Fast Radio Bursts

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NCTS-TCA Summer Student Program 2022 workshop, 5 July 2022

Outline

1. Introduction:

   FRBs and dispersion measure

2. The origin of FRBs

   2-1. Localization
   2-2. host galaxies
   2-3. number density of FRBs
   2-4. FRB classification

3. Applications of FRBs

   If time is allowed

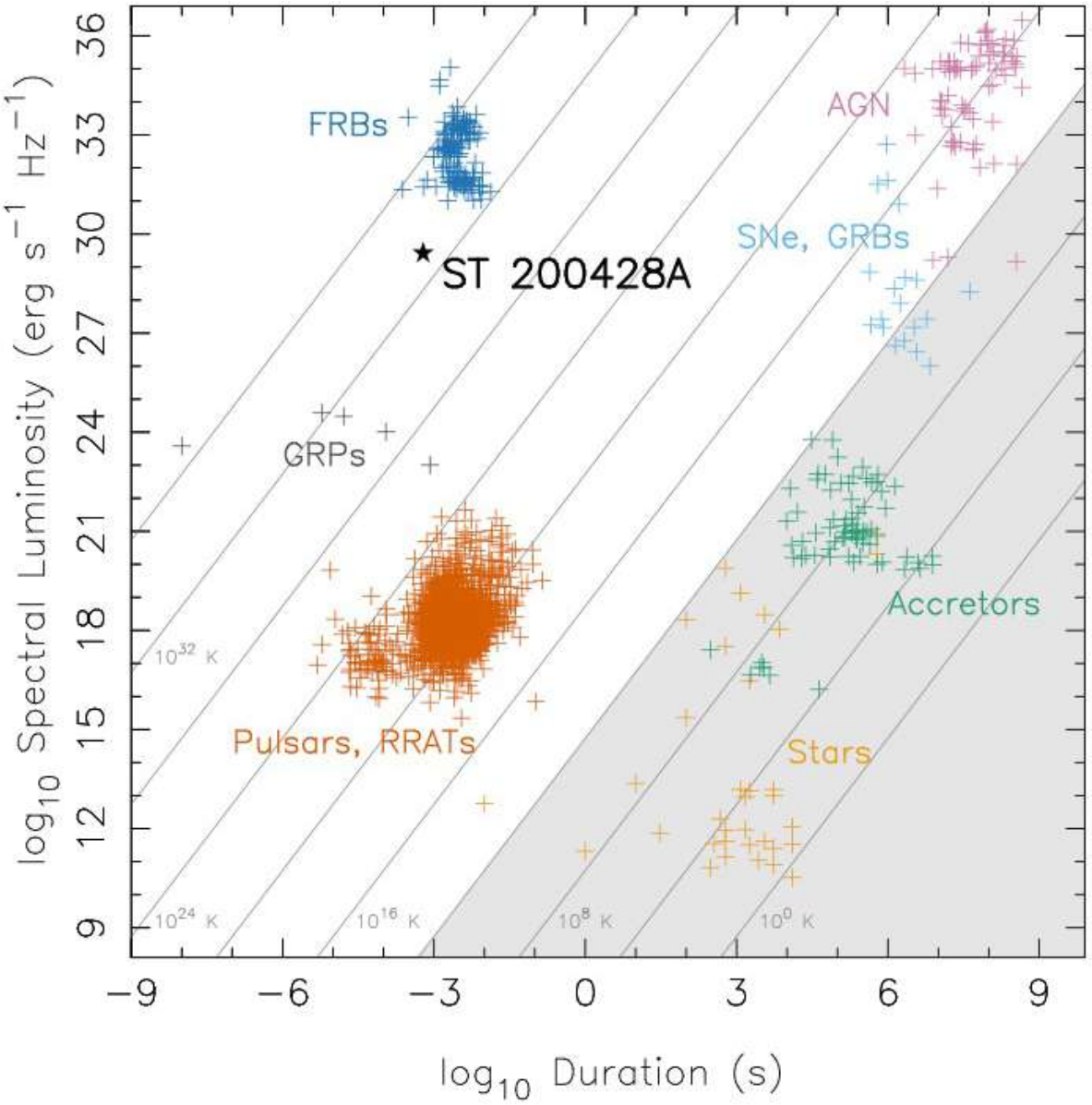
   3-1. missing baryon problem
   3-2. testing general relativity
   3-3. dark energy
   3-4. cosmic reionization

4. A new telescope plan in Taiwan: BURSTT


Optical
Credit: the Murchison Widefield Array (MWA)

Intro: Fast radio burst (FRB)

Intro: new parameter space

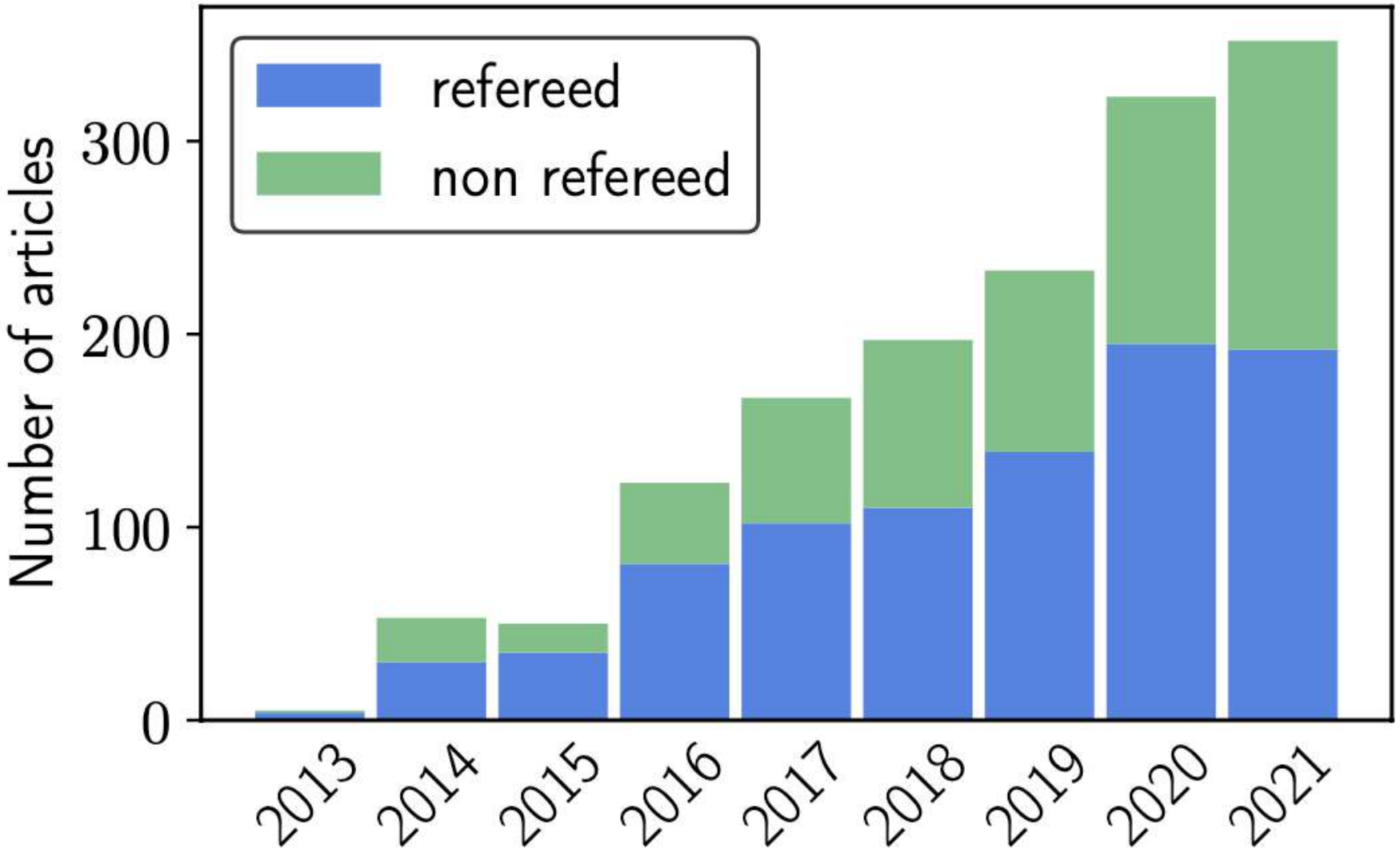


Bochenek et al 2020

Game changers!

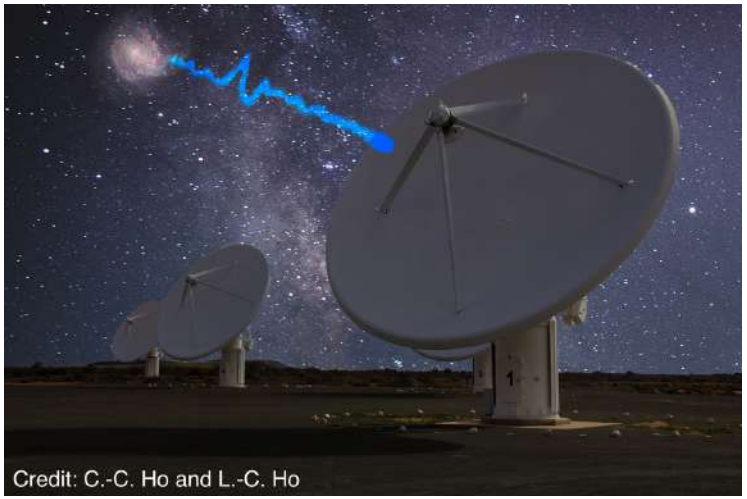
Intro: fast-growing field

Petroff et al. 2021

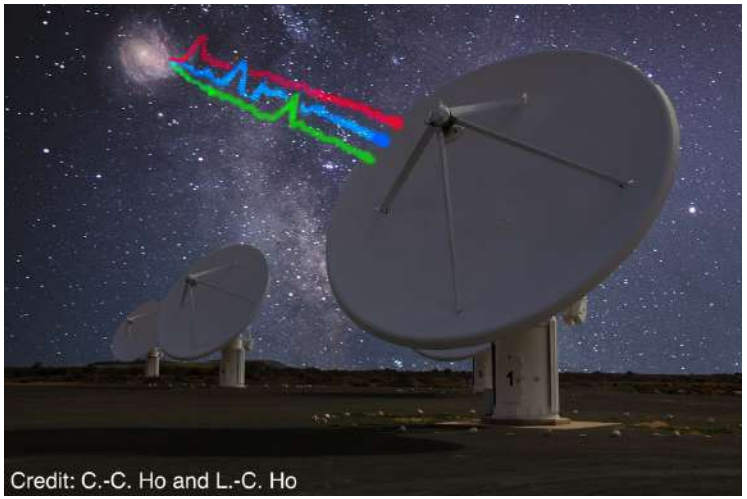


Intro: Two types of FRBs

Non-repeating FRBs



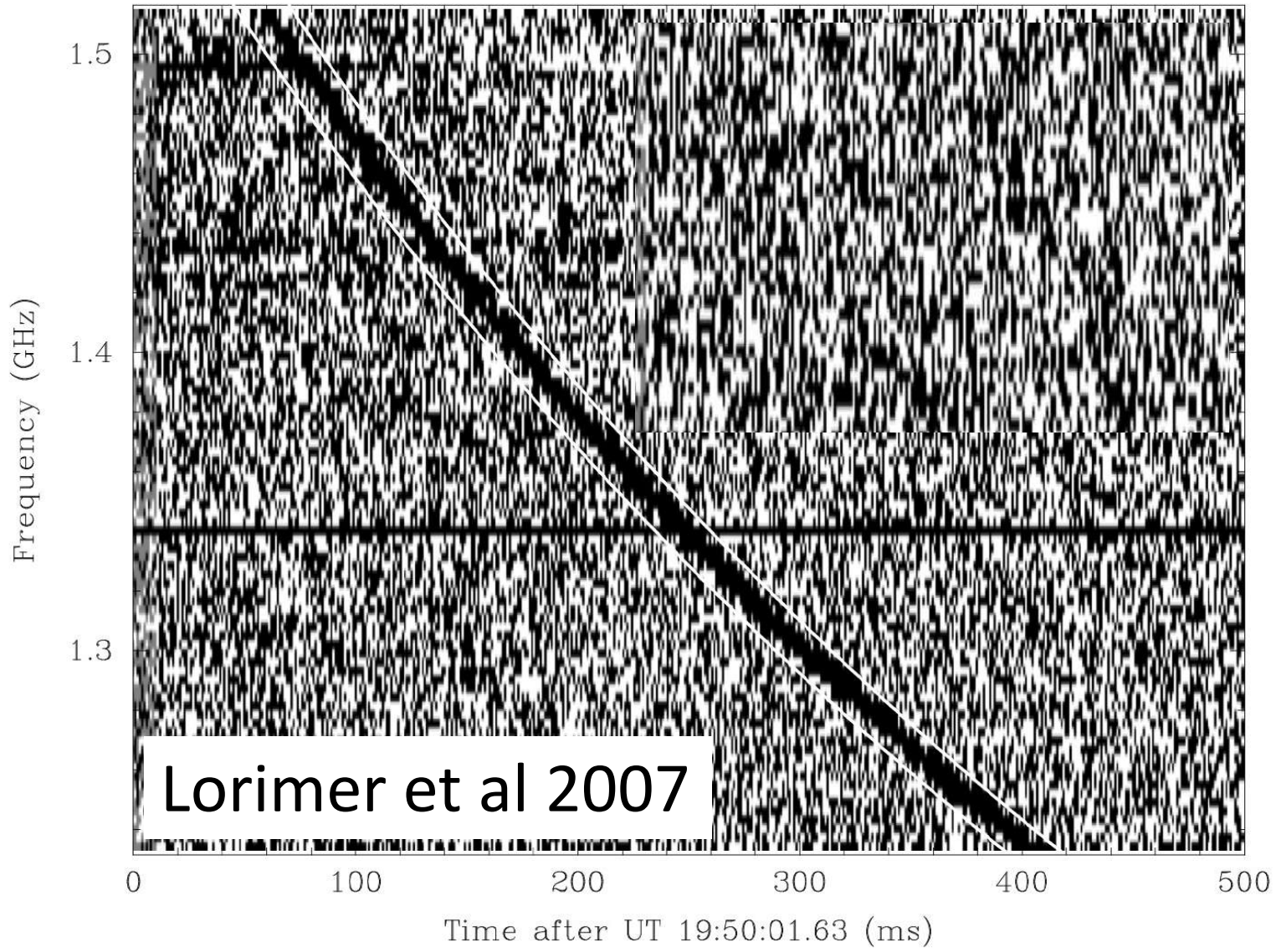
Repeating FRBs



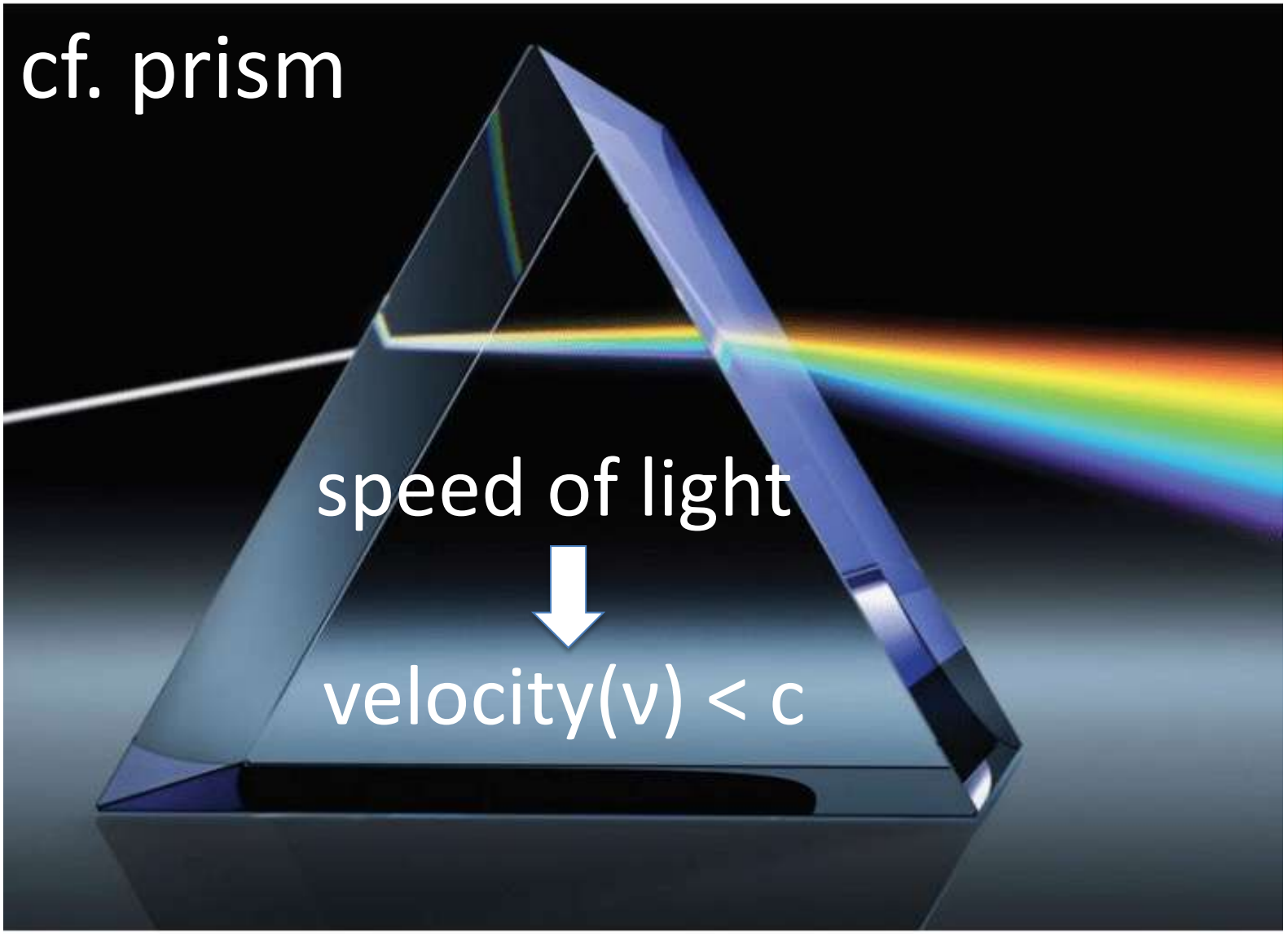
More than 1000 FRBs on sky every day!

Their origins are unknown

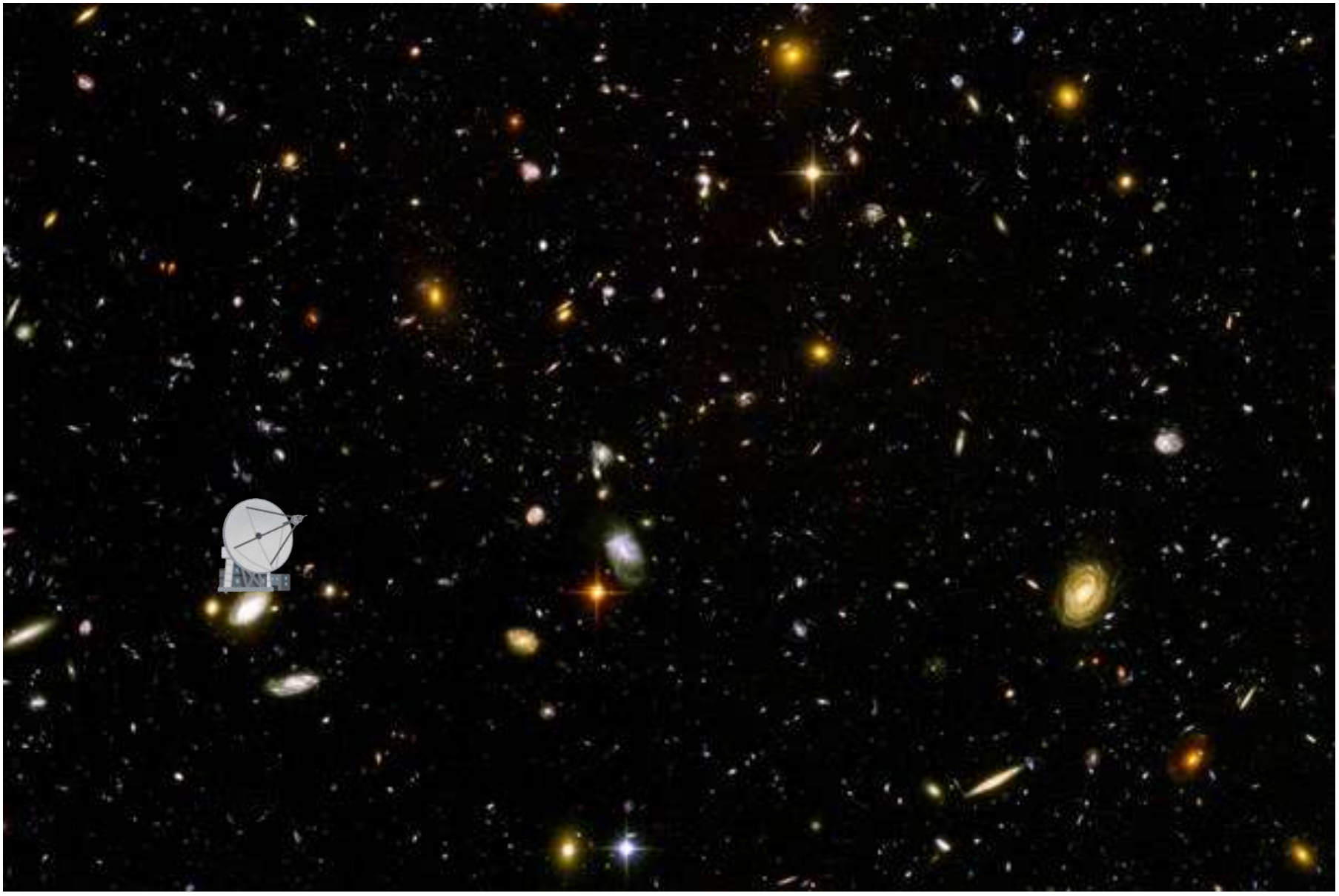
Intro: the detection of an FRB



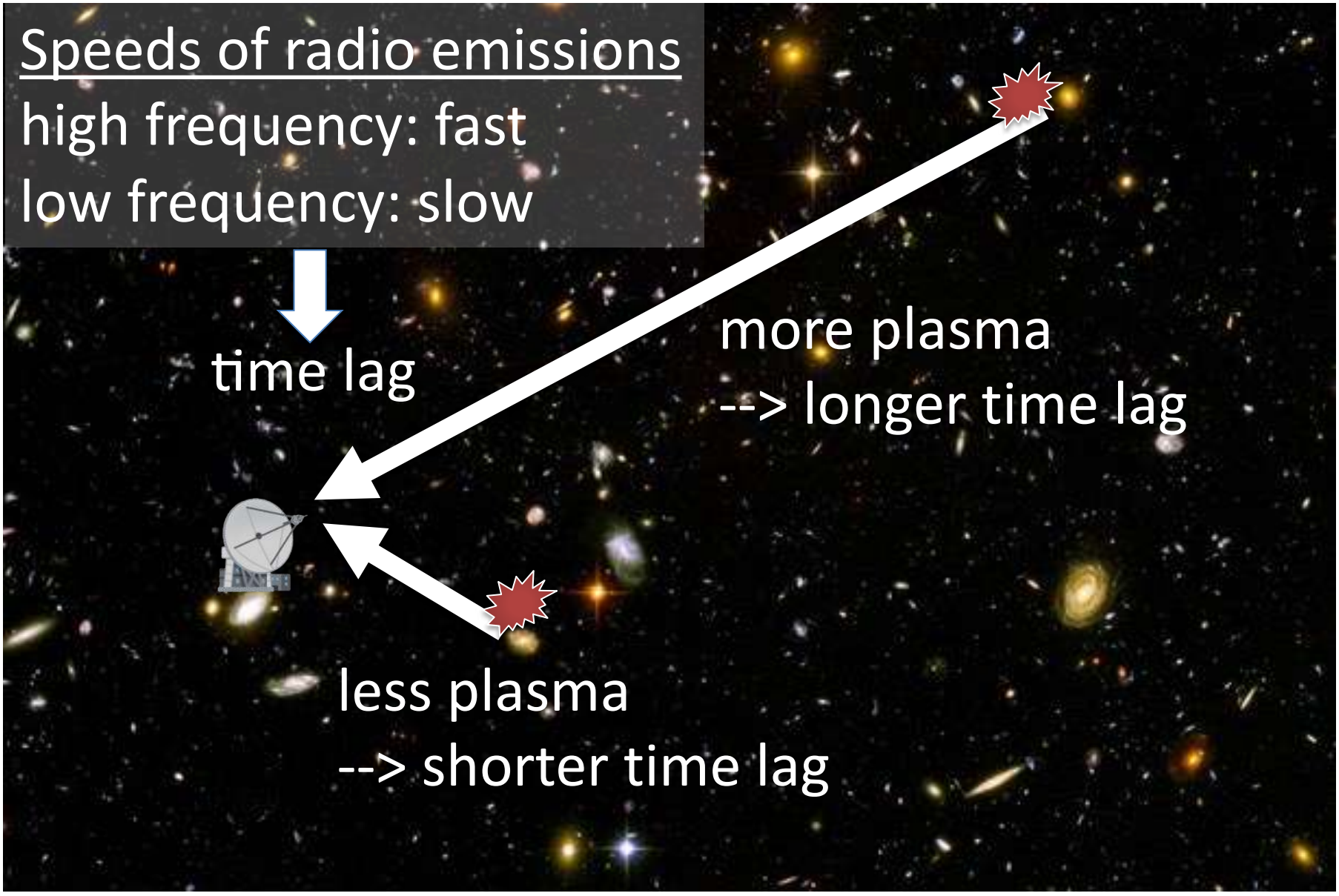
***Intro*: unique observable, 'dispersion measure'**



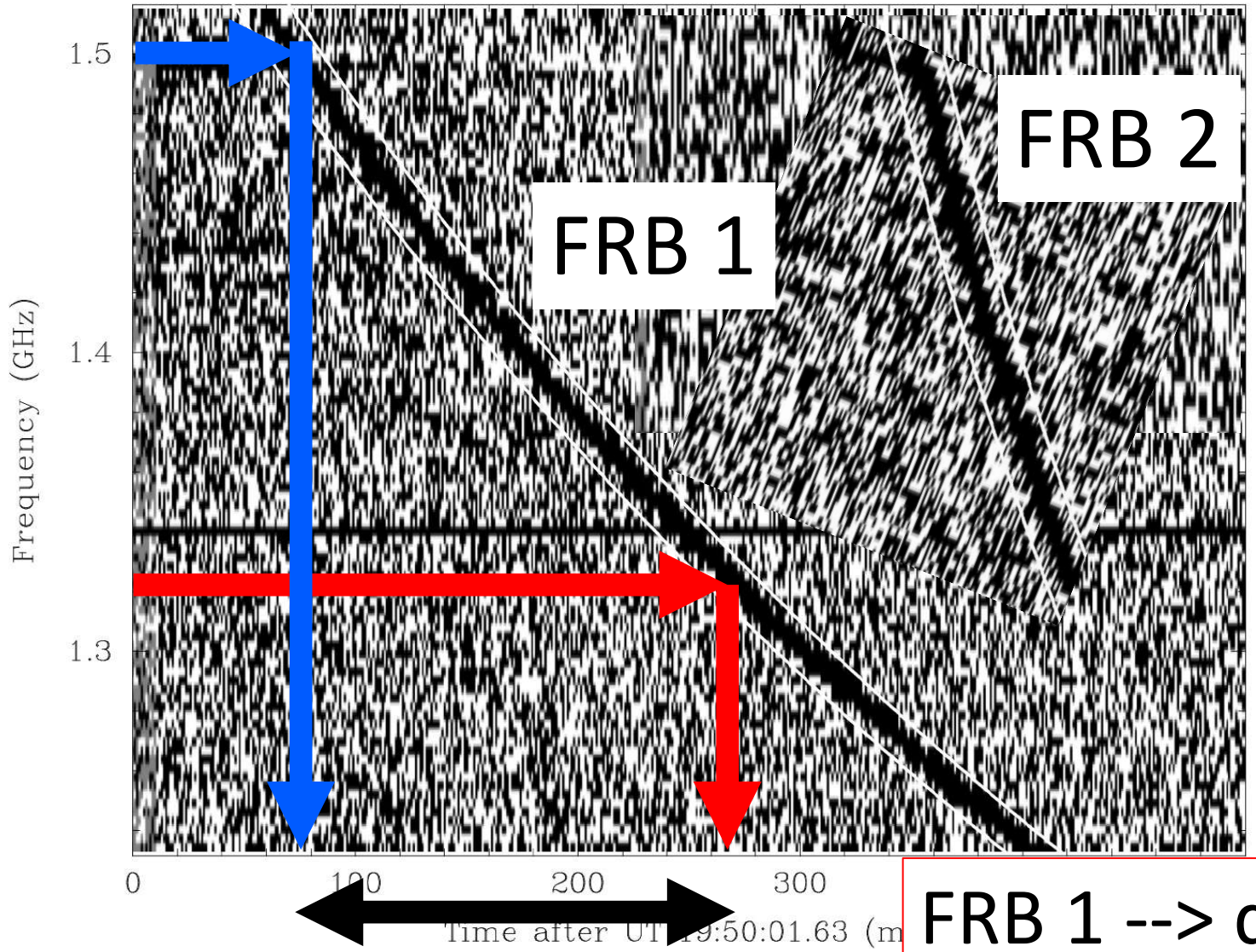
***Intro*: the Universe is filled with plasma**



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

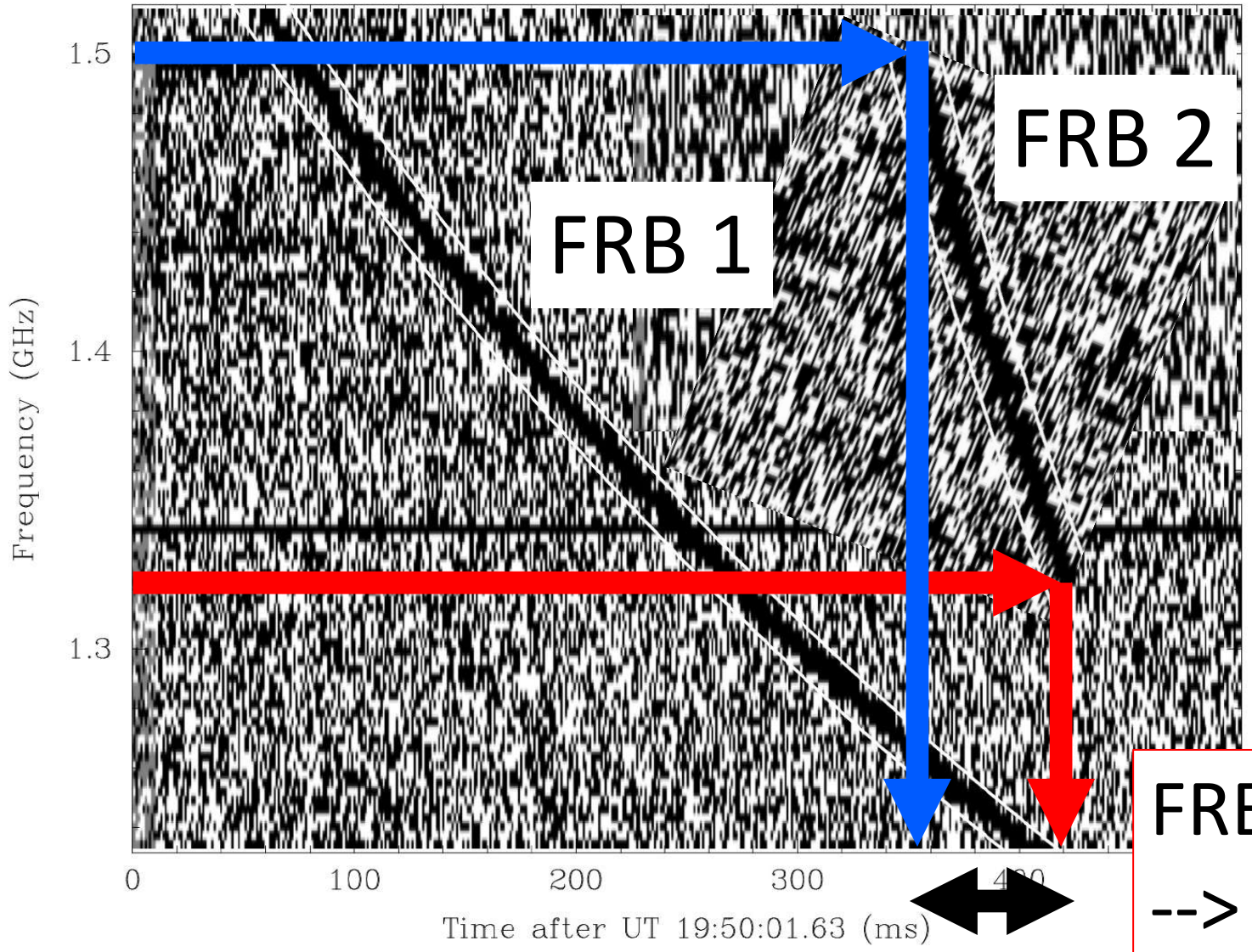


Intro: time lag = dispersion measure = distance indicator



FRB 1 --> distant

Intro: time lag = dispersion measure = distance indicator



2. The origin of FRBs

Origin: possible FRB origins

White dwarf

Old neutron star

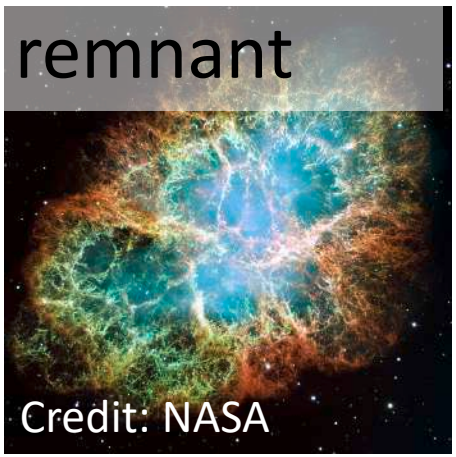
Old stellar-mass black hole (BH)

Magnetar

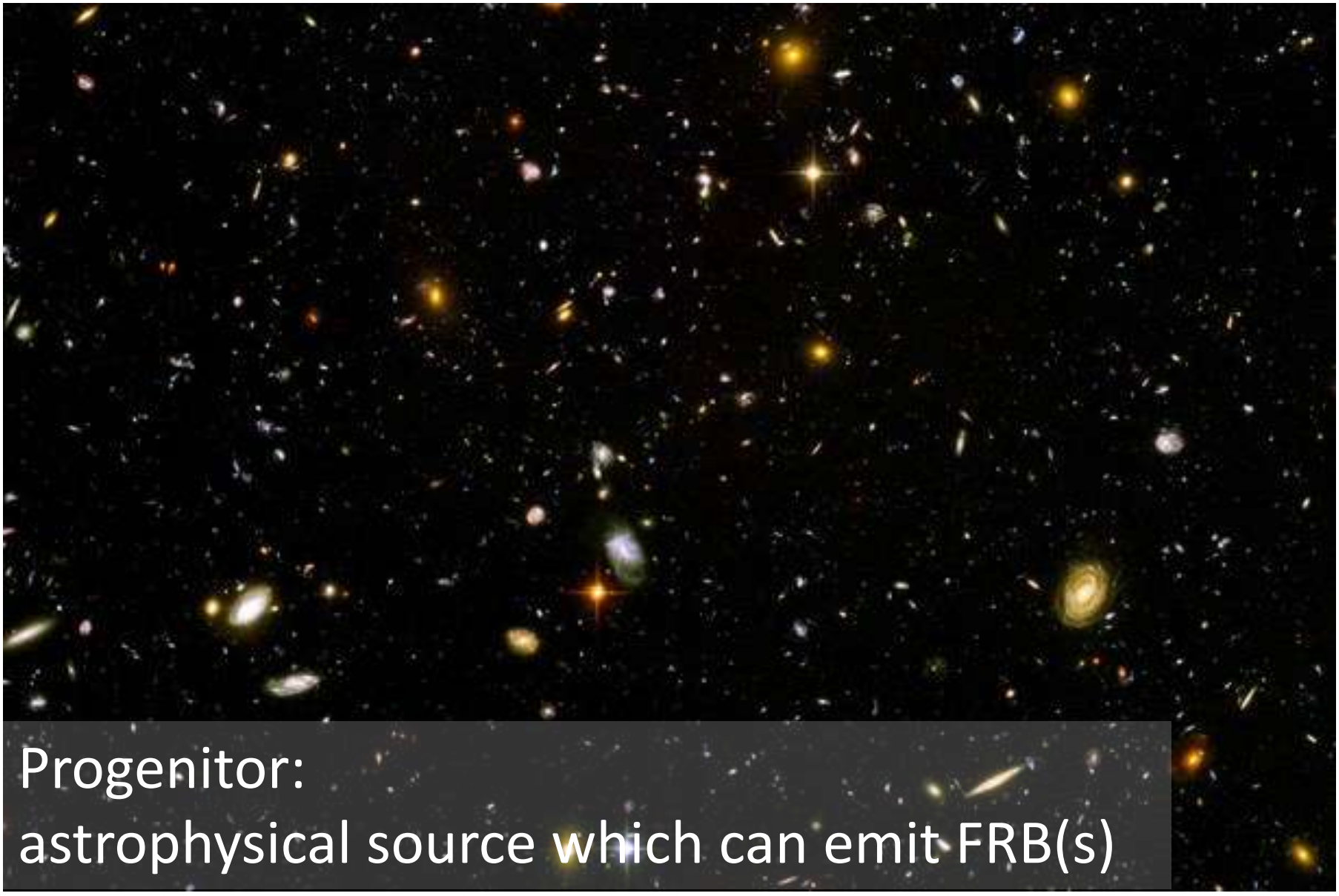
Young pulsar

Super massive BH

Supernova remnant



Origin: How can we identify the progenitor?



Progenitor:
astrophysical source which can emit FRB(s)

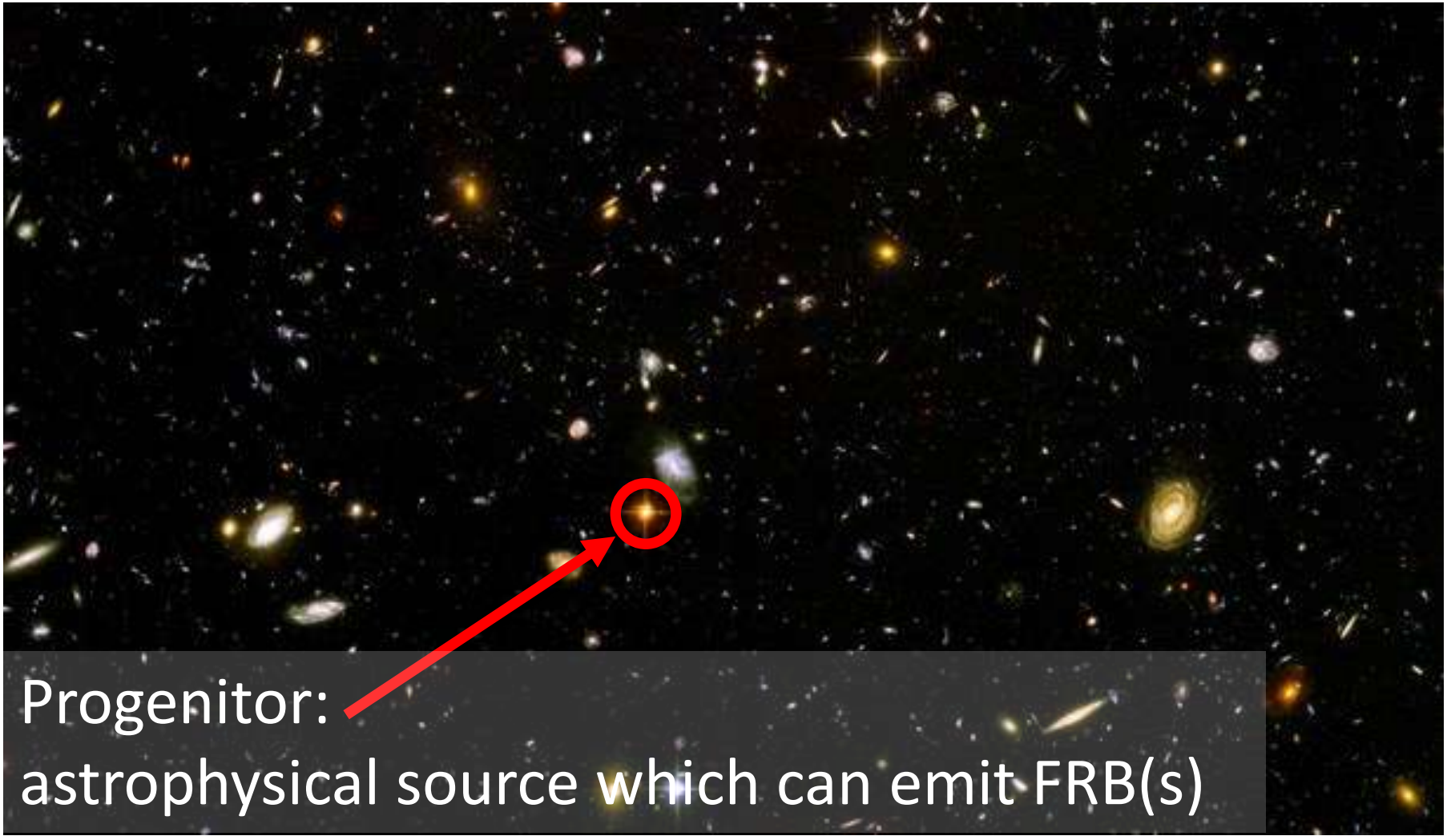
Origin: where does the FRB come from?

Positional uncertainty (cf. CHIME)

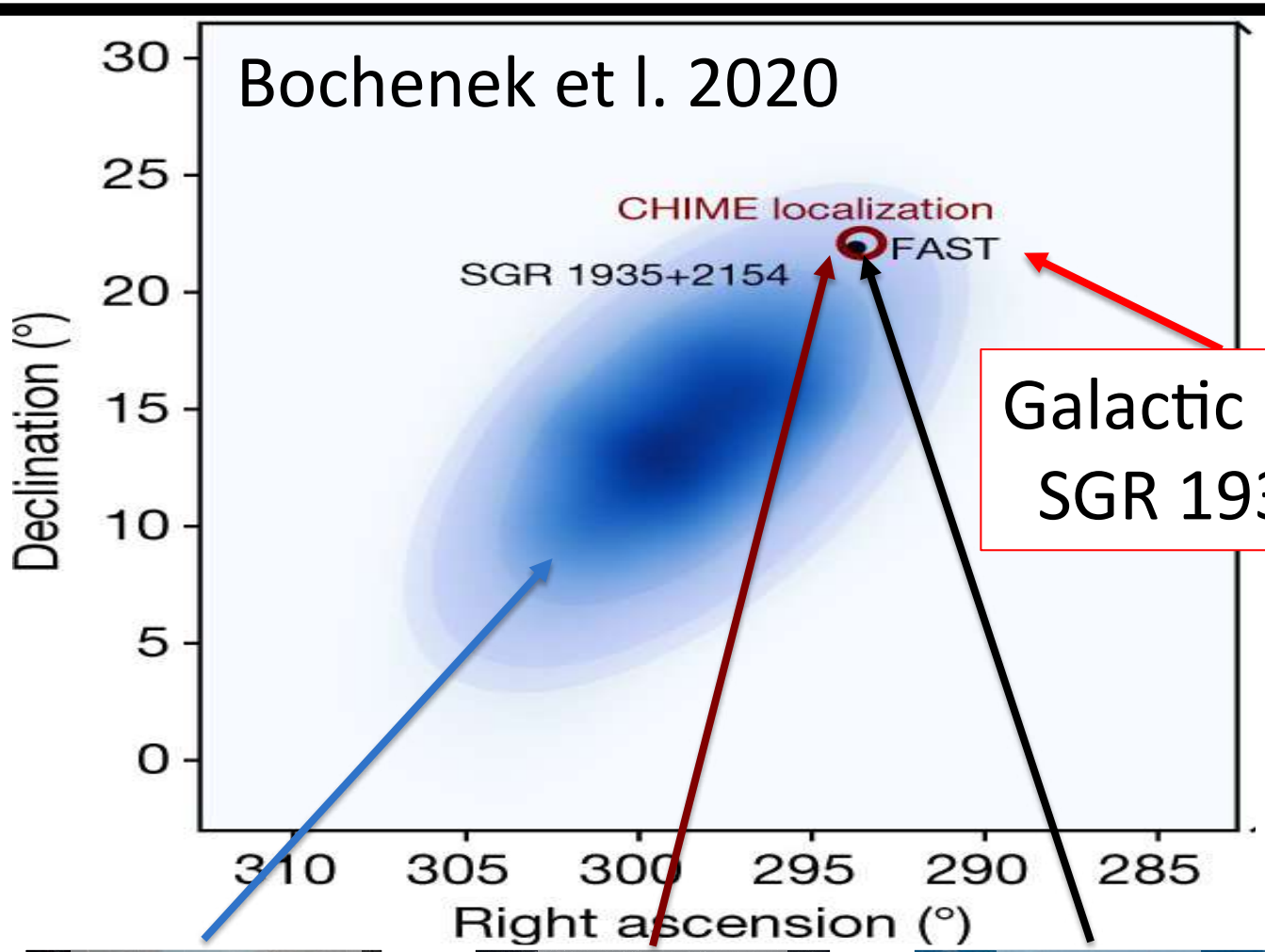
Progenitor:
astrophysical source which can emit FRB(s)

Origin: the localization identifies the progenitor

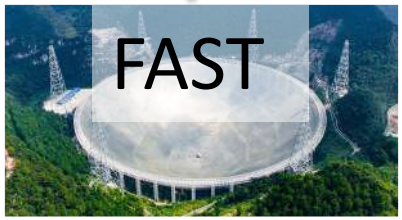
Localization (cf. interferometric obs.)



Origin: the localized FRB at a Galactic magnetar

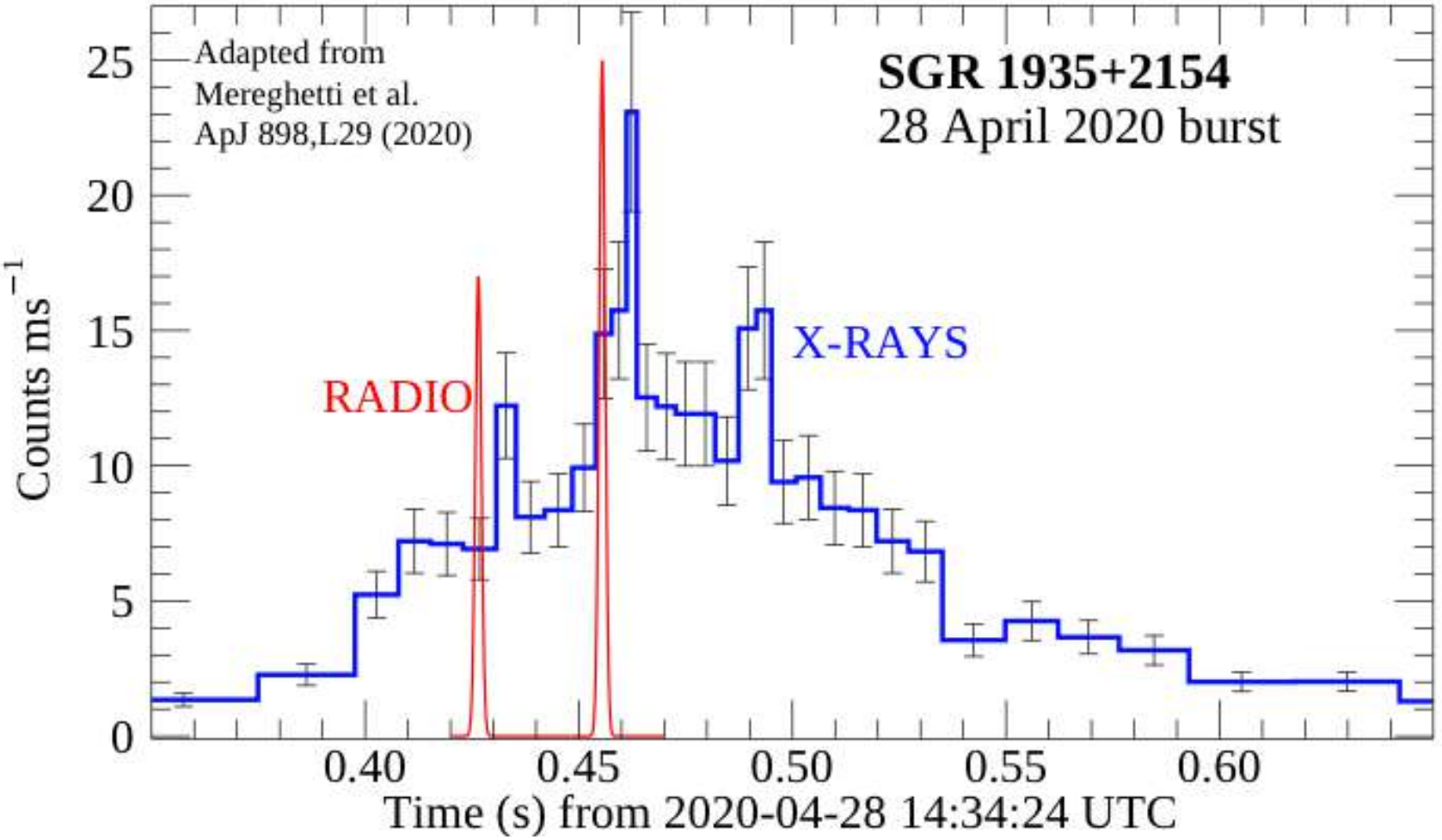


Galactic magnetar
SGR 1935+2154



Origin: the localized FRB at a Galactic magnetar

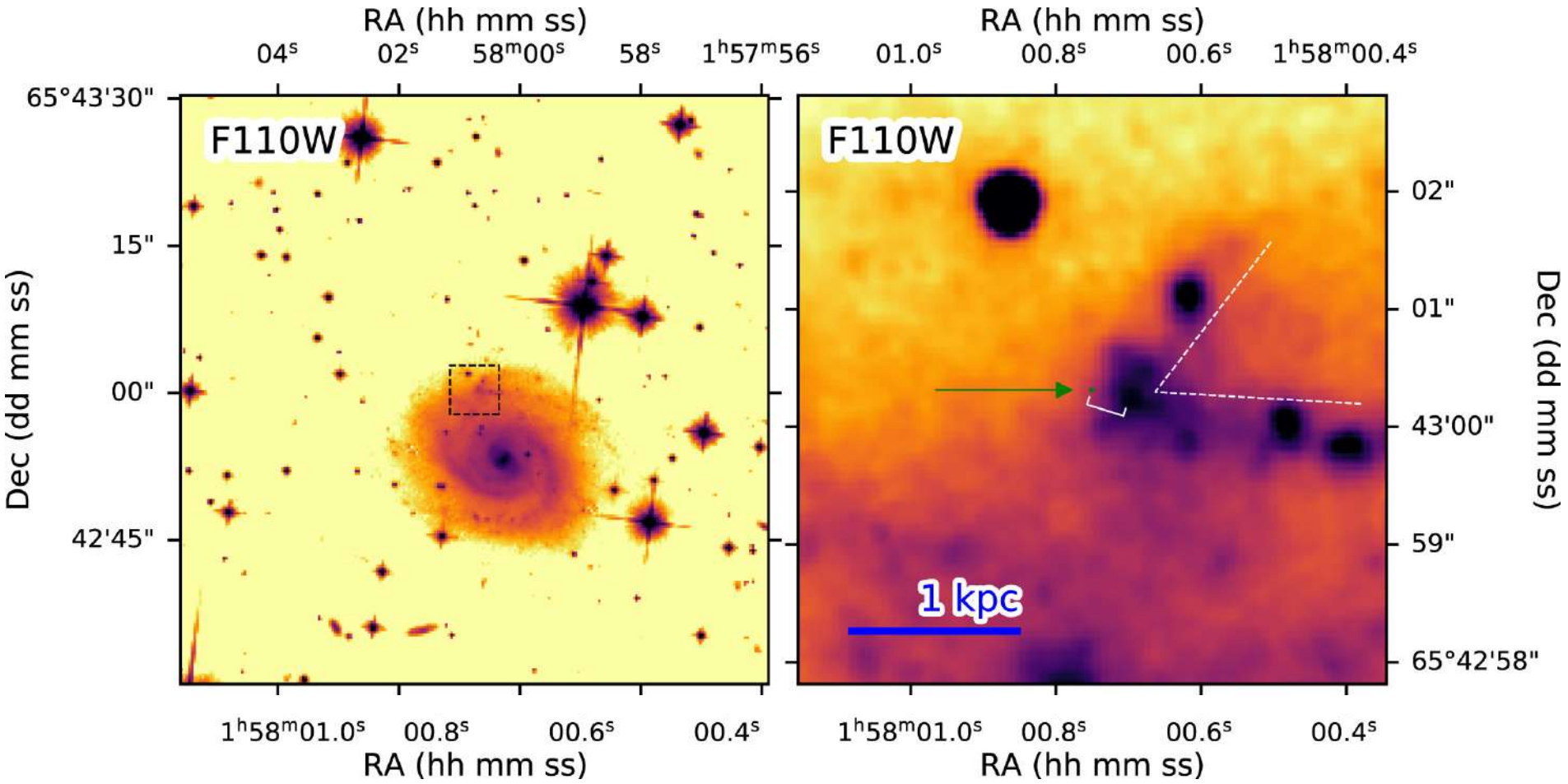
Mereghetti et al. 2020



Problem: no more ‘direct’ confirmation of the FRB progenitor

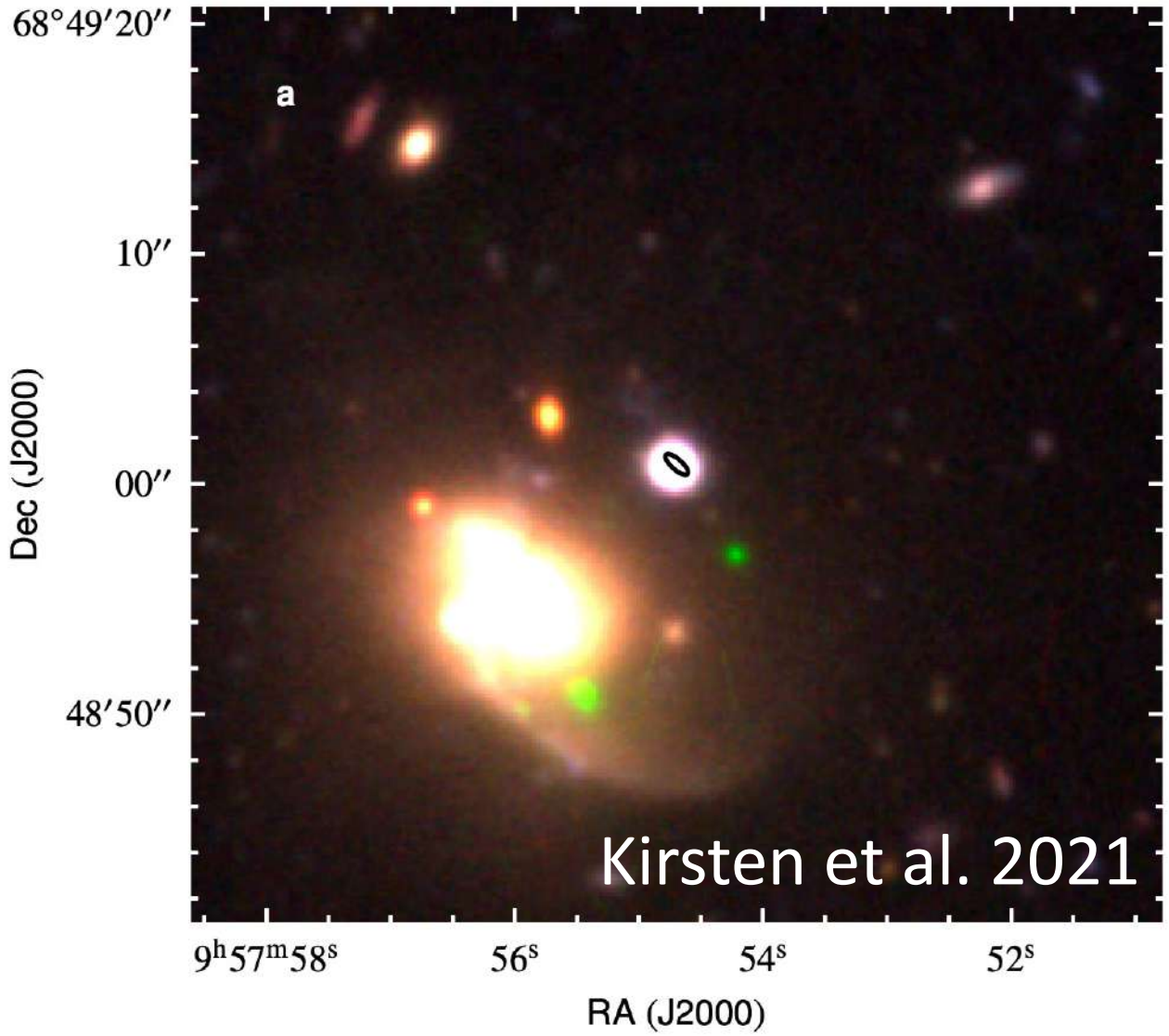
Origin: an extragalactic repeating FRB source localized at a star-forming region

Tendulkar et al. 2021



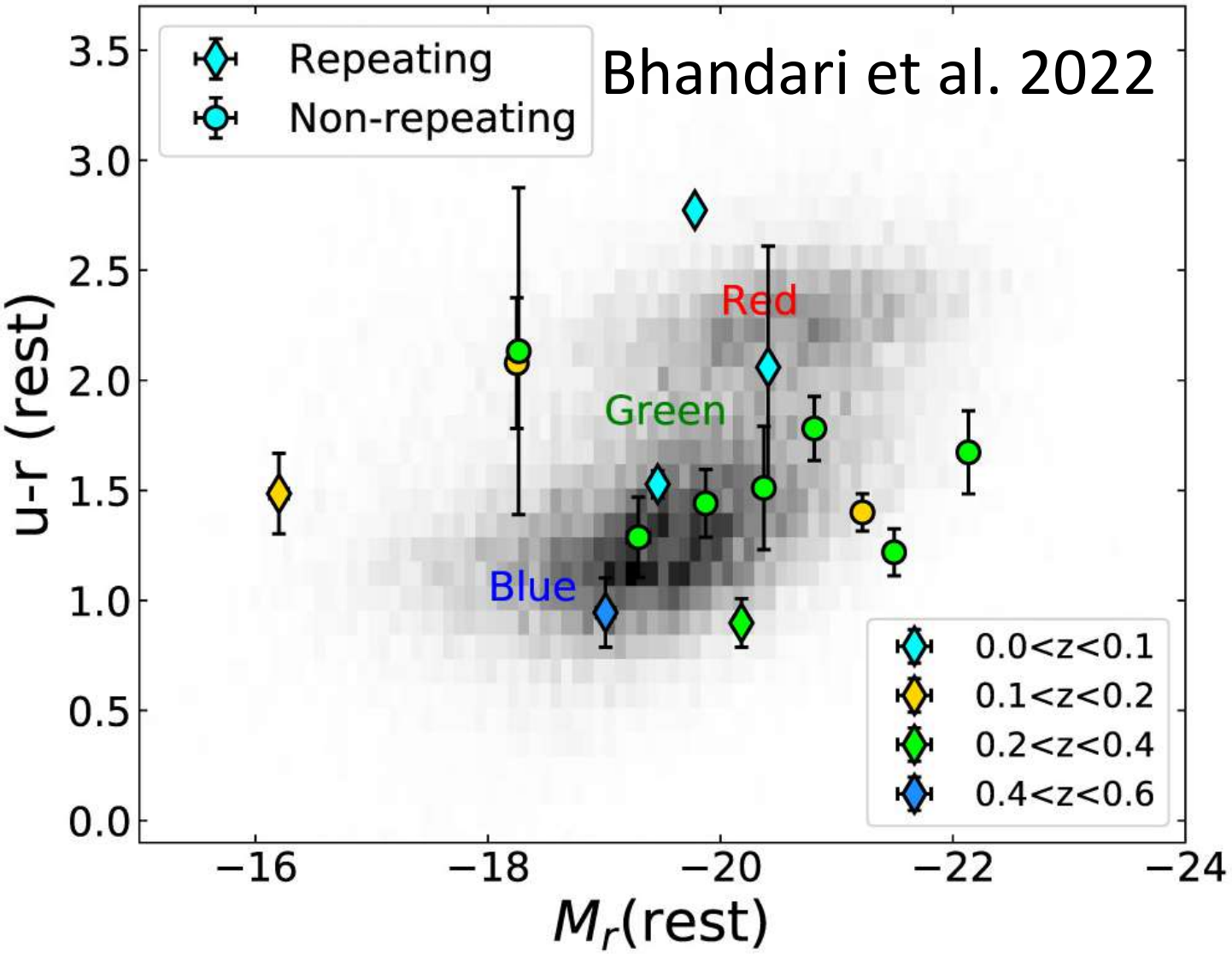
FRB 20180916B --> star-forming region

Origin: an extragalactic repeating FRB source localized at a globular cluster



FRB 20200120E --> globular cluster (old stellar system)

Origin: FRB host galaxies: FRBs happen in any type of galaxies(?)



Problem: only ~20 host galaxies identified so far

Problem

Previous research: tried to 'localize' FRB positions in the sky to reveal their origins

→ didn't work well

Solution (this work)

We changed the point of view

→ focus on the history of FRBs

(x10 more samples than before)

Origin: possible FRB origins

White dwarf

Old neutron star

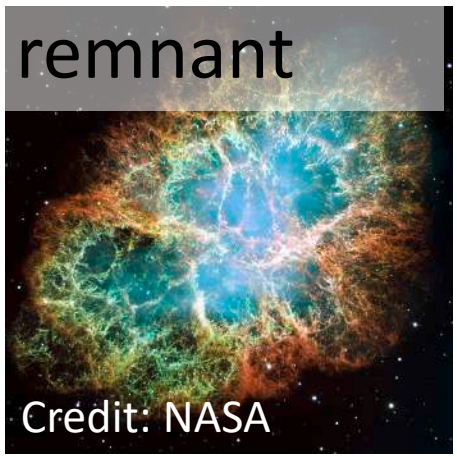
Old stellar-mass black hole (BH)

Magnetar

Young pulsar

Super massive BH

Supernova remnant



Origin: possible FRB origins

White dwarf

Old neutron star

Old stellar-mass black hole (BH)

Old objects ∝ stellar mass

Credit: Tetsuya Hashimoto

Credit: Mark Garlick

Credit: B. Kiziltan/ I. Karacan.

?

Magnetar

Young pulsar

Super massive BH

Supernova remnant

Young objects ∝ star formation

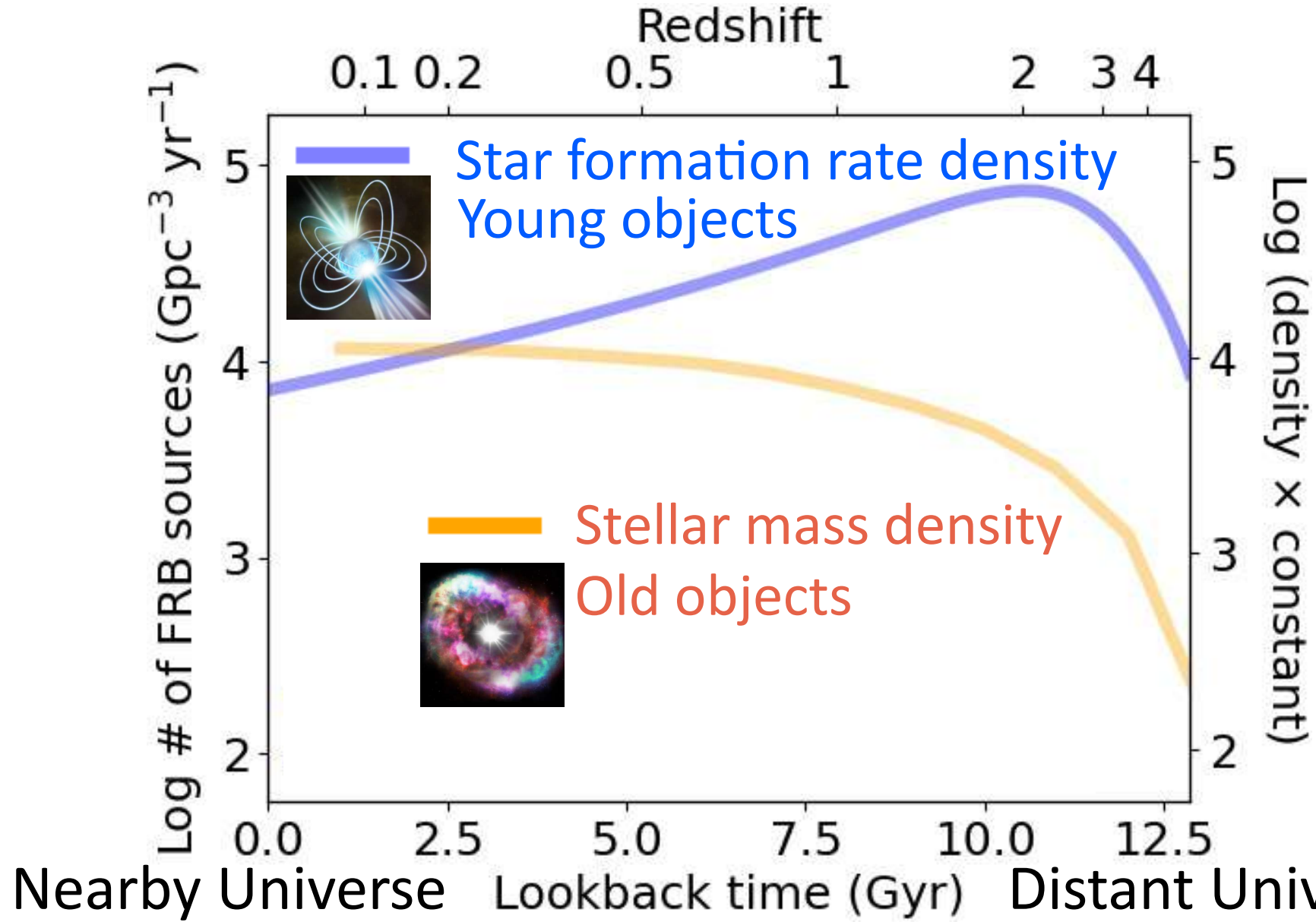
Credit: Tetsuya Hashimoto

Credit: Nature astronomy

Credit: MIT Kavli

Credit: NASA

Origin: Old vs Young

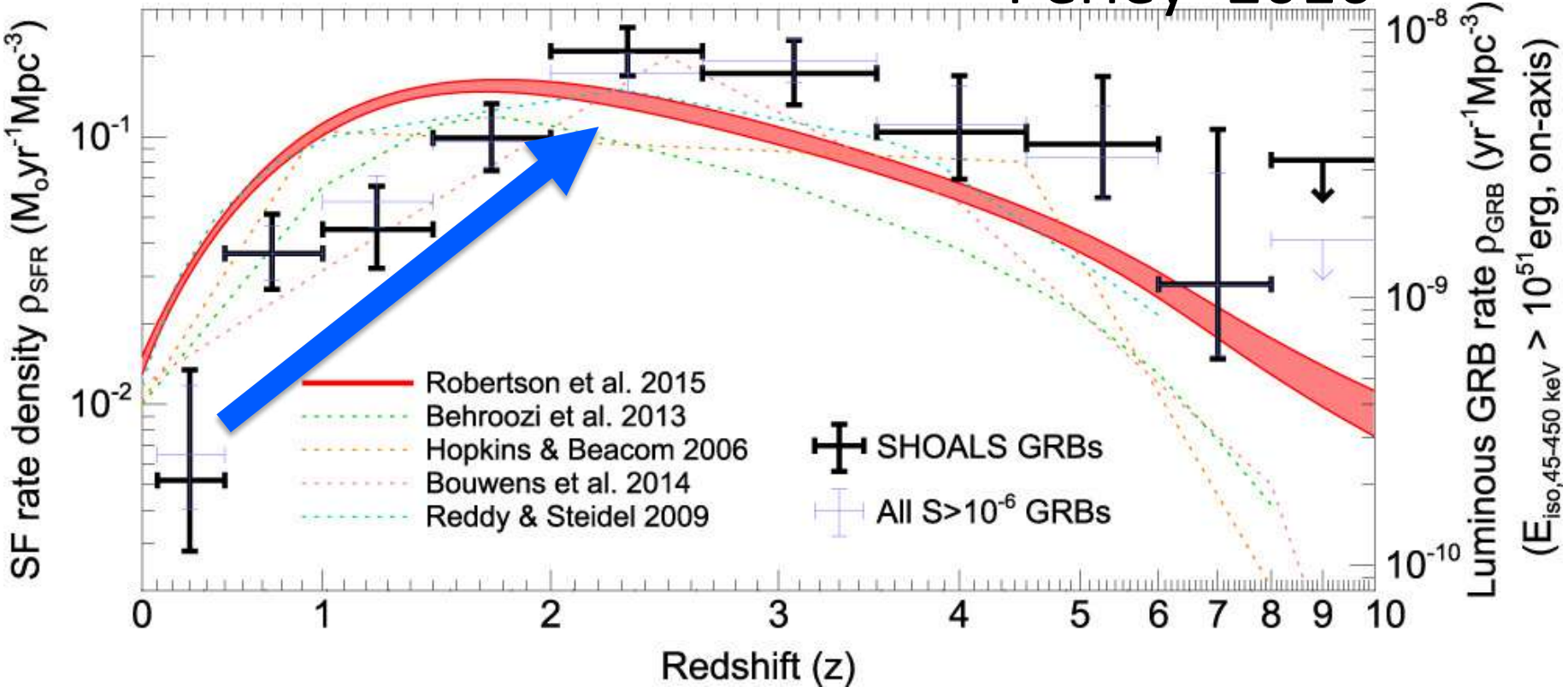


Origin: example (LGRBs)

Long Gamma-ray bursts

∝ star formation

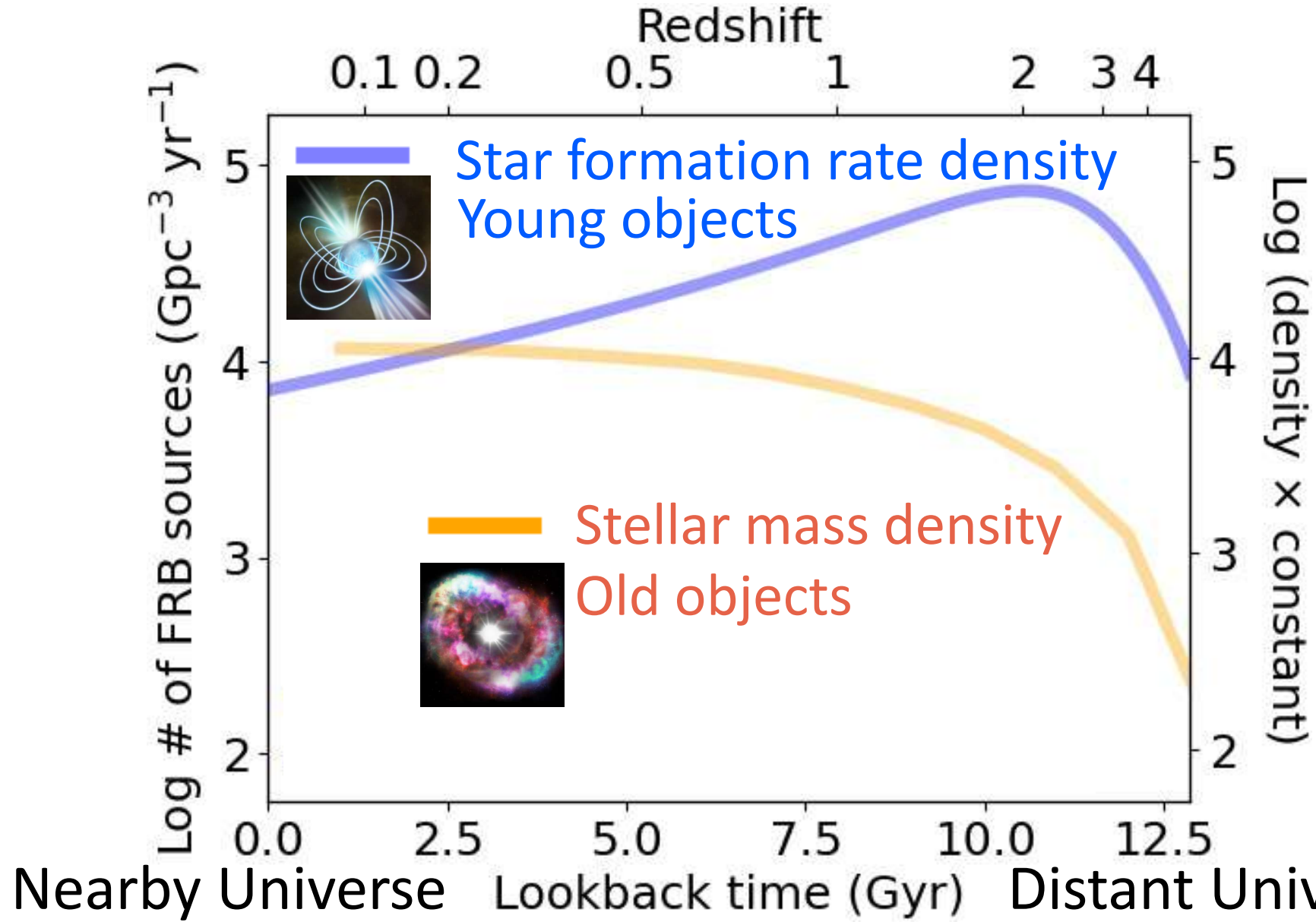
Perley+2016



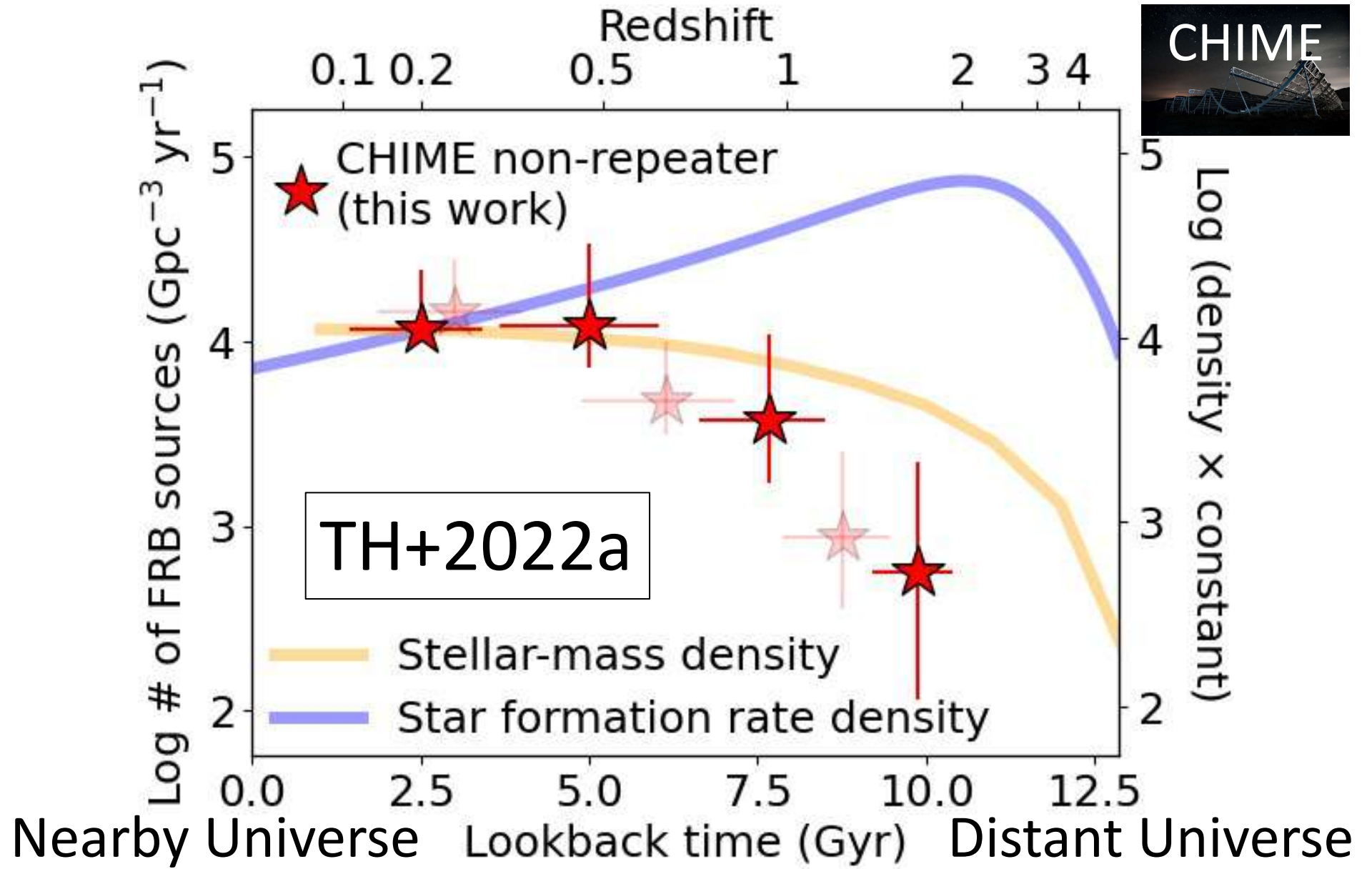
Origin: Let's see the answer!

CHIME: ~500 non-repeating FRBs in 2021!

Origin: Old vs Young



Our result: Non-repeater → Old



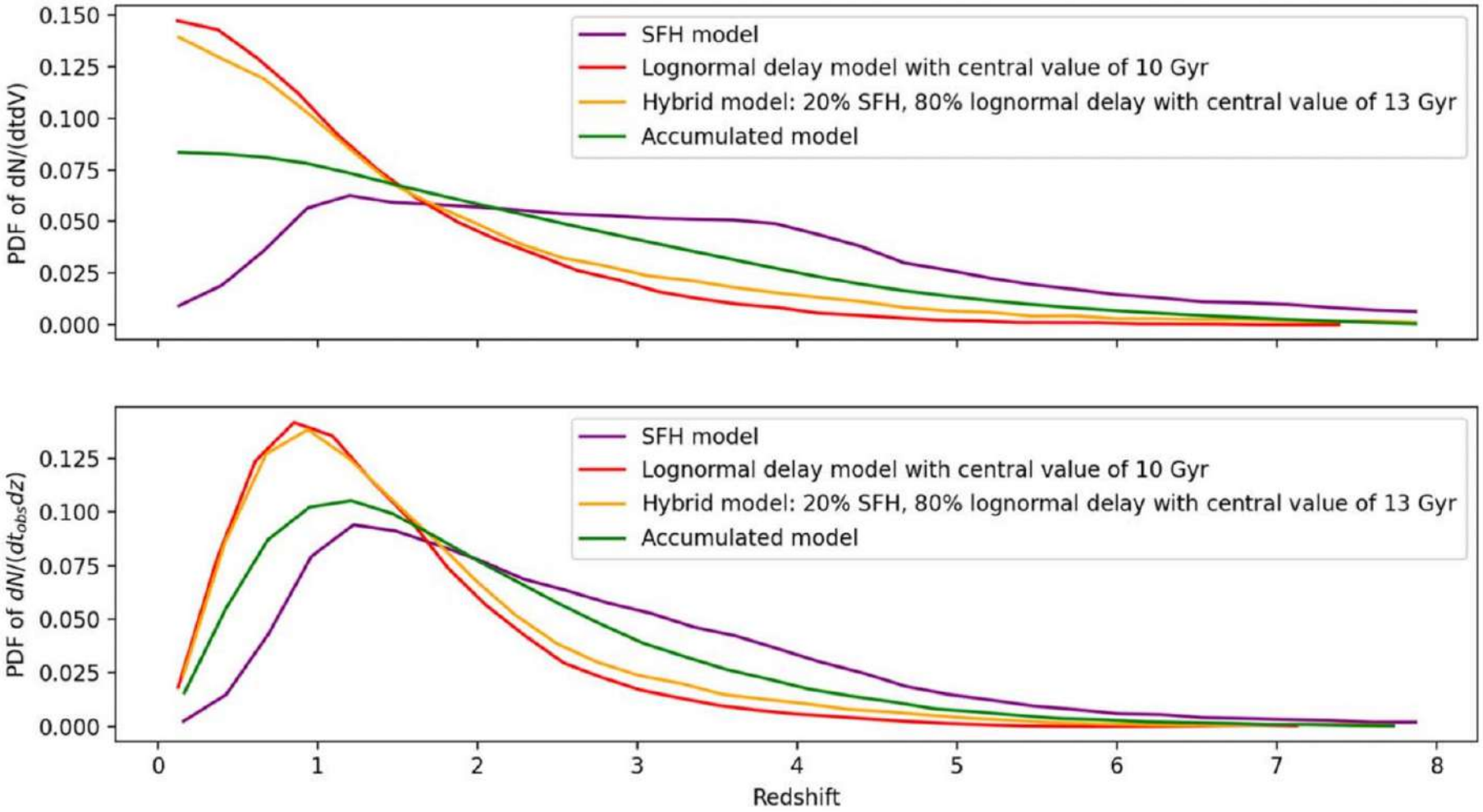
Origin: other FRB population analyses

Author	free from the z-evolution assumption?	test an old population scenario?	sample	homogeneous sample?	conclusion
TH+2022a	Yes	Yes	CHIME	Yes	Old pop.
Zhang&Zhang 2022	No	Yes	CHIME	Yes	Old pop.
James+2022	No	No	ASKAP/Parkes	No	Young pop.
Arcus+2021	No	Yes	ASKAP/Parkes	No	Both young and no-evo pops.
Zhang+2021	No	Yes	ASKAP/Parkes	No	Both pops.
TH+2020c	Yes	Yes	Parkes	Yes	Old. pop.

Origin: FRB population model

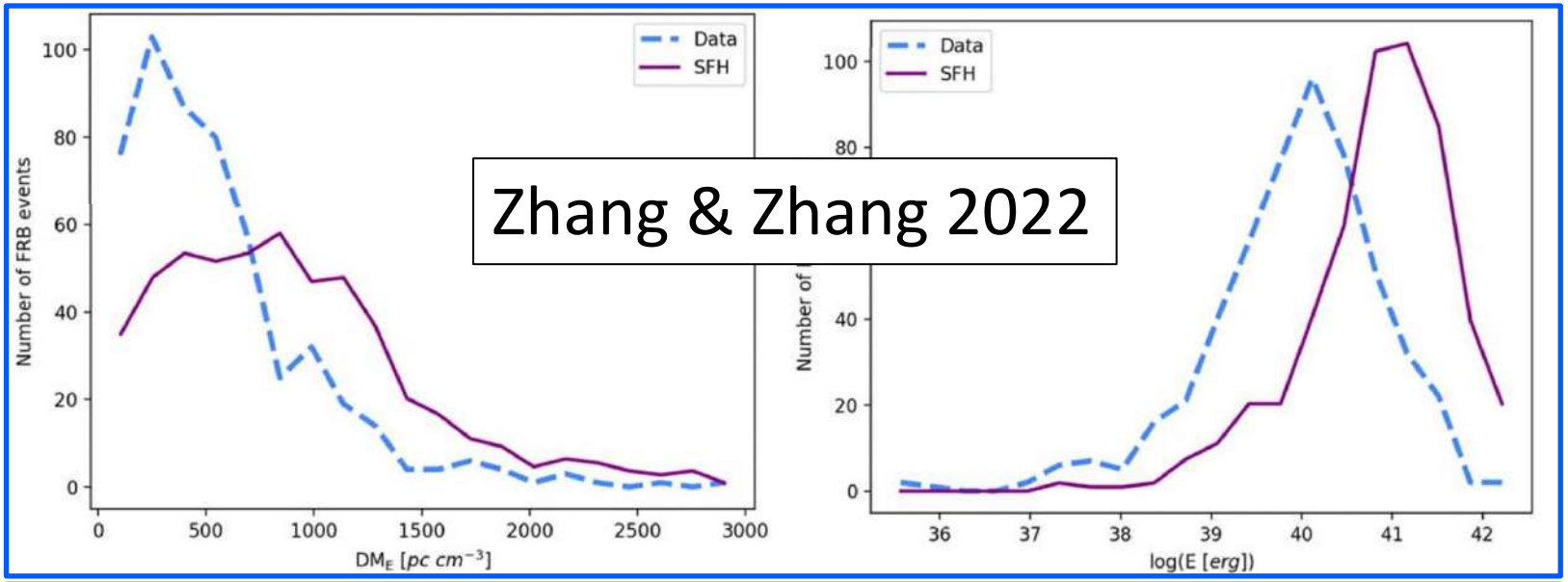
$$dN/dE \propto E^{-\alpha}$$

Zhang & Zhang 2022



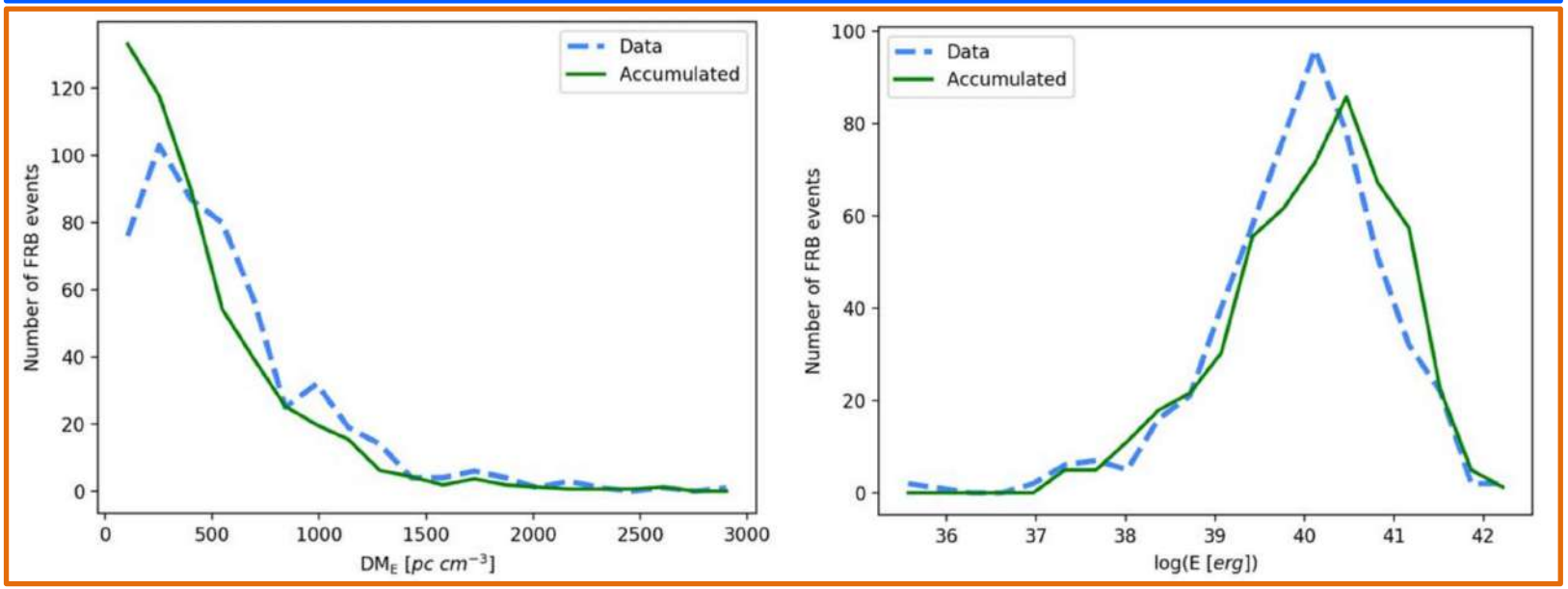
Origin: the stellar-mass scenario better explains

Star formation



Zhang & Zhang 2022

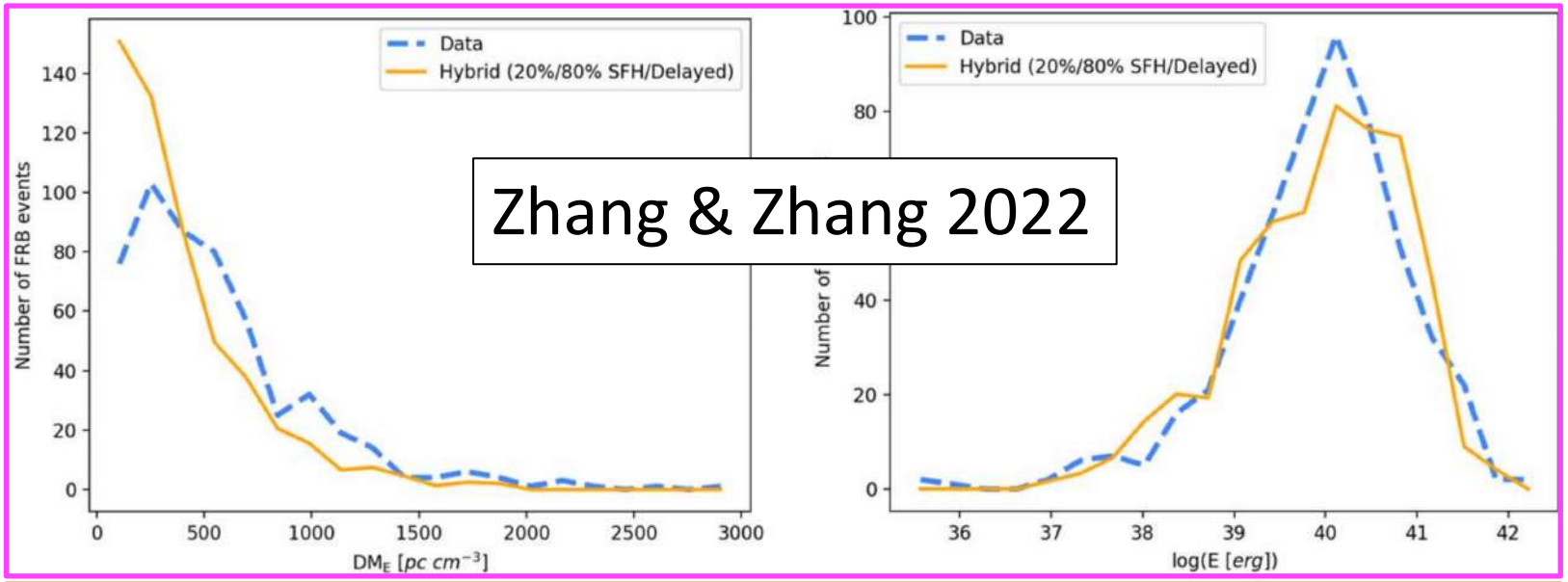
Stellar mass



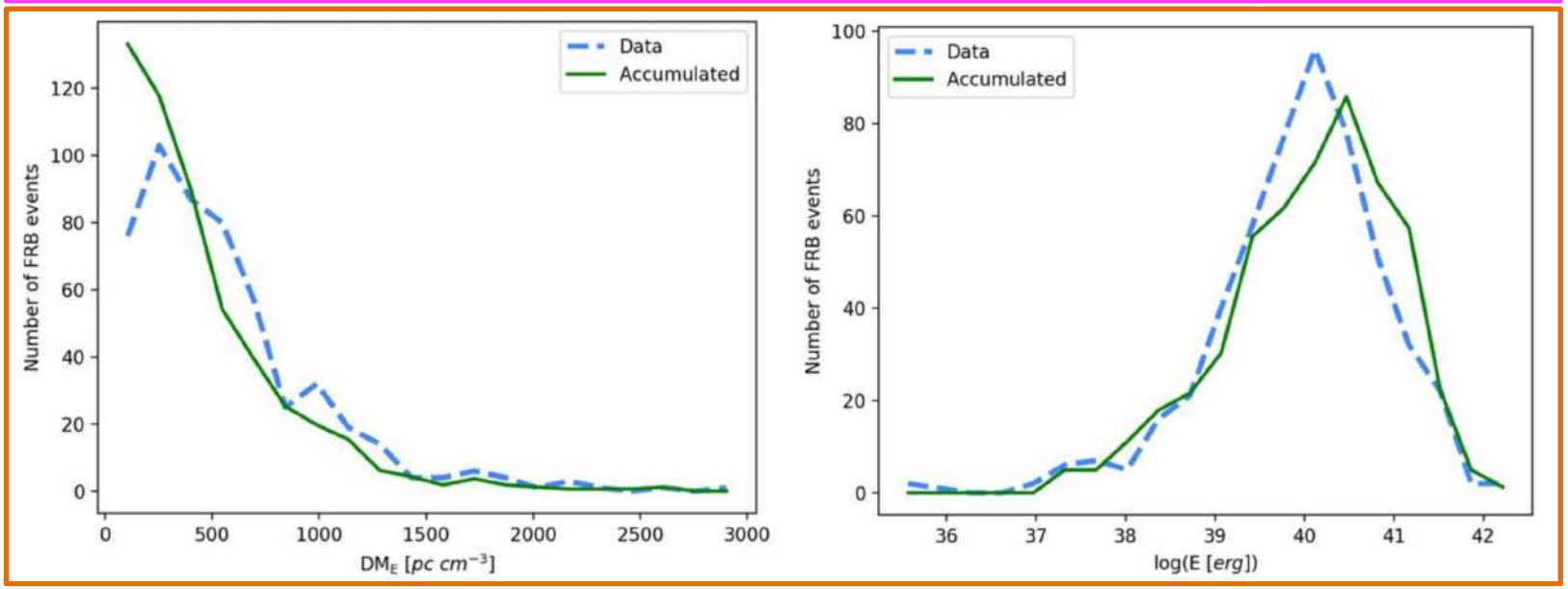
Origin: including the old population better explains

Hybrid

Stellar mass



Zhang & Zhang 2022



Conclusion

TH+2022a

x10 more samples than before

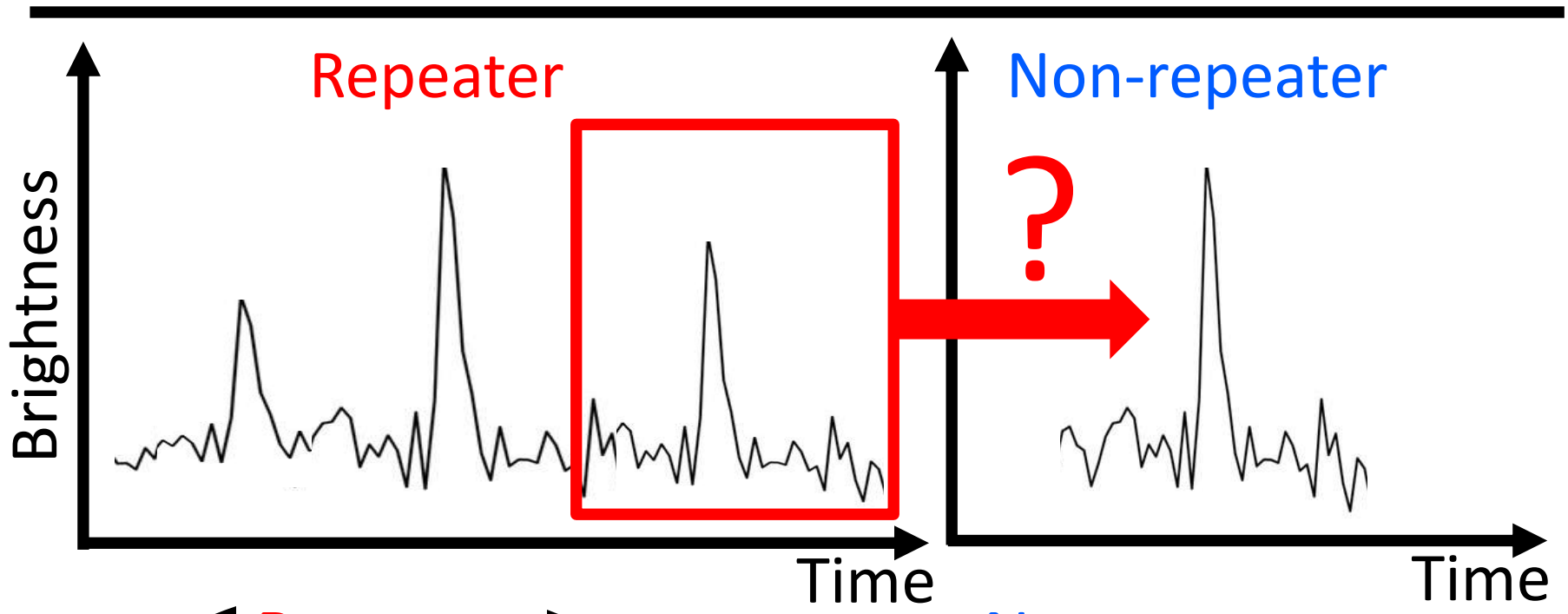
Non-repeater → Old objects

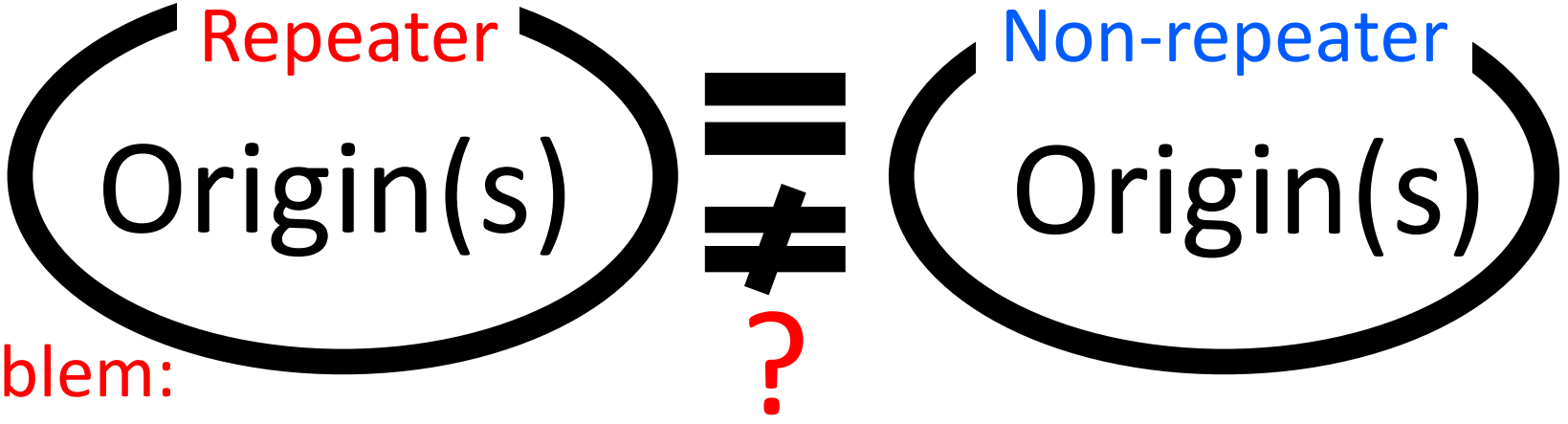
White dwarf

Old neutron star

Old stellar-mass black hole (BH)

Origin: hard to classify Repeater/Non-repeater





Problem:

need long monitoring observations with a high sensitivity

Oliver
(Bo Han Chen)

ML may resolve it?

Chen+2022

Machine Learning

Hidden repeating
FRB sources?

testing w/ FAST

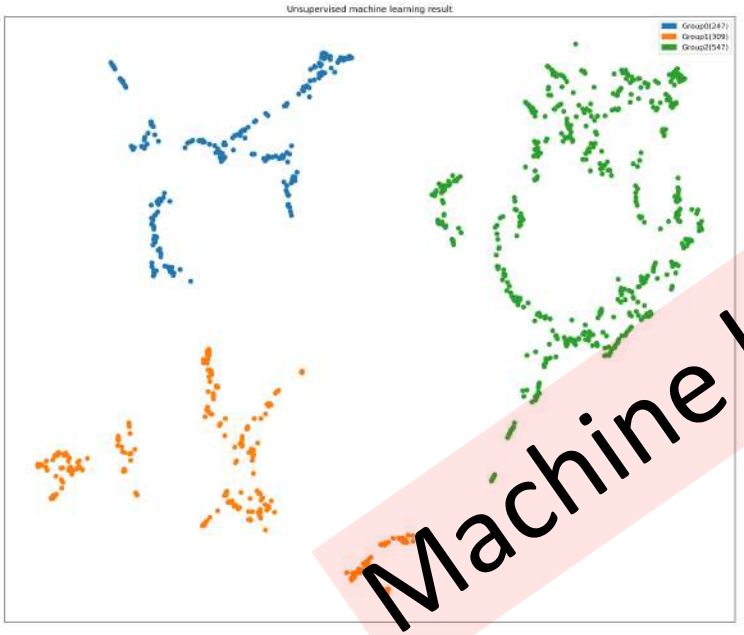
- Repeater
- Repeater candidate
- Non-repeater

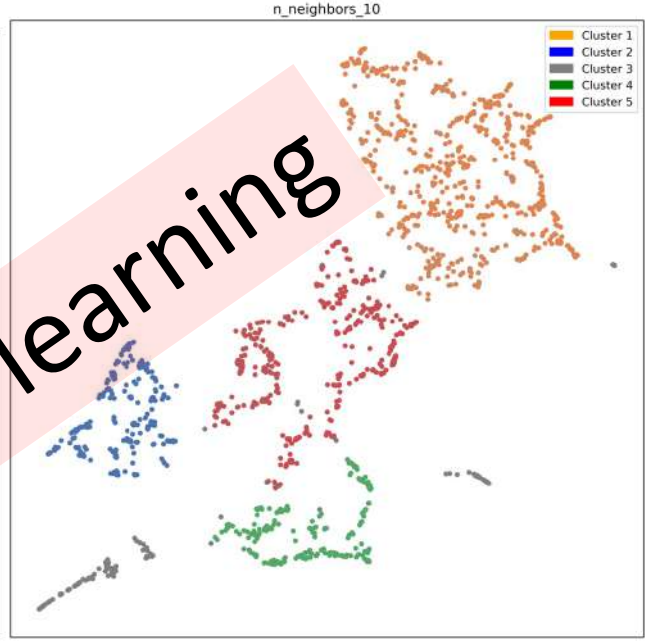
ML classification of repeating FRBs

Oliver
(Bo Han Chen)

Chen+ in prep.

Jasper+ in prep.





Machine learning

FRB20201124 source

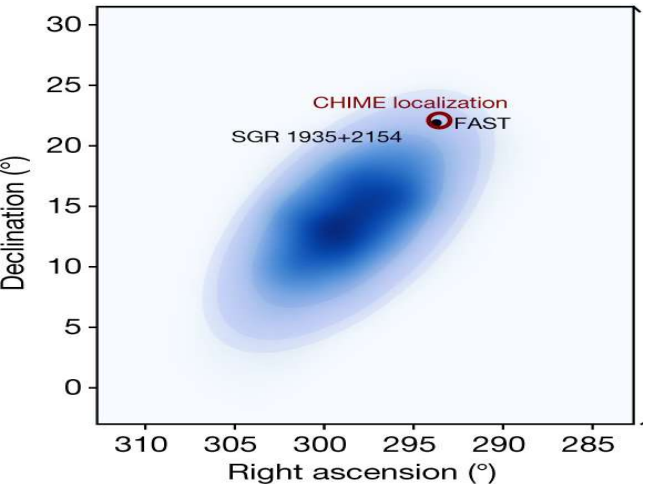
FRB121102 source

Jasper@RTU

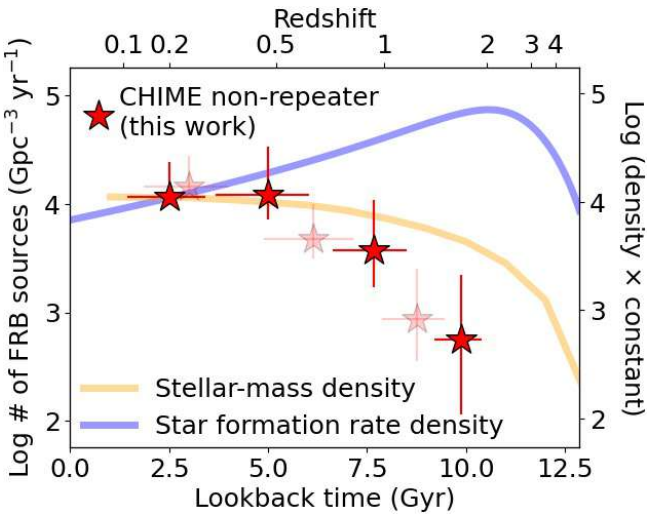
Different physical mechanisms for each FRB source?

Origin of FRBs: summary

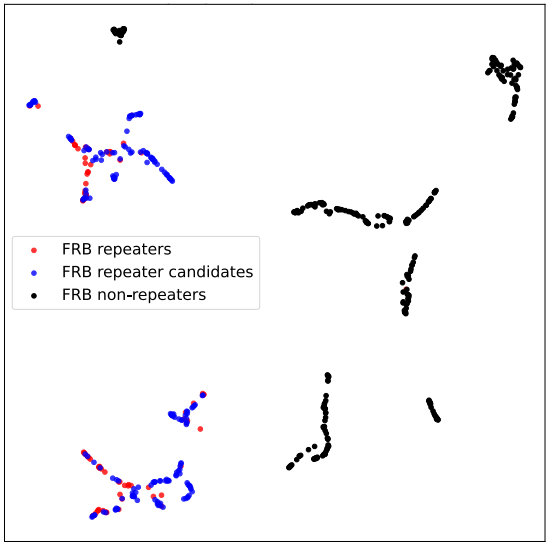
e.g. Bochenek+2020



e.g. TH+2022



e.g. Chen+2022



One confirmed case of a Galactic magnetar (repeater)

The number of non-repeaters

old population

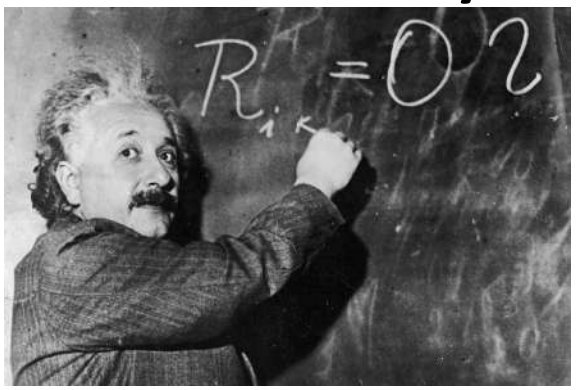
ML approaches became feasible due to CHIME and FAST

3. Applications of FRBs

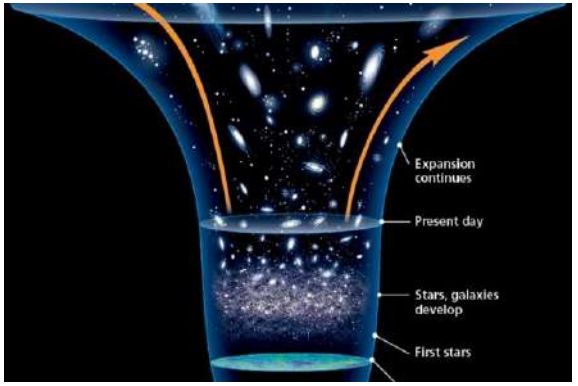
App: key sciences to be addressed by FRBs

Missing baryon problem

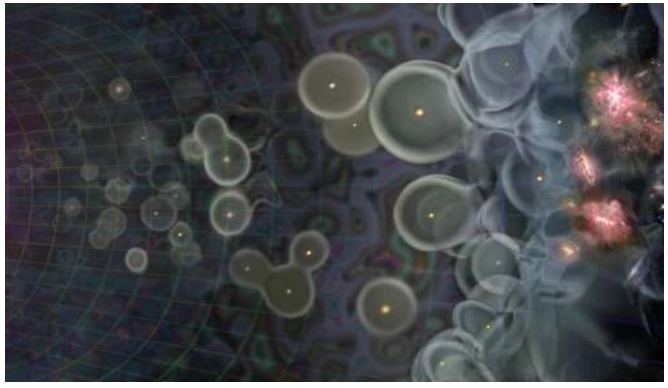
General relativity



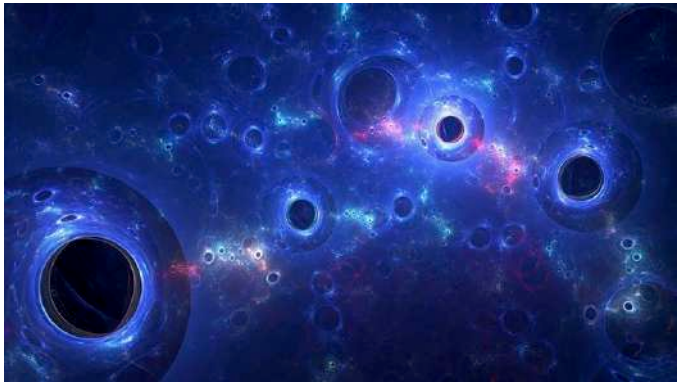
Dark energy



Cosmic reionization



Dark matter

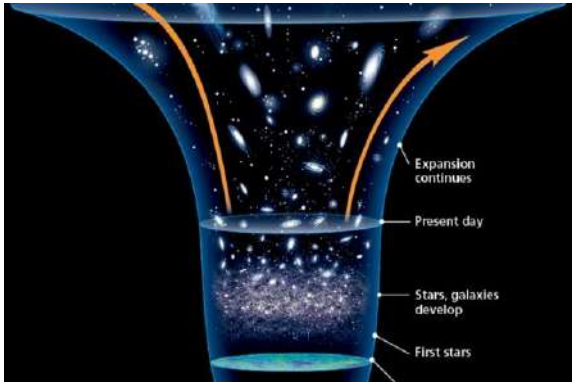


App: key sciences to be addressed by FRBs

Missing baryon problem

General relativity

Dark energy

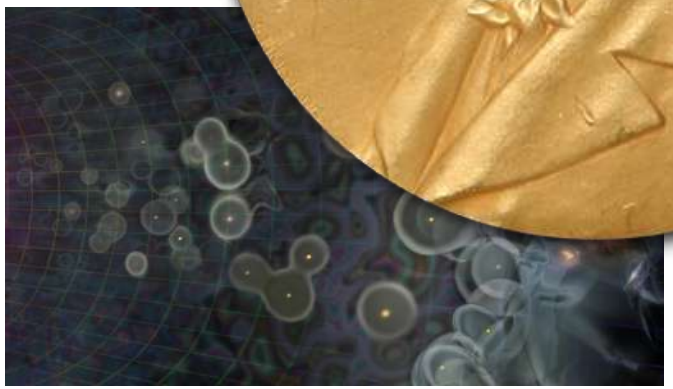


Co

reio

k matter

?



App: key sciences to be addressed by FRBs

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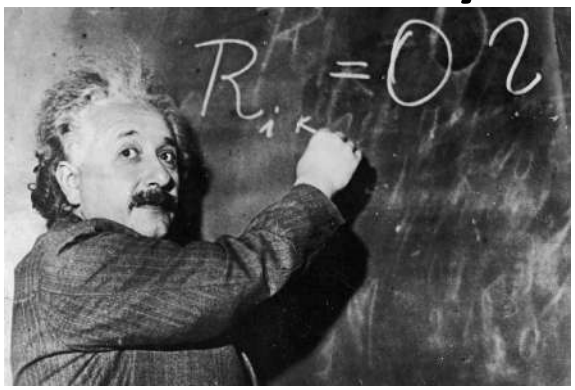
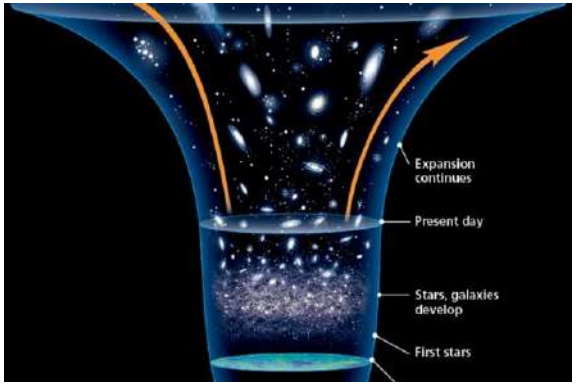
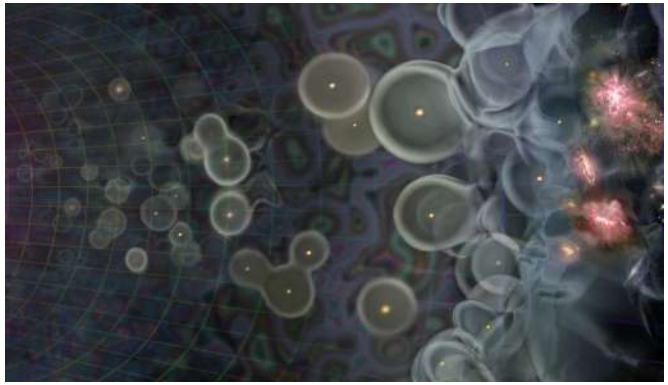
General relativity



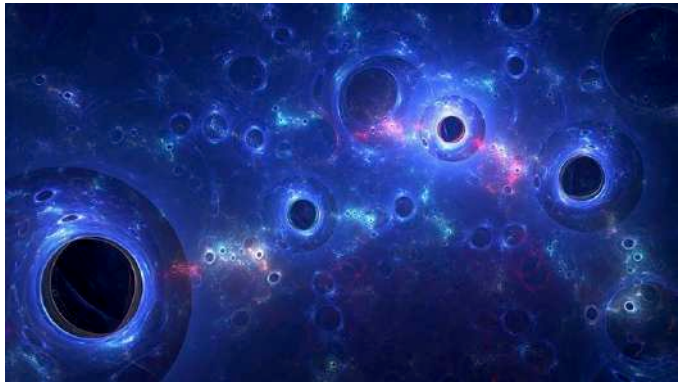
Dark energy



Cosmic reionization



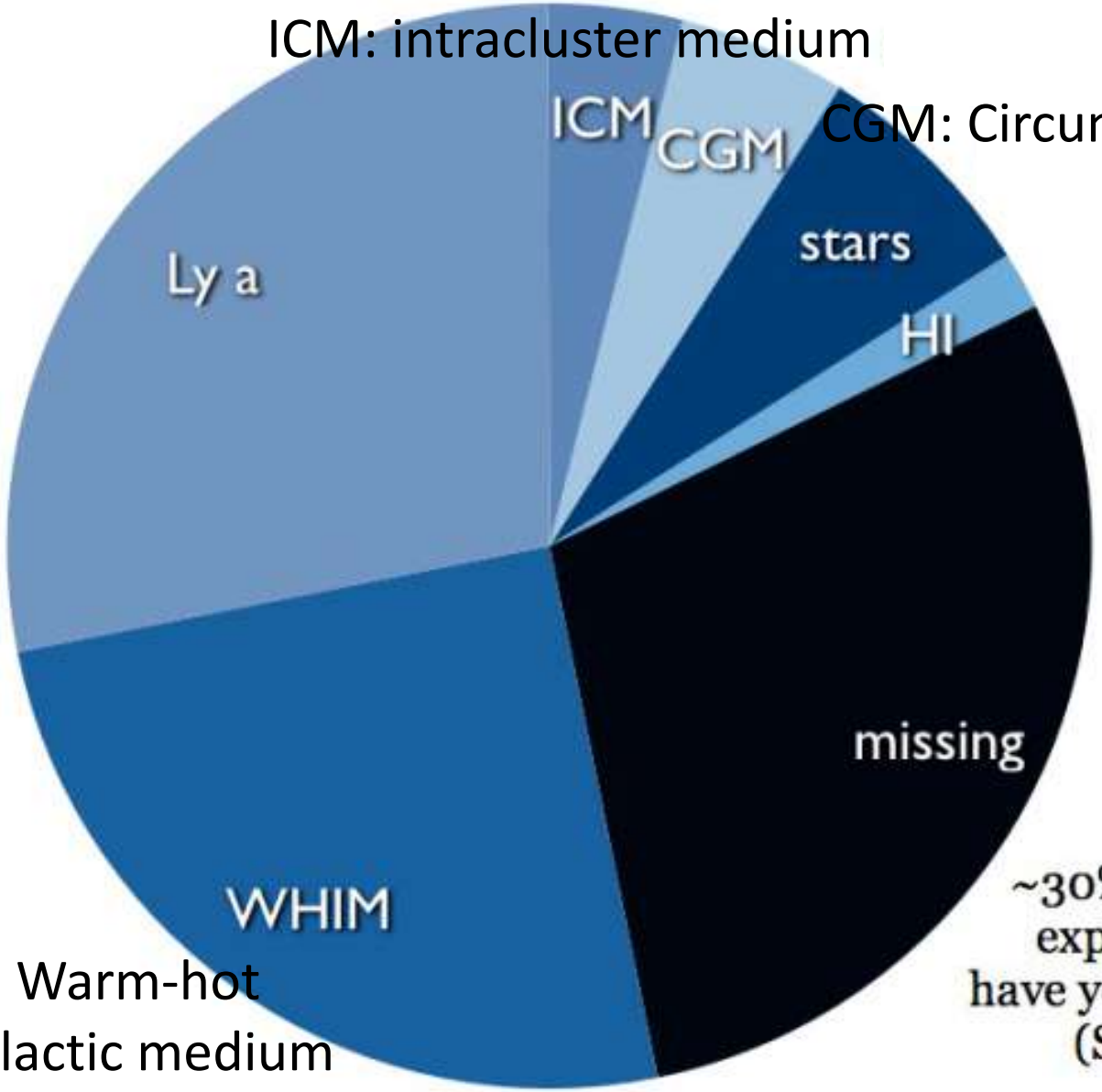
Dark matter



App: the missing baryon problem

ICM: intracluster medium

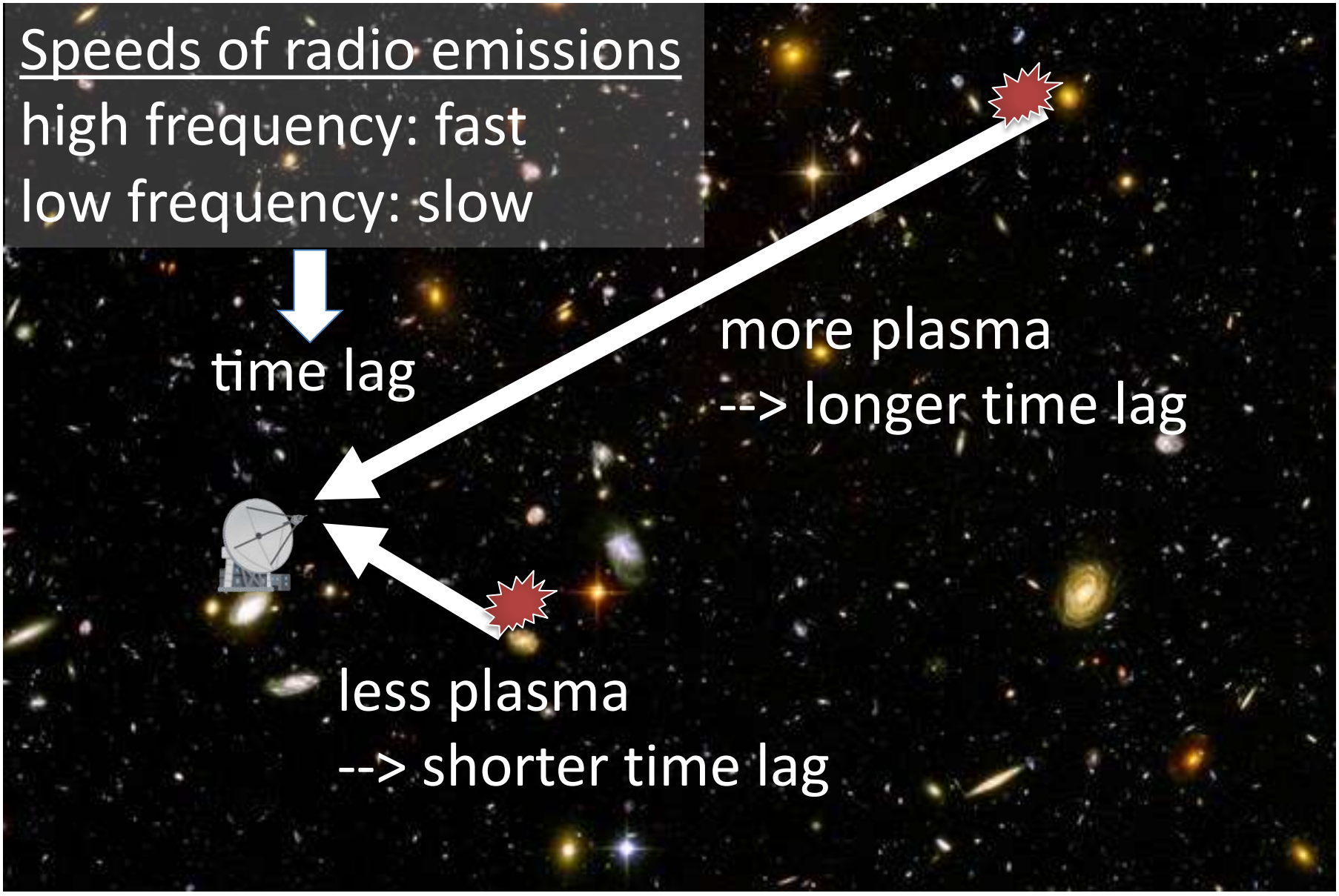
CGM: Circum Galactic Medium



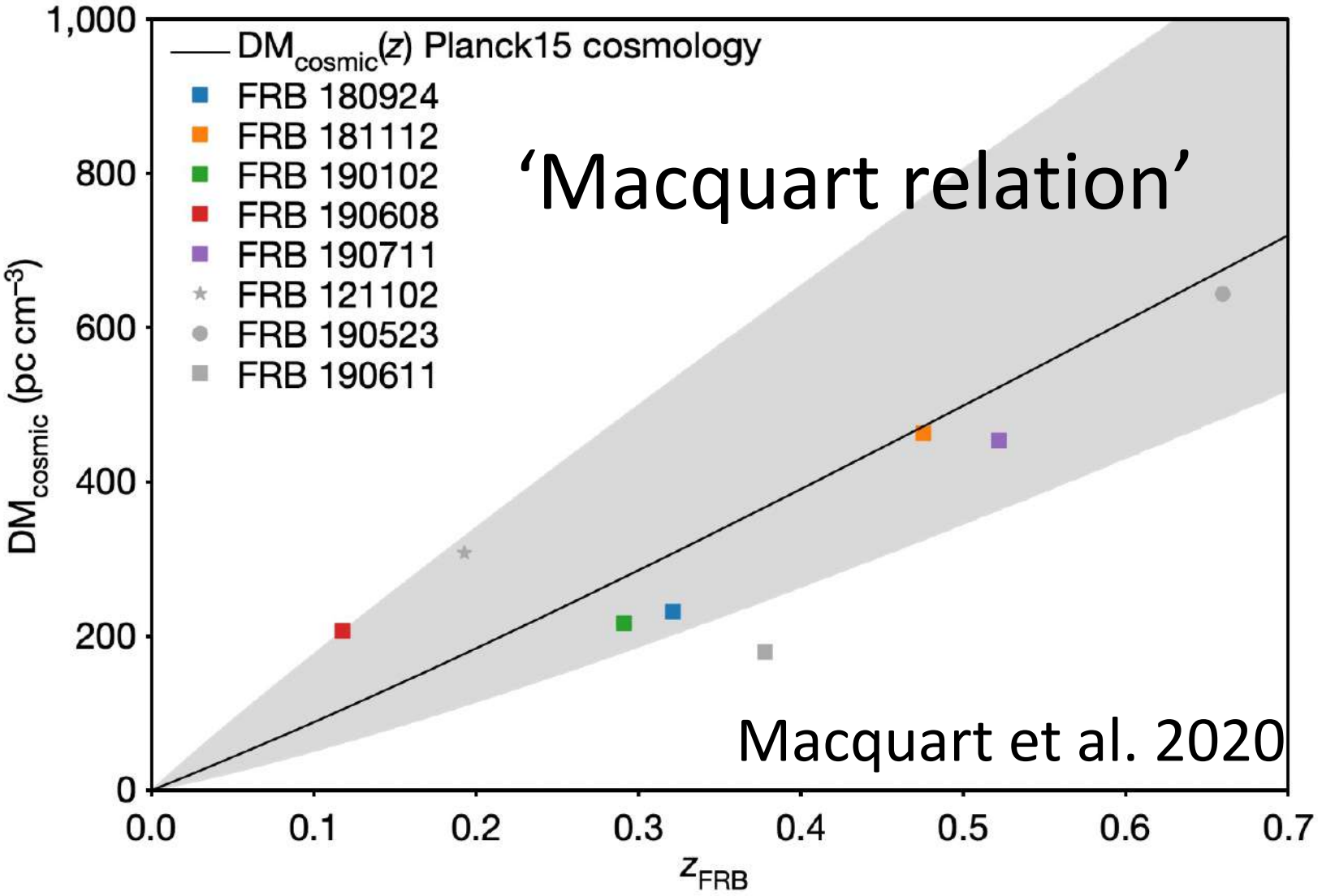
WHIM: Warm-hot intergalactic medium

~30% of the baryons expected from BBN have yet to be detected (Shull et al. 2012)

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



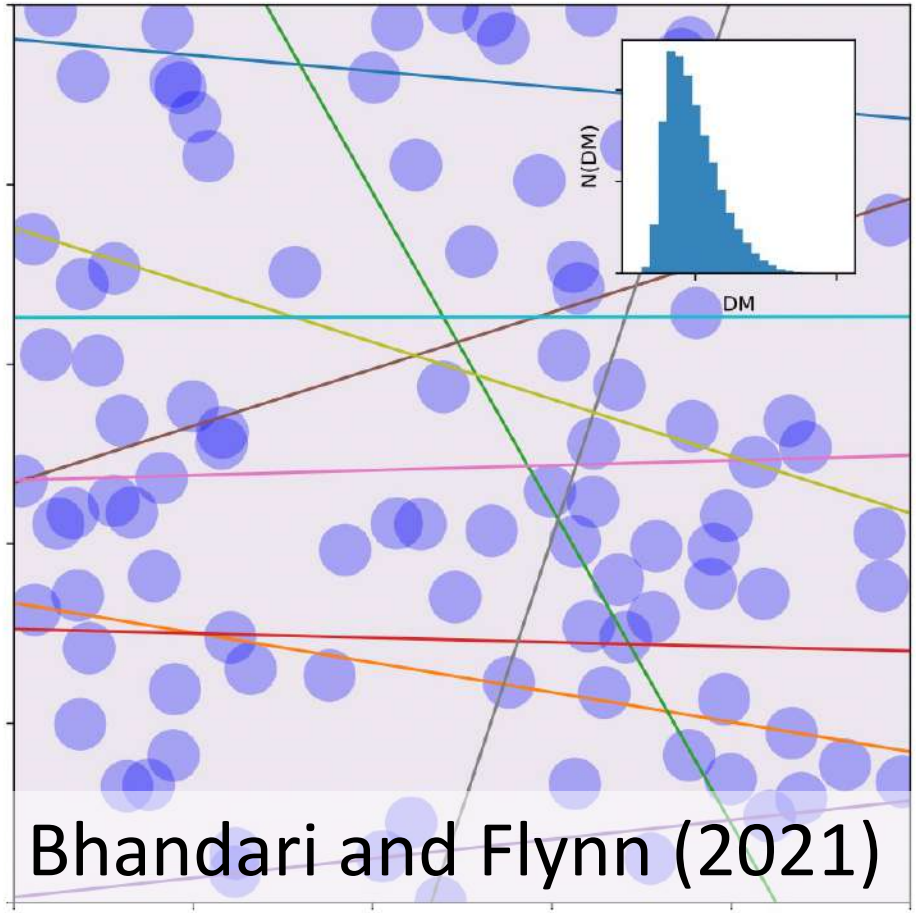
App: the missing baryon problem



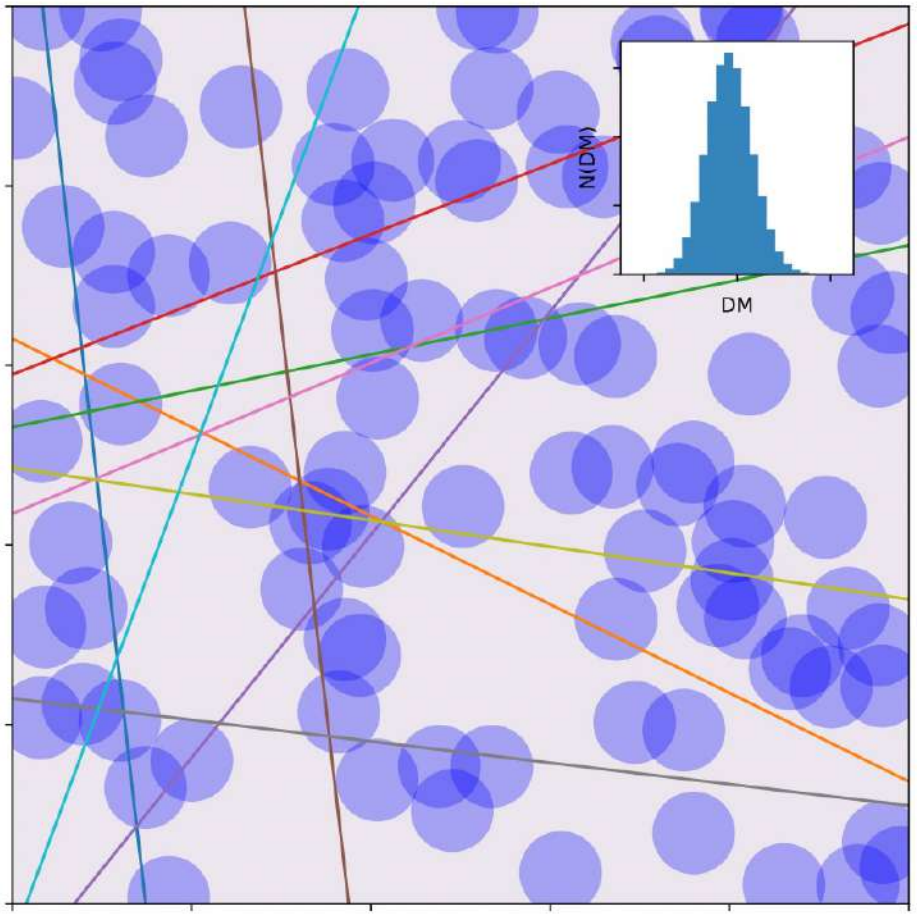
The next step would be the spatial distribution of baryon

App: ~100 localized FRBs may reveal the baryon distribution

Predictions of dispersion measure distributions at a fixed redshift



Bhandari and Flynn (2021)



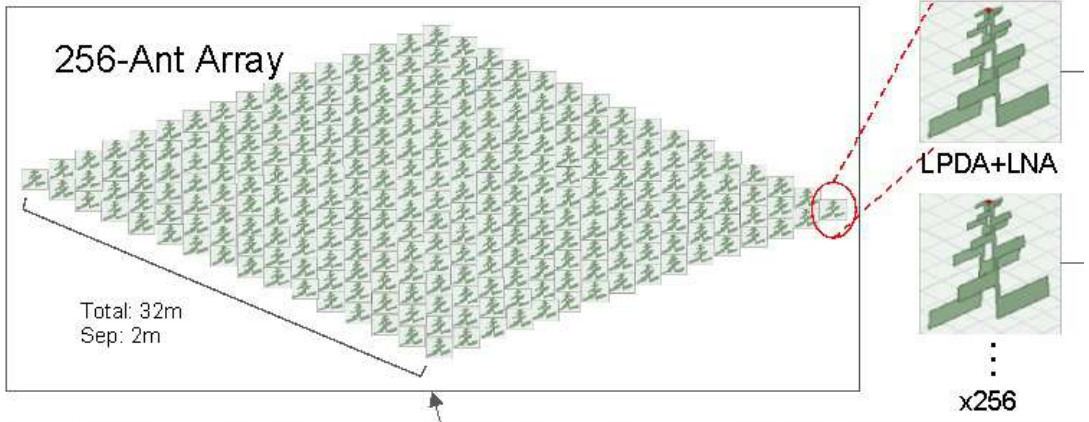
4. A new telescope plan in Taiwan: BURSTT

BURSTT: what are the bottlenecks of observations?

- lack of localization capability
  - e.g., CHIME ~ arcmin
  - spec-z, host galaxy, progenitor etc.
- small FoV and low cadence
  - e.g., CHIME: 5-10 min per day (<1% of the day)
  - missing population of FRBs?
  - expensive for follow-up telescopes
- mismatched distance
  - GWs, neutrinos, high-time resolution follow-up
  - --> nearby Universe

Future FRB telescope in Taiwan

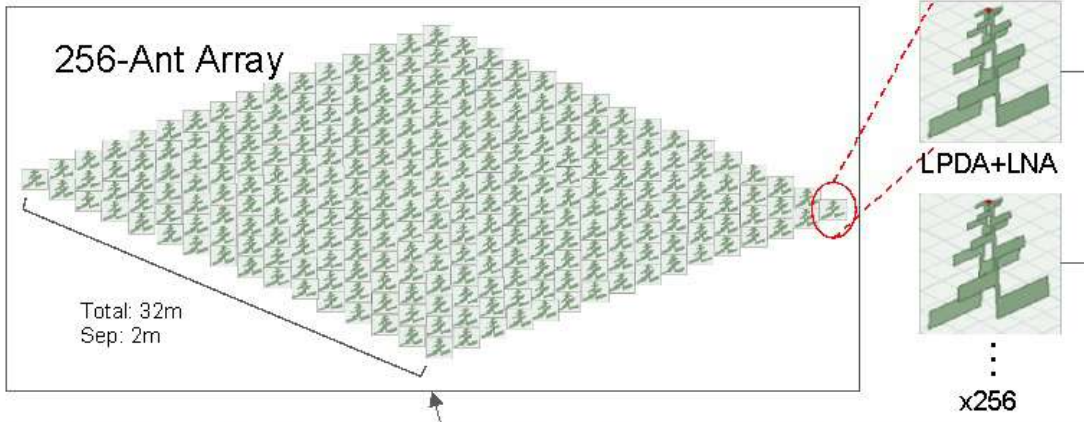
Bustling Universe Radio Survey Telescope in Taiwan (BURSTT)



led by
Prof. Pen, Ue-Li

Future FRB telescope in Taiwan

Bustling Universe Radio Survey Telescope in Taiwan (BURSTT)

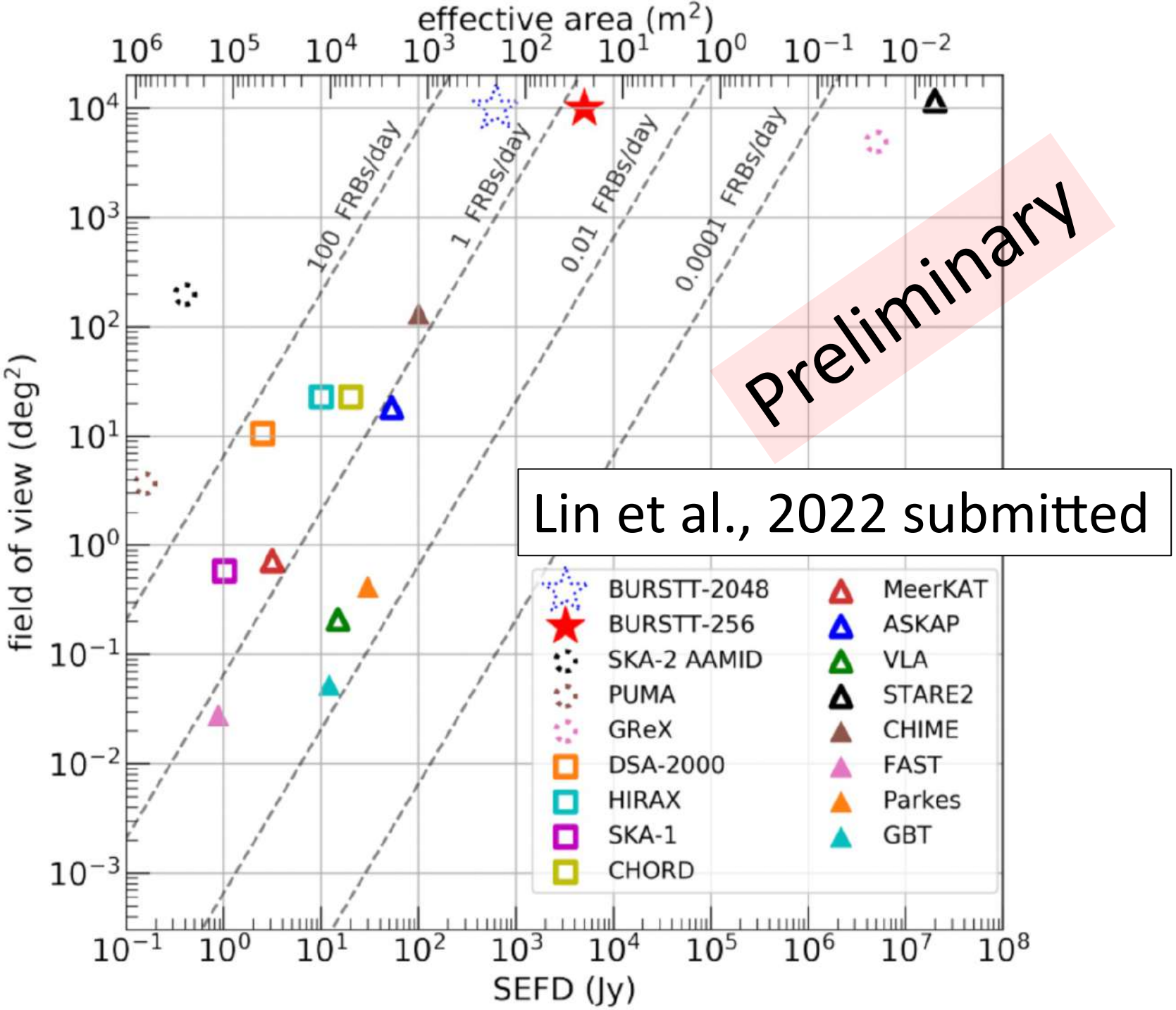


led by
Prof. Pen, Ue-Li

The world-best telescope to detect nearby FRBs

BURSTT will resolve the bottlenecks

- lack of localization capability
  - BURSTT: sub-arcsecond
  - e.g., CHIME ~ arcmin
- small FoV and low cadence
  - BURSTT: 25 times better than that of CHIME
  - e.g., CHIME: 5-10 min per day (<1% of the day)
- mismatch in distance
  - BURSTT: dedicated to the nearby Universe
  - GWs, neutrinos, high-time resolution follow-up
  - --> nearby Universe

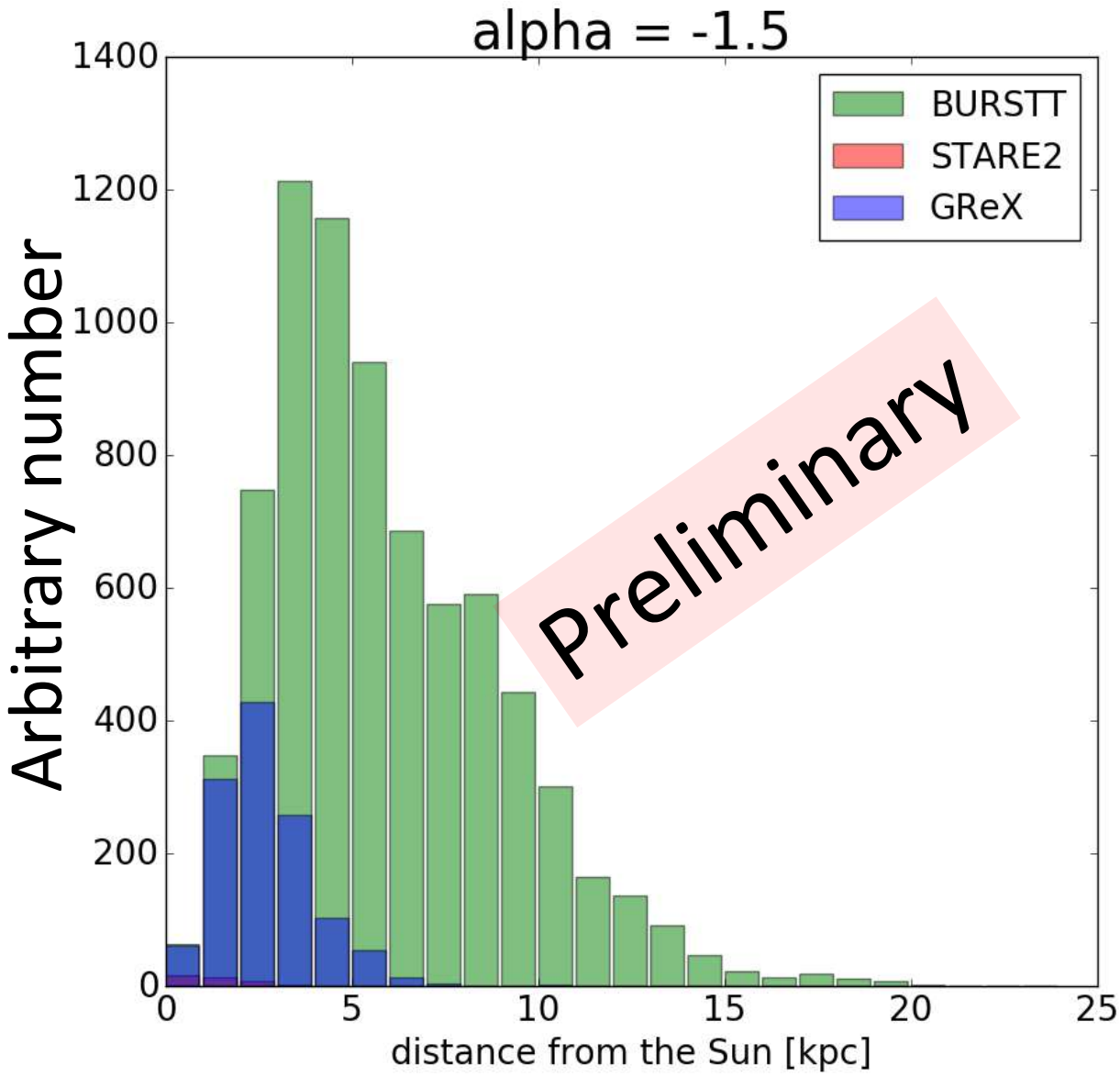

effective area (m²)
field of view (deg²)
SEFD (Jy)
100 FRBs/day
1 FRBs/day
0.01 FRBs/day
0.0001 FRBs/day
Preliminary
Lin et al., 2022 submitted
BURSTT-2048
BURSTT-256
SKA-2 AAMID
PUMA
GReX
DSA-2000
HIRAX
SKA-1
CHORD
MeerKAT
ASKAP
VLA
STARE2
CHIME
FAST
Parkes
GBT

Predictions of BURSTT FRBs

Number prediction of Galactic FRB-like events ($E>10^{32}$ erg)

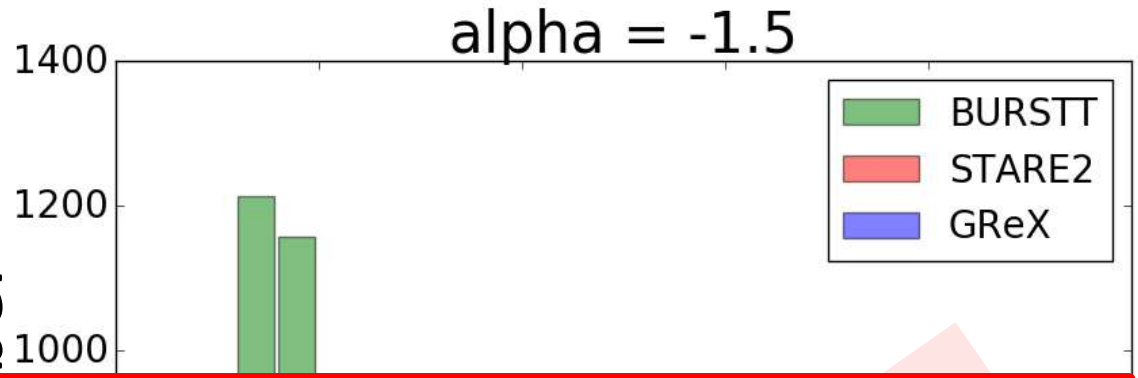
cf. FRB from SGR 1935+2154: $10^{34\text{-}35}$ erg

Decmend Lin



Predictions of BURSTT FRBs

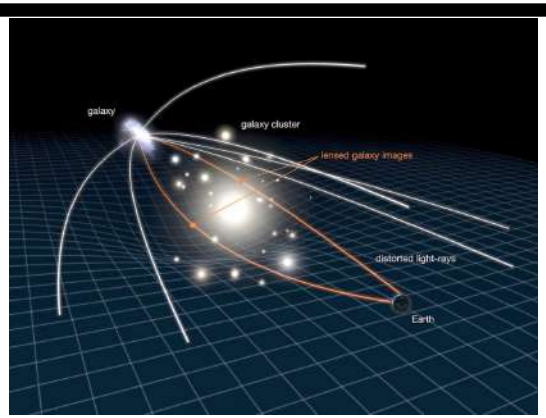
Number prediction of Galactic FRB-like events (E>10^{32} erg)



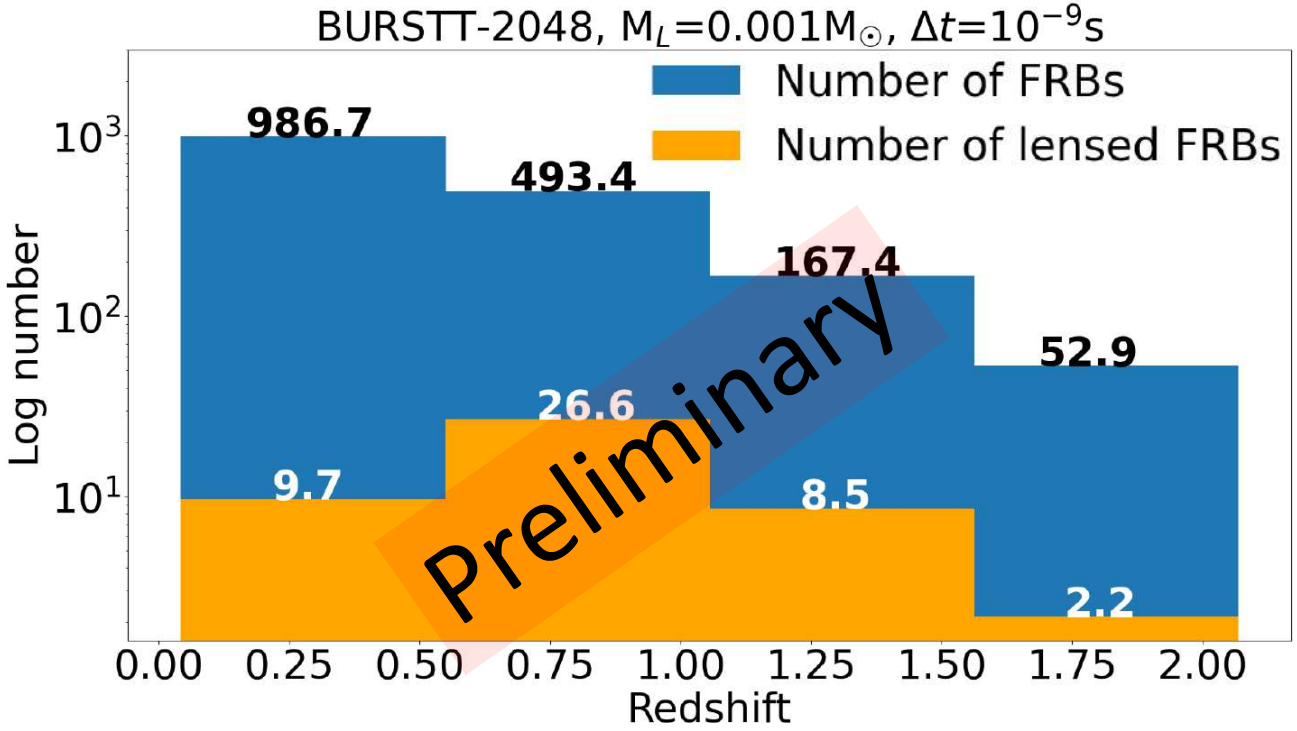
System parameters	Ratio of value compared with STARE2	Ratio of detection rate
Area of antenna	× 56 larger	10
SEFD	× 20000 more sensitive	28
Central frequency	× 2 smaller	0.7
Bandwidth	× 2 larger	1.6
Field of view (FoV)	× 1.4 larger	5
	Expected detection rate	156.8

Predictions of BURSTT FRBs

Number prediction of gravitationally lensed FRBs



Simon C.-C. Ho

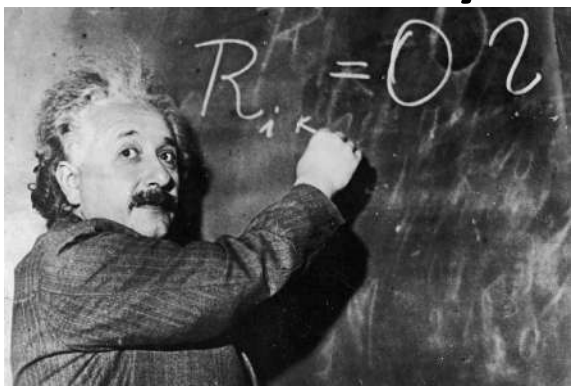


→ to constrain dark matter and cosmological parameters

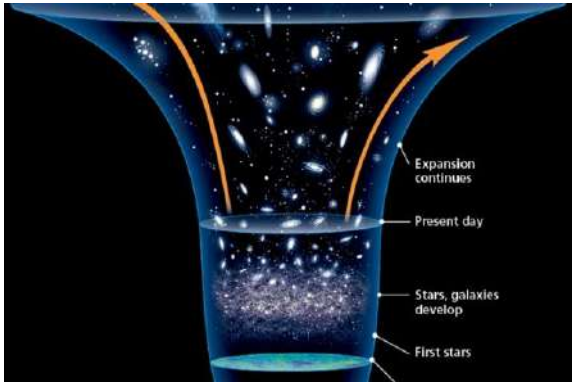
Conclusion: FRB science is exciting

Missing baryon problem

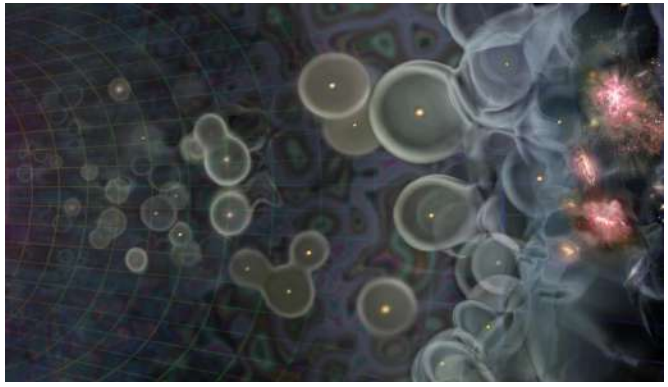
General relativity



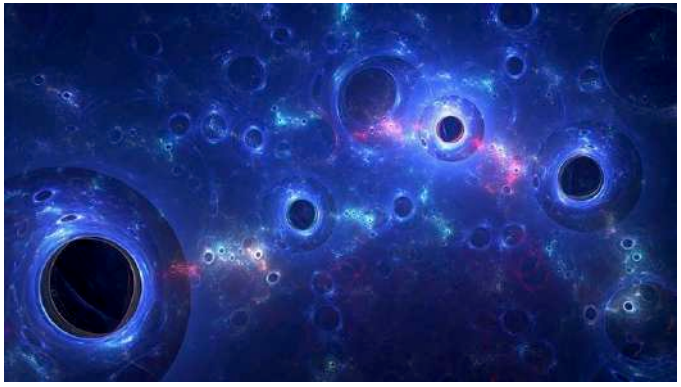
Dark energy



Cosmic reionization



Dark matter



The origin of FRBs

Backup slides

Seong Jin Kim

Our result:

do CHIME FRBs show the correlation?

➡ Yes, at z<0.3

Kim et al. 2022