Radio Transient Searches

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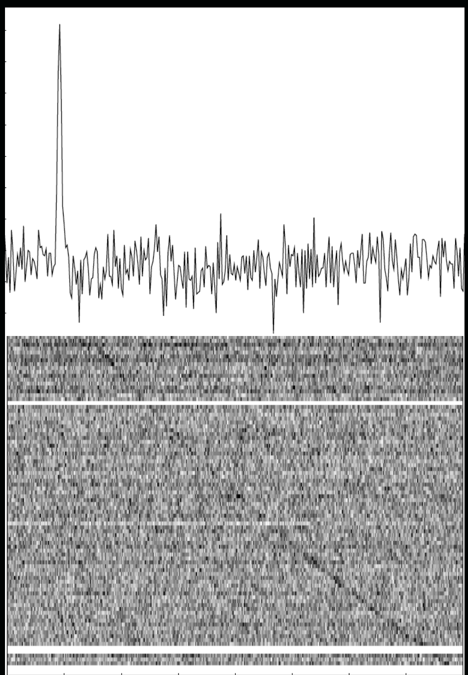

Astroparticle Meeting
4th February 2013,
Bonn, Germany.

Max-Planck-Institut
für Radioastronomie

Radio Transients

- Why? How?
- Searches for fast radio transients
- A famous burst and its friends
- Musings

Radio Transients

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  1. Enables study of interesting physical environments.
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- e.g. Pulse of 1 Jy lasting 1 ms from 1 kpc at obs freq. of 1 GHz (all very typical numbers!)
  -> Causality implies source < 300 km
  -> Brightness Temp >= 10^{23} K
  -> Compact objects + non-thermal coherent emission
  -> extreme astrophysical environments.

Radio Transients

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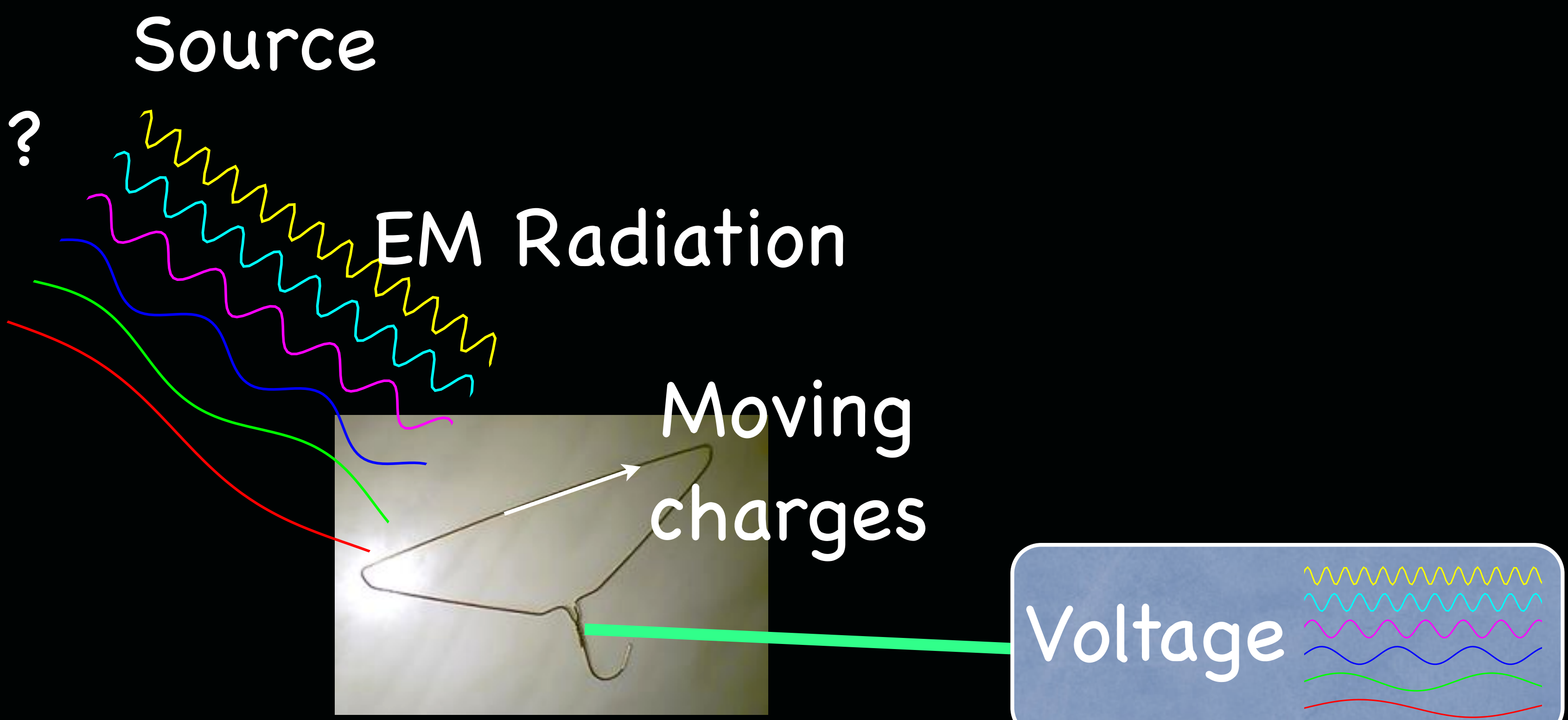
  1. Enables study of interesting physical environments.
  2. You can't avoid them!

- Detected in abundance by TNG radio instruments (LOFAR, FAST, ATA, MWA, ASKAP, MeerKAT, ..., SKA).
  -> would be nice to know what they are!



Basic Radio Antenna



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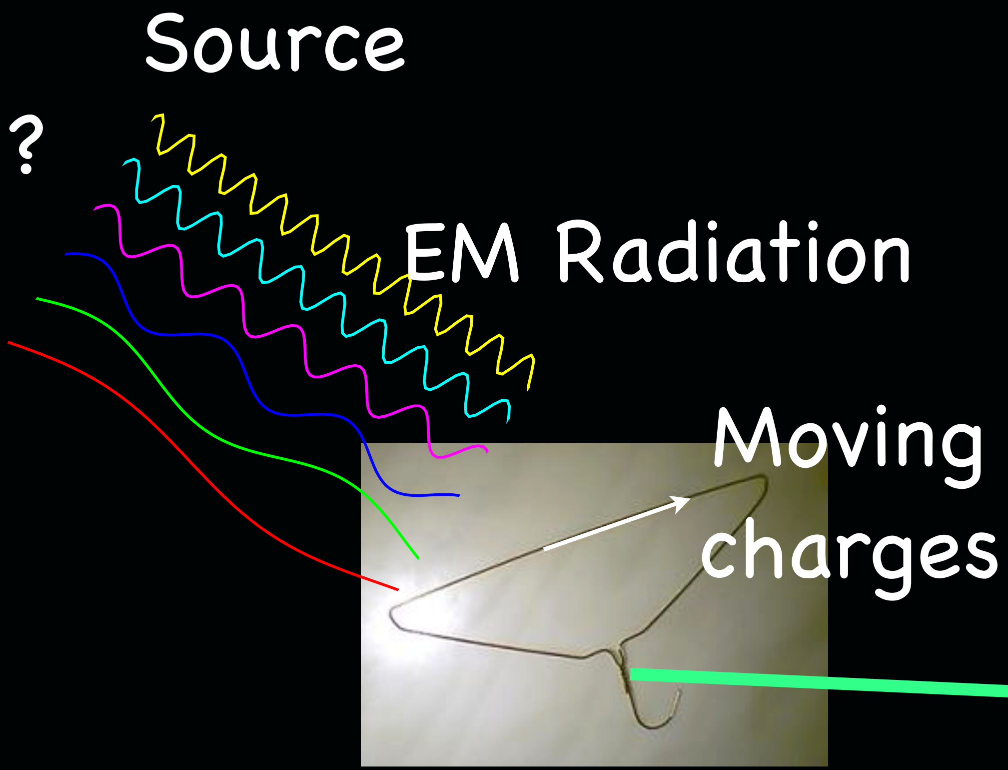
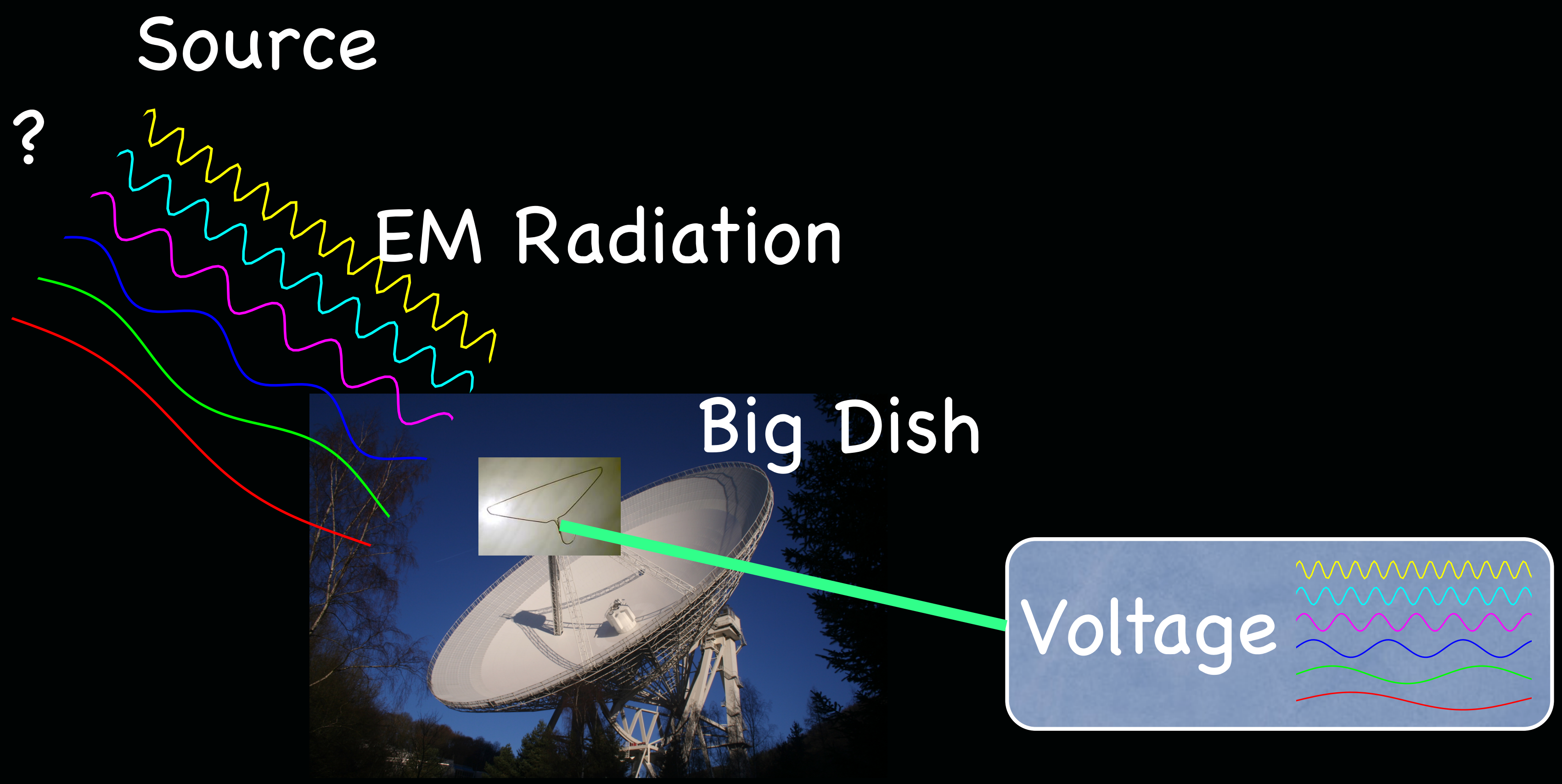
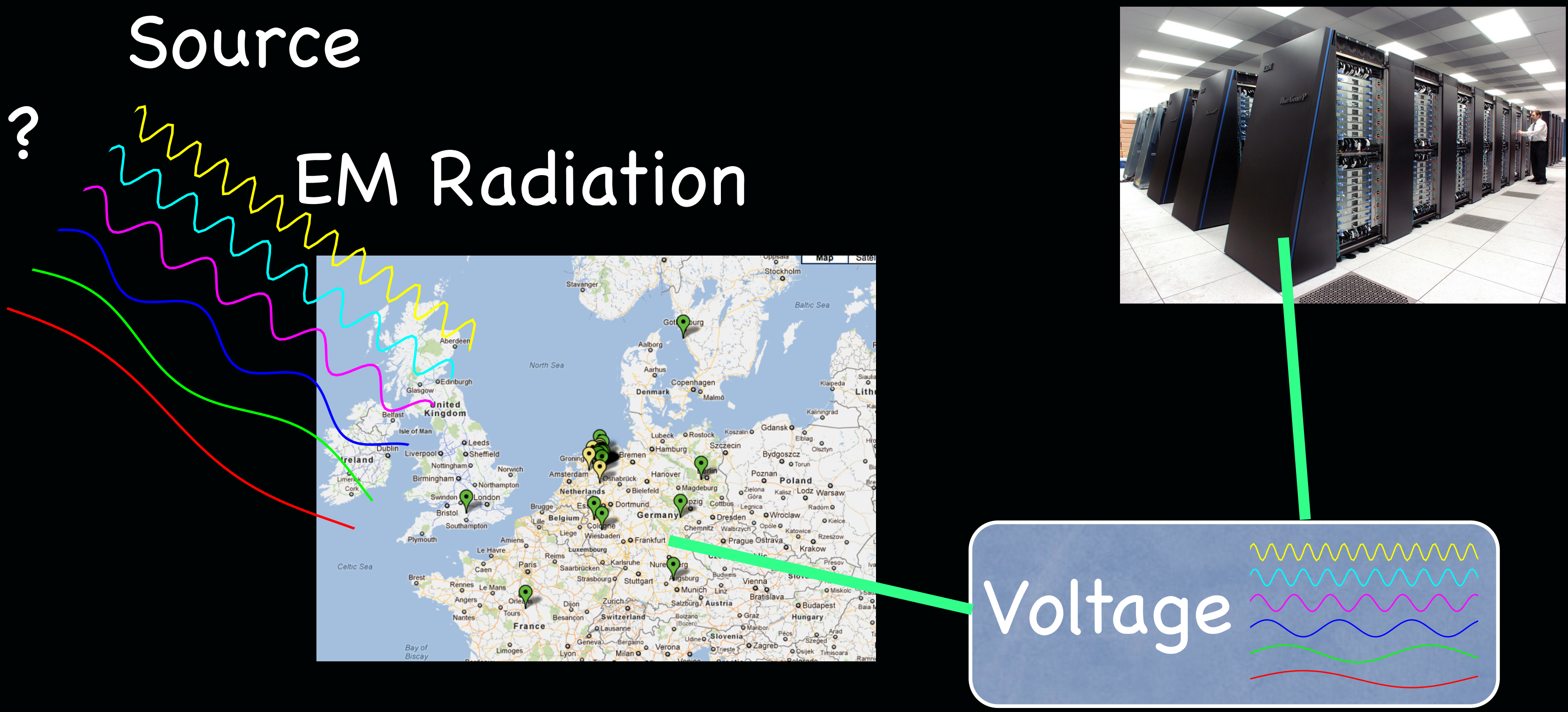


Voltages directly proportional to the E fields.

Big Dishes



Arrays



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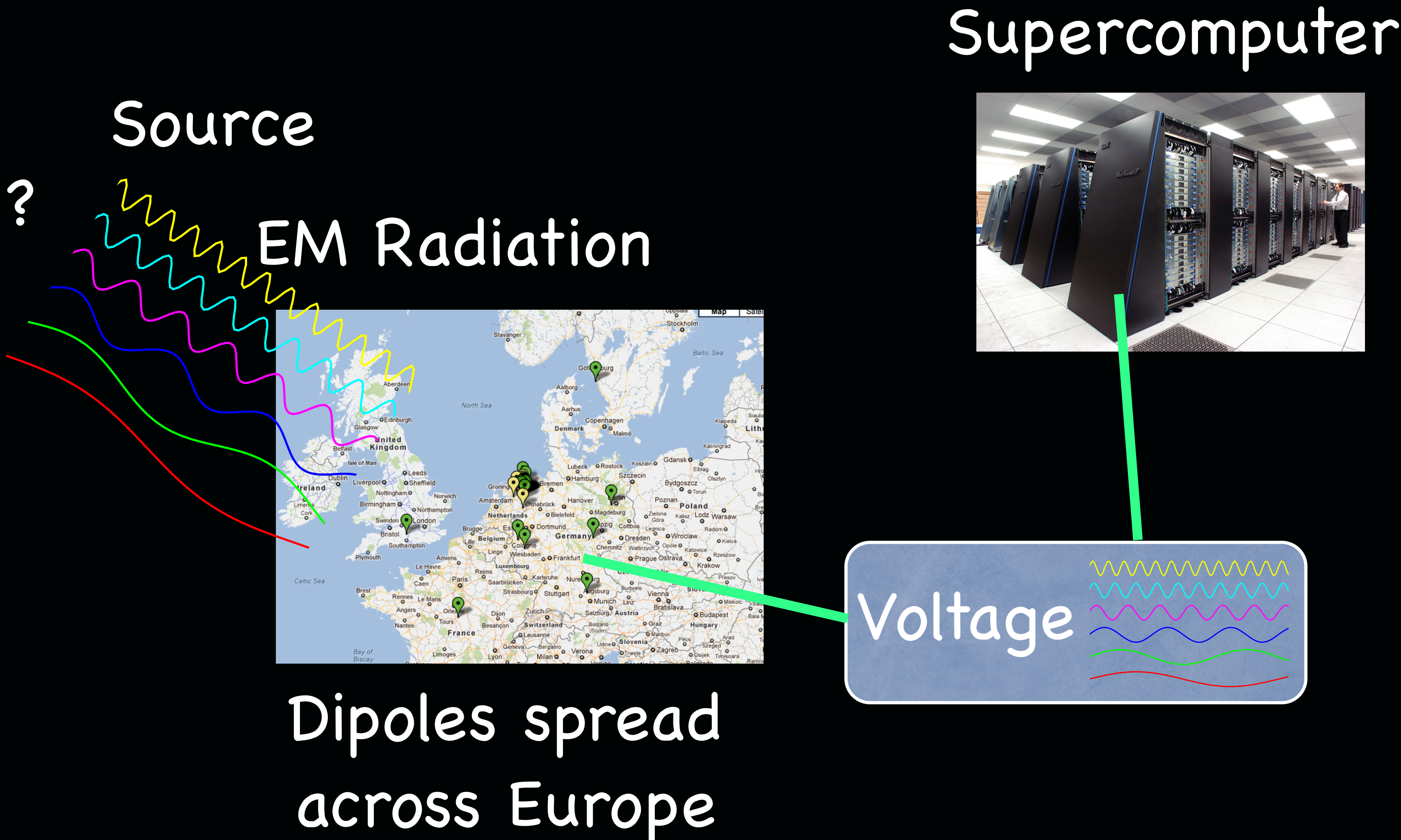
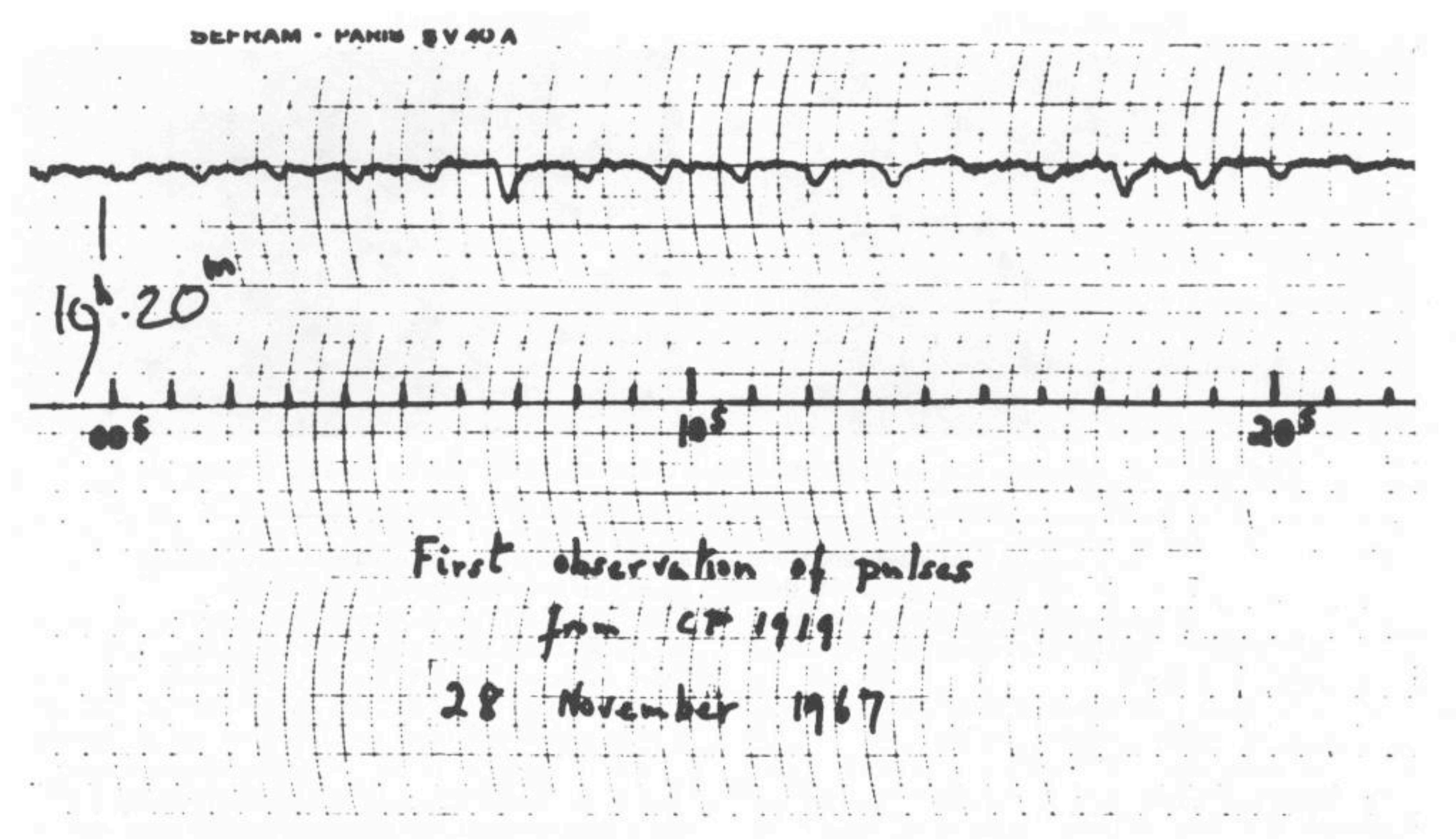

Supercomputer
Source
?
EM Radiation
Voltage
Dipoles spread across Europe

Pulsars

- First pulsars were found using narrowband instruments and slow time sampling

- Strips of pen chart paper
- Once bright ones were all found, quickly realised that to increase sensitivity more BW needed
- Need to account for interstellar dispersion "may need as many as 2 frequency channels"

Pulsars



"I got it on a fast recording. As the chart flowed under the pen I could see that the signal was a series of pulses . . . 1⅓ seconds apart." (Deflections are down).

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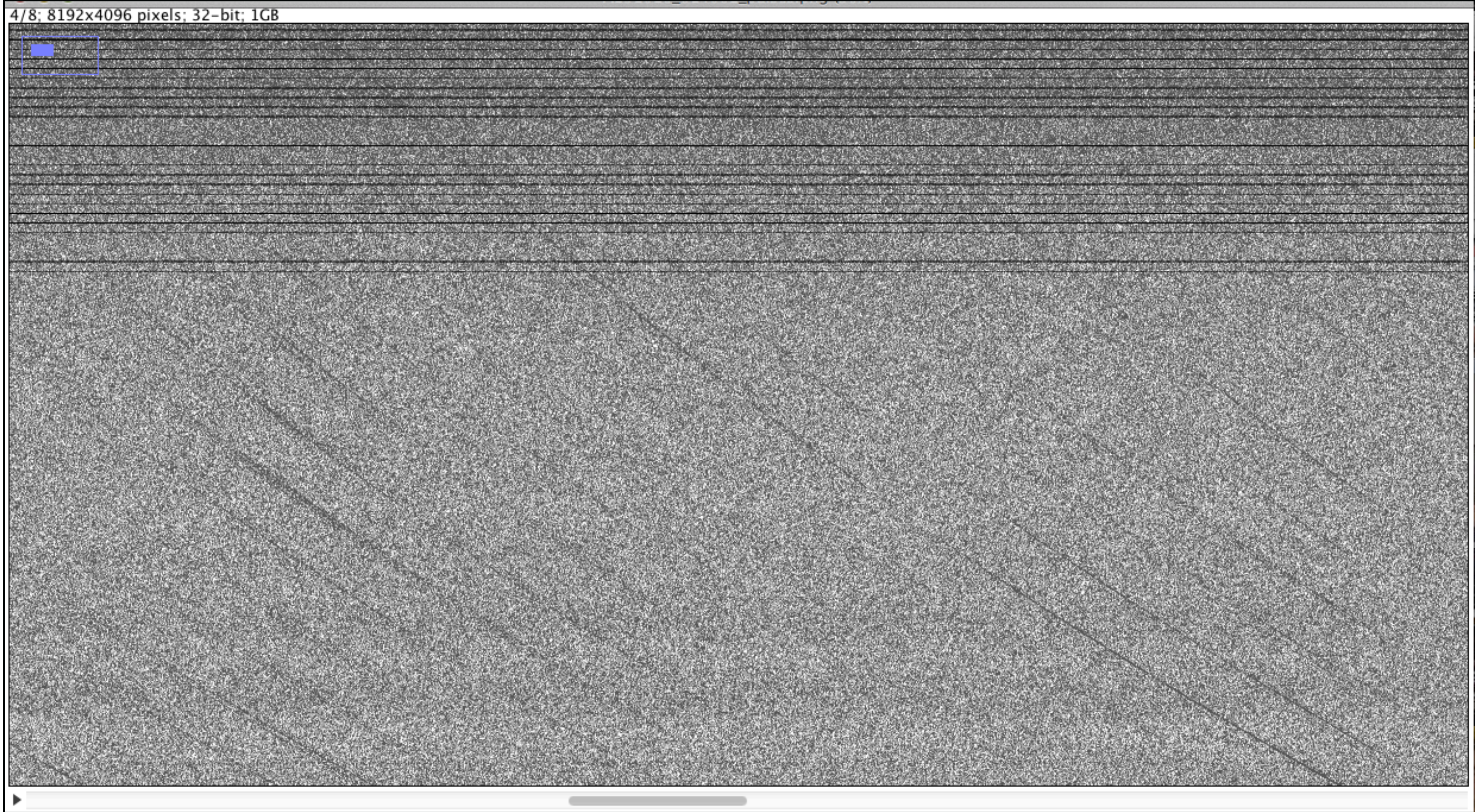

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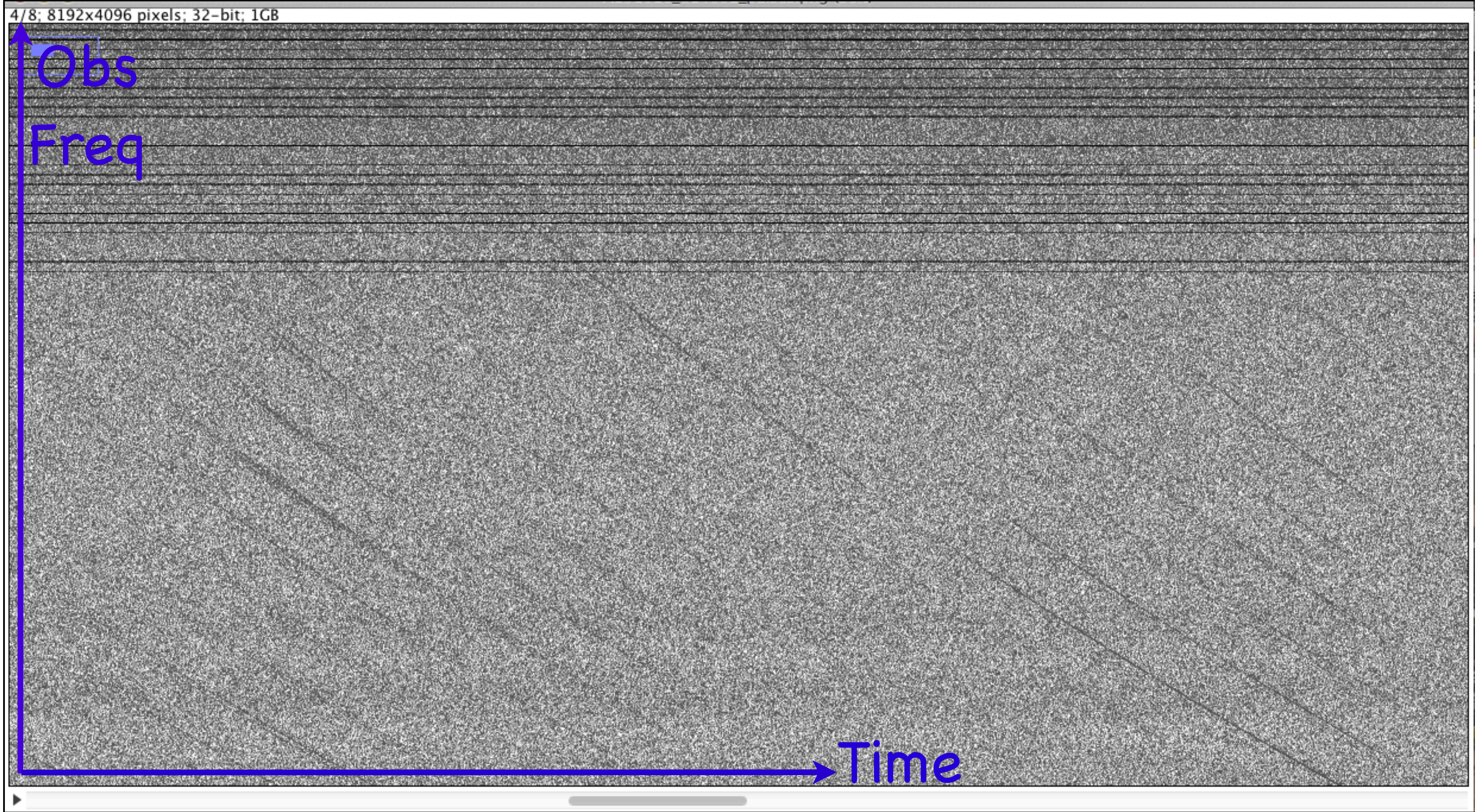

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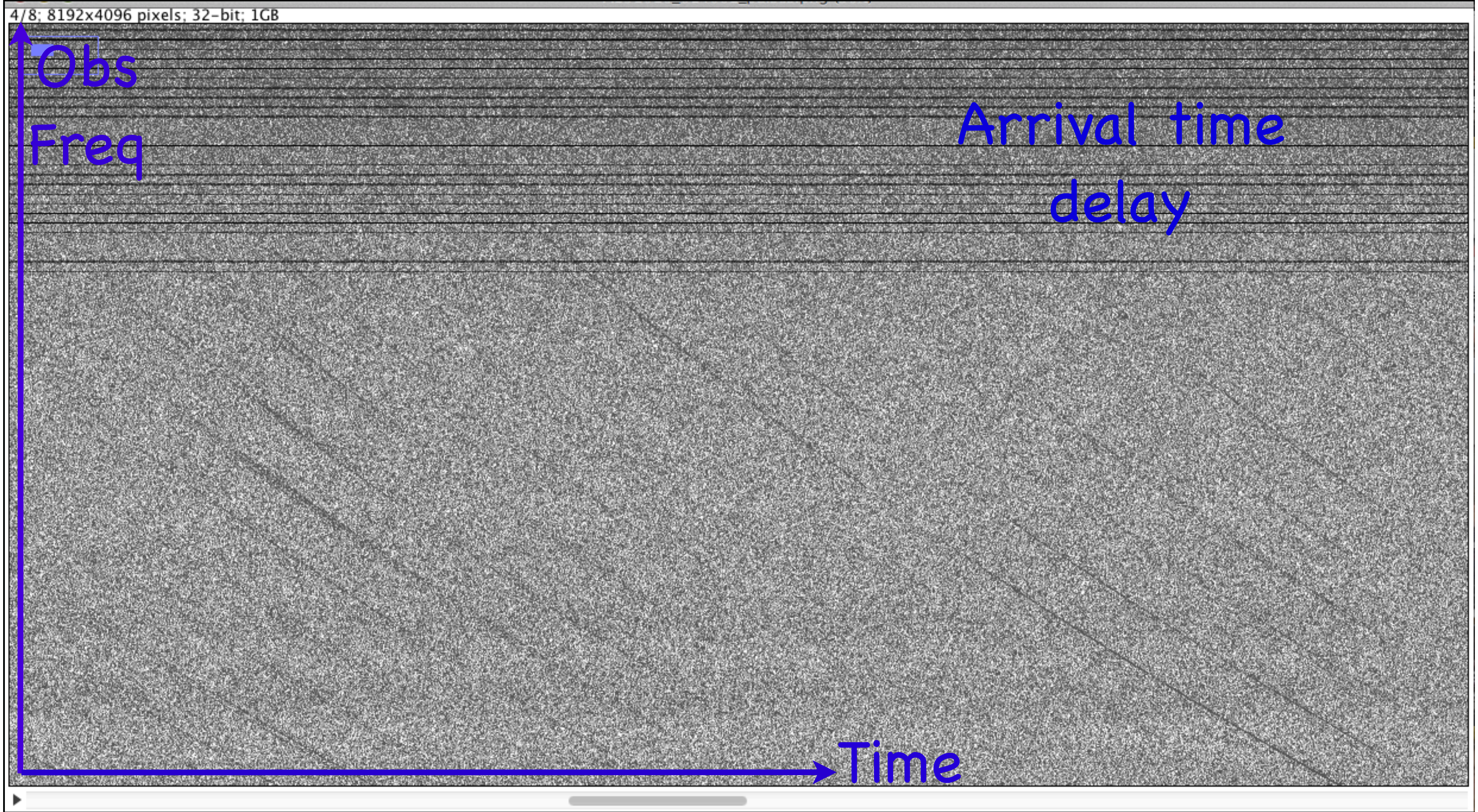
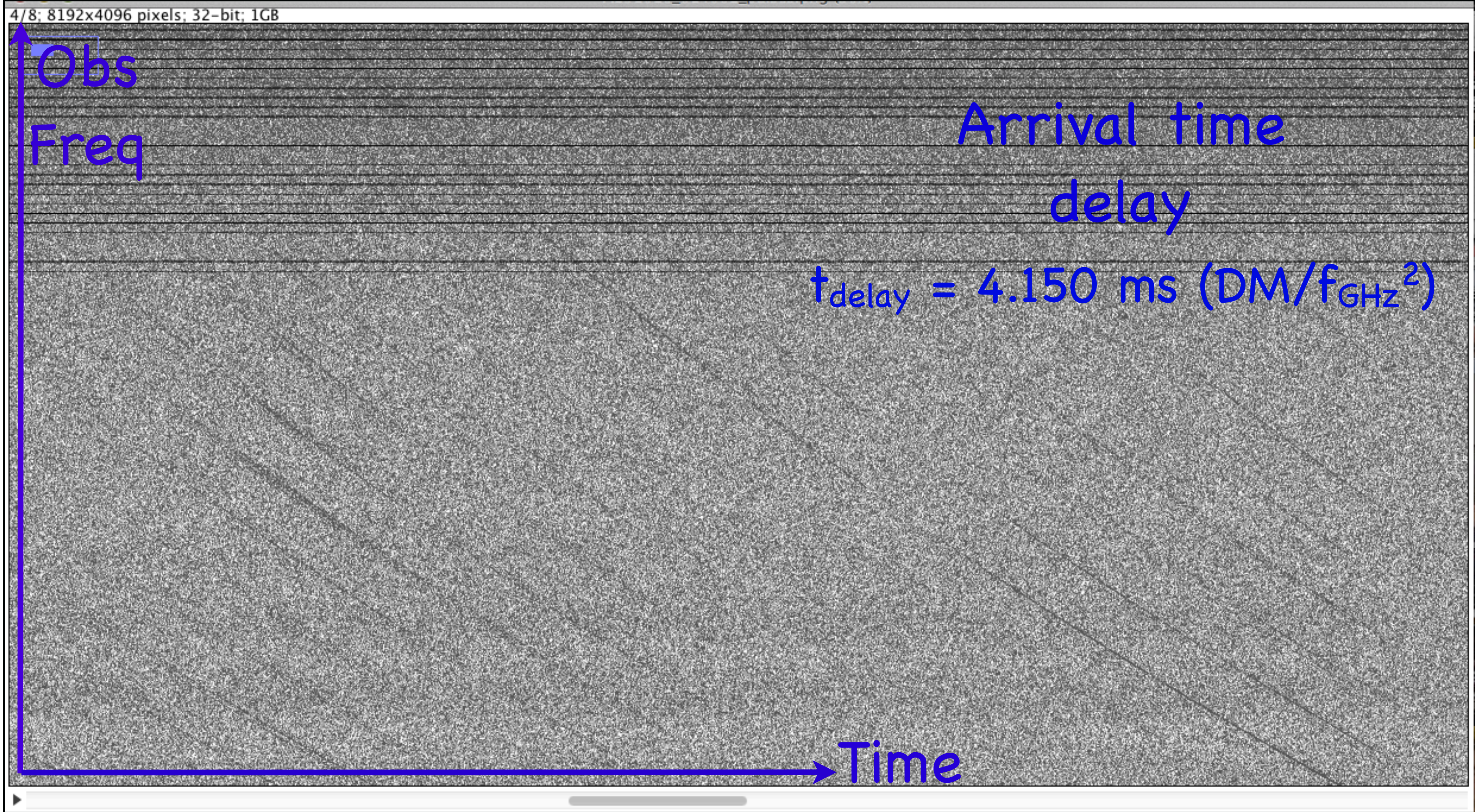


4/8; 8192x4096 pixels; 32-bit; 1GB
Obs
Freq
Arrival time
delay
Time

Pulsars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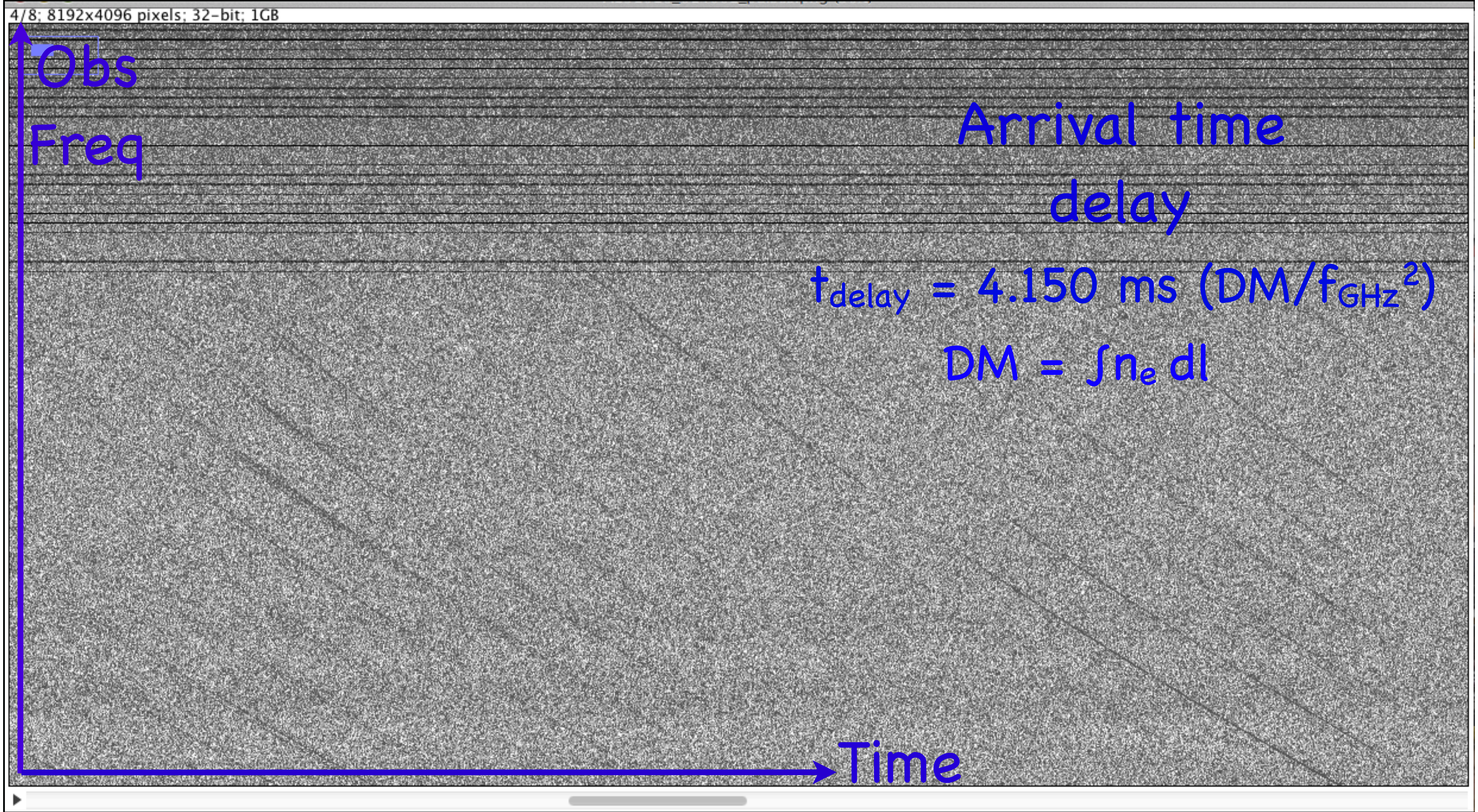
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Obs Freq
Arrival time delay
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DM = $\int n_e\, dl$
Time

Pulsars

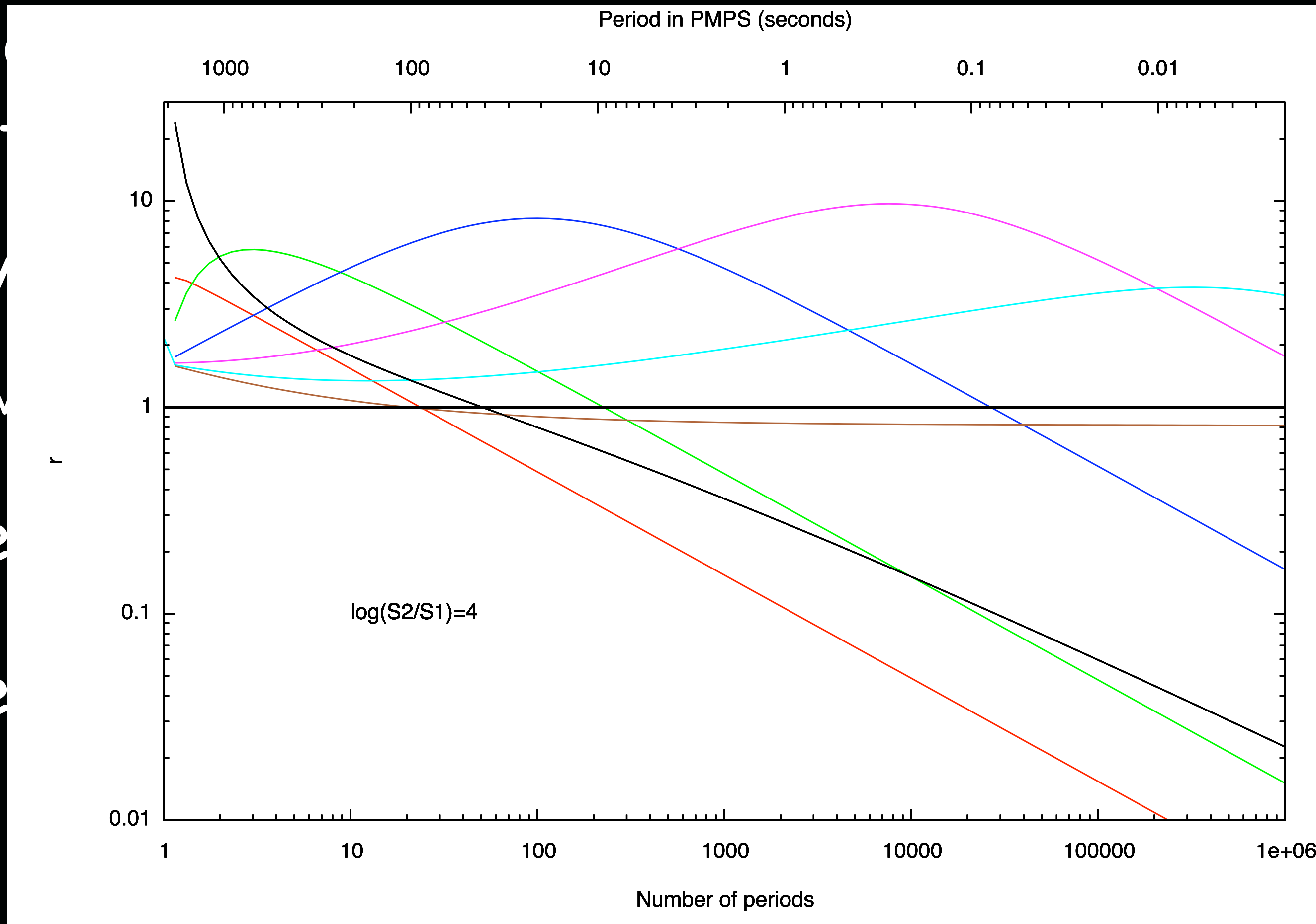
- Also realised that effective S_{min} can be better by $N^{1/2}$, where $N=T_{obs}/P$, as PSRs very periodic
- To 1st order PSR signal is a Shah function
  -> many harmonics
- FFTs more and more doable -> FFT searches became the standard PSR search method
- SP searches forgotten about well before FFTW (1997) arrived

Pulsars

- Single Pulse Searches still a good way to find pulsars (and other things …)
- If $r = (S/N_{SP})/(S/N_{FFT})$ then easy to show that:
  $r = A\ (S_{peak}/S_{ave})\ N^{-1/2}$ (A const. of order 1)
- $N=T_{obs}/P$ -> period selection effect for a given T_{obs}
- S_{peak}/S_{ave} depends on PSR pulse amplitude distribution … PSR signal is not a Shah function …

Pulsars

- Single Pulse S… pulsars (and o…
- If r = (S/N$_{SP}$)/… r = A (S_{peak}/S_{av}…
- N=T_{obs}/P -> pe…
- S_{peak}/S_{ave} depe… distribution …



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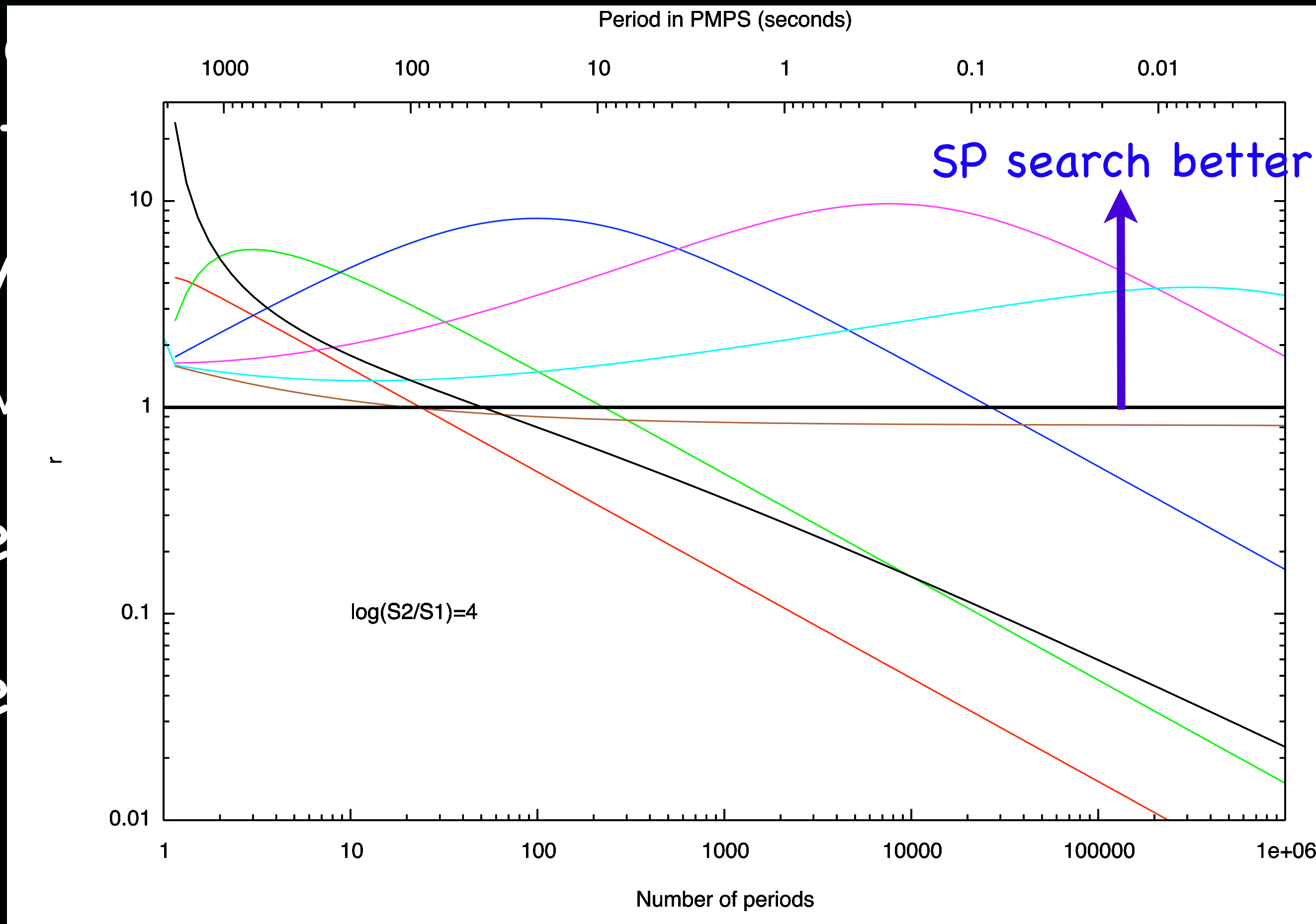

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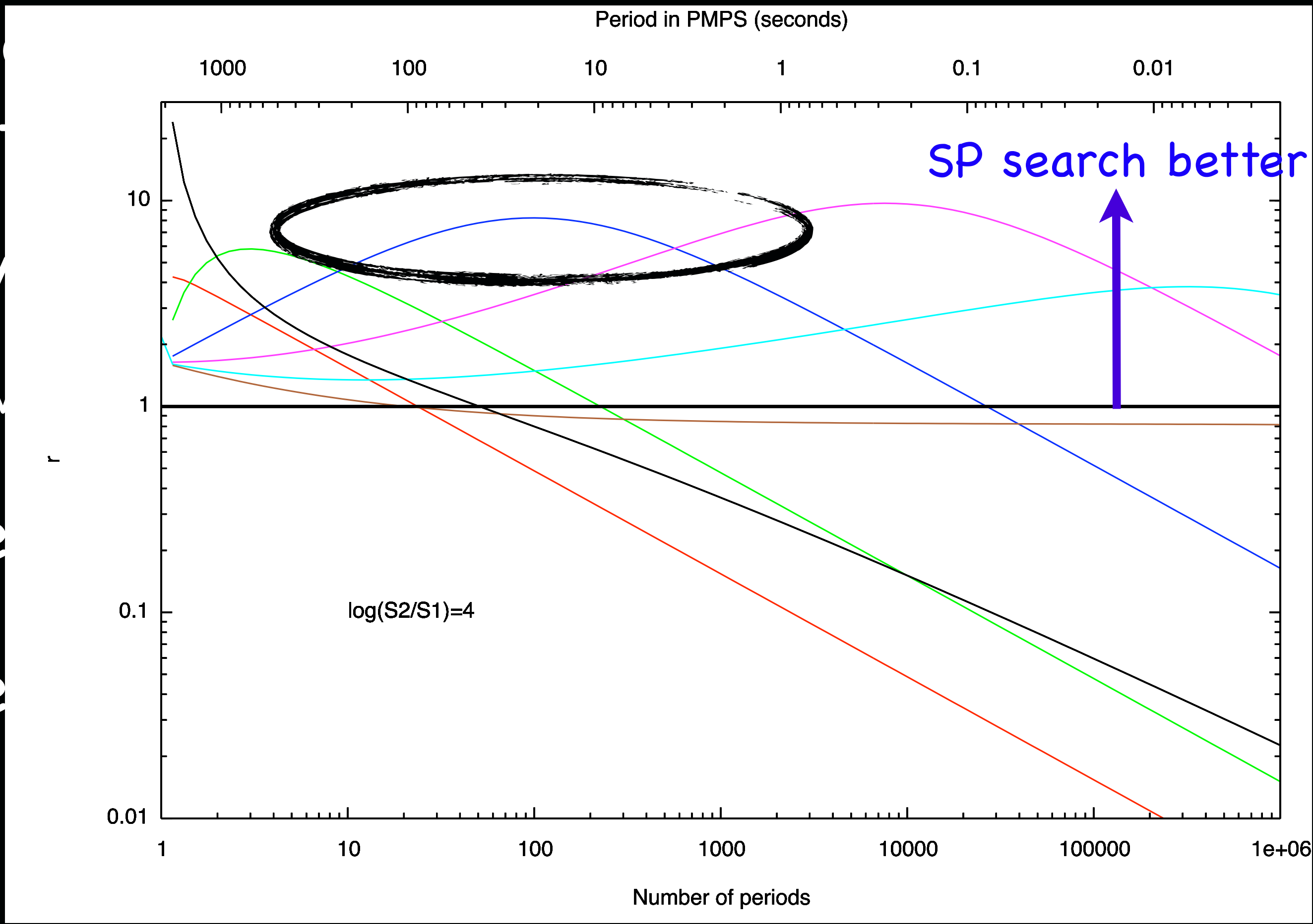
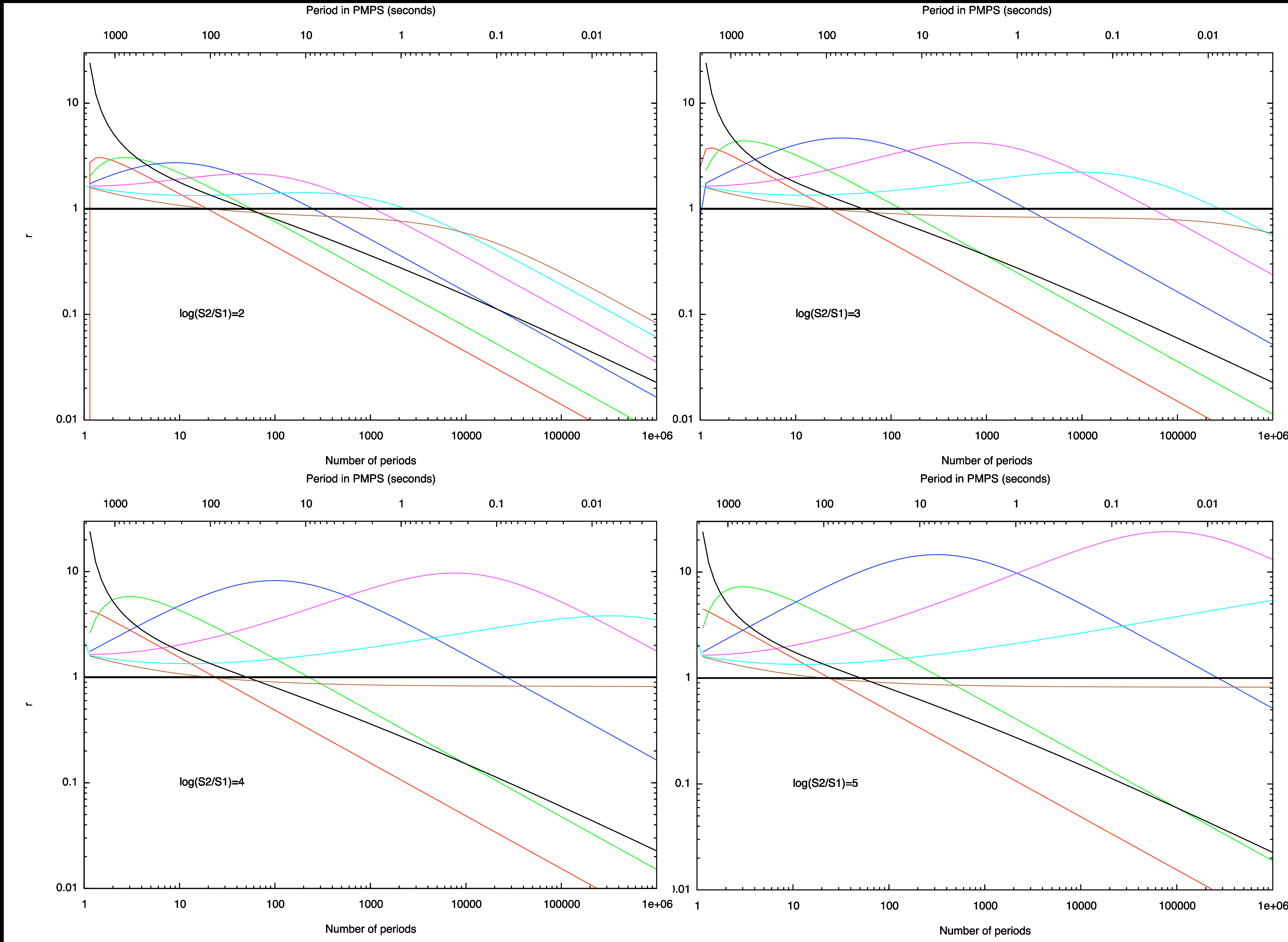
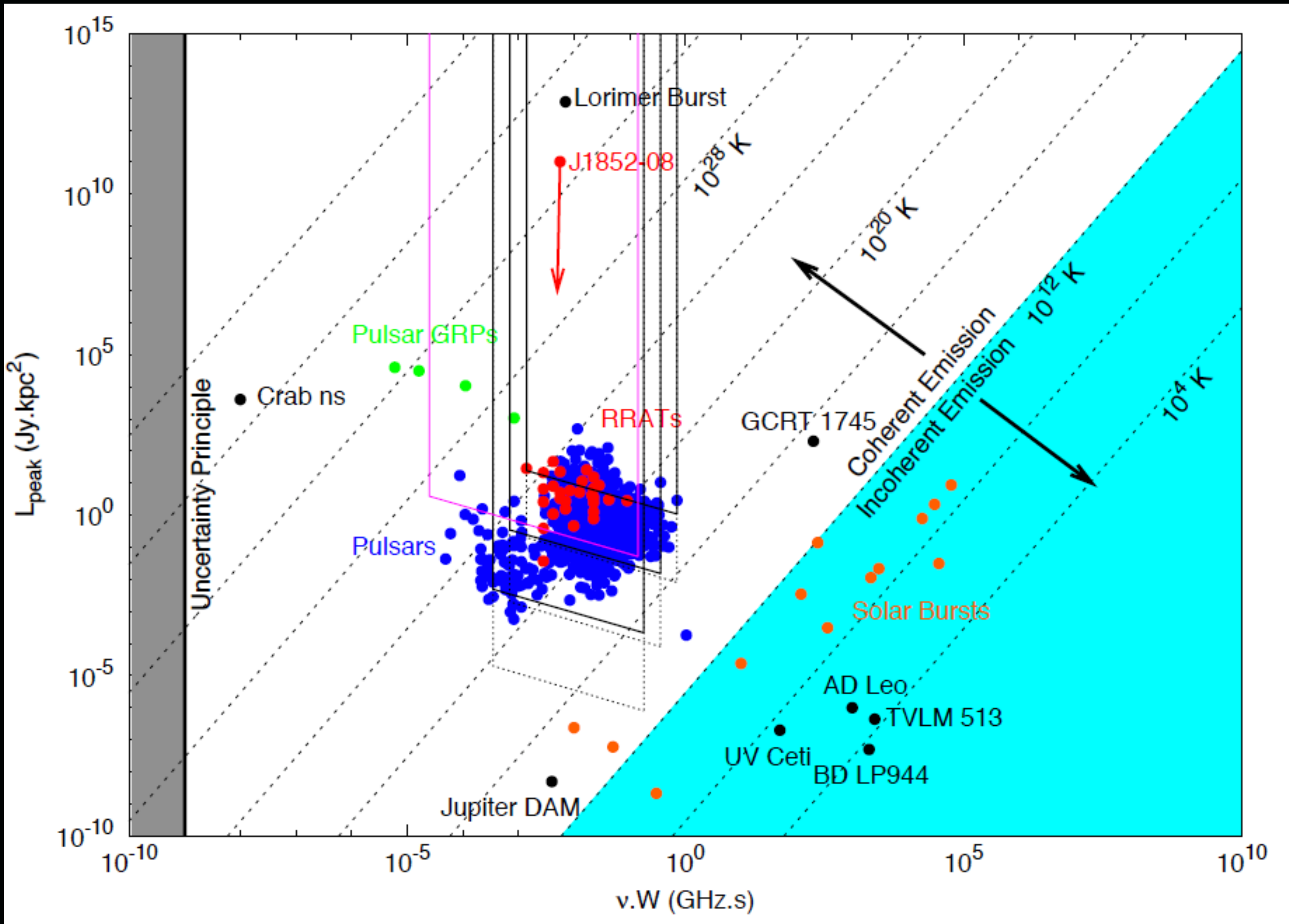




Period in PMPS (seconds)
1000
100
10
1
0.1
0.01
r
log(S2/S1)=2
Number of periods
Period in PMPS (seconds)
log(S2/S1)=3
Number of periods
Period in PMPS (seconds)
r
log(S2/S1)=4
Number of periods
Period in PMPS (seconds)
log(S2/S1)=5
Number of periods

Transient Parameter Space



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- De-dispersed time series' are match-filter searched for events of various durations and shapes

The Lorimer Burst

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- Typical PSR survey of SMC & surroundings
  - in Australia
  - observed at L-band (1.4 GHz)
  - BW of few 100 MHz
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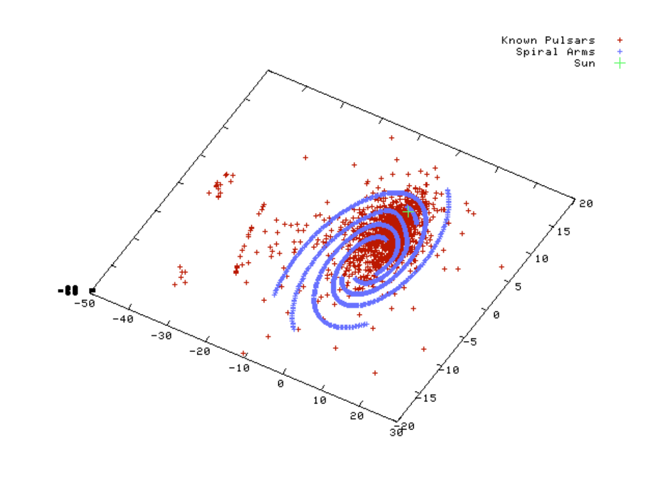

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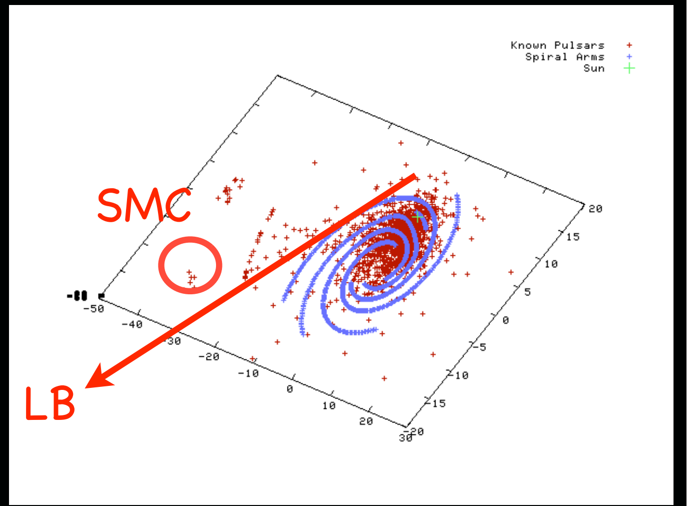

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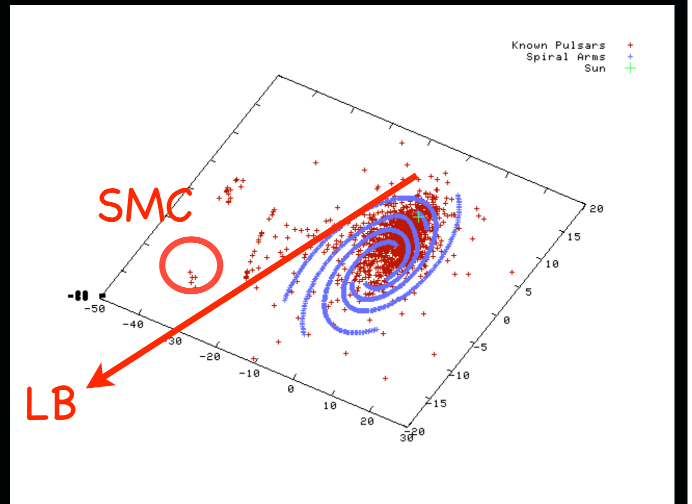

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A bright millisecond radio burst of extragalactic origin

D. R. Lorimer,[1,2*] M. Bailes,[3] M. A. McLaughlin,[1,2]
D. J. Narkevic,[1] F. Crawford[4]

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  DM = 375 $cm^{-3}pc$
  τ_{obs} = 5 ms
  detected in 3 of 13 beams as expected
  obeys the theoretical DM law $t_{delay} \propto f^{-2}$
  obeys a scattering law of the form $W \propto f^{-4.8(4)}$

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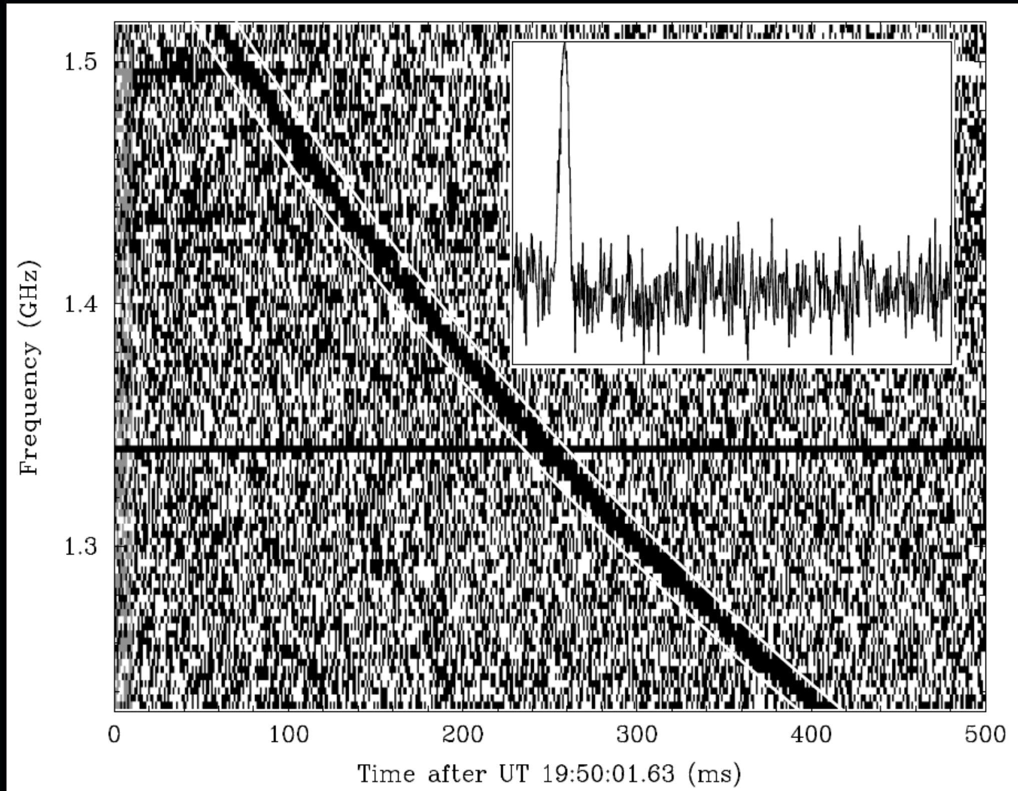

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  -> Only 25 $cm^{-3}pc$ due to Galaxy
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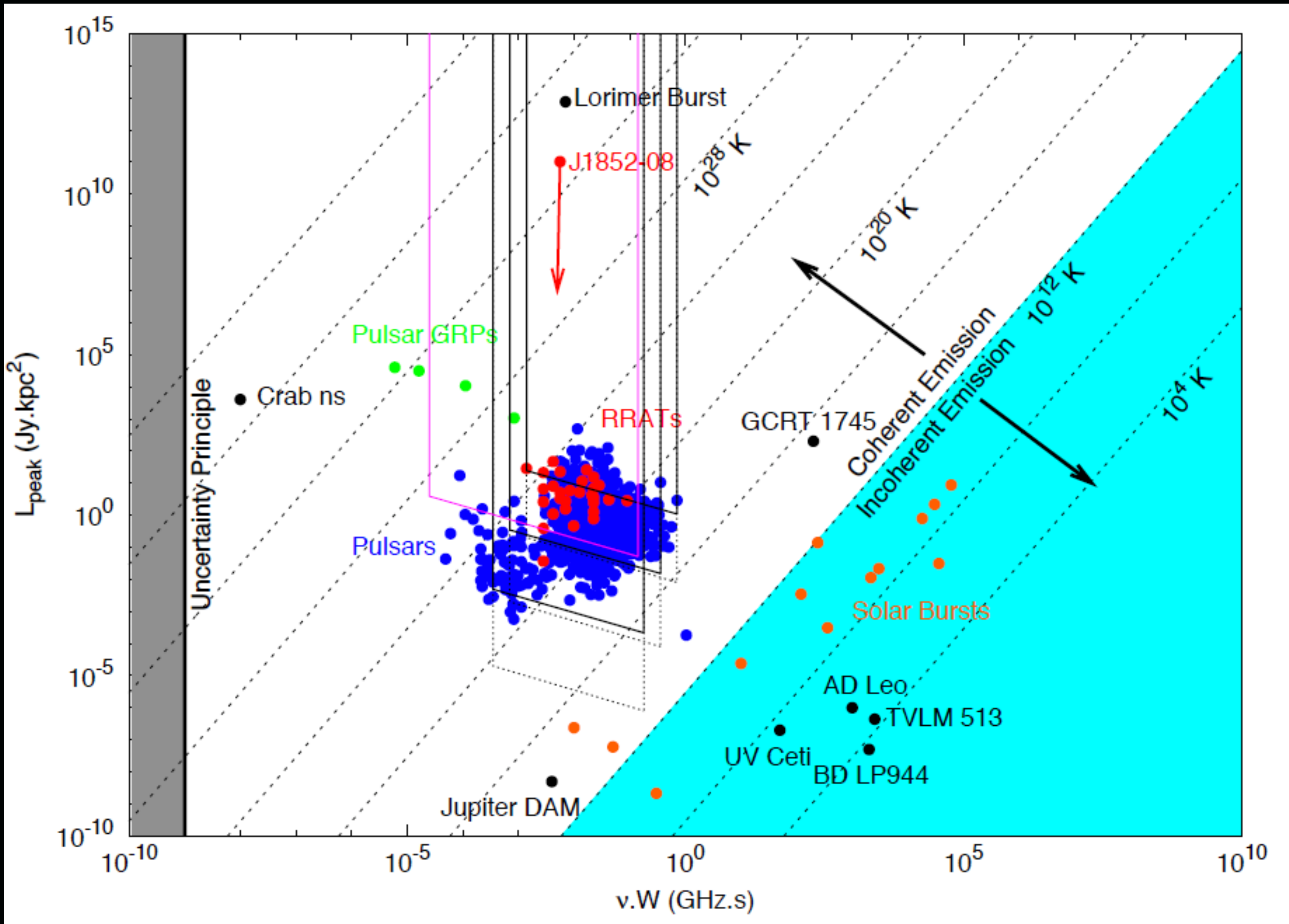
- Extragalactic with $z \sim 0.2$!!
  -> Distance huge -> Luminosity huge!

Transient Parameter Space



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- No evident host galaxy
- Lots of excitement about the discovery
- But then the astrophysical origin of the burst was called into question!

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- ~30 sources, known as "perytons" found
  -> detected in all 13 of 13 beams
  -> not very strong in any of them
- Their frequency-delay structure is roughly similar to the f^{-2} dependence of an astrophysical signal
  but not exactly the same as weird "kinks" seen

Perytons

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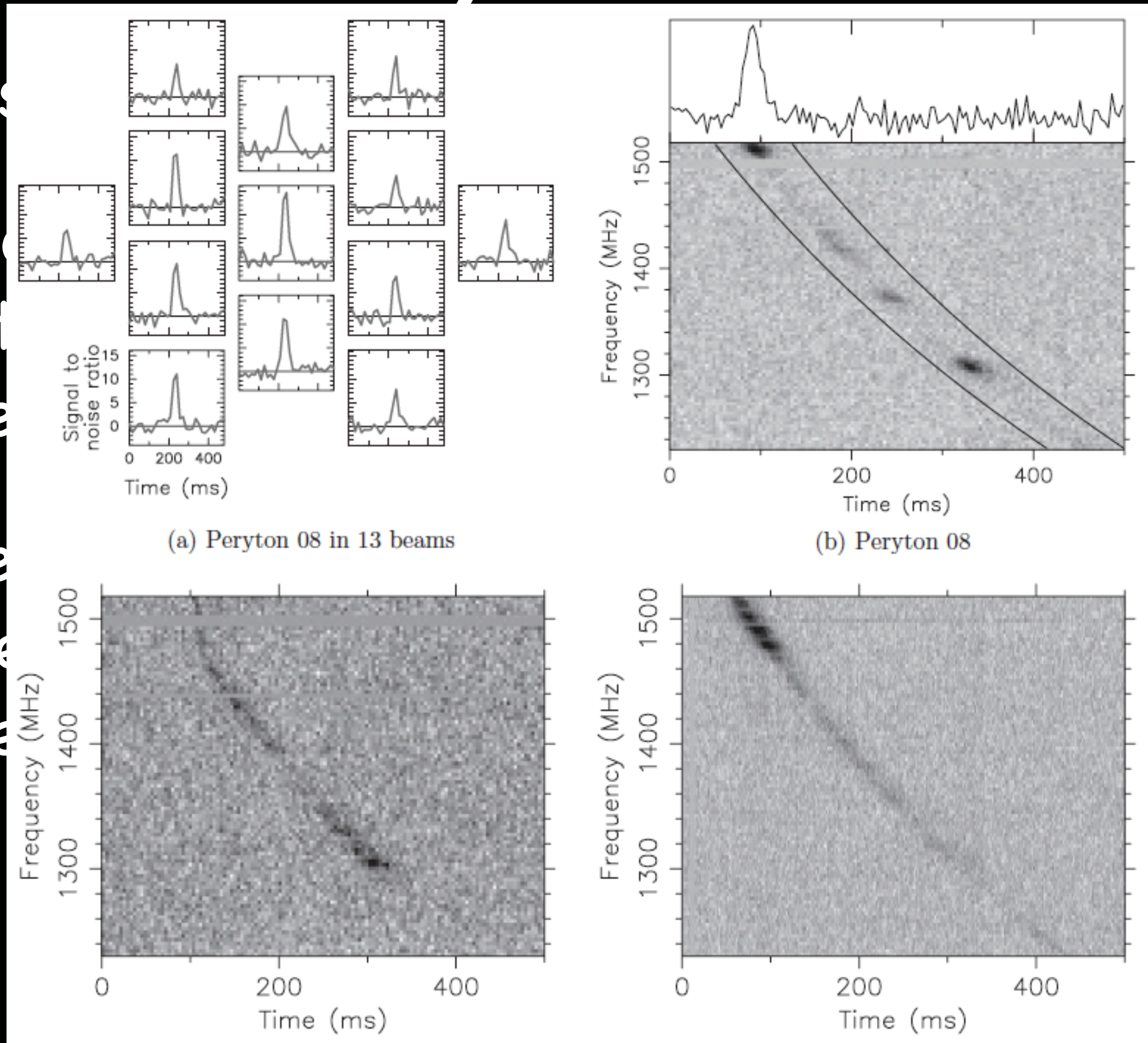

(a) Peryton 08 in 13 beams

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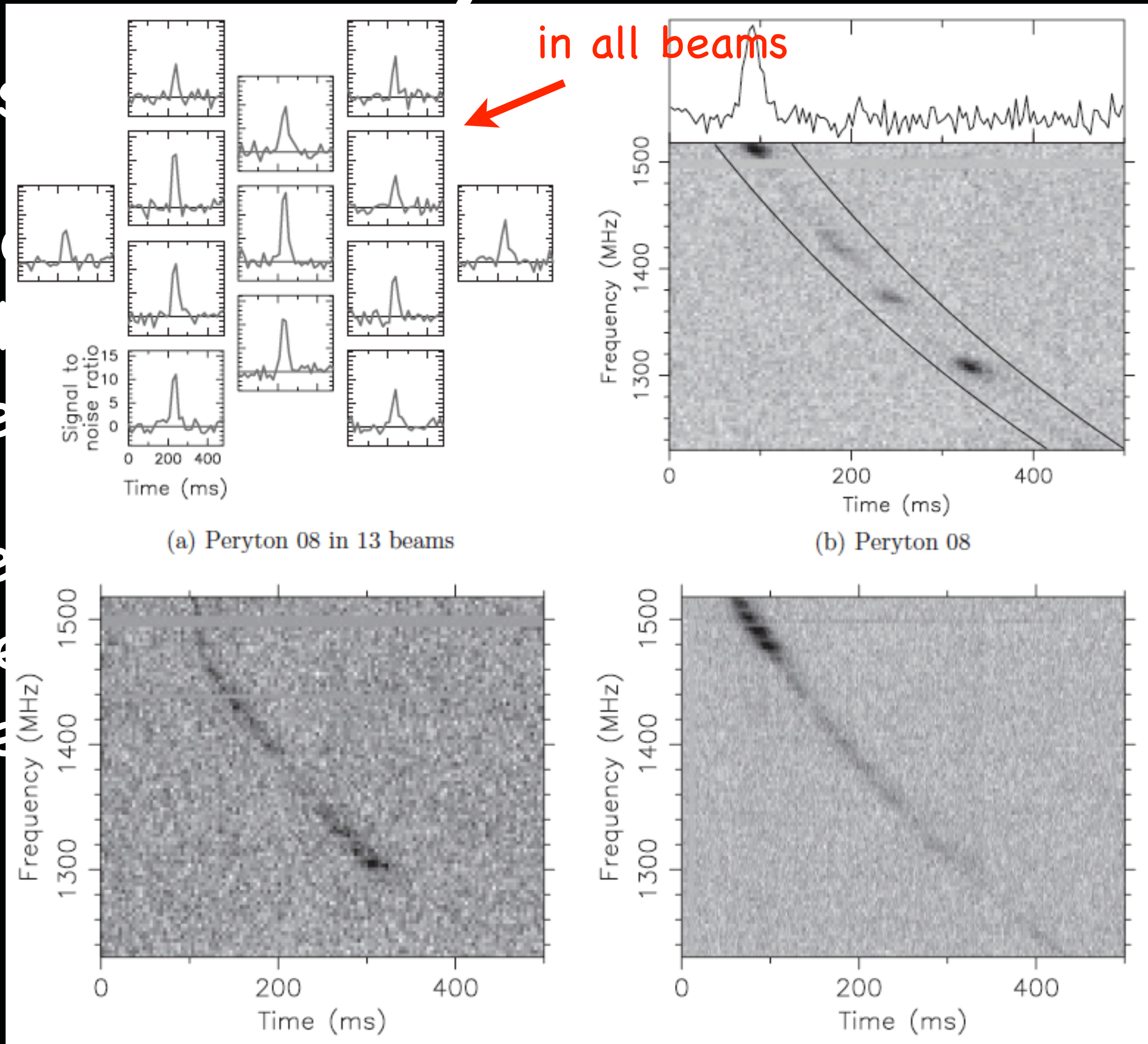

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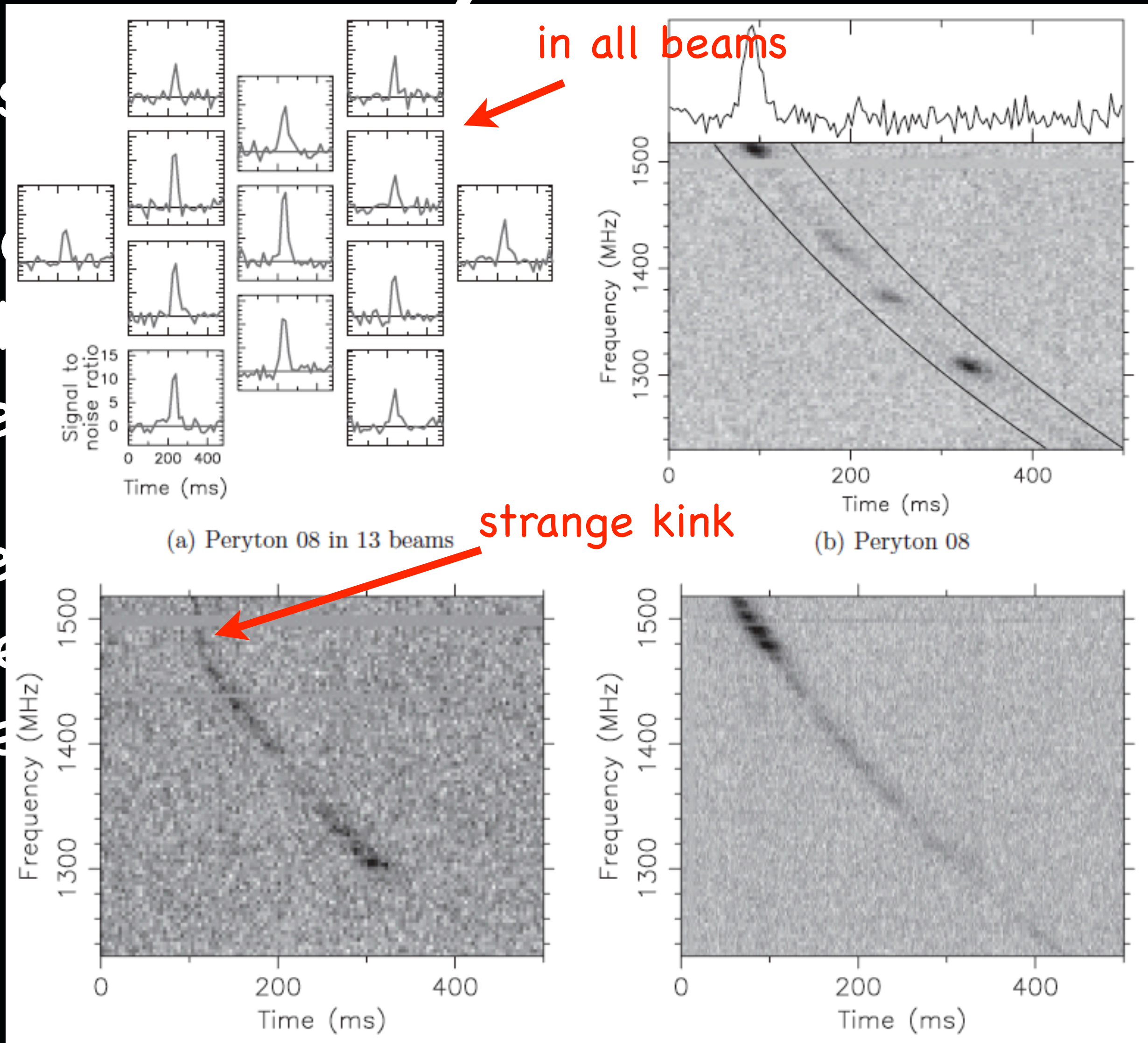

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decl. -75.17 ± 0.08. That is, the relative signal levels of the LB conform to those expected from a boresight signal, in agreement with the same conclusion of Lorimer et al. (2007). Therefore,

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- I searched PMPS with new methods/algorithms etc. for DMs <=2000 $cm^{-3}pc$
- One unexplained isolated bright burst of interest which I will elaborate upon ...

Signal Properties

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- Single pulse S/N = 16.3
  DM = 745 $cm^{-3}pc$
  τ_{obs} = 7.8 ms (dedispersed to 1516.5 MHz, top of band)
  gl = 25.4°, gb = -4.0°
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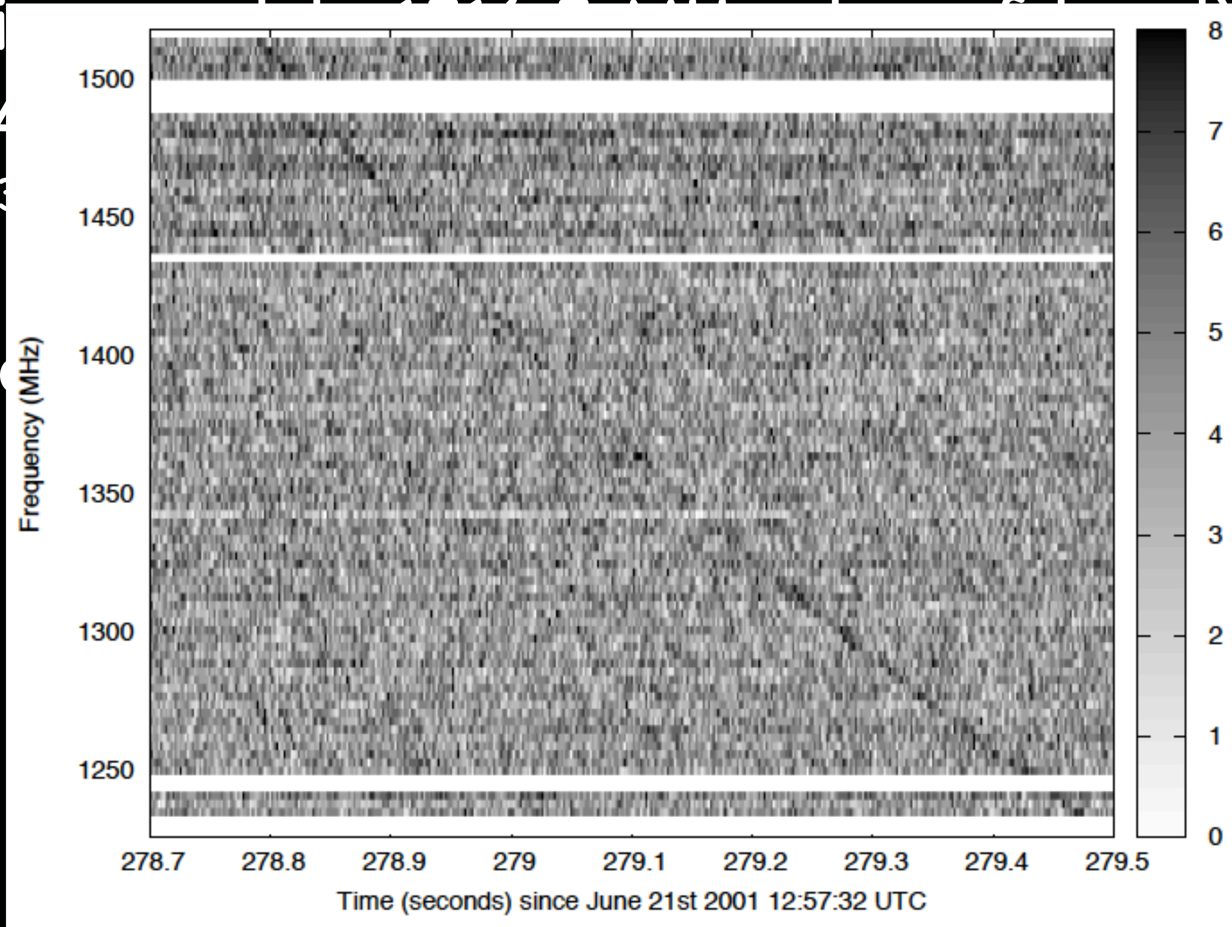

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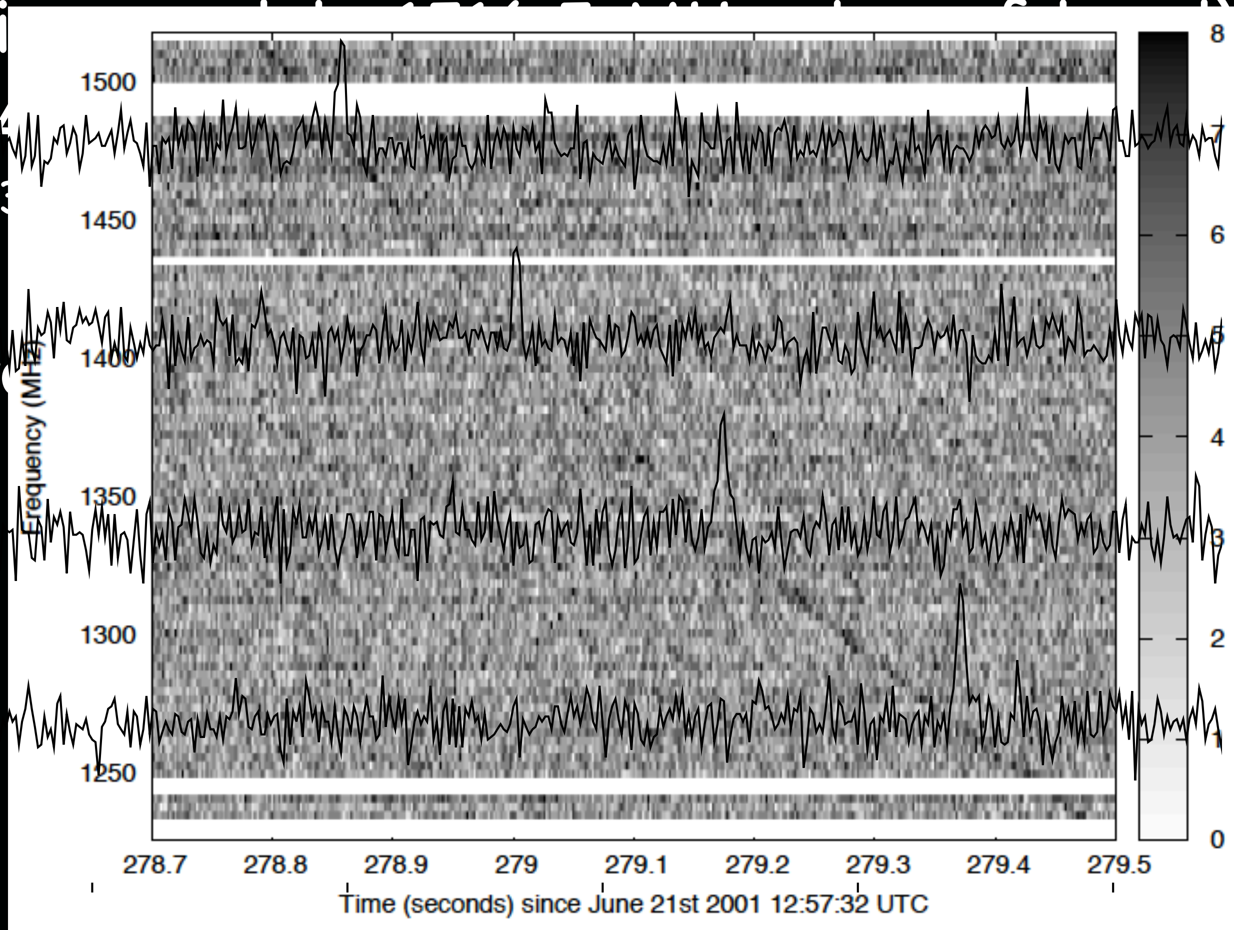

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- Only in 1 of 13 beams
- Not seen to repeat in 15.5 hours of follow-up from Parkes observations in April 2011!

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- $\tau_{obs} = (\tau_{int}^2 + \tau_{DM}^2 + \tau_{BW}^2 + \tau_{scat}^2)^{1/2}$
- τ_{obs} just slightly larger than τ_{DM}
  -> τ_{scat} is at most 3 ms but extra width could be intrinsic -> don't know

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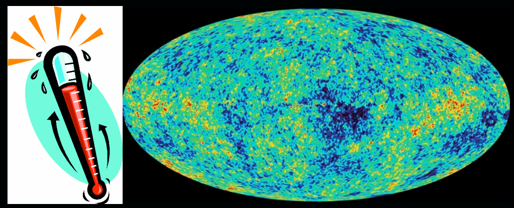

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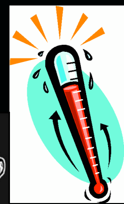
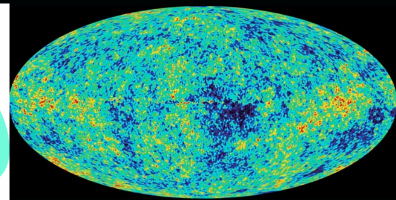

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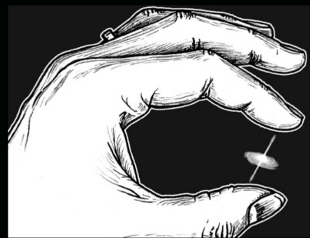

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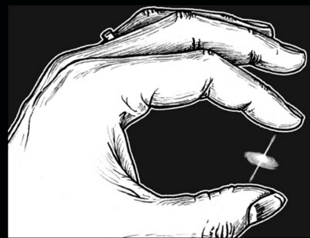
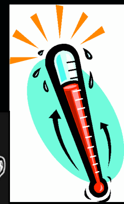
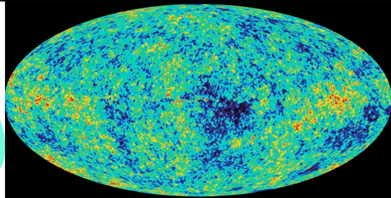

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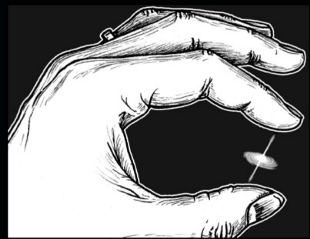
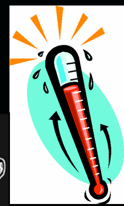
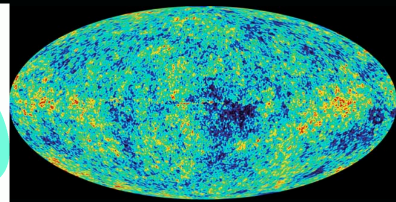

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- Consider bit heavier than this, $M_{BH} = 10^{13}$ kg, i.e. where $kT_{BH} > 2m_ec^2$ -> BH radiation can make e^-–e^+ pairs ...

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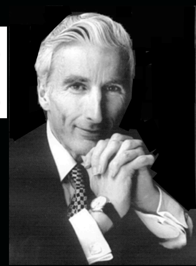

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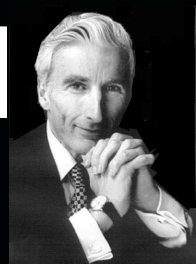

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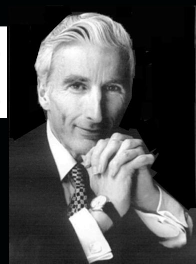

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- If $M_{crit}c^2 = 10^{30}/\gamma$ J of energy released we can get expanding 'fireball' of pairs with $E = 10^{25}\eta/\gamma_5$ Joules

Radio Signal

Radio Signal

- Conducting sphere of pairs expanding relativistically into surrounding B-field -> surface currents -> radio burst, possible only for $10^5 < \gamma < 10^7$
- Energy spectrum of pulse (Blandford) is $\varepsilon = 10^{15}\, \eta^{4/3}\, \gamma_5^{-8/3}\, B_{5\mu G}^{-2/3}\, |F(\nu/\nu_c)|^2$ J Hz^{-1}

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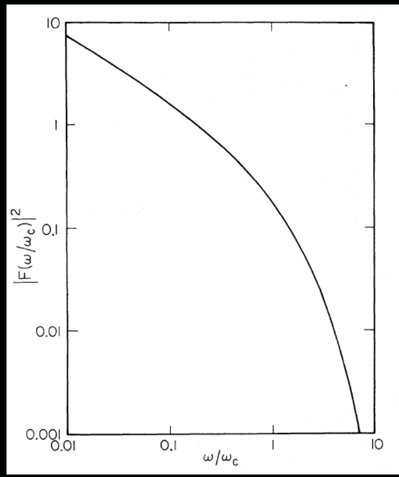

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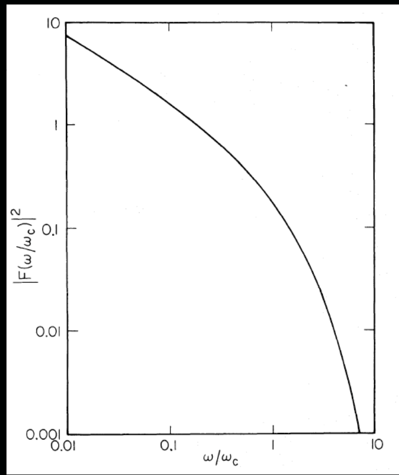

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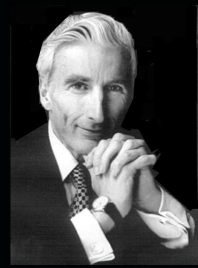
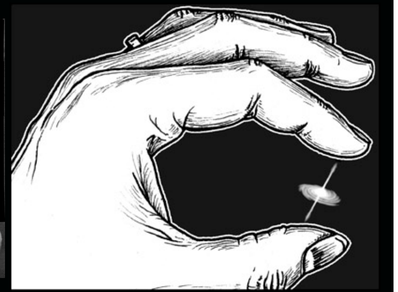
- $T_{obs} = (T_{int}^2 + T_{DM}^2 + T_{BW}^2 + T_{scat}^2)^{1/2}$
  $T_{obs} \simeq T_{DM} = 8.3\ \mu s\ DM\ \Delta\nu_{MHz}\ \nu_{GHz}^{-3}$

  e.g. for DM = 745, $\Delta\nu_{MHz} = 3$, $\nu_{GHz} = 1.4$, $T_{obs} = 6.8$ ms

ABHs?





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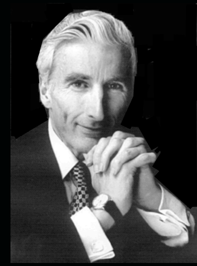
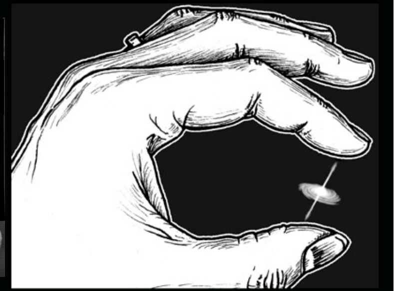

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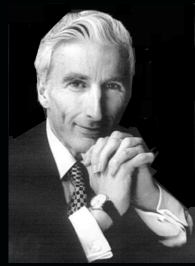

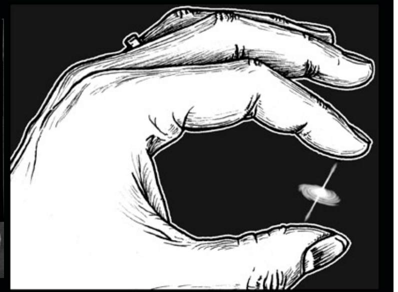

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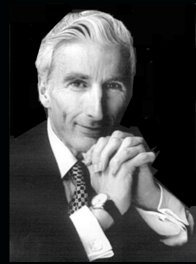

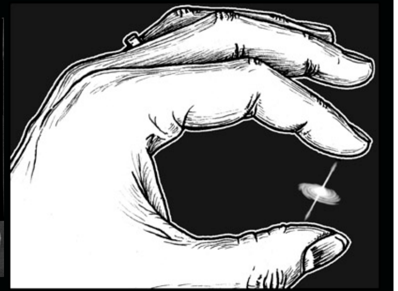

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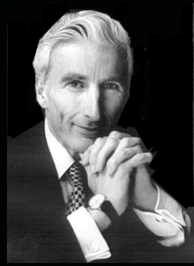

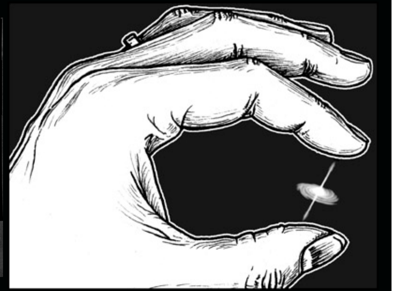

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- If we knew τ_{scat}, could settle this as ABH scenario requires scattering! If $\tau_{scat} \ll 3$ ms -> ABH ruled out

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- "Perytons", Burke-Spolaor&Bailes 2011
  -> terrestrial interference, unrelated

The Future

- These bursts will start pouring in with LOFAR, SKA & pathfinders -> large arrays connected with powerful supercomputers
- Can look in >100 directions at once over entire sky!
- No slewing time! Instant discoveries!
- And it works -> the future is now!

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- Many more expected imminently (in the next talk even!)
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September 28, 2012 9:13 pm

Boom and burst in outer space

By Clive Cookson

"there are many mysteries to unravel" about their origins, says Evan Keane of the Max Planck Institute for Radioastronomy in Germany, who led the discovery of the

Thank You
(questions, comments?)

@evanocathain