Lens statistics with GRAMORs

Galaxies and Cosmology in Light of Strong Lensing
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What is "GRAMORs"

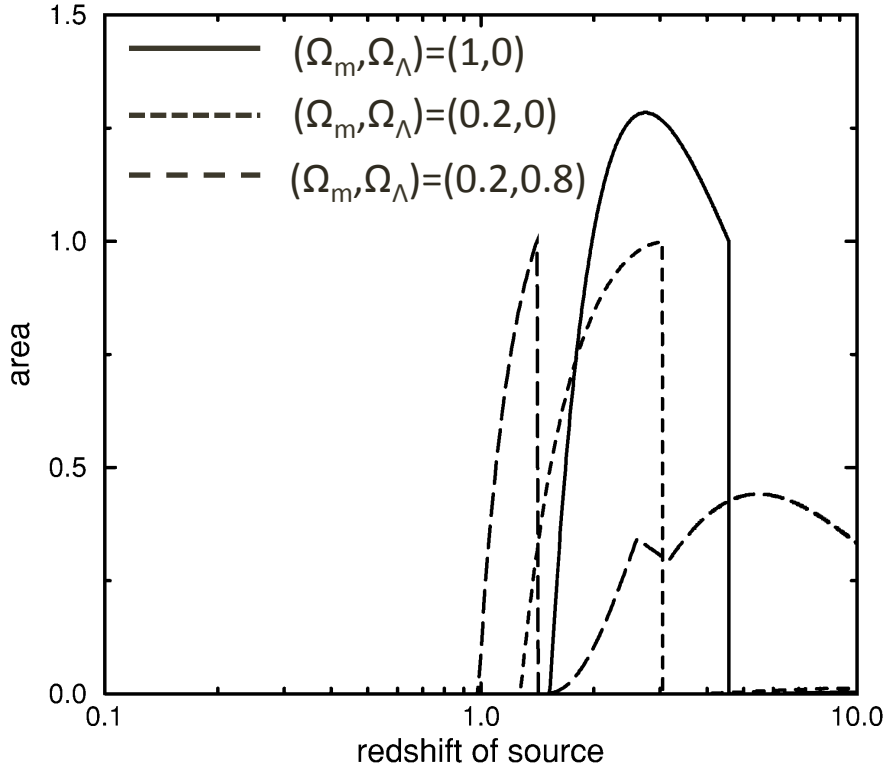
- GRAMORs = "Gravitationally highly magnified yet morphologically regular images"
  (Futamase et al. 1998)

- The definition of GRAMORs : **1/3<R<3 and 10<A.**
  R : the ratio between the length and width of image
  A : the magnification parameter

- The existence of this image was expected in the end of 1990's (Williams&Lewis 1998, Futamase et al. 1998).

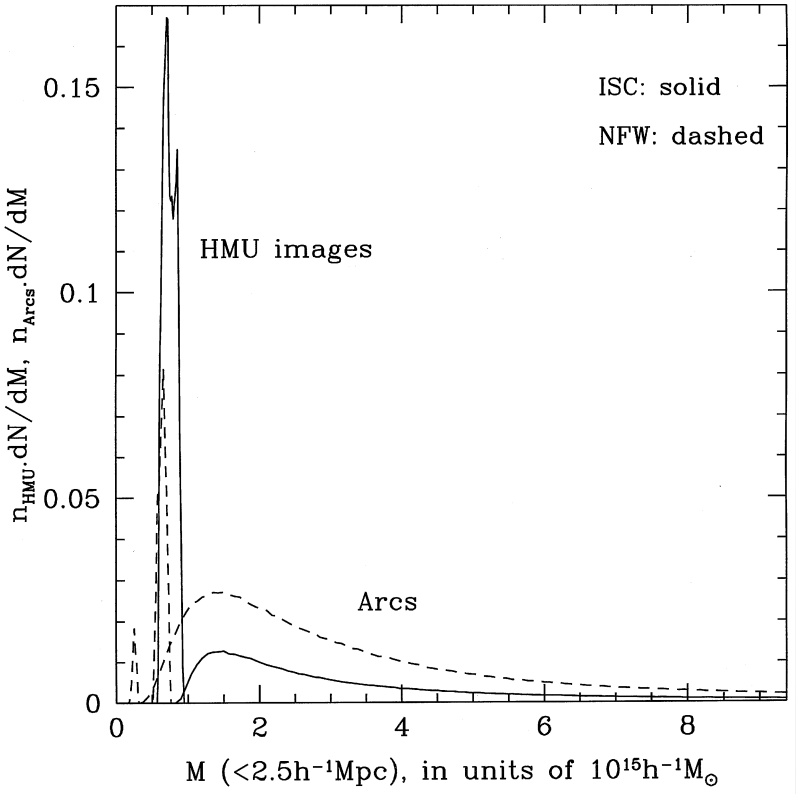
Previous Work

The dependence of the cross-section for GRAMORs on z_s and $(\Omega_m,\Omega_\Lambda)$.



(Futamase,Hattori&Hamana 1998)

The dependence of the expected number of GRAMORs(HMU) on the lens mass.



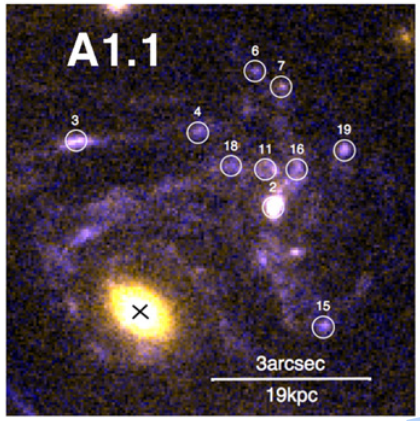
(Williams & Lewis 1998)

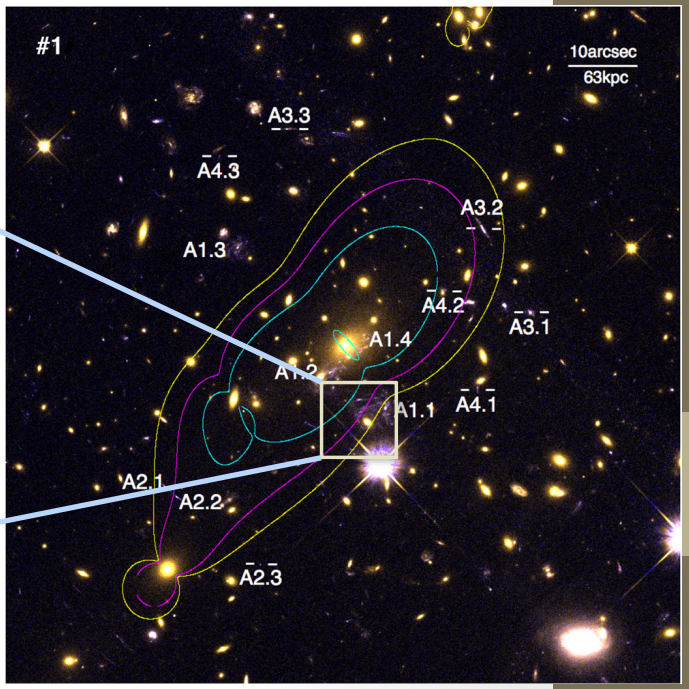
What is "GRAMORs"

- In 2009, first GRAMOR is detected at the center of cluster, MACS J1149.5+2223(Zitrin & Broadhurst 2009) , and this is the only one GRAMOR that is detected so far.

Observed data	
z_l	0.544
z_s	1.49
A	23

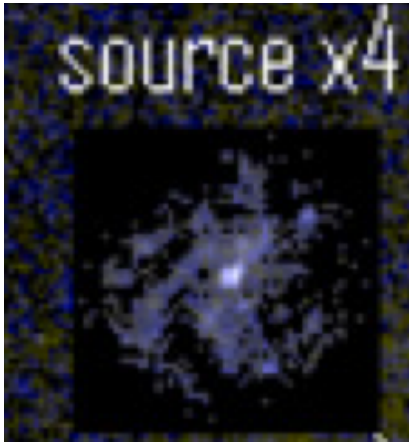
Spiral galaxy



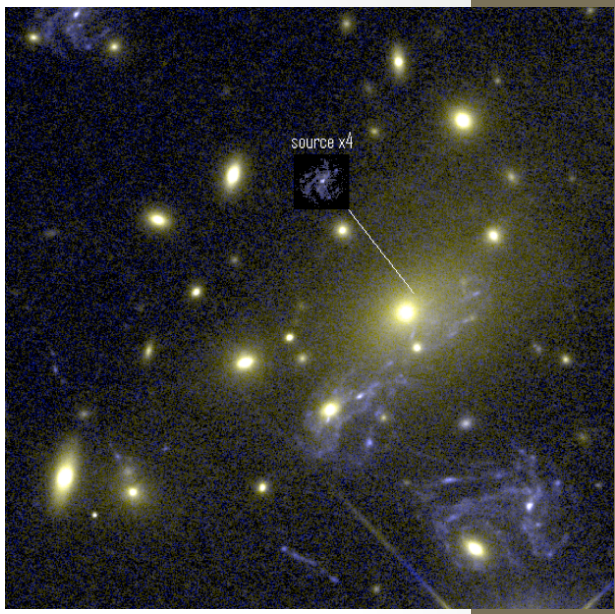


(Smith et al. 2009)

The center of MACS J1149.4+2223

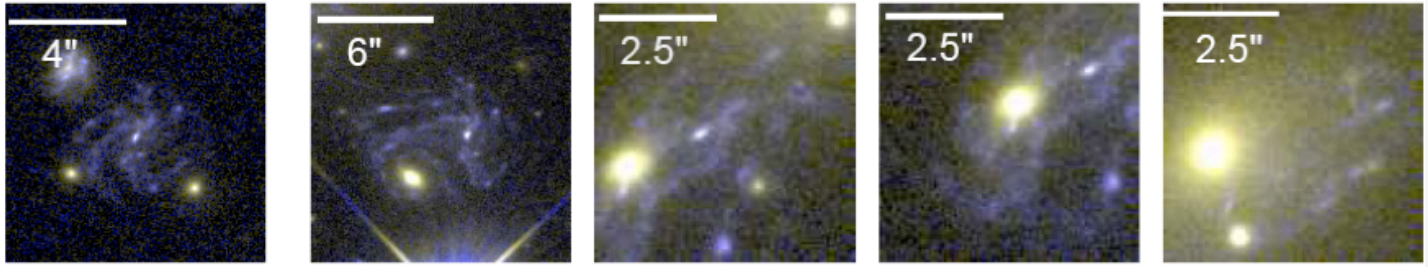


Delensed Source

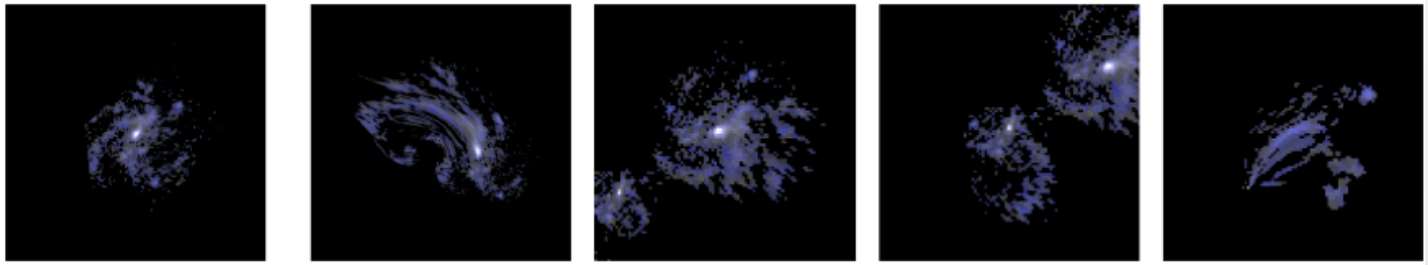


1.1 1.2 1.3 1.4 1.5

Observed images



Generated Images



Zitrin & Broadhurst 2009

Questions

- Which clusters are good to search for GRAMORs??
- Can we use GRAMORs for constrain the cosmological parameter??

Method

- Lens Statistics
  - The useful tool in observational cosmology because the statistics of strong lensing event are sensitive to the cosmological parameters.

$$\frac{dN}{dz_s} = \sigma(z_s) n_s(z_s) \frac{cdt}{dz_s}$$

$$= \sigma(z_s) n_s(z_s) \frac{c}{H_0} \frac{dz_s}{(1+z_s)\sqrt{\Omega_0 (1+z_s)^3 + \Omega_\Lambda}}$$

- Lens model
- Cosmological parameters

- The source distribution

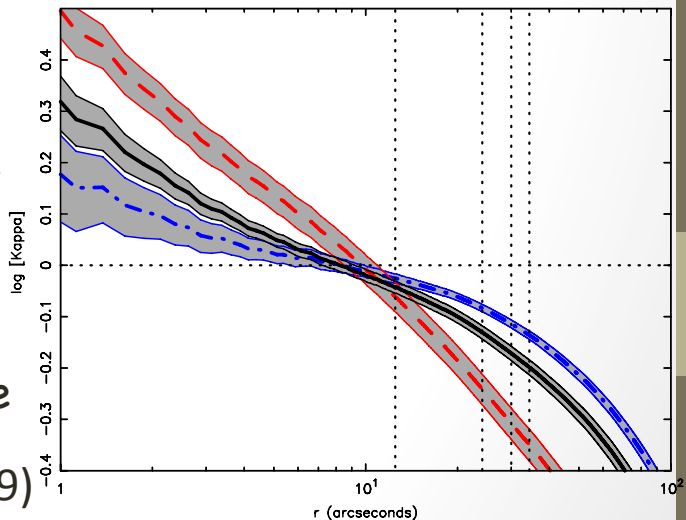
- Cosmological parameters

Lens model

- ***NFW profile***
  - 4 set of the NFW profile parameter
  - This data sets are based on LoCuSS sample.
    - To investigate the feature of the cluster which make it easy to discover other GRAMORs

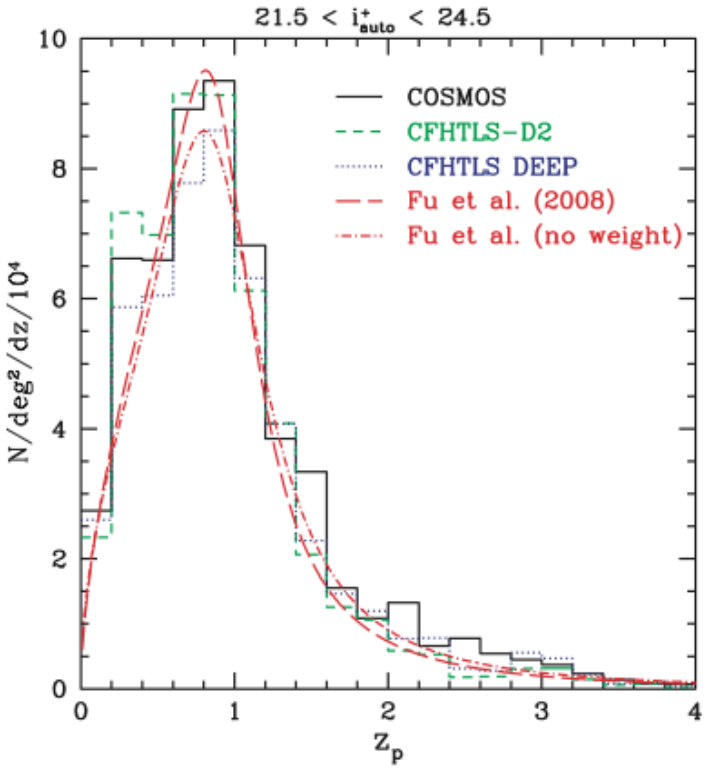
	M_{vir} [$10^{14}h^{-1}M_{sun}$]	C_{vir}	r_s [h^{-1}kpc]	r_{vir} [h^{-1}kpc]
A	3.230	5.762	217.41	1252.92
B	6.011	4.419	350.98	1551.0
C	7.587	4.299	387.06	1664.06
D	12.678	3.663	537.83	1970.47

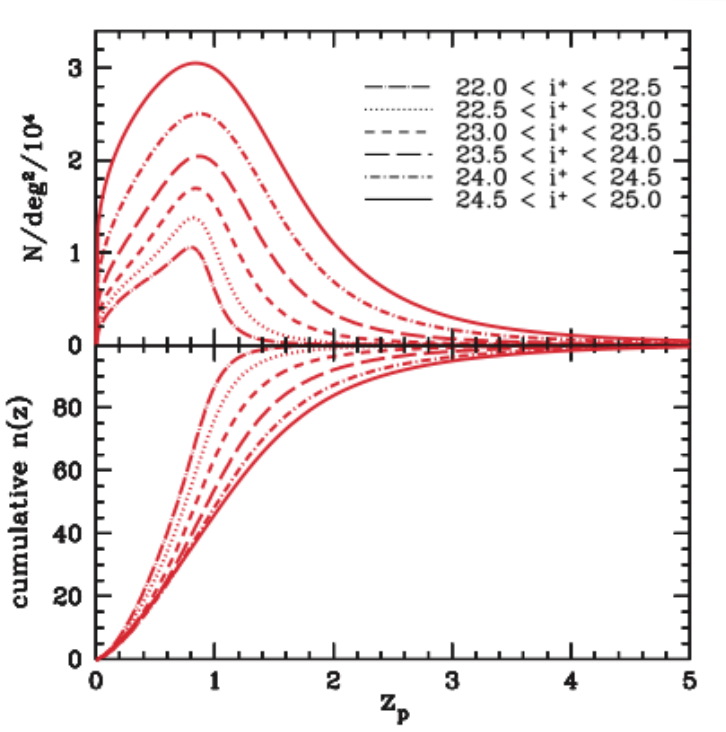
- ***MACS J1149.5+2223***
  - We derived the κ-profile of MACS J1149.5+2223 from the black solid line of the figure. $$\kappa = 3.5\frac{D_{ds}}{D_s}\theta^{-0.3}$$
    - To use GROMARs as the constraint to the cosmological parameters.



(Smith+09)

The number density of the background galaxies.





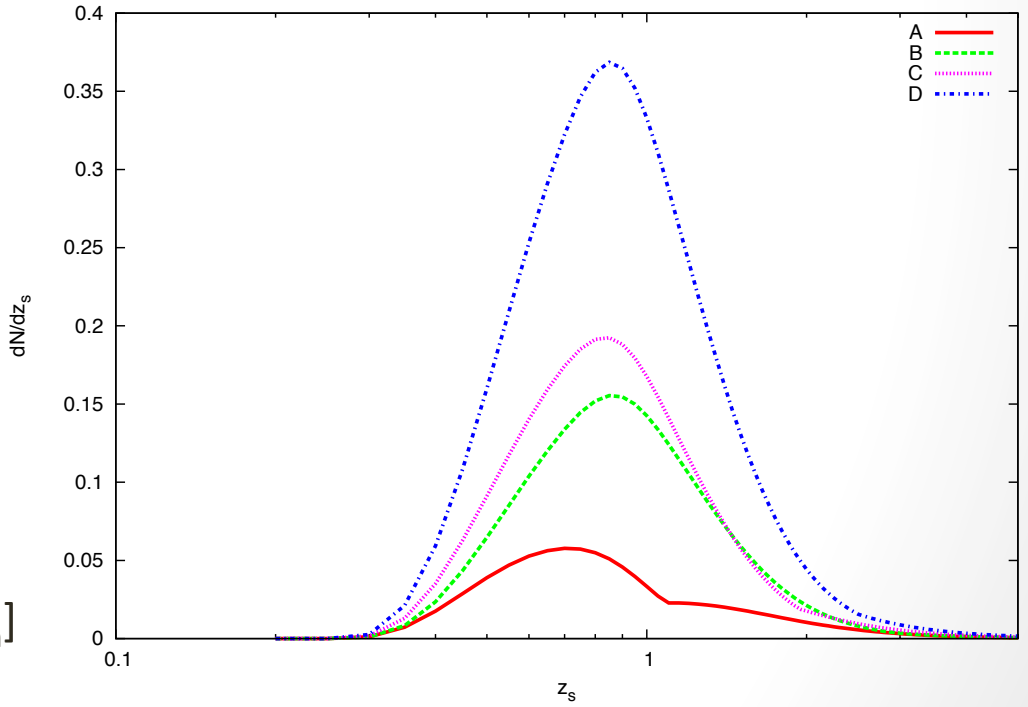
$$n_s(z_s) = A\frac{z^a + z^{ab}}{z^b + c} \qquad A = \left(\int_0^\infty \frac{z^a + z^{ab}}{z^b + c} dz\right)^{-1}$$

Fu et al. 2009

Results with NFW profile

- The dependence on the NFW profile parameters
  - z_l=0.2
  - $(\Omega_m,\Omega_\Lambda)$ =(0.27,0.73)
  - (M_A,C_A)=(3.230,5.76)
  - $(M_B\ C_B)$=(6.011,4.41)
  - $(M_C\ C_C)$=(7.587,4.29)
  - $(M_D\ C_D)$=(12.678,3.66)

[10^{14} h^{-1} M_{sun}]



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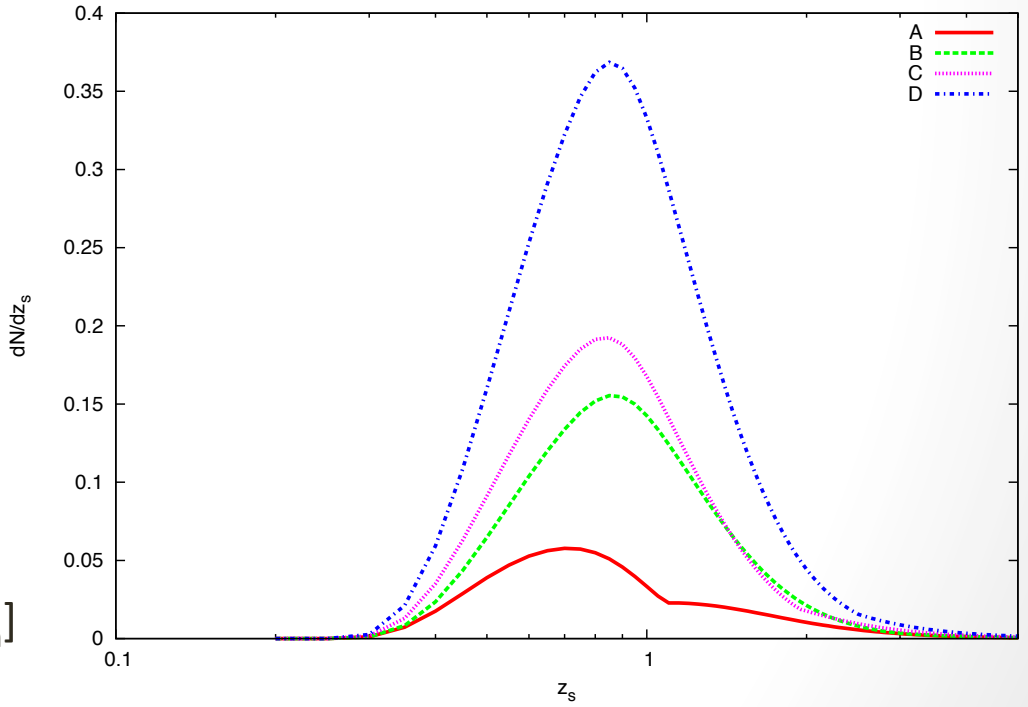
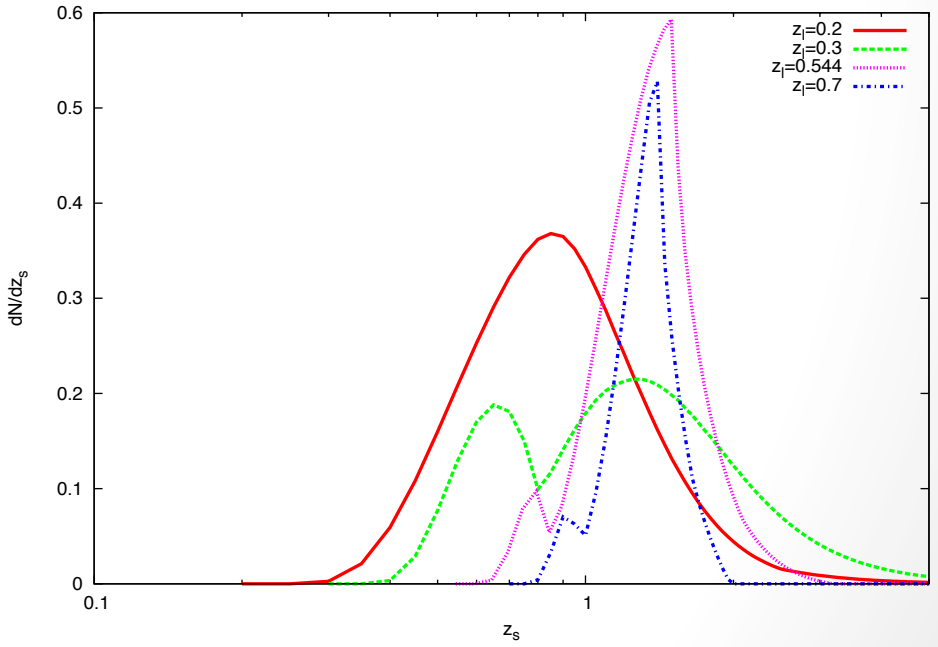


Results with NFW profile

- The dependence on the redshift of the lens (z_l)
  - z_l=0.2, 0.3, 0.544, 0.7
  - (Ω_m,Ω_Λ) =(0.27,0.73)
  - Lens model : D
    - (M_D C_D)=(12.678,3.66)



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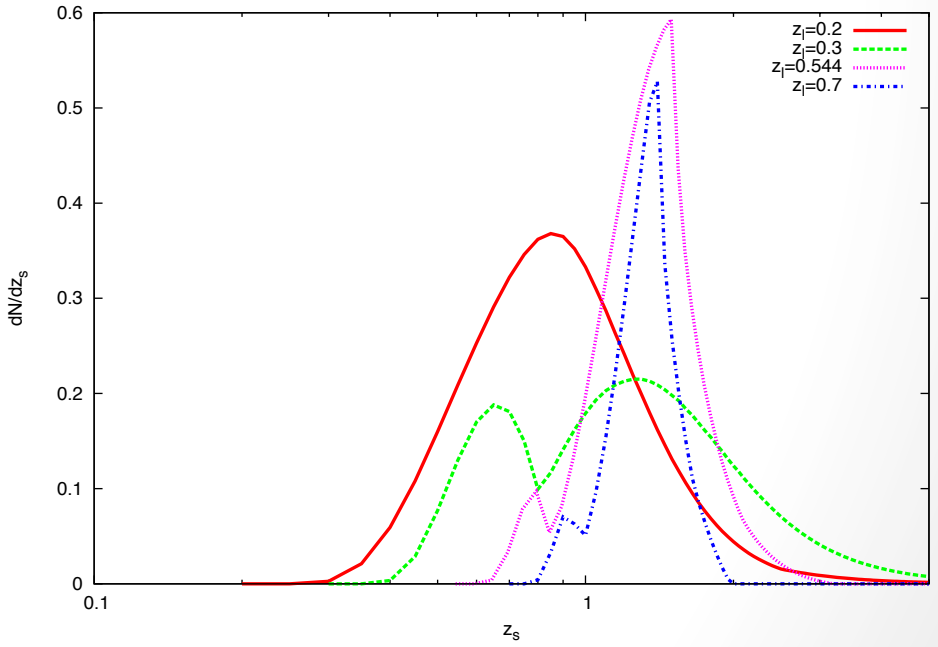
  - z_l=0.2, 0.3, **0.544**, 0.7
  - $(\Omega_m, \Omega_\Lambda)$ =(0.27,0.73)
  - Lens model : D
    - $(M_D\ C_D)$=(12.678,3.66)

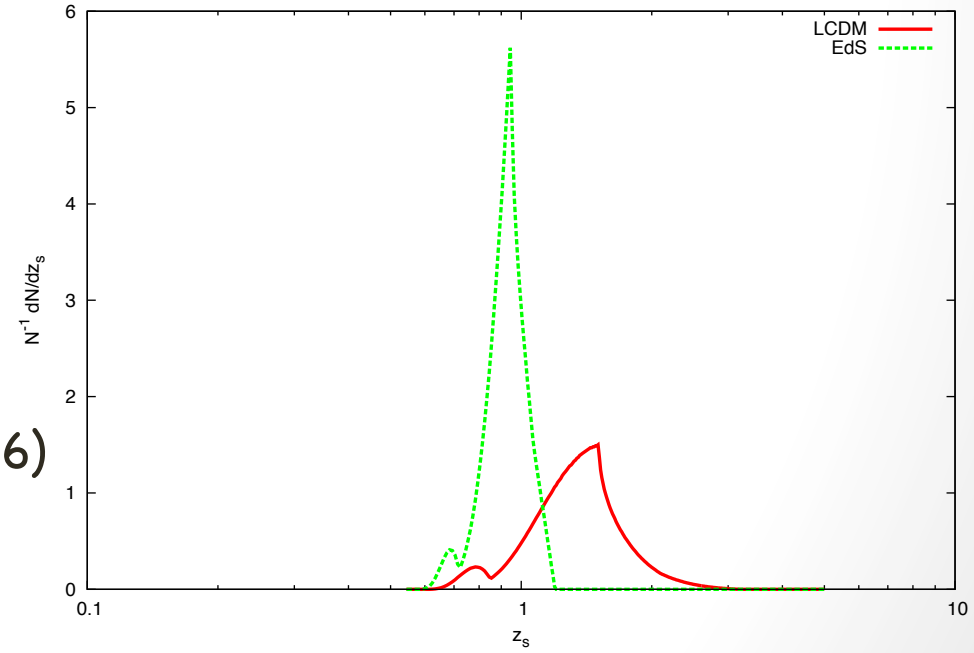
The expected number of GRAMORs

N=2.17



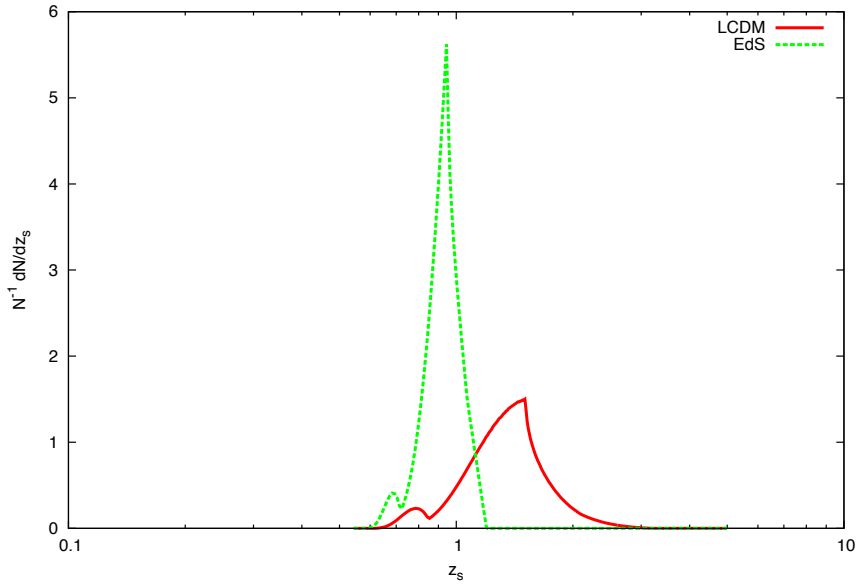
Results with NFW profile

- The dependence on the cosmological parameters
  - z_l=0.544
  - $(\Omega_m, \Omega_\Lambda)$
    =(0.27,0.73)
    =(1,0)
  - Lens model : D
    - $(M_D\ C_D)$=(12.678,3.66)

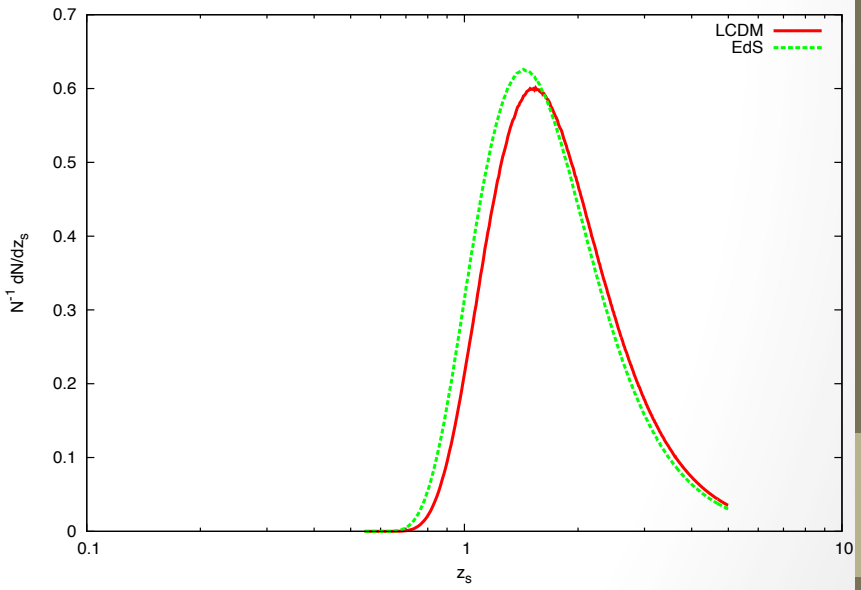


Comparison between GRAMORs & Arcs

GRAMORs (1/3<R<3, 10<A)

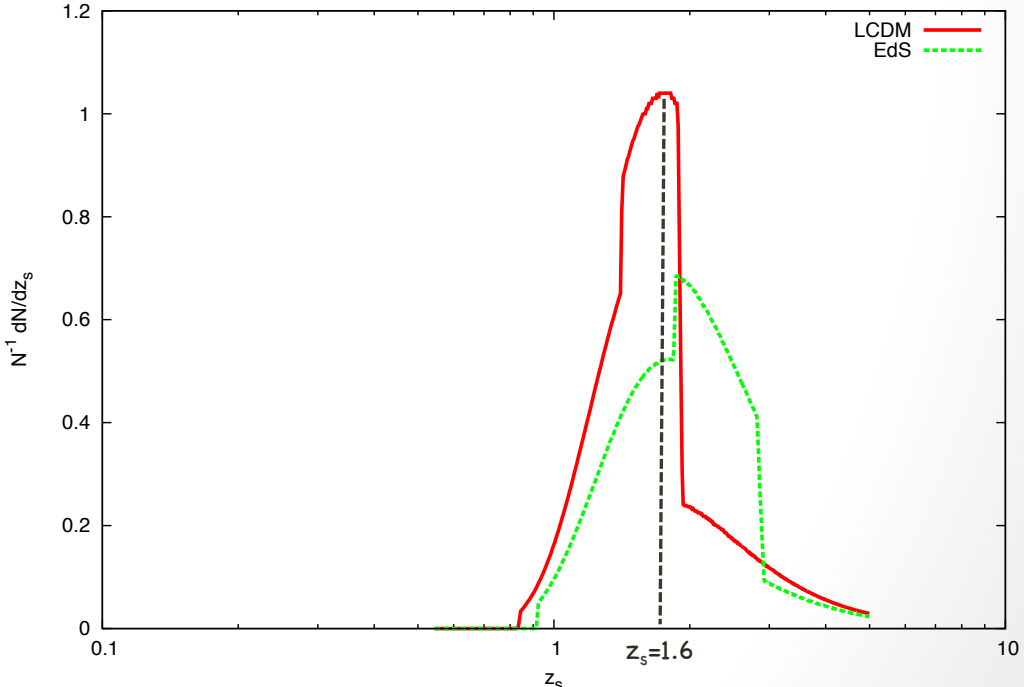


Arcs (10<R)



Result with MACS J1149.5

- The dependence on the cosmological parameters in the case of MACS J1149.5+2223
  - z_l=0.544
  - $(\Omega_m, \Omega_\Lambda)$
    =(0.27,0.73)
    =(1,0)
  - Lens model :
    MACS J1149.5
  - 22<A<24



Answers (Summary)

- Which clusters are good to search for GRAMORs??
  - The massive and flatter core
  - The lens redshift $z_l \sim 0.5\text{-}0.6$

- Can we use GRAMORs for constrain the cosmological parameter??
  - YES!!
    - The strong dependence of the expected number on the cosmological parameters.
    - The calculation for the MACS J1149 can reproduce the observed results.

Future Works

- Take into account of the source size in order to estimate the more realistic detectability.

- Estimate the actual impact of having a GRAMOR compared not having a GRAMOR.

Thank You.