CRASIES: Pulsars and Fast Radio Bursts (Why they are so cool, in <25 minutes)

Robert Main, May 27 2026

robert.main@mcgill.ca

Grew up in Midland Ontario
(‘Tiny Can’)

Bachelors and Masters: University of Waterloo

AGN Feedback
(completely different!)

PhD at University of Toronto

Pulsar “scintillometry”

Post Doc at MPIfR in Bonn, Germany

Scintillometry, pulsar timing arrays

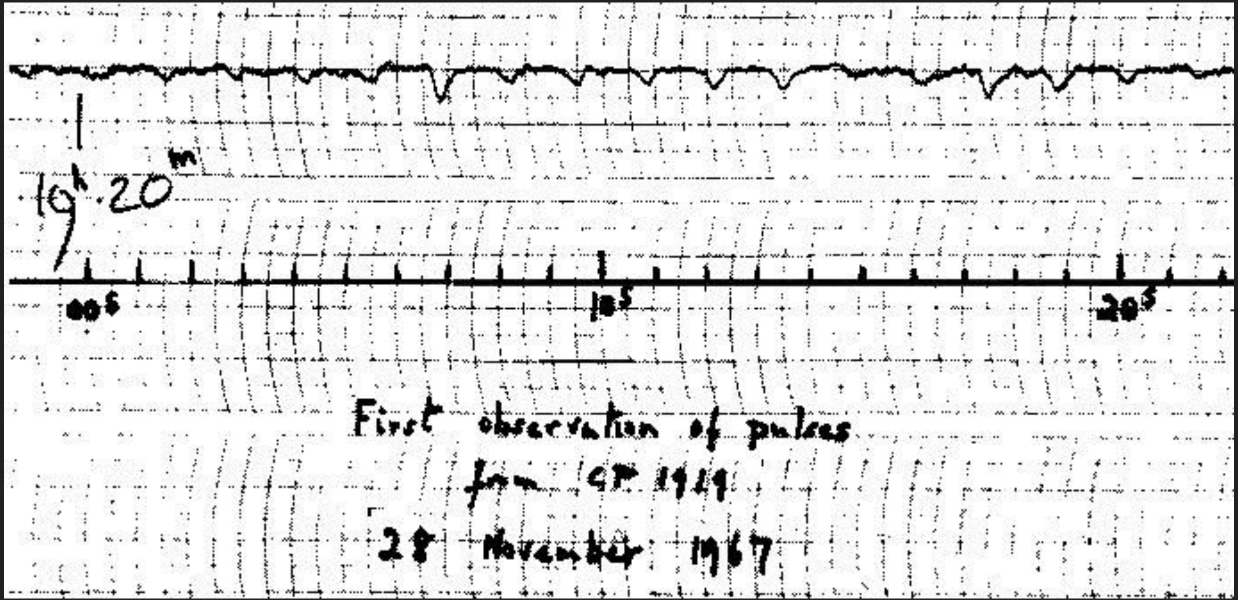
Post Doc at McGill (here!)

CHIME pulsar search
(+ sprinkling of FRBs)

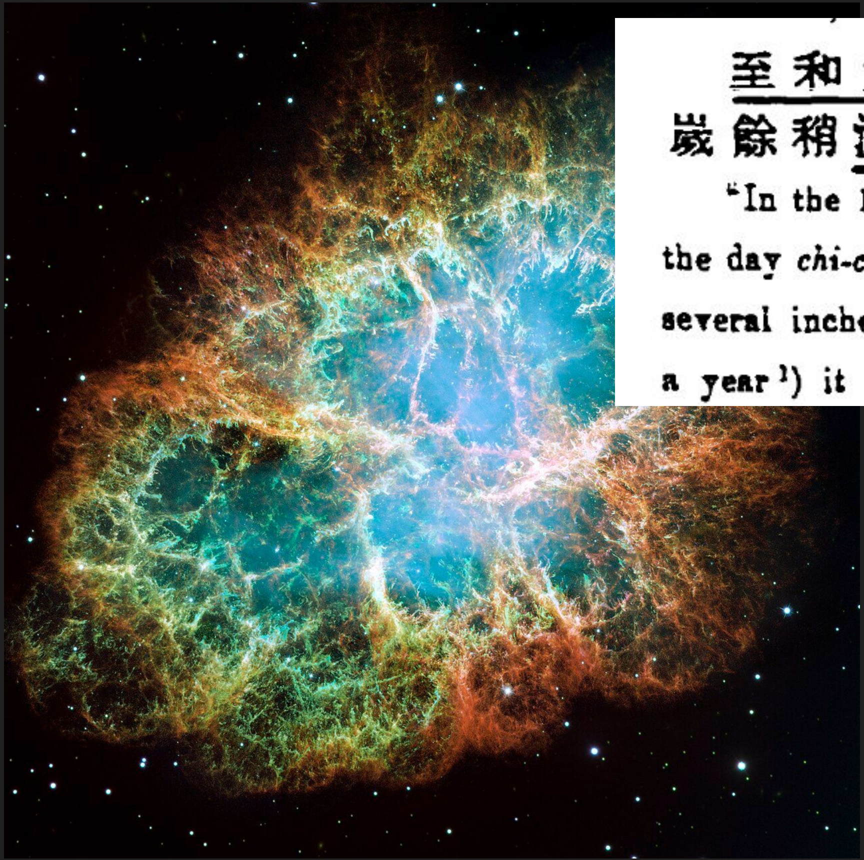
The ‘Interplanetary Scintillation Array’, Cambridge England..

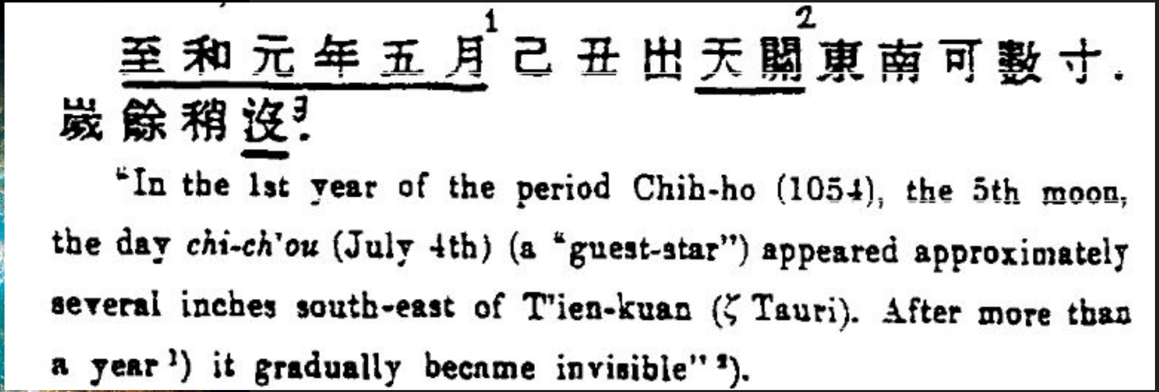
Viewing the radio sky at high time resolution

Jocelyn Bell Burnell



Pulsars = ‘pulsating stars’

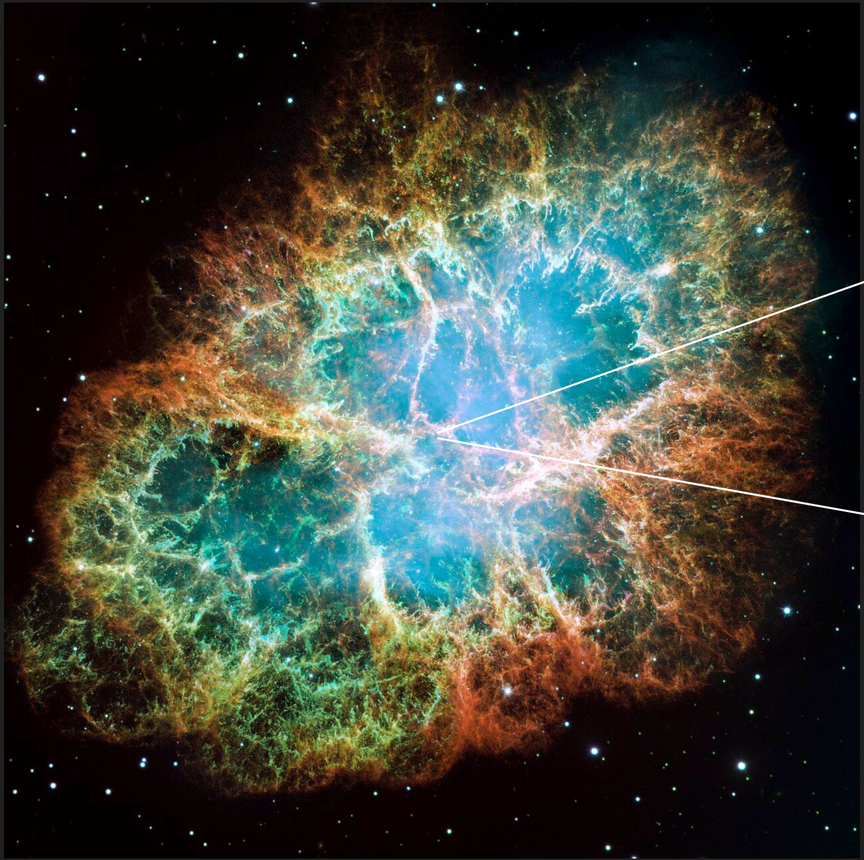




至和元年五月[1]己丑出天關[2]東南可數寸. 歲餘稍沒[3].

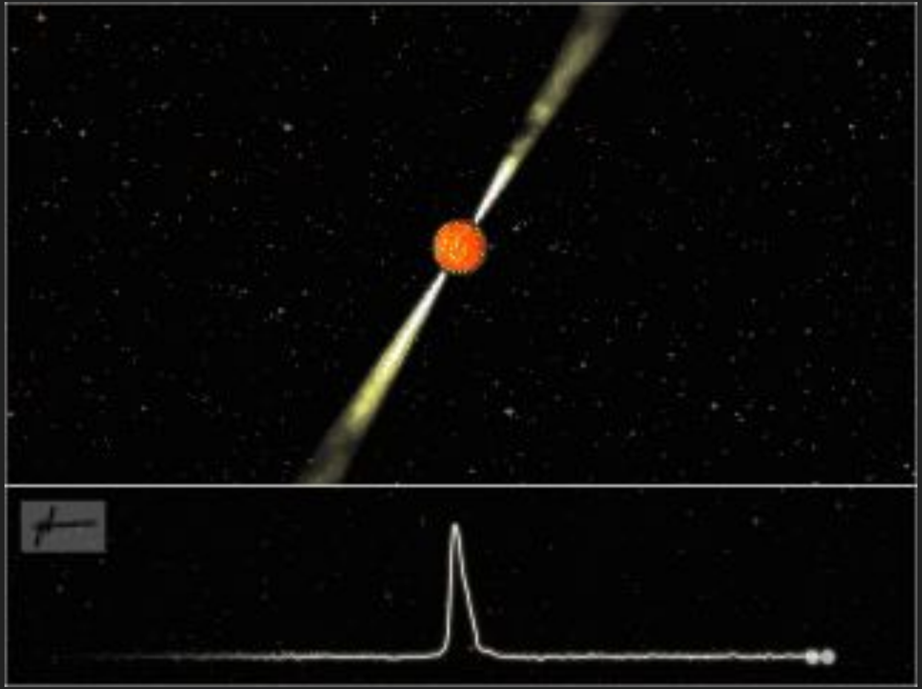
“In the 1st year of the period Chih-ho (1054), the 5th moon, the day *chi-ch'ou* (July 4th) (a “guest-star”) appeared approximately several inches south-east of T'ien-kuan (ζ Tauri). After more than a year[1]) it gradually became invisible”[2]).

Pulsars = ‘pulsating stars’ = neutron stars!



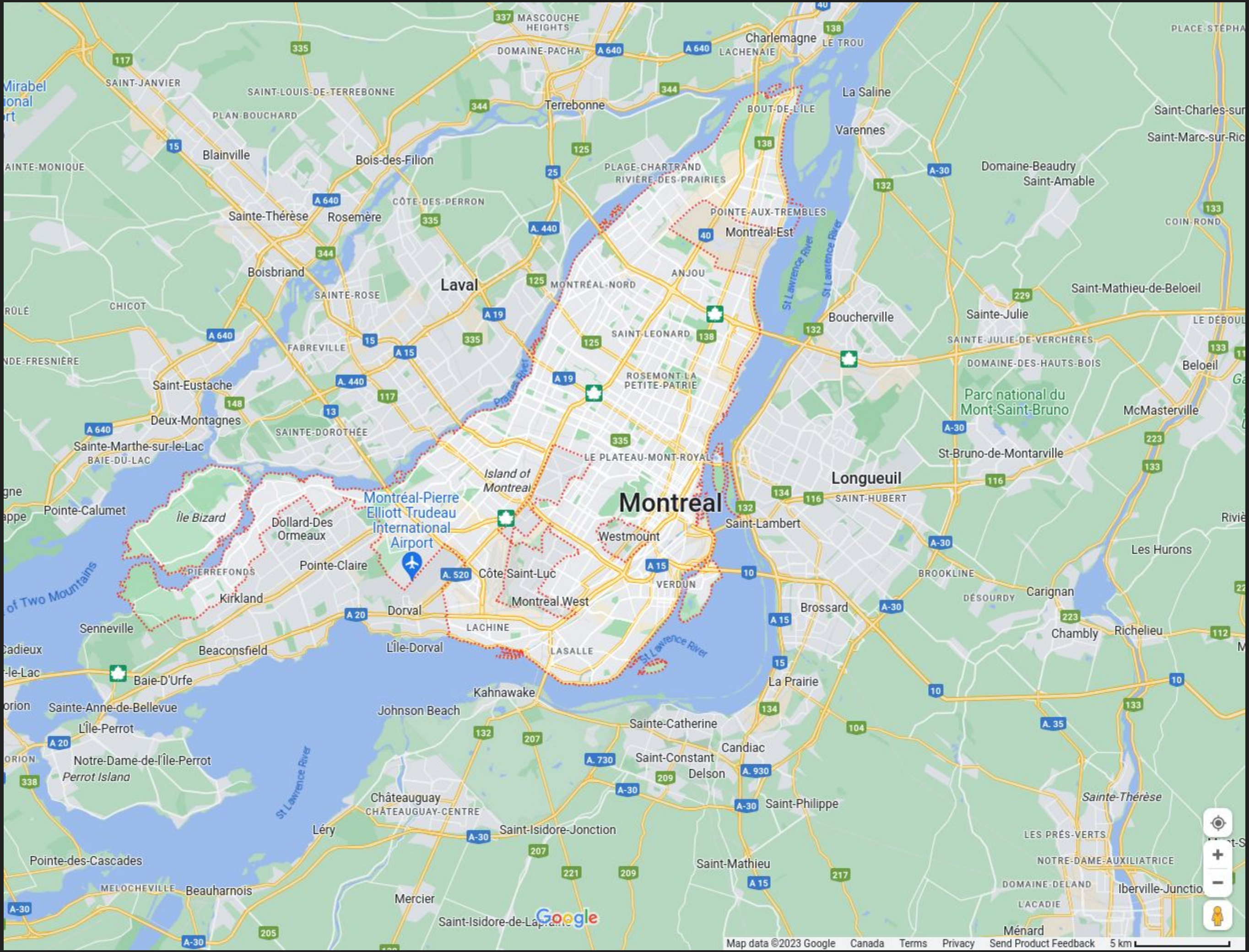
33milliseconds

Pulsars: astrophysical lighthouses



Gif credit: Joeri van Leeuwen

Mass ~ 1.4 $M_\odot$, Radius ~ 10km, Magnetic Field ~ 10^8 - 10^{15} G, Spin Period ~ 1ms - 100s



Mascouche Heights
Domaine-Pacha
Charlemagne
Lachenaie
Le Trou
Saint-Janvier
Saint-Louis-de-Terrebonne
Plan-Bouchard
Terrebonne
La Saline
Bout-de-l'Île
Varennes
Blainville
Bois-des-Filion
Plage-Chartrand
Rivière-des-Prairies
Domaine-Beaudry
Saint-Amable
Saint-Charles-sur
Saint-Marc-sur-Ric
Sainte-Thérèse
Rosemère
Côte-des-Perron
Pointe-aux-Trembles
Montréal-Est
Coin-Rond
Boisbriand
Laval
Montréal-Nord
Anjou
St Lawrence River
Sainte-Rose
Chicot
Saint-Mathieu-de-Beloeil
Boucherville
Sainte-Julie
Le Déboul
Fabreville
Saint-Léonard
Sainte-Julie-de-Verchères
Domaine-des-Hauts-Bois
Beloeil
Saint-Eustache
Rosemont-La Petite-Patrie
Prairies River
Parc national du Mont-Saint-Bruno
McMasterville
Deux-Montagnes
Sainte-Dorothée
Sainte-Marthe-sur-le-Lac
Baie-du-Lac
Le Plateau-Mont-Royal
St-Bruno-de-Montarville
Island of Montreal
Longueuil
Saint-Hubert
Montréal-Pierre Elliott Trudeau International Airport
Montreal
Pointe-Calumet
Île Bizard
Dollard-Des Ormeaux
Saint-Lambert
Westmount
Les Hurons
Pierrefonds
Pointe-Claire
Côte Saint-Luc
Verdun
Brookline
Lake of Two Mountains
Kirkland
Montreal West
Désourdy
Carignan
Brossard
Dorval
Senneville
Lachine
Chambly
Richelieu
L'Île-Dorval
Beaconsfield
LaSalle
St Lawrence River
Baie-D'Urfe
La Prairie
Kahnawake
Sainte-Anne-de-Bellevue
Johnson Beach
Sainte-Catherine
L'Île-Perrot
Candiac
Notre-Dame-de-l'Île-Perrot
Saint-Constant
Delson
Perrot Island
St Lawrence River
Saint-Philippe
Sainte-Thérèse
Châteauguay
Châteauguay-Centre
Léry
Saint-Isidore-Jonction
Les Prés-Verts
Pointe-des-Cascades
Saint-Mathieu
Notre-Dame-Auxiliatrice
Melocheville
Beauharnois
Domaine-Deland
Iberville-Junctio
Mercier
L'Acadie
Saint-Isidore-de-Laprairie
Ménard
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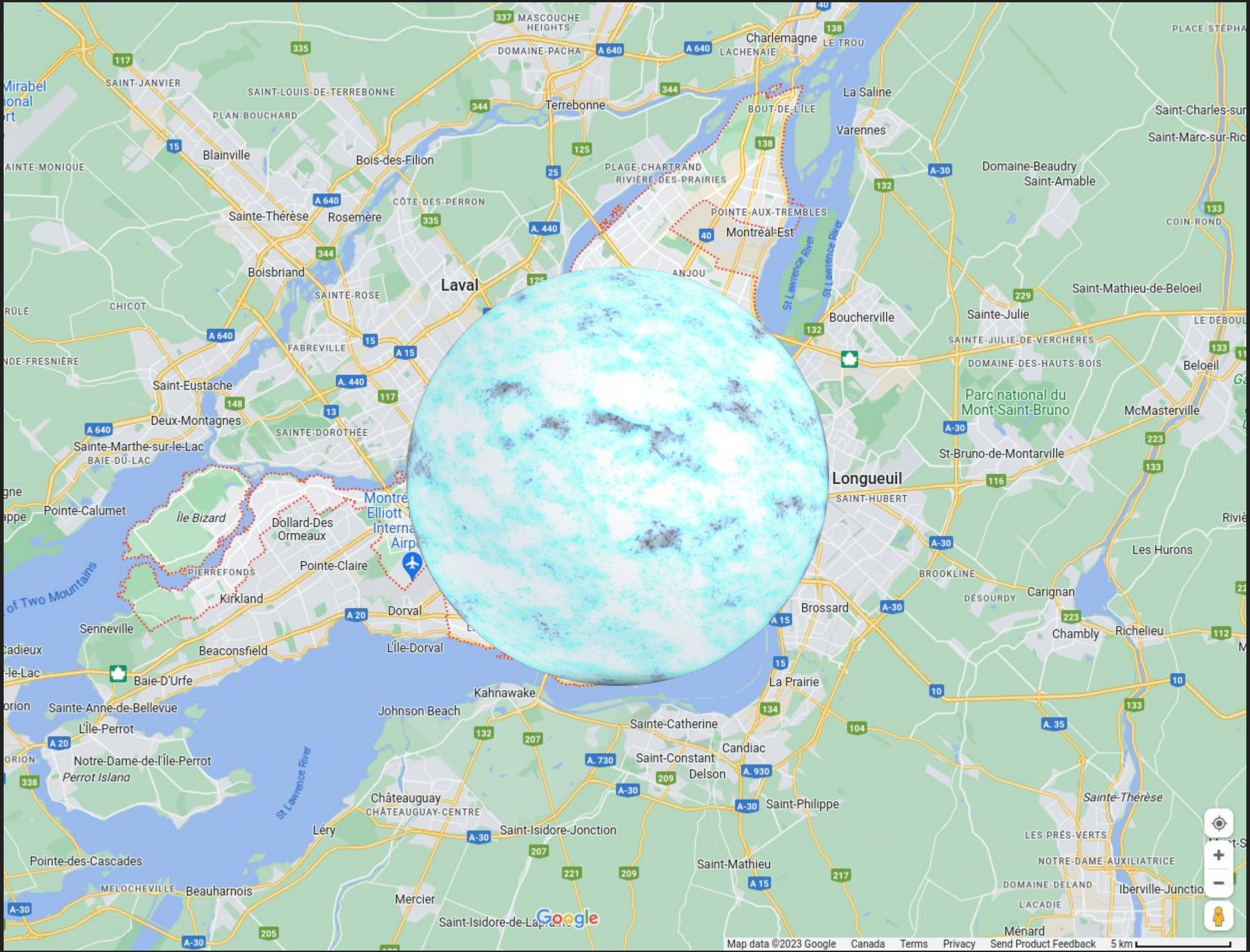
5 km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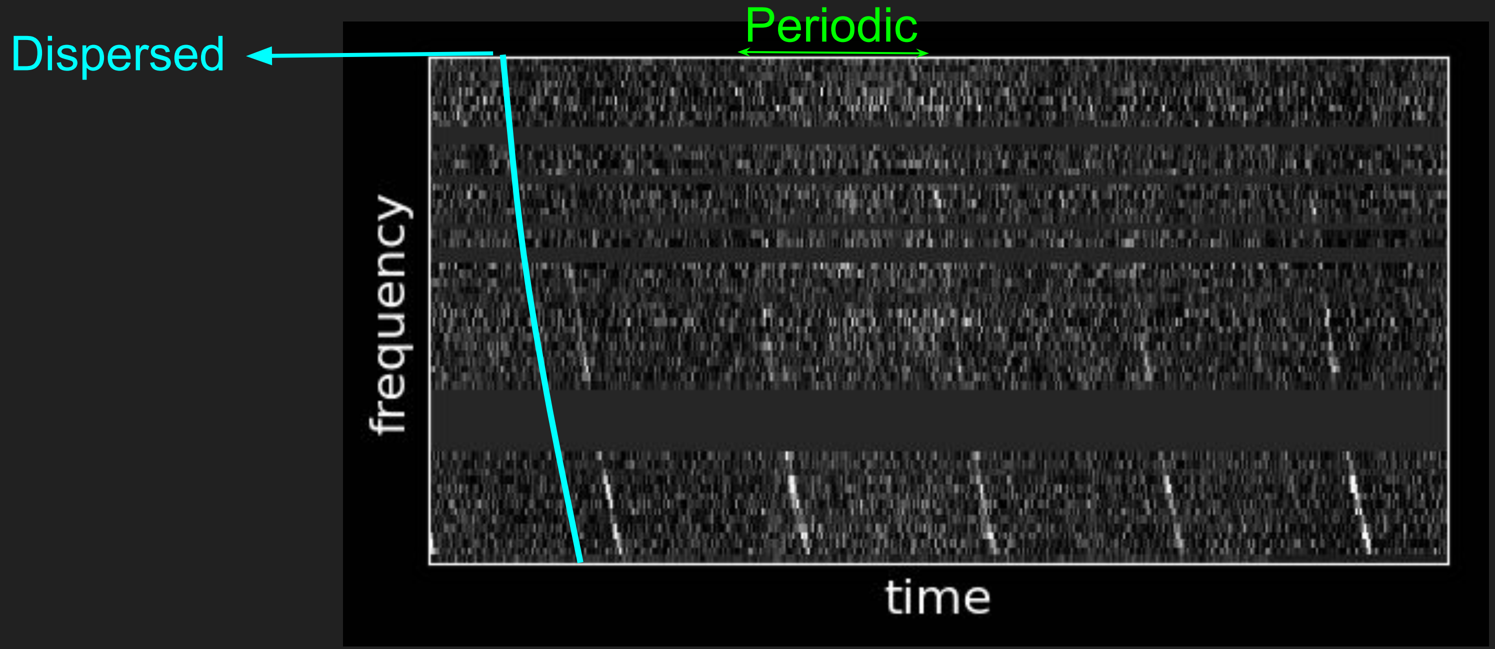
5 km

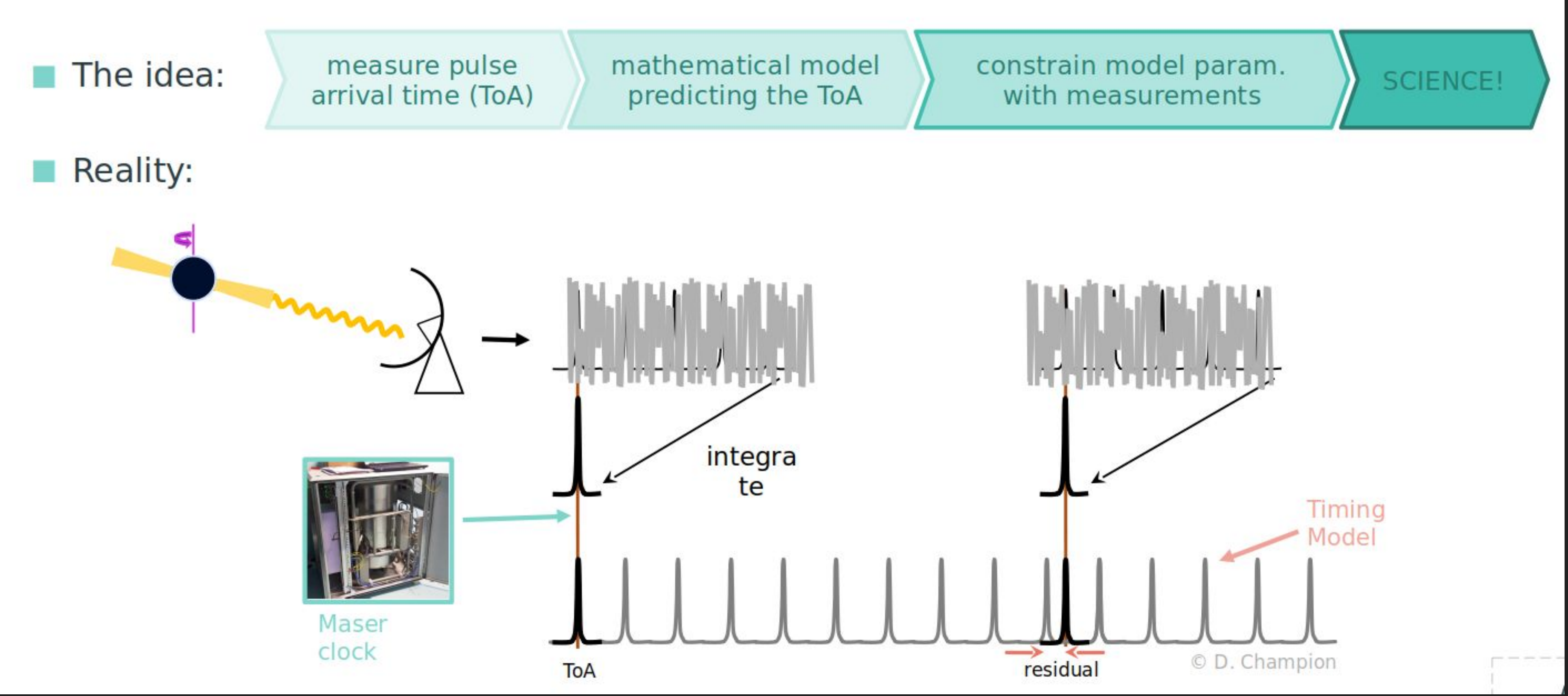
Pulsars are…



740ms between pulses

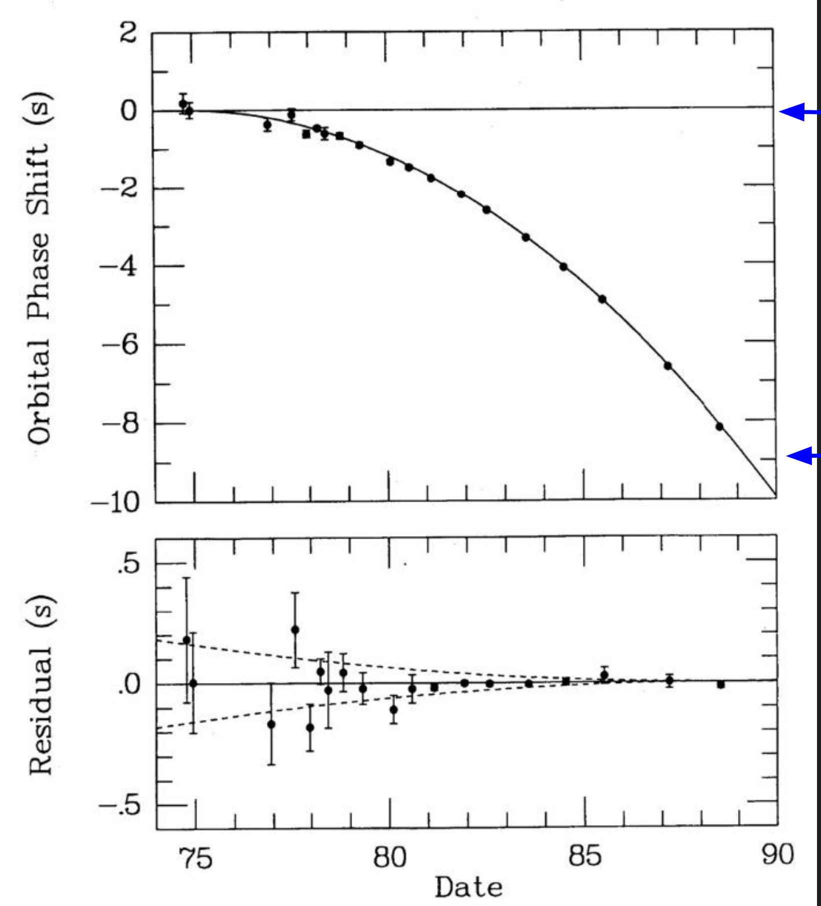
Pulses 'sweep' from high to low radio frequencies

Pulsars: incredibly precise clocks



PSR J1909-3744: rotates 339.315687218483(1) times/second!

First (indirect) detection of gravitational waves

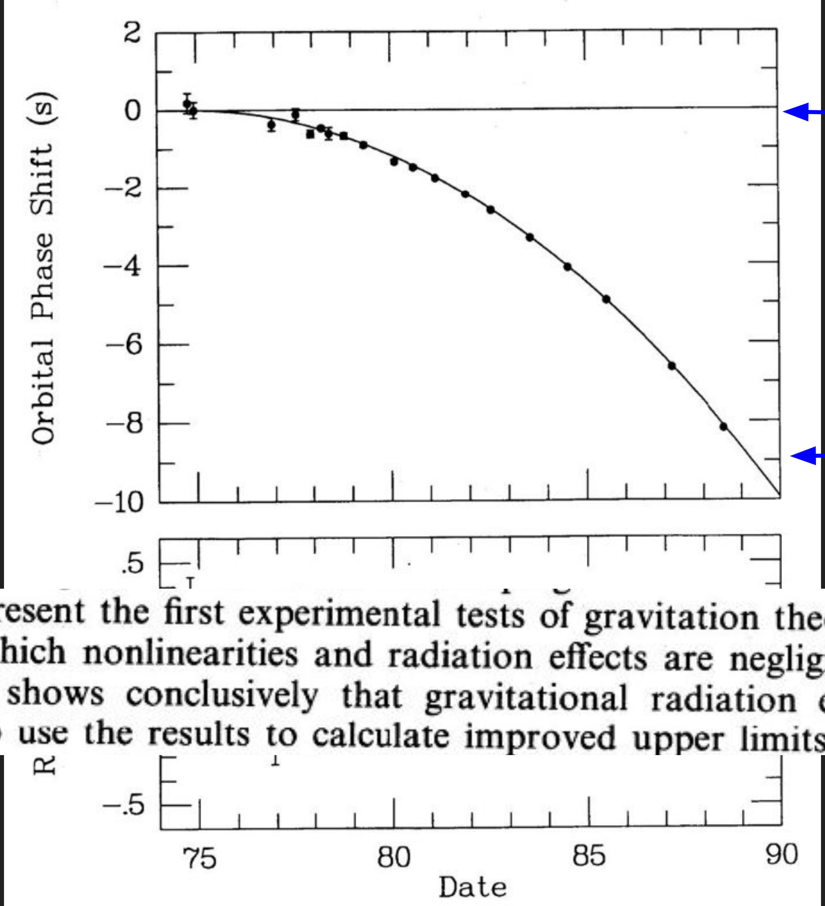


Classical Prediction

Prediction from General Relativity

Taylor & Weisberg 1989

First (indirect) detection of gravitational waves



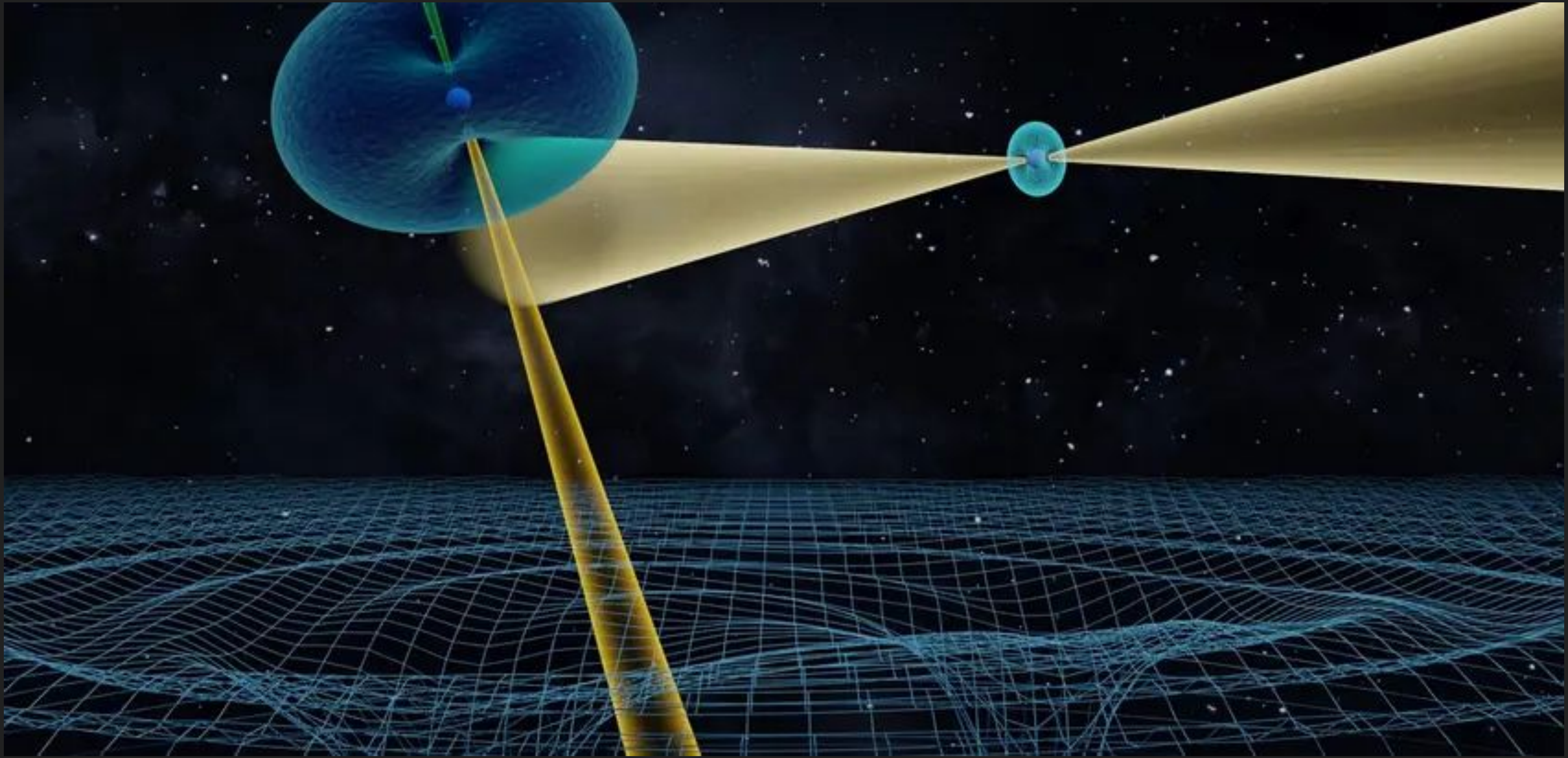
Classical Prediction

Prediction from General Relativity

Our results represent the first experimental tests of gravitation theory not restricted to the weak-field, slow-motion limit in which nonlinearities and radiation effects are negligible. The excellent agreement of observation with theory shows conclusively that gravitational radiation exists, at the level predicted by general relativity. We also use the results to calculate improved upper limits on the rate of change of the Newtonian

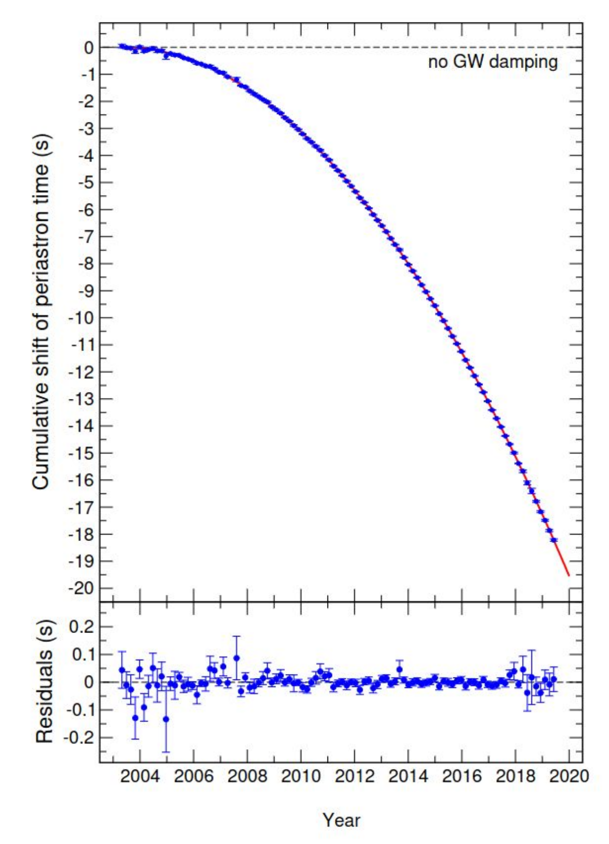
Taylor & Weisberg 1989

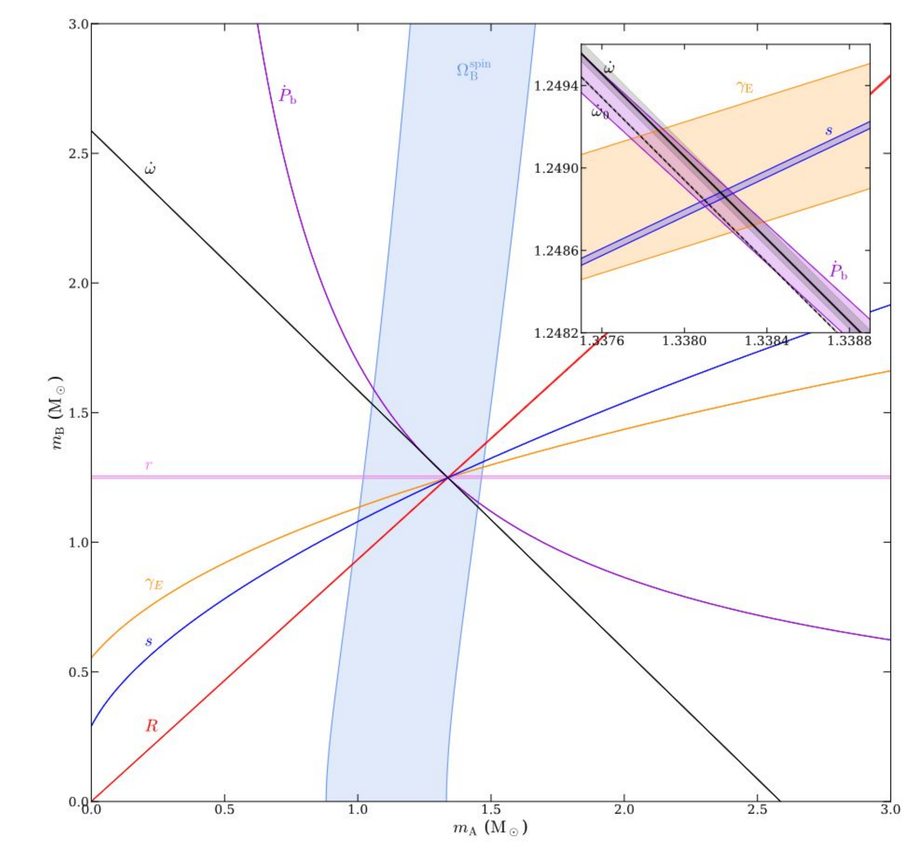
Double Pulsar: Precision tests of General Relativity



Kramer et al. 2021

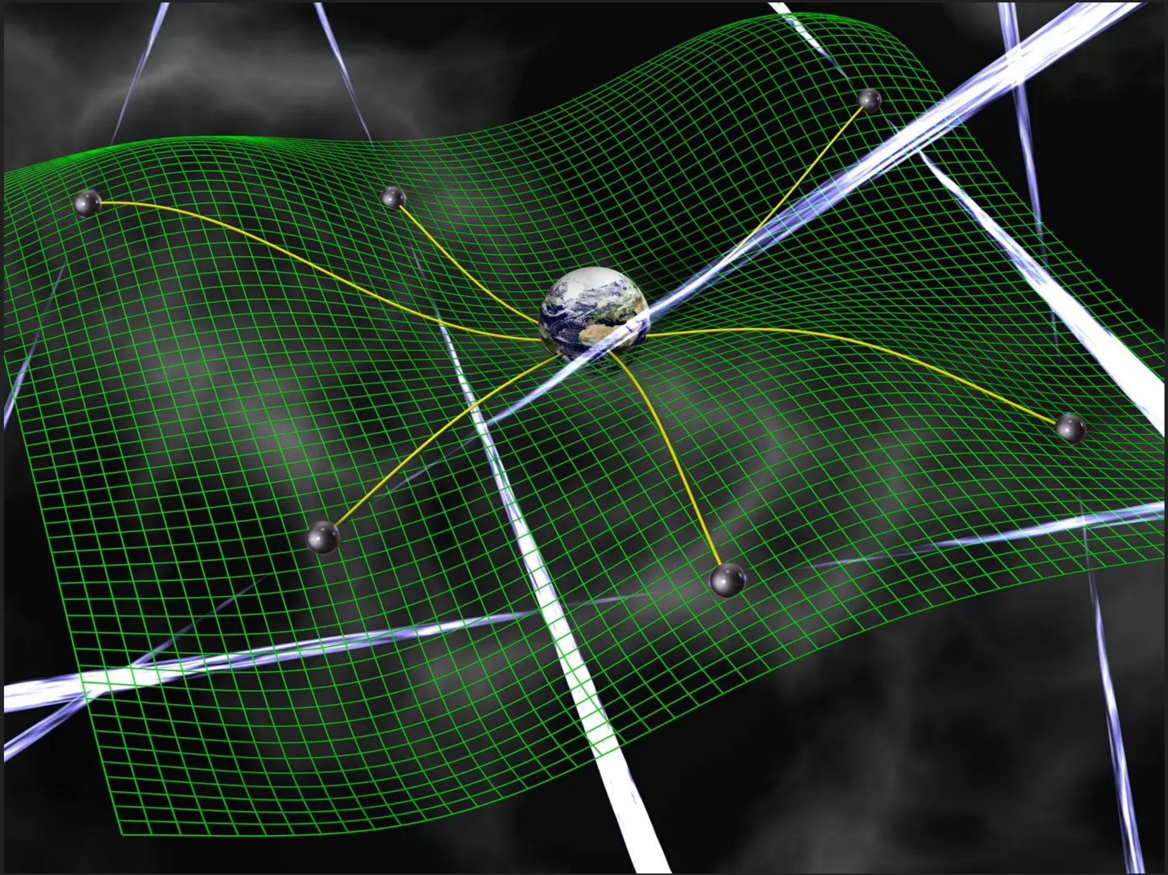
Double Pulsar: Precision tests of General Relativity





Kramer et al. 2021

Pulsar Timing Arrays: *Directly* detect nHz gravitational waves



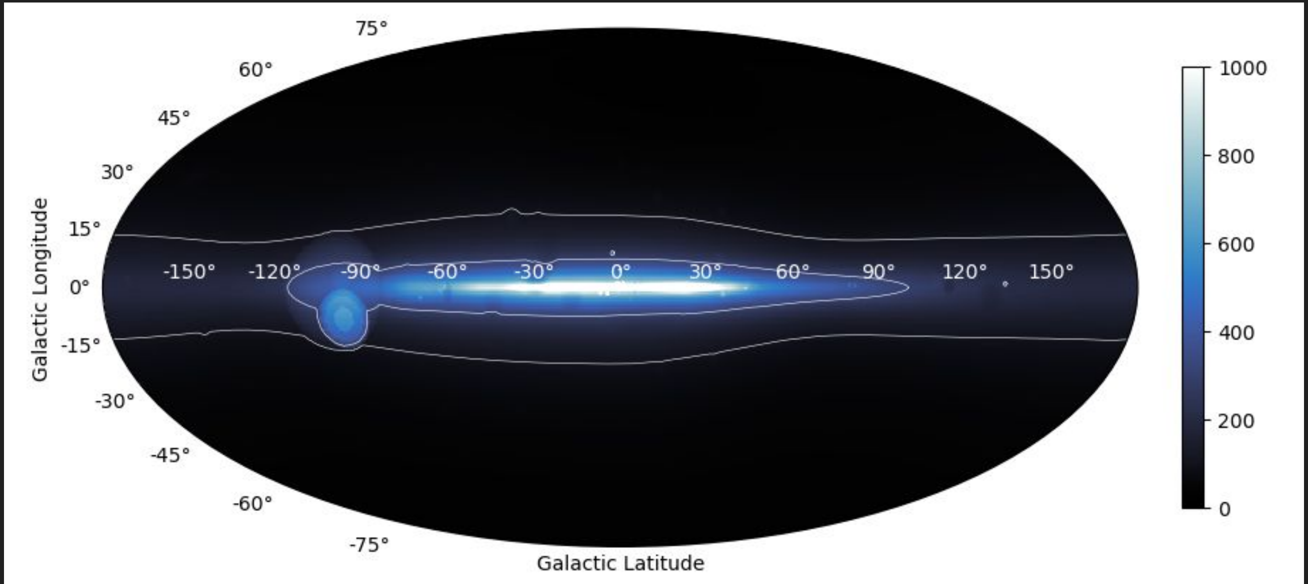
Credit: David Champion

Pulsar Dispersion Measure: Map Milky Way's Plasma

$$DM = \int_0^D n_e dl \qquad [pc/cm^3]$$

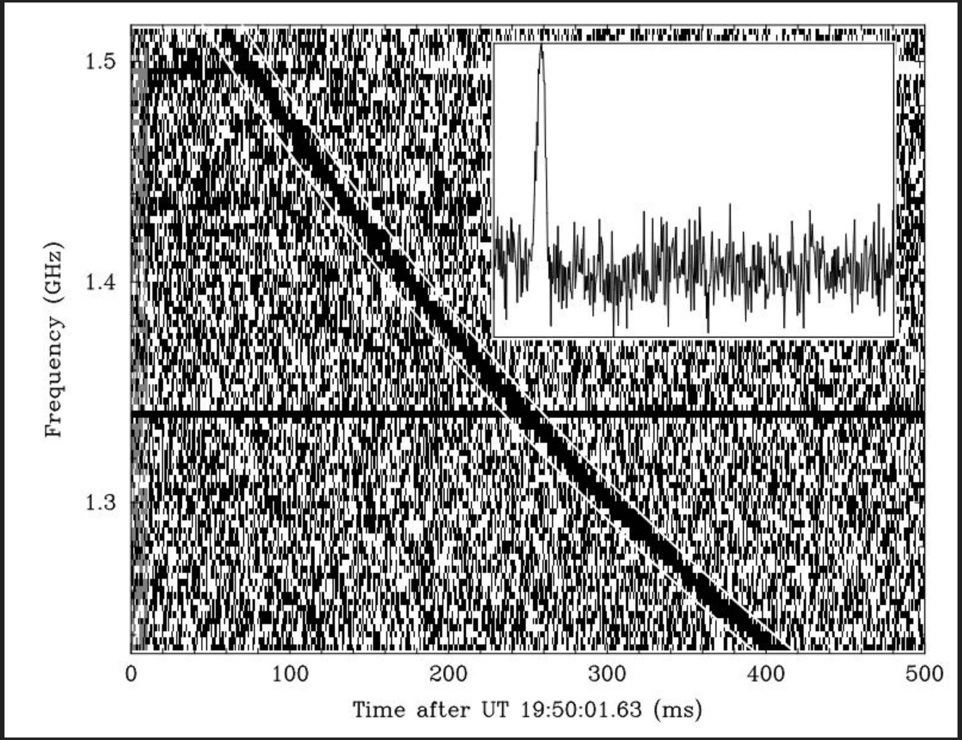
DM + electron density → distance

Calibrated in Milky Way using many known pulsars with measured distance



Yao+17, Ocker&Cordes 26

An *Extragalactic* ‘Fast Radio Burst’



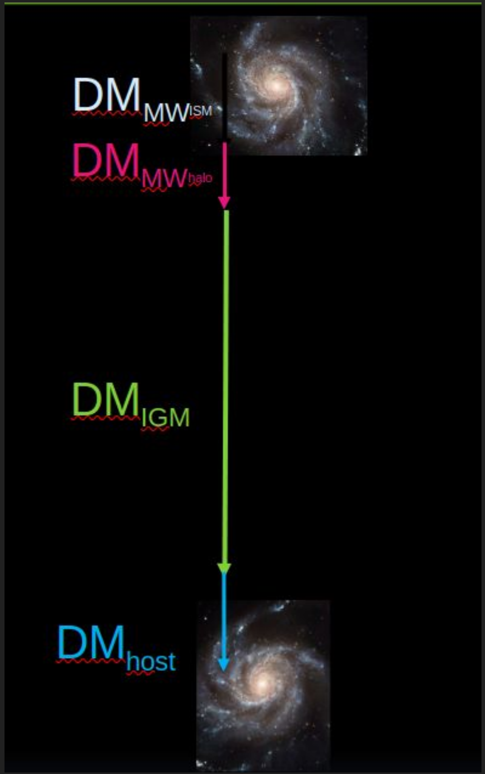
Lorimer et al. 2007

$\boxed{DM = 375pc/cm^3}$

$\boxed{DM_{max} = 25pc/cm^3}$

$n_{e,IGM} \sim 0.16m^{-3}$

$D_L \sim 1Gpc$



Fast μs – ms duration

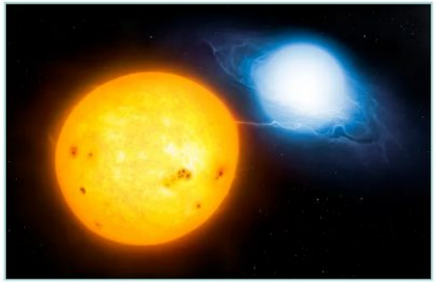
Radio 0.1 – 8 GHz

Bursts 10^35 – 10^43 erg

But what are they?

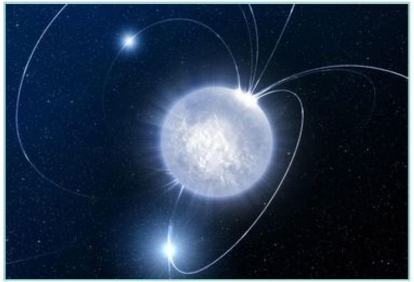
Black hole merger

Magnetars



Interacting binary

Supernova

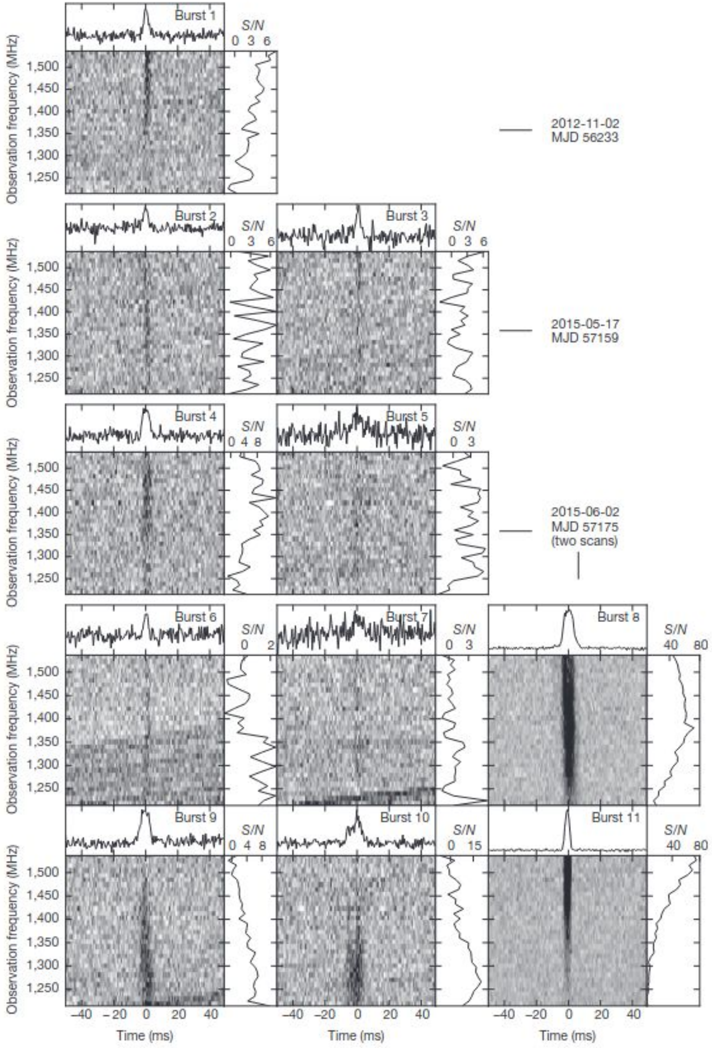


Giant pulses
from a pulsar

Slide credit: Alice Curtin

FRB121102 Repeats…
(discovered here at McGill)!

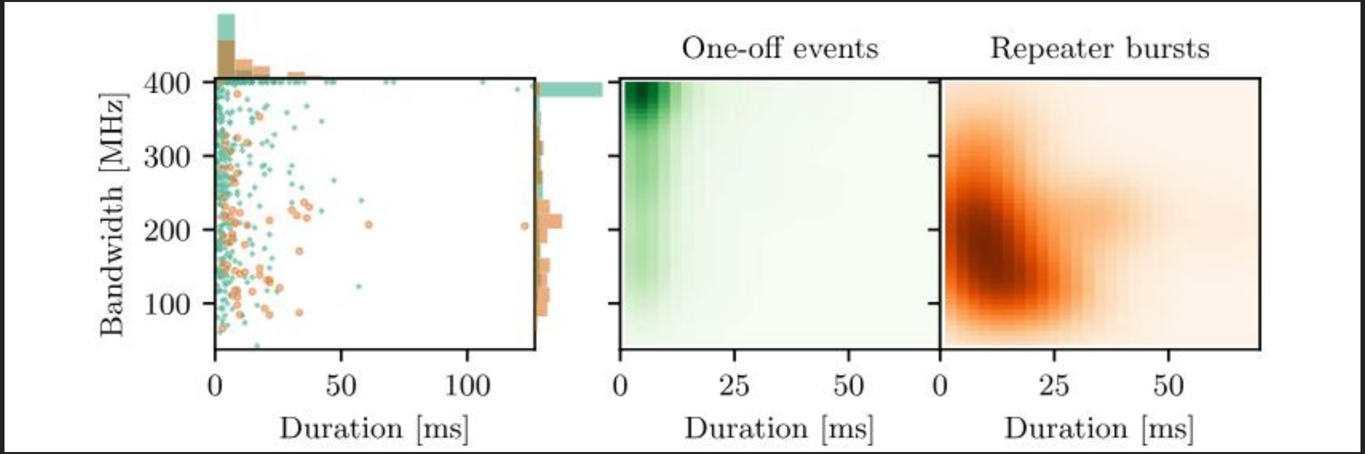
Spitler+16



Many FRBs (~3%) Repeat!

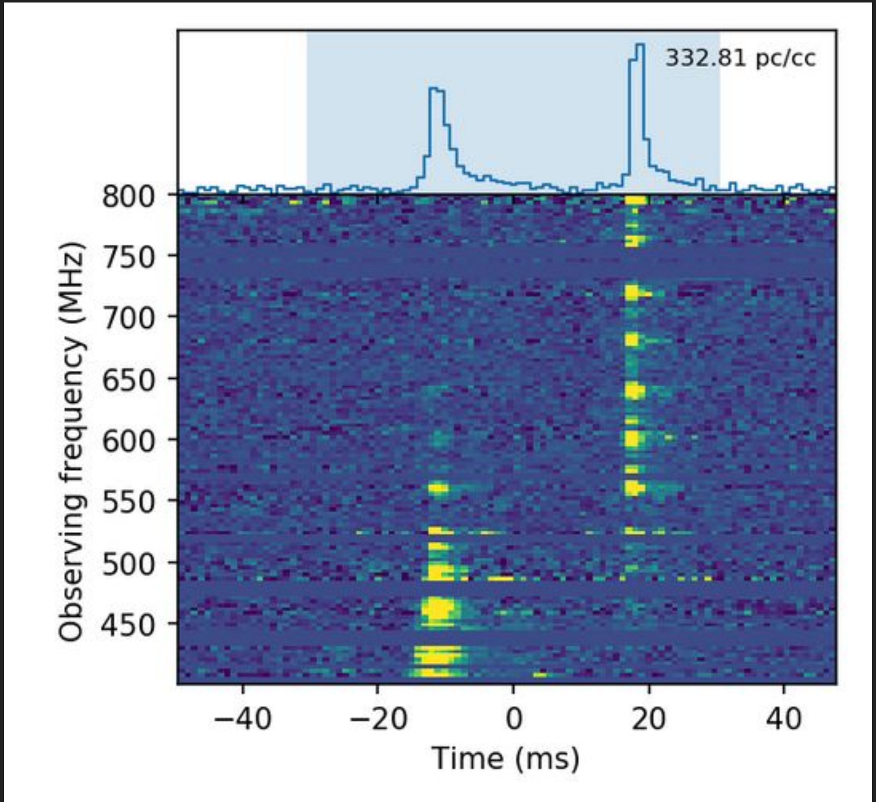
Do *all* FRBs repeat?

Poll from FRB2025, here at McGill!



Pleunis+21, Curtin+25

What are FRBs? Bright Radio Burst from a Galactic Magnetar



CHIME Collaboration, 2020

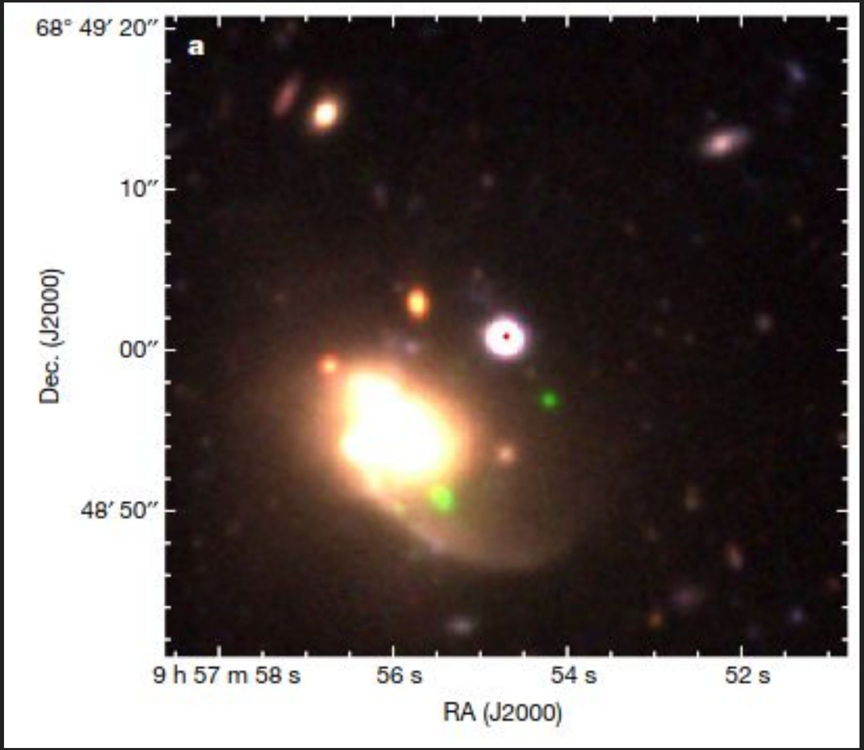
Seen by CHIME, 22 degrees away

+ Algonquin Radio Observatory 10m
+ STARE2 (antennae, no dish)

Bright enough to see in nearby galaxy!

Coincident with X-ray burst

What are FRBs? Most nearby FRB to date, in a globular cluster



Kirsten+21

In M81, *only* 3.6Mpc away

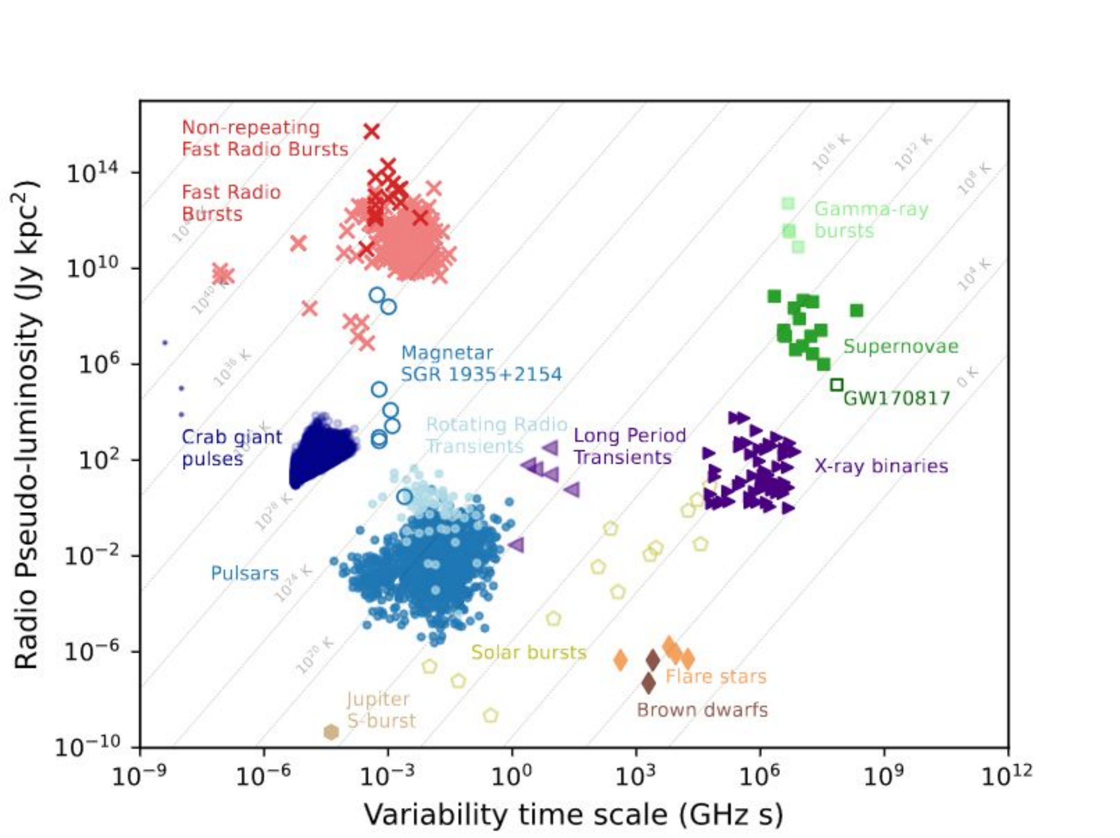
Globular clusters host old stars,
no formation channel for magnetar

No X-ray emission $E_{x,burst} \lesssim 10^{41} erg$

$L_x \lesssim 10^{37} \mathrm{erg/s}$

Pearlman+25

Fast Radio Bursts in Context



Credit: Laura Spitler

What are FRBs? Many other hints..

Extreme magnetoionic local environment (Michilli+18)

Variable dispersion measures (1000x larger than pulsars, SNR?)   (e.g. Pandhi+25)

Persistent, extremely bright continuum radio sources (Chaterjee+17)

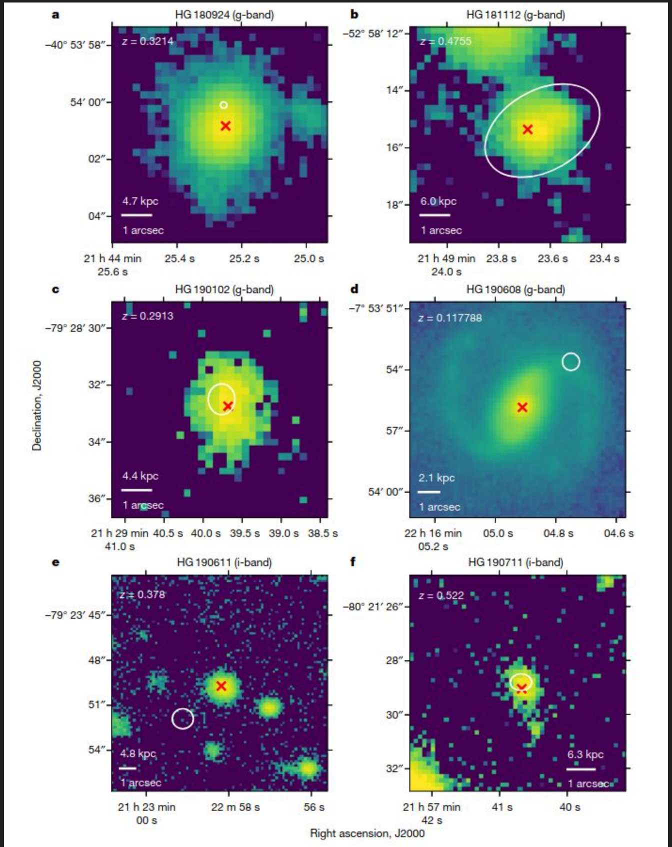
16.3 day activity window in FRB 20180916A (CHIME/FRB Collaboration et al. 2020)

Polarization swing, pulsar-like? (Mckinven+25)

No extragalactic multiwavelength associations

No clear periodicities

Discover with an interferometer: FRBs localized to galaxies



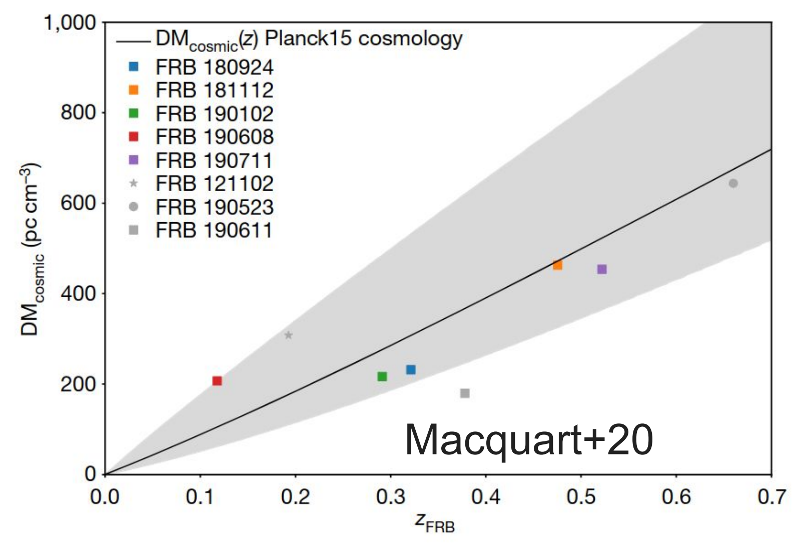
Macquart+20

FRB Dispersion Measure: Mapping *Universe's* Baryons

$$DM = \int_0^D n_e dl \qquad [pc/cm^3]$$

DM + electron density → ~~distance~~ redshift

Calibrated in IGM using many known FRBs with measured redshifts



FRB Dispersion Measure: Mapping *Universe's* Baryons

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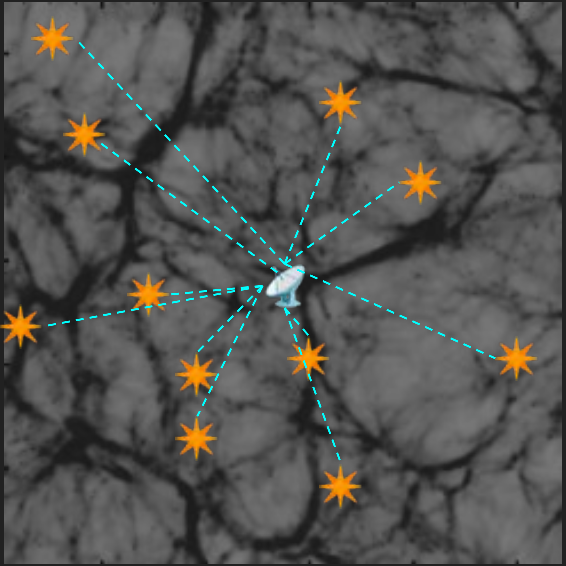
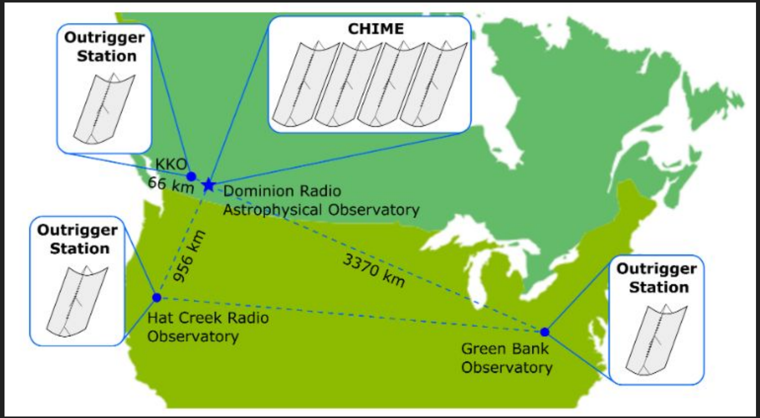


Need to localize many FRBs – CHIME/Outriggers

Photo credits: Richard Shaw, Nicolas Séguin, Kenzie Nimmo, Kiyoshi Masui

$$\mathrm{resolution} = \lambda/\mathrm{b}$$



Pulsars and Fast Radio Bursts in <25 minutes

Radio astronomy at <ms timescales!

Pulsars: periodic, dispersed

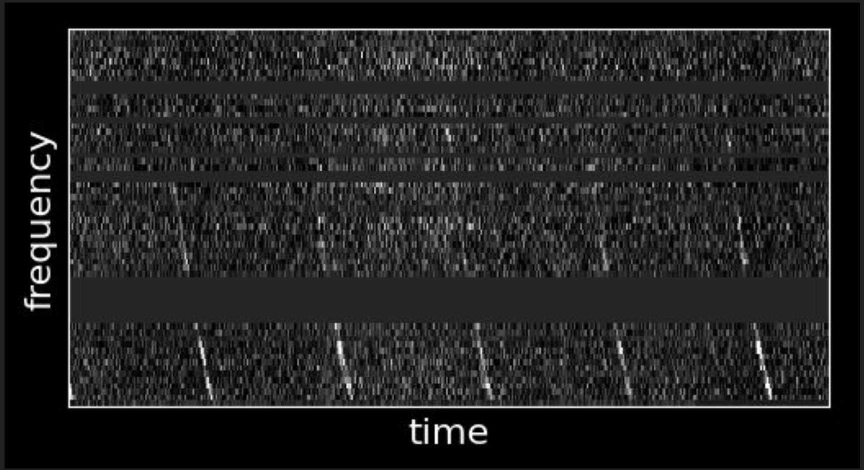
Probe of fundamental physics

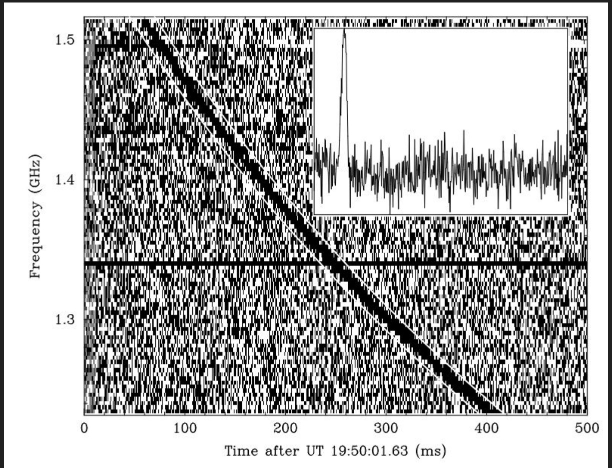
Map of Galactic plasma

FRBs: highly dispersed bursts

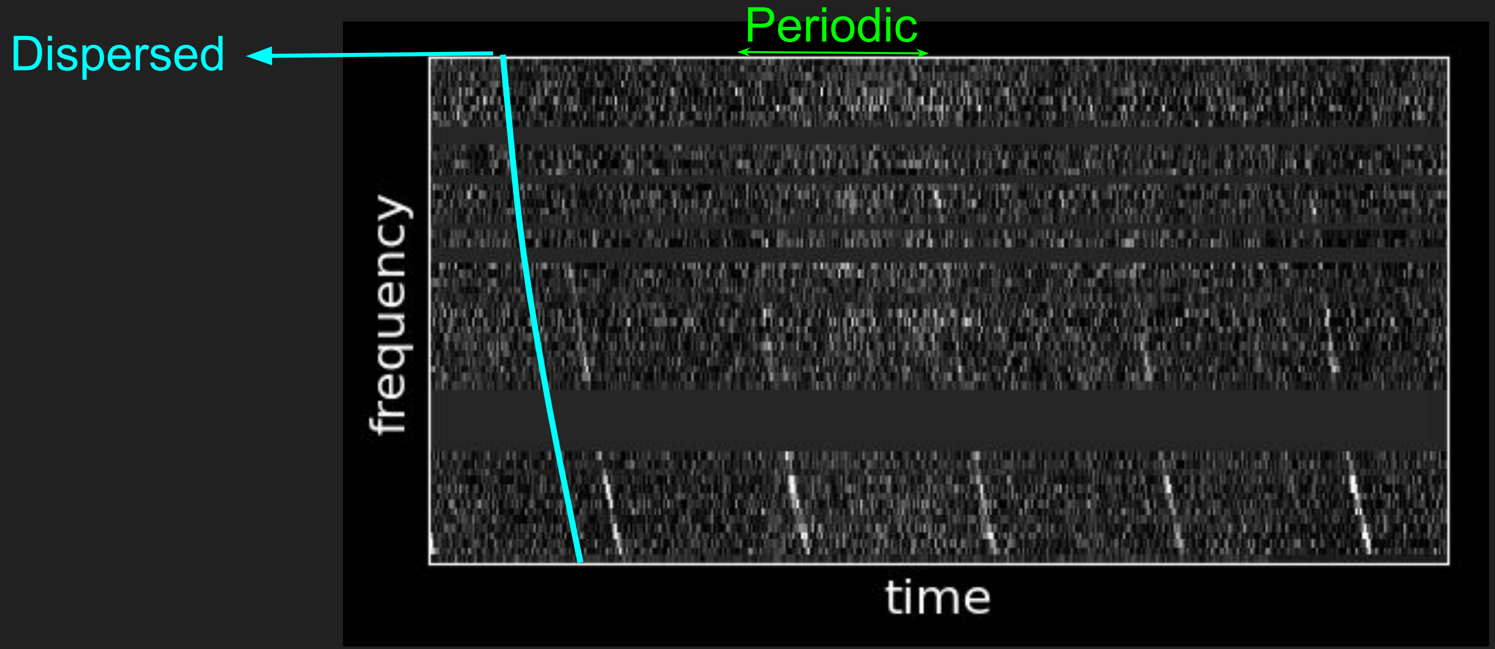
Cosmic mystery! (magnetars?)

Cosmological probe





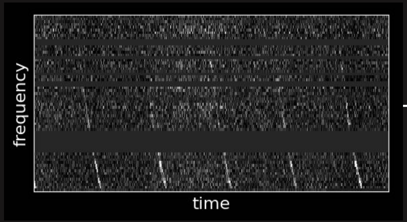
Let's Find a pulsar! Pulsar signals are…



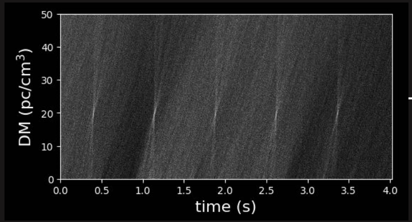
740ms between pulses

Pulses 'sweep' from high to low radio frequencies

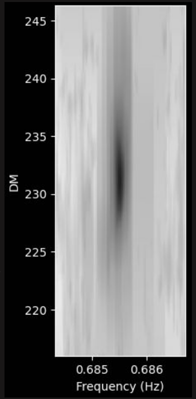
Searching for Pulsars



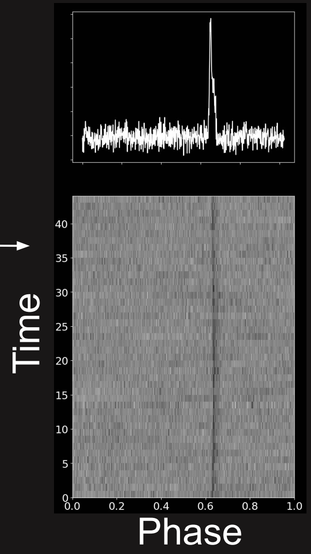
Starting Data
Intensity vs time, frequency



De-dispersed at many DMs

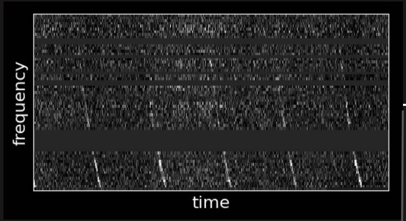


Fourier transformed in time
(and squared, forming
'power spectrum')



'Fold' on peaks of DM, freq

Searching for Pulsars



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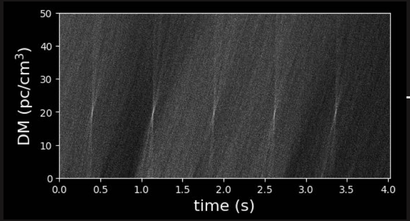
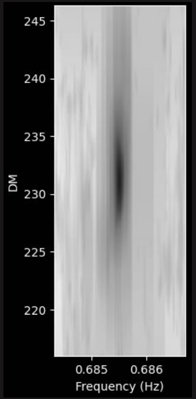
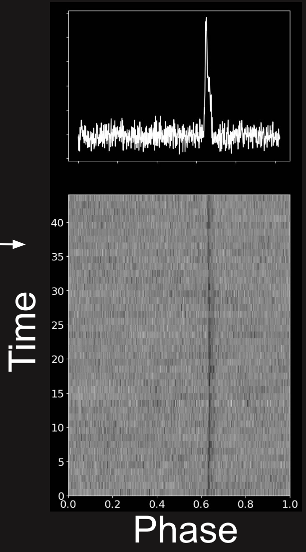
Intensity vs time, frequency



De-dispersed at many DMs



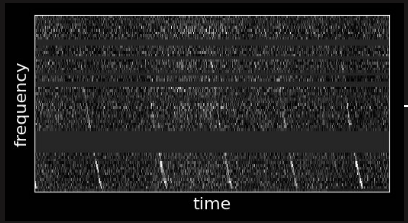
Fourier transformed in time
(and squared, forming
'power spectrum')



'Fold' on peaks of DM, freq

Blanked frequency channels were
'Radio Frequency Interference' (RFI)
Step 1 is often to find, and mask / set to 0

Searching for Pulsars



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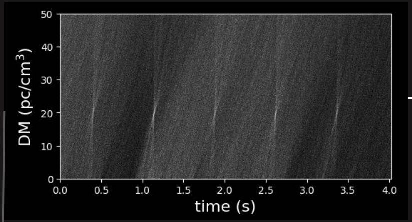
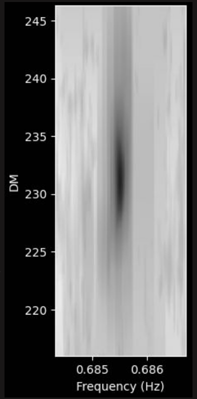
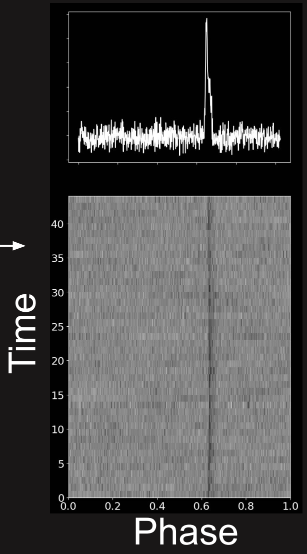
Intensity vs time, frequency



De-dispersed at many DMs



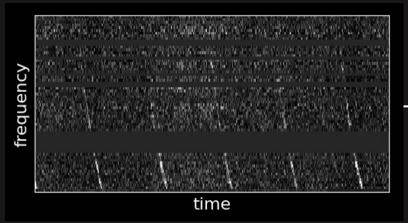
Fourier transformed in time (and squared, forming 'power spectrum')



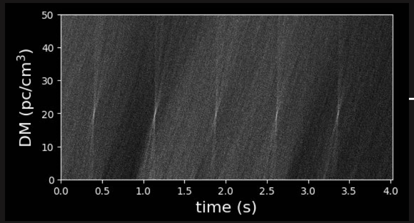
'Fold' on peaks of DM, freq

$$DM = \int_0^D n_e dl \qquad \Delta t = k_{DM} DM \nu^{-2} \qquad k_{DM} = 4149.4 cm^3 pc^{-1} MHz^2 s$$

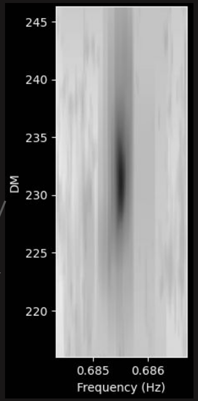
Searching for Pulsars



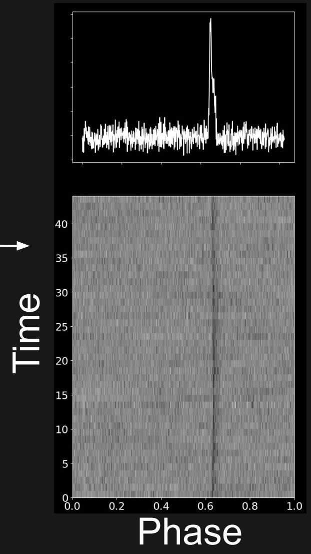
Starting Data
Intensity vs time, frequency



De-dispersed at many DMs



Fourier transformed in time
(and squared, forming
'power spectrum')

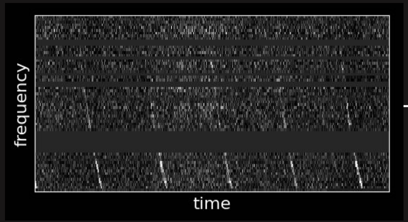


'Fold' on peaks of DM, freq

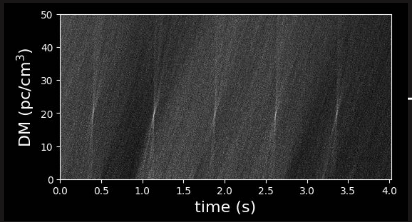
Fast Fourier Transform (FFT)

periodic signal at spin frequency!
(and higher harmonics)

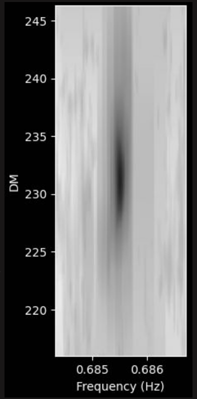
Searching for Pulsars



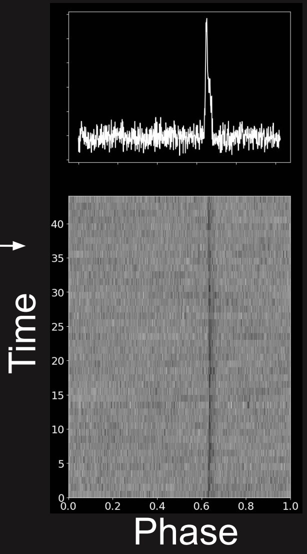
Starting Data
Intensity vs time, frequency



De-dispersed at many DMs



Fourier transformed in time
(and squared, forming
'power spectrum')

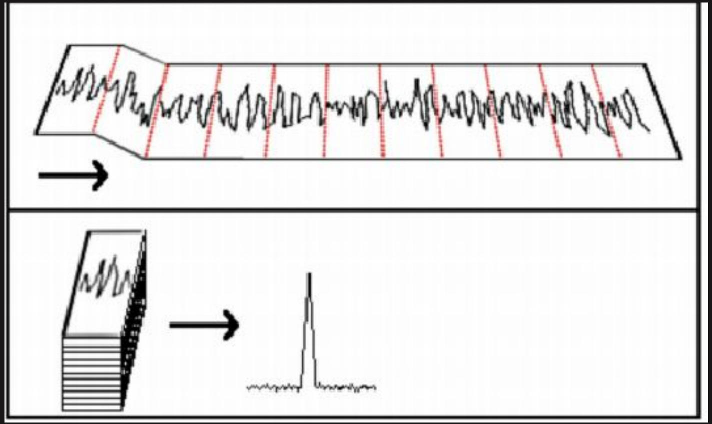


'Fold' on peaks of DM, freq

"Folding"

For a given spin period:
Remap I(time) → I(phase)

phase = (t%Pspin)/Pspin



This Project: Finding Pulsars!

Included in this project is ~1minute of data from the CHIME telescope, in a pointing towards a known pulsar

The goal is to create the steps to discover, fold on the pulsar, and determine:

1) What is the pulsar's DM, P_spin?
2) Which pulsar it is?

There is a jupyter notebook with the steps of reading in the data, and written instructions on the steps needed to find and identify the pulsar

https://github.com/ramain/CRASIES2026_pulsarsearch/tree/main

Pulsar Resources

ATNF Pulsar Catalogue: https://www.atnf.csiro.au/research/pulsar/psrcat/

Pulsar Survey Scraper (up to date, inc. unpublished pulsars): https://pulsar.cgca-hub.org/

Essential Radio Astronomy: https://www.cv.nrao.edu/~sransom/web/Ch6.html

Handbook of pulsar astronomy (not available online):