Models

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Why Neutron Stars

- Need 10^{40} ergs
- Need 10^{-3} s time scale
- Need Coherent emission ($T_b \sim 10^{35}$K)

There will be a meeting on neutron star models of FRB in Amsterdam in February.

A natural source of short, energetic, bright events

- Large magnetic energy $\sim 3 \times 10^{41} B_{12,eq}^2$ ergs
- Large rotational energy $0.5 \times 10^{53} \omega_4^2$ ergs
- Short time scale $\sim 3 \times 10^{-5}$ s

Neutron Star Models: Giant Pulsar Pulses I

What this gets right:

- $T_b \sim 10^{37}$K in nanoshots
- Erratic—"nulled" pulses
- RRAT—most pulses missing

Neutron Star Models: Giant Pulsar Pulses II

What this gets wrong:

- Absence of periodicity
  - Even RRAT have an underlying period
- Power *vs.* energetics
  - If fast and strongly magnetized enough to provide observed power, lifetime is too short < 5 y for the repeater

Giant Pulsar Pulse Model—Absence of Periodicity

Two kinds of periodicity:

Absolute periodicity
: Intervals are integer multiples of an underlying period

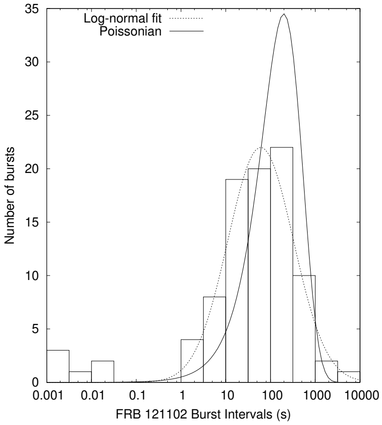
Periodic modulation
: Likelihood and strength of bursts are modulated by a periodic function of time

- Absolute periodicity excluded for FRB 121102 by precise timing

$$P = \frac{t_i - t_j}{n_{ij}} \; \forall (i,j) \text{ for some integer } n_{ij}. \tag{1}$$

- Periodic modulation of FRB 121102 limited to $\lesssim 30\%$

FRB 121102: 93 bursts in 5 hours (Zhang *et al.* 2018)



Not Poissonian. Short intervals may be substructure of longer bursts. Characteristic repetition time ~ 60 (depends on detection threshold). No obvious interpretation of log-normal fit.

Energetics of Pulsar Models

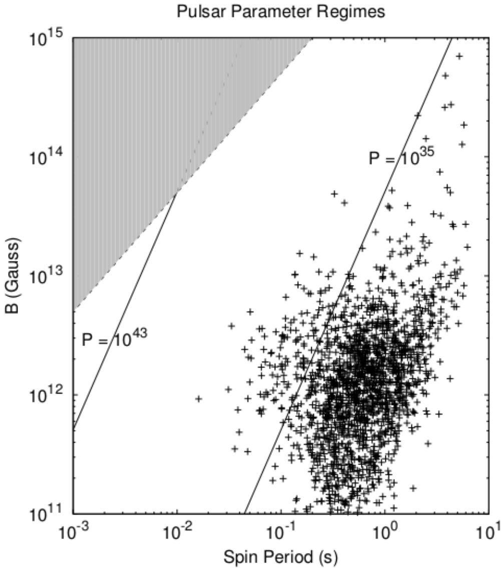
Pulsars have no energy store between rotation and particle acceleration

This implies a spindown power $10^{43}/\epsilon$ ergs/s (ϵ is efficiency of converting rotational energy to coherent GHz radiation, $\epsilon < 10^{-2}$ in pulsars).

Possible loopholes:

- Could there be transitions between different magnetospheric solutions with differing electrostatic energy?
- Could the radiation be narrowly collimated?

Collimation might save giant pulsar pulse model



Soft Gamma Repeater Model—Magnetostatic Energy

- SGR rise times $\lesssim 300\,\mu$s, consistent with FRB

But

- SGR appear to be entirely thermal events (nearly black body X-ray spectra)
  - However, first ms contributes negligibly to integrated spectrum
- No FRB was observed coincident with SGR 1806-20
  - Fortuitous observation at 35° from FRB
  - An isotropic Galactic FRB would have been 50 dB above noise, even 35° out of beam

Collimation might save SGR model

Requires $\gtrsim$ 50 dB reduction out of beam (proximity in Galaxy adds 110 dB to signal, but far sidelobes down by 60 dB)

Collimation also reduces the power available to scatter out of beam

An out-of-beam SGR would appear in all Parkes or ASKAP beams; suppressed as interference?

Why Not Neutron Stars

- Energetic difficulties in PSR models
- Failure to observe FRB during SGR1806-20 outburst
- Sky distribution not like that of stars or neutron stars

We need new ideas

Opening up the model space

Look for different models for repeating and non-repeating FRB

Using information from all FRB to guide us to a single model led us to a dead end

Freedom from requiring consistency with both kinds of FRB

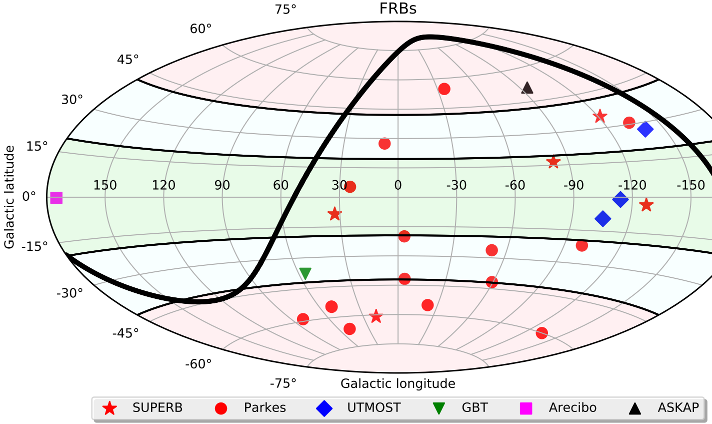
Precedent from GRB astronomy—progress required recognizing that SGR (Galactic) are not GRB

Sky distribution

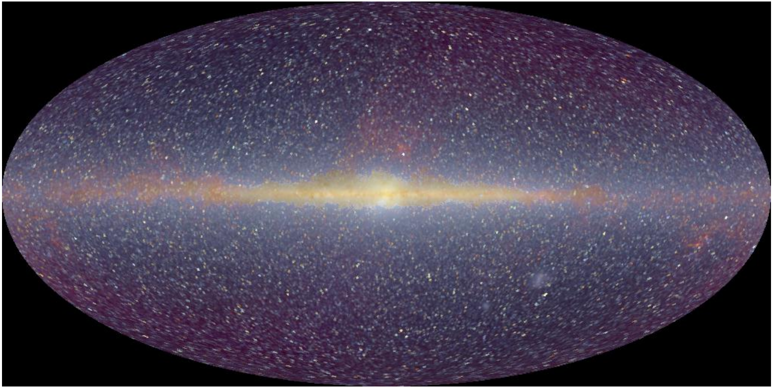
FRB are not distributed like neutron stars

Look for different classes of models

FRB (Bhandari *et al.*)

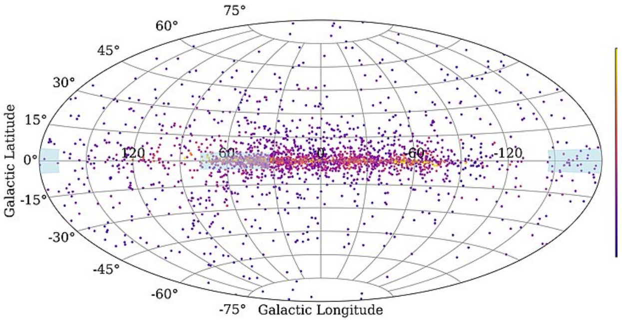


Starlight (JKL IR to minimize extinction; COBE/DIRBE)



Pulsars (Taylor PALFA 1993)

800px-Pulsars_skymap_PALFA.jpg (JPEG Image, 8... https://upload.wikimedia.org/wikipedia/commons...



X-Ray sources, mostly neutron stars (HEAO)

The Repeating FRB 121102

- Many repetitions (93 in one five-hour observation)
  - Decreases with increasing detection threshold
  - Large number, possibly diverging, of weak bursts
  - Weak bursts may dominate energy output—no characteristic size
- Identification with star-forming small galaxy
- Consistent with localization to variable persistent source resembling an AGN ($p < 10^{-3}$ if if distributed as starlight)
- Rotation measure similar to that of PSR J1745-2900 near Galactic Center, and within $\times 10$ of Sgr A*.

Take the hint: Could repeating FRB be related to AGN?

- Solves the energy/lifetime problem—can repeat indefinitely
- How?
  - Magnetic reconnection?
    - Naturally collimated
    - Runaway current drives instability and charge bunching
- Has entire accretional power as possible source

Where in AGN?

Not in disc—density is too high ($n_e > 10^{10}\mathrm{cm}^{-3}$) to propagate GHz radiation.

Jet is more promising

$$n_e = \frac{L_{jet}}{\Omega r^2 \mu \gamma_{jet} c^3} \tag{2}$$

For plausible values ($L_{jet} = 10^{40}$ ergs/s, $\Omega = 0.01$ sterad, $r = 10 r_{Sch;\,10^7 M_\odot}$, μ is rest mass/lepton)

$n_e = 2 \times 10^7/\gamma_e$ cm^{-3} for baryonic jet, $n_e = 4 \times 10^{10}/\gamma_e$ cm^{-3} for leptonic jet ($\omega_p \propto {\gamma_e}^{-1/2}$).

Non-repeaters—consider catastrophic events

Rejected if a single model must also explain repeaters

Constrained by FRB rate $\sim 10^6$/y in Universe (to $z \sim 1$)

Much less than SN rate

Require plausible EM signature—must be nonthermal

Begin with an existing idea

Falcke & Rezzolla suggested collapse of despinning overmassive neutron stars to black holes

Disappearing magnetic moment makes $\sim 10^4$ Hz radiation

But no obvious target to convert this to GHz FRB

Fast neutron stars have very small magnetic energy ($B^2 r^3/3 \sim 10^{35}$ ergs); FRB are 10^{40} ergs if uncollimated

Collimation would multiply the required event rate.

X-ray binaries contain accreting neutron stars

Neutron stars born at $1.25 M_\odot$; mass limit about $2.2 M_\odot$

Some observed close to upper mass limit—they can accrete enough to collapse

Magnetic energy $\sim 3 \times 10^{41} B_{12}^2$ ergs; many with $B_{12} = 1$–10, some (non-accreting?) with $B_{12} \sim 10^3$.

Disappearing magnetic moment makes EMF in accretion flow

Large EMF accelerates electrons, radiate in curved magnetic field

Is event rate sufficient?

Repetition time

$$t_{rep} = \frac{\Delta M \epsilon_{acc} c^2}{L_{XNS}} \quad (3)$$

Nearby star-forming galaxies have $L_{XNS} \lesssim 10^{42}$ ergs/s and $t_{rep} \sim 3000$ y

What about the sky distribution?

Accreting neutron stars are distributed like (*are*) binary X-ray sources

Collapses are very rare events

Averaged over long enough, FRB distribution on sky would resemble that of starlight

"Long enough" would be $> t_{rep}$ ($\sim 10^6$ y for Milky Way)

In this model FRB have a characteristic size like SN, GW, GRB (no nano-FRB). Averages are dominated by these rare large events, and no such Galactic events have been observed (or will be on a human time scale)