Commensal Radio Astronomy FAST Survey

首創： UNprecedented

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

Di Li @ Fermi2018
Chief Scientist of FAST
NAOC

Past, Present, Future

Initiates a journey of Discoveries

Five-hundred-meter Aperture Spherical radio Telescope

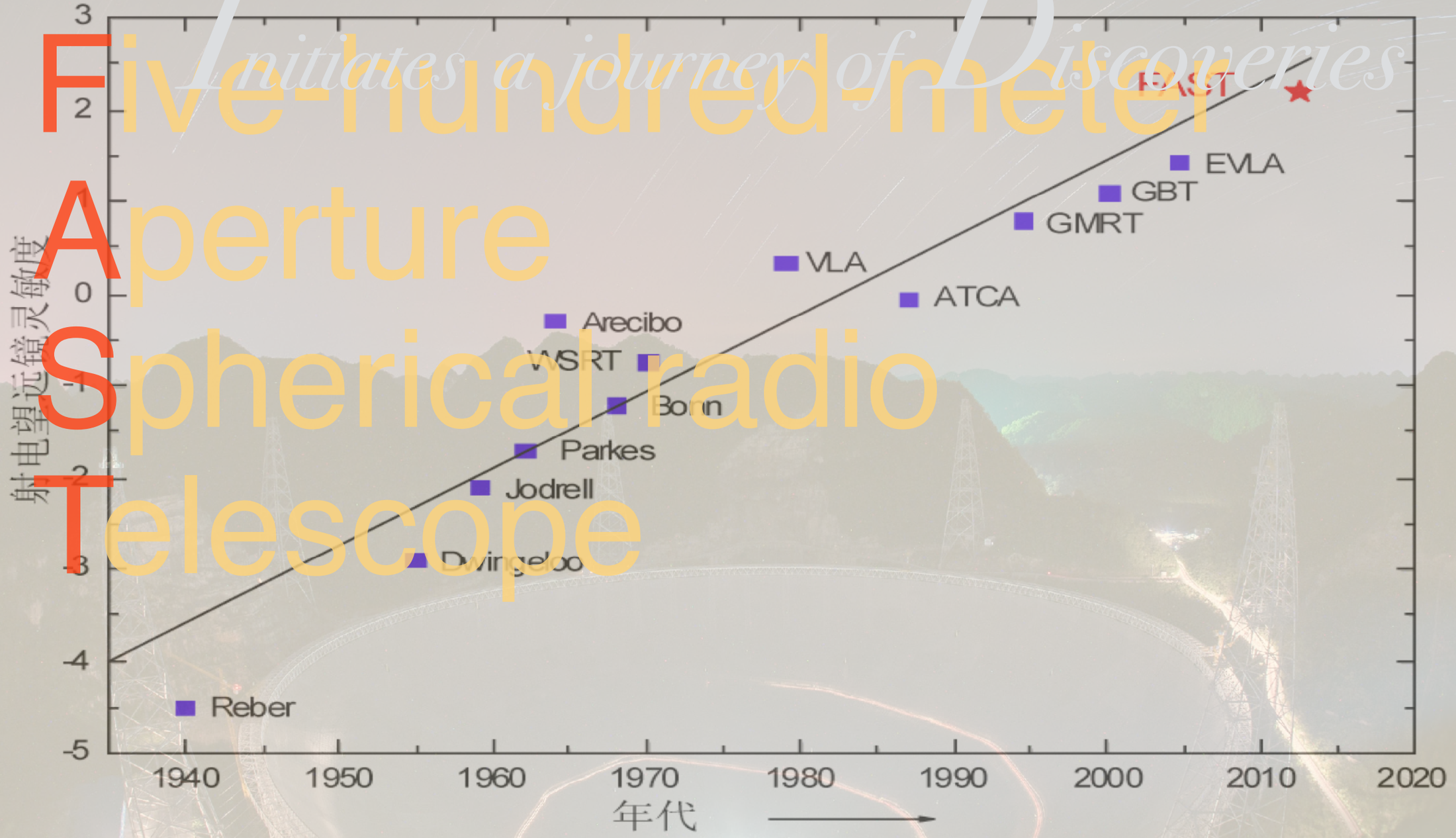


图 1-2 望远镜灵敏度发展曲

Timeline

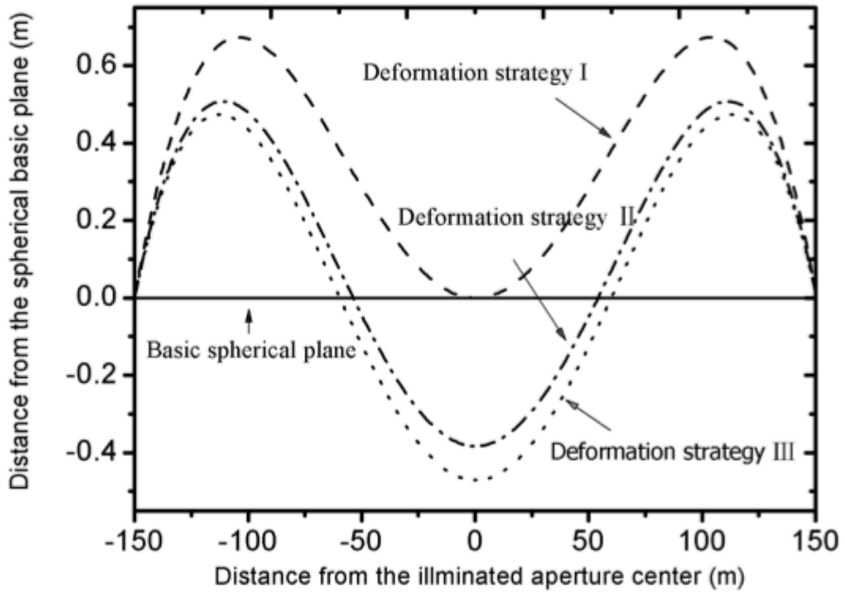
- **Project Approval:** December, 2007
- **Construction Commence:** March, 2011 (¥1.15Billion)
- **Openning ceremony:** Sep. 25, 2016
- **Commissioning:** 2016 - ~2018

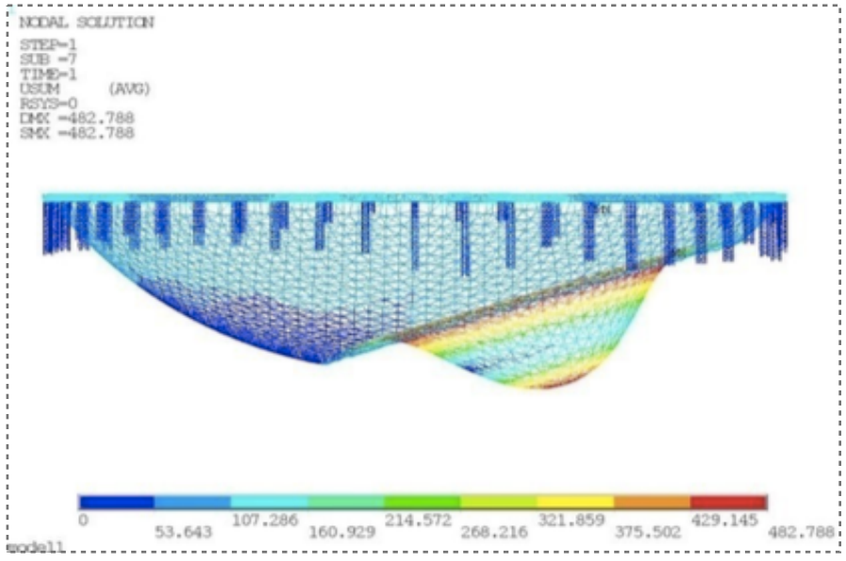
  19 beam L-band array: installed in May, 2018

  Backend upgrade (for commensal survey): under development, initial testing in September, 2018
- **Operation starts:** ~2019

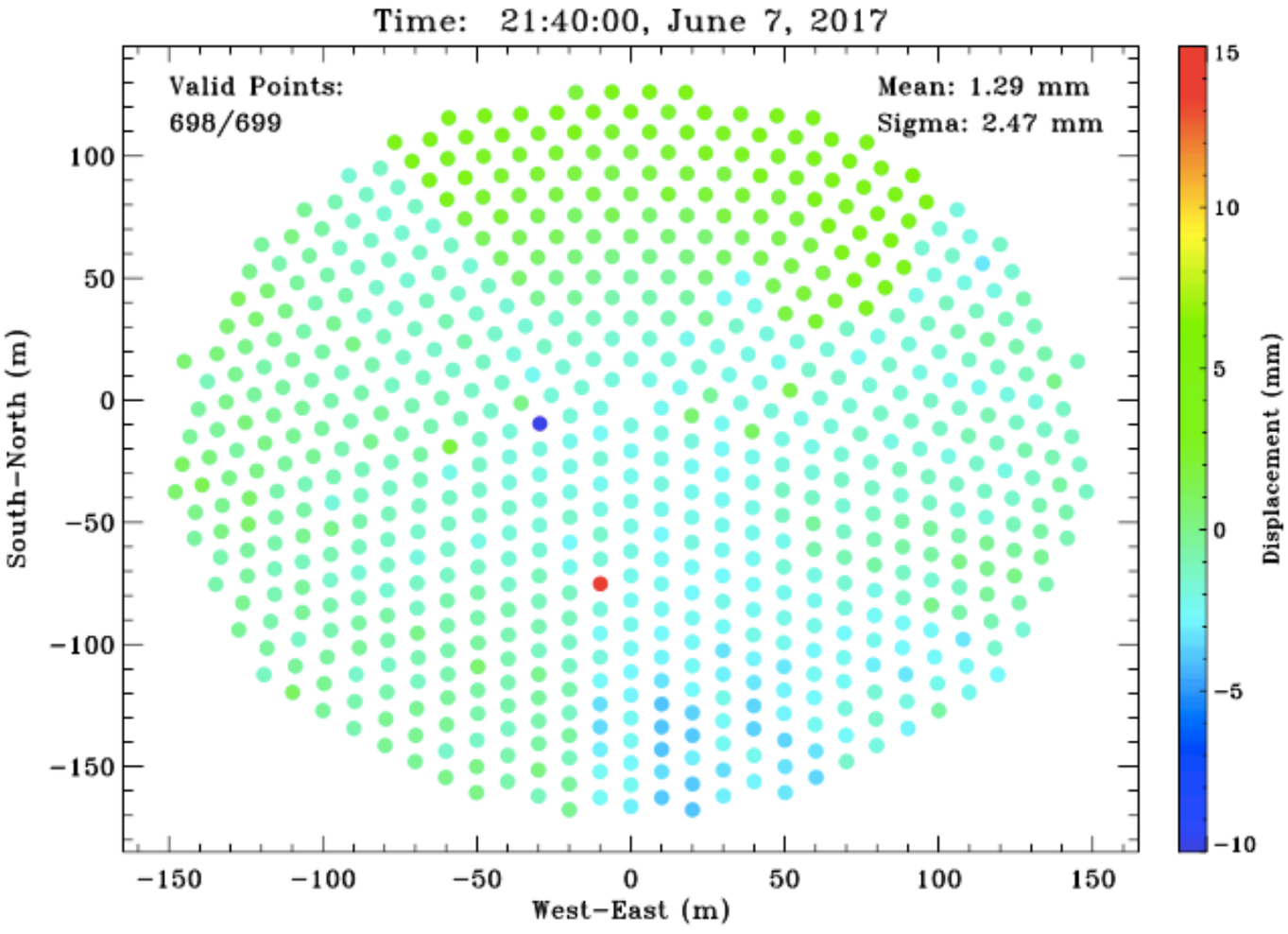
“中国天眼”

Surface Offsets





Jiang et al. 2015 *"Studying solutions for the fatigue of the FAST cable-net structure caused by the process of changing shape"*, Research in Astronomy and Astrophysics



June 2017
Measurements and Modeling

Observables

continuous coverage
70MHz～3GHz

a)21cm HI (galaxies and ISM)

b)Spectral lines

c)Pulsars

d)VLBI

e)SETI

Review

International Journal of Modern Physics D
Vol. 20, No. 6 (2011) 989–1024

DOI: 10.1142/S0218271811019335

World Scientific
www.worldscientific.com

THE FIVE-HUNDRED-METER APERTURE SPHERICAL RADIO TELESCOPE (FAST) PROJECT

RENDONG NAN*,†,§, DI LI*,‡,¶, CHENGJIN JIN*, QIMING WANG*,
LICHUN ZHU*, WENBAI ZHU*, HAIYAN ZHANG*,†,
YOULING YUE* and LEI QIAN*

Nan, **Li,** Jin et al. 2011, IJMR-D, 20, 989 (>150 citations)

Li & Pan, 2016, Radio Science, 51, 7
Li et al. 2018, IEEE Microwave, Vol. 19, Issue 3

ASKAP-FAST HI Gals Survey

a)

3.8π sky survey

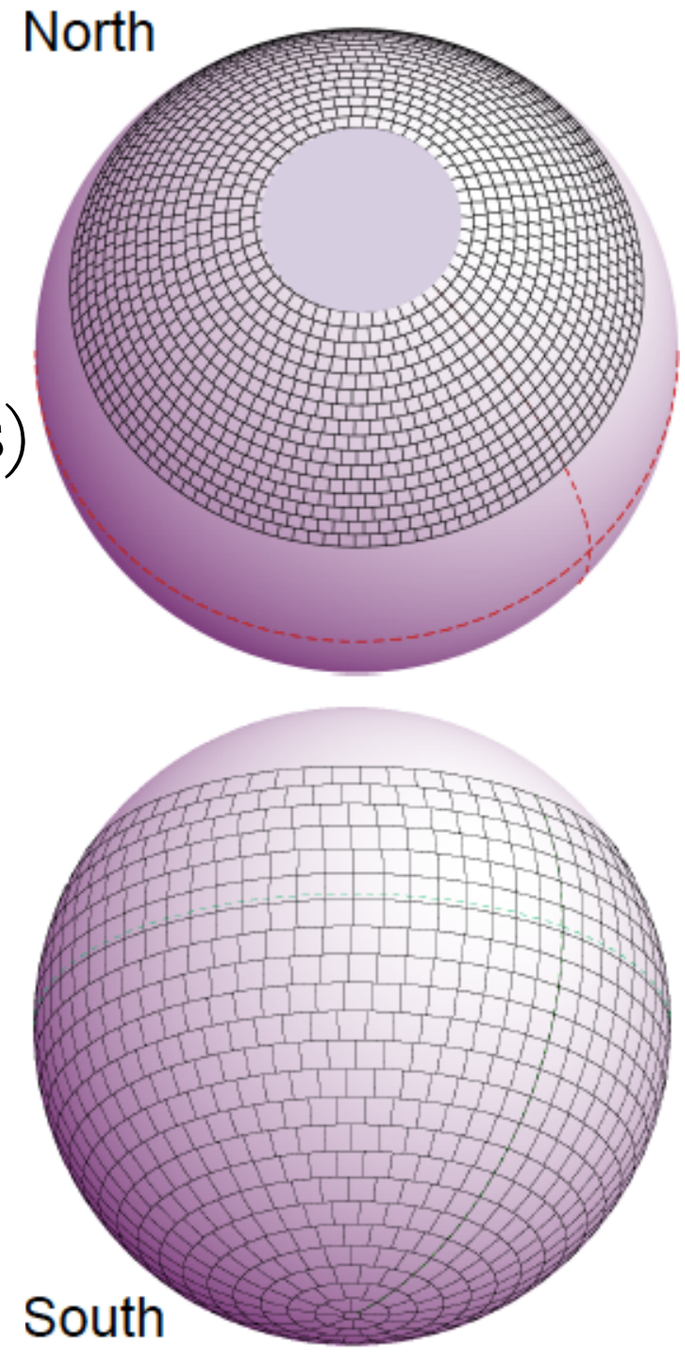
- 1201 ASKAP fields – 9600 hrs
- 110 FAST driftscans – 2700 hrs
- $0 < z < 0.26$
- 1,000,000 galaxies vs ALFALFA (30000 galaxies)

INcrease
gaseous galaxies x30

- Velocity resolution 4 km s^{-1}
- 30”-3’ resolution

Matching Optical Surveys?

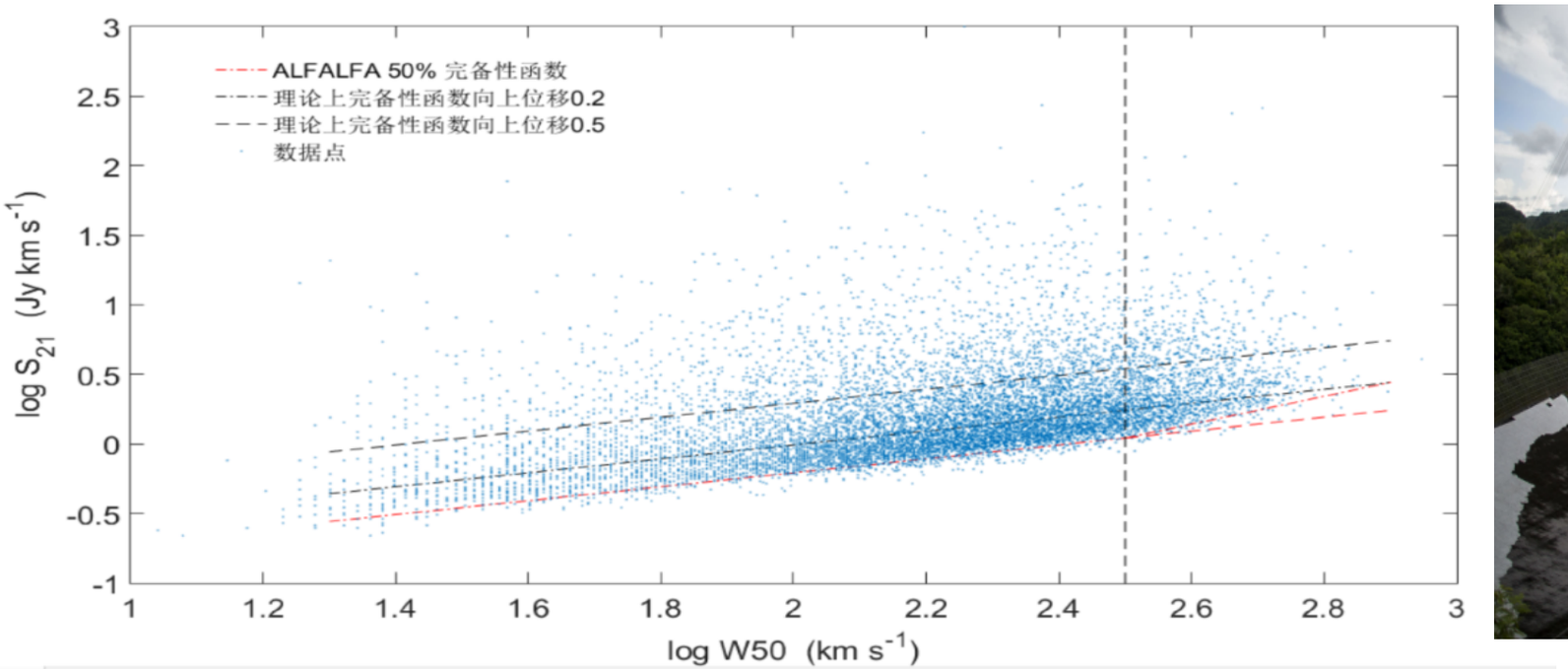
Credit: Lister Staveley-Smith (UWA)

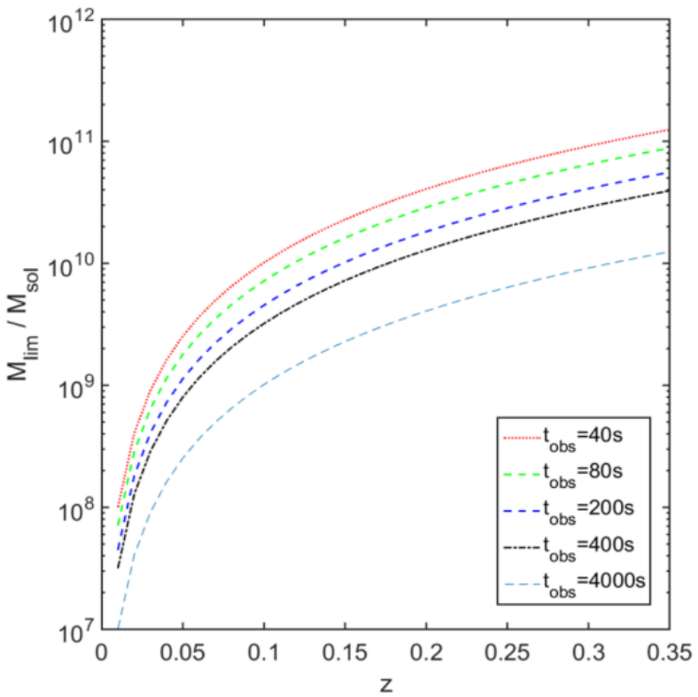


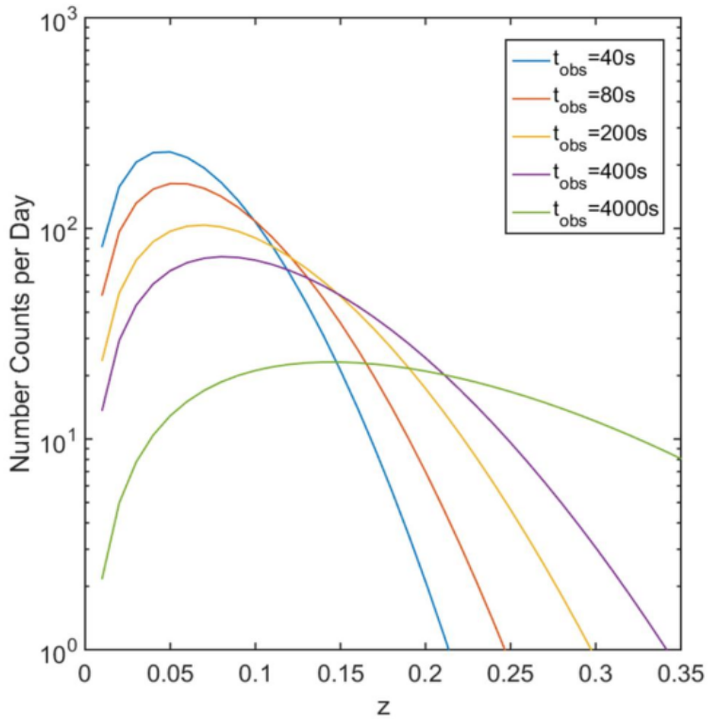
FAST Outlook

HI Galaxies from a Drift-Scan Survey

a)







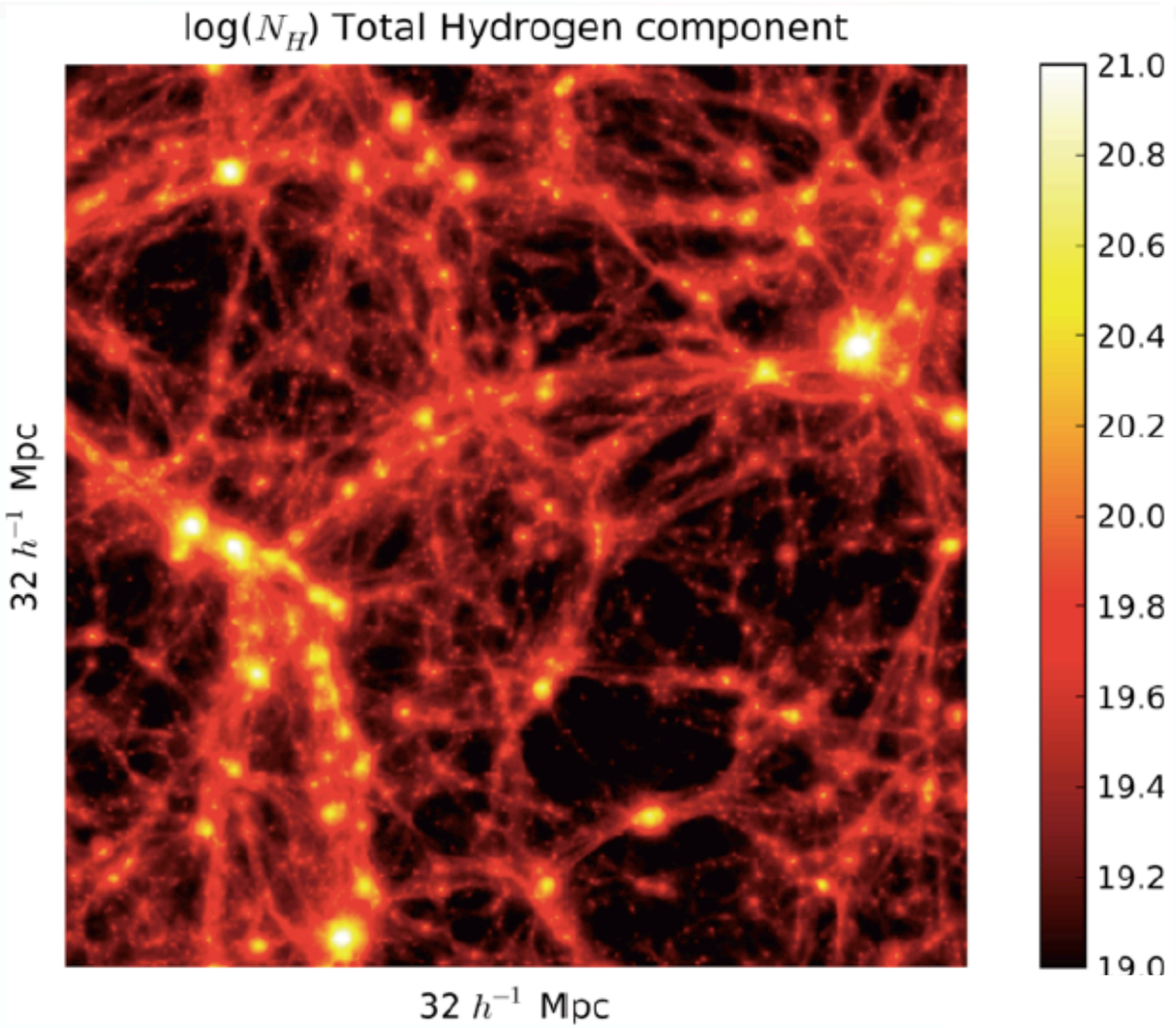
N ($>7\sigma$; 2.3 π)
$\approx 7.1\times10^5$

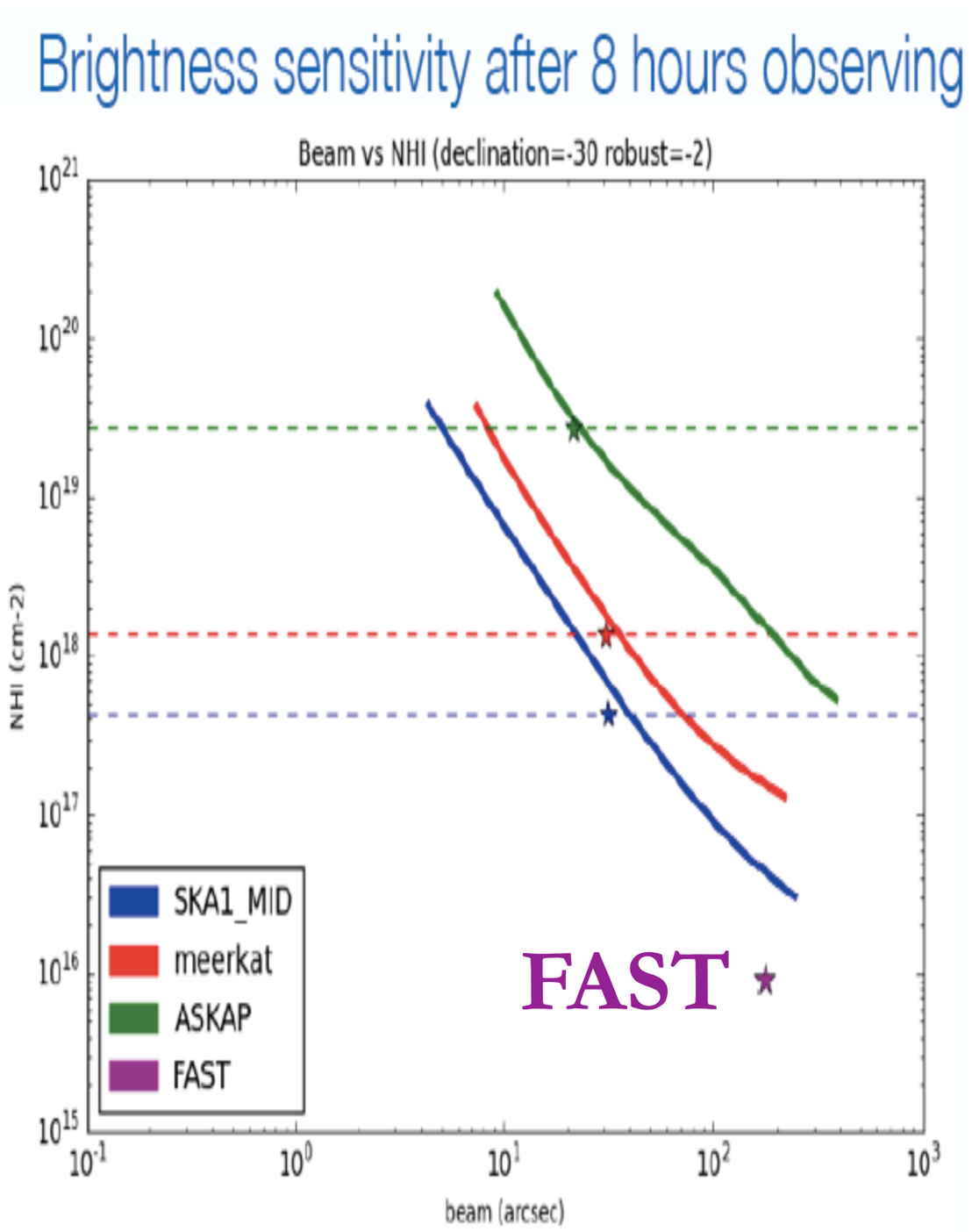
$<z>\approx0.08$

Zhang, Wu, **Li** et al. in prep.
c.f. Duffy et al. 2008

The Cosmic Web

a)





Credit: A. Popping (UWA)

"Dark Gas" Absorption Survey
Pacific Rim Interstellar Medium Observers

b)

PRIMO

"环太平洋"星际介质国际合作团队

State-of-Art: **Arecibo** telescope **79** sources
Heiles & Troland 2003, ApJ (I+II>400 citations)

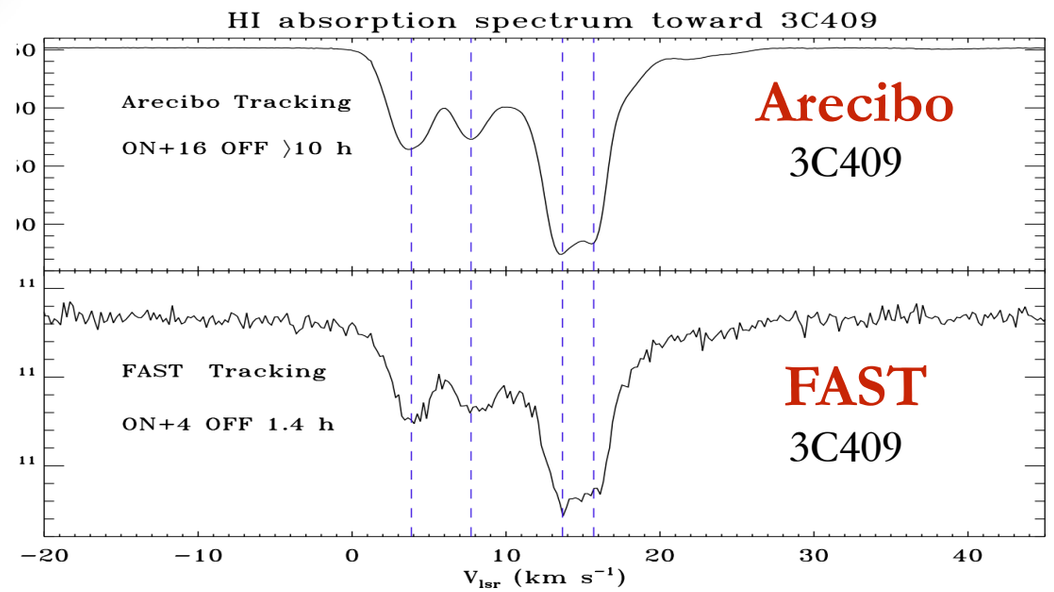
Goal: **FAST** 5 yrs **800** quasars

INcrease
quasar abs. samples x10

合作网站@国家天文台

Publications:

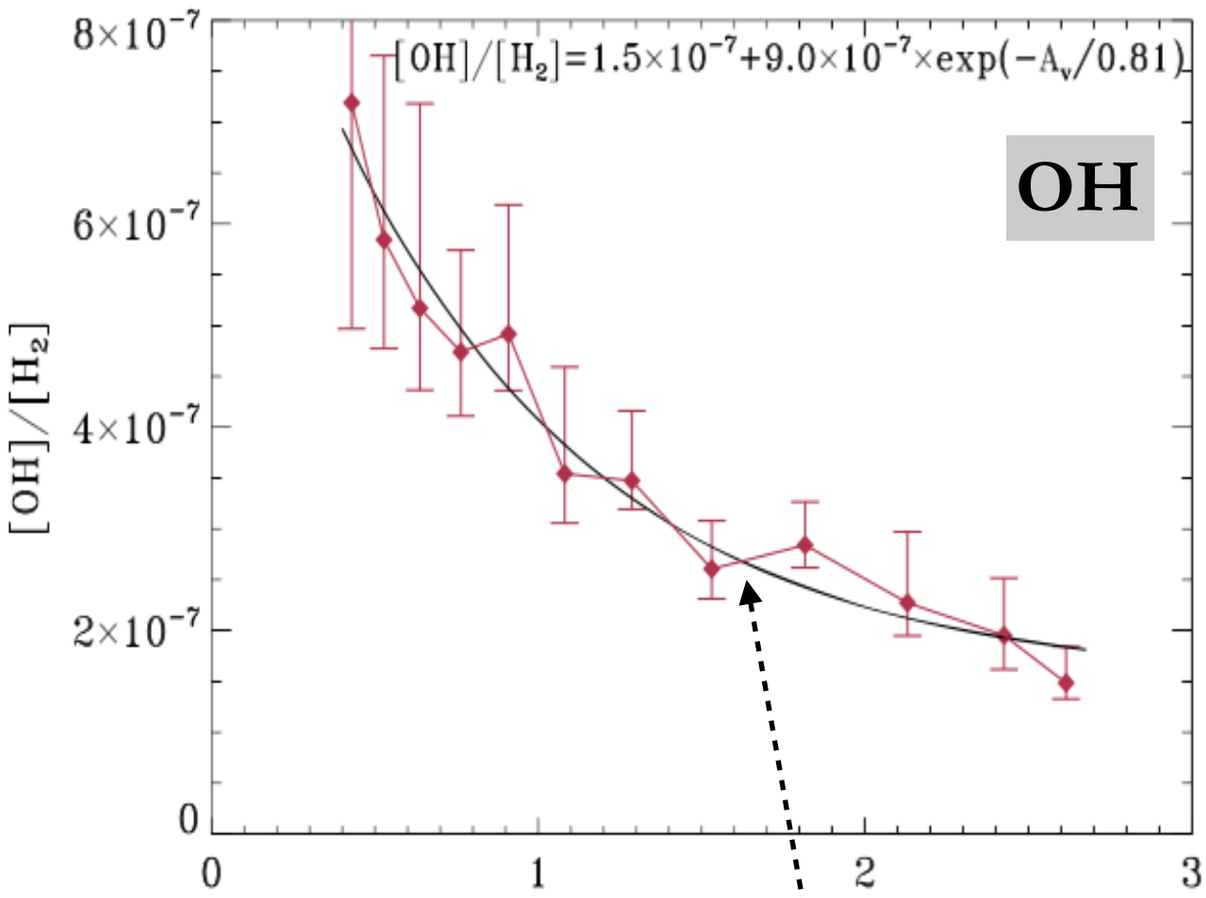
1. **Li** et al. 2015, *Quantifying Dark Gas*, PKAS
2. Tang et al. 2016, *Physical Properties of CO-dark Molecular Gas Traced by C+*, A&A
3. Xu & **Li** 2016, ApJ, paper I, II
4. Tang & **Li** et al. 2017, *OH Survey along Sightlines of Galactic Observations of Terahertz C+*, ApJ, 839, 8
5. Pan & **Li** et al. 2017, *Large-Scale Spectroscopic Mapping of the -Ophiuchi Molecular Cloud Complex I. The C2H to N2H+ Ratio as a Signpost of Cloud Characteristics*, ApJ, 836, 194
6. Tatematsu, Ken'ichi et al. 2017, *Astrochemical Properties of Planck Cold Clumps,* ApJS, 228, 12
7. **Li**, Tang & PRIMO 2018, *Where is OH and Does It Trace the Dark Molecular Gas (DMG)?*, ApJS, 235, 1



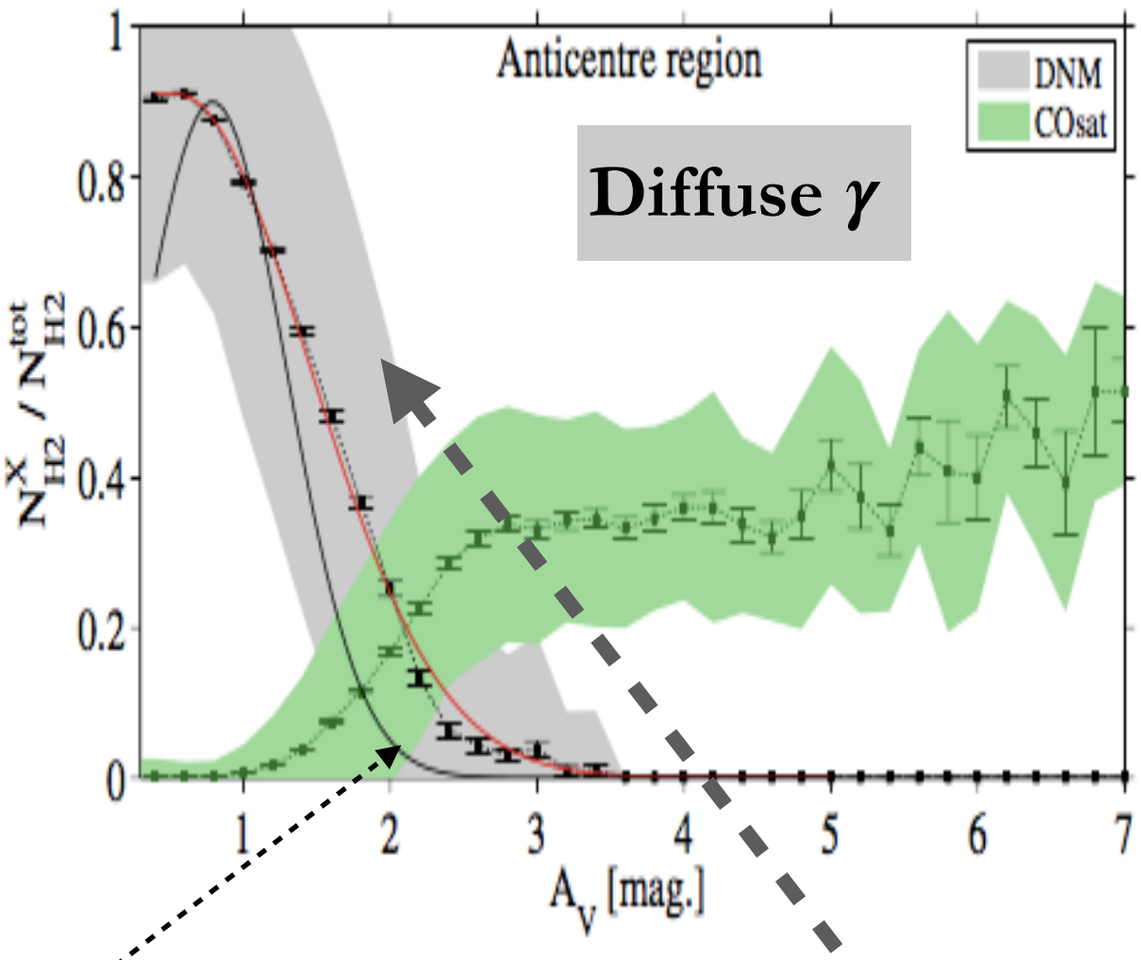
2017.9.23: FAST吸收线测试结果

DMG & DNM
Intermediate Av ~ 0.1-2

b)



OH abundance co-evolve with CO, N(H), and DGF



Remy, Grenier et al. 2017
Based on **Fermi**

$$\mathrm{DGF} = 0.90 \times \exp\left(-\left(\frac{A_v - 0.79}{0.71}\right)^2\right).$$

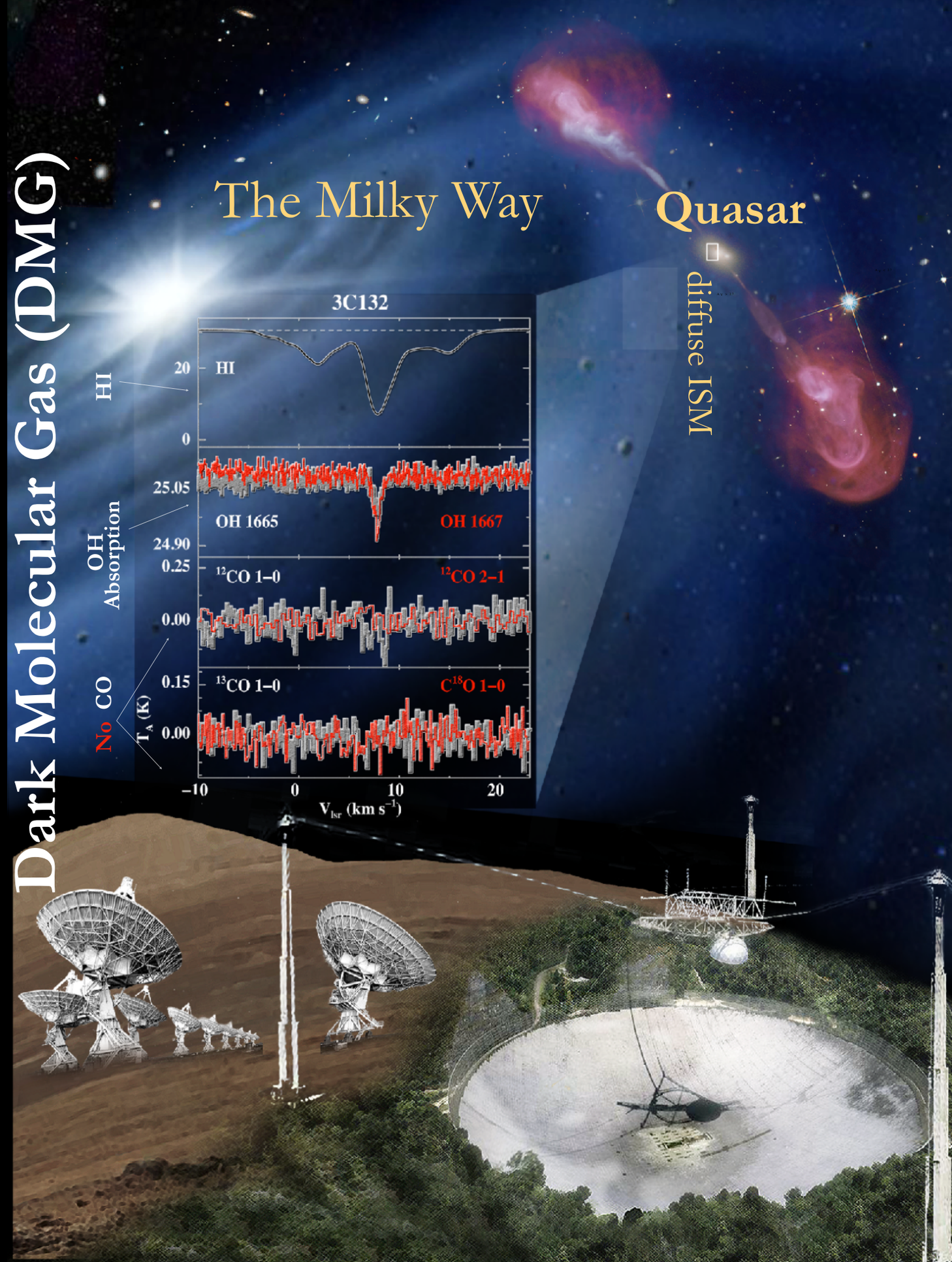
Xu, **Li+** et al. 2016 ApJ

Pacific Rim Interstellar Observer (PRIMO)

"Where is OH and Does it Trace the Dark Molecular Gas (DMG) ?"

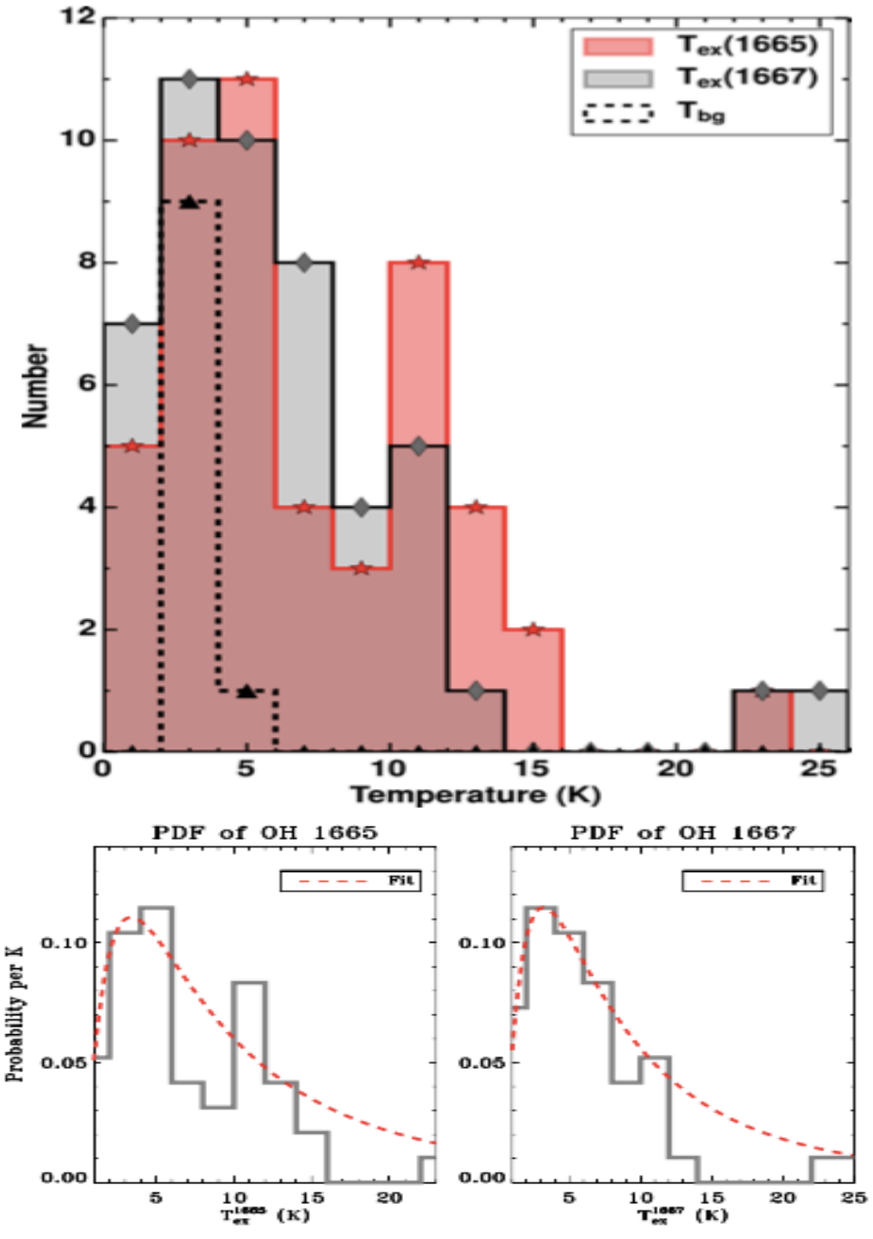
Li, Tang, +PRIMO, ApJS, 235,1

- OH excitation temperature peaks around CMB
- OH abundance tracks DMG fraction
- FAST will supersede Arecibo by x10. Tests underway

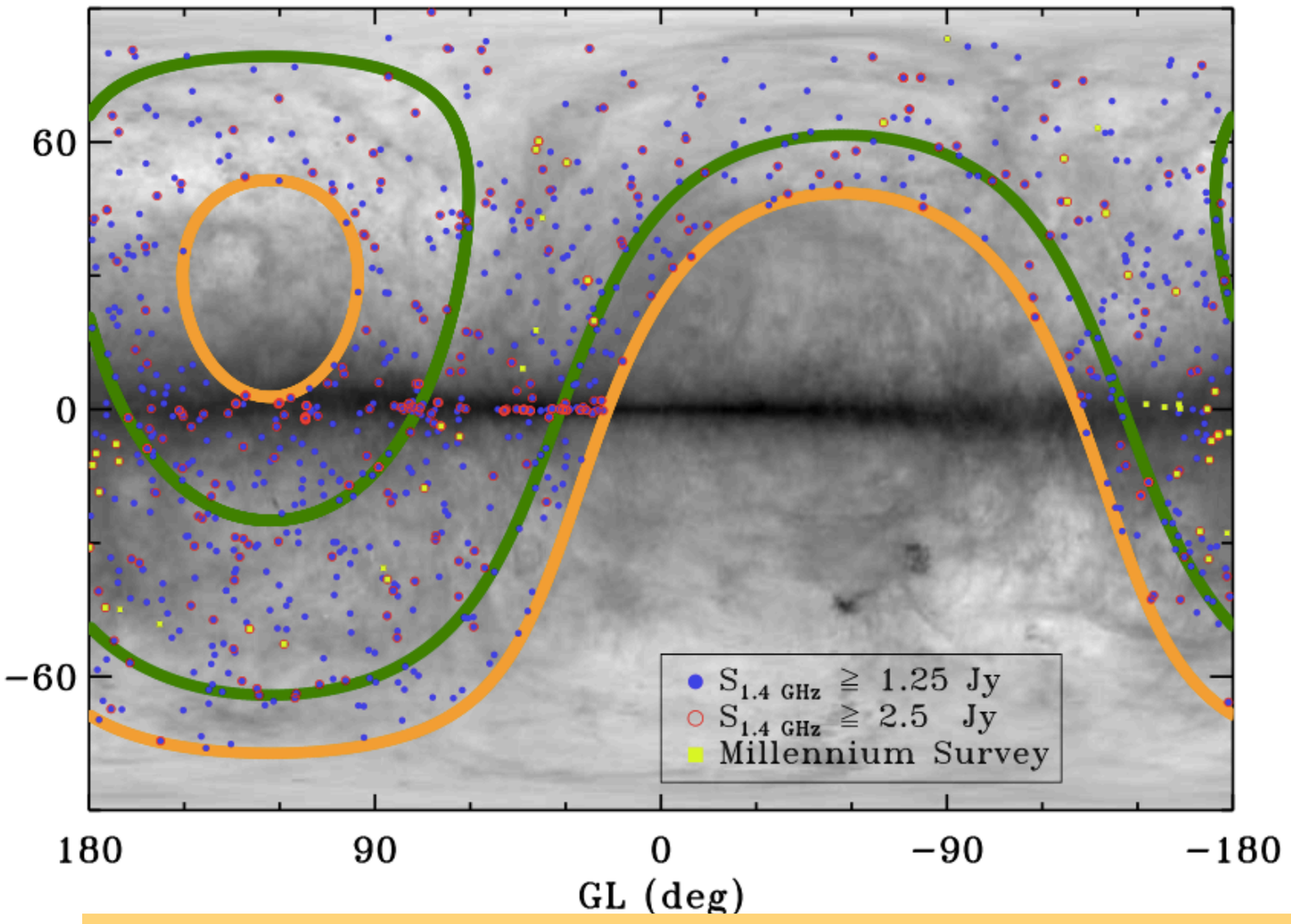


OH Excitation

b)



$$f(T_{\rm ex}) \propto \frac{1}{\sqrt{2\pi}\sigma}\exp[-\frac{[\ln(T_{\rm ex})-\ln(3.4\ {\rm K})]^2}{2\sigma^2}]$$



The FAST "Absorption Sky"

(cf. N. McClure-Griffiths et al. 2015 for SKA)

Li, Tang, +**PRIMO** 2018, ApJS

Pulsar Surveys

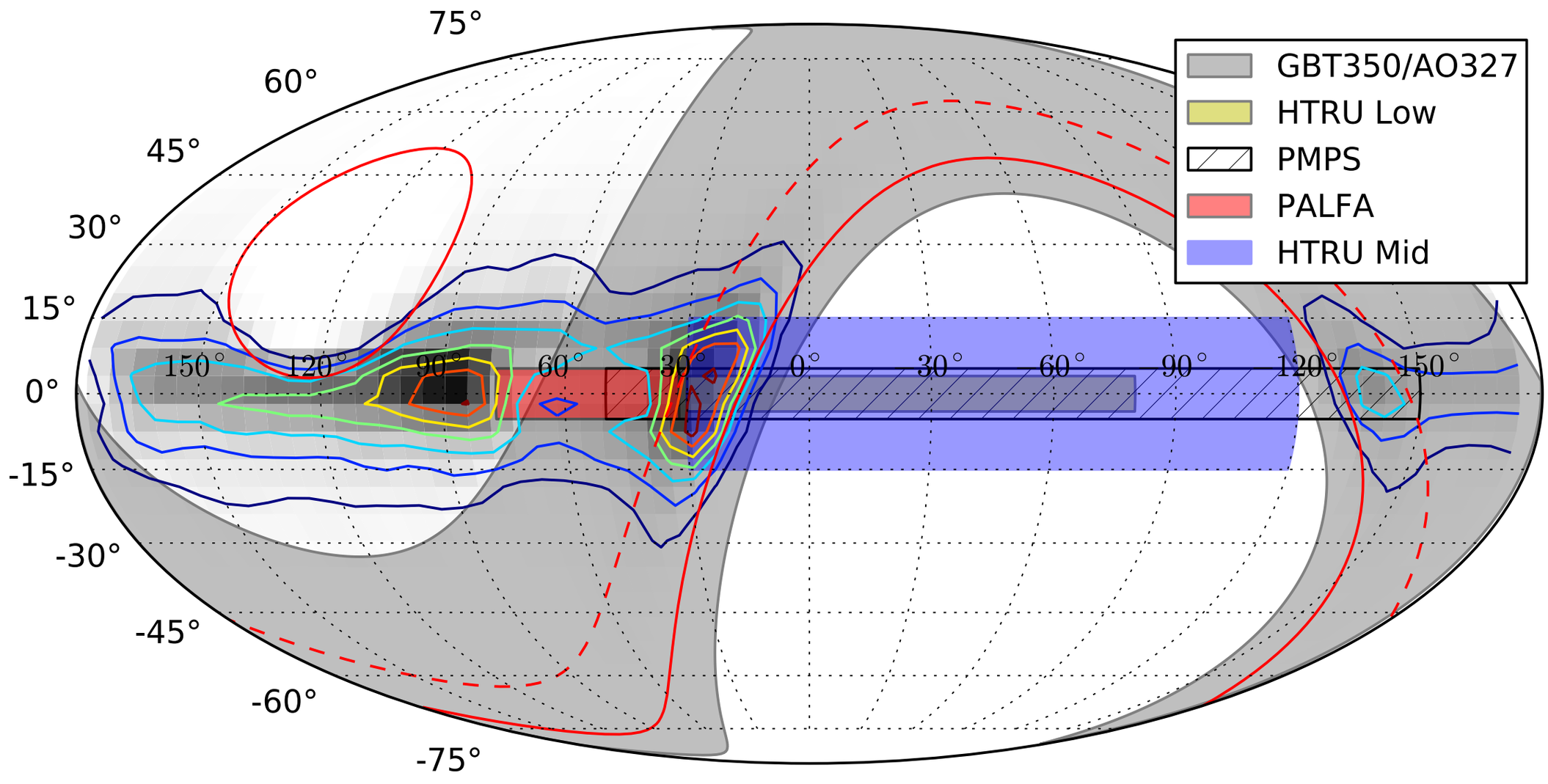
c)

AO 327 MHz drift scan

LOFAR pulsar survey

Galactic centre search

PMPS re-analysis E@H



HTRU-N low-latitude

HTRU-N medium-latitude

HTRU-N high-latitude

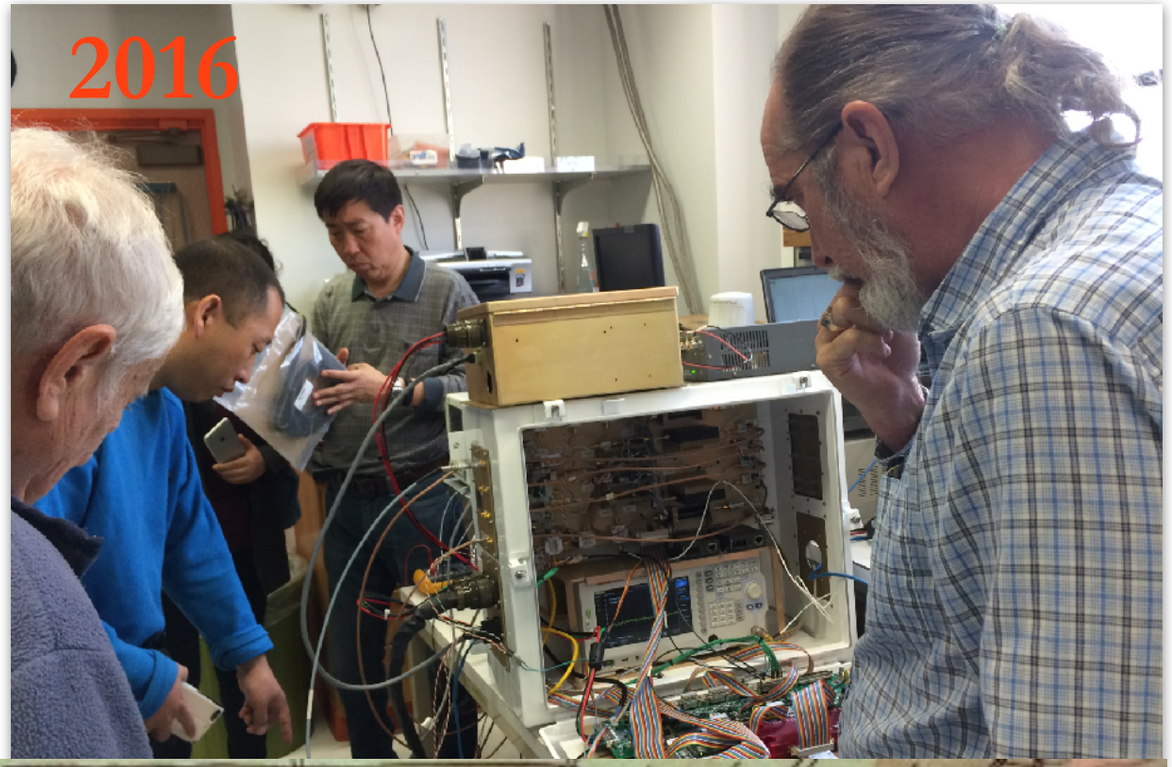
HTRU-S low-latitude

HTRU-S medium-latitude

HTRU-S high-latitude

Dai & Zhu

270 MHz - 1.62 GHz: 超寬帶接收機



Jocelyn Bell Burnell

Inbox - nao.cas.cn 14 February 2018 at 12:25 AM

JB

Happy New Year!

To: Di Li

Bets wishes to you and all at FAST for the Chinese New Year!

Jocelyn

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Tel: +44 (0)1865 2733[illegible]; fax +44 (0)1865 273390.
Also MANSFIELD COLLEGE

Message from Dr. Bell

Oct. 10, 2017

First FAST Science Results

2018.2

>60 candidates

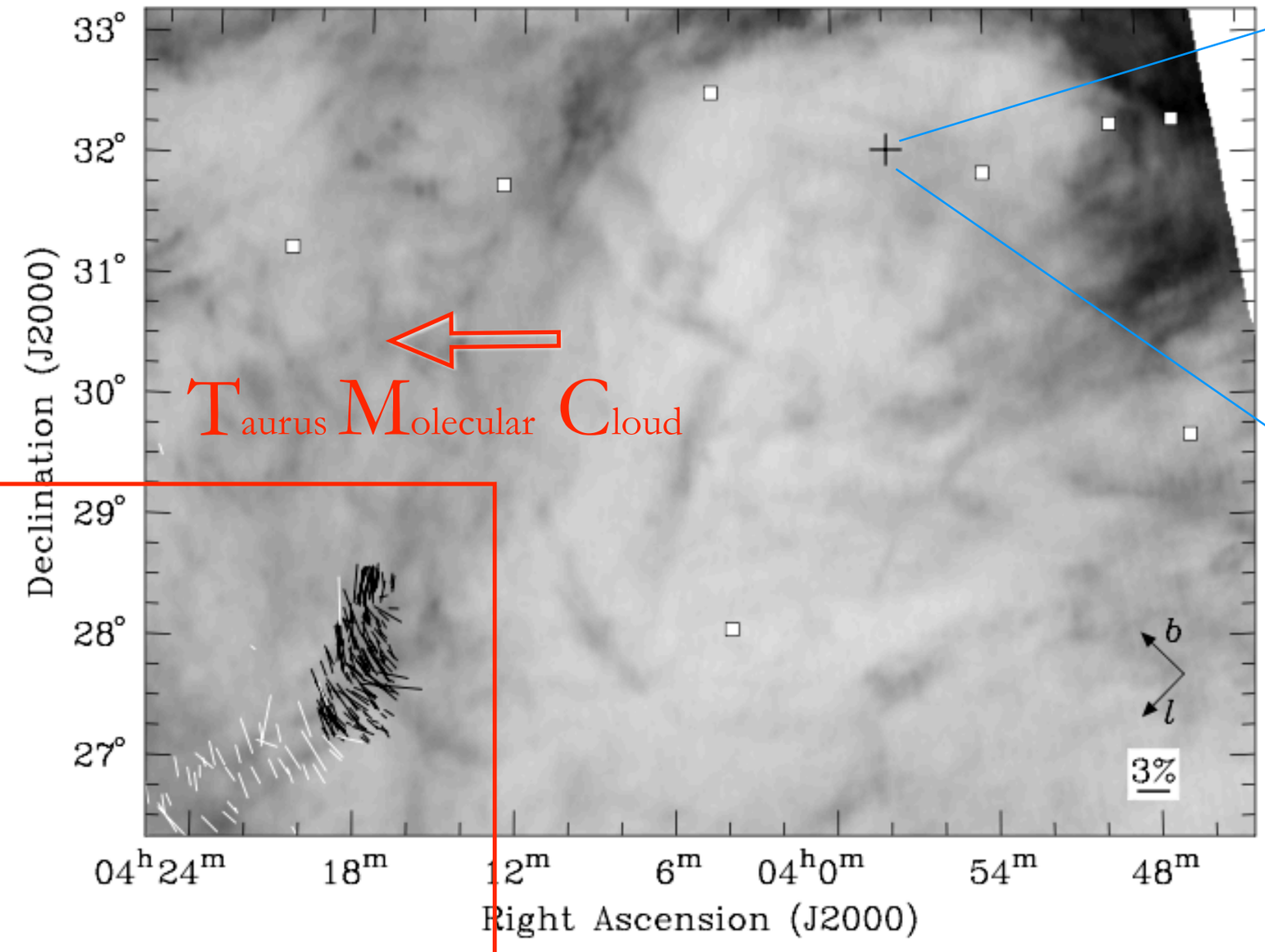
>40 confirmed discoveries


Per
NGC 1499
IC 348
B4
B1
B219
B7
B22
B19
B18
LDN 1548
1746
1817
Tau
Taurus Molecular Cloud
Pleiades
Hyades
© 2009 Jerry Lodriguss / AstroPix.com

The "Taurus" Pulsar

FAST discovers radio pulses from J0357

c)



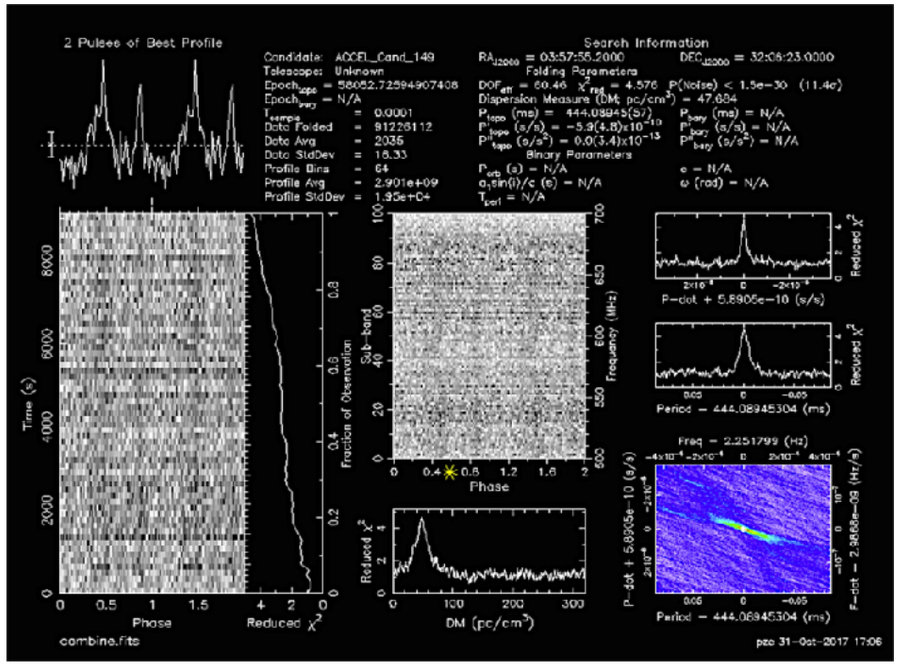
Chapman … **Li**+ et al. ApJ 2011

P= 0.444 s

DM=47.6

Confirmed by Arecibo DDT observations; AO timing underway

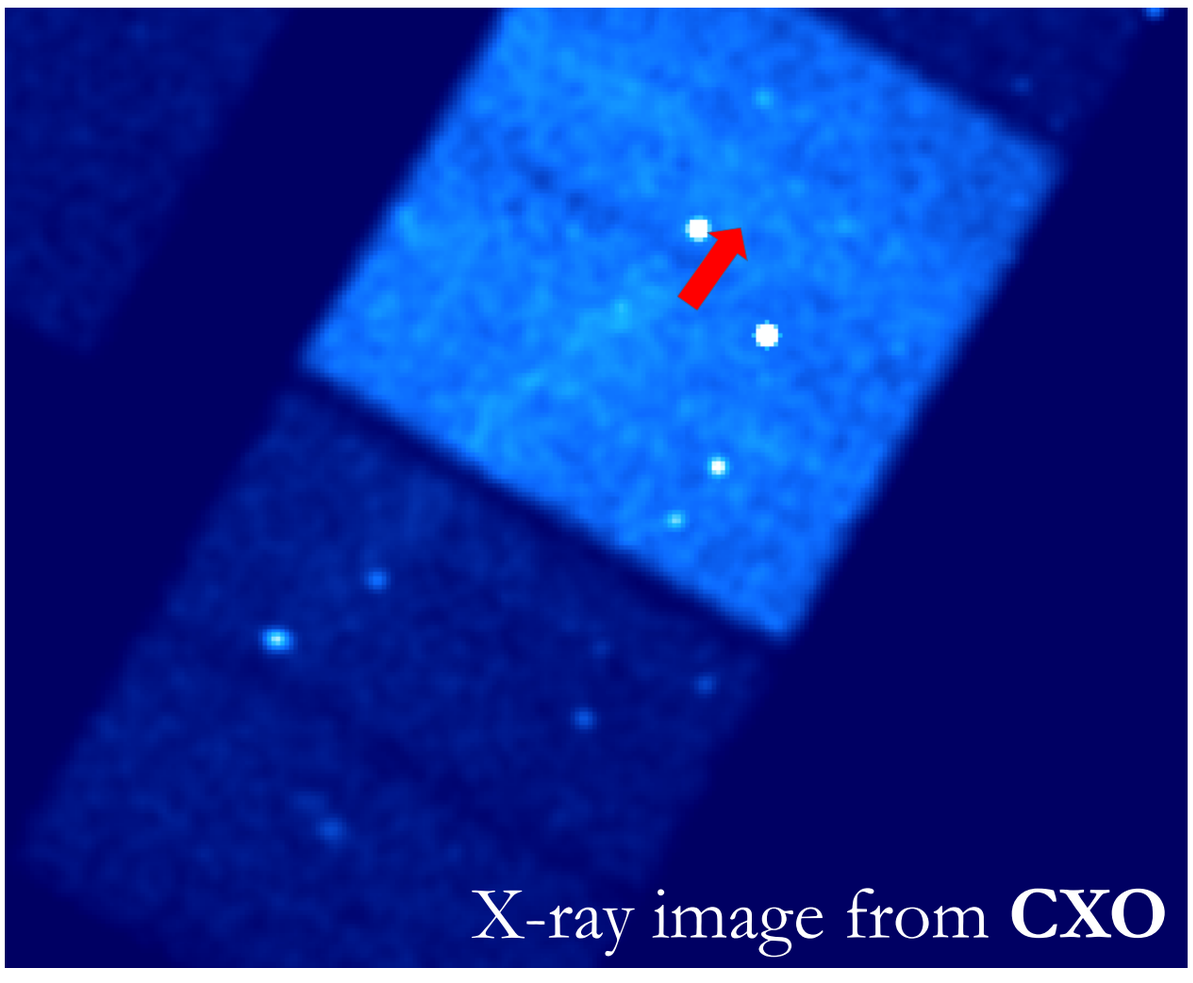
Chandra X-ray Image
De Luca et al. 2011



Closest or Fastest?

c)

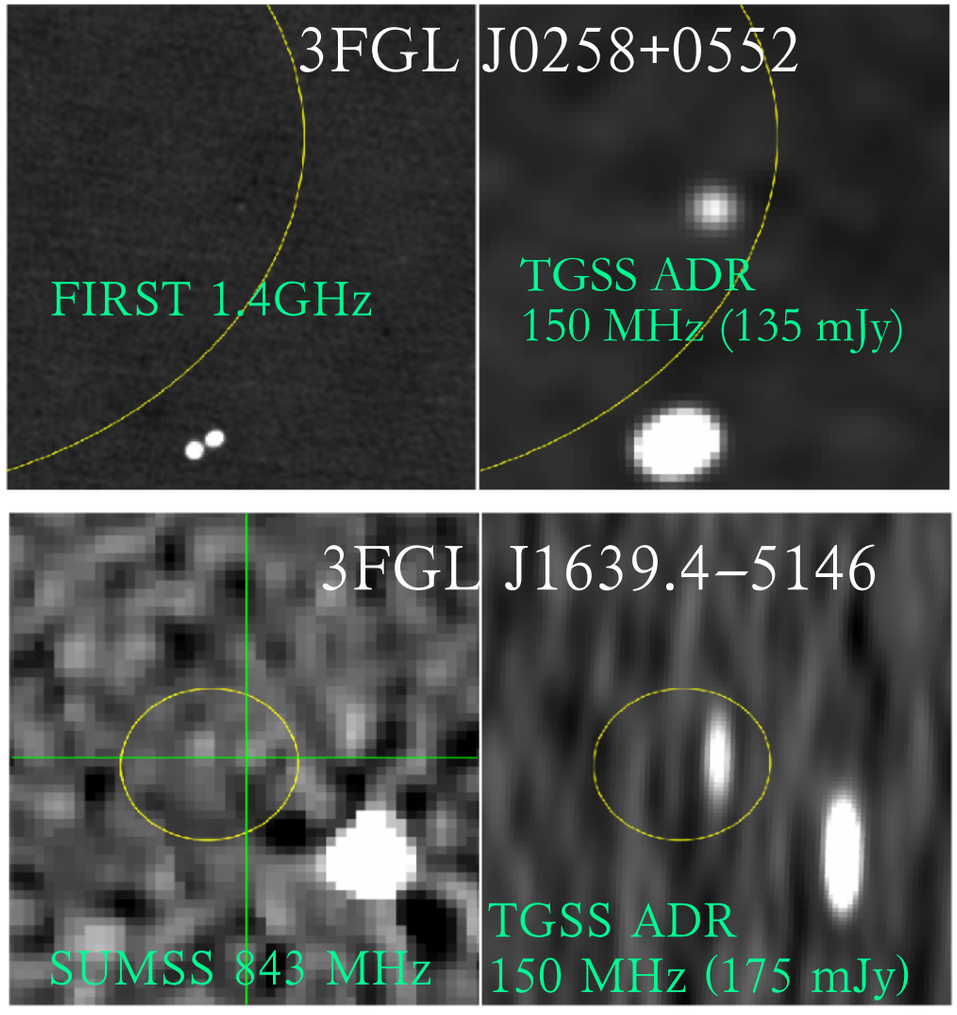
- Consistent with Fermi's periodicity of 0.444s
- No radio detection until FAST
- Visible X-ray tail
- Very * **high** * apparent proper motion
- X-ray absorption column + DM estimates => **1Kpc ?**

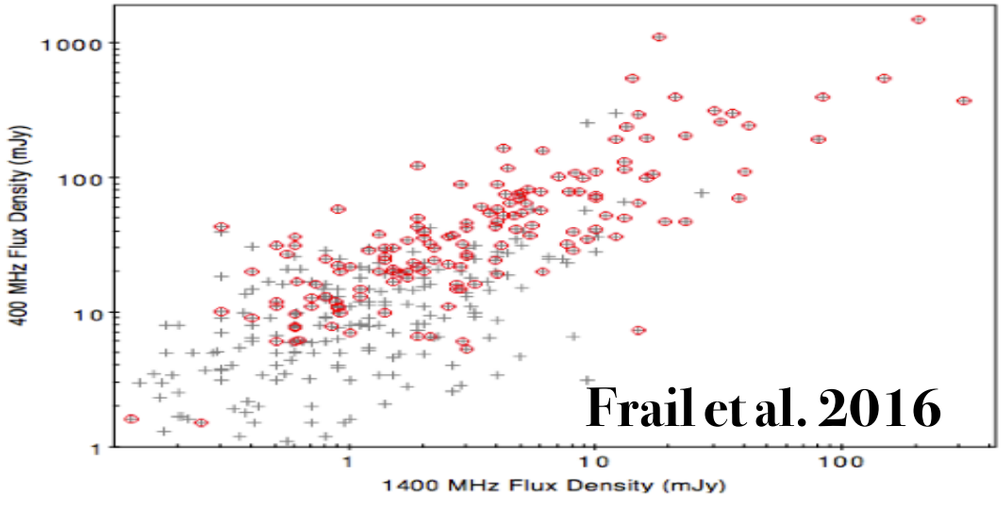


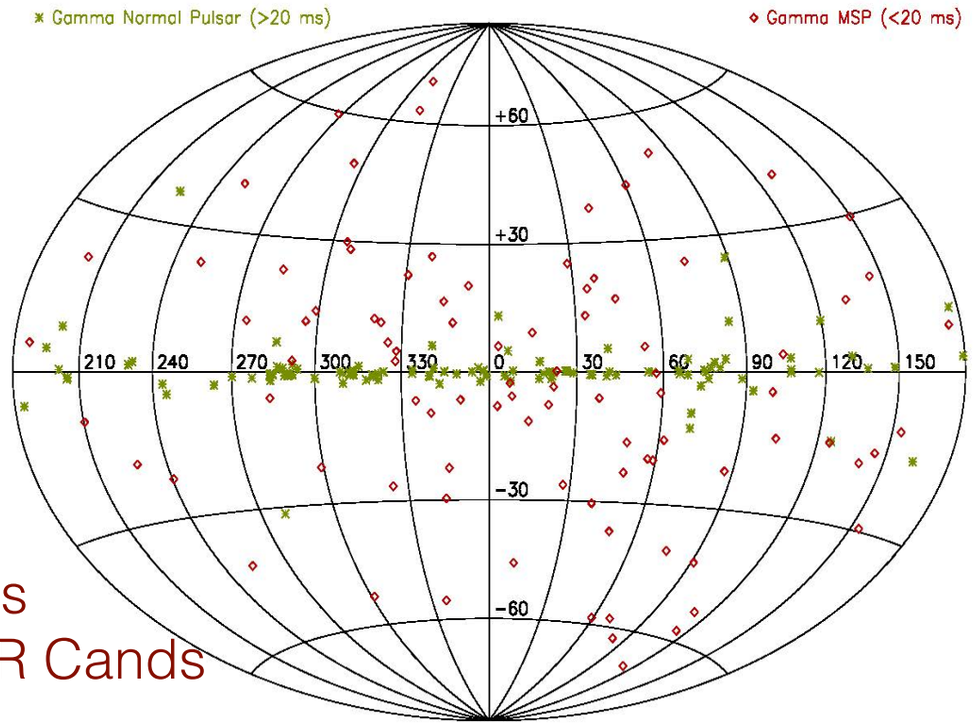
Possibly one of the most nearby pulsars ?
Or one of the fastest-moving pulsars ?

FAST-Fermi

The High-Energy Neighbourhoods



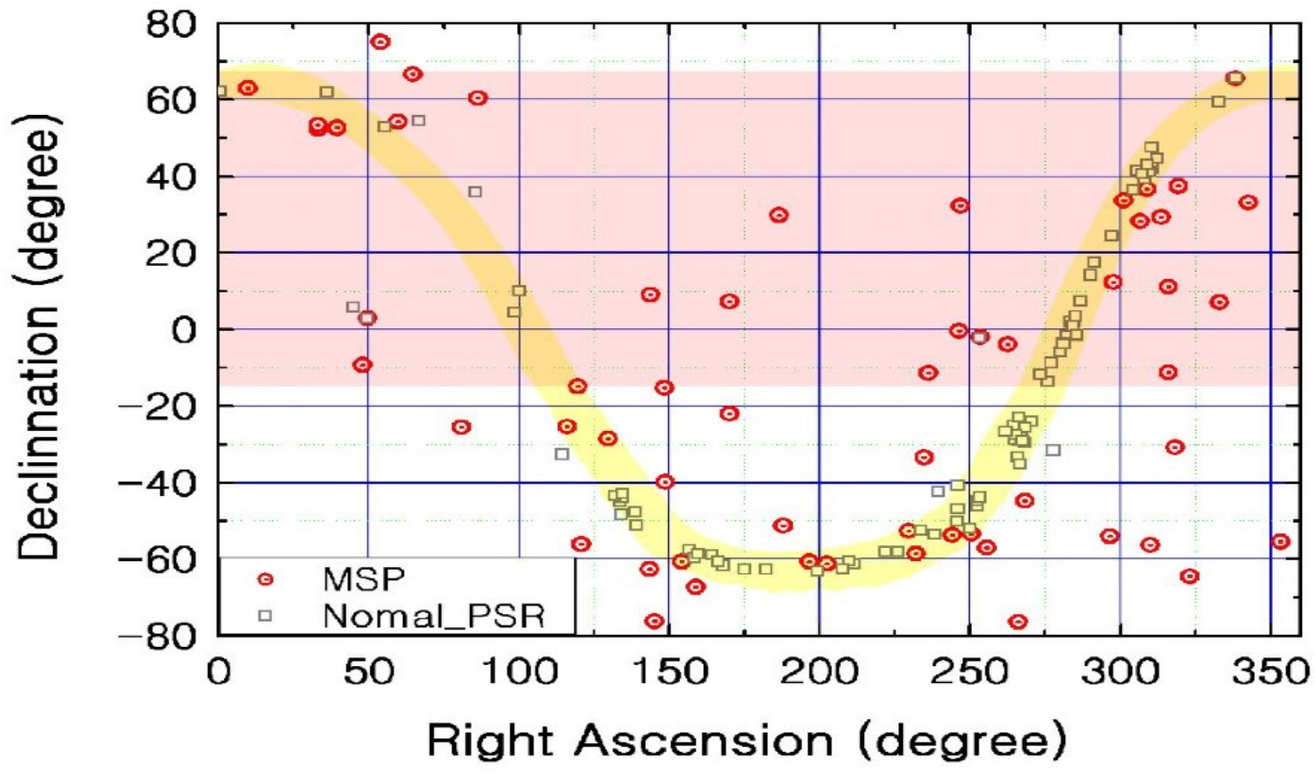




In FAST sky

41 MSP Cands

39 Nomal_PSR Cands



MSPs at high latitude

- Mapping from interferometer + Spectral index
- Machine learning method (Saz. Parkinson et al. 2016)

FAST's First MSP

c)

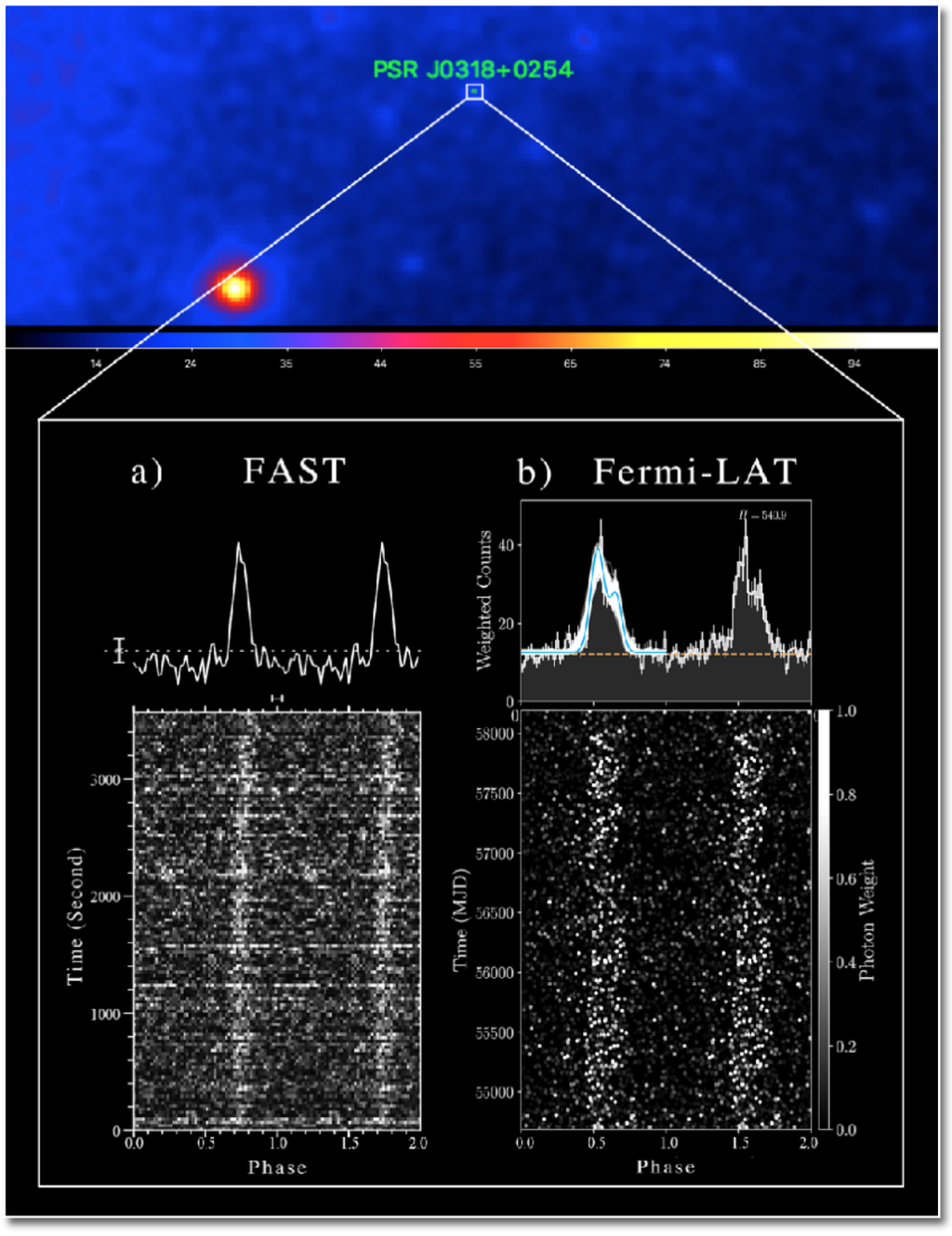
3FGL J0318.1+0252
FL8Y J0318.2+0254

- Fermi unidentified source
- GBT, Arecibo non-detection

PSR J0318+0253

p 5.19 ms; **DM** 26 pc cm^{-3}

- **2018.2.27** FAST one hour tracking
- **2018.4.12** Wang Pei and GZNU group discovered the candidate
- **2018.4.18** Colin Clark found the γ-counterpart
- **2018.4.23** Pablo confirmed no X-ray, provided limits
- **2018.4.28** Published on Atel #10851
- **2018.5.02** IPTA released J0318+0253 to its members



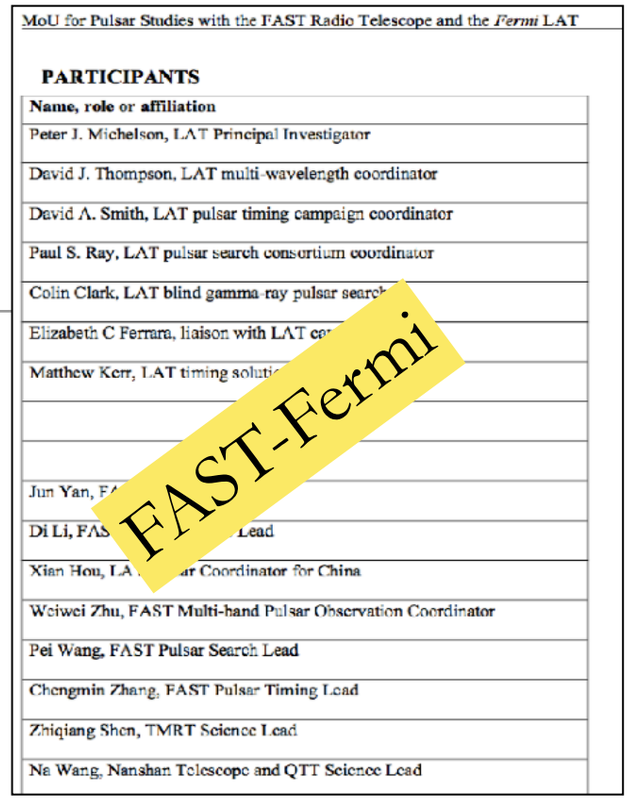
Wang et al. 2018, Atel # 10851

"FAST's Discovery of a New Millisecond Pulsar (MSP) toward the Fermi-LAT unassociated source 3FGL J0318.1+0252"

FAST-Fermi

#Type:
#1. New Pulsar discoved
#2. Pulsar Candidate

#Source_name	Ra(J2000)	Dec(J2000)	Receiver	Obs_time	Type	Proc.
FL8Y_J1120.6+0713	11:20:38	07:13:12	19Beam(1.05-1.45)	2018/08/04 14:15-15:15		
FL8Y_J0652.9+4708	6:52:58	47:07:48	19Beam(1.05-1.45)	2018/07/19 10:40-11:40		
FL8Y_J0546.6+0026	5:46:41	00:26:24	19Beam(1.05-1.45)	2018/07/15 10:35-11:35		
FL8Y_J0506.0+5028	5:06:05	50:28:48	19Beam(1.05-1.45)	2018/07/12 09:55-10:55		
FL8Y_J0541.2+3515	5:41:17	35:15:36	19Beam(1.05-1.45)	2018/07/11 10:40-11:40		
FL8Y_J0431.3+3500	4:31:24	35:00:36	19Beam(1.05-1.45)	2018/07/10 10:30-11:30		
FL8Y_J0430.6+3533	4:30:41	35:33:00	19Beam(1.05-1.45)	2018/07/10 09:15-10:15	2	Y
FL8Y_J0427.8+3631	4:27:50	36:31:12	19Beam(1.05-1.45)	2018/07/08 10:40-11:40		Y
FL8Y_J0344.4+3202	3:44:24	32:02:24	19Beam(1.05-1.45)	2018/07/07 09:15-10:15		Y
FL8Y_J0342.3+3154	3:42:19	31:54:36	19Beam(1.05-1.45)	2018/07/04 10:05-11:05		Y
3FGL_J0318.1+0252	3:18:17	02:54:36	UWB(290-802)	2018/02/27 16:50-17:50	1	Y
3FGL_J1949.3+2433	19:49:18	24:33.00	UWB(290-802)	2018/02/26 09:00-10:00		Y
3FGL_J2028.5+4040c	20:28:30	40:40:12	UWB(290-802)	2018/02/26 10:25-11:45		Y
PSR_J1906+0722	19:06:31	7:22:55.2	UWB(290-802)	2018/02/25 09:00-10:00		Y
3FGL_J2026.8+2831	20:27:07	28:11:24	UWB(290-802)	2018/02/25 10:15-11:45		Y
3FGL_J0258.9+0552	2:58:54	05:52:11.2	UWB(290-802)	2018/02/24 16:45-17:45		Y
3FGL_J1627.8+3217	16:27:52.3	32:17:55.7	UWB(290-802)	2018/01/03 09:50-10:20		Y
3FGL_J1925.4+1727	19:25:24	17:27:00	UWB(290-802)	2017/12/21 15:20-15:50		Y
3FGL_J1950.2+1215	19:50:12	12:24:00	UWB(290-802)	2017/12/19 15:45-16:15		Y
3FGL_J0357.9+3206	03:57:55.2	32:06:23	UWB(290-802)	2017/12/17 22:24-23:34		Y
3FGL_J2028.5+4040c	20:28:30	40:40:12	UWB(290-802)	2017/11/06 19:20-19:50	2	Y
3FGL_J2053.9+2922	20:53:54	29:22:01.2	UWB(290-802)	2017/11/02 19:55-20:25		Y
3FGL_J2250.6+3308	22:50:36	33:07:58.8	UWB(290-802)	2017/11/02 20:55-21:25		Y
3FGL_J2035.0+3634	20:35:01.92	36:34:53	UWB(290-802)	2017/11/01 19:55-20:25		Y
3FGL_J1120.6+0713	11:20:41.28	7:13:24.6	UWB(290-802)	2017/10/30 09:00-09:07		Y
3FGL_J1225.9+2953	12:25:54	29:52:48	UWB(290-802)	2017/10/30 09:50-10:30		Y
3FGL_J2117.6+3725	21:17:41	37:25:32.2	UWB(290-802)	2017/10/30 19:30-20:00		Y
3FGL_J2212.5+0703	22:12:35.28	7:03:35.3	UWB(290-802)	2017/10/28 19:30-20:00		Y
PSR J0357.8+3205	03:57:48	32:05:00	UWB(290-802)	2017/10/27 01:25-04:00	1	Y
3FGL_J1627.8+3217	16:27:52.32	32:17:55.7	UWB(290-802)	2017/10/24 16:00-16:30		Y
3FGL_J2004.4+3338	20:04:24.72	33:38:42.4	UWB(290-802)	2017/10/24 19:00-19:30		Y


MoU for Pulsar Studies with the FAST Radio Telescope and the *Fermi* LAT

PARTICIPANTS

Name, role or affiliation
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David J. Thompson, LAT multi-wavelength coordinator
David A. Smith, LAT pulsar timing campaign coordinator
Paul S. Ray, LAT pulsar search consortium coordinator
Colin Clark, LAT blind gamma-ray pulsar search
Elizabeth C Ferrara, liaison with LAT co
Matthew Kerr, LAT timing soluti
Jun Yan, FA
Di Li, FAS Lead
Xian Hou, LA r Coordinator for China
Weiwei Zhu, FAST Multi-band Pulsar Observation Coordinator
Pei Wang, FAST Pulsar Search Lead
Chengmin Zhang, FAST Pulsar Timing Lead
Zhiqiang Shen, TMRT Science Lead
Na Wang, Nanshan Telescope and QTT Science Lead

FAST-Fermi

Extra-galactic Pulsars

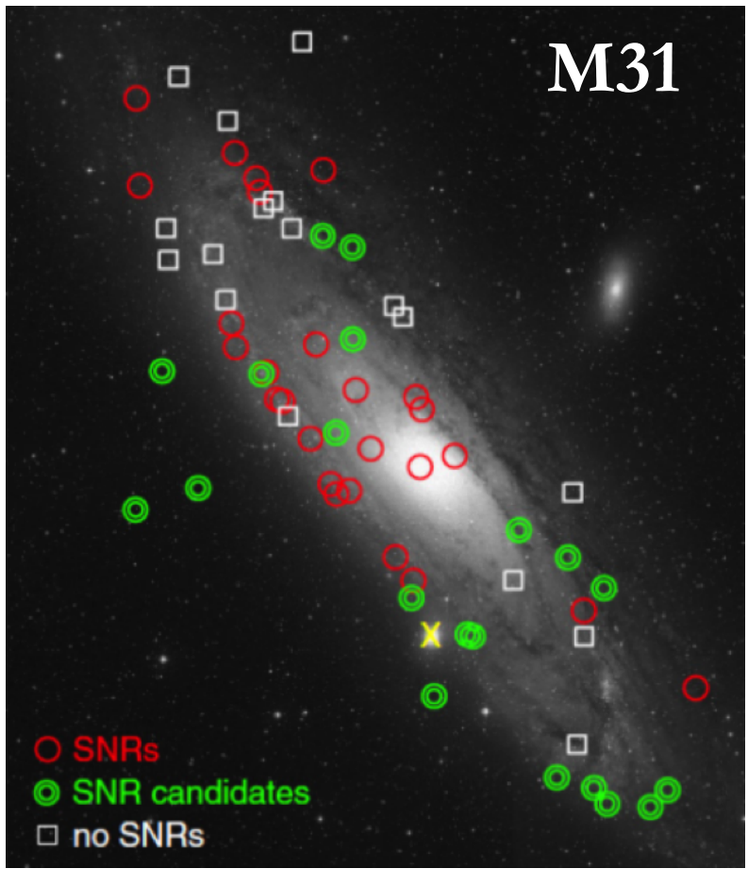
c)

Bahcall, Rees & Salpeter 1970

$$M_v(t) = -13.7 + 10 \log \left[\frac{P(t)}{P_{\min}}\right] - 2.5 \log \left[\frac{PdP/dt}{(PdP/dt)_{\text{Crab}}}\right]$$

Manchester et al. 2000
LMC, SMC: now > 15 pulsars, also X-ray
Bachetti et al. 2014: M82, Chandra, 1.37s

M33: None
M31: ?



Sakai et al. 2014

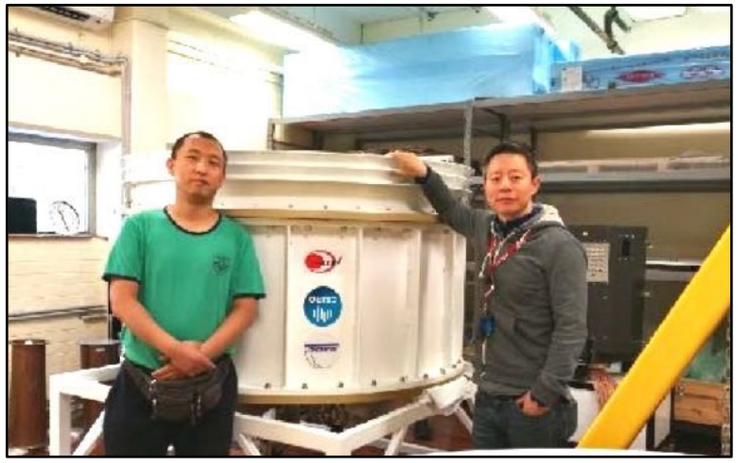
50-80 normal pulsars detectable by FAST (Smits et al. 2009)
Giant pulse **Credit**: Crawford, Cordes & DL

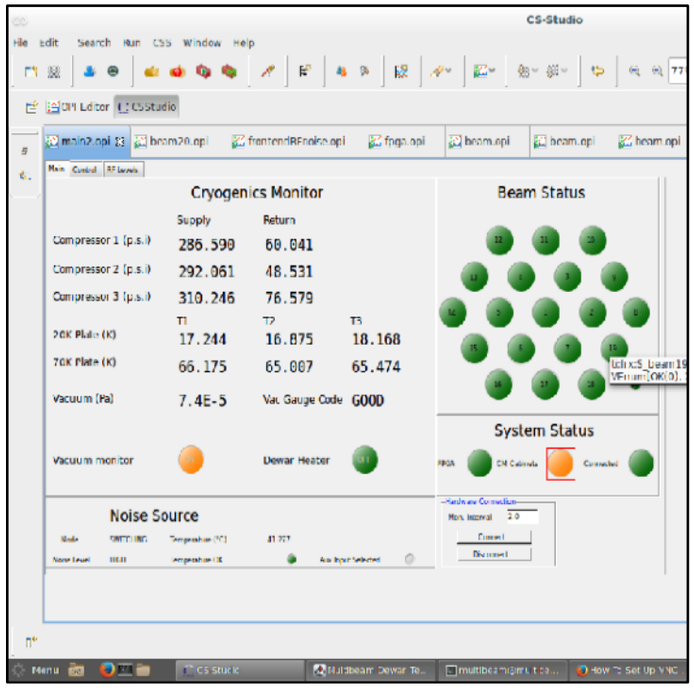
	LOW	HIGH
Freq(MHz)	560	1295
BW (MHz)	580	680
Nchan	5220	5850
T_drift (sec)	33	14

LOW: one detection every 0.7 to 2.0 minutes
HIGH: one detection every 180 to 540 minutes

FLAN

FAST L-band Array of Nineteen beams

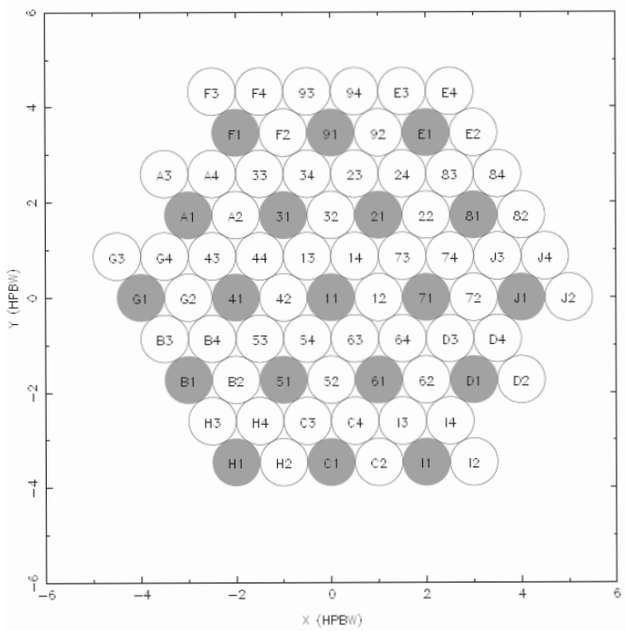




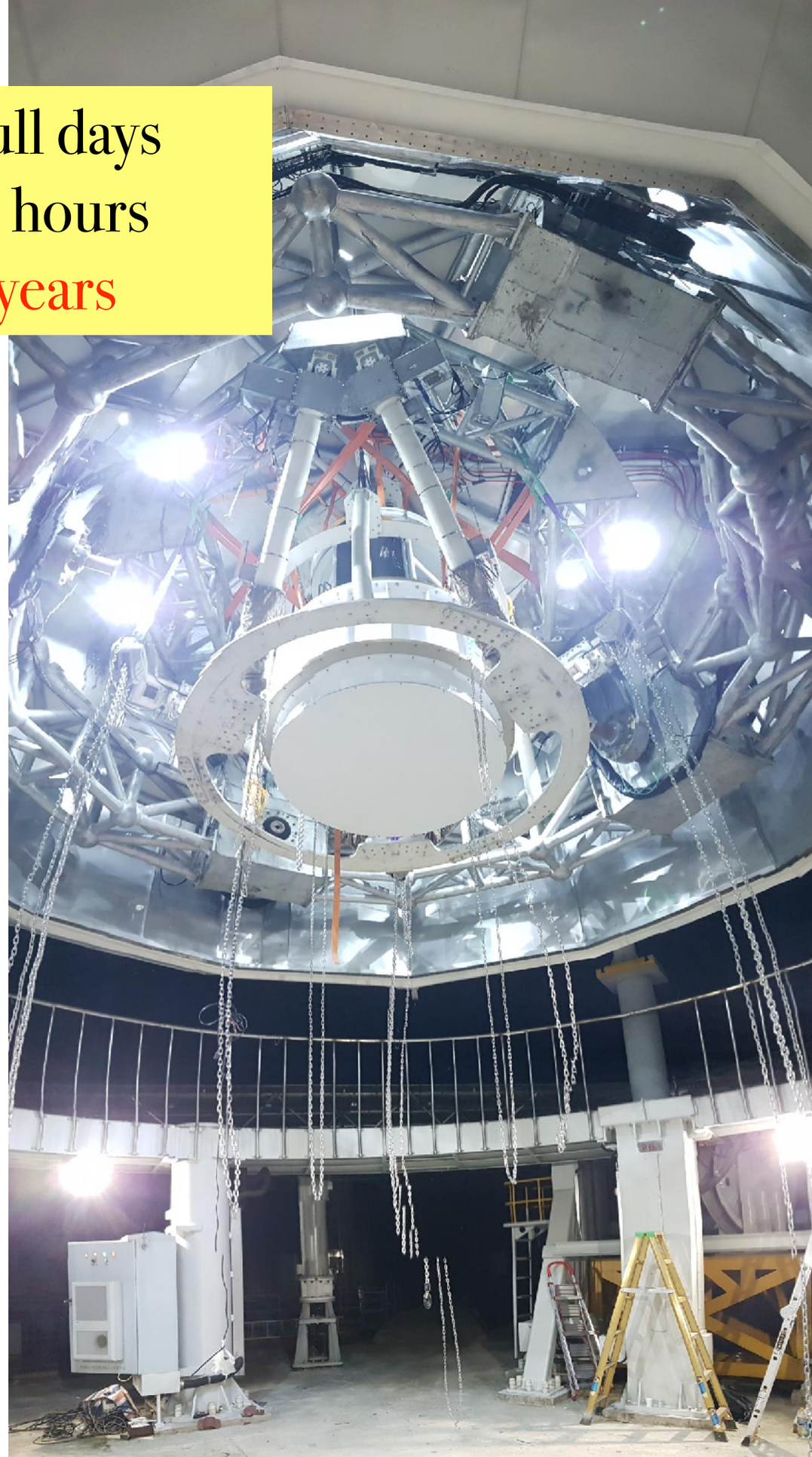
CSIRO

The Largest L-band feed-horn array

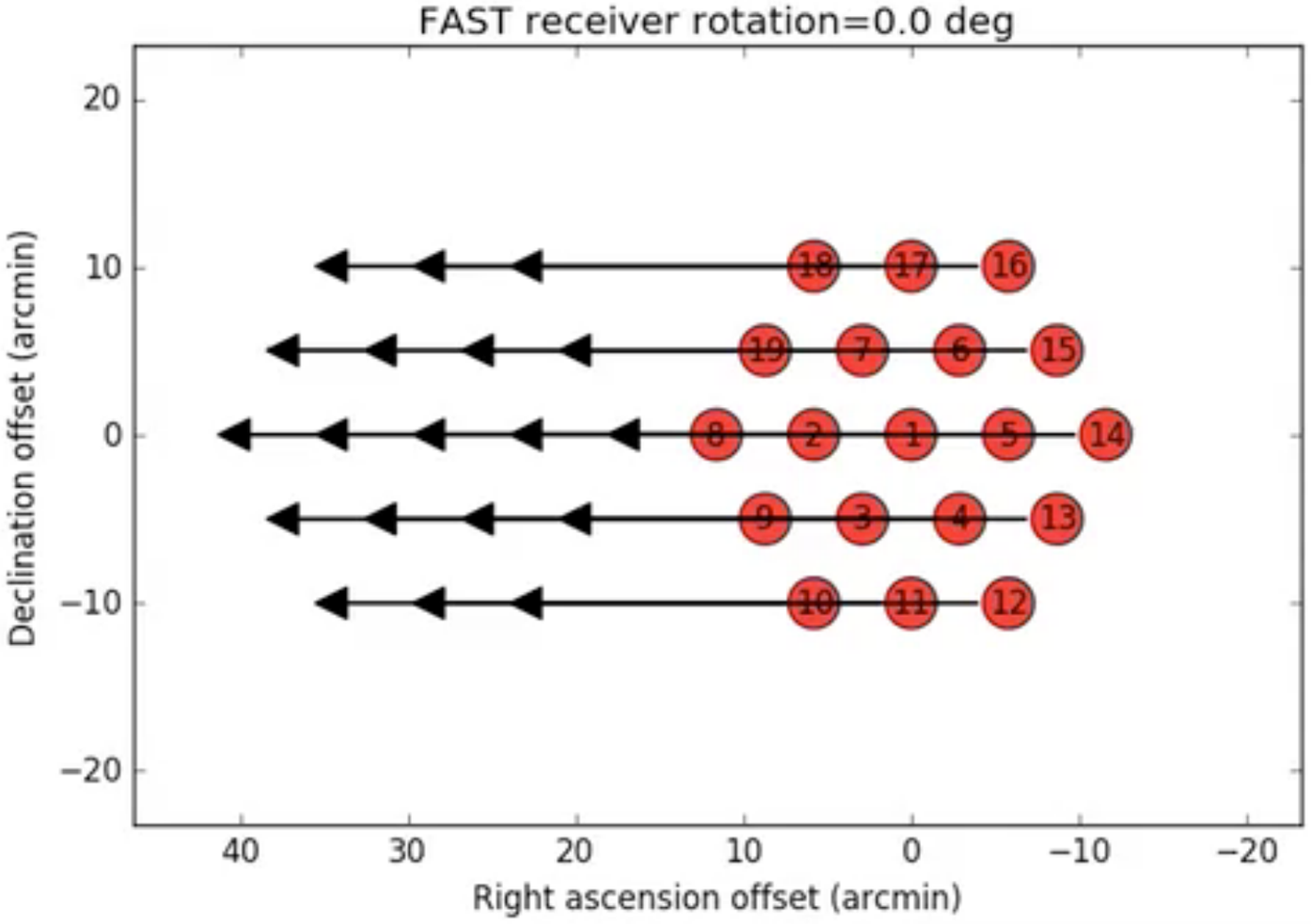
- 1.05 – 1.45 GHz
- 18K T_{sys}
- 19 BEAM FEED ARRAY
- BEAM WIDTH 2.9’ at 21cm
- BEAM SPACING 270mm (~6’)
- DUAL LINEAR POLARIZATION
- POL. CROSS-COUPLING <-30 dB



220 full days
5280 hours
2-3 years



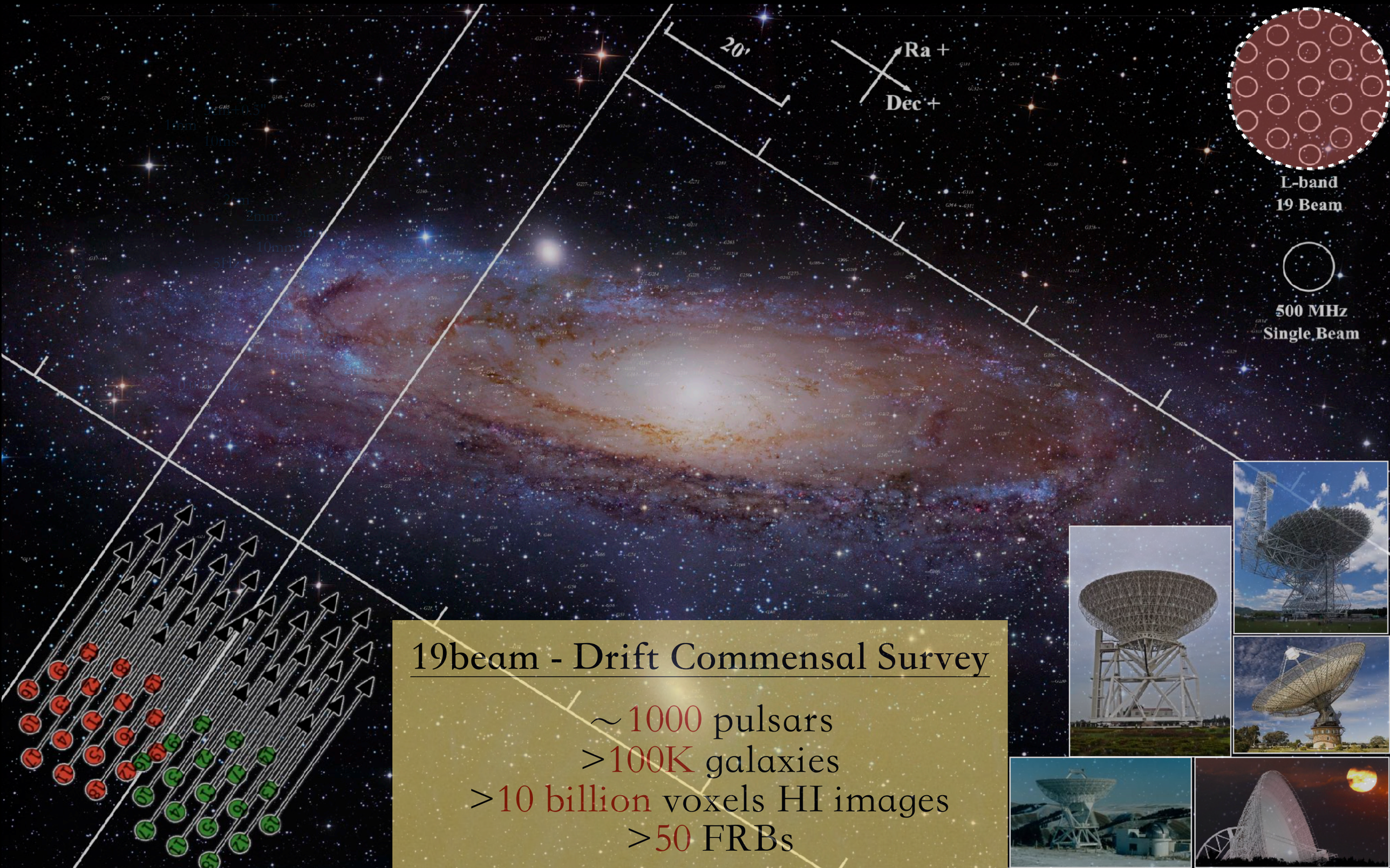
Credit: L. Staveley-Smith



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

Commensal Radio Astronomy FAST Survey

32m-dish beam



19beam - Drift Commensal Survey

~1000 pulsars
>100K galaxies
>10 billion voxels HI images
>50 FRBs

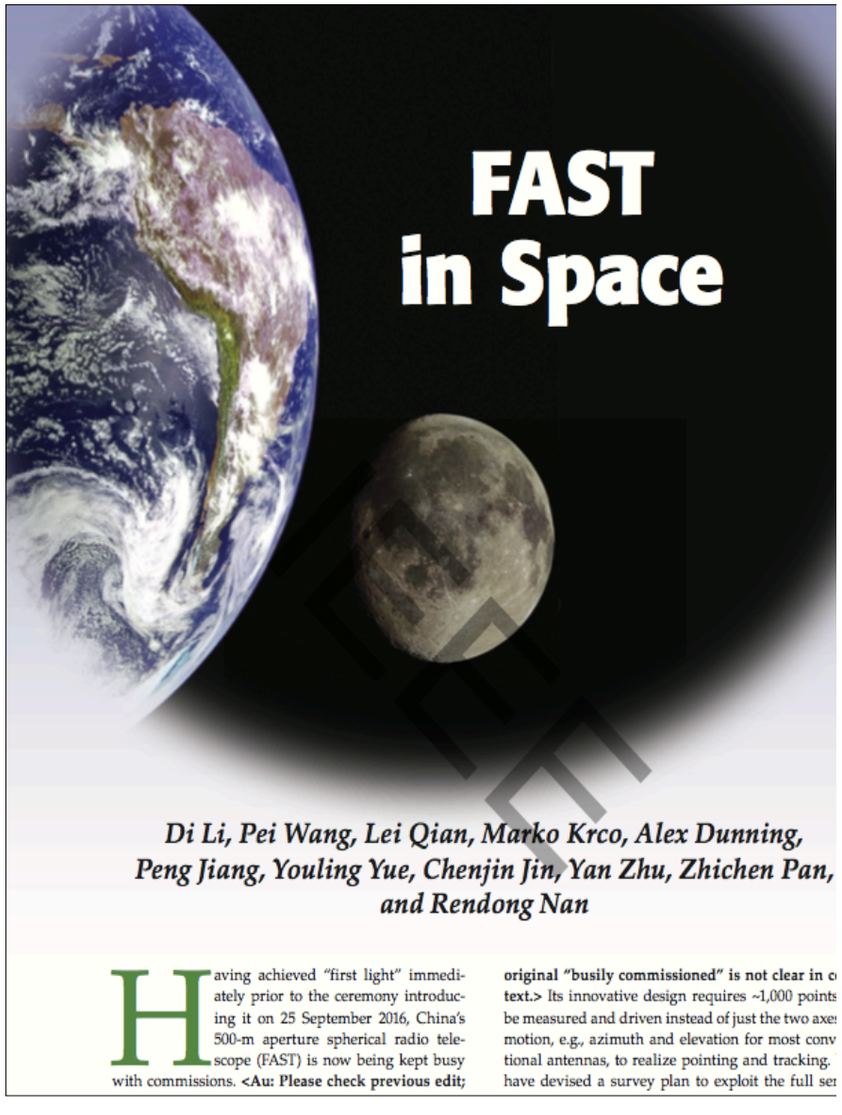
Commensal Radio Astronomy FAST Survey

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

CRAFTS

unprecedented **commensality**:
pulsar, galaxy, imaging, and FRB

- Commissioning and survey demonstration
- **1500 hours Parkes** time for follow-up
- Negotiation with **GBT** underway
- Through collaboration with MPIfA, 100 hours/semester **Effelsberg** for follow-up
- PI programs (**11**) with proposing lead from PKU, NJU, SHAO, XAO, BNU, etc.
- Secured **Arecibo DDT**, Effelsberg open time
- GBT, Arecibo, Chandra, VLBI, GMRT, MWA proposals etc. submitted
- Data facility (**20PB+200 Tflop+100Gbs**) contract signed

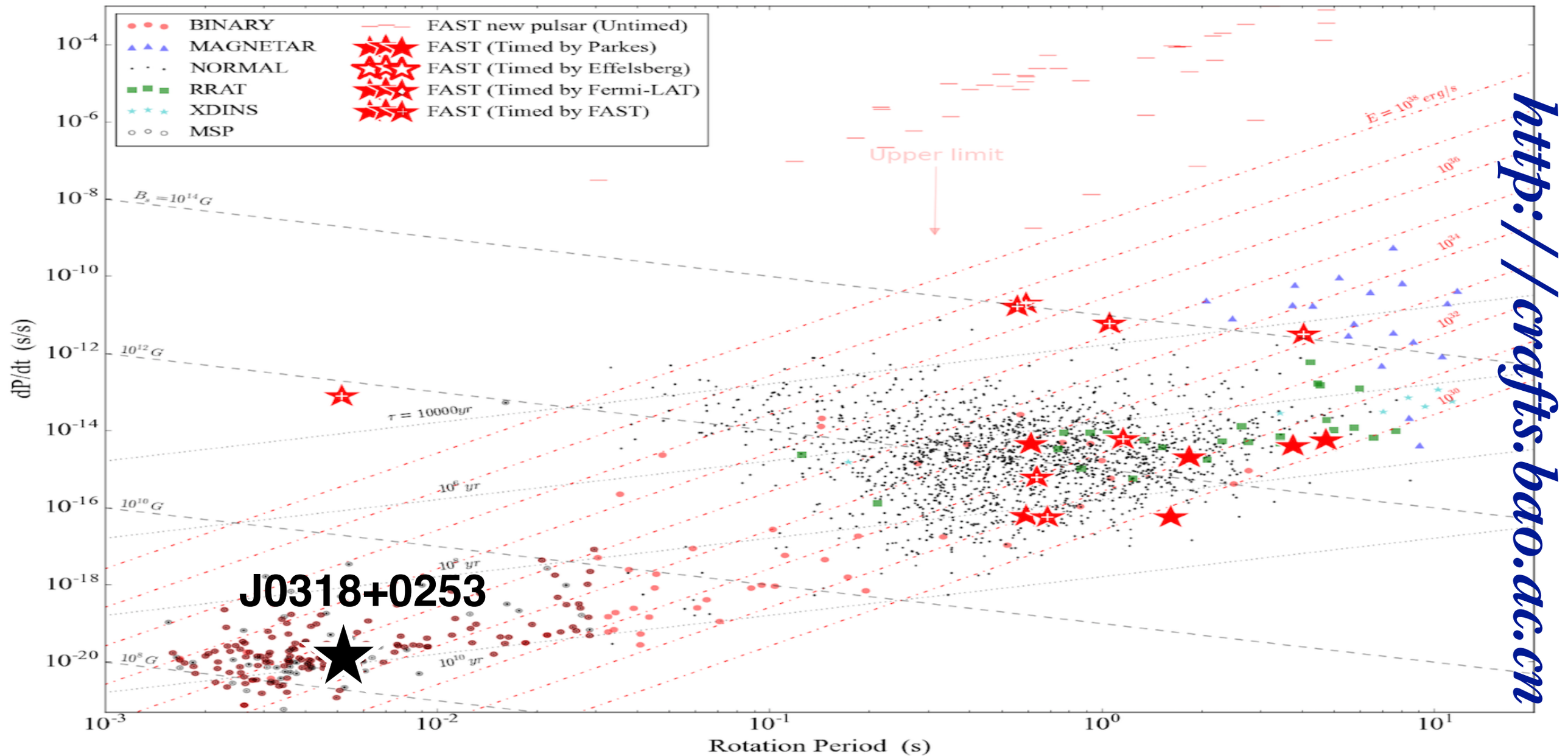


The Commensal Radio Astronomy FAST Survey
FAST多科学目标同时扫描巡天

Li et al. 2018, Invited Review
IEEE Microwave, Vol 19, Issue 3, p112

FAST巡天规划网页

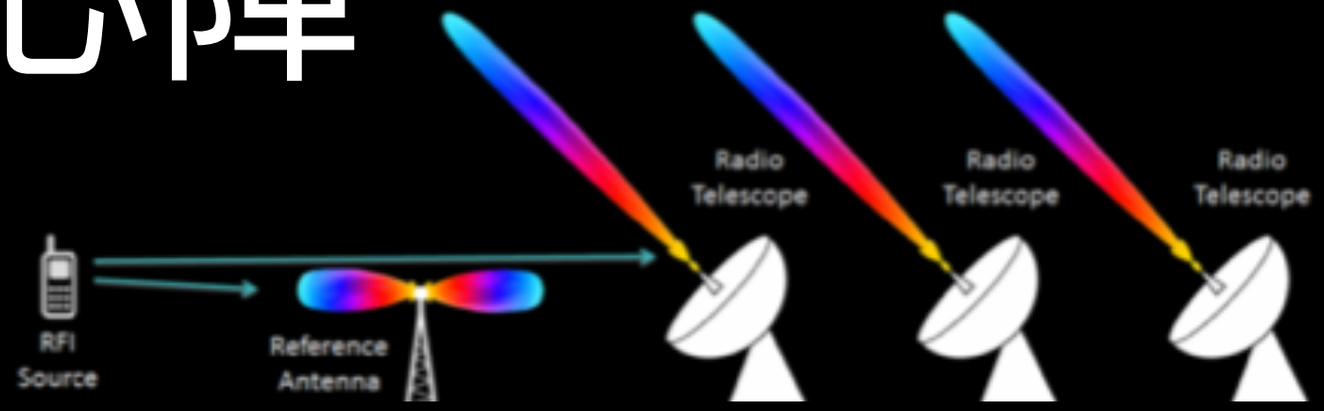
http://crafts.bao.ac.cn



http://crafts.bao.ac.cn

FAST 核心陣 （Aplus）

FAST - Aplus 核心陣



RFI removal

"Fast Converging Digital Adaptive Filter"

Finger, Curotto, Fuentes, Duan, Bronfman, Li 2018

- **LIGO Event: GW Sources**

利用FAST 10%的預算

提升FAST关键性能 x10-100

* 空間分辨率 ~1"
* 点源探测灵敏度 ~0.1 mJy

- **Exoplanet + Brown dwarf**

- **Tidal Disruption Event**

- **Fast Radio Brust**

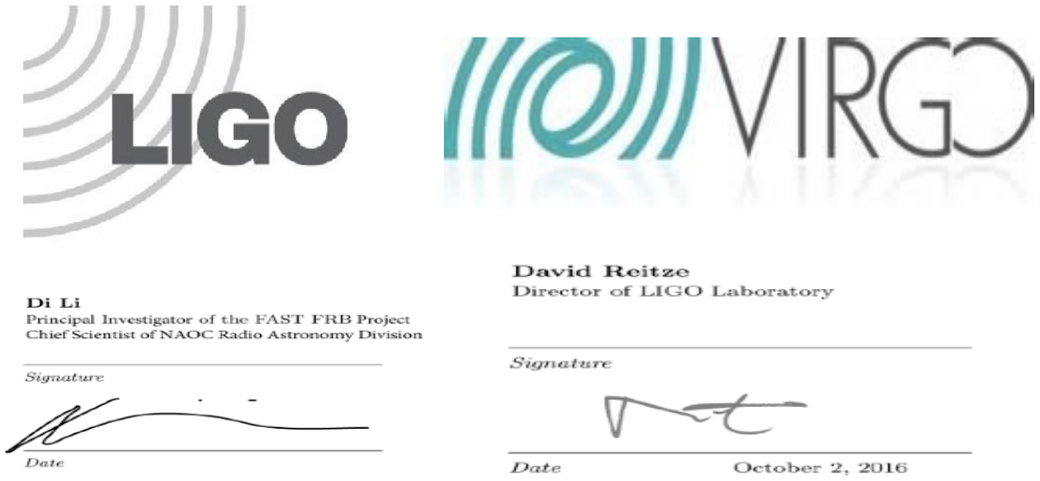
Breakthrough Potentials

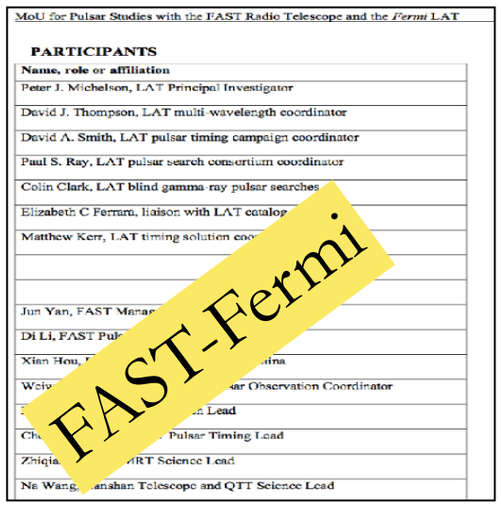
FAST + new tech. → New Parameters

post-FAST establishment:
current revolution in radio astronomy

- GW: LIGO
- 快速射电爆: FRB
- 相控阵技术: PAF
- Time Domain Astronomy
- AI/ML
- Multi-messenger

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





Known Knowns; Known Unknowns, Unknown Unknowns