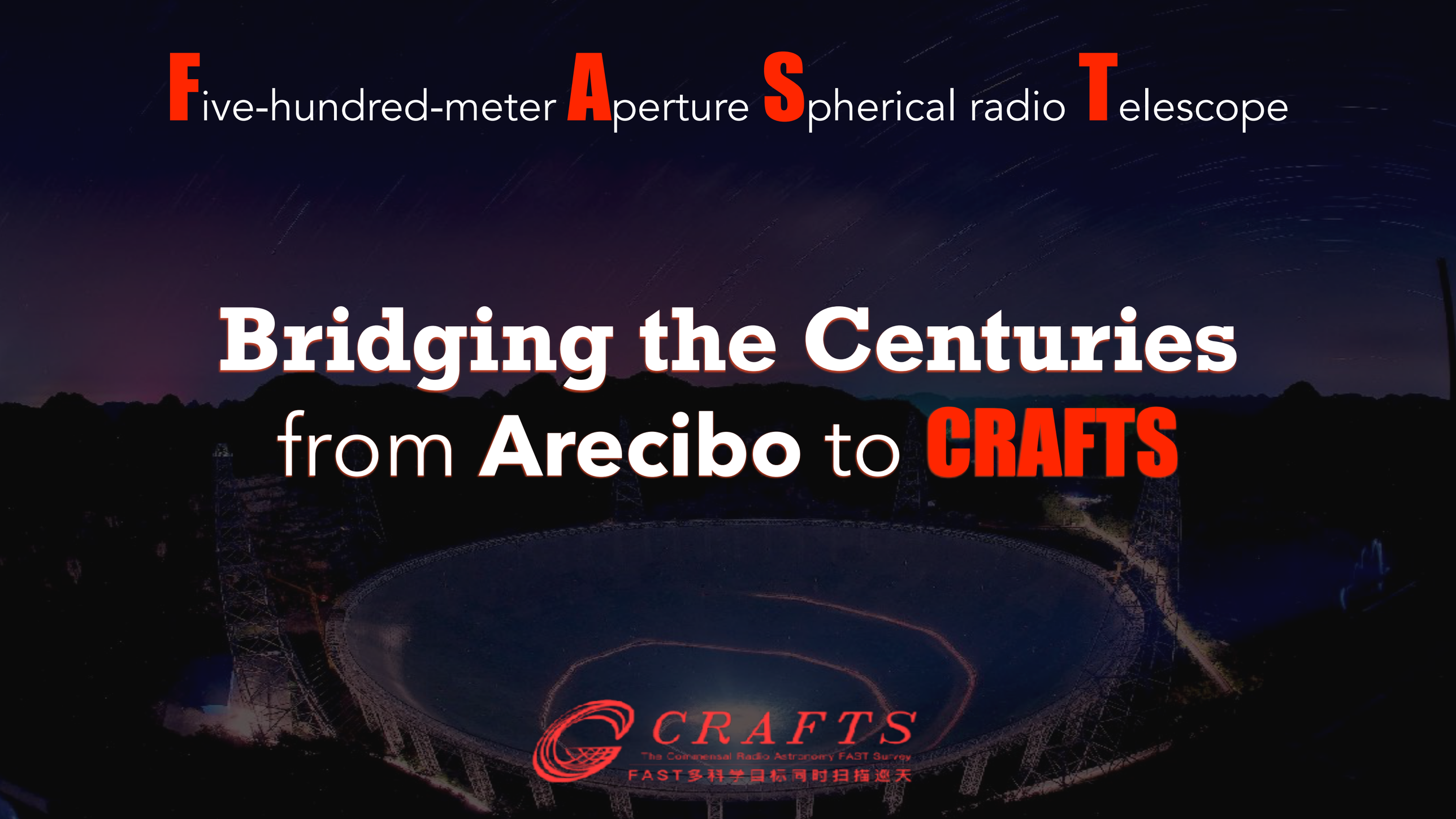
Five-hundred-meter **A**perture **S**pherical radio **T**elescope

Bridging the Centuries from Arecibo to CRAFTS



中国天眼 FAST

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

Guizhou, China

1994 proposed
2007 funded
2020 operation

1963 commissioned

mercury spin, double neutron stars, the first exoplanet etc.

1993 Nobel prize in Physics

2020.12.1 collapsed

Arecibo

Puerto Rico

(1963-2020)

William E. Gordon
Cornell University

Beautiful Mistake

1958.5.29 proposed by W.E. Gordon as an ionosphere radar

- Gordon: **300 m**
- Ken Bowles: 30 m
- 1958 URSI meeting: Gordon also 30m

ARPA–(**A**dvanced **R**esearch **P**rojects **A**gency)
decided to sponsor a super-dish !

Eisenhower 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 … America’s wish for peace on earth and good will to men everywhere.”

1958.7 National Aeronautics and Space Agency

With Space program out of its portfolio, **ARPA** decided to fund **Arecibo** as its first project.

ARPA later became **DARPA**

George Kennan 1946

“Long Telegram”

We must formulate and put forward for other nations a much more positive and constructive picture of sort of world we would like to see than we have put forward in past.


Rendong Nan
Yuhai Qiu
1996
SHOT ON MI 9
PHOTO BY QIU


Pointing 1 min - 10 min
DEC -14d ~ 66d
Mode drift，OTF，track
升舱— 2018.08.14

Observables

a) HI 21cm (imaging & galaxies)

b) Pulsars (FRBs)

c) Molecular Spectroscopy

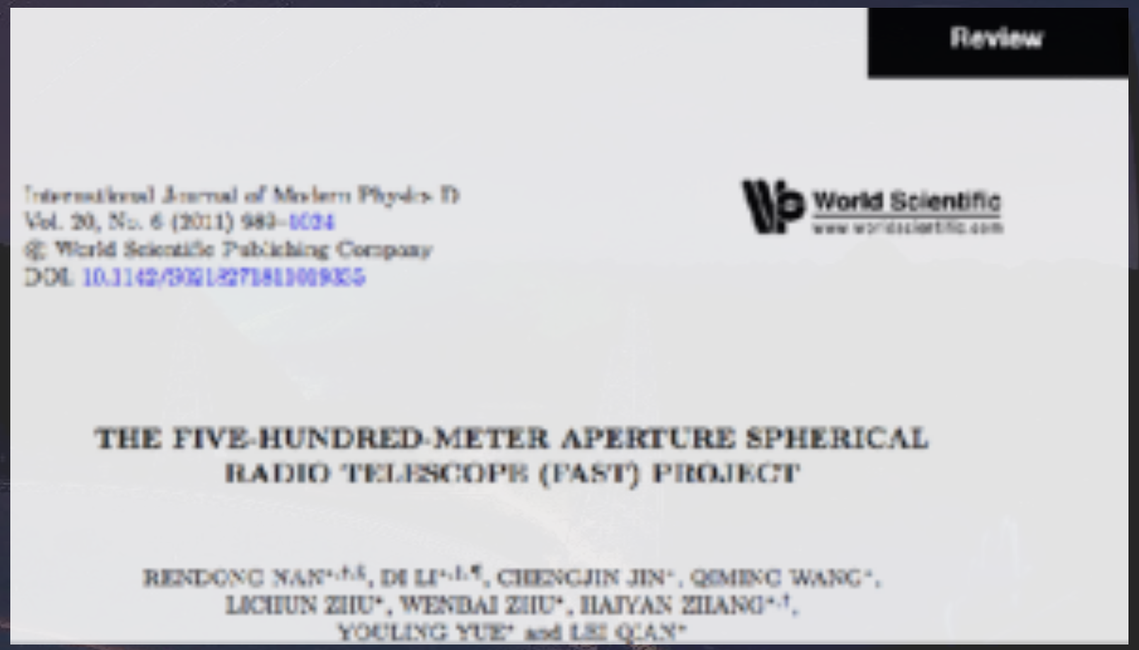
d) VLBI

e) SETI

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

continuous coverage

70 MHz～3 GHz

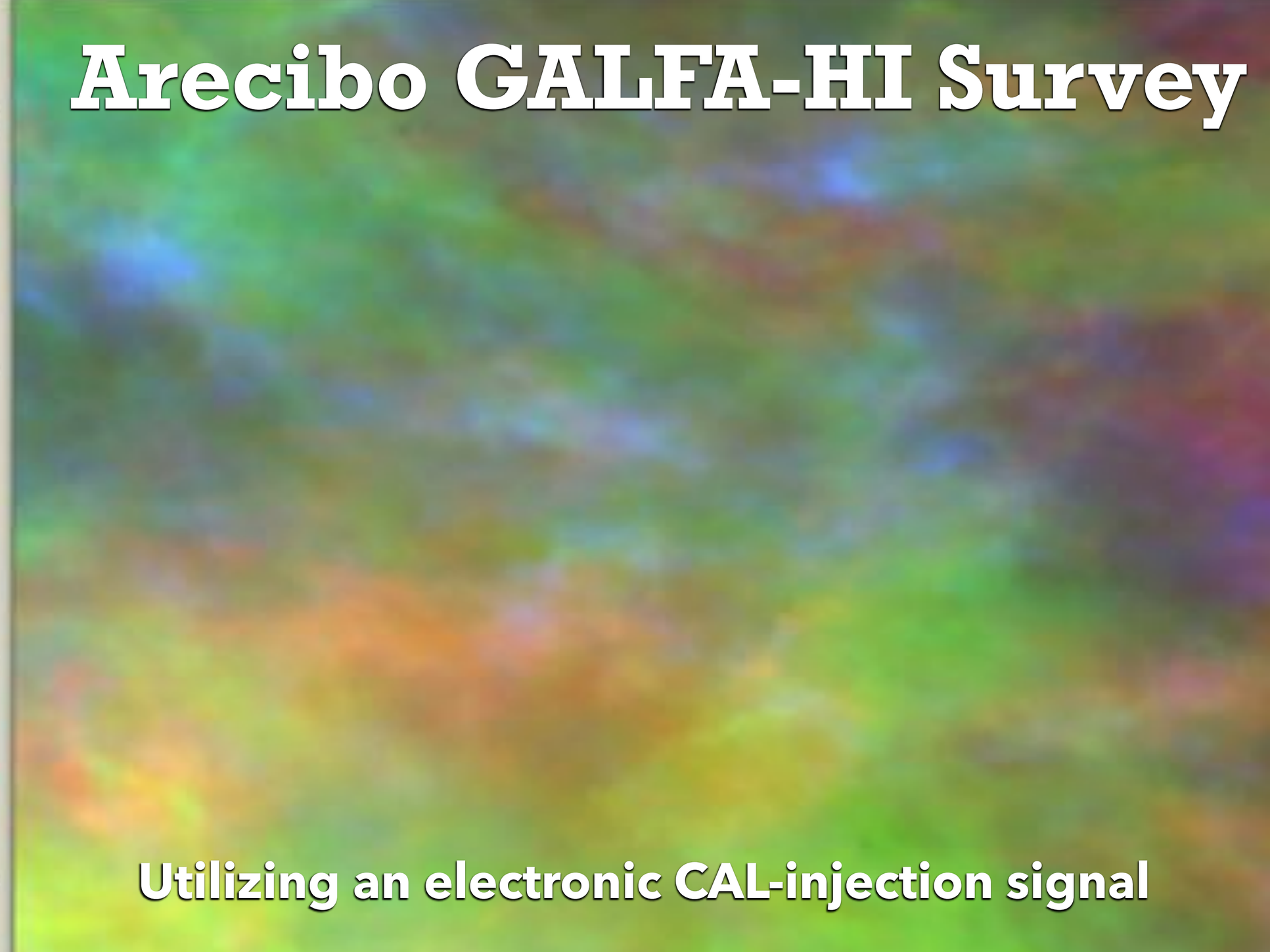


Nan, **Li,** Jin et al. 2011, IJMR-D, 20, 989
(Citations google >**700** ADS >**400**)

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

Arecibo GALFA-HI Survey

baseline ripple calibration	✓
crossing-point gain calibration	✓
first sidelobe calibration	✗

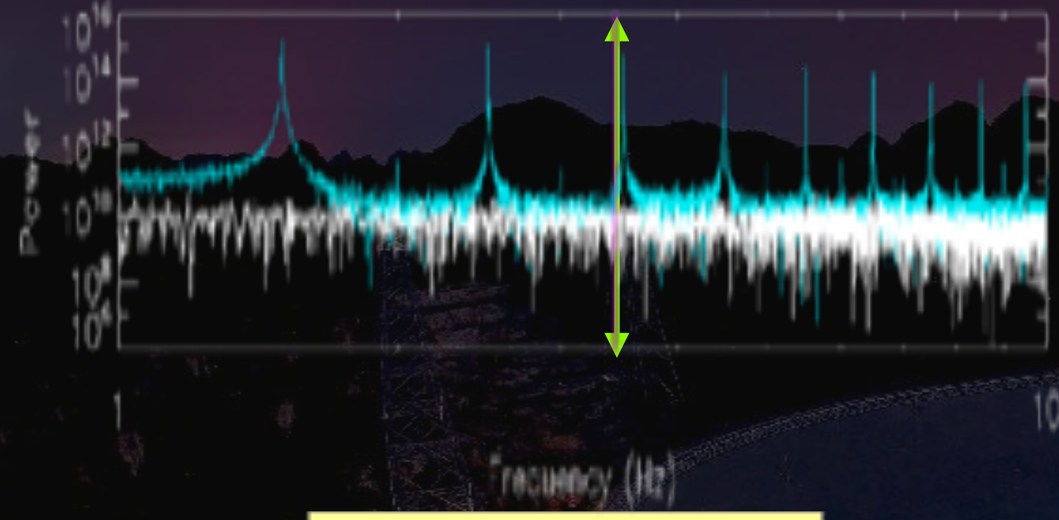


Utilizing an electronic CAL-injection signal

Novel Technique

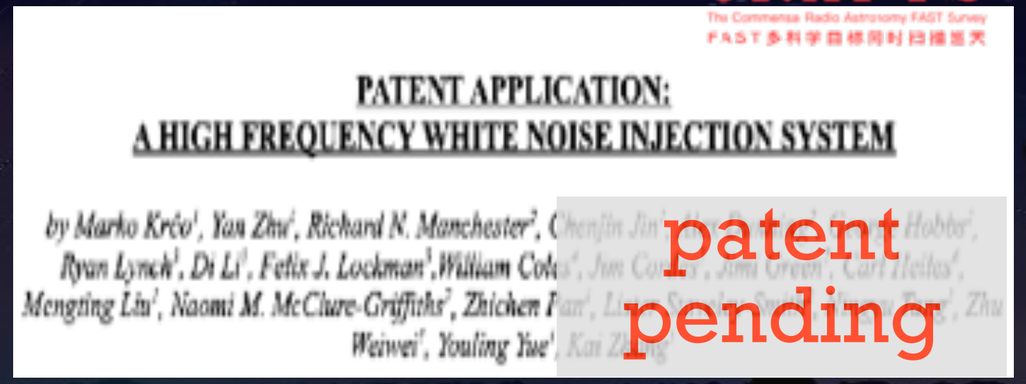
HI/pulsar commensality!

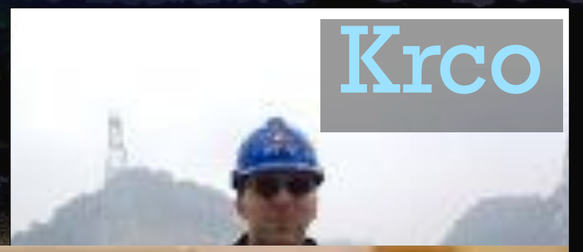
The CAL Problem

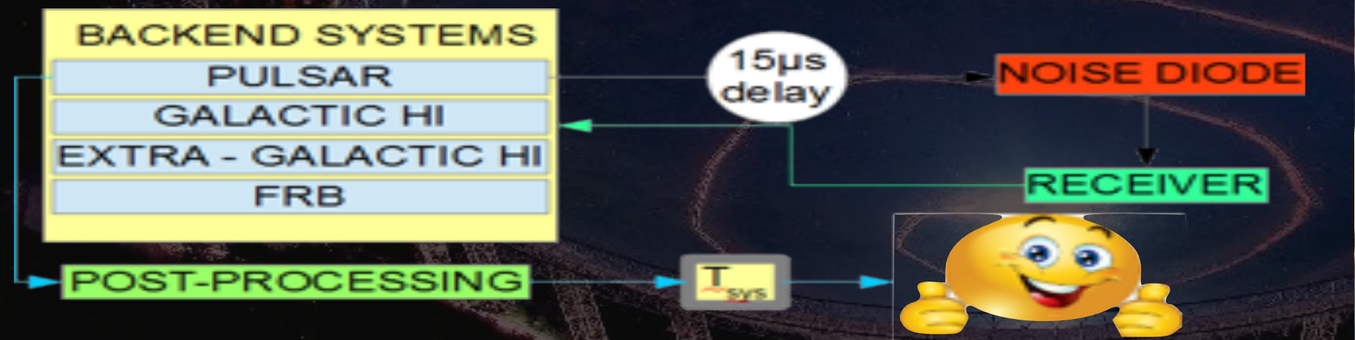


High Cadence CAL

- "winking" CAL at the pulsar backend sampling rate (~100 μs)
- Pulsar backend trigger automatic CAL
- post-processing pulsar data to recover Tsys
- CAL timing information to backend with all groups.







Commensal Radio Astronomy FAST Survey

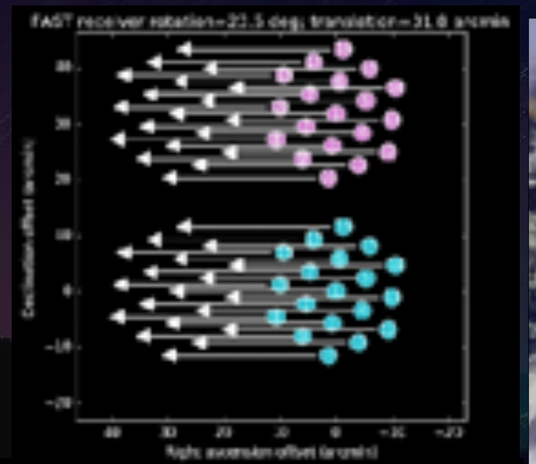
CRAFTS
The Commensal Radio Astronomy FAST Survey
FAST多科学目标同时扫描巡天

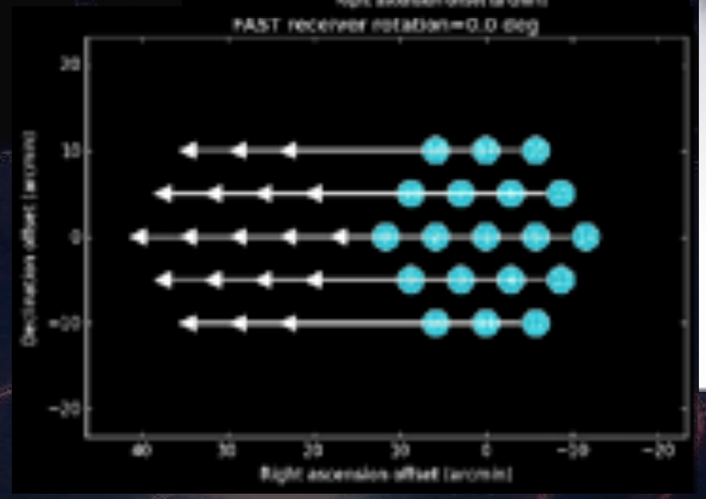
unprecedented commensality
pulsar, galaxy, imaging, and FRB

Proprietary high-cadence CAL injection

FAST **'big data'** stream

- 6 GB/s 10 PB/ year



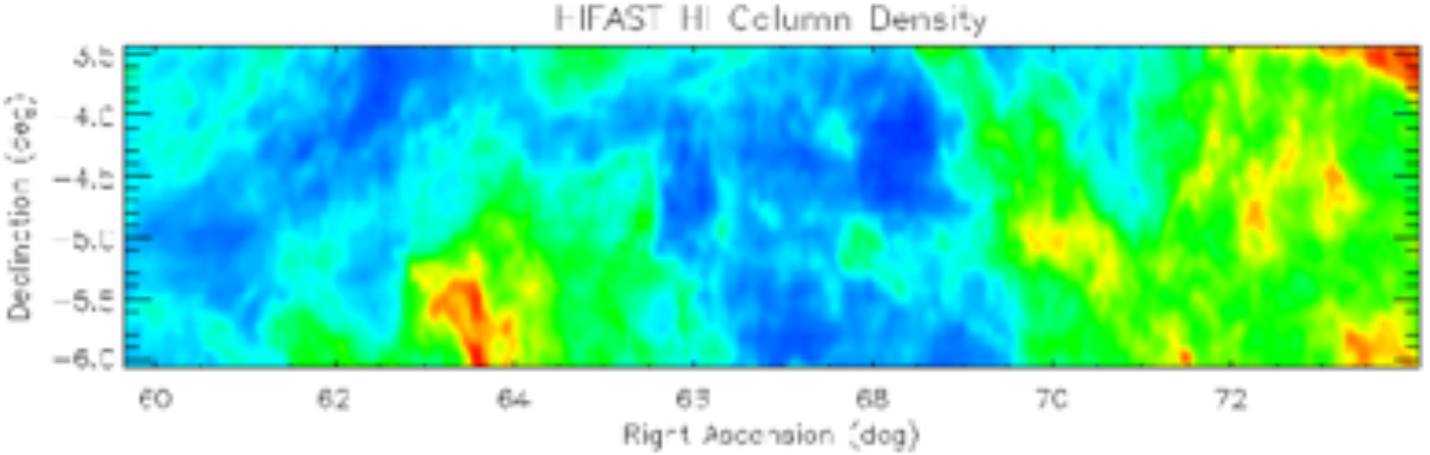


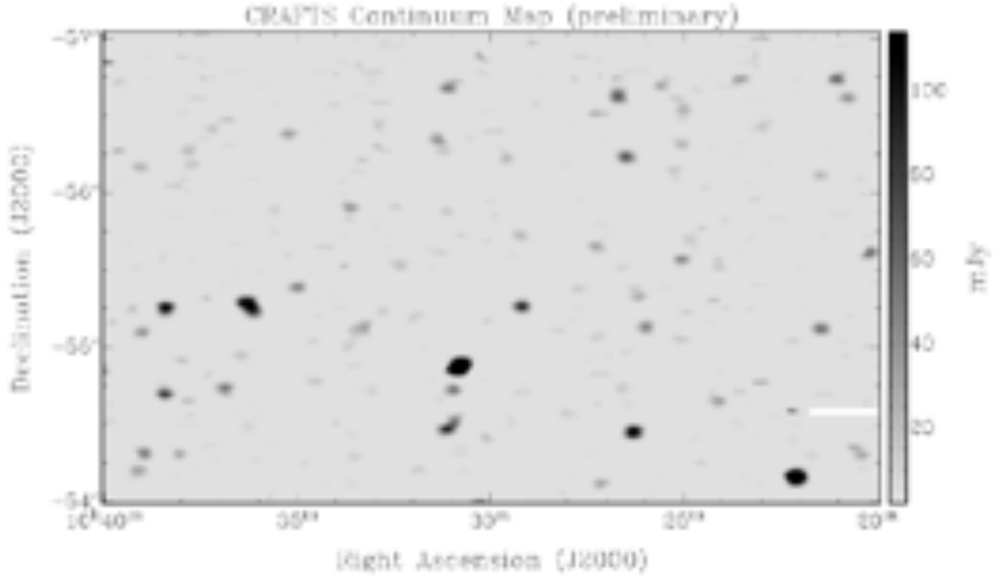
The Commensal Radio Astronomy FAST Survey
FAST多科学目标同时扫描巡天

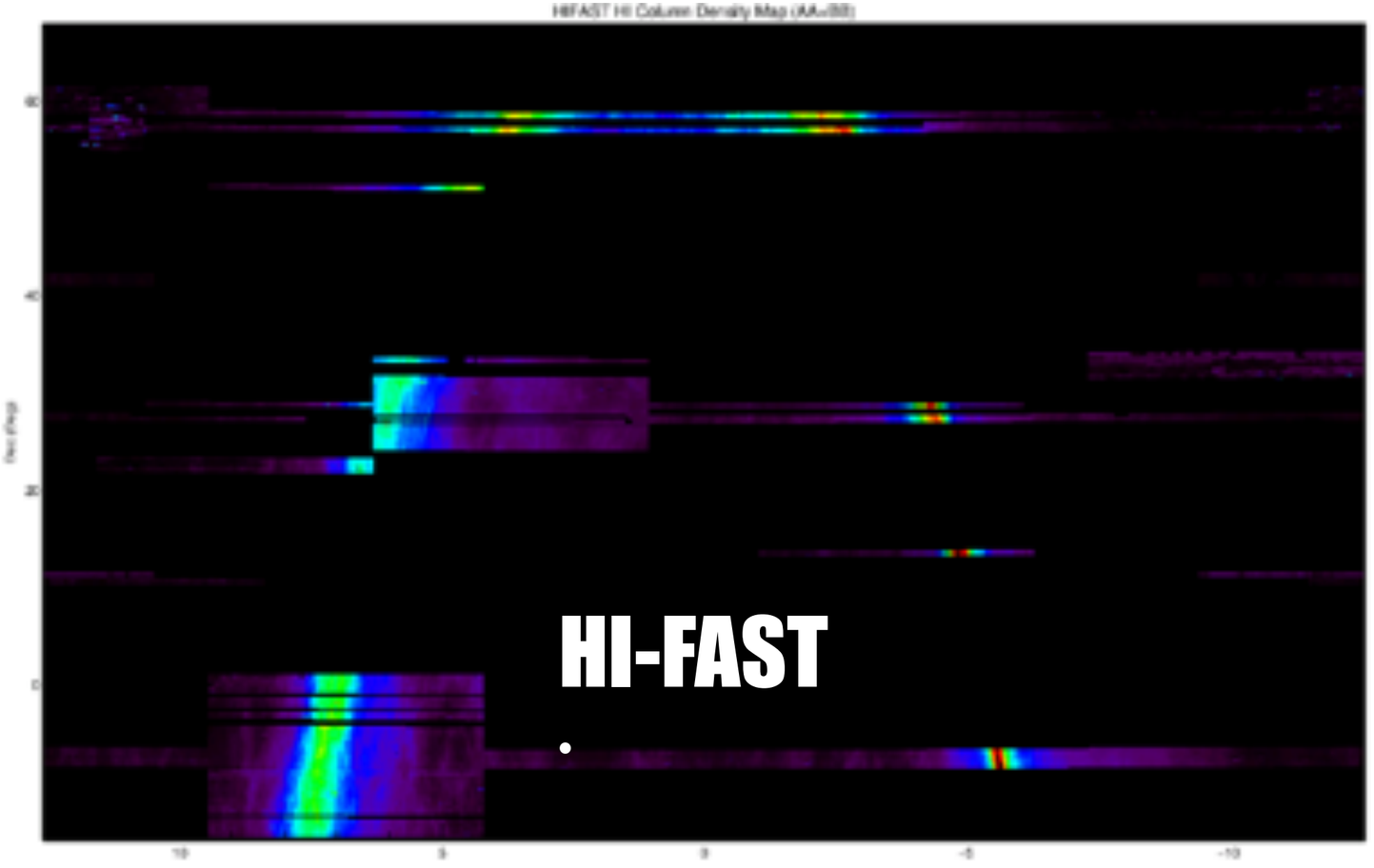
Li et al. 2018, Invited Review
IEEE Microwave, Vol 19, Issue 3, p112

HI-FAST

- The CRAFTS' HI product, namely HI-FAST, achieves absolute flux calibration.
- **18%** of CRAFTS completed.
- **<1% flux uncertainty**! (cf. GALFA, HI4PI, LAB)
- The pipeline is ready.
- The first data release expected in two months.



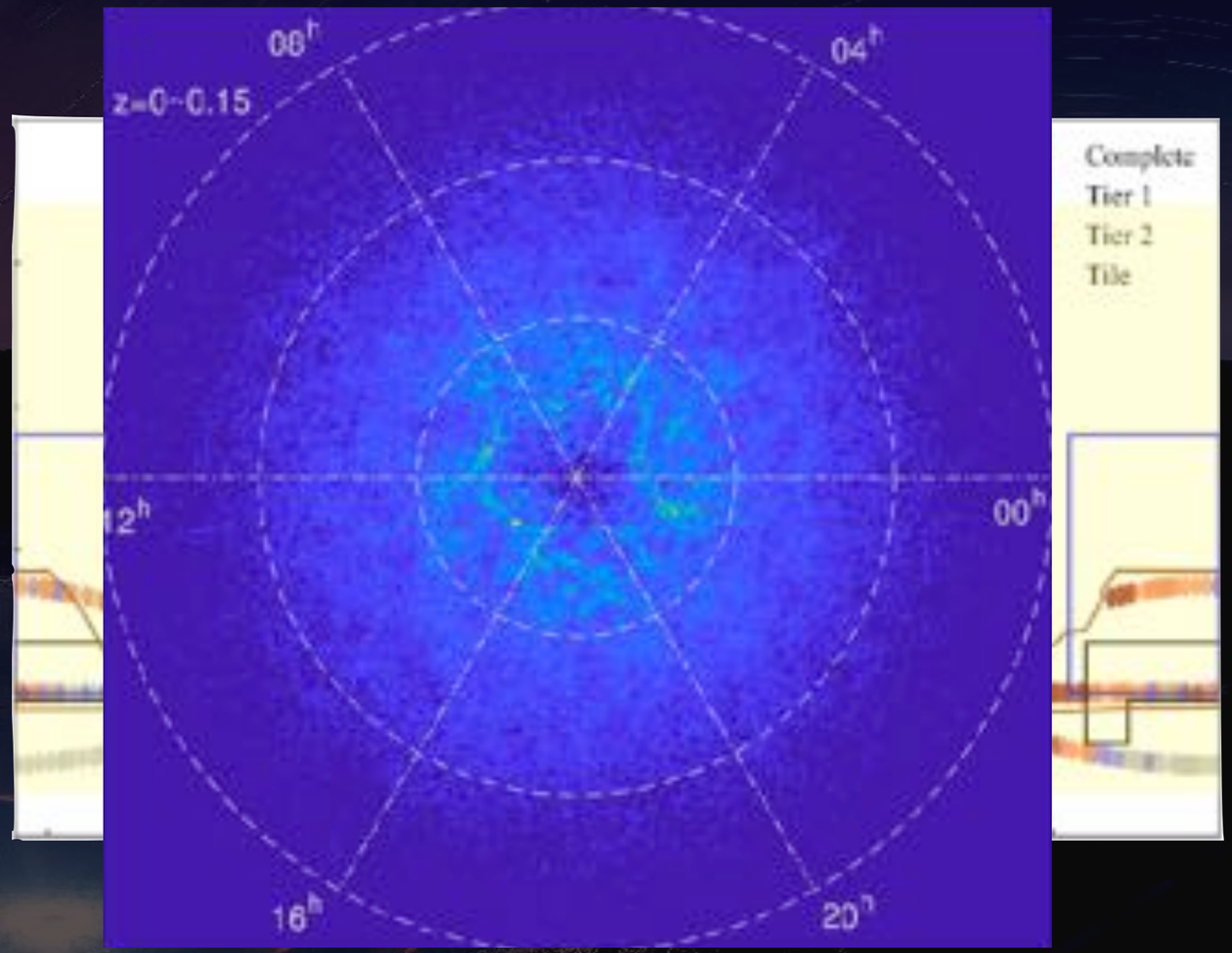




NAOC 中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES, CHINESE ACADEMY OF SCIENCES

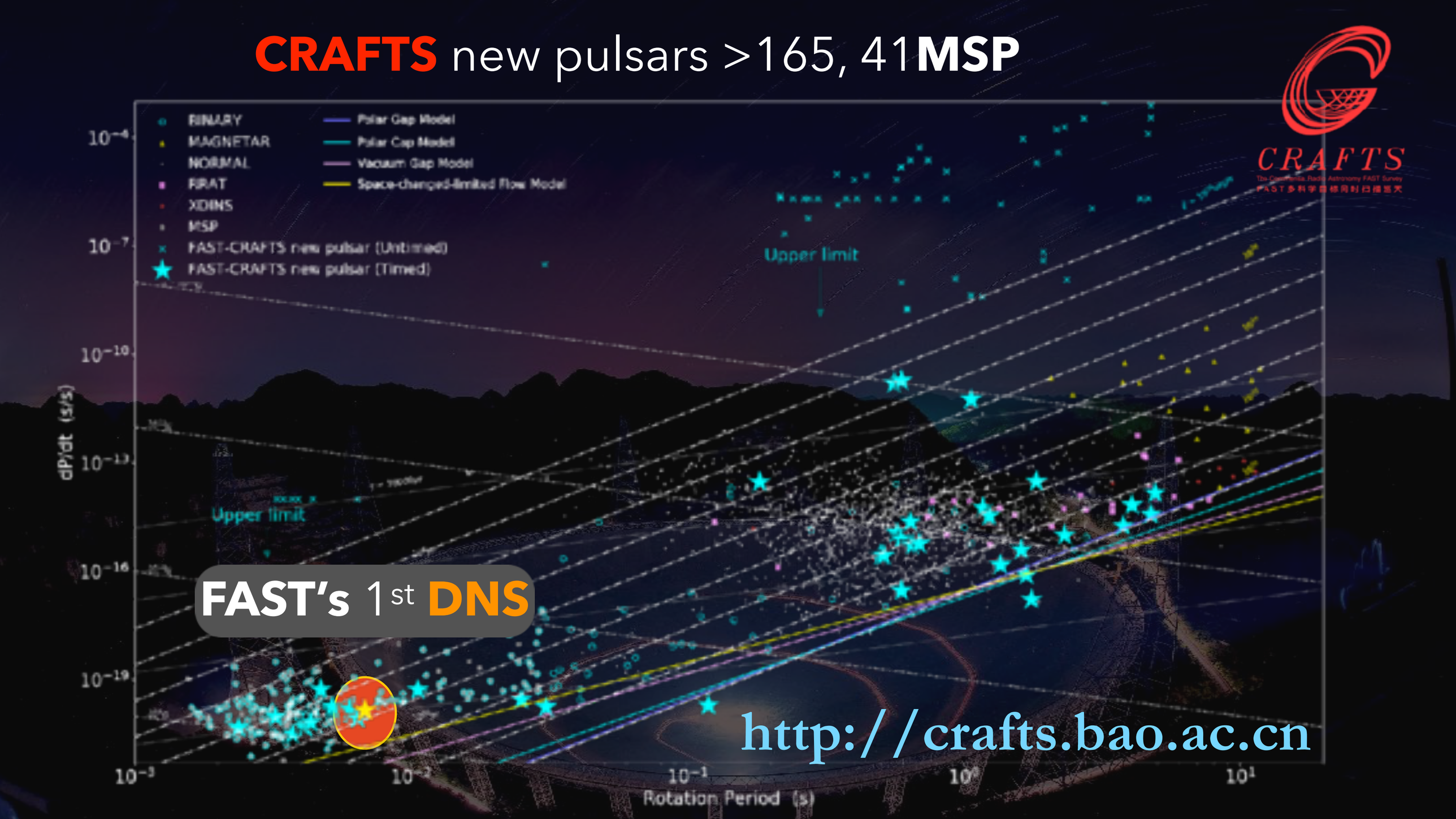
CRAFTS

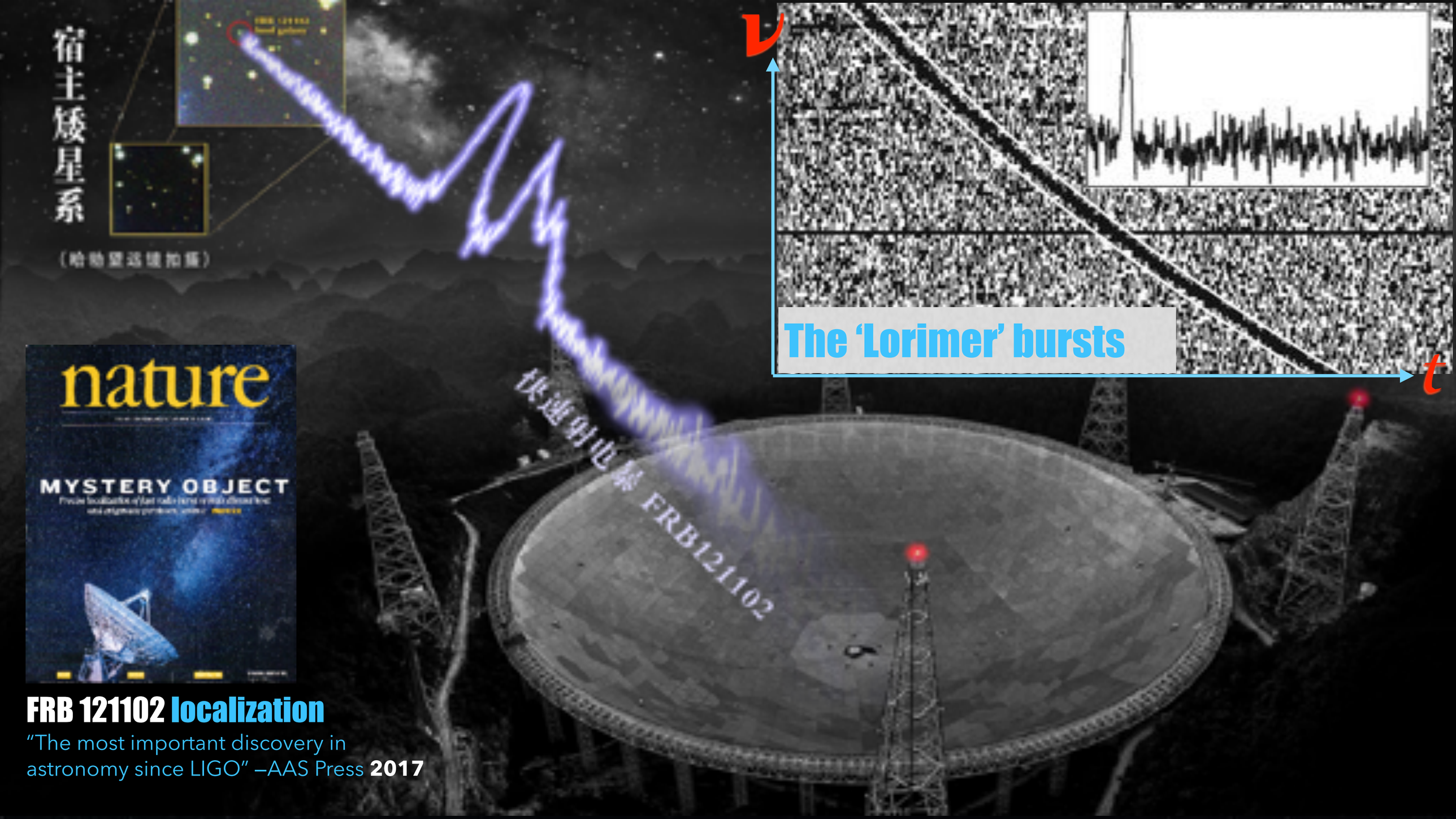
CRAFTS: galaxies



cf. Li+2018; Zhang+2020

CRAFTS new pulsars >165, 41**MSP**





FRB 121102 localization

“The most important discovery in astronomy since LIGO” –AAS Press **2017**

Contents [hide]

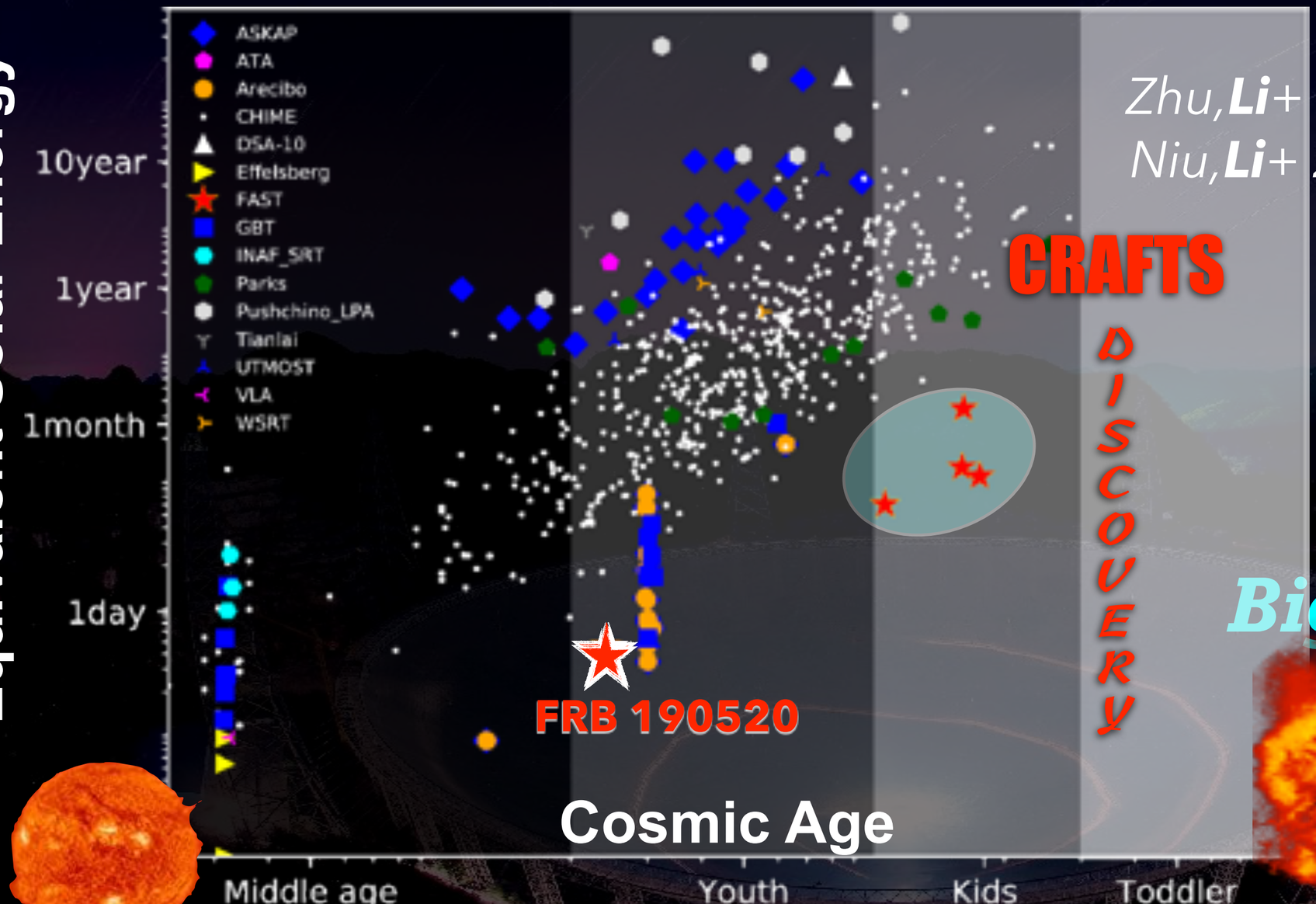
> **50** categories of models

No clear consensus

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-Cavity	AGN	Jet-Cavity Interaction	Both	Electron scattering	Brems.	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

CRAFTS reveals a high event rate **>120K** per day!



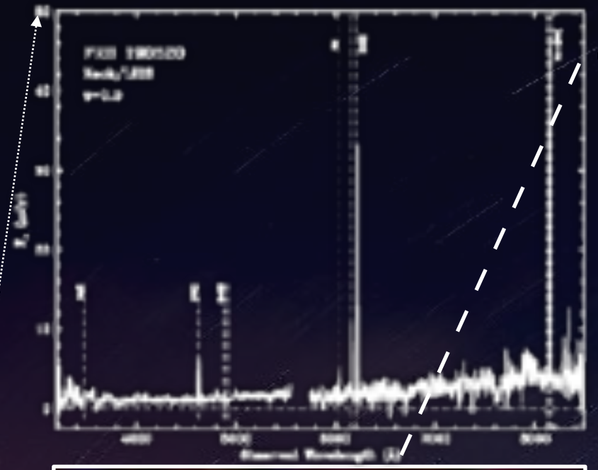
*Zhu,**Li**+ 2020 ApJL*
*Niu,**Li**+ 2021 ApJL*

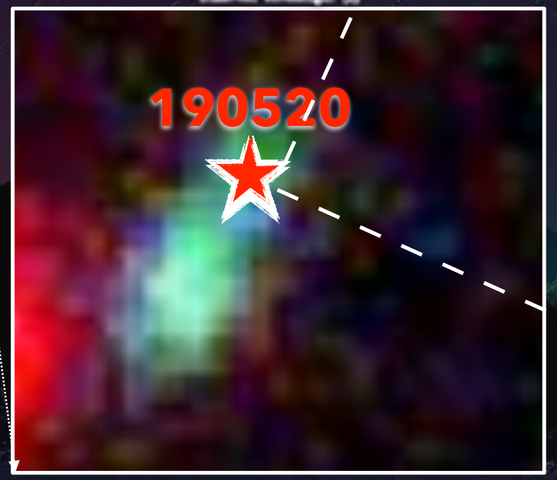
Big Bang

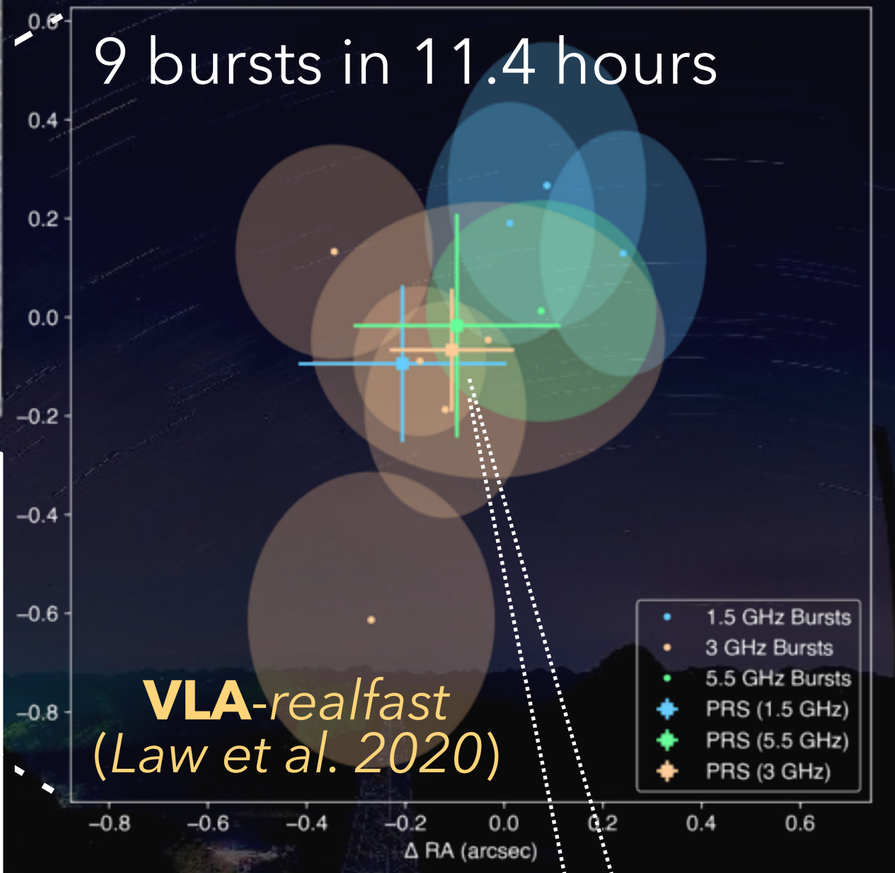
CRAFTS

2019.5.20 **CRAFTS** scan: discovery

2022.6.30 《 **Nature** 》





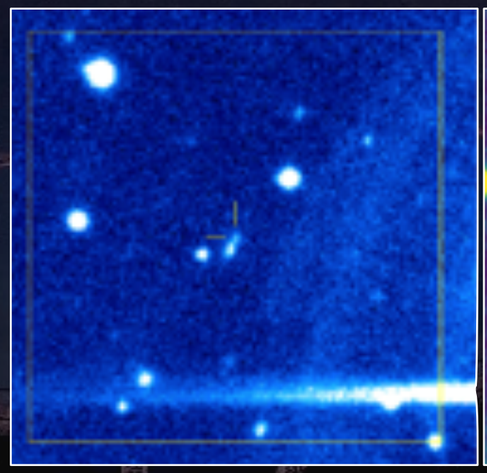


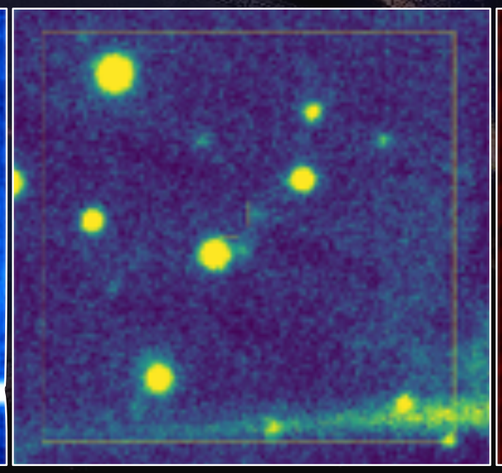
z=0.241 << z(DM$_{excess}$)~1

PRS: **~ 260 μJy**

FRBs - PRS within **~0.25"**

accidental-association prob. **≈ 6×10^{-6}**





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

FAST: D. Li, C.-H. Niu, W.-F. Yu, J.M. Yao, P. Wang, Y.-K. Zhang, Y. Feng, B. Zhang, W.-W. Zhu, J. Cordes, S. Ocker et al.

Parkes: Shi Dai, Yi Feng, Chen-Hui Niu. Di Li et al.

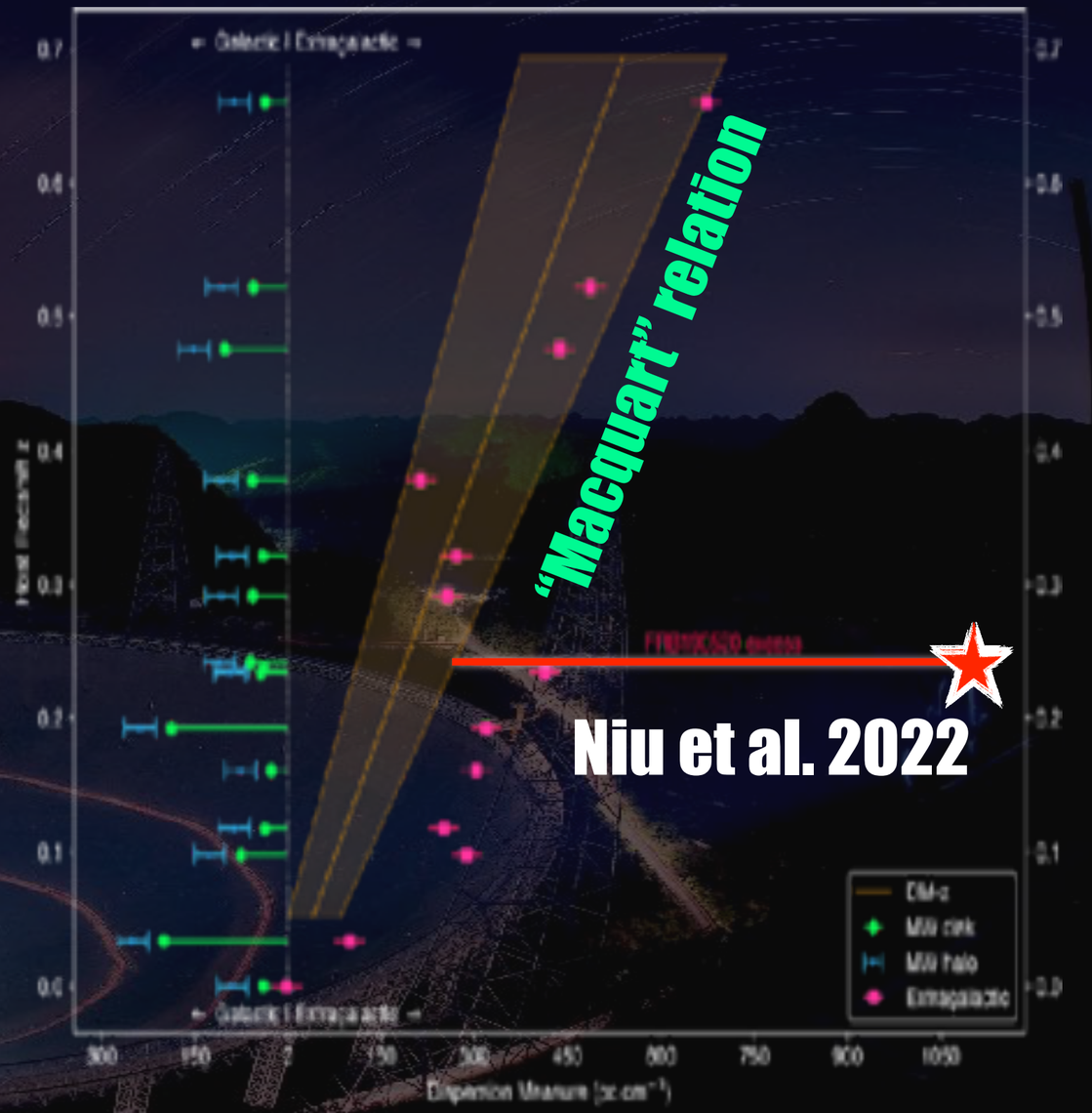
Effelsberg/EVN: Marilyn Cruces, Bo Zhang, Chenhui Niu et al.

JVLA: Casey Law Wen-Fei Yu, Sarah Burke-Spolaor, et al.

GBT: Yi Feng, Shi Dai, Ryan Lynch, Sarah Burke-Spolaor et al.

VLBA: Wen-Fei. Yu, Casey Law, Shami Chatterjee et al.

Optical/High E: Chao-Wei Tsai, Chris Bochenek, Yuu Niino et al.

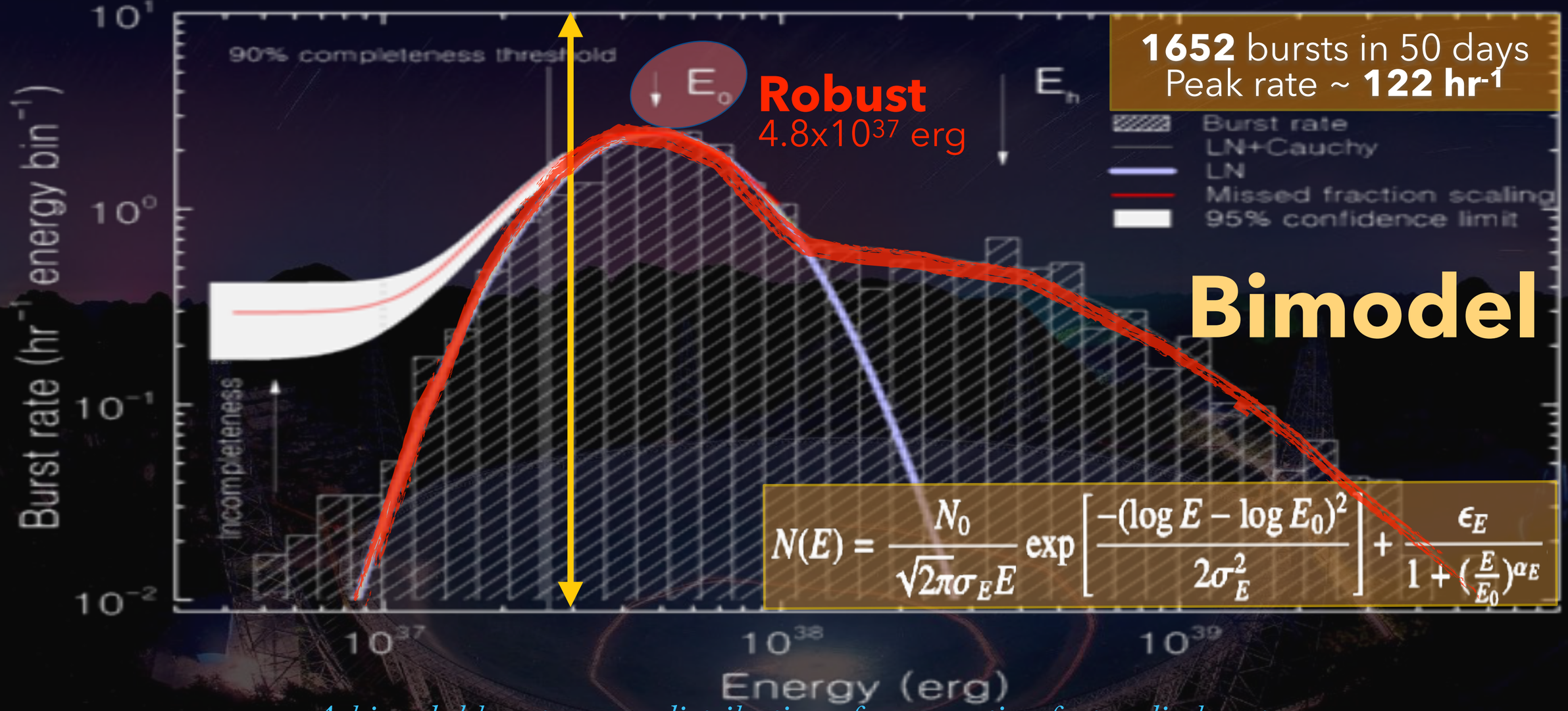


"The first persistently active FRB"

- 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.

FRB 121102

Burst Rate Energy Distribution



A bimodal burst energy distribution of a repeating fast radio burst source

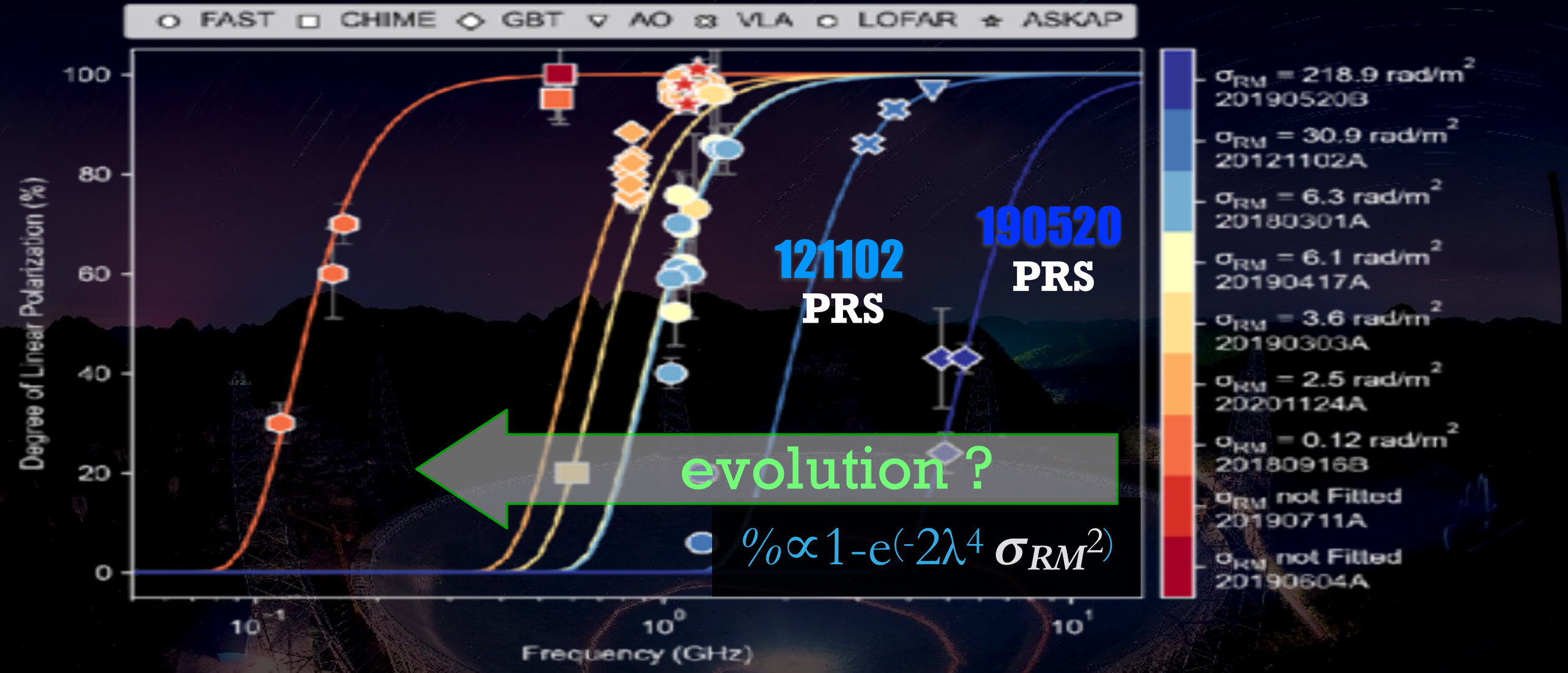
Li*, Wang et al. 2021 **Nature**, 598,267

China's Top 10 scientific breakthroughs in 2021

1. Tianwen 1 landed on Mars
2. China′s space station core Tianhe in orbit
3. Synthesizing starch from carbon dioxide
4. Chang′e-5 returned with lunar rocks
5. Cryo-EM structure of an extended SARS-CoV-2
6. FAST caught largest set of fast radio bursts
7. High-performing woven lithium-ion fiber batteries
8. Programmable superconducting quantum processor
9. Soft robot 10,000 meters under the ocean′s surface
10. Spatio-temporal dynamics of bird migration routes

Unified characterization of all FRBs - σ_{RM}

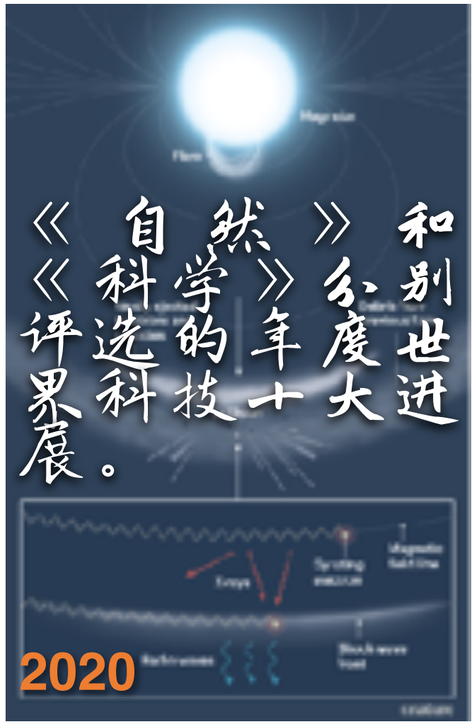
2022



Feng et al. 2022, **Science**, 375, 1266–1270

快速射电暴领域FAST相关成果

通讯或一作（含Nature/Science 5篇）　参与合作



《自然》和《科学》公布年度大科技评选的十大世界科学进展。

- FRB **200428**, Lin et al., ***Nature*** (Cf. Bochenek+ & Chime+ **Nature**)
- FRB **180301**, Luo et al., ***Nature***
- FRB **181123**, Zhu et al., *ApJL*

- FRB **121102** Li et al., **Nature**; Yang & Zhang, 2021, ApJ
- **3** new FRBs Niu et al., ApJL; (Cf. **CHIME/FRB** Catalog 1 ApJS.

More to come

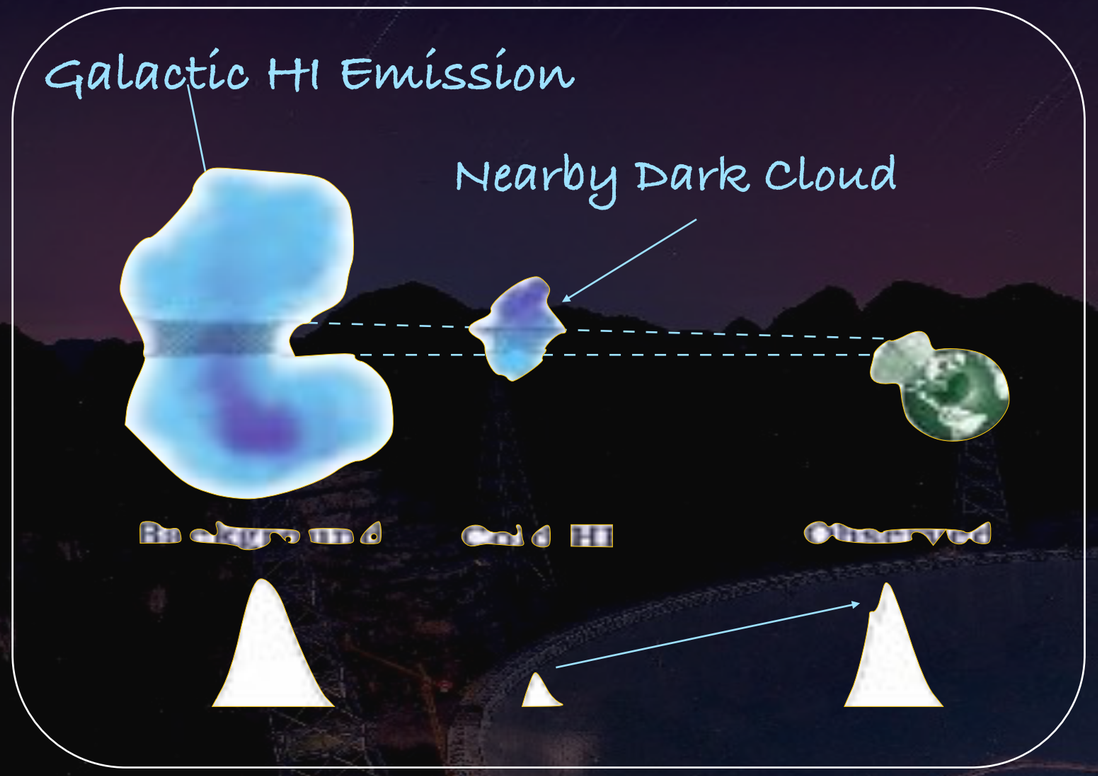
- FRB **190520B**
  Niu et al., **Nature**;
  Feng et al., **Science**;
  Feng et al., **Science Bulletin**; Anna-Thomas, Feng et al. **Science** (accepted)
  Zhang et al. **Nature Astronomy**, under review

190520-models
Wang et al., **Nature Communications**;
Ocker et al., ApJ

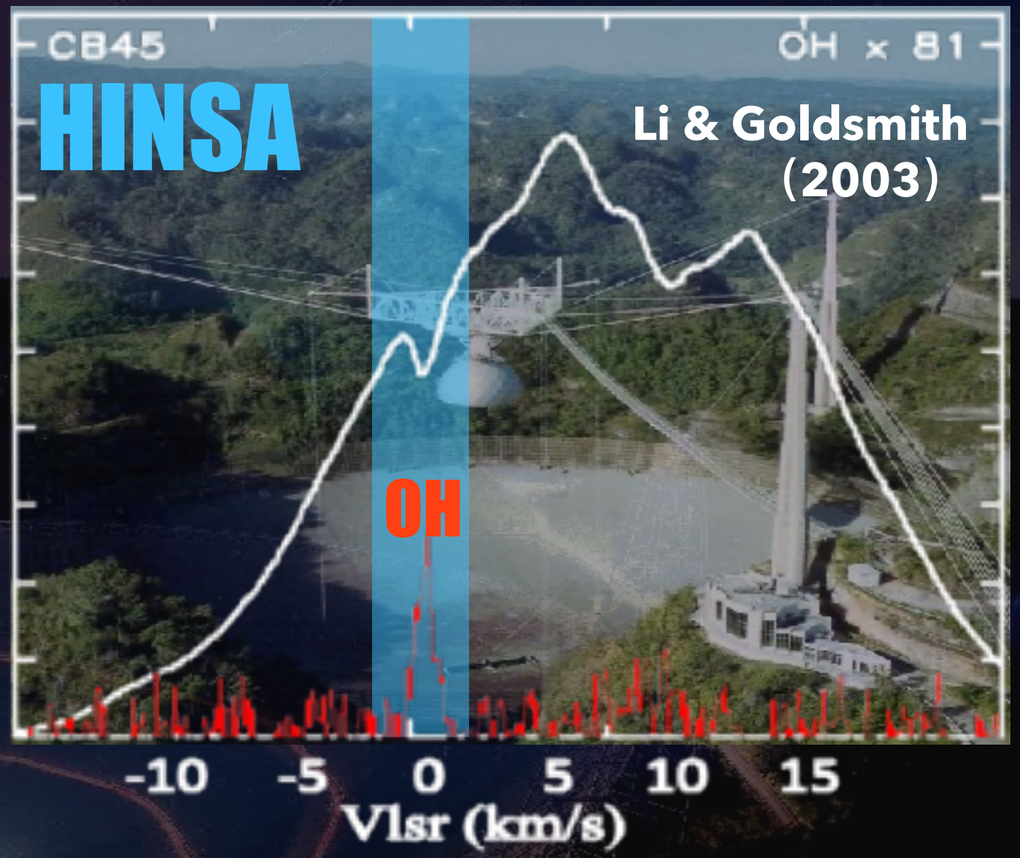
- FRB **201124A**
  Xu et al., **Nature**;
  Zhou et al., Zhang et al., Jiang et al., and Niu et al., 4 papers in RAA

氢气的窄线自吸收（HI Narrow Self-Absorption）

阿雷西博望远镜



Arecibo

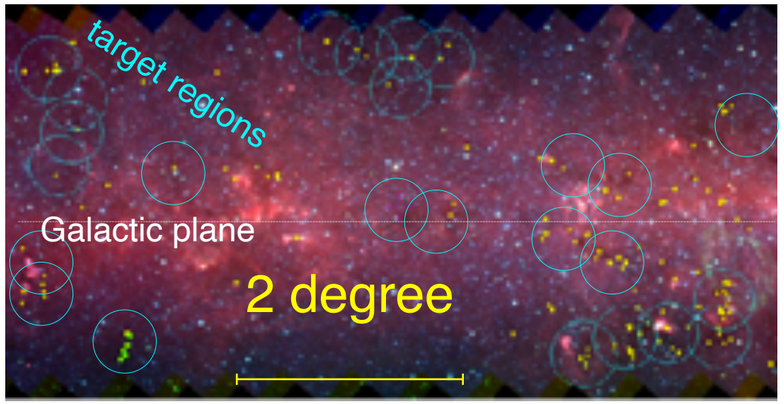


创新天文观测方法—测量暗云的年龄(氢记年）

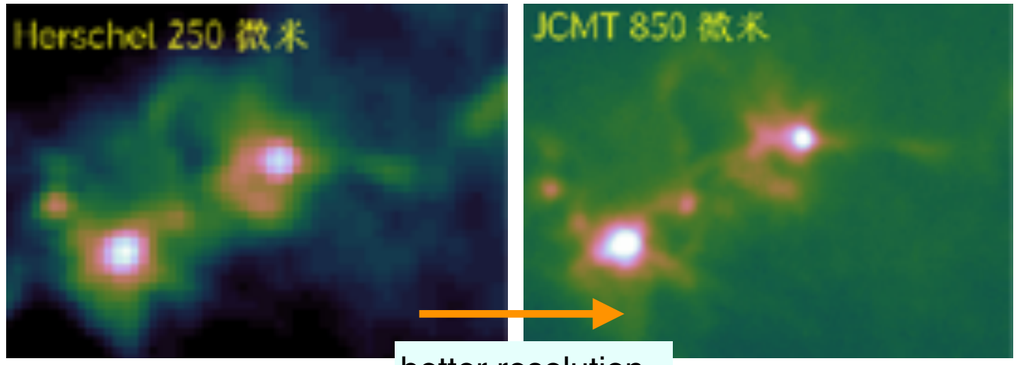
'Hydrogen-dating' the molecular clouds, constrains the time scale of star formation

JCMT Large program

ALOHA (**A** **L**ei **O**f the **H**abitat and **A**ssembly of IRDCs)

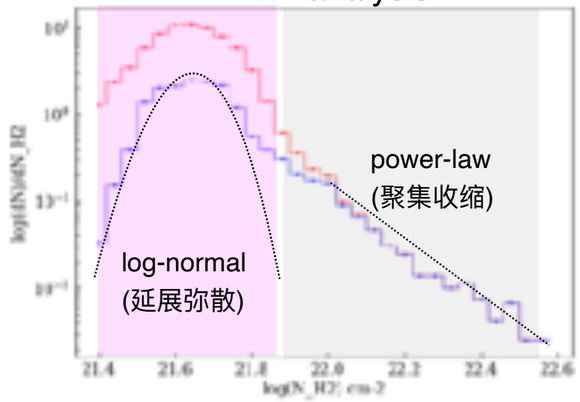


Better images than Herschel



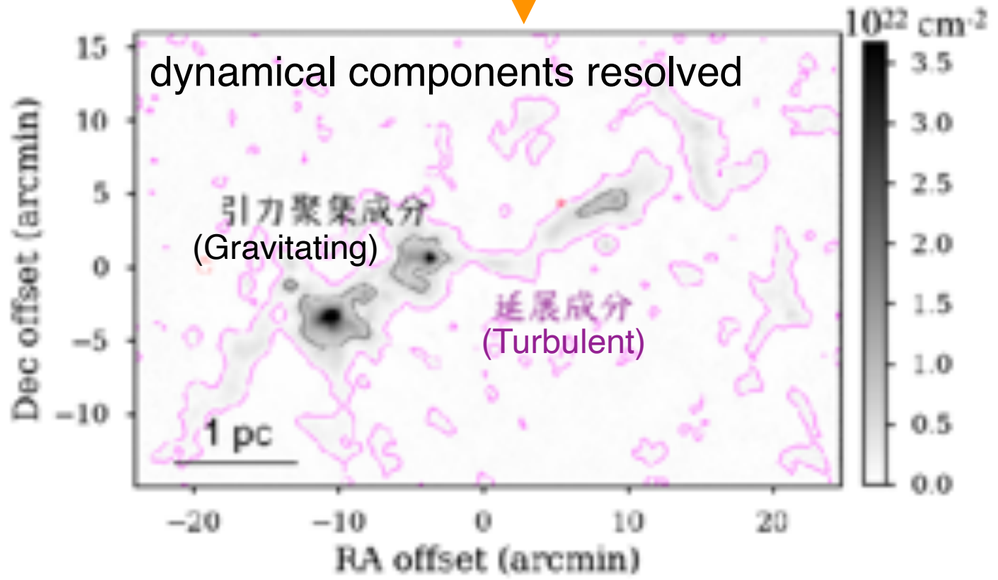
better resolution
and lower noise

NPDF analysis



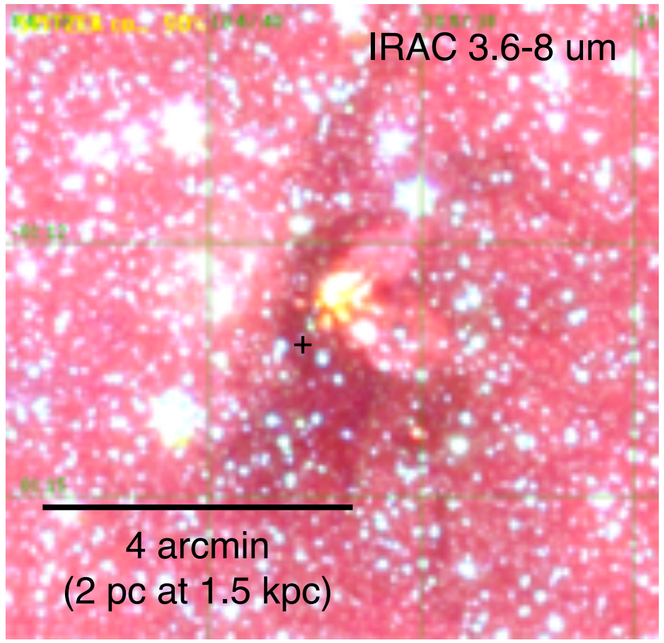
Sensitive image + NPDF analysis

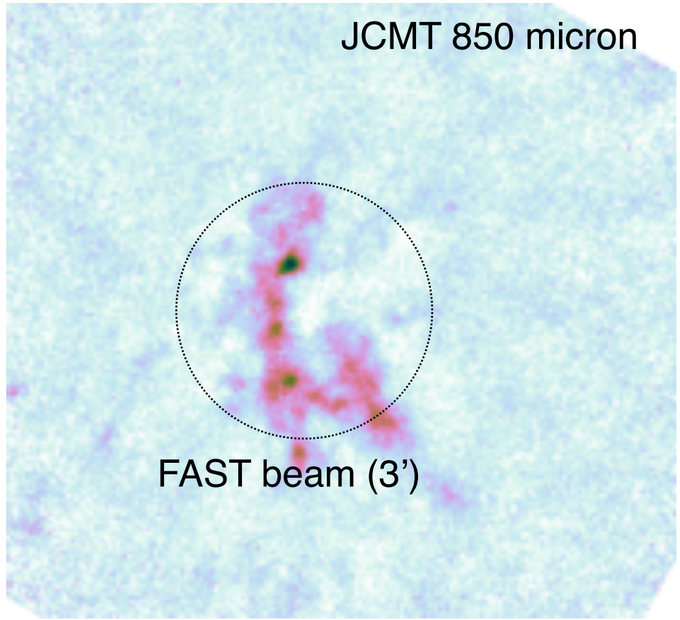
- Most sensitive single-dish dust continuum IRDC Survey
  Achieve JCMT's highest dynamical range:
  rms=5 mJy/bm (2×10^{21}cm^{-2}) to S_{peak}=1 Jy/bm (2×10^{23}cm^{-2})
  -Major Science output：
  — complete spatial coverage: extended gas to gravitating cores
  — complete NPDF profile (fully detect the turbulent gas)
  — Largest core catalogue for nearby IRDCs (D<2.5 kpc)
  ~1500 cores from 12 regions, ~500 totally IR-dark cores.

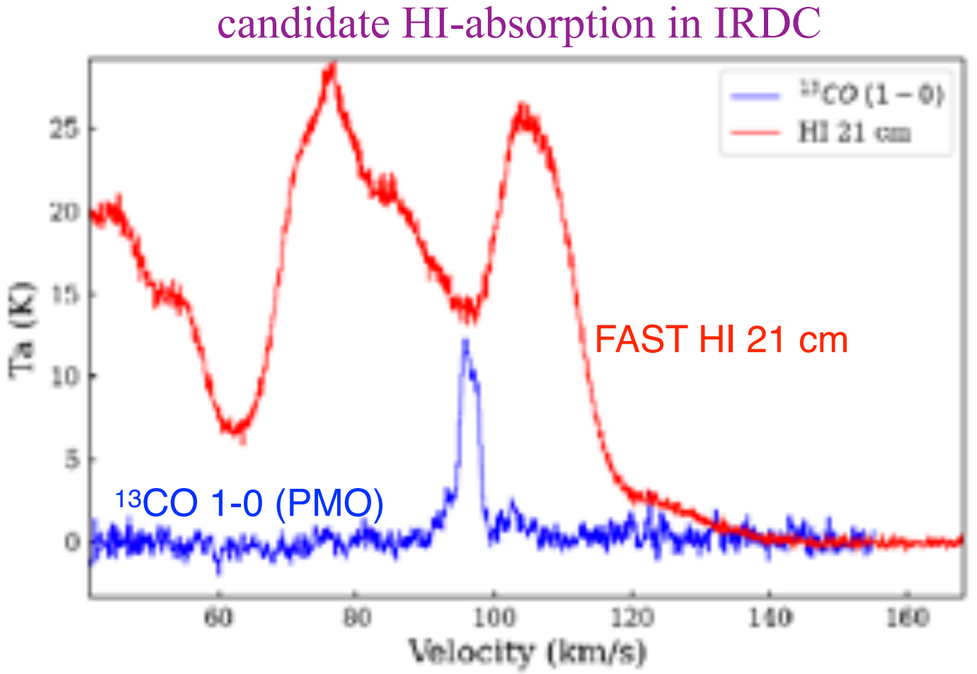


ALOHA Science Highlights - Joint study with the FAST 500-m telescope

- ⭐ FAST HI-21cm self-absorption (HINSA and HISA) — cold atomic envelope of IRDC
  — FAST data: 42 dense clumps are selected for FAST HI-21 cm observation. (in progress)

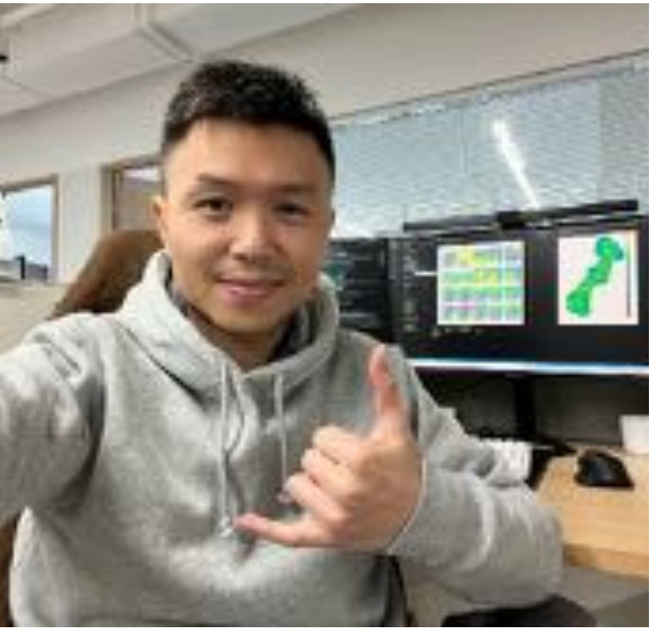






- ⭐ Initial result: IRDCs tend to have broad HI absorption dip (ΔV = 5-10 km/s)
  — cold atomic gas around IRDCs but with large velocity dispersion
  — dynamical conditions to be further analyzed (turbulence, shock, infall, interaction ?).

之江实验室 ZHEJIANG LAB



XUEJIAN JIANG

蒋雪健

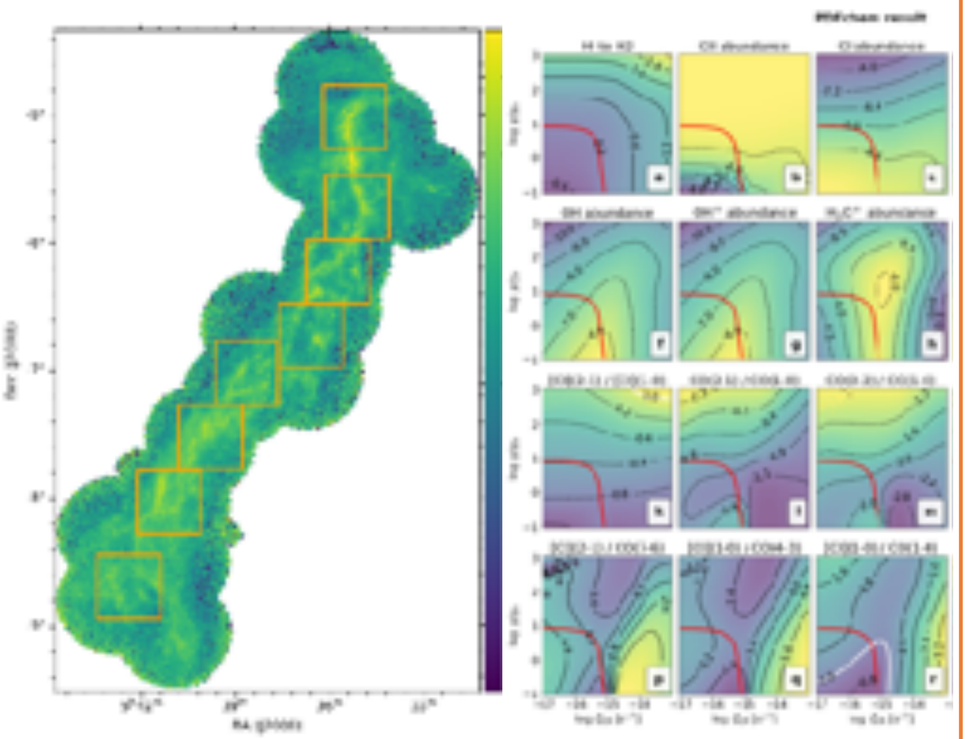
(*EAO Fellow 2019-22*)

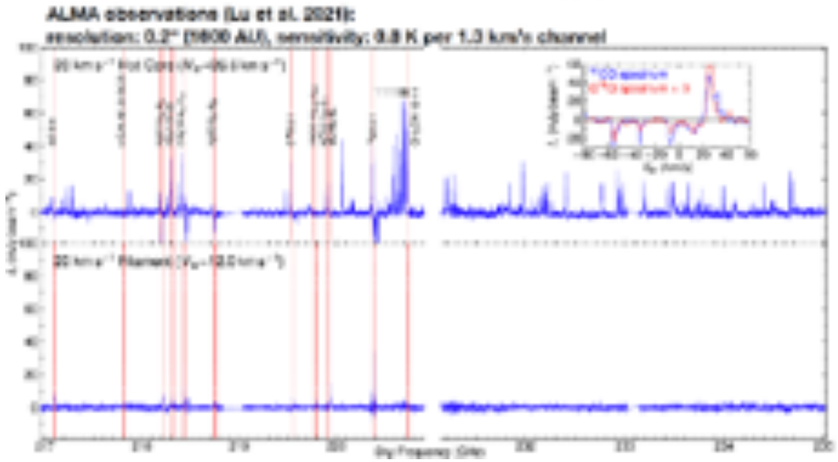
STAFF SCIENTIST

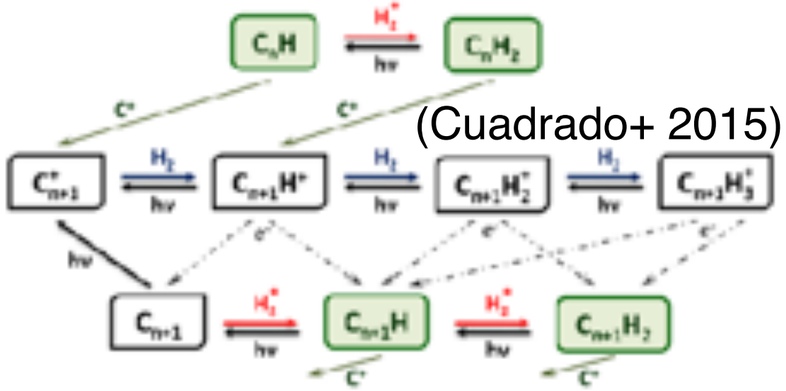
Zhejiang Lab

Current Research Projects --Astrochemistry

1. Analyze the chemical composition of the ISM with models and H_2 column density from dust continuum data (SCUBA-2 etc.) [with Donghui Quan, Thomas Bisbas, Di Li et al.]
2. Study the astrochemical properties of the Central Molecular Zone of the Milky Way with ALMA “line forest” (e.g. carbon-chains or Complex Organic Molecules)





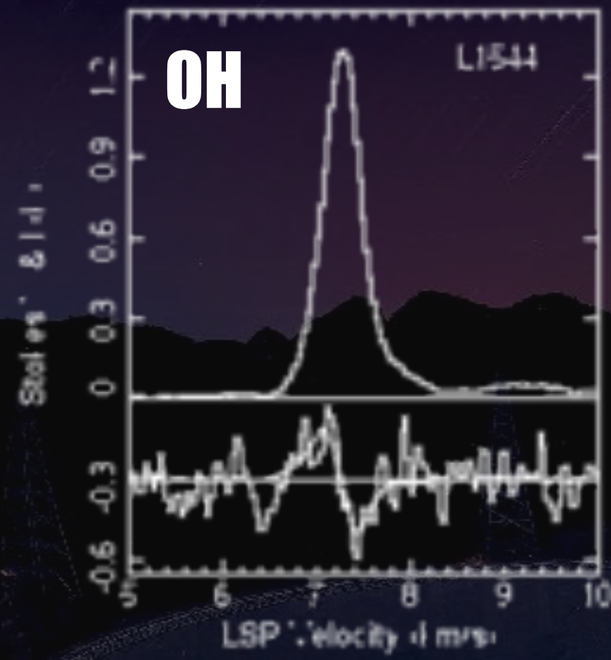


3. Member of the FAST-**CRAFTS** pipeline dev. team.

Zhejiang Computational Astronomy

Now: 5 PIs, 23 full time staffs, 9 postdocs

Zeeman Effect (**B**) in Molecular Gas



OH Crutcher et al. 2000

CN Crutcher et al. 1999

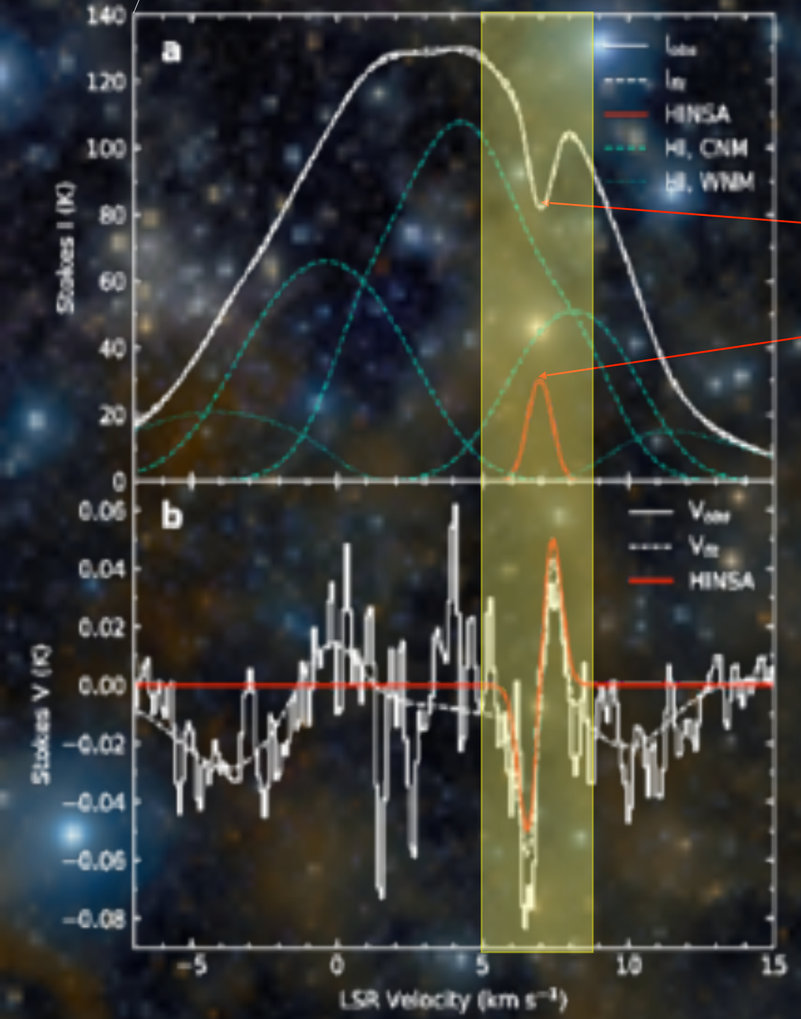
CCS Nakamura et al. 2019

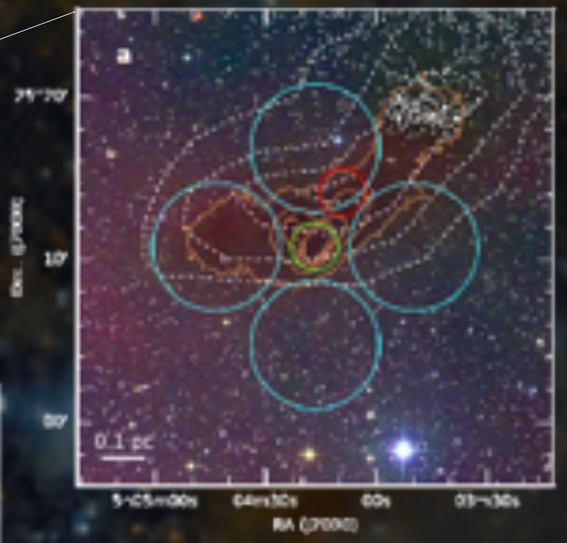
HI Narrow

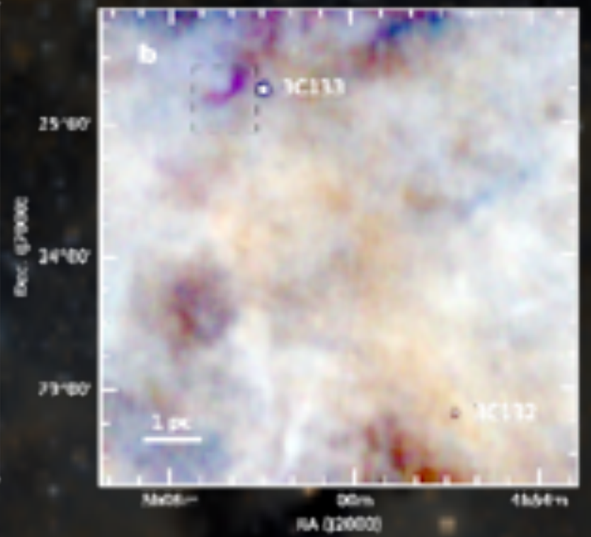
Zeeman

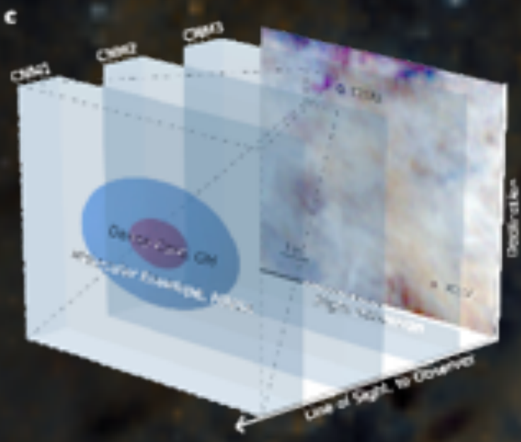

Ching

金牛座分子云
Lyn 1544









HINSA 氢气的窄线自吸收

The First HINSA Zeeman Detection

- ISM field strength in Taurus B = 3.8 ± 0.3 μG
- Reveals a weak coherent field that puts the molecular cores into supercritical state
- Provide an observational foundation for solving the“magnetic flux”, one of the three classical problems, in star formation

"A **new** (创新) method that informs us of star formation. "
– **《Nature》** comment, senior editor

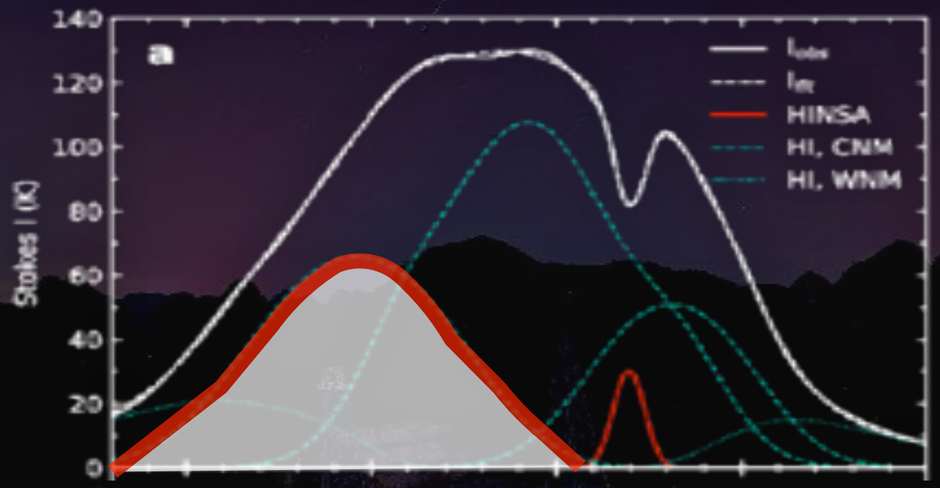
"An **extremely important** (极端重要) observation …"
– **《Nature》** perspective, Prof. Crutcher

"…**revolutionary** (革命性) for the star formation community"
– **《Science》** news, Prof. Caselllli

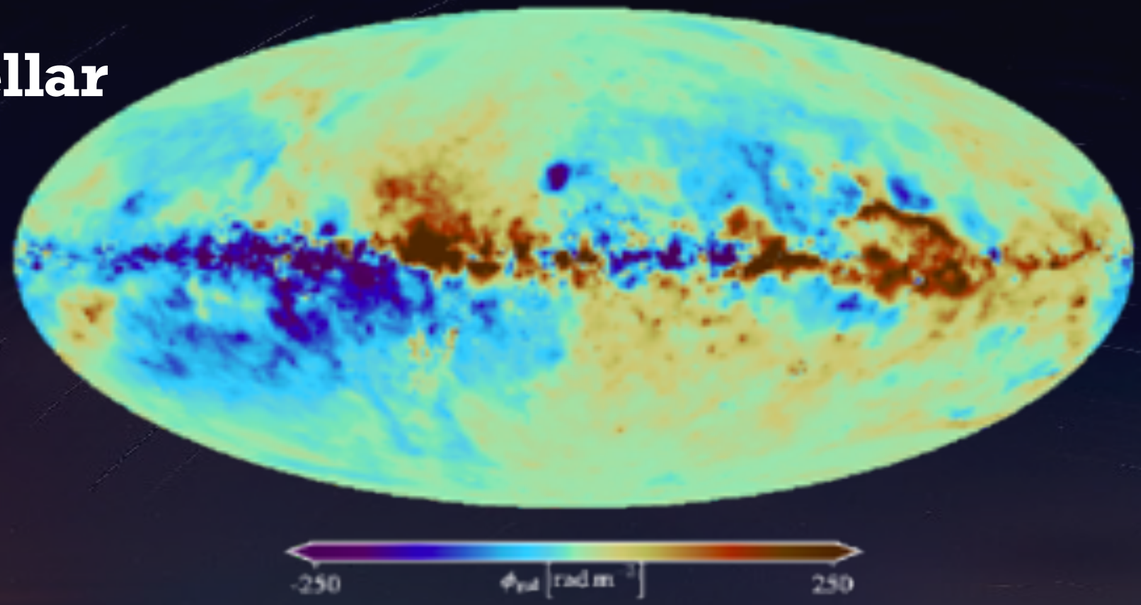
Ching et al. 2022

CRAFTS to draw the first 3D interstellar magnetic-field-strength map

HI + HINSA **Zeeman**



- Resolution ~1 degrees
- > 20000 pixels

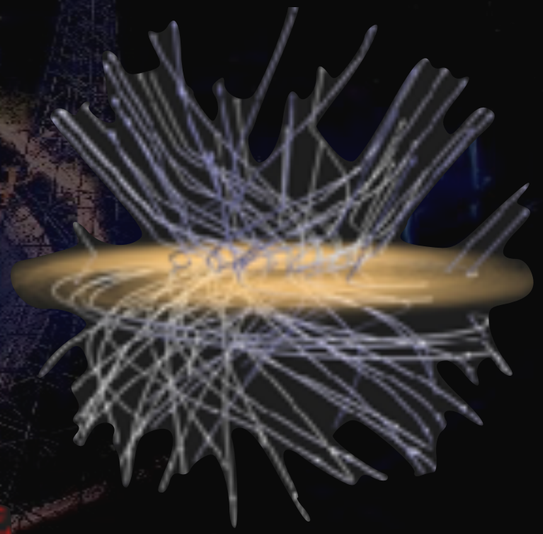


Hutschenreuter et al. 2021

55190 pints of RM

Science Driver

- Galactic dynamo?
- Fermi bubble
- Field reversal
- Magnetic dissipation
- Galactic evolution



Farrar 2016

Galactic B-field model

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

ANNOUNCEMENT

Call for FAST Science Observing Proposals

2022-03-31

The Five-hundred-meter Aperture Spherical radio Telescope (FAST), a Chinese national science facility, welcomes submission of science proposals for the upcoming observing period scheduled from August 2022 to July 2023. Users of any nationalities or affiliations are invited to submit proposals before the deadline at **16:00 UT on 16th May 2022** through the website **http://fast.bao.ac.cn/proposal_submit**. Information on the techniques and current performance of the telescope are available at http://fast.bao.ac.cn.

The FAST science operation covers both regular science programs and large programs. Please note that this Call only solicits regular science proposals, which usually take observing time no more than 100 hours. It is anticipated that about 2000 hours of observing time will be allocated to regular science programs. All proposals should make it clear that why the FAST is necessary for the requested observations. Based on the statistics of the last observing period, the oversubscription rate is 3.6 on average, and reaches 5.2 for the LST range of 18 to 22 hours, which approximately corresponds to the Galactic plane time for the FAST.

The FAST started its full operation in January 2020, and is now completing its second science observing period. A list of previously accepted science proposals, including both regular science and large programs, can be found at https://fast.bao.ac.cn/cms/category/approved_projects_en/. Note that information of future approved proposals, including titles, PI names, abstracts, and scheduling priorities, will also be posted at the website. Science data obtained through a regular science program have a proprietary period of 12 months. Please see the FAST Data Policy posted at https://fast.bao.ac.cn/cms/article/66/ for more details. To avoid duplication, proposers should query the FAST archive at https://fast.bao.ac.cn/observation_log/observed_source_search before planning observations to check if any existing data meet their scientific goals.

Should you have any further question about the telescope operation and proposal submission, please contact us at fast-proposal-support@nao.cas.cn.

CoP

fast.bao.ac.cn/cms/article/164/

Help

fast-proposal-support@nao.cas.cn

Di Li

dili@nao.cas.cn

中国天眼 FAST

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

Guizhou, China

5 Legacy programs

～**400 PI** programs

> **150** journal papers, including

7《**Nature**》+**2**《Nature Astronomy》

2《**Science**》

2《**SCPMA**》cover articles

1《**Science Bulletin**》cover article

ARECIBO - 天眼FAST

bridging the centuries