An aerial photograph of the Five-hundred-meter Aperture Spherical Telescope (FAST) in China. The telescope is a large, circular dish antenna built into a natural sinkhole. It is surrounded by a forested mountainous area with winding roads and smaller buildings. Several blue circles are overlaid on the image, highlighting specific features of the telescope and its surroundings.

# HI Survey with FAST

Yougang Wang (NAOC), Yichao Li (NEU),  
Wenkai Hu (LAM), Xuelei Chen (NAOC)

# 21cm line from the HI

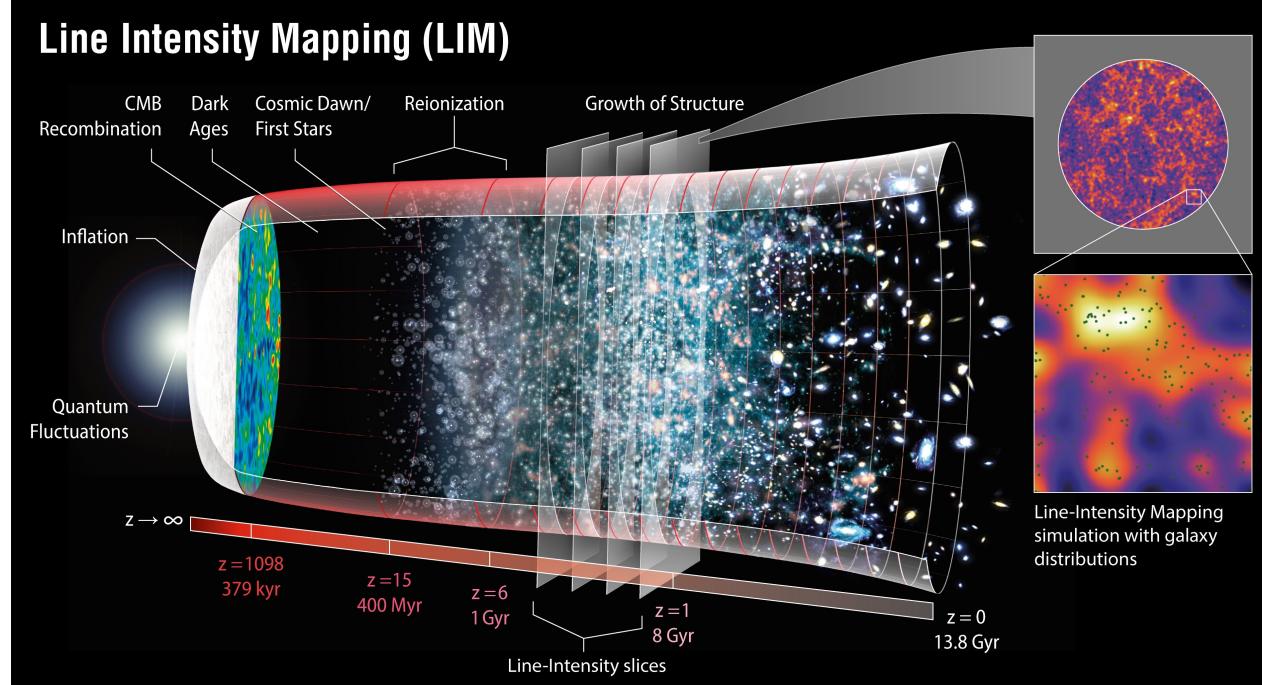
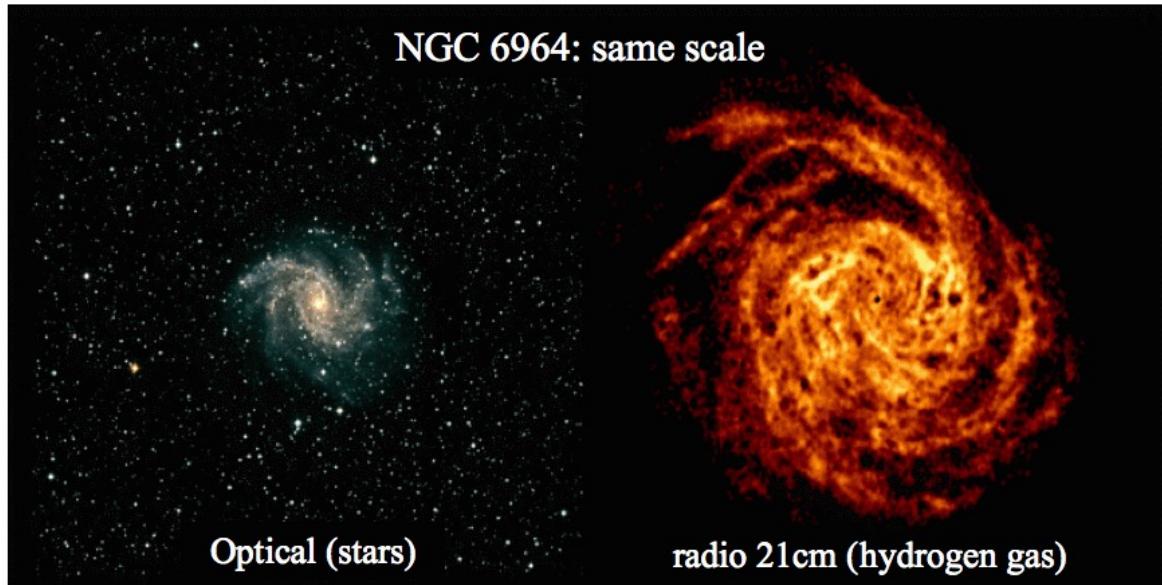
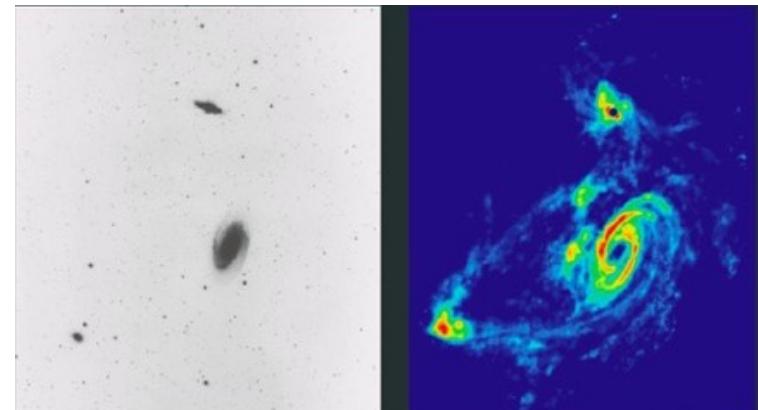


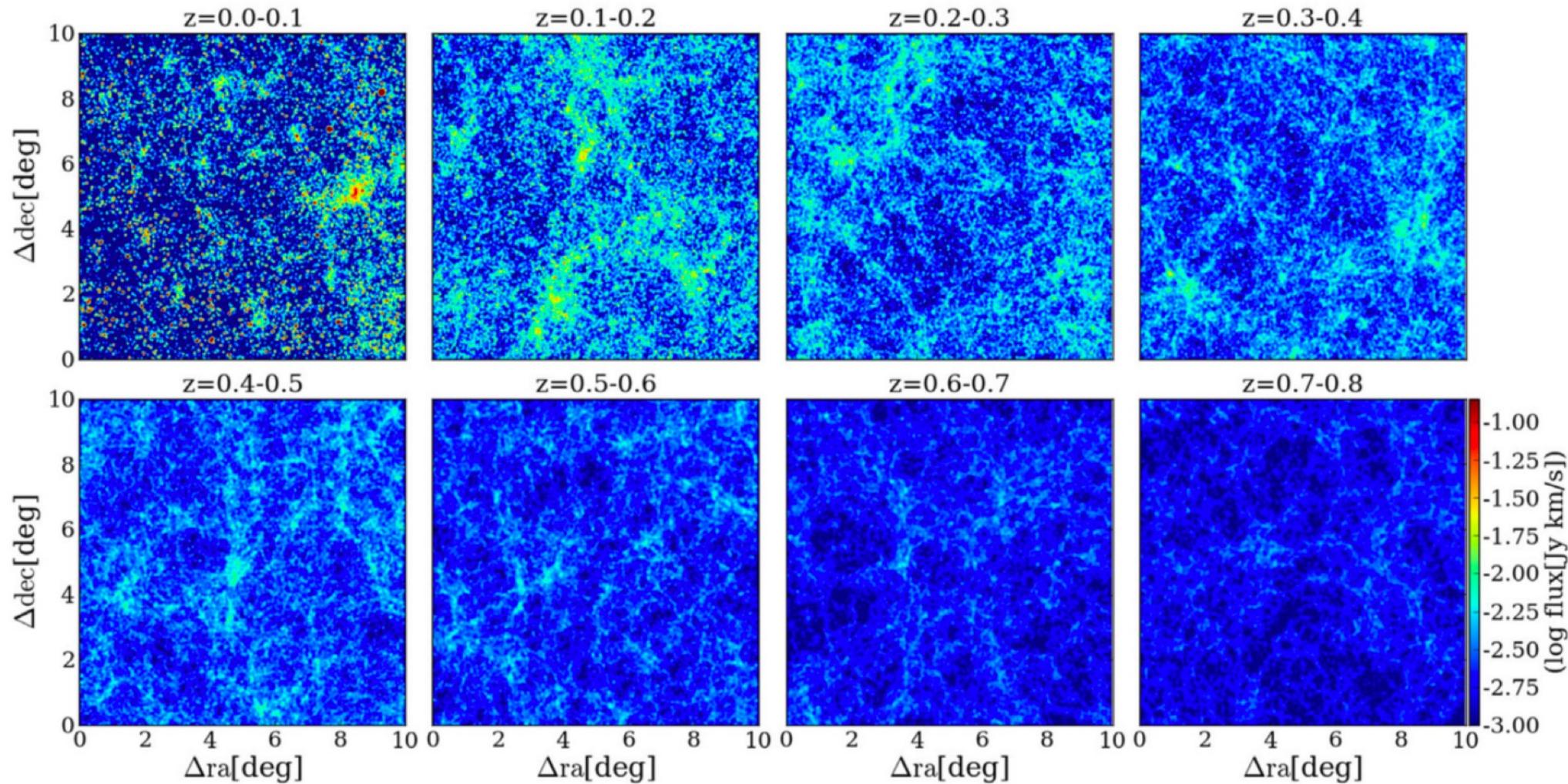
Image Credit: NASA / LAMBDA Archive Team



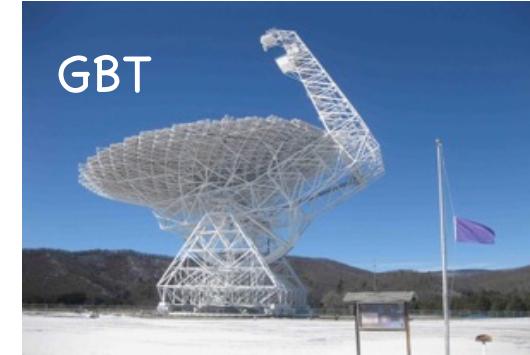
M81 group

- There is a lot of hydrogen, 76% of baryons
- Hydrogen is primordial, observable over large redshift ranges
- A different perspective compared with optical survey

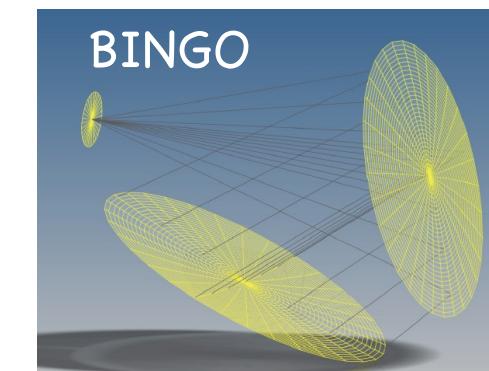
# HI galaxy and intensity mapping



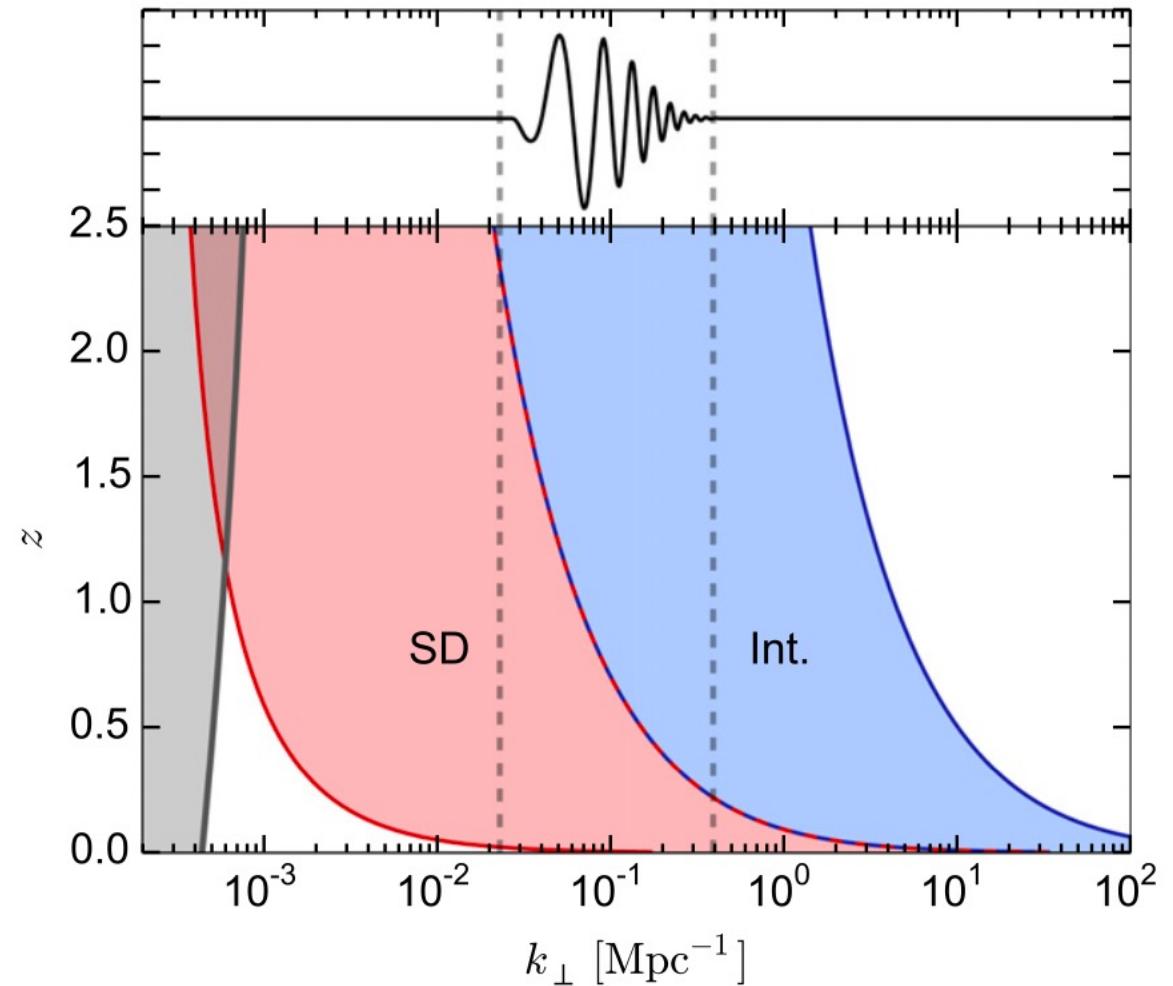
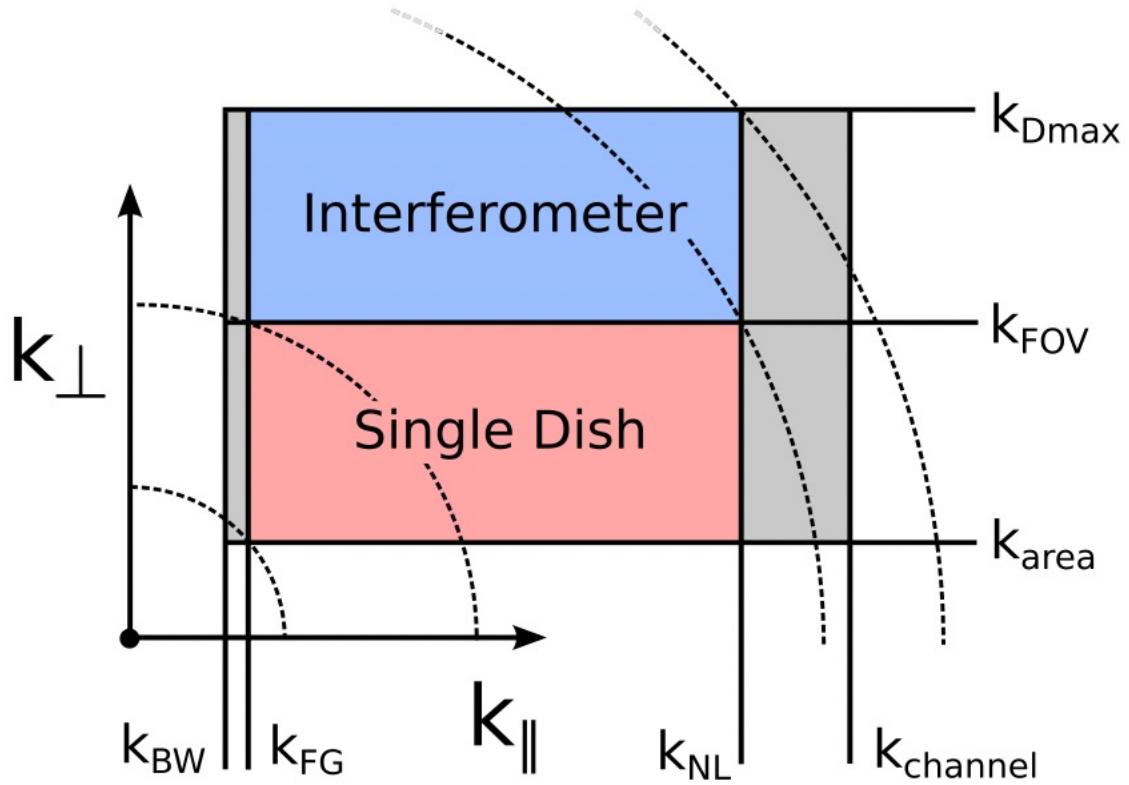
# Mid-redshift IM Experiments



Caption: CSIRO's Parkes radio telescope. Credit: David McClenaghan, CSIRO

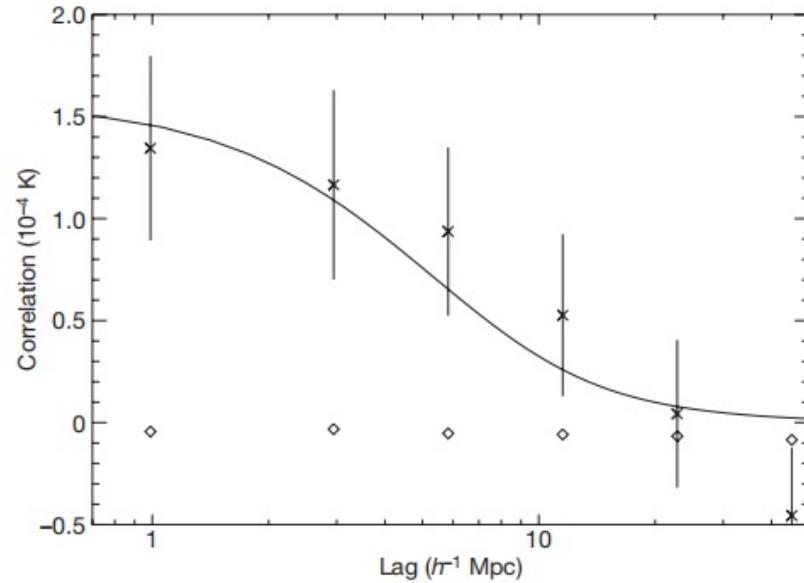


# single dish and the interferometer

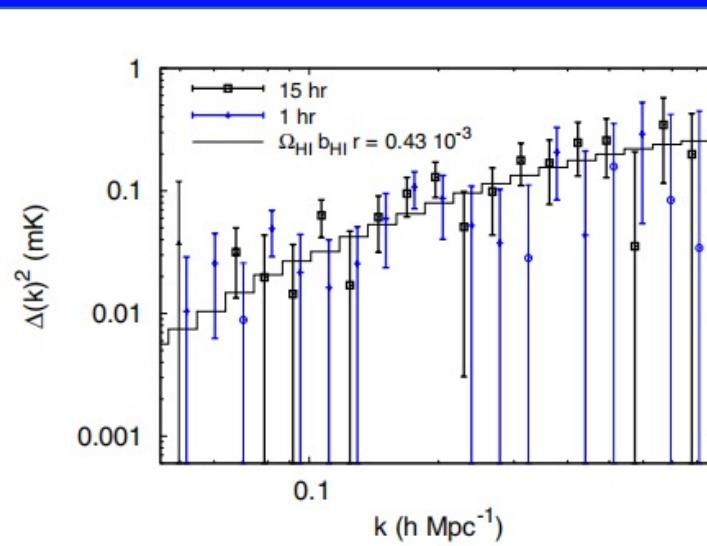


Bull et al. 2015

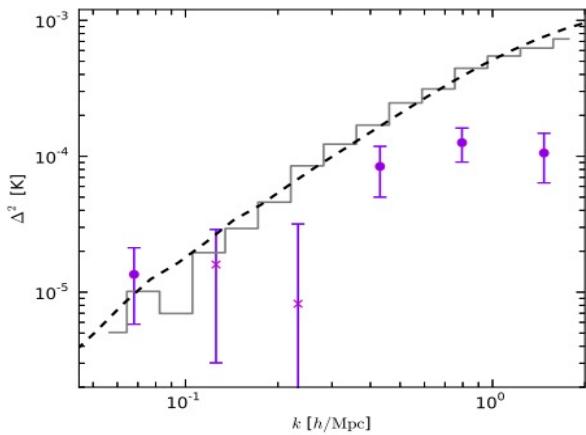
# Observational Progress



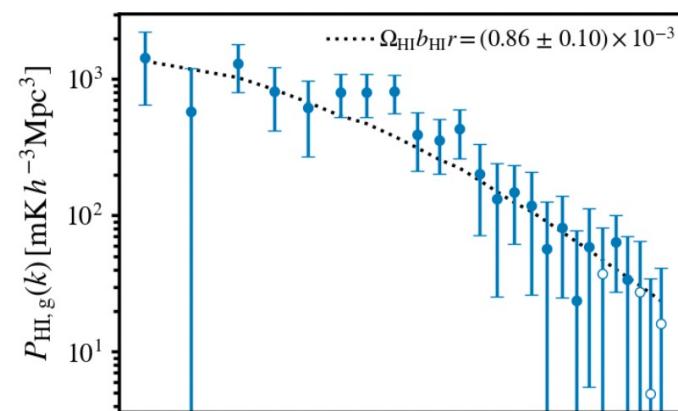
GBT × DEEP2 (Chang et al. 2010)



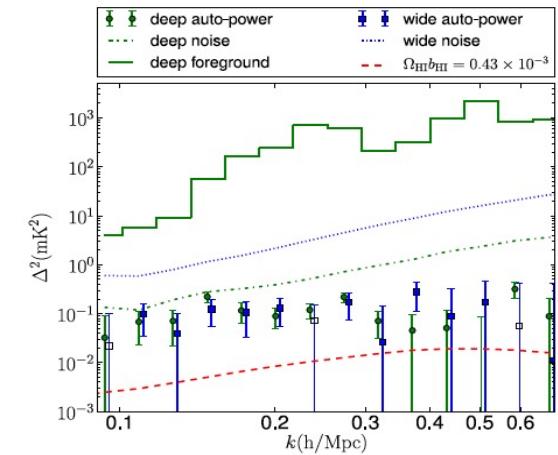
GBT × WiggleZ (Masui et al. 2013)



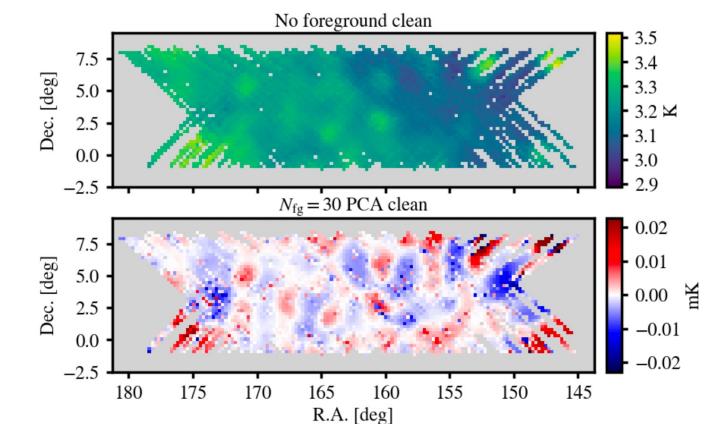
Parkes × 2dF  
(Anderson et al. 2017)



MeerKAT × WiggleZ (Cunnington et al. 2022)



GBT autocorrelation (Switzer et al. 2013)

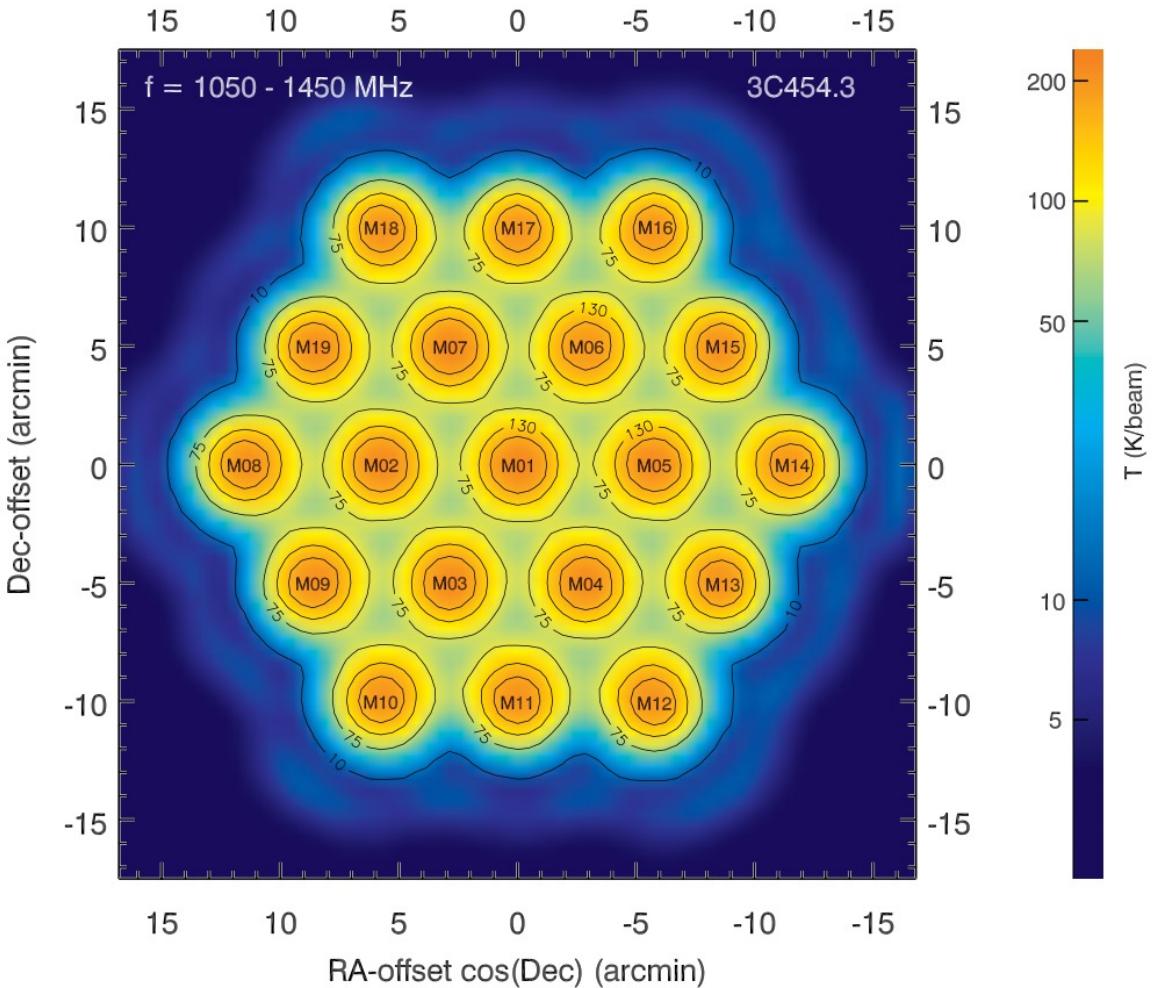


# Basic parameters of FAST



- Instant aperture: 300m
- zenith for FAST ( $25^{\circ} 39' 9''$  N)
- survey region:  $-14^{\circ} \sim +66^{\circ}$
- L band 1050-1450 MHz

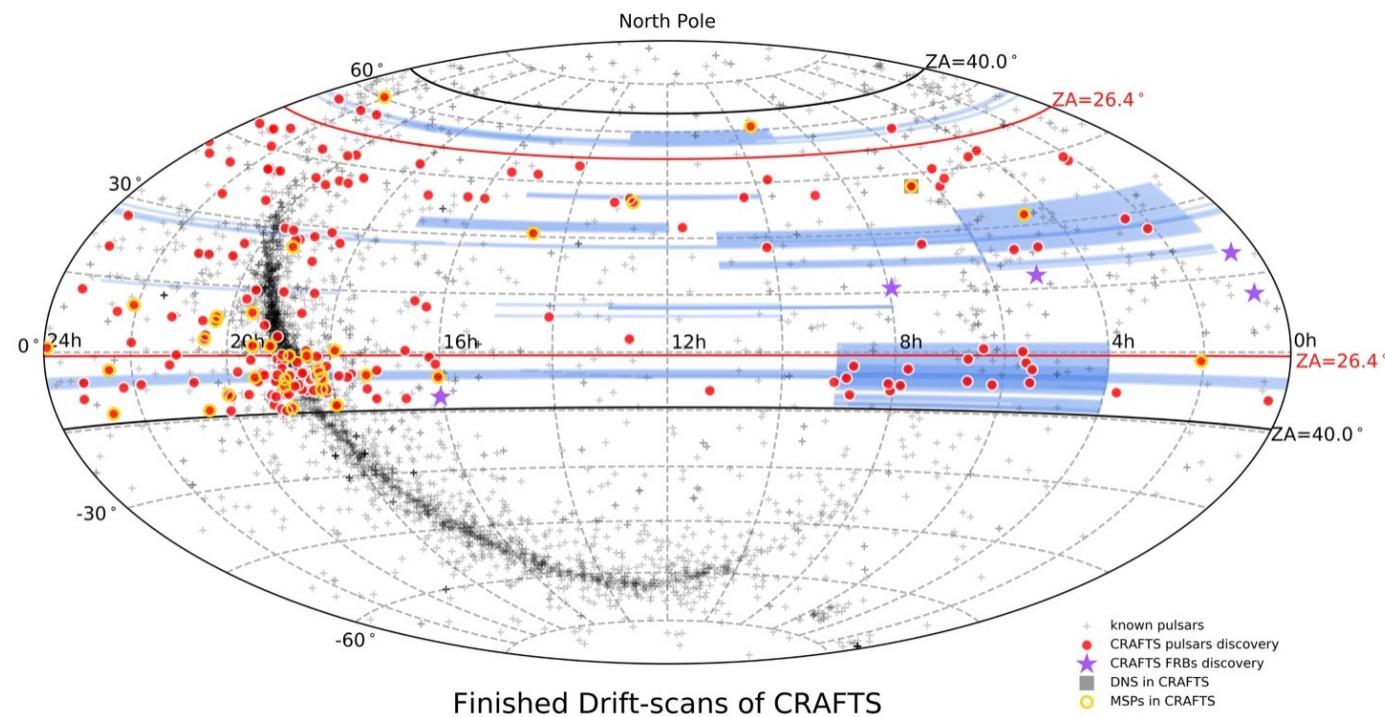
$$\theta \sim \frac{21(1+z) \text{ cm}}{30000 \text{ cm}} \sim 3(1+z) \text{ arcmin}$$



Jiang et al. 2020

# Key Project

- The commensal Radio Astronomy FAST Survey (CRAFTS)
- The Galactic Plane Pulsar Snapshot (GPPS) survey
- Pulsar timing: Chinese pulsar timing array
- HI Mapping and pulsars searching toward M31 region
- Fast radio burst searches and multi-wavelength observations
- Pulsar timing: Physics and evolution of pulsars

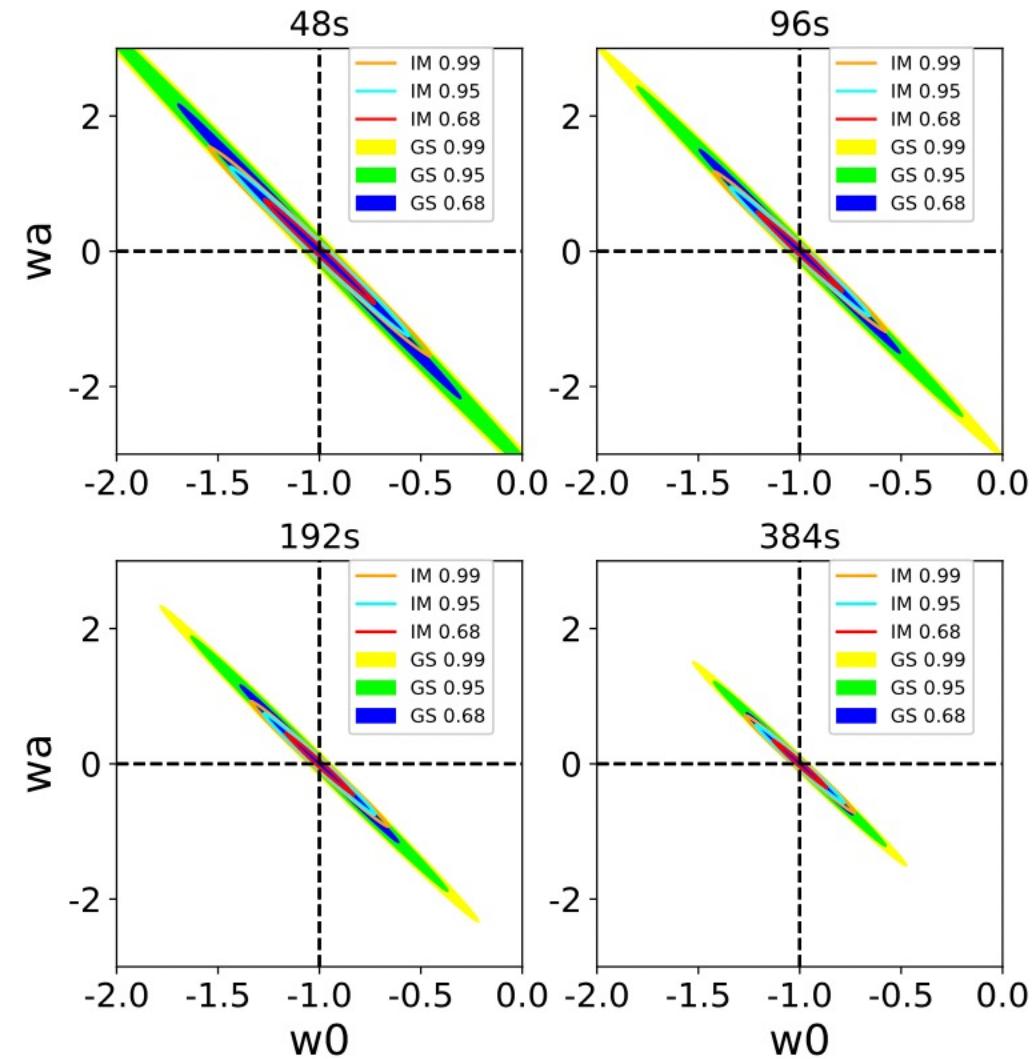


# Forest from the FAST HI survey



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)

Hu et al. 2020



# Forest from the FAST HI survey



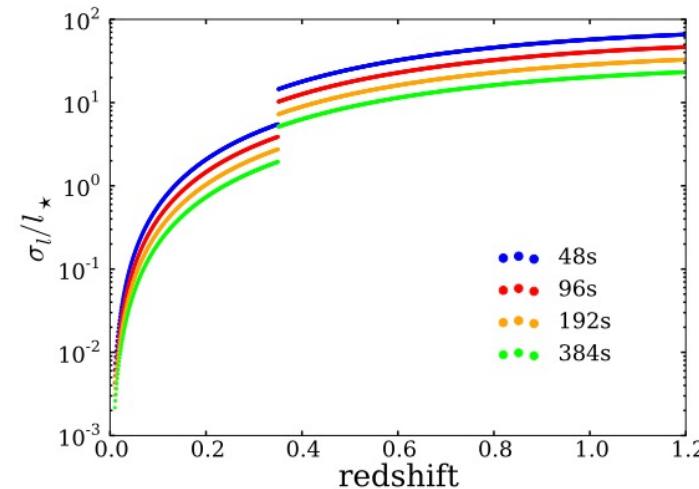
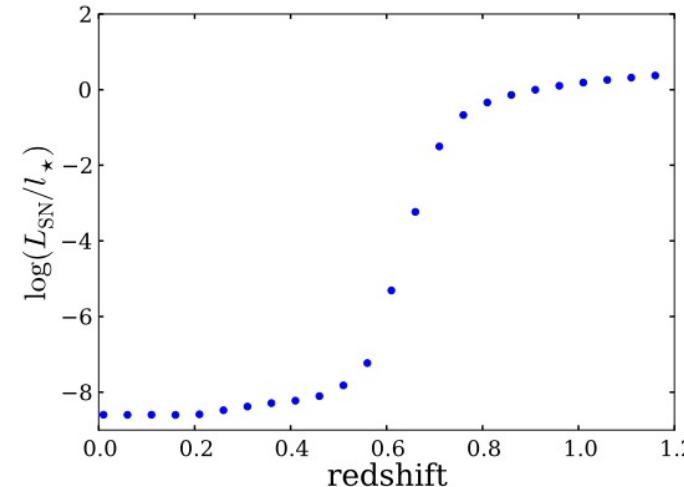
- The optimal strategy for survey can be described by three parameters:

$L_{\text{SN}}$  is the luminosity scale on which the voxels are susceptible to shot noise,

$\sigma_L$  refers to the rms noise per voxels

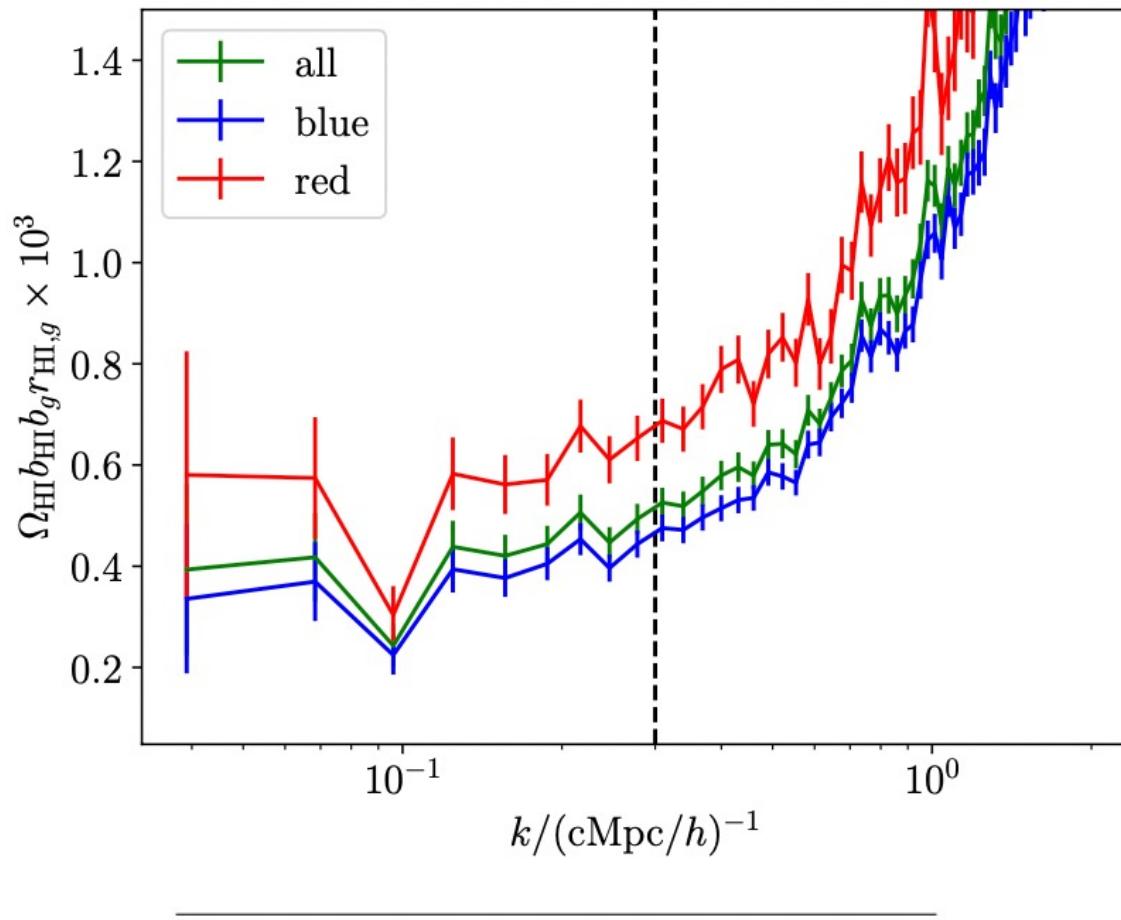
$l_*$  is the characteristic luminosity

Number	Regime	Optimal strategy
1	$L_{\text{SN}} < \sigma_L < l_*$	Galaxy detection
2	$\sigma_L < L_{\text{SN}} < l_*$	Galaxy detection/intensity mapping <sup>a</sup>
3	$L_{\text{SN}} < l_* < \sigma_L$	Intensity mapping
4	$l_* < L_{\text{SN}}$	Intensity mapping

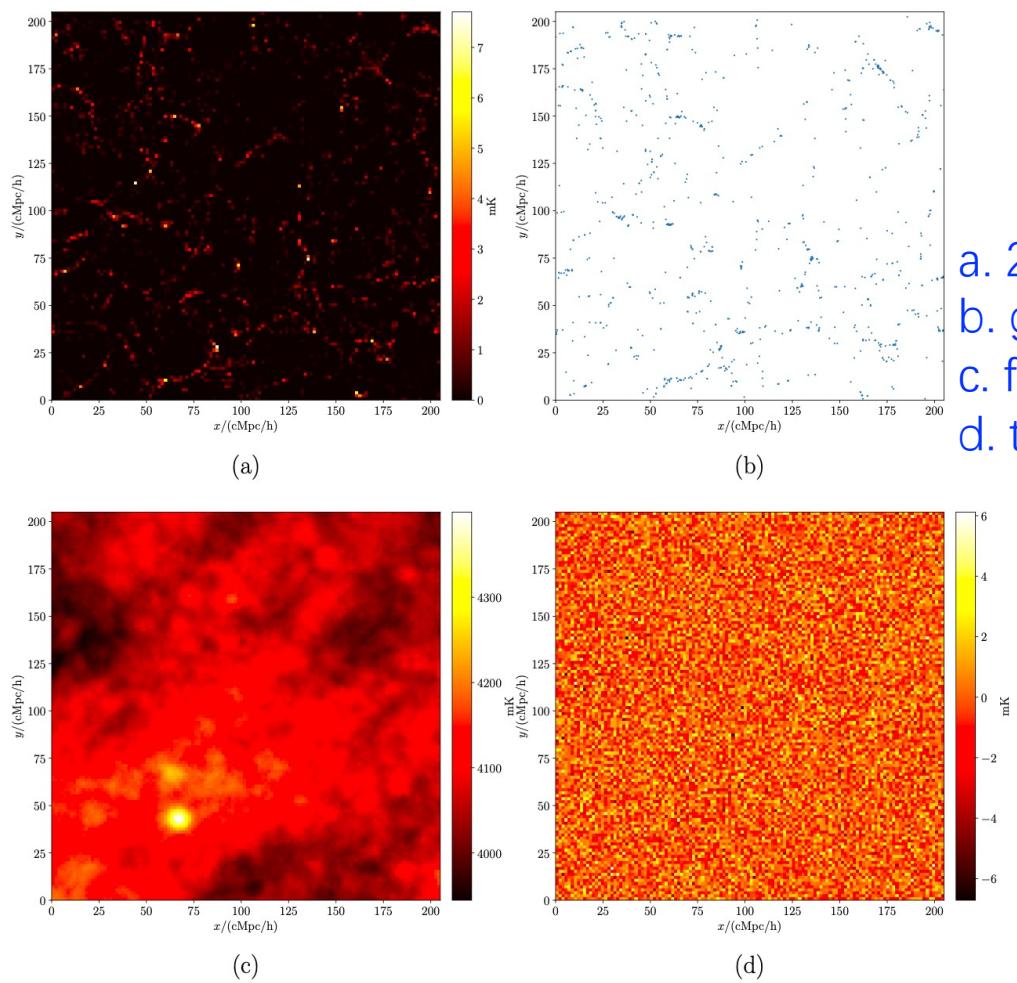


$z \leq 0.13, 0.16, 0.19, \text{ and } 0.23$  for different time is the optimal strategy for galaxy survey

# Forecast of the FAST HI IM × CSST survey



Catalog	snap84	snap78
all	$0.5118 \pm 0.0029$	$0.5226 \pm 0.0022$
blue	$0.5176 \pm 0.0029$	$0.5231 \pm 0.0022$
red	$0.4770 \pm 0.0030$	$0.5020 \pm 0.0024$

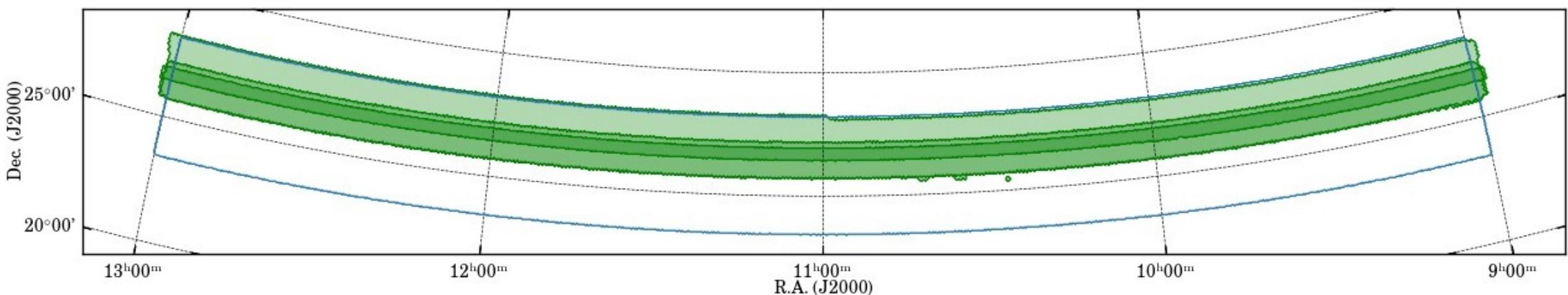
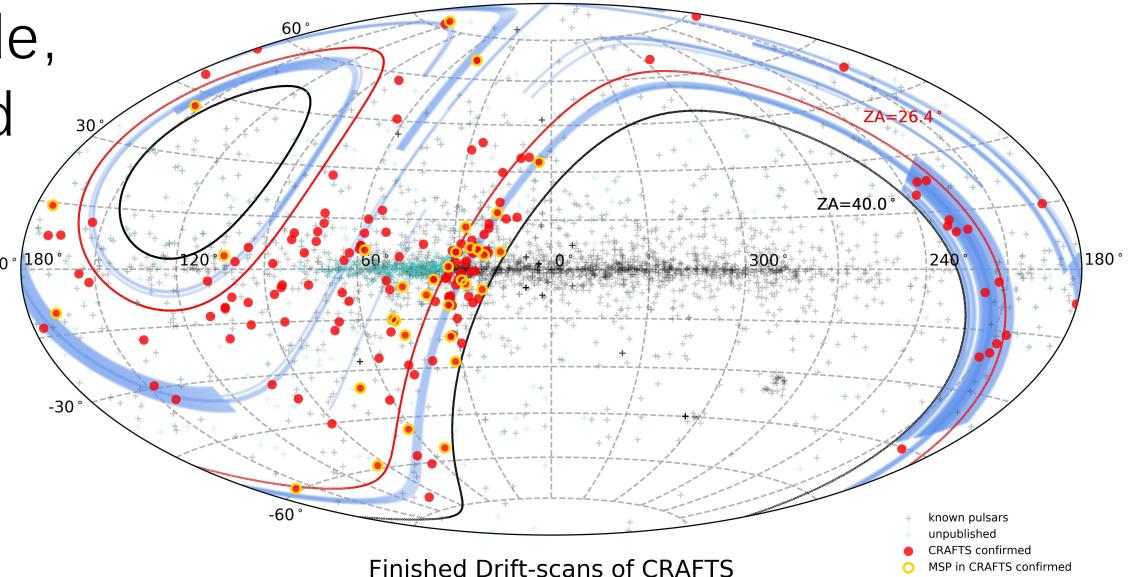


A relative error of  $\sim 0.6\%$  for  $\Omega_{\text{HI}}$  can be achieved at  $z=0.3$  if  $10000 \text{ deg}^2$  overlapping sky area (Deng et al. 2022)

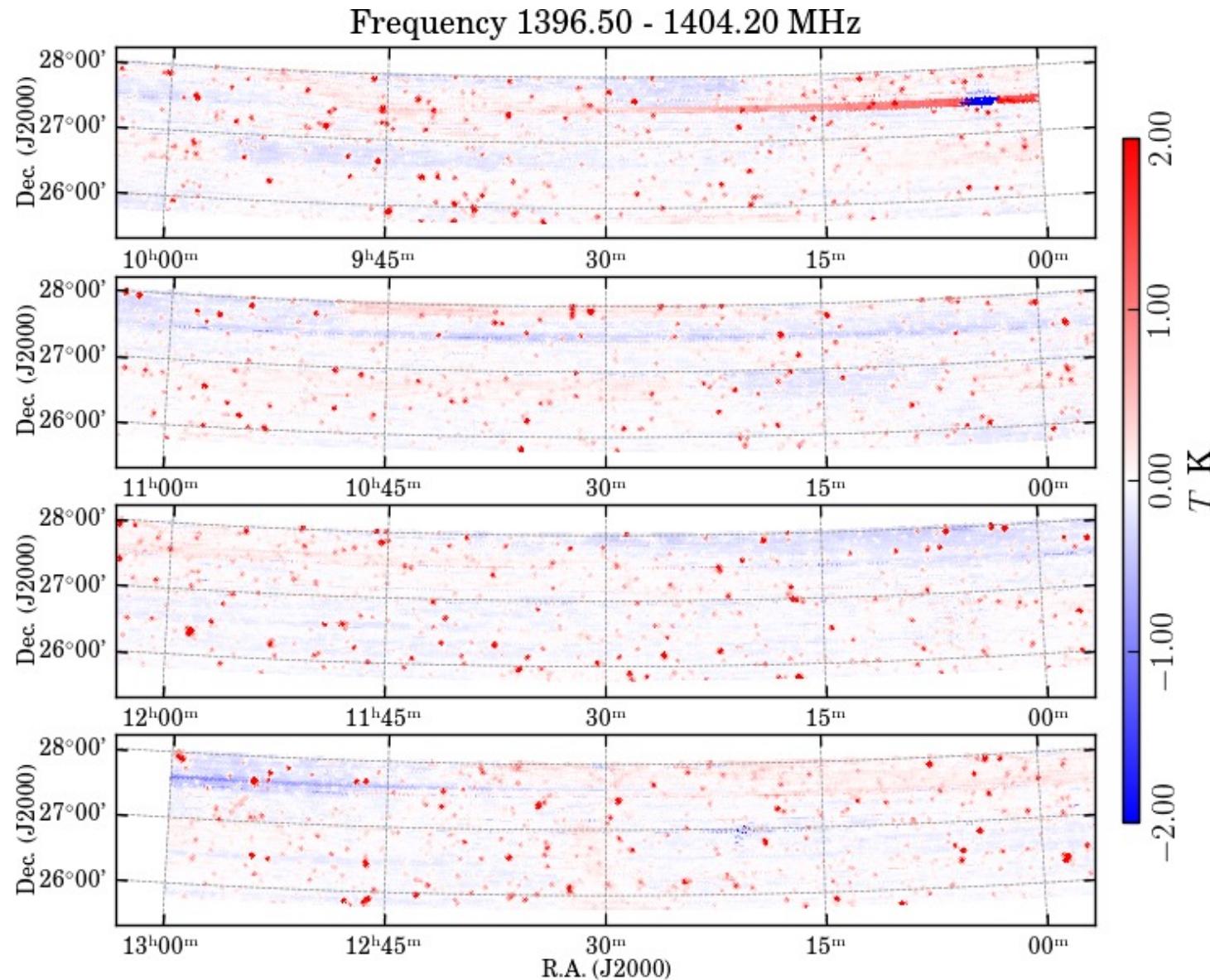
# CRAFTS and our drift scan

CRAFTS : high-cadence injection of the noise diode,  
196.608 us, including pulse and spectrum backend

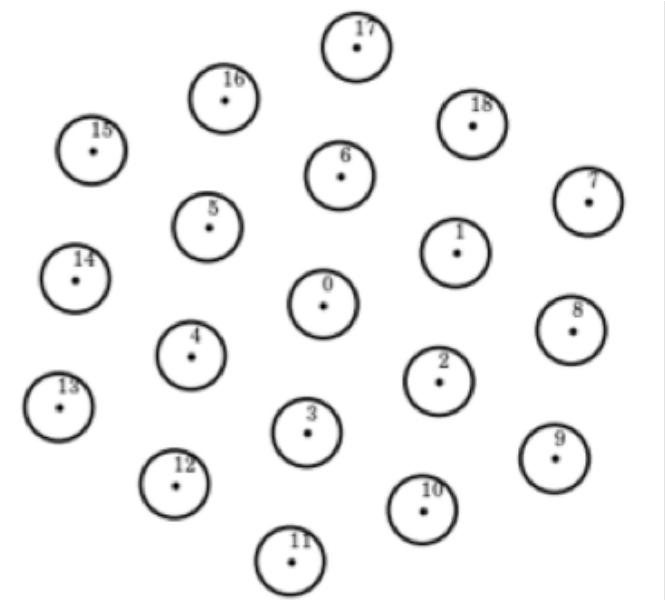
Our drift scan: Noise injection every eight seconds



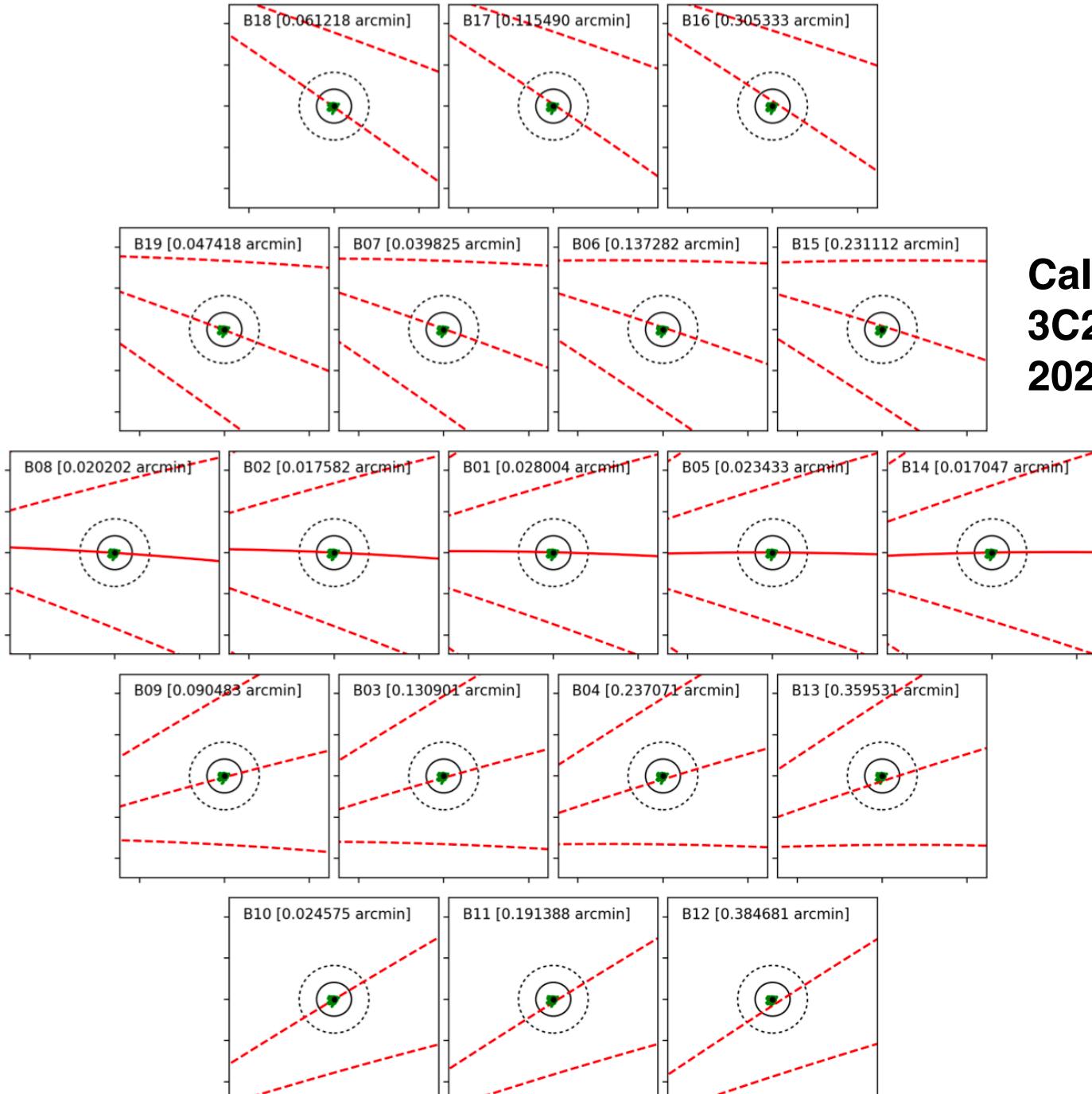
# DRIFT survey by FAST



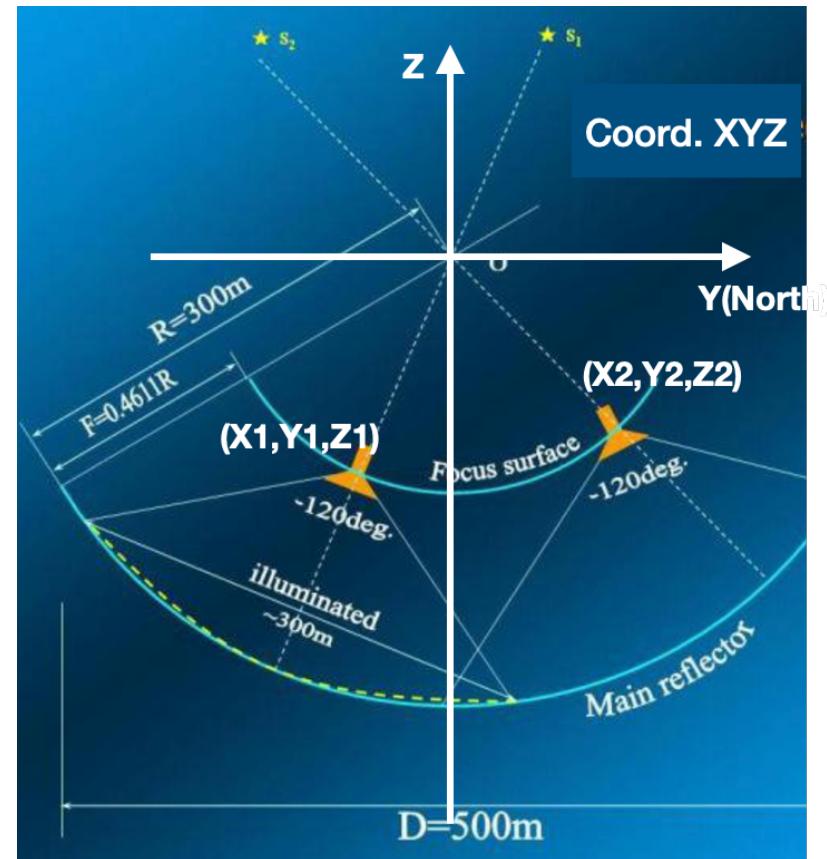
100 hrs observation  
150 deg<sup>2</sup>



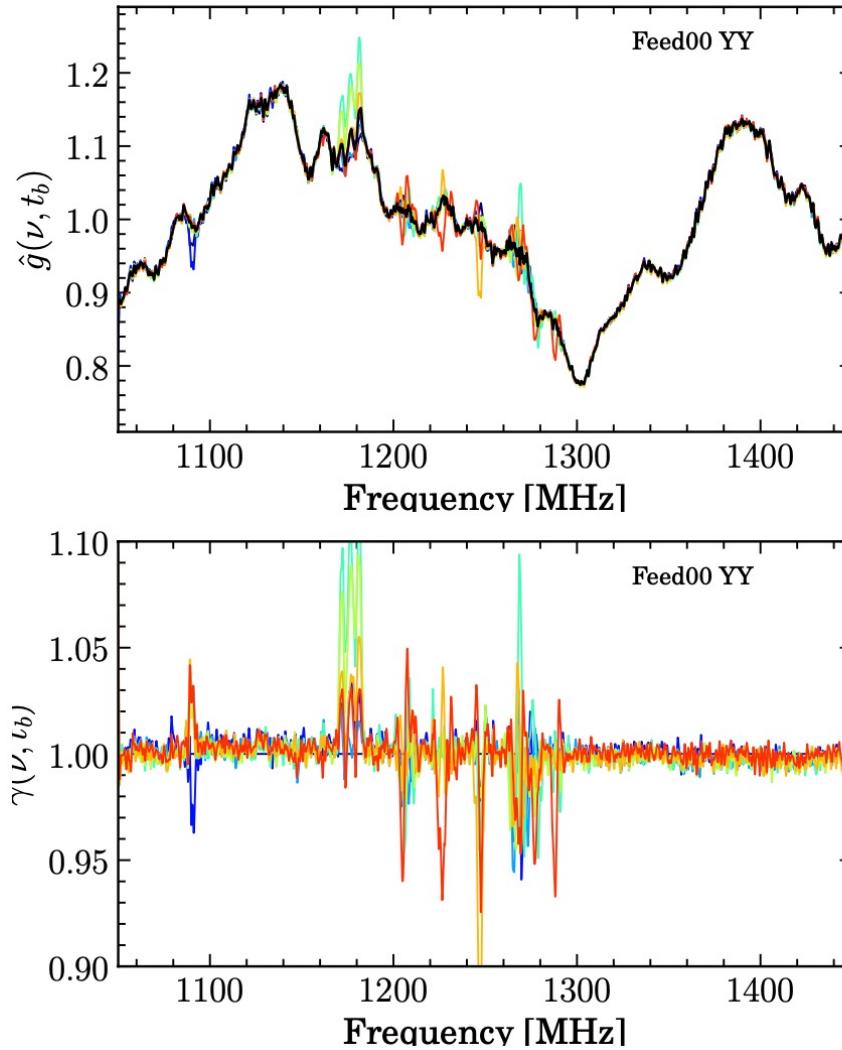
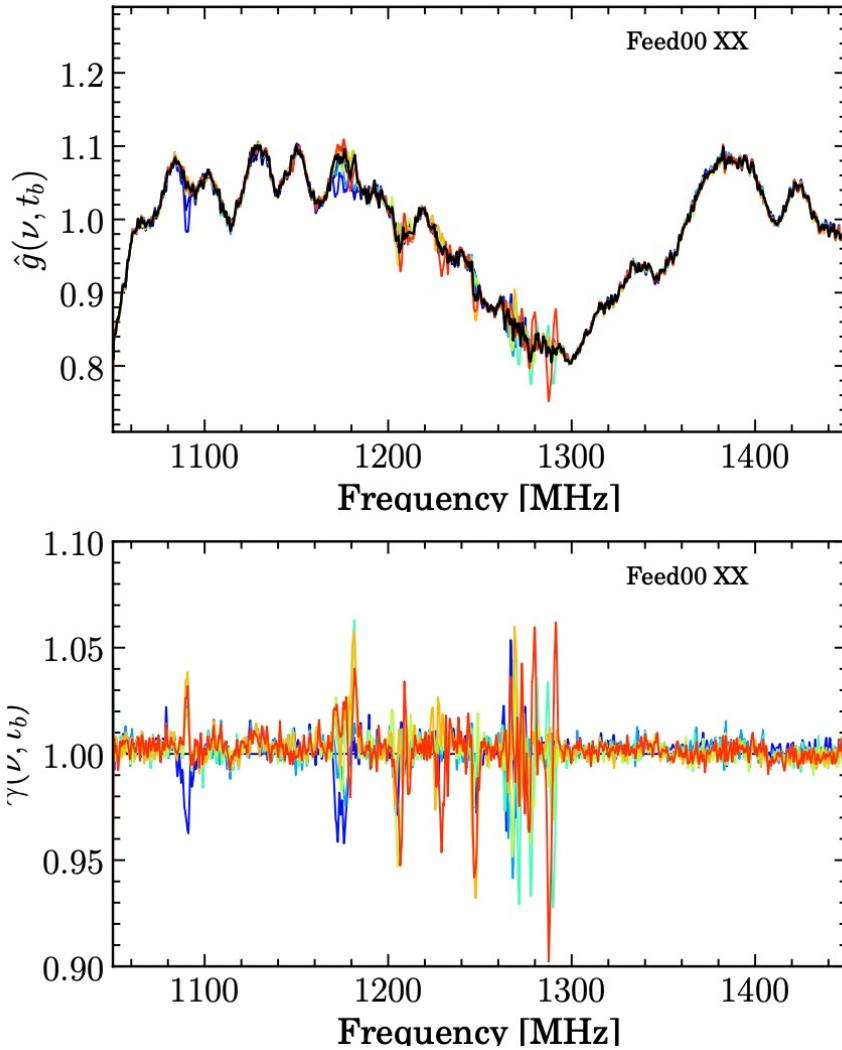
Feed rotated by 23.4 degree



**Calibration source:  
3C286  
2020.5.8**



# Bandpass

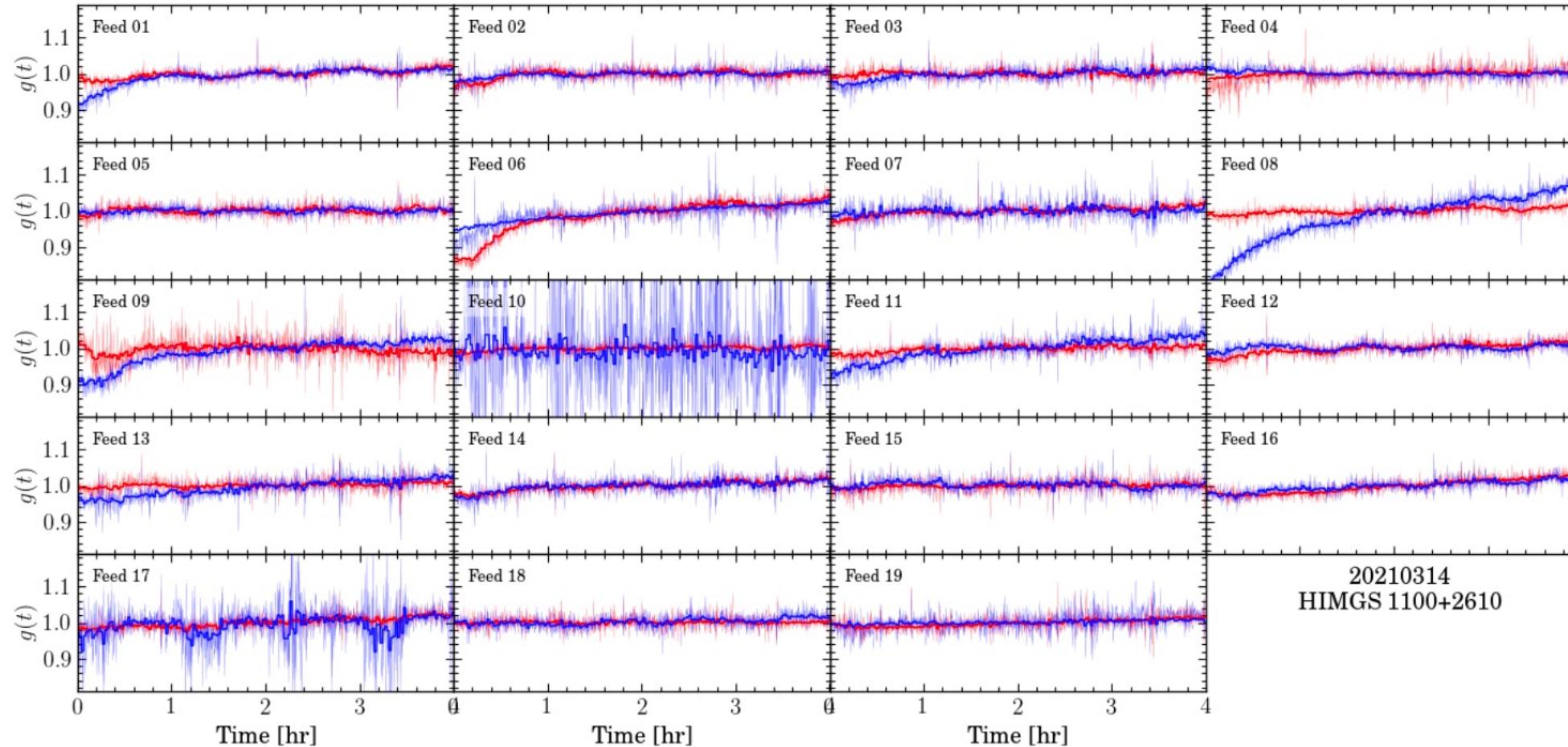


$$g(\nu, t_b) = \frac{\langle V_{\text{NDon}}(t, \nu) - V_{\text{NDoff}}(t, \nu) \rangle_{t_b}}{T_{\text{ND}}(\nu)}$$

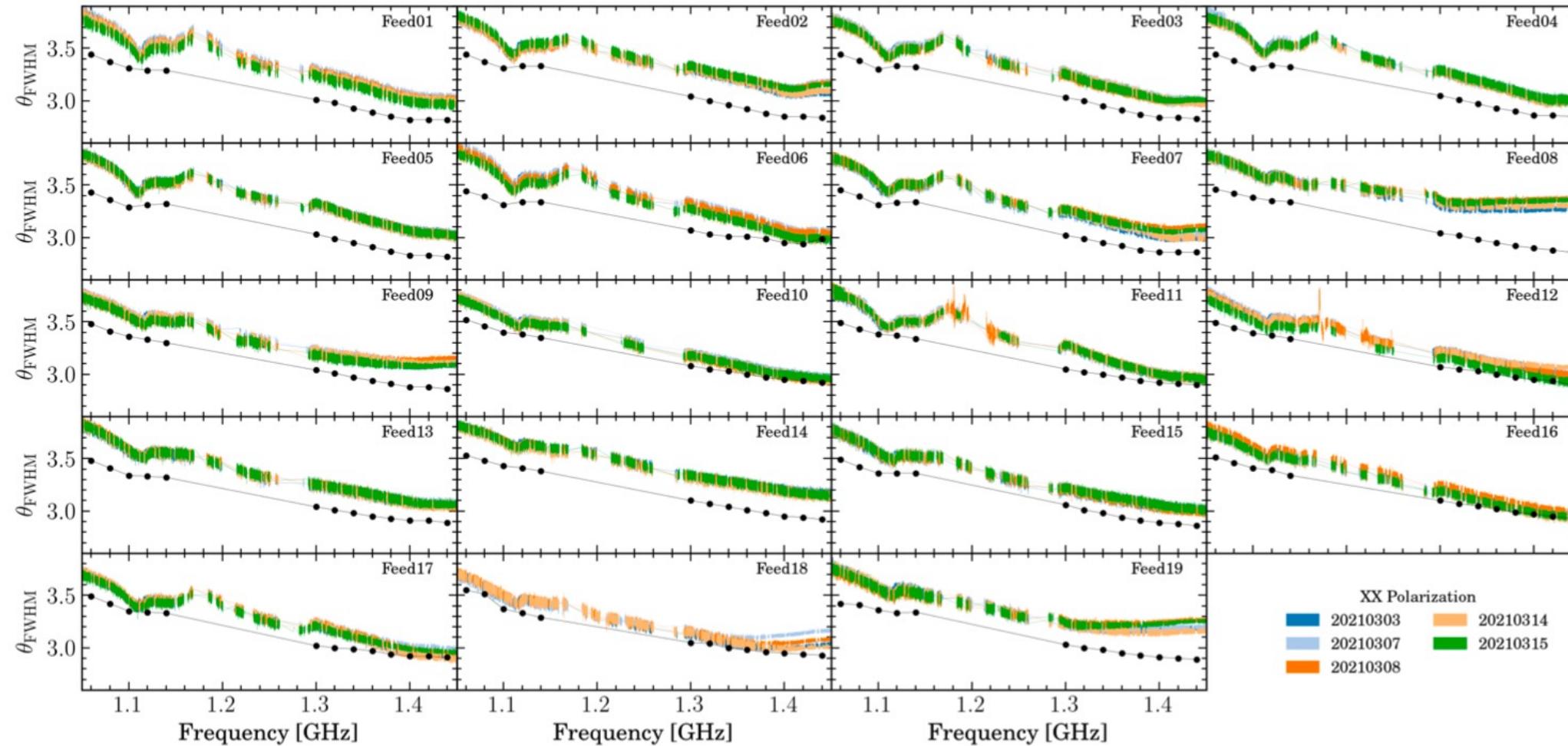
$$\hat{g}(\nu, t_b) = g(\nu, t_b) / \langle g(\nu, t_b) \rangle_\nu$$

$$\gamma(\nu, t_b) = \frac{\hat{g}(\nu, t_b)}{\hat{g}(\nu, t_0)}$$

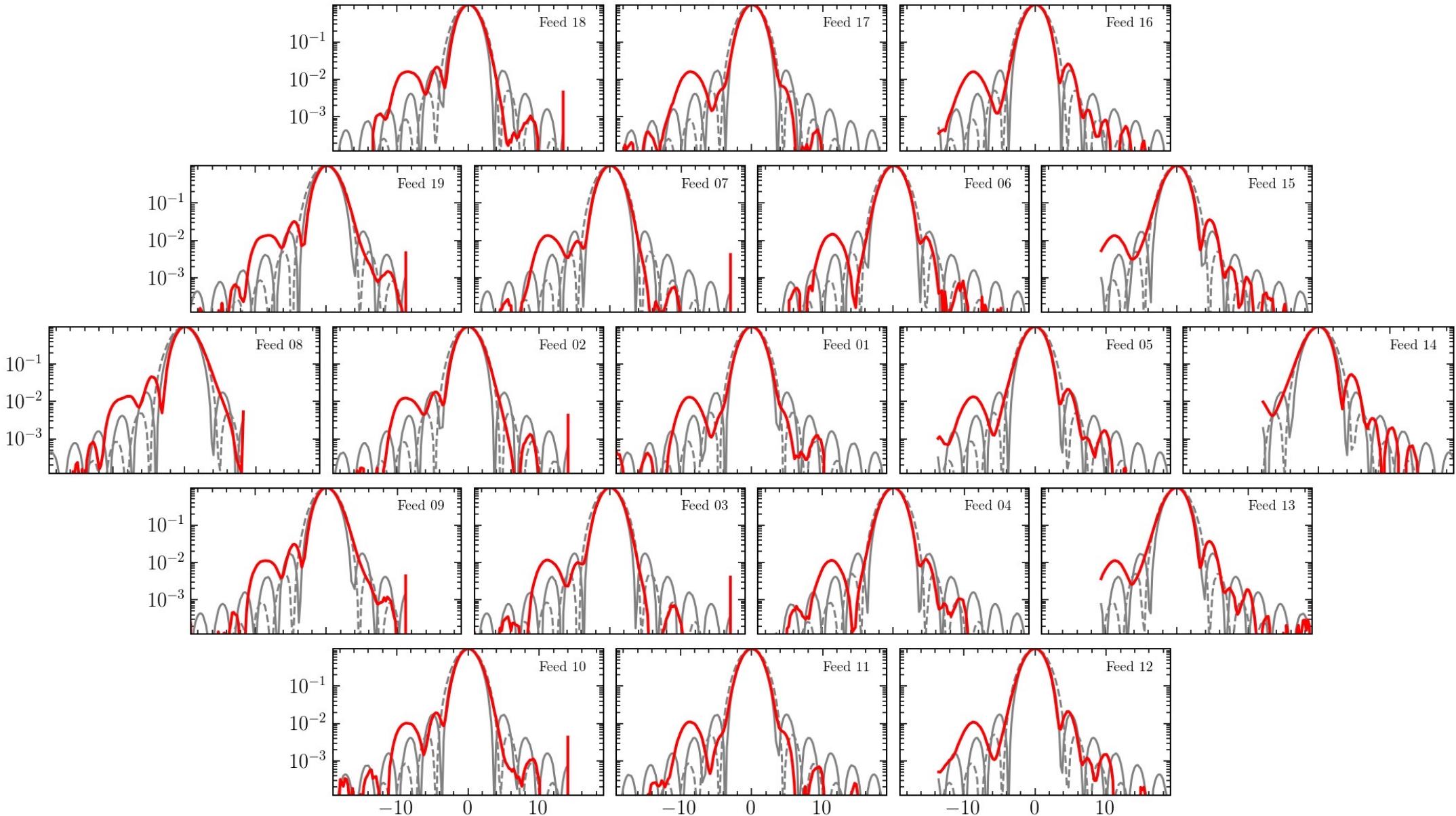
# Gain |



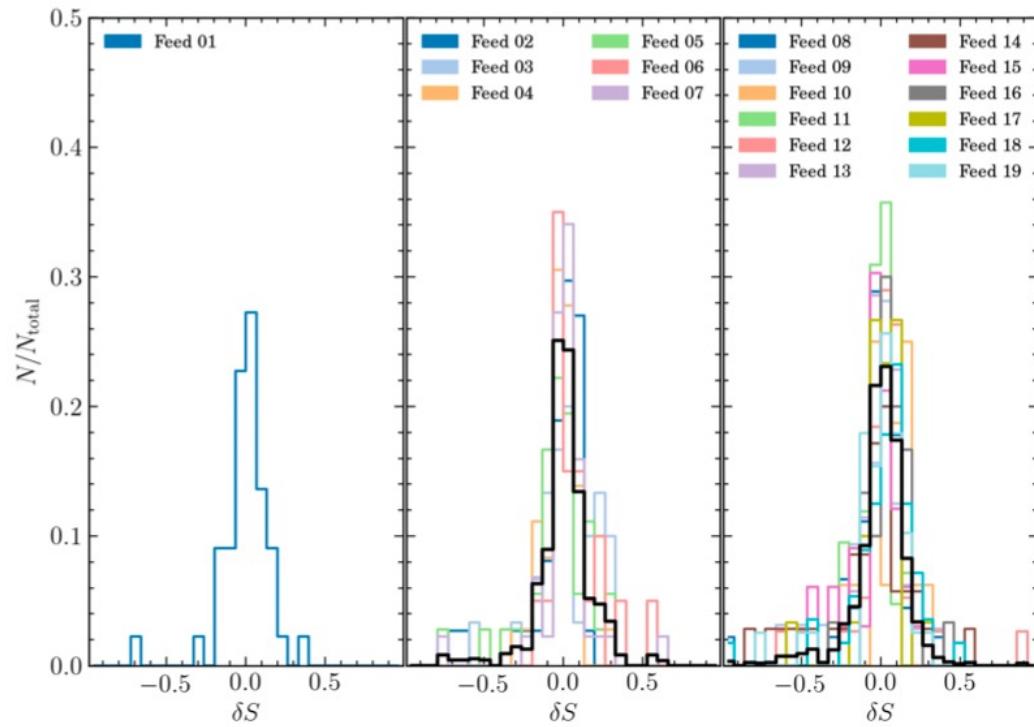
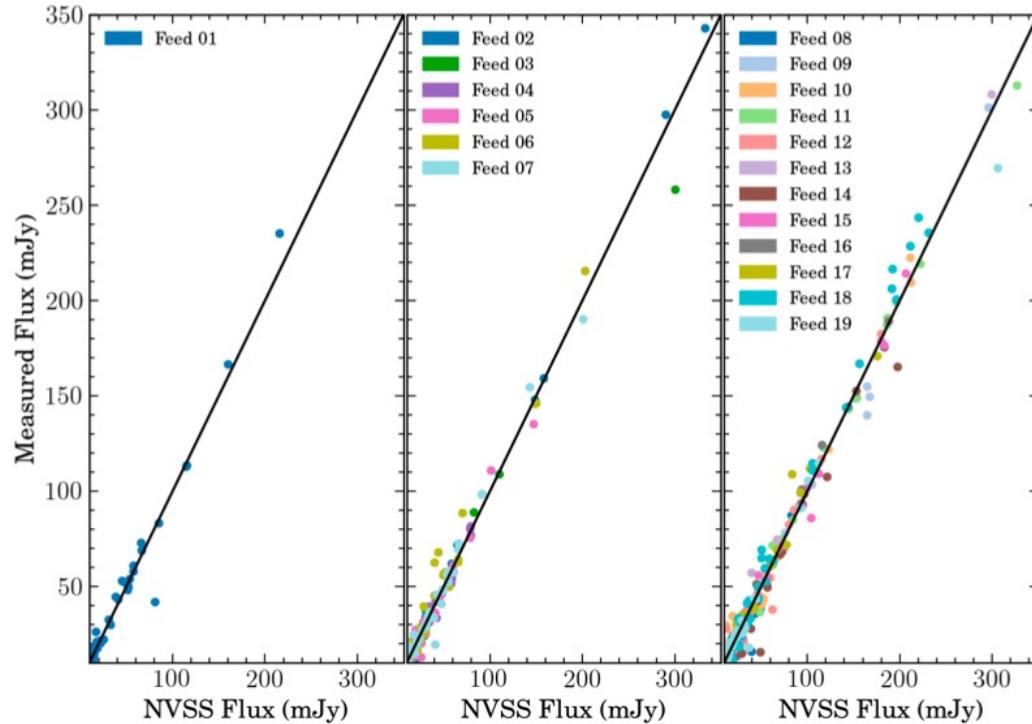
# FAST Beam



# FAST Beam



# Flux comparison



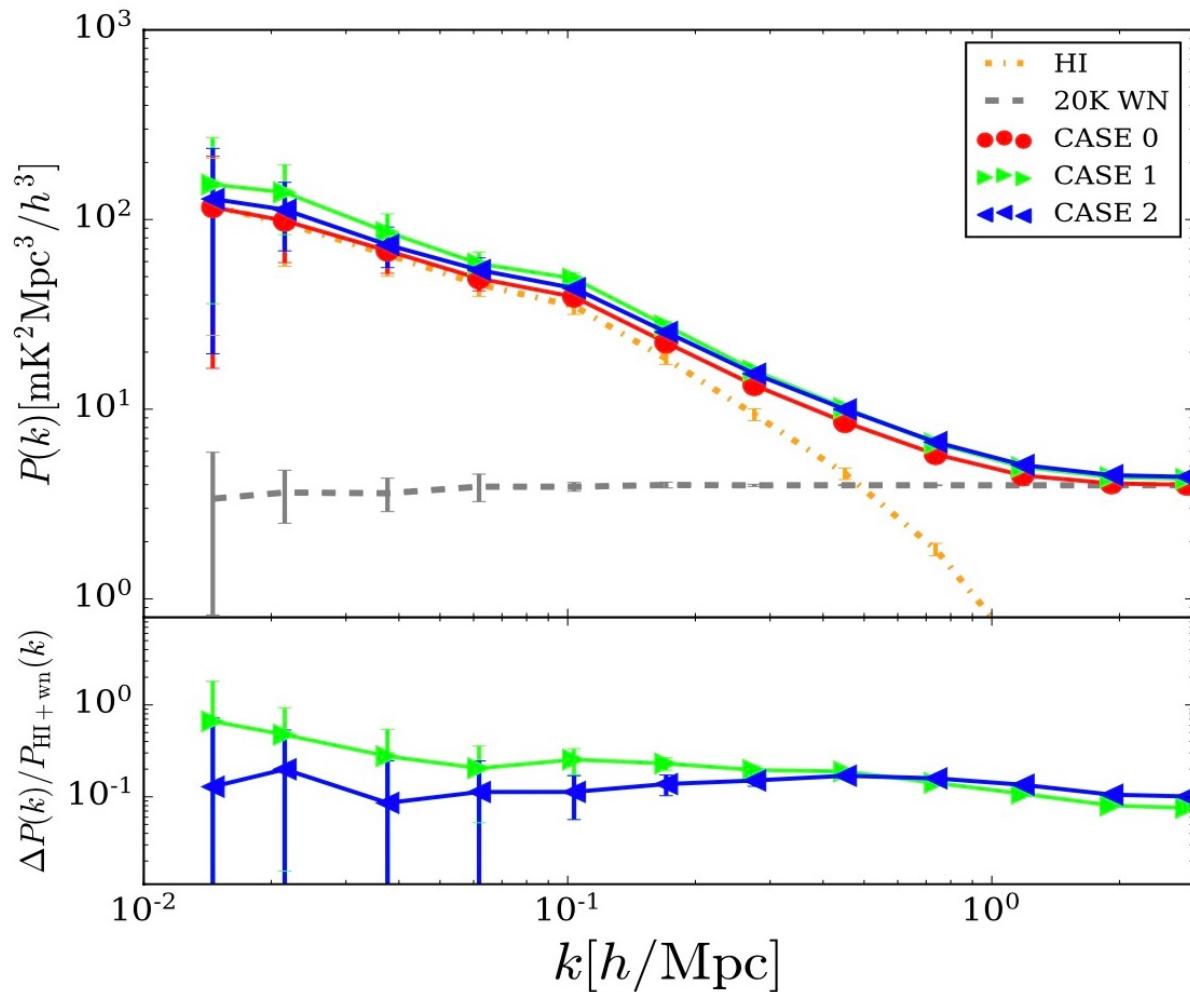
# 1/f noise

We compare the simulated noise for the following cases:

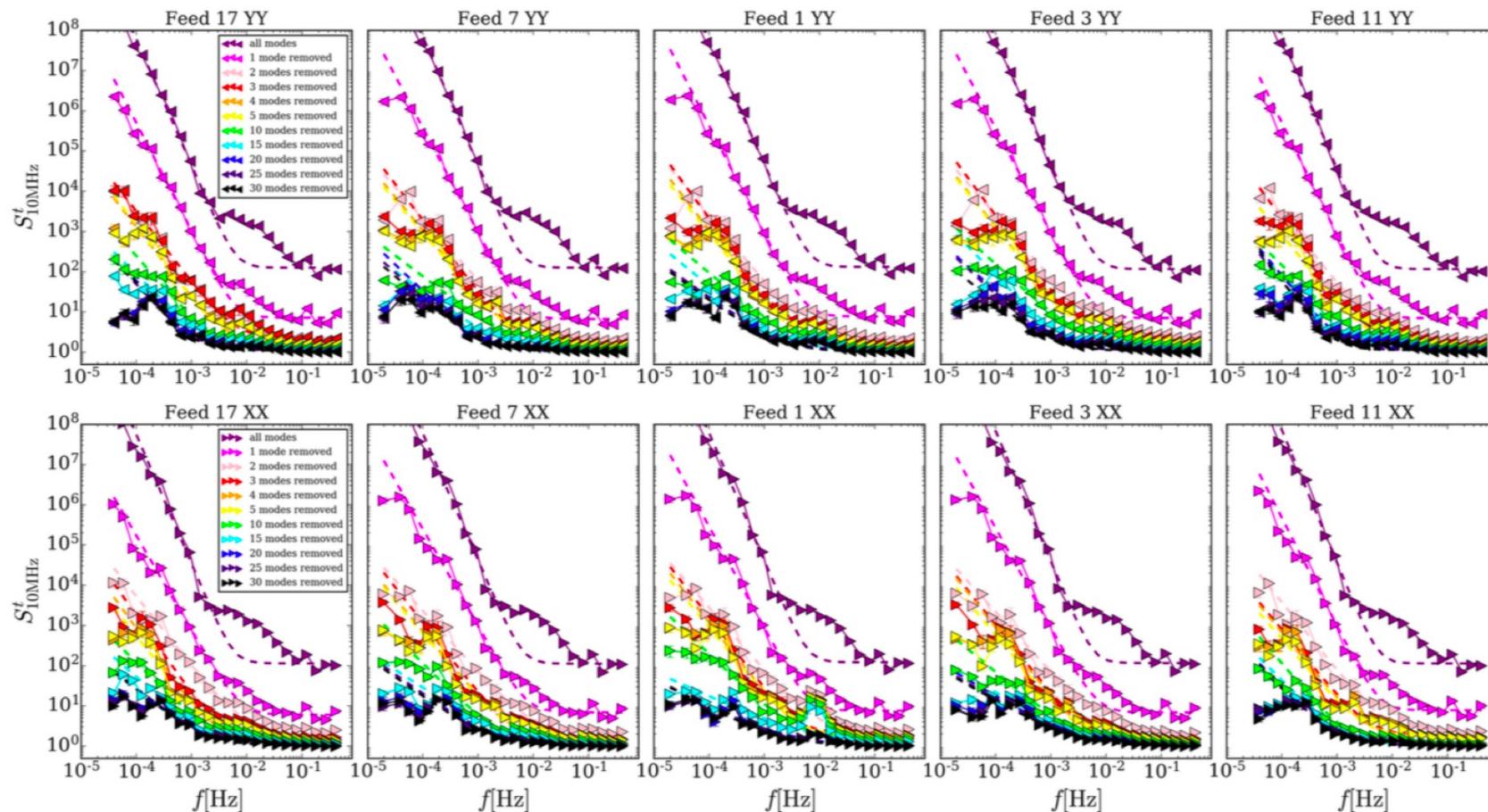
(CASE 0) 20K white noise;

(CASE 1) 20 K white noise and 1/f-type fluctuations, using the noise parameters after subtracting 20 modes

(CASE 2) Same as above, except after subtracting 30 modes.

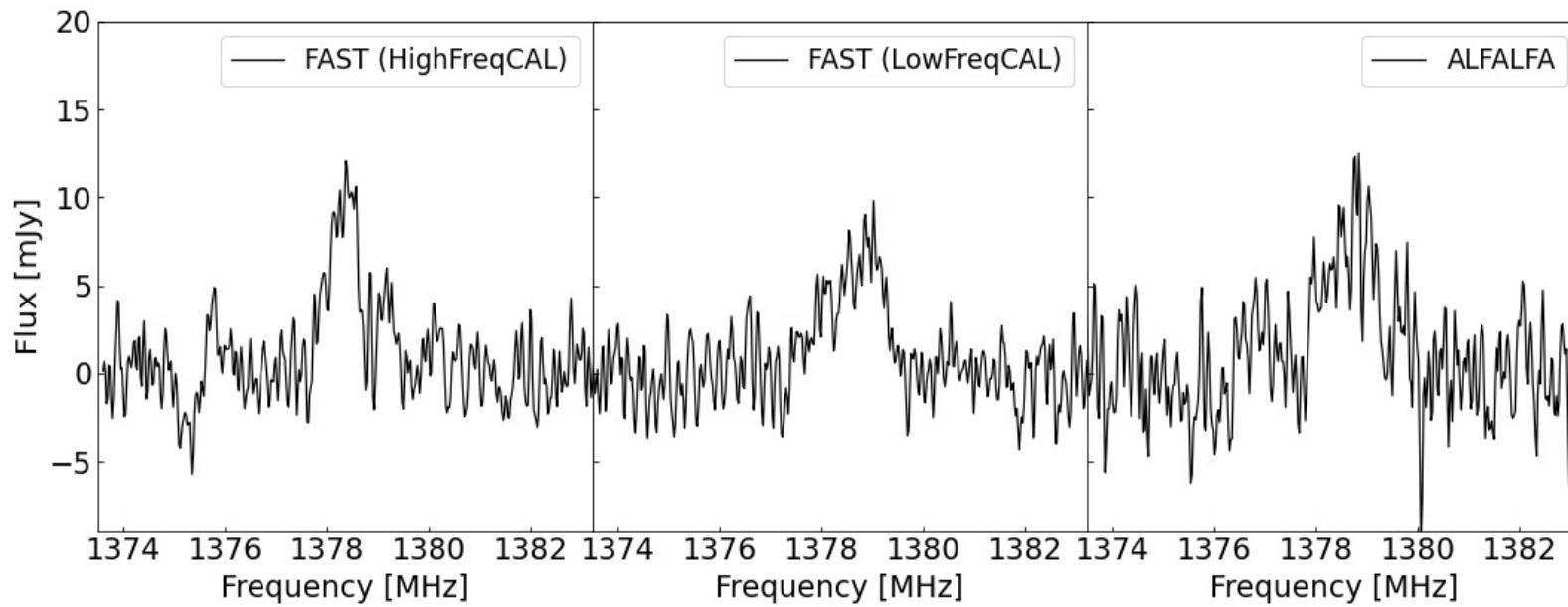


# 1/f noise



Within 1000 seconds, the white noise dominated, beyond this time, the 1/f noise will dominate. (Hu et al. 2021)

# Comparison with ALFALFA



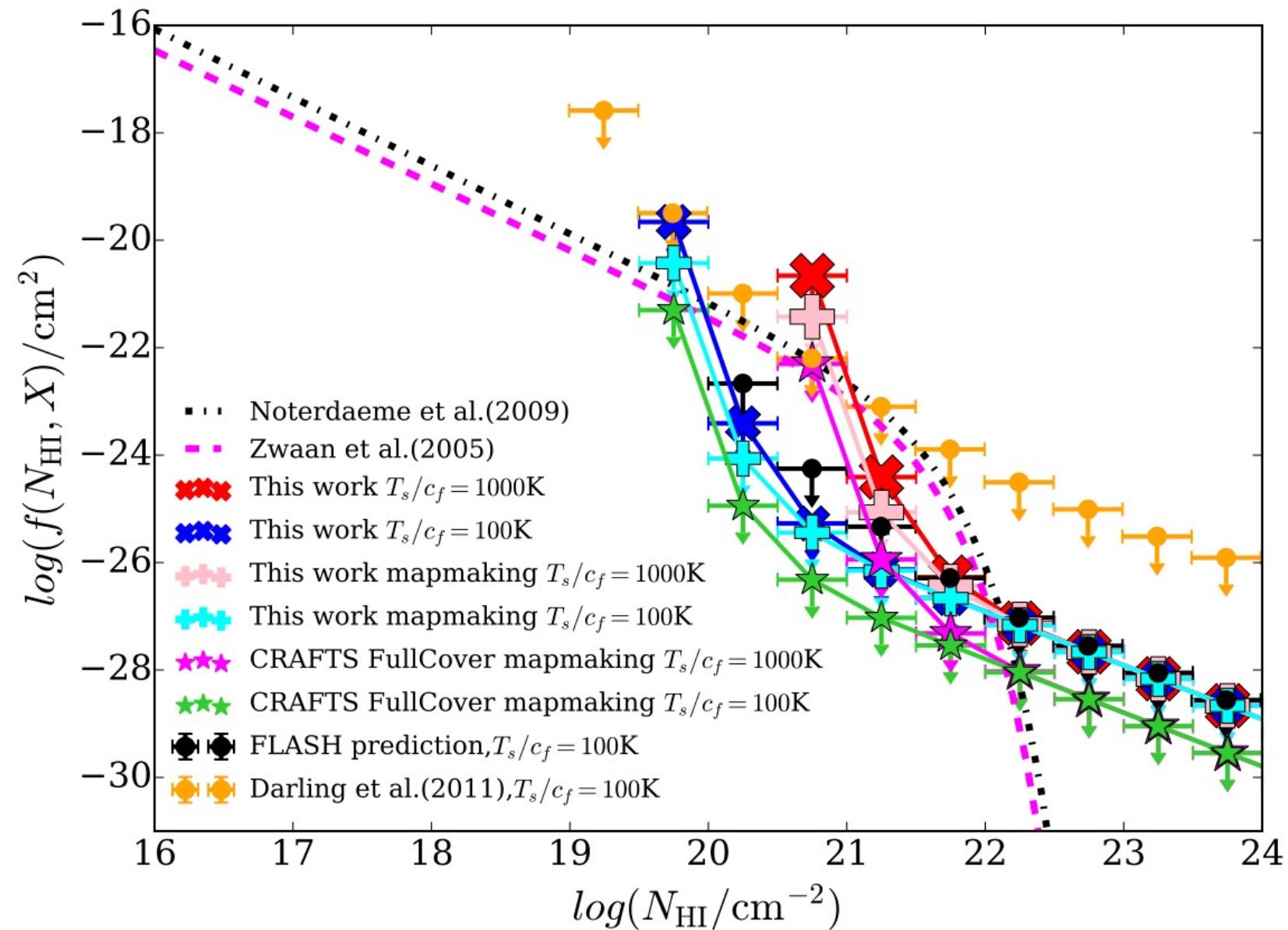
AGC201847	High Cadence	Low Cadence	ALFALFA
Flux (Jy·km/s)	1.88	1.74	1.97
S/N	25.4	24.7	17.13
rms(mJy)	1.74	1.67	2.62

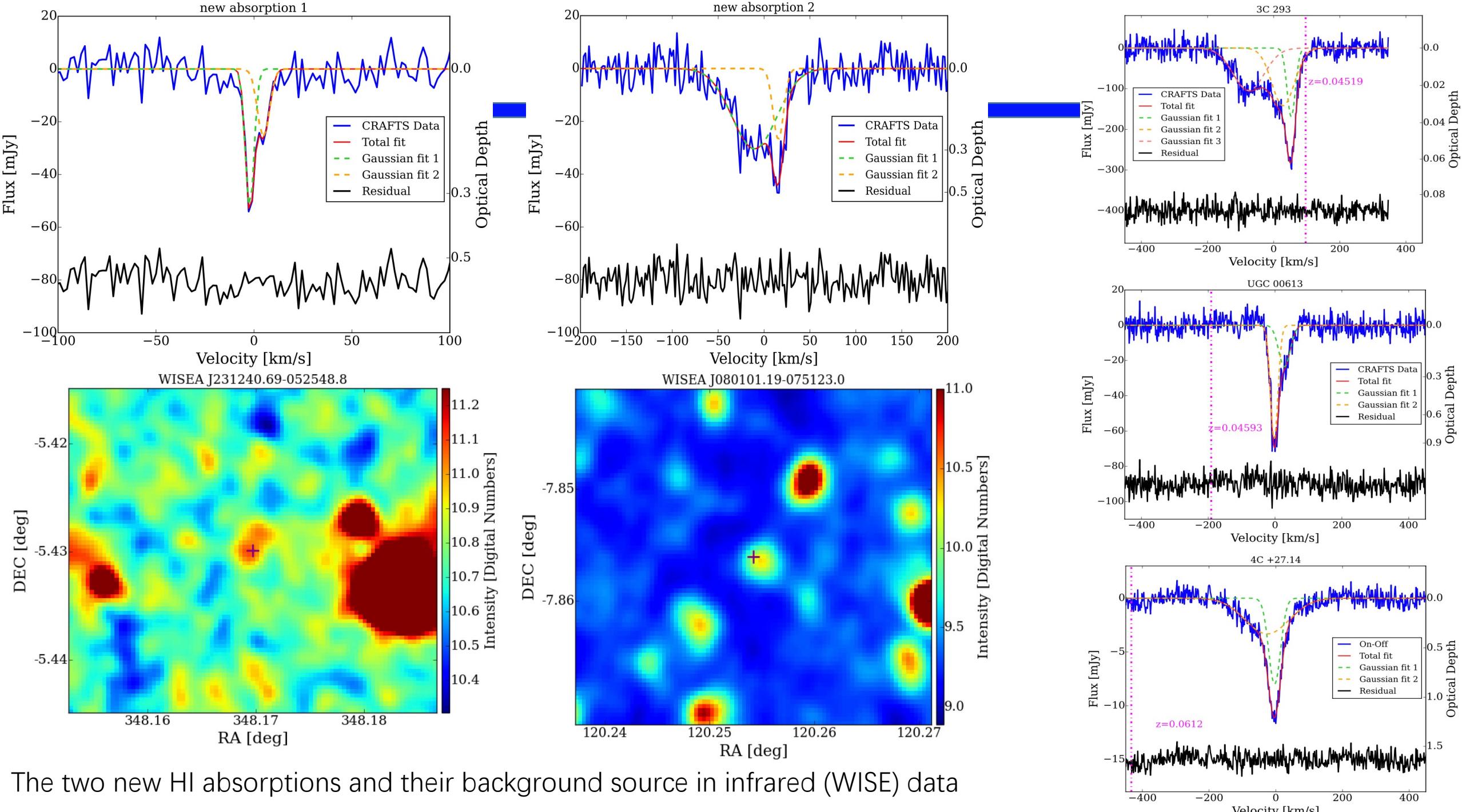
# Blind HI absorption searching in CRAFTS



The 95 percent upper limits on the HI column density frequency distribution ( $f(N_{\text{HI}}, X)$ ), for FAST HI absorption searching.

Three known HI absorbers (UGC 00613, 3C 293 and 4C +27.14) and two new HI absorbers are detected blindly. More are in prepared !





# Future work



- Data reduction (RFI flagging, foreground removing, et al.)  
in our observation data
- Mapping for the large area with CRAFTS
- Cross-correlation between the HI map with the SDSS galaxies
- Blind survey for the HI galaxies and absorbers
- Related sciences (DM properties, HI cosmic density, galaxy physics, et al.)