Statistical inference of fast radio burst environments using galaxy number density: similarities between CHIME repeaters and non-repeaters

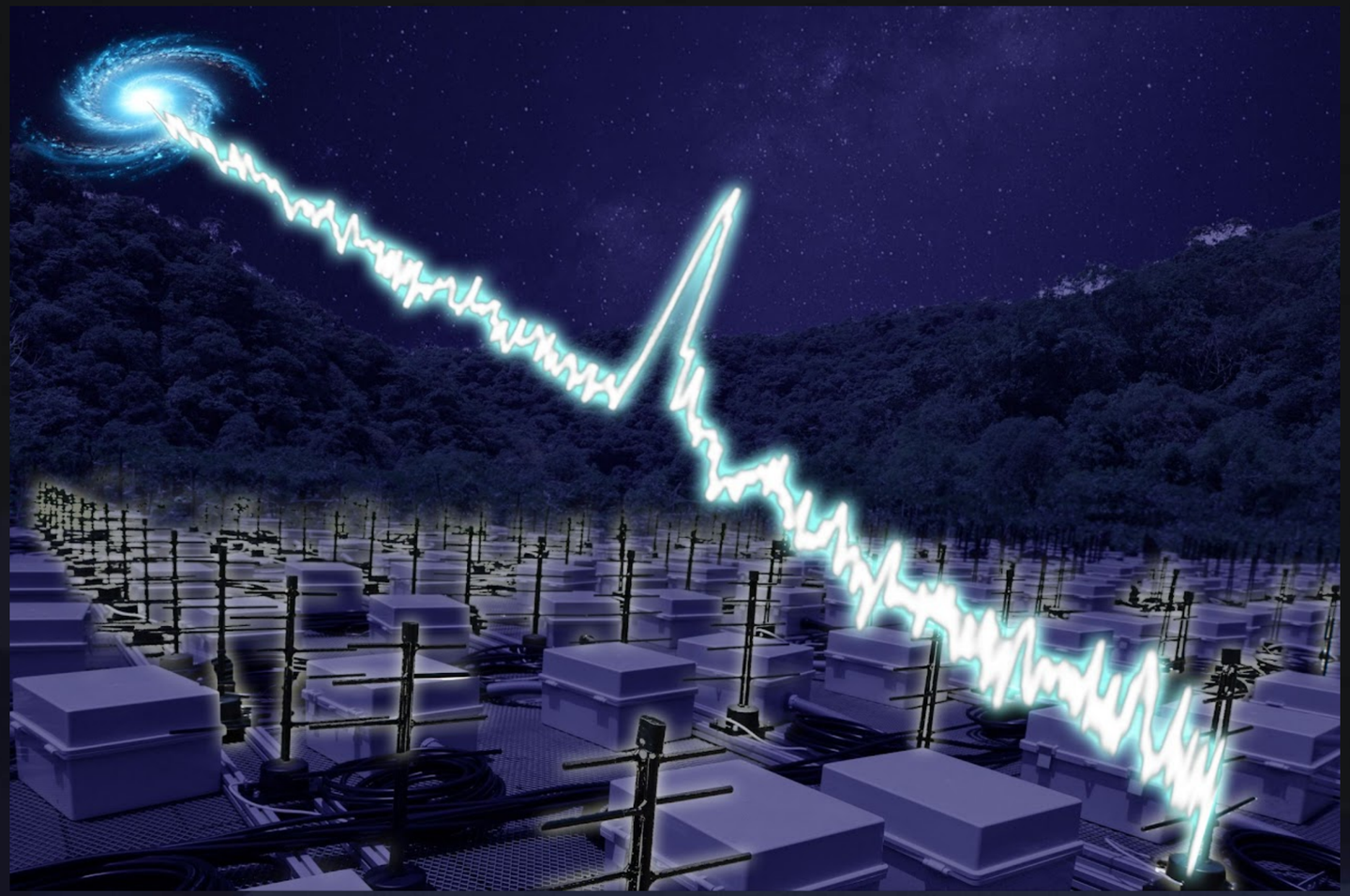
Vignesh V V*

National Chung Hsing University

Tetsuya Hashimoto, Tomo Goto,Shotaro Yamasaki,Mohanraj Madheshwaran,Tzu-Yin Hsu, Sridhar Gajendran,Simon C.-C. Ho,Terry Long Phan, Hiroto Masaoka, Amos Y.-A.Chen, and Tomoki Wada

Fast Radio Bursts

- Millisecond bright radio pulses from cosmological distances
- High all sky event rate (more than 1000 events/day)
- Two types of FRBs based on their repetition nature
  - Repeaters
  - Non-repeaters



An image of a fast radio burst
Image credits: Tomo Goto

Possible progenitors of repeaters and non-repeaters

Repeater ⟷ Non-repeater

Image credits: Shotaro Yamasaki

Different?

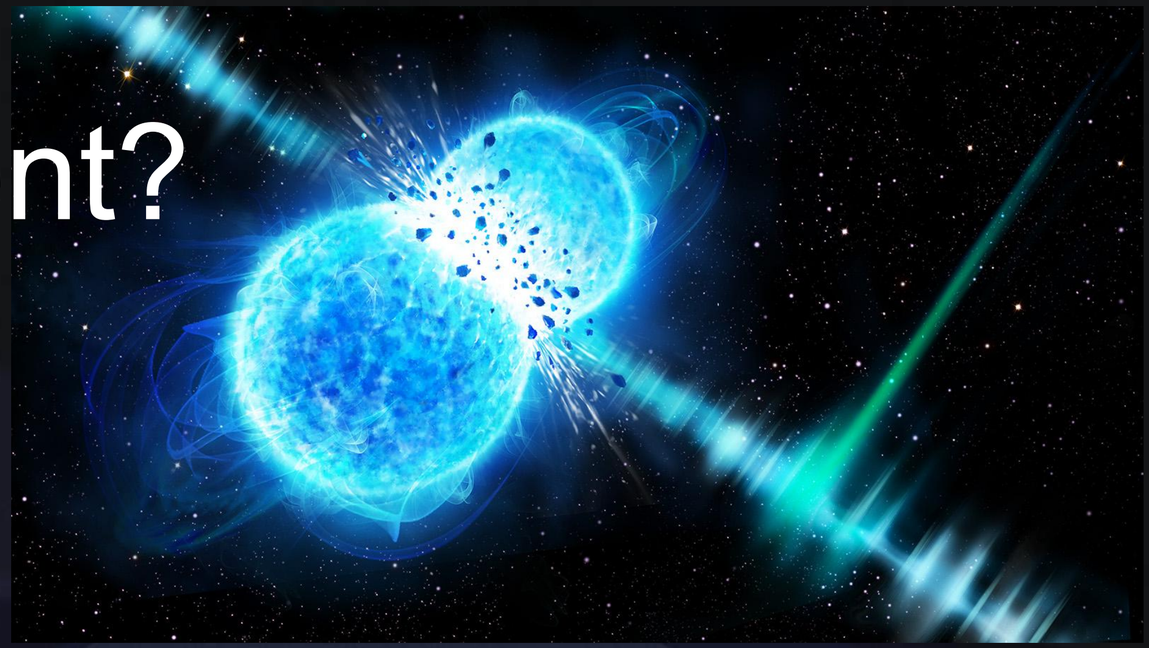


Image credits: Shotaro Yamasaki

Important to understand the difference/similarity

Our work (schematic picture)

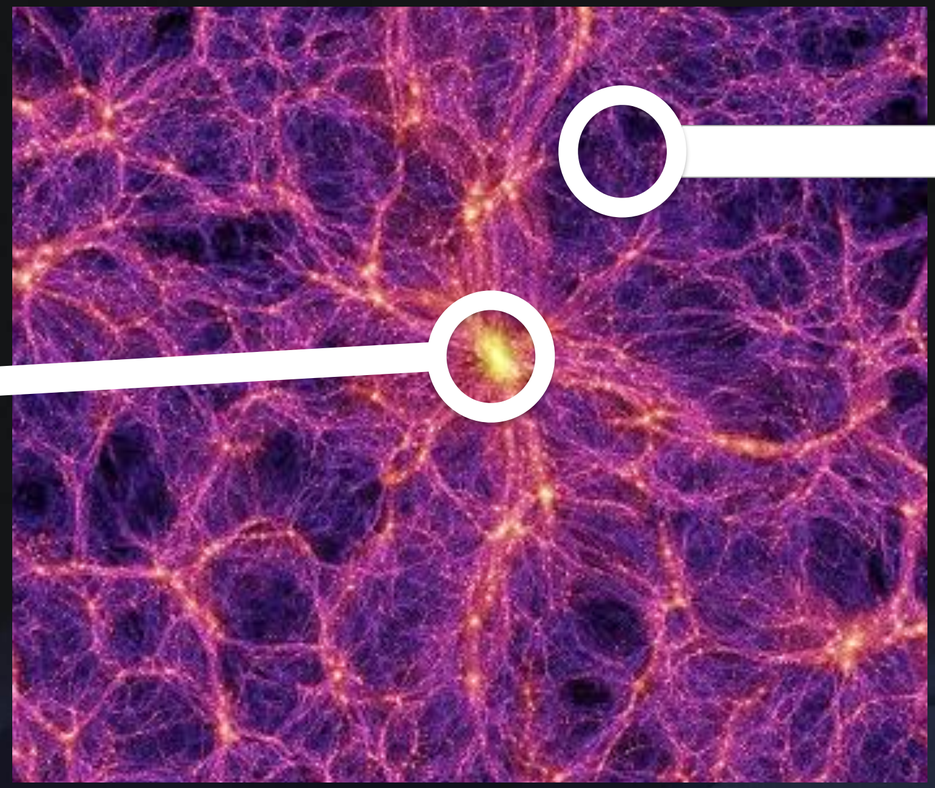


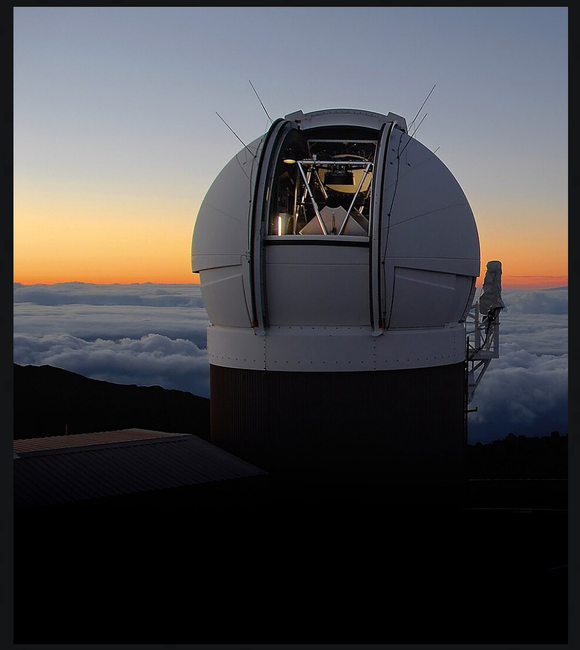
Image credits: Volker Springel / Max Planck Institute For Astrophysics

Do the one off FRBs and repeater FRBs live in same or different environment???

FRB sample selection

Sky map of CHIME FRB catalog-1
Image credits:CHIME Collaboration

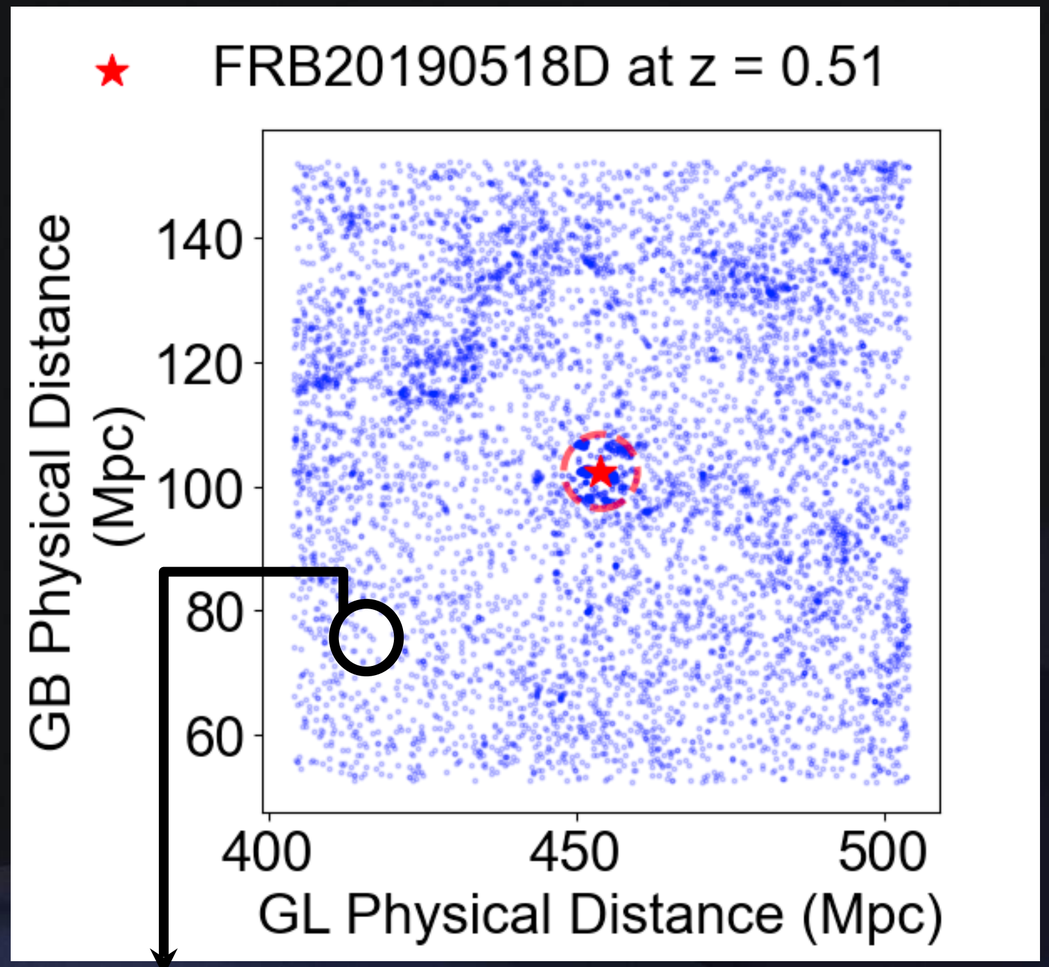
Galaxies sample selection



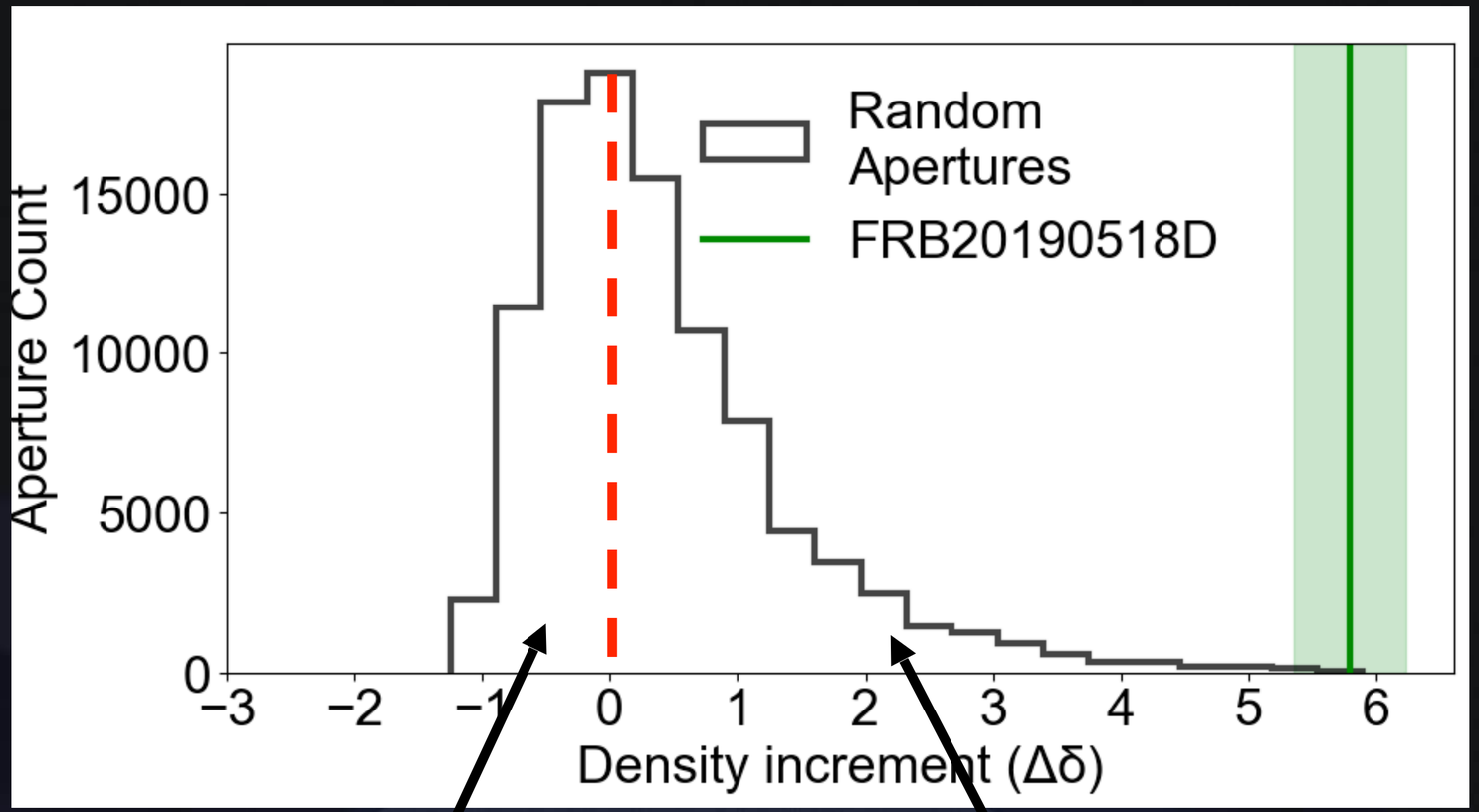
WISE X PS1
Image credits: NASA/JPL-Caltech (WISE) R. Ratkowski - Pan-STARRS Observatory (PS1)

- Improved sample size by a factor of 2 (non-repeaters (238) and repeaters (26)) (CHIME/FRB Collaboration et al. 2021 golden samples(Chime/FRB Collaboration et al. 2023))

Example of an FRB sample: density increment



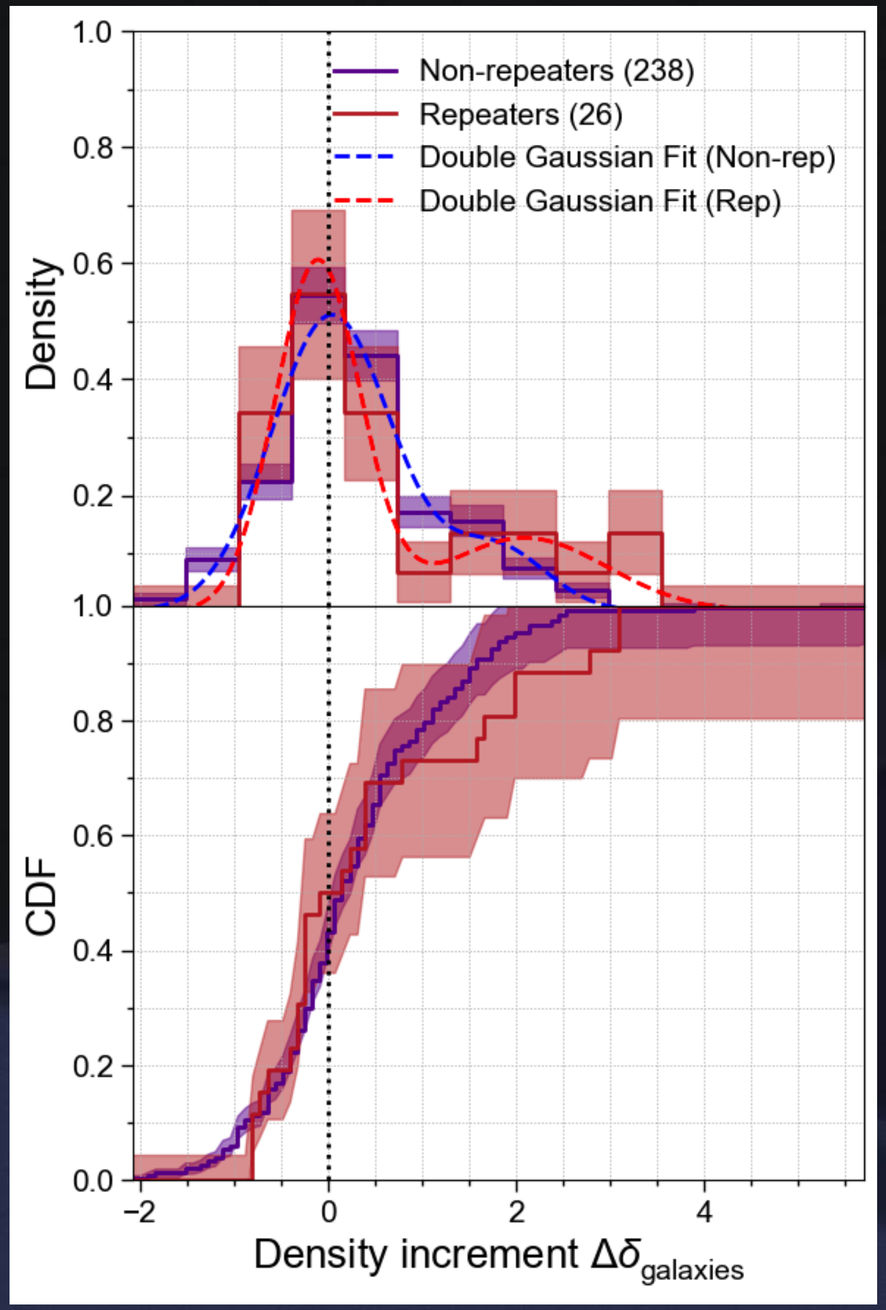
Random aperture



Low density

High density

Result 1



KS test: repeater v.s. non-repeater

↓

p-value: 0.405

↓

No significant differences found

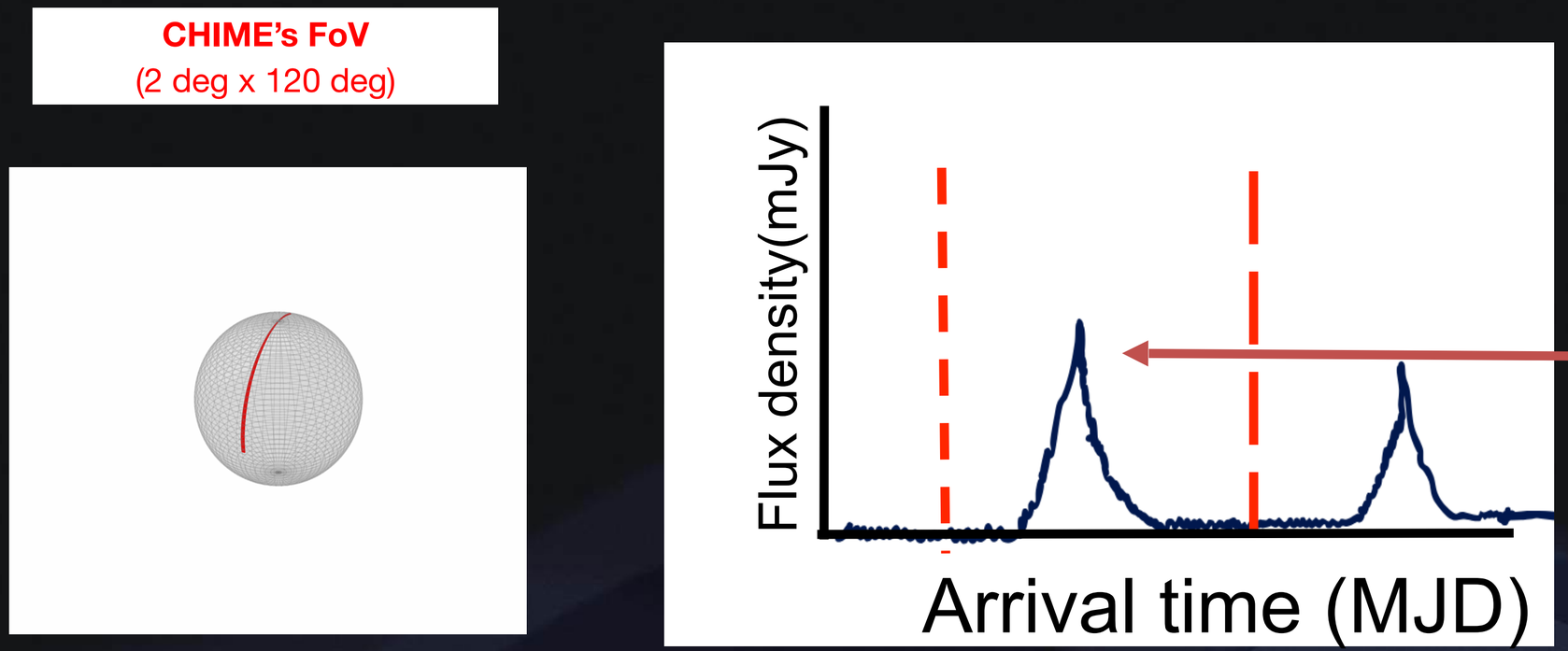
Discussion

Do both repeaters and non-repeaters live in same galactic environment????

We found no significant difference between them however

Are CHIME non-repeaters contaminated by repeaters? (eg.,Yamasaki et.al, 2024)

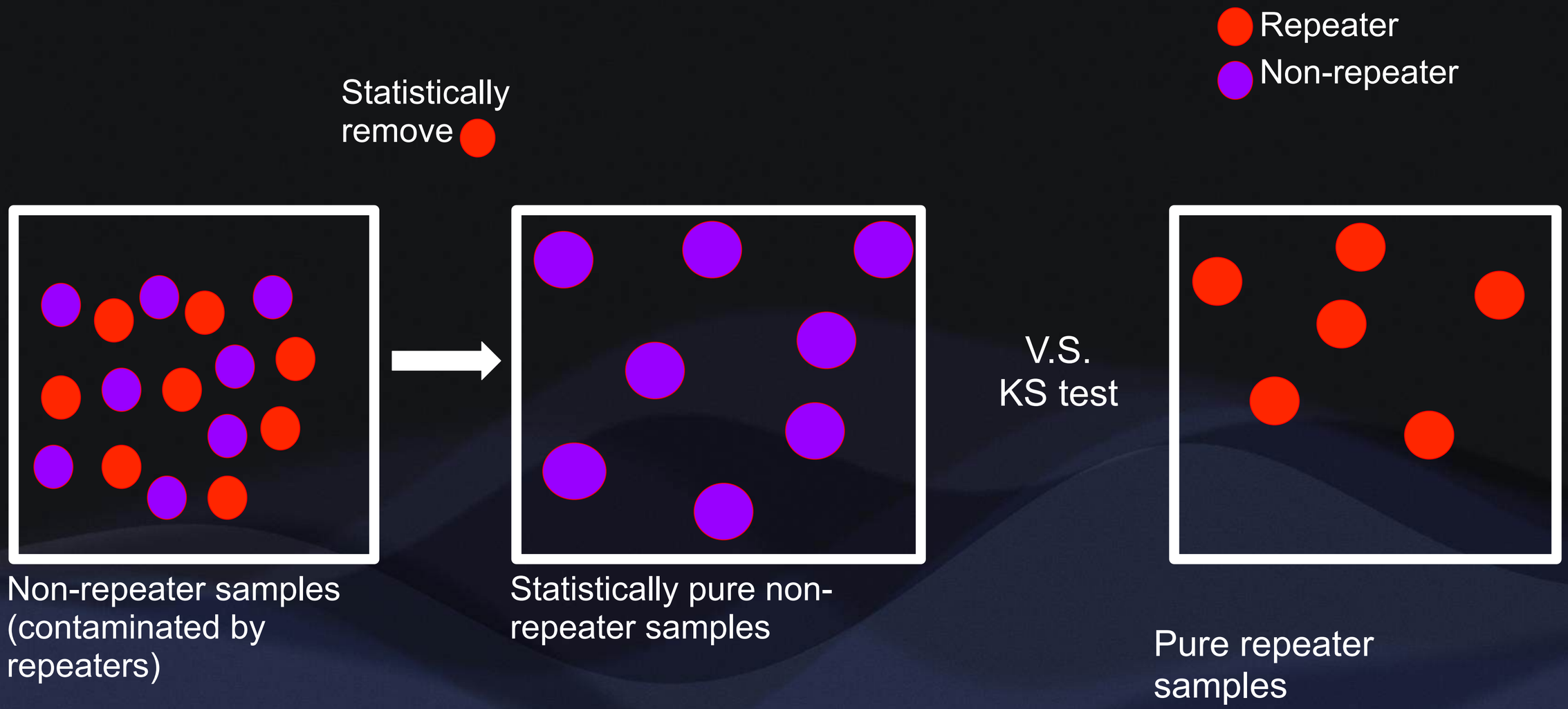
Discussion: (Concept) possible contamination of repeaters in non-repeaters



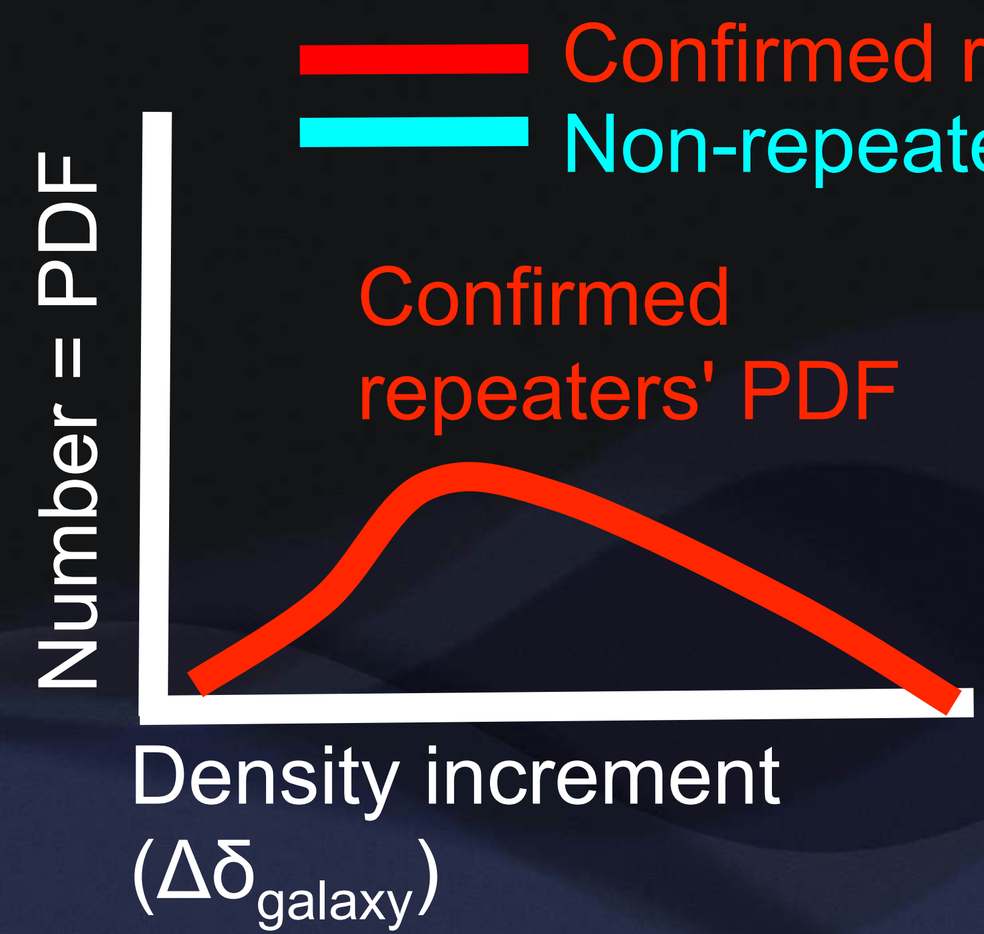
A schematic representation of misclassification of repeaters

- Assumed 50% of non-repeaters tend to repeat according to the previous literatures (eg.,James 2023; Yamasaki et al. 2024)
- Removed 50% of non-repeater sample from our analysis

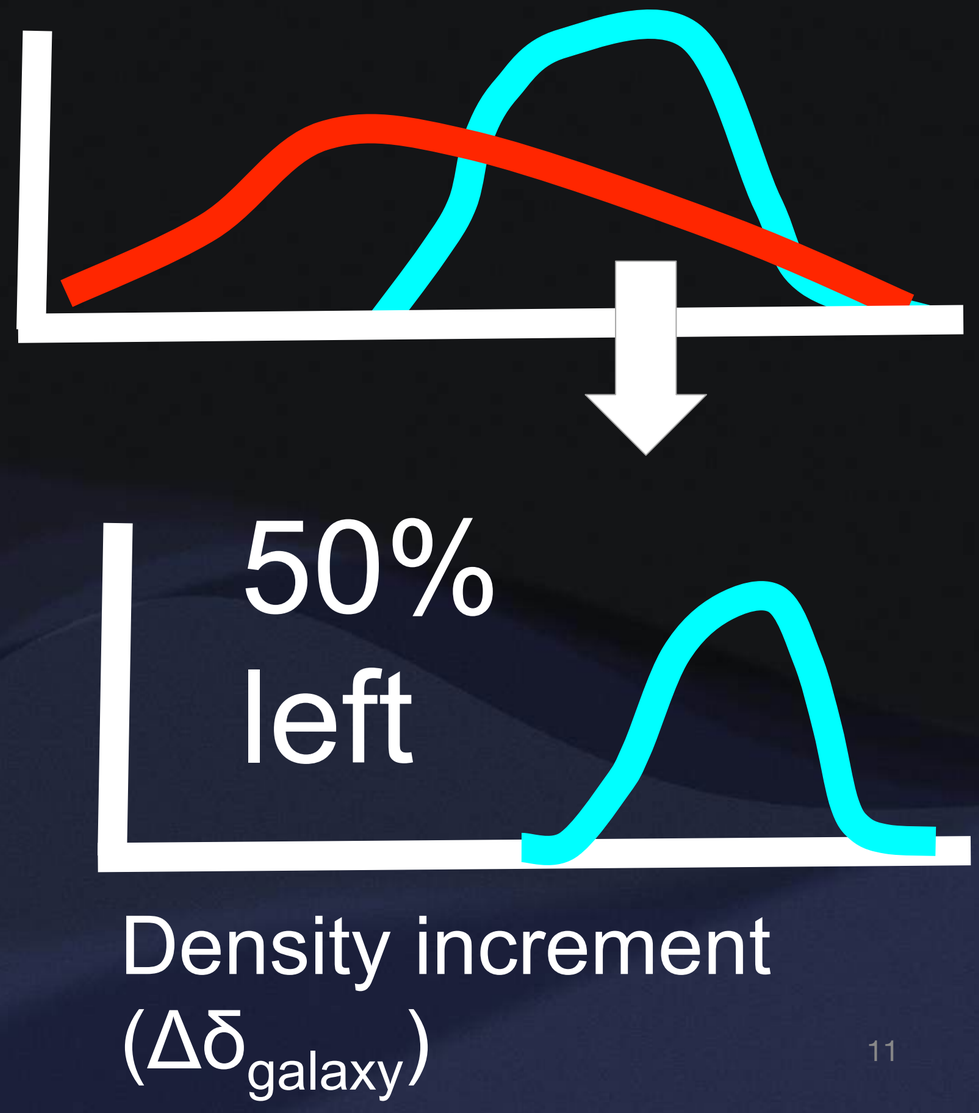
Discussion: (Concept) Removing possible contamination of repeaters in non-repeaters



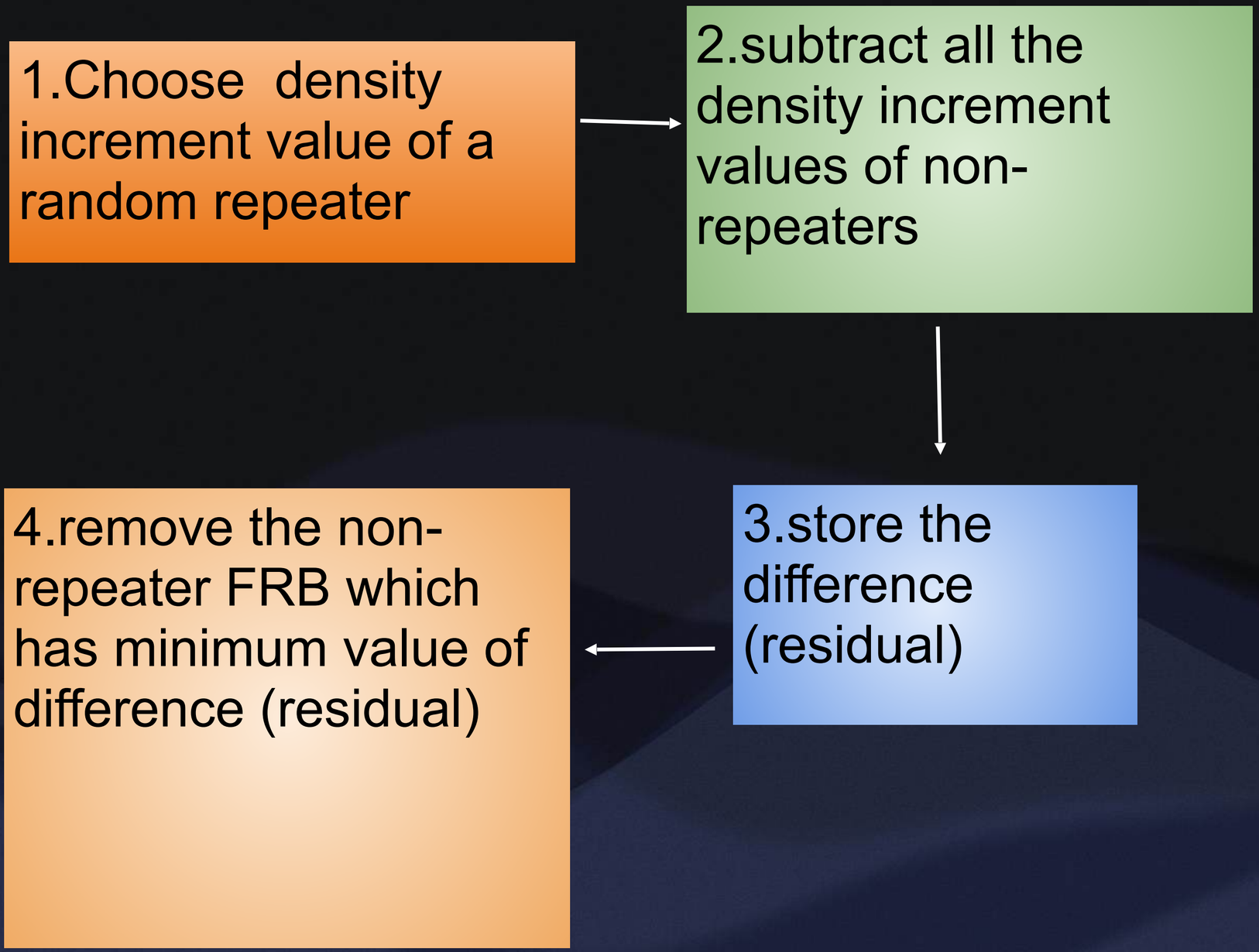
Schematic picture of the process

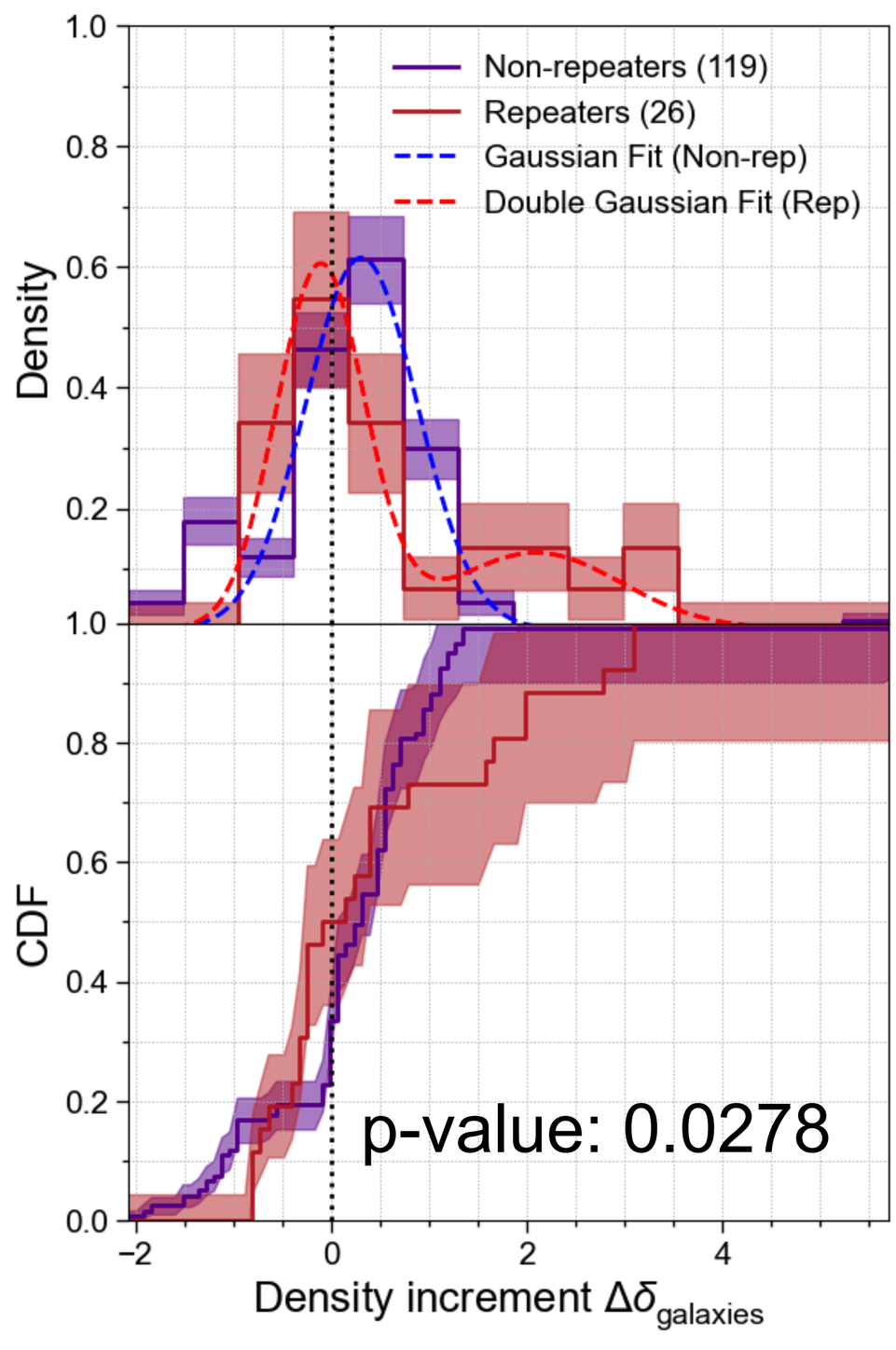


Remove 50% non-repeaters following the repeater's PDF



Flow chart of the removal process





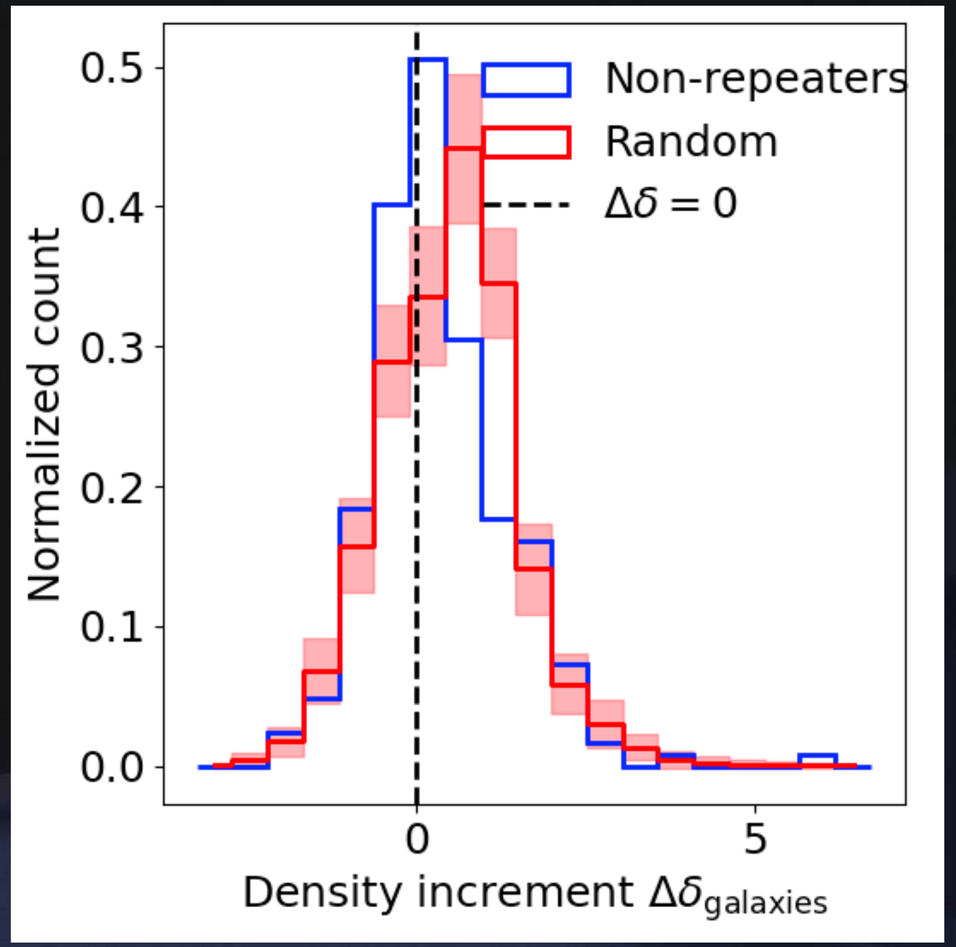
Galactic environment of repeaters ≠ Galactic environment of non-repeaters

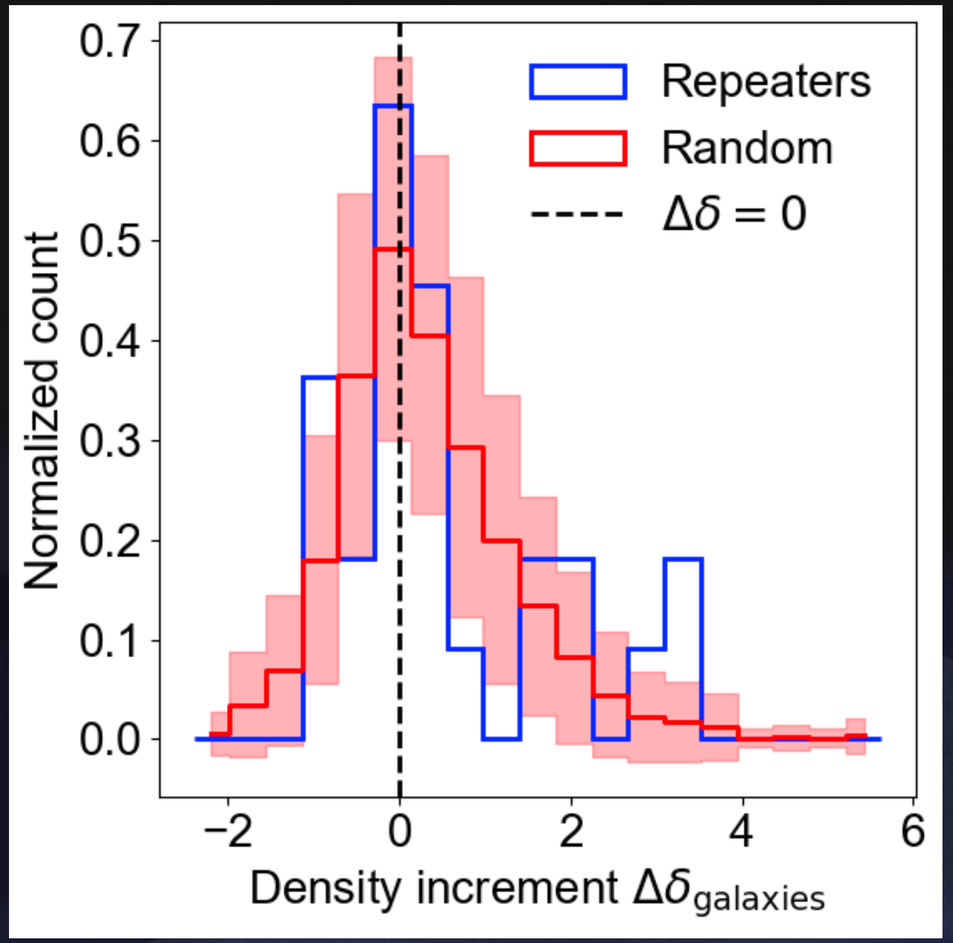
Repeaters v.s. Non-repeaters

Repeaters → low dense environment

Non-repeaters → high dense environment

Result 2: Comparison of density increment values of FRB to randomly selected galaxies





KS test: FRBs v.s. random

p-value: 2.78×10^{-2}

p-value: 0.4

Conclusions

- New statistical approach → galactic environments of repeaters and non-repeaters
- Significant difference in galactic environment of FRBs → might suggest the different progenitor type for repeaters and non-repeaters

Future works

- Compare the galaxy number density around FRBs with that of different progenitor scenarios such as AGNs, supernovae (SNe), and long gamma-ray bursts (LGRBs).

- Investigate possible correlations between FRB environments and these progenitor types to constrain the underlying mechanisms responsible for FRBs.

Backup slides

Possible Progenitor candidates

White dwarf etc=Old celestial object

White dwarf

Neutron star

Black hole (BH)

Magnetar etc=Young celestial object

Magnetar

Young pulsar

Super massive BH

Supernova remnant

Credit: Tetsuya Hashimoto

FRB sample selection

For data we use Canadian Hydrogen Intensity Mapping Equipment (CHIME)

- The FRB is located within the sky coverage of WISE ×PS1
- |b| > 20 degree
- 0<z < 0.8
- Removed the FRB samples which have negative values of redshifts also which has abnormal distribution of galaxies as keeping it could bring uncertainties in number density calculations.

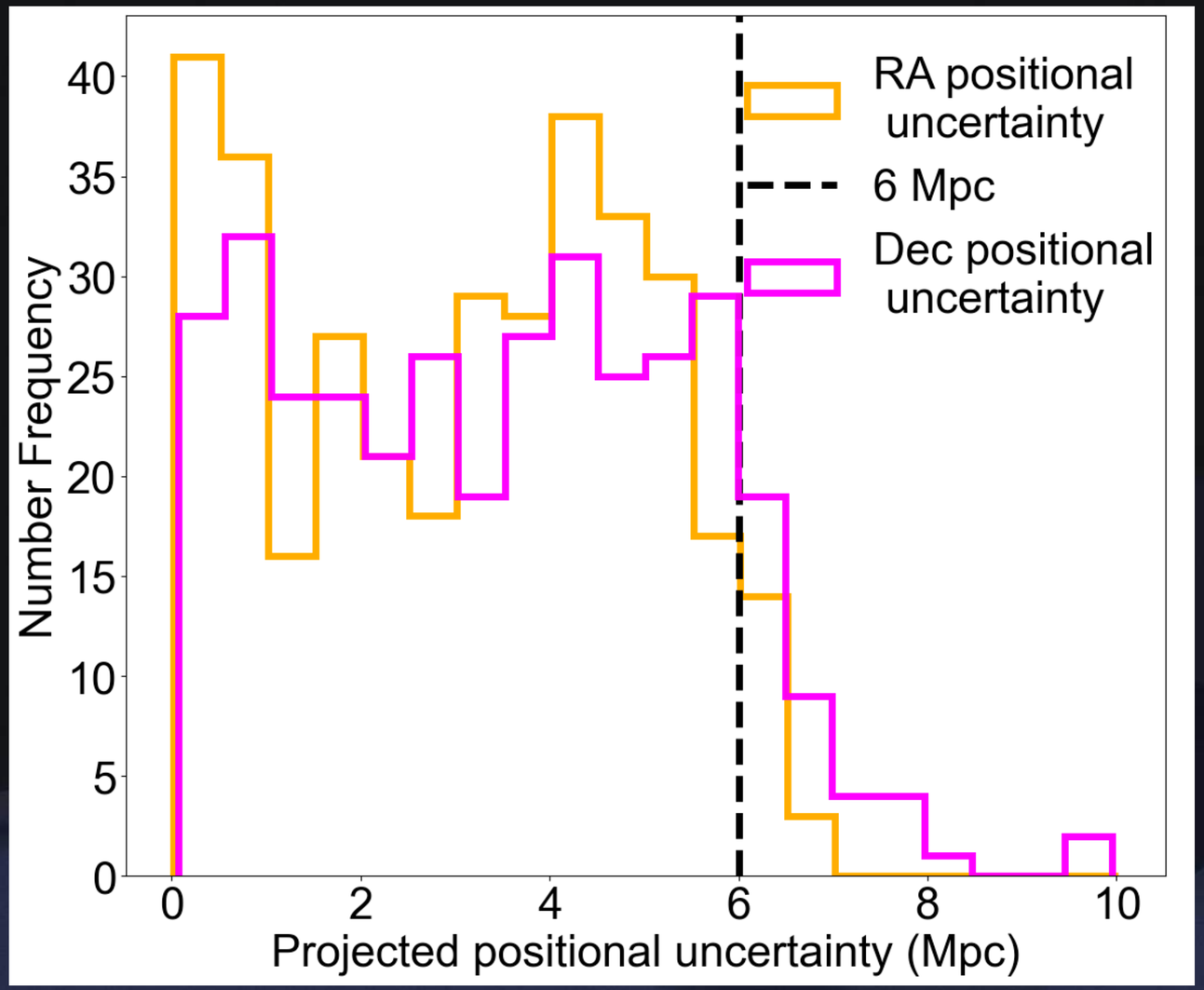
Galaxies sample selection

For data we use WISE x PS1 catalog.

- The galaxies are selected inside a 100x100 Mpc^{-2} around the position of FRB with the help of angular diameter distance
- The galaxy samples inside this region are subjected to a vega magnitude cut of W1 < 16.8 magnitude.
- A redshift cut was made with the help of FRBs error in redshift and galaxies are selected within this redshift

- Improved sample size by a factor of 2 (non-repeaters (238) and repeaters (26)) (CHIME/FRB Collaboration et al. 2021 golden samples(Chime/FRB Collaboration et al. 2023))

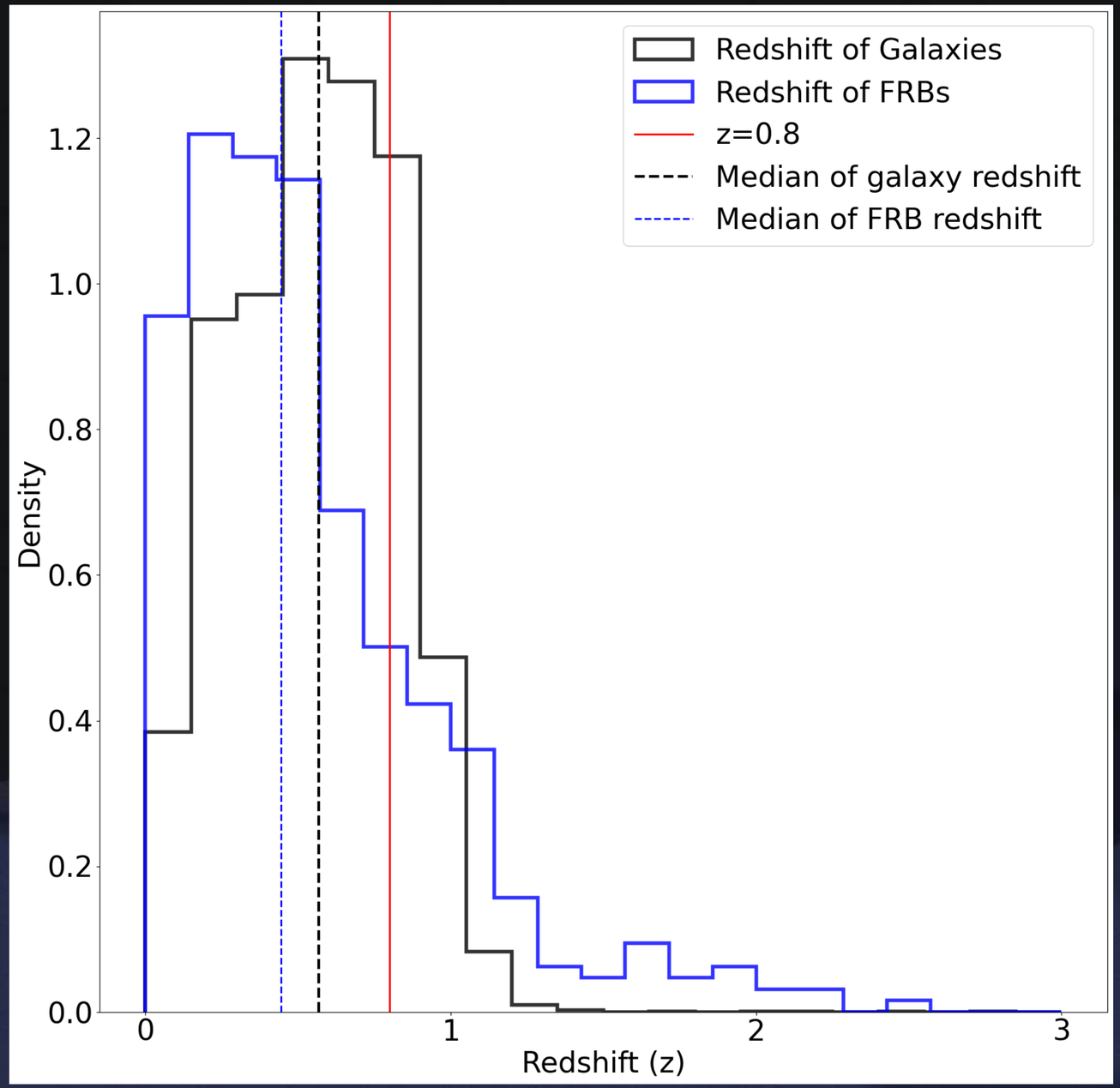
Positional Uncertainties of FRB



Mostly(~90%) the positional errors of CHIME FRB < 6Mpc

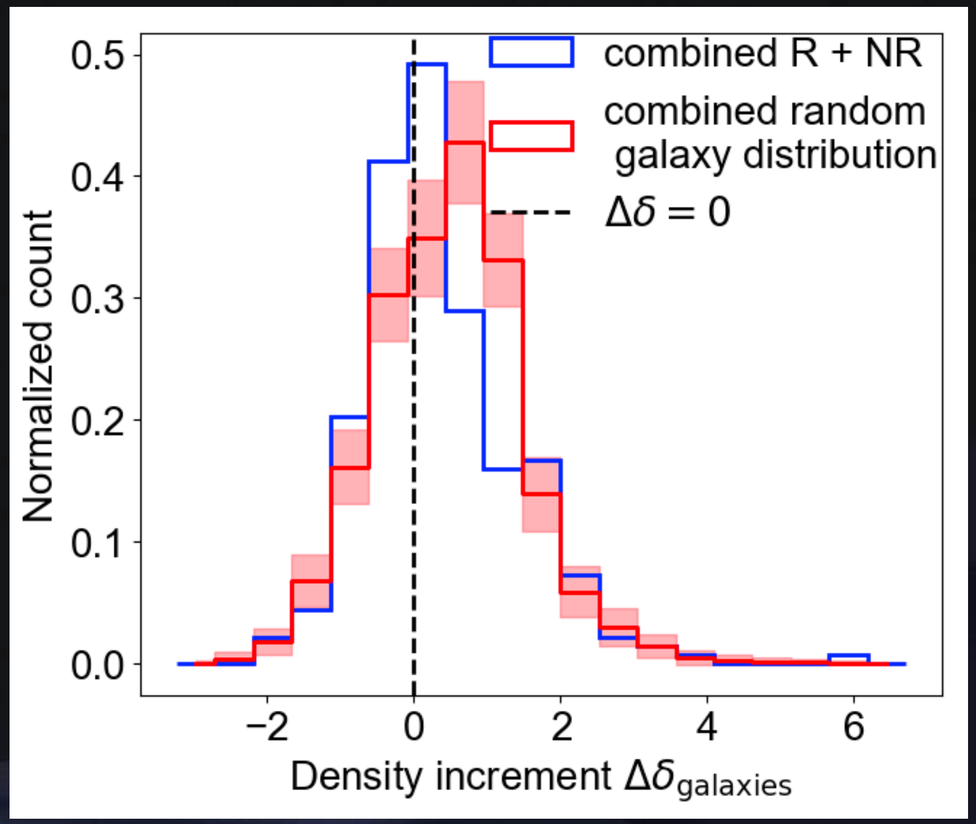
Used this 6Mpc value to create a aperture and calculate

Redshift selection of FRB



- More than 80% galaxies and 78% of FRBs are inside the redshift of 0.8
- As a result we selected a redshift cut of 0.8, due to the fact that completeness of the data decreases beyond this redshift value of the galaxies

Result 2: Comparison of density increment values of FRB to randomly selected galaxies

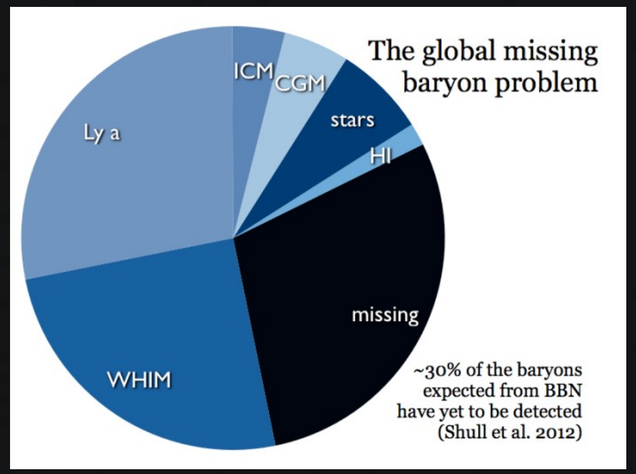


FRBs are different from random galaxy density increments

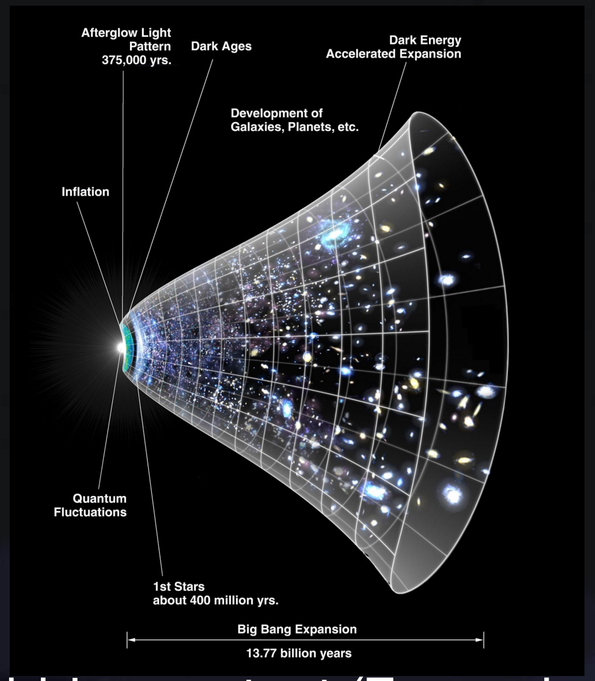
KS test: FRBs v.s. random

p-value: 2.78×10^{-2}

Applications of Fast Radio Bursts

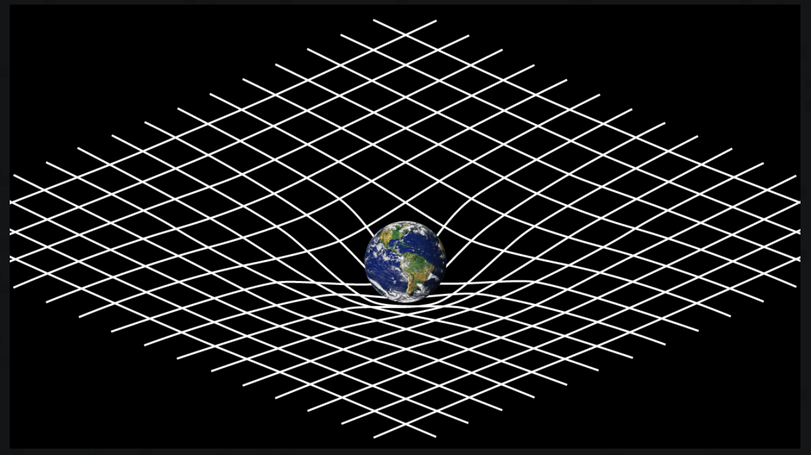


Missing Baryon problem (Shull et al. 2012)

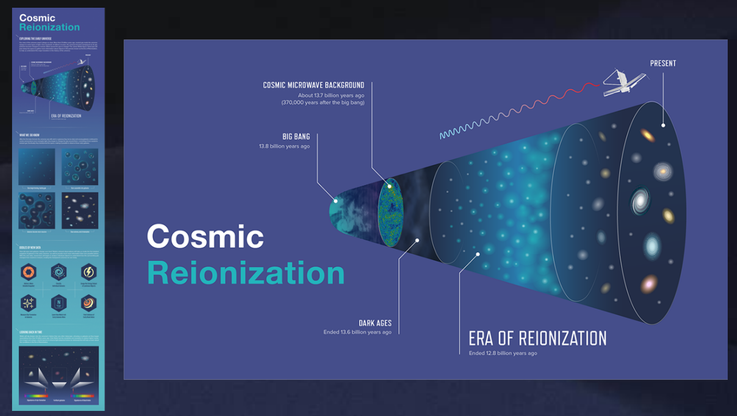


Hubble constant (Expansion of the universe)
Credit: NASA/WMAP Science Team/ Art by Dana Berry

Also refer Yang, T.-C., Hashimoto, T., Hsu, T.-Y., Goto, T., Ling, C.-T., Ho, S. C.-C., … Kilerci, E. (2024). Constraining the Hubble constant with scattering in host galaxies of fast radio bursts. *arXiv E-Prints*, arXiv:2411.02249. doi:10.48550/arXiv.2411.02249



General relativity (Weak equivalence principle)
Credit: NASA (Hashimoto et al., 2021.)



Cosmic reionization
Credits: NASA, ESA, CSA, Joyce Kang (STScI)

Dark matter
Credits: sakkmesterke/iStock
Ho, S. C.-C., et al. (2023). *The Astrophysical Journal, 950*(1), 53.