HI absorption blind survey in CRAFTS

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Absorption (Lyman series, 21-cm lines):

arising from foreground gas absorbing the flux of background bright source

detectability of the HI absorption depends only on the column density of foreground gas and strength of the background radio sources.

Could be a complement to the observation of the HI emission at higher redshifts.

The light emitted by a quasar that is absorbed by HI gas clouds and galaxies =>

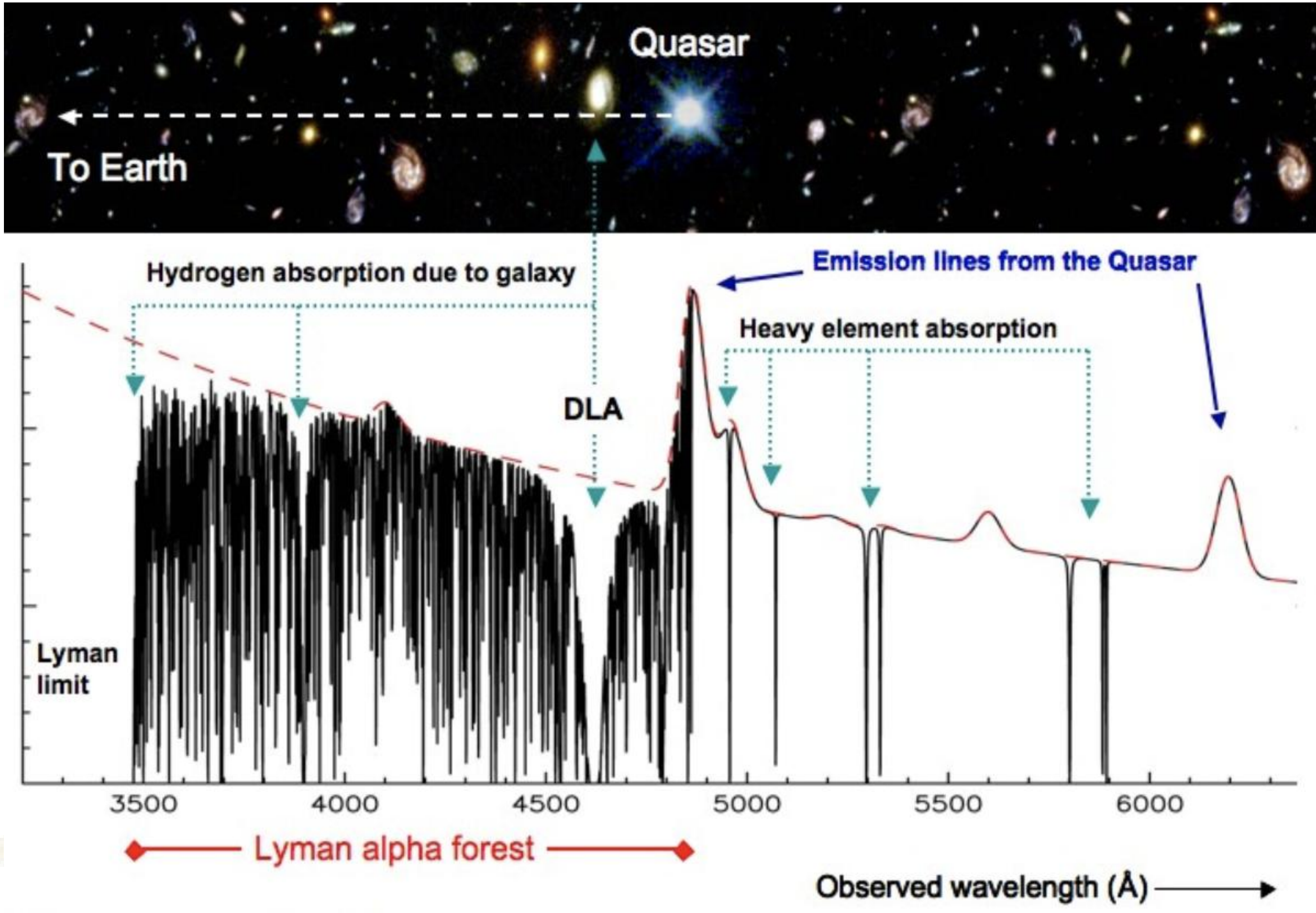
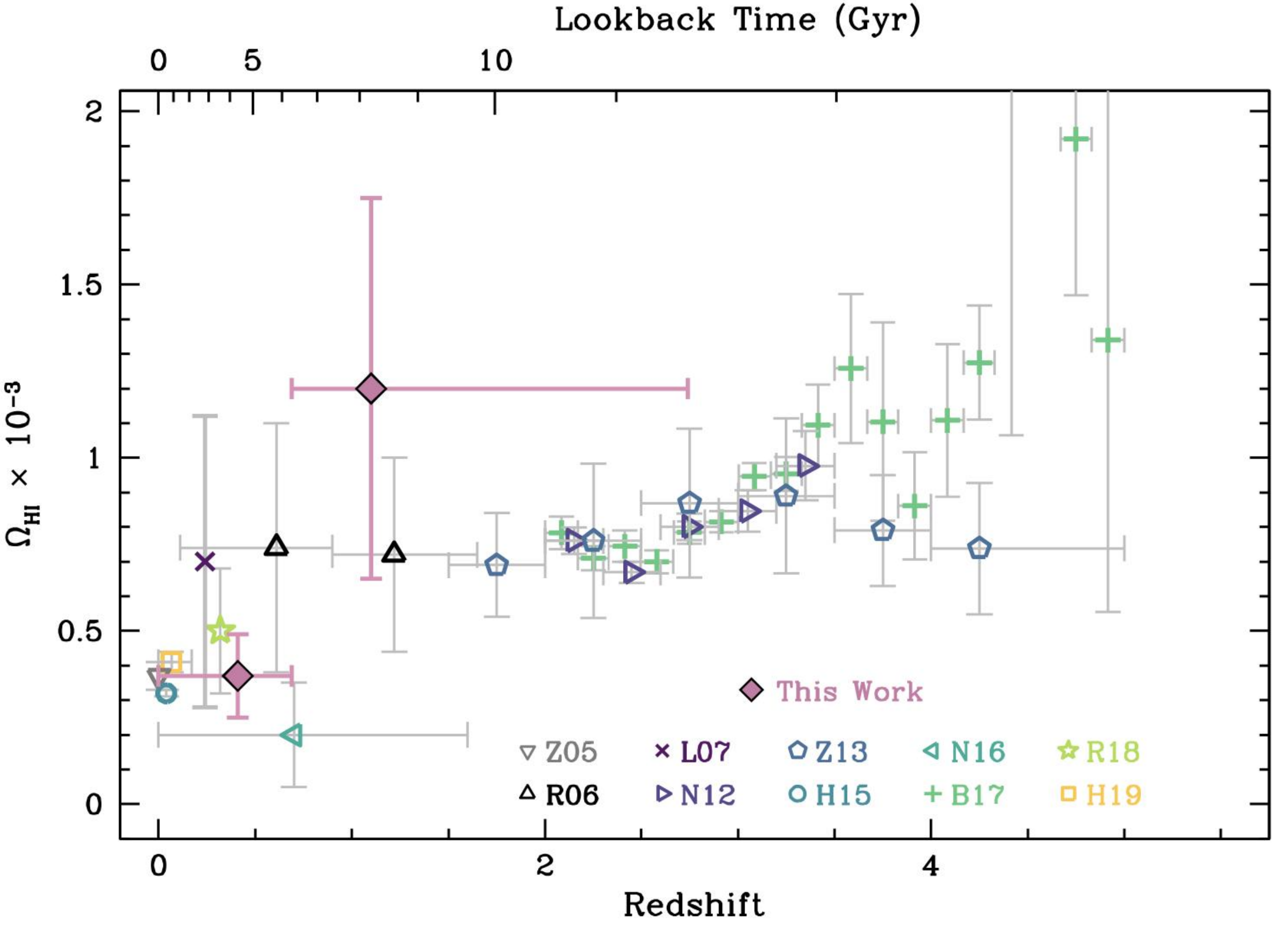


Illustration courtesy of John Webb

N16:DLA survey with the HST
R06:DLA survey from the HST;
N12: DLA survey from the SDSS-DR9
Z13:VLT/UVES survey of DLAs
B17:DLA survey from the SDSS-DR12

Others: HI emission



(Grasha et al. 2020 : a blind search for intervening HI 21 cm absorption towards bright radio sources)

Absorption Type

Associated absorption :

the absorbing gas is loacted in the same object that emits the background bright continuum.

concentrate on the object (usually an AGN) and its interaction with the ISM within the same object.

some discoveries, still limited by small sample sizes, and there is a lack of observational evidence for HI playing a role in fuelling the central SMBH.

Intervening absorption :

results from gas in a foreground object absorbing the flux of a bright background source that is not related.

investigate the ISM in both our Galaxy and distant galaxies (DLAs).

Searching HI absorption: targeting at bright QSOs. The blinding light of the background QSOs makes it difficult to observe the optical emission from the DLA system itself.

The physical nature of the DLAs remains an unsolved problem.

Unbiased blind radio absorption searches:

enables a detailed study of DLA without interference from a bright background, and produces a more comprehensive depiction of the interaction between the ISM and host galaxy.

For now:

untargeted blind radio searches : 2 HI absorbers (towards UGC 6081 and 3C 286)

targeted blind radio searches : 18 HI absorbers, among which 16 still have bright optical QSO

FLASH (the First Large Absorption Survey in HI) :

FLASH will be carried out with the Australian Square Kilometre Array Pathfinder (ASKAP) radio telescope and is planned to cover the sky south of $\delta \approx +40^{\circ}$ at frequencies between 711.5 and 999.5 MHz ($0.4<z<1.0$).

MALS (The MeerKAT Absorption Line Survey) :

1655 hrs for the sensitive search of HI 21-cm and OH 18-cm absorption lines to map the evolution of cold atomic and molecular gas in galaxies at $0<z<2$: the redshift range where most of the evolution in the star-formation rate density takes place.

SHARP (Search for HI absorption with APERTIF) :

using the broad band of APERTIF (300 MHz) over the frequency range 1050 - 1400 MHz (redshift 0 - 0.3) combined with the large field of view to perform a blind search for HI absorption against radio sources

The FAST can play an important role in blind survey of HI absorption.

Spherical reflector: Radius = 300 m,
Aperture = 500 m
Illuminated aperture: Dill = 300 m
Sky coverage: +-40° from zenith angle
(FullCover ~ 24000 deg^2)
Resolution (L-Band): 2.9'
Pointing accuracy: 8"

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

receivers relevant for HI

CRAFTS Data

Commensal Radio Astronomy FasT Survey (CRAFTS) :
a multi-purpose drift-scan survey using the FAST L-band Array of 19 feed-horn

two passes of drift-scans in plan
with the 19-beam feed rotated by 23.4° to achieve a super-Nyquist sampling.
Sky cover: over 24000 deg2 (DEC : −14◦ and 66◦)
redshift : up to 0.35

Limited by the allocated time, there is only one survey pass at present.

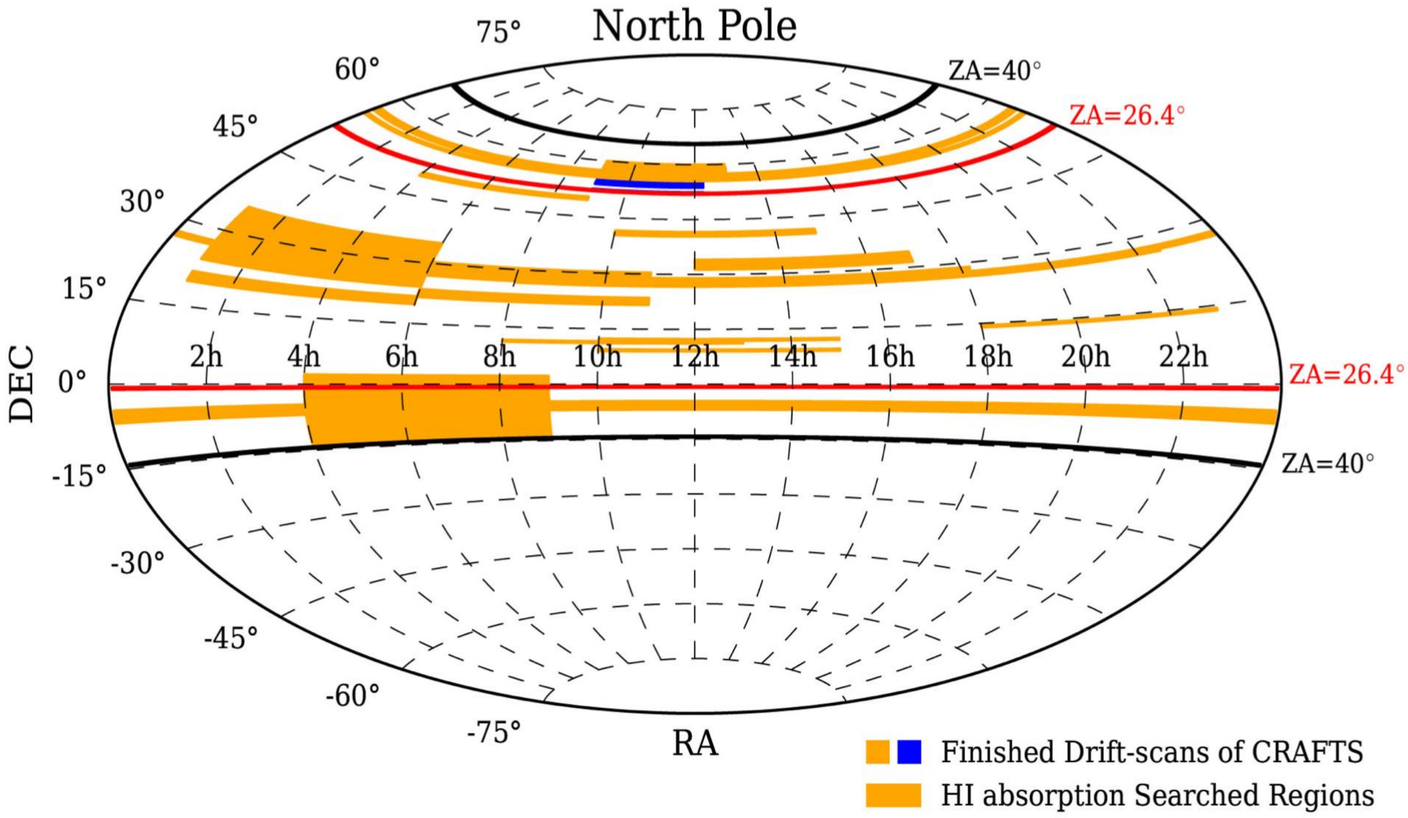
Considering our scientific objectives and computing capacity, we further rebin the data into a time resolution of 12/ cos δ s (~ the transit time in drift scan), where δ is the declination of the pointing

CRAFTS Data

Totally blind searching

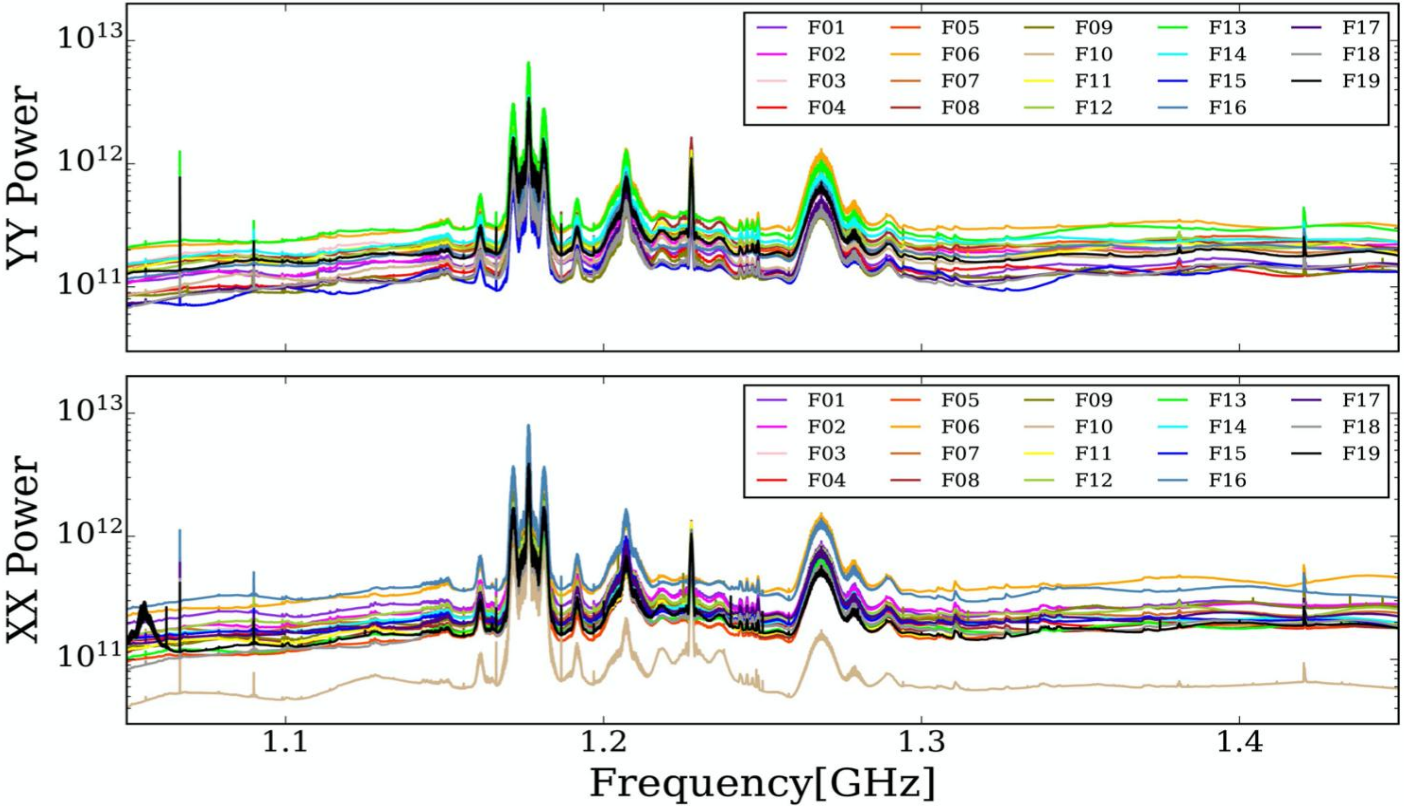
~5000 deg^2, all frequency band is searched (more detections) by now.

~3155 deg^2 region, 1300-1450MHz is searched (5 detections) for HI absorption in the first paper (Hu et al 2023, A&A);



The CRAFTS sky coverage in Equatorial coordinates, as up to 2022-05-07

CRAFTS Data



The raw time-averaged frequency spectra for the 19 feeds of the FAST L-band multi-beam receiver feeds.

Data Processing

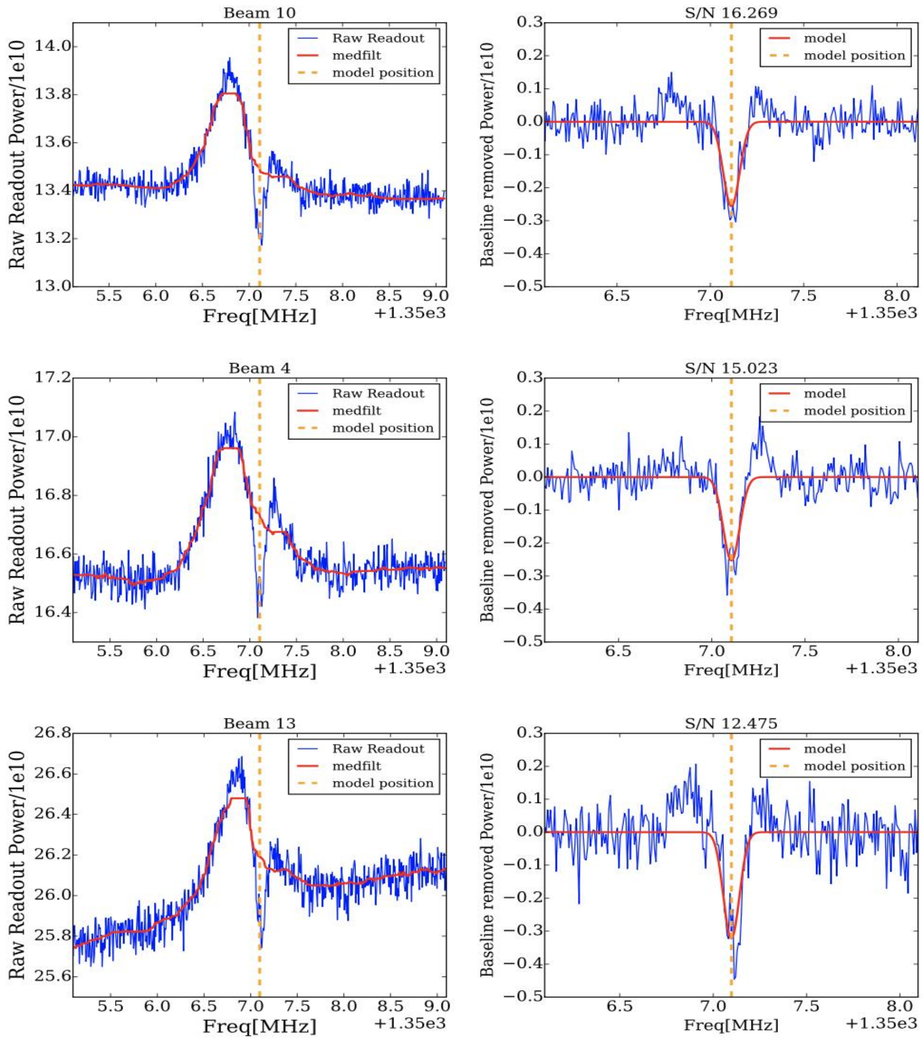
1. Spectra at each time point were extracted from the data cubes;

2. Removal of the baseline of the bandpass (medfilt function);

3. The matched-filtering approach was applied to find the absorption profiles;

4. Selecting candidates with total S/N > 5.5 and also detected in both XX and YY polarizations at the same frequency ($\Delta\nu < 0.05$MHz) with S/N > 3.5.

5. The final candidates are selected by use of the transit information recorded by the 19-beams of FAST.



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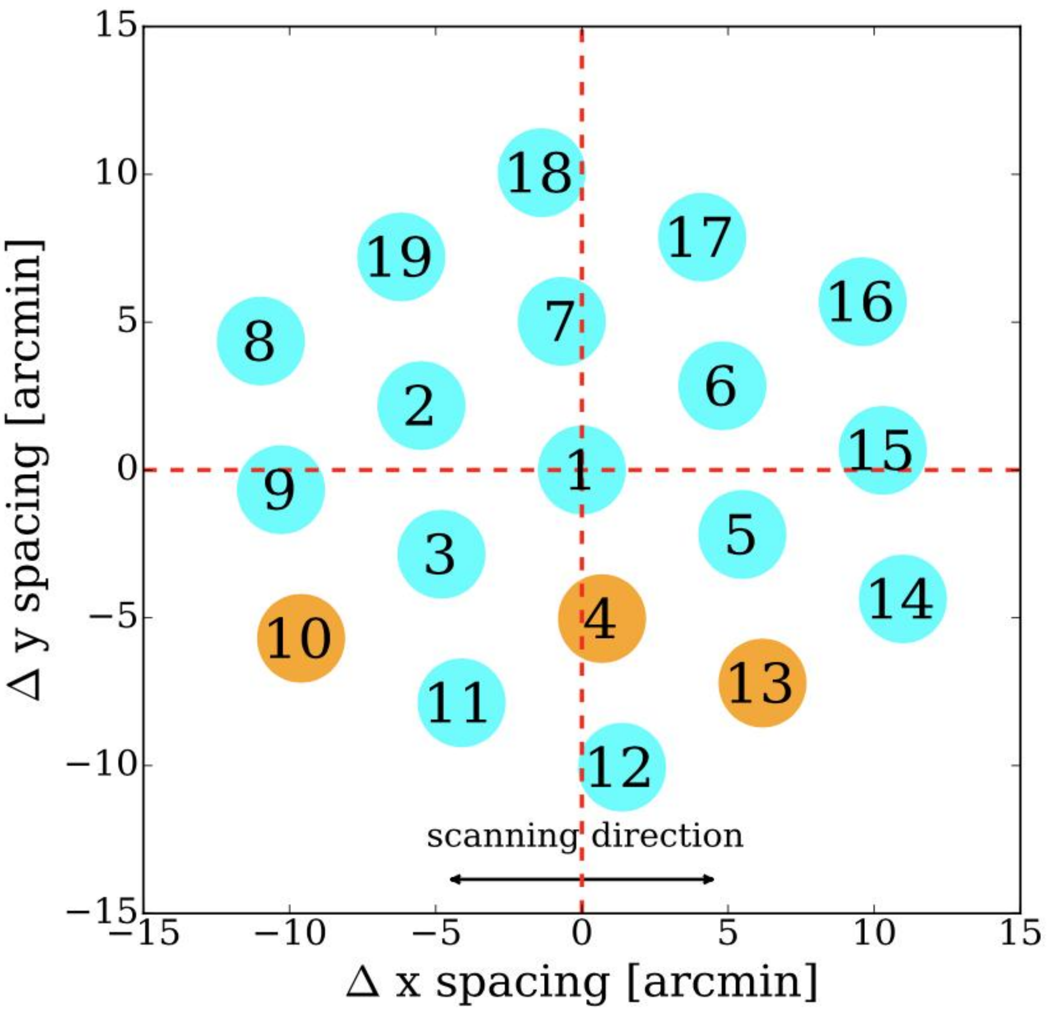
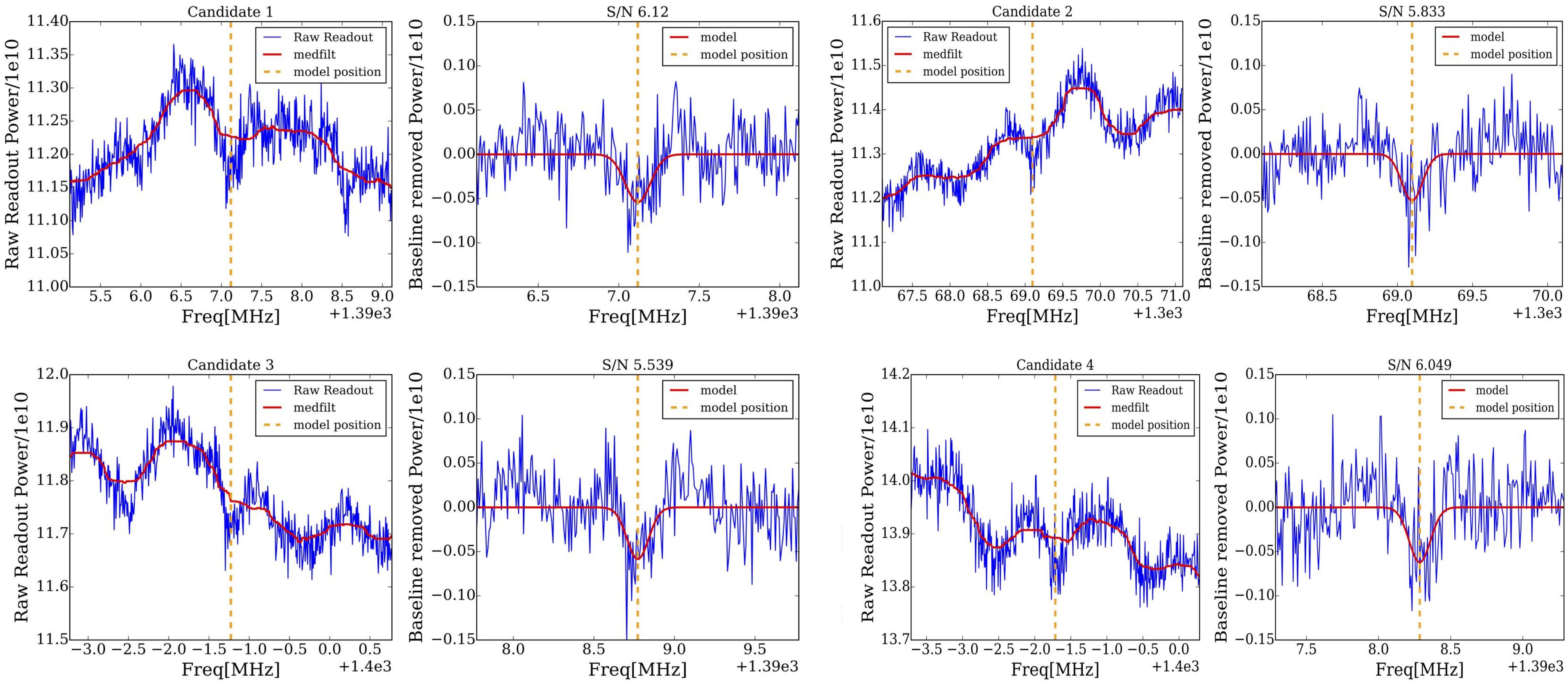
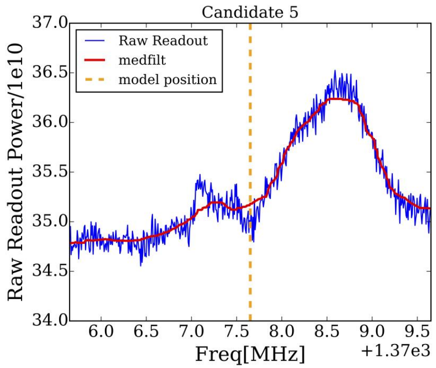


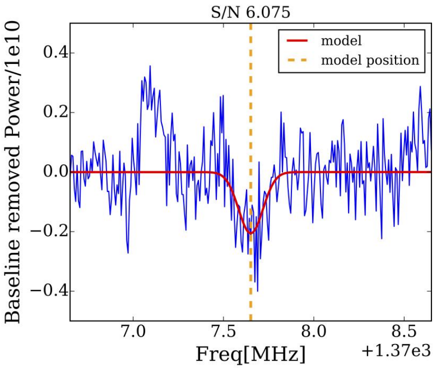
The spectra of the (previously known) Hi absorption system UGC 00613.

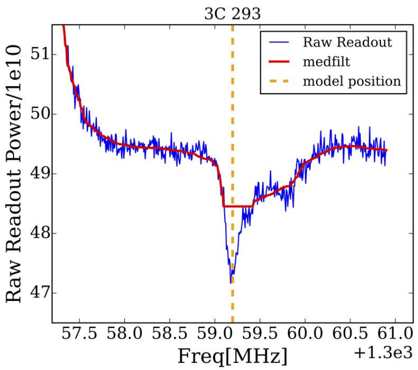
Results

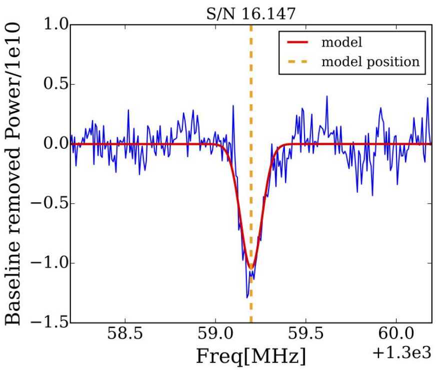
After processing the data, we find 10 candidates, including 3 previously known ones: UGC 00613, 3C 293 and 4C +27.14. The spectra of these 10 candidates (UGC 00613 has been shown before)

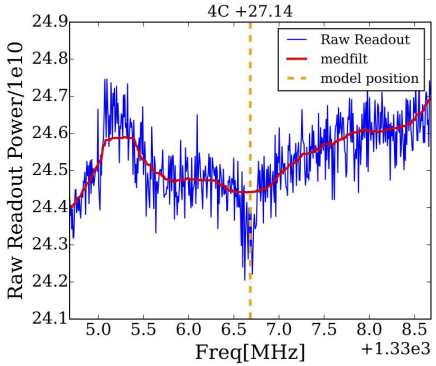


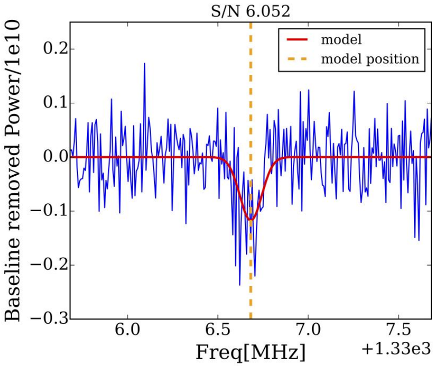

Candidate 5
Raw Readout
medfilt
model position
Raw Readout Power/1e10
Freq[MHz]
+1.37e3


S/N 6.075
model
model position
Baseline removed Power/1e10
Freq[MHz]
+1.37e3


3C 293
Raw Readout
medfilt
model position
Raw Readout Power/1e10
Freq[MHz]
+1.3e3


S/N 16.147
model
model position
Baseline removed Power/1e10
Freq[MHz]
+1.3e3


4C +27.14
Raw Readout
medfilt
model position
Raw Readout Power/1e10
Freq[MHz]
+1.33e3


S/N 6.052
model
model position
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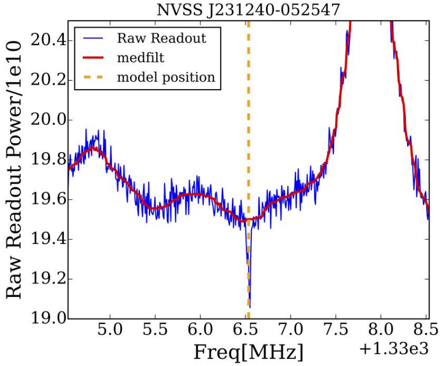
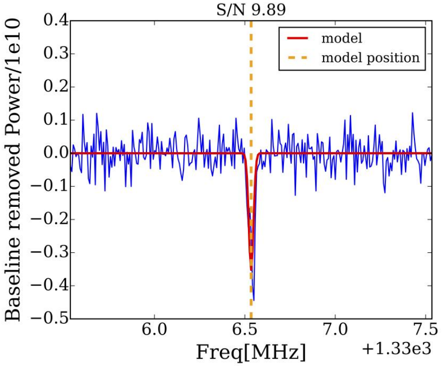
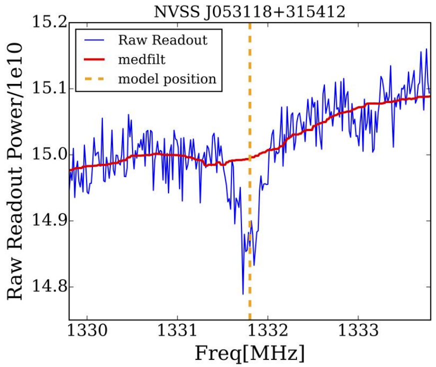
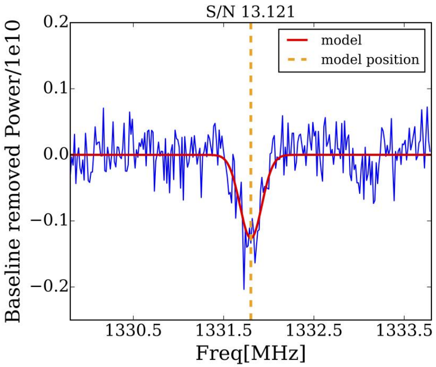
Freq[MHz]
+1.33e3


NVSS J231240-052547
Raw Readout
medfilt
model position
Raw Readout Power/1e10
Freq[MHz]
+1.33e3


S/N 9.89
model
model position
Baseline removed Power/1e10
Freq[MHz]
+1.33e3


NVSS J053118+315412
Raw Readout
medfilt
model position
Raw Readout Power/1e10
Freq[MHz]


S/N 13.121
model
model position
Baseline removed Power/1e10
Freq[MHz]

Verifying using follow-up observation

FAST follow-up observations: ON-OFF tracking observation mode, with 990 s integration on each.

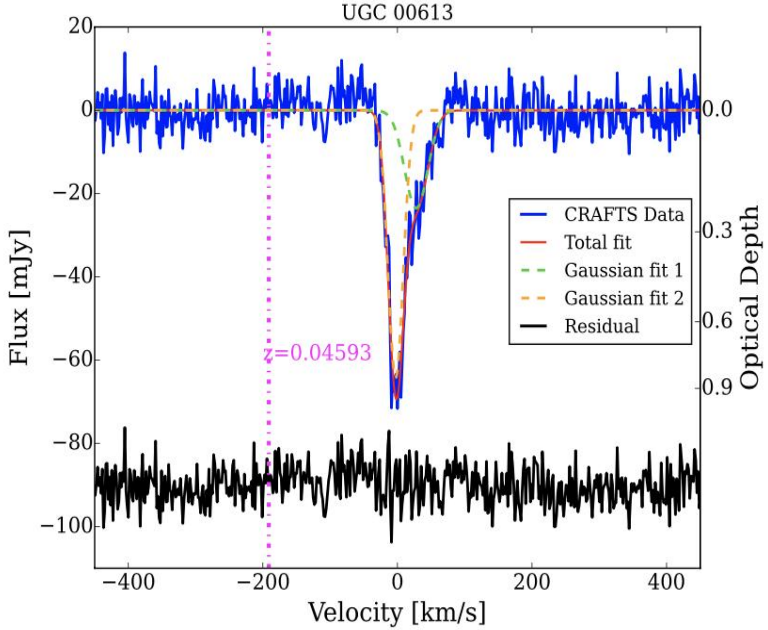
Besides the 3 previously known ones, 2 are confirmed to be new absorbers (along the l.o.s. towards NVSS J231240- 052547 and NVSS J053118+315412)

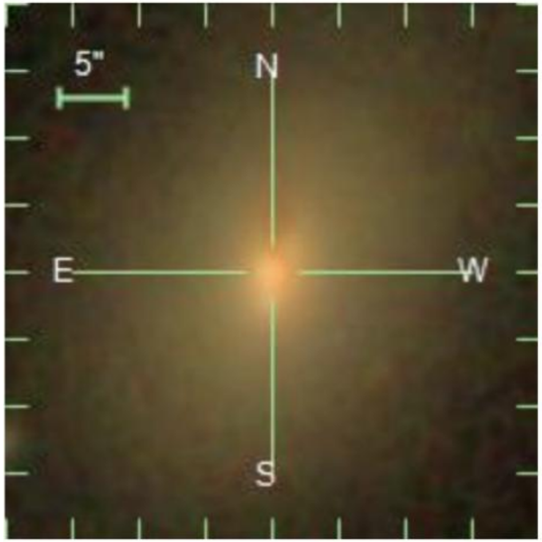
The other 5 candidates : fluctuations in the bandpass, or the combined features from the HI emission and bandpass ripples.

We fit the profiles of the true HI absorptions with multi-components Gaussian functions.

Known absorptions

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

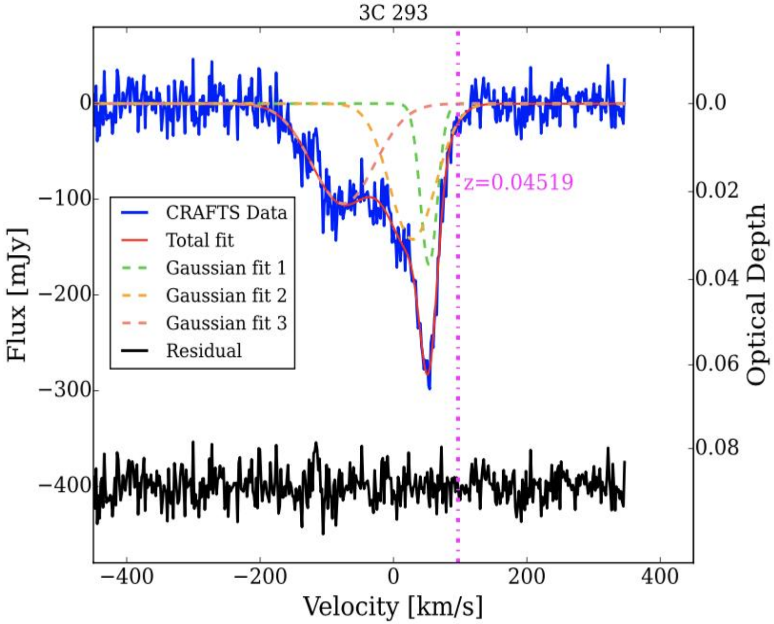


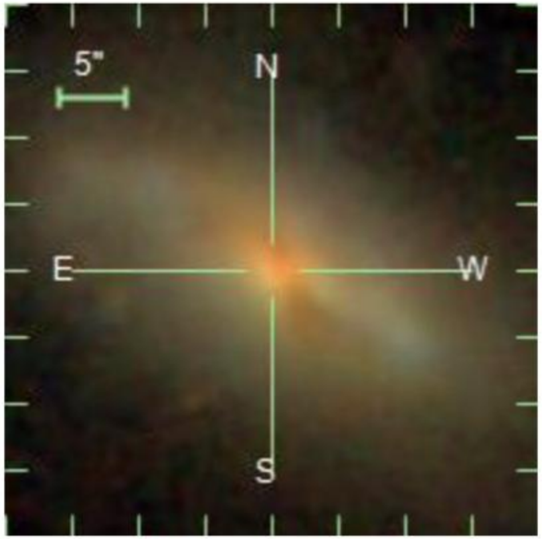


UGC00613 (associated absorption system) is a flat-spectrum extended radio source which probably locates in a unrelaxed, merging system.

Known absorptions

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

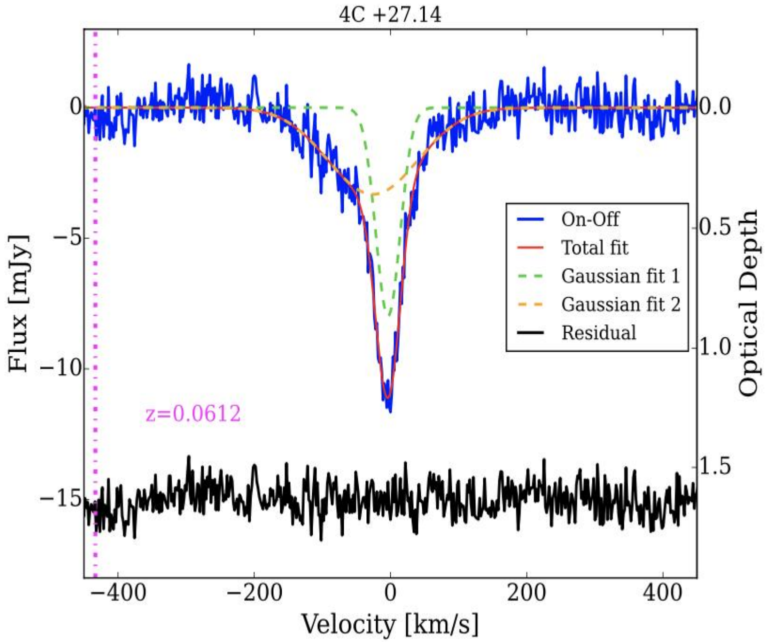




3C 293 (associated absorption system) is a Fanaroff and Riley type II (FR II) radio galaxy, with a compact core of steep spectrum and multiple knots in the radio lobe. The outflow of HI had also been detected, which is probably driven by the radio jet. It's also a disk galaxy with an optical jet or tidal tail toward its companion galaxy. Extremely broad and multi-components HI absorption feature, indicating a rotating HI disk.

Known absorptions

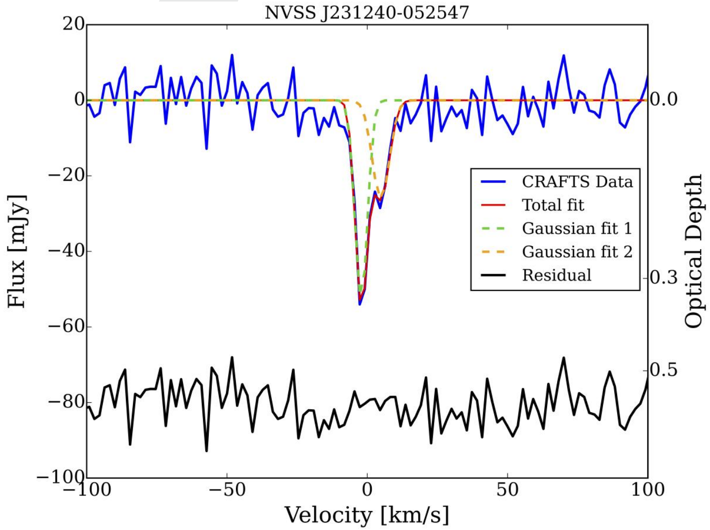
Three known HI absorbers (UGC 00613, 3C 293 and 4C +27.14) and two new HI absorbers are detected blindly.

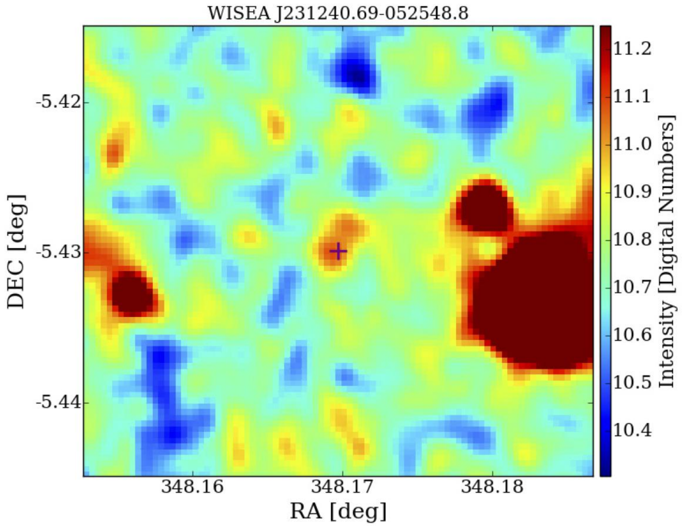


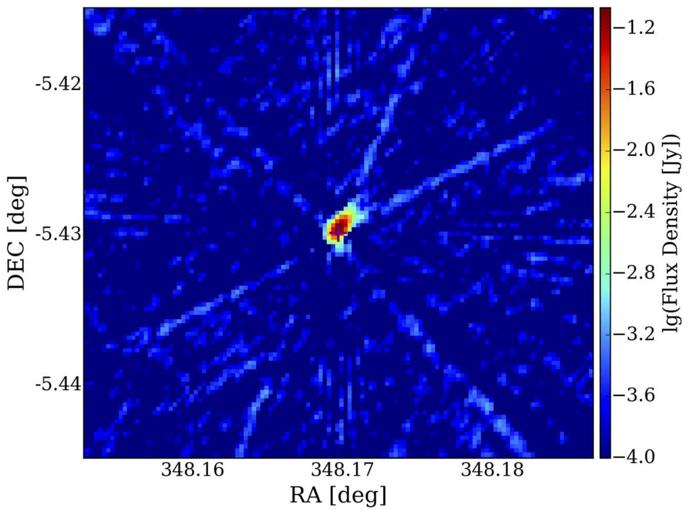
4C +27.14 (associated absorption system) is a Type II Seyfert galaxy and displays the properties of radio loud active galactic nucleus (AGN).

New absorptions

Towards NVSS J231240-052547, at z ~ 0.063.







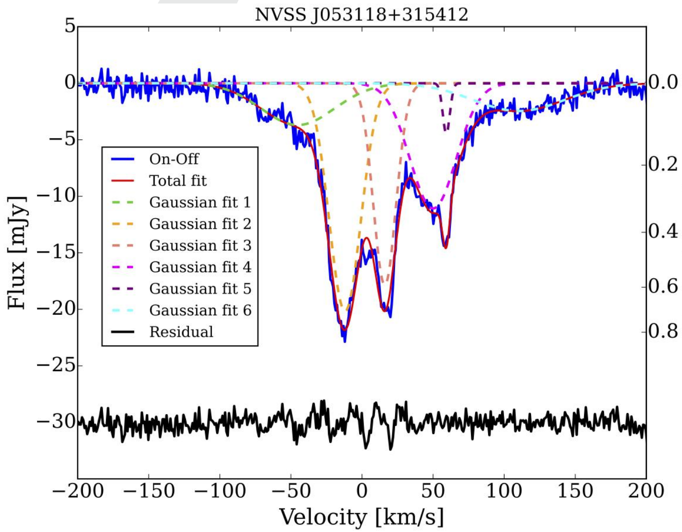
NVSS J231240-052547:S(1.4GHz):181.9 mJy, S(abs):−54.04mJy, FWHM:9.12km/s, N_HI:0.05Ts×10^20 cm^-2 K^-1.

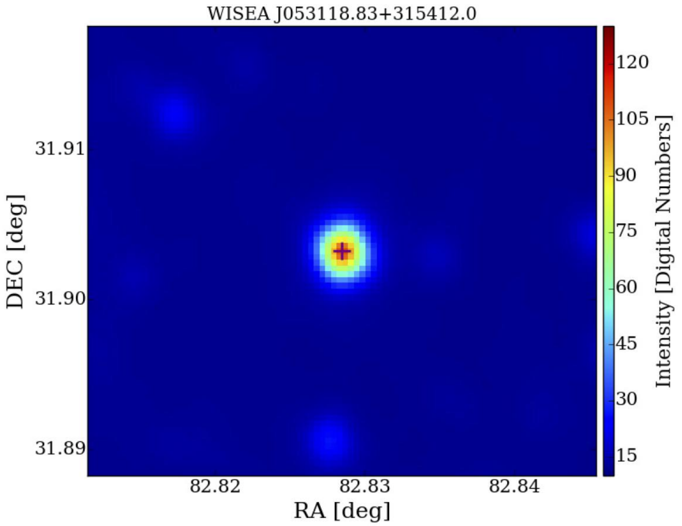
W1[3.4μm] : 16.937, W2[4.6μm] : 16.110, W3[12.1μm] : 12.358, W4[22.2μm] : 9.016. W1-W2 = 0.827, indicates that is an AGN candidate. W2-W3 = 3.752 mag, may be Seyferts and the Ultra-luminous Infrared Galaxies (ULIRGs) according to WISE color–color diagram.

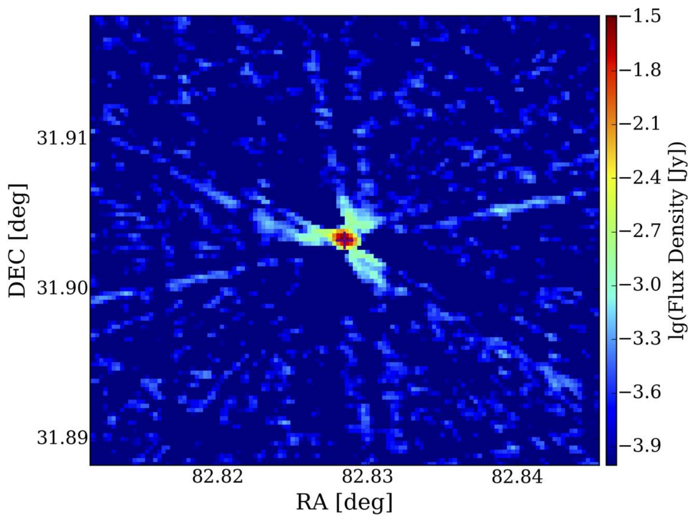
Optical counterpart (SDSS J231240.73-052541.1), photoZ = 0.091 ± 0.036.
u = 20.66, g = 19.68, r = 19.37, i = 19.16 and z = 19.09.

New absorptions

Towards NVSS J053118+315412, at z ~ 0.066.







NVSS J231240-052547:S(1.4GHz):40.2 mJy, S(abs):−21.85mJy, FWHM:89.53km/s, N_HI:1.016Ts×10^20 cm^-2 K^-1.

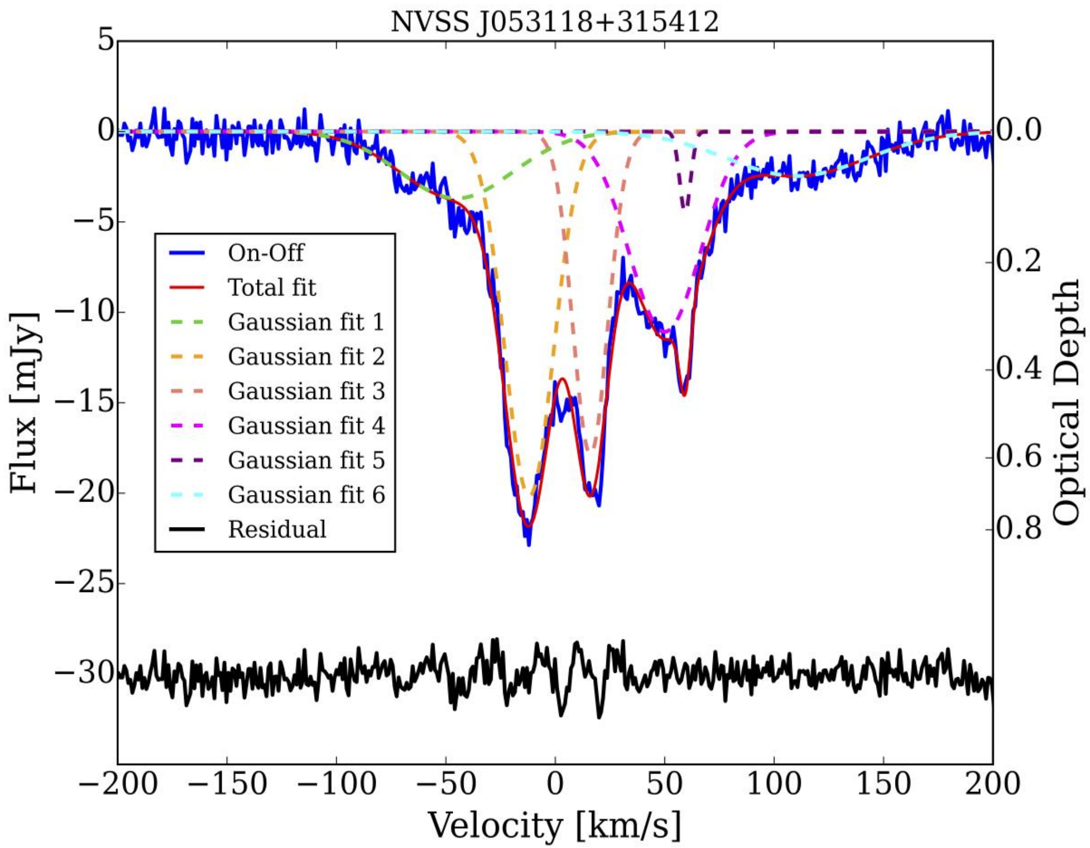
W1[3.4μm] : 11.607, W2[4.6μm] : 9.977, W3[12.1μm] : 6.379, W4[22.2μm] : 3.613. W1-W2 = 1.630, indicates that is an AGN candidate. W2-W3 = 3.598 mag, may be a QSO according to WISE color–color diagram.

New absorptions

Symmetric absorption spectrum (Gaussian components 2 and 3) relative to the systemic velocity of its host galaxy, suggesting that the HI gas traces a regular rotating structure.

Asymmetric absorption wings (Gaussian components 1 and 6) in the absorption profile are generally indicative of unsettled gas structures, such as gas outflows that are propelled by the radio jet or tidal gas streams.

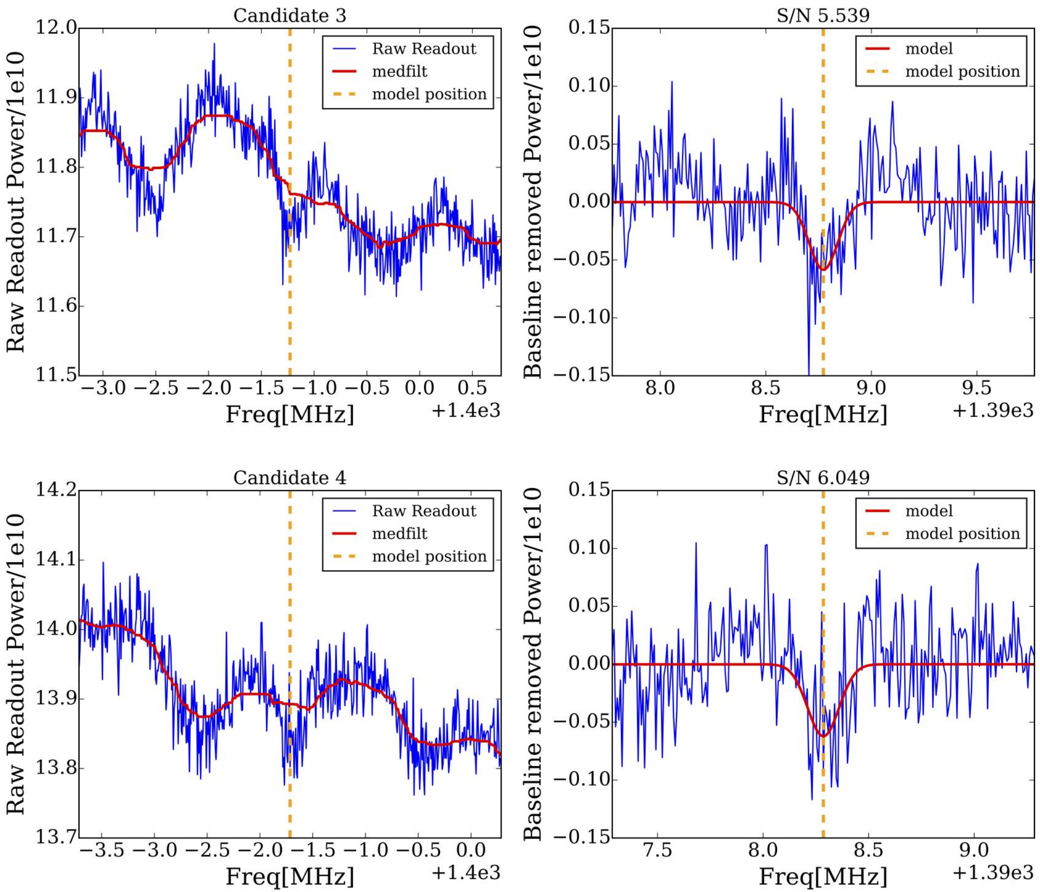
The redshifted absorption components (Gaussian components 4 and 5) could be evidence of accretion onto the SMBH.

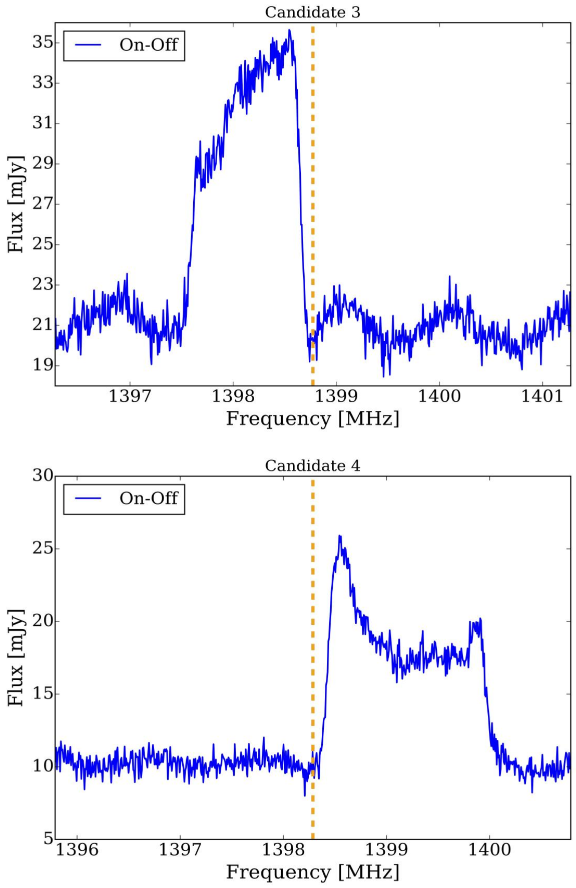


Precise identification of infalling HI can only be achieved via high-resolution observations.

False Detections

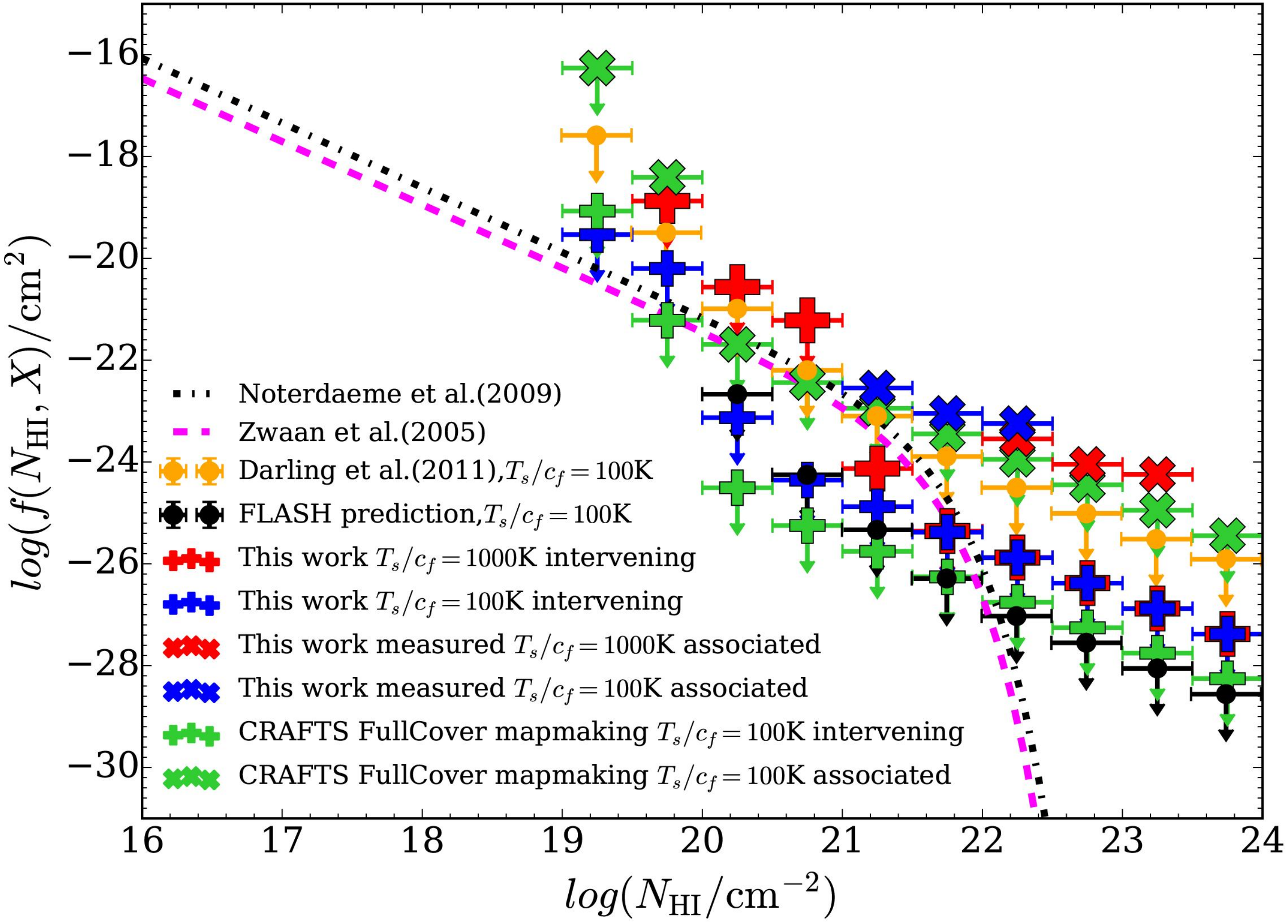
The other 5 candidates in the follow-up observations are also checked and found to be not true Hi absorptions. The spectra of these sources, together with 4C +27.14, are shown below:





N_HI Frequency Distribution Function

The 95 percent upper limits on the HI column density frequency distribution (f(N_HI,X)), for FAST HI absorption searching.



On-going and In-plan Work

Standing Waves :

A careful study on the small-scale fluctuations may help improve the calibration.
In the near future, after the 2-pass drift scan is finished, more time-varied RFI and other fluctuations can be excluded by comparing the data covering the same sky at different time.

Information from Neighboring Beams :

All of the data from the scans of the 19 beams can be utilized fully without losing information by using the linear map-making method (Tegmark 1997).
We have developed an effective map-making pipeline for FAST to combine the data from the 19 beams and make the high signal-to-noise ratio map (Y. Li et al, in preparation).

Counterparts to the Foreground and Background:

New optical telescope time are applied for follow-up observations.

More data Processing :

More data is under processing.

Radio Source	Source Type	RA(J2000)	DEC(J2000)	cz ($\mathrm{km\,s^{-1}}$)	$S_{1.4GHz}$ (mJy)
UGC 00613	Diffuse Radio Source	00h 59m 24.42s	+27d 03m 32.6s	13770.07 ± 23.08	112.6 ± 4.0
3C 293	Extended Radio Source	13h 52m 17.842s	+31d 26m 46.50s	13547.51 ± 3.00	4690
4C +27.14	Compact Radio Source	04h 59m 56.08s	+27d 06m 02.10s	18347.30 ± 0	857
NVSS J231240-052547	Radio Source	23h 12m 40.73s	-05d 25m 47.50s	27281.11 ± 10912.44	181.9 ± 5.5
NVSS J053118+315412	Radio Source	05h 31m 18.83s	+31d 54m 11.7s	18359.29 ± 0	40.2 ± 1.3

Radio Source	absorption type	Component	cz_{peak} ($\mathrm{km\,s^{-1}}$)	FWHM ($\mathrm{km\,s^{-1}}$)	$S_{\text{HI},peak}$ (mJy)	$\int S_{\text{HI}}\,dv$ ($\mathrm{mJy\,km\,s^{-1}}$)	τ_{peak}	$\int \tau dv$ ($\mathrm{km\,s^{-1}}$)	N_{HI} ($10^{20}\mathrm{cm^{-2}K^{-1}}$)
UGC 00613	associated	1	13988.71	40.34	-23.50	-1016.51	0.23	9.78	$0.18T_s$
		2	13958.76	27.03	-64.31	-1826.04	0.84	21.17	$0.39T_s$
		Total	13958.76	31.74	-69.46	-2842.55	0.96	32.75	$0.60T_s$
3C 293	associated	1	13483.28	29.93	-168.09	-5354.07	0.036	1.16	$0.02T_s$
		2	13458.66	80.60	-141.90	-12164.45	0.031	2.62	$0.05T_s$
		3	13354.95	110.95	-104.45	-12331.98	0.023	2.65	$0.05T_s$
		Total	13481.49	61.54	-283.33	-29850.50	0.062	6.47	$0.12T_s$
4C +27.14	associated	1	18776.96	42.09	-7.98	-357.40	0.87	38.72	$0.7T_s$
		2	18755.13	155.74	-3.32	-550.31	0.36	59.51	$1.08T_s$
		Total	18776.96	54.58	-11.11	-907.70	1.21	98.37	$1.79T_s$
NVSS J231240-052547	unknown	1	18790.52	5.20	-53.17	-294.82	0.33	1.82	$0.03T_s$
		2	18797.77	7.15	-26.10	-198.50	0.15	1.15	$0.02T_s$
		Total	18797.77	9.12	-54.04	-493.32	0.34	3.01	$0.05T_s$
NVSS J053118+315412	associated	1	19899.88	60.81	-3.70	-239.20	0.097	6.19	$0.113T_s$
		2	19933.06	26.08	-20.17	-559.72	0.702	17.53	$0.319T_s$
		3	19960.99	18.78	-17.84	-356.73	0.591	10.81	$0.197T_s$
		4	19994.99	38.18	-11.08	-450.01	0.324	12.55	$0.229T_s$
		5	20004.30	5.94	-4.47	-28.25	0.118	0.74	$0.013T_s$
		6	20055.36	75.00	-2.46	-196.30	0.063	5.02	$0.091T_s$
		Total	19944.95	89.53	-21.85	-1830.21	0.790	55.81	$1.016T_s$