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 @ IAU2018
Chief Scientist of FAST
NAOC

Past, Present, Future

Initiates a journey of Discoveries

Five-hundred-meter Aperture Spherical radio Telescope

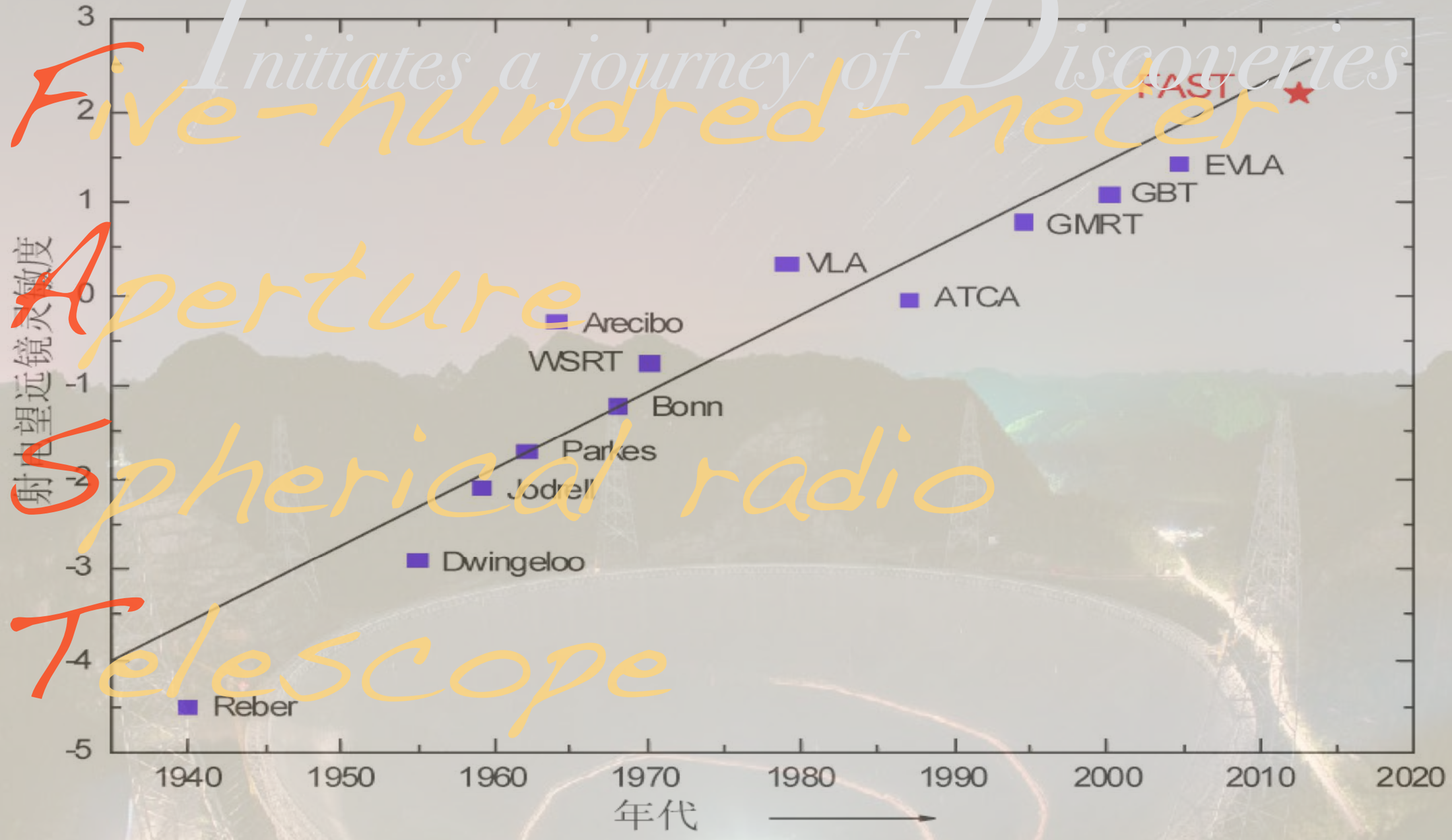


图 1-2 望远镜灵敏度发展曲

Timeline

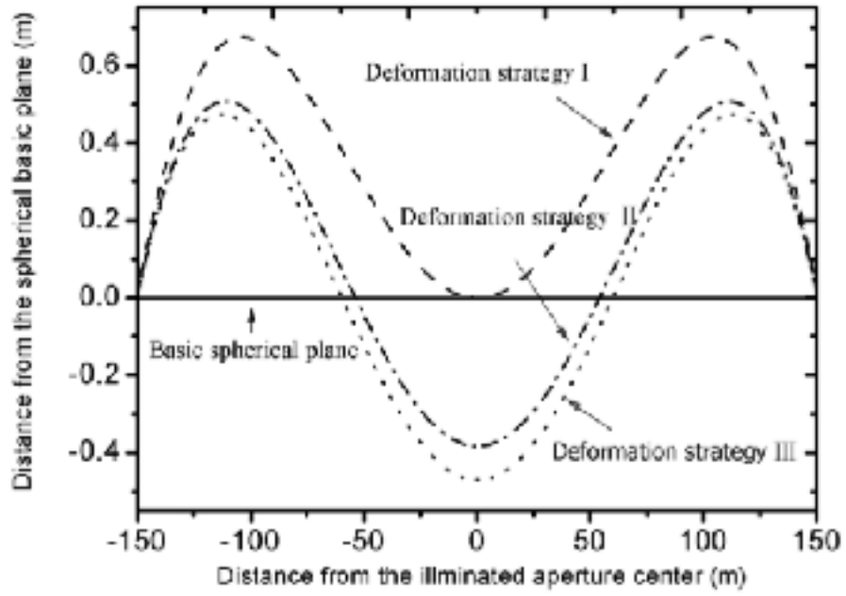
- **Project Approval:** December, 2007
- **Construction Commence:** March, 2011 (¥1.15Billion)
- **Openning ceremony:** Sep. 25, 2016
- **Commissioning:** 2016 - ~2018

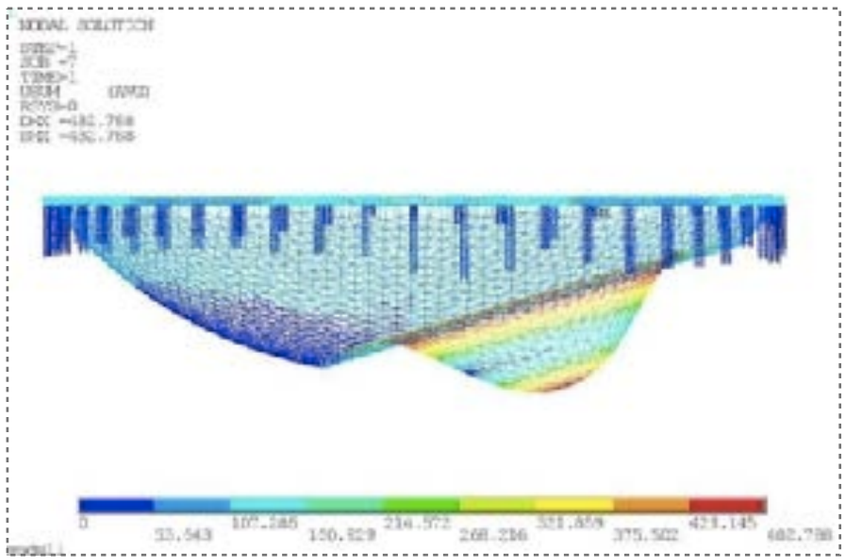
  19 beam L-band array: to be delivered in Nov., 2017

  Backend upgrade (for commensal survey) under development, to be expected in early 2018
- **Operation starts:** ~2019

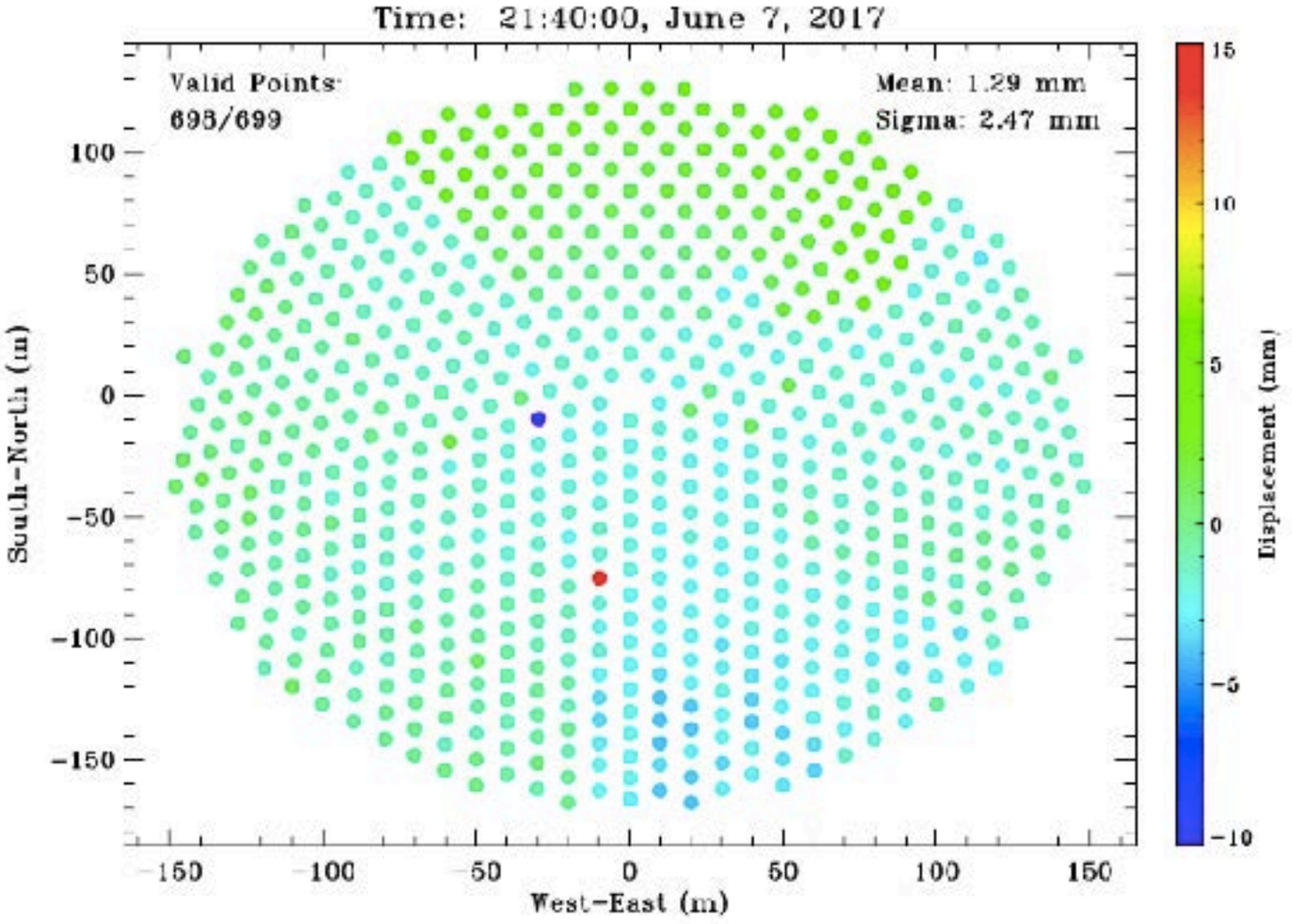
“中国天眼”

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

¥ 667M until 2016.3
¥1.15B until 2016.9

Strength in Numbers

4500 panels
30-ton dome
6 “thin” cables
10 laser total stations
>100K fibers

A really CHEAP mega-facility!

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
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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*, WENDAI ZHU*, HAIYAN ZHANG*,†,
YOULING YUE* and LEI QIAN*

Nan, **Li,** Jin et al. 2011, IJMR-D, 20, 989

ASKAP-FAST HI Gals Survey a)

3.8π sky survey

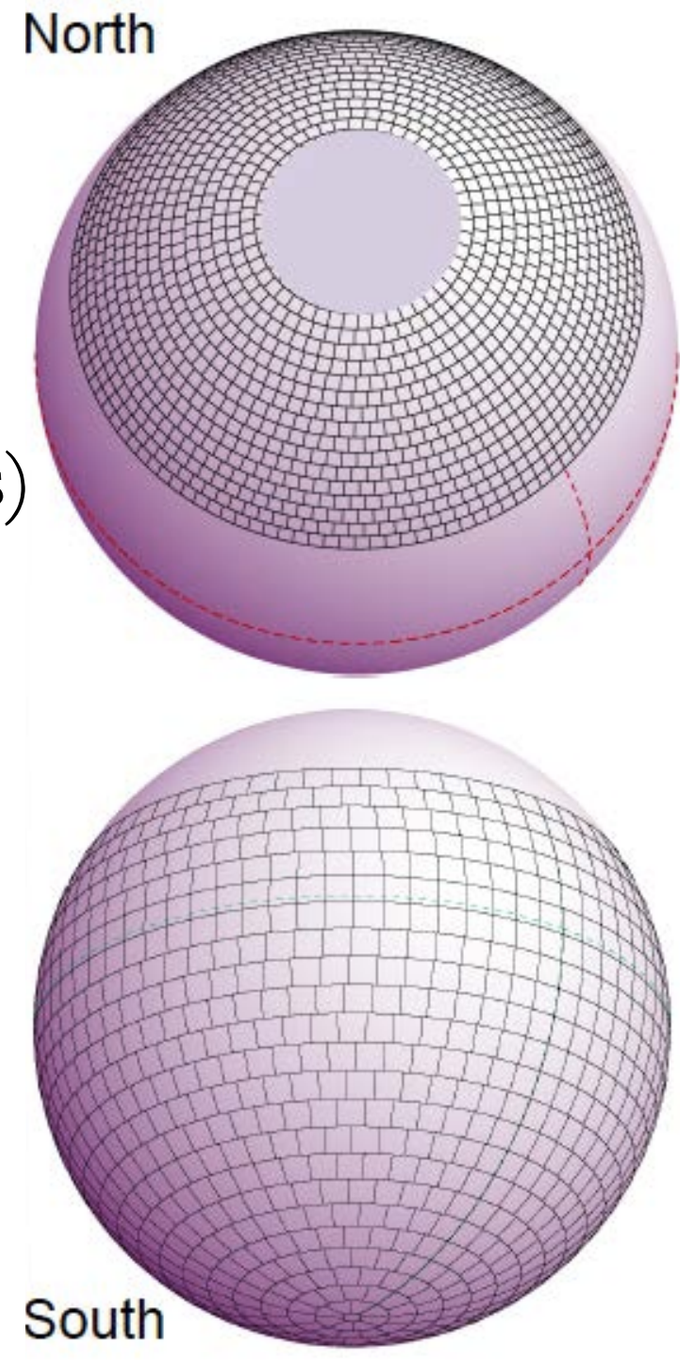
- 1201 ASKAP fields – 9600 hrs
- 110 FAST driftscans – 2700 hrs
- $0 < z < 0.26$
- 1,000,000 galaxies vs ALFALFA (31000 galaxies)

INcrease
gaseous galaxies x30

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

Matching Optical Surveys?

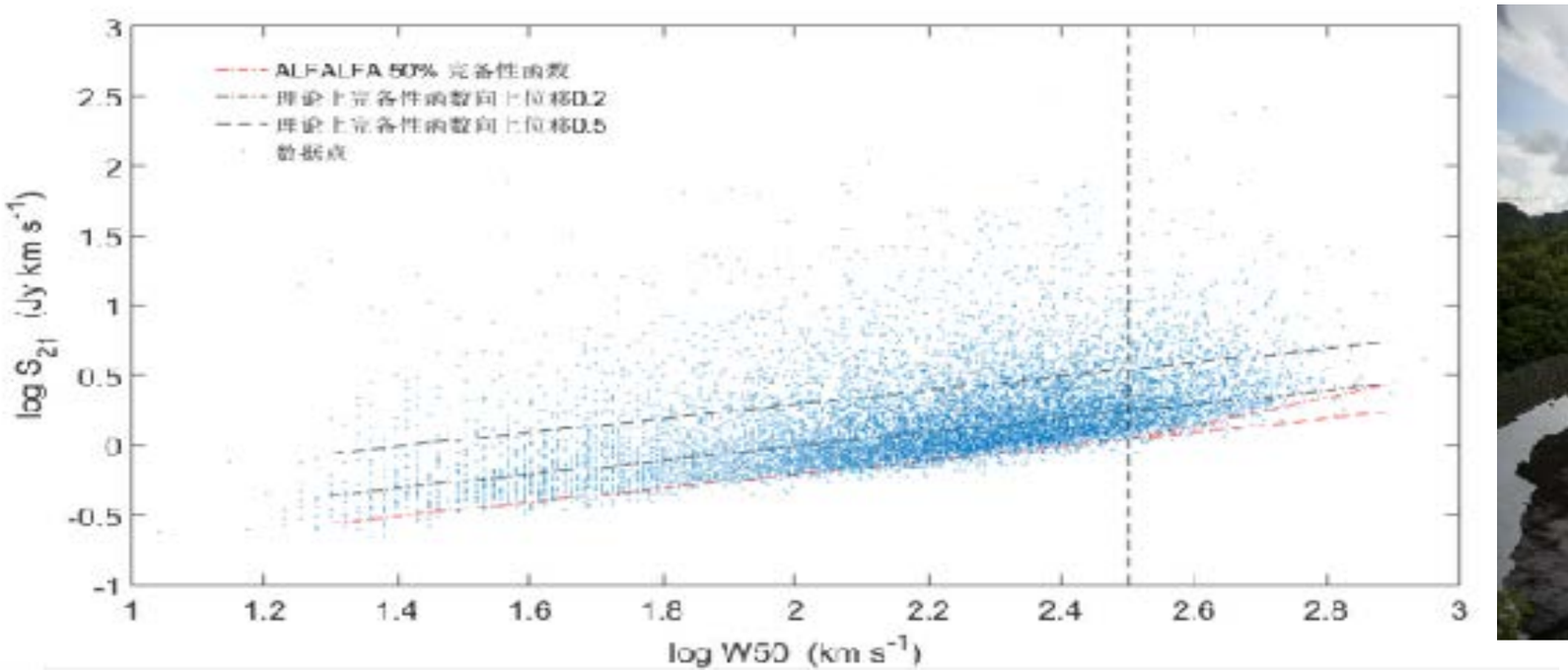
Credit: Lister Staveley-Smith (UWA)

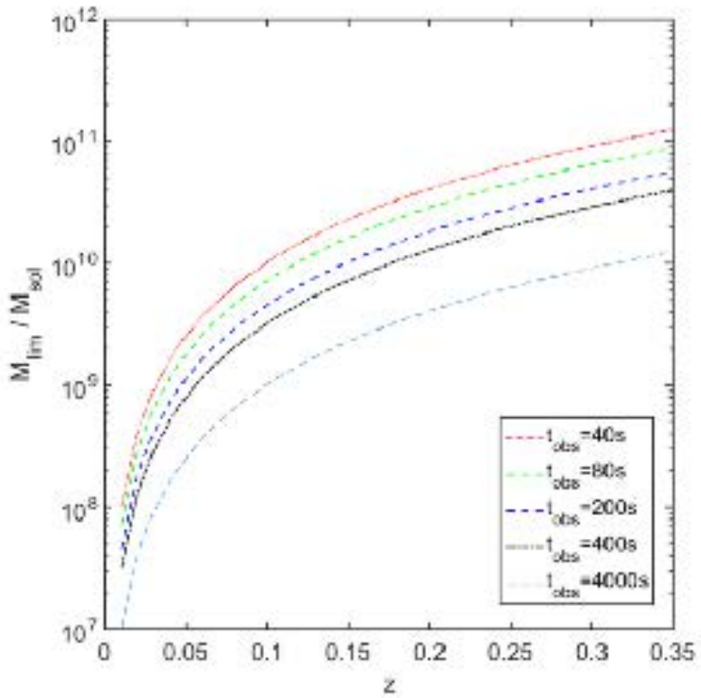


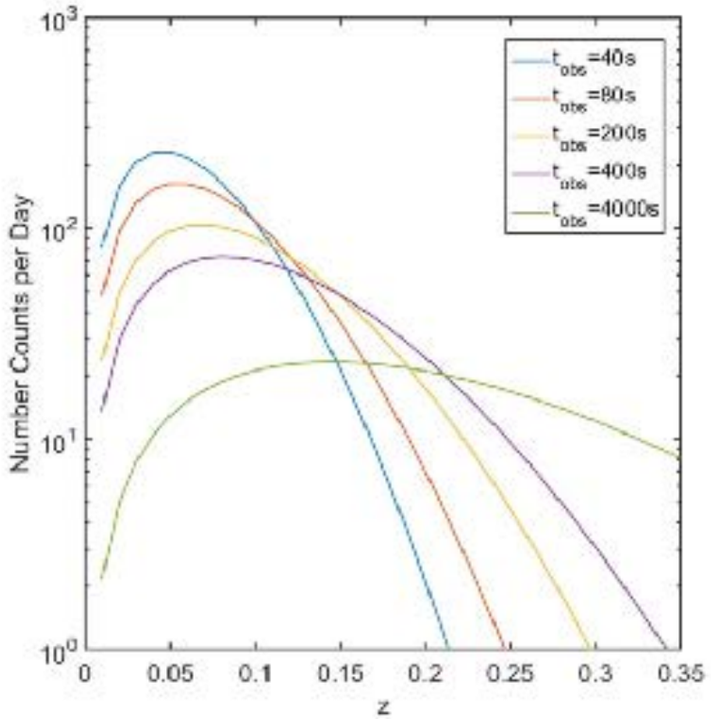
FAST Outlook

HI Galaxies from a Drift-Scan Survey

a)







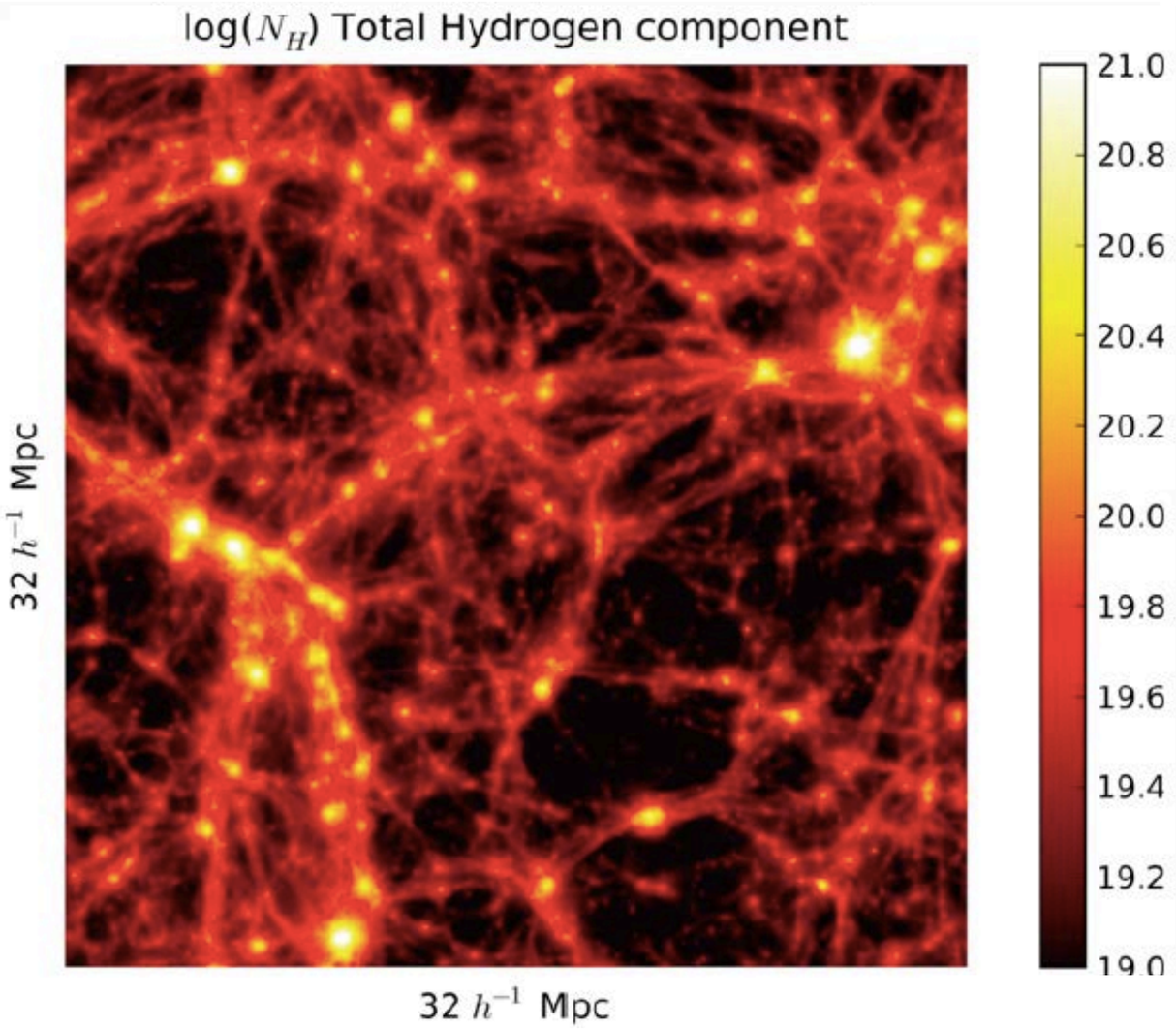
N ($>7\sigma$; 2.3 π)
$\approx 7.1\times10^5$

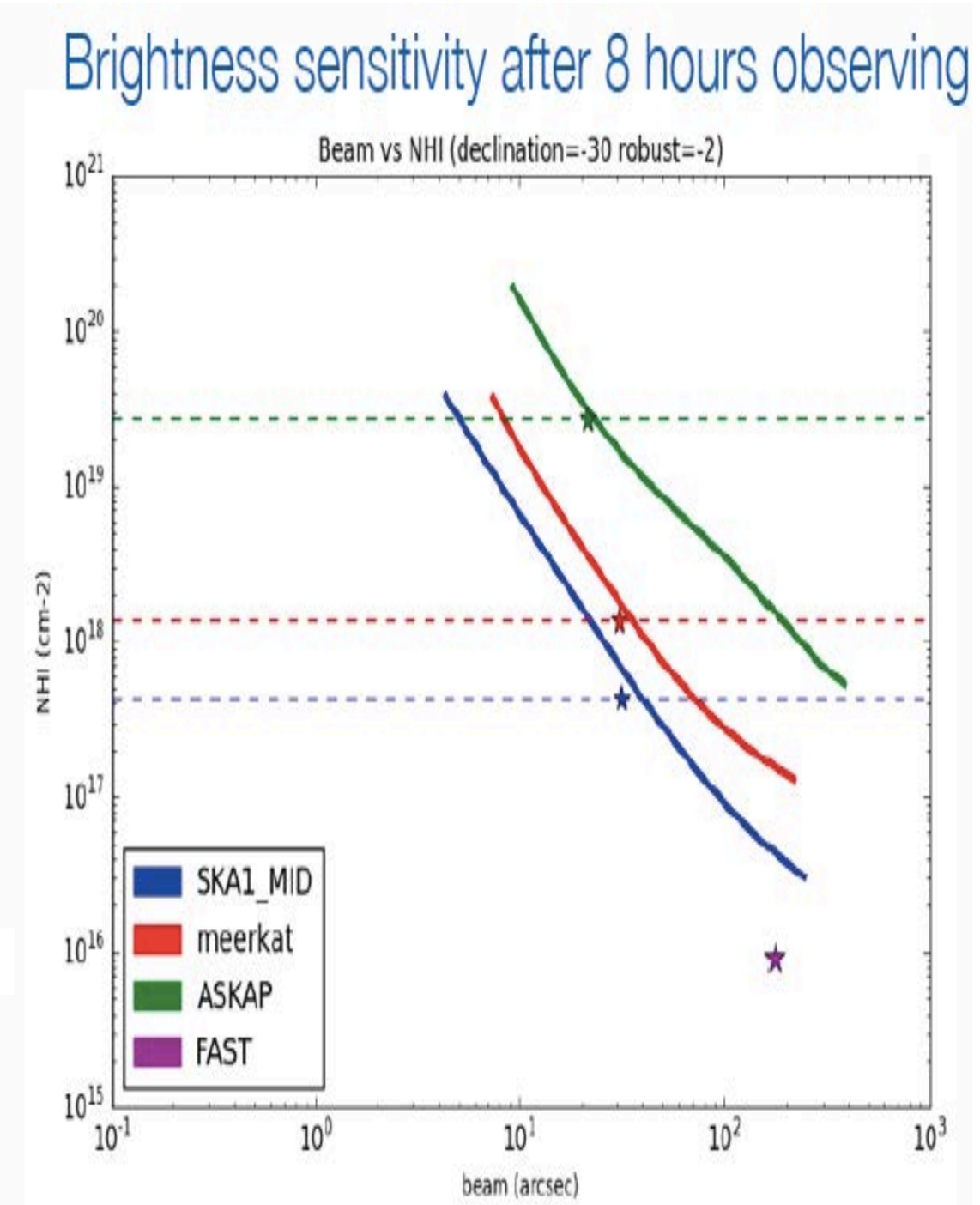
$<z>\approx0.08$

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)

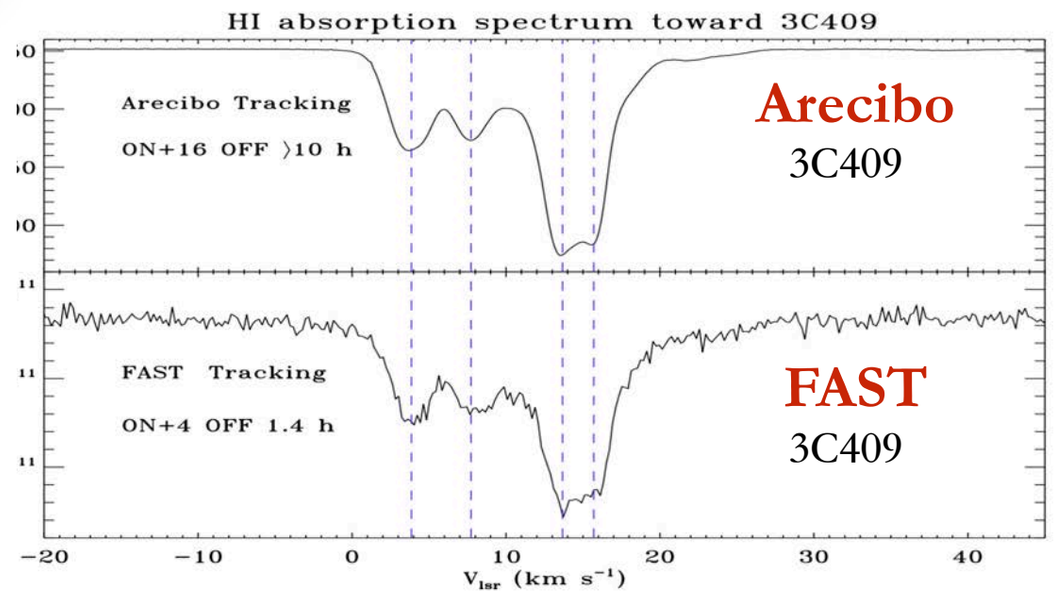
Goal: **FAST** 5 yrs **800** quasars

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

Pacific Rim Interstellar Observer (PRIMO)

"Where is OH and Does it Trace the Dark Molecular Gas (DMG) ?"
Li, Tang, +PRIMO, ApJS, 235,1

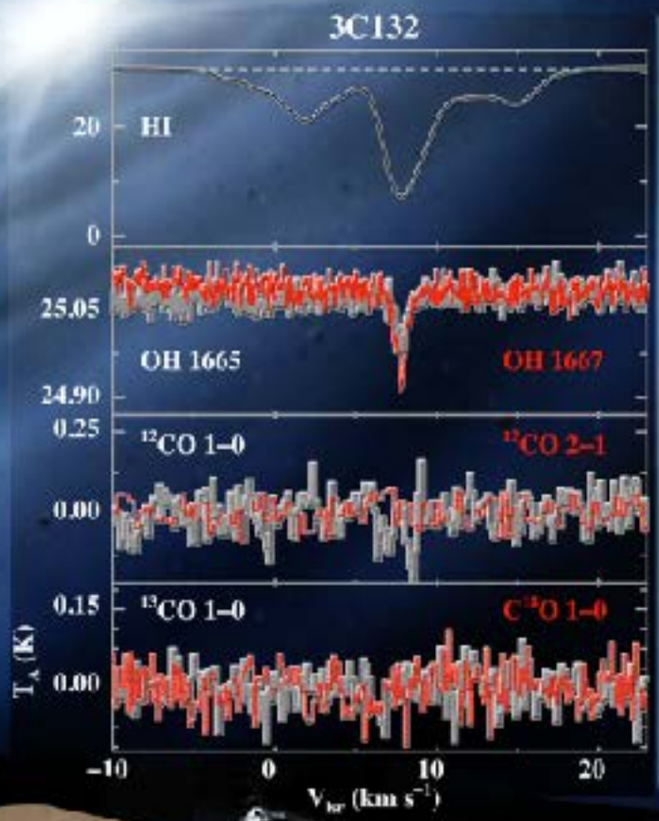
- OH excitation temperature peaks around CMB
- OH abundance tracks DMG fraction
- FAST will supersede Arecibo by x10. Tests underway

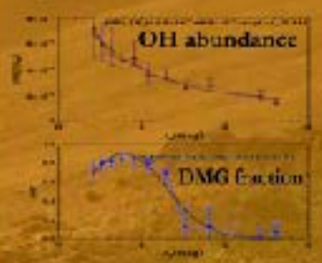
Hydroxyl (OH) Traces Dark Molecular Gas (DMG)

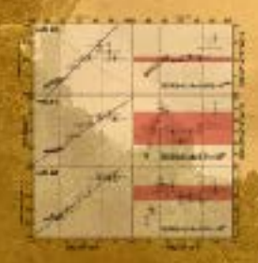
The Milky Way

Quasar

diffuse ISM







Publications

Li, D., Tang, N., Nguyen, H. et al. & the PRIMO collaboration, *"Where is OH and Does It Trace the Dark Molecular Gas (DMG)?"*, ApJS, 235, 1

Tang, N., **Li, D.**, Heiles, C. et al. 2017, *"OH Survey using Multilines of Galactic Observations of Terahertz (GOT) Lines"*, ApJ, 839, 8

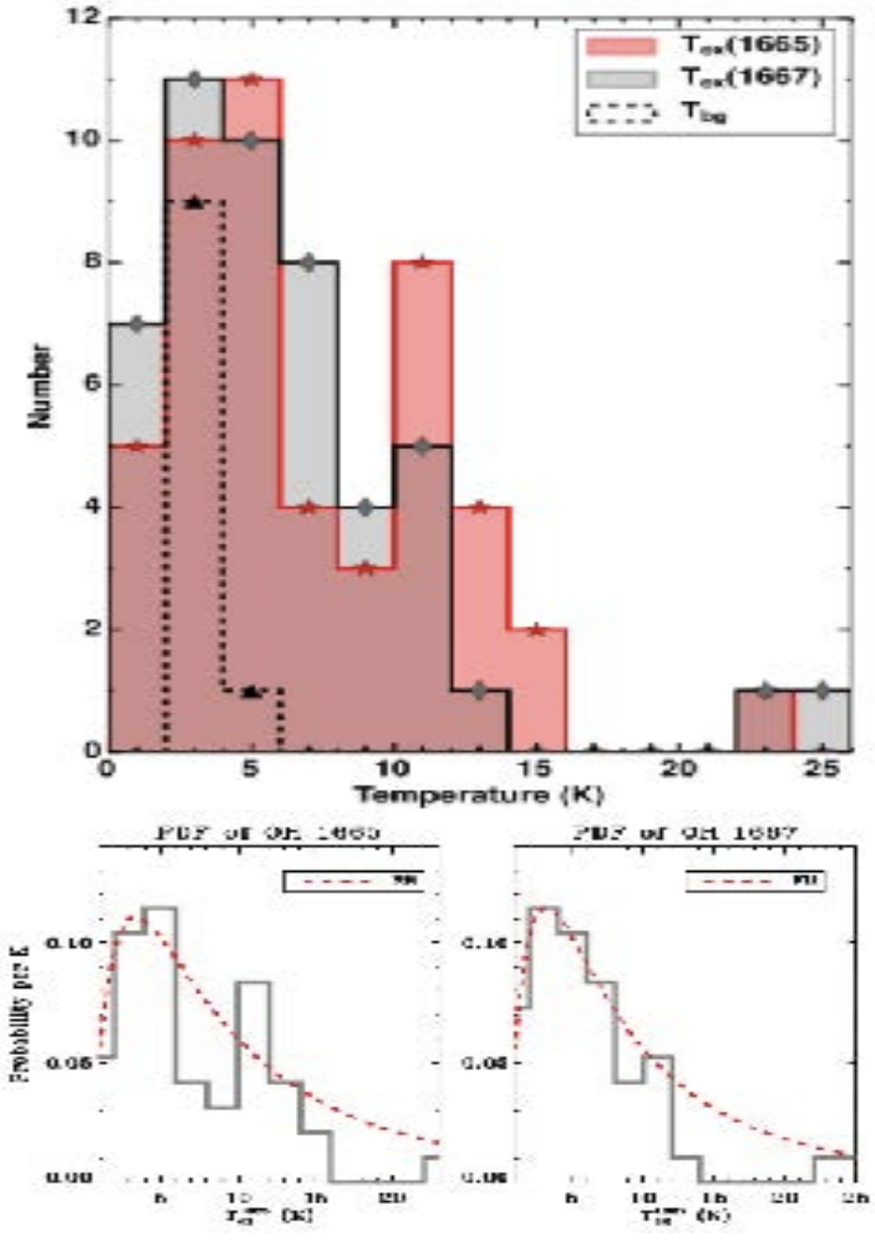
Tang, N., **Li, D.**, Heiles, C. et al. 2016, *"Physical properties of CO-dark molecular gas traced by OH"*, A&A, 593, A42

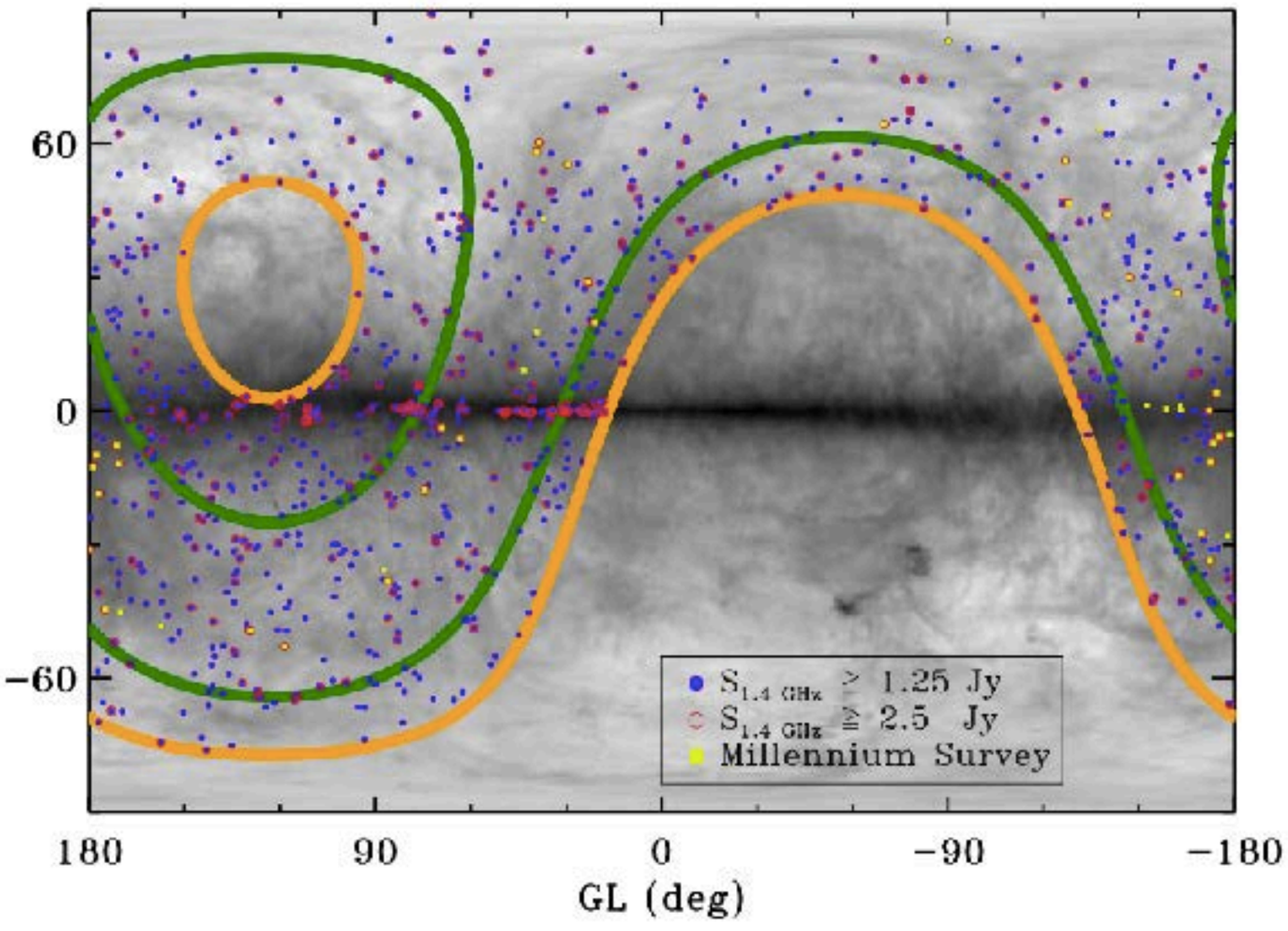
Xu, D., **Li, D.**, Yue, N. et al. 2016, *"Evolution of OH- and CO-Dark Molecular Gas Fraction across a Molecular Cloud Boundary in Taurus"*, ApJ, 819, 22

Xu, D. & **Li, D.** 2016, *"CH as a Molecular Gas Tracer and C-shock Tracer Across a Molecular Cloud Boundary in Taurus"*, ApJ, 833, 90

OH Excitation

b)





The FAST "Absorption Sky"

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

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

Pulsar Surveys

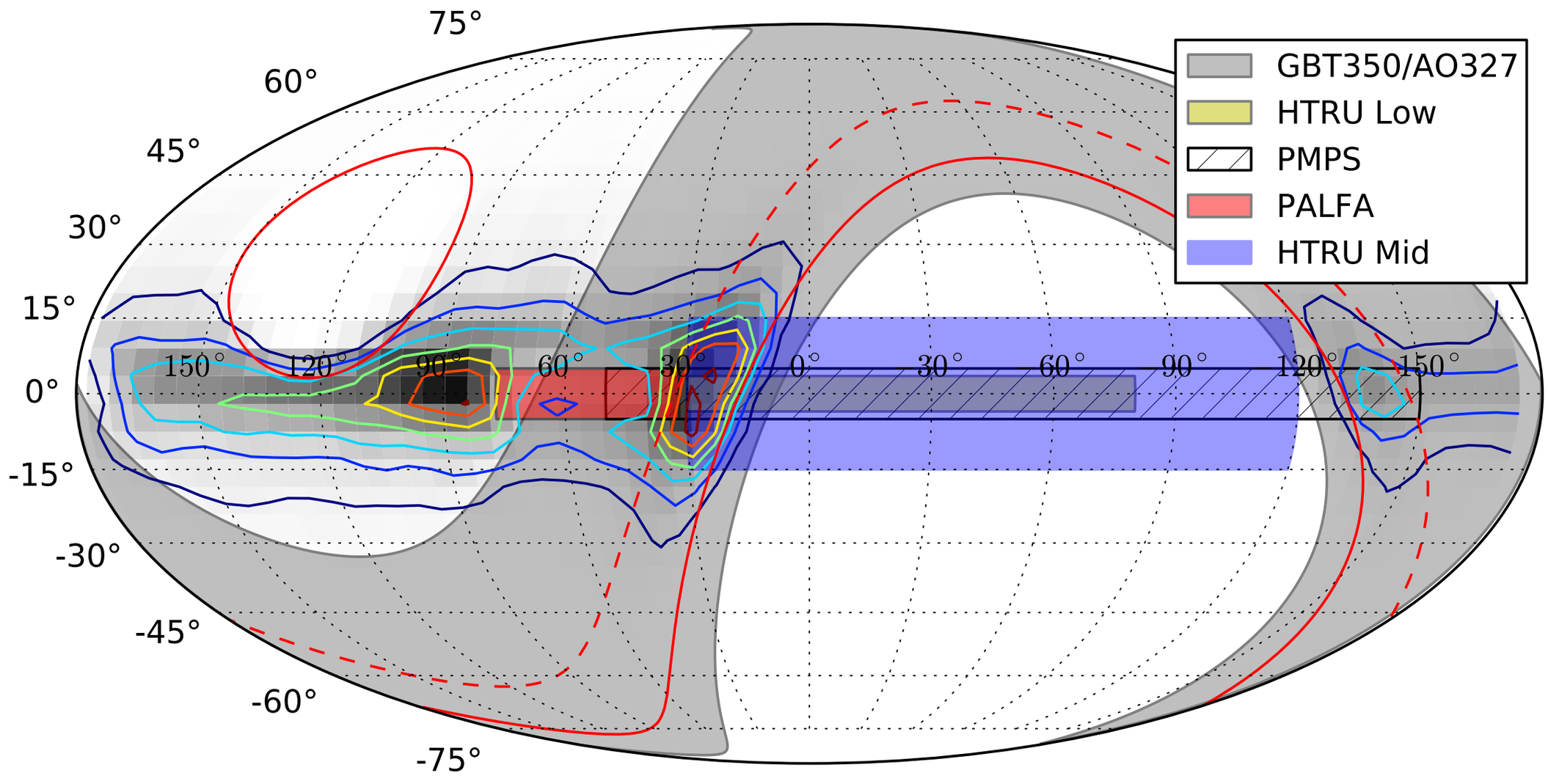
c)

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

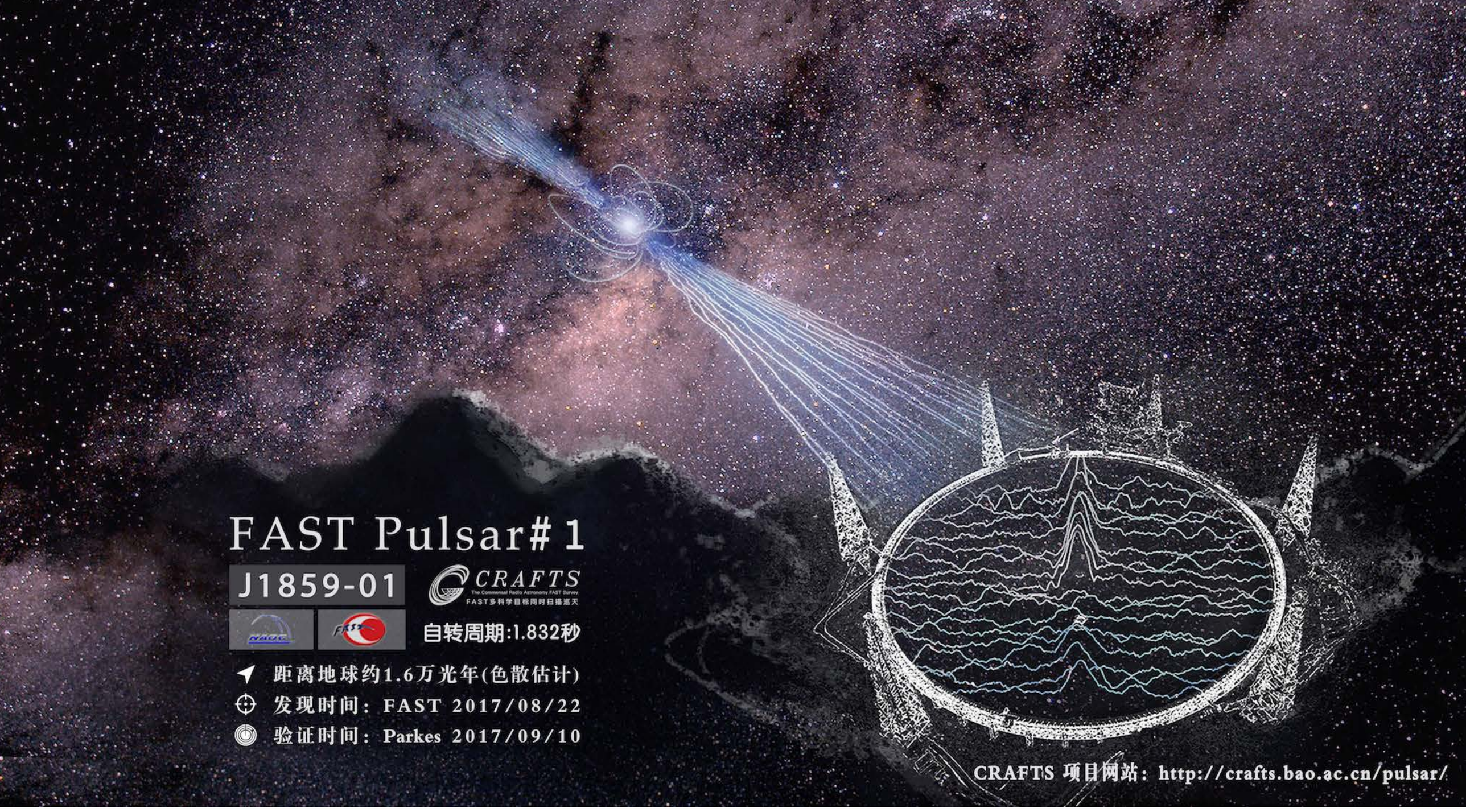
HTRU-S low-latitude

HTRU-S medium-latitude

HTRU-S high-latitude

Dai & Zhu

270 MHz - 1.62 GHz UWBR



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

Jocelyn BELL BURNELL, Visiting Professor, Astrophysics, University of Oxford, Denys Wilkinson Building, Keble Road, Oxford OX1 3RH, UK.
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

2018.5

>60 candidates

>40 confirmed discoveries

FAST's First MSP

c)

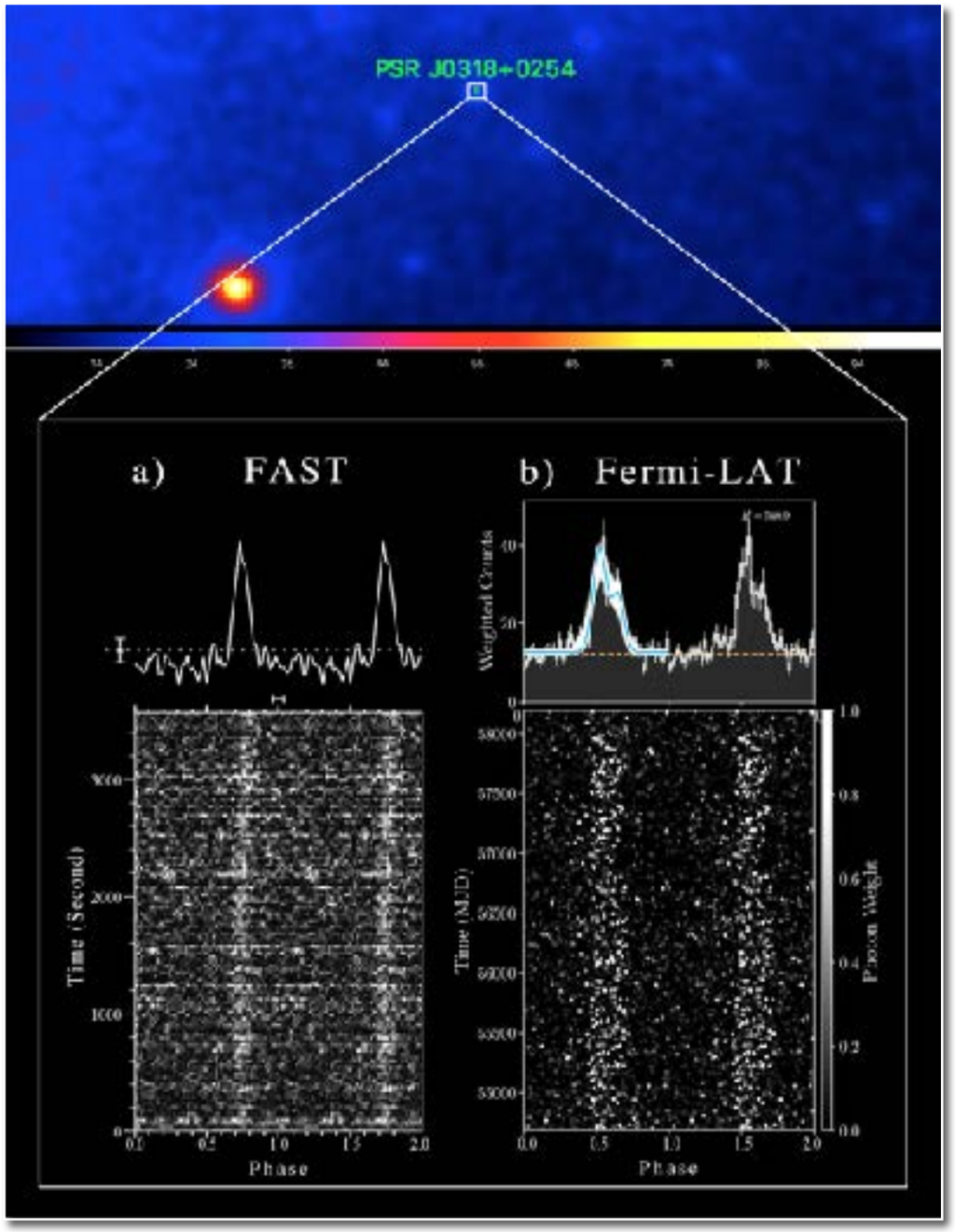
3FGL J0318.1+0252
FL8Y J0318.2+0254

- 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 Saz Parkingson confirmed no X-ray, provided limits
- **2018.4.28** Published on Atel #10851
- **2018.5.02** IPTA released J0318+0253 to its members



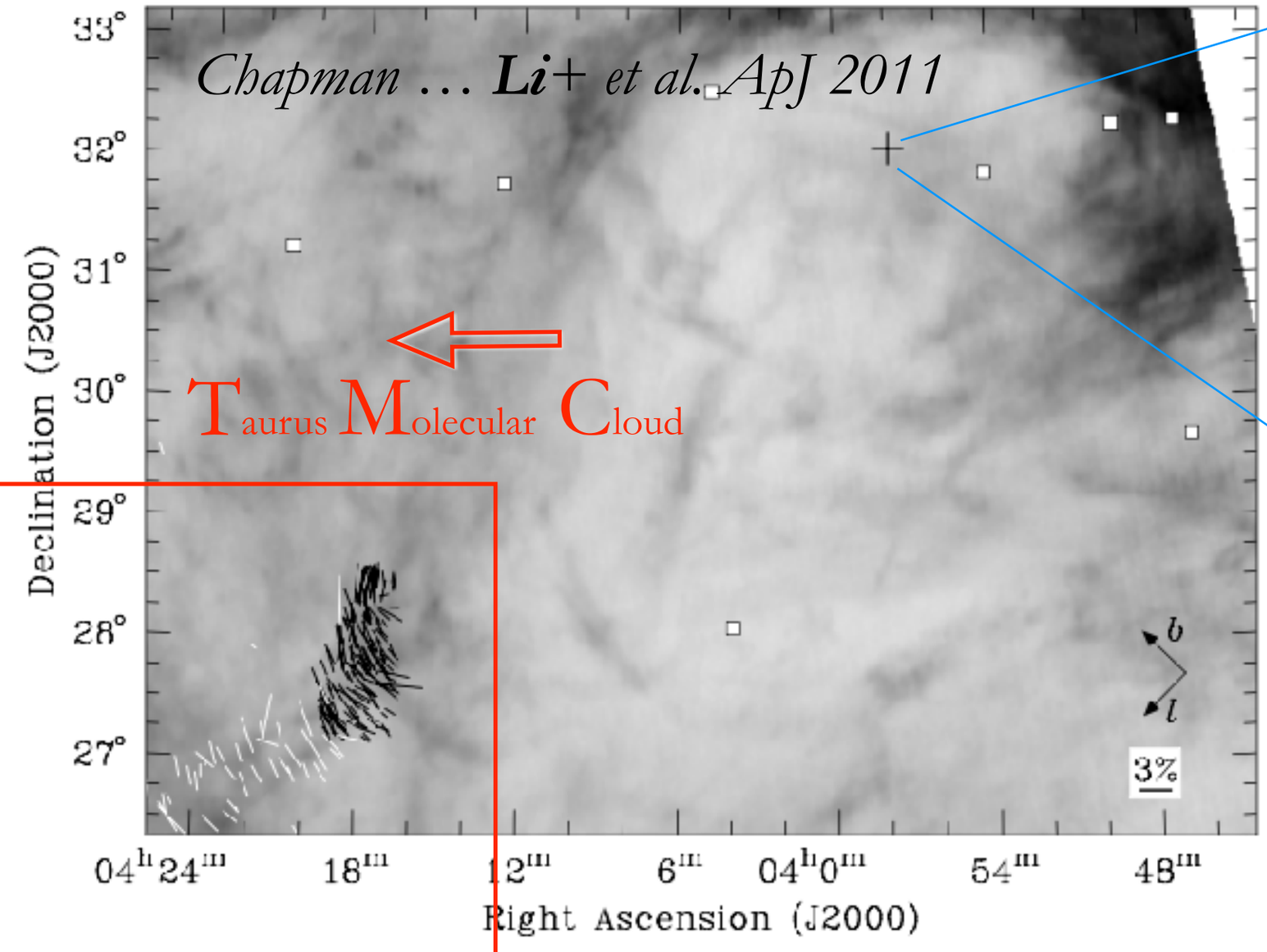
Wang et al. 2018, Atel # 10851

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

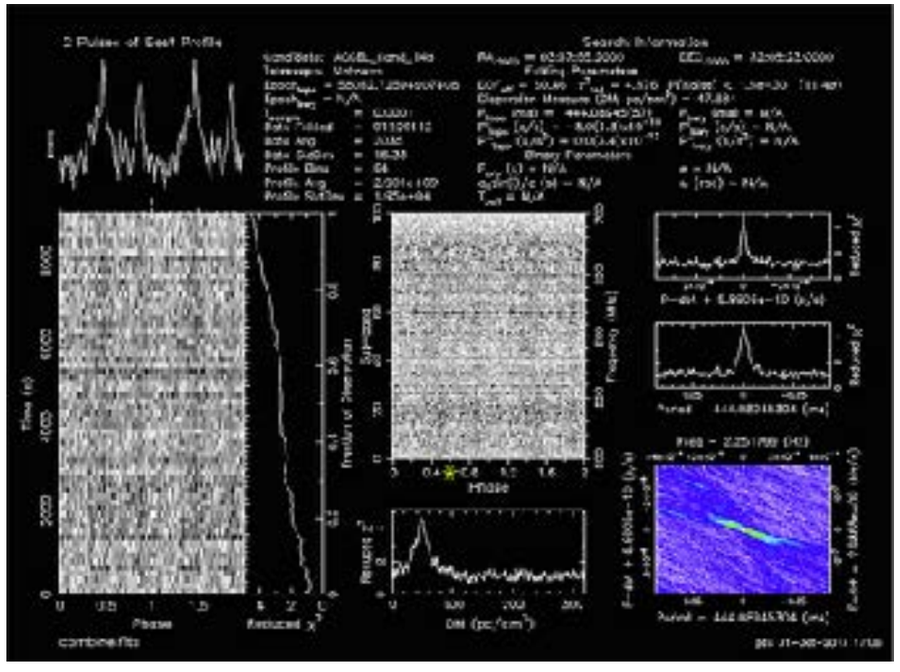
The "Taurus" Pulsar

FAST discovers radio pulses from J0357

c)



Chandra X-ray Image
De Luca et al. 2011

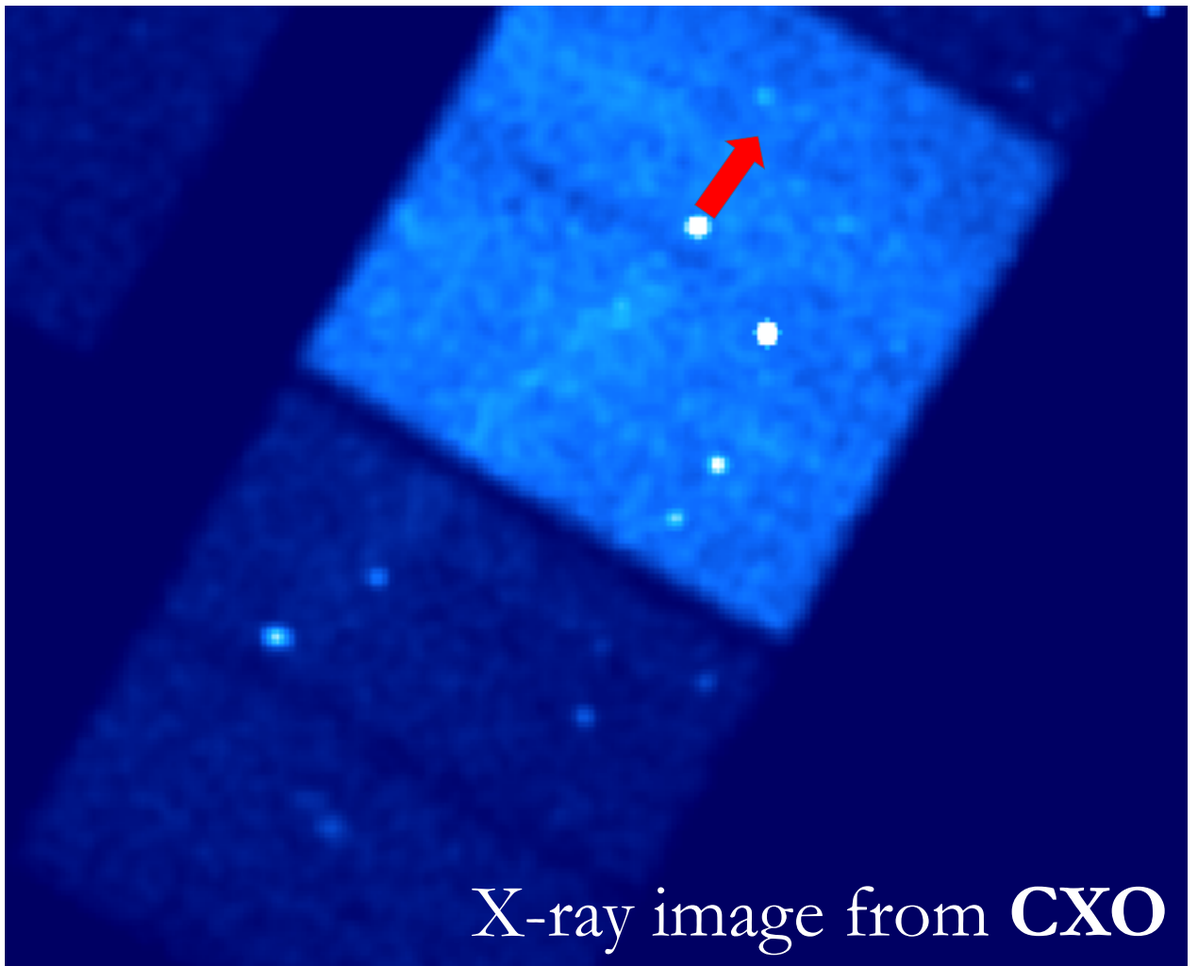


P= 0.444 s
DM=47.6

Confirmed by Arecibo DDT observations

Closest or Fastest?

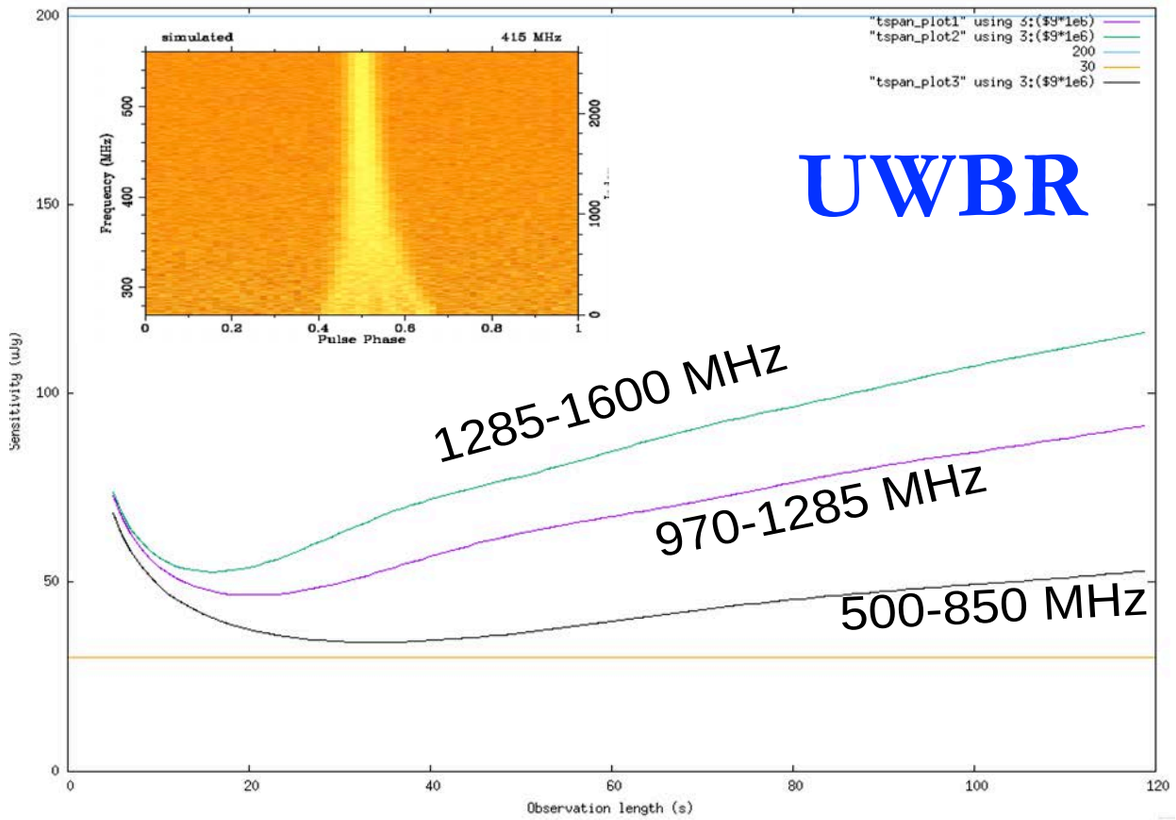
- Consistent with Fermi's periodicity of 0.444s
- No radio detection until FAST
- Visible X-ray tail
- Very * **high** * apparent proper motion
- X-ray absorption column + DM estimates => **1Kpc ?**



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

Globular Clusters

c)

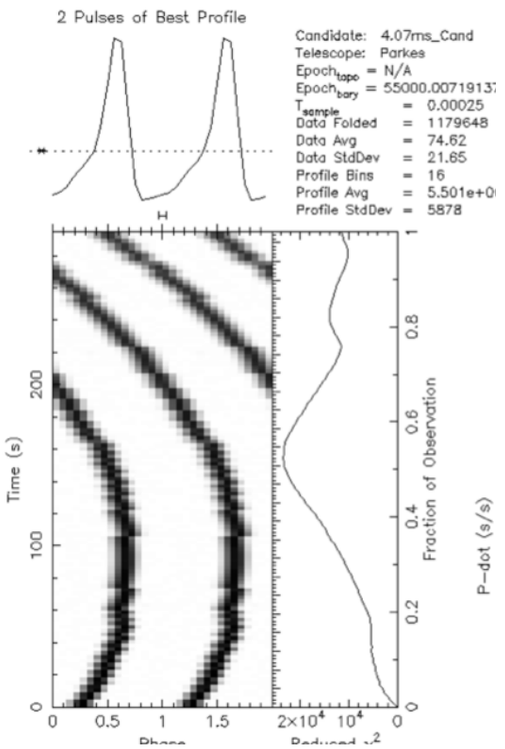


Zhang, Hobbs & **Li** et al. 2016, RAA

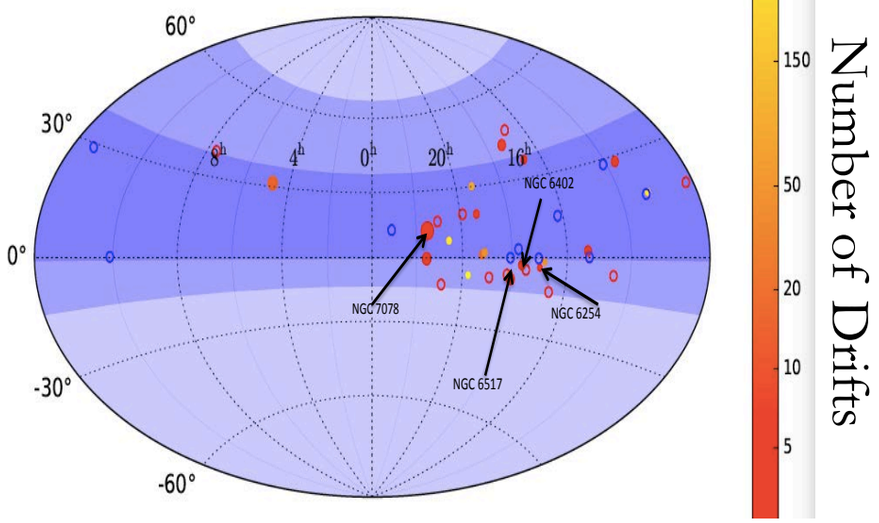
Continuous data stream in time

Beam forming by weighted Fourier transform

RFI rejection by utilizing time domain information



Simulated Binary Pulsars



Discovery of Two New Pulsars in 47 Tucanae (NGC104)

ABSTRACT

We discovered two new (may be more?) millisecond pulsars in 47 Tucanae (NGC104), named J0024-7204aa and J0024-7204ab, by reprocessing all the existed observation data in ATNF/CSIRO database(?) with our new method, which is frequency domain statistic search, and acceleration search by PulsaR Exploration and Search TOolkit (PRESTO). The pulsar J0024-7204aa has a rotation frequency of ~541 Hz, which is higher than any other known pulsars in 47 Tucanae. Its DM is also the higest one among all the known pulsars in 47 Tuc. The pulsar J0024-7204ab is in a binary system with orbit period () days. (need binary timing solution!!!) Comparing with the acceleration search of PRESTO, the frequency domain statistic search is more sensitive to the binary pulsars with short orbit periods.

Pulsar Name	Possible Flux When Appears (mJy)	DM	Rotation Period (ms)
J0024-7204aa	0.1	24.869	1.8453804735
J0024-7204ab	0.05	24.376	3.704639405

Pan, Hobbs, **Li** et al. 2016 MNRAS

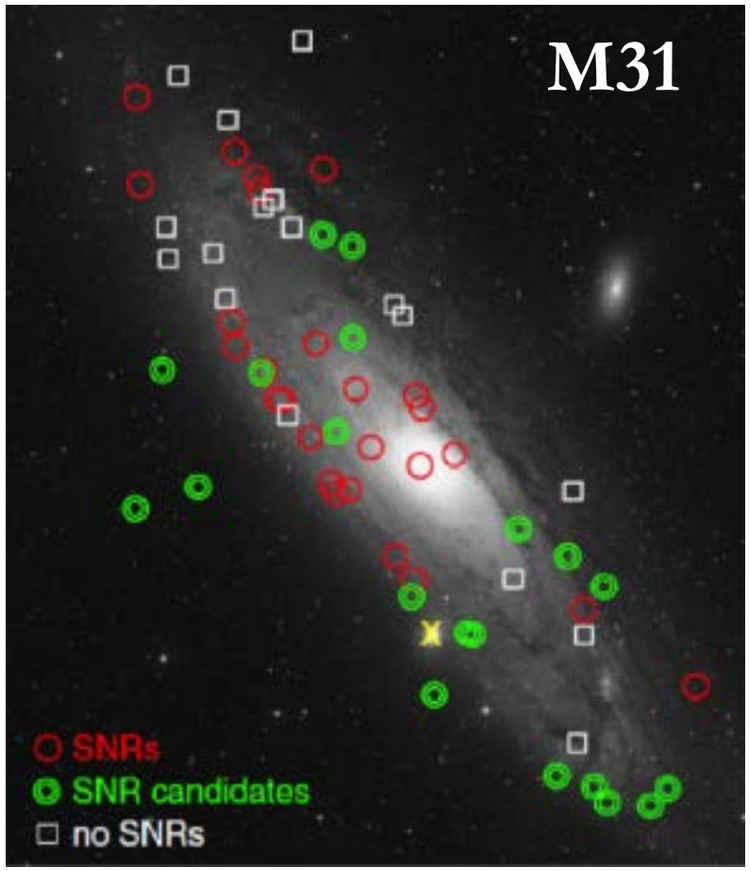
Extra-galactic Pulsars

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

Giant pulse **Credit**: Crawford, Cordes & DL

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

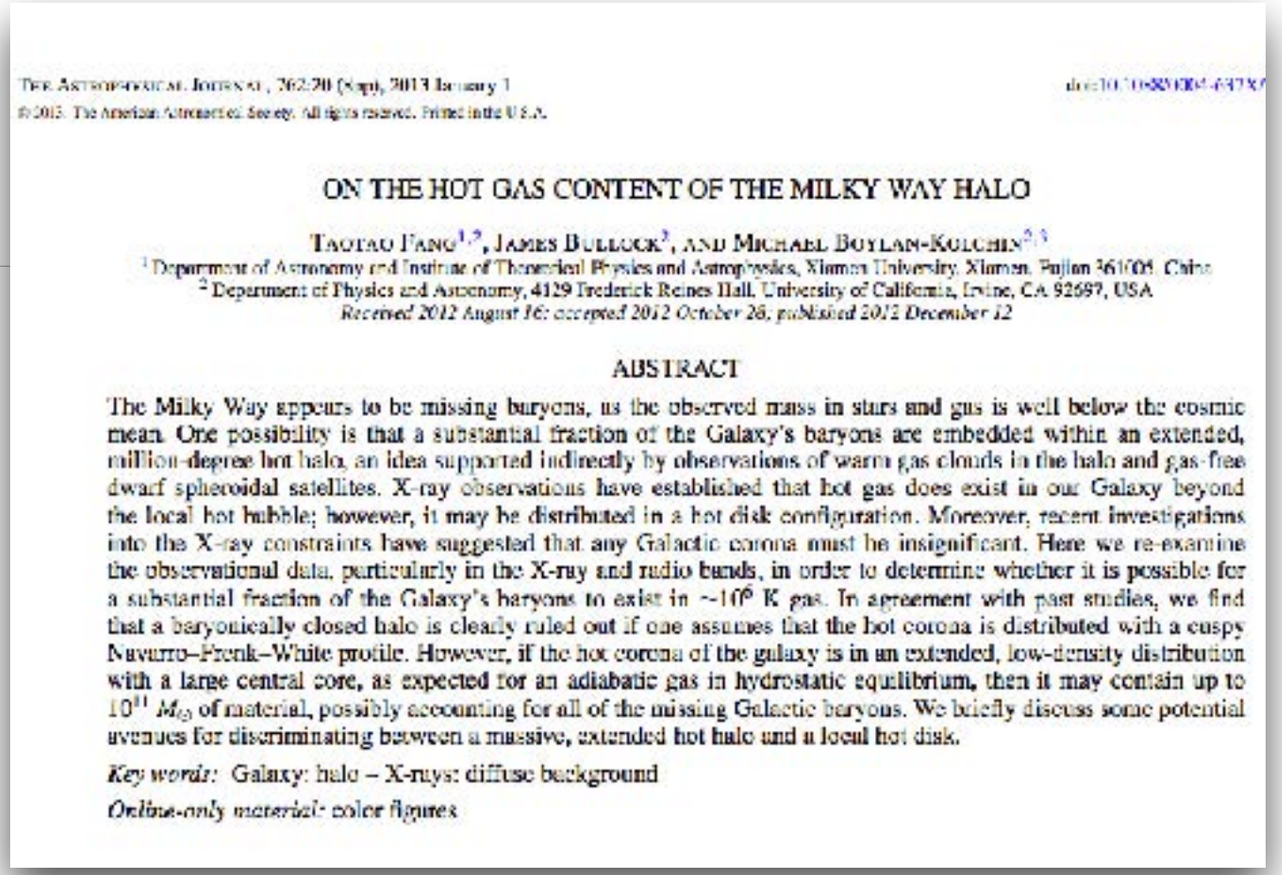
LOW: one detection every 0.7 to 2.0 minutes
HIGH: one detection every 180 to 540 minutes

Probe MW Halo with M31 pulsars

50-80 normal pulsars in M31 detectable by FAST (Smits et al. 2009)

Fang et al. (2014) re-examine the observational data, particularly in the X-ray / radio bands and pulsar DM, in order to determine whether it is possible for a substantial fraction of the Galaxy's baryons to exist in a hot halo. Extragalactic pulsar DM may provide the crucial distinguishing evidence.

- Extended Adiabatic Halo: **MB**
- Cuspy Halo: **NFW**
- Local Model: **DISK**



The Astrophysical Journal, 762:20 (8pp), 2013 January 1 doi:10.1088/0004-637X/762/1/20

ON THE HOT GAS CONTENT OF THE MILKY WAY HALO

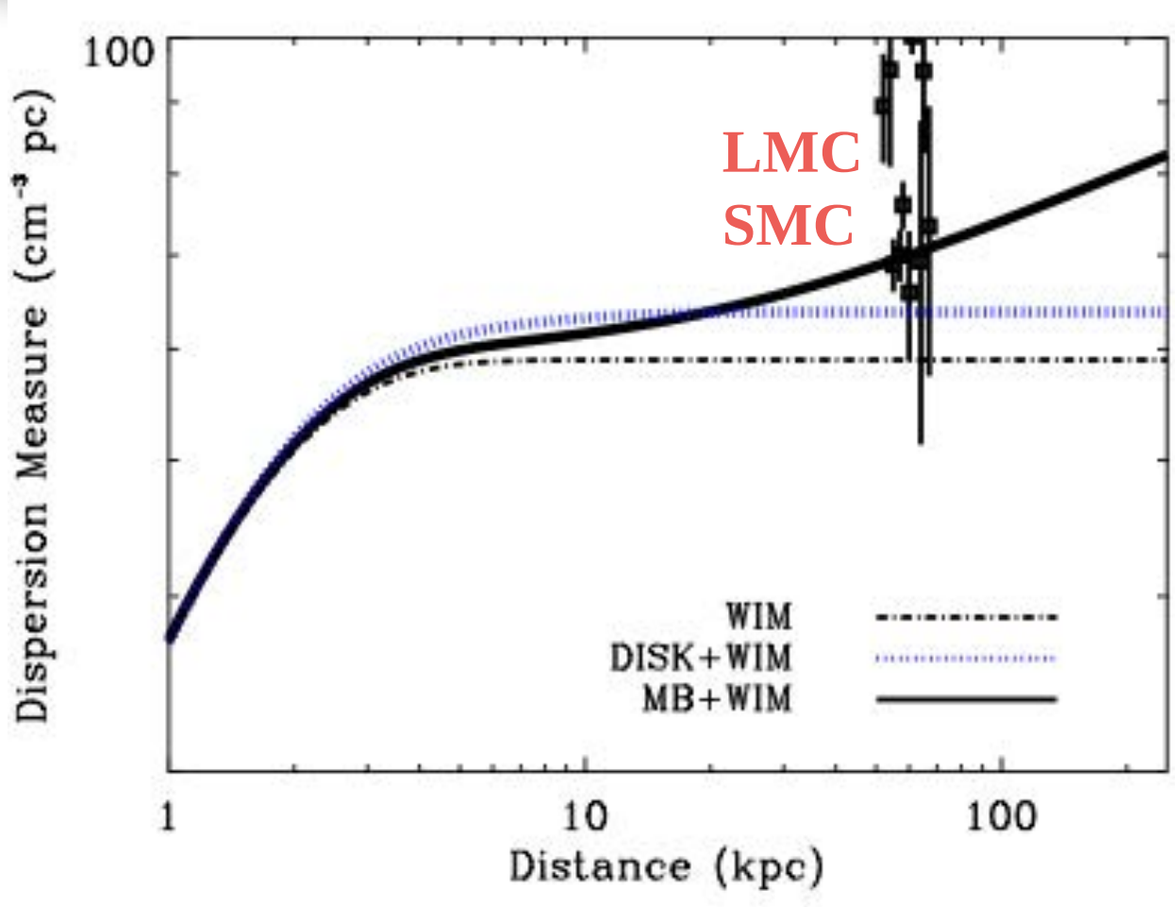
Taotao Fang[1,2], James Bullock[2], and Michael Boylan-Kolchin[2,3]
[1] Department of Astronomy and Institute of Theoretical Physics and Astrophysics, Xiamen University, Xiamen, Fujian 361005, China
[2] Department of Physics and Astronomy, 4129 Frederick Reines Hall, University of California, Irvine, CA 92697, USA
Received 2012 August 16; accepted 2012 October 26; published 2012 December 12

ABSTRACT

The Milky Way appears to be missing baryons, as the observed mass in stars and gas is well below the cosmic mean. One possibility is that a substantial fraction of the Galaxy's baryons are embedded within an extended, million-degree hot halo, an idea supported indirectly by observations of warm gas clouds in the halo and gas-free dwarf spheroidal satellites. X-ray observations have established that hot gas does exist in our Galaxy beyond the local hot bubble; however, it may be distributed in a hot disk configuration. Moreover, recent investigations into the X-ray constraints have suggested that any Galactic corona must be insignificant. Here we re-examine the observational data, particularly in the X-ray and radio bands, in order to determine whether it is possible for a substantial fraction of the Galaxy's baryons to exist in $\sim 10^6$ K gas. In agreement with past studies, we find that a baryonically closed halo is clearly ruled out if one assumes that the hot corona is distributed with a cuspy Navarro–Frenk–White profile. However, if the hot corona of the galaxy is in an extended, low-density distribution with a large central core, as expected for an adiabatic gas in hydrostatic equilibrium, then it may contain up to 10^{11} $M_\odot$ of material, possibly accounting for all of the missing Galactic baryons. We briefly discuss some potential avenues for discriminating between a massive, extended hot halo and a local hot disk.

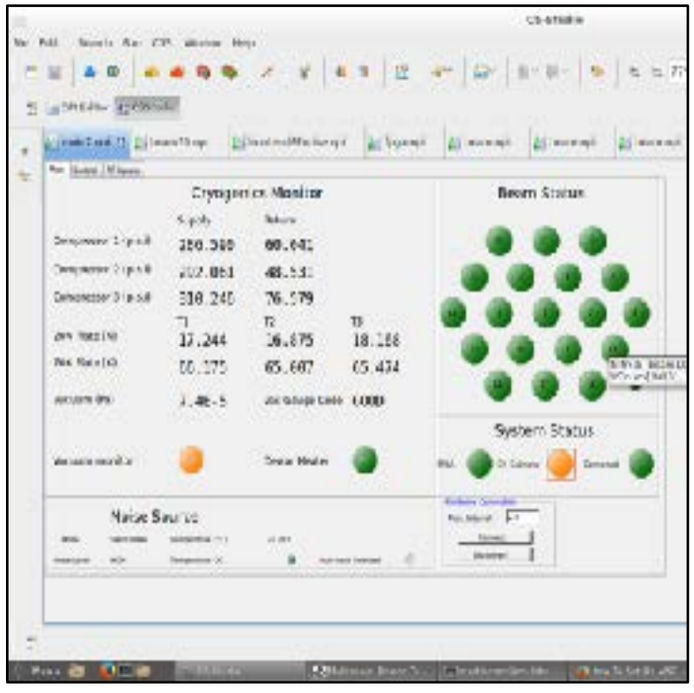
Key words: Galaxy: halo – X-rays: diffuse background

Online-only material: color figures



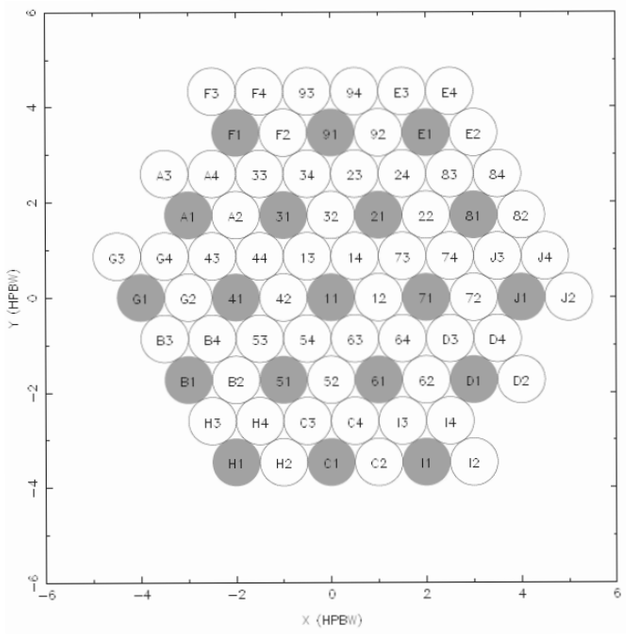
FLAN

FAST L-band Array of Nineteen beams



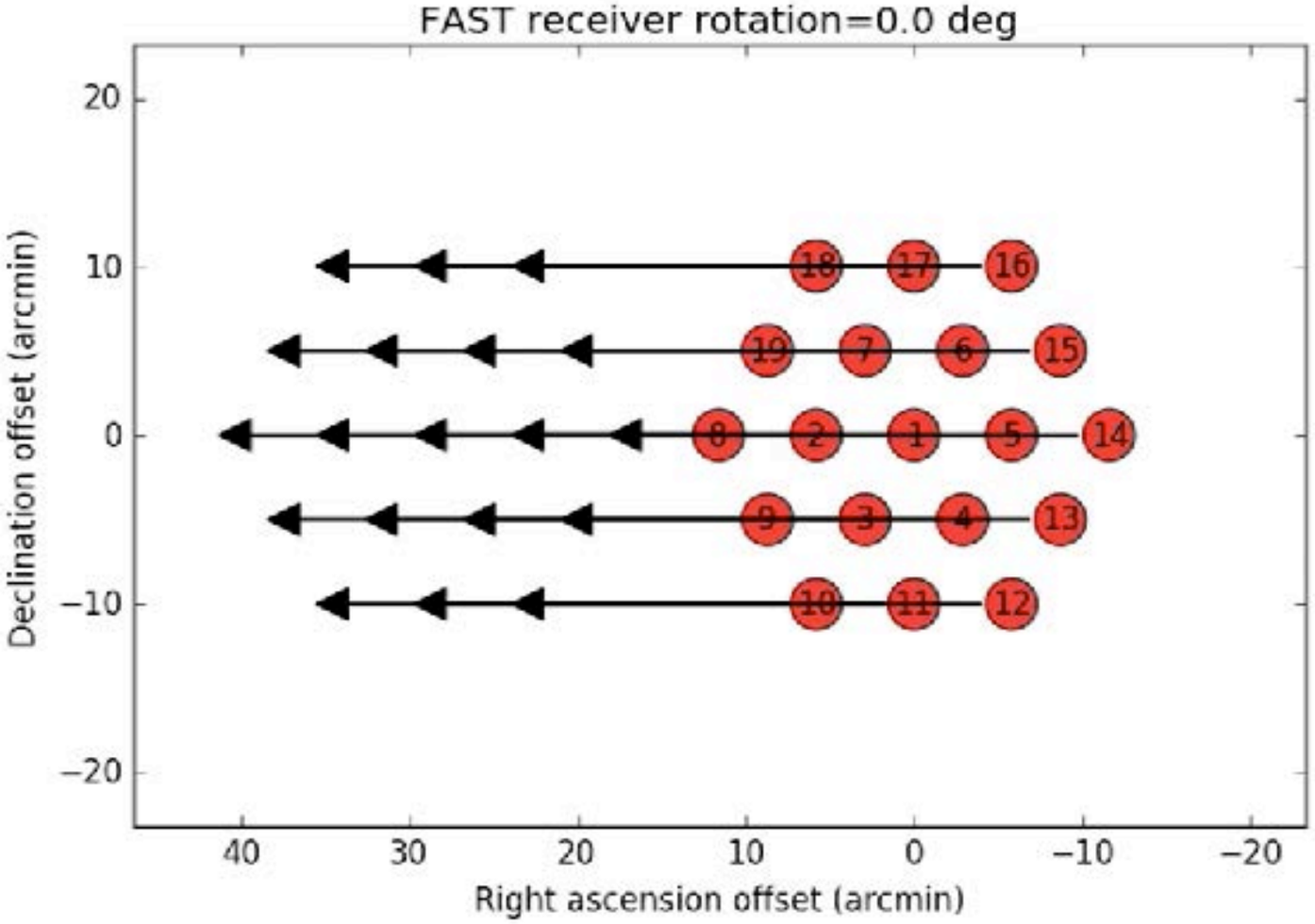
The Largest
L-band feed-horn array

- 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

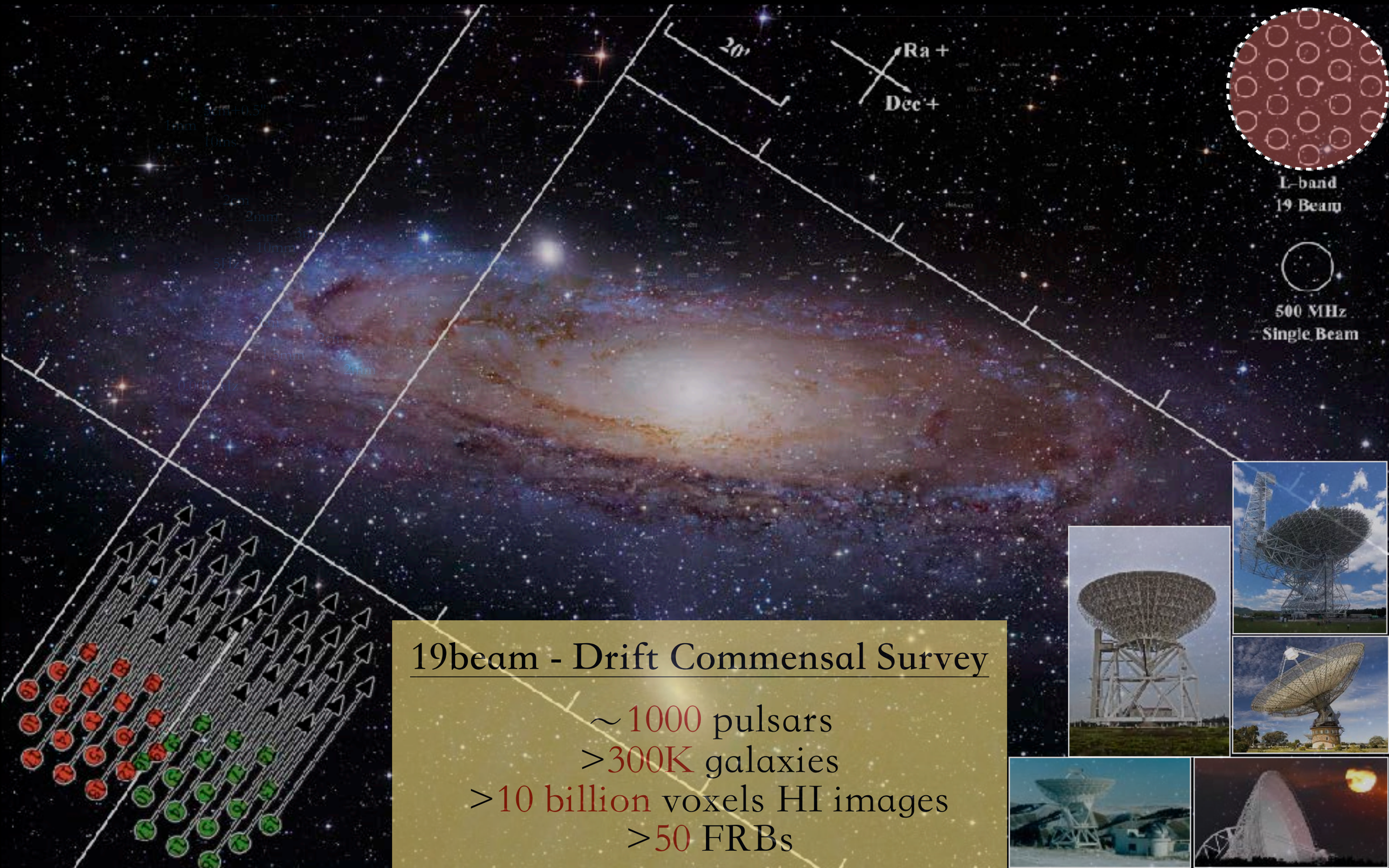
Credit: L. Staveley-Smith



Commensal Radio Astronomy FAST Survey

CRAFTS

32m-dish beam



19beam - Drift Commensal Survey

~1000 pulsars
>300K galaxies
>10 billion voxels HI images
>50 FRBs

CRAFTS Team on Site

with Dr. Neil deGrasse Tyson
@ June 21, 2018

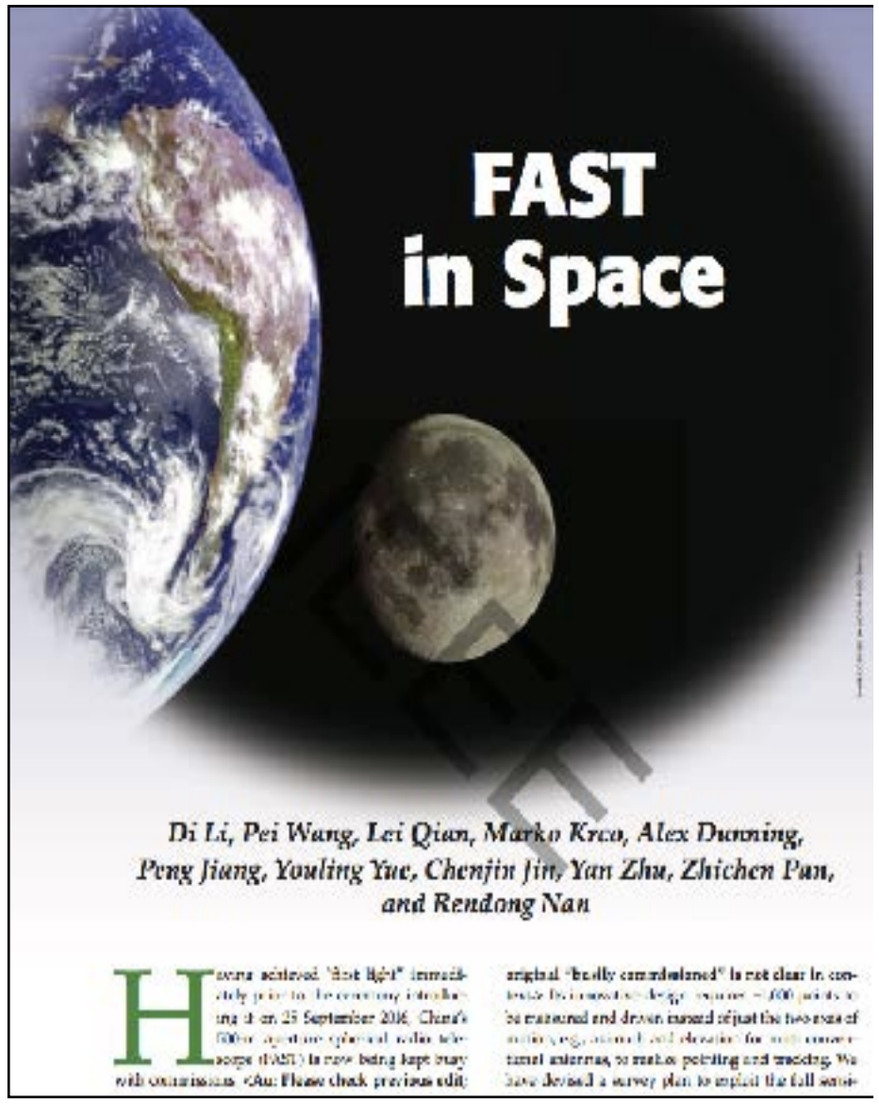
Commensal Radio Astronomy FAST Survey

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/semsester 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 proposals etc. submitted
- Data facility (**20PB+200 Tflop+100Gbs**) contract signed

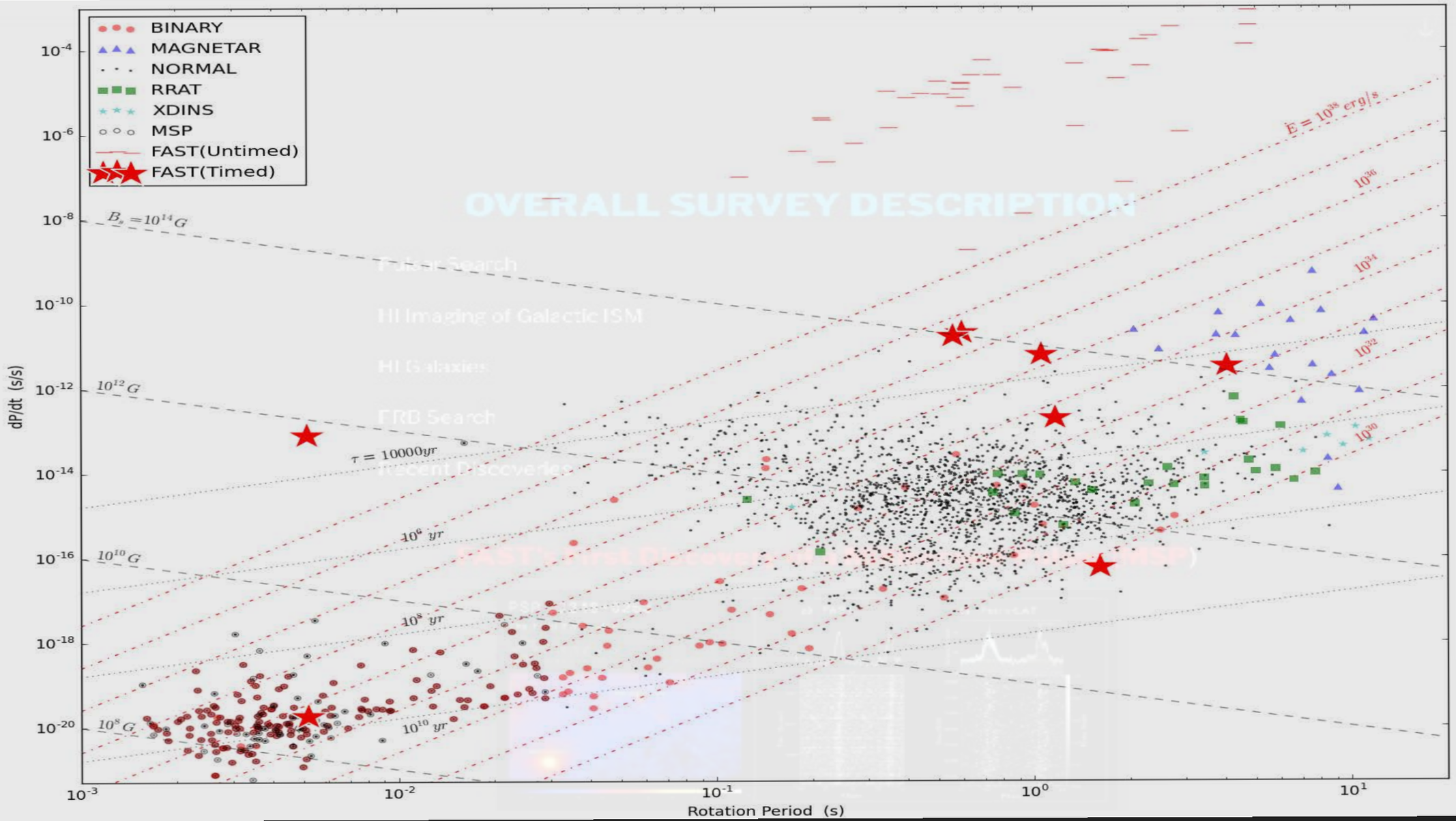


Li et al. 2018, Invited Review
IEEE Microwave, Vol 19, Issue 3

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

FAST巡天规划网页

http://crafts.bao.ac.cn



Computing Challenges

宽带 (UWB)

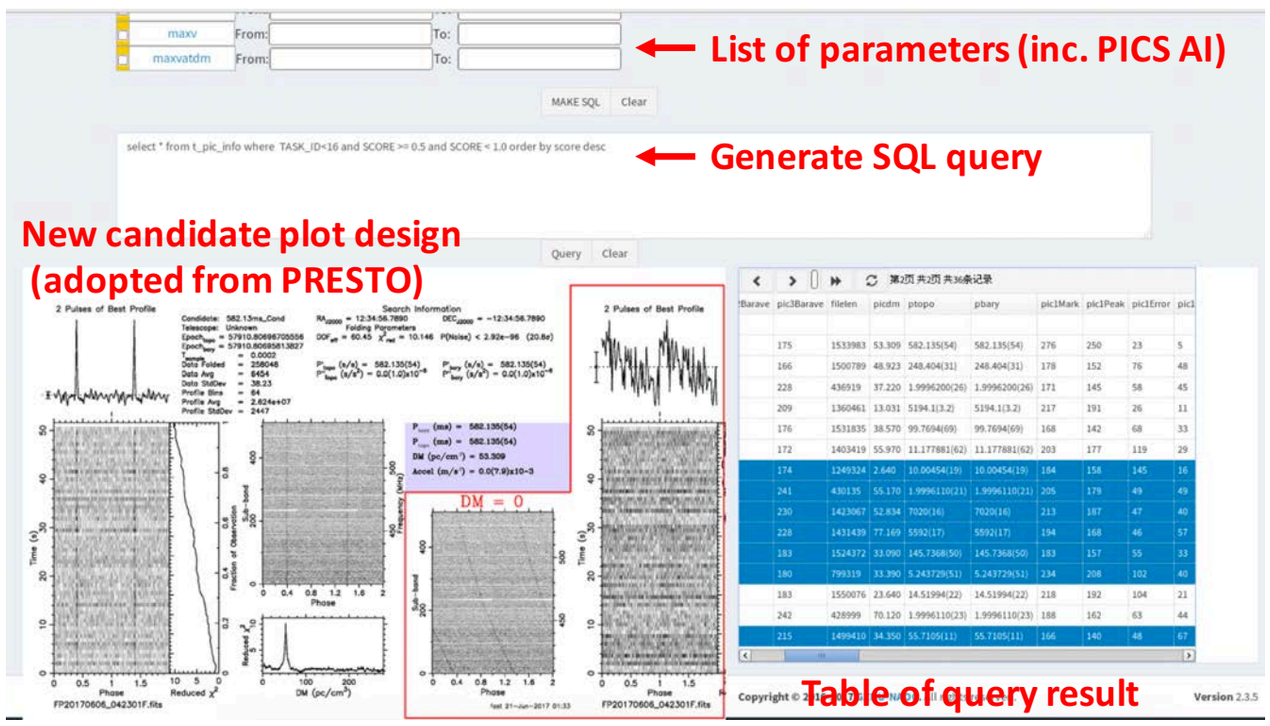
8b; 0-1GHz+1-2GHz; 1min (drift)→ 120MB; ~1hr (track) →2M FFT

19波束 (19-beam)

8b x 10^4 x 2 x 4k x 19 per second => 1.6GB/s => 10-20 PB/yr

Requirements: 50-100 PB; 1peta-flop; ¥50M/year

Current: 100 Gbs, 20 PB; 0.2peta-flop; ¥20M/year (x3)



A database + AI + IP pulsar search pipeline designed and tested

Customized GPU boards.

Three patents (NAOC+GZNU) application filed.

Working with SPC.

XIANTANGXIANG
塘地乡
DIJIXIANG
托亭乡
TONGZHOUZHEN
通州镇
BAIRUZHEN
摆布镇
KEDUZHEN
克度镇
30km
TANGBIANZHEN
塘边镇
S312
DONGJIAXIANG
董架乡
SHUCHANGXIANG
甜场乡
DONGDANGXIANG
董当乡
S312
PINGYANXIANG
平岩乡

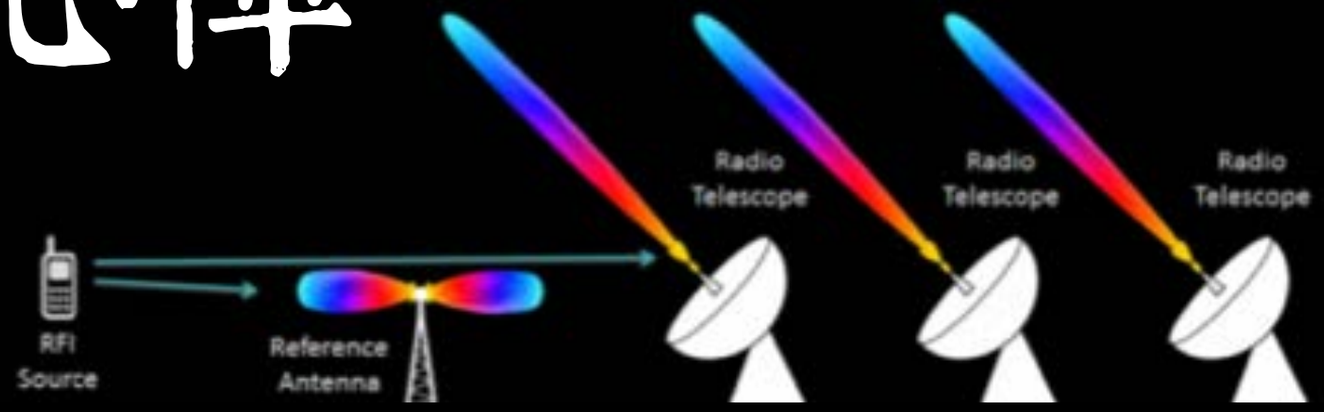
FAST 核心陣 （Aplus）

FAST - Aplus 核心陣

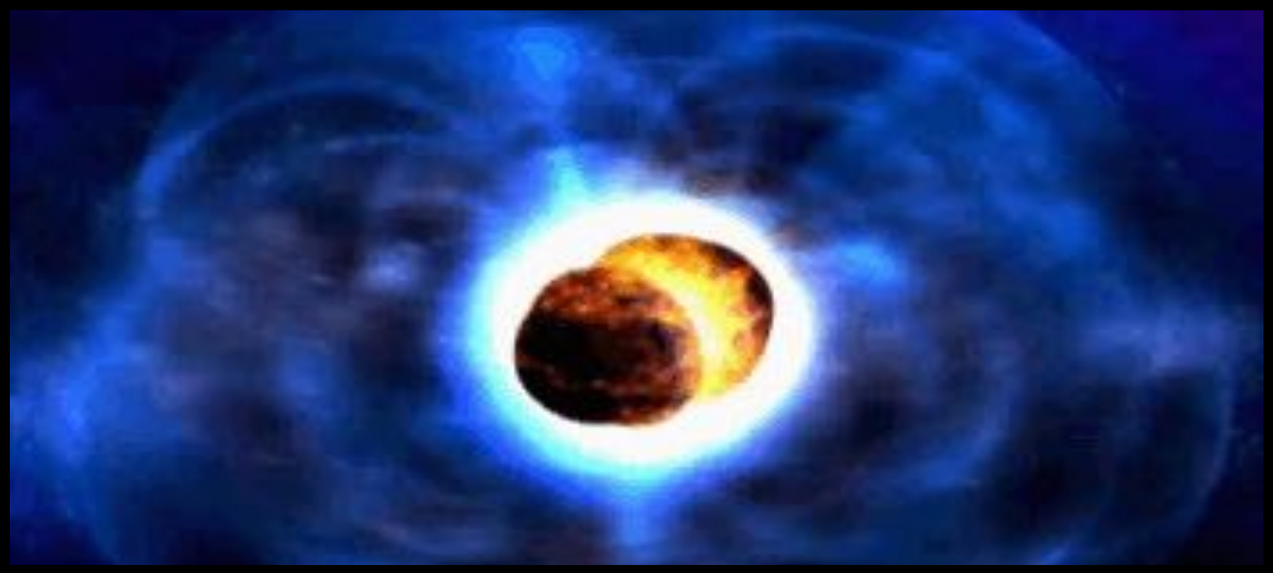
RFI removal

"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**

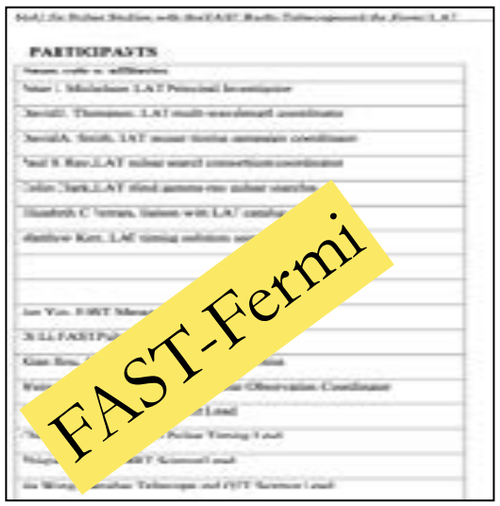
- **Fast Radio Brust**

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



Known Knowns; Known Unknowns, Unknown Unknowns