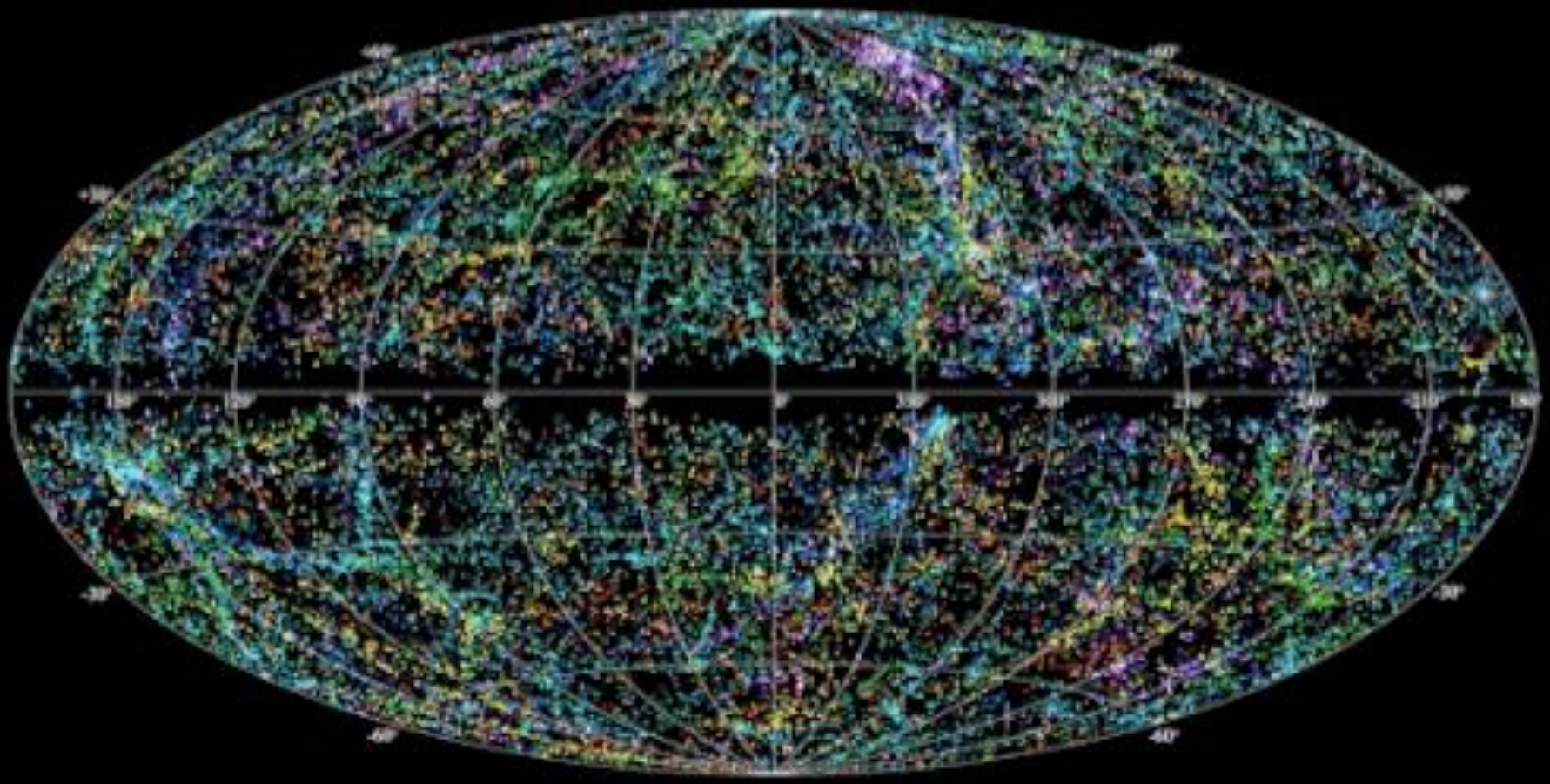
Fast Radio Bursts & CHIME/FRB

Shriharsh Tendulkar
McGill University



What are FRBs?

Introduction, Observations, Models

Recent Results

The repeating FRB 121102

The CHIME/FRB Project

Prodigious FRB Finder

The Era of Thousands

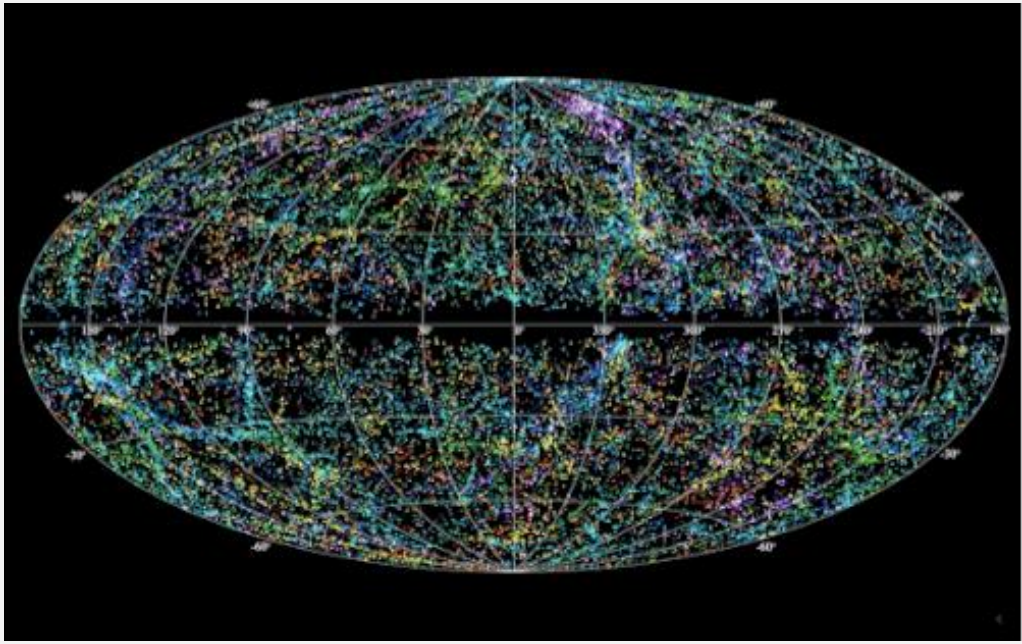
WHAT ARE FRBS?

Very short (~ms), very bright (~Jansky), radio flashes

Similar to pulsar signals
(but not periodic, almost all single)

Rate ~10^3 /sky/day
at 1 Jy (Lawrence+2017, ++)

35 reported since 2007

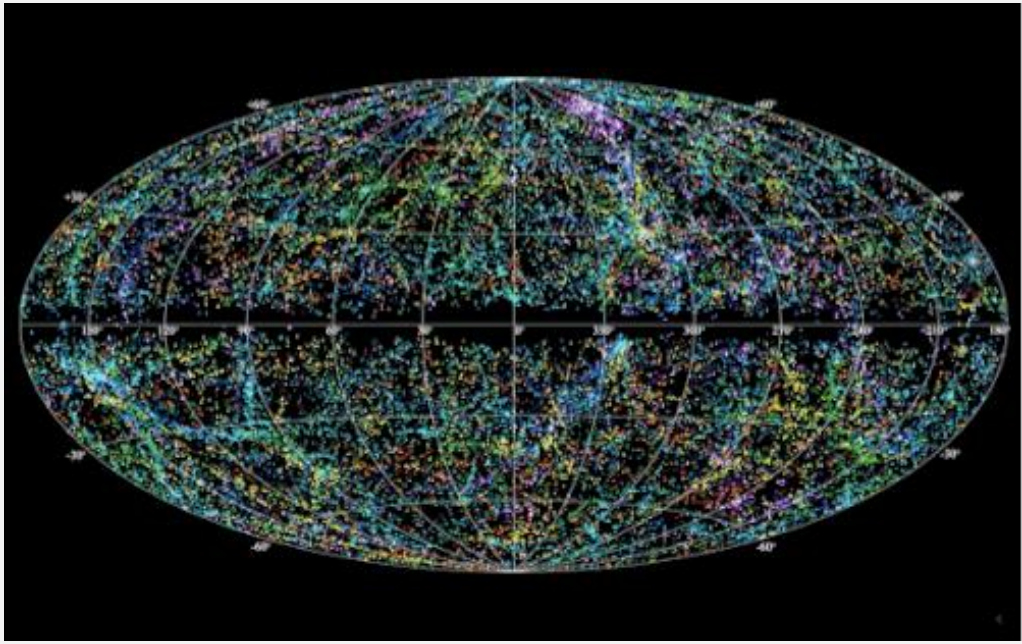


WHAT ARE FRBS?

400

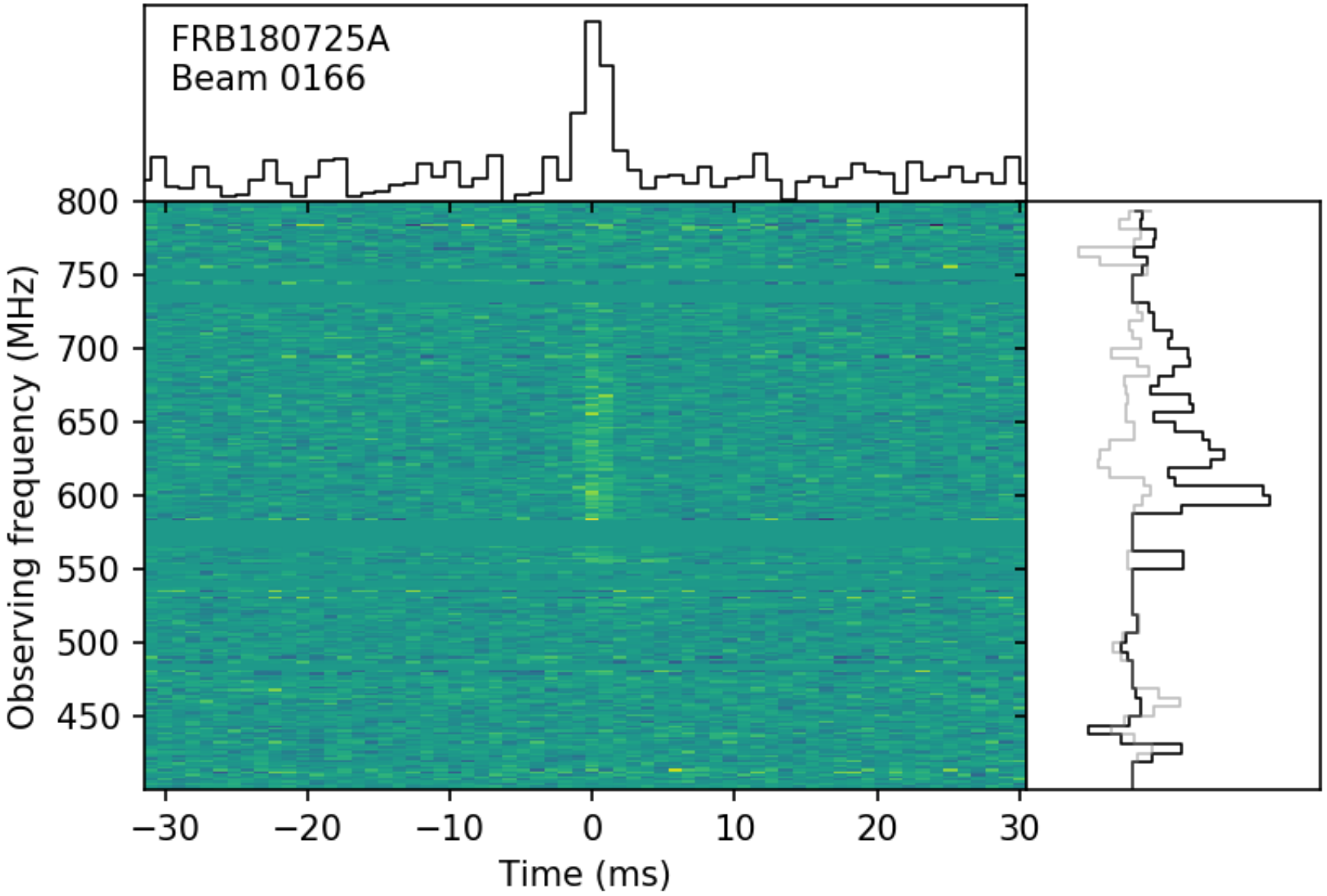
Detected between ~~800~~ MHz–8 GHz

All surveys between
400 MHz–1.8 GHz



Heteregenous sample

- Spectra
- Complexity
- Polarization
- Faraday rotation


FRB180725A
Beam 0166
800
750
700
650
600
550
500
450
Observing frequency (MHz)
−30
−20
−10
0
10
20
30
Time (ms)

NEUTRON STARS

Dense stellar remnants

10 km radius – 3 x10^{30} kg mass

- Core densities of 10^{17} kg m^{-3}
- B-field ~$10^{14–15}$ gauss

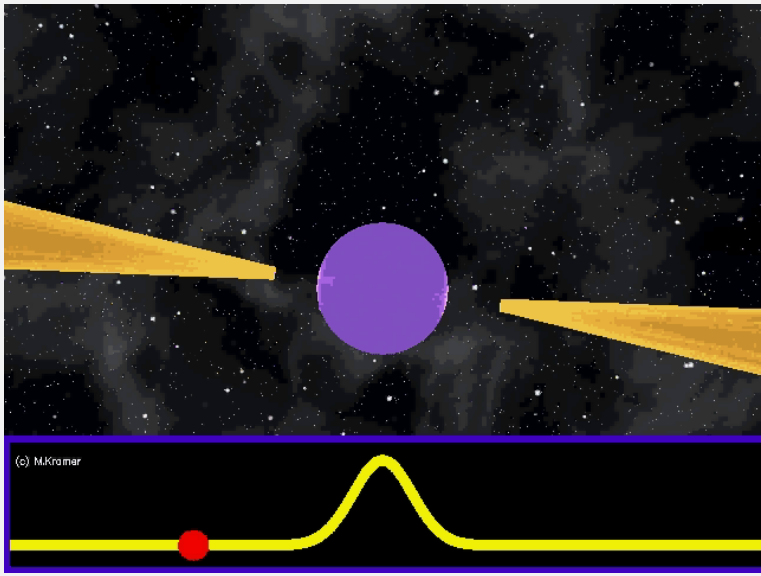
Lose energy into EM radiation

Radio pulsars → Rotation powered

- Periodic radio pulsations

Magnetars → Magnetic field powered

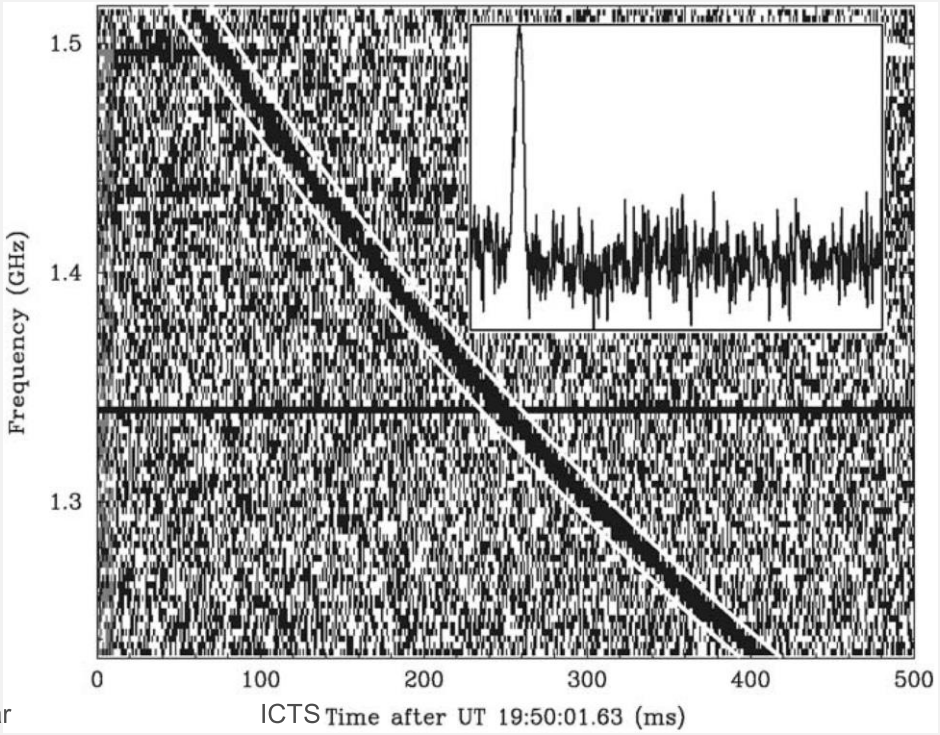
- Intense X-ray/gamma-ray bursts



DISPERSION MEASURE

$\Delta t \propto DM \times freq^{-2}$

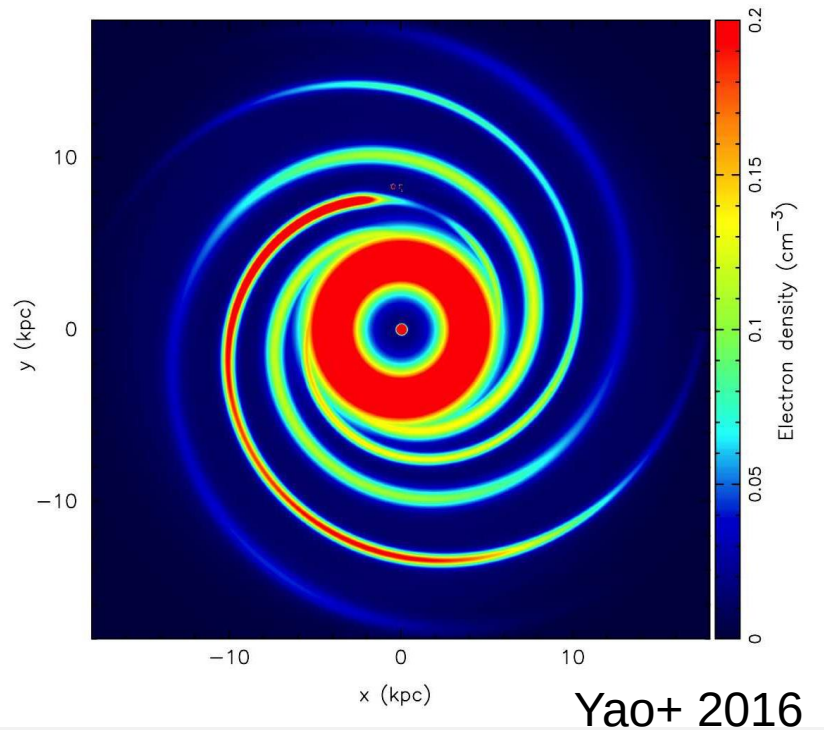
DM (pc cm^{-3}) == total number of electrons from obj. to obs.



Lorimer (2007)

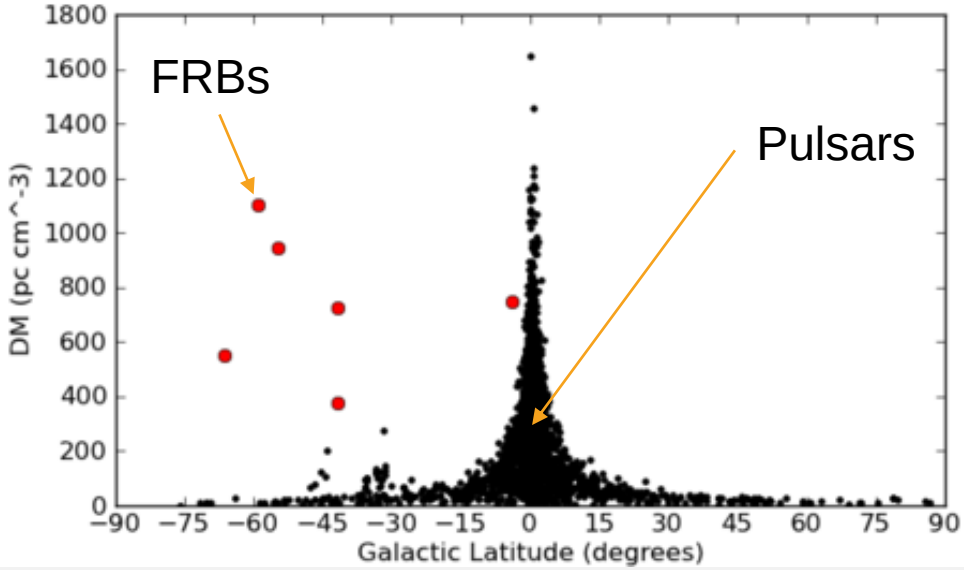
DISPERSION MEASURE

Electron density model of the Milky Way



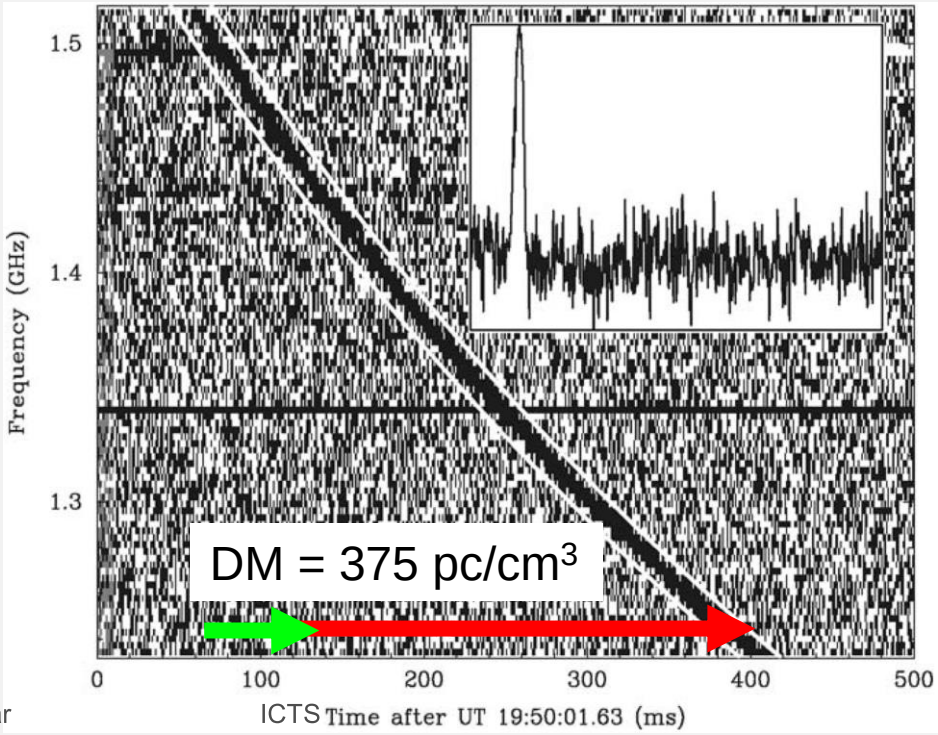
Yao+ 2016

DM measurements of pulsars



DISPERSION MEASURE

IGM dispersion → cosmological distances
→ 10^{12} times brighter than pulsars!



Lorimer (2007)

WHAT ARE FRBS?

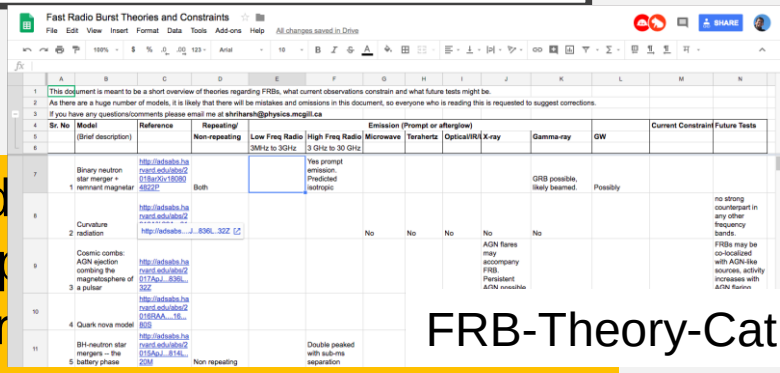
Pulsars on steroids
(don't last long)

Magnetar giant flares
(rate inconsistency, X-ray counterparts)

Merging compact objects (NS-NS, NS-BH, WD-WD)
(X-ray, GW counterparts)

Accretion induced instability on NS

Supercond
Dicke's sup
Pulsar "cor
Current sheets
Cosmic string cusps
Exotic forms of matter – axion stars, quark novae



As experimenters —
How do we test these?

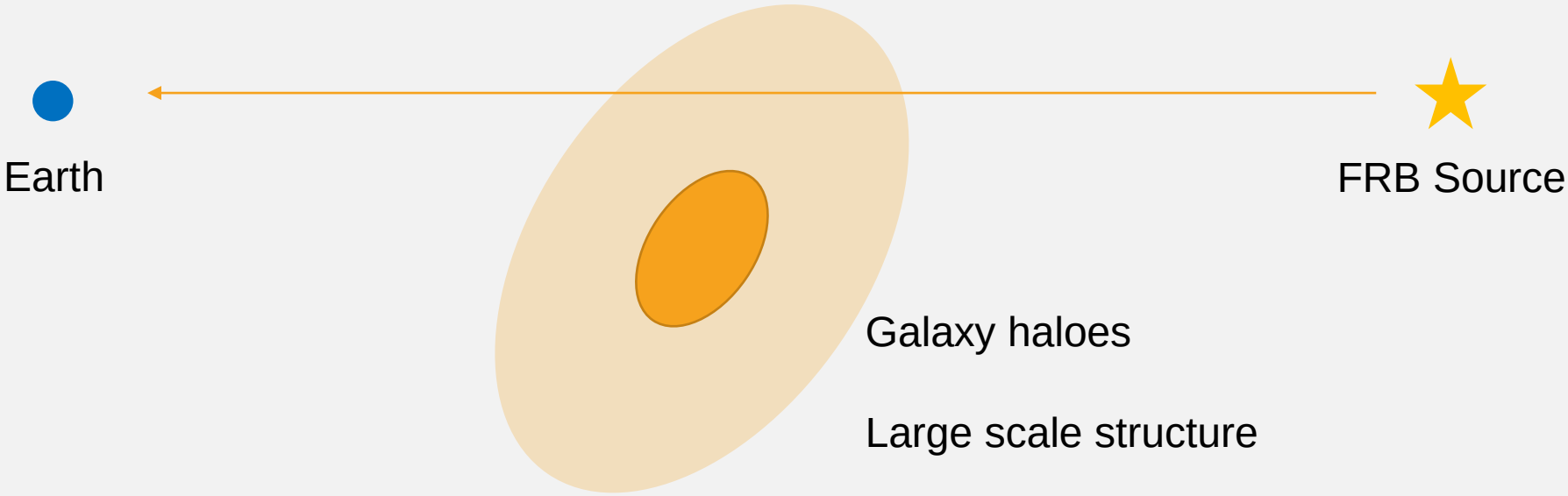
FRBS AS PROBES

Distances of ~ Gpc (3×10^{25} m)

FRBS AS PROBES

Increased dispersion measure, absorption

Probe the **missing baryon** problem (30-40% of baryons untracked)
Traced to Warm-Hot Ionized Medium (Nicastro+2018, de Graff+2017)
Completely new probe of WHIM

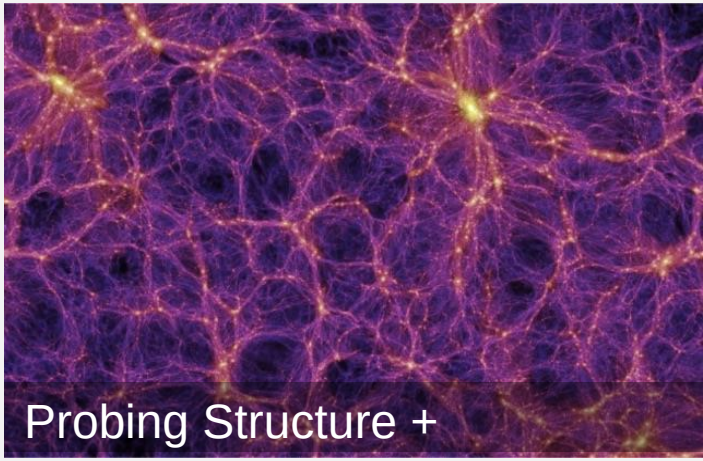


FRBS AS PROBES

Scattering, scintillation

Small scale structure (plasma turbulence)

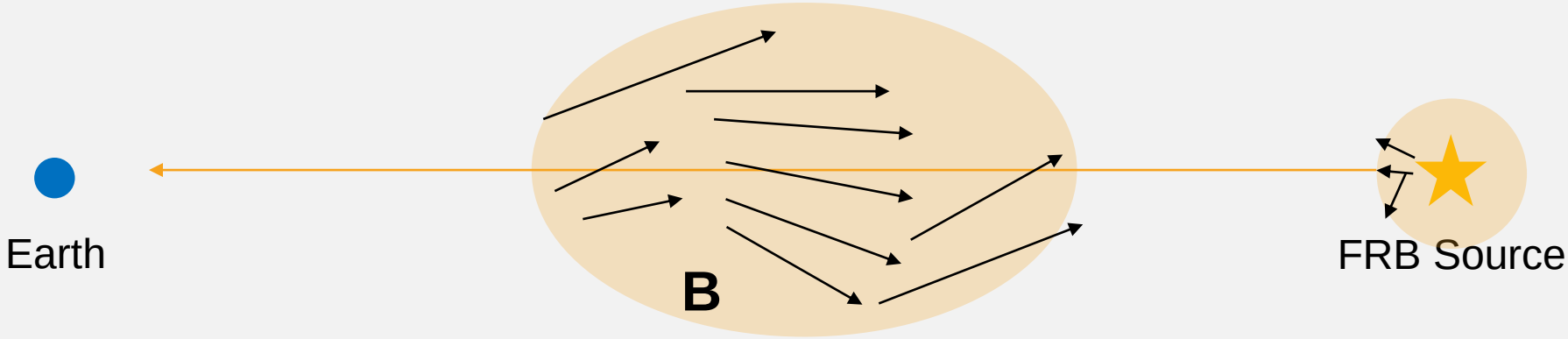
Turbulence in host or Milky Way



FRBS AS PROBES

Magnetic fields → Faraday rotation

Probe the primordial magnetic field distribution (Akahori+ 2017)



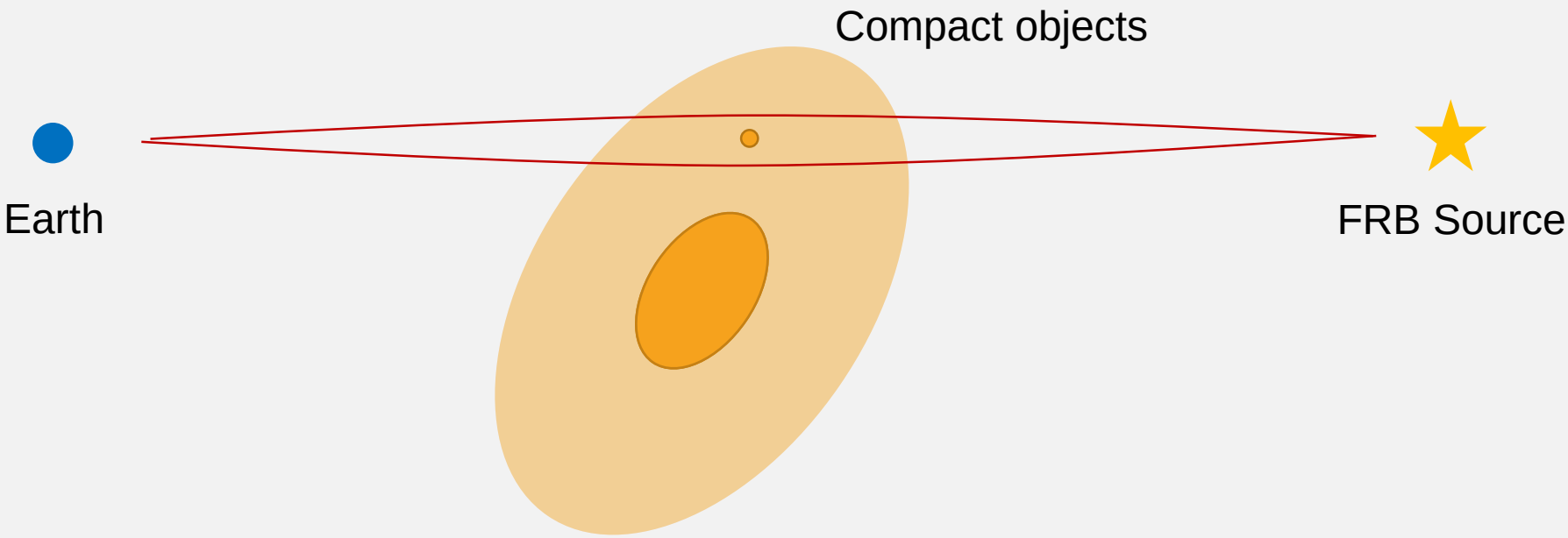
Also probe environments around the FRB (Michilli+ *Nature* 2018)

FRBS AS PROBES

Gravitational Lensing, millisecond time delays

Limit the fraction of dark matter in compact objects (Wang+ 2018)

1 in $10^{4\text{-}5}$ FRBs could be detectably lensed



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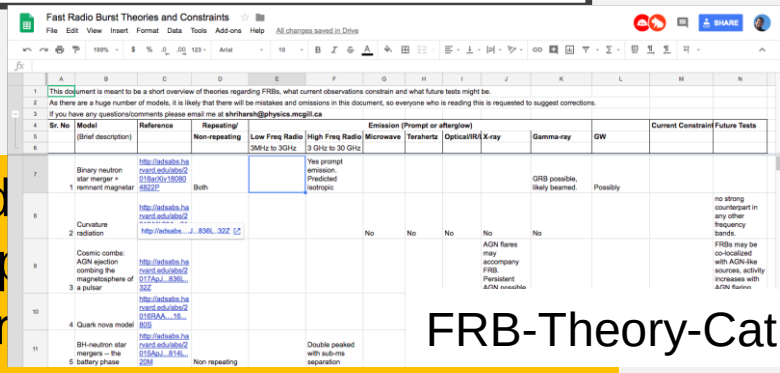


FRB-Theory-Cat

As experimenters —
How do we test these?

TESTING MODELS

Intrinsic properties:

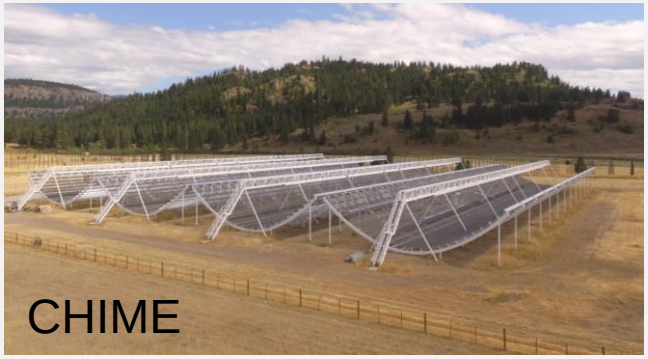
- Spectra
- Widths, substructure
- Polarization

Astrophysical correlations:

- NS-NS, NS-BH mergers → old stellar populations, elliptical galaxies
- Magnetars → young stellar populations, high star formation rate
- AGNs → FRBs near galactic nuclei
- Dark matter → Halo cores

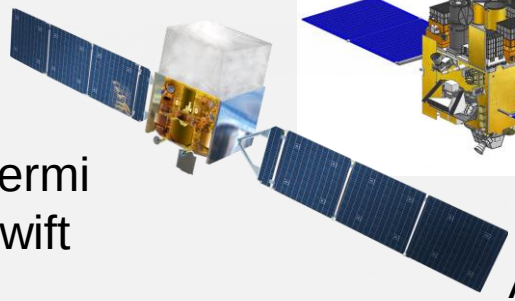
Prompt counterparts

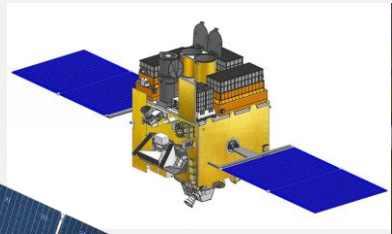
- X-ray/gamma-ray bursts
- Gravitational wave events
- Neutrino emissions?


CHIME


Arecibo


VLA, GMRT


Fermi
Swift


Astrosat


LIGO

RECENT RESULTS

The repeating FRB 121102

MOST FRBS ARE SINGLE SHOTS ...

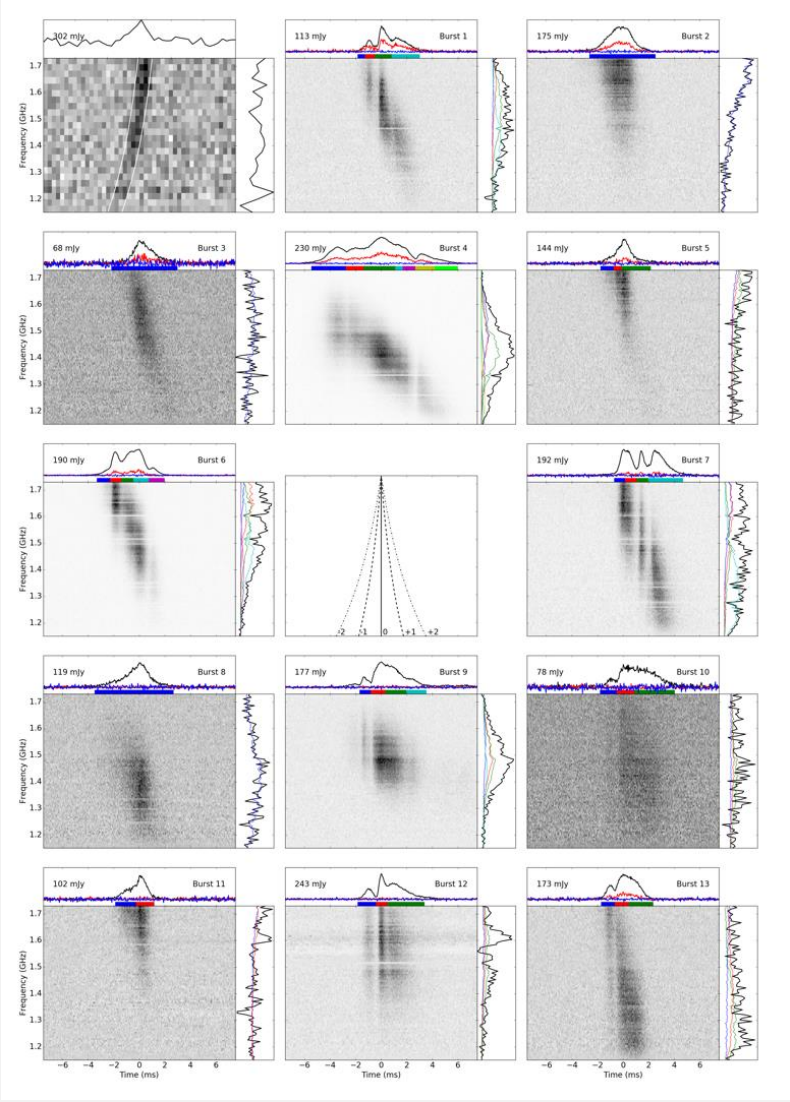
But one of them repeats
Spitler et al 2016 (Nature)

Very sporadically
(No periodicity, not poisson)

Weird Bursts (Hessels+ in prep)

→
Fantastic follow up opportunity for localization

3 arcmin → 0.1 arcseconds

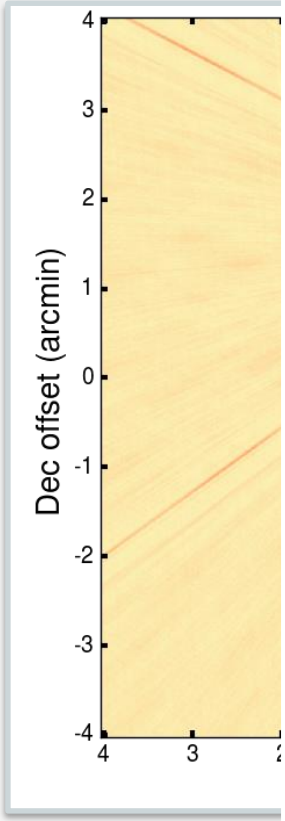


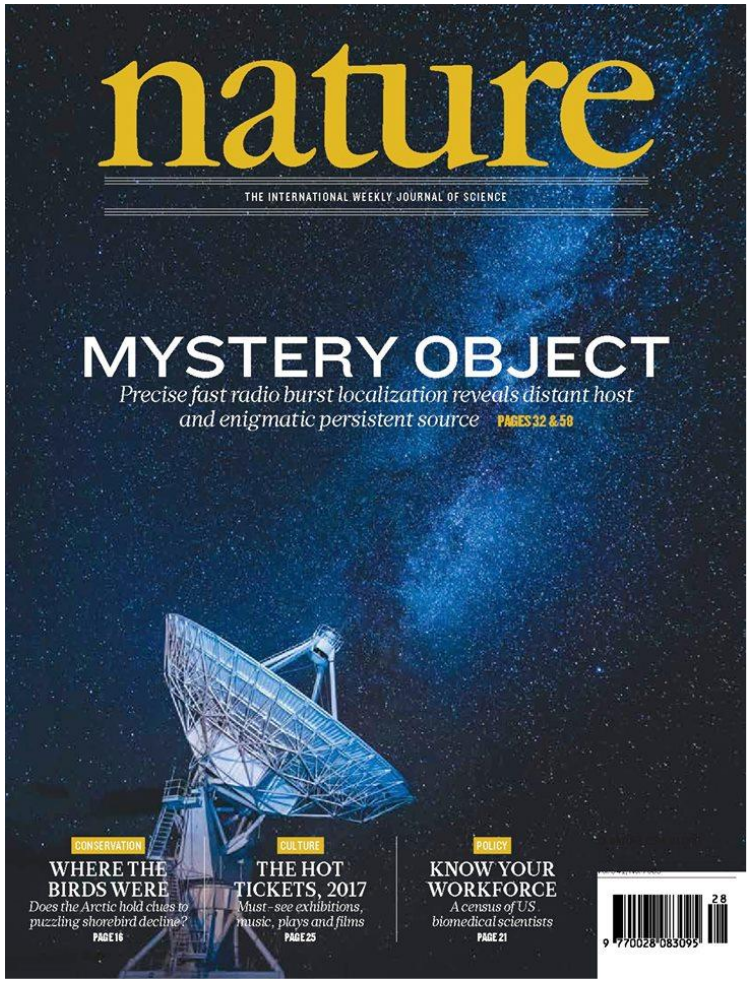
LOCALIZATION

FRB localized (Chatterjee+2017)

In a dwarf galaxy at z=0.1932

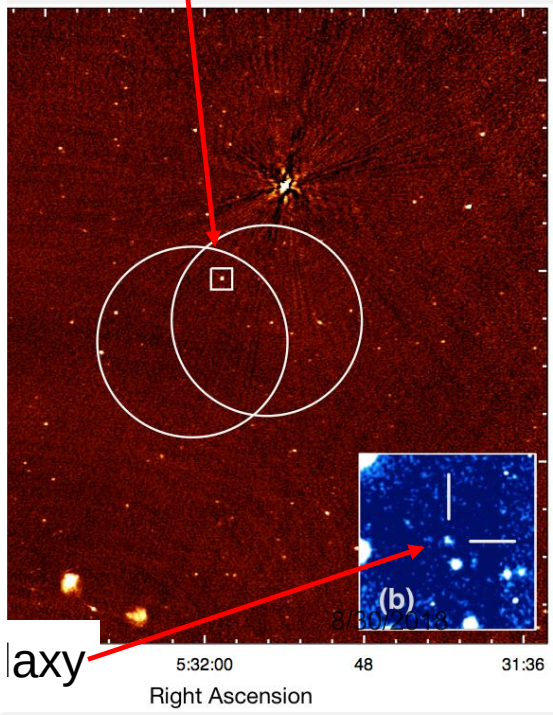
(Tendulkar+2017)





RB 121102

ersistent radio source



laxy

WHY IS IT IN A DWARF GALAXY?

Mass ≈10^8 M_{sun} (Tendulkar+2017)

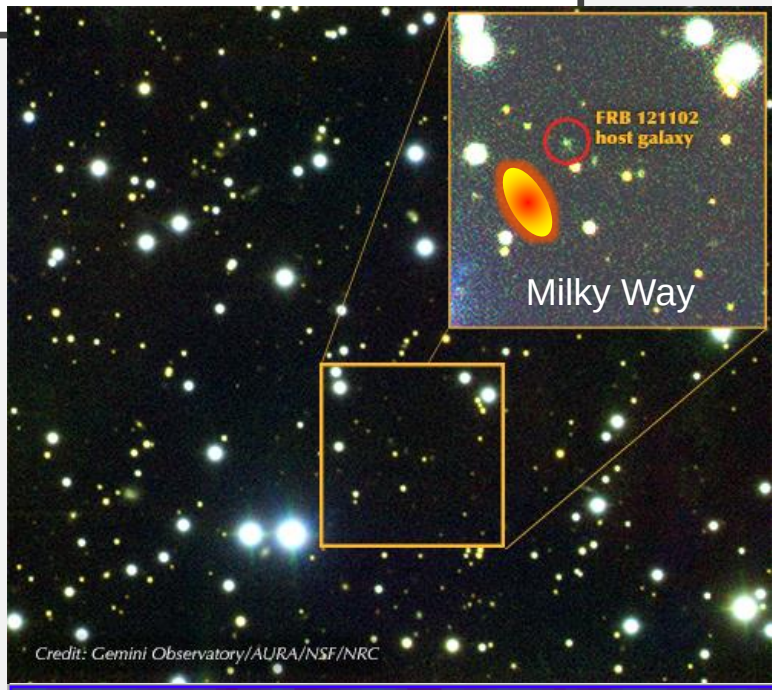
Star formation rate ≈ 0.1 M_{sun} yr^{-1}

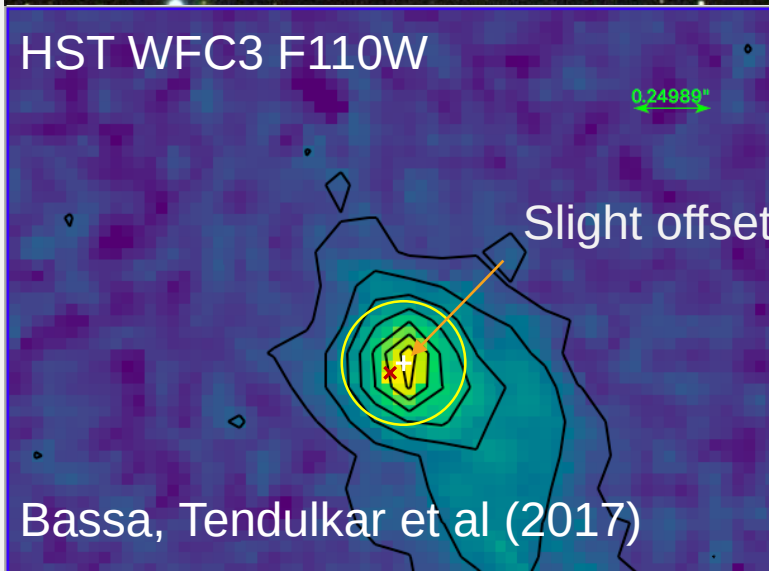
Metallicity, log[O/H] = 8.0±0.1

Similar to LGRB/SLSNe-I hosts

Millisecond magnetar model (Metzger et al 2017)

Could repeating FRBs trace decades old LGRBs/SLSNe-I?





ROTATION MEASURE

Huge rotation measure (RM) $\propto \int n_e B_{||} ds$

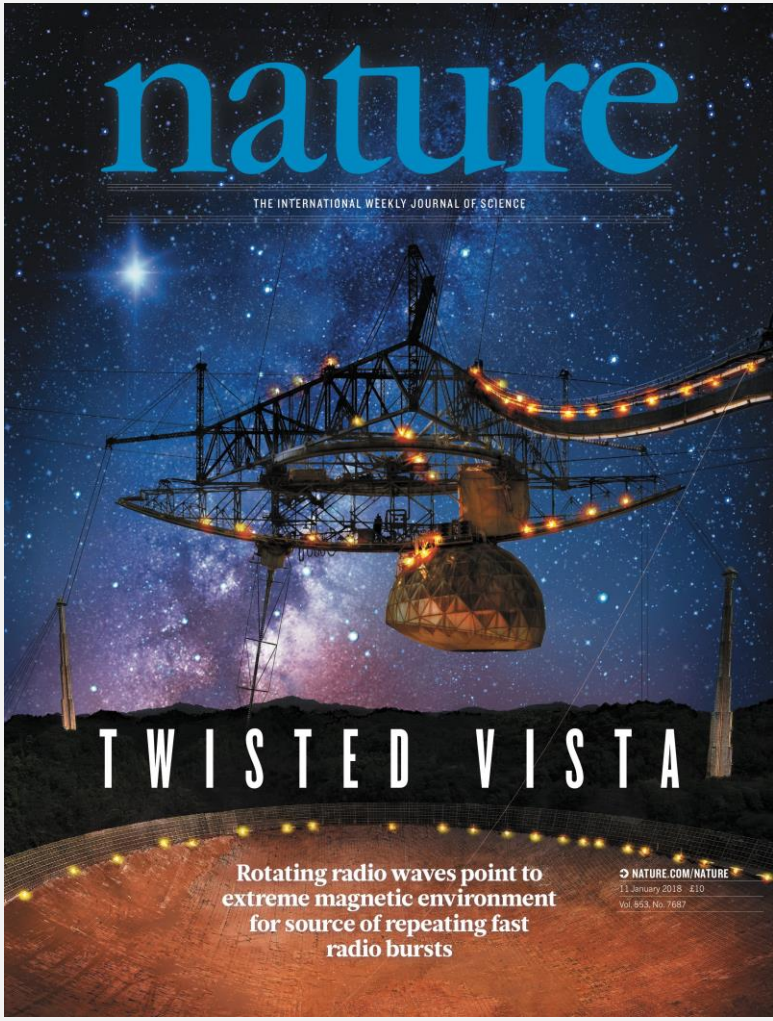
$RM = 1.3 \times 10^5$ rad m^{-2}

(Huge and variable!)

Extreme environment only found near supermassive blackholes

Some theoretical combinations T_e, n_e and L for supernova remnants possible

Still consistent with the LGRB/SLSNe-I connection



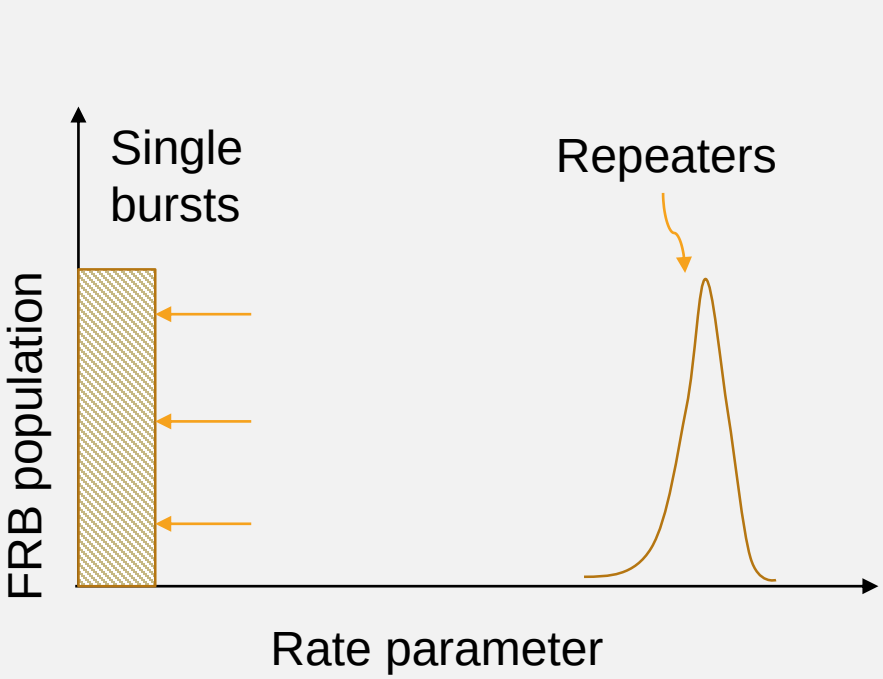
Michilli D. ++ SPT 2018

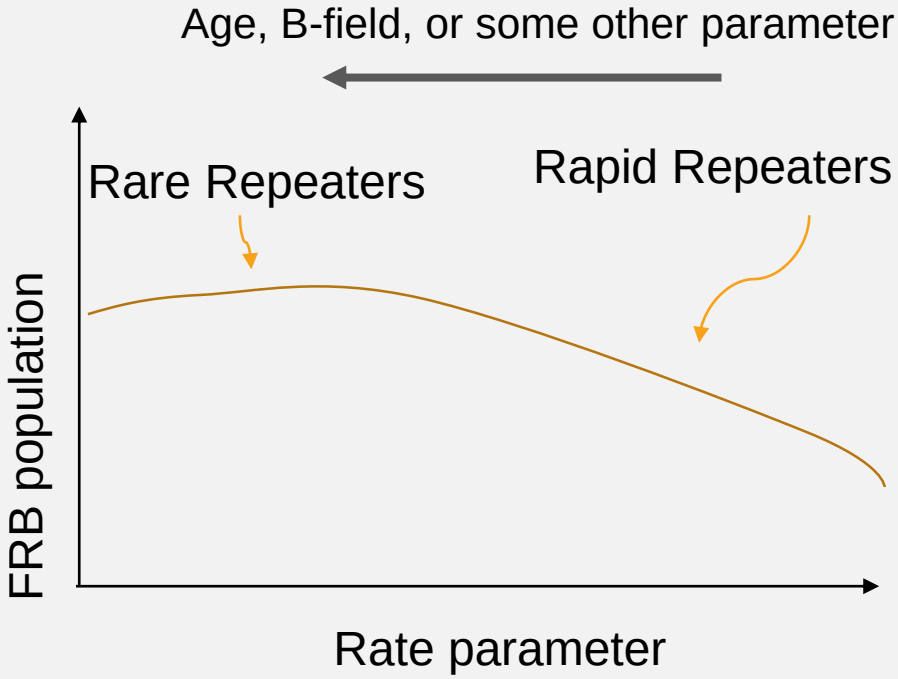
IS THIS UNIQUE OR COMMON?

IS IT UNIQUE?

Are there two distinct populations of repeaters and single bursts?

Or is it a smooth distribution?





Temporal clustering makes it *very* challenging to draw conclusions (Opperman & Pen 2017)

SAMPLE OF FRBS

In the past decade → 35 FRBs

With a heterogeneous set of telescopes and detection pipelines.

What we need is a statistically homogenous sample that is sensitive to repeaters.

1. Large single survey
2. Careful instrument + pipeline design
3. Sensitivity testing and monitoring

CHIME/FRB

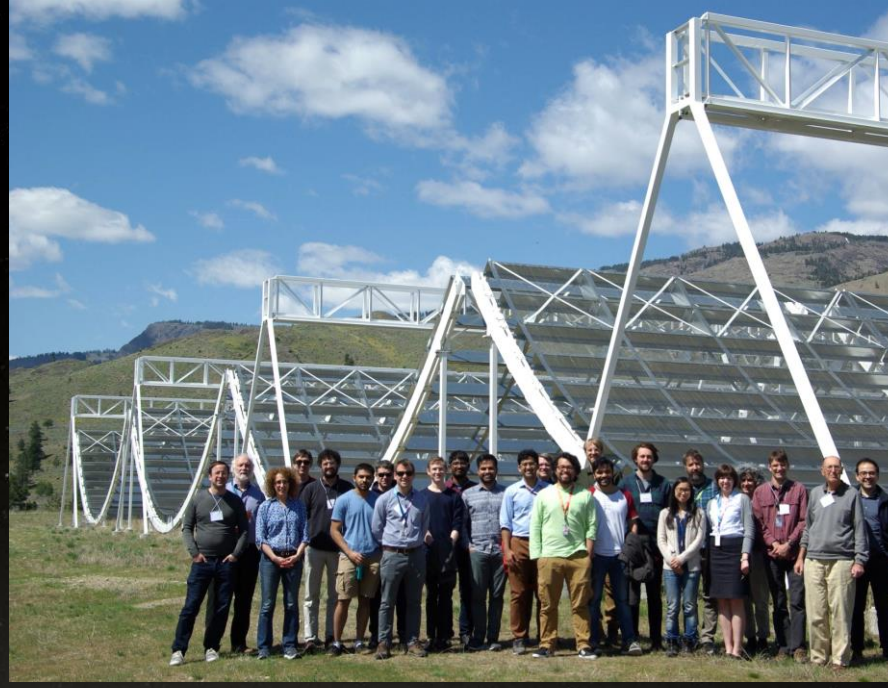


Photo credit: Andre F

CHIME

Canadian Hydrogen Intensity Mapping Experiment

Transit telescope designed to study Baryon Acoustic Oscillations at z=0.8–2.5

Four 20m x 100m North-South cylinders

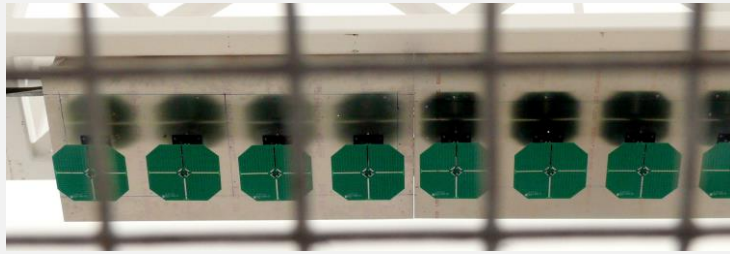
256 dual-pol feeds on each cylinder

400-800 MHz bandwidth

FOV: E-W ~2.5^{o}–1.3^{o},
N-S ~120^{o}

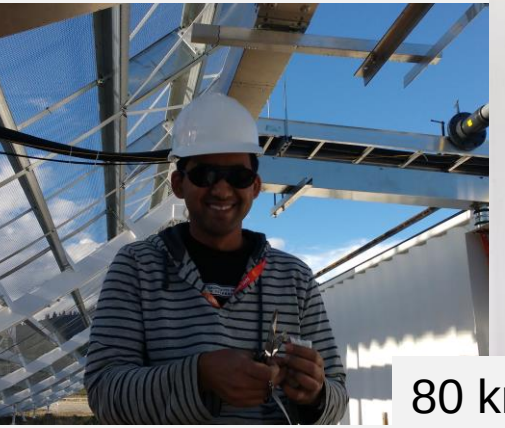
~250 sq deg
Parkes: 0.6 sq deg
Arecibo: 0.02 sq deg

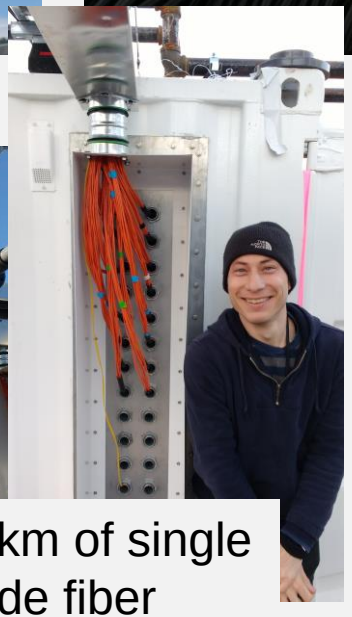
CFI funded FRB backend for real-time detection: CHIME/FRB



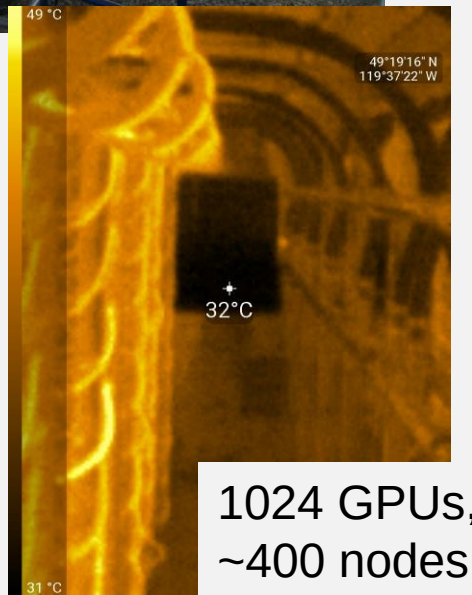
THE SWEAT AND GRIME BEHIND THE PRISTINE UNIVERSE

128 km of coax





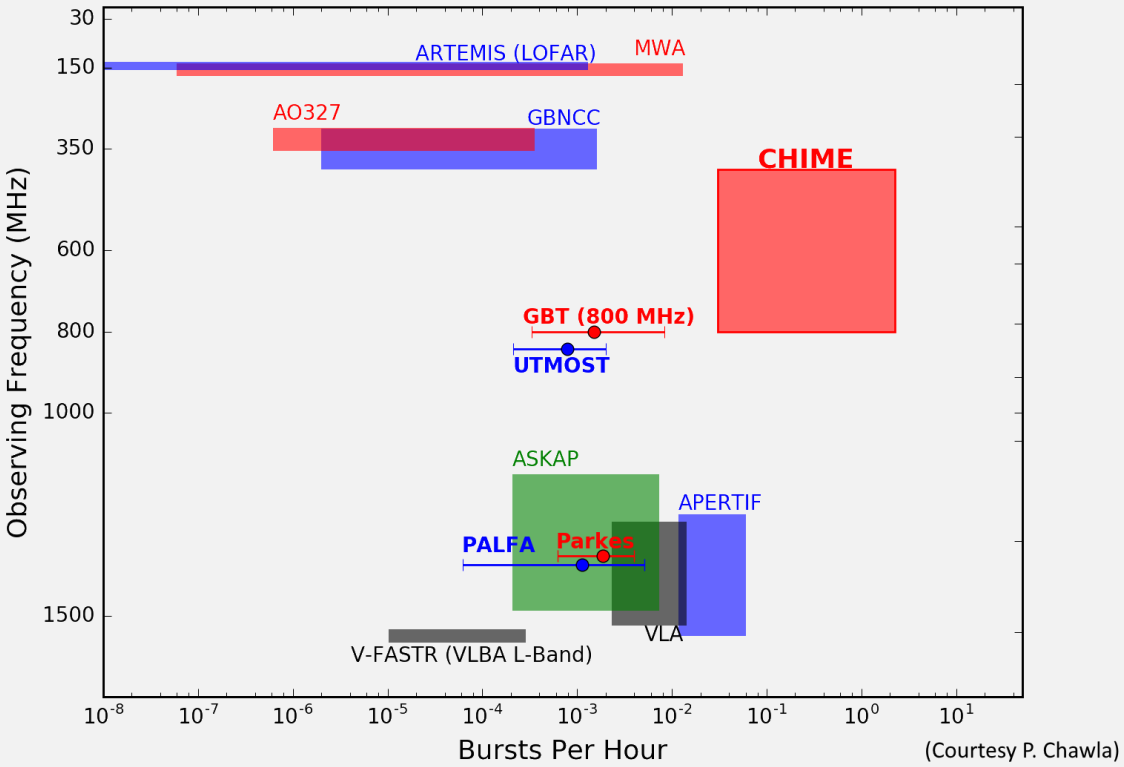
80 km of single mode fiber



1024 GPUs, ~400 nodes

CHIME FRB RATES

Work by Pragya Chawla (Chawla+2017)



1 – 10 FRBs per day!

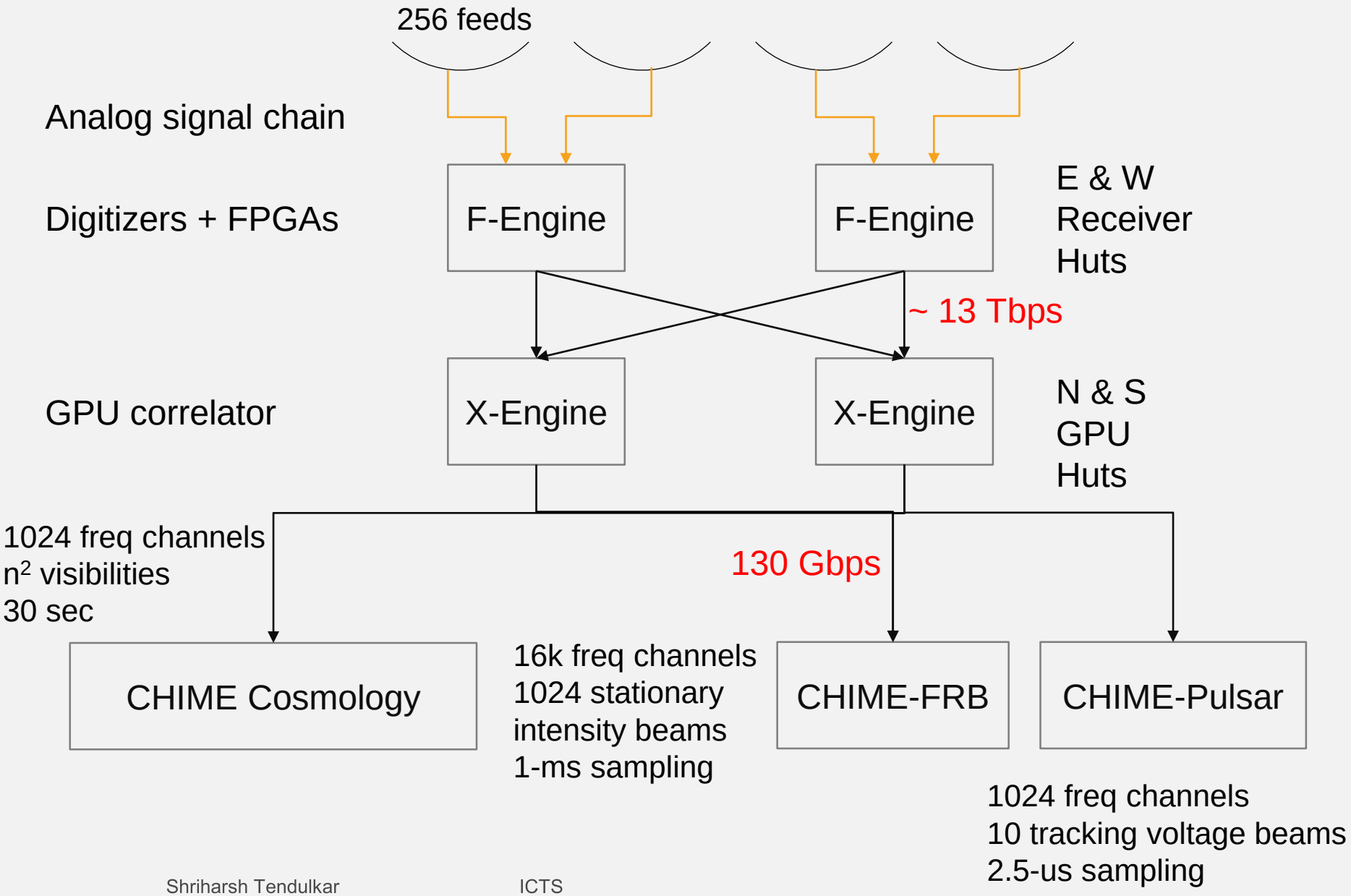
Uncertainty due to spectral distribution etc.

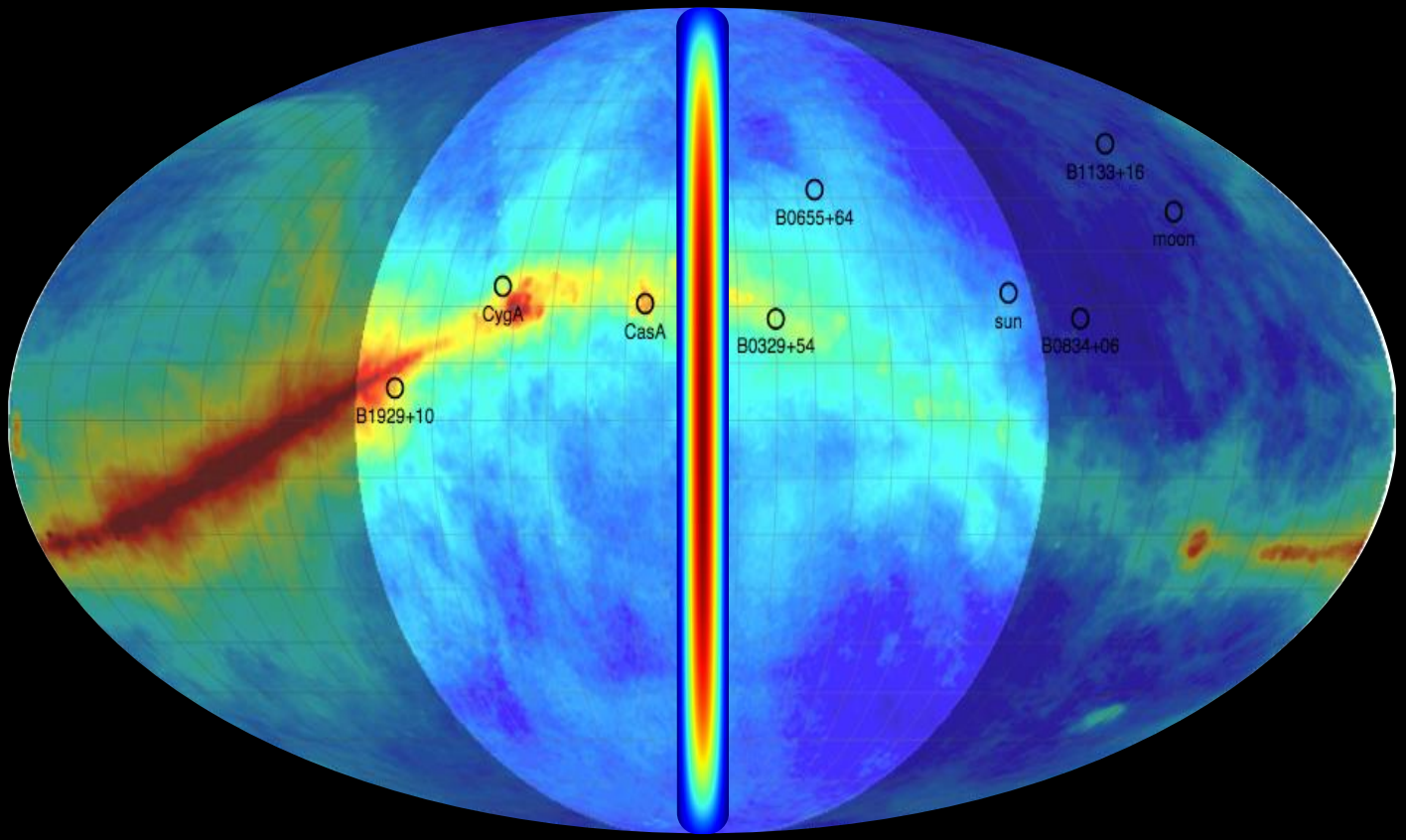
Frequency band where no FRBs existed

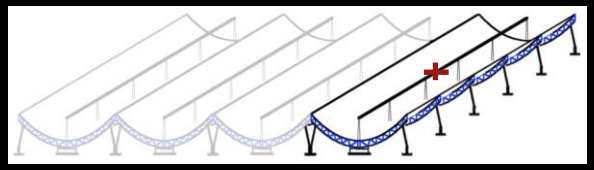
FRBS AND CHIME

What we want	Can CHIME deliver?
Thousands of events for event rate, flux distribution, angular distribution, DM distribution, scattering vs DM, …	Yes Flux, spectra corrected for beam sensitivity
Find Repeaters	Yes
Real-time triggers	Yes → GCN, VO, ATel Digest
Sensitivity to polzn vs freq, vs time	Yes
Localization: Absolutely necessary for distinguishing models	Arcminutes: Within CHIME (SNR dependent) Arcseconds: Maybe, if optical/X-ray bursts/afterglows exist* OR VLBI

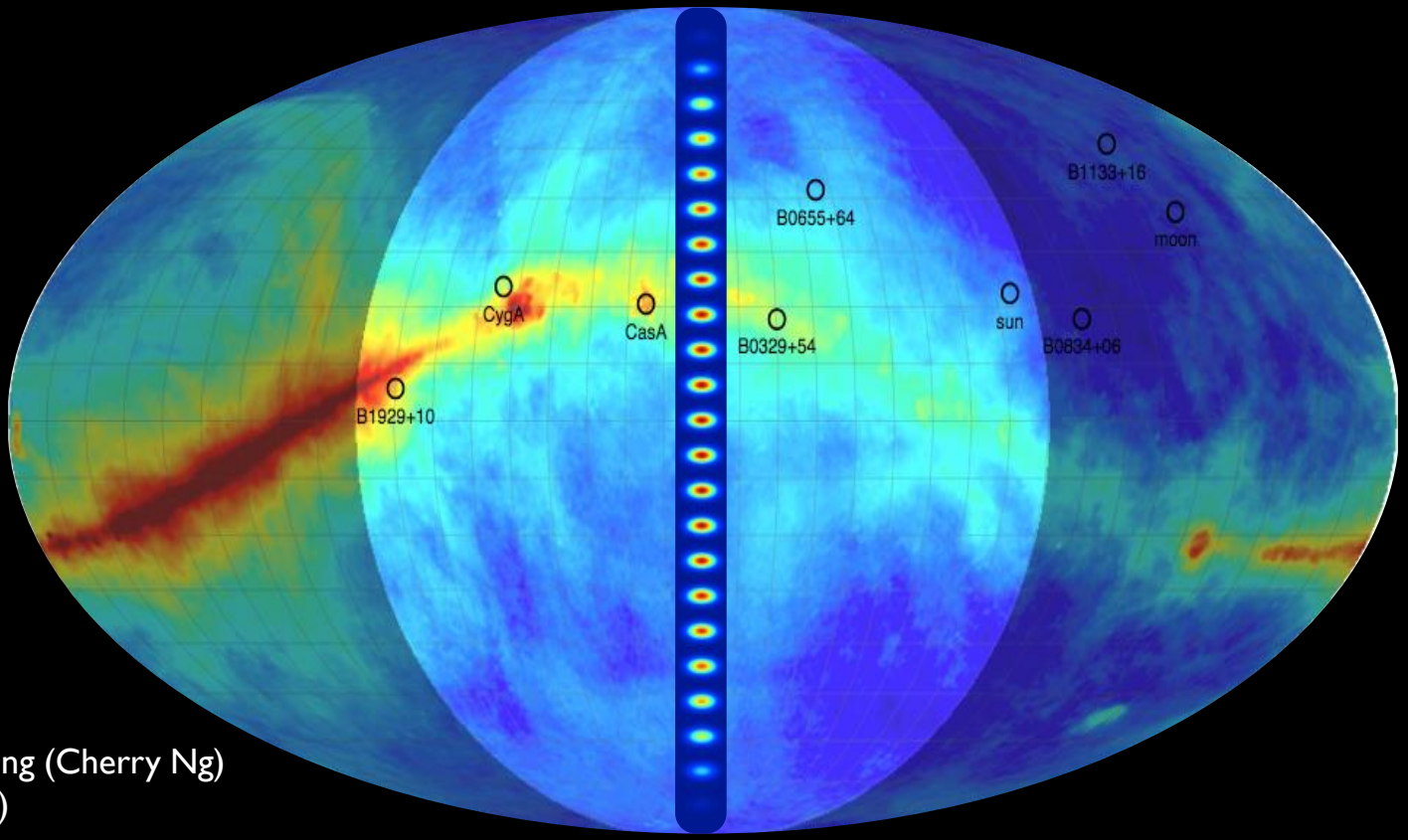
CHIME


256 feeds
Analog signal chain
Digitizers + FPGAs
F-Engine
F-Engine
E & W
Receiver
Huts
~ 13 Tbps
GPU correlator
X-Engine
X-Engine
N & S
GPU
Huts
1024 freq channels
n2 visibilities
30 sec
130 Gbps
CHIME Cosmology
16k freq channels
1024 stationary
intensity beams
1-ms sampling
CHIME-FRB
CHIME-Pulsar
1024 freq channels
10 tracking voltage beams
2.5-us sampling

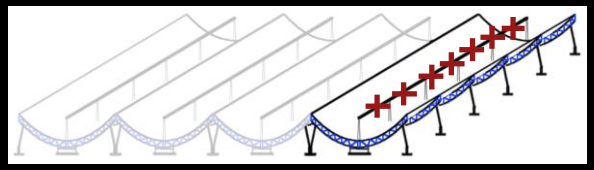




- Cylinder focuses light only in EW direction
- Gives us large FOV

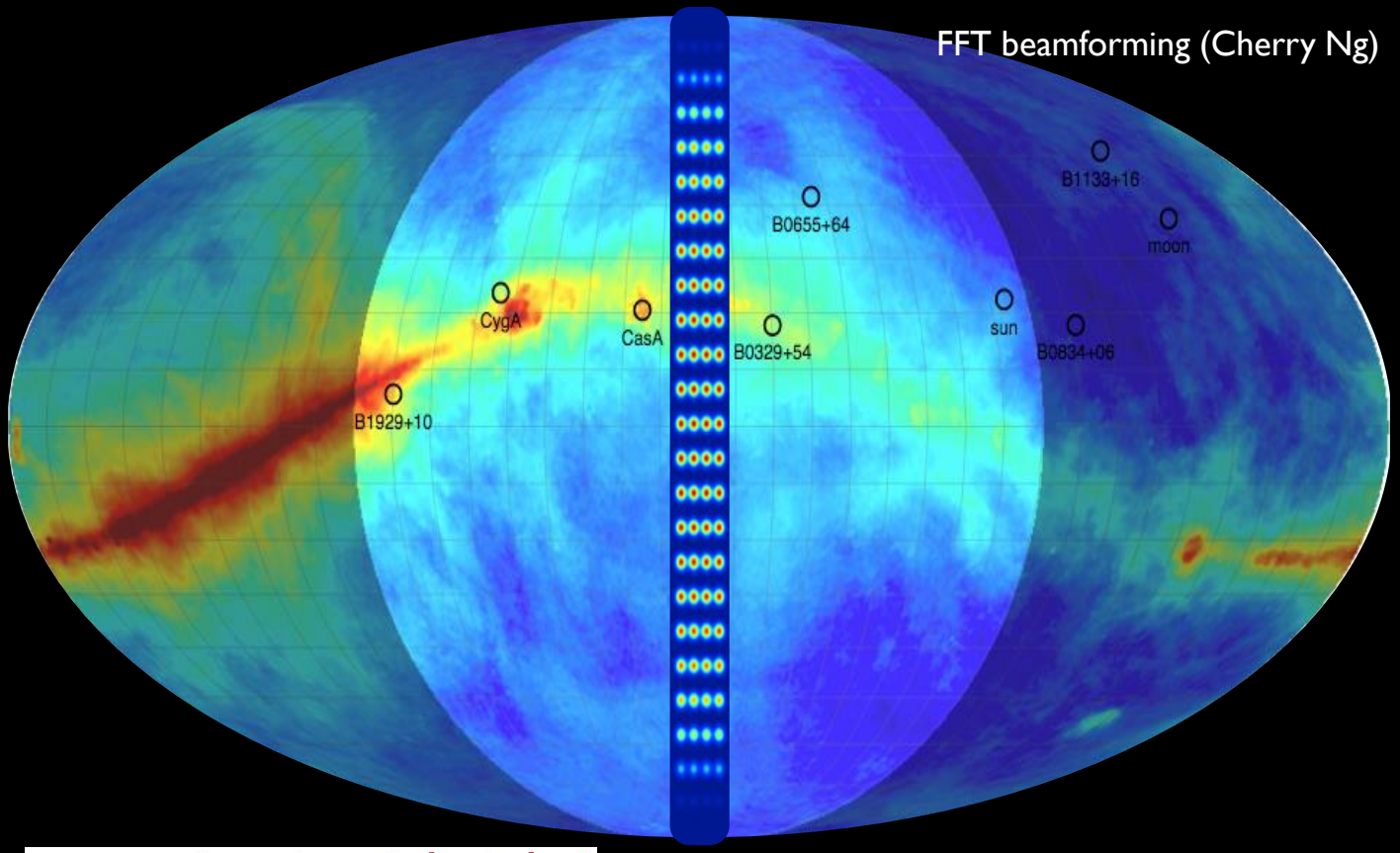


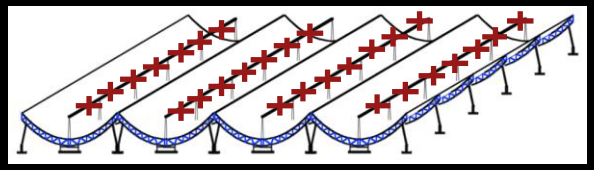
FFT beamforming (Cherry Ng)
(See Ng+ 2017)



- FFT telescope in NS direction
- 256 beams per cylinder

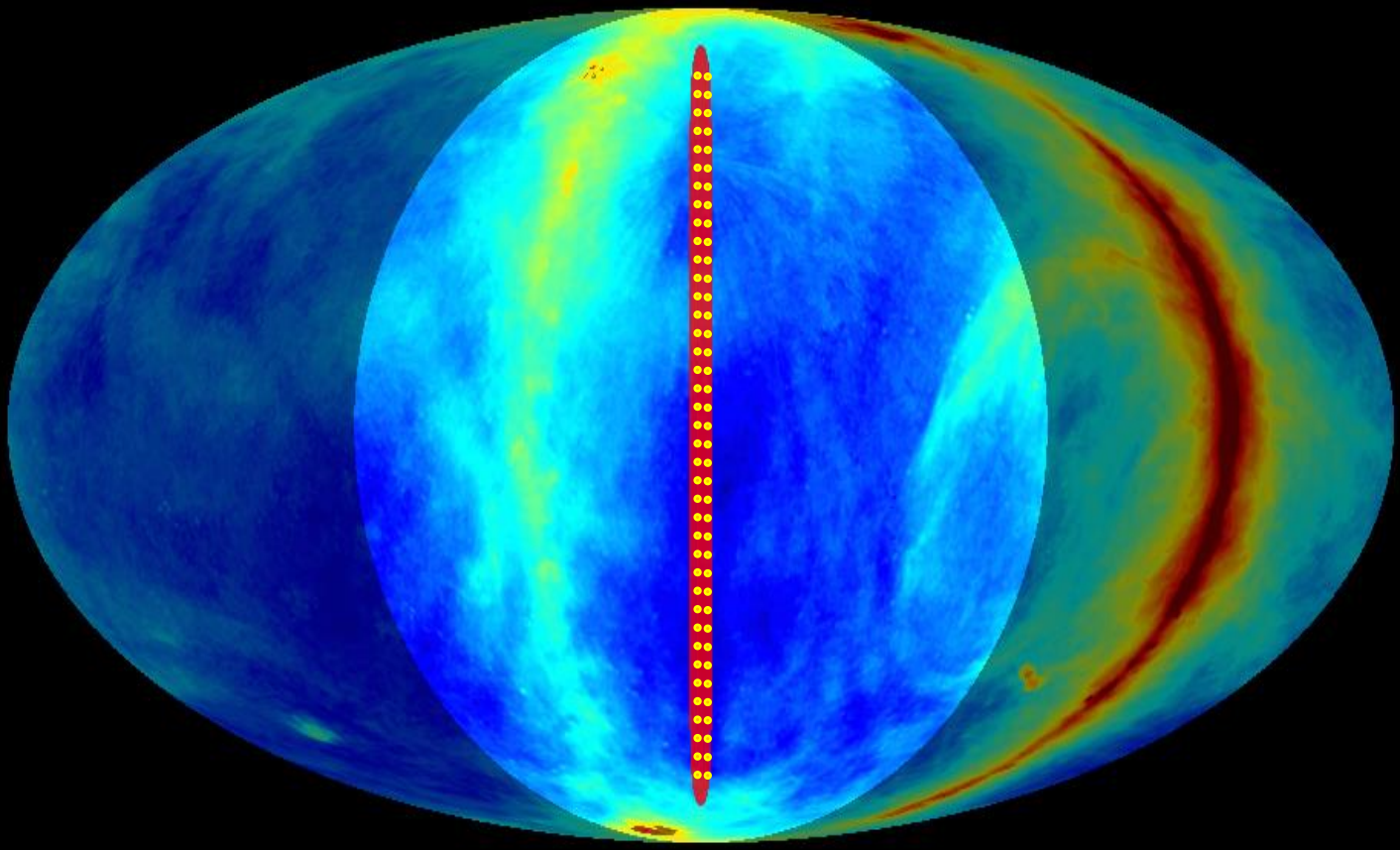
FFT beamforming (Cherry Ng)



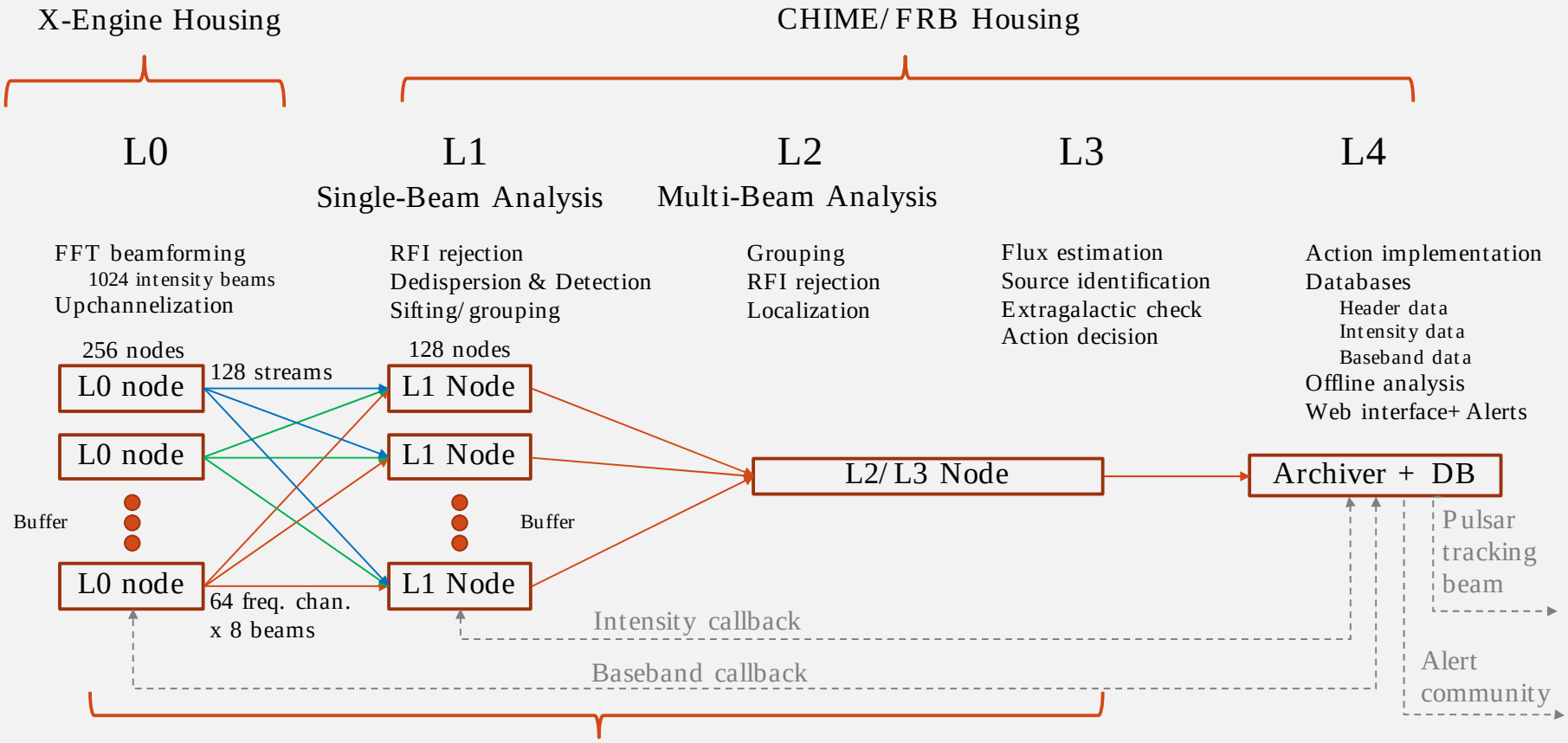


- 1024 beams from full 4-cylinder CHIME

As the day passes



CHIME/FRB PIPELINE



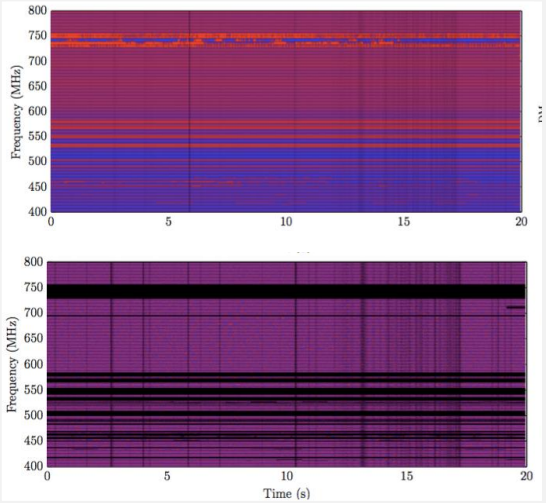
M. Boyce, P. Boyle, S. Brar, D. Cubranovic, E. Fonseca, U. Giri, A. Josephy, V. Kaspi, K. Masui, A. Naidu, C. Ng,
C. Patel, Z.Pleunis, M. Rafaiei, P. Scholz, K. Smith, SPT

RFI EXCISION AND FILTERING

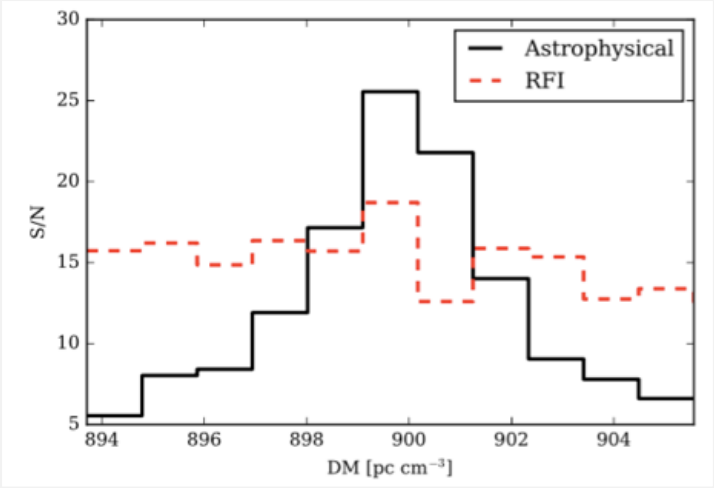
Three stages of RFI detection: Intensity data, single beam event information and multi-beam information.

Combination of outlier rejection statistics + machine learning with large samples

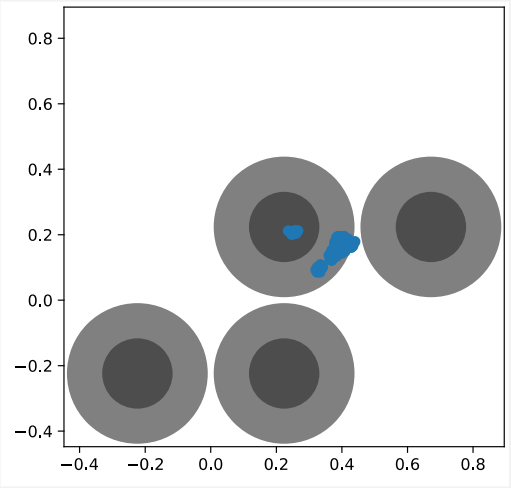
One real signal for 10^5 false signals



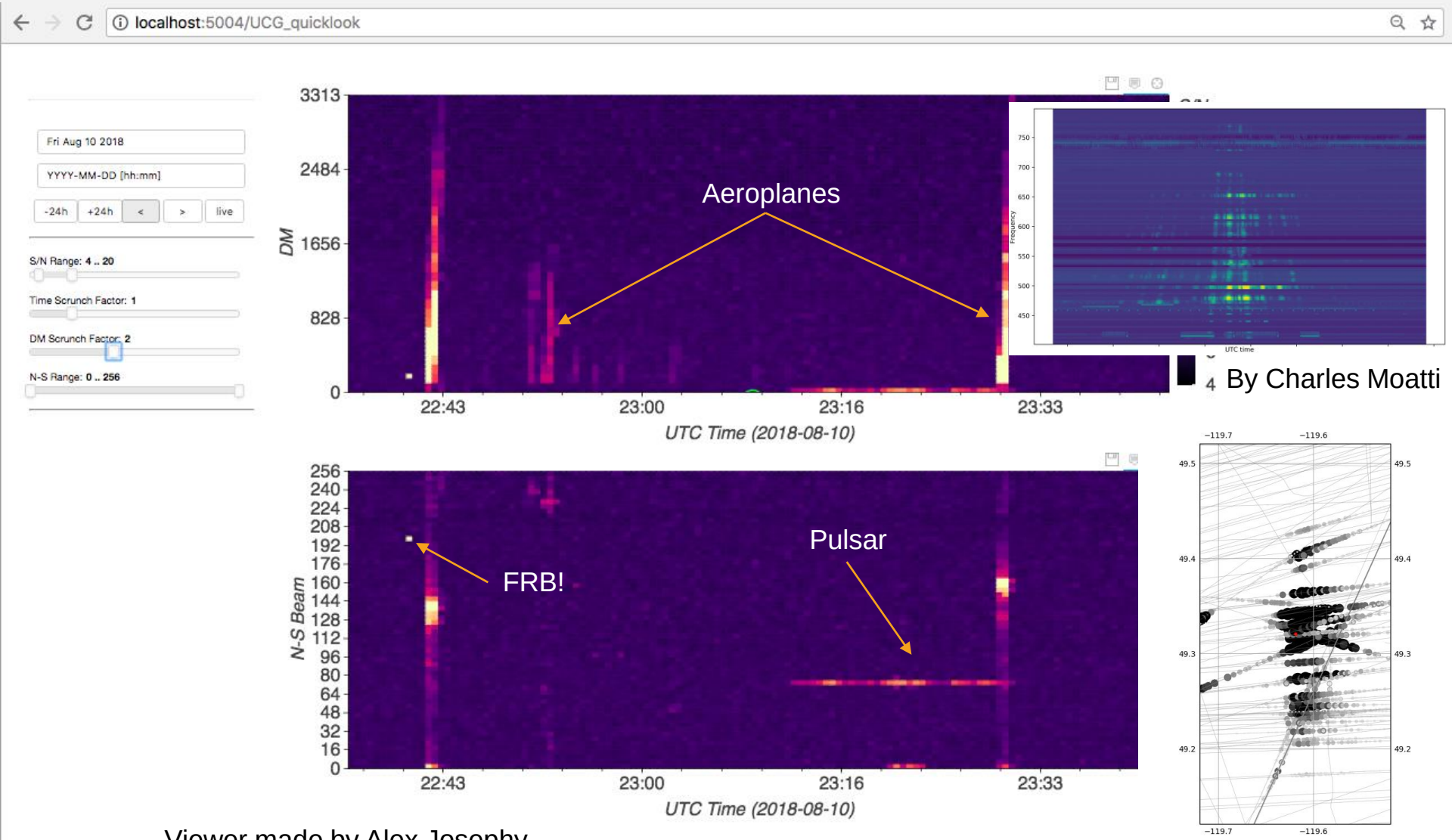
Intensity data



Broadbandedness



Multibeam distribution



Viewer made by Alex Josephy

FIRST FRB

Chitrang Patel 2:22 PM
@shriharsh check out this event.
on the ultra coarse grain plots.
At UTC 18:00
Beam ~166 and DM 716.

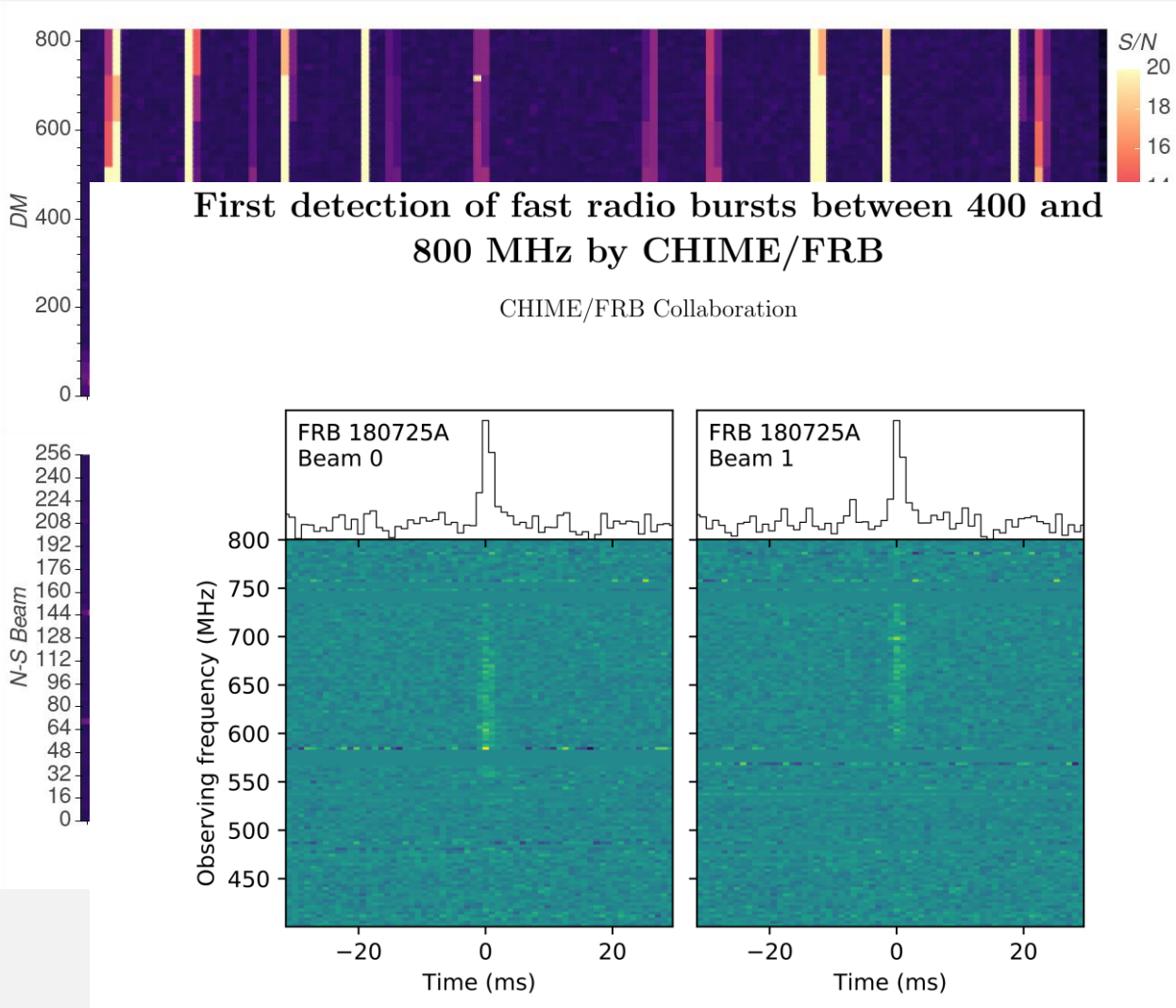
Shriharsh Tendulkar 2:23 PM
oooh!
tantalizing
but why is it on an RFI spike?

Shriharsh Tendulkar 2:33 PM
9386707

Chitrang Patel 2:36 PM
Yeah

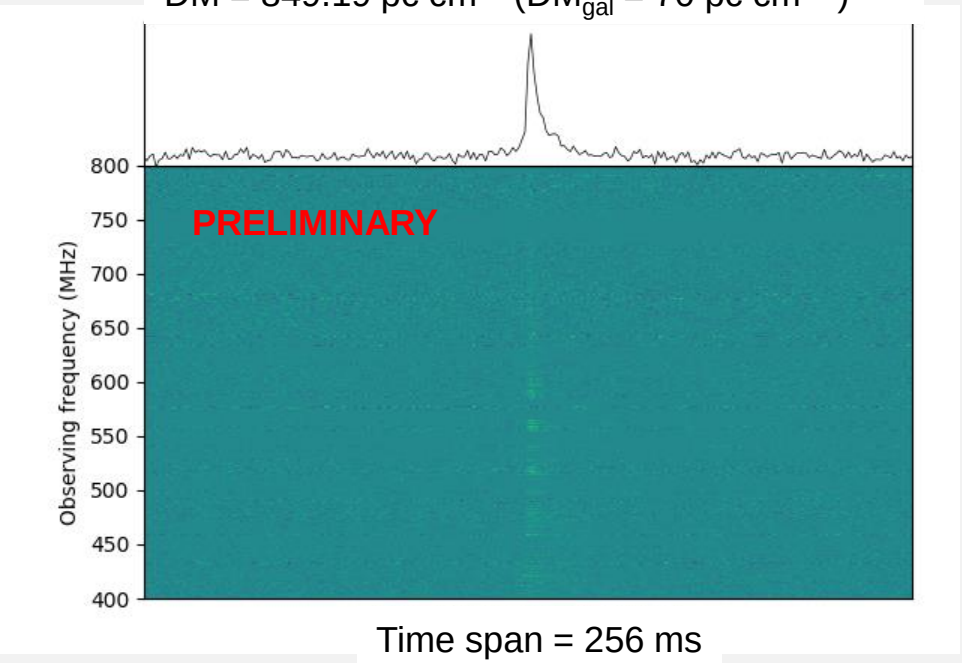
Shriharsh Tendulkar 2:36 PM
there's raw data
going in to look at it

Chitrang Patel 2:37 PM
`/frb-archiver-1/2018/07/25/astro_9386707/intensity/raw/`



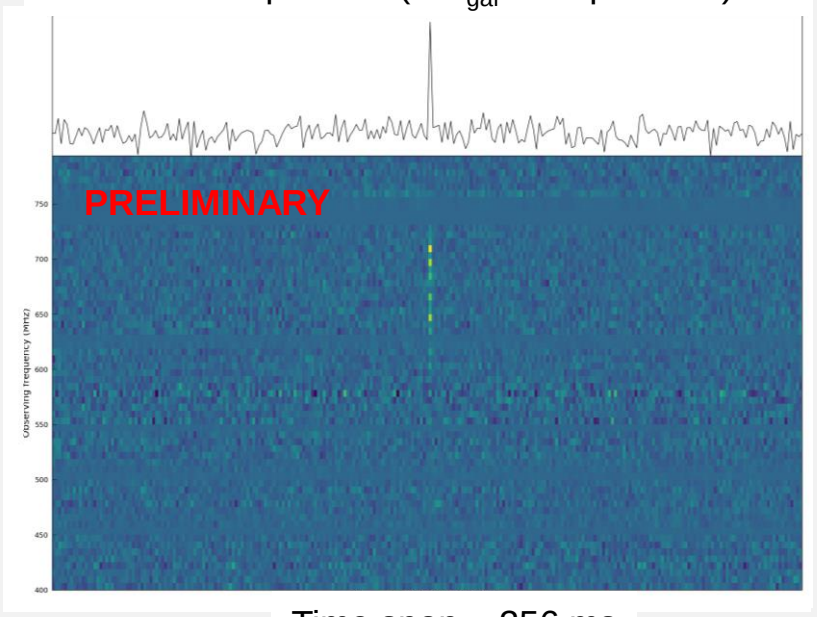
CHIME FRBS

DM = 849.19 pc cm^{-3} (DM$_{gal}$ = 70 pc cm^{-3})



Time span = 256 ms

DM = 316.93 pc cm^{-3} (DM$_{gal}$ = 80 pc cm^{-3})



Time span = 256 ms

CHIME COMMISSIONING

Increasing number of active beams on the sky: 550 → 1024

Network checks --> Ensure packet flows

Beam calibration

Push down the SNR threshold

Sensitivity + Completeness

→ Setup a parallel pipeline with injected pulses

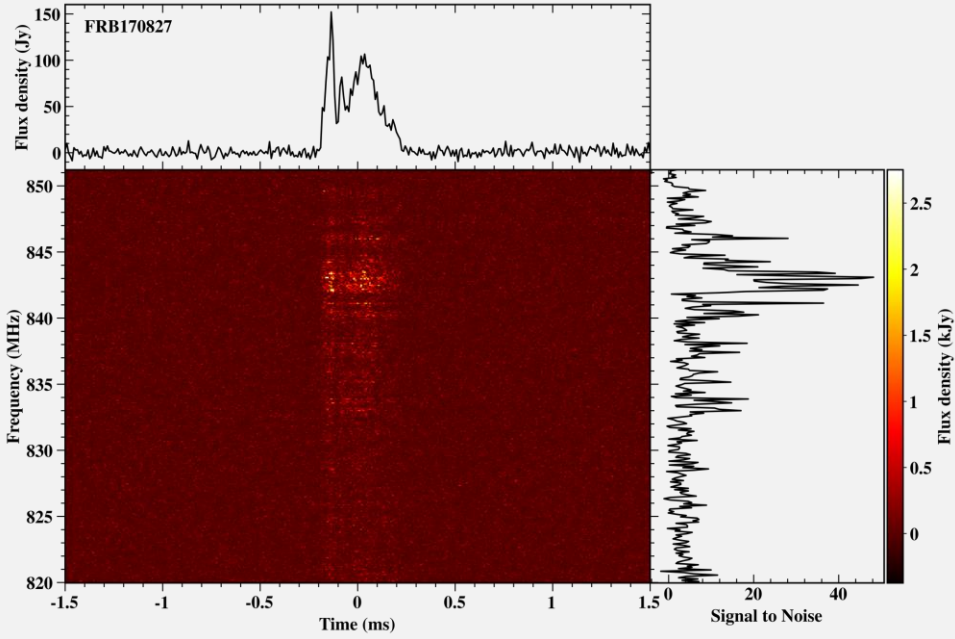
Testing voltage buffer dumps → Polarization, Beamforming

BRIGHT, NEARBY FRBS

FRB spectra has been shown to be spiky (2kJy in < 100 kHz) especially at high bit-depth

Detectable by smaller, large FoV telescopes.

Need very high time and freq res



Can we optimize algorithms to not search broadband?

Large datarate machine learning problem (Prateek Yadav MSc thesis, UBC)

Need a pixel-to-pixel RFI prediction

CHIME FUTURE

CHIME Full operation → October 2018
Detect 350 – 3600 FRBs per year

CHIME-VLA effort to localize repeaters
(Get similar capability at GMRT soon)

CHIME Outriggers → Phase 0 study (Sept 2018 — early 2019)
Baselines of 1000s kms to give milliarcsecond localization