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NWU Pulsar Timing Workshop
25 Sept 2023



Pulsars: What they are and how to find them

Part 1: WHAT ARE PULSARS?

Default (GPT-3.5)



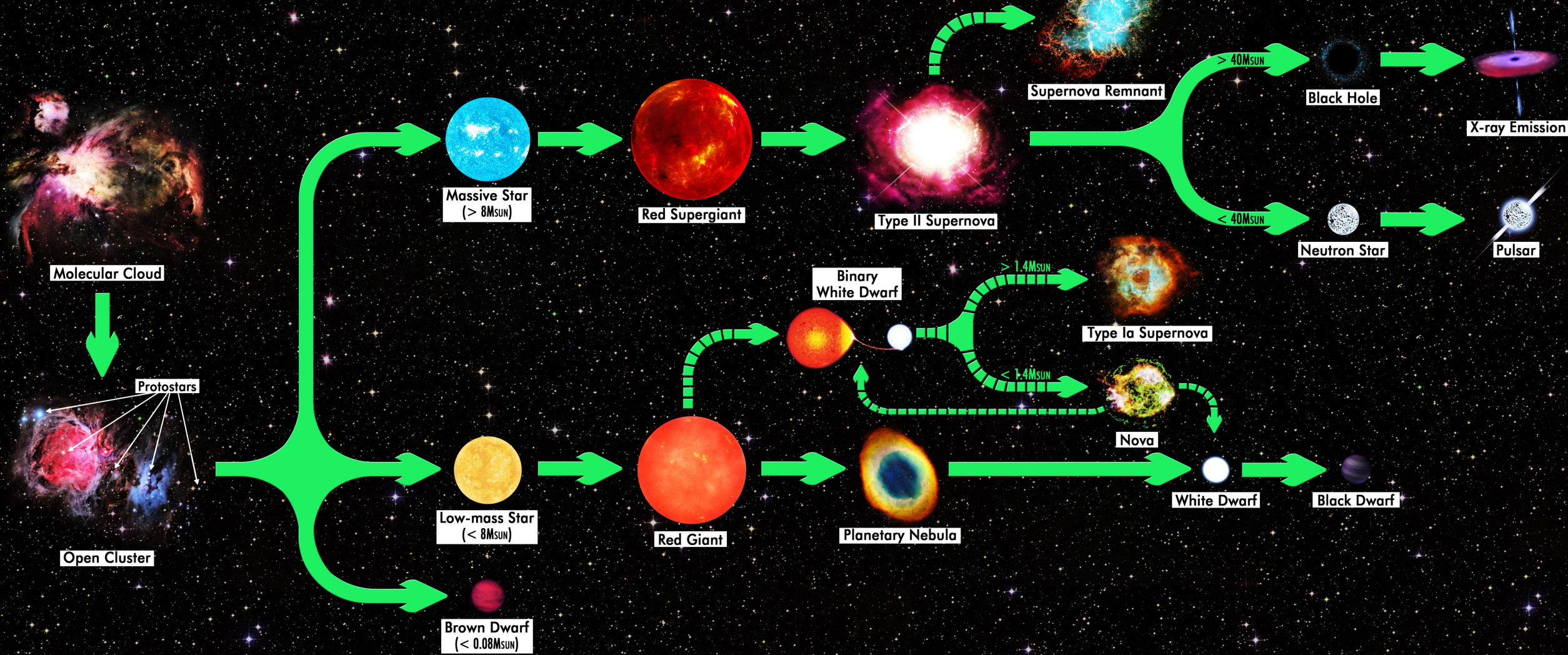
Explain to me what a pulsar is in a single sentence.



A pulsar is a highly magnetized, rapidly rotating neutron star that emits beams of electromagnetic radiation, including radio waves, with a regular and precise pulsing pattern.

“Highly magnetised, rapidly
rotating neutron stars...”

STELLAR LIFE CYCLE



Birth

Main Sequence

Old Age

Death

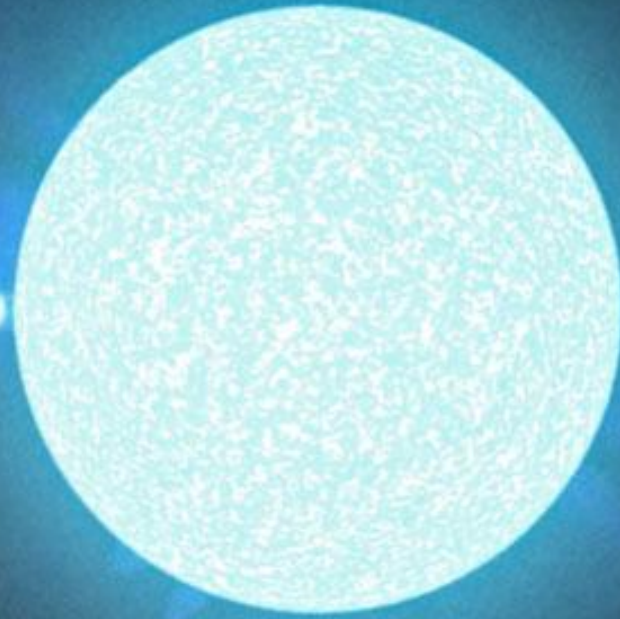
Remnant

Neutron Star matter

1.4 M_{sun}

20 km diameter

$\therefore \sim 10^{17} \text{ kg/m}^3$



1 tbsp. of Earth = 0.02 kg

1 tbsp. of the Sun = 2 kg

1 tbsp. of a NS = 900 billion kg

“Highly magnetised, rapidly
rotating neutron stars...”

Rapidly rotating

$$\Omega_f = \Omega_i \left(\frac{R_i}{R_f} \right)^2$$

$$R_i \sim 10^6 \text{ km}$$

$$R_f \sim 10 \text{ km}$$

\therefore factor 10^{10} speed-up

Spin periods = 1 ms - 76 s

Highly magnetic

$$R_i \sim 10^6 \text{ km}$$

$$R_f \sim 10 \text{ km}$$

\therefore factor 10^{10} amplification

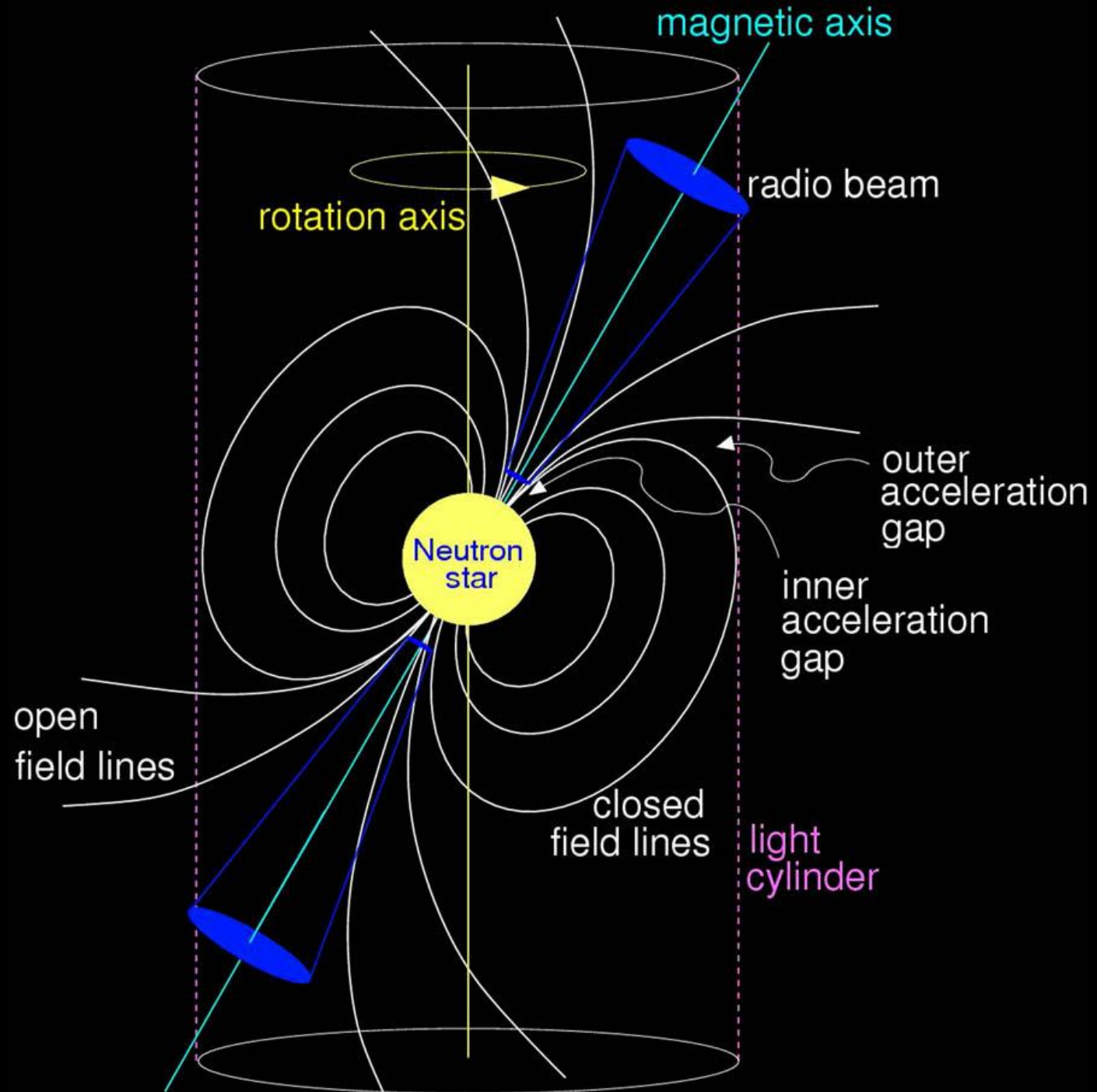
$$B_f = B_i \left(\frac{R_i}{R_f} \right)^2$$

Earth: $\sim 10^{-4}$ T

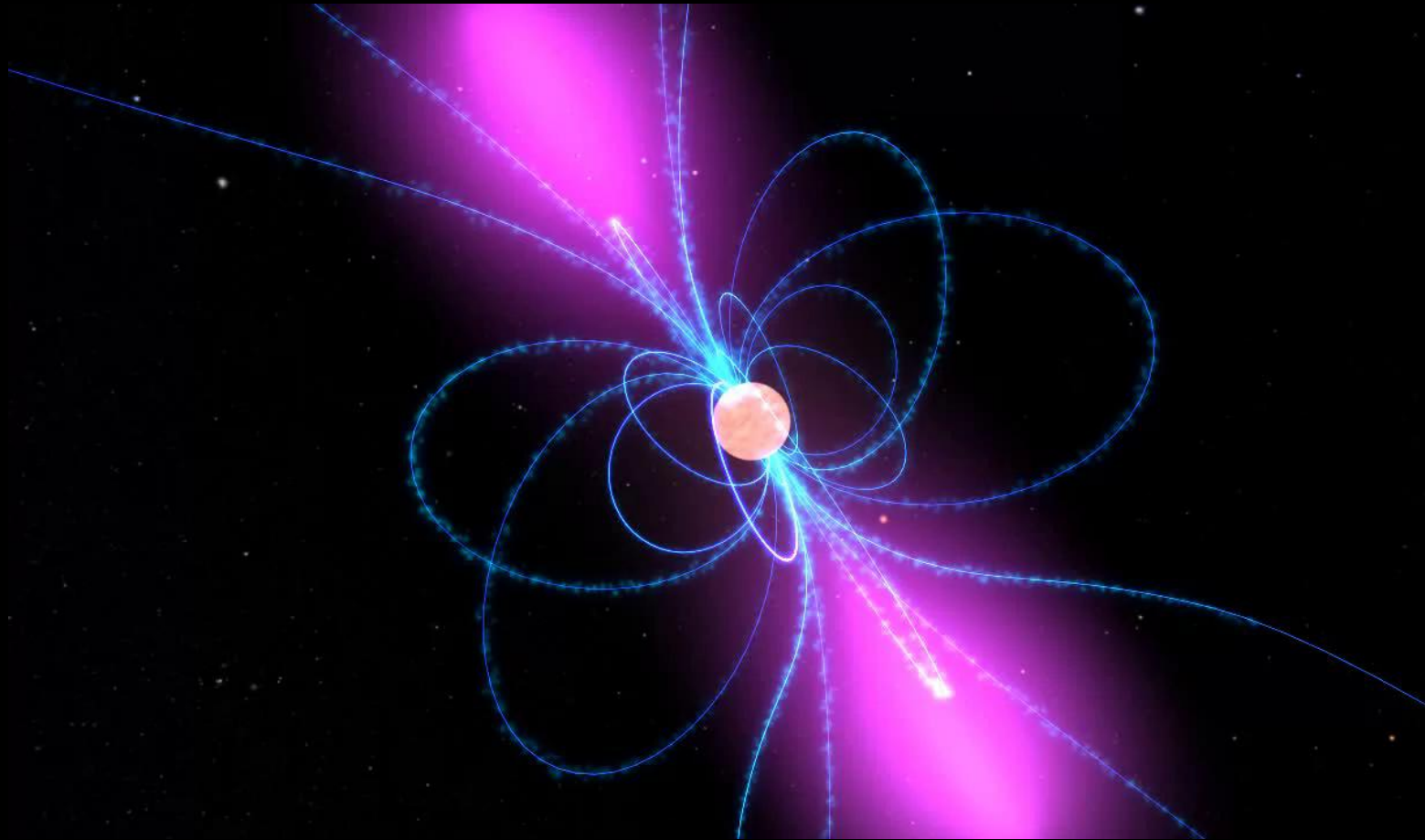
Strongest manmade: 45 T

Strongest NS: 1.6×10^9 T

“...neutron stars that emit
beams of electromagnetic
radiation...”

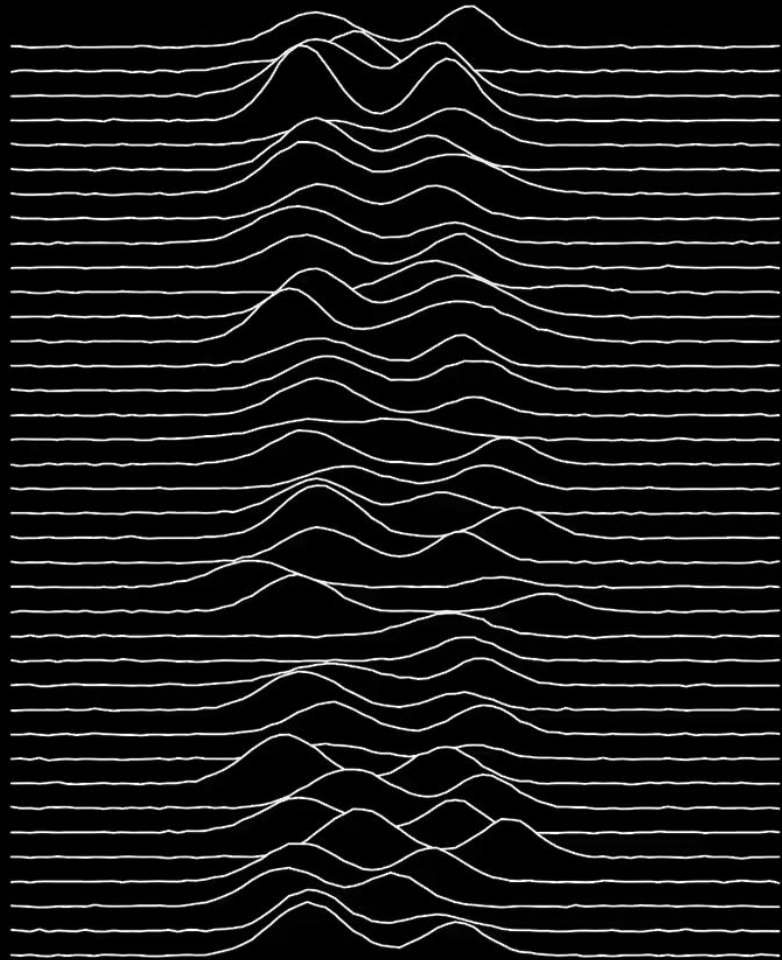


“...with a regular and precise
pulsing pattern.”



Single Pulses

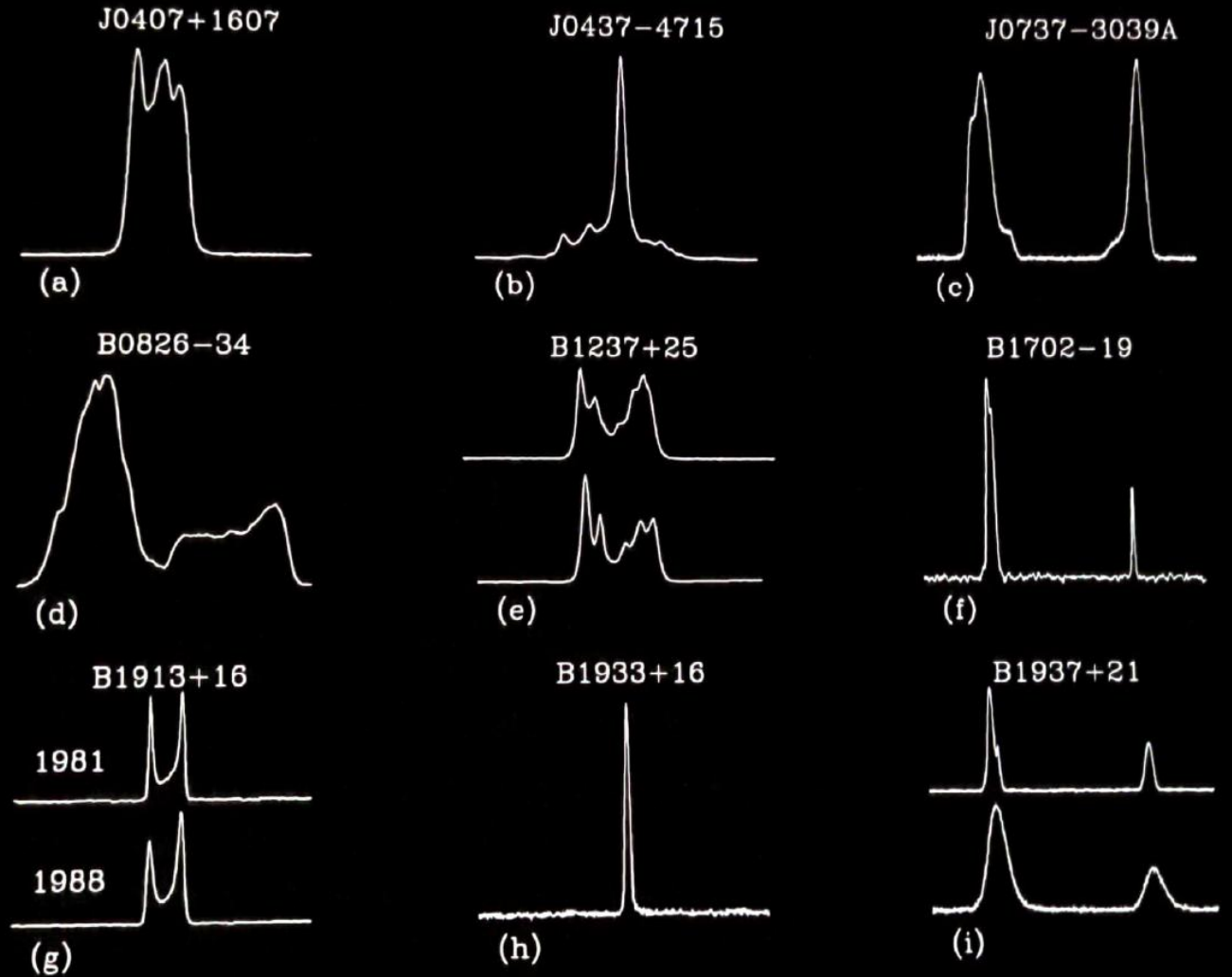
Pulsar B1919+21



15th June 2019

Jodrell Bank Observatory
The University of Manchester

Integrated Pulses

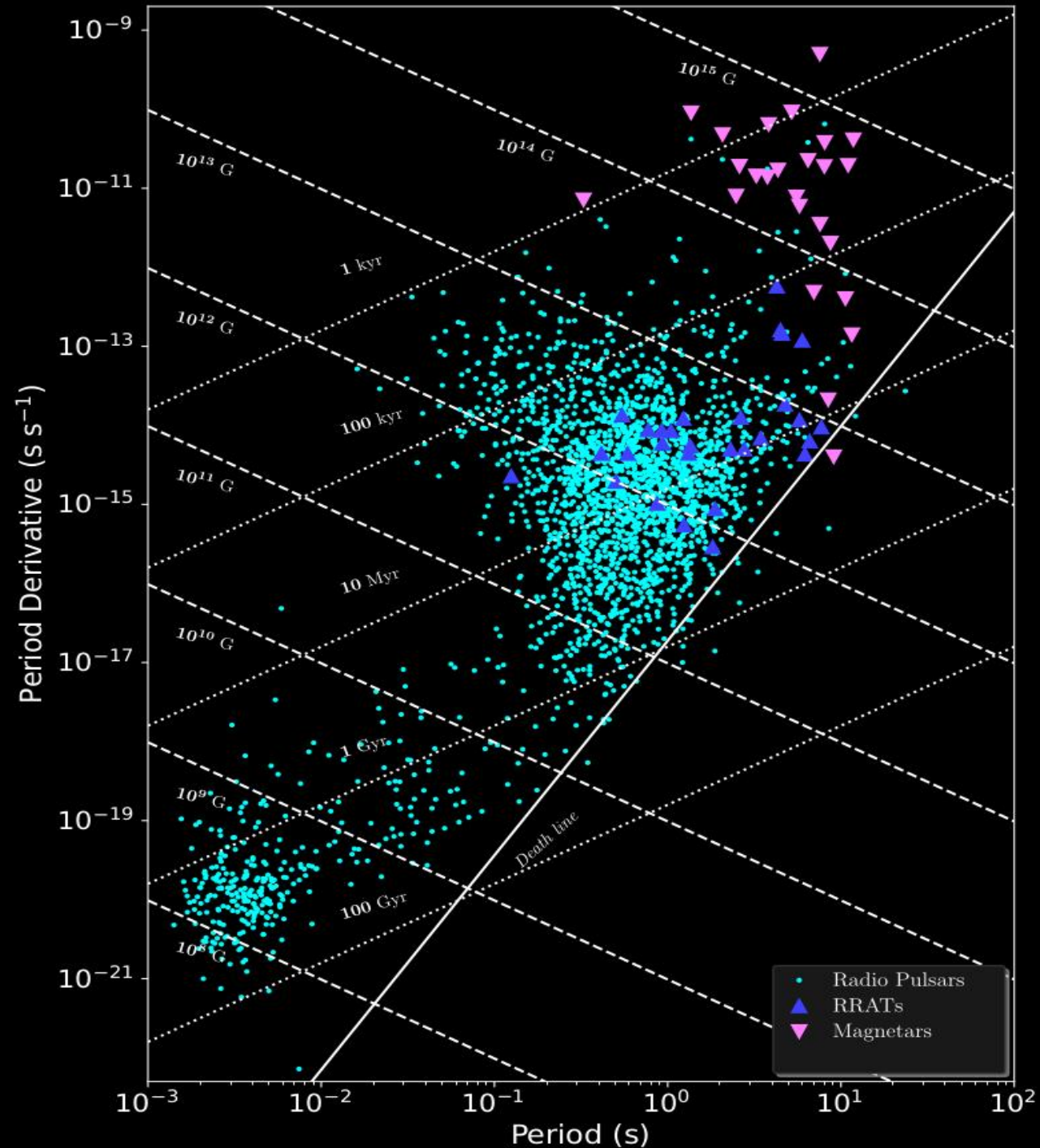


$$E_{\text{dot}} = -\frac{4\pi^2}{P^2} I \dot{P}$$

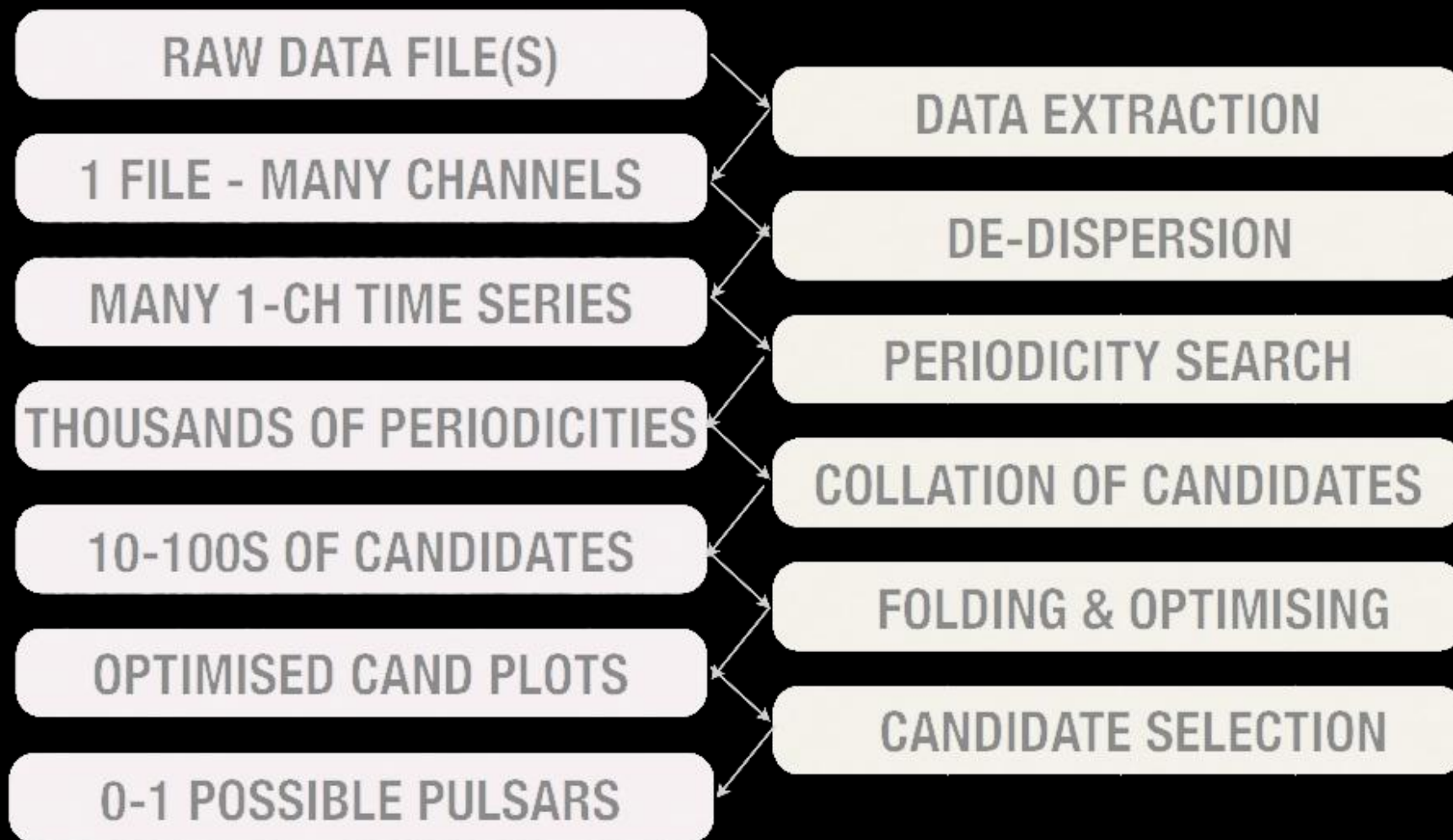
$$\tau_c = \frac{P}{2\dot{P}}$$

$$B_s = 3.2 \times 10^{19} \sqrt{P \dot{P}} \text{ G}$$

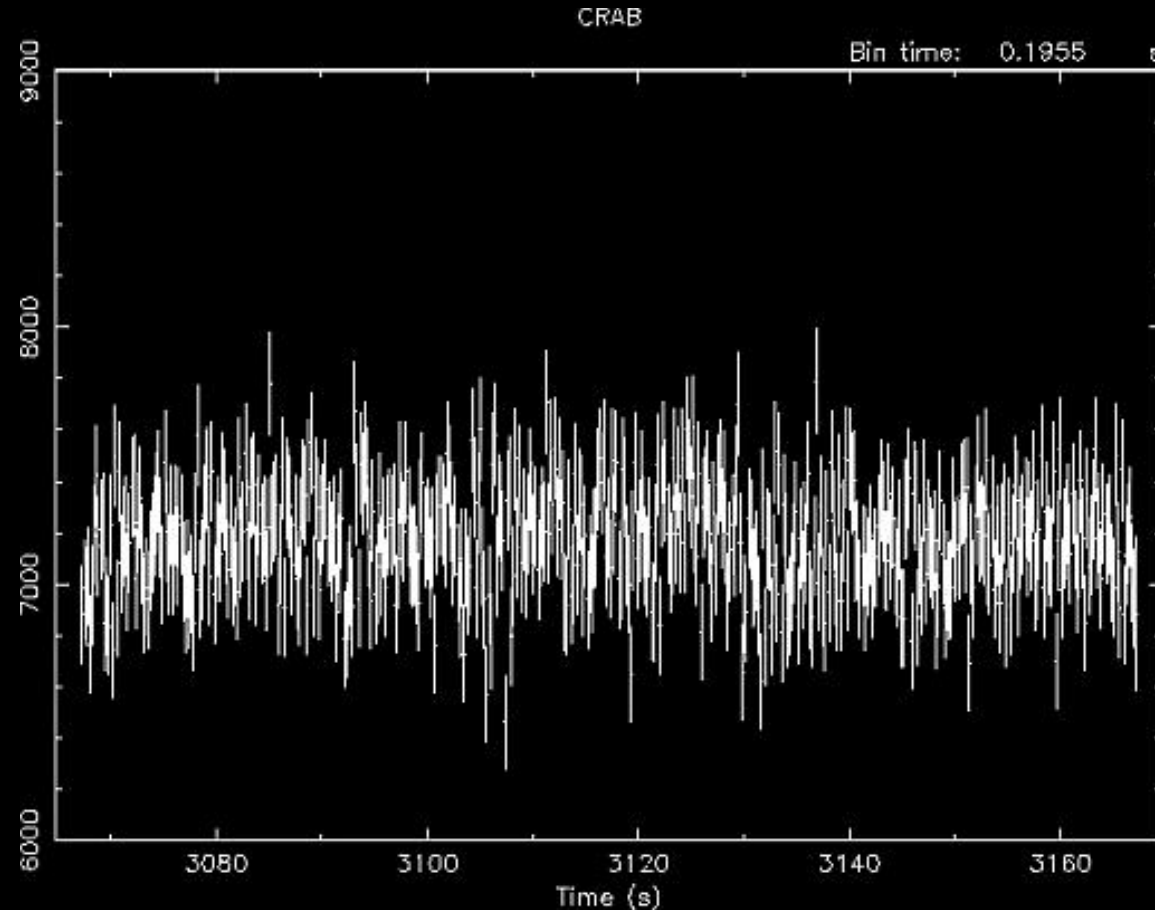
Numbers so far:
3000 radio pulsars
120 RRATs
30 magnetars



Part 2: HOW DO WE FIND THEM?



Periodicity Searches: Picking the signal out of the noise

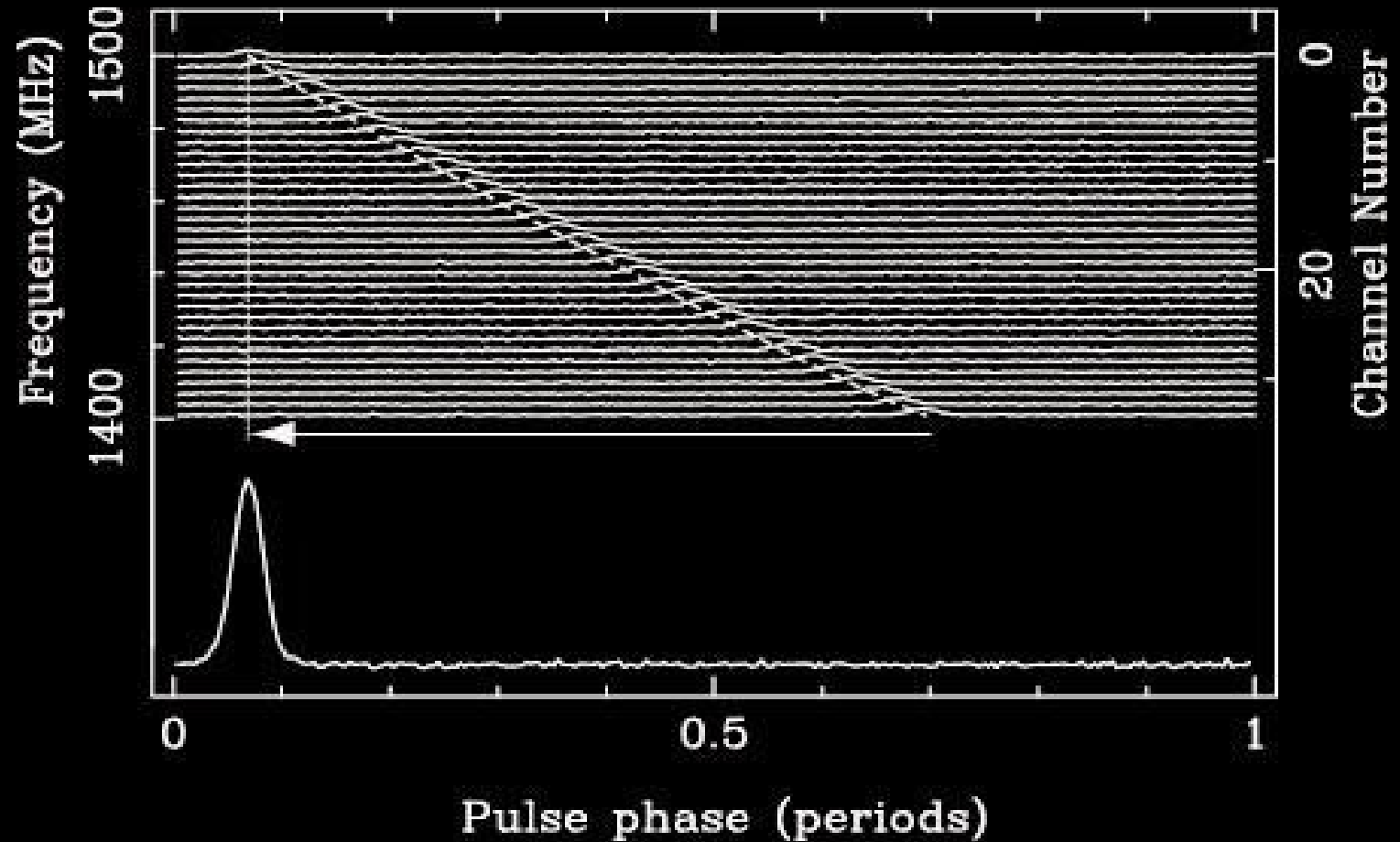


Start Time 10098 22:51: 7:281 Stop Time 10098 22:52:47:204

De-dispersion

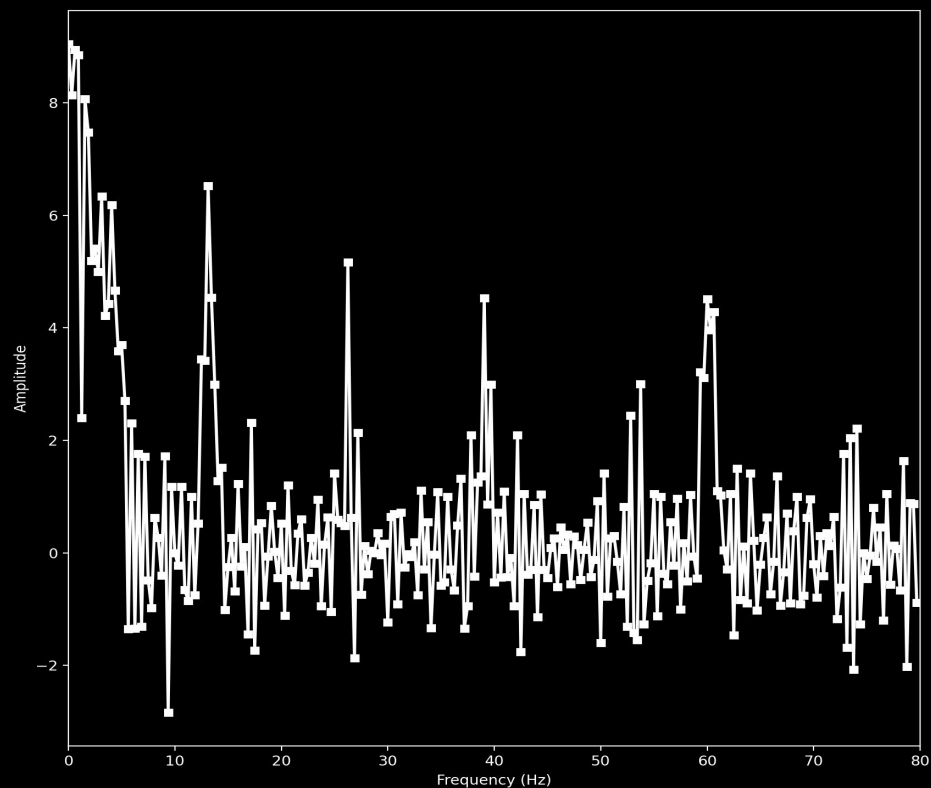
$$\Delta t_{\text{DM}} = 8.3 DM \nu^{-3} B \mu\text{s},$$

$$DM \equiv \int_0^S n_e(l) dl$$



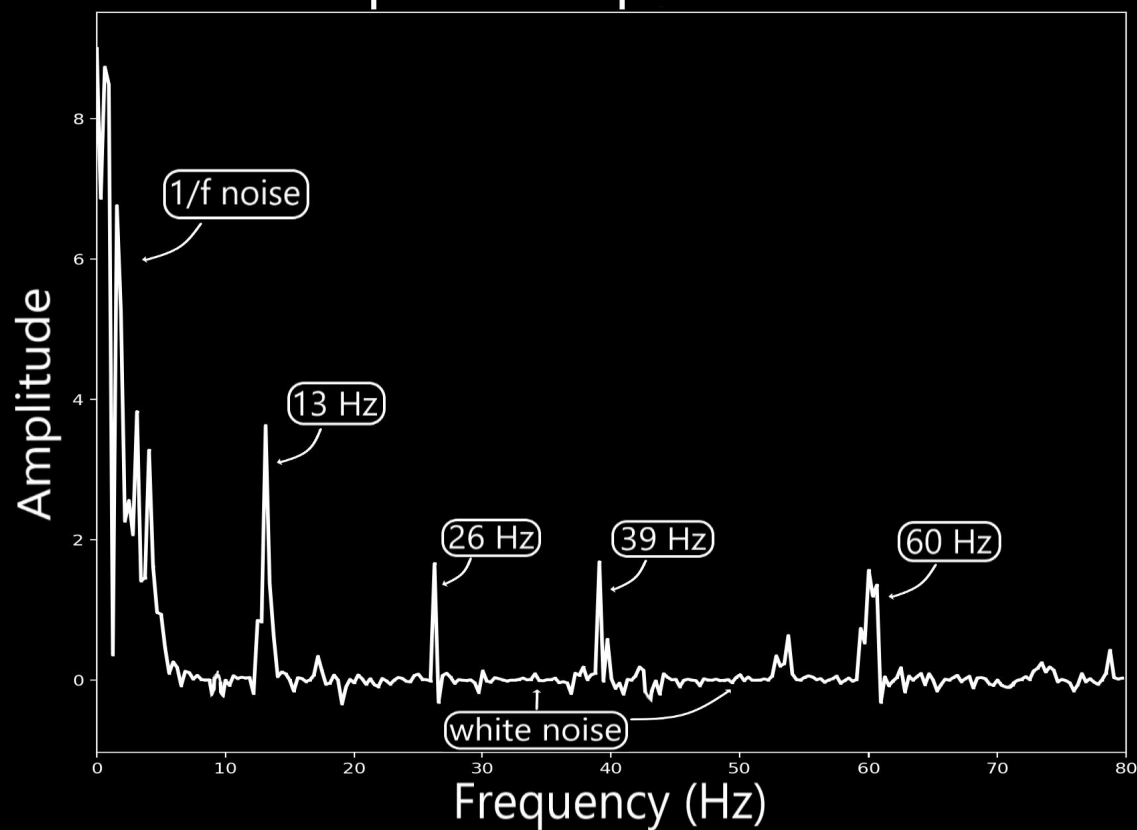
Fourier Transform

Amplitude Spectrum



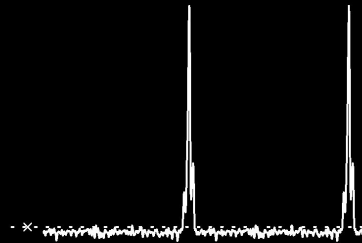
Averaging

Amplitude Spectrum



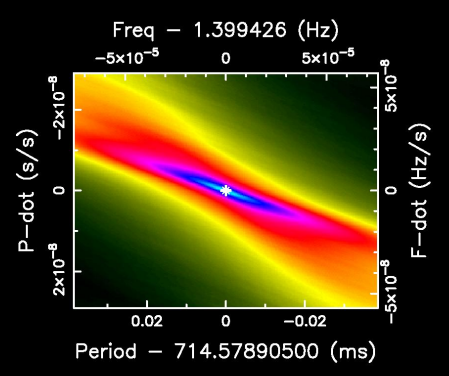
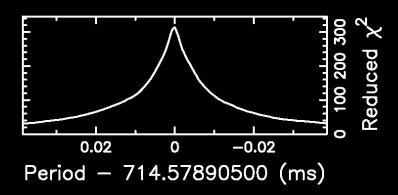
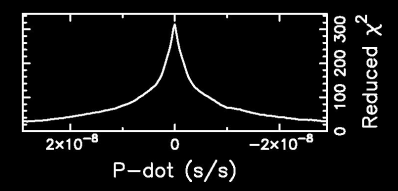
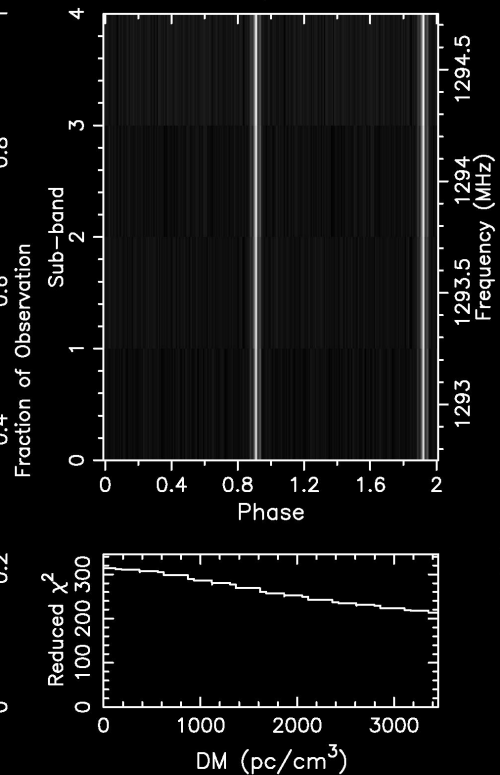
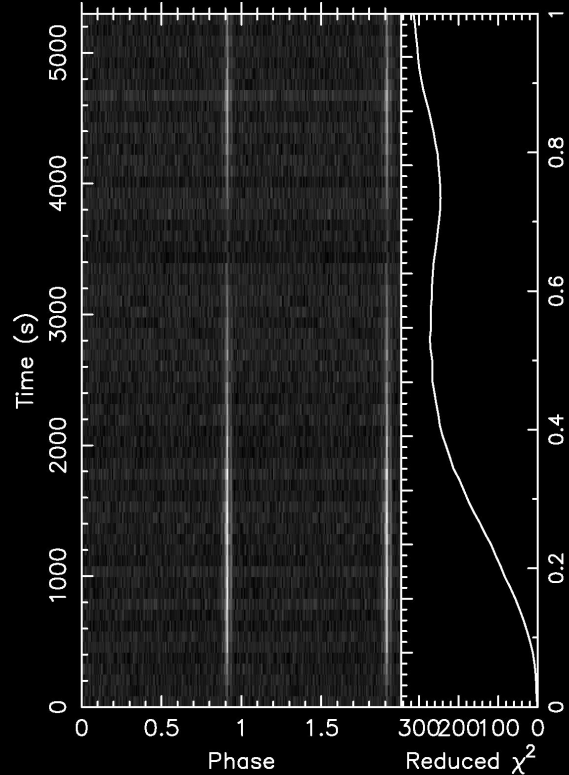
Refolding & Classifying

2 Pulses of Best Profile

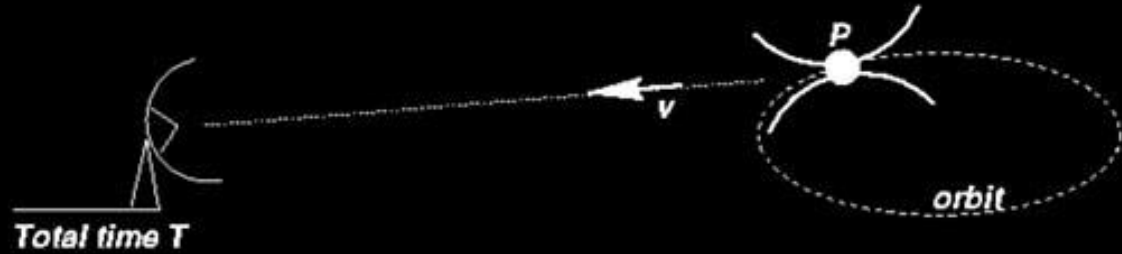


Candidate: 714.58ms_Cand
 Telescope: Unknown
 Epoch_{topo} = 57794.38909722222
 Epoch_{bary} = N/A
 T_{sample} = 0.0005
 Data Folded = 10596000
 Data Avg = 514.9
 Data StdDev = 62.15
 Profile Bins = 500
 Profile Avg = 1.091e+07
 Profile StdDev = 9047

Search Information
 RA_{J2000} = 03:32:59.3700 DEC_{J2000} = 54:34:43.5700
 Folding Parameters
 DOF_{eff} = 443.35 χ^2_{red} = 314.078 P(Noise) ~ 0 (391.6 σ)
 Dispersion Measure (DM; pc/cm³) = 0.000
 P_{topo} (ms) = 714.578905(77) P_{bary} (ms) = N/A
 P \dot{topo} (s/s) = 0.0(1.1)x10⁻¹⁰ P \dot{bary} (s/s) = N/A
 P \ddot{topo} (s/s²) = 0.0(1.4)x10⁻¹³ P \ddot{bary} (s/s²) = N/A
 Binary Parameters
 P_{orb} (s) = N/A e = N/A
 a₁sin(i)/c (s) = N/A ω (rad) = N/A
 T_{peri} = N/A

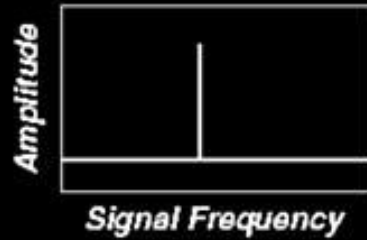


Acceleration Searches:



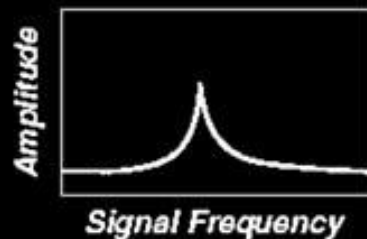
Apparent Period = $P (1 + v/c) \sim P (1 + at/c)$ i.e. time dependent

Case (a)
Isolated Pulsar



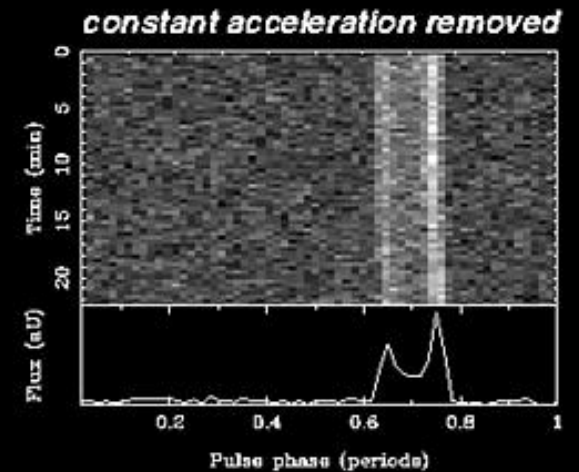
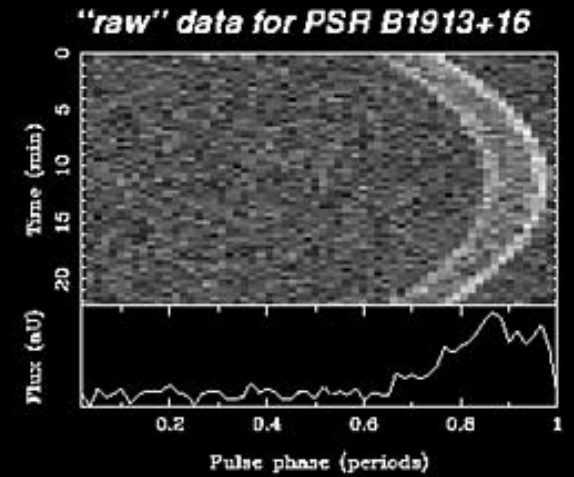
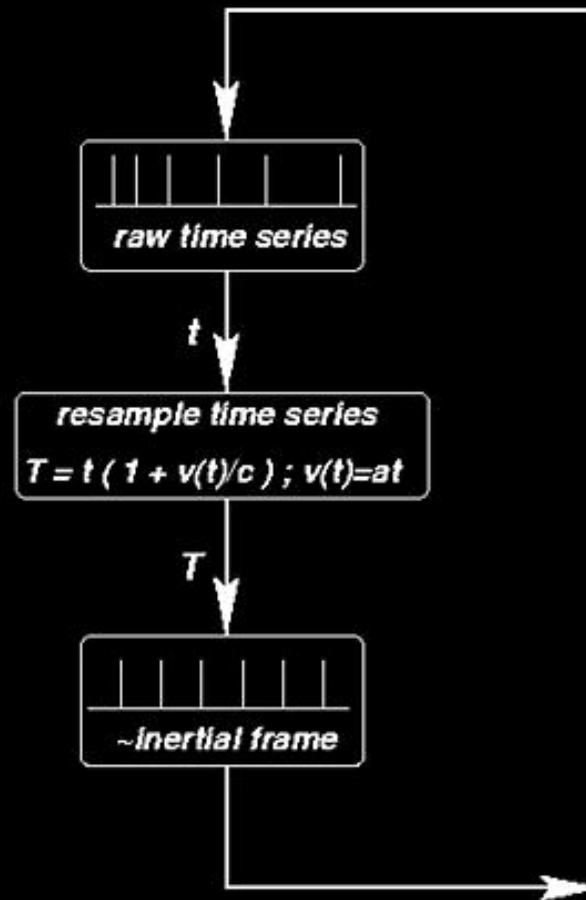
$\Delta f \sim aT/Pc \ll 1/T$

Case (b)
Binary Pulsar



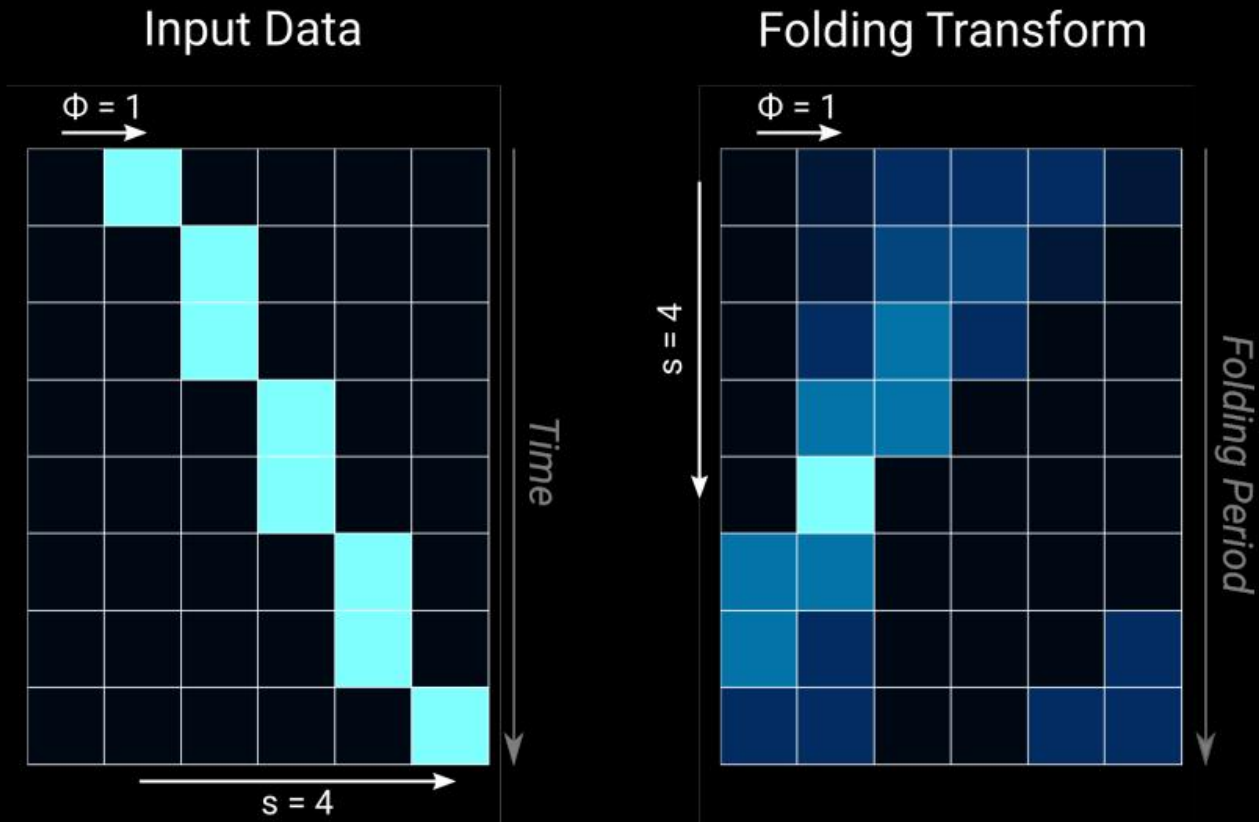
$\Delta f \gg aT/Pc$

$aT^2/Pc \gg 1$

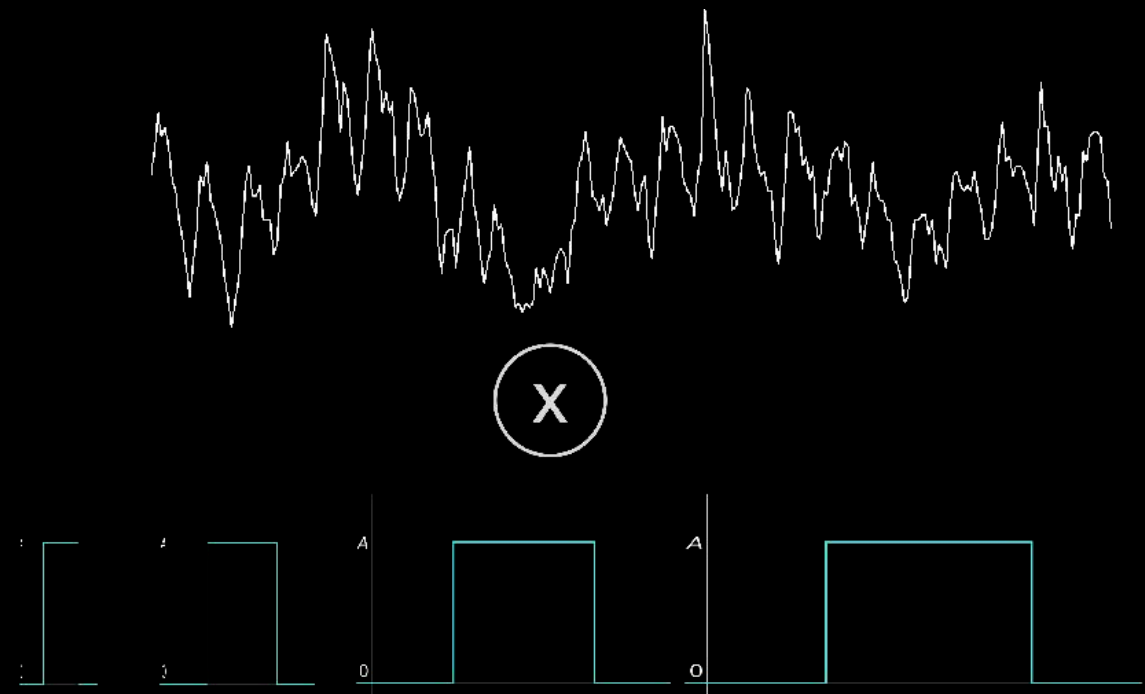


OR:

Fast Folding Algorithms



Single Pulse Searches



But what about the hardware?

Pulsar discovery tally:

1441 | Murriyang
392 | Arecibo
362 | Green bank
262 | FAST
198 | MeerKAT



What does the future hold?

SKA 1-Mid: ~7 000 canonical pulsar
 + ~900 MSPs

SKA 2-Mid: ~24 000 - 30 000 pulsars

(Keane et al; 2015)

