Cosmology with Fast Radio Bursts Localized by CHIME/FRB

New England Theoretical Cosmology, Gravity and Fields 2020

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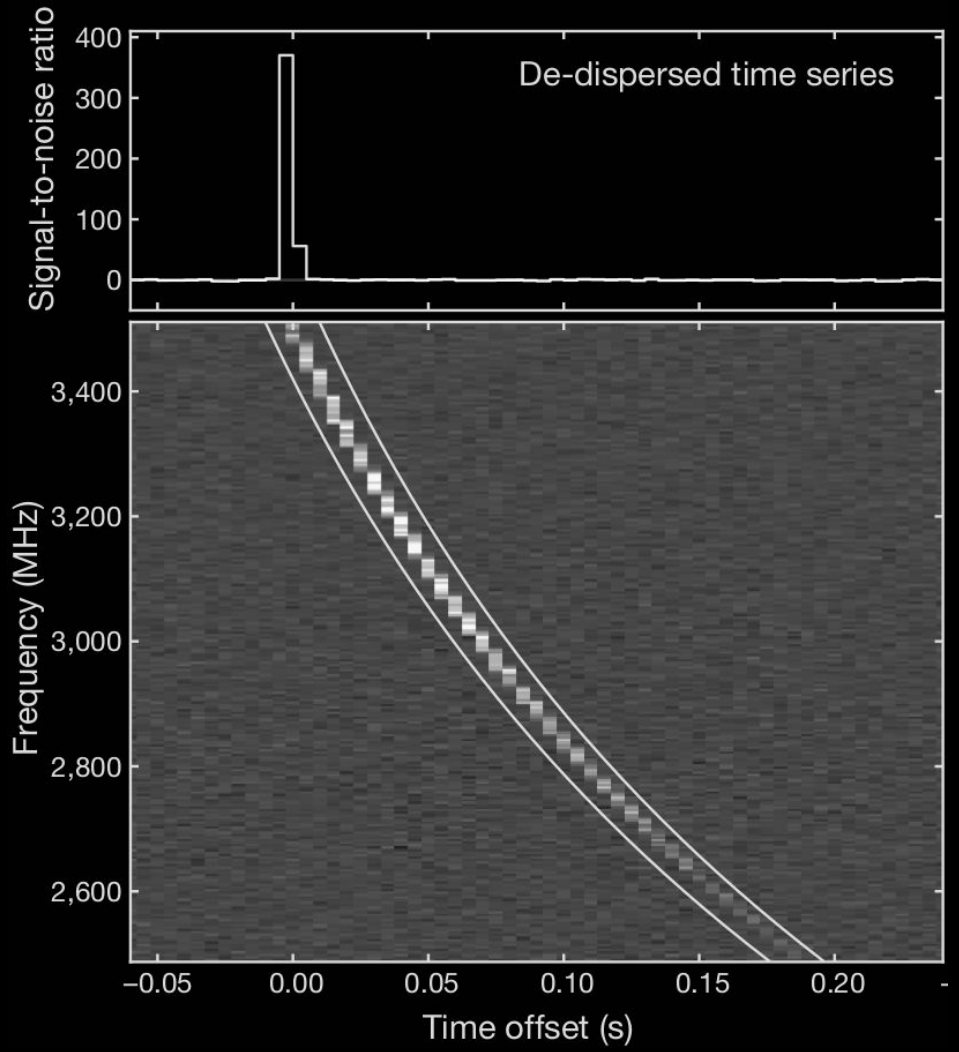
Advisor: Kiyo Masui

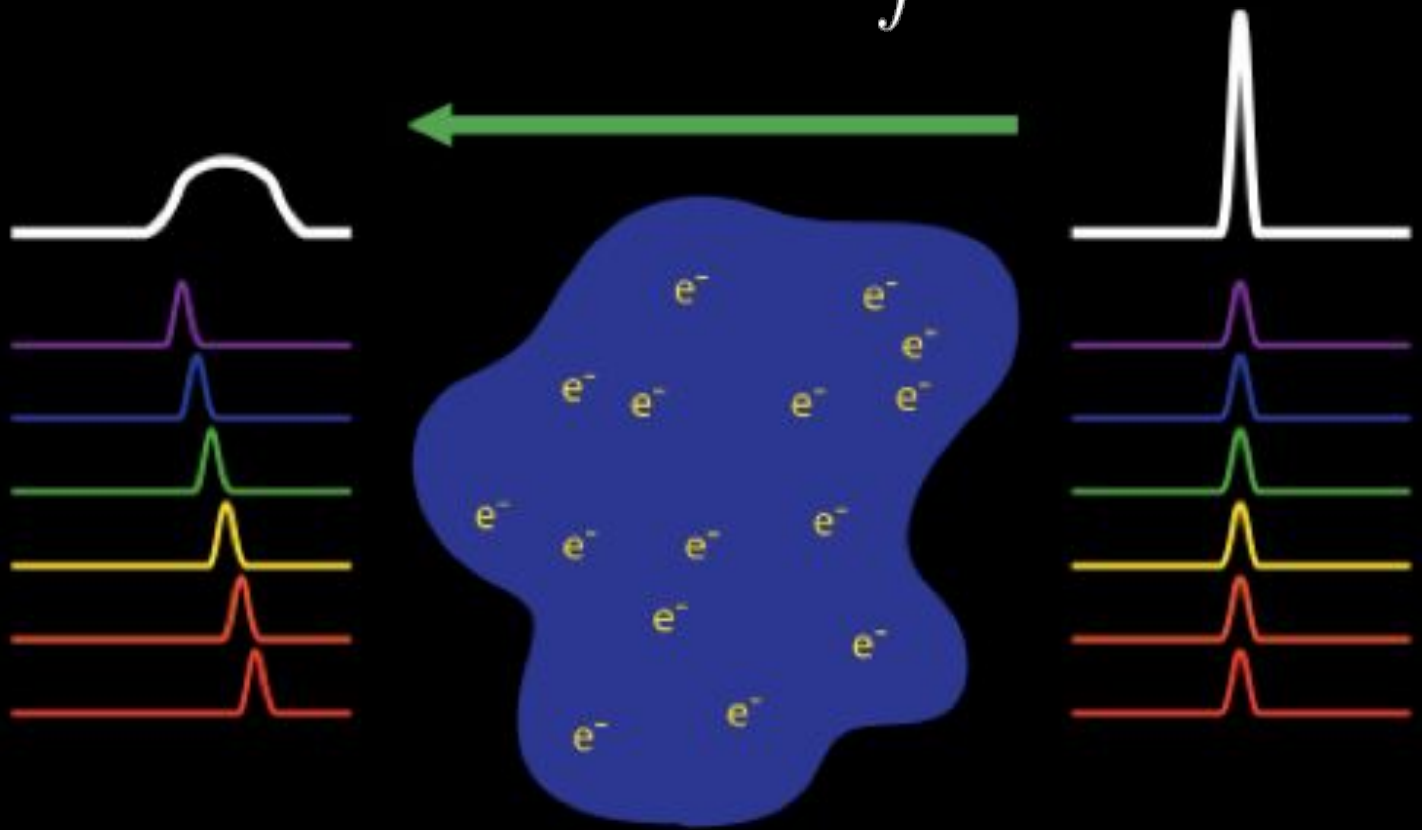
Fast Radio Bursts

Bright (~1 Jy)
Brief (0.01 - 10 ms)
Non repeating (~90%)
Extragalactic (0.01 < z < ??)
Magnetar Origin
Frequent (1000 / sky / day)
Polarized + Faraday Rotated
Dispersed by cold plasma (!)

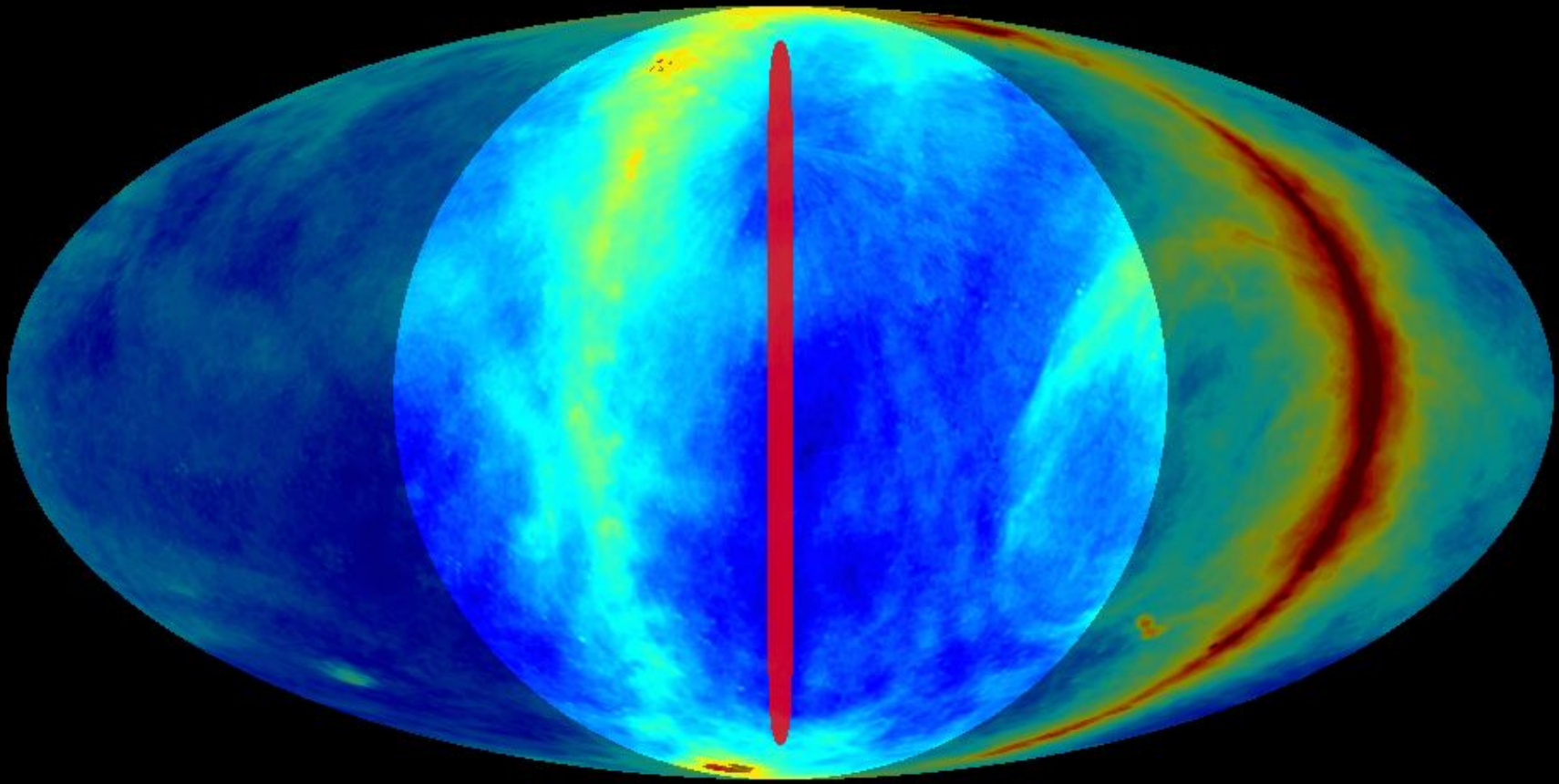
$$v_g = c\sqrt{1 - \frac{\omega_p^2}{\omega^2}}$$



FRBs for Cosmology? $$DM = \int n_e \, d\ell$$



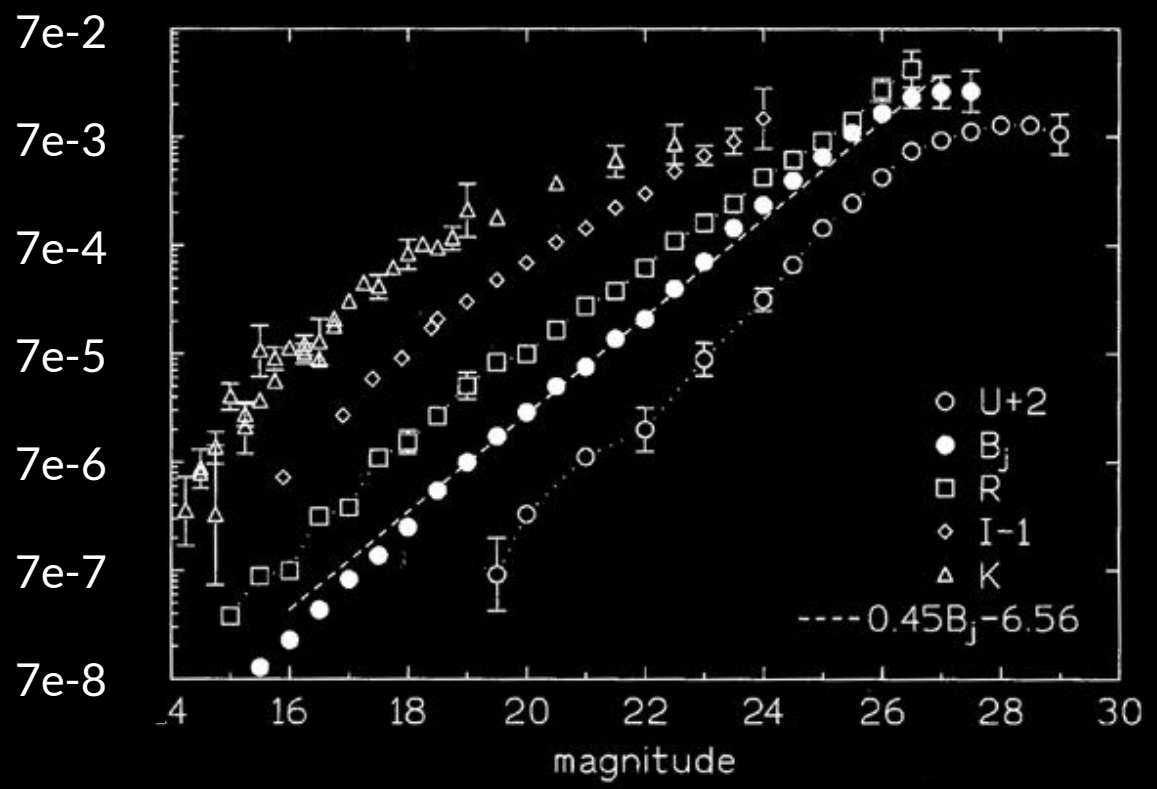

CHIME
The Canadian Hydrogen Intensity Mapping Experiment
2007-2018: ~50 FRBs
CHIME in 2018-2019: ~700 FRBs



What's the Catch?

CHIME loses in localization to win in discovery rate.

Localization area: ~10^6 arcsec^2



Precision Localizations Will Enable FRB Cosmology

CHIME Outriggers: ~1000 FRBs / yr and 50 mas localization

FRB Environments and Host Galaxies

Precision

Milliarcsecond

- Giant pulses from distant pulsars?
- Shock Waves from Young Magnetars?
- Magnetar Population Studies?
- Galactic Halos?

\+ Green Bank (3000 km)
\+ Algonquin (3000 km)

ASKAP (10-100 / yr)

\+ Pathfinder (1 km)
\+ Allenby (100 km)

CHIME (>1000 / yr)

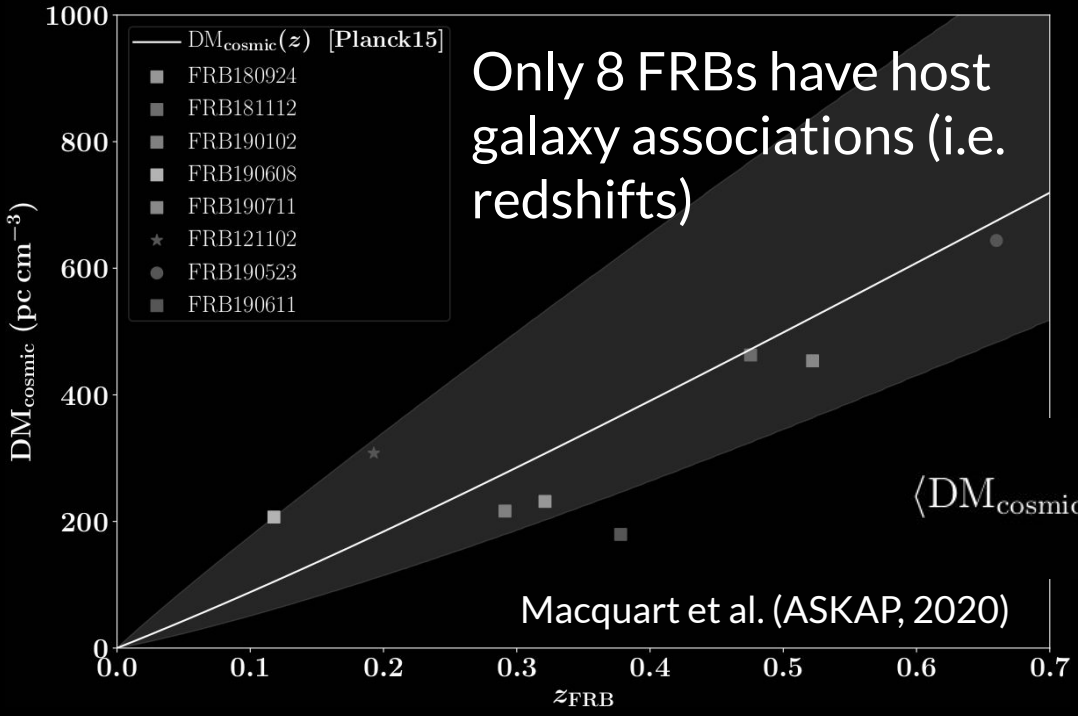
Cosmology with FRBs

Arcsecond
- Missing Baryons? (Macquart 2020)
- Electron P.S. (Madhavacheril 2019)
- Magnetic Fields (Hackstein 2019)
- Find Strong Lenses for H0 (Li 2018)
- FRB Interferometry (Wucknitz 2020)

Arcminute
- Galaxy Cross Corr. (Rafiei-Ravandi 2019)
- MACHO Microlensing (Munoz 2016)

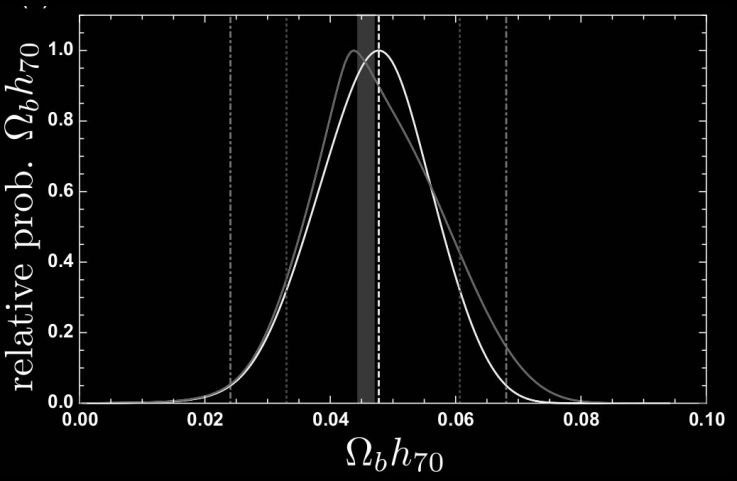
2020 2021 2022 Time

Missing Baryons with CHIME/FRB Outriggers



Only 8 FRBs have host galaxy associations (i.e. redshifts)

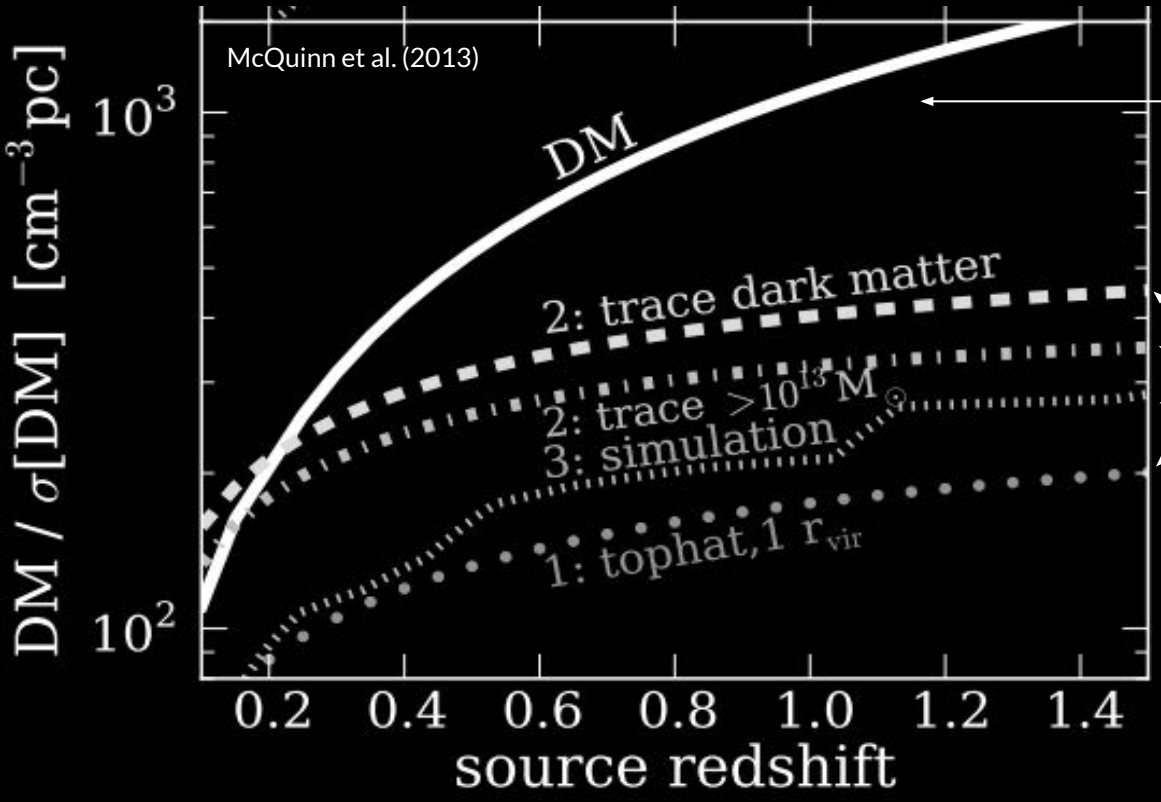
Macquart et al. (ASKAP, 2020)



$$\langle \mathrm{DM_{cosmic}} \rangle = \int_0^{z_{\mathrm{FRB}}} \frac{c \bar{n}_e(z) dz}{H_0 (1+z)^2 \sqrt{\Omega_m (1+z)^3 + \Omega_\Lambda}}$$

Mean of Macquart Relation sensitive to Omega_b!

Missing Baryons with CHIME/FRB Outriggers



Measure Mean DM

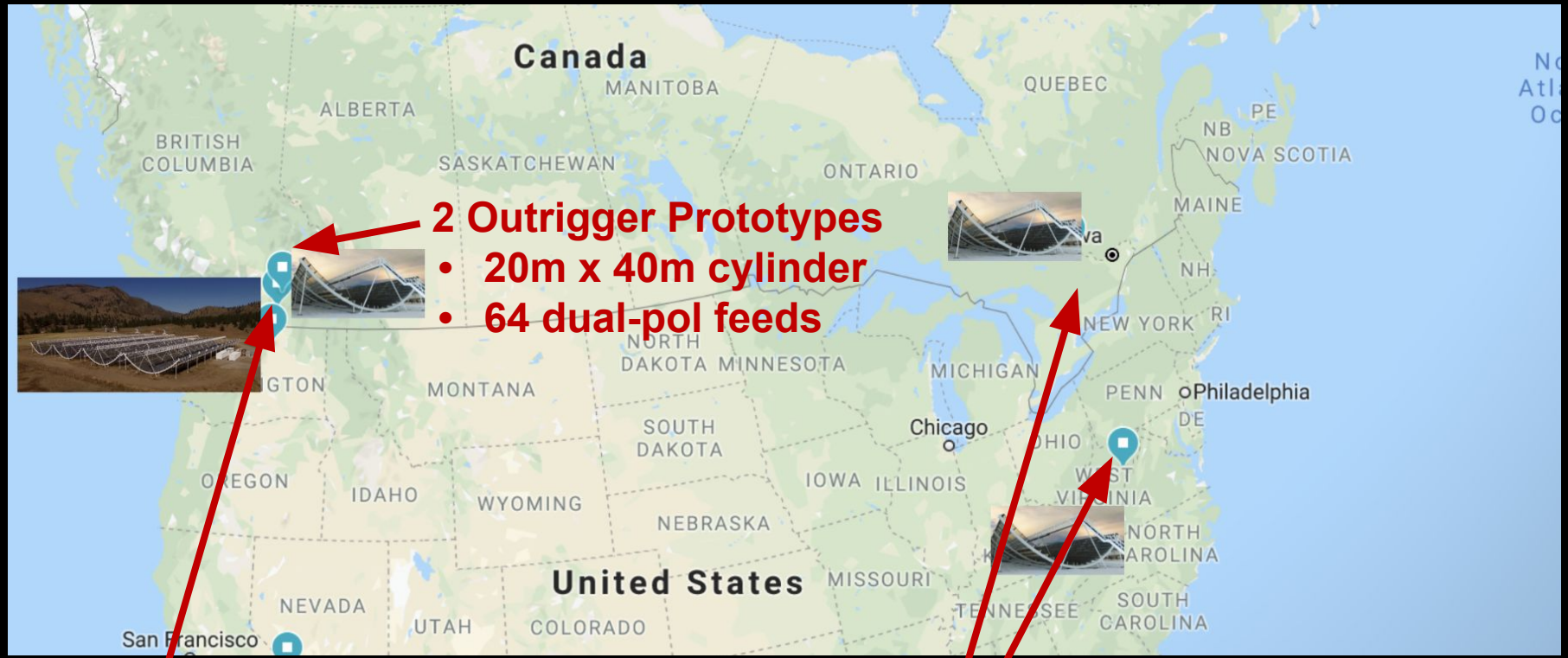
Measure Variance DM(z)

More generally: measure electron column two-point function!

Questions?

Localizing Fast Radio Bursts

CHIME Outriggers Program

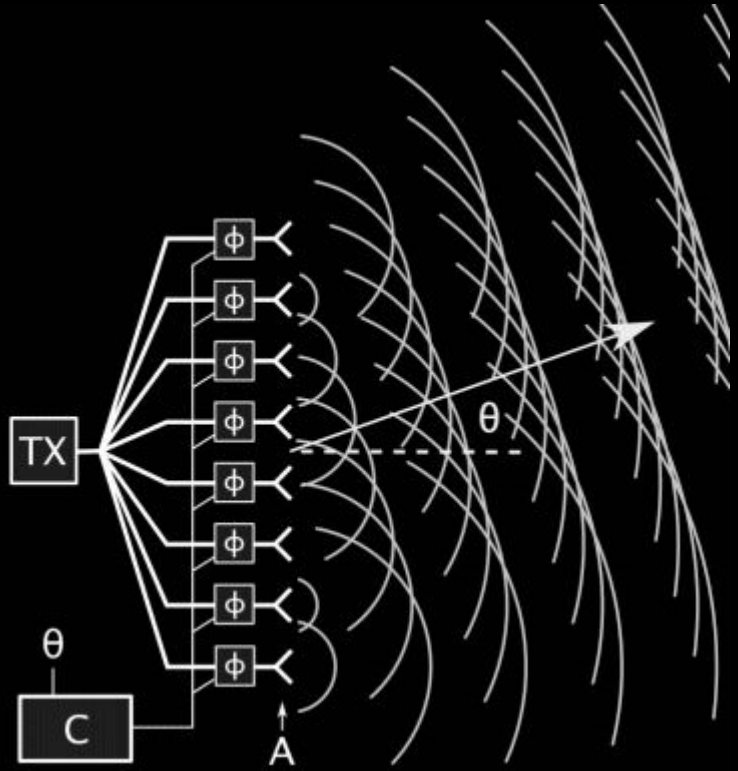


CHIME
- four 20m x 100m cylinders
- 1024 dual-pol feeds

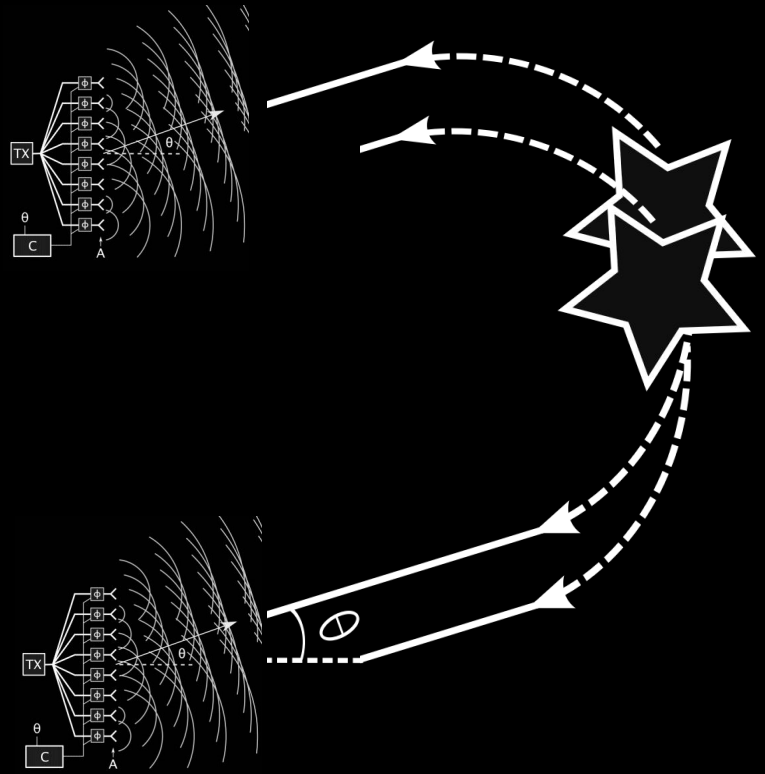
2 Outriggers
- 20m x 64m cylinder (matched FoV)
- 128 dual-pol feeds

How this differs from traditional VLBI

Advantage: Phased Arrays

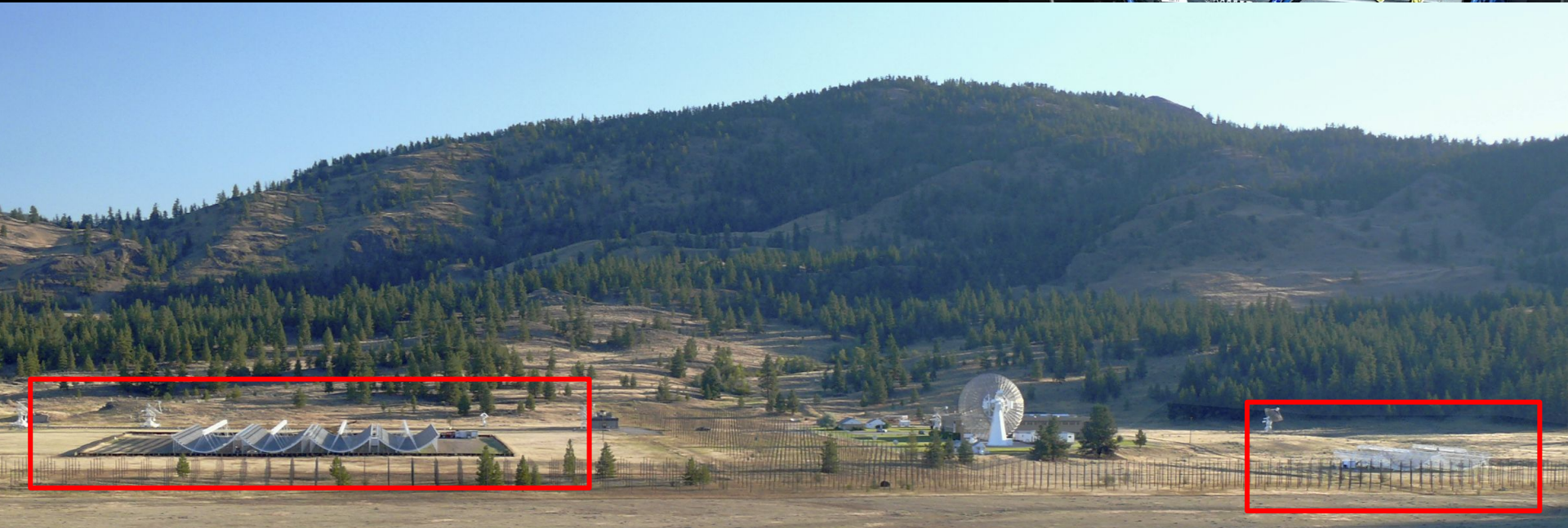


New Challenge: Unknown source, high data rate (100x EHT)

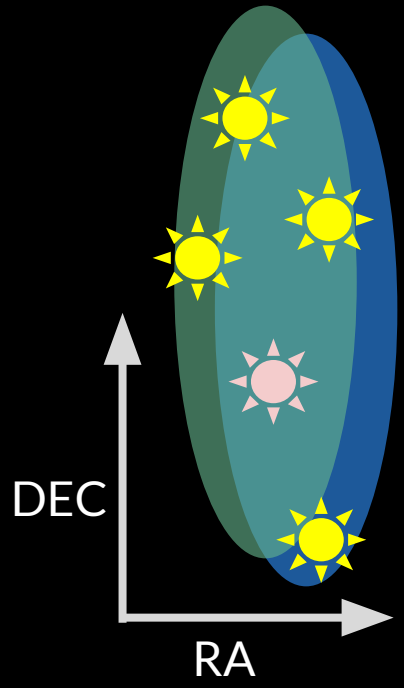


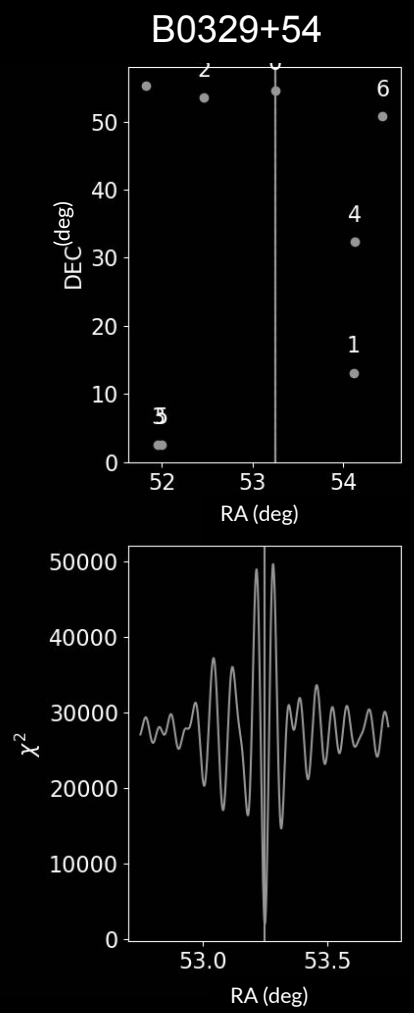
MIT Synoptic Radio Lab: Instrumentation + Analysis

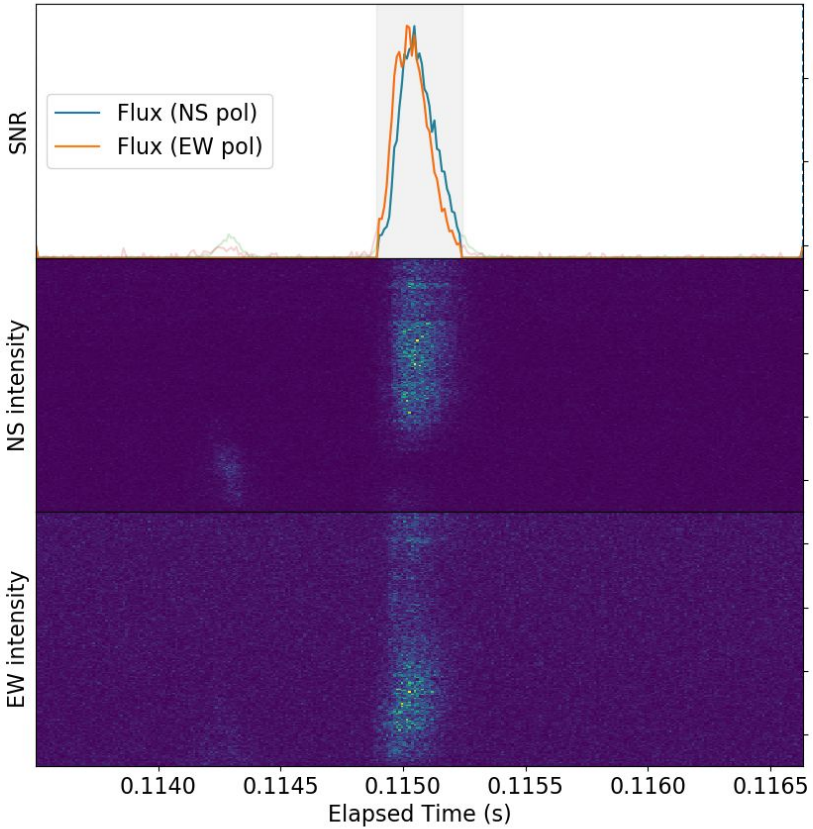
CHIME Pathfinder:
400 meter baseline, independent clocks

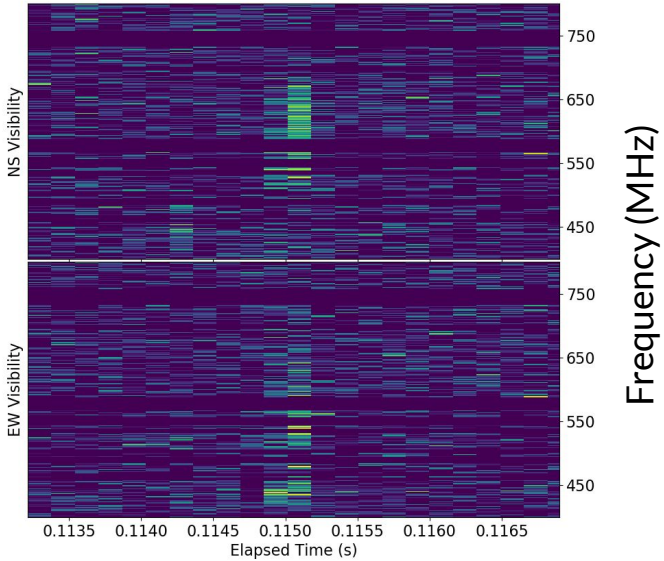


Demonstration on a pulsar....









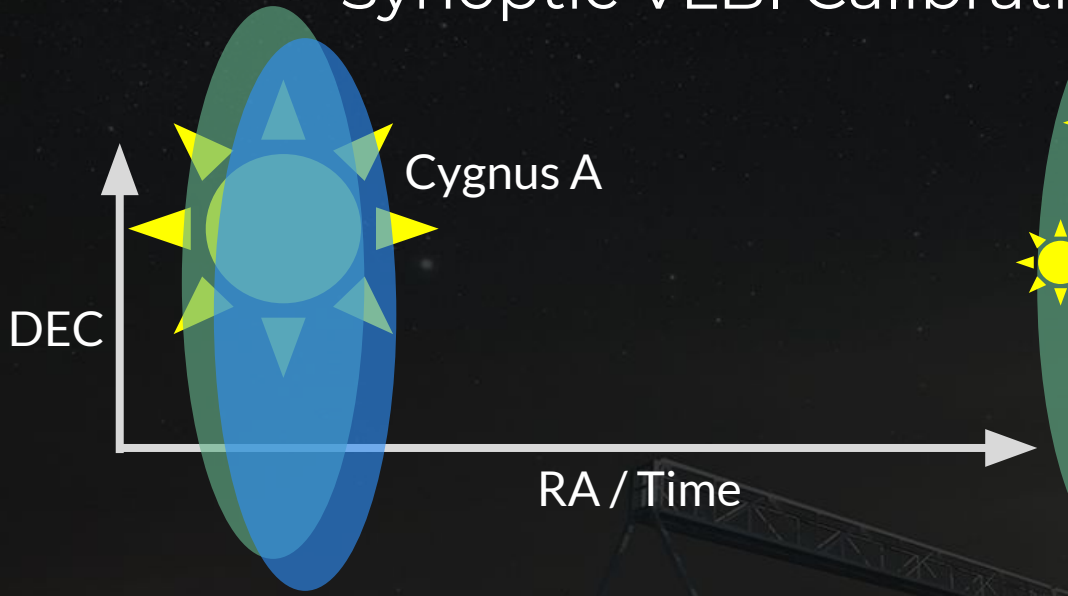
O(10) FRBs detected in cross-correlation, many to come!

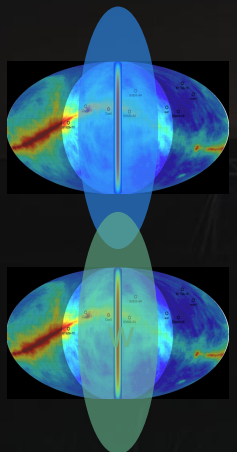
Leung, Mena Para, Masui, et al. (In progress)


McGill
UBC
Thanks! (+ Questions?)
PERIMETER INSTITUTE
chime
Canada
NRC·CNRC
Yale
VELUT ARBOR ÆVO
NRAO
West Virginia University
Massachusetts Institute of Technology

Backup Slides

Synoptic VLBI Calibration





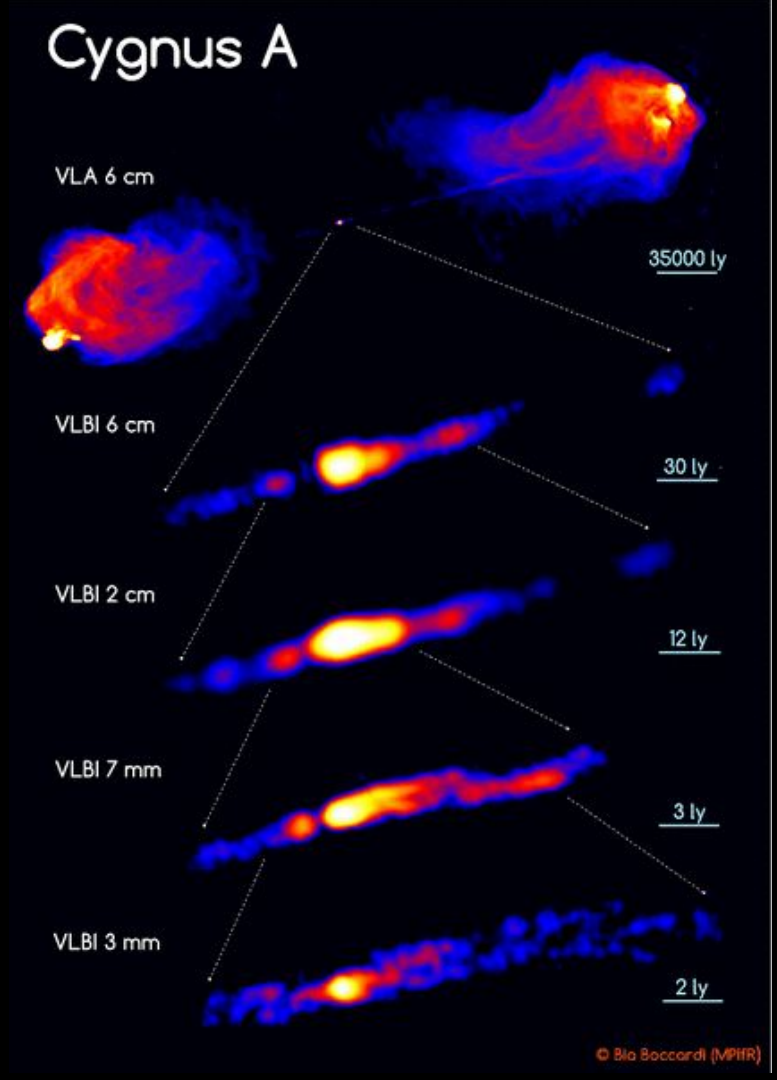
CHIME FOV 2048 antennas x 1024 frequencies

Outrigger FOV 256 antennas x 1024 frequencies

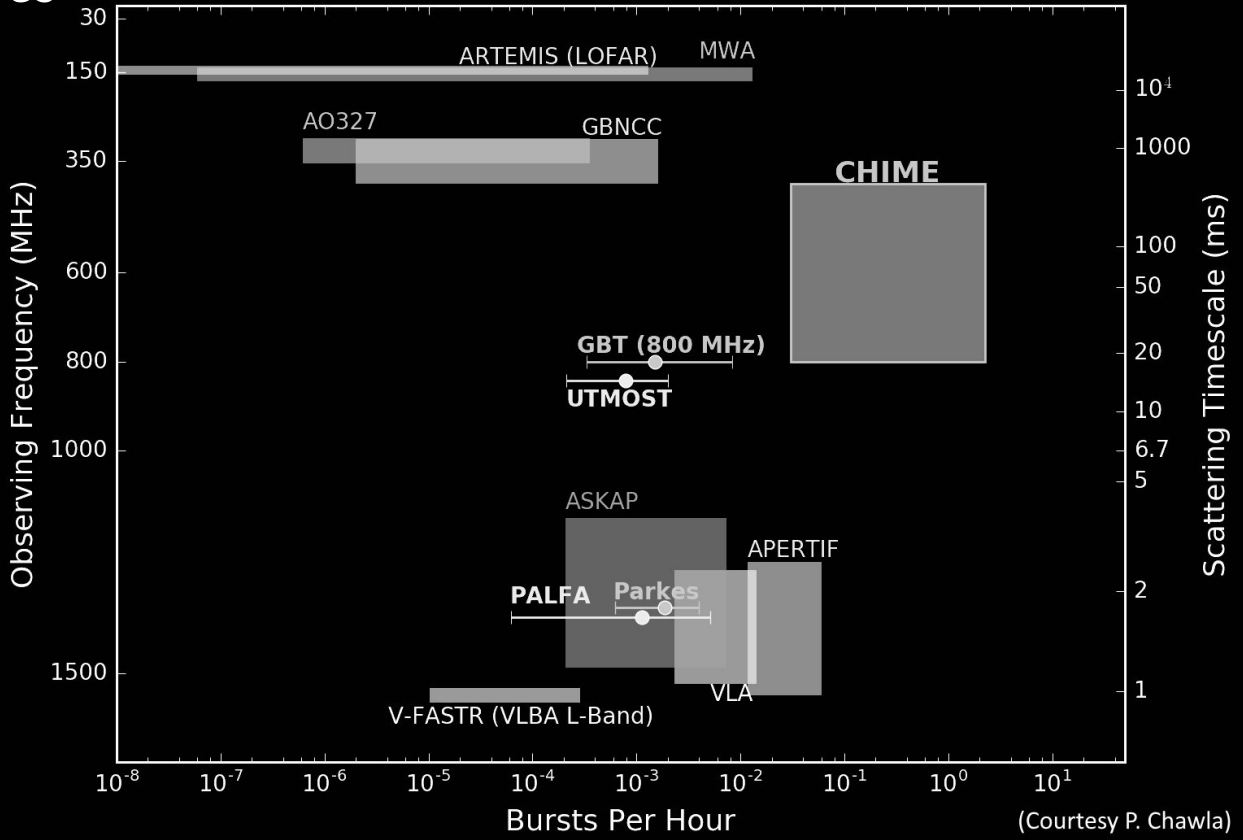
1 phase x 1024 frequencies
1 time delay

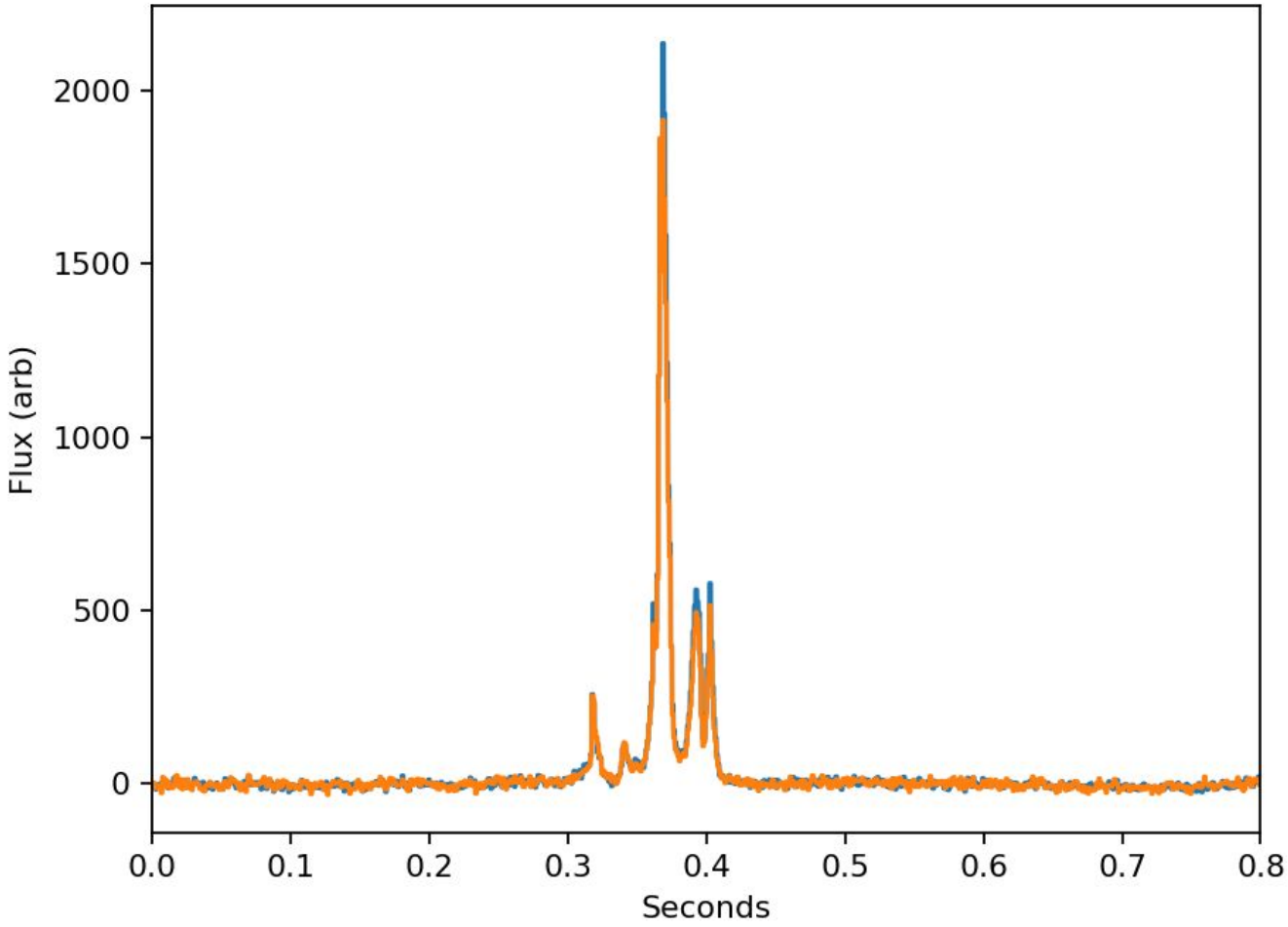
Scaling to Long Baselines

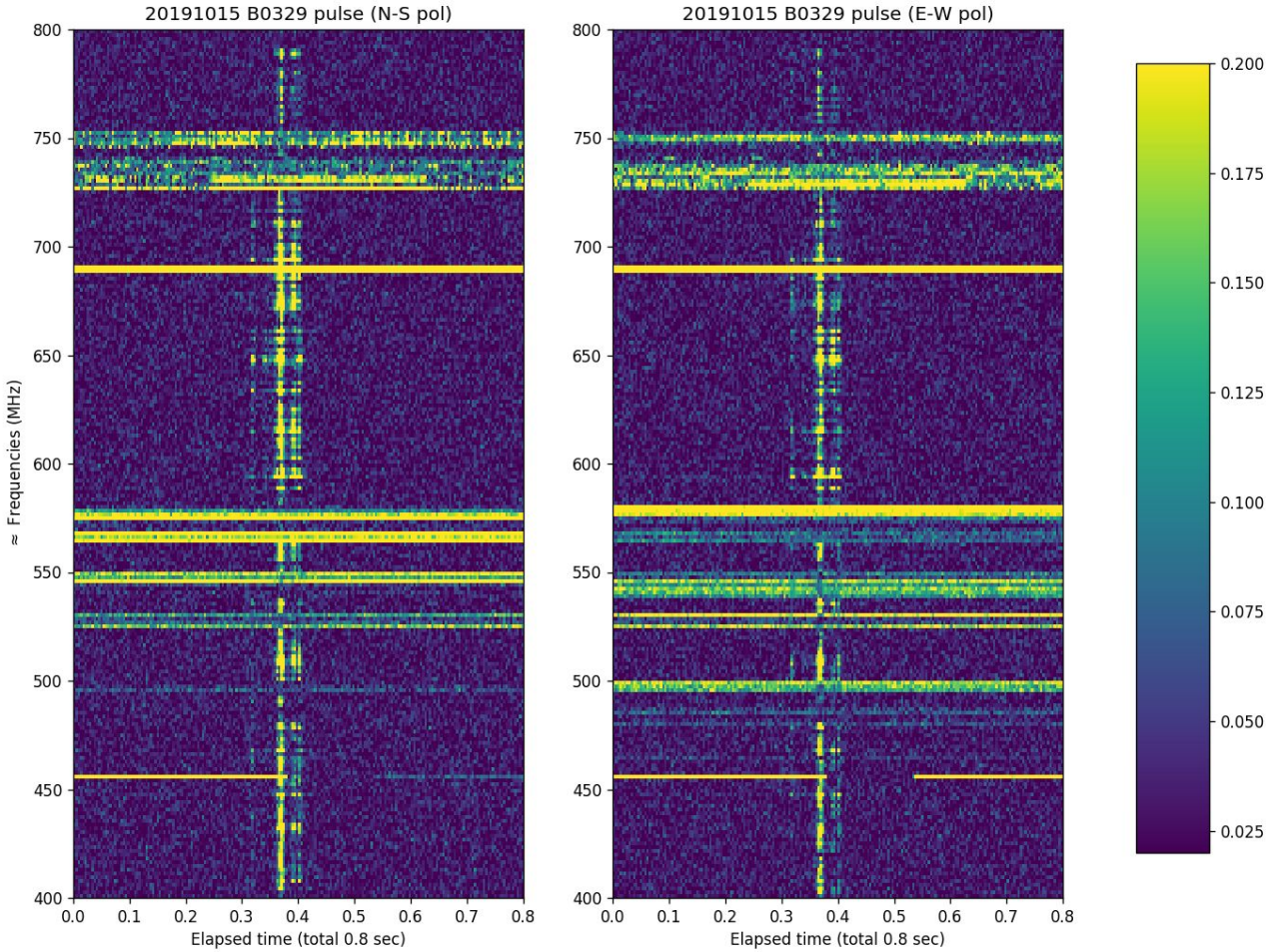
Problem: We don't know when an FRB comes in!
Solution: Track a well-understood VLBI calibrator, all day, every day.
Problem: VLBI Calibrators potentially useless!
Solution: Use automated pulsar VLBI to calibrate FRB observations, because pulsars are compact at low frequencies.
Problem: Pulsars are faint and need long integration times, but we have an enormous data rate.
Solution: Phase the array in real time to track a pulsar for 10 minutes. Have a catalog of pulsars to follow around all day, every day.

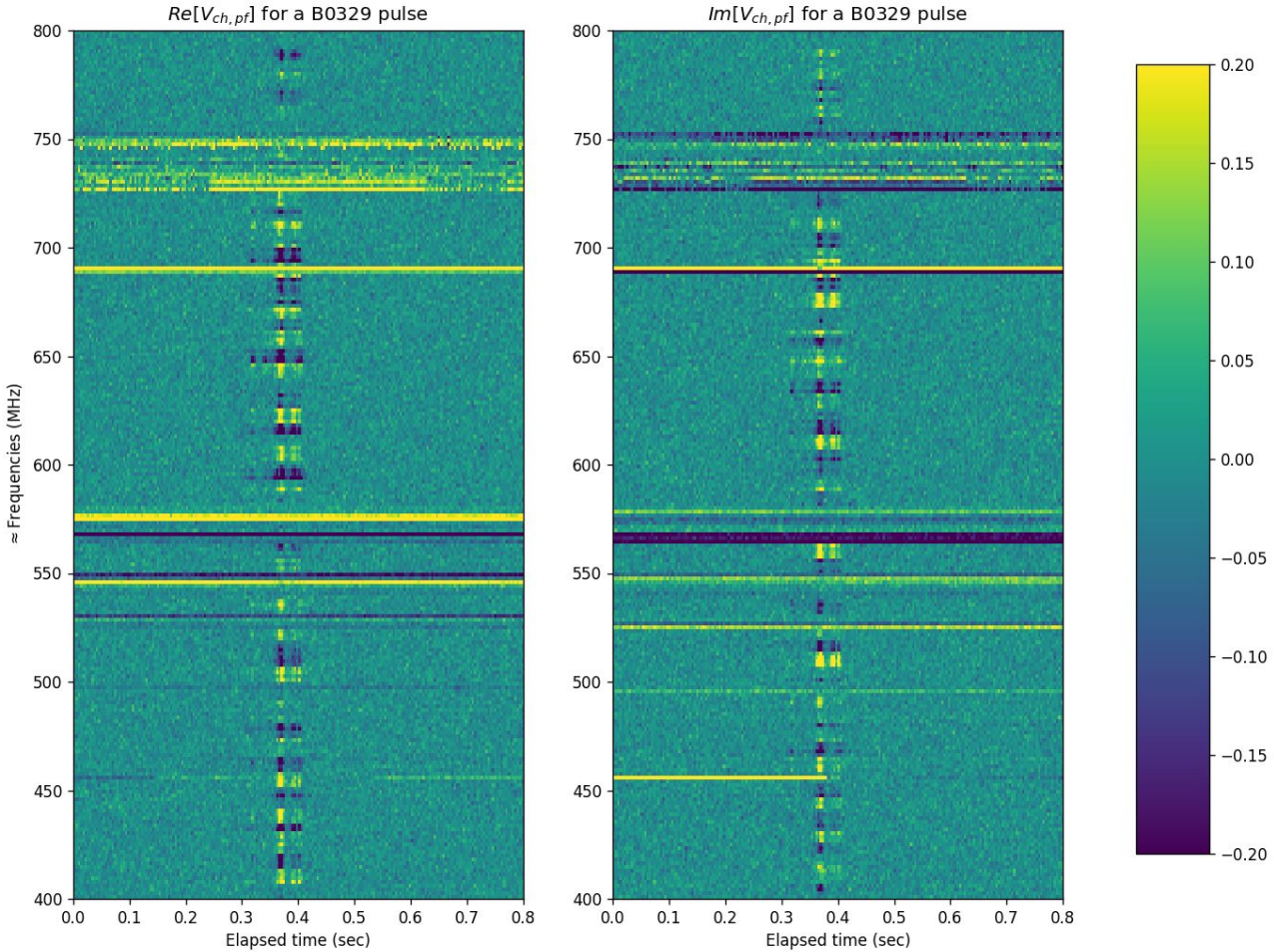


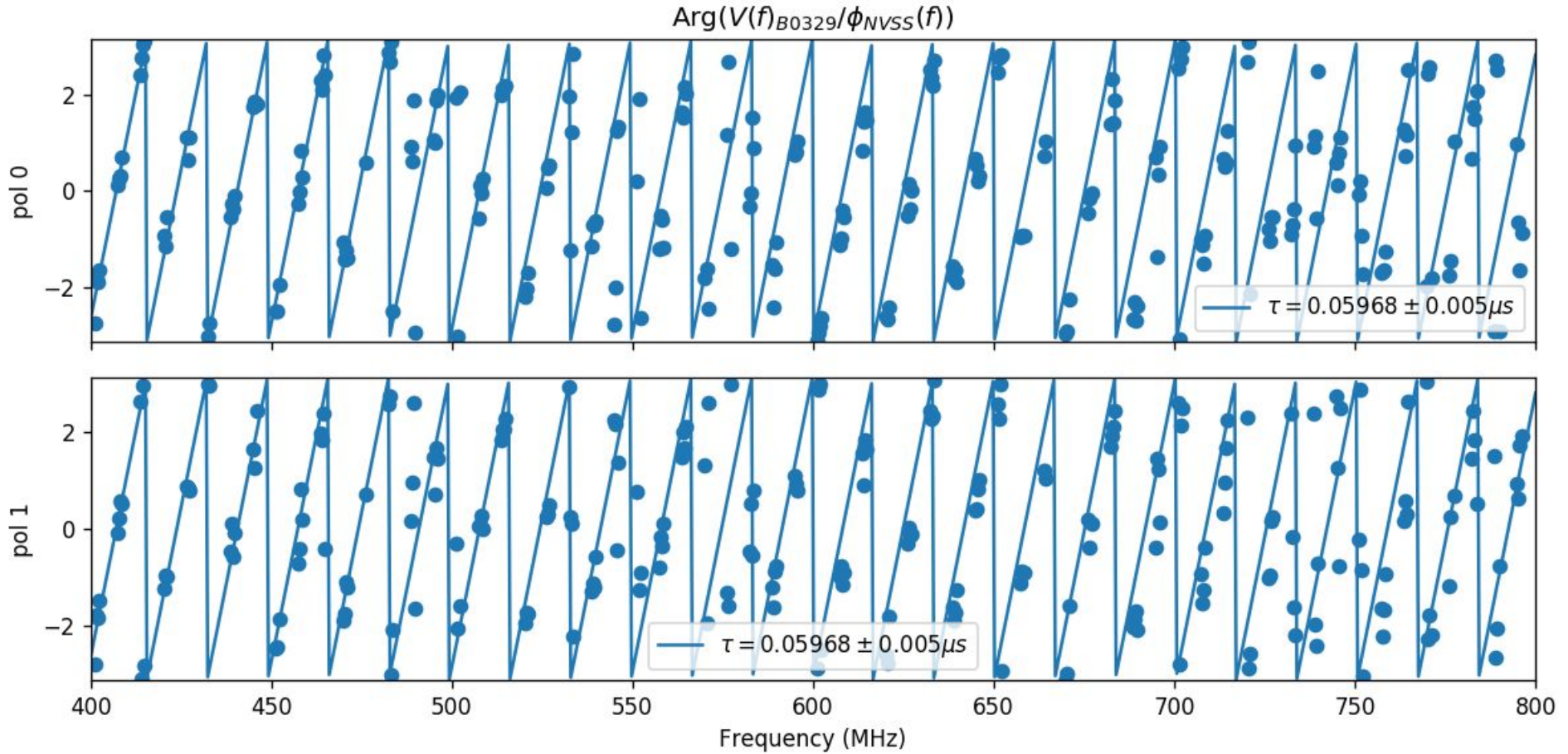
Some Other Telescopes

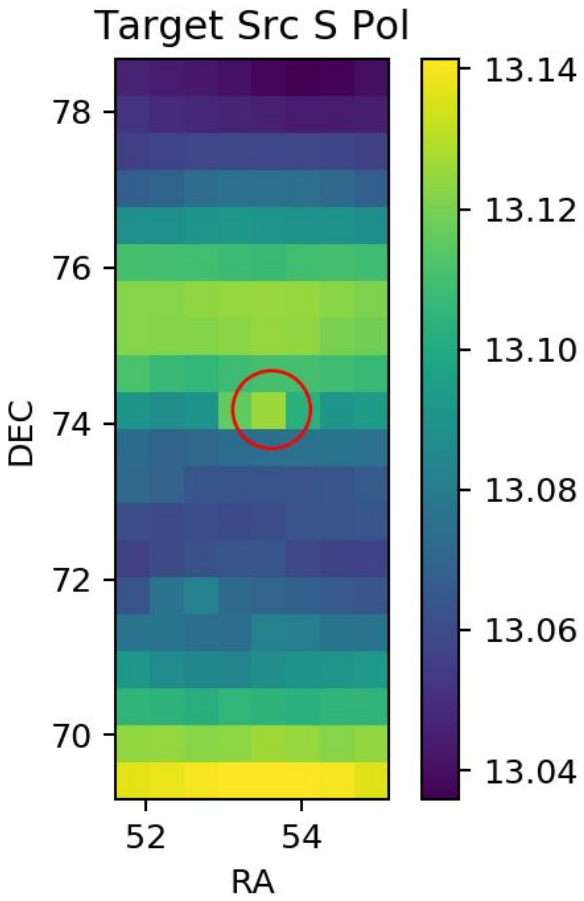


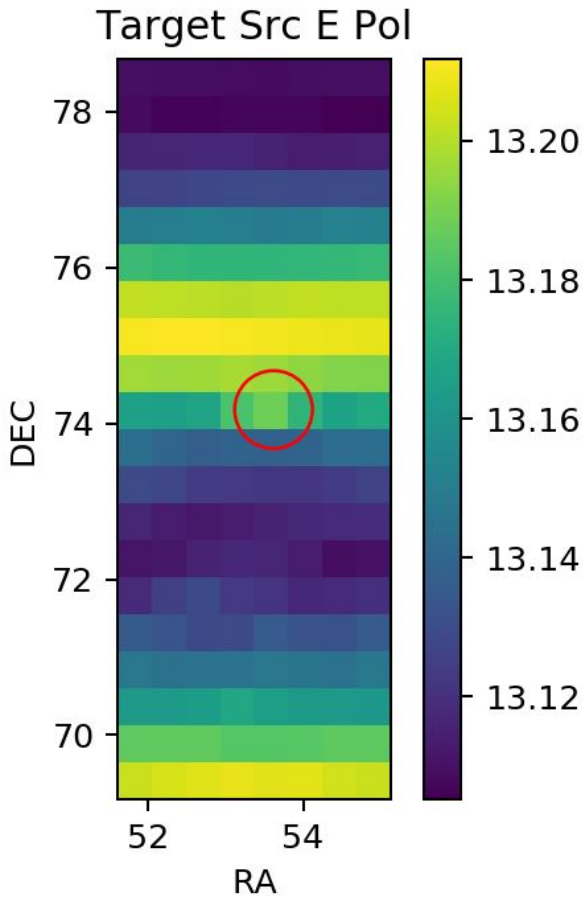

2000
1500
1000
500
0
Flux (arb)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Seconds


20191015 B0329 pulse (N-S pol)
20191015 B0329 pulse (E-W pol)
≈ Frequencies (MHz)
800
750
700
650
600
550
500
450
400
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Elapsed time (total 0.8 sec)
Elapsed time (total 0.8 sec)
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025


$Re[V_{ch,pf}]$ for a B0329 pulse
$Im[V_{ch,pf}]$ for a B0329 pulse
≈ Frequencies (MHz)
800
750
700
650
600
550
500
450
400
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Elapsed time (sec)
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20


$\mathrm{Arg}(V(f)_{B0329}/\phi_{NVSS}(f))$
pol 0
pol 1
2
0
−2
$\tau = 0.05968 \pm 0.005\mu s$
$\tau = 0.05968 \pm 0.005\mu s$
400
450
500
550
600
650
700
750
800
Frequency (MHz)


Target Src S Pol
78
76
74
72
70
DEC
52
54
RA
13.14
13.12
13.10
13.08
13.06
13.04


Target Src E Pol
78
76
74
72
70
DEC
52
54
RA
13.20
13.18
13.16
13.14
13.12

Parameter	Full CHIME	Pathfinder
Structure	Four 20 × 100 m cylinders	Two 20 × 37 m cylinders
Number of feeds per cylinder	256	64
Feed spacing	30 cm	30 cm
Frequency range	400 MHz - 800 MHz	400 MHz - 800 MHz
E-W Field of View	$2.6° - 1.3°$	$2.6° - 1.3°$
N-S Field of View	$90°$	$90°$
Synthesized beam size	$0.4° - 0.2°$	$1.4° - 0.7°$
Receiver noise temperature	$\lesssim 50$ K	$\lesssim 50$ K

Networking Details

CHIME Pathfinder:

1024 frequencies x 256 inputs x 800 MHz

MIT Triggered Baseband Recorder:

256 frequencies x 256 inputs x 800 MHz over 8x10G QSFP+ links

4 x NICs (Silicom PE 31640G2QI71/QX4)

1 TB RAM - 40 seconds of data