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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?

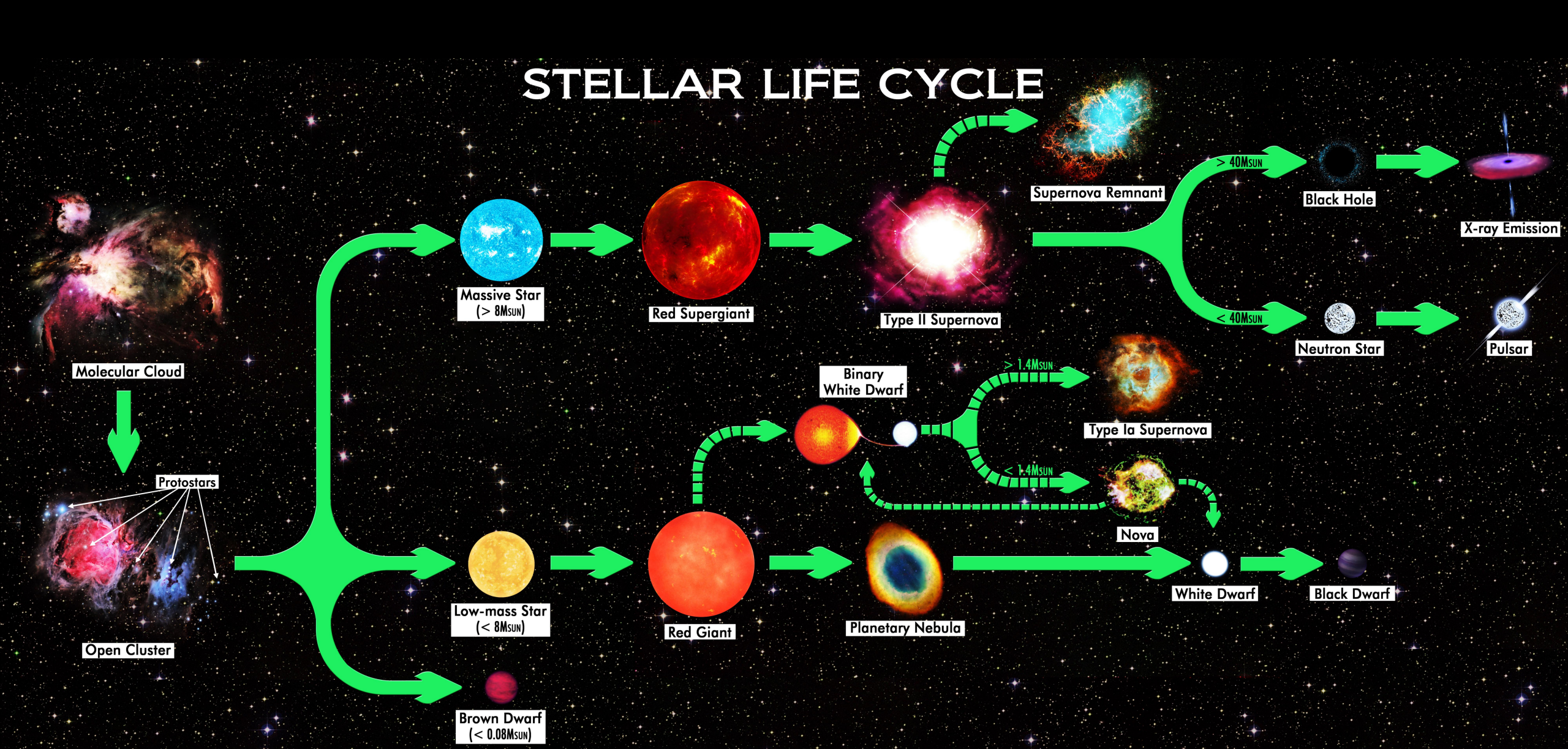
Default (GPT-3.5)

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



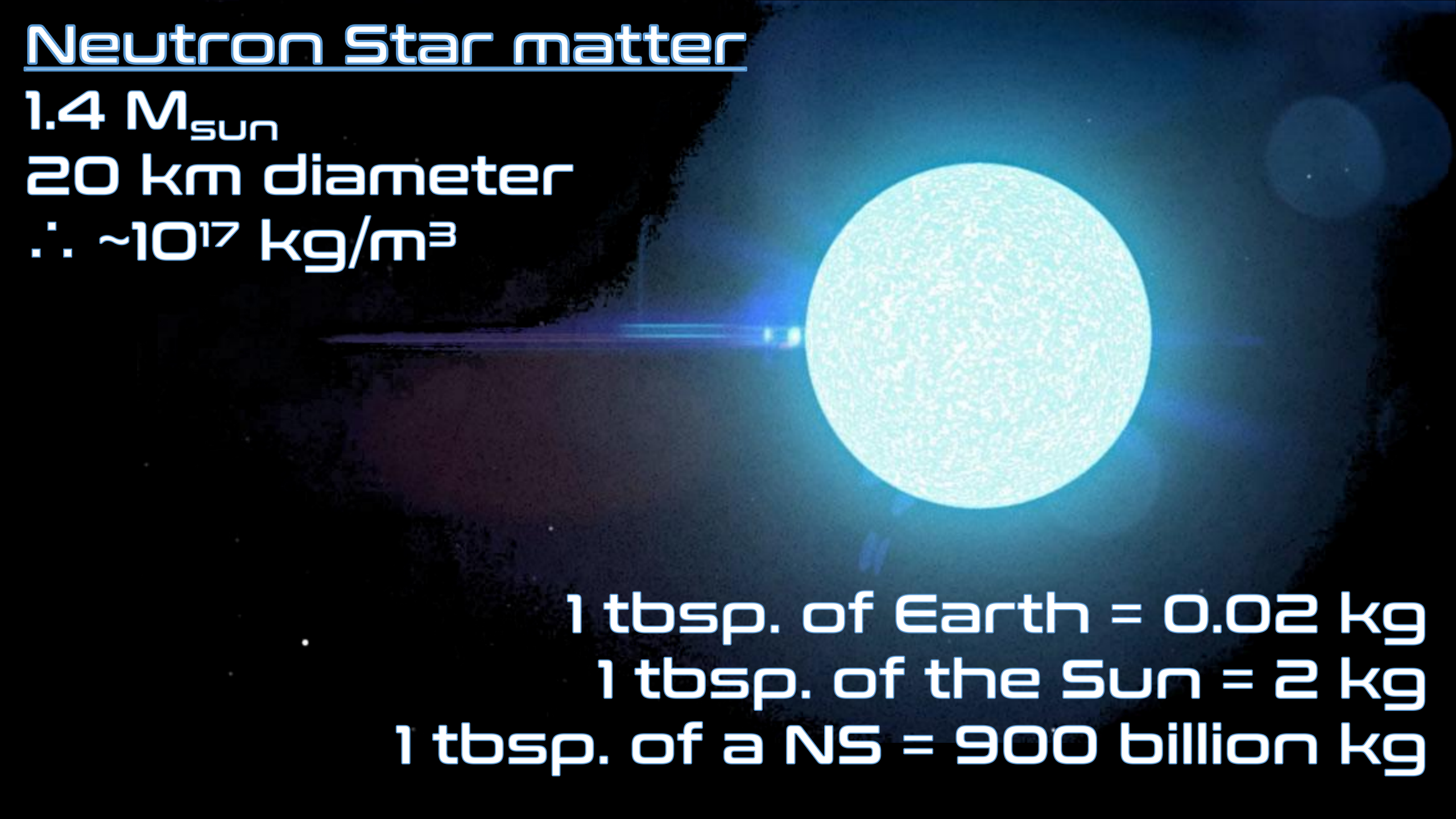
Birth	Main Sequence	Old Age	Death	Remnant

Neutron Star matter

1.4 M_{sun}

20 km diameter

$\therefore$ ~10^{17} 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

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

$R_i \sim 10^6$ km
$R_f \sim 10$ km
$\therefore$ factor 10^{10} speed-up

Spin periods = 1 ms - 76 s

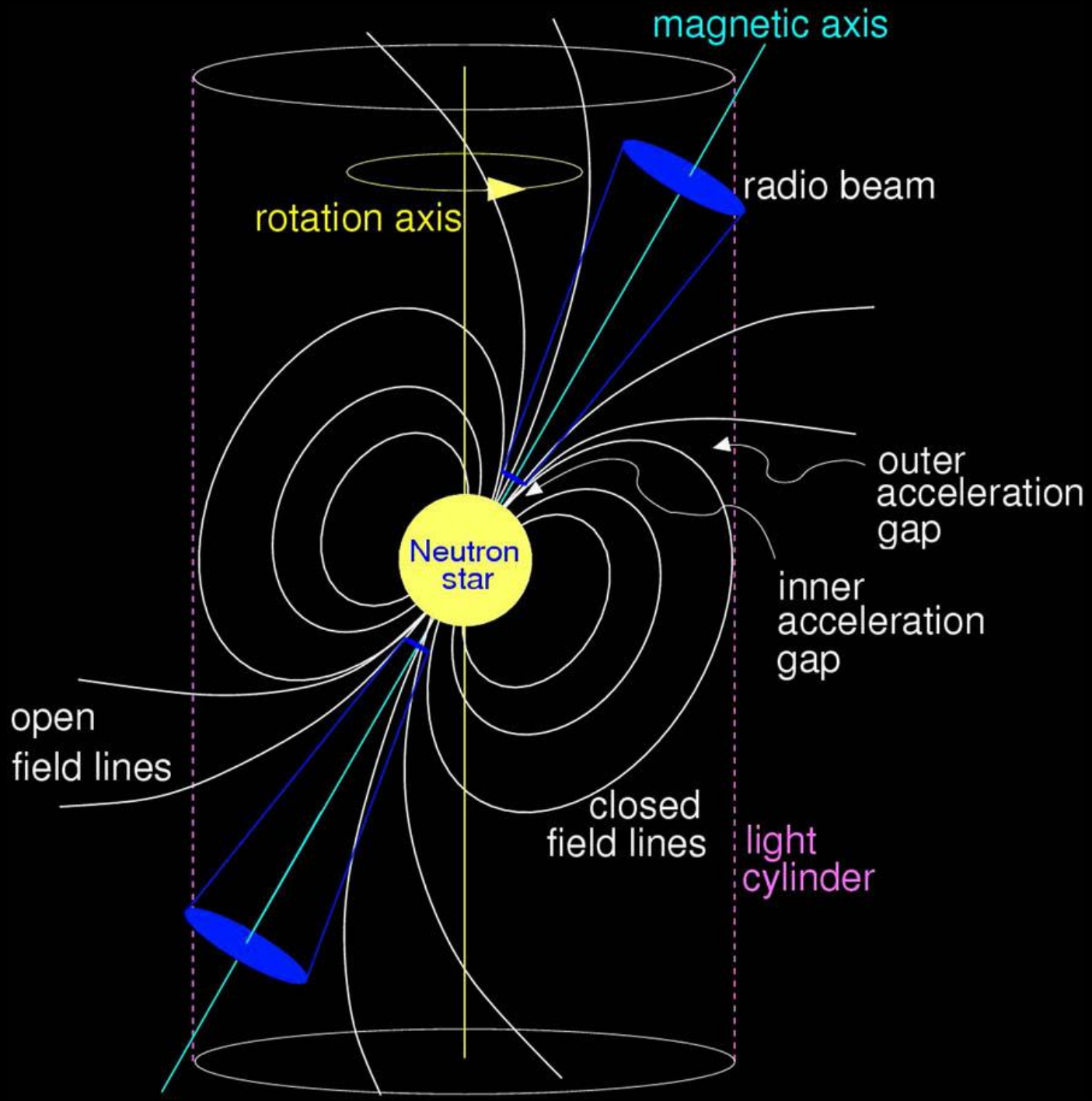
Highly magnetic

$R_i \sim 10^6$ km
$R_f \sim 10$ km
$\therefore$ factor 10^{10} amplification

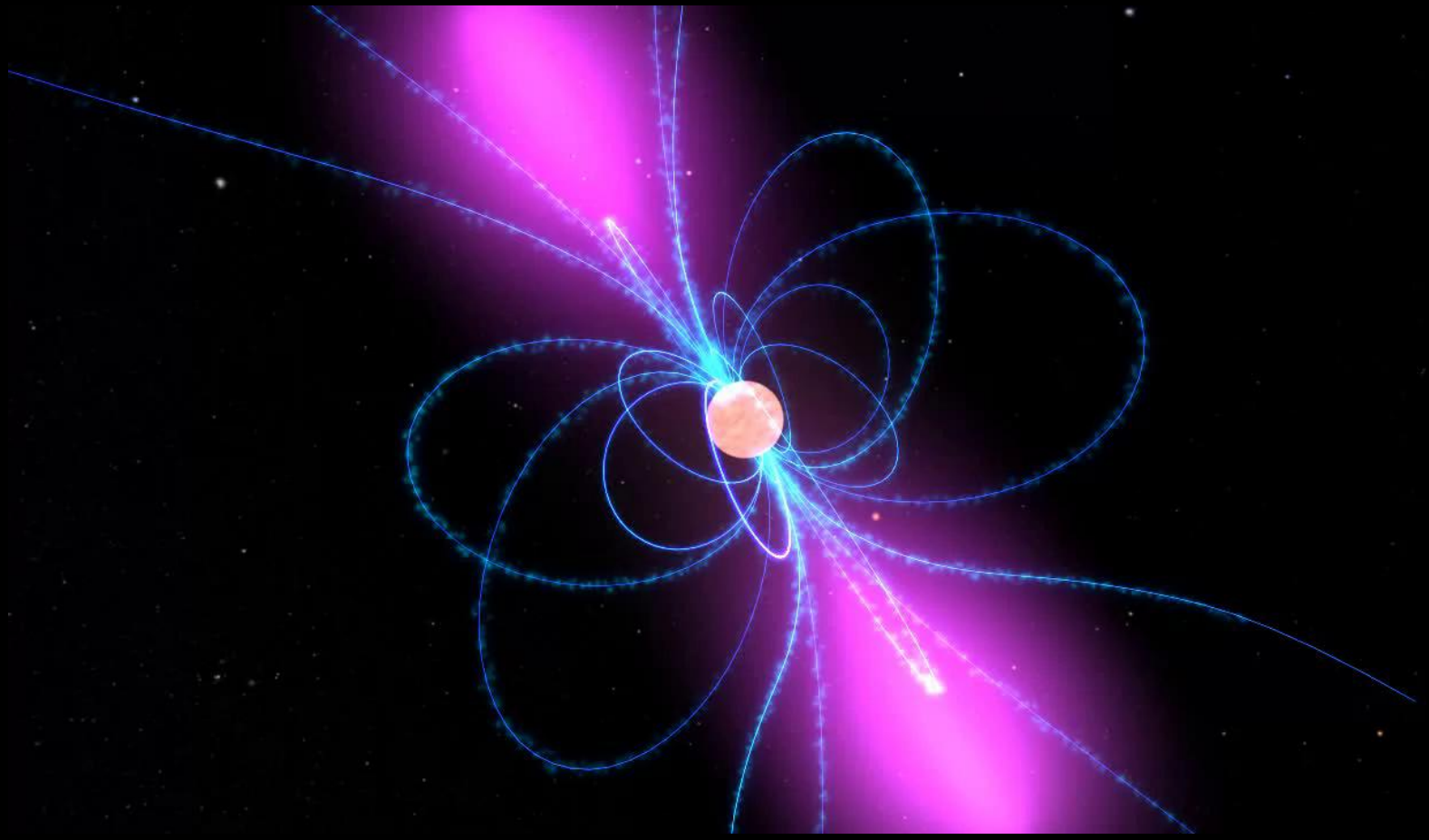
$$B_f = B_i \left(\frac{R_i}{R_f} \right)^2$$

Earth: ~10^{-4} T
Strongest manmade: 45 T
Strongest NS: 1.6 x 10^9 T

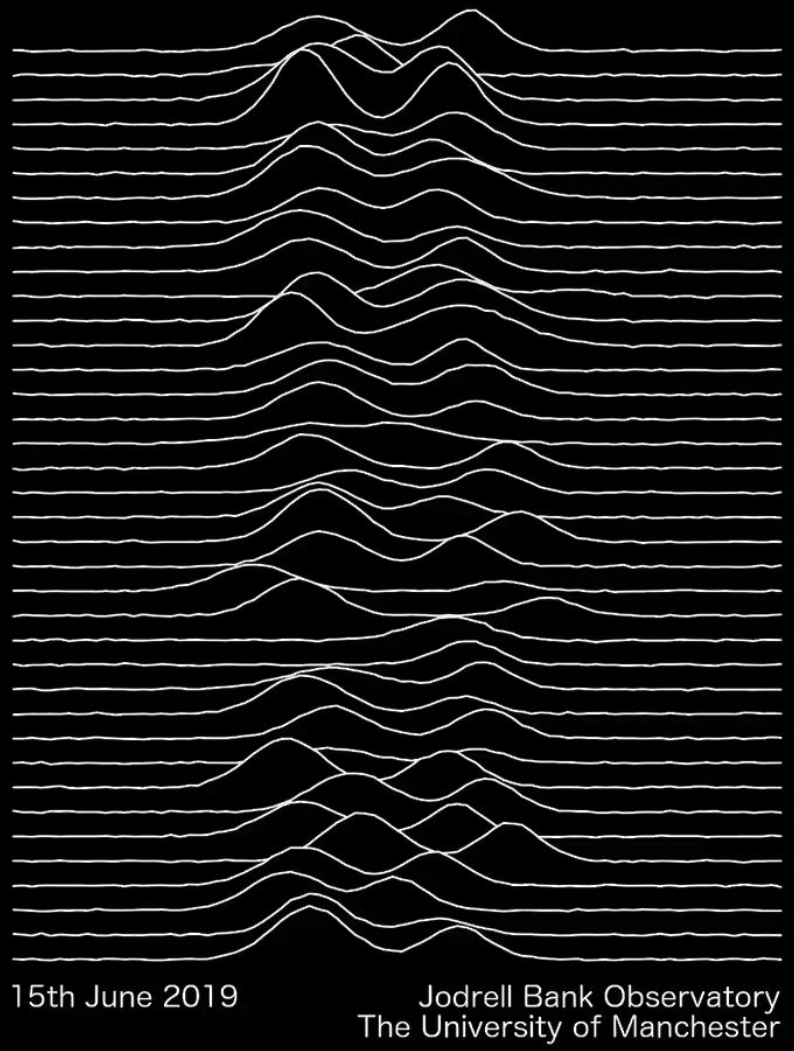
“...neutron stars that emit beams of electromagnetic radiation...”


magnetic axis
rotation axis
radio beam
outer
acceleration
gap
Neutron
star
inner
acceleration
gap
open
field lines
closed
field lines
light
cylinder

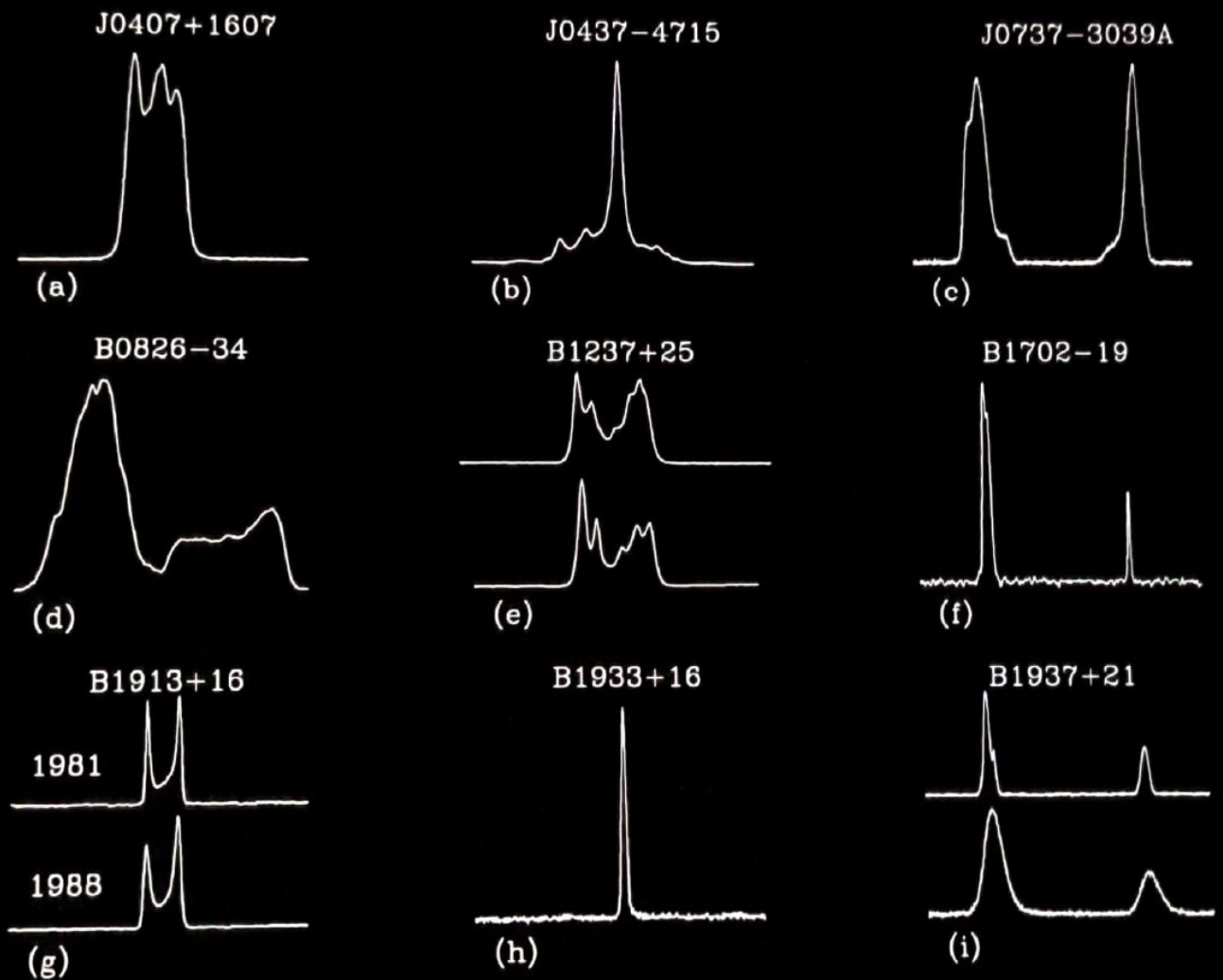
“...with a regular and precise pulsing pattern.”



Single Pulses



Integrated Pulses



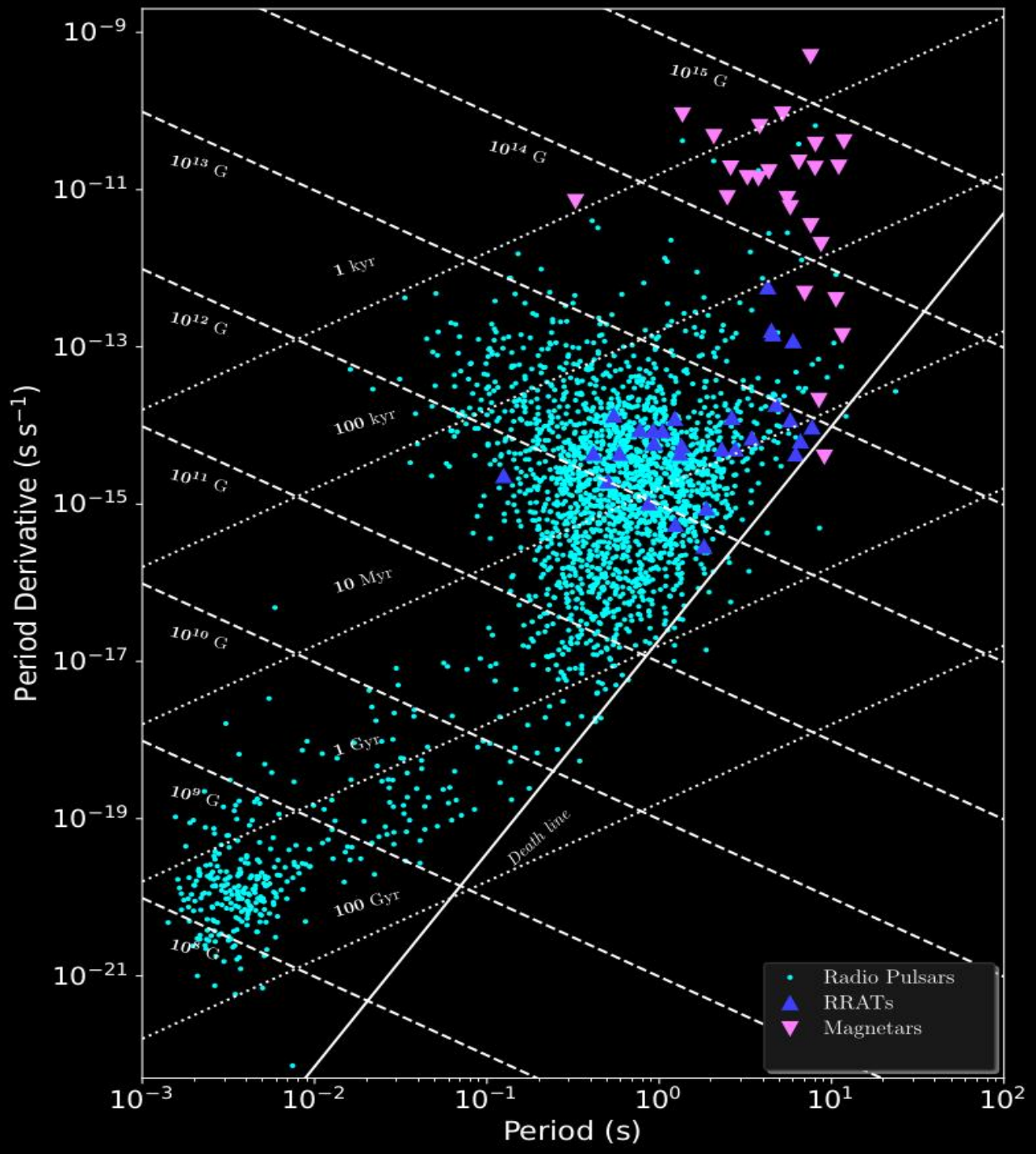
$$E_{\rm dot} = -\frac{4\pi^2}{P^2} I \dot{P}$$

$$\tau_{\rm c} = \frac{P}{2\dot{P}}$$

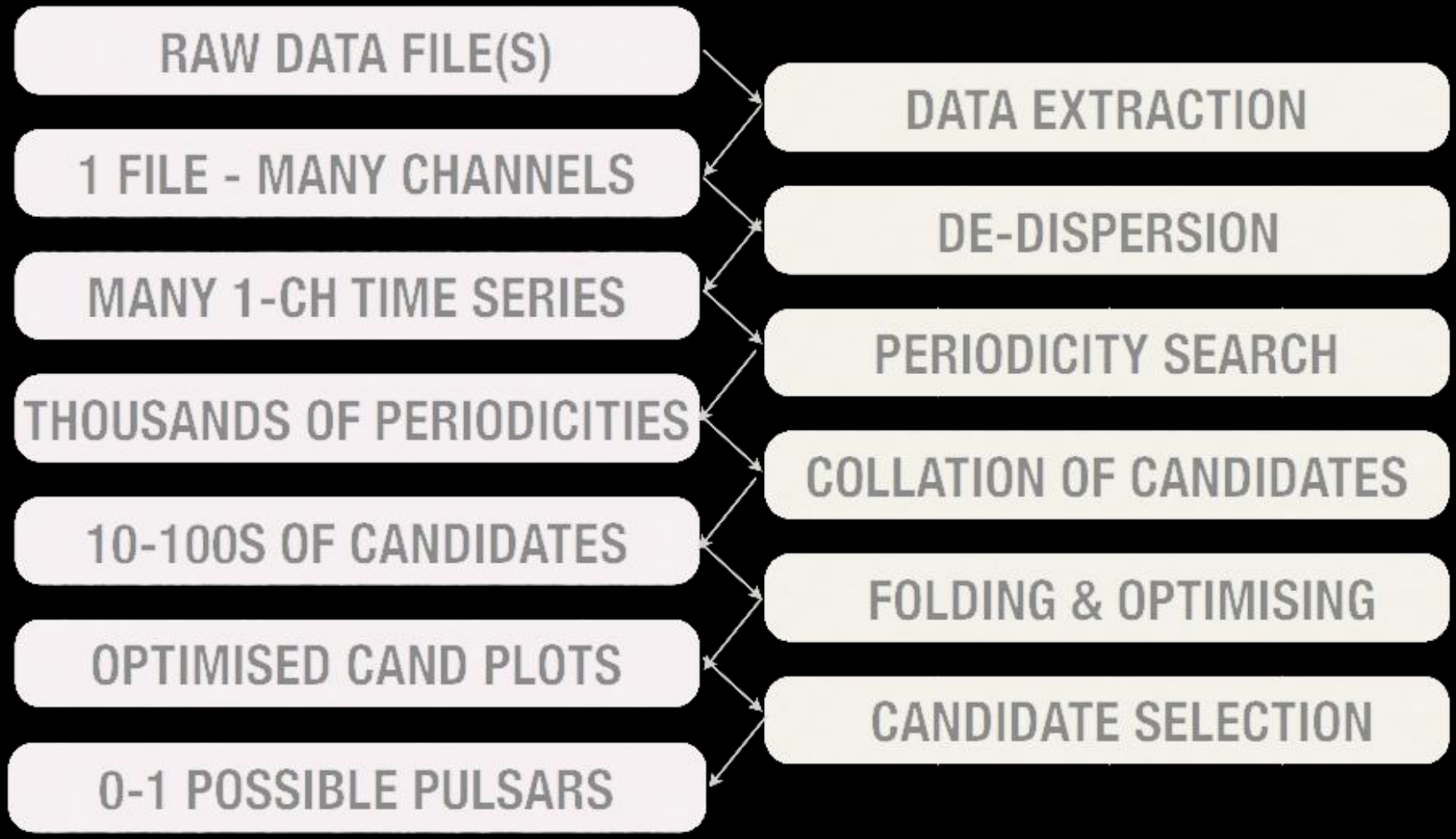
$$B_{\rm S} = 3.2 \times 10^{19} \sqrt{P\dot{P}}\ {\rm G}$$

Numbers so far:

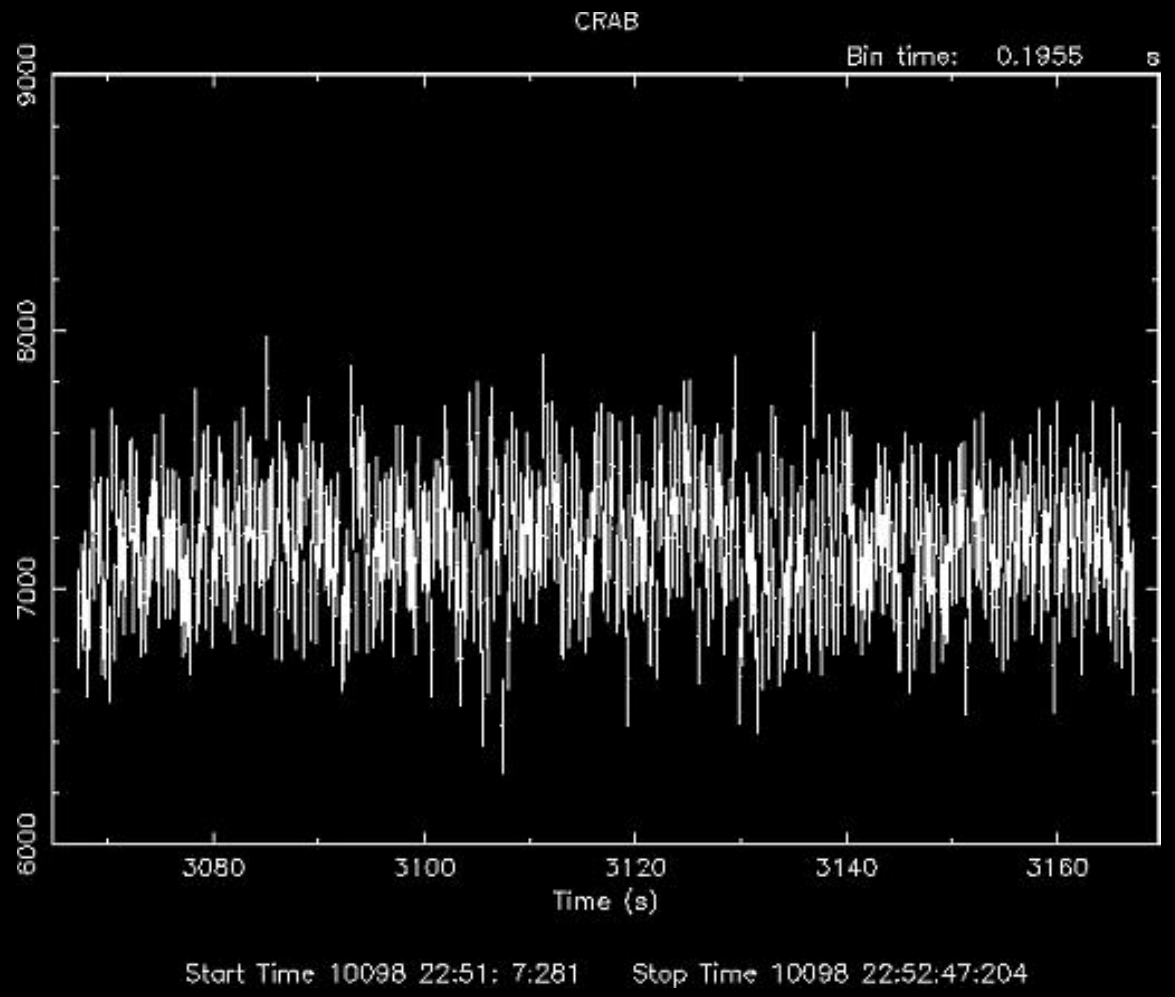
3000 radio pulsars
120 RRATs
30 magnetars



Part 2: HOW DO WE FIND THEM?



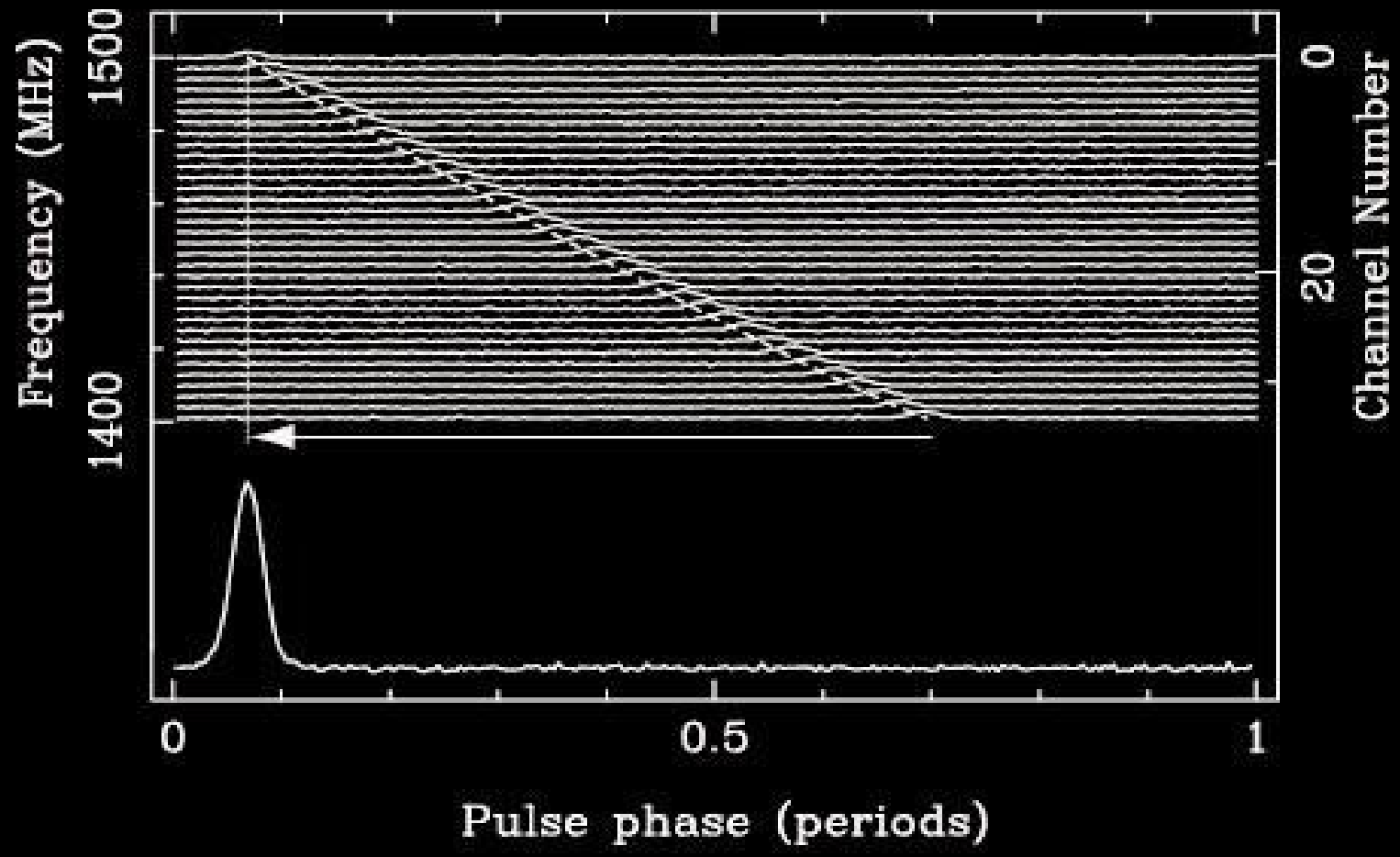
Periodicity Searches:
Picking the signal out of the noise



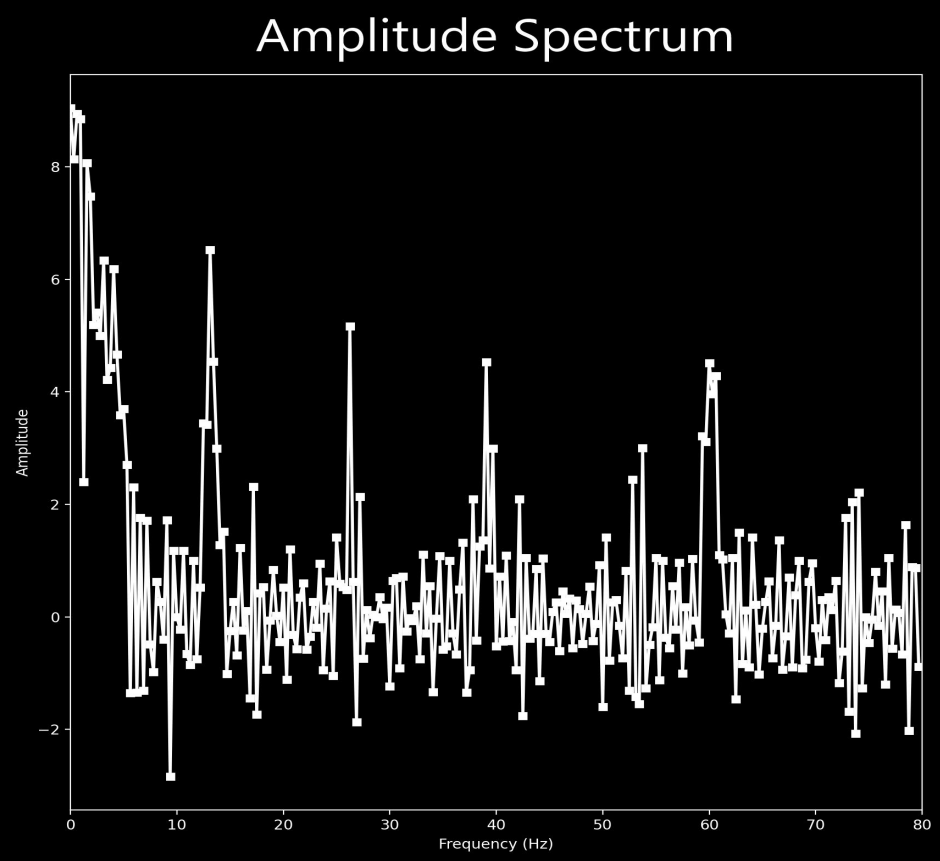
De-dispersion

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

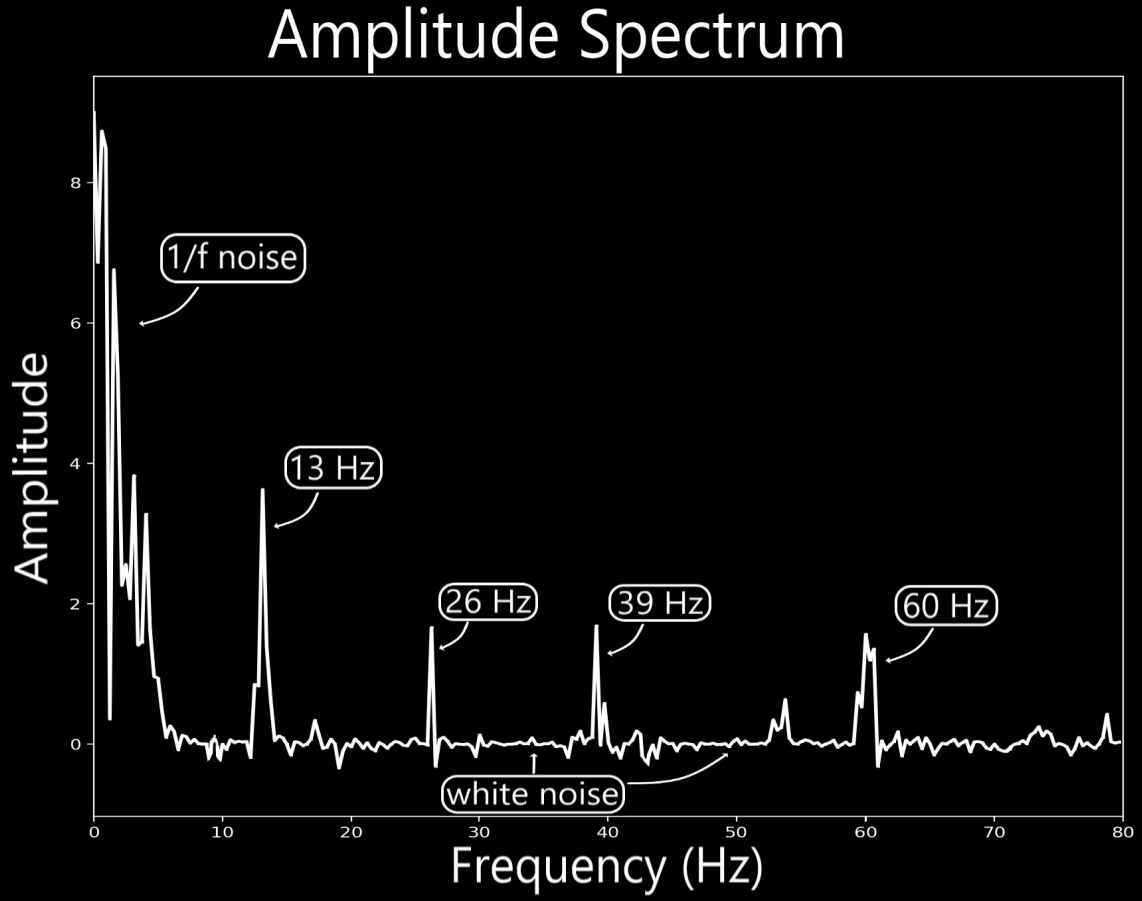
$$DM \equiv \int_{\mathrm{O}}^{\mathrm{S}} n_{\mathrm{e}}(l)\, dl$$



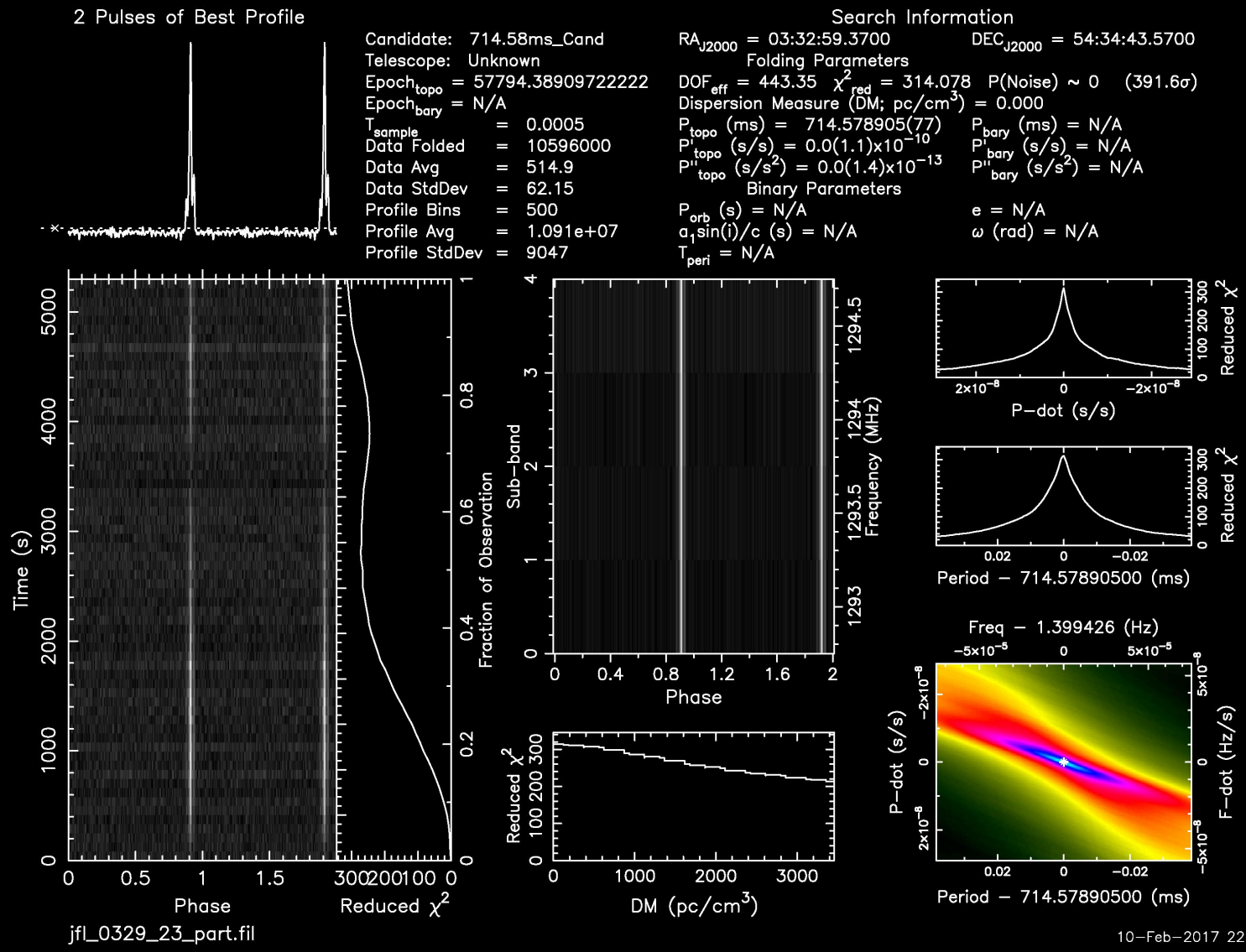
Fourier Transform



Averaging



Refolding & Classifying



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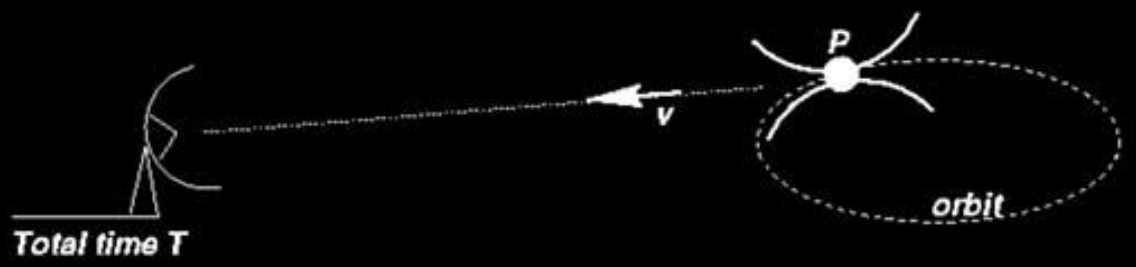
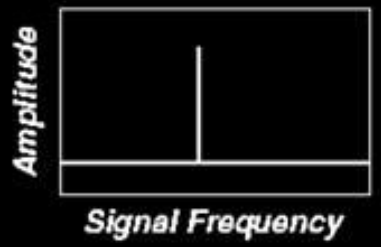
Acceleration Searches:



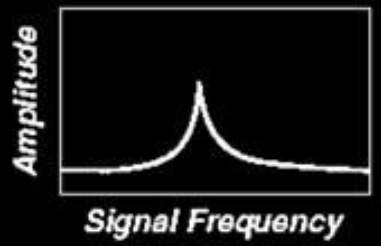
Apparent Period = P (1 + v/c) ~ P (1 + at/c) i.e. time dependent

Case (a)
Isolated Pulsar



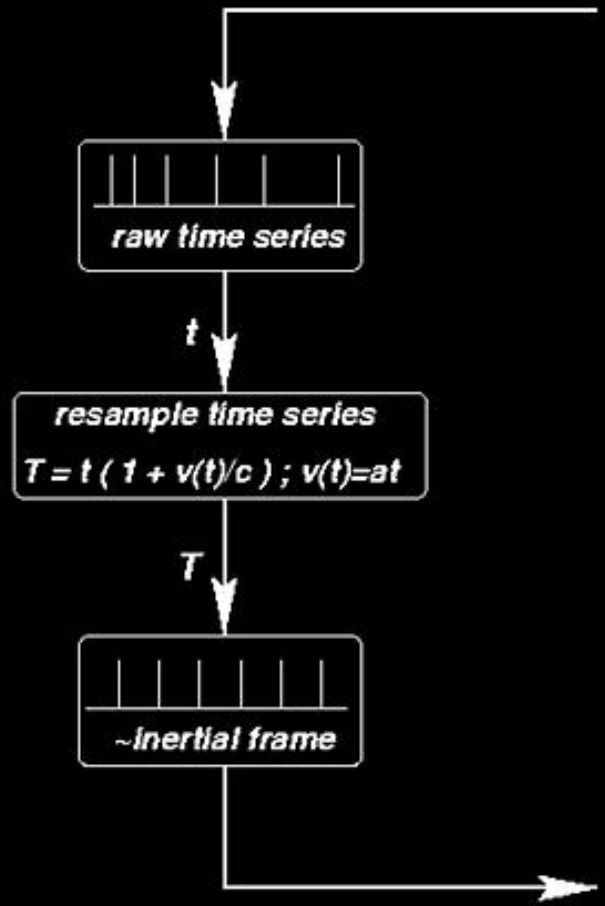
$\Delta f \sim aT/Pc \ll 1/T$

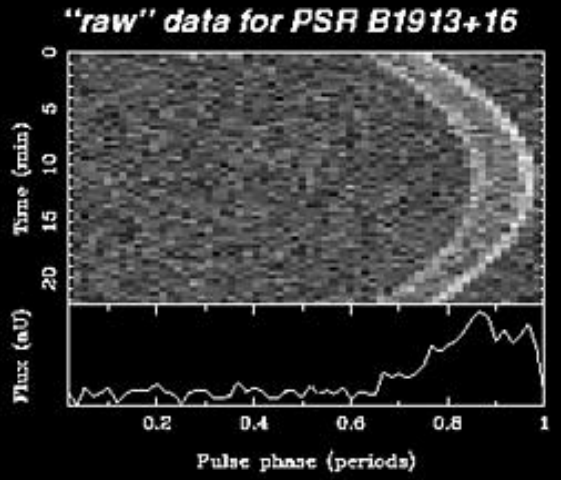
Case (b)
Binary Pulsar

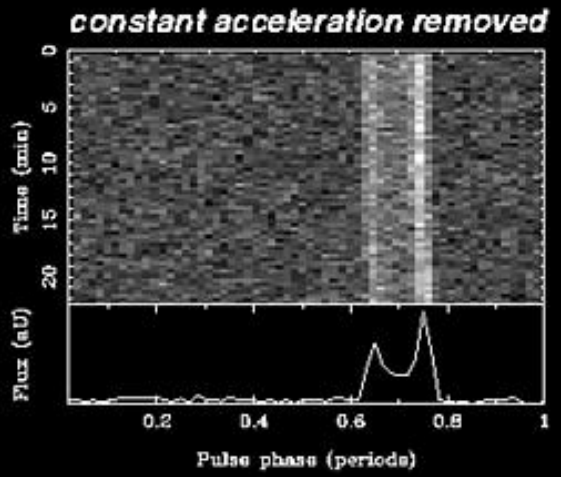


$\Delta f \gg aT/Pc$

$aT^2/Pc \gg 1$

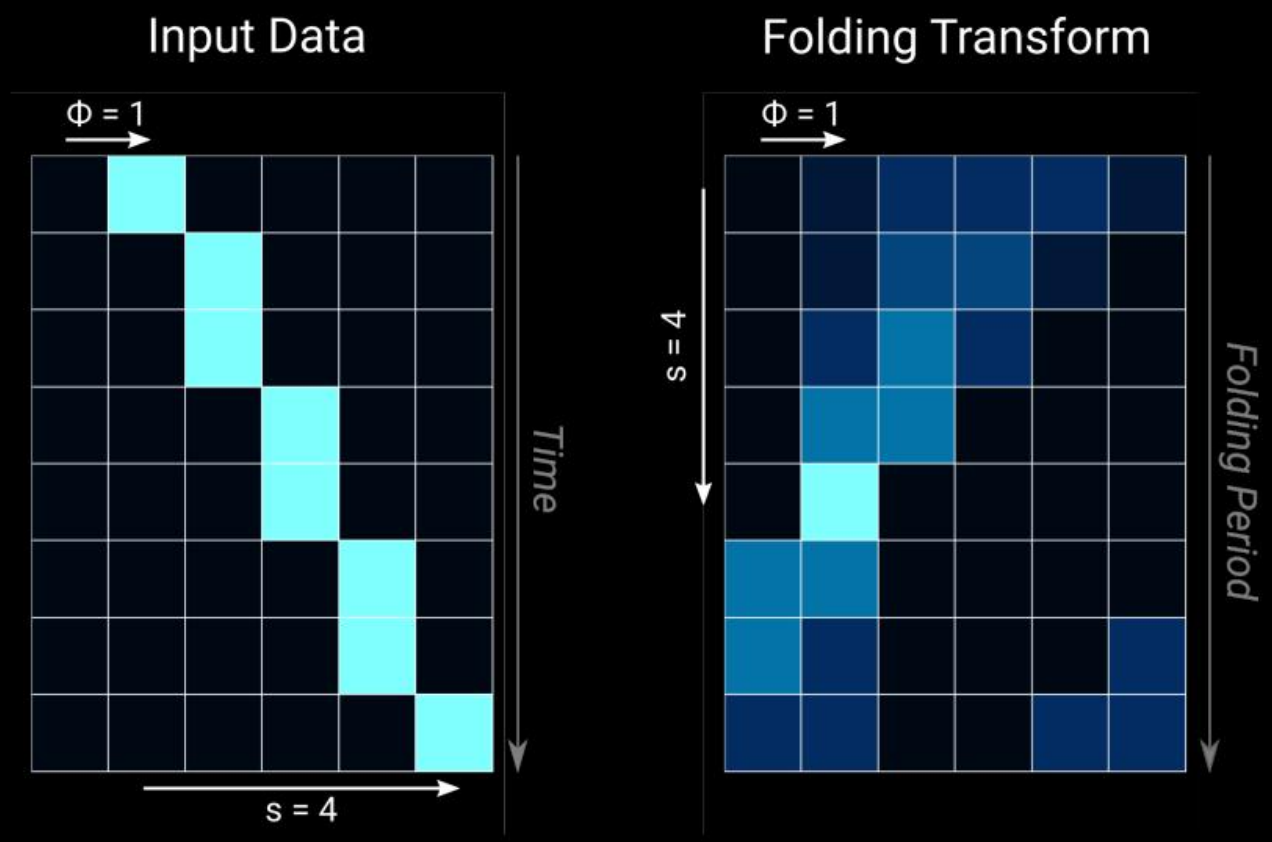




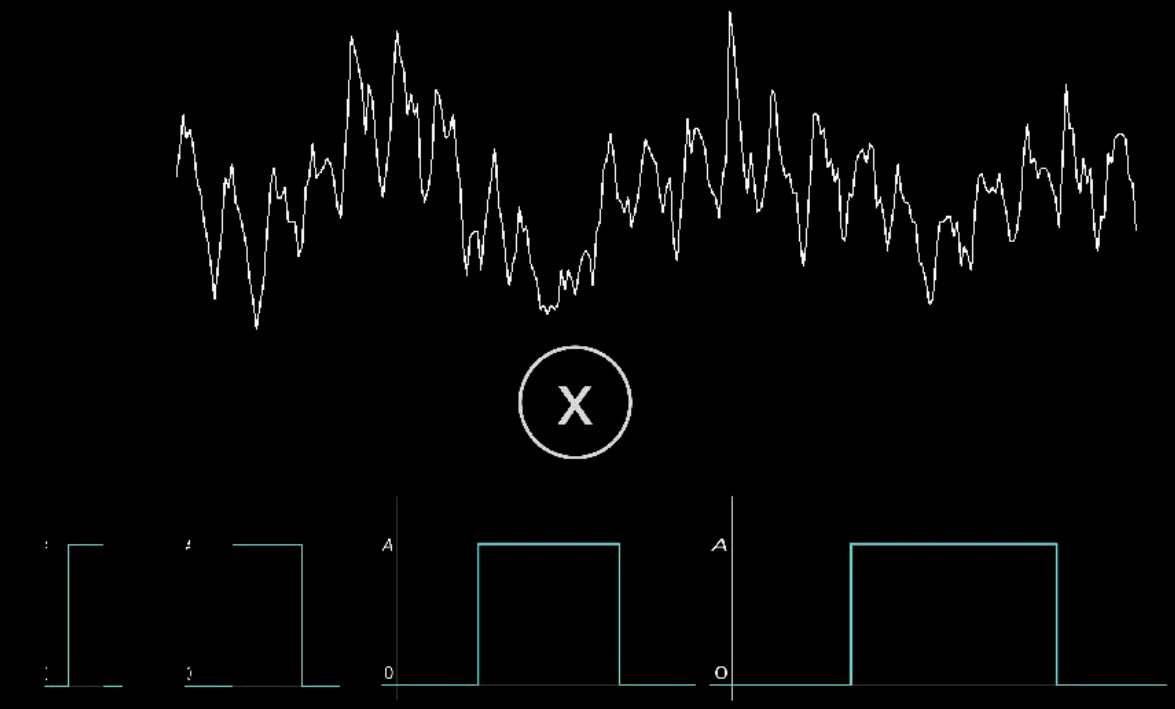


OR:

Fast Folding Algorithms



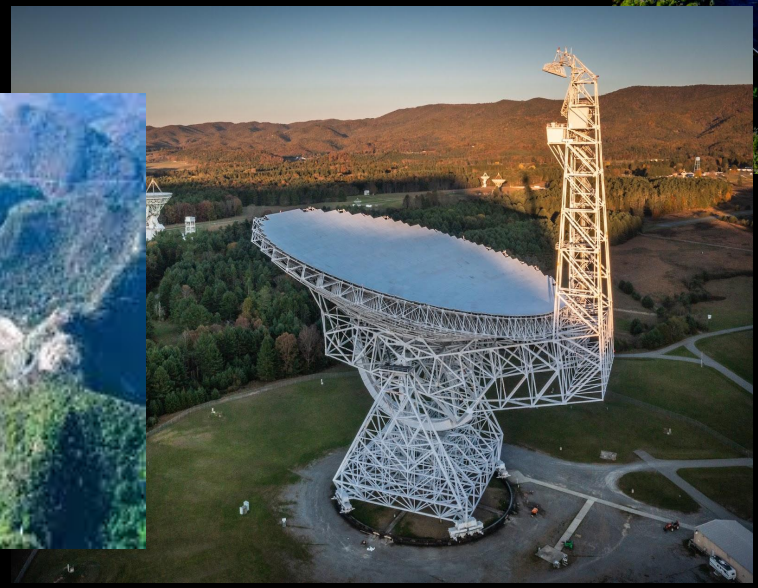
Single Pulse Searches



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)