A Large HST Project to Explore the Nature of Dark Energy

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Presentation posted at
http://www.astro.northwestern.edu/~ulmer/private/Bologna_2008.ppt

Primary Goal: To get accurate enough determinations of w_0 and w_a that we will know where we stand, e.g.

If GR is correct and $w_a = 0$ and $w_0 = -1$, then the model is a cosmological constant.

If we find w_a non-zero then we have new(er) physics; $w = f(w_0, w_a, z)$,

$P = w\rho c^2 = -\rho c^2$ for a cosmological constant.

Secondary Goal: Accumulate a great data set to study the origin and evolution of clusters of galaxies and galaxies.

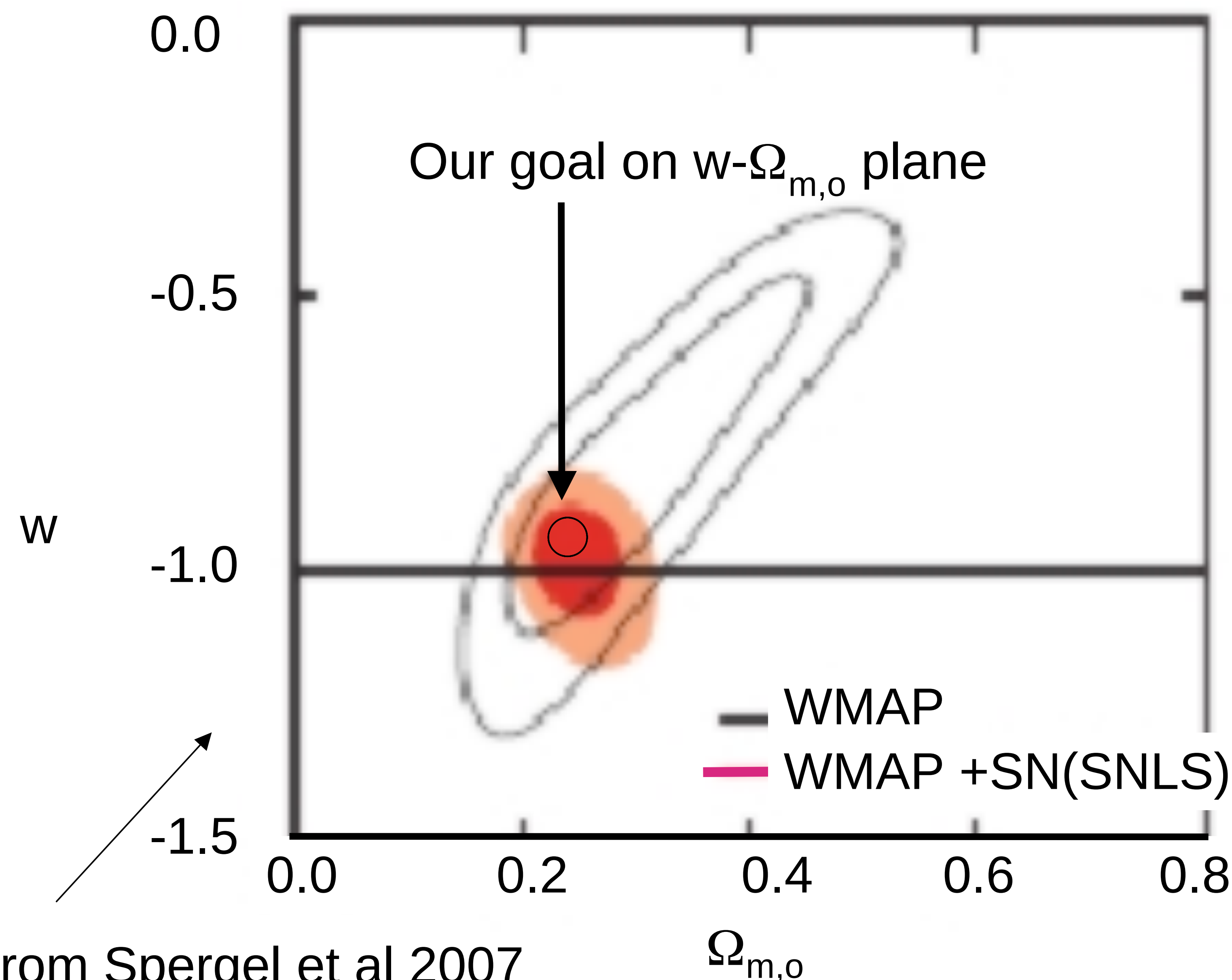
→ Observe 1,000 clusters with 1,000 HST Orbits (ACS/WFC F814W)

And there's more:

Parallels with WFPC-3

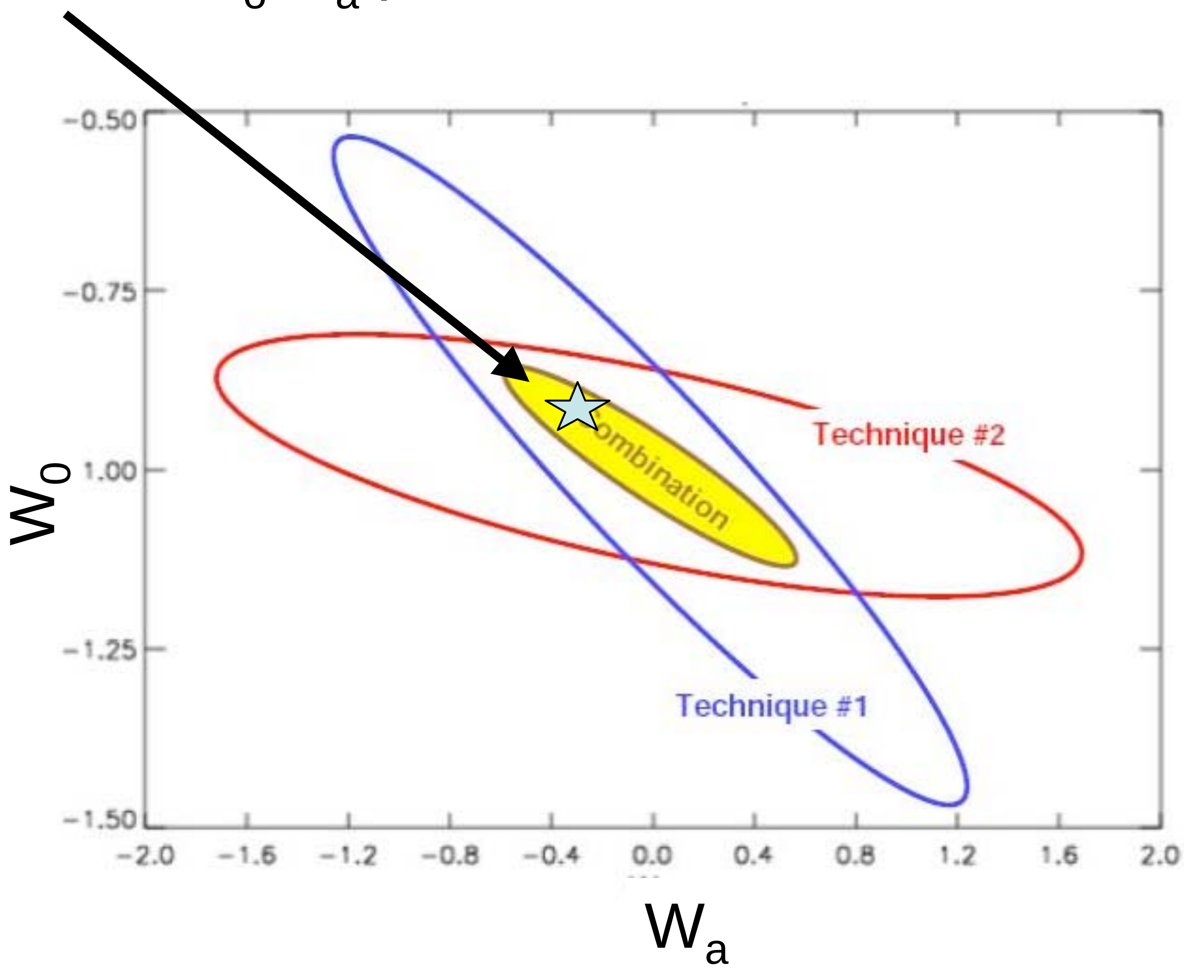
Offset is about 6 arc min (center to center), for z = 0.4 cluster ~ 1.9 Mpc

For z =1.5 cluster ~3 Mpc => explore outer reaches of cluster

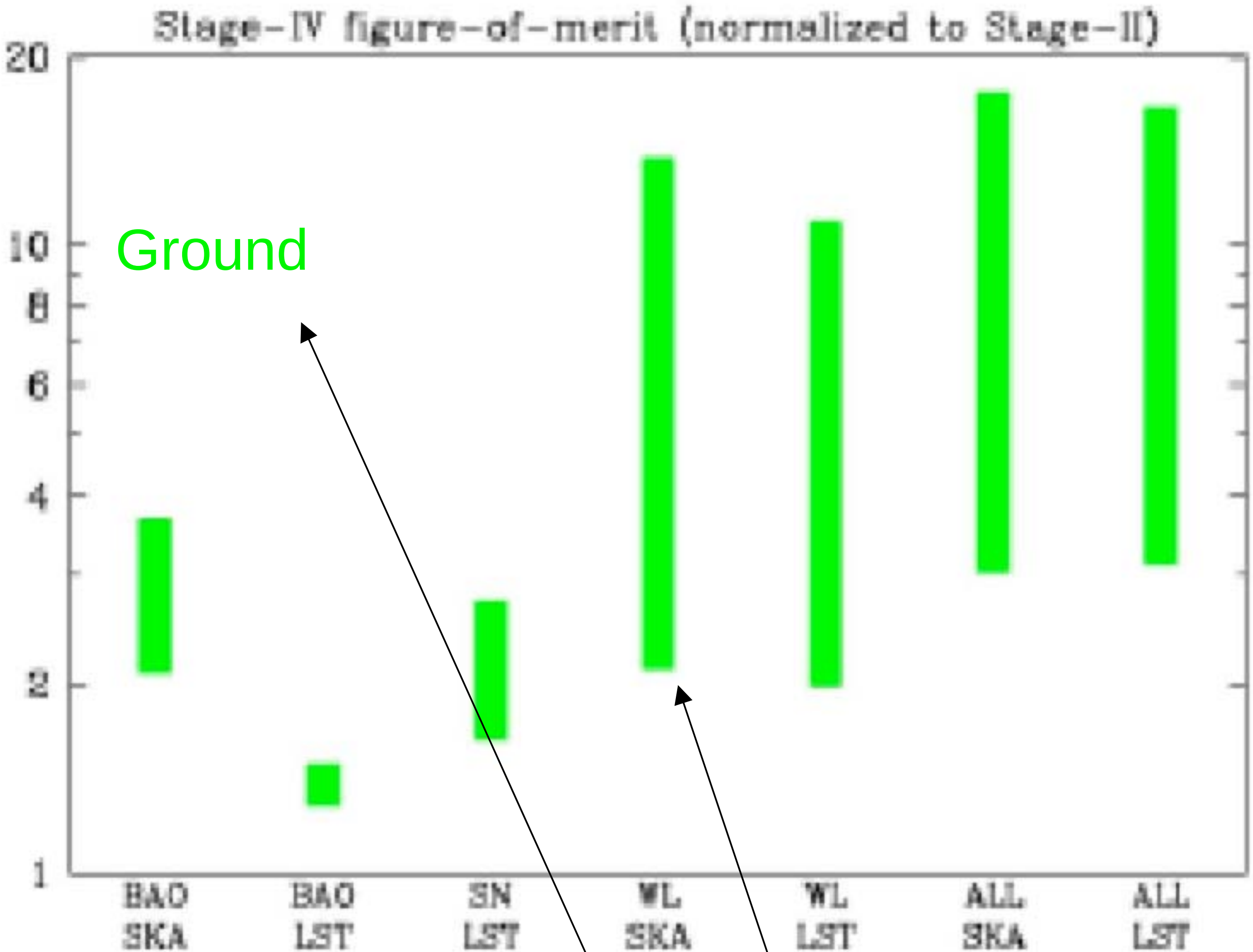


From Spergel et al 2007

Our goal on w_o-w_a plane



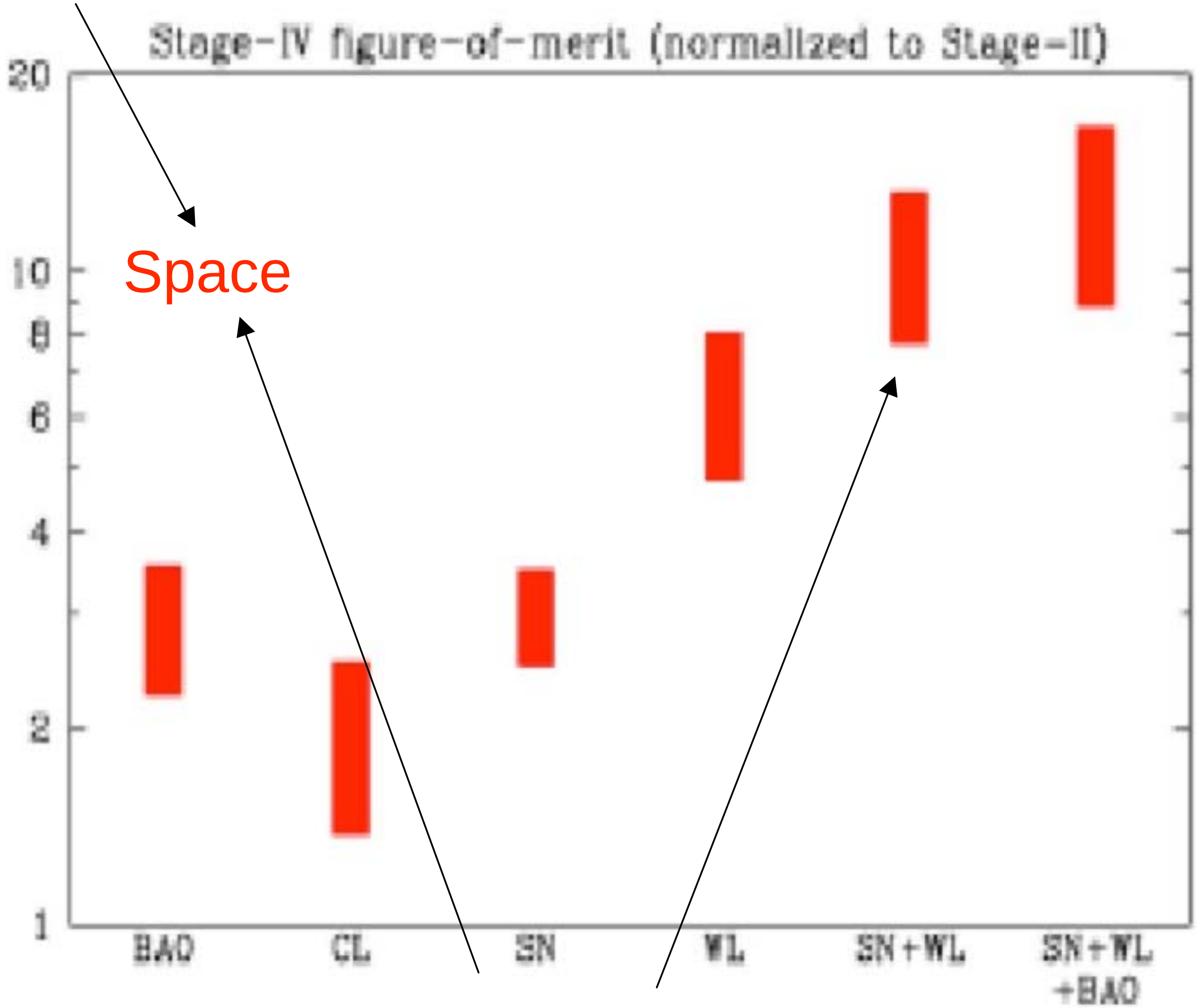
Why HST part 1



From DETF

Huge uncertaities

Why HST part 2



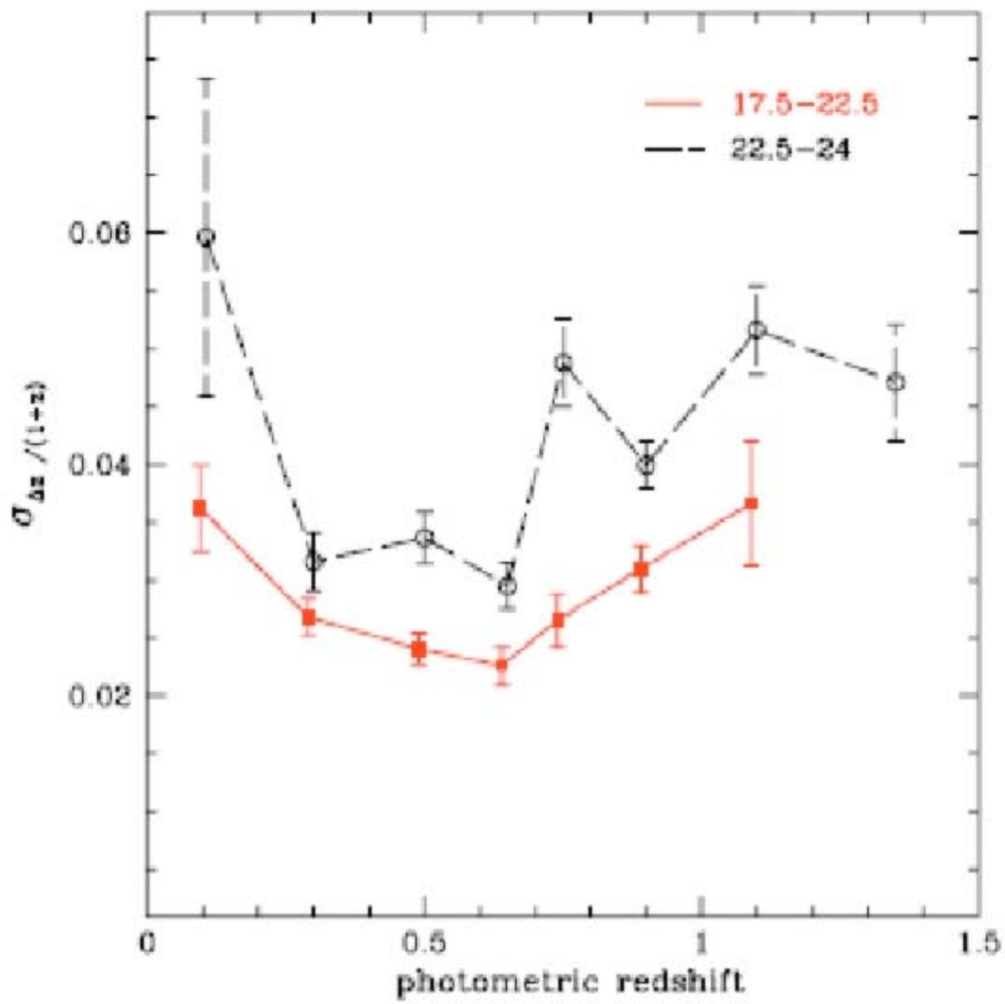
From DETF

Much more of a sure thing

Why HST part 3

Weak lensing uncertainties: PSF and photo-z; in space with HST, psf is greatly reduced, and can go to fainter magnitudes => See more a background galaxies

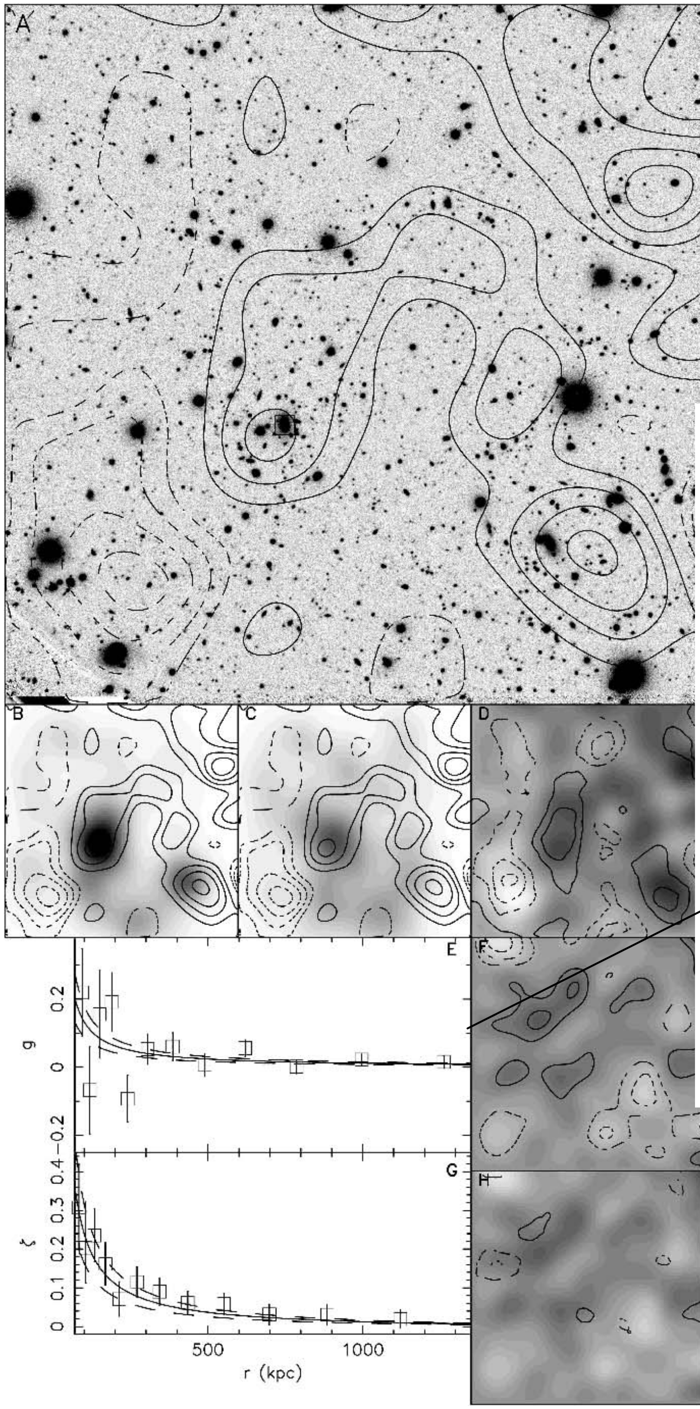
Shows uncertainty in photo-z with 5 filters from Ilbert et al, 2006



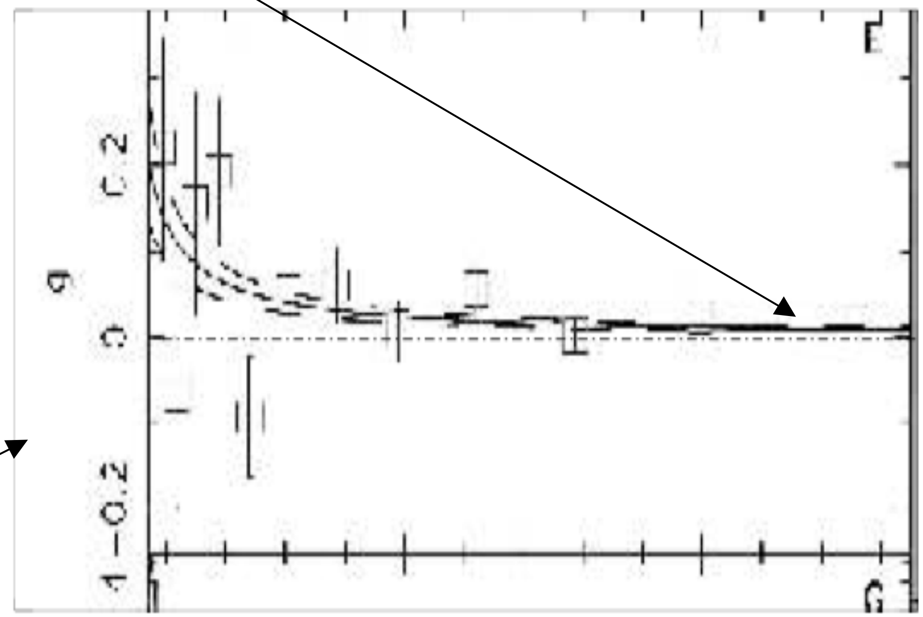
Estimated uncertainty in w from Bernstein and Jain 2004*, scaled to cluster where our 3 sq degrees = equivalent to 300 sq degrees in their blank field calculation => uncertainty alone = 0.1, and combined with other results = 0.05 (hence previous slides)

Why can we scale like this =>

*photo-z σ assumed 0.03(1+z)



Example of massive cluster with weak lensing signal; min is ~ 0.04 or g^2 = 1.6 x 10^{-3}

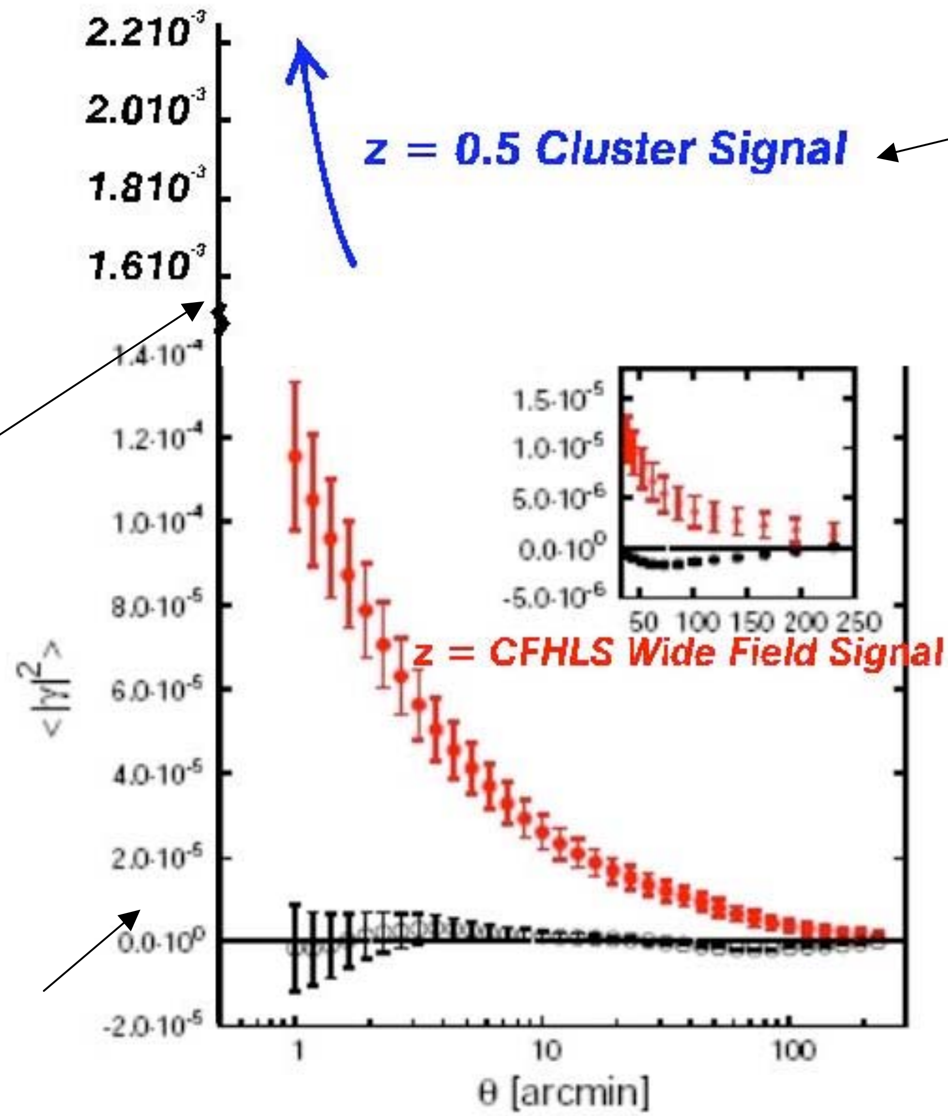


z = 0.5

From Clowe et al

=> The weak lensing signal is much stronger than blank field

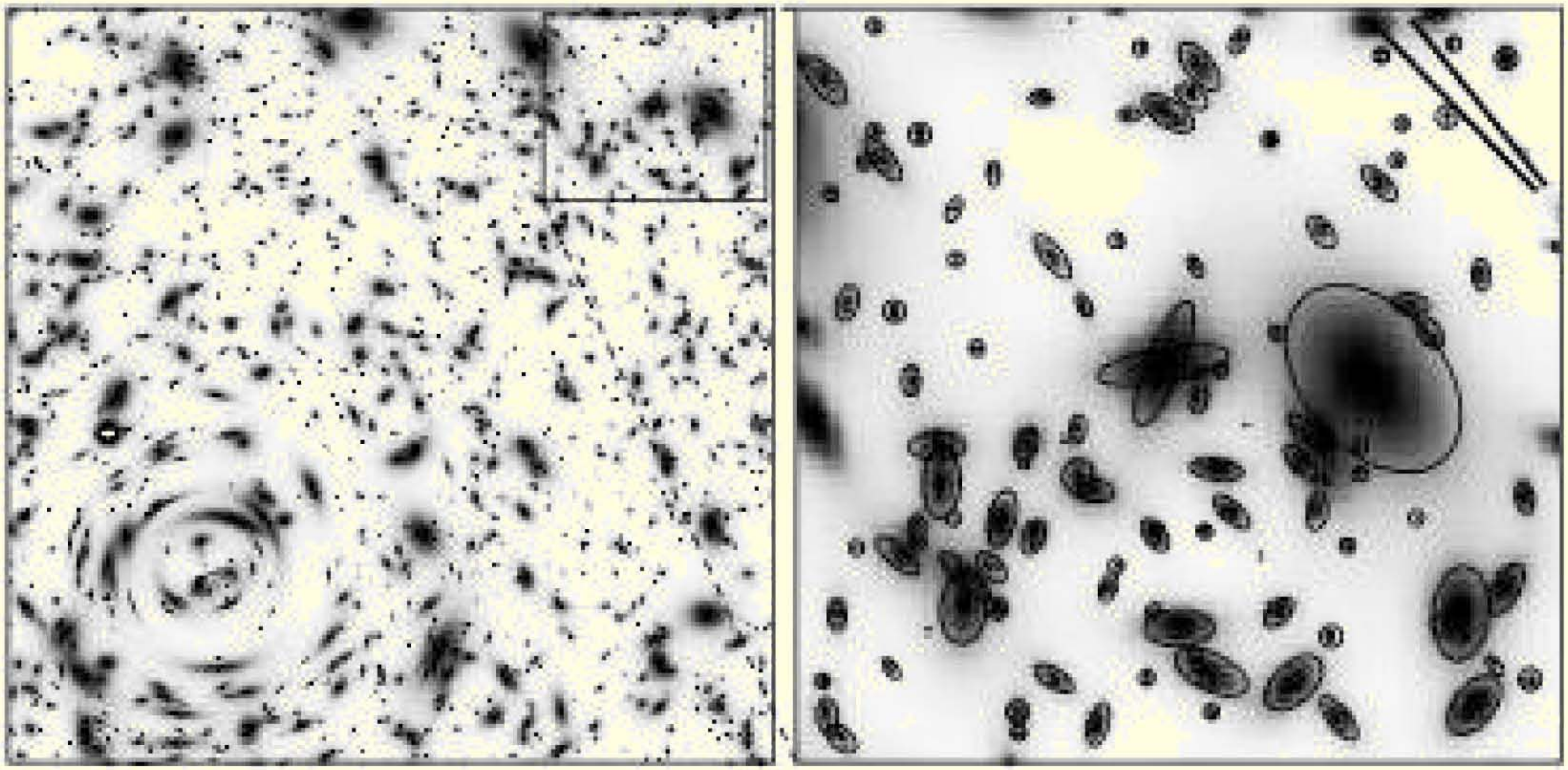
Notice change in scale



from previous slide

From Fu et al, 2007

What is weak lensing?



A measurement of the ellipticity of a galaxy provides an unbiased but noisy measurement of the gravitational lensing shear

From Hoekstra on web

Key points of **weak lensing tomography**: Does not depend of knowing the physics of objects (beyond secondary of photo-z). **It is purely geometrical**

How it works in general: fit ratios of angular distances to cluster models with self-consistency such that the cosmological world models are adjusted for a best fit. Thus derive w_o, w_a, H_o and $\Omega_{m,o}$ and $\Omega_{\Lambda o}$.

Will use two techniques : Bartleman and Narayan and also Jain and Taylor. The later is easier to visualize:

With cluster model with two galaxies at same radius from cluster center, take ratio of weak lensing signal, then cluster model drops out and left with a ratio of weak lensing signals that depends only on the redshifts of the galaxies and the formula for the angular distance

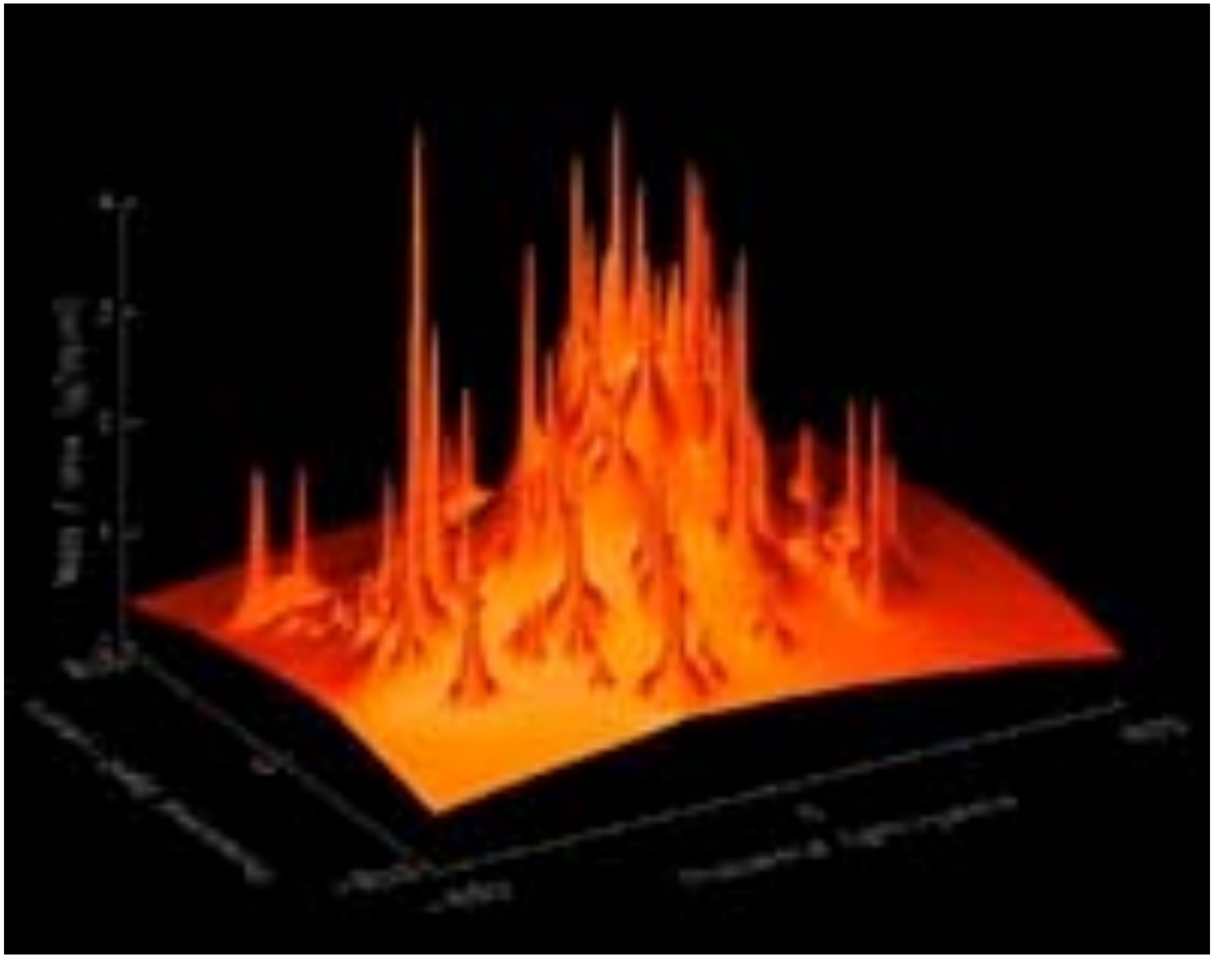
$d_a = f(z, w_o, w_a, \Omega_{m,o}, \Omega_{\Lambda,o}, H_o)$

detailed equations posted on a web page. The most sensitive ratios to world models are with ones a background galaxy relatively close to the cluster redshift and one far away. Combined with where $\Omega_{\Lambda,o}$ is important leads to z requirements for the clusters to observe and on photo-z capabilities.

A perfect training set already exists and work on it is already in progress.

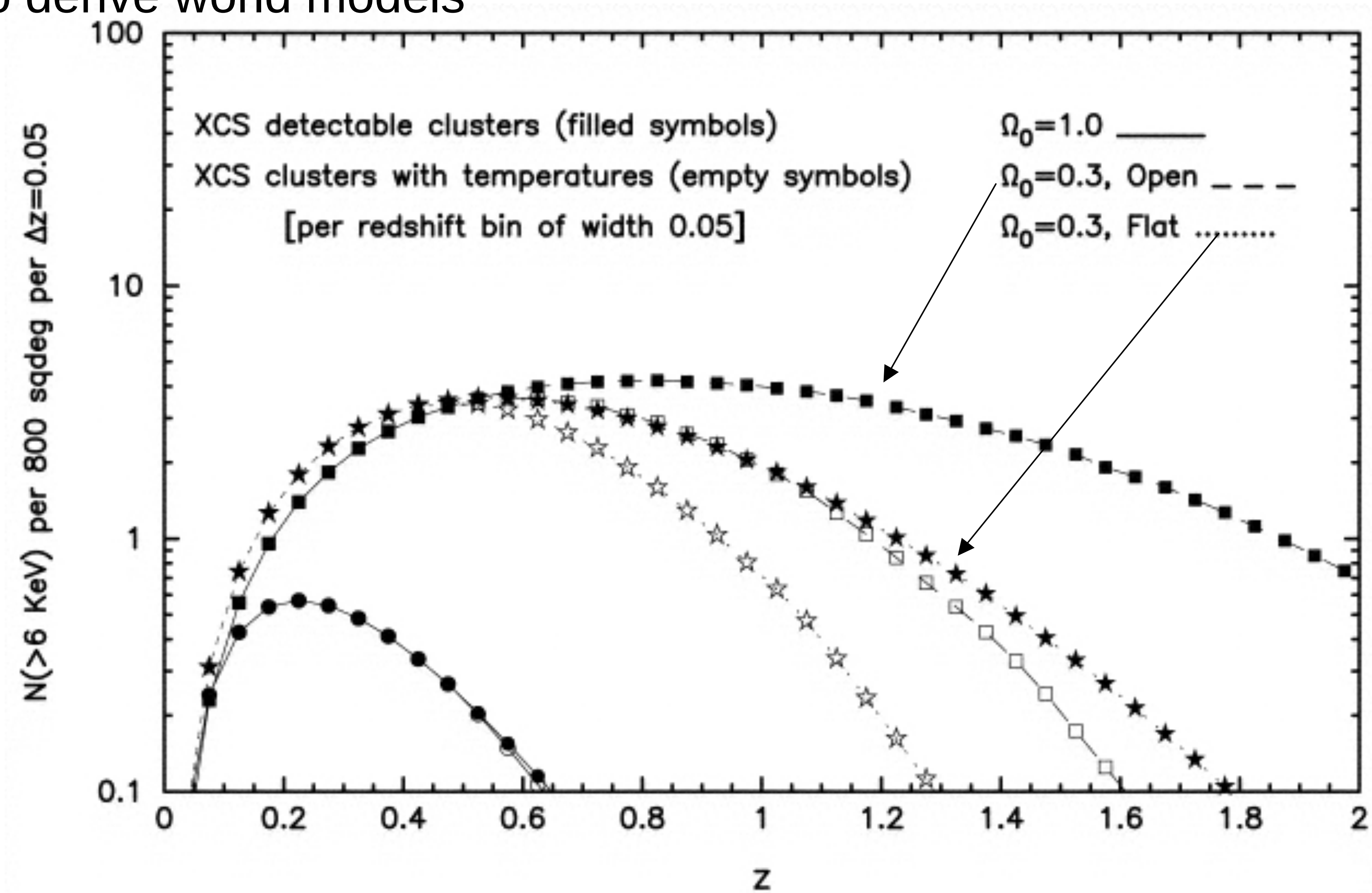
There already exist 100 clusters in the Hubble archive and we have proposed and will propose again for funding to carry out the HST analysis while in parallel NSF/DOE funding to obtain and analyze the ground based data to generate the photo-zs. We already have 2 nights coming to enable 10 clusters to be analyzed from beginning to end with photo-zs plus HST.

And there's more! The process will derive mass model for each cluster => 1,000 cluster masses



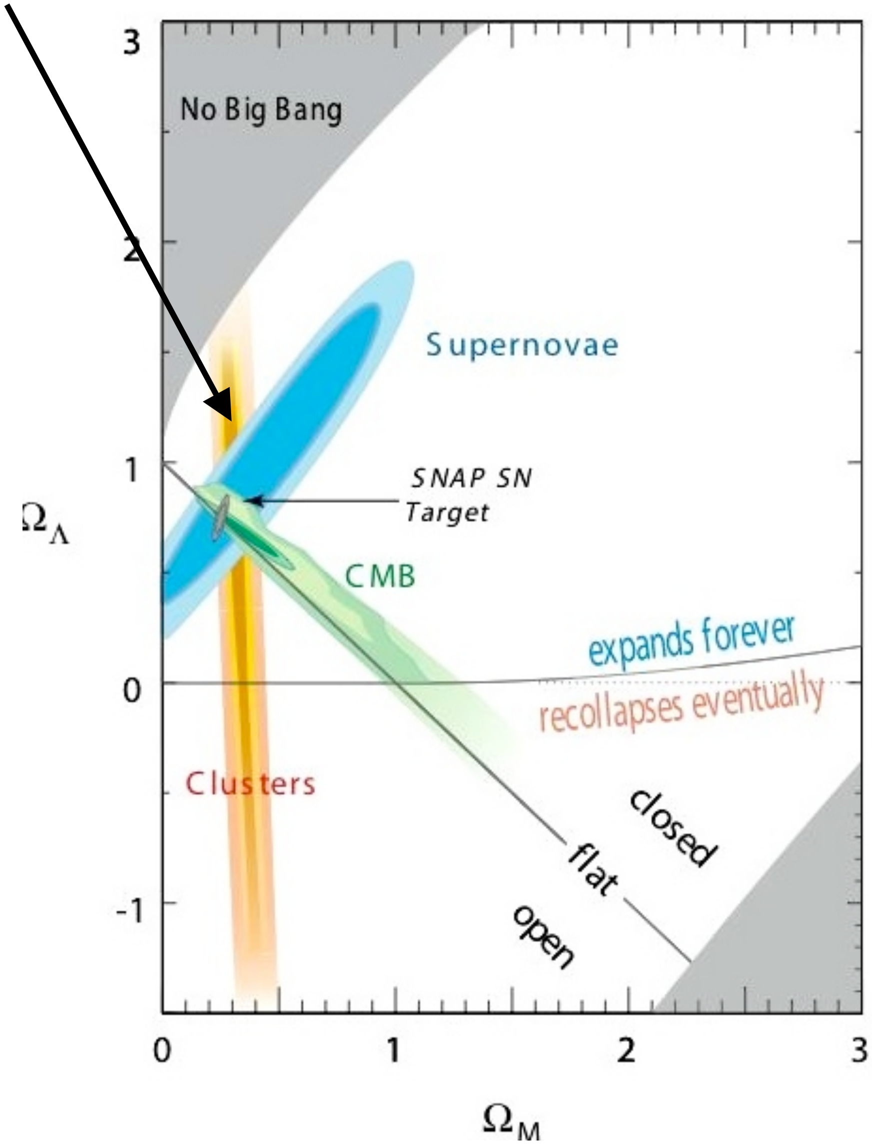
Sample mass model from Tyson et al on the web

With cluster masses can 1,000 clusters can do cluster counting to derive world models



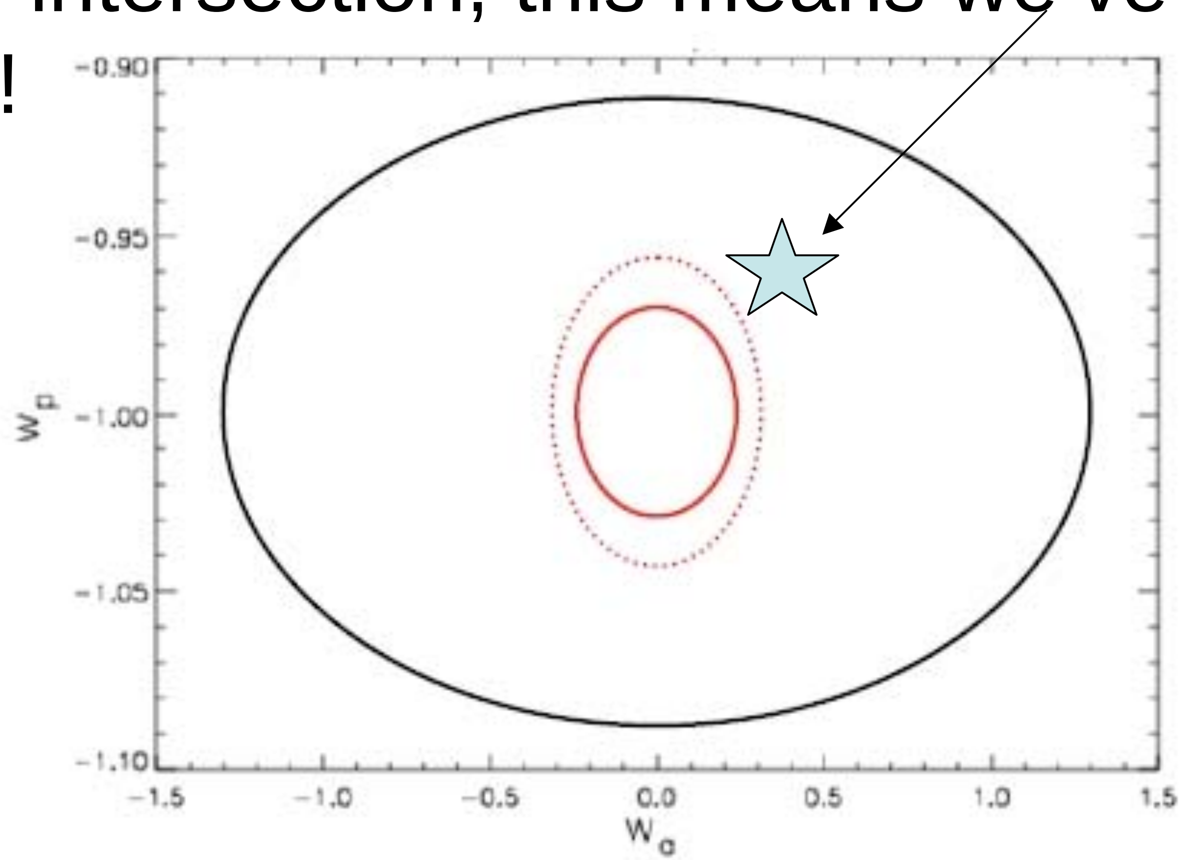
From Romer et al

With cluster masses can 1,000 clusters evolution models derive a tie breaker between CMB and SN



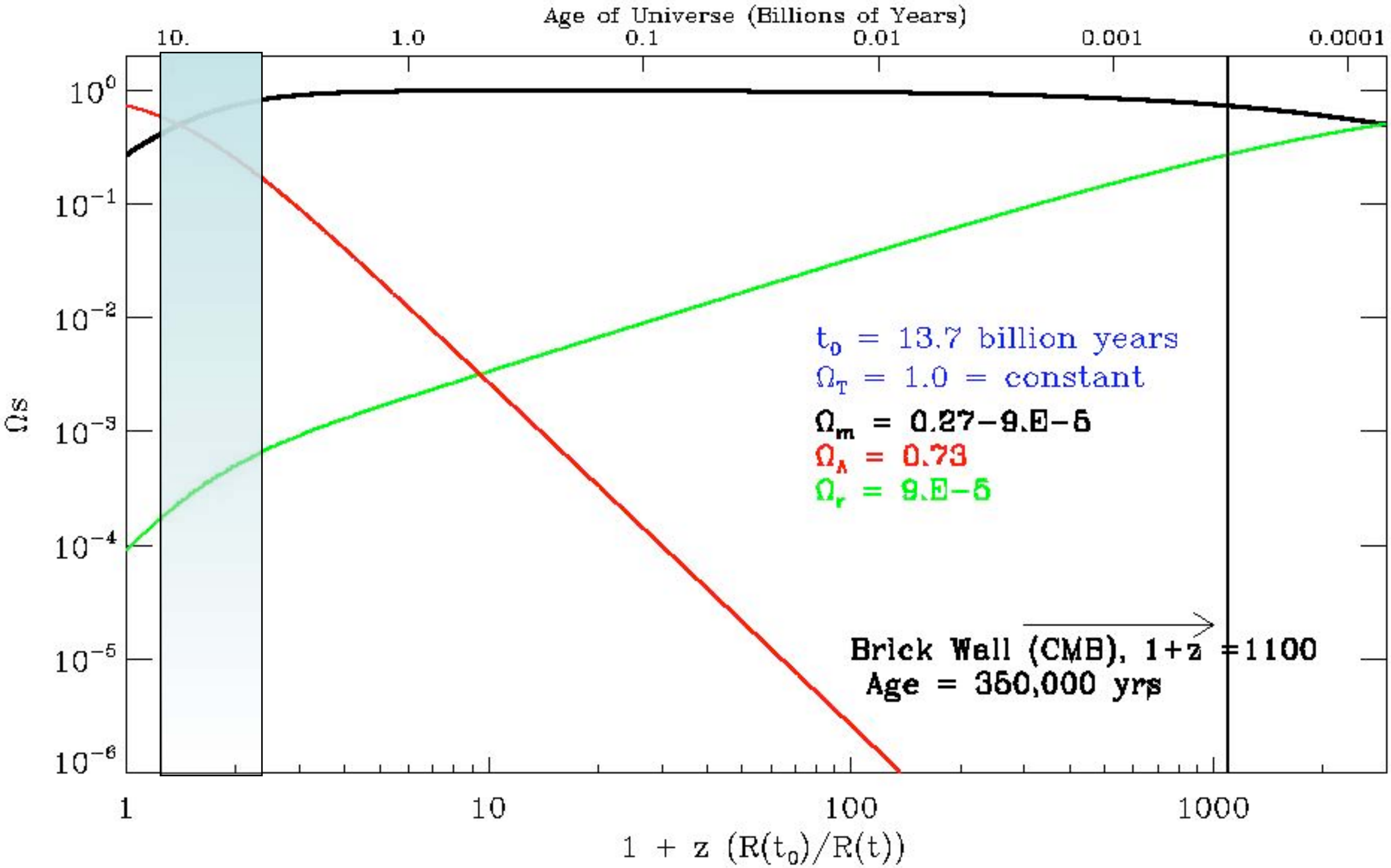
From SNAP web page

Suppose cluster derivation doesn't cross CMB and SN intersection, this means we've likely got this!



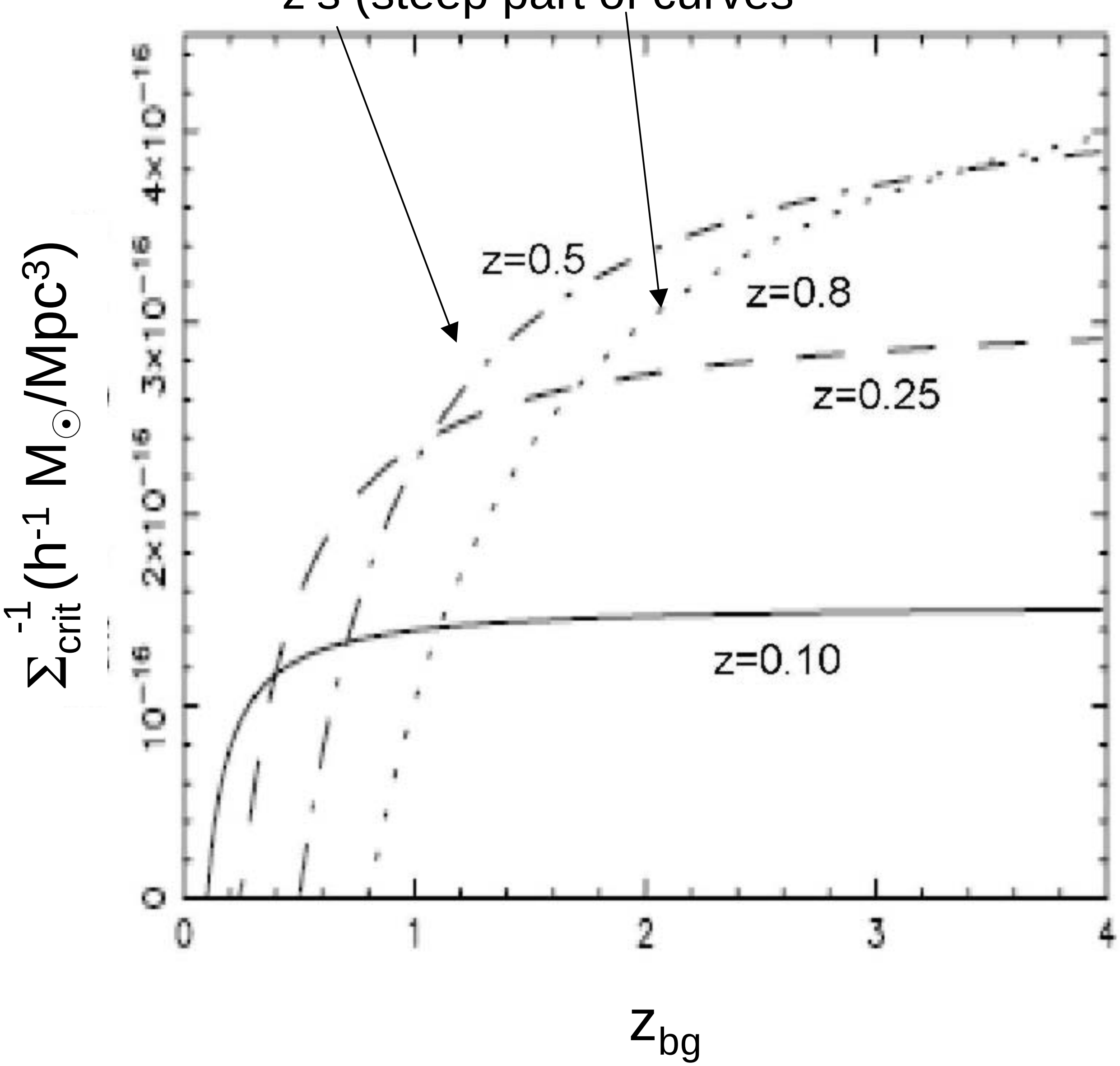
From DETF

Why we want z = 0.4-1.5 from point of view of Ω



Why we want z = 0.4-1.5 from point of view of weak lensing

Curves sensitive to world model only at higher z's (steep part of curves



Feasibility: 1 orbit in F814 is deep enough (27.5; cf. COMOS team), spread over 5 years is 200 orbits/year out of about 5,000 = 4% of observing time

FOV of ACS/WFC is 202'' x 202'' => 800 kpc radius at z =1 and 500 kpc at z= 0.4
typical core radius = 150-250 kpc => will get adequate coverage with one orbit.

For photo-zs 4 additional colors on the ground is quite feasible; 80 nights per year for 5 years on 8 meter class telescopes (and not necessarily the same telescope!; at least 4 in north and 4 in south) to get down to 25 mag s/n = 8; Note if we use 3 filters with HST, we only need ½ the time on the ground, and if we can use Spitzer we can cut in ½ again = 20 nights /year!

How many clusters do we have know between 0.4 and 1.5?

Already have 100 with known redshifts in HST archive!

NED gives another 150 with known redshifts

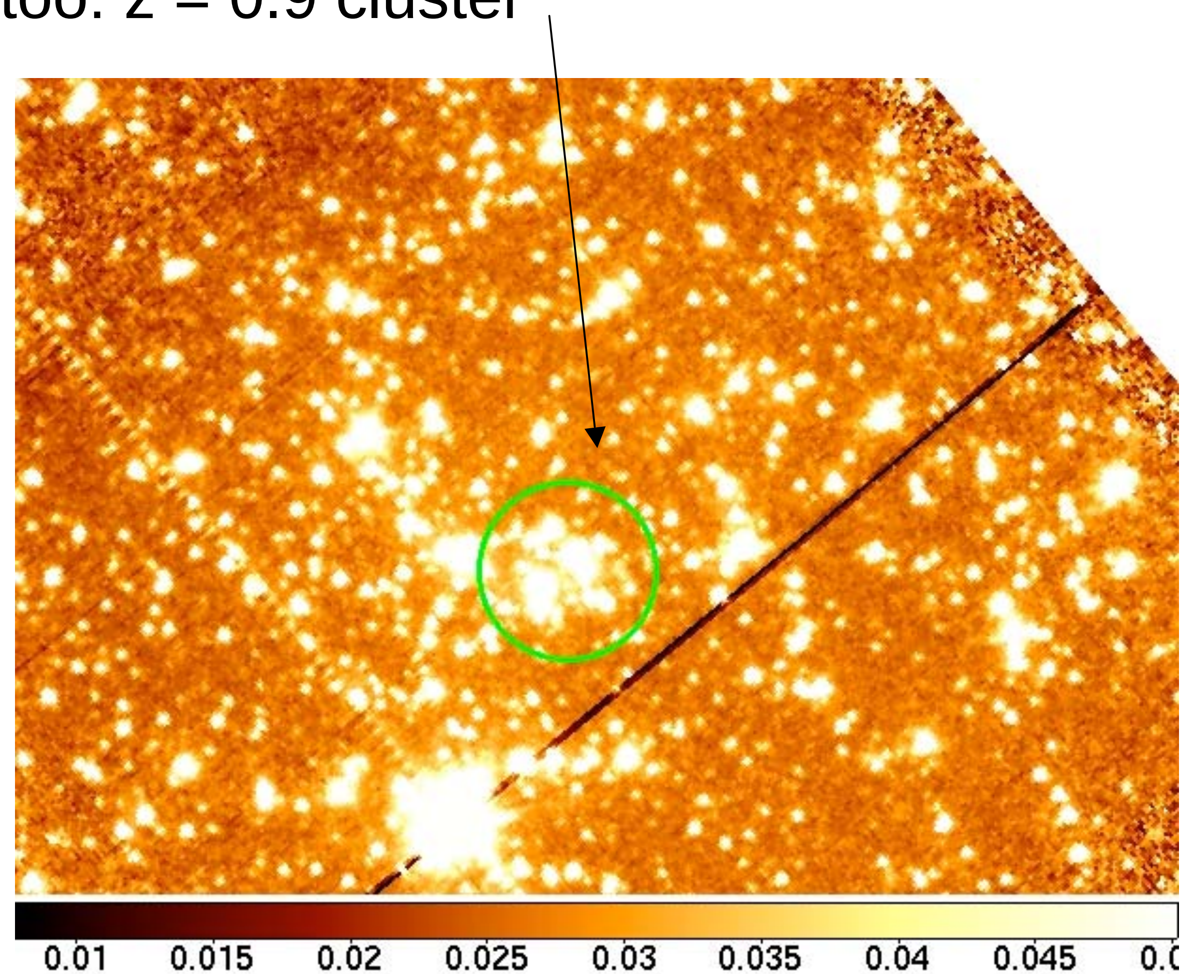
Red Sequence Cluster Survey has over 900 candidates between 0.35 and 0.95, in the deepest 72 sq degrees of the CFHLS

CFHTLS wide covers 170 sq degrees in all

SDSS stripe 82 (Co-adds; comparable to CFHTLS) covers 300 sq degrees. Also extremely well calibrated good photometry

=> 1,000 clusters are easy just in optical, this ignores the SPT, ACT, APEX, and Planck which will give between ~100/survey and > 1000/survey depending on the mass cut.

Why warm Spitzer would be nice too: z = 0.9 cluster



Summary and Conclusions

Part 1

The existing Great Observatories with Hubble in the lead can take a great leap forward in understanding the nature of Dark Energy by imaging 1,000 clusters in at least 1 color with HST.

The rest can be done on the ground, with the trade-off being much more observing time needed on the ground, but larger FOV good for extended FOV models and cross checking.

The primary technique used will be **weak lensing tomography** which requires no physical understanding of the test objects. And is the approach most favoured by the Dark Energy Task Force

HST Archive provides a great training set

Summary and Conclusions

Part 2

Secondary approach will be to used will be cluster evolution models

We anticipate being able to determine, when all is said and done, w to 0.05, with 3σ uncertainty. => We should know if we have to "cope with" a cosmological constant (currently off a by factor fo 10^{100} or more) or not.

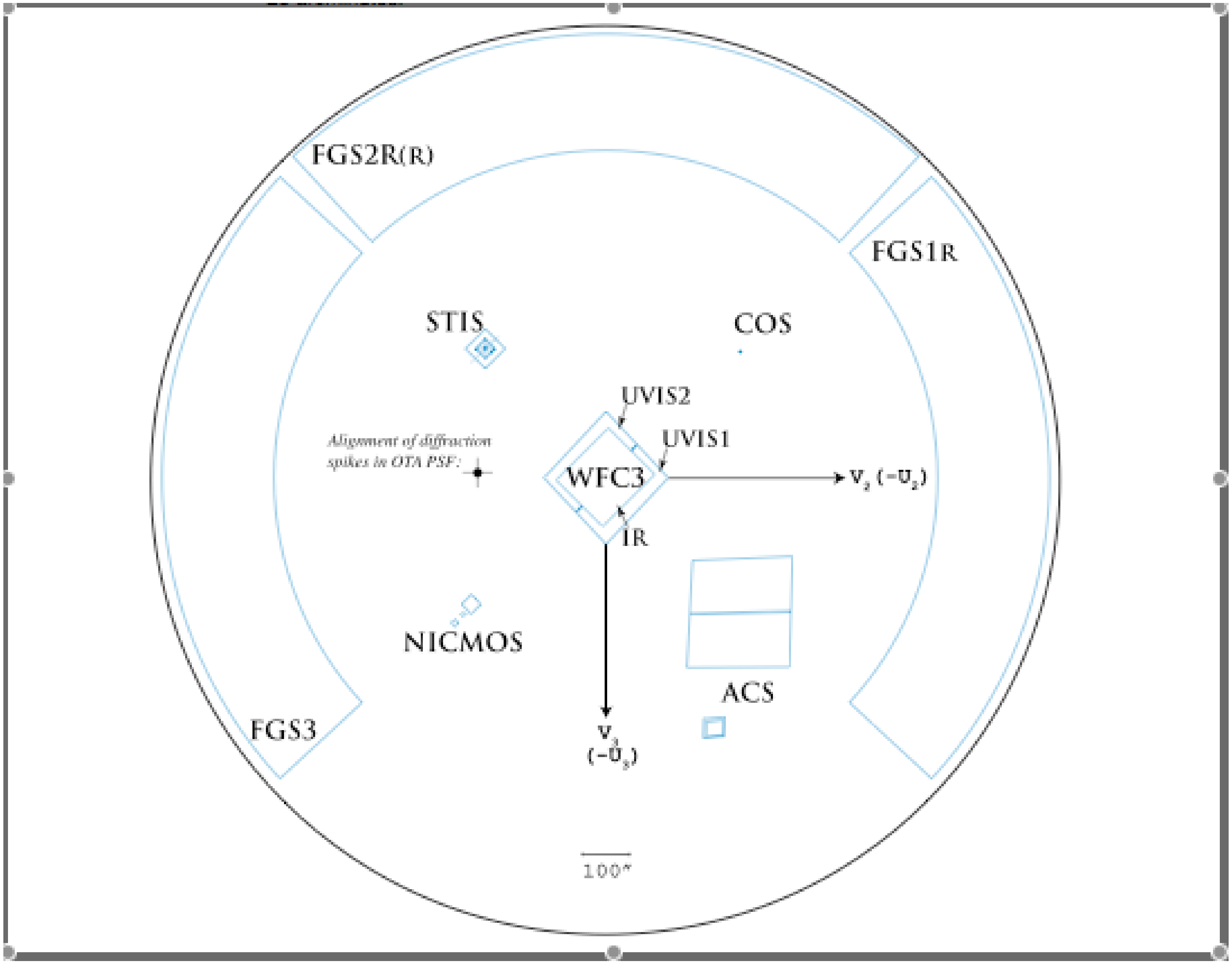
This project will beautifully complement JDEM missions, ground based projects, and it will also be treasure trove for studies of cluster-galaxy evolution.

Supporting equations (see also Bernstein and Jain, 2004) and references are posted at:

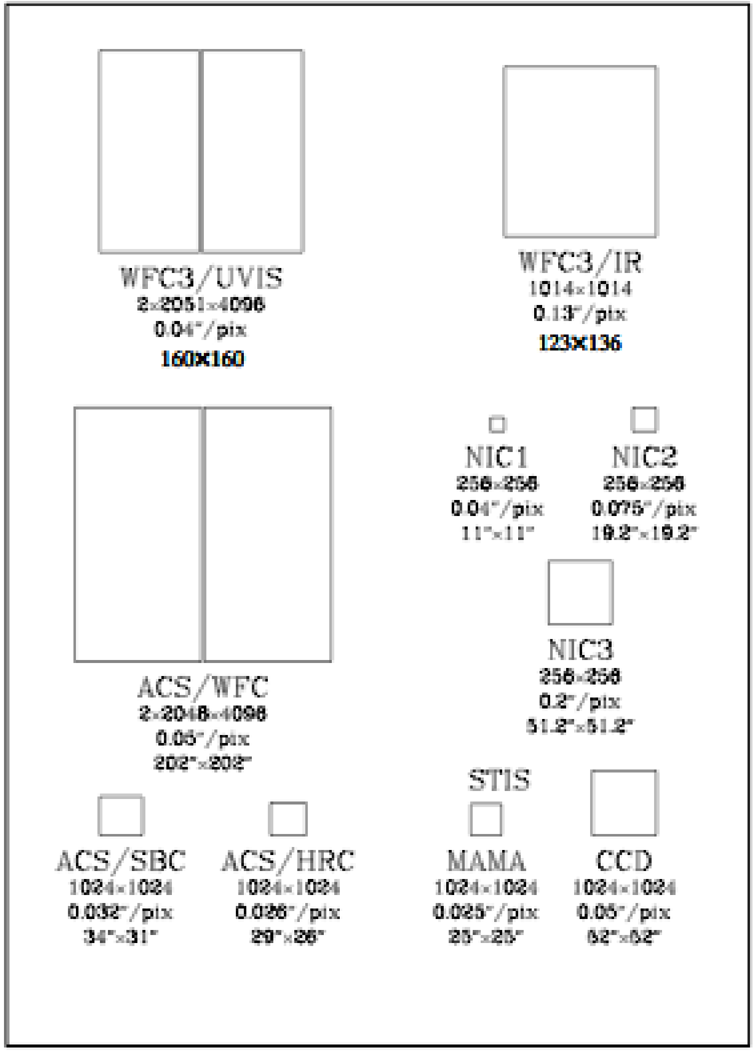
http://www.astro.northwestern.edu/~ulmer/private/Bologna_2008_references.pdf

http://www.astro.northwestern.edu/~ulmer/private/Bologna_2008_equations.pdf

Supporting slides on HST FOV, instruments, optical surveys follow



From WFC3 handbook



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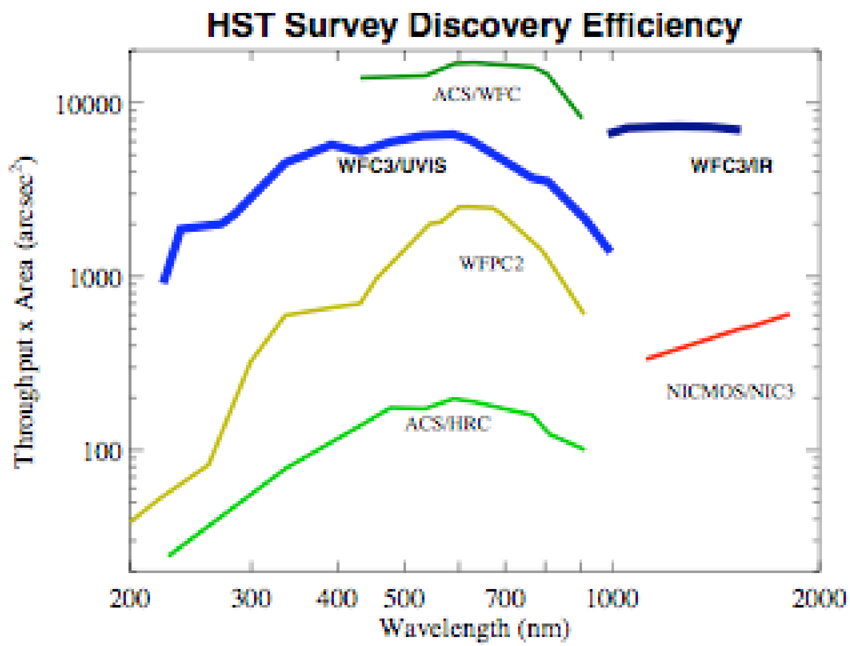

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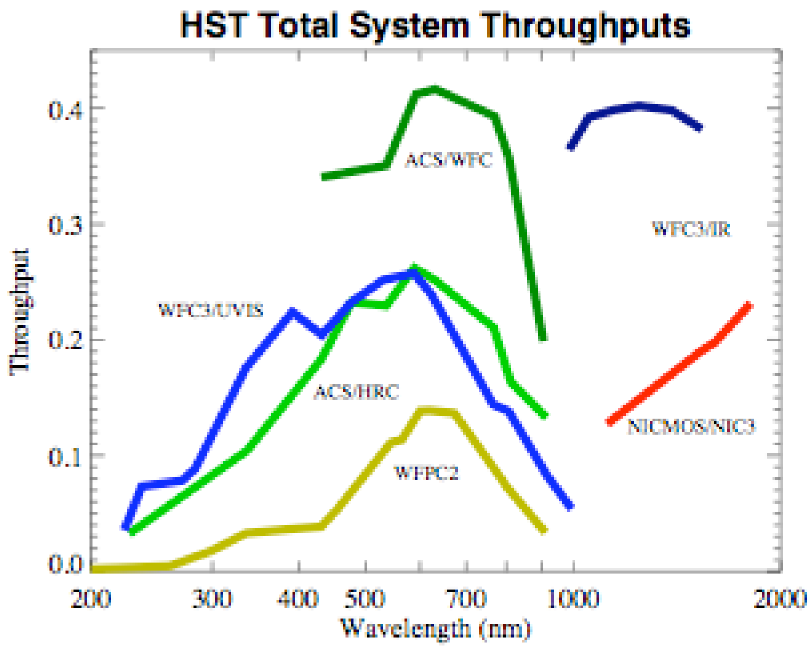

From WFC3 handbook

SDSS Southern vs. Other Cosmic Shear Surveys

	CTIO Blanco Survey (completed)	CFHT Wide	BCS	SDSS Southern
Area	75 sq deg (12 Fields)	~170 sq deg (22 deg published) (3 Fields)	100 sq deg (2 fields)	300 sq deg (1 field)
Bands	R (no photoz's)	ugriz (i published, no photoz's yet)	griz	ugriz
Limiting mag	R<23	i<24.5	g<24,r<23.9	r<23.7
Seeing	1.05"median (0.9"-1.3")	0.76" (<1.0")	<1.3"	<1.5"

Jeff Kubo/Fermilab

Training Data Set: 100 clusters 0.4 <= z <= 0.9