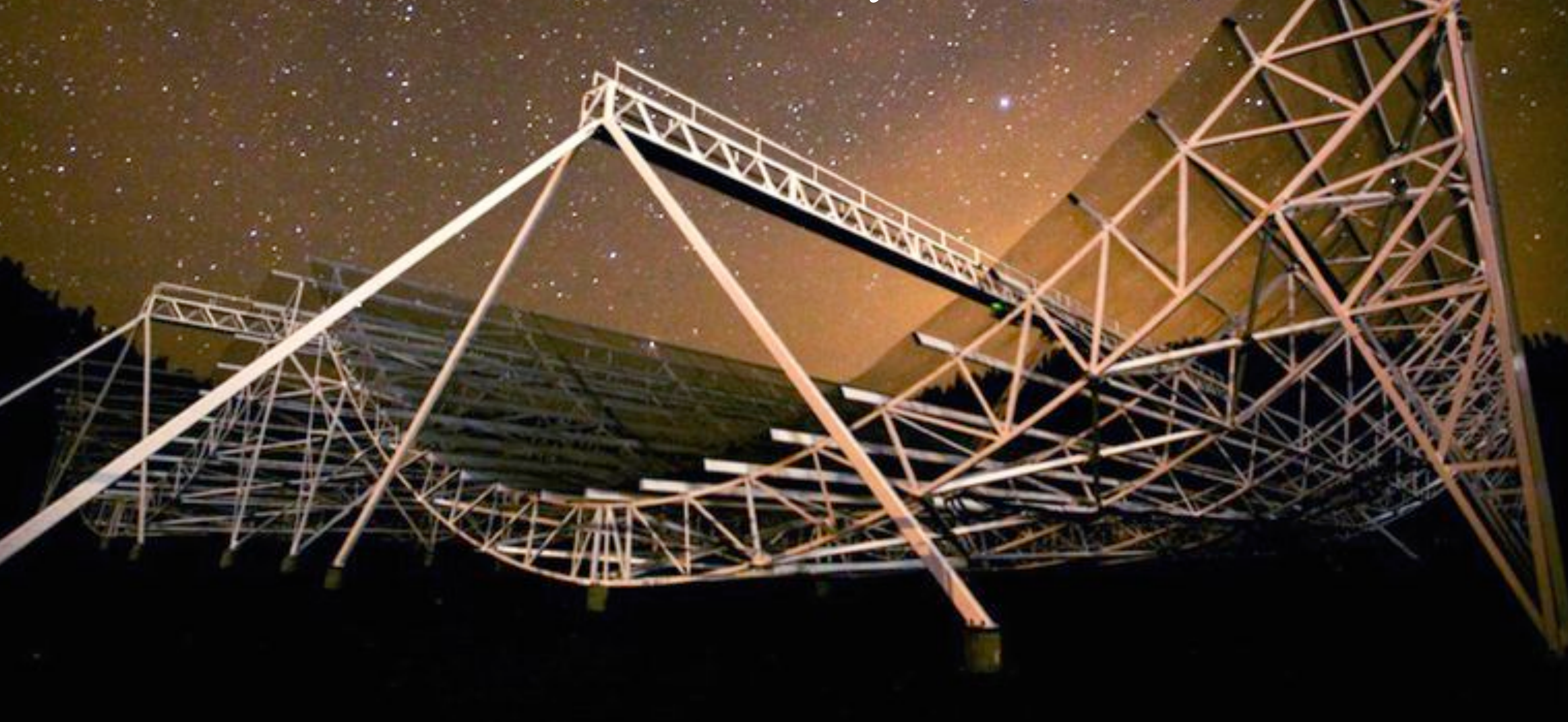
CHIME: The Canadian Hydrogen Intensity Mapping Experiment

Kendrick Smith (Perimeter Institute)

LBNL, February 2019



CHIME collaboration

Lead institutions:

+ Smaller teams at these institutions:

CHIME telescope

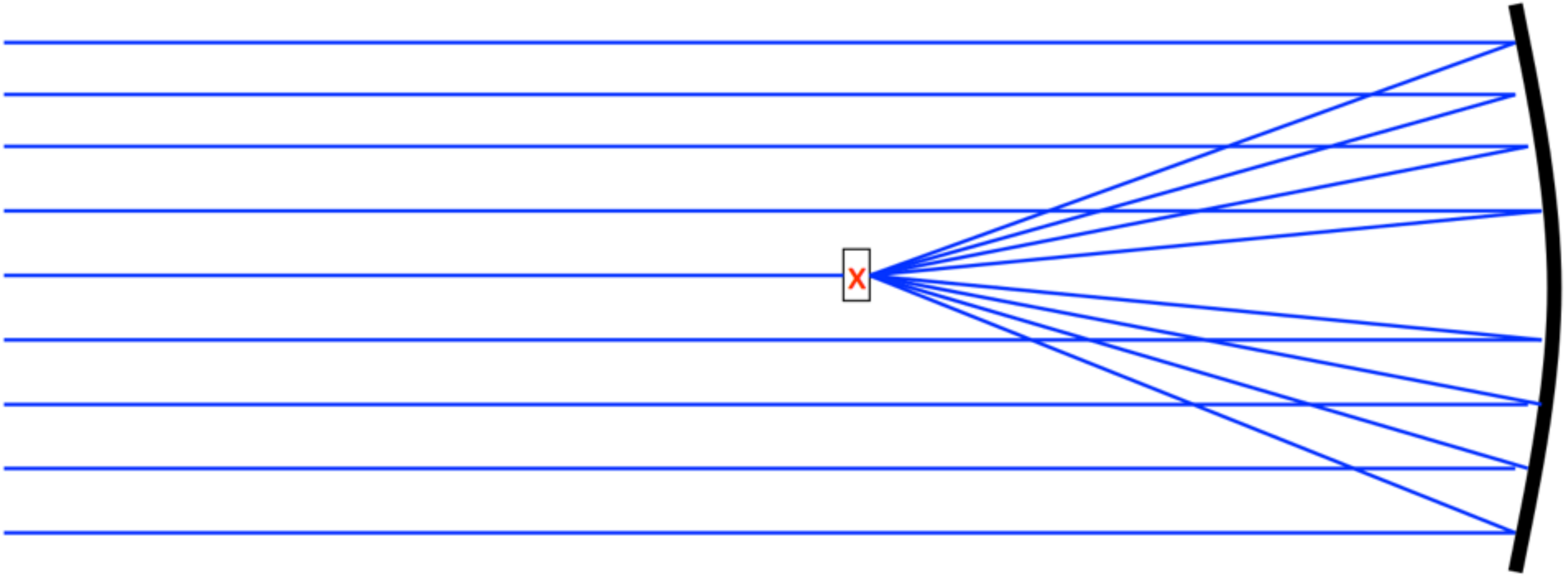
- In British Columbia (at DRAO). First new Canadian research telescope in several decades!
- Compact interferometer with no moving parts, uses Earth rotation to survey sky.
- Four cylinders, (4 x 256) dual-polarization feeds, total collecting area $(80\ \mathrm{m})^2$.
- Frequency range 400-800 MHz. Selected for 21-cm cosmology in redshift range $0.8 < z < 2.5$.

1. The CHIME concept
2. CHIME science goals
3. Challenges
4. The real-time CHIME FRB pipeline
5. Recent CHIME FRB results
6. Concluding thoughts

CHIME

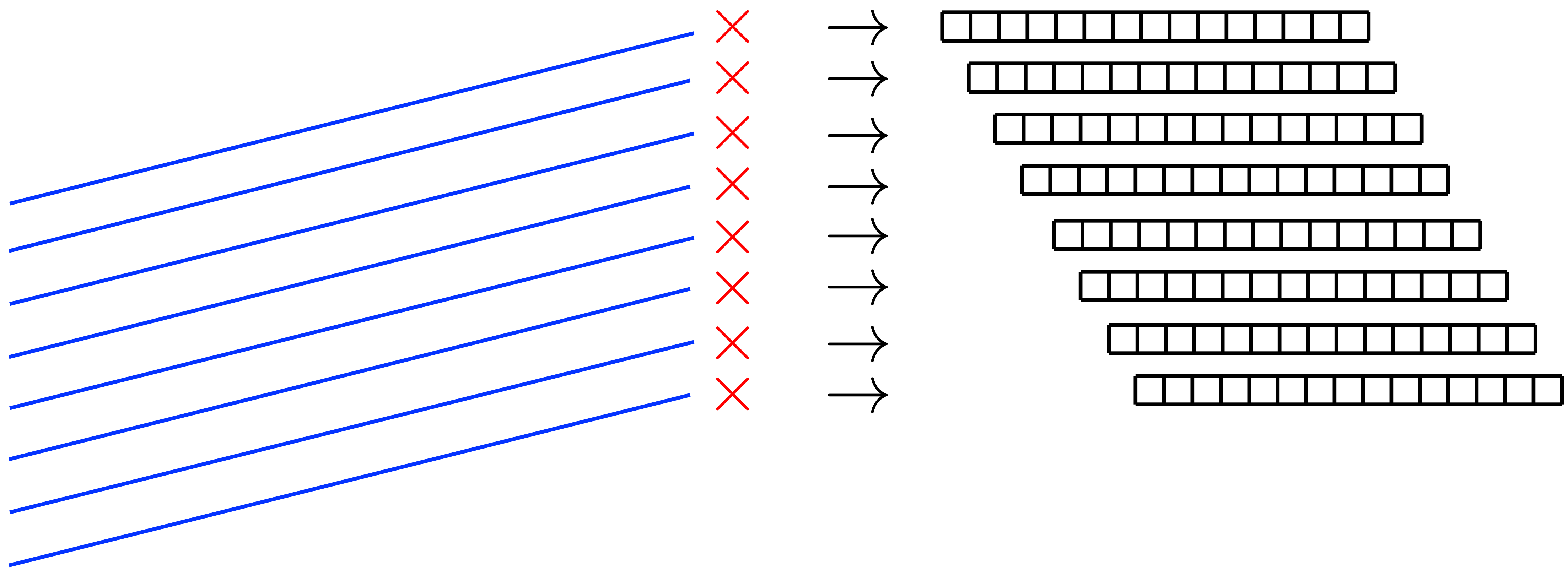
Traditional radio telescope

Single-feed radio telescope



Focuses via physical delays: constructive interference only occurs for a specific direction on the sky

Phased-array interferometer

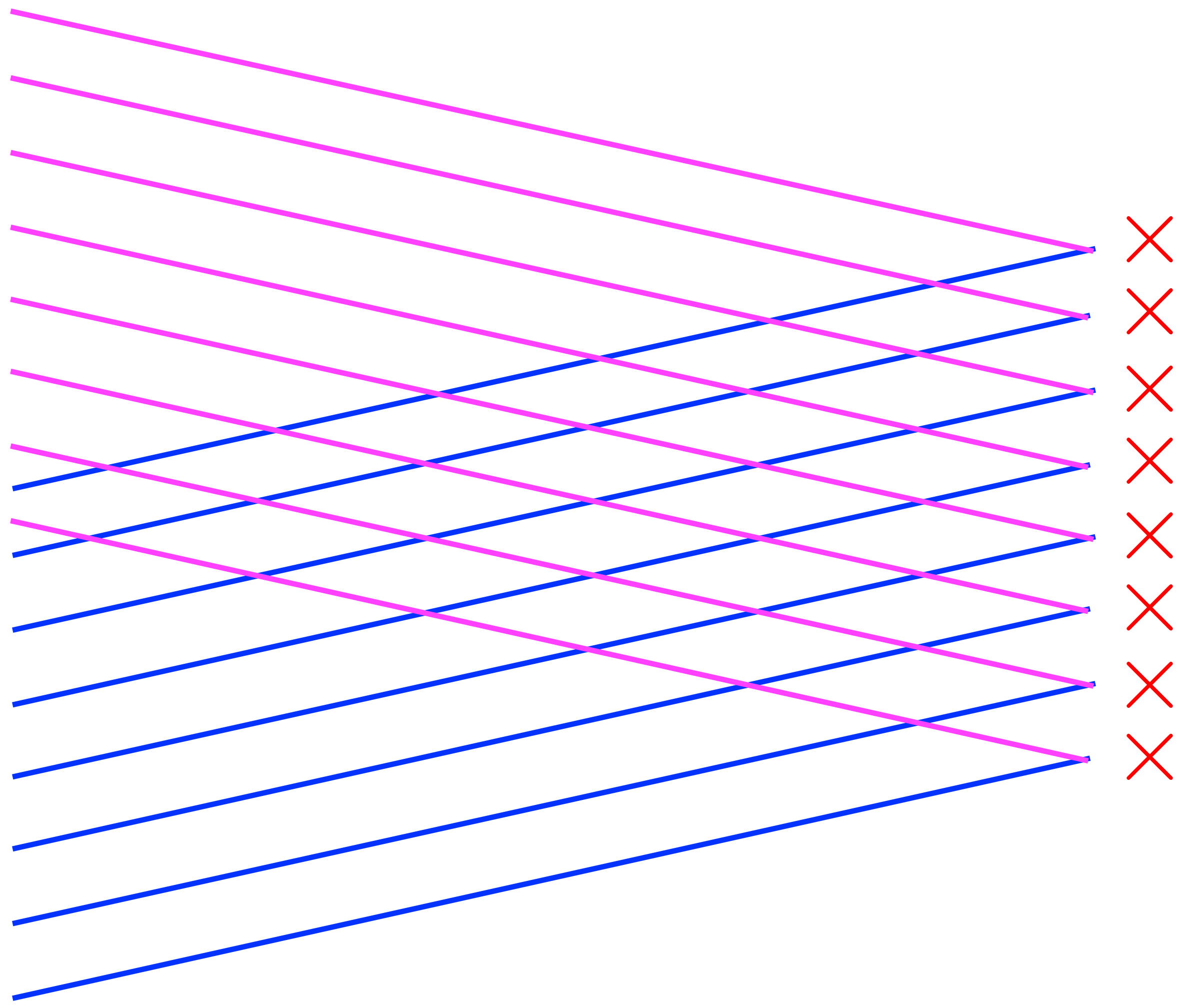


Dish is replaced by an array of antennas whose signals are digitized.

By summing signals with appropriate delays, can simulate the dish in software, and focus on part of the sky.

Can "repoint" telescope by changing delays.

Beamforming interferometer



Copy the digitized signals and repeat the computation N times (in parallel). Equivalent to N telescopes pointed in different directions.

CHIME

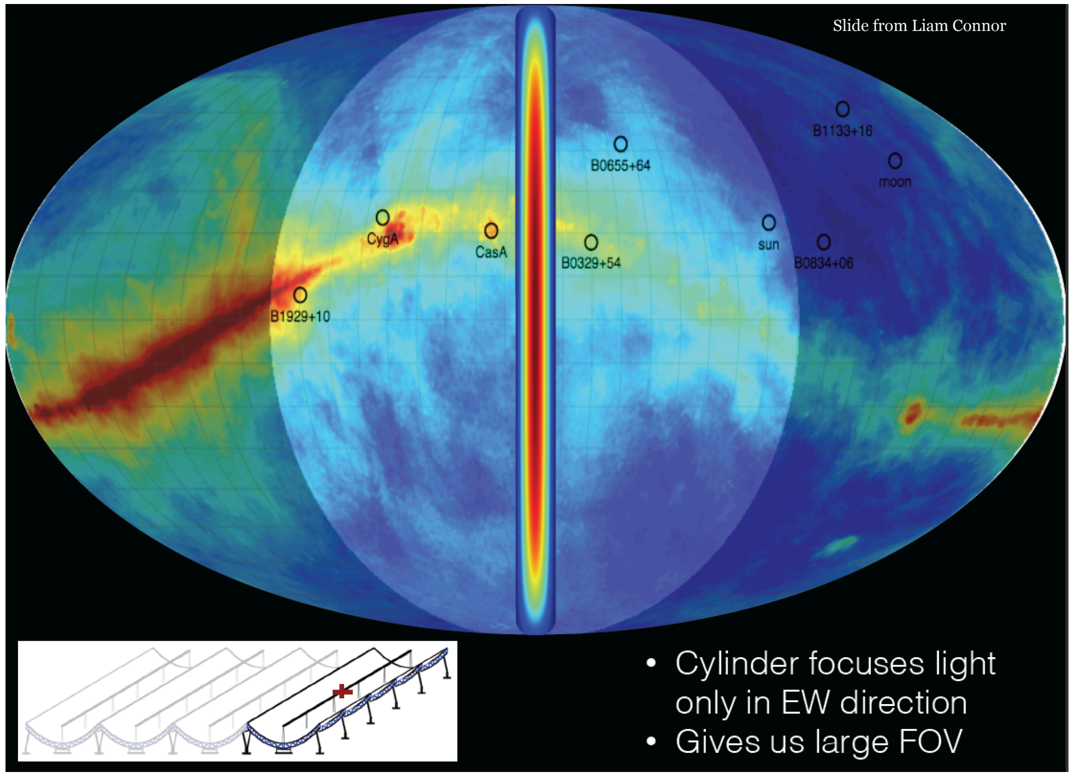
- CHIME has a 4 x 256 array of antennas and can form all 1024 independent beams in real time. Raw sensitivity is the same as 1024 single-feed radio telescopes!

80m

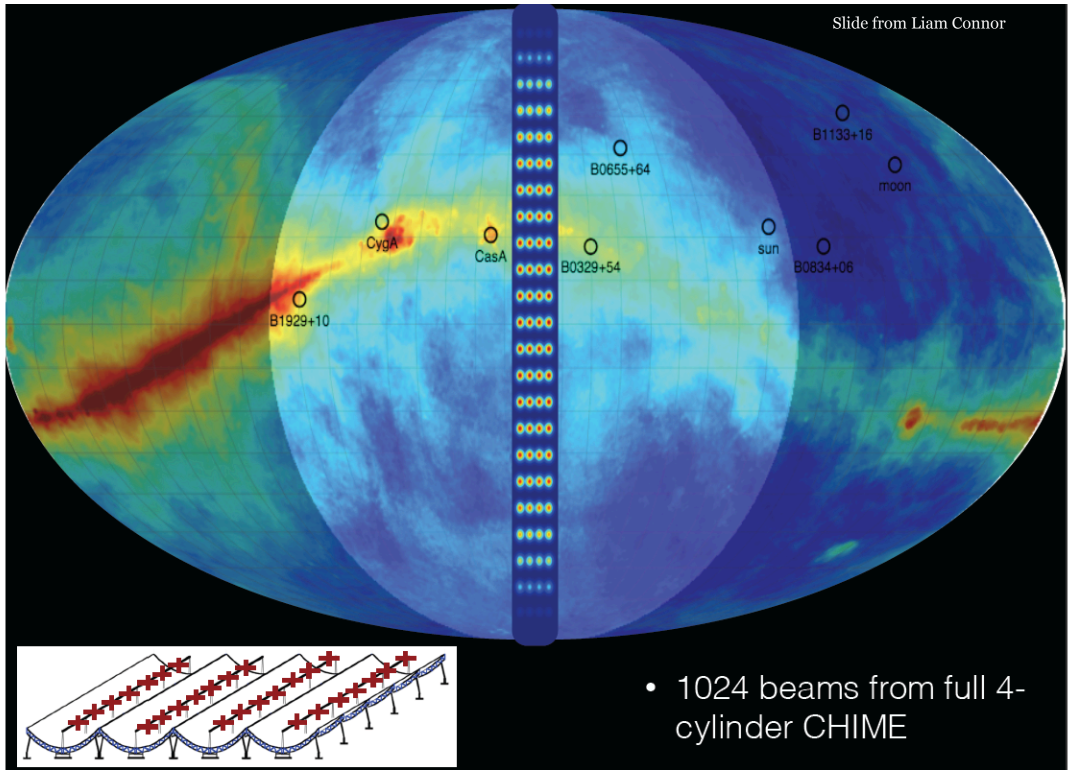
CHIME beamforming, cartoon form

Each antenna sees a narrow strip on the sky ("primary beam").

By beamforming in software as previously described, we can make 1024 "formed" beams with size ~0.3 degree.



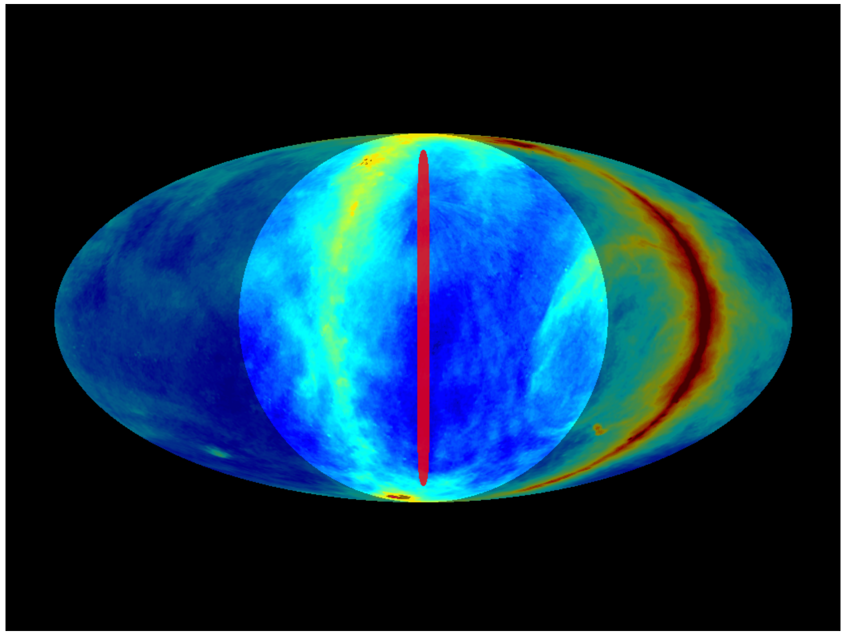
primary beam

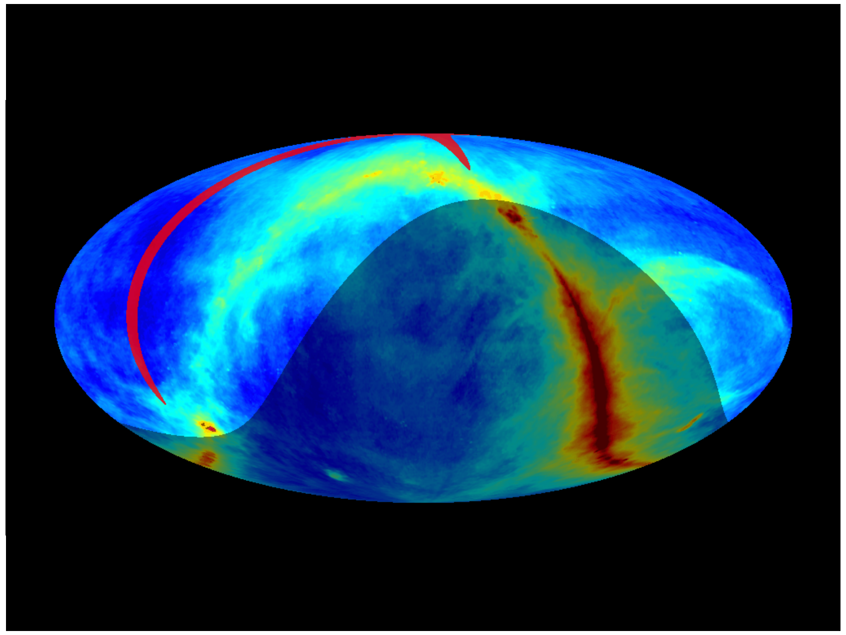


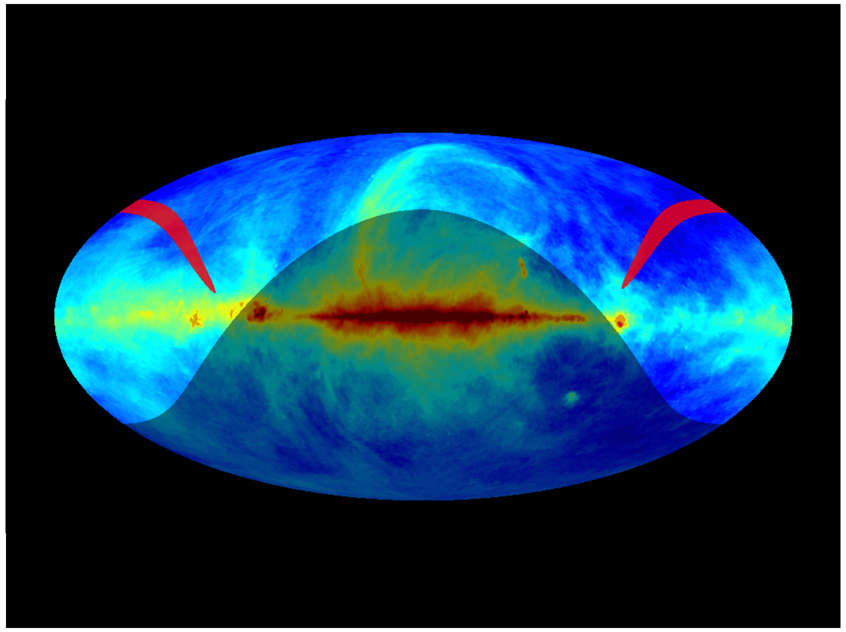
formed beams

CHIME beamforming, cartoon form

As the Earth rotates, the primary and formed beams sweep over the sky.







Every 24 hours, we make an image of the sky with 0.3 degree resolution (= size of formed beams), in frequency range 400-800 MHz.

Mapping speeds (back-of-envelope)

For many purposes, the statistical power of a radio telescope can be quantified by its mapping speed:

$$M \approx (\text{Collecting area } A) \times (\text{Number of beams}) \\ \times (\text{order-one factors})$$

	A	N_{beams}	$M/(10^5 \text{ m}^2)$
Parkes 64m	3200 m^2	13	0.41
Green Bank 100m	7850 m^2	7	0.55
Arecibo 300m	70000 m^2	7	4.9
FAST 500m	200000 m^2	19	38
CHIME	6400 m^2	1024	66

=  CHIME ?!

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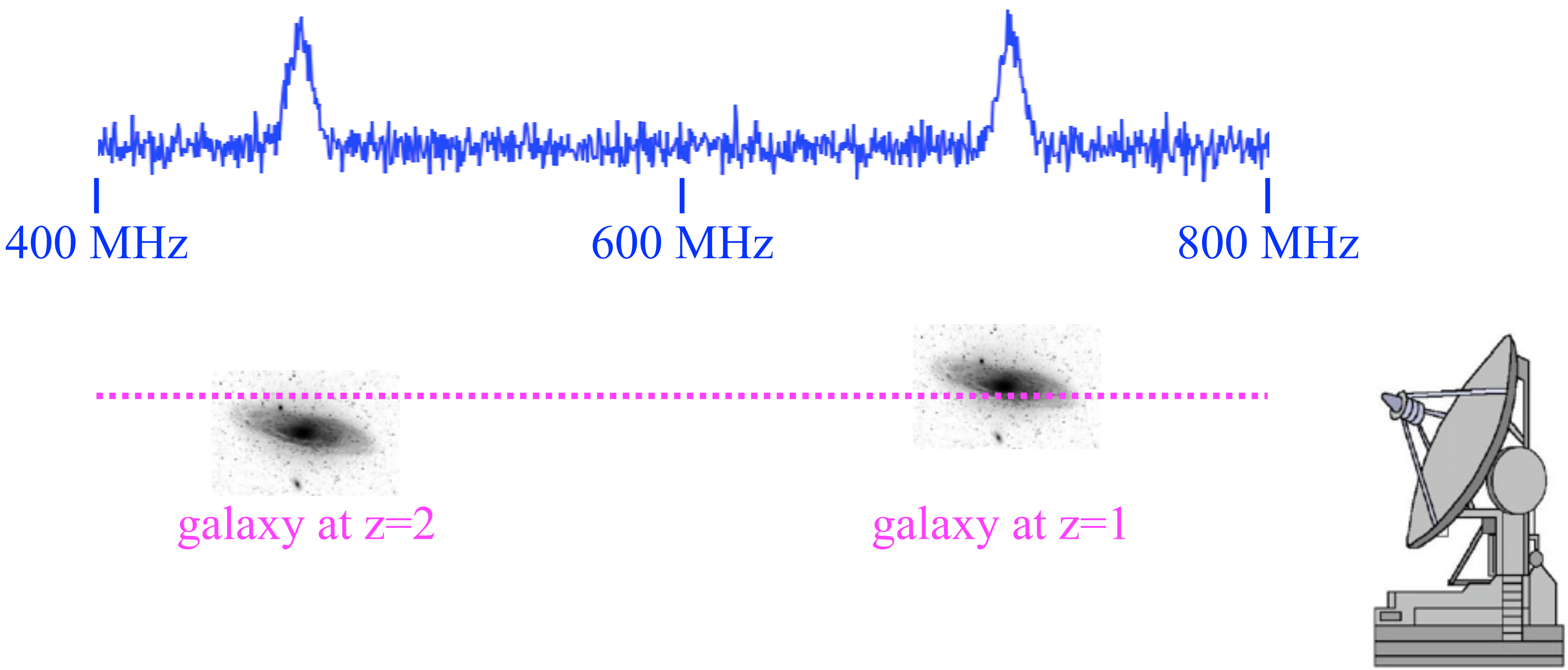
21-cm cosmology

CHIME constrains cosmology by making a 3D map of neutral hydrogen on cosmological scales, via the 21-cm spectral line.

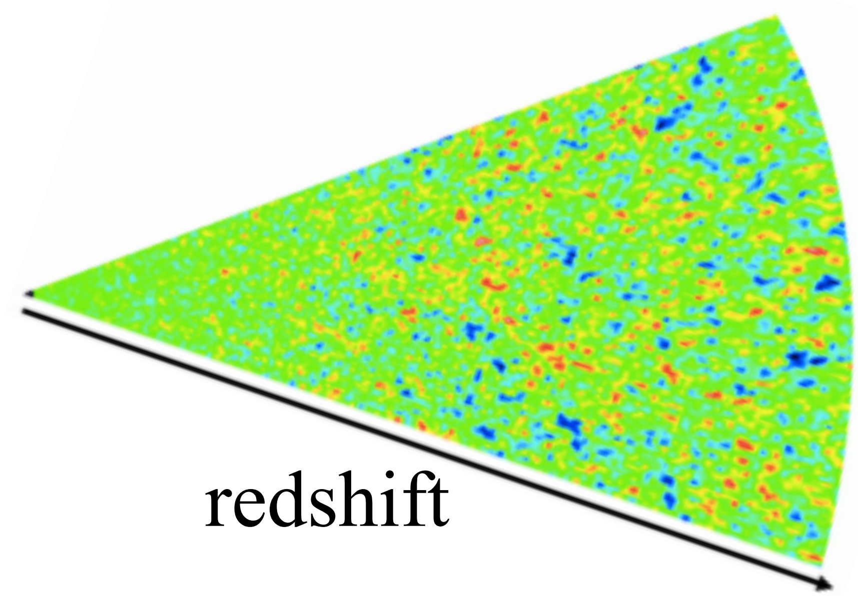
First consider the frequency spectrum of a single line-of-sight. Can be interpreted as a 1D noisy map, in the radial direction.



21-cm cosmology

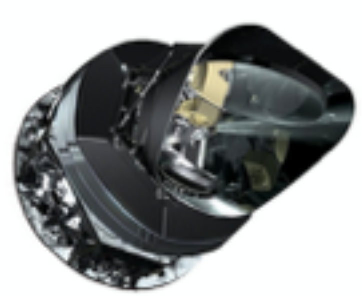
CHIME measures a 1D spectrum at each 2D sky location (θ, ϕ). Get a 3D map of neutral hydrogen in the universe. (Individual galaxies not resolved, but many Fourier modes are measured.)

CHIME

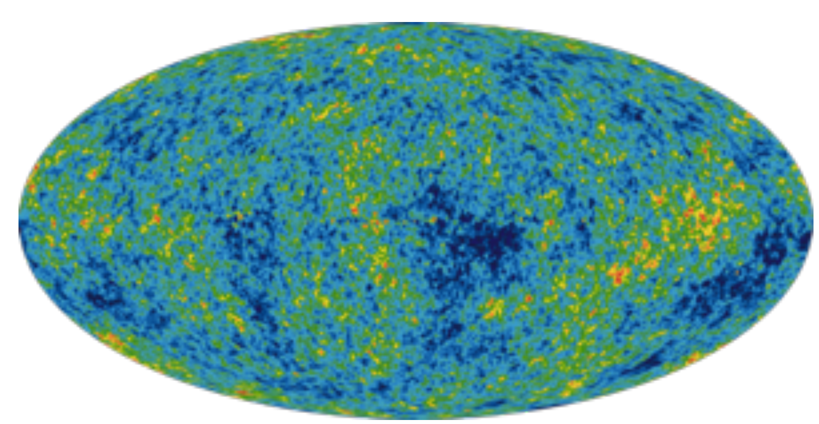


neutral hydrogen density

Conceptually similar to CMB, but much more information is potentially available! (many more modes in 3D than 2D)



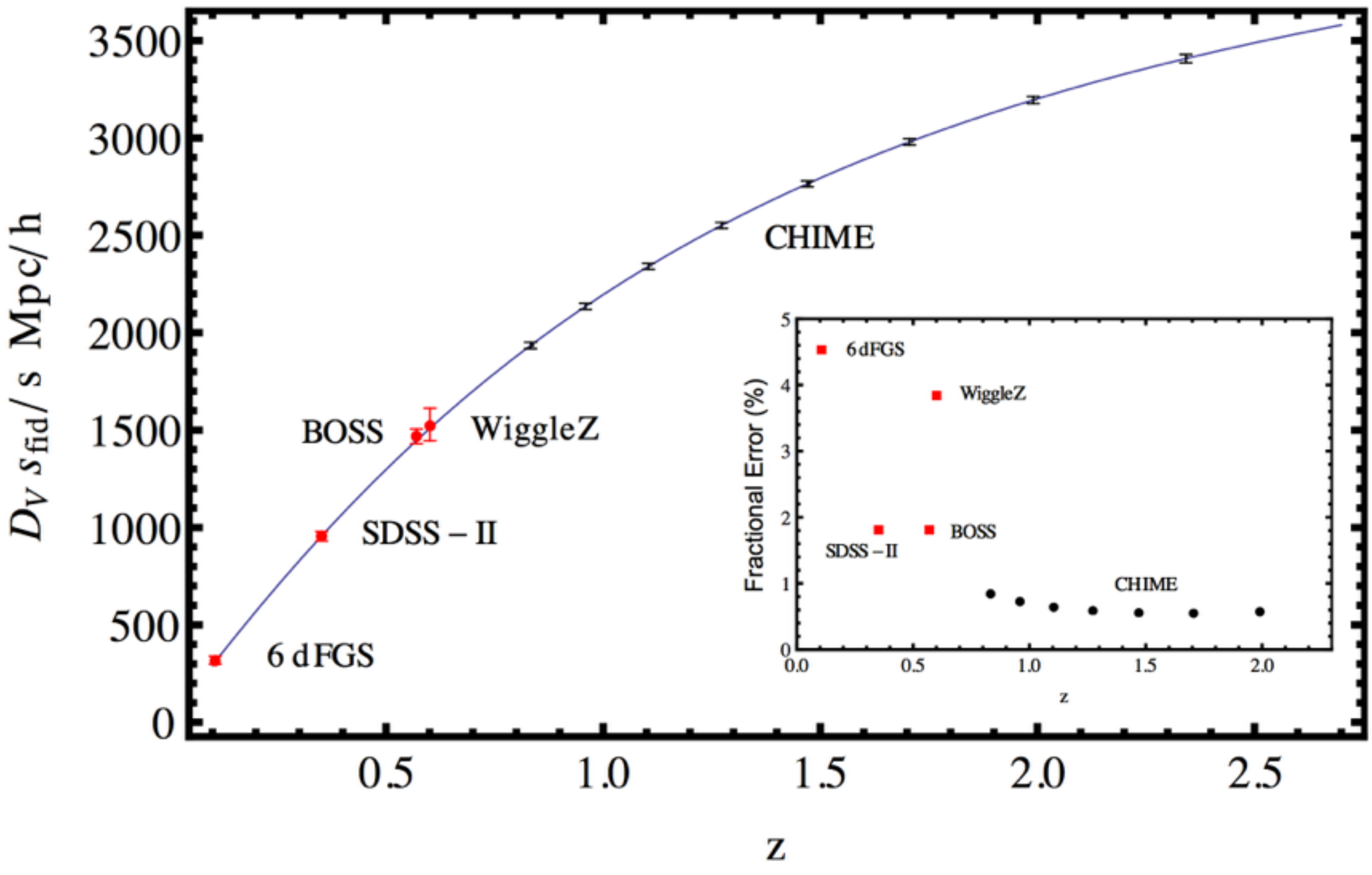
Planck satellite



cosmic microwave background

21-cm cosmology

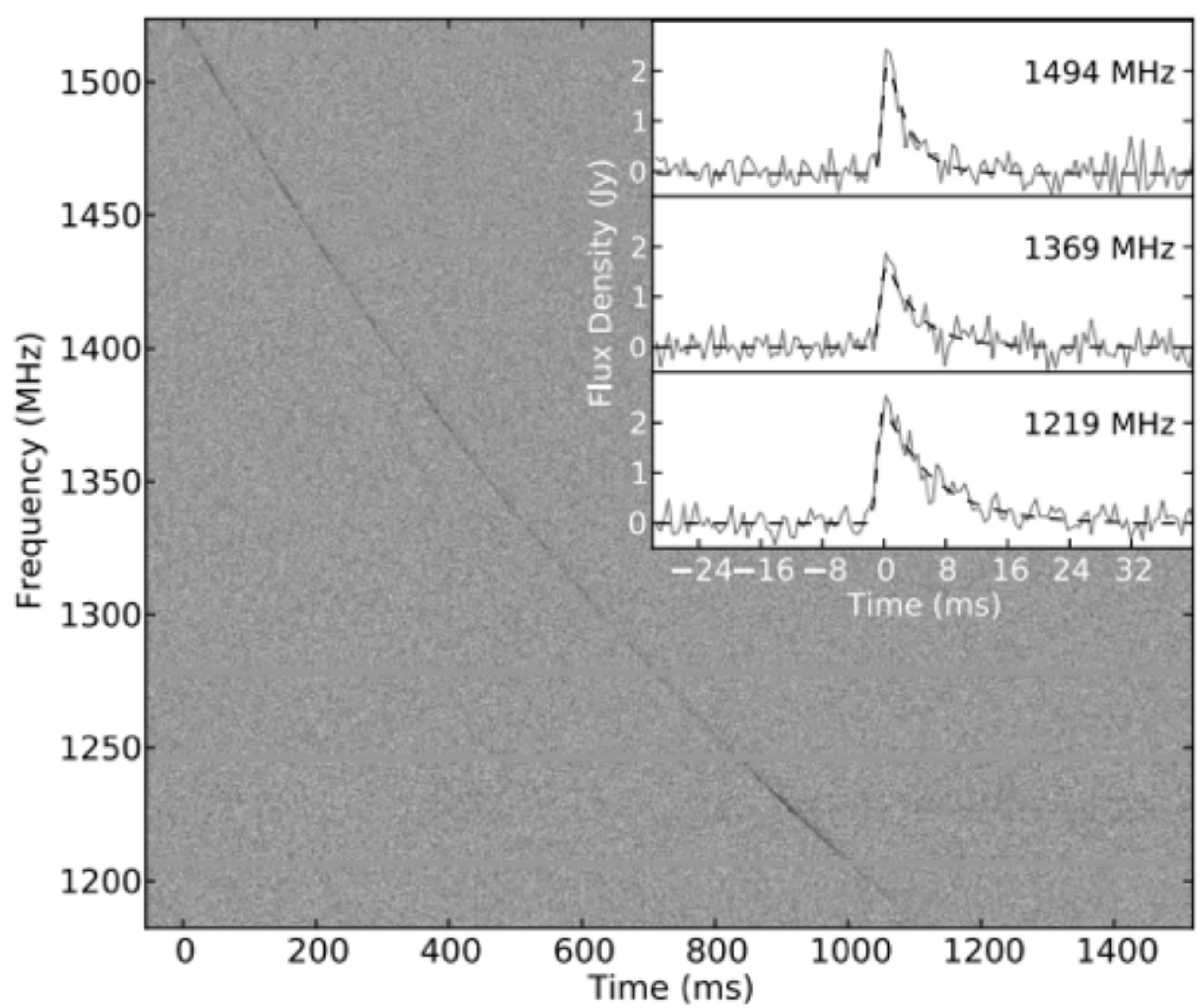
CHIME BAO forecasts are competitive with next-generation surveys (Euclid, LSST, etc.) and probe the "redshift desert"



Fast radio bursts

Fast radio bursts (FRB's): an astrophysical mystery!

Very occasionally, a bright, short (1 ms) pulse of radio emission is observed with very large dispersion (=frequency-dependent delay).



Fast radio bursts

Fast radio bursts (FRB's): an astrophysical mystery!

Very occasionally, a bright, short (1 ms) pulse of radio emission is observed with very large dispersion (=frequency-dependent delay).

The large implied electron column density (+ isotropic sky distribution) suggests that the pulse originates outside our galaxy.

Understanding the origin of these pulses has become a central unsolved problem in astrophysics.

Due to its high mapping speed, we anticipate that CHIME will discover significantly more FRB's than all other radio telescopes combined (!)

A Living Theory Catalogue for Fast Radio Bursts

E. Platts[a,*], A. Weltman[a], A. Walters[b,c], S. P. Tendulkar[d], J.E.B. Gordin[a], S. Kandhai[a]

	Progenitor	Mechanism	Emission	Counterparts	Type	References
Merger	NS–NS	Mag. brak.	—	GW, sGRB, afterglow, X-rays, kilonovae	Single	Totani (2013)
		Mag. recon.	Curv.		Both	Wang et al. (2016)
		Mag. flux	—		Both	Dokuchaev and Eroshenko (2017)
	NS–SN	Mag. recon.	—	None	Single	Egorov and Postnov (2009)
	NS–WD	Mag. recon.	Curv.	—	Repeat	Gu et al. (2016)
		Mag. recon.	Curv.	—	Single	Liu (2017)
	WD–WD	Mag. recon.	Curv.	X-rays, SN	Single	Kashiyama et al. (2013)
	WD–BH	Maser	Synch.	X-rays	Single	Li et al. (2018)
	NS–BH	BH battery	—	GWs, X-rays, γ-rays	Single	Mingarelli et al. (2015)
	Pulsar–BH	—	—	GWs	Single	Bhattacharyya (2017)
	KNBH–BH (Inspiral)	Mag. flux	Curv.	GWs, sGRB, radio afterglow	Single	Zhang (2016b)
	KNBH–BH (Magneto.)	Mag. recon.	Curv.	GW, γ-rays, afterglow	Single	Liu et al. (2016)
Collapse	NS to KNBH	Mag. recon.	Curv.	GW, X-ray afterglow & GRB	Single	Falcke and Rezzolla (2014) Punsly and Bini (2016) Zhang (2014)
	NS to SS	β-decay	Synch.	GW, X- & γ-rays	Single	Shand et al. (2016)
	NS to BH	Mag. recon.	Curv.	GW	Single	Fuller and Ott (2015)
	SS Crust	Mag. recon.	Curv.	GW	Single	Zhang et al. (2018)
SNR (Pulsar)	Giant Pulses	Various	Synch./ Curv.	—	Repeat	Keane et al. (2012) Cordes and Wasserman (2016) Connor et al. (2016)
	Schwinger Pairs	Schwinger	Curv.	—	Single	Lieu (2017)
	PWN Shock (NS)	—	Synch.	SN, PWN, X-rays	Single	Murase et al. (2016)
	PWN Shock (MWD)	—	Synch.	SN, X-rays	Single	Murase et al. (2016)
SNR (Mag.)	MWN Shock (Single)	Maser	Synch.	GW, sGRB, radio afterglow, high energy γ-rays	Single	Popov and Postnov (2007) Murase et al. (2016) Lyubarsky (2014)
	MWN Shock (Clustered)	Maser	Synch.	GW, GRB, radio afterglow, high energy γ-rays	Repeat	Beloborodov (2017)
AGN	Jet–Caviton	e^- scatter	Bremsst.	X-rays, GRB, radio	Repeat	Romero et al. (2016)
					Single	Vieyro et al. (2017)
	AGN–KNBH	Maser	Synch.	SN, GW, γ-rays, neutrinos	Repeat	Das Gupta and Saini (2017)
	AGN–SS	e^- oscill.	—	Persistent GWs, GW, thermal rad., γ-rays, neutrinos	Repeat	Das Gupta and Saini (2017)
	Wandering Beam	—	Synch.	AGN emission, X-ray/UV	Repeat	Katz (2017b)
Collision/Interaction	NS & Ast./ Comets	Mag. recon.	Curv.	None	Single	Geng and Huang (2015) Huang and Geng (2016)
	NS & Ast. Belt	e^- stripping	Curv.	γ-rays	Repeat	Dai et al. (2016) ?
	Small Body & Pulsar	Maser	Synch.	None	Repeat	Mottez and Zarka (2014)
	NS & PBH	Mag. recon.	—	GW	Both	Abramowicz and Bejger (2017)
	Axion Star & NS	e^- oscill.	—	None	Single	Iwazaki (2014, 2015a,b) Raby (2016)
	Axion Star & BH	e^- oscill.	—	None	Repeat	Iwazaki (2017)
	Axion Cluster & NS	Maser	Synch.	—	Single	Tkachev (2015)
	Axion Cloud & BH	Laser	Synch.	GWs	Repeat	Rosa and Kephart (2018)
	AQN & NS	Mag. recon.	Curv.	Below IR	Repeat	van Waerbeke and Zhitnitsky (2018)
Other	Starquakes	Mag. recon.	Curv.	GRB, X-rays	Repeat	Wang et al. (2018)
	Variable Stars	Undulator	Synch.	—	Repeat	Song et al. (2017)
	Pulsar Lightning	Electrostatic	Curv.	—	Repeat	Katz (2017a)
	Wandering Beam	—	—	—	Repeat	Katz (2016d)
	Tiny EM Explosions	Thin shell related	Curv.	Higher freq. radio pulse, γ-rays	Repeat	Thompson (2017b,a)
	WHs	—	—	IR emission, γ-rays	Single	Barrau et al. (2014, 2018)
	NS Combing	Mag. recon.	—	Scenario	Both	Zhang (2017, 2018)
	Superconducting Cosmic Strings	Cusp decay	—	GW, neutrinos, cosmic rays, GRBs	Single	Costa et al. (2018)
	Galaxy DSR	DSR	Synch.	—	Both	Houde et al. (2018)
	Alien Light Sails	Artificial transmitter	—	—	Repeat	Lingam and Loeb (2017)
Inviable	Stellar Coronae	N/A	N/A	N/A	N/A	Loeb et al. (2014) Maoz et al. (2015)
	Neutral Cosmic Strings	N/A	N/A	N/A	N/A	Brandenberger et al. (2017)
	Annihilating Mini BHs	N/A	N/A	N/A	N/A	Keane et al. (2012)

Table 1: Tabulated Summary

arxiv:1810.05836

Searching for new pulsars

Over the last 50 years, pulsar science has been an exceptionally fertile area of astronomy.

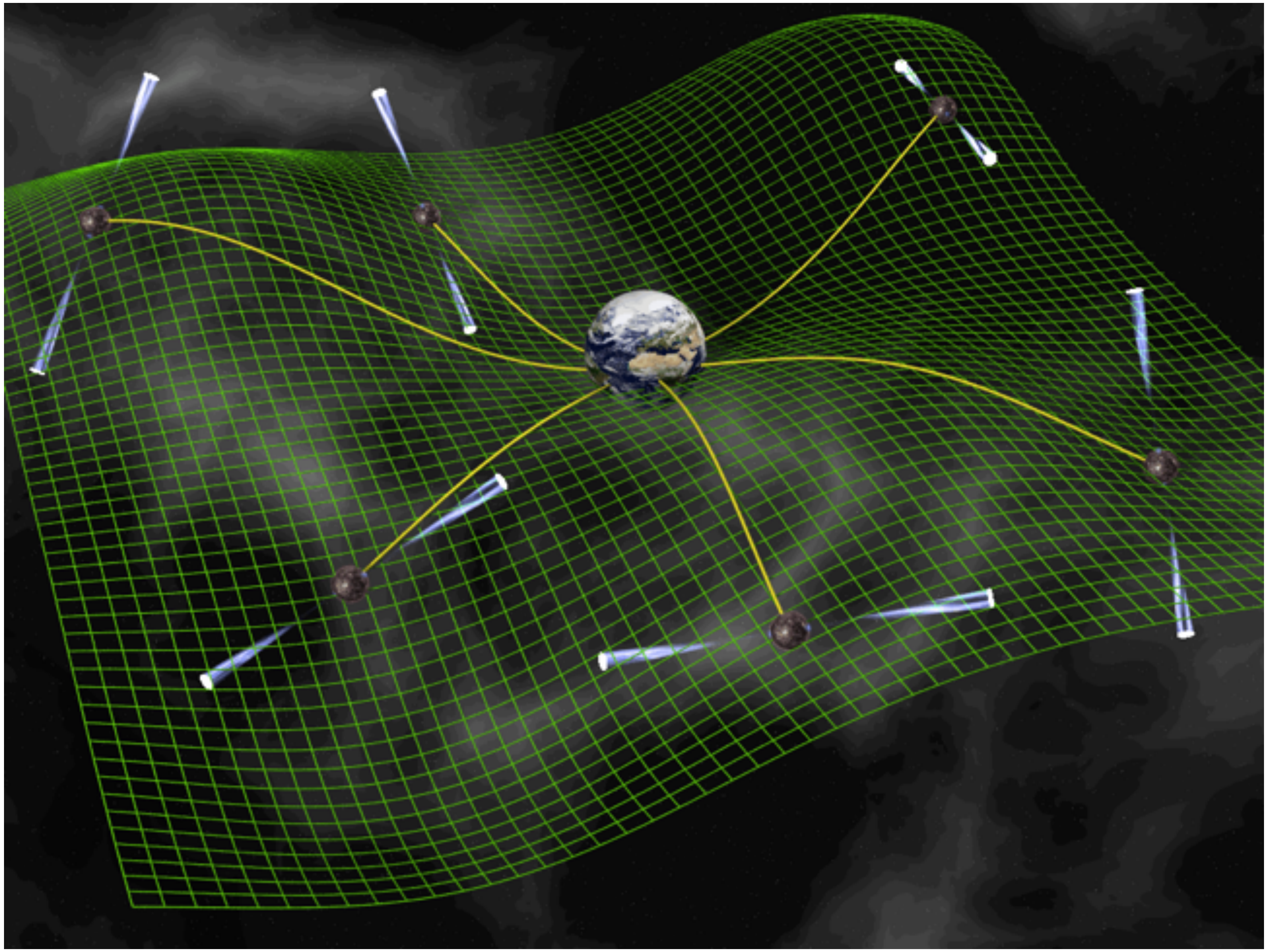
- First observational evidence of gravitational waves
- Exceptionally precise tests of GR
- New astrophysics (e.g. magnetars)
- Many astronomically interesting “oddball” systems

Around 2500 pulsars have been found, but the total population is predicted to be $\sim 10^5$. Many new discoveries to be made!

CHIME’s daily sensitivity is comparable to the entire GBNCC survey, one of the most powerful pulsar searches to date. Suggests that CHIME can be an amazing instrument for finding new pulsars!

Forecasts: timing bright pulsars

- Daily timing of known pulsars can contribute to global efforts to detect gravity waves with ~light-year wavelengths.



Forecasts: timing bright pulsars

- Daily timing of known pulsars can contribute to global efforts to detect gravity waves with ~light-year wavelengths.

- CHIME observes at low frequencies (400-800 MHz) where ISM propagation effects can broaden pulses significantly.

- Not ideal for pulsar timing on its own, but when combined with higher-frequency measurements, can improve timing solutions by pinning down ISM-related nuisance parameters

- CHIME will be part of the NANOGRAV pulsar timing collaboration, and we estimate that CHIME can improve timings for most NANOGRAV pulsars by a factor ~2.

CHIME forecasts: summary

- Due to its high mapping speed, CHIME has amazing forecasts in several areas (cosmology, fast radio bursts, pulsar science).
- CHIME is relatively inexpensive, and any one of these forecasts would fully justify a larger project.
- Too good to be true?

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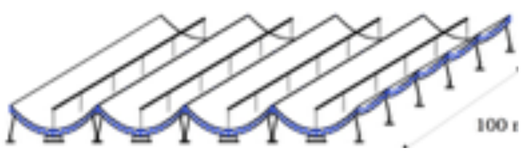
The challenge

	A	N_{beams}	$M/(10^5\ \mathrm{m}^2)$
Parkes 64m	3200 m^2	13	0.41
Green Bank 100m	7850 m^2	7	0.55
Arecibo 300m	70000 m^2	7	4.9
FAST 500m	200000 m^2	19	38
CHIME	6400 m^2	1024	66

In principle, sensitivity is proportional to mapping speed M, but computational cost is proportional to N_{beams} (or worse).

What we have really done is move difficulty from hardware to software.

CHIME computing

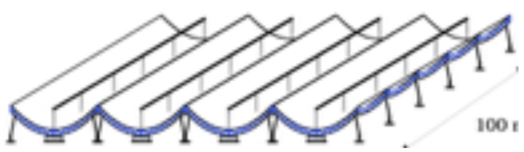


FPGA digitizer/ channelizer

800 GB/sec

- Raw data rate is 800 GB/s = 70 PB/day

CHIME computing



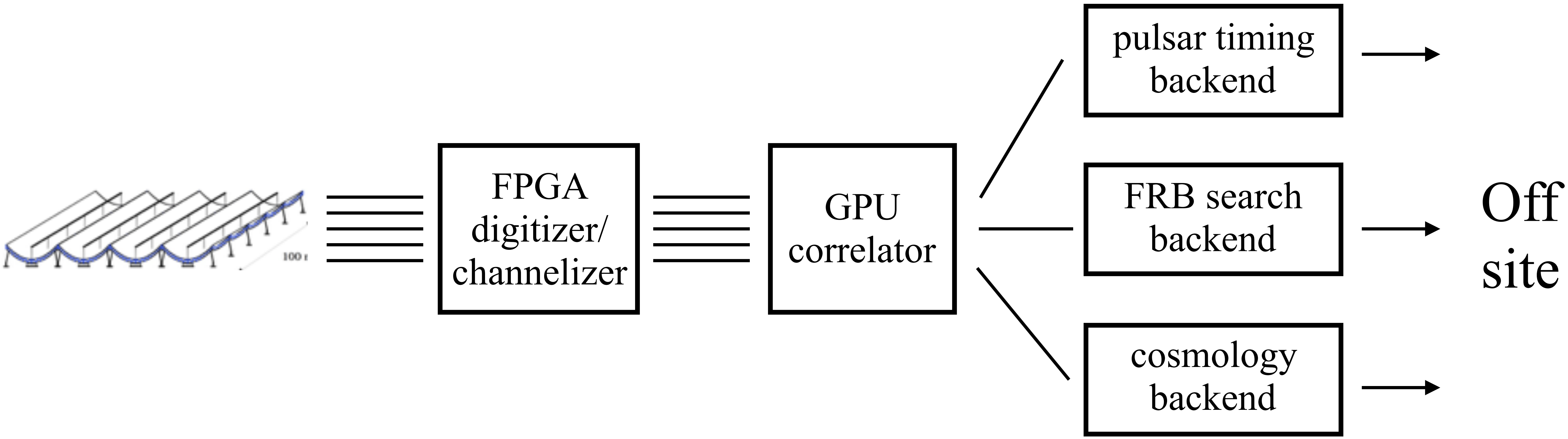
FPGA
digitizer/
channelizer

800 GB/sec
(= LSST x 5000)

- Raw data rate is 800 GB/s = 70 PB/day
  = 5000 LSST telescopes!

LSST: 15 TB/day

CHIME computing



- Raw data rate is 800 GB/s = 70 PB/day
- Purpose-built backends:
  - pulsar timing backend: electric field at 10 sky locations (0.7 PB/day)
  - FRB backend: channelized intensity in 1024 sky locations (N_{freq}=16384, dt=1 ms, 1.5 PB/day)
  - cosmology backend: visibility matrix every 10 seconds (0.1 PB/day)

Realizing CHIME's potential requires solving hard problems:

1. Searching for fast radio bursts

Challenge: CHIME is the world's largest FRB search (in data volume) by a factor of ~200!

2. Removing RFI (for real-time transient detection)

Challenge: CHIME needs a very low false positive rate, since the data volume is so large.

3. Searching for new pulsars

Challenge: current algorithms are too expensive when applied to non-contiguous observations. We have proposed improvements (Smith, arxiv:1610.06831), but implementation is still in an early stage.

4. Cosmology

Challenge is separating Galactic foregrounds from cosmological signal. Requires characterizing instrumental response very precisely. In progress!

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CHIME/FRB Collaboration

UBC
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- Dr. Davor Cubranic
- Meiling Deng
- Deborah Good
- Mateus Fandino
- Prof. Mark Halpern
- Carolin Hofer
- Dr. Alex Hill
- Prof. Gary Hinshaw
- Nikola Milutinovic
- Tristan Pinsonneault-Marotte
- Dr. Richard Shaw
- Prof. Ingrid Stairs
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WVU
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- Chitrang Patel
- Ziggy Pleunis
- Dr. Seth Siegel
- Dr. Shriharsh Tendulkar
- Andrew Zwaniga

Yale
- Prof. Laura Newburgh

“bonsai”: CHIME FRB search software

The CHIME FRB search algorithm is:

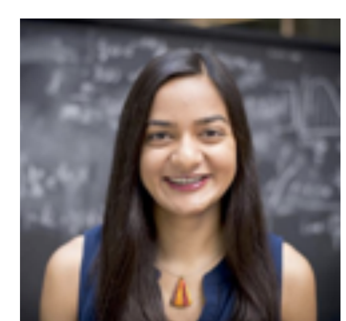
- orders of magnitude faster than other search software
- near statistically optimal
- real-time, (few-second) latency
- searches a huge parameter space (e.g. max DM 13000)
- runs on a dedicated 128-node cluster (and searches 1.5 PB/day!)

Kendrick Smith

Dustin Lang

Masoud Rafiei-Ravandi

Utkarsh Giri



Maya Burhanpurkar

```c
void transpose(float *dst, const float *src, int n)
{
    for (int i = 0; i < n; i++)
        for (int j = 0; j < n; j++)
            dst[i*n+j] = src[j*n+i];
}
```

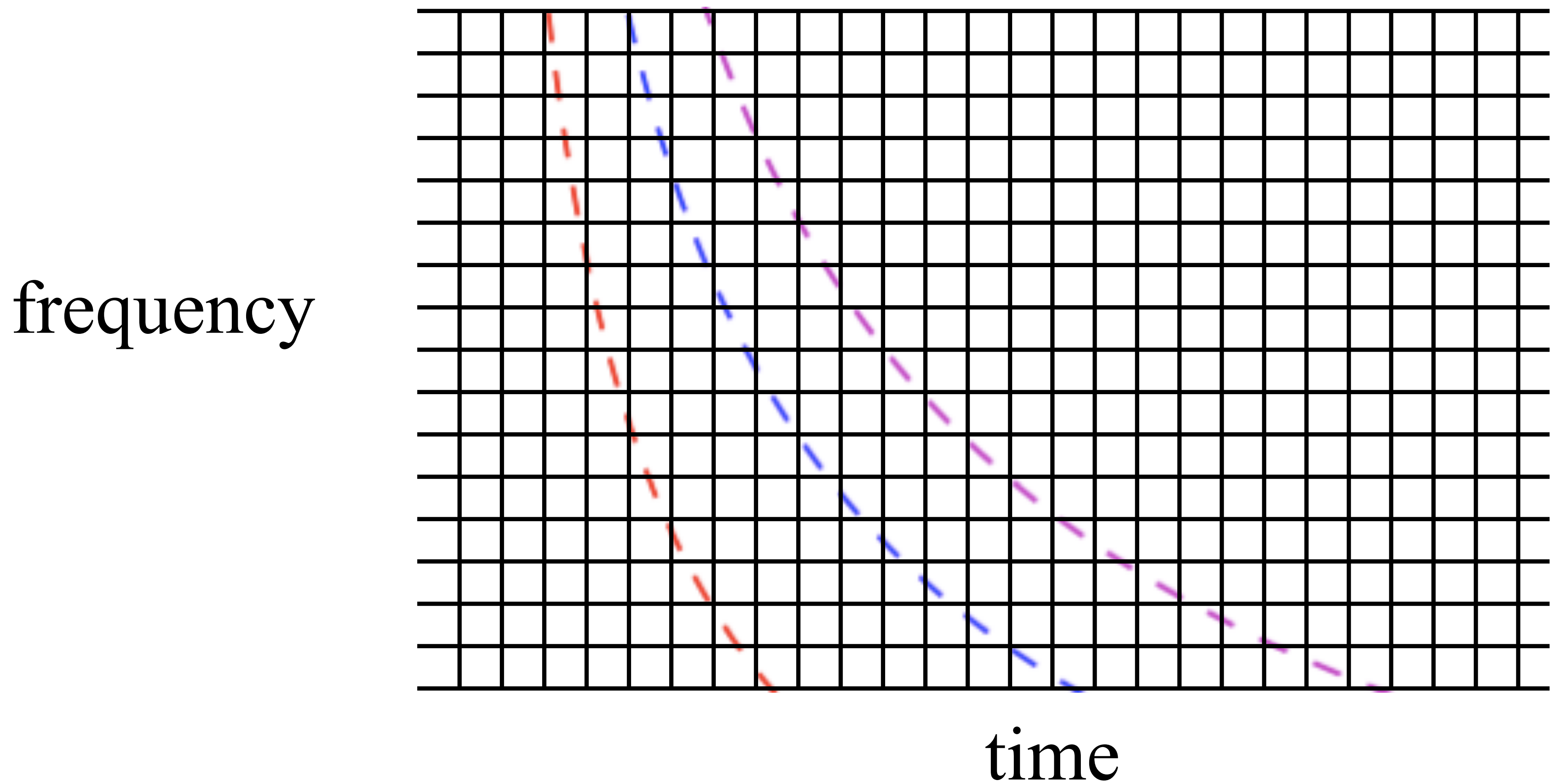
4 times faster!

```
void transpose_256b(float *dst, const float *src, int n)
{
    for (int i = 0; i < n; i += 8) {
        for (int j = 0; j < n; j += 8) {
            __m256 x0 = _mm256_load_ps(src + j*n + i);
            __m256 x1 = _mm256_load_ps(src + (j+1)*n + i);
            __m256 x2 = _mm256_load_ps(src + (j+2)*n + i);
            __m256 x3 = _mm256_load_ps(src + (j+3)*n + i);
            __m256 x4 = _mm256_load_ps(src + (j+4)*n + i);
            __m256 x5 = _mm256_load_ps(src + (j+5)*n + i);
            __m256 x6 = _mm256_load_ps(src + (j+6)*n + i);
            __m256 x7 = _mm256_load_ps(src + (j+7)*n + i);

            __m256 z0 = _mm256_permute2f128_ps(x0, x4, 0x21);
            x0 = _mm256_blend_ps(x0, z0, 0xf0);
            x4 = _mm256_blend_ps(x4, z0, 0x0f);

            __m256 z1 = _mm256_permute2f128_ps(x1, x5, 0x21);
            x1 = _mm256_blend_ps(x1, z1, 0xf0);
            x5 = _mm256_blend_ps(x5, z1, 0x0f);

            __m256 z2 = _mm256_permute2f128_ps(x2, x6, 0x21);
            x2 = _mm256_blend_ps(x2, z2, 0xf0);
            x6 = _mm256_blend_ps(x6, z2, 0x0f);

            __m256 z3 = _mm256_permute2f128_ps(x3, x7, 0x21);
            x3 = _mm256_blend_ps(x3, z3, 0xf0);
            x7 = _mm256_blend_ps(x7, z3, 0x0f);

            __m256 a0 = _mm256_shuffle_ps(x0, x2, 0x44);
            __m256 a1 = _mm256_shuffle_ps(x1, x3, 0x11);

            x0 = _mm256_blend_ps(a0, a1, 0xaa);
            x1 = _mm256_blend_ps(a0, a1, 0x55);
            x1 = _mm256_permute_ps(x1, 0xb1);

            __m256 a2 = _mm256_shuffle_ps(x0, x2, 0xee);
            __m256 a3 = _mm256_shuffle_ps(x1, x3, 0xbb);

            x2 = _mm256_blend_ps(a2, a3, 0xaa);
            x3 = _mm256_blend_ps(a2, a3, 0x55);
            x3 = _mm256_permute_ps(x3, 0xb1);

            __m256 a4 = _mm256_shuffle_ps(x4, x6, 0x44);
            __m256 a5 = _mm256_shuffle_ps(x5, x7, 0x11);

            x4 = _mm256_blend_ps(a4, a5, 0xaa);
            x5 = _mm256_blend_ps(a4, a5, 0x55);
            x5 = _mm256_permute_ps(x5, 0xb1);

            __m256 a6 = _mm256_shuffle_ps(x4, x6, 0xee);
            __m256 a7 = _mm256_shuffle_ps(x5, x7, 0xbb);

            x6 = _mm256_blend_ps(a6, a7, 0xaa);
            x7 = _mm256_blend_ps(a6, a7, 0x55);
            x7 = _mm256_permute_ps(x7, 0xb1);

            _mm256_store_ps(dst + i*n + j, x0);
            _mm256_store_ps(dst + (i+1)*n + j, x1);
            _mm256_store_ps(dst + (i+2)*n + j, x2);
            _mm256_store_ps(dst + (i+3)*n + j, x3);
            _mm256_store_ps(dst + (i+4)*n + j, x4);
            _mm256_store_ps(dst + (i+5)*n + j, x5);
            _mm256_store_ps(dst + (i+6)*n + j, x6);
            _mm256_store_ps(dst + (i+7)*n + j, x7);
        }
    }
}
```

The FRB search problem

Setting up the problem. The FRB backend incrementally receives a 2D array with (time, frequency) axes. We want to sum over all "tracks" with the shape shown.

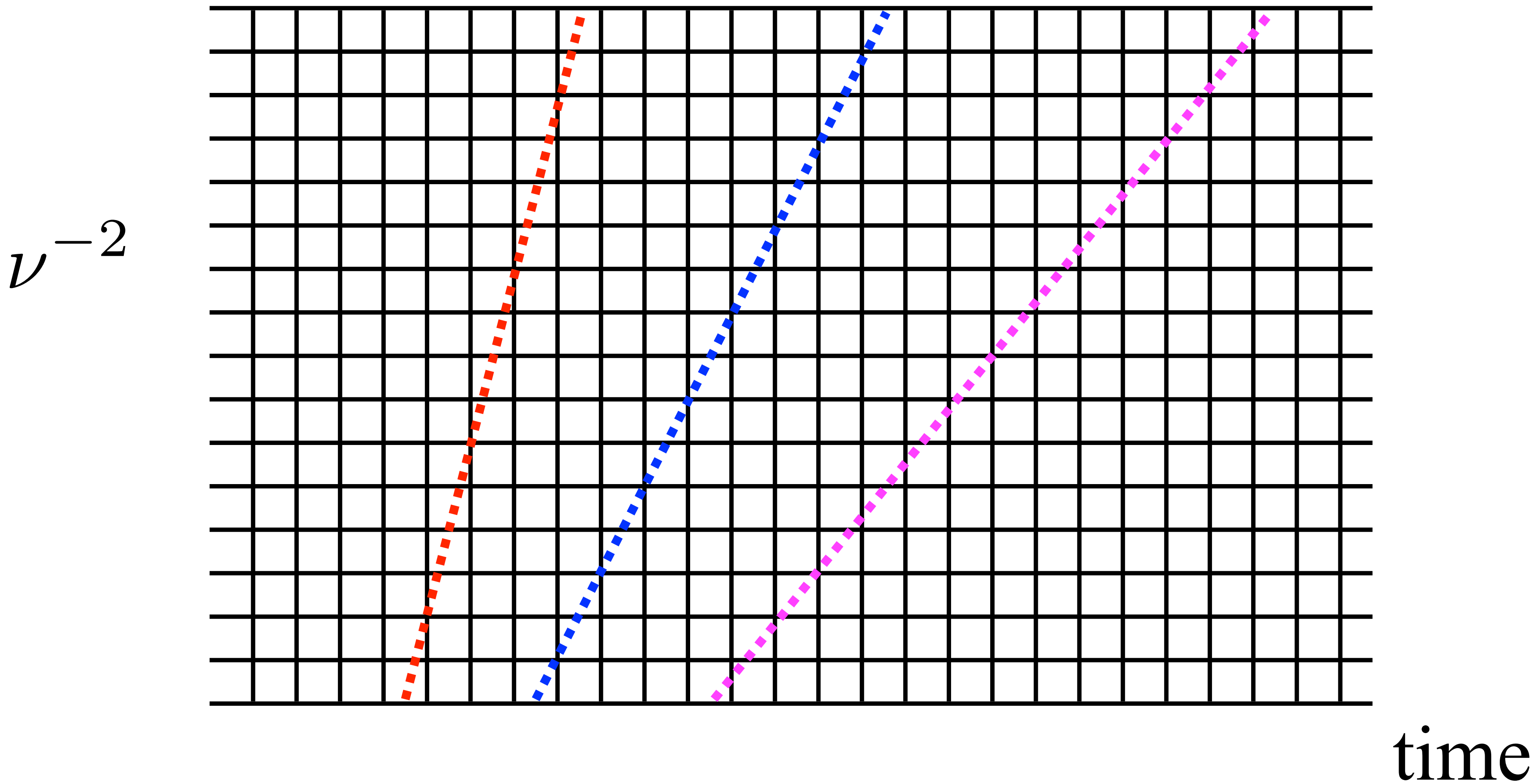
We use a recursive tree algorithm, described in the next few slides.



Tree dedispersion: the basic idea

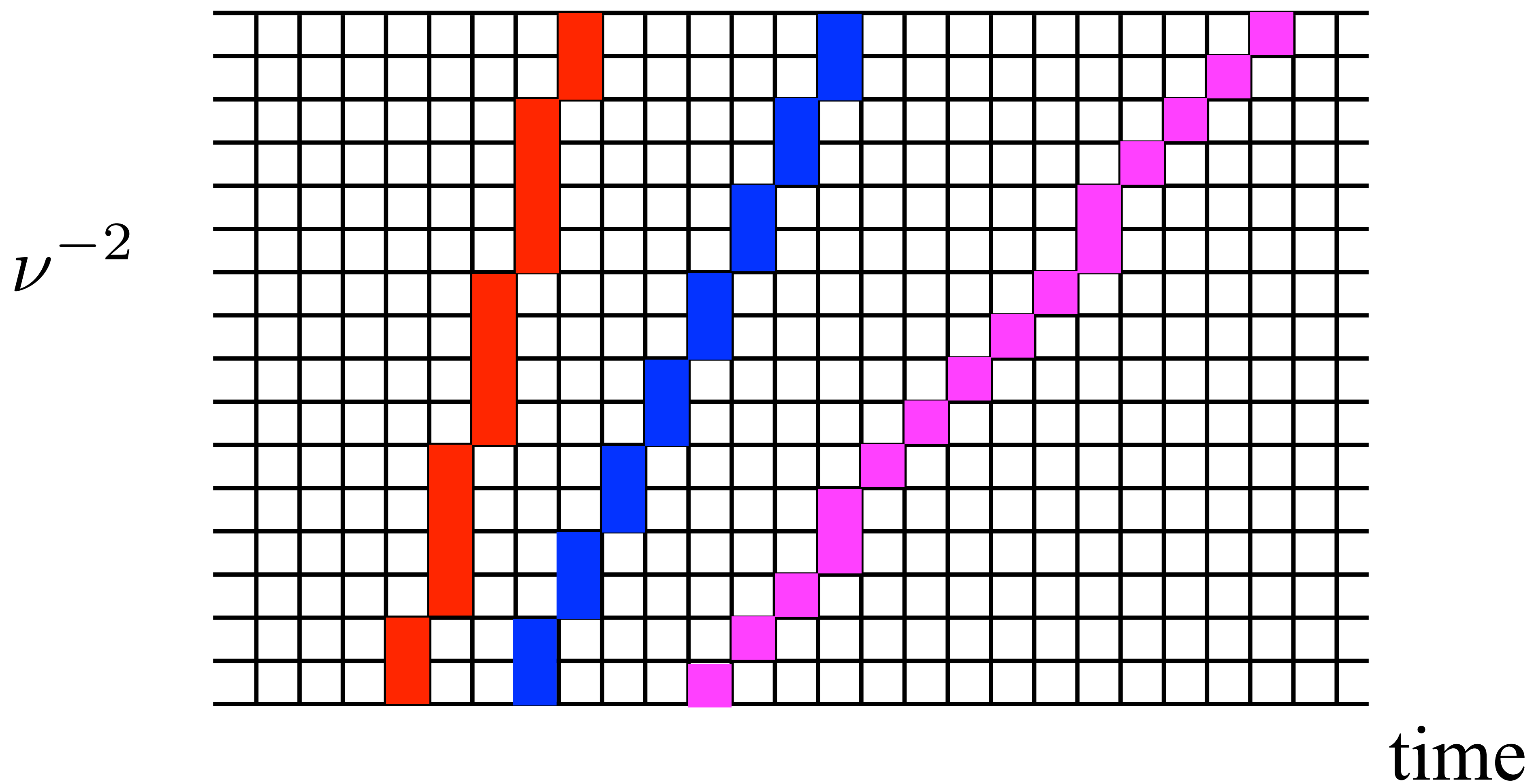
Regrid the input array so that the y-axis corresponds to ν^{-2}, rather than frequency ν.

Then an FRB looks like a straight line. Need a fast algorithm for summing array elements over all straight lines.



Tree dedispersion: the basic idea

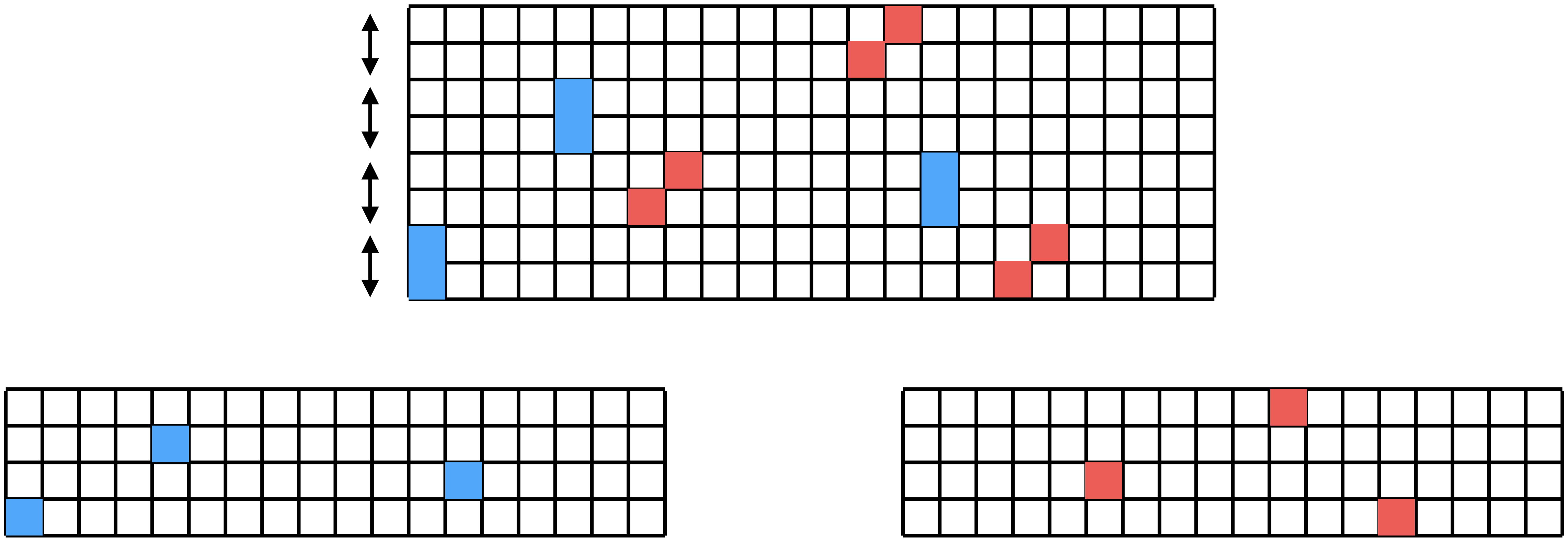
Tree dedispersion will approximate each straight-line track by a jagged sum of samples. The sums are built up recursively as explained in the next few slides.



Tree dedispersion: the basic idea

First iteration: group channels in pairs. Within each pair, we form all “vertical” sums (blue) and “diagonal” sums (red).

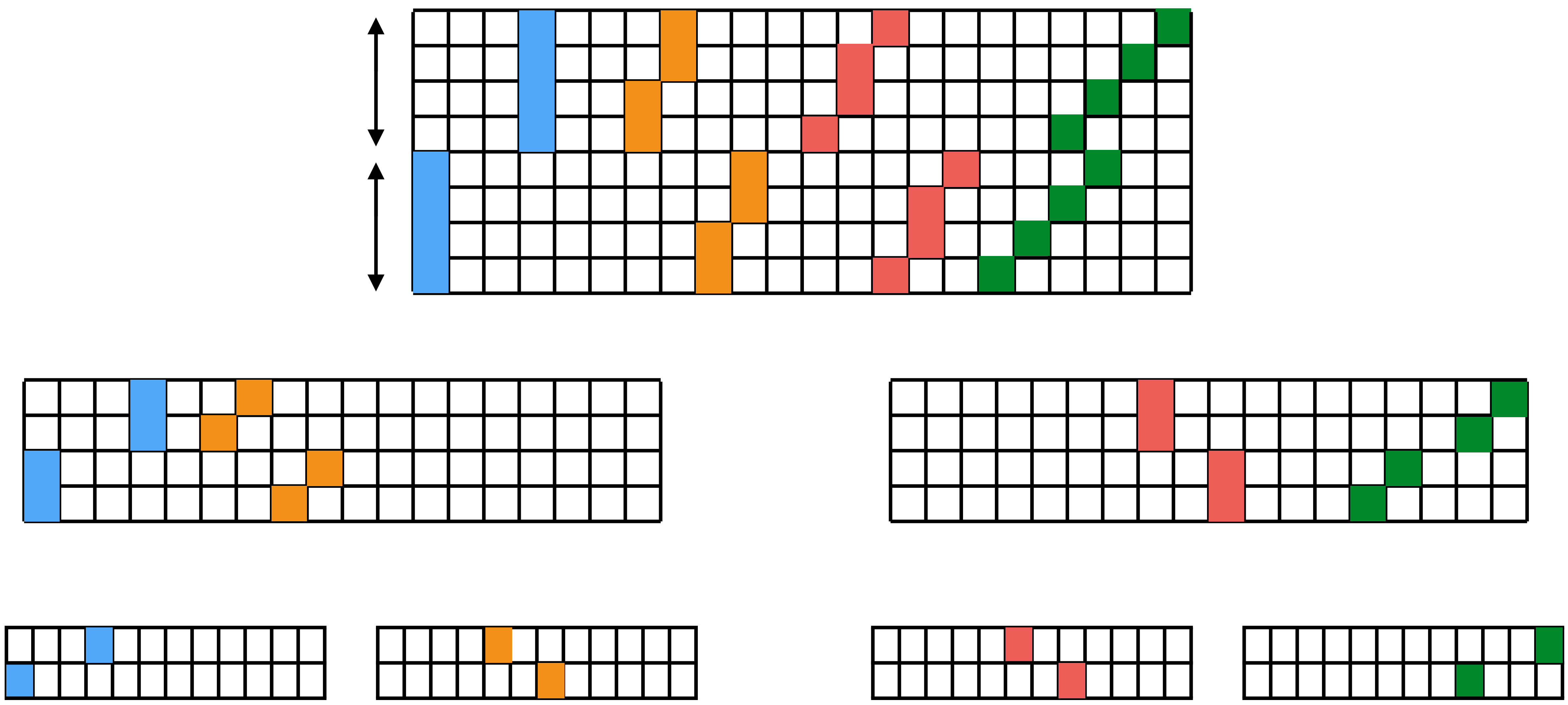
Output is two arrays, each half the size of the input array.



Tree dedispersion: the basic idea

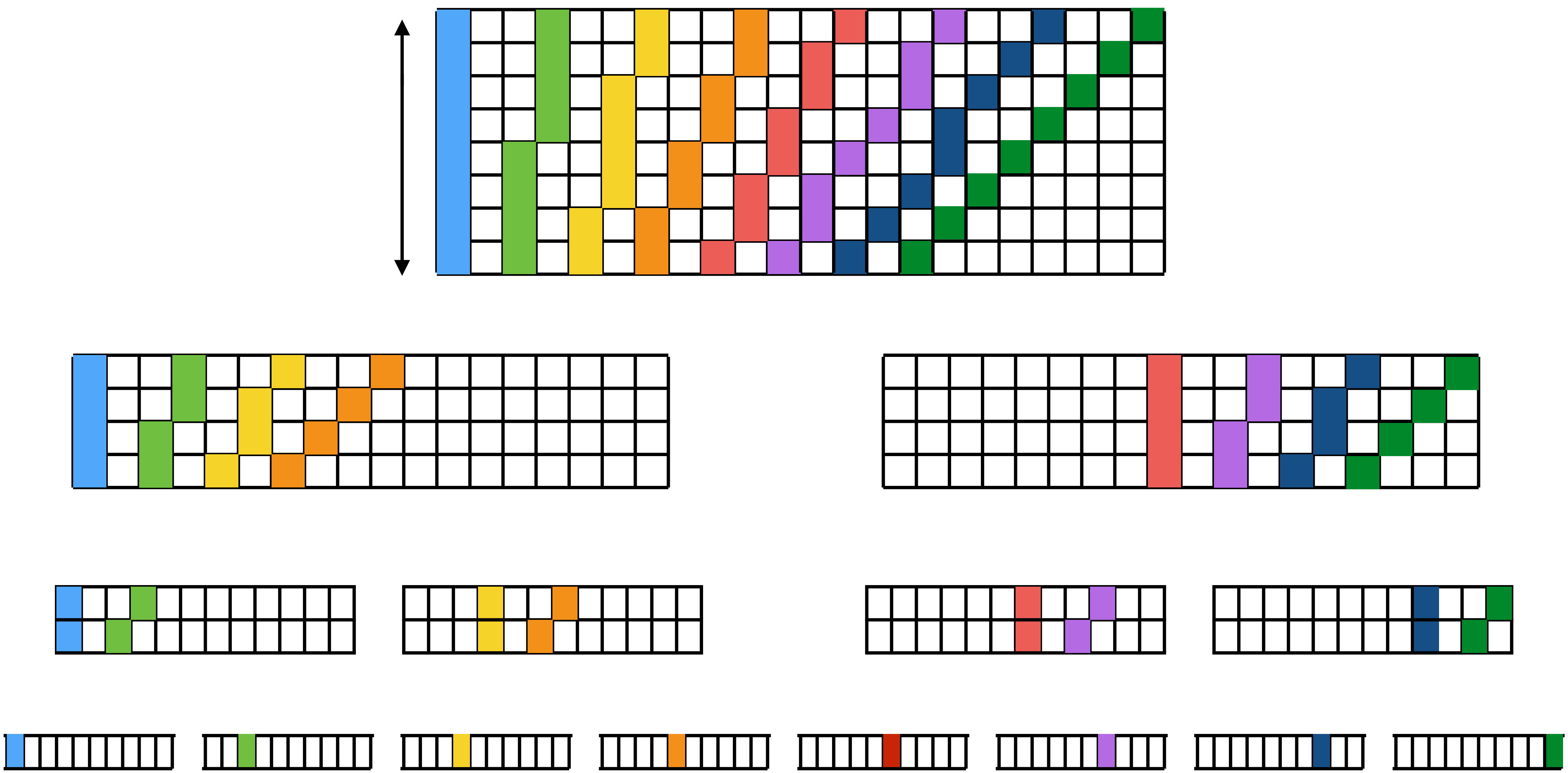
Second iteration: sum pairs into "pairs of pairs".

Frequency channels have now been merged in quadruples.
Within each quadruple, there are four possible sums.

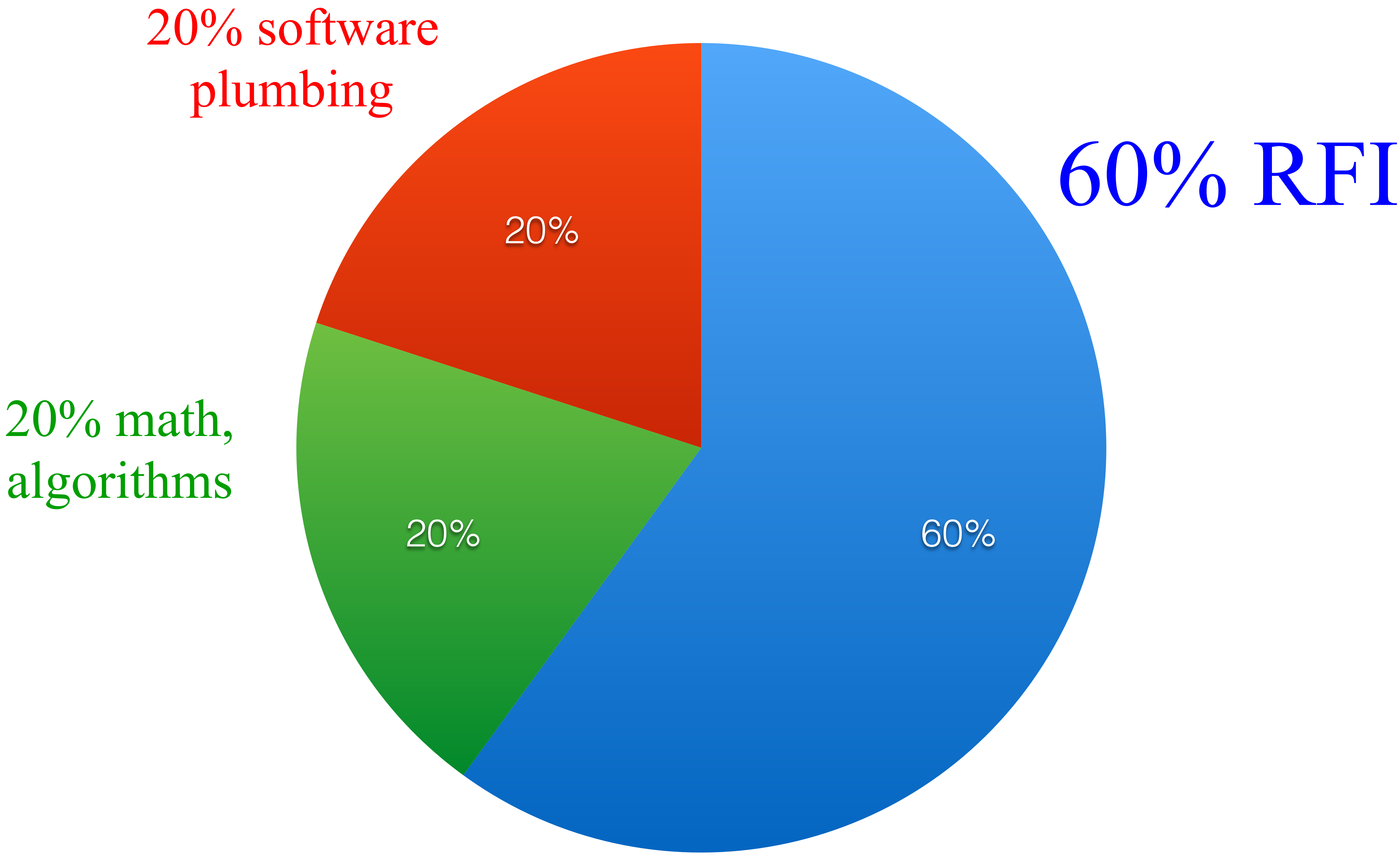


Tree dedispersion: the basic idea

Last iteration: all channels summed.



How I spend my time



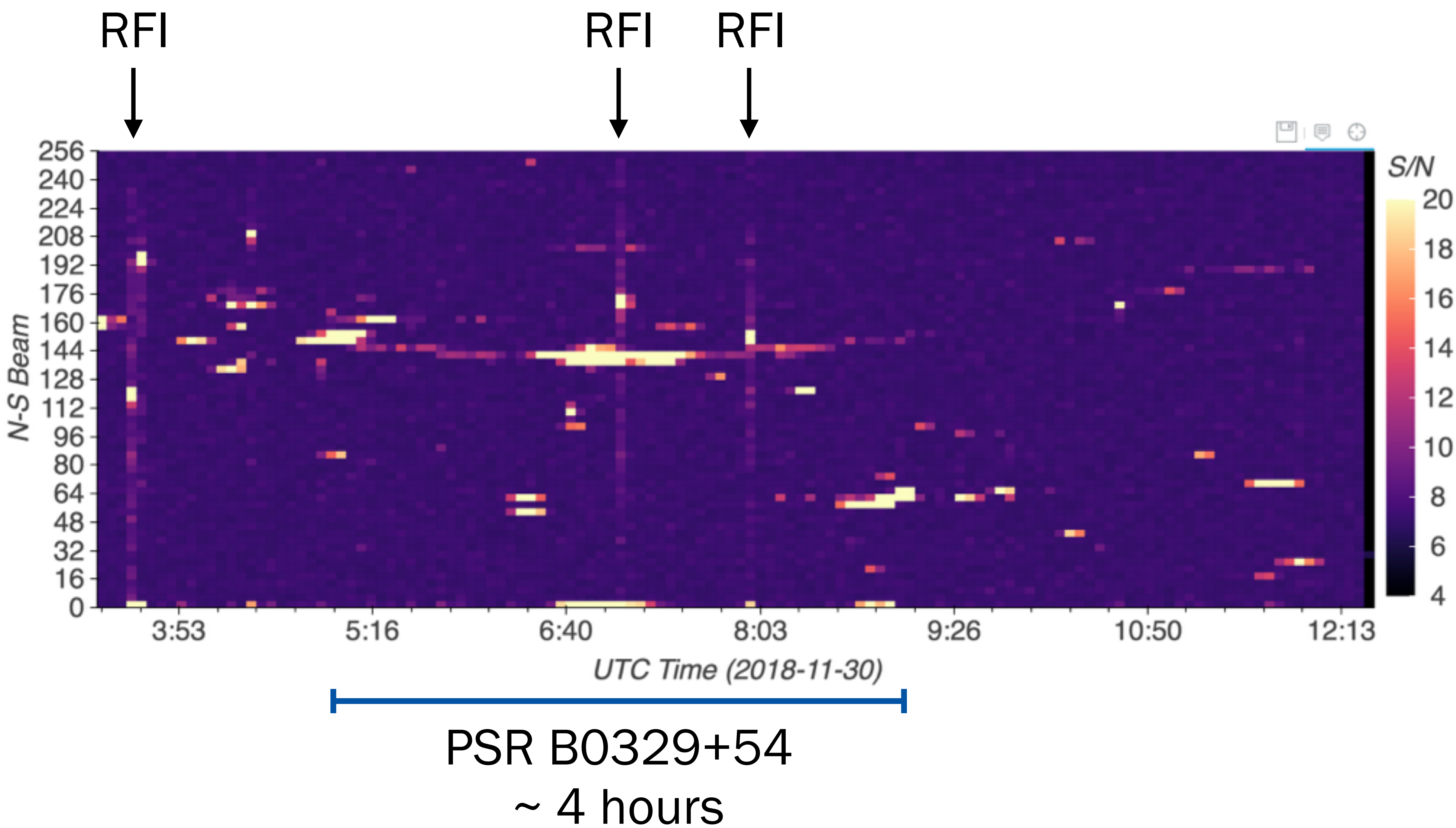
RFI removal

- For an FRB or pulsar search, the largest instrumental effect (by far!) is radiofrequency interference (RFI), i.e. human-made radio transmissions.

- Main tool for mitigating RFI is masking the data in the (time, frequency) plane, before the FRB search.

- Standard RFI removal software packages do not suffice for CHIME:
  - too slow
  - latency too high
  - false positive rate too high (a few false positives per beam per hour = 10^5 events per day!)

Per-beam triggers after RFI excision, dedispersion and peak finding

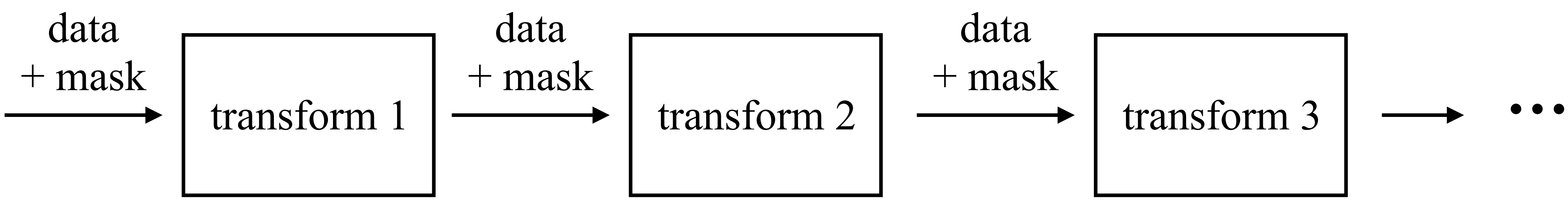


Signal collapsed over 4 East-West beams

Ziggy Pleunis

Our approach to RFI removal

Represent RFI removal as a sequence of "transforms" which operate on the data + mask.



For example:

- Clipping based on intensity
- Clipping based on variance of intensity (voltage "kurtosis")
- Detrending the data in either time or frequency axis
- Upsampling/downsampling the data/mask

Our key transforms are assembly-language-kernelized, but can be chained together and run from high-level languages (python).

Our approach to RFI removal

Current RFI strategy consists of ~100 transforms!

This iterative approach has proven to be extremely powerful.

```
wi_sub_pipeline(nfreq_out=1024,nds_out=1)
wi_sub_downsampler
       badchannel_mask(mask_path="/data/pathfinder/rfi_masks/rfi_20160705.dat")
       std_dev_clipper(nt_chunk=1024, axis=AXIS_TIME, sigma=3, Df=1, Dt=1, two_pass=1)
       std_dev_clipper(nt_chunk=2048, axis=AXIS_TIME, sigma=3, Df=1, Dt=1, two_pass=1)
       std_dev_clipper(nt_chunk=6144, axis=AXIS_TIME, sigma=3, Df=1, Dt=1, two_pass=1)
       std_dev_clipper(nt_chunk=6144, axis=AXIS_FREQ, sigma=3, Df=1, Dt=1, two_pass=0)
       std_dev_clipper(nt_chunk=6144, axis=AXIS_FREQ, sigma=3, Df=1, Dt=1, two_pass=0)
            ...
       intensity_clipper(nt_chunk=1024, axis=AXIS_FREQ, sigma=5, niter=9, iter_sigma=5, Df=1, Dt=1, two_pass=0)
       intensity_clipper(nt_chunk=1024, axis=AXIS_TIME, sigma=5, niter=9, iter_sigma=5, Df=1, Dt=1, two_pass=0)
       intensity_clipper(nt_chunk=1024, axis=AXIS_NONE, sigma=5, niter=9, iter_sigma=3, Df=2, Dt=16, two_pass=0)
       intensity_clipper(nt_chunk=1024, axis=AXIS_FREQ, sigma=5, niter=9, iter_sigma=3, Df=2, Dt=16, two_pass=0)
       polynomial_detrender(nt_chunk=1024, axis=AXIS_TIME, polydeg=4, epsilon=0.01)
       spline_detrender(nt_chunk=0, axis=AXIS_FREQ, nbins=6, epsilon=0.0003)
       wi_sub_upsampler
   polynomial_detrender(nt_chunk=1024, axis=AXIS_TIME, polydeg=4, epsilon=0.01)
   spline_detrender(nt_chunk=0, axis=AXIS_FREQ, nbins=6, epsilon=0.0003)
```

Masoud Rafiei-Ravandi

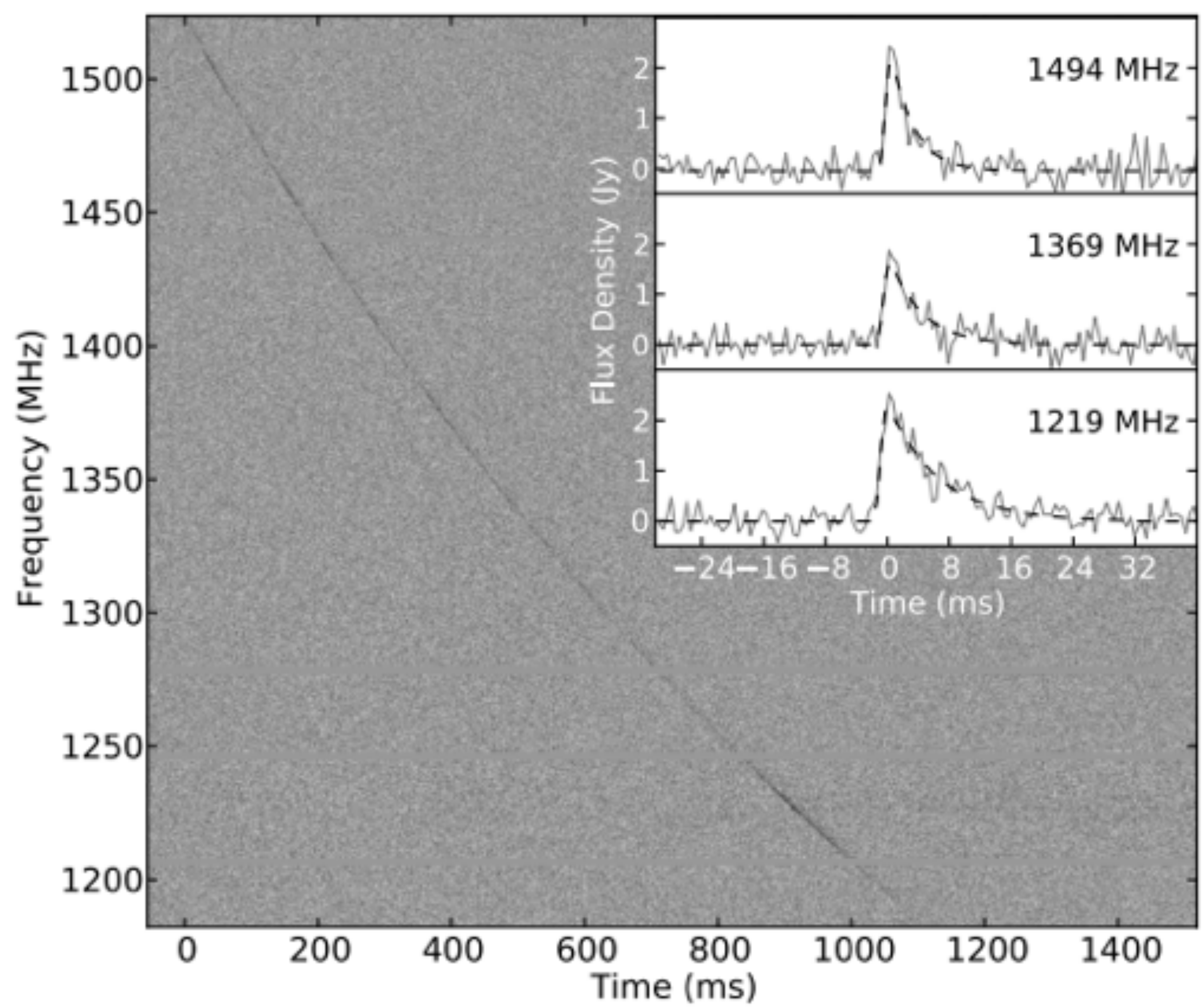
1. The CHIME concept
2. CHIME science goals
3. Challenges
4. The real-time CHIME FRB pipeline
5. Recent CHIME FRB results
6. Concluding thoughts

FRB's are dispersed: arrival time is frequency-dependent.

$$t_{\mathrm{arr}} \propto (\mathrm{DM})\ \nu^{-2}$$

The coefficient (DM) is the "dispersion measure". Proportional to electron density integrated along the line-of-sight (units pc cm^{-3}).

$$\mathrm{DM} \propto \int \rho_e(x)\, dx$$



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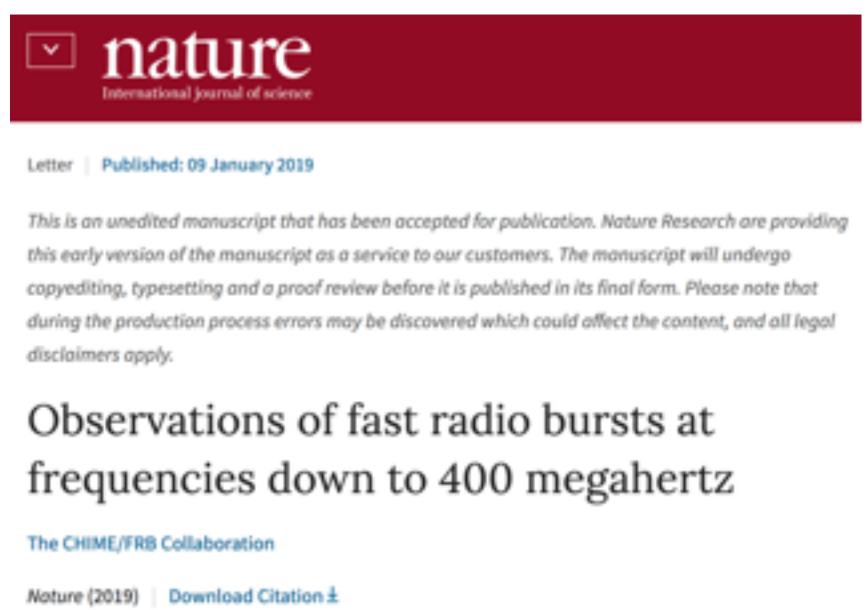
FRB's are bright pulses whose DM is much larger than the max DM from the Milky Way, suggesting a cosmological population. (Also isotropic on sky, i.e. not associated with Galactic plane.)

Before CHIME, around 50 FRB's had been discovered, including one repeating FRB ("the" repeater).

The repeater is much better studied than the non-repeating FRB's, in particular the host galaxy has been determined (at z=0.2).

In January, we published two CHIME FRB science papers, describing 13 events found during precommissioning.

A much longer set of preliminary results will be presented at the Amsterdam FRB conference on Monday.)


nature
International journal of science

Letter | Published: 09 January 2019

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Observations of fast radio bursts at frequencies down to 400 megahertz

The CHIME/FRB Collaboration

Nature (2019) | Download Citation

arxiv:1901.04524


nature
International journal of science

Letter | Published: 09 January 2019

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A second source of repeating fast radio bursts

The CHIME/FRB Collaboration

Nature (2019) | Download Citation

arxiv:1901.04525

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Canadian astronomers discover 2nd mysterious repeating fast radio burst

nature

NEWS · 07 JANUARY 2019

CORRECTION 07 JANUARY 2019

Bevy of mysterious fast radio bursts spotted by Canadian telescope

Bounty includes second known example of a repeating burst.

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Science & Environment

Mysterious radio signals from deep space detected

The New York Times

Broadcasting from Deep Space, a Mysterious Series of Radio Signals

The Canadian Hydrogen Intensity Mapping Experiment, or Chime, a radio telescope array in British Columbia. Soon after it was turned on last summer, it picked up a set of odd radio bursts from deep space. Will Ivy/Alamy Stock Photo

CNN Health + Live TV

SPACE + SCIENCE

A second mysterious repeating fast radio burst has been detected in space

The Guardian

Alien life

Mysterious fast radio bursts from deep space 'could be aliens'

Repeating bursts of radio waves detected for first time since initial accidental discovery in 2007

!!!

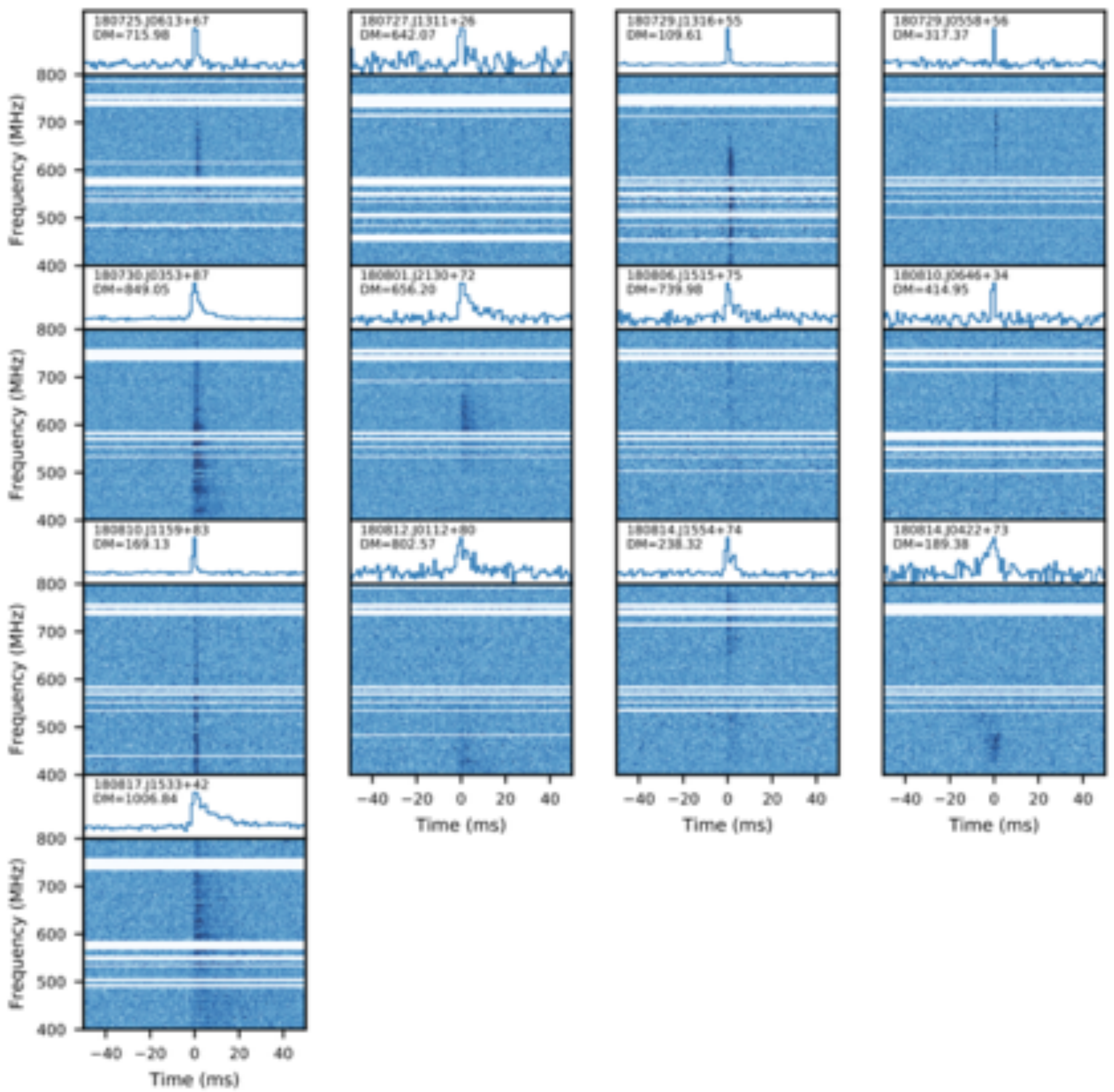
Main results:

- 13 new FRB's discovered, in new freq range (400-800 MHz)
- Best measurement of FRB "scattering" (will define shortly)
- New repeating FRB found! (will elaborate shortly)
- These results based on ~1 month of engineering data, at subscale capacity.

Lots of caveats. New telescope, still under construction!

- Don't have polarization data yet.
- Uncalibrated, can't measure absolute frequency spectrum.
- Angular resolution currently suboptimal (can be improved with "baseband dumps")
- Selection function not well-characterized yet.

13 new FRB's from CHIME



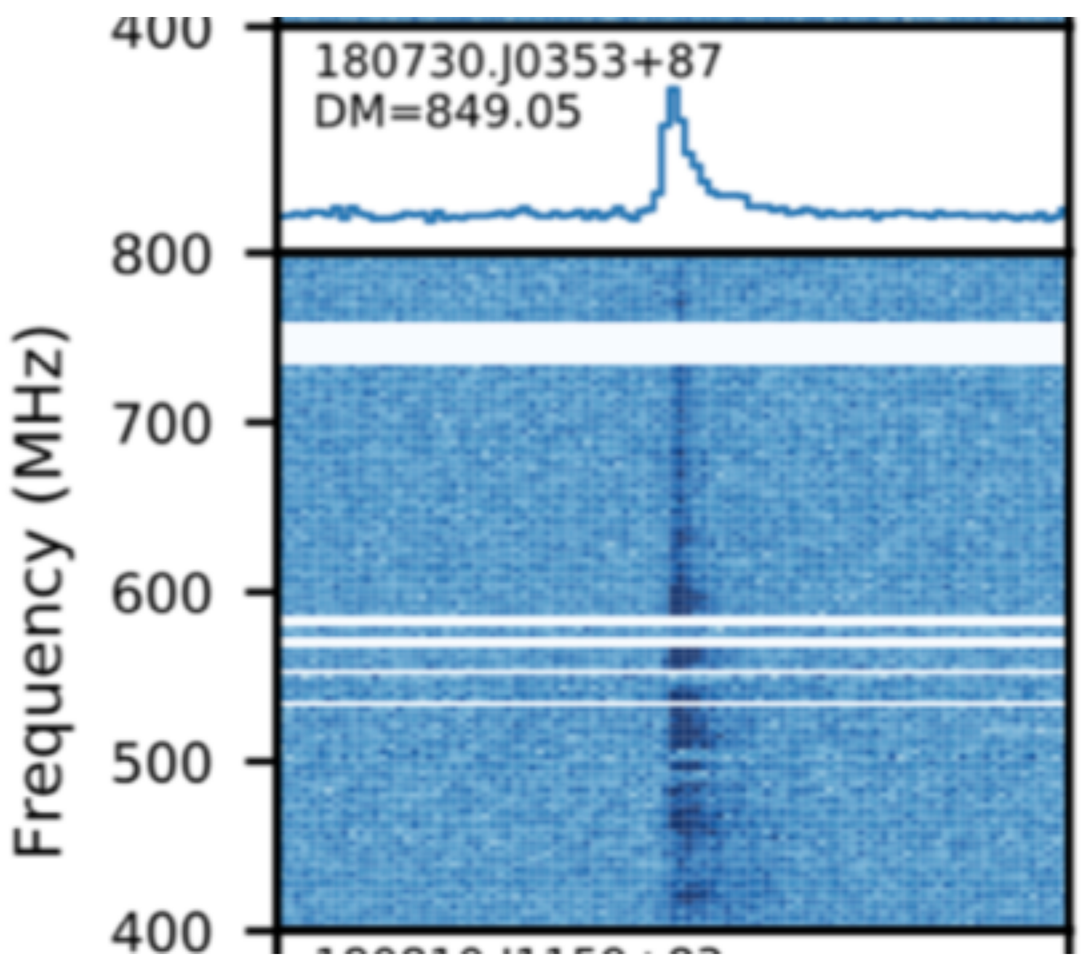
FRB	Width (ms)	DM (pc cm^{-3})	DM_{MW} (pc cm^{-3})	R.A. (hh:mm)	Dec. (dd:mm)	Dec. FWHM (deg)	SNR	τ (ms)
180725.J0613+67	$0.31^{+0.08}_{-0.07}$	$715.98^{+0.02}_{-0.01}$	71, 80	06:13	+67:04	0.34	34.5	$1.18^{+0.13}_{-0.12}$
180727.J1311+26	0.78 ± 0.16	642.07 ± 0.03	21, 20	13:11	+26:26	0.35	14.2	0.6 ± 0.2
180729.J1316+55	0.12 ± 0.01	109.610 ± 0.002	31, 23	13:16	+55:32	...	243.1	< 0.15
180729.J0558+56	< 0.08	317.37 ± 0.01	95, 120	05:58	+56:30	0.32	25.2	< 0.26
180730.J0353+87	0.42 ± 0.04	849.047 ± 0.002	57, 58	03:53	+87:12	0.44	92.4	1.99 ± 0.05
180801.J2130+72	0.51 ± 0.09	656.20 ± 0.03	90, 108	21:30	+72.43	0.35	41.1	5.0 ± 0.3
180806.J1515+75	< 0.69	739.98 ± 0.03	41, 34	15:15	+75.38	0.56	17.5	3.6 ± 0.8
180810.J0646+34	< 0.27	414.95 ± 0.02	104, 140	06:46	+34.52	0.33	17.7	< 0.40
180810.J1159+83	0.28 ± 0.03	169.134 ± 0.002	47, 41	11:59	+83.07	0.38	56.7	< 0.18
180812.J0112+80	$1.25^{+0.49}_{-0.47}$	802.57 ± 0.04	83, 100	01:12	+80:47	0.38	19.8	$1.9^{+0.3}_{-0.4}$
180814.J1554+74	< 0.18	238.32 ± 0.01	41, 35	15:54	+74:01	0.58	29.7	2.4 ± 0.3
180814.J0422+73	2.6 ± 0.2	189.38 ± 0.09	87, 100	04:22	+73:44	0.35	24.0	< 0.40
180817.J1533+42	< 0.37	1006.840 ± 0.002	28, 25	15:33	+42:12	0.32	69.9	8.7 ± 0.2

- At lower frequencies than previous FRB observations (400-800 MHz)
- Previously, almost all FRB's were detected at 1.4 GHz, with the exception of a few at ~800 MHz.
- All searches at <~ 200 MHz have been unsuccessful, suggesting a spectral cutoff.
- However, ~half of the CHIME FRB's are bright at 400 MHz.

“Scattering”

If the plasma along the line of sight is turbulent, then multipath propagation (“scattering”) will broaden the pulse in a frequency-dependent way:

$$\text{Width} \propto \nu^{-4}$$



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“Scattering”

If the plasma along the line of sight is turbulent, then multipath propagation (“scattering”) will broaden the pulse in a frequency-dependent way:

$$\text{Width} \propto \nu^{-4}$$

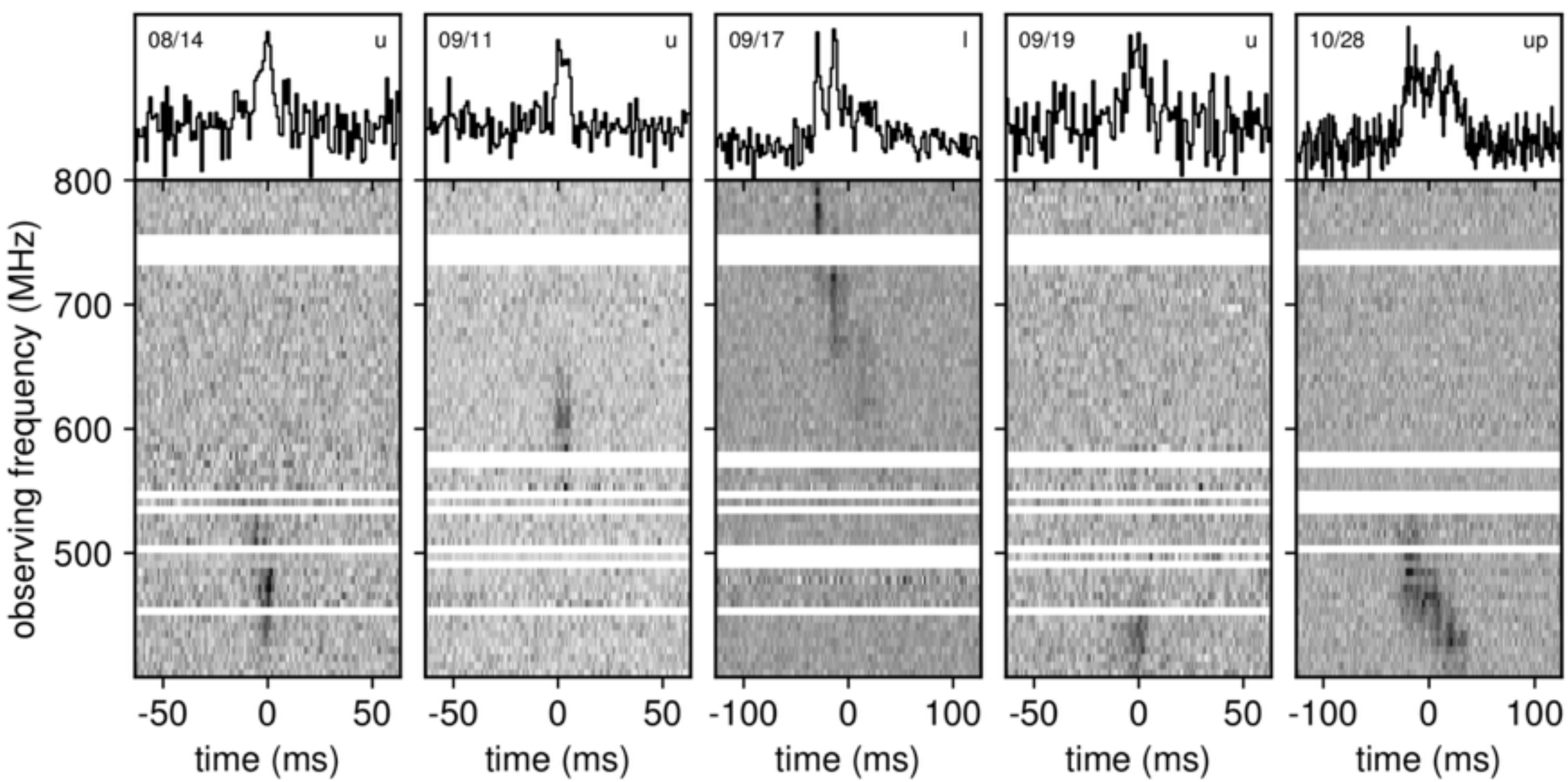
Because CHIME is at low frequencies, it gives the best constraints on FRB scattering. Around half of our 13 FRB’s are significantly scattered.

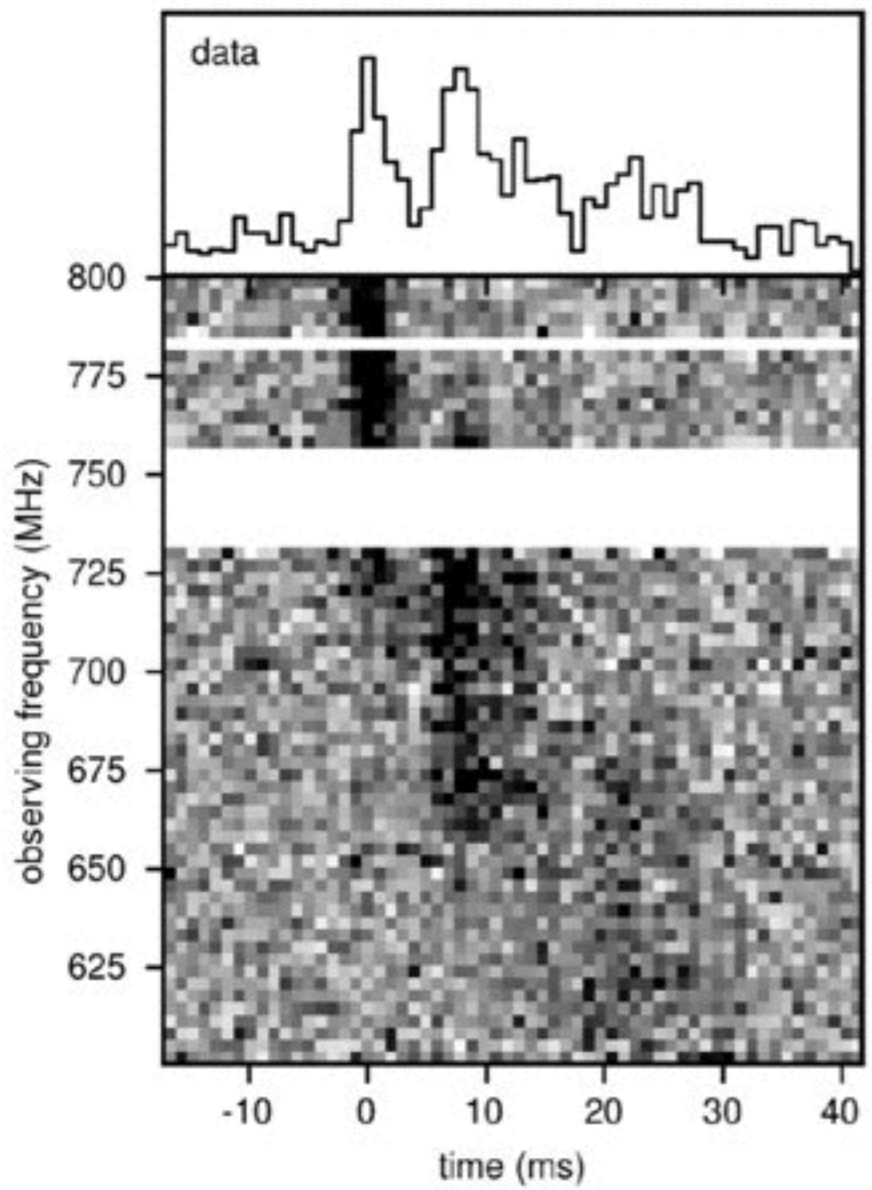
Scattering may arise either from our galaxy, the host galaxy, or the local environment of the FRB (like dispersion!). The level of scattering seen in CHIME is higher than simple models of the host galaxy (+ our galaxy) predict.

Suggests that some scattering/turbulence is local to the FRB.

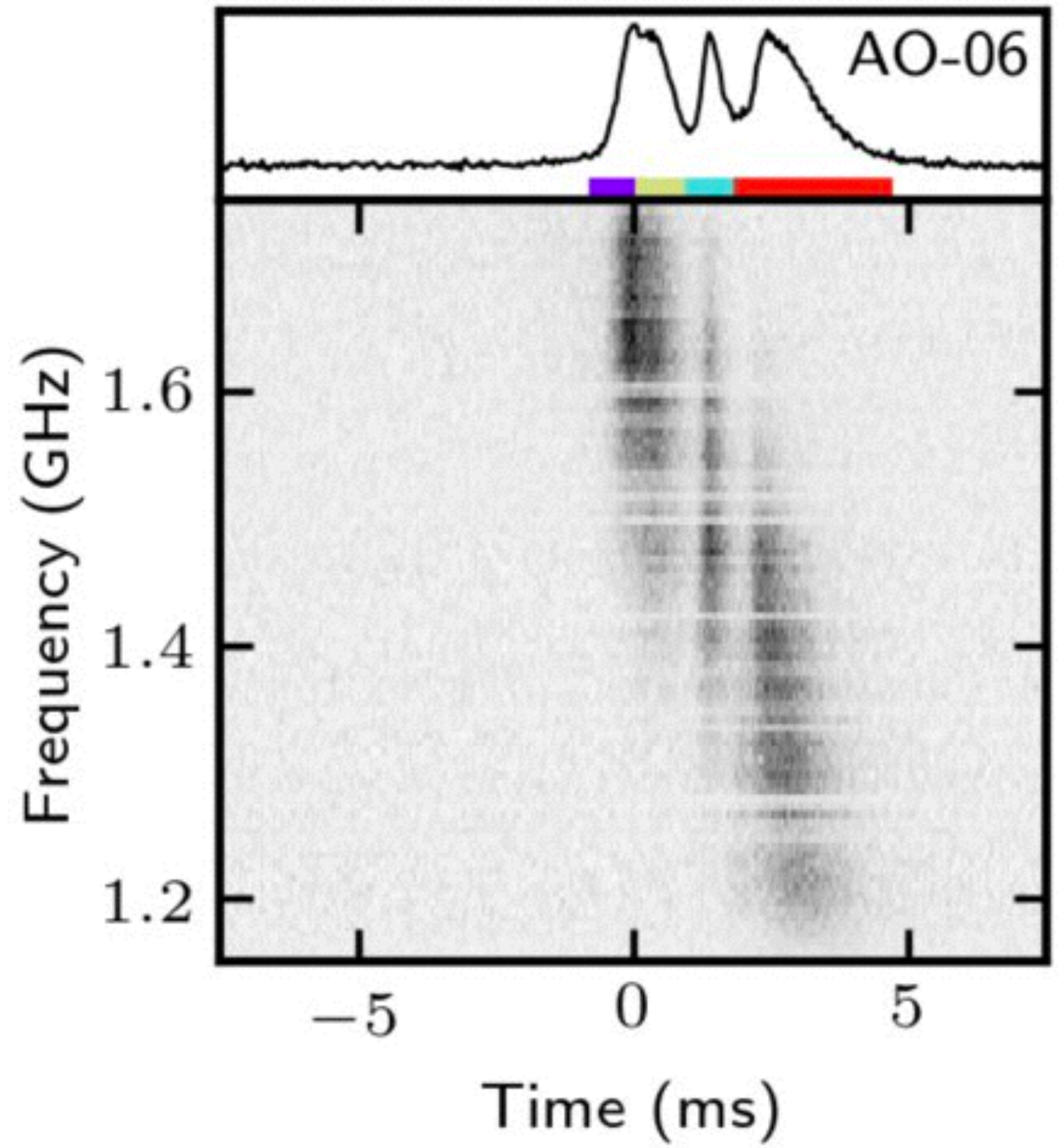
New repeating FRB!

Dispersion measure: DM=189 (max galactic DM ~95 along its line of sight)





CHIME repeater (R2)



“The” repeater (R1)

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Concluding thoughts

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- CHIME is a testbed for improving radio astronomy algorithms/software, to handle unprecedented data volumes.

Concluding thoughts

- For $15M, you can build the world's most powerful radio telescope!
- … but you will have an immense data rate, and you'll need to solve extremely hard computing problems.
- CHIME is a testbed for improving radio astronomy algorithms/software, to handle unprecedented data volumes.
- If these improvements are successful, there is a clear path to scaling up the CHIME hardware by a factor of ~100 or so (in mapping speed) in the near future.

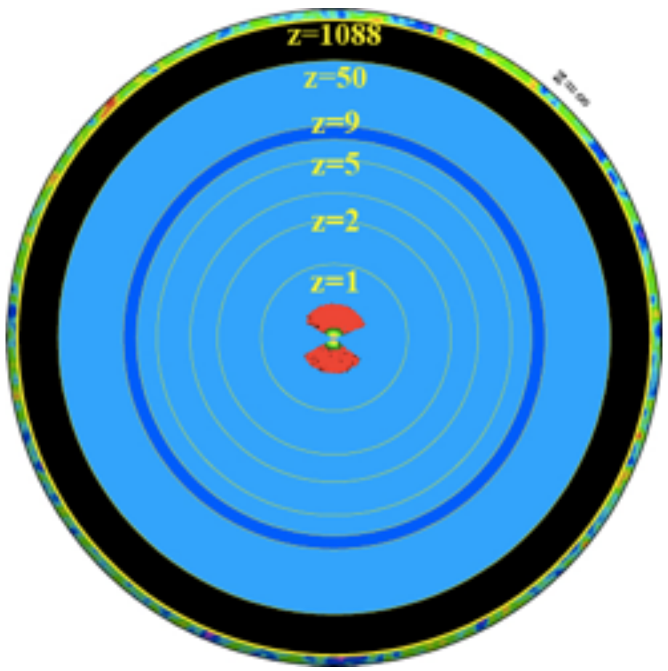
- HIRAX, a South African “sister” project to CHIME
    - Array of 1024 dishes (no cylinders)
    - Outrigger telescopes for very high resolution!
    - In Southern hemisphere (more pulsars)

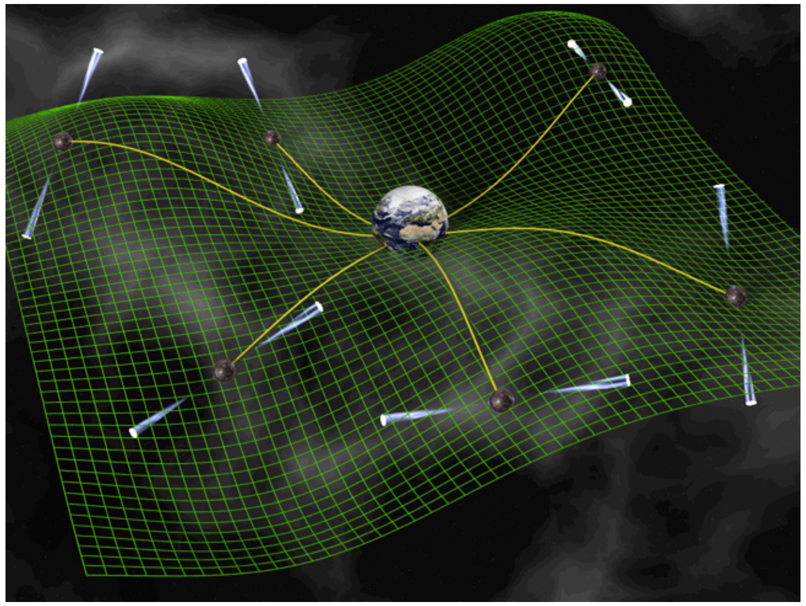
- HIRAX has ~4 times the collecting area of CHIME, and the same number of beams, so 4 times CHIME mapping speed.

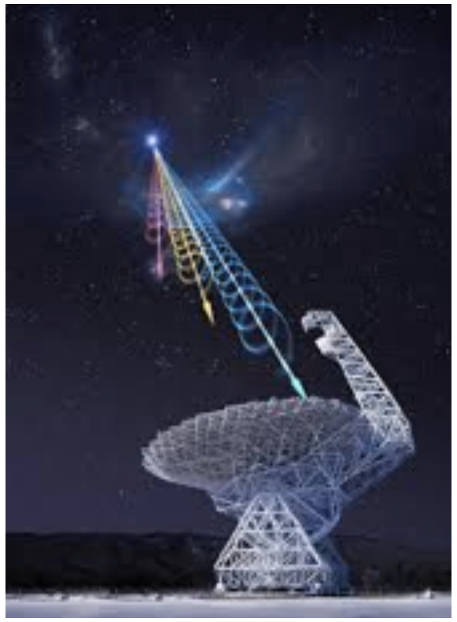
- Expanding HIRAX to 2048 dishes would give 16 times CHIME mapping speed.

Concluding thoughts

Radio astronomy may be "scaled up" by orders of magnitude in the near future. The discovery space is huge!







Cosmology:

- 3D "super CMB"
- most powerful way (?) to measure many cosmological parameters (early universe, neutrinos, dark matter, etc.)

Pulsars:

- new tests of GR
- new probe of gravity waves
- rich astrophysics

Fast radio bursts:

- what are they?
- potential applications…?

Thanks!