The origin of fast radio bursts implied from the cosmic stellar-mass density evolution

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YITP workshop Fast Radio Bursts and Cosmic Transients 7 June 2022

Outline

1. Introduction

2. FRB population analyses

   TH+2022, MNRAS, 511, 1961

   TH+2020c, MNRAS, 498, 3927

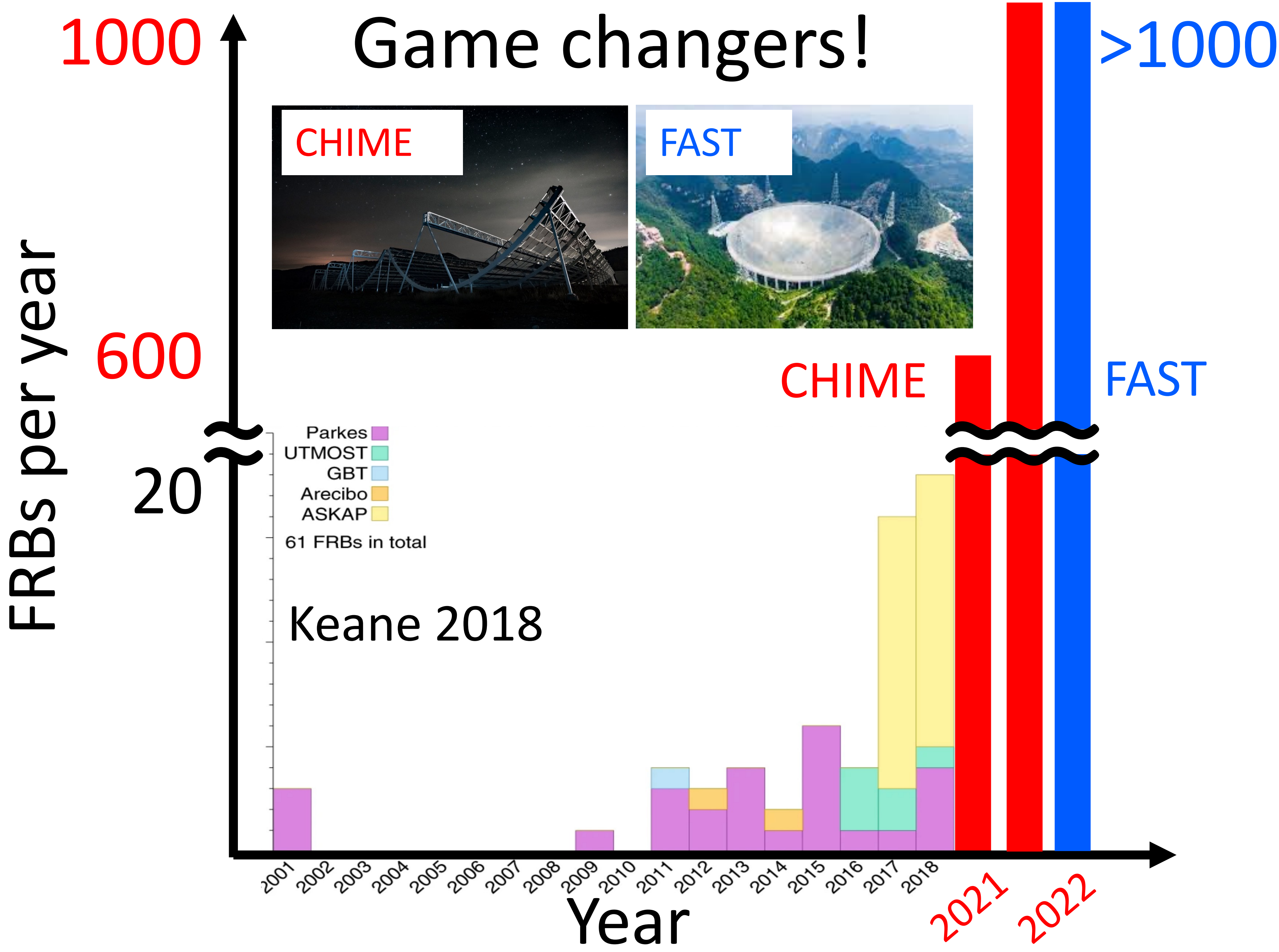
3. Testing general relativity using FRBs

   TH+2021b, PhysRevD, 104, 124026

   Sen, TH+2022, MNRAS, 509, 5636

4. A new telescope plan in Taiwan BURSTT

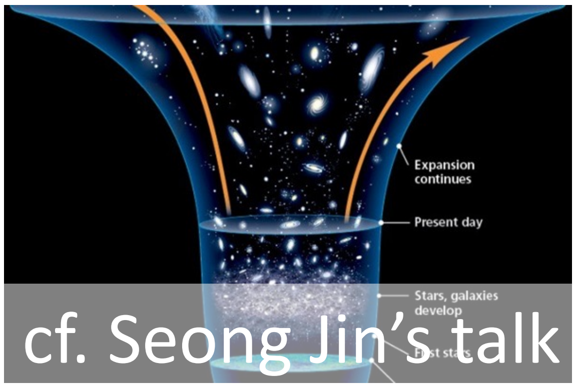
   Lin et al including TH in prep.



Game changers!
1000
600
20
FRBs per year
CHIME
FAST
CHIME
FAST
>1000
Parkes
UTMOST
GBT
Arecibo
ASKAP
61 FRBs in total
Keane 2018
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2021
2022
Year

Key sciences to be addressed by FRBs

Dark energy

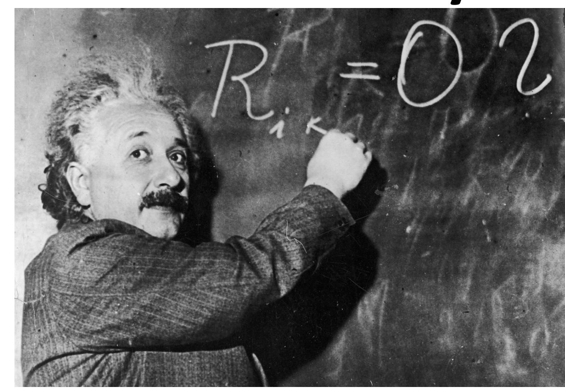


cf. Seong Jin's talk

Missing baryon problem


cf. Ilya/Ryuichi talks

General relativity



Cosmic reionization


cf. Prof. Kumar's talk

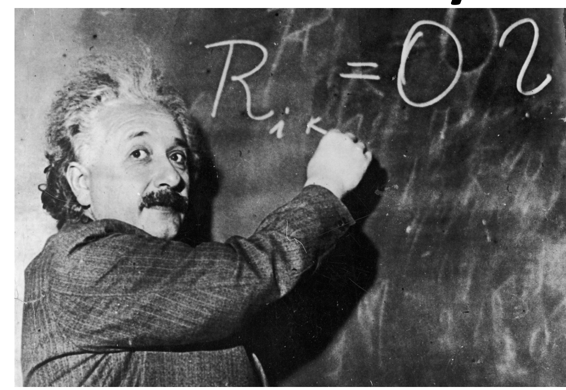
Dark matter

Key sciences to be addressed by FRBs

Dark energy

Missing baryon problem

General relativity



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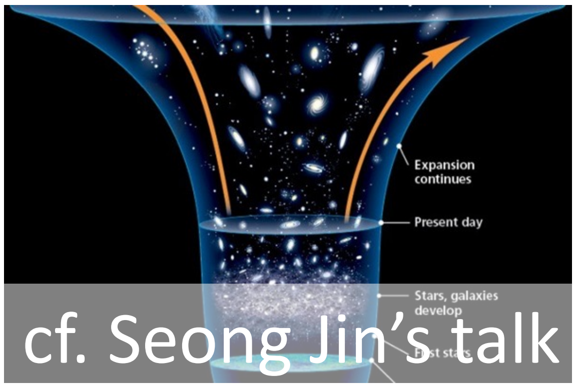
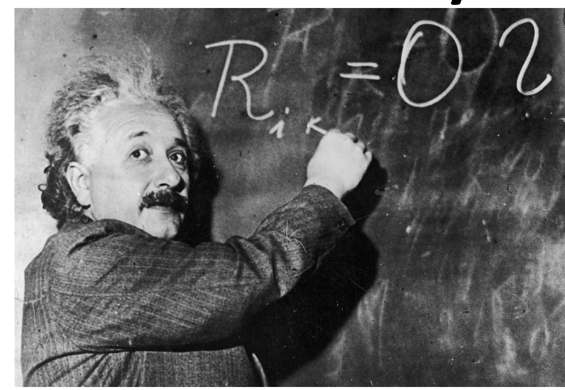
Key sciences to be addressed by FRBs

Dark energy

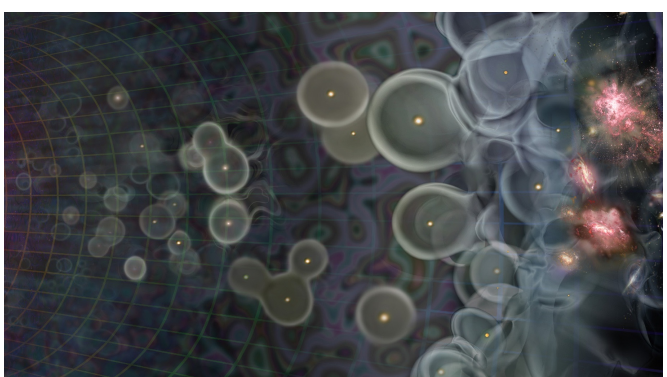


Missing baryon problem

General relativity



Cosmic reionization



Dark matter

The origin of FRBs

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)

Introduction: possible FRB origins

White dwarf

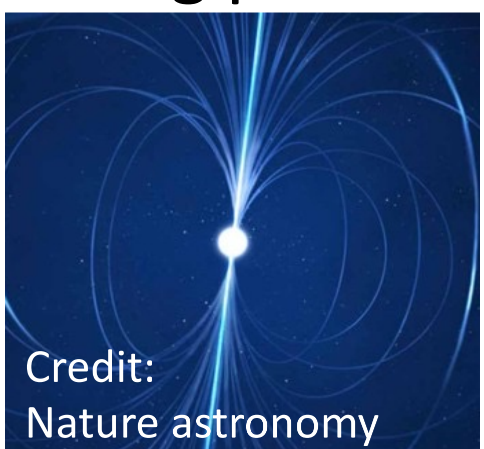
Old neutron star

Old stellar-mass black hole (BH)

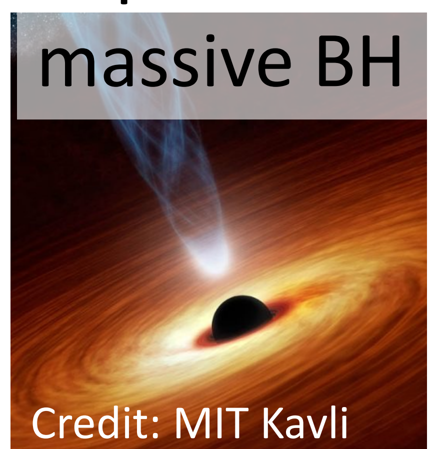
?

Magnetar

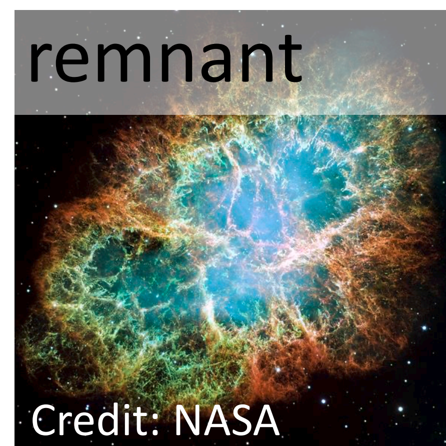
Young pulsar



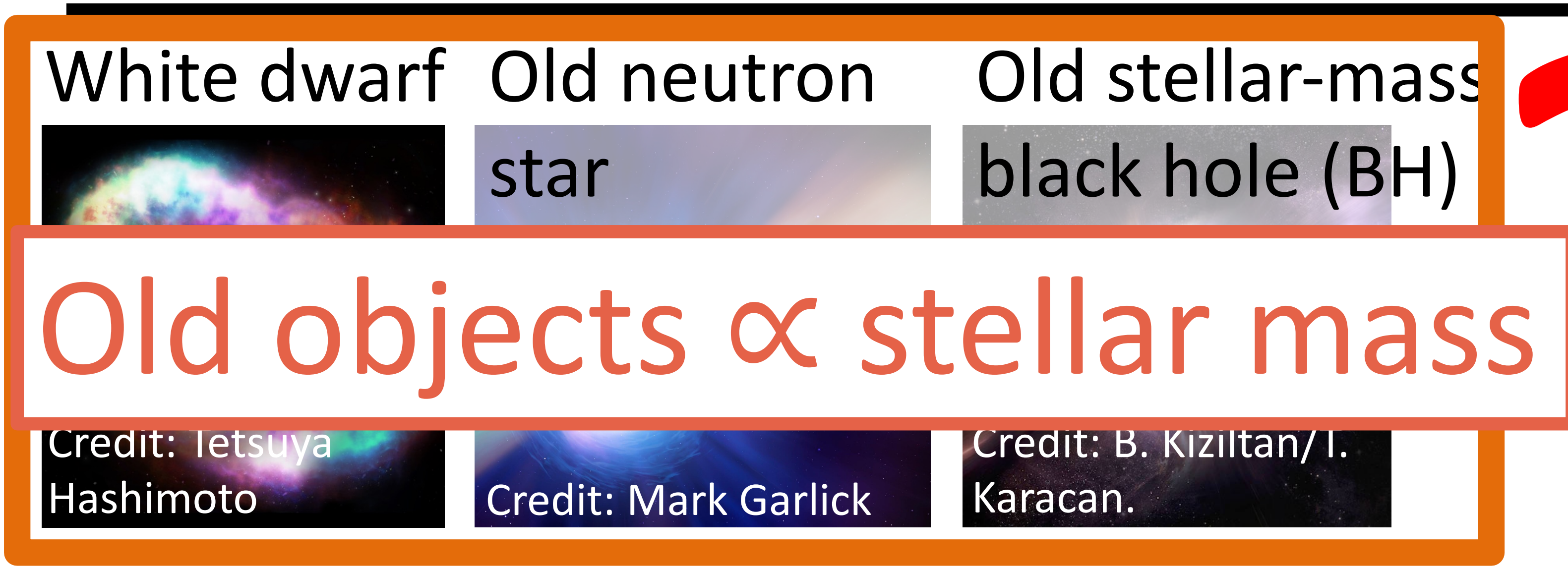
Super massive BH



Supernova remnant

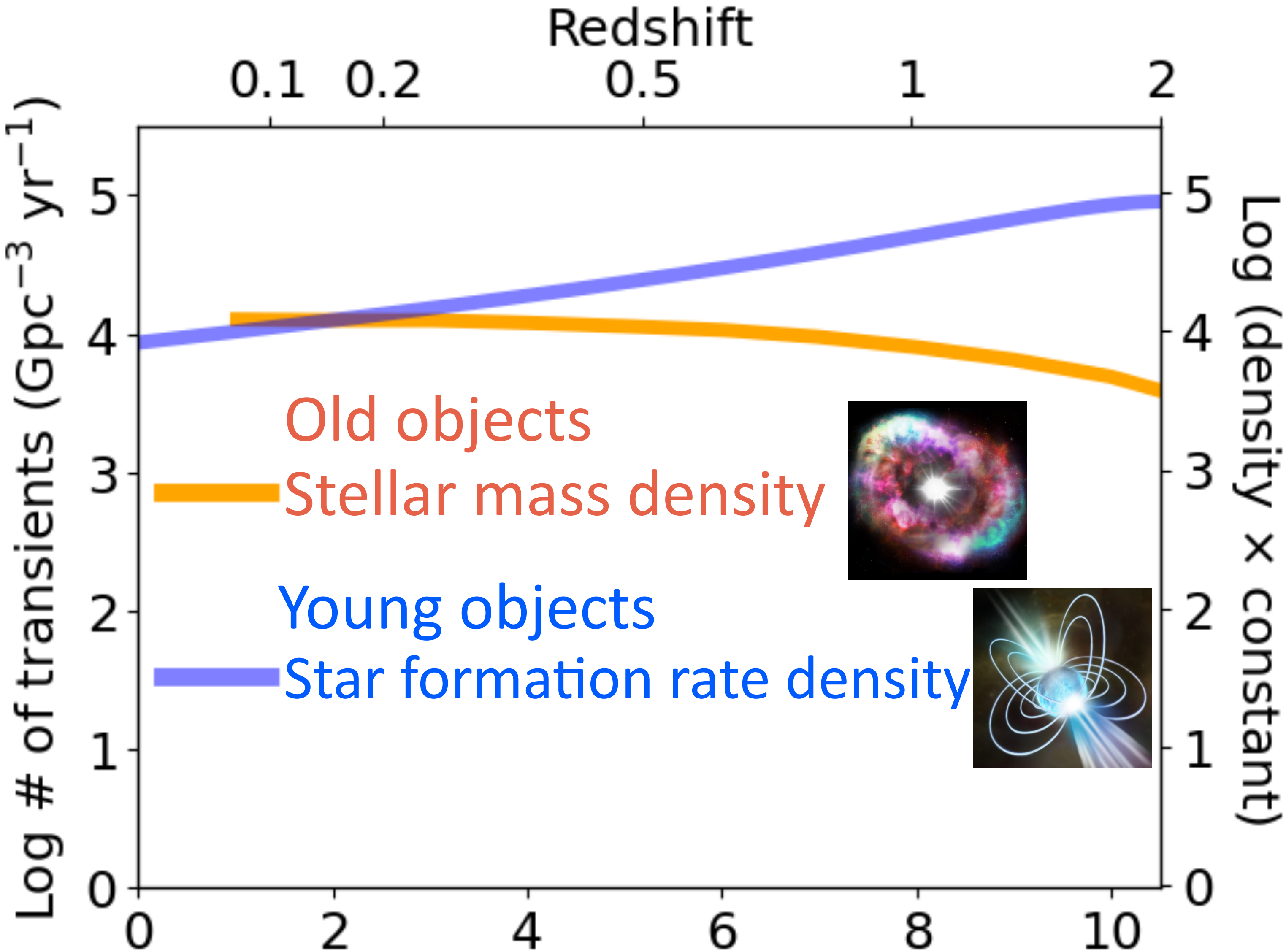


Introduction: possible FRB origins



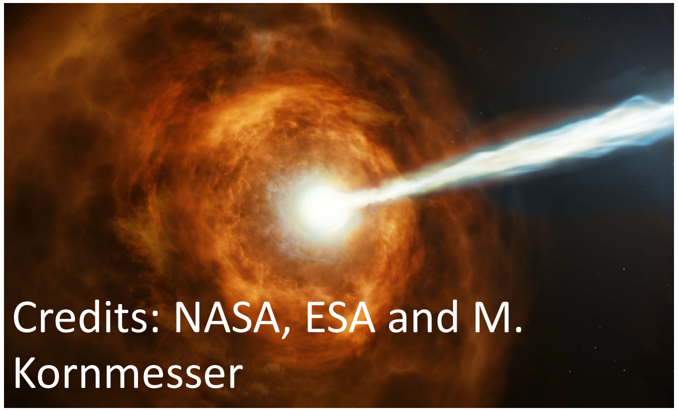
?

Introduction: Old vs Young

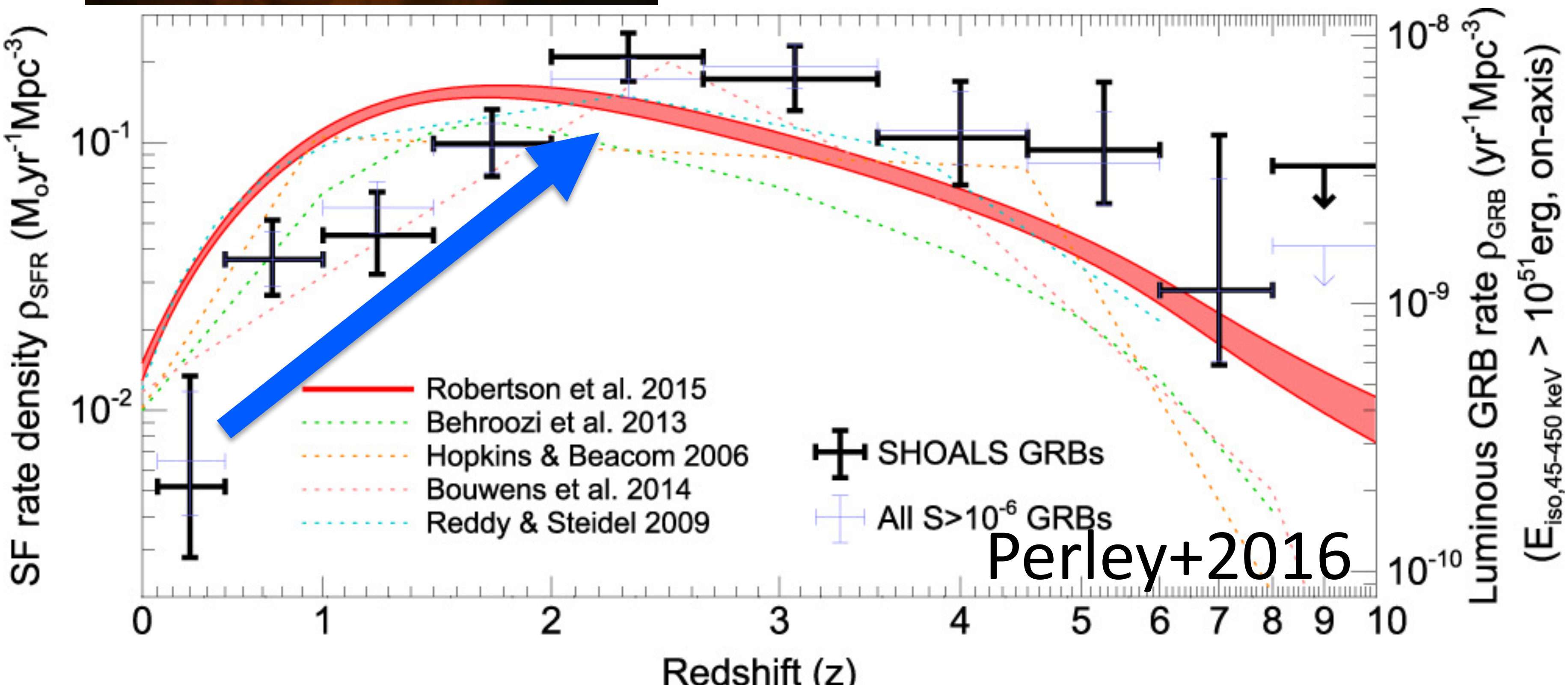


Nearby Distant

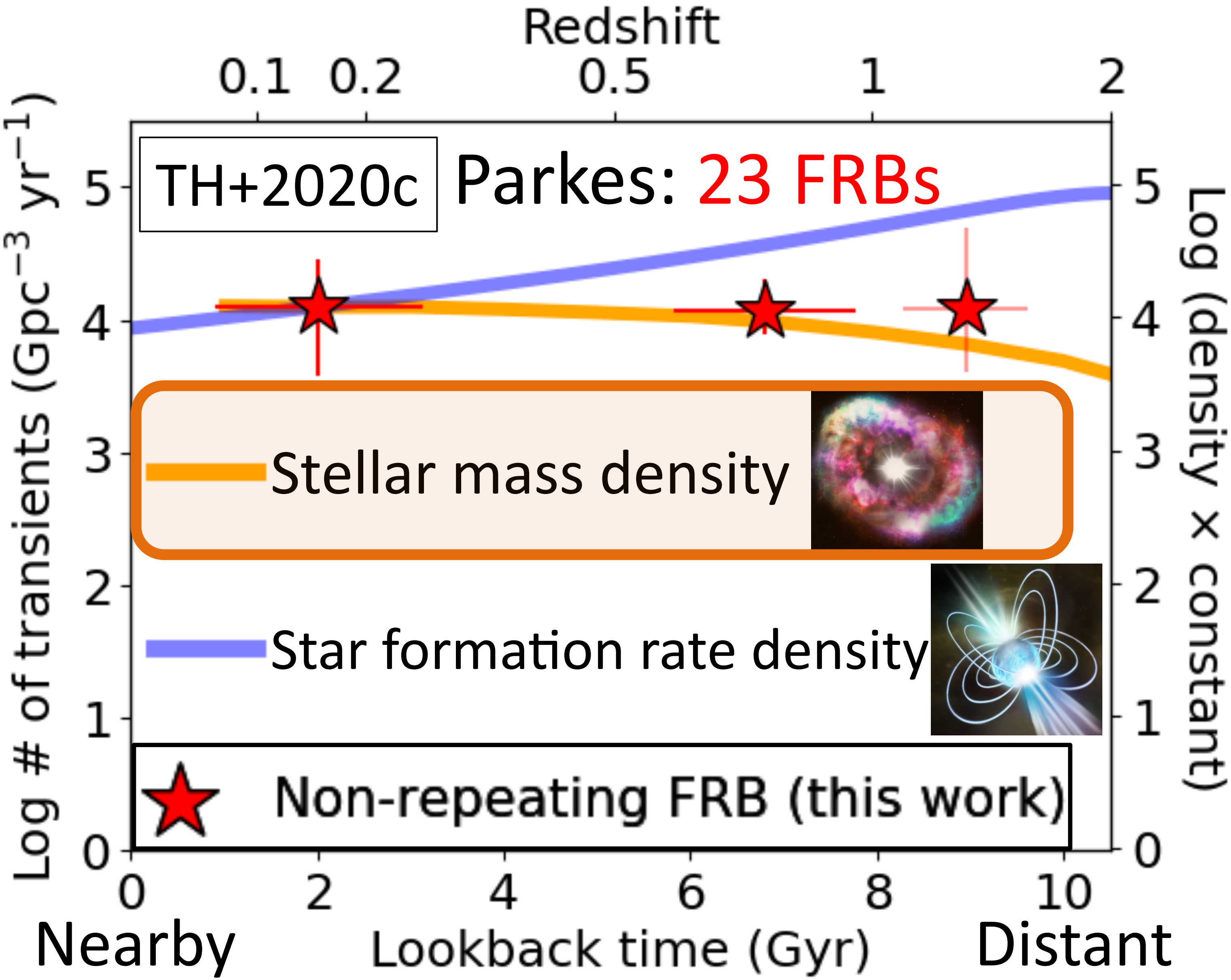
Introduction: Example (LGRBs)



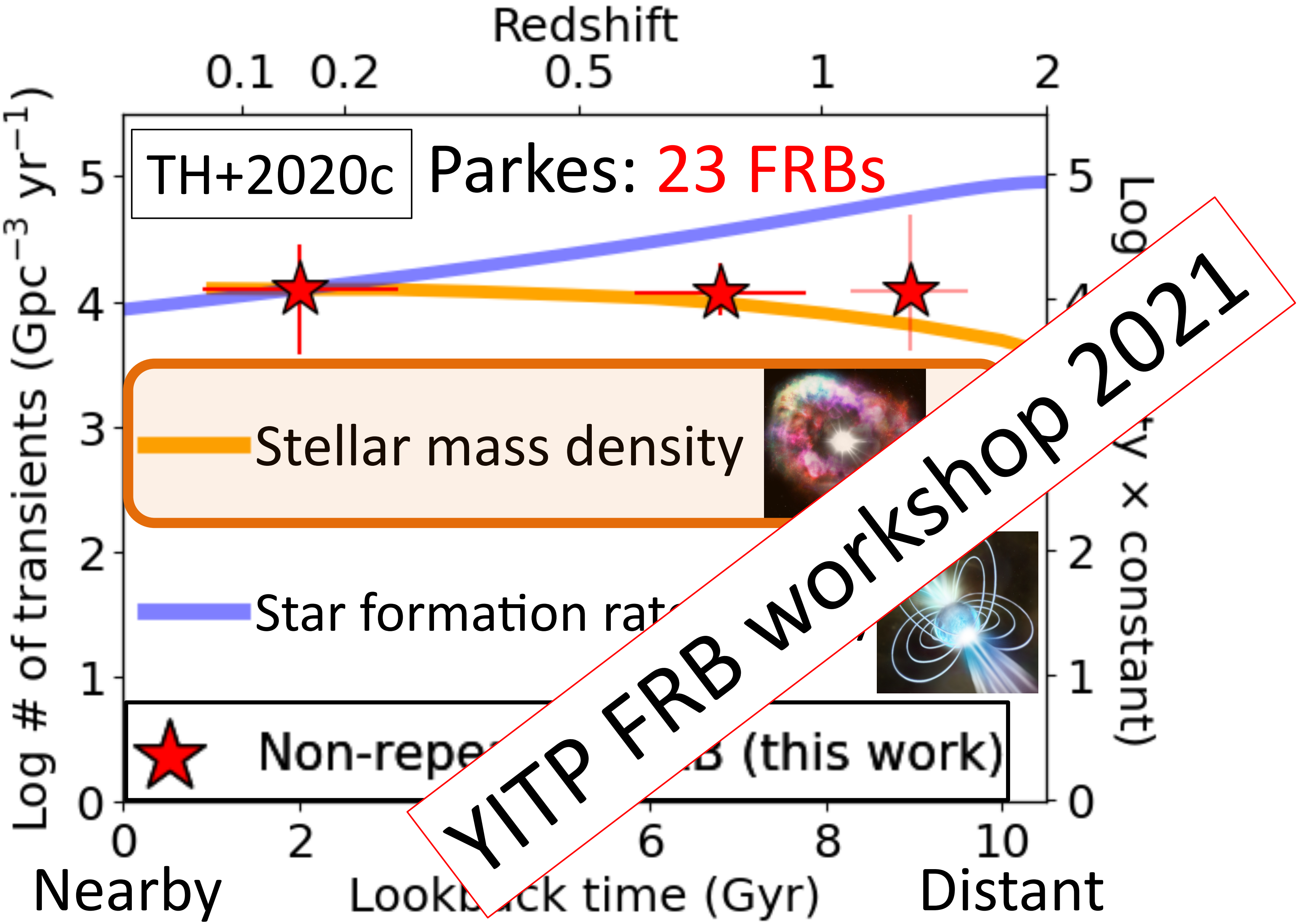
Long Gamma-ray bursts
$\propto$ star formation



Introduction: Non-repeating FRBs



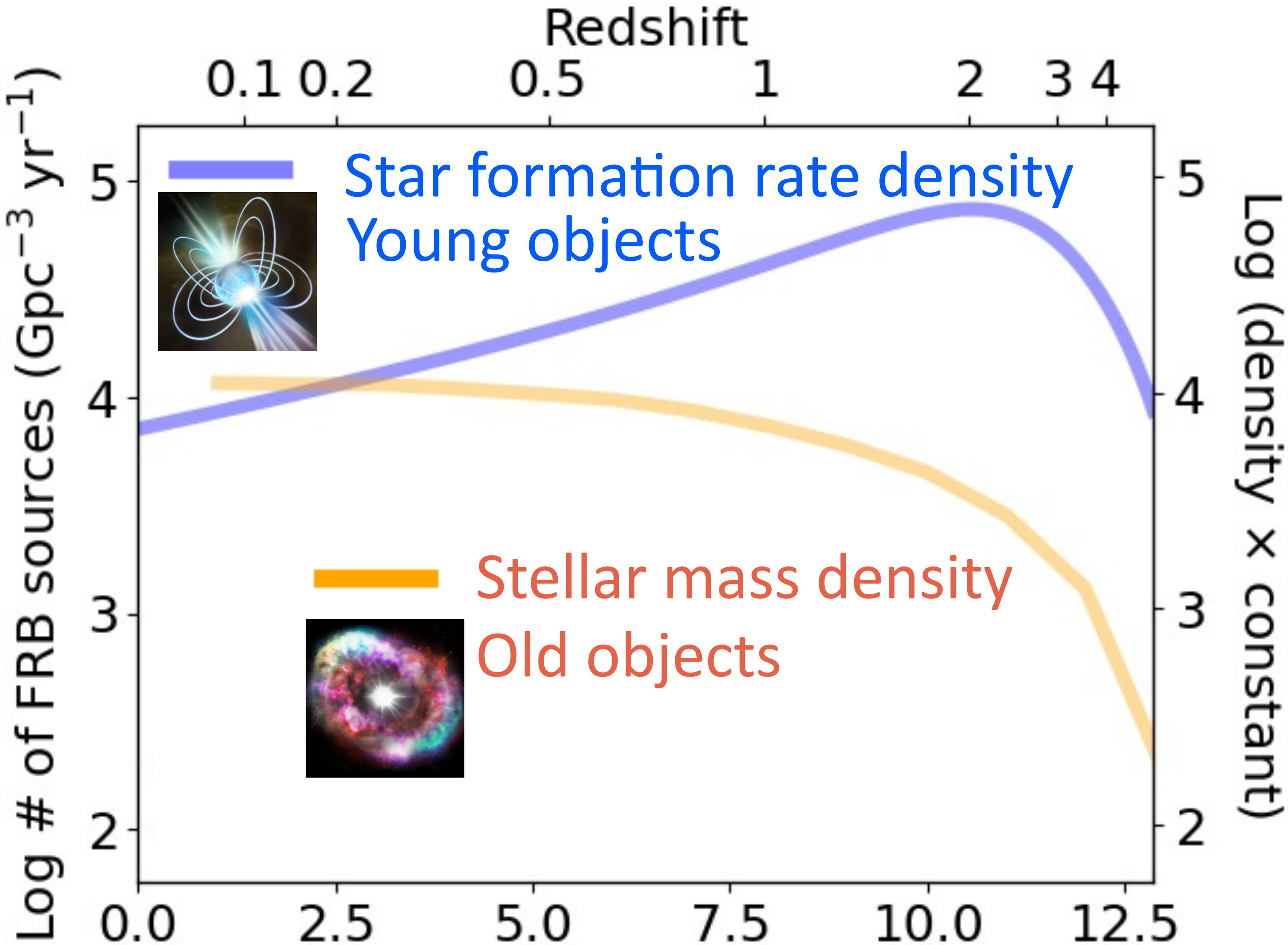
Introduction: Non-repeating FRBs



Let's see the answer!

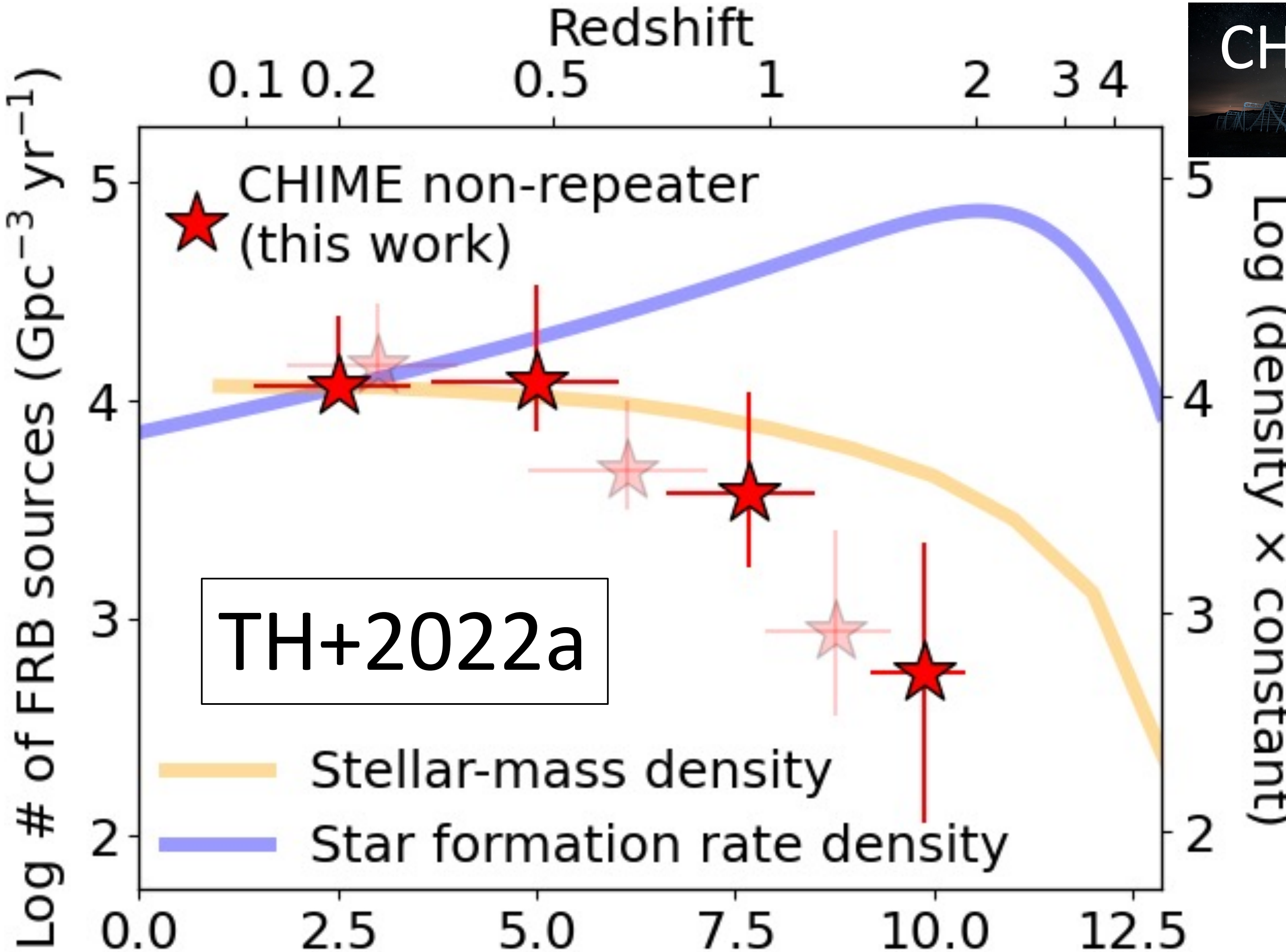
CHIME: ~500 non-repeating FRBs in 2021!

Introduction: Old vs Young



Nearby Universe   Distant Universe

Our result: Non-repeater → Old



Nearby Universe Distant Universe

FRB population analyses

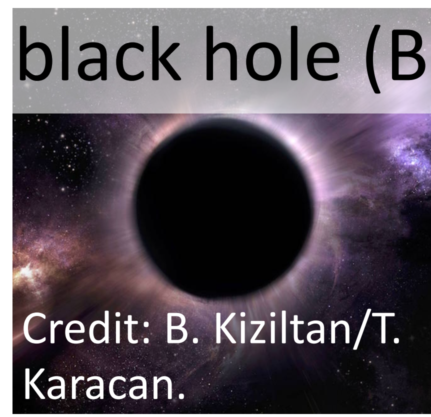
Author	free from the z-evolution assumption?	test an old population scenario?	sample	homogeneous sample?	conclusion
TH+2022a	Yes	Yes	CHIME	Yes	Old pop.
Zhang&Zhang 2022	No	Yes	CHIME	Yes	Old pop.
James+2022	No	No	ASKAP/Parkes	No	Young pop.
Arcus+2021	No	Yes	ASKAP/Parkes	No	Both young and no-evo pops.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

Conclusion

TH+2022a

x10 more samples than before

Non-repeater → Old objects

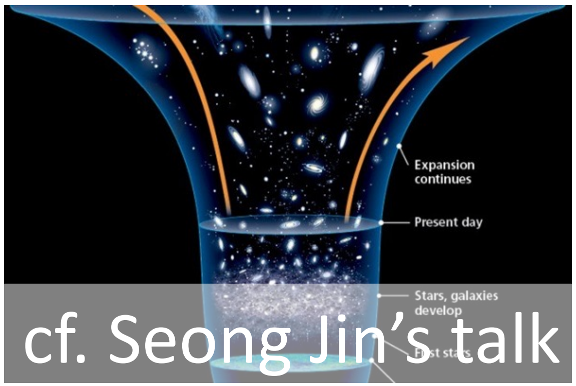
White dwarf	Old neutron star	Old stellar-mass black hole (BH)
		
Credit: Tetsuya Hashimoto	Credit: Mark Garlick	Credit: B. Kiziltan/T. Karacan.

Cautions
- high scattering
- faint bursts

→ missed by CHIME

Key sciences to be addressed by FRBs

Dark energy



Missing baryon problem

General relativity

Cosmic reionization

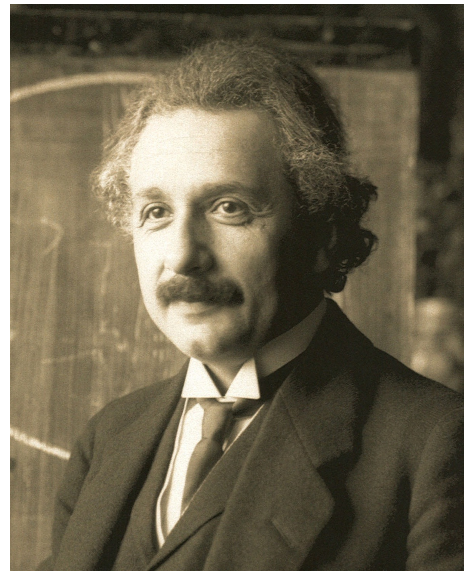
Dark matter

The origin of FRBs

Newtonian mechanics

General relativity (GR)

?



Isaac Newton

Albert Einstein

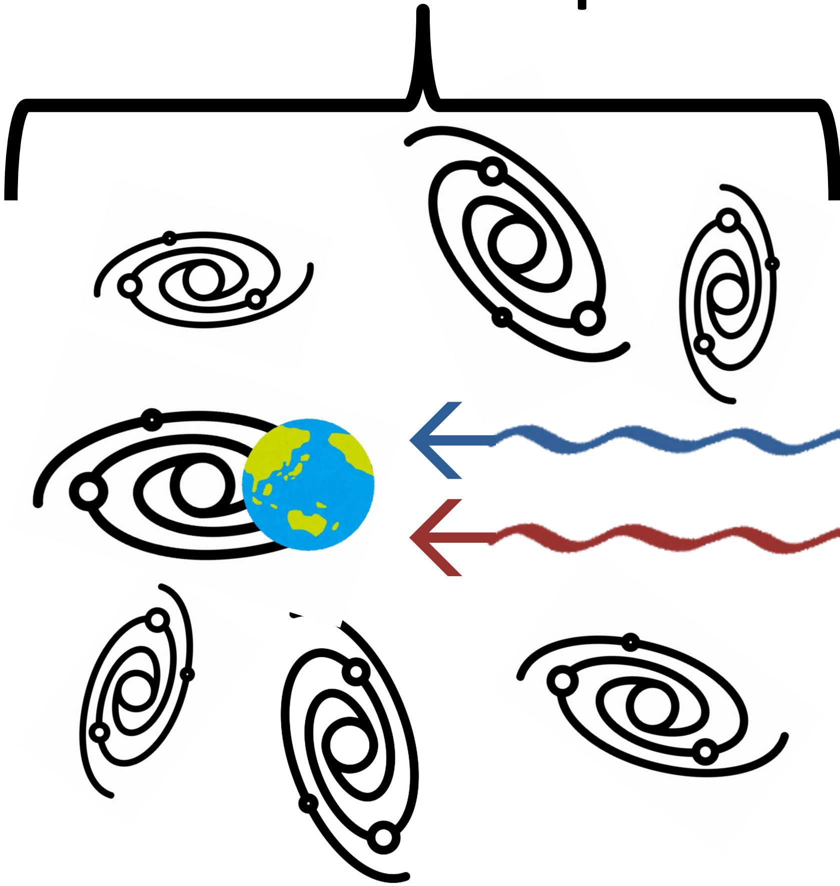
Michelson-Morley experiment

Speed of light = constant

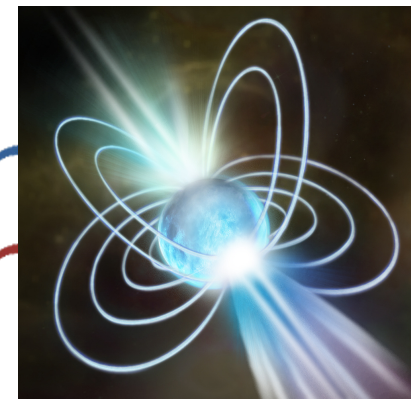
Testing the speed of light with fast radio bursts (FRBs)

Einstein's weak equivalence principle (WEP)

Gravitational potential



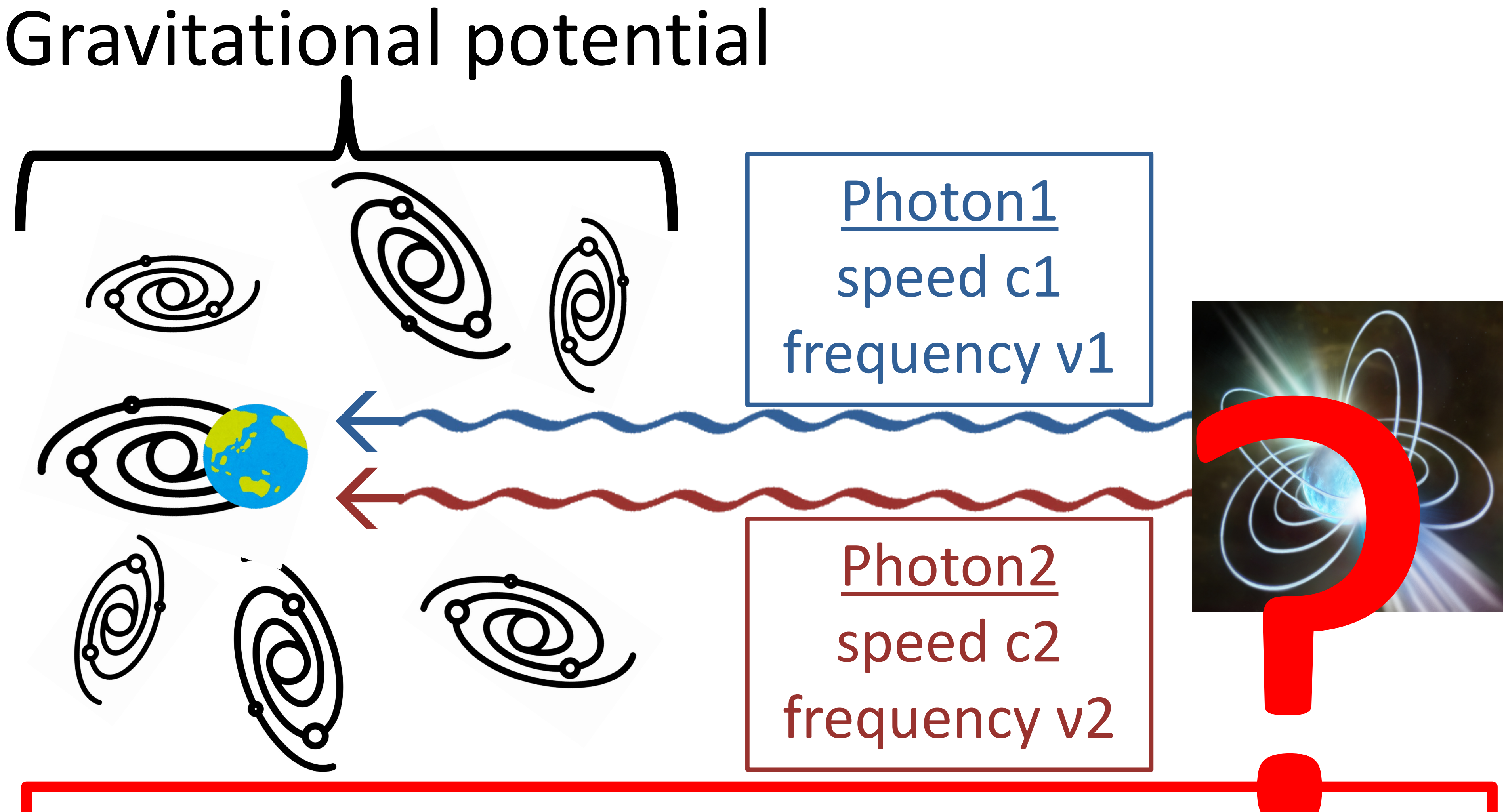
Photon1
speed c1
frequency v1



Photon2
speed c2
frequency v2

General relativity assumes c1 = c2

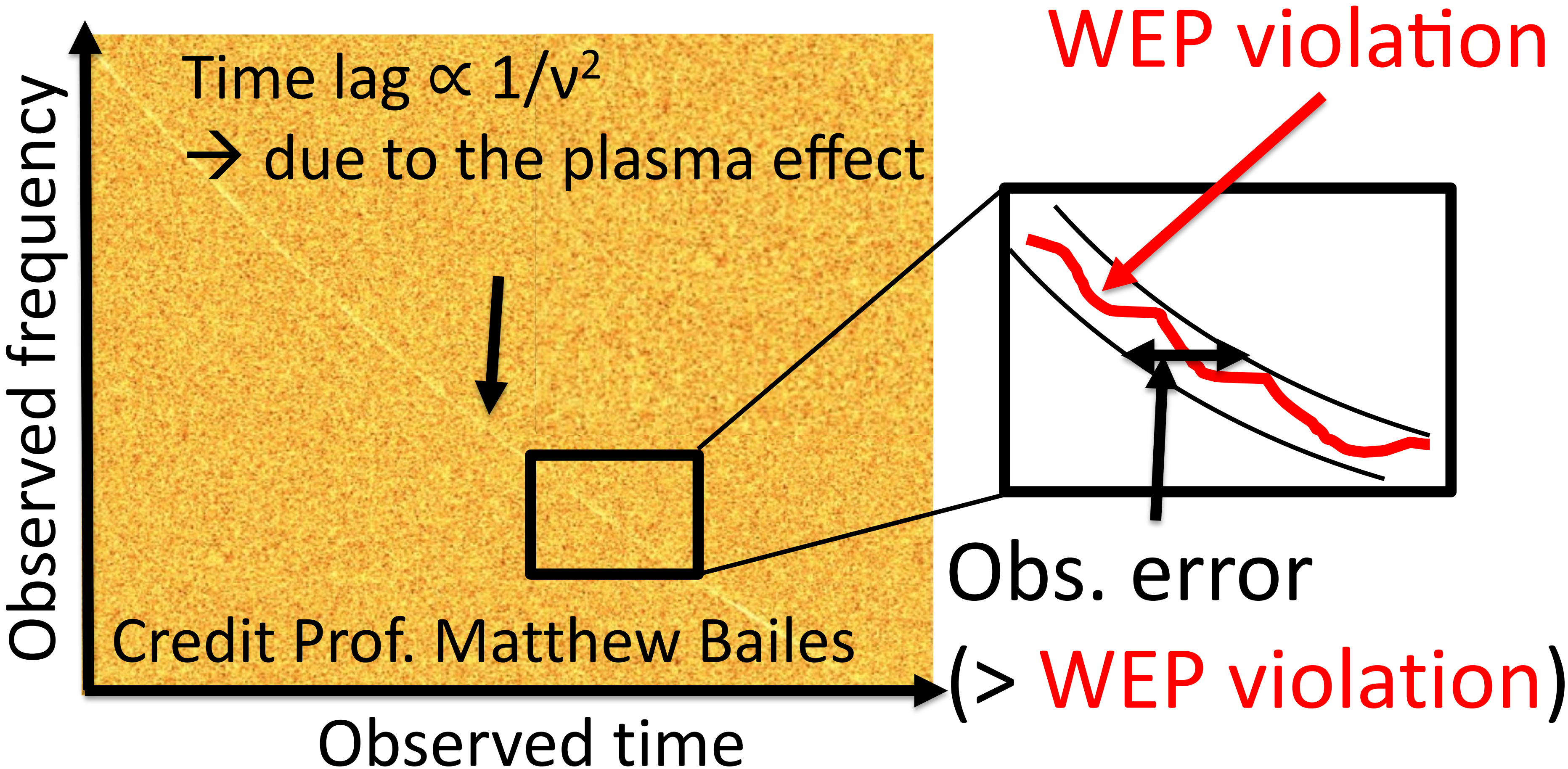
Einstein's weak equivalence principle (WEP)



General relativity assumes c1 = c2

Introduction: FRB is the ideal laboratory

because they travel the cosmological distances, and we measure millisecond timescales eventually.



Introduction: FRB is the ideal laboratory

e.g. Minazzoli+2019

$$\Delta\gamma := \gamma_2 - \gamma_1 < \left(\underline{\Delta t_{\mathrm{obs}}} - \underline{\Delta t_{\mathrm{DM}}}\right) \frac{6c^3}{\Omega_m H_0^2 \underline{d_S^3}}. \quad (7)$$

Observed time lag between ν_1 and ν_2

Time lag due to the dispersion

Distance to the source

$$\Delta t_{\mathrm{obs}} - \Delta t_{\mathrm{DM}} < \underline{\delta \Delta t_{\mathrm{DM}}}. \quad (10)$$

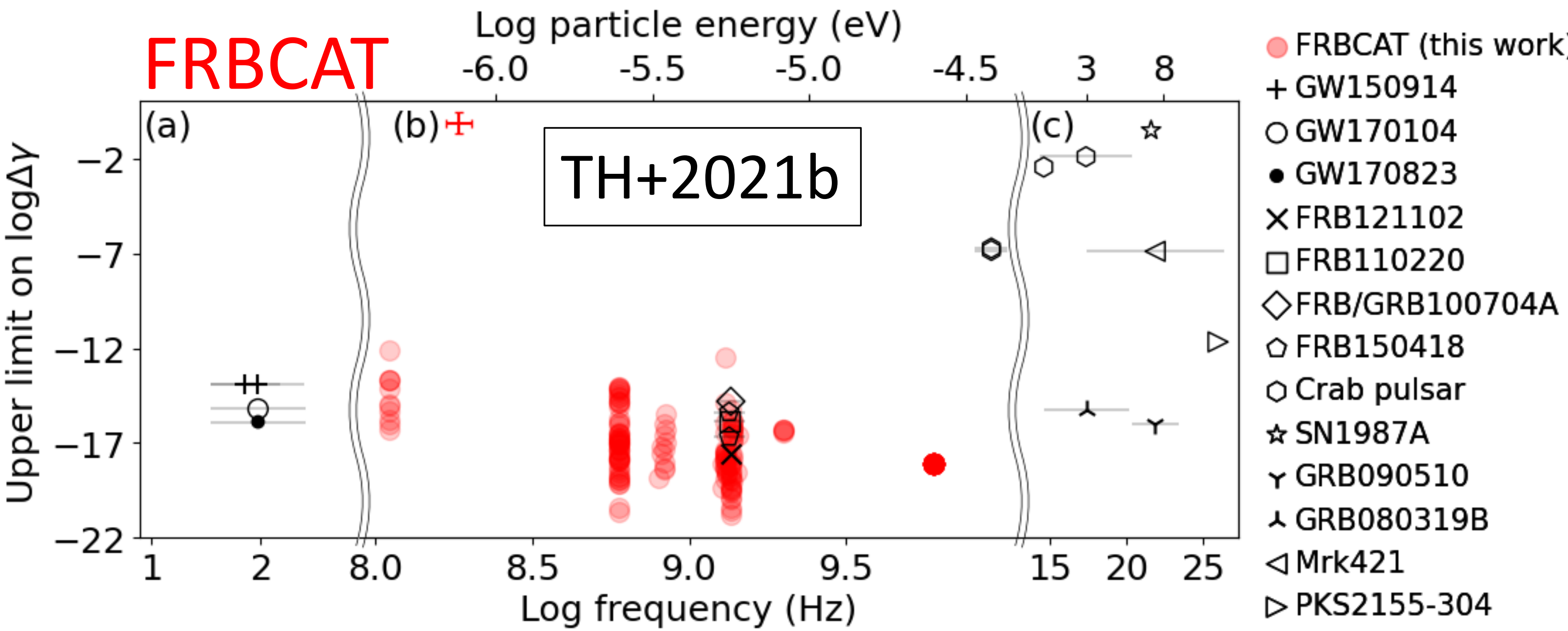
New

Observational uncertainty of the arrival time due to the uncertainty of dispersion measure

Results: the most accurate test than ever!

Δγ=γ1-γ2 for photons with ν1 and ν2, respectively

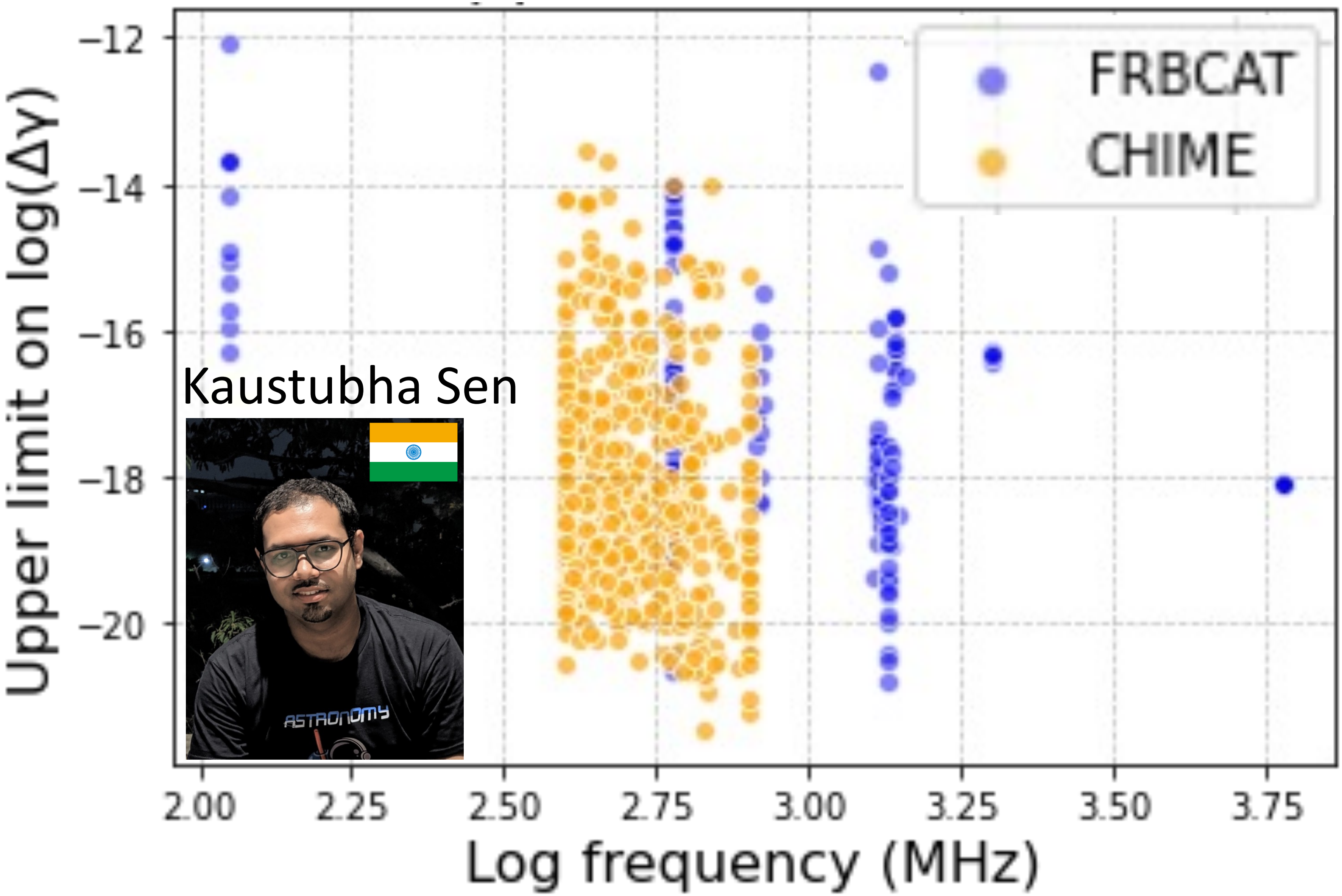
Δγ=γ1-γ2=1-1=0 if WEP is not violated



More than three order of magnitude better than previous works

Sen, TH et al. 2022

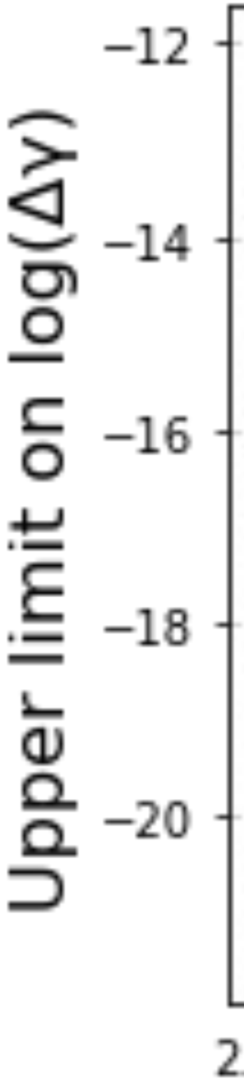
WEP with CHIME FRBs

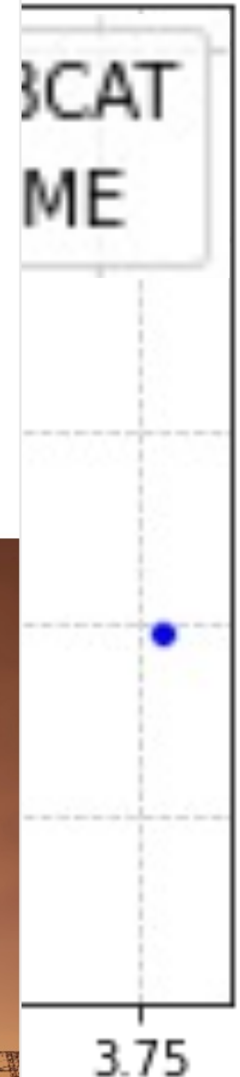


Kaustubha Sen

Sen et a

Bs



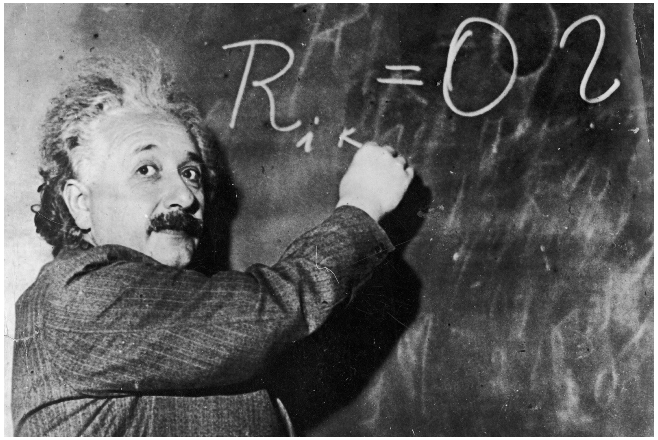


Testing Einstein's Work Using Observations of Fast Radio Bursts

Two recent papers use data from radio telescopes as a way of testing Einstein's Theory of General Relativity

Christopher Carroll Dec 5, 2021 · 5 min read ★

Conclusion:



TH+2021b

Sen, TH et al. 2022

- A new method to constrain the WEP violation using FRBs

- The most accurate test than ever:

Old catalogue: three orders of magnitude better

New CHIME: even one order of magnitude better

A future FRB telescope in Taiwan BURSTT

What are the bottlenecks?

- 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

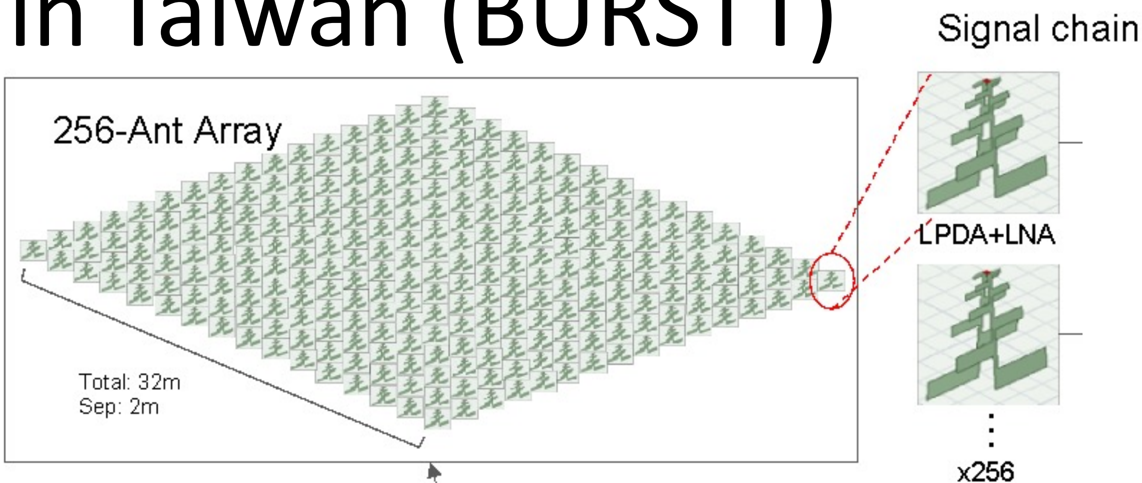
  GWs, neutrinos, high-time resolution follow-up

  --> nearby Universe

cf. Sota's and Yuu's talks

Future FRB telescope in Taiwan

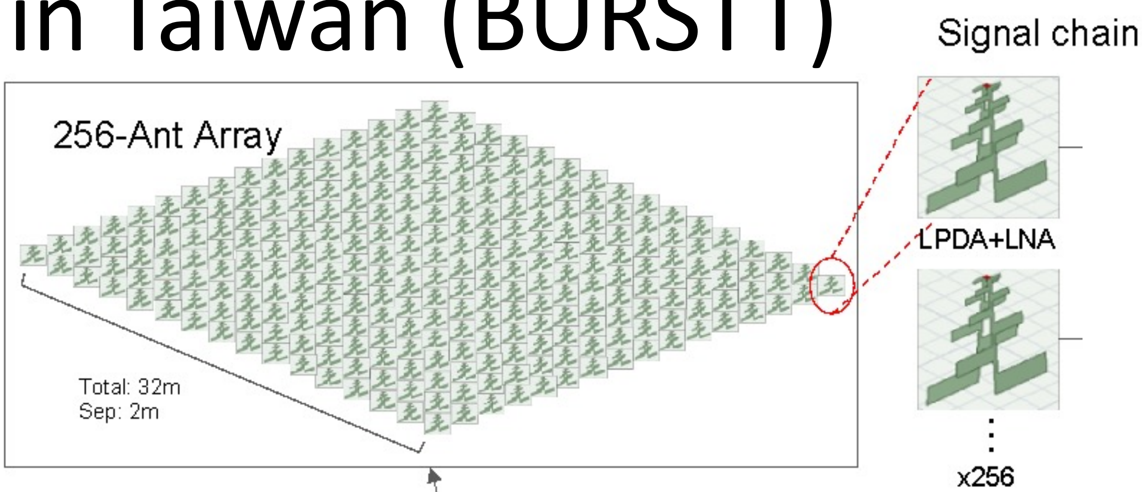
Bustling Universe Radio Survey Telescope in Taiwan (BURSTT)



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

cf. Sota's and Yuu's talks

Predictions of BURSTT FRBs

Bustling Universe Radio Survey Telescope in Taiwan (BURSTT)

Number prediction of gravitationally lensed FRBs

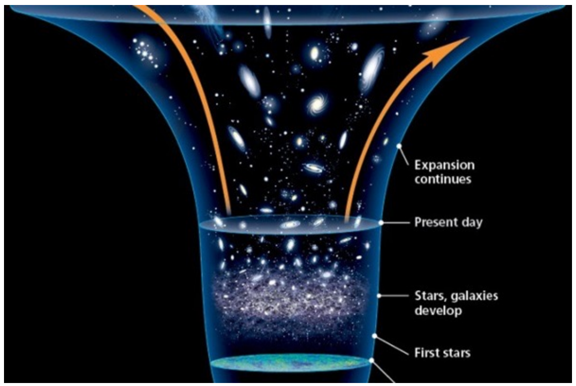
Number prediction of Galactic FRB-like events

Simon C.-C. Ho

Decmend Lin

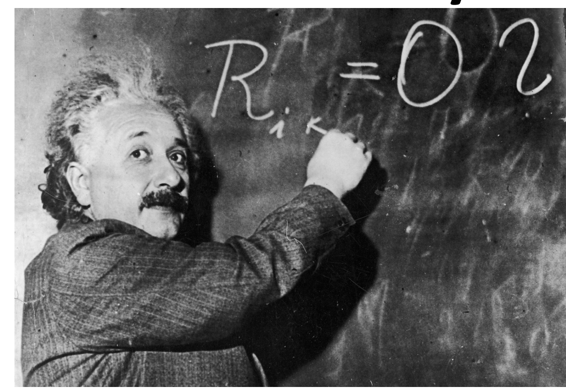
Conclusion: *FRB science is exciting*

Dark energy

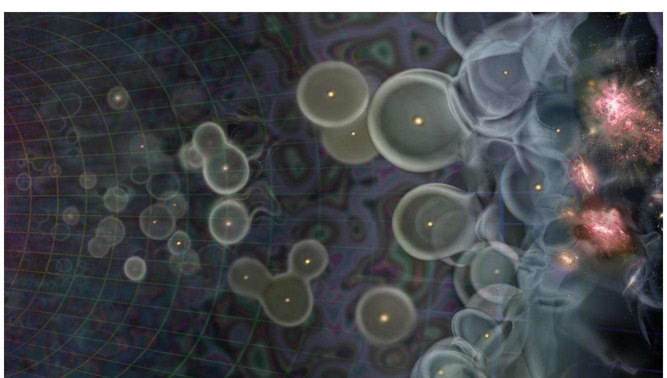


Missing baryon problem

General relativity



Cosmic reionization



Dark matter

The origin of FRBs

Backup slides

Redshifts derived from dispersion measures