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

GAS

FAST Surveys
&
FAST A+

CRAFTS Commensal **R**adio **A**stronomy **F**A**S**T **S**urvey

GAS Galactic-plane and **A**ndromeda **S**urvey

Gain: FAST > 2 x Arecibo; **Beam #:** Arecibo 7 vs FAST 19

Arecibo Sky: 0^d - 39^d DEC vs FAST Sky: -14^d - 66^d DEC

Survey Speed: FAST ~ 10 x Arecibo

可観測量

a)HI

b)pulsars

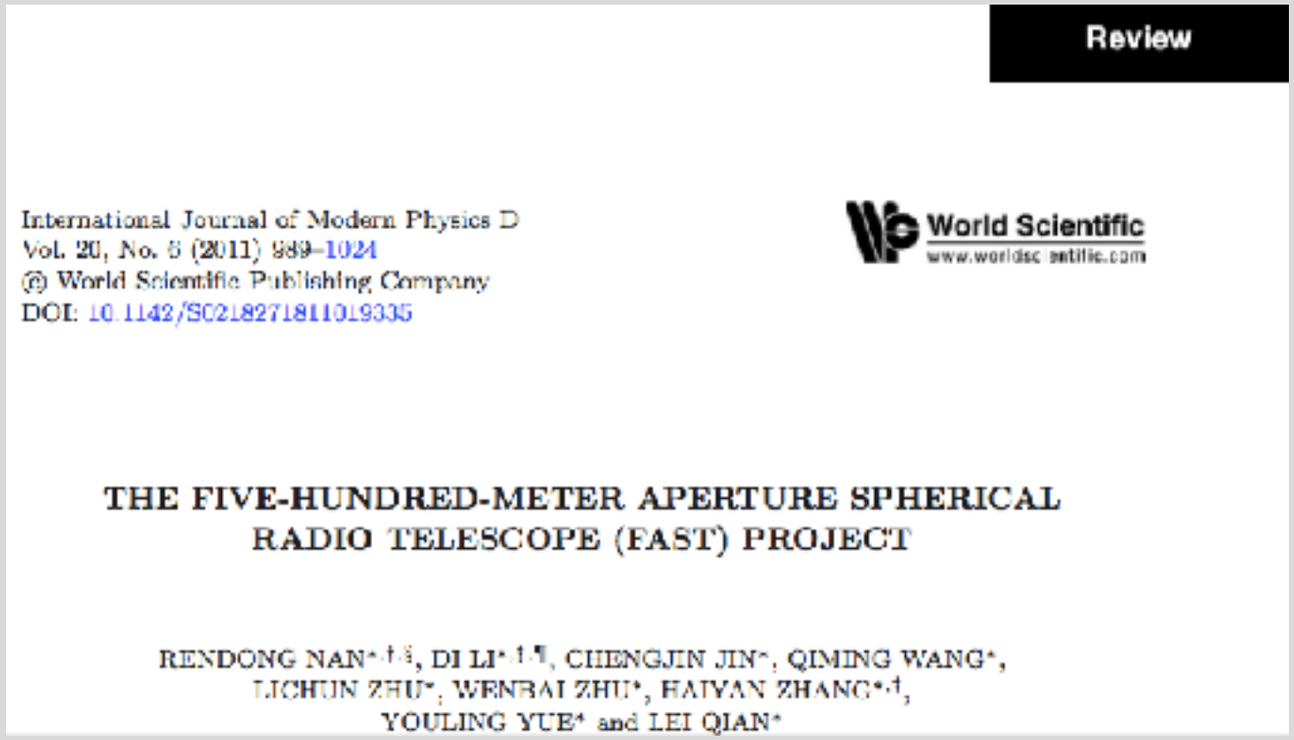
c)Spectroscopy

d)VLBI

e)SETI

continuous coverage

70MHz～3GHz



Review

International Journal of Modern Physics D
Vol. 20, No. 6 (2011) 989–1024
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DOI: 10.1142/S0218271811019335

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www.worldscientific.com

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

RENDONG NAN[a,b,§], DI LI[a,b,¶], CHENGJIN JIN[c], QIMING WANG[a], LICHUN ZHU[a], WENBAI ZHU[a], HAIYAN ZHANG[a,d], YOULING YUE[a] and LEI QIAN[a]

Nan, **Li**, Jin+ et al. 2011, IJMR-D, 20, 989
(>190 citations)

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

RAA Mini-Volume （中国唯一英文SCI天文专业期刊）
FAST科学能力展望《天文与天体物理研究》专刊


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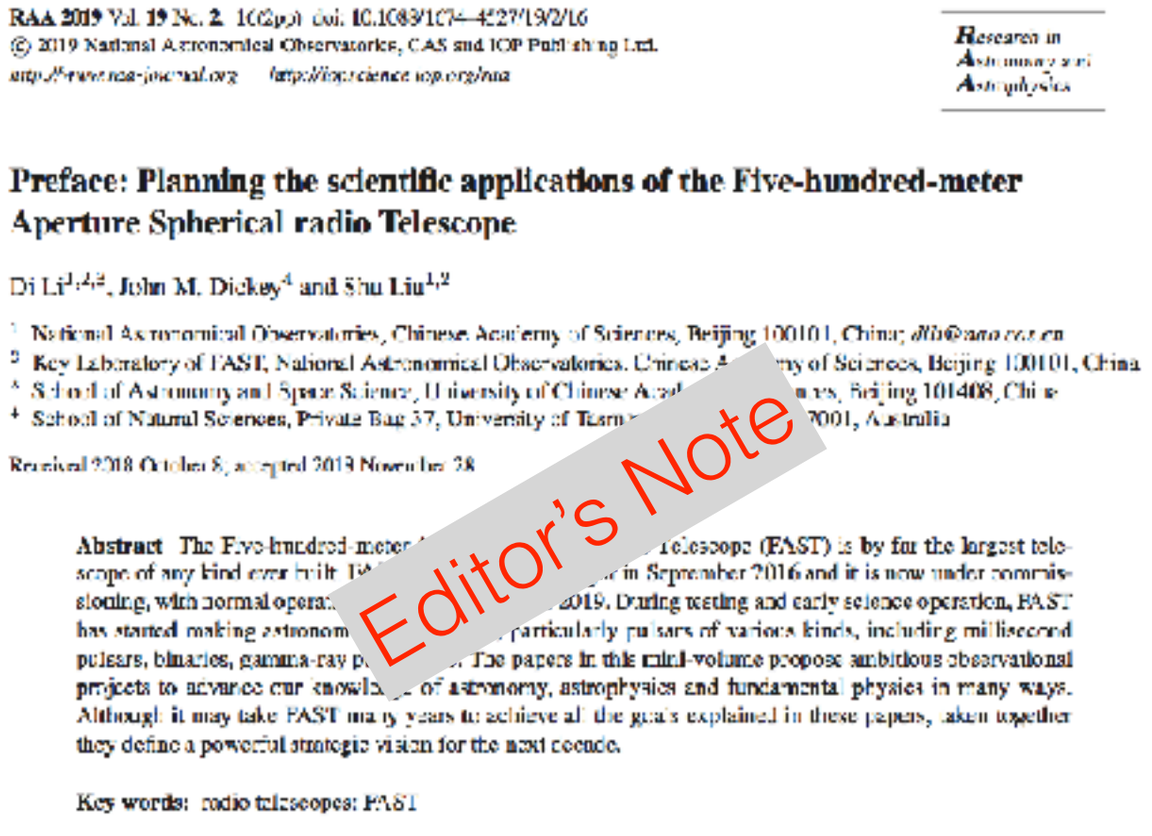
IMPACT FACTOR 2018

1.227

A Mini-Volume on the Science Potential of the Five-hundred-meter Aperture Spherical radio Telescope (FAST)

Research in Astronomy and Astrophysics (RAA) has published a mini-volume on the science potential of FAST. Having released its first call for shared-risk proposals, FAST is near the end of its commissioning phase and on track to become a national facility before the end of 2019. In this RAA volume, the authors quantified the science potential of FAST in ambitious and forward-looking manners. High interest targets discussed here include ultra-high-energy cosmic rays, fundamental constants, neutrinos, exoplanets, gravitational waves, etc. Along with a fast growing body of literature on related topics published in other peer-reviewed journals, the drive to facilitate major breakthroughs with the FAST telescope gets underway in earnest.


RAA 2019 Vol. 19 No. 2, 16(3pp) doi: 10.1088/1674-4527/19/2/16

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http://www.raa-journal.org http://iopscience.iop.org/raa

Research in Astronomy and Astrophysics

Preface: Planning the scientific applications of the Five-hundred-meter Aperture Spherical radio Telescope

Di Li[1,2,3], John M. Dickey[4] and Shu Liu[1,2]

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2 Key Laboratory of FAST, National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100101, China
3 School of Astronomy and Space Science, University of Chinese Academy of Sciences, Beijing 101408, China
4 School of Natural Sciences, Private Bag 37, University of Tasmania, Hobart, TAS 7001, Australia

Received 2018 October 8; accepted 2018 November 28

Editor's Note

Abstract The Five-hundred-meter Aperture Spherical radio Telescope (FAST) is by far the largest telescope of any kind ever built. It was completed in September 2016 and it is now under commissioning, with normal operations expected by 2019. During testing and early science operation, FAST has started making astronomical discoveries, particularly pulsars of various kinds, including millisecond pulsars, binaries, gamma-ray pulsars, etc. The papers in this mini-volume propose ambitious observational projects to advance our knowledge of astronomy, astrophysics and fundamental physics in many ways. Although it may take FAST many years to achieve all the goals explained in these papers, taken together they define a powerful strategic vision for the next decade.

Key words: radio telescopes: FAST

http://iopscience.iop.org/journal/1674-4527

A Mini-Volume on the Science Potential of FAST

Research in Astronomy and Astrophysics has published a mini-volume on the science potential of FAST … The authors quantified the science potential of FAST in ambitious and forward-looking manners. … the drive to facilitate major breakthroughs with the FAST telescope gets underway in earnest.

- Fundamental Constants (Chen et al. 2019)
- Cosmic Rays (James et al. 2019)
- Exoplanets (Zarka et al. 2019);
- Gravitational radiation (Hobbs et al. 2019)
- Pulsar magnetospheres (Wang et al. 2019)
- Phases of the Interstellar Medium (Heiles et al. 2019)
- Megamasers (Zhang et al. 2019)

《中国科学》
FAST专刊

Science China

Physics, Mechanics & Astronomy

[1] Jiang P., et al. Commissioning Progress of FAST, Sci. China-Phys. Mech. Astron. xx, xx (2019)

[2] Lu J. G., et al. Rotating Radio Transients Observed with FAST, Sci. China-Phys. Mech. Astron. xx, xx (2019)

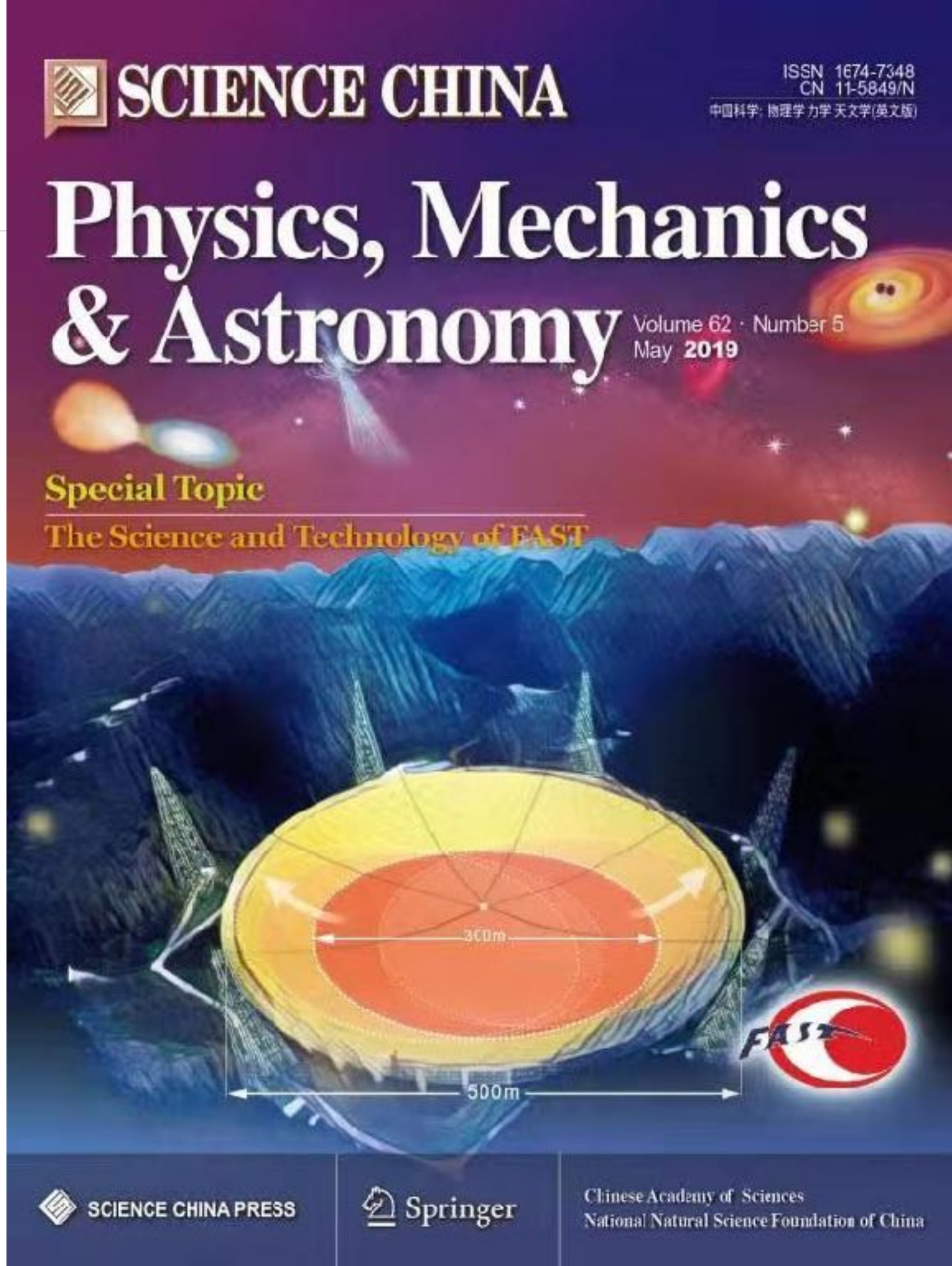
[3] Yu Y., et al. FAST ultra-wideband observation for the abnormal emission-shift event of PSR B0919+06, Sci. China-Phys. Mech. Astron. xx, xx (2019)

[4] Lu J., et al. The Radiation Structure of PSR B2016+28 Observed with FAST, Sci. China-Phys. Mech. Astron. xx, xx (2019)

[5] Zhang K., et al. Status and Perspectives of the CRAFTS extragalactic HI survey, Sci. China-Phys. Mech. Astron. xx, xx (2019)

[6] Wang H. F., et al. Pulsar Candidate Selection with Ensemble Nets for FAST Drift-scan Survey, Sci. China-Phys. Mech. Astron. xx, xx (2019)

[7] Qian L., et al. The First Pulsar Discovered by FAST, Sci. China-Phys. Mech. Astron. xx, xx (2019)



“Shared-Risk” Open Call

Day time 360h + Night time 960h

133 proposals, **2250h** requested, **21 PI** institutes, CoI: **583**
NAOC, PKU, NJU, SHAO, YNU, HKU, etc.

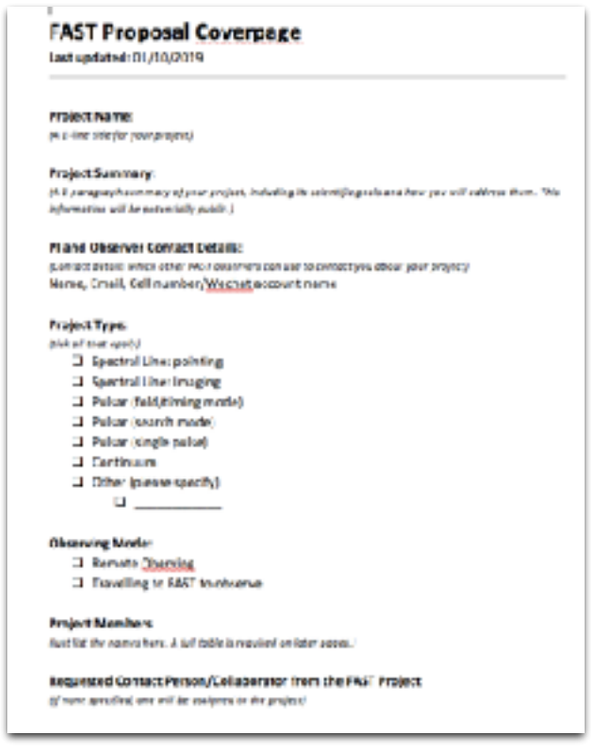
The oversubscription ratio for day time hours **>5**

中国科学院国家天文台

中国科学院国家天文台关于征集“中国天眼”
调试阶段风险共担观测申请的通知

Objectives

Pulsars (48 36.1%)
Galaxies (32, 24.1%)
ISM (17, 12.8%)
Compact Objects (14, 10.5%)
FRB (8, 6.0%)
Exoplanet, GW etc. (14, 10.5%)



FAST Proposal Coverpage

Last updated: 01/10/2019

Project Name:

(e.g. one line for your project)

Project Summary:

(A 3 paragraph summary of your project, including its scientific goals and how you will address them. This information will be potentially public.)

PI and Observer Contact Details:

(contact details which other FAST observers can use to contact you about your project)

Name, Email, Cell number, Wechat account name

Project Type:

(pick all that apply)

- ❑ Spectral Line: pointing
- ❑ Spectral Line: imaging
- ❑ Pulsar: fold(timing mode)
- ❑ Pulsar: search mode
- ❑ Pulsar: single pulse
- ❑ Continuum
- ❑ Other (please specify)
  - ❑ _____

Observing Mode:

- ❑ Remote Observing
- ❑ Travelling to FAST to observe

Project Members:

(List the names here. A full table is required on later pages.)

Requested Contact Person/Collaborator from the FAST Project

(if more specialist ones will be required on the project)

FAST时间分配委员会

主 任：沈志强 中科院上海天文台
副主任：李 菂 中科院国家天文台
委 员：方陶陶 厦门大学
韩金林 中科院国家天文台
何子山 北京大学
姜 鹏 中科院国家天文台
毛淑德 清华大学/中科院国家天文台
彭 勃 中科院国家天文台
邱科平 南京大学
徐 烨 中科院紫金山天文台
王 娜 中科院国家天文台新疆天文台

FAST时间分配咨询委员会

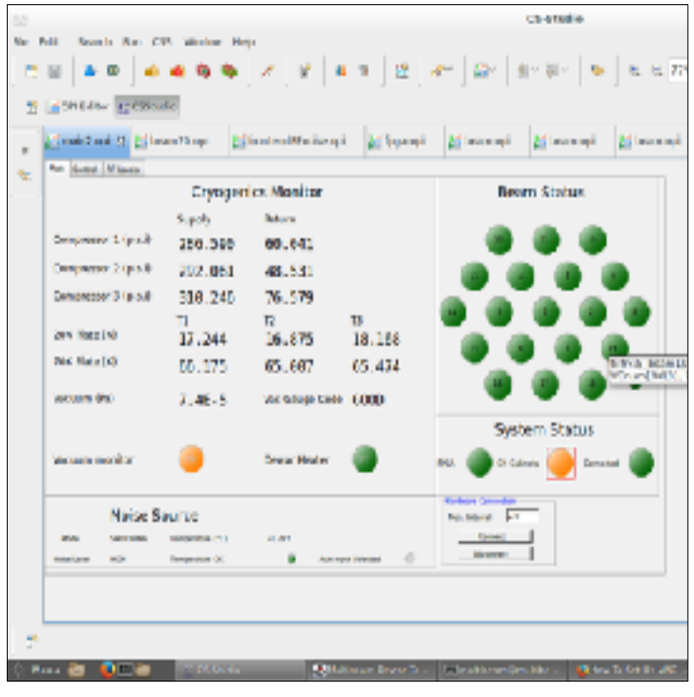
Paul Ho 东亚天文台
张其洲 哈佛史密松天体物理中心
张 冰 内华达大学/中科院国家天文台

FLAN

FAST L-band Array of Nineteen beams

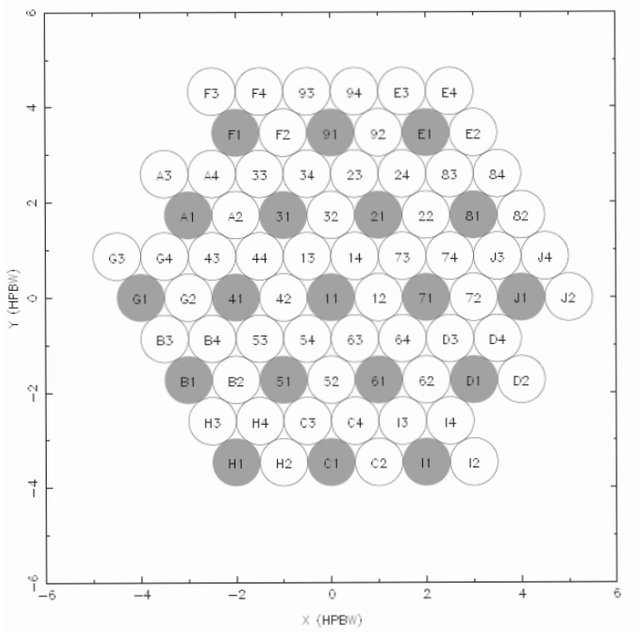
CSIRO

The Largest
L-band feed-horn array



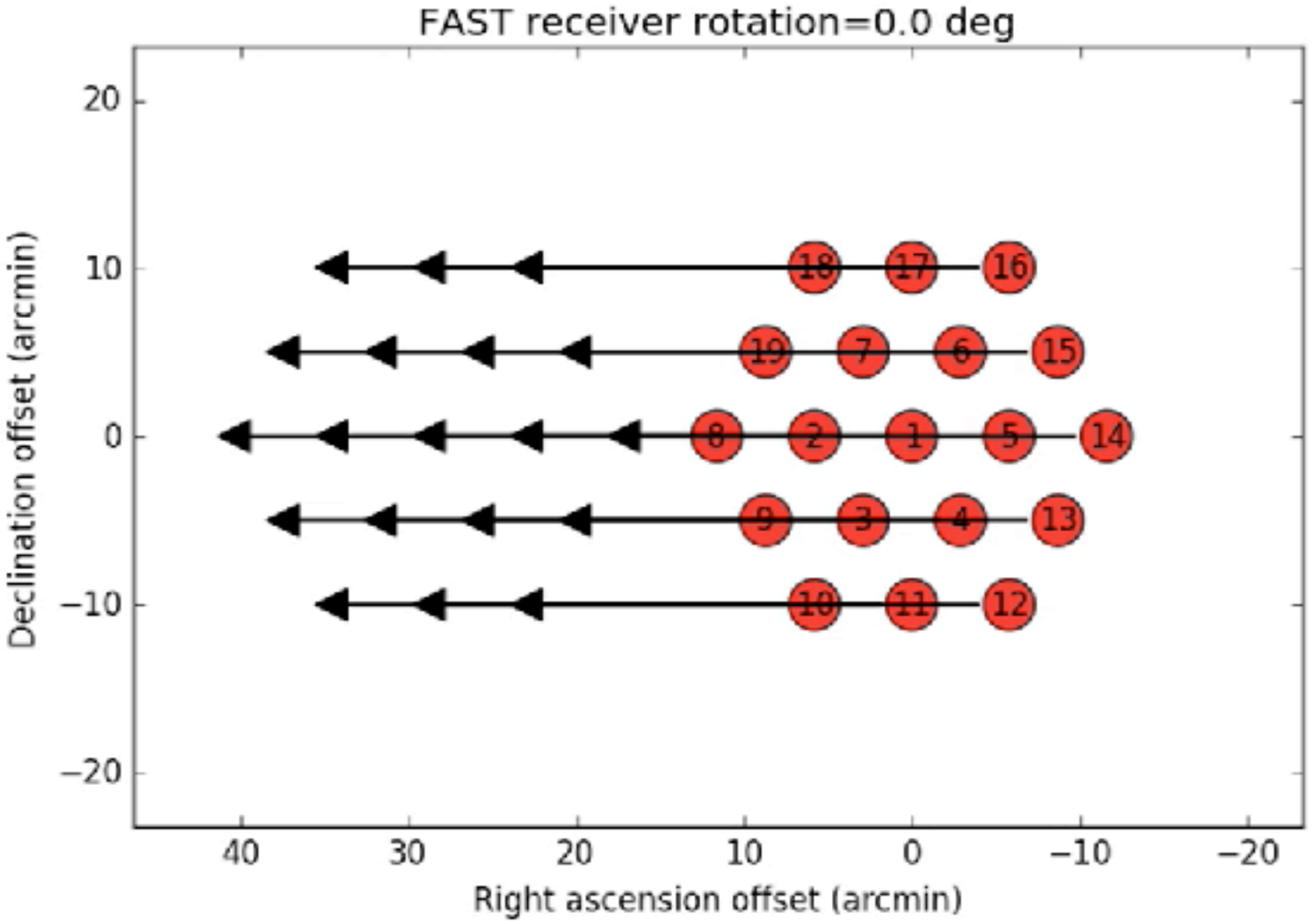
- 1.05 – 1.45 GHz
- 18K T_{sys}
- 19 BEAM FEED ARRAY
- BEAM WIDTH 2.9’ at 21cm
- BEAM SPACING 270mm (~6’)
- DUAL LINEAR POLARIZATION
- POL. CROSS-COUPLING <-30 dB

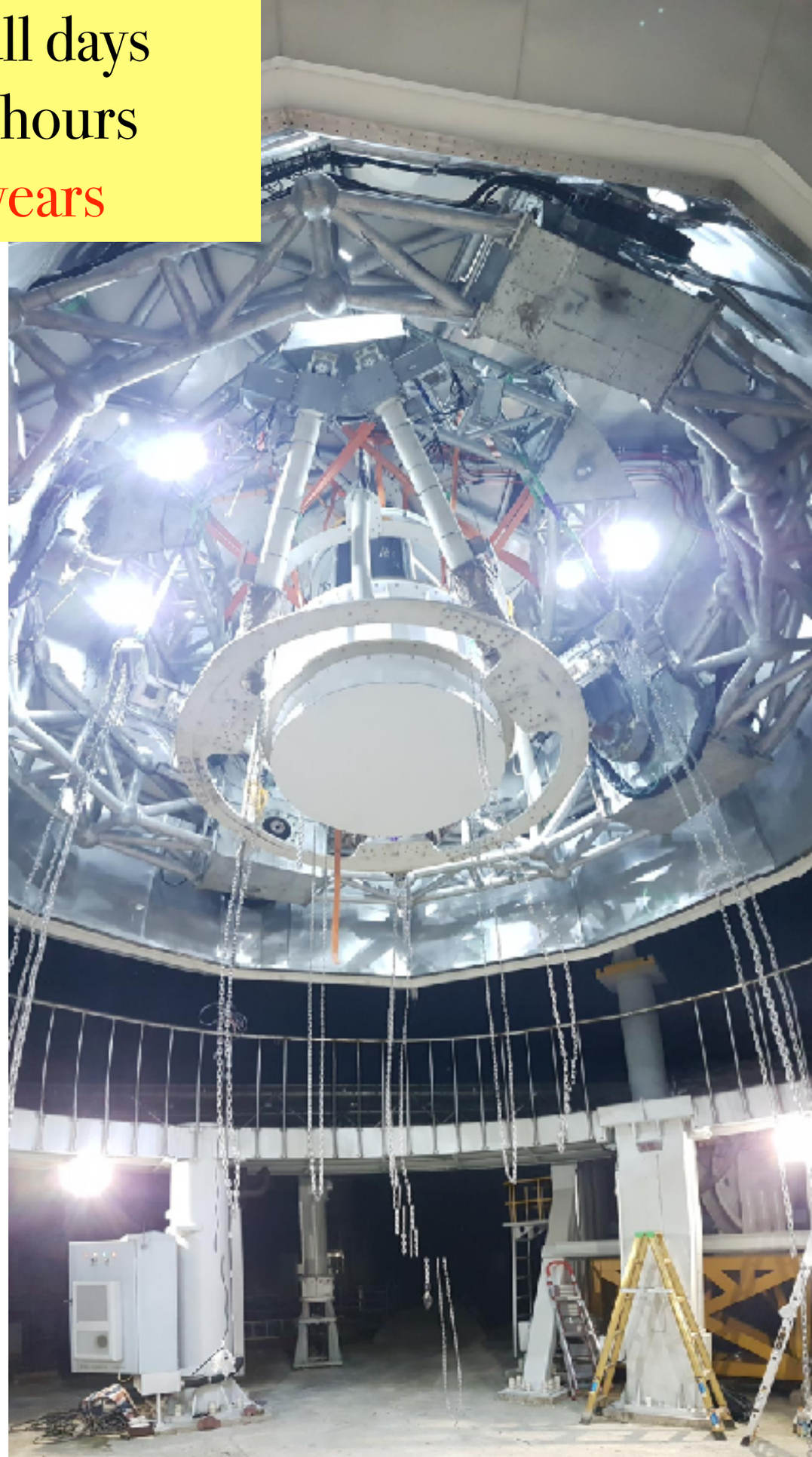
220 full days
5280 hours
2-3 years



Drift （sidereal)： 漂移扫描

Credit: L. Staveley-Smith





FAST Pulsar#1

J1859-01

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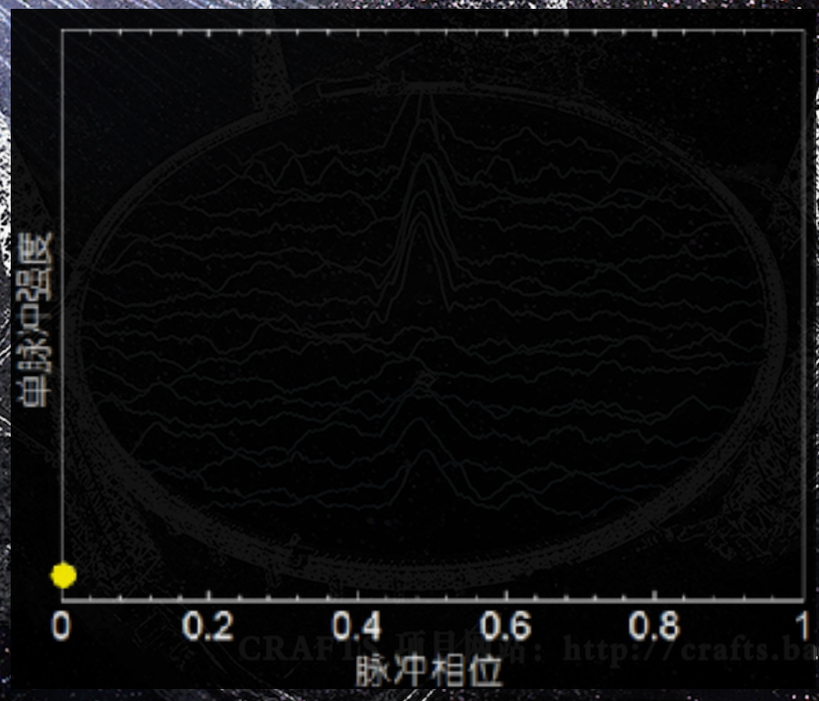
自转周期:1.832秒

距离地球约1.6万光年(色散估计)

发现时间：FAST 2017/08/22

验证时间：Parkes 2017/09/10



CRAFTS项目网站：http://crafts.bao.ac.cn/pulsar/

Message from Dr. Bell

Oct. 10, 2017

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 273306/2; fax +44(0)1865 273390.
Also MANSFIELD COLLEGE

First FAST Science Results

2019.7

>120 candidates

>80 confirmed

FAST's First MSP

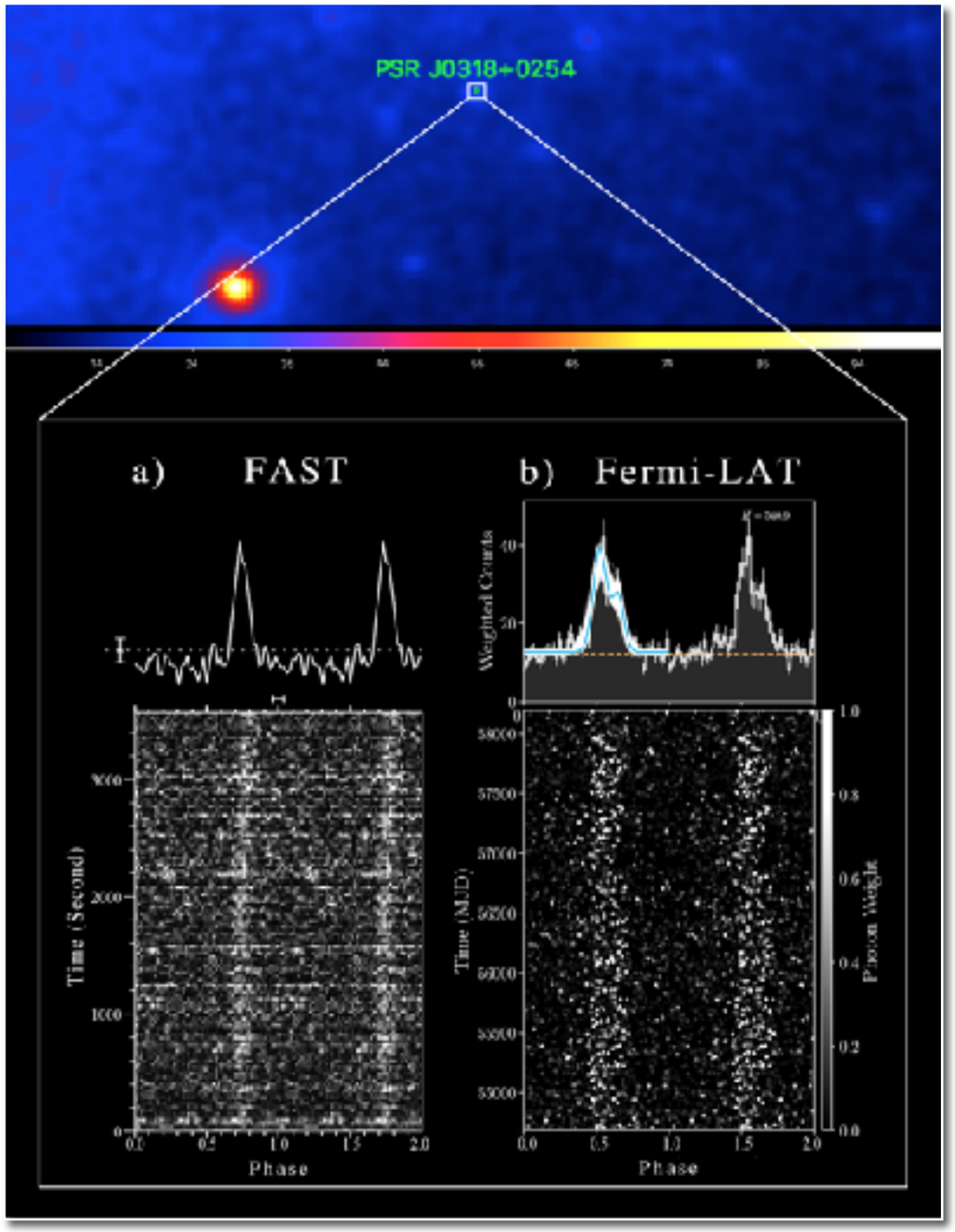
3FGL J0318.1+0252
FL8Y J0318.2+0254

- 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"

Pulsar Emission Mechanism

FAST Pulsar C12

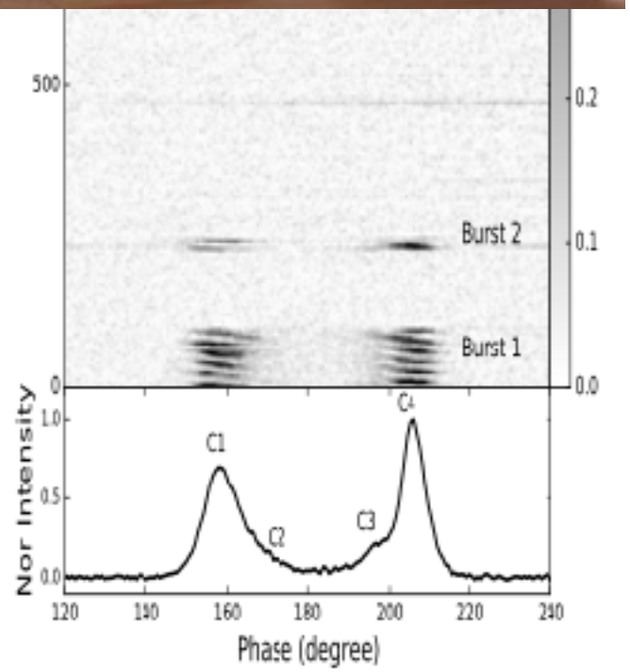
2017.08.31 FAST drift discovery
2017.10.07 Parkes confirmation

P0=1608.88971 ms
DM=85

Zhang, **DL** et al. 2019 ApJ

"PSR J1926-0652: A Pulsar with Interesting Emission Properties Discovered at FAST "

"…These complexities **pose challenges** for the classic carousel-type models. "



Commensal Radio Astronomy FAST Survey

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

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** follow-up
- PI programs (**11+9**) 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 (**15PB+200 Tflops+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 Outlook
HI Galaxies from CRAFTS

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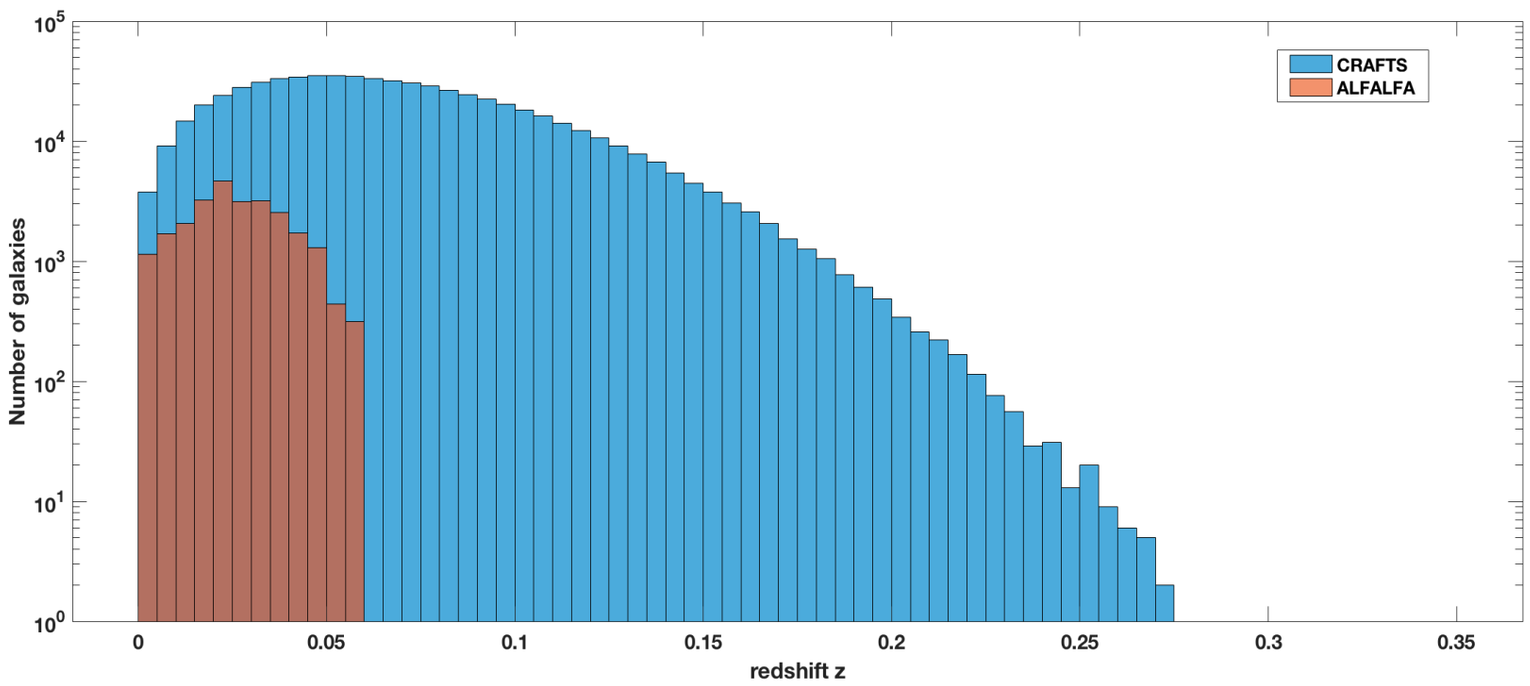
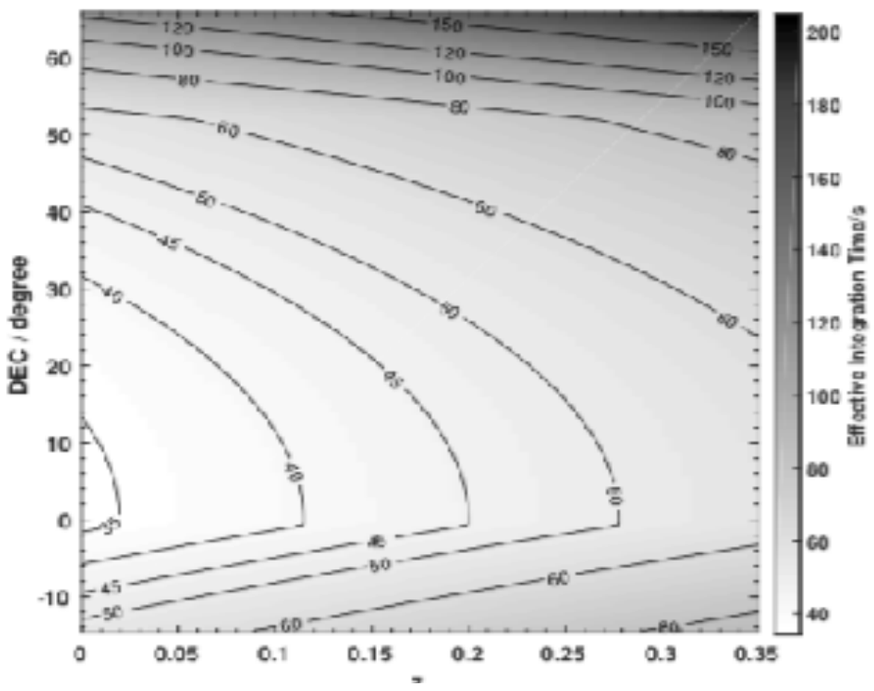
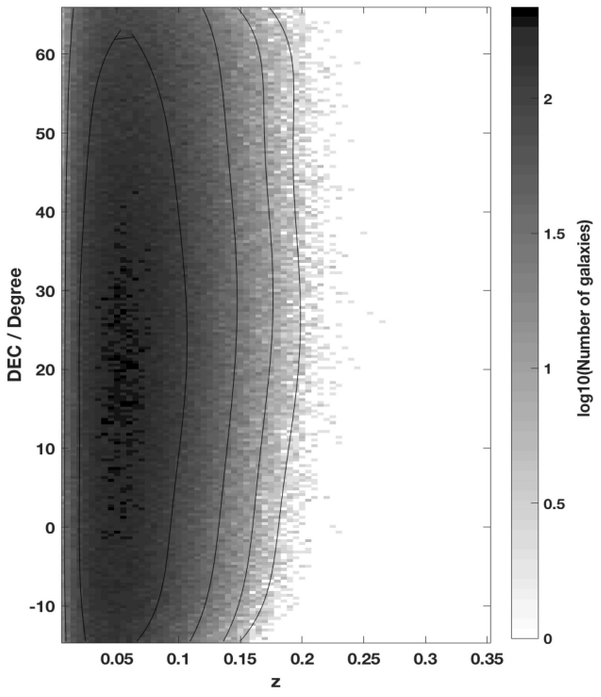
FAST多科学目标同时扫描巡天







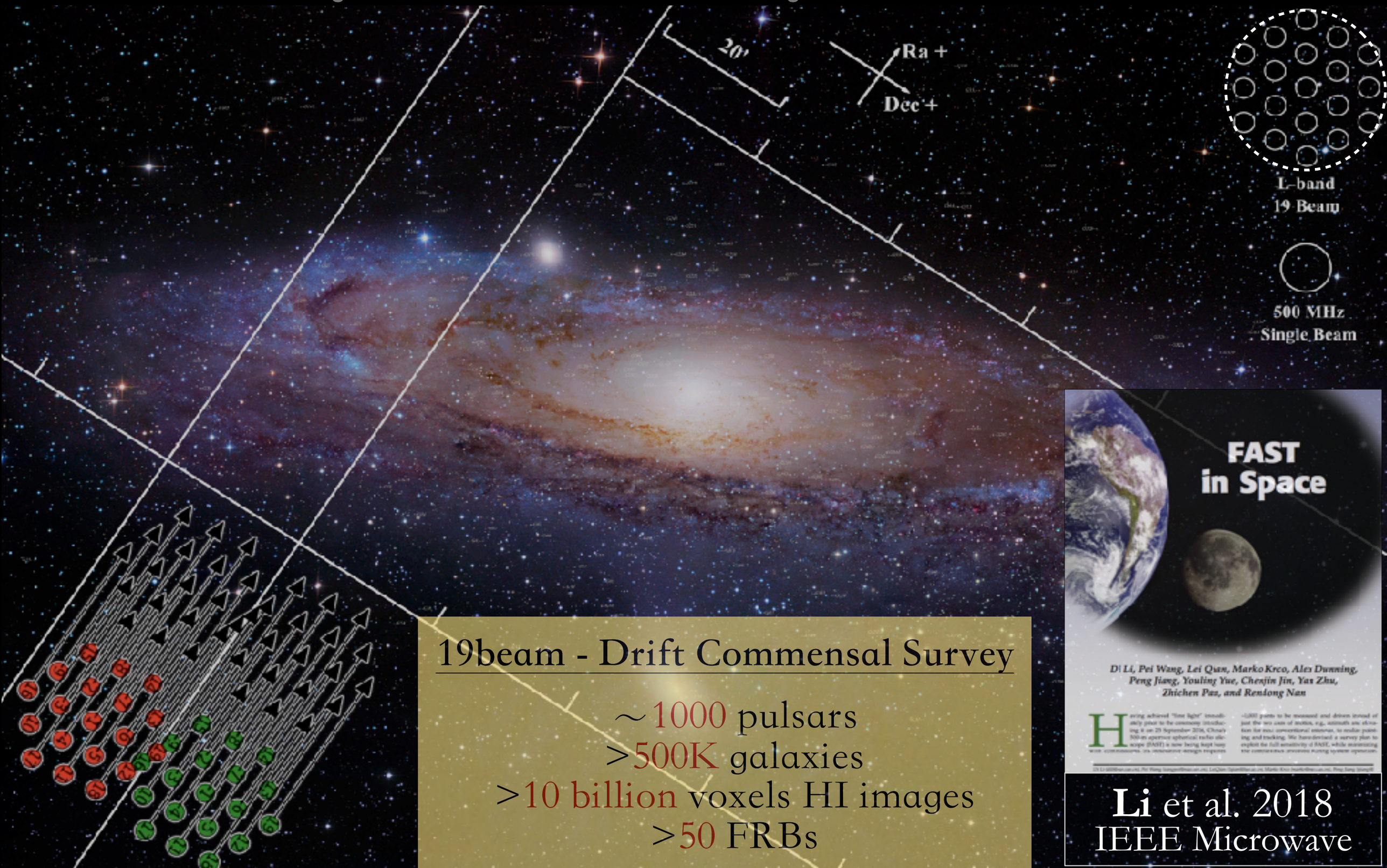
N ($>8\sigma$; 2.3 π)
$\approx 6.5\times10^5$
$\langle z\rangle\approx0.07$

INcrease
gaseous galaxies x20

Zhang, Wu, **Li** et al. 2019
c.f. Duffy et al. 2008

Commensal Radio Astronomy FAST Survey

CRAFTS

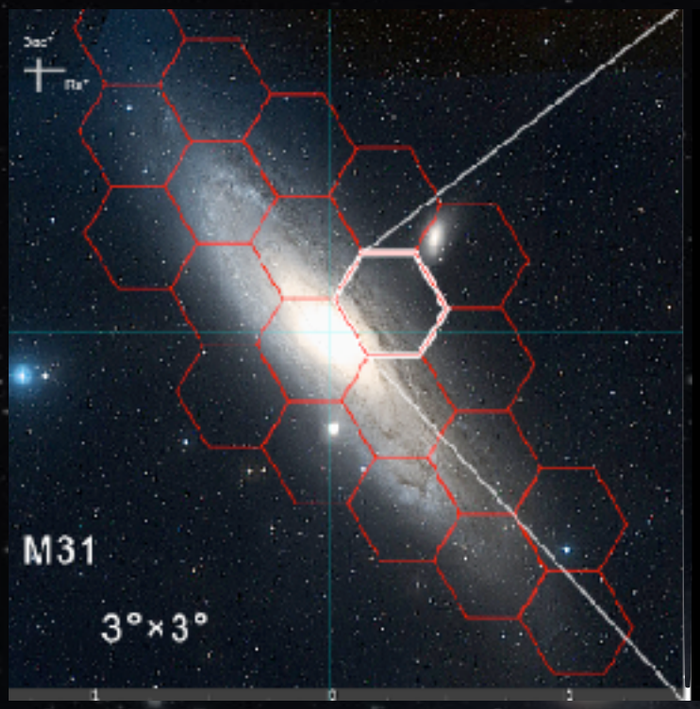


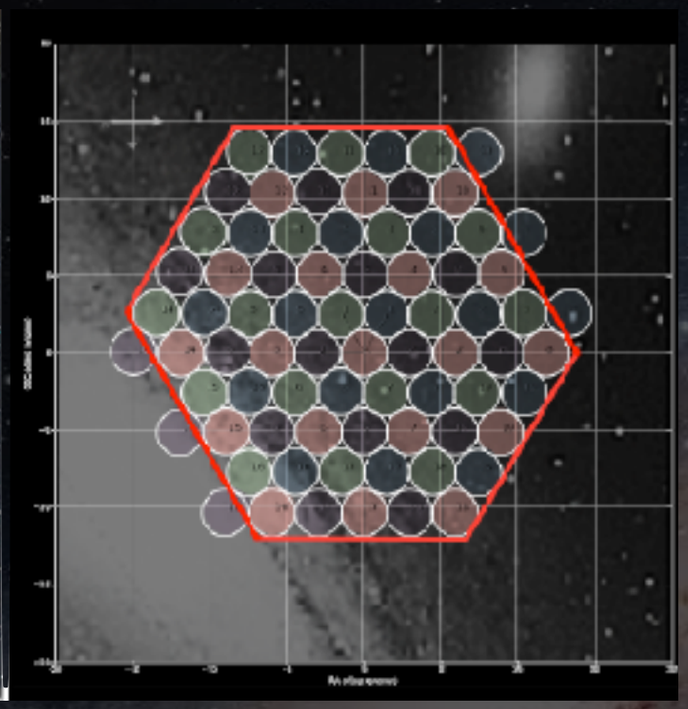
19beam - Drift Commensal Survey

~1000 pulsars
>500K galaxies
>10 billion voxels HI images
>50 FRBs

Li et al. 2018
IEEE Microwave

NAOC 中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES, CHINESE ACADEMY OF SCIENCES



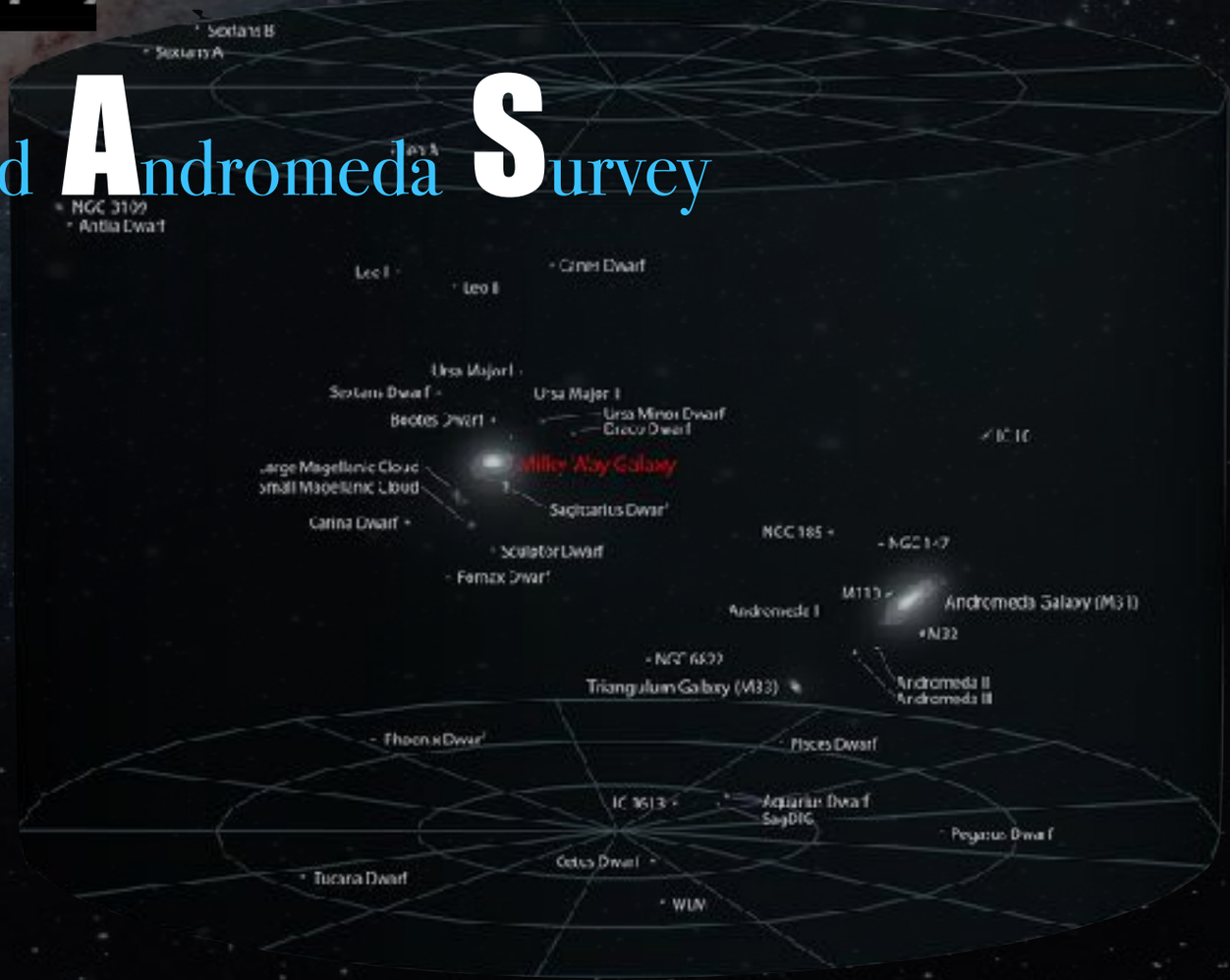


M31: Andromeda

- Closest spiral galaxy at 0.8Mpc
- No radio pulsar ever detected
- dwarf groups + HVCs

Galactic-plane and Andromeda Survey

- Deep coverage (1hr per pointing)
- Column density ~ 5×10^{16} cm^{-2}
- pulsar: 0.01 mJy; ~1000 new msp
- Dwarf galaxy groups around M31
- Galactic plane



Pacific Rim Interstellar Matter Observer

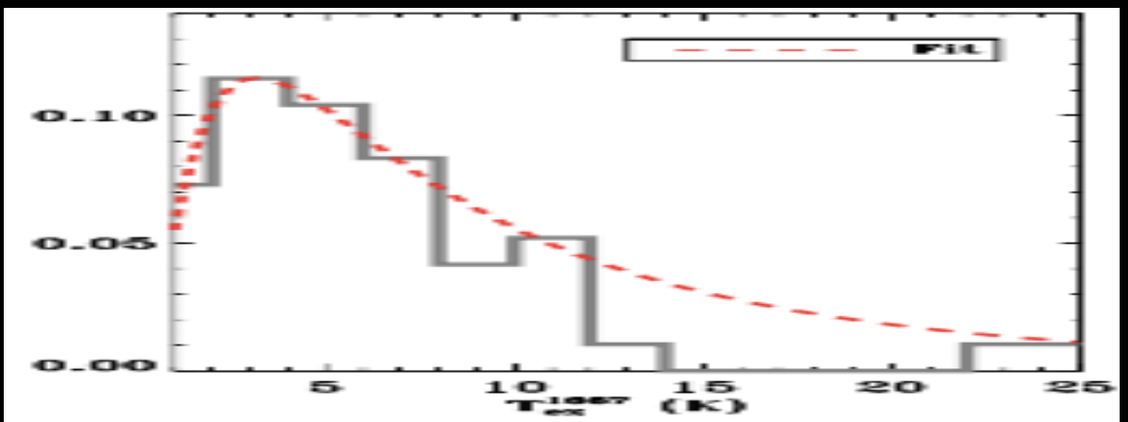
PRIMO

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

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

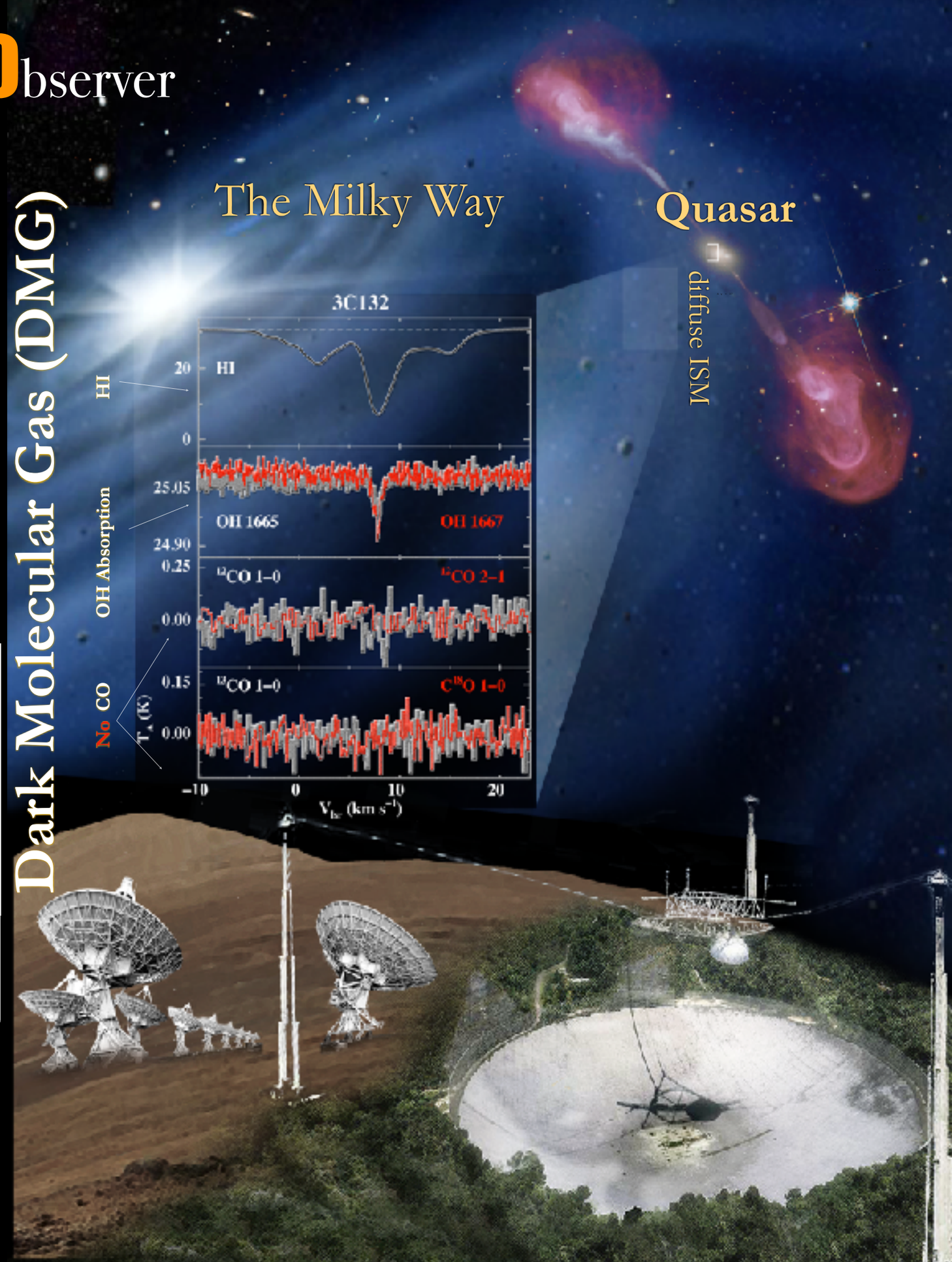
"Dust–Gas Scaling Relations and OH Abundance in the Galactic ISM"

Nguyen…**Li**+**PRIMO**, ApJ



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

- OH excitation temperature peaks around CMB
- OH abundance tracks DMG fraction



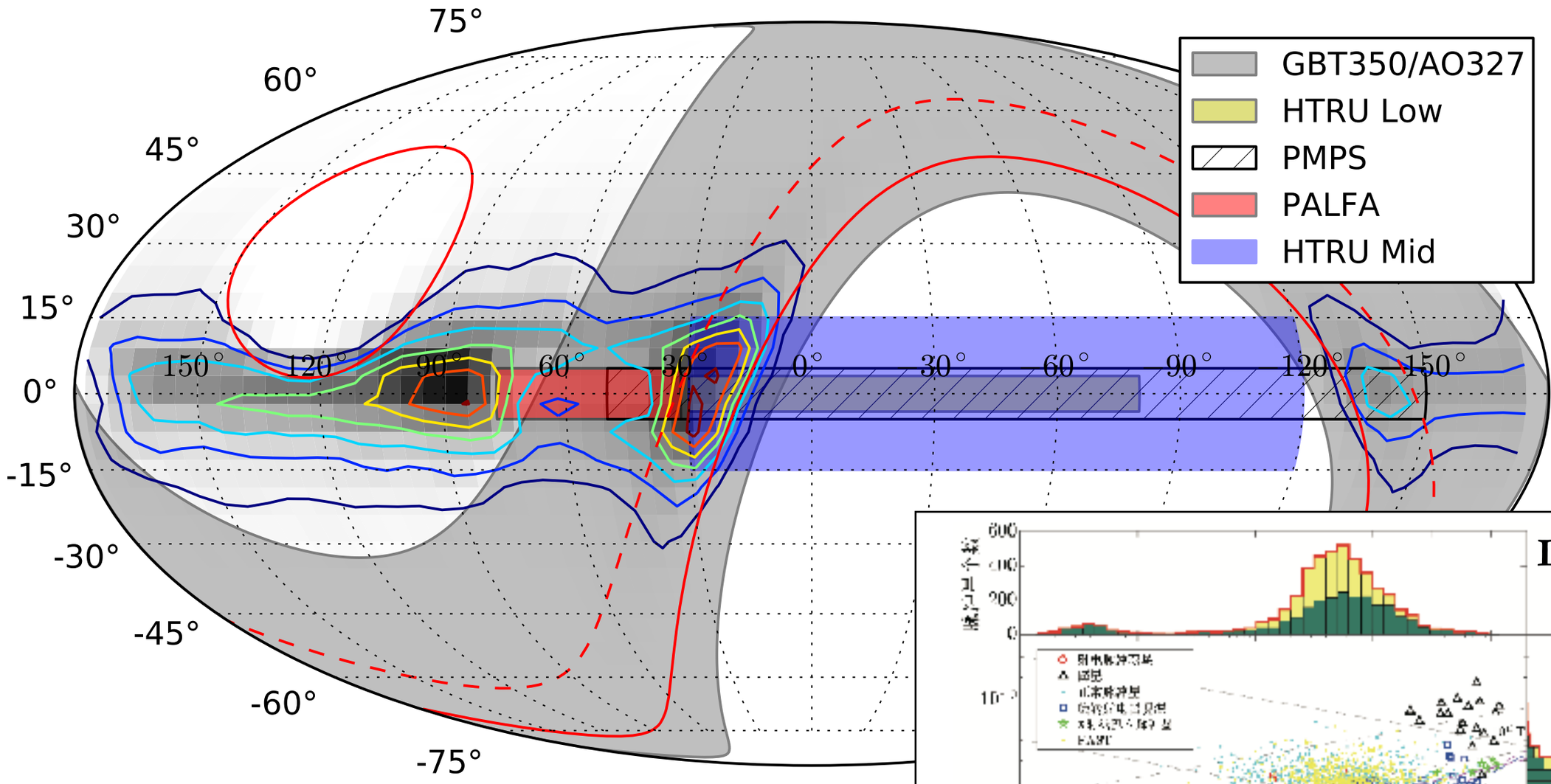
Pulsar Surveys

AO 327 MHz drift scan

LOFAR pulsar survey

Galactic centre search

PMPS re-analysis E@H

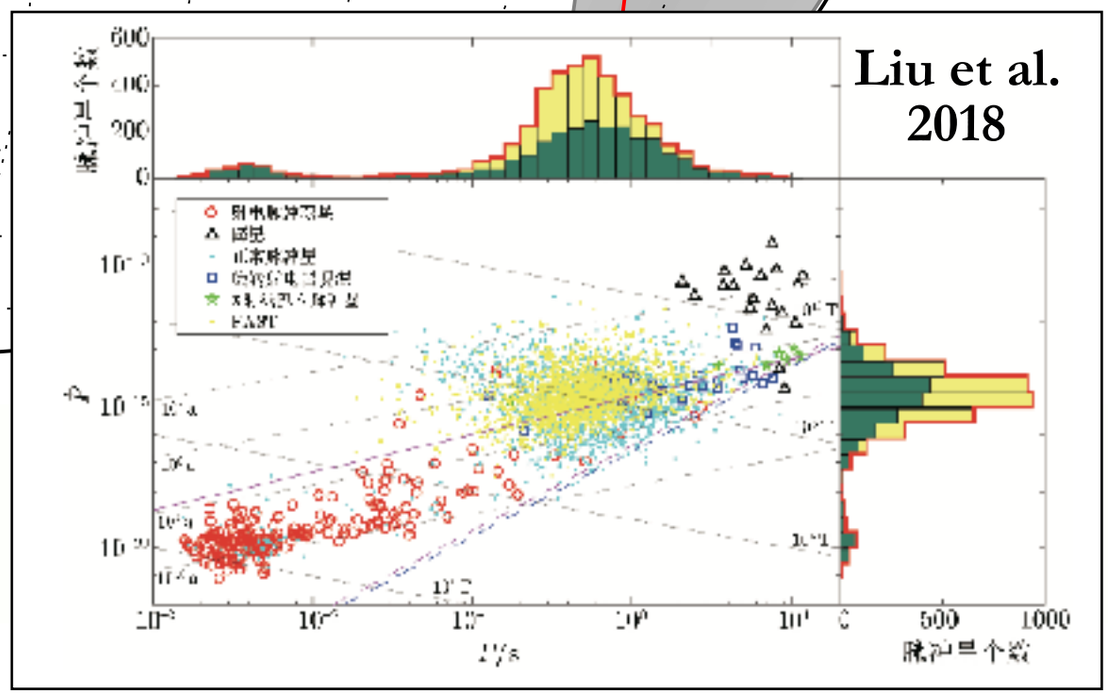


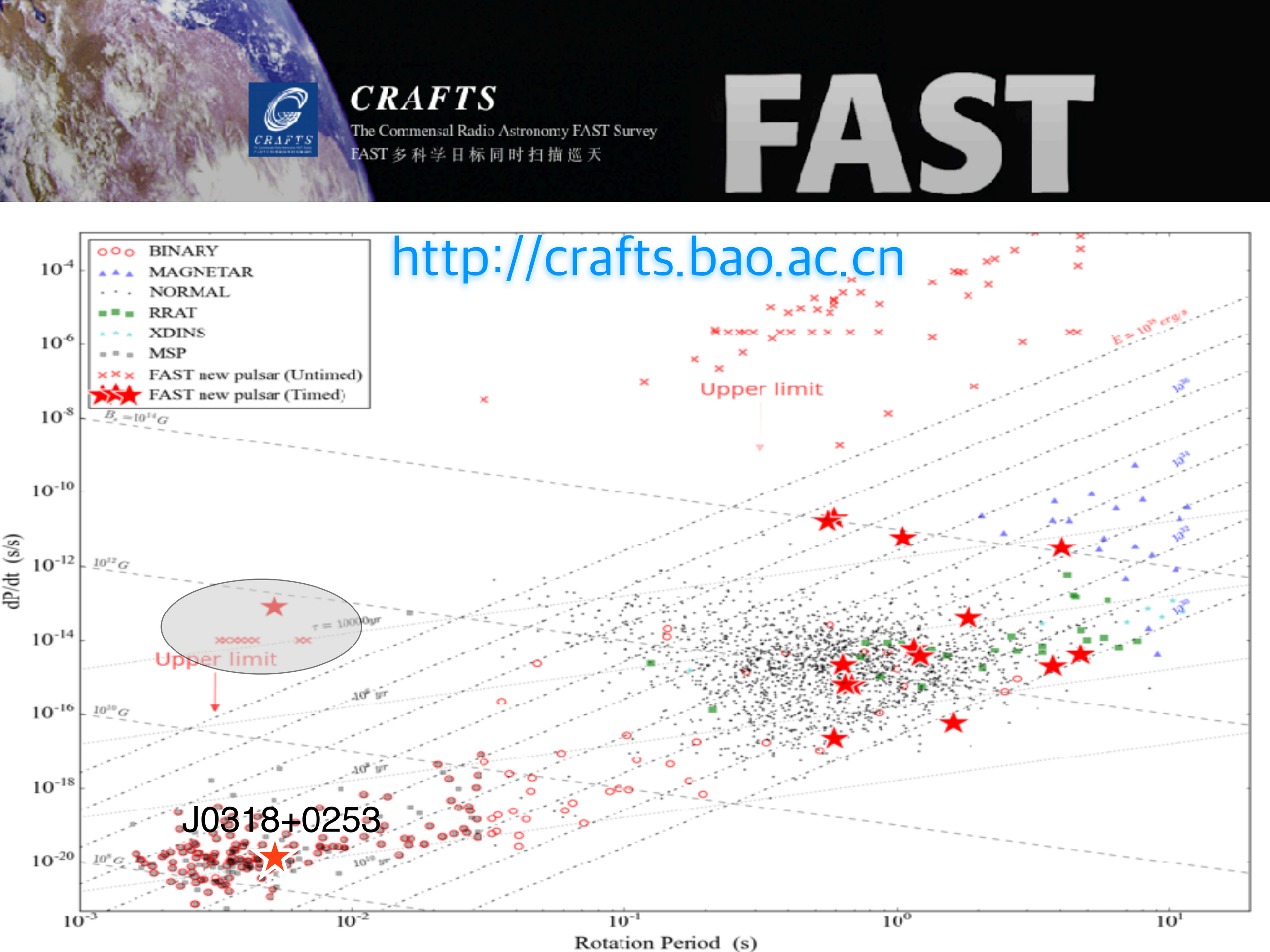
HTRU-N low-latitude

HTRU-N medium-latitude

HTRU-N high-latitude

Dai & Zhu




CRAFTS
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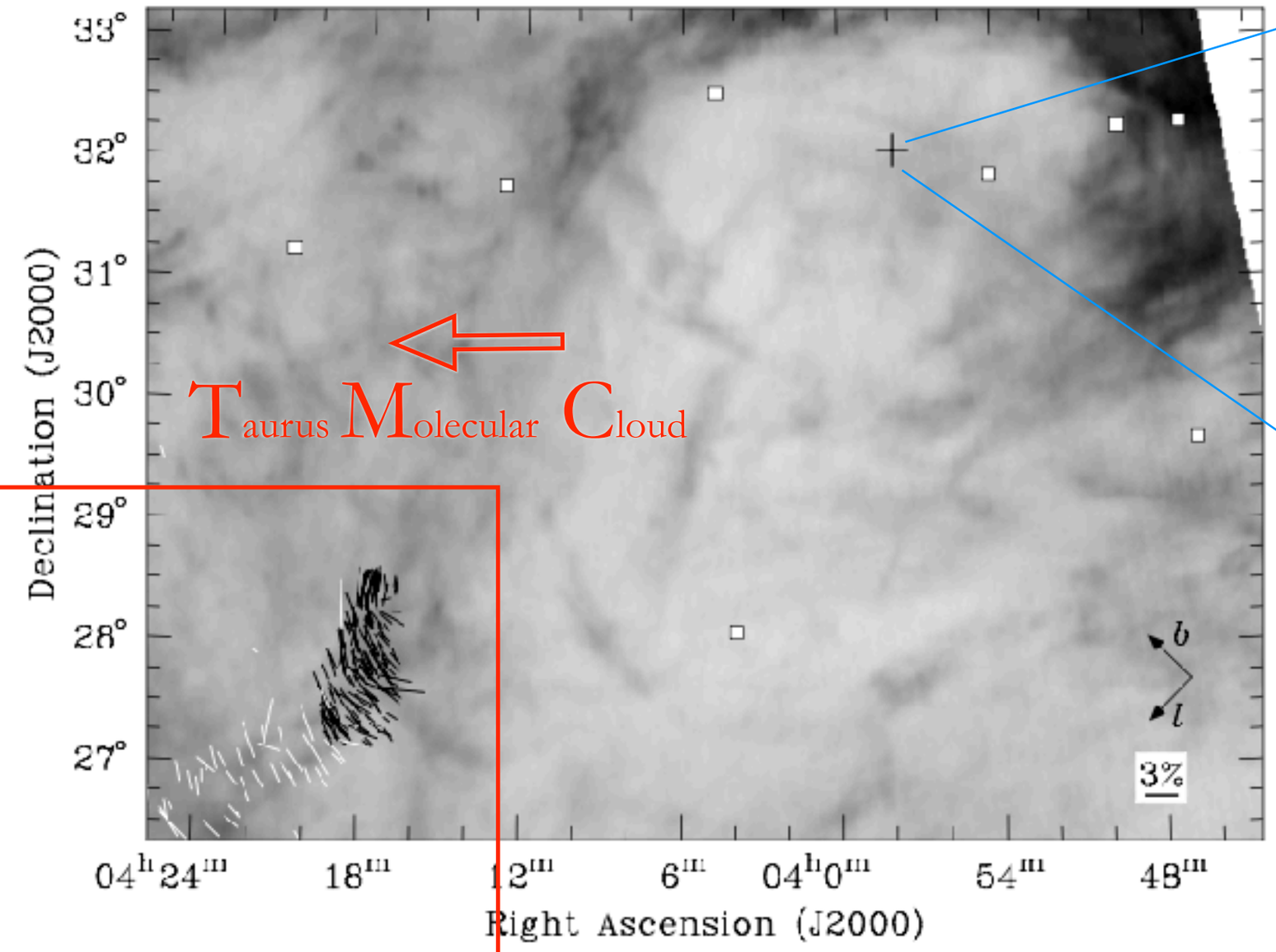
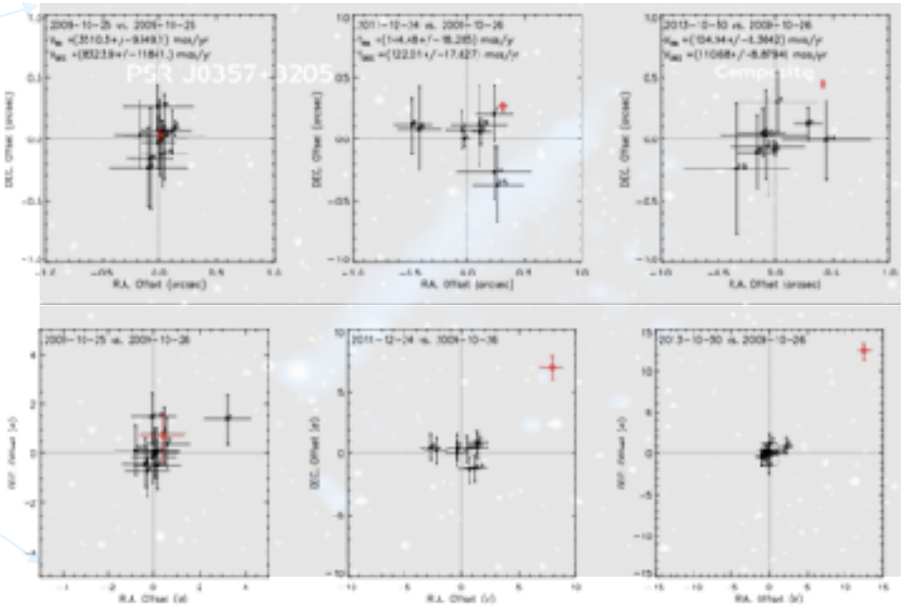
FAST 多科学目标同时扫描巡天
FAST
http://crafts.bao.ac.cn
BINARY
MAGNETAR
NORMAL
RRAT
XDINS
MSP
FAST new pulsar (Untimed)
FAST new pulsar (Timed)
Upper limit
Upper limit
J0318+0253
dP/dt (s/s)
Rotation Period (s)

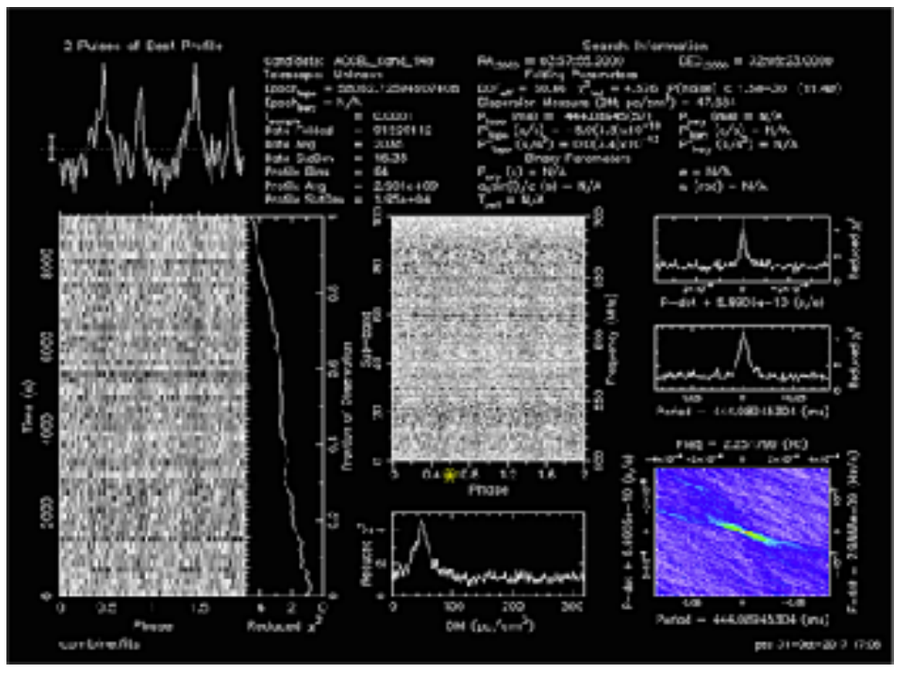
The "Taurus" Pulsar

FAST discovers radio pulses from J0357





Chandra X-ray Image
De Luca et al. 2011



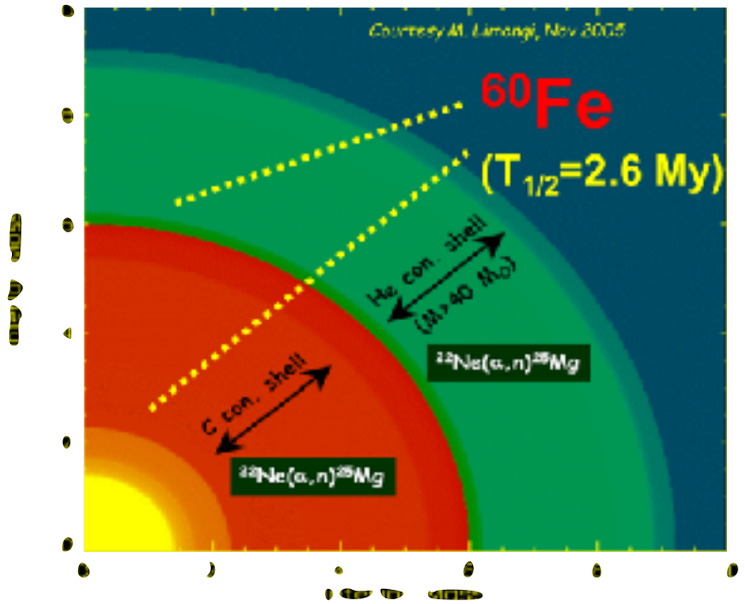
Chapman … **Li**+ et al. ApJ 2011

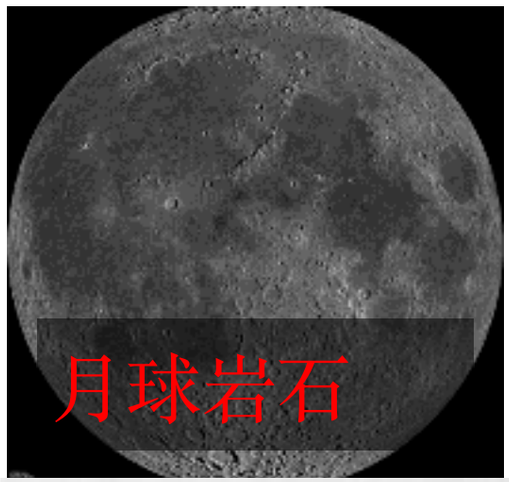
P= 0.444 s; DM=47.6

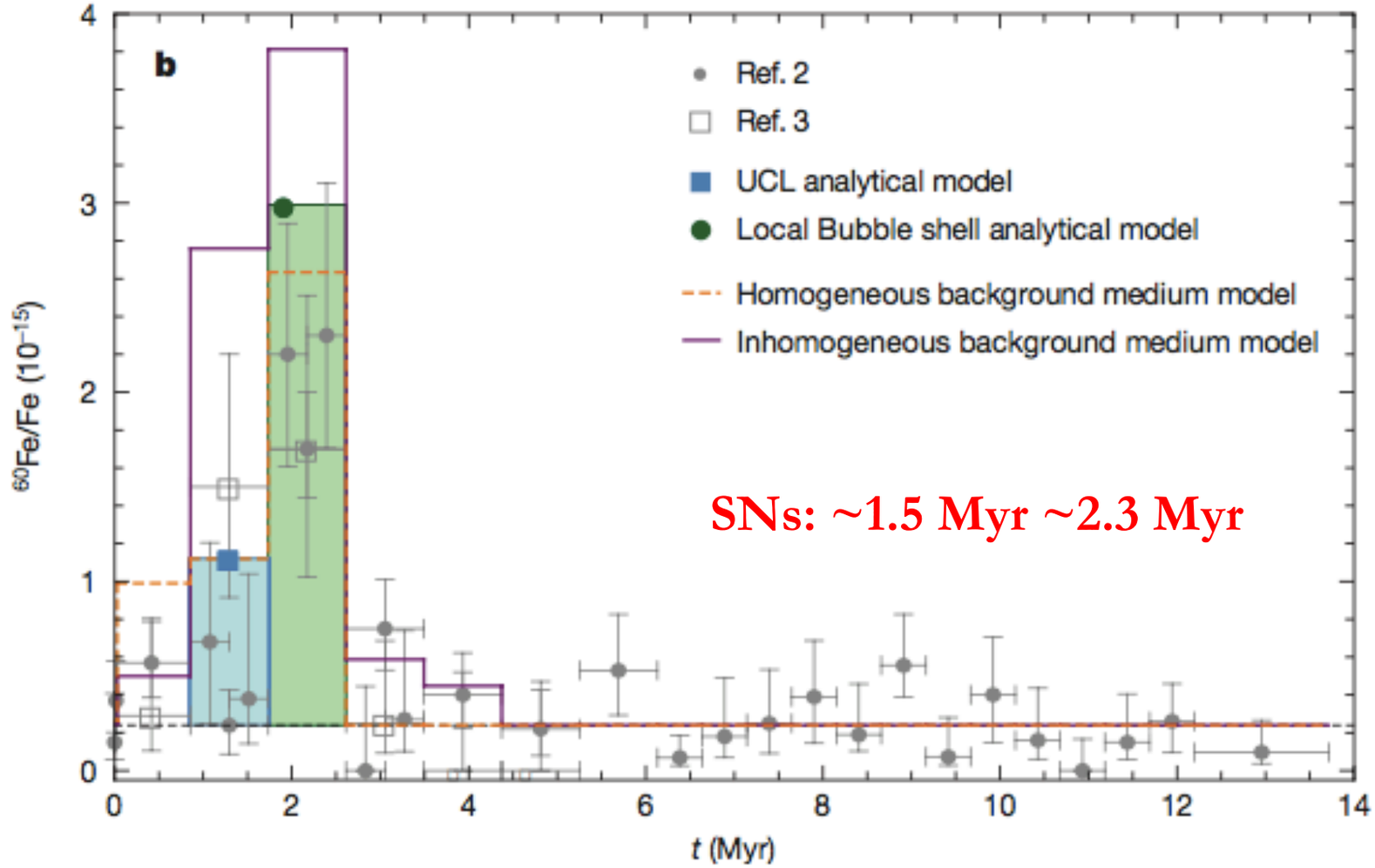
0.04 mJy ~500 MHz, 0.15mJy ~350 MHz

Li+ 2019 in prep.

The Sign of **Cosmic Explosion** on Earth ?







SNs: ~1.5 Myr ~2.3 Myr

Breitschwerdt et al. 2016 **Nature**
cf. Wallners et al. 2016 **Nature**

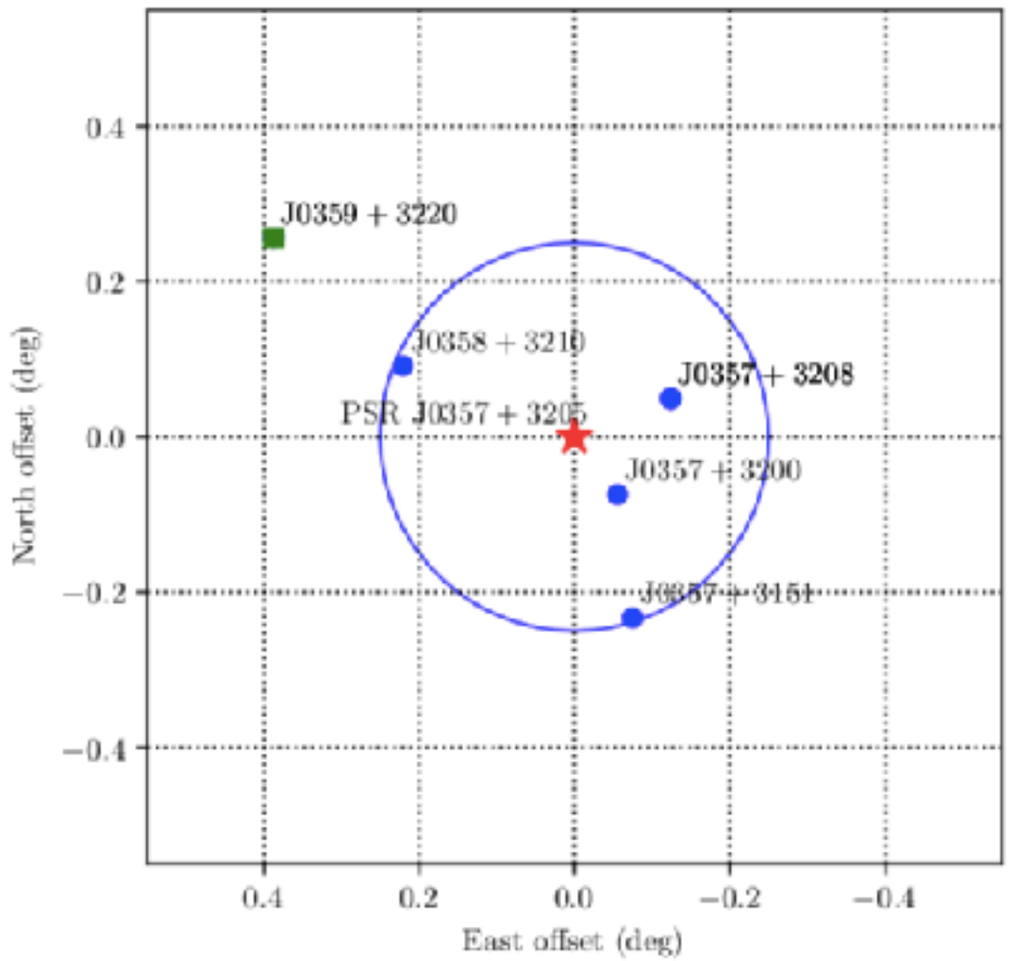
FAST discovered the first
nearby, recent supernova explosion?

Knie, K. et al. 2004, Phys. Rev. Lett.
Fimiani, L. et al. 3016, Phys. Rev. Lett.

Taurus Pulsar VLBI Obs. Strategy

Challenges in P-band VLBI astrometry:

- Very weak: 150 uJy at 327 MHz.
- Only 32 MHz bandwidth at P-band
- Very few VLBI observatories at 327 MHz.
- in-beam referencing



Known calibrators (squares) and AO in-beam calibrators (dots) around PSR J0357+3205 (star) .

Step 1: in-beam calibrator

VLBA --- waiting for correlation

Step 2: VLBI detection of target

VLBA + GBT + AO + FAST

Step 3: multi-epoch VLBI parallax measurement

VLBA + GBT + AO + FAST

FAST VLBI Challenges

- moving observatory coordinate
- ‘virtual’ phase reference point
- No down-conversion
- 38 synced digitization data stream
- reference antenna?
- A FAST ‘Core’ Array

A Lost (maybe) argument to Carl Heiles in Sydney Harbor, on April 21st, 2018

FAST VLBI System

FAST Front End

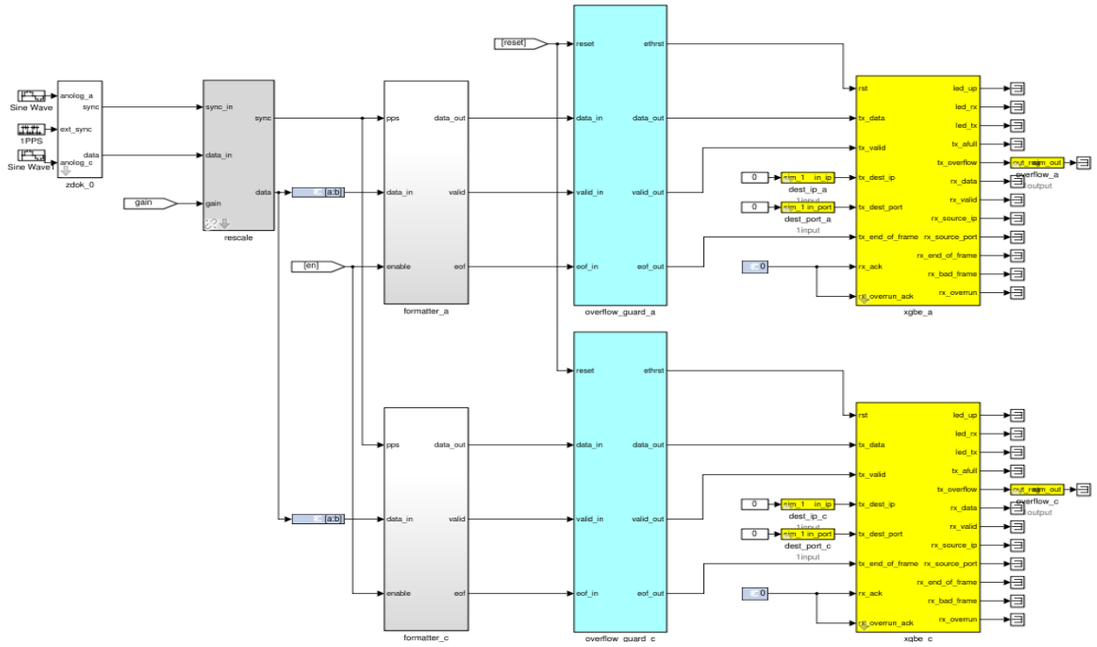
Converter

H-Maser

ADC + ROACH 2

Correlator

Mark VI



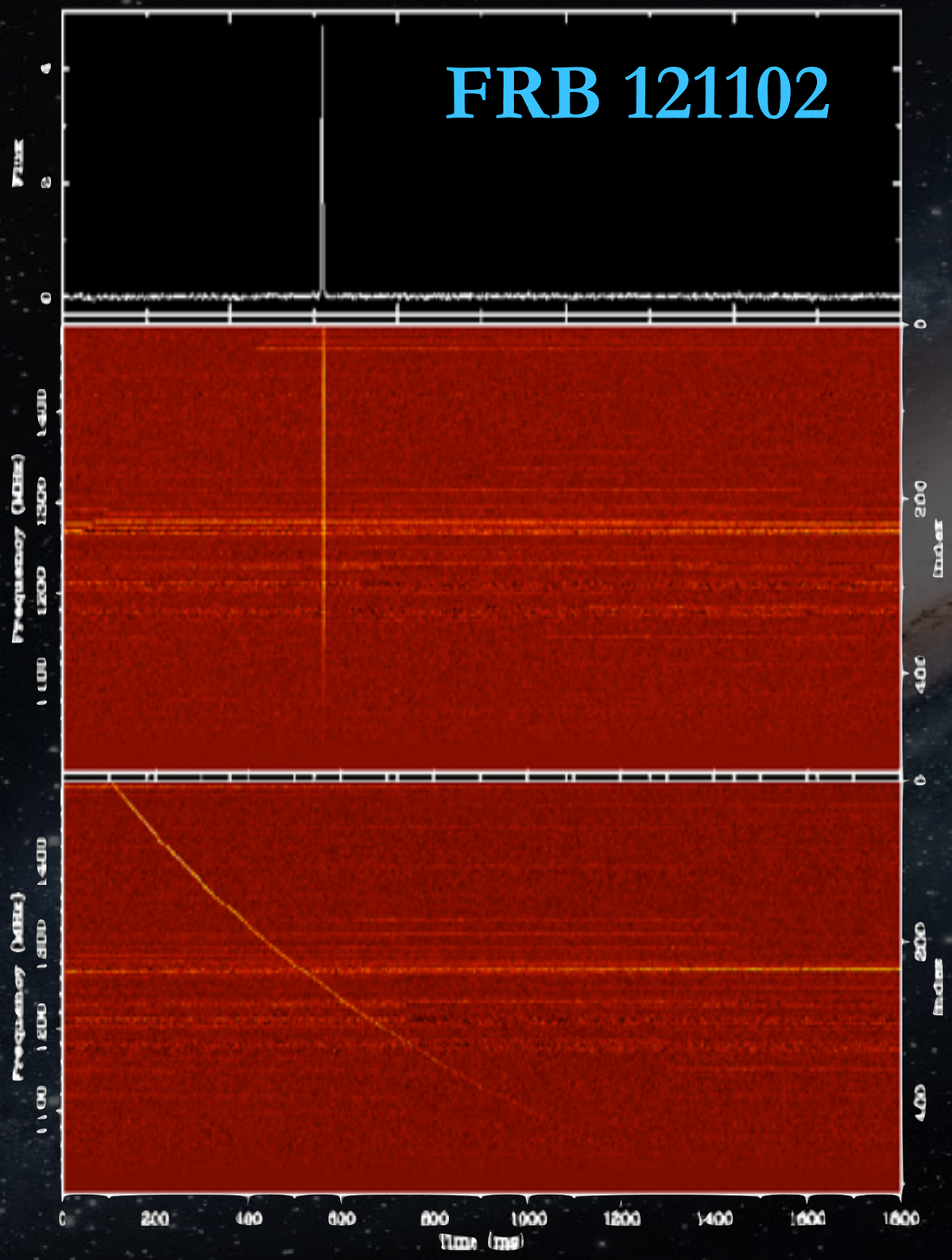
FAST (SEFD~1.4 Jy@L-band)
Recording rate 512 Mbits/s, Integration time = 60 min

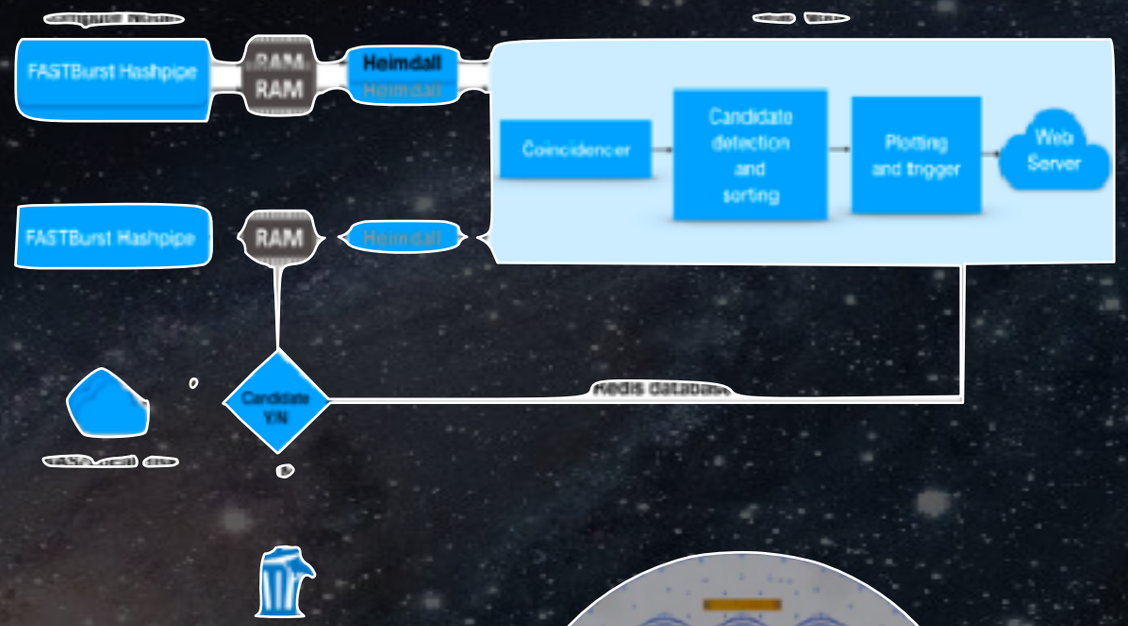
VLBI network	Image sensitivity (μJy/beam)
Full HSA (Effersberg + GBT + phased VLA + Arecibo + VLBA)	4.7
USA HSA (GBT + phased VLA + Arecibo + VLBA)	5.5
EVN (including Tianma 65 m)	16.4
EVN (including Tianma 65 m) + Arecibo	6.3
EVN (including Tianma 65 m) + FAST	4.5

FAST VLBI team (Zhang, H.Y. et al.) and Zhang, Bo 2017

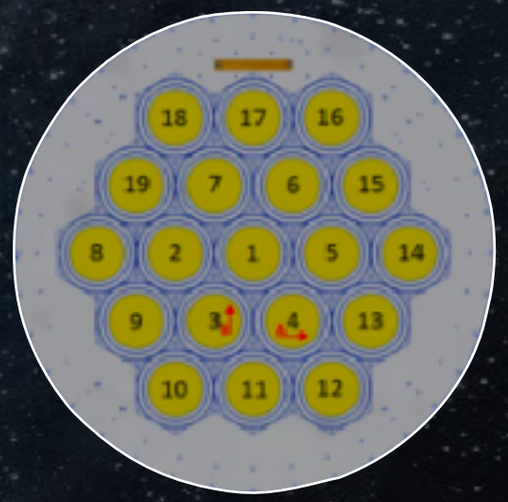
NAOC 中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES, CHINESE ACADEMY OF SCIENCES

FRB 121102





Duan et al. 2019
Zhang et al. 2018



FAST Detects Multiple Bursts in L-band from FRB 121102

ATel #13064; *Di Li (NAOC), Xinxin Zhang (NAOC), Lei Qian (NAOC), Weiwei Zhu (NAOC), Ran Duan (NAOC), Dan Werthimer (Berkeley), Vishal Gajjar (Berkeley), Yan Zhu (NAOC), Jeff Cobb (Berkeley), Youling Yue (NAOC), Chengjin Jin (NAOC), Bing Zhang (UNLV), Christian Gouiffes (CEA), Shen Wang (NAOC), Laura Spitler (MPIfR), Mary Cruces (MPIfR), Jason Hessels (University of Amsterdam), Andrew Seymour (Arecibo), Eric Korpela (Berkeley), Jingtao Luo, HengQian Gan (NAOC), Peng Jiang (NAOC), Hui Li (NAOC), Qi Li (NAOC), HongFei Liu (NAOC), Chenchen Miao (NAOC), Chenhui Niu (NAOC), GaoFeng Pan (NAOC), Zhichen Pan (NAOC), Bo Peng (NAOC), JingHai Sun (NAOC), Ningyu Tang (NAOC), QiMing Wang (NAOC), Pei Wang (NAOC), Xin Pei (XAO), Jun Yan (NAOC), Rui Yao(NAOC), DongJun Yu (NAOC), Hao Yuan (NAOC), Haiyan Zhang (NAOC), Lei Zhang (NAOC), ShuXin Zhang (NAOC), and and FAST Collaboration (NAOC)*
on 2 Sep 2019; 01:32 UT
Credential Certification: Di Li (dili@nao.cas.cn)

Subjects: Radio, Fast Radio Burst

Referred to by ATel #: 13073, 13075

Tweet

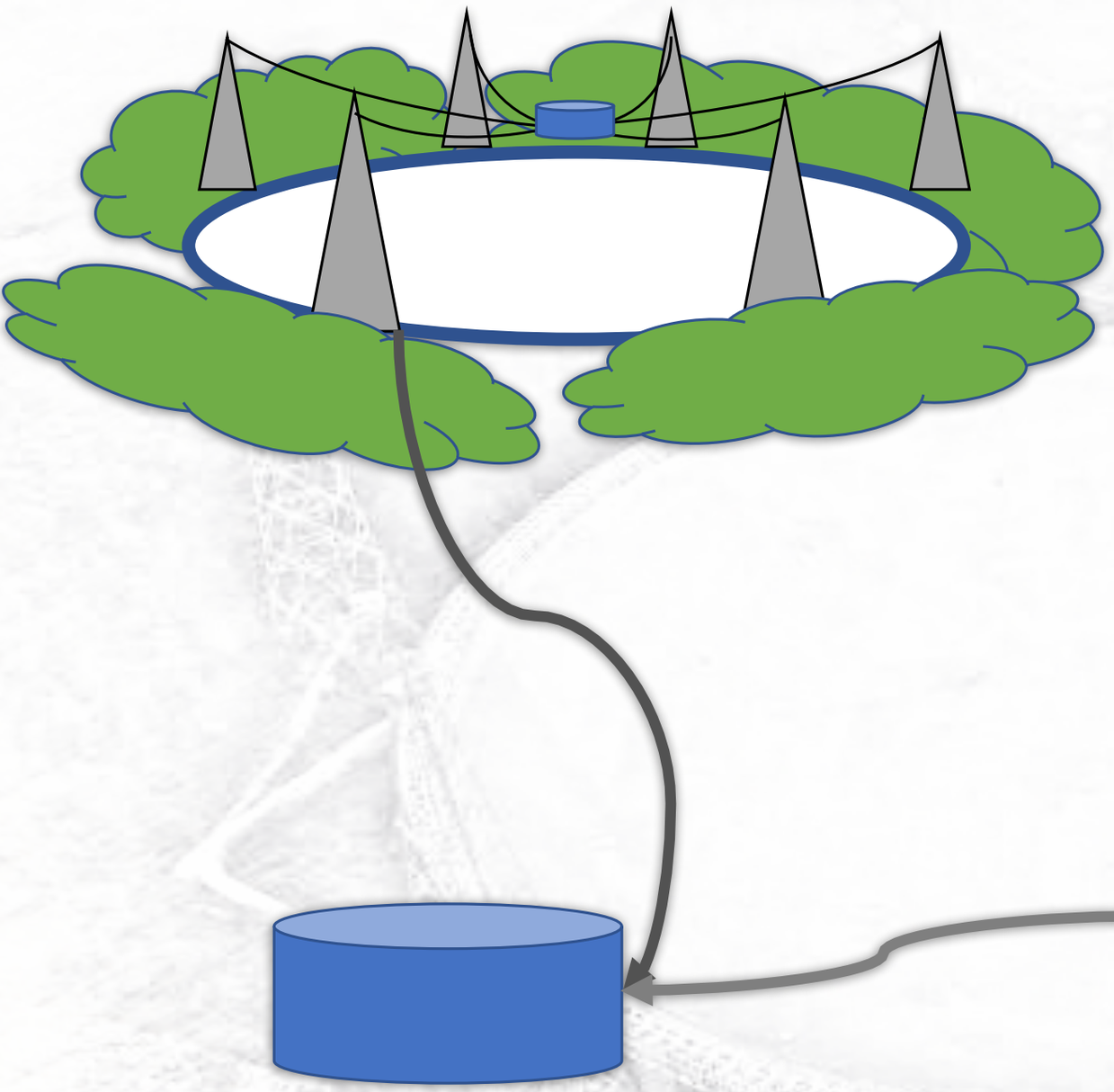
Tracking observations of FRB 121102 were carried out with the newly commissioned Five-hundred-meter Aperture Spherical radio Telescope (FAST). We used the FAST L-band Array of 19-beams (FLAN), which has a FWHM of ~2.95' for individual beams and a ~26' footprint. The source was placed in the central beam, while all 19 beams were recorded. The bursts were firstly identified by the FRB backend on August 29th (UT), whichÂ performs real time signal processing of 19-beams data and automatic candidate selection/triggering. The subsequent single pulse search using multiple pipelines have turned up many tens of pulses with significant SNR in observations carried out so far, on the 29th, 30th, and 31st (UT). While careful cross-check are being carried out, the majority of these detections are expected to be credible. FAST has been targeting FRB 121102 since April of this year. In addition to the regular on-going FRB follow-up programs, the current observations was also motivated by timely and valuable alerts from our colleagues in the INTEGRAL team, Arecibo team, Max-Plank Institute for Radio Astronomy, Berkeley, and Cornell University. Given the significance of this source and its now apparent active state, FAST is executing more observations under the auspice of engineering testing time and multiple approved PI-led programs, which targeted FRB 121102. We encourage more ToO observations with other facilities.

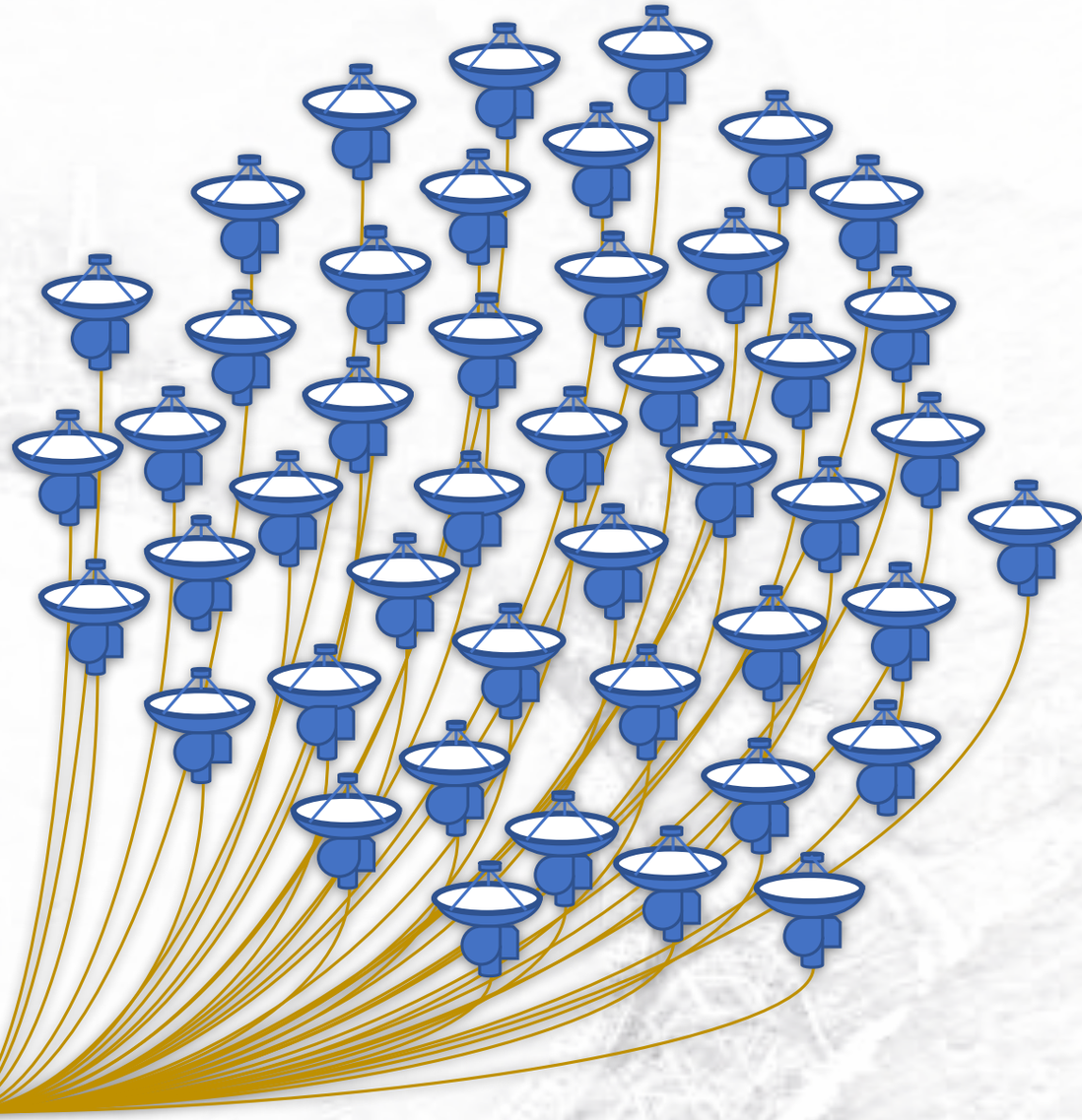
FAST pulsar survey results

Astronomer's Telegram

Hundreds of pulses from FRB121102, more than all previous detections combined.

- **Periodicity** search
- **logN-LogS**
- Polarization: **RM**
- **DM** variation
- HI **absorption**





FAST - Aplus 核心融合陣

FAST A+ vs DSA

FAST扩展阵与DSA主要指标对比

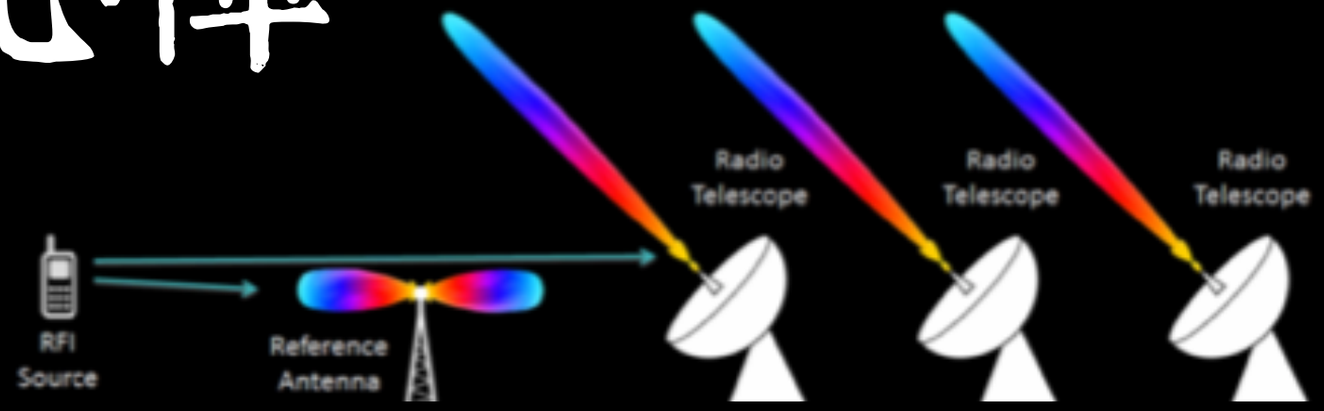
	FAST (19 beam)	36xAT5	FAST+ 36xAT5	DSA 10	DSA 110
Aperture	70,686	707	71,393	159	1949
Tsys (1.4GHz)	20K	30K	30K	60K	30K
Gain (A/T, m^2/K)	2600	15	2615	1.7	42
Long baseline (m)	300	30,000	30,000	1,183	>21,318
$\Delta\Theta$ (1.4GHz)	3’	1.8”	1.8”	45”	<2.5”
FoV (1.4GHz, d^2)	0.1	10	10	11	12

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 5%的预算

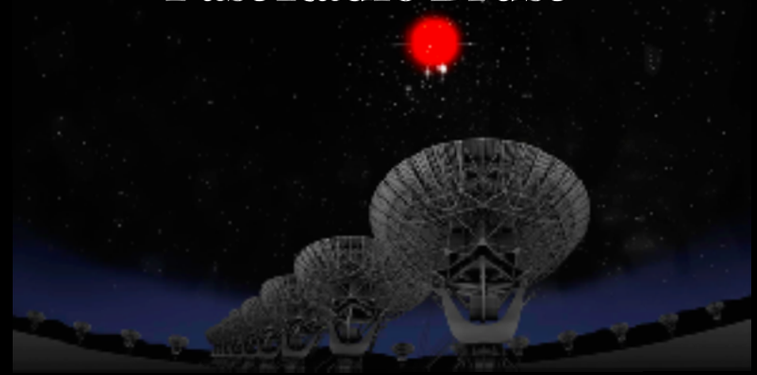
提升FAST关键性能 x10-100

* 空間分辨率 ～1”
* 点源探测灵敏度 ～0.01 mJy

- **Exoplanet + Brown dwarf**

- **Tidal Disruption Event**

- **Fast Radio Brust**



Commensal Radio Astronomy FAST Survey

57% (2.3PI) Sky; drift scan; galaxies, imaging, pulsars

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

&

GAS

Galactic-plane and Andromeda Survey

M31+Galactic plane; 1h; $5x10^{16}$ cm^{-2} +1000 msp

HI, HI+OH Absorption, Pulsar DM, PTA(GW)

=> **A FAST View of Baryons**