Probing the Fast Radio Burst Population(s?) with CHIME

Canadian Hydrogen Intensity Mapping Experiment

SHRIHARSH P. TENDULKAR

McGill Space Institute
Institut Spatial de McGill

+ CHIME-FRB TEAM

CHIME/FRB Collaboration

UBC
- Dr. Davor Cubranic
- Deborah Good, PhD student
- Prof. Mark Halpern
- Prof. Gary Hinshaw
- Dr. Kiyo Masui
- Dr. Cherry Ng
- Prof. Kris Sigurdson
- Prof. Ingrid Stairs

DRAO
- Dr. Tom Landecker
- Dr. Paul Scholz

Perimeter Institute
- Utkarsh Giri, PhD student
- Dr. Dustin Lang
- Masoud Ravandi, PhD student
- Prof. Kendrick Smith

WVU
- Prof. Kevin Bandura

NRAO
- Dr. Paul Demorest
- Dr. Scott Ransom

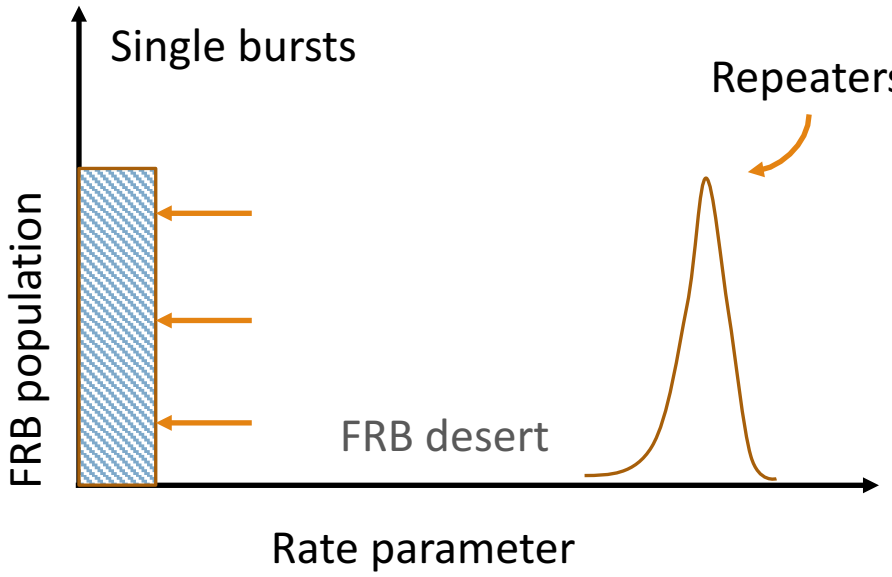
University of Toronto
- Prof. Dick Bond
- Nolan Denman, PhD student
- Prof. Bryan Gaensler
- Prof. Ue-Li Pen
- Andre Recnik
- Prof. Keith Vanderlinde

McGill
- Dr. Michelle Boyce
- Dr. Jojo Boyle
- Shiny Brar
- Prof. Matt Dobbs
- Dr. Emmanuel Fonseca
- Prof. David Hanna
- Alex Josephy, MSc student
- Prof. Vicky Kaspi
- Dr. Arun Naidu
- Chitrang Patel
- Ziggy Pleunis, PhD student
- Dr. Shriharsh Tendulkar

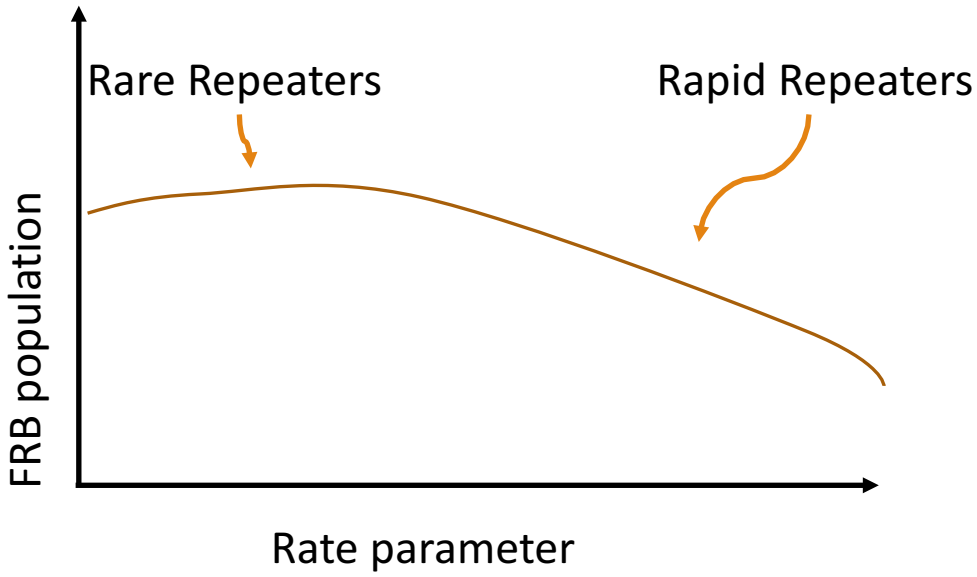
Are we fighting one horse-sized duck or a hundred duck-sized horses?

FRB Zoo (Repetition)

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)

Also, propagation affects detectable repetition.

FRB Zoo (Polarization)

Unpolarized/Low polarization

 FRB 150418 — Lin polzn 8.5% (Keane et al 2016)

Strong circular polarization

 FRB 140514 — ~23% circ polzn (Petroff et al 2017)

Strong linear polarization

 FRB 150807 — 80% Polzn (Ravi et al 2017)

 FRB 110523 — 44% Polzn (Masui et al 2017)

 FRB 150215 — 43% Polzn (Petroff et al 2017)

 FRB 121102 — 100% Polzn (Michilli et al 2018)

No information about the rest

FRB Zoo (Radio Frequency)

Most FRB surveys have been at L band (1.4 GHz)

- Reasonably well-determined rate

4 detections at ~ 800 MHz (GBT + UTMOST)

But no detections at 350 MHz with the GBNCC survey (Chawla et al 2017)

Is this due to free-free absorption, scattering or is it intrinsic?

FRB Zoo — Propagation effects

- Intervening medium affects
  - Intensity,
  - Scattering,
    hence detectability
  - Also polarization

- Boosting due to diffractive scintillation
- Suppression due to free-free absorption

- Some statistical evidence of higher rates at high galactic latitudes (Vander Weil et al 2016 but see Macquart+2018)

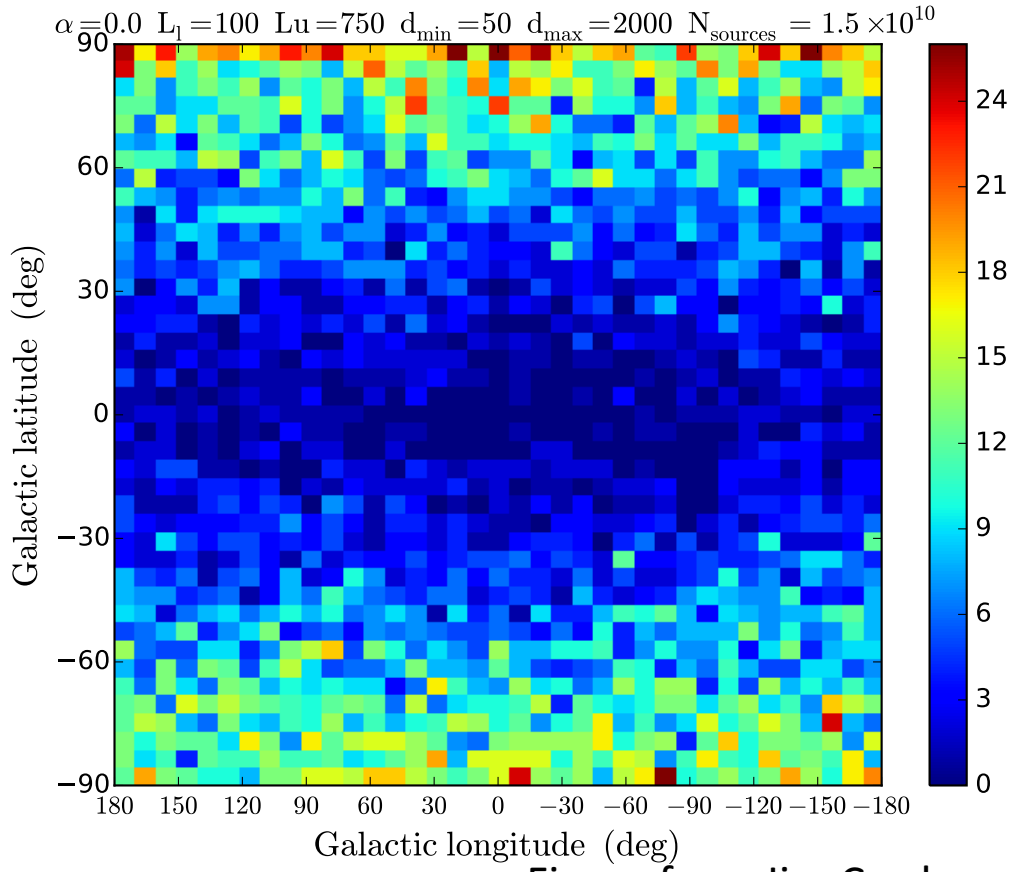


Figure from Jim Cordes
(Cordes et al, in preparation)

What do we want?*

1. Rate of FRBs (with a good understanding of completeness and sensitivity)
    1. As a function of galactic latitude
    2. As a function of fluence (w/o telescope beam pattern)
    3. As a function of DM_{excess}
    4. As a function of frequency (say, 400-600 MHz vs 600-800 MHz)
2. Repetition!
    1. Are there other repeaters?
    2. Do they cluster at low galactic latitudes?
    3. Rates and temporal clustering properties
3. Spectral, polarization and scattering properties
    1. Distributions and correlations

*incomplete list

How do we get it?

1. Single large survey
2. Careful instrument + pipeline design
3. Sensitivity testing and monitoring

CHIME: Canadian Hydrogen Intensity Mapping Experiment

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

Four 20 m x 100 m cylinders

256 dual-pol feeds on each cylinder

400-800 MHz

FOV: E-W ~2.5°–1.3°,
N-S ~120° } ≈220 sq. deg.

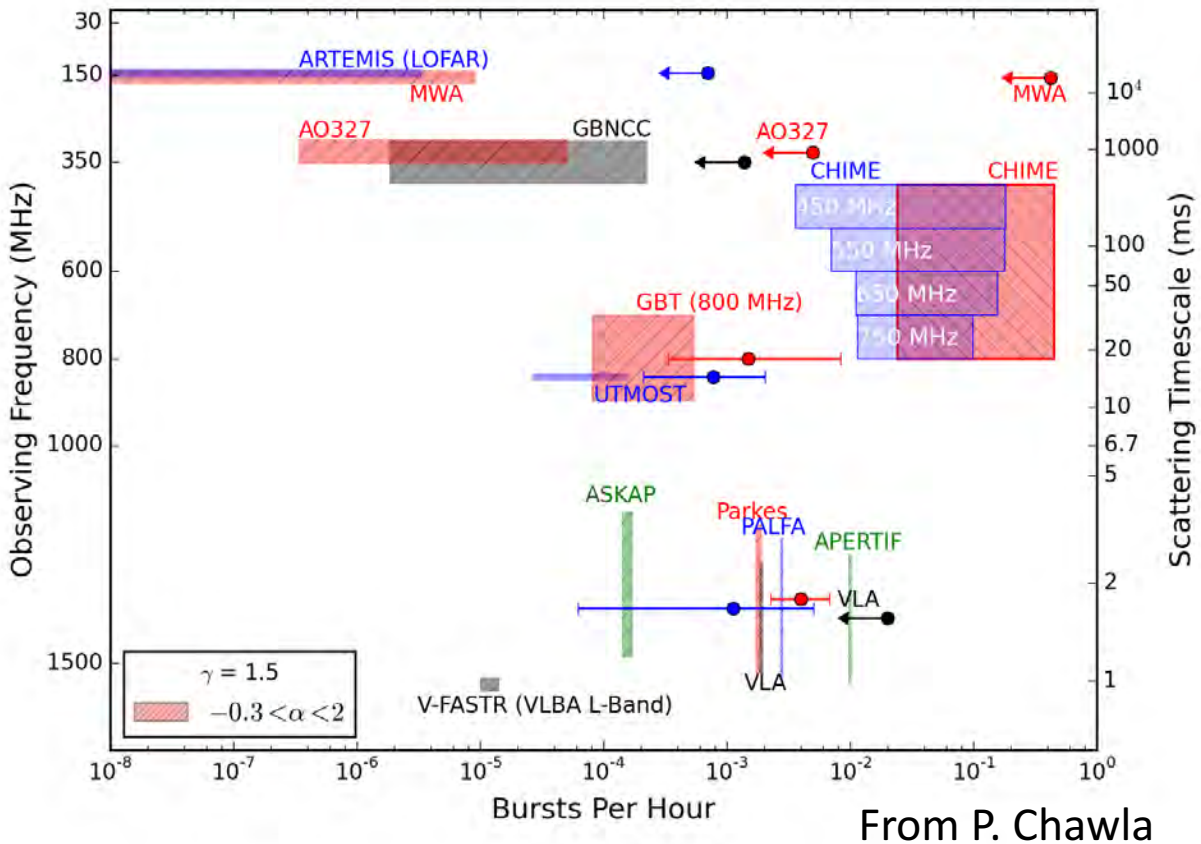
Beam size 0.5°–0.3°

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

CHIME FRB Rates

Based on Lawrence et al 2017 rates
(5.9×10^2 sky^{-1} day^{-1} @1.4 GHz, 1 Jy)

CHIME is expected to detect
0.6-11 FRBs per day (above 10-sigma)
(and more at 8-sigma)

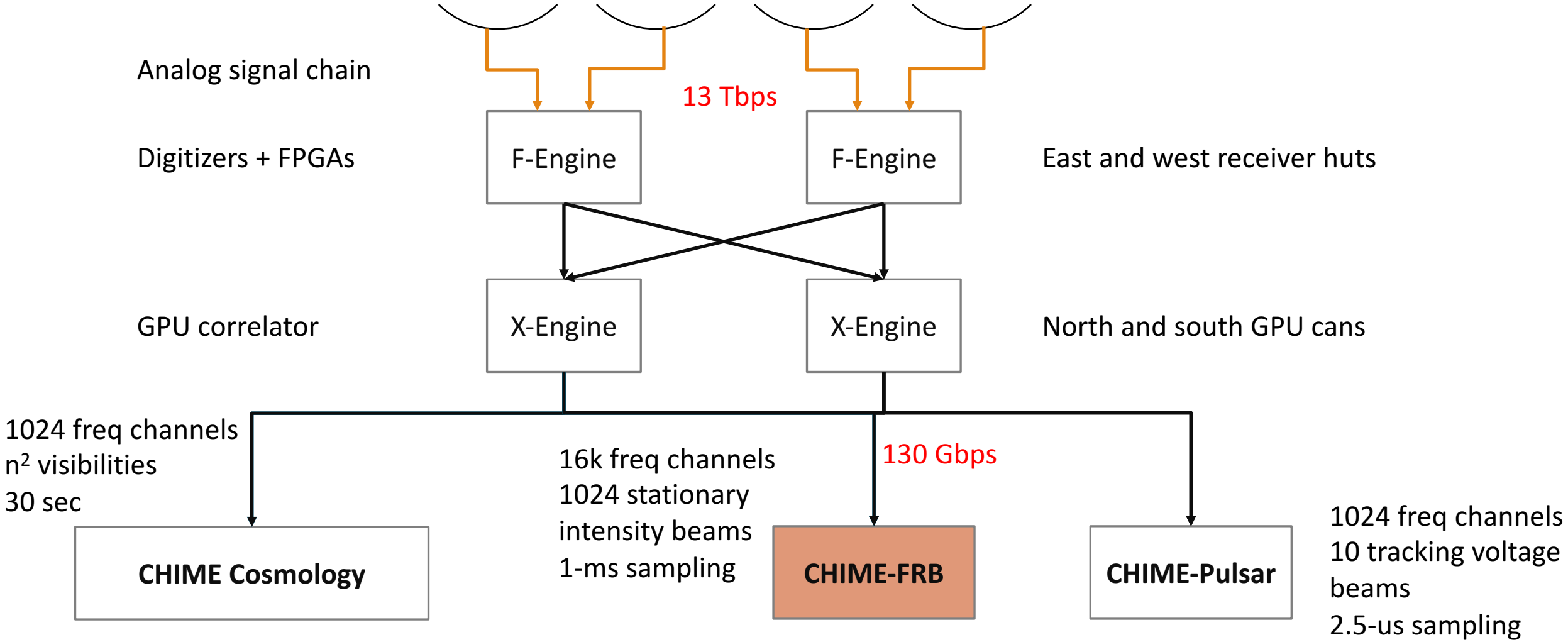


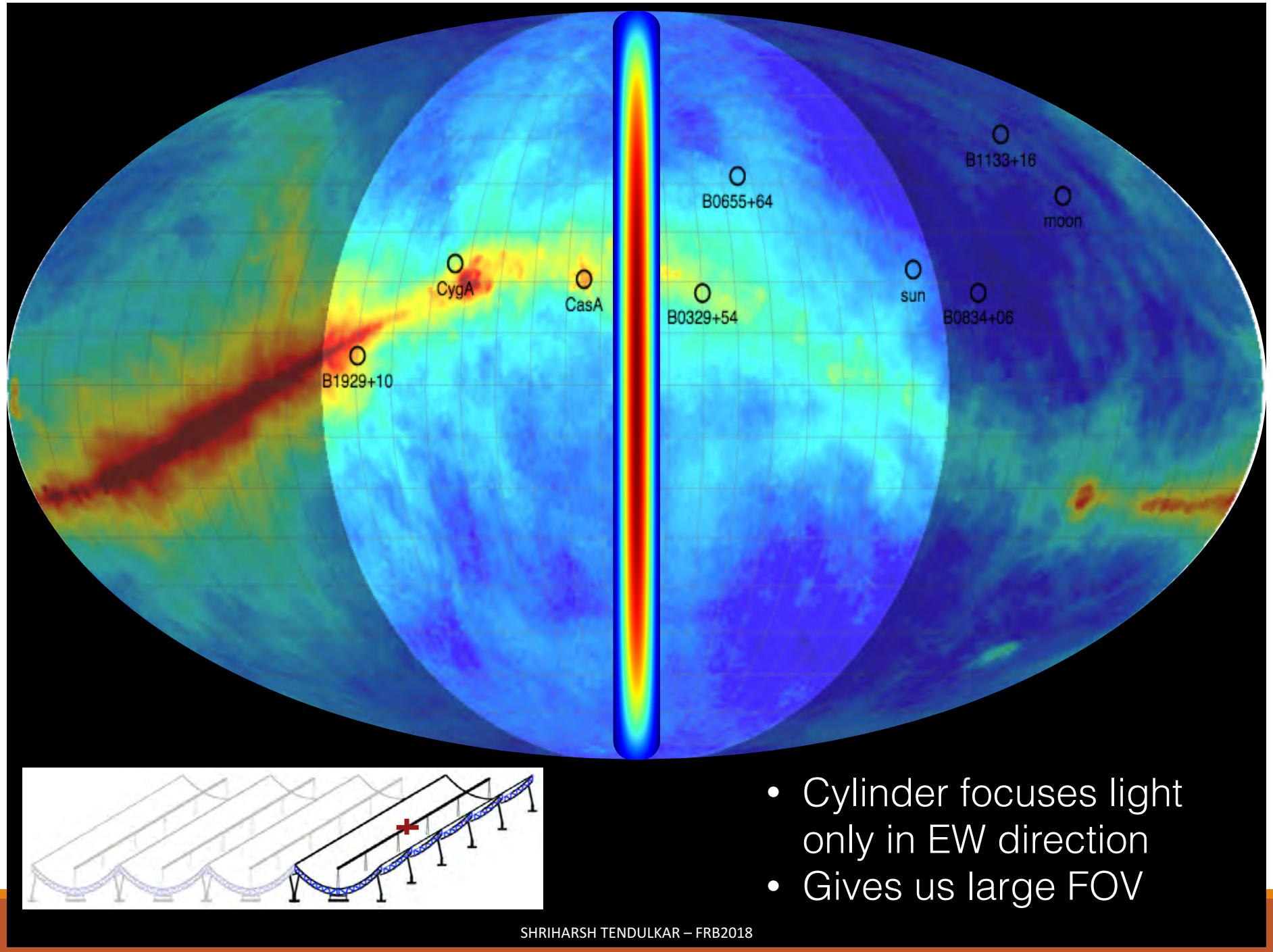
From P. Chawla

FRBs and CHIME

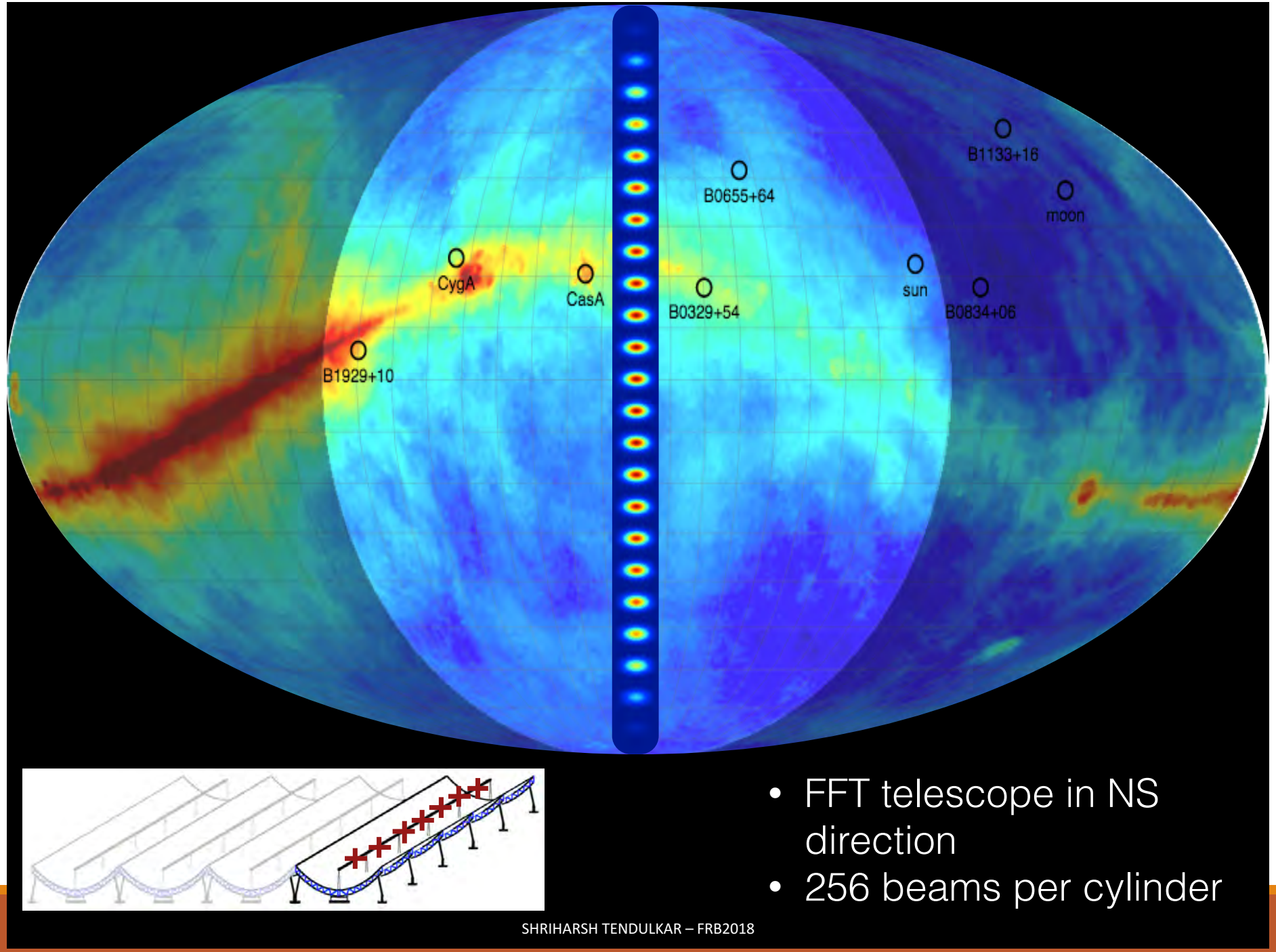
What we want	Can CHIME deliver?
Thousands of events for event rate, flux distribution, angular distribution, DM distribution, scattering vs DM, …	Yes
Repeated observations	Yes
Real-time triggers	Yes → GCN, VO, ATel Digest
Sensitivity to polzn vs freq, vs time	Yes
Localization: Absolutely necessary for distinguishing models	Arcminutes: Within CHIME (SNR dependent) Arcseconds: Maybe, if optical/X-ray counterparts exist, are long-lived & bright OR VLBI (down the road, outriggers?)

CHIME

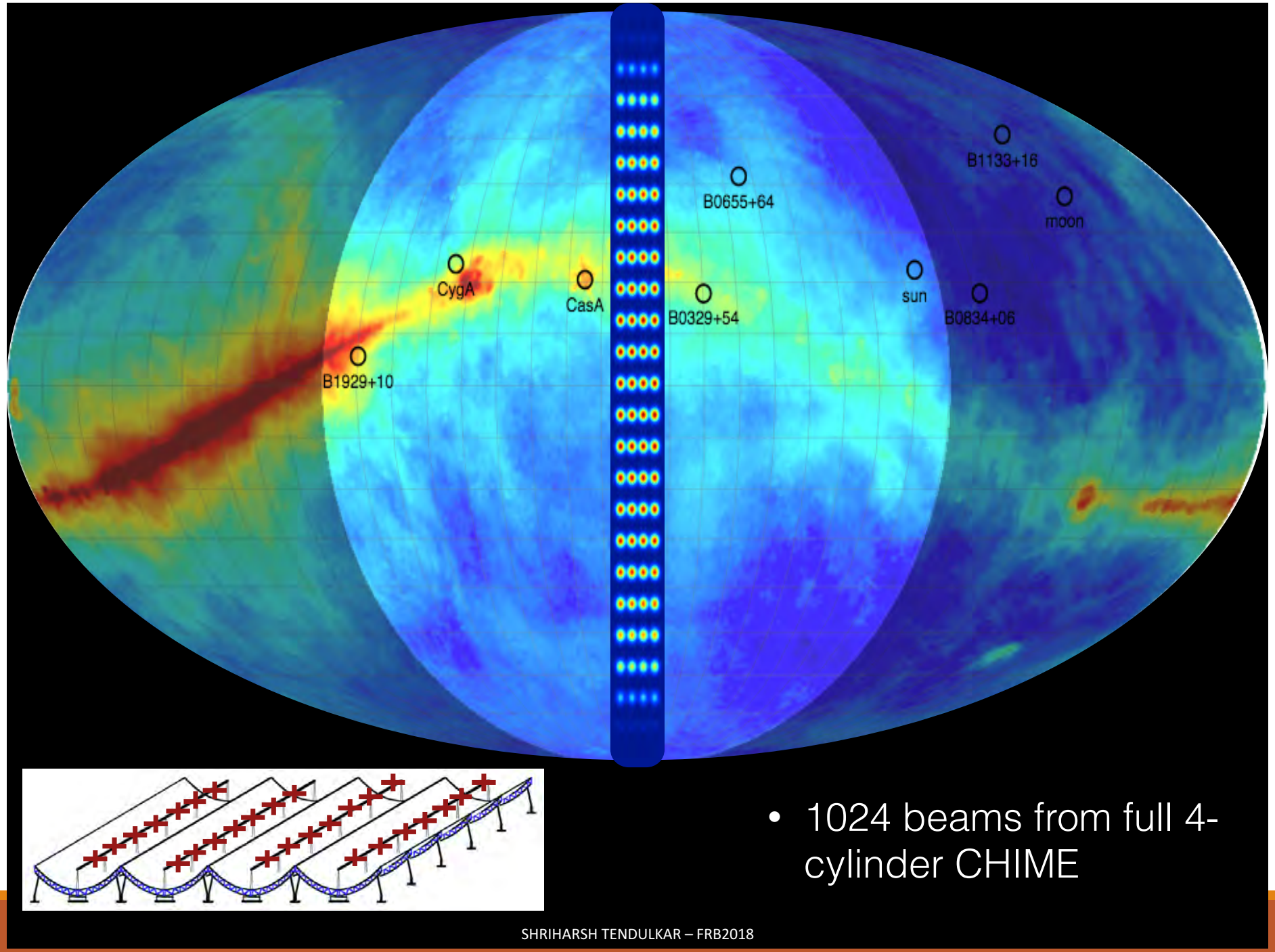

Analog signal chain
13 Tbps
Digitizers + FPGAs
F-Engine
F-Engine
East and west receiver huts
GPU correlator
X-Engine
X-Engine
North and south GPU cans
1024 freq channels
n2 visibilities
30 sec
16k freq channels
1024 stationary
intensity beams
1-ms sampling
130 Gbps
CHIME Cosmology
CHIME-FRB
CHIME-Pulsar
1024 freq channels
10 tracking voltage
beams
2.5-us sampling



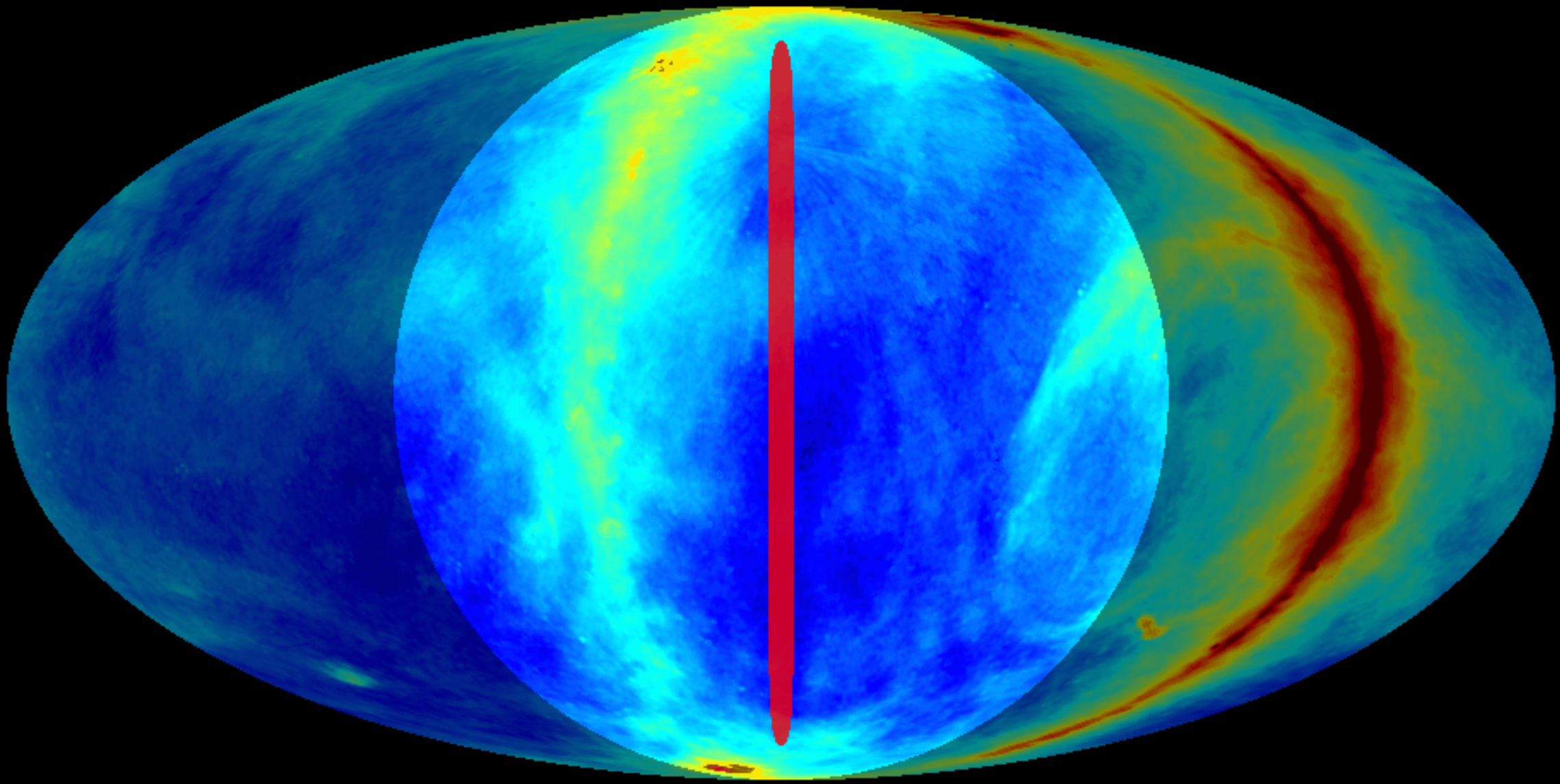
- Cylinder focuses light only in EW direction
- Gives us large FOV



- FFT telescope in NS direction
- 256 beams per cylinder



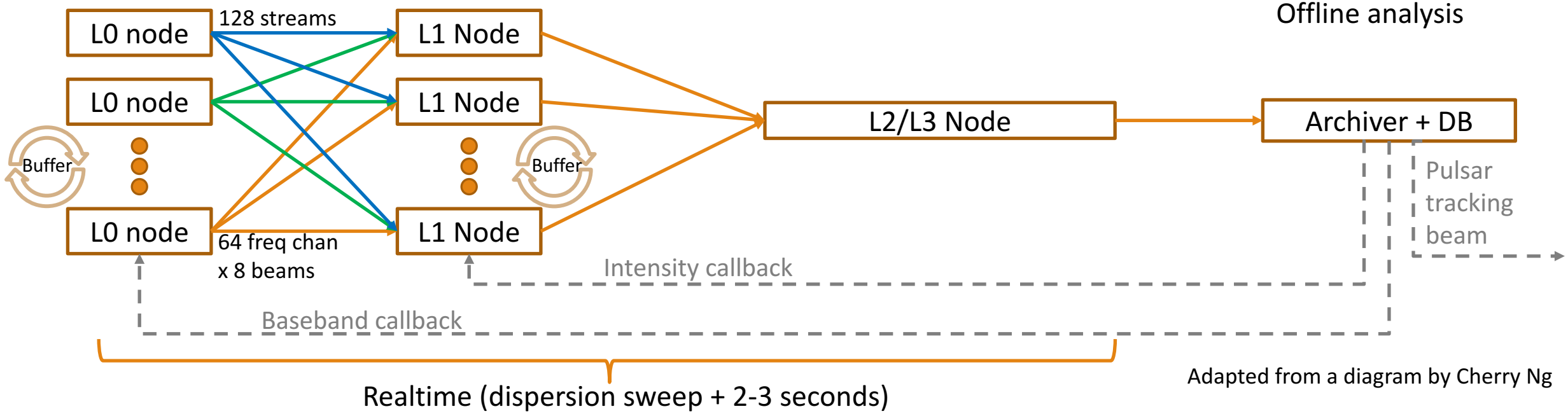
- 1024 beams from full 4-cylinder CHIME



CHIME-FRB Pipeline

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

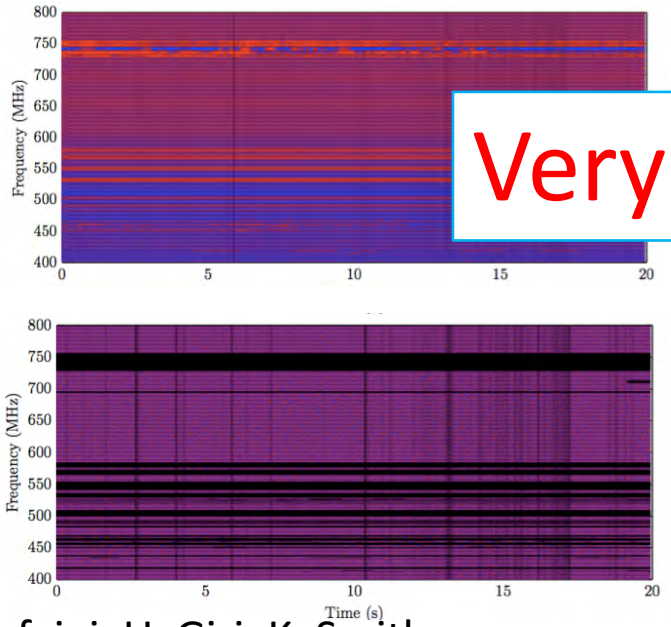
L0	L1	L2	L3	L4
FFT Beamforming 1024 intensity beams	RFI removal Dedispersion More RFI rejection	Multi-beam grouping Multi-beam RFI removal Localization	Identification Action choice	Database for headers Intensity data Baseband data Offline analysis



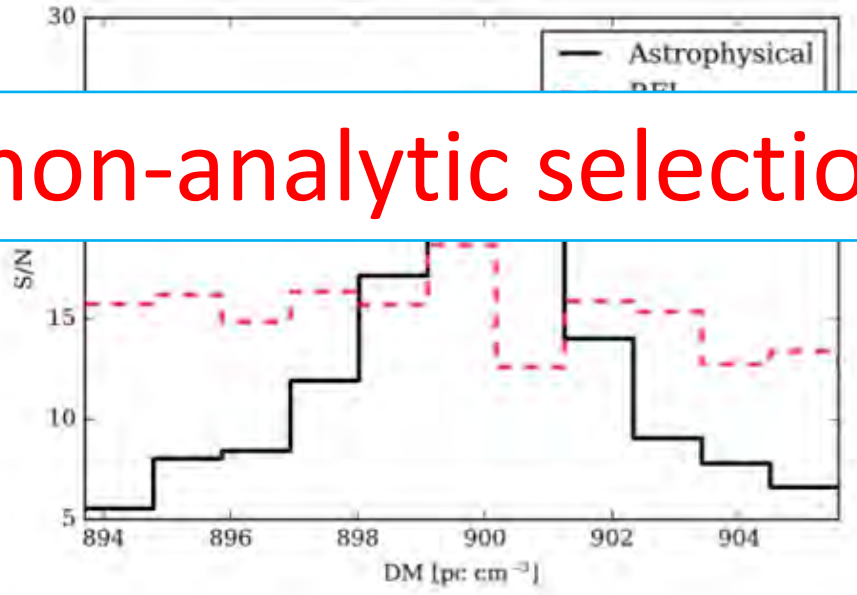
Adapted from a diagram by Cherry Ng

RFI excision & filtering

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

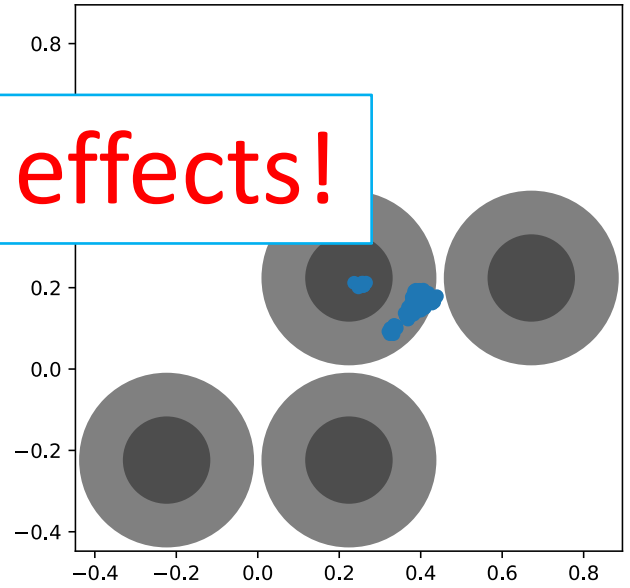


M. Rafaiei, U. Giri, K. Smith



A. Josephy

Very non-analytic selection effects!



SPT

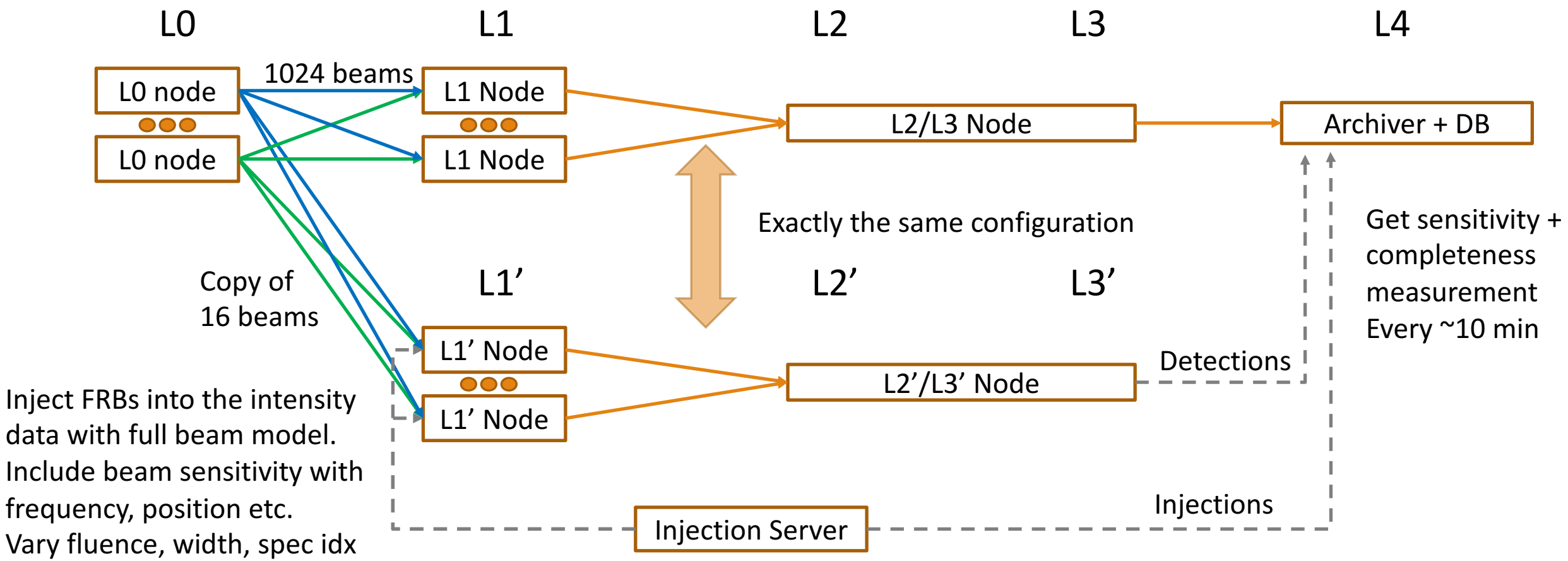
Keeping tabs on completeness

A careful population study needs an understanding of sensitivity and completeness.

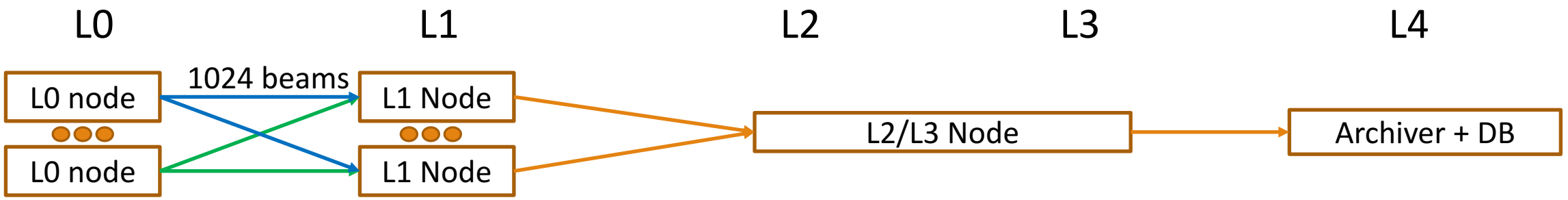
We want to:

1. Maintain detailed configuration history database (re-runnable)
   - Which software version, which configuration (both versioned with git)
2. Run injection tests in real data for testing completeness
3. Log all instrument & data quality parameters
   - Track exposure, sensitivity

Live Sensitivity Testing Goal



Logging Data Quality & Health



active frequency channels (sensitivity)
active feeds (beam shape)
ADC scaling (sensitivity)

nodes alive (search sky area)
L0-L1 packet loss (sensitivity)
RFI metrics (sensitivity, false alarm rate) Spectrum, Mask Fraction
Event/reject/accept rate (sensitivity, sanity check)
Processing delays, latencies

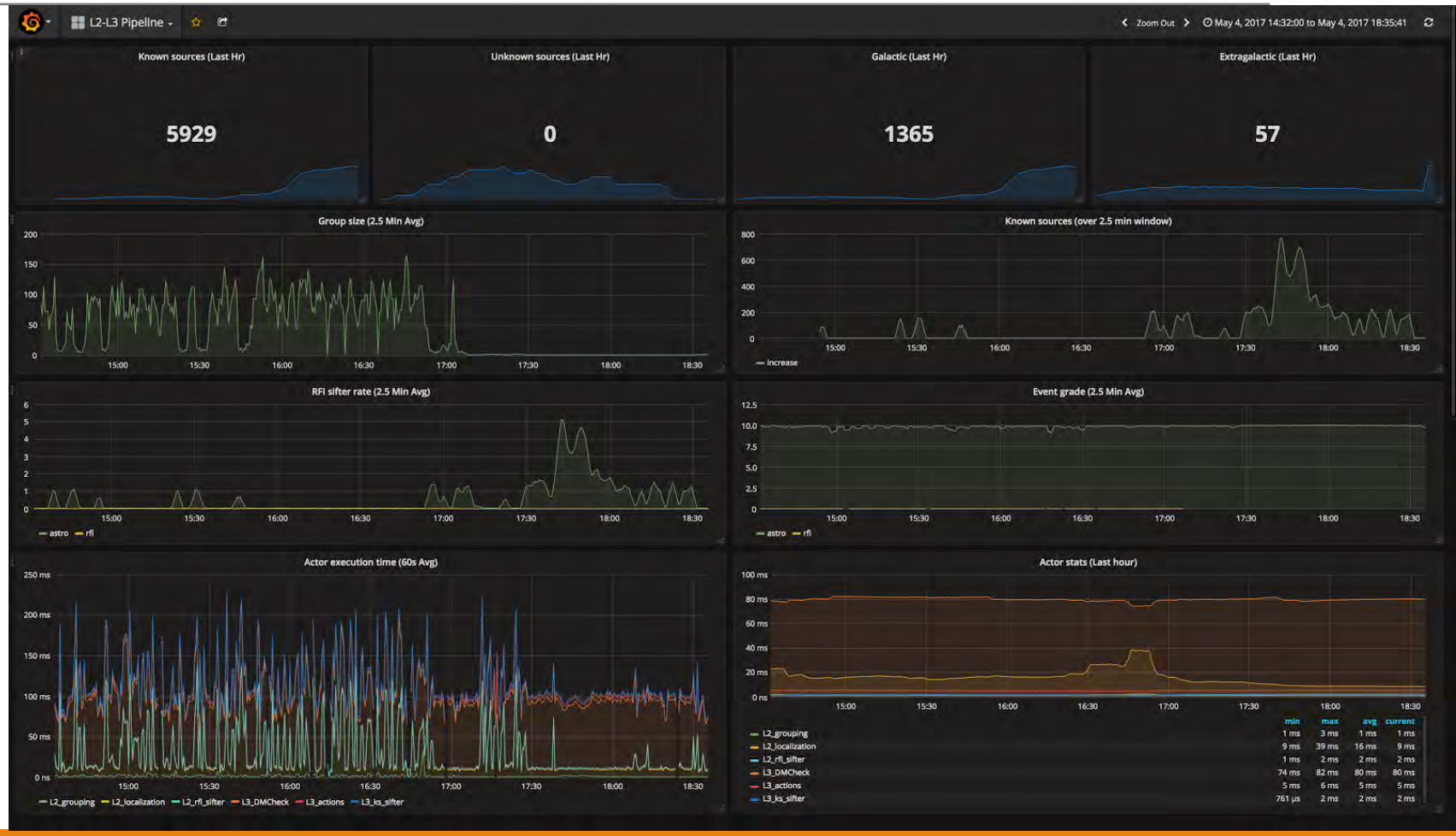
L1 node delays (sanity check)
Event rate (sanity check)
Known sources in the past hour/day (sanity check)

L3/L4 Event rate
Intensity data call back rate
Successful/unsuccessful actions
Diagnostic plots

Monitoring Dashboards

Prometheus + Grafana based monitoring dashboards

- For data quality
- Sanity checks
- Hardware health checks



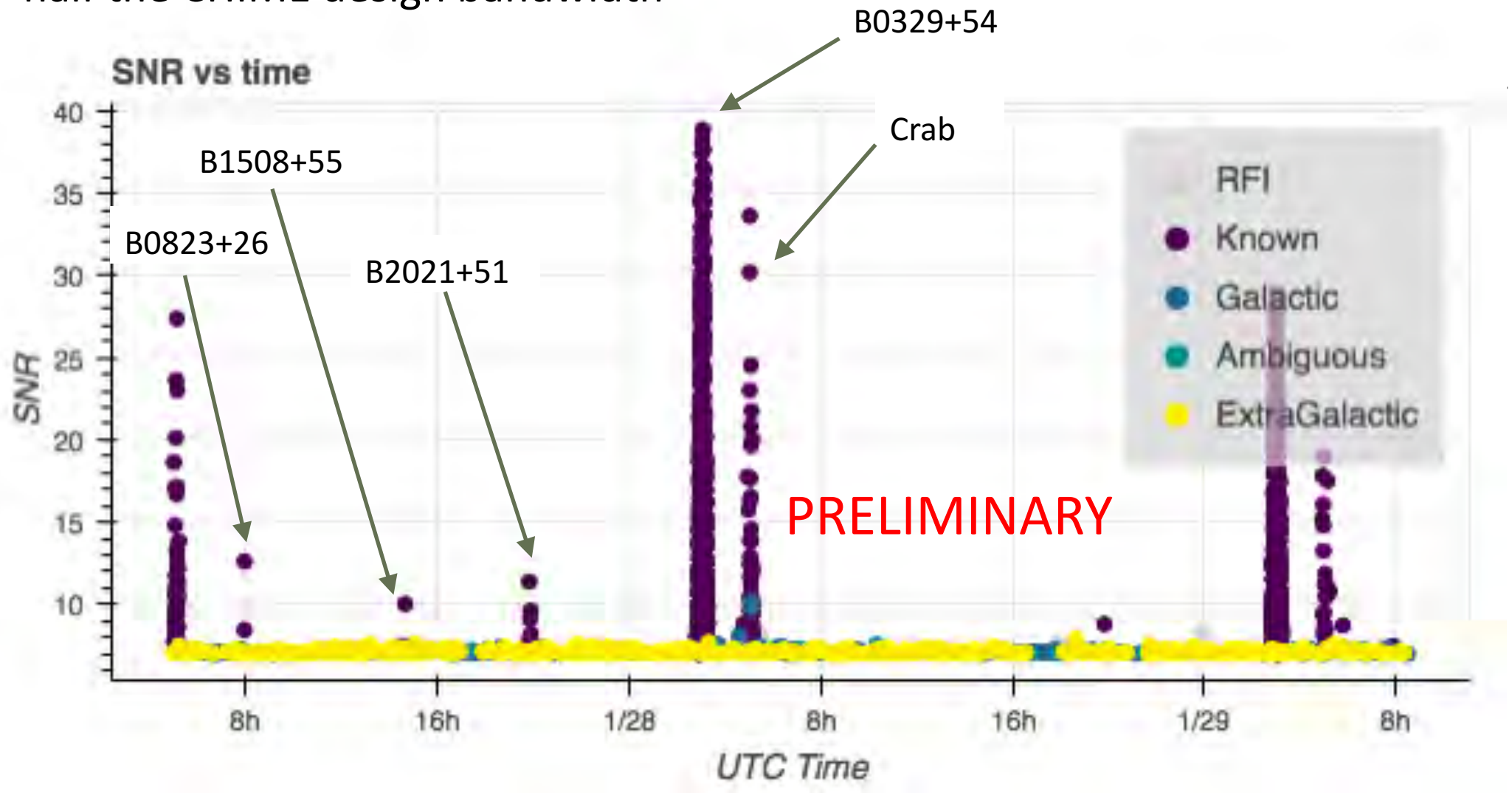
CHIME-FRB Pilot

- Commissioning a 8-node pilot cluster with 64 beams on sky
- Thoroughly test the system architecture and software pipeline

- 64 beams → 0.06 – 0.6 FRBs per day (1-10 per 2 weeks, at Lawrence et al rates)

- Nodes + storage etc installed on site.
- Data path tested with incoherent beam.

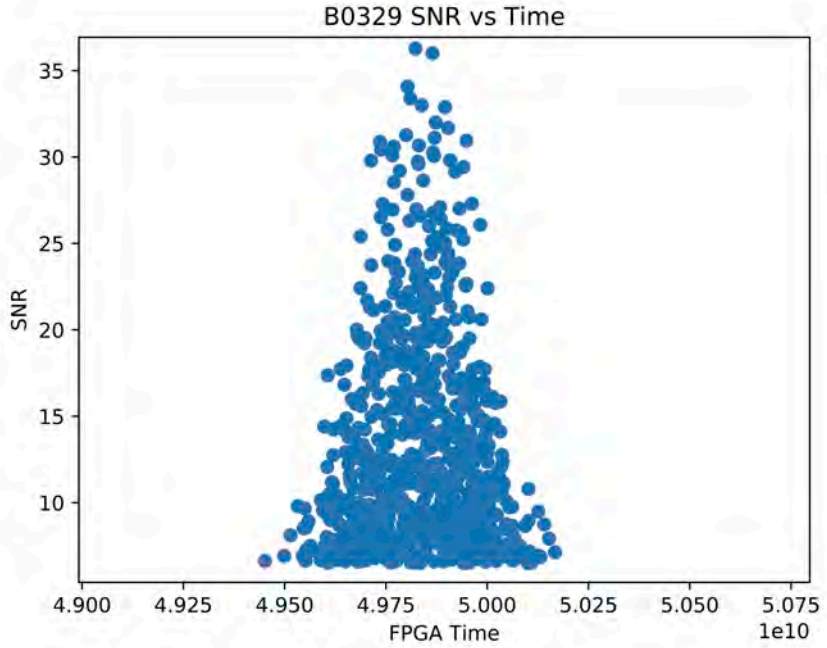
52 hour run with the incoherent beam
~half the CHIME design bandwidth

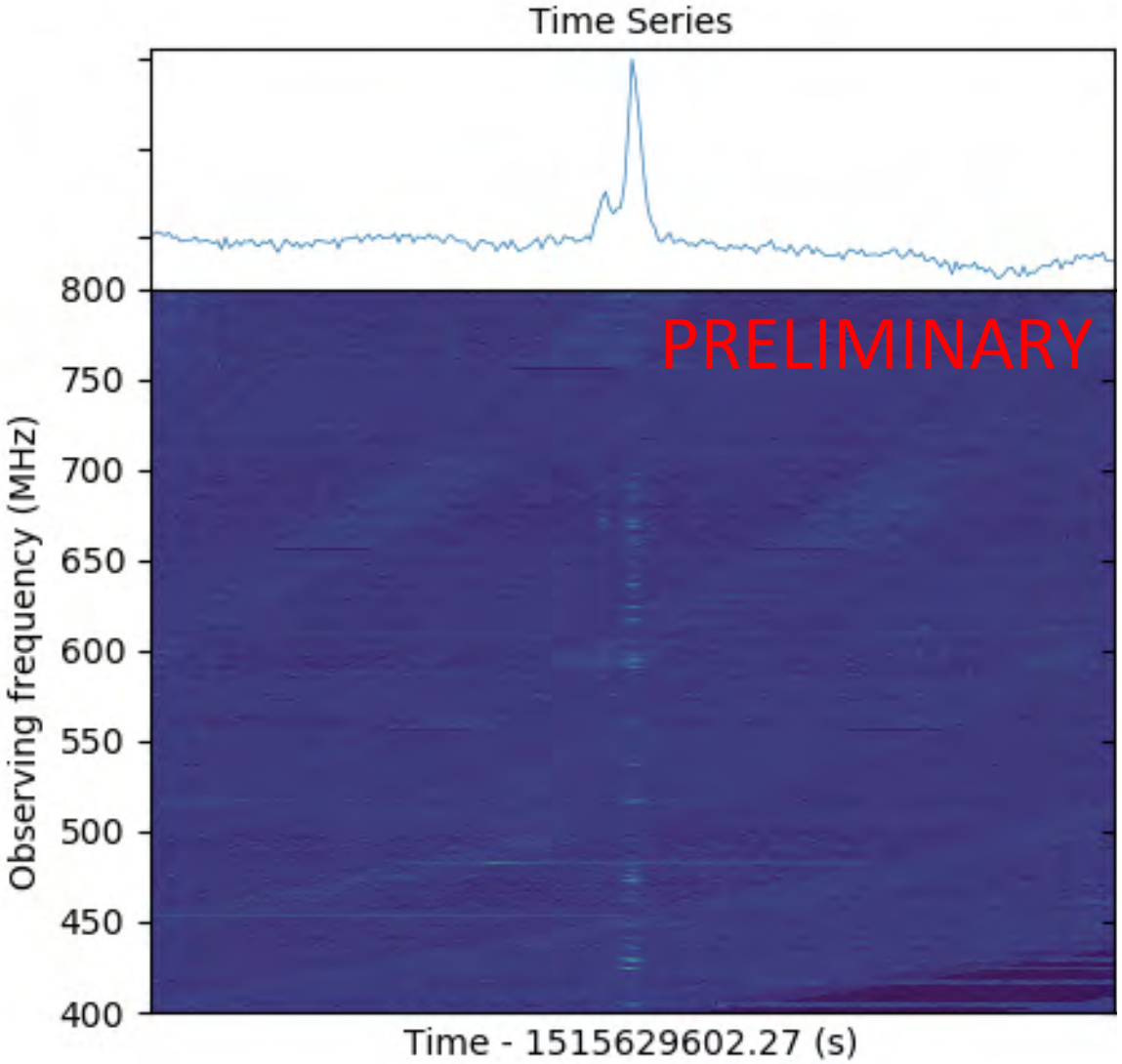


B0329+54

Preliminary RFI cleaning

Missing channels filled with median values





CHIME Status

- Working hard to debug and commission phase-coherent beams
- Phase coherent solutions being tested as we speak
- Acquiring full 128-node system

Stay tuned!