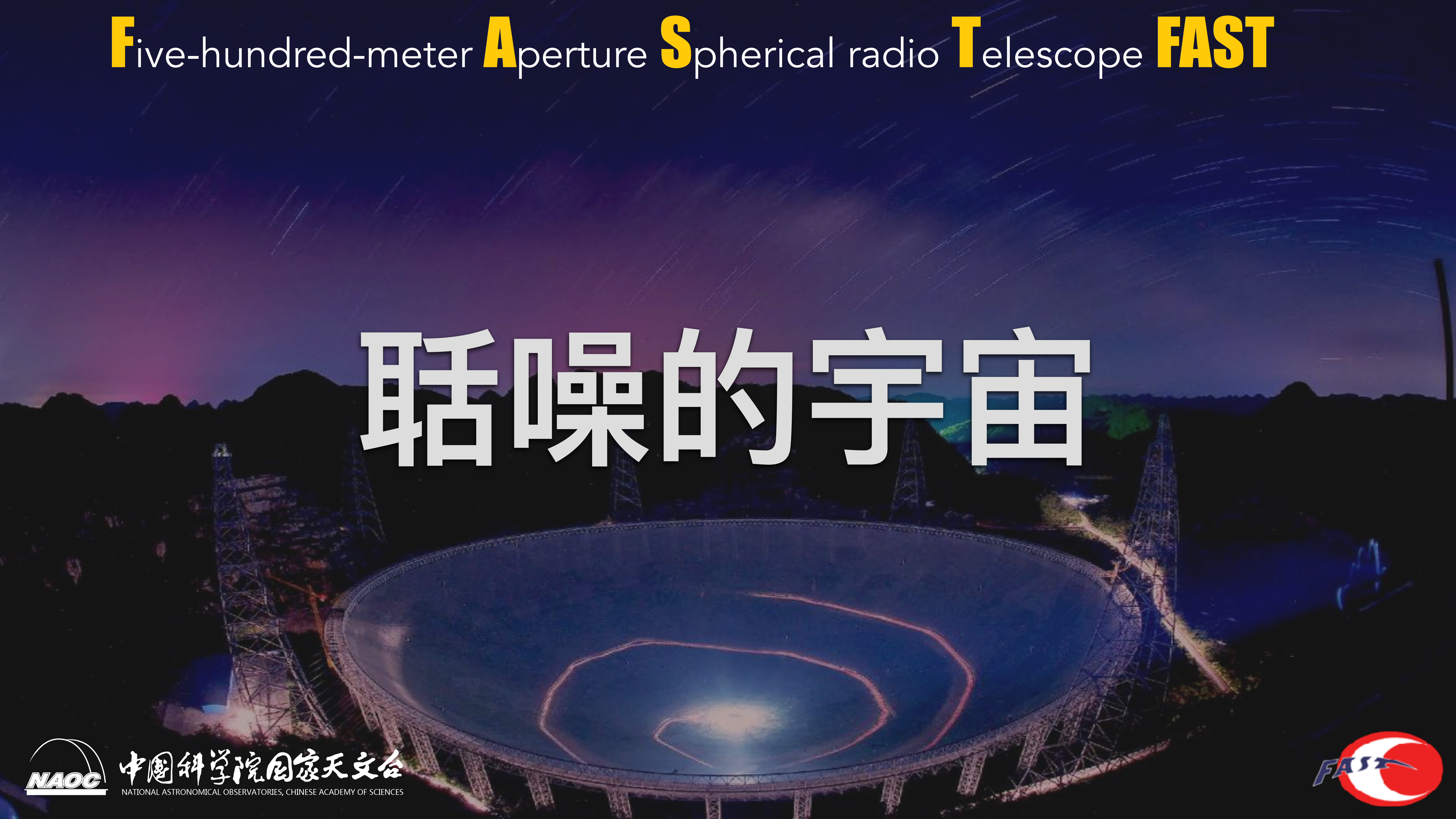

Five-hundred-meter Aperture Spherical radio Telescope FAST
聒噪的宇宙
NAOC
中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES, CHINESE ACADEMY OF SCIENCES
FAST

Immanuel Kant （1724–1804）

《The Critique of Pure Reason》

Preface

Human reason, in one sphere of its cognition, is called upon to consider questions, which it cannot decline, as they are presented by its own nature;

but which it cannot answer, as they transcend every faculty of the mind.

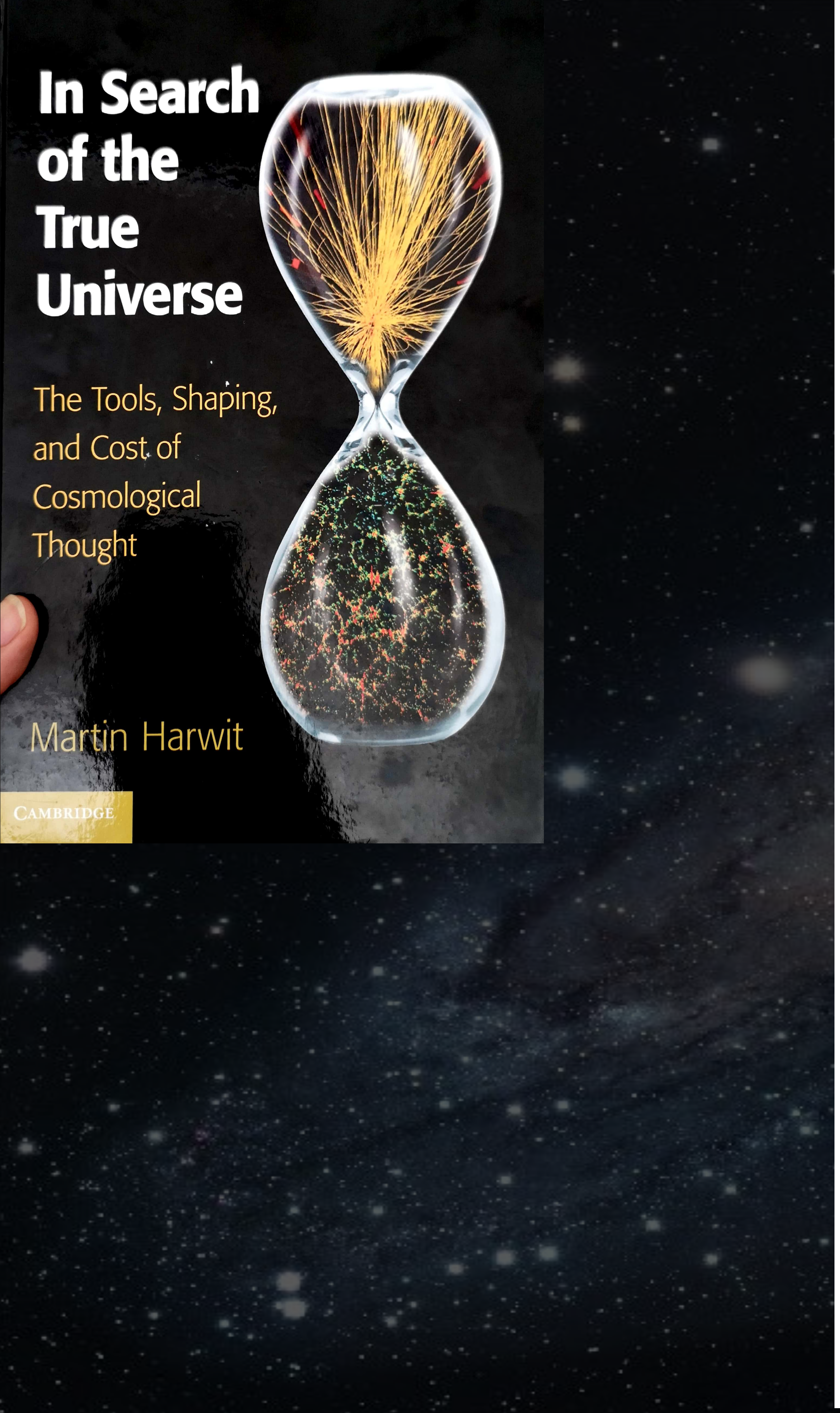
Looking Back

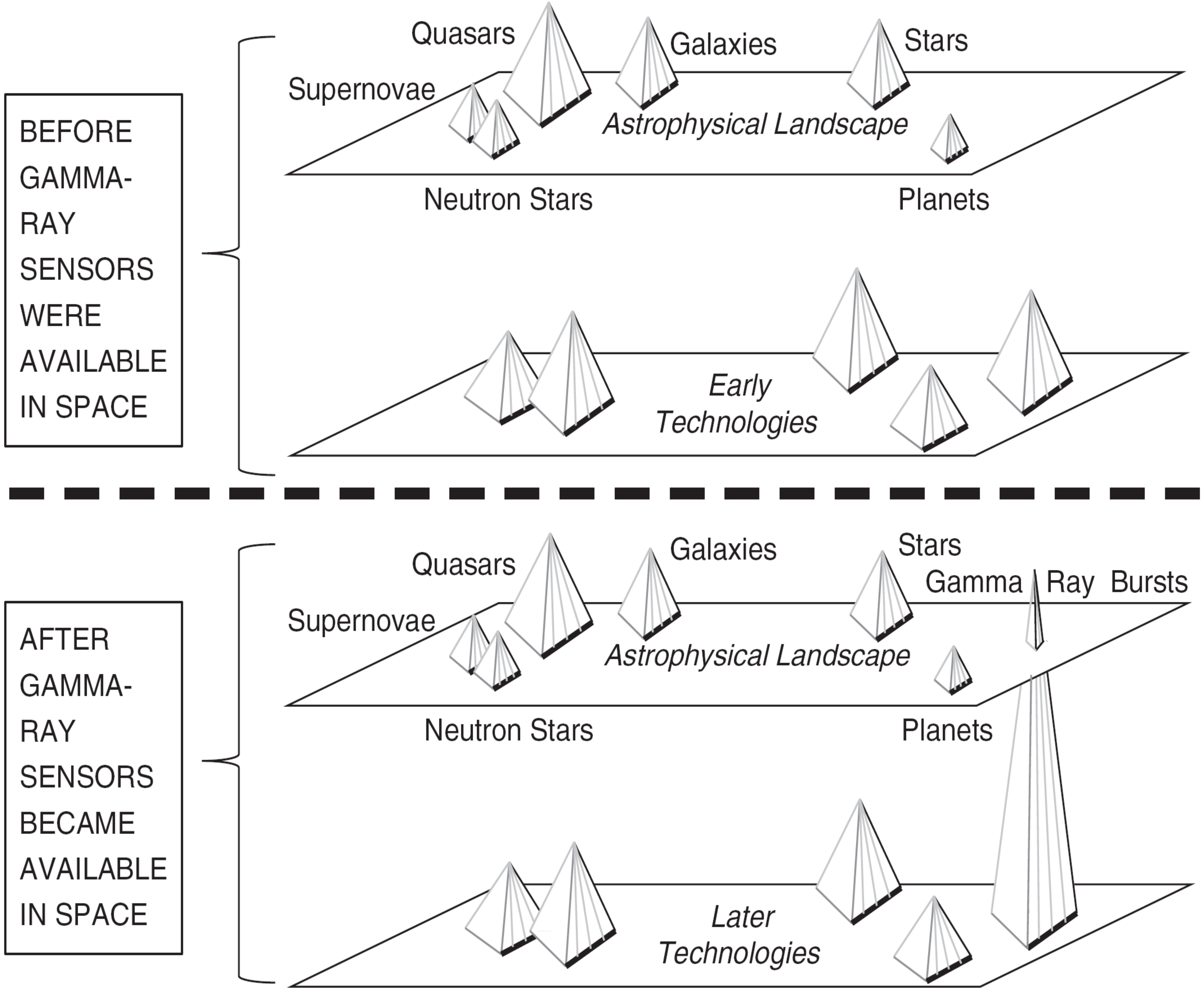
Between the end of World War II and the early 1970s, astronomy was enriched through the discovery of some 14 new and unanticipated major phenomena listed below. Only two of the discoveries resulted from observations in the optical regime. Both could well have been made with instrumentation available before World War II, or with marginally improved techniques. These two involved:

Magnetic Variable stars, 1947, and
Flare stars, 1949

But twelve other major discoveries became possible only through the use of techniques and instrumentation initially designed for military purposes during World War II or the Cold War. This list of discoveries included:

Radio galaxies, 1946–54
X-ray stars, 1962
Quasars, 1963
The Cosmic microwave background, 1965
Infrared stars, 1965
X-ray galaxies, 1966
Cosmic masers, 1967
Pulsars, 1967
Superluminal radio sources, 1971
Infrared galaxies, 1970–72
Interstellar magnetic fields, 1972
Gamma-ray bursts, 1973


In Search of the True Universe
The Tools, Shaping, and Cost of Cosmological Thought
Martin Harwit
CAMBRIDGE

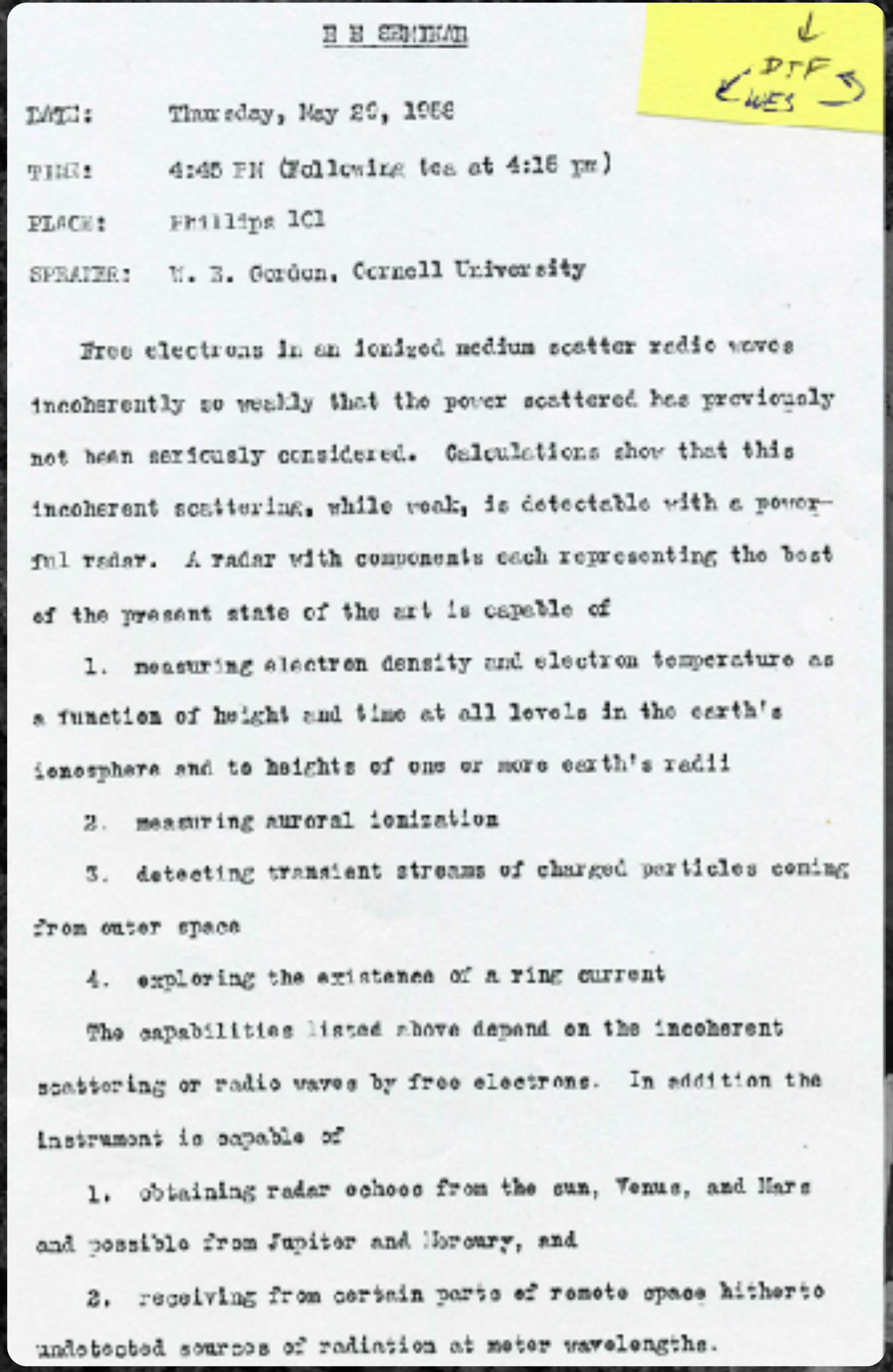

BEFORE GAMMA-RAY SENSORS WERE AVAILABLE IN SPACE
Quasars
Galaxies
Stars
Supernovae
Astrophysical Landscape
Neutron Stars
Planets
Early Technologies
AFTER GAMMA-RAY SENSORS BECAME AVAILABLE IN SPACE
Quasars
Galaxies
Stars
Gamma Ray Bursts
Supernovae
Astrophysical Landscape
Neutron Stars
Planets
Later Technologies


FAST
Guizhou, China


Arecibo
Puerto Rico

1958

美丽的“错误”



E E SEMINAR

DTF
WES

DATE: Thursday, May 29, 1958

TIME: 4:45 PM (Following tea at 4:15 pm)

PLACE: Phillips 101

SPEAKER: W. E. Gordon, Cornell University

Free electrons in an ionized medium scatter radio waves incoherently so weakly that the power scattered has previously not been seriously considered. Calculations show that this incoherent scattering, while weak, is detectable with a powerful radar. A radar with components each representing the best of the present state of the art is capable of

1. measuring electron density and electron temperature as a function of height and time at all levels in the earth's ionosphere and to heights of one or more earth's radii
2. measuring auroral ionization
3. detecting transient streams of charged particles coming from outer space
4. exploring the existence of a ring current

The capabilities listed above depend on the incoherent scattering or radio waves by free electrons. In addition the instrument is capable of

1. obtaining radar echoes from the sun, Venus, and Mars and possible from Jupiter and Mercury, and
2. receiving from certain parts of remote space hitherto undetected sources of radiation at meter wavelengths.

报告人： William E. Gordon

地点： 康奈尔大学电子工程系

时间： May 29, **1958**

Scatter from individual electrons

=> Echo bandwidth of 100s of kHz=》 需要**数百米级天线**！

Ken Bowles （美国国家标准局）

– bandwidth reflected ion velocities not electron velocities.

Gordon： 1958 URSI meeting

公布了修正的结果**只需几十米天线**。但是康奈尔大学和

ARPA–(**A**dvanced **R**esearch **P**rojects **A**gency)

依然决定资助**超大型**望远镜！

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

1957-1958

大国博弈

1957.12.16

美国海军
首次卫星实验

JPL

Jet Propulsion Laboratory

California Institute of Technology

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

“和平”的太空竞赛 1946-1958

“This is the President of the United States speaking. Through the marvels of scientific advance, my voice is coming to you from a satellite circling in outer space. My message is a simple one. Though this unique means, I convey to you and all mankind, America’s wish for peace on earth and good will to men everywhere.”

National Aeronautics and Space Agency

July, 1958; 美国政府通过建立“航空航天局”

航天计划从**ARPA**转向**NASA**

- Internal conflicts of capitalism inevitably generate wars.
- Much depends on health and vigor of our own society.

（赢得冷战）我们必须规划和展现一个远比过去更为正面的和有建设性的世界蓝图。。。

乔治-凯南"长电报"-1946

“Long Telegram” 1946

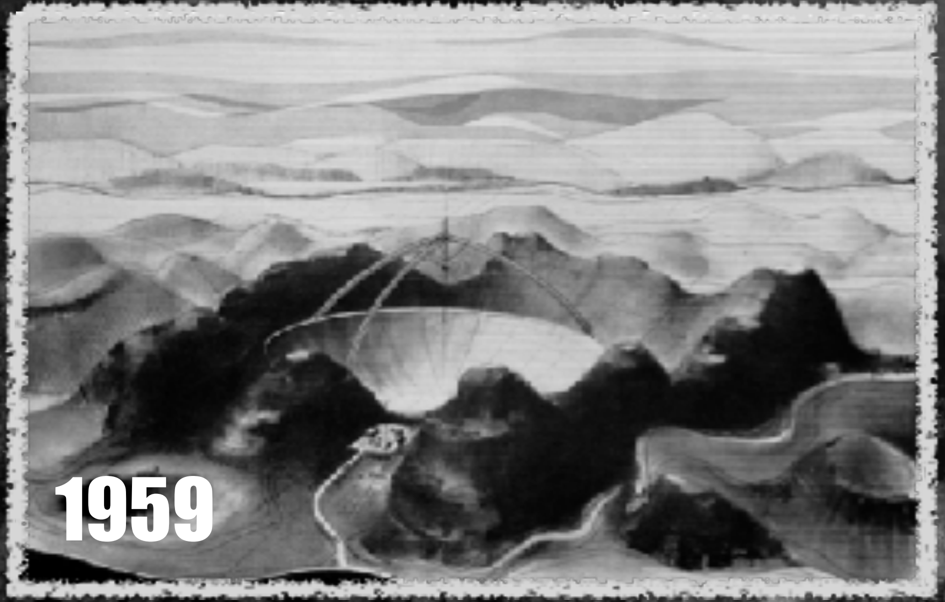
Arecibo: 巨人的梦想

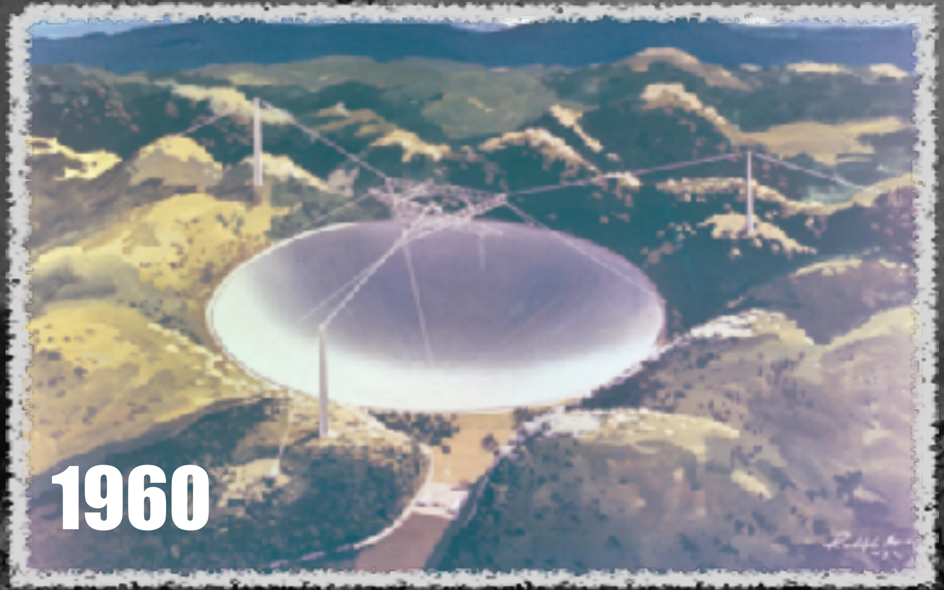
1963

Cornell faculty, William Gordon, proposed the project around 1958 to

ARPA–(Advanced Research Projects Agency)

- **Construction between 1960-1963**
- **Total cost: $9.3M**





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

发现 • 双中子星

1973-1993

阿雷西博望远镜里程碑

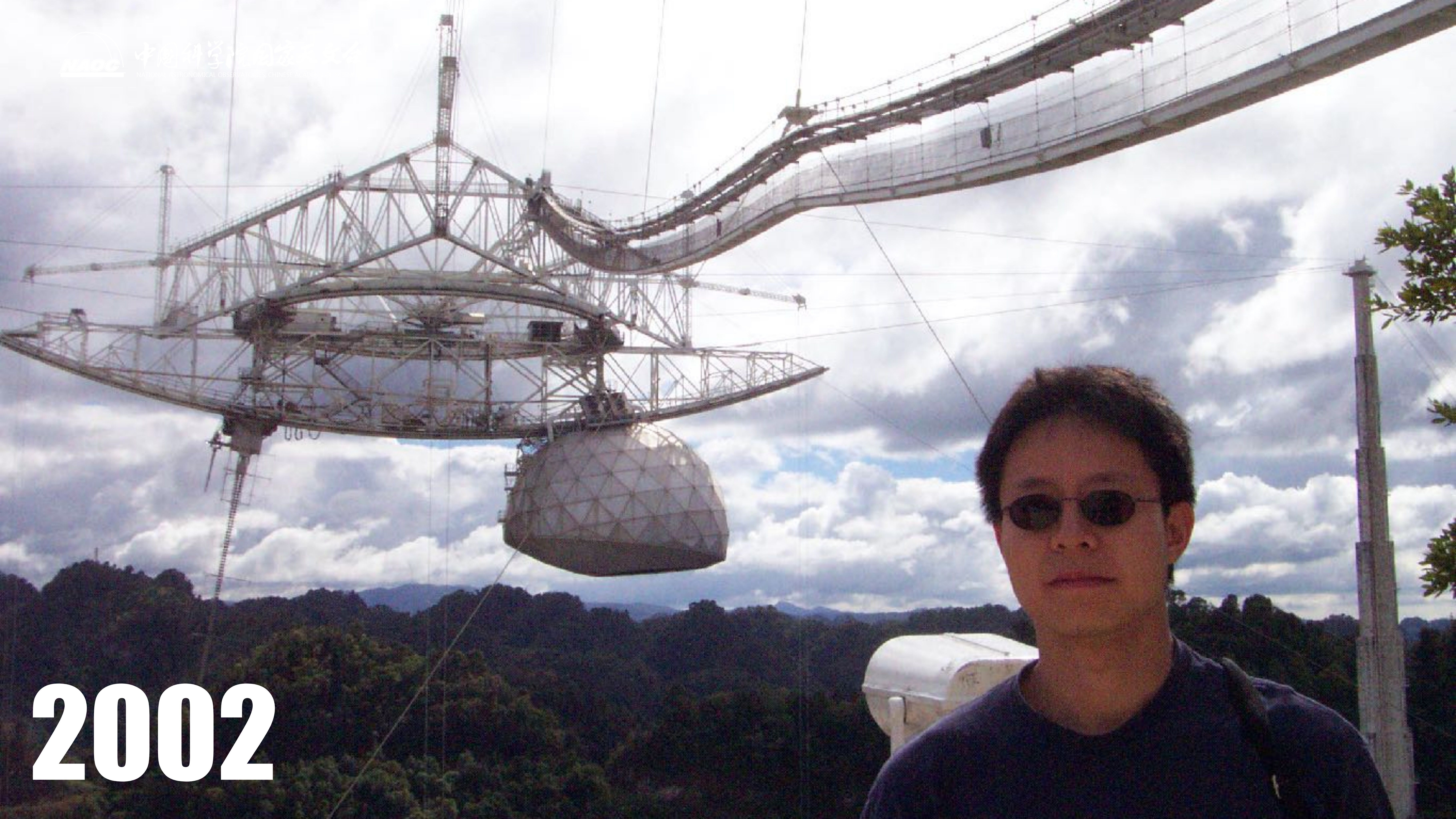
"We find that Einstein's theory passes this extraordinarily stringent test with a fractional accuracy better than 0.4%."

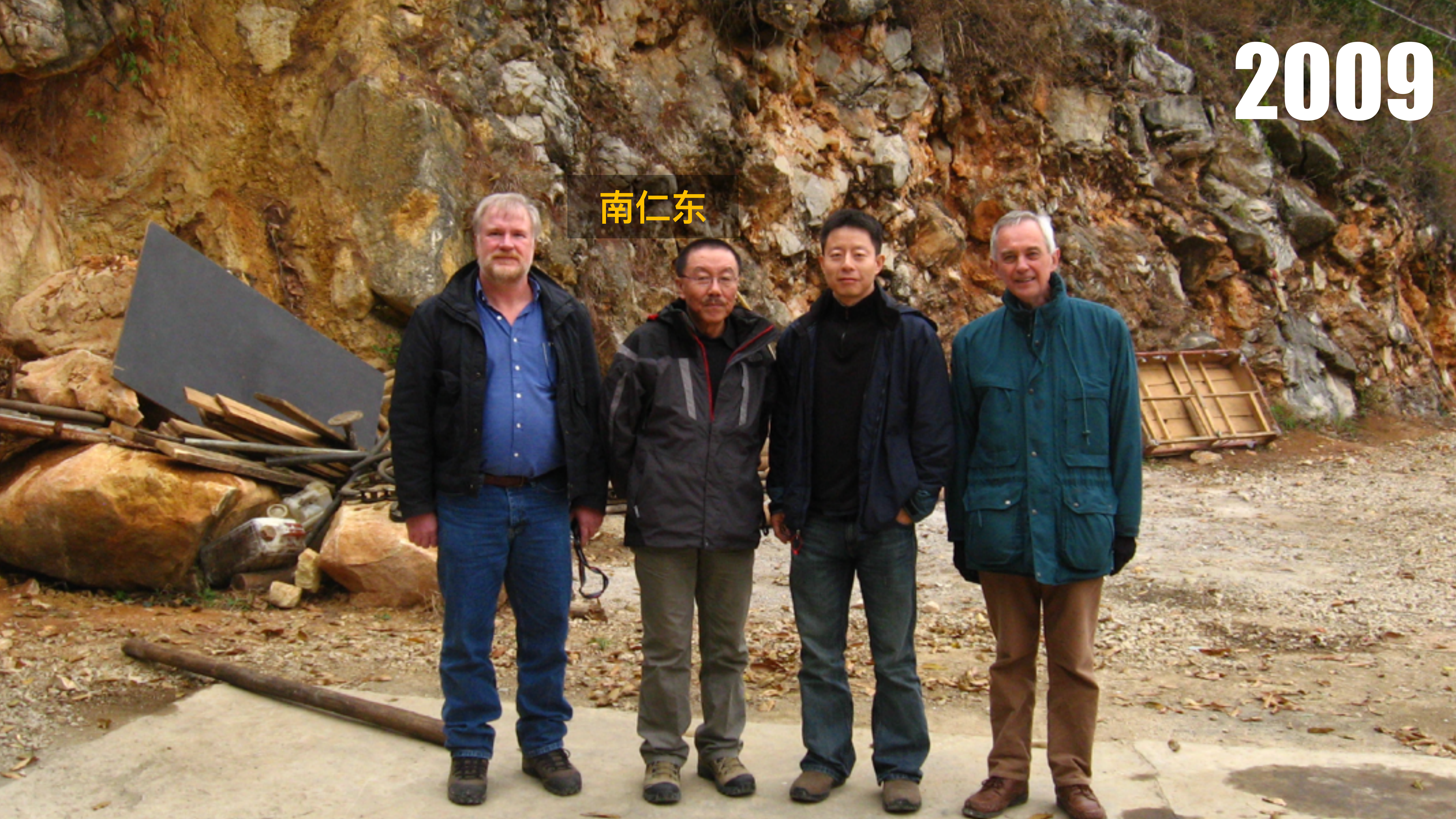
"It necessarily follows that gravitational radiation exists and has a quadrupolar nature."

Gravitational Wave Exists!

——Nobel speech by J.Taylor (1993)

1996


2002


2009
南仁东

2012

2012年2月14日

“射电天文前沿及FAST早期科学”973项目启动会

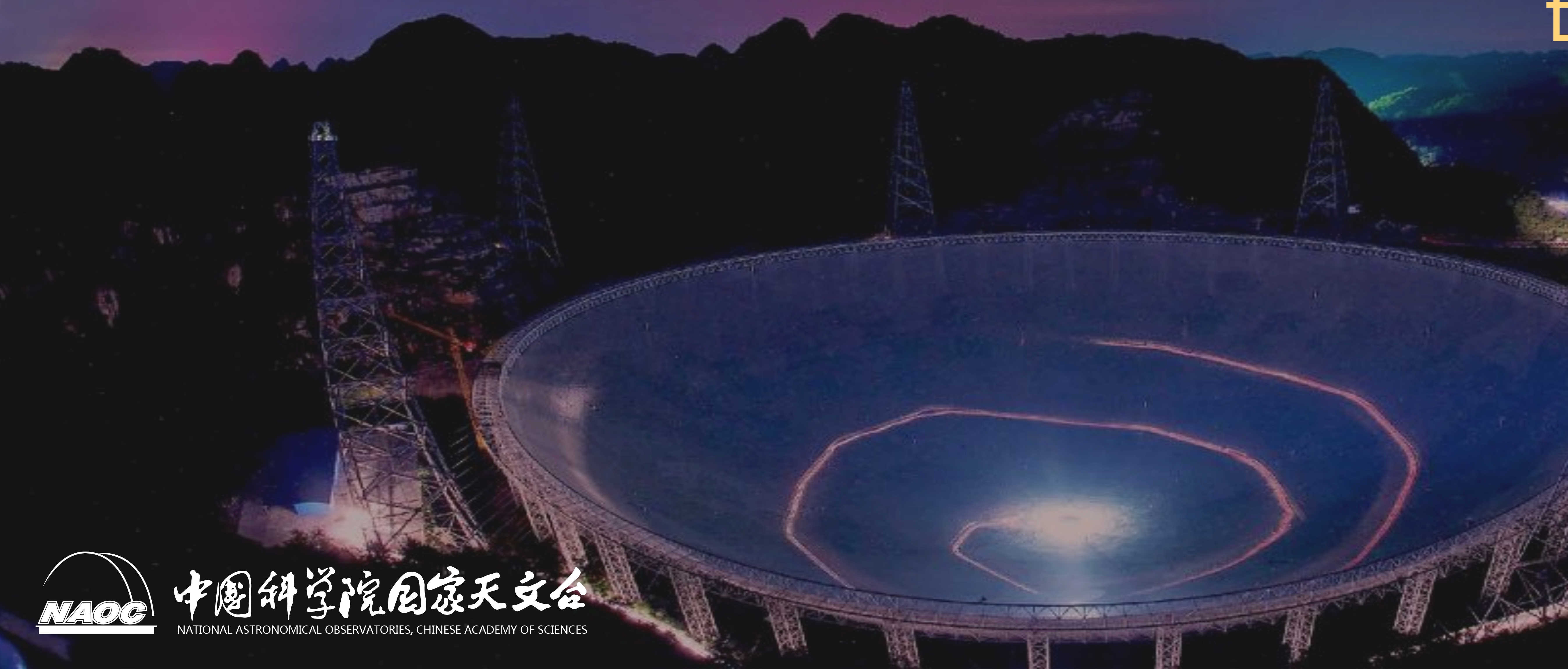

2011

2015-2016

first light

2016.9.19

Five-hundred-meter Aperture Spherical radio Telescope
FAST



世界最大射电望远镜

工期5年半，造价11.5亿

(Nan et al. 2011; Li et al. 2018)

- 4500 主动反射面
- 30 吨悬吊精控馈源仓
- 6 座高超百米支撑塔
- 数10万根光纤

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

Observables

a) HI 21cm (imaging & galaxies)

b) Pulsars (FRBs)

c) Molecular Spectroscopy

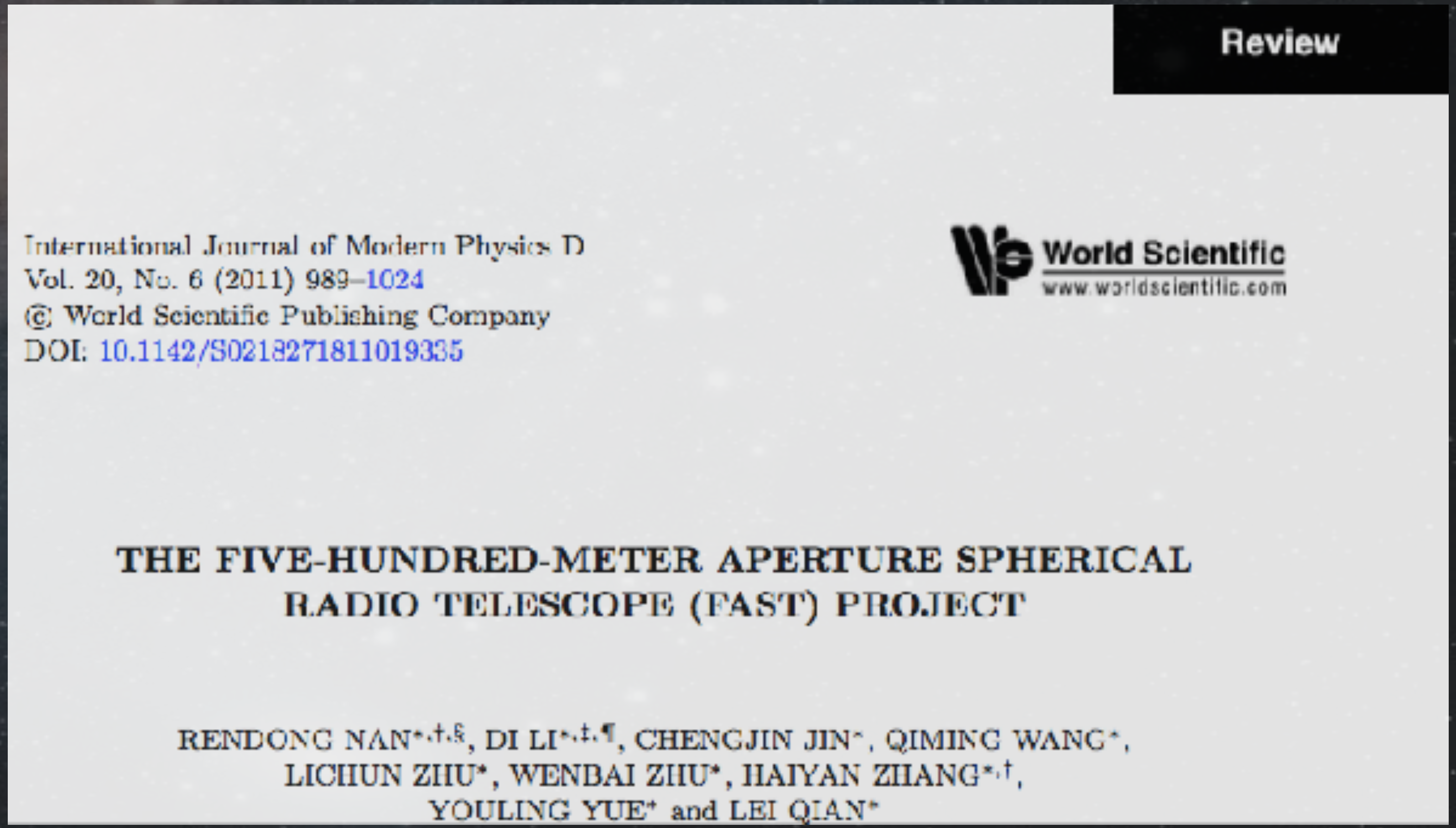
d) VLBI

e) SETI

NO large-scale survey has simultaneously observed HI and pulsar. Why?

continuous coverage

70 MHz～3 GHz


Review

International Journal of Modern Physics D
Vol. 20, No. 6 (2011) 989–1024
© World Scientific Publishing Company
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
(>500 google scholar citations)

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

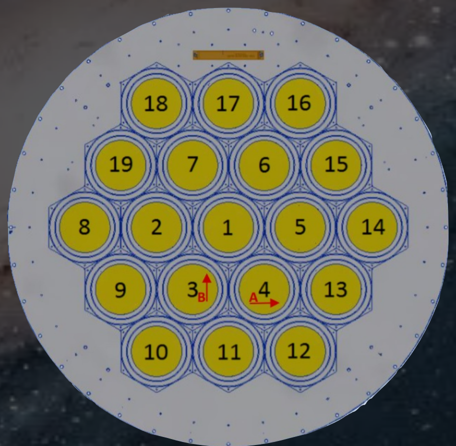
Commensal Radio Astronomy FAST Survey

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

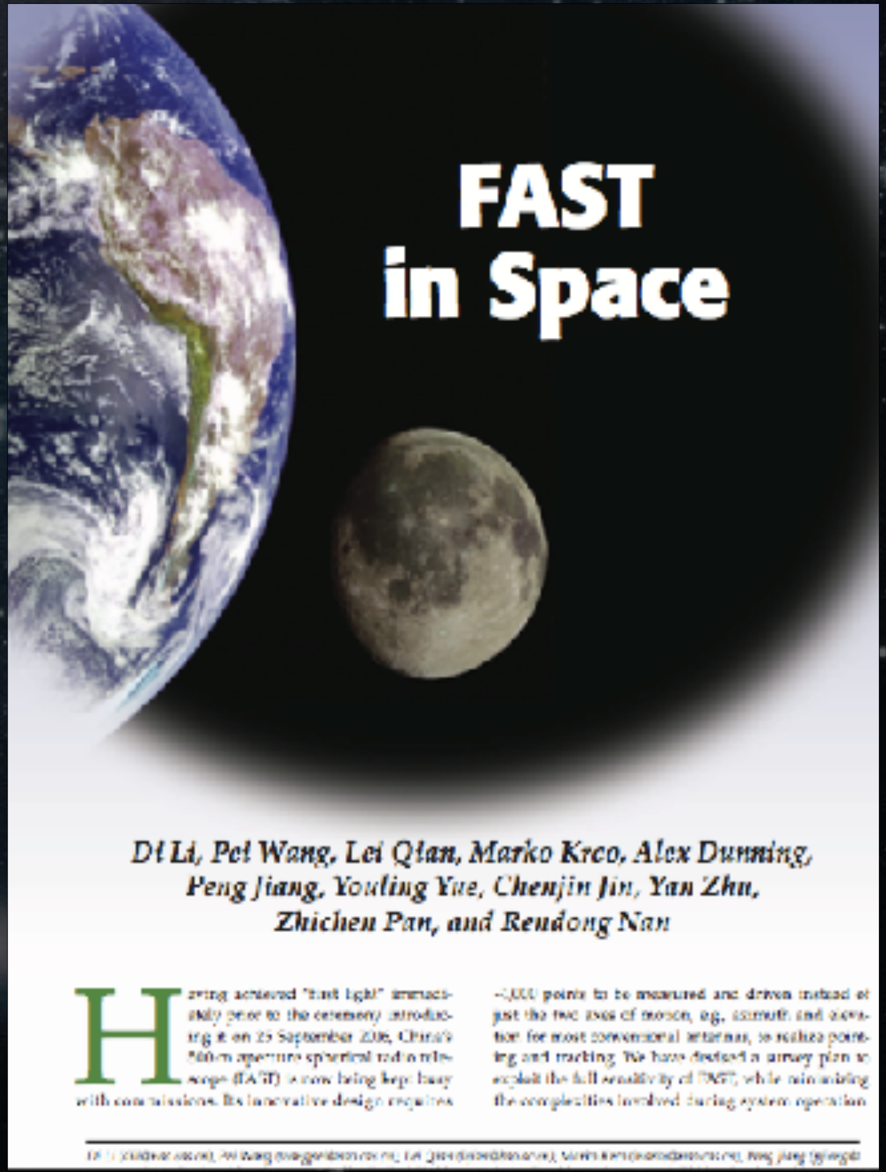
unprecedented commensality
pulsar, galaxy, imaging, and FRB

利用高时频噪声注入**自主专利**技术，**世界首创**了脉冲星搜索、中性氢成像、星系搜索和快速射电暴同时观测巡天。

FAST 'big data' stream
pulsar: 19 x 8bit x 4 x 4k x 2×10^4 per second
HI: 19 x 8bit x 4 x 1M x 2 /s

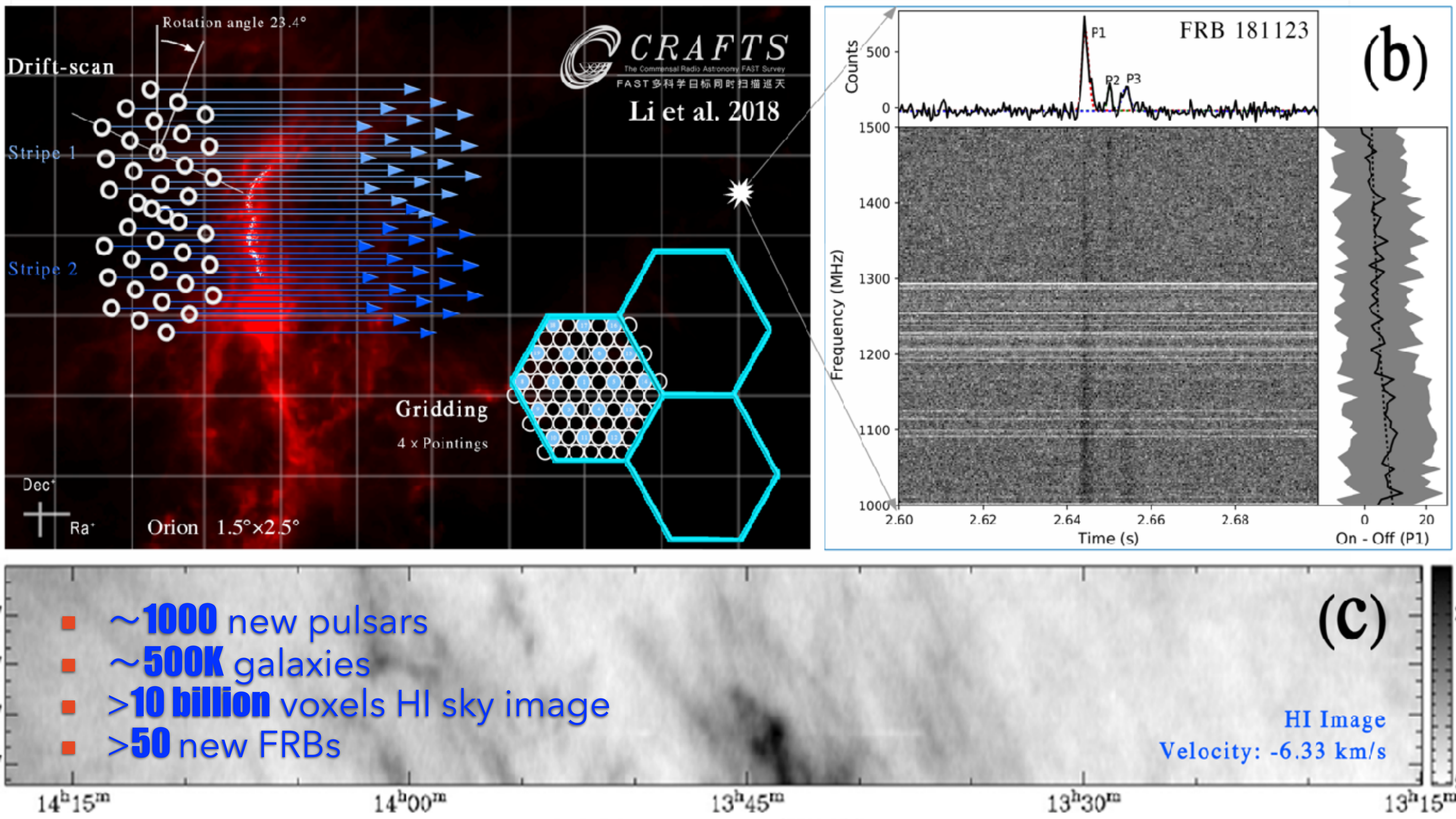


- 6 GB/s
- 25TB/h
- 550TB/day
- 10 PB/ year

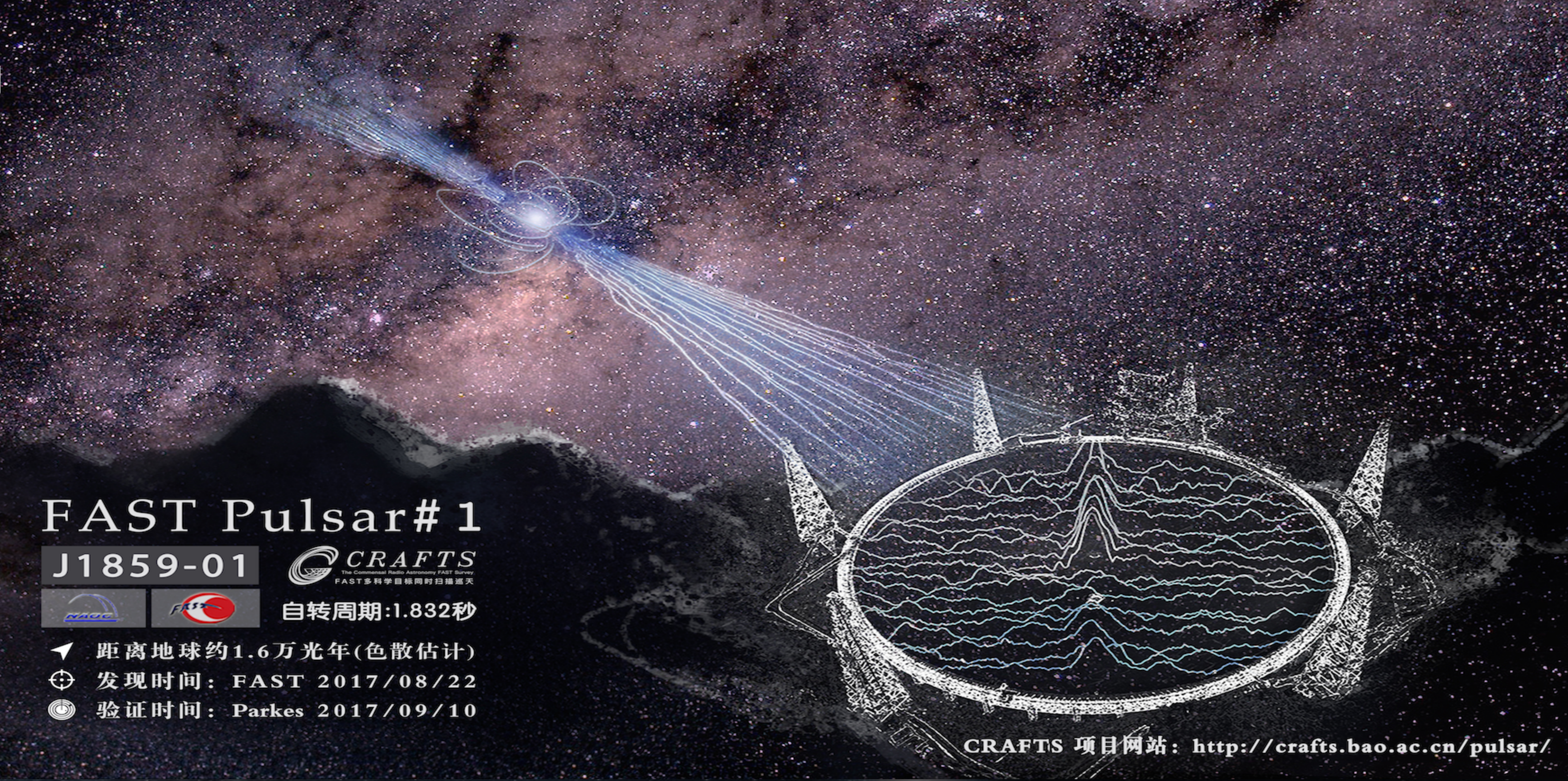


Li et al. 2018, Invited Review
IEEE Microwave, Vol 19, Issue 3, p112

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


Rotation angle 23.4°
Drift-scan
Stripe 1
Stripe 2
CRAFTS
The Commensal Radio Astronomy FAST Survey
FAST 多科学目标同时扫描巡天
Li et al. 2018
Gridding
4 x Pointings
Dec
Ra
Orion 1.5°×2.5°
FRB 181123
(b)
P1
P2
P3
Counts
500
0
1500
1400
1300
1200
1100
1000
Frequency (MHz)
2.60
2.62
2.64
2.66
2.68
Time (s)
0
20
On - Off (P1)
(c)
~1000 new pulsars
~500K galaxies
>10 billion voxels HI sky image
>50 new FRBs
HI Image
Velocity: -6.33 km/s
14h15m
14h00m
13h45m
13h30m
13h15m

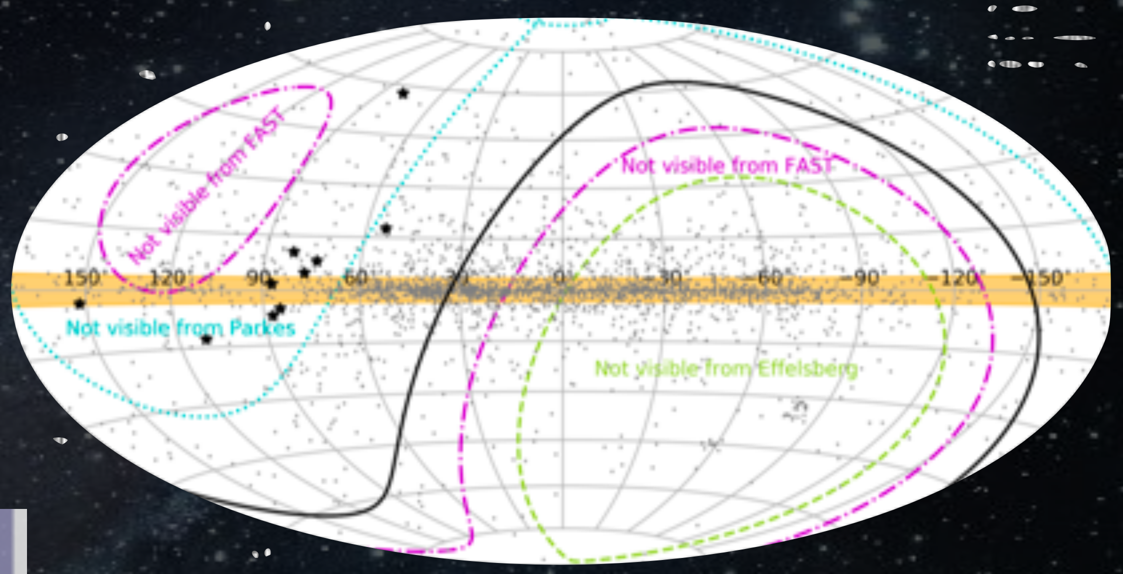
2017



Oct. 10, 2017

First FAST Science Results

Systematic Timing of **CRAFTS** pulsars



First papers on systematic follow up timing of FAST pulsars

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS 495, 3515–3530 (2020) doi:10.1093/mnras/staa1328
Advance Access publication 2020 May 14

An in-depth investigation of 11 pulsars discovered by FAST

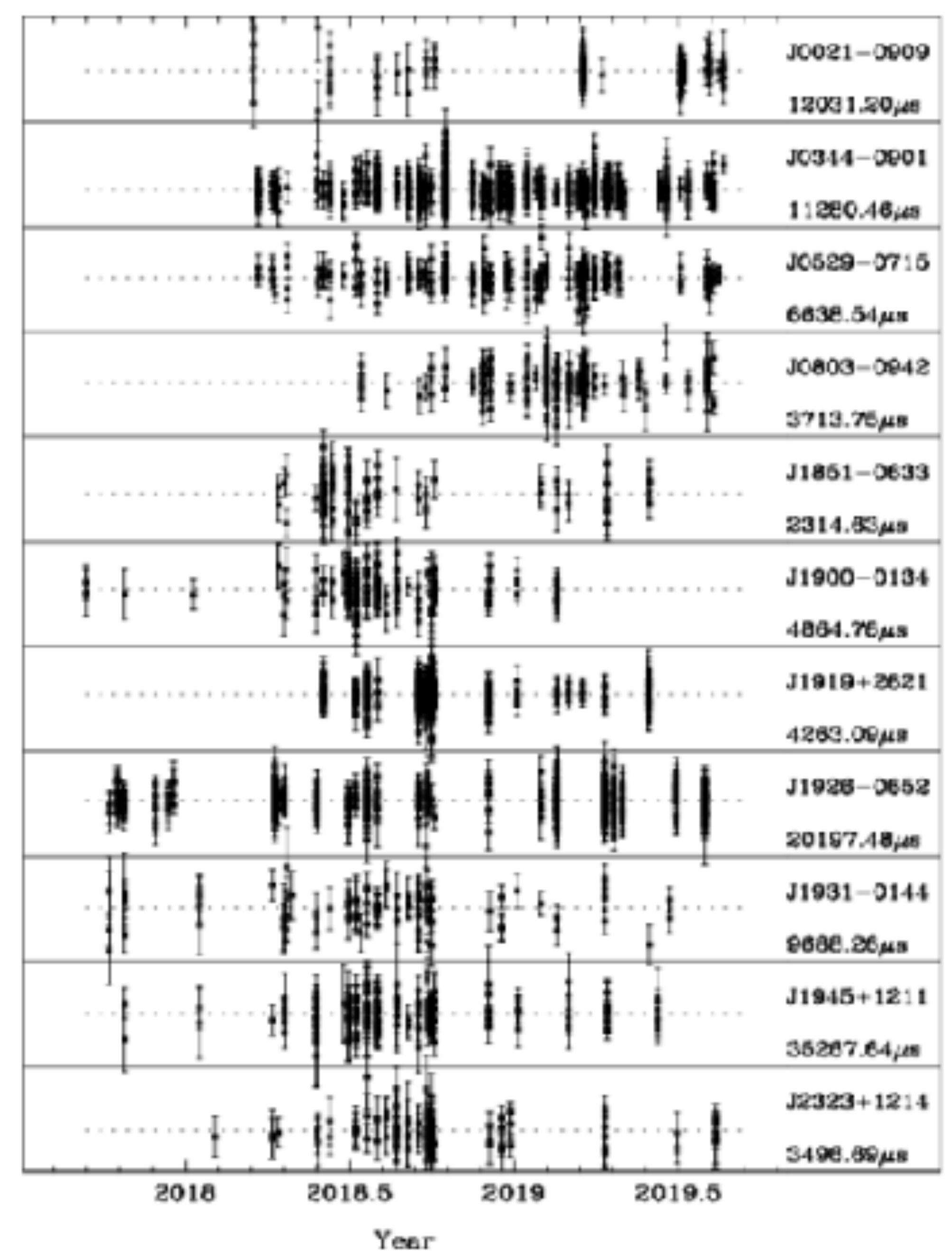
A. D. Cameron,[1,2★] D. Li,[1,3★] G. Hobbs,[1,2] L. Zhang,[1,2,3] C. C. Miao,[1,3]

Cameron, **Li** et al. 2020 (MNRAS)

FAST early discoveries: Effelsberg follow-up

M. Cruces,[1*] D. Champion,[1] D. Li,[2] M. Kramer,[1] W. W. Zhu,[2] P. Wang,[2] A. D. Camero[3,4,5] G. Hobbs,[3] P. Freire,[1] E. Graikou[1] Y. Mao,[2] and the CRAFTS collaboration
[1] Max Planck Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany
[2] CAS Key Laboratory of FAST, NAOC, Chinese Academy of Sciences, Beijing 100101, China
[3] CSIRO Astronomy and Space Science, PO Box 76, Epping, NSW 1710, Australia
[4] Centre for Astrophysics and Supercomputing, Swinburne University of Technology, Mail H30, PO Box 218, VIC 3122, Australia.
[5] ARC Center of Excellence for Gravitational Wave Discovery (OzGrav), Swinburne University of Technology, Mail H11, PO Box 218, VIC 3122, Australia.

Cruces, Champion, **Li** et al. 2021 (accepted A&A)



FAST's first Milli-Second Pulsar (MSP)

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

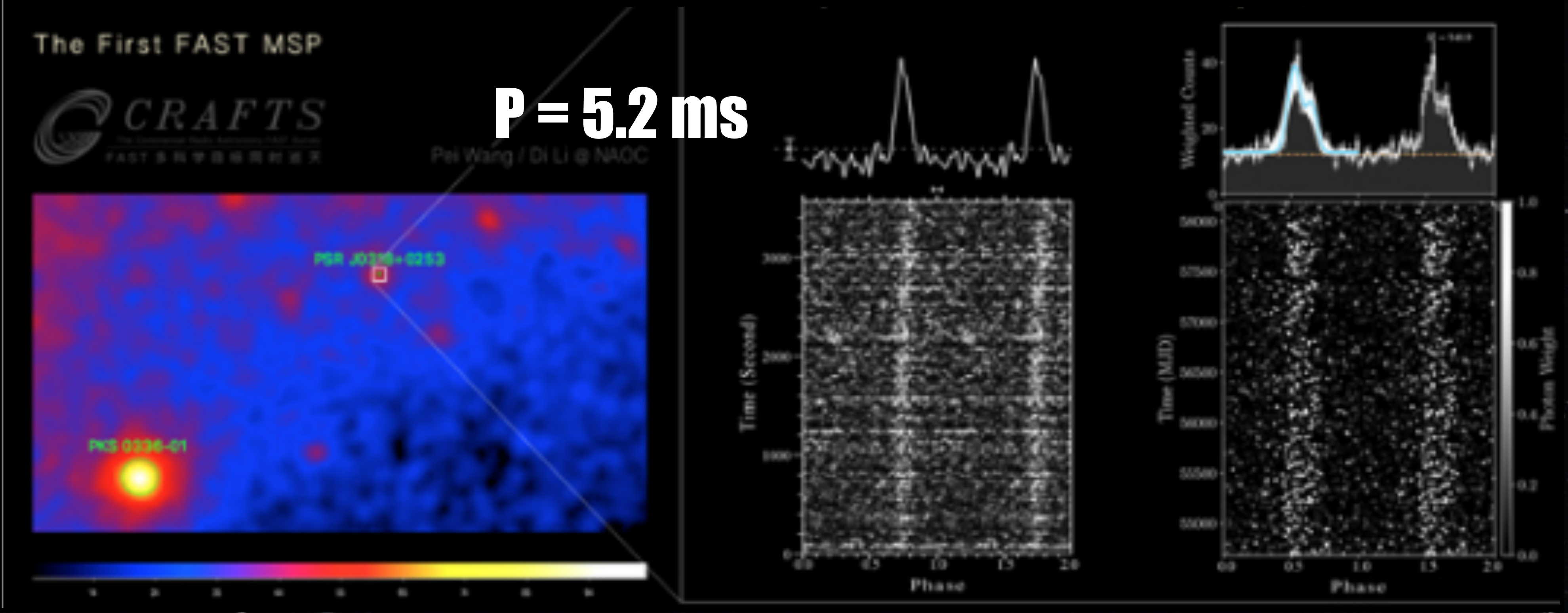
Fermi unidentified source
GBT, Arecibo non-detection

2018

- **2018.2.27** 1hr tracking with FAST's UWB
- **2018.4.12** Wang, P. et al. detected the signal using GZNU servers
- **2018.4.18** C. Clark of the Fermi team identify the γ-ray pulsar counterpart
- **2018.4.23** HKU's Pablo confirms its lack of X-ray
- **2018.4.28** ATel announcement （Wang et al. Atel#10851,《SCPMA》）
- **2018.5.2** International pulsar timing array （IPTA) distribute the ephemeris to its partners

×	Arecibo, 327 MHz， 3h <60 μJy
√	FAST, 550 MHz， 1h ~60 μJy
×	FAST, 1.25 GHz， 4h ~20 μJy

A New MSP toward the Fermi-LAT unassociated source 3FGL J0318.1+0252

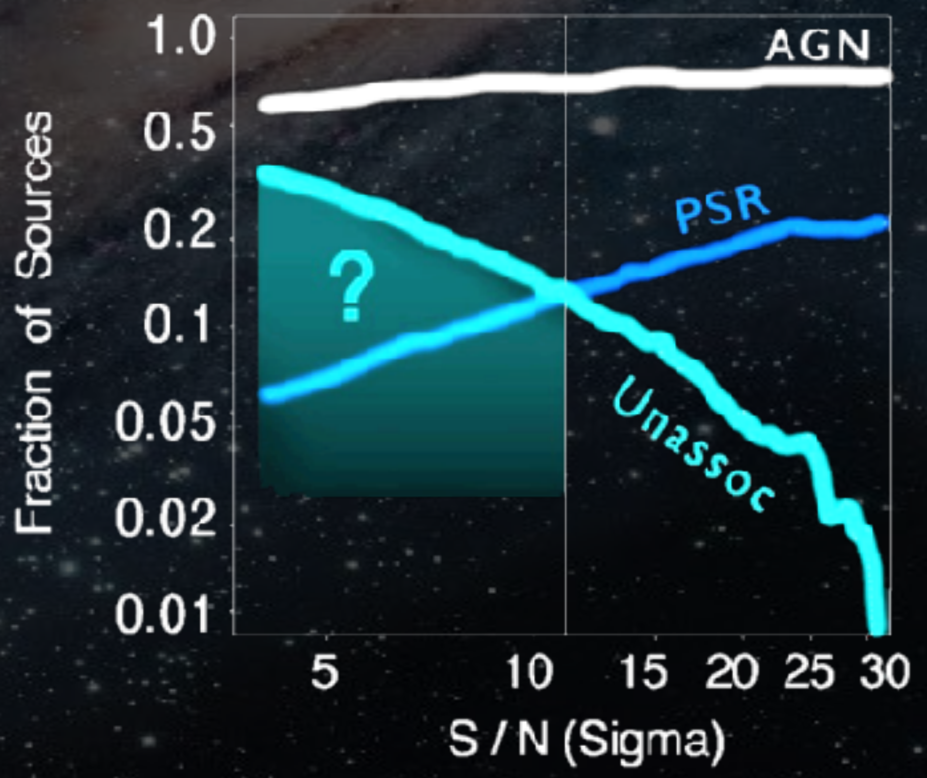


Pulsar searches of Fermi sources with FAST

FAST-Fermi•LAT MoU

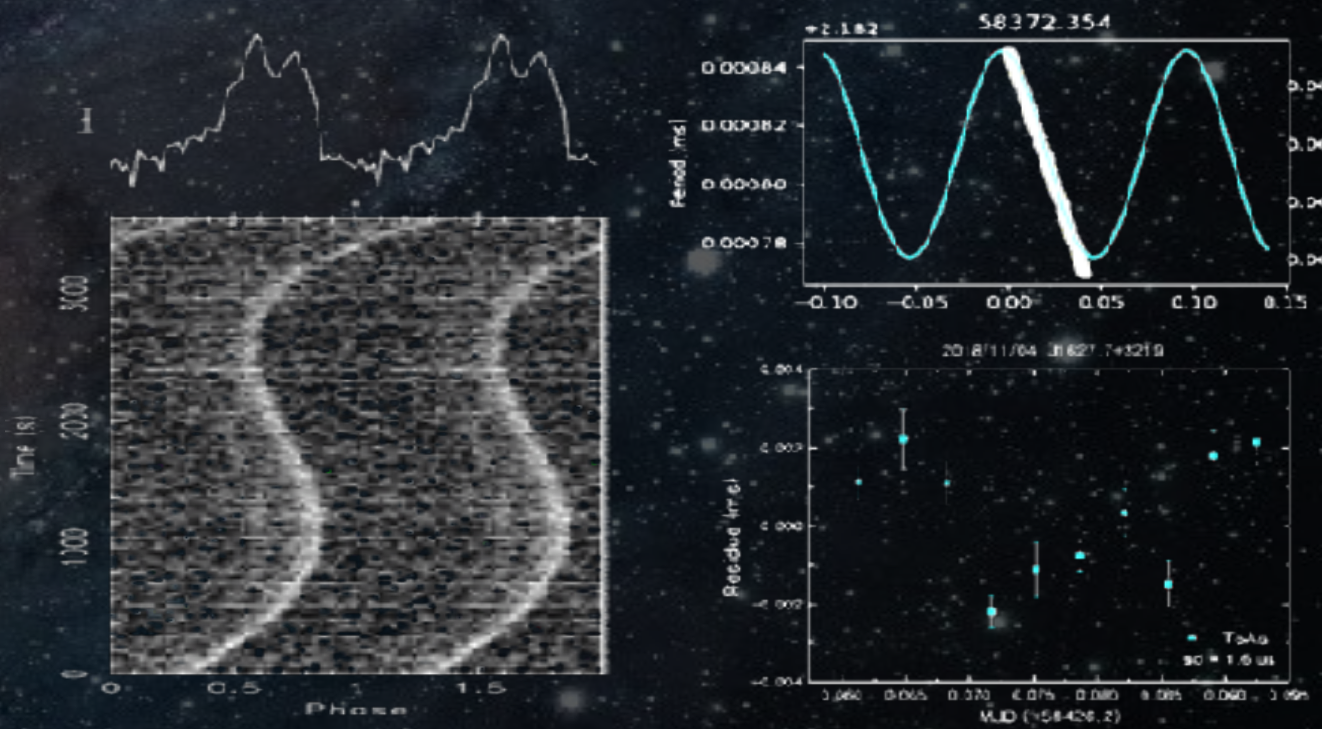
- December 2017, MoU signed between the FAST team and the LAT Collaboration
- >3033 sources in 3FGL, 1904 have confirmed, AGN (1738), PSR (>200), ~1129 unconfirmed sources
- More than 30 targets be searched, **5** new pulsars/ MSPs are discovered by FAST.

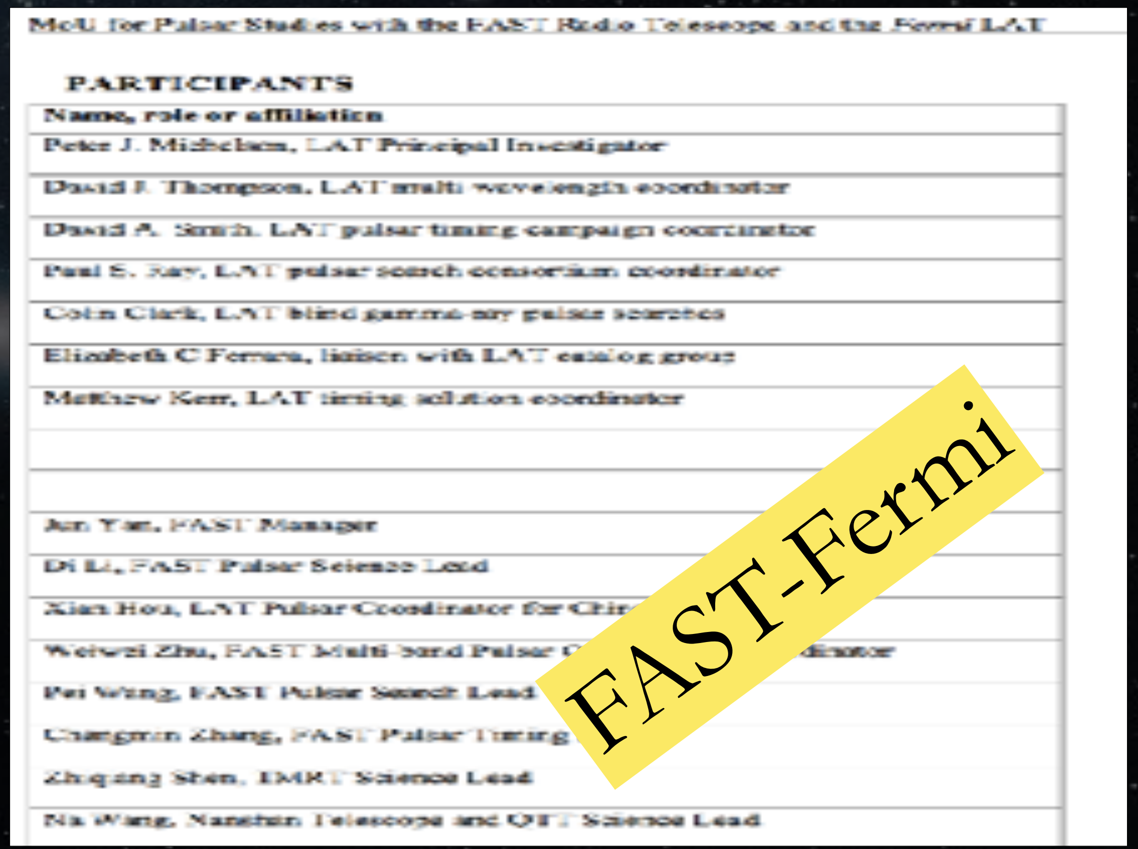
Spin period is **2.2 milliseconds**, an estimated distance of about **4.4 kpc**, and as potentially one of the shortest orbital period binary systems (**4.2 hours**).



Saz. Parkinson et al. 2016

4FGL J1627.7+3219





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

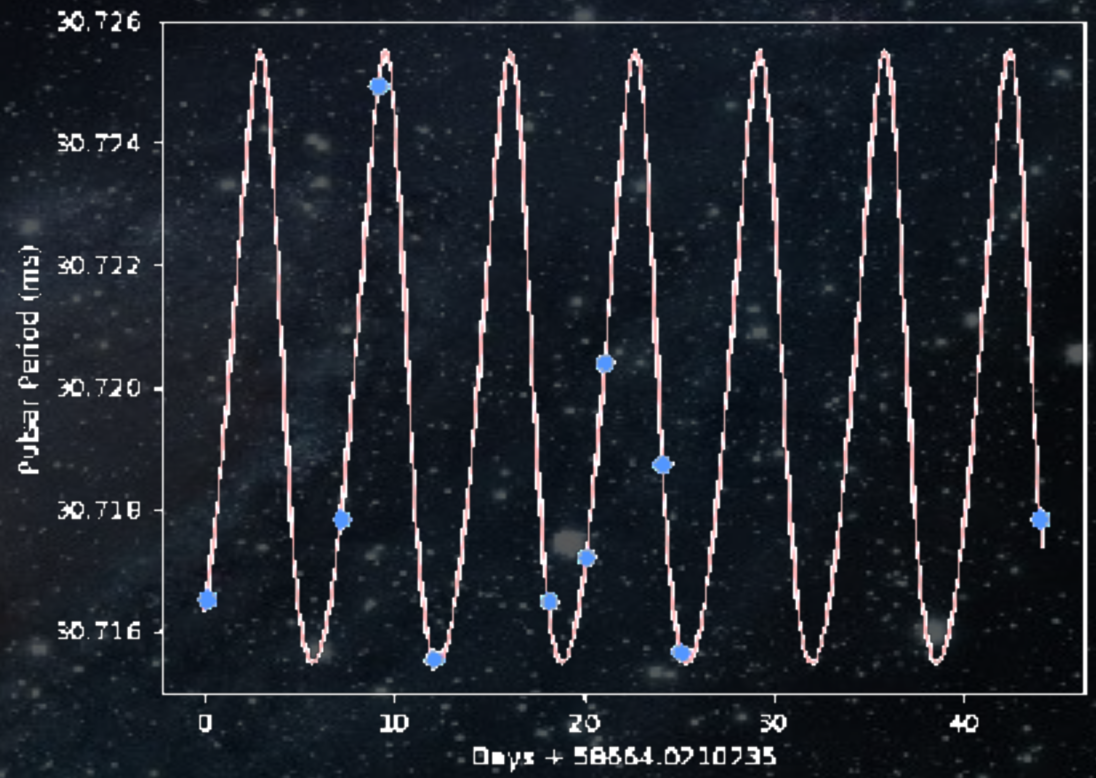
PARTICIPANTS

Name, role or affiliation
Peter J. Michelson, LAT Principal Investigator
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 searches
Elizabeth C Ferrara, liaison with LAT catalog group
Matthew Kerr, LAT timing solution coordinator
Jun Yan, FAST Manager
Di Li, FAST Pulsar Science Lead
Xian Hou, LAT Pulsar Coordinator for Chi…
Weiwei Zhu, FAST Multi-band Pulsar C… …dinator
Pei Wang, FAST Pulsar Search Lead
Changmin Zhang, FAST Pulsar Timing …
Zhiqiang Shen, TMRT Science Lead
Na Wang, Nanshan Telescope and QTT Science Lead

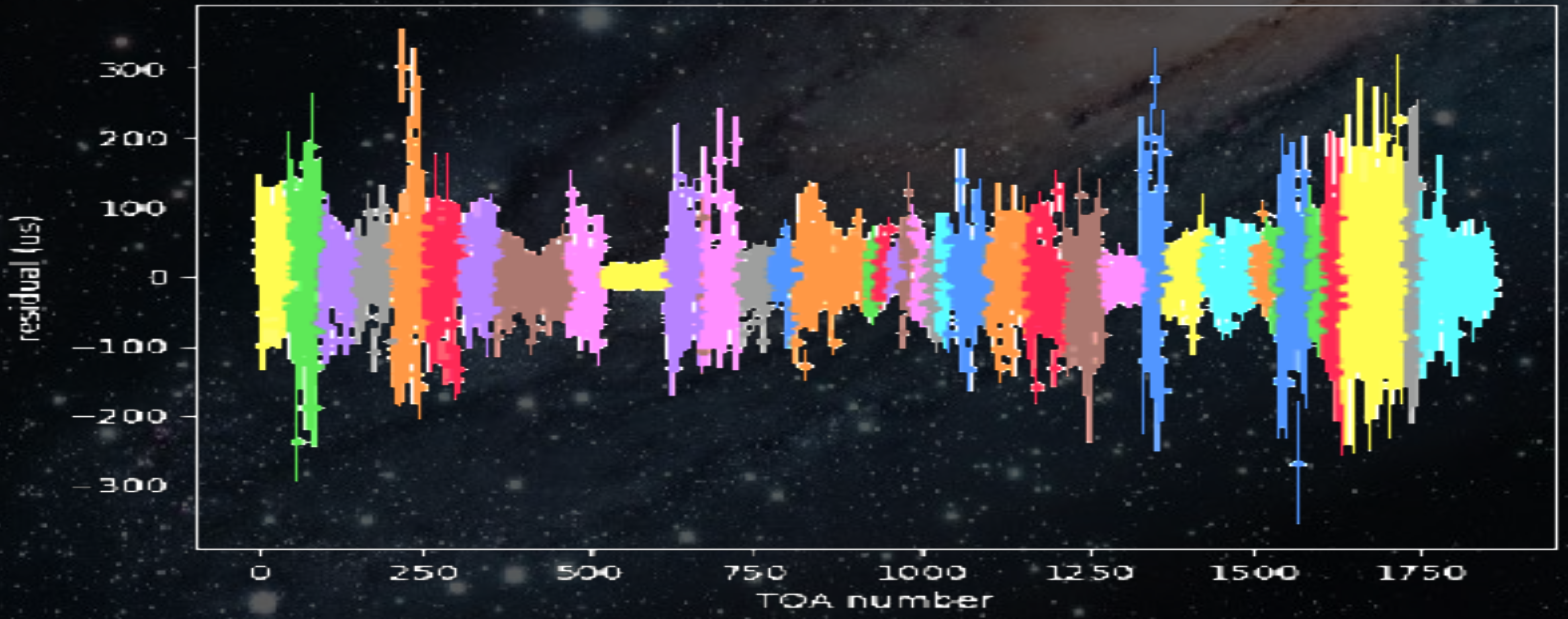
FAST首个双中子星系统

C69-DNS system （W.W. Zhu）

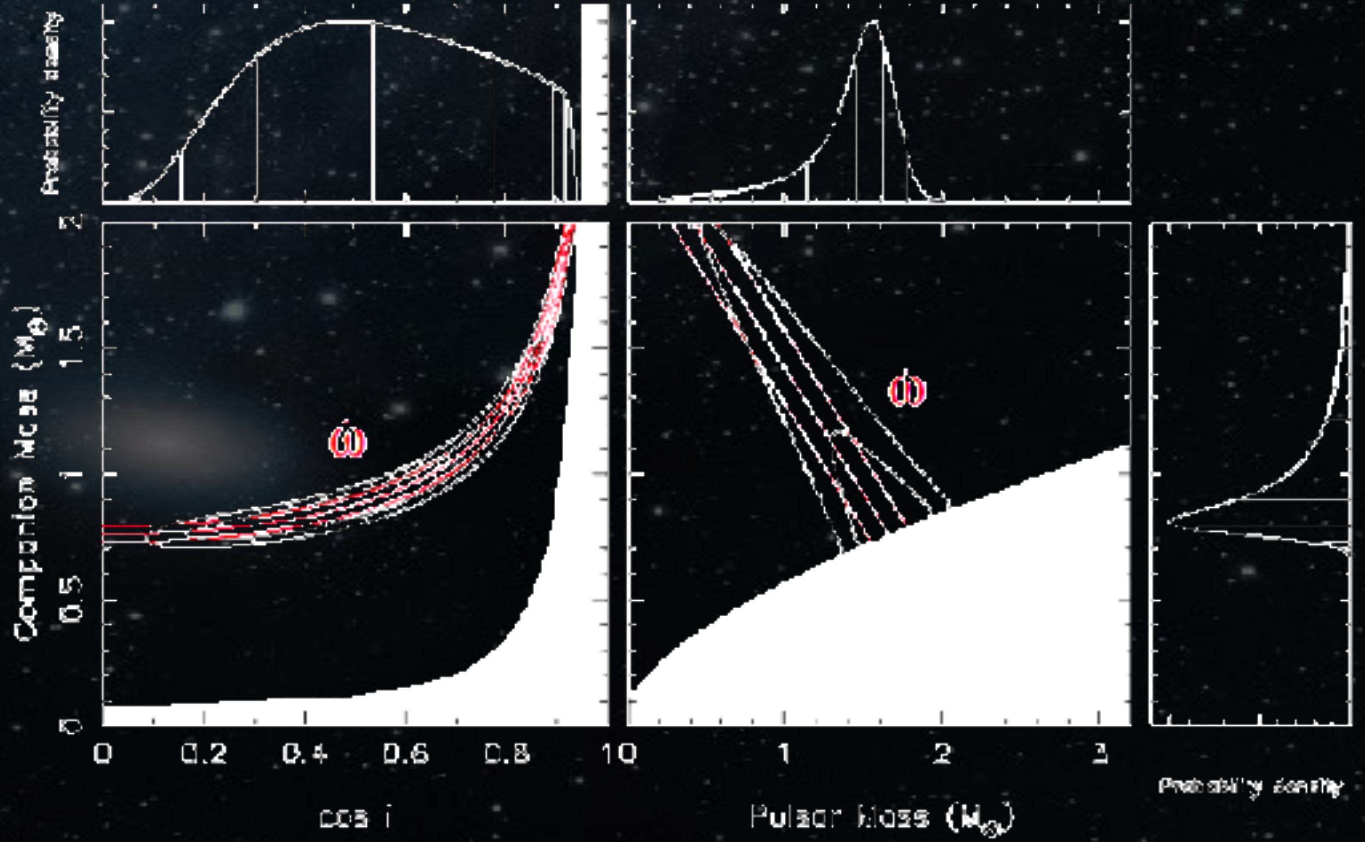
- Total 44 sessions of observations span 339 days
- 23 sessions 2019a-082-P (Chenchen Miao)
- 15 sessions orbital campaign DDT (Weiwei Zhu)
- 6 sessions Timing KSP （Nina Wang）



Chenchen Miao & Weiwei Zhu



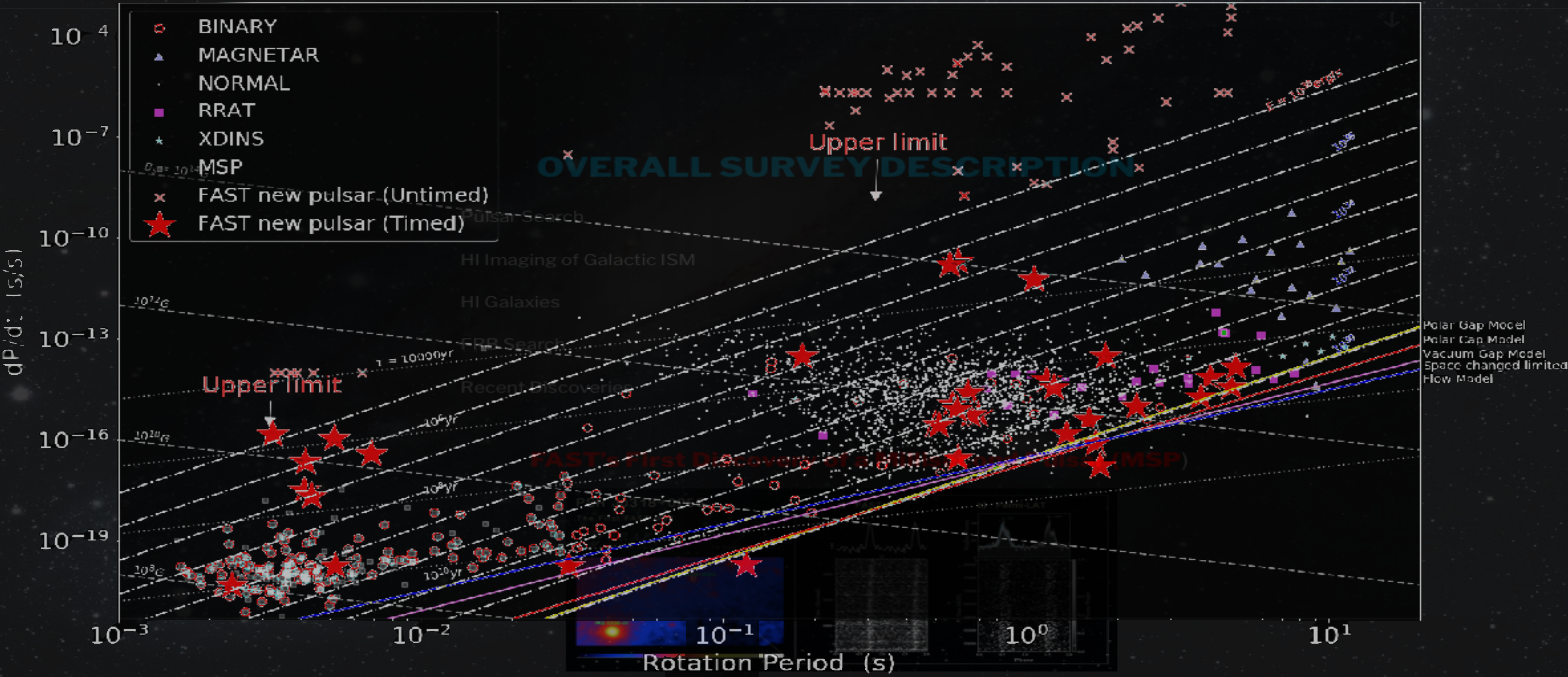
Fully connected timing solution using DDGR



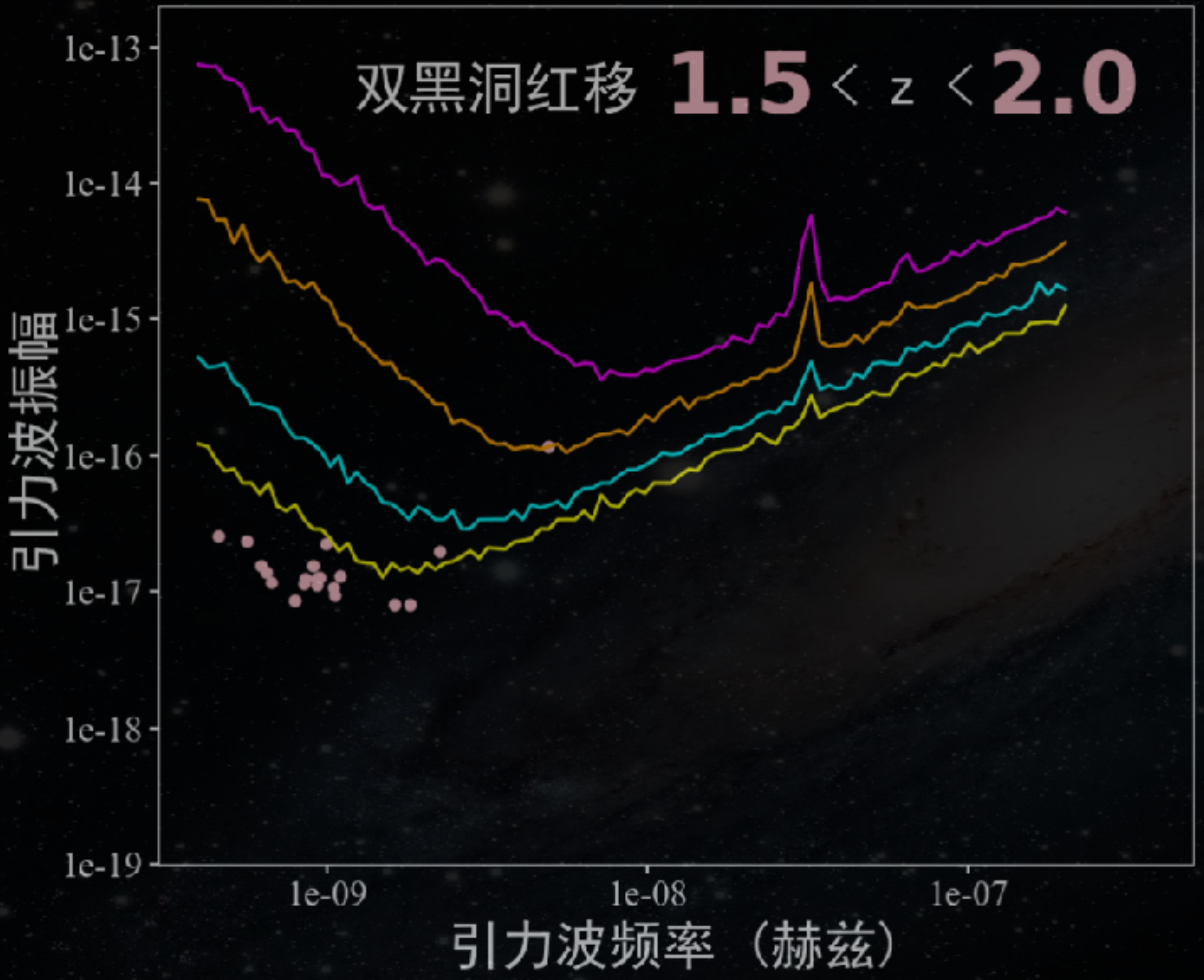
双中子星整体质量小，有可能是特殊系统！

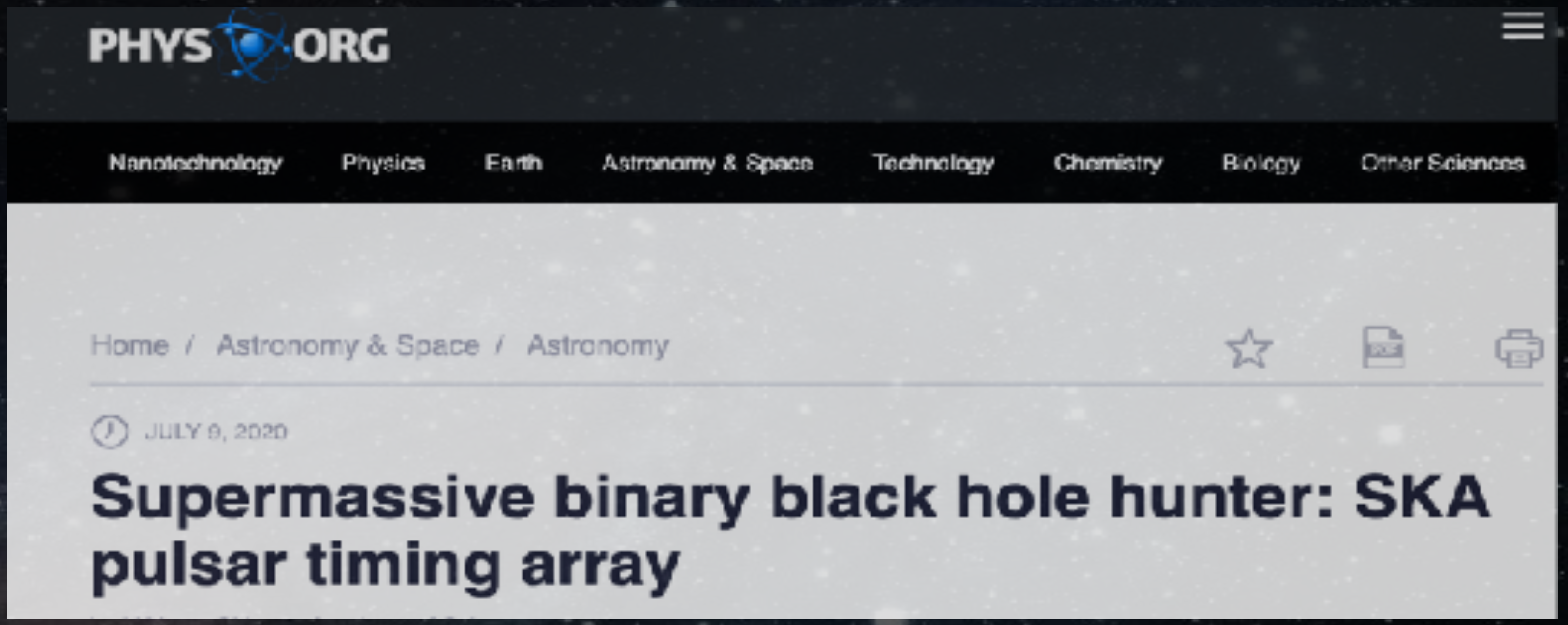
Confirmed new pulsars > 130, including >44 MSPs, binaries (DNS), etc.

http://crafts.bao.ac.cn



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

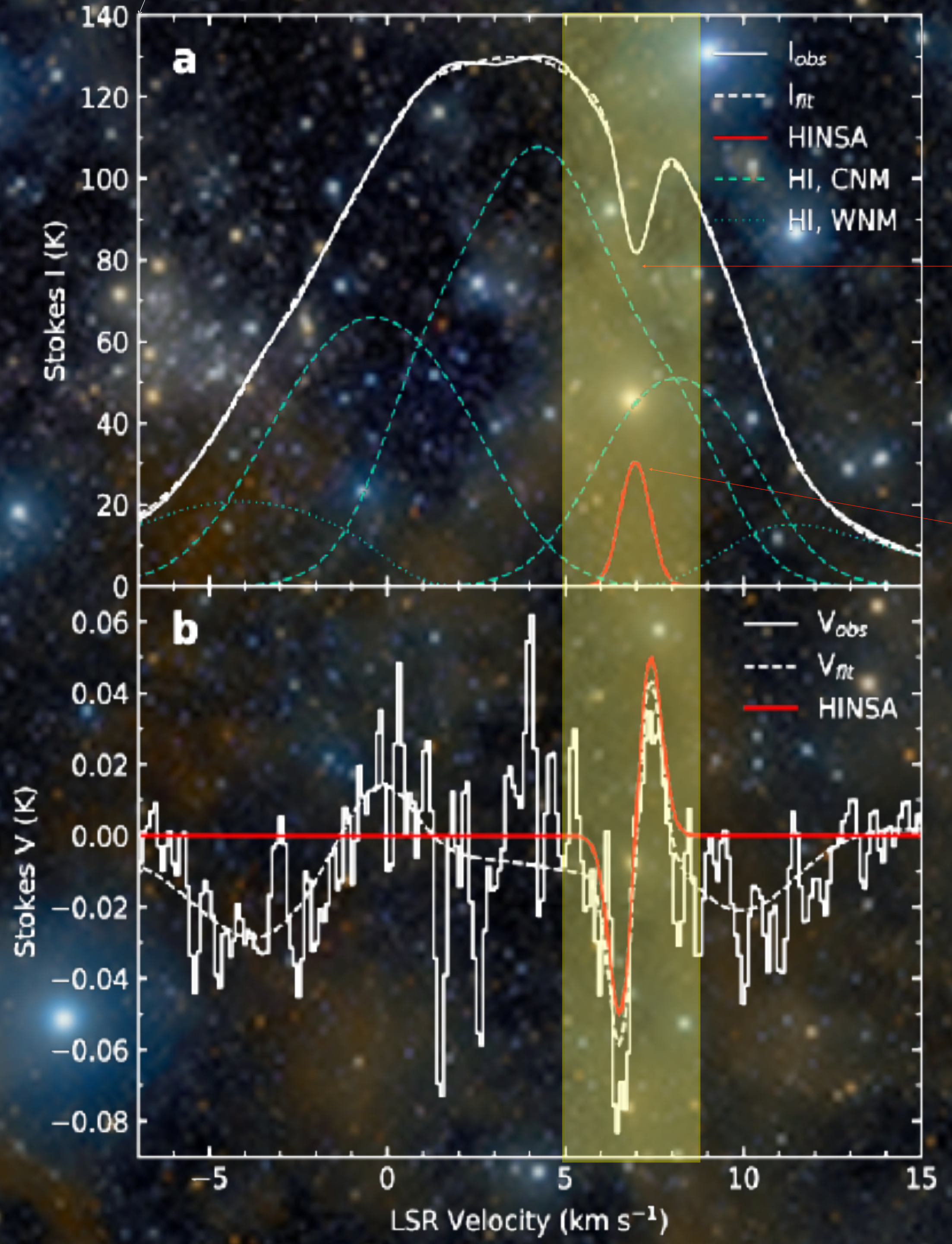


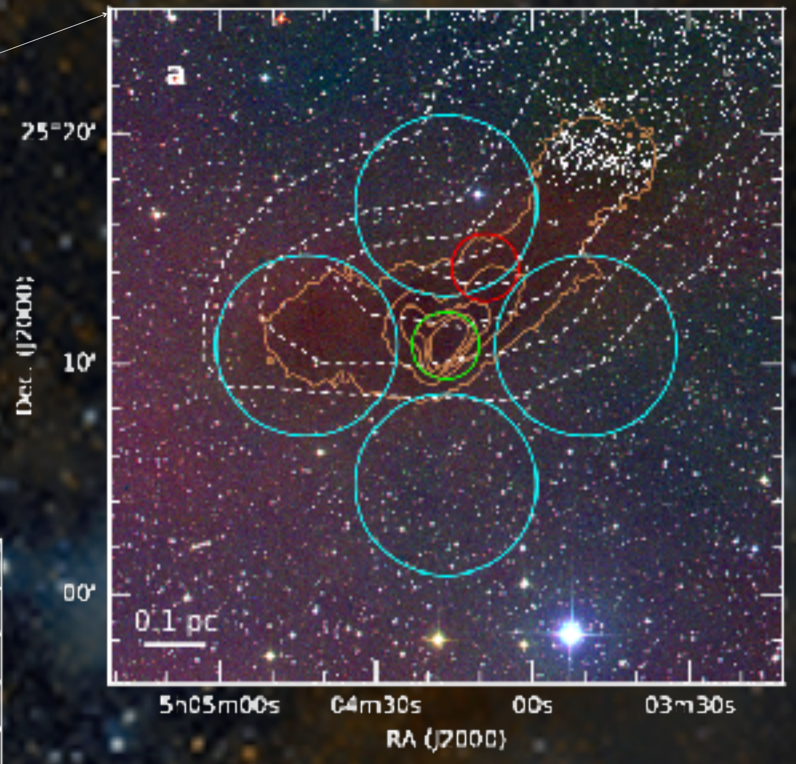


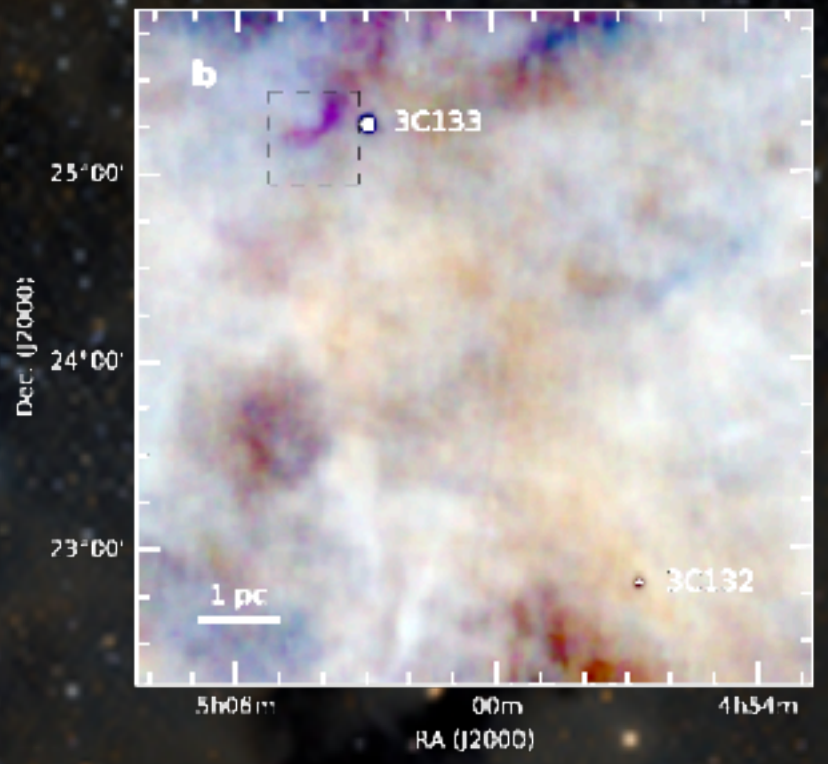
- ✦ Forcast the performance of a SKAPTA made up by only ~20 high quality MSPs;
- ✦ Quantified, for the first time, how SKA would trace the redshift evolution SMBBHs up to z=2 through gravitational wave observations。
- ✦ SKAPTA expects the first detetion within 5 years, achieve a detection rate of 100/yr within 10 years, and over 10,000 SMBBHs within 30 years.

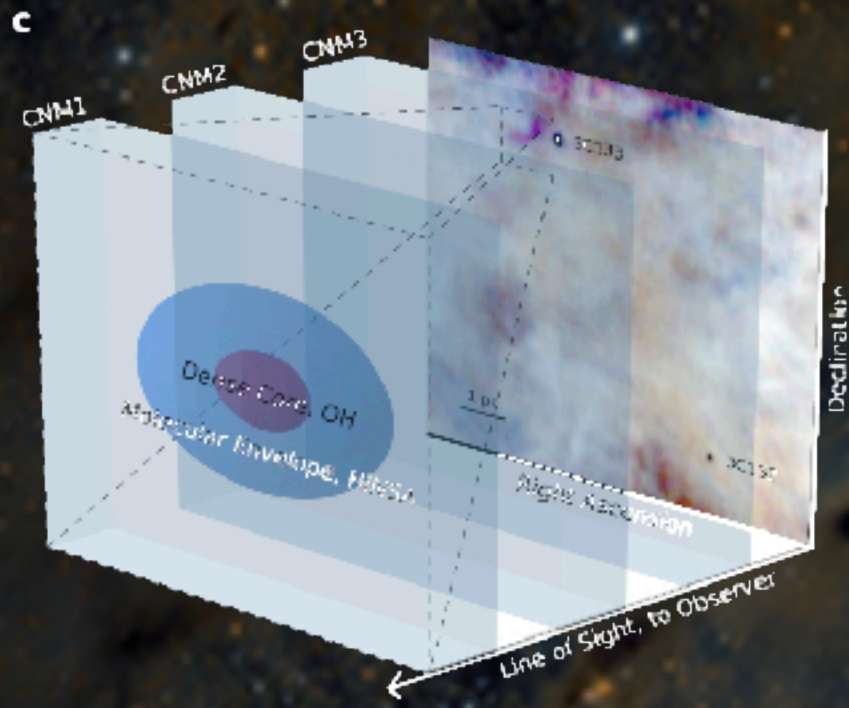
Feng, Y., **Li, D.**, + 2020 (Physical Review D, 102, 023014)
"Supermassive Binary Black Hole Evolution can be traced by a small SKA Pulsar Timing Array"

Lyn 1544









HI Narrow Self–Absorption HINSA

Li & Goldsmith (2003)

- First detection of magnetic field strength in dense molecular gas with an atomic tracer (HINSA): **B = 3.8 ± 0.3 μG**
- Revealing **a coherent B** structure from atomic gas to diffuse molecular gas, to dense molecular gas.

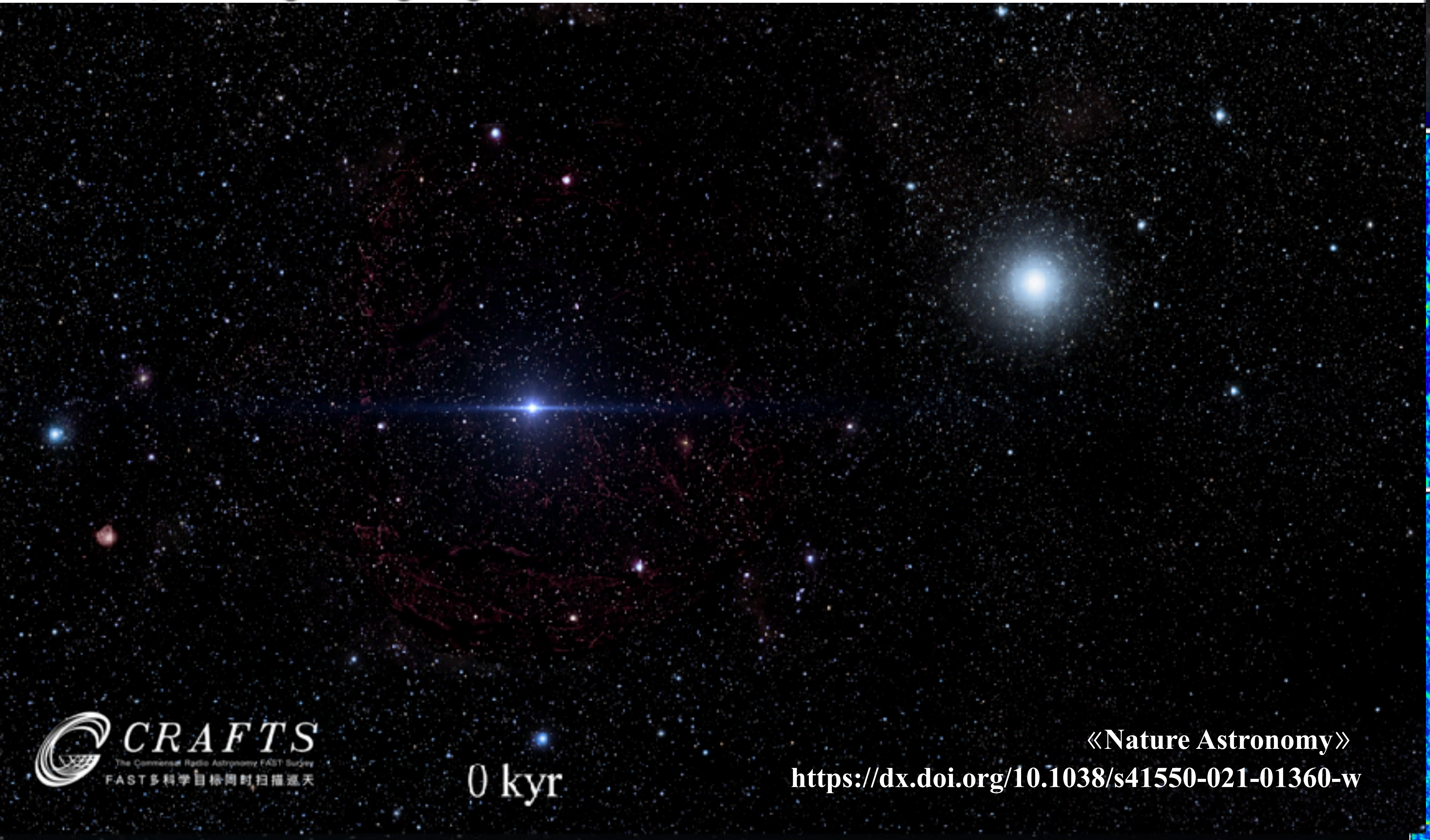
(Ching, **Li**, Heiles+ 2021 submitted to **Nature**
referee： *"strongly recommend for publication"*)

“眨眼睛的脉冲星”

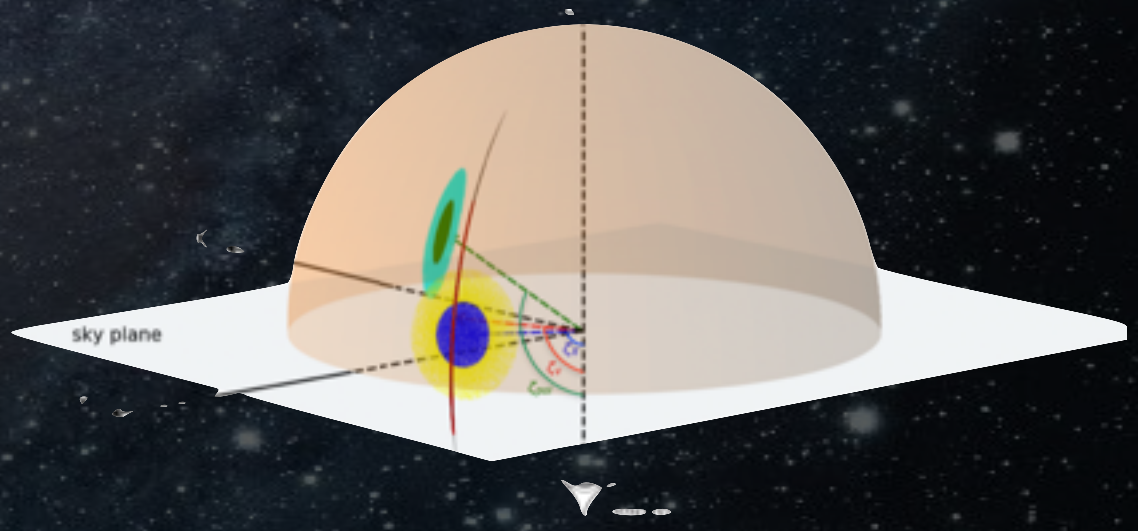
nature astronomy
LETTERS
https://doi.org/10.1038/s41550-021-01360-w
Check for updates

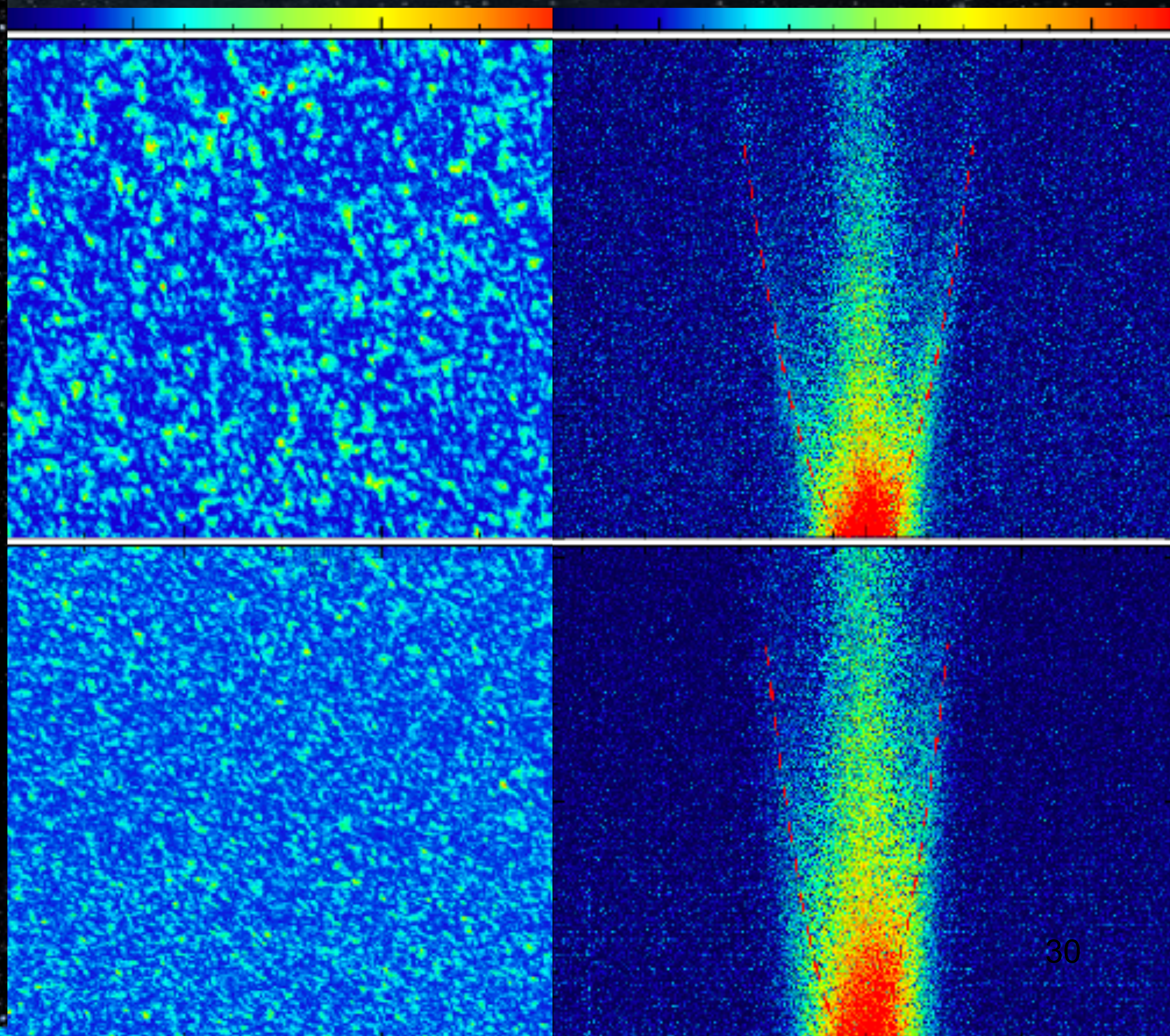
Evidence for three-dimensional spin–velocity alignment in a pulsar

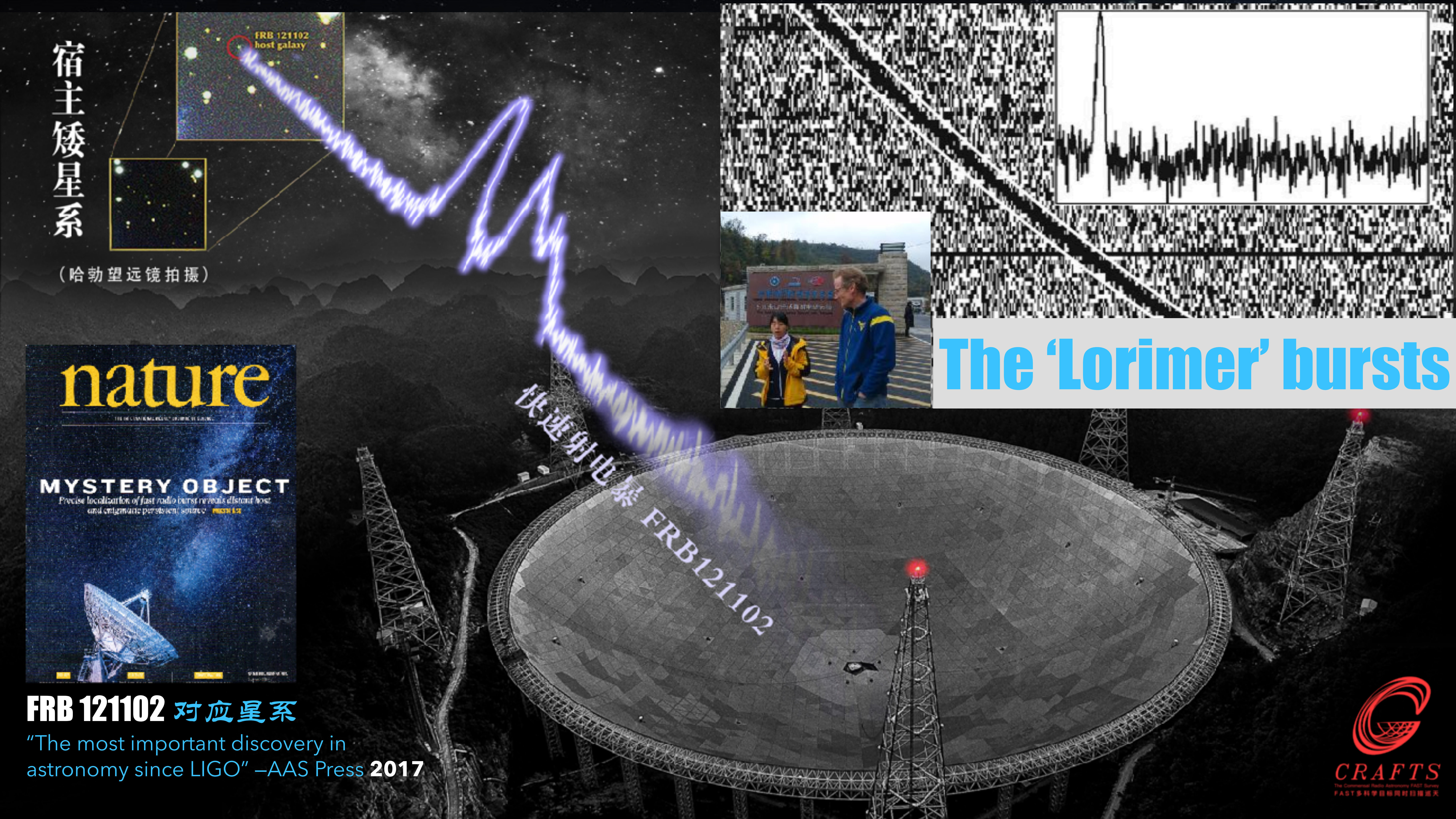
Jumei Yao[1,2], Weiwei Zhu[1], Richard N. Manchester[3], William A. Coles[4], Di Li[1,5,6], Na Wang[2], Michael Kramer[7,8], Daniel R. Stinebring[9], Yi Feng[1], Wenming Yan[2], Chenchen Miao[1], Mao Yuan[1], Pei Wang[1] and Jiguang Lu[1]



«Nature Astronomy»
https://dx.doi.org/10.1038/s41550-021-01360-w






宿主矮星系
（哈勃望远镜拍摄）
FRB 121102
host galaxy
快速射电暴 FRB121102
The 'Lorimer' bursts
nature
MYSTERY OBJECT
Precise localization of fast radio burst reveals distant host and enigmatic persistent source
FRB 121102 对应星系
"The most important discovery in astronomy since LIGO" –AAS Press 2017
CRAFTS

Contents [hide]

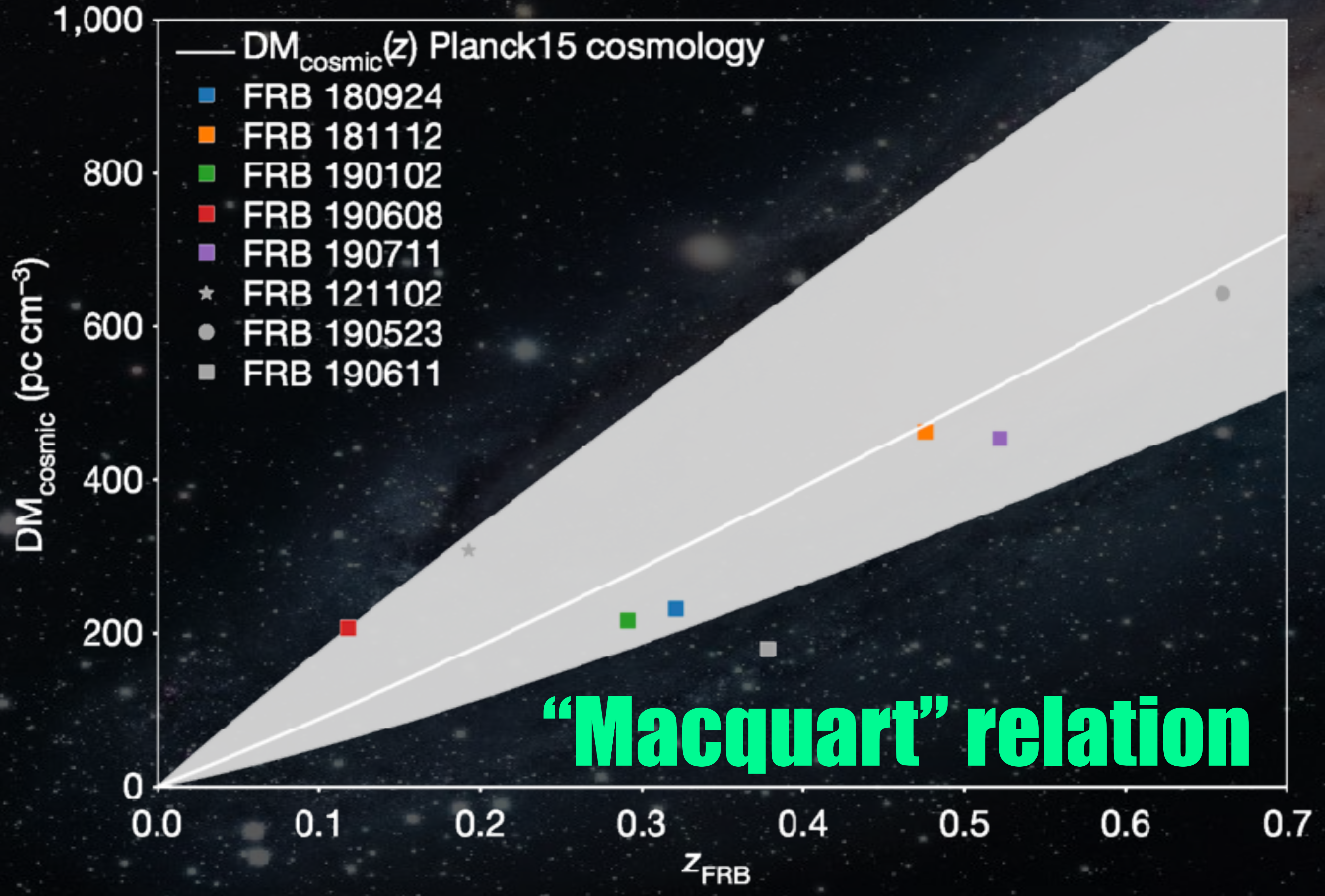
Hosted by the Institut Spatial de McGill McGill Space Institute in collaboration with UNIVERSITY OF KWAZULU-NATAL INYUVESI YAKWAZULU-NATALI

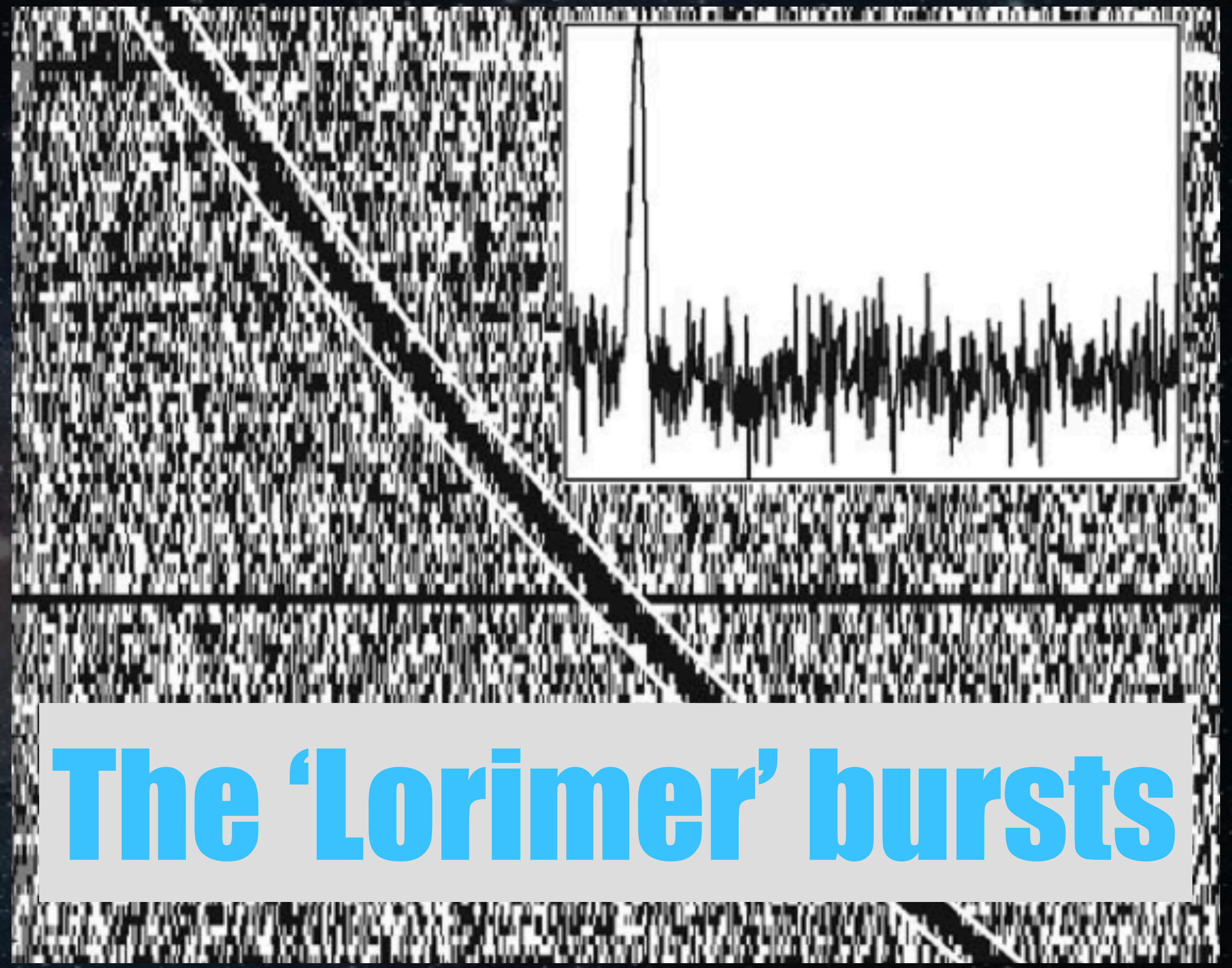
Welcome to the FRB Theory Wiki!

Name	Category	Progenitor	Type	Energy Mechanism	Emission Mechanism	LF Radio Counterpart	HF Radio Counterpart	Microwave Counterpart	THz Counterpart	OIR Counterpart	X ray Counterpart	Gamma ray Counterpart	GW Counterpart
NS-WD Accretion	Accretion	NS-WD	Repeat	Mag. reconnection	Curv.	Yes	--	--	--	--	--	Yes, but unlikely detectable	--
AGN-KBH	AGN	AGN-KBH Interaction	Repeat	Maser	Synch.	Yes	--	--	--	Supernova	--	Yes	Yes
AGN-SS	AGN	AGN-Strange Star Interaction	Repeat	Electron oscillation	--	Yes	--	--	--	Thermal	--	Yes	Yes
Jet-Caviton	AGN	Jet-Caviton Interaction	Both	Electron scattering	Bremsst.	Yes	Yes	--	--	--	--	Possible GRB	Yes
Wandering Beam	AGN	Wandering Beam	Repeat	--	Synch.	Yes	--	--	--	--	Yes	--	--
NS to BH (DM-Induced)	Collapse	NS to BH	Single	Mag. reconnection	Curv.	Yes	--	--	--	--	--	--	Yes
NS to KNBH	Collapse	NS to KNBH	Single	Mag. reconnection	Curv.	Yes	--	--	--	--	Possible afterglow	Possible GRB	Yes
NS to Quark Star	Collapse	NS to Quark Star	Single	β-decay	Synch.	Yes	--	--	--	--	Yes	Yes	Yes
SS Crust	Collapse	Strange Star Crust	Single	Mag. reconnection	Curv.	Yes	--	--	--	--	--	--	Yes
Axion Cloud and BH	Collision / Interaction	Superradiant Axion Cloud and BH	Repeat	Laser	Synch.	Yes	--	--	--	--	--	--	Yes

FRB: a Cosmic Probe

$$\mathrm{DM_{FRB}}(z) = \mathrm{DM_{MW,ISM}} + \mathrm{DM_{MW,halo}} + \mathrm{DM_{cosmic}}(z) + \mathrm{DM_{host}}(z)$$



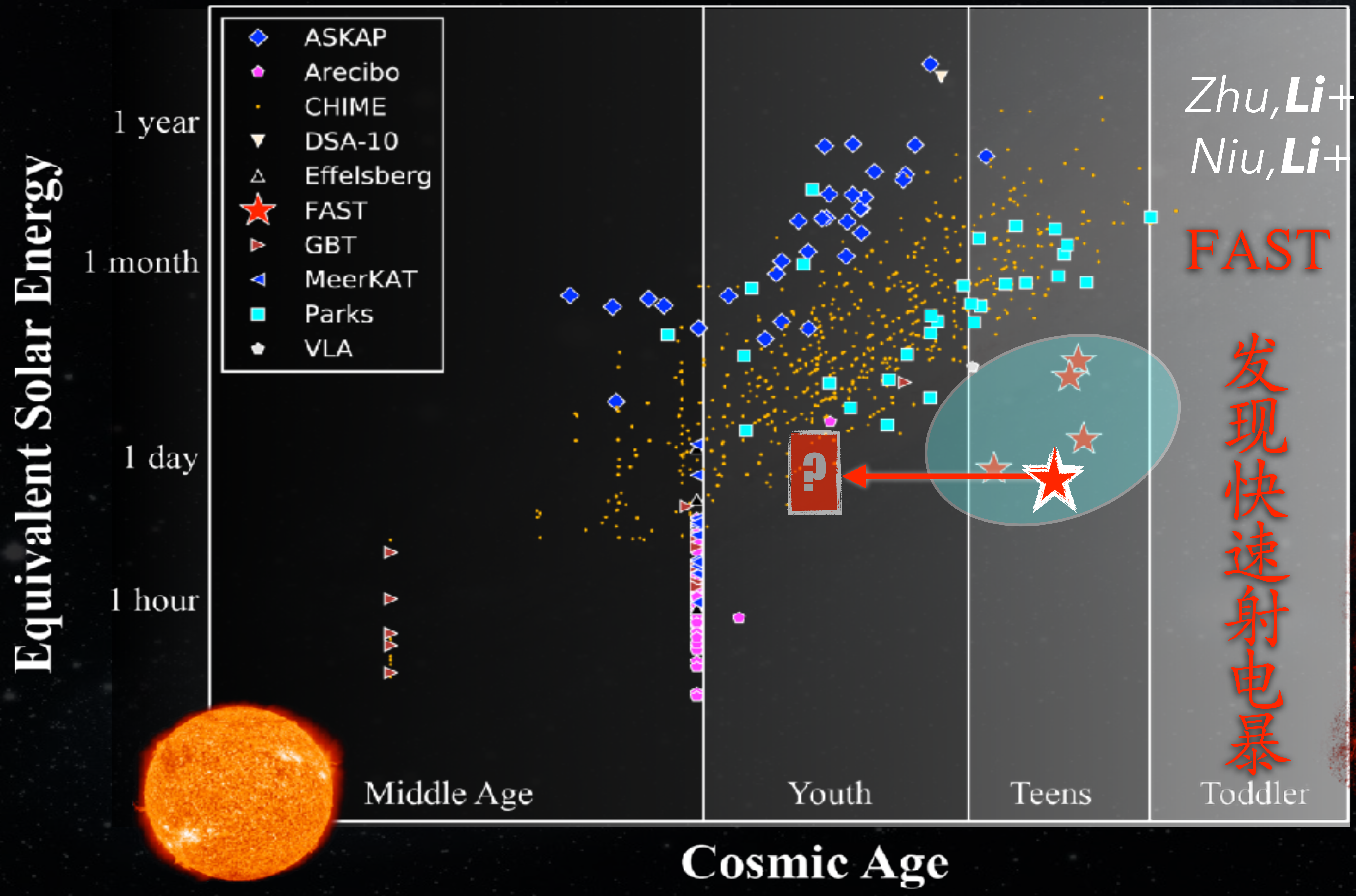


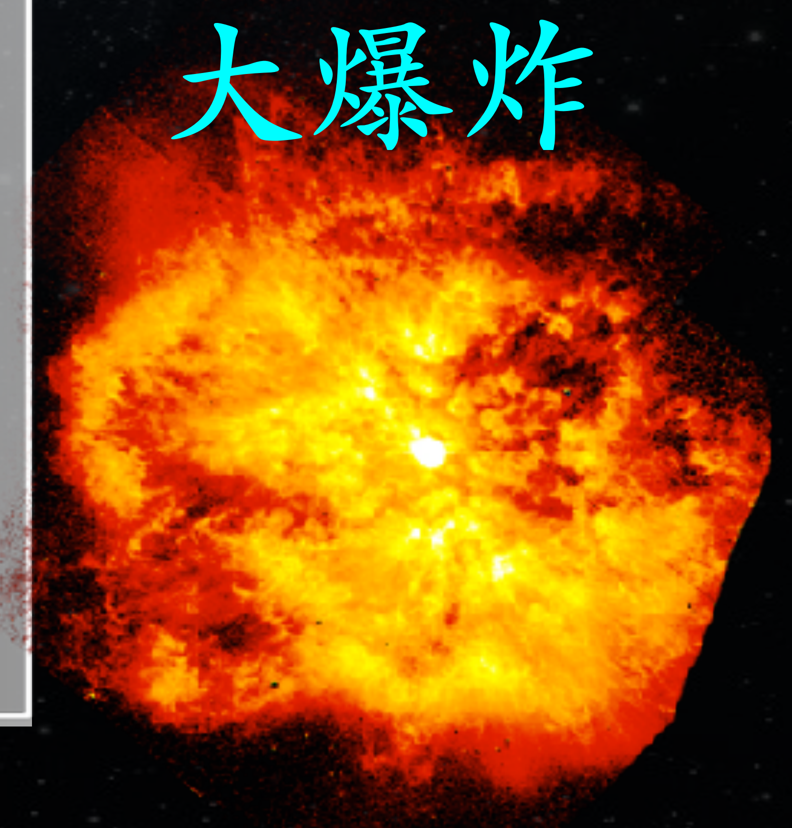
$$\langle \mathrm{DM_{cosmic}} \rangle = \int_0^{z_{\mathrm{FRB}}} \frac{c\bar{n}_e(z)\mathrm{d}z}{H_0(1+z)^2\sqrt{\Omega_m(1+z)^3+\Omega_\Lambda}}$$

Macquart+ 2020, *A census of baryons in the Universe from localized fast radio bursts*, **Nature**

Commensal Radio Astronomy FAST Survey

Zhu,**Li**+ 2020 ApJL
Niu,**Li**+ 2021 ApJL



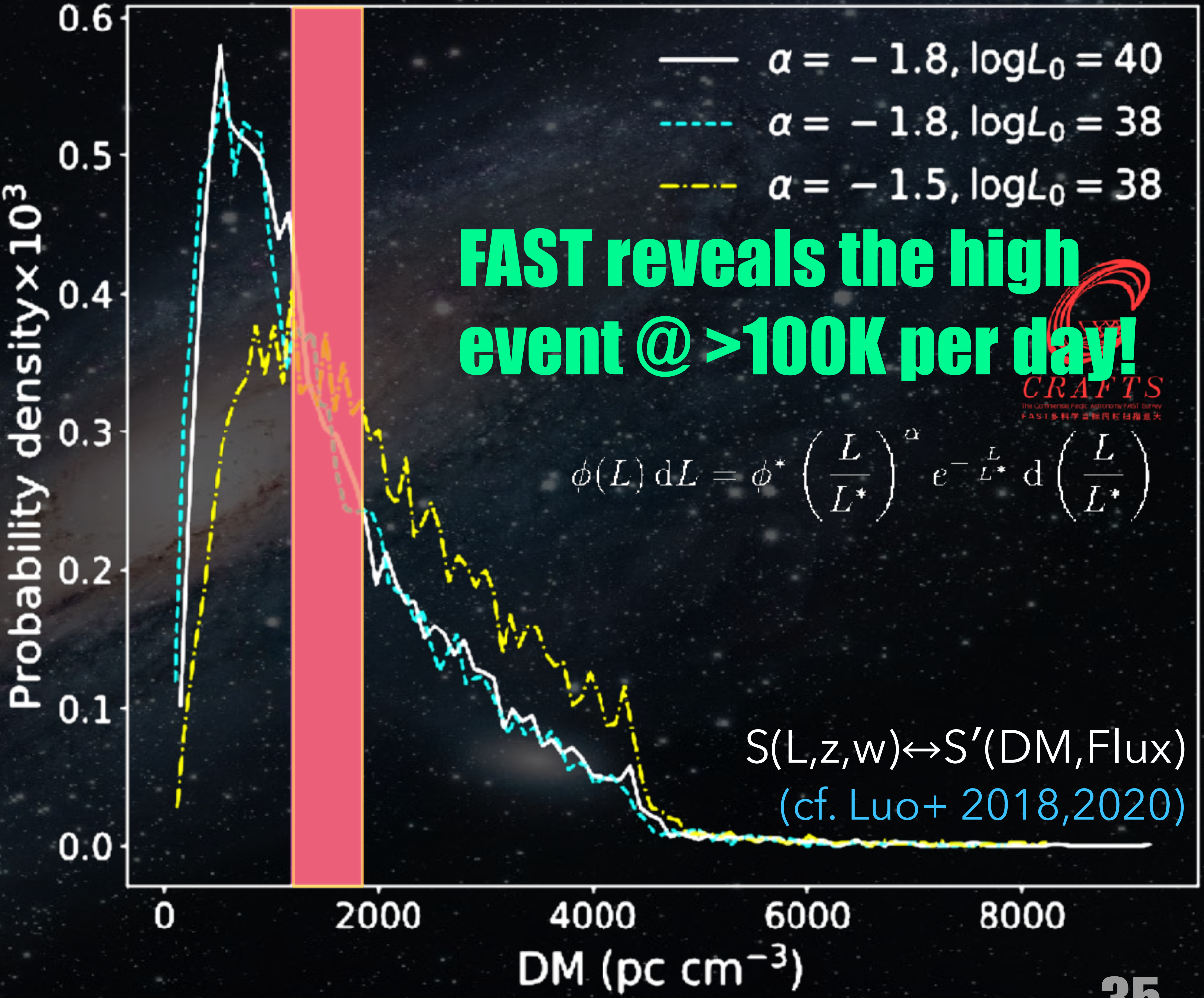


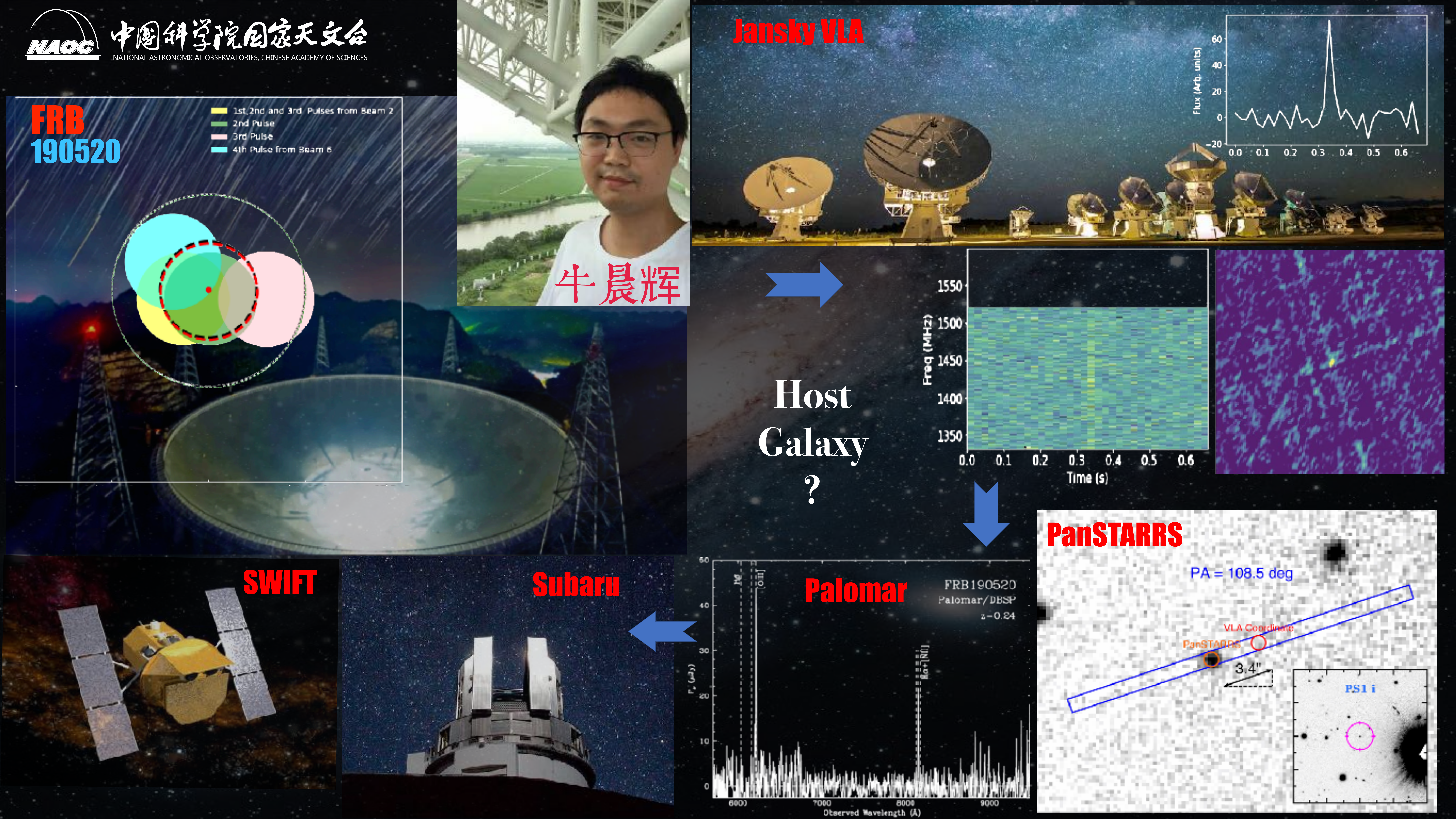
CRAFTS

CRAFTS 2018 FRBs

- **Four** events in a total of **1667 hours** in 2018, corresponds to an all sky rate of **1.2×10^5 sky^{-1} day^{-1}** at the 95% confidence interval above 0.0146 Jy ms, by far the deepest such estimate.
- ~1 per 400 FLAN hours (cf. Li 2016)

- PDF of FAST-FRB's DM is more sensitive to the slope of the luminosity function than the cutoff brightness L_0.
- FAST will have significant detection probability (>10%) for DM > 3000 pc cm^{-3} (Also Zhang 2018)



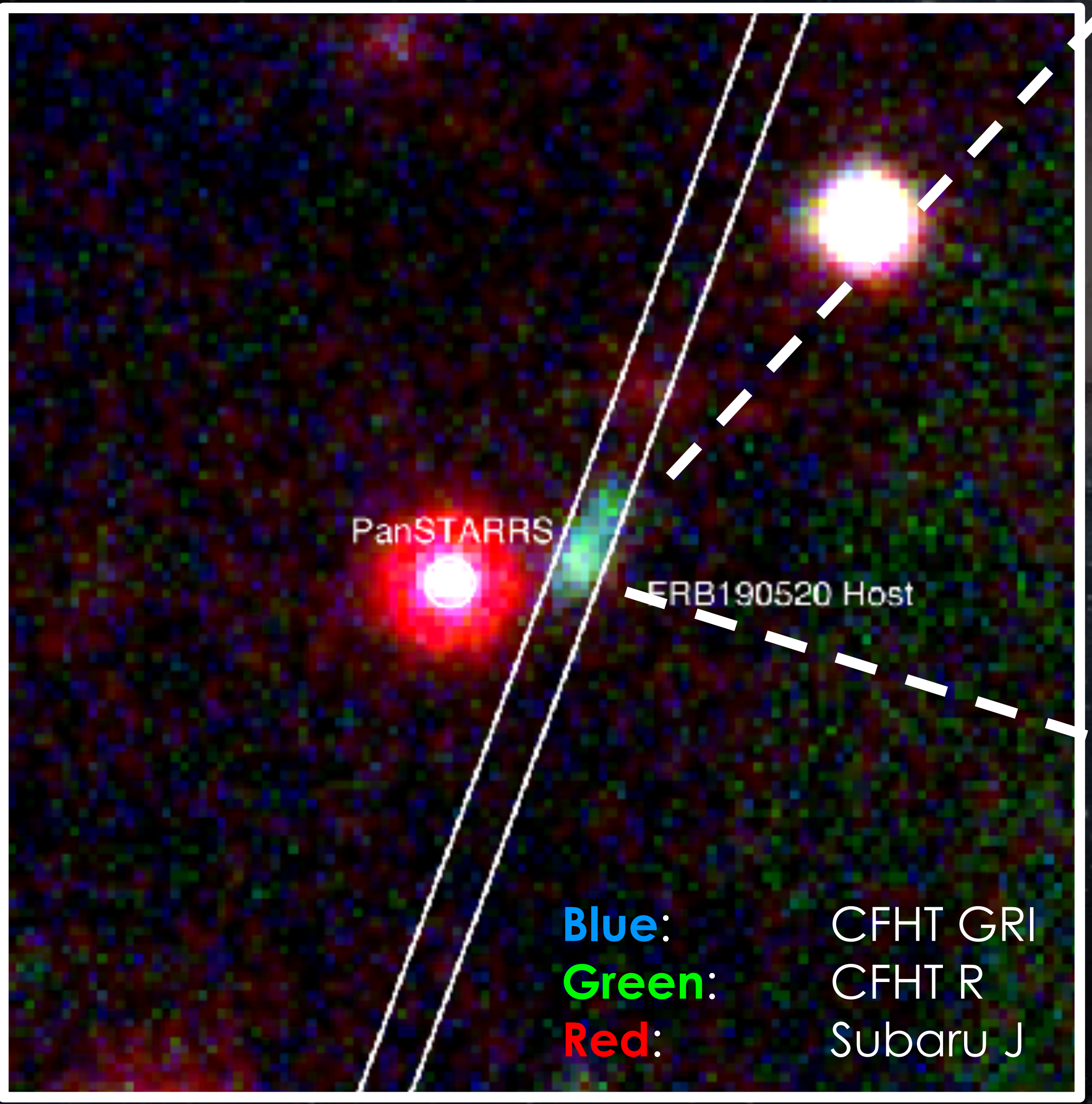


NAOC
中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES, CHINESE ACADEMY OF SCIENCES
FRB
190520
1st, 2nd and 3rd Pulses from Beam 2
2nd Pulse
3rd Pulse
4th Pulse from Beam 6
牛晨辉
Jansky VLA
Flux (Arb. units)
Host
Galaxy
?
Freq (MHz)
Time (s)
PanSTARRS
PA = 108.5 deg
VLA Coordinate
PanSTARRS
3.4"
PS1 i
SWIFT
Subaru
Palomar
FRB190520
Palomar/DBSP
z~0.24
Observed Wavelength (Å)

Host galaxy of FRB 190520

a Star-forming dwarf galaxy

Tsai et al. 2021
In prep.



Analogy: NGC1140
a dwarf irregular galaxy

FRB 190520: *the hipper and weirder brother of 121102*

In Review | nature portfolio

"this is a highly significant result and well worthy of publication."

PHYSICAL SCIENCES - ARTICLE

A highly active repeating fast radio burst in a complex local environment

Di Li, C.H. Niu, Kshitij Aggarwal, Xian Zhang, Shami Chatterjee, Chao-Wei Tsai, Wenfei Yu, Casey Law, Sarah Burke-Spolaor, James Cordes, Yongkun Zhang, Stella Ocker, Jumei Yao, P. Wang, Yi Feng, Yuu Niino, Christopher Bochenek, Marilyn Cruces, Liam Connor, Ji-an Jiang, Shi Dai, Rui Luo, Guodong Li, C.C. Miao, J.R. Niu, Reshma Anna-Thomas, Daniel Stern, Weiyang Wang, Mao Yuan, Youling Yue, D.J. Zhou, Zhen Yan, Weiwei Zhu, Bing Zhang

BADGES

Prescreen

PEER REVIEW TIMELINE

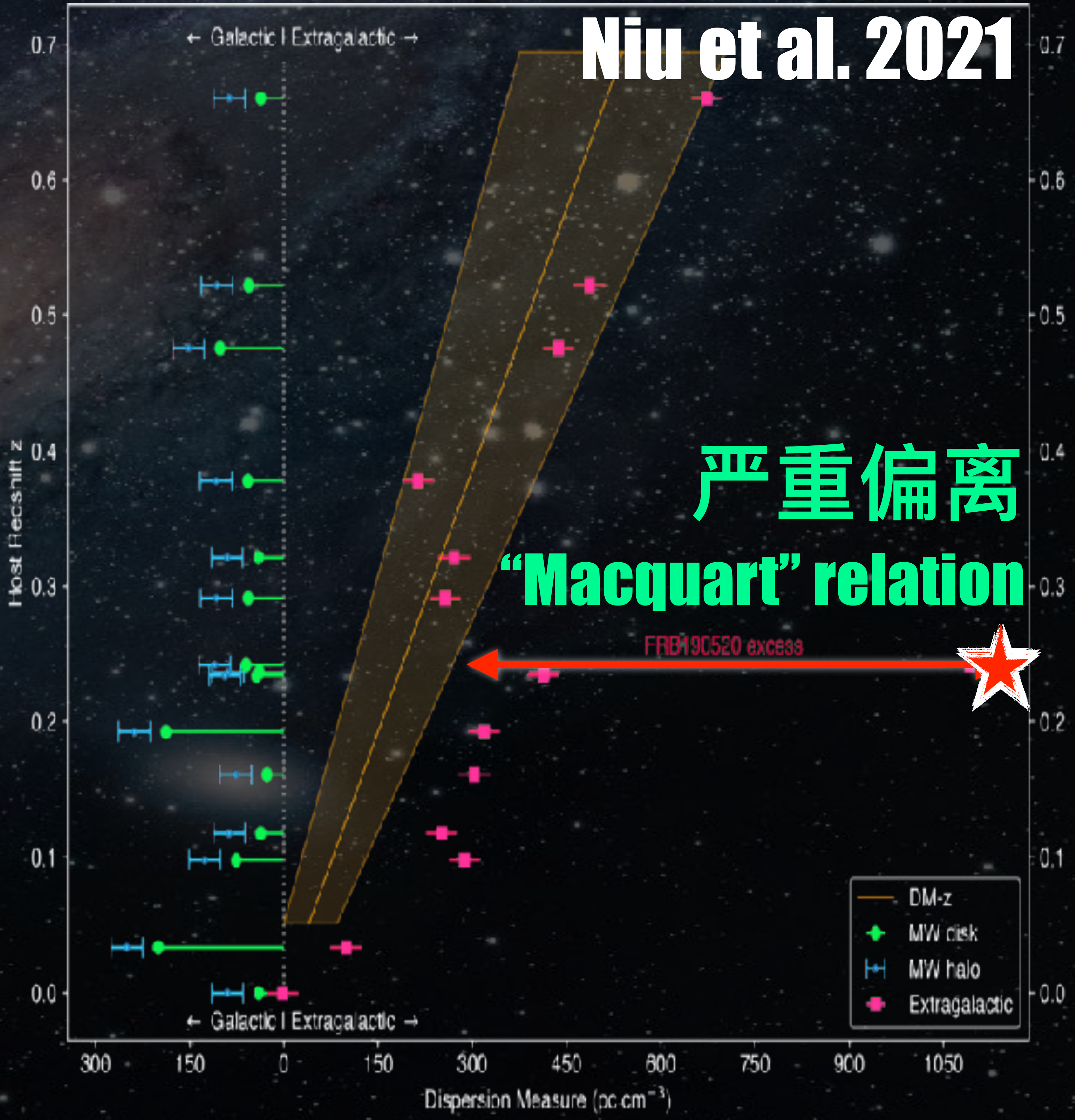
CURRENT STATUS: UNDER REVIEW

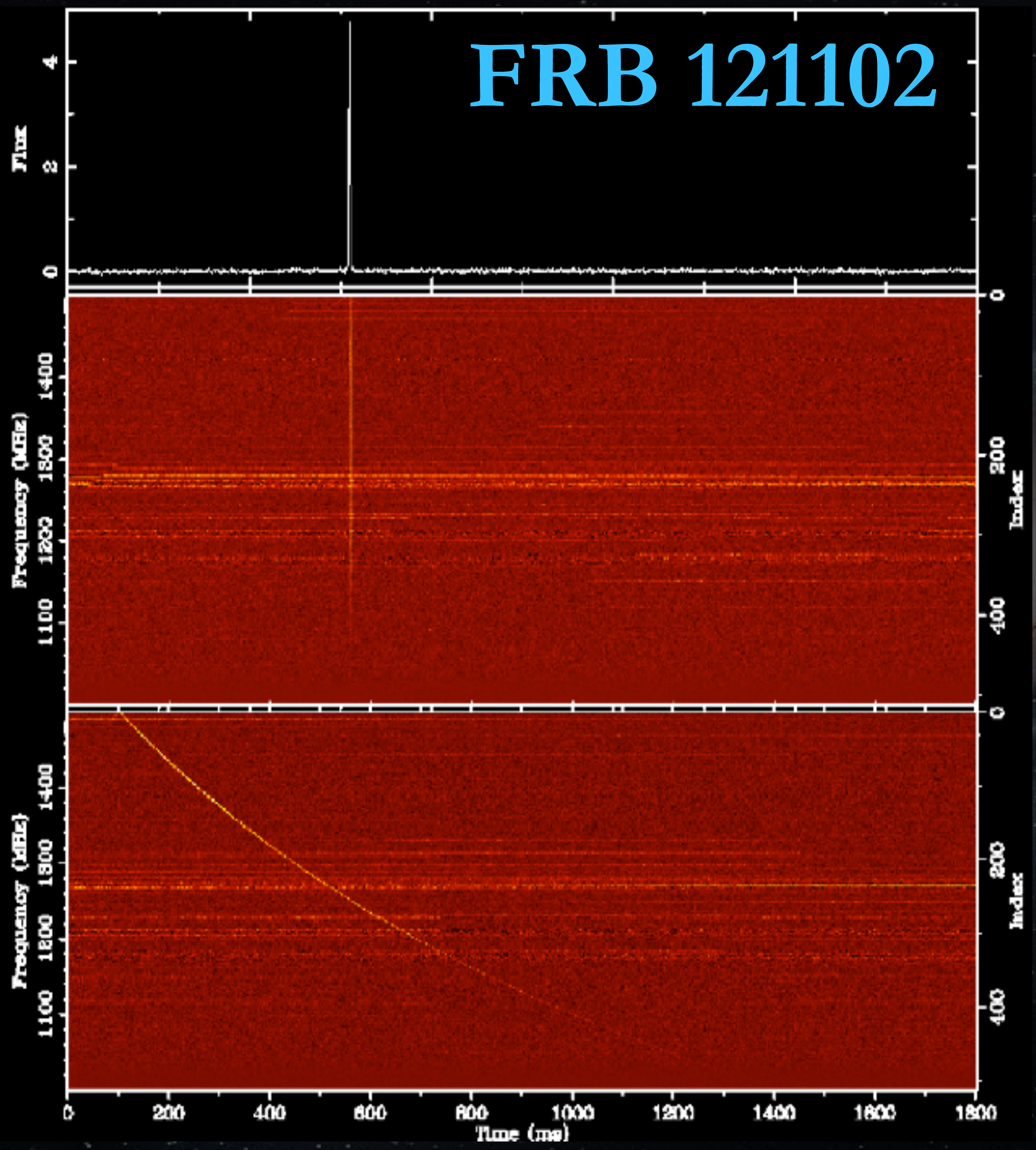
Version 1

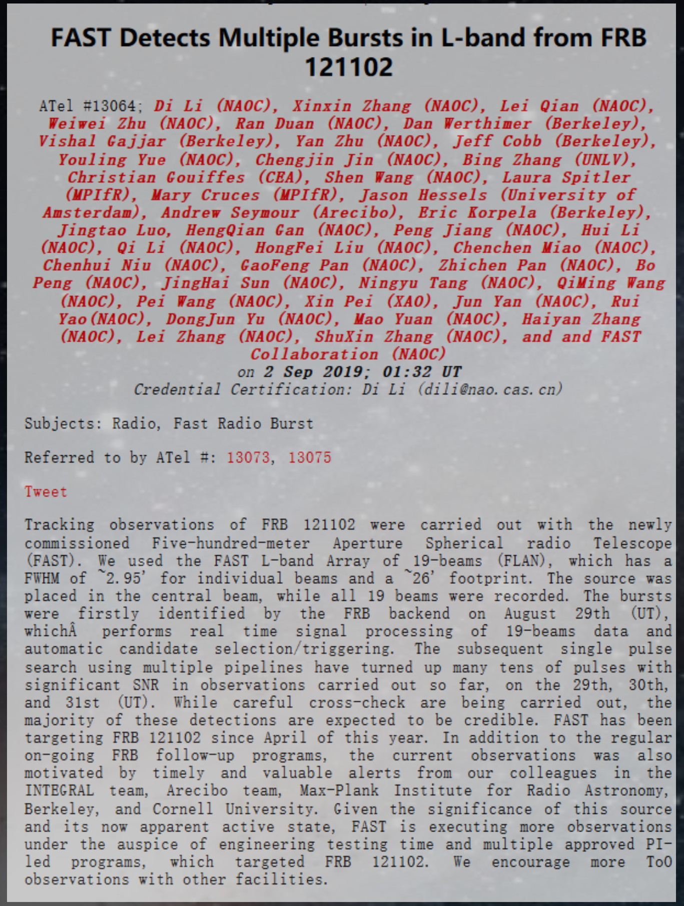
Posted 28 Jul, 2021

Extraordinary Properties

- ❖The **highest DM$_{host}$** ~ 912 pc cm-3
- ❖The **2nd compact PRS** confirmed to co-locate with a FRB
- ❖ **Extreme Activity**: ~300 bursts by FAST, JVLA, Parkes, GBT and VLBA in multiple bands.







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), Mao 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)

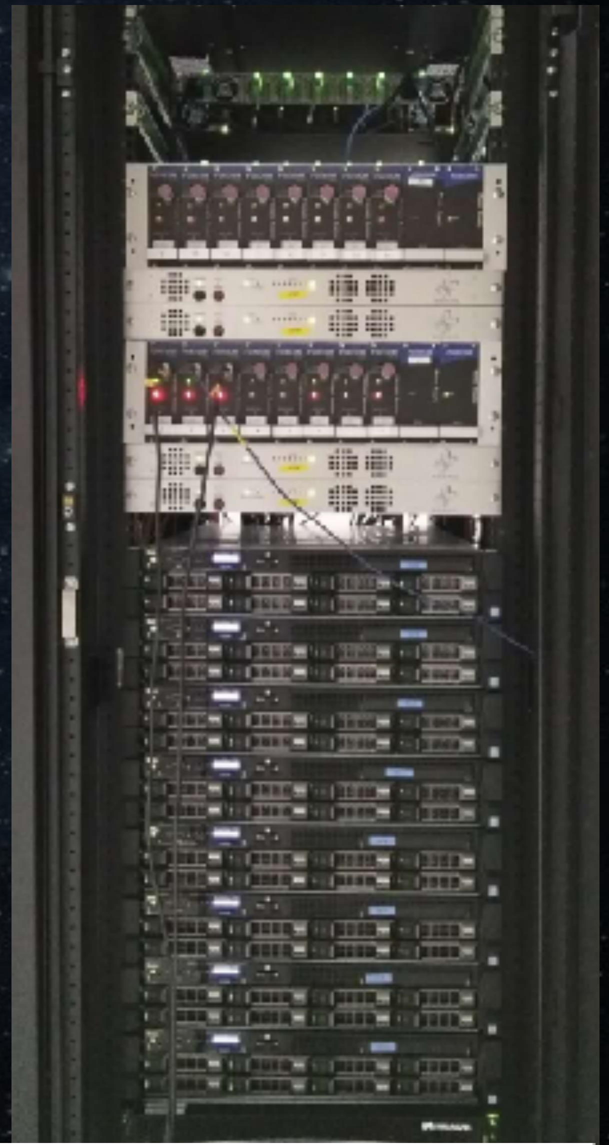
Subjects: Radio, Fast Radio Burst

Referred to by ATel #: 13073, 13075

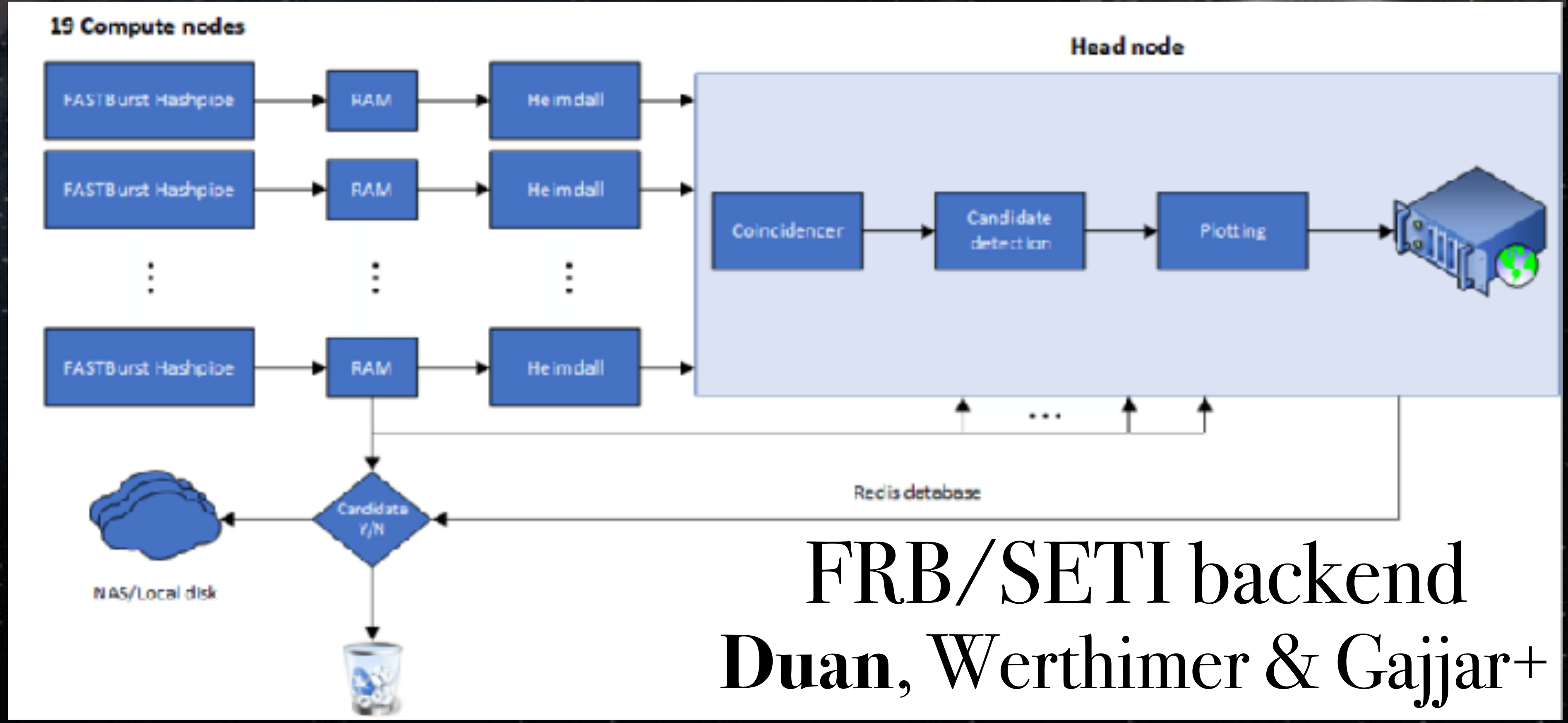
Tweet

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.

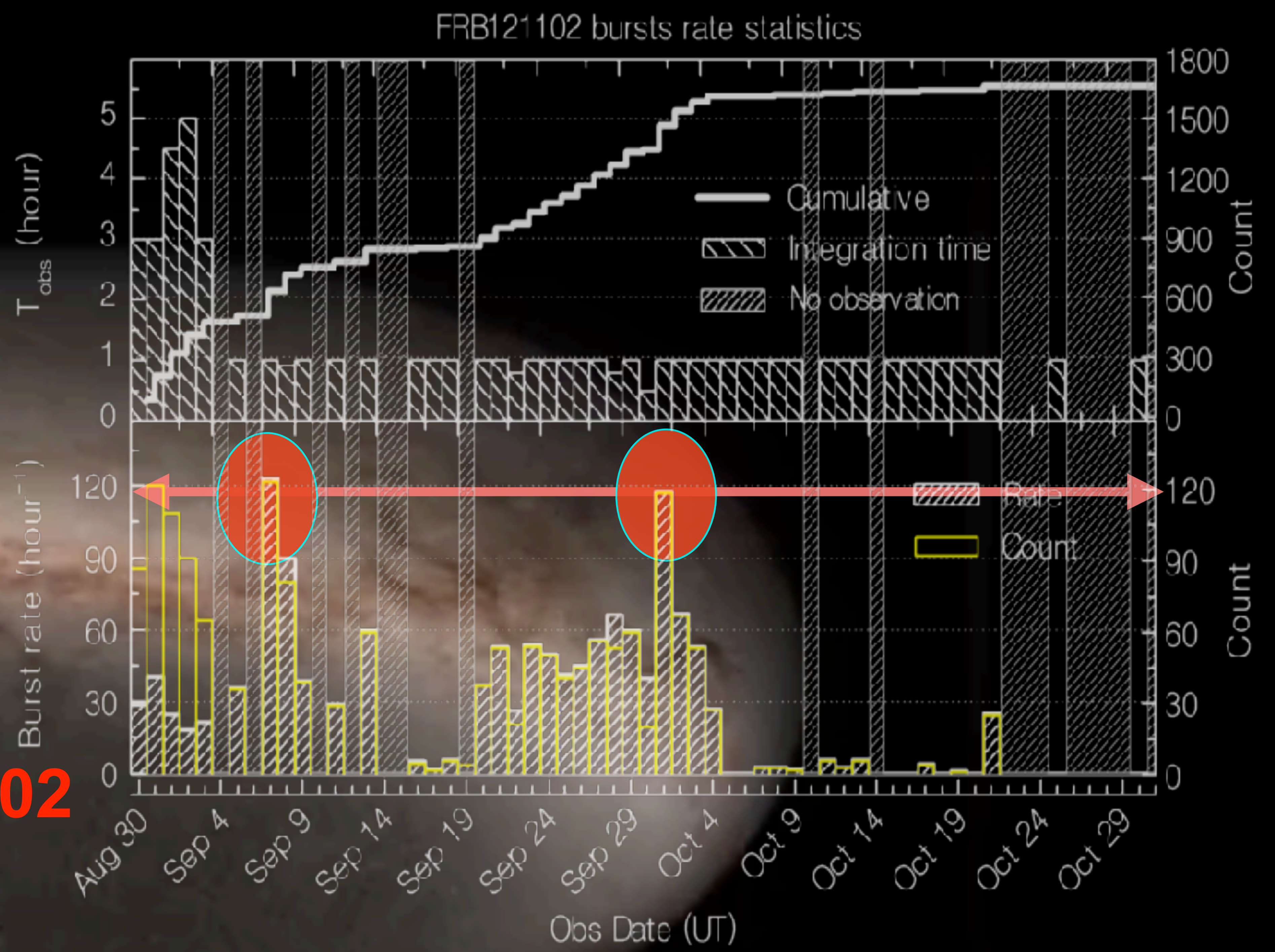
Zhang+ 2019



Li et al. 2019 ATel *#13064*



FRB/SETI backend
Duan, Werthimer & Gajjar+



FRB 121102

2021

"1652 pulses in 59 days!" - Li et al. 2021

FRB121102 Burst Energy Statistics

$$E \simeq \frac{4\pi D_L^2}{(1+z)} \mathcal{F}_\nu \nu_c$$
$$= (10^{39}\ \mathrm{erg}) \frac{4\pi}{(1+z)} \left(\frac{D_L}{10^{28}\ \mathrm{cm}}\right)^2 \frac{\mathcal{F}_\nu}{\mathrm{Jy} \cdot \mathrm{ms}} \frac{\nu_c}{\mathrm{GHz}}$$

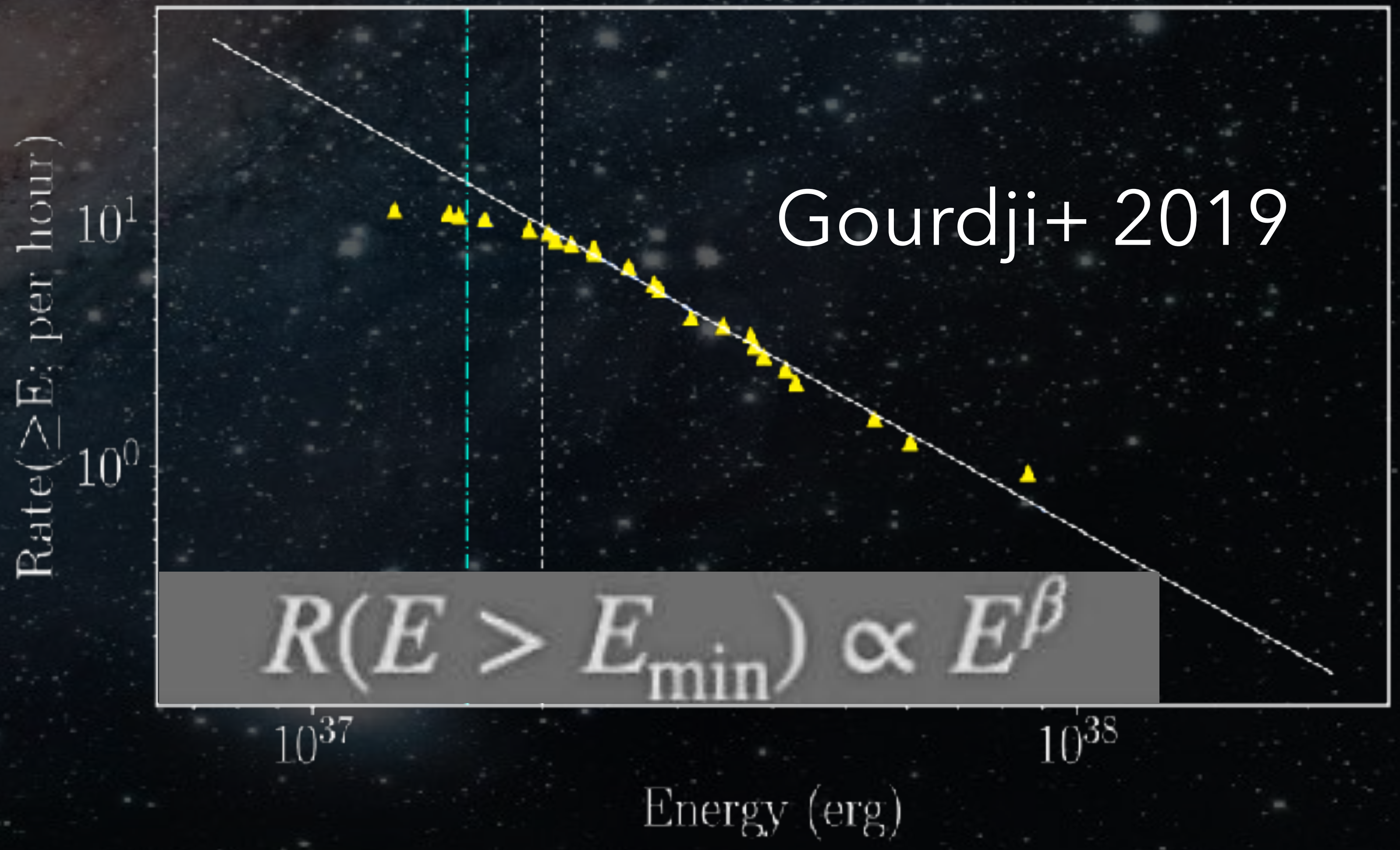
(Zhang 2018)

Cumulative burst energy distribution:

β= -0.7 JVLA, AO, GBT Law+ 2017

β= -1.8±0.3 AO Gourdji+2019

β= -1.2±0.2 Effelsberg Cruces+ 2020

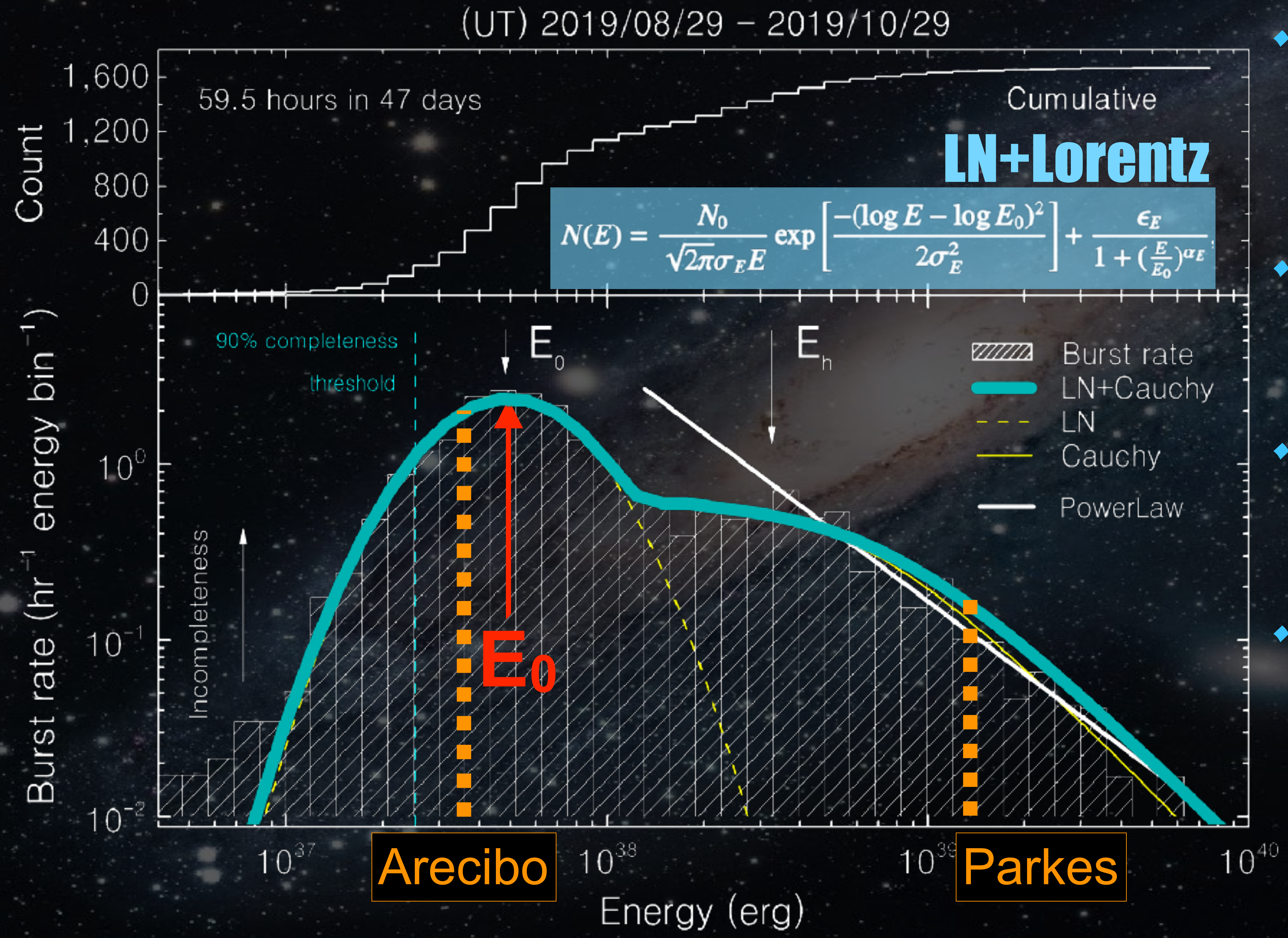


FAST L-band 1.25GHz flux calibration

1σ = 2.1 mJy (1ms) z=0.193, D_L=949Mpc, 1Jy ms = 1.07x 10^{39} erg

7σ = 15 mJy **4 x 10^{36} erg < Energy < 8.0 x 10^{39} erg**

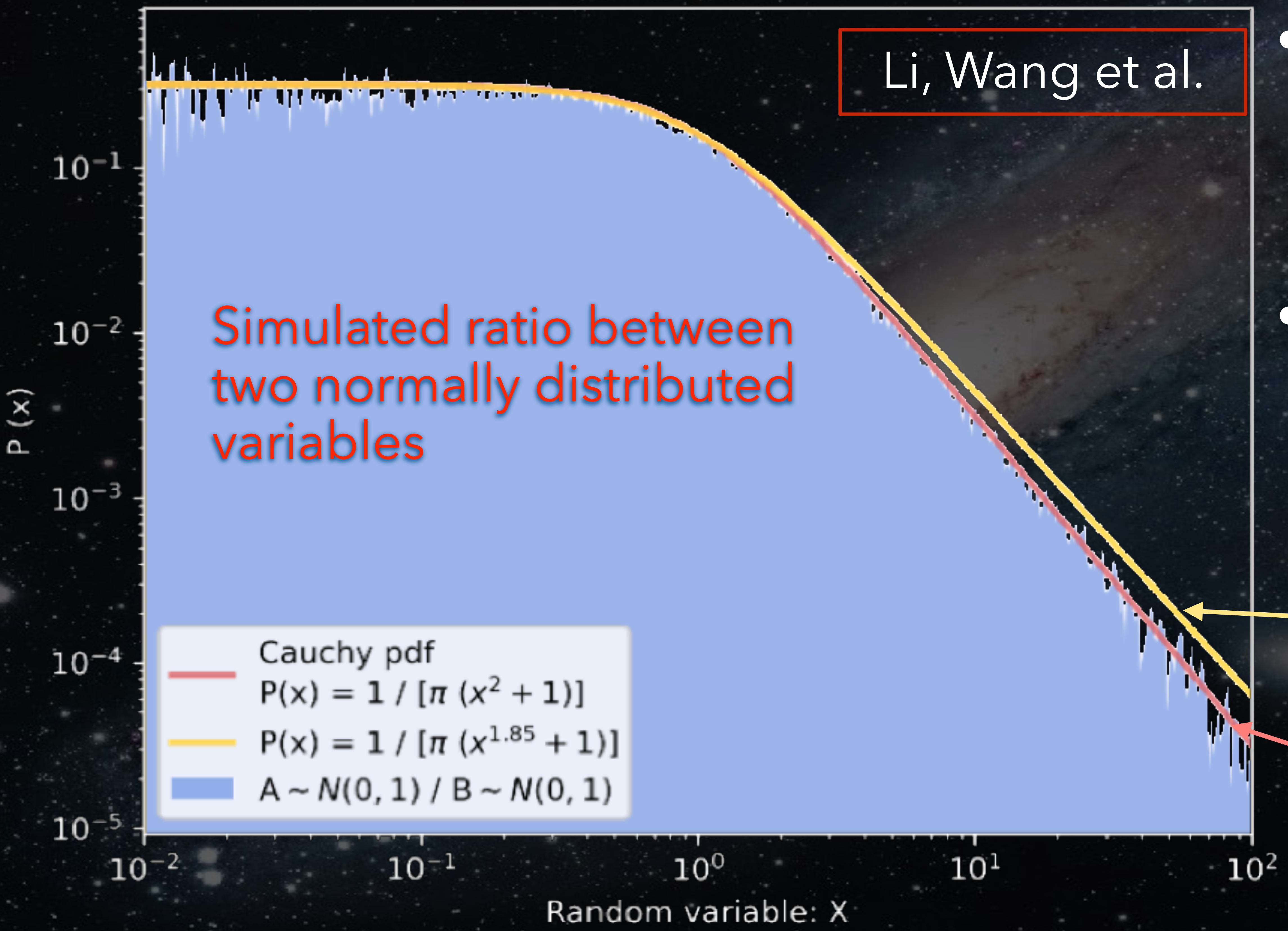
获取世界最大的FRB事件集合 首次确定FRB特征能量



- 2019年8月30日至10月30日，FAST成功监测FRB-121102的极端活动期，最剧烈时段达到117次爆发每小时；
- 累计获取共1652个高信噪比的爆发信号，跨越了3个数量级的亮度范围。
- FRB的爆发率存在特征能量E_0，并由低能端的正则对数加高能端的洛伦兹函数共同描述。
- 排除了单一磁星起源等多种模型，为理解FRB的物理机制提供了重要约束。

Li, **Wang** et al. 2021

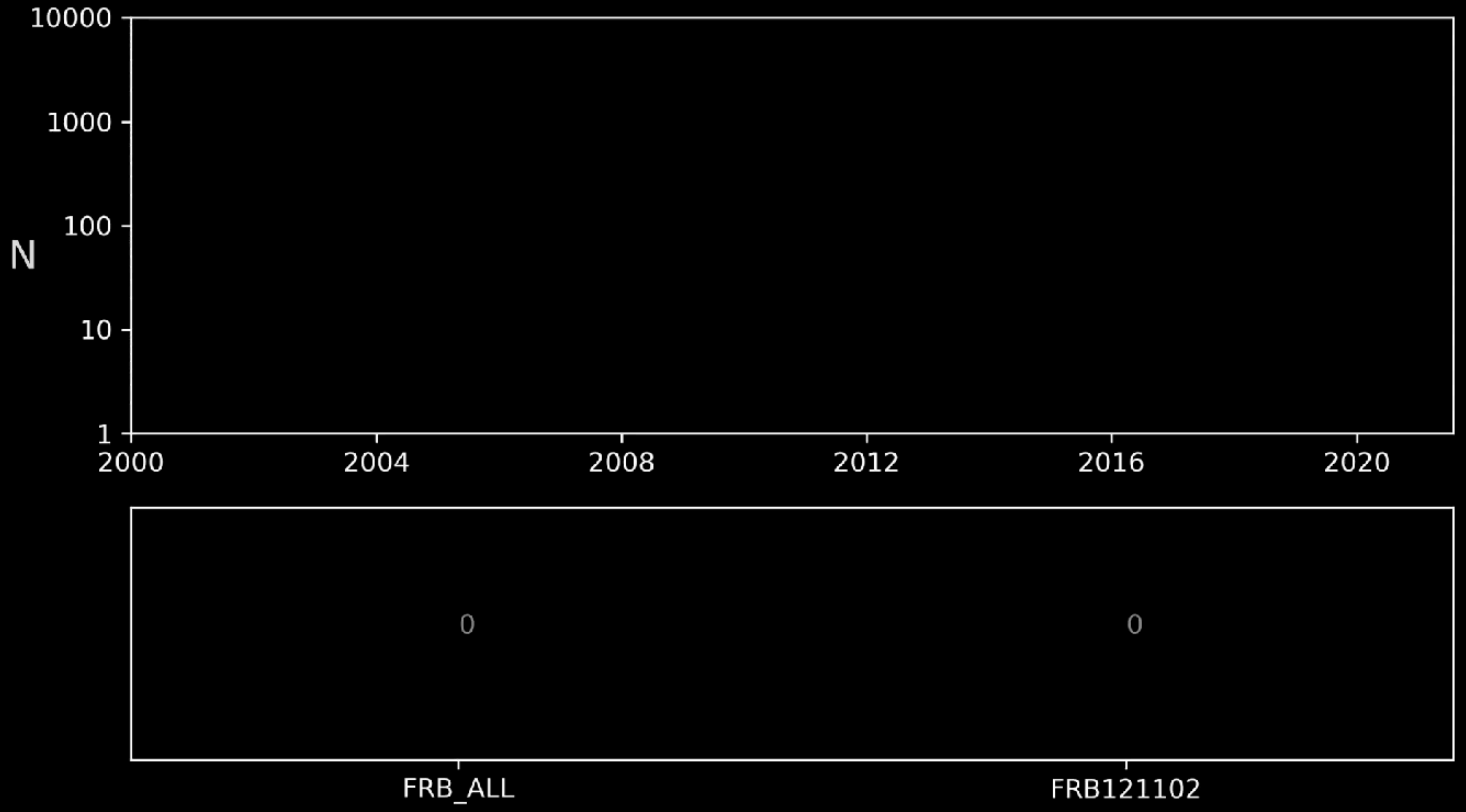
Burst Rate Energy Distribution - bimodel



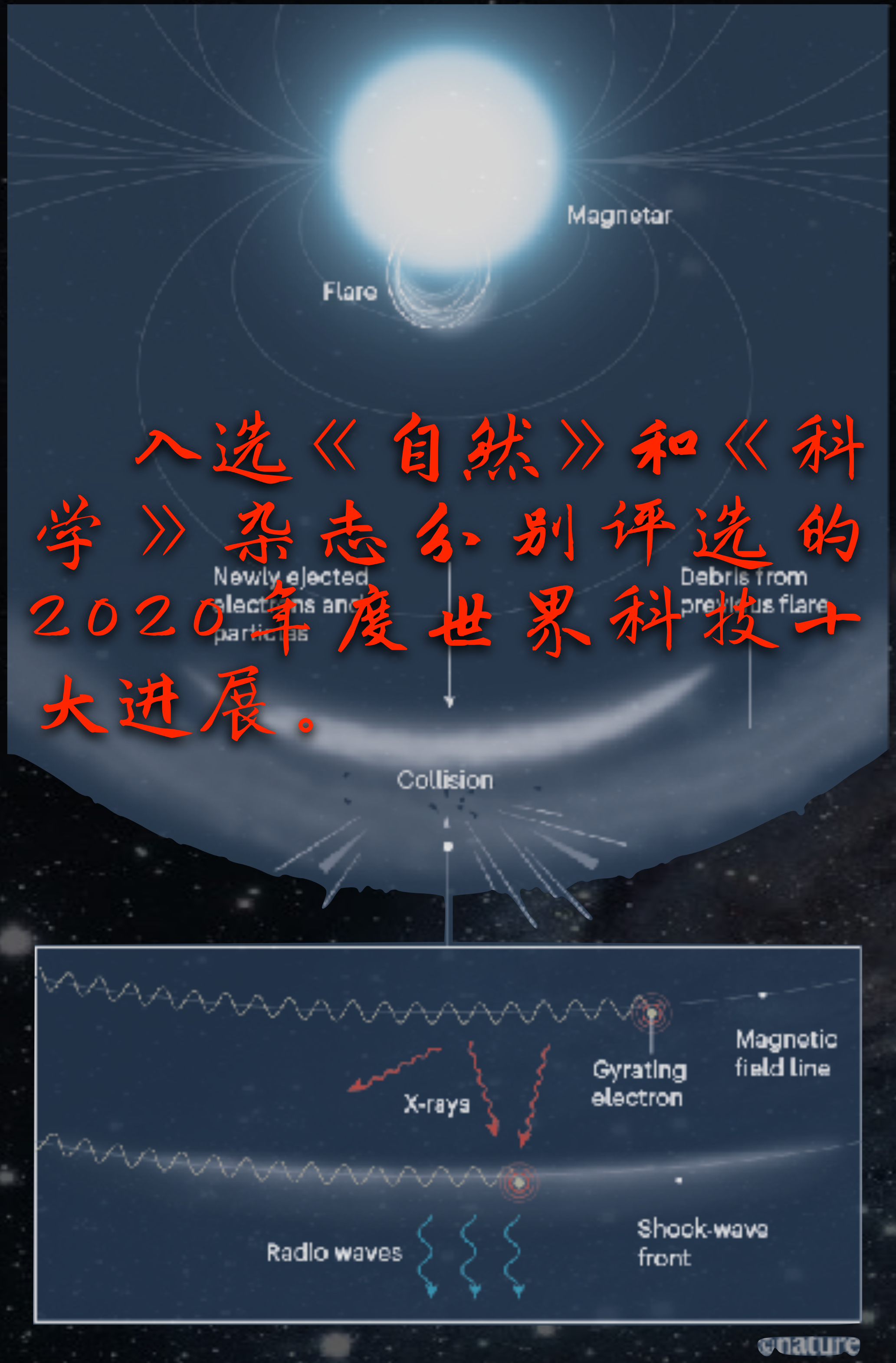
- The Lorentz/Cauchy function describe the ratio between two normally distributed variables
- The best-fit index of 1.85 (generalized Cauchy function) is close to 2 within one σ ~ 0.3

$$p\left(x\right) = \frac{1}{\pi\left(x^{\alpha}+1\right)}$$

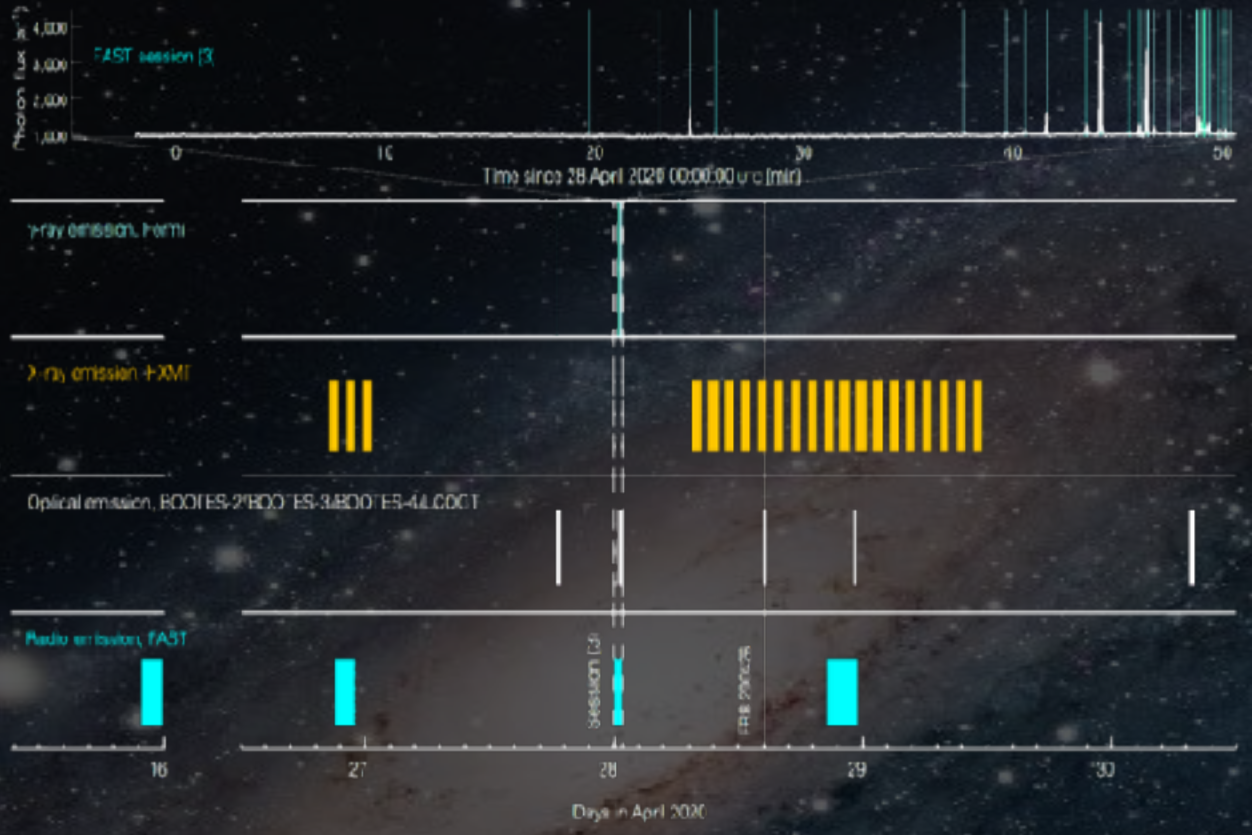
$$p\left(x\right) = \frac{1}{\pi\left(x^{2}+1\right)}$$

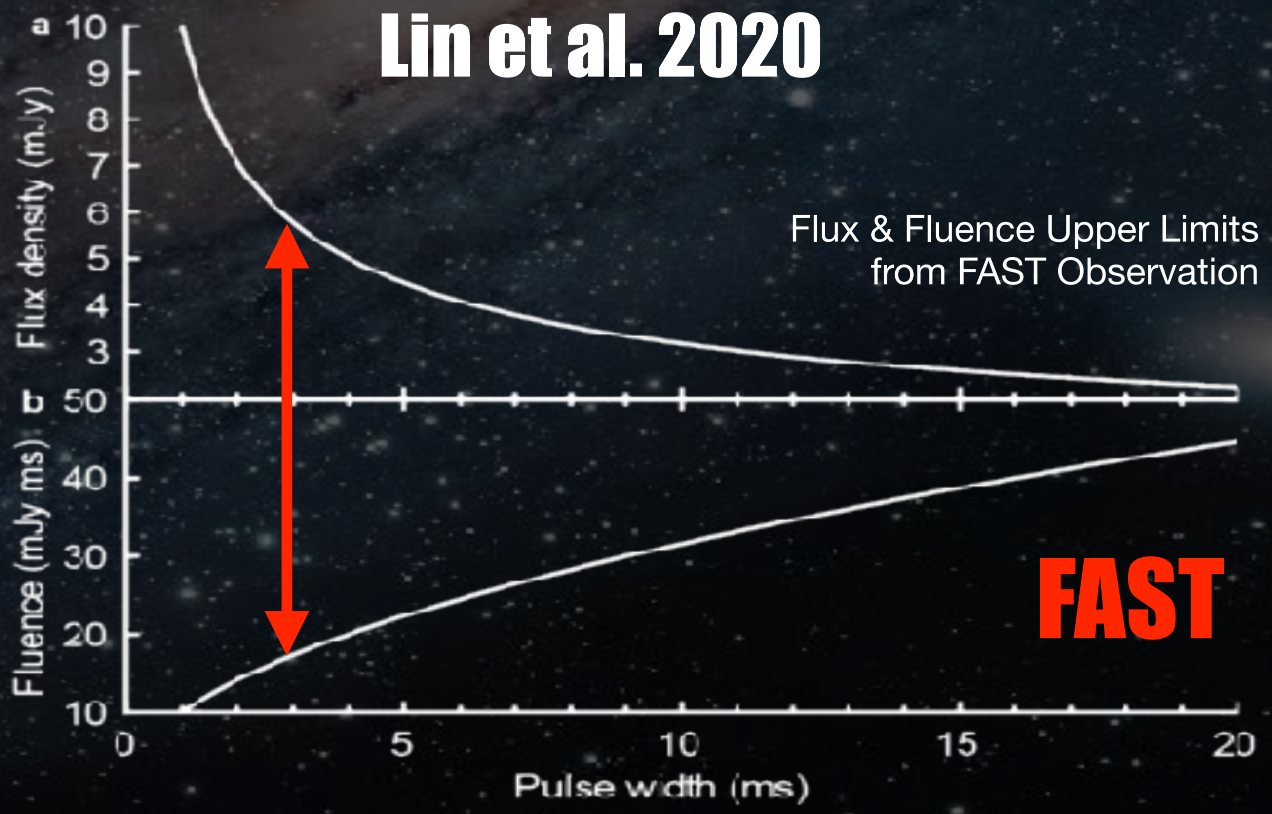

10000
1000
100
N
10
1
2000
2004
2008
2012
2016
2020
0
0
FRB_ALL
FRB121102

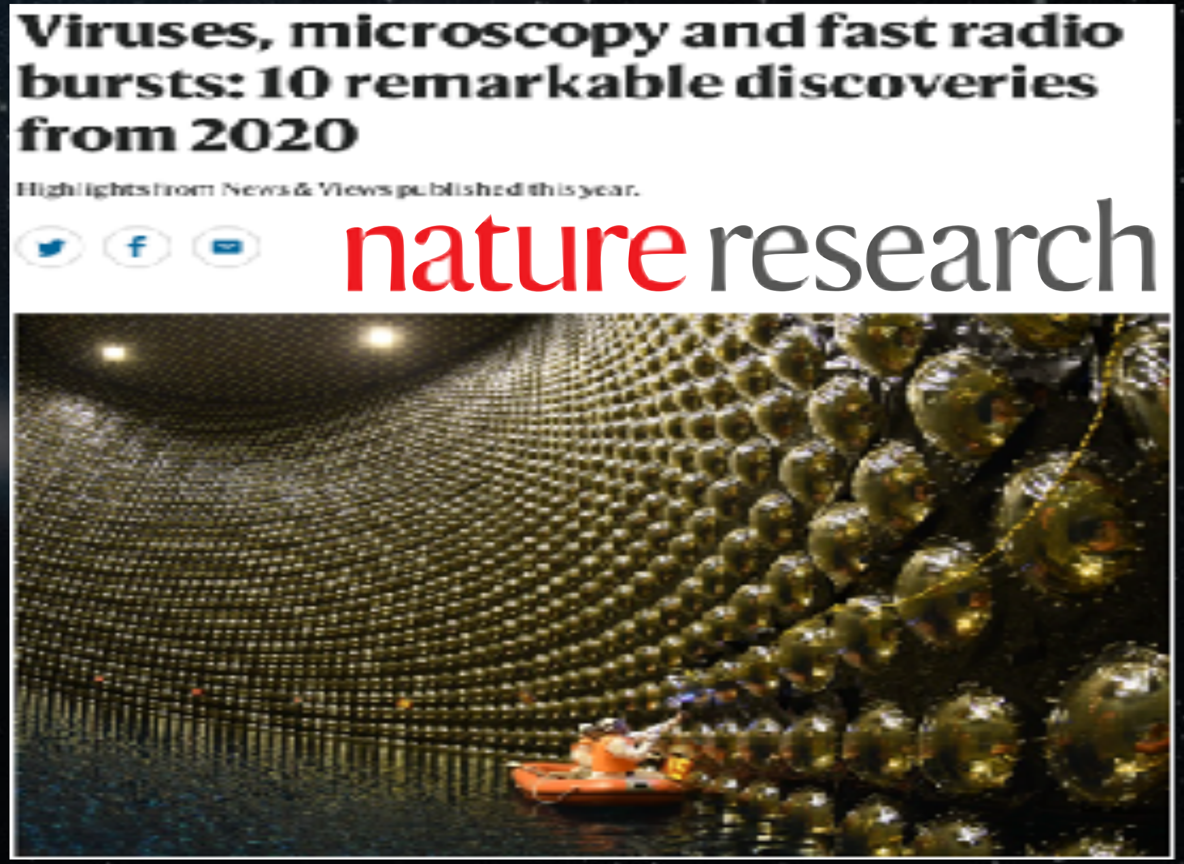
SGR J1935+2154 / FRB 200428 - the first Galactic FRB?



入选《自然》和《科学》杂志分别评选的2020年度世界科技十大进展。

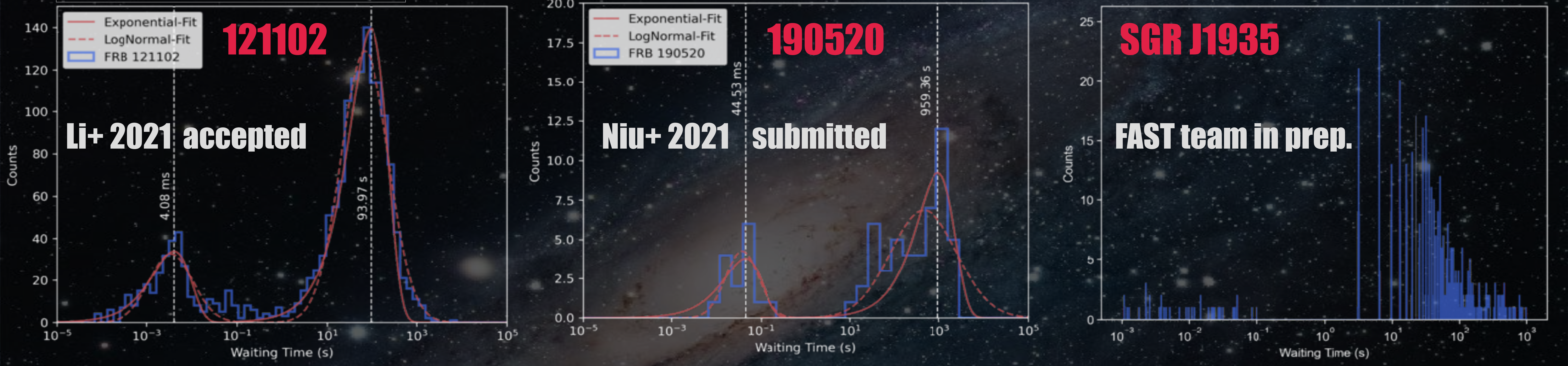


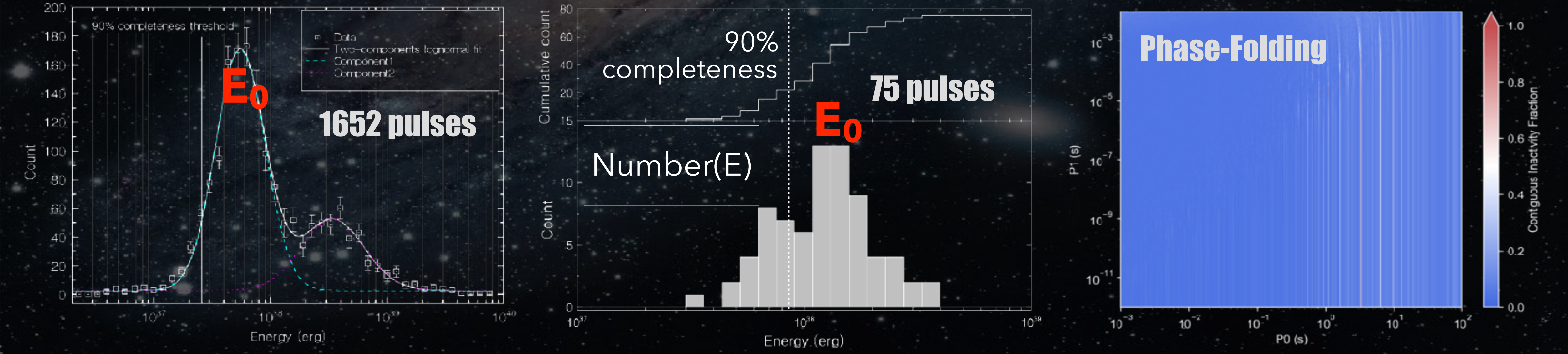


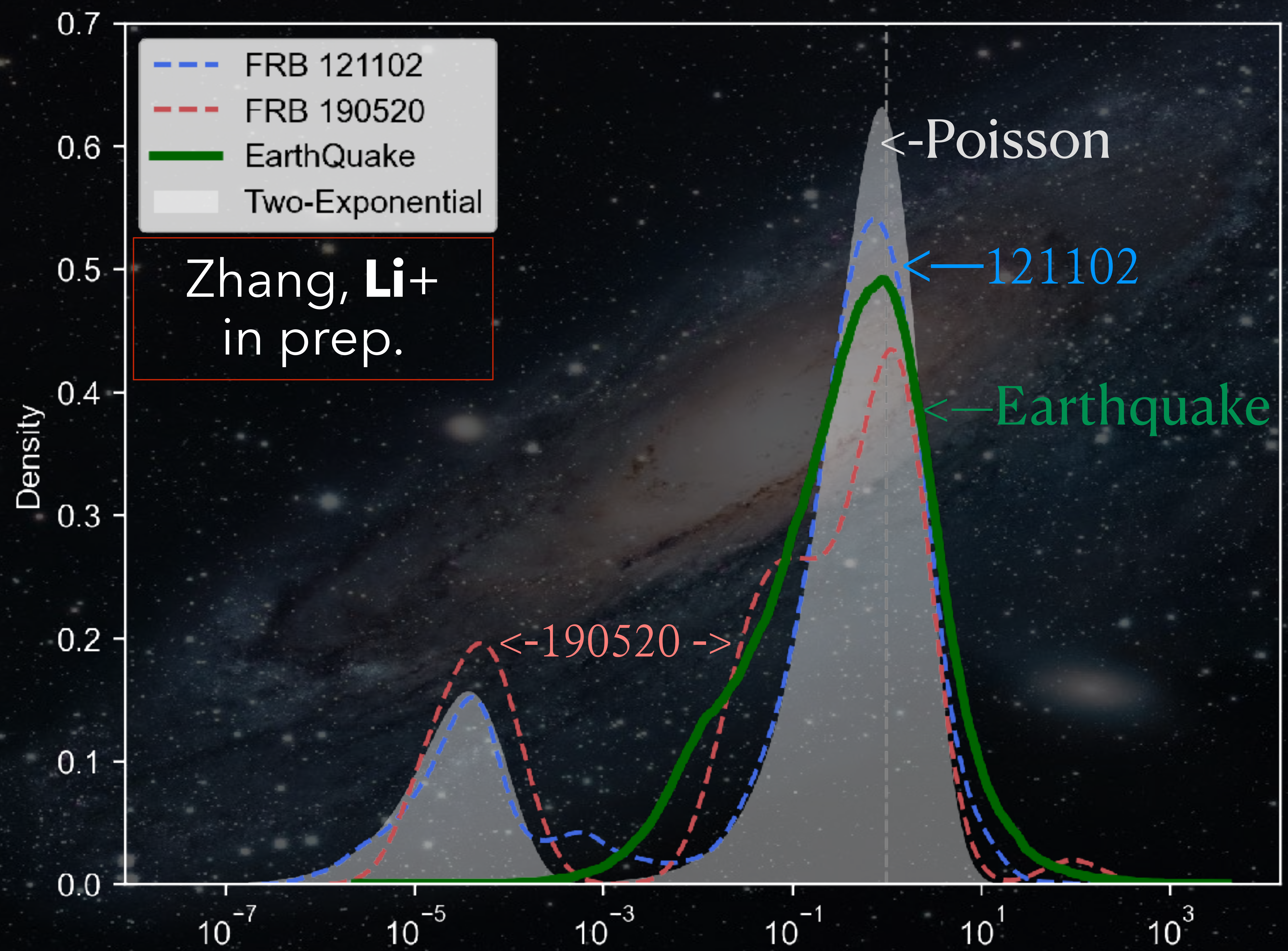


Sibling *Rivalry*?

Waiting Time (s)



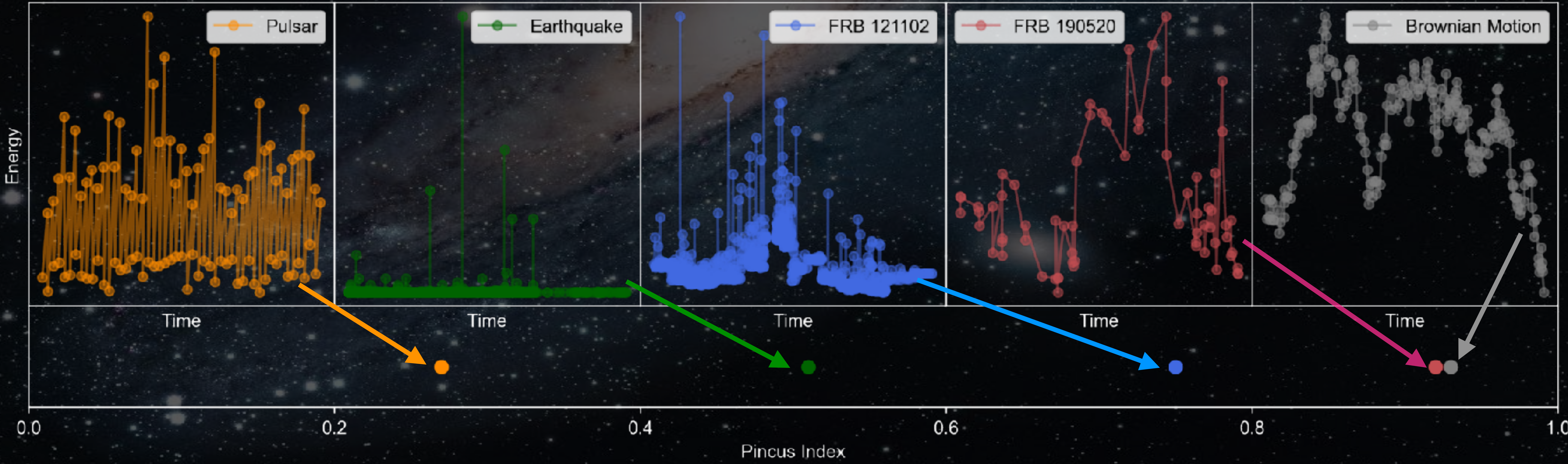


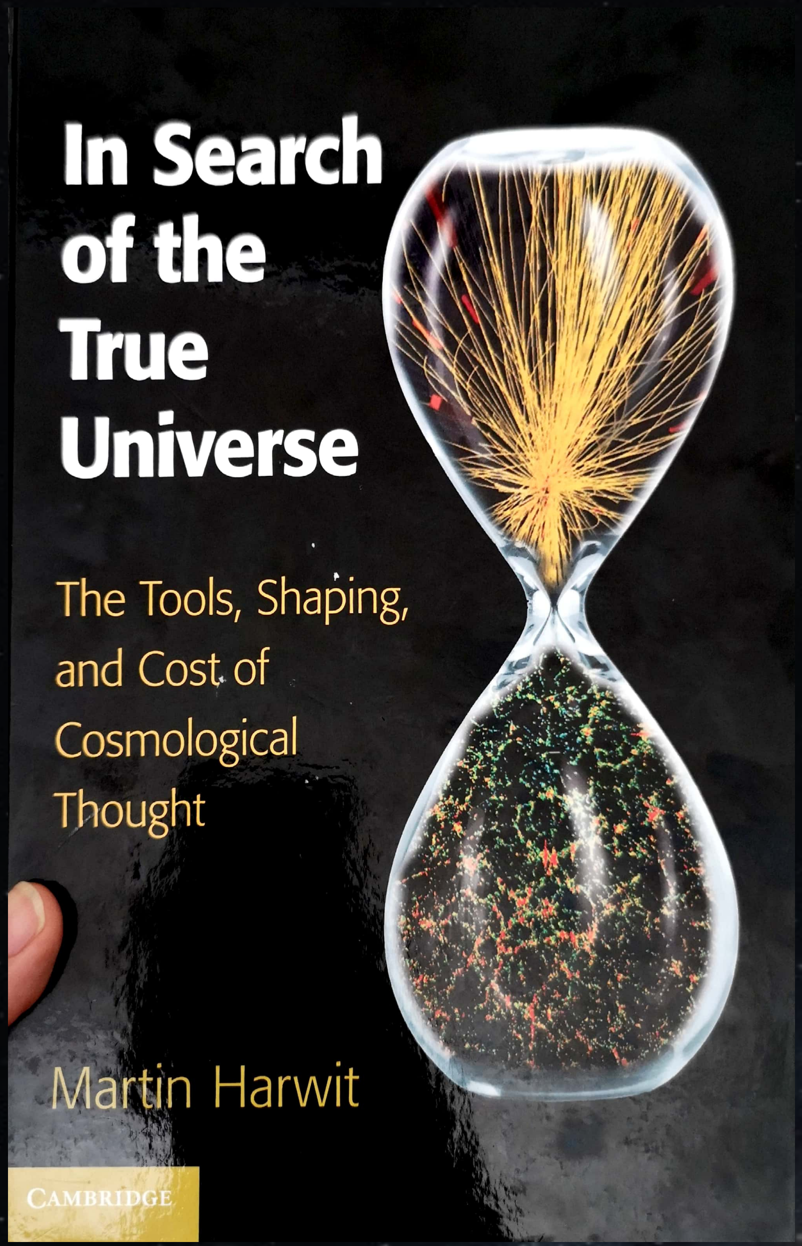


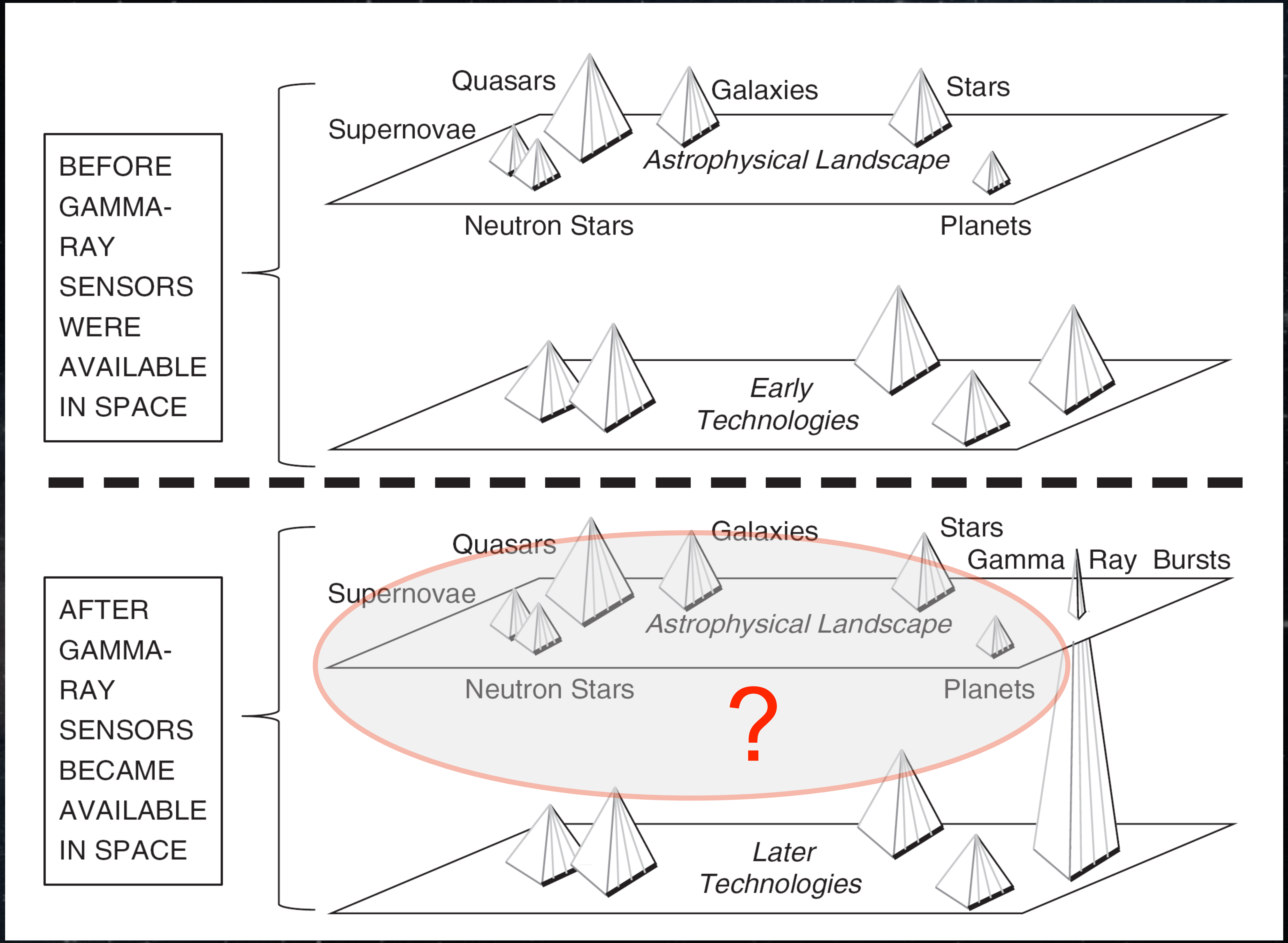
Normalized Waiting Time of two FRBs and Earthquake

Pincus Index

$$MaxApEn = \max_{r} \left(-\frac{1}{N-m} \sum_{i=1}^{N-m} \log \frac{\sum_{j=1}^{N-m} dist(x_j, x_i) < r}{N-m} \Bigg|_{m}^{m+1} \right)$$




In Search of the True Universe
The Tools, Shaping, and Cost of Cosmological Thought
Martin Harwit
CAMBRIDGE


BEFORE GAMMA-RAY SENSORS WERE AVAILABLE IN SPACE
Quasars
Galaxies
Stars
Supernovae
Astrophysical Landscape
Neutron Stars
Planets
Early Technologies
AFTER GAMMA-RAY SENSORS BECAME AVAILABLE IN SPACE
Quasars
Galaxies
Stars
Gamma Ray Bursts
Supernovae
Astrophysical Landscape
Neutron Stars
Planets
?
Later Technologies

Immanuel Kant （1724–1804）

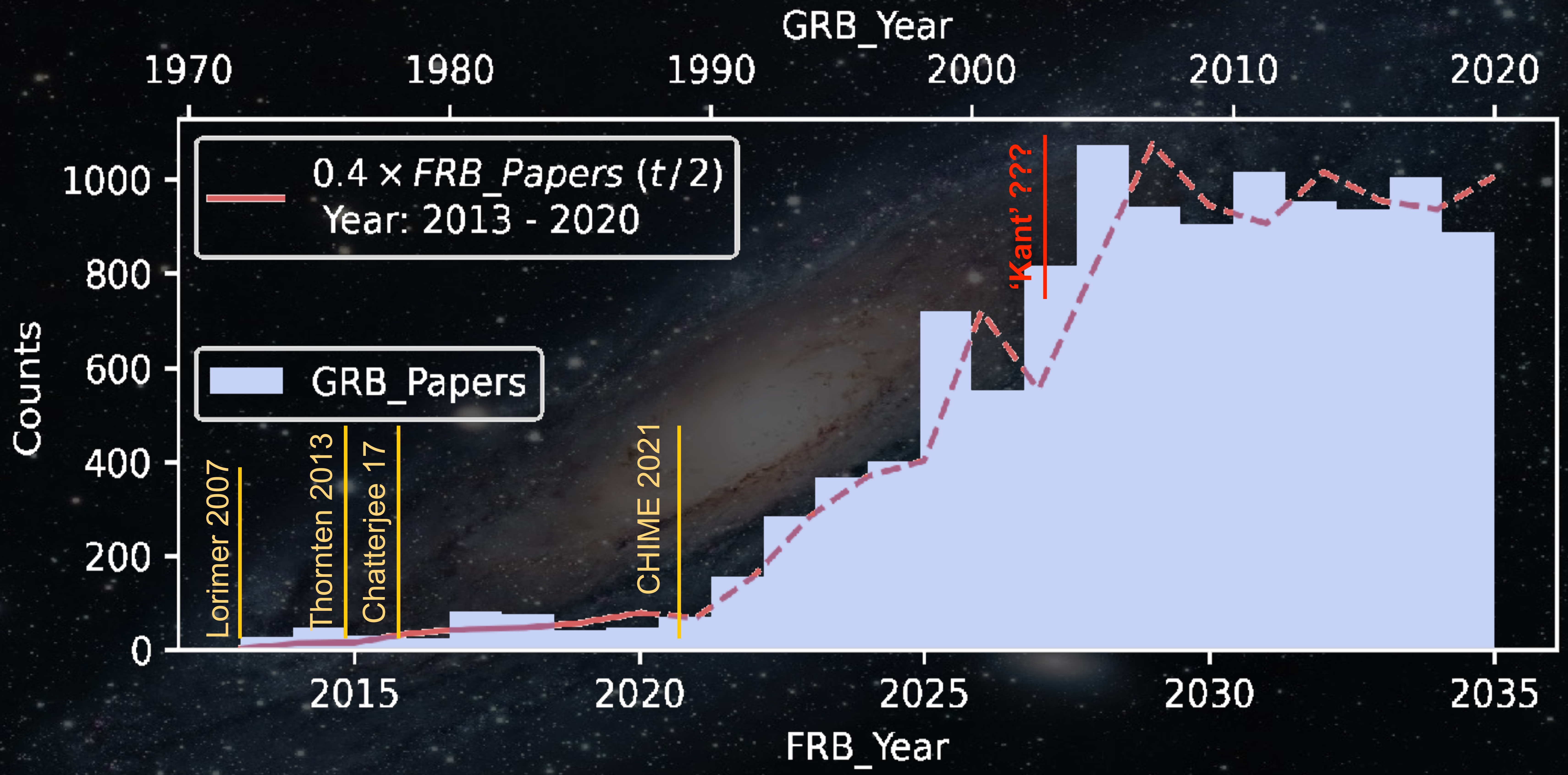
《The Critique of Pure Reason》

A Copernicus revolution: reason within experience

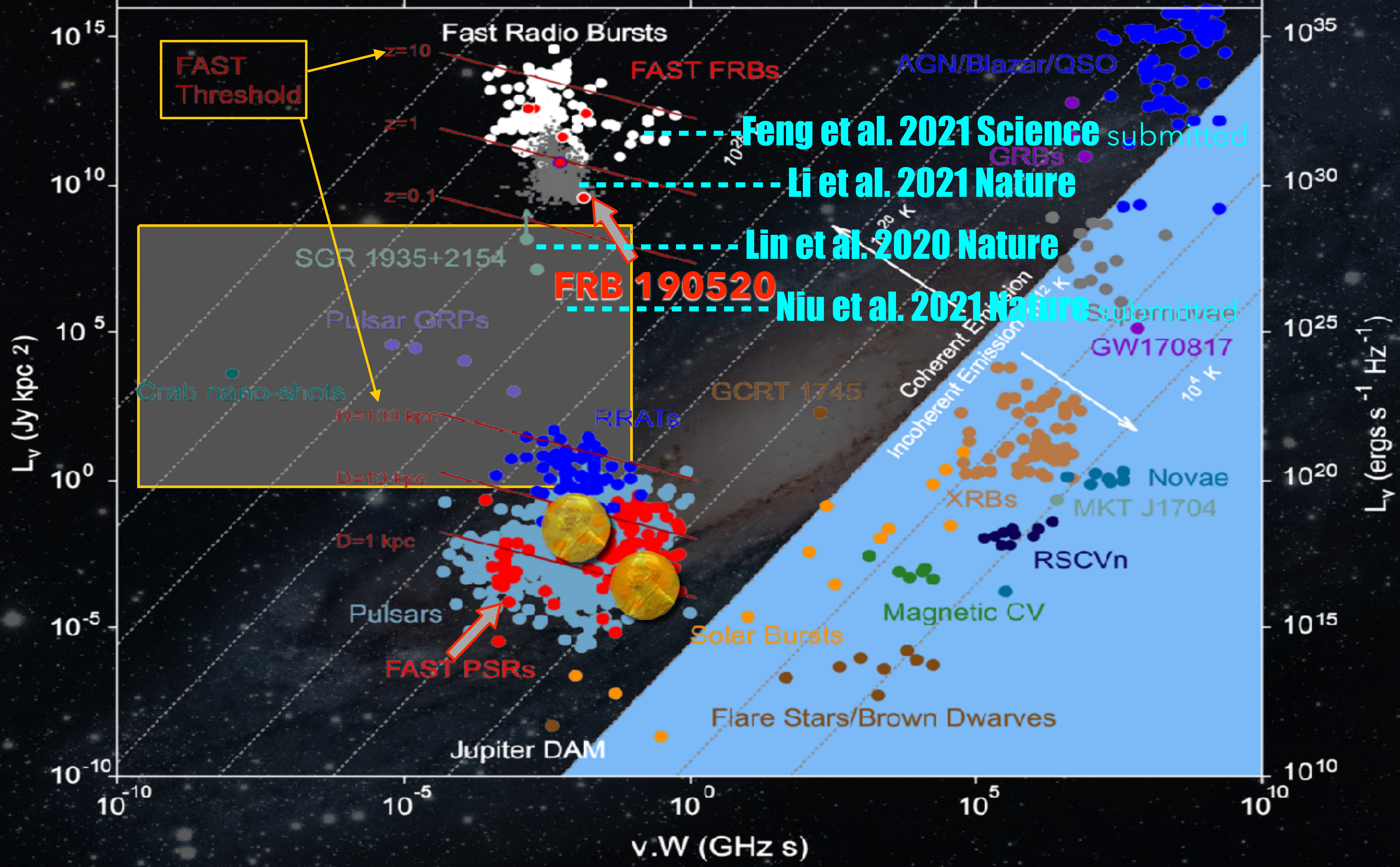
Definitional truth: the agreement of cognition with its object

A priori knowledge: pulsars produces pulses, so do many other processes

Synthetic posteriori judgement: FRB origin?



Li et al. 2021 《科学通报》



FAST

Reveal the Tran-sient Sky

Credit：Wang, Zhang & Niu (cf. Keane 2018 "The Future of FRBs")

Descartes: *"I think therefore I am."*

Kant: *"Thoughts without content are empty. Intuition without concept are meaningless."*

Mach: *"When the human mind, with its limited powers, attempts to mirror in itself the rich life of the world…it has every reason for proceeding economically. In reality, the law always contains less than the fact itself, because it does not reproduce the fact as a whole but only in that aspect of it, which is important for us, the rest being intentionally or from necessity omitted.*


FAST More to come ...
CRAFTS the first commensal survey of pulsars, HI, and transients
CRAFTS discovers hundreds of new pulsars and FRBs
FRB 121102 more pulses than all other FRB publications combined
FRB 190520 the hipper and weirder brother of 121102