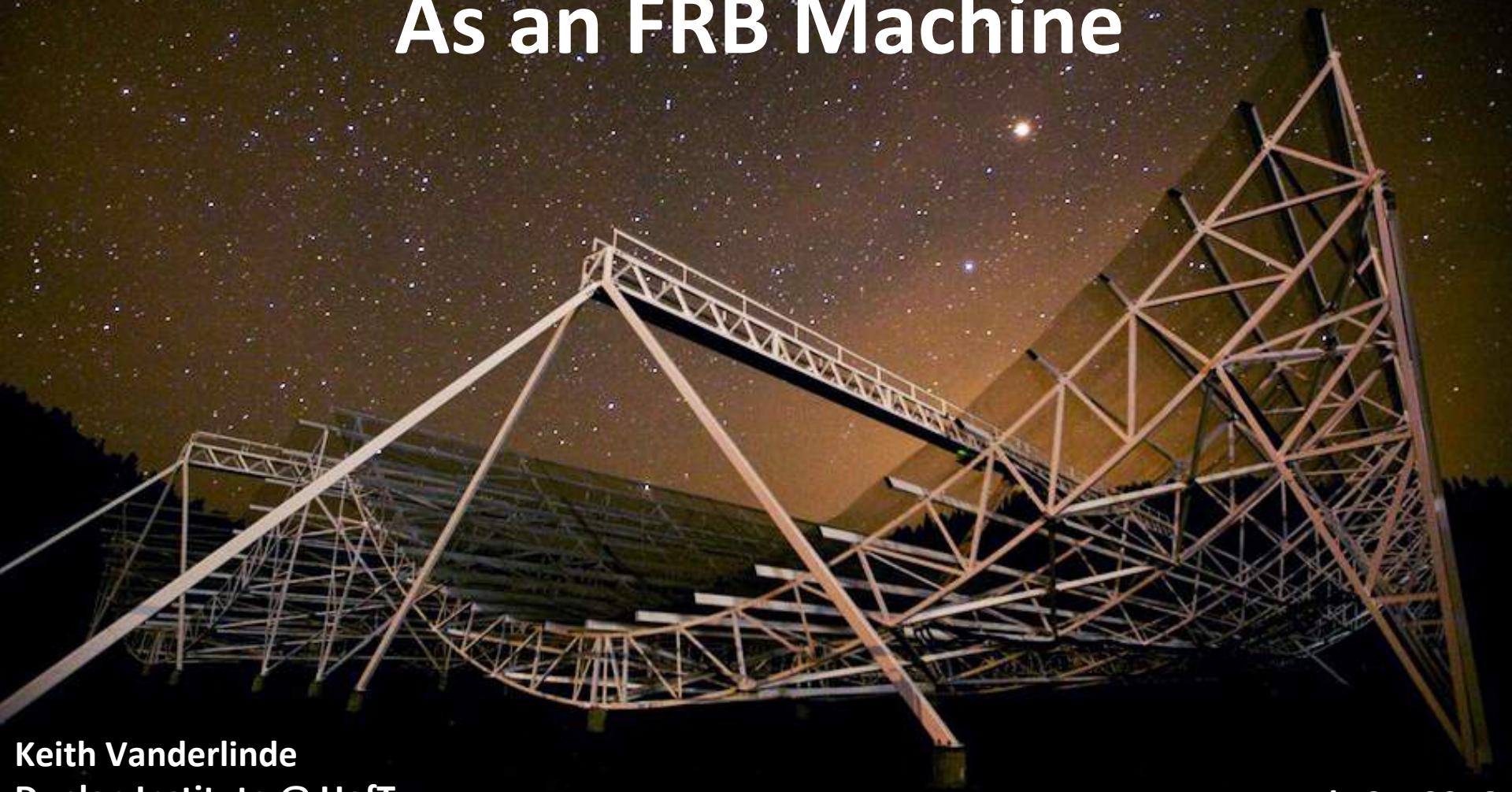


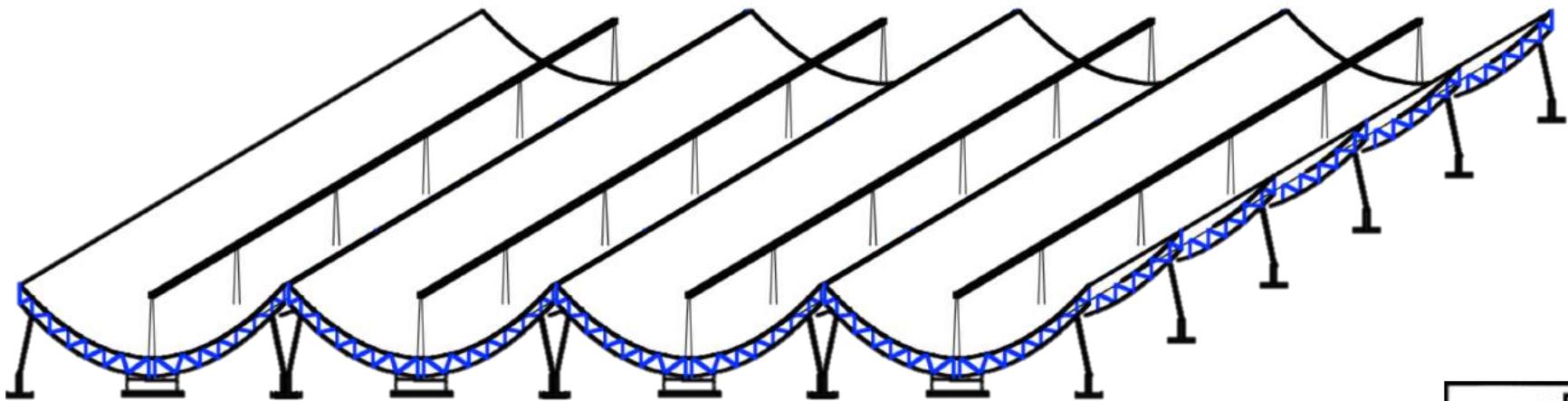
Canadian Hydrogen Intensity Mapping Experiment As an FRB Machine



Keith Vanderlinde
Dunlap Institute @ UofT
(For the CHIME-FRB Team)

July 21, 2016
Boutiques & Experiments

CHIME



- 400-800MHz band
21cm from $z \sim 0.8 - 2.5$
- Resolution: 400kHz, 13-26'
3rd BAO peak resolved
- Drift scan, no moving parts
>20,000 deg² coverage
- 1024 Dual-polarization feeds
Cosmic-variance-limited



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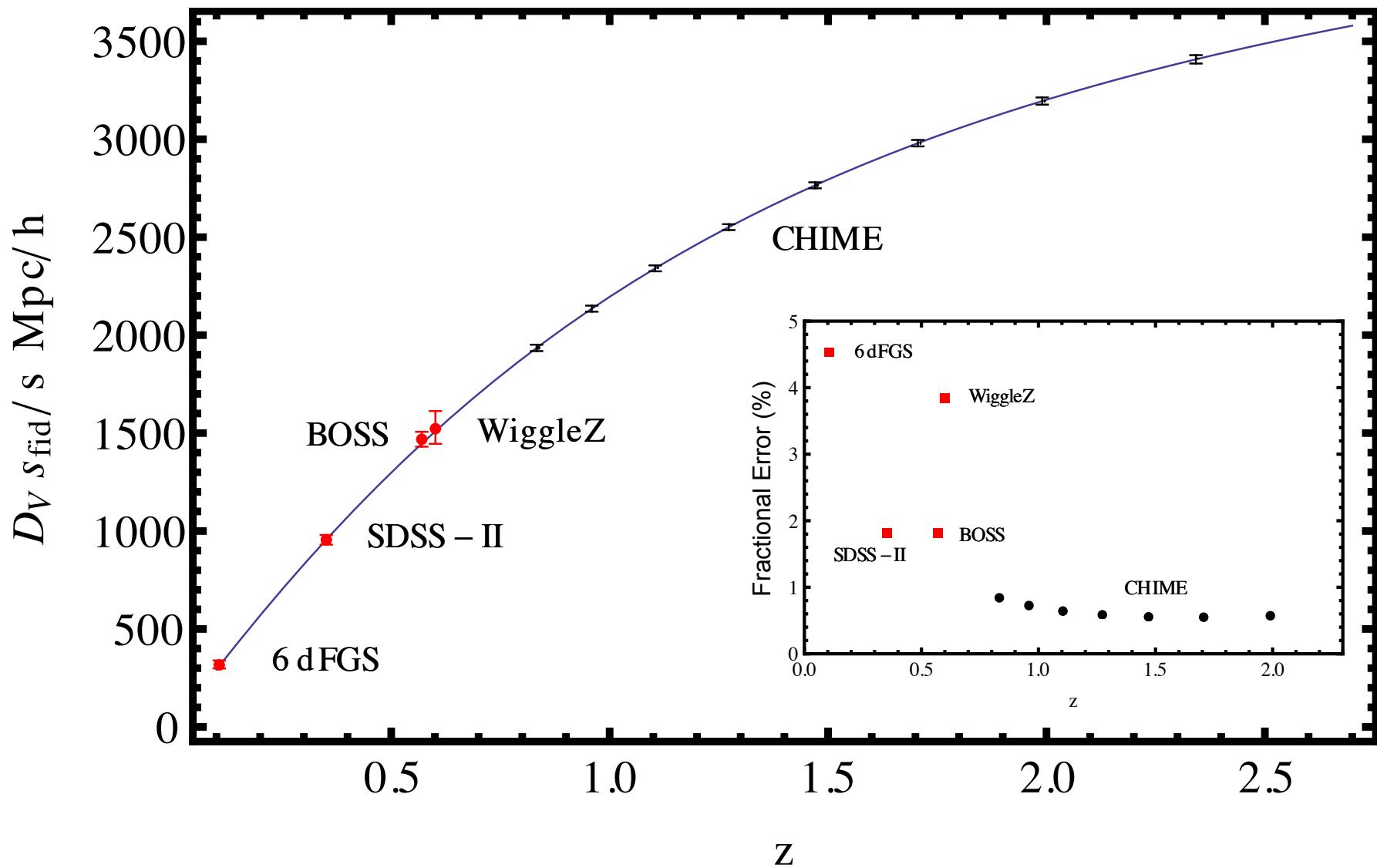


McGill



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TORONTO

CHIME Cosmology



CANADA

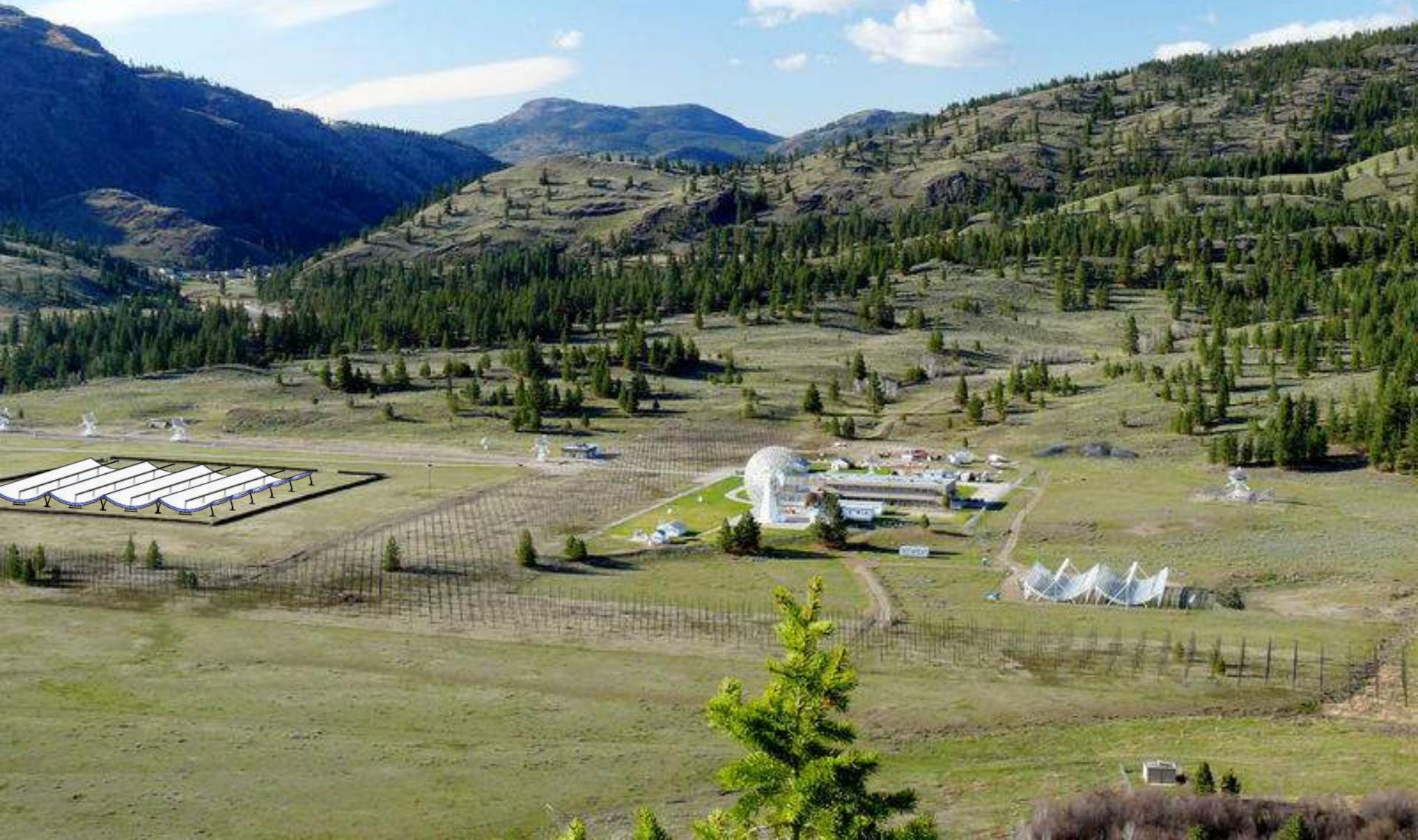
CHIME



CHIME Site: DRAO

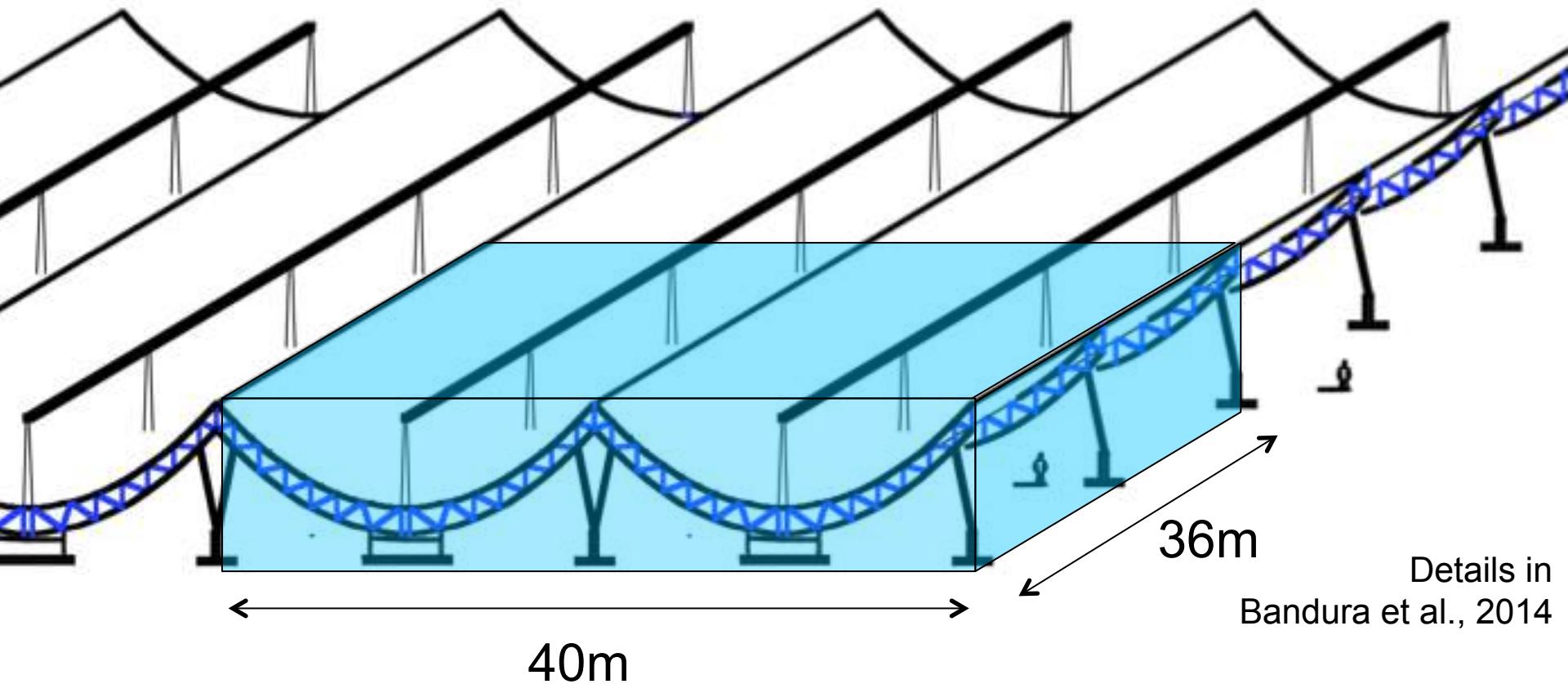


CHIME Site: DRAO

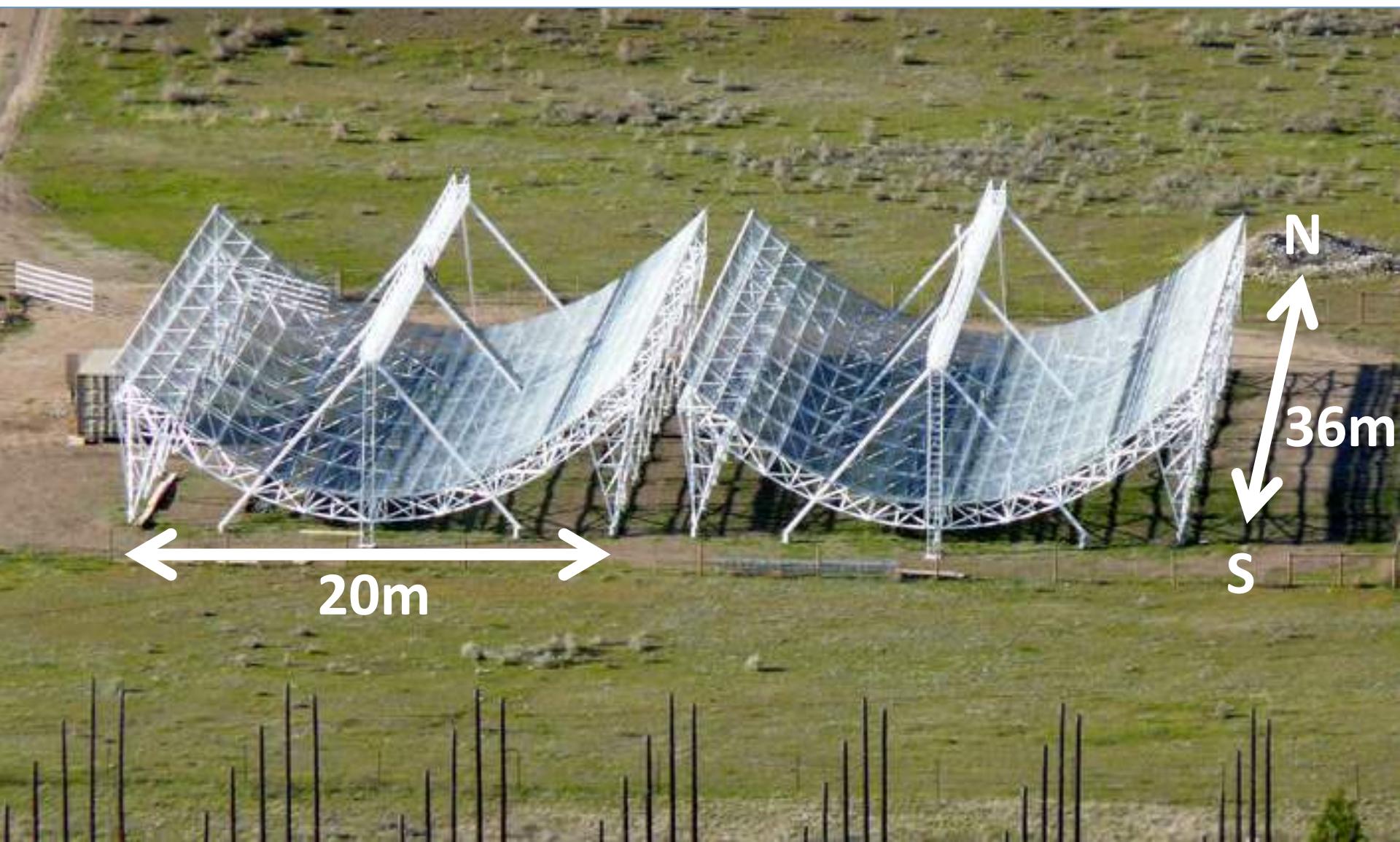


The CHIME Pathfinder

64 dual-pol antennas per cylinder (256 total channels)

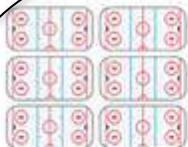


Pathfinder Cylinders

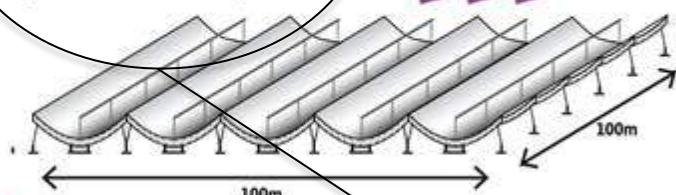


Infographic from the Globe and Mail

- ① The telescope gathers radio waves from a swath of sky directly above the observatory near Penticton, B.C.

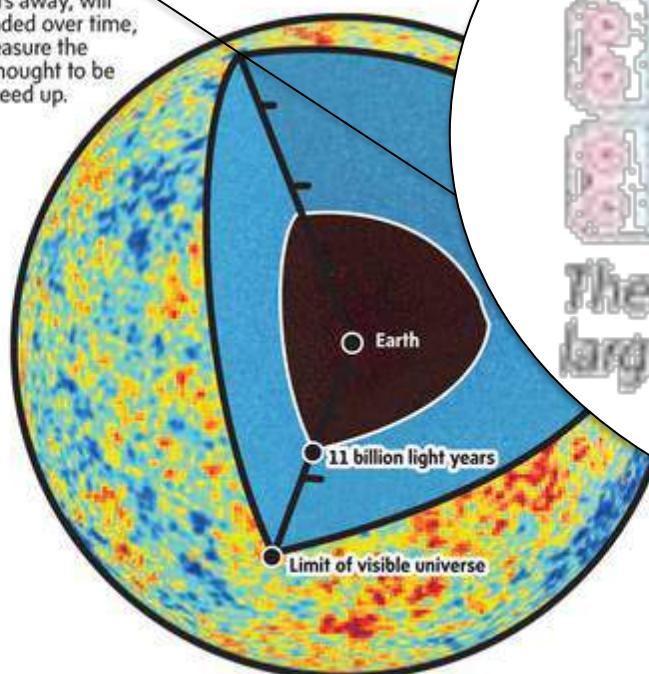


The telescope array will cover an area larger than six NHL hockey rinks

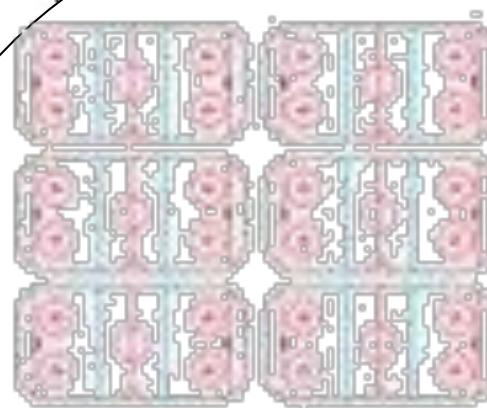


- ② As Earth turns the telescope will sweep through a vast volume of space, mapping out the location of clouds of hydrogen gas that emit radio waves.

- ③ The distribution of the clouds, ranging from 7 to 10 billion light years away, will reveal how space has expanded over time, allowing astronomers to measure the influence of 'dark energy,' thought to be causing the expansion to speed up.



The telescope array will cover an area larger than six NHL hockey rinks











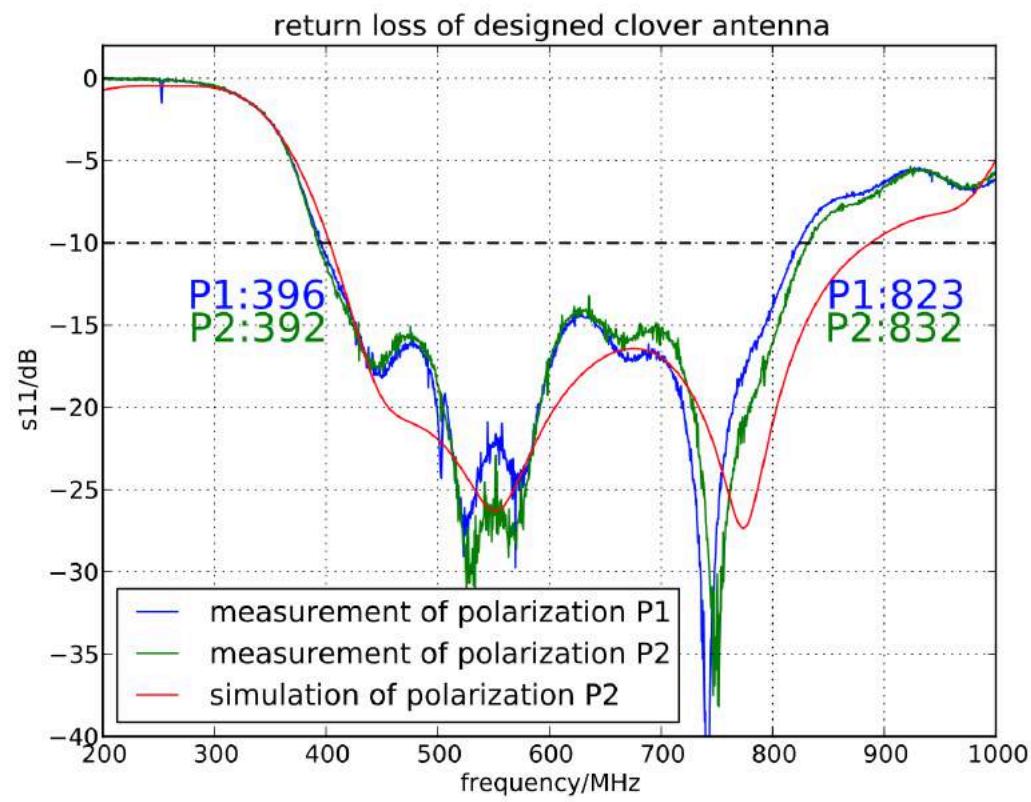
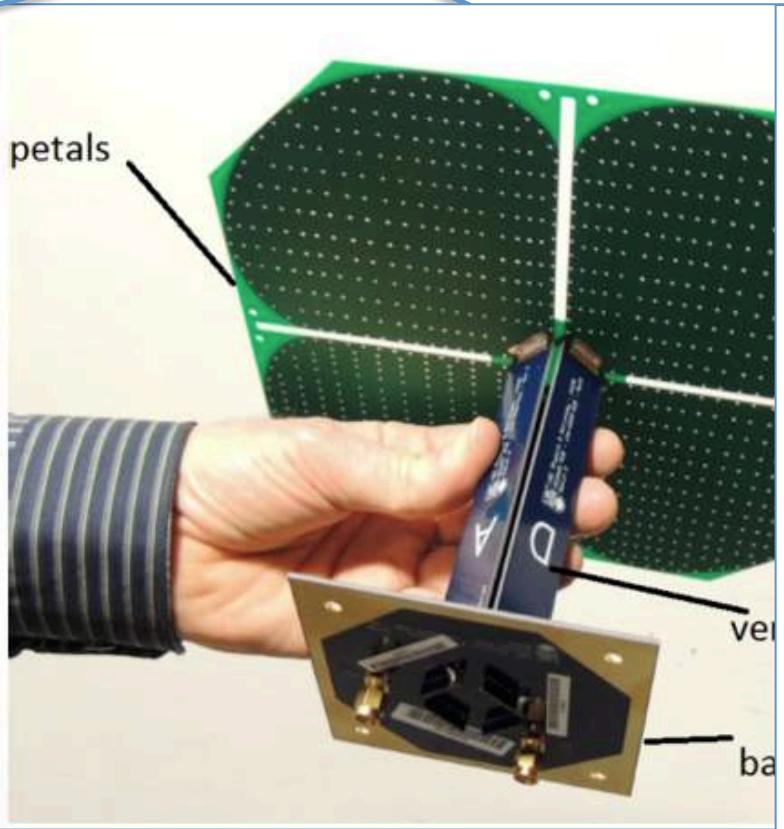
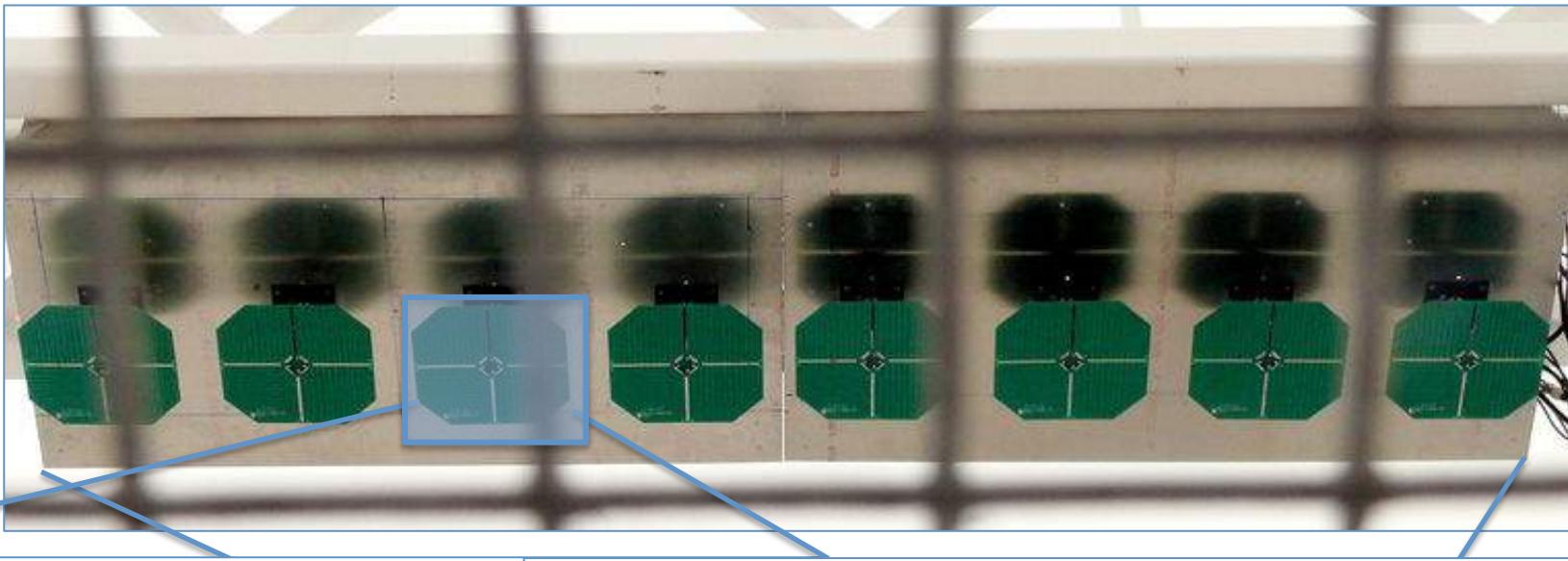


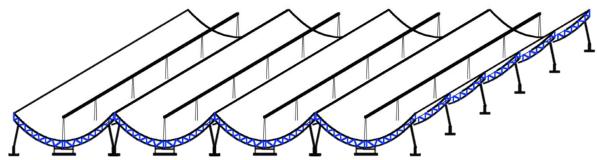
Big Building



GREYBACK
CONSTRUCTION







Reflectors



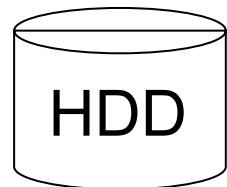
Analog Frontend
Amps, filters, etc



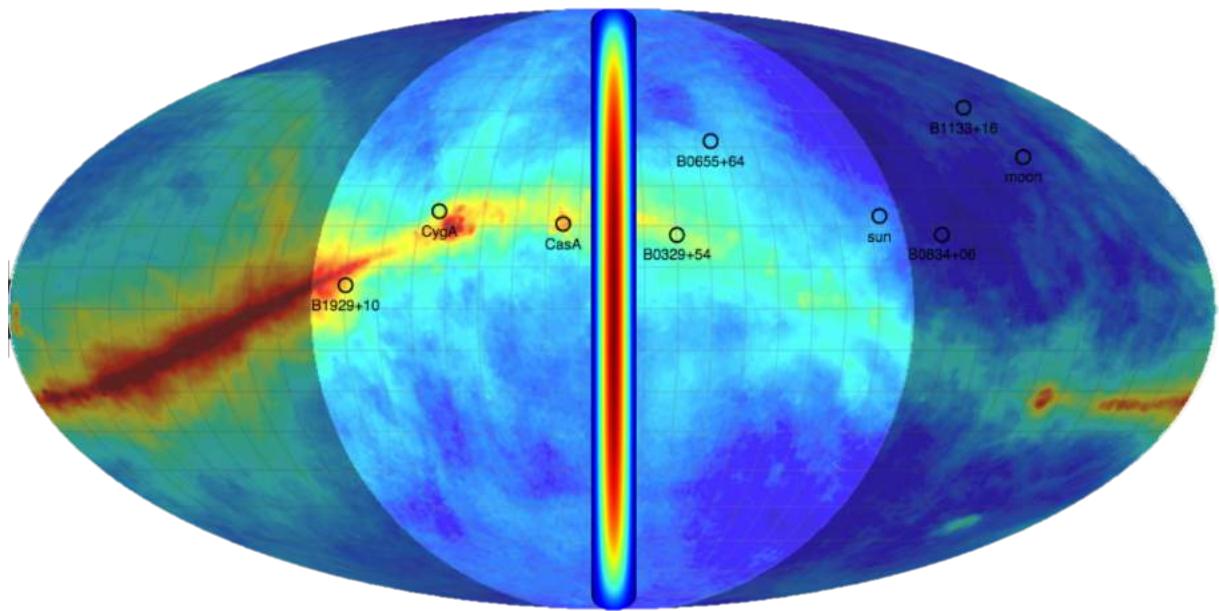
FPGA Digitizer /
Channelizer



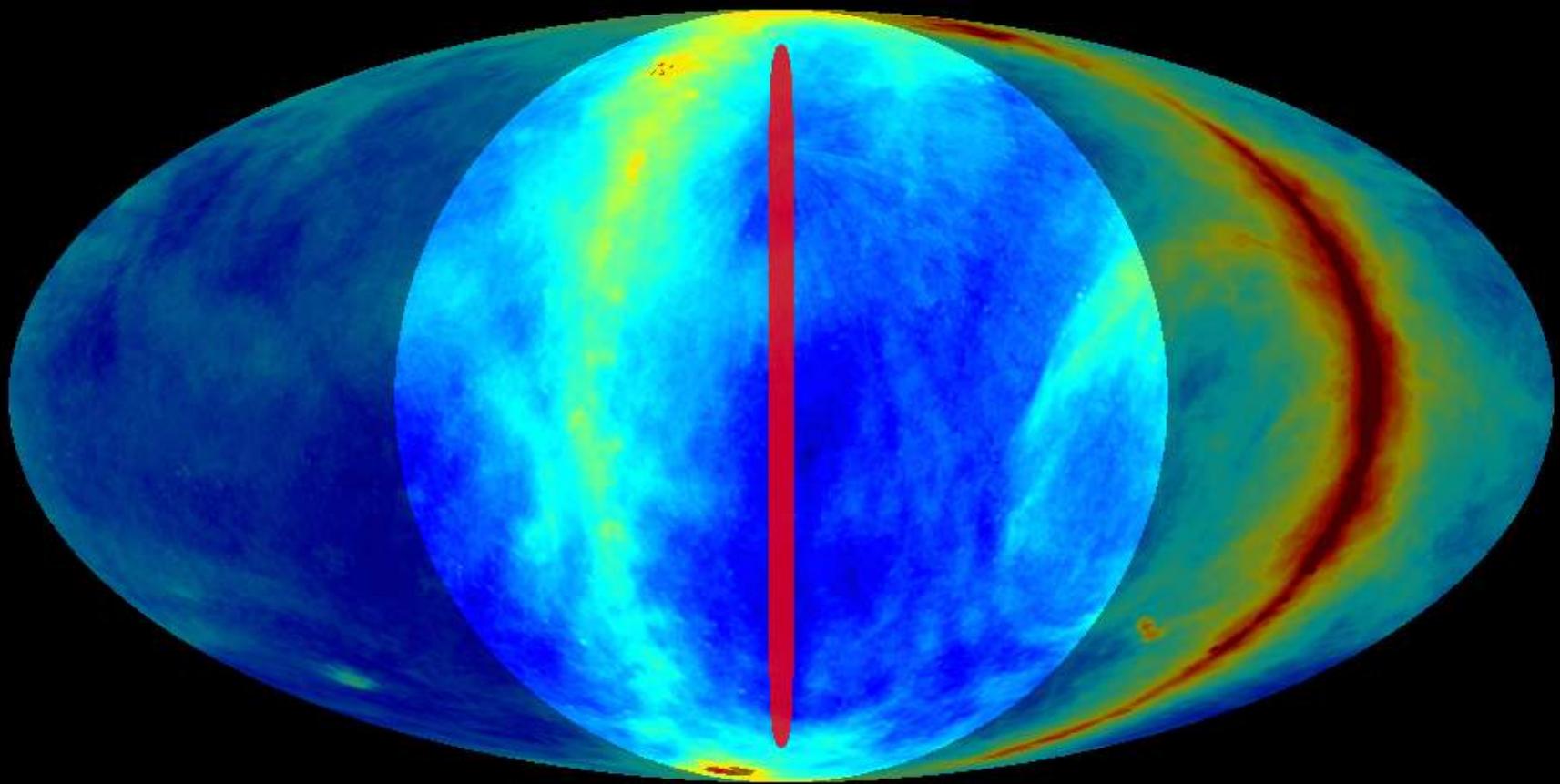
GPU Correlator

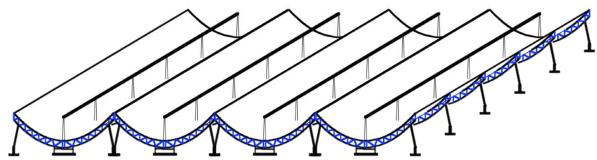


System Overview



- 1024 dual-polarization feeds
- each sees a broad N-S band



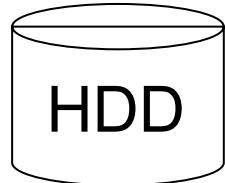


Reflectors

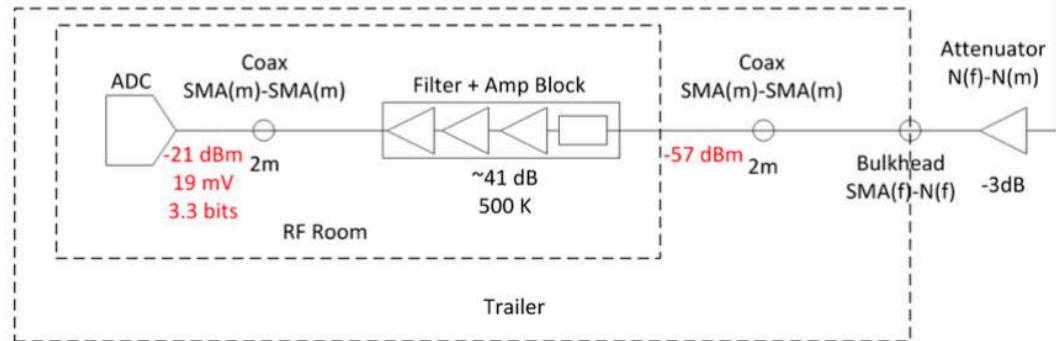
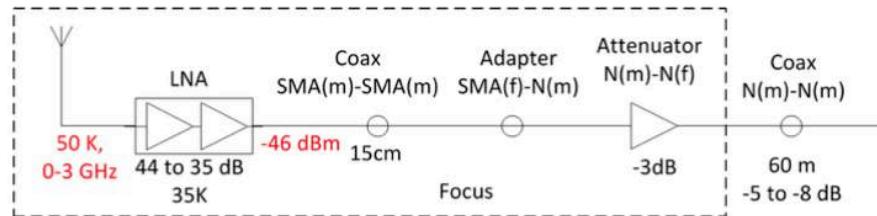
Analog Frontend
Amps, filters, etc

FPGA Digitizer /
Channelizer

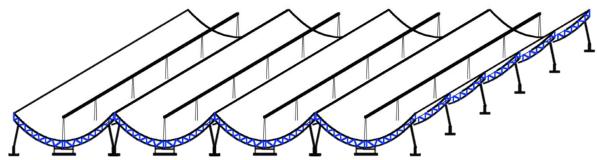
GPU Correlator



System Overview



- LNA $T_{\text{sys}} < 50\text{K}$
- Lots of coax
- 40dB cutoff bandpass,
 $400\text{MHz} < \nu < 800\text{MHz}$



Reflectors



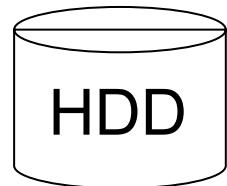
Analog Frontend
Amps, filters, etc



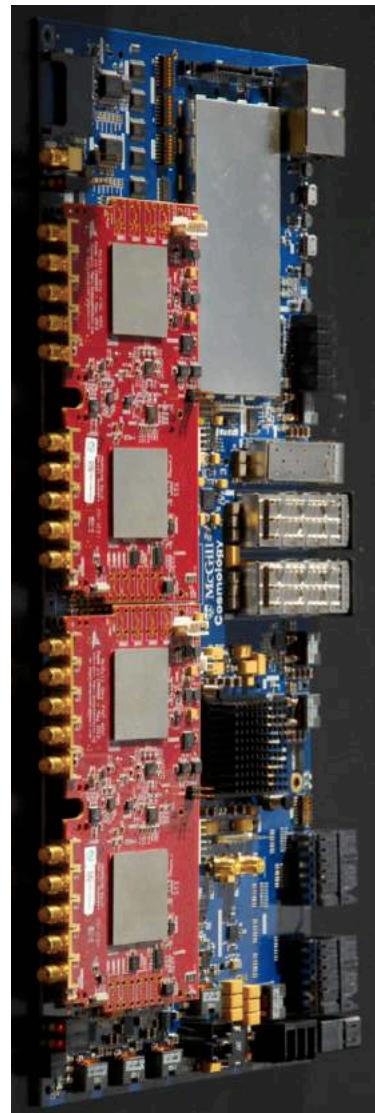
FPGA Digitizer /
Chanelizer



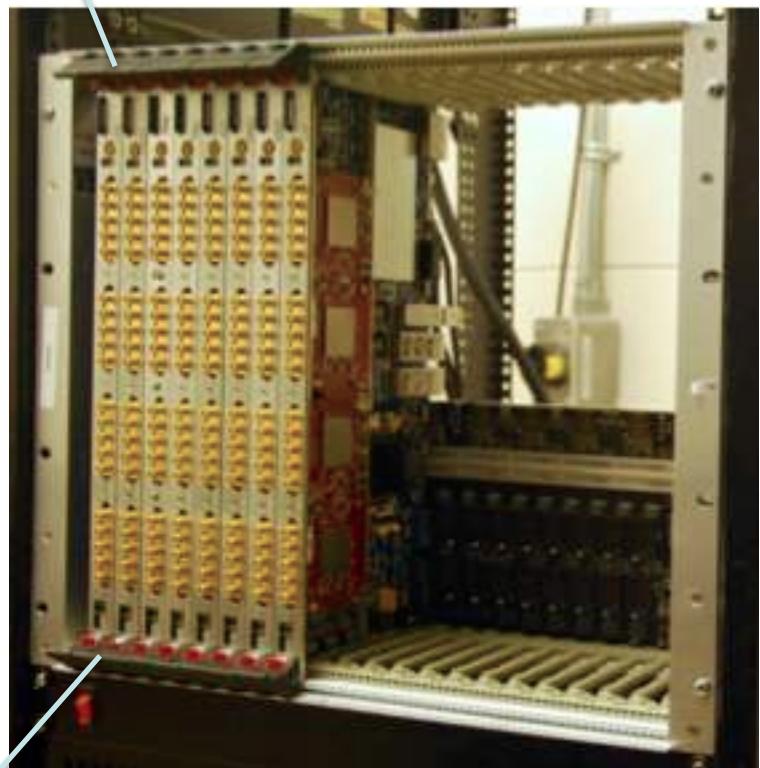
GPU Correlator



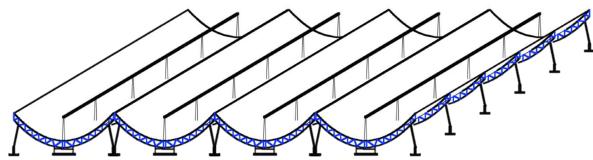
System Overview



Digitizes at 800MHz
Splits into 1024 freqs
via 4-tap PFB



16 / crate, 8 crates



Reflectors



Analog Frontend
Amps, filters, etc



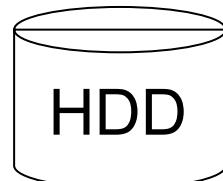
FPGA Digitizer /
Chanelizer



\approx TBps

GPU Correlator

\approx GBps

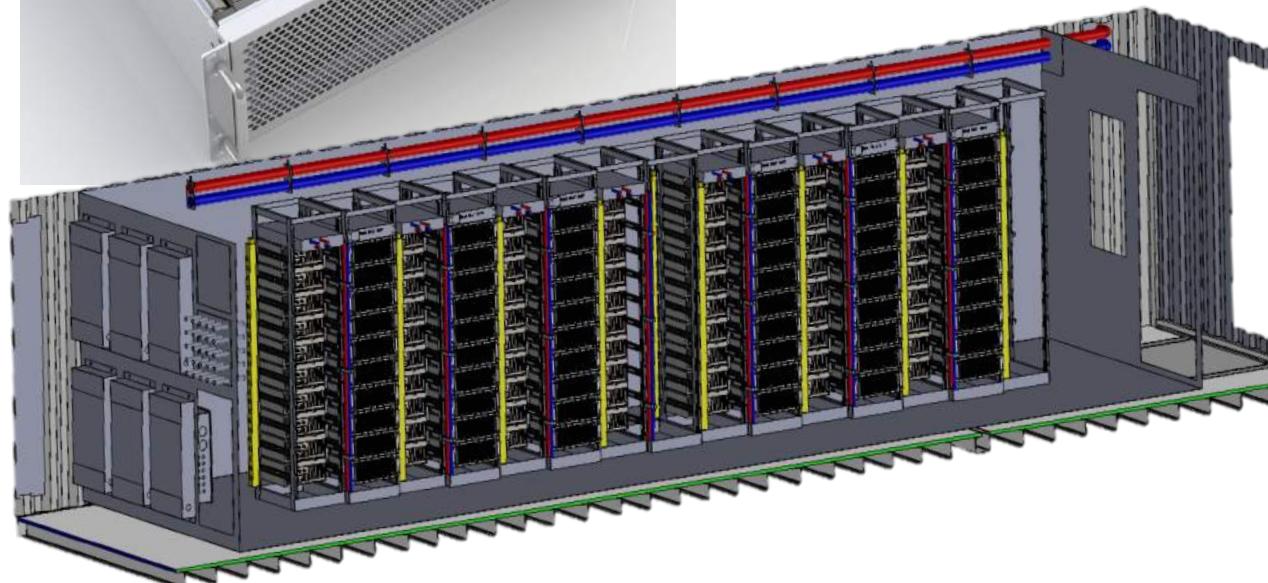


System Overview

AMD GPU-based X-Engine



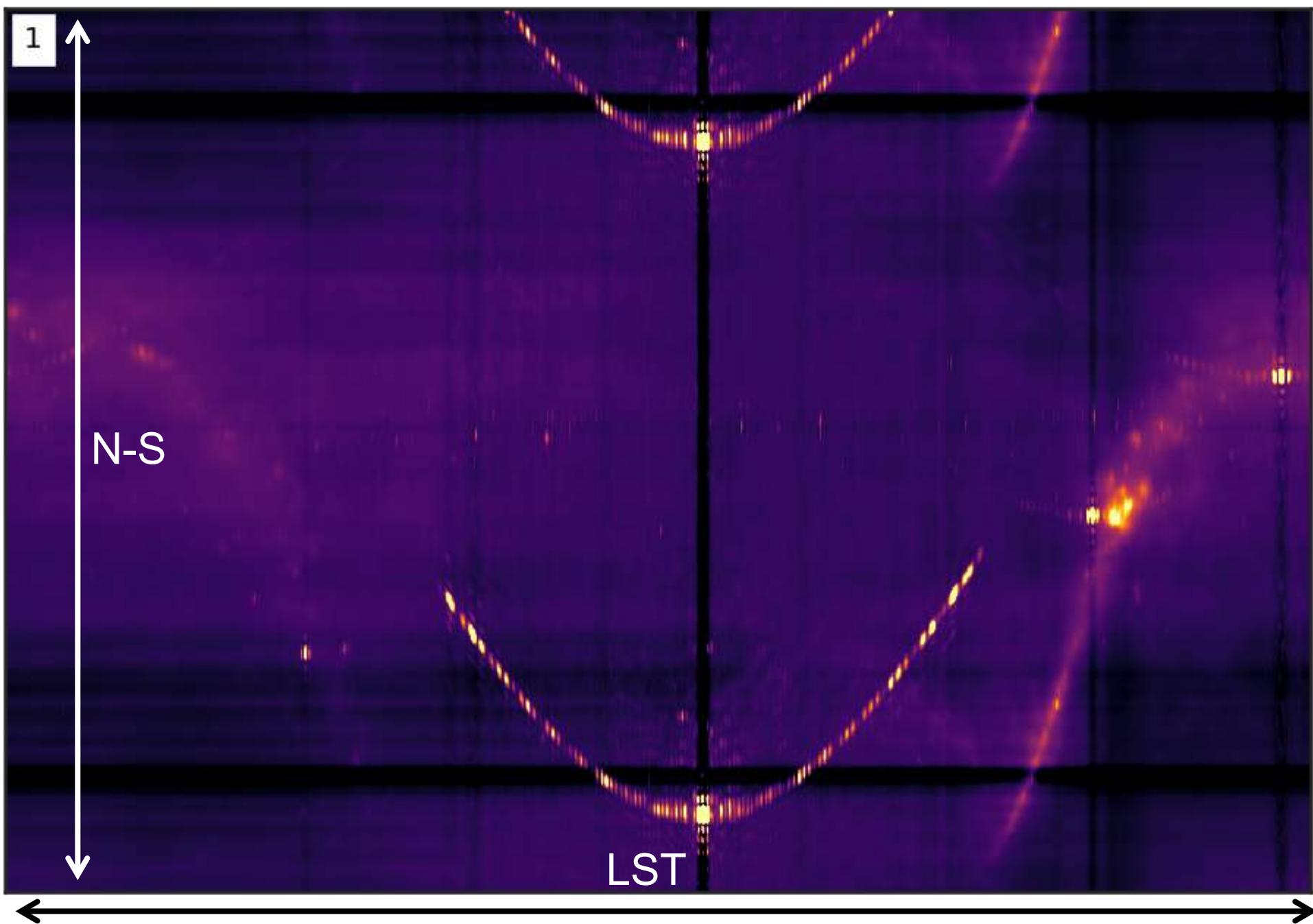
- Indep. Nodes
- Full N^2 corr
- Liquid cooled
- Fits in a SeaCan



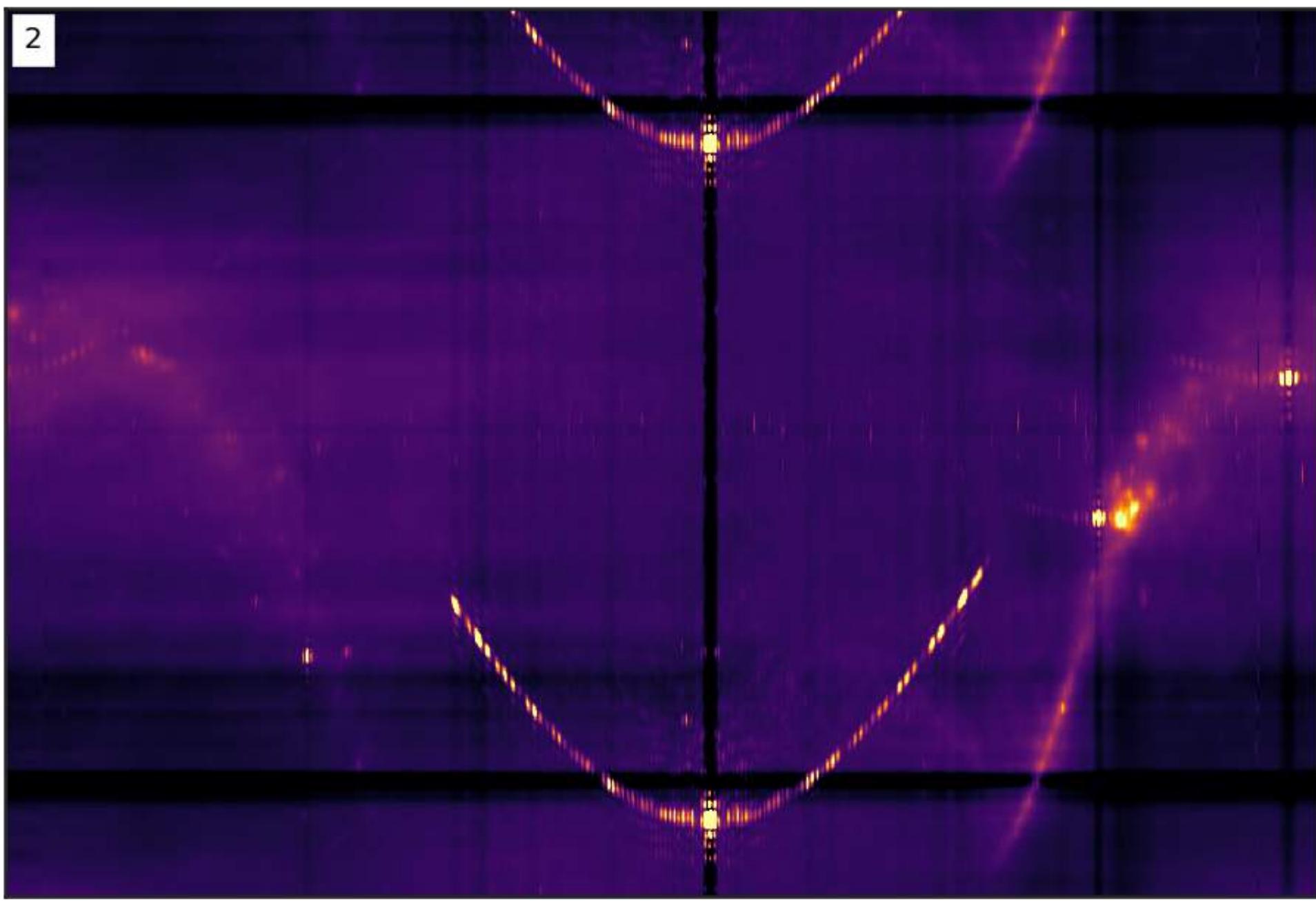
Full $N^2 \approx 10^{15}$ cMAC/s ≈ 8 PFLOP/s

Meanwhile, on the
Pathfinder...

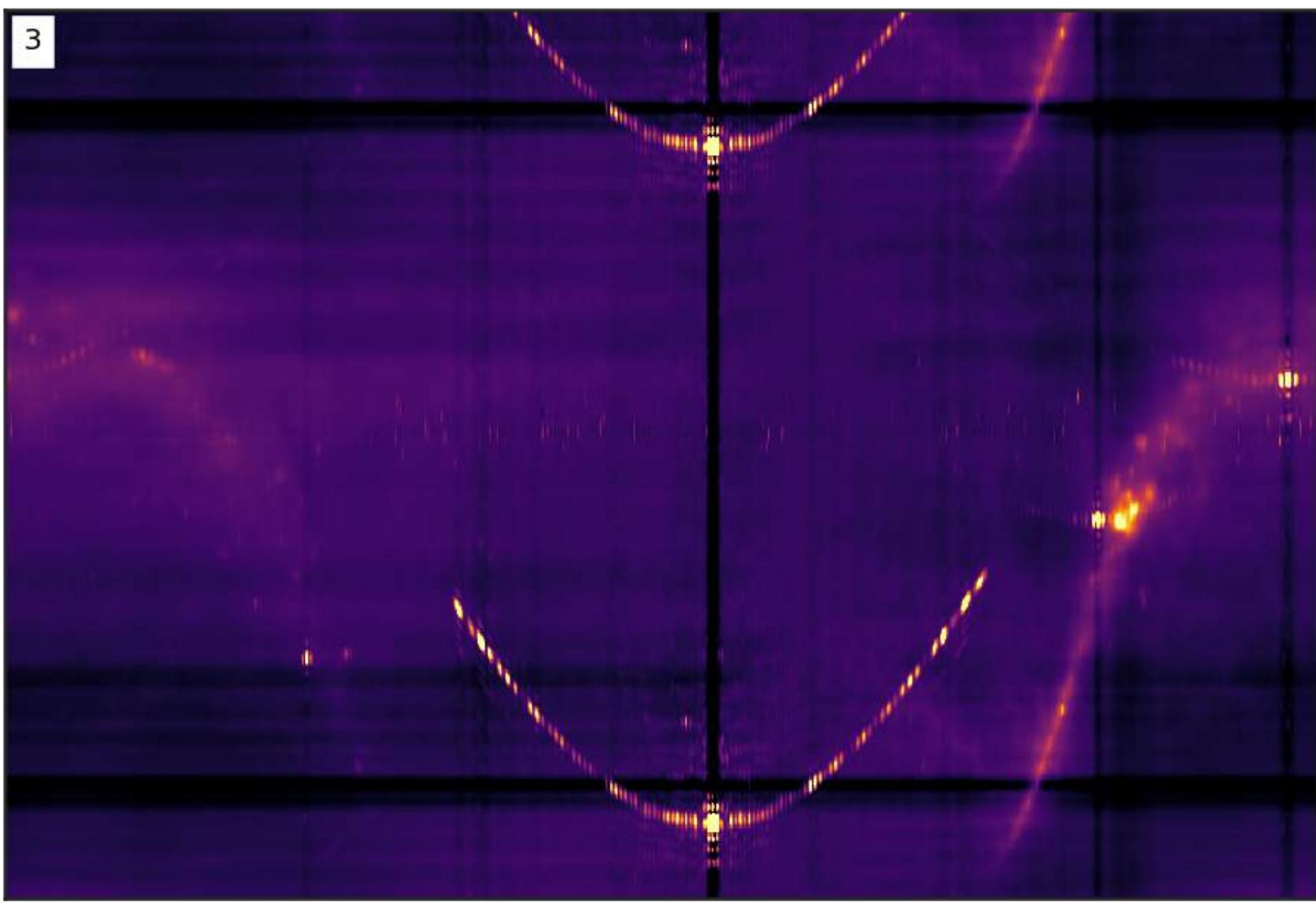




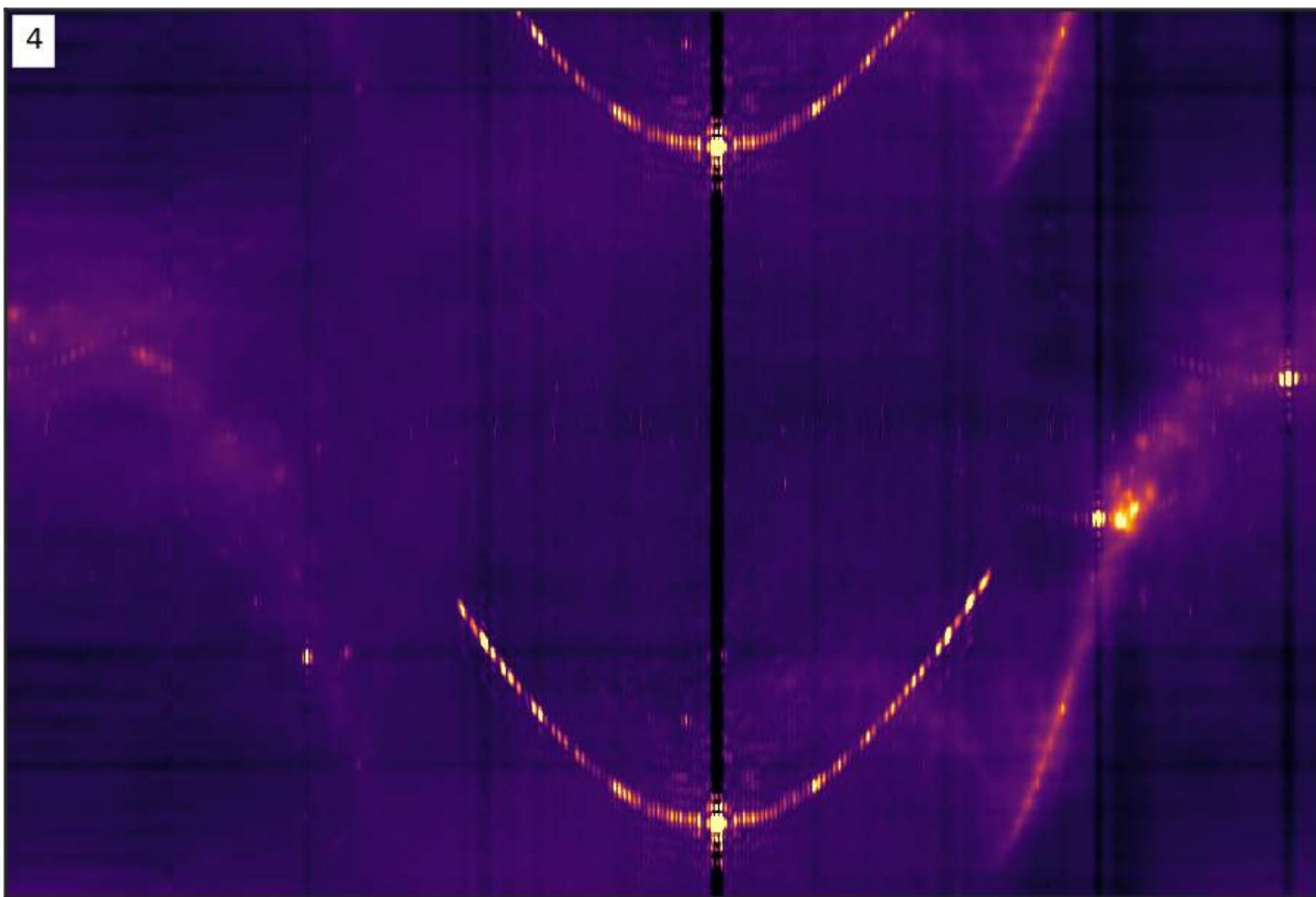
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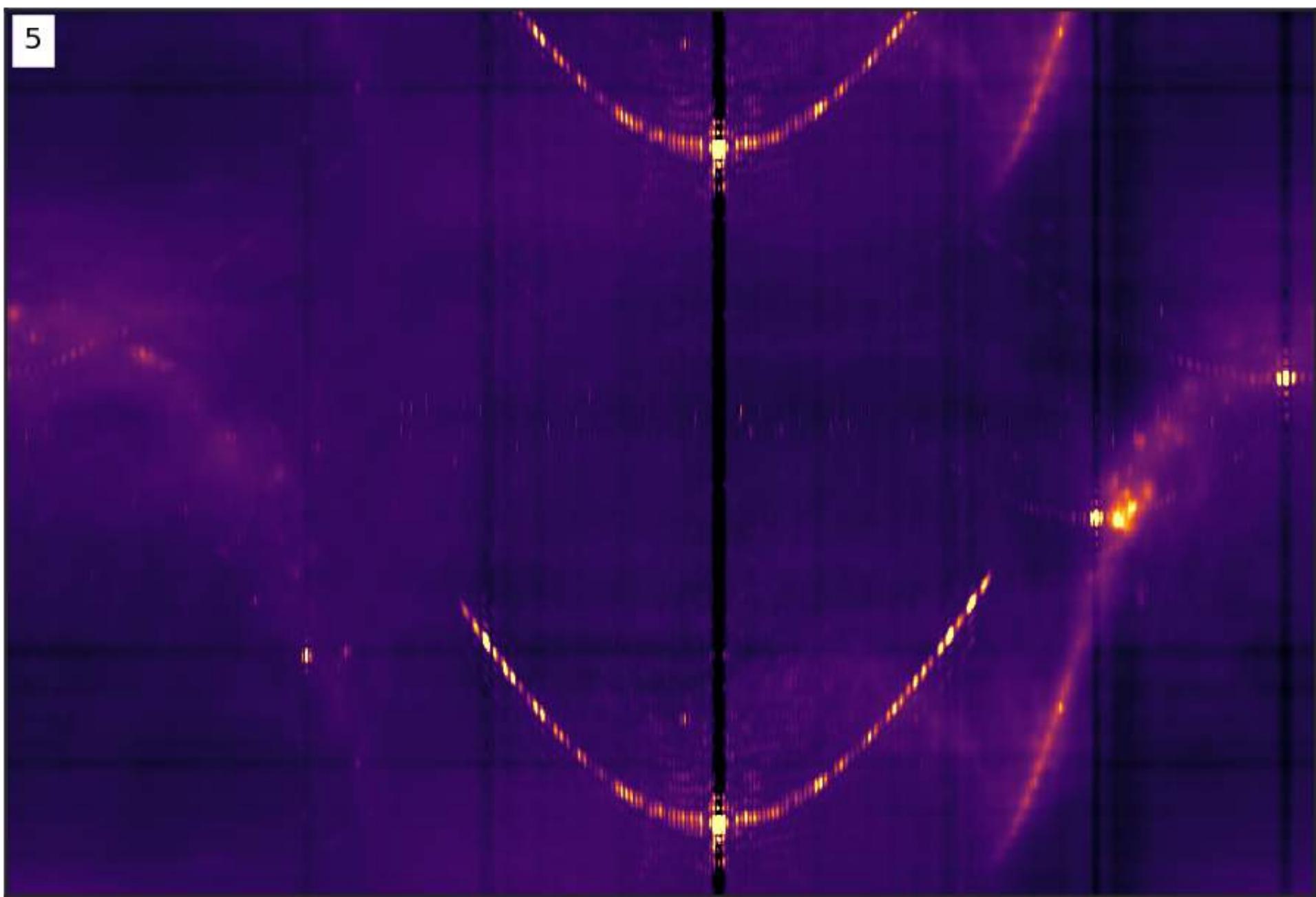
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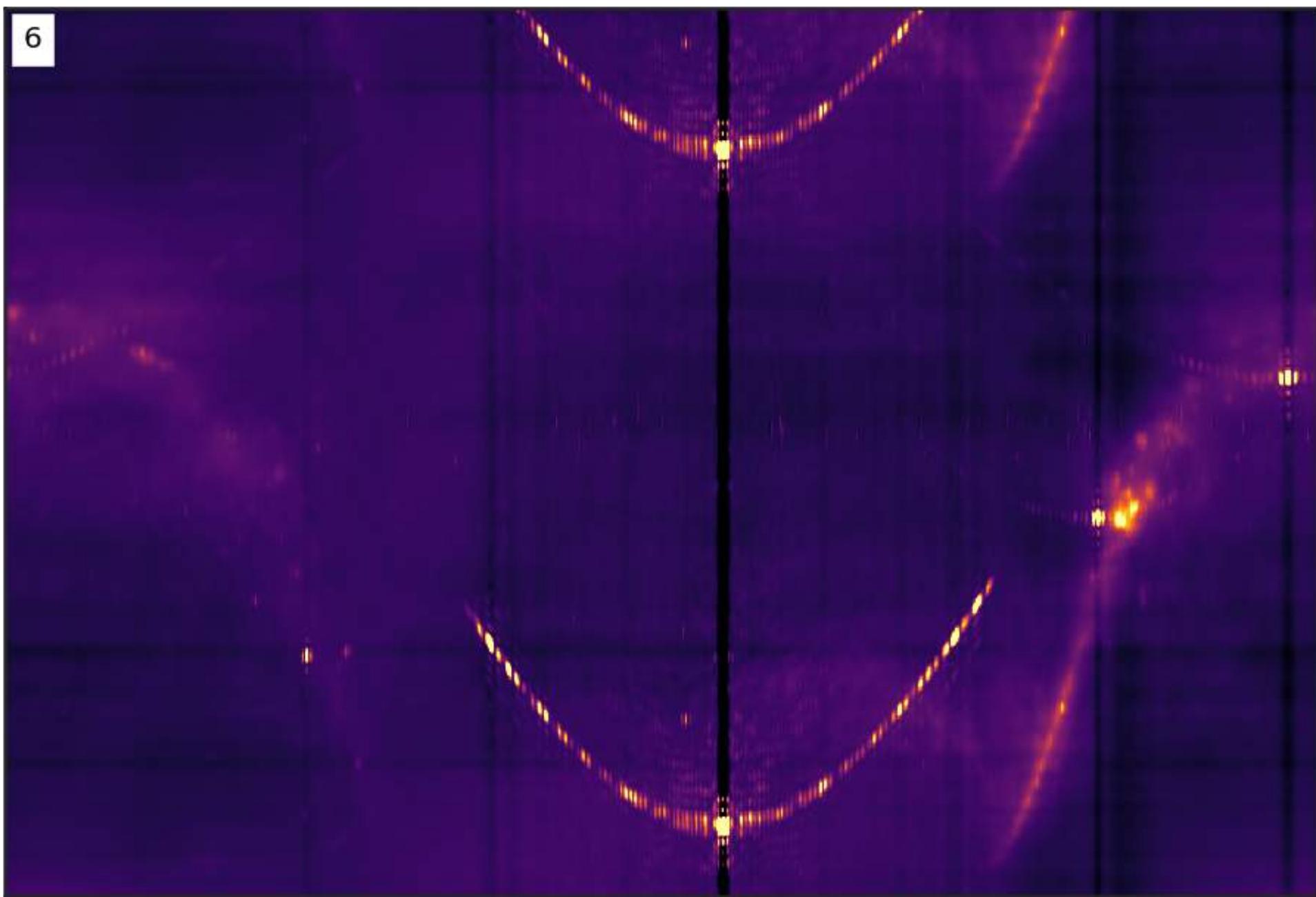
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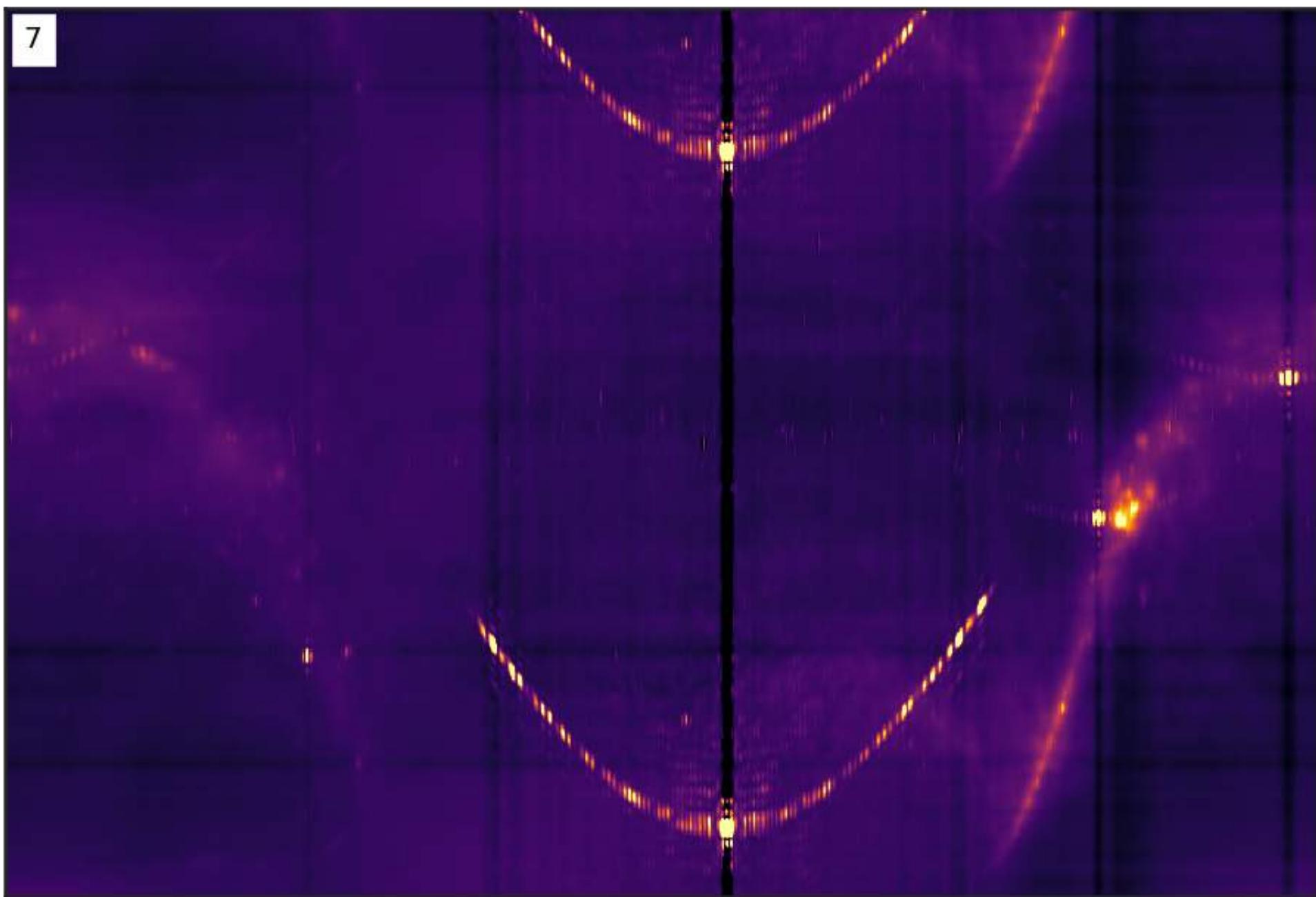
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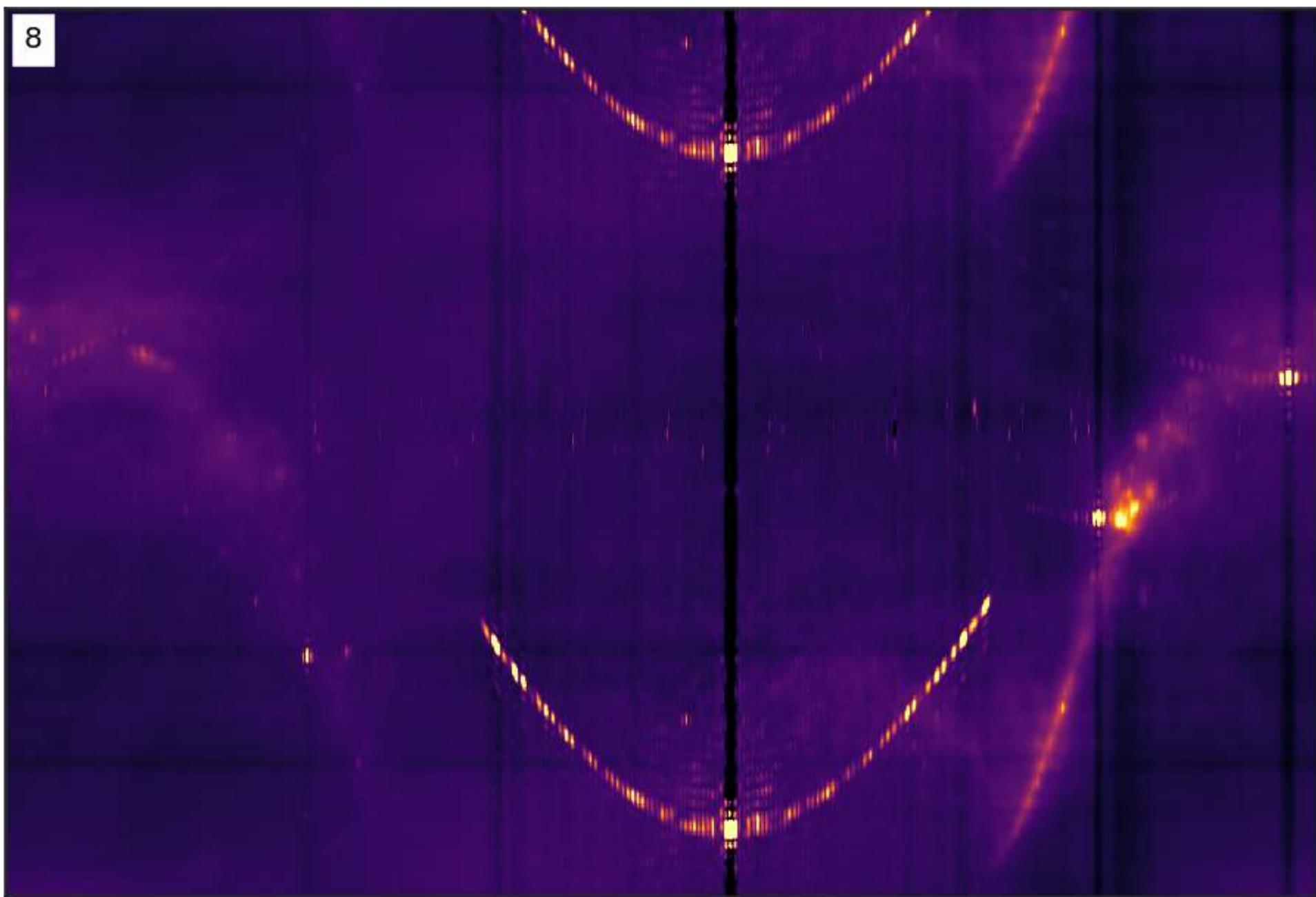
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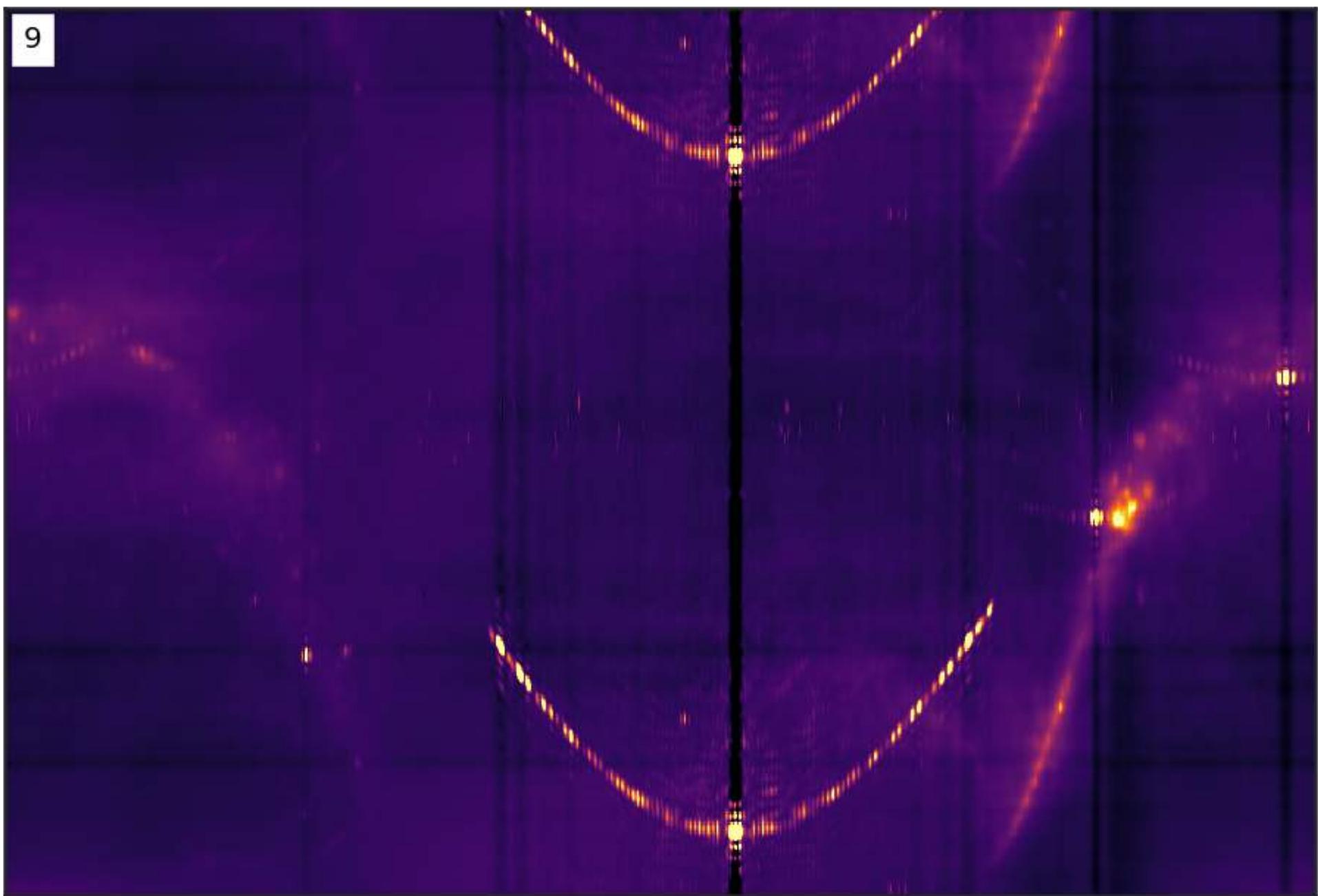
7



8



9



CHIME as a Survey Machine

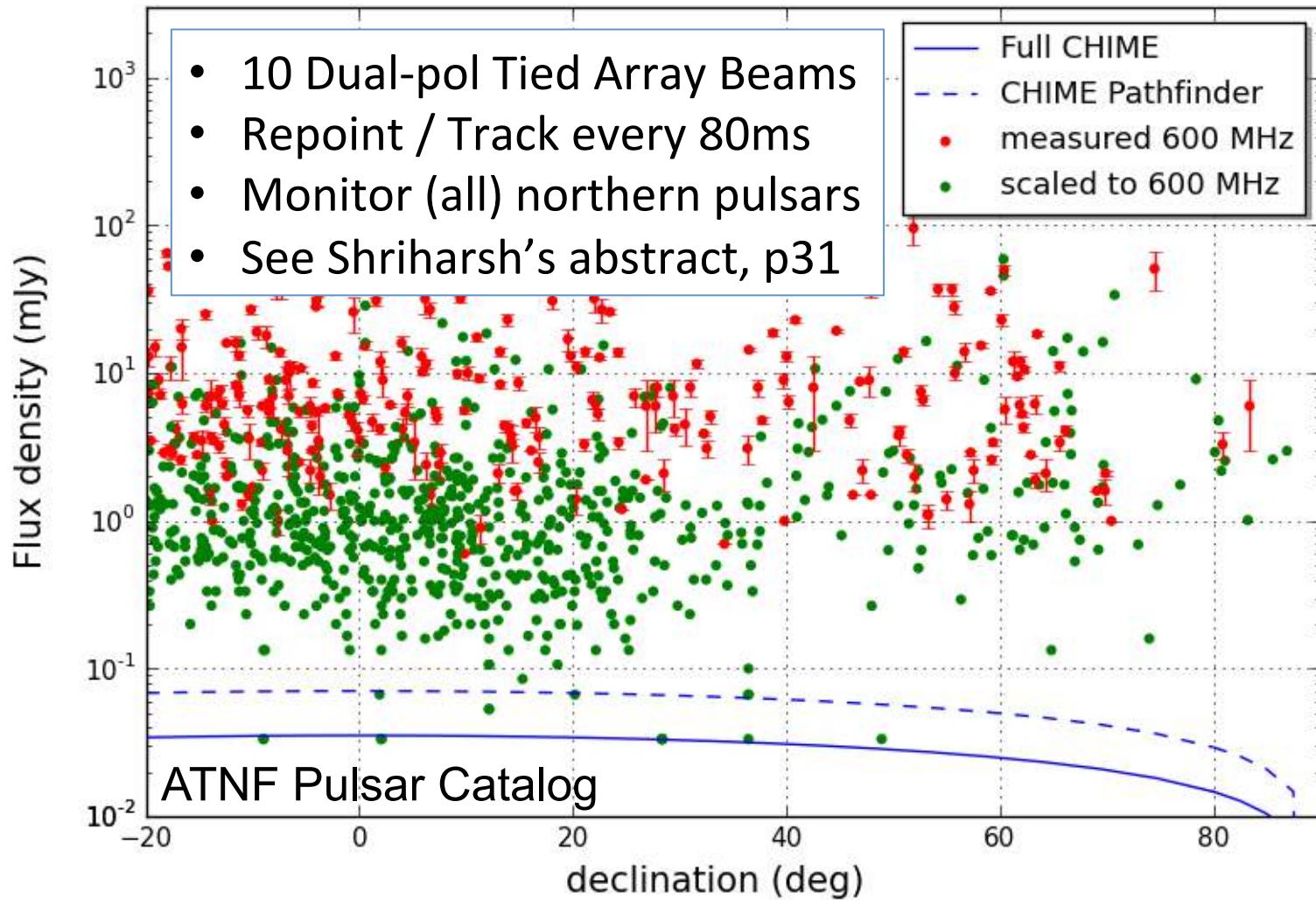
Pros

- 25,000 deg² coverage
- 8,000 m² collecting area
- Few- μ Jy noise floor
- Daily visitation
- 50 μ Jy / day noise
- \approx 250 deg² FoV
- Hugely flexible backend
- Parallel operation
- 0.1% Calibration (spec)

Cons

- Run by cosmologists
- Limited time on target
- Big beams (20-40')
- Still commissioning
- We're busy!

CHIME-Pulsar



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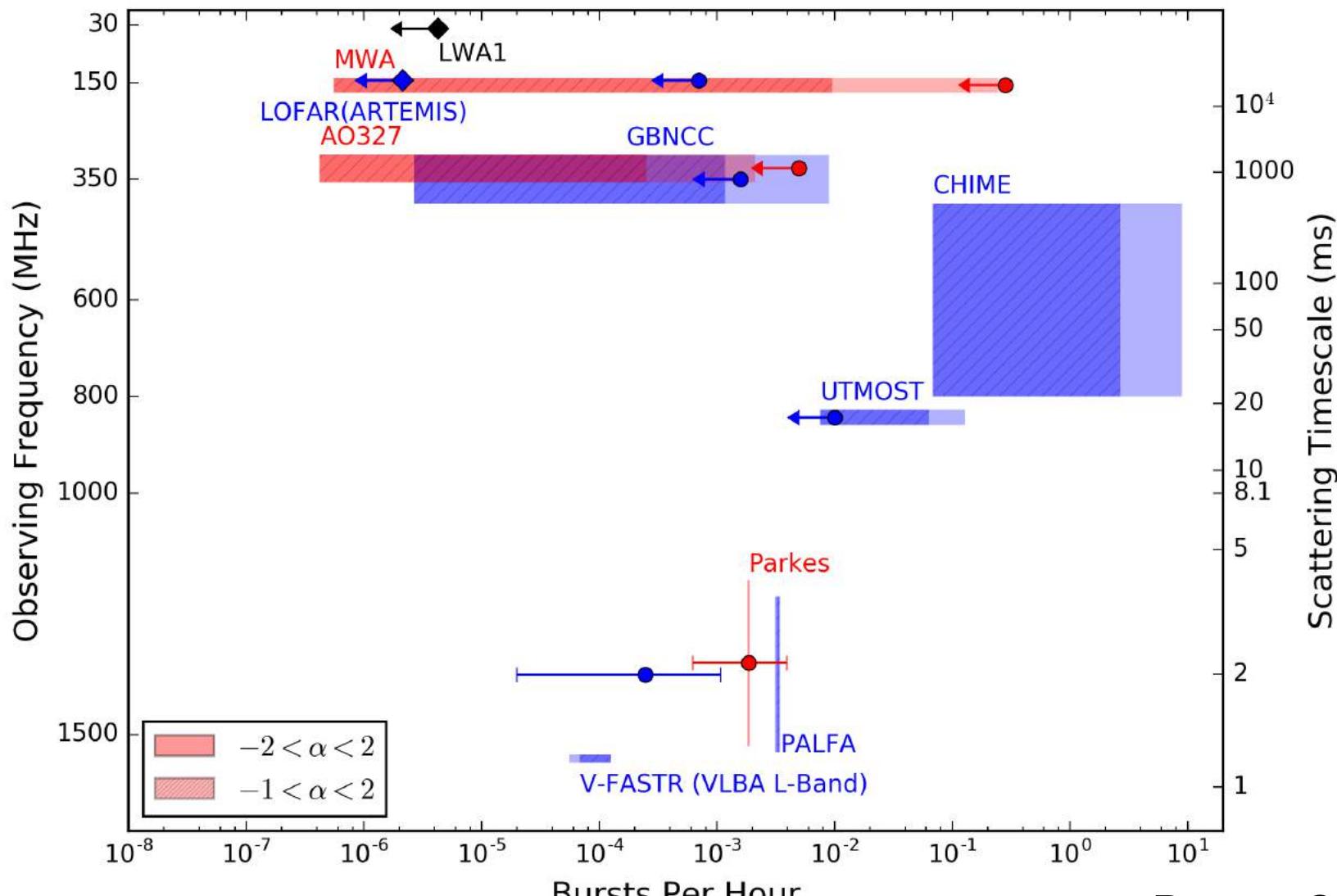
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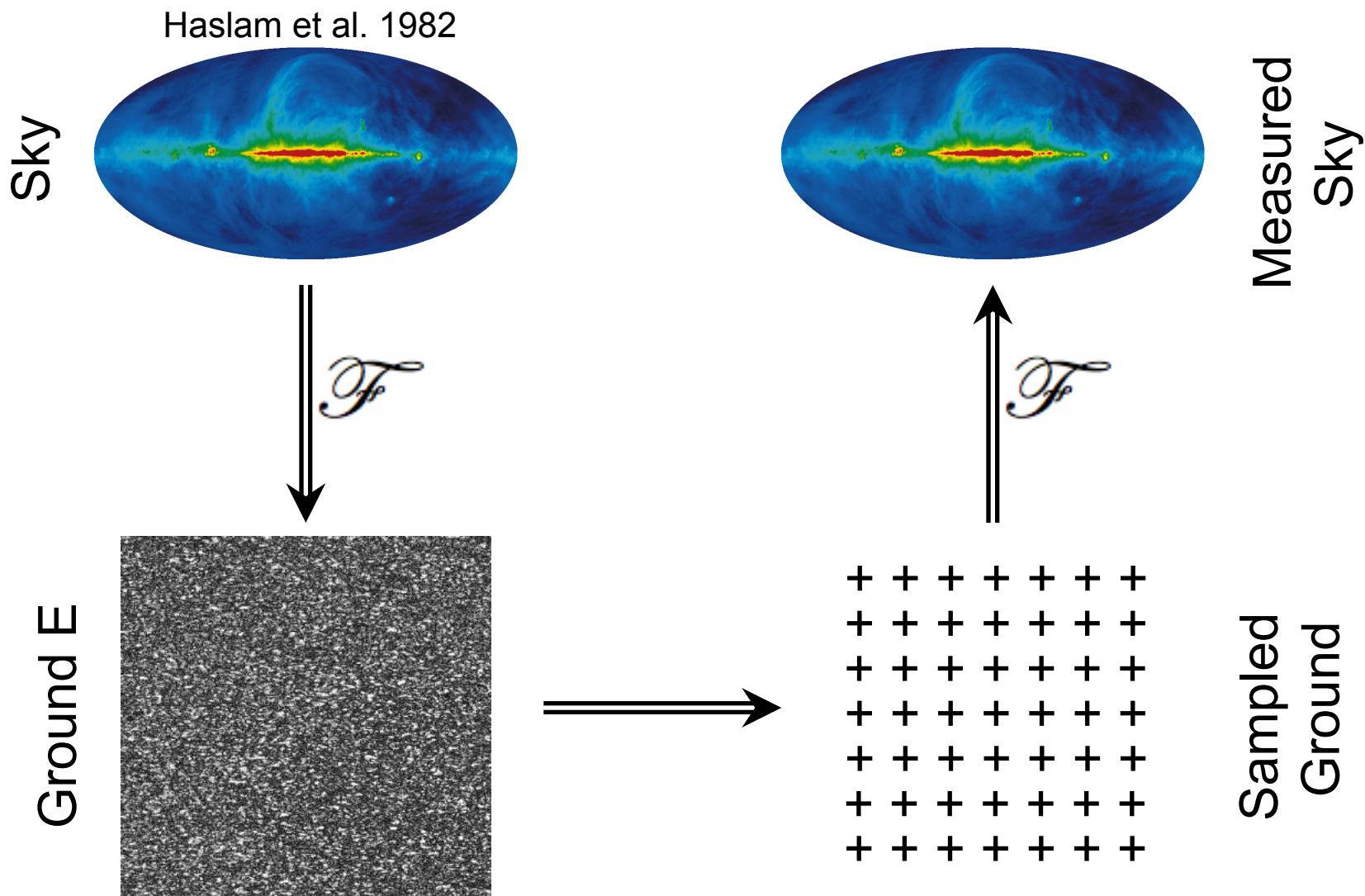
NRC · CRAO

FRB Search?

(Many Unknowns and Caveats)

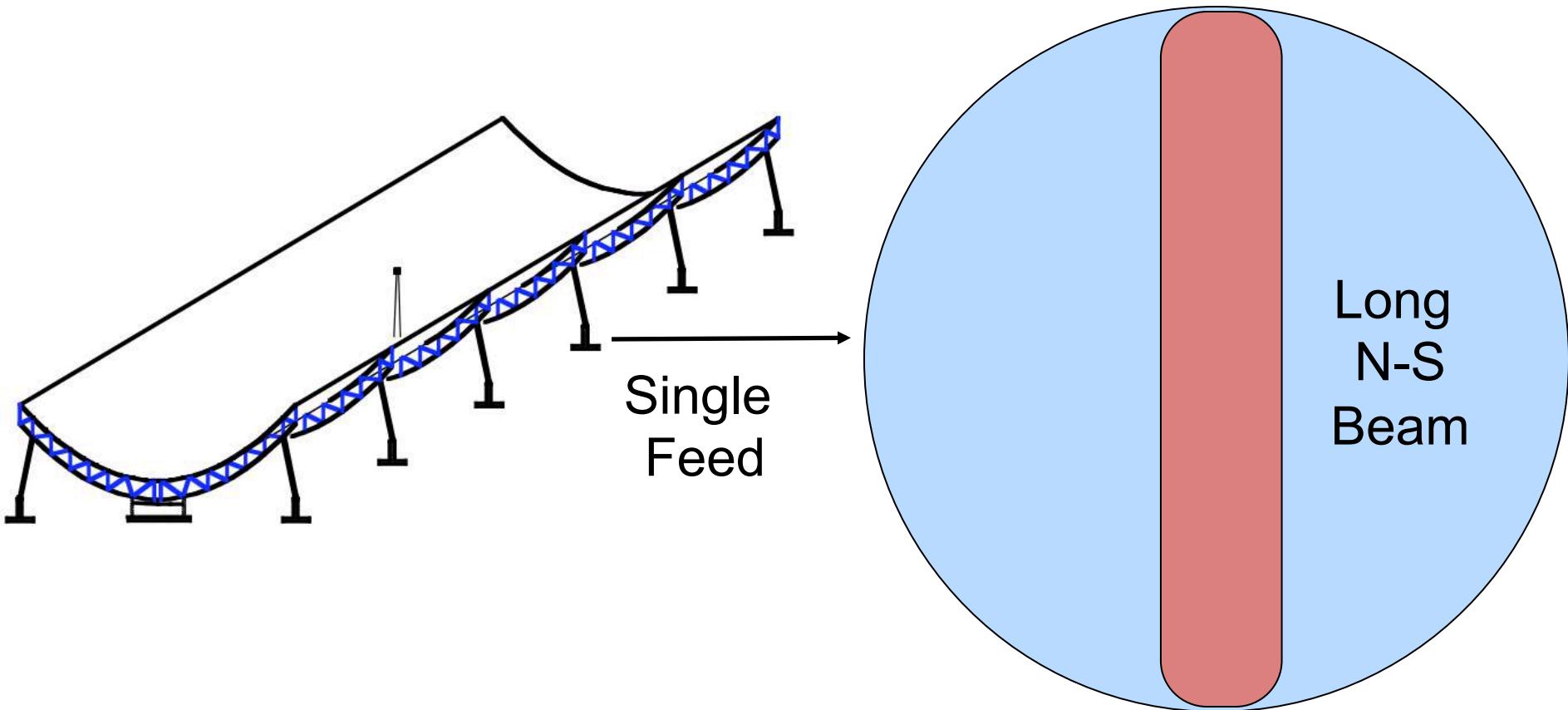


FFT Telescope



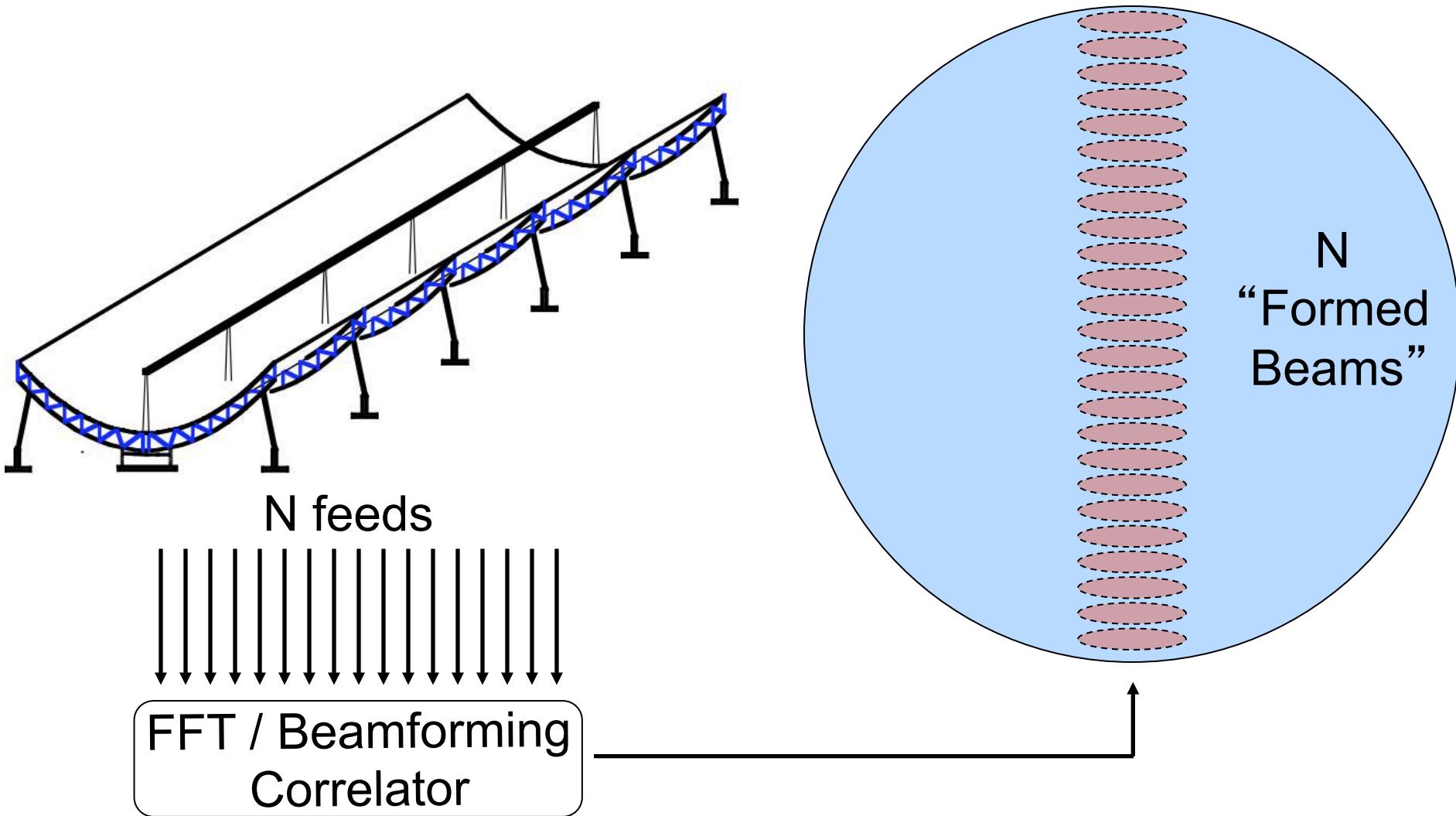
Computational Cost $\sim N \log(N) \sim D^2 \log(D)$

Cylinder Antenna



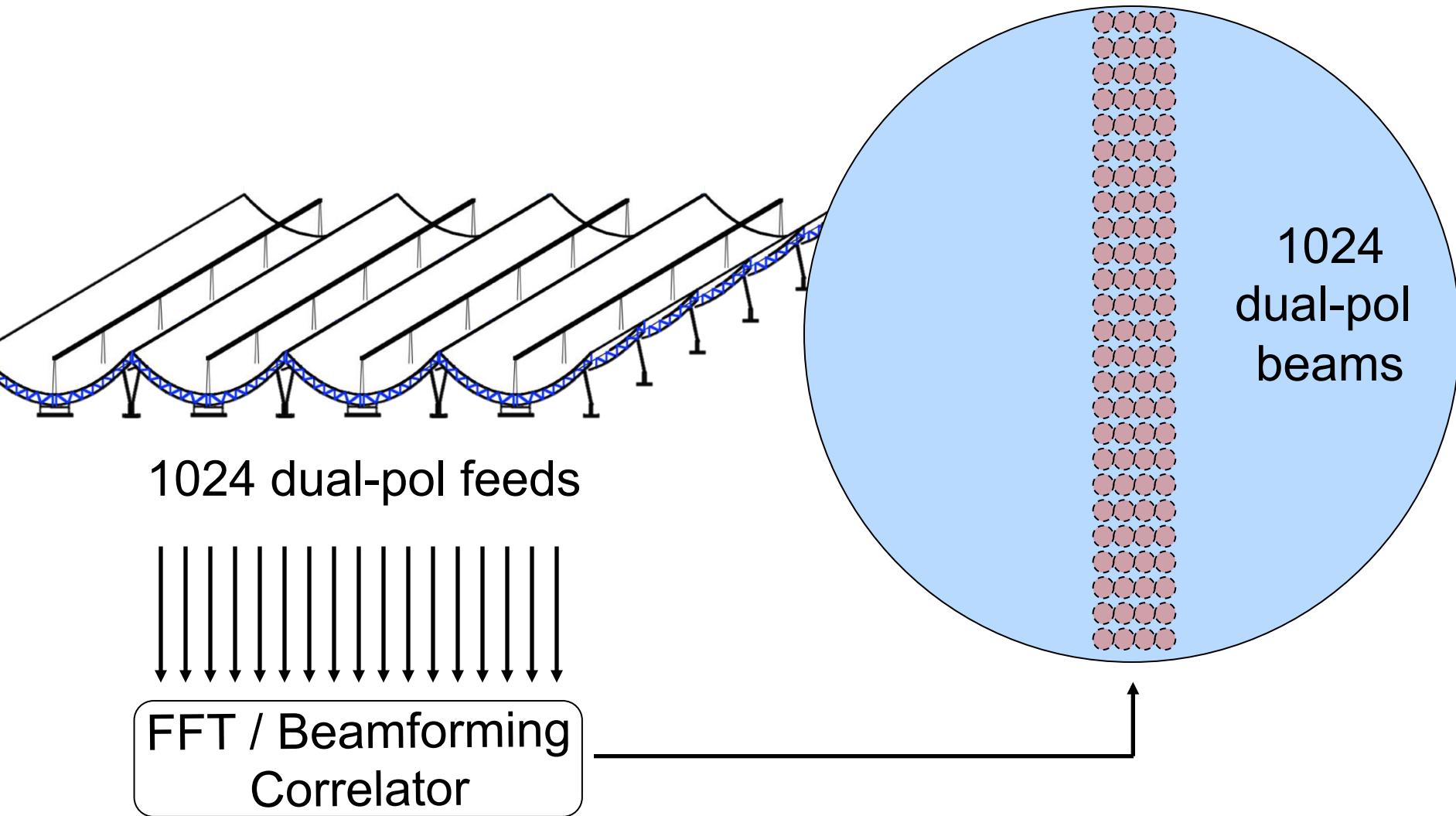
Cylinder Telescope

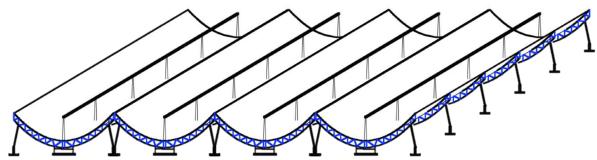
Hybrid: 1D Dish + 1D Interferometry



CHIME

1D Dishes + 2D Interferometry





Reflectors

Growing CHIME

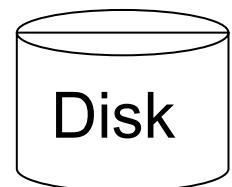
Analog Frontend
Amps, filters, etc

FPGA Digitizer /
Chanelizer

≈TBps

GPU Correlator

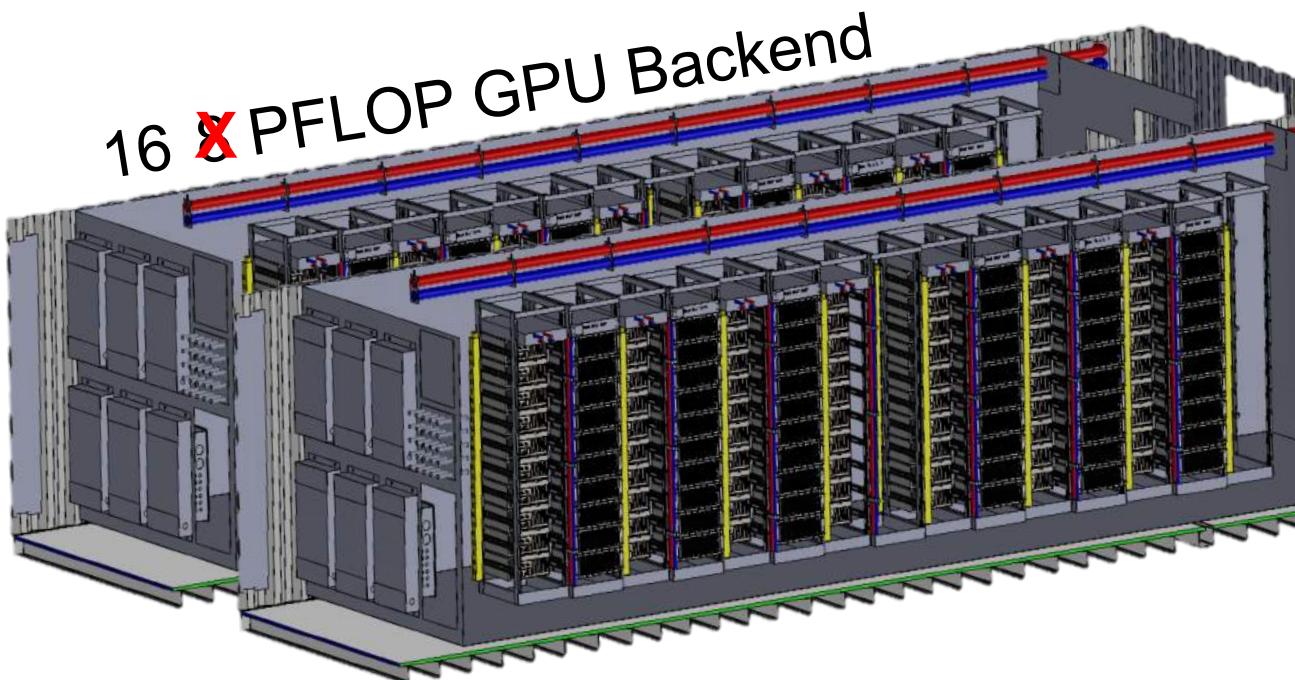
≈GBps



Disk

≈16GBps

Realtime
Backend(s)

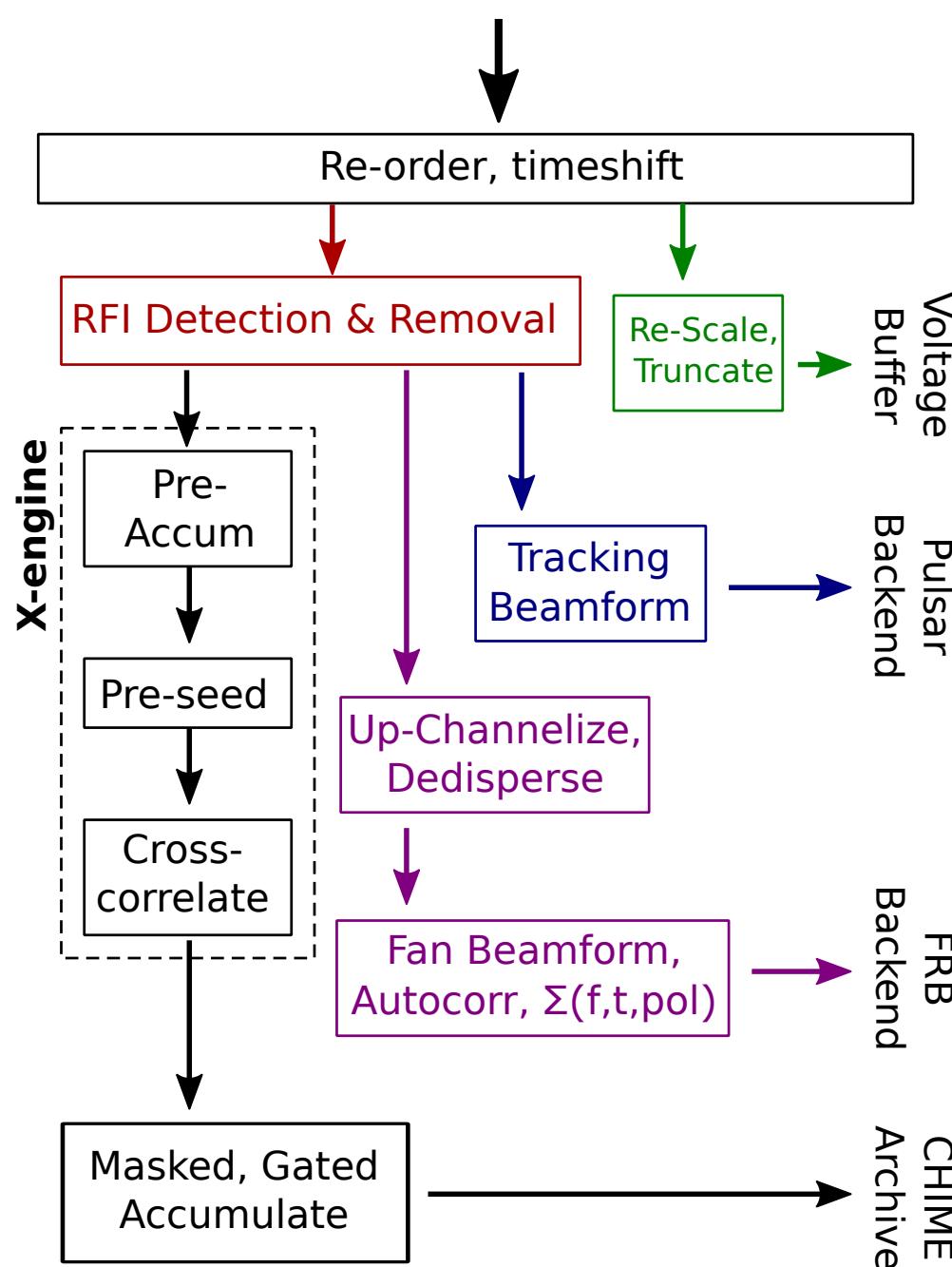


Full N^2 ($\approx 10^{15}$ cMAC/s = 8 PFLOP/s)
+ 10 Tied-array Coherent Beams
+ 1024 Fan beams @ 24kHz, 1ms

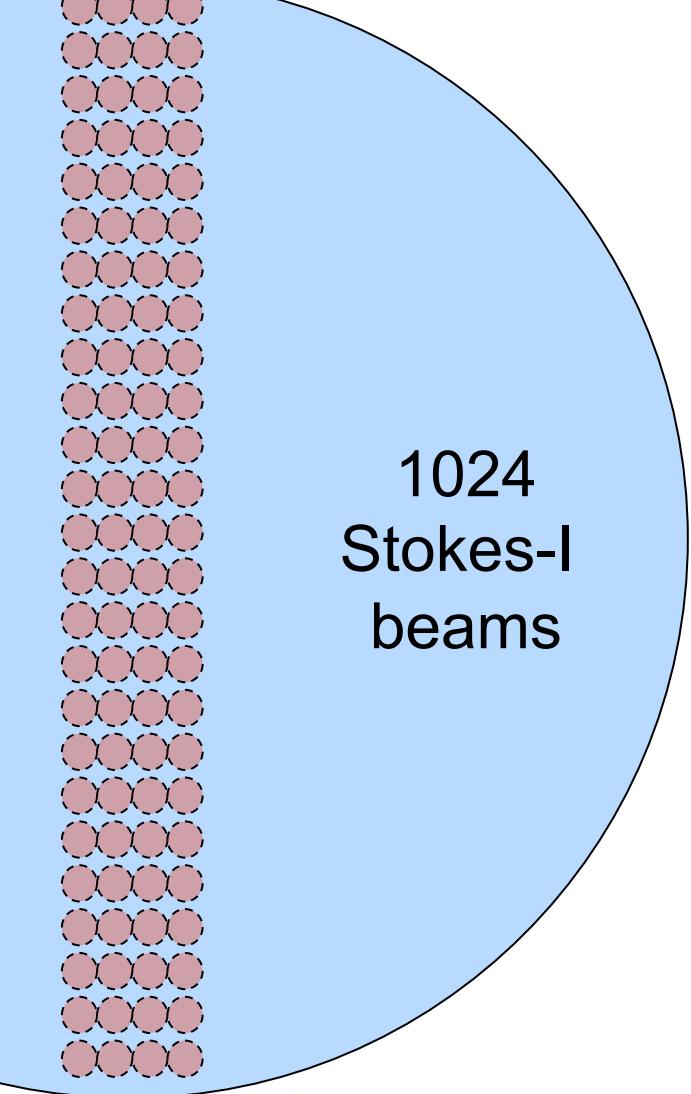
GPU

Processing

- Lots to be done in GPU, both CHIME and L0.
- Fully Implemented in lab
- Fan Beamform, Baseband not yet on sky



CHIME-FRB



1024
Stokes-I
beams

Siphon off data stream of:

- 1024 FFT/Fan Beams
- Stokes-I, $\Delta\tau=1\text{ms}$, $\Delta\nu=24\text{kHz}$
- $8,000\text{m}^2$ collecting area
- 400-800MHz bandwidth

Feed into search cluster, search
everywhere in CHIME, always.



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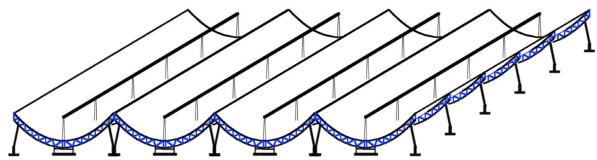


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Reflectors



Analog Frontend
Amps, filters, etc



FPGA Digitizer /
Channelizer



GPU Correlator



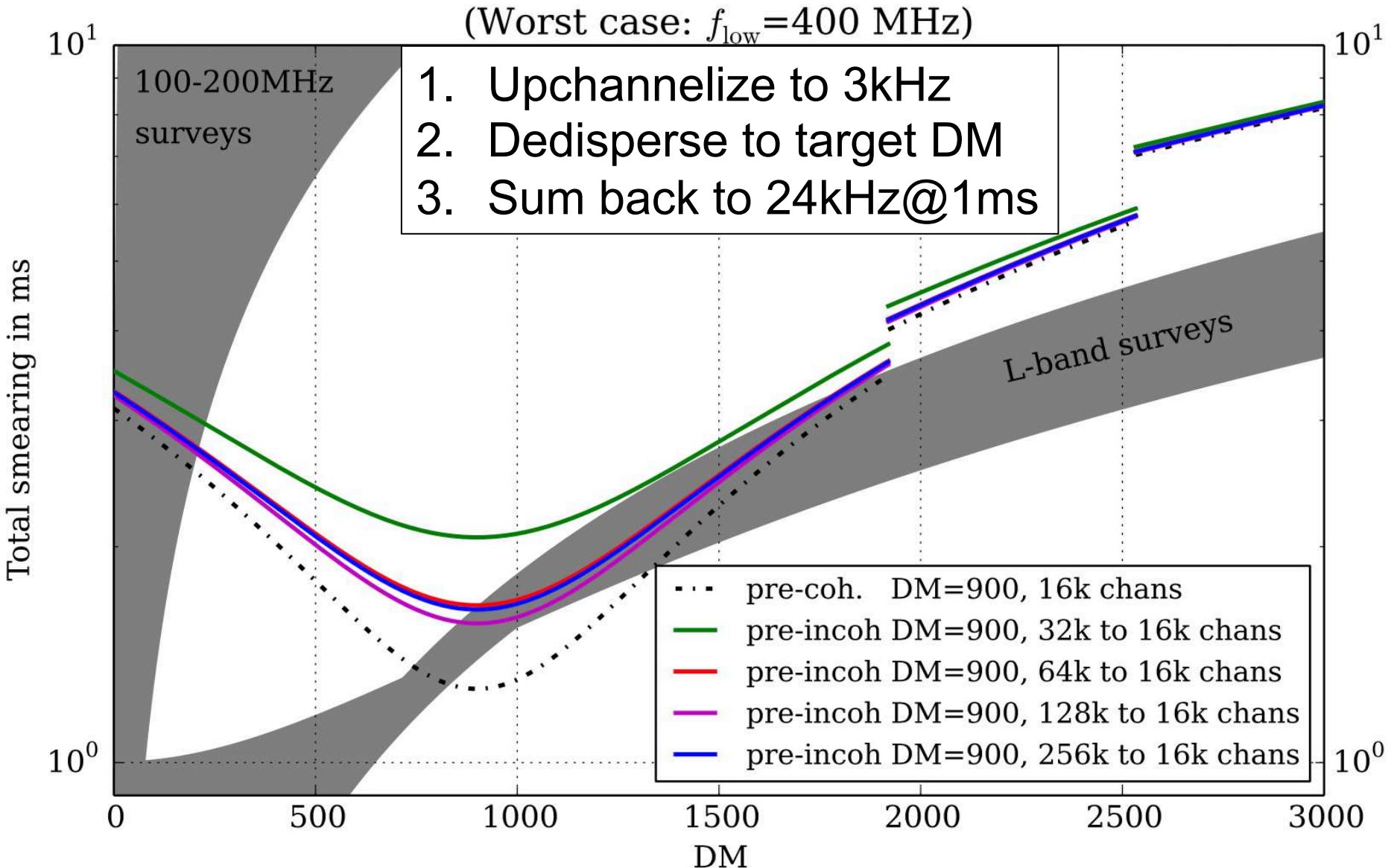
FRB Search
Engine

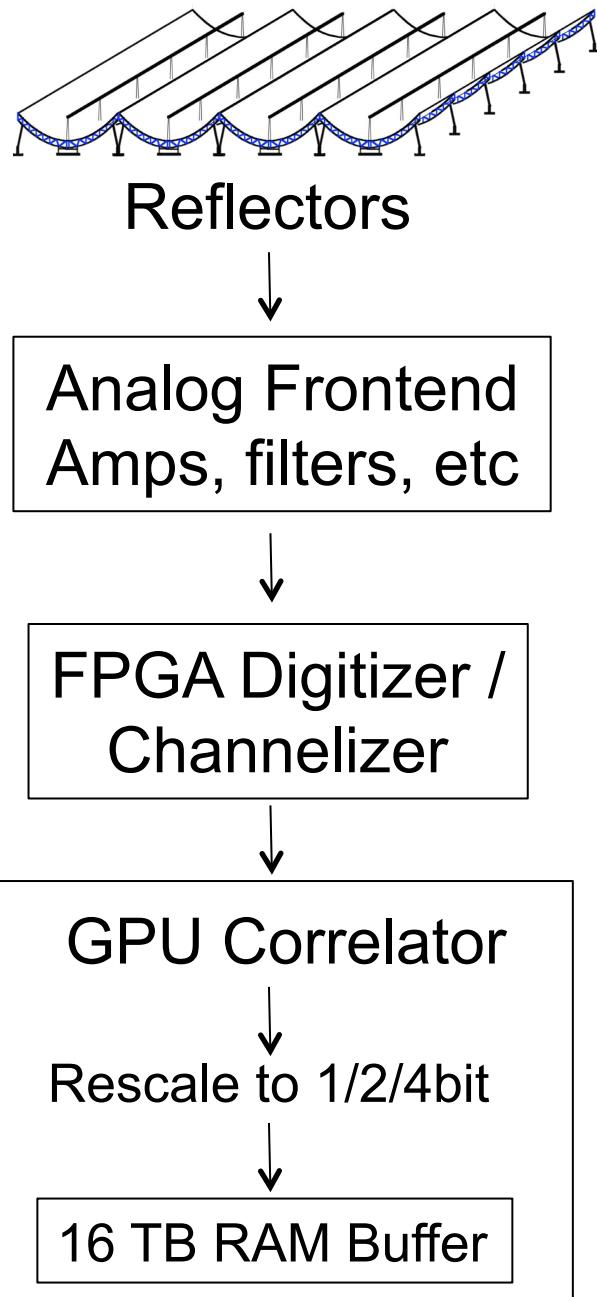
Searching a Beast

- Naïvely, very expensive to search 1024 beams over 400MHz to high DM, across α , W, ...
- Tree-dedispersion, $>10^4$ DMs
 - Last-stage fan-out: DM, Spectral Index, Scattering Tail, Pulse profile, ...
 - Extremely low latency, ≈ 2 s
- Multiple Levels of Proc & Triggers
 - L0 Beamform
 - L1 Tree Dedispersion & Peak Search
 - L2 Group & Sift

Pre-Dedispersion

In-band smearing significant at 400MHz!





Baseband Buffer

- $DM=10,000 \rightarrow \Delta t \approx \text{mins!}$
- Rescale kernel converts to 1/2/4-bit voltages
- Buffer 20/40/80s full dual-pol complex samples
- Reprocess events offline: pol'n, position, ... (VLBI?)

DRAO, Pathfinder



GPU & FRB Seacans

Receiver Seacans

The End

Exciting things in the next year...

