

Hubble-Depth Survey Project

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Changbom Park

(Korea Institute for Advanced Study)

The Hubble-Depth Survey
with SPM-twin telescopes

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The Hubble Depth Survey
with the Korean Large Spectroscopic Telescope

Survey Science Group Meeting
Jan. 20-23, 2025

Changbom Park (KIAS)

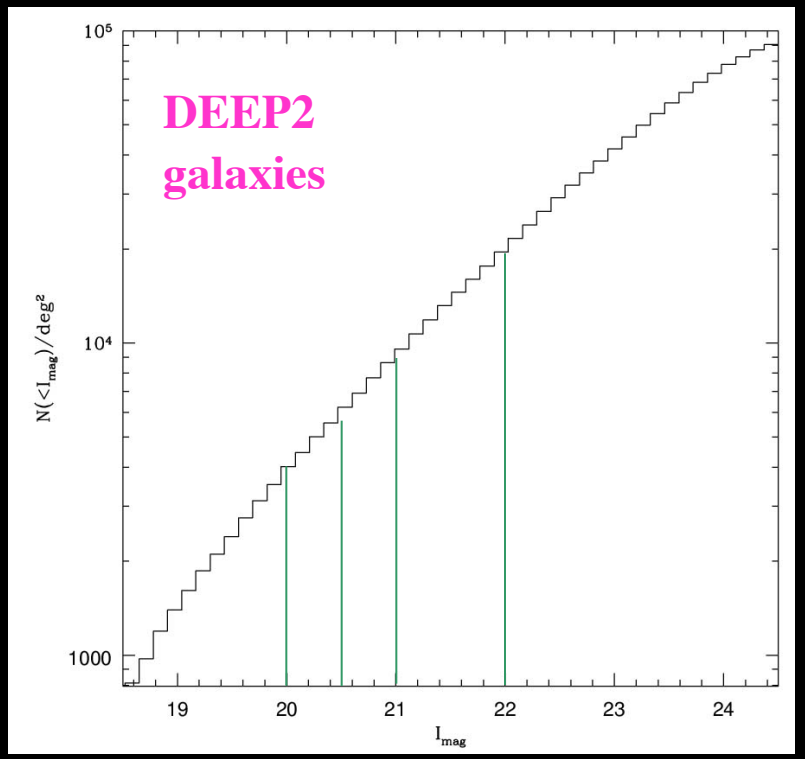


Survey specifications

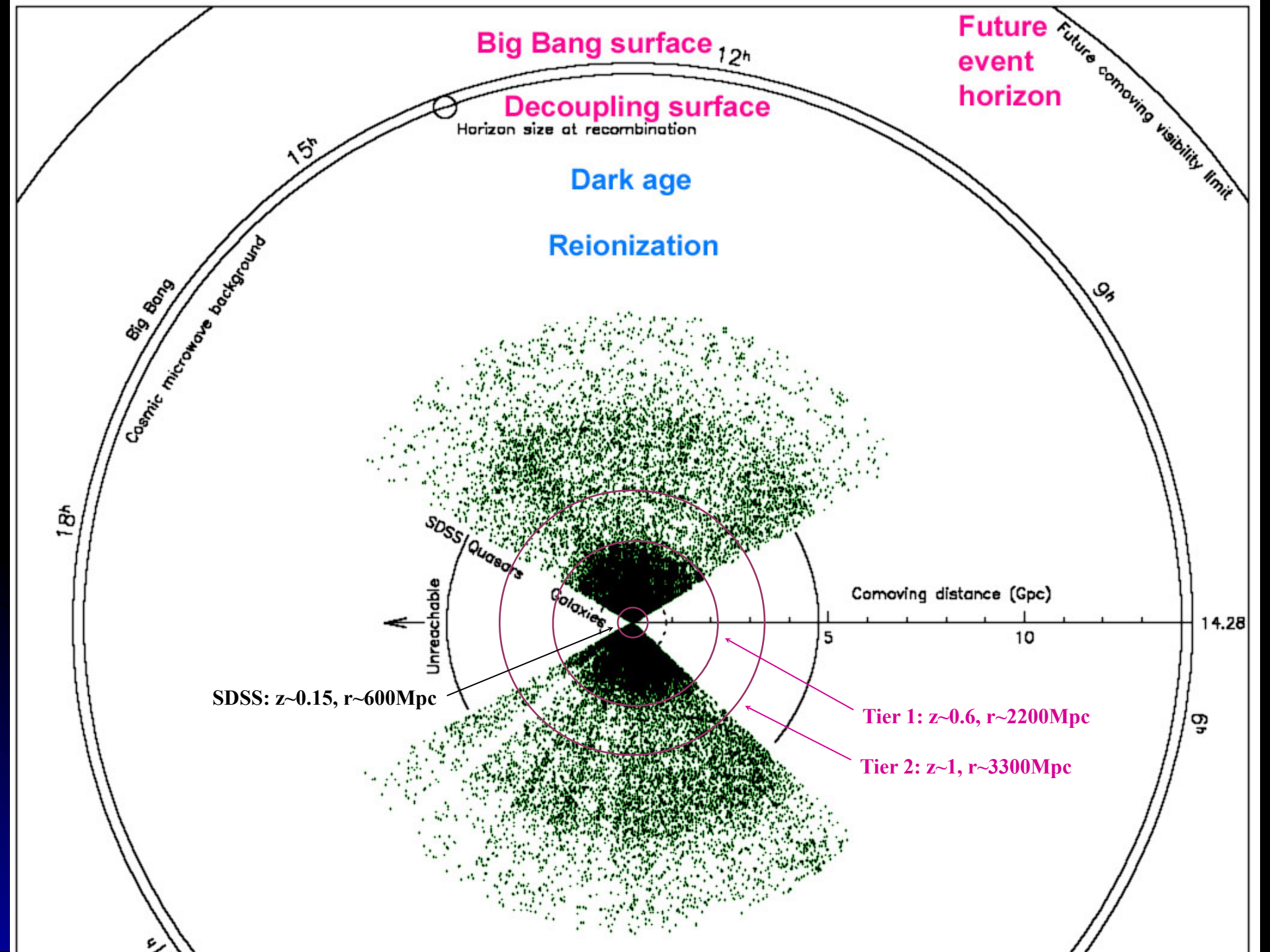
1. Photometric catalogs from LSST

Tier 1: Galaxies with i_{limit} = 20 (or r_{limit} = 20.5, z_{max} ~0.6, r_{comove}~2200Mpc)
→ n_{sky} = 4,000 gal/deg^2

Tier 2: Galaxies with i_{limit} = 21.5
(or r_{limit} = 22, z_{max} ~1, r_{comove}~3300Mpc)
→ n_{sky} = 20,000 gal/deg^2



I_{lim}<22:	Surface density ~ 20,000 /deg^2
I_{lim}<21:	Surface density ~ 10,000 /deg^2
I_{lim}<20.5:	Surface density ~ 6,000 /deg^2
I_{lim}<20:	Surface density ~ 4,000 /deg^2


Big Bang surface
12h
Future event horizon
Future comoving visibility limit
Decoupling surface
Horizon size at recombination
15h
Dark age
Reionization
Big Bang
Cosmic microwave background
9h
18h
SDSS Quasars
Galaxies
Unreachable
Comoving distance (Gpc)
5
10
14.28
6h
SDSS: z~0.15, r~600Mpc
Tier 1: z~0.6, r~2200Mpc
Tier 2: z~1, r~3300Mpc

Survey specifications

2. Spectroscopic surveys with two 6.5m's

Tier 1: 100M galaxies flux-limited with $i<20$ over ~24,000 deg^2
spectral R=6000. ~0.5hr exposures, multiplexing of 2x10,000
a few x 350 days (assuming 7 hours per day)

Tier 2: 50M galaxies flux-limited with $i<21.5$ over ~2,500 deg^2
spectral R=6000. ~2hr exposures, multiplexing of 2x10,000
a few x 700 days (assuming 7 hours per day)
--- This Tier 2 survey can continue

Hubble Depth Survey Exposure Time Calculator (정하은 박사)
주소: https://hdsetc.astrohchung.com/
분광분해능 2000 (at 6000A) & 노출시간 600초 & S/N per resolution element = 3 일때 은하한계 등급

1) Select Calculation Type - Limiting Flux Calculation 선택
2) Target S/N =3, exposure time = 600 입력
3) 왼쪽 메뉴 제일 아래쪽에서 Base Spectral Resolution 을 2000으로 변경하면 오른쪽 Limiting Flux 에서 결과값을 확인하실 수 있습니다.
현재 설정으로 R=2000, 600초 노출시 한계등급 21.69 Mag, R=6000, 600초 노출시 한계등급은 20.6 Mag.

Expecting major competitions in the future, we need to seek for a **unique** & productive path that will result in the maximal science return.

Uniqueness of the wide & dense HDS

- **Feasibility**: Relatively easier survey with immense science returns on low-z astrophysics
- **Competition**: Orthogonal to other future competing surveys focusing on the high-z universe.
  Needs higher R>2000 to be new.
- **Major advantage**:
  i. Full low-z astrophysics
  ii. The best period of the universe to examine the various effects of the dark energy.

Science from HDS - MANY!

Past light cone science - GEE(Geometry, Expansion & Evolution)

1. LSS Sciences

Large survey volume

→ Power spectrum over wide k-range, Baryon-oscillation

Densely sampled LSS

→ high-order statistics sensitive to galaxy forma. mech. & cosmological parameters

2. Galaxies

Complete knowledge of recent evolution of structures

→ Galaxy biasing, Environment effects as a function of time, Origin of morphology

Evolution of corr. function, PS, L function, N density since z~1

3. Rare Objects (r_{limit} >>22)

QSO survey out to the edge of the world of QSOs

→ L function, N density evolution, clustering

Ly-a clouds → clustering at small & large scales

4. Faint Objects

Faint galaxies at each z → late time G formation in voids

Satellites ……. among others

Cosmological sciences with large volume, dense & deep spectroscopic sample

1. Dark energy - Expansion history of the universe

: Large V, high n & deep redshift data → resolve the cosmological tensions

2. Initial conditions of the universe

: Large V & high n → measure the high-order moments accurately

→ constrain the primordial density fluctuation generation mechnisms

3. Large-scale structures in the universe

: High n & deep redshift data → Cosmic zoology/Environmental sciences & cosmological parameters from growth of structures

4. Dark matter halo

: Density profile and mass function of dark matter halos down to the galactic scale

1. Expansion history of the universe

Why do we need to survey the low-redshift universe more?

Dark energy domination
starts at z~0.7 and puts the maximal effects at z=0

The best way to constrain the DE accurately via the expansion history is to increase the low-z sample size (i.e. wider. smaller cosmic variance) & to increase the accuracy of measurement of statistics (i.e. denser)!

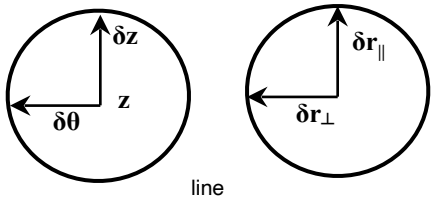
왜 low-z data is so important

i. Standard shape of cosmic structures: The Alcock-Paczynski test

Comoving sizes

$$\delta r_{\parallel} = \frac{c\delta t}{a} = \frac{c\delta z}{H(z)}$$

$$\delta r_{\perp} = r\delta\theta = (1+z)D_A\delta\theta$$



line of sight

where

$$D_A = ar = \frac{c}{(1+z)}\int_0^z \frac{dz}{H(z)}$$

$$H^2 = H_0^2\left[\Omega_m(1+z)^3 + \Omega_{DE}\exp\left\{3\int_0^z \frac{dz}{1+z}[1+w(z)]\right\}\right]$$ (flat universe)

Standard shape: Objects/statistics whose shape $\frac{\delta r_{\parallel}}{\delta r_{\perp}} \propto \frac{1}{D_A(z)H(z)}$ **does not evolve**

Choice of a wrong cosmology in r(z) → incorrect $D_A H$ **nt evolution of** $\frac{\delta r_{\parallel}}{\delta r_{\perp}}$

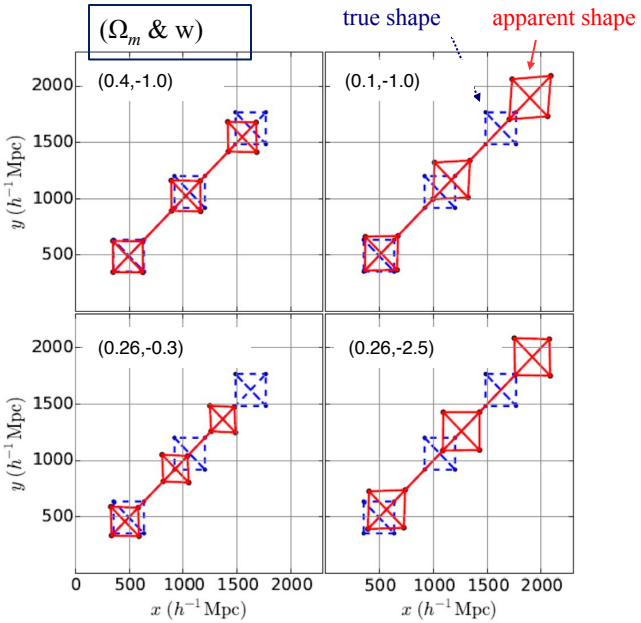
==> constraints on Ω_m **& w by comparing** $\frac{\delta r_{\parallel}}{\delta r_{\perp}}$ **us redshifts.**

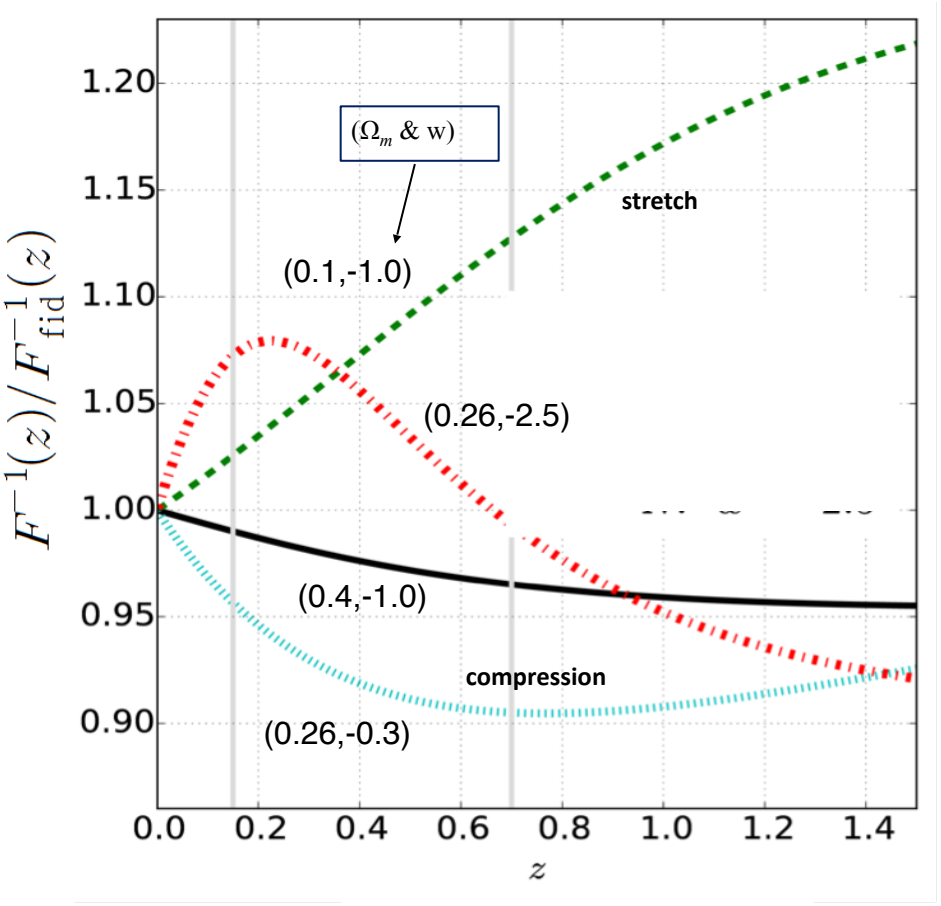
Note! **(No absolute size/shape(z) used. Only shape conservation is used across z's!)**

Uses only shape - purely geometrical & ~independent of size, mass & clustering evolution!

Shape of structures

seen in a flat universe with Ω_Λ=0.74, Ω_m=0.26 & w=-1



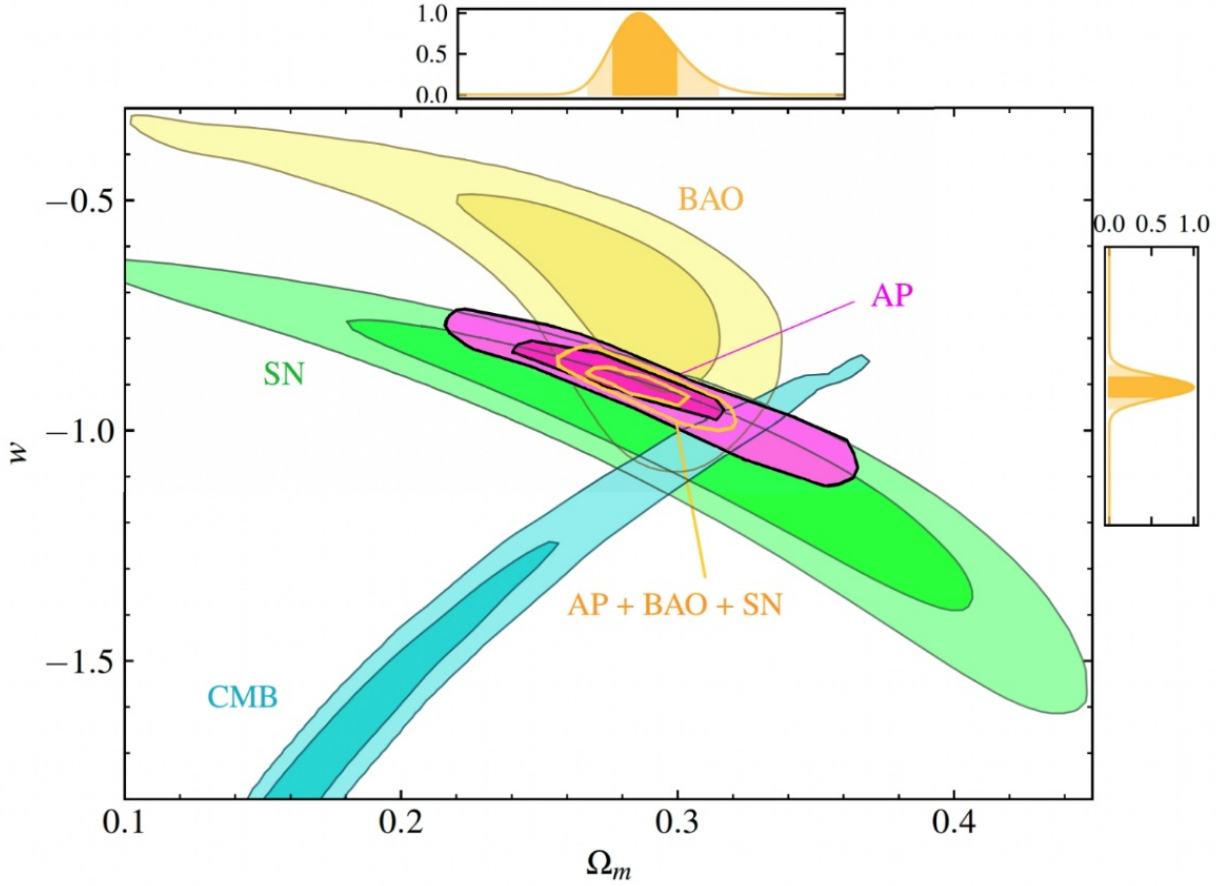


where $F(z) \equiv \frac{(1+z)}{c} D_A(z) H(z)$

Extended Alcock-Paczynski test on SDSS [Dong et al. 2023]

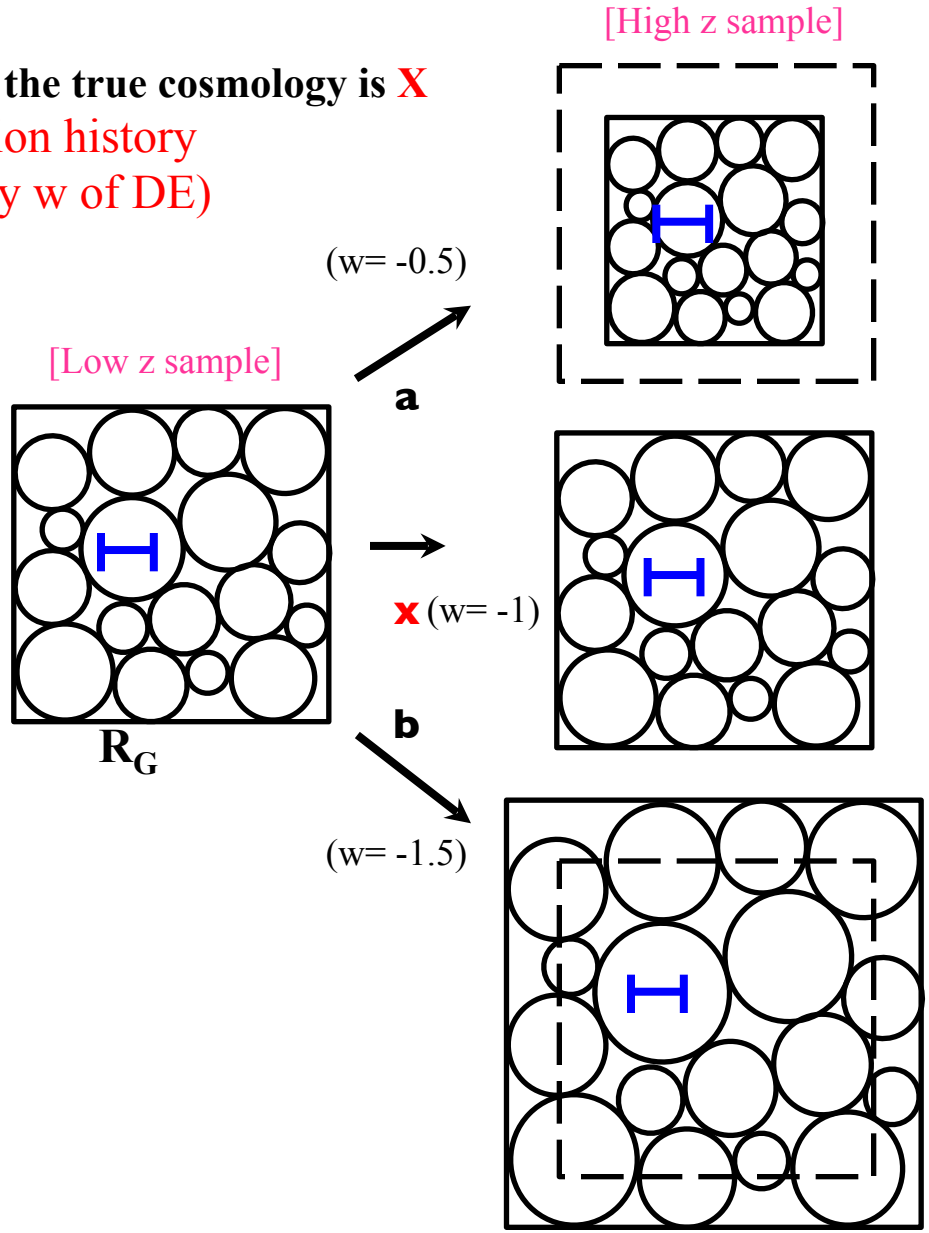
: SDSS AP + SDSS BAO + SN (without CMB combined!)

$w_{eff}(z=0\sim0.7) = -0.903 \pm 0.023$ **4.2σ away from ΛCDM w=-1!**



ii. Standard population

Suppose the true cosmology is X
(expansion history
varied by w of DE)



looking at a larger smoothing scale
+ taking a larger unit volume

(Park & YR Kim 2010)

genus per unit comoving volume in a wrong cosmology

= G(X) at scaled R_G * volume factor of true cosmology / volume factor of wrong cosmology

Measured genus density when a wrong cosmology 'Y' is adopted

$$g_{\rm Y}(z;R_G) = g_{\rm X}(R'_G)V_{\rm X}(z)/V_{\rm Y}(z)$$

$$R'_G = \lambda_{XY}(z)R_G \qquad \lambda_{XY}(z) = [V_X(z)/V_Y(z)]^{1/3}$$

where $V = D_A^2/H(z)$

$$r(z) = \int_0^z \frac{dz'}{H(z')}$$

$$H(z) = H_0\sqrt{\Omega_m(1+z)^3 + \Omega_X \exp\left[3\int_0^z \frac{1+w(z)}{1+z}dz\right]}$$

Prediction (Gaussian)

$$g = (\langle k^2 \rangle / 3)^{3/2} / 2\pi^2$$

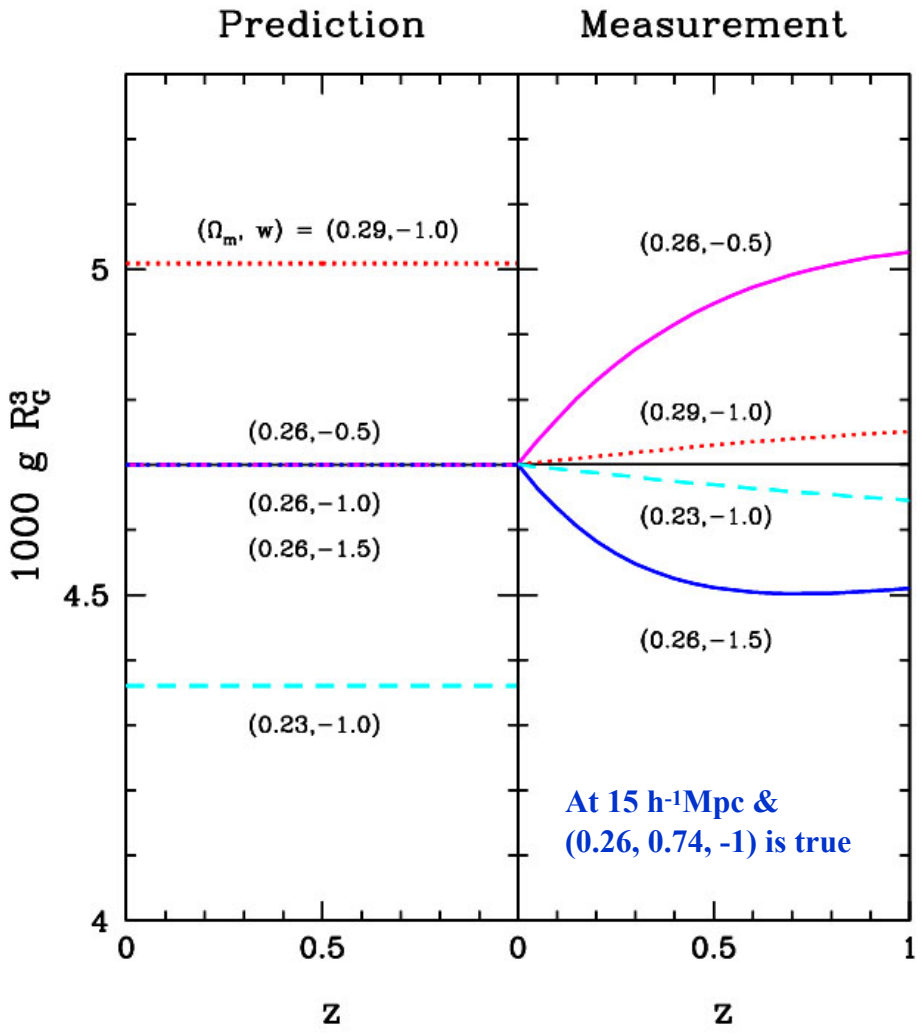
$$\langle k^2 \rangle = \int P_s(k) k^2 d^3k / \int P_s(k) d^3k$$

Measured genus

$$g_Y(z; R_G) = g_X(R'_G) V_X(z) / V_Y(z)$$

$$R'_G = \lambda_{XY}(z) R_G$$

$$\lambda_{XY}(z) = [V_X(z)/V_Y(z)]^{1/3}$$

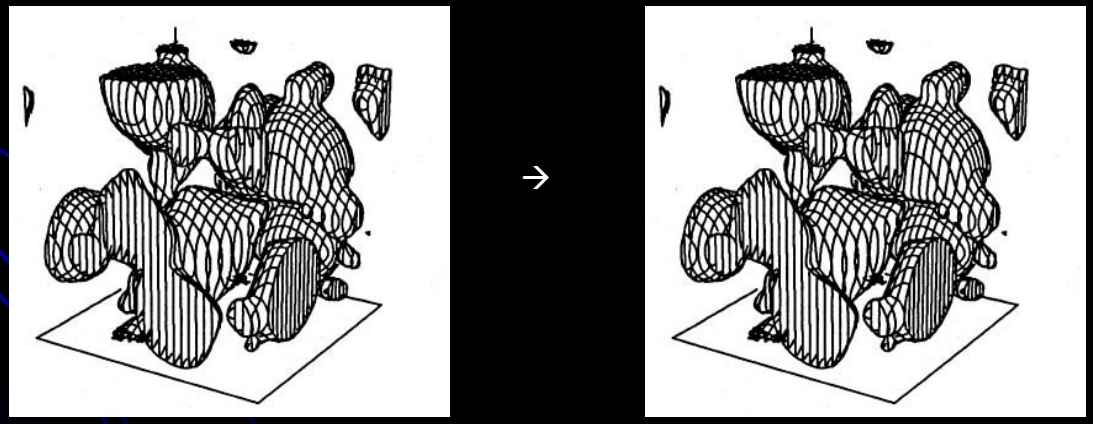


~1% effects for Δw=0.1

2. Initial conditions of the universe

Large volume & dense redshift survey → Linear regime sciences!

- **Power spectrum on very large scales**
  Large volume HDS → Matter-radiation density equality epoch
  Expansion and energy density evolution before decoupling. Cosmological parameters
- **Gaussianity of the initial matter fluctuations**
  On large scales, LSS is still in its primordial state & the large dense HDS will allow measuring the non-Gaussianity of the initial matter fluctuations with high precision



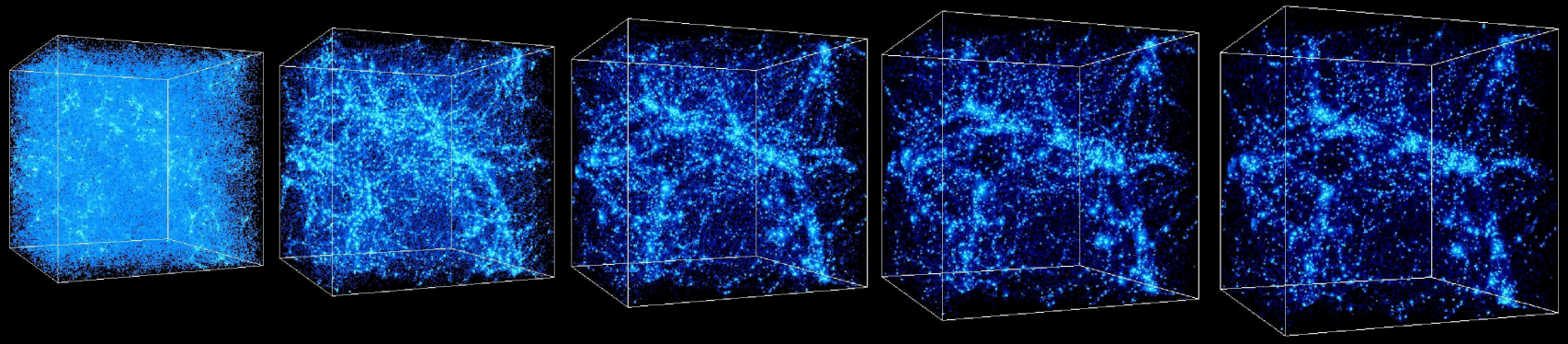
3. Large-scale structures in the universe

Dense 3D map of LSS → LSS sciences and cosmic zoology

- Development of the cosmic web from redshift desert to the present with a large dynamic range
  Connection between the initial conditions and the cosmic web
- Co-evolution of LSS and galaxies
  Constraining on cosmology and galaxy formation mechanisms.

Large-scale peculiar velocity map in the local universe

- Growth factor
  HDS giving spectra with R~6000 → accurate densely-sampled σ_v & v_{pec} map
- Kinematics within galaxy clusters, groups, & galactic satellite systems
  Constraining DM and DE in the universe



4. Dark matter halo science

Dark matter halo survey

: A volume-limited sparsely sampled galaxy-scale dark matter halos down to Mabs ~ -12mag with v ~10km/s (or M_{DH}~$10^8 M_\odot$).

mid-resolution R~6000! (DHS + diverse astrophysics with spectral lines)

i. DM & DE constraint

- **Dark Matter Halo mass function**
- **DH mass profile**
- **DH and host properties**
- **Stellar-to-halo mass relation**

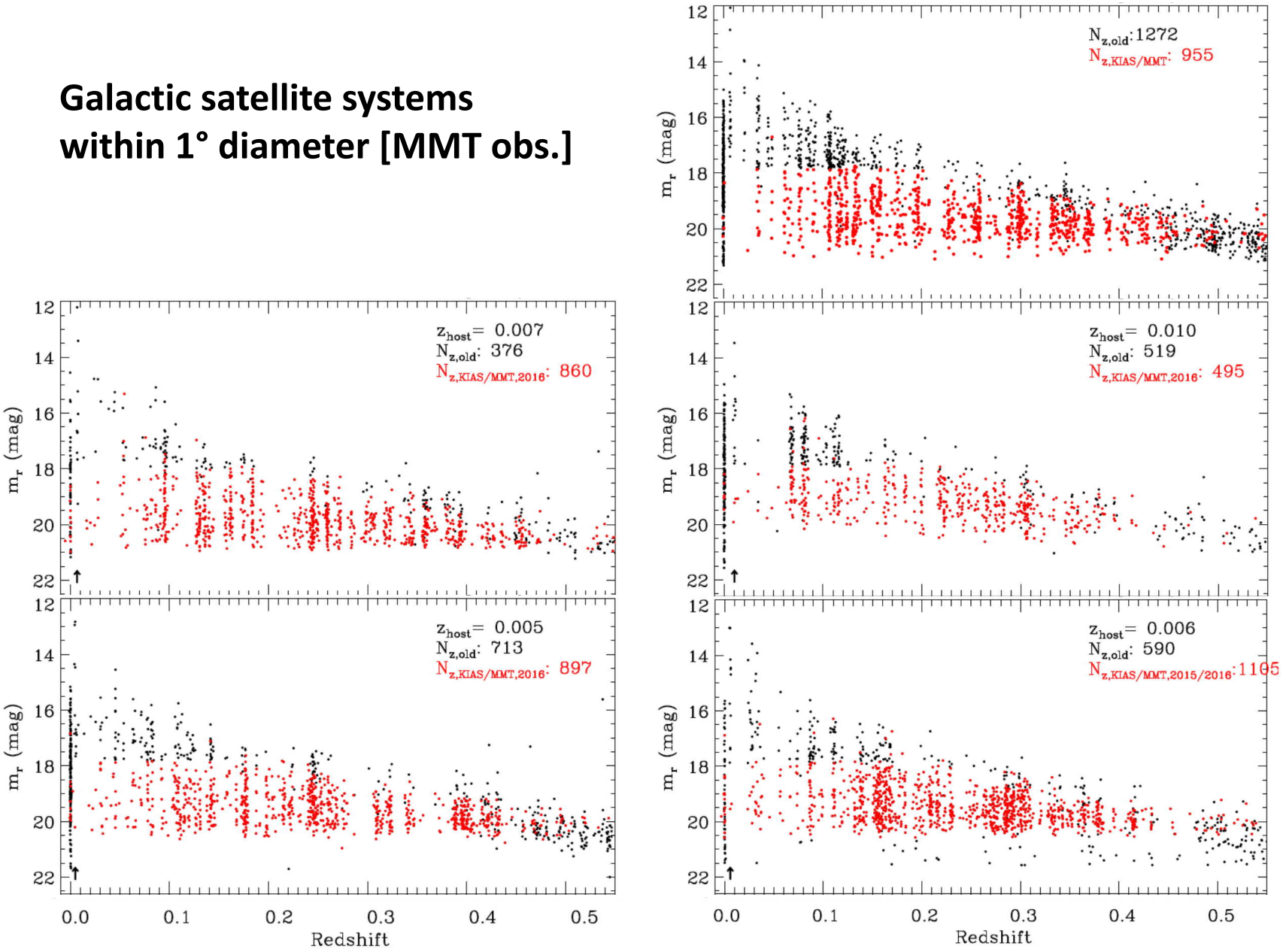
ii. Satellite systems

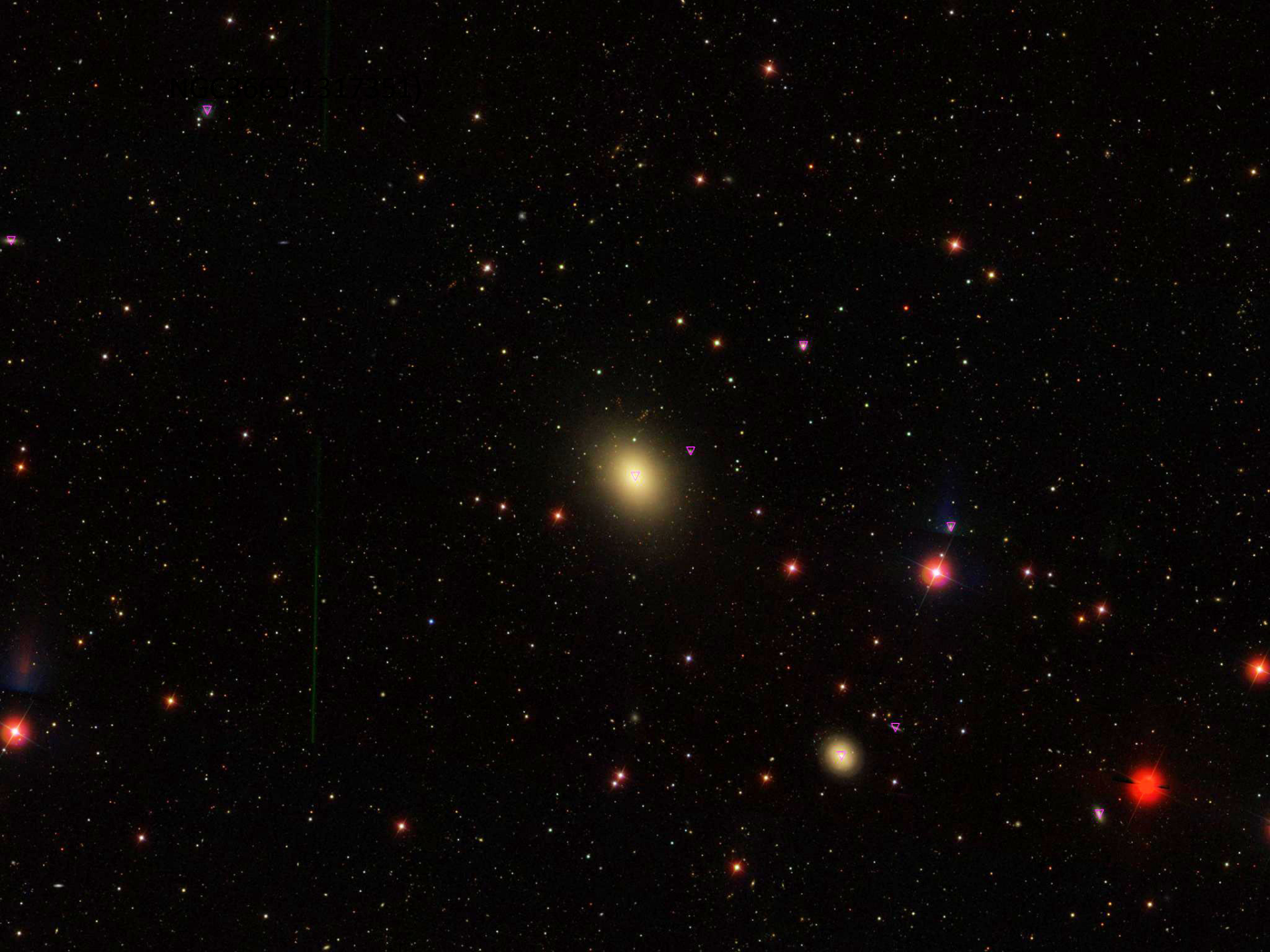
- **Satellite luminosity function, morphology distribution**
- **Relation with hosts & environment**

iii. Properties of faint galaxies

- **Void galaxies, Dwarf galaxies**
- **Faint end of galaxy luminosity function as f(z)**

Galactic satellite systems within 1° diameter [MMT obs.]






Satellites << 10 typically

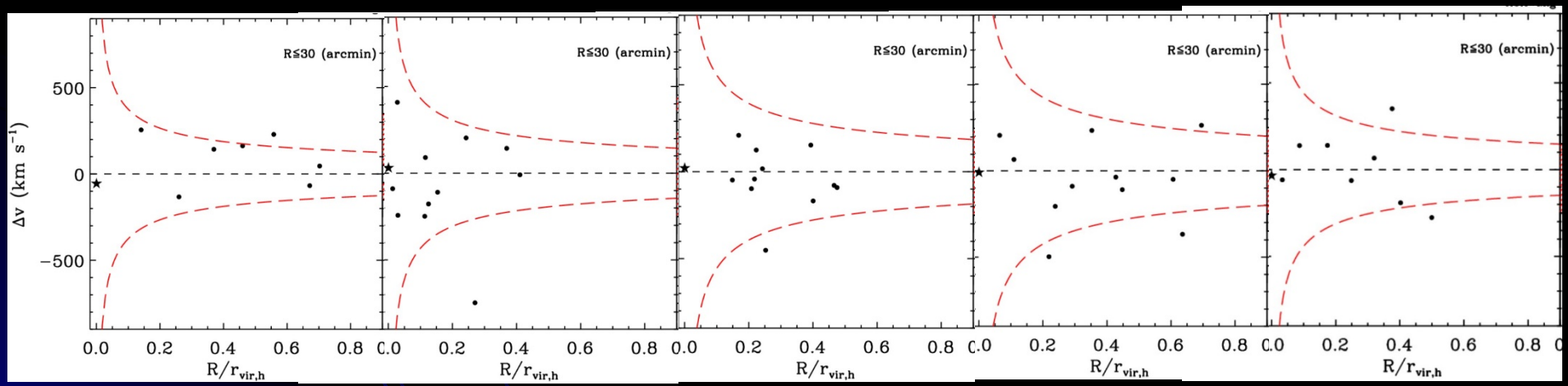
Identification of satellites

Difference from the system velocity < $v_{esc} \propto (M_{host}/R)^{1/2} \propto (L_{host}/R)^{1/2}$

➔ $v_{\rm esc} = v_0 10^{-0.4(M_{r,h}-M_0)/3}(R/r_{\rm vir,h})^{-1/2}$ where M_0=-21, v_0=250km/s

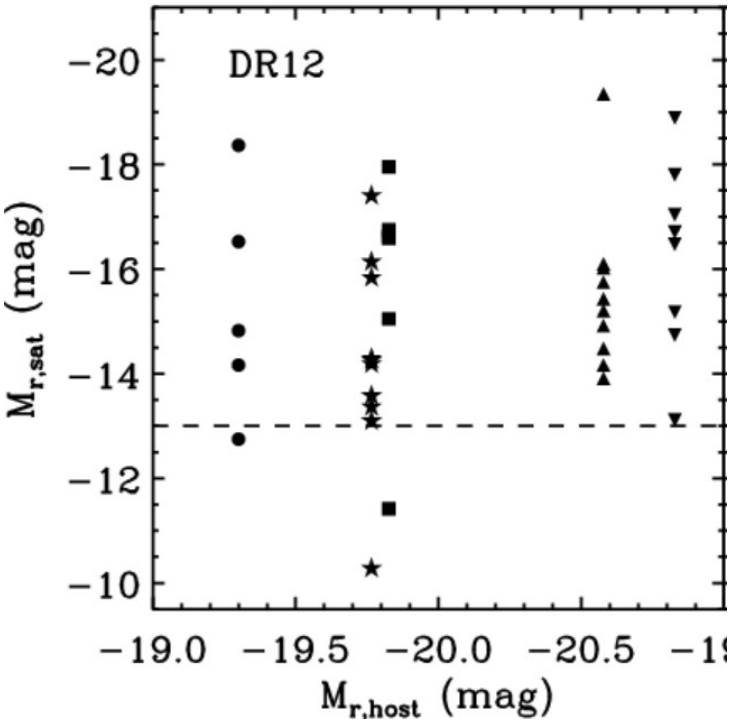
& the host-centric distance < 0.7 $r_{vir,h}$

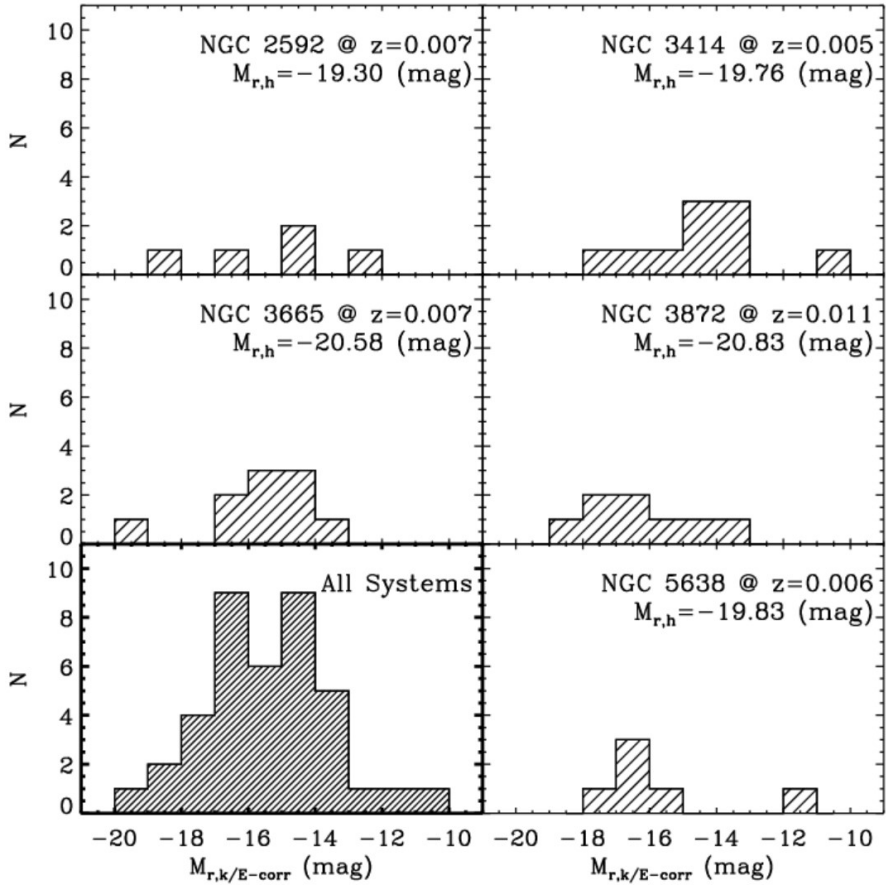
NGC2592 (1142165) | NGC3414 (2204882) | NGC3665 (1317351) | NGC3872 (1122257) | NGC5638 (485766)



Luminosity function of satellites

There exists a cut-off in the LF of satellites of early-type host galaxies!





New eyes on cosmology with a dedicated spectroscopic telescope

The 2030's will be the beginning of the main **era of spectroscopy** in astronomy

The proposals like MSE, MegaMapper, DESI-2, Spec-S5, and upcoming/on-going surveys like PFS, HETDEX etc. all give us more justification for the bright future of large spectroscopic surveys of galaxies in the 2030's and beyond.

Expecting major competitions in the future, we need to seek for a **unique** & productive path that will result in the maximal science return.

Summary

Hubble-Depth Survey

1. Deep (z ~ 1, r ~ 3000 Mpc)

→ Evolution sciences on tracers & universe. Easy to reach in optical band

2. Wide (area > 20000 deg^2)

→ Large angle & scale structure sciences

3. Dense sampling (mean d < 10 h^{-1}Mpc)

→ Physics of galaxy formation. Environment well-defined

High order statistics (topology, void, $<\delta_1\delta_2\delta_3>$ …)

Faint objects → GF & evolution, Satellites ($\Delta m \approx 6$!) & Dark halos (**DHS**)

4. Complete/unbiased sampling

→ No sampling biases. Unexpected findings

5. Compatibility with parallel surveys

→ LRG, ELG & QSO surveys

Nov. 2005 @ Mexico