Fast Radio Bursts

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(National Chung Hsing University)

FRB conf in Yilan (宜蘭)
last week

TCA mini workshop
2 July 2024

National Chung Hsing University

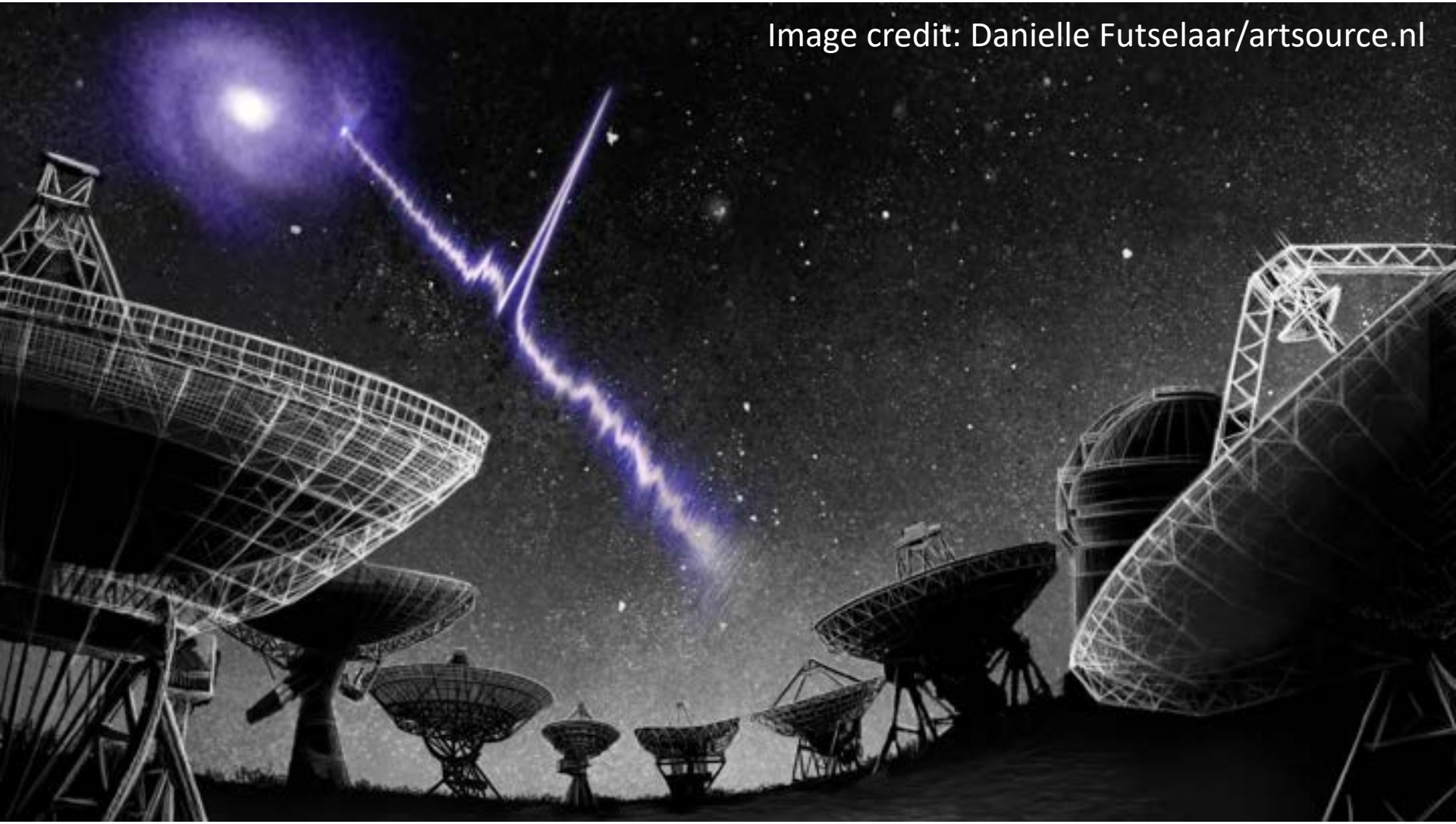
國立中興大學
NATIONAL CHUNG HSING UNIVERSITY

Outline

1. Mysterious Fast Radio Burst (FRB)
2. What is the origin?🤔
3. FRBs to understand the Universe
4. BURSTT project


Optical
Credit: the Murchison Widefield Array (MWA)

Fast Radio Burst (FRB)



Fast Radio Burst (FRB)

- Radio fireworks within
  0.001 seconds = 1 ms

- Human's reaction speed: ~0.2s
- blink: ~0.1s
- 100m run: measured in 0.01s
- thunder: ~ 0.001 seconds

Fast Radio Burst (FRB)

Fast Radio Burst (FRB)

The total energy of an FRB

10^{13} times higher than that humans use in a year (10,000,000,000,000 times)

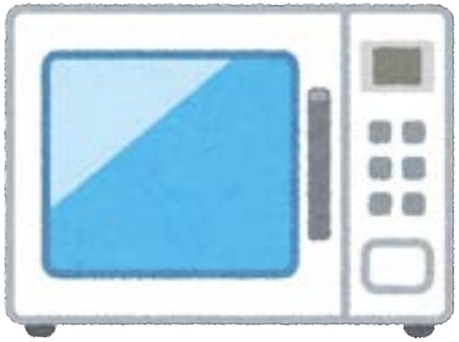
At least 1000 FRBs happen every day in the sky

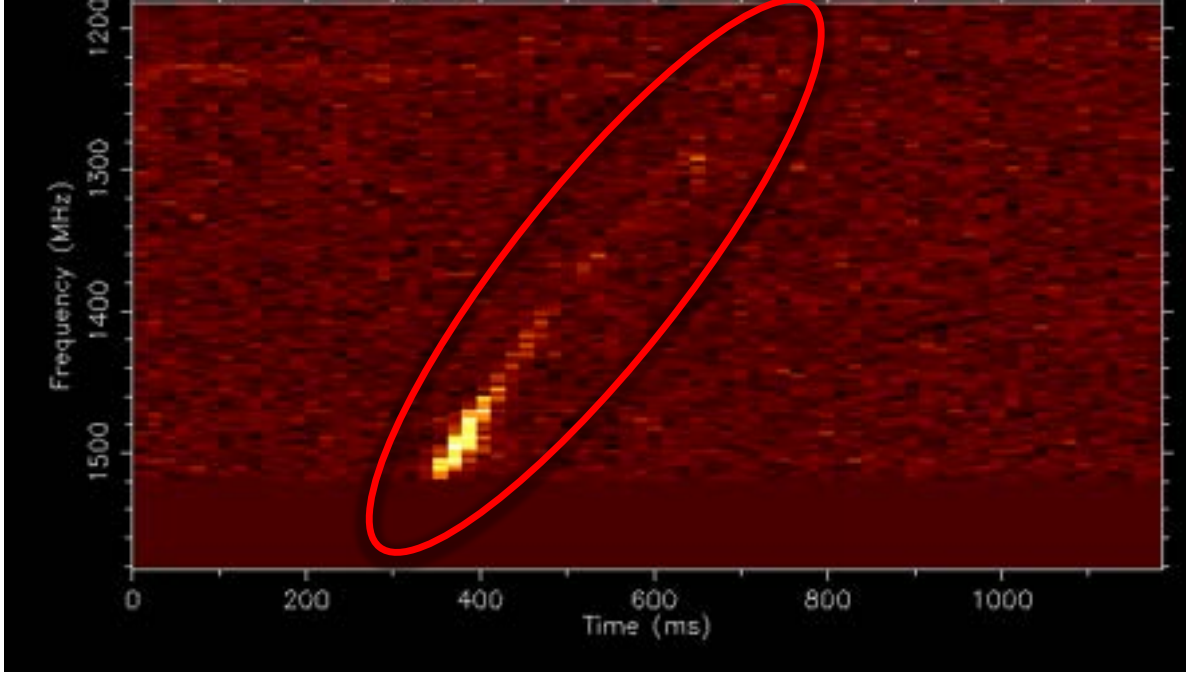
(The Earth is OK because they are far away)

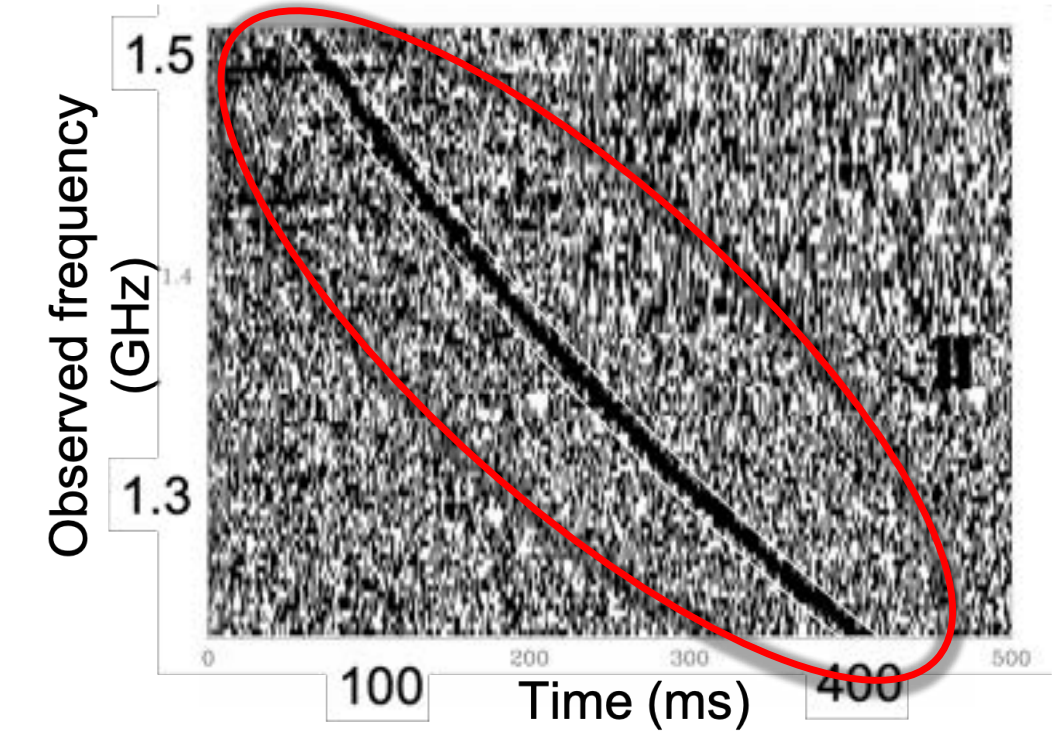
Quiz 🤔

FRB

or

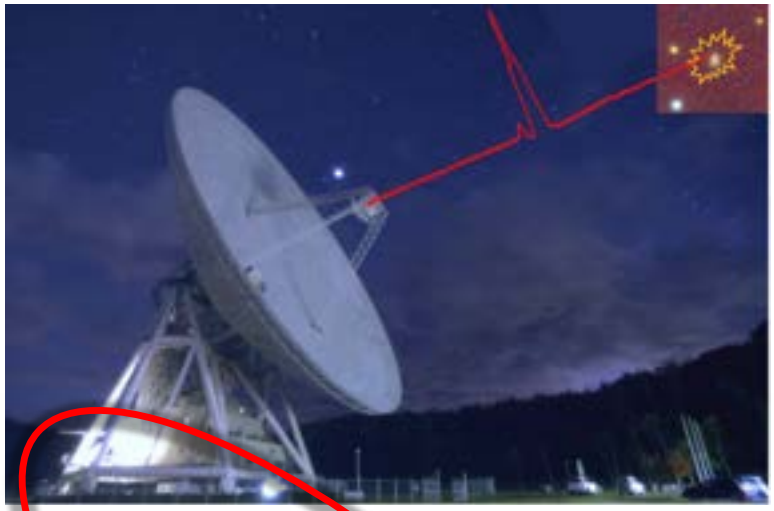


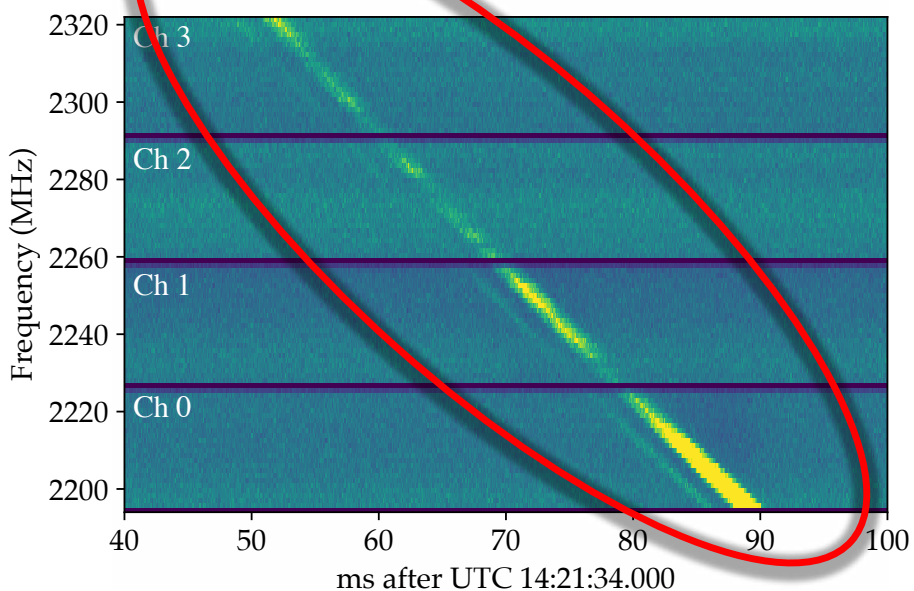

Frequency (MHz)
1200
1300
1400
1500
0
200
400
600
800
1000
Time (ms)


Observed frequency (GHz)
1.5
1.4
1.3
0
100
200
300
400
500
Time (ms)

The first detection in Japan

Ikebe et al. inc. TH 2023





祝

YAHOO! JAPAN ニュース

トップ 速報 ライブ 個人 オリジナル みんなの意見 ランキング

主要 国内 国際 経済 エンタメ スポーツ IT 科学 ライフ 地域

日本で初めて高速電波バーストを検出　JAXAの64mパラボラアンテナを使用

1/25(水) 20:00 配信

sorae 宇宙へのポータルサイト

日本で初めて高速電波バーストの検出に成功したJAXA臼田宇宙空間観測所の64mパラボラアンテナ（中央）

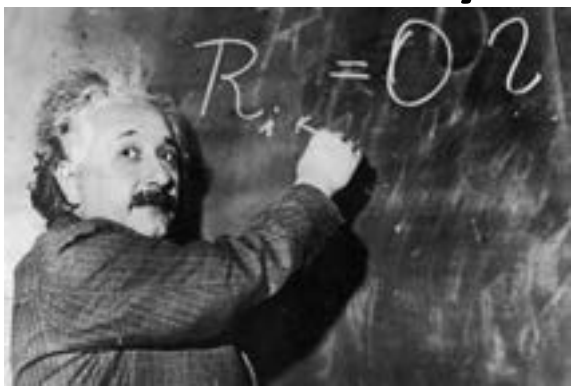
東京大学大学院理学系研究科天文学専攻の大学院生・池邊蒼太さんを筆頭とする研究チームは、日本の電波望遠鏡を使って初めて「高速電波バースト（FRB：Fast Radio Burst）」を検出することに成功したとする研究成果を発表しました。

2007年に初めて観測された高速電波バーストは、千分の数秒というごく短時間だけ強力な電波パルスが放出される突発的な現象です。その発生源や電波が放出される仕組みについては不明な点が多いものの、一度しか電波を放出しない「単発型（非反復型）」と、電波パルスを繰り返し放出する「リピート型（反復型）」に分類できることが知られています。また、2020年には天の川銀河内のマグネター（強力な磁場を持つ中性子星）が発生源の一つだとする研究

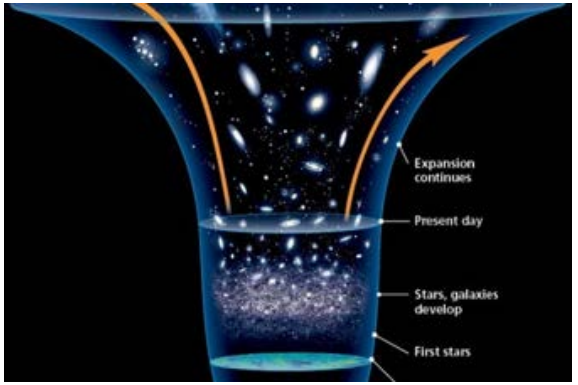
Key sciences to be addressed by FRBs

Missing baryon problem

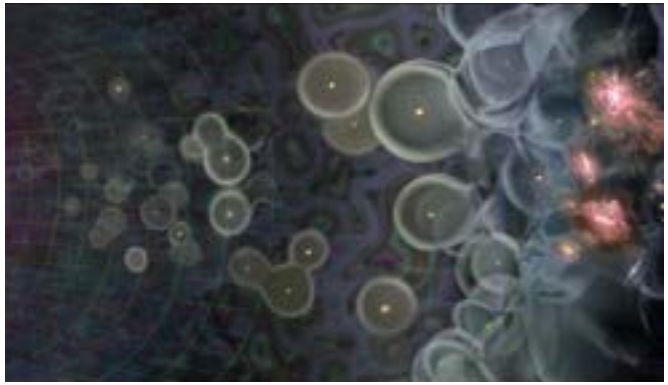
General relativity



Dark energy/ H0



Cosmic reionization

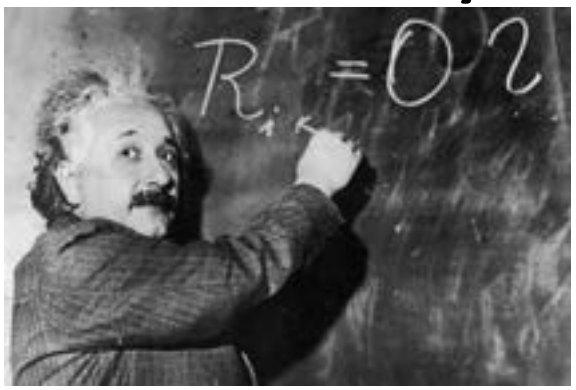


Dark matter

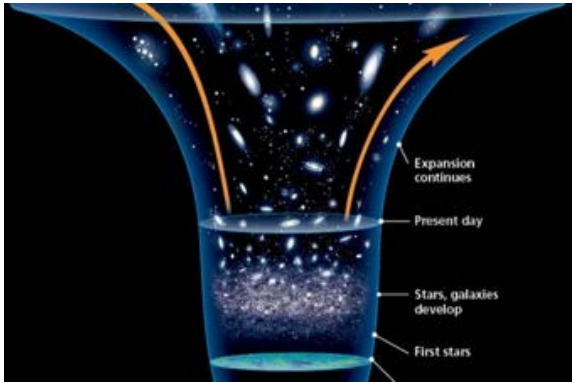
Key sciences to be addressed by FRBs

Missing baryon problem

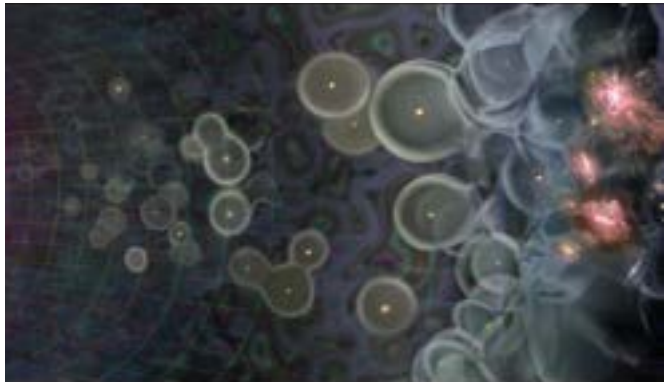
General relativity



Dark energy/ H0



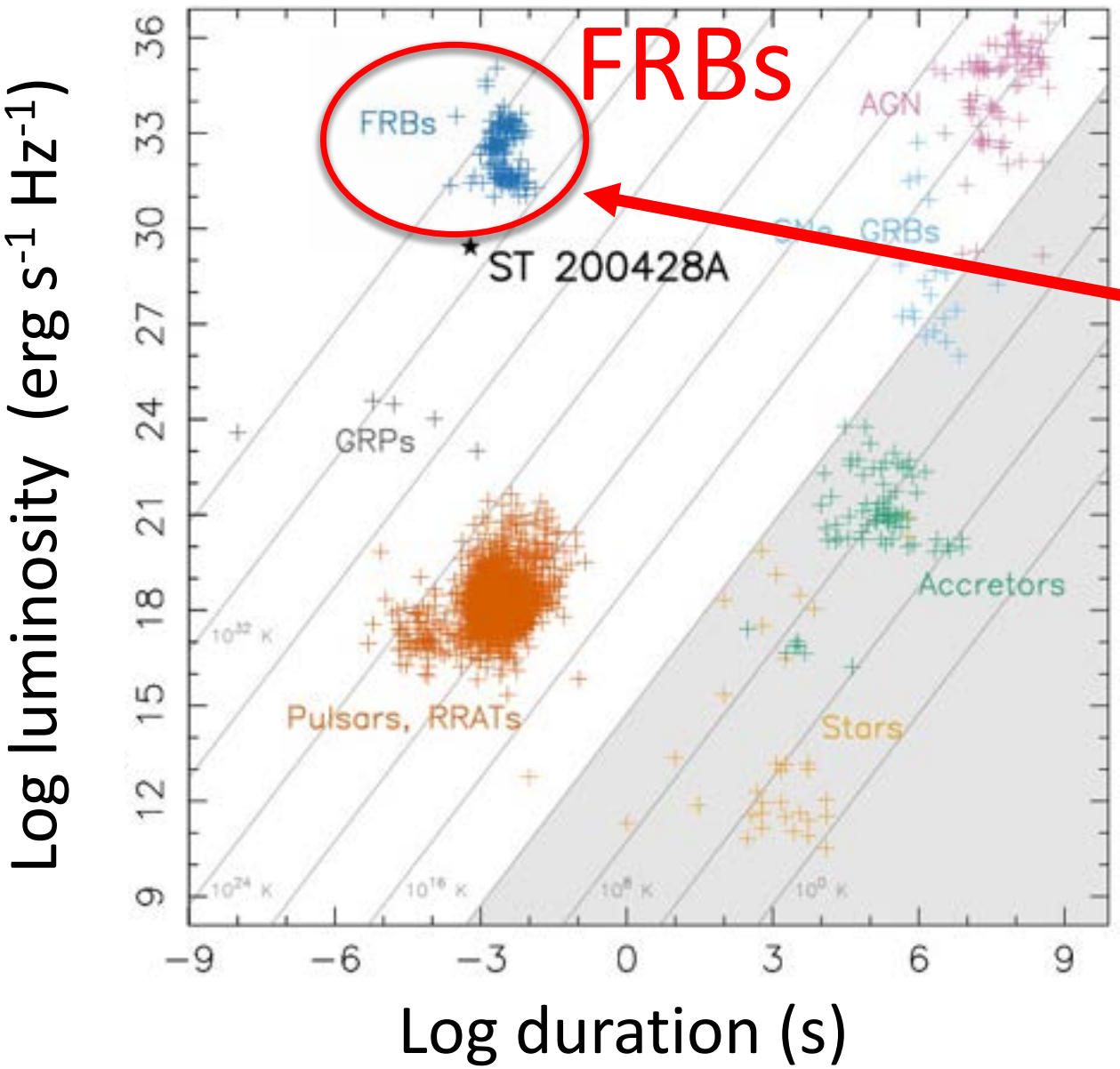
Cosmic reionization



Dark matter

The origin of FRBs

Why special? 🤔 new parameter space



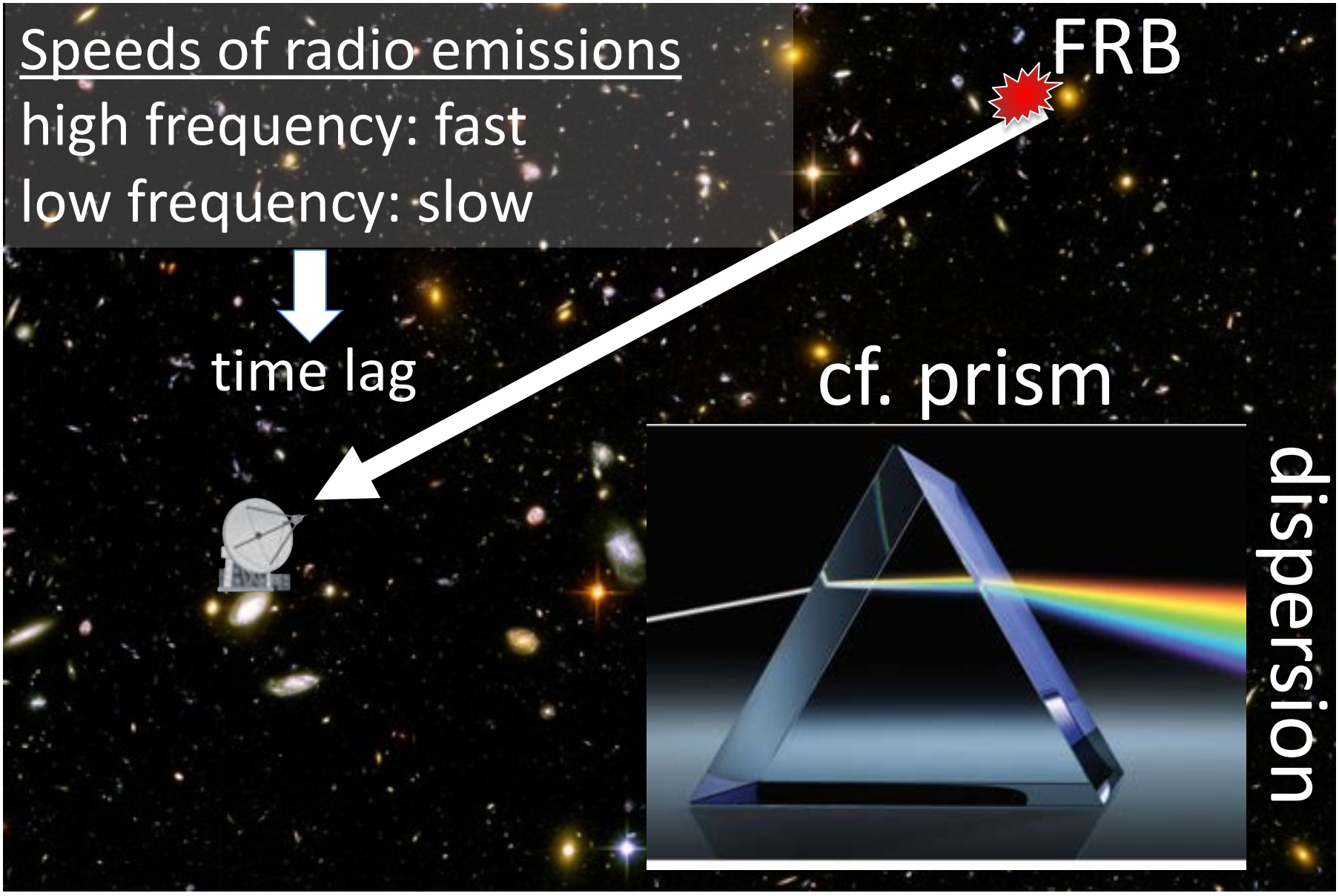
Bochenek et al 2020

Bright
and
Short timescale

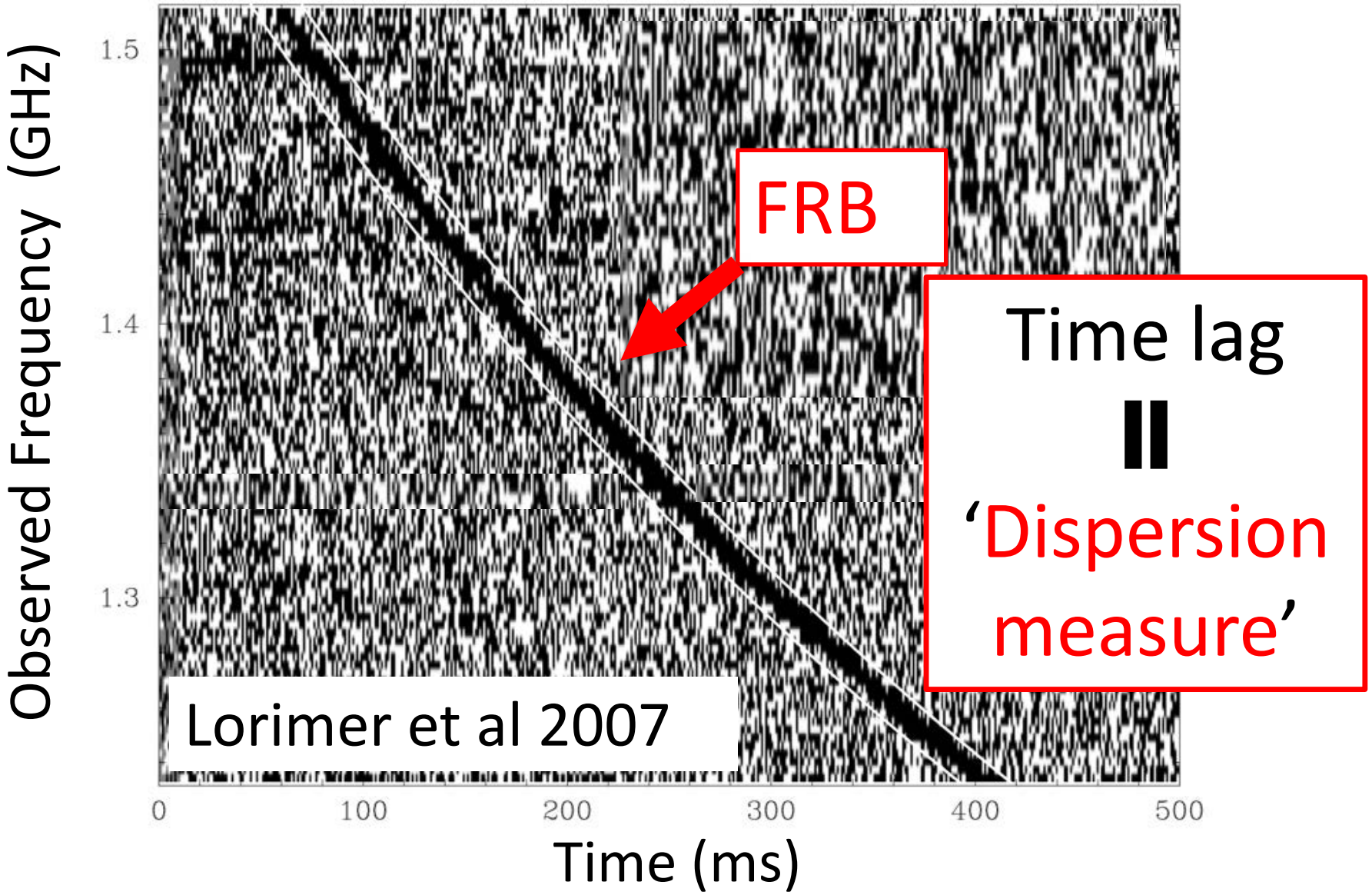
Extremely useful
(next slides)

***Intro*: the Universe is filled with plasma**

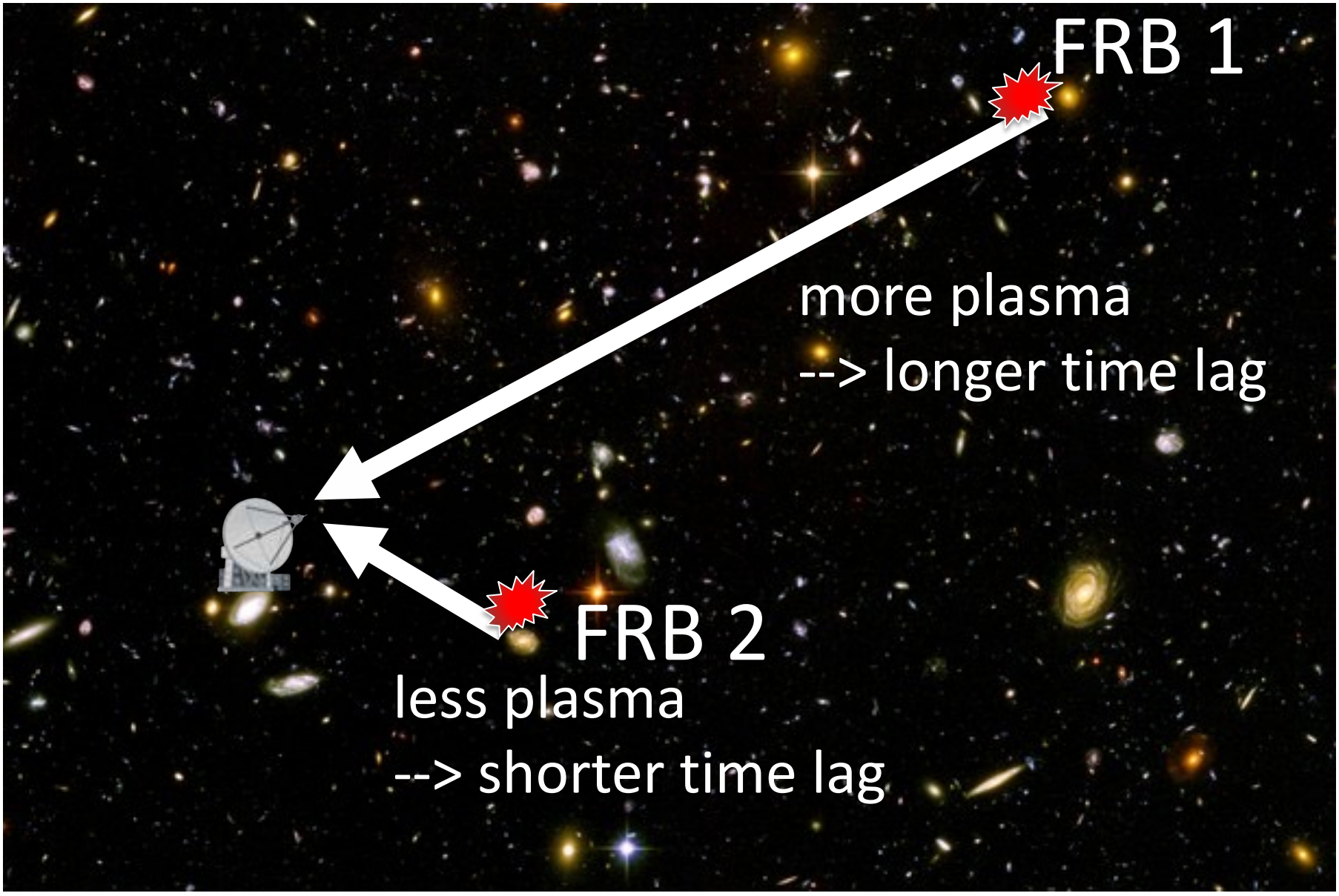
***Intro*: the speed of light changes in plasma**



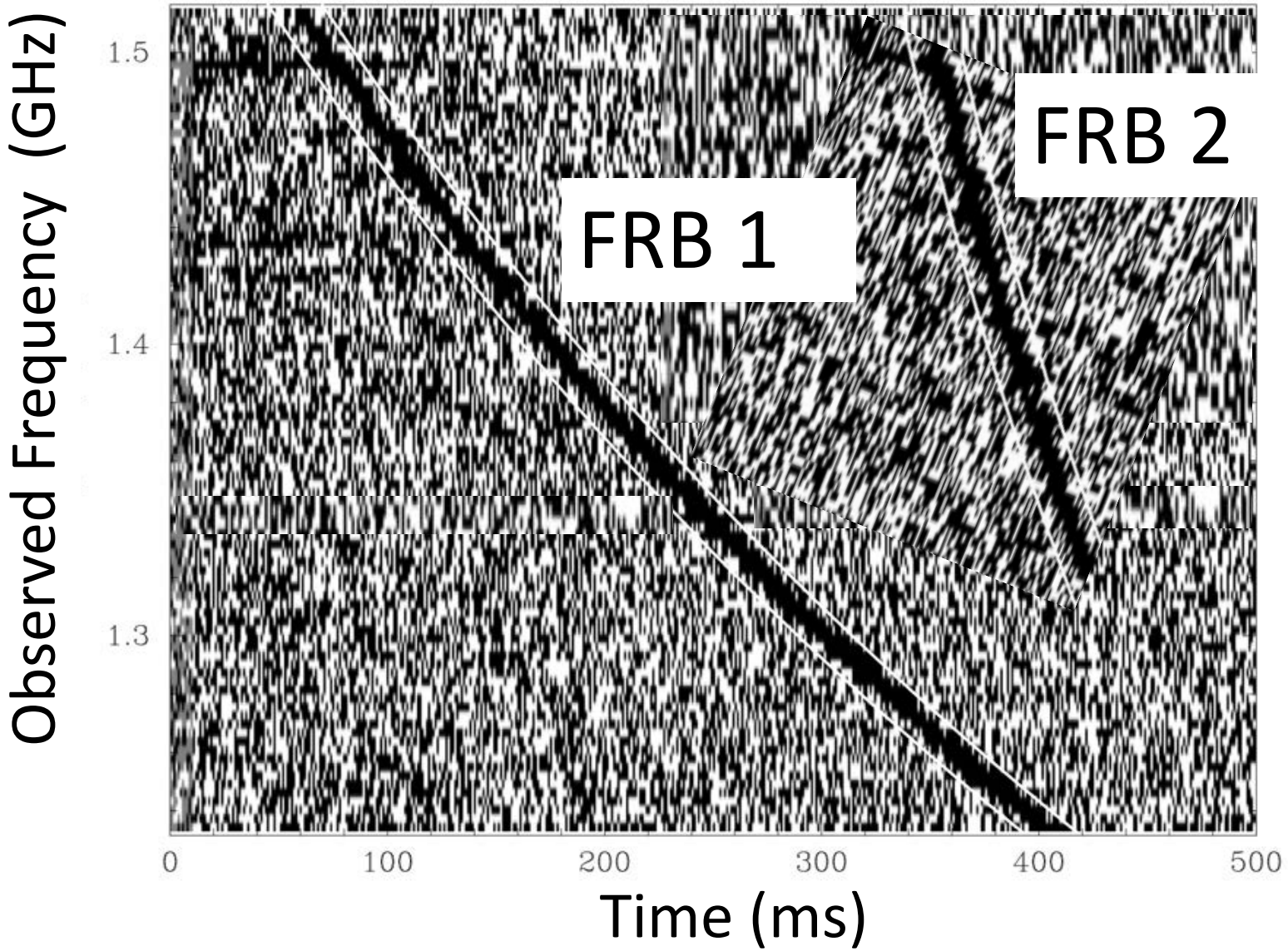
Intro: the detection of an FRB



Intro: the speed of light changes in plasma



***Intro*: time lag = dispersion measure**
= distance indicator



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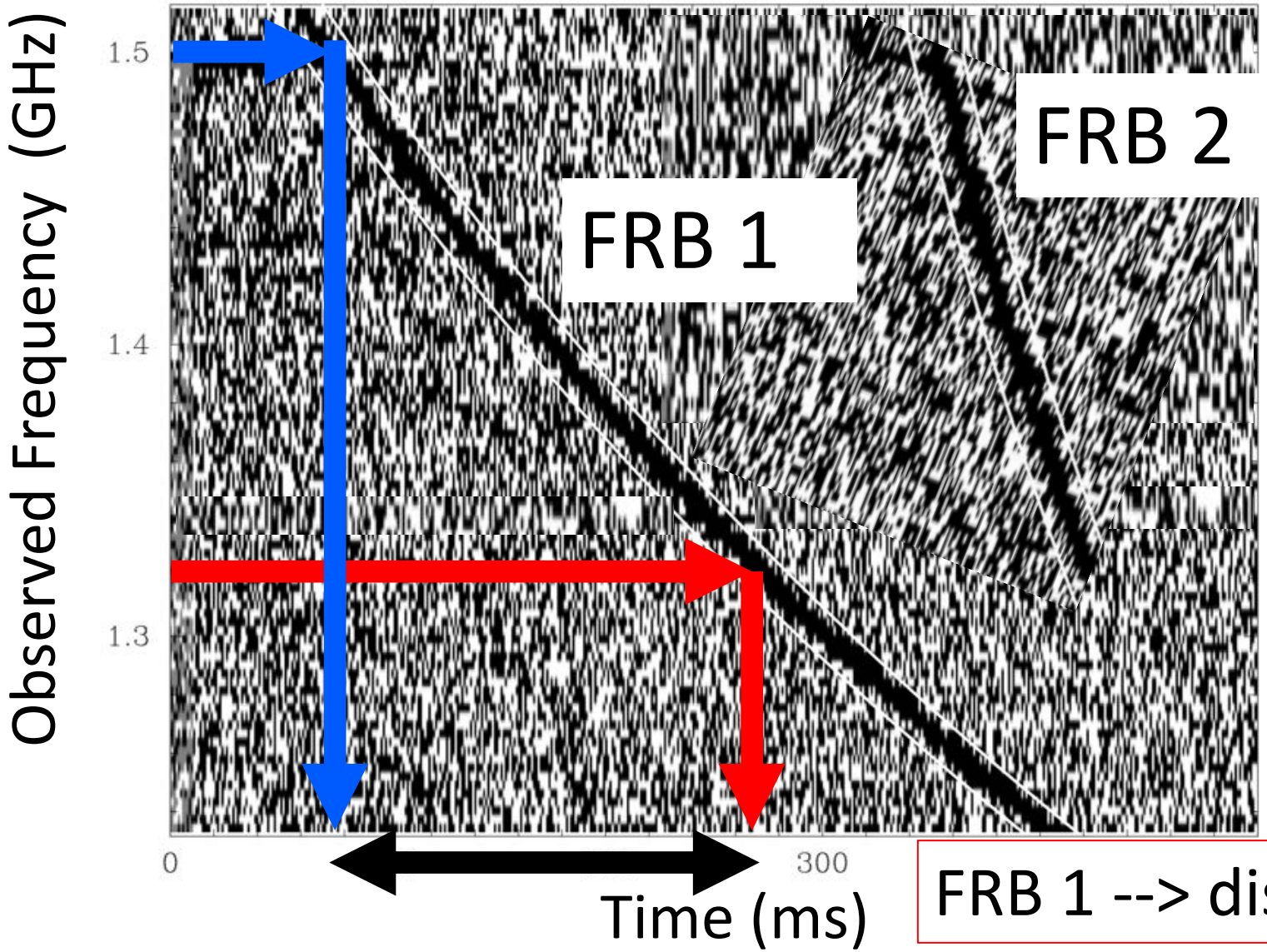
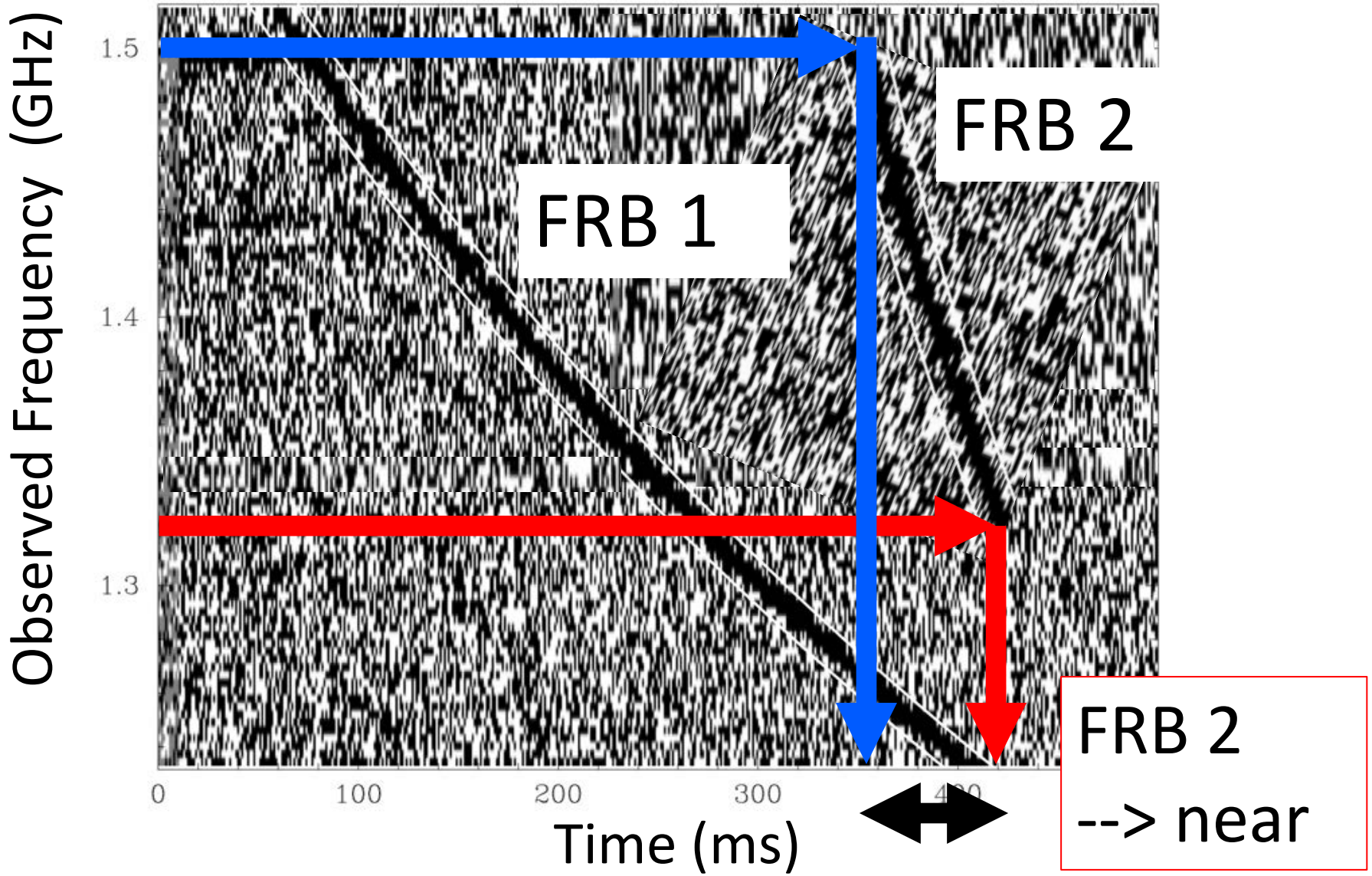


FRB 1 --> distant

Intro: time lag = dispersion measure = distance indicator



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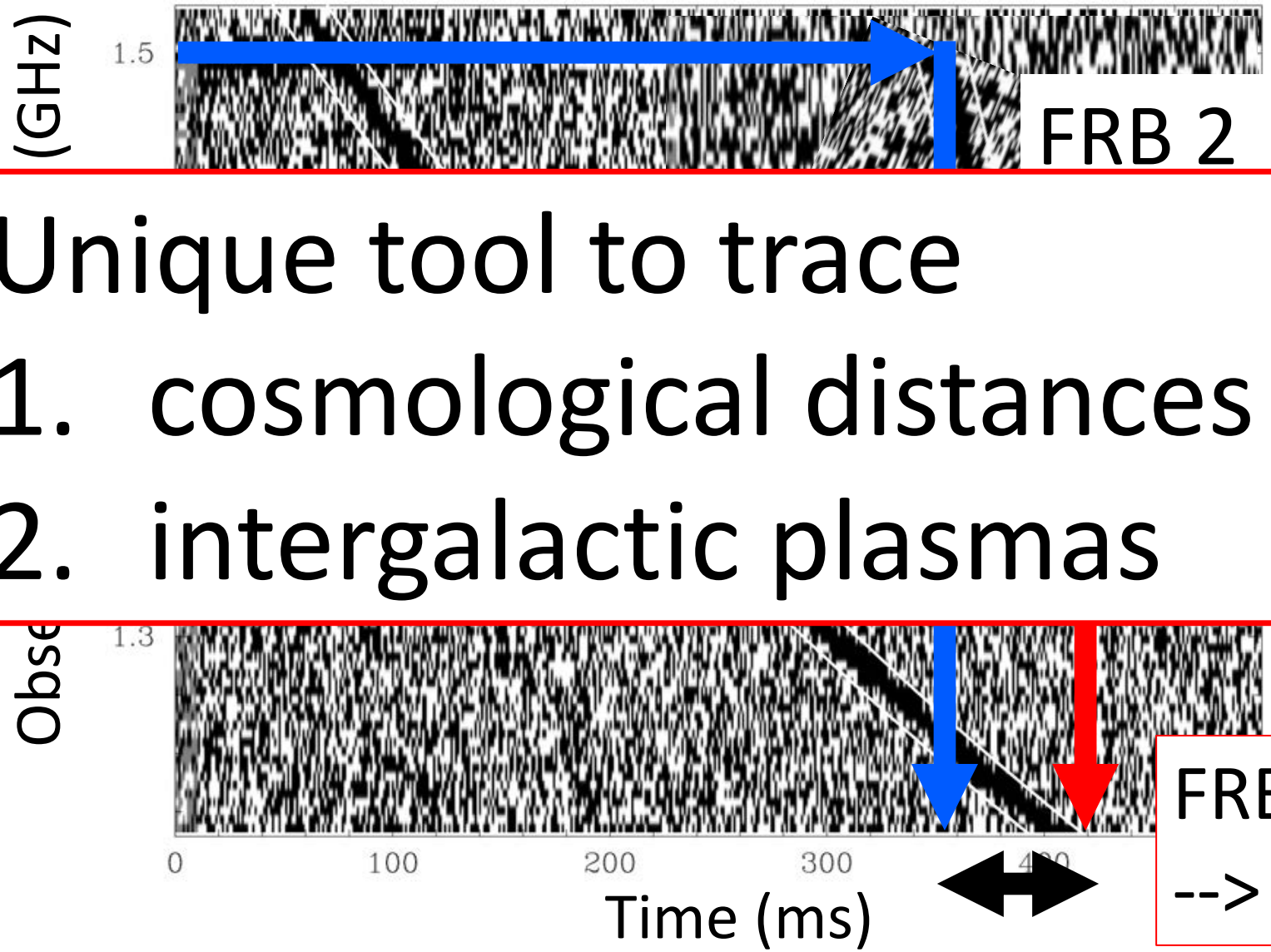


Unique tool to trace

1. cosmological distances
2. intergalactic plasmas

Game changers!

1000

>1000

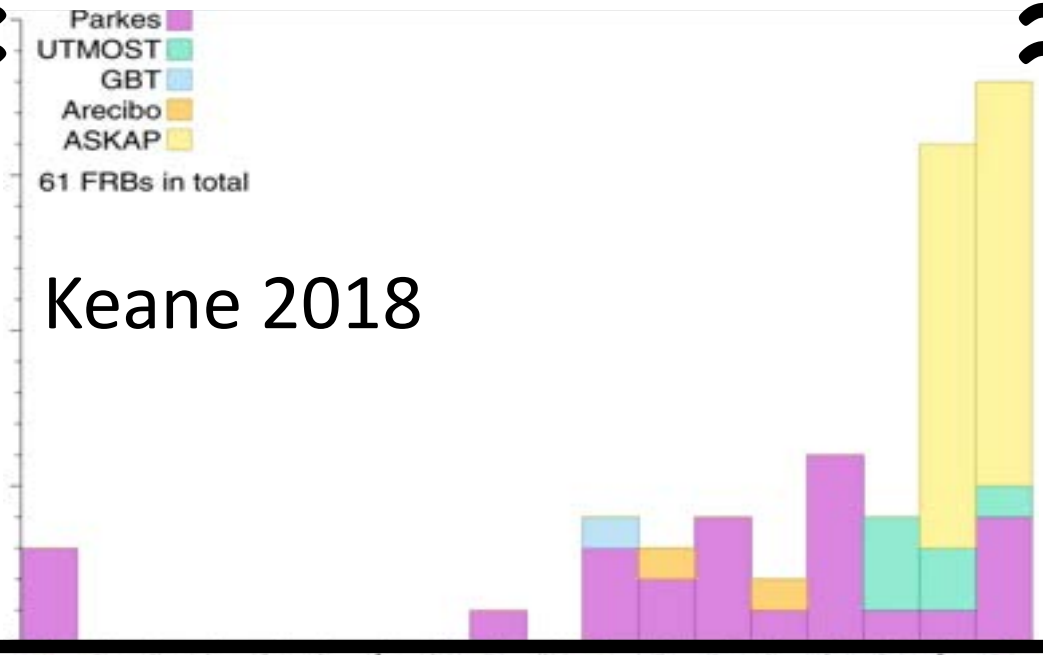
600

CHIME

FAST

FRBs per year

20



Year

2021

2022

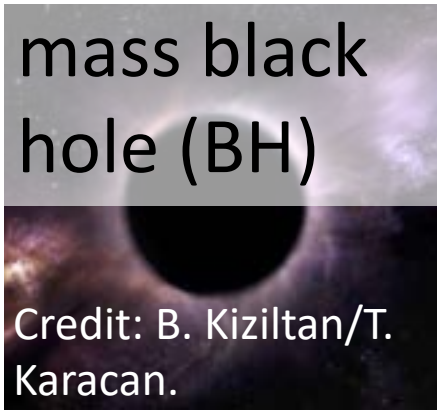
2. What is the origin?🤔

The origin is still unknown

White dwarf

Neutron-star binary

Old stellar-mass black hole (BH)

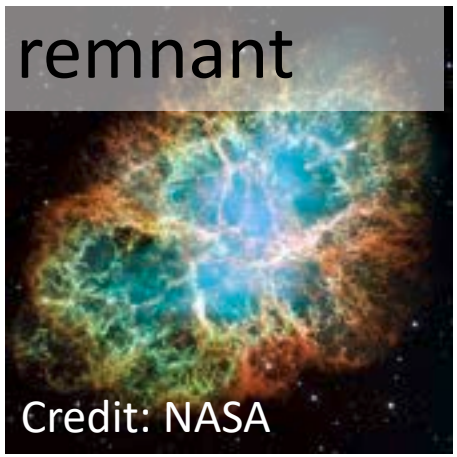


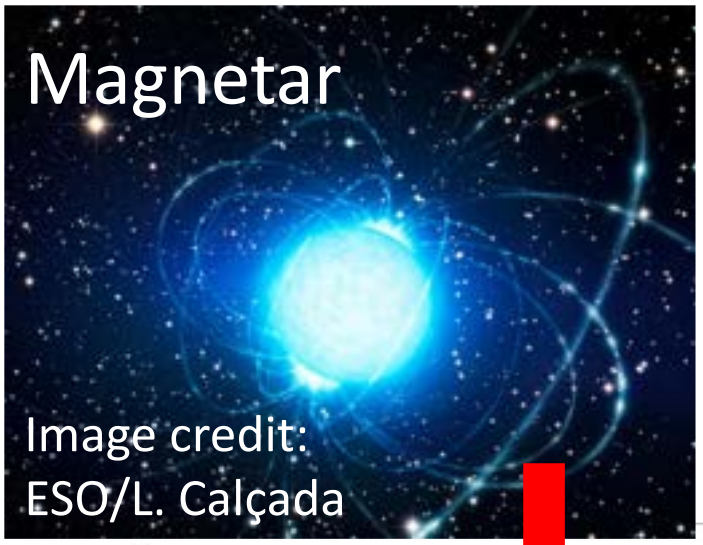
Magnetar

Young pulsar

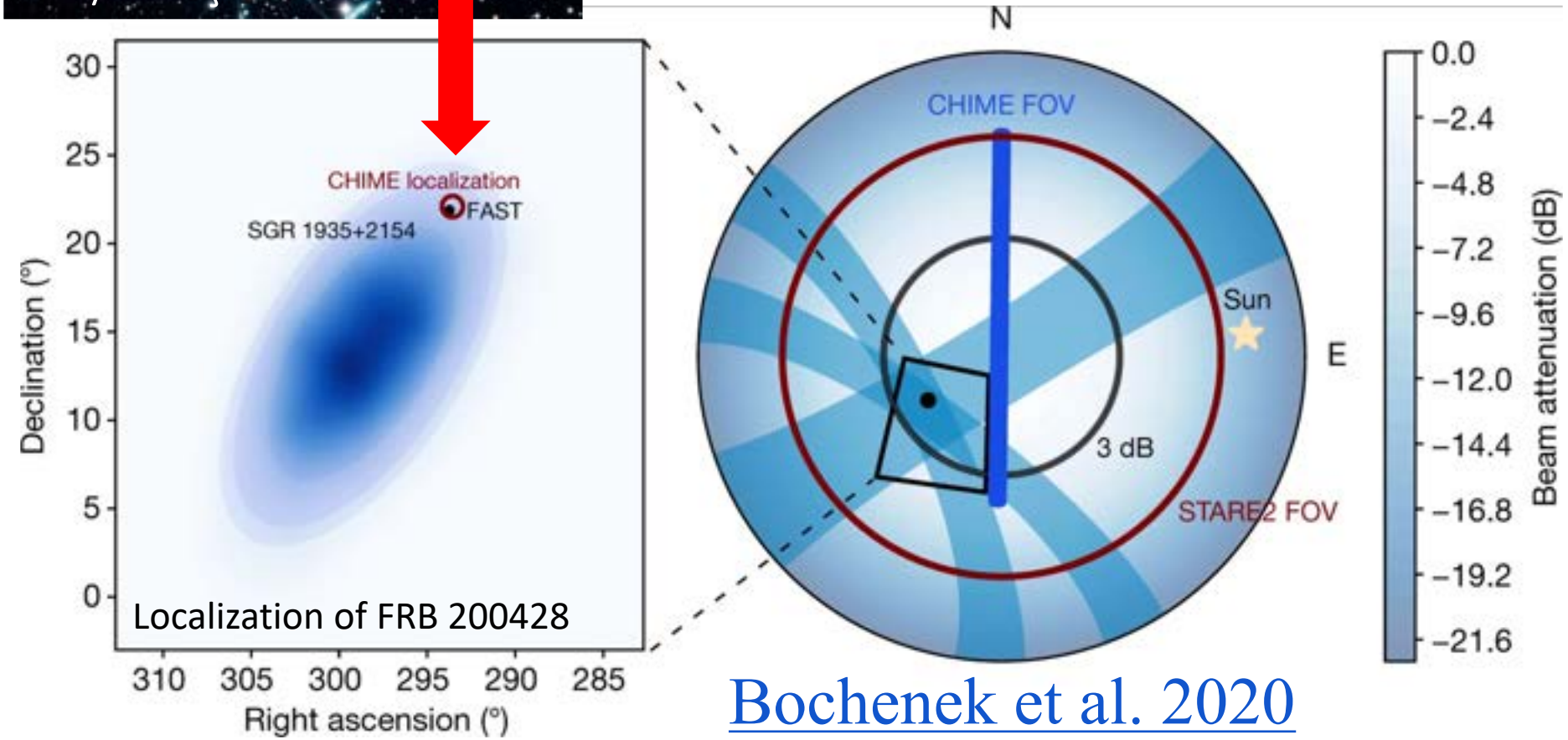
Super massive BH

Supernova remnant





One case study (only one so far)



Bochenek et al. 2020

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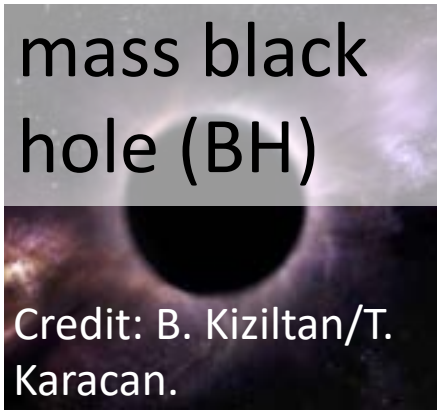

Magnetar

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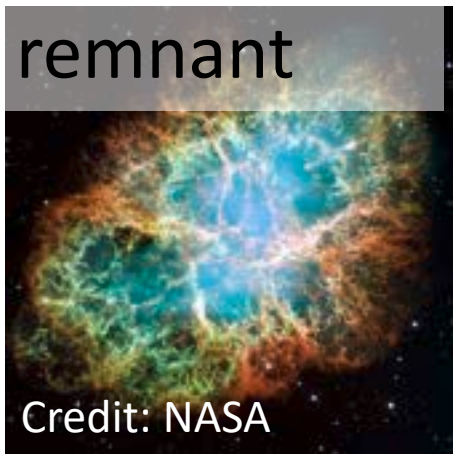
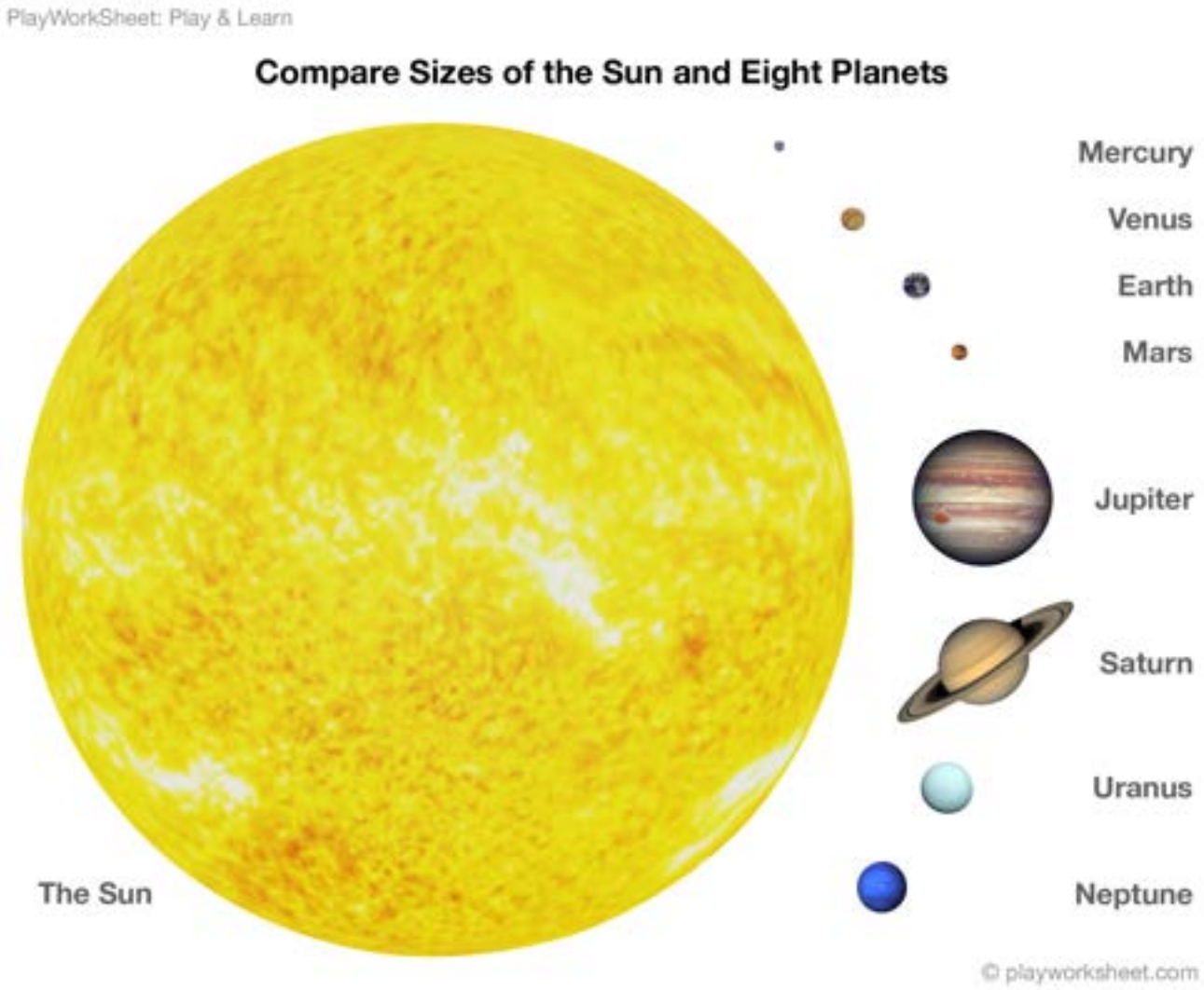


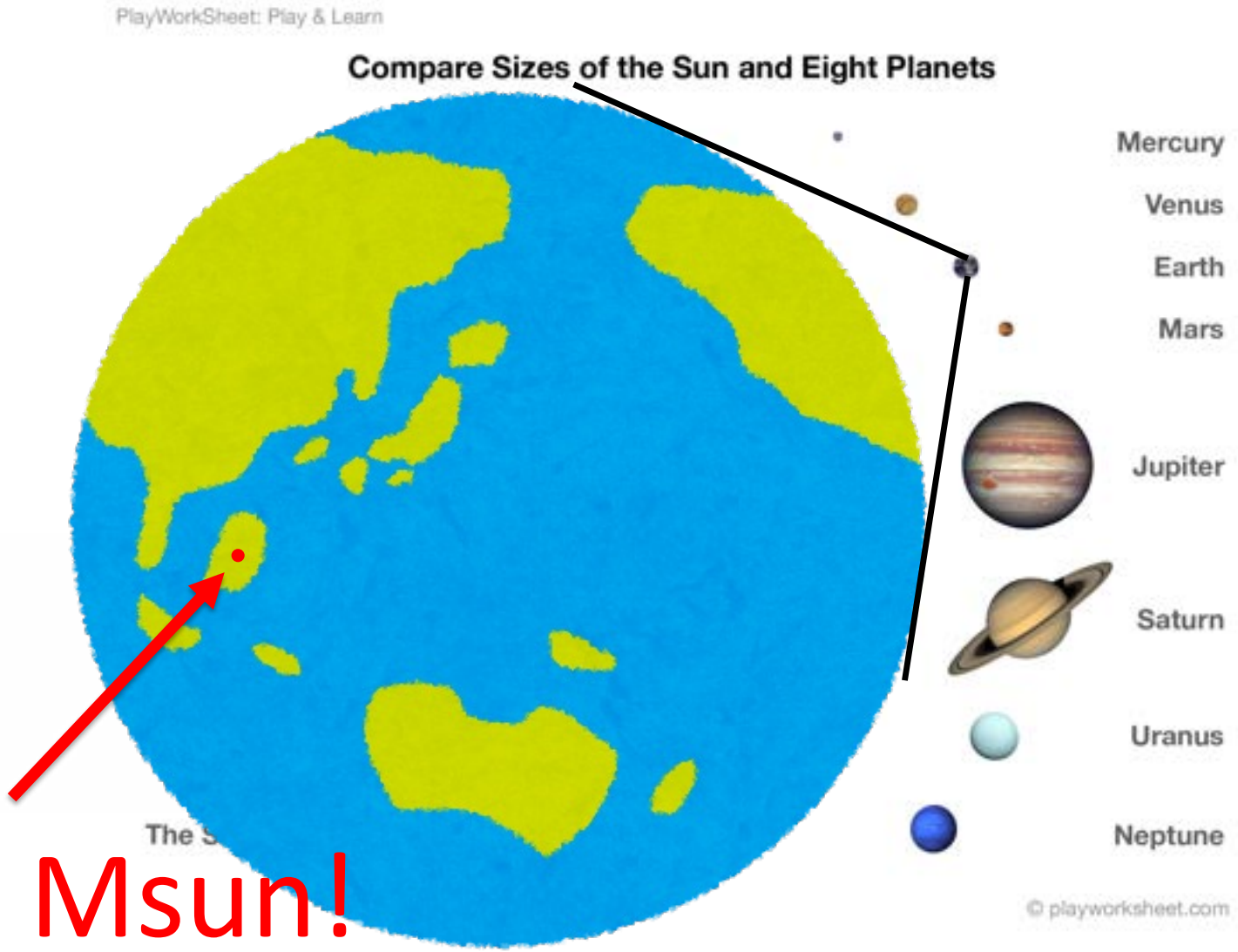
What is the magnetar?🤔

- remnant of supernova
- composed of neutrons
- ~1.4 Msun
- ~10-15 km radius
- extremely strong magnetic field

Sun and Earth



Earth and 10 km



1.4 Msun!

A spoonful of magnetar

A. 1 ton

B. 1×10^6 tons

C. 1×10^9 tons

A spoonful of magnetar

>

A. 1 ton

B. 1×10^6 tons

C. 1×10^9 tons

cf. Total mass of human

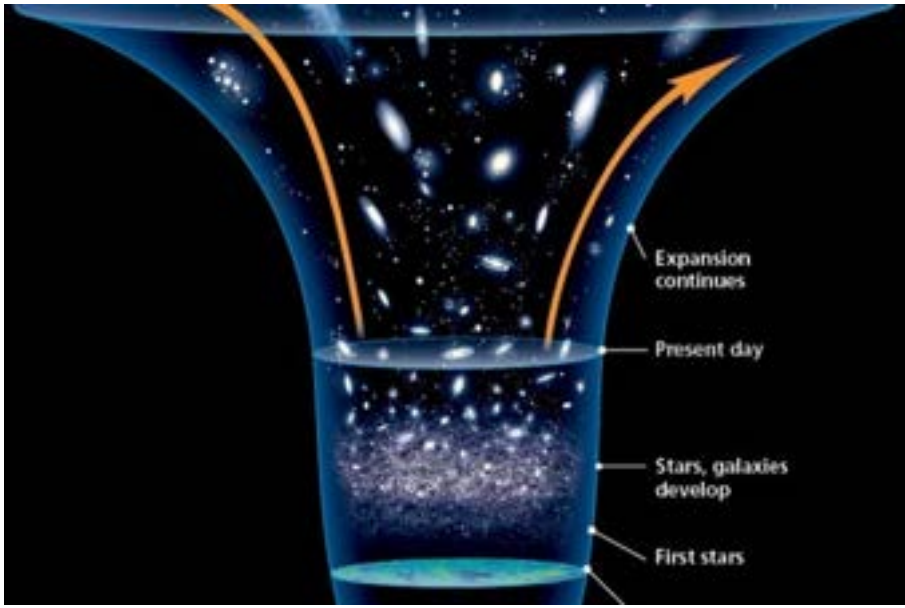
~8e+9 x 0.05 (ton) = 0.4×10^9 tons

2. FRBs to understand the Universe

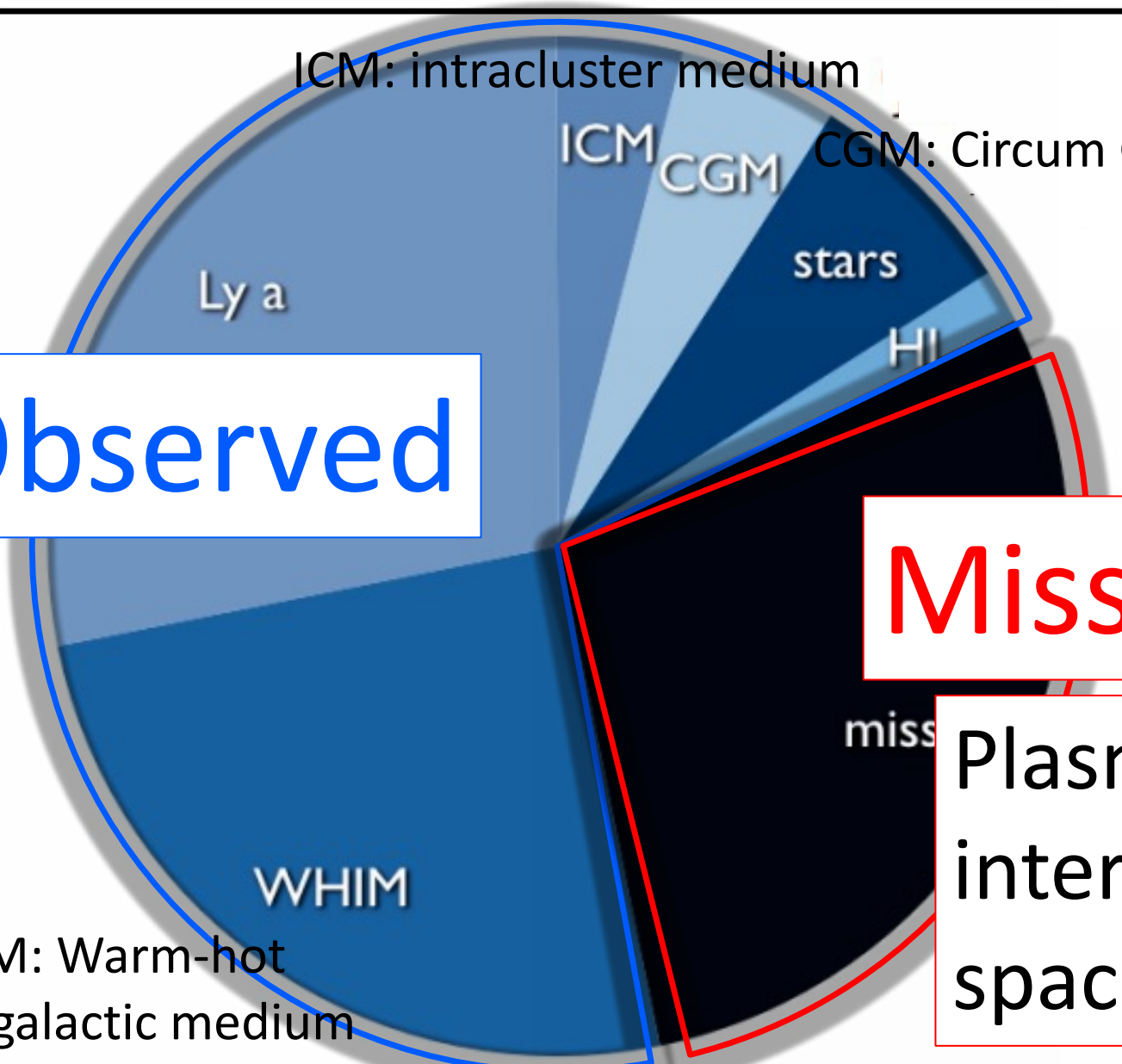
FRBs are useful in addressing

Missing baryon problem

Cosmic expansion



Missing baryon problem🤔



ICM: intracluster medium

CGM: Circum Galactic Medium

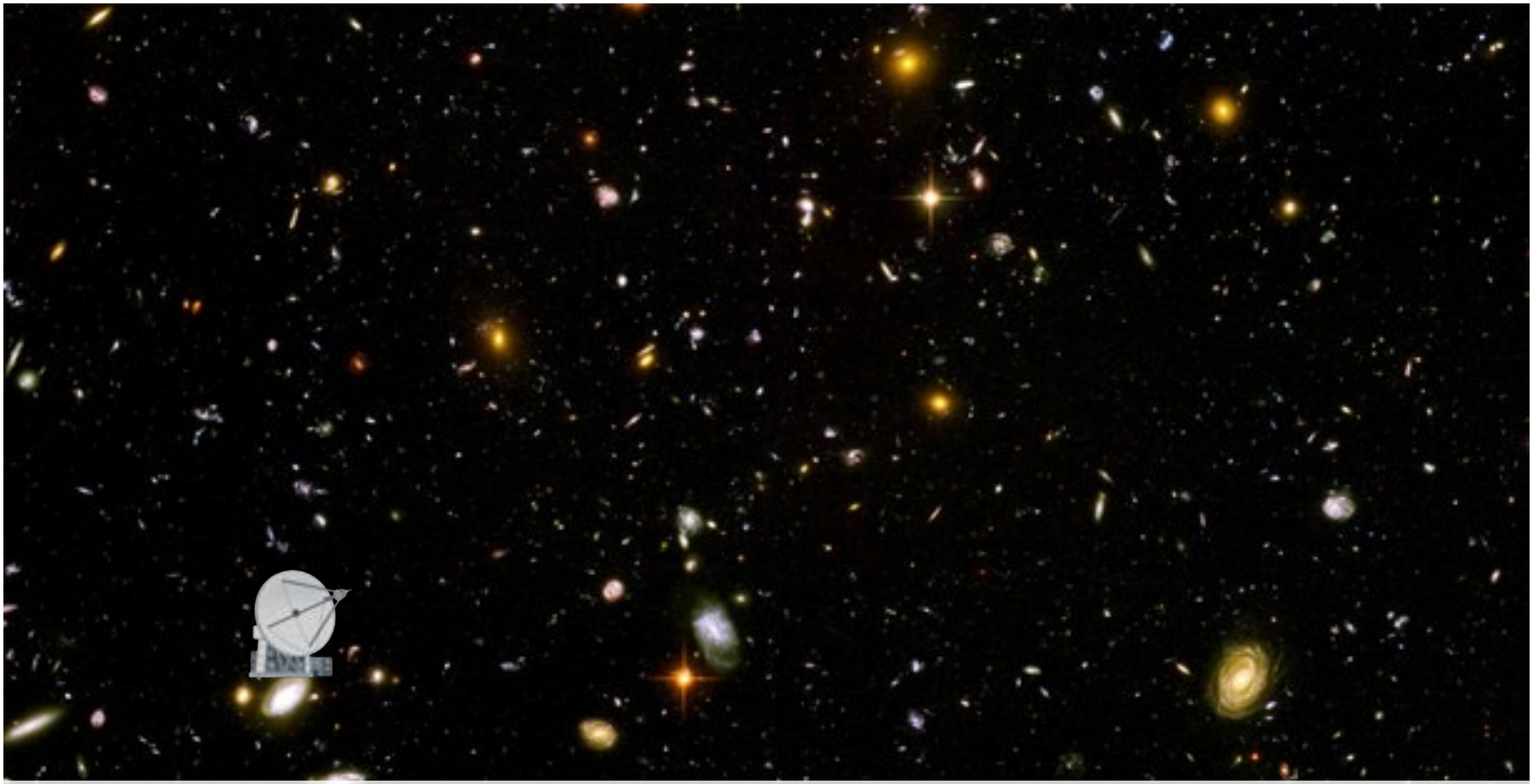
Observed

Missing

Plasma in intergalactic space?🤔

WHIM: Warm-hot intergalactic medium

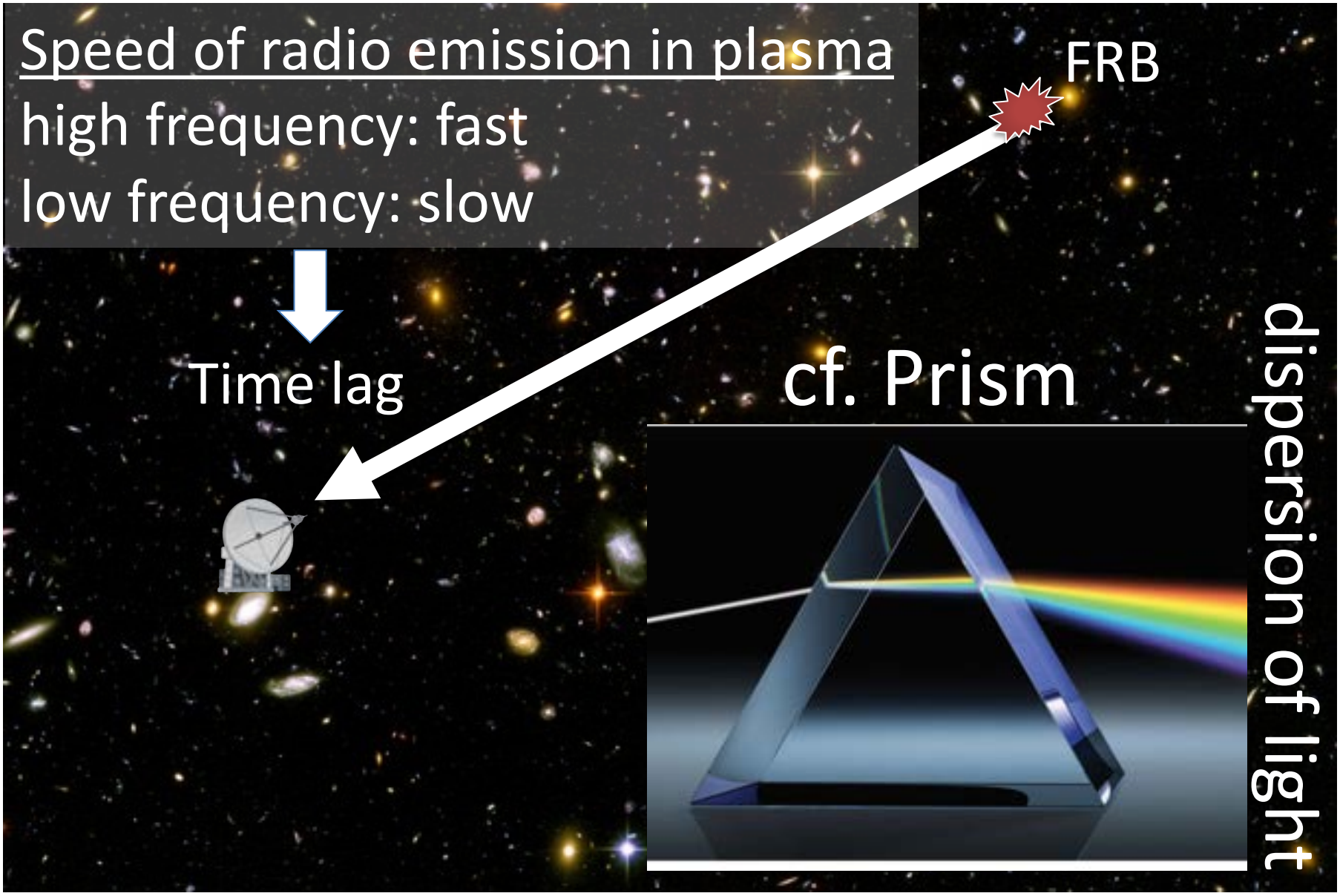
Hard to observe the plasma



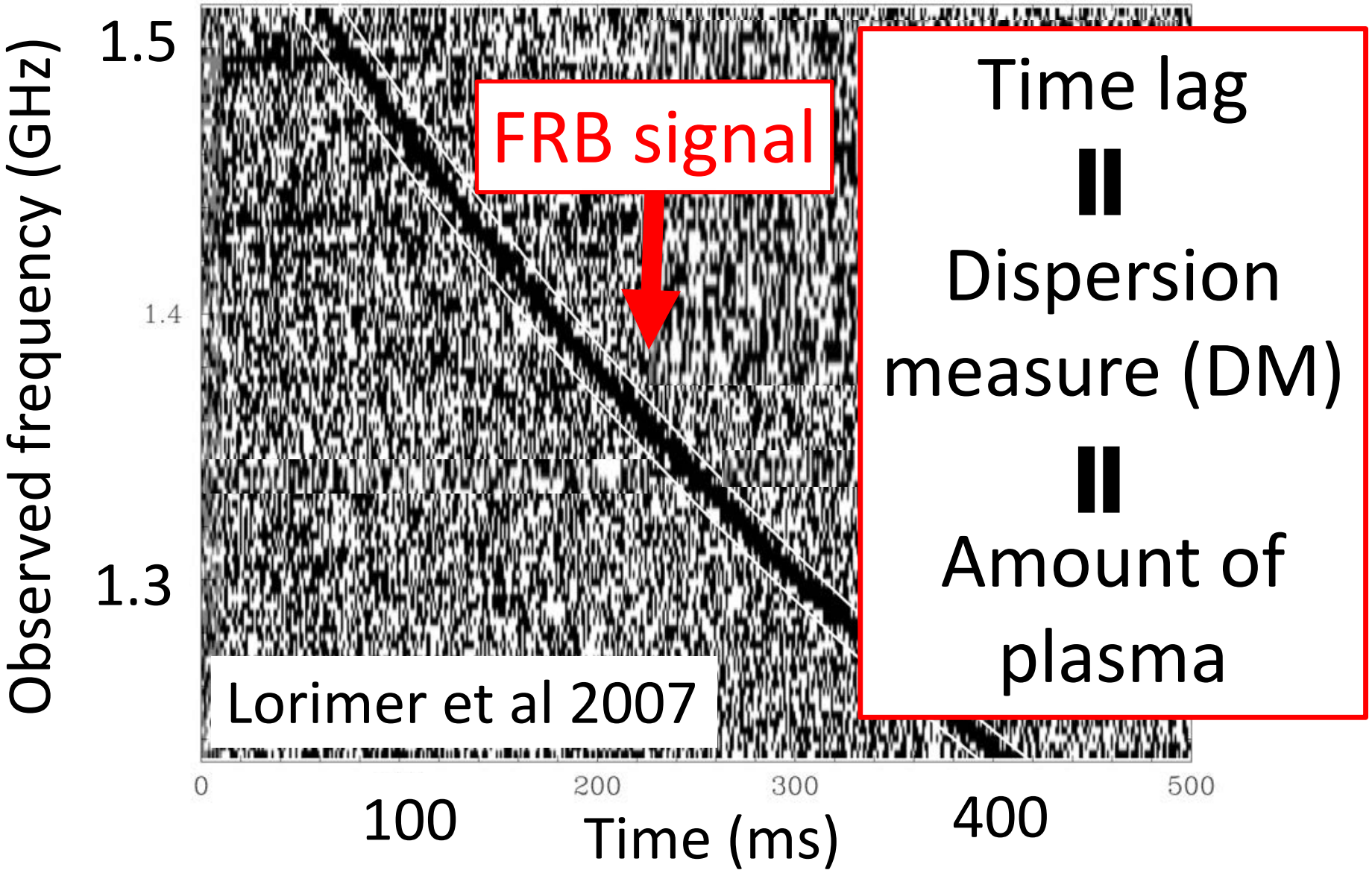
Plasma in the intergalactic space

→ But, plasma doesn't emit bright EM waves

Game changer! FRB is useful



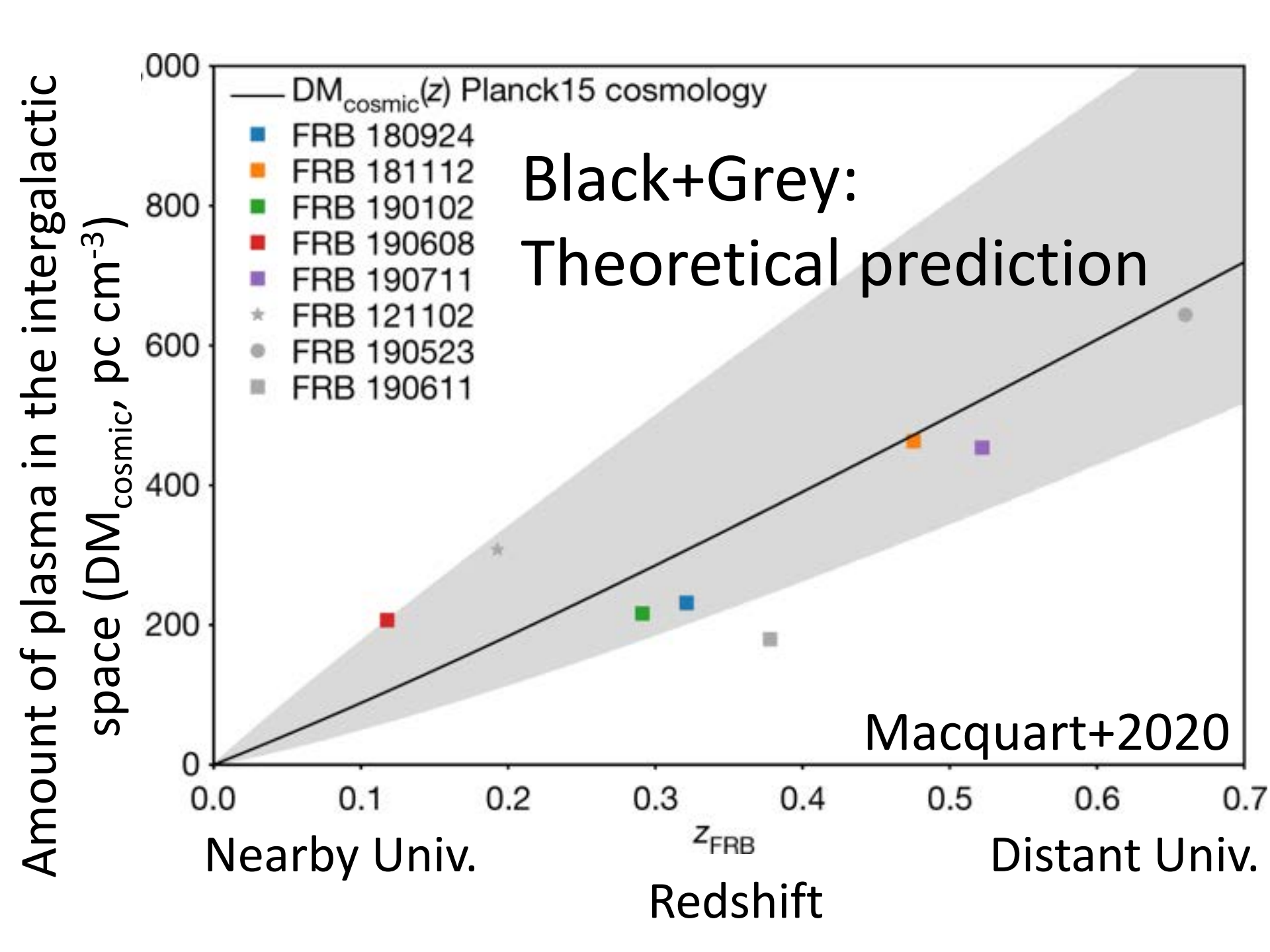
Detection of an FRB

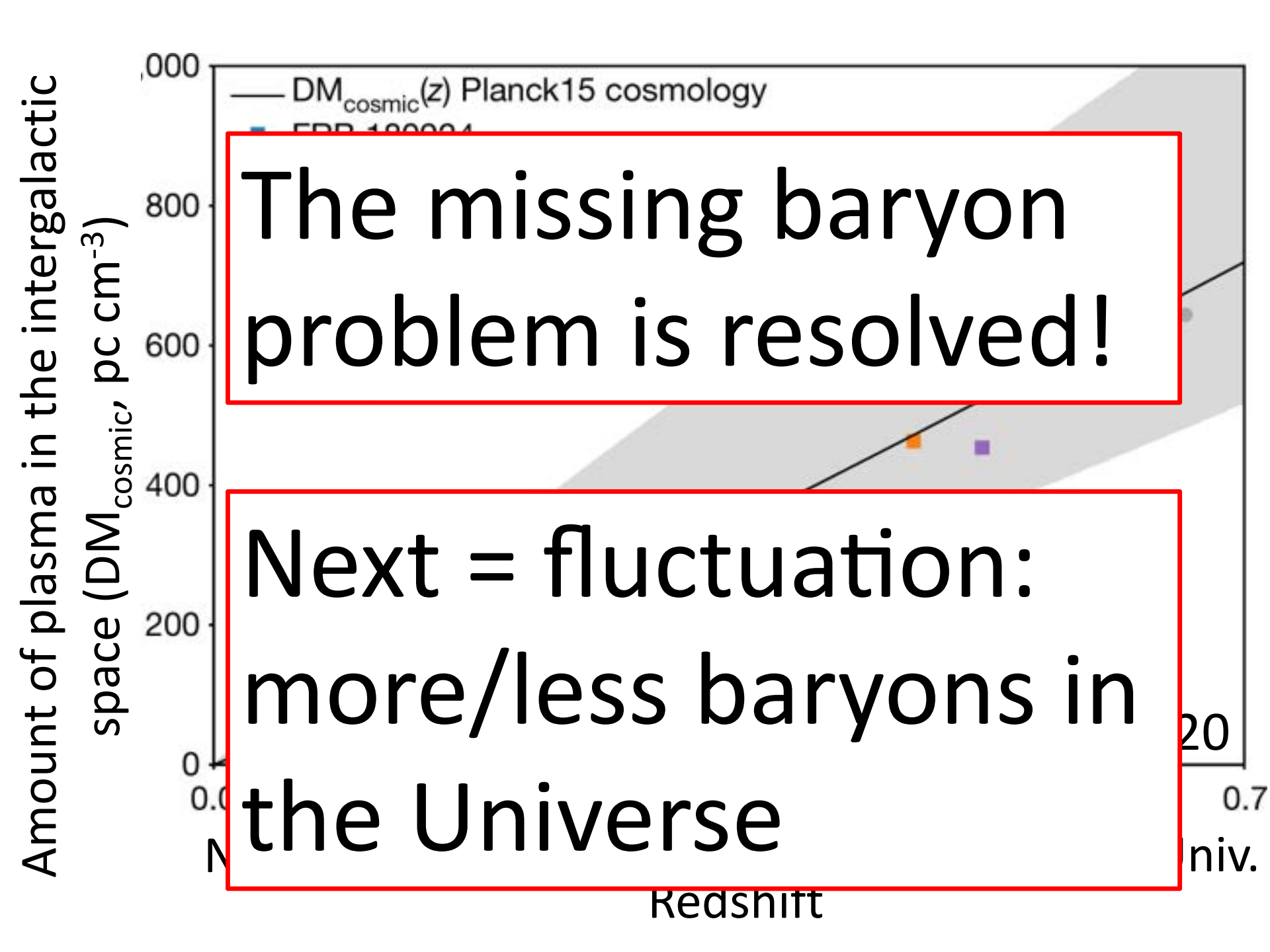


Game changer! FRB is useful

Direct probe of the intergalactic plasma!

→ towards resolving the missing baryon problem


Amount of plasma in the intergalactic space (DM_{cosmic}, pc cm^{-3})
000
800
600
400
200
0
$DM_{cosmic}(z)$ Planck15 cosmology
FRB 180924
FRB 181112
FRB 190102
FRB 190608
FRB 190711
FRB 121102
FRB 190523
FRB 190611
Black+Grey:
Theoretical prediction
Macquart+2020
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
z_{FRB}
Nearby Univ.
Distant Univ.
Redshift



The missing baryon problem is resolved!

Next = fluctuation: more/less baryons in the Universe

Credit: Tzu-Yin Hsu

Quantifying the cosmological baryonic fluctuation

More foreground galaxy: More baryons in the intergalactic space?

Less foreground galaxy: Less baryons in the intergalactic space?

Credit: Tzu-Yin Hsu

Case study of DM excess

FRB 20220914 intersect galaxy cluster

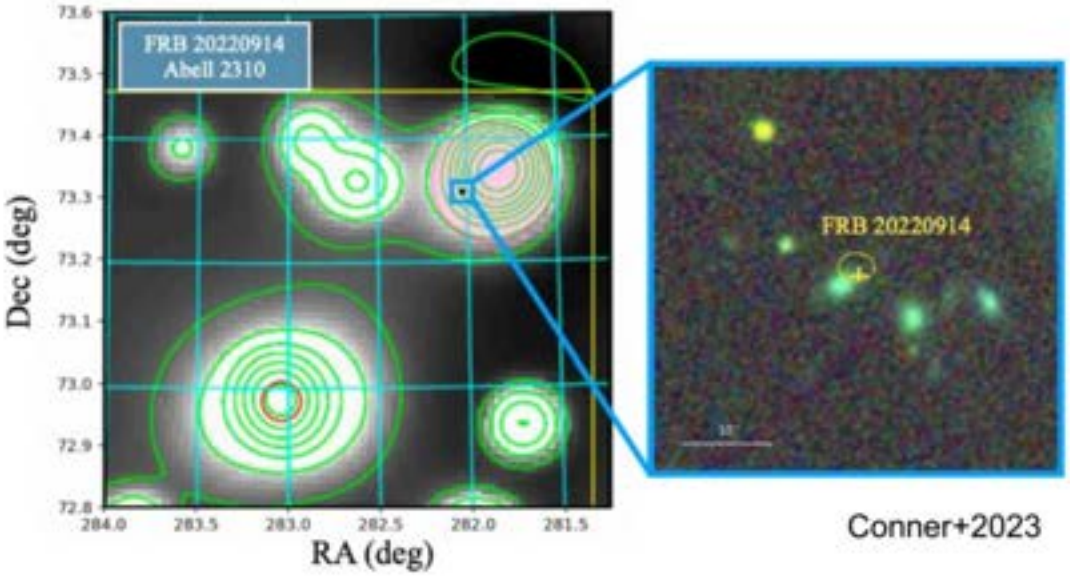
Galaxy number density:

WISE x PS1: $9.5\sigma \pm 1.5\sigma$
WISE x SCOS: $7.4\sigma \pm 1.4\sigma$

DM excess:

$\Delta DM_{cosmic} = 305 \pm 81$ pc cm^{-3}

X-ray image of Abell 2310



Conner+2023

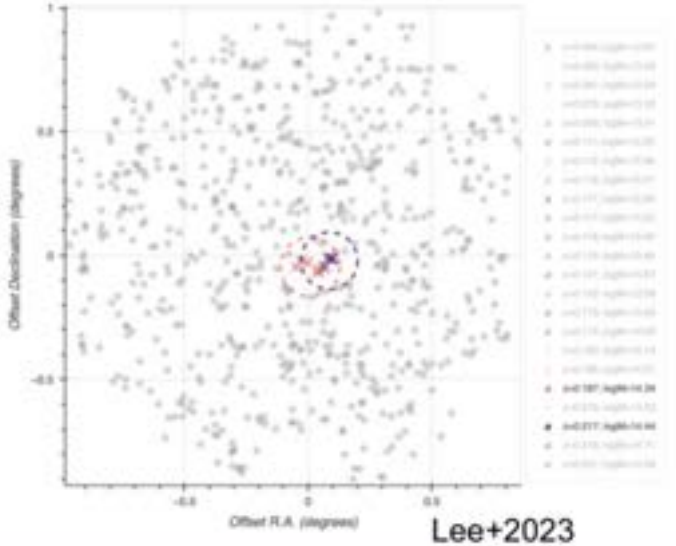
Credit: Tzu-Yin Hsu

Case study of DM excess

FRB intersects galaxy cluster or galaxy group

FRB 20190520B

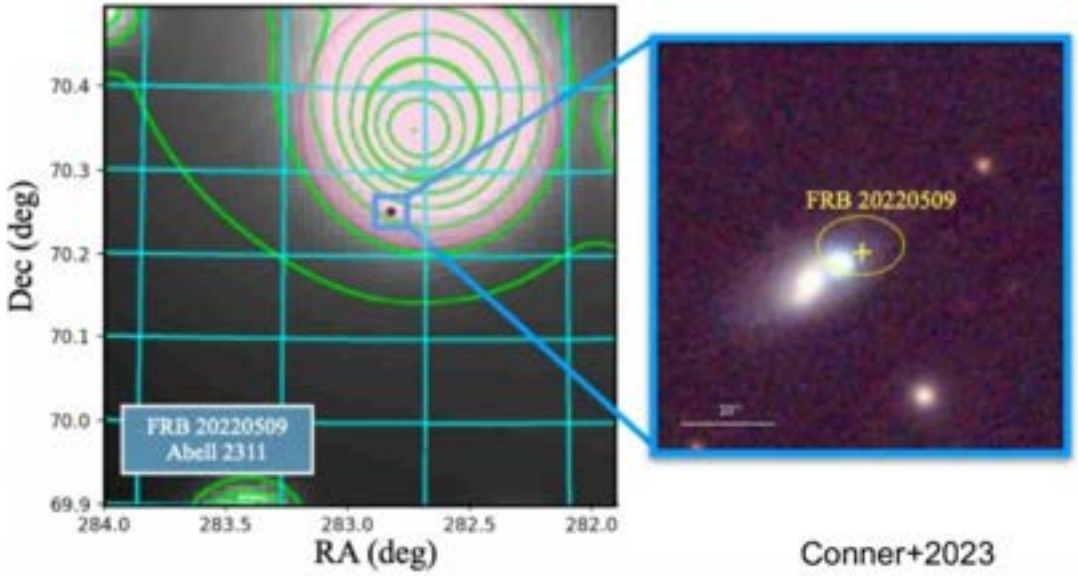
DM excess contributed by foreground galaxy cluster or galaxy group



Lee+2023

FRB 20220509

DM excess possibly contributed by ICM

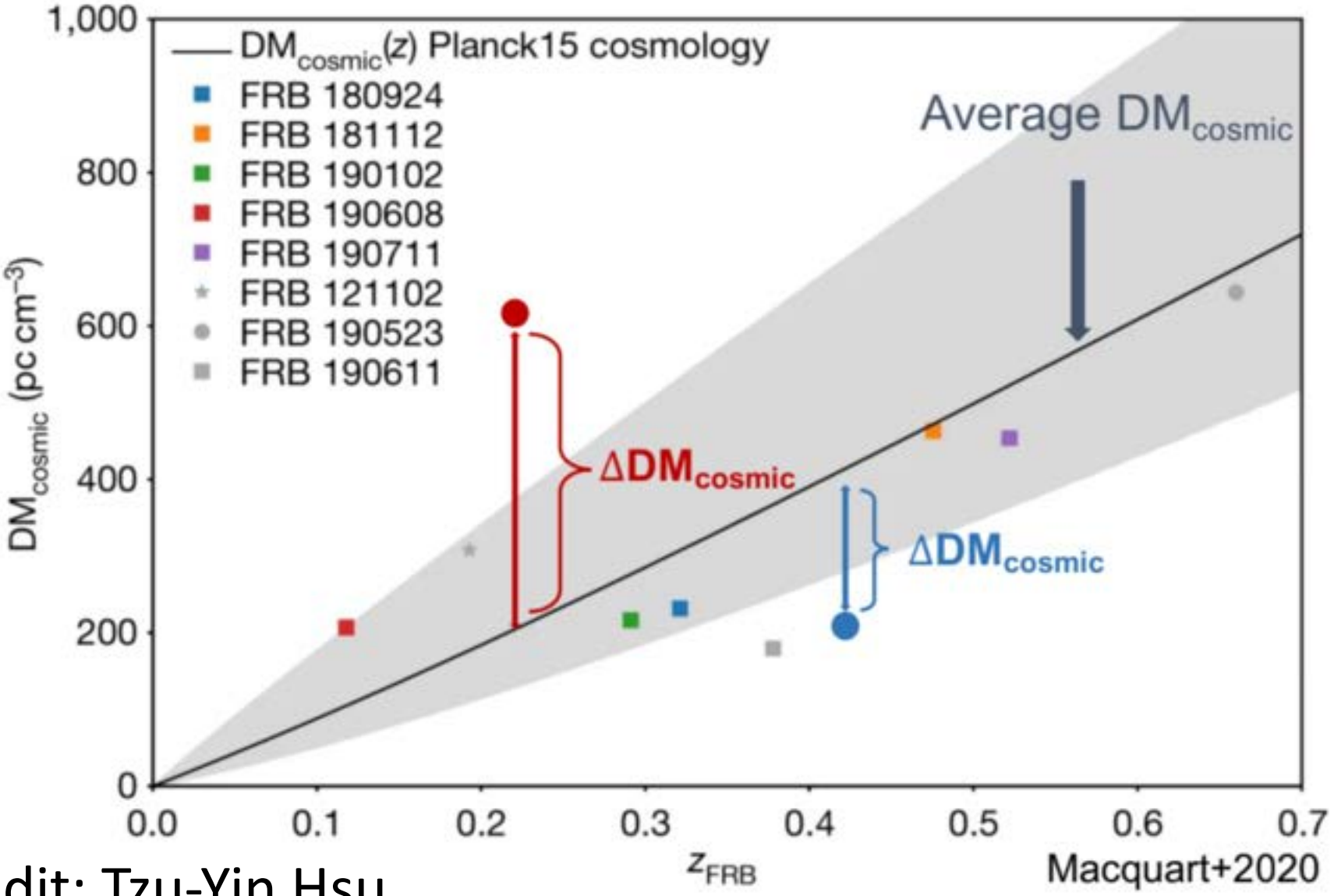


Conner+2023

Problem:

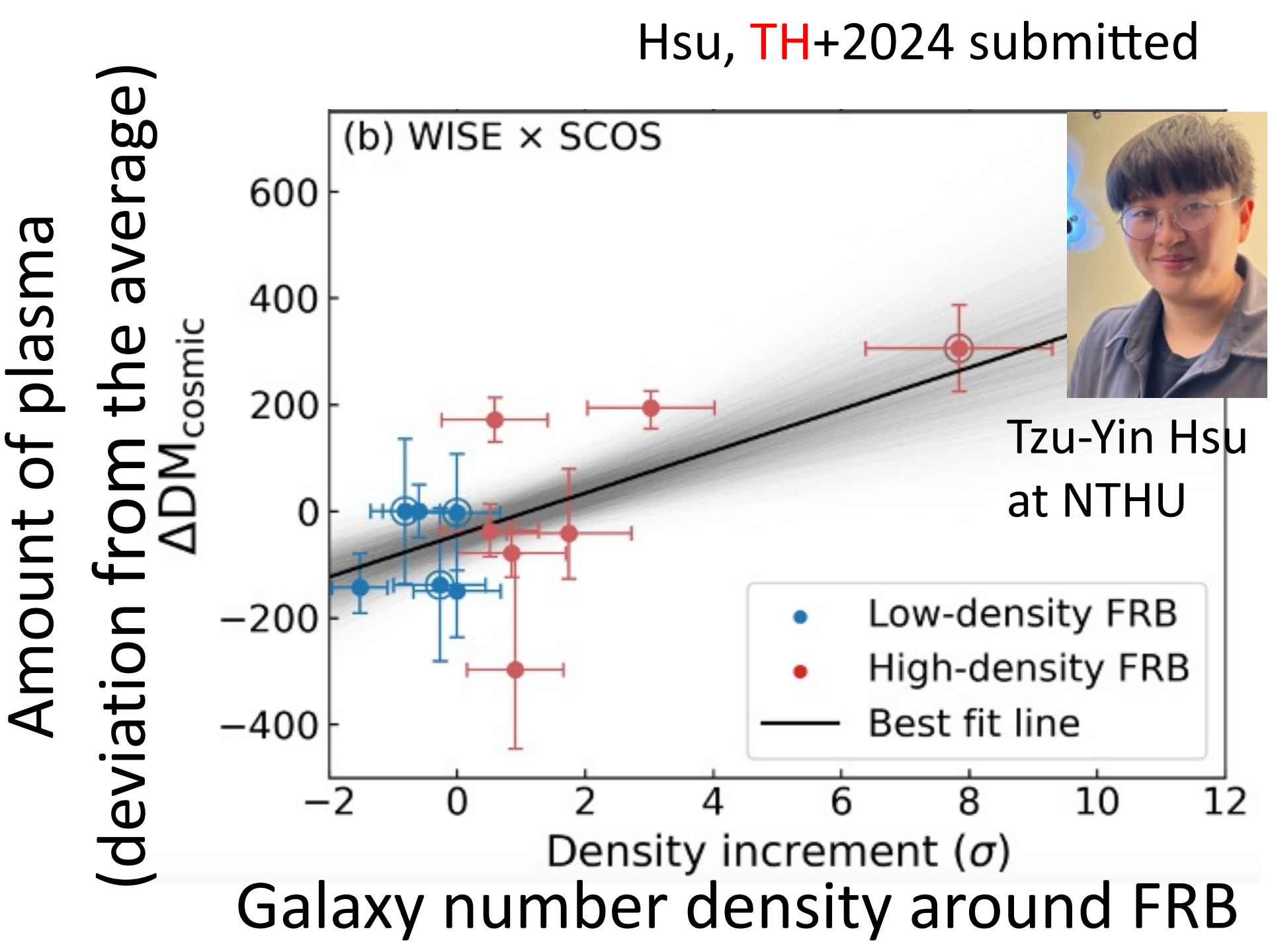
limited to case studies only for high galaxy-density regions

This work:
quantitatively treat both high/low density regions



Credit: Tzu-Yin Hsu

Hsu, TH+2024 submitted



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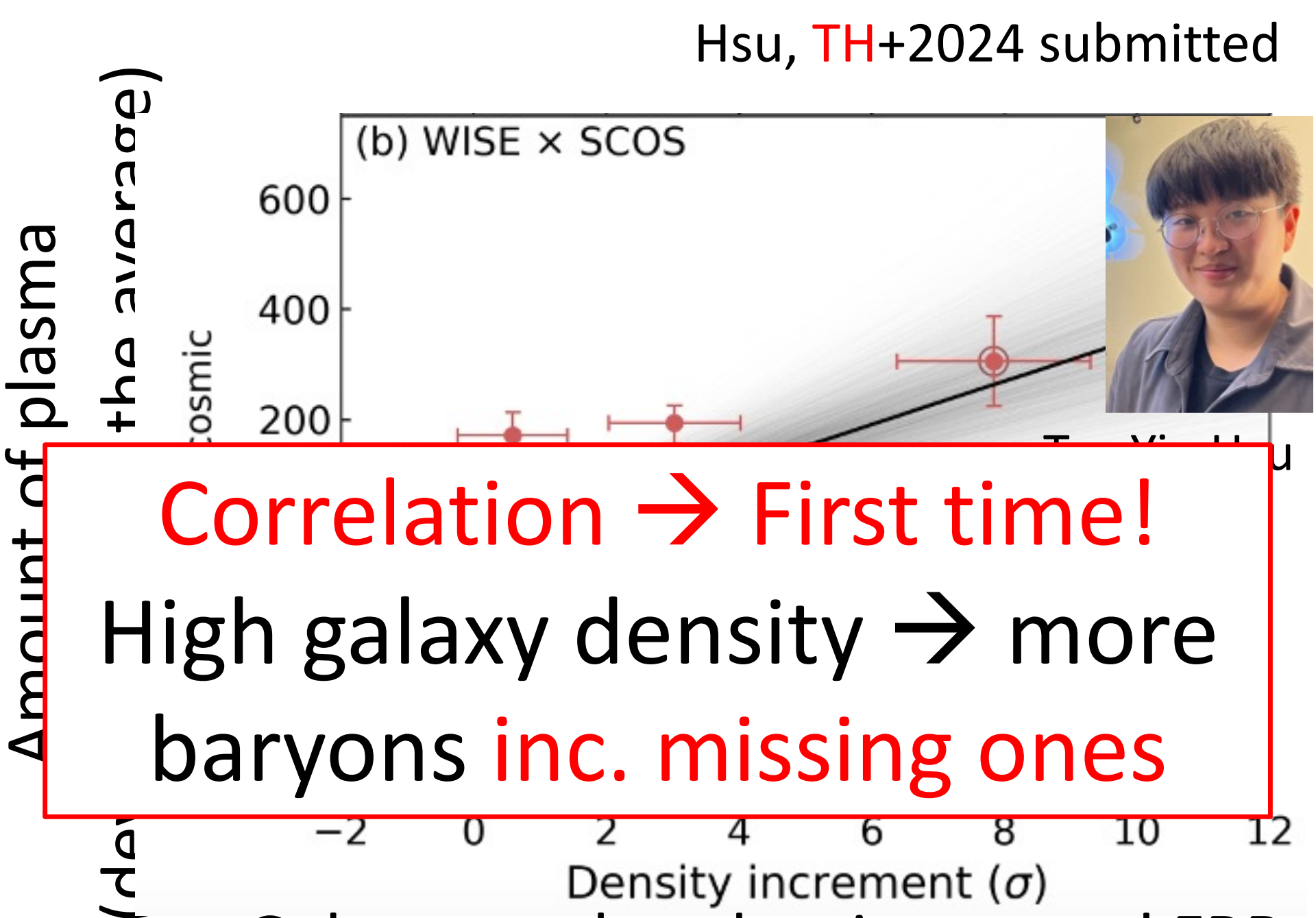
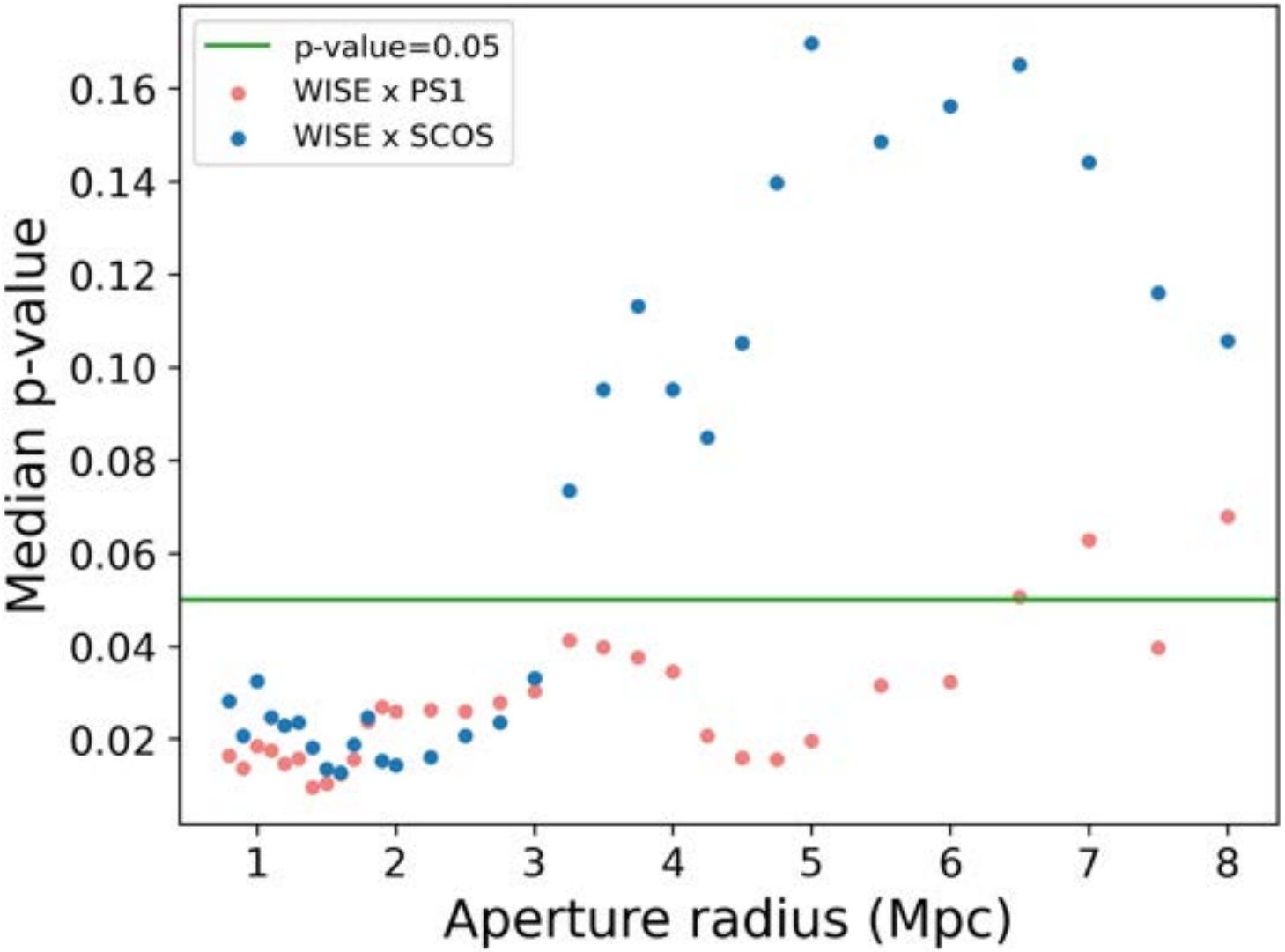


Correlation → First time!

High galaxy density → more baryons inc. missing ones

Typical baryonic fluctuation scale < 6Mpc

Hsu, TH+2024 submitted

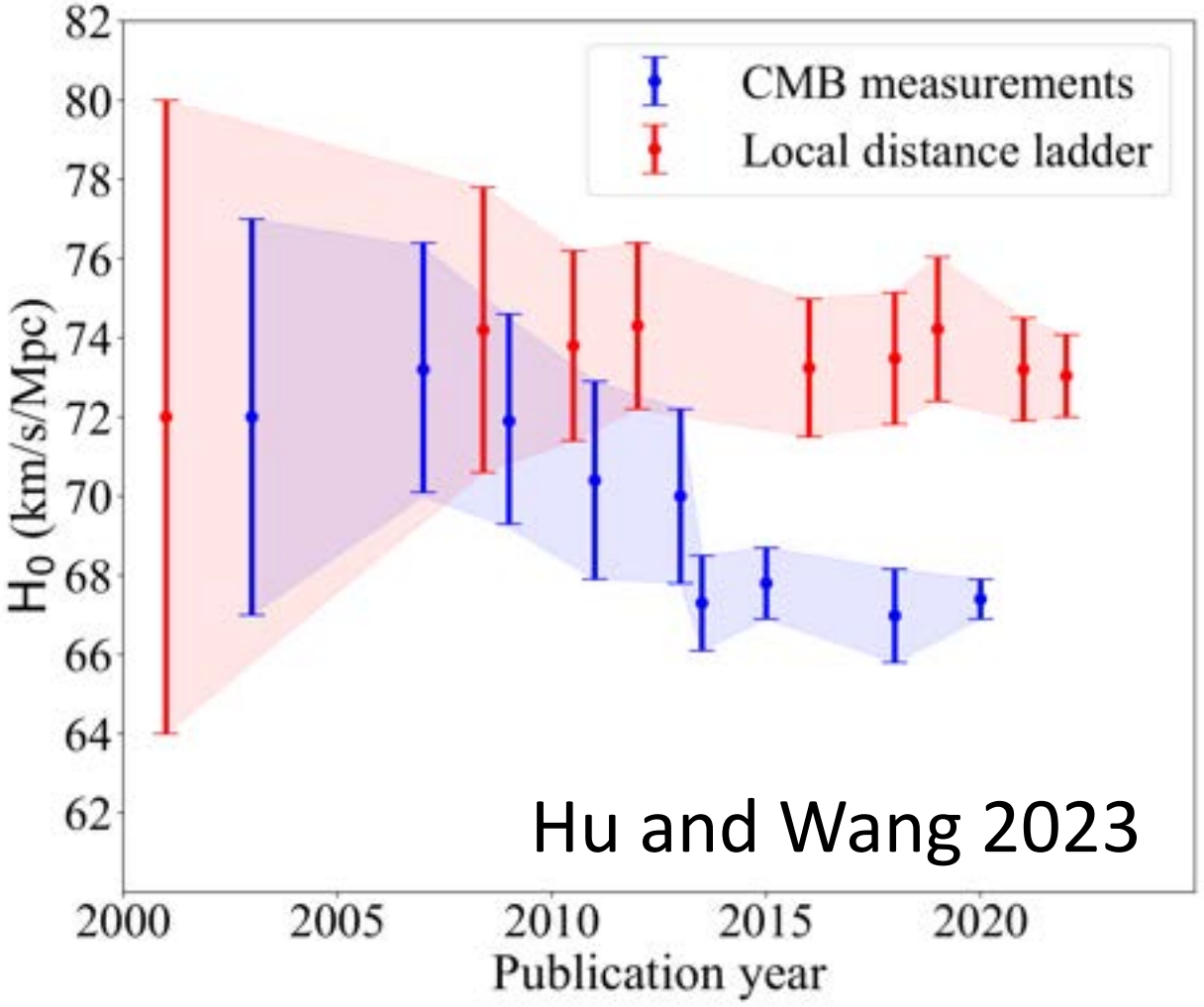


FRBs are useful in addressing

Missing baryon problem

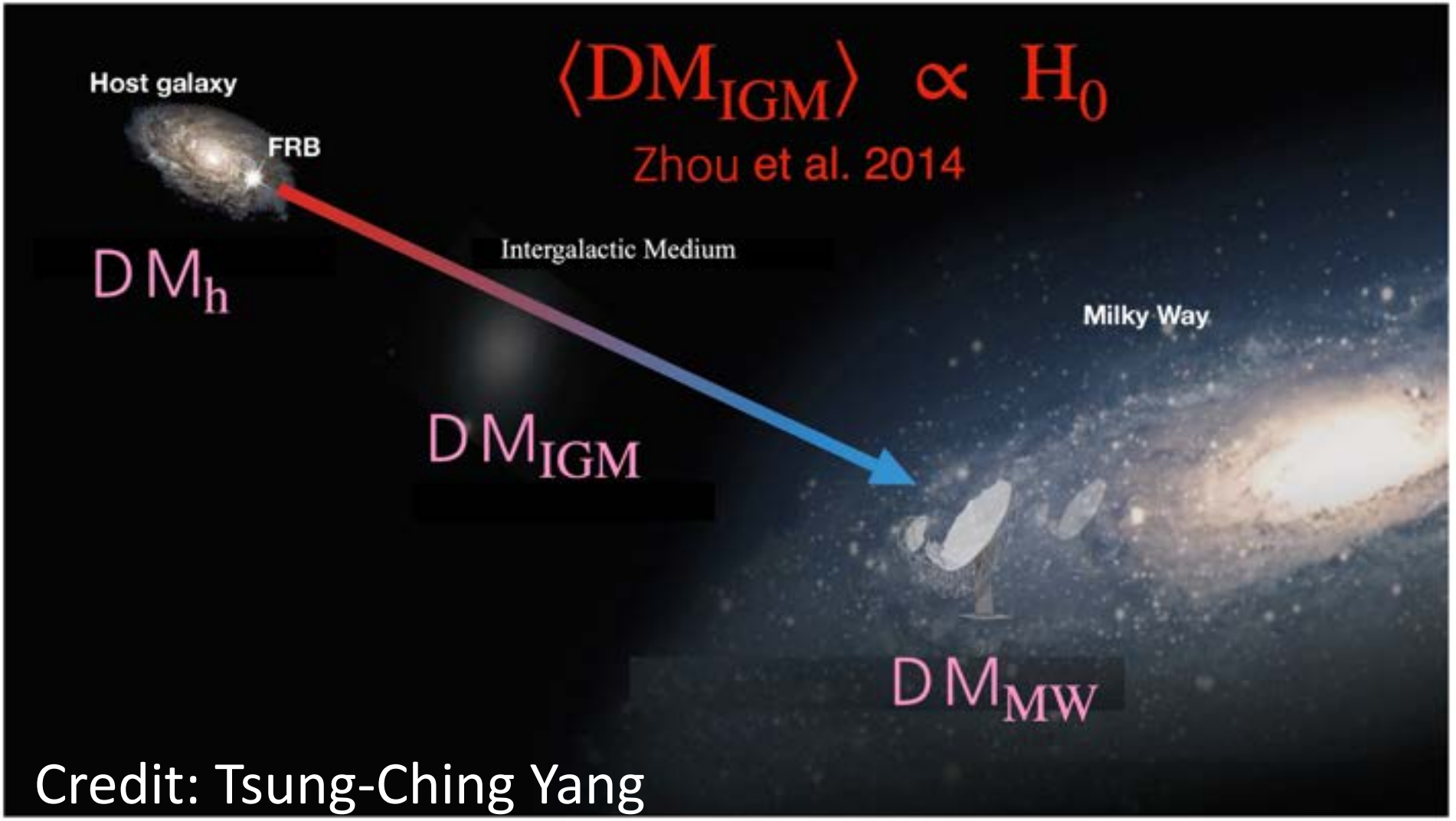
Cosmic expansion

Hubble Tension: ~10% systematics



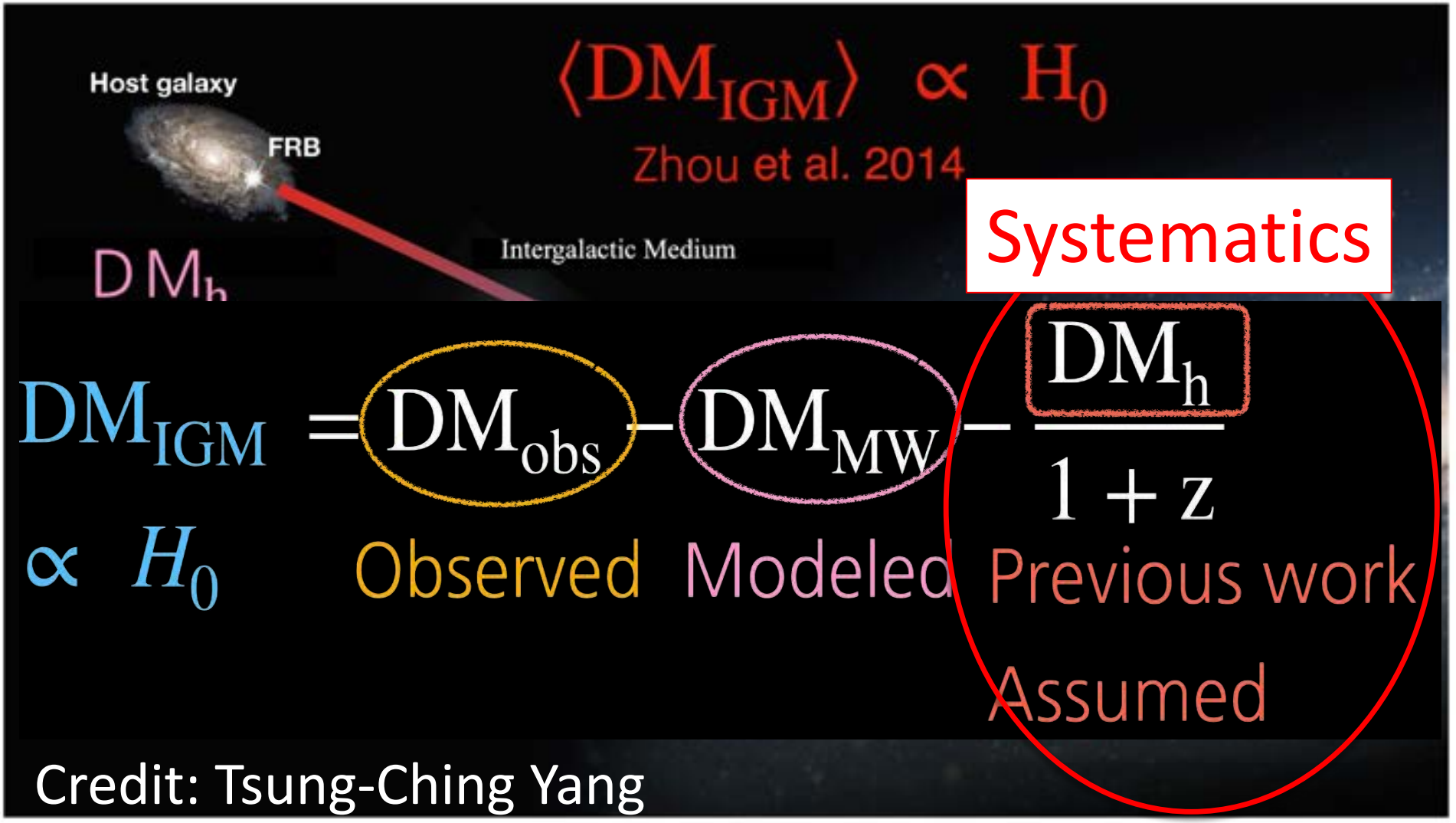
Independent measurement is important

FRB's Dispersion Measure (DM) may be useful



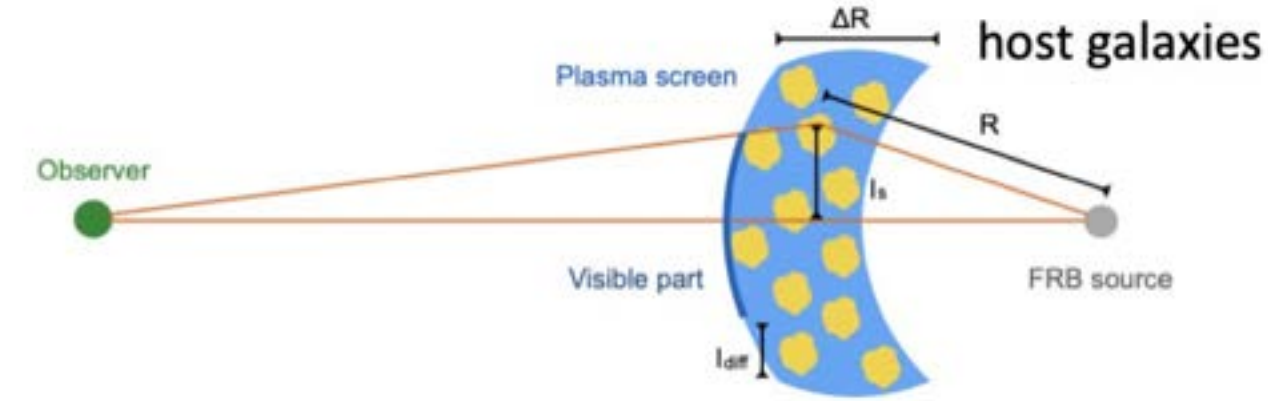
Credit: Tsung-Ching Yang

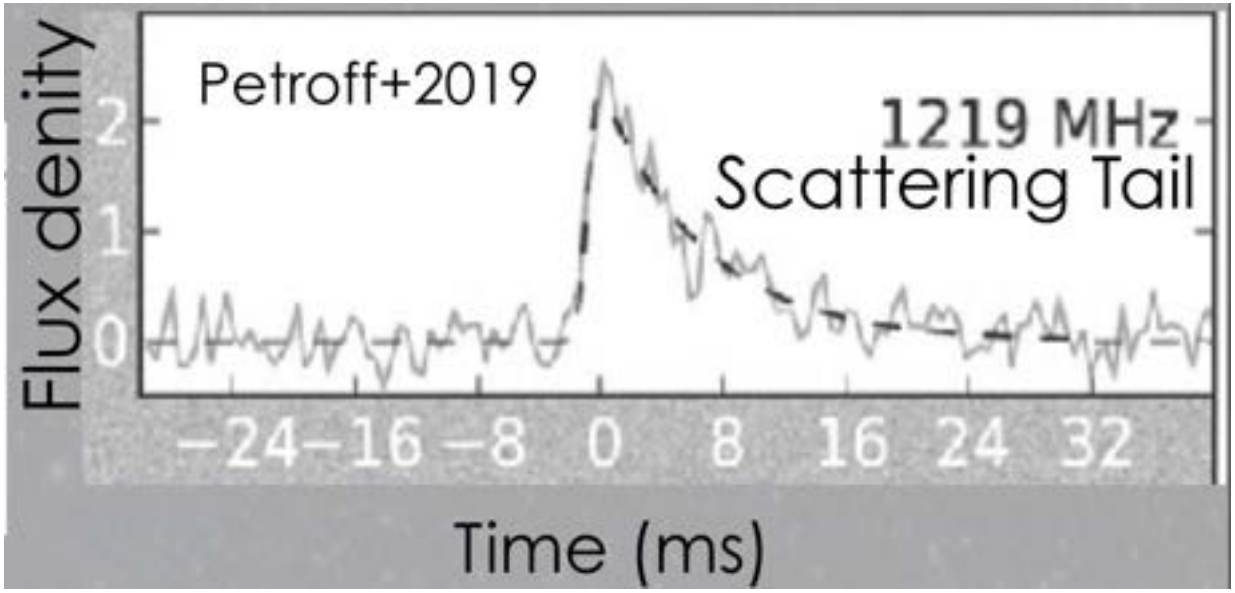
Problem in the previous FRB method



Our solution: using scattering

Yuan-Pei Yang + 2022





Measure scattering

↓

Measure DM_h

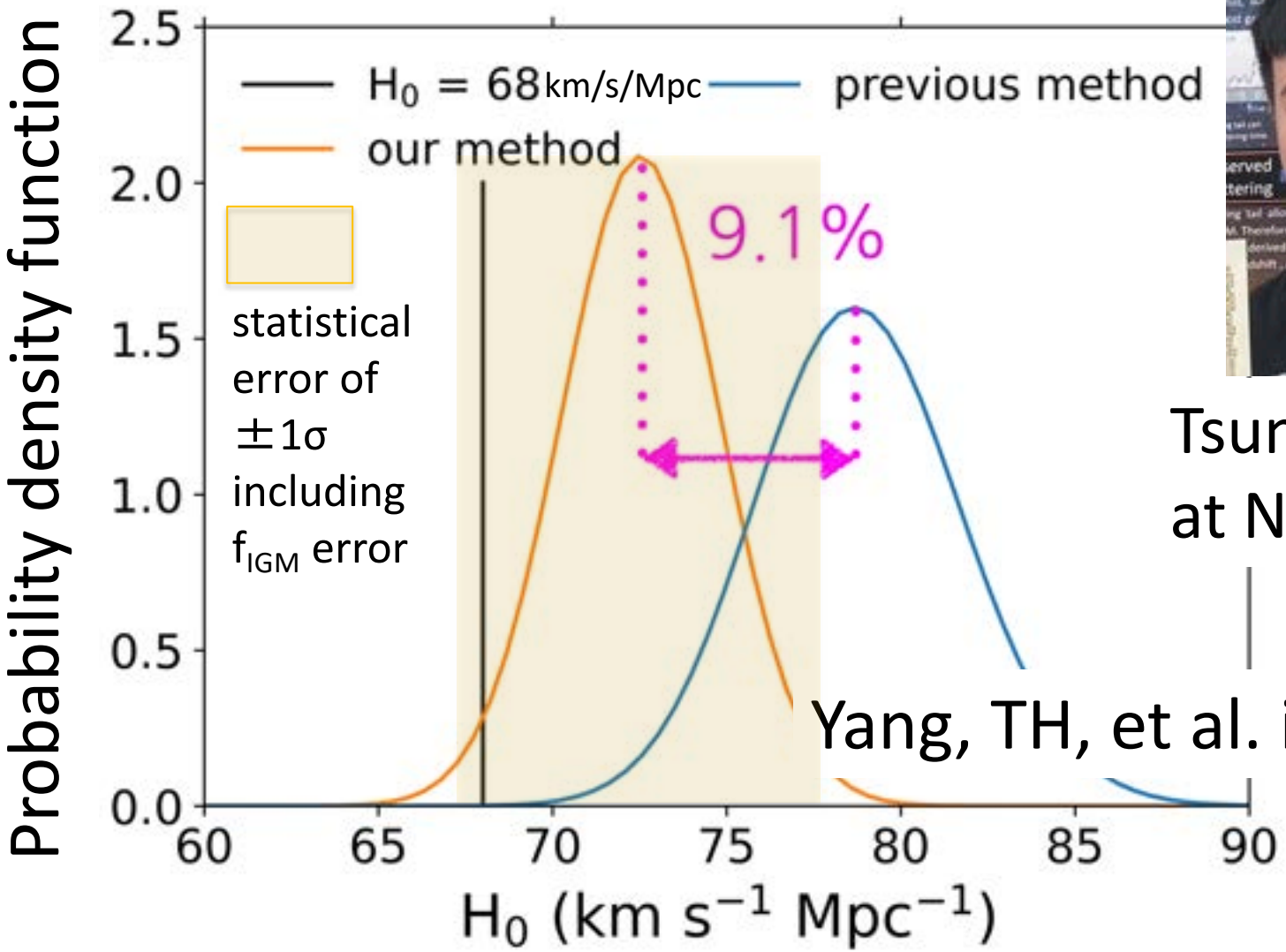
↓

DM_{IGM} and H_0

Our method: systematics reduces

Simulations with 100 mock FRB data

Tsung-Ching at NCHU

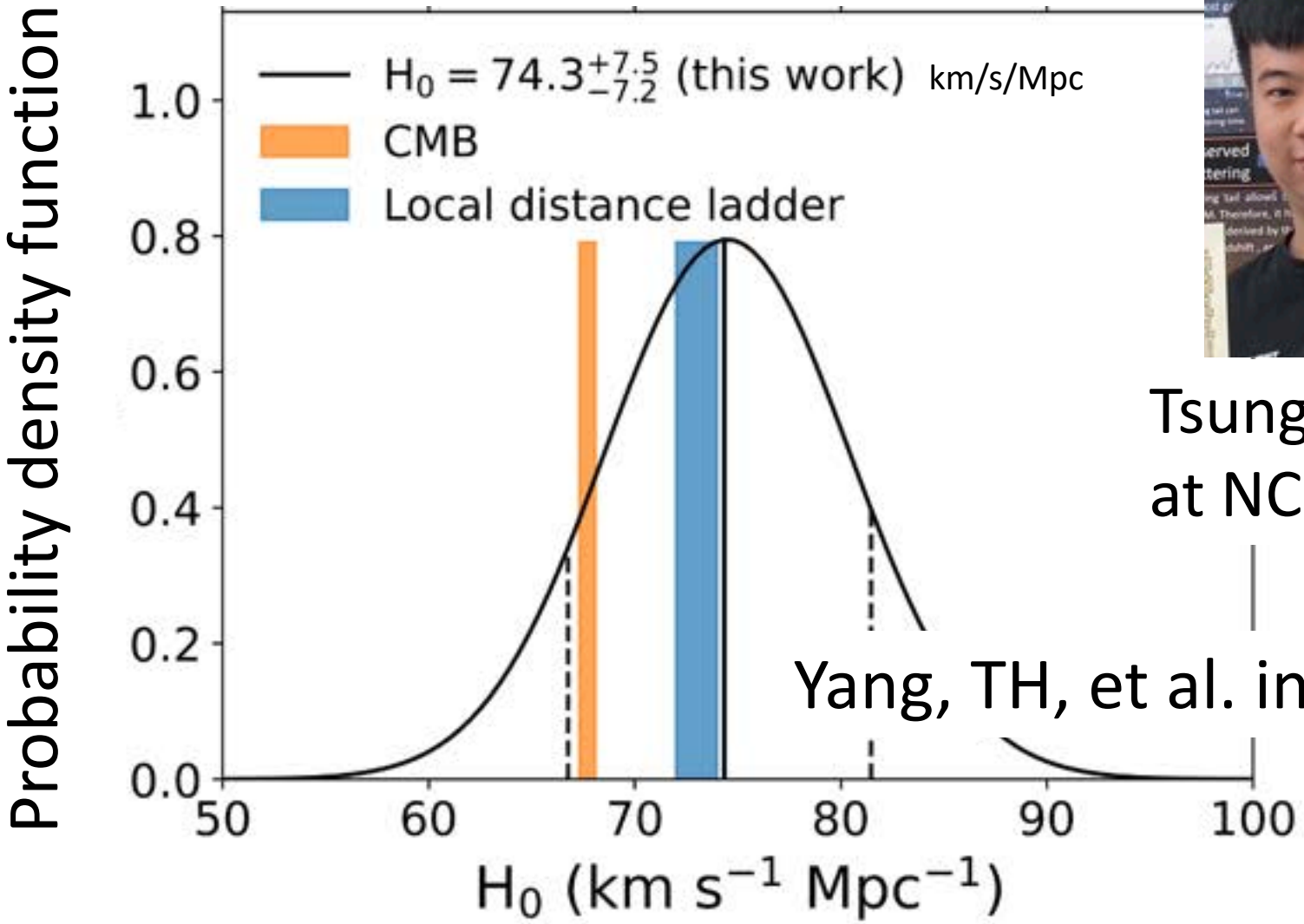


Yang, TH, et al. in prep

Our method: ~10% statistical error

30 observed FRB samples

Tsung-Ching at NCHU



Yang, TH, et al. in prep

Our method: ~10% statistical error

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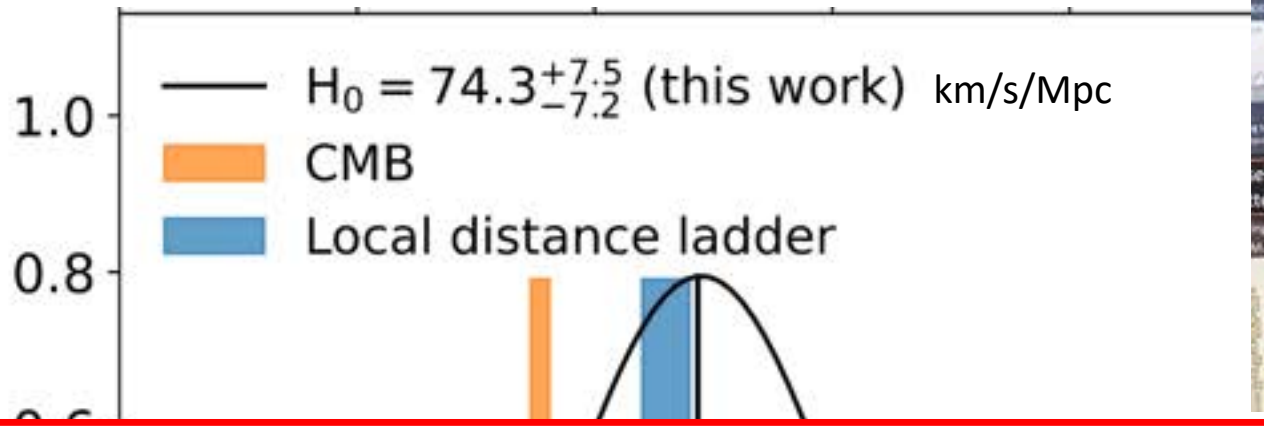


x10 more samples

→~3% statistical error

→FRBs support which?

Bustling Universe Radio Survey Telescope in Taiwan (BURSTT, PI: Ue-Li Pen)
台灣宇宙電波爆廣角監測實驗

Bottlenecks and our solutions

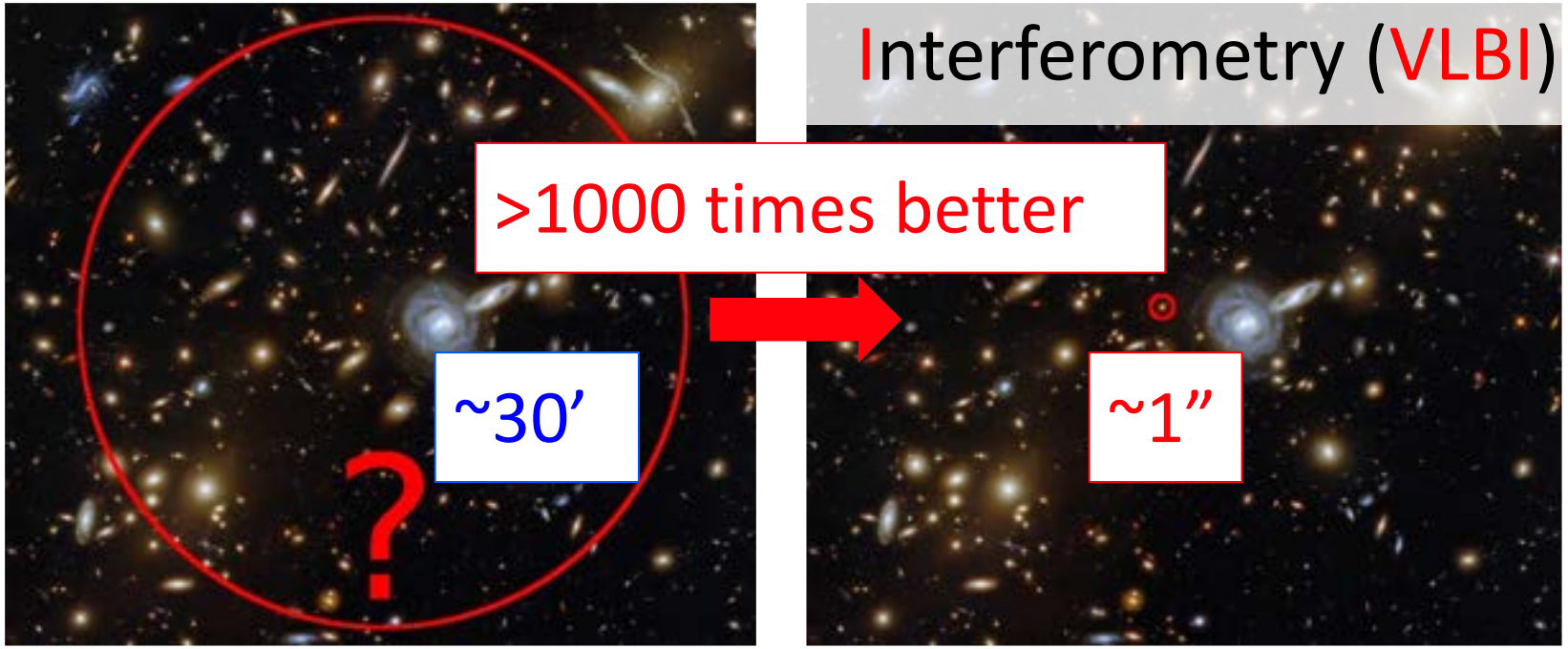
Previous observations

Poor localization capability

Need

Accurate localization

⇒ Very Long Baseline Interferometry (VLBI)



We don’t know where they come from

We can identify progenitors/host galaxies

Bottlenecks and our solutions

Previous observations

Narrow FoV

Short obs. Time

Need

Extremely wide FoV

Long obs. time

No detection if an FRB happens here

can detect

Bottlenecks and solutions

Previous observations

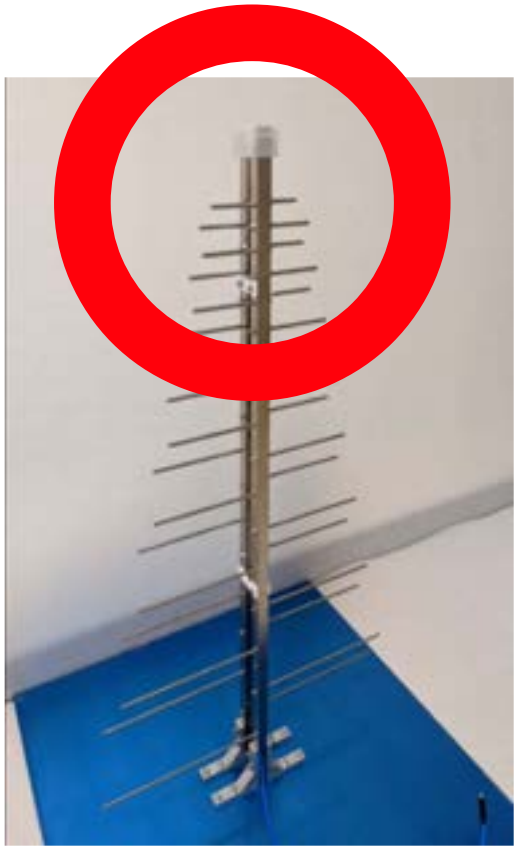
Narrow FoV

Short obs. Time

Need

Extremely wide FoV

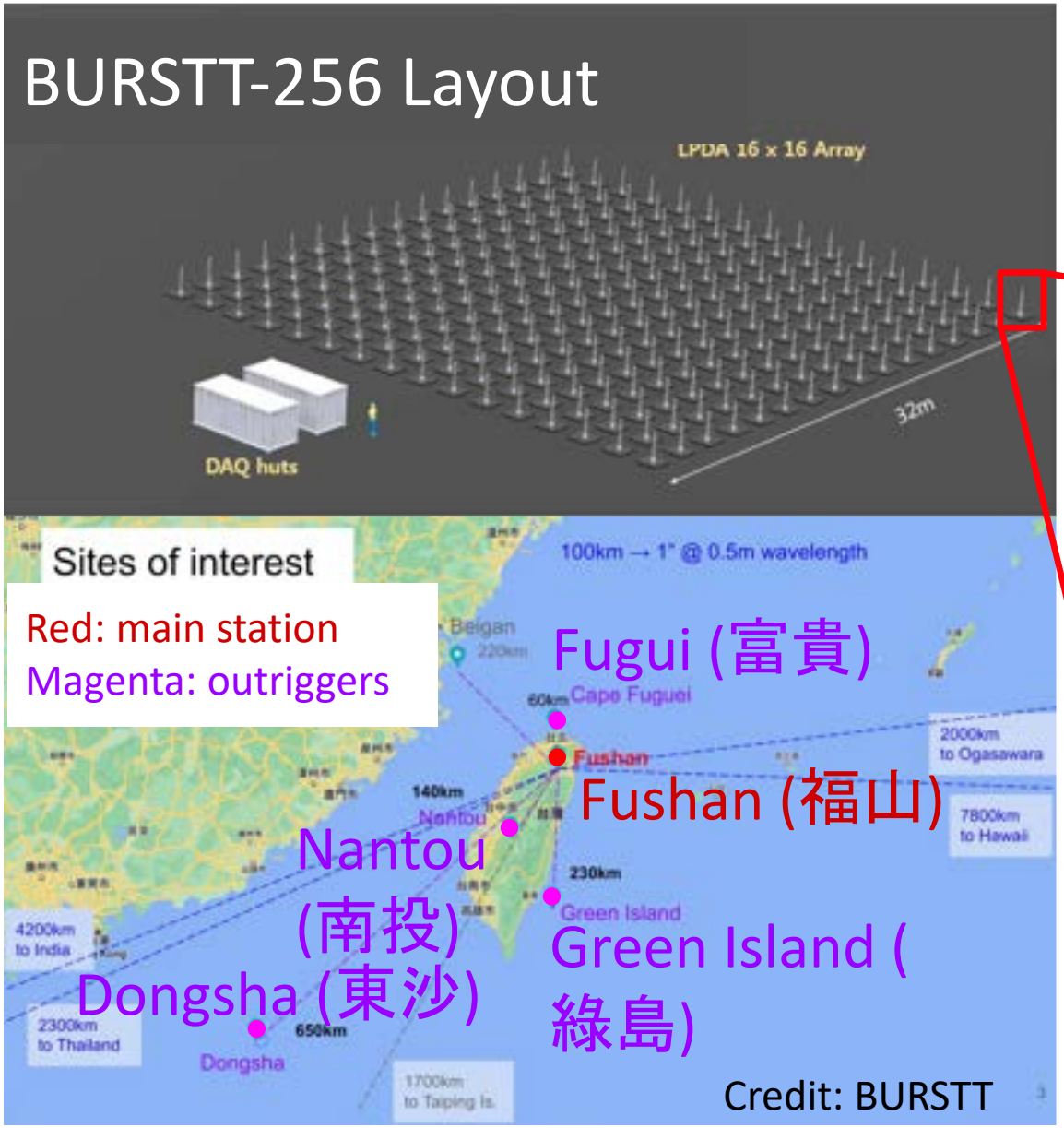
Long obs. time



Bustling Universe Radio Survey Telescope in Taiwan (BURSTT, PI: Ue-Li Pen)

Wide FoV

VLBI



BURSTT

Log-Periodic Dipole Array (LPDA) antenna for the main station

Antenna design

BURSTT

X256

(main station)

Field of view on the sky

BURSTT

120°X60°

~25 times better than CHIME

Size of the moon

CHIME

(120°x2°)

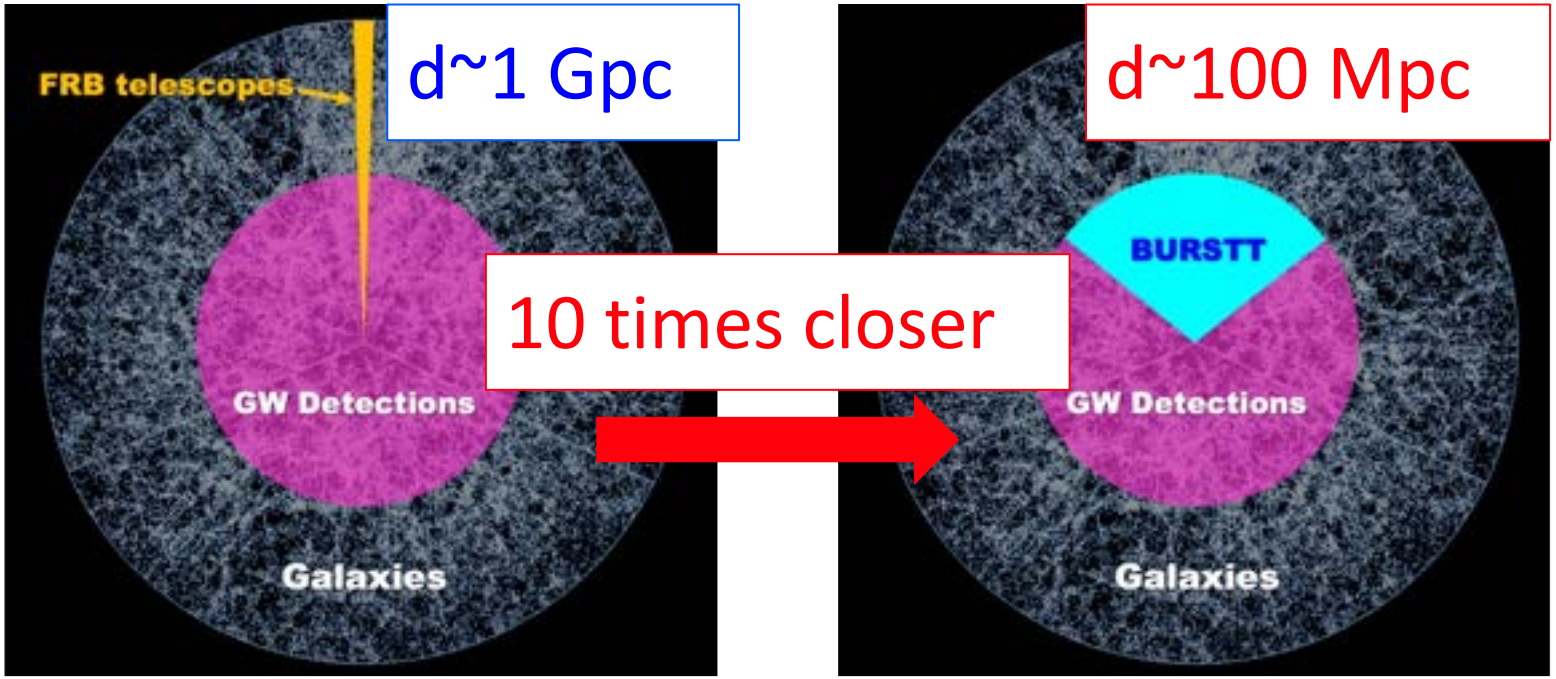
Bottlenecks and our solutions

Previous observations

Mismatch with multi-messengers

BURSTT

Synergy with multi-messengers



A very small overlap in the survey volume

Maximize the chance of multi-messenger detection

BURSTT explores unique param. space

BURSTT

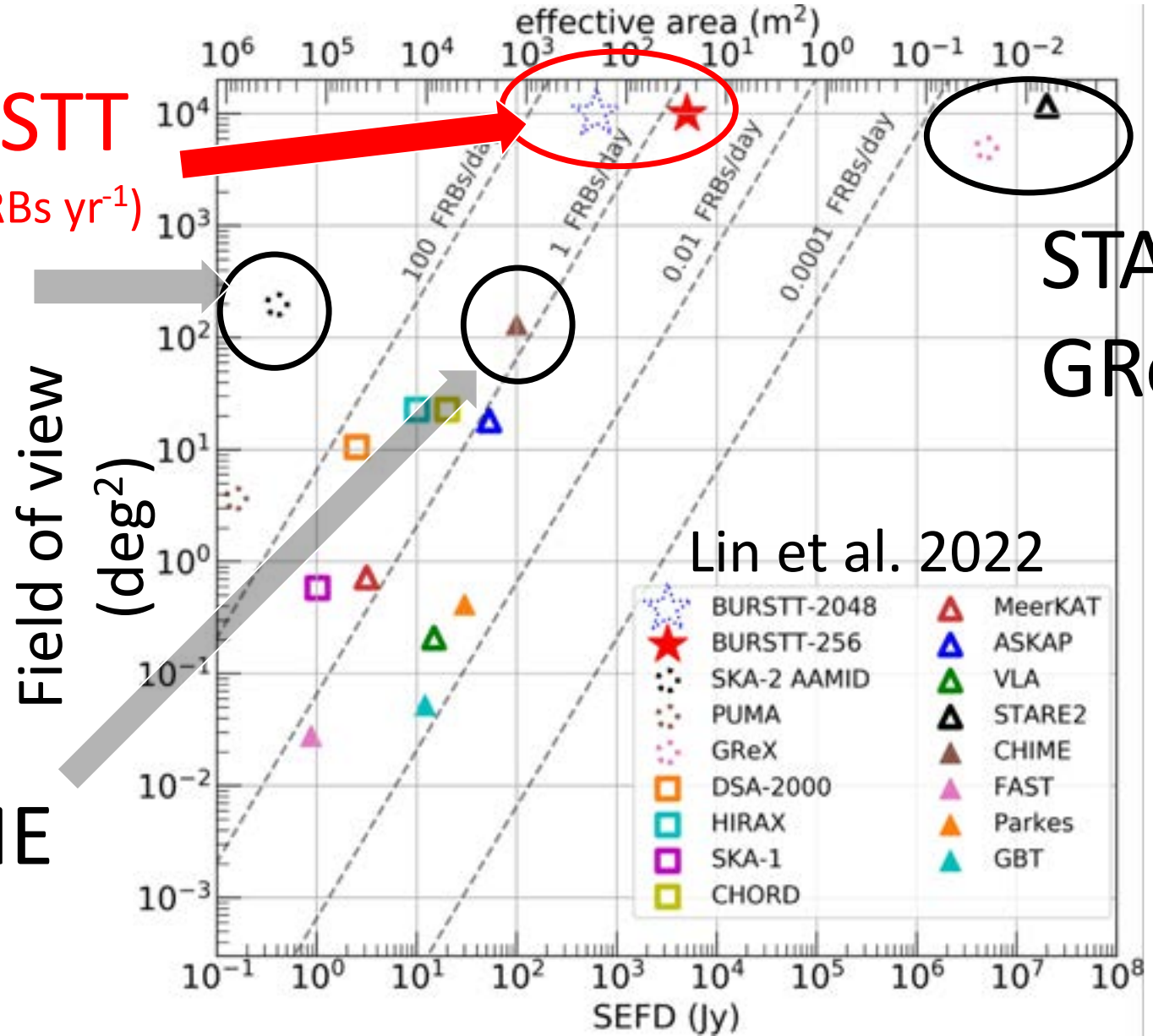
(~100 FRBs yr^{-1})

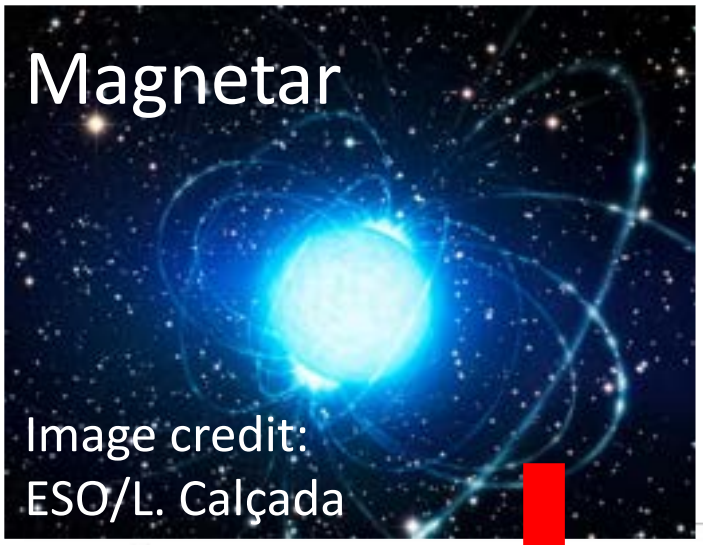
SKA2

CHIME

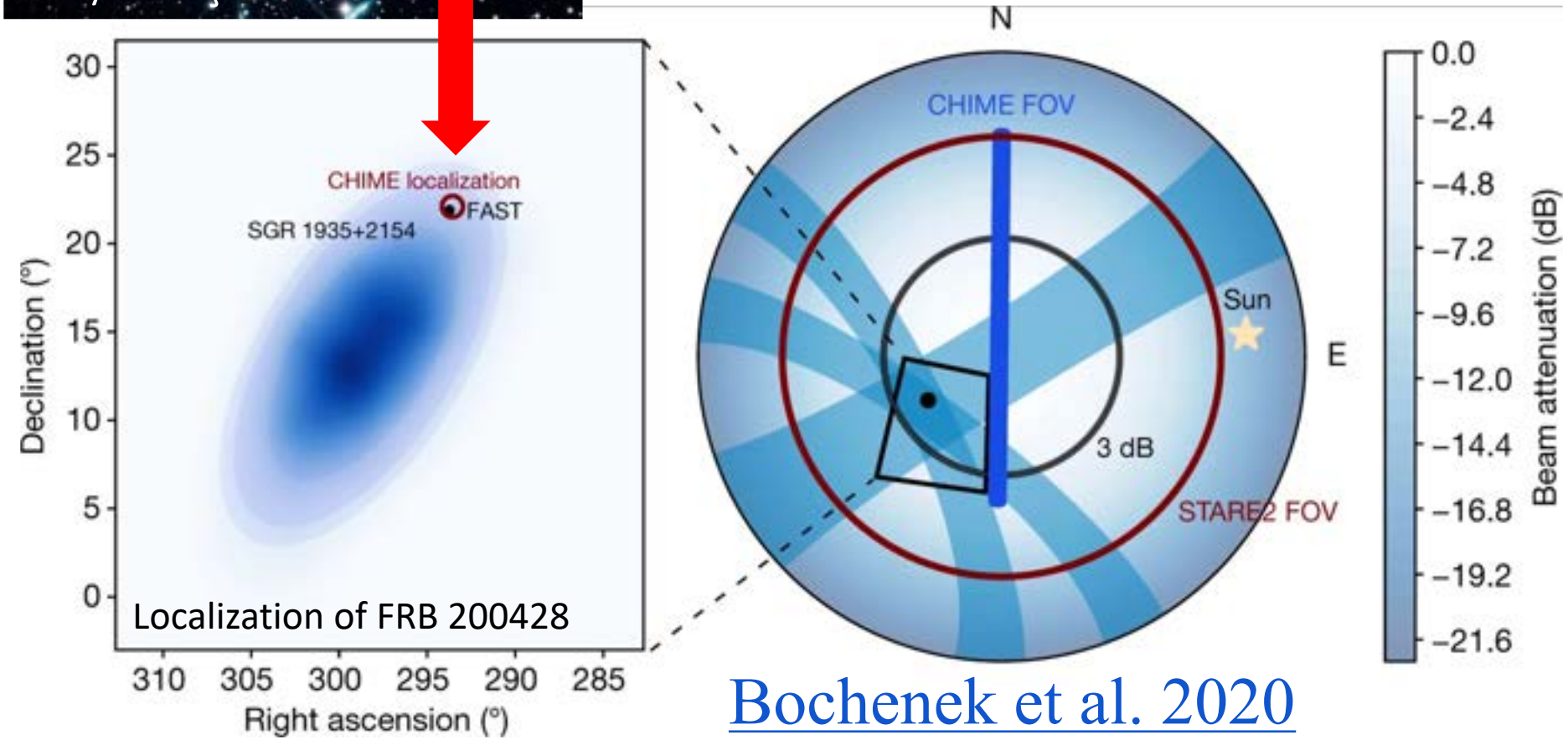
STARE2

GReX





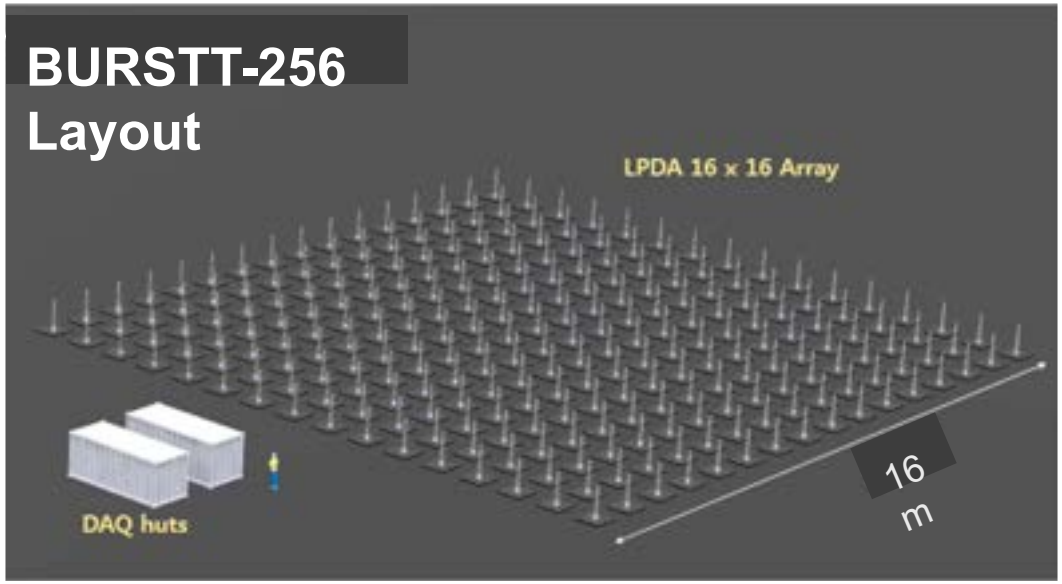
1. Direct identification of FRB progenitors



Bochenek et al. 2020

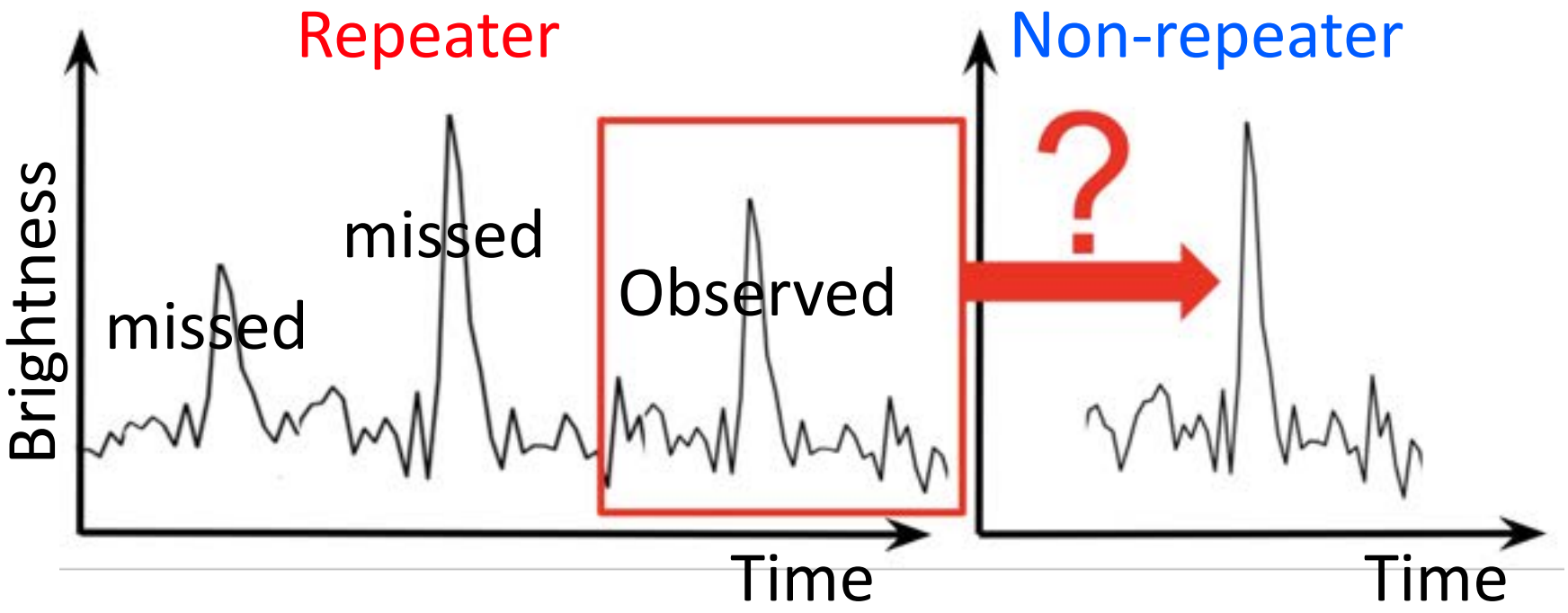
1. Direct identification of FRB progenitors

BURSTT



→ increase progenitor ids.

2. Complete census of nearby FRBs

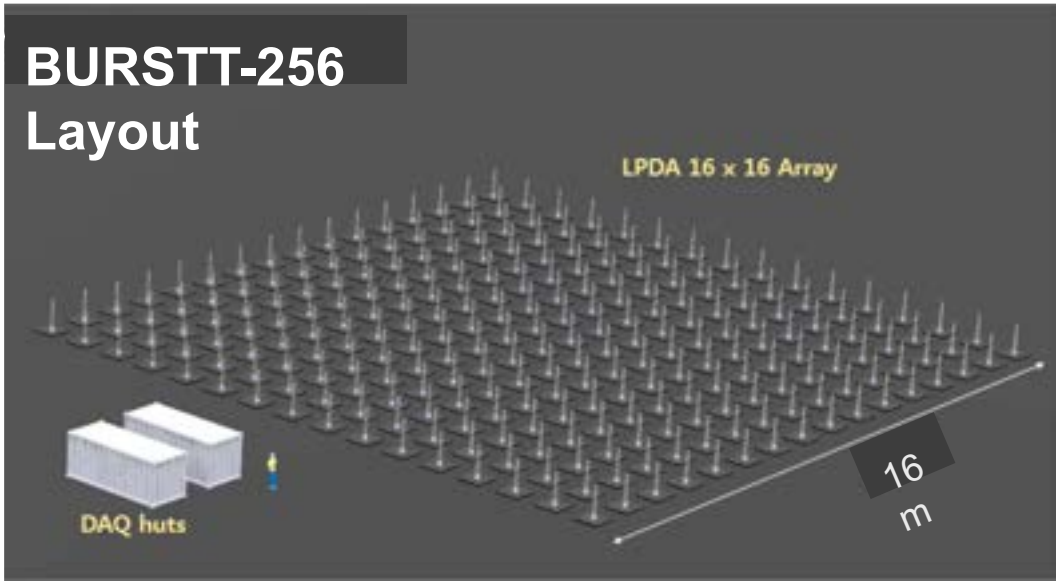


- The true number fraction of repeaters/non-repeaters (f_{rep}) ➡ ?
- True repeating rates

need long monitoring observations with high cadences

2. Complete census of nearby FRBs

BURSTT will answer



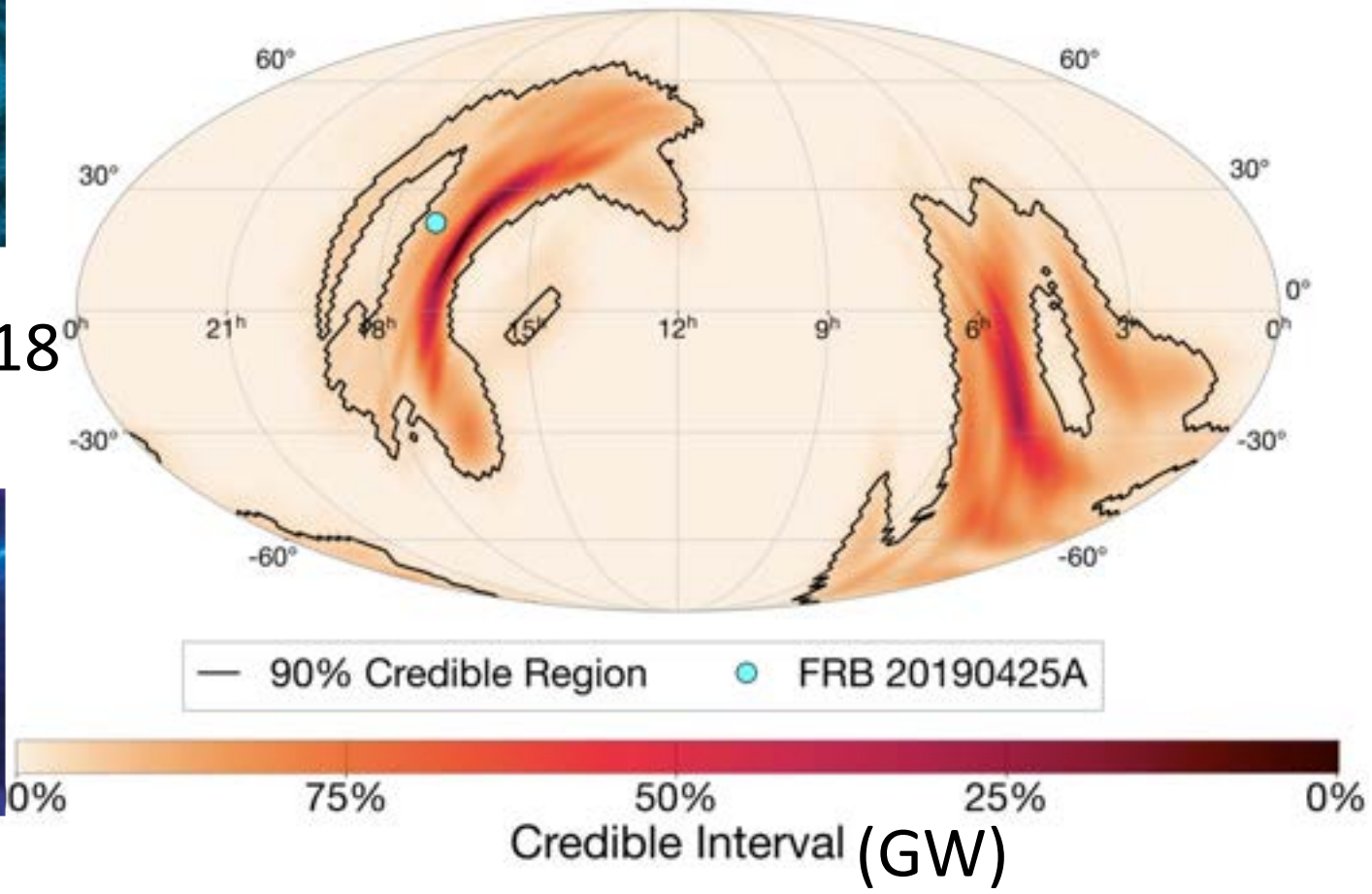
- The true number fraction of repeaters/non-repeaters (f_{rep}) ➡ ?
- True repeating rates

with 25 times larger (longer) FoV (obs. time) than CHIME

3. FRB counterparts

3.1 Multi-messenger

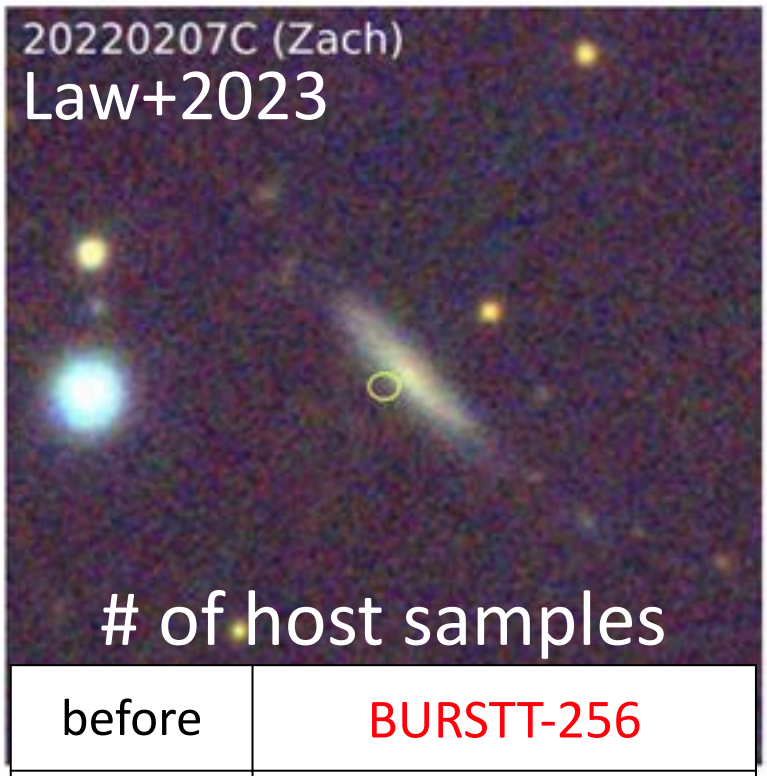
cf. Yamasaki+2018



Moroianu et al. 2023, *Nature Astronomy*

3.2 Multi-wavelengths

Host identification

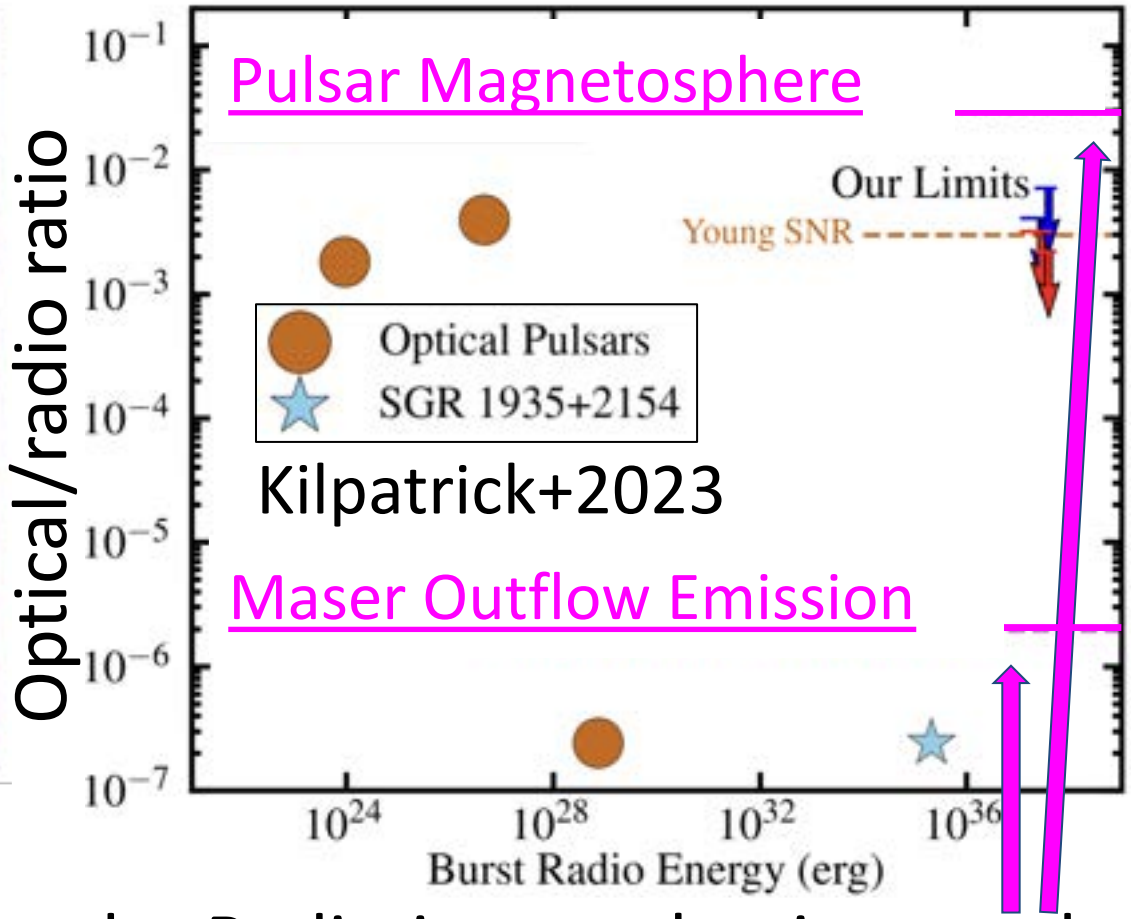


# of host samples

before	BURSTT-256
~40	~100 yr^{-1} (max)

Physical environments and progenitor types

Burst counterparts



Radiation mechanisms and progenitors (eg. LOT)

BURSTT main station

Completed: 256/256 antennas

@Fushan Botanical Garden in northern Taiwan

Credit: Sujin Eie

Domestic outrigger stations

Deployed: 16/64

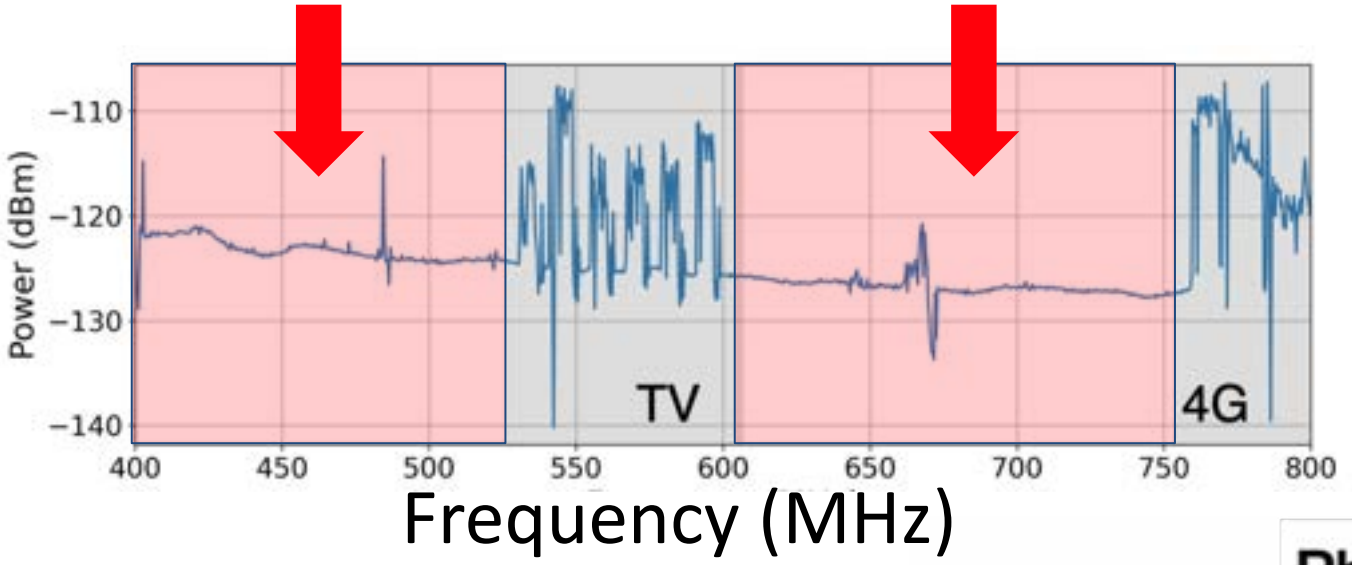
Completed: 64/64

64/64 in July

Testing site

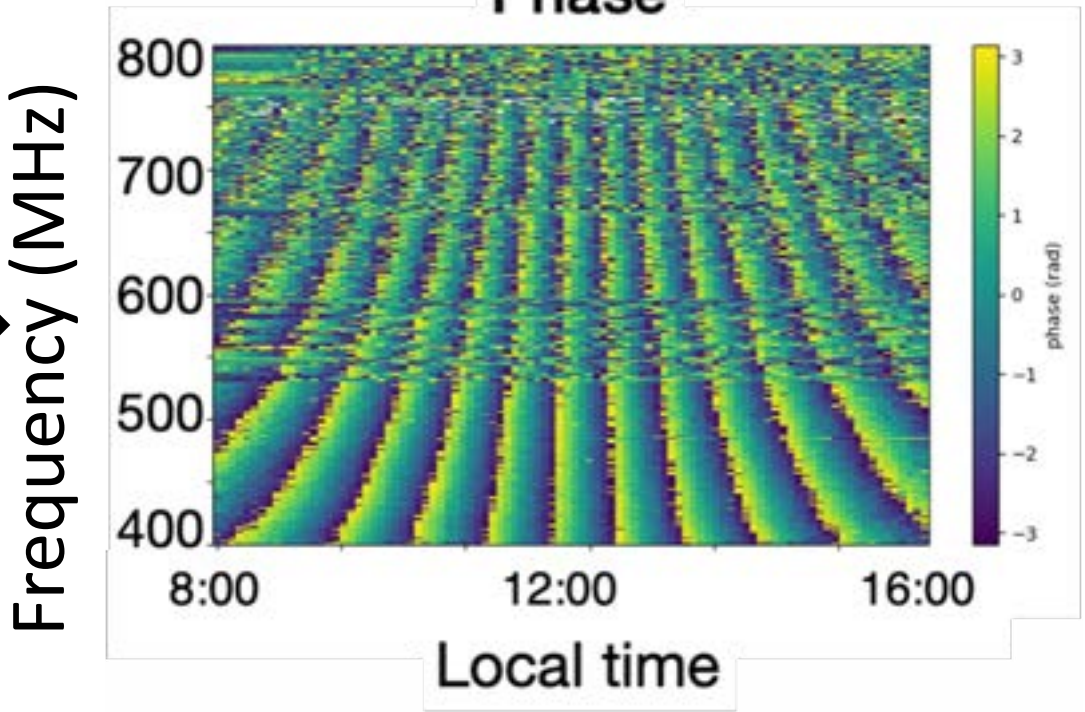
Credit: Sujin Eie

Very low background noise



Success:

Detection of the interferometric solar fringe



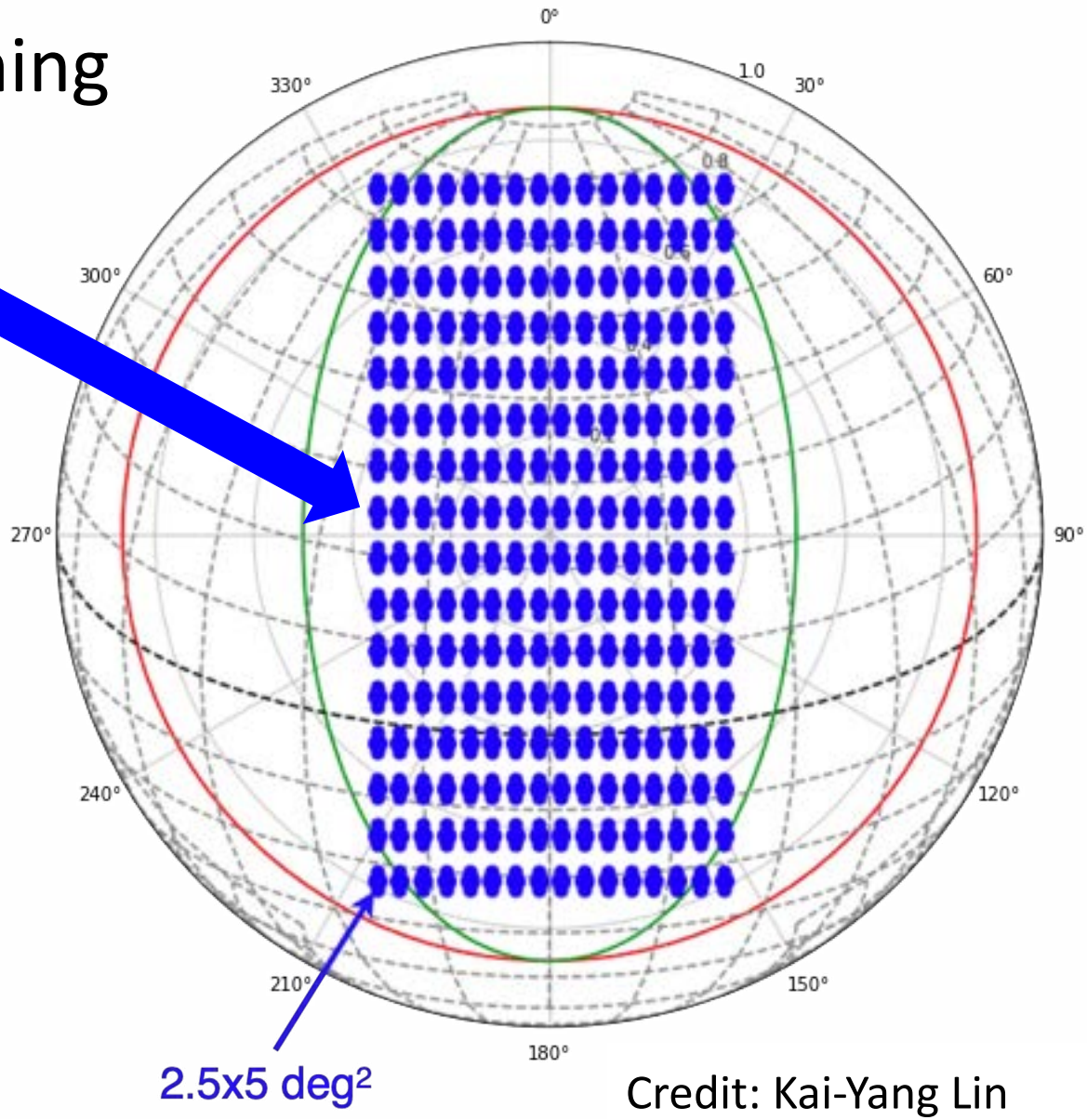
Credit: Sujin Eie

Sensitivity map (beamforming)

Real-time beamforming

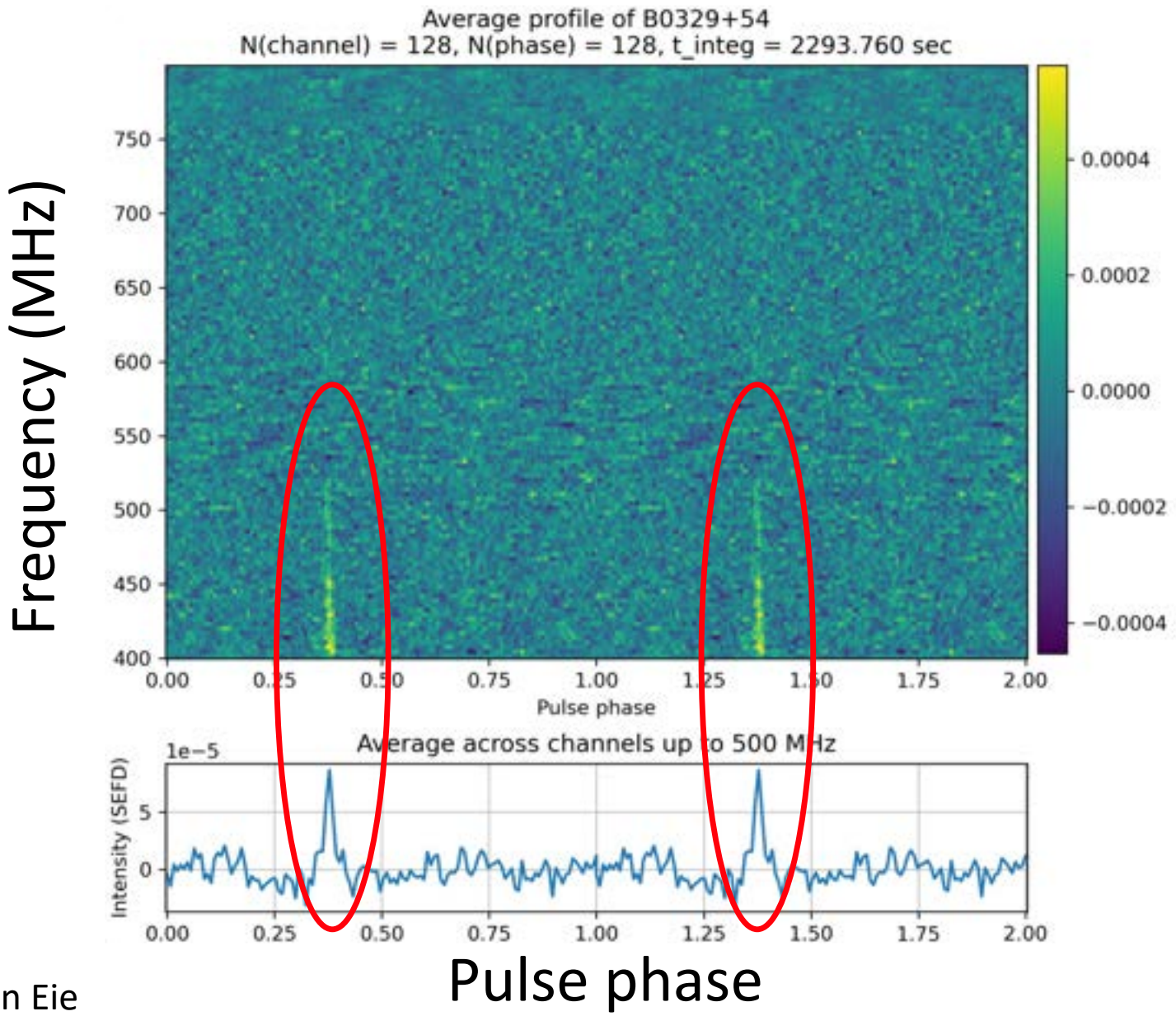
Goal in 2024:
256 beams with
256 antennas

Success:
16-antenna x 4 =
64 beams



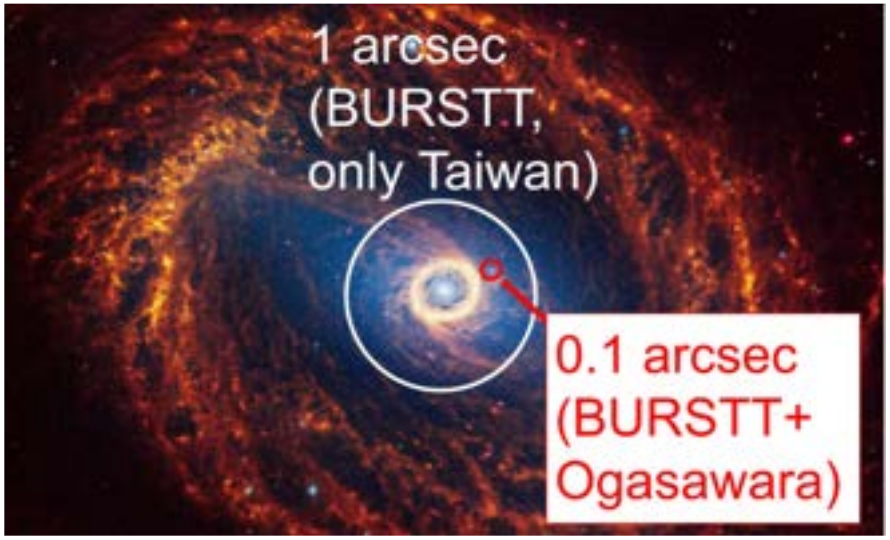
Credit: Kai-Yang Lin

Success: detection of a bright pulsar



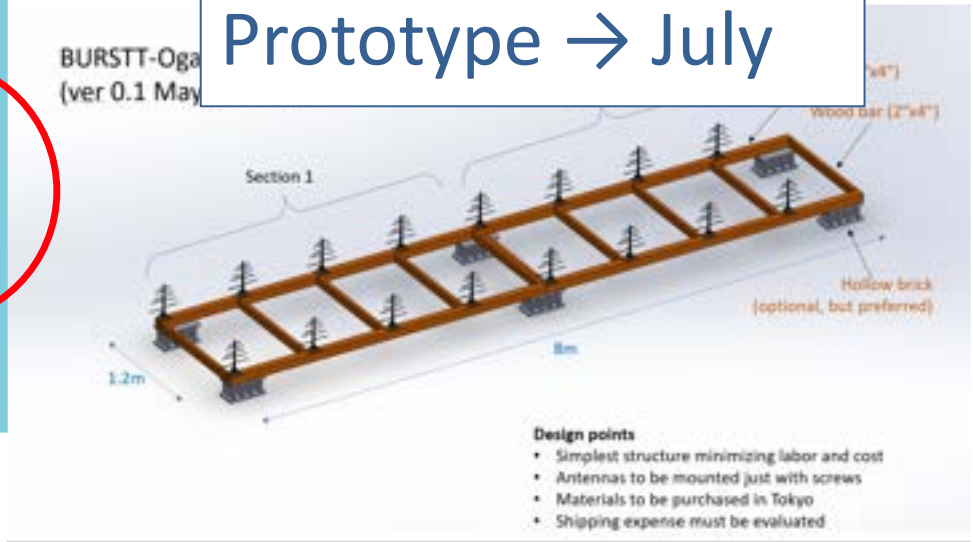
Credit: Sujin Eie

International collaboration (Japan)



Prof. Honma Mr. Masaoka

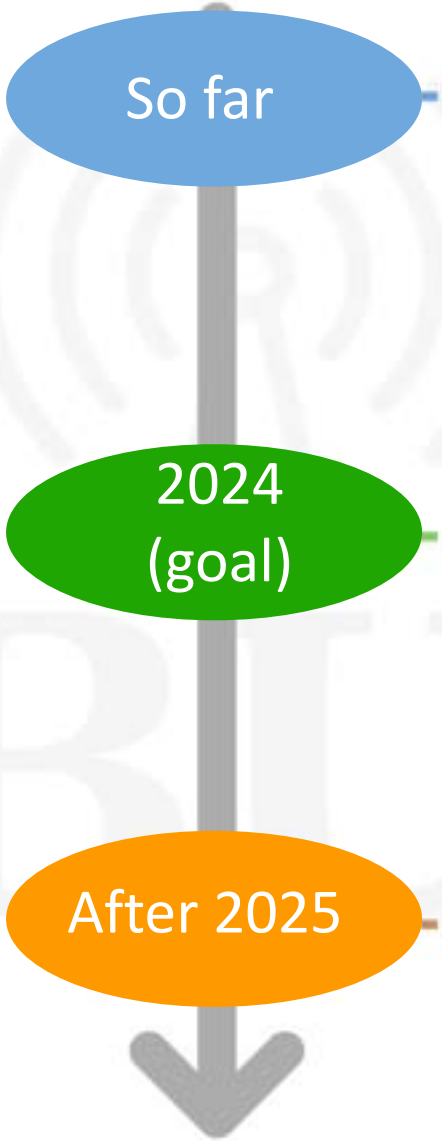
Prototype → July



International collaboration (India)

Testing interferometric observations (VLBI)

Where are we now?



BURSTT-256 (close) + 1 outrigger

- **256** antennas at the main station
  + 64, 16 antennas at two outrigger stations
- Real-time 2D beamforming with 64 antennas
- Testing VLBI with GPS timing

BURSTT-256 + 2(+) outriggers

- Beamforming with 256 antennas
- First BURSTT FRB
- ~100 localized FRBs/yr >> 40 (now)

BURSTT-2048* + 8(+) outriggers

- ~10 FRBs per day (10,000 FRBs for 3 years)

*2048 is our plan

BURSTT-256 is covered by Vanguard

Credit: Sujin Eie

Research and educational opportunities

International conferences 2023 and 2024

Construction

Media exposure

IIPP

Conclusion

- BURSTT: the first FRB telescope with an extremely wide field of view and the localization capability in the world
- BURSTT starts this year with ~100 localized FRBs per year
- FRB origin and cosmological probes such as missing baryons and cosmic expansion etc