# FastSound から SWIMS へ？

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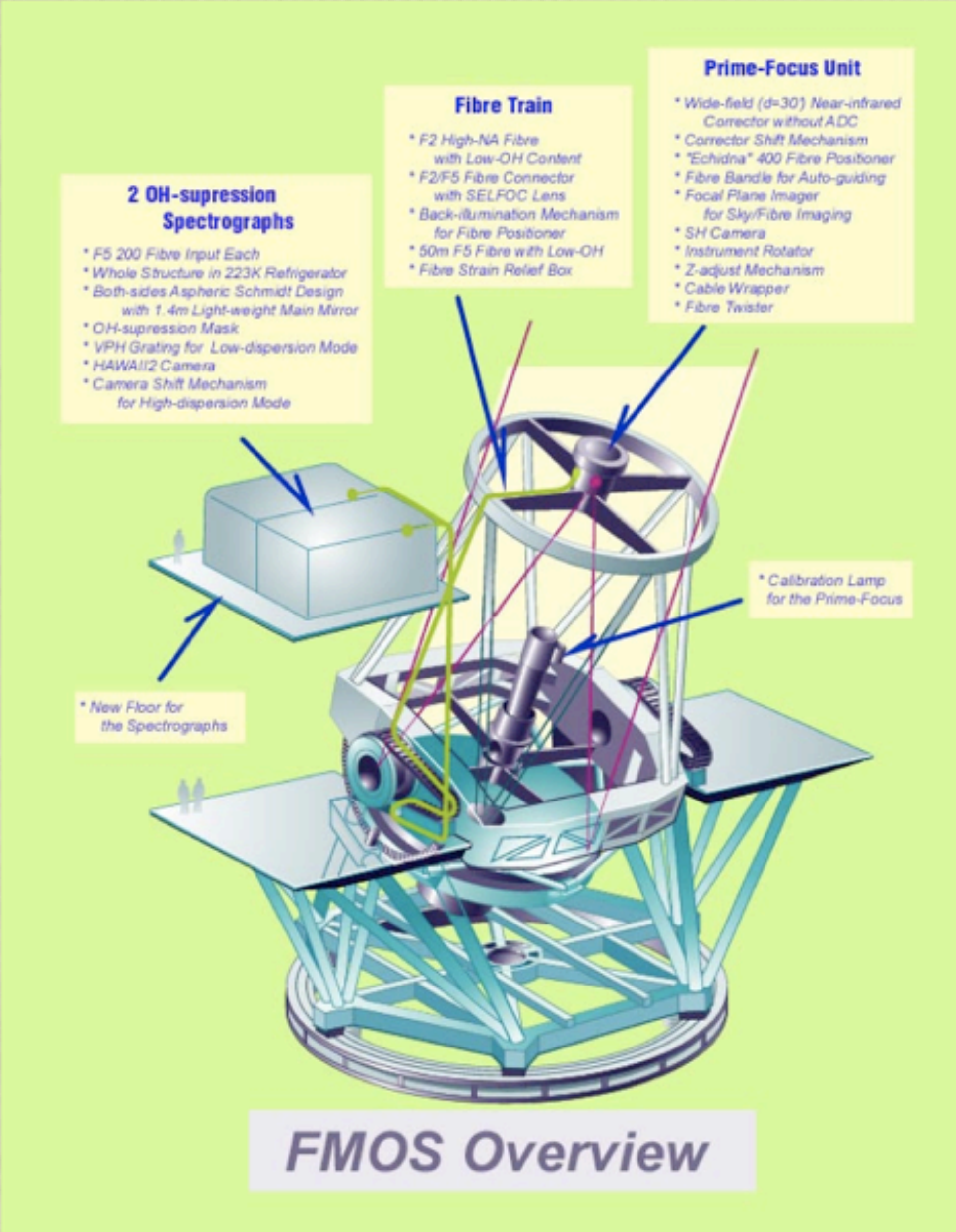
# talk plan

- FastSound の現状紹介
- FastSound の継続／発展版をSWIMS で！？

# Subaru/FMOS

- Fiber Multi-Object Spectrograph in NIR for Subaru
  - constructed by Japan-UK collaboration
- 400 fibres in circular FOV (30’ Φ)
  - hexagonal arrangement with 1.4’ separation
  - fiber aperture 1.25” $\phi$
- wavelength coverage: 0.9um - 1.8um
- Spectral resolution
  - Low resolution mode: R=500
  - High resolution mode: R=2200
- Limiting magnitude (1 hr, S/N=5)
  - J ~ 22.0
  - H ~ 20.0
  - Line ~ 1 x $10^{-16}$ erg/s/$cm^2$
  - OH airglow suppression system



# FastSound

- The name comes from…
  - FMOS 暗黒世界探査 (Ankoku Sekai Tansa = Dark World Survey)
  - Subaru Observation Understanding Nature of Dark energy
- The team ~40 members from Japan, UK + Int'l:

**PI & Co-PI**

- Tomonori Totani (PI, Kyoto University)
- Naruhisa Takato (Co-PI, NAOJ/Subaru)

**Japan:**

- Masayuki Akiyama (Tohoku)
- Tomotsugu Goto (IfA, Univ. Hawaii)
- Chiaki Hikage (Princeton)
- Masatoshi Imanishi (NAOJ/Subaru)
- Takashi Ishikawa (Kyoto)
- Yoichi Itoh (Hyogo)
- Fumihide Iwamuro (kyoto)
- Tsutomu Kobayashi (Tokyo)
- Toshinori Maihara (Kyoto)
- Takahiko Matsubara (Nagoya)
- Takahiro Nishimichi (Tokyo)
- Kouji Ohta (Kyoto)
- Hiroyuki Okada (Kyoto)
- Teppei Okumura (IEU, Ewha Womans Univ., Korea)
- Shinki Oyabu (Nagoya)
- Shun Saito (JSPS, UC Berkeley)
- Masanao Sumiyoshi (Kyoto)
- Ryuichi Takahashi (Hirosaki)
- Naoyuki Tamura (Tokyo)
- Atsushi Taruya (Tokyo)
- Motonari Tonegawa (Kyoto)
- Shinji Tsujikawa (Tokyo Sci. Univ.)
- Kiyoto Yabe (NAOJ)
- Naoki Yoshida (Tokyo)

**UK:**

- Andrew Bunker (Oxford Univ.)
- Gavin Dalton (Oxford Univ.)
- Pedro Ferreira (Oxford Univ.)
- Carlos Frenk (Durham Univ.)
- Edward Macaulay (Oxford Univ.)
- Will Percival (Univ. Portsmouth)
- Tom Shanks (Durham Univ.)

**International Members:**

- Stephane Arnouts (CFHT)
- Chris Blake (Swinburne)
- Jean Coupon (Taiwan)
- Richard Ellis(Caltech)
- Karl Glazebrook (Swinburne)
- Henry McCracken (Terapix)
- Lee Spitler (Swinburne)
- Istvan Szapudi (IfA, Hawaii)

# FastSound: Quick Summary

- Cosmology-purpose redshift survey by Subaru/FMOS
  - targeting H$\alpha$ emitting galaxies at z~1.2-1.5 (1.44-1.65 um, HR mode of FMOS)
  - ~5,000 galaxy redshifts in 30 deg$^2$ in CFHTLS Wide fields
- Primary science goal: testing gravity theory by measuring structure growth rate using redshift space distortion (RSD)
  - ~20% accuracy measurement of $f\sigma_8$ at z~1.35
  - the first significant detection of RSD at z > 1
- Observing details:
  - target selection: ugriz photo-z calculation of z_exp and H$\alpha$ flux
  - ~30 min exposure on source per field-of-view (0.2 deg$^2$), 1.4 hr including overhead
  - ~40 nights in 2012 Mar. - 2014 Feb. (A Subaru Strategic Program)

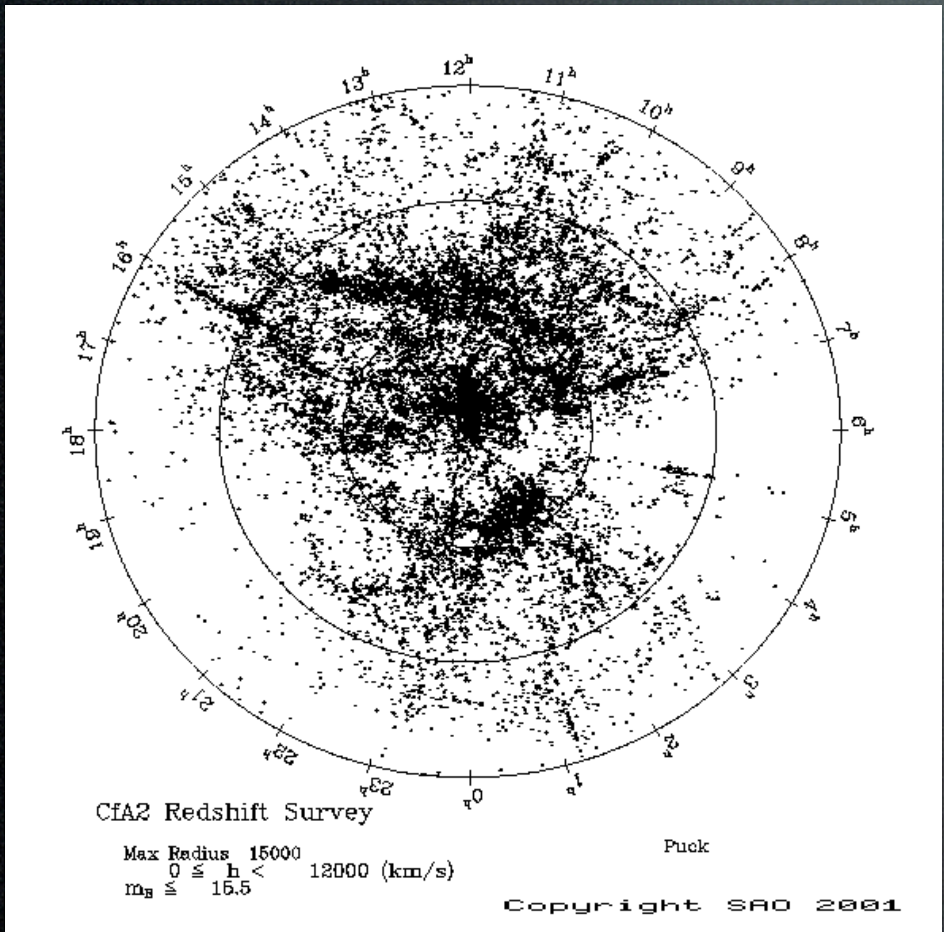
# Cosmology by redshift space distortion (RSD)

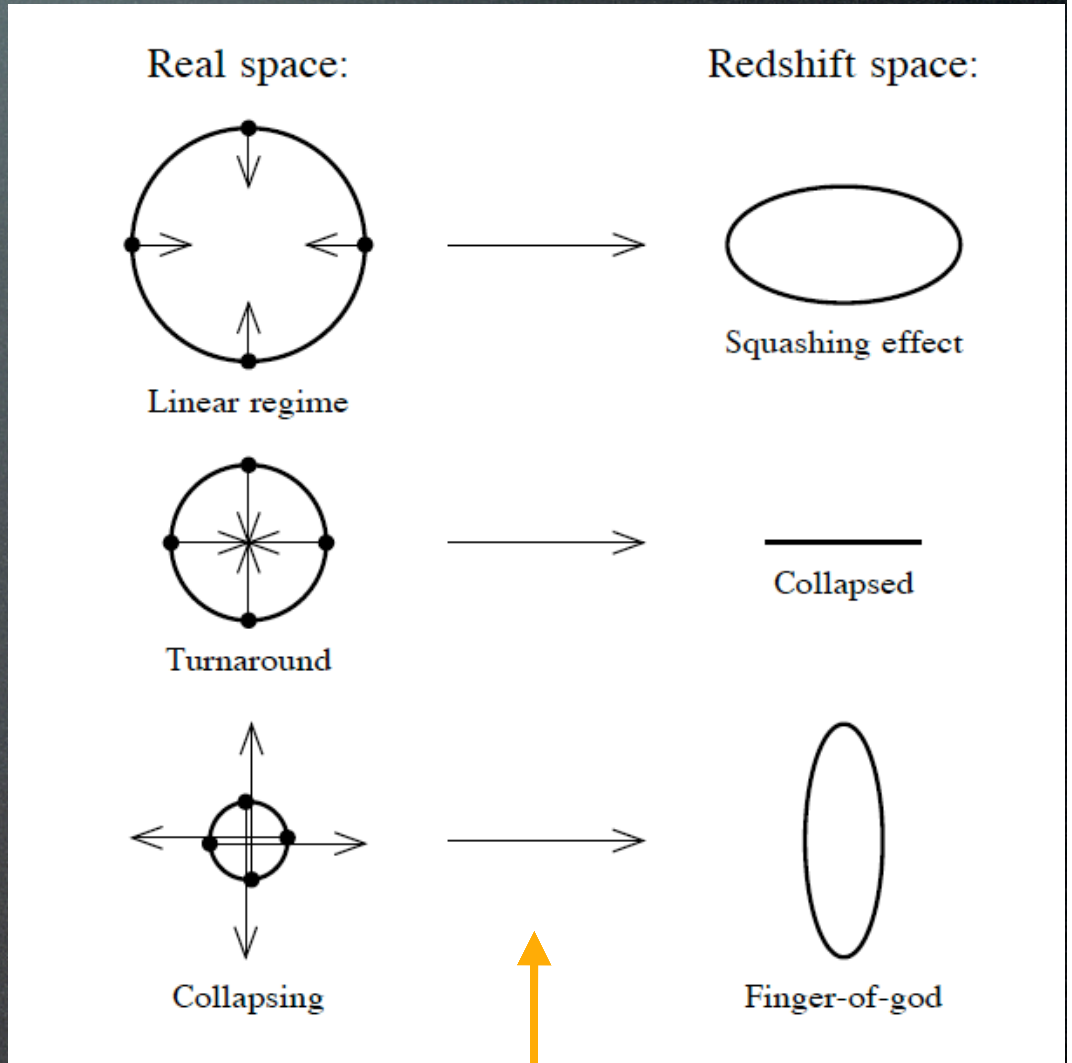
- $\Lambda$CDM supported by many observations
- what is $\Lambda$ ?
  - dark energy?
    - cosmological constant, or unknown form of energy density
  - modified gravity on cosmological scales?
- Tests of gravity theory on cosmological scales are important!
  - RSD found in galaxy redshift surveys provides one of such tests

# Redshift Space Distortion (RSD)

- observed P(k) or $\xi$(r) is distorted by line-of-sight peculiar velocity of galaxies

Hamilton '98




observer

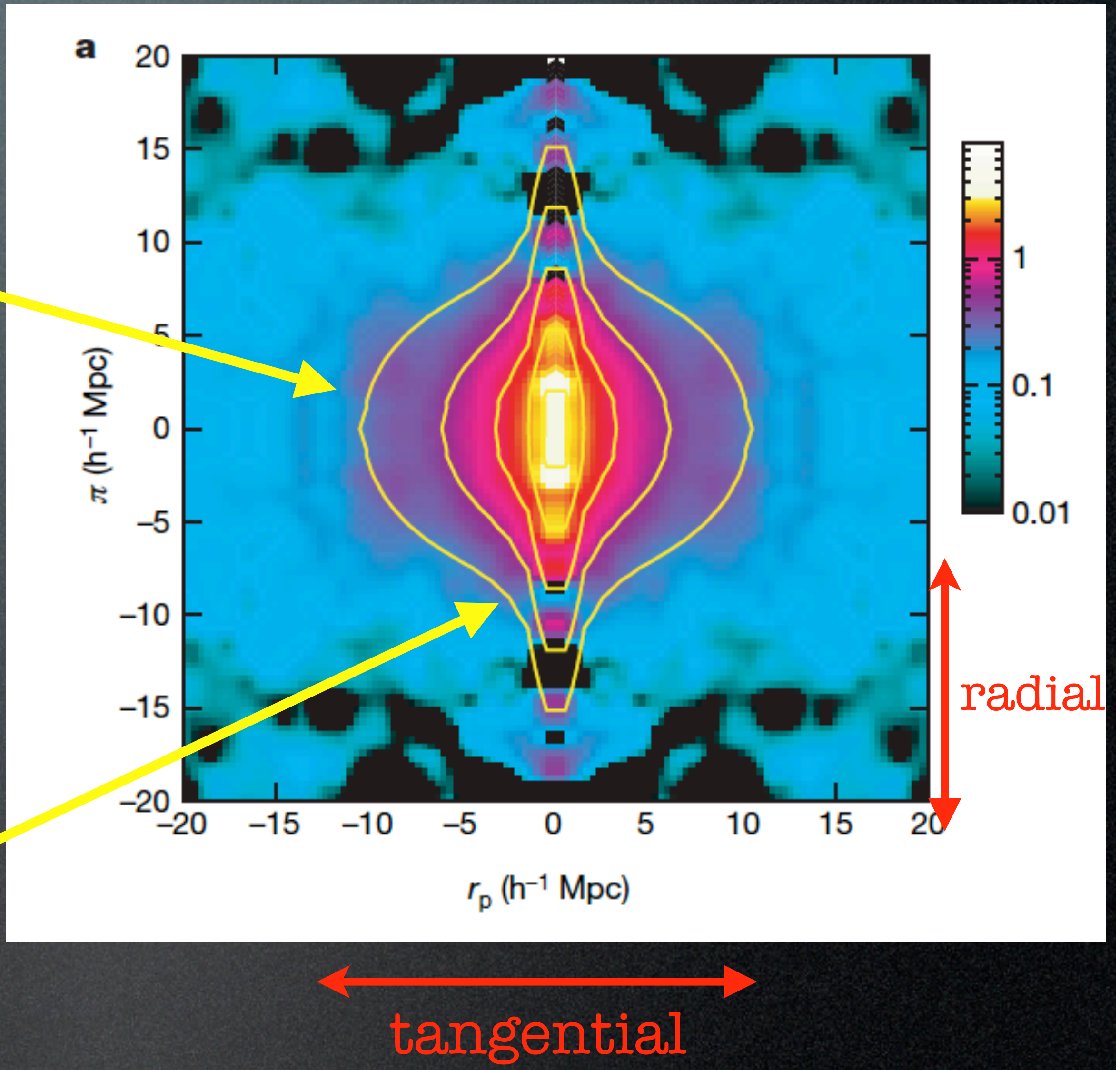
# RSD in P(k) or ξ(x)

- In the linear regime:
  - the Kaiser effect

$$P^s(\boldsymbol{k}) = (1 + \beta\mu_{\boldsymbol{k}}^2)^2 P(k)$$

  - $\beta$: the anisotropy parameter
  - $\mu$=cos$\theta$ （$\theta$: angle to line-of-sight）
  - scale independent
- In the non-linear regime:
  - Fingers of God

2D contour of ξ(r)




Guzzo+'08

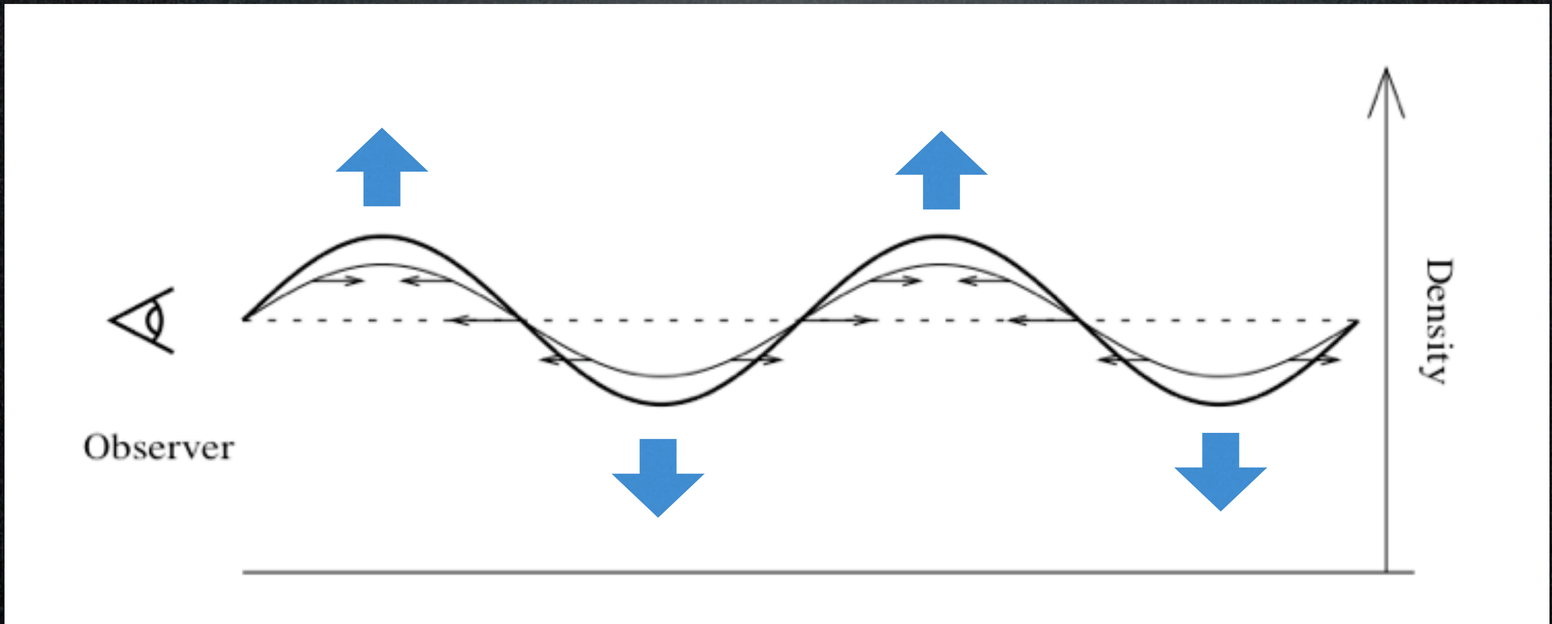
# RSD gives a measure of structure growth rate

- anisotropy parameter $\beta$ = infall velocity of large scale structure
- related to the speed of density fluctuation growth
  - simply by mass conservation, independent of gravity theory

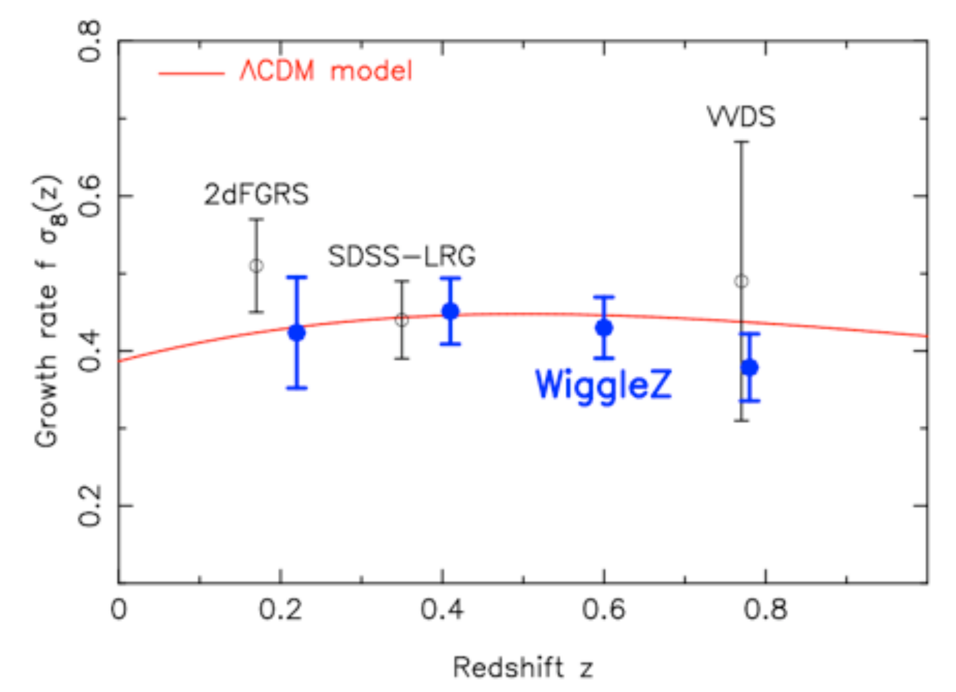
$$f \equiv \frac{H_0 a_0}{H a} \frac{d \ln D}{d\tau} = \frac{d \ln D}{d \ln a} \,.$$

structure growth rate,
$D(t) \propto \delta(t)$

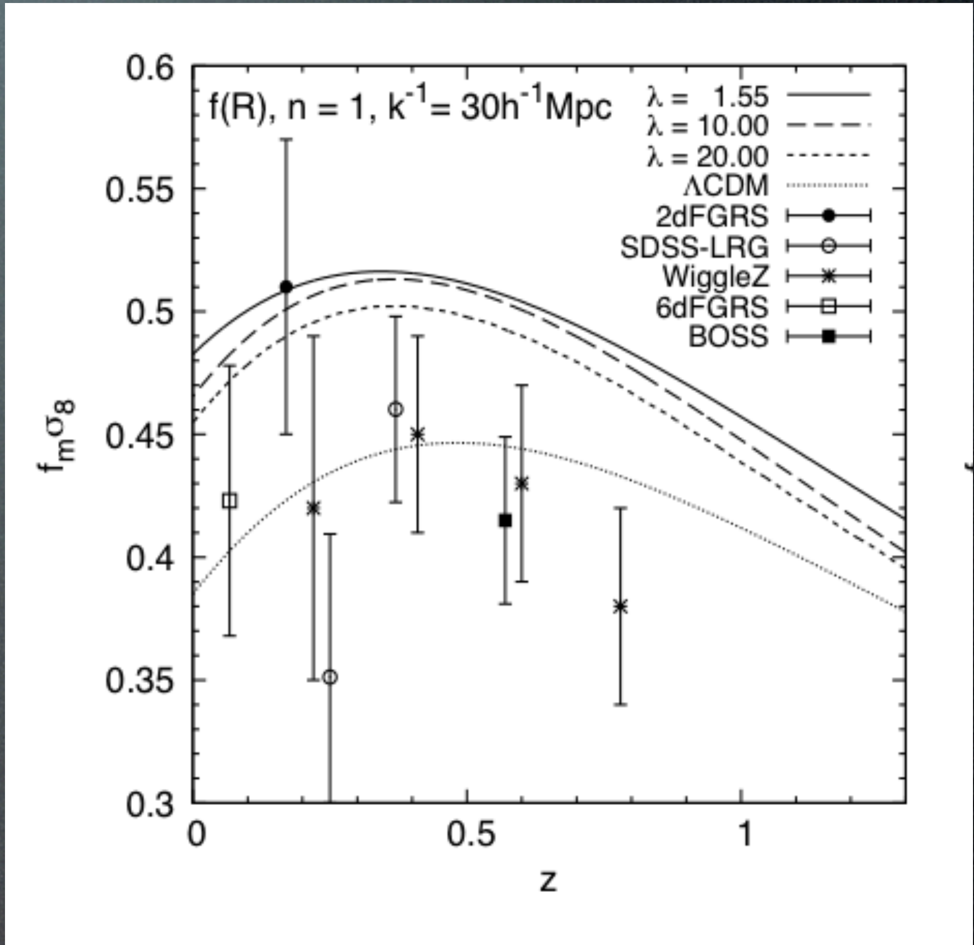
- $\beta \rightarrow f/b$ or $f\sigma_8 \rightarrow$ test of gravity on cosmological scale!



# RSD testing Gravity Theory

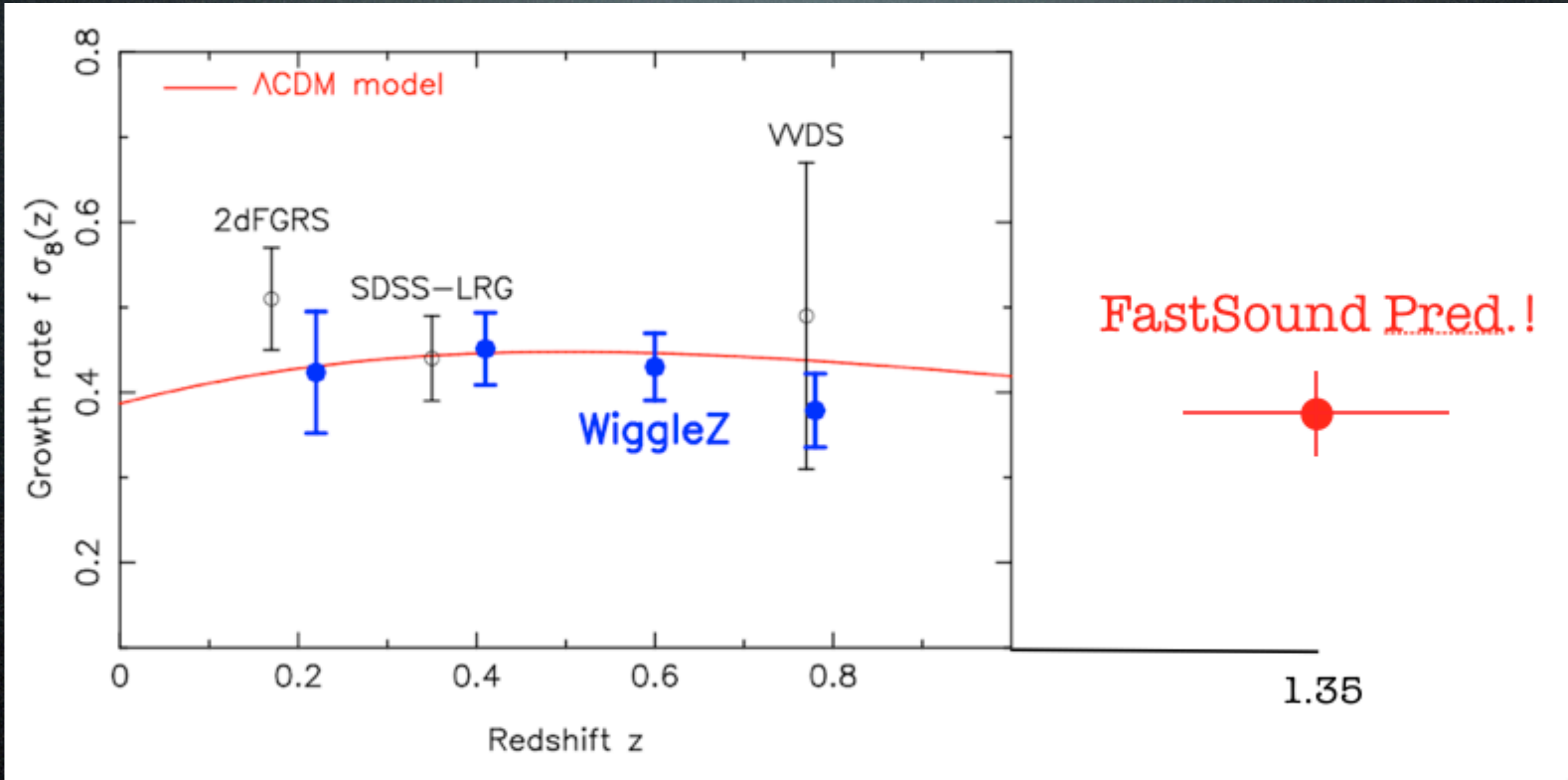



Blake+'11




Okada+'13

# $f\sigma_8$ from RSD: Expected Impact




- our goal: the first RSD and $f\sigma_8$ measurement at $z > 1$
- stronger constraint on gravity theory by a wide z range, combined with lower-z data

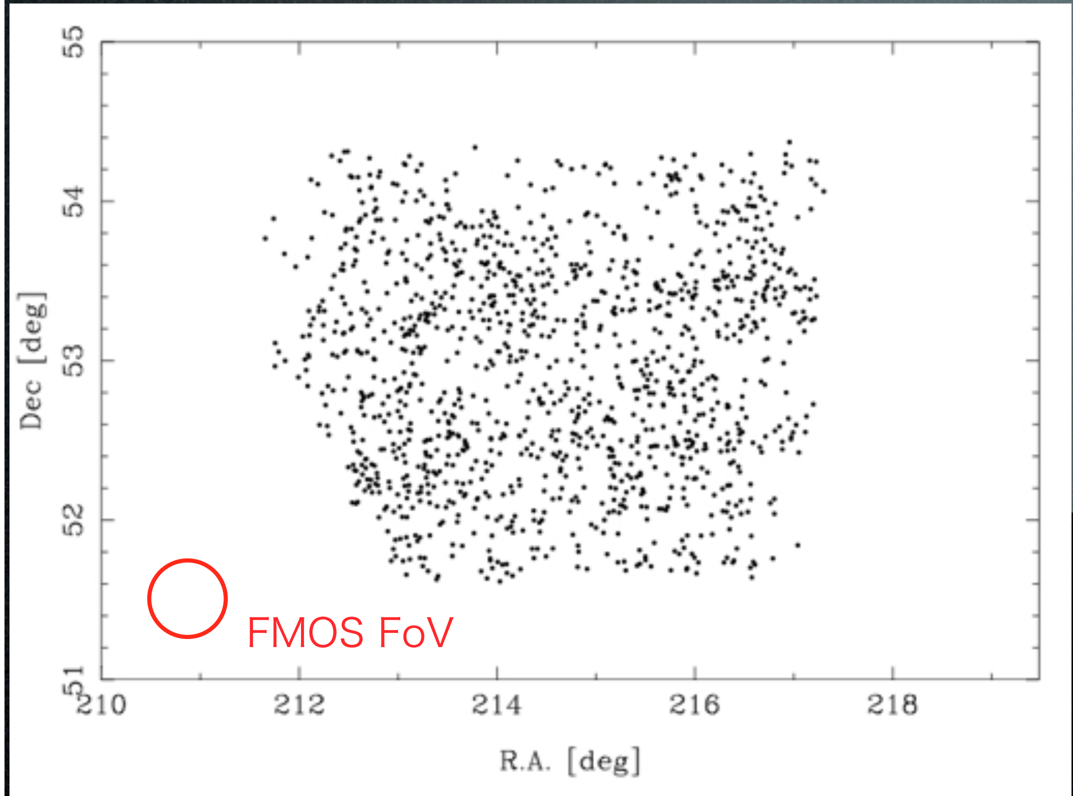
# Other Science Cases

- Cosmology:
  - combination of RSD and other observations (e.g., lensing) would give stronger constraints
- Galaxy Science
  - cosmic star formation history using H$\alpha$ at z ~ 1.35
  - bias and clustering of star forming galaxies in large volumes
  - star formation of galaxies in different environments
  - metallicity study for bright line emitters

# Survey Status

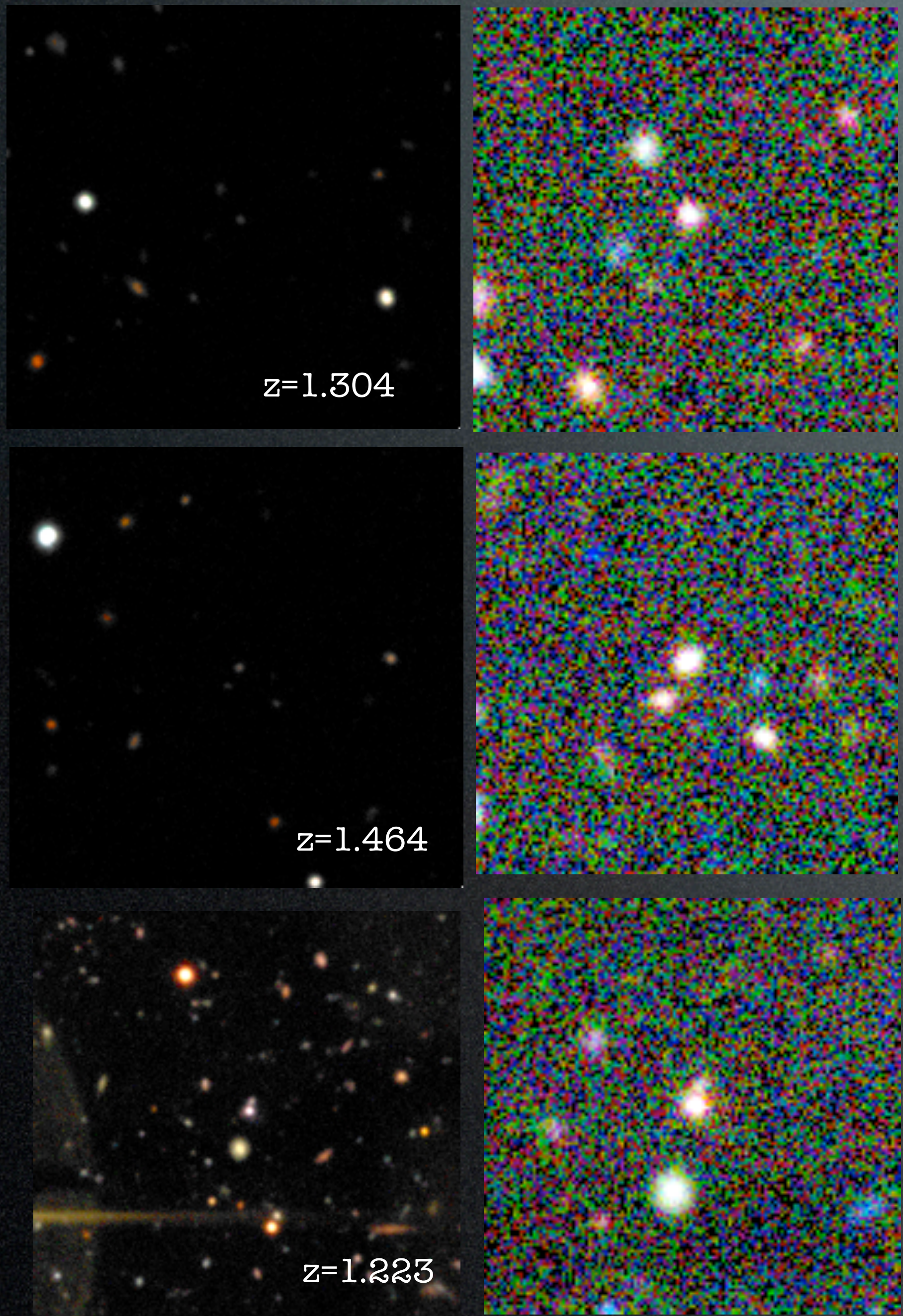
- about 3/4 of the survey finished
- the W3 field is already surveyed up to the planned surface area
  - > 1100 galaxies detected by a preliminary analysis

# FastSound Galaxies in CFHTLS W3




# Example Images of FastSound Galaxies

1 arcmin 24 arcsec



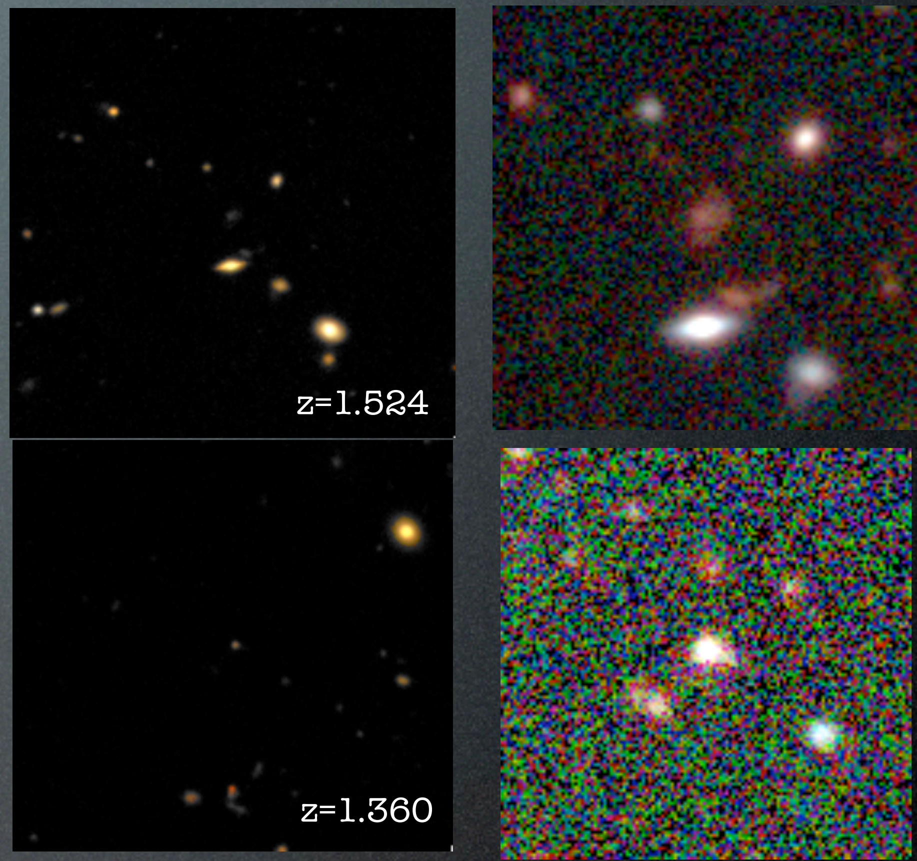
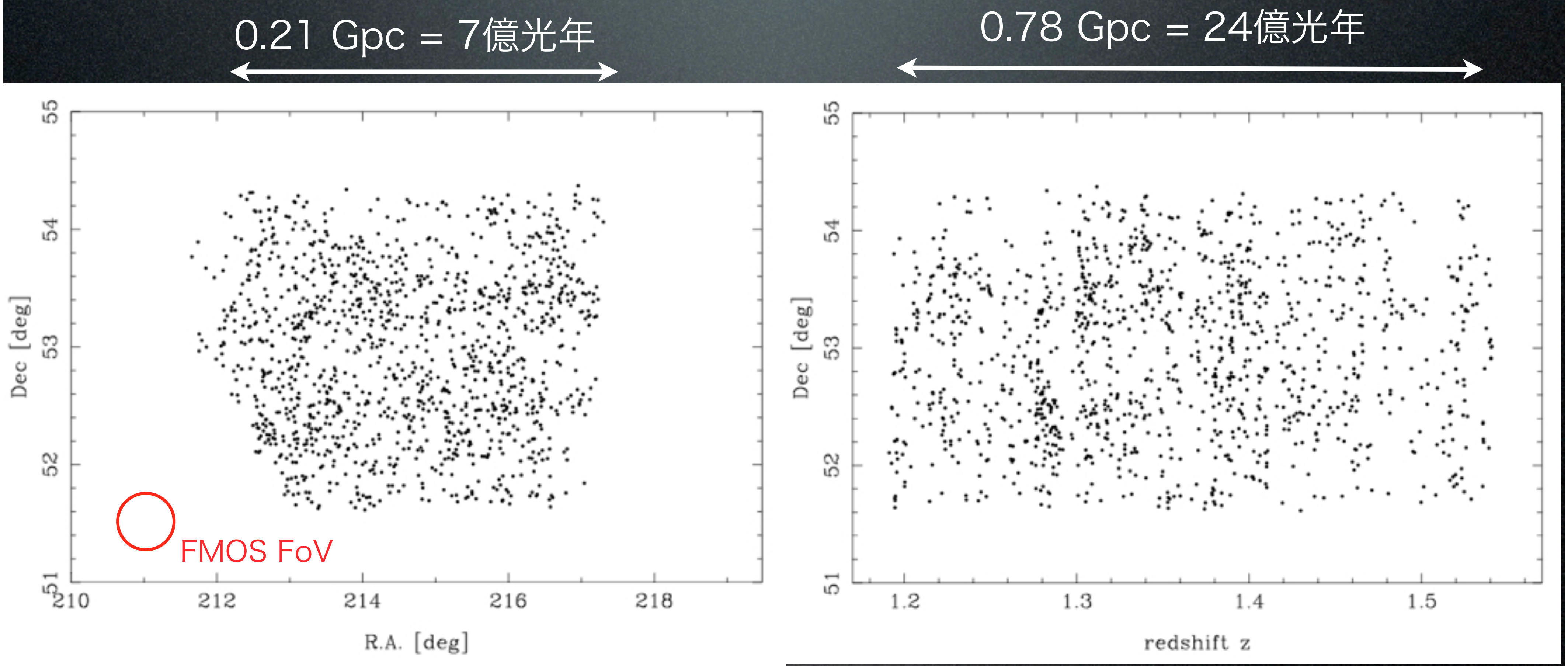




Image credit: CFHTLS, CFHTLenS, CDAC

# The FastSound Real Galaxy 3D Map!

- >1100 galaxies in 7 $deg^2$, z ~ 1.2-1.5
  - comoving distance = 4.0 Gpc = 120億光年
  - age at this redshift = 4.7 Gyr (c.f. 13.7 Gyr now)
  - comoving volume = 0.04 $Gpc^3$



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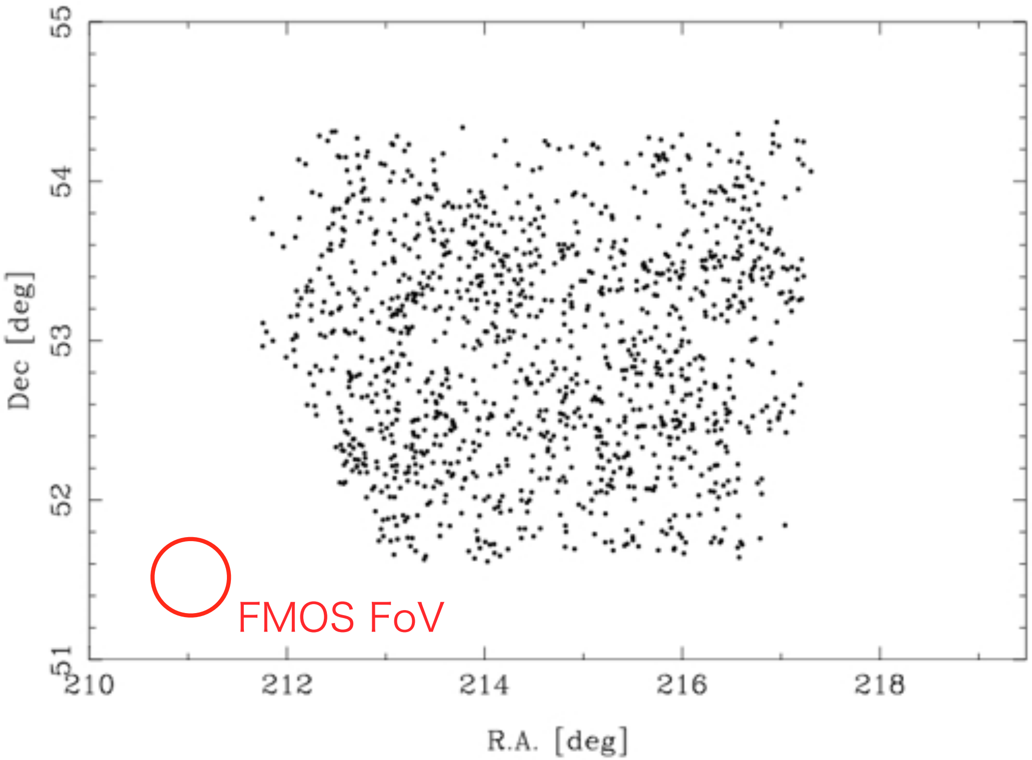
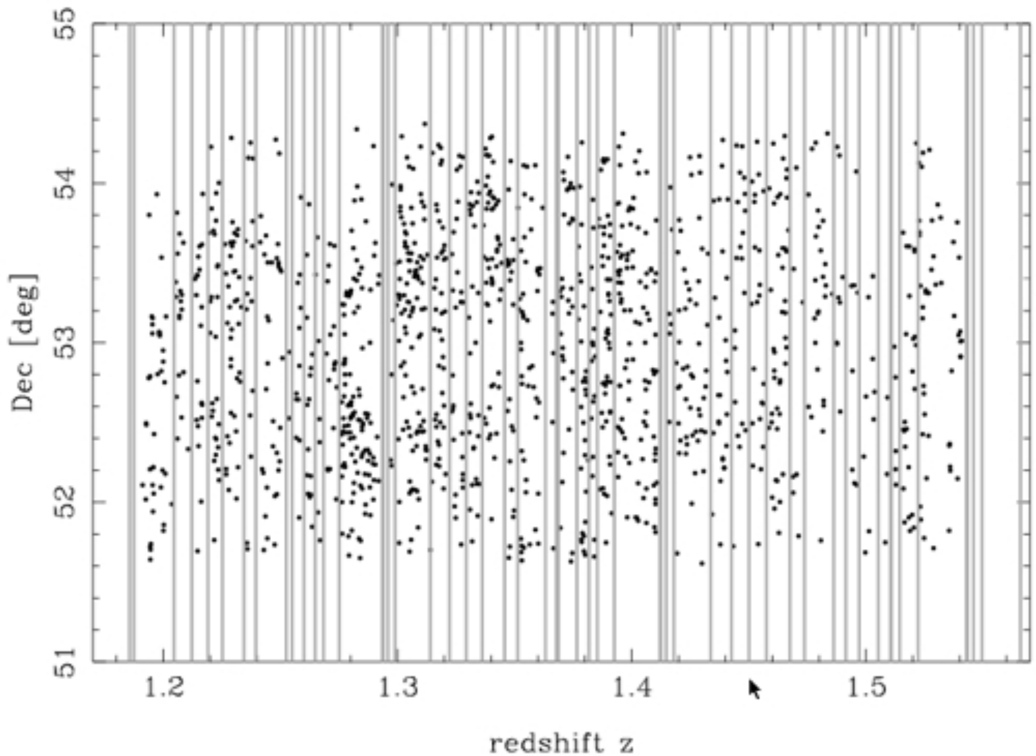
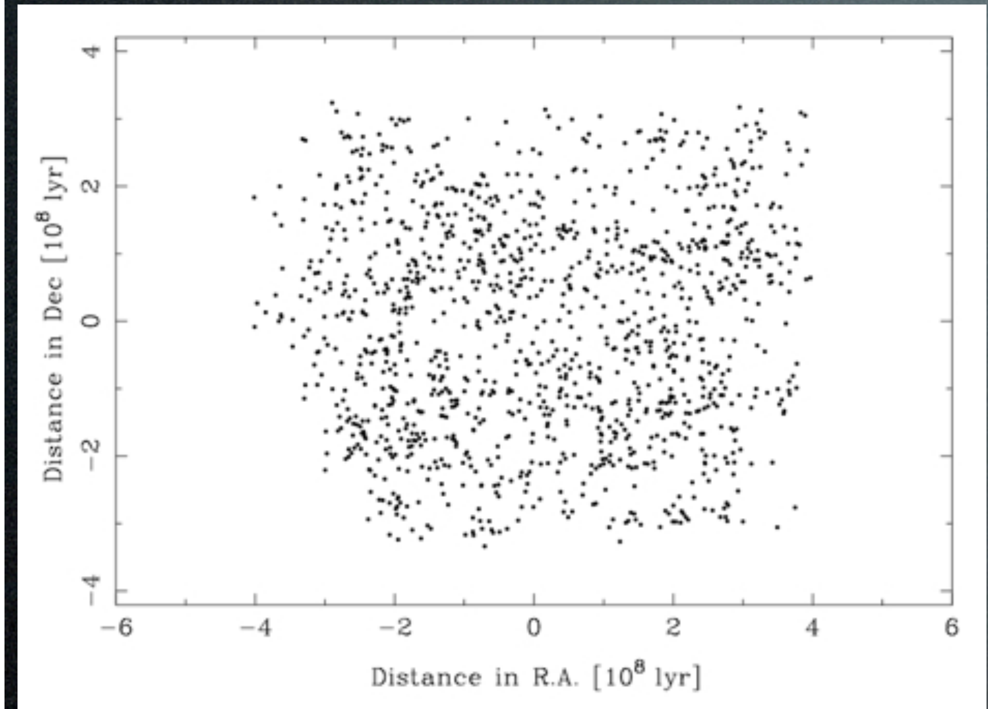
0.21 Gpc = 7億光年

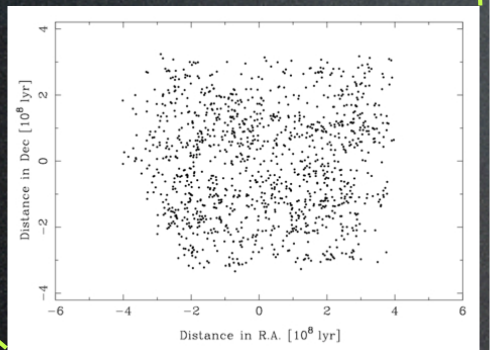


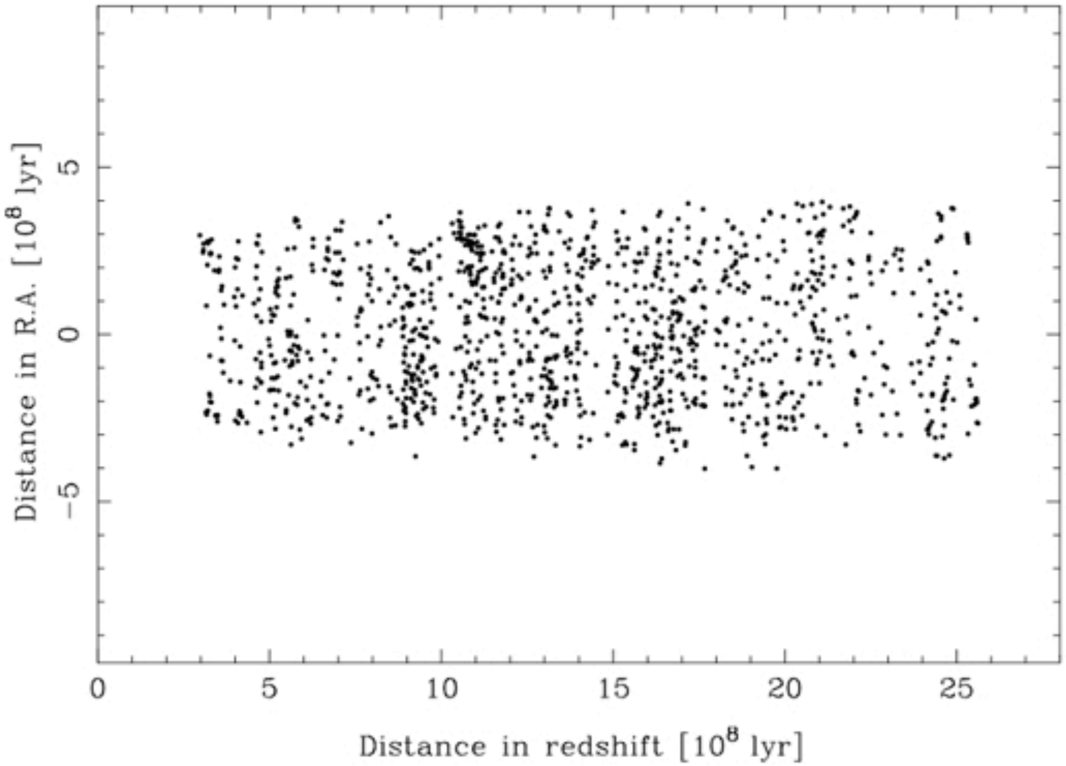

0.78 Gpc = 24億光年

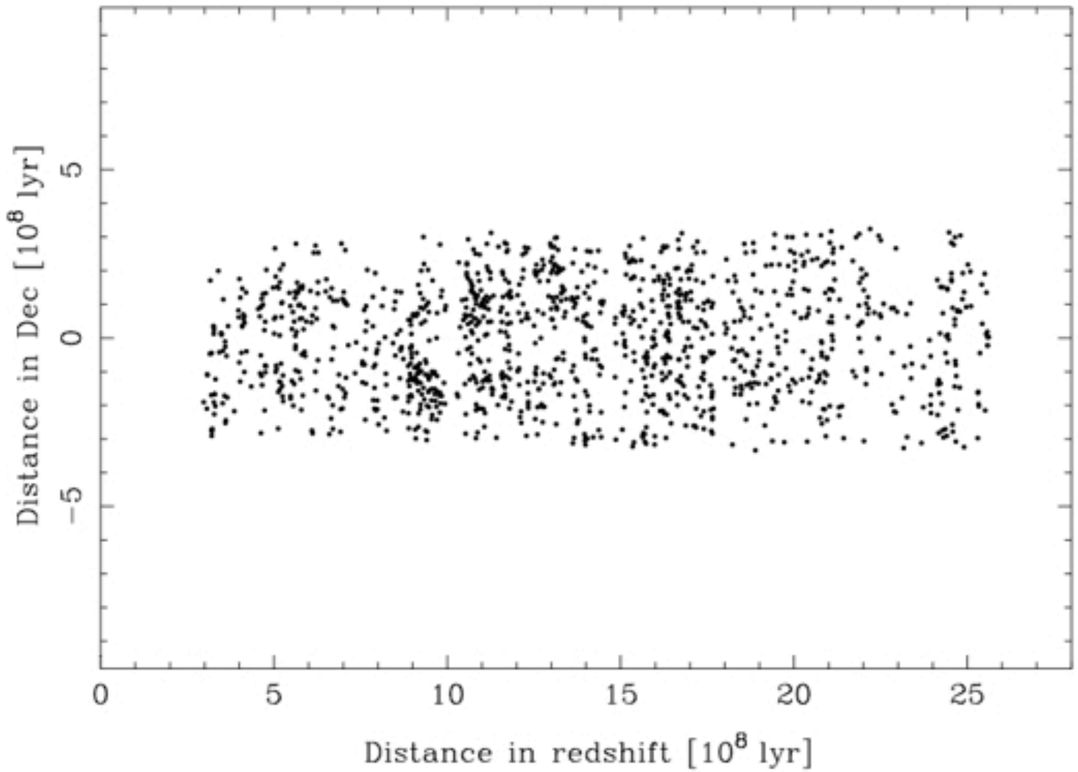


# 3D map in comoving coordinate

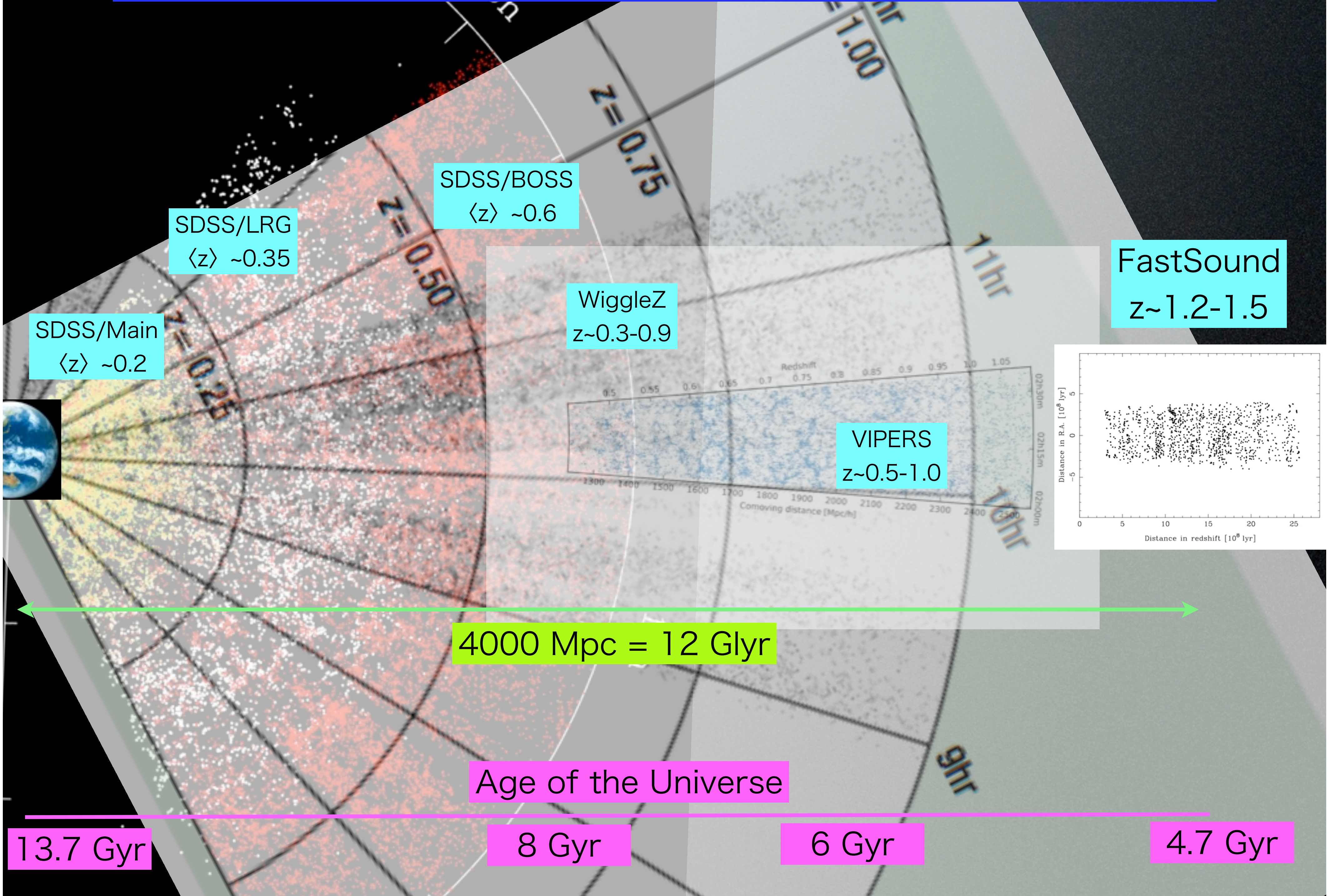


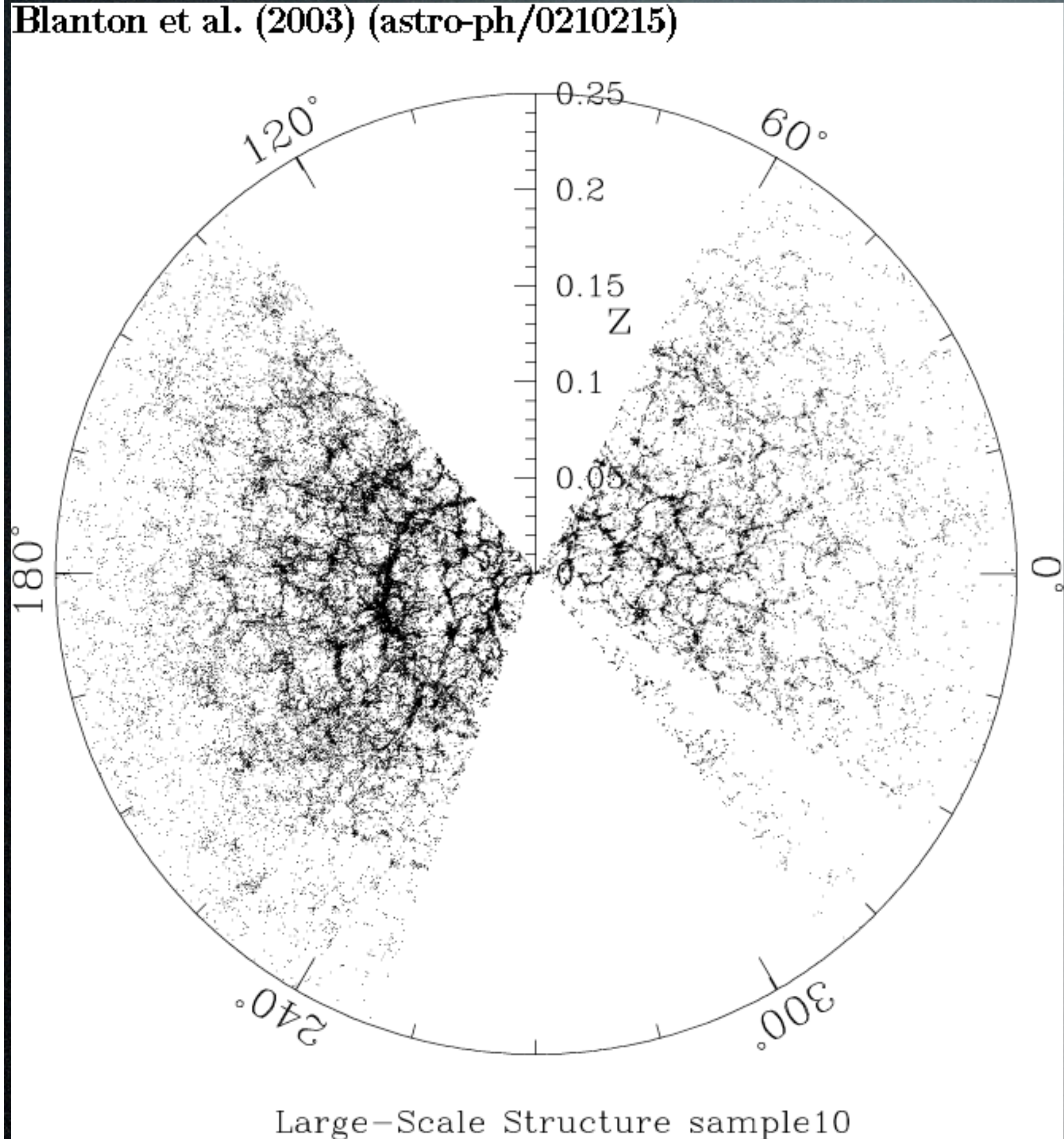



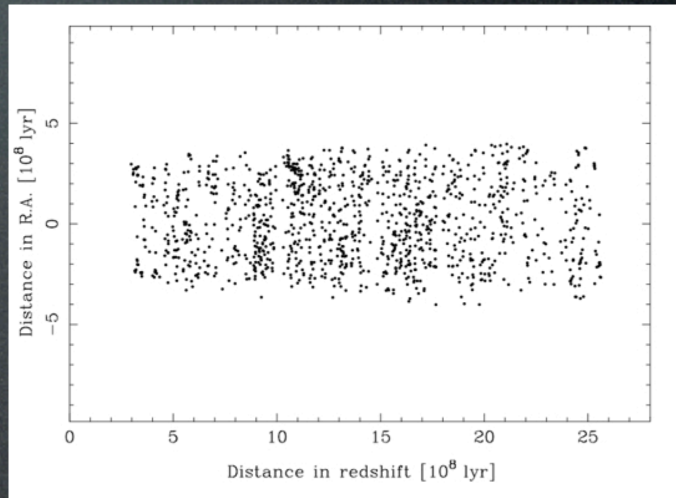



# 3D galaxy maps by various surveys



# Large Scale Structure: Past vs. Present



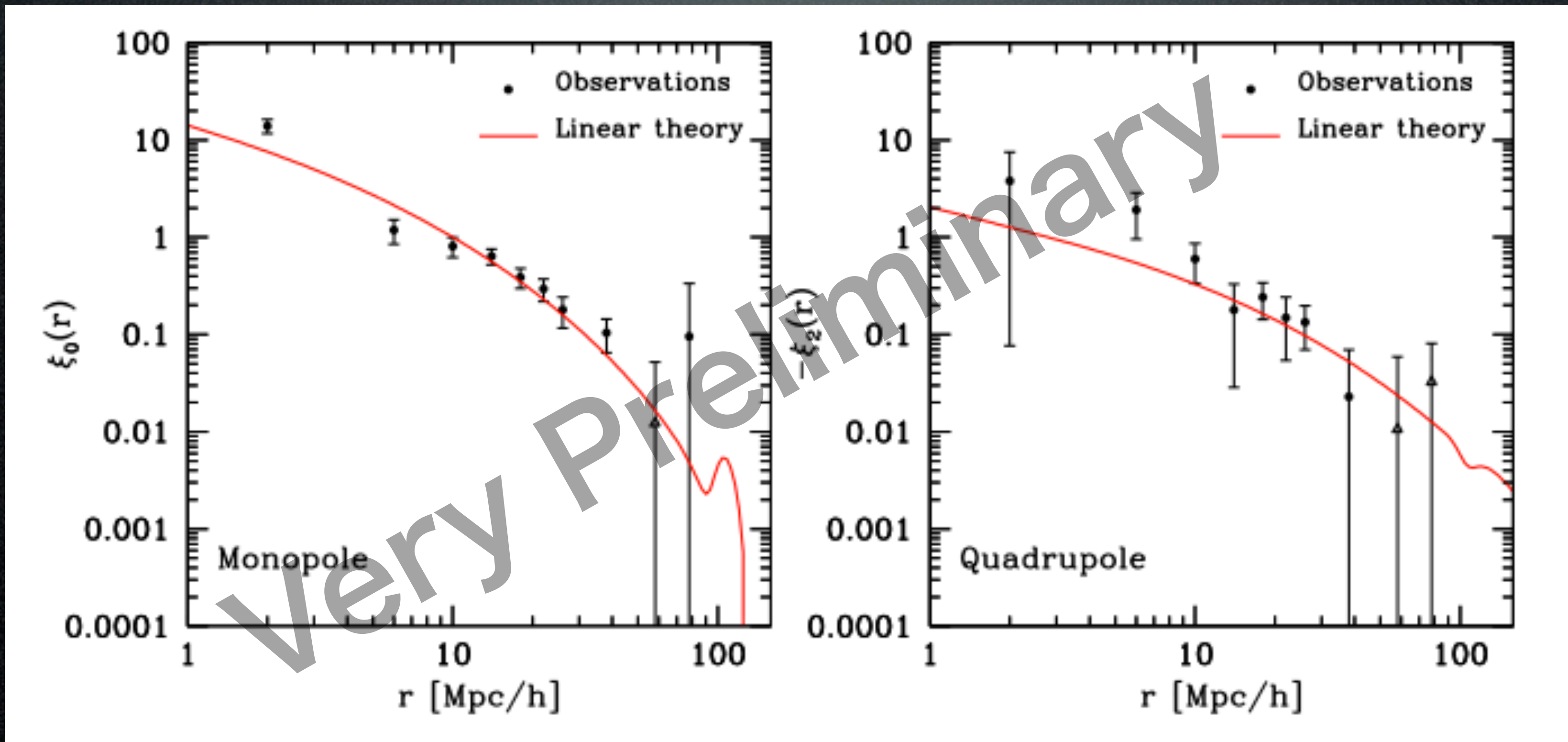




4.7 Gyr old

13.7 Gyr old

# Test Calculation of correlation function $\xi(r)$

- monopole & quadrupole component of $\xi(r)$ clearly detected
- roughly consistent with linear theory + b~3
- anisotropy is mainly by RSD rather than the Alcock-Paczynski effect
- fractional error of $f\sigma_8$ = 44%
    - → ~5$\sigma$ detection expected by the final catalog (x4 than now)




Calculations done by C. Hikage, also by T. Okumura

# FastSound から SWIMS へ？(1)

- FMOS  on Subaru
  - 0.9-1.8 um (FastSound は HR mode で 1.44-1.65 um)
  - FoV 30’ $\phi$
  - 400 fibers
  - telescope 8.2m

- SWIMS on TAO
  - 0.9-2.4 um
  - FoV 9.6’ $\phi$
  - MOS for ~40 objects
  - telescope 6.5m

# FastSound から SWIMS へ？(2)

- negative:
  - 視野は 1/10 (ただし天体数の面密度は同じ）
  - 6.5m rather than 8.2m telescope
- positive:
  - 広い波長域 0.9-2.4 um
    - beyond z = 1.5 up to z = 2.6 for H$\alpha$
    - 複数ライン検出で同定がより確実
  - throughput better than FMOS(?)
  - TAO の豊富な観測時間
  - HSC など、最新の撮像カタログによる、より high-z, より高い効率でのターゲット選択
- TAO/SWIMS 完成時の情勢によるが、cosmology by RSD と H$\alpha$による銀河進化サイエンスで、大規模な z = 0.7 - 2.6 での系統的H$\alpha$サーベイ？

# back up slides

# 様々な銀河分光サーベイによる立体地図