HI FOR FAST: FROM GALAXIES SURVEY TO INTENSITY MAPPING

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INTRODUCTION

The neutral hydrogen is an excellent tracer of the total mass distribution

Baryon Acoustic Oscillations (BAO) , Dark Energy

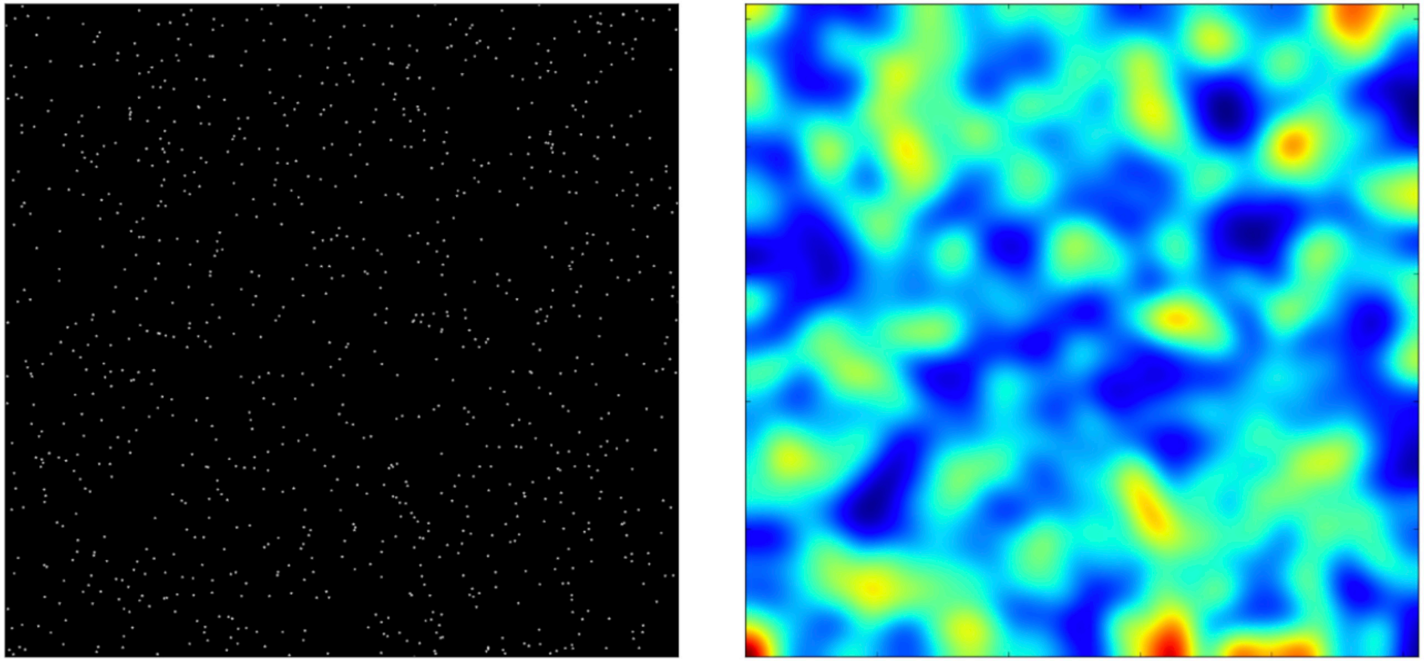
Detections:

Galaxy Redshift Surveys (HIPASS, ALFALFA): resolve individual galaxies,

Intensity Mapping: map the unresolved emission of all HI at each frequency (Chang et al. 2008)

INTRODUCTION

(UWC Astrophysics)



Left: galaxies. Right: HI intensity map of the same region.

IM experiments are confusion limited, but they do not need to resolve individual galaxies, they can more easily push to high redshifts

Rather than a telescope with very high resolution and sensitivity, and fast survey speed, with IM we only need to design for fast survey speed

EXPERIMENTS

- The following telescopes have either hosted intensity mapping surveys, or plan to carry them out in future.

- CHIME(Canada)
- TIANLAI (China)

- BINGO (Brazil/Uruguay/UK)

- FAST (China)
- Parkes(Australia)
- GREEN BANK TELESCOPE (USA)

- HIRAX (South Africa)
- MeerKAT (South Africa)
- PAPER (USA/South Africa/Australia)
- SKA (South Africa/Australia)

FAST： THE FIVE-HUNDRED-METER APERTURE SPHERICAL RADIO TELESCOPE

Spherical reflector: Aperture=500m

Illuminated aperture： 300m

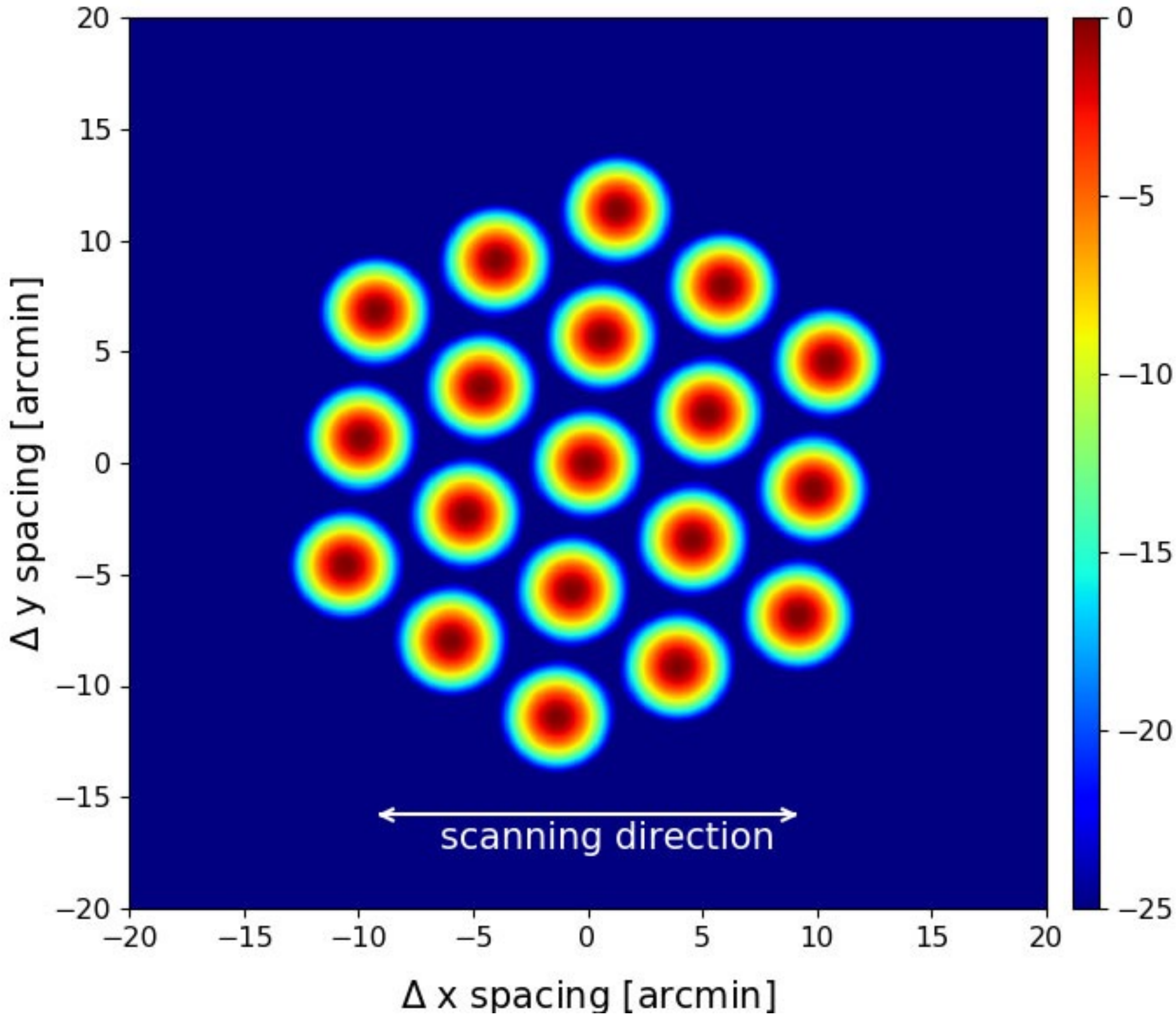
Focal ratio： f/D=0.4665

Sky coverage： zenith angle +-40 deg
(20,000 deg^2)

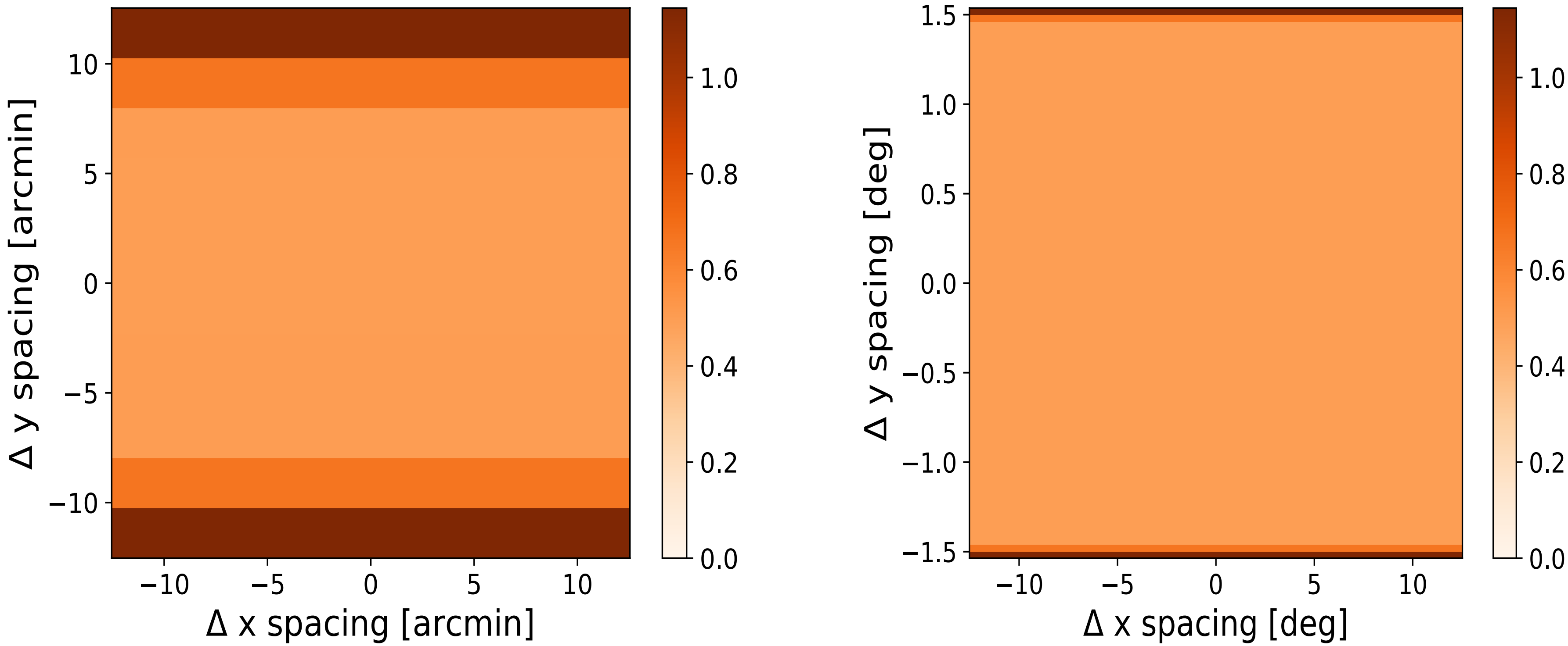
Sensitivity(L-Band): system temperature :20k

Multi-beam(L-Band): beam number = 19, beam size： 2.94(1+z) arcmins

Tilted an angle of 23.4 deg



The sky is covered by shifting the whole array in declination by 21.9 arcmin for the next scan.



Receiver	Band (GHz)	Beams	T_{rec} (K)	t_{sur} (days)
L-band	1.05–1.45	19	20	220
Wide-band	0.27–1.62	1	60	1211
UHF PAF (future)	0.5–1.0	81	30	135

For a full drift scan of ±40 deg from the centre declination of FAST

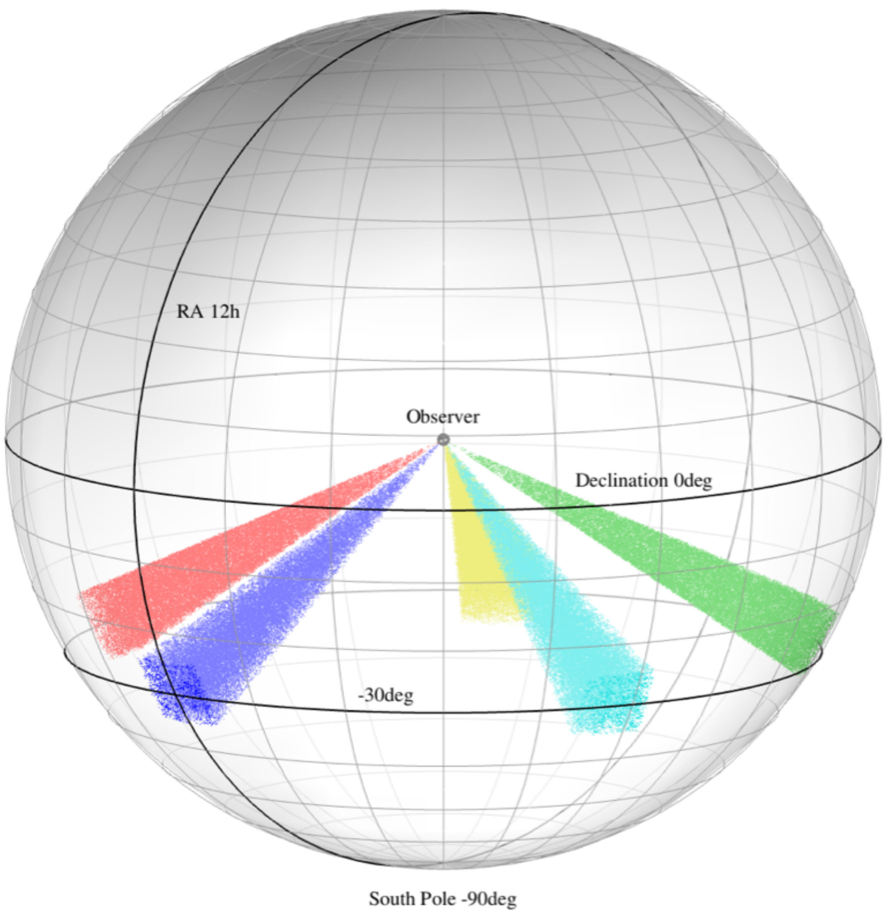
SIMULATED SKY

Semi-Analytic Suite of the SKA Simulated Skies, *S*3-SAX

Semi-analytic models (De Lucia & Blaizot 2007) based on the millennium *N*-body simulation

HI , H_2 : Obreschkow et al, 2009a,b,c

100 deg^2 Mock Galaxy Cone for HI Surveys



Col	Symbol	Unit	Description
1	ID	–	Unique galaxy identifier in the Munich Semi-Analytic Model "DeLucia2006a"
2	RA	deg	Right ascension of galaxy centre
3	Dec	deg	Declination of galaxy centre
4	z	–	Apparent redshift of galaxy centre, including the Doppler component due to peculiar motion relative to the Hubble expansion
5	i	deg	Galaxy inclination defined as the smaller angle ($0° - 90°$) between the line-of-sight and the rotational axis of the galaxy
6	T	–	Numerical Hubble type (−6...0 for ellipticals, 0...10 for spirals, 99 for morphologically unresolved objects, mostly dwarfs)
7	M_*	$M_\odot$	Stellar mass
8	$M_{\rm H\,I}$	$M_\odot$	Mass of neutral atomic hydrogen H I, without helium
9	$M_{\rm H_2}$	$M_\odot$	Mass of molecular hydrogen H_2, without helium
10	$S^{\rm int}_{\rm H\,I}$	$\rm Jy\,km\,s^{-1}$	Velocity-integrated flux of the redshifted 21 cm H I emission line, with velocity units defined in the galaxy rest-frame
11	$S^{\rm peak}_{\rm H\,I}$	Jy	Peak flux density of the H I emission line; typically the flux density of the 'horns'
12	$S^{\rm int}_{\rm CO}$	$\rm Jy\,km\,s^{-1}$	Velocity-integrated flux of the redshifted 115.27 GHz ^{12}CO(1–0) emission line, with velocity units defined in the galaxy rest-frame
13	$S^{\rm peak}_{\rm CO}$	Jy	Peak flux density of the ^{12}CO(1–0) emission line; typically the flux density of the 'horns'
14	$W^{50}_{\rm H\,I}$	$\rm km\,s^{-1}$	Width of the H I emission line, in galaxy rest-frame velocity units, measured at 50% of the peak flux density
15	$W^{20}_{\rm H\,I}$	$\rm km\,s^{-1}$	Width of the H I emission line, in galaxy rest-frame velocity units, measured at 20% of the peak flux density
16	$r^{\rm edge}_{\rm H\,I}$	arcsec	Apparent H I radius along the major axis out to a H I disk surface density of $1\,M_\odot pc^{-2}$, corresponding to a face-on column density of $1.25 \cdot 10^{20} cm^{-2}$
17	$r^{\rm half}_{\rm H\,I}$	arcsec	Apparent H I half-mass radius along the major axis
18	$M_{\rm R}$	mag	Absolute Vega *R*-band magnitude, corrected for intrinsic dust extinction; 99 if stellar mass and star formation history are insufficiently resolved to compute $M_{\rm R}$
19	$m_{\rm R}$	mag	Apparent Vega *R*-band magnitude; value 99 if no absolute magnitudes available
20	$r_{\rm e}$	arcsec	Effective radius, here approximated as the radius containing half the stellar mass if the galaxy were viewed face-on

a. HI mass profiles:

$$\Sigma_{\rm H\,I}(r) = \frac{\tilde{\Sigma}_{\rm H} e^{-r/r_{\rm disk}}}{1 + R^{c}_{\rm mol} e^{-1.6r/r_{\rm disk}}}$$

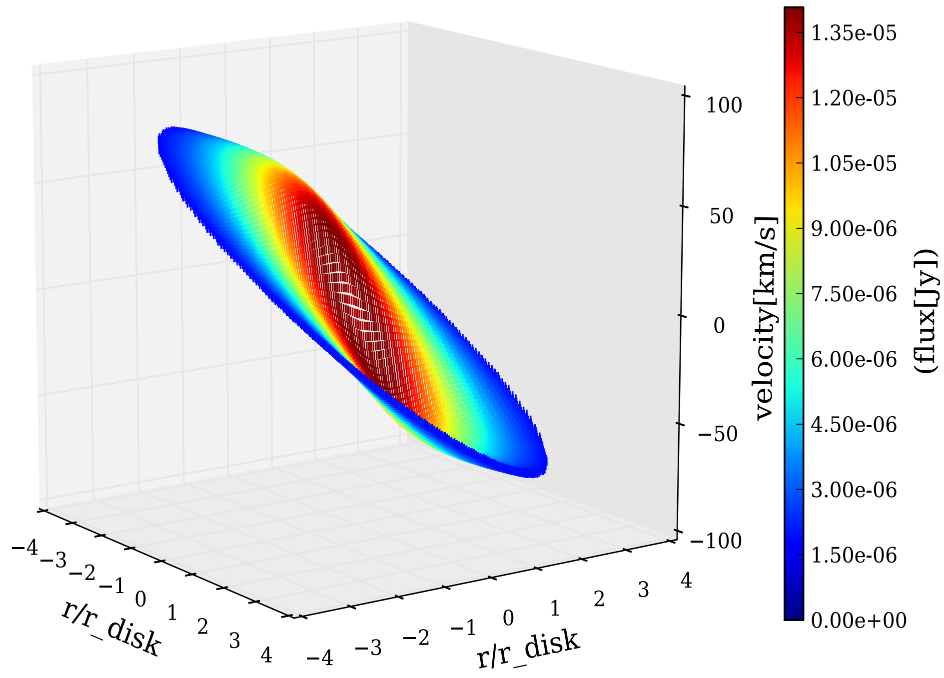
b. Circular velocity profiles:

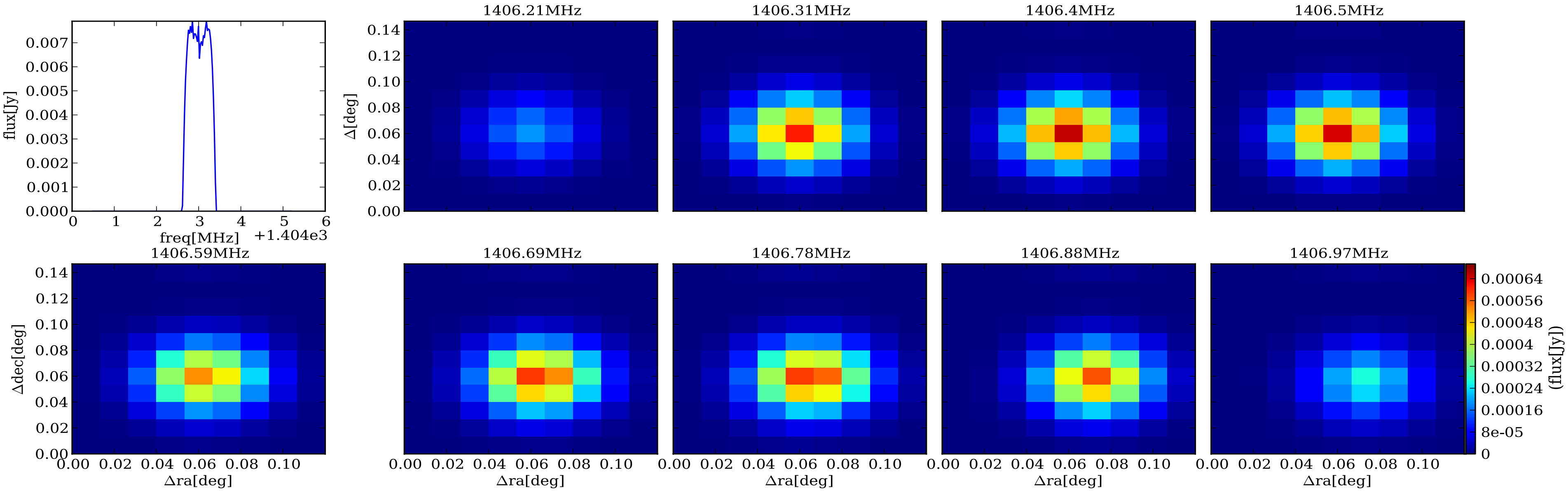
(Polyex model)

$$V_{\rm PE}(r) = V_0 (1 - e^{-r/r_{\rm PE}}) \left(1 + \frac{\alpha r}{r_{\rm PE}}\right)$$

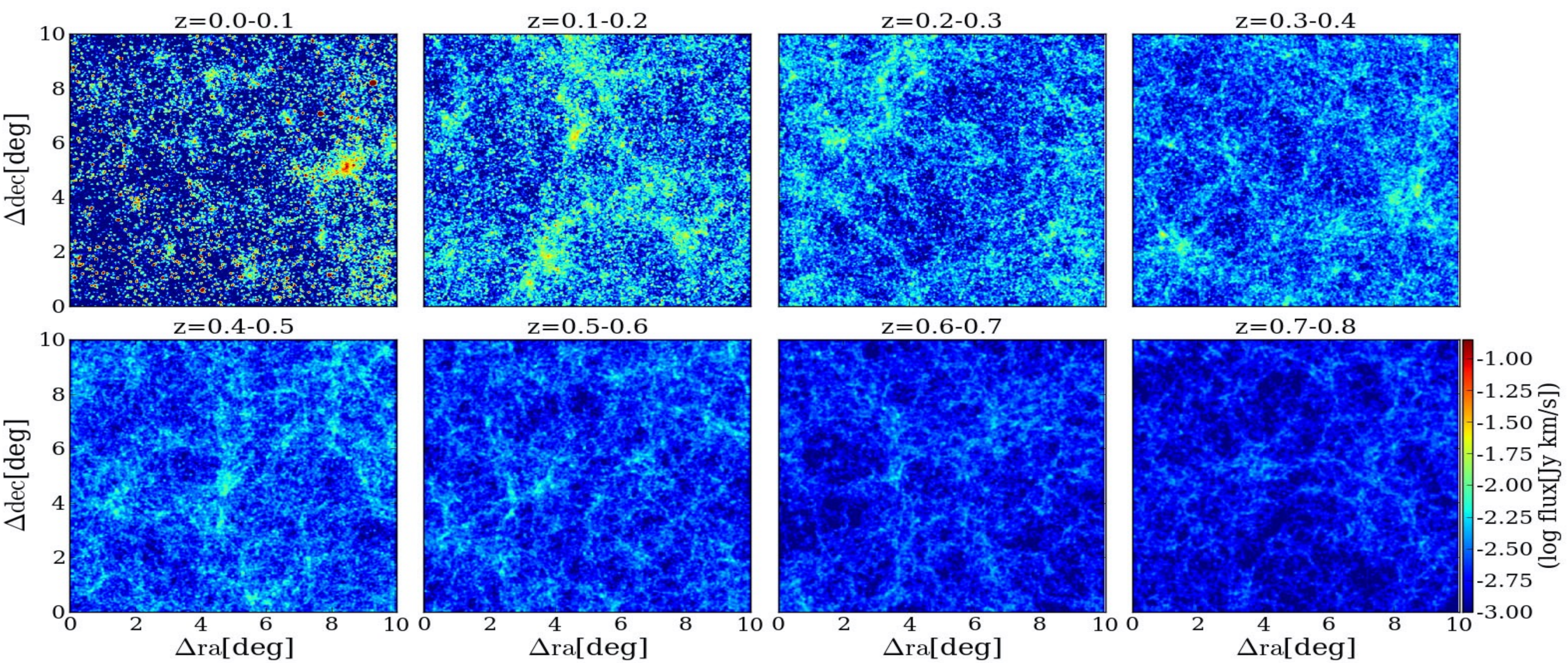
c. HI intensity:

$$\frac{M_{\rm H\,I}}{\rm M_\odot} = 2.36 \times 10^5 \left(\frac{D_{\rm L}}{\rm Mpc}\right)^2 \frac{S_{\rm i}}{\rm Jy} \frac{dv}{\rm km}\, {\rm s}^{-1} (1+z)^{-2}$$





flux[Jy]
freq[MHz]
+1.404e3
1406.21MHz
1406.31MHz
1406.4MHz
1406.5MHz
1406.59MHz
1406.69MHz
1406.78MHz
1406.88MHz
1406.97MHz
Δ[deg]
Δdec[deg]
Δra[deg]
(flux[Jy])



z=0.0-0.1
z=0.1-0.2
z=0.2-0.3
z=0.3-0.4
z=0.4-0.5
z=0.5-0.6
z=0.6-0.7
z=0.7-0.8
Δdec[deg]
Δra[deg]
(log flux[Jy km/s])

NOISE MODEL

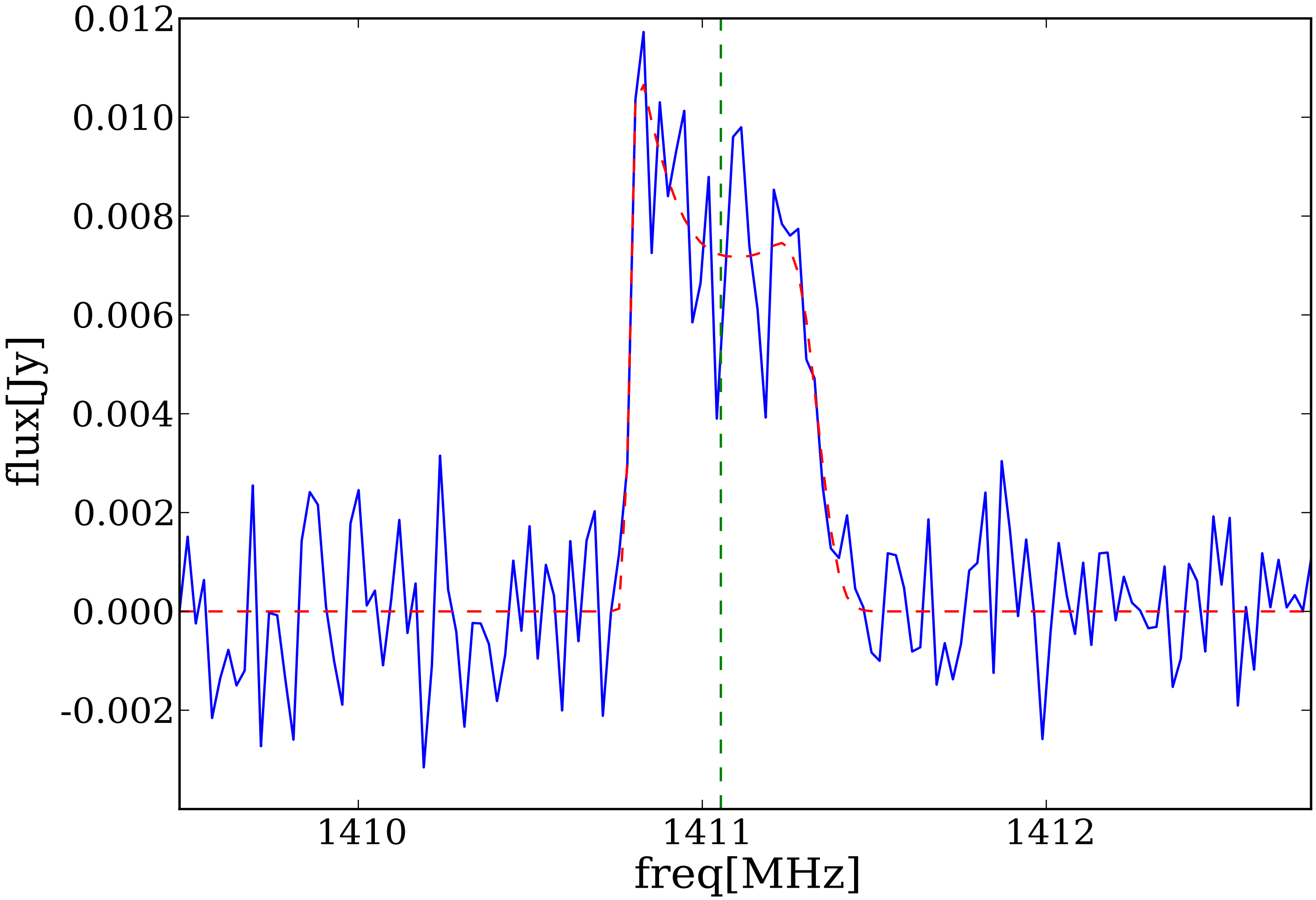
$$\sigma_{\text{noise}} = \sqrt{2}\frac{k_{\text{B}} T_{\text{sys}}}{A_{\text{eff}}} \frac{1}{\sqrt{\Delta \nu t}}$$

$$T_{\text{sys}} = T_{\text{rec}} + T_{\text{sky}}$$

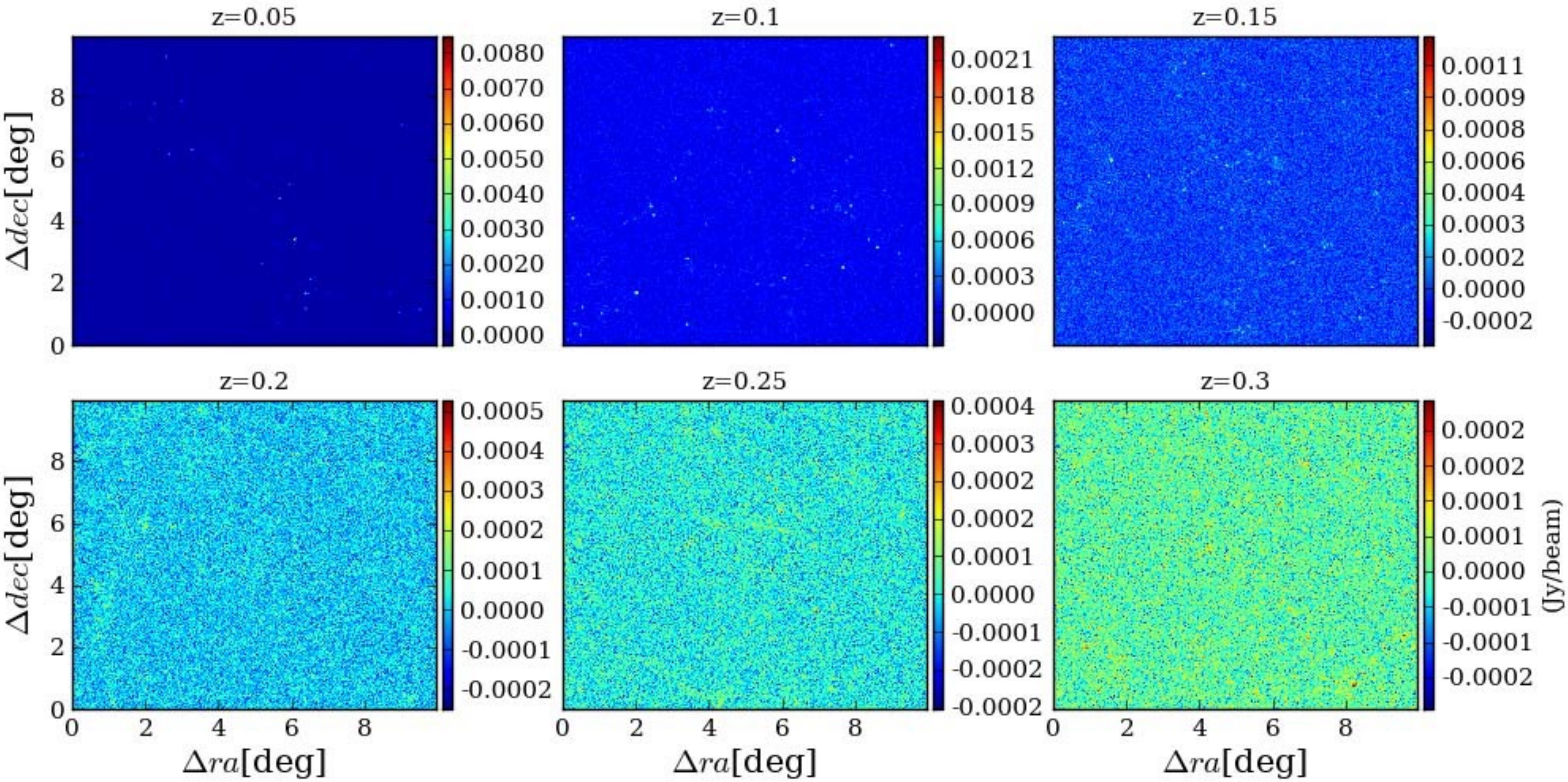
$$T_{\text{sky}} = 2.73 + 25.2 \times (0.408/\nu_{\text{GHz}})^{2.75} K$$

$$t_{\text{pix}} = 2.9(1+z)\,\text{arcmin}/(\omega_{\text{e}} \cos\delta)$$ (48s in a scan)

A velocity line width of 5 km/s and 48s integration time per beam, the sensitivity of FAST will be 0.86 mJy.



0.012
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
flux[Jy]
1410
1411
1412
freq[MHz]



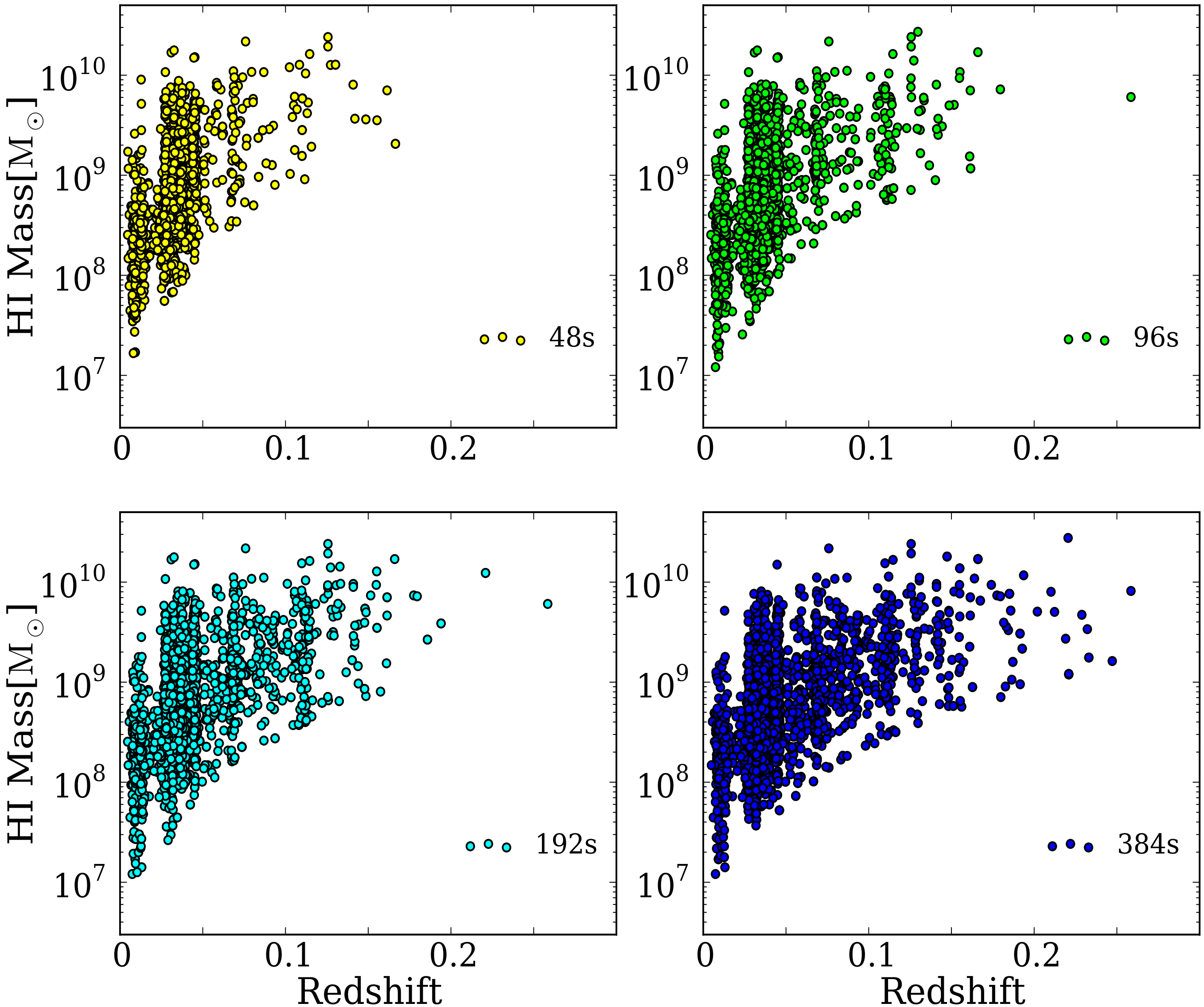
The galaxy flux and noise both are computed with a bandwidth of 1 MHz and a integration time of 192 s per beam

GALAXY SURVEY

(i) Coarse resolution search. Re-bin the noise-filled data to an angular resolution of 0.08 deg and a frequency resolution of 0.473 MHz (corresponding to velocity resolution of 100 km/s at redshift 0), setting a threshold of 3σ , and detect voxels above the threshold.

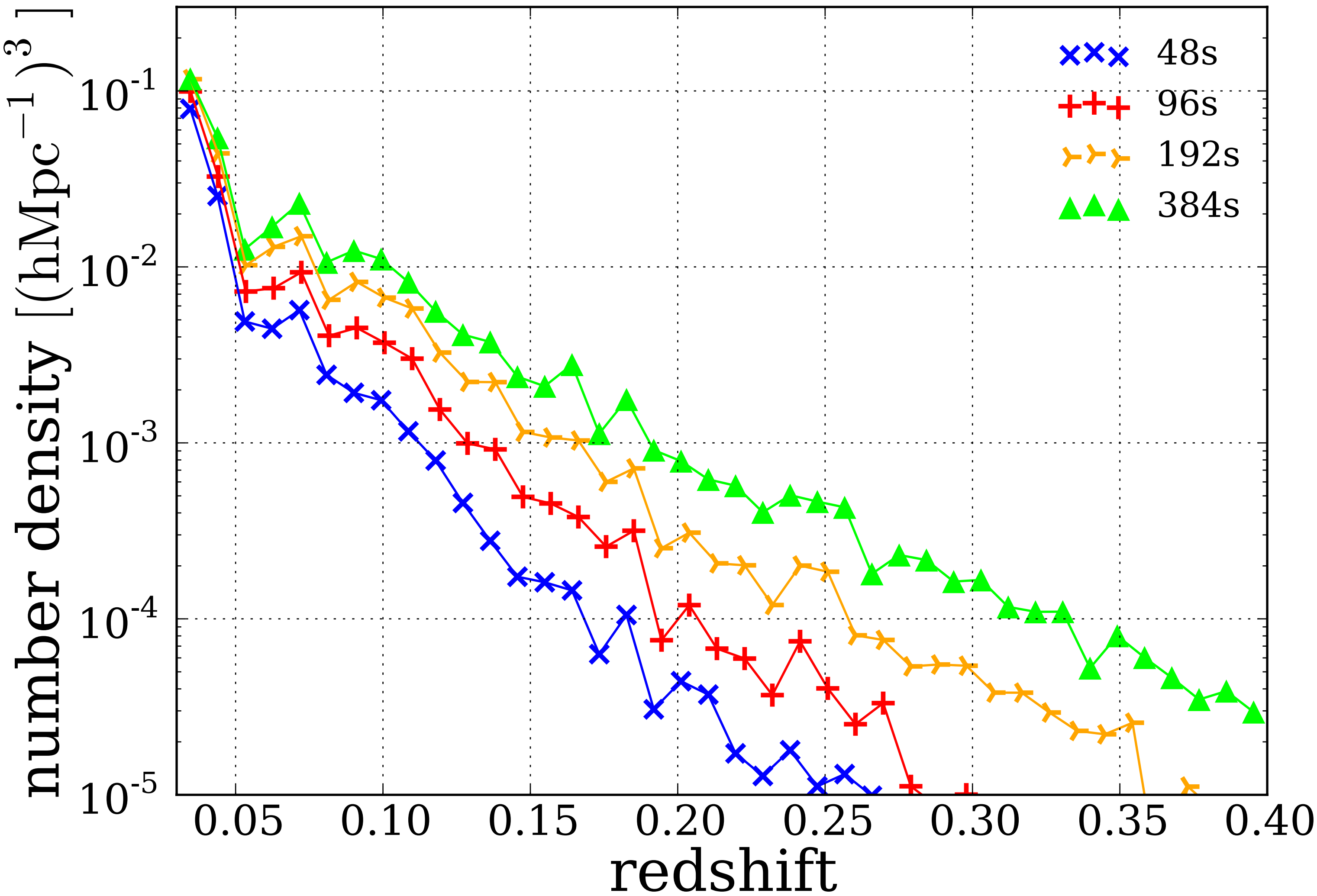
(ii) Fine resolution fit. For galaxies detected in the coarse search, use a finer frequency resolution (0.0236 MHz, corresponding to velocity resolution of 5 km/s at redshift 0) to fit its spectrum in the data cube with a parametrized profile function. If successful, we integrate the HI profile and the candidate is selected as a galaxy if the total flux exceeds 5σ.

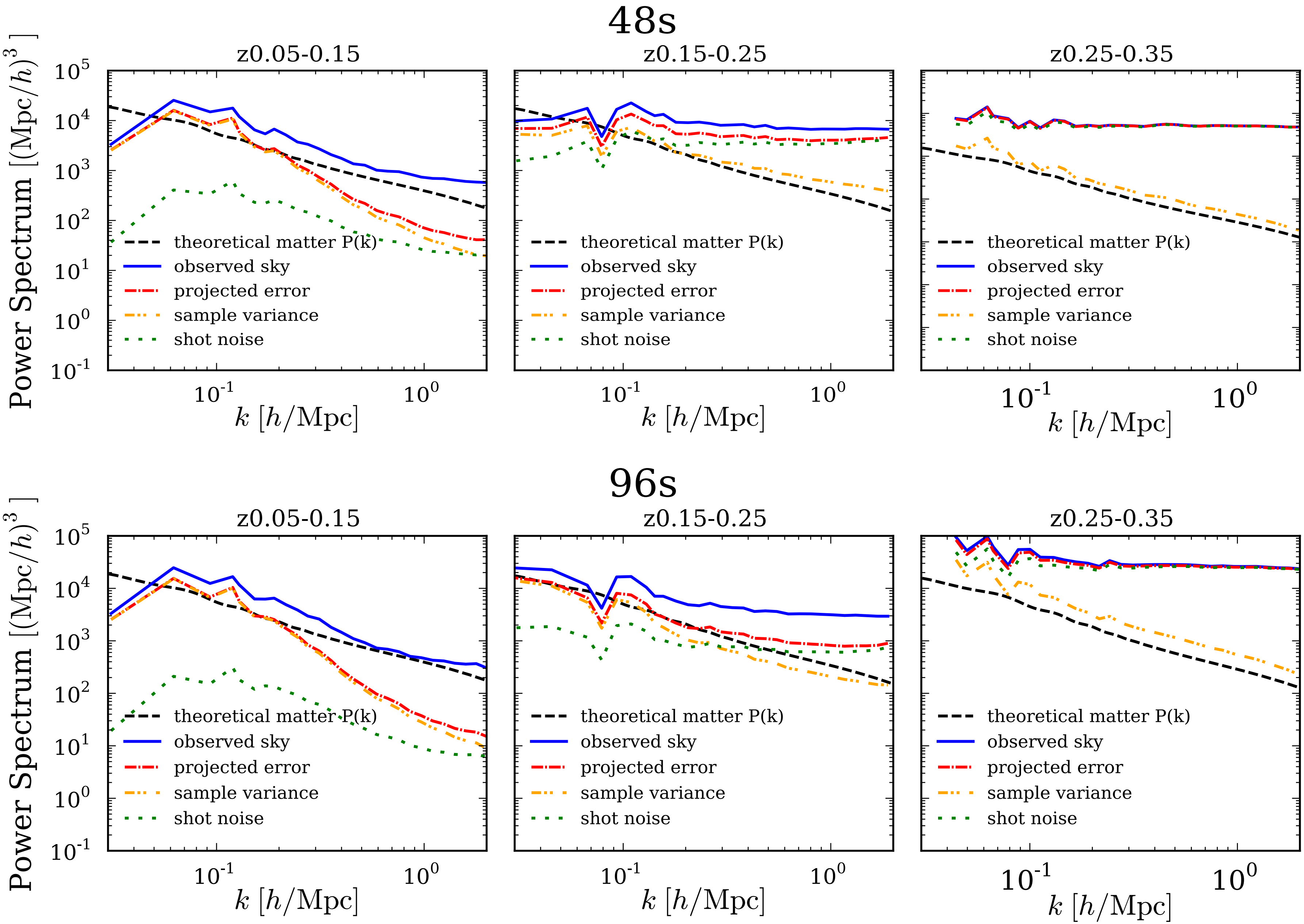
GALAXY SURVEY



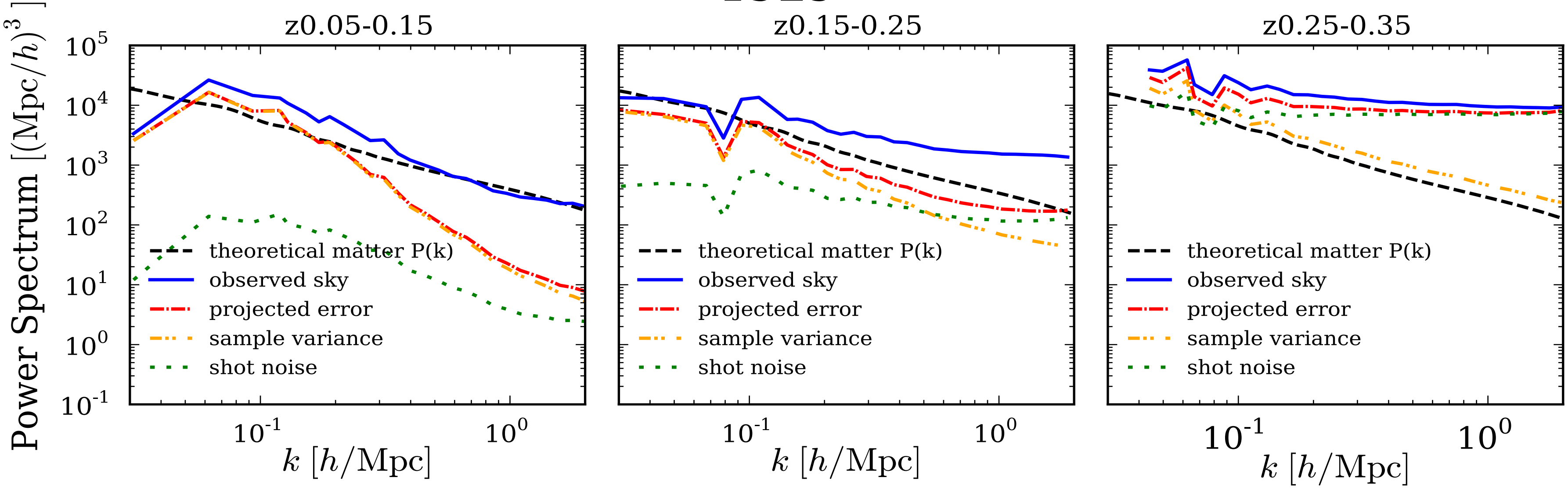
The distribution of the H I mass of the galaxy candidates from the 15 × 15 ×600 h−3 Mpc3 comoving volume.

GALAXY SURVEY



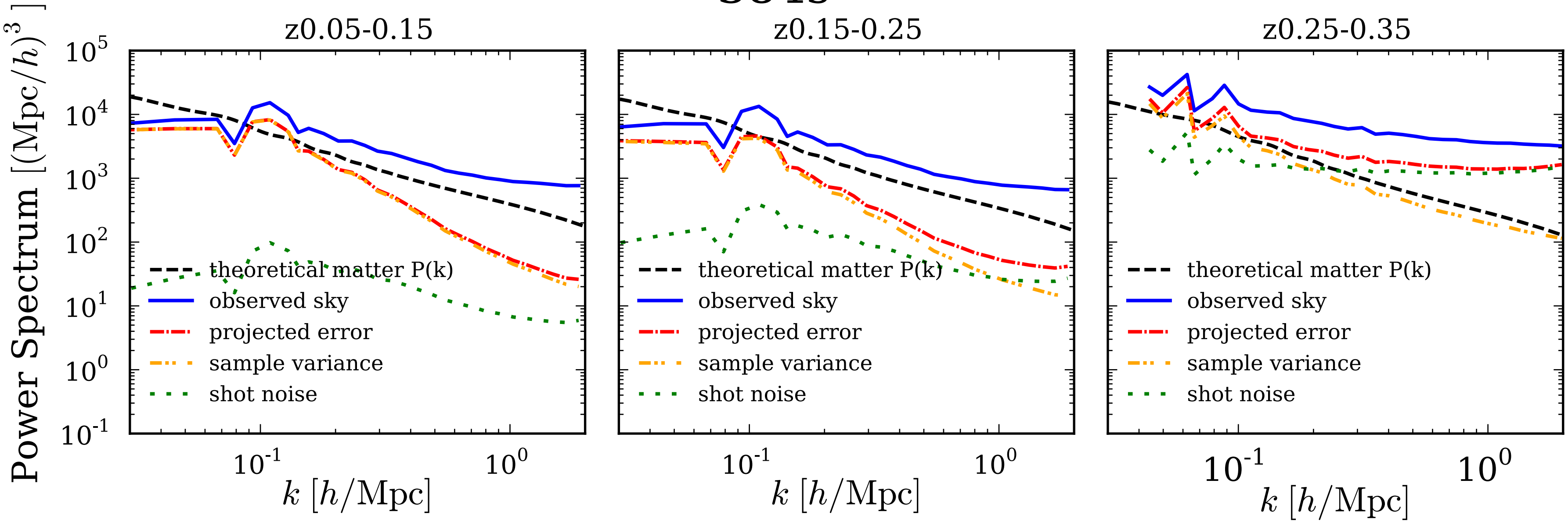

48s
96s
z0.05-0.15
z0.15-0.25
z0.25-0.35
Power Spectrum [(Mpc/h)^3]
k [h/Mpc]
theoretical matter P(k)
observed sky
projected error
sample variance
shot noise

192s



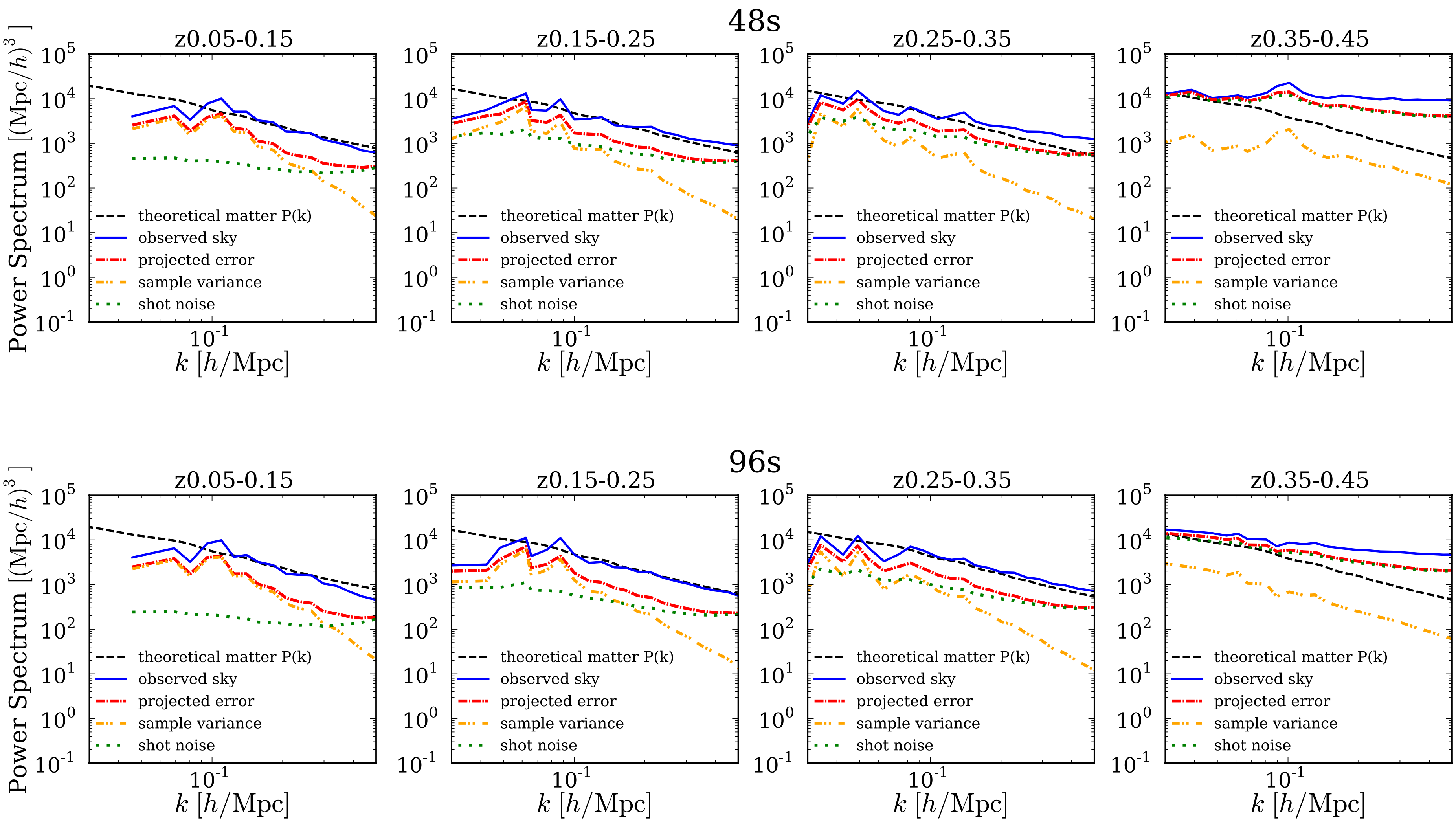
z0.05-0.15
z0.15-0.25
z0.25-0.35
Power Spectrum [(Mpc/h)^3]
k [h/Mpc]
theoretical matter P(k)
observed sky
projected error
sample variance
shot noise

384s

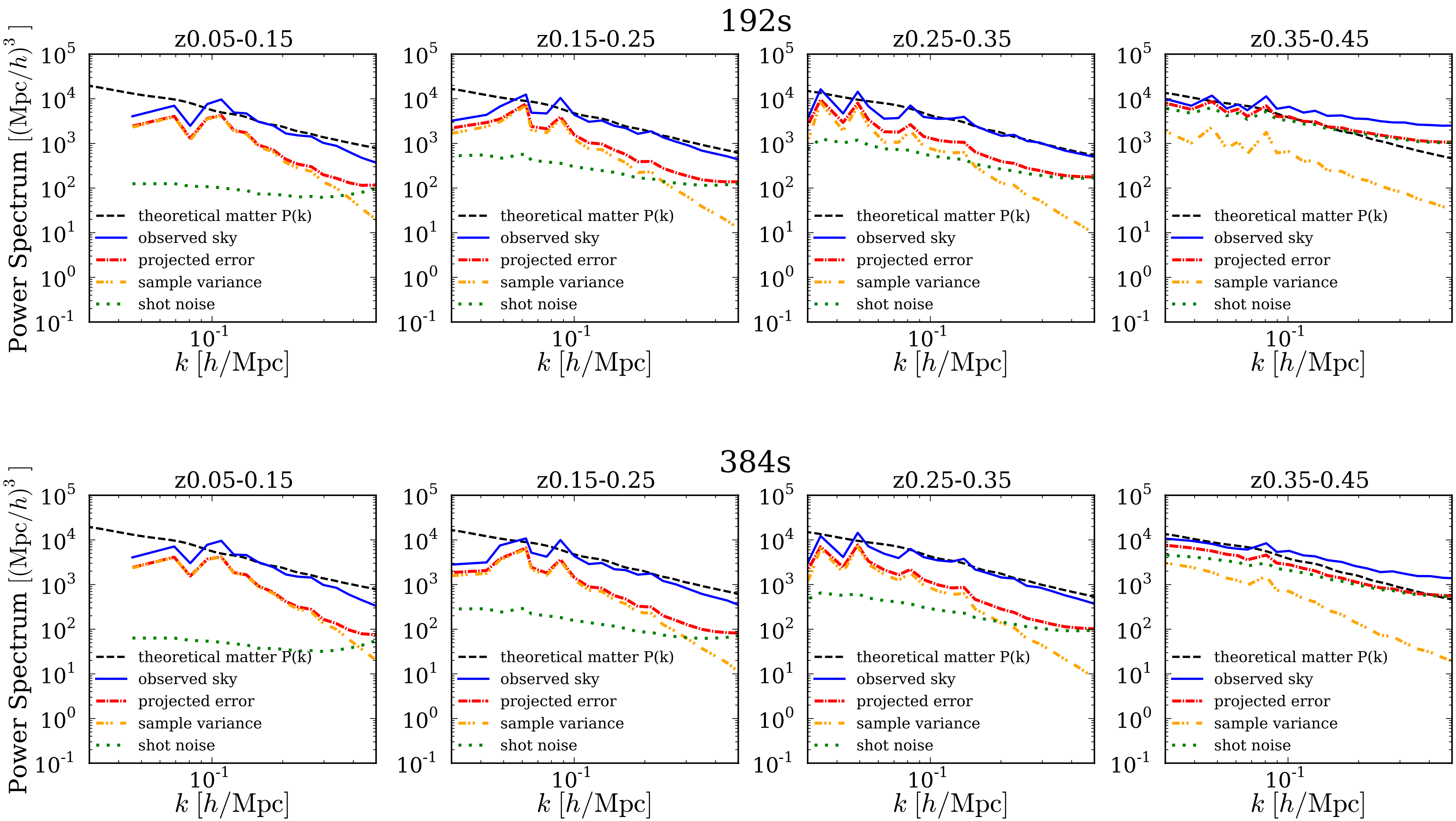


z0.05-0.15
z0.15-0.25
z0.25-0.35
Power Spectrum [(Mpc/h)^3]
k [h/Mpc]
theoretical matter P(k)
observed sky
projected error
sample variance
shot noise

INTENSITY MAPPING

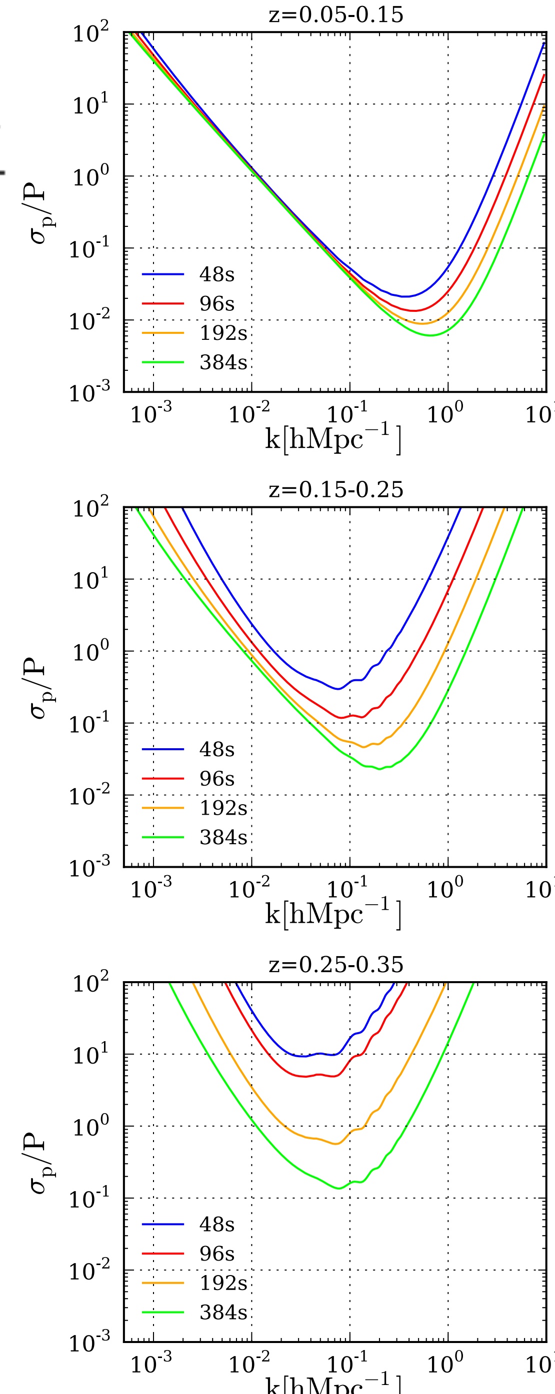


INTENSITY MAPPING



$$\frac{\sigma_P}{P} = \sqrt{2\frac{(2\pi)^3}{V_{\rm eff}}\frac{1}{4\pi k^2\Delta k}\frac{P(k)+1/n}{P(k)}}$$

$$V_{\rm eff}(k) = \int \left[\frac{n(\vec{r})P(k)}{n(\vec{r})P(k)+1}\right]^2 d^3\vec{r}$$

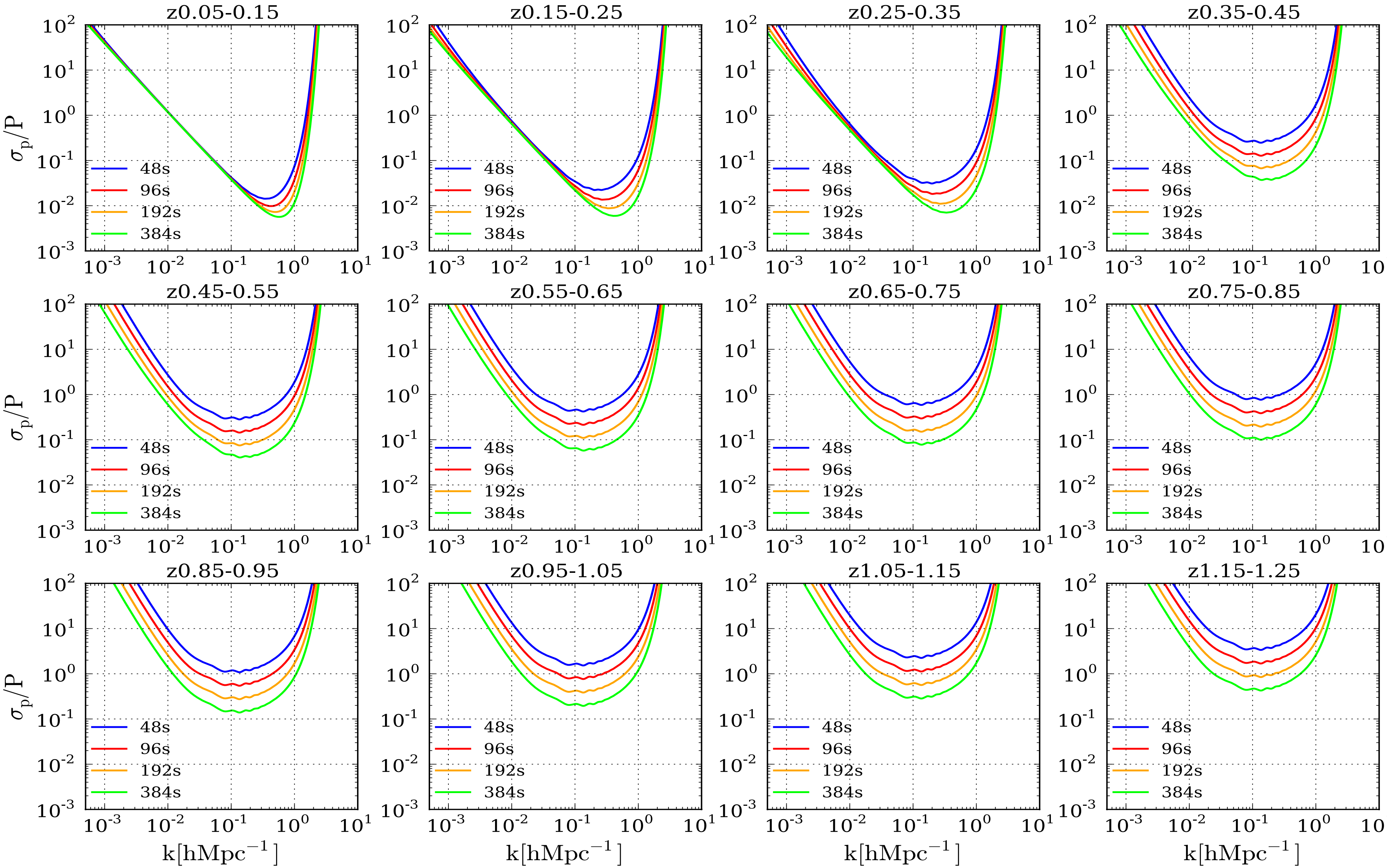


20000- deg^2

$\Delta k/k = 0.125$

At the BAO scale $k \approx 0.07$ h/Mpc, the signal-to- noise ratio can reach 5.0 at z ≈ 0.2, 0.25, 0.3, and 0.35, respectively.

IM: $\frac{\sigma_P}{P} = 2\pi\sqrt{\frac{1}{V_{\rm eff}(k)k^2\Delta k}}$ $\quad V_{\rm eff}(\vec{k}) = V_{\rm sur}\left(1 + \frac{\sigma_{\rm pix}^2 V_{\rm pix}}{[\bar{S}(z)]W(\vec{k})^2 P} + \frac{1/\bar{n}}{P}\right)^{-2}$



S/N can reach 5.0 until redshift of 0.35, 0.55, 0.75, and 1.05

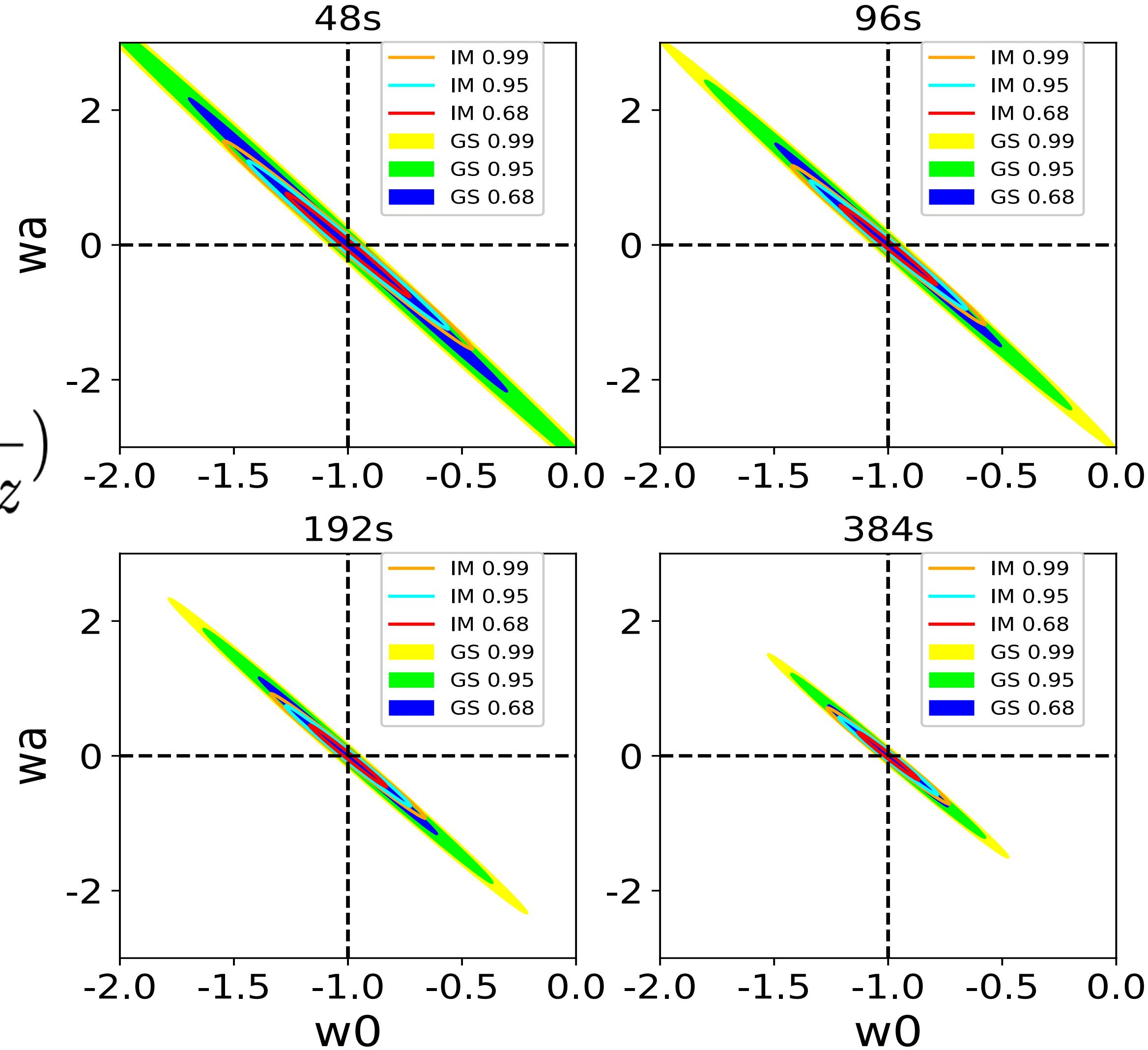
COSMOLOGICAL CONSTRAINTS

$$F_{ij} = \int_{\vec{k}_{\min}}^{\vec{k}_{\max}} \frac{\partial \ln P(\vec{k})}{\partial p_i} \frac{\partial \ln P(\vec{k})}{\partial p_j} V_{\text{eff}}(\vec{k}) \frac{d\vec{k}}{2(2\pi)^3}$$

For a model with dark energy equation of state parametrized in the form

$$w(z) = w_0 + w_a\left(\frac{z}{1+z}\right)$$

kmin = 10^-3 h/Mpc
kmax = 0.1 h/Mpc



COSMOLOGICAL CONSTRAINTS

Survey	GS $(\sigma_{w_0}, \sigma_{w_a})$	IM $(\sigma_{w_0}, \sigma_{w_a})$	Observation time (day)
L 48 s	(0.46, 1.44)	(0.19, 0.53)	220
L 96 s	(0.33, 1.00)	(0.15, 0.43)	440
L 192 s	(0.25, 0.77)	(0.13, 0.36)	880
L 384 s	(0.17, 0.49)	(0.12, 0.33)	1760
(L + w) 48 s	(0.46, 1.44)	(0.18, 0.50)	220 (L) + 2422 (w)
(L + w) 96 s	(0.33, 1.00)	(0.14, 0.39)	440 (L) + 4844 (w)
(L + w) 192 s	(0.25, 0.77)	(0.11, 0.30)	880 (L) + 9688 (w)
(L + w) 384 s	(0.17, 0.49)	(0.09, 0.23)	1760 (L) + 19376 (w)
L(192 s) + P (216 s)	–	(0.05, 0.12)	880 (L) + 135 (P)
L(384 s) + P (432 s)	–	(0.04, 0.10)	1760 (L) + 270 (P)

SUMMARY

1. We make a detailed study of large area drift scan HI survey with the FAST telescope.

2. We find that the FAST can effectively detect the individual galaxy till $z \approx 0.2, 0.25, 0.3$, and 0.35, or map the LSS with intensity mapping till $z \approx 0.35, 0.55, 0.75$, and 1.05, respectively, if we assume 48 s, 96 s, 192 s, and 384 s integration time per beam.

3. We find that the FAST HI intensity mapping survey can produce a good measurement of the underlying power spectrum and use the BAO method to measure the dark energy equation of state parameters.