Dark Matter Properties of Groups and Clusters of Galaxies via Weak Gravitational Lensing

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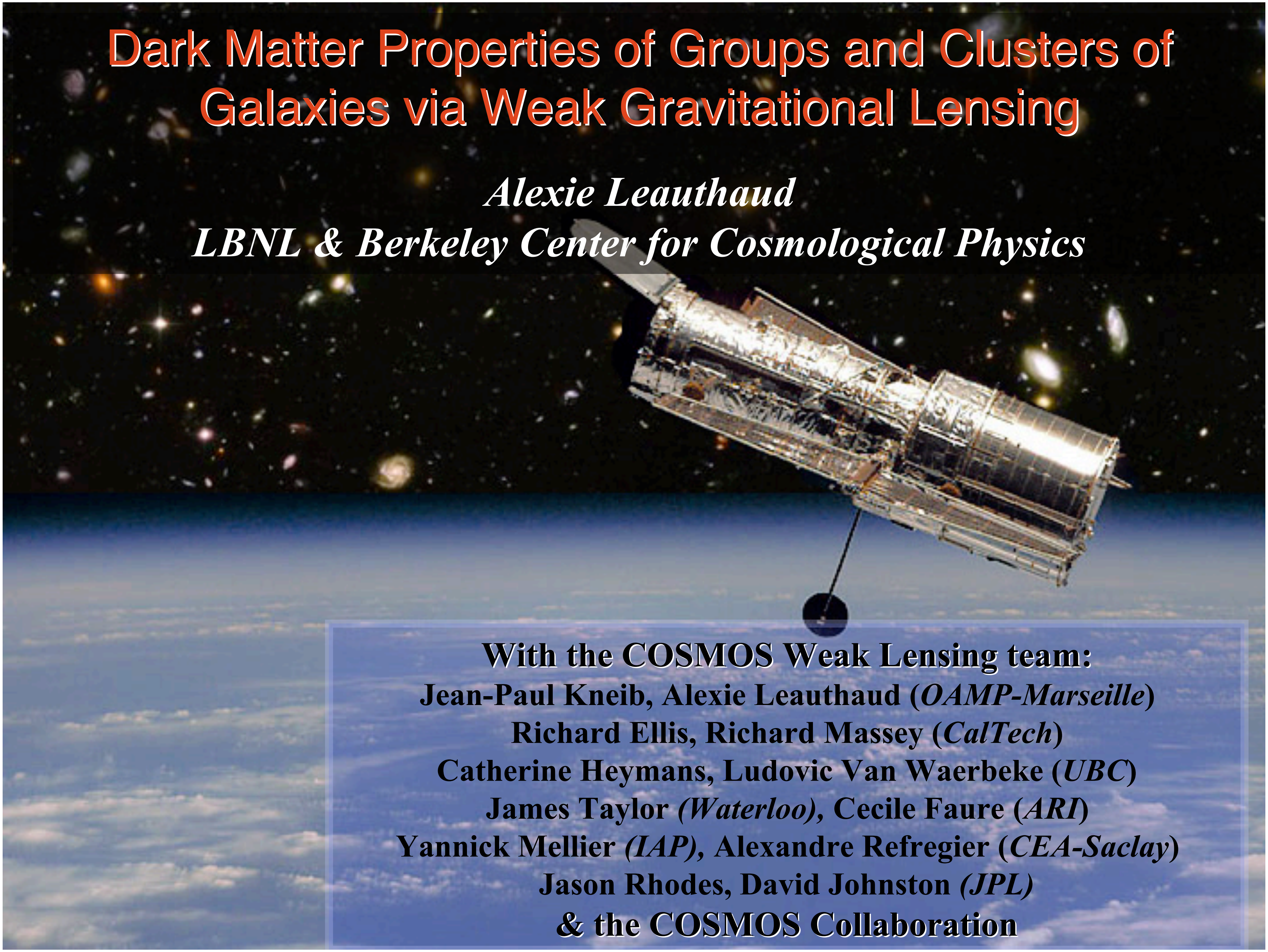

With the COSMOS Weak Lensing team:

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Catherine Heymans, Ludovic Van Waerbeke (*UBC*)

James Taylor *(Waterloo),* Cecile Faure (*ARI*)

Yannick Mellier *(IAP),* Alexandre Refregier (*CEA-Saclay*)

Jason Rhodes, David Johnston *(JPL)*

& the COSMOS Collaboration

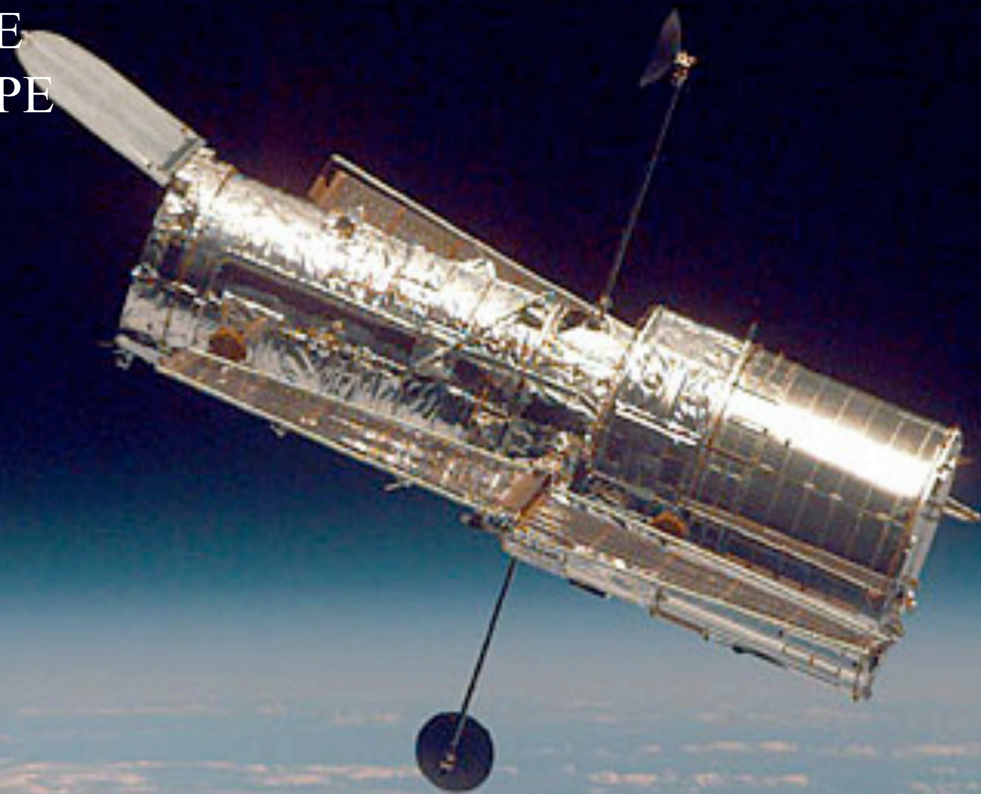
OUTLINE

I. THE COSMOS-HST SURVEY

II. WEAK LENSING WITH THE HUBBLE SPACE TELESCOPE

III. MOTIVATION FOR THIS STUDY

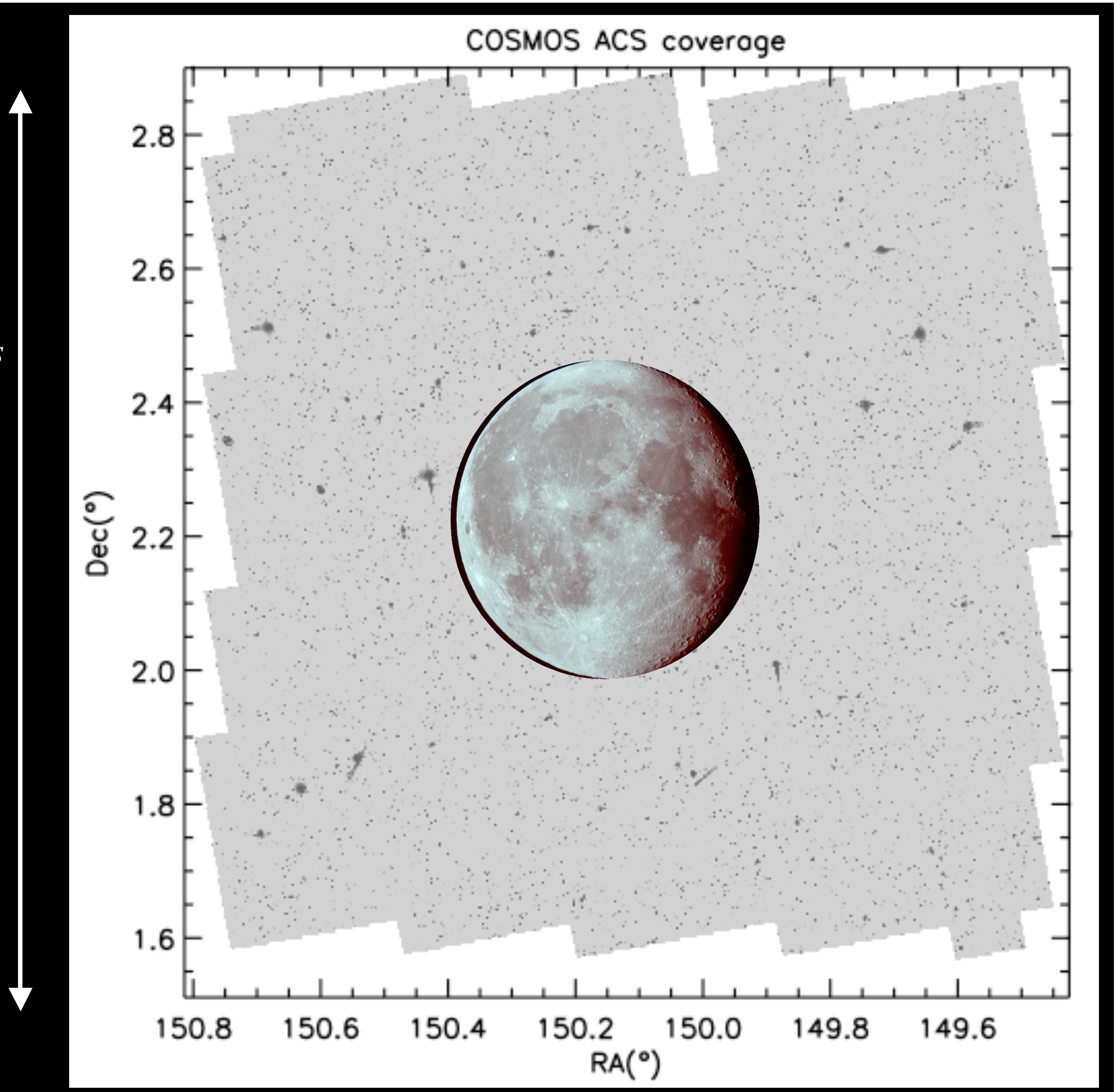
IV. GROUPS & CLUSTERS OF GALAXIES



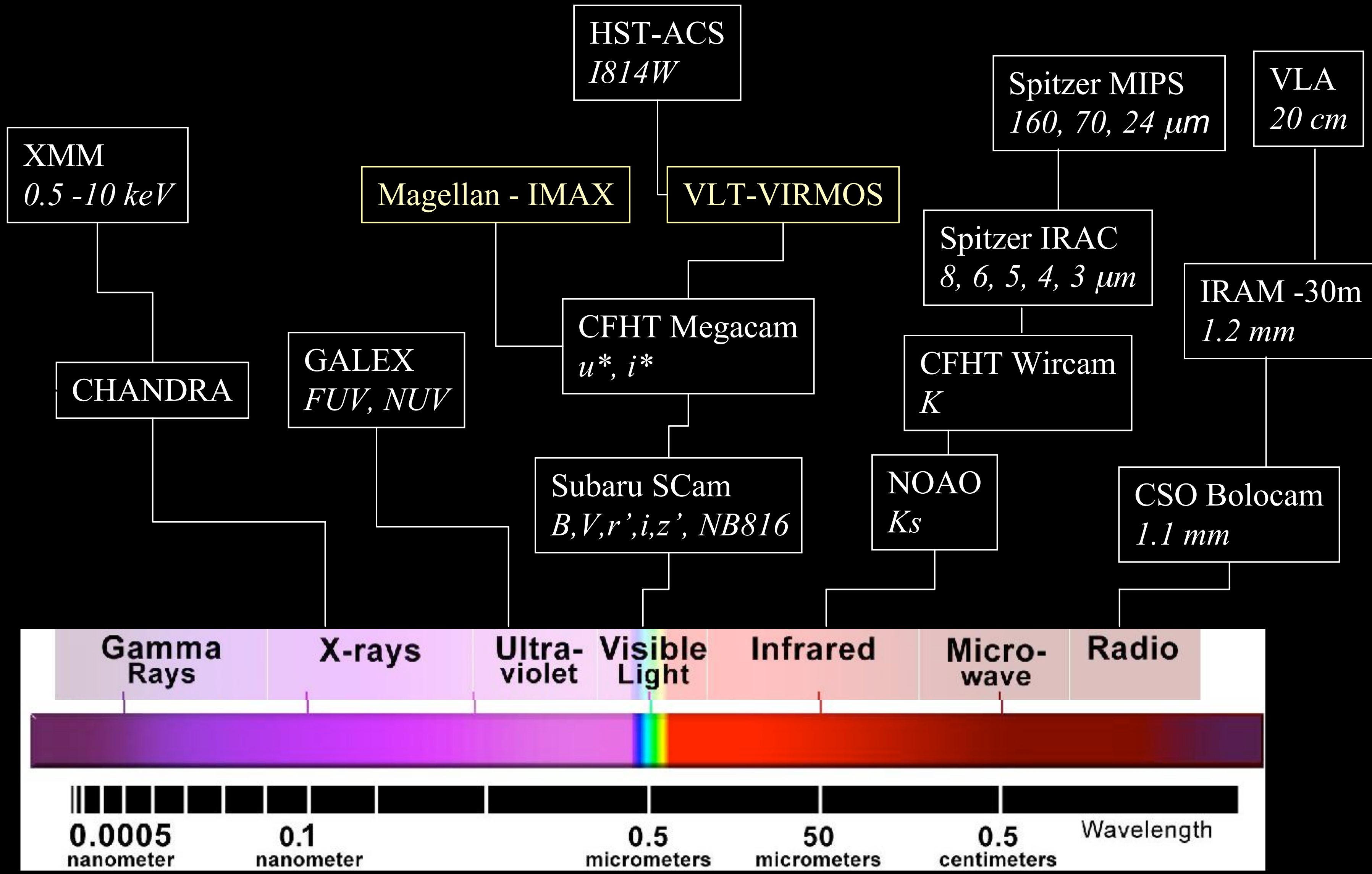
THE COSMOS SURVEY

The largest contiguous image ever taken with the Hubble Space Telescope (HST)

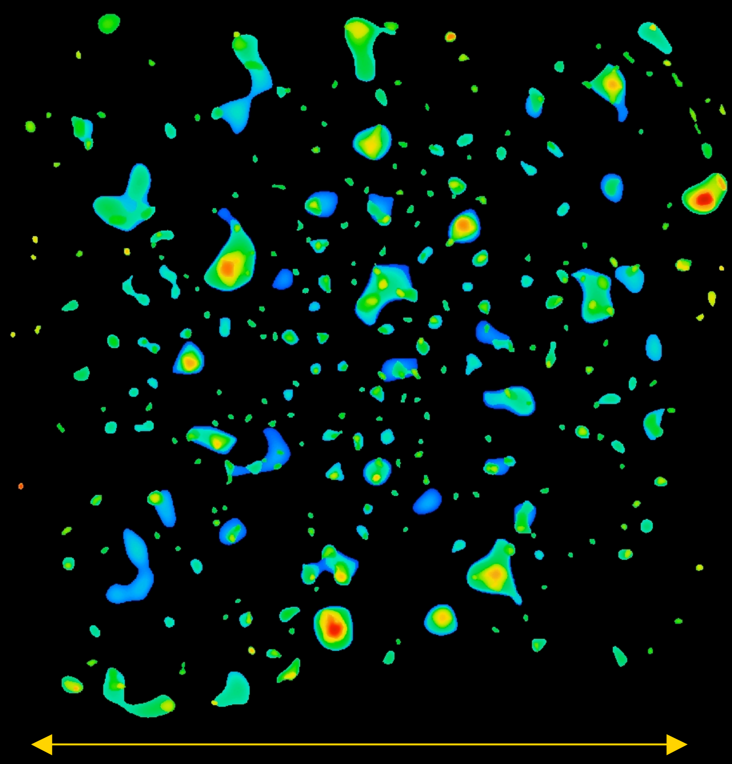
HST ACS
Cycles 12 & 13
590 orbits



I. COSMOS: A PANCHROMATIC SURVEY



I. THE COSMOS XMM GROUP SAMPLE



1.3 deg^2

COSMOS survey
CHANDRA + XMM
A. Finoguenov et al. 2007

❖ ~ 180 groups detected through extended XMM emission
Finoguenov et al. 2007

❖ 1.67 deg^2 of contiguous ACS data - high background number density (60 gals/$arcmin^2$) - no issues with the mass sheet degeneracy
Leauthaud et al. 2007, Rhodes et al. 2007

❖ State of the art photometric redshifts (30 bands of data including IR and u band)
Ilbert et al. 2008

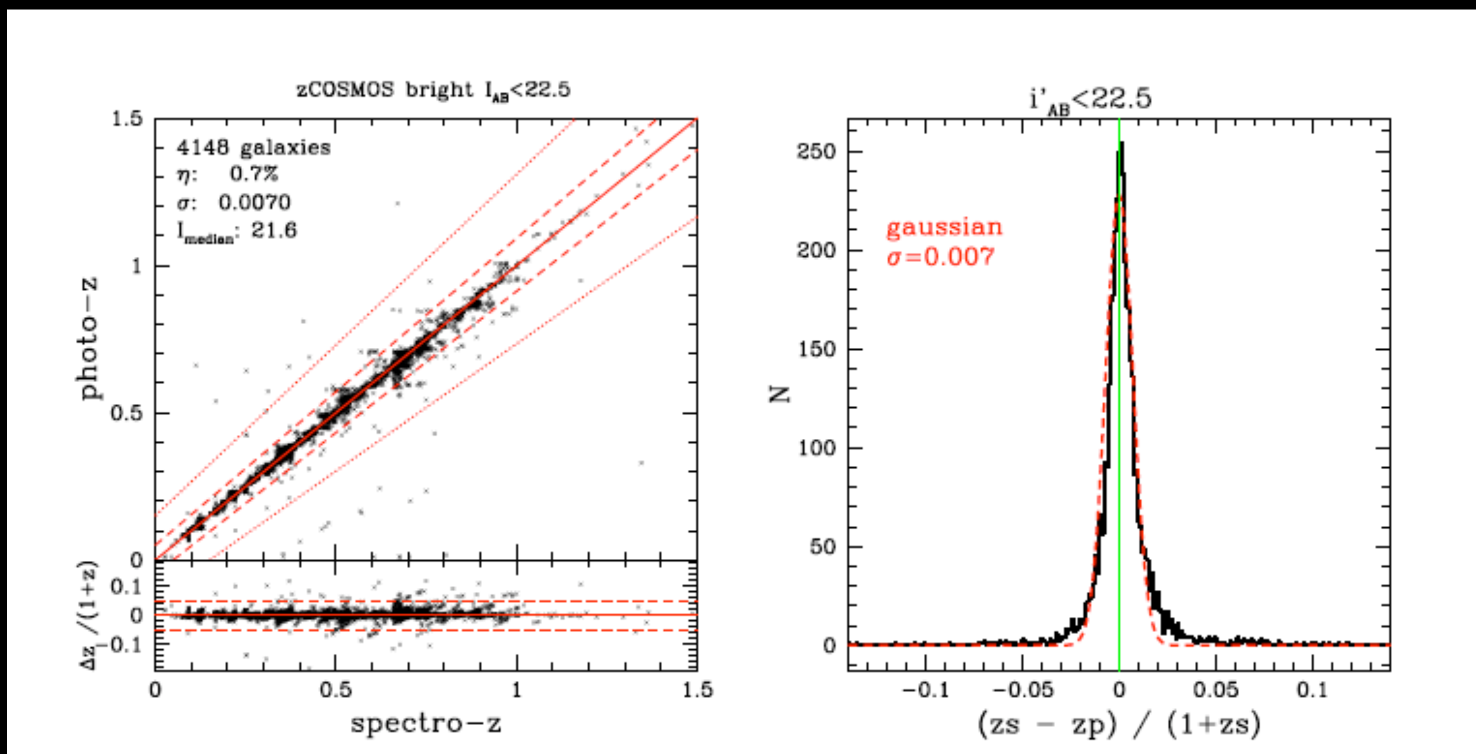
❖~ 10 000 spectroscopic redshifts for photoz calibration
Lilly et al. 2007

I. THE THIRD DIMENSION: PHOTOZ'S

The Z-COSMOS bright sample is magnitude limited at $i^{+}_{AB} < 22.5$:
A comparison to the Z-COSMSO bright sample shows that in this magnitude range, the COSMOS photometric redshifts reach an accuracy of:

$$\sigma z/(1+z) = 0.007$$, catastrophic failures < 1 %

PHOTO-Z

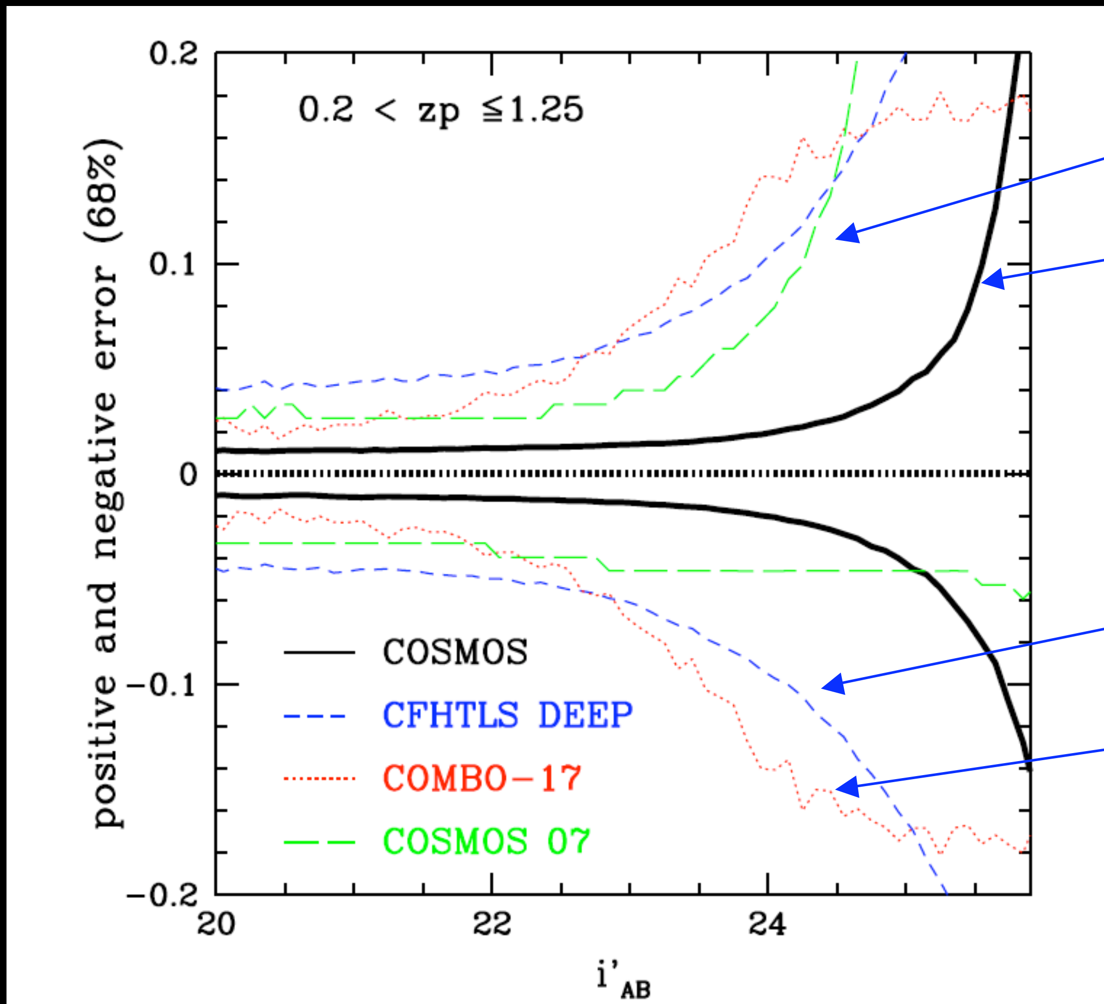


SPECZ

Ilbert et al. 2008

I. Errors as a Function of Magnitude

68% ERROR



Old COSMOS

New COSMOS

CFHTLS Deep

COMBO - 17

Ilbert et al. 2008

i^{+}_{AB}

I. COSMOS REDSHIFT DISTRIBUTION

N/deg^2/10^4

Cumulative n(z)

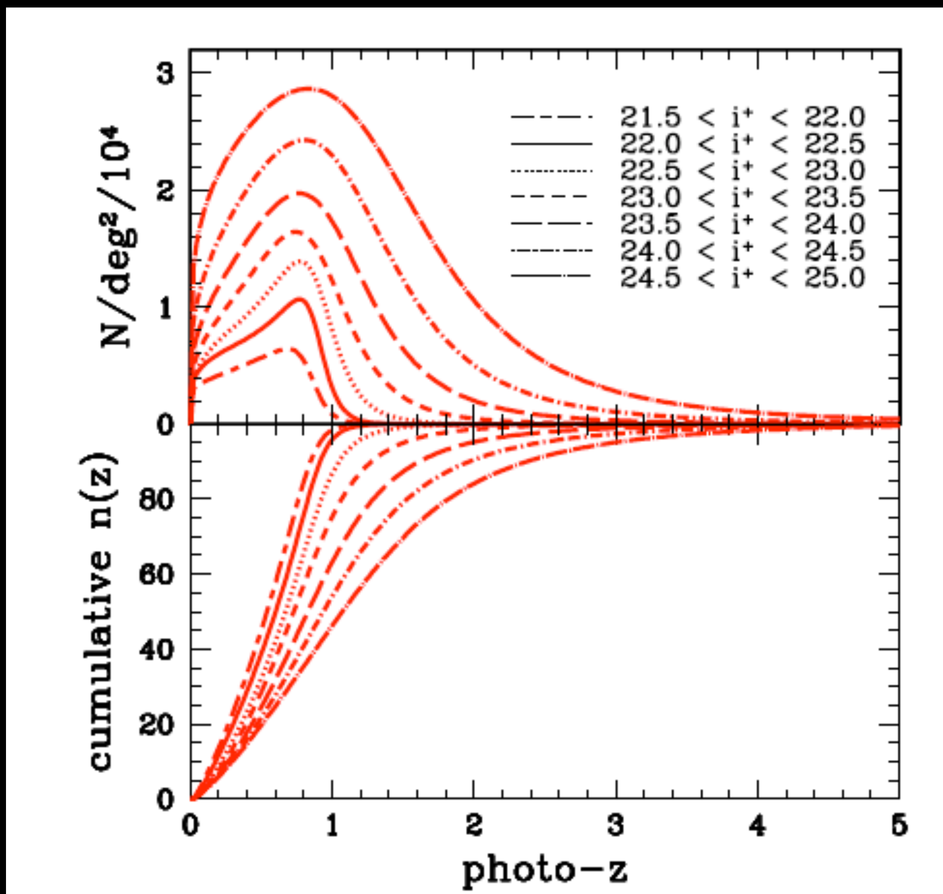


Photo-z

Ilbert et al. 2008

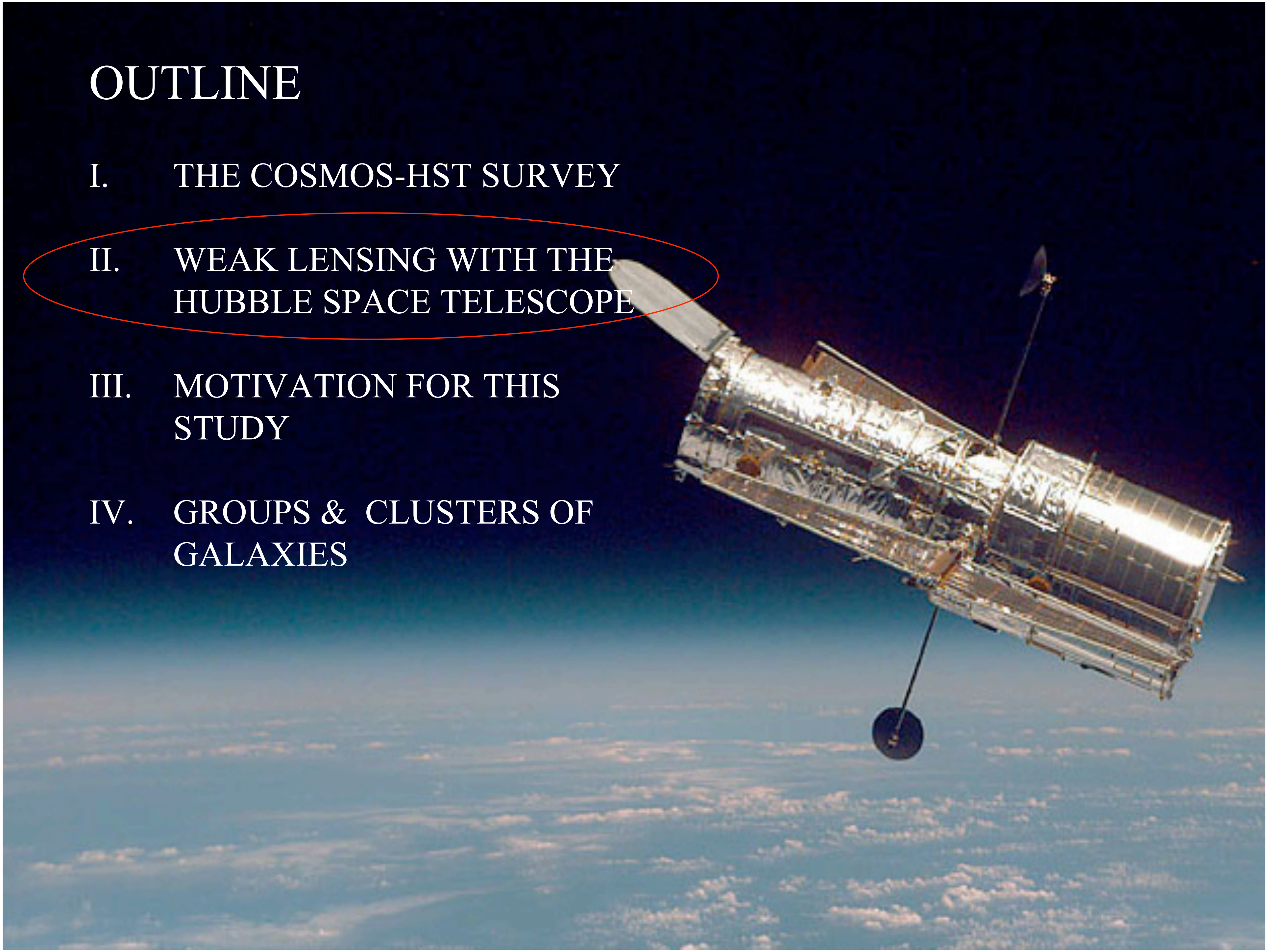
Note: Photometric redshifts are a key element to weak lensing studies because the strength of the lensing signal depends on the angular diameter distances D_{OS} D_{OL} D_{LS} in particular through a quantity known as the *critical surface mass density*:

$$\Sigma_{crit} = \frac{c^2}{4\pi G}\frac{D_{OS}}{D_{OL}D_{LS}}$$

D_{OS}: distance Observer-Source
D_{OL}: distance Observer-Lens
D_{LS}: distance Lens-Source

(*more details soon …*)

I. Shear: Space versus Ground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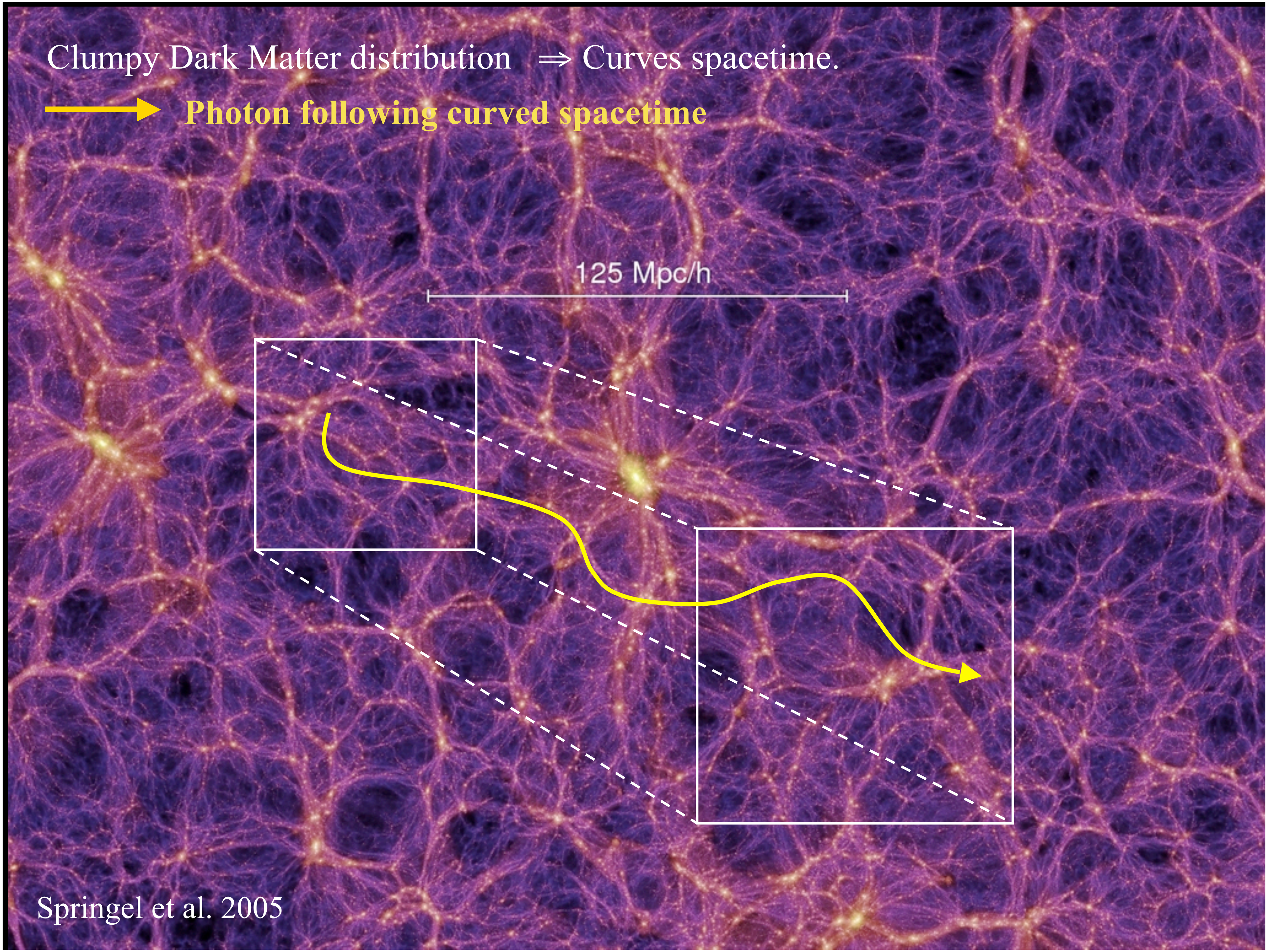

Clumpy Dark Matter distribution ⇒ Curves spacetime.
Photon following curved spacetime
125 Mpc/h
Springel et al. 2005

II. Weak Gravitational Lensing

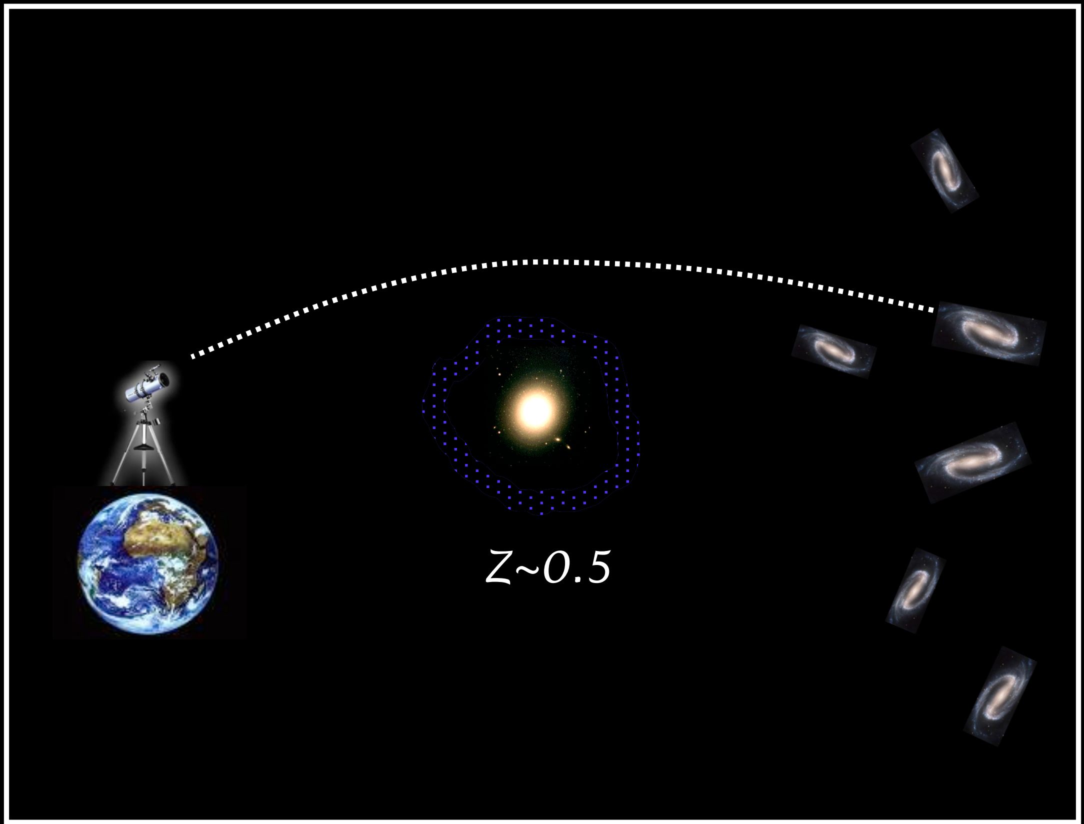
Simulation of the gravitational lens effect created by a massive object that passes in front of the Hubble Deep Field (HDF)

L. L. Christensen (ESA)

II. Weak Gravitational Lensing

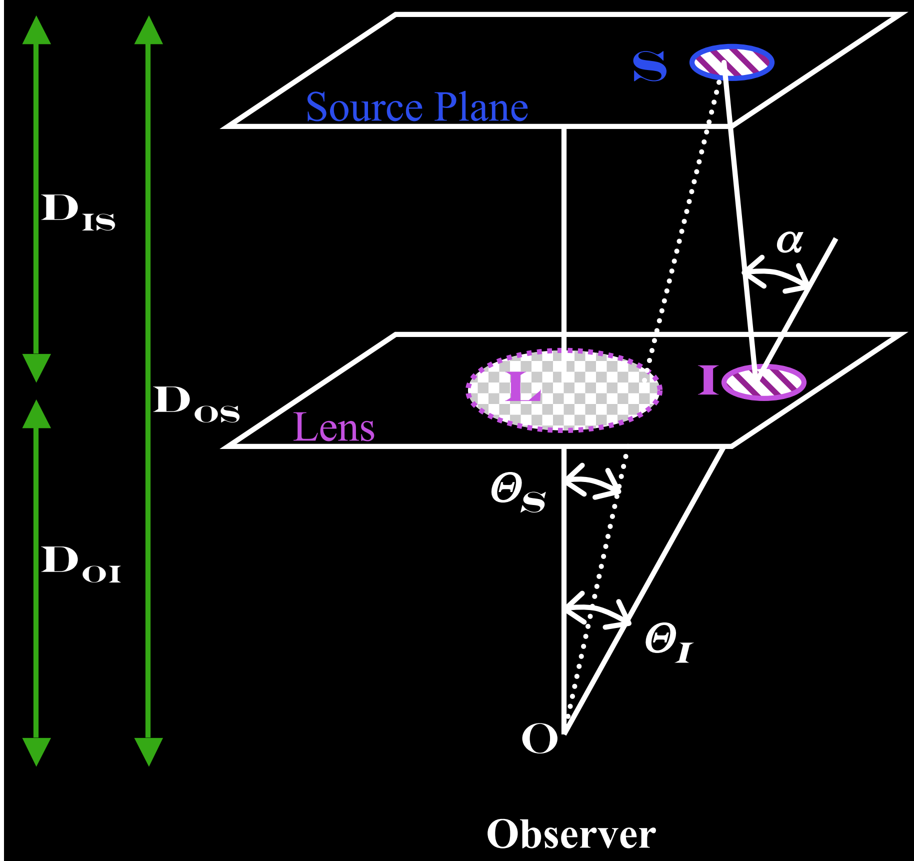
Weak gravitational lensing

Strong gravitational lensing



Simulation of the gravitational lens effect created by a massive object that passes in front of the Hubble Deep Field (HDF)

II. Galaxy-Galaxy Lensing



We study the tangential component of the shear in circular annuli around a set of galaxies (~ 500). The quantity that we seek to measure is *Delta Sigma* which is the product of the shear and *Sigma Crit* :

$$\Delta\Sigma(r) \equiv \overline{\Sigma}(<r) - \overline{\Sigma}(r) = \Sigma_{crit} \times \gamma_t(r)$$

In this equation, *Sigma* represents the surface mass density of the central lens. In order to calculate *Delta Sigma*, we must calculate *Sigma Crit* for each lens-source pair :

$$\Sigma_{crit} = \frac{c^2}{4\pi G}\frac{D_{OS}}{D_{OL}D_{LS}}$$

→ *Photo-Z*

To calculate *Sigma Crit* we must know the angular diameter distances between the observer, the source and lens (D_{OS}, D_{OL}, et D_{LS}). These distances are given by the COSMOS photometric redshifts.

II. The Scientific Promise of Gravitational Lensing

I. Weak lensing by large-scale structure ('**Cosmic shear'**) → evolution of the non-linear power spectrum & constraints on cosmological parameters $\mathbf{\Omega_M}$, $\boldsymbol{\sigma_8}$, $\boldsymbol{w}$, $\boldsymbol{w'}$…complementing and breaking degeneracies present in other methods (SN, CMB).

II. Direct mapping of the dark matter distribution

III. Weak shear around galaxy clusters → estimate of total cluster mass and mass reconstruction of low redshift clusters.

IV. The average weak lensing shear of distant galaxies and groups (**'galaxy-galaxy lensing'**) → ensemble average properties of dark matter halos → connecting mass and light.

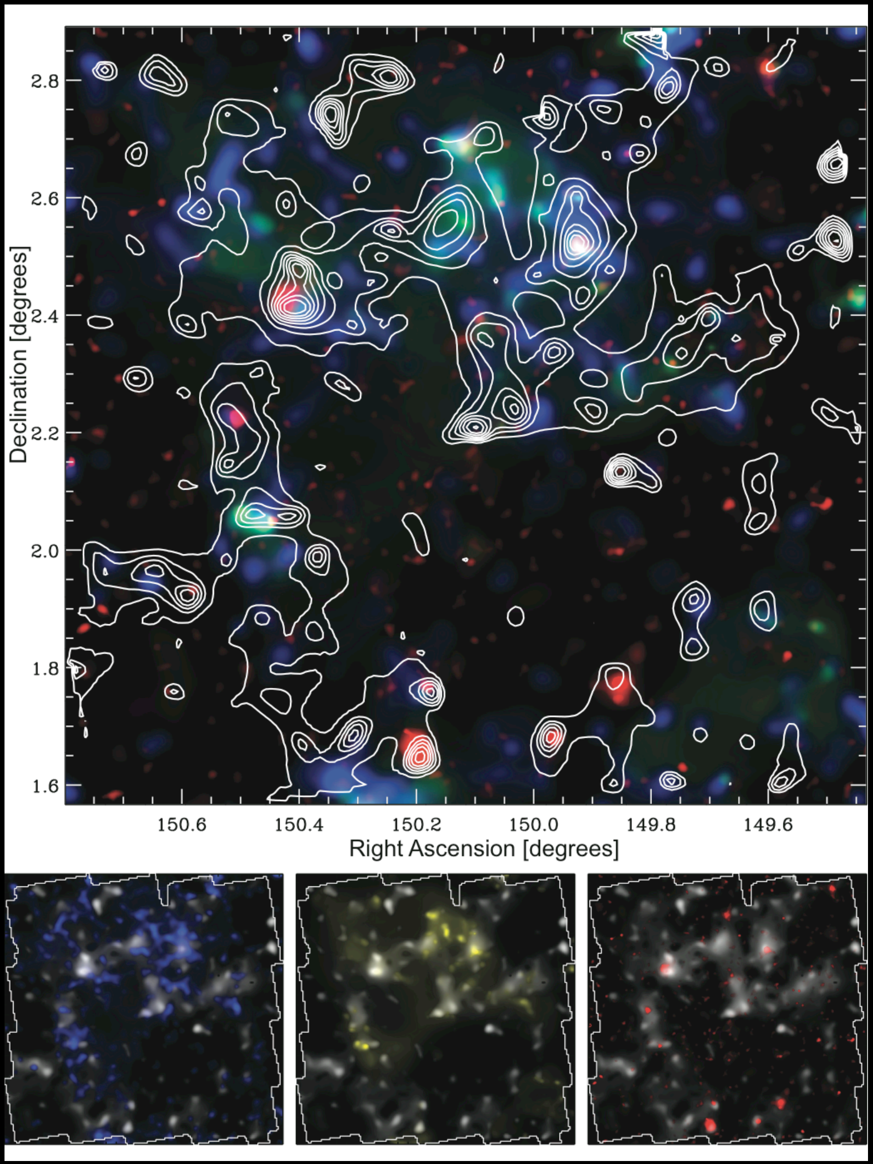
II. A MAP OF THE DARK MATTER

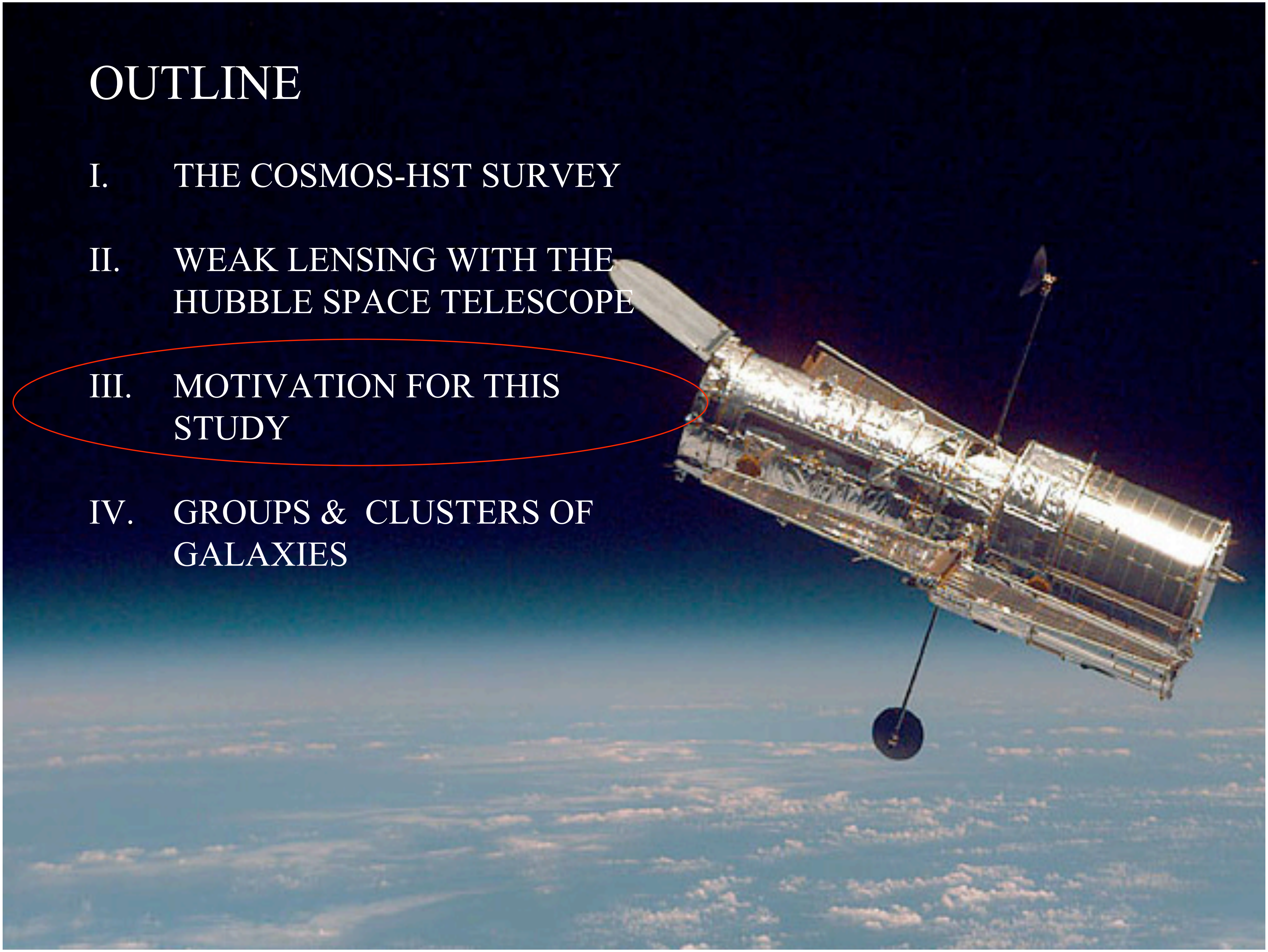
Massey *et al.* 2007

BLUE Mass of the stars

YELLOW Galaxy density

RED X-rays

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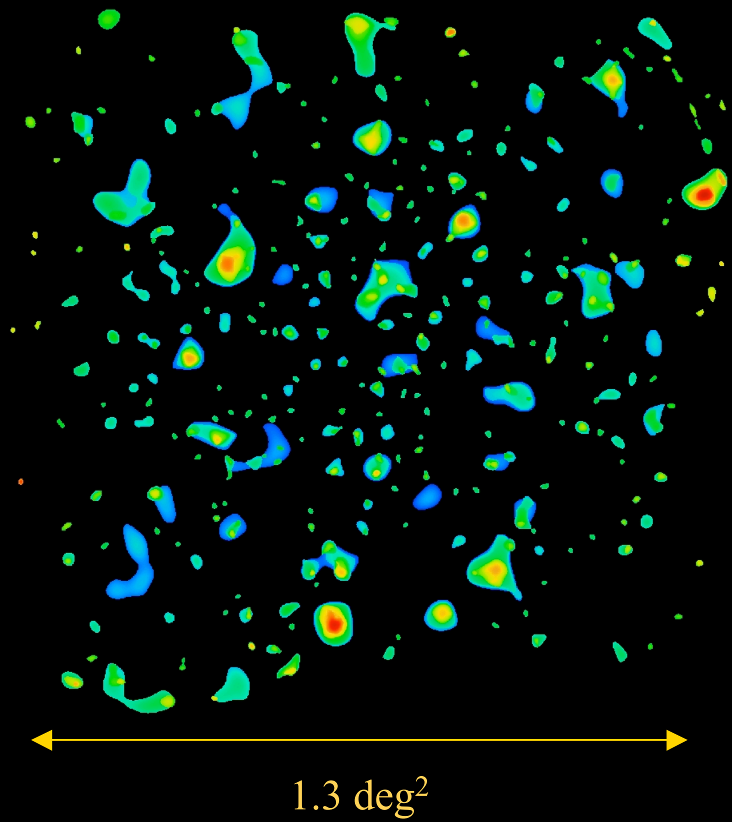
III. AIM OF THIS WORK



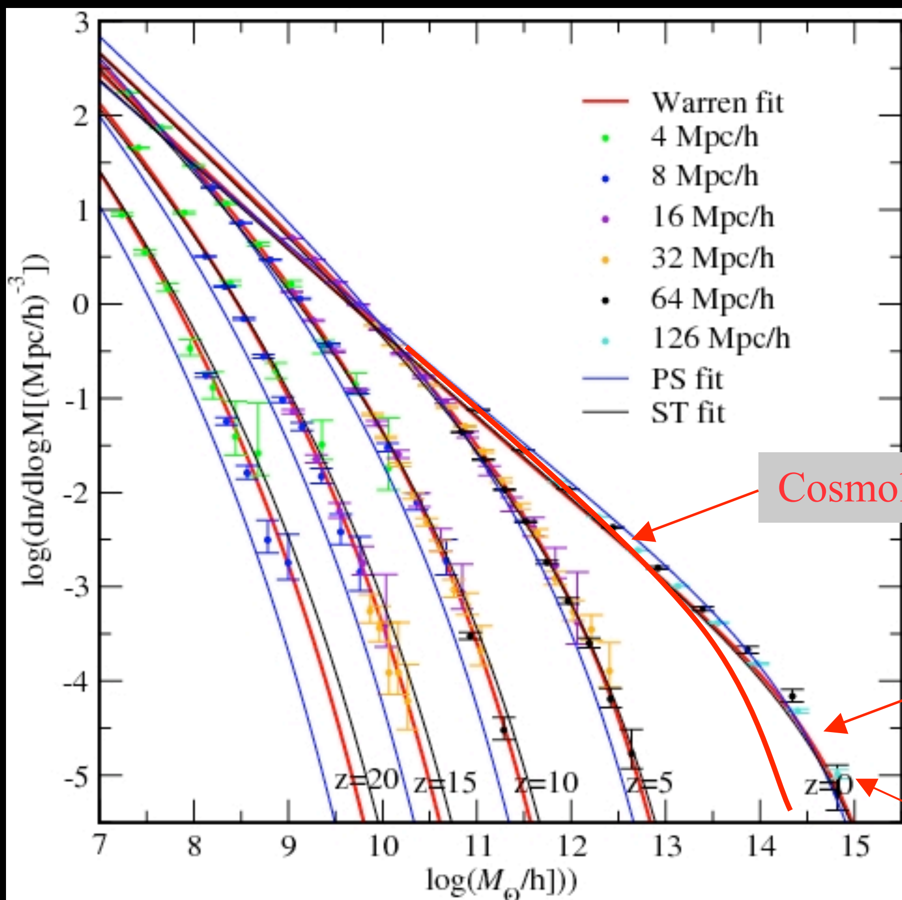
COSMOS survey
CHANDRA + XMM
A. Finoguenov et al. 2007

- Study the Dark Matter properties of a sample of ~150 groups/clusters detected via extended XMM emission in the COSMOS survey

- This is one of the largest samples of it's kind and is comprised of groups with halo masses $M_{200} \sim 5.10^{13}\ h^{-1}\ M_{sun}$.

- Together with the SDSS, this is one of the first studies to probe the dark matter halos of low mass groups via weak-lensing.

III. Motivations for pushing down to the low end of the mass function



The growth of the Dark Matter Mass Function over cosmic time - Heitmann et al. 2006

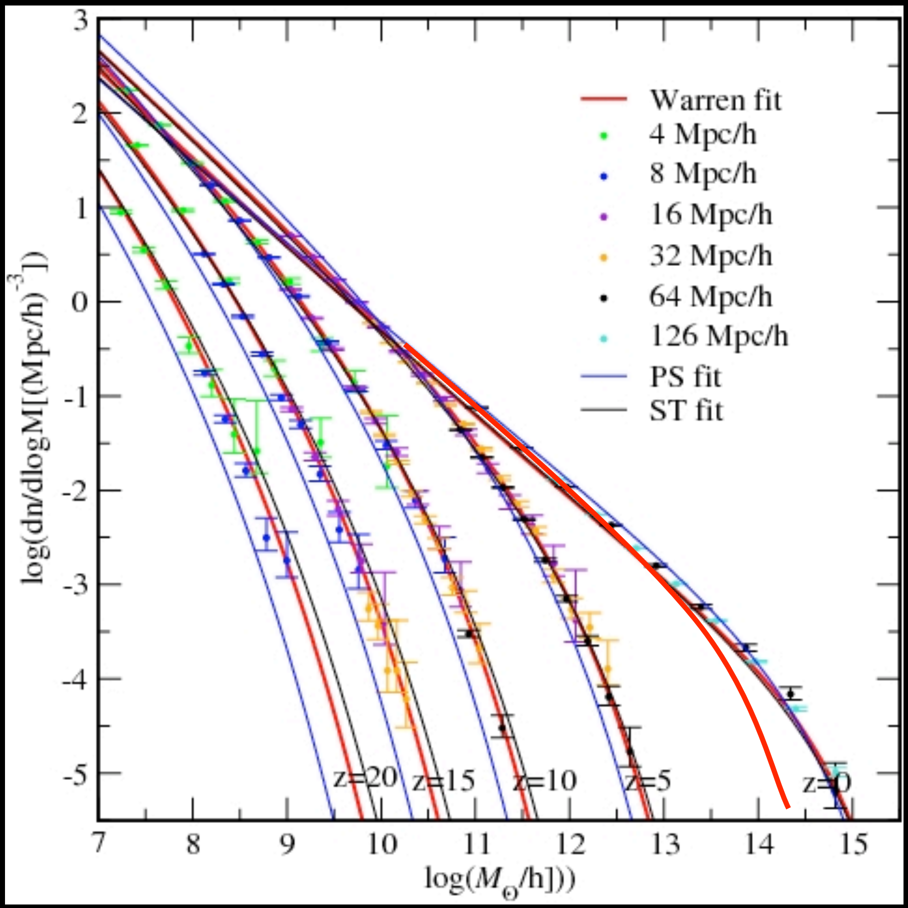
Cosmological volume element, dV/dz

Growth function

Most massive systems:
- *low numbers*
- *mergers/ non relaxed*
- *triaxiality*

I. Constraints on cosmological parameters can be improved by extending measurements down to the low end of the mass function *(on condition that masses can be measured correctly for groups).*

III. Motivations for pushing down to the low end of the mass function

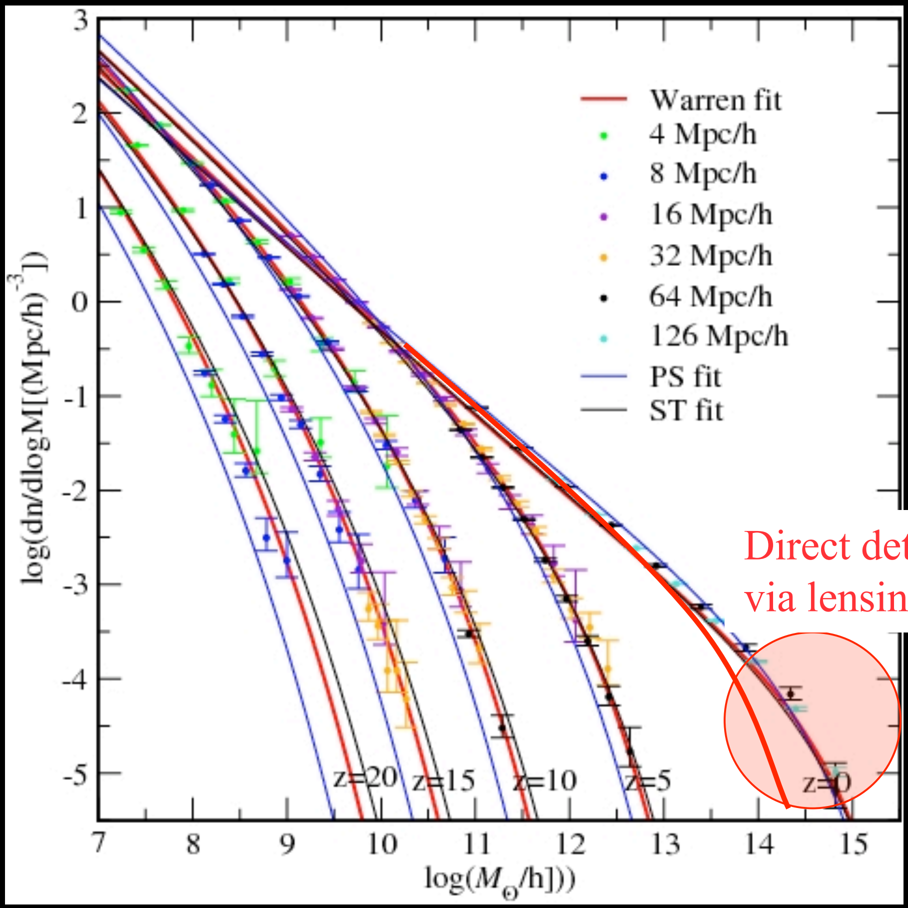


The growth of the Dark Matter Mass Function over cosmic time - Heitmann et al. 2006

I. Constraints on cosmological parameters can be improved by extending measurements down to the low end of the mass function *(on condition that masses can be measured correctly for groups).*

II. Understanding the scaling relations of galaxy groups will lead to a better handle on the slope and amplitude of the scaling relations of more massive systems.

III. Motivations for pushing down to the low end of the mass function



The growth of the Dark Matter Mass Function over cosmic time - Heitmann et al. 2006

I. Constraints on cosmological parameters can be improved by extending measurements down to the low end of the mass function *(on condition that masses can be measured correctly for groups).*

II. Understanding the scaling relations of galaxy groups will lead to a better handle on the slope and amplitude of the scaling relations of more massive systems.

III. Galaxy groups also play in key role in processes of galaxy formation (low velocity dispersions ⇒ galaxies are more likely to merge)

III. Recommendations of the Dark Energy Task Force

❖ *We recommend that the Dark Energy program have multiple techniques at every stage, at least one of which is a probe sensitive to the growth of cosmological structure in the form of galaxies and clusters of galaxies.*

❖ *Among the projects that can contribute to this goal are:*

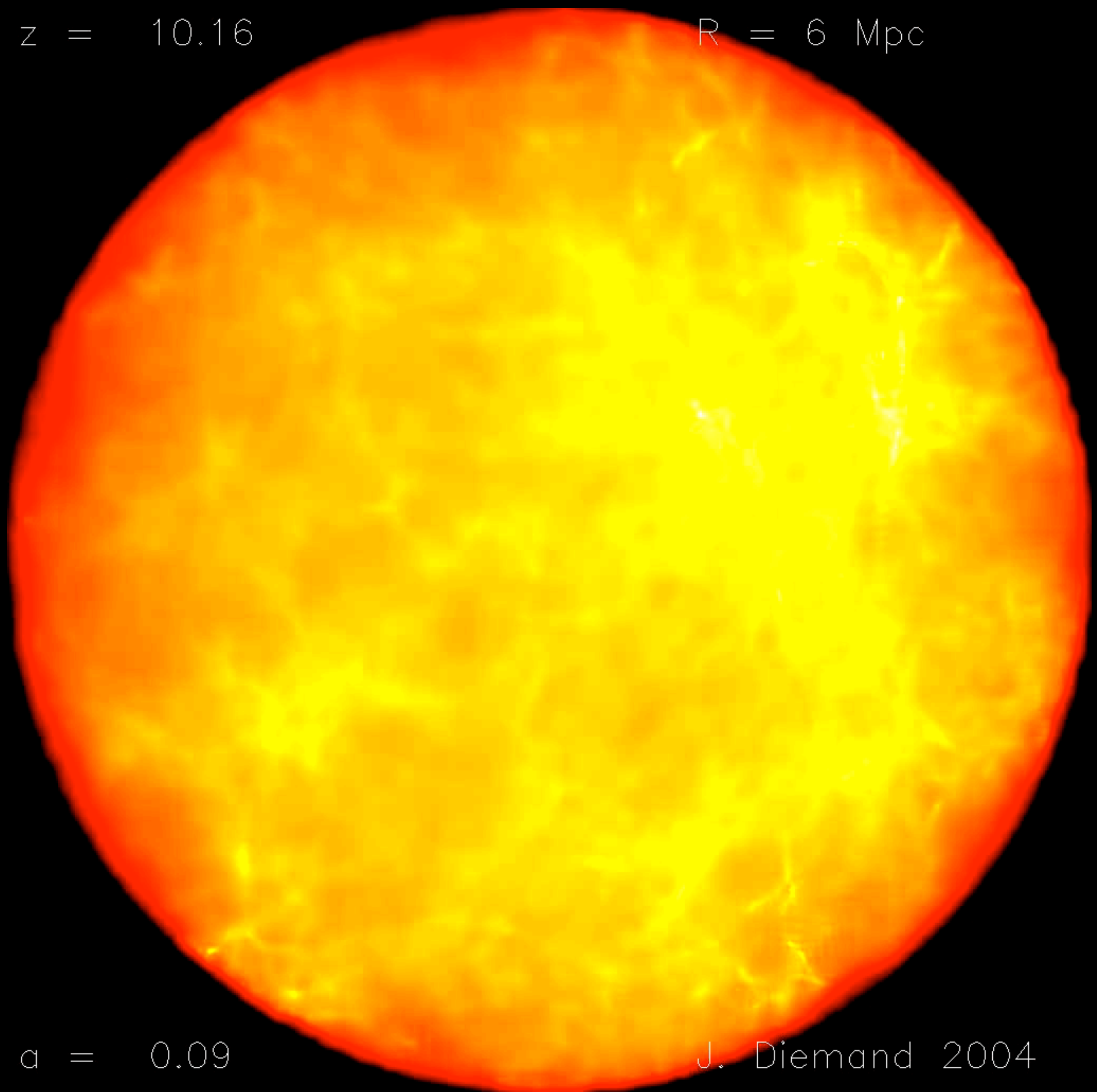
F) Better characterization of cluster-mass observable relations through joint X-ray, SZ, and weak lensing studies and also via numerical simulations including the effects of cooling, star-formation, and active galactic nuclei.

In this project, we have looked into the calibration of the X-ray Luminosity (Lx) - Halo mass (M_{200}) relation. Nevertheless, the method outlined here can be applied to other mass proxies such as Temperature, Richness, Velocity Dispersion, etc.

$Lx - M_{200}$ $T - M_{200}$ $N_{200} - M_{200}$ $\sigma_{dyn} - M_{200}$ $M_{SZ} - M_{200}$

A better understanding of each of these scaling relations is necessary for DE studies but will also shed light on the the underlying physical processes within groups & clusters.

III. The Physics of Cluster Formation



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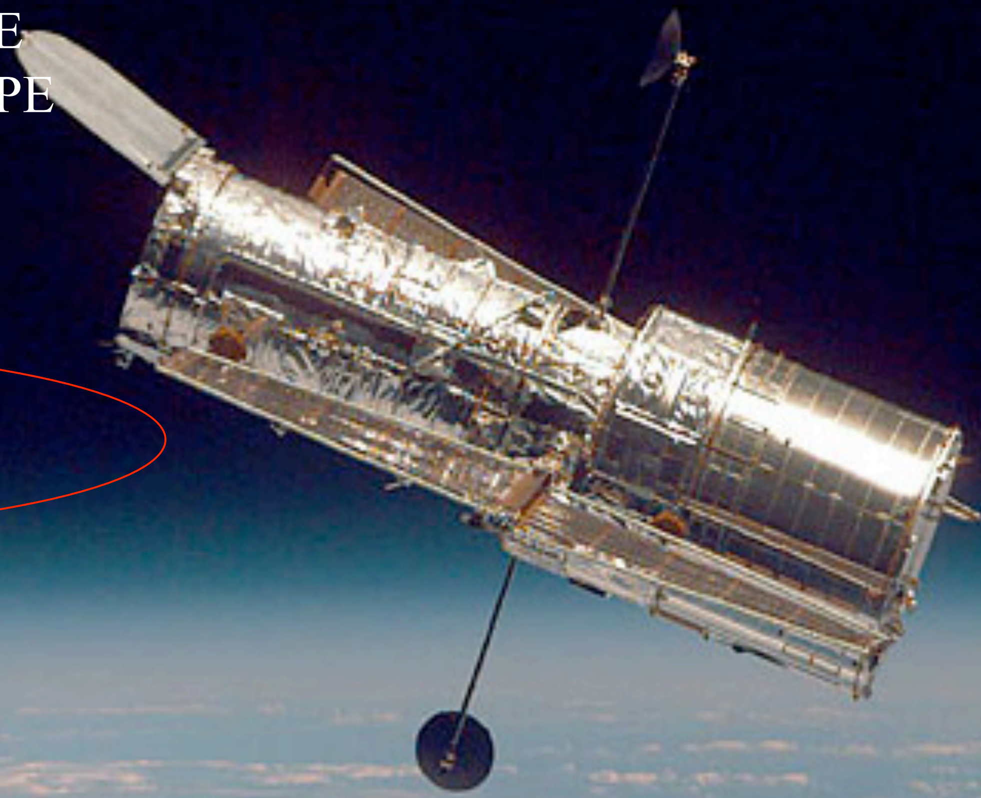
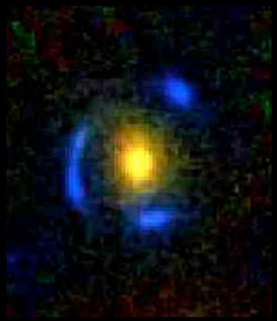
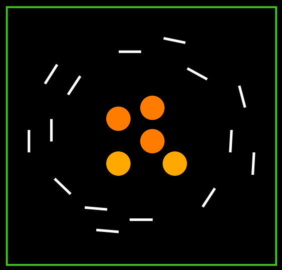


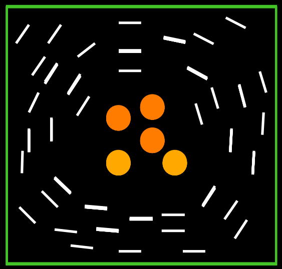
IV. THE THREE MAIN LENSING TECHNIQUES



I. Strong Lensing - Probes the mass within the Einstein Radius - Limited number of systems - Representative sample?



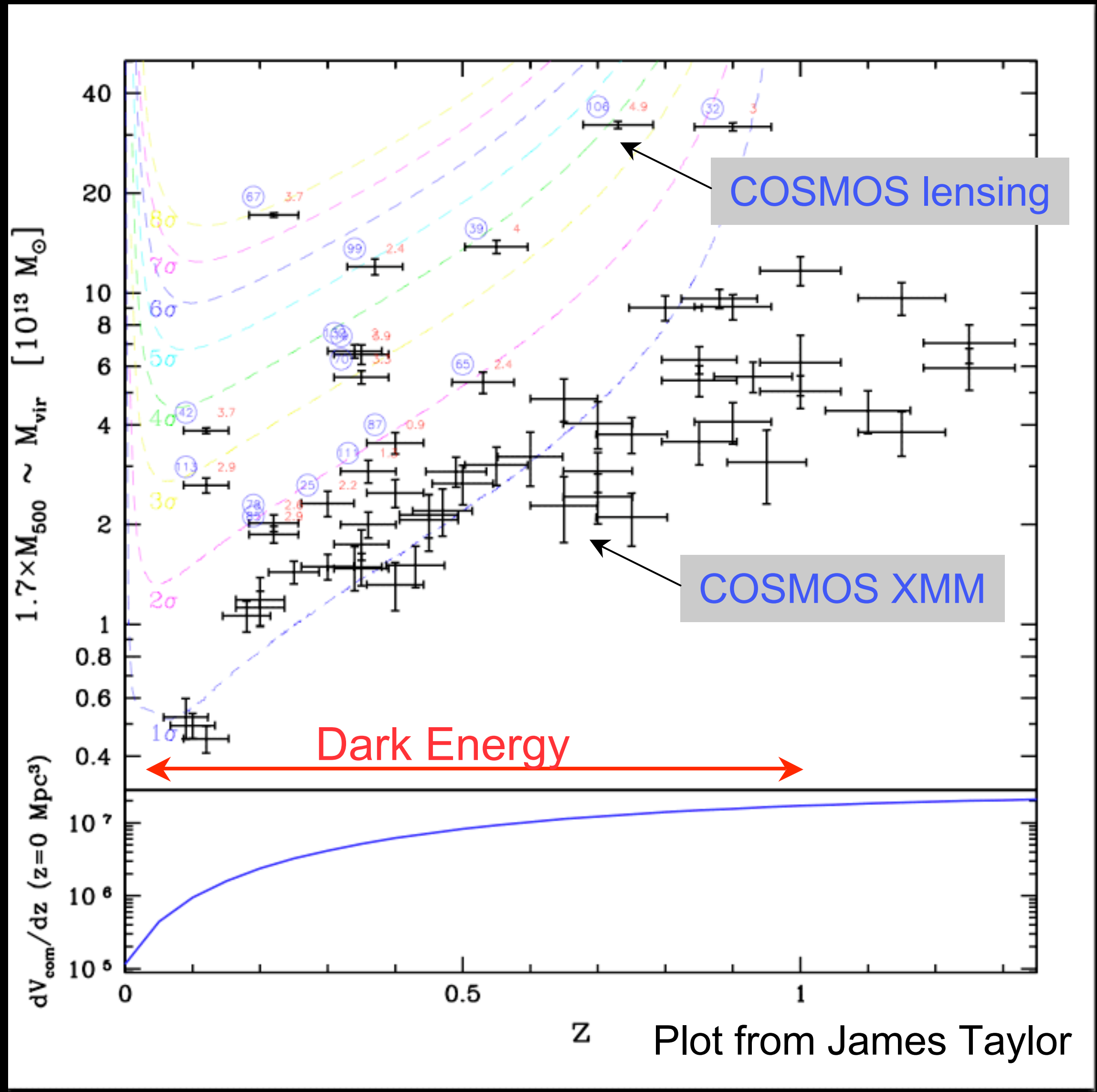
II. Weak lensing on an object by object basis - Only works for the most massive systems - Limited by the shape of the lensing weight function - Projection effects.



III. Stacked weak lensing - Can measure the mass for potentially ANY systems - Can reduce the statistical noise - Not affected by projection effects - Need to know center - No longer access to the scatter.

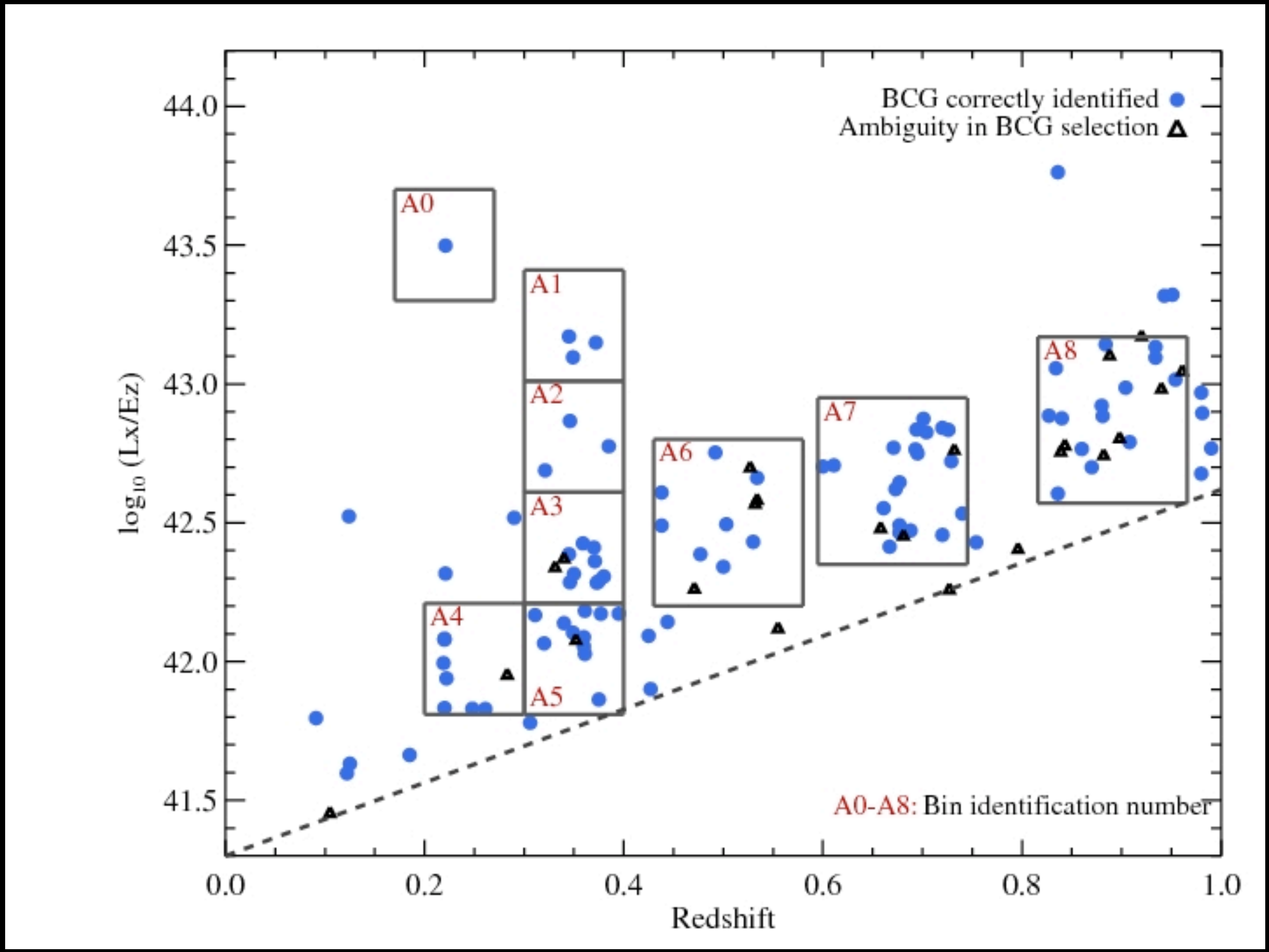
IV. Probing structures beyond the limits of direct lensing detections

- If you are interested in Dark Energy you will want to probe: z = [0 , 1]
- You will also want to consistently calibrate scaling relations over z = [0 , 1] (redshift evolution?)
- For magnitude limited observations, the lensing detection significance is limited by the lensing weight function.
- Stacking techniques can go well below this limit techniques (all you need is a centre and a mass proxy for the structures to probe)



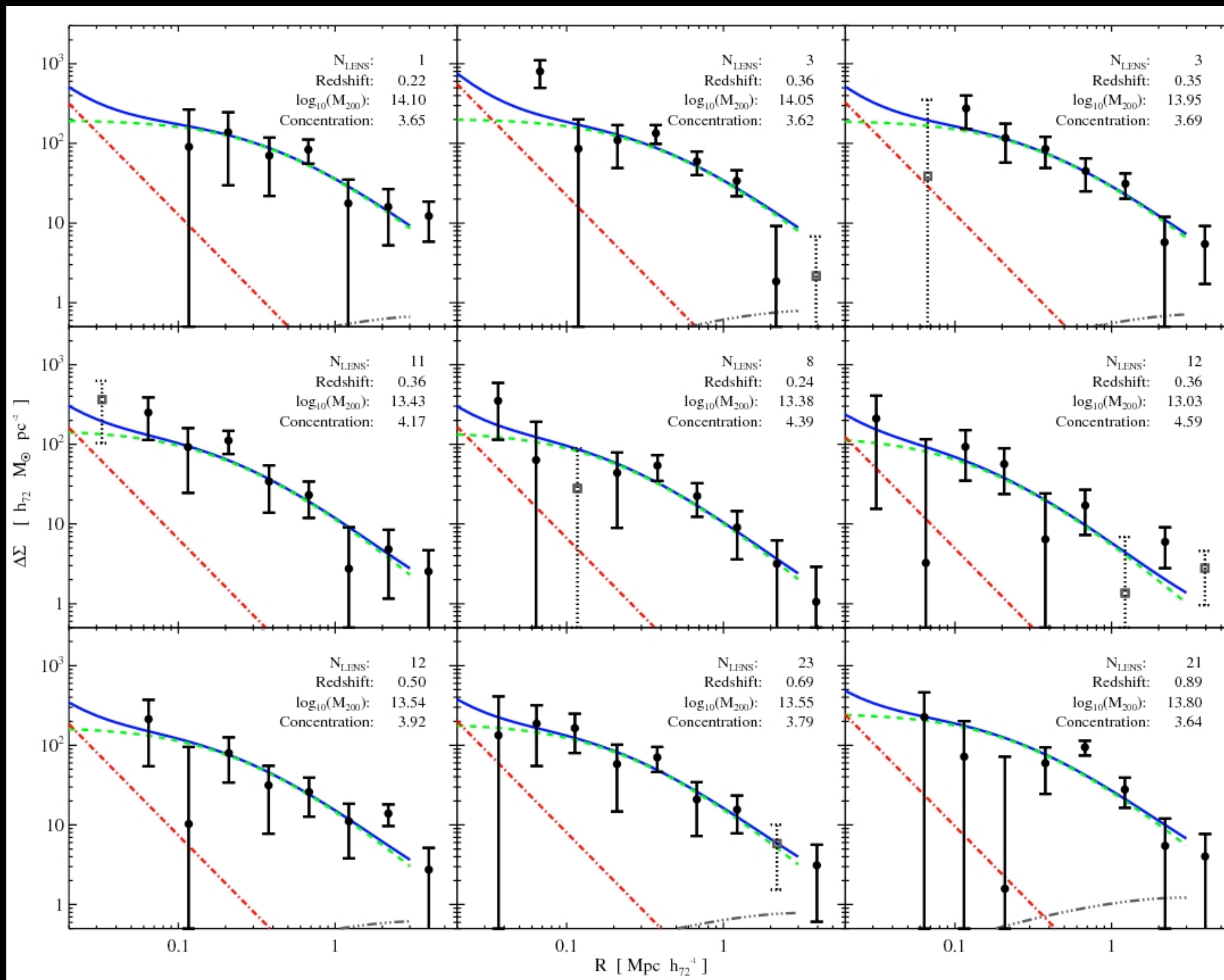
IV. COSMOS GROUP SAMPLE

Log10(Lx.Ez^{-1})



REDSHIFT

IV. Results: Stacked Weak Lensing Signals

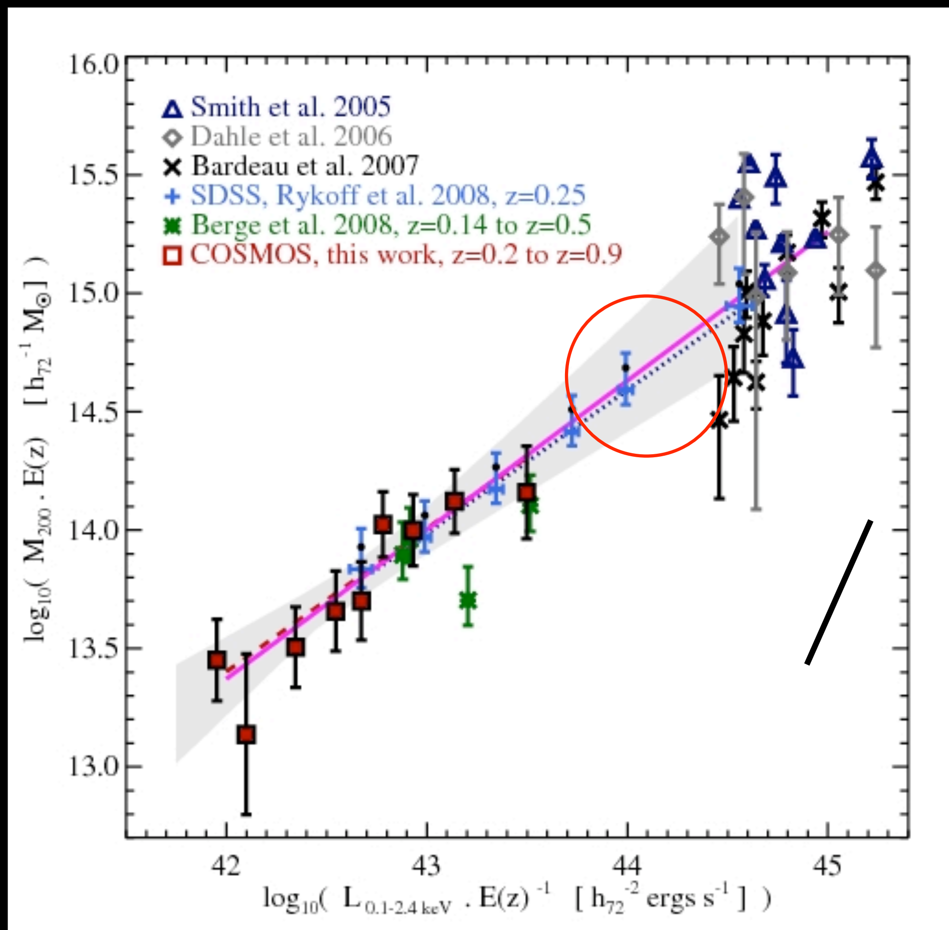


$\Lambda\Sigma$ [Msun pc^{-2} h_{72}^{-1}]

R [Mpc h_{72}^{-1}]

Leauthaud et al 2008 in prep

IV. THE M_{200} - L_X RELATION



$Log_{10}(M_{200}.E(z)^{-1} h_{72}^{-1} Msun)T$

$Log_{10}(Lx.E(z)^{-1} h_{72}^{-2} ergs\ s^{-1})$

❖ Form of the M_{200} - L_X relation:

$$\frac{M_{200}\times E(z)}{M_0} = A\times\left[\frac{L_X\times E(z)^{-1}}{L_0}\right]^{\alpha}$$

❖ We find a slope : $\alpha \sim 0.62$ in good agreement with Stanek *et al*. 2007 and Rykoff *et al*. 2008.

❖ Cluster data alone can be misleading : Bardeau et al. 2007 find $\alpha \sim 1.2$!

❖ Current relation is limited by measurement of cluster masses.

❖ In addition to the determination of the slope and normalization, a better understanding of the scatter in the Lx-M_{200} relation is also necessary. One could measure this scatter with weak lensing for Lx $E(z)^{-1}$ =[44,45].

DISCUSSION & CONCLUSIONS

❖ We observe a striking relation between Lx and halo mass over several decades in mass and luminosity. These are encouraging results in view of calibrating mass-observable relations for DE studies and to gain a better understanding of cluster and galaxy physics.

❖ The slope that we measure ($\alpha \sim 0.62$) is inconsistent with simple models of self-similar evolution which predict $\alpha = 0.75$. Additional physics beyond simple gravitational collapse are necessary (e.g pre-heating, AGN & galaxy feed-back, etc.).

❖ Extending halo mass measurements down to the group regime is necessary in order to obtain an accurate determination of the slope.

❖ The current measurement of the Lx-M200 relation is limited by systematic errors in the determination of individual cluster masses via weak lensing.

❖ This work will enable studies of baryonic physics as a function of halo mass:

⇒ determination of the baryon fraction in groups (Giodini *et al*. in prep)
⇒ galaxy properties within groups as a function of halo mass
⇒ the assembly of the most massive galaxies, the central BCG's.


THE END
DOMO ARIGATO !