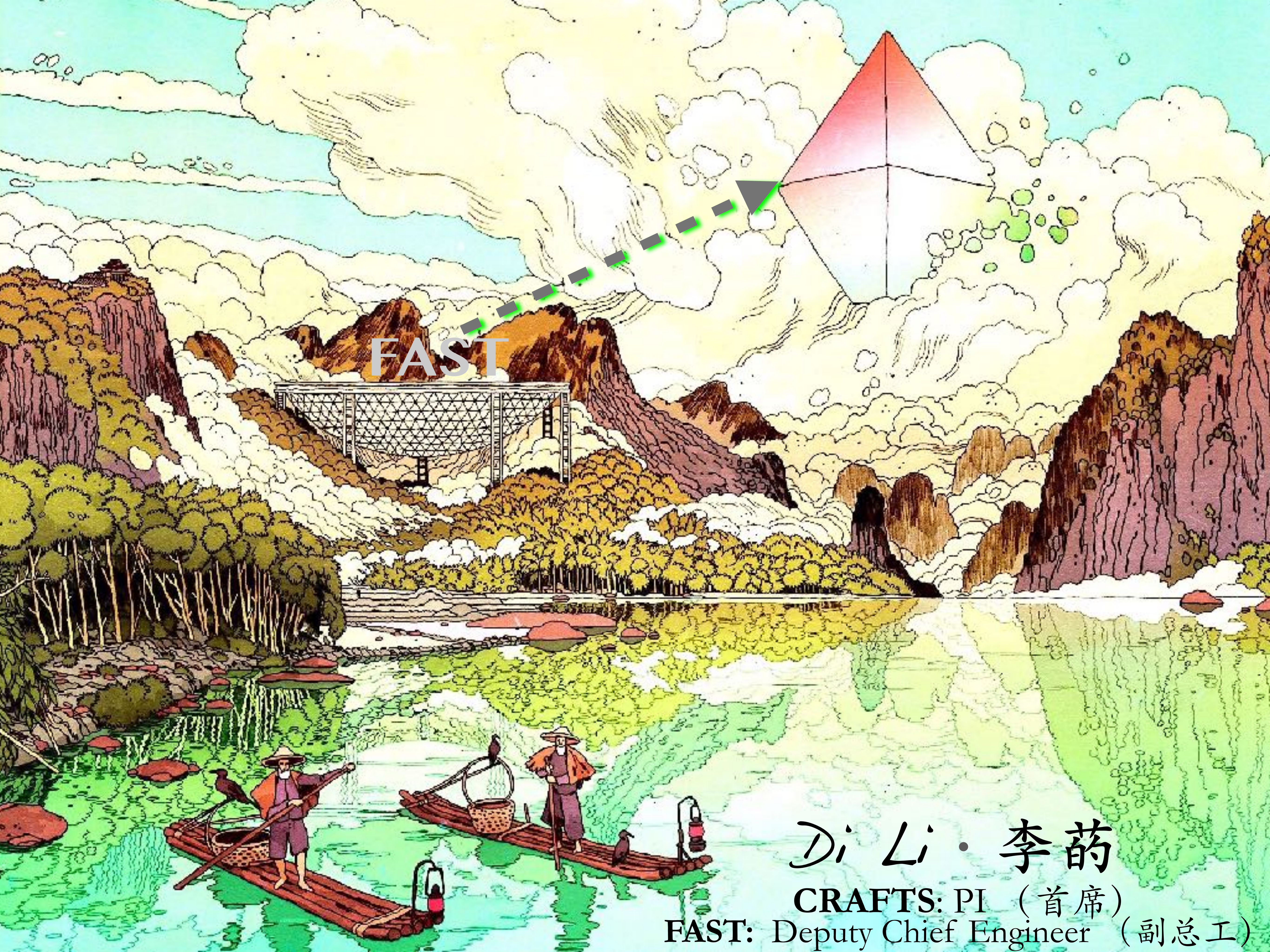
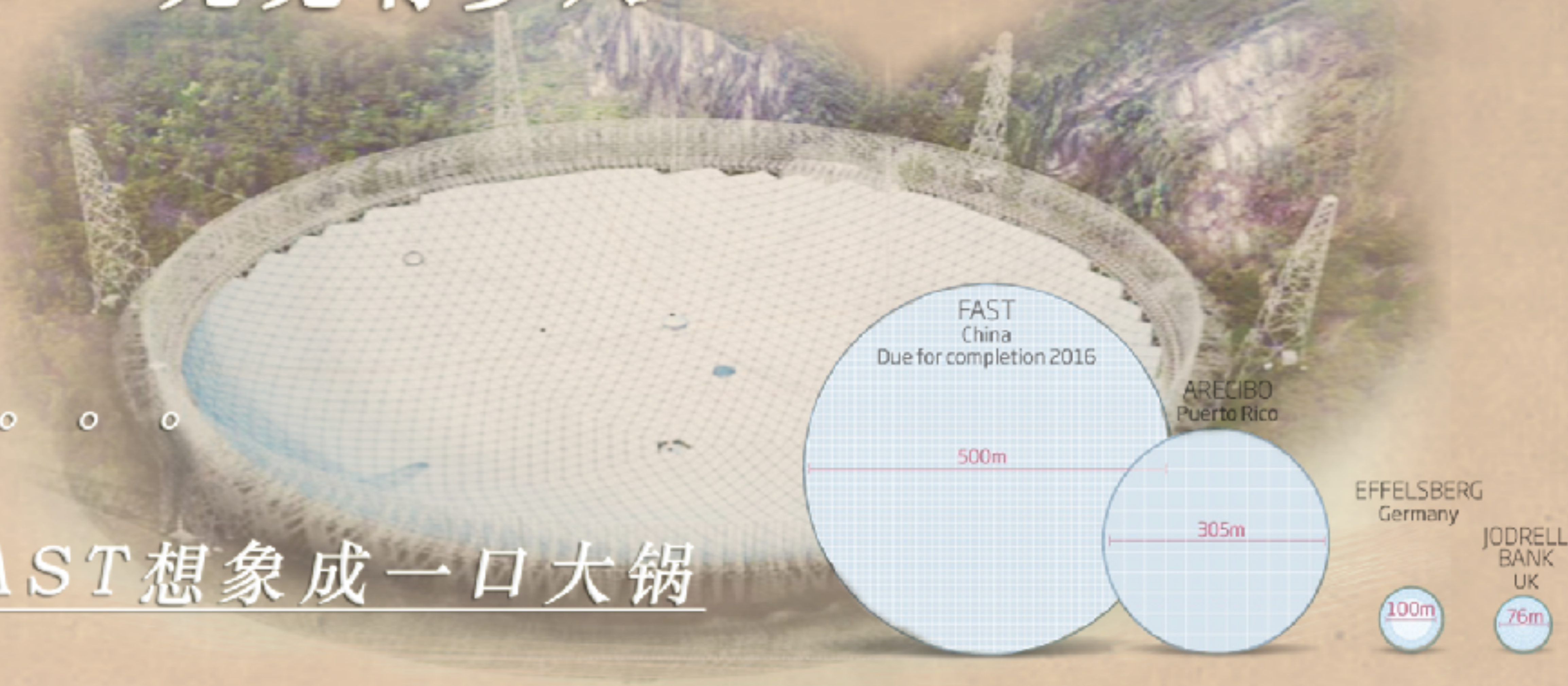

FAST
Di Li · 李菂
CRAFTS: PI （首席）
FAST: Deputy Chief Engineer （副总工）

FAST 究竟有多大？



如果。。。

把FAST想象成一口大锅

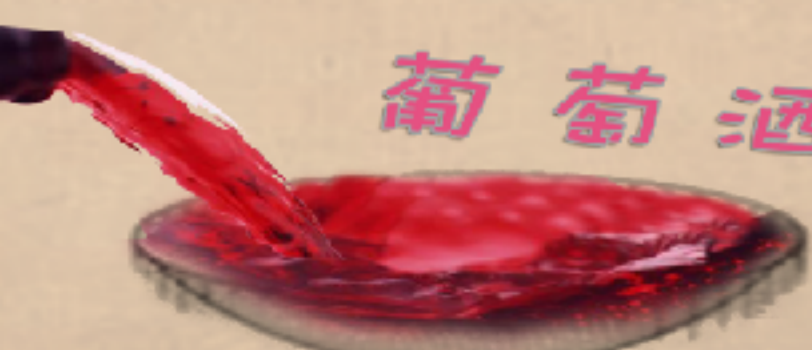
蛋炒饭

重约7.3×10^5吨 （每碗100g）

= 世界每人  ×2

中国每人  ×9

葡萄酒



体积约1.4×10^9L （每瓶500ml）

= 世界每人  ×0.4

中国每人  ×2

Outline

- FAST Concepts and Innovations
- Science Preparation and Potentials
- The Commensal Radio Astronomy FAST Survey (CRAFTS)
  Unprecedented radio survey mode
- Challenges and Breakthroughs
  Unprecedented challenges

Timeline

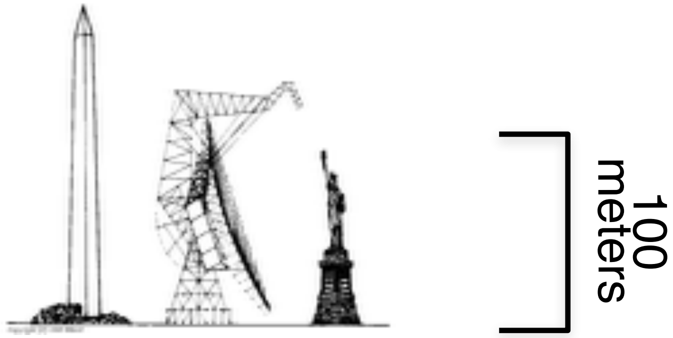
- **Project Approval:** December, 2007
- **Construction Commence:** March, 2011 (¥1.15Billion)
- **Openning ceremony:** Sep. 25, 2016
- **Commissioning:** 2016 - ~2018

  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

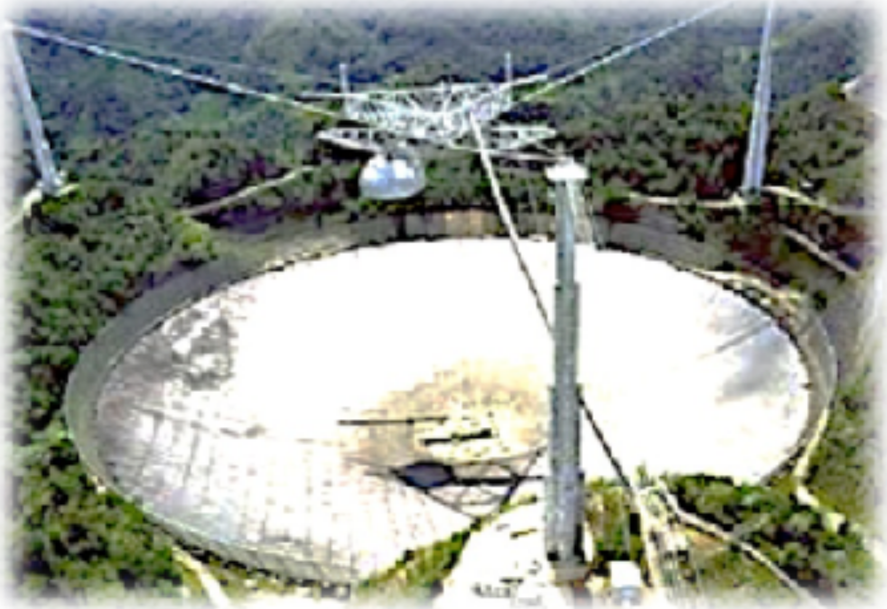
"中国天眼"

Five-hundred-meter **A**perture **S**pherical radio **T**elescope (**FAST**)



GBT

100 m



FAST 500 m

Arecibo 300 m

Measurement

(1) Anchor Grids

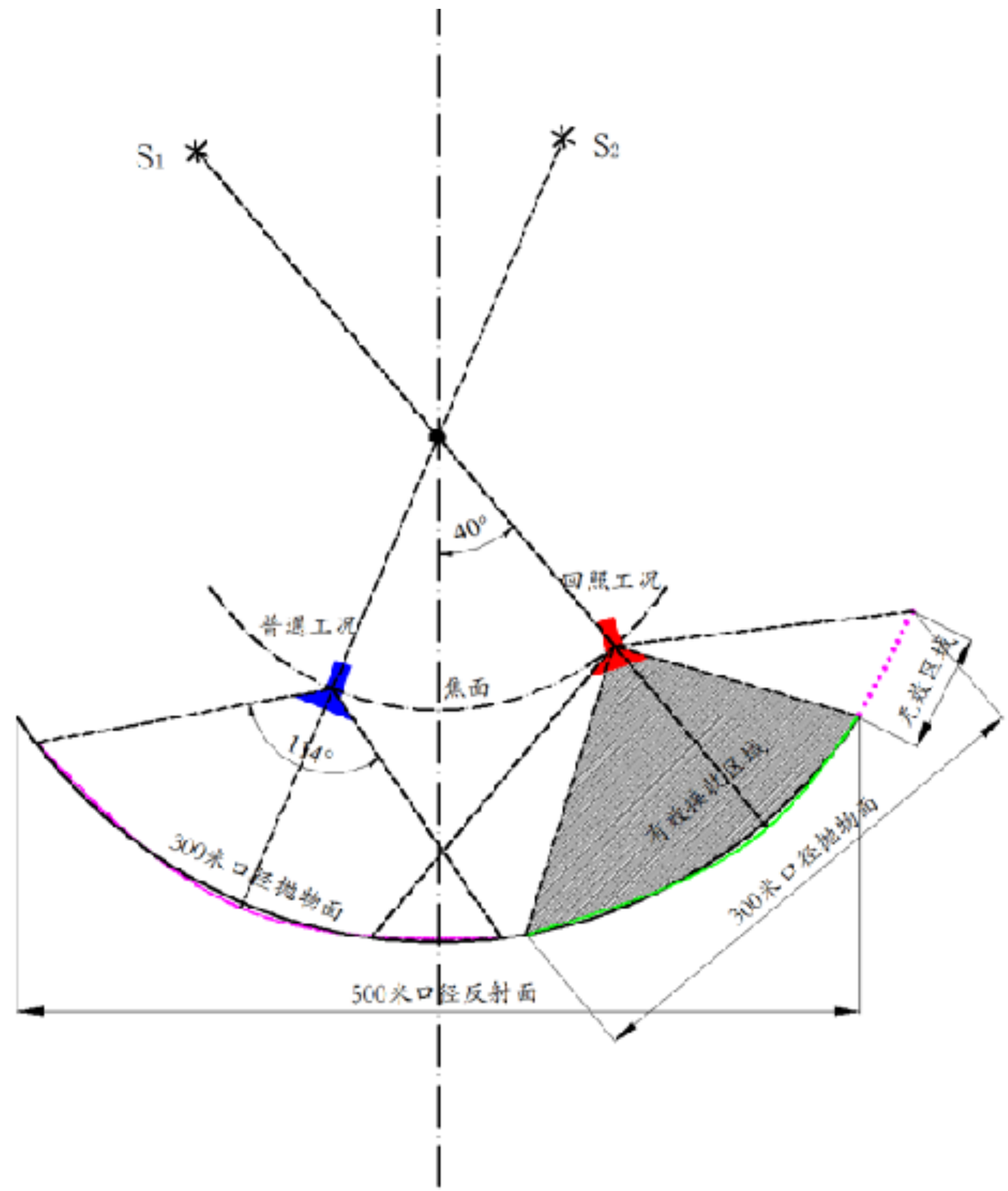
Anchor points: 5cm+0.5"
Baseline: 1mm
Time accuracy: 10ms

(2) Feed Cabin

Supporting tower: 2cm
Cabin Initial Position: 2mm
Cabin dynamic measurement: 3mm
Cabin dynamic control: 10mm
Frequency: 5Hz

(3) Primary Panels

Actuator anchor point: 2cm
Cable mesh system anchor point: 2cm
Panel connecting nodes: 1.5mm
Nodes dynamic measure and control: 2mm
Frequency: 0.0017Hz



FAST Optics

Dynamic Fibers

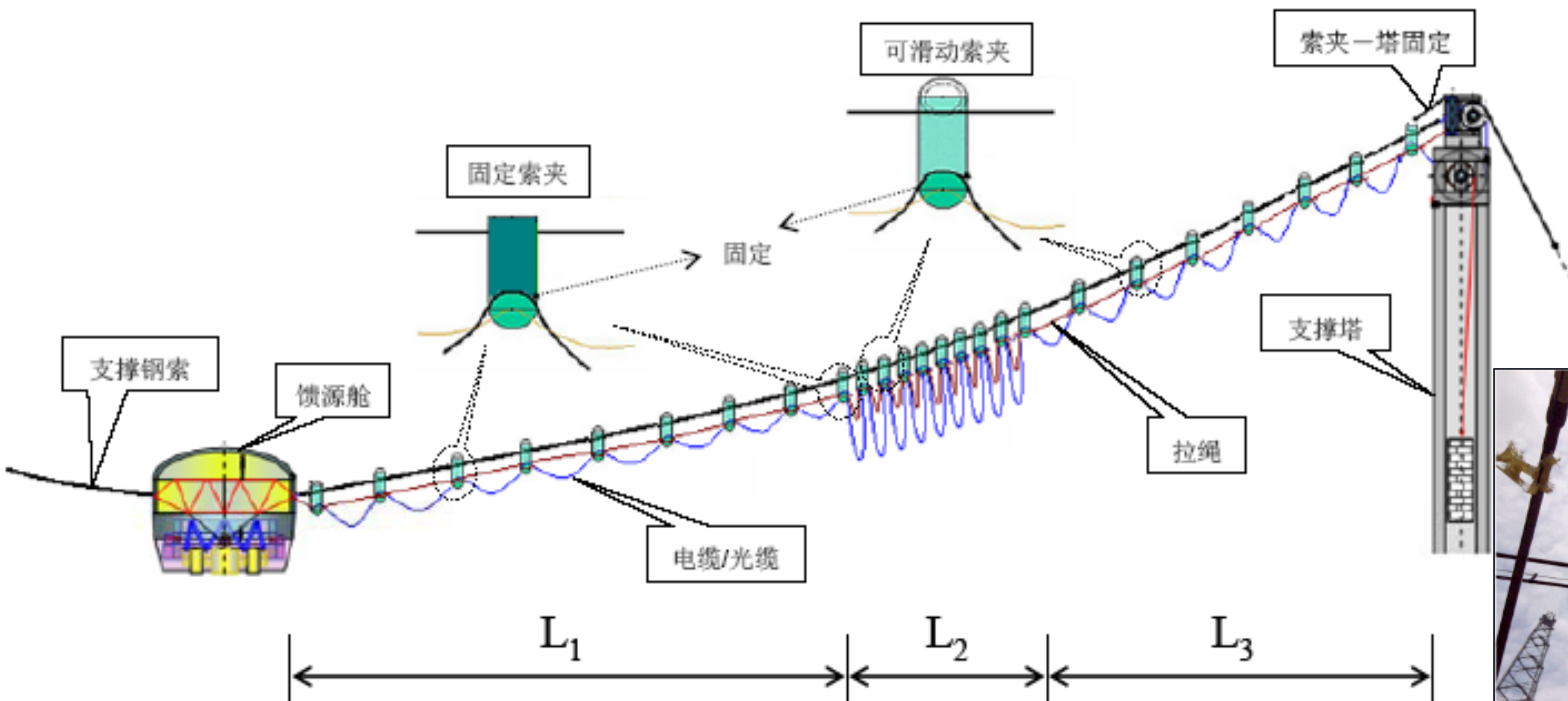


图 1 窗帘式缆线入舱方案示意图

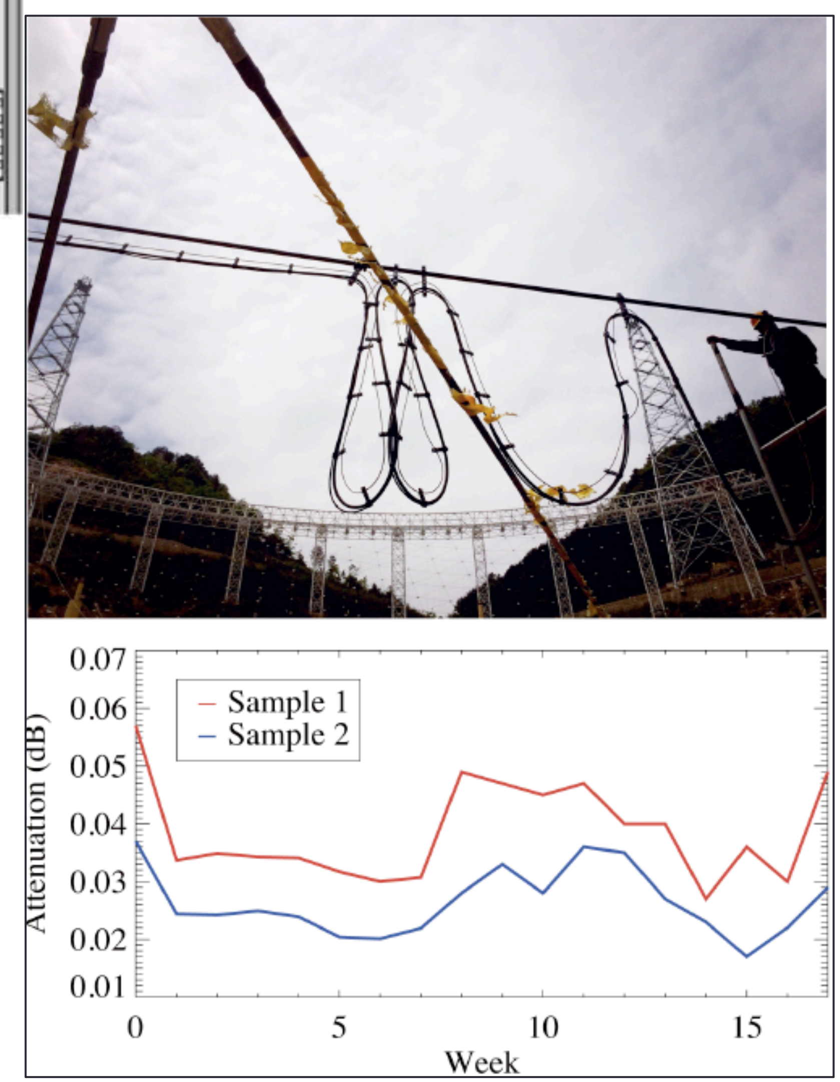


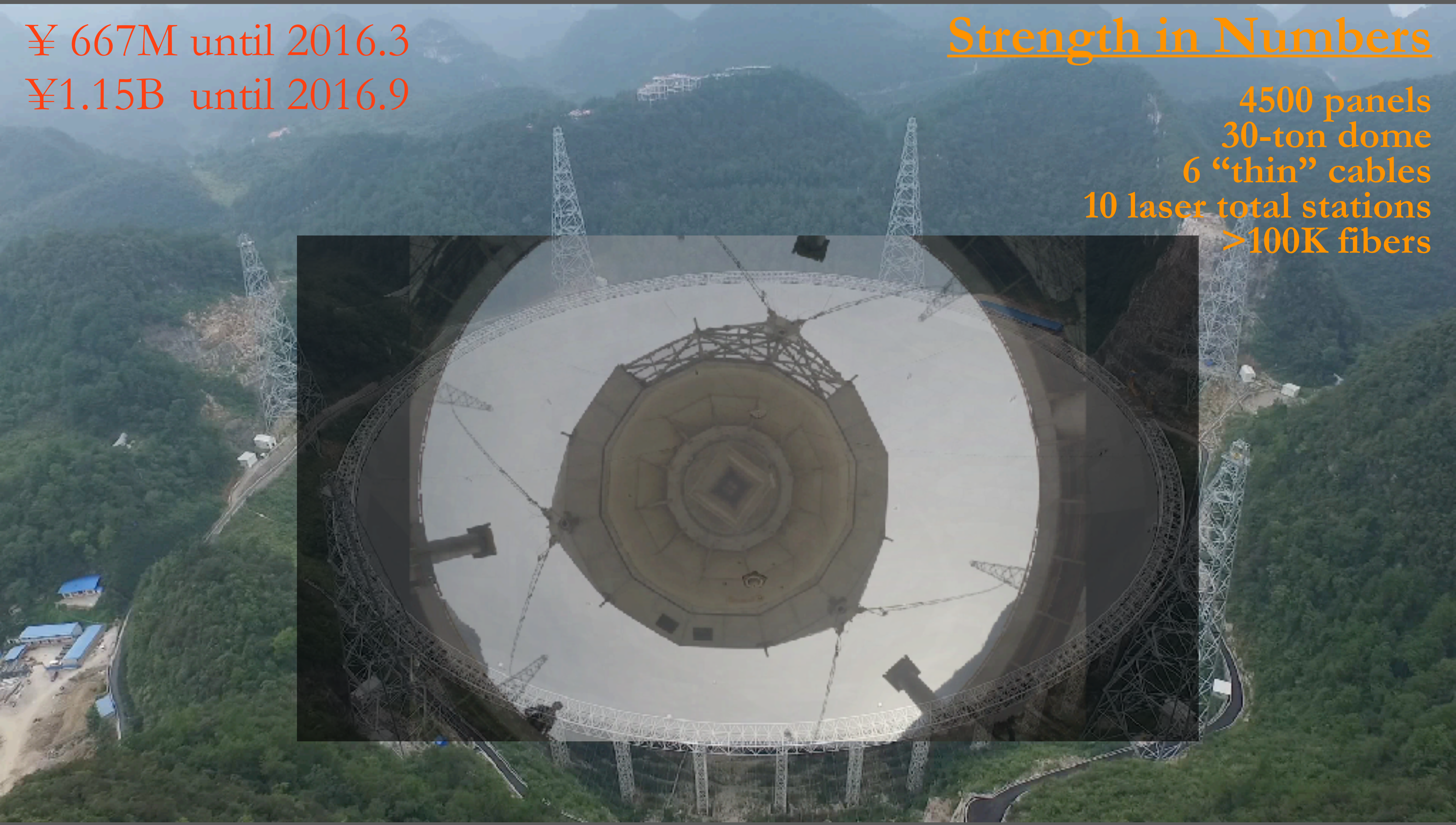
Figure 3. *Upper*: Installation of a suspension cable equipped with optical fiber and power cables. *Lower*: The attenuation of two optical fibers. Data are provided by Beijing BLADE Telecommunication Technical Development Co.

DL et al. 2015

¥ 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



FAST *Now vs Then*

FAST对技术进步的贡献 之 索网结构

超强的疲劳性能	超高的精度要求	超大的索网跨度

超强的疲劳性能

- ✓ 依托FAST 研制的高性能钢索结构，在200 万次循环加载条件下的疲劳强度可达500MPa，是目前相关标准规范的2.5倍，在国际范围内尚未见先例。
- ✓ 超高的疲劳性能使该种钢绞线在一些特种领域中有良好的应用前景，例如：摩天轮辐射索、体育场馆及航空母舰阻拦索等。

超高的精度要求

- ✓ 在FAST工程需求的牵引下，建立了高精度索结构生产体系，实现了我国索结构工业的精细化管理。目前精度为±1mm，标准规范为±15mm。
- ✓ 该生产体系已经在港珠澳大桥斜拉索等其它项目中得以应用，使我国的钢索结构生产制造水平得到巨大提升。

超大的索网跨度

- ✓ 大跨度索膜结构安装技术：FAST 工程索网结构有500米的跨度，这在世界范围内极为罕见，加之地处山区，场地限制极为苛刻。
- ✓ 在制造、安装过程中产生了大量具有我国自主知识产权的专利技术，也发表了10余篇文章。

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Observables

continuous coverage
70MHz～3GHz

a) 21cm HI (galaxies and ISM)

b) Pulsars

c) Spectral lines

d) VLBI

e) SETI

Review

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

DOI: 10.1142/S0218271811019335

World Scientific

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 & **DL** et al. 2011, IJMR-D, 20, 989 (128 citations)

“Radio Astronomy Frontiers & FAST Early Sciences”

Feb. 2012 – Aug. 2016

- ## Science Outputs

– **Published 339 papers in all (273 in SCI, 8 in EI)**

– Organized 30 international conferences: **RAF symposium series, HI, pulsar, gals topical workshops, etc.)**

– **51 PhD and 8 Postdoctoral Fellows**

– International Leadership: **SKA Board Member, SKA SWG Chairs, ATNF Steering Committee, Breakthrough Listen Advisory Committee, etc.**

- ## High Impact Results

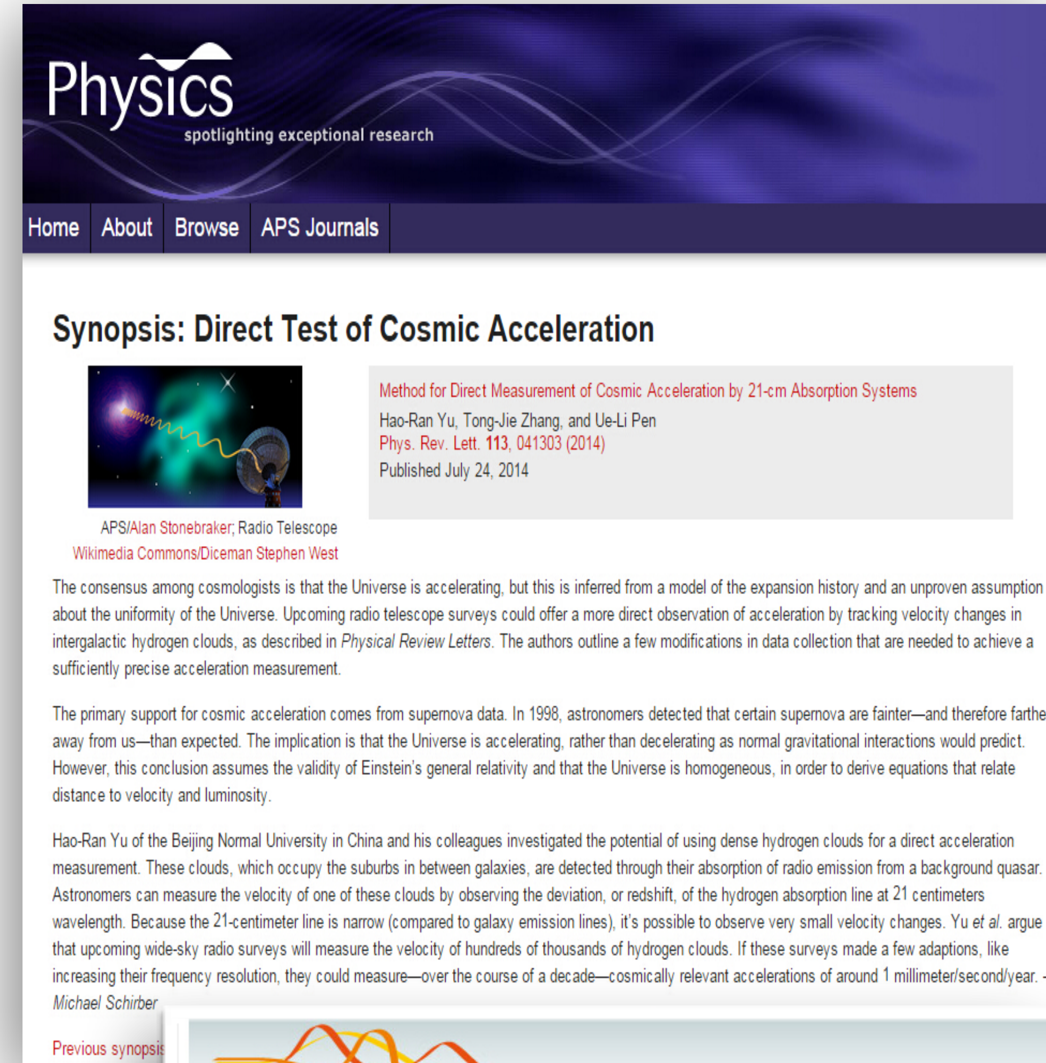
– **Direct Test of Cosmic Acceleration** (Yu, Zhang & Pen 2014)

– **Discover New Types of Megamasers (Wang et al. 2014)**

–Most Comprehensive Statistical Research of Pulsar Glitches (Yu et al. 2013)

– Complete molecular dynamic structures in Taurus (Li, **DL** et al. 2015)

– Discover New Millisecond Pulsars (Pan et al. 2016)



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Synopsis: Direct Test of Cosmic Acceleration

Method for Direct Measurement of Cosmic Acceleration by 21-cm Absorption Systems
Hao-Ran Yu, Tong-Jie Zhang, and Ue-Li Pen
Phys. Rev. Lett. 113, 041303 (2014)
Published July 24, 2014

APS/Alan Stonebraker; Radio Telescope Wikimedia Commons/Diceman Stephen West

The consensus among cosmologists is that the Universe is accelerating, but this is inferred from a model of the expansion history and an unproven assumption about the uniformity of the Universe. Upcoming radio telescope surveys could offer a more direct observation of acceleration by tracking velocity changes in intergalactic hydrogen clouds, as described in *Physical Review Letters*. The authors outline a few modifications in data collection that are needed to achieve a sufficiently precise acceleration measurement.

The primary support for cosmic acceleration comes from supernova data. In 1998, astronomers detected that certain supernova are fainter—and therefore farther away from us—than expected. The implication is that the Universe is accelerating, rather than decelerating as normal gravitational interactions would predict. However, this conclusion assumes the validity of Einstein's general relativity and that the Universe is homogeneous, in order to derive equations that relate distance to velocity and luminosity.

Hao-Ran Yu of the Beijing Normal University in China and his colleagues investigated the potential of using dense hydrogen clouds for a direct acceleration measurement. These clouds, which occupy the suburbs in between galaxies, are detected through their absorption of radio emission from a background quasar. Astronomers can measure the velocity of one of these clouds by observing the deviation, or redshift, of the hydrogen absorption line at 21 centimeters wavelength. Because the 21-centimeter line is narrow (compared to galaxy emission lines), it's possible to observe very small velocity changes. Yu *et al.* argue that upcoming wide-sky radio surveys will measure the velocity of hundreds of thousands of hydrogen clouds. If these surveys made a few adaptions, like increasing their frequency resolution, they could measure—over the course of a decade—cosmically relevant accelerations of around 1 millimeter/second/year. – *Michael Schirber*

Previous synopsis

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NATURE COMMUNICATIONS | ARTICLE OPEN

SiO and CH_3OH mega-masers in NGC 1068

Junzhi Wang, Jiangshui Zhang, Yu Gao, Zhi-Yu Zhang, Di Li, Min Fang & Yong Shi

Affiliations | Contributions | Corresponding author

Nature Communications 5, Article number: 5449 | doi:10.1038/ncomms6449
Received 05 September 2014 | Accepted 02 October 2014 | Published 11 November 2014

PDF | Citation | Reprints | Rights & permissions | Article metrics

Abstract

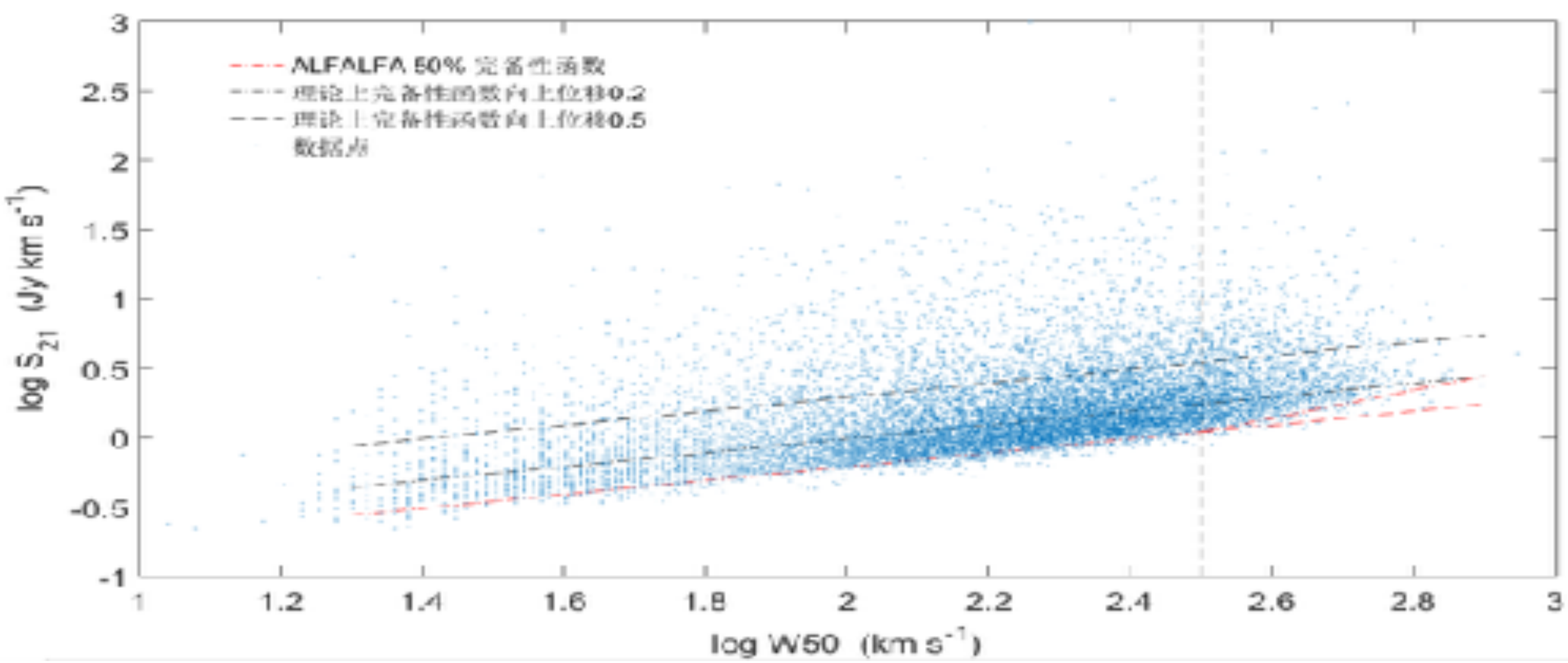
Abstract • Introduction • Results • Discussion • Methods • Additional information • References • Acknowledgements • Author information • Supplementary information

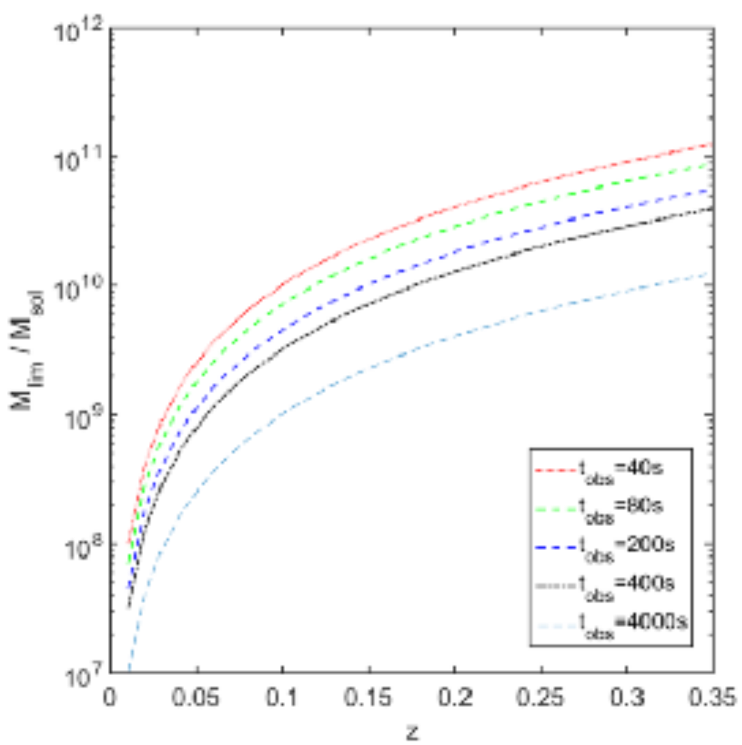
Maser is an acronym for microwave amplification by stimulated emission of radiation; in astronc mega-masers are masers in galaxies that are $\geq 10^6$ times more luminous than typical galactic maser sources. Observational studies of mega-masers can help us to understand their origins a characteristics. More importantly, mega-masers can be used as diagnostic tracers to probe the

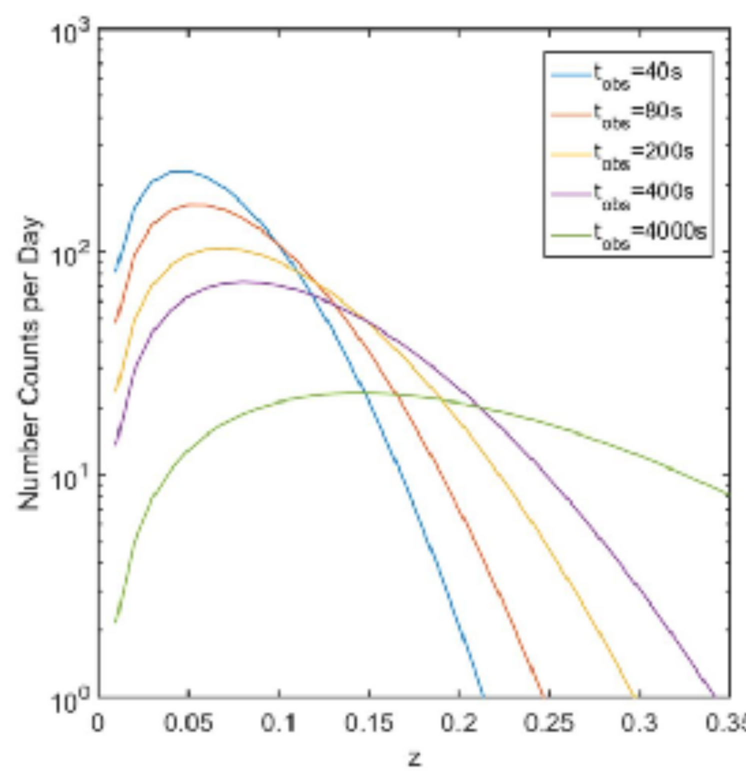
FAST 预期

中性氢星系巡天

a)







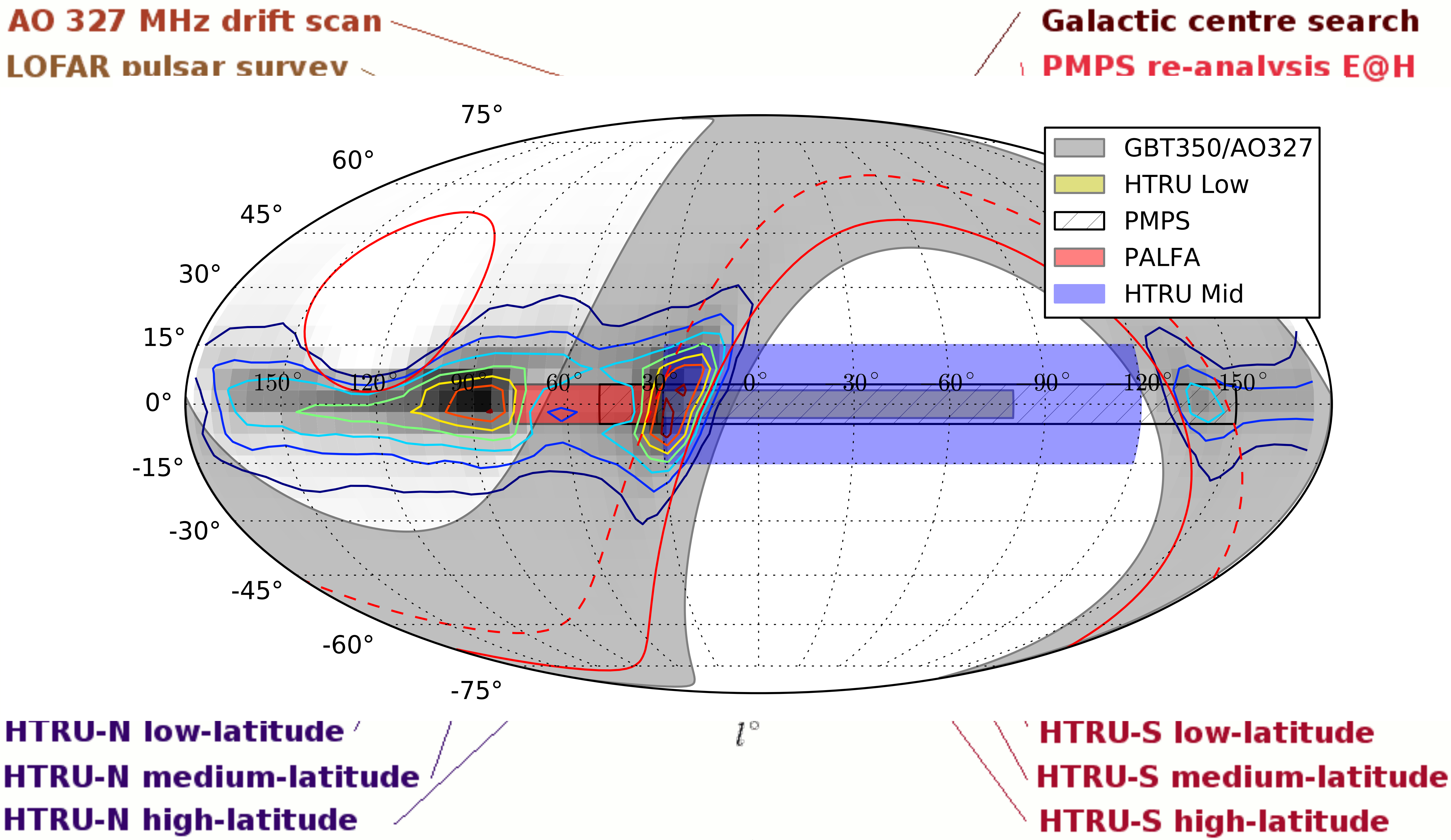
N ($>7\sigma$;2.3 π)
$\approx 7.1\times10^5$

$<z>\approx0.08$

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

Pulsar Surveys

b)



Dai & Zhu

Extra-galactic Pulsars

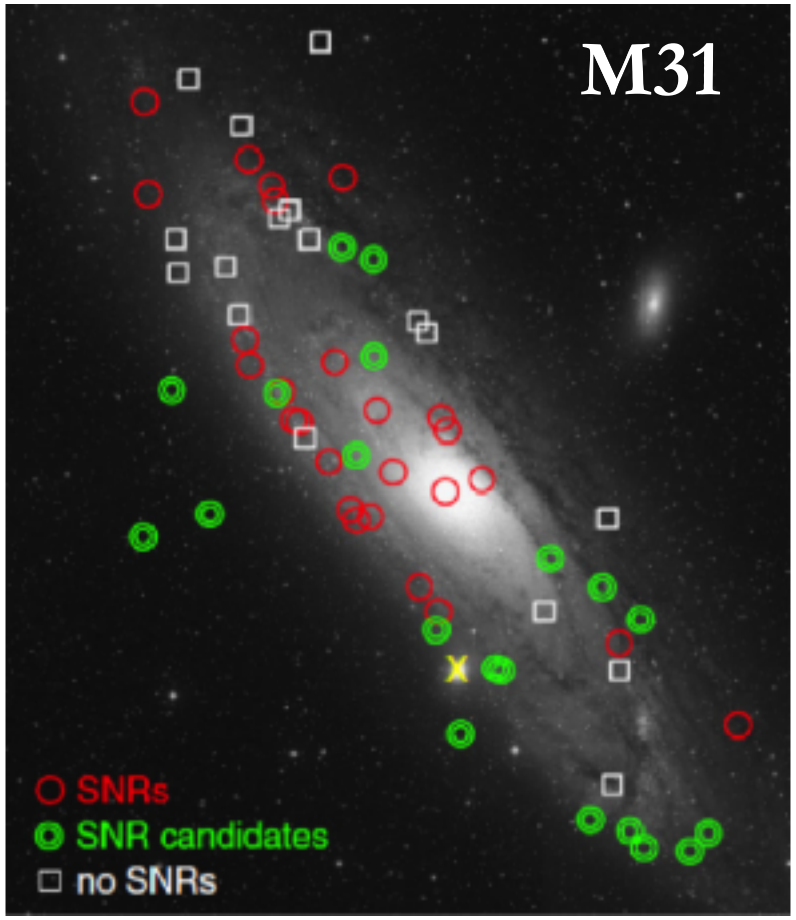
b)

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

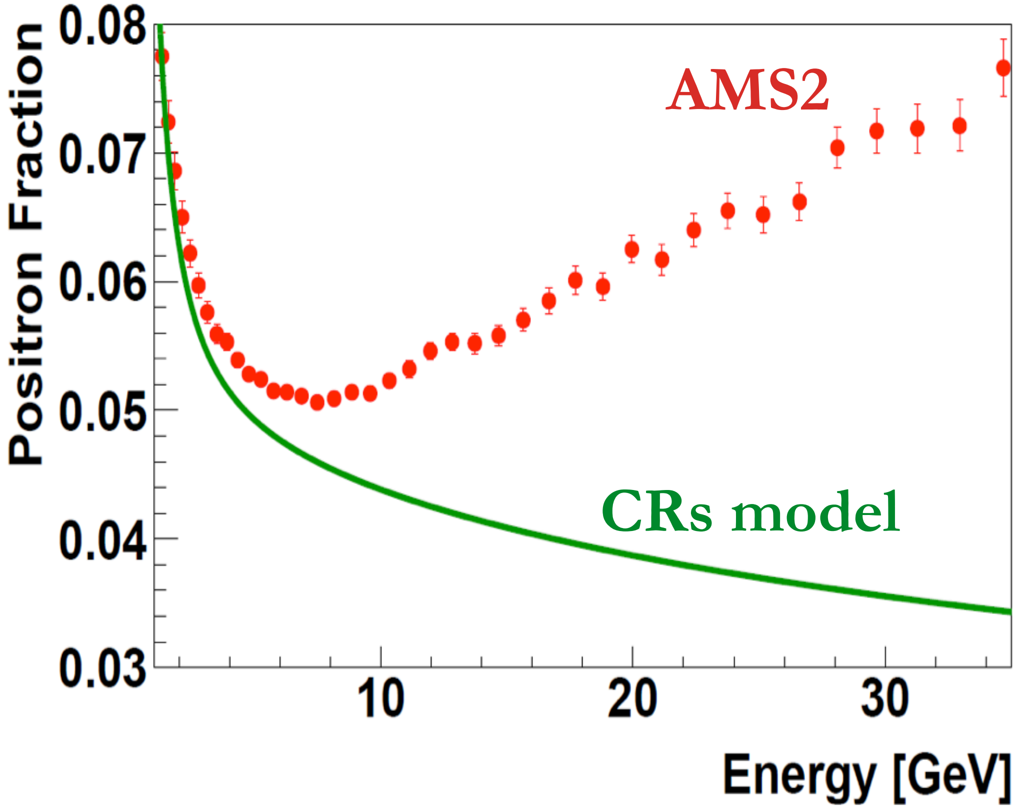
50-80 normal pulsars detectable by FAST (Smits et al. 2009)
Giant pulse **Credit**: Crawford, Cordes & DL

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

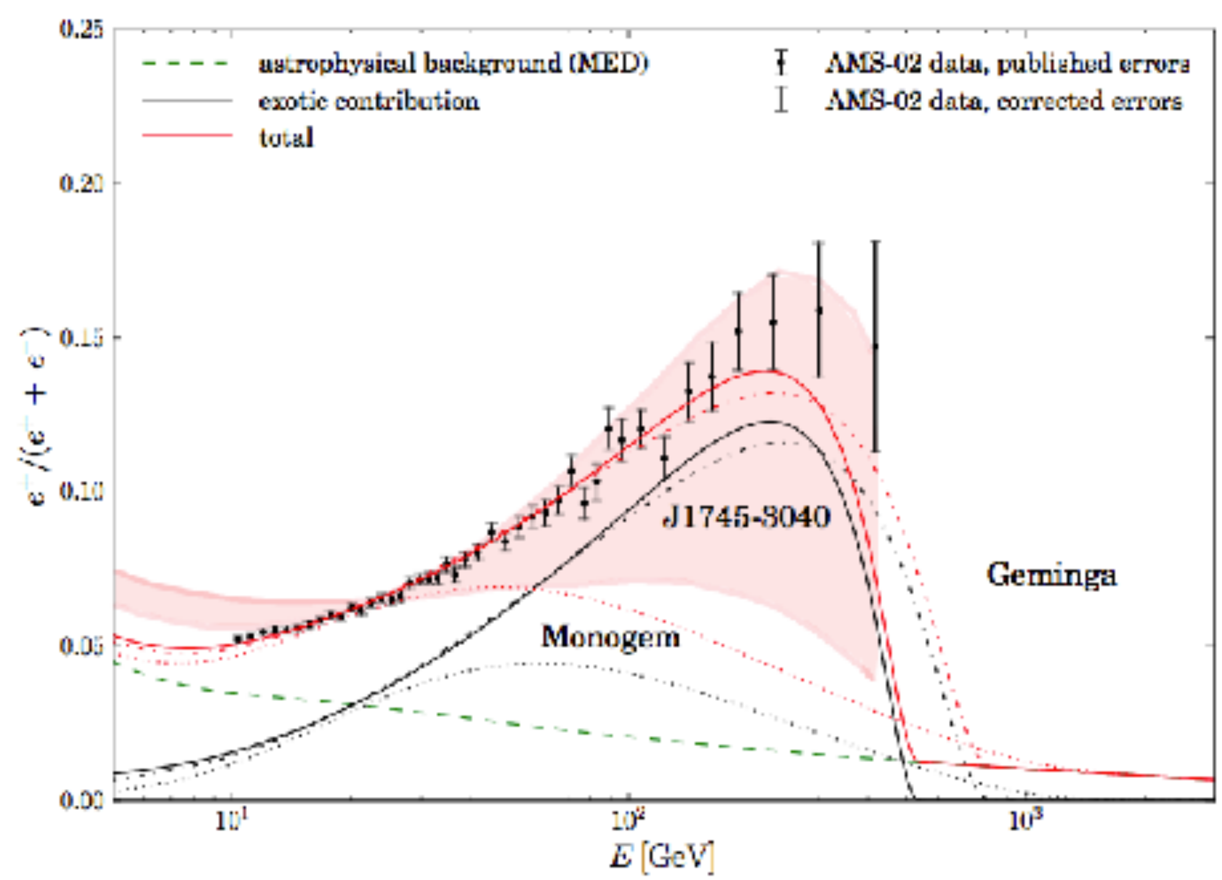
LOW: one detection every 0.7 to 2.0 minutes
HIGH: one detection every 180 to 540 minutes

A Pulsar Origin of Positron Excess

b)

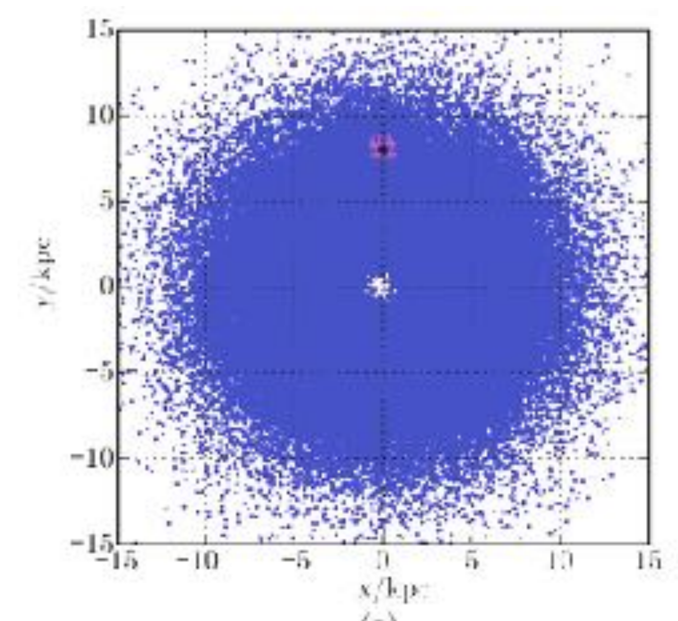


Accardo et al. 2014 PRL, 113, 121101



Wang, **DL**, & Bi et al. in prep.

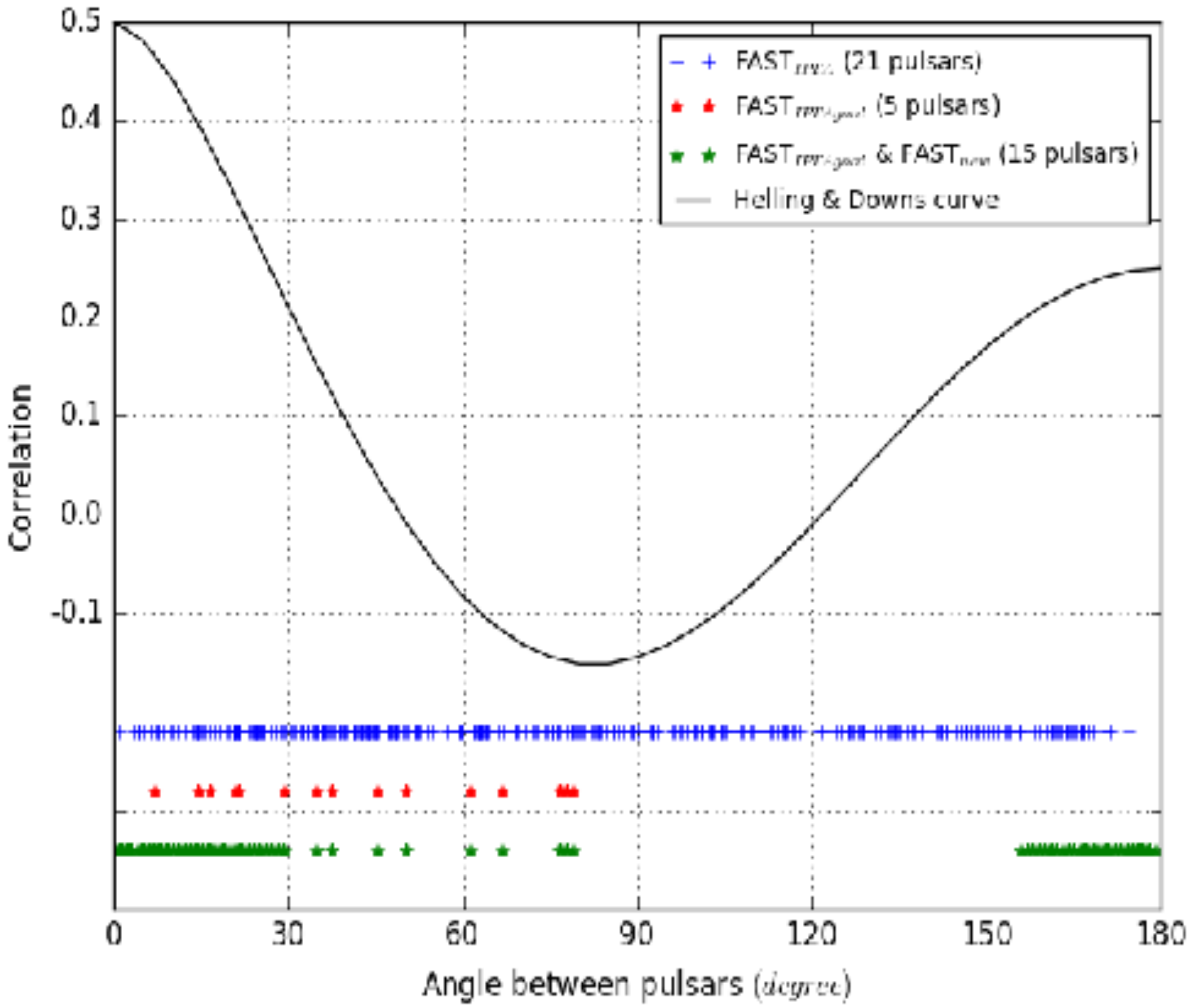
- Testing validity of method by using 3 nearest known pulsars.
- Injecting positron （fraction： right) from the sum of all nearby pulsars throughout the Milky Way.
- Additional component of e^+/e flux from local pulsar sources can set stringent constraints on dark matter interpretation.



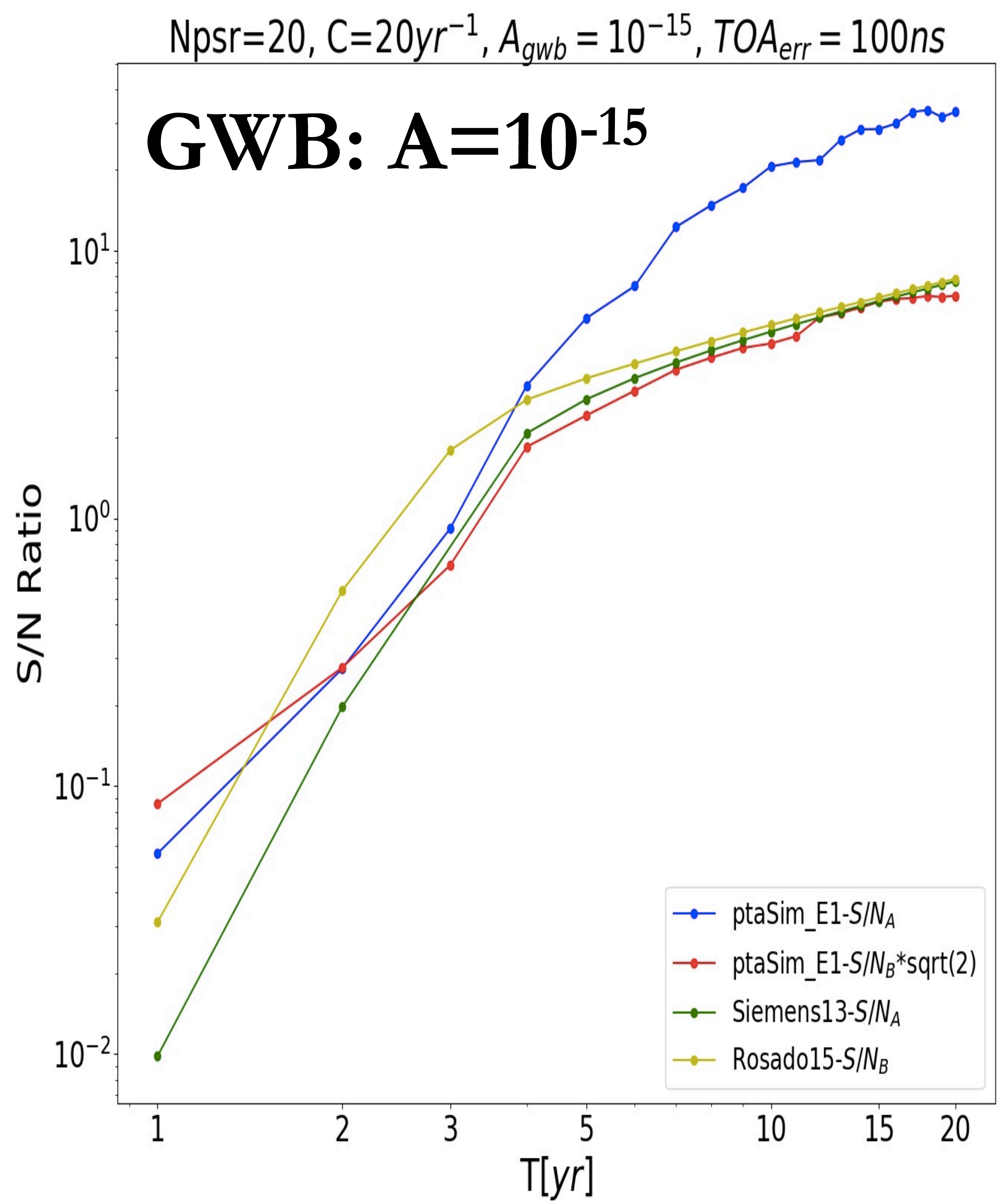
Zhang et al. 2015

FAST GW
Analytic + Simulation Predictions

b)



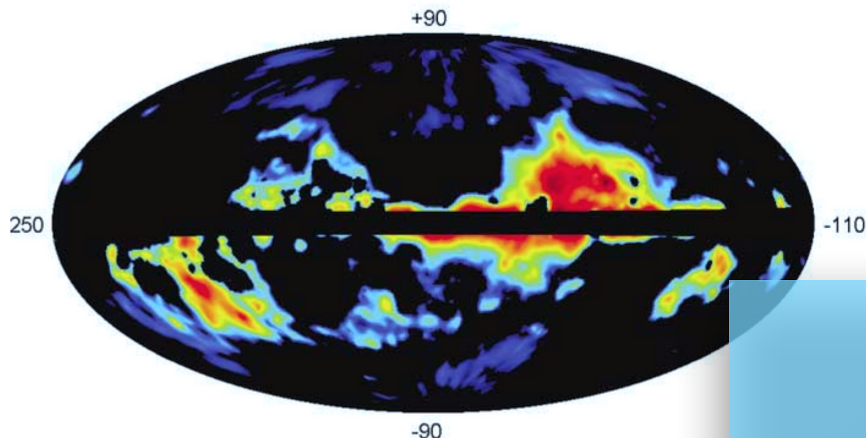
Zhang, Hobbs, Coles, **DL**, Zhu
et al. in prep.



ISM Inventory

IRAS

[IRAS – (HI + X*CO)]



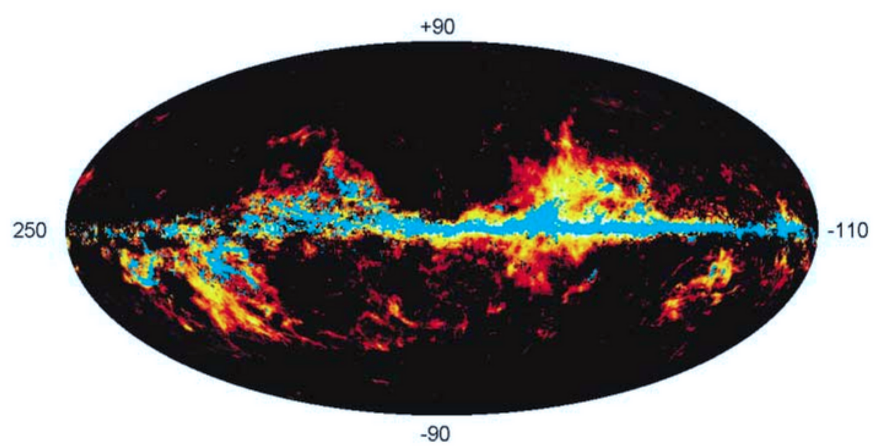
Dark Gas

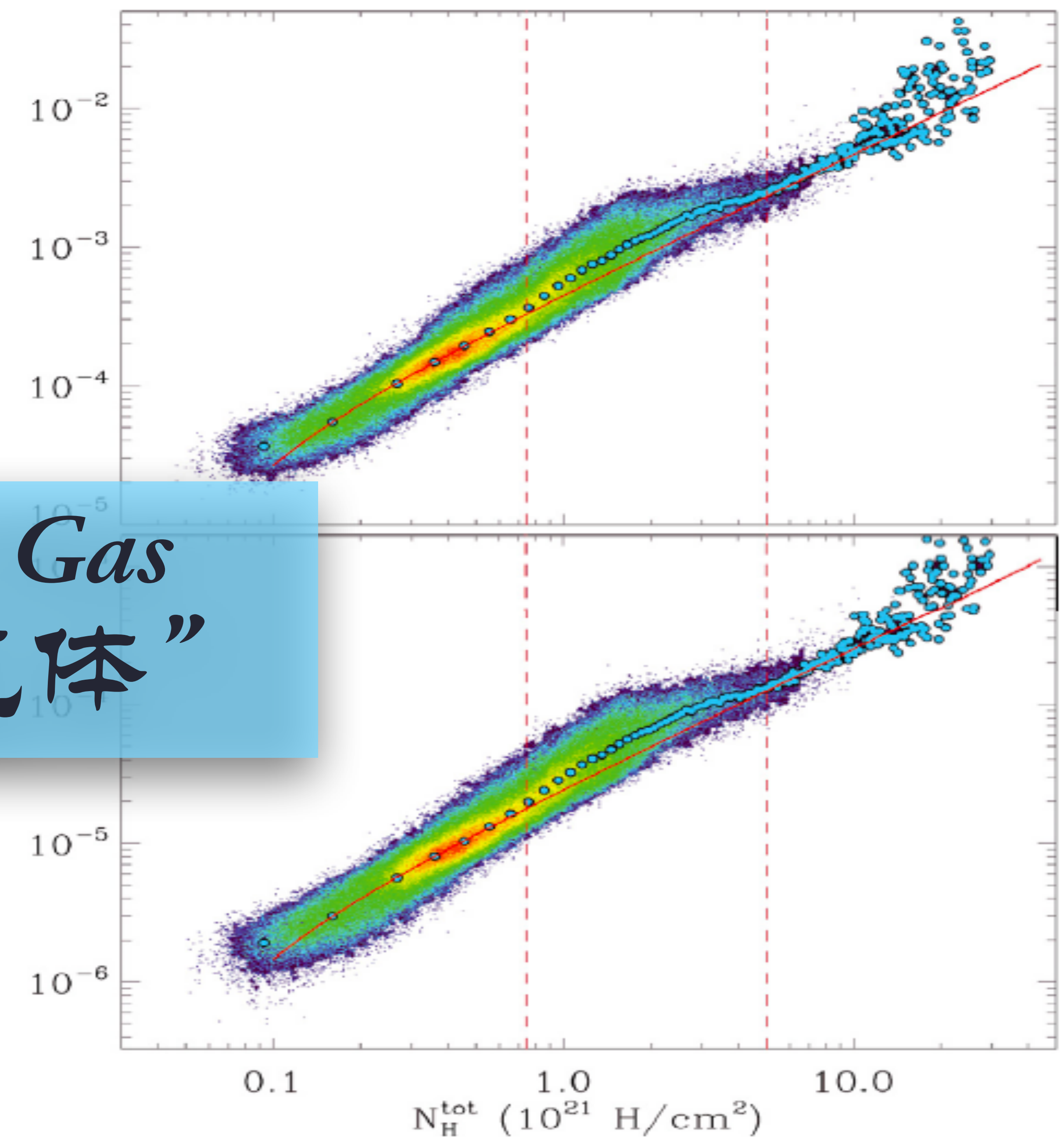
"暗气体"

EGRET

[CR/H-nuclei] - (HI + X*CO)

Grenier et al. 2005 ***Science***

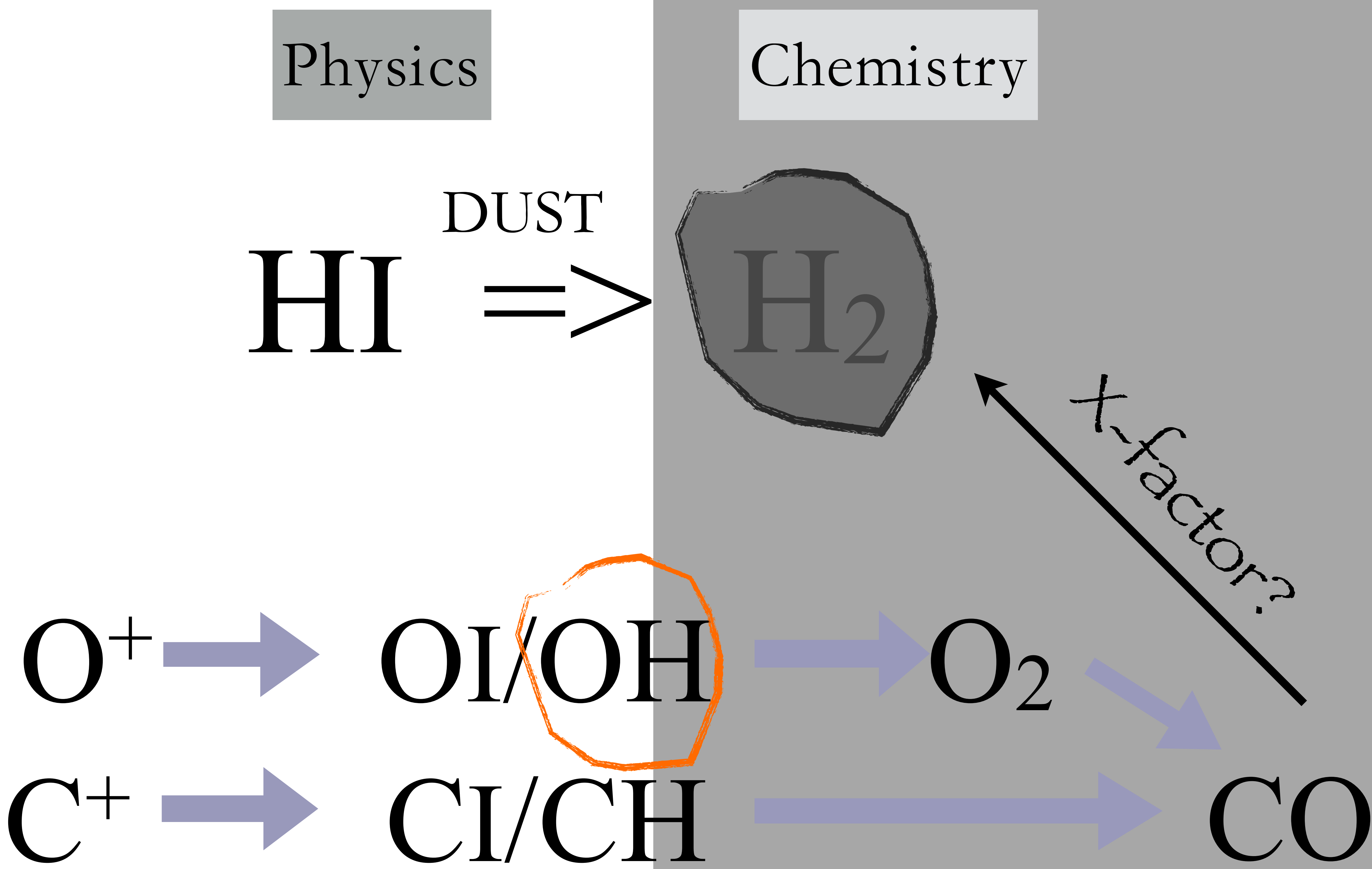




Planck

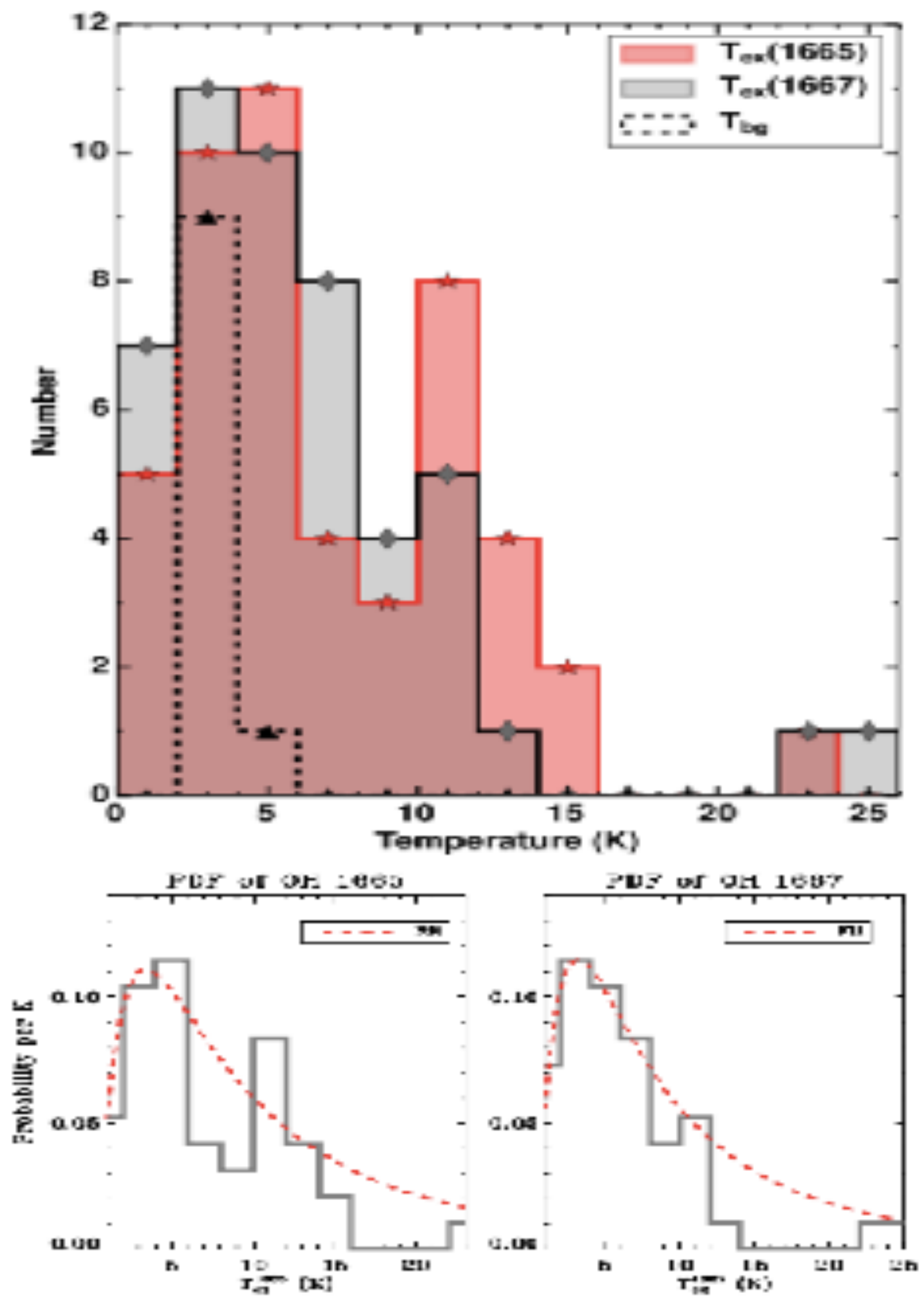
Dust Opacity vs (HI+X*CO)

ISM Evolution

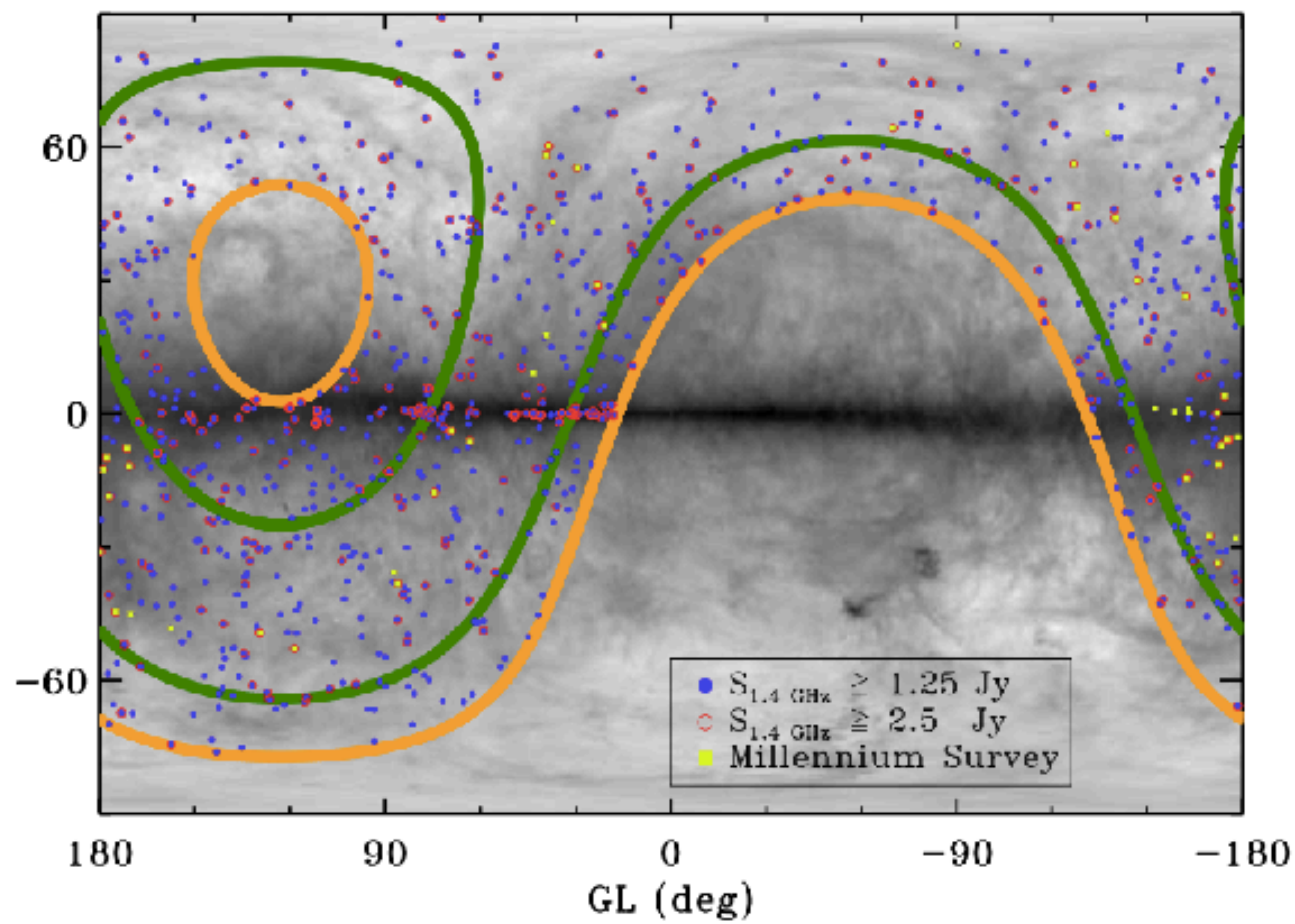


OH Excitation

c)



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



The FAST "Absorption Sky"

DL, Tang, Nguyen, Dawson, +**PRIMO** 2018

"Dark Gas" Absorption Survey
Pacific Rim Interstellar Medium Observers

c)

PRIMO

"环太平洋"星际介质国际合作团队

Heiles & Troland, 2003, ApJ I & II
- **Arecibo** telescope
- 79 sources, >400 citations

FAST: 800 quasars in 5 years

INcrease
Quasar Abs. Sample x10

Publication:

1, Li et al. 2015, *Quantifying Dark Gas*

2, Tang et al. 2016 A&A, *Physical Properties of CO-dark Molecular Gas Traced by C*$^+$

3, Xu & Li 2016, ApJ, paper I, II

4, Tang et al. 2017 ApJ, *Pilot OH Survey along Sightlines of Galactic Observations of Terahertz C+*

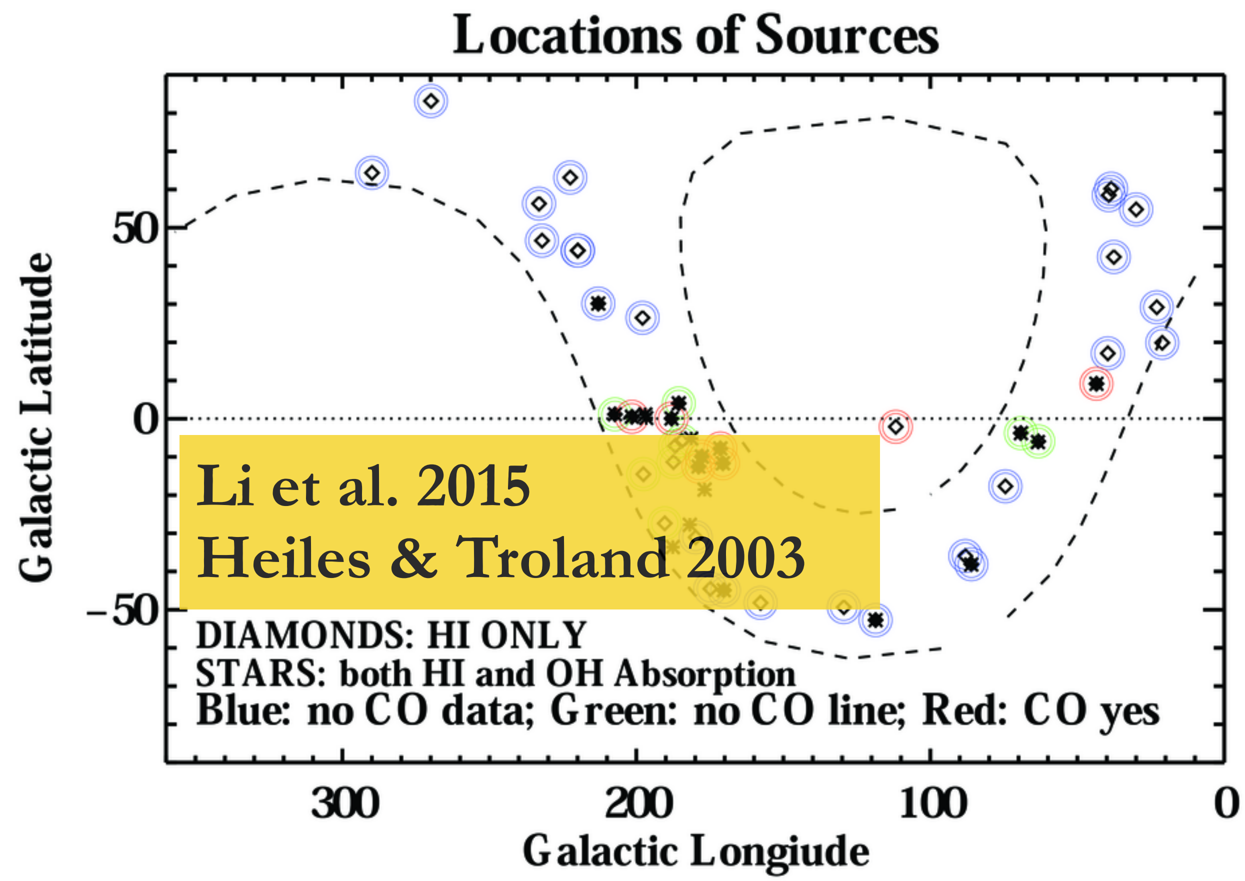


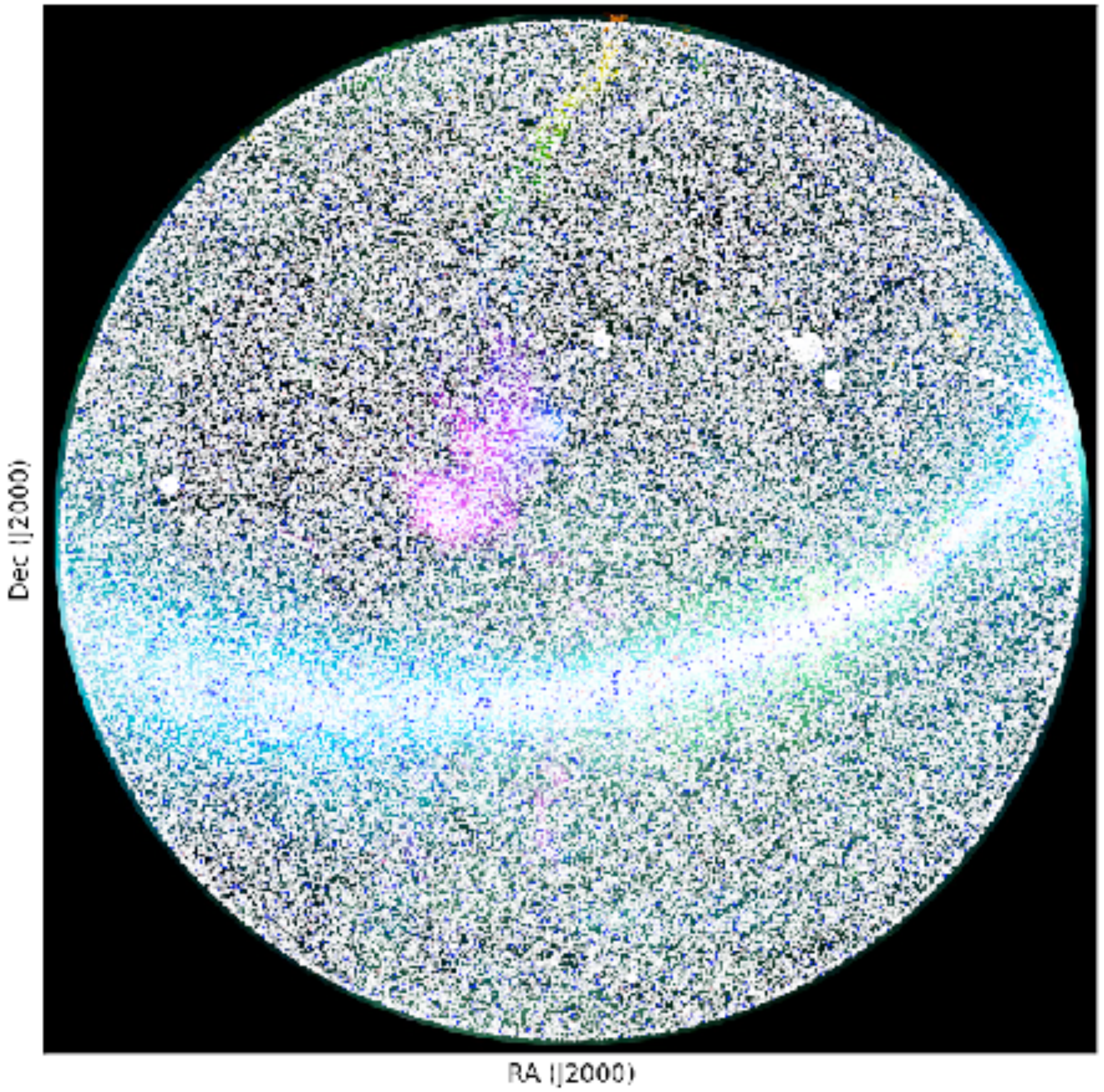
Fig. 5.— Map of sources observed in the Millennium survey. Diamonds are sources showing HI absorption only. Stars show both HI and OH absorption. Blue circles show sources having no CO data. Green circles show sources having CO data, but no detected CO line. Red circles show sources having detected CO line.

PoS PROCEEDINGS OF SCIENCE

Galactic and Magellanic Evolution with the SKA

Naomi M. McClure-Griffiths*[1], Snežana Stanimirović[2], Claire E. Murray[2], Di Li[3], John M. Dickey[4], Enrique Vázquez-Semadeni[5], Josh E. G. Peek[6], Mary Putman[6], Susan E. Clark[6], Marc-Antoine Miville-Deschênes[7], Joss Bland-Hawthorn[8], Lister Staveley-Smith[9], on behalf of the H I Science Working Group

Absorption Imaging



@ L-band

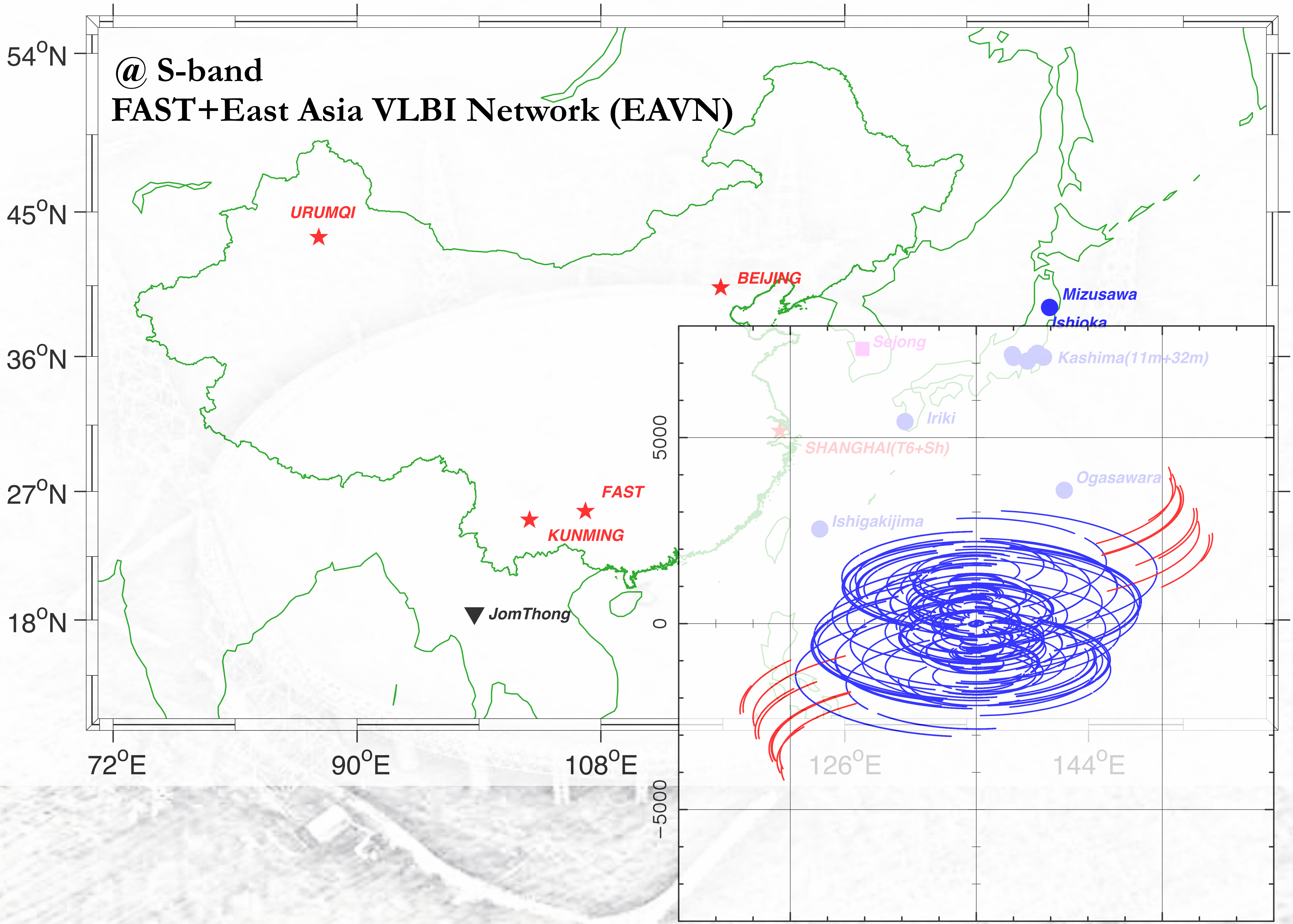
VLBI (+FAST) Imaging Sensitivity

d)

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 (SEFD~1.4 Jy@L-band)

Recording rate 512 Mbits/s Integration time = 60 min



@ S-band
FAST+East Asia VLBI Network (EAVN)
URUMQI
BEIJING
FAST
KUNMING
JomThong
Mizusawa
Ishioka
Sejong
Kashima(11m+32m)
Iriki
SHANGHAI(T6+Sh)
Ogasawara
Ishigakijima
54°N
45°N
36°N
27°N
18°N
72°E
90°E
108°E
126°E
144°E
5000
0
−5000
−5000
0
5000

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- FAST Concepts and Innovations
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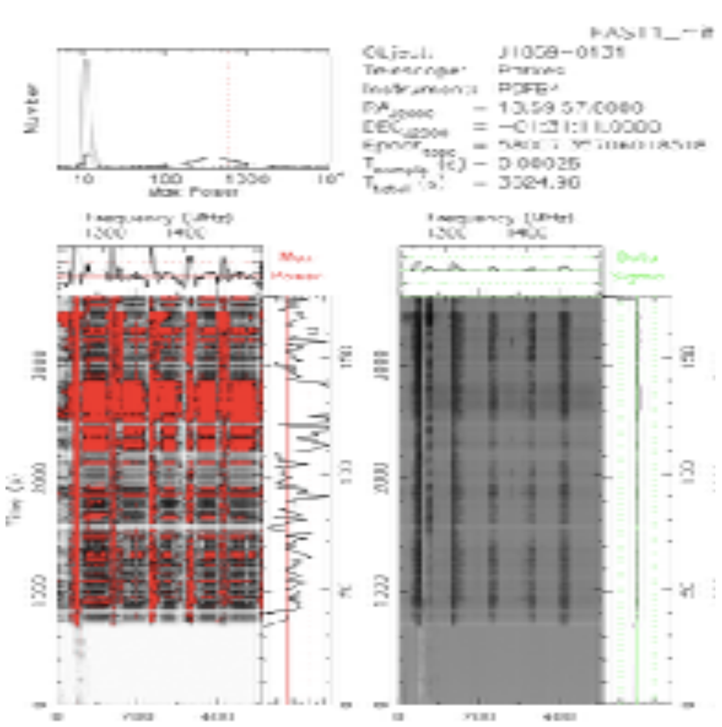
  Unprecedented radio survey mode
- Challenges and Breakthroughs

  Unprecedented challenges

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



Camillo, Li, Hobbs, Zhu etc.
2017.9.11

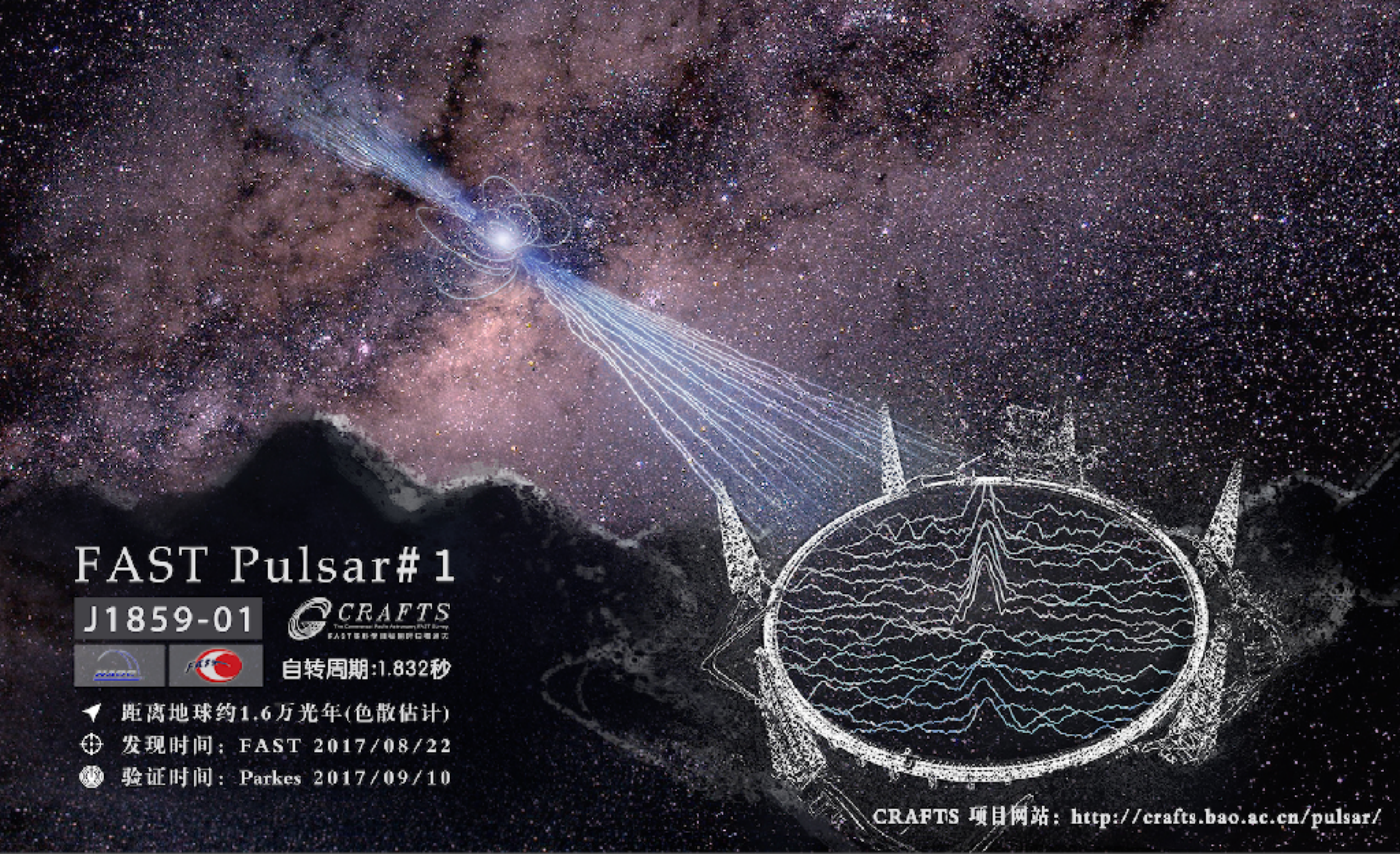
发件人： NAOC
发送日期： 2017年09月13日 11:28
收件人： Rendong Nan
抄送人： 姜 鹏， Youling Yue， Lei Qian
主题： 脉冲星

南老师，

调试组的进展非常快。目前指向、波束形状、接收机温度都符合预期。

PMPS巡天再处理的结果，昨晚处理了Parkes director's time 的初步检验结果，现在可以确认一颗是真的。现在的情况是，如果报给脉冲星最通用的星表（psrcat), Dick Manchester不认可未发表的结

致南老师邮件 2017.9.13



FAST 首成果-

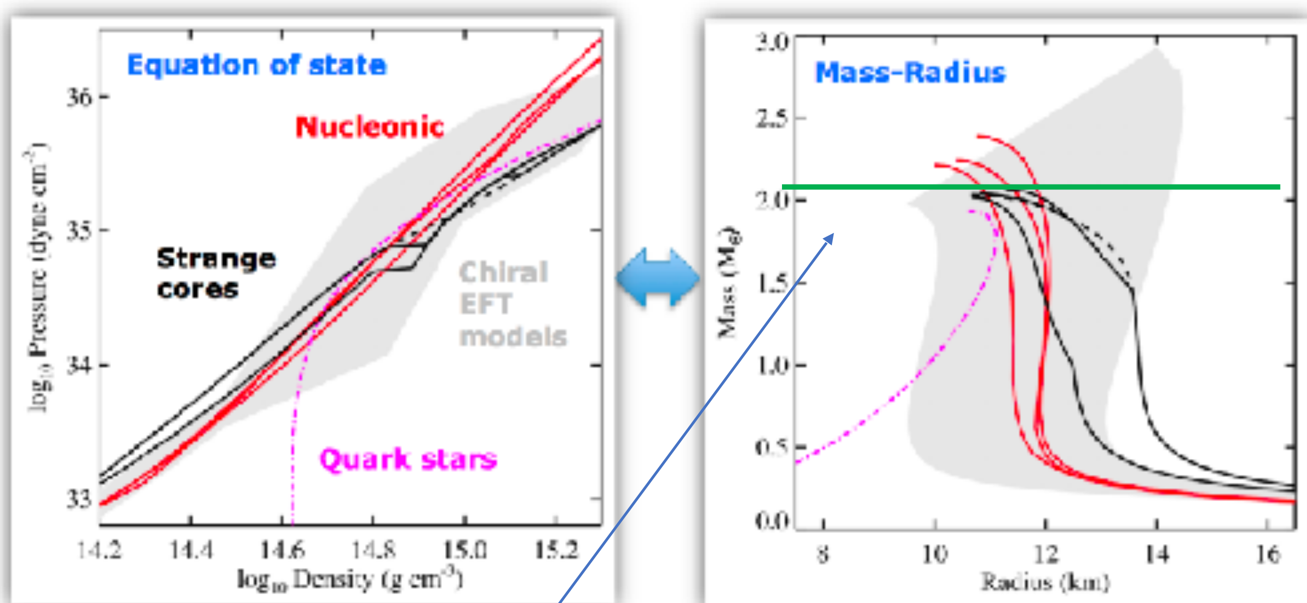
开启中国设备**系统原创**发现的时代

Binary NS System
Physics-Astronomy

b)

Understanding the state of ultra-dense matter at low temperatures

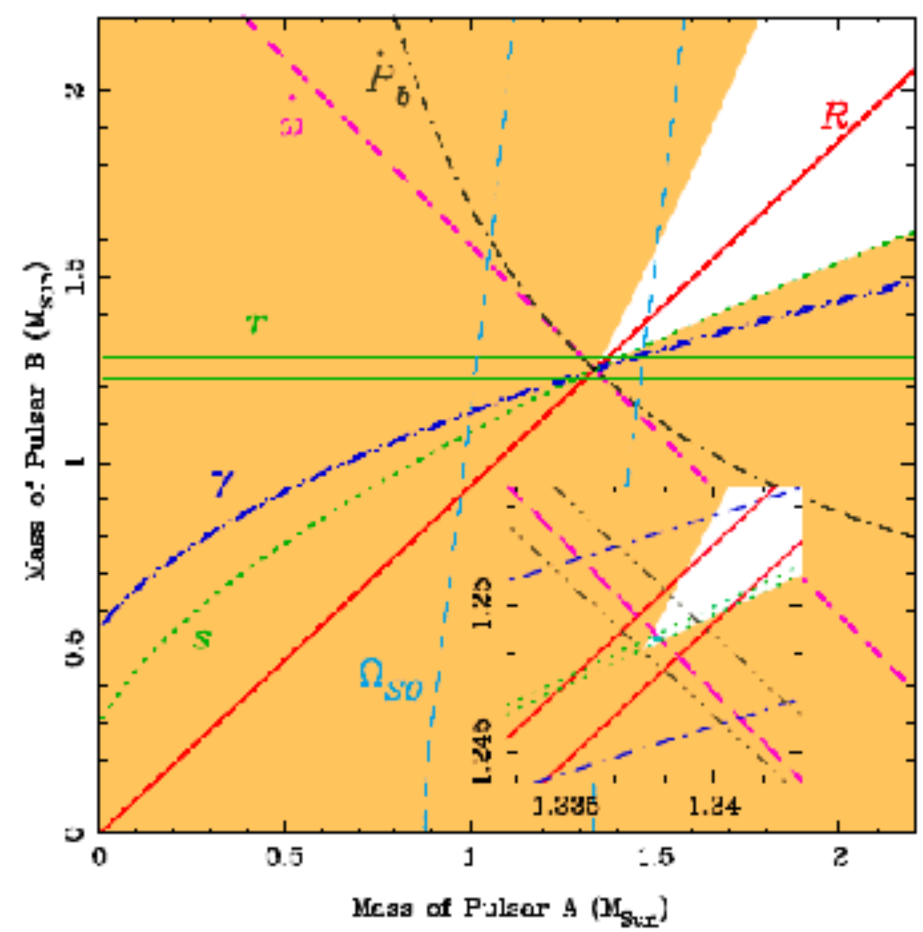
Watts et al. (2014)



Precise mass measurements of massive NS (>$2M_{sun}$) can put tight constraints on the equation of state (EoS)

- Demorest et al. 2010, Nature, 467, 1081 (1571 citations)
- Antoniadis et al. 2013, Science, 340, 448 (1039 citations)

Testing gravity theories in strong gravitational fields

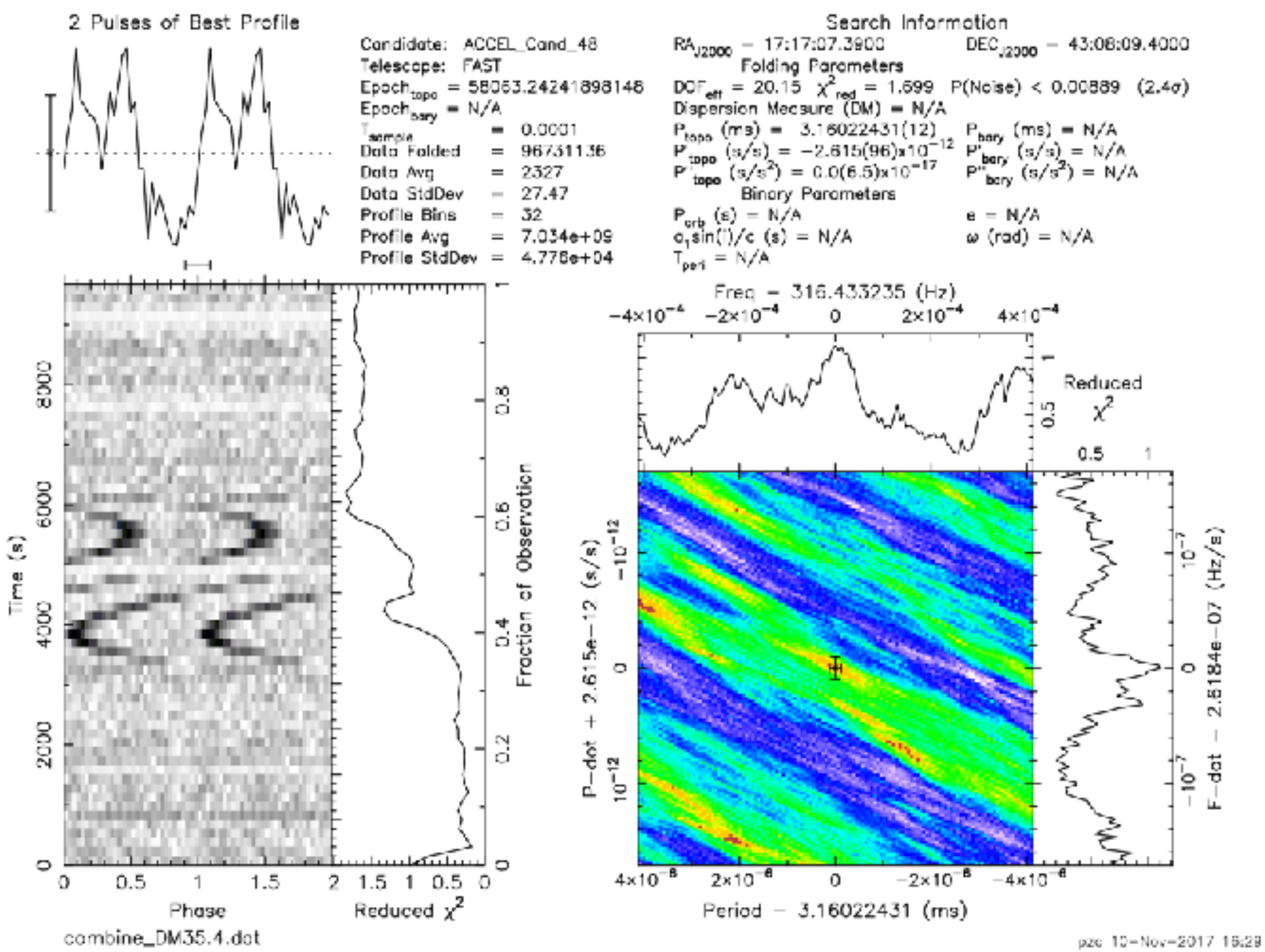


Mass-mass diagram of J0737-3039A/B

Kramer et al. 2006, Science, 314, 97 (418 citations)

The First
FAST MSP in a Binary?!

b)



P= 3.2 ms

a- P_dot ?

Orbital period:
~ 1 day/n ?

GBT + Effelsberg
Follow up

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

Fast Radio Burst

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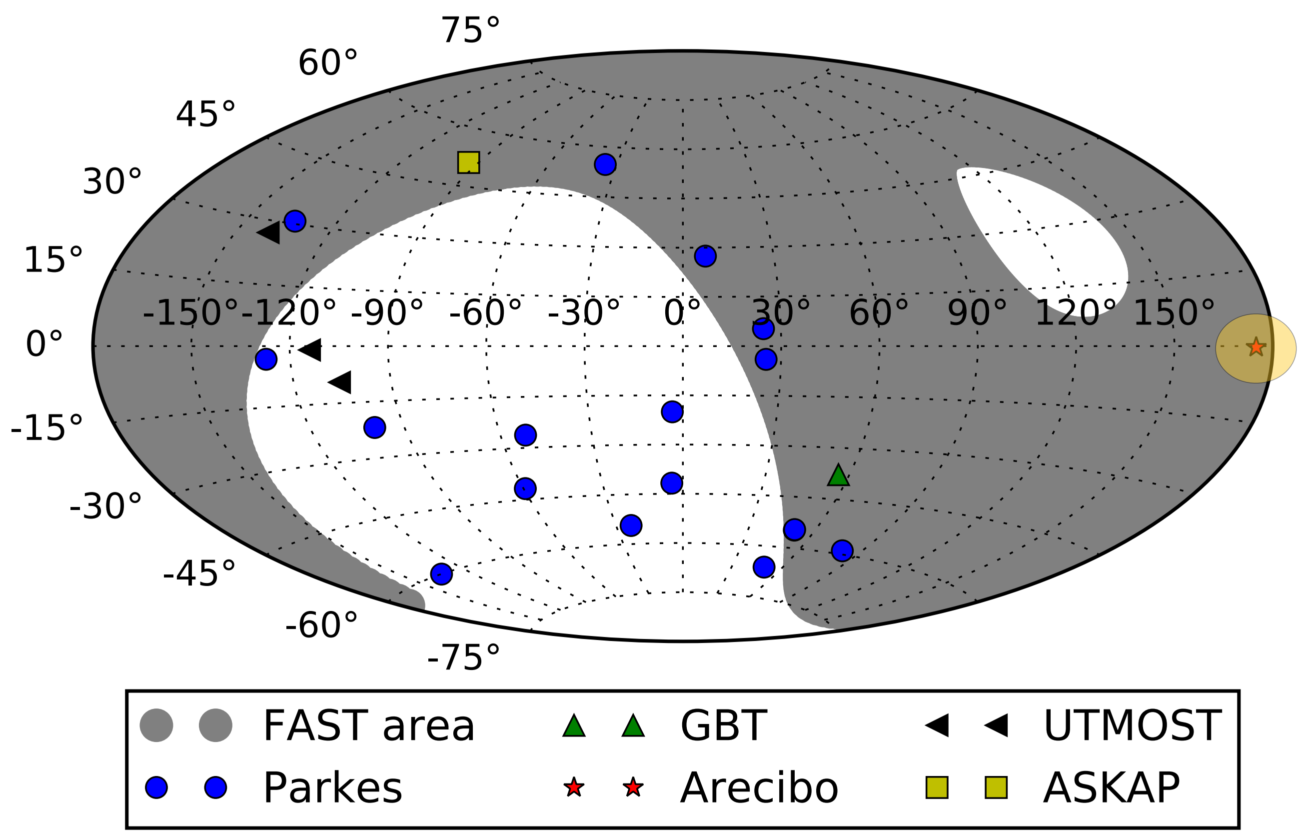

Name	Telescope	UTC	RAJ	DECJ	NE2001 DM Limit	DM (cm^-3pc)	Width(ms)	Flux (Jy)	DM/DM_ne
FRB121102	arecibo	2012-11-2 6:35	5:32:09	33:05:13	188	557	3	0.4	2.96
		2015-6-2 16:38	5:32:01	33:07:53		555	4.6	0.04	
		2015-6-2 16:47				558	8.7	0.02	
		2015-5-17 17:42		33:07:56		560	3.8	0.03	
		2015-5-17 17:51				566	3.3	0.03	
		2015-6-2 17:49	5:31:55	33:08:13		559	2.8	0.02	
						559	6.1	0.02	
		2015-6-2 17:50				556.5	6.6	0.14	
		2015-6-2 17:53				557.4	6	0.05	
		2015-6-2 17:56				558.7	8	0.05	
		2015-6-2 17:57				556.5	3.06	0.31	
FRB130628	parkes	2013-6-28 3:57	9:03:02	3:26:16	52.58	469.88	0.64	1.91	8.94
FRB110523	GBT	2011-5-23 15:06	21:45:12	-00:09:37	43.52	623.3	1.73	0.6	14.32
FRB110703	parkes	2011-7-3 18:59	23:30:51	-02:52:24	32.33	1103.6	4.3	0.5	34.14
FRB130729		2013-7-29 9:01	13:41:21	-05:59:43	31	861	15.61	0.22	27.77
FRB130626		2013-6-26 14:55	16:27:06	-07:27:48	66.87	952.4	1.98	0.74	14.24
FRB010621		2001-6-21 13:02	18:52:05	-08:29:35	523	748	8	0.53	1.43
FRB140514		2014-5-14 17:14	22:34:06	-12:18:46	34.9	562.7	2.8	0.471	16.12
FRB110220		2011-2-20 1:55	22:34:38	-12:23:45	34.77	944.38	5.6	1.3	27.16

24 FRBs' location, 11 are in the FAST sky.
(e.g. FRB121102, FRB130628, FRB110523, FRB110703, FRB130729, FRB130626, FRB010621, FRB140514, and FRB110220).

$$R_{FAST} \sim (3.33 \pm 0.66) \times 10^4 \times \frac{0.15\deg^2}{41253\deg^2} day^{-1} = 0.121 \pm 0.024 day^{-1}$$

Li et al. 2016 《RAA》
FAST 19beam: 5-10 FRB/1000hrs

Uniquely FAST

Gain： 1600-2000 m^2/K

- Slewing time: 1.5min - 10min FAST is slow.
- Beam and FOV: 3’ in L-band, ~26’ with 19 beam
- Drift Scan: only feasible mode for large surveys in early years and the most efficient

- Sky coverage: DEC -14° to 66° (-1° to 52° with full gain)
- Confusion limited: in 1 s @ ~1 mJy
- VLBI/Timing: moving phase center?

Commensal
Radio Astronomy FasT Survey

多科学目标漂移扫描同时巡天

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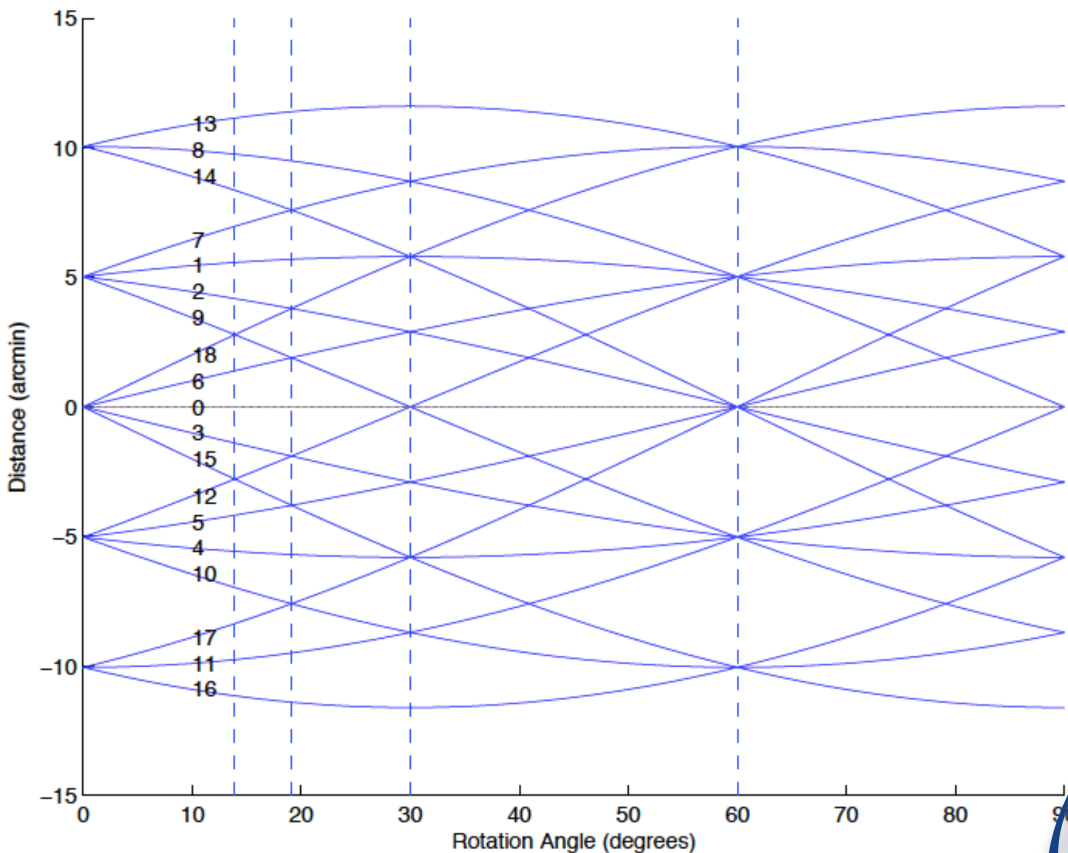
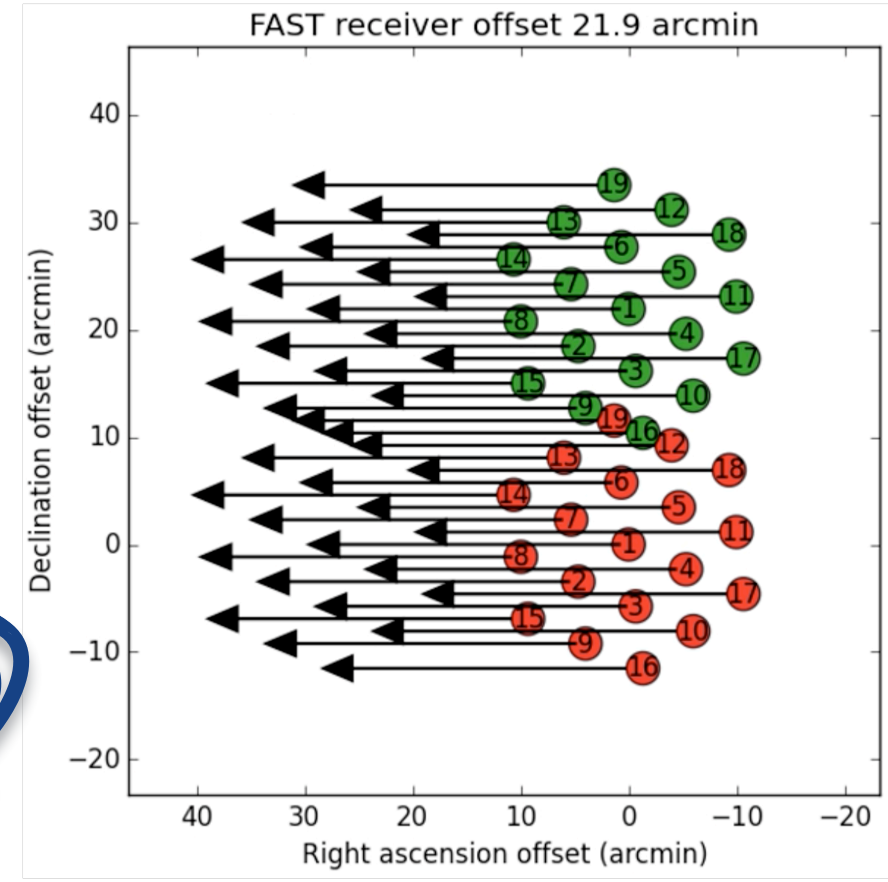
FAST多科学目标同时扫描巡天

世界**首创**：**Un**precedented





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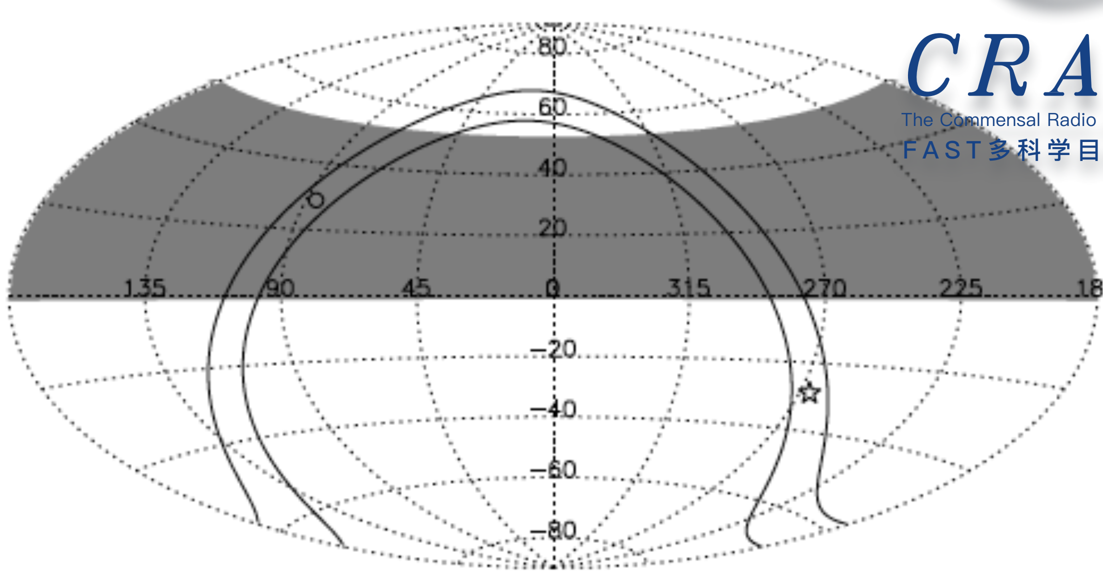
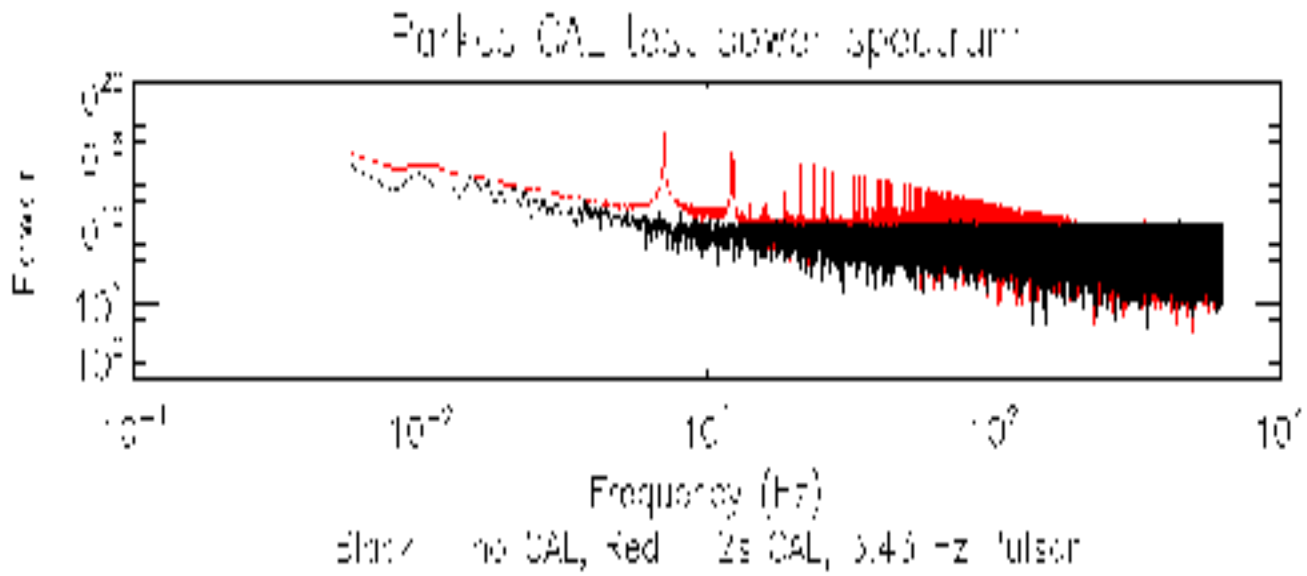


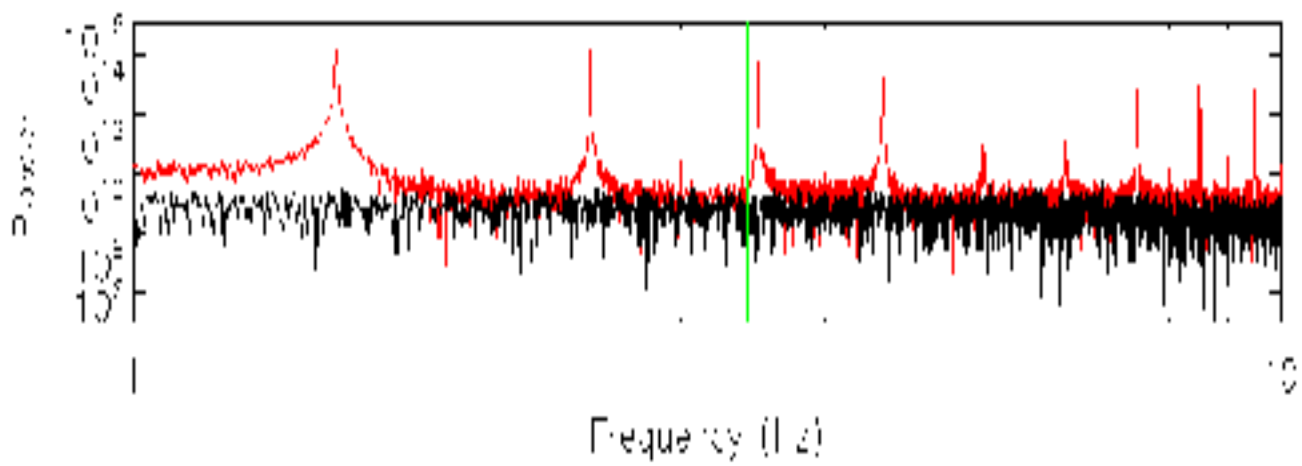
~ 220 24-hour Scans

For the full FAST sky

Drift（sidereal)：多波束漂移扫描规划

WHY THERE'S A PROBLEM

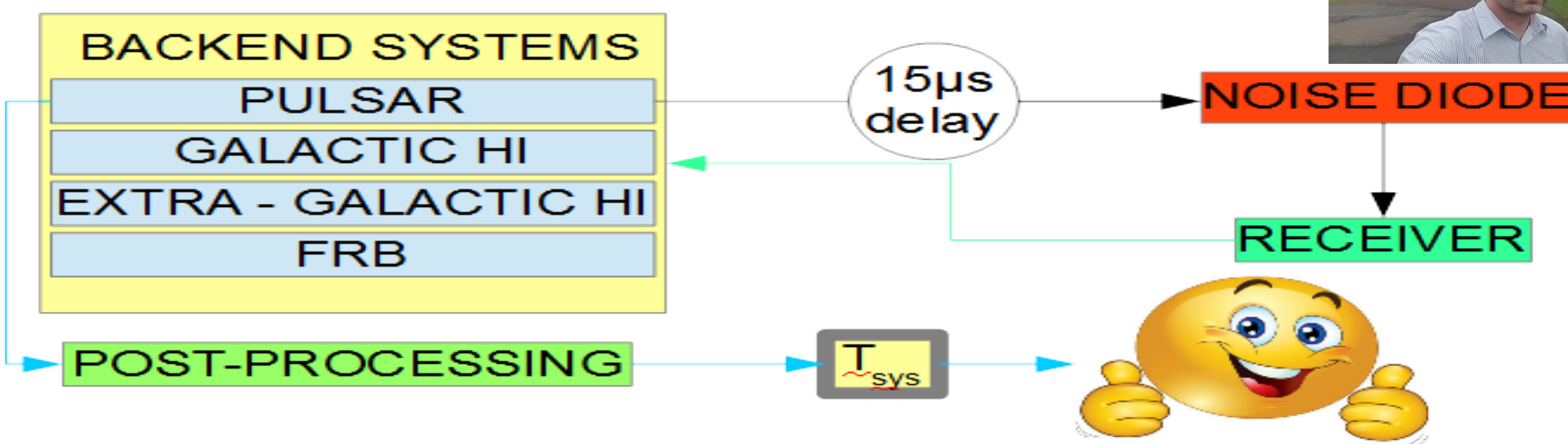




CAL SCHEME

Marko Krčo, Di Li, Dick Manchester,, George Hobbs, Bill Coles, Jim Cordes, Alex Dunning, Y. Zhu, Lister Staveley-Smith …

- Run a "winking" CAL at the Pulsar backend sampling rate (~100 μs)
- CAL should not influence Pulsar search
- Pulsar backend must trigger CAL
- Automated Post-processing of Pulsar data recovers T_{sys} and CAL timing information to be shared with all groups.



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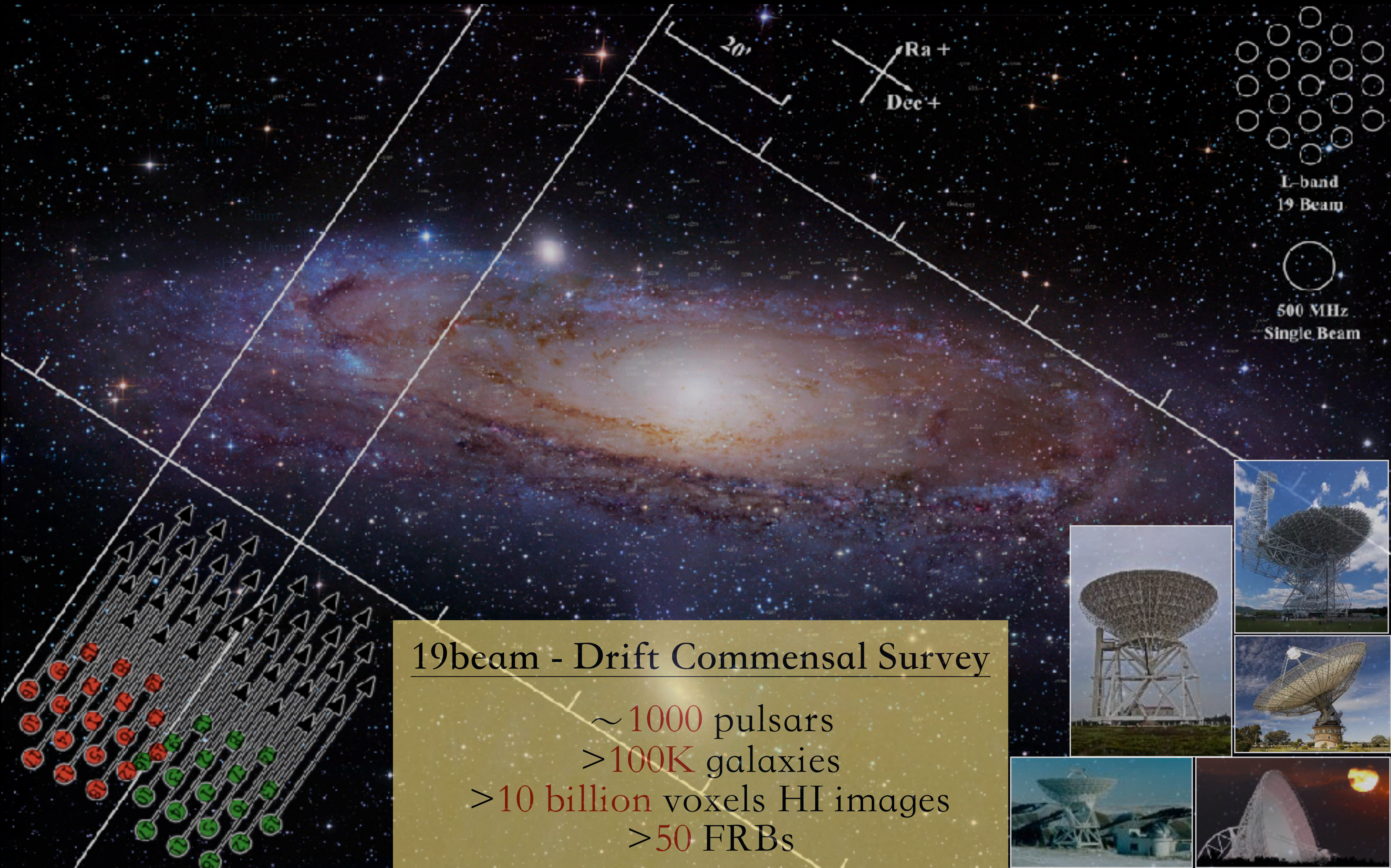
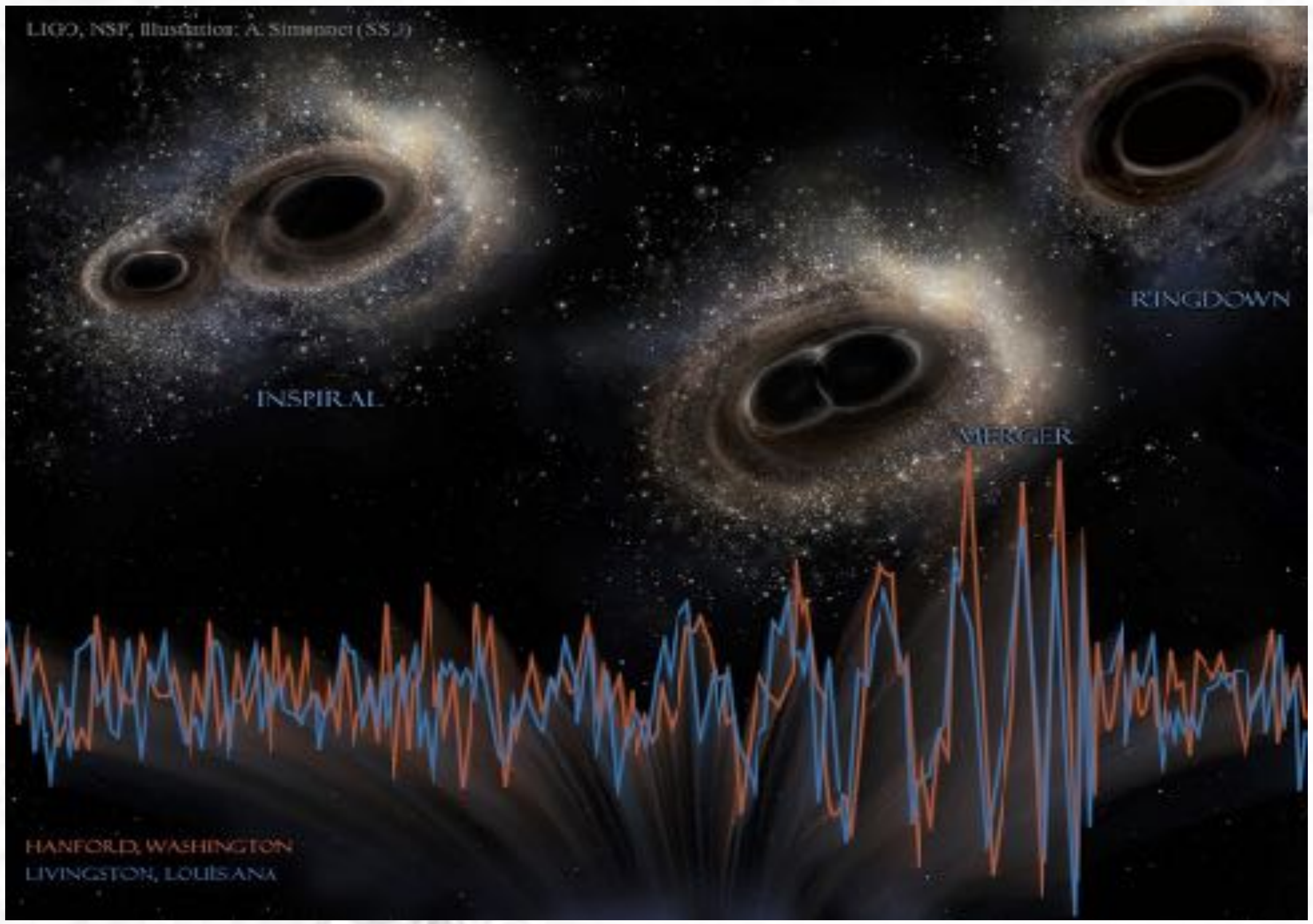


19beam - Drift Commensal Survey

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

FAST-LIGO-VIRGO



Di Li Principal Investigator of the FAST FRB Project Chief Scientist of NAOC Radio Astronomy Division	David Reitze Director of LIGO Laboratory
Signature	Signature
Date	Date October 2, 2016

LIGO-M1600222, VIR-0417A-16

Memorandum of Understanding between FAST and LIGO and VIRGO regarding mutual follow up observation of potential gravitational wave events

Outline

- FAST Concepts and Innovations
- Science Preparation and Potentials
- The Commensal Radio Astronomy FAST Survey (CRAFTS)

  Un*precedented radio survey mode*
- Challenges and Breakthroughs

  Un*precedented challenges*

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CRAFTS
Data Challenges

FAST 'big data' stream

8bit x 10^4 x 2 x 4k x 19 per second

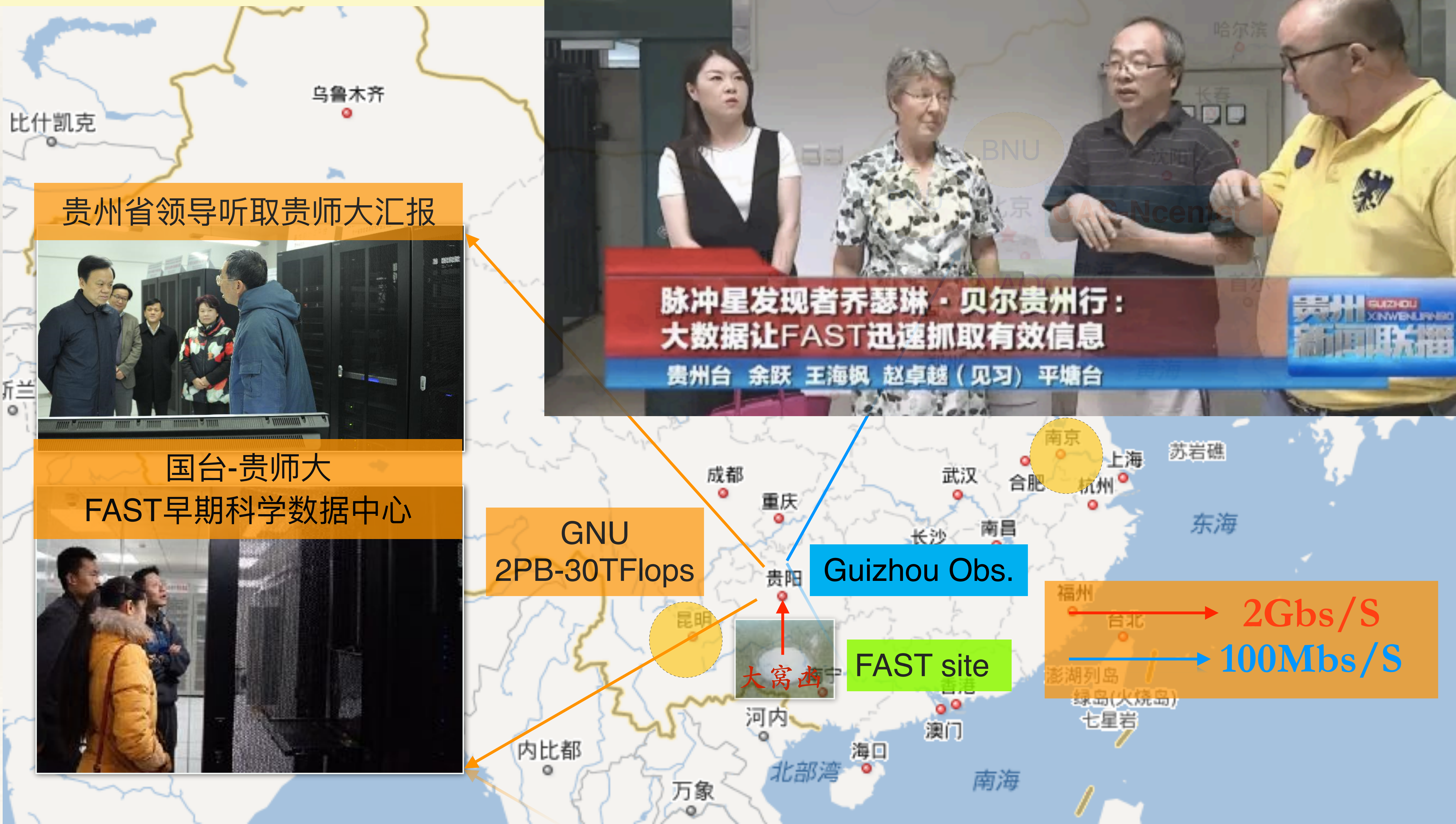
- 1.6 GB/s
- 5.8TB/h
- 144TB/day
- 10-20PB/ year

Requirements: 50-100PB; 1peta-flop; ¥25M/year

Have Now: FAST: 0; CAS: ¥15M; NAOC: ~¥2M

FAST *Distributive Processing/Storage Plan*

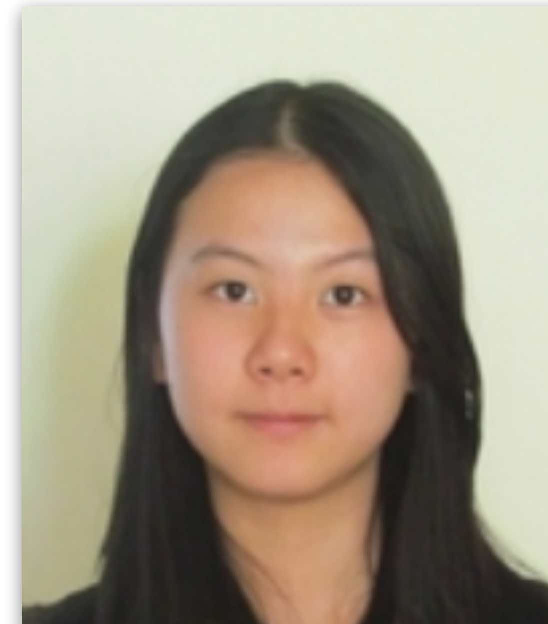
100Gbs Transmission; 100PB Storage; 1 PFLOPS;
NGAS（Next Generation Archive System）



Collaborations

- Personale exchanges

- Technology Developments
  - Receivers
  - Big data, HPC, Cloud



Shana Li
Shana.Li@oberlin.edu

- Joint Observation, Operation, and Analysis
  - Gravitational Wave; FRB; TDE
  - SETI - HXMT- Subaru - VLBI

AI vs. Human Intelligence

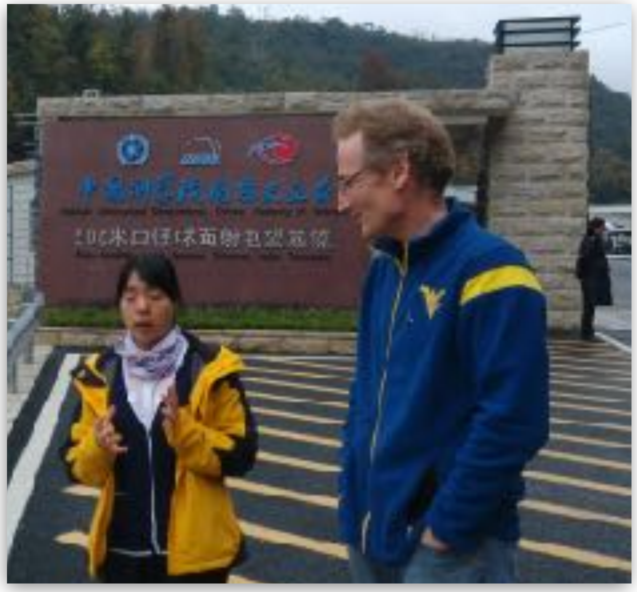
- A Global Vision: synergy with SKA?

> If you make your observations by writing a set of instructions for a telescope operator to carry out, and then write a set of instructions for a computer to extract some data from the results, then it is rather unlikely that you are going to find anything other than what you are looking for.
>
> **—John Bolton, 1964**

FAST
Opportunities in China

- National and CAS Talent Program
  - $500K -$1M package (supervising postdocs) , professorship (tenured) [*W.W. Zhu (MPifA), J.W. Wu (UCLA)*, etc.]

- NAOC FAST Fellowship
  - Senior Visiting Fellow: ~$7K support， access to commissioning data [*Ue-li Pen, P. Goldsmith, D. Lorimer* etc.]
  - FAST Postdoctoral Fellows: ~$35K/year + $10K grant + bonus, lead FAST science papers [*M. Krco (Cornell), R. Duan (Caltech), C. Tao (Taiwan Tsinghua/ Harvard)*, etc.]



- CAS PIFI Fellows
  - PIFI Visiting Fellow: 1-2 month, ~$10-20K support，
  - access to commissioning data [*G. Hobbs, C. Heiles*, etc.]

- Key Foreign Talent Program: $150k/yr

Discoveries
Radio Astronomy

No.	Discovery
1	Cosmic radio emission
1	Non thermal radiation
1	Solar radio emission
1	Solar radio bursts
3	Radio galaxies
2	HI
2	Jupiter radio bursts
1	Evolving Universe
2	Radio Recombination Lines
1	Venus rotation
1	Quasars
1	4th test of GR

No.	Discovery
2	Mercury Rotation
3	Interplanetary Scintillations/solar wind
4	Interstellar molecules
2	CMB
4	cosmic masers
5	Pulsars - neutron stars
2	CO and Giant Molecular Clouds
7	Superluminal motion
1	Gravitational lensing
2	Gravitational radiation
2	Solar deflection confirming GR
2	Exoplanets
5	Fast Radio Bursts

Repeating FRB

Ken Kellerman 2016
@ RonFest

Arecibo

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- Will our searches be RFI limited?
- Will we get in the game in time for FRB and GW?
- Can we preserve the unknown unknowns in the data?

UN*precedented surveys*

UN*precedented hardships*

UN*precedented potential*

"Building telescope is a game of shrinking dreams"

"We STILL have a Dream"

—2013 Australia-China Science Academies Symposia Series @ Nanjing

Ides of Jan, 2018 @ NAOJ

CRAFTS

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