41st ESLAB Symposium: The impact of HST on European Astronomy

Galaxy formation and evolution

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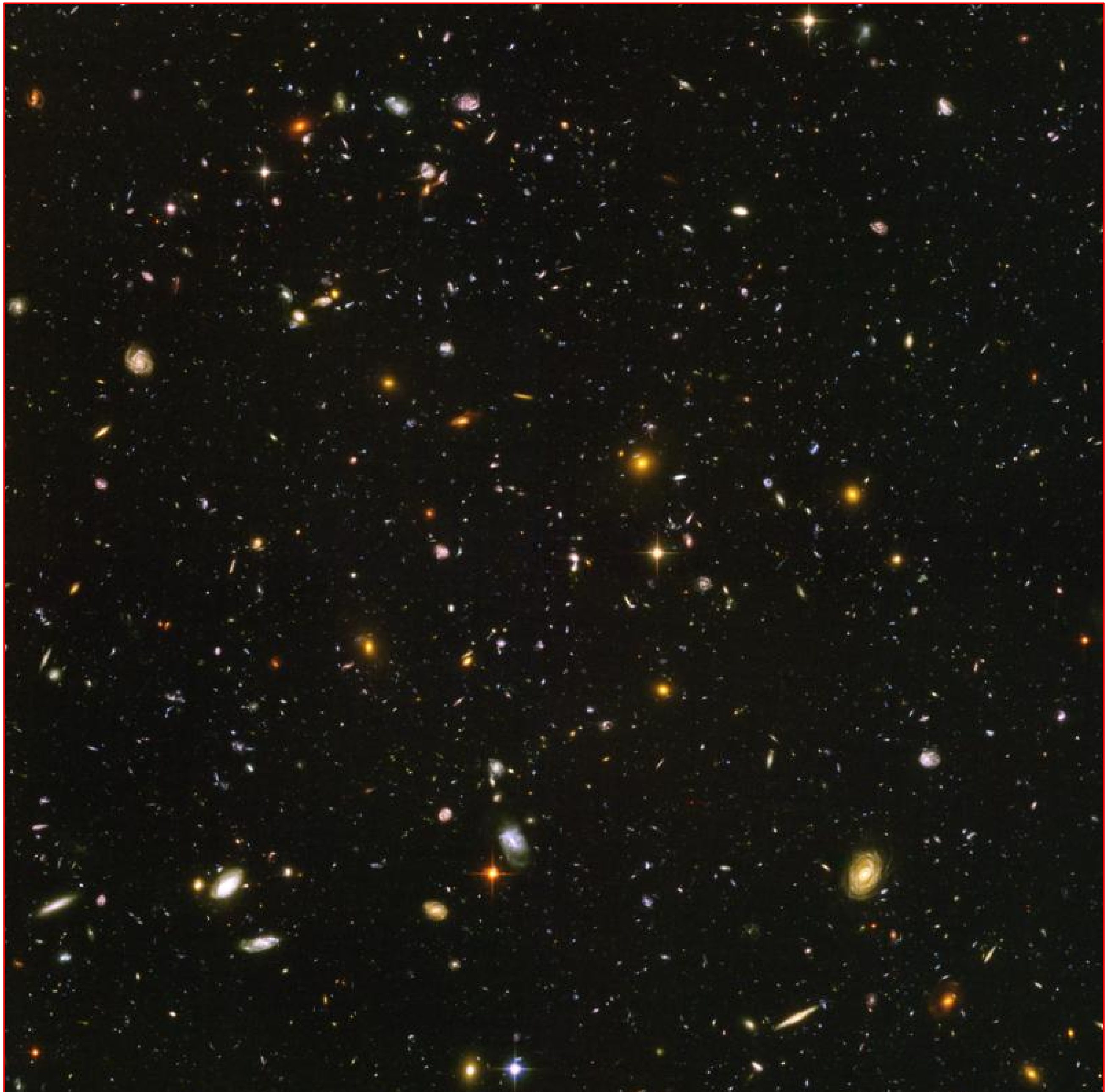
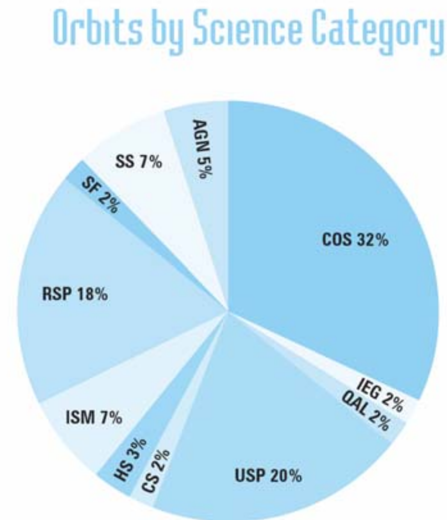




AGN: Active Galactic Nuclei
CS: Cool Stars
COS: Cosmology
HS: Hot Stars
IEG: ISM in External Galaxies
ISM: Interstellar Medium
QAL: Quasar Absorption Lines
RSP: Resolved Stellar Populations
SF: Star Formation
SS: Solar System
USP: Unresolved Stellar Populations

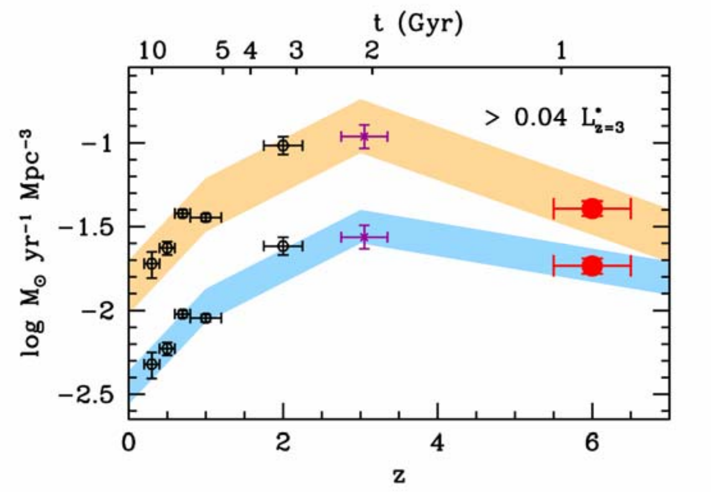
Cycle 15: 60% of orbits are allocated to panels EXGAL 1-5, concerned either directly or indirectly with the formation and evolution of galaxies, and cosmology

Major developments since 1992

1995	First major redshift surveys beyond z ~ 0.2, out to z ~ 1
1996	Lyman break galaxies (LBG) at z ~ 3
1996	Systematic HST morphologies in field and clusters to z ~ 1 and beyond
1998	Resolution of the SMB, sub-mm ULIRGS at z ~ 2-3
1998	uv-selected galaxies (incl. Lyman α emitters LAE) to z ~ 6.5 and the faint LF
1999	A new cosmology
2000	The red population at z ~ 2-3
2004	Resolution of the XRB and the full SED of high-z galaxies from Spitzer
2004	The full LF evolution of AGN
2005	First indications of objects at z ~ 7 - 9

- HST has played an enabling or strongly supporting role in almost all of these, either directly or indirectly
- Almost all of these, have come from a combination of facilities, i.e. the "observatory system"
- Europeans have been very well served by their "system"
- Statistics have needed large Legacy-type surveys, e.g. HDFs, UDF, GOODS, COSMOS

A. Certainly to z ~ 5, the major galactic populations have likely now been identified. SFR(z) and Mstar(z) are broadly defined and self-consistent



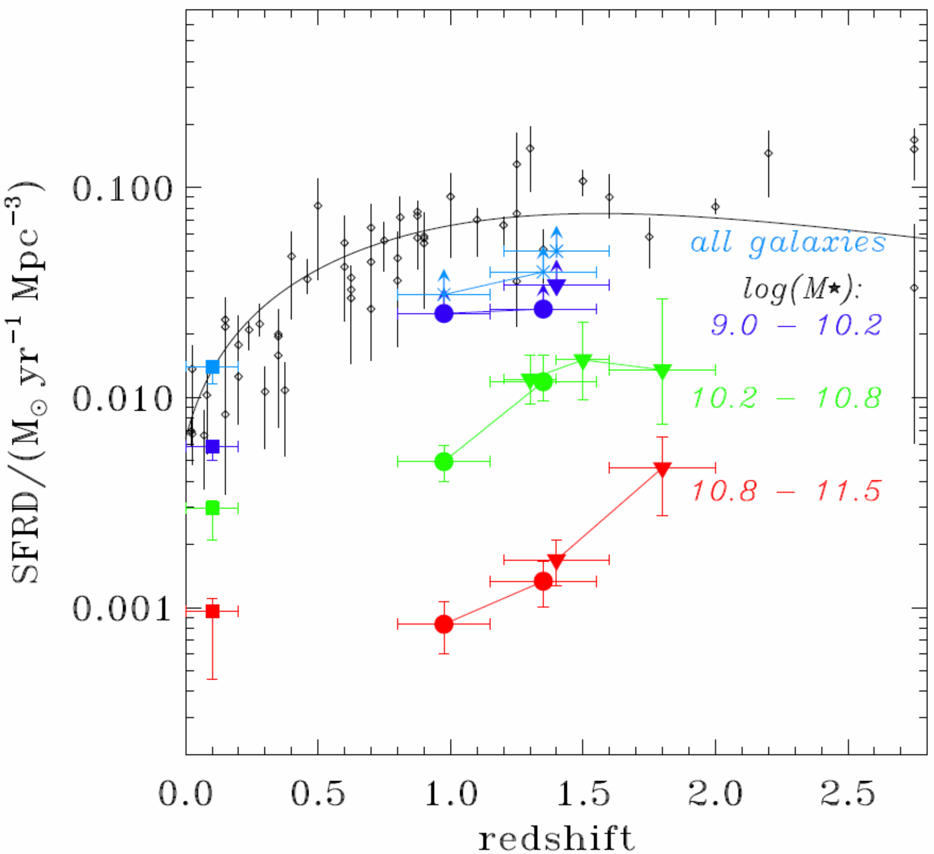
B. Underlying cosmogony is very likely to be Λ-CDM. relative to basic model expectations, two initially surprising concepts:

“Downsizing”

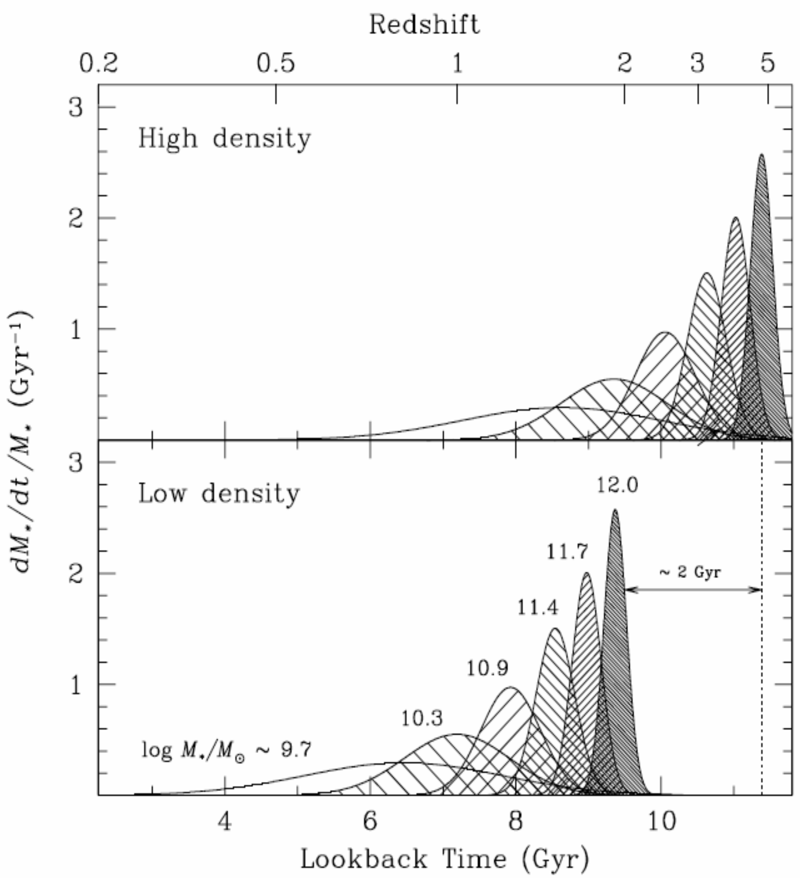
and, more controversial and more recent

“lack of mass-upsizing”

Two examples of down-sizing....



Juneau et al (2005)

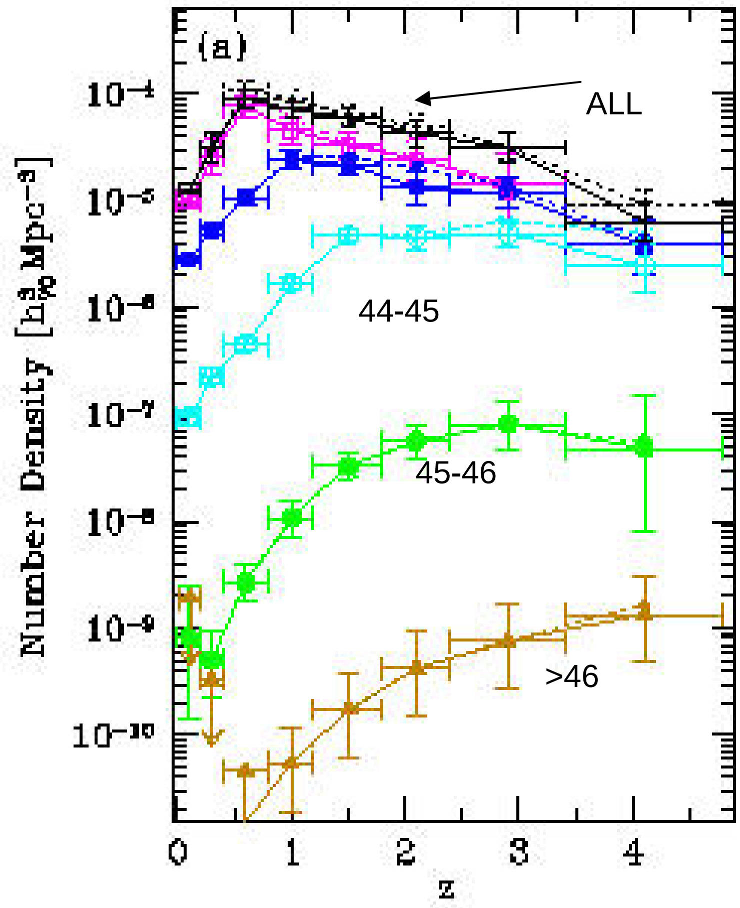


Thomas et al (2005)

The threshold for SF (and AGN) activity shifts to lower masses as Universe ages since z ~ 3

→ need to suppress SF activity (e.g. cooling etc.) in massive objects: AGN feedback?

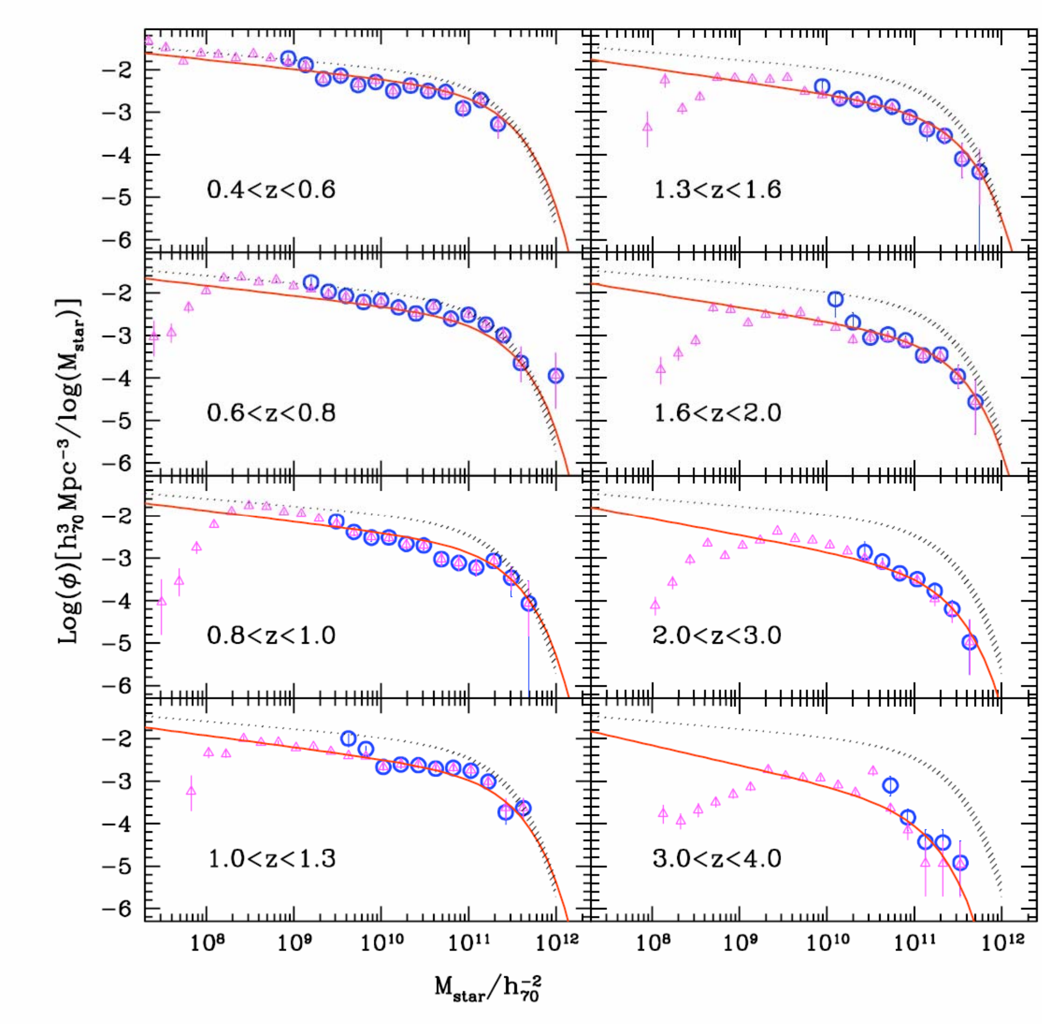
Also seen in AGN luminosities...



Hasinger, Miyaji & Schmidt 2005

→ need to suppress SF activity (e.g. cooling etc.) in massive objects: AGN feedback?

Examples of lack of mass up-sizing....



Fontana et al. 2006 (GOODS)

Lack of “mass-upsizing”

Number density of most massive objects changes rather little

→ may need to suppress merging activity of galaxies relative to that of DM haloes

Major observational questions in the formation and evolution of galaxies

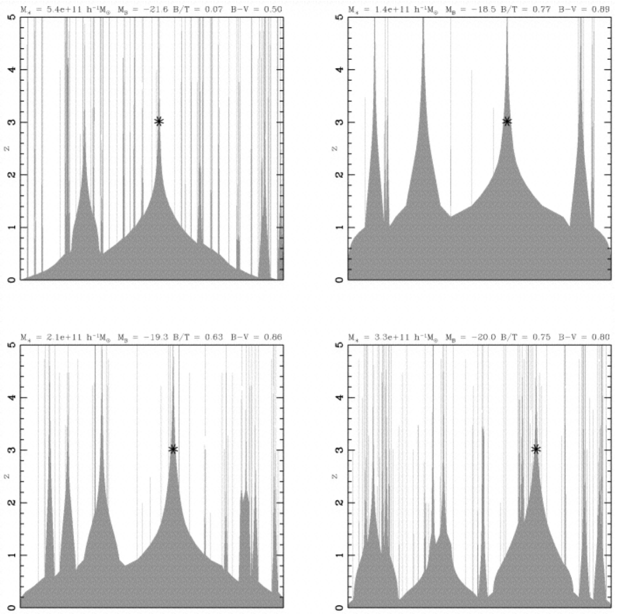
(A) The assembly of stellar mass in galaxies

(i) What is the evolution of the galaxian stellar mass function over time?

(ii) For different types of galaxies, what are the relative number of stars that are formed slowly in situ, brought in during a merger, or formed in a burst triggered by a merger?

(iii) What is the epoch-dependent merger rate as a function of type, mass, and environment? How is this best defined, and how is it best determined?

(iv) Why is there little evidence for mass-upsizing as expected in hierarchical models?



What are the pathways to today’s galaxies?

Major observational questions in the formation and evolution of galaxies

(B) The origin of the internal structure of galaxies (Hubble Sequence)

(i) When, and in what proportions, do the different morphological (structural) types appear in the Universe, also as f(mass) and environment?

(ii) When, and with what scatter, are the web of global scaling relations linking velocity dispersions, sizes, metallicities, morphological structure, and stellar populations, established and what are the physical mechanisms for doing this?

(iii) How are galactic disks built up and how does this solve the apparent angular momentum problem?

(iv) What are the relative importance of internally and externally driven processes in the structural transformation of galaxies from one type to another?

What are the physical processes shaping the galaxy population?

Major observational questions in the formation and evolution of galaxies

(C) The role of black-holes in galaxy evolution

(i) What is the physical origin of the black hole/bulge mass and related relations?

(ii) How in detail does AGN-feedback, which seems to cure several prominent deficiencies of galaxy evolution in ΛCDM, actually work?

(D) The interaction between galaxies and the IGM

(i) How important are winds and cooling flows in exchanging baryonic material between galaxies and the IGM?

(ii) Is there evidence for so-called “cold accretion” flows onto galaxies and do these behave as predicted?

Gastrophysics: Feedback, gas exchange

Major observational questions in the formation and evolution of galaxies

(E) Dwarf galaxies

(i) How and why does the faint end of the galaxy LF evolve?

(ii) What if anything does this tell us about the “missing satellite” problem in ΛCDM?

(F) Modes of star-formation in the early Universe

(i) Are stars formed in high redshift galaxies in broadly similar environments to those seen locally (e.g. GMC in disks, nuclear star-bursts in mergers) or are different phenomena in play (e.g. large scale disk instabilities)?

(ii) What is happening in the (much more common) LIRGs/ULIRGs at high redshift?

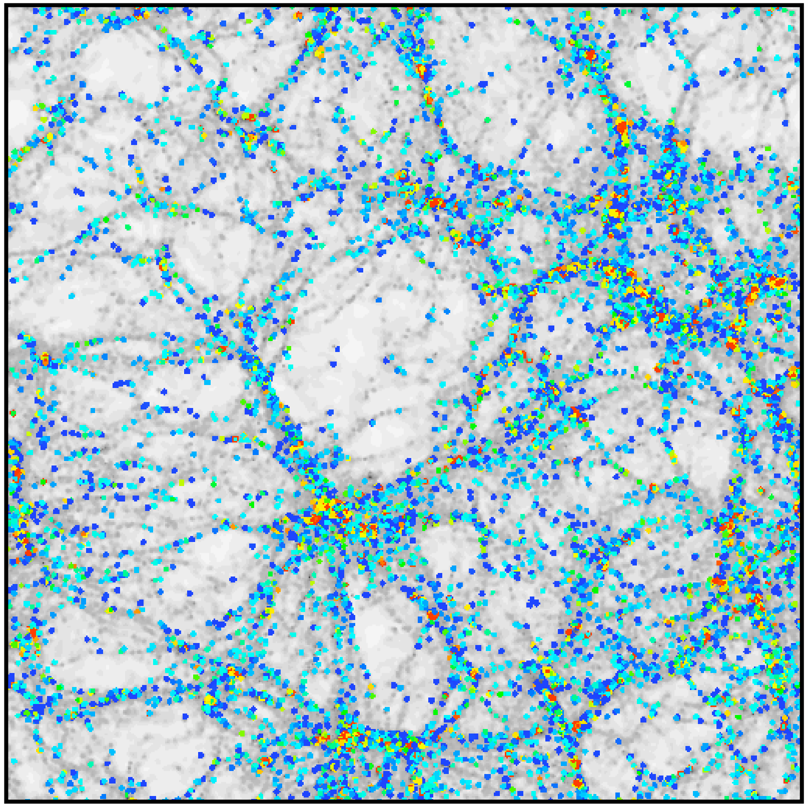
Major observational questions in the formation and evolution of galaxies

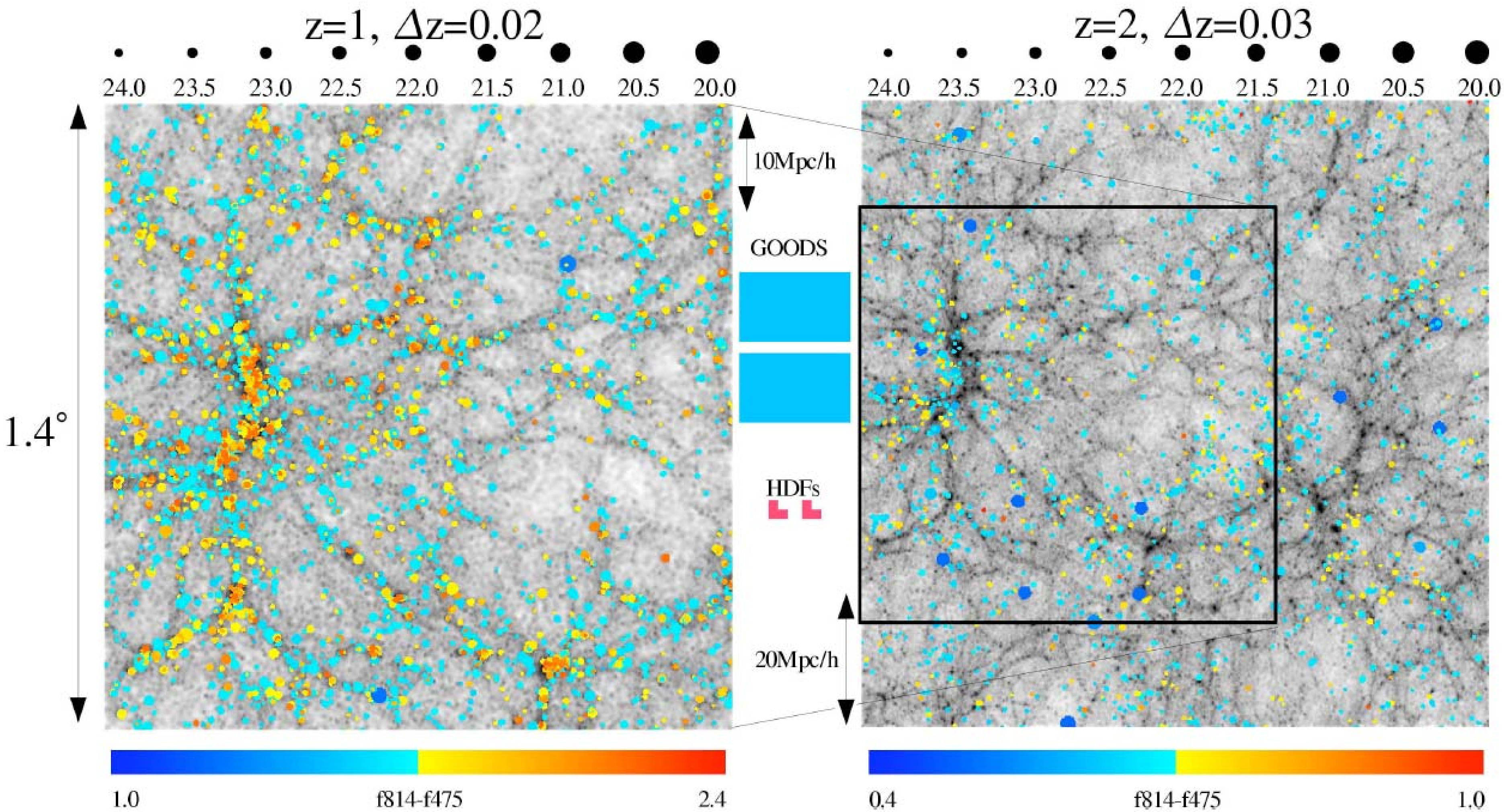
(G) The role of the environment

Many, and possibly all, of the answers to the above questions may be heavily influenced, or even controlled, by the galaxian environment, either directly or indirectly.
What are the physical mechanisms whereby this occurs?

The likely major role of the environment from group scales up to cosmic web

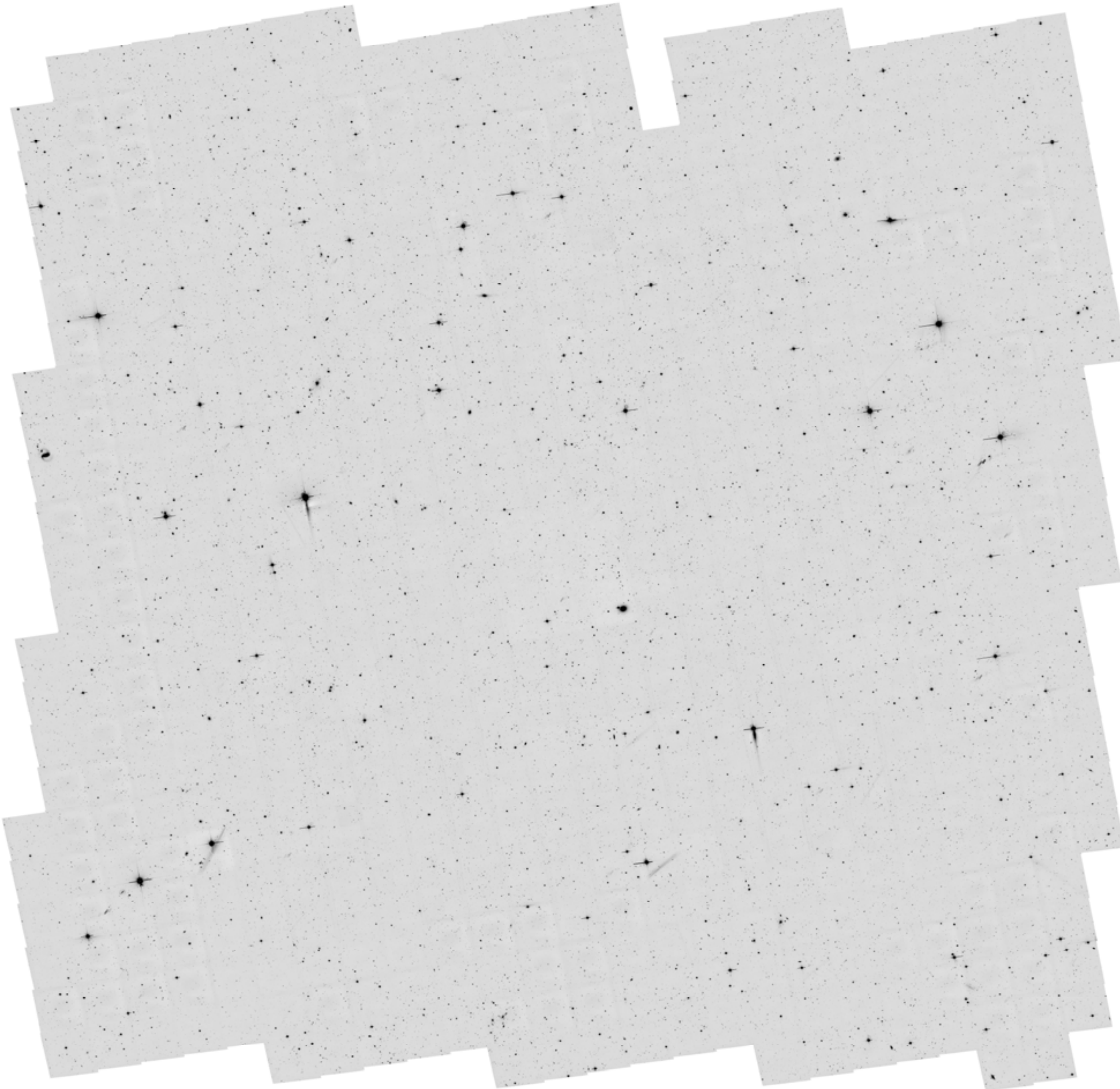
- Present-day properties of galaxies are clearly f(environment)
- Accretion of DM and stars during hierarchical growth
- Cooling of gas and energy injection from AGN etc
- Interaction with high pressure IGM in clusters
- Mergers between galaxies
- Internal dynamical evolution through instabilities (e.g. bars) triggered by interaction
- Cosmological collapse timescales

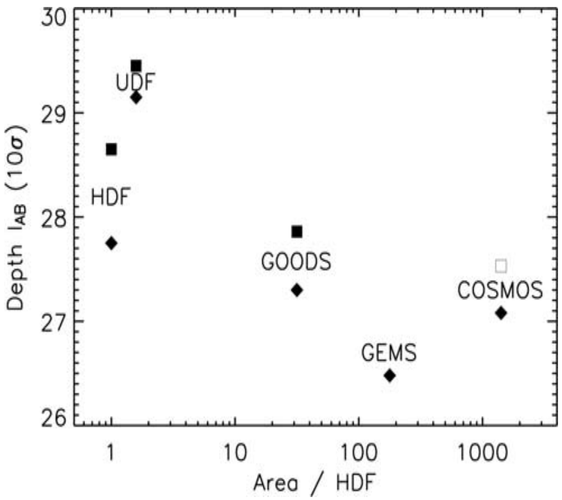




COSMOS: A truly global collaboration to study an (unfortunately) single large area (with approx 100 Mpc transverse dimension) with all of the tools developed in the last decade for observations of high redshift galaxies, AGN, IGM and dark matter structures

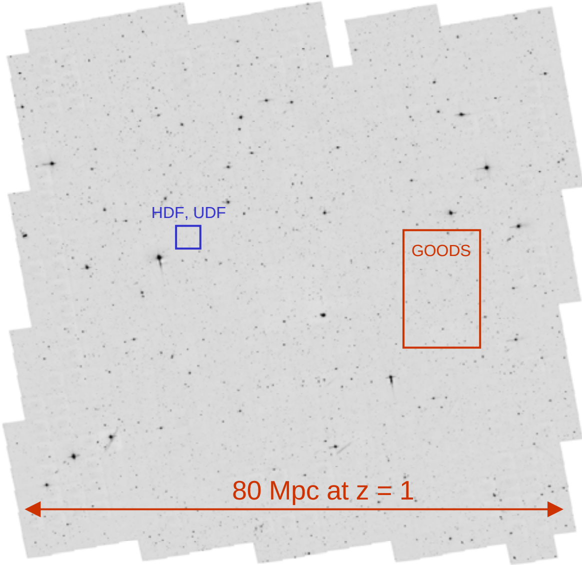
600-ACS pointings/orbits (P.I. N. Scoville, Caltech)

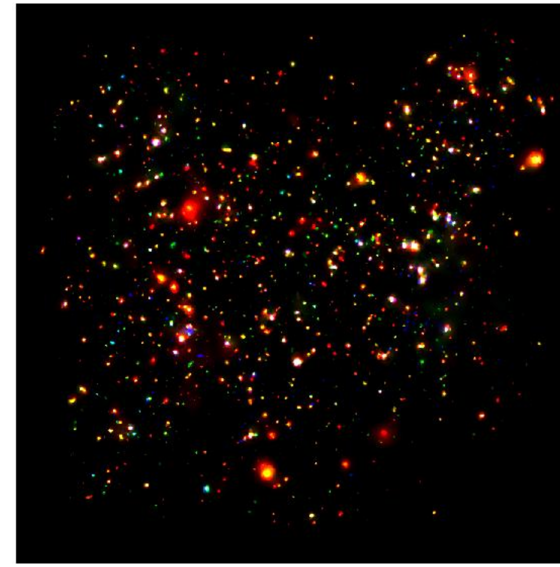




ACS field

+ NICMOS-3 parallel
1.6 μm -- 24mag
~7% of area



Imaging

HST images (F814W)	Galaxy structures, morphologies	600 orbits	Scoville
Subaru 8-m (BVGRIZ)	One million+ galaxies, optical-nearIR spectral	21 n.+	Taniguchi
various 4-m (UJHK)	energy distributions, photometric redshifts	~40 n.	various
XMM-Newton (X-ray)	AGN + hot gas in clusters	1.4 Msec	Hasinger
Chandra (X-ray)	AGN + stellar pops		Elvis
Spitzer (3-170 μm)	Galaxy masses, obscured star-formation	610 h.	Sanders
VLA (5 GHz)	AGN, star-bursts	335 h.	Schinerrer
CSO, JCMT, APEX	Sub-mm ultraluminous infrared galaxies	~45 n.	various

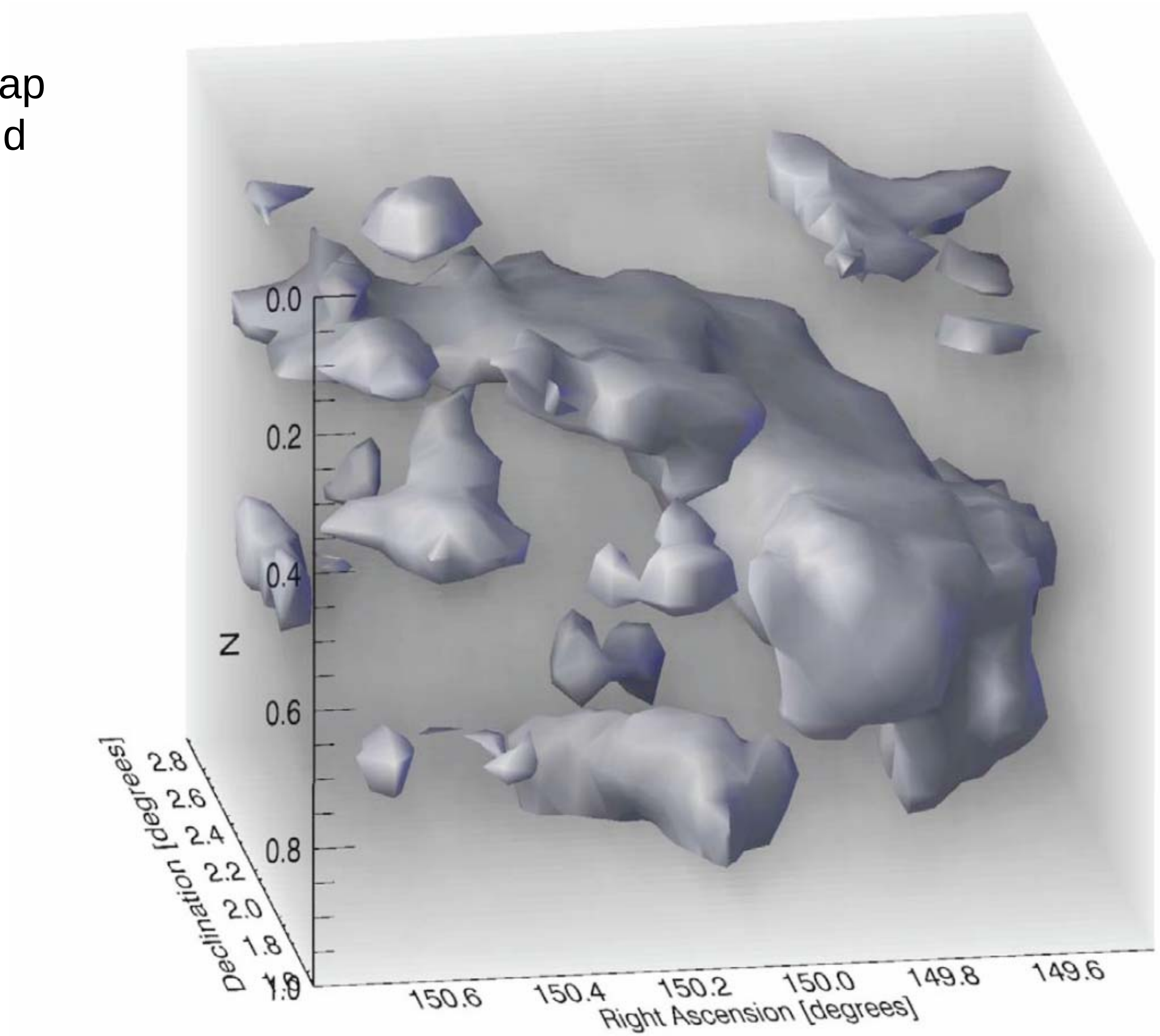
Spectroscopy

VLT 8-m	spectroscopy (30,000 faint galaxy redshifts 0.2 < z < 3.0)	600 h.	Lilly
Magellan 6-m	spectroscopy (2,000 AGN redshifts)		Impey

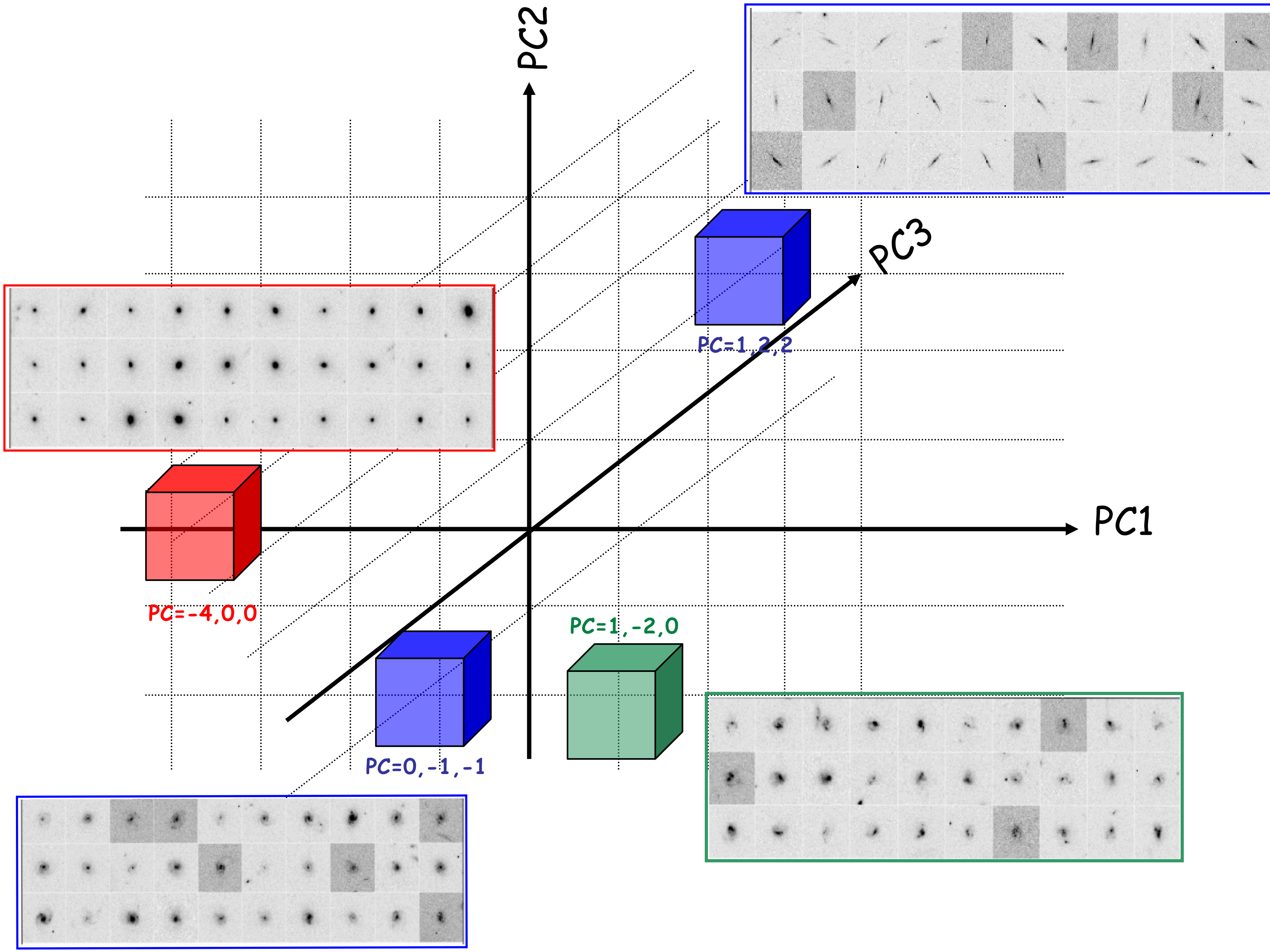
50+ COSMOS papers already, many more coming.....

e.g. COSMOS DM map from weak lensing and photo-z

Massey et al (2007)

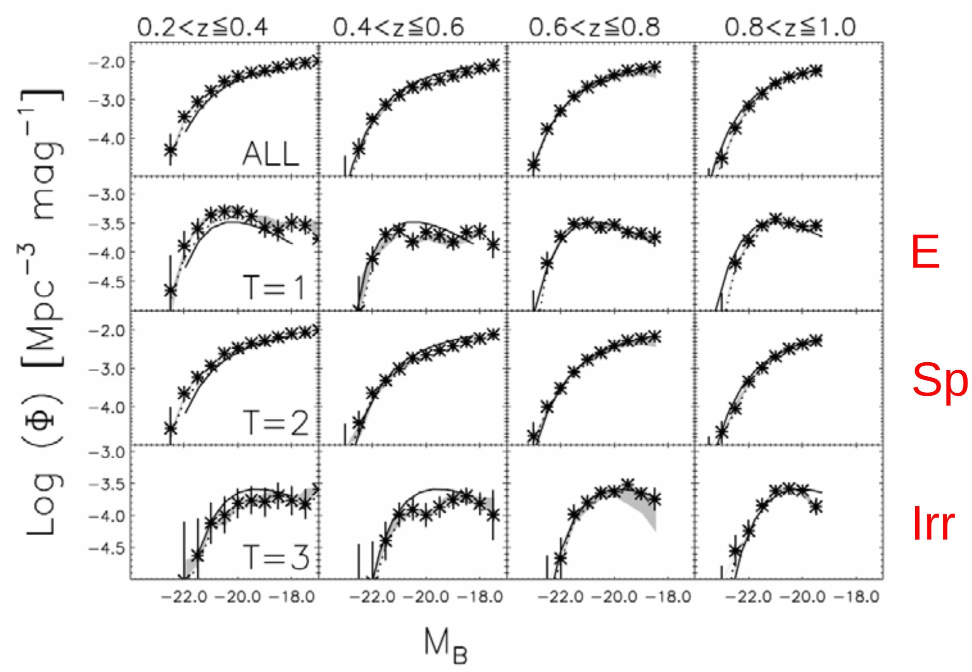


ZEST - Automated morphological classification of 10^5 COSMOS galaxies using Principal Component Analysis (Scarlata, Carollo, SJL et al.)

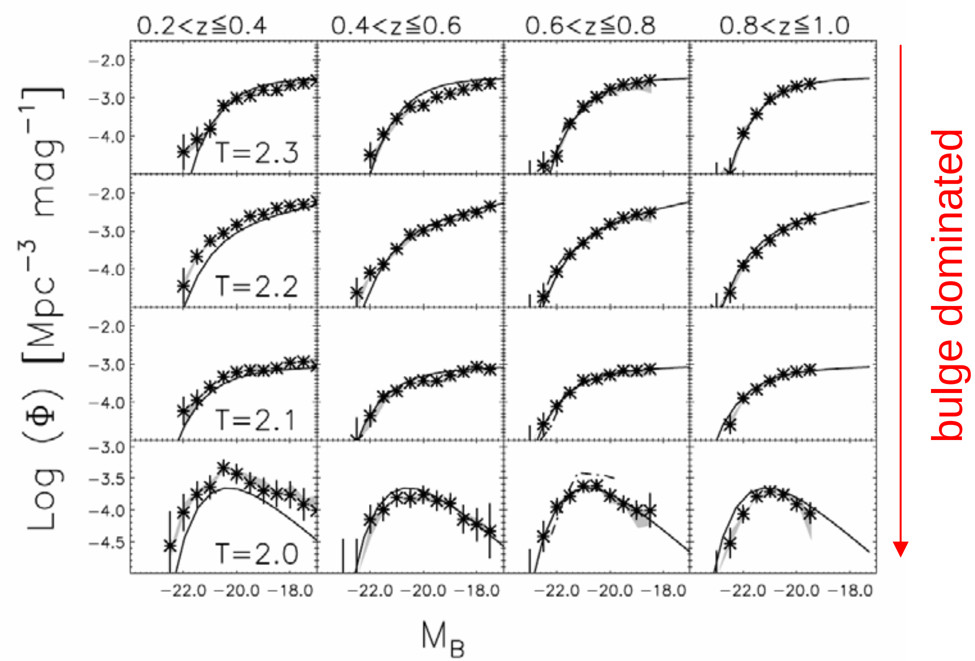


56,000 I_{AB} < 24 COSMOS galaxies with photo-z

Scarlata, Carollo, SJL + COSMOS et al (2007a)

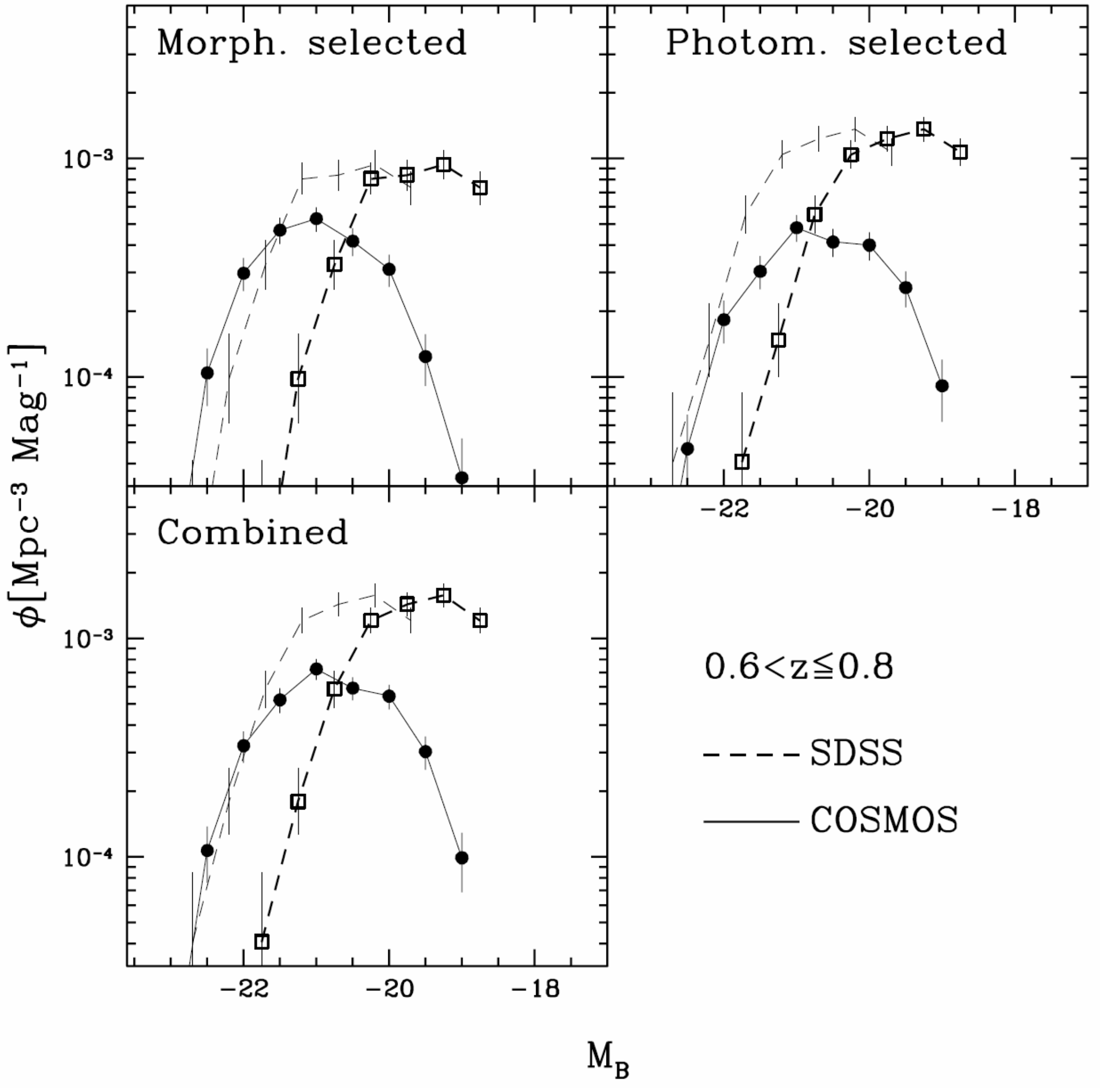


Smooth evolution characterised by systematic brightening at levels given by passive evolution



4000 early-type galaxies selected by morphology, by colour, and by both, and compared with translated SDSS sample

Scarlata, Carollo, SJL + COSMOS et al (2007a)



→ little change in number of most massive early-type galaxies to z ~ 0.7

Quantitative structural parameters of COSMOS galaxies

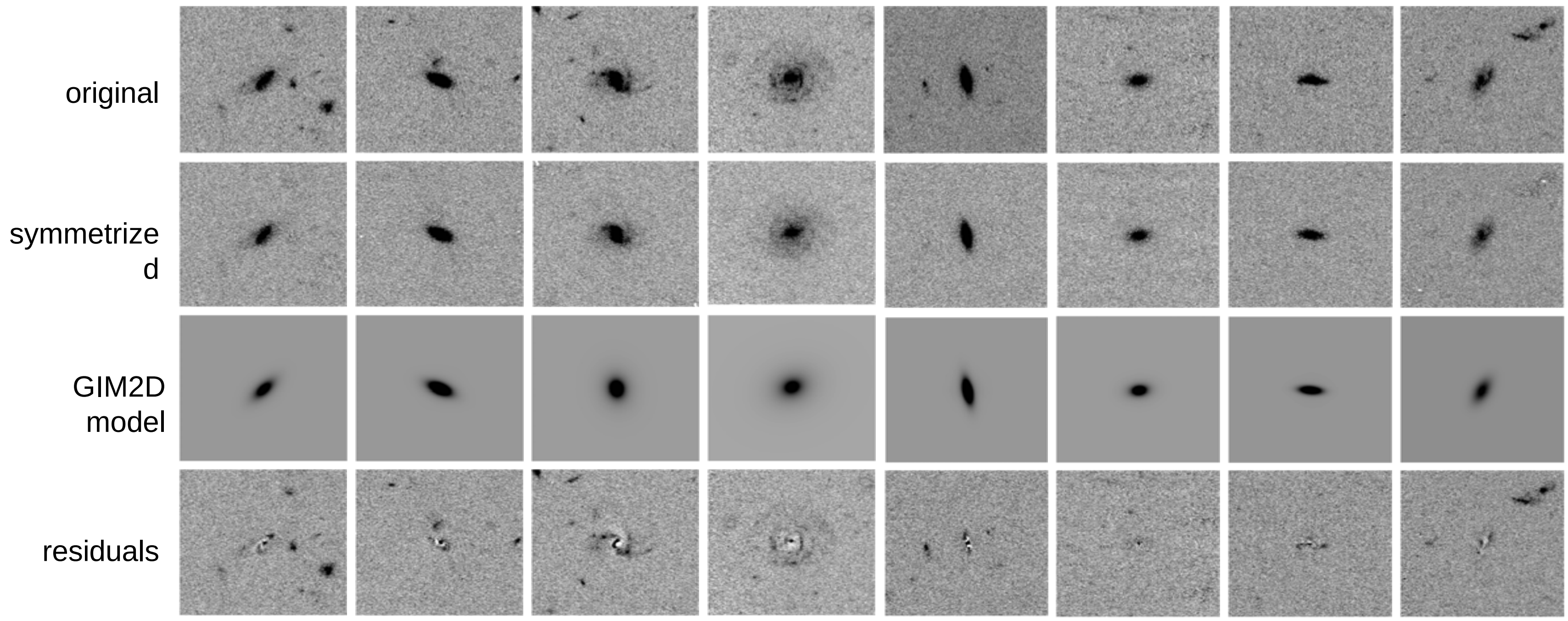
Sargent, Carollo, SJL + COSMOS et al

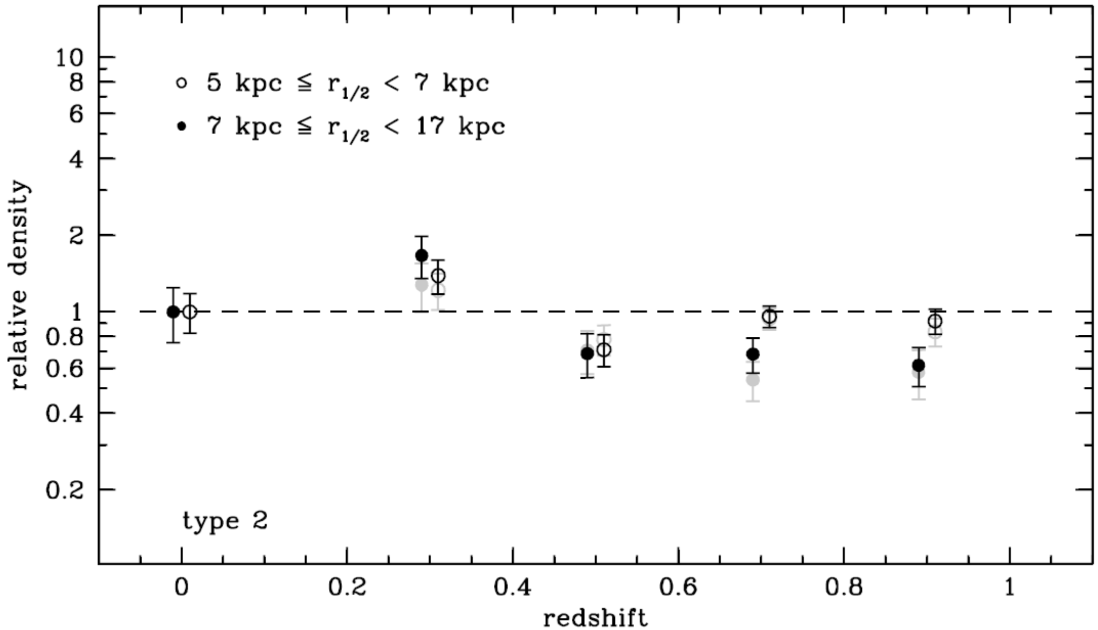
"Parametric" parameters of 10,000 I_{AB} < 22.5 galaxies, e.g. sizes, surface brightnesses, Sersic indices, Bulge-to-Disk etc using GIM2D

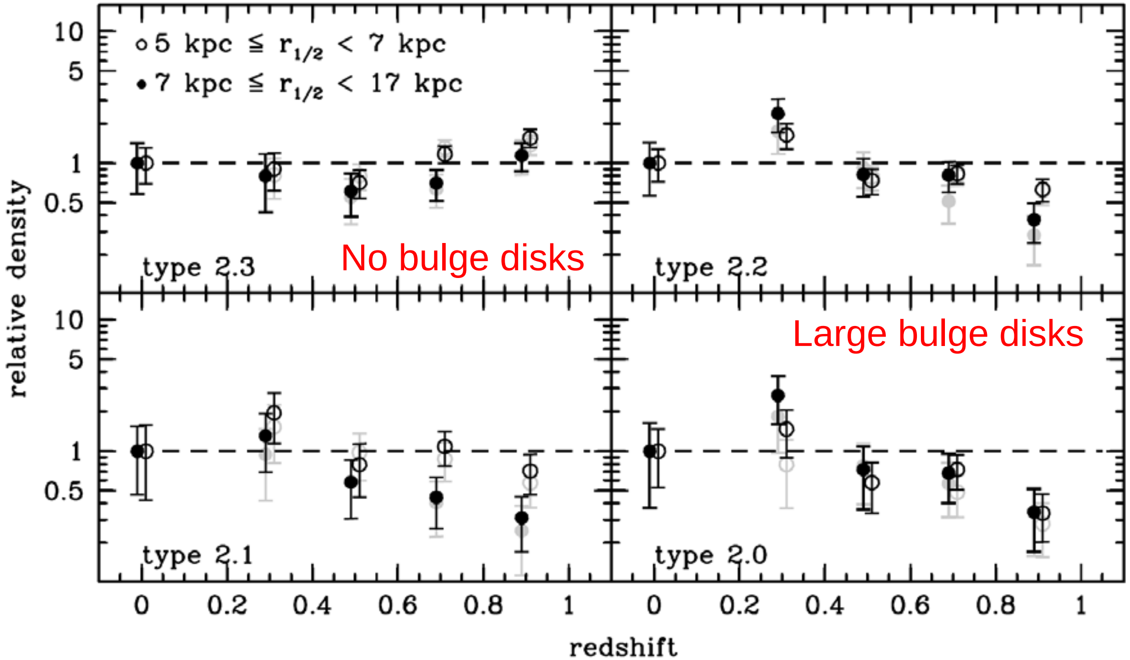
$\rightarrow$size functions, $\phi(r)$, $\phi(r,L)$ etc. $\rightarrow$ disk evolution etc

$\rightarrow$residuals $\rightarrow$ bars, spiral arms etc

e.g. 8 random COSMOS galaxies at z ~ 0.7







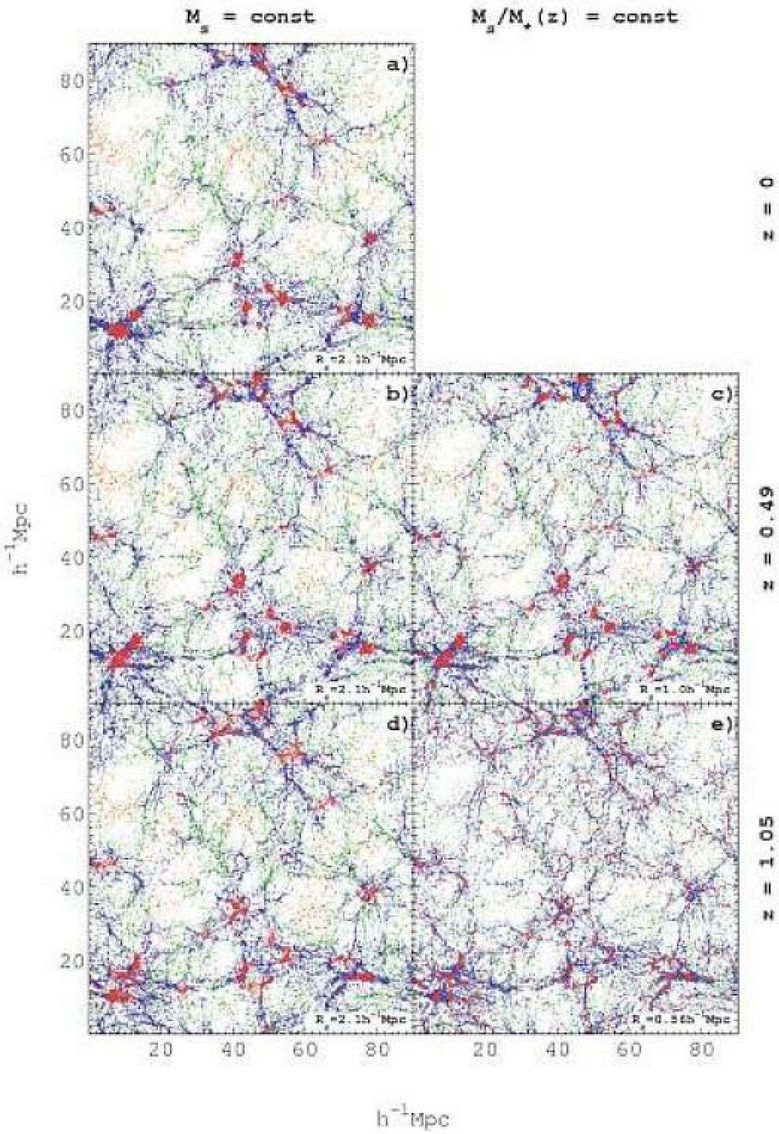
Remarkable constancy of the size function of disks

Disks of $r_{1/2}$ ~ 6 kpc are present in the same numbers at z ~ 0.7 as locally

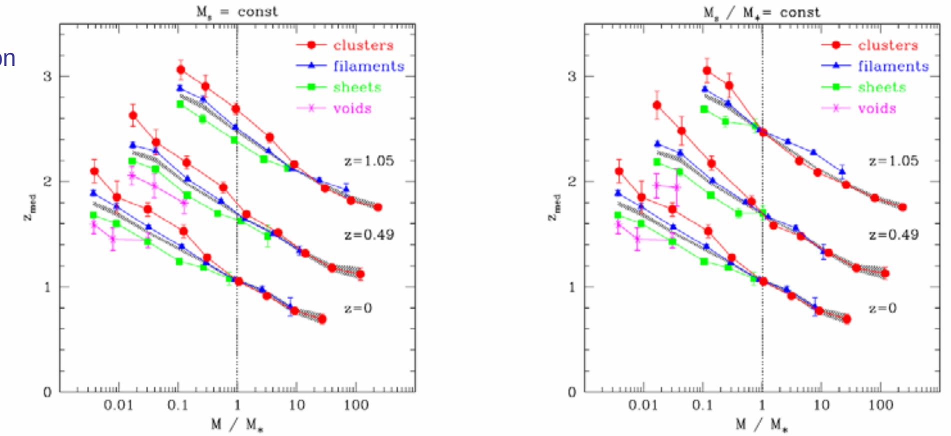
Possible deficiency in largest disks at z ~0.7

Some evidence for fewer large bulge disks at early times (N.B. not k-correction etc)

⇒ Evidence for secular generation of (some) bulges at late times ?

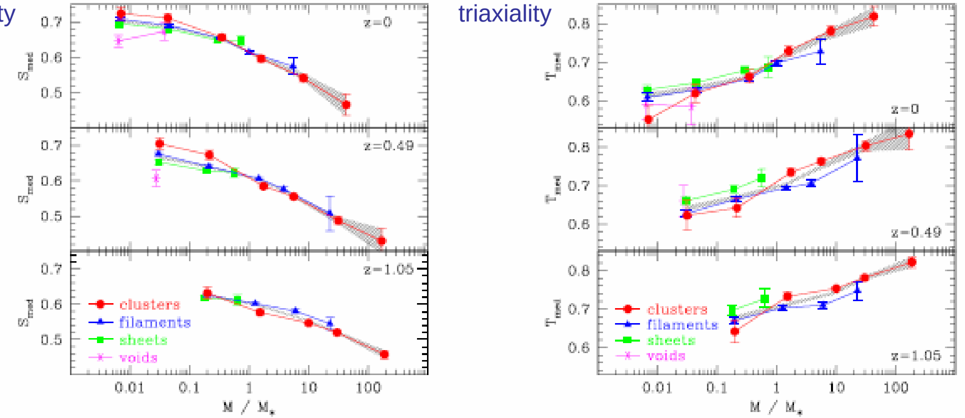


formation redshift

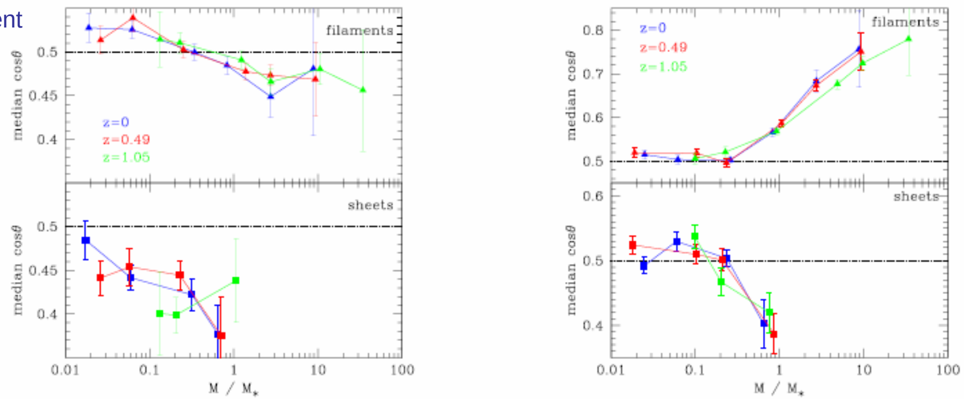


sphericity

triaxiality



alignment



DM halo properties as f(environment) from N-body simulations

e.g. Hahn et al (2007)

zCOSMOS: 35,000 galaxy redshift survey using 600 hrs of VIMOS/VLT, designed for

- 0.1 < z < 3.5 in "-bright" (1.7 deg^2) and colour-selected "-deep" (0.9 deg^2) samples
- high success rate (~ 90% bright, ~ 80% deep)
- high sampling rate (~ 70%)
- velocity accuracy ~ 100 kms^{-1}

Multi-institute collaboration

ETH Zurich

LAM Marseille

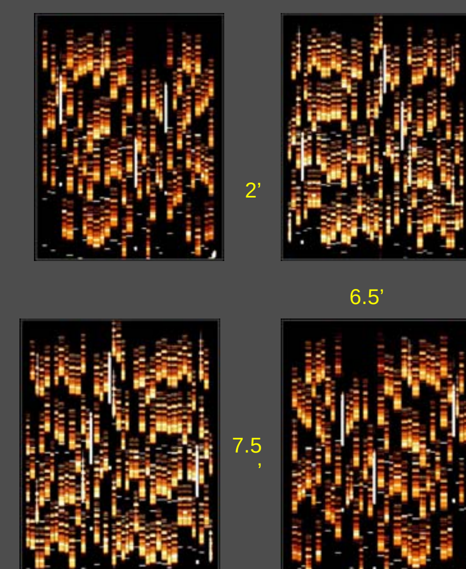
LAOMP Toulouse

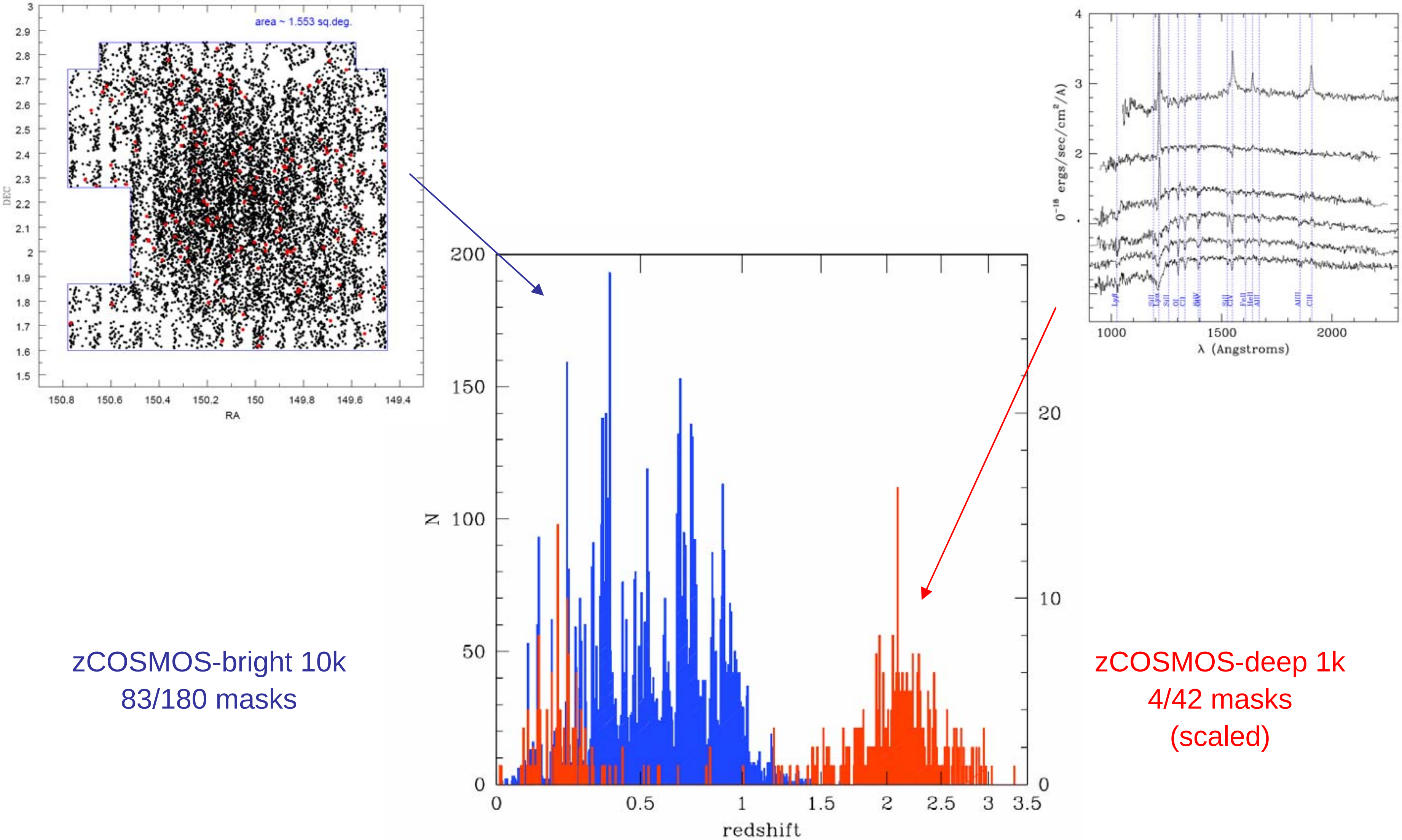
INAF Milano

INAF Bologna

MPE Garching

Very hard to reliably automate redshift measurements from faint spectra → ~ 30 FTE effort





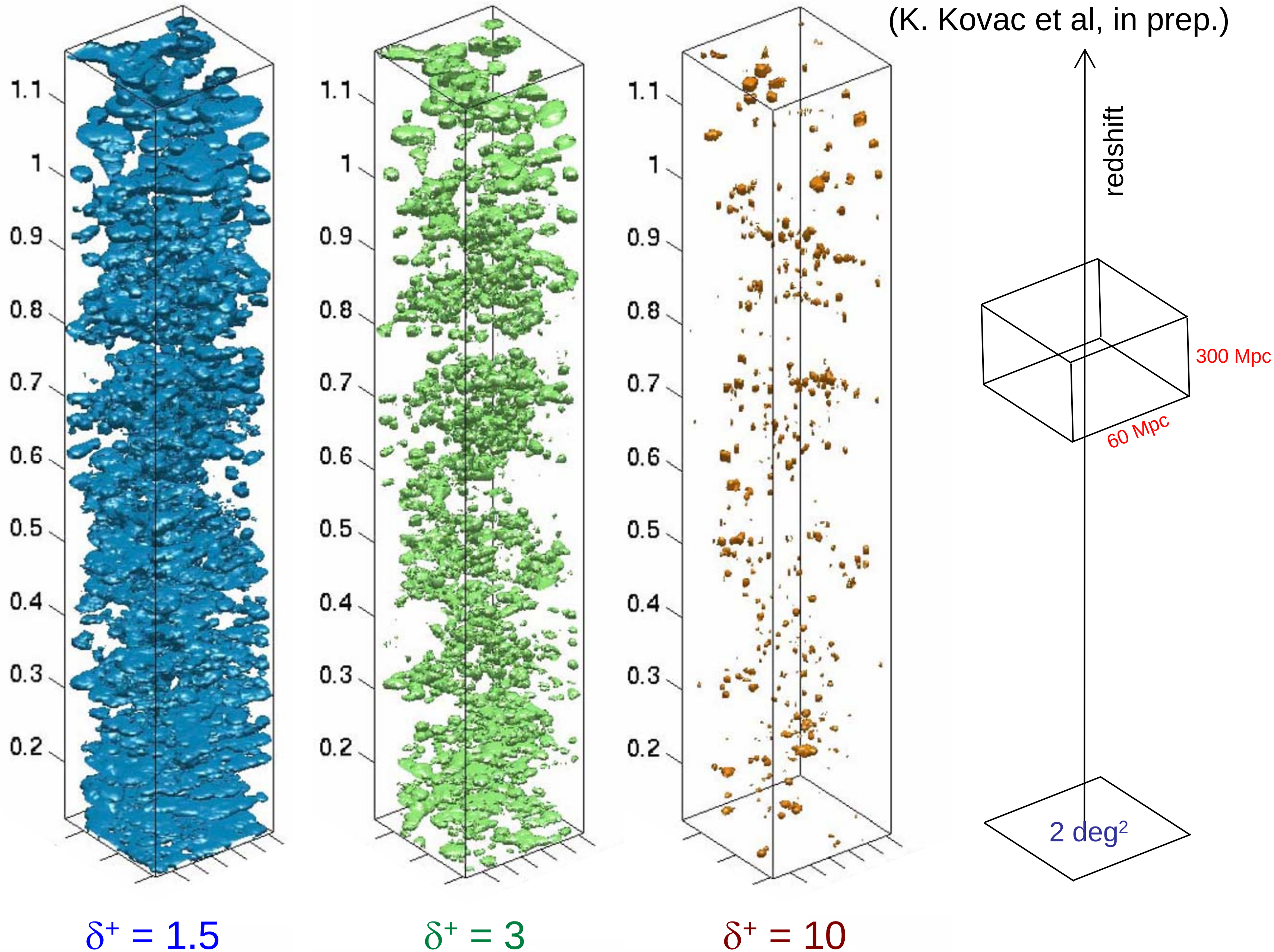
zCOSMOS-bright 10k
83/180 masks

zCOSMOS-deep 1k
4/42 masks
(scaled)

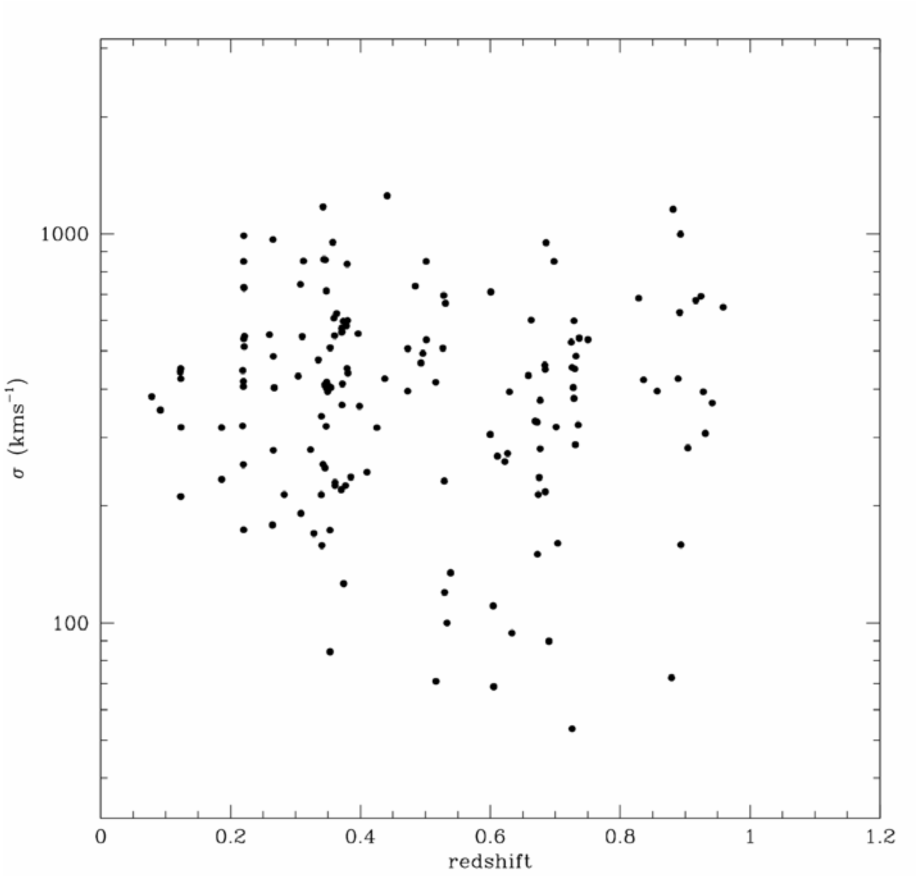
zCOSMOS - current status (data from 2005 + 2006 seasons)

ZADE combination of 10,000 zCOSMOS spectro-z + 30,000 photo-z

(K. Kovac et al, in prep.)



Characterisation of individual group-sized environments



preliminary 160-group catalogue

(K. Knobel et al., in prep)

(should have 400+ to z ~ 1 by end of program)

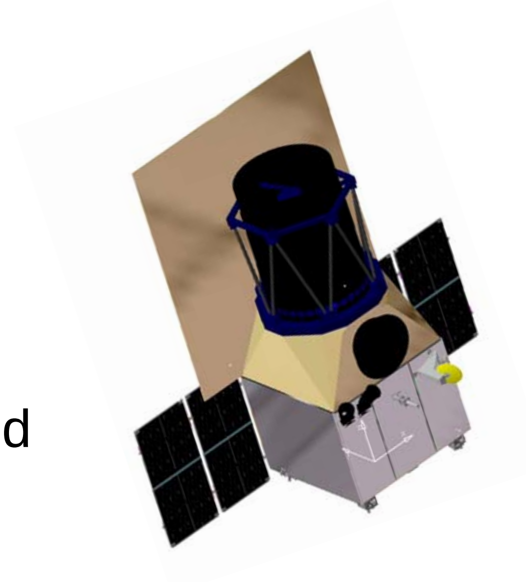
Two directions for the future:

1. COSMOS is a start, but...

   20,000 deg^2 of sky to be covered by panoramic surveys from the ground (PanStars, LSST etc) and space (DUNE?) - the “genome of extragalactic astrophysics”

   ... but why are statistics so important?

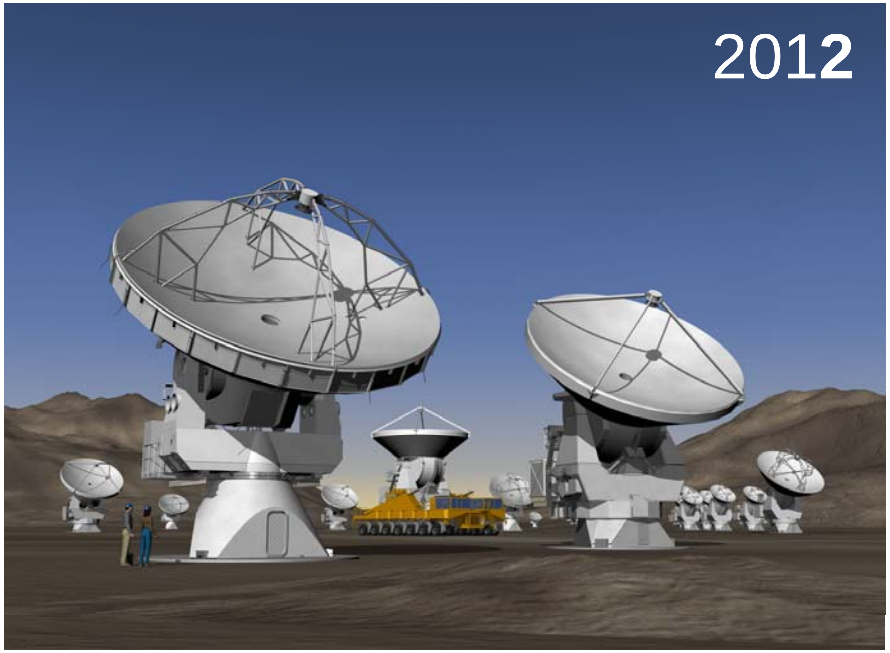
and...

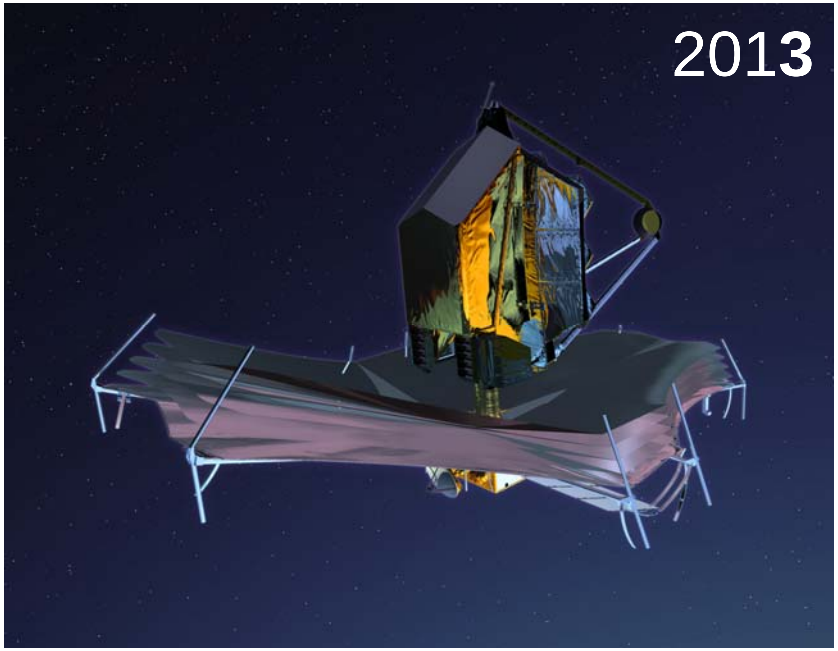


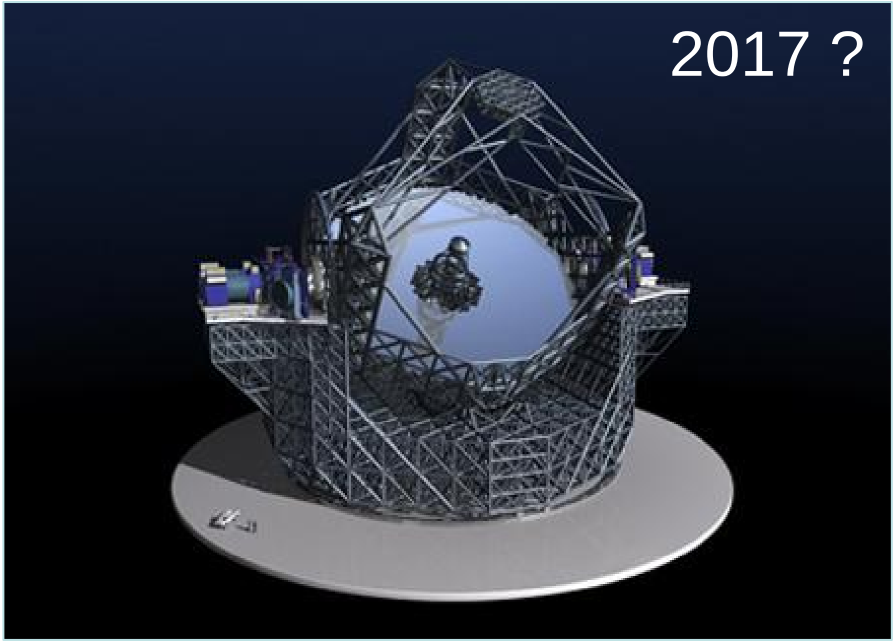
DUNE concept

... astrophysics within galaxies with next generation of observatories

JWST, ALMA, the 20-40m class telescopes... SKA etc

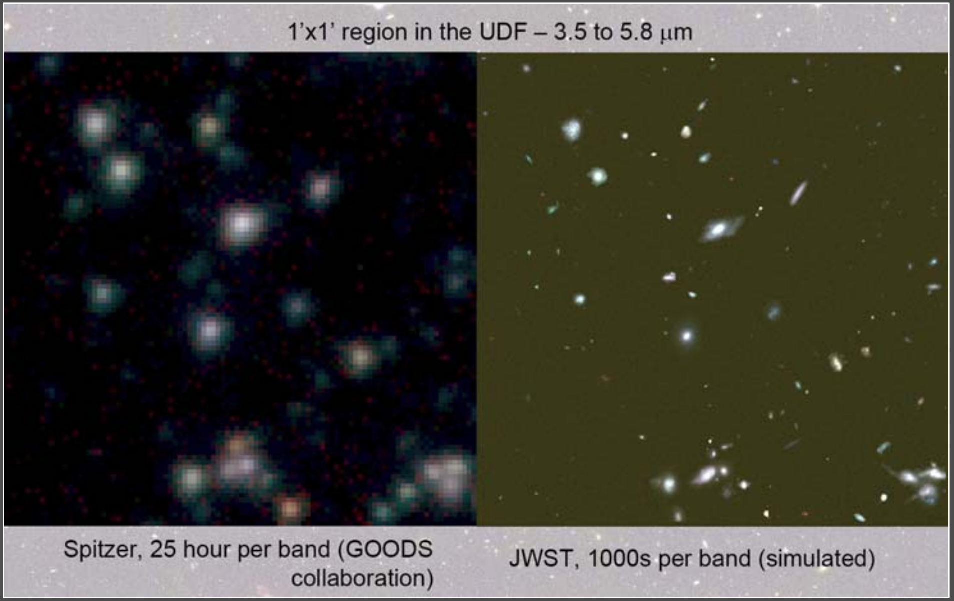

2012


2013


2017 ?


2020 ??

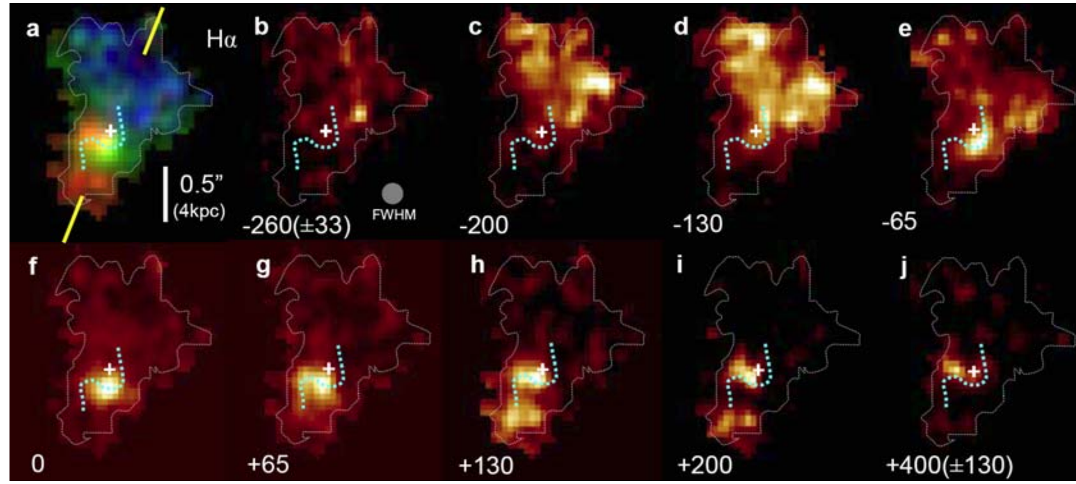
HST - JWST comparison



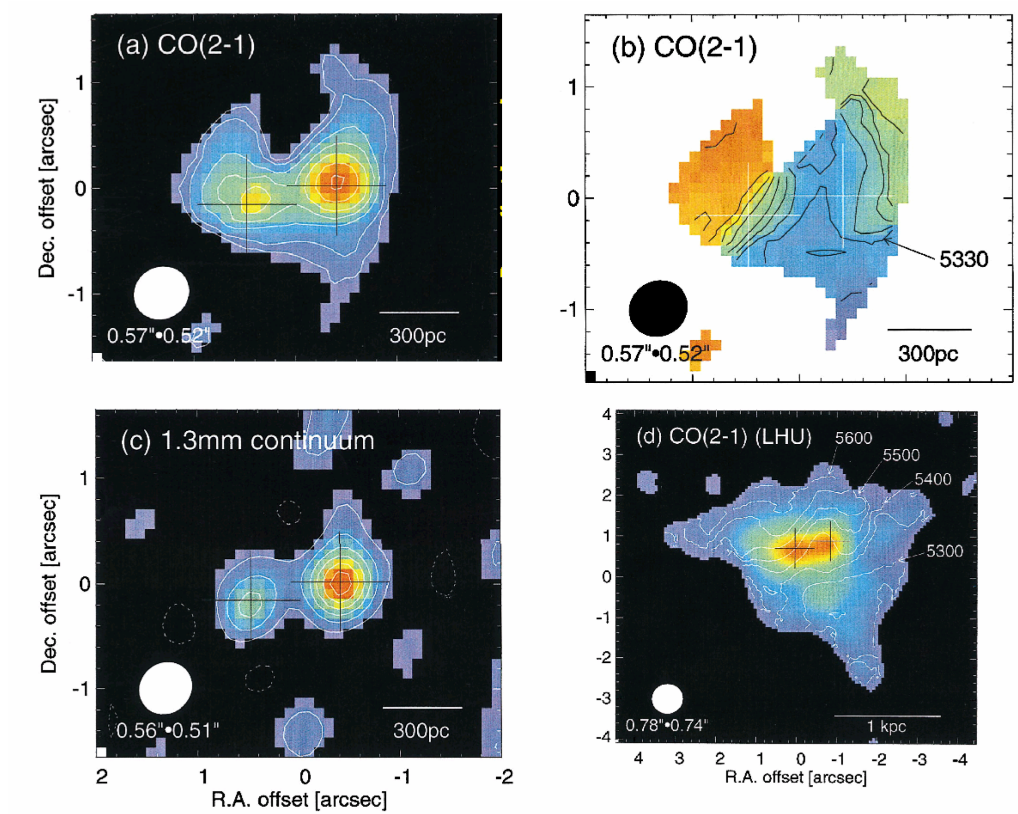
Spitzer - JWST comparison

courtesy Massimo Stiavelli

VLT/Sinfoni galactic disks at z ~ 2 (Genzel et al 2006)



Arp 220 – Sakamoto et al (1999) – as a preview of ALMA



Arp 220 (z = 0.02) → z = 2

0.5” beam CO 2–1 at 2–8 mJy beam^{-1}(30 kms^{-1} channel)

0.02” beam CO 5–4 at 0.4–1.6 μJy beam^{-1} (“)

Summary

- HST has been, and continues to be, central to the continuing dramatic progress in exploring the evolving Universe of galaxies
- Synergy with other facilities on the ground and in space has been absolutely vital to this progress
- Large Legacy-style surveys instituted on HST have had immense value (HDFs, GOODS, UDF, Gems, COSMOS) and have changed the paradigm for carrying out research in this field
- Europeans, with an excellent observatory “system”, have been fully able to play a full role in these developments
- The ground/space synergy will continue with the new facilities ALMA, JWST, ELT... SKA etc.