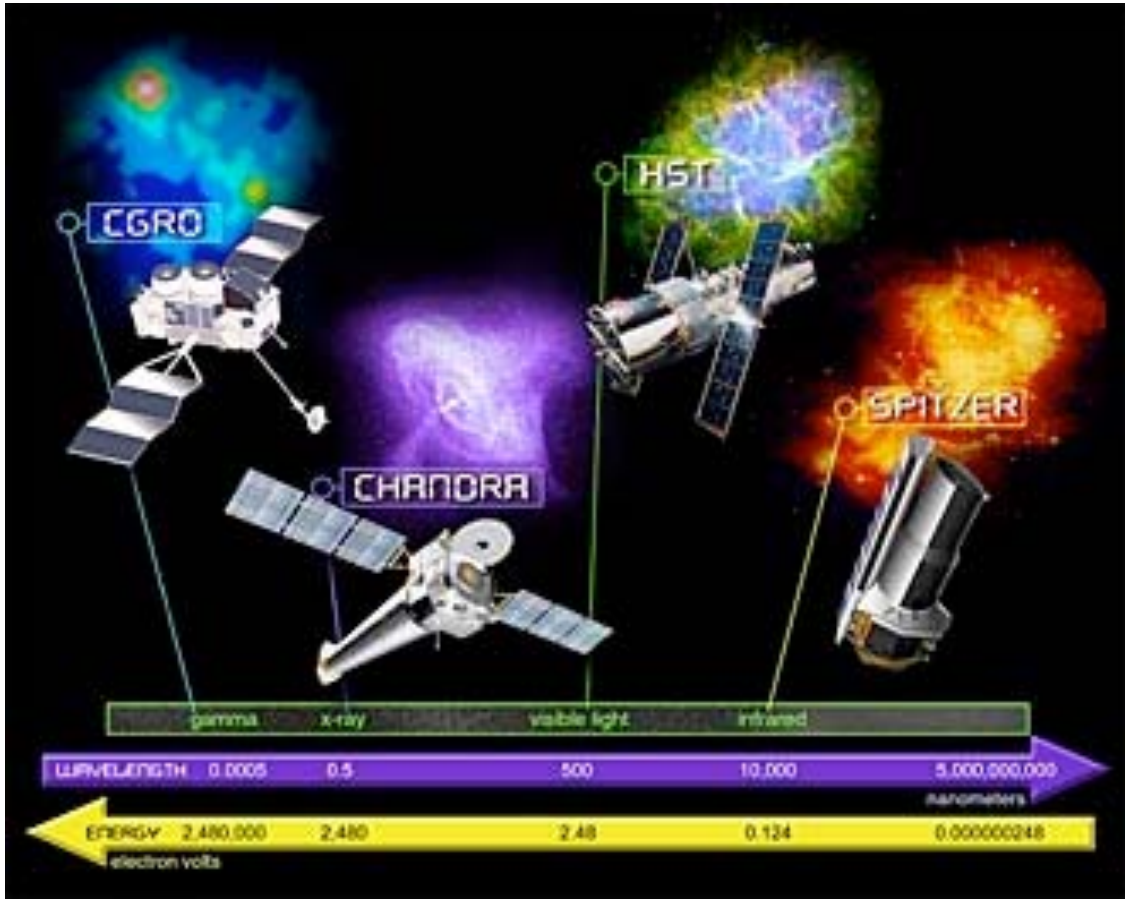
Making the Most of the Great Observatories

Richard Ellis (Caltech)

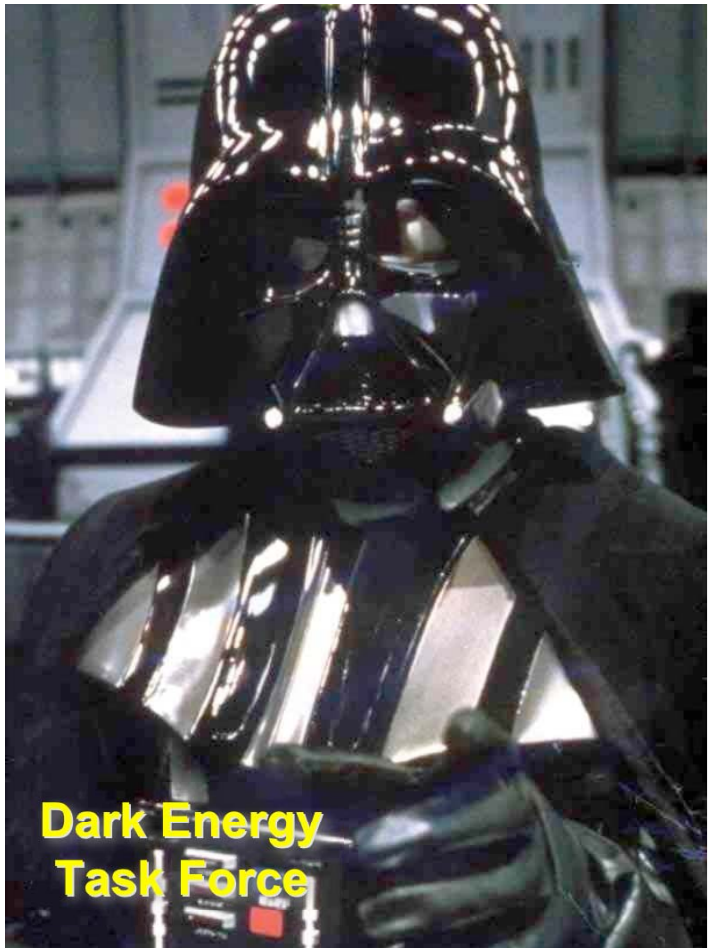


Plan

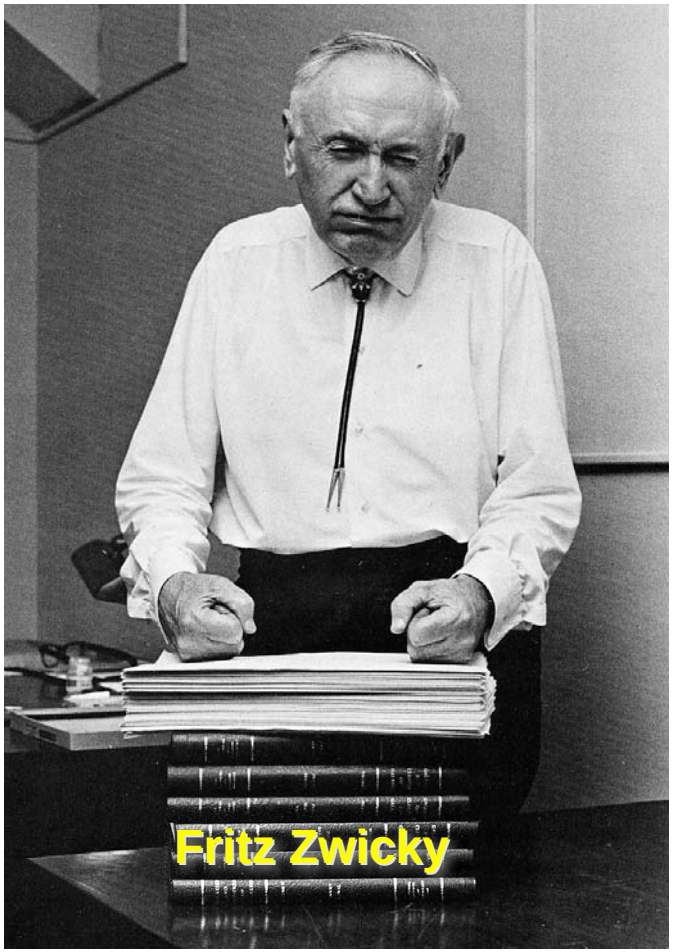
- Current & past programs are successful & synergistic!
- Science imperatives
  - I: Cosmology
  - II: Reionization and first light
  - III: Galaxy evolution and large scale structure
  - IV: Hubble Sequence & Stellar Populations
- Strategic Issues
  - Key projects / more surveys…?
  - TAC-ology

I - Cosmology: two rogue ingredients

Dark Energy



Dark Matter



What should Great Observatories do in this area?

Dark Energy: theorists are having a field day…

***"The issue of dark energy dynamics is perhaps the most pressing today in cosmology"* (Bassett et al 2004)**

Riess et al. 2004, ApJ, 607, 665
"Type Ia Supernova Discoveries…Constraints on Dark Energy Evolution"
w(z)=w(z,w0,w')
"Our constraints are consi
and value of w expected f
inconsistent with very rap

aastro-ph/0311622, revised Apr 2004
"Cosmological parameters from supernova observations"
Choudhury and Padmanabhan

aastro-ph/0405446
Gong
lysis of dark energy I:
t forms
zations, no firm conclusions.

astro-ph/0403292
"New dark energy constraints
supernovae, microwave back
galaxy clustering"
Wang and Tegmark
w(z)=w(z,w1,wa,etc)
"We have reported the most a
measurements to date of the
density as a function of time,
universe. We have found that
constraining power, the spect
high-z supernova measureme
no hints of departures from th
corresponding to Einstein s c
constant."

1378
Padmanabhan
straints on low redshift
lark energy"
t combining the supernova
vations {\it with the
om WMAP observations}
icts any possible variation of
edshifts. The results rule out
nge in w(z) in recent epochs
letely consistent with the
constant as the source of

astro-ph/0404468
"No evidence for Dark En
Metamorphosis ?"
Jonsson et al
w(z)=summation(Ak,z), p
"For the ansatz proposed b
energy evolution is both fa
and forced...Our best fit to
additional high redshift su
consistent with the cosmol
the 68% confidence level.

07094
on the dark energy equation
recent supernova data"
,w1)
models for the equation of
rk energy will remain
a mug's game until there
tially more data at higher
i.e., data not highly

aastro-ph/0407364
"The essence of quintessence and the cost of compression"
Bassett, Corasaniti, Kunz
w(z)=w(a,a_t,w0,wm,delta); allows rapid changes
"Rapid evolution provides a superlative fit to the current SN Ia data...[significantly better than lambda]"

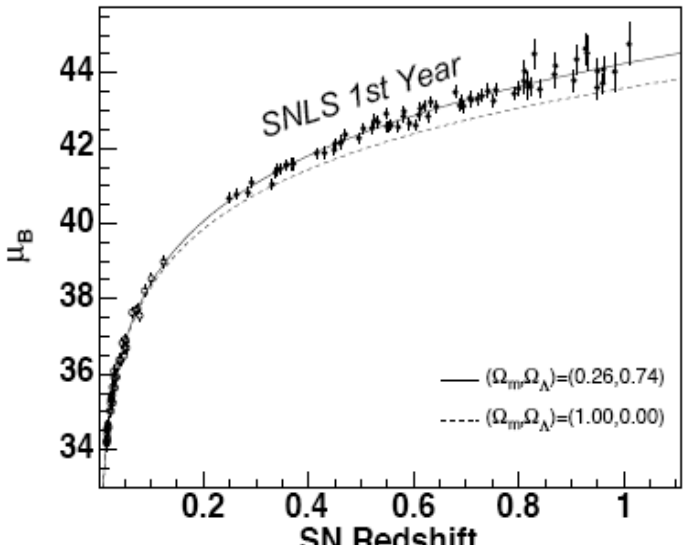
astro-ph/0407372
"Cosmological parameter analysis including SDSS..."
Seljak et al.
w(z)=w(a,w0,w1)
"We find no evidence for variation of the equation of state with redshift.."

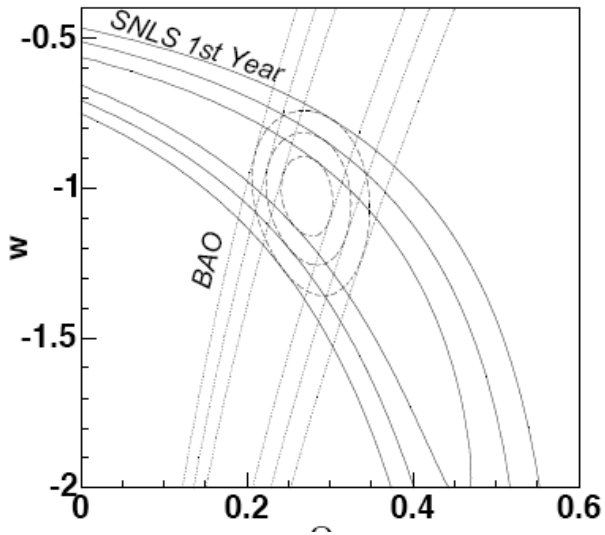
astro-ph/0407452
Probing Dark Energy with Supernovae : a concordant or a convergent model?
Virey et al.
w(z)=w(z,w0,w')
Worries that wrong prior on omega_m will bias the result. Suggests weaker prior, data consistent with lambda or significant DE evolution.

astro-ph/0408112
"Scaling Dark Energy"
Capozziello,Melchiorri,Schirone
w(z)=w(z,zb,zs); phenomenological
"We found that the current data does not show evidence for cosmological evolution of dark energy...a simple but theoretically flawed cosmological constant still provides a good fit to the data."

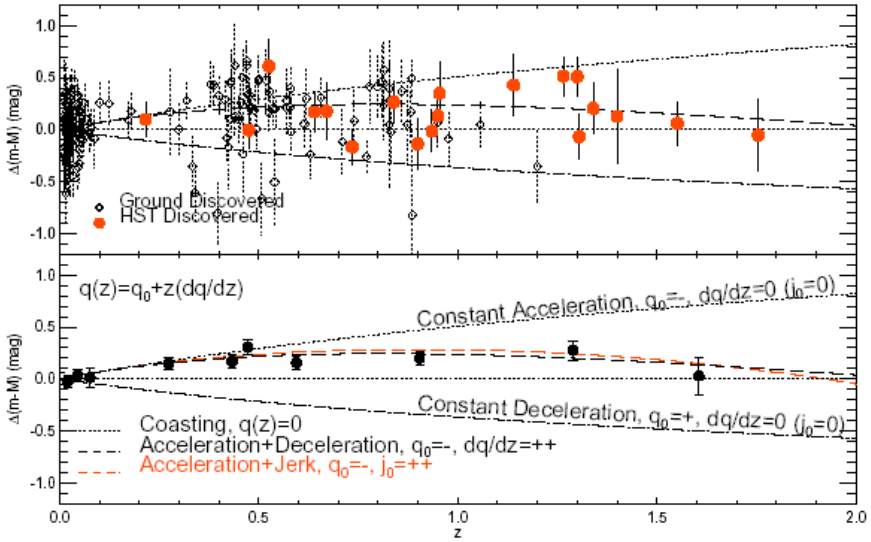
Dark Energy & SNe: State of the Art

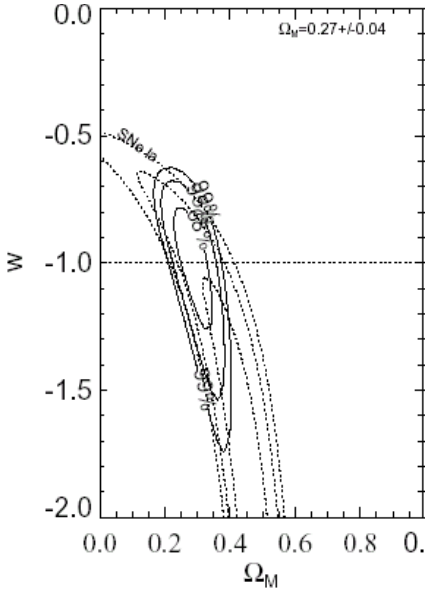
Astier et al (2006): SNLS Year 1: 71 SNe Ia z<1 w = -1.023 ± 0.09





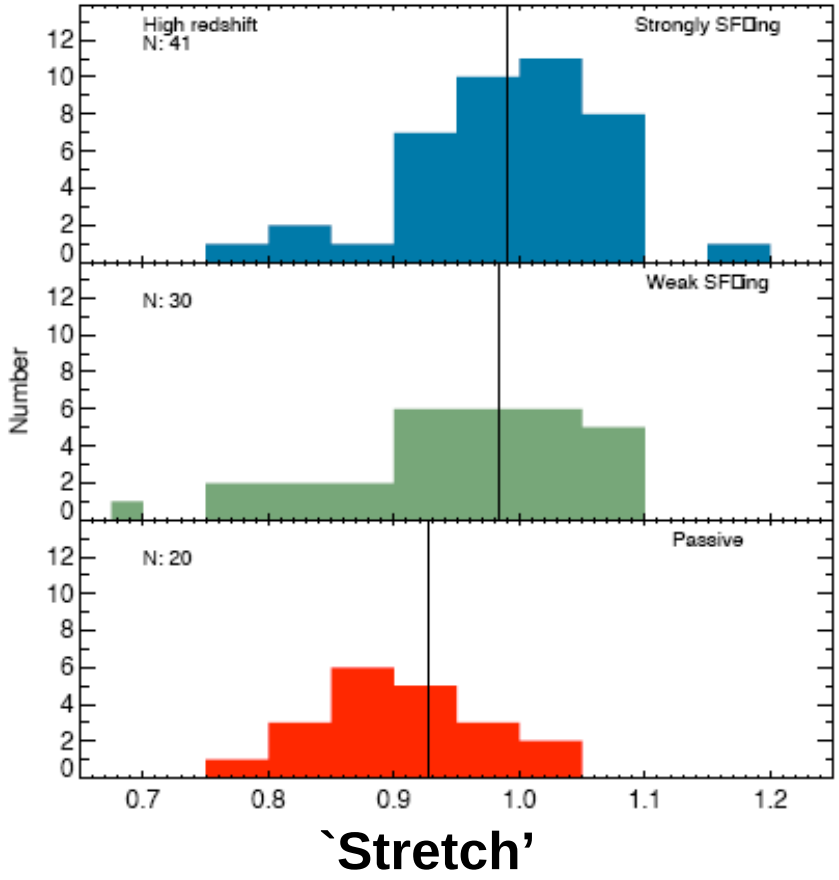
Riess et al (2004): GOODS SNe Ia z > 1 w = -1.02 ± 0.16



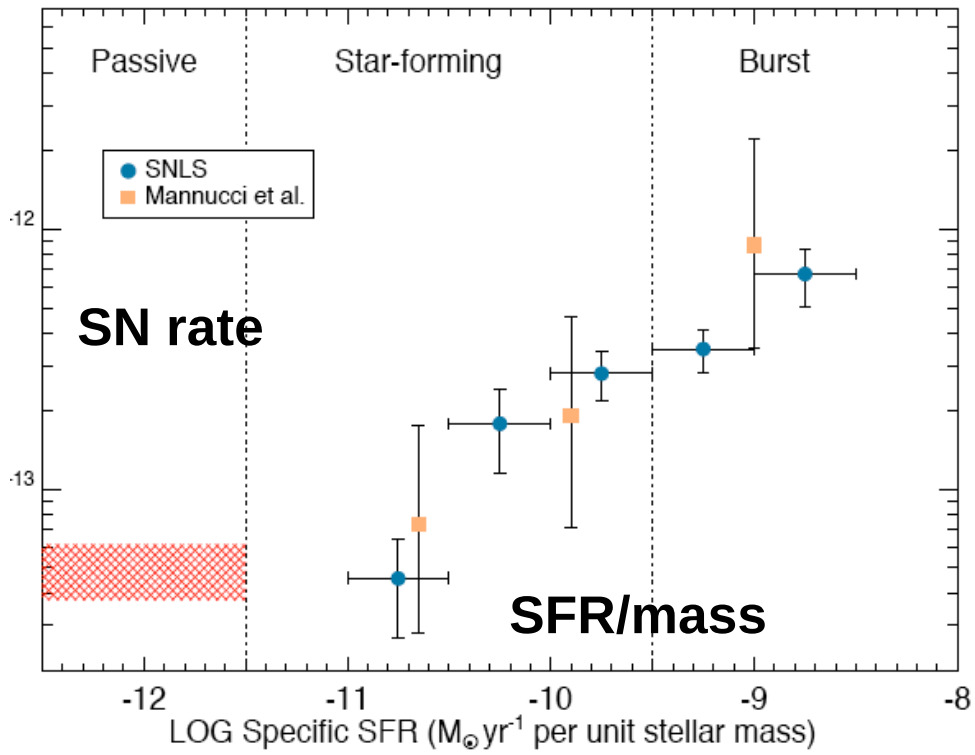


Verifying SNe Ia as cosmological probes

Supernova are *not* a single-parameter (stretch=luminosity) sample!
Light curve shapes & rates depend on host galaxy type
What does this mean? Does it imply >1 progenitor type with different delays?
How does this impact on their use for probing dark energy?

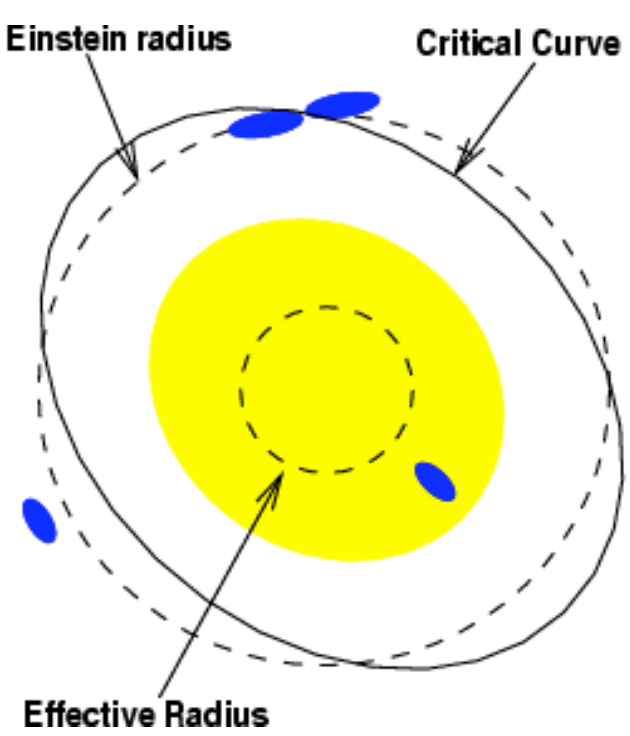


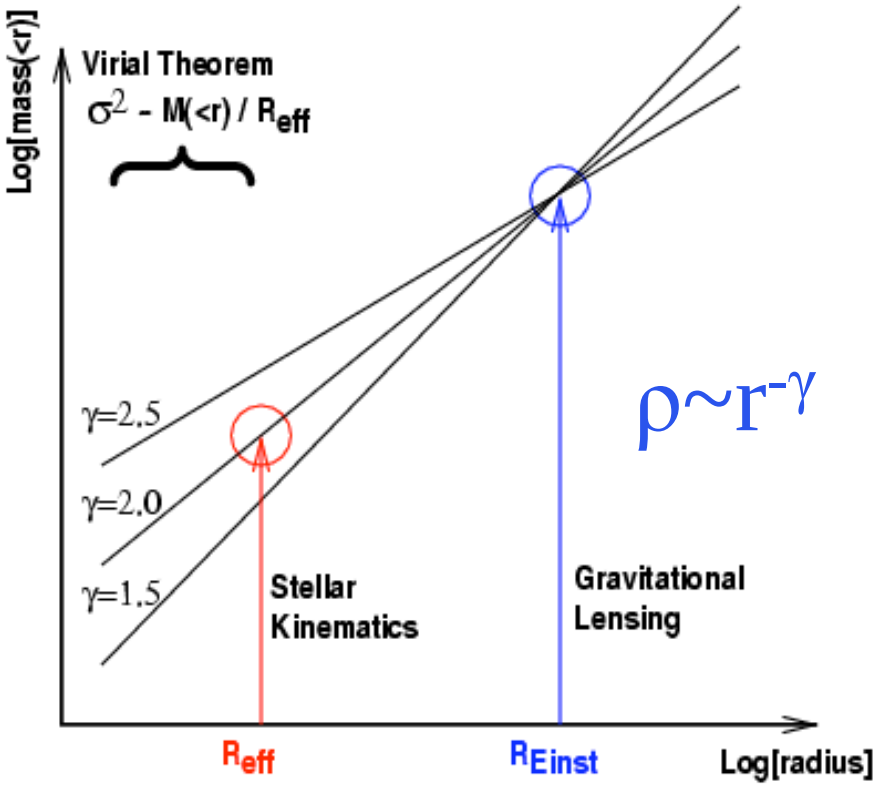
Sullivan et al (2006) SNLS



Should use our resources to verify possible systematics pre-JDEM

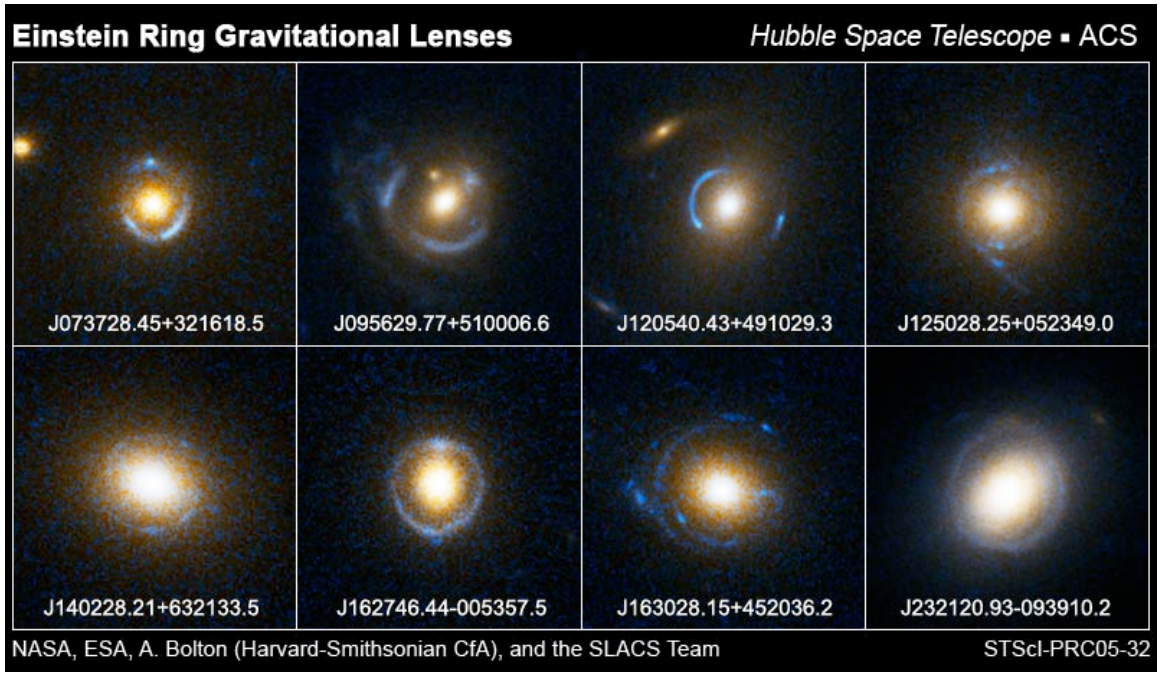
Dark Matter: Lensing & Stellar Dynamics

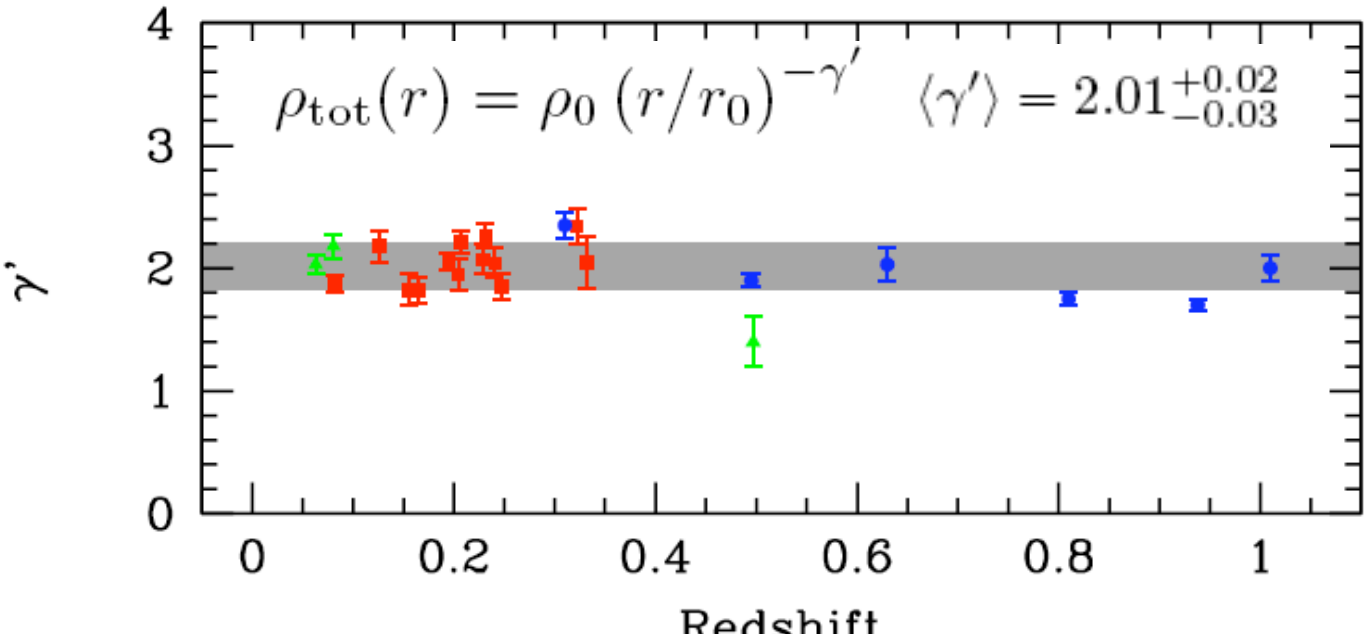




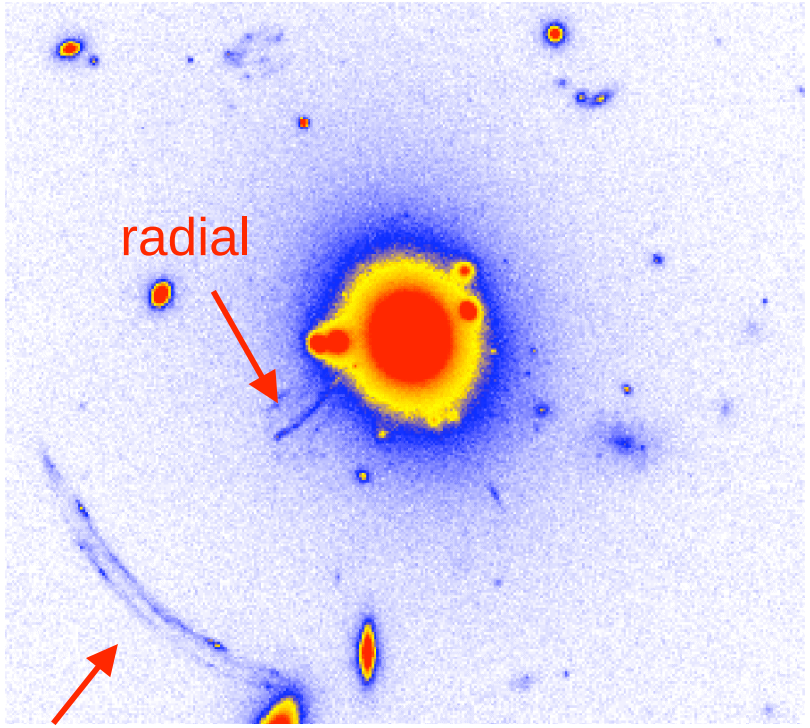
In elliptical galaxies, lensing and stellar dynamics provide constraints on the mass distribution on complementary scales. In combination, therefore, they constrain the slope, γ , of the total mass distribution

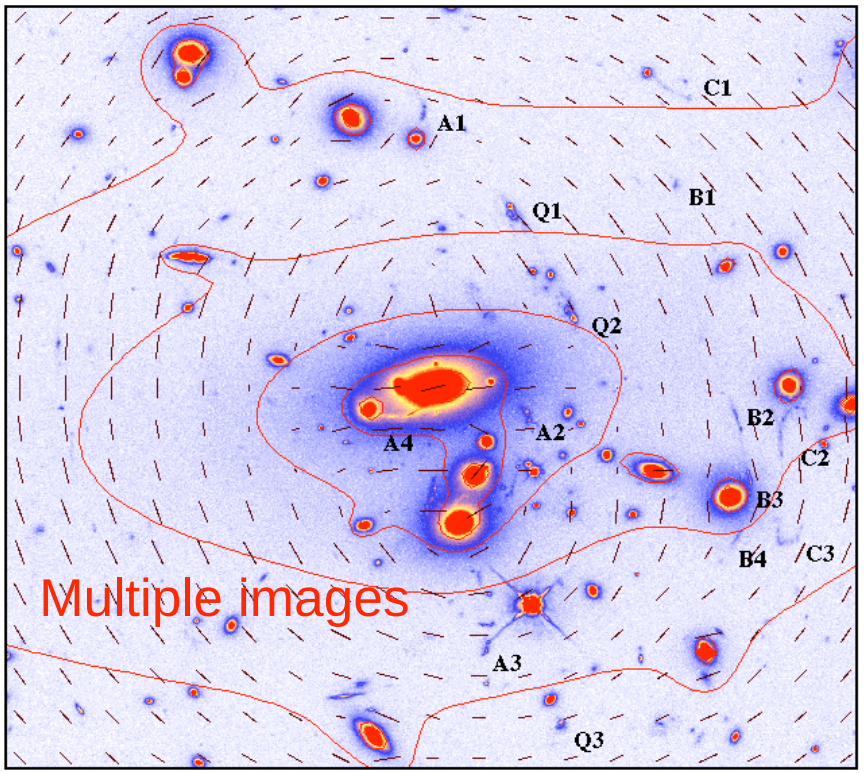
Einstein Rings: DM as f (L, z)





Dark Matter Profiles in Cluster Cores

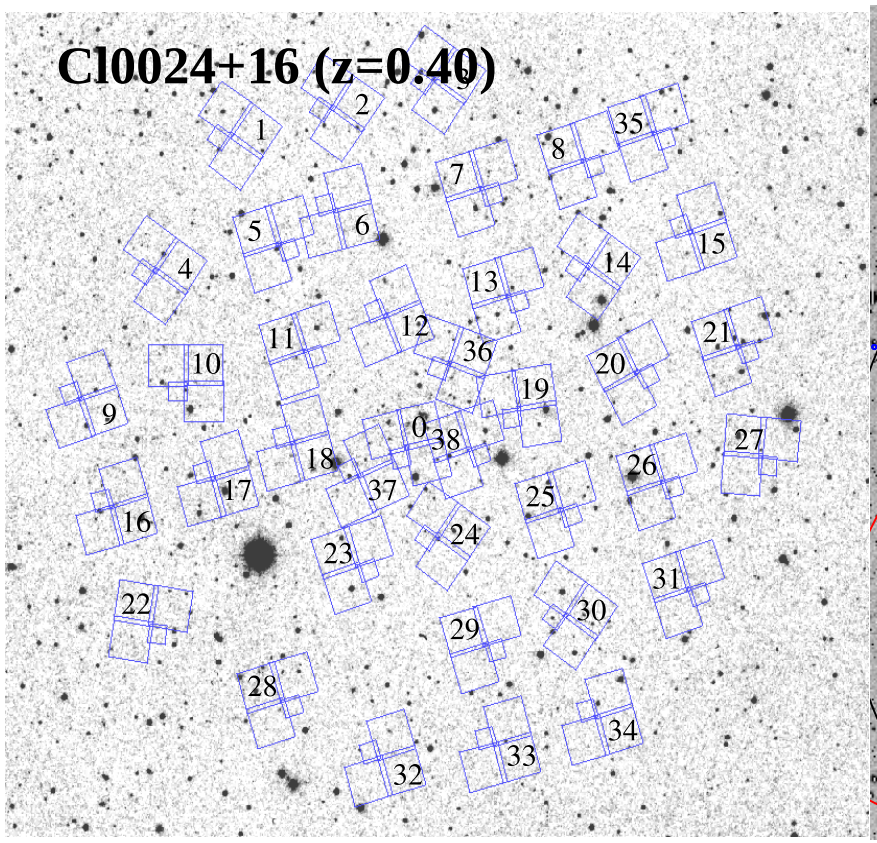


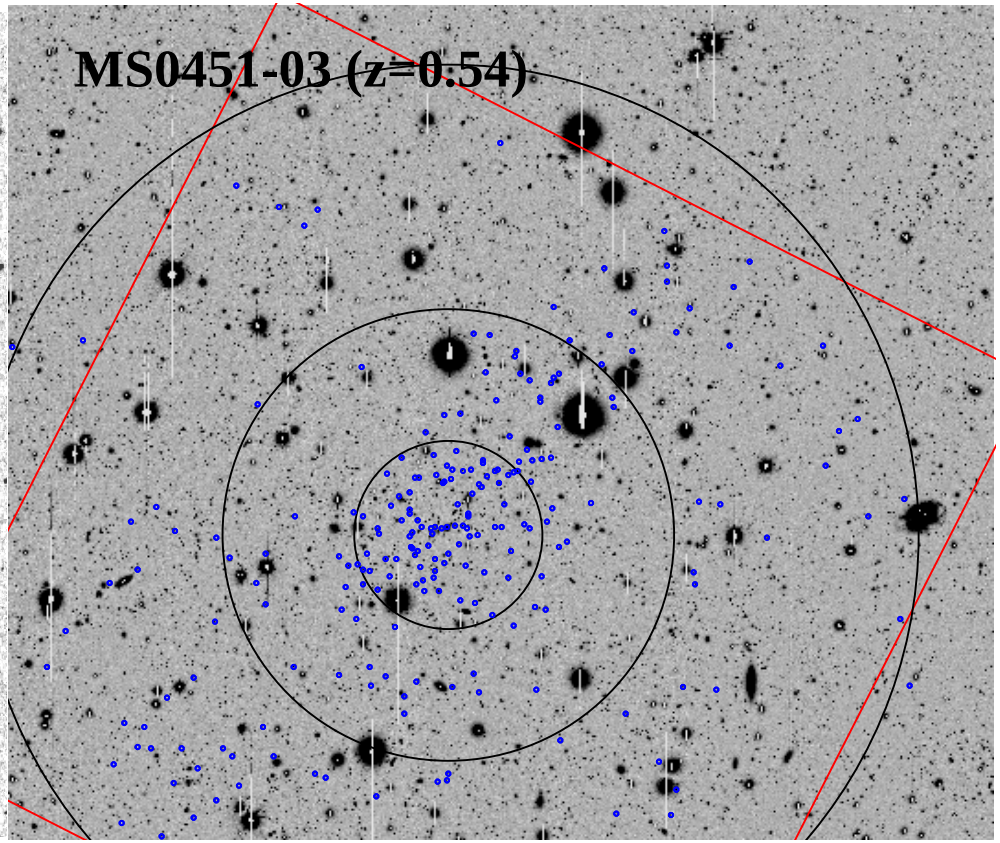


AC114 HST/WFPC2 Smail, Kneib, Ellis 96

Combination of strong lensing (only recognized with HST) & baryonic probes (Chandra resolution + stellar dynamics) in clusters is only way to *separate* DM and baryons on small scales.

Panoramic Imaging of Lensing Clusters



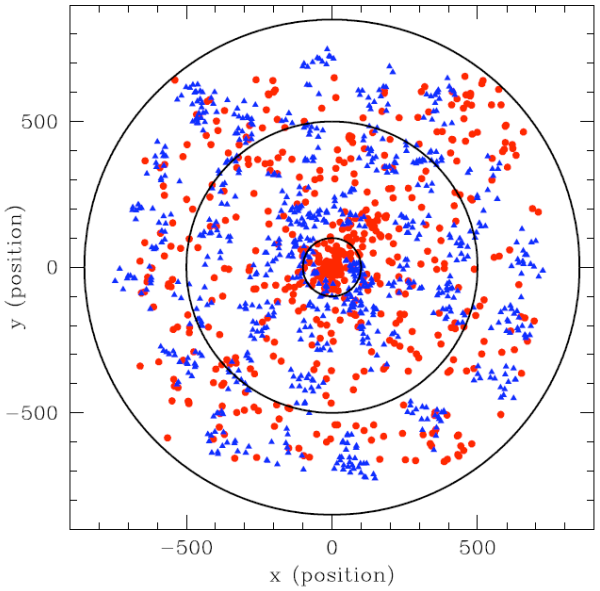


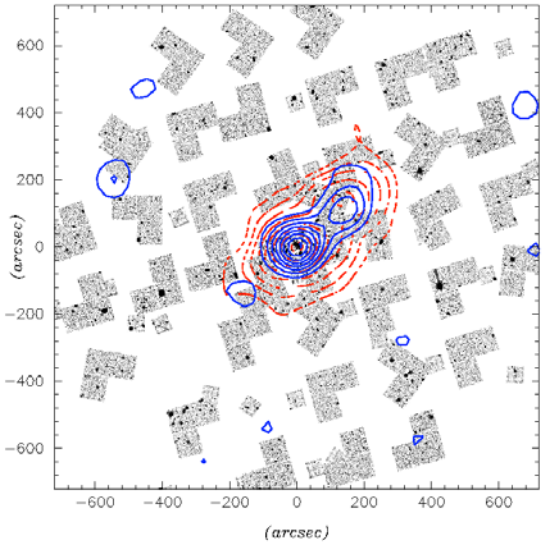
Only <u>two</u> clusters(!) with X-ray data have been imaged by HST to the turn-around radius (R~5 Mpc) simply because mosaics are required.

What do you learn about DM by probing larger scales?

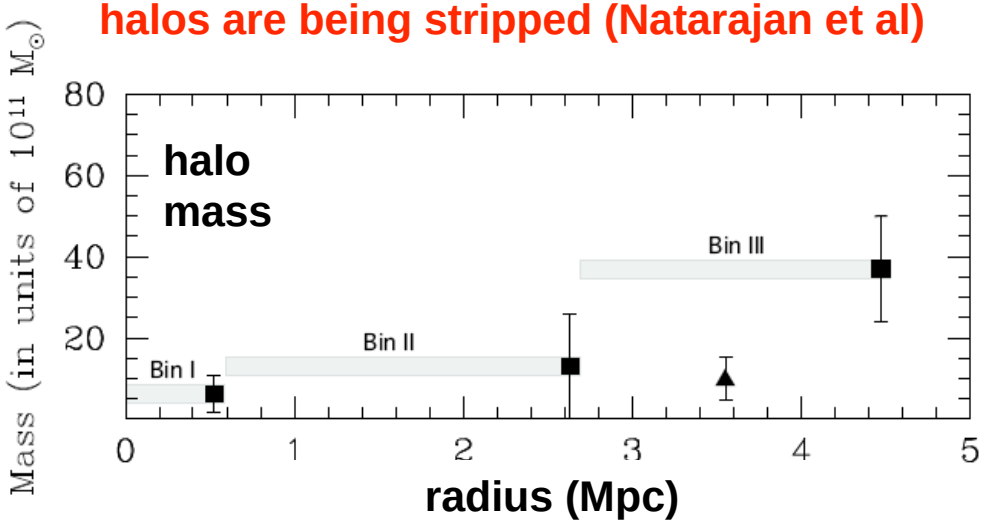
Panoramic Imaging of Clusters

10 Mpc

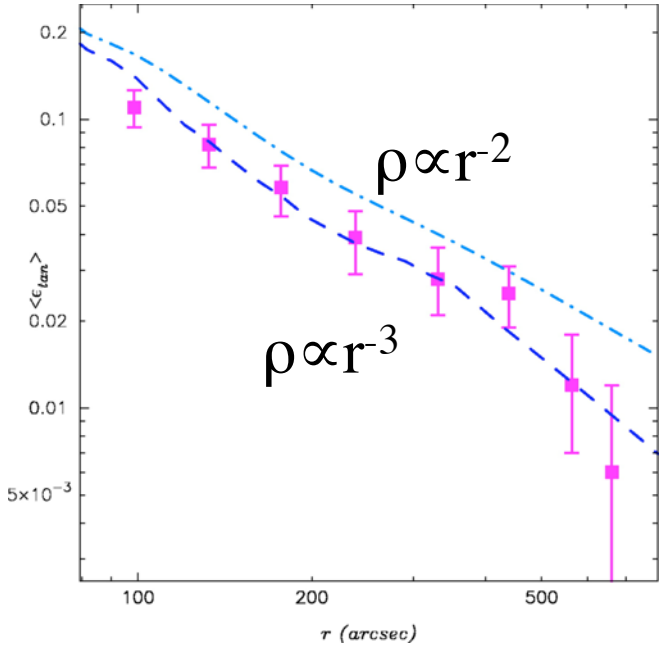




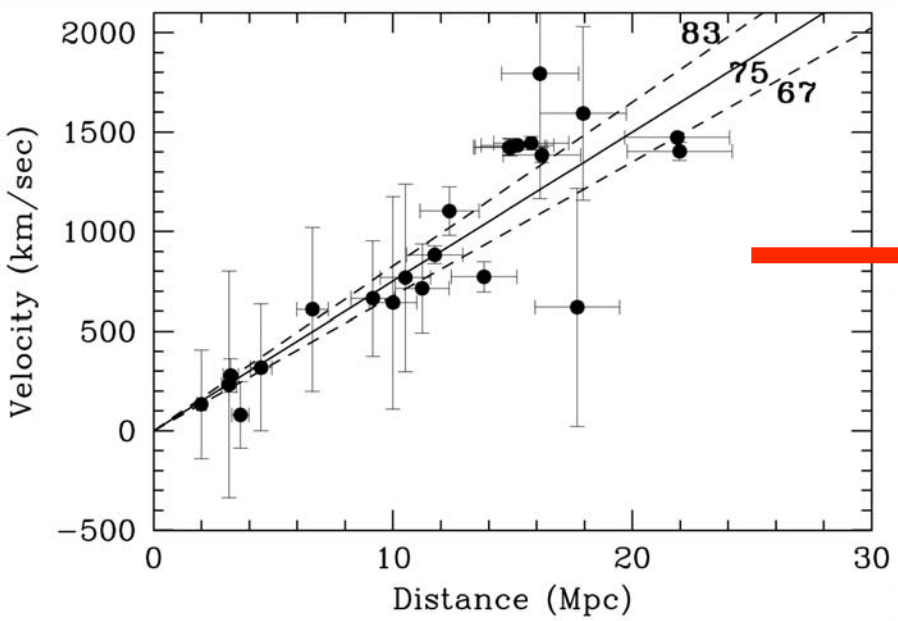
Galaxy-galaxy lensing demonstrates halos are being stripped (Natarajan et al)



Weak shear falls off as predicted in CDM simulations



Cosmic Expansion and H_0



Primary Cepheid calibration of distances to nearby spirals (affected by galaxy peculiar velocities & Cepheid metallicities)

Cepheids in Coma cluster will explore practicality of primary measure of Hubble's constant to 100 Mpc

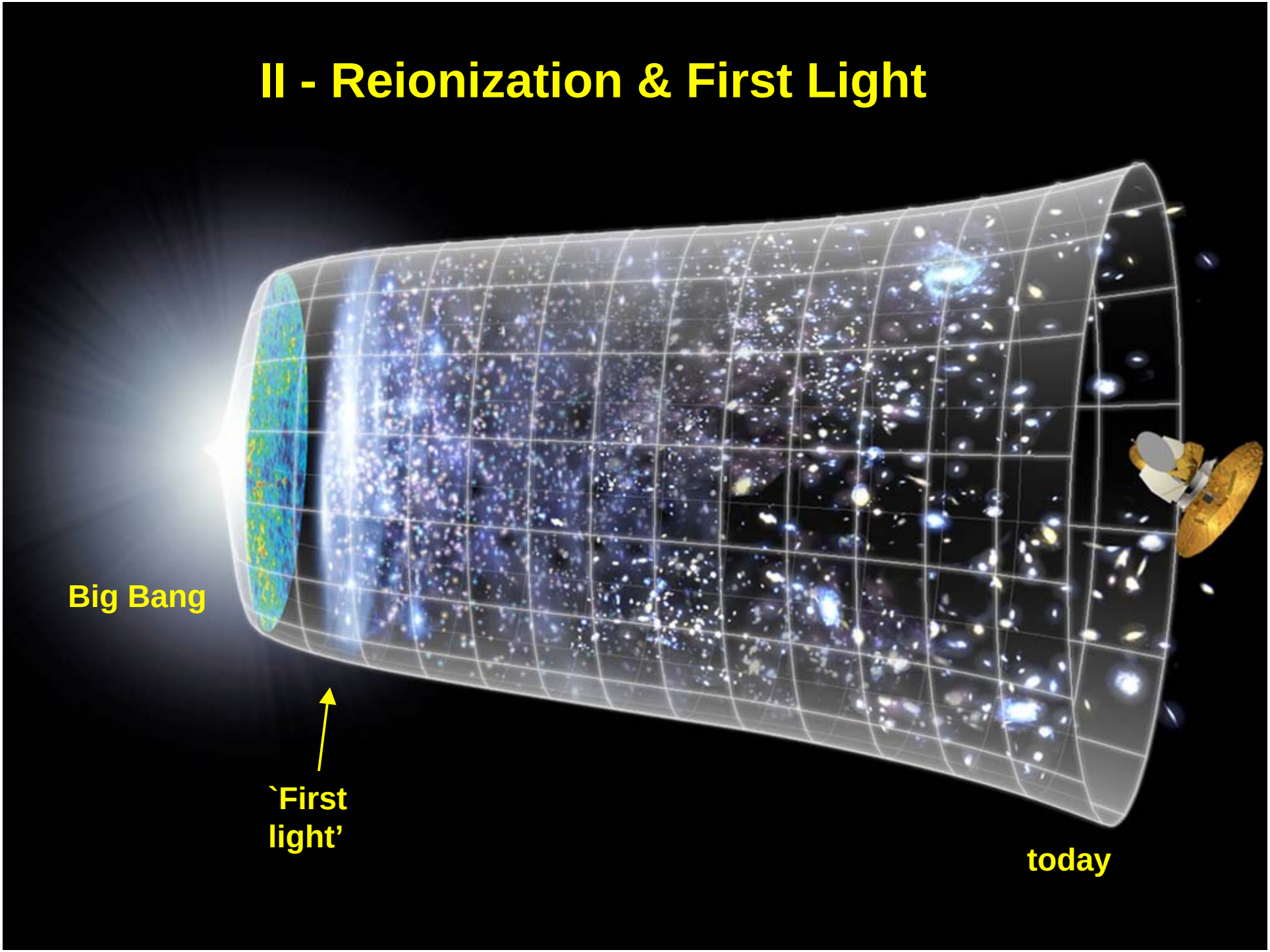
Freedman et al 2001: H_0=72 ± 8 kms s^{-1} Mpc^{-1}

Tammann, Sandage & Saha 2003: H_0=58.5 ± 6.3 kms s^{-1} Mpc^{-1}

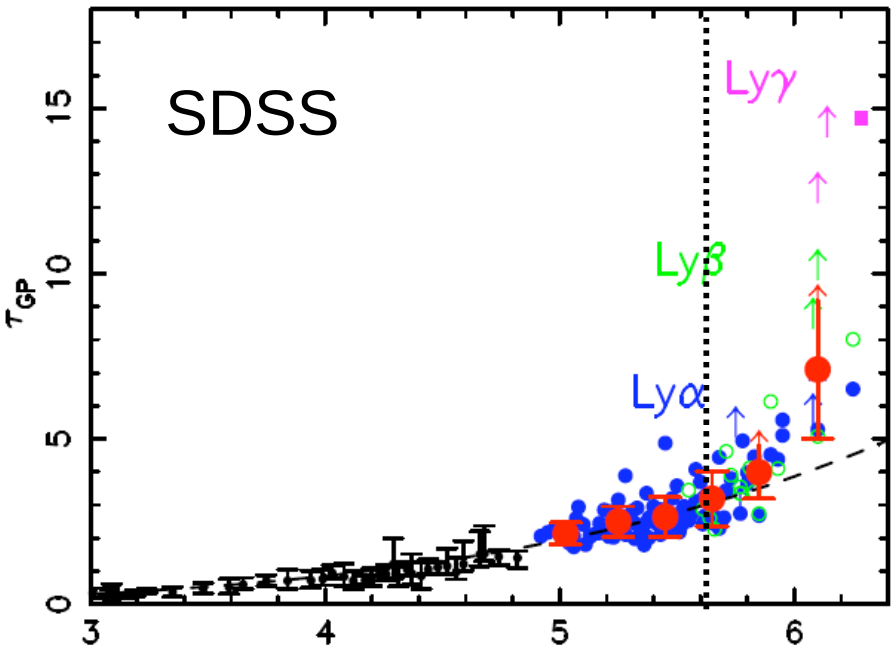
Cosmological thoughts:

- Great Observatories unlikely to be competive with dedicated missions (PanSTARRS, LSST, JDEM) in probing dark energy but can play valuable role in verifying utility of future tracers..sounds boring but it's crucial, especially for SNe Ia.
- HST/Chandra uniquely effective in exploiting lensing to probe DM on galactic & cluster scales. Clusters as generic targets somewhat undervalued by HST wrt Chandra (especially panoramic imaging)
- Cepheid distances to Coma might open a Pandora's box..therefore worth settling this issue..a lower H_0 is worth eliminating/knowing now.

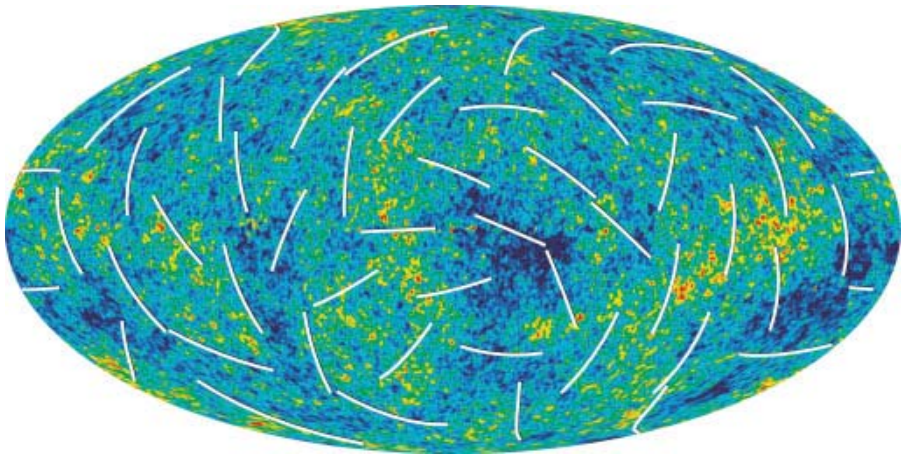
II - Reionization & First Light



Something Happened Between 6 < z < 20



WMAP3



SDSS QSOs (Fan et al 2006) reveal a tantalizing upturn in hydrogen absorption beyond z=5.5

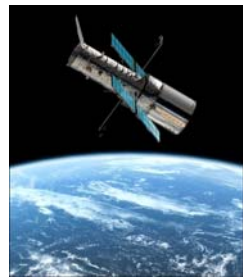
Angular correlations in WMAP3 polarization data suggest ionized gas resides in 6 < z < 20 (NB: the redshift localization is pretty uncertain!)

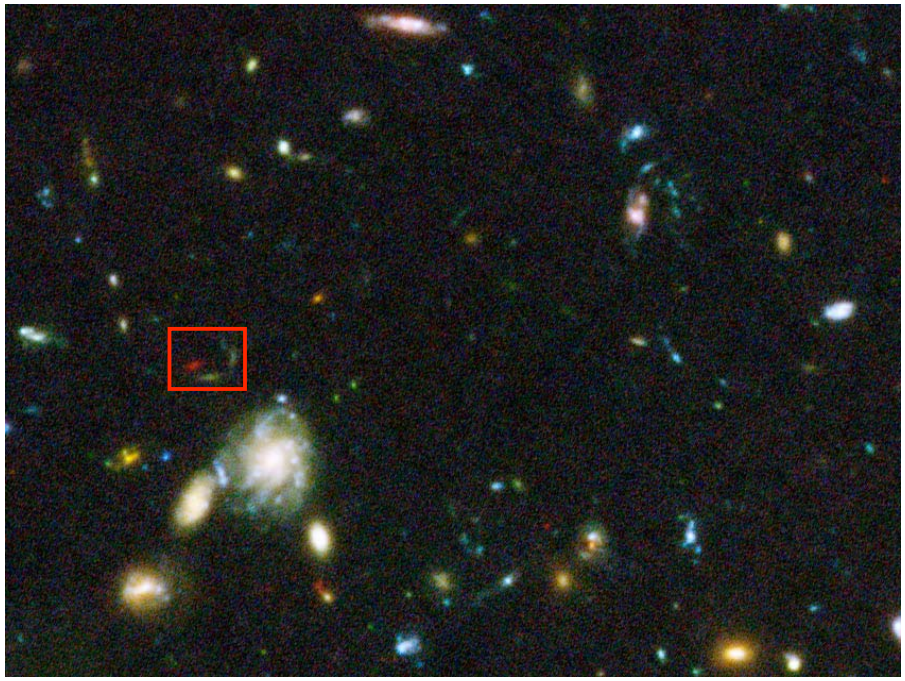
21cm surveys may trace tomography of cold hydrogen

But only OIR facilities can trace sources responsible for reionization?

ANY information ahead of JWST/TMT will be helpful in guiding us

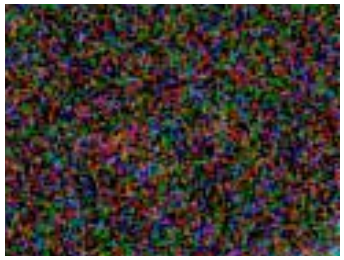
The Ultra Deep Field

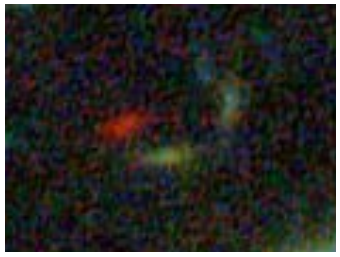




GOODS field – 13 orbits

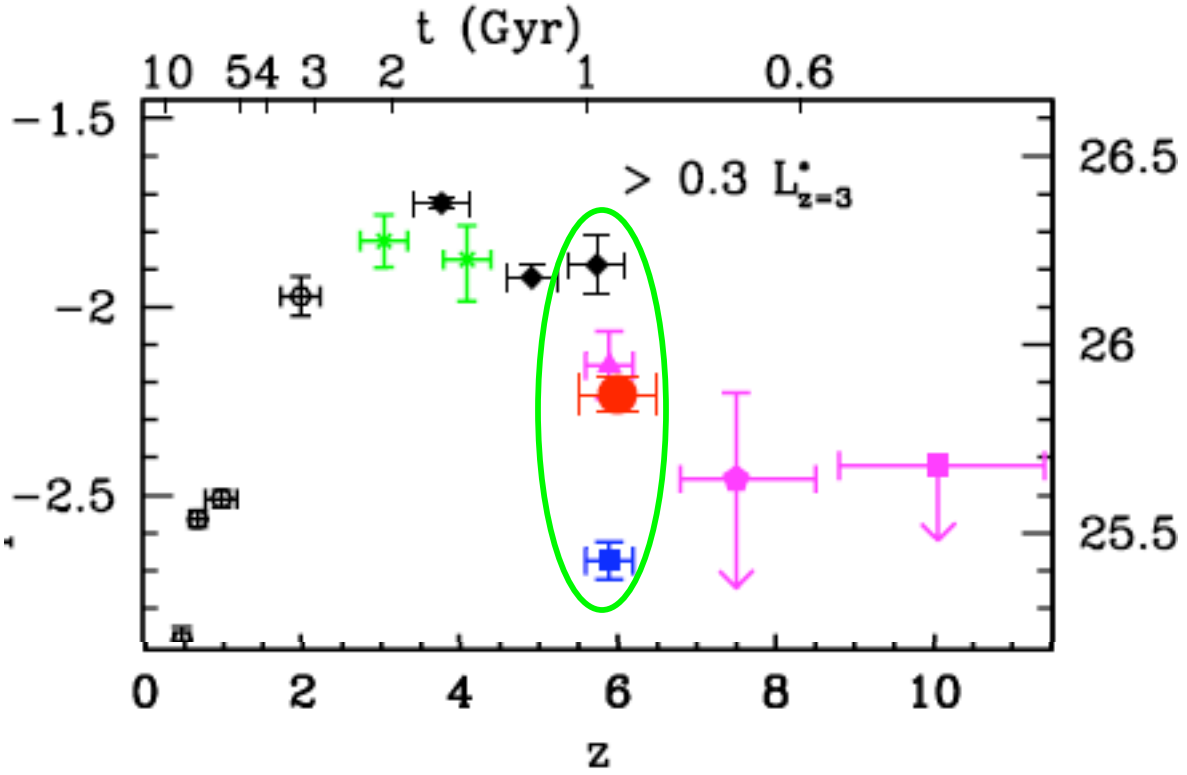
HUDF – 400 orbits





We've looked as deep as we can for a while...

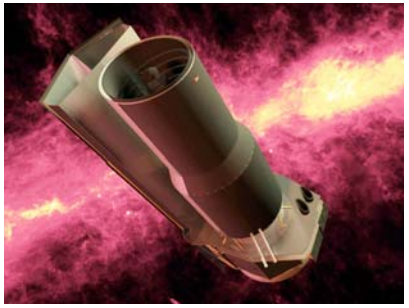
Density of star formation Mpc^{-3}



Controversy reigns on:

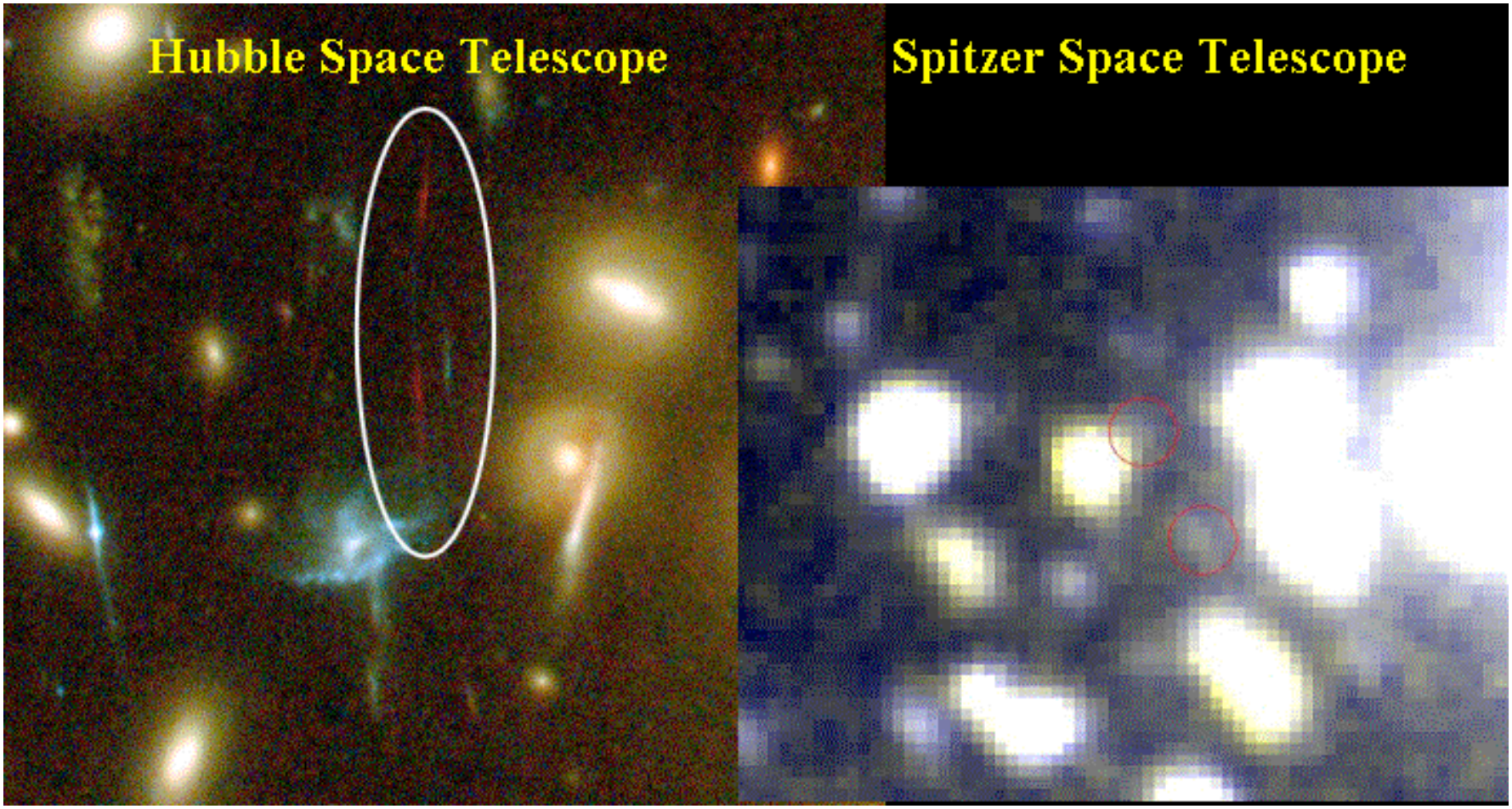
- abundance of z~6 objects (most don't have spectra)
- is abundance of z>6 sources sufficient for reionization?

WFC3 will clearly help but we will need UDF-depth ACS i+z fields

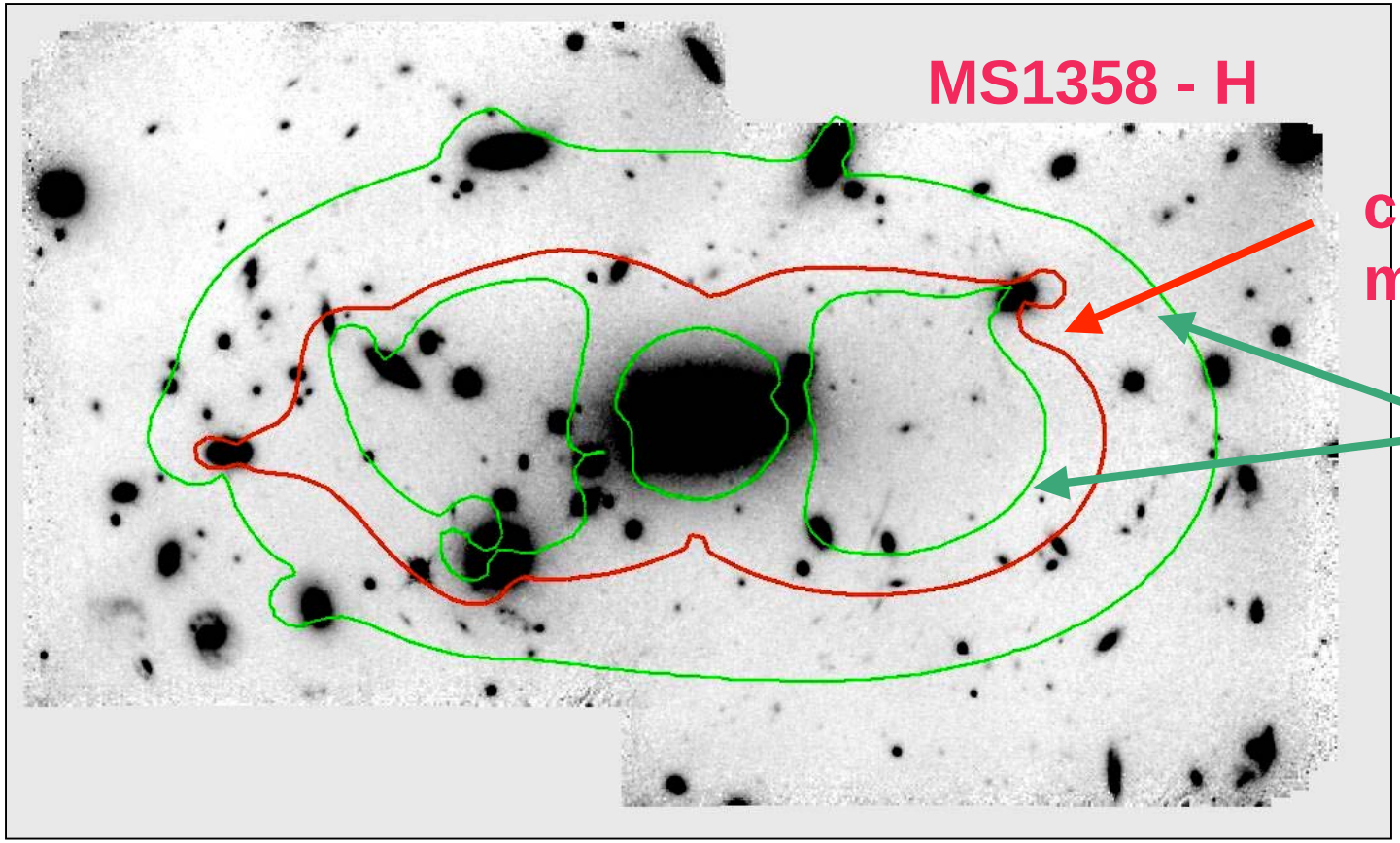


Spitzer detection of multiply-imaged z~6.8 source (Egami et al 2005)

Abell 2218 magnifies this source by x25



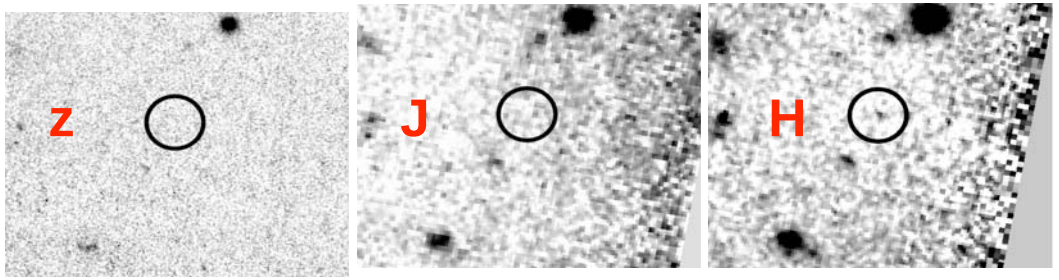
Pushing Further Back - Hubble & Spitzer



Imaging of 8 clusters (Johan Richard's poster)

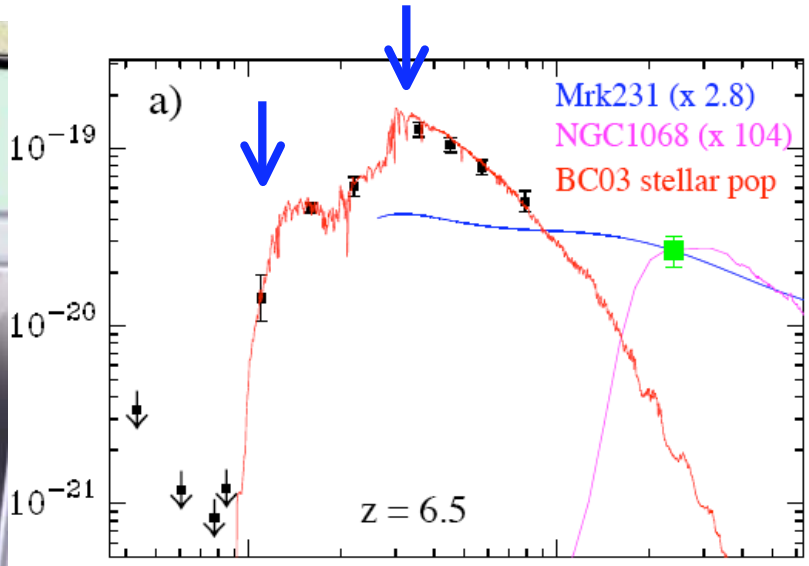
Drop outs with z~8-12 being found

Aim: confirm with Keck/VLT (v hard!)



candidate with z~11

Massive `2-break' Galaxies at High Redshift?



M=2-7 10^{11} $M_\odot$

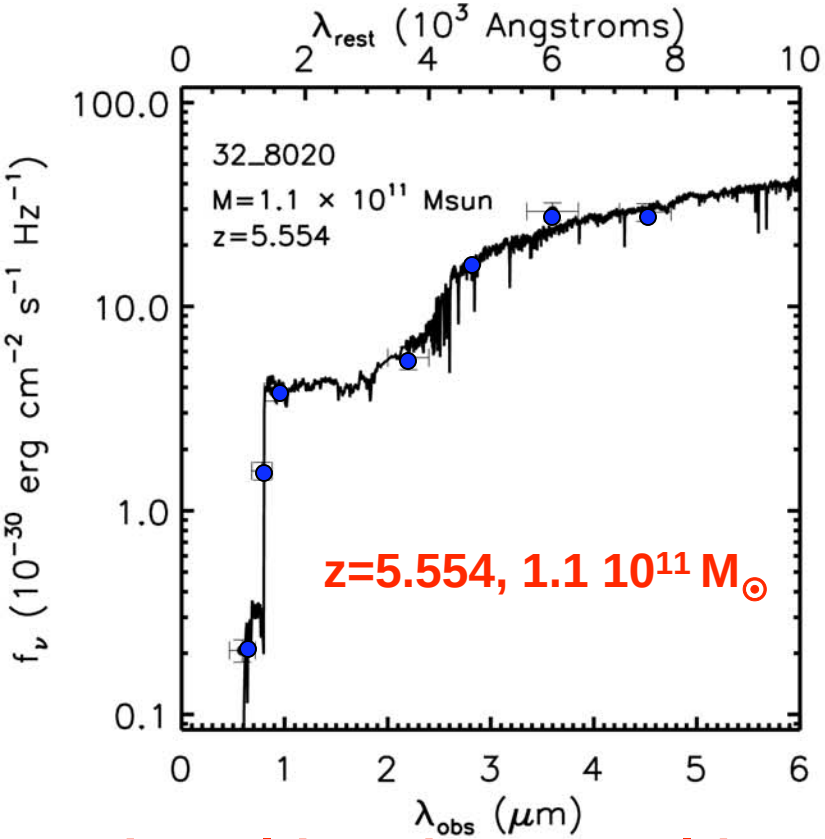
Mobasher et al (2005)

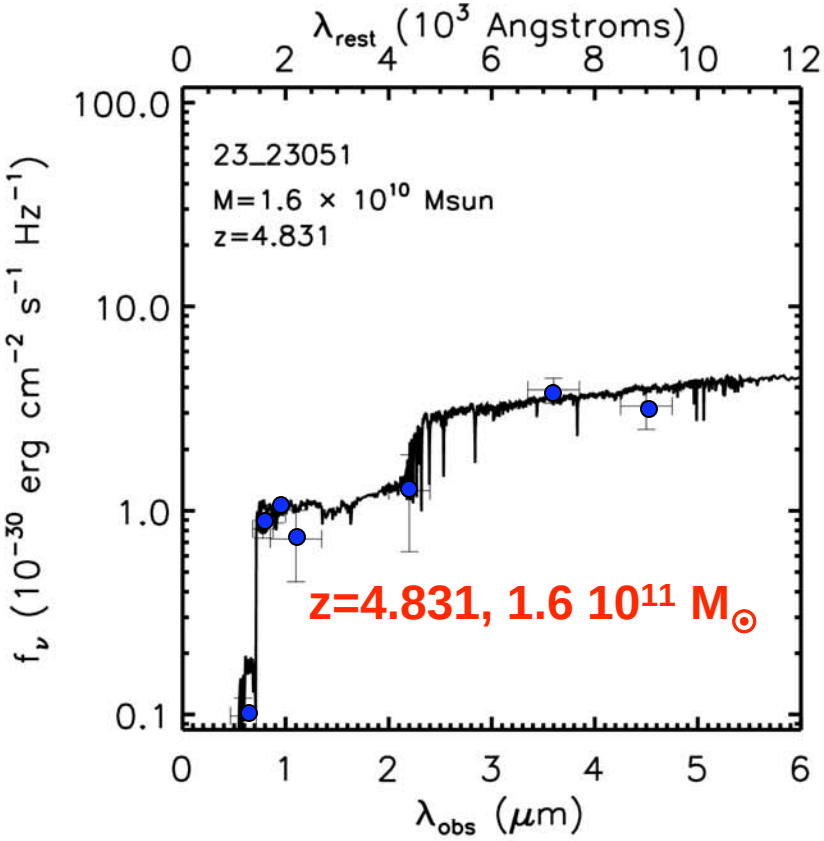
It appears such 2-break objects are not unique - if at z>5 they represent massive, quiescent, well-formed galaxies 1 Gyr after Big Bang!

Census of Stars in Place at Redshift 5

Spitzer and Hubble have the capability to do a definitive job on the already assembled stellar mass at z=5-6. This must be the integral of past SF activity

Key issues: spectroscopic z's (worth the effort on Keck/VLT)
reliability of SEDs and masses (calibration)





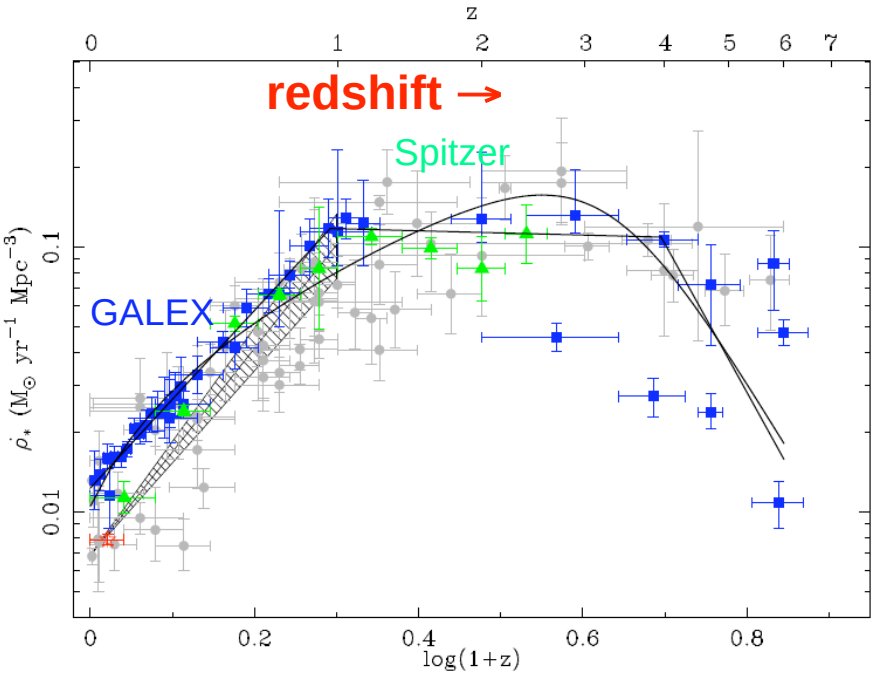
Stark et al (2006); Yan et al (2006)

First Light Thoughts..

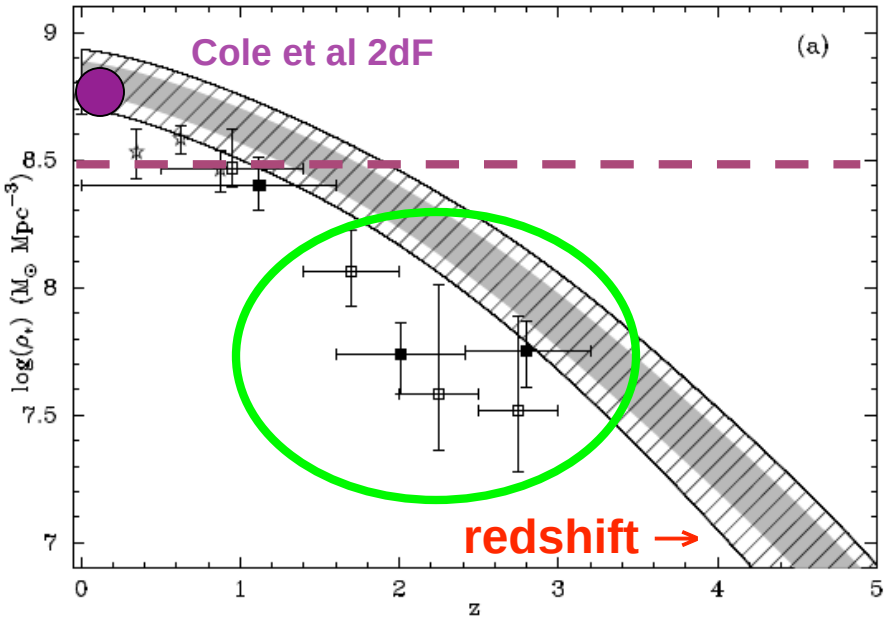
- Theoretical predictions are very uncertain so only data from HST/Spitzer/Chandra can show the way for JWST/TMT
- Should throw as much resources as we can to explore $7 < z < 12$ using coordinated WFC3/IRAC deep fields and lensing studies (increasing sample of clusters)
- EBL studies important: indirect evidence on early SF (IRAC fluctuation analyses & DC level experiments)
- Census of stellar mass @z~5 measures integral of past activity
- GRB studies offer only realistic insight into z>6 IGM

III - Galaxy Evolution: Star Formation z < 5

Star formation history



Mass assembly history



Hopkins & Beacom (2005) integrate self-consistent cosmic SFH to reproduce present stellar density (2dF): 50% stars were in place z~1.5

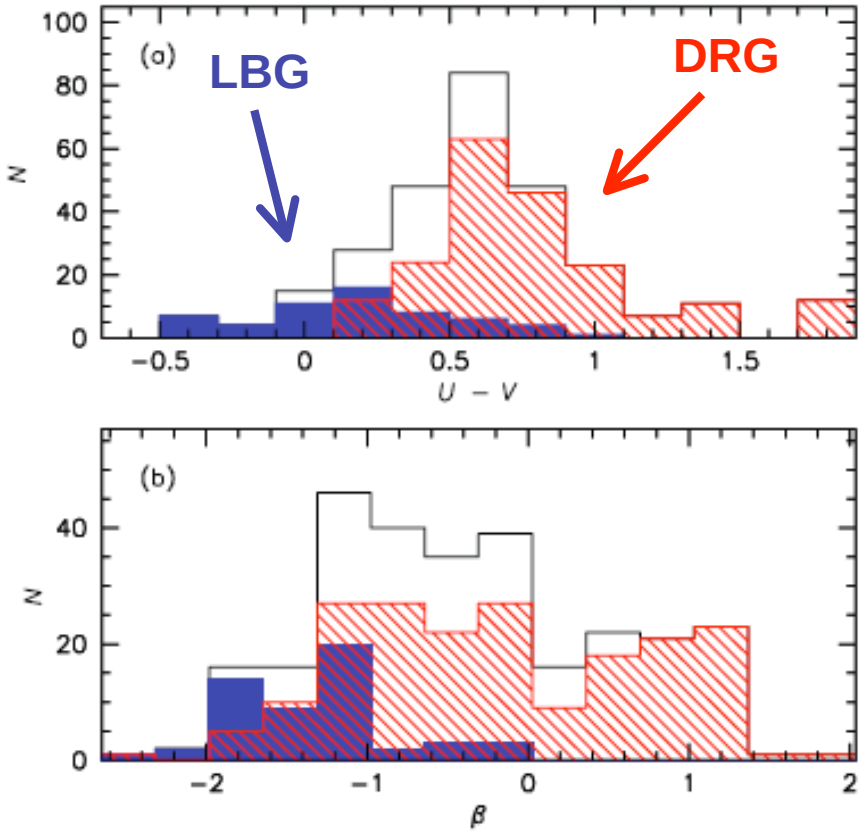
Yet ultimate test: direct measures of stellar mass at z>1 appear to be inconsistent with SFH: what's going on?

How reliable are stellar masses? Missing populations? AGN contribns?

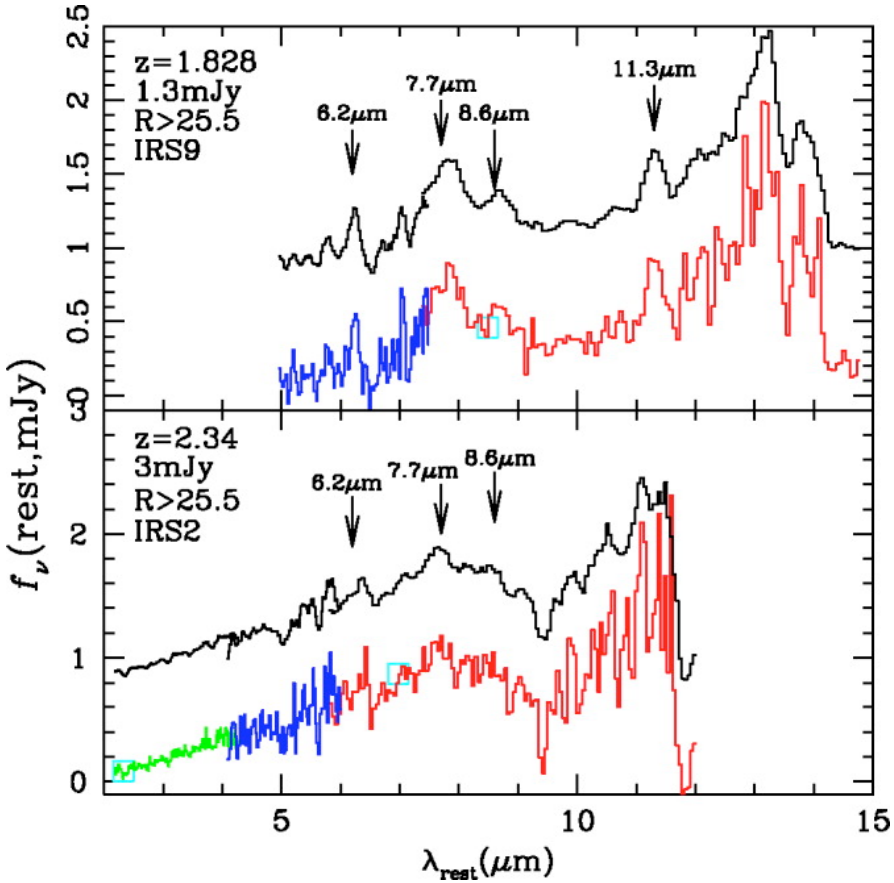
What is relationship between, e.g. sub-mm/Lyman Break/DRGs?

Spitzer Census Studies 2<z<3

IRAC Masses



IRS Spectra



Most M>$10^{11}M_\odot$ gals are DRGs(77%)
LBGs constitute only 17%

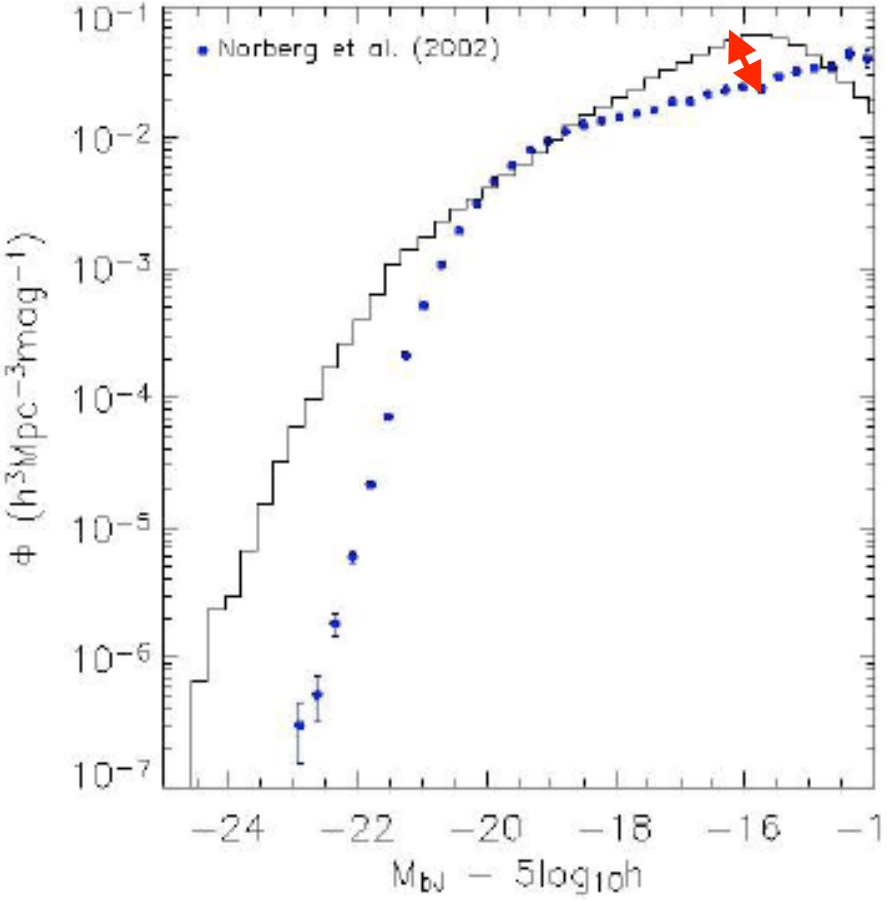
van Dokkum et al (2006)

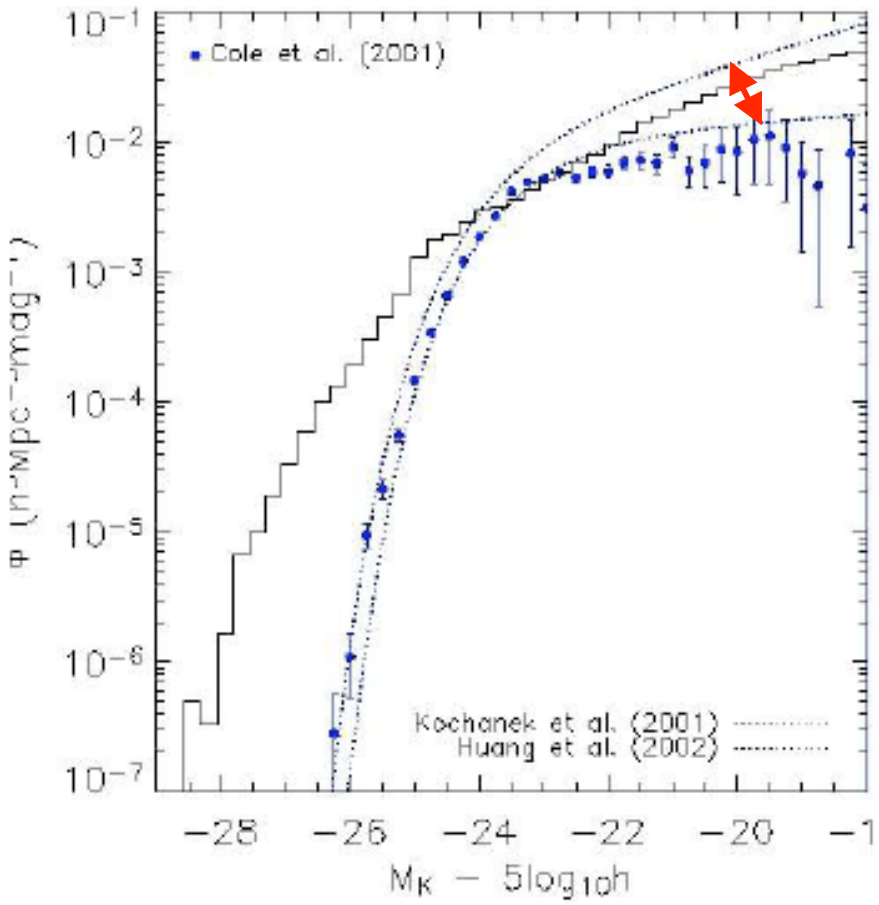
z>2 ULIRGs spectra
demonstrates potential of IRS

Yan et al (2005), Houck et al (2005)

Feedback & Downsizing: Terrifying Concepts

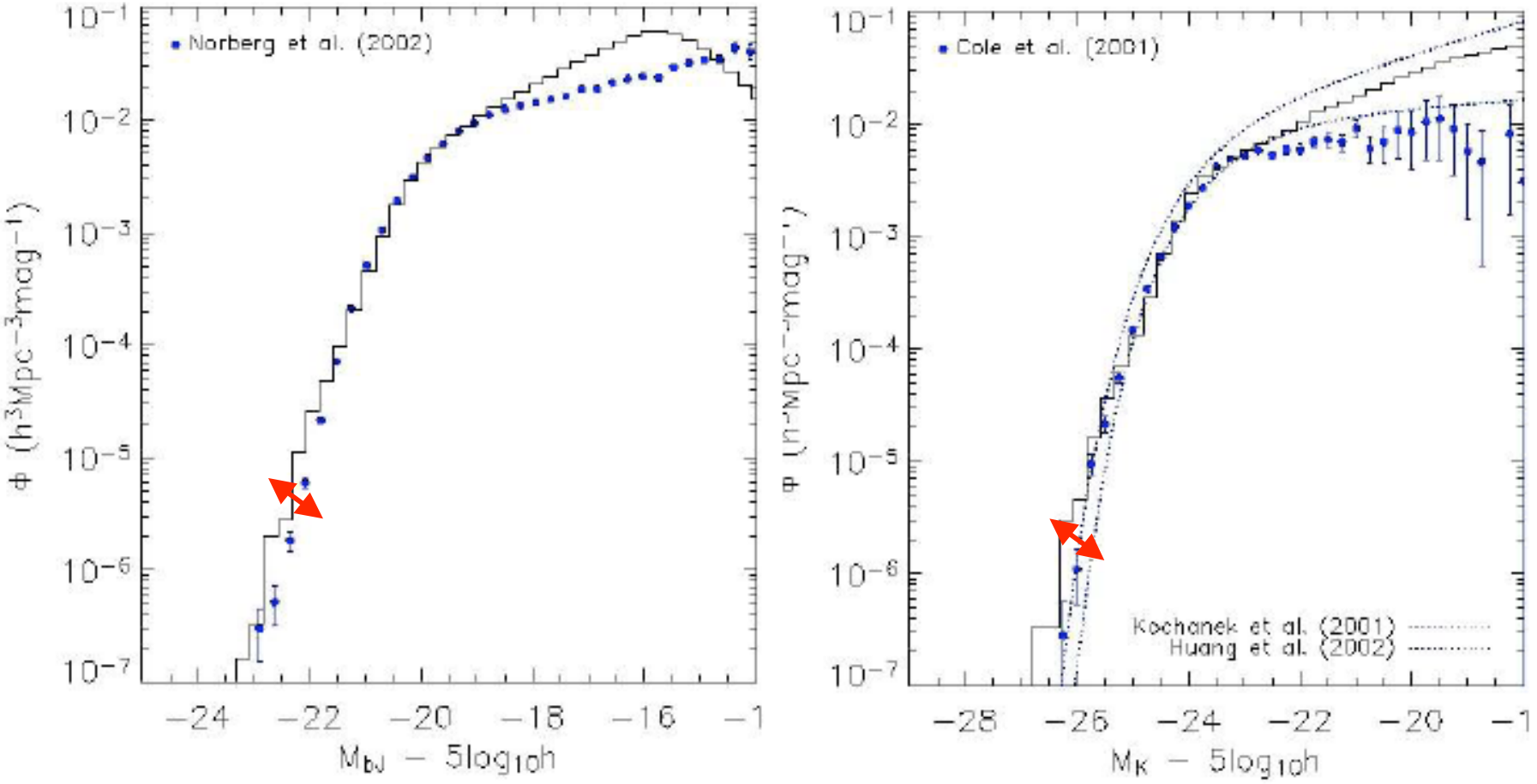
Effect of feedback on the Luminosity Function





Full model with ~~reionisation~~, ~~AGN~~ and SN feedback Croton et al 2004

Effect of feedback on the Luminosity Function



Full model with ~~reionisation~~, AGN and SN feedback Croton et al 2004

Mass Threshold: Downsizing in Action

Bundy et al (2005)

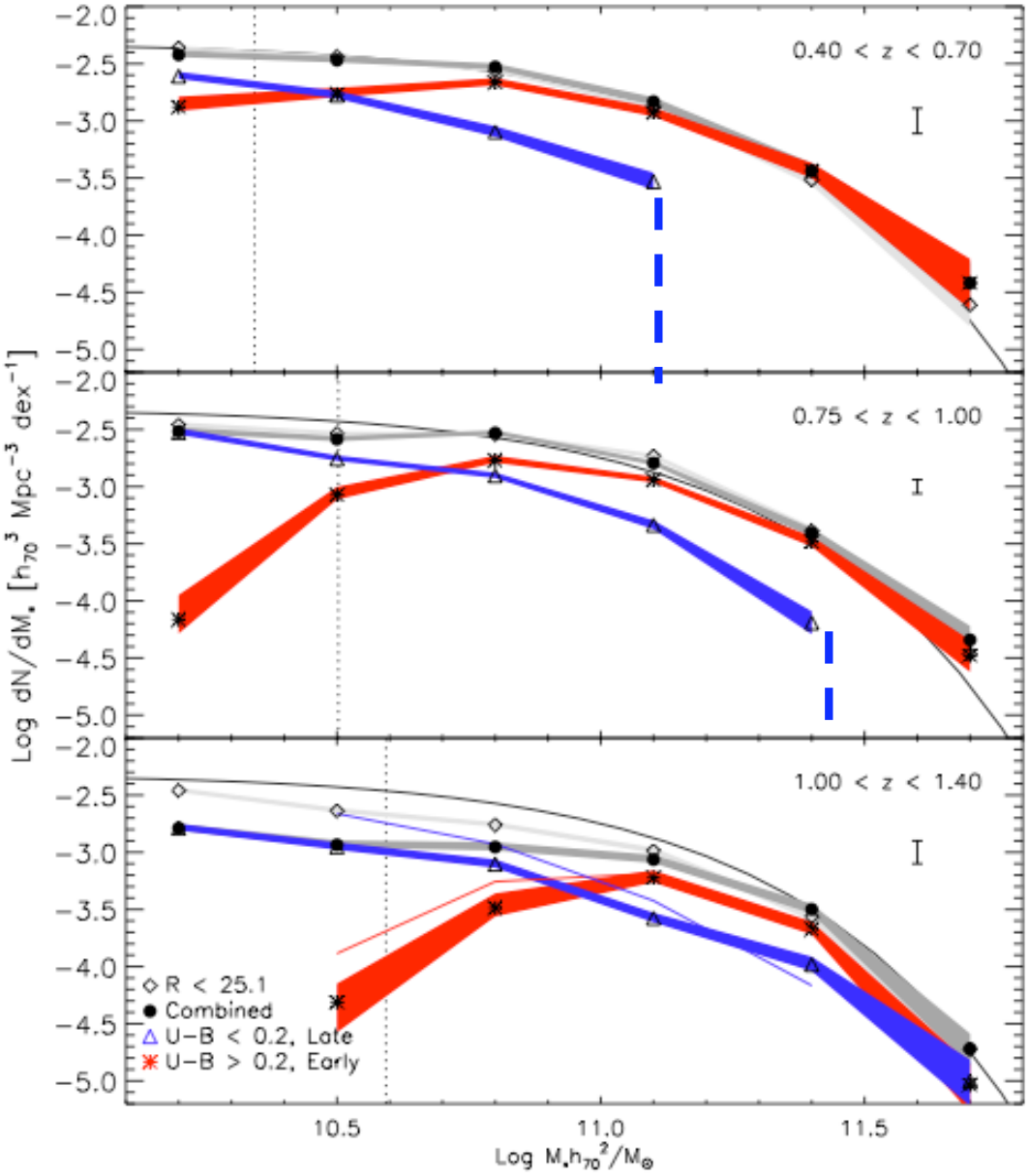
8,000 galaxies with Keck spectroscopic redshifts & K-band based stellar masses in 4 fields (1.5deg^2)

Find threshold mass above which SF is suppressed (using several diagnostics)

Threshold mass evolves to lower values at later times

What is the physical suppression mechanism?

If AGN and/or SNe are responsible how can we verify this?



Galaxy Evolution Thoughts..

- We have now explored the territory (cosmic SFH and mass assembly), but integrating over the populations is mere accounting: we don't really understand what's going on!

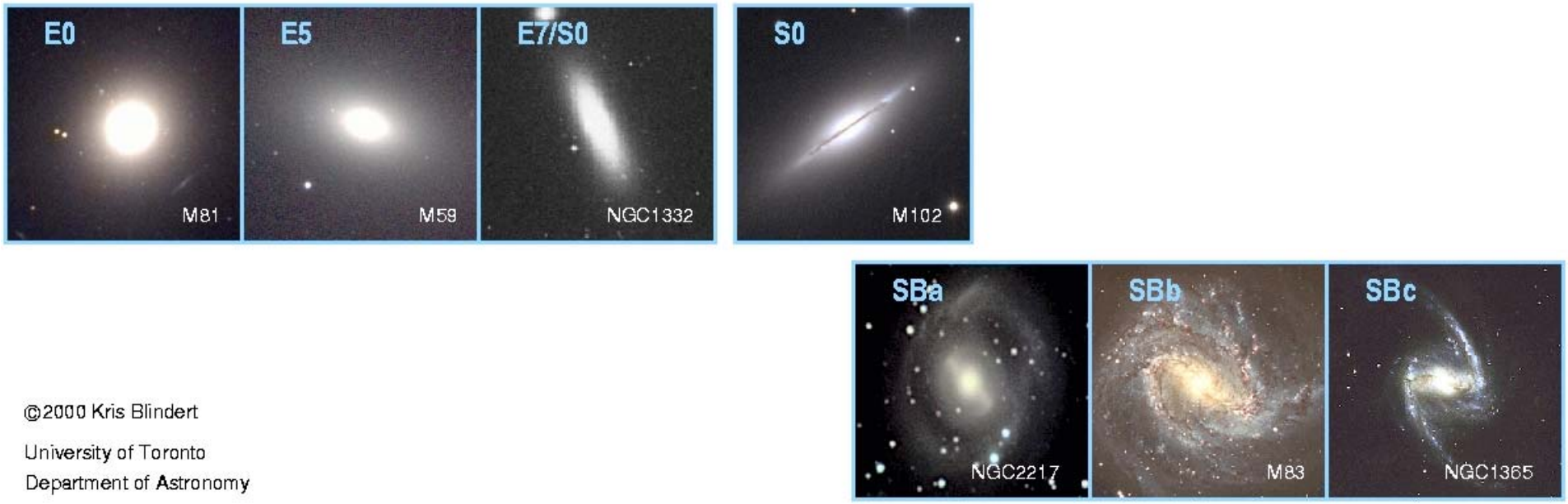
- Connecting diverse populations is key: linking SF in sub-mm/ULIRGs/LBGs, linking AGN & star-formation, linking stellar masses and dynamical maturity (AO?):
  $\Rightarrow$ overlapping census surveys are important.

- Feedback and downsizing requires data: theorists are running amok! Can we design a suitable strategy for testing AGN and SNe contributions (applies to low & hi z)

- Building a legacy of IRAC z~2 clusters for JWST/TMT

- IGM puzzles: low z baryon census (probes of cool gas) and Fe genesis problem in clusters

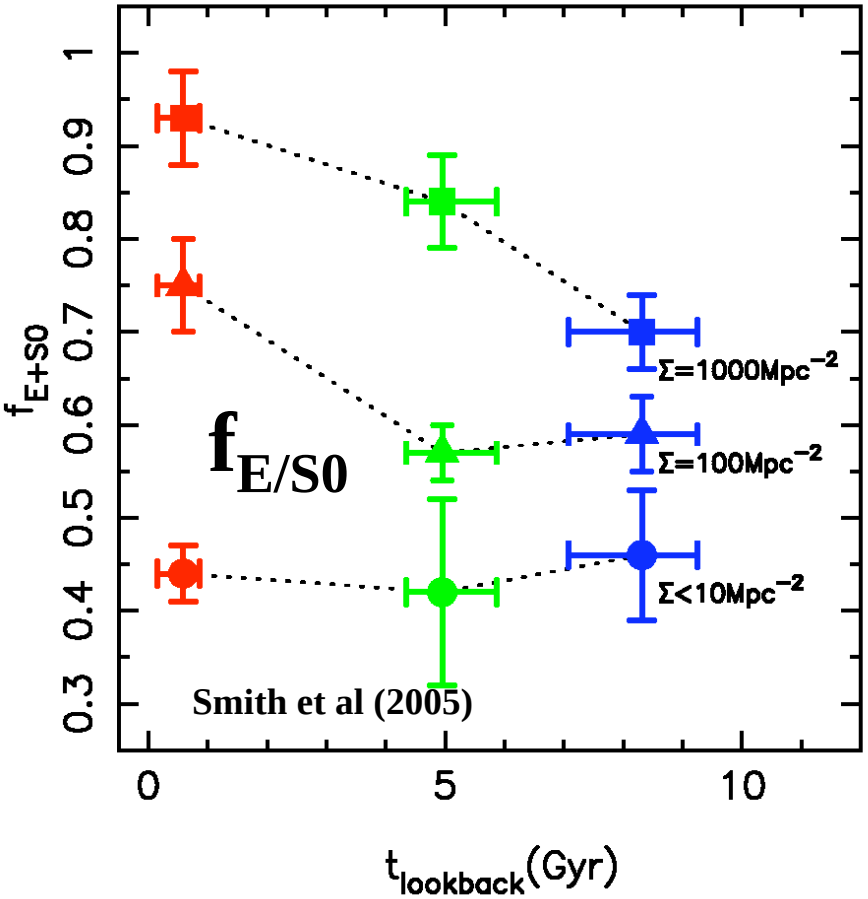
IV: - Hubble Sequence & Stellar Populations



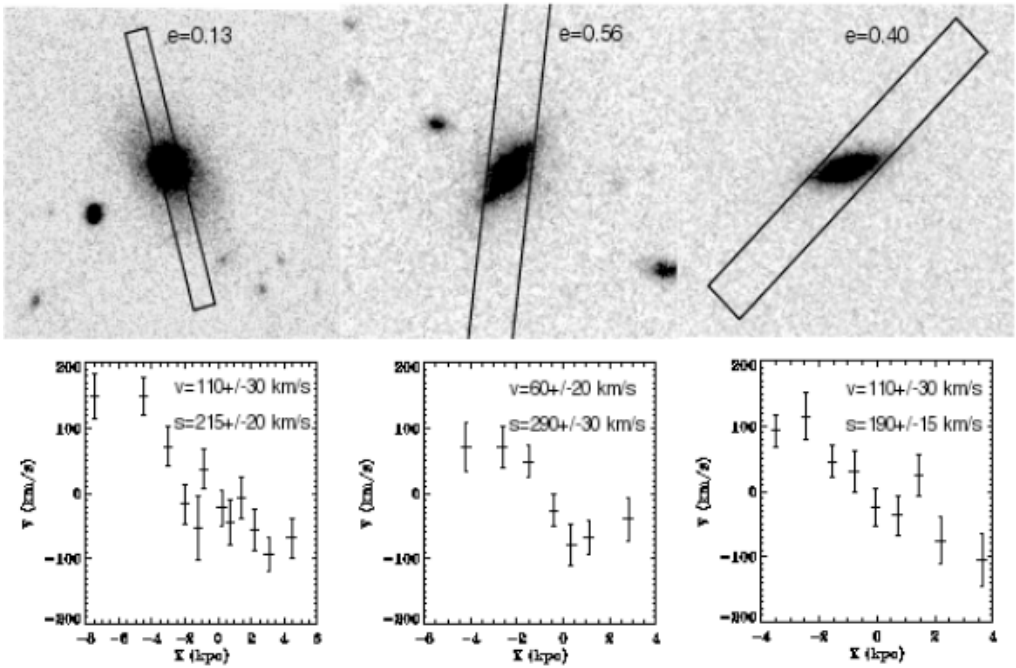
University of Toronto
Department of Astronomy

Issues: Angular momentum in disks
Origin of S0s
History of bulges (important c.f. SMBH)
Nature of SF, IMFs, mergers etc etc

Origin of S0s: Morphology - Density Relation



Dynamical separation of E:S0s?



Are S0s spirals transformed by environmental processes in clusters?

Ca we (via AO-fed spectroscopy or otherwise) determine their growth rate?

Mass Assembly History of Bulges

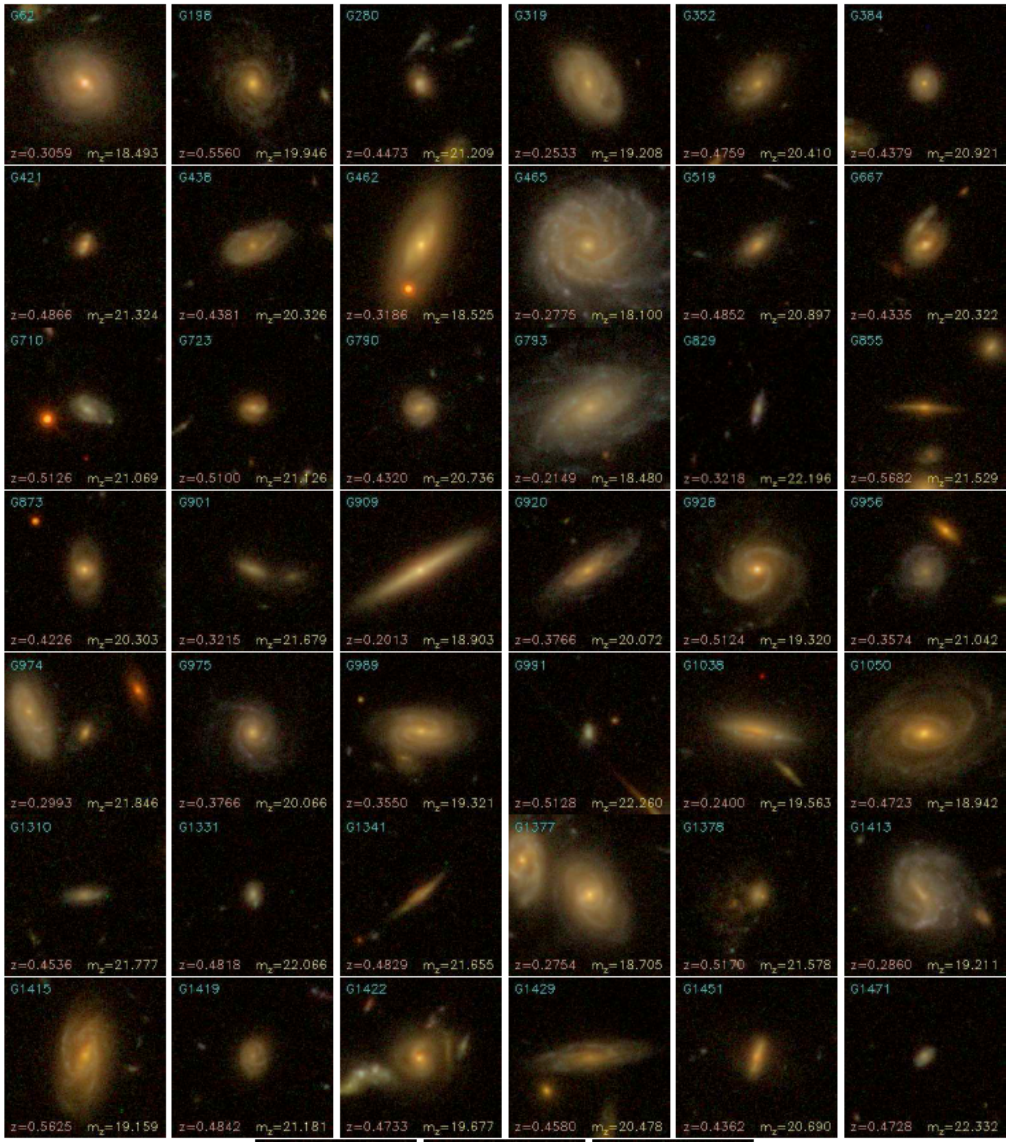
Good seeing (z<0.5) and AO-corrected (z<1) bulge dynamics is now practical with 8-10m telescopes

-how do they grow wrt black holes?

- what is origin of their diversity?

- only GOODS has multi-color data of adequate depth

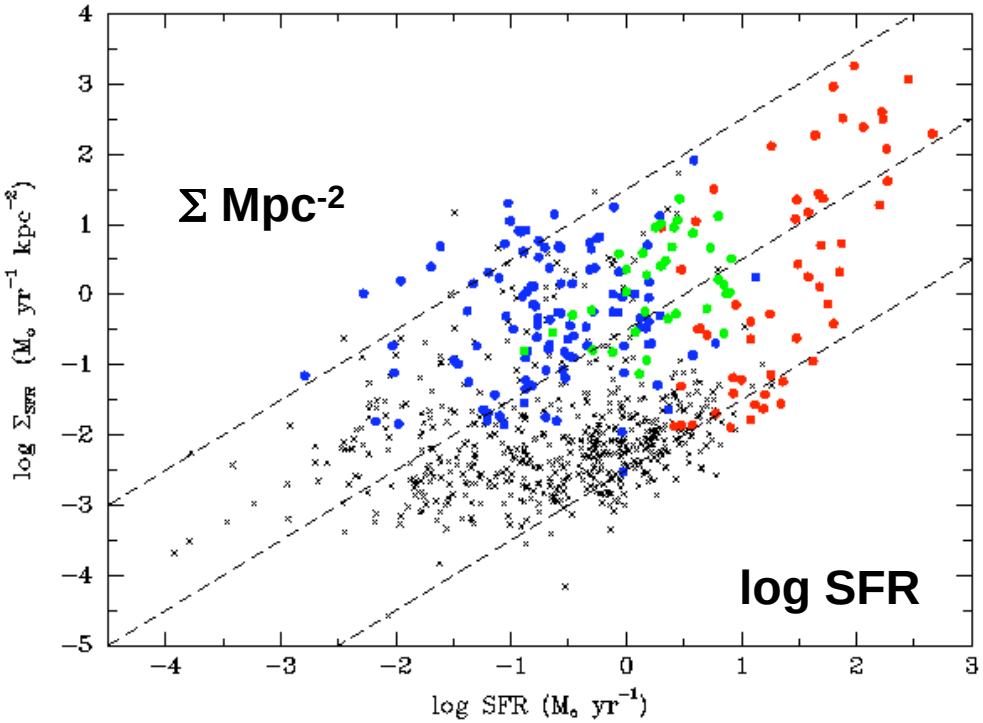
- Will it be sufficient for future AO surveys?



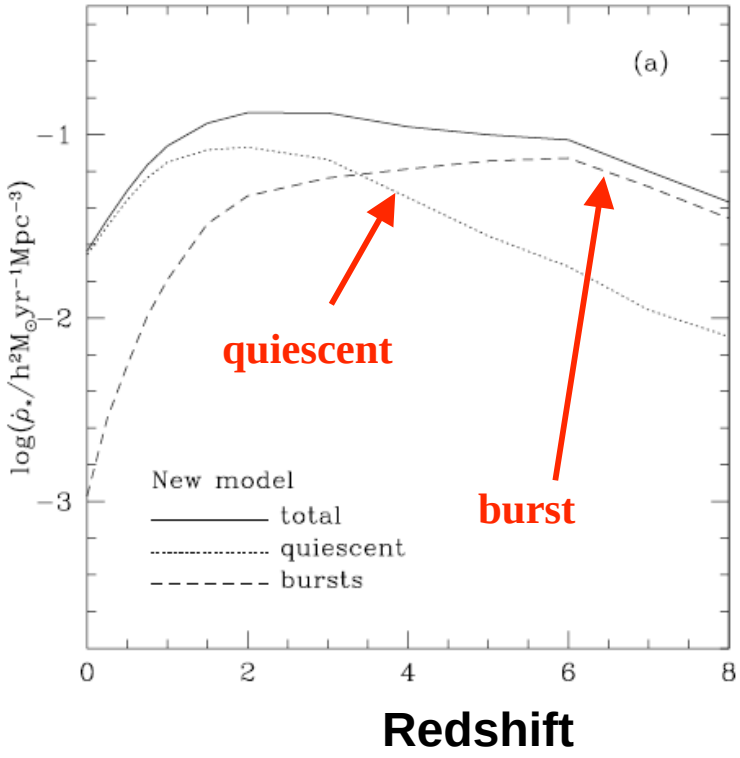
GOODS sample: MacArthur et al (N~80 with vel dispersions 0.2<z<0.5)

Nature of Star Formation in Nearby Galaxies

Kennicutt: diversity of local SF

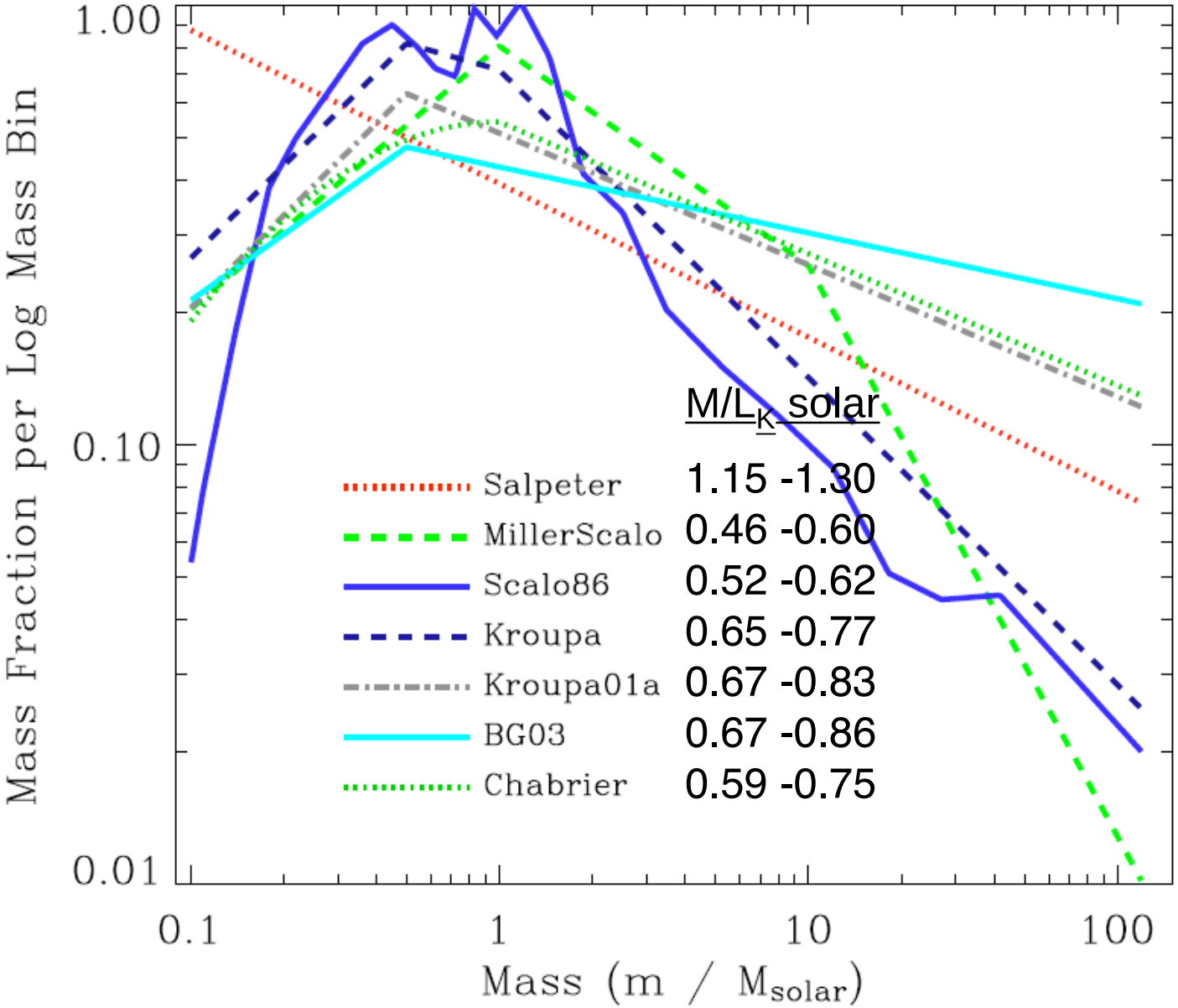


Baugh et al 2005 SF histories



Hard to unravel the nature of SF in z~2 sub-mm galaxies (until ALMA) so we must explore physical differences (e.g. IMF) between local quiescent (spiral) & active (LIRG) sources: how can this be done?

Unanimity on the IMF?



Hubble Sequence Thoughts..

- Origin of S0s deserves attention: are these produced by environmental processes?
- Bulge-AGN connection: can we independently trace the mass assembly history of bulges (now feasible with AO-fed spectrographs)
- Vexing question of IMF variations across the range of SF observed in spirals and LIRGS
- More concerted campaigns on nearby systems (esp. starbursts to explore cycling/winds)
- Many issues in local group galaxies: origin of streams, merger histories etc..

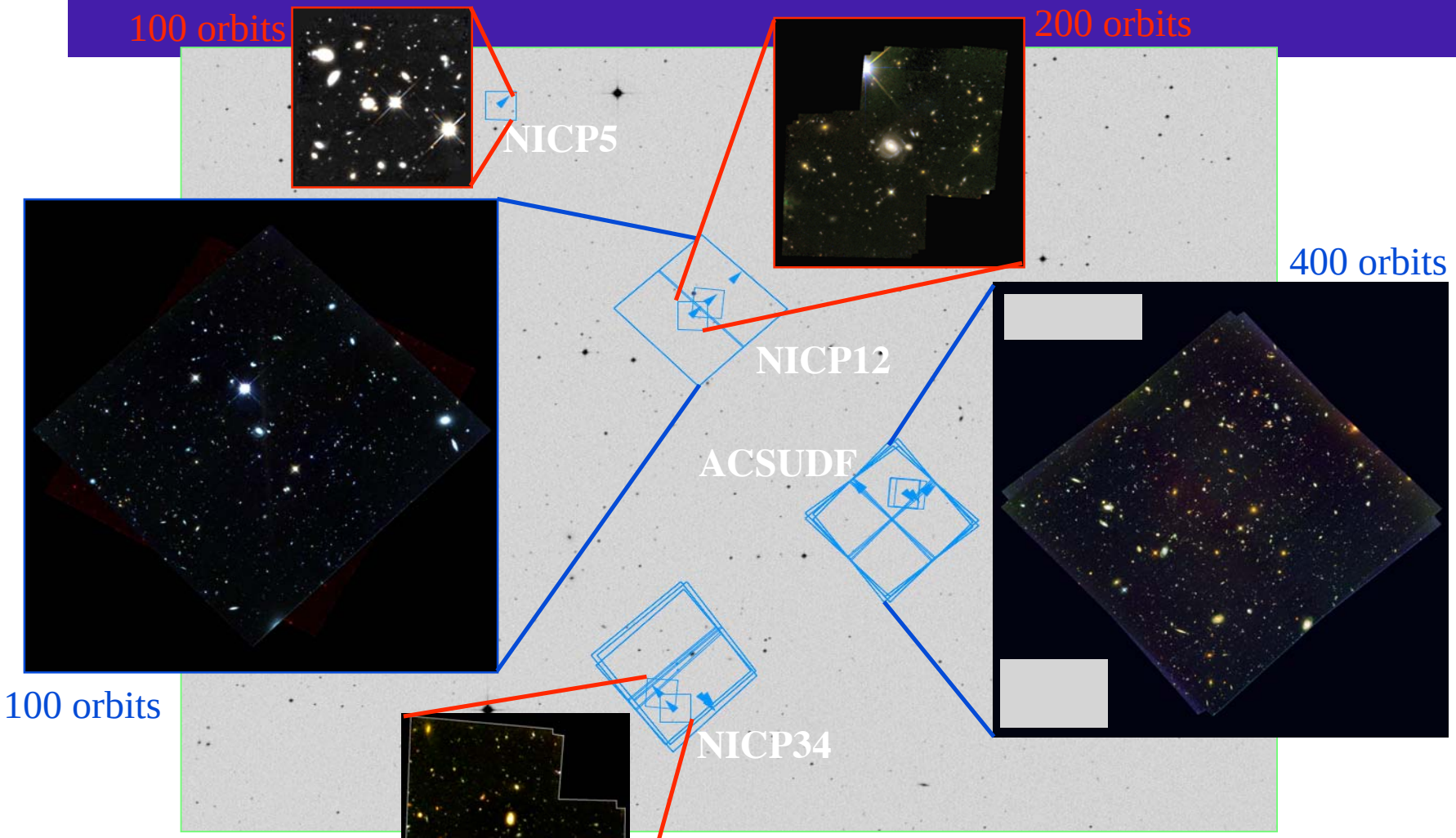
Strategic Issues

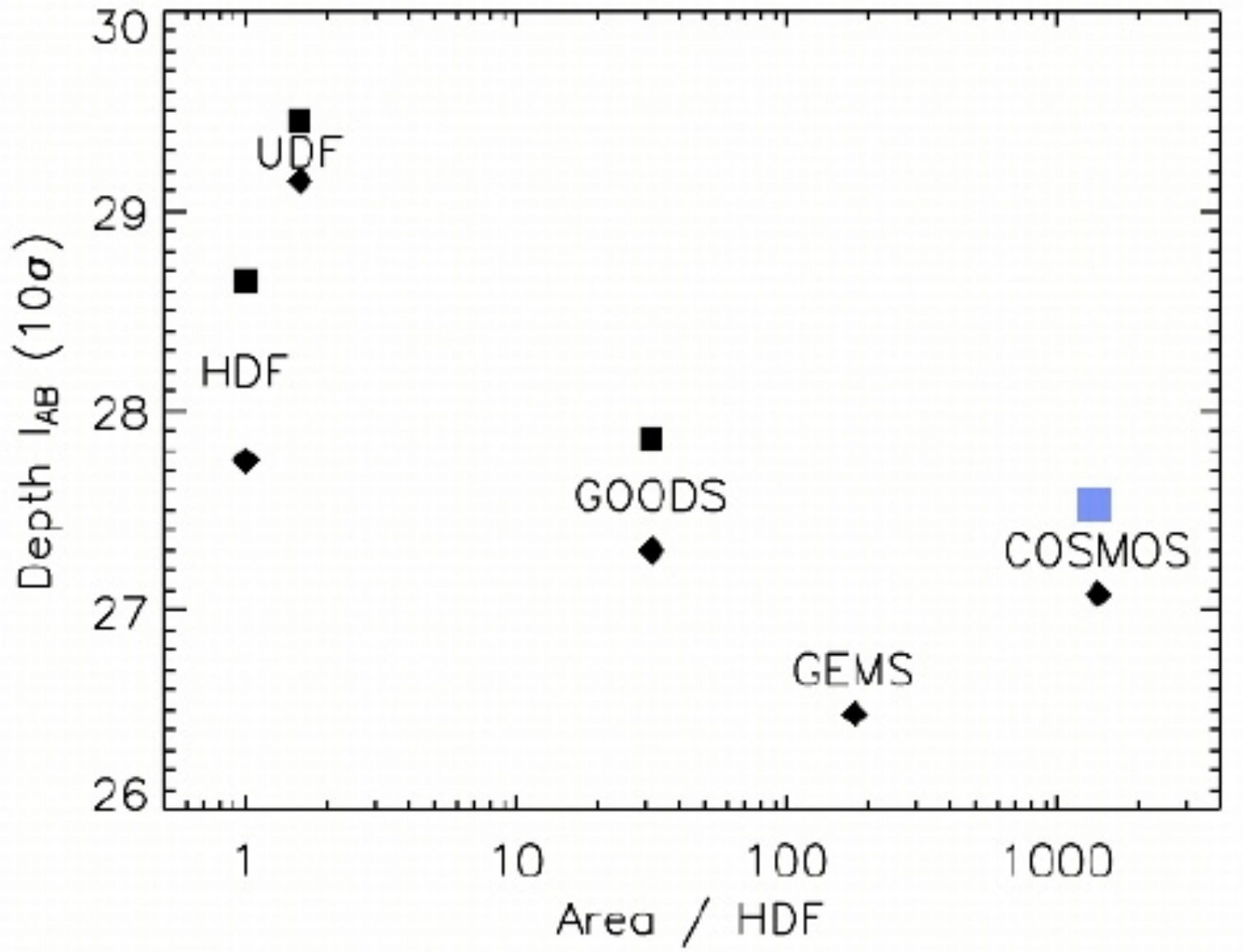
- Improve synergy with new ground-based capabilities (AO & IFUs on 8-m's, radio capabilities, ALMA..)
- Ultra Deep Fields: hard to justify pre-WFC3 (NB: parallel fields)
- Generic Large Surveys: do we need more `panoramic' fields?
  - we've had quite a few! GOODS/GEMS/EGS/COSMOS/SWIRE
  - burden of justification should be much higher: can be soporific
  - invest first in field already taken (e.g. Chandra on COSMOS)
  - broadest utility is GOODS depth (multicolor, faint s.b.) but clearly expensive
  - More targetted science (Chandra exposures)
- Archives: cross-linking to improve coordination
- Cross-calibration issues (NIC/IRAC) important
- Public relations images - hard to see we could do any better

TAC-adjustments

- Should Large/Legacy projects involving >1 GO have a separate `superTAC' route?
  - GOODS is an example of why not: it succeeded 3 times with independently-justified science cases..and why not?
  - A single 2-3 GO case could be generic (soporific) leading to assessment on less rigorous criteria
  - Ambitious/costly surveys should satisfy broad communities
- How, then, to encourage multi-GO science?
  - Consider `Key Projects' for widely-agreed scientific goals
  - Better balancing of medium initiatives across GO boundaries
- Consider `engineering' or `pilot' programs to explore/verify potential of future facilities (e.g. JWST, JDEM)? Hard to see working.
- Faster turn-around proposals (broadening scope of DDT science)

More Deep Fields




30
29
28
27
26
Depth I_{AB} (10σ)
UDF
HDF
GOODS
COSMOS
GEMS
1
10
100
1000
Area / HDF