The sizes of z ~ 6-8 lensed galaxies from the Hubble Frontier Fields data of Abell 2744

Kawamata+15, ApJ, 804, 103

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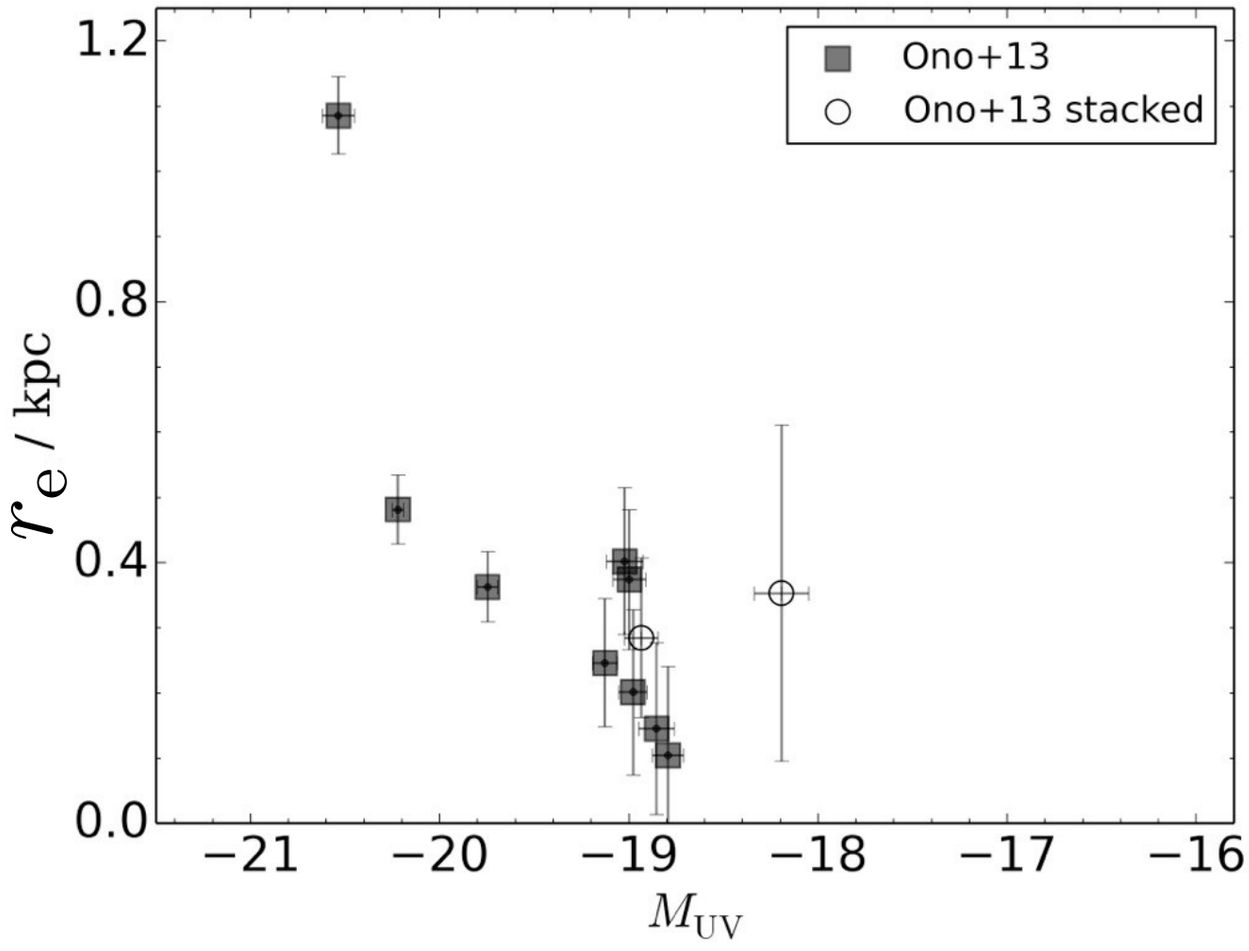
OUTLINE

- Measurements of sizes and magnitudes
- Results
    - Properties of z~6-8 galaxies
    - The redshift evolution of sizes and its implication for disk formation and evolution

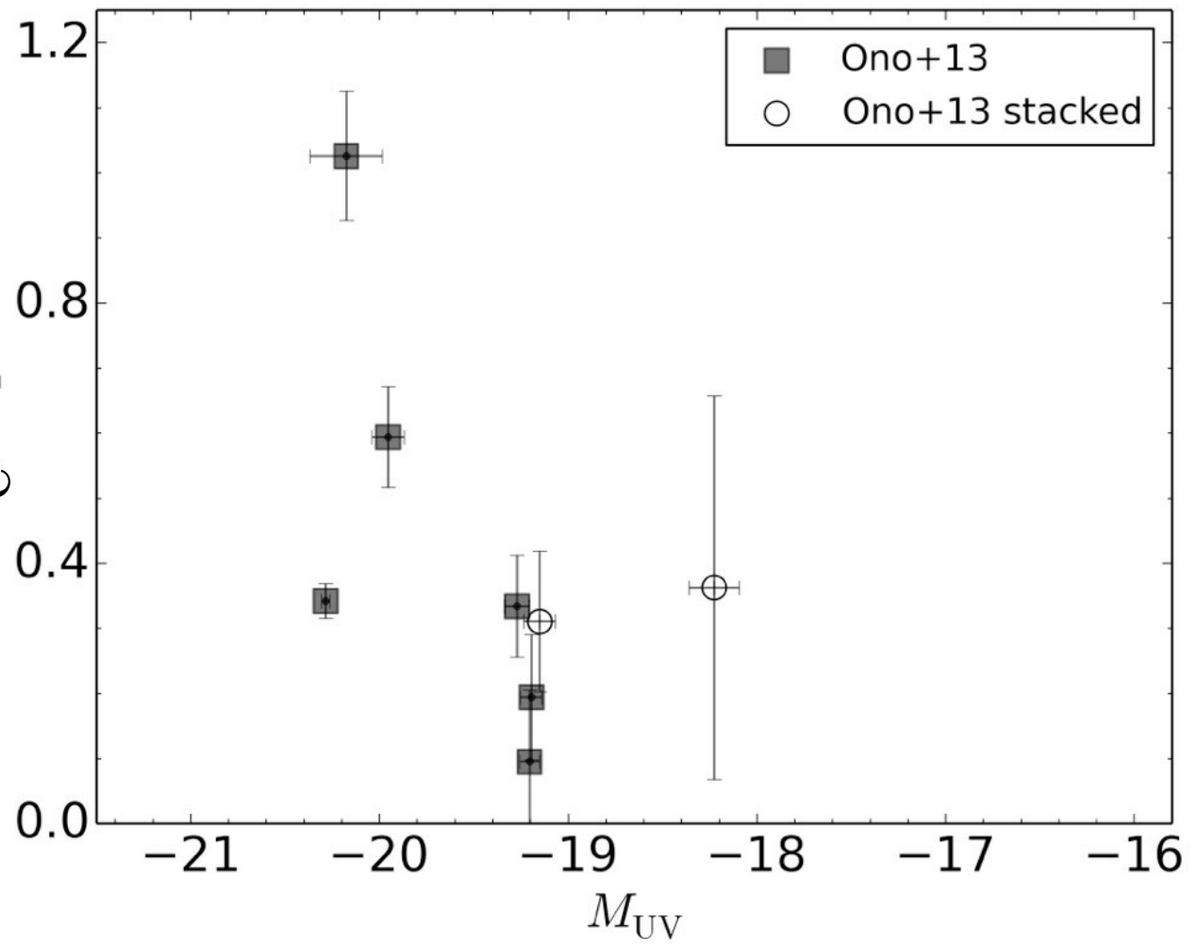
PREVIOUS SAMPLES OF Z~7 & 8

Faint galaxies with accurate size measurement from HUDF12

z~7: 9 galaxies



z~8: 6 galaxies



Ono+13

PREVIOUS SAMPLES OF Z~7 & 8

Faint galaxies with accurate size measurement

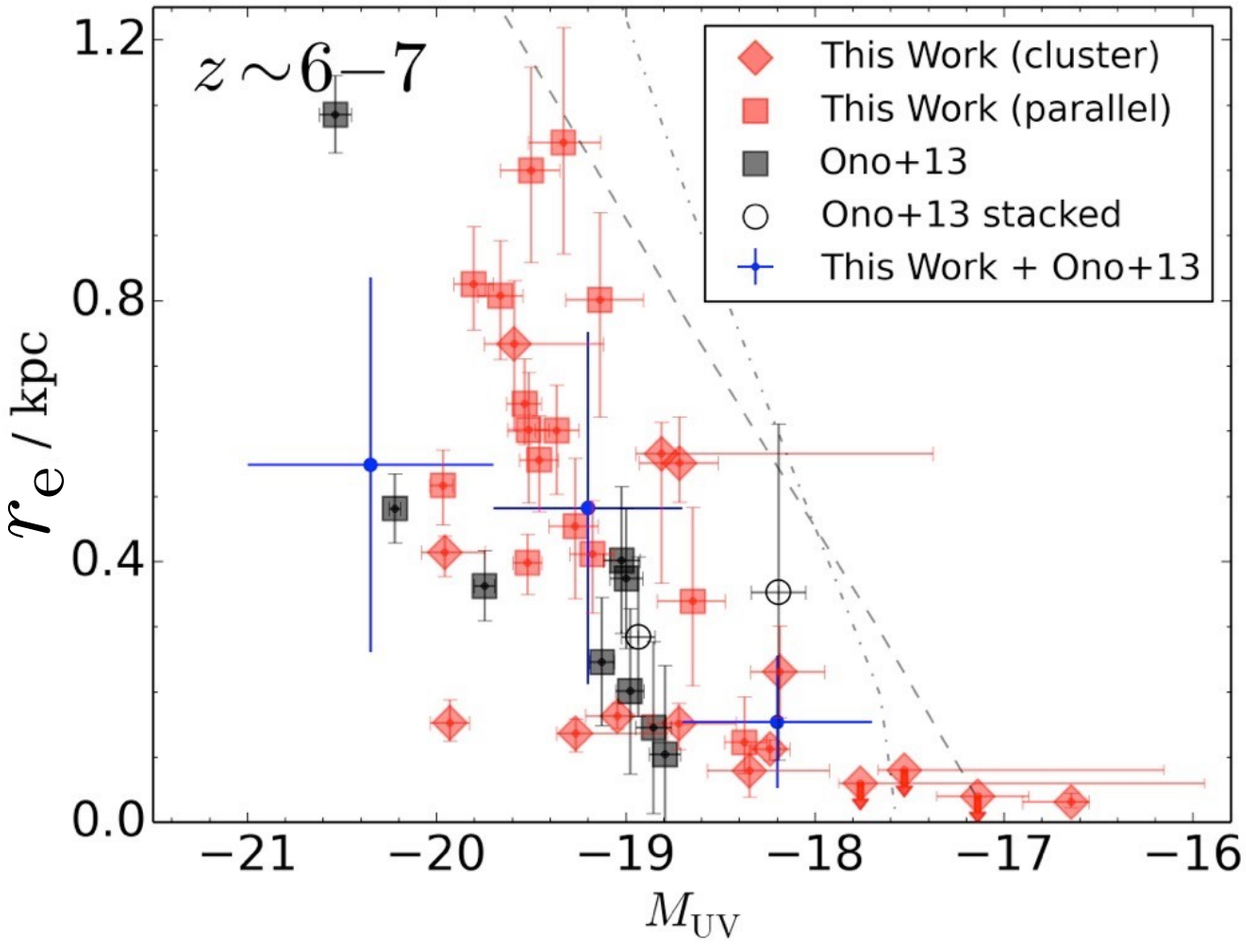
from HUDF12+HFF

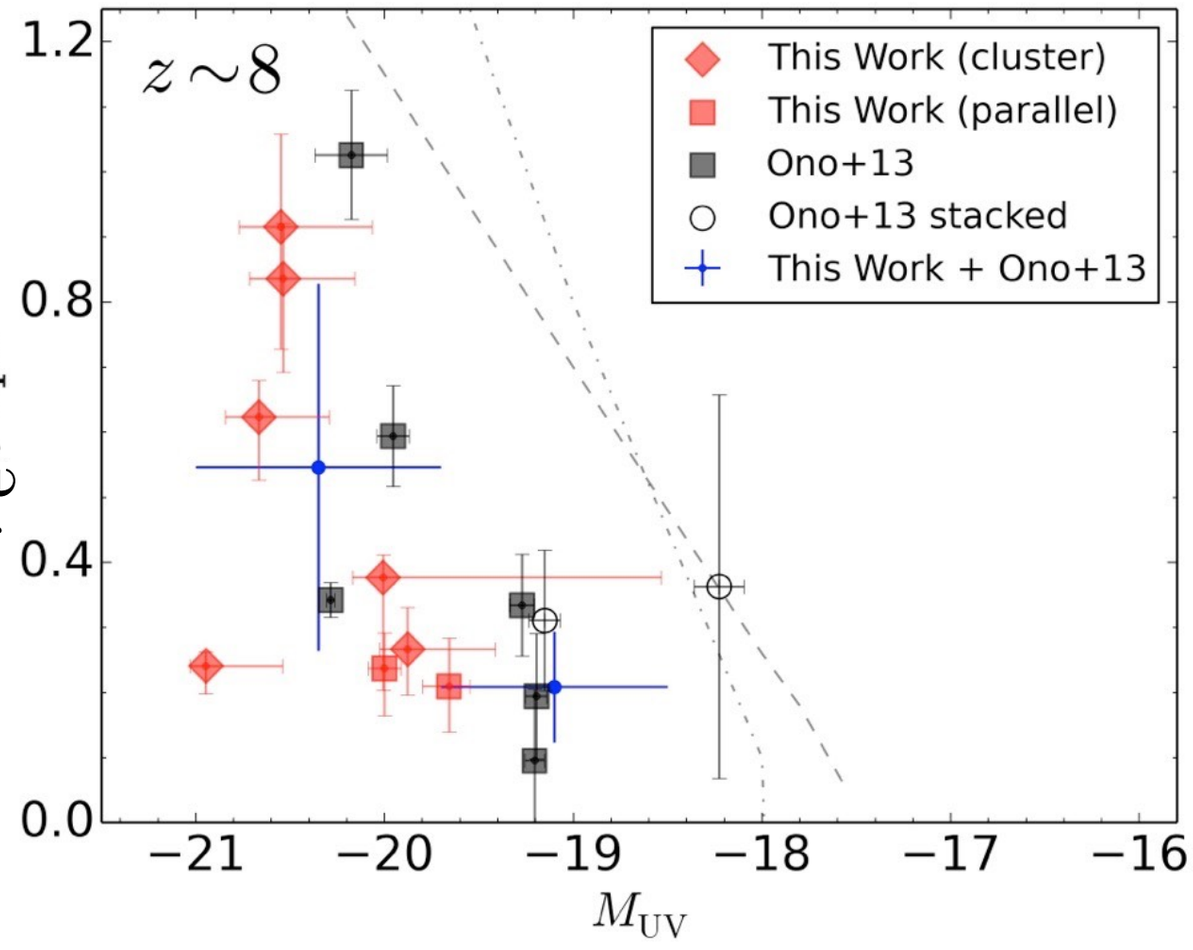
40

z~6-7: ~~9~~ galaxies

14

z~8: ~~6~~ galaxies





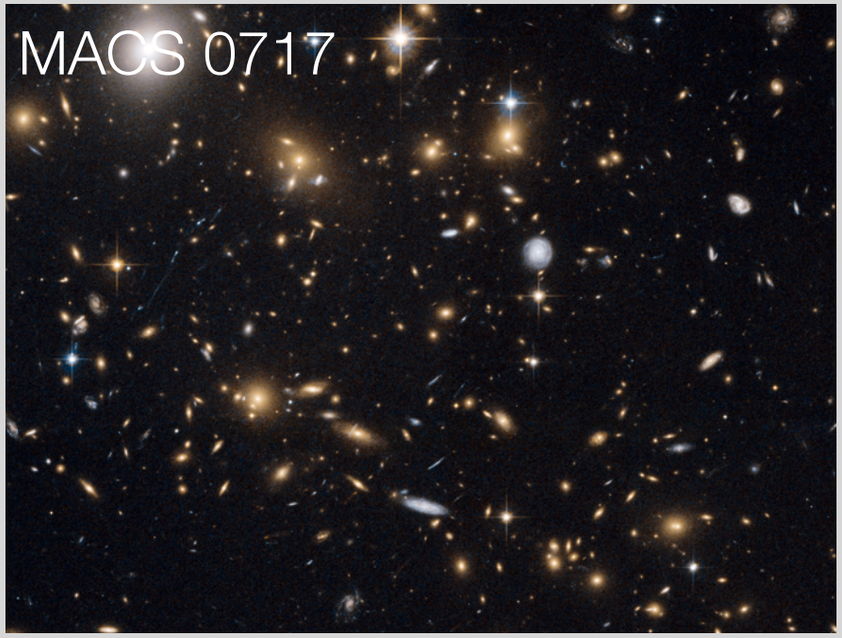
RK+15

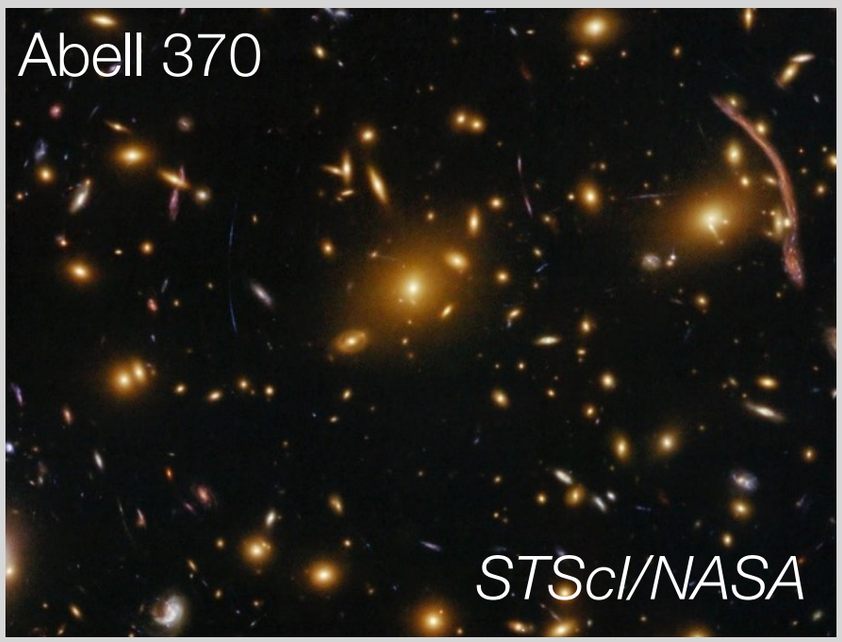
HUBBLE FRONTIER FIELDS PI: J. Lotz

Deep and **high-resolution** observations by HST

+

Strong gravitational lensing effects by clusters

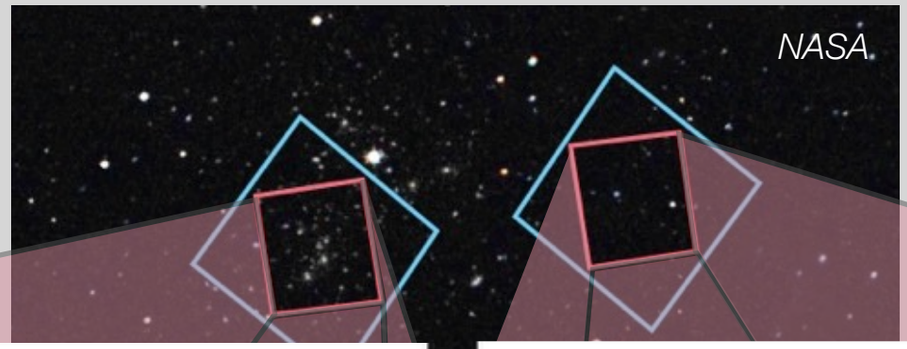




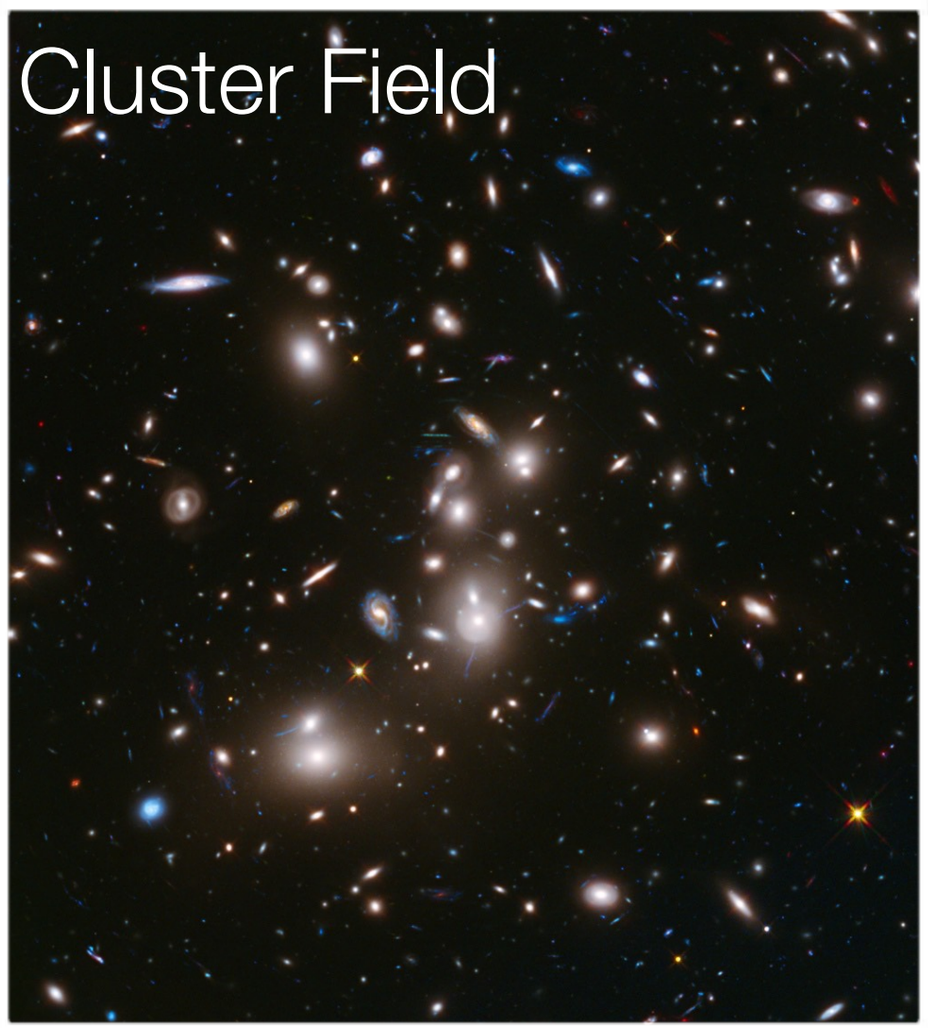
ABELL 2744 FIELDS

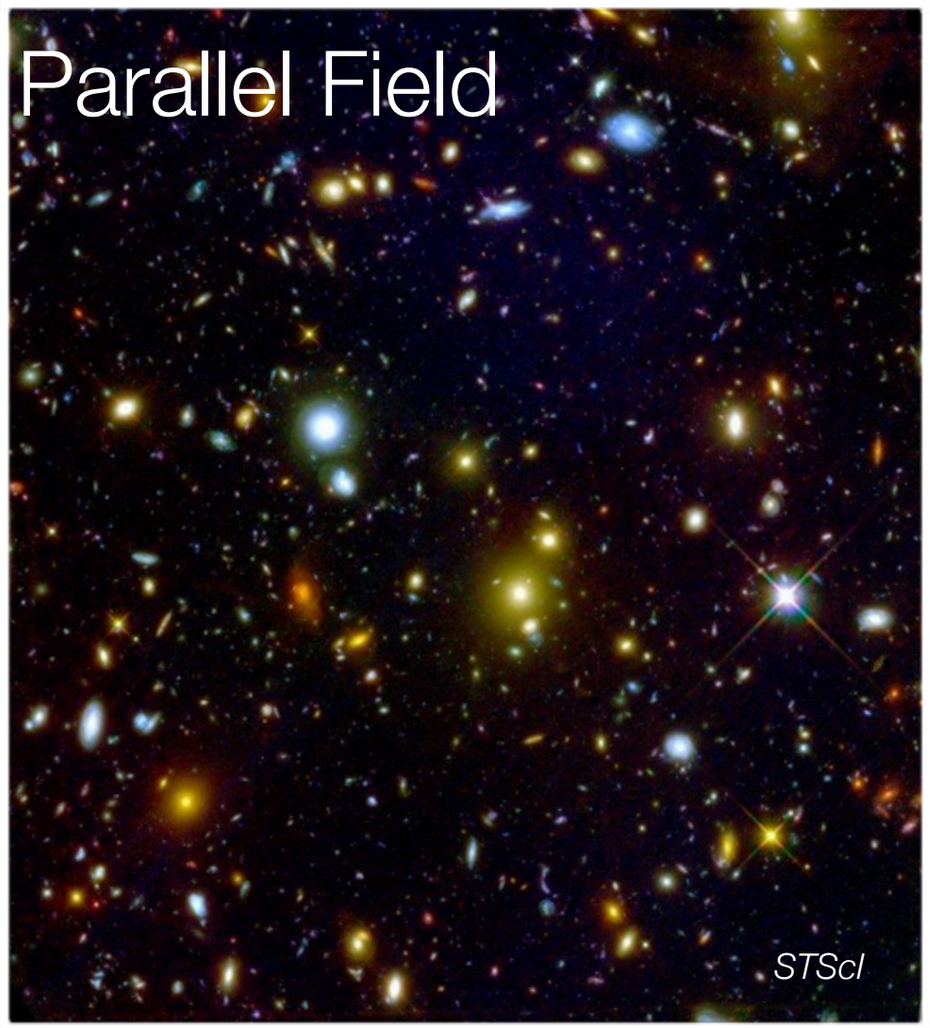
Brighter galaxies from the samples in Ishigaki, RK+2015

31 galaxies at z~6-7 (i-drop), 8 galaxies at z~8 (Y-drop)



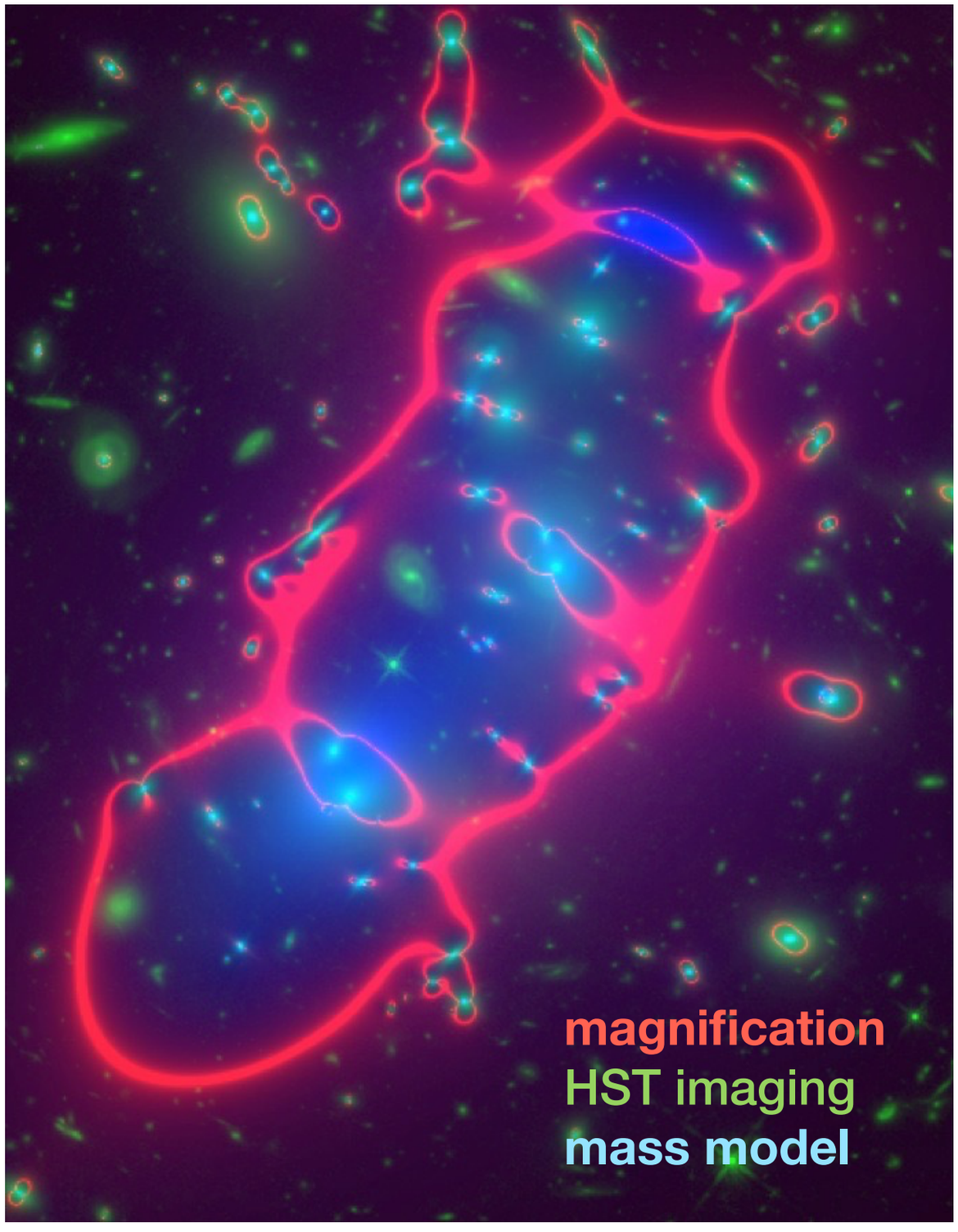
WFC3/IR: Near Infra red
ACS: Optical





MASS MODEL CONSTRUCTION

- glafic (Oguri 2010)
- Parametric modeling method
- Mass components
    - Cluster dark halos:
      NFW profiles
    - Member galaxies:
      elliptical pseudo-Jaffe models
    - External shear
- 24 sets of multiple images

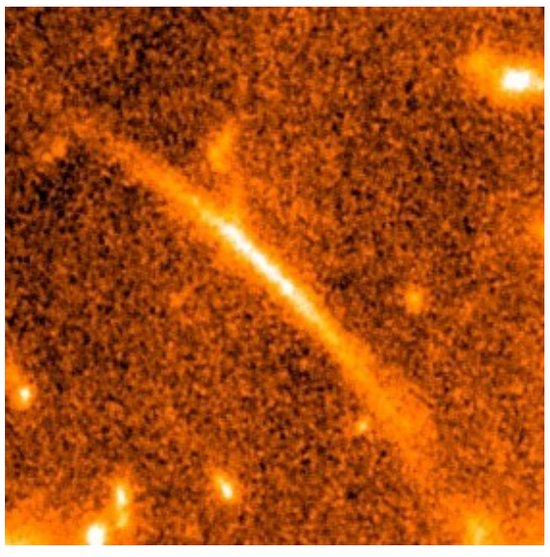


SIZE MEASUREMENT

Fit galaxy light profiles with
lensed and distorted Sérsic profiles

Our Method

Observed Image

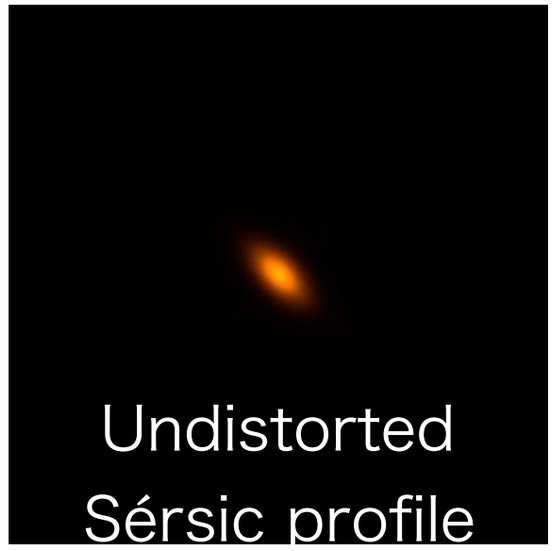


Profile fitting

Image Plane

Lensed by the mass map

Source Plane



Ordinary Method

Profile fitting

Correct the output re & MUV for magnification

OUTLINE

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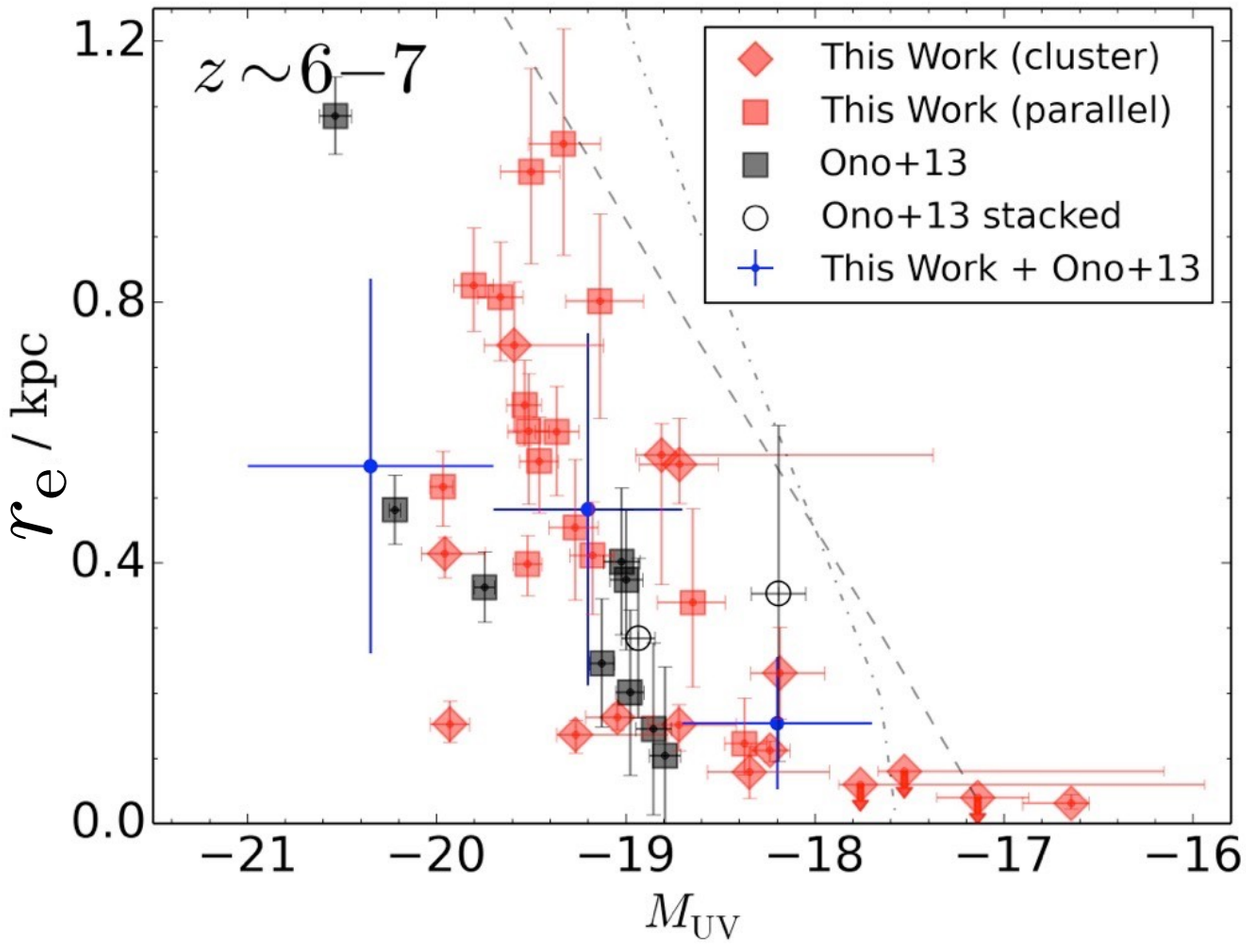
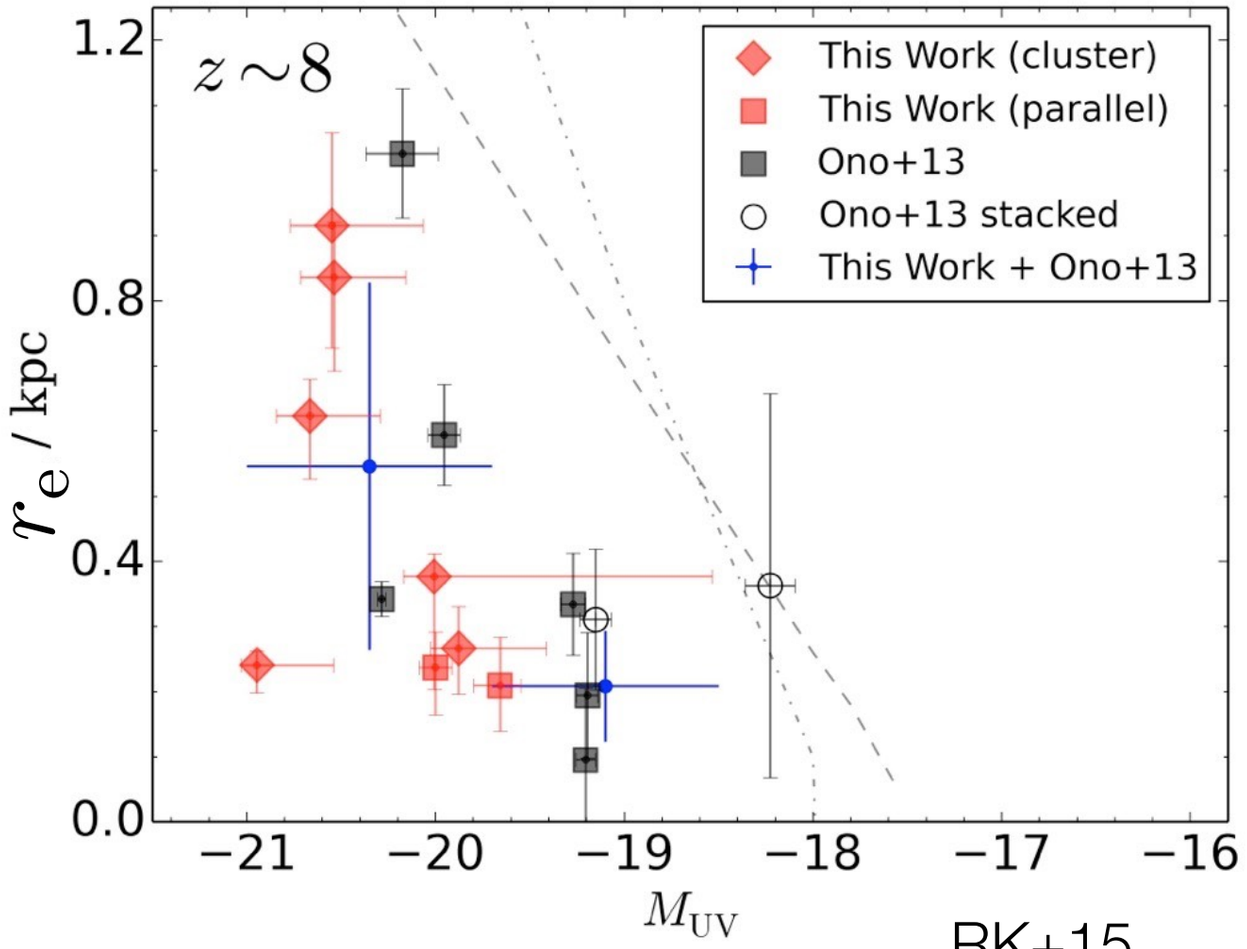
SIZE-LUMINOSITY RELATION

z~6-7: 40 galaxies



z~8: 14 galaxies

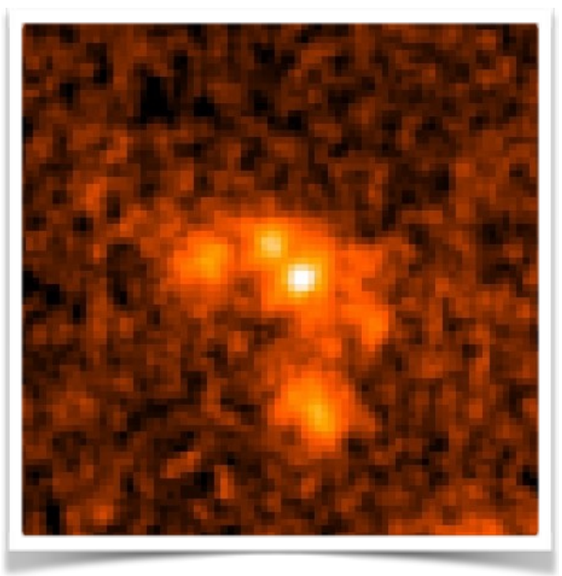


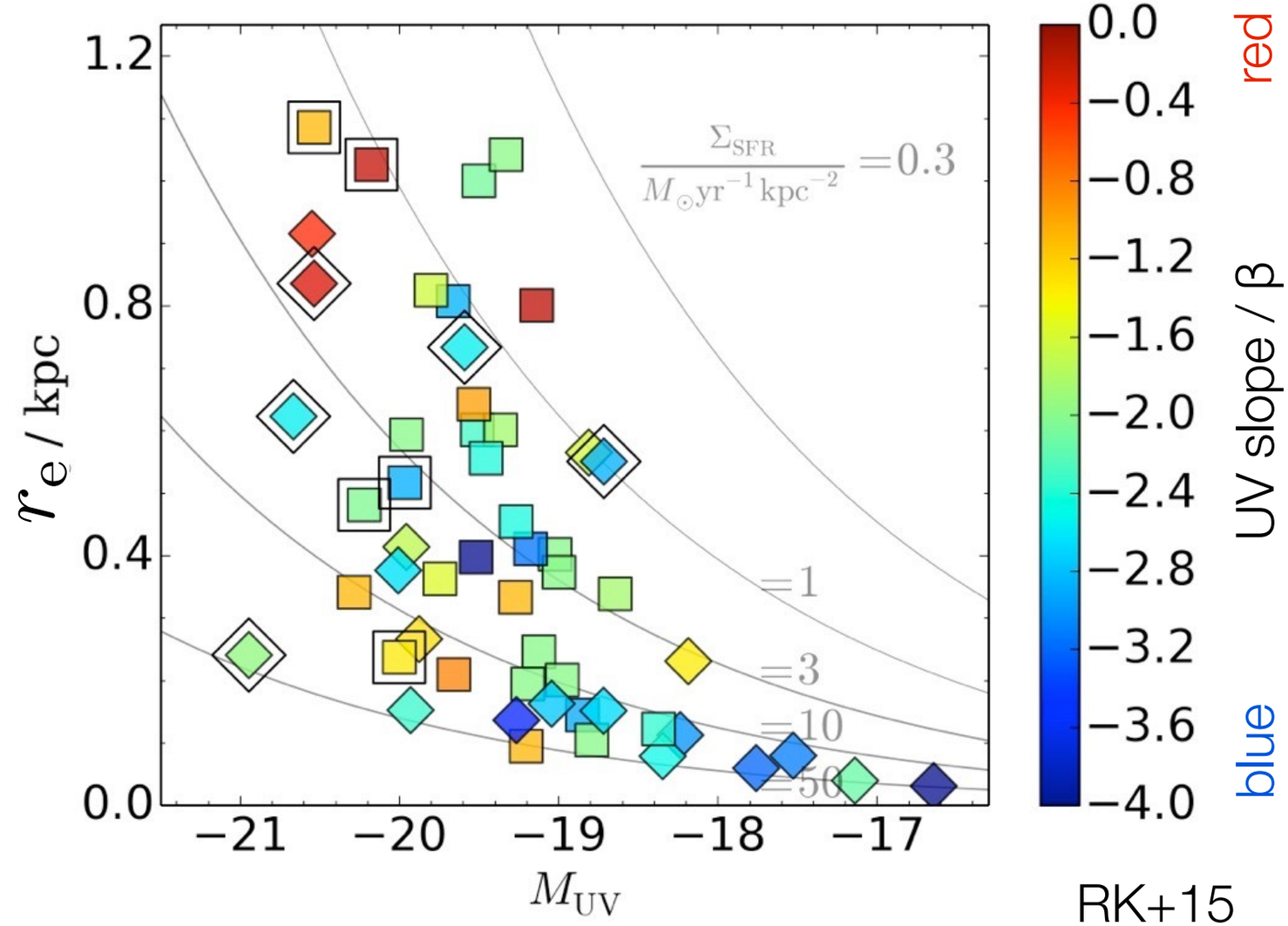
RK+15

- Positive but weak correlation
- Large scatter as expected from the simulated halo spin parameters

DEPENDENCE ON COLOR & MULTIPLICITY

z~6-7 & 8:
54 galaxies





RK+15

- Largest galaxies are mostly red and smallest galaxies are mostly blue
- Galaxies with multiple cores (⧈, ◈) are bright

OUTLINE

- Measurements of sizes and magnitudes
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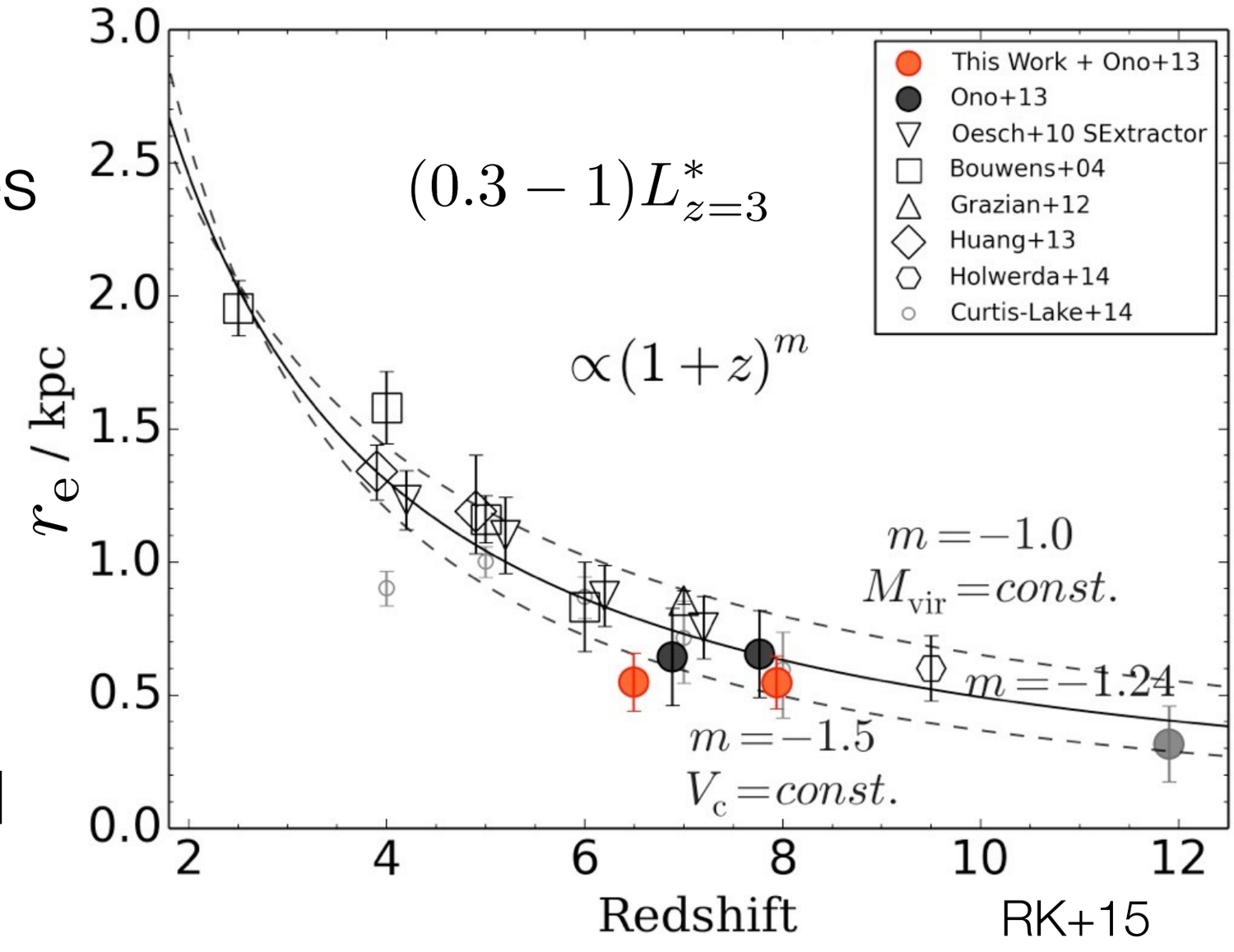
PREVIOUS INTERPRETATION

Assumption:

the half-light radius scales with the virial radius



One can get information on what halos are traced

1. Based on the unconfirmed assumption
2. No absolute value for M_{vir} discussed

ESTIMATING HALO RADII FROM MUV

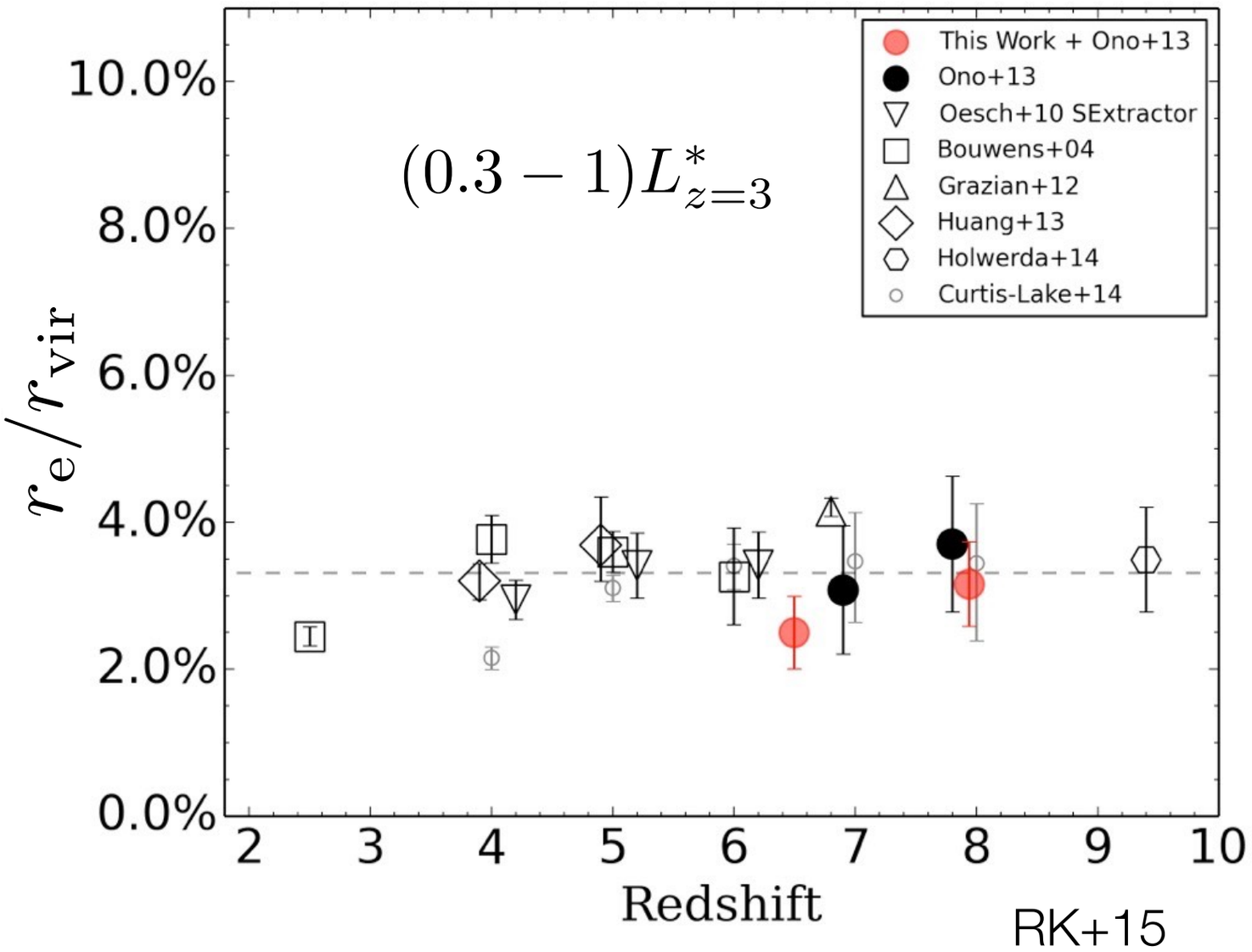
Luminosity

↓ Mass-Luminosity Relation (González+2011 etc.)

Stellar Mass

↓ Abundance matching (Behroozi+2013)

Halo Mass,
Halo Radius



RK+15

The size ratio of disk to halo is constant at 3.3% over z~2.5-9.5

DISK FORMATION MODEL

$$\frac{r_{\rm e}}{r_{\rm vir}} = \frac{1.678}{\sqrt{2}} \left(\frac{j_{\rm d}}{m_{\rm d}} \lambda \right) f_{\rm c}(c)^{-1/2} f_{\rm R}(j_{\rm d}/m_{\rm d}, m_{\rm d}, \lambda, c)$$

Mo+1998

j_d: angular momentum ratio of disk to halo

m_d: mass ratio of disk to halo

λ: spin parameter of halo

c: concentration parameter of halo

- **λ** and **c** are parameters of the **halo**
  ← **well determined** by N-body simulations
  (e.g. Bullock+01)

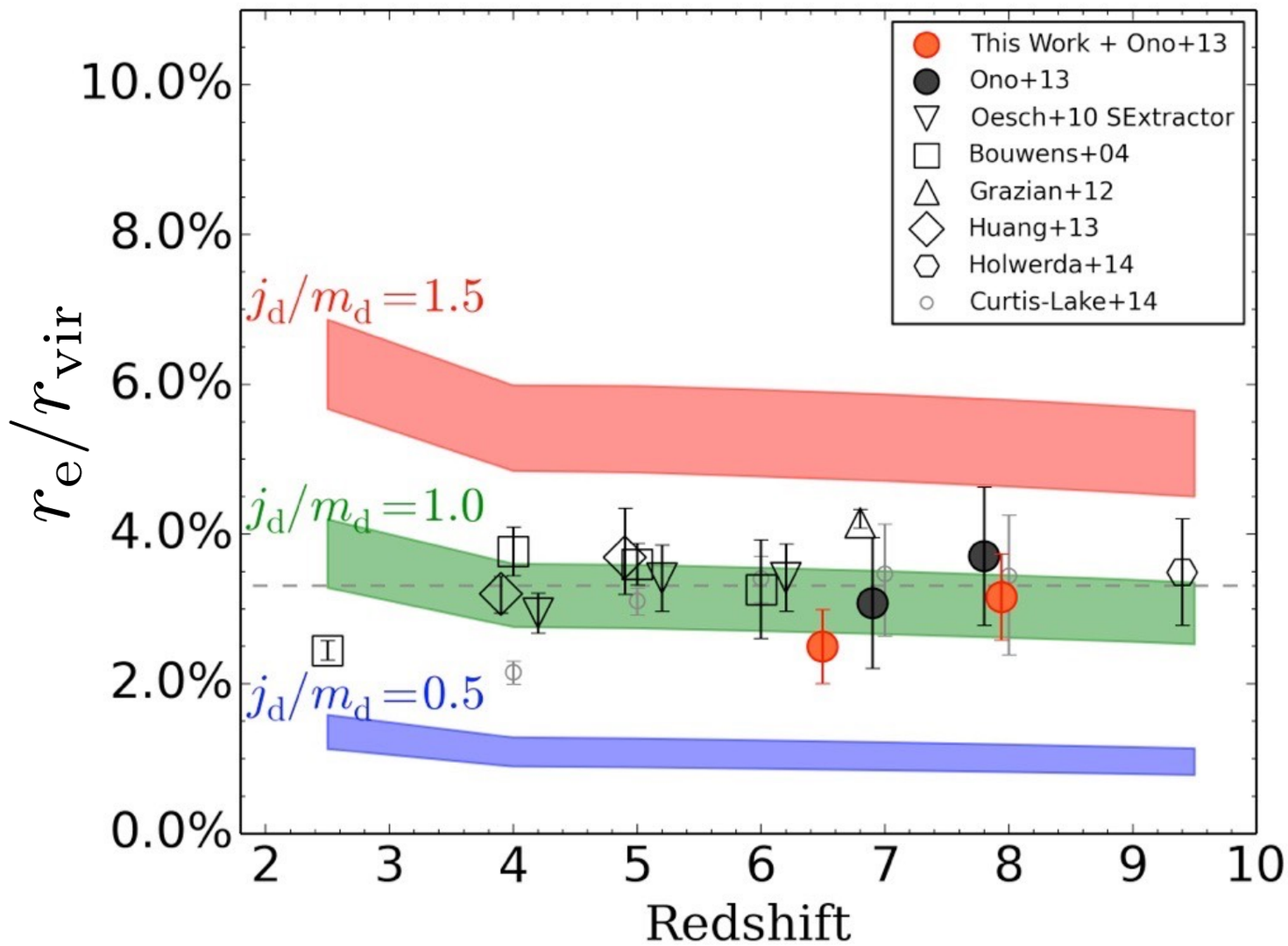
↕

- **j_d** and **m_d** are parameters of the **disk**
  ← depend on baryonic physics
  and are **not reliably predicted**

j_d/m_d OF HIGH-Z GALAXIES

$$\frac{r_{\rm e}}{r_{\rm vir}} = \frac{1.678}{\sqrt{2}} \left(\frac{j_{\rm d}}{m_{\rm d}} \lambda \right) f_{\rm c}(c)^{-1/2} f_{\rm R}(j_{\rm d}/m_{\rm d}, m_{\rm d}, \lambda, c)$$

Mo+1998



The observed size ratio is consistent with $j_d/m_d = 1$

MEANING OF $j_d/m_d \sim 1$

$$\frac{j_{\rm d}}{m_{\rm d}} = \frac{J_{\rm d}/M_{\rm d}}{J_{\rm h}/M_{\rm h}}$$

J_X: angular momentum
M_X: mass
X: disk or halo

Specific angular momentum of the disk and halo are the same

Each disk formation model predicts the different angular momentum distribution to the disk and halo

Constrain the disk formation models

HUBBLE FRONTIER FIELDS PI: J. Lotz

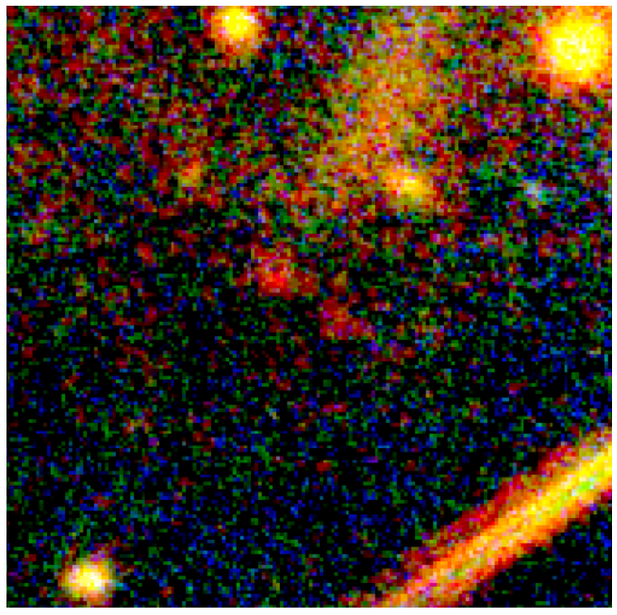
Deep and **high-resolution** observations by HST

+

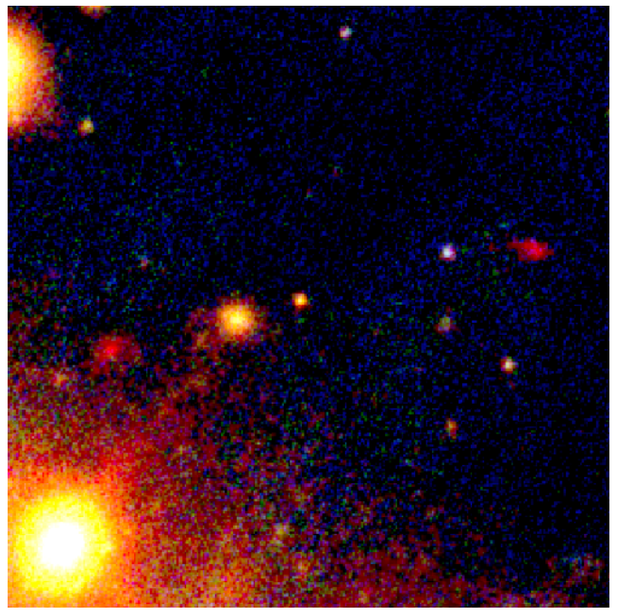
Strong gravitational lensing effects by clusters

TARGETS FOR ALMA FOLLOW UP

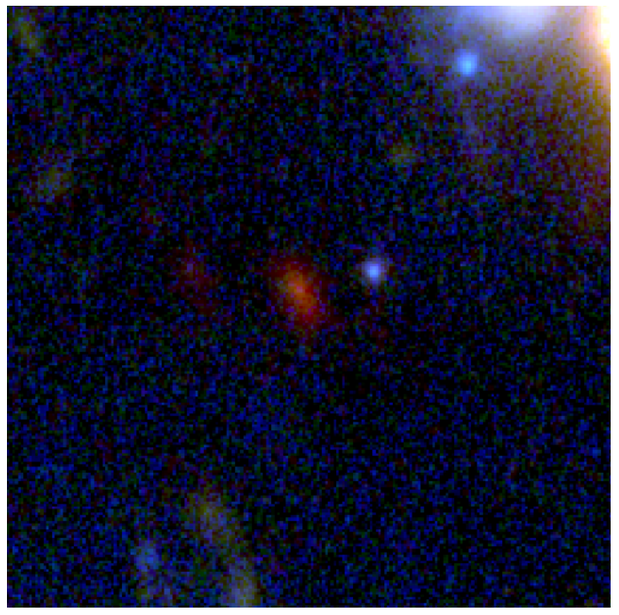
- Galaxies found in HFFs, especially strongly lensed ones, are good targets to detect [OIII] & [CII] emission lines and dust continuum with ALMA (see also Infante+2015)
- For those multiply imaged, the redshifts are doubly checked by the photo-z and mass models



z~8.5, μ>40,
H_{160} ~ 28.2

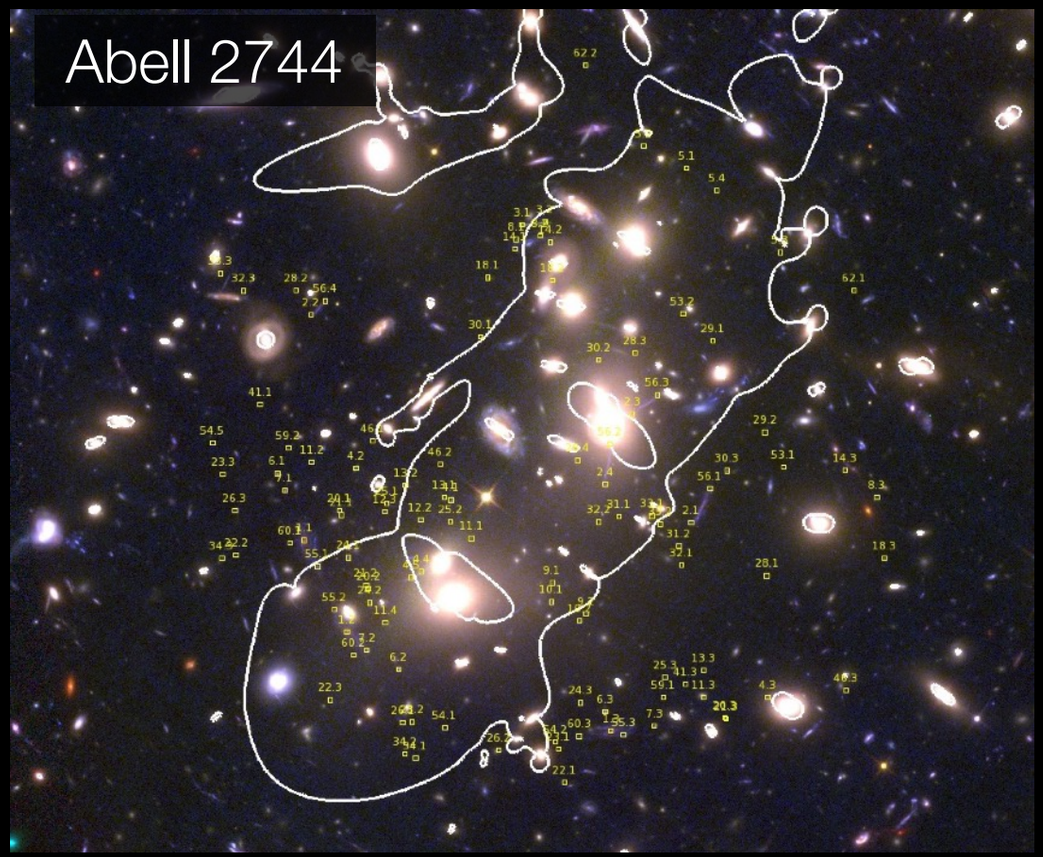


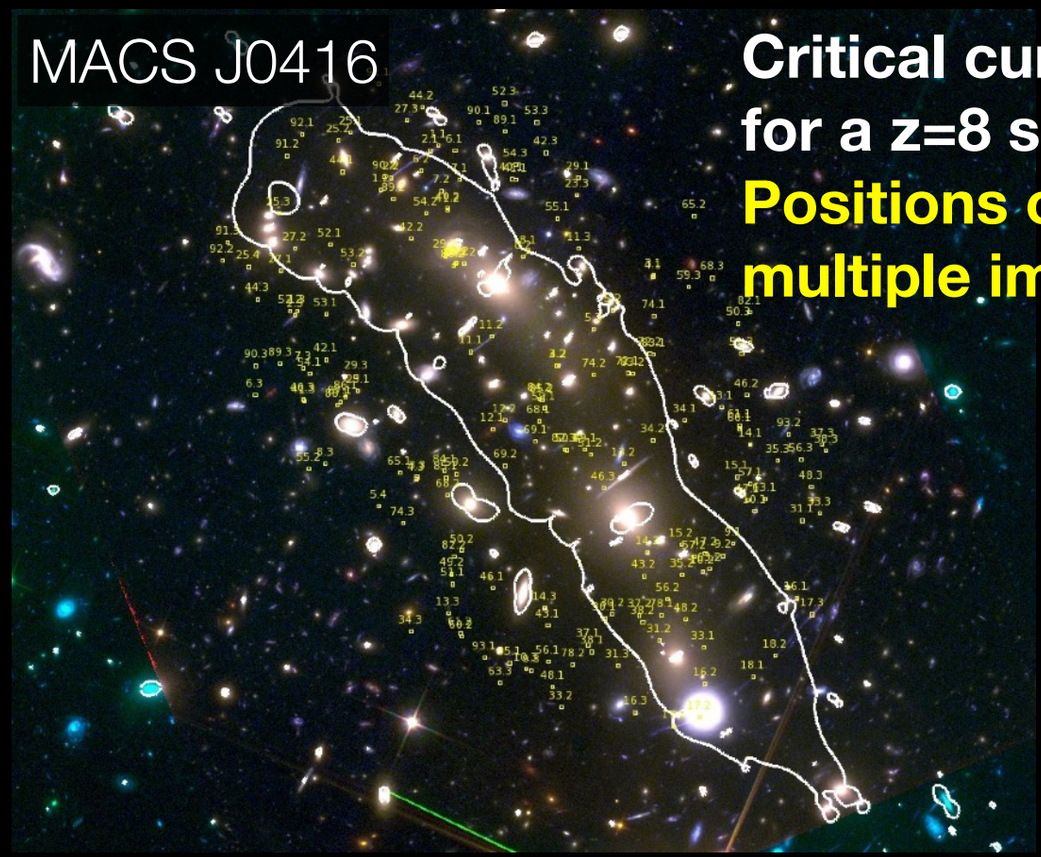
z~8.4, μ~30,
H_{160} ~ 25.6



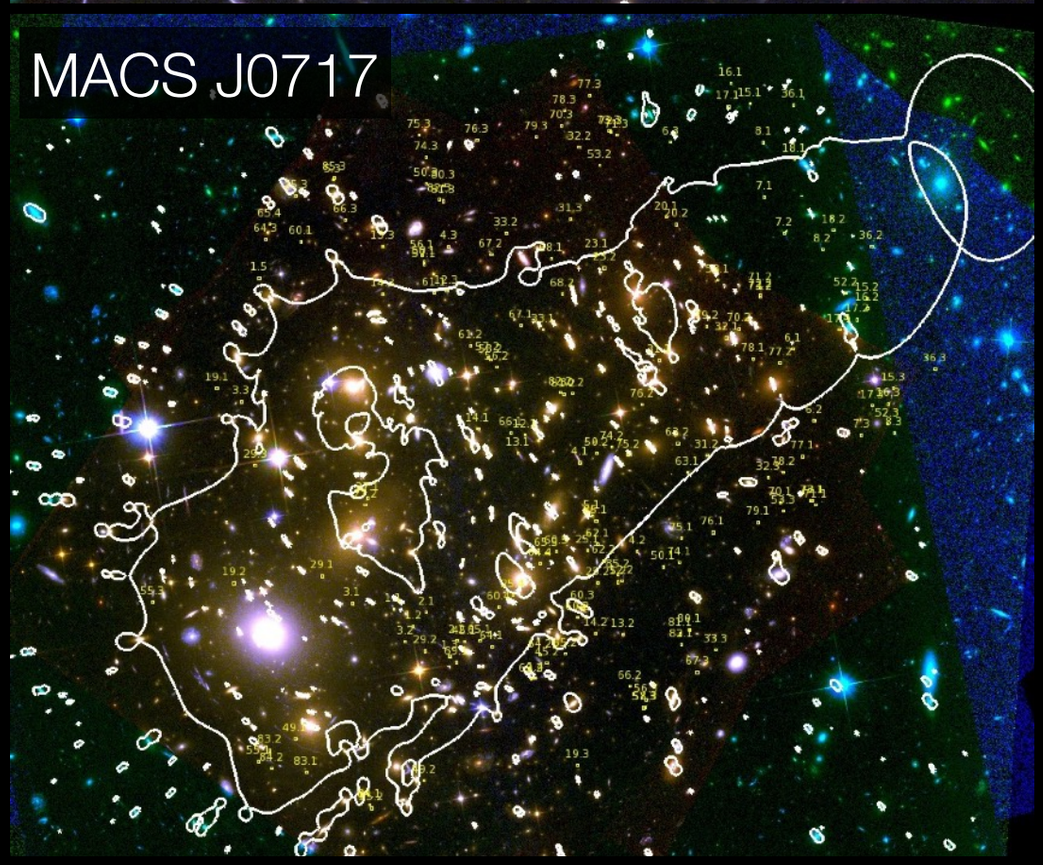
z~7.8, μ~8.8,
H_{160} ~ 25.5

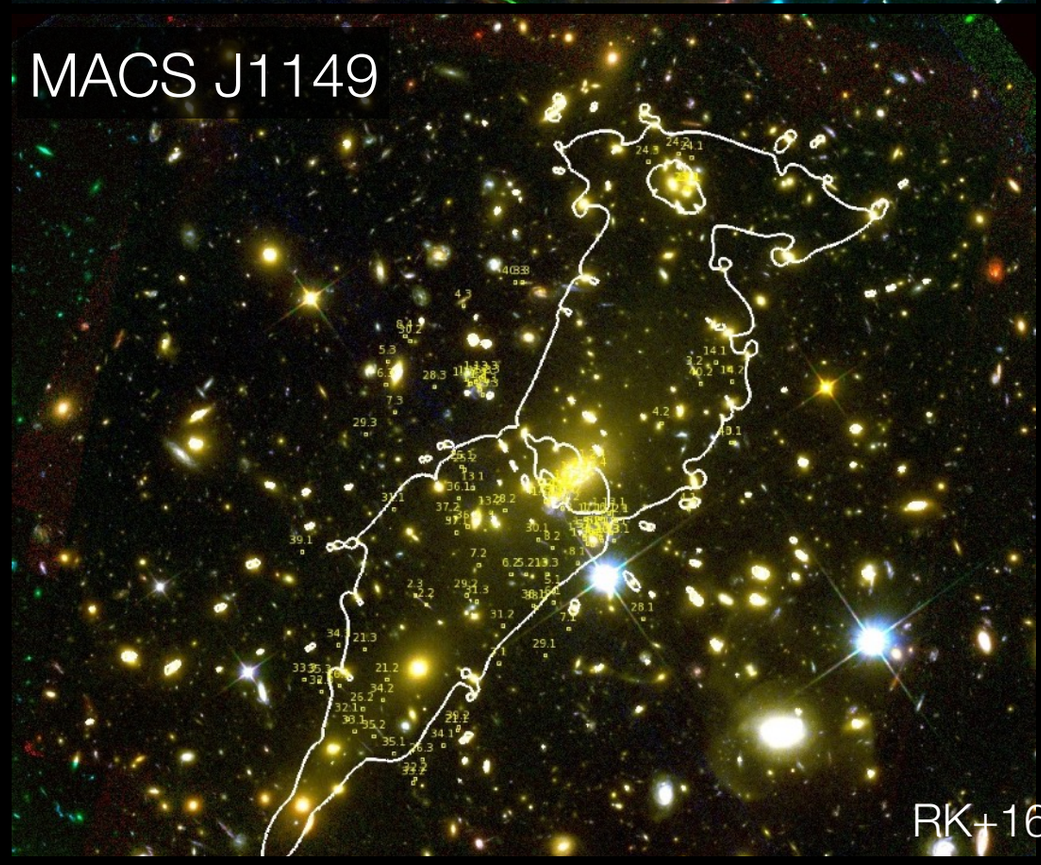
GLAFIC TEAM'S MASS MODELS





Critical curves for a z=8 source
Positions of multiple images



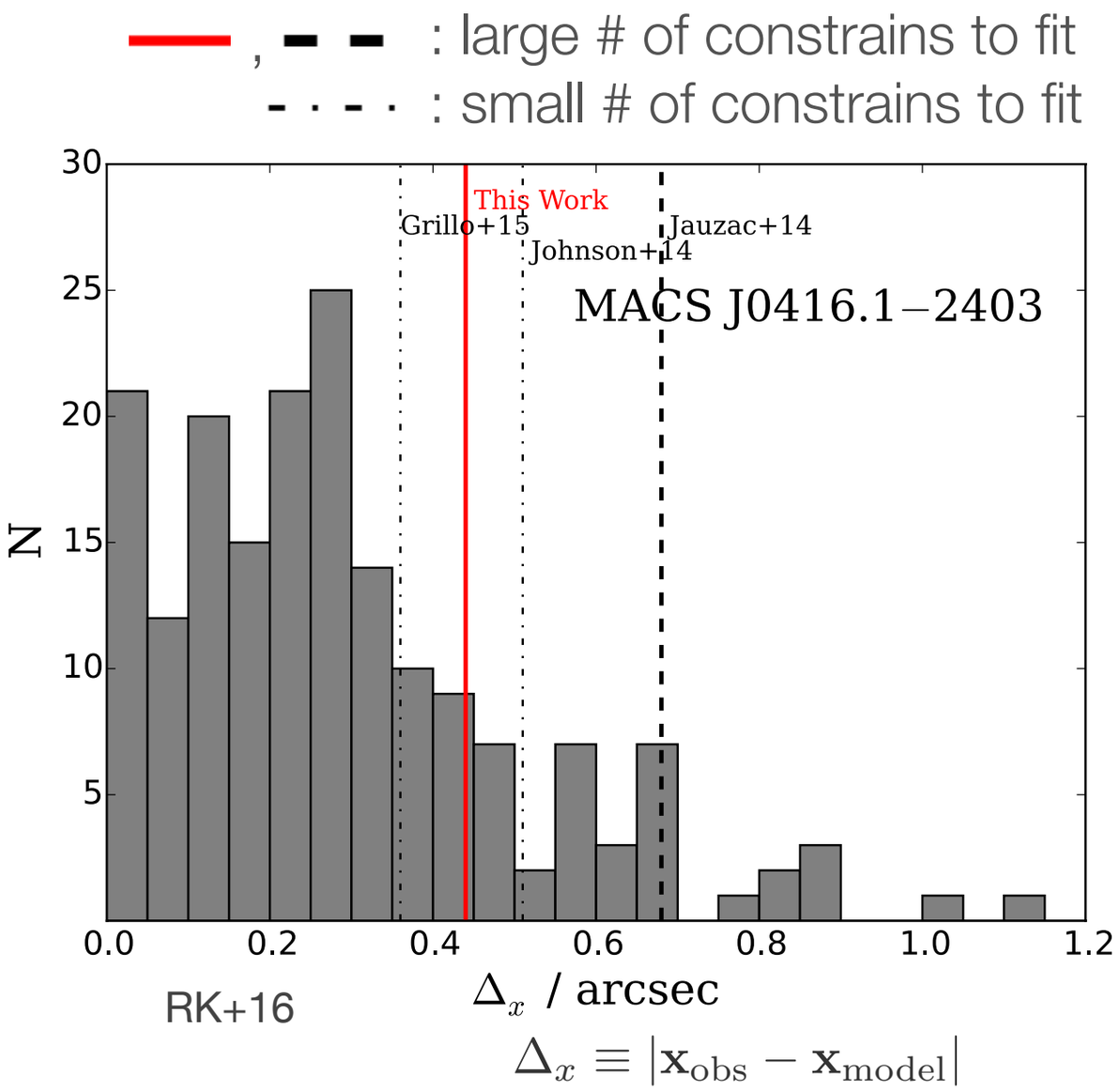


RK+16

PRECISE MASS MODELS

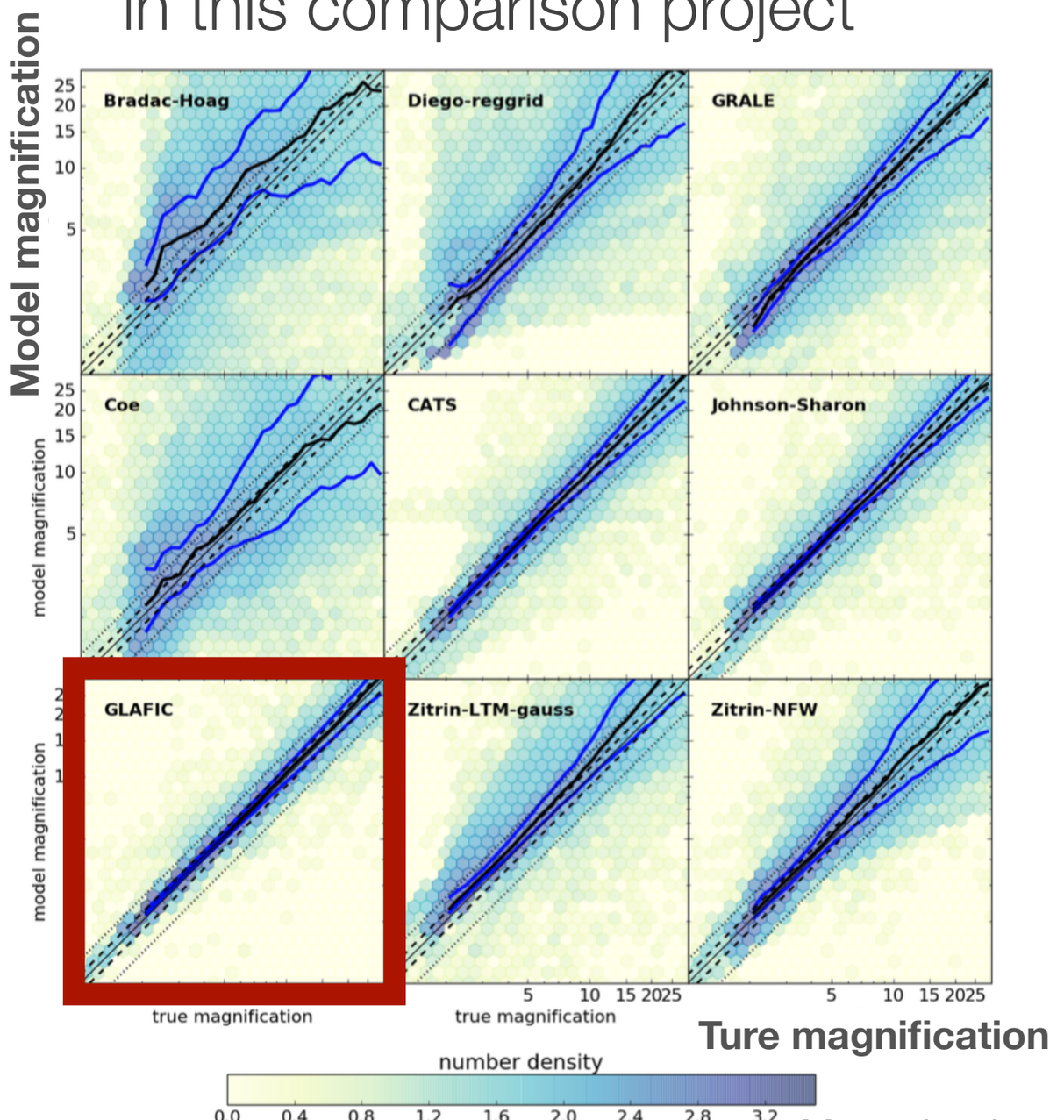
Distances between observed and model-predicted image positions

- Our models achieve good accuracy despite a large # of constrains



Lens modeling test using simulated clusters

- Our models preformed best in this comparison project



SUMMARY

- Measured sizes of 31 z~6-7 and 8 z~8 lensed galaxies using our own mass map
- The ratio of half-light radius to virial radius is constant at 3.3%, which is consistent with $j_d/m_d = 1$
- Positive but weak correlation between r_e and L_{UV}
- Largest galaxies are red, and smallest galaxies are blue
- Galaxies with multiple cores are bright
- HFF provides with good target galaxies for ALMA follow-up observations
- Our mass models are proved to be accurate and precise