FAST Early Science Programs

Five-hundred-meter Aperture Spherical radio Telescope (FAST) is a Chinese mega-science facility, currently under commissioning. The early science programs were designed to generate timely science returns as well as to help commission key observing capabilities for FAST. FAST early science programs have started to bear fruits as demonstrated by more than 60 new pulsar discoveries and early science papers already under review for SCPMA, RAA, and ApJ.

FAST early science has three stages 1）full system integration 2）full system testing operation 3）early operation. In the next 6 months, FAST will focus on two complementary goals 1) establish and refine key FAST observing modes, quantify their science potential; 2)utilize FAST's unique capabilities, such as its absolute gain and sky coverage, to obtain important science results, while avoid its technical limitations, such as long source-changing time.

This document categories early science programs into 8 groups (1-8). Two approved survey programs, namely, Commensal Radio Astronomy FAST Survey (CRAFTS) and Galactic-plance and Andromeda Surve (GAS), are described separately toward the end of this document. The sensitivity and other capabilities for programs listed here are based on Nan et al. (2011，IMJPD).

EARLY Science Group 1
Project Name: Pulsar Science

Science Goal: Pulsar Science is one of the primary science goals of FAST since the beginning. We plan to obtain tracking observations of a set of bright pulsars and investigate their single pulses, giant pulses, polarizations, pulse profiles, fluences, pulse drifts, nulling, and scintillations. Through these observations, we will study pulsar radiation mechanism, neutron star physics, and the interstellar medium and make early breakthroughs in pulsar science.

The unique advantages of FAST: high sensitivity
Required receivers: ultra-wideband, 19 beams
Project investigators: Shen Wang, Pei Wang, Jiguang Lu, Chenming Zhang, Lei Zhang, Weiwei Zhu, Jumei Yao, Youling Yue, Bo Peng, Yezhao Yu, Lin Wang, Feifei Kou, Zhichen Pan

Source List (59 sources):

Source Name	RA	Dec
B0301+19	3:04:33	+19:32:51.4
B0320+39	3:23:27	+39:44:52.9

B0329+54	3:32:59	+54:34:43.5
B0525+21	5:28:52	+22:00:04
B0540+23	5:43:10	+23:29:05
B0611+22	6:14:17	+22:30:36
B0626+24	6:29:06	+24:15:43.3
B0820+02	8:23:10	+01:59:12.4
B0834+06	8:37:06	+06:10:14.5
B0919+06	9:22:14	+06:38:23.3
B1112+50	11:15:38.4	+50:30:12.2
B1133+16	11:36:03	+15:51:04.4
B1237+25	12:39:40	+24:53:49.2
B1541+09	15:43:39	+09:29:16.3
B1612+07	16:14:40.9	+07:37:31.0
B1737+13	17:40:07	+13:11:56.6
B1859+03	19:01:32	+03:31:05.9
B1859+07	19:01:39	+07:16:34.8
B1900+01	19:03:30	+01:35:38.3
B1900+06	19:02:50	+06:16:33.4
B1905+39	19:07:35	+40:02:05.7
B1907+02	19:09:38	+02:54:50.6
B1907+03	19:10:09	+03:58:28.0
B1907+10	19:09:49	+11:02:03.3
B1913+10	19:15:30	+10:09:43.6
B1915+13	19:17:40	+13:53:56.9
B1918+19	19:21:04	+19:48:44.7
B917+00	19:19:50.663	+00:21:39.8
B1919+21	19:21:45	+21:53:02.2
B1920+21	19:22:53	+21:10:41.9
B1923+04	19:26:24	+04:31:31.6
B1929+10	19:32:14	+10:59:32.4
B1929+20	19:32:08	+20:20:46.4
B1933+16	19:35:48	+16:16:39.9
B1937+21	19:39:39	+21:34:59.1
B1944+17	19:46:53	+18:05:41.2
B1946+35	19:48:25	+35:40:11.0
B1953+50	19:55:19	+50:59:55.2
B2000+40	20:02:44	+40:50:53.9
B2011+38	20:13:10	+38:45:43.3
B2016+28	20:18:04	+28:39:54.2
B2020+28	20:22:37	+28:54:23.1
B2021+51	20:22:49.8	+51:54:50.2
B2053+36	20:55:31	+36:30:21.4
B2106+44	21:08:20	+44:41:48.8
B2111+46	21:13:24	+46:44:08.8

B2113+14	21:16:13.752	+14:14:21.04
B2154+40	21:57:02	+40:17:45.9
B2217+47	22:19:48	+47:54:53.9
B2303+30	23:05:58	+31:00:01.7
B2310+42	23:13:09	+42:53:13.0
B2315+21	23:17:57.8	+21:49:48.0
J0218+4232	02:18:06.3	+42:32:17.3
J0249+58	2:49:24	+58:51:47.00
J1246+22	12:46:38	+22:53
J1532+2745	15:32:10.364	+27:45:49.40
J1800+50	18:01:00	+50:28
J1913+0832	19:13:00.5	+08:32:05.1
J1932+1059	19:32:13.9	+10:59:32.4
J2001+42	20:02:00	+42:43

Early Science Group 2
Project Name: Pulsar Timing

Science Goal: Pulsars are accurate cosmic clocks. From their pulse arrival time, we could make precise measurements of physical pulsar's position, distance, the binary orbit, or even the mass of the stars. Through the timing of very stable pulsars, we could test general relativity in strong fields, constrain the state of matter in super-nuclear density, and possibly detect low-frequency gravitational waves. We plan to conduct regular timing of a set of pulsars. Through this program, we will test the FAST telescope's time system performance, build FAST pulsar timing capability, and produce some early science results. This plan included the timing of high-precision pulsars and some peculiar systems such as close-binary, eclipsing pulsars, and some observations of binary orbit and pulsar masses.

The unique advantages of FAST: high sensitivity, sky coverage
Required receivers: ultra-wideband, 19 beams
Project investigators: Jiguang Lu, Shi Dai, Yi Feng, Weiwei Zhu, Lei Zhang, Youling Yue, Heng Xu, Jiangping Yuan, Renxin, Xu, Mao Yuan, Feifei Kou, Lin Wang, Chenchen Miao

Source List (71 sources):

Source Name	RA	Dec
J0023+0923	0:23:16	+09:23:23
3FGL J0212.1+5320	2:12:11	+53:21:36.8
J0218+4232	2:18:06	+42:32:17.3
J0251+26	2:51:08	+26:05:00
J0348+0432	3:48:43	+04:32:11

SGR 0501+4516	5:01:07	+45:16:33.92
B0525+21	5:28:52	+22:00:04
J0534+2200	5:34:32	+22:00:52.0
J0627+0706	6:27:44	+07:06:12.7
B0656+14	6:59:48	+14:14:21.5
J0751+1807	7:51:09	+18:07:38.4
B0823+26	8:26:51	+26:37:23.7
B0919+06	9:22:14	+06:38:23.30
J0943+1631	9:43:30	+16:31:37
J0953+0755	9:53:09	+07:55:35.7
J1022+1001	10:22:58	+10:01:52.7
J1023+0038	10:23:48	+00:38:40.84551
J1115+5030	11:15:38	+50:30:12.2
XDINS J1308.6+2127	13:08:48	+21:27:06.8
J1518+0204	15:18:33	+02:04:47.8153
J1532+2745	15:32:10	+27:45:49.40
J1543-0620	15:43:30	-06:20:45.25
XDINS J1605.3+3249	16:05:19	+32:49:18.0
J1640+2224	16:40:17	+22:24:08.8
J1641+3627E	16:41:41	+36:27:37
J1713+0747	17:13:49	+07:47:37.4
J1741+1351	17:41:31	+13:51:44.1
J1810+1744	18:10:37	+17:44:37
B1825-0935	18:25:31	-09:35:22.3
B1832+0029	18:32:51	+00:29:27
J1839+15	18:39:00	+15:00:00
B1849+0409	18:49:03	+04:09:42.3
B1852-0635	18:52:57	-06:35:57
J1854+0306	18:54:03	+03:06:14
J1857+0943	18:57:36	+09:43:17.1
J1906+0746	19:06:49	+07:46:25.90
SGR 1900+14	19:07:14	+09:19:20.1
J1909+21	19:09:32	+21:03:00
B1907+03	19:10:09	+03:58:28.0
J1910+0517	19:10:38	+05:17:56.1
J1911+0102A	19:11:11	+01:02:09.74
J1911+00	19:11:48	+00:37
J1913+1330	19:13:18	+13:30:32.8
J1913+1102	19:13:29	+11:02:05.70
B1917+00	19:19:51	+00:21:39.8
B1923+04	19:26:24	+04:31:31.6
B1929+1357	19:29:11	+13:57:35.9
J1913+1330	19:33:38	+24:36:39.6
SGR 1935+2154	19:34:56	+21:53:47.79
B1937+21	19:39:39	+21:34:59.1

J1949+3106	19:49:30	+31:06:03.8
J1953+1846A	19:53:46	+18:47:04.8472
B1957+20	19:59:37	+20:48:15.12
SGR 2013+34	20:13:57	+34:19:48
J2017+0603	20:17:23	+06:03:05.5
B2020+28	20:22:37	+28:54:23.104
B2035+36	20:37:24	+36:21:24.1
J2043+1711	20:43:20.8	+17:11:28.9
J2043+2740	20:43:43.5	+27:40:56
J2047+1053	20:47:00	+10:53:00
J2052+1218	20:52:47	+12:18:00
B2113+14	21:16:14	+14:14:21.04
J2129-0429	21:29:45	-04:29:05.59
XDINS J2143.0+0654	21:43:03	+06:54:17.0
J2145-0750	21:45:50	-07:50:18.499
J2215+5135	22:15:32	+51:35:39
B2217+47	22:19:48	+47:54:53.93
J2302+4442	23:02:47	+44:42:22.0
J2317+1439	23:17:09	+14:39:31.2
J2339-0533	23:39:39	-05:33:05.59
J1048+2339	10:48:43:4270	+23:39:53.503

Early Science Group 3
Project Name: Pulsar Search

Science Goal: FAST is the most sensitive single-dish radio telescope in the world and equipped with a state-of-the-art multi-beam receiver, this makes it one of the superior pulsar search machine. Using tracking mode to conduct searches for weak pulsars is the strength and priority of this telescope. We plan to search for pulsars using tracking observations from a set of high-value targets, such as globular clusters, supernova renaments, known binaries, Fermi point sources, and close-by satellite galaxies, etc.

The unique advantages of FAST: high sensitivity, sky coverage
Required receivers: ultra-wideband, 19 beams
Project investigators: Meng Yu, Pei Wang, Lin Wang, Shi Dai, Weiwei Zhu, Kuo Liu, Jun Yan, Di Li, Wenfei Yu, Chenming Zhang, Lei Zhang, Ping Zhou, Xian Hou, Youling Yue, Bo Peng, Zhichen Pan, Yezhao Yu

Source Name	RA	Dec	Type
M3	13:42:12	+28:22:38.2	Globular Cluster
M5	15:18:33	+02:04:51.7	Globular Cluster

M13	16:41:41	+36:27:35.5	Globular Cluster
NGC7089	21:33:27	-00:49:23.7	Globular Cluster
M53	13:12:55	+18:10:05.4	Globular Cluster
NGC6229	16:46:59	+47:31:39.9	Globular Cluster
Pal 14	16:11:01	+14:57:28	Globular Cluster
M15	21:29:58	+12:10:01.2	Globular Cluster
M92	17:17:07	+43:08:09.4	Globular Cluster
M71	19:53:46	+18:46:45.1	Globular Cluster
NGC2419	7:38:08	+38:52:56.8	Globular Cluster
Triangulum II	2:13:17	+36:10:42.4	satellite galaxies
Segue 2	2:19:16	+20:10:31	satellite galaxies
Leo T	9:34:53	+17:03:05	satellite galaxies
Segue 1	10:07:04	+16:04:55	satellite galaxies
Leo I	10:08:27	+12:18:27	satellite galaxies
Sextans Dwarf Spheroidal	10:13:03	-01:36:53	satellite galaxies
Ursa Major I Dwarf	10:34:53	+51:55:12	satellite galaxies
Willman 1	10:49:21	+51:03:00	satellite galaxies
Leo II	11:13:29	+22:09:17	satellite galaxies
Leo V	11:31:10	+02:13:12	satellite galaxies
Leo IV	11:32:57	-00:32:00	satellite galaxies
Virgo I	12:00:10	-00:40:48	satellite galaxies
Coma Berenices	12:26:59	+23:55:09	satellite galaxies
Canes Venatici II	12:57:10	+34:19:15	satellite galaxies
Canes Venatici I	13:28:03	+33:33:21	satellite galaxies
Boötes III	13:57:00	+26:48:00	satellite galaxies
Boötes II	13:58:00	+12:51:00	satellite galaxies
Boötes I	14:00:06	+14:30:00	satellite galaxies
Hercules	16:31:02	+12:47:30	satellite galaxies
Pegasus III	22:24:23	+05:25:12	satellite galaxies
Pisces II	22:58:31	+05:57:09	satellite galaxies
M32	0:41:00	+40	satellite galaxies
NGC205	0:00:40	+41:41	satellite galaxies
NGC598	0:01:34	+30:39	satellite galaxies
Canes I	12:18:00	+35.8	satellite galaxies
M101	14:03:00	+54.6	satellite galaxies
NGC672	1:51:00	+27.8	satellite galaxies
NGC5194	13:09:00	+44	satellite galaxies
Canes II	12;22	+45.4	satellite galaxies
NGC2541	8:12:00	+49.9	satellite galaxies
NGC7640	23:24:00	+40.9	satellite galaxies
NGC925	2:28:00	+33.8	satellite galaxies
Coma I	12:36:00	+31	satellite galaxies
NGC1023	2:35:00	+39.9	satellite galaxies
NGC4062	12:03:00	+31.6	satellite galaxies

NGC3675	11:23:00	+43.2	satellite galaxies
NGC628	1:38:00	+15.3	satellite galaxies
B1534+12	15:37:10	+11:55:55.43387	DNS
J1518+4904	15:18:17	+49:04:34.25119	DNS
J1829+2456	18:29:35	+24:56:18.193	DNS
B1913+16	19:15:28	+16:06:27.3868	DNS
J1906+0746	19:06:49	+07:46:25.9	DNS
G074.0-08.5	20 51 00	+30 40 12	SNR
G039.2-00.3	19 04 04.5	+05 27 12	SNR
G063.7+01.1	19 47 52.08	+27 45 00	SNR
G065.7+01.2	19 52 13.7	+29 25 08	SNR
G020.0-00.2	18 28 07.0	-11 34 60	SNR
G024.7+00.6	18 34 46.08	-07 05 49.2	SNR
G027.8+00.6	18 38 52.01	-04 16 16	SNR
G049.2-00.7	19 23 49.92	+14 06 00	SNR
G38.7-1.3	19 07 16	+04 32 30	SNR
G67.7+1.8	19 54 28	+31 29 02	SNR
J2032+3937	6:43:12	+39.62	GAIA2 binary
J2037+4322	3:50:24	+43.49	GAIA2 binary
J1949+2513	17:45:36	+25.36	GAIA2 binary
J2035+4121	6:28:48	+41.59	GAIA2 binary
J2027+4003	17:45:36	+39.90	GAIA2 binary
J2022+3840	14:52:48	+38.84	GAIA2 binary
Swift J185003.2-005627	18 50 03.20	-00 56 27.0	LMXB
IGR J00291+5934	00 29 03.06	59 34 19.0	LMXB
Aql X-1	19 11 16.05	00 35 05.8	LMXB
J0357+3205	3:57:53	+32:05:25	Taurus/Fermi PSR
3FGL_J1322.3+0839	13:22:20	+08:39:20	Fermi-LAT-FAST
3FGL_J1309.0+0347	13:09:02	+03:47:27	Fermi-LAT-FAST

Early Science Group 4
Project Name: Galactic HI

Science Goals: HI is one of the main observables of FAST. We plane to use FAST to map the Galactic HI within the FAST sky (the large scale mapping tests have been included in CRAFTS survey, see the survey plan), and to observe some important targets, including the Zeeman effect of HI narrow self-absorption (HINSA) in molecular clouds, high velocity HI cloud associated with γ-ray supernova remnants.

Advantage of FAST: high sensitivity, larger sky coverage than Arecibo

List of participants: Pei Zuo, Hui Shi, Tao-Chung Ching, Ningyu Tang, Ming Zhu, Li Xiao, Xinxin Zhang, Lei Qian, Carl Heiles, Marko Krco

Source List (7 sources):

Source Name	RA	Dec
DR4	20:20:50	+40:26
HB21	20:45:00	+50:35
CTB109	23:01:35	+58:53
4C+00.77	20:21:01.91	+00:44:42.6
4C+01.76	20:14:34.64	+01:14:31.5
4C+01.46	19:55:13.72	+01:54:10.6
4C+00.74	19:55:25.28	+00:50:25.3

Early Science Group 5
Project Name: Molecular Lines

Science Goals: Spectroscopy is one the main science capabilities of FAST. Spectral line observations other than those of HI are grouped here. We plan to observe some important sources with FAST, recording data streams of HI and molecular lines simultaneously. These sources include, Orion molecular cloud (previous project ID: 3001, 3043), Quasars (absorption by Galactic ISM, previous project ID: 3002, 3007), Smith high velocity HI cloud and Lockman hole (previous project ID: 3030), OH maser (previous project ID: 3006, 3031), Planck Galactic cold clumps (previous project ID: 3025), yellow supergiant (previous project ID: 3029), Comets (previous project ID: 3034).

Advantage of FAST: high sensitivity, larger sky coverage than Arecibo
List of participants: Junzhi Wang, Hui Shi, Jing Tang, Ningyu Tang, Zhiyuan Ren, Xiaohu Li, Di Li, Juan Li, Jiangshui Zhang, Xinxin Zhang, Gan Luo, Yan Duan, Lei Qian, Shengli Qin, Chunhua Qi, Carl Heiles, Marko Krco

Source List (more than 500 sources, only list part of the sources):

Source Name	RA	Dec
Orion BN/KL	05:35:14.16	-05:22:21.5
Orion Bright Bar	05:35:22.30	-05:24:33.0
ulirg10	04:34:00.03	+08:34:44.6
ulirg59	16:52:58.97	+02:24:01.7
χ Cygni	19:50:33.92	+32:54:50.6
Comet 46P…	-	-
Lockman Hole	10:51:56	+57:25:32
L1489	04:04:43.0	+26:18:57.0
L1544	05:04:17.2	+25:10:42.8
B 68	17:22:38.2	-23:49:54.0
J18517+0312	18:54:13.4	+03:16:10

J18574+0812	18:59:51.4	+08:16:47
J18422+0104	18:44:46.8	+01:08:03
J19240+1806	19:26:17.0	+18:12:15
J18485+0010	18:51:08.9	+00:14:32
TMC 2-3	04:29:57.6	+24:11:26
L1527 A-1	04:35:05.1	+26:08:37
L1534	04:36:36.4	+25:35:14
TMC1CP	04:38:38.5	+25:36:30

Early Science Group 6
Project Name: Exploratory Programs

Science: There are some exploratory projects, e.g. radio flare of nearby stars (especially brown dwarfs), radio observation of exoplanets, star wind-planet interaction, interplanetary scintillation (use FAST calibrators).

Advantage of FAST: high sensitivity, larger sky coverage than Arecibo
List of participants: Jing Tang, Nannan Yue, Lijia Liu, Lei Qian, Yang Gao
Source List (more than 500 sources, only list part of the sources):

Source List (more than 500 sources, only list part of the sources):

Source Name	RA	Dec
HD 189733	20:00:43.71	+22:42:39.1
V830 Tau	04:33:10.0	+24:33:43
BD+20 1790	07:23:44.0	+20:24:51
AD Leo	10:19:36.277	+19:52:12.06

Early Science Group 7
Project Name：Searching for Radio Recombination Lines and HI/OH Absorption Lines in the Extragalactic Galaxy systems

Science

Galaxies with neutral hydrogen line absorption:

Using FAST to examine the existence of neutral hydrogen (HI) line absorption in the galaxies candidates selected from the ALFAFA sky survey, likely double the sample size of known HI-line-absorption galaxies. Combining with the observed HI emission line properties to efficiently determine physical properties of HI gas in the extragalactic system such as temperature, optical depth, etc.

Extragalactic HI and OH line absorption search:

Due to the relatively weak HI and OH emission line strength, the only approach to detect these lines in the high redshift systems is through absorption against a background radio continuum sources (e.g. Allison et al. 2015, Gereb et al. 2014, Maccagni et al. 2017). Using a large sample of HI absorption system, we can map the HI gas distribution at large scale, and also detect the dense gas structure near AGNs. For the OH absorption, so far there is only one confirmed detection in the high-redshift system. The high sensitivity of FAST can allow us to detect more high-z OH absorption systems, to increase the sample size to better constrain the models of the molecular gas distribution at high-redshift.

<u>Extragalactic low-frequency radio recombination line observations:</u>
The cold neutral medium (CNM) in the interstellar medium can be traced by low-frequency (<1GHz) carbon radio recombination line (C-RRL). The physical parameters of CNM gas such as electron temperature and density can be derived from the the strength of emission lines, based on the corresponding transitions between quantum numbers. Using the line ratios between carbon and hydrogen radio recombination lines (H-RRL), one can study the thermal dynamical condition of the gas, and estimate the ion abundance and ionization parameters of gas. By cross-matching with far-IR fine structure line [CII] 158-micron, HI line absorption, one can study the different compositions in the CNM gas abundance from galaxies, and investigate the regulations of transition processes between neutral hydrogen and molecular hydrogen.

So far, the most successful extragalactic low-frequency C-RRL detection was done in M82 by LOFAR. Using FAST to search for extragalactic C-RRL can expand the sample size of such systems. Also, FAST can cover larger frequency rage than LOFAR's, thus provide more comprehensive CNM condition models from more corresponding recombination line series. Besides, this project will search for H-RRL 1-1.7 GHz (~25 lines) by stacking these lines in order to obtain the physical properties of the warm interstellar medium with high sensitive.

Advantage of FAST: high sensitivity, larger sky coverage than Arecibo
List of participants: Ming Zhu, Bin Liu, Zhongzu Wu, Zheng Zheng, Bo Peng, Hui Shi

Source list:

Source Name	RA	Dec
NGC1052-DF2	02:41:46.80	-08:24:12.0
M77	02:42:40.7	-00:00:47.8
J000520.21+052411.80	00:05:20.22	+05:24:10.1
J045647.17+040052.94	04:56:47.17	+04:00:53.2
J0741+3111	07:41:10.70	+31:11:59.8
J075525.51+172836.59	07:55:25.42	+17:28:37.5
3C190	08:01:33.5	+14:14:42.2
J084307.11+453742.8	08:43:07.11	+45:37:42.8
J090325.54+162256.0	09:03:25.54	+16:22:56.0
J0954+1743	09:54:56.80	+17:43:31.1
NGC3079	10:01:57.8	+55:40:48.5

J1009+0713	10:09:02.10	+07:13:43.9
J102230.29+304105.11	10:22:30.31	+30:41:05.8
J102400.53+511248.1	10:24:00.53	+51:12:48.1
J103932.12+461205.3	10:39:32.12	+46:12:05.3
J104117.16+061016.92	10:41:17.16	+06:10:16.5
NGC3628	11:20:17.0	+13:35:22.2
J112332.04+235047.8	11:23:32.04	+23:50:47.8
NGC3690	11:28:31.3	+58:33:41.8
J124707.32+490017.9	12:47:07.32	+49:00:17.9
J130132.61+463402.7	13:01:32.61	+46:34:02.7
3C293	13:52:17.8	+31:26:46.7
J142210.81+210554.1	14:22:10.81	+21:05:54.1
J152446.01+230723.5	15:24:46.01	+23:07:23.5
J153452.95+290919.8	15:34:52.95	+29:09:19.8
J155902.70+230830.4	15:59:02.70	+23:08:30.4
J162439.08+234512.20	16:24:39.42	+23:45:17.5
J170815.25+211117.7	17:08:15.25	+21:11:17.7
Cyg A	19:59:28.3	+40:44:02.0
J223246.80+134702.04	22:32:46.28	+13:47:00.7
Cas A	23:23:19.7	+58:48:42.0
ALFALFA bright radio sources within the FAST sky coverage with signature of absorption in other wavebands		

Early Science Group 8
Project Name：Targeted Extragalactic HI Study

Scientific Justification

Searching for HI in the high CO/HI ratio galaxies:

This project targets a sample of 19 galaxies with CO (which is the most important tracer of molecular hydrogen H_2) but no detection of HI emission line. It is not clear the astrophysical explanation for the existence of this type of galaxies with molecular hydrogen gas but no neutral atomic hydrogen gas, especially considering that H2 molecules are formed from HI gas, and H2 clouds should be surrounded by the HI in general. This project aims to measure the HI contents in this type of galaxies using FAST, and further study the role of the HI-H2 transformation in the galaxy evolution.

HI gas in UDGs:

Ultra diffuse galaxies (UDGs) are a type of extremely low surface brightness galaxies discovered using ultra-deep imaging technique in the past few years, with central surface brightness $\mu_{g,0}$> 24 mag/arcsec^2 and effective radius r_e> 1.5 kpc. The stellar masses of these galaxies are at two order of magnitudes lower than the normal galaxies. The observation results reveals two types of UDGs: one type of UDGs with redder color (g-i ~0.8) and rounder morphology, most often in the cluster

environment; the other type has bluer color (*g*-*i*~0.4), irregular morphology, and can be in either galaxy groups or isolated in the field. Many blue UDGs are gas rich, with M_{HI}/M_{*}~ 1-100. Because of the low surface brightness of the UDGs, it is very expensive to obtain their redshifts and the crucial dynamical information using optical and near-IR spectroscopic measurements. It requires seveal hours of observation time of 8-m class telescope. However, it could be easier to obtain redshift and rotational speed via HI emission line using single dish observation.
ALFALFA has discovered 115 UDGs using Arecibo (Leisman et al 2017), and that work has demonstrated the power of radio observations in studying UDGs. There are two major theoretical models to explain the formation of UDGs: first model suggests a formation mechanism in the dark halo with relatively larger angular momentum (Amorisco& Loeb 2016), while the other model require gas removal to larger radius due to the feedback in the process of galaxy formation (Di Cintio et al. 2017). FAST observation on the UDGs can direclty measure the HI contents in UDGs, and further help to reveal the UDG formation mechanism.

Blue galaxies with lower-than expected HI contents**:**
In the overlap sky area between Arecibo sky coverage and SDSS, some of the blue galaxies have expected HI contents estimated by the luminosities and colors to be 3 times higher than the detection limit (which is 4.5σ), but show no ALFALFA detection. These galaxies are likely to be rare and unusual. With the greater sensitivity of FAST, this project will target on HI contents in these galaxies using tracking observations, examine the deviation of this type of galaxies from the normal correlation between the stellar mass from the optical data and HI mass of galaxies.

Observing neutral hydrogen in the high-redshift galaxy cluster:
It is suggested by the B-O effect (Butcher & Oemler 1984) that the blue galaxy fraction in the cluster of galaxies increases at redshift higher than z ~ 0.1. In comparison, the galaxies in the low-z cluster (z ~ 0) are mostly red. The blue galaxies are generally full of neutral hydrogen, and in contrast, the red galaxies are lack of gas. Based on the observation results of Butcher-Oemler (1984), the blue galaxy fraction in the clusters to reaches 20%-40% at z ~0.4, indicating that cluster of galaxies contain more younger and HI-rich galaxies. Within 4 Gyr, the galaxy color, morphology, gas contents, and stellar population composition have changed dramatically. Due to the limitation of sensitivity of existing facilities, it is difficult to study this B-O effect directly from the HI contents in these systems. More specifically, ALFALFA sky survey reaches redshift up to z~0.06, and HIPASS survey has cz=12000km/s at most in redshift; data from either of these two surveys can provide sufficient data to investigate this galaxy evolution effect in details. So far, WSRT telescope array has detected 160 galaxy members in two Abell clusters with long integrations. The high sensitivity of FAST is capable to detect the HI in the blue-galaxy-rich clusters to z~0.2. Probing the targeted two clusters using FAST provides a foundation of investigating the HI signals at cluster scale at higher redshift, and also offer the opportunities to investigate the galaxy evolution and interaction with environment.

The properties and evolution of neutral gas in the intra-cluster medium:

The ram-pressure stripping process in the intra-cluster medium (ICM) can efficiently remove the cold gas in the late-type galaxies in the cluster of galaxies. However, due to lack of clear understanding of thermal transfer and viscosity properties of hot gas, many details of the heating process of stripped cold gas mixing with the ICM requires further investigations. Also, the mixed multi-phased gas also change the physical properties of ICM and its radiative characteristics. How long can this heating and mixing process last? What is the fraction of the cold gas can turn into young stars? (e.g. Sun et al. 2007)? Can the mixing process of cold and hot gas create some special radiative characteristics? (such as charge-exchange process, Zhang et al. 2014)? These questions require coherent analysis on more multi-wavelength data, especially on the stripped HI gas from deep observations.
Late type galaxy NGC4388 locates in the Virgo cluster (D = 17 Mpc), and lost its 85% of its HI gas (Cayatte et al. 2010) by ram-pressure stripping about 200 million years ago (Vollmer 2009). The stripped gas forms an elongated, 100kpc long tail along the north-east direction (Oosterloo & van Gorkum 2005, Figure 1). On the NGC4388 side, the neutral gas coincides with the ionized gas traced by Hα (Yoshida et al. 2002). The morphology of the tail and the gas contents provide valuable information to study the ram-pressure stripping and cold-hot gas mixing process (Roediger et al. 2006; Vollmer & Huchtmeier 2007, VH07).
However, limited by the aperture and exposure time of telescopes, the observations can detect HI down to $N_{\mathrm{H}}>10^{19}$ cm^{-2}. The WSRT observation can capture the radiation from the high column density structure. The single dish telescopes, however, suffers from large beam sizes (e.g. 9.3″ for Effelsberg-100m). Besides, due to the interference of radio continuum emission from the nearby M87, only limited information of HI is obtained. The larger light gathering surface and smaller beam size of FAST by its large aperture will provide more comprehensive information of the stripped neutral gas from NGC4388, especially on the diffused, low column density structure. By analyzing the CO, Hα, X-ray and other multi-wavelength data for studying the general properties and radiative characteristics of the multi-phase gas, one can obtain more clear understanding of neutral gas in the ICM.

Program member: Mei Ai, Ming Zhu, Li Ji, Wei Sun, Shuinai Zhang, Zheng Zheng, Zheng Zheng, Jian Hu, Lei Qian Xuejian Jiang, Jei Wang, Bo Zhang

Source list:

Source name	**RA**	**Dec**
COLDGASS_124006	00:19:47.33	+00:35:26.8
[TT2009]30	02:22:54.7	+42:42:45
COLDGASS_108080	08:01:34.49	+09:18:17.5
COLDGASS_56319	08:03:22.76	+09:57:45.8
PID3033-18	08:50:56.79	+29:12:0.66
PID3033-22	09:13:39.47	+29:59:34.58
PID3033-12	09:16:1.78	+17:35:23.33
MaNGA_8250-6104	09:21:38.74	+43:43:34.1
COLDGASS_109045	09:25:15.42	+10:53:12.2
PID3033-3	09:29:7.2	+30:8:26.85

MaNGA_8439-6102	09:31:06.76	+49:04:47.1
COLDGASS_109097	09:38:34.45	+08:53:16.4
PID3033-5373	09:59:59.7	+05:19:52
PID3033-13	10:07:30.67	+14:58:2.5
Abell963	10:17:3.9	+39:01:31
PID3033-5721	10:32:17.9	+27:40:03
PID3033-5826	10:42:09.1	+13:44:45
PID3033-5840	10:43:31.0	+24:55:14
PID3033-5882	10:46:45.4	+11:49:21
KKH65	10:51:59.2	+28:21:45
PID3033-1	10:57:55.12	+8:30:16.25
PID3033-6	10:58:00.04	+8:25:4.34
PID3033-30	10:58:28.32	+24:22:23.33
NGC3521sat	11:05:40.7	+00:07:15
PID3033-9	11:08:24.97	+28:36:42.18
PID3033-6277	11:15:06.0	+14:47:02
PID3033-6350	11:20:14.7	+13:35:21
COLDGASS_12460	11:20:48.31	+03:50:21.0
N3625-DGSAT-4	11:21:40.79	+57:24:37.0
N3669-DGSAT-3	11:26:38.78	+57:41:19.1
PID3033-24	11:52:42.6	+20:37:52.7
PID3033-27	11:40:41.67	+20:20:34.61
PID3033-25	11:44:2.15	+19:56:59.36
PID3033-11	11:44:47.8	+19:46:24.29
PID3033-5	12:01:47.64	+21:5:8.58
COLDGASS_112106	12:03:36.94	+02:37:49.7
PID3033-15	12:06:38.92	+28:10:26.88
COLDGASS_24094	12:20:30.18	+11:20:27.4
NGC4388NE(30â€™x30â€™)	12:26:30	+12:50:00
PID3033-23	12:35:41.17	+26:31:23.06
PID3033-7772	12:36:19.9	+25:59:34
NGC4631dw1	12:40:57.0	+32:47:33
PID3033-7961	12:47:47.0	+04:20:07
PID3033-8024	12:54:07.4	+27:09:09
PID3033-8054	12:55:48.5	+04:18:15
PID3033-29	12:56:27.86	+26:59:14.7
PID3033-28	12:57:31.96	+28:28:36.97
PID3033-8	12:58:35.19	+27:35:46.95
PID3033-10	12:58:35.33	+27:15:52.85
PID3033-19	12:59:35.71	+27:57:33.35
PID3033-16	13:00:08.13	+27:58:36.98
PID3033-7	13:00:33.68	+27:38:15.91
COLDGASS_113100	13:00:35.68	+27:34:27.3
PID3033-14	13:00:37.86	+28:3:29.12
PID3033-20	13:03:49.95	+28:11:8.62

KDG218	13:05:43.9	-07:45:32
PID3033-17	13:24:10.01	+13:58:35.52
COLDGASS_7050	13:49:09.69	+02:45:11.6
PID3033-21	13:52:22.75	+21:32:21.66
KK227	13:56:10.1	+40:18:12
PID3033-8853	13:56:11.0	+05:00:39
M101-DF5	14:04:28.1	+55:37:00.4
M101-DF7	14:05:48.3	+55:07:58.4
M101-DF4	14:07:33.4	+54:42:36.6
M101-DF6	14:08:19.0	+55:11:24.8
PID3033-26	14:08:30.7	+8:55:54.87
COLDGASS_7286	14:14:32.05	+03:11:24.9
COLDGASS_114048	14:28:55.80	+25:44:15.5
PID3033-9436	14:39:11.1	+05:22:07
COLDGASS_9704	14:40:59.30	+03:08:13.5
PID3033-4	14:42:49.59	+8:47:43.61
PID3033-9915	15:35:23.5	+12:02:51
PID3033-9935	15:37:36.9	+05:58:28
COLDGASS_26958	15:46:54.34	+05:53:28.4
PID3033-10041	15:49:00.8	+05:11:27
Abell2192	16:26:37	+42:40:18
COLDGASS_10943	22:15:40.59	+13:36:17.0
COLDGASS_10948	22:16:36.89	+13:15:14.4
COLDGASS_10952	22:16:57.96	+13:32:35.1
PID3033-2	23:13:40.5	+14:1:15.57
PegII-UDG37	23:22:08.2	+09:54:47
PegII-UDG25	23:22:19.5	+09:37:07

FAST 巡天规划和测试计划

FAST 多科学目标同时扫描巡天
Commensal Radio Astronomy FasT Survey (CRAFTS)

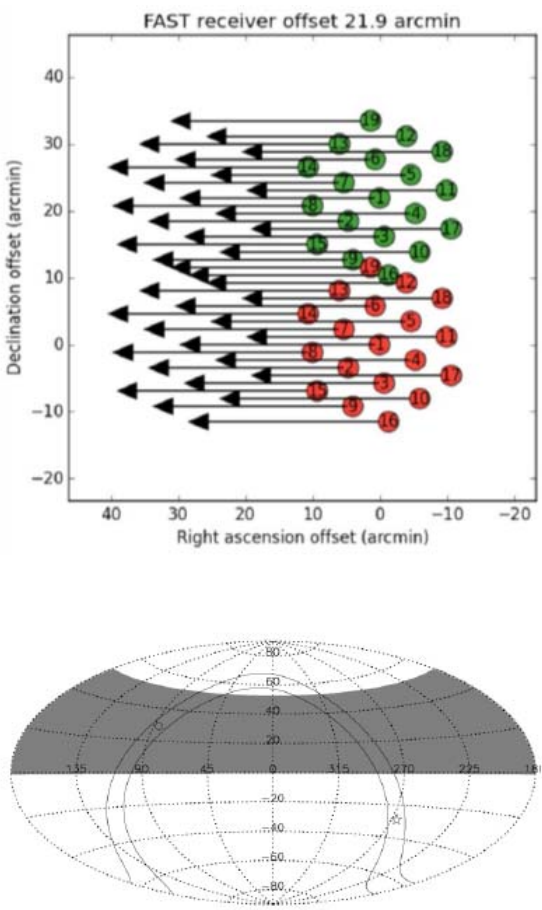
银道面与仙女座大星系巡天
Galactic plane and Andromeda Survey (GAS)

CRAFTS and GAS are accepting new members through this proposal call. Formal requests in the form of a proposal describing specific research based on the survey data is welcome by the TAC during this call. A successful proposal can be granted survey data access in coordination with the survey team.

FAST 多科学目标同时扫描巡天
Commensal Radio Astronomy FasT Survey (CRAFTS)

As FAST's first large-scale survey plan, CRAFTS was reviewed by a national panel and supported by the National Key R&D Program from 2017, which is administered by the Ministry of Science and Technology (MOST). CRAFTS aim to cover all FAST sky between a declination of -14 to 66 degrees with the 19-beam receiver in drift-scan mode. CRAFTS will obtain pulsar-search, HI imaging, and HI galaxies, and FRB data streams simultaneously, realizing an unprecedented commensal capability. The frequency range will be between 1.05-1.45 GHz, with a beam width of about 2.9'at 1.4GHz, a beam passing time of ~12s, and a point source effective integration time of about 6s. One scan coverage takes about 220 full days, i.e., more than 5000 hours.

Main Objectives：Make breakthrough discoveries in pulsar and FRB; obtain high quality single-pulse data, promote PTA capabilities in low frequency gravatiational wave detection; discover more than 100,000 HI galaxies; publish a full northern sky HI image with the highest spatial dynamic range, shed lights into the Galactic gas structure and ISM evolution; search for OH megamasers, complex organic molecules, and other tracers related to the origin of life.



A drift-scan survey strategy by the FAST 19-beam receiver.
Upper panel: Rotation angles and scan mode of the 19-beam receiver.
Lower panel: The drift-scan survey collecting area. The solid lines show galactic latitude ±5°, pentagram shows the Galactic center, the circle shows the Galactic anticenter.

Members of the CRAFTS program
课题成员：

Project 1 “FAST Pulsar Search through Drift-scan” : Di Li (team leader), Lei Qian, Zigao Dai, Weiwei Zhu, George Hobbs, Minmin Chi
课题 1“FAST 漂移扫描脉冲星巡天搜索”：李菂（负责人）、钱磊、戴子高、朱炜玮、George Hobbs、池明旻

Project 2 “Pulsar physics and gravitational wave detection based on FAST observation” : Renxin Xu (team leader), Youling Yue, Jianping Yuan, Kejia Li, Li Zhang, Junqing Xia
课题 2“基于 FAST 观测的脉冲星物理及引力波探测”：徐仁新（负责人）、岳友岭、袁建平、李柯伽、张力、夏俊卿

Project 3 “HI galaxy survey”: Ming Zhu (team leader), Tongjie Zhang, Taotao Fang, Shuo Cao, Xu Kong
课题 3“中性氢星系巡天”：朱明（负责人）、张同杰、方陶陶、曹硕、孔旭

Project 4 “Galactic structure studies based on the CRAFTS program”: Keping Qiu (Team leader), Junzhi Wang, Jingwen Wu, Yang Chen, Yuefang Wu
课题 4 “利用 FAST 漂移扫描多科学目标同时巡天的银河系结构研究”：邱科平（负责人）、王均智、吴京文、陈阳、吴月芳

Advisory Panel: Jun Yan, Guojun Qiao, Xingwu Zheng, Xiangping Wu, Ji Yang, Qizhou Zhang, Zhiqiang Shen, Na Wang, Zonghong Zhu, Xuelei Chen, Peng Jiang, Di Li, Xiaonian Zheng, Jun Pan, Chenggang Zuo
项目专家组：严俊、乔国俊、郑兴武、武向平、杨戟、张其洲、沈志强、王娜、朱宗宏、陈学雷、姜鹏、李菂、郑晓年、盘军、左成刚

Current Pilot Observing Plans

HI Blank Survey Test: night time drift-scans

Test the rotation angles and image qualities of the 19-beam

Imaging the Lockman hole，testing calibration schemes on this lowest HI column density region among the whole sky, compare it with the LAB，GBT，HI4PI surveys.

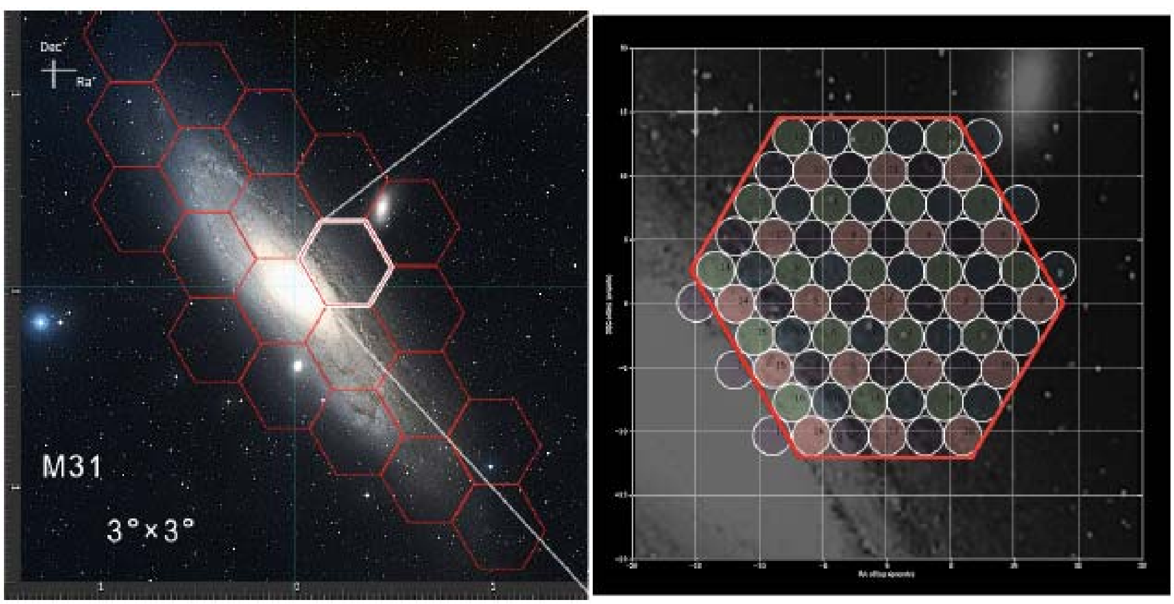
Confirmation and followup of FAST pulsar candiates. Two gridding observation of one hour each will be needed for each target. We expect to discover ~100 new pulsars in 2019.

Fully commission the FRB backend developed as part of CRAFTS, searh for possible new repeating FRBs.

银道面与仙女座大星系巡天
Galactic plane and Andromeda Survey (GAS)

GAS aims to obtain deep integration toward the Galactic plane and M31. Compared to CRAFTS, GAS will further utilize FAST's sensitivity. Through combined analyses with other methods, such as diffuse X-ray, and numerical simulations, GAS will provide important insights into the baryon and dark matter of the local group. GAS will utilize a gridding mode to combine four beam-sampled pointings into a hexagon. Each individual pointing require one hour integration, which requires about 100 hours to cover the optical extent of M31. The key goal of GAS is to reach a HI surface sensitivity of $5x10^{16}$ cm^{-2}.

Main Goals: Establish the most comprehensive radio pulsar sample in the Galaxy; discover pulsars in a spiral galaxy beyond the MW for the first time; conduct gravity test and galaxy dynamic studies; obtain the most comprehensive information of the cold gas in the Galactic plan and compare to CO surveys ("银河画卷"in particular) to study ISM evolution; carry out comparative studies with the diffuse X-ray, pulsar dispersion measure modeling and etc., to survey the hot gas content within and around the galaxies; carry out high resolution dark matter and gas simulations to facilitate quantatitive interpretation of the GAS MW-M31 data sets.



Gridding observing plan of M31. Each hexagon comprises of 4 pointings of the FAST's 19-beam array.

Current Pilot Observing Plans

Carry out pulsar search and HI imaging in the gridding mode toward the Galactic plane, particularly the portion outside of the Arecibo sky. The goal is to obtain significant discoveries as soon as possible in the window before the SKA1 and its precussor arrays' operaiton.

Test our original commensal survey mode and its calibration, study the extent of the M31 gas disk.

Test data compression, RFI mitigation, data transimission, etc.