

ICECUBE
NEUTRINO OBSERVATORY



Department of Physics
UNIVERSITY OF WISCONSIN-MADISON



WIPAC
WISCONSIN ICECUBE
PARTICLE ASTROPHYSICS CENTER

IceCube Search for Neutrinos from Thousands of Fast Radio Bursts

Alicia Mand on behalf of the IceCube Collaboration

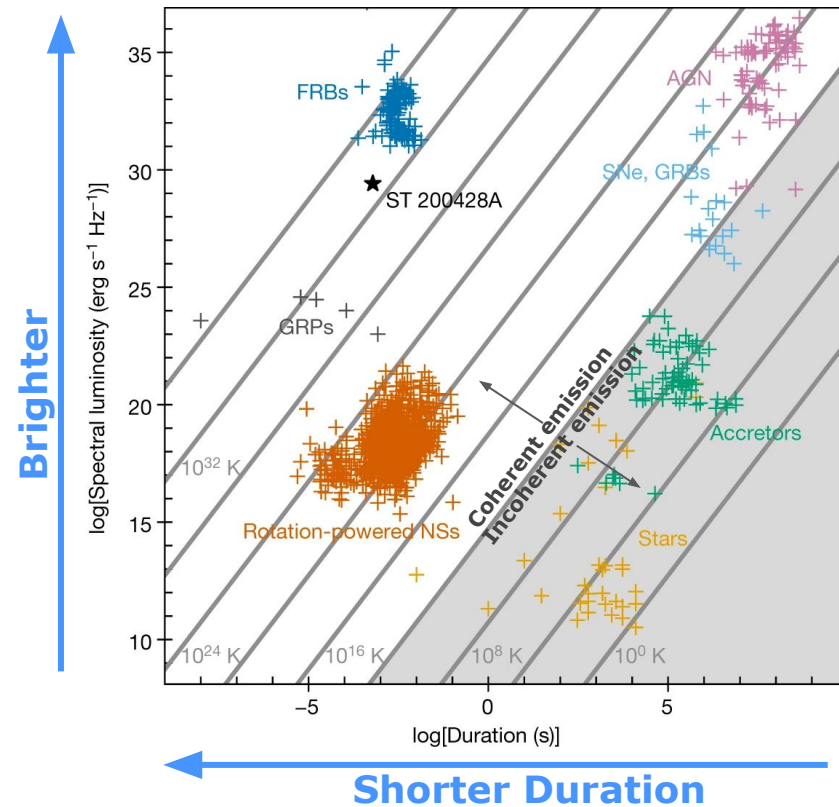
October 14, 2026

IceCube Particle Astrophysics Symposium, Madison, WI

Fast Radio Bursts (FRBs)

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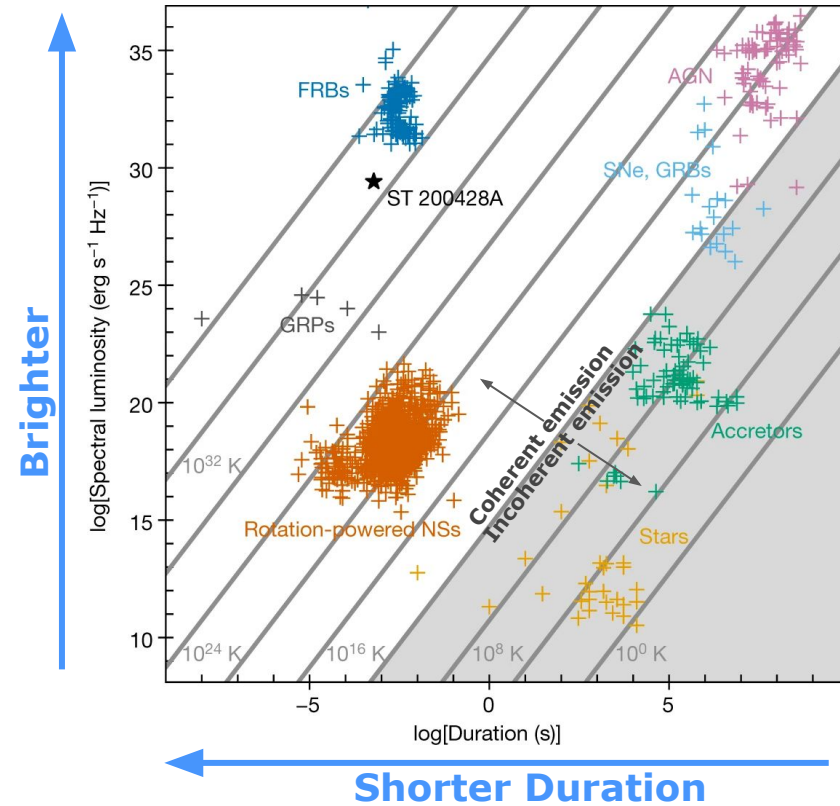
- Brief, intense, bursts of radio waves
 - Short (~millisecond) and bright (~jansky)



Bochenek, C.D., Ravi, V., Belov, K.V. *et al. Nature* **587**, 59–62 (2020)

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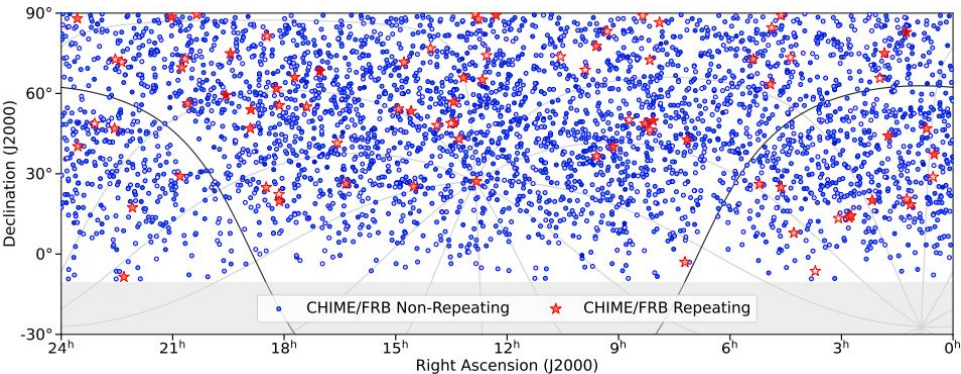
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 - Short (~millisecond) and bright (~jansky)
- (Mostly) extra-galactic



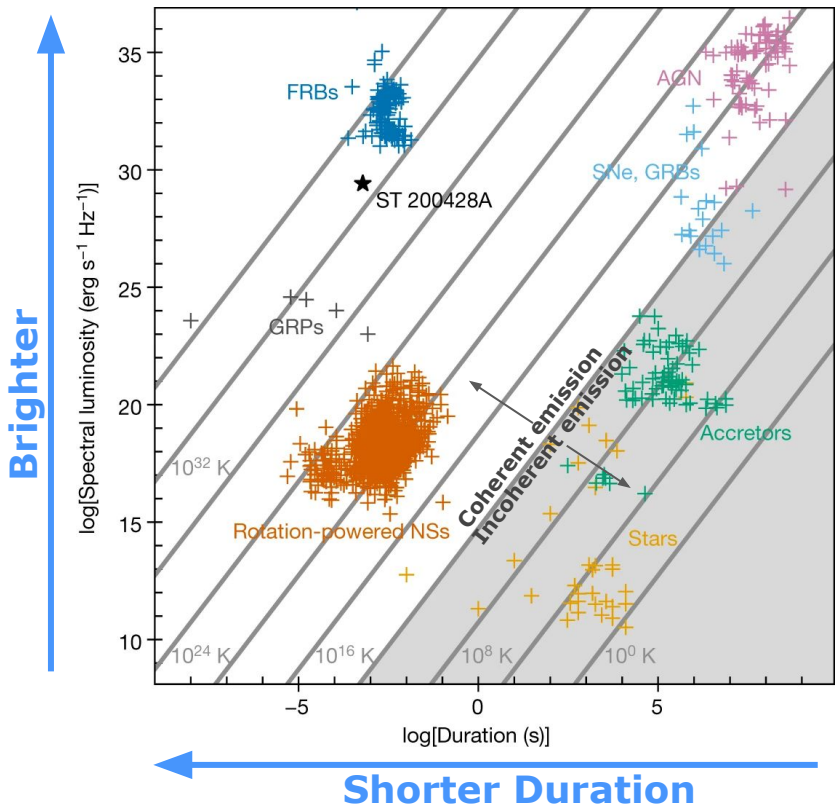
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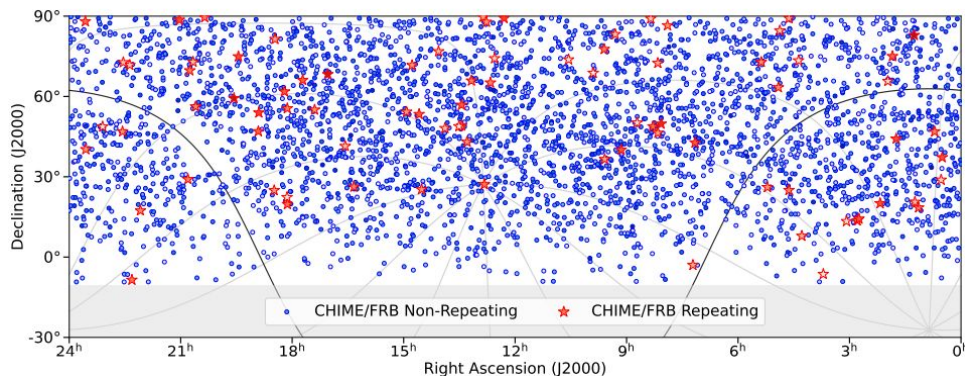
The CHIME/FRB Collaboration, *ApJS* **283**,34(2026)
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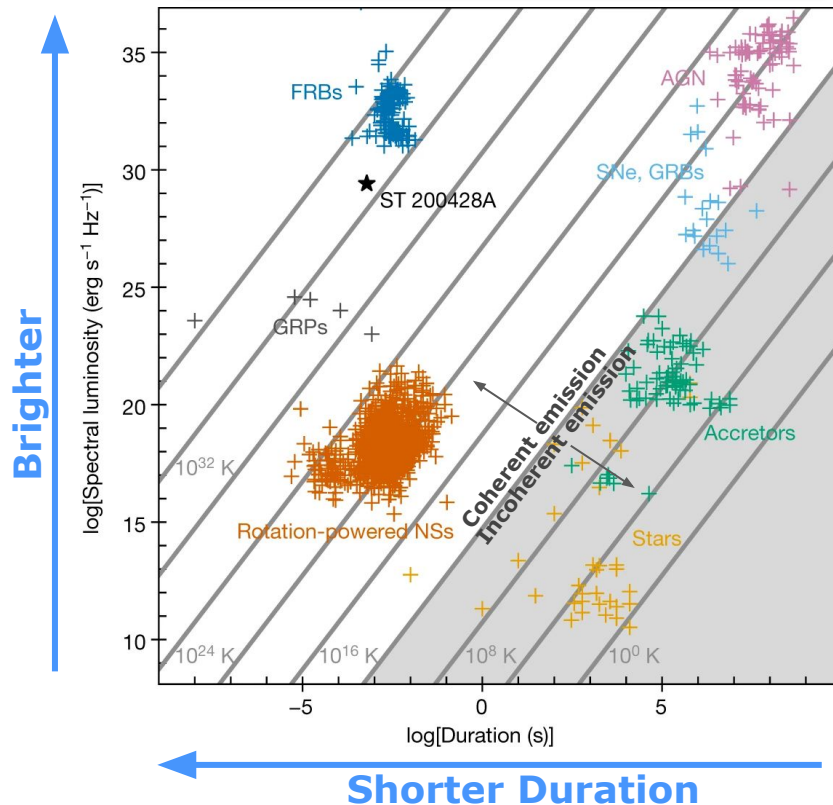
* Some models predict neutrino emission

- Brief, intense, bursts of radio waves
 - Short (~millisecond) and bright (~jansky)
- (Mostly) extra-galactic
- Occur all over the sky
- Physical origin remains unknown*
 - Many models proposed (esp. magnetars)



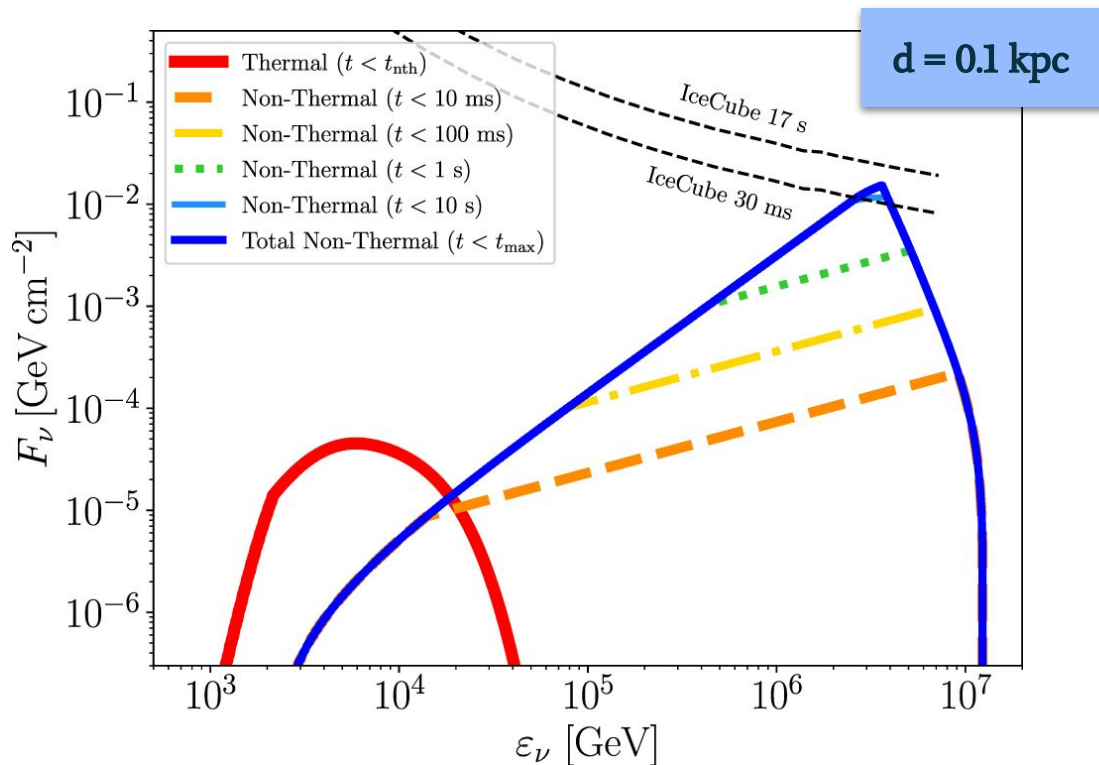
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Neutrino Emission from Magnetar FRBs

- Ultra-relativistic shock propagating into external magnetized medium
- Photo-hadronic interactions of relativistic protons produce neutrinos



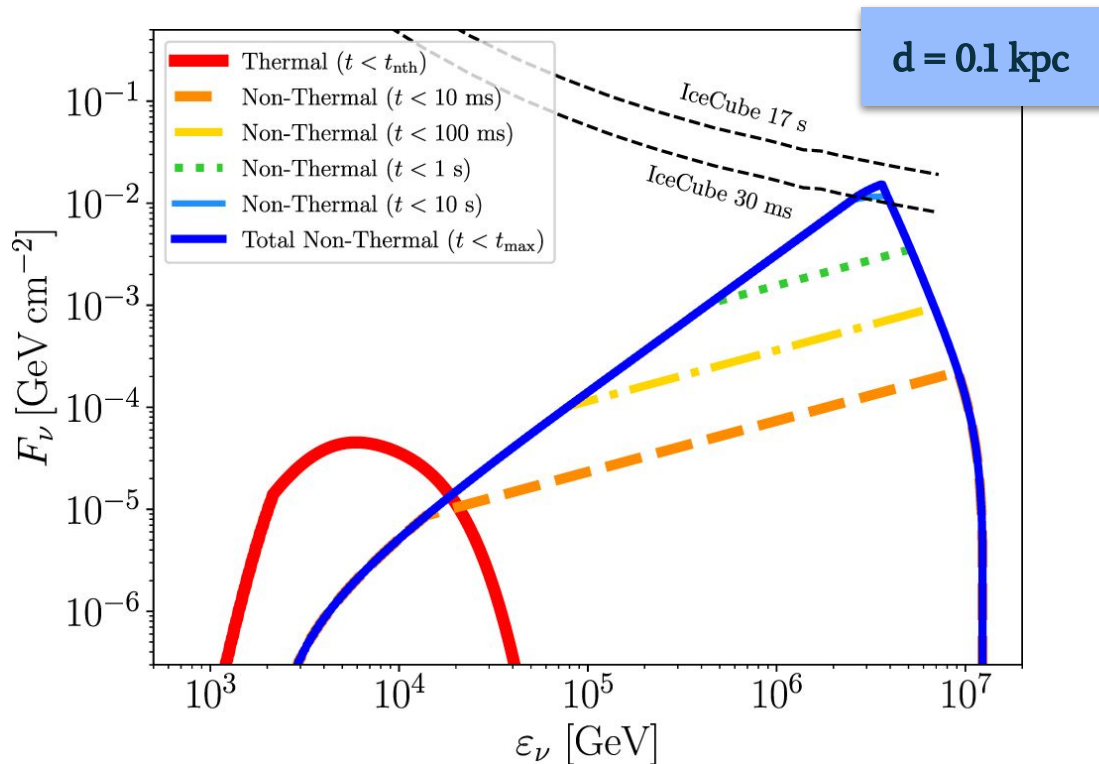
B. D. Metzger and K. Fang 2020 ApJL 902 L22

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Advantages:

- Neutrinos may be observable by IceCube
- TeV-PeV gamma rays may be observable by HAWC



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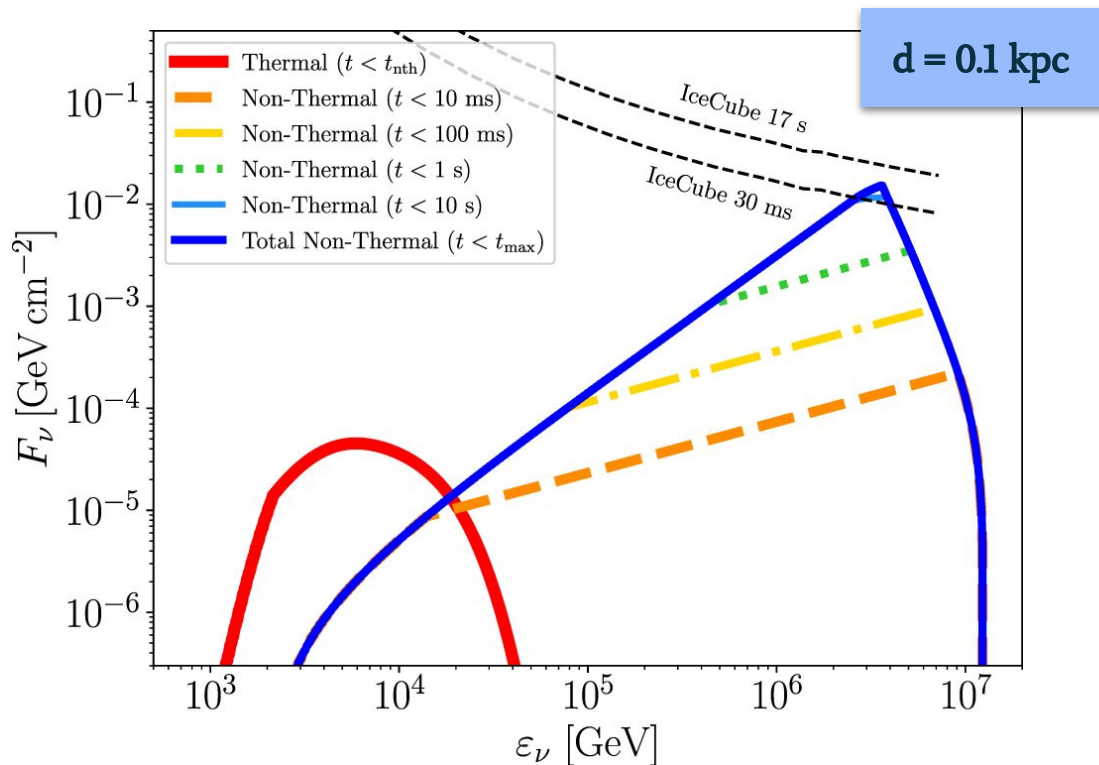
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Drawbacks:

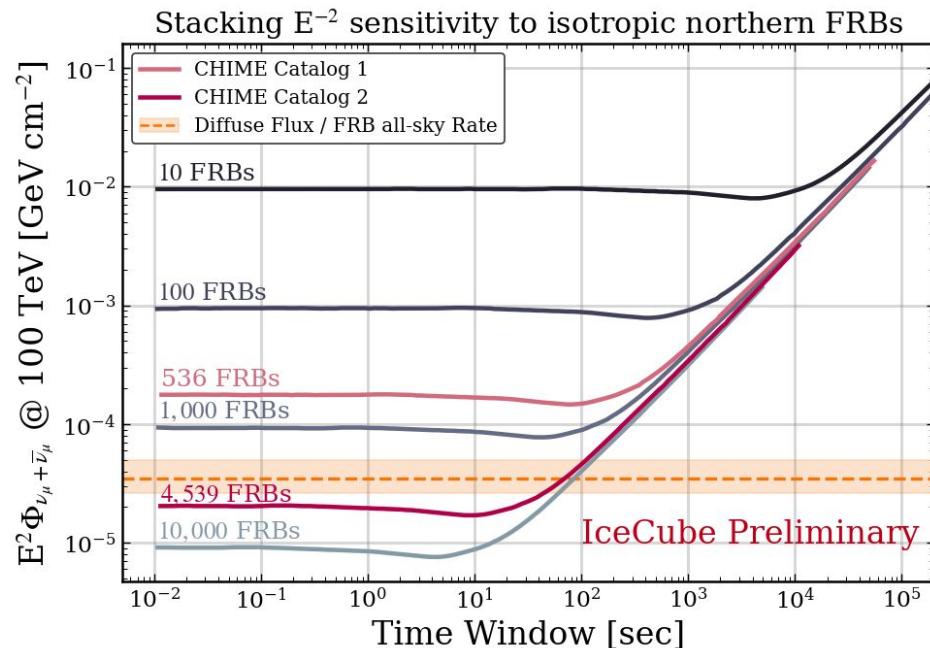
- Analytical model with order-of-magnitude estimation
- Assumes an E^{-2} proton spectrum



B. D. Metzger and K. Fang 2020 ApJL 902 L22

Previous IceCube Follow-ups of FRBs

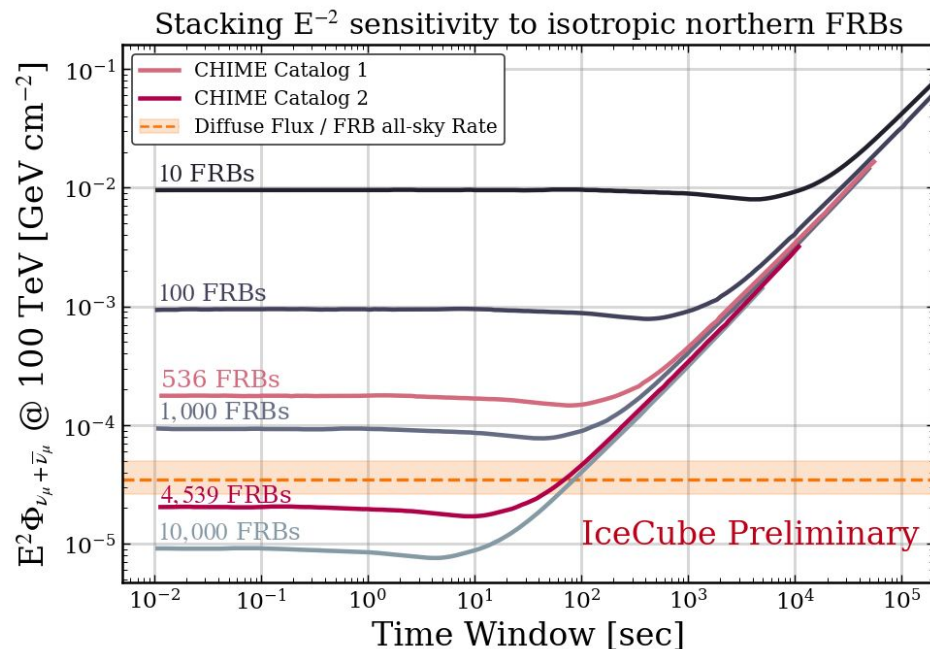
- Five previous searches have been conducted using IceCube data
 - Three in-collaboration searches, two using public datasets
- No significant neutrino emission was found
- Various time-windows
 - 10 ms - time-integrated
- All in-collaboration searches used fewer than 30 FRBs



More FRBs → Better Sensitivity
Shorter time window → Better Sensitivity

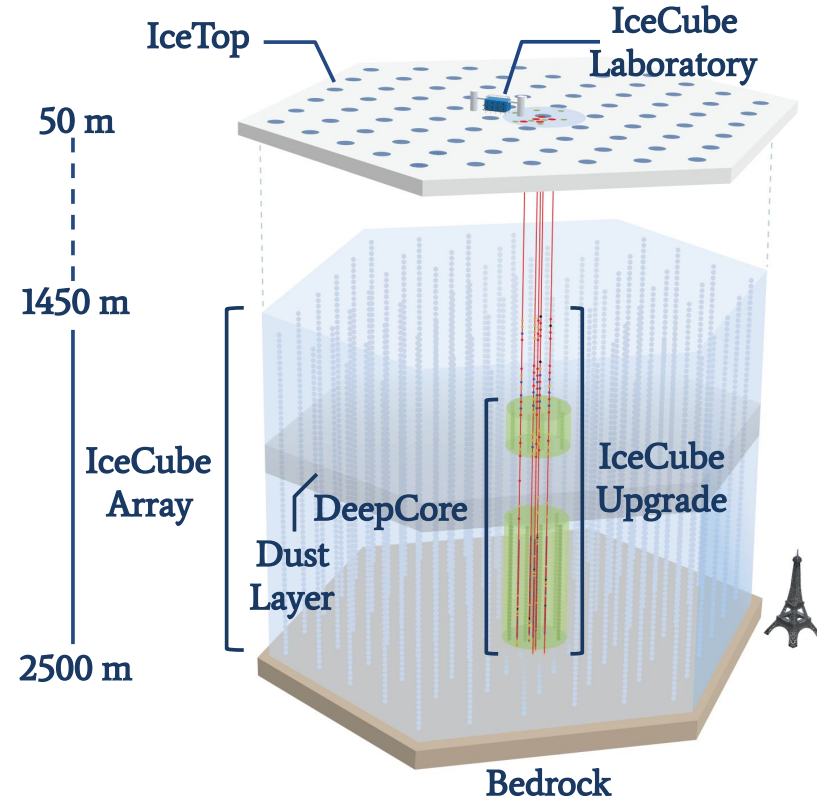
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- All in-collaboration searches used fewer than 30 FRBs
- **CHIME's new catalog (Catalog-2) has more than 4500 FRBs!**



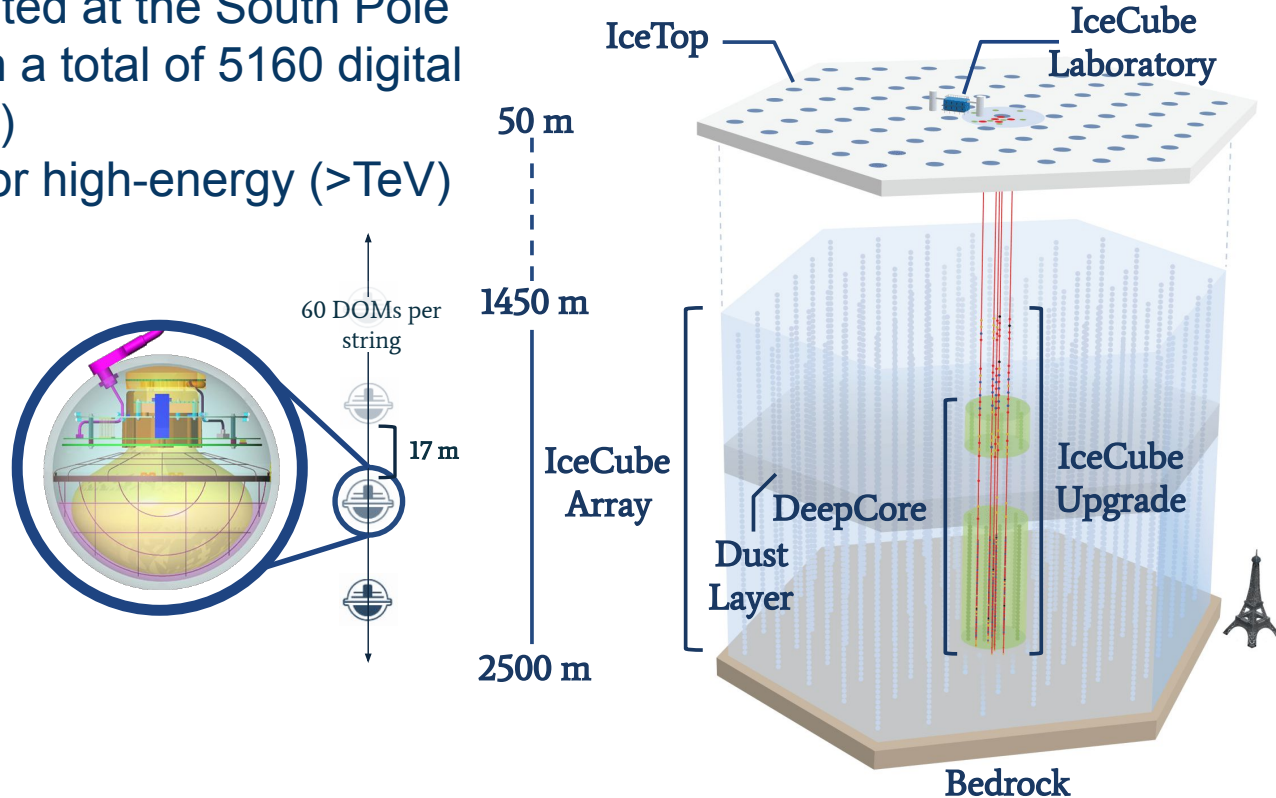
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IceCube Neutrino Observatory



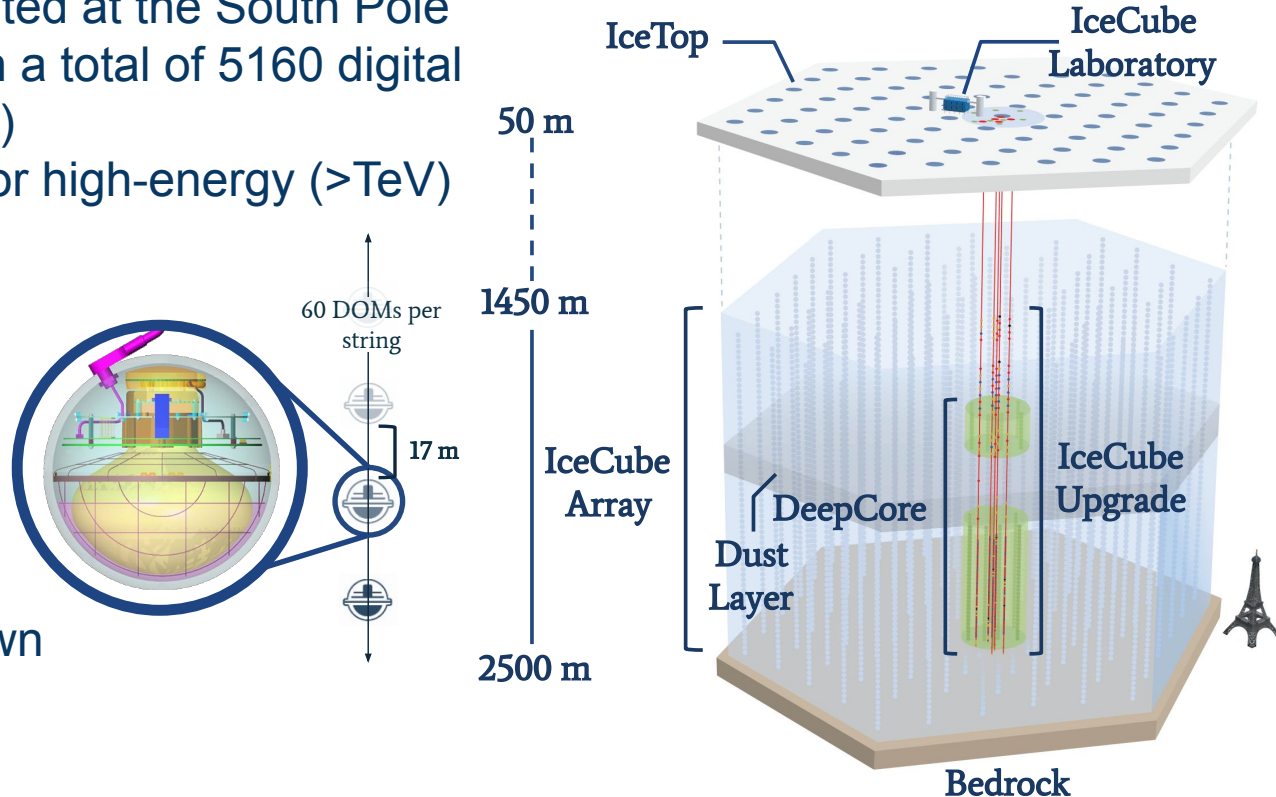
IceCube Neutrino Observatory

- Neutrino telescope located at the South Pole
- 86 (now 91) strings with a total of 5160 digital optical modules (DOMs)
- Main array: optimized for high-energy ($> \text{TeV}$) neutrinos



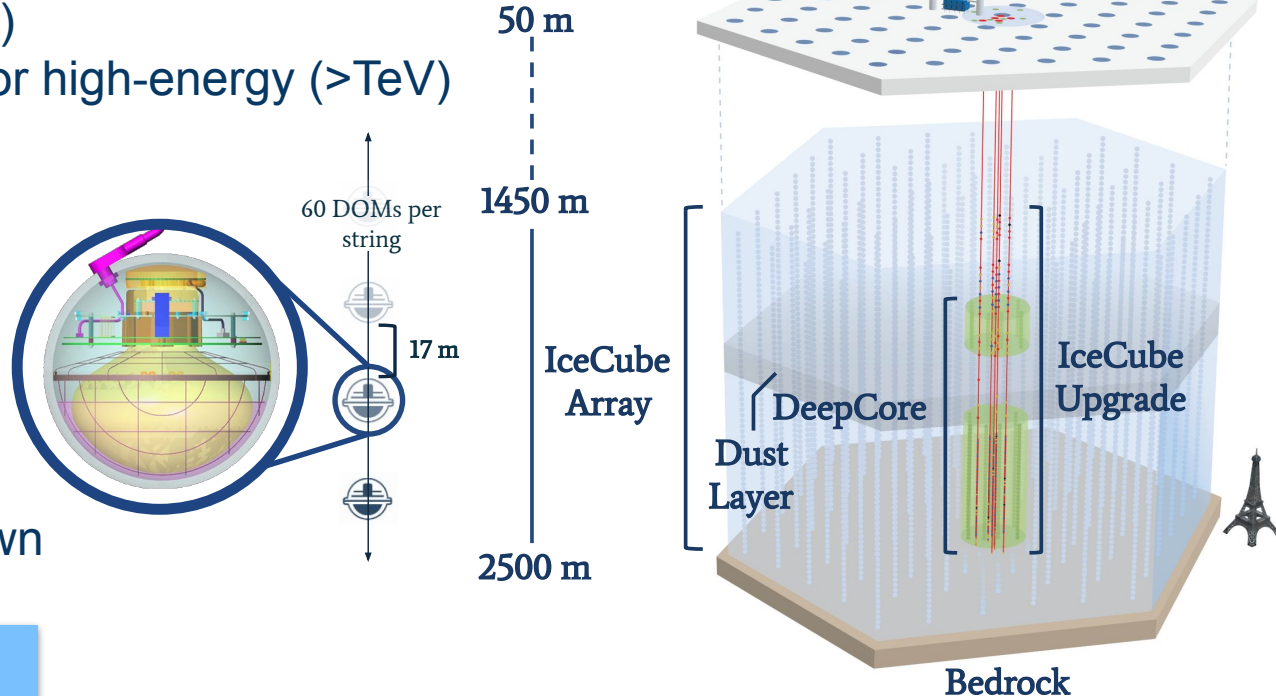
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See D. Butterfield's talk on
Friday!

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- Hydrogen mapping experiment
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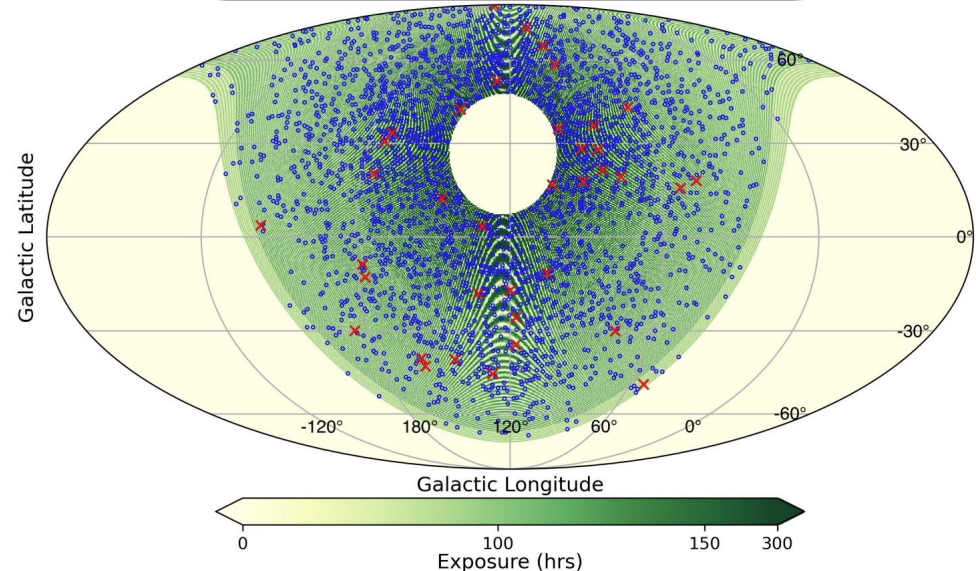
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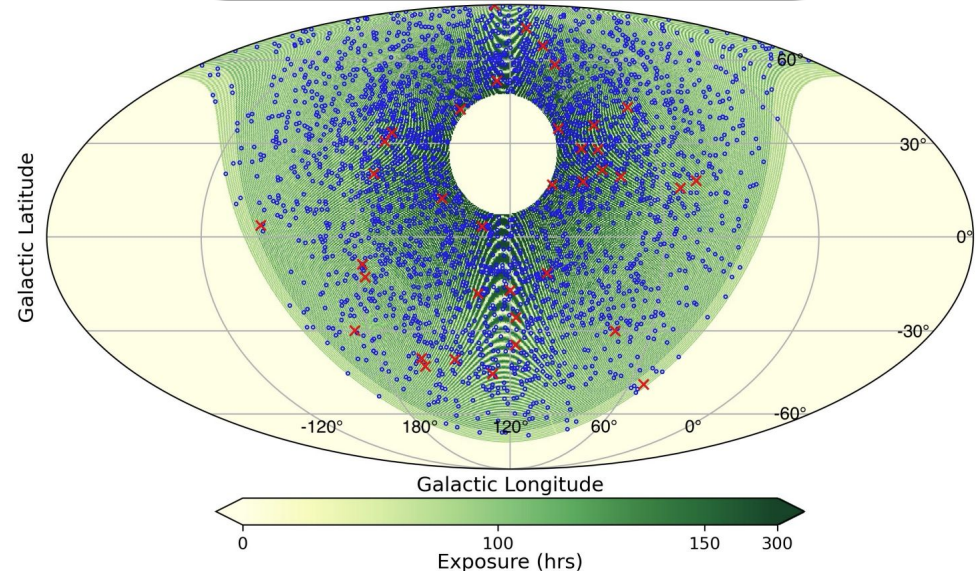
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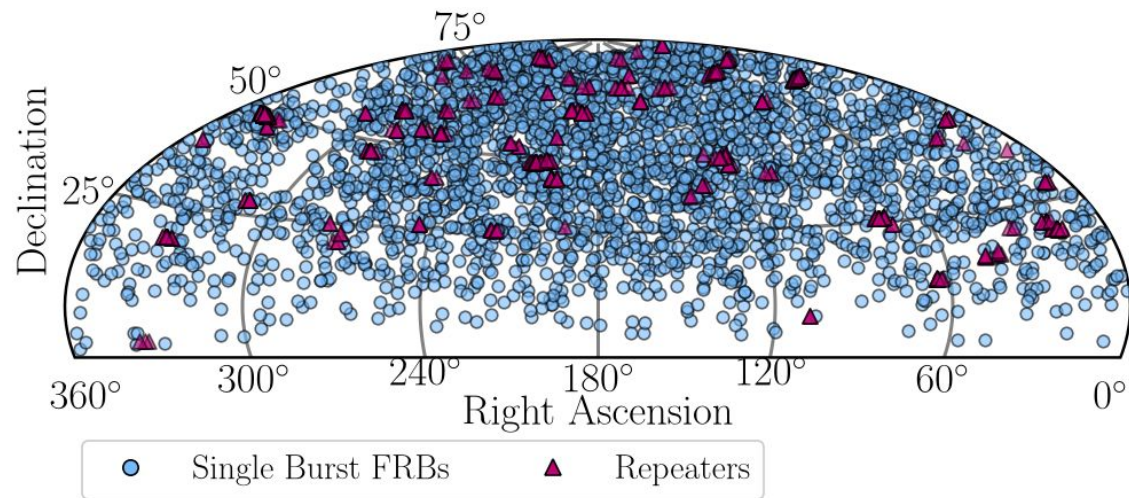
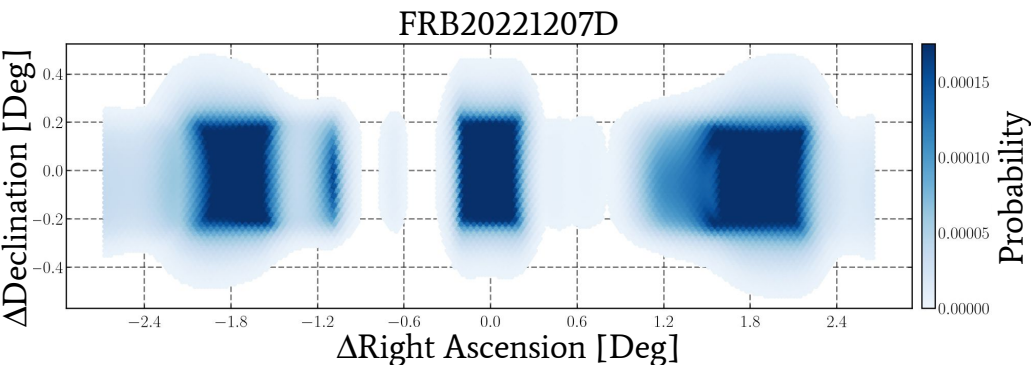
CHIME Is a Hydrogen Mapping Experiment that happens to be **really good** at detecting FRBs!

The CHIME/FRB Collaboration, *ApJS* **283**,34(2026)

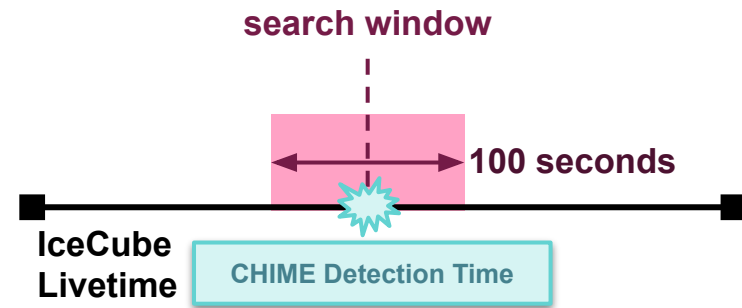


IceCube Follow-up of FRBs

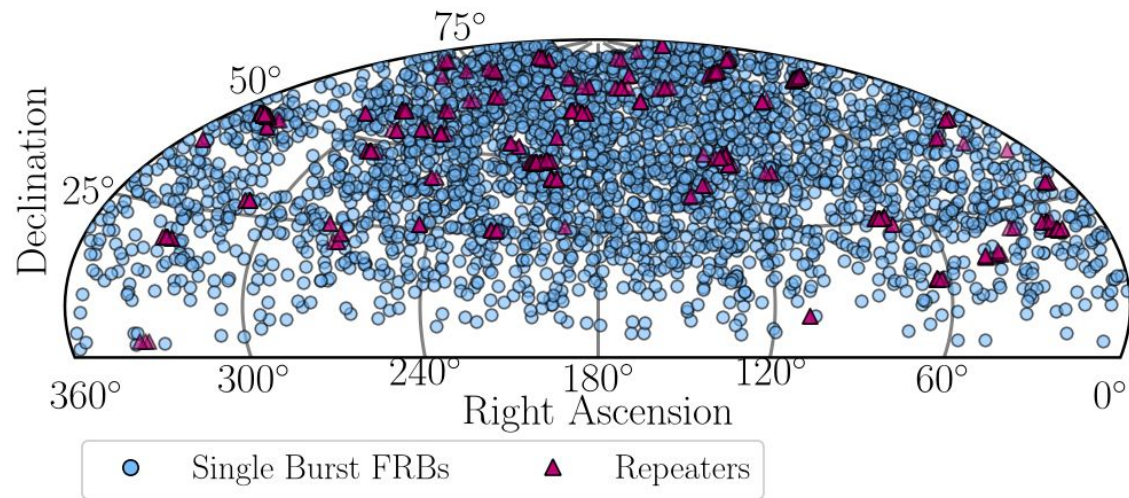
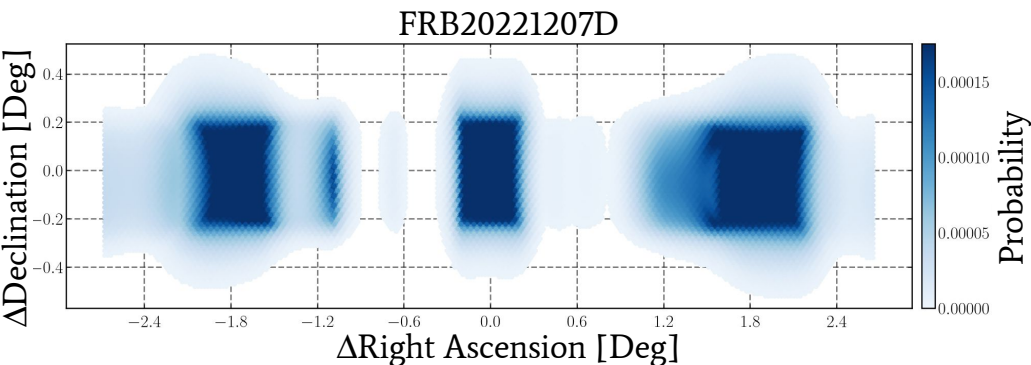
We are searching for **spatial** and **temporal** (± 50 seconds of burst detection time) coincidence of neutrinos with fast radio bursts



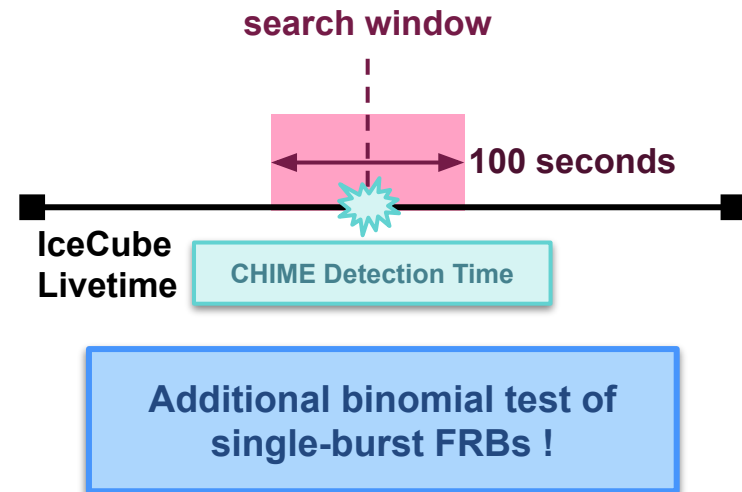
- Incorporating CHIME's localization information as a spatial prior
- Apply unbinned likelihood method
- Maximize the test statistic across the entire spatial prior



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Results

Burst Name	(RA, Dec)	MJD	TS_{fit}	ns_{fit}	γ_{fit}	Pre-trial p_{val}	Post-trial p_{val}	Pre-Trial Significance	Post-trial Significance	RA_{fit}, Dec_{fit}	Class	Repeater Name
FRB20221207D	(20.88, 20.50)	59920.18	17.54	1.00	4.73	6.083e-05	4.831e-02	3.84	1.66	(22.85, 20.34)	Repeater	FRB20220529A
FRB20200614A	(29.11, 65.73)	59014.69	6.79	0.99	4.61	1.082e-03	-	3.07	-	(24.96, 65.6)	Repeater	FRB20180916B
FRB20210213A	(191.72, 83.28)	59258.47	5.87	0.98	2.74	2.781e-03	-	2.77	-	(206.64, 83.05)	Single Burst	-
FRB20230629G	(65.41, 77.54)	60124.74	5.78	0.98	4.85	2.777e-03	-	2.77	-	(60.98, 77.37)	Single Burst	-
FRB20220331A	(288.67, 82.53)	59669.10	5.62	0.98	3.10	2.669e-03	-	2.79	-	(302.68, 82.32)	Single Burst	-
FRB20201229A	(202.54, 44.24)	59212.62	5.52	0.98	3.25	1.129e-03	-	3.05	-	(200.19, 44.2)	Single Burst	-
FRB20191107A	(66.09, 73.60)	58794.89	4.55	0.96	2.41	2.373e-03	-	2.82	-	(59.92, 73.68)	Repeater	FRB20180814A
FRB20210429B	(355.62, 78.80)	59333.20	4.05	0.95	1.67	2.275e-03	-	2.84	-	(355.91, 78.93)	Single Burst	-
FRB20190609D	(115.92, 51.69)	58643.94	3.31	0.92	3.96	1.359e-03	-	3.00	-	(113.05, 51.64)	Single Burst	-

Best-fit (RA, Dec)
reported by CHIME

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MJD Detection time
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IceCube unblinded test
statistic



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Best-fit spectral index



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Trials factor = # Single
(repeat) bursts considered

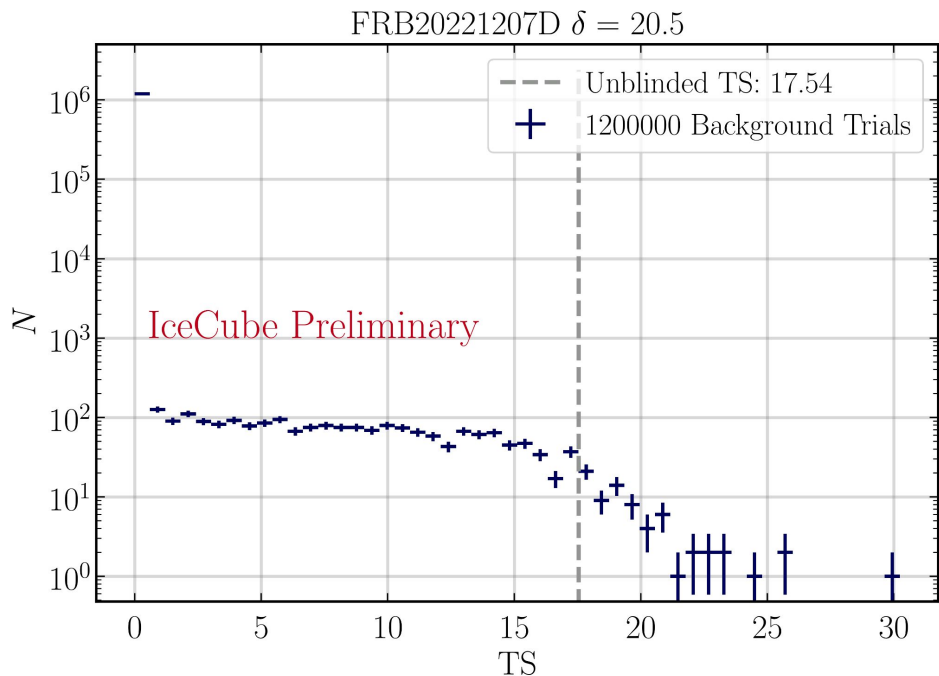
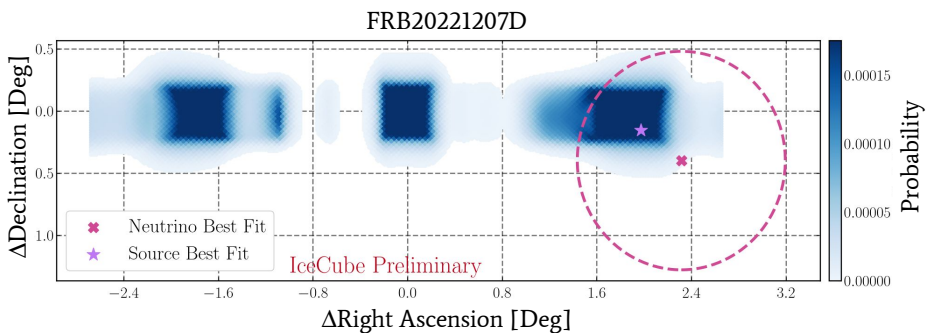
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IceCube best-fit source
location within prior

Burst Name	(RA, Dec)	MJD	TS _{fit}	ns _{fit}	γ_{fit}	Pre-trial p_{val}	Post-trial p_{val}	Pre-Trial Significance	Post-trial Significance	RA _{fit} , Dec _{fit}	Class	Repeater Name
FRB20221207D	(20.88, 20.50)	59920.18	17.54	1.00	4.73	6.083e-05	4.831e-02	3.84	1.66	(22.85, 20.34)	Repeater	FRB20220529A
FRB20200614A	(29.11, 65.73)	59014.69	6.79	0.99	4.61	1.082e-03	-	3.07	-	(24.96, 65.6)	Repeater	FRB20180916B
FRB20210213A	(191.72, 83.28)	59258.47	5.87	0.98	2.74	2.781e-03	-	2.77	-	(206.64, 83.05)	Single Burst	-
FRB20230629G	(65.41, 77.54)	60124.74	5.78	0.98	4.85	2.777e-03	-	2.77	-	(60.98, 77.37)	Single Burst	-
FRB20220331A	(288.67, 82.53)	59669.10	5.62	0.98	3.10	2.669e-03	-	2.79	-	(302.68, 82.32)	Single Burst	-
FRB20201229A	(202.54, 44.24)	59212.62	5.52	0.98	3.25	1.129e-03	-	3.05	-	(200.19, 44.2)	Single Burst	-
FRB20191107A	(66.09, 73.60)	58794.89	4.55	0.96	2.41	2.373e-03	-	2.82	-	(59.92, 73.68)	Repeater	FRB20180814A
FRB20210429B	(355.62, 78.80)	59333.20	4.05	0.95	1.67	2.275e-03	-	2.84	-	(355.91, 78.93)	Single Burst	-
FRB20190609D	(115.92, 51.69)	58643.94	3.31	0.92	3.96	1.359e-03	-	3.00	-	(113.05, 51.64)	Single Burst	-

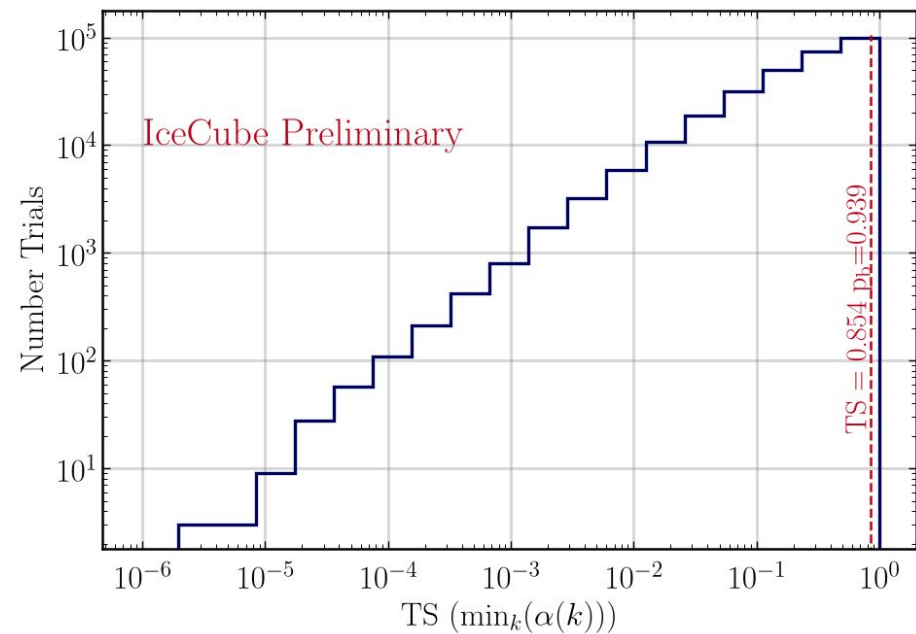
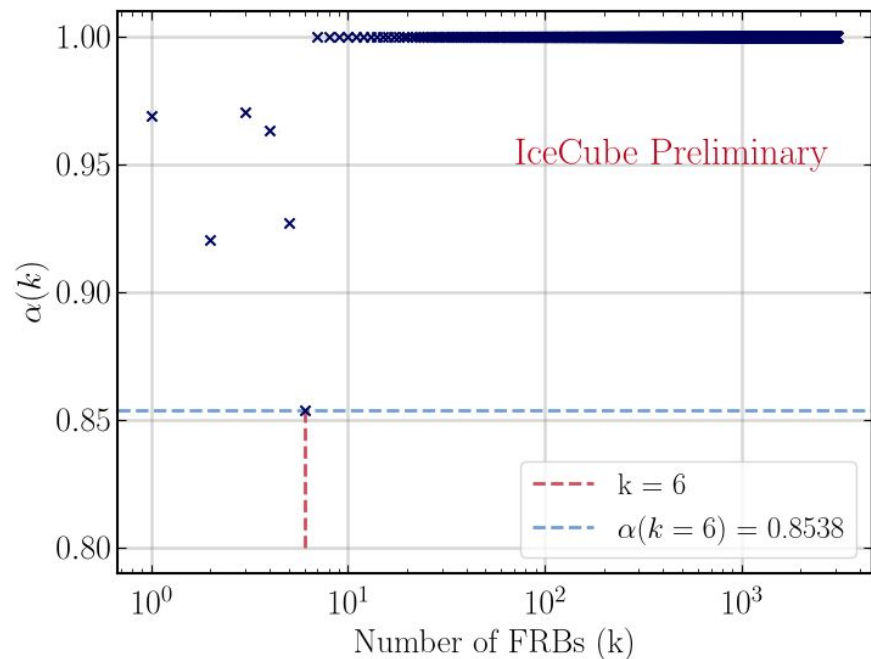
Highest pre-trials significance of 3.84σ :
 FRB 20211207D (Repeater of FRB 20220529A)
 DM of 246.26 [pc/cm³]
 SNR of 9.97
 Repeater has 31 Bursts in CHIME Catalog 2



Burst Name	(RA, Dec)	MJD	TS_{fit}	ns_{fit}	γ_{fit}	Pre-trial p_{val}	Post-trial p_{val}	Pre-Trial Significance	Post-trial Significance	RA_{fit}, Dec_{fit}	Class	Repeater Name
FRB20221207D	(20.88, 20.50)	59920.18	17.54	1.00	4.73	6.083e-05	4.831e-02	3.84	1.66	(22.85, 20.34)	Repeater	FRB20220529A
FRB20200614A	(29.11, 65.73)	59014.69	6.79	0.99	4.61	1.082e-03	-	3.07	-	(24.96, 65.6)	Repeater	FRB20180916B
FRB20210213A	(191.72, 83.28)	59258.47	5.87	0.98	2.74	2.781e-03	-	2.77	-	(206.64, 83.05)	Single Burst	-
FRB20230629G	(65.41, 77.54)	60124.74	5.78	0.98	4.85	2.777e-03	-	2.77	-	(60.98, 77.37)	Single Burst	-
FRB20220331A	(288.67, 82.53)	59669.10	5.62	0.98	3.10	2.669e-03	-	2.79	-	(302.68, 82.32)	Single Burst	-
FRB20201229A	(202.54, 44.24)	59212.62	5.52	0.98	3.25	1.129e-03	-	3.05	-	(200.19, 44.2)	Single Burst	-
FRB20191107A	(66.09, 73.60)	58794.89	4.55	0.96	2.41	2.373e-03	-	2.82	-	(59.92, 73.68)	Repeater	FRB20180814A
FRB20210429B	(355.62, 78.80)	59333.20	4.05	0.95	1.67	2.275e-03	-	2.84	-	(355.91, 78.93)	Single Burst	-
FRB20190609D	(115.92, 51.69)	58643.94	3.31	0.92	3.96	1.359e-03	-	3.00	-	(113.05, 51.64)	Single Burst	-

Most significant single-burst FRBs used in binomial test

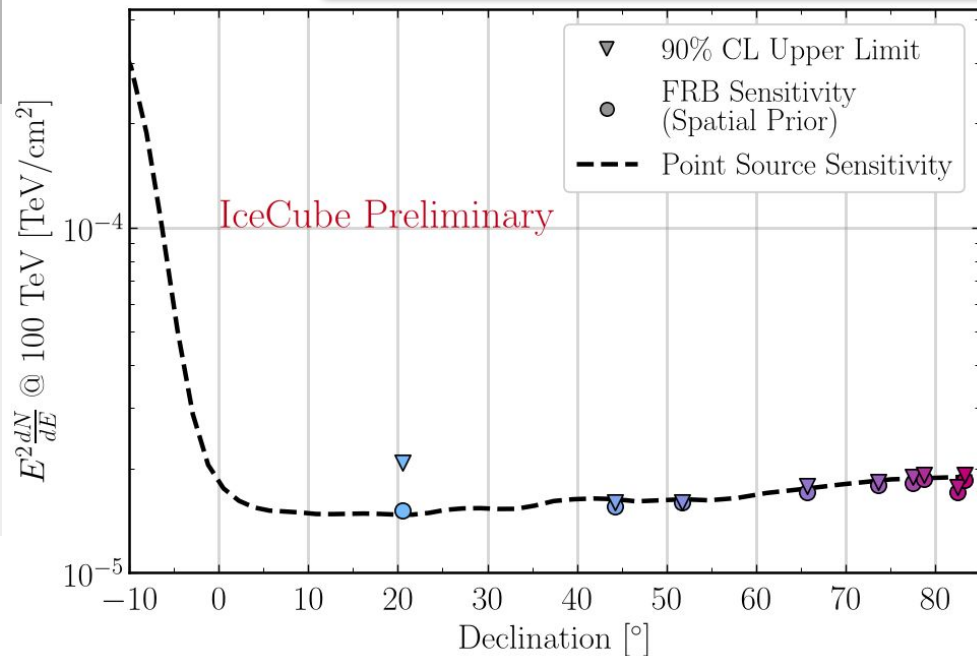
Burst Name	(RA, Dec)	MJD	TS_{fit}	ns_{fit}	γ_{fit}	Pre-trial p_{val}	Post-trial p_{val}	Pre-Trial Significance	Post-trial Significance	RA_{fit}, Dec_{fit}	Class	Repeater Name
FRB20221207D	(20.88, 20.50)	59920.18	17.54	1.00	4.73	6.083e-05	4.831e-02	3.84	1.66	(22.85, 20.34)	Repeater	FRB20220529A
FRB20200614A	(29.11, 65.73)	59014.69	6.79	0.99	4.61	1.082e-03	-	3.07	-	(24.96, 65.6)	Repeater	FRB20180916B
FRB20210213A	(191.72, 83.28)	59258.47	5.87	0.98	2.74	2.781e-03	-	2.77	-	(206.64, 83.05)	Single Burst	-
FRB20230629G	(65.41, 77.54)	60124.74	5.78	0.98	4.85	2.777e-03	-	2.77	-	(60.98, 77.37)	Single Burst	-
FRB20220331A	(288.67, 82.53)	59669.10	5.62	0.98	3.10	2.669e-03	-	2.79	-	(302.68, 82.32)	Single Burst	-
FRB20201229A	(202.54, 44.24)	59212.62	5.52	0.98	3.25	1.129e-03	-	3.05	-	(200.19, 44.2)	Single Burst	-
FRB20191107A	(66.09, 73.60)	58794.89	4.55	0.96	2.41	2.373e-03	-	2.82	-	(59.92, 73.68)	Repeater	FRB20180814A
FRB20210429B	(355.62, 78.80)	59333.20	4.05	0.95	1.67	2.275e-03	-	2.84	-	(355.91, 78.93)	Single Burst	-
FRB20190609D	(115.92, 51.69)	58643.94	3.31	0.92	3.96	1.359e-03	-	3.00	-	(113.05, 51.64)	Single Burst	-



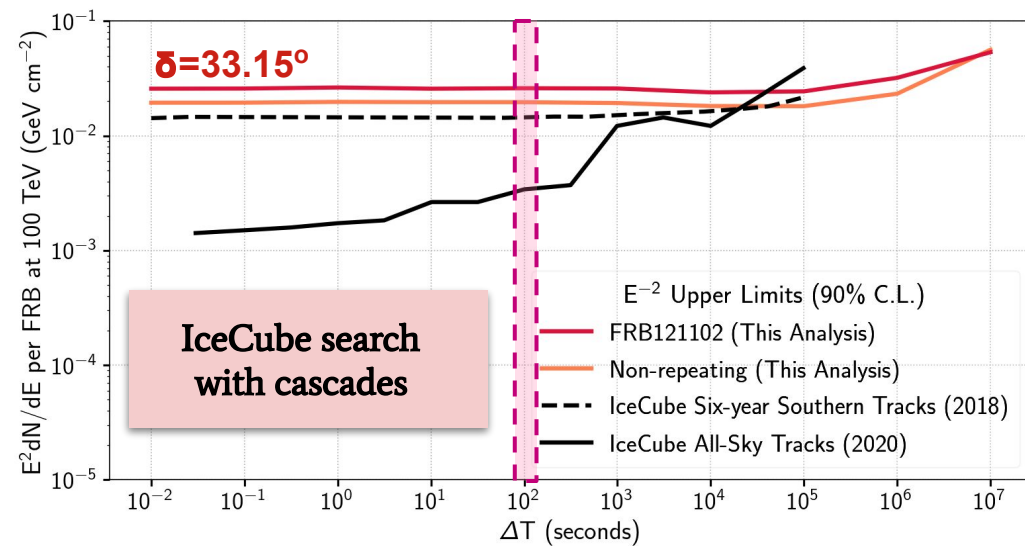
Upper limits

Point source sensitivity differs slightly from spatial prior sensitivity

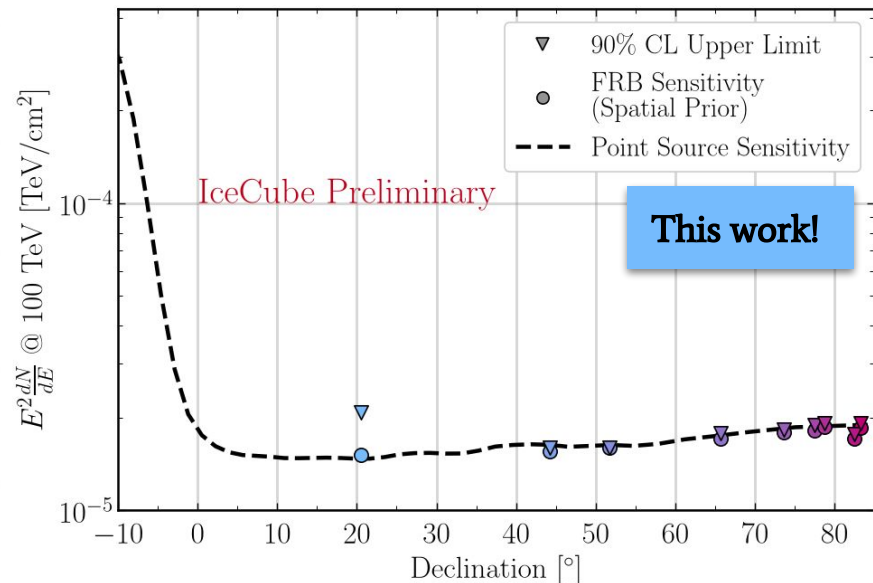
FRB	Classification	Declination [°]	Upper Limit [TeV/cm ²]
FRB 20221207D	Repeater	20.5	2.08×10^{-5}
FRB 20201229A	Single	44.24	1.60×10^{-5}
FRB 20190609D	Single	51.69	1.60×10^{-5}
FRB 20200614A	Repeater	65.73	1.79×10^{-5}
FRB 20191107A	Repeater	73.6	1.84×10^{-5}
FRB 20230629G	Single	77.54	1.90×10^{-5}
FRB 20210429B	Single	78.8	1.92×10^{-5}
FRB 20220331A	Single	82.53	1.77×10^{-5}
FRB 20210213A	Single	83.28	1.92×10^{-5}



Comparing to Previous Limits



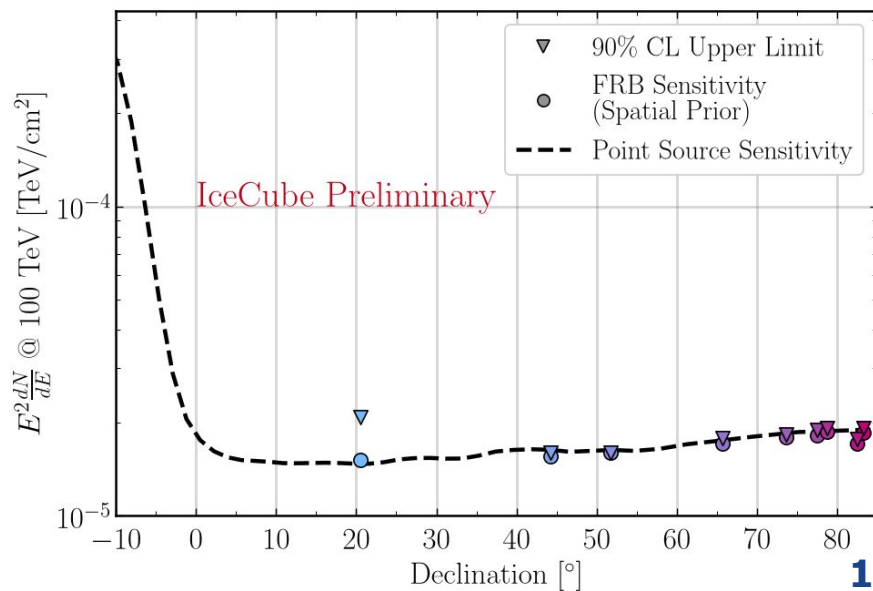
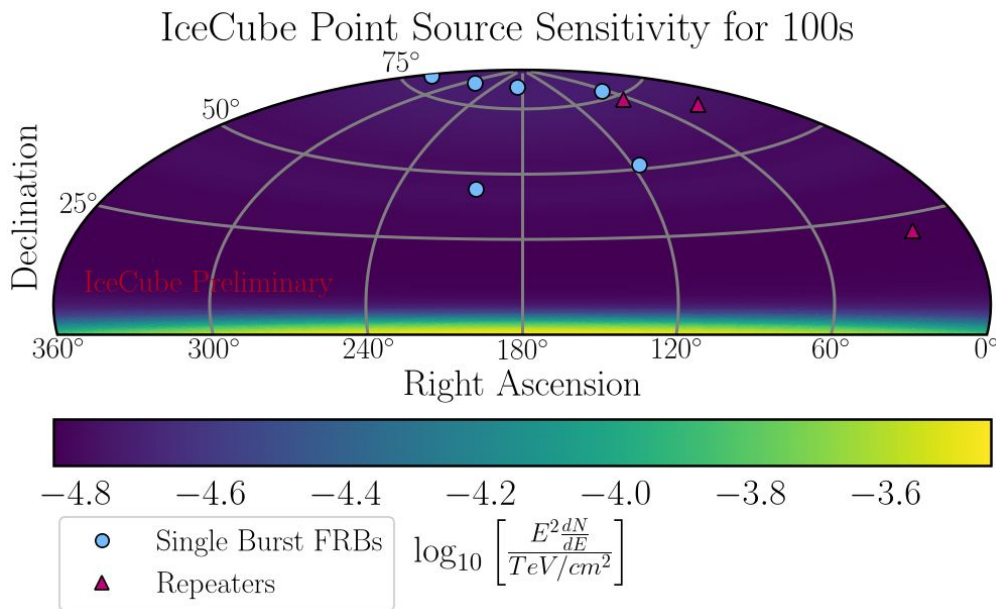
Orange and black lines are stacking limits



This analysis' limits are ~2 orders of magnitude stronger than previous analyses

Conclusions

- We have conducted the largest search for neutrinos from FRBs
 - Results consistent with background expectation
- Our most significant (pre-trials correction) max-burst result is 3.84σ (post: 1.66σ)
- We set upper limits for our most significant FRBs



BACKUP

Maximum Likelihood Method

We apply an unbinned maximum likelihood method in order to search for sources:

$$\mathcal{L}(n_s, \gamma) = \frac{(n_s + n_b)^N}{N!} e^{-(n_s + n_b)} \times \prod_{i=1}^N \left(\frac{n_s}{n_s + n_b} \mathcal{S}(\mathbf{x}_i | \gamma) + \frac{n_b}{n_s + n_b} \mathcal{B}(\mathbf{x}_i) \right)$$

Likelihood that there are n_s neutrinos from the source

Signal term: probability that the i^{th} event originates from this source

Background term: probability that the i^{th} event is a background event

Poisson term: extended likelihood term to account for fluctuations in the number of events observed (specific to transient analyses)

$$\text{TS} = \max_{n_s, \gamma} \left[2 \ln \left(\frac{\mathcal{L}(n_s, \gamma)}{\mathcal{L}(n_s = 0)} \right) \right] \quad \text{Test Statistic (TS): log-likelihood ratio between best fit parameters and null hypothesis } (n_s = 0)$$

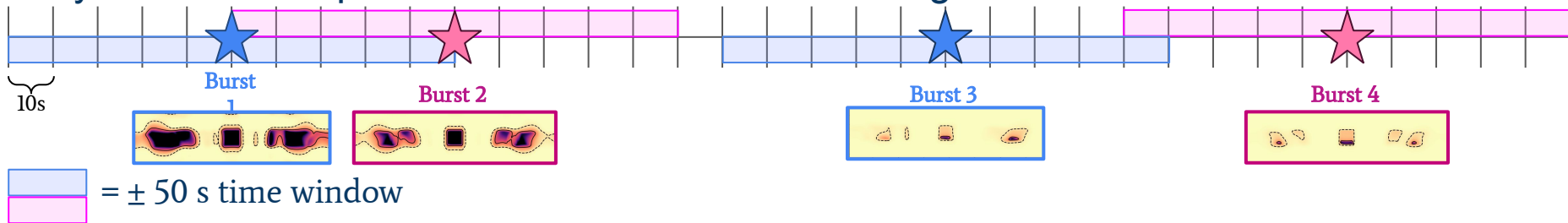
Binomial Test

$$TS_{new} = \min_k(\alpha(k))$$

where:

$$\alpha(k) = P(n \geq k | N, p_k) = \sum_{m=k}^M \frac{M!}{(M-m)!m!} p_k^m (1-p_k)^{N-m}$$

Say we have a repeater which exhibits the following behavior:



We observe:

Case A: Burst 1 & Burst 2 have time-windows with significant overlap ($>25\%$)

Case B: Burst 3 & Burst 4 have time-windows with moderate overlap ($< 25\%$)

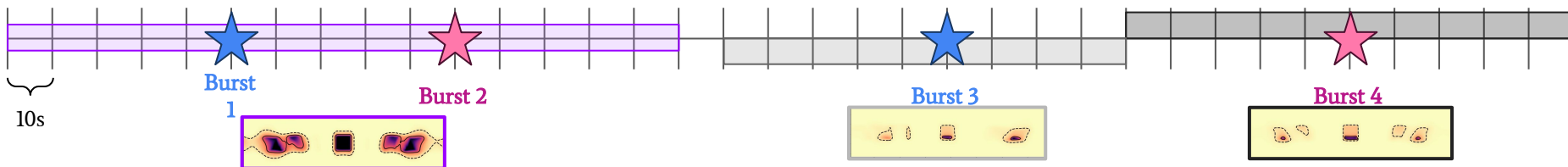
We adopt the following approach

Case A:

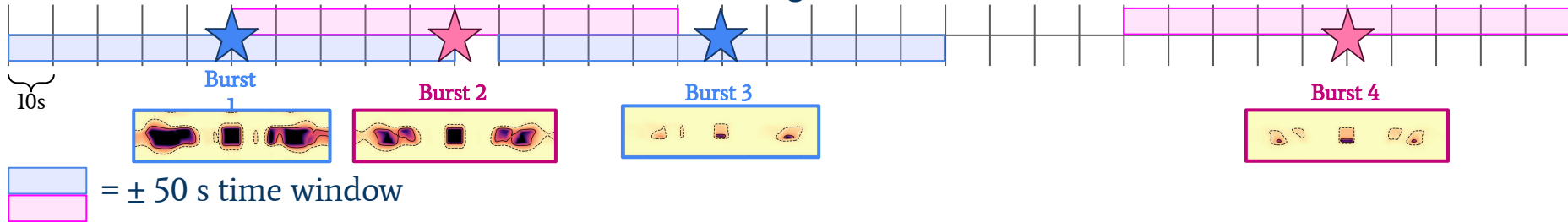
- Extend a single time-window to the ends of the combination of the two
 - Use the best (least-uncertainty) localization
- 1 time-window,
1 localization

Case B:

- Shorten first burst time-window to hit start of second burst
 - Use both localizations for each bursts
- 2 time-windows,
2 localizations



What if we have a bunch of bursts close together?



We observe:

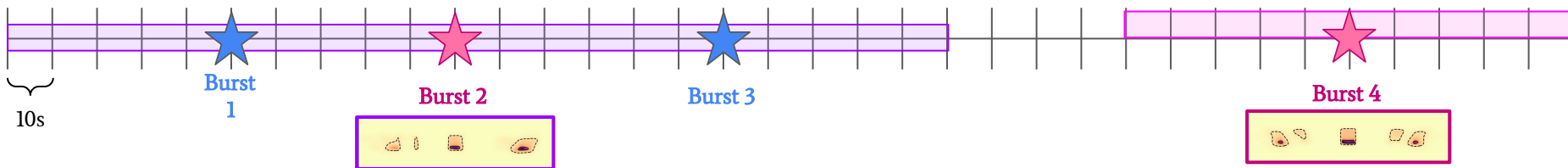
Three bursts which are very close together, while burst 1 and 3 have no overlap, the combination of 1, 2, and 3 all have overlap

We adopt the following approach (case A from previous slide)

Case A:

- Extend a single time-window to the ends of the combination of all
- Use the best (least-uncertainty) localization

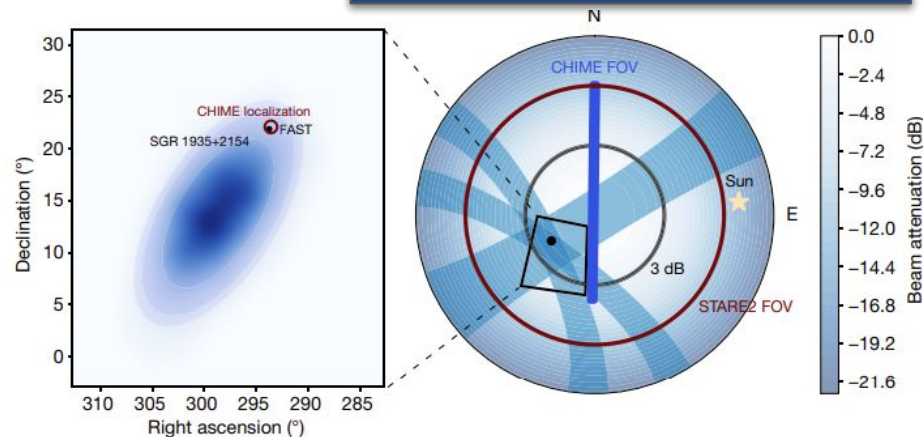
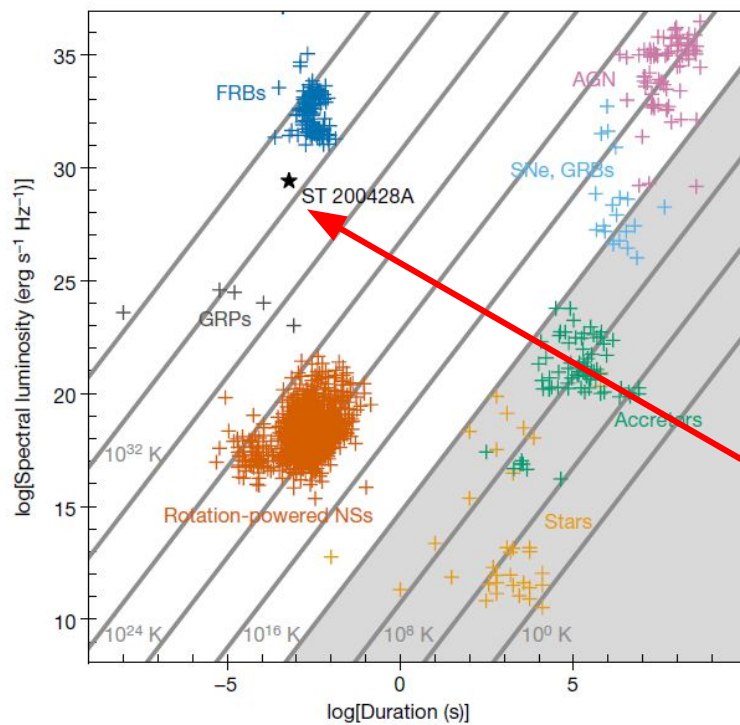
1 time-window,
1 localization



Association of Magnetar with FRB 200428

Typically referred to as
FRB-like signal

- SGR 1935+2154 observed by FAST in X-rays at same time as CHIME and STARE2 FRB observation

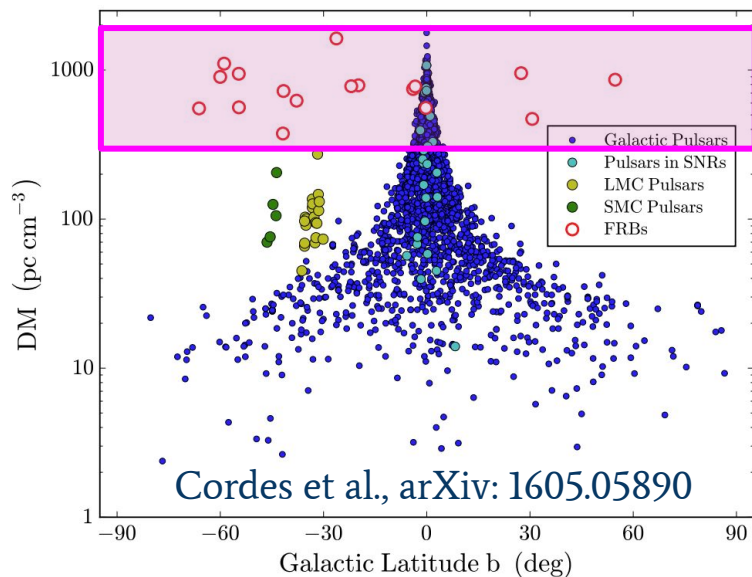


- First FRB-Like signal from known source class (magnetars)
- Low energy compared to weakest FRB signals (30x less energetic than weakest)
- Galactic origin (all other FRBs are extragalactic)
- Luminosity roughly consistent with FRB signals

Bochenek, C.D., Ravi, V., Belov, K.V. *et al.* A fast radio burst associated with a Galactic magnetar. *Nature* 587, 59–62 (2020).
<https://doi.org/10.1038/s41586-020-2872-x>

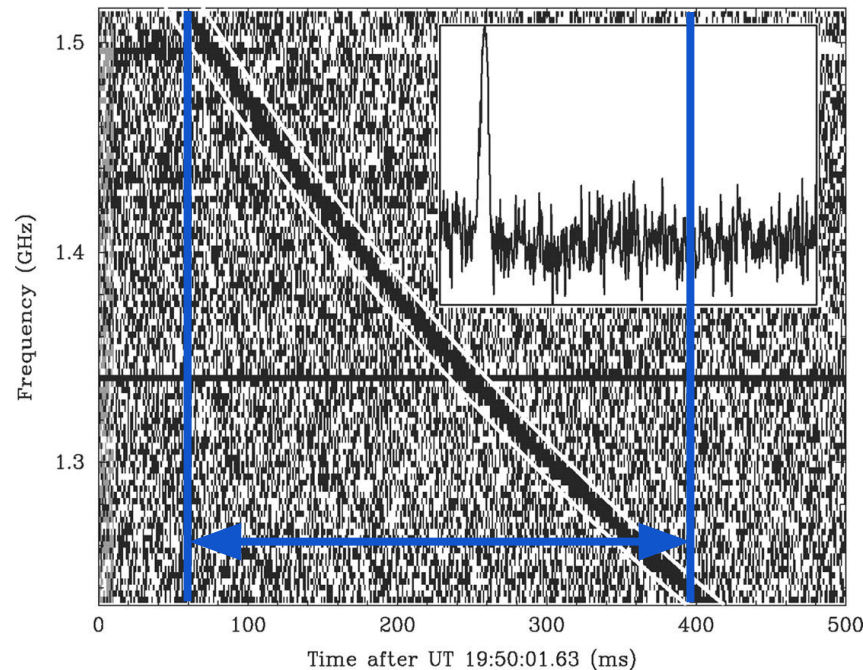
Follow-up of FRBs

Localizing FRBs



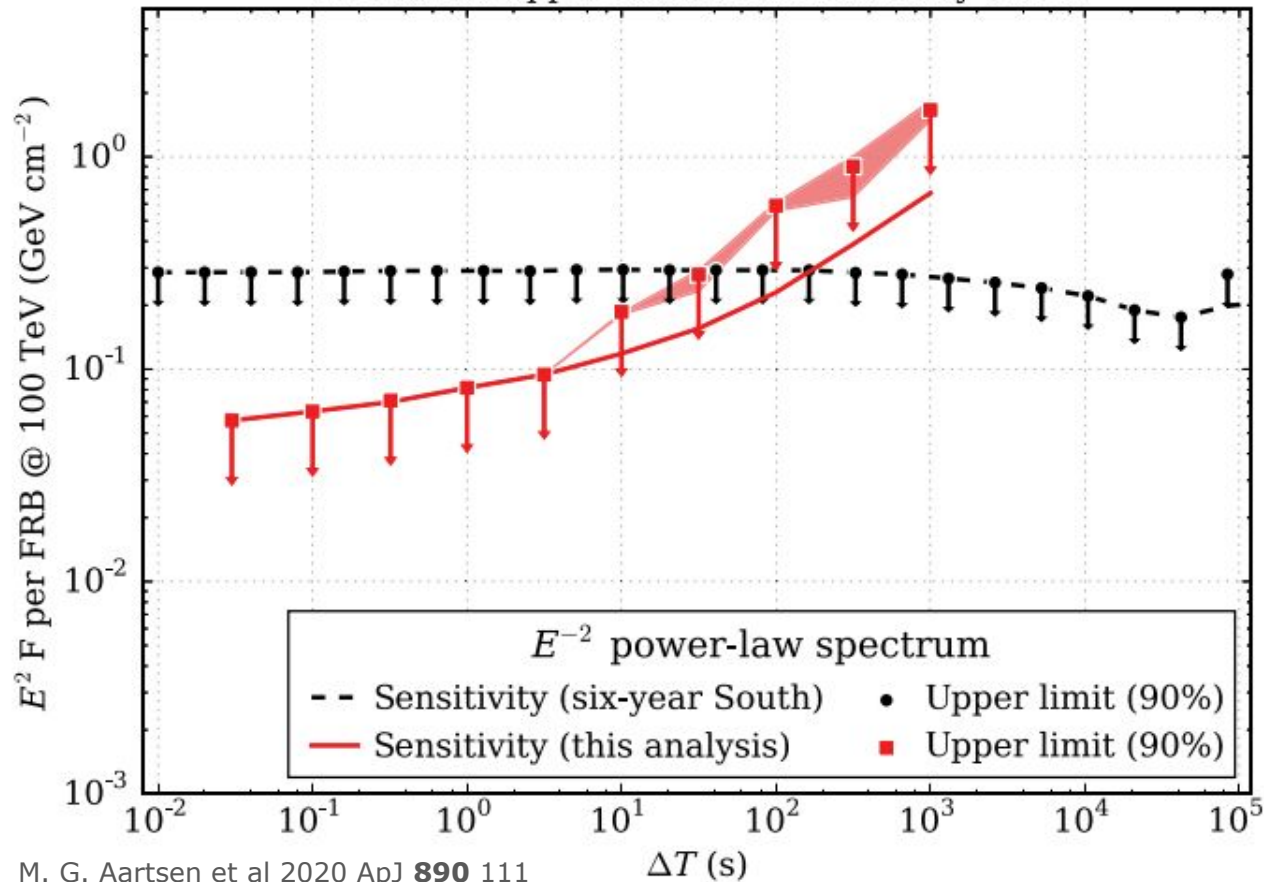
Dispersion Measure (DM): measure of integrated column density of free electrons measured along the line of sight

- DMs larger than what Milky Way alone can provide
- Consistent with **extragalactic origin**

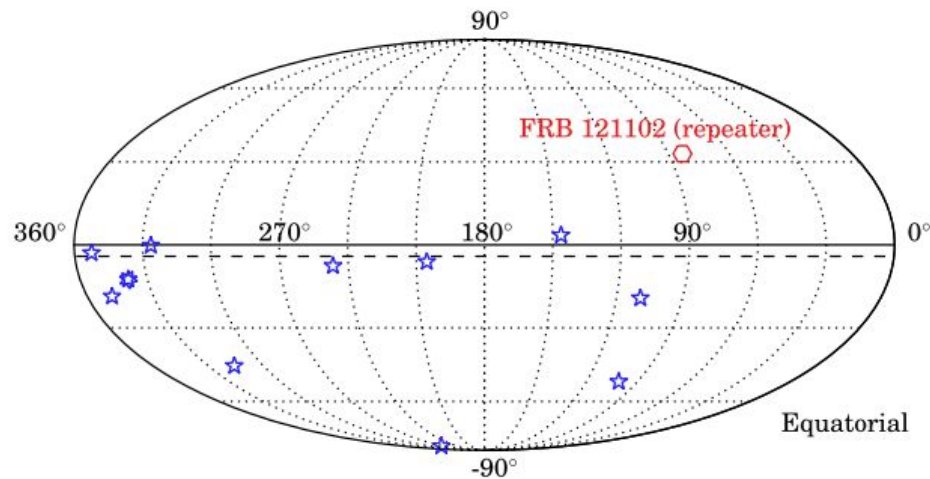
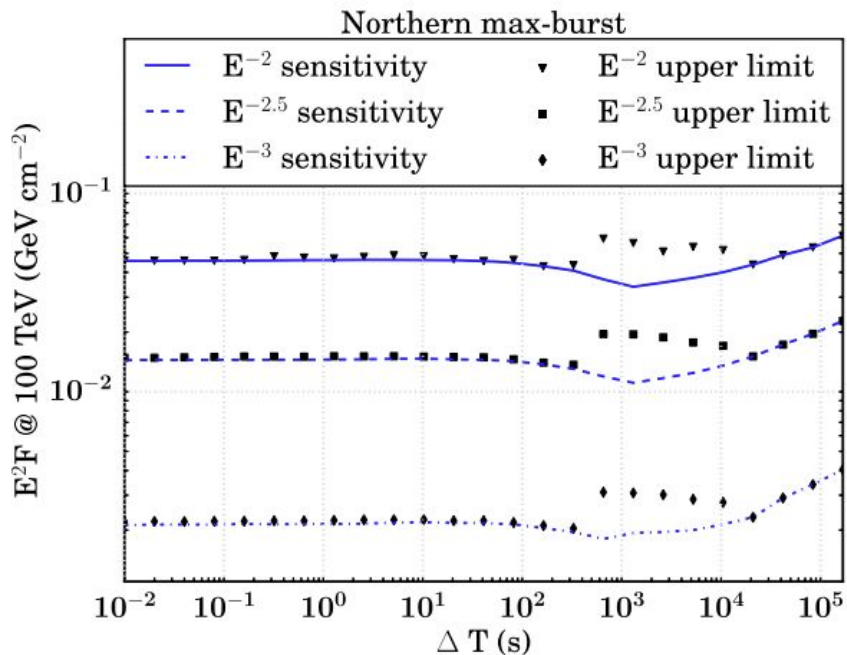


$$\Delta t = \frac{e^2}{2\pi m_e c} (\nu_{\text{lo}}^{-2} - \nu_{\text{hi}}^{-2}) \text{ DM} \approx 4.15 (\nu_{\text{lo}}^{-2} - \nu_{\text{hi}}^{-2}) \text{ DM ms}$$

Max-burst Upper Limits and Sensitivity vs. ΔT



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M. G. Aartsen et al 2018 ApJ **857** 117