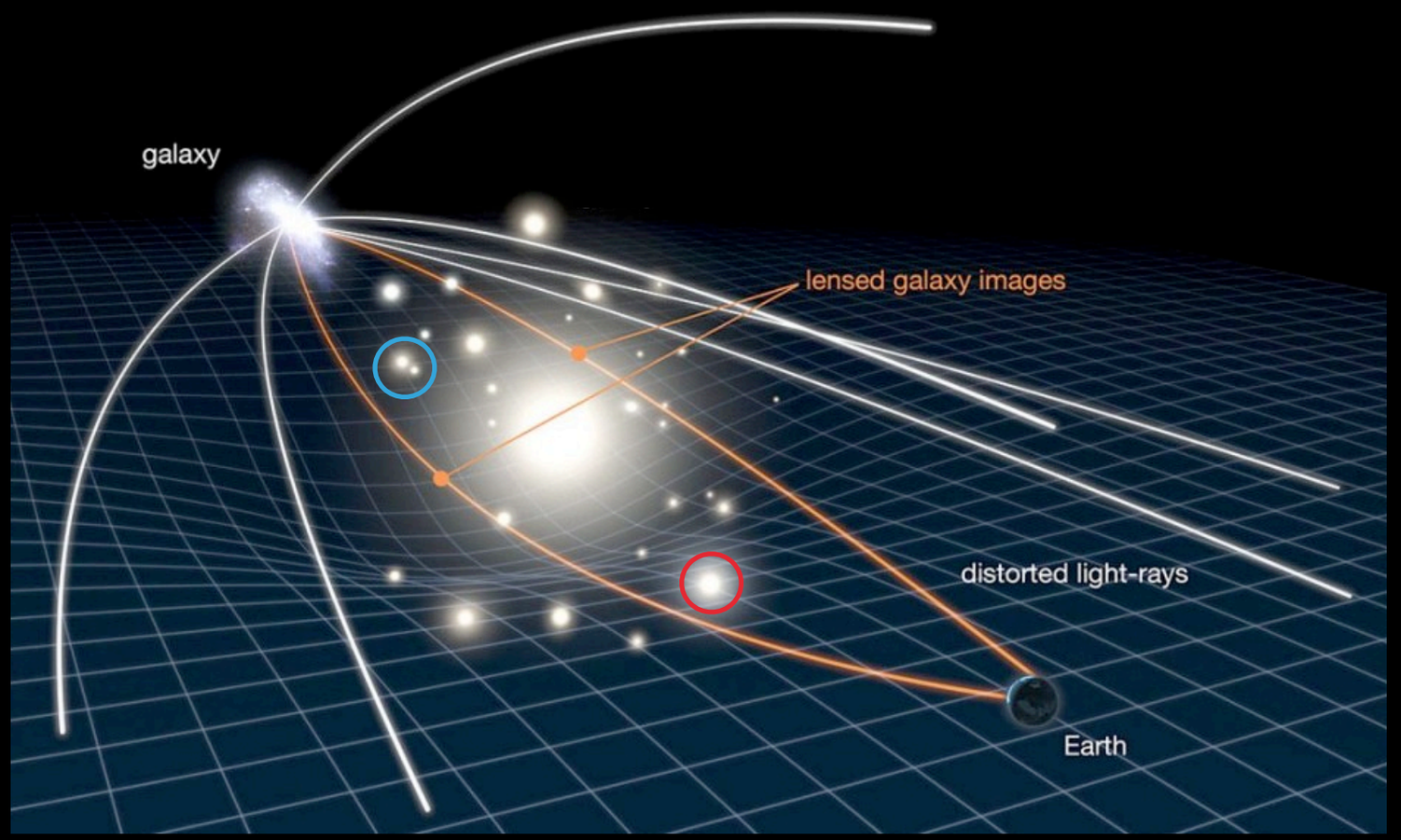
*(See constrains from flux-ratio-anomalies from Hsueh et al. 2019 or Gilman et al. 2019)*

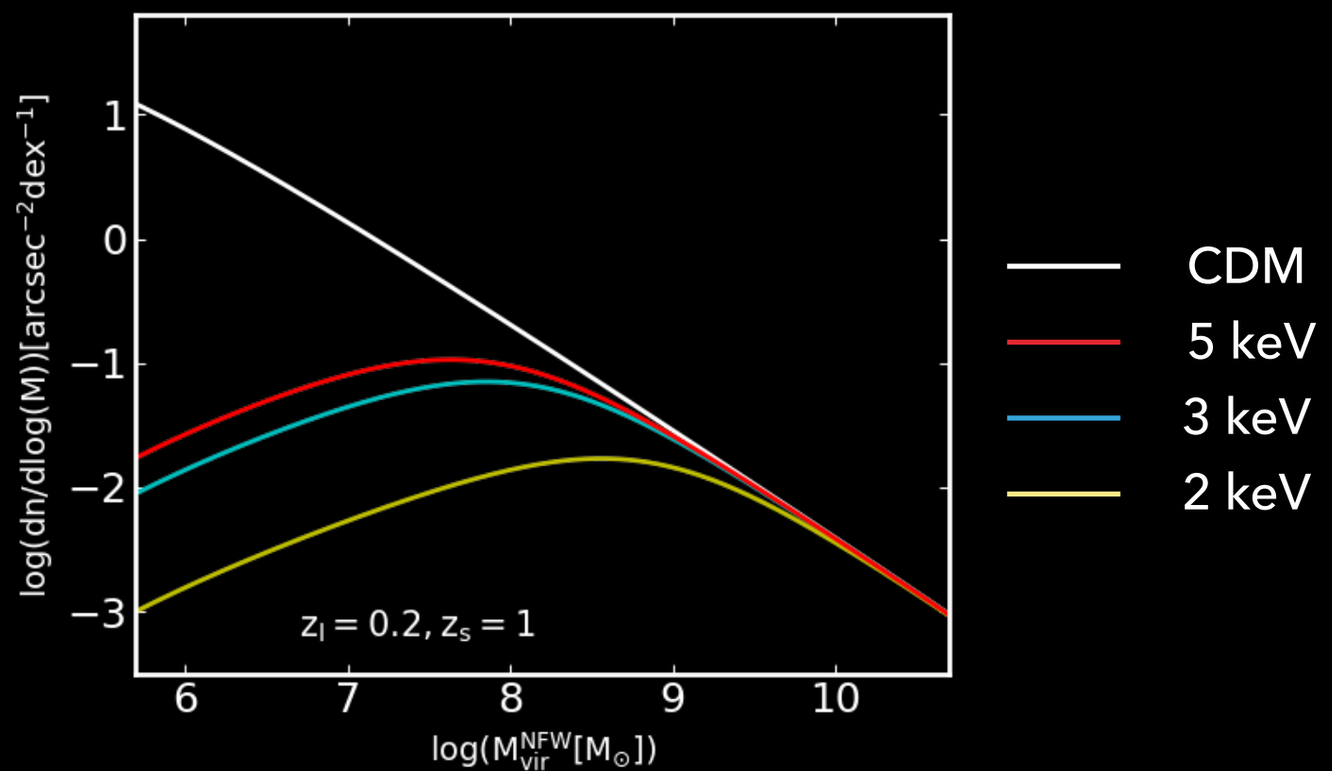
# STRONG LENSING & DM

properties of the small scale structures in the lens or **along the line-of-sight**



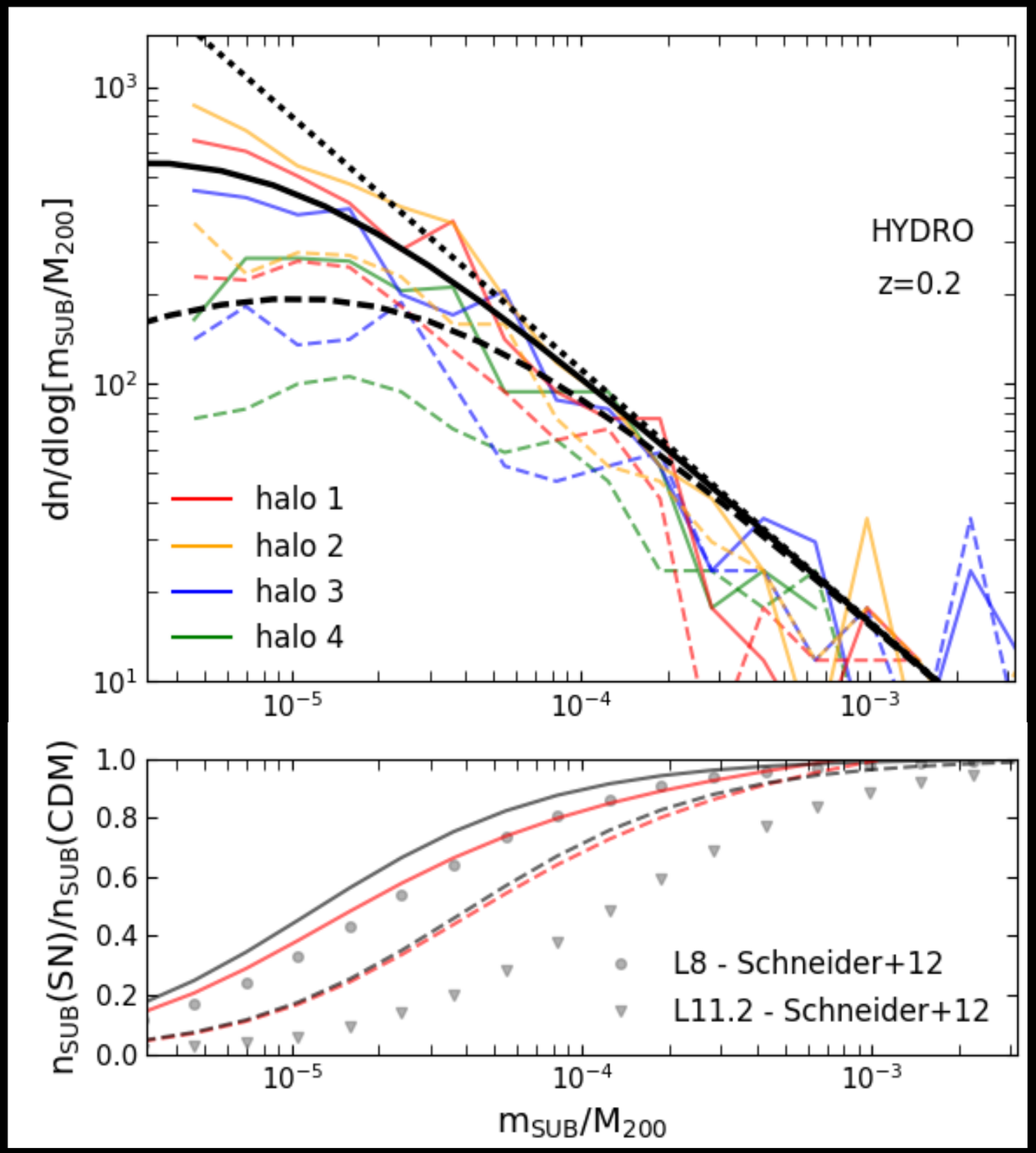

test CDM and discriminate between CDM and **WDM** (and SIDM)



*(Despali, Lovell et al. 2019)*

# STERILE NEUTRINO WDM

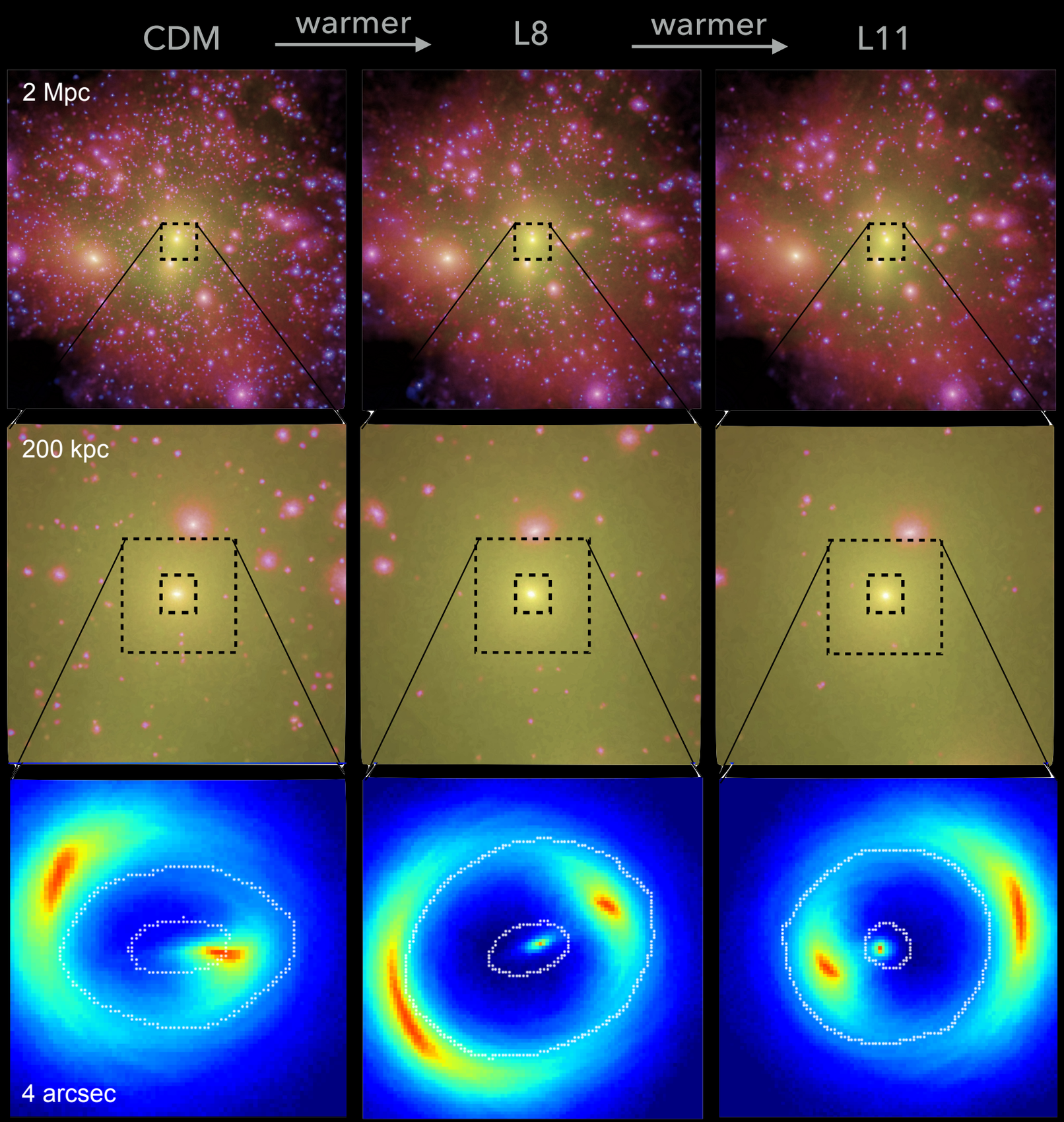



$$\frac{n_{WDM}}{n_{CDM}} = (1 + \gamma M_{hm} M^{-1})^{\beta}$$

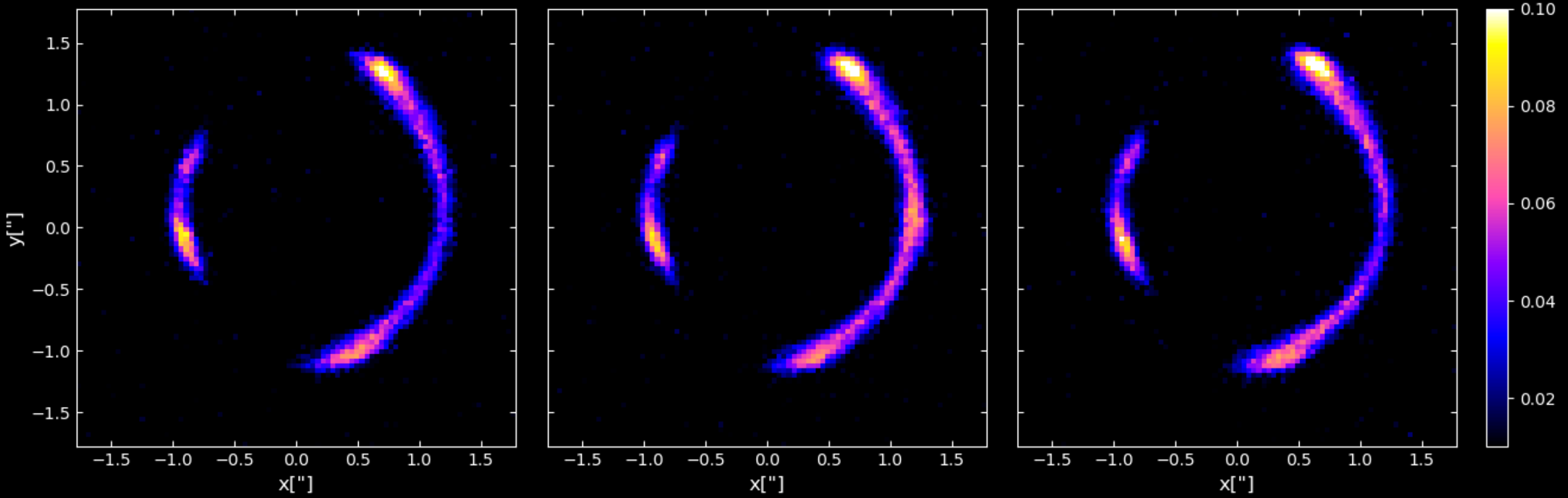
| Mass function parameters | | | | |
|---|---|---|---|---|
| model | source | $\gamma$ | $\beta$ | $M_{hm}[M_\odot]$ |
| L8-DMO | this work | 0.53 | -1.3 | $1.28 \times 10^8$ |
| L11-DMO | this work | 0.27 | -1.3 | $8.25 \times 10^8$ |
| L8-HYDRO | this work | 0.35 | -1.3 | $1.28 \times 10^8$ |
| L11-HYDRO | this work | 0.18 | -1.3 | $8.25 \times 10^8$ |
| WDM(th. rel.) | Schn+12 | 1 | -1.16 | - |
| WDM(th. rel.) | Lov+14 | 1 | -1.3 | - |
| WDM(th. rel.) | Lov+14(sub) | 2.7 | -0.99 | - |

*(Despali, Lovell et al. 2019)*

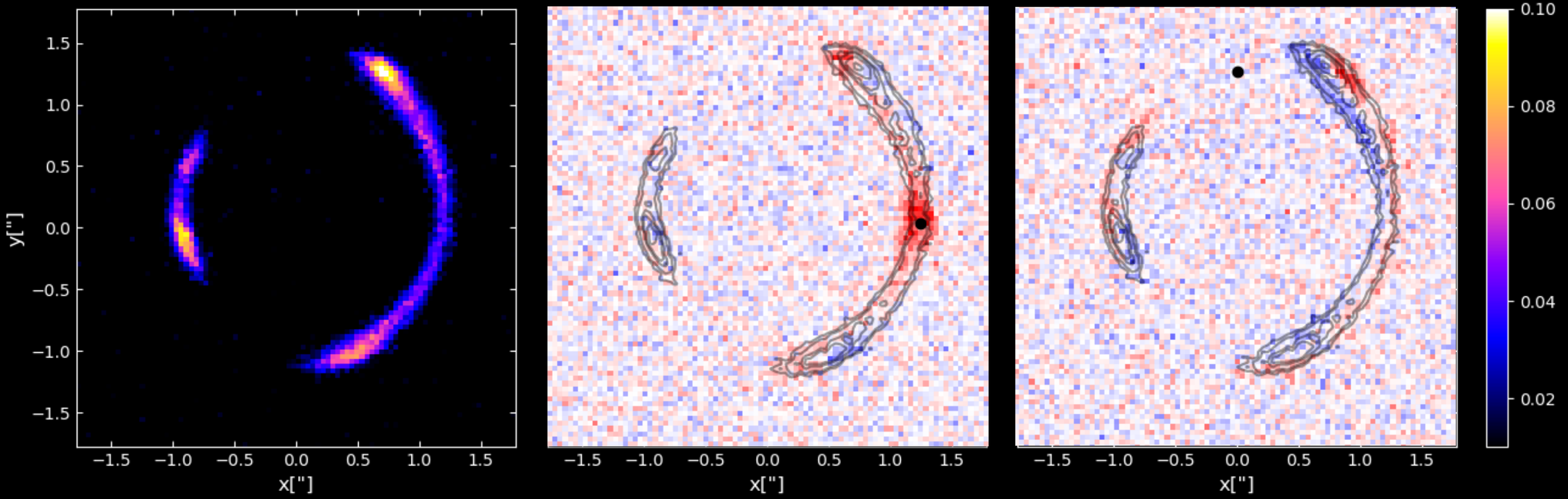
# STERILE NEUTRINO - WDM



# OBSERVATIONAL TECHNIQUE



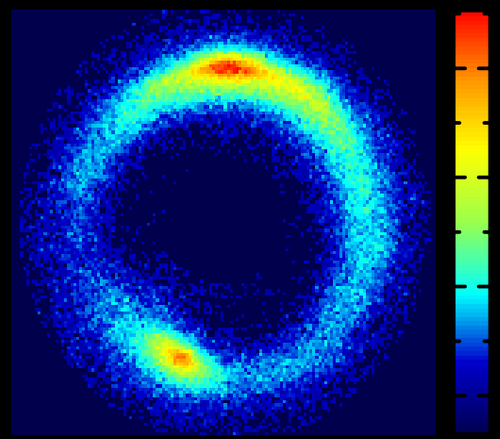
# OBSERVATIONAL TECHNIQUE



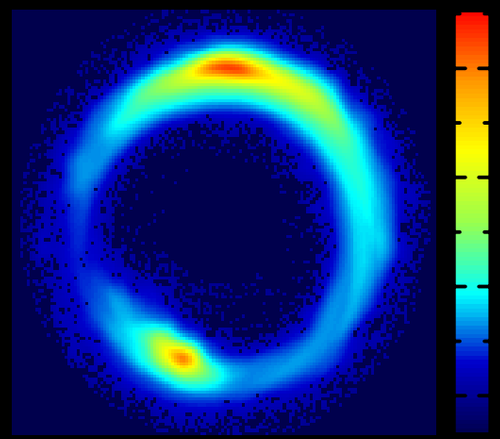
# GRAVITATIONAL IMAGING

*(Vegetti et al. 2012)*

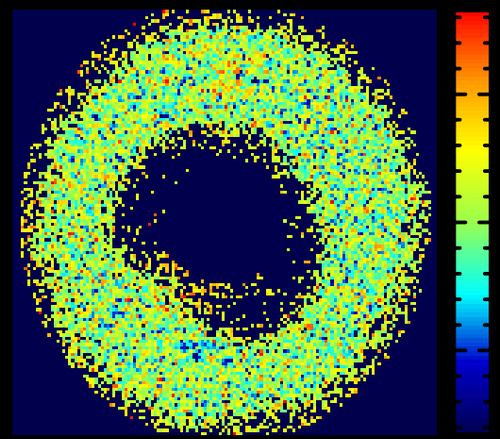
IMAGE



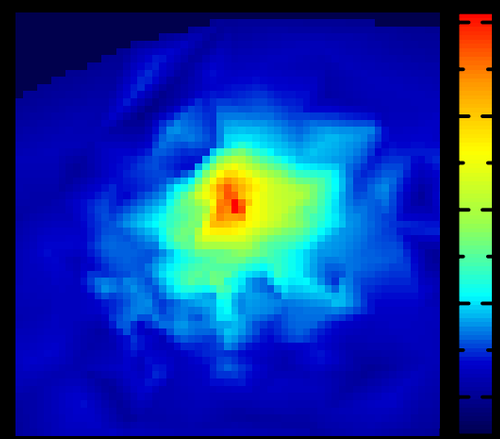
MODEL



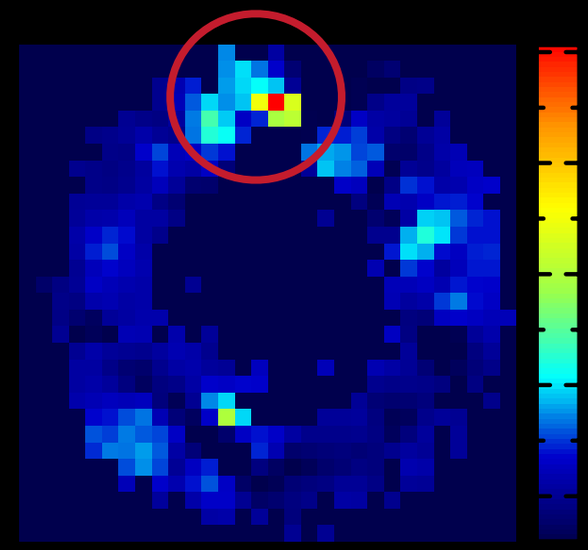
RESIDUALS



RECONSTRUCTED SOURCE



DENSITY CORRECTION



- Small mass clumps are detected as corrections to an overall smooth potential, based on perturbations in the surface brightness distribution
- if present, more than one can be detected and we can quantify its mass
- in order to claim a detection, we require the smooth lens+clump model to fit the data better than the smooth lens alone at the $10\sigma$ level

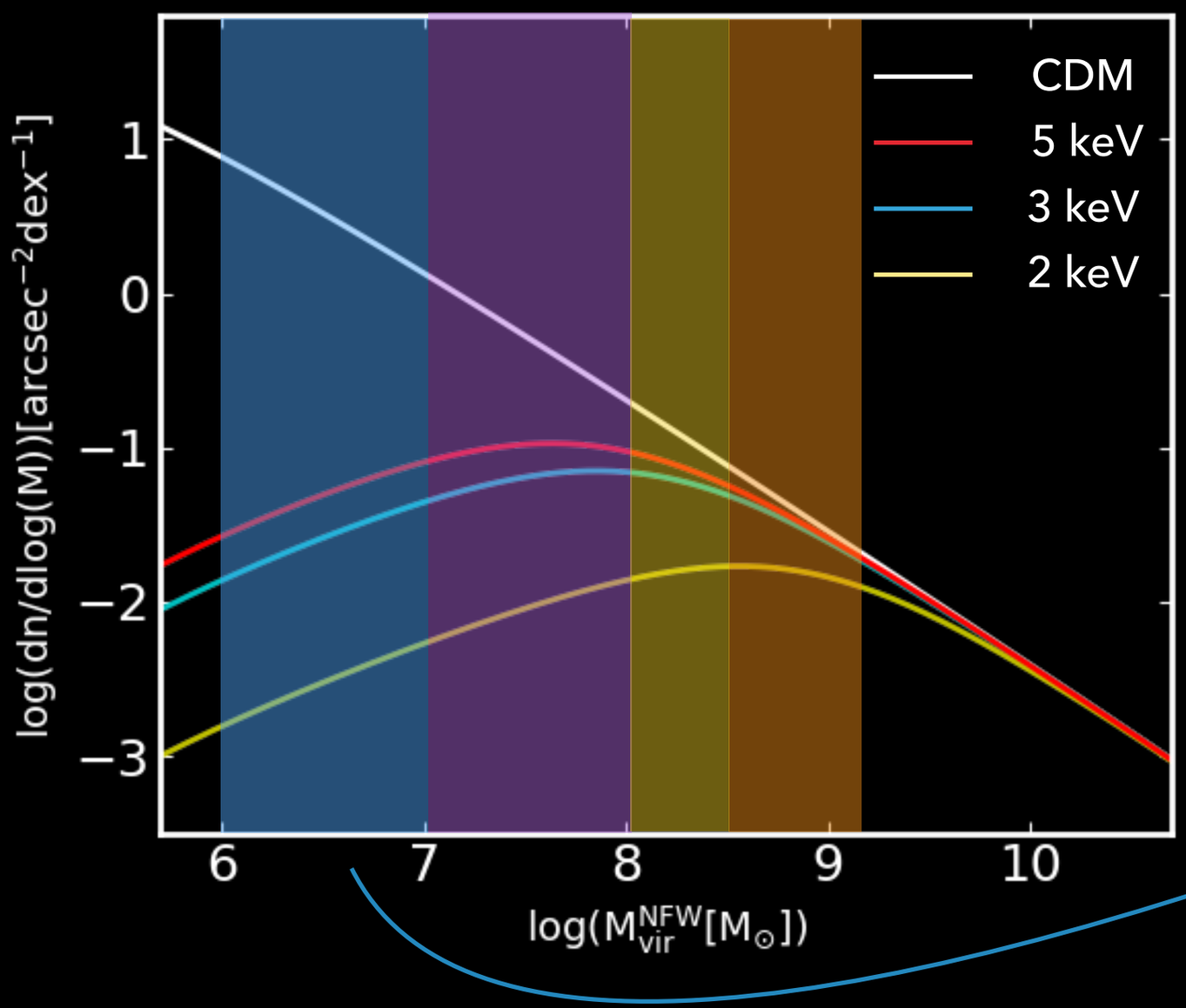
*Detections in Vegetti et al. 2010, 2012, Hezaveh et al. 2016*

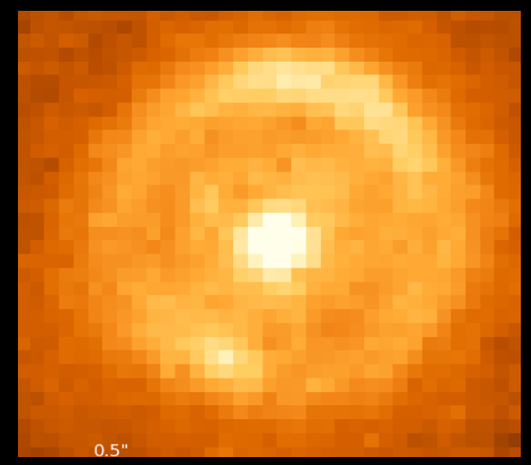
# EXPECTED NUMBER OF PERTURBERS

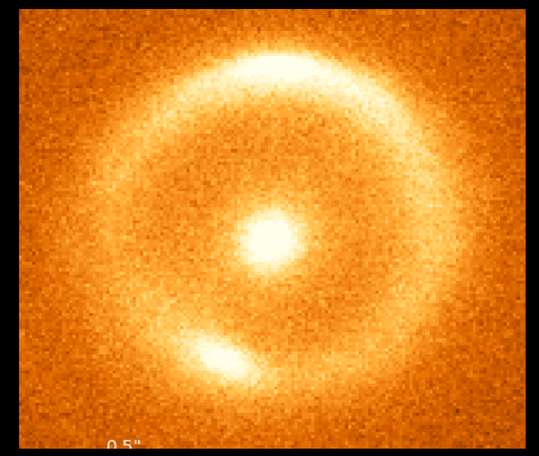
*(Despali et al. 2018)*

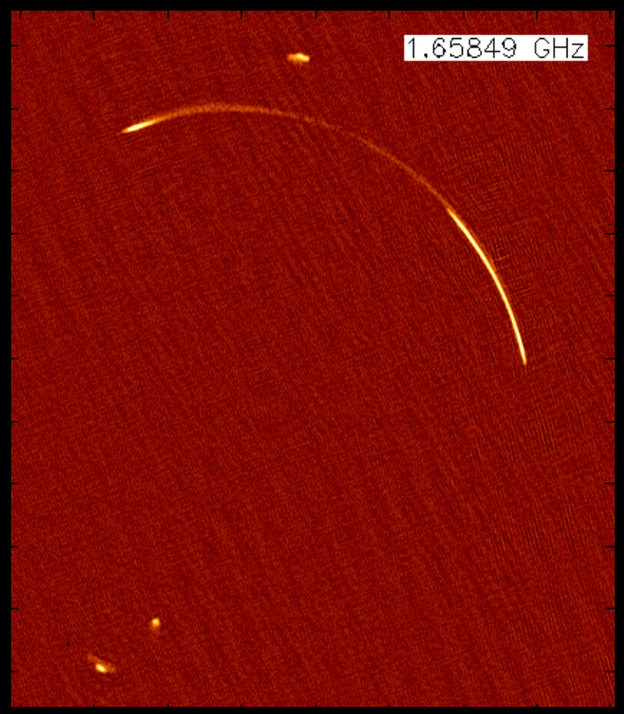
SIMULATIONS

$$\frac{n_{WDM}}{n_{CDM}} = (1 + \gamma M_{hm} M^{-1})^{\beta}$$



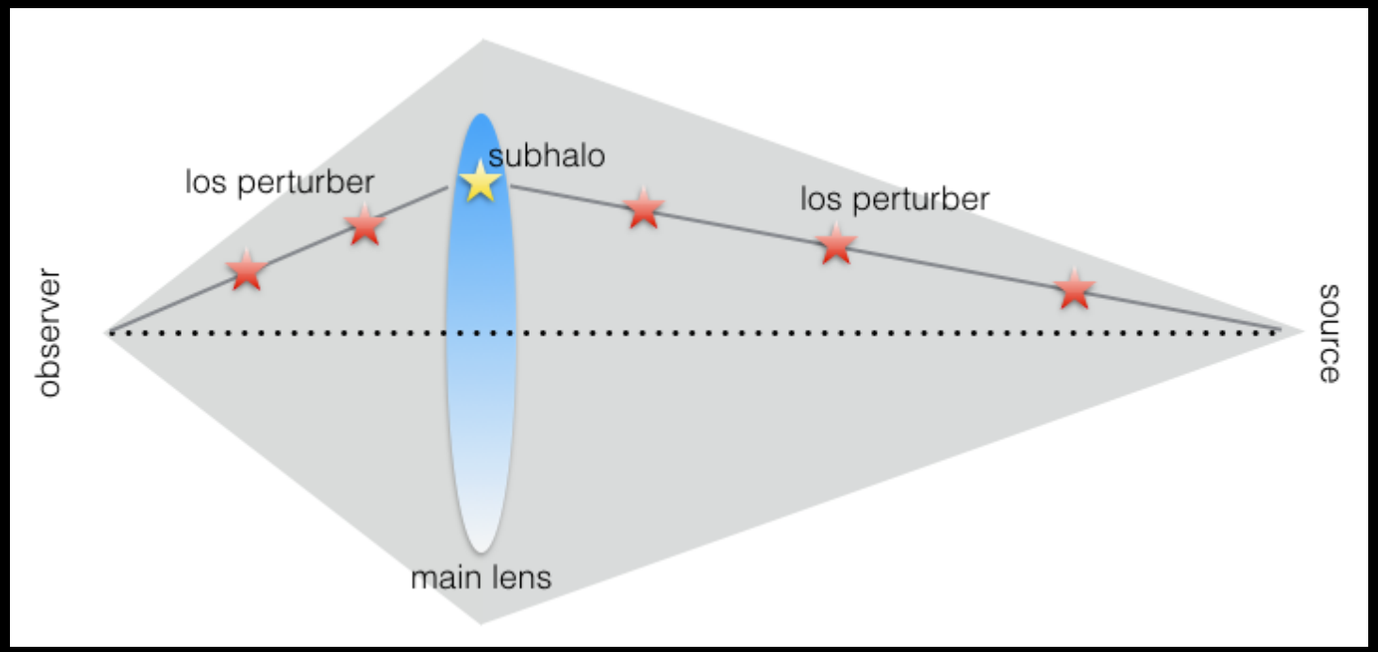



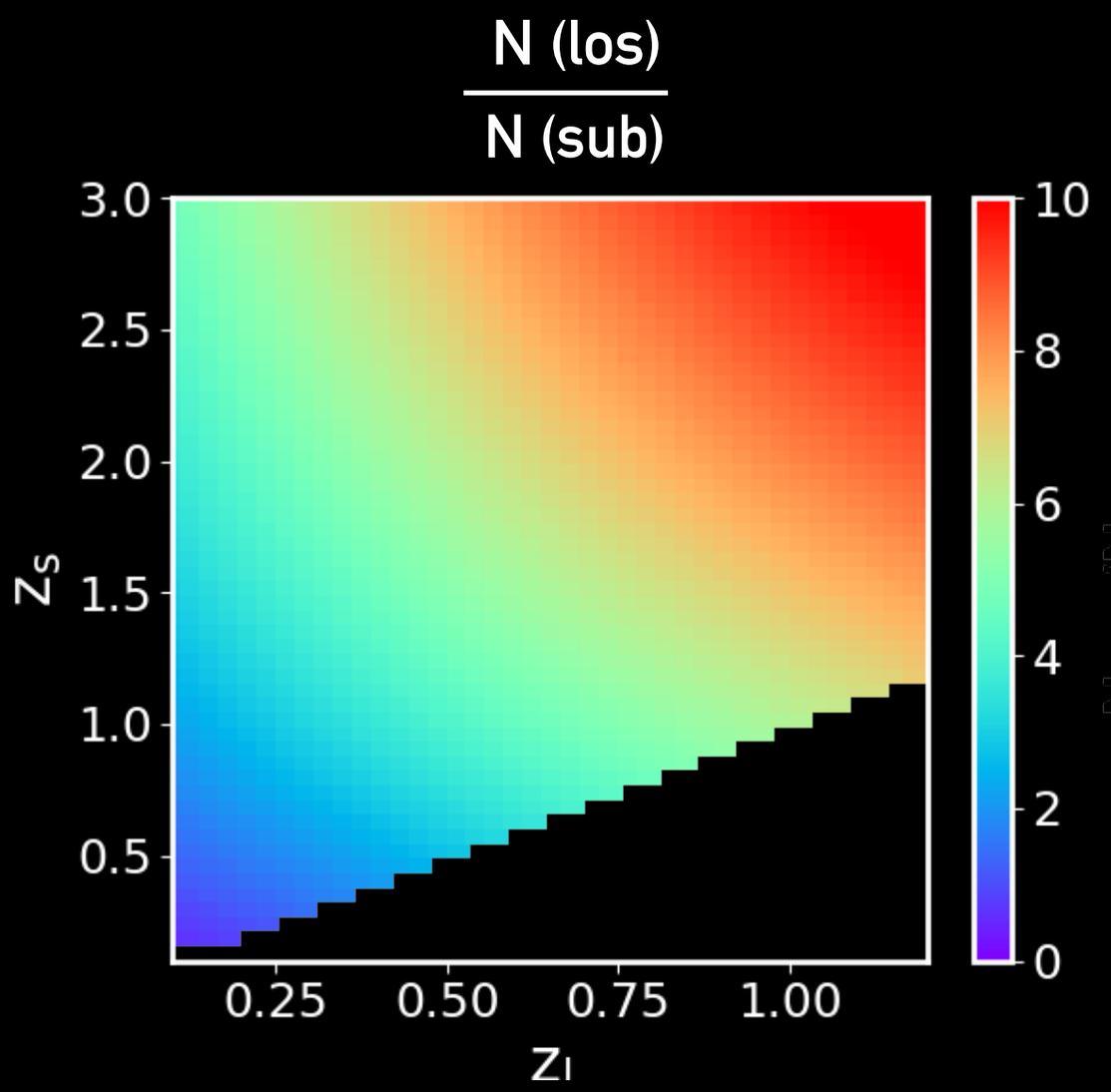



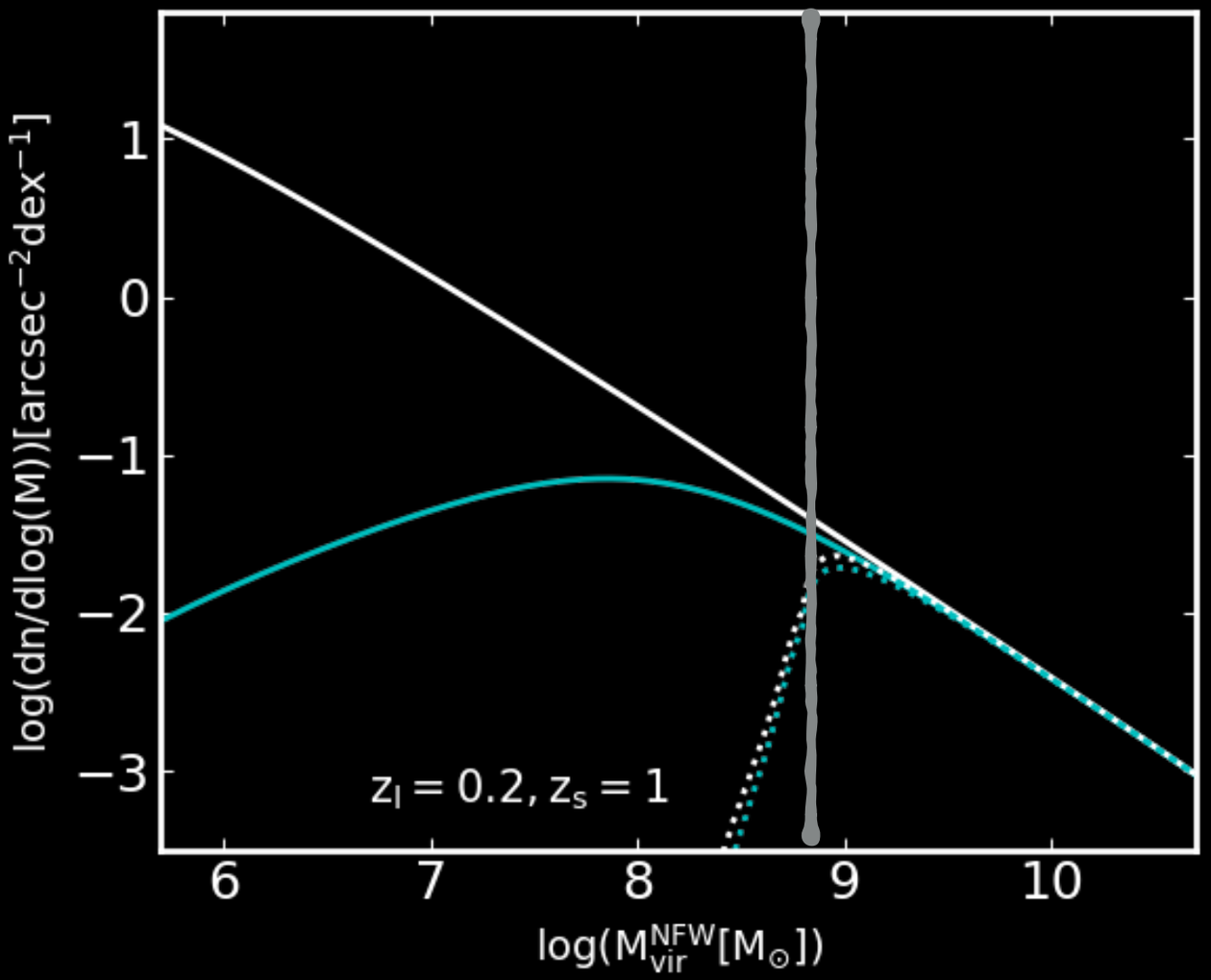
# EXPECTED NUMBER OF PERTURBERS *(Despali et al. 2018, Li et al. 2017)* SIMULATIONS

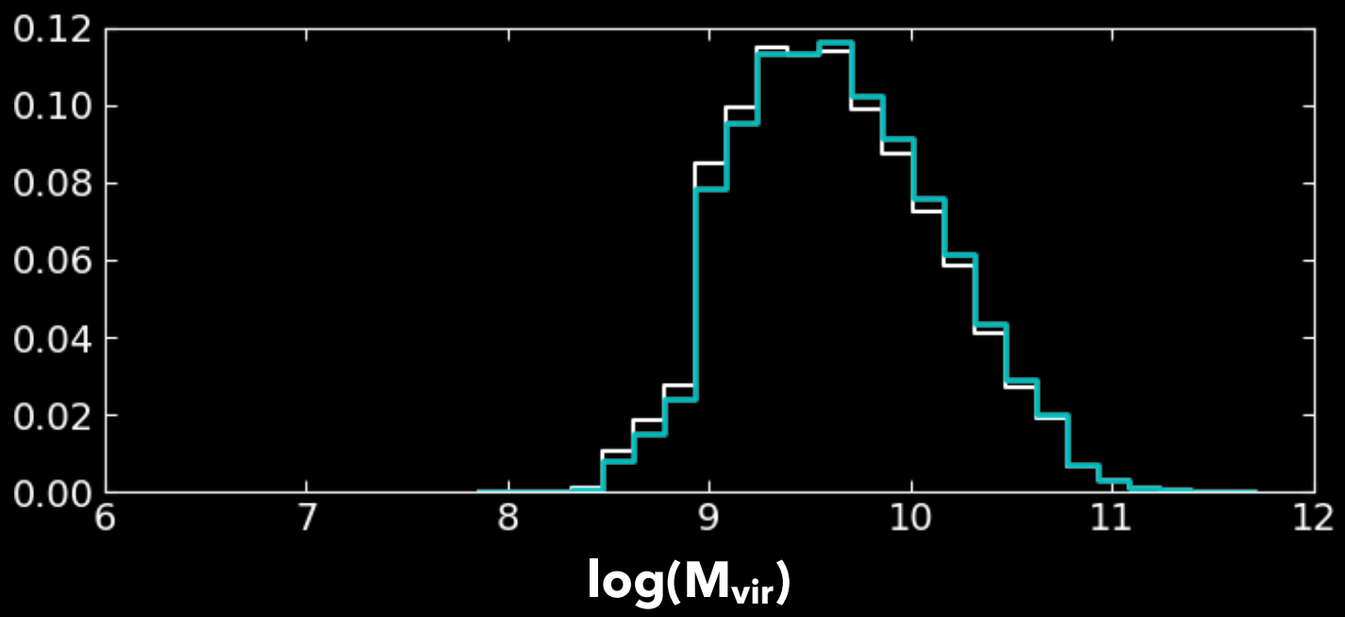
$$\frac{n_{WDM}}{n_{CDM}} = (1 + \gamma M_{hm} M^{-1})^{\beta}$$

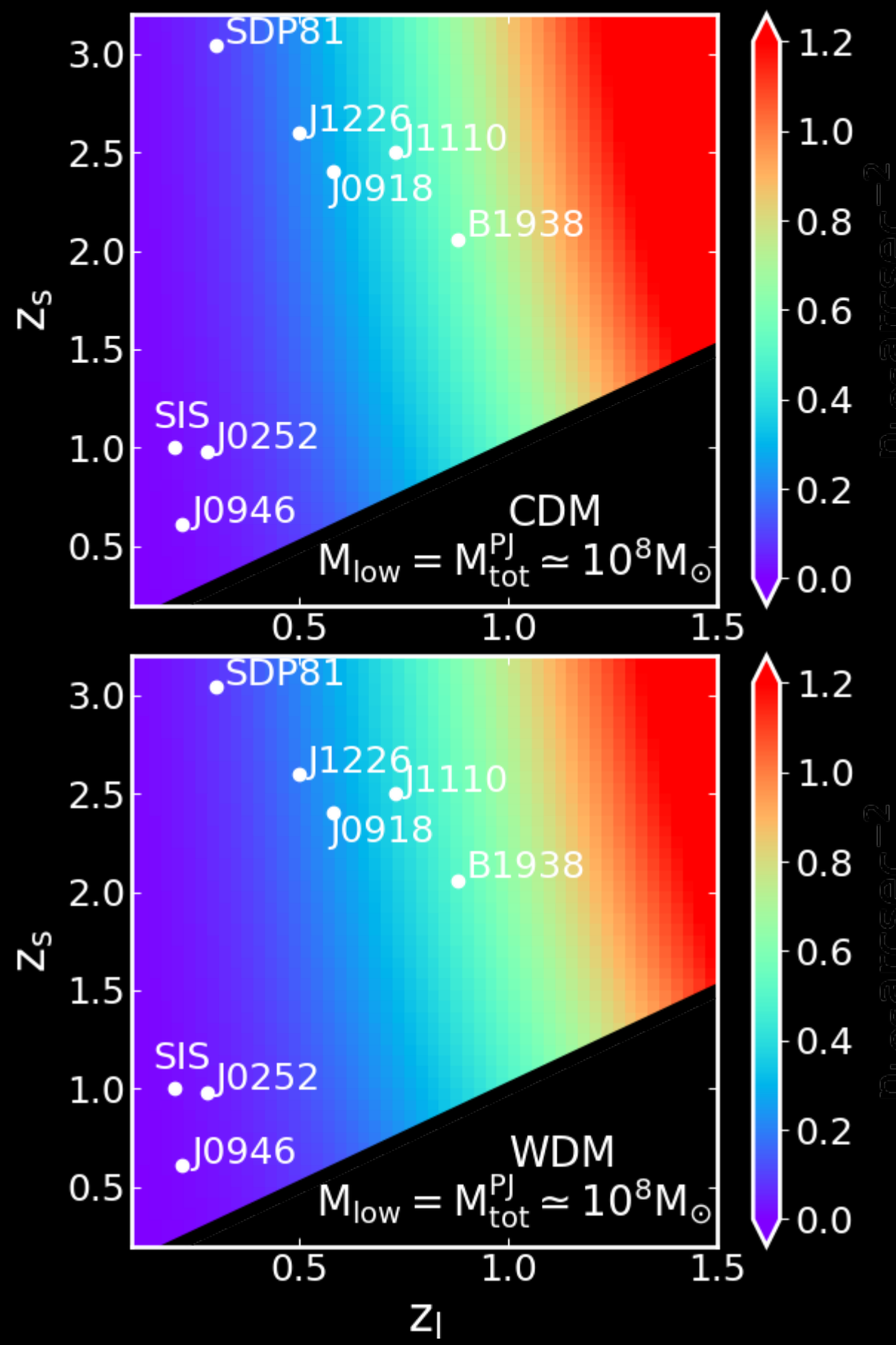
$$N_{LOS} = \int_0^{z_S} \int_{M_{LOW}(z)}^{M_{max}} n(m,z) dm \frac{dV}{dz} dz$$

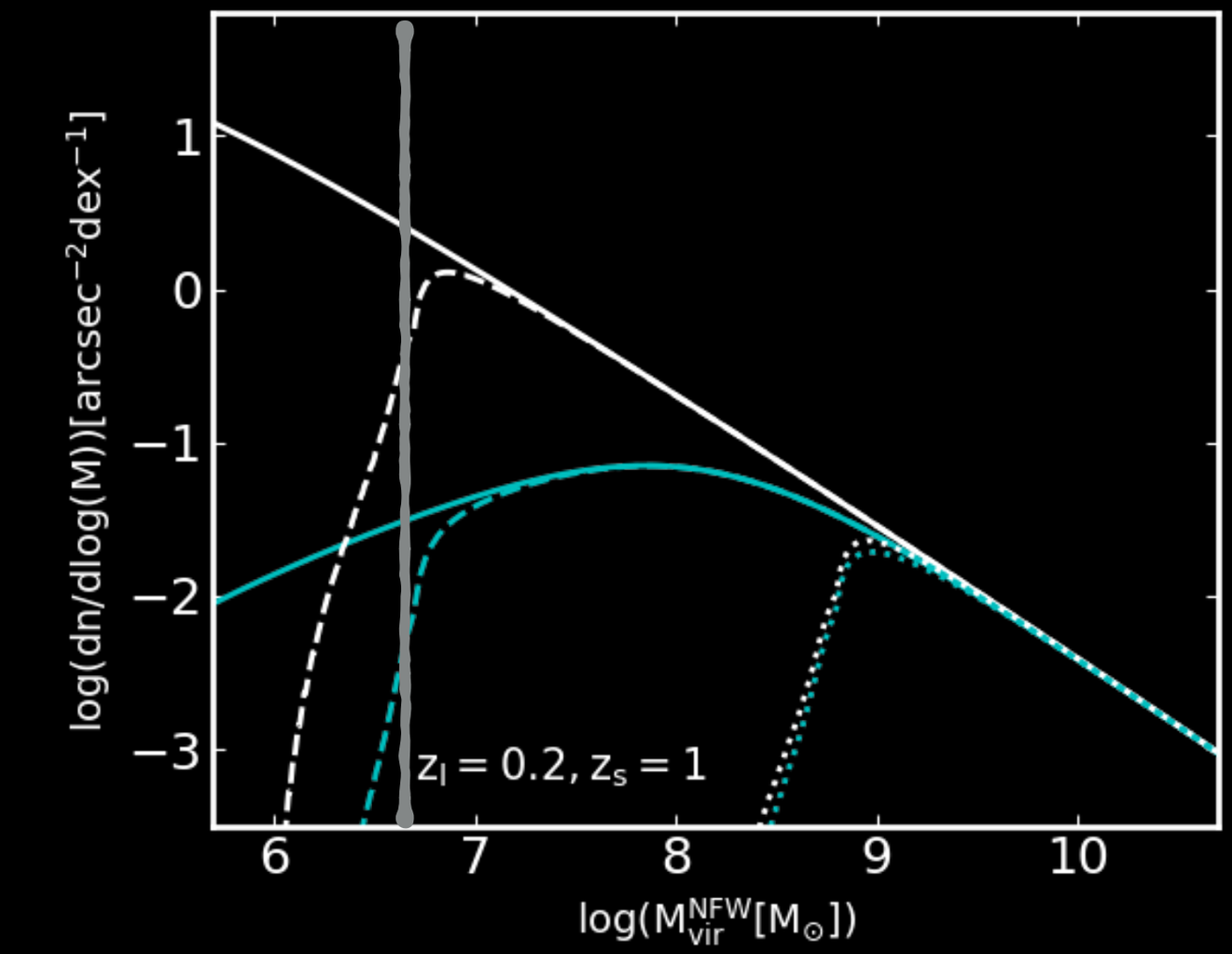


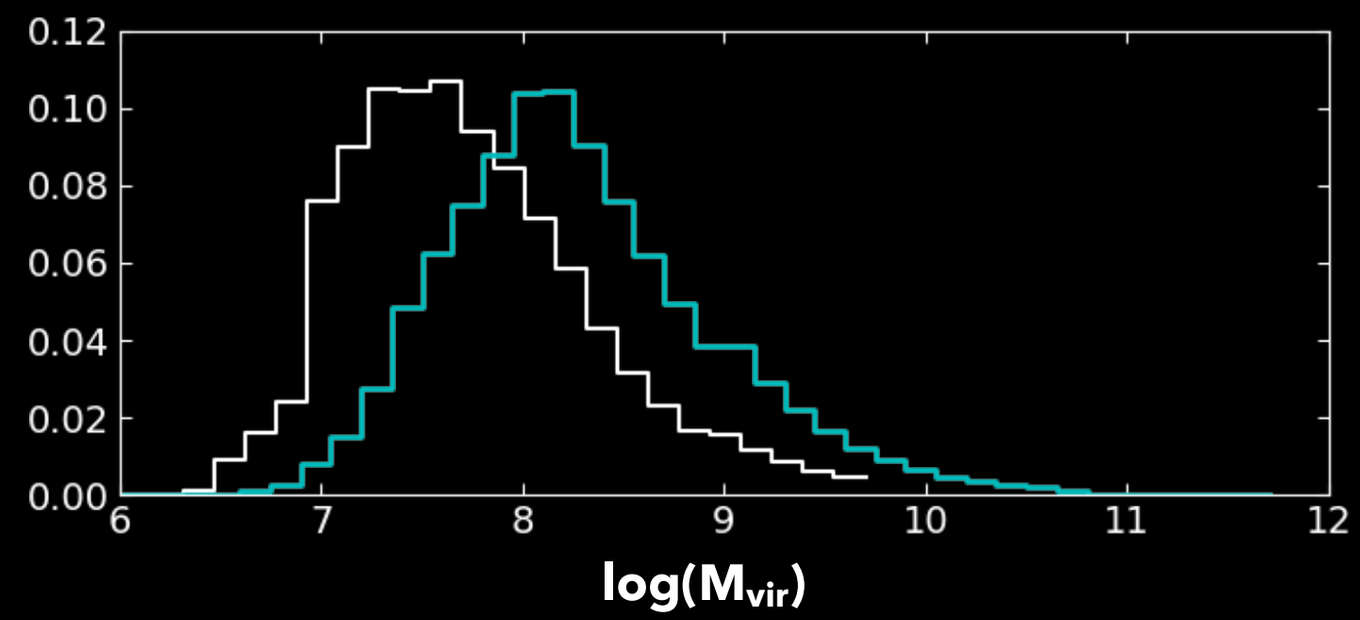



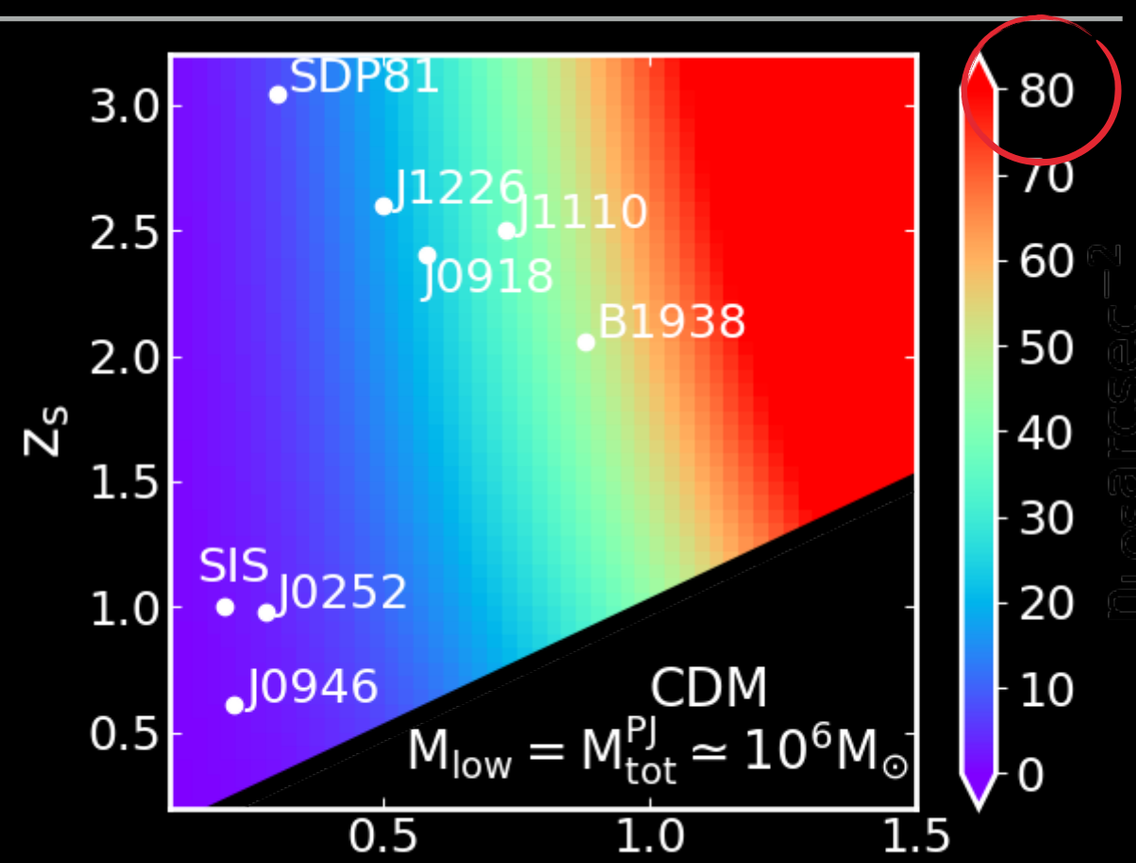

log(dn/dlog(M))[arcsec$^{-2}$dex$^{-1}$]
1
0
−1
−2
−3
$z_l = 0.2, z_s = 1$
6
7
8
9
10
log($M_{vir}^{NFW}[M_\odot]$)

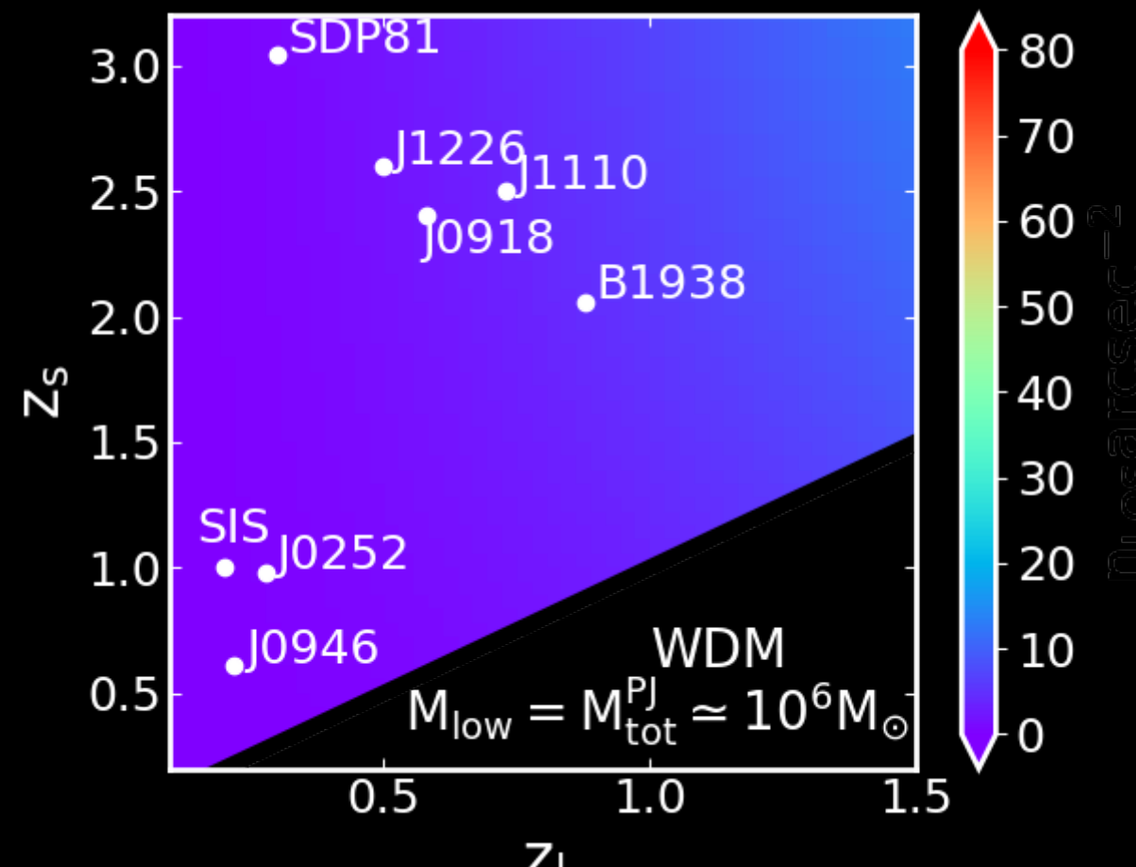

0.12
0.10
0.08
0.06
0.04
0.02
0.00
6
7
8
9
10
11
12
log($M_{vir}$)


SDP81
J1226
J1110
J0918
B1938
SIS
J0252
J0946
CDM
$M_{low} = M_{tot}^{PJ} \simeq 10^8 M_\odot$
WDM
$M_{low} = M_{tot}^{PJ} \simeq 10^8 M_\odot$
$z_s$
$z_l$
3.0
2.5
2.0
1.5
1.0
0.5
1.2
1.0
0.8
0.6
0.4
0.2
0.0
$n_{LOS}$arcsec$^{-2}$


log(dn/dlog(M))[arcsec$^{-2}$dex$^{-1}$]
log($M_{vir}^{NFW}$[$M_\odot$])
$z_l = 0.2, z_s = 1$


log($M_{vir}$)


SDP81
J1226
J1110
J0918
B1938
SIS
J0252
J0946
CDM
$M_{low} = M_{tot}^{PJ} \simeq 10^6 M_\odot$
$z_s$
$n_{los} arcsec^{-2}$

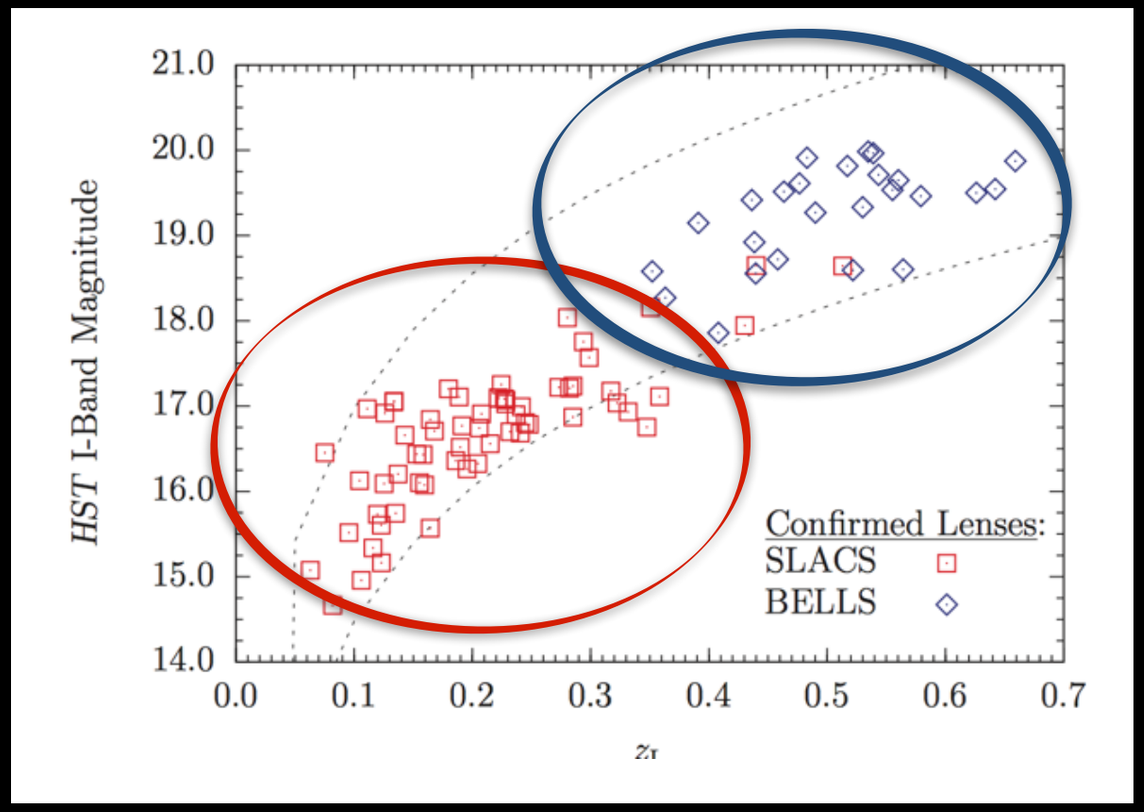

SDP81
J1226
J1110
J0918
B1938
SIS
J0252
J0946
WDM
$M_{low} = M_{tot}^{PJ} \simeq 10^6 M_\odot$
$z_s$
$z_l$
$n_{los} arcsec^{-2}$

*(Vegetti et al. 2018, Ritondale et al. 2019)*

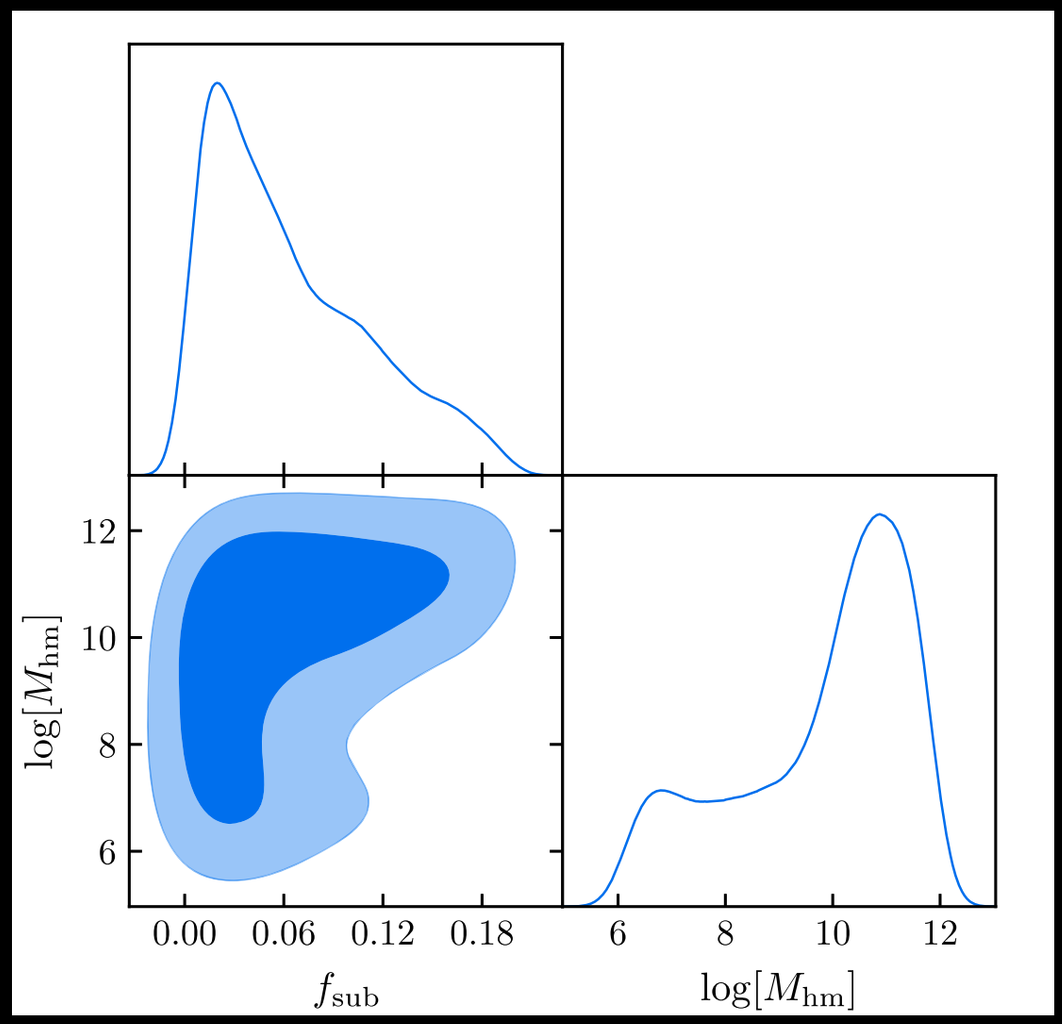
# COMBINING MULTIPLE HST SAMPLES

11 SLACS + 17 BELLs lenses, only **1 detection**

consistent with CDM and most WDM

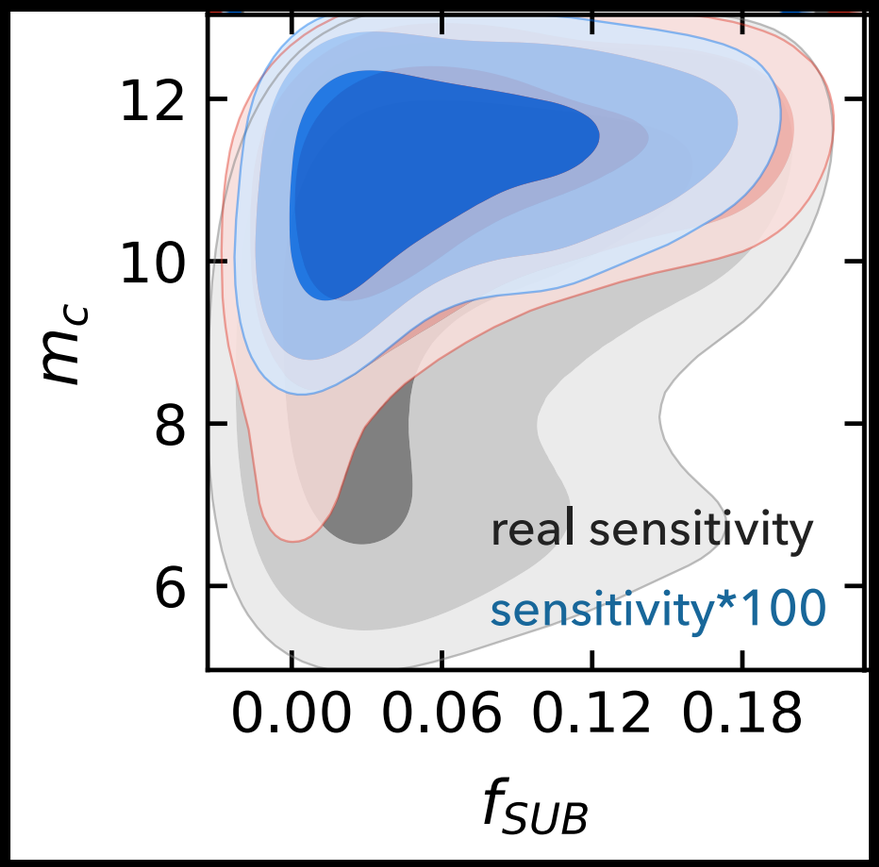



$$\frac{n_{WDM}}{n_{CDM}} = (1 + \gamma M_{hm} M^{-1})^{\beta}$$



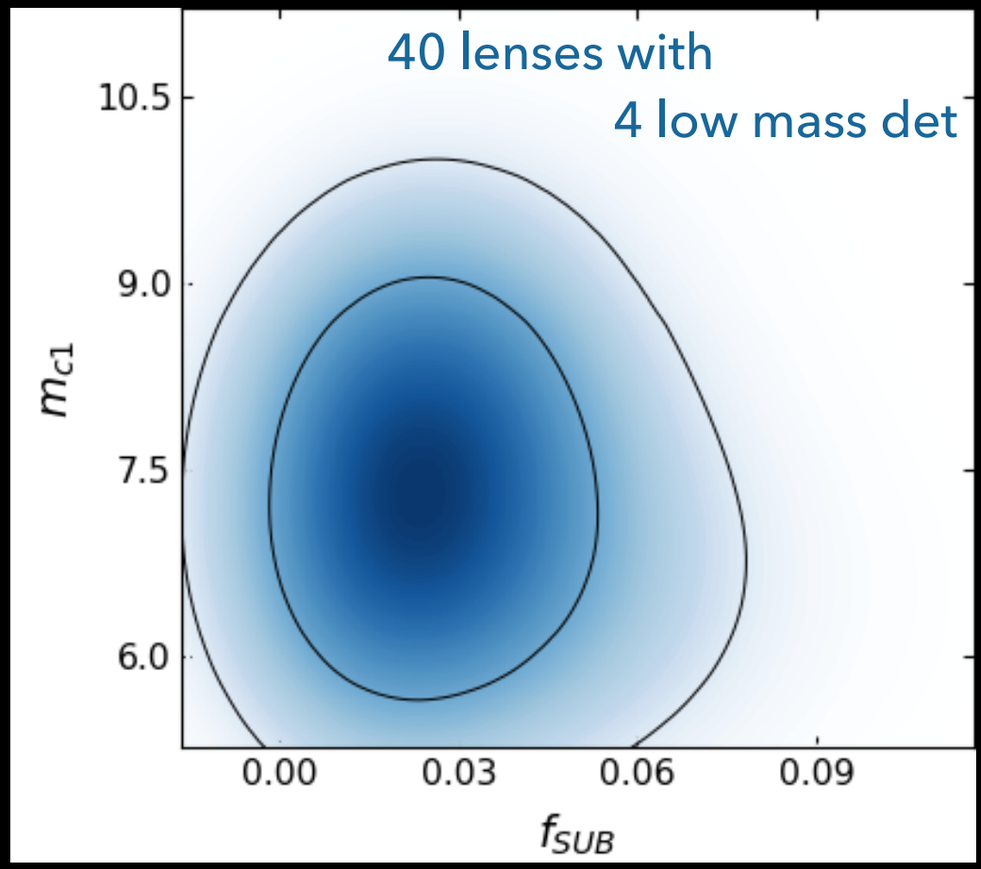
*(Vegetti et al. 2018)*

with higher resolution




in the case of no detections or only massive detection we could challenge CDM

with larger samples




in the case of more detections we exclude some WDM models

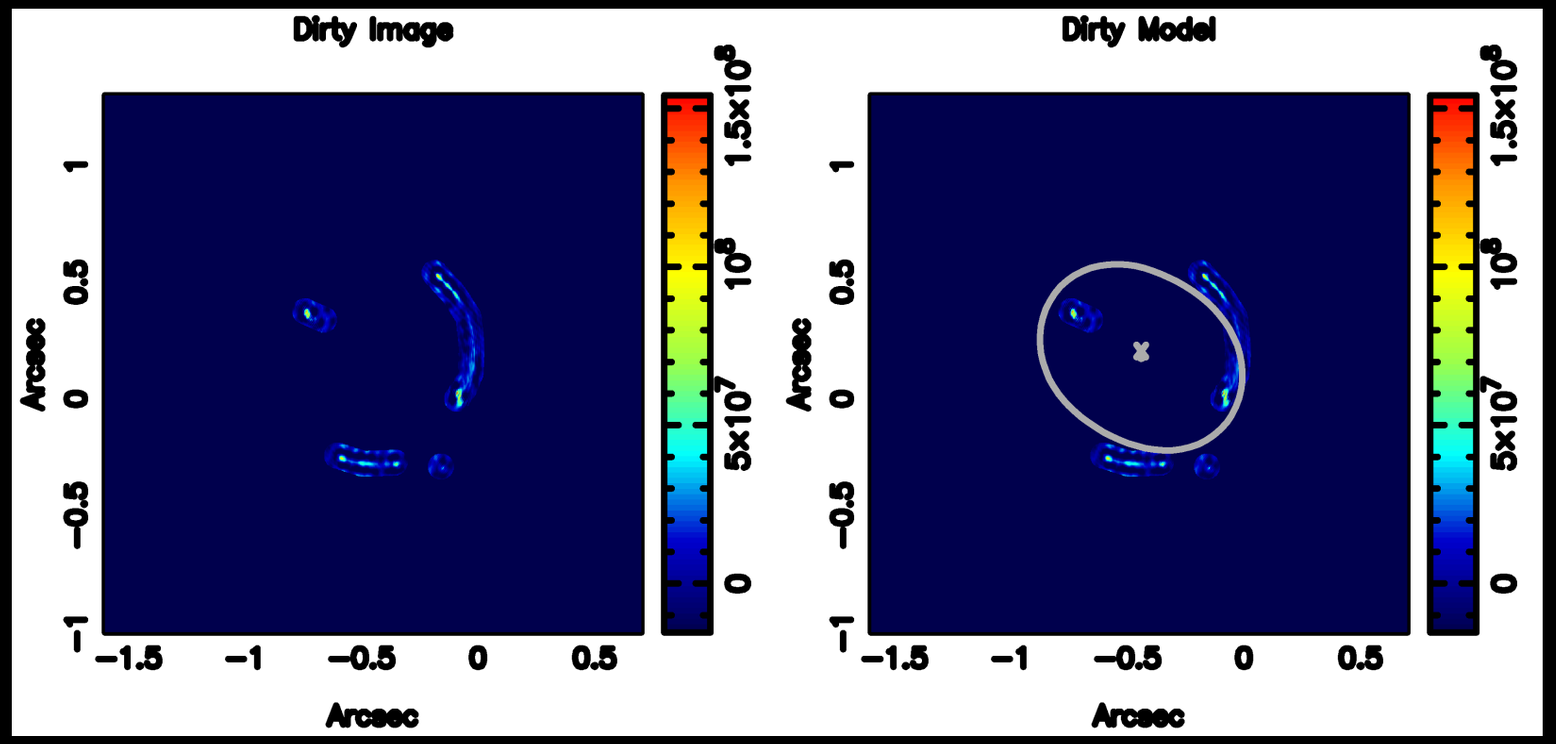
*(Powell et al. in prep)*

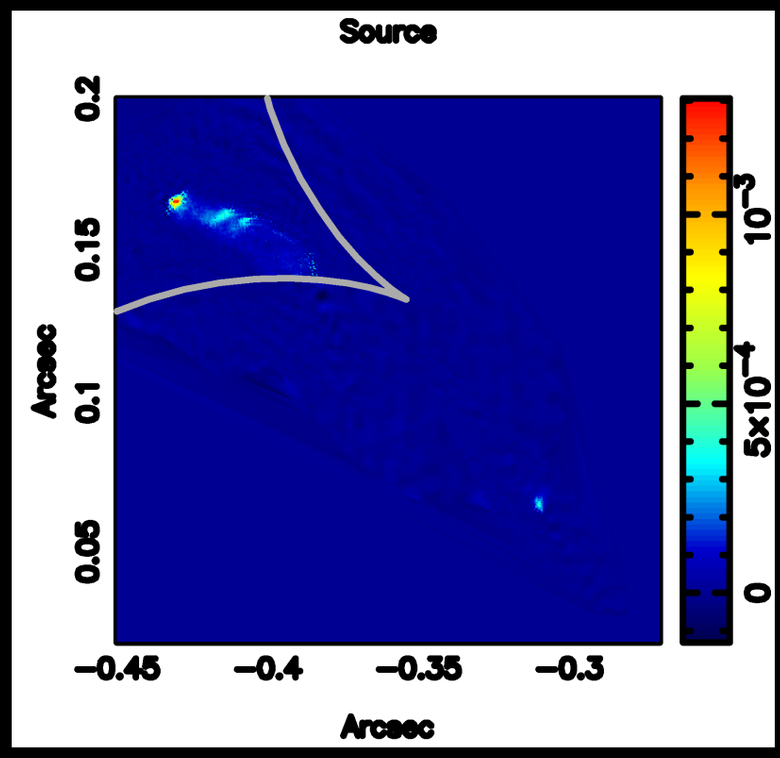
# VLBI OBSERVATIONAL RESULTS

- highest angular resolution imaging of extended gravitational arcs from a gravitational lens

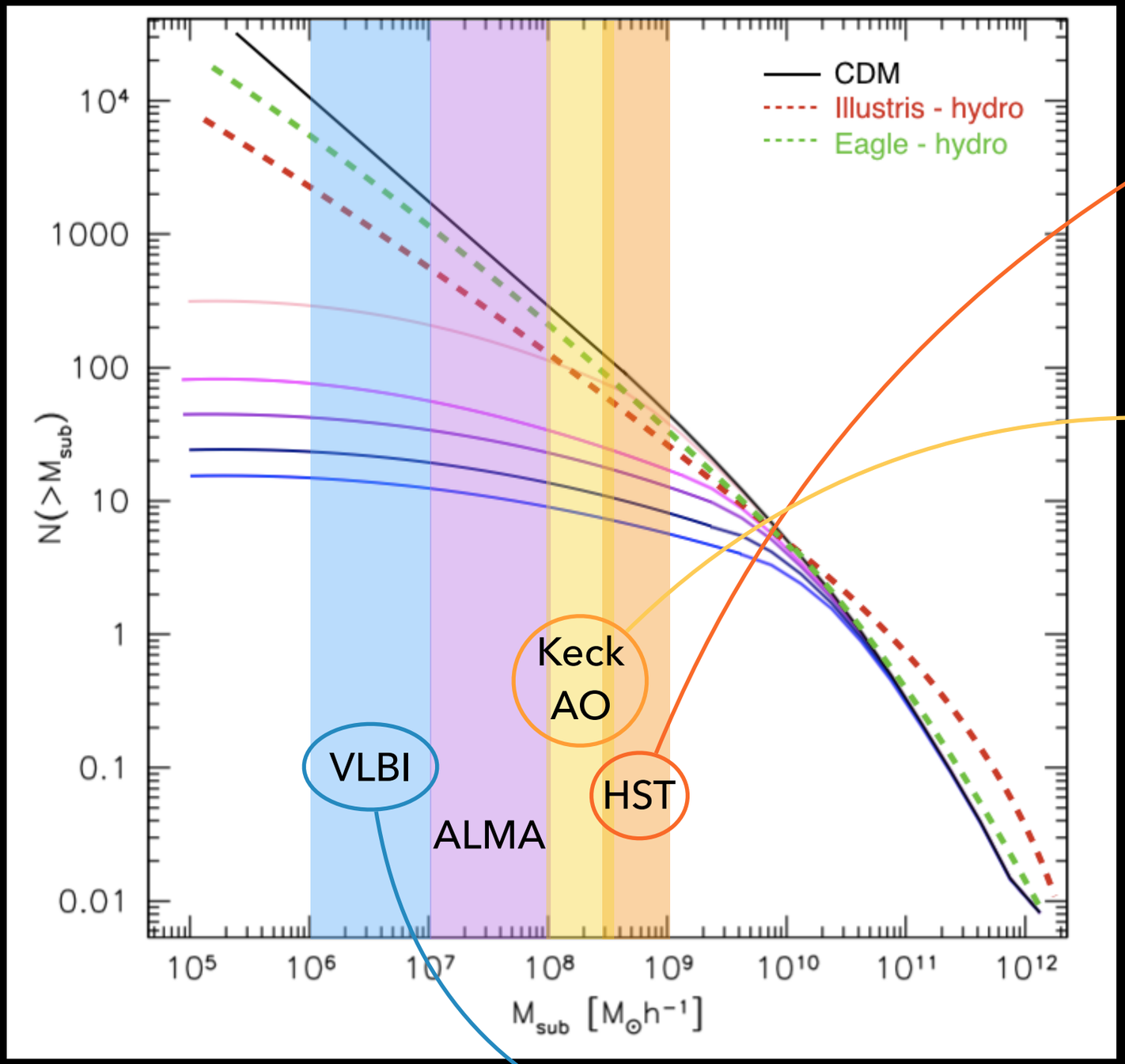
- we can measure astrometric anomalies of the order of ~ **<u>1mas</u>**

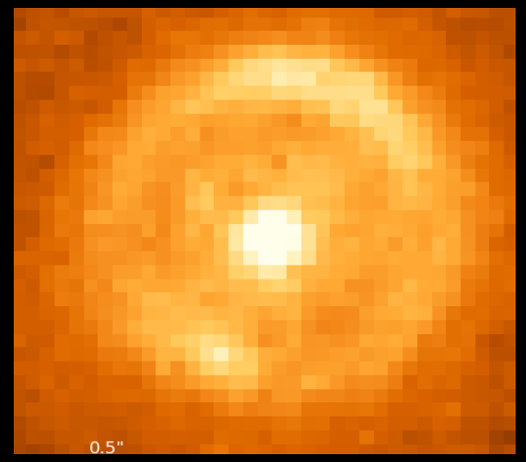
- price to pay: huge data and more complex analysis (400 million visibilities)



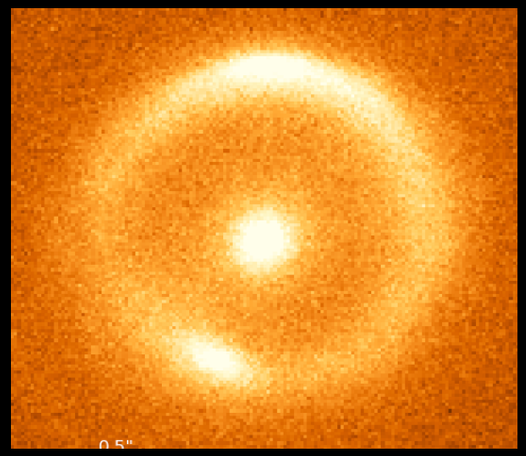



# SUMMARY

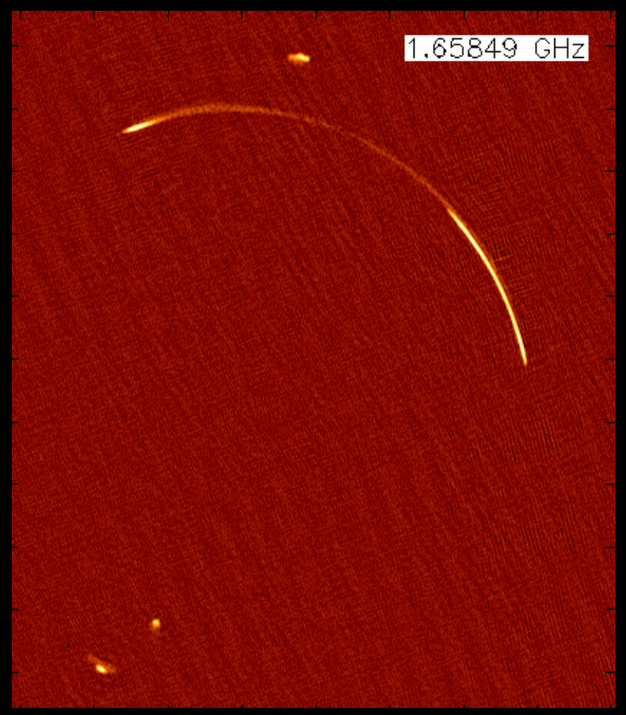



HST




KECK AO




RADIO GVLBI