Testing the Young FRB Progenitor Hypothesis: A Crossmatch of Catalog-1 CHIME Bursts with Historical Local Universe Supernovae

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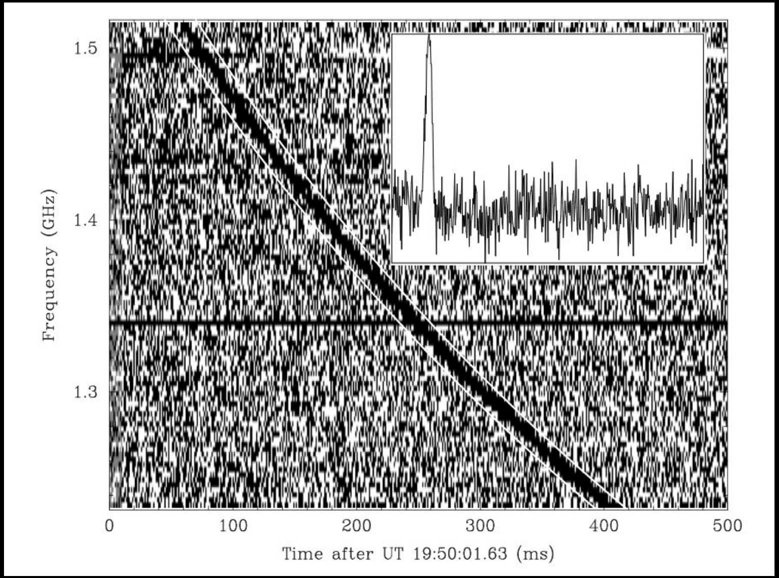
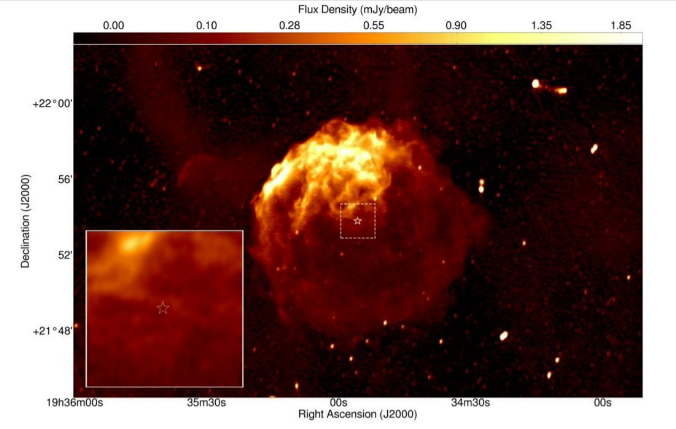
Fast Radio Burst (FRB)

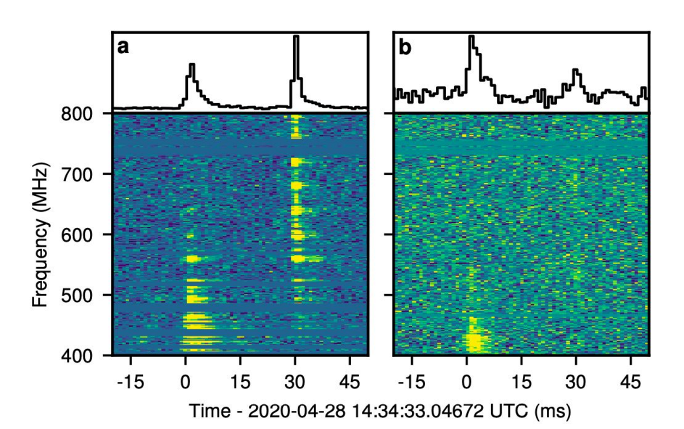
- Intense burst of radio waves of millisecond duration
- Originated from extragalactic Sources (> 1 Mpc)
- First reported in 2007 [1]
- As of today, astronomers have detected over 1,000 frbs
- **Origin still unknown!**
- The most promising potential origin of FRB: young magnetar



Observations

1. **FRB-like emission detected from a known magnetar formed from core-collapse supernova (SGR 1935+2154)**
2. Host galaxies where FRBs were formed are mostly star-forming galaxies
3. Several FRB models [1] propose that **young** (< 1000 yrs) and highly magnetized neutron stars can produce FRBs





Hypothesis

Young magnetars formed from core-collapse supernovae are sources of FRBs

Methodology:

cross matching catalog-1 CHIME FRBs with type II and type I core-collapse historical supernovae.

Canadian Hydrogen Intensity Mapping Experiment (CHIME)

- A transient telescope for FRBs
- **Area: 800 m^2**
- **Field of view: ~ 200 deg^2**
- Surveying the northern sky in the 400–800 MHz band

Catalog-1: 474 non-repeating FRBs

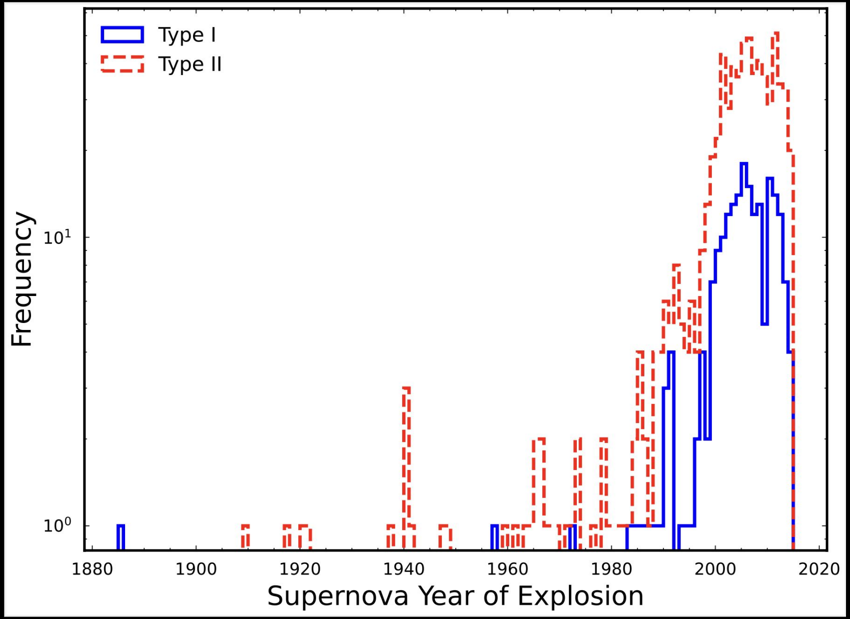
128 baseband Localization

2 side-lobes FRBs localization

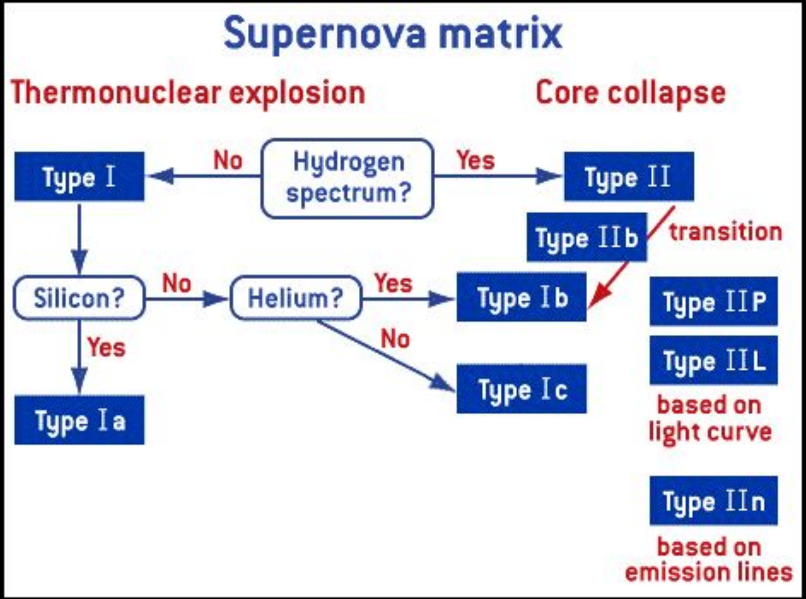
344 header localization

SAI Supernova Catalog

6546 pre-2014 Supernovae in total



Include only **Type II** and **Type I core-collapse SNe**



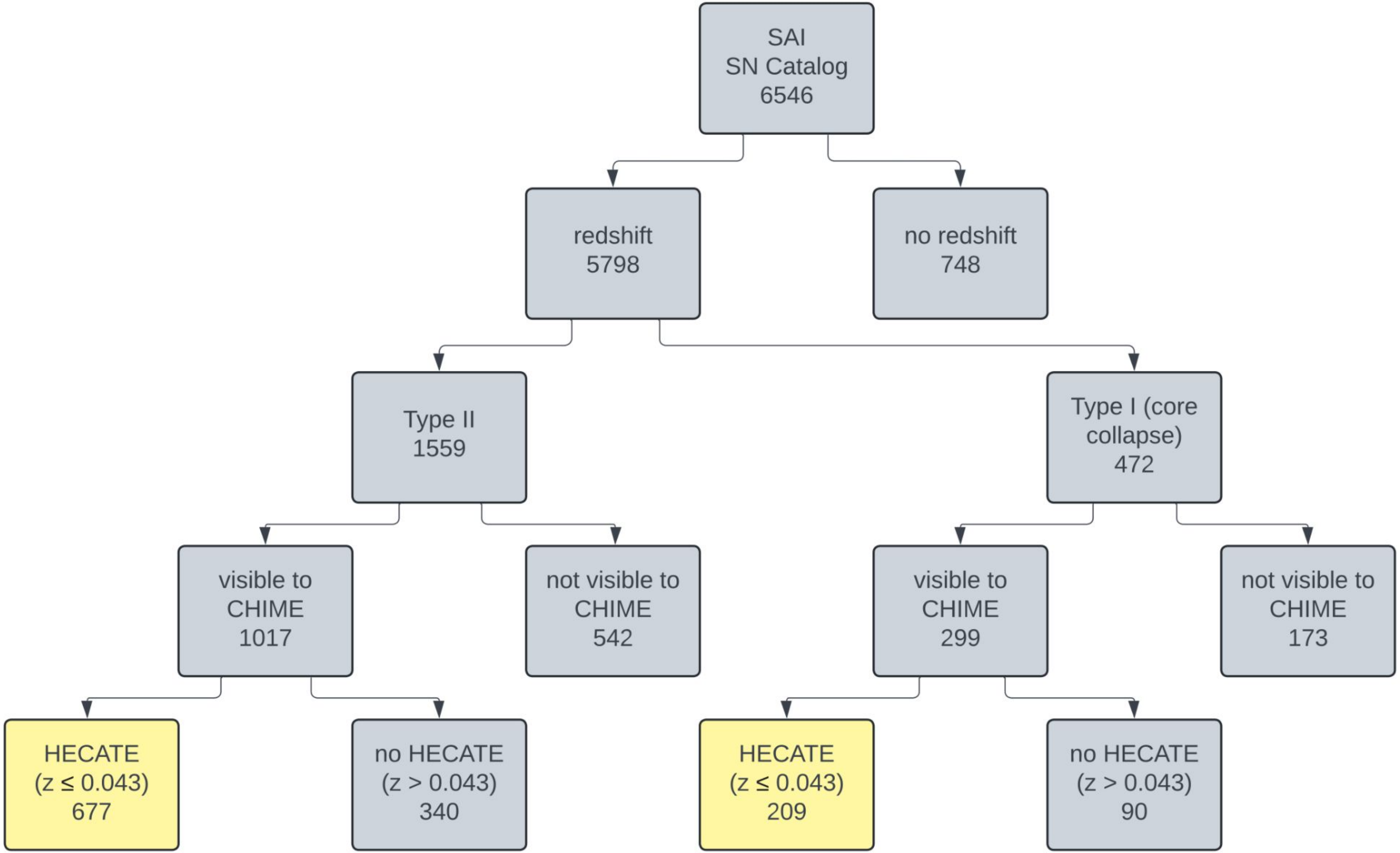
Criteria for Data Sampling

SNe:

- Redshift existence in SAI catalog
- Type II and Type I core-collapse SNe
- Visibility to CHIME
- Host Galaxy properties detectability by HECATE Catalog
- Redshift ≤ 0.043 (200 Mpc)

FRB:

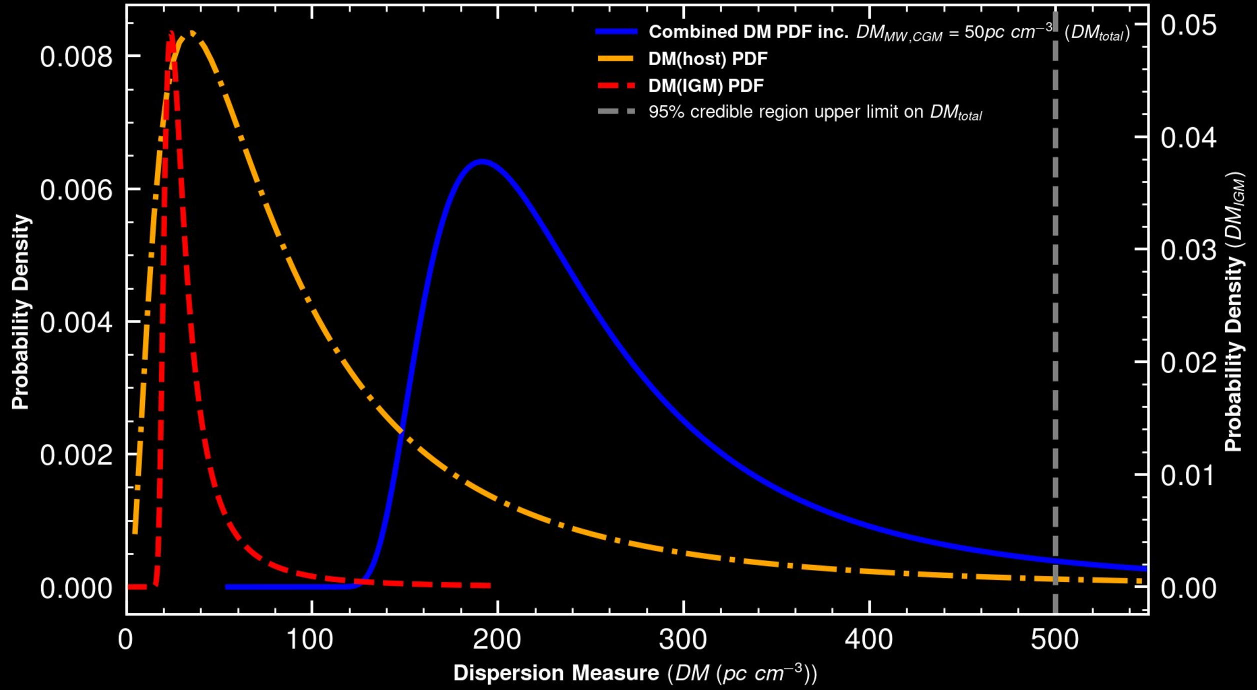
- Repeater vs. Non-repeater
- Excess DM ≤ 500 pc cm^{-3}
- Baseband Localization
- Sidelobes FRBs Localization (2)
- Header Localization

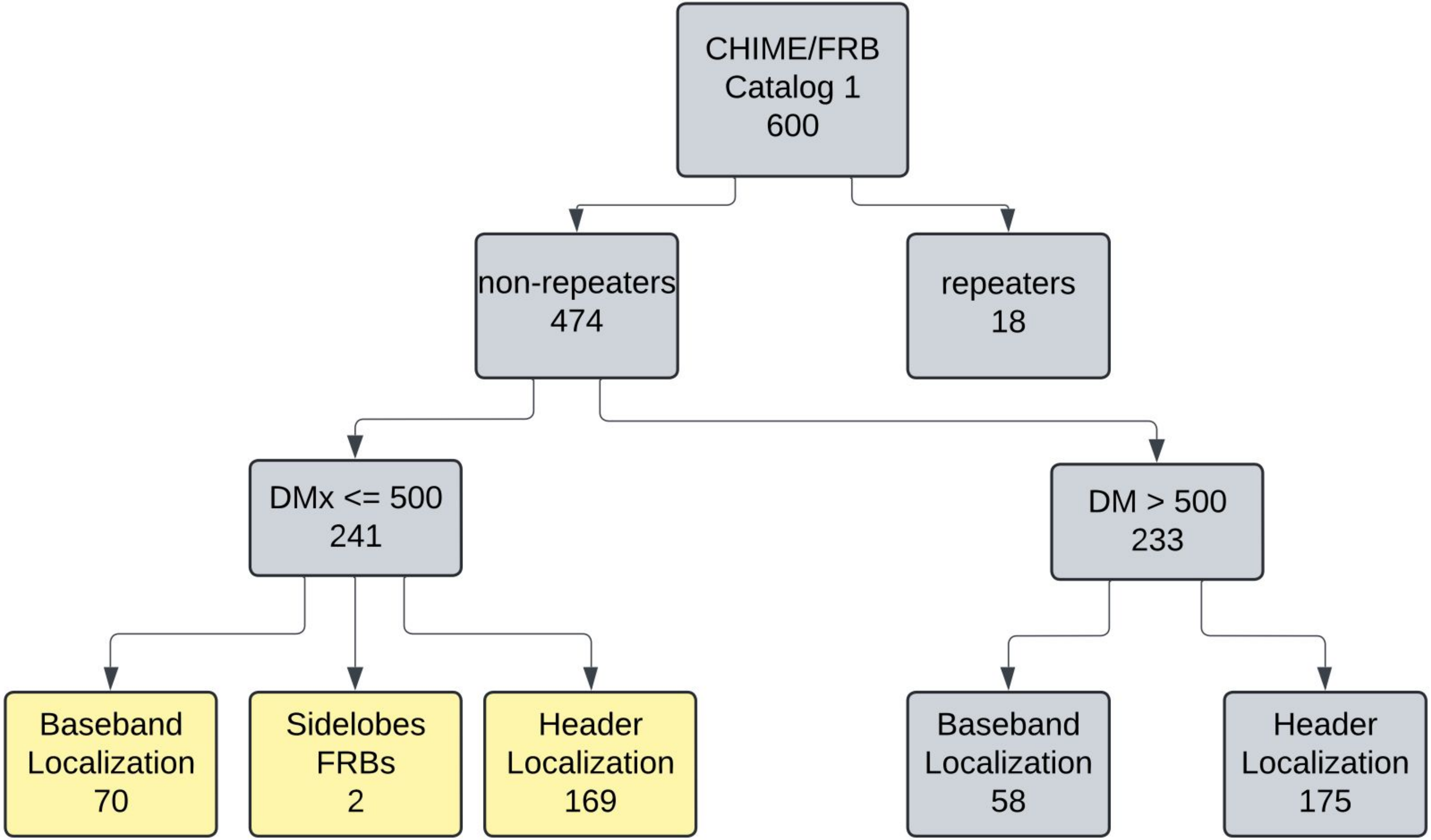

SAI
SN Catalog
6546
redshift
5798
no redshift
748
Type II
1559
Type I (core collapse)
472
visible to CHIME
1017
not visible to CHIME
542
visible to CHIME
299
not visible to CHIME
173
HECATE
(z ≤ 0.043)
677
no HECATE
(z > 0.043)
340
HECATE
(z ≤ 0.043)
209
no HECATE
(z > 0.043)
90

DM Estimation

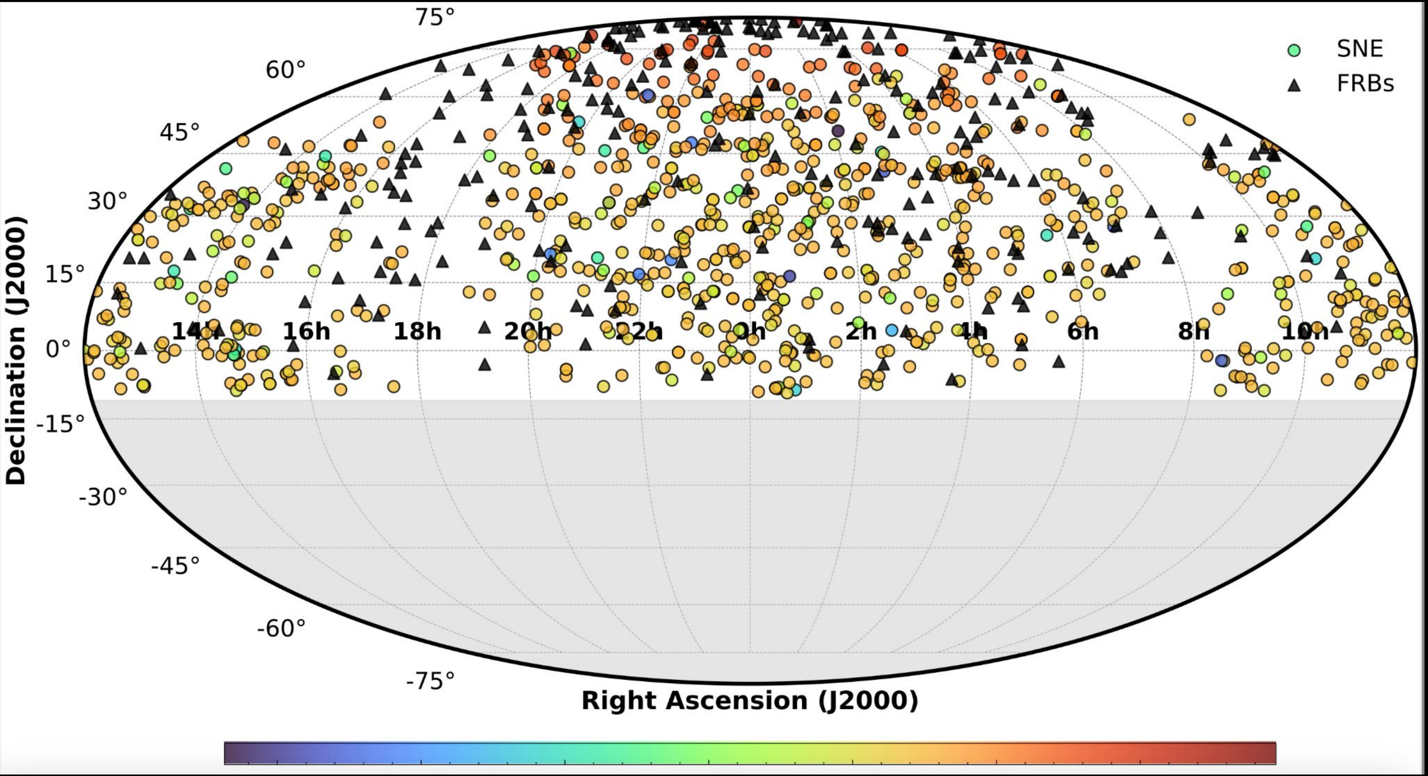
CHIME Catalog-1: $DM_{excess} = DM_{host} + DM_{IGM} + DM(MW,CGM)$

A distance of ≤ 200 Mpc corresponds to an $DM_{excess} \leq 500$ pc cm^{-3}




CHIME/FRB
Catalog 1
600
non-repeaters
474
repeaters
18
DMx <= 500
241
DM > 500
233
Baseband
Localization
70
Sidelobes
FRBs
2
Header
Localization
169
Baseband
Localization
58
Header
Localization
175

Sky distribution Map



886 supernovae with host galaxy properties from HECATE

241 FRBs with DM excess less than 500 pc cm^{-3}

Result

FRB 20190204A & SN 2003la

FRB 20190218B & SN 2014ay

FRB 20190412B & SN 2009gi

FRB 20190414B & SN 2001ab

only plausible pair: based on host DM estimated using scattering timescale

Scattering Time → DM_{excess}

Using scattering time τ to place an upper limit on the host-galaxy DM ($DM_{host,\tau}$) [6] → combine with the Milky-Way halo DM (50 pc cm^{-3}) and the IGM contribution at the supernova redshift

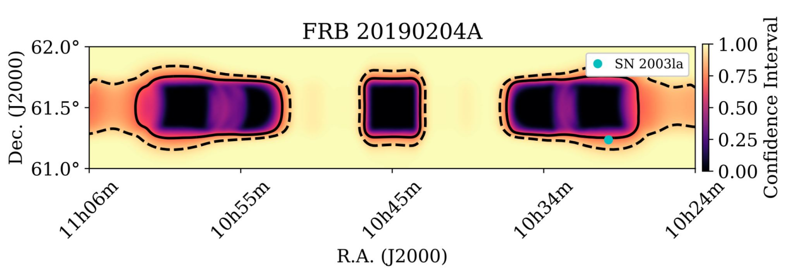
$$\mathrm{DM}_{\mathrm{excess}} \lesssim \mathrm{DM}_{\mathrm{MW,halo}} + \mathrm{DM}_{\mathrm{IGM}} + \mathrm{DM}_{\mathrm{host},\tau,\mathrm{max}}$$

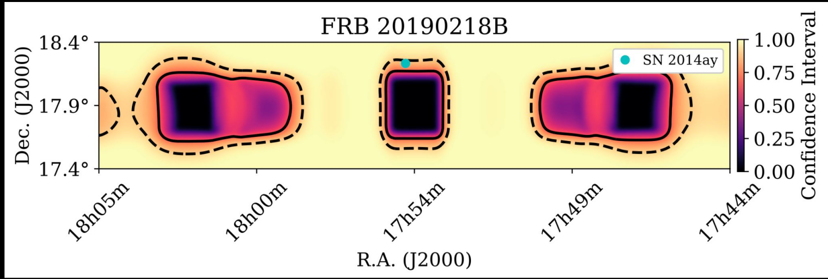
Only FRB 20190412B satisfies this inequality

(if SN 2009gi is assumed to be associated with the FRB)

FRB20190204A

- DM: 449.639 pc cm^{-3}
- **Excess DM: 423.3**
- Scattering Timescale: 0.0008(2) s
- redshift: 0.031



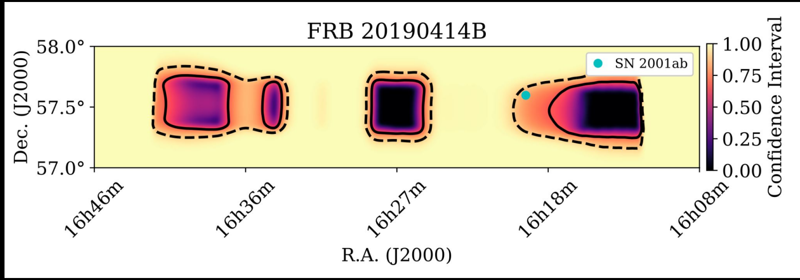


FRB20190218B

- DM: 547.9 pc cm^{-3}
- **Excess DM: 466**
- Scattering Timescale: 0.014(2) s
- redshift: 0.011

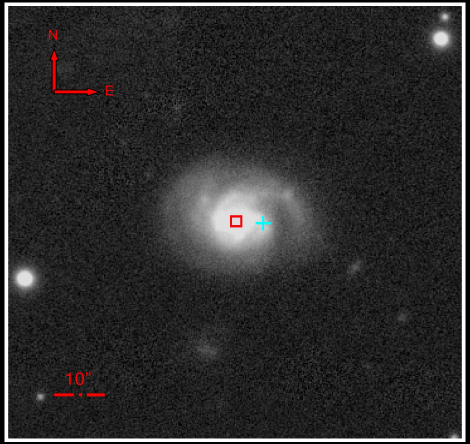
FRB20190414B

- DM: 506.489 pc cm^{-3}
- **Excess DM: 475.8**
- Scattering Timescale: <0.0058 s
- redshift: 0.017



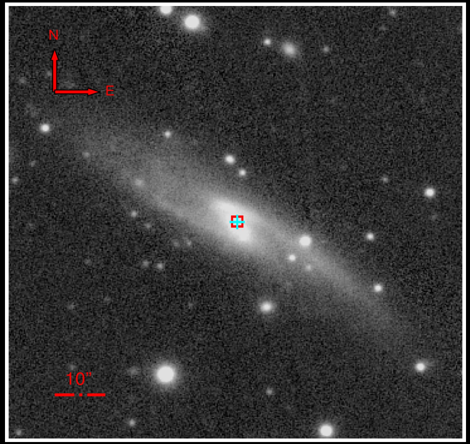
SN 2003la

- SN_redshift: 0.031
- Type: II
- Exposure: 21.5 h



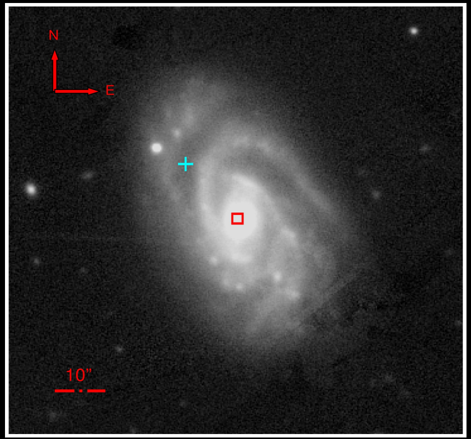
SN 2014ay

- SN_redshift: 0.011
- Type: II
- Exposure: 15.6 h



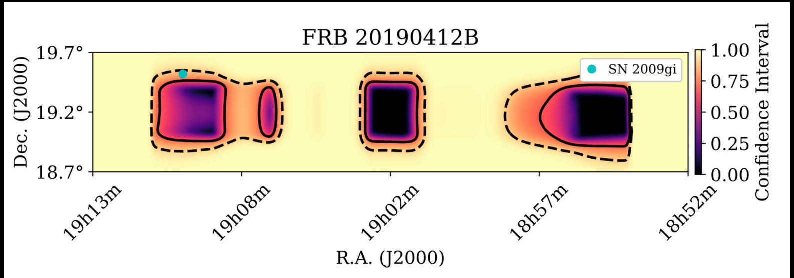
SN 2001ab

- SN_redshift: 0.017
- Type: II
- Exposure: 29.6 h



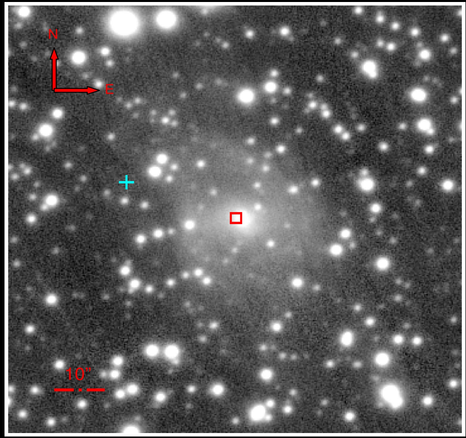
FRB20190412B

- DM: 375.75 pc cm^{-3}
- **Excess DM: 110.1** pc cm^{-3}
- Scattering Timescale: 0.015(3) s
- redshift: 0.013



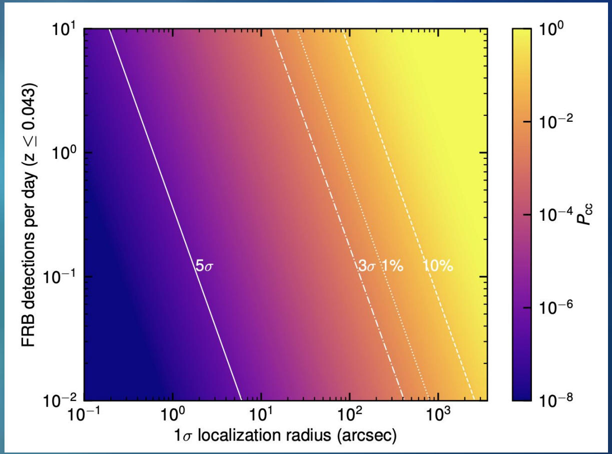
SN 2009gi

- Host Galaxy offset: 6.3 kpc
- **SN_redshift: 0.013**
- **Type: IIb**
- Exposure: 14.4 h
- Stellar mass: 10.62 $log_{10}(M/M_\odot)$
- Inclination angle: 62.8



Chance Association

- 886 pseudo-supernovae (RA and DEC) visible to CHIME
- Randomly sampled & Uniformly distributed
- Cross-matching 10,000 times
    - Baseband Localization
    - two Sidelobes FRBs
    - Healpix Map (Header Localization)



Pcc (k ≥ 4) = 0.966

(at least four coincidences happened in 96.6% of the trials)

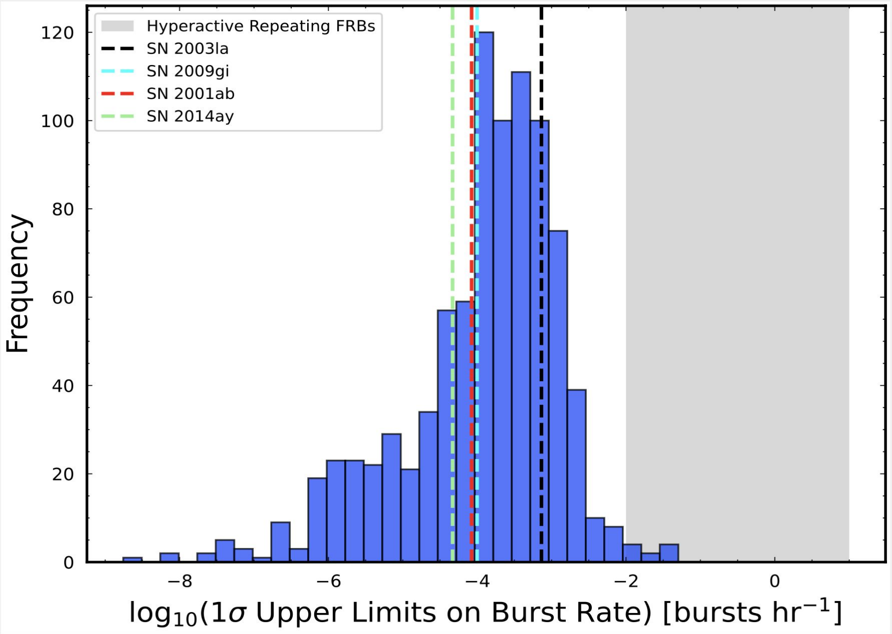
Free-free Optical Depth Constraint

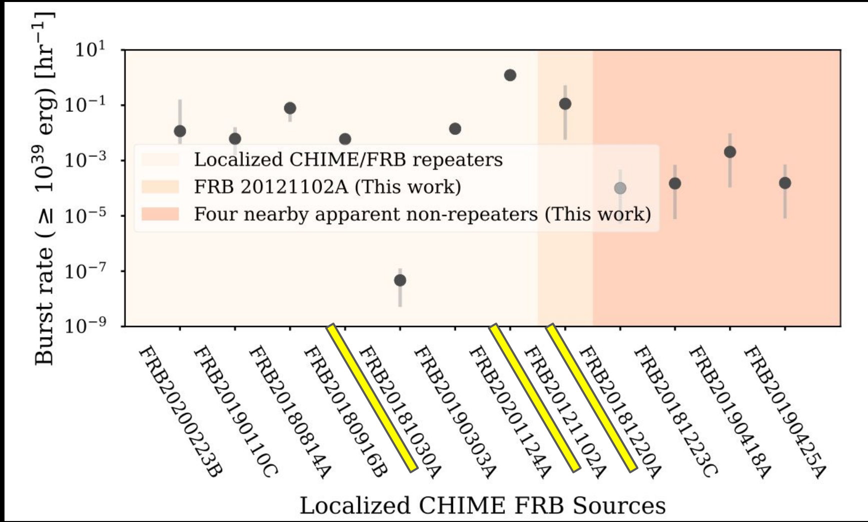
- The dense SN ejecta could significantly impact the observability of FRBs
- Low-frequency radio waves (FRBs) suffer free-free absorption while escaping
- As the ejecta expands and thins, FRBs become more observable
- Define a free-free transparency timescale t_{ff} = time till the free-free optical depth $\tau_{ff} = 1$ (FRBs are absorbed and cannot escape)
  - Type Ib/Ic: ~26 years
  - Type IIP: ~91 years
- Real ejecta isn't smooth → create low-density paths → FRBs could escape earlier
- Implications of early FRB detections
  - Suggest unusual explosion conditions
  - Point to jet-like outflows, ionizing central engines, or ultra-sripped progenitors
- FRB 20190412B–SN 2009gi remain plausible

Burst Rate Estimation

The one sigma (poisson) upper limit of burst rate estimation of 886 supernovae

Hyperactive FRB: ~1 event / h (at max) at 10^{39} erg

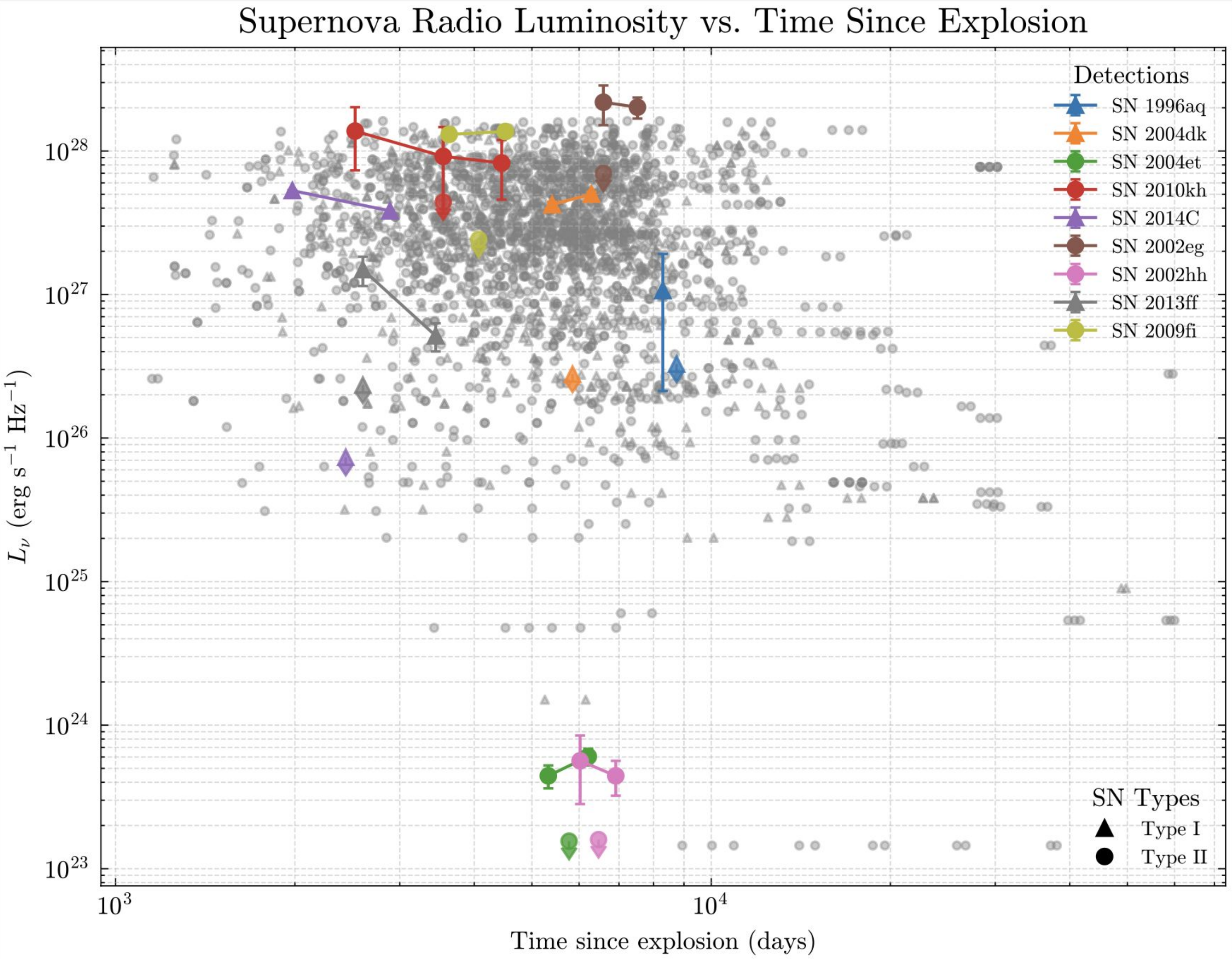




Search for Counter Radio Emission (VLASS)

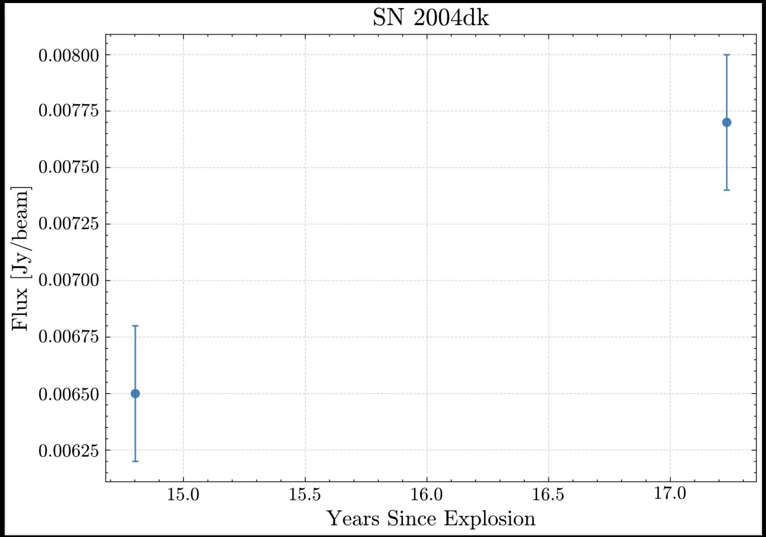
- Motivation: Young magnetars are also known to have radio counterpart
- Purpose: **Identify and report new discoveries of radio counterparts to further test the young neutron stars hypothesis of FRBs**

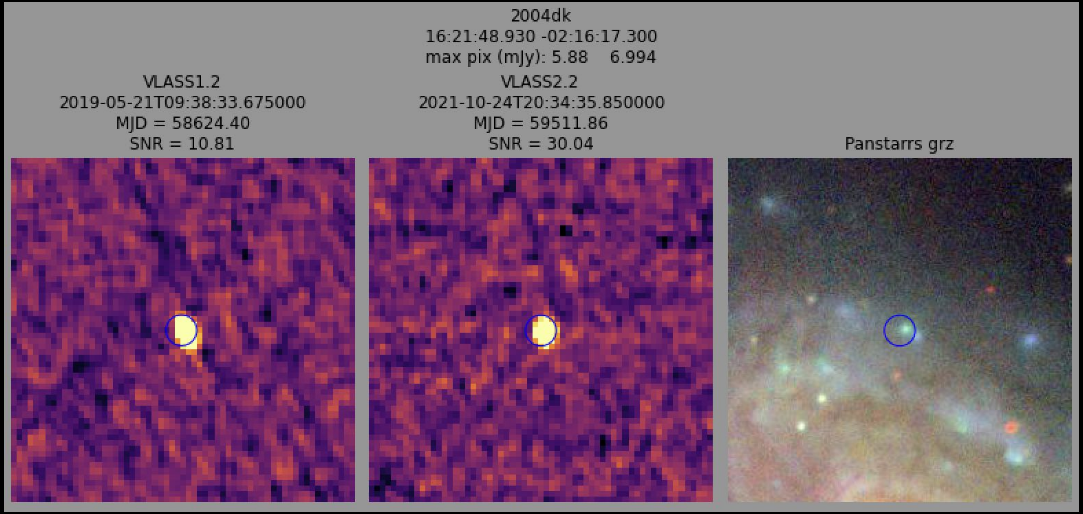
    - Database: CHIME-visible core-collapse supernovae in SAI catalog (886)
    - None of the 4 detections are radio sources
    - Found 9 detections
        - → 4 type I, 5 type II


Supernova Radio Luminosity vs. Time Since Explosion
Detections
SN 1996aq
SN 2004dk
SN 2004et
SN 2010kh
SN 2014C
SN 2002eg
SN 2002hh
SN 2013ff
SN 2009fi
SN Types
Type I
Type II
L_ν (erg s^{-1} Hz^{-1})
10^{28}
10^{27}
10^{26}
10^{25}
10^{24}
10^{23}
10^3
10^4
Time since explosion (days)

For each source, we will analyze:

- Observed Variability
- Evidence of Persistent Emission
- Supernova Age and Relevance
- Comparison to Expected Radio SN Behavior





SN 2004dk

Type Ib

Off-centered

→ transient (monotonic rising)

Conclusions

- We found 4 detections, one indicates a plausible association.
- Pcc is very large.
- If hyperactive FRBs are located at the site the supernova, CHIME should have detected it.
- Free-free Absorption might be a factor for high chance association
- Future Work: Assuming null FRB-SNe association, we can constrain our evolution of magnetar as FRB source activity with time

Extra slide

- remove DM constraint only:
  - 7 more detection pairs
- remove HECATE constraint only:
  - 3 more detection pairs
- DM cut-off at excess DM = 450
  - 2 detections pairs

References

1] Kshitji Aggarwal Yunpeng Men. “Non-detection of fast radio bursts from six gamma-ray burst remnants with possible magnetar engines”. In: Monthly Notices of the Royal Astronomical Society 489 (3 2019), pp. 3643–3647. https://academic.oup.com/mnras/article/489/3/3643/5556542

[2] https://science.howstuffworks.com/supernova4.htm

[3] HECATE Catalog. https://hecate.ia.forth.gr/catalog.php

[4] Margalit, Ben; Metzger, Brian D. "A Concordance Picture of FRB 121102 as a Flaring Magnetar Embedded in a Magnetized Ion-Electron Wind Nebula". In: The Astrophysical Journal Letters, Volume 868, Issue 1, article id. L4, 7 pp. (2018). https://ui.adsabs.harvard.edu/abs/2018ApJ...868L...4M/abstract

[5] The Canadian Hydrogen Intensity Mapping Experiment. “https://chime-experiment.ca/en.

[6] Cordes, J. M., Ocker, S. K., & Chatterjee, S. 2022, ApJ, 931, 88, doi: 10.3847/1538-4357/ac6873