Current and Future Work on Fast Transient Search Algorithms

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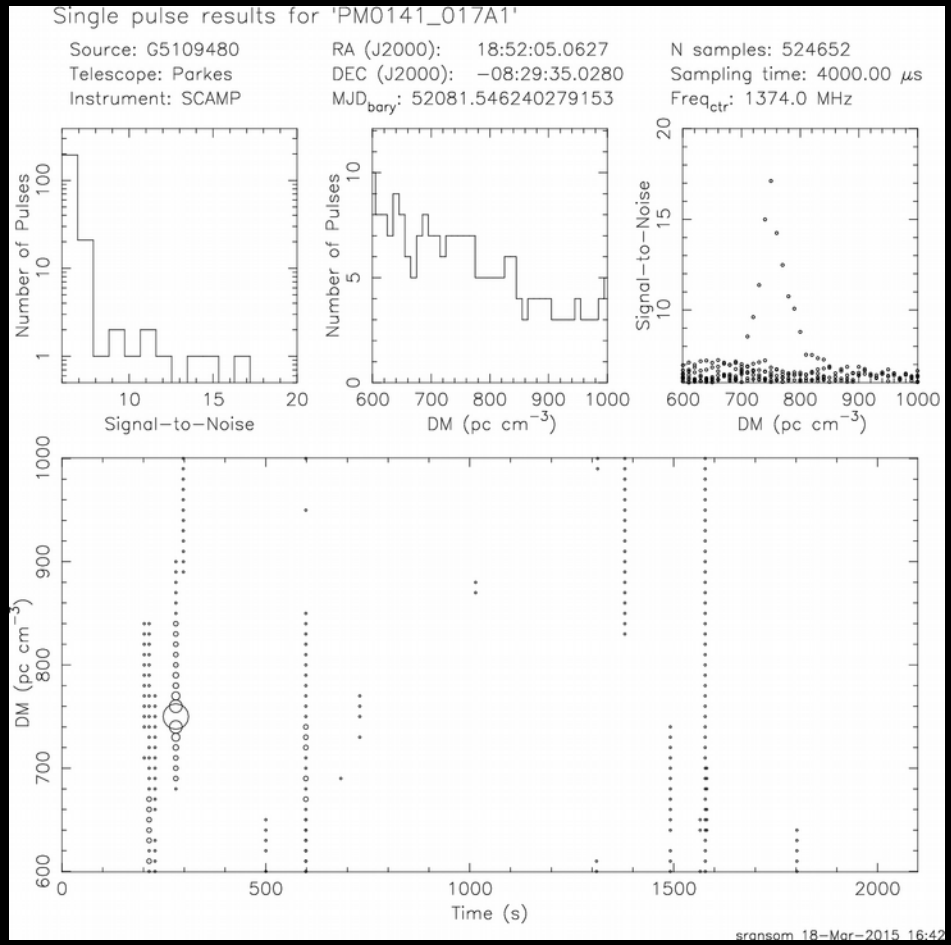


Basic FRB Search Algorithm

- The following is done *per beam*
  - RFI characterization / excision
  - De-dispersion
  - Matched Filter Search (usually boxcar)
  - Candidate sifting
- Since there is no (or very little) integration, algorithm can be pipelined and realtime
- De-dispersion is by far the most expensive step

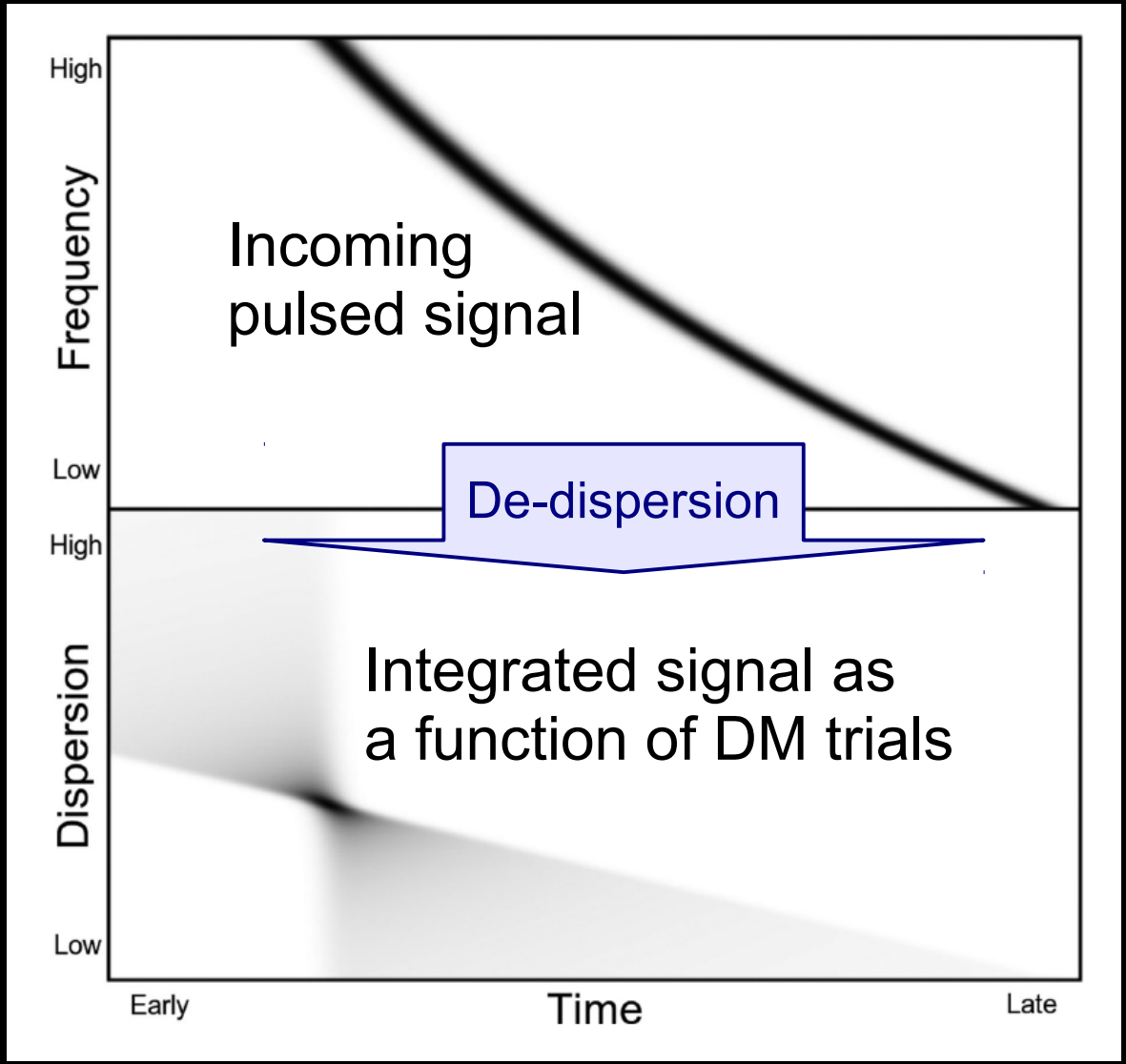
Dispersion

Lower frequency radio waves are delayed with respect to higher frequency radio waves by the ionized interstellar medium (ISM)

$\Delta t \propto DM\nu^{-2}$

(DM = Dispersion Measure)

- Need ~10^4 frequency channels
- DM for undiscovered pulsar/FRB is unknown
- Must search over ~few x 10^4 trial DMs!
- This multiplies data rate by factor of few
- De-dispersion is very I/O intensive



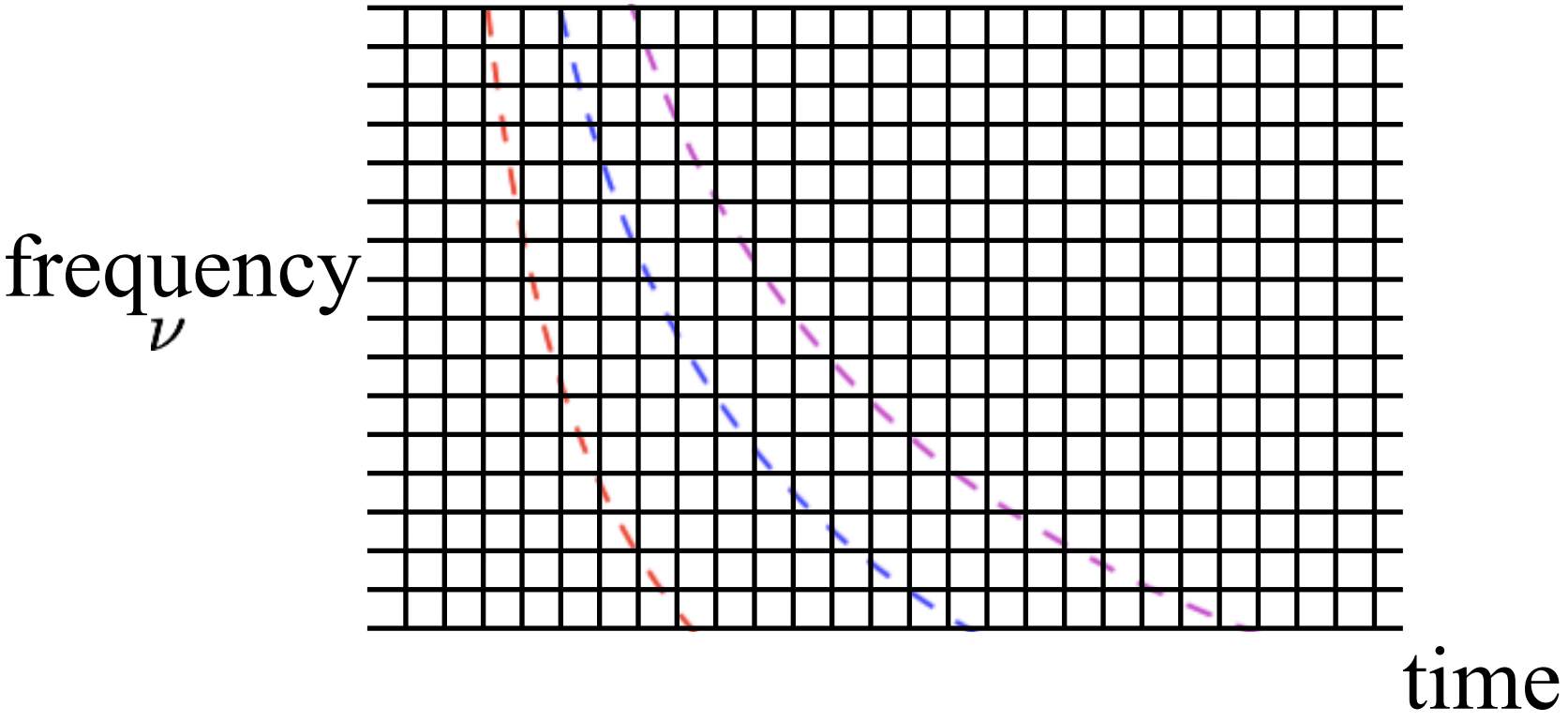
Barsdell et al 2012

De-dispersion State-of-the-Art

- All de-dispersion is limited by memory bandwith
  - Arithmetic intensity per memory access is low
- Brute force dedisp ~$O(N_{chan}^2)$
  - Often use GPUs:
    - *dedisp* (in HEIMDALL), ARTEMIS, Maggro code…
  - Very flexible (e.g. DM spacing, optimality)
- Tree Algorithms ~$O(N_{chan} \log_2 N_{chan})$
  - Known since early 1970s, but often ignored
  - New variants fix lots of “problems”
    - FDMT (Zackay et al. 2016), *bonsai* (Smith et al., in prep)

Incoherent dedispersion

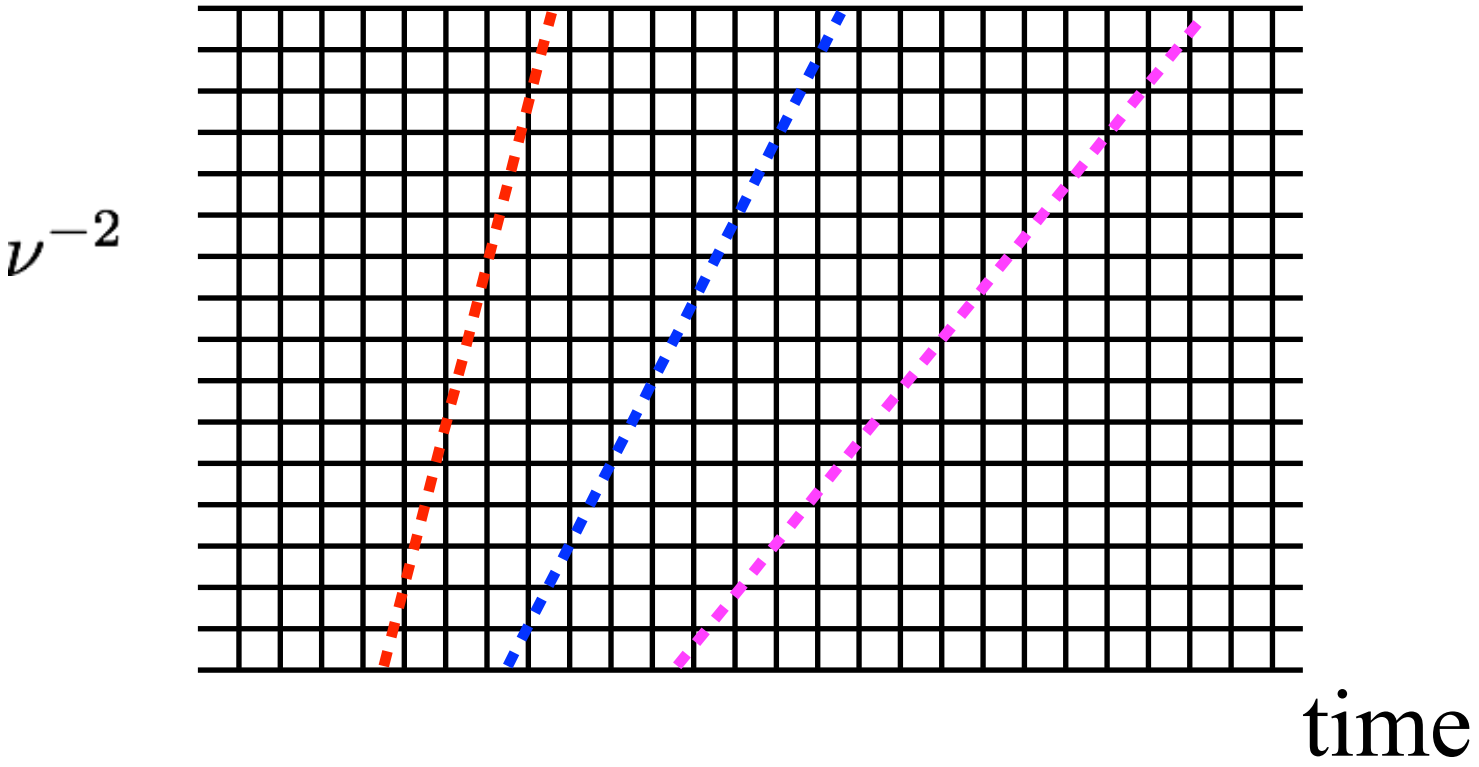
FRB backend incrementally receives a 2D array with (time, frequency) axes. We want to sum over all “tracks” with the shape shown.



Slide from Kendrick Smith

Incoherent dedispersion

The first step is to change variables $\nu \rightarrow \nu^{-2}$
in order to transform the curves to straight lines.



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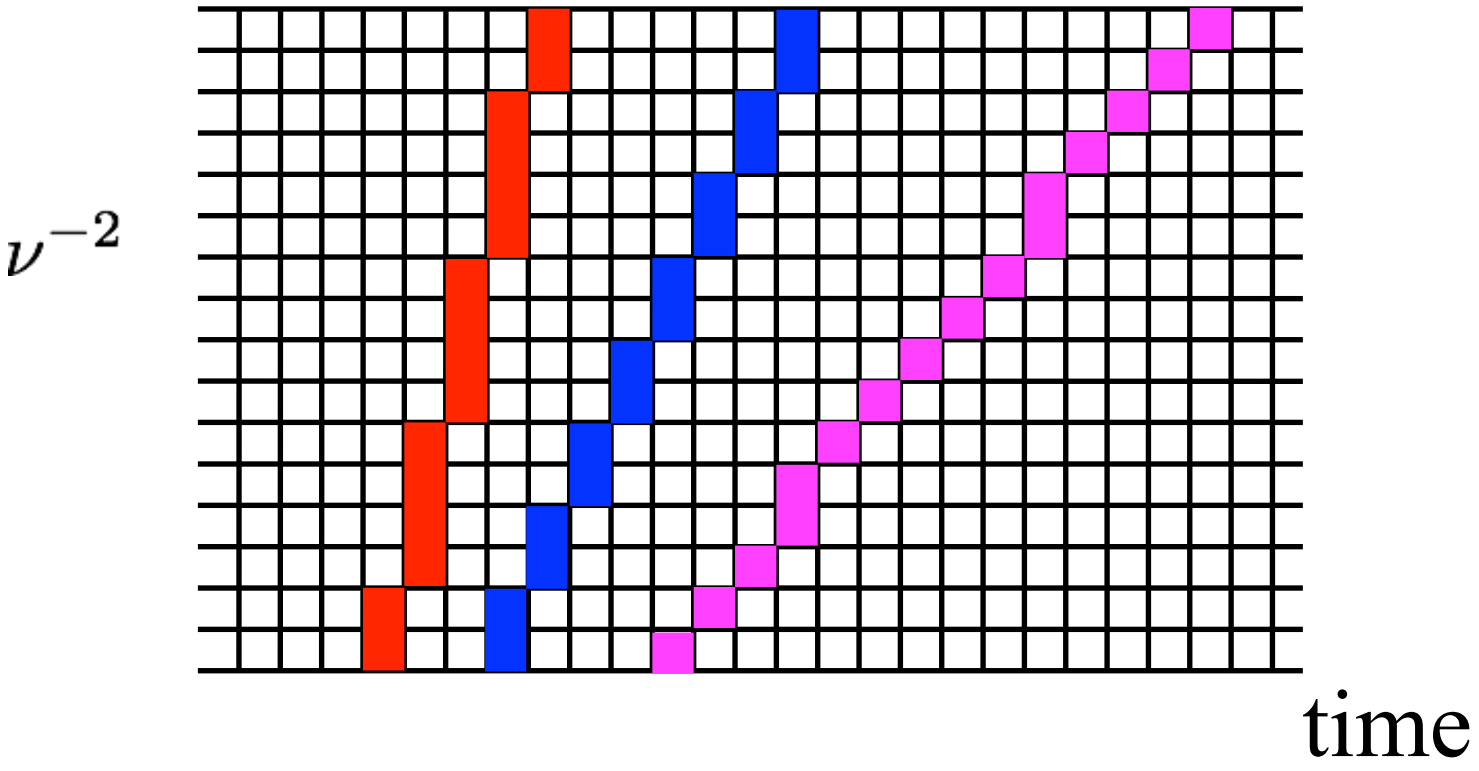
Tree dedispersion

The algorithm I'll describe is a "tree" algorithm which ends up approximating each straight-line track by a jagged sum of samples.



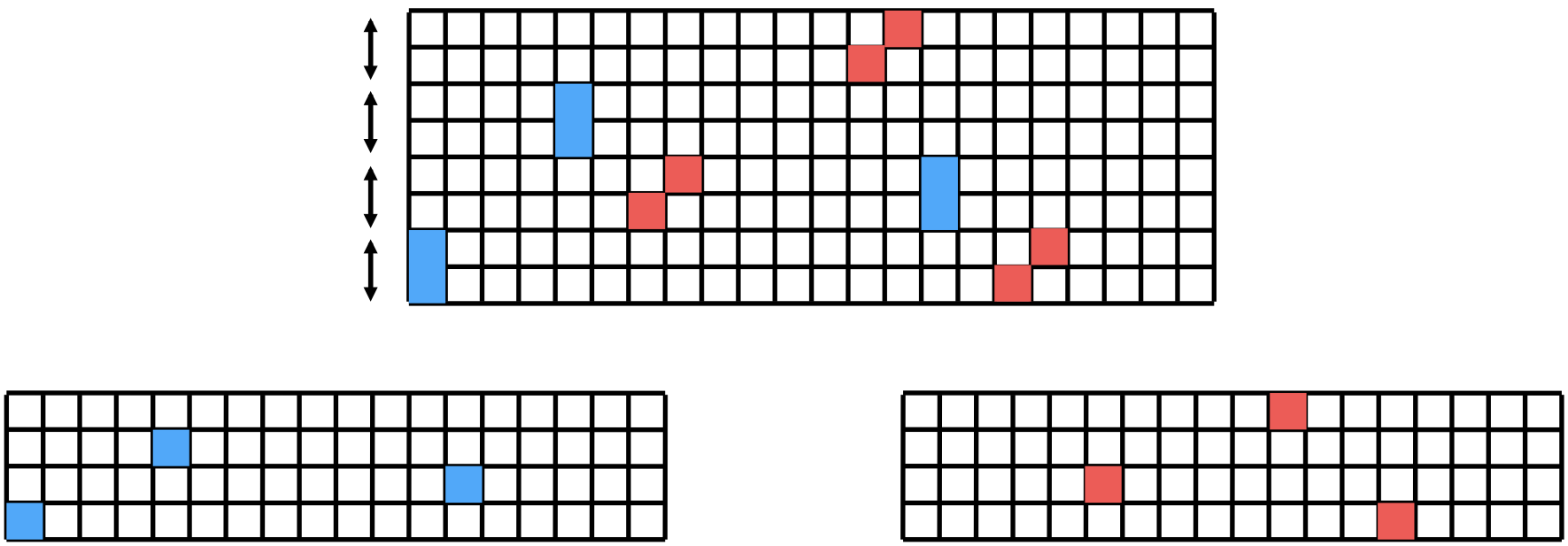
The sums are built up recursively.

Slide from Kendrick Smith

Tree dedispersion

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.



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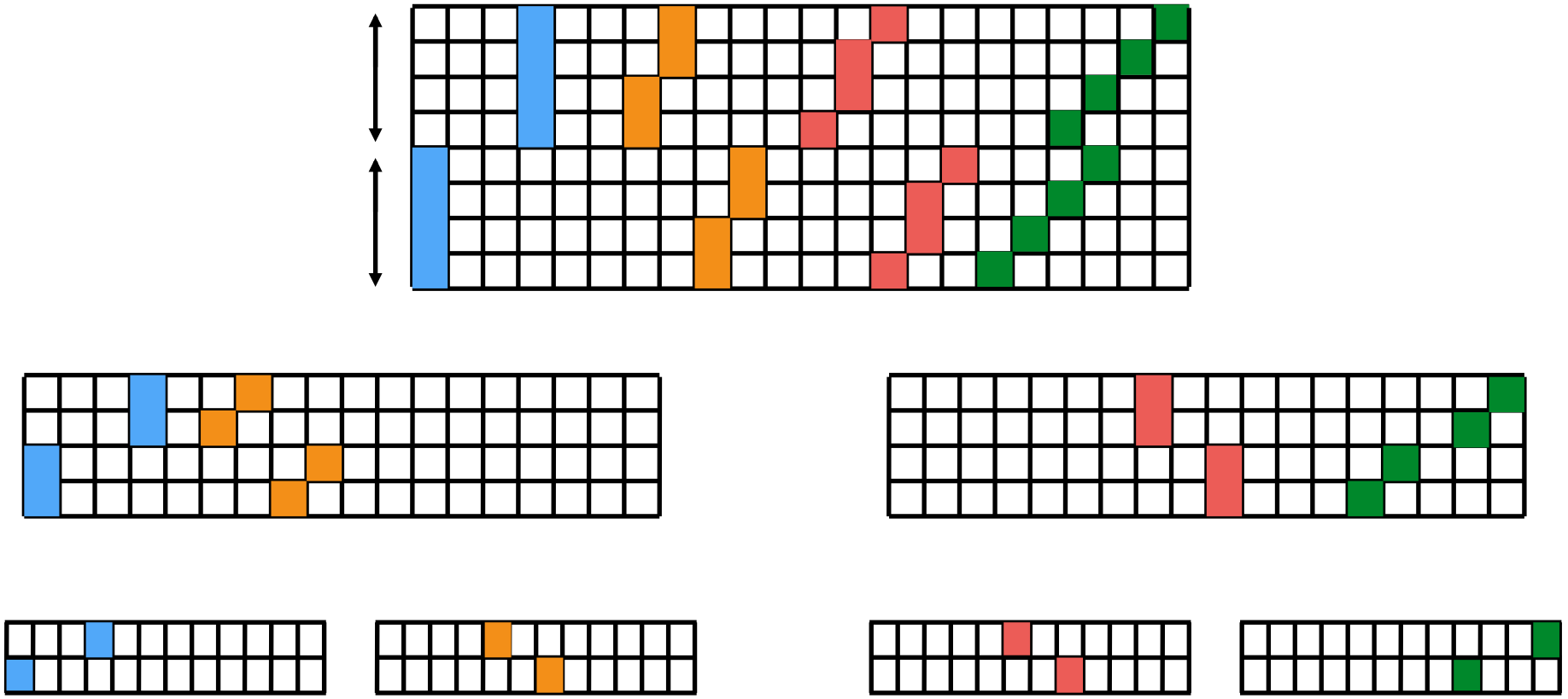
Tree dedispersion

Second iteration: sum pairs into “pairs of pairs”.

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



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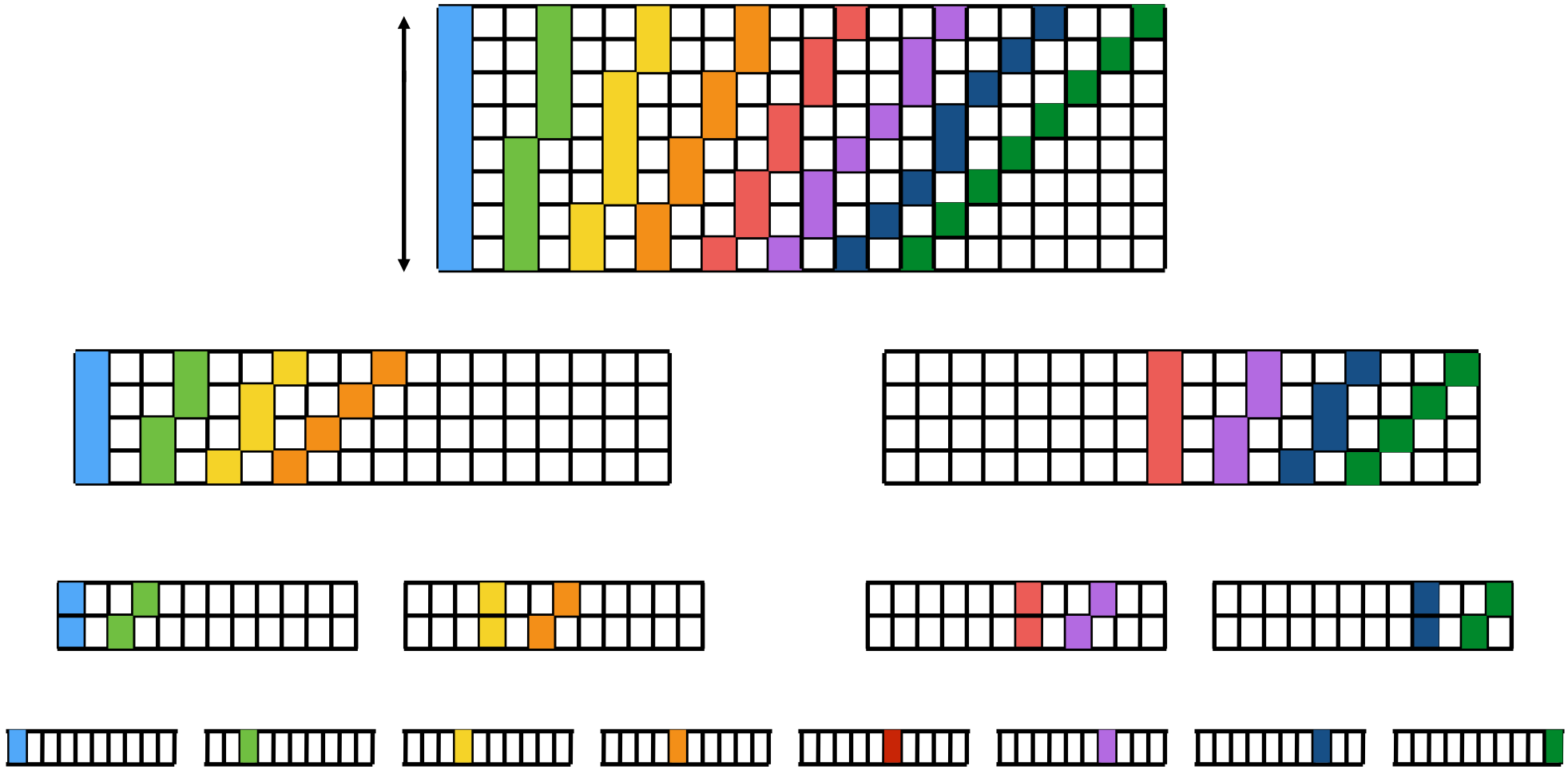
Tree dedispersion

Last iteration: all channels summed.



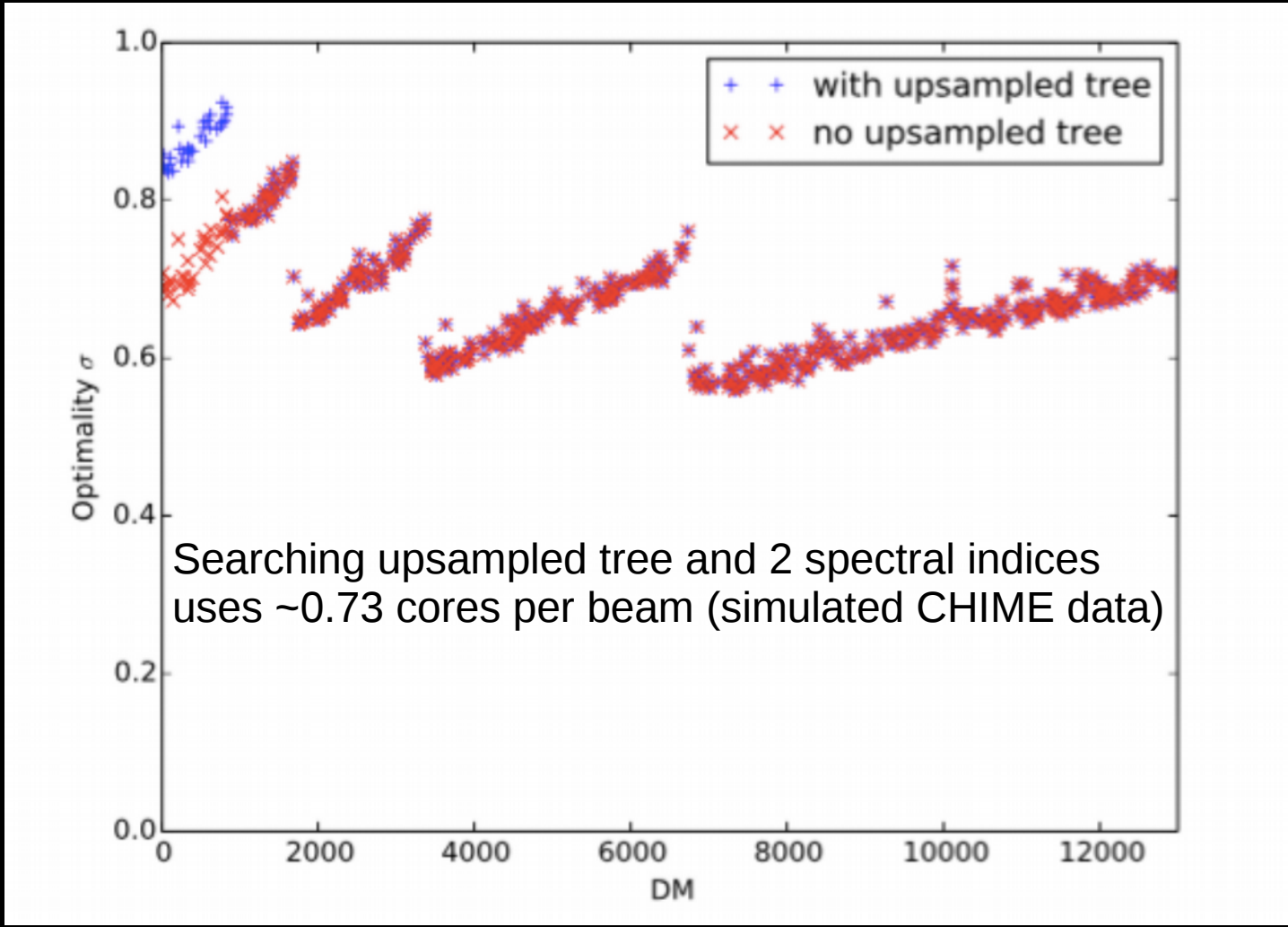
Slide from Kendrick Smith

bonsai by Kendrick Smith

- Highly optimized, multi-core, CPU-based, tree code (based on already good code by Jonathan Sievers)
- Mathematically proved that a “proper” tree-code could be made arbitrarily close to optimum
  - Increase N_{chan}, “smear” channels, upsampled (in time) tree
- Showed it could be generalized to search over spectral indices, scattering index, intrinsic width
- “Blocked” formulation allow extreme cache friendliness, better parallelism, and partial-band triggers
- Hand-optimized: vector intrinsics, linear speedup on multicore, special techniques for memory BW

Extensive Monte-Carlo Testing

- Random pulse injections with various pulse parameters (phase, width, scattering, spectral index)



Dedispersion Summary

- Because of low arithmetic intensity, GPUs are *not* the end-all-be-all solution for dedispersion
  - Rise of multi-core CPUs and GPU “extra” power-usage both contribute to this
- A better algorithm (i.e. “proper” tree-dedisp) makes a huge difference
- *bonsai* will be released on github soon

Dealing with Many Beams at Once

- Each beam is independent
  - Leads to pipelined processing per beam
  - Requires zero communications between beams
  - “pleasingly” parallel
- RFI is huge problem, and contributes to some or all beams (i.e. inter-beam correlations)
- Inter-beam communication to deal with RFI can cause significant loss of parallelism
  - Need to ensure communication costs are low
  - This is typically handled in the “sifting” stage

FRB Searching with Interferometers

- Generate sky pixels vs time by 1 of 2 ways:
  - Beamforming: sum delayed antenna voltages via hardware implementation or highly-vectorized DSP code
    - De-disperse the pixel channels via tree-dedispersion
  - Imaging: transform post-correlator visibilities into an image via FFT
    - De-disperse the visibilities via tree-dedispersion
- Casey Law's *rtpipe* for *realfast* is a great example
- Potentially innovative ways to use autocorrelations (or other correlator products) for RFI removal

Summary

- For single beams, de-dispersion is most costly step
- For interferometers, can be dedisp or imaging
- Use NlogN algorithms whenever possible!
  - Tree-dispersion has seen many improvements
- GPUs are no longer the “obvious” answer
  - Need to carefully check power requirements
  - Weigh pros/cons of CPU speed vs. flexibility and GPU speed vs. programming difficulties and power/cost
- Auto-tune your algorithm to your hardware! (e.g. very cool work by Alessio Sclocco et al. 2016).
- While not trivial, FRB searching is still *much* simpler than searching for binary millisecond pulsars….