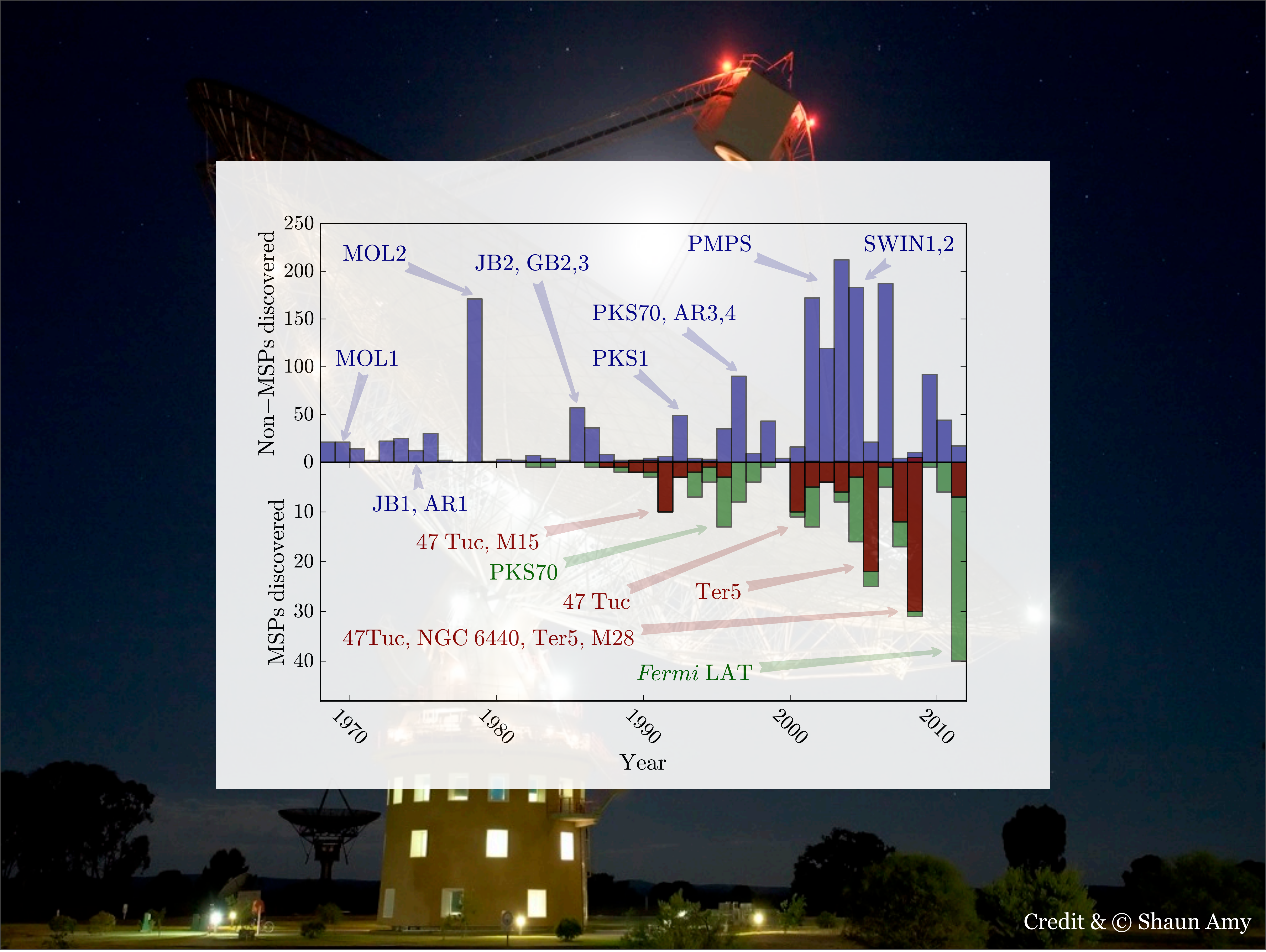
Survey for Pulsars and Extra-galactic Radio Bursts

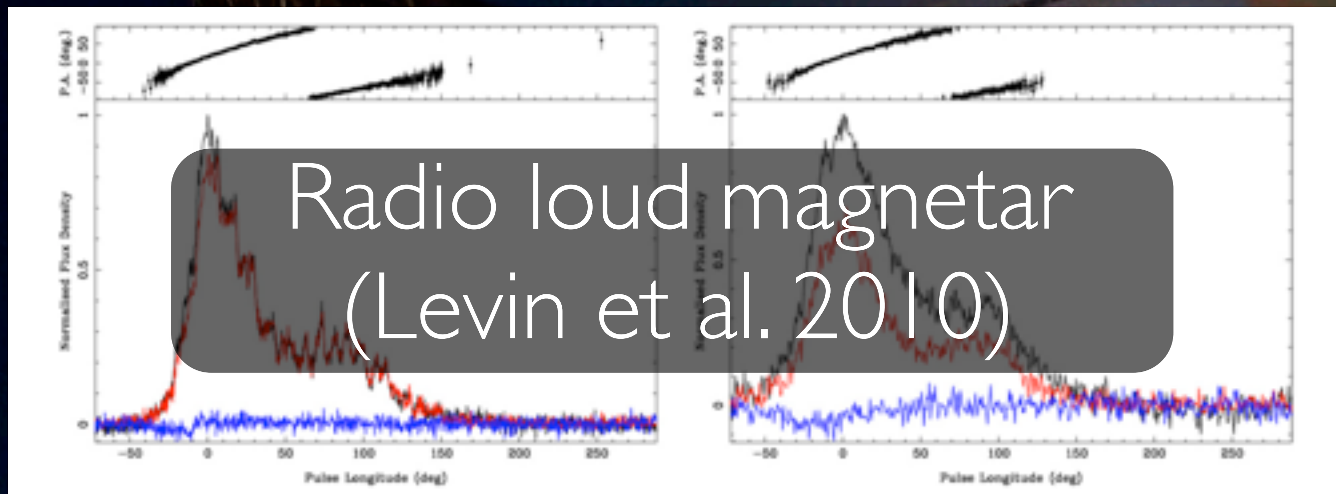
Ewan Barr
SKA Senior Research Fellow,

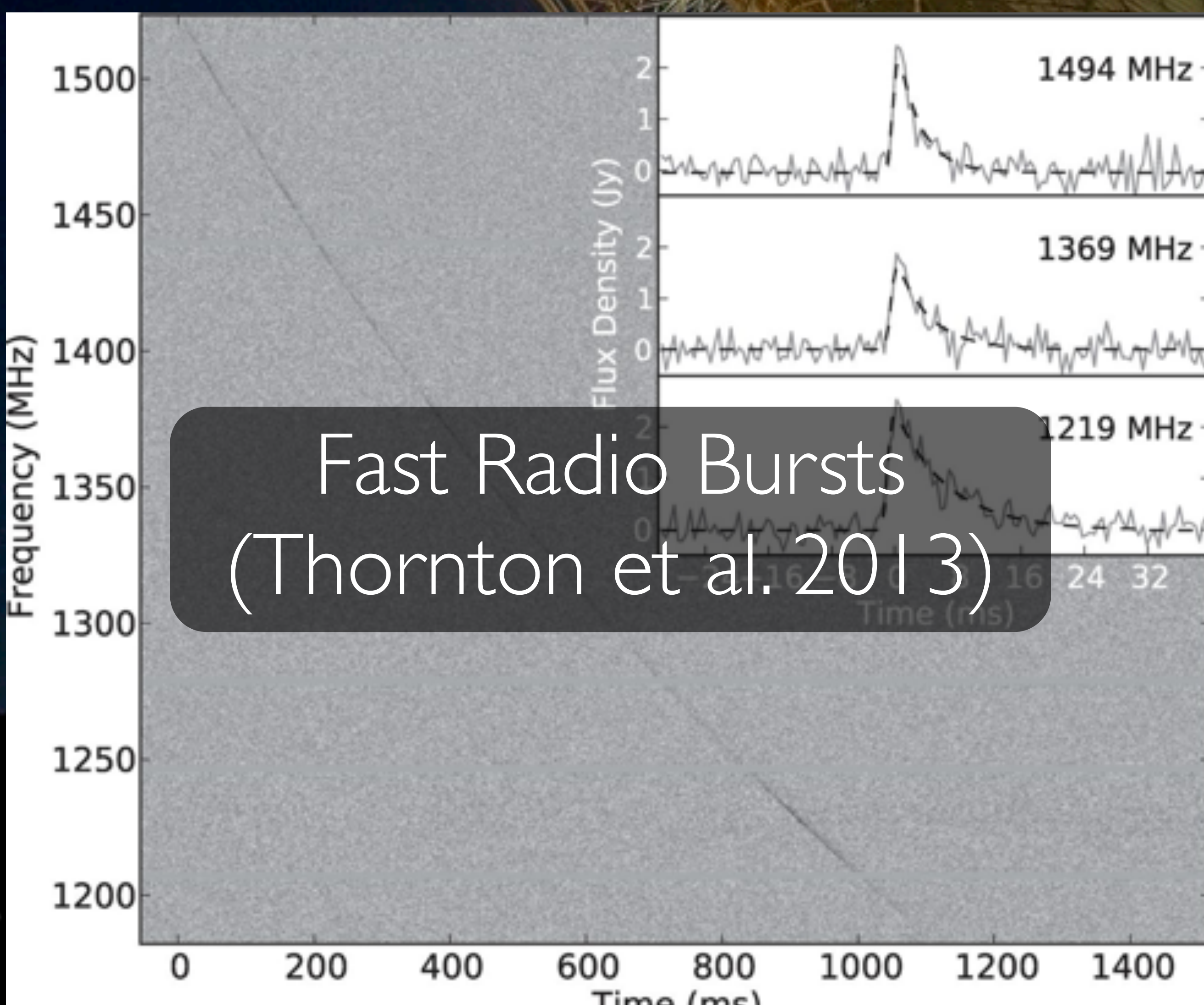

Credit & © Shaun Amy

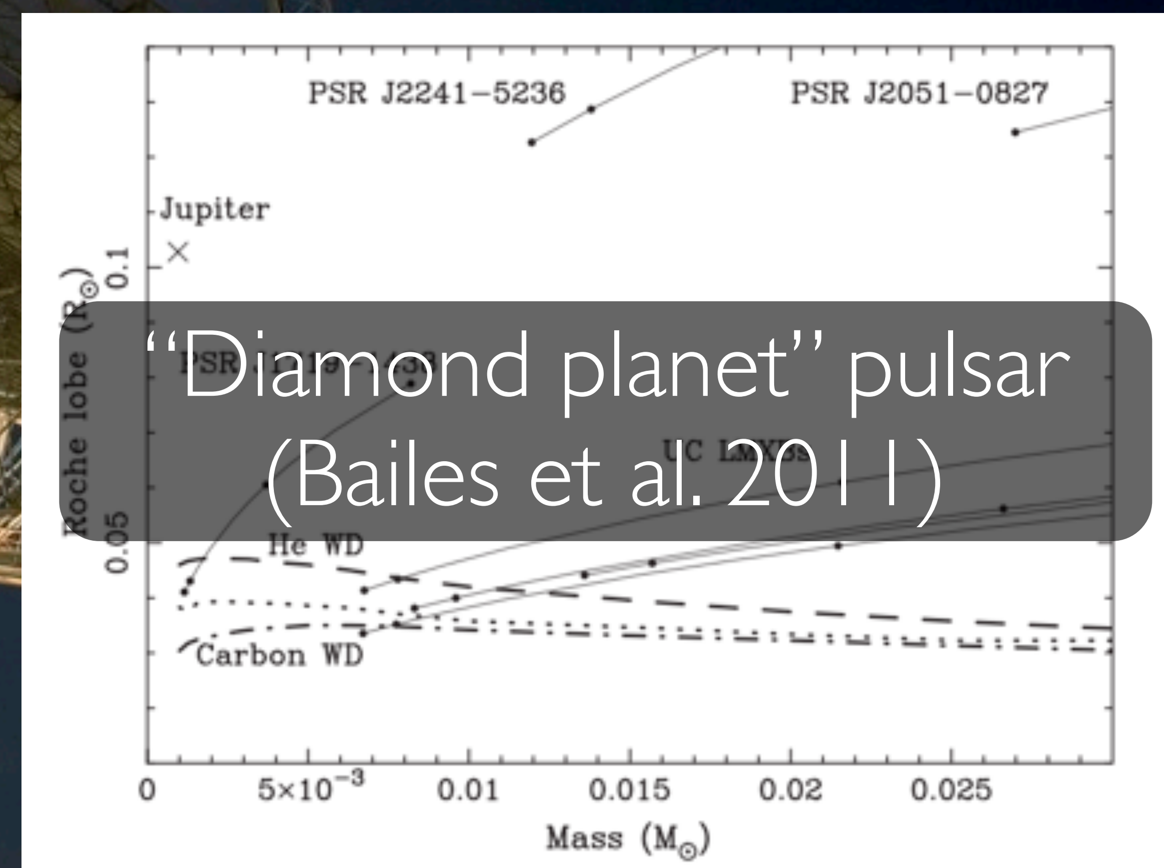


Non−MSPs discovered
MSPs discovered
250
200
150
100
50
0
10
20
30
40
MOL2
JB2, GB2,3
PMPS
SWIN1,2
PKS70, AR3,4
MOL1
PKS1
JB1, AR1
47 Tuc, M15
PKS70
47 Tuc
Ter5
47Tuc, NGC 6440, Ter5, M28
Fermi LAT
1970
1980
1990
2000
2010
Year
Credit & © Shaun Amy

HTRU Discoveries







WHAT NEXT?

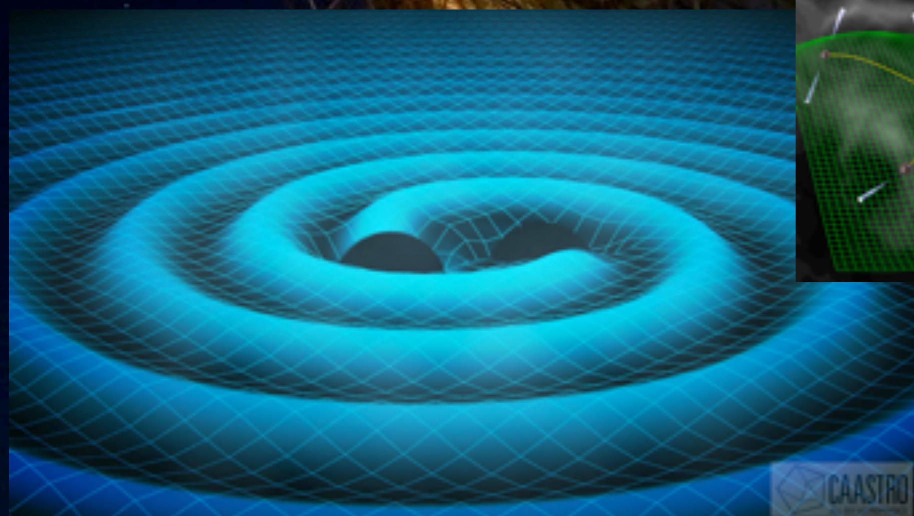
- Desire to keep momentum with new Parkes discoveries
- Many pulsars to be found before MeerKat, FAST and company come online
- Exotic systems often require multiple passes of any given survey field to be detected (scintillation is your frenemy)
- New processing tools available due to the wide availability high performance accelerator hardware
- New facilities available to perform shadowing and follow-up
- Many mysteries still to be solved and much science to be done (pulsars just keep giving)

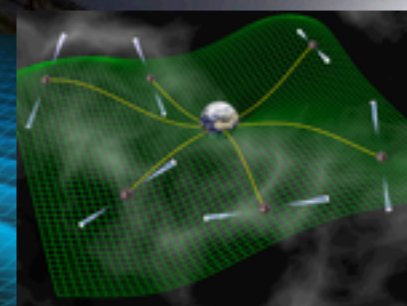
Survey for Pulsars and Extra-galactic Radio Bursts

SUrvey for **P**ulsars and **E**xtra-galactic **R**adio **B**ursts


SUPERB

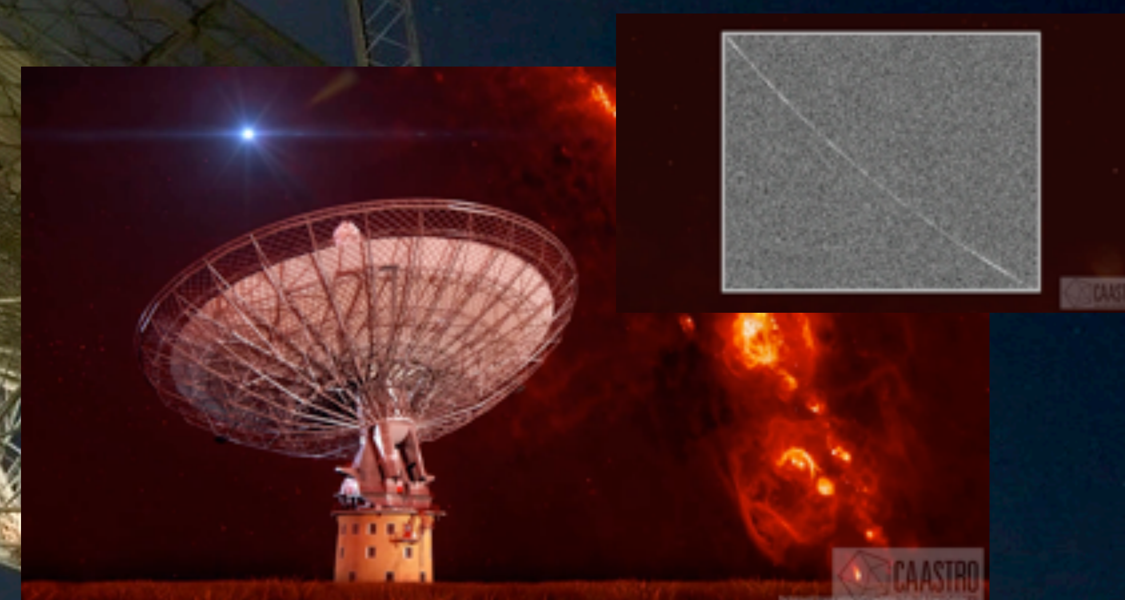
KEY SCIENCE





MSPs for GW experiments

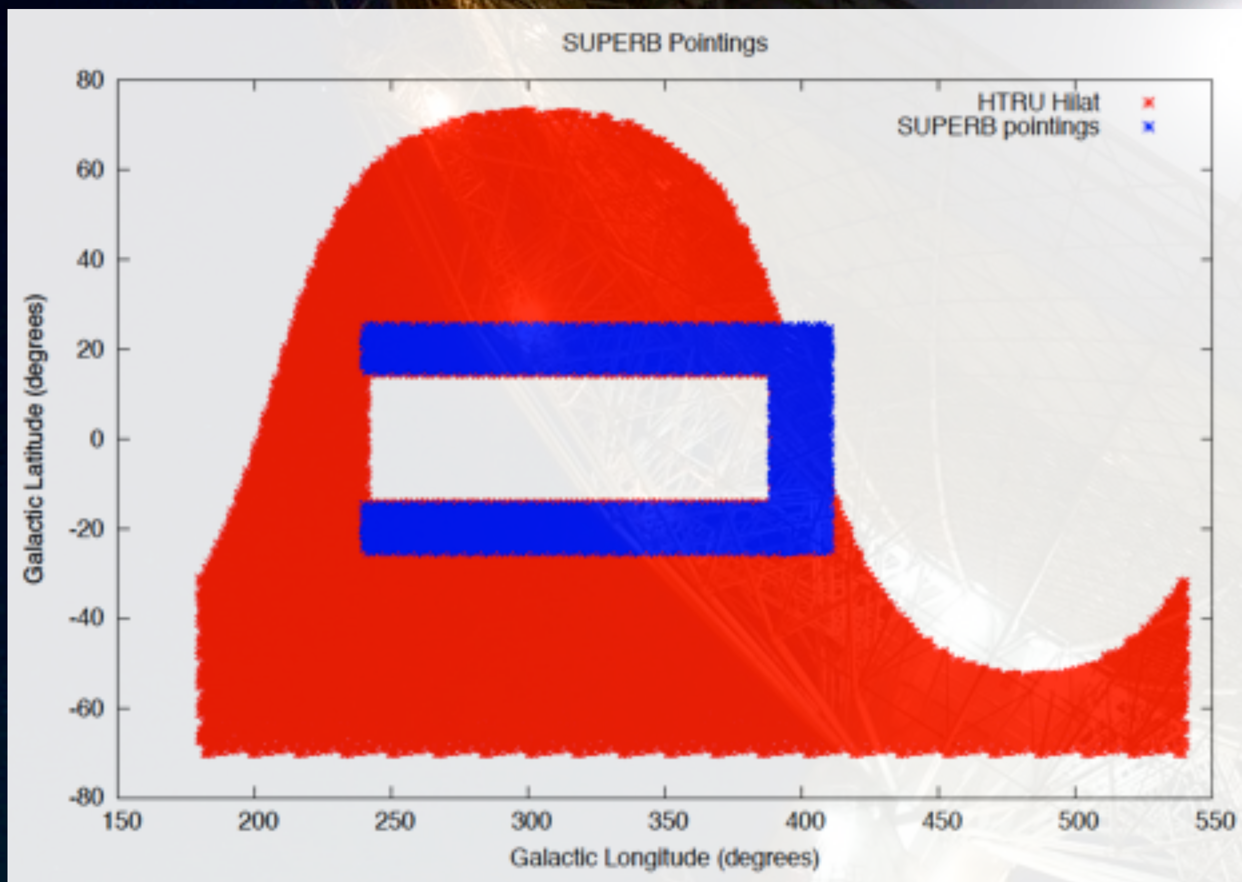
Find extreme systems



FRB localisation, spectrum and polarisation properties

Technology demonstration for next-generation instruments

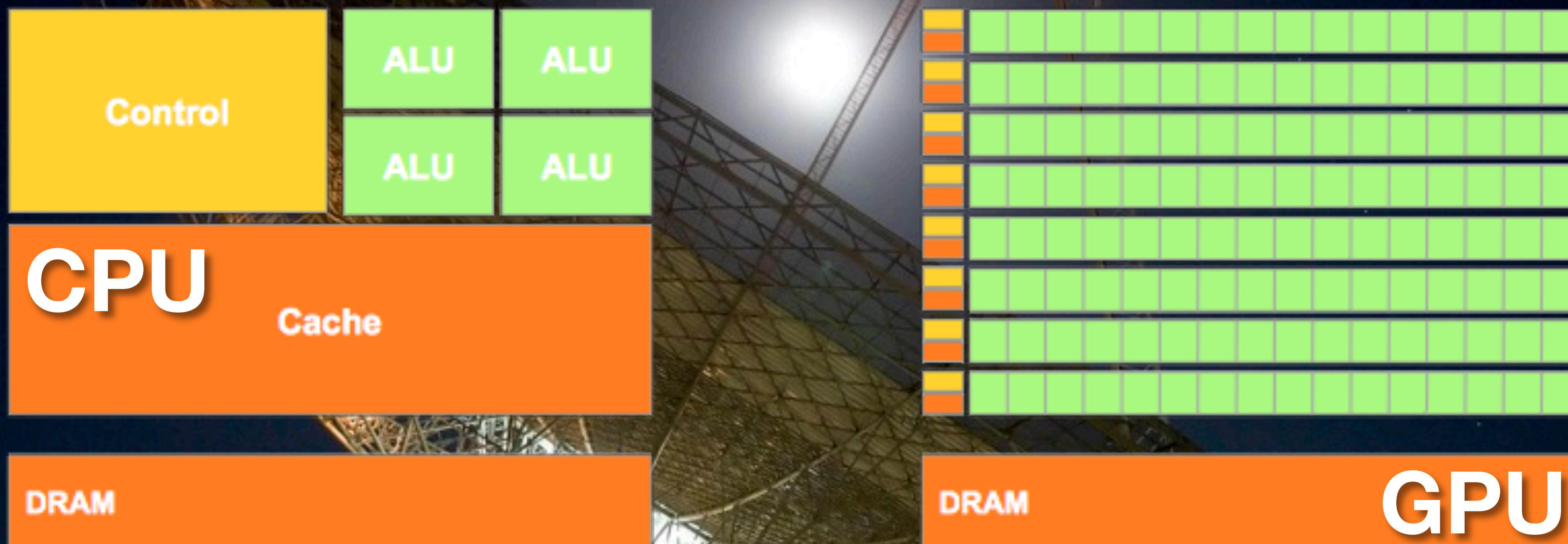
TARGET FIELD



Tobs	9 minutes
Bandwidth	340 MHz
Gain	~0.6 K/Jy
Nbeams	86372
Ttotal	1000+ hours

- Extends the HTRU medium latitude survey out to +-25 degrees
- Fills in "gaps" in HTRU high latitude tessellation pattern
- Probing latitudes known to contain FRBs

TECHNOLOGY



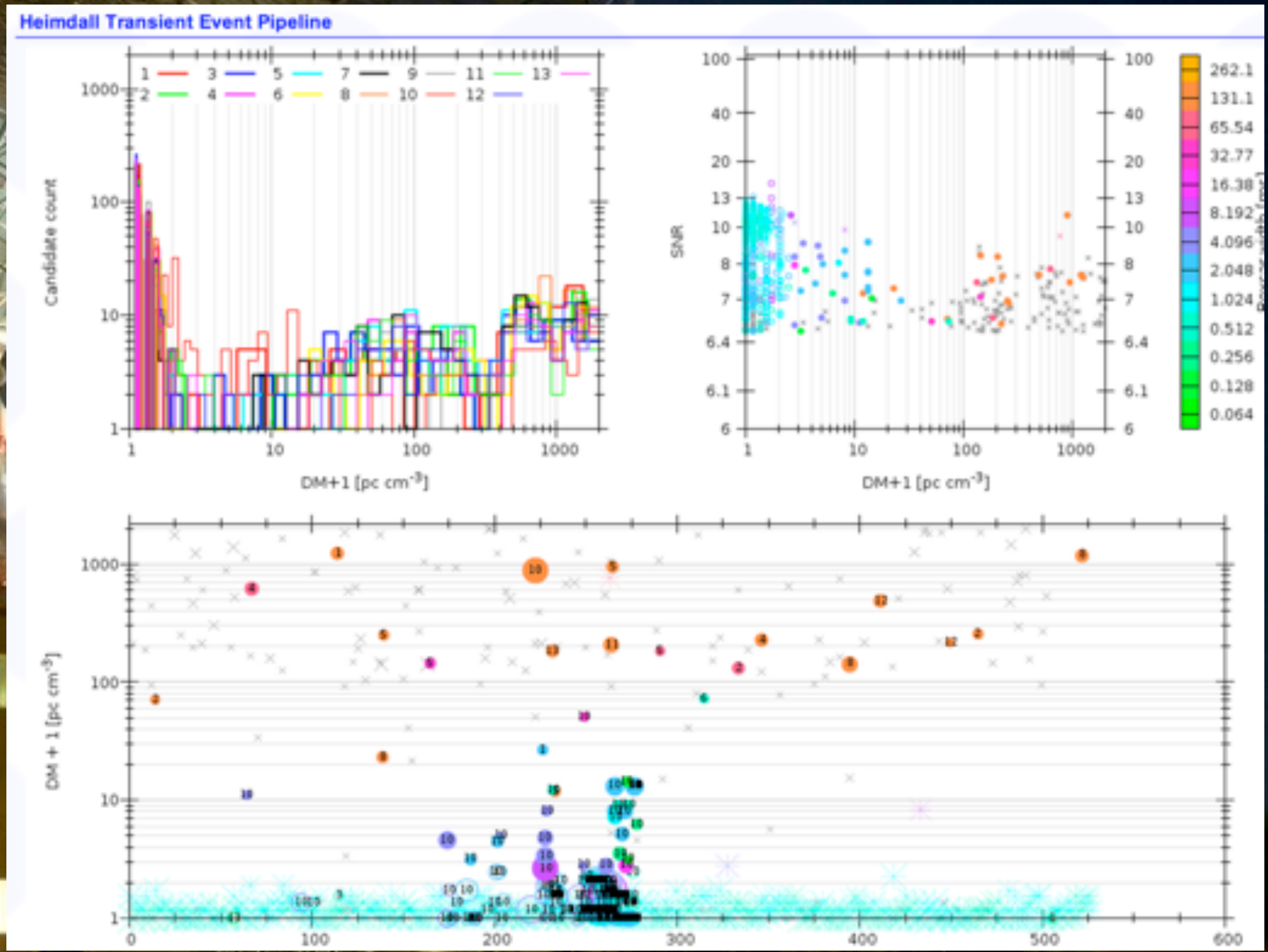
- gSTAR / swinSTAR cluster
- 249 C2070, M2070 and K10 class GPUs
- BPSR pulsar search backend
- 14 C2070 class GPUs

REAL-TIME TRANSIENTS

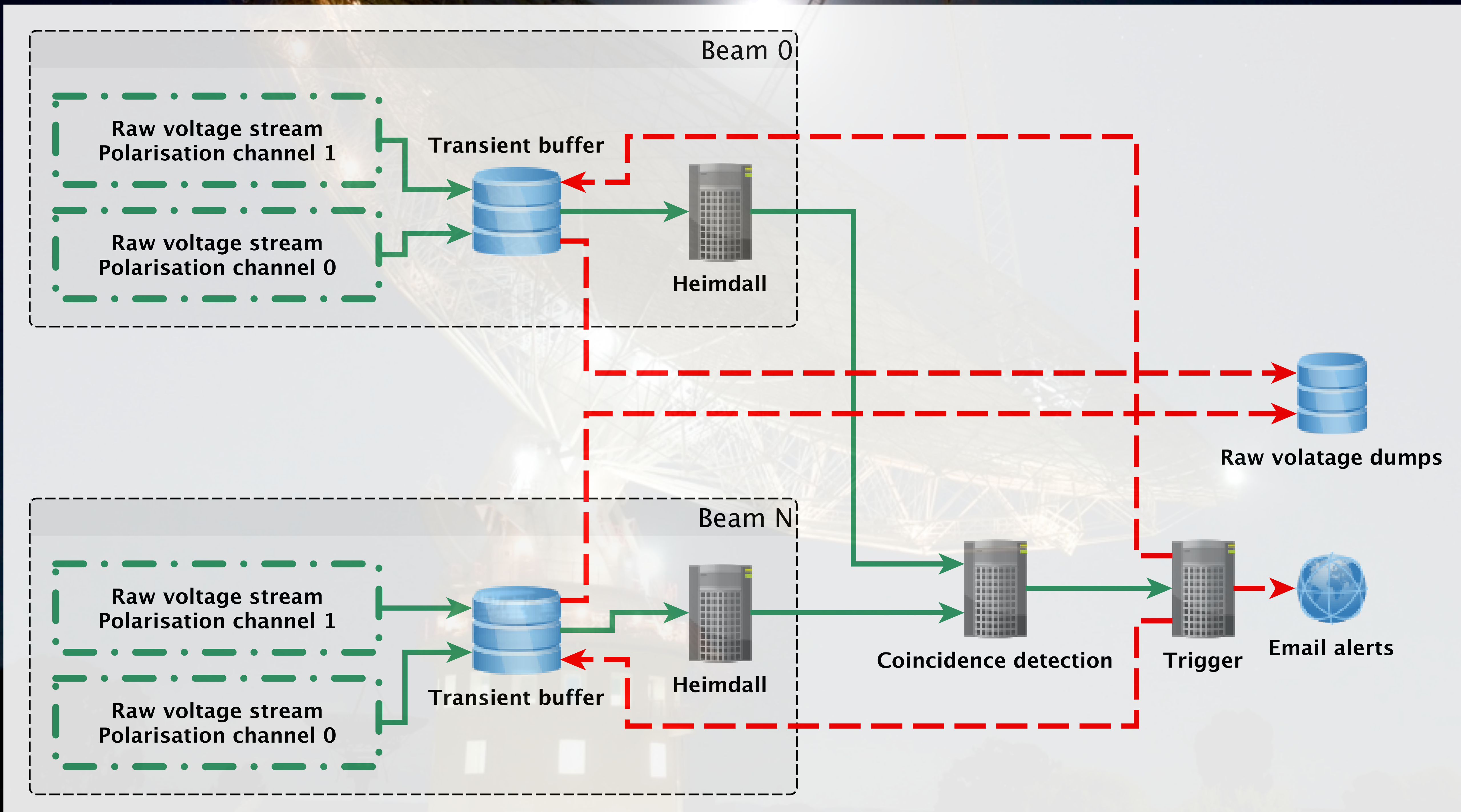
HEIMDALL

(Barsdell et al. in prep.)

- Searches out to a DM of 2000 pc/cc
- Sensitive to pulses as narrow as 64 us
- Discovered several FRBs and RRATS



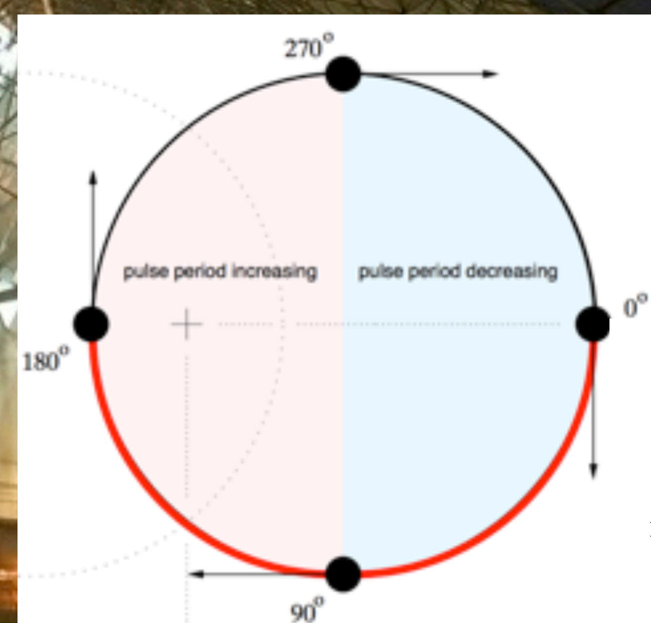
TRANSIENTS BUFFERS

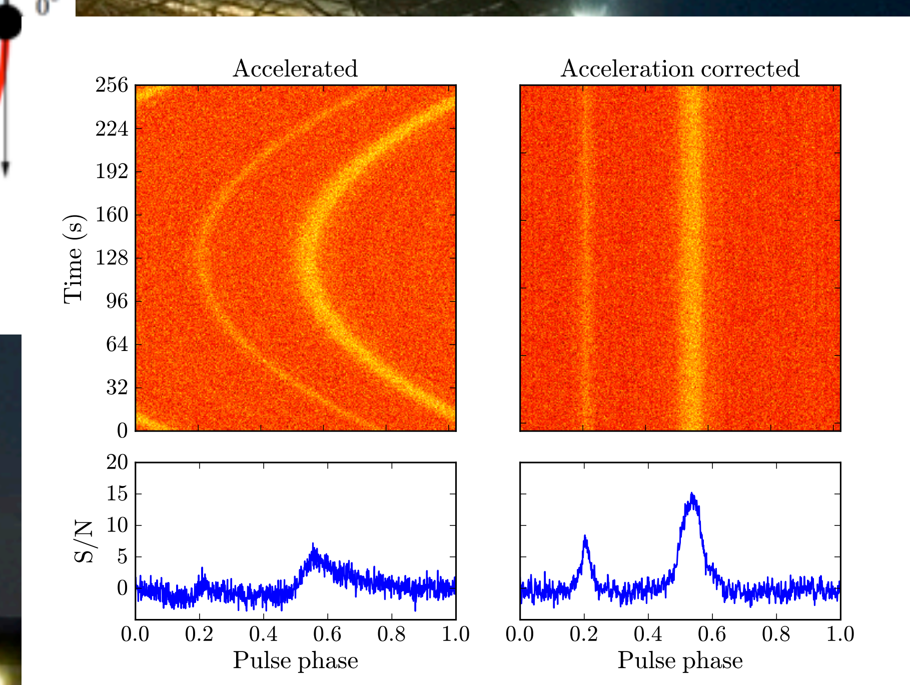


REAL-TIME ACCELERATION SEARCH

PEASOUP
(Barr et al. in prep.)

- Capable of high speed linear acceleration correction
- Required for detection of relativistic binaries
- Fastest ever pulsar searching system (100 times)



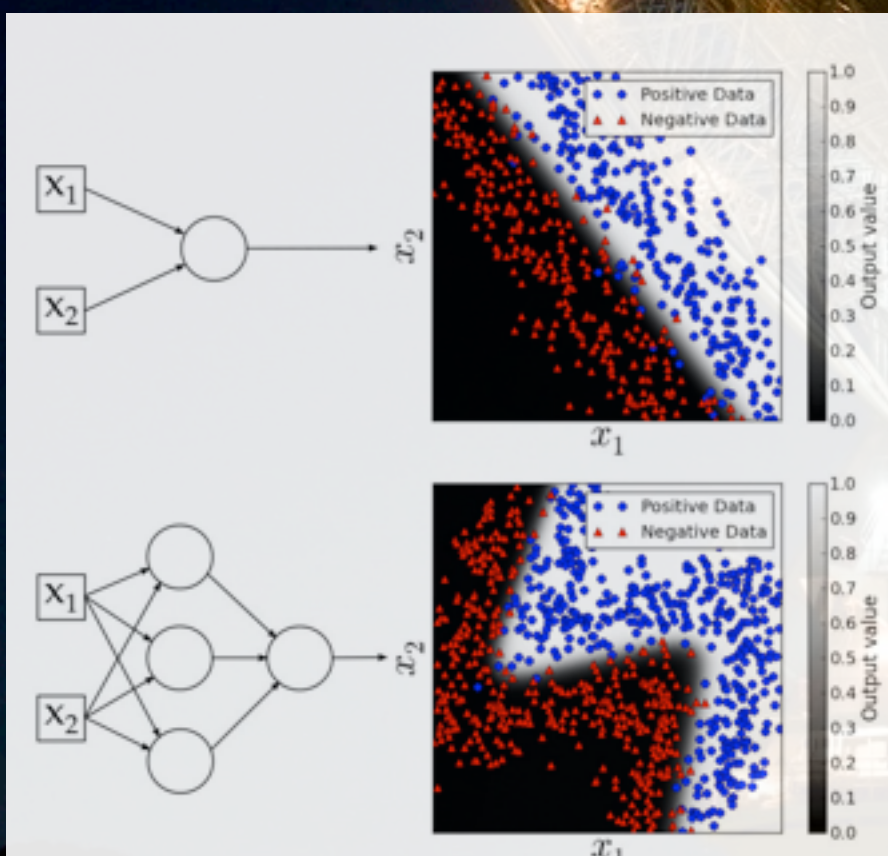


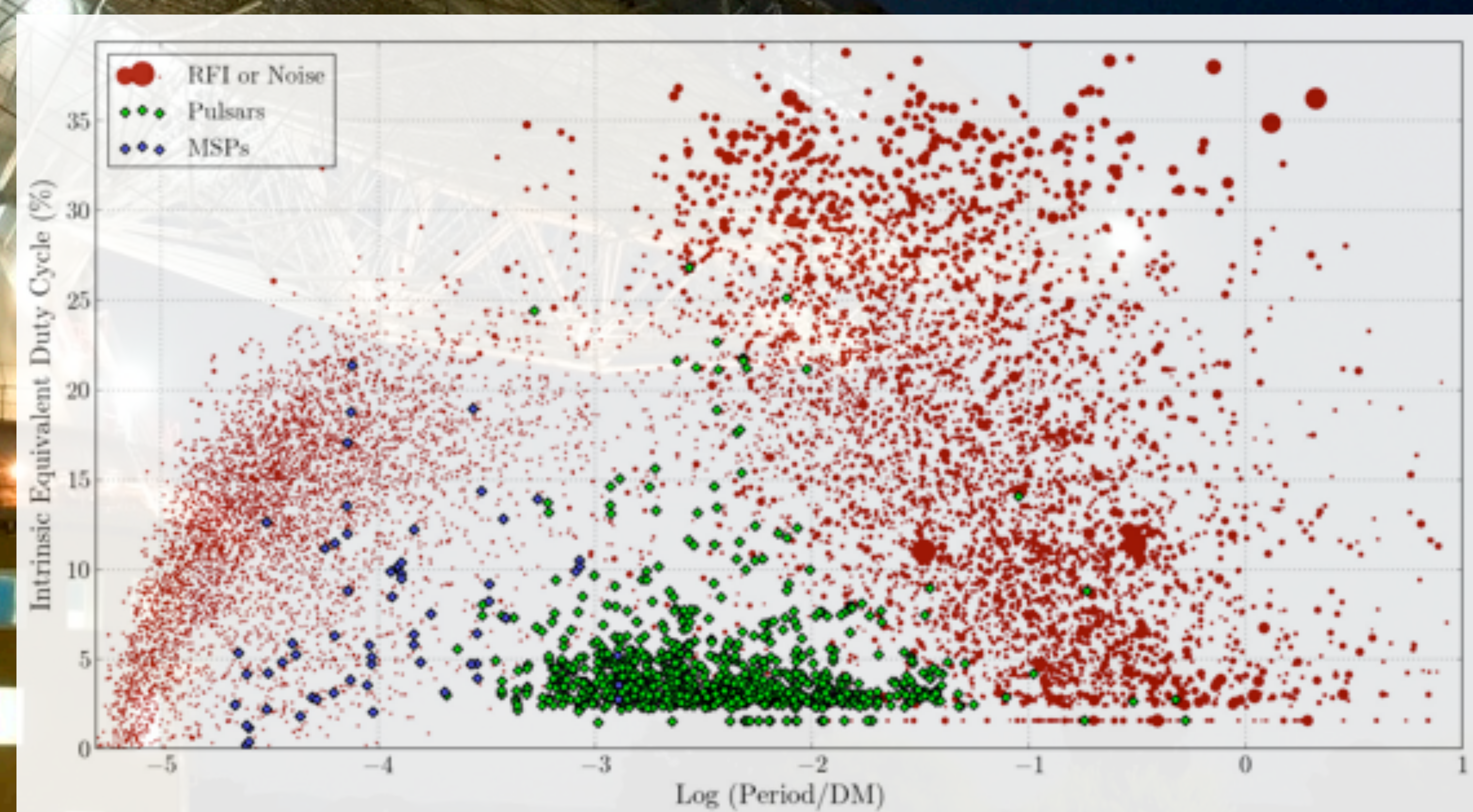
MACHINE LEARNING & CANDIDATE CLASSIFICATION

SPINN

(Morello et al. 2014)

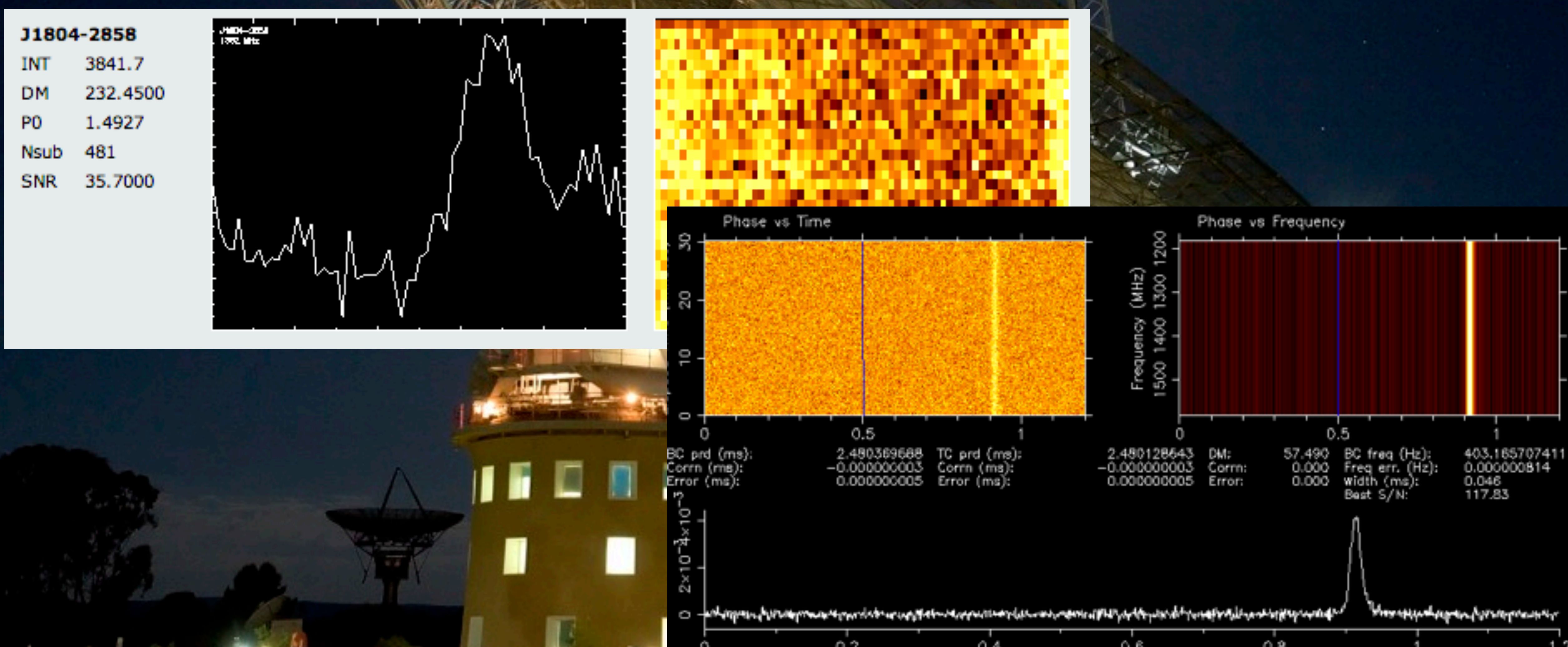
- "Minimalist" neural network implementation
- Implements multibeam candidate pre-selection
- Overcomes overspecification issues of predecessors
- 0.01% false positives for 100% recall rate





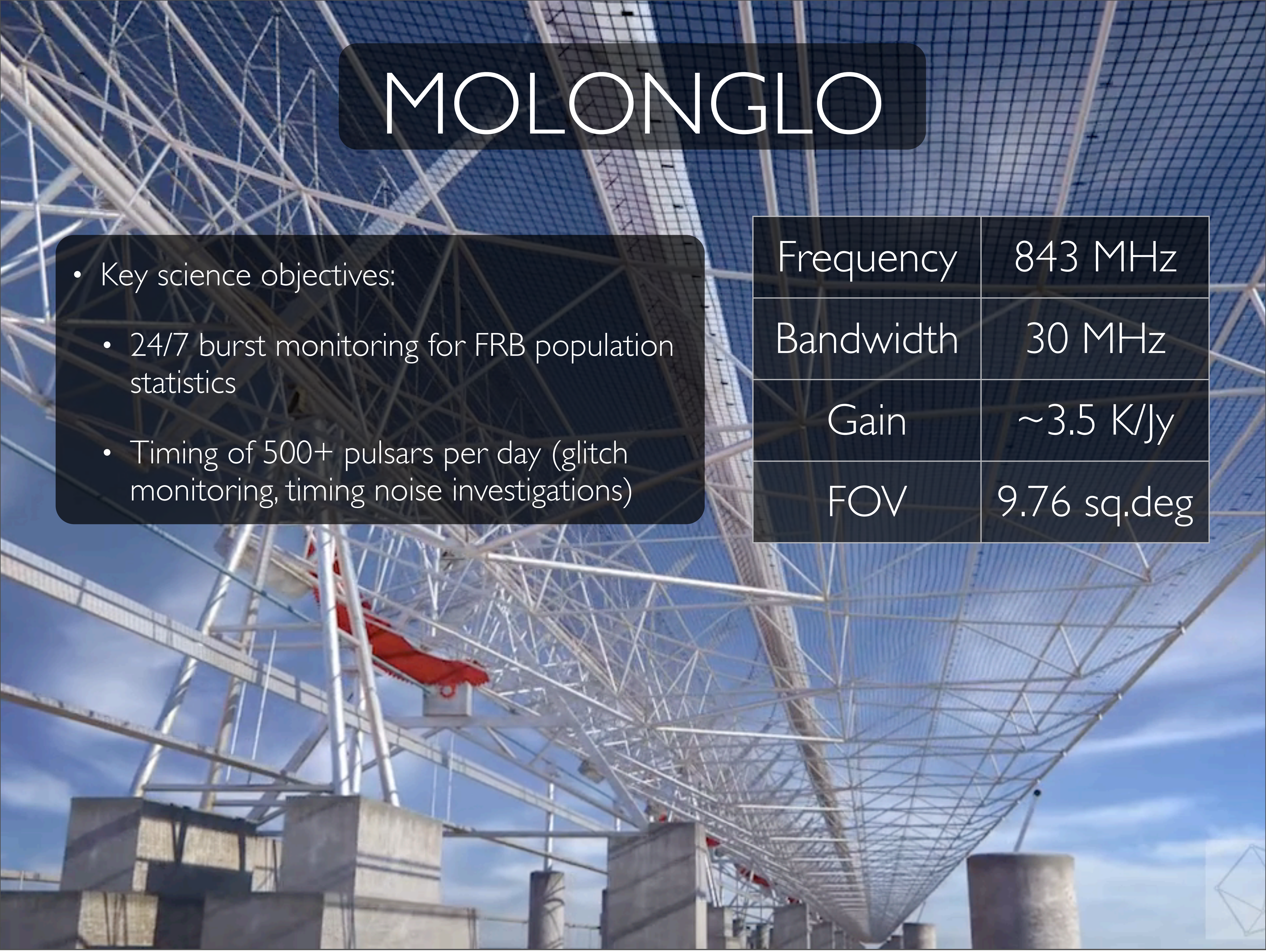
PEASOUP + SPINN

- Pipeline tested on HTRU medlat survey (50 m/s/s and 0-400 pc/cc)
- 7 new pulsars discovered (3 confirmed in real time)
- 3 MSPs including fastest pulsar outside of a globular cluster (669 Hz)




SYNERGIES
Shadowing
Multi-λ followup
MOST
GMRT
ATCA
Swift
LIGO
Magellan
Thai
PTF
Faulkes

MOLONGLO



MOLONGLO

- Key science objectives:
  - 24/7 burst monitoring for FRB population statistics
  - Timing of 500+ pulsars per day (glitch monitoring, timing noise investigations)

Frequency	843 MHz
Bandwidth	30 MHz
Gain	~3.5 K/Jy
FOV	9.76 sq.deg

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- Key SUPERB synergies:
  - Confirmation of the astrophysical origin of FRBs ! ! !
  - Better FRB localisation for optical/x-ray/radio follow-up
  - Much better constraints on the intrinsic spectra of FRBs (and on DM sweep index)

MOLONGLO

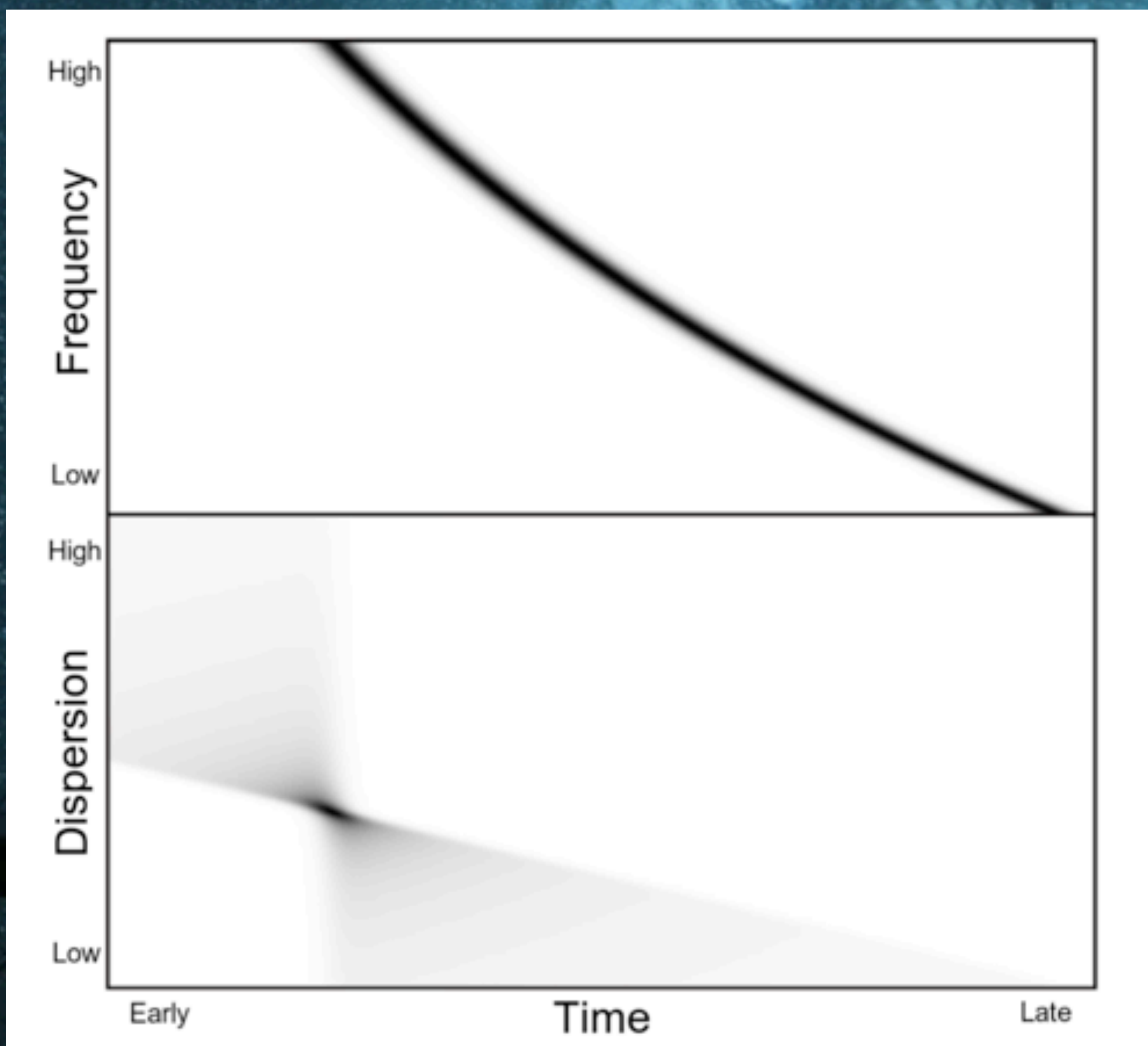
- Well on way to full operation, 80 % of hardware in place
- GPU powered correlator, coherent dedispersion backend and burst searching systems
- Automatic baseband dump triggers from Parkes

- Socialist science... all timing data will be public "instantaneously"
- Co-observations with PPTA for precision DM discrimination
- Potential for HI mapping for BAO at z~0.7

CONCLUSIONS

- SUPERB will:
  - Find a host of new pulsar systems (~20 MSPs and ~100 normal pulsars)
  - Find & localise FRBs
  - Constrain FRB spectra
  - Provide the first FRB polarisation information
  - Solve the "June problem" and improve rate estimates
  - Demonstrate the immense power of GPUs for pulsar and transient searching
  - ...much more

PULSAR SEARCH:
DEDISPERSION



$$D_{\mathrm{DM,t}} = \sum_{\nu}^{N_\nu} A_{\nu, t+\Delta t(\mathrm{DM}, \nu)}$$

Sum all frequencies along lines of constant dispersion measure

$$\mathcal{O}(N_t N_\nu N_{\mathrm{DM}})$$

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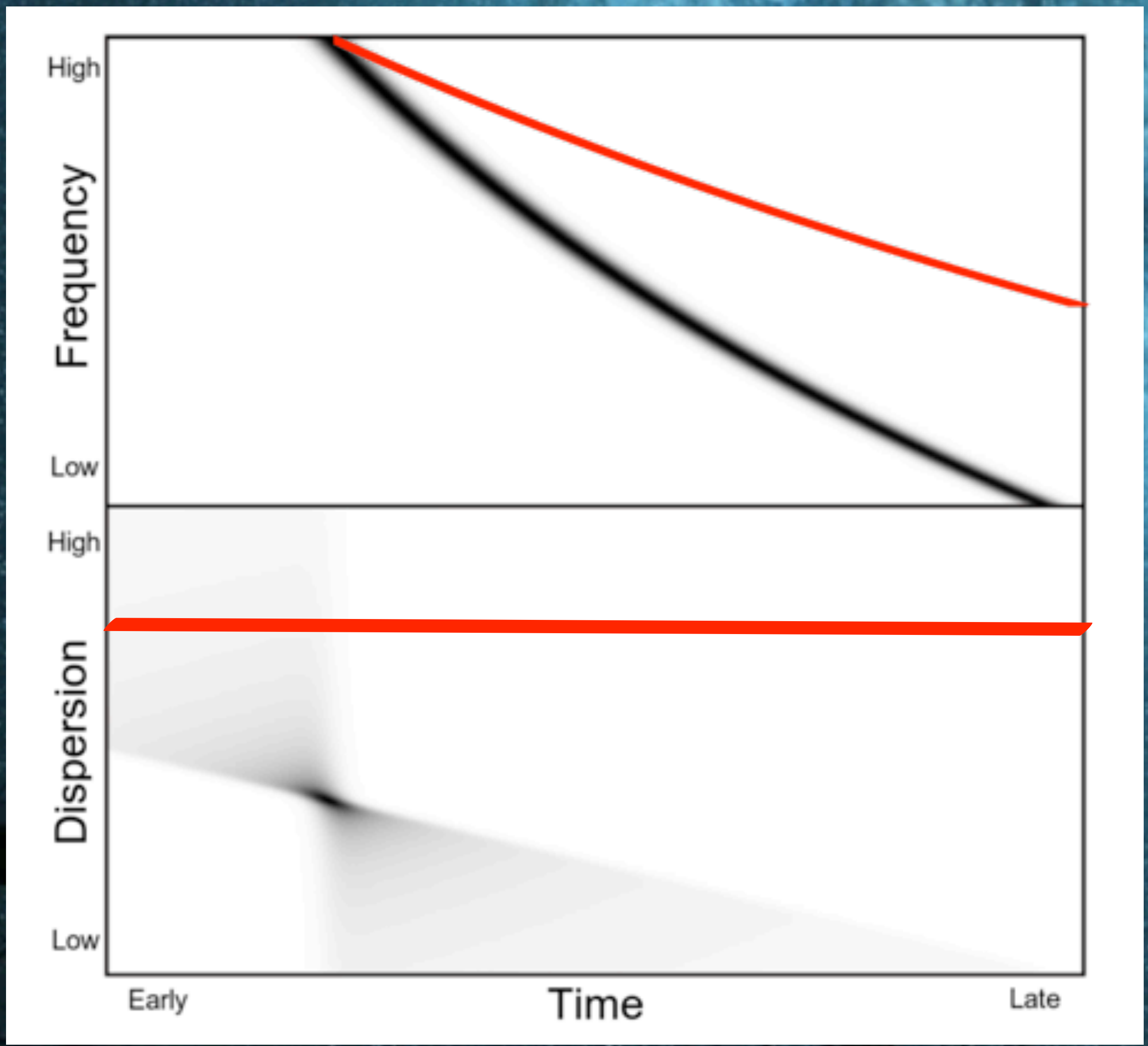
DEDISPERSION



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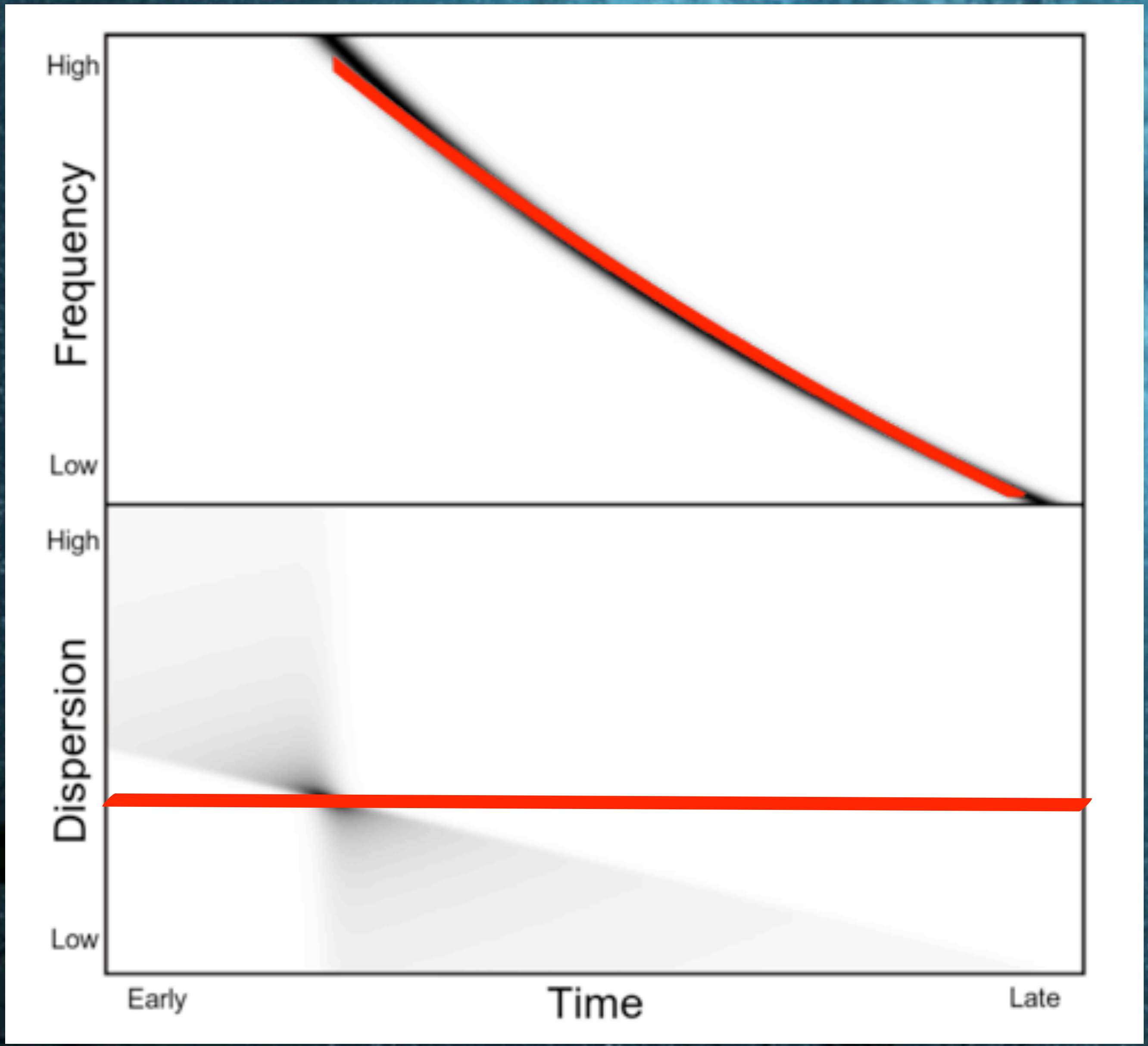

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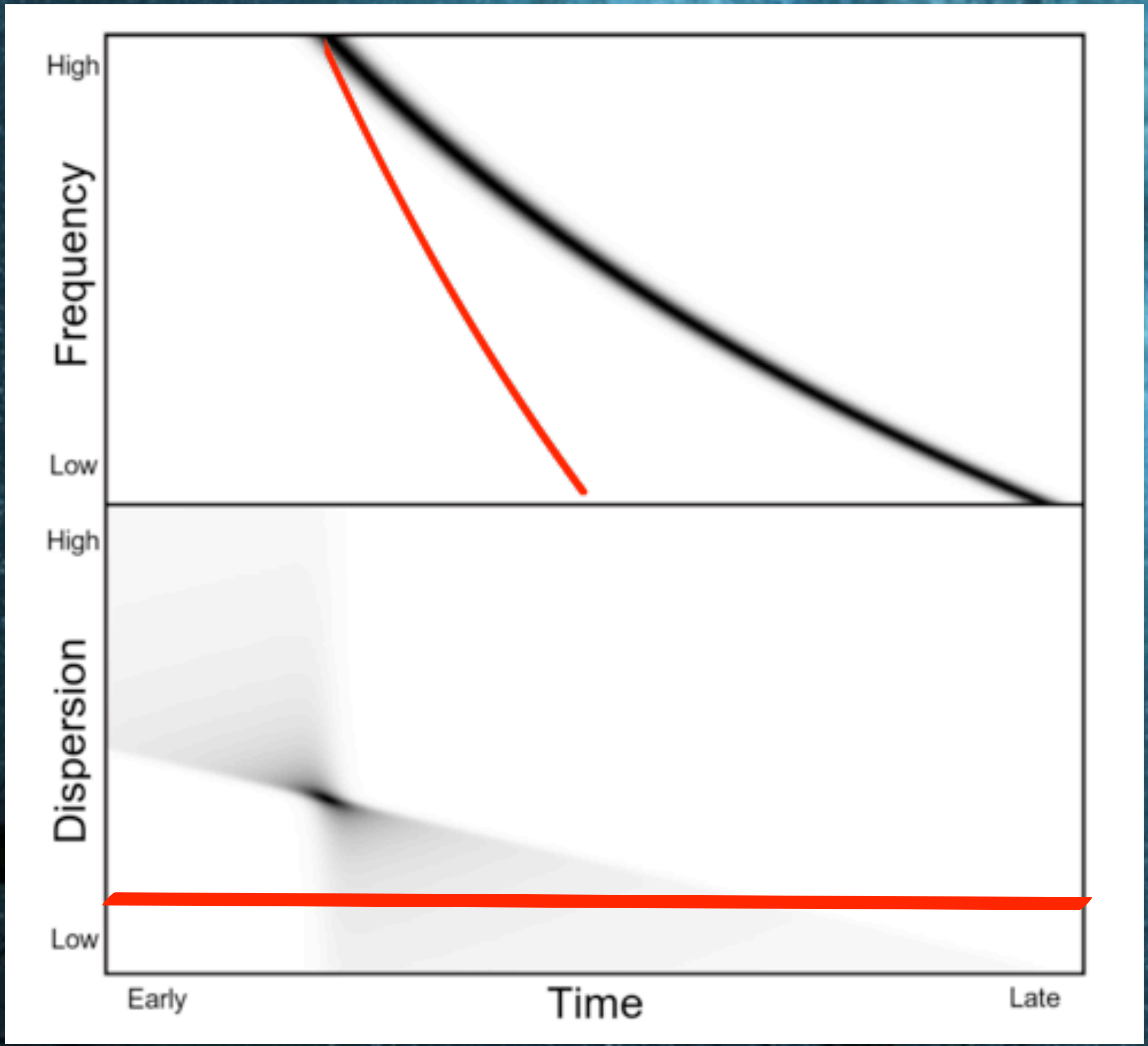

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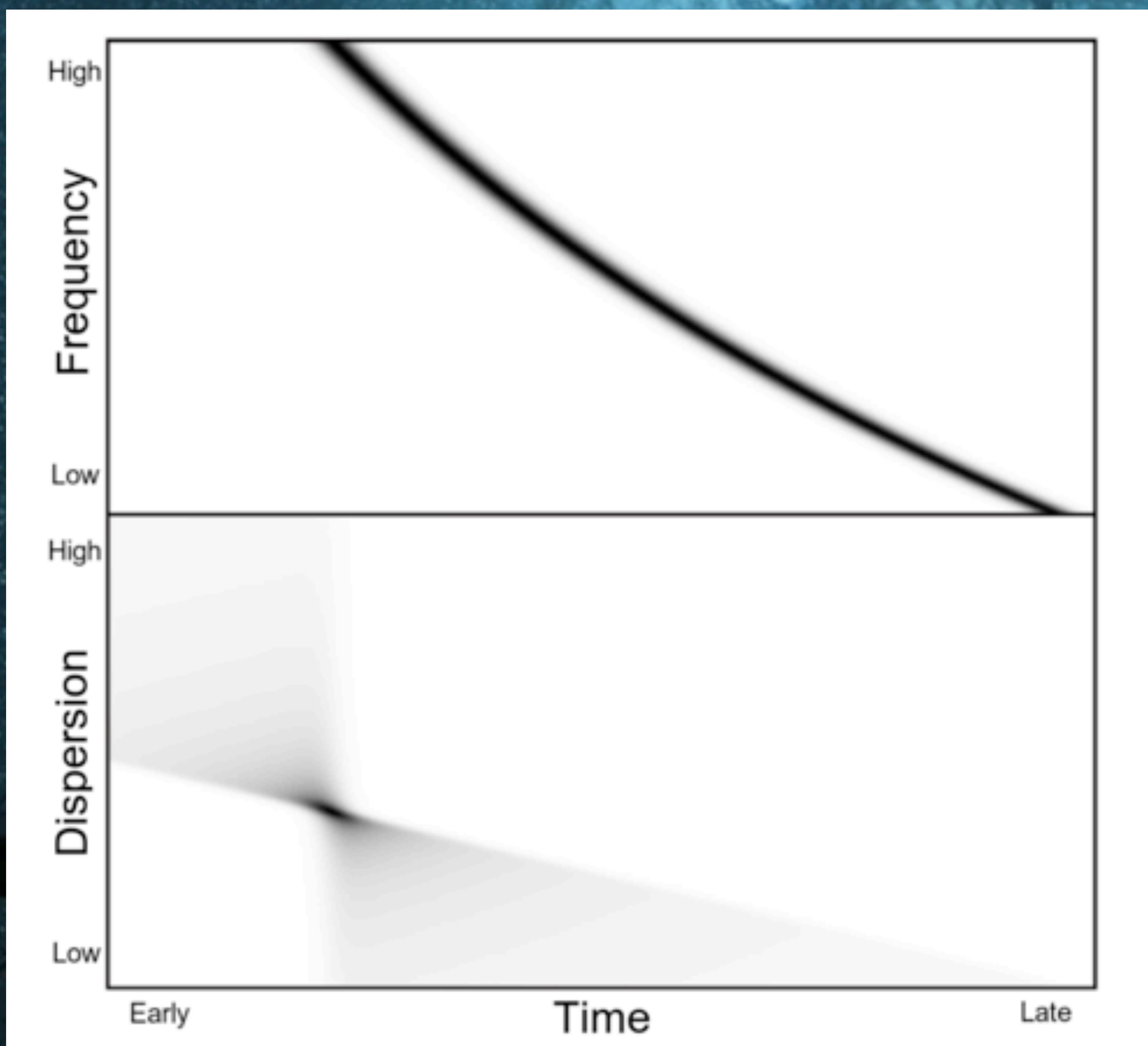

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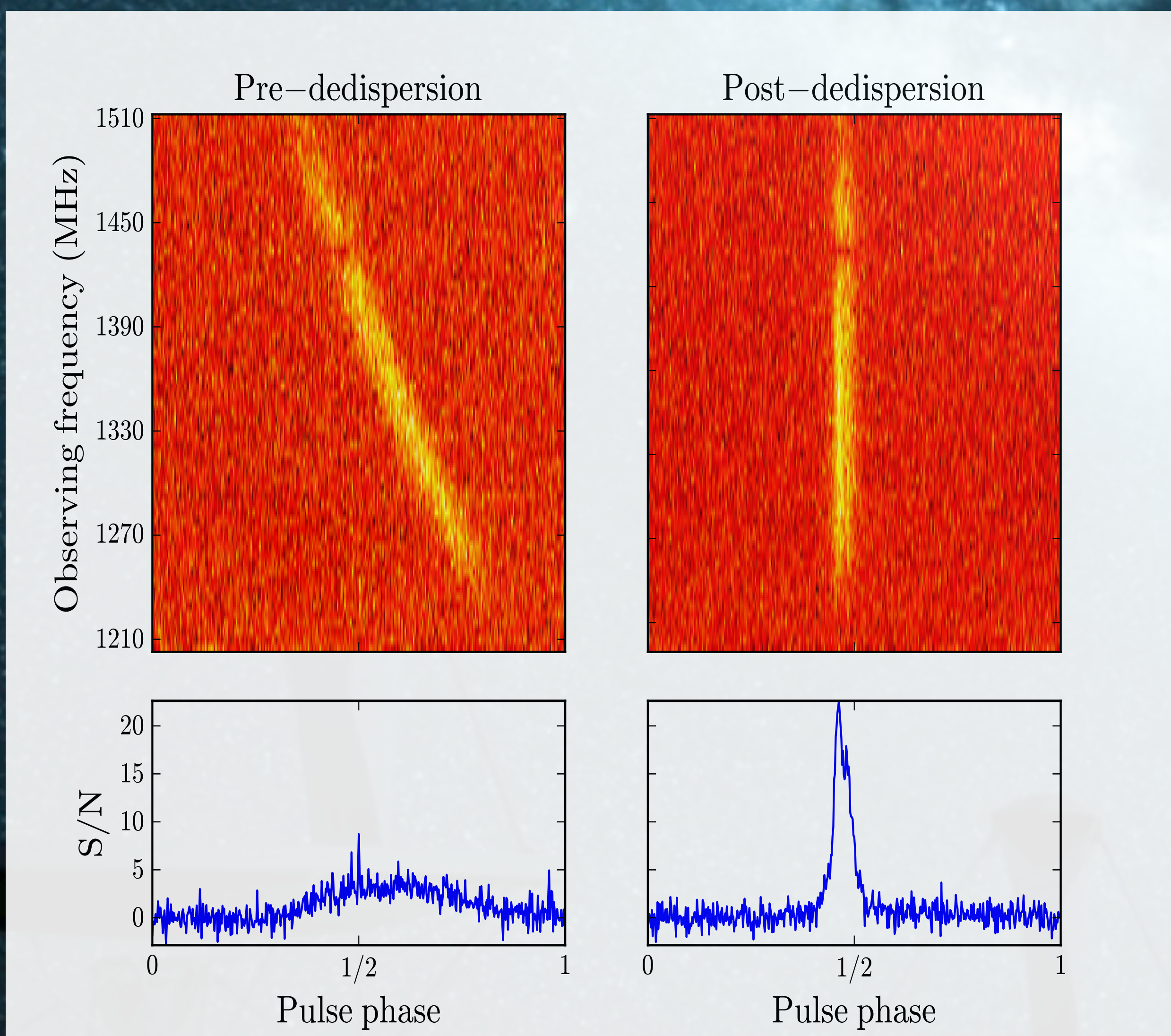
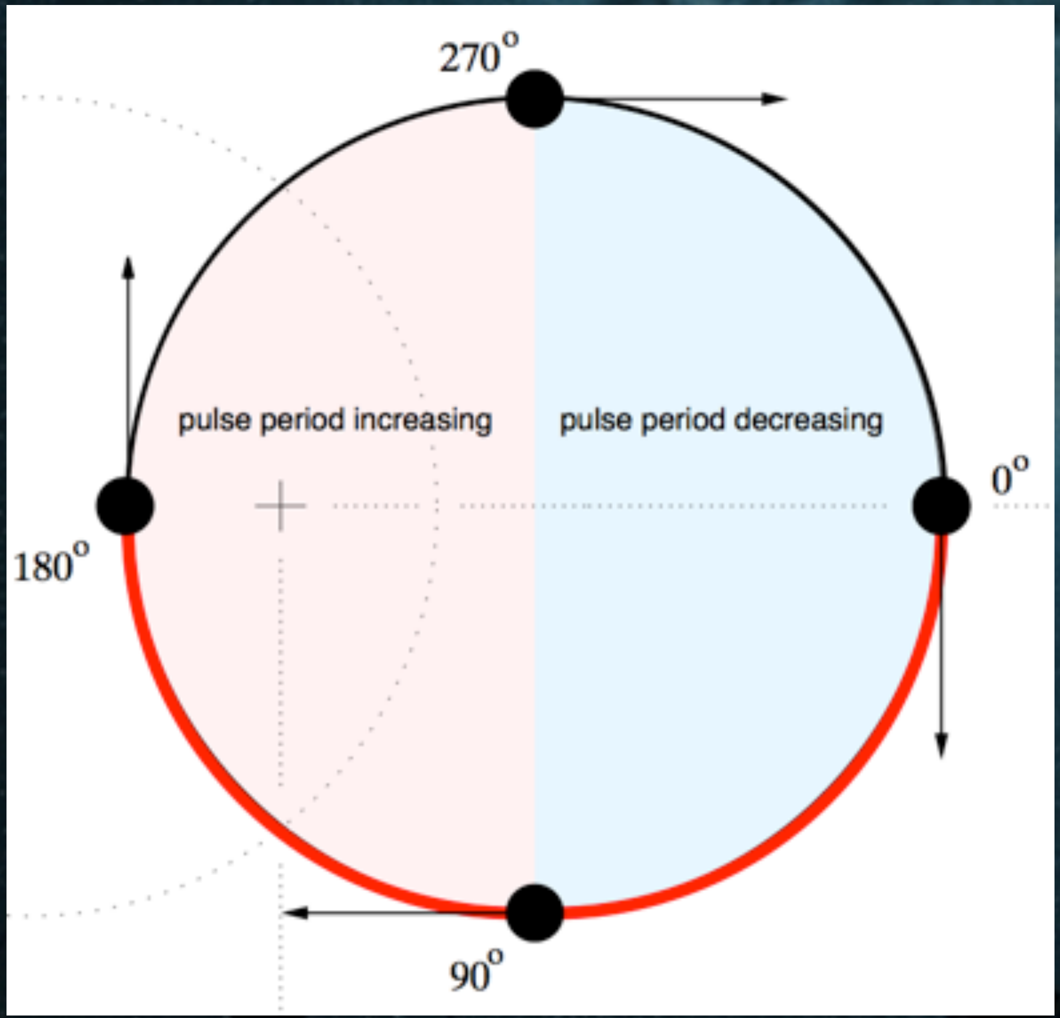


$$\Delta\mathrm{DM} = \frac{-4\pi m_e c \nu_a^2 \beta (\epsilon \Delta\nu - \nu_a)^2}{e^2 \epsilon \Delta\nu (\epsilon\Delta\nu - 2\nu_a)}$$

$$\beta = \sqrt{w_{\mathrm{int}}^2 + t_{\mathrm{samp}}^2 + t_{\mathrm{DM_{chan}}}^2}$$

Typically ~3000 trials

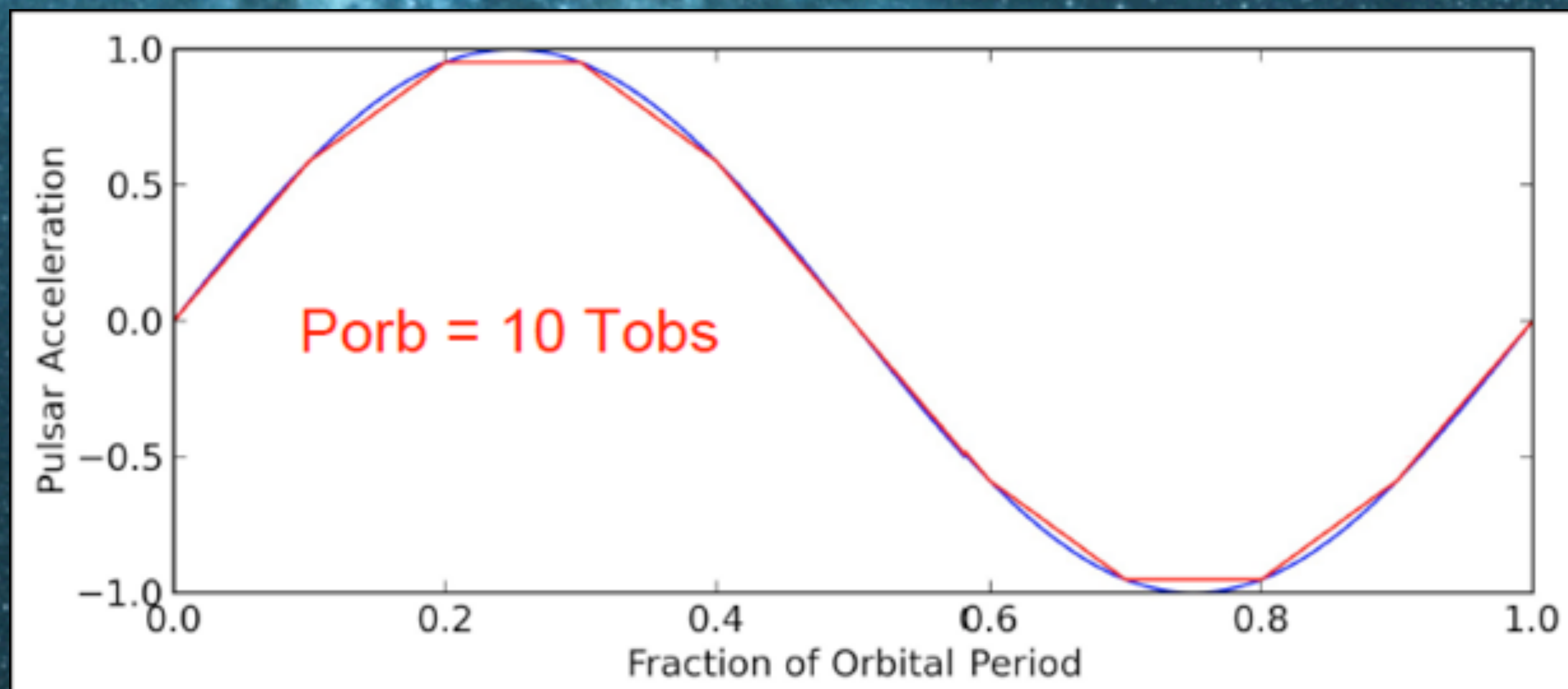
PULSAR SEARCH:
ACCELERATION SEARCHING



- Spin frequency of pulse is Doppler shifted by motion in orbit.
- Spreads signal in the Fourier domain, lowering S/N.
- df/dt dependent on orbital acceleration.

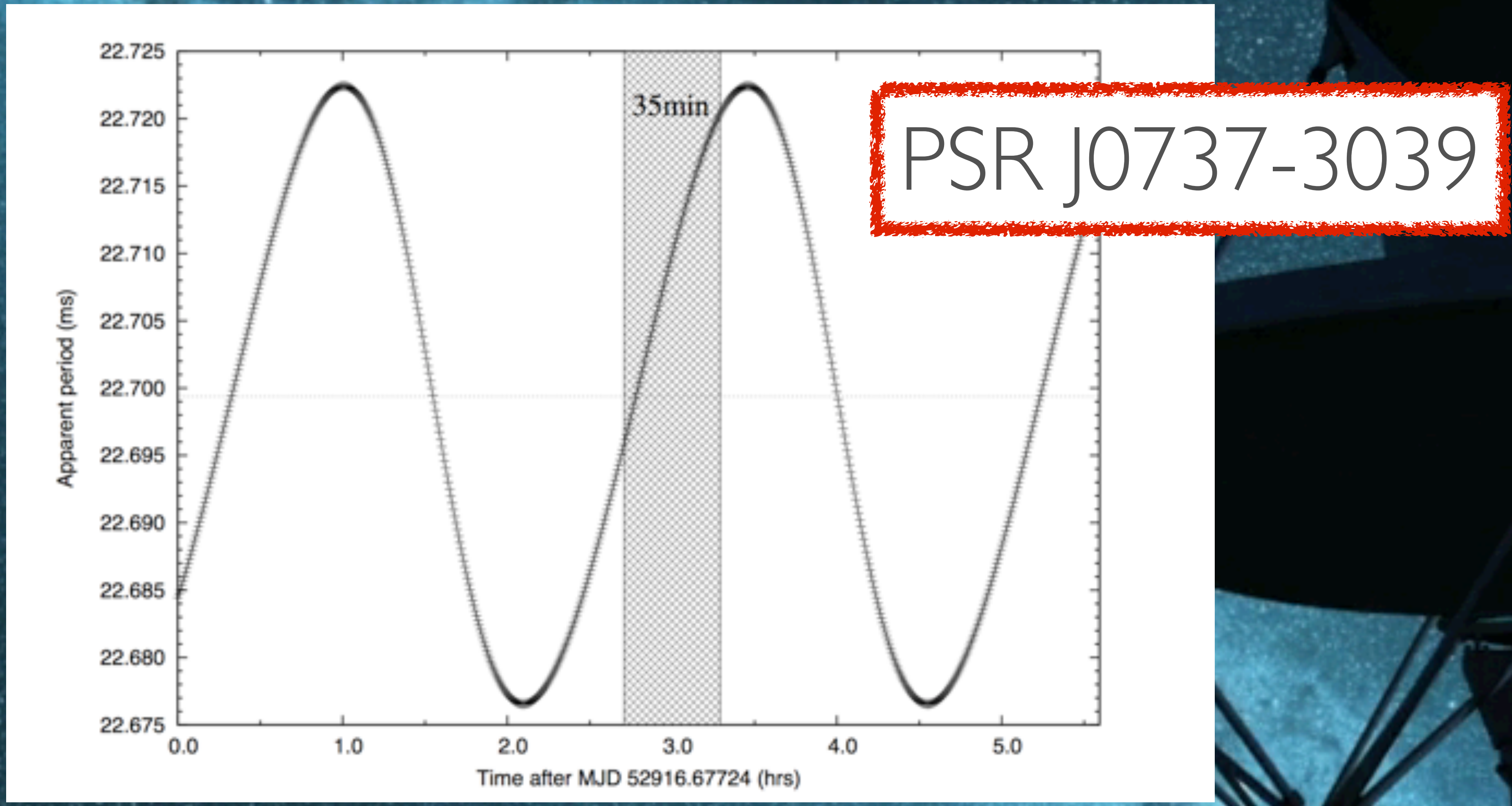
$$a(A_T) = -\Omega_b^2 \frac{a_p \sin i}{1 - e^2} (1 + e \cos A_T)^2 \sin(\omega + A_T)$$

PULSAR SEARCH:
ACCELERATION SEARCHING



- Searching all orbital parameters is too costly.
- Approximate df/dt as constant over segments of orbit.
- Valid approximation for circular orbits where $T_{obs} < P_{orb}/10$.

PULSAR SEARCH:
ACCELERATION SEARCHING



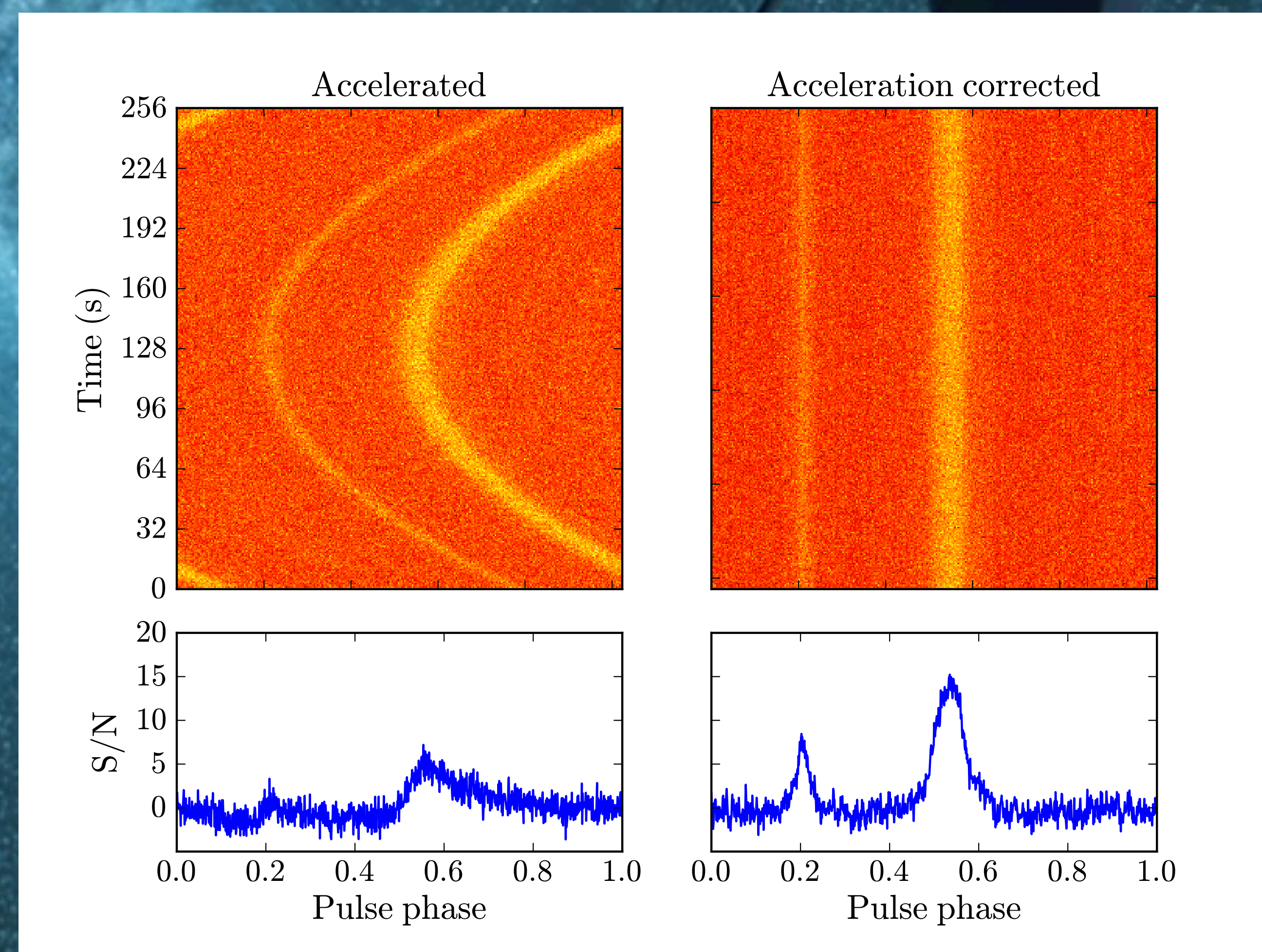
- For eccentric orbits, approximation breaks down.
- Either break observation and re-search, or reobserve in the hope of a better orbital phase.

PULSAR SEARCH:
TIME DOMAIN RESAMPLING

$$A_{a,t} = B_{t[1+a(t-t_{\rm obs})/2c]}$$

Stretch and compress time series to emulate frequency drift

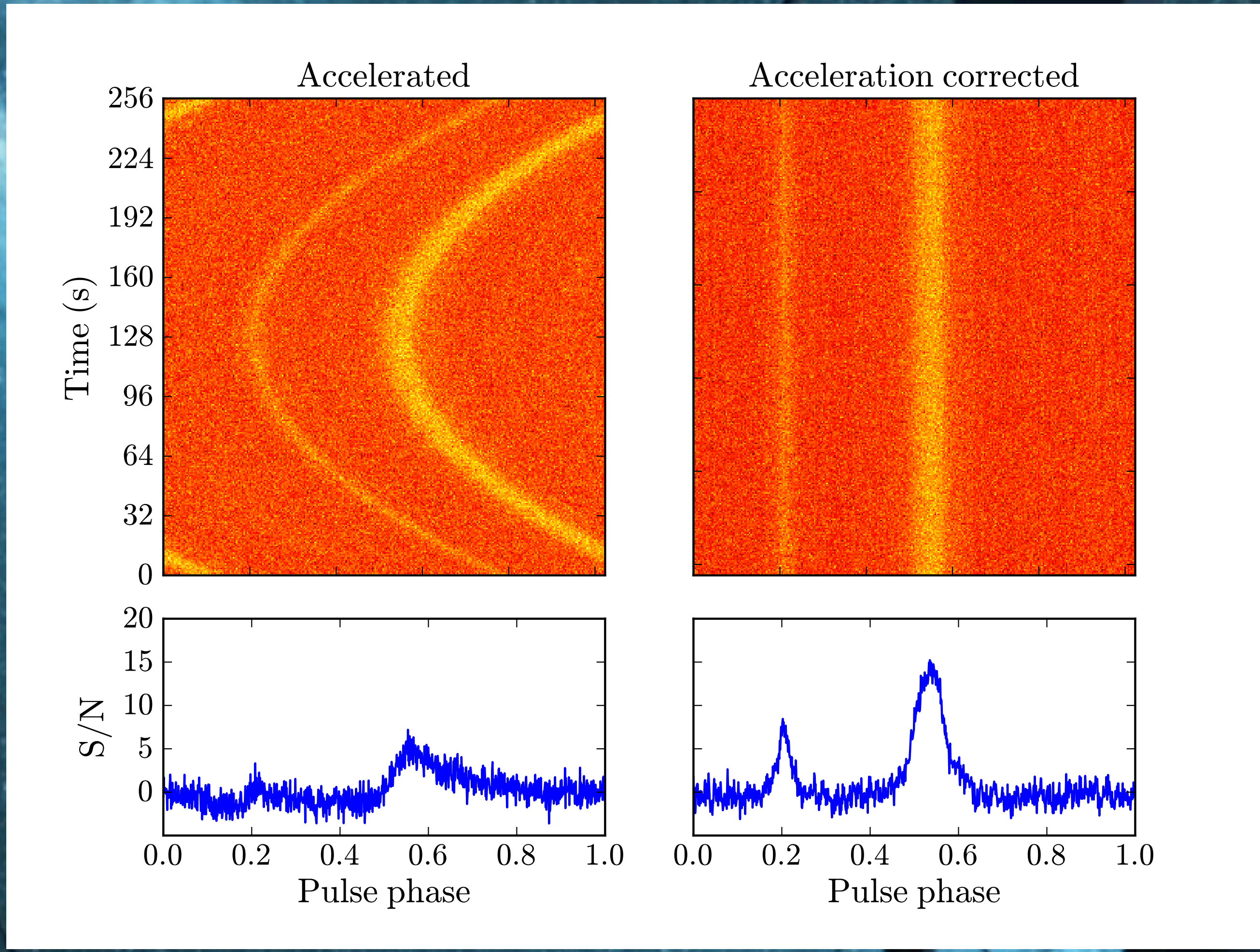
$$\mathcal{O}(N_a N_t N_{\rm DM})$$



PULSAR SEARCH:
TIME DOMAIN RESAMPLING

$$\Delta a = \frac{48\beta c}{t_{\mathrm{obs}}^2}\sqrt{\left(\frac{1}{\epsilon^4} - 1\right)}$$

Ntrials depends on t_{obs}^2
(10 mins gives 700 trials)



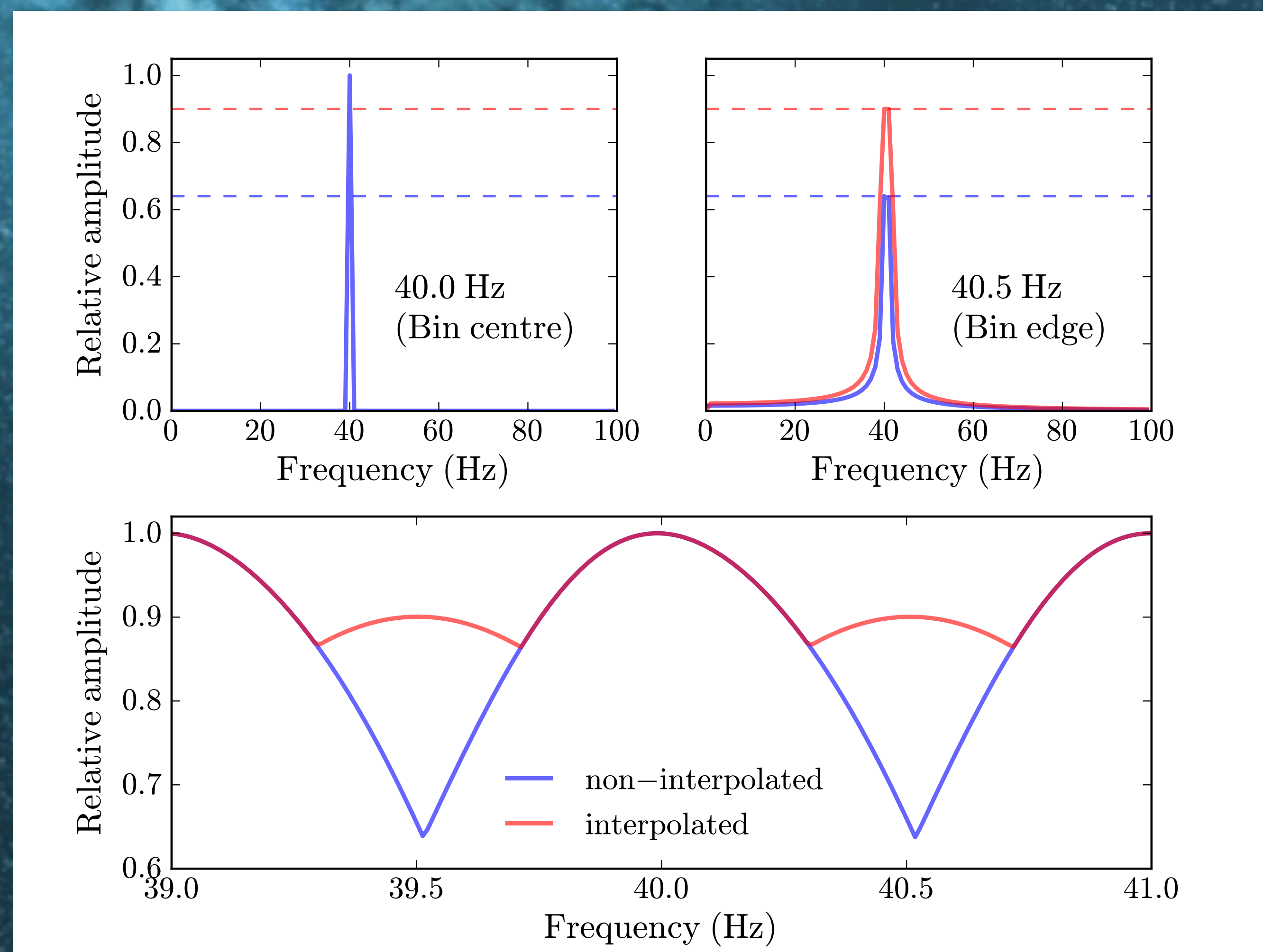
PULSAR SEARCH:
FAST FOURIER TRANSFORM

$$\mathcal{O}(N_a N_{\mathrm{DM}} N_t \log_2 N_t)$$

Best performance with prime factorable N

Real to complex FFT, exploits Hermitian symmetry to reduce complexity

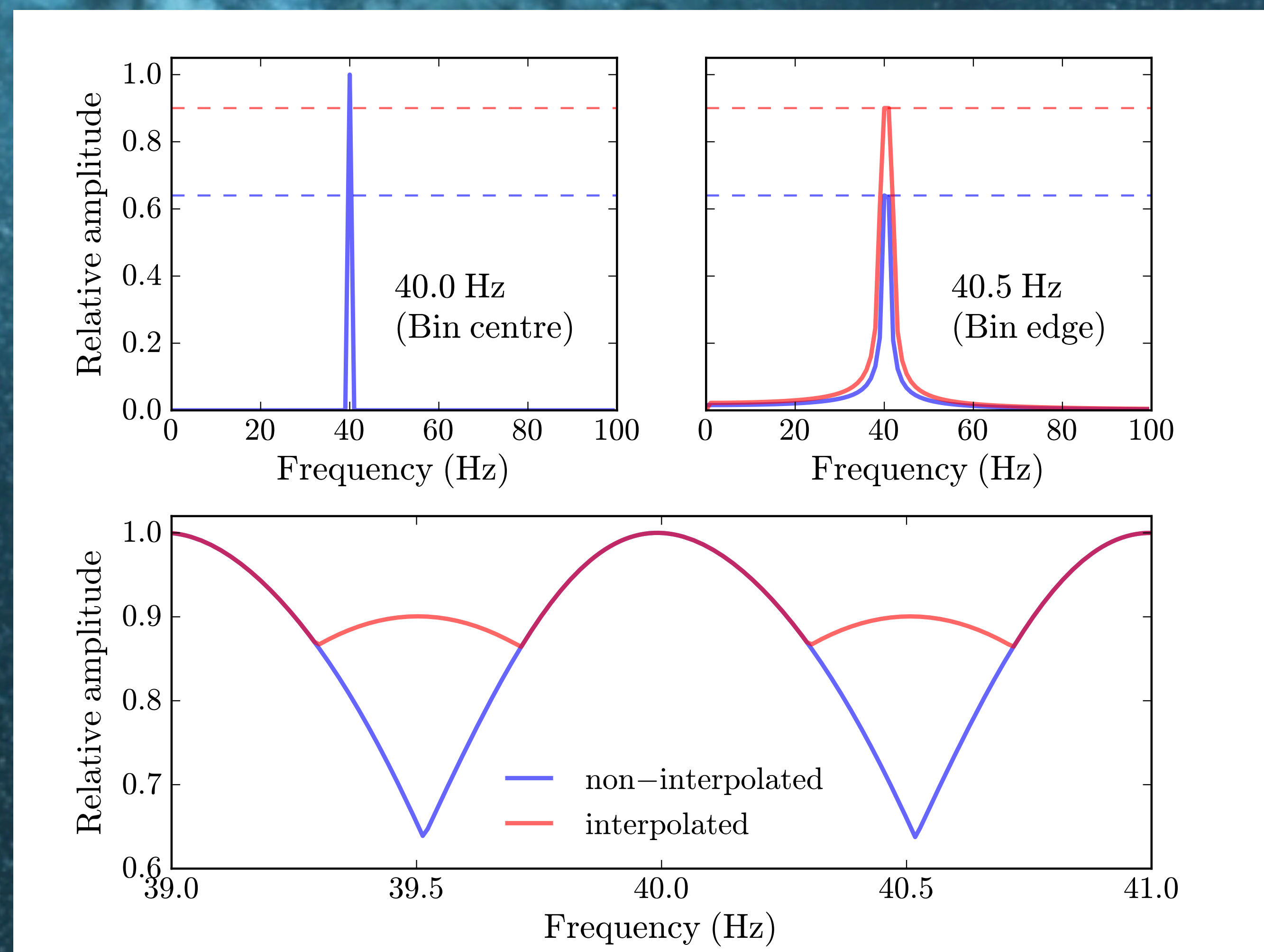
PULSAR SEARCH:
SPECTRAL INTERPOLATION



DFT response is imperfect at bin edges

Interpolate to improve response to arbitrary frequencies

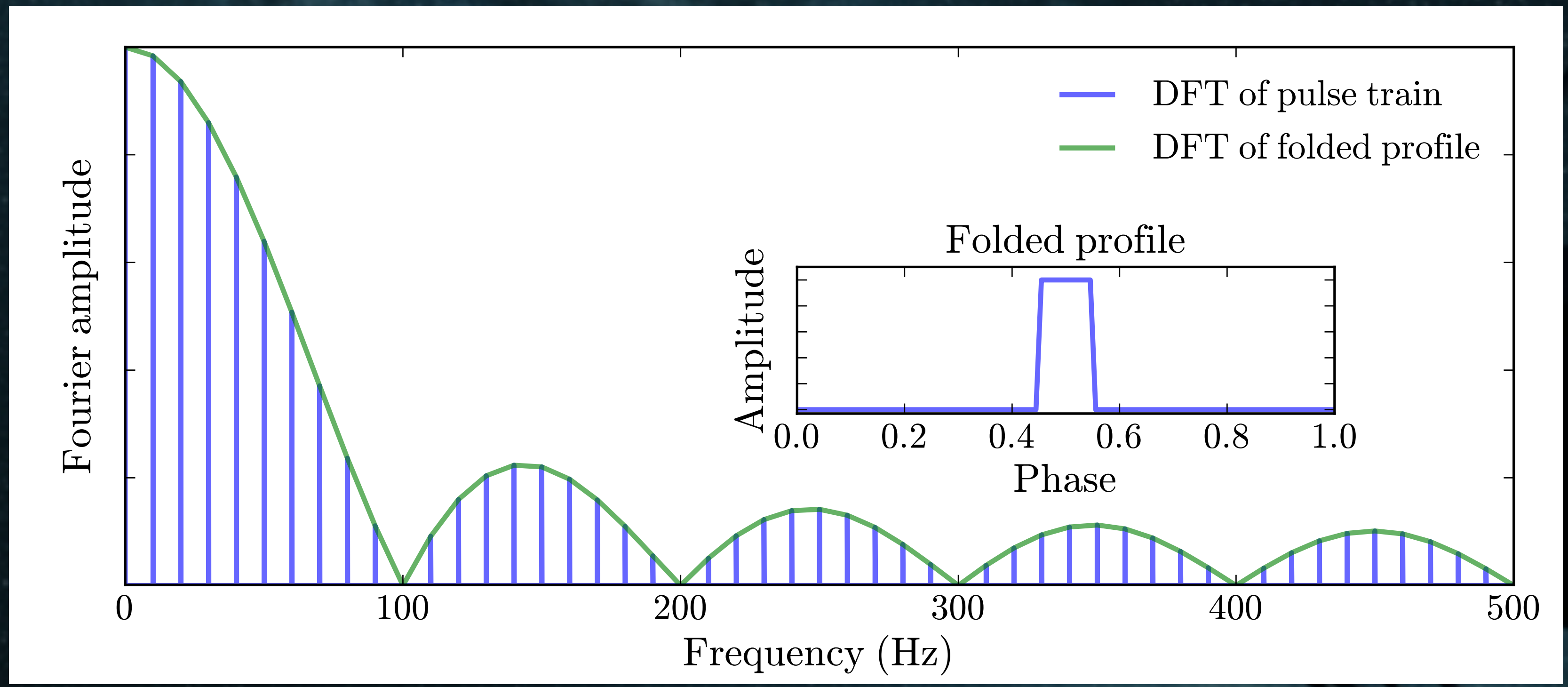
PULSAR SEARCH:
SPECTRAL INTERPOLATION



$$A_i = \max\left(B_i, \frac{1}{\sqrt{2}}(B_i + B_{i+1})\right)$$

$$\mathcal{O}(N_a N_{\mathrm{DM}} N_t)$$

PULSAR SEARCH:
HARMONIC SUMMING



- Pulse power spread in Fourier domain.
- Incoherently add harmonics to increase signal.
- For N_h harmonic numbers.

PULSAR SEARCH:
HARMONIC SUMMING / PEAK FINDING

$$A_{i,N_h} = \frac{1}{\sqrt{N_h}}\left(B_i + \sum_{h}^{N_h} B_{(ih/N_h)}\right)$$

$$\mathcal{O}(2^{N_h} N_a N_{\mathrm{DM}} N_t)$$

- After each harmonic sum we threshold the spectrum and mark candidates above the threshold.
- Sort candidates above threshold by signal-to-noise or power.
- Store candidates for application of clustering algorithms.

$$\mathcal{O}(N_h N_a N_{\mathrm{DM}} N_t)$$