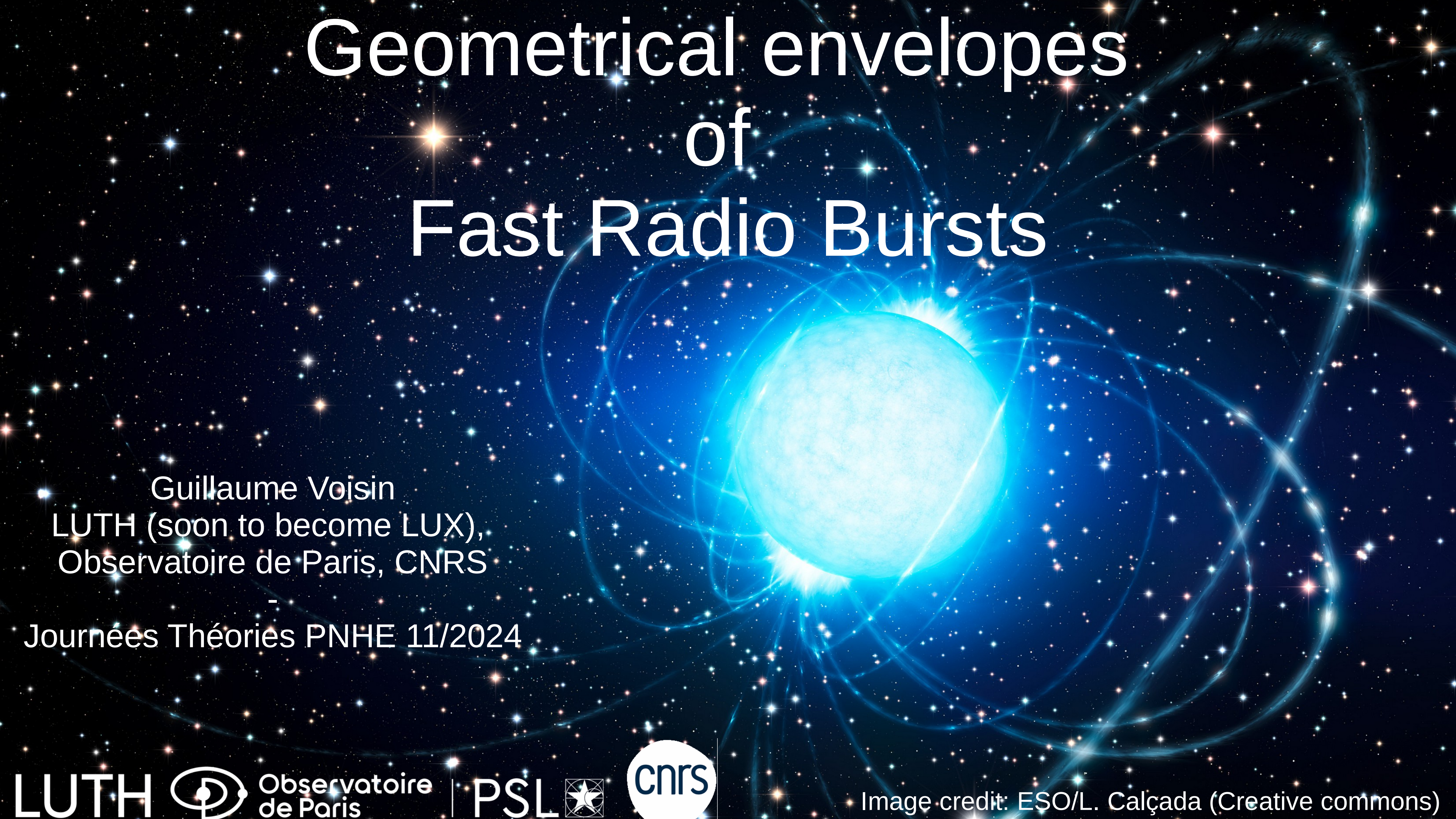

Geometrical envelopes of Fast Radio Bursts

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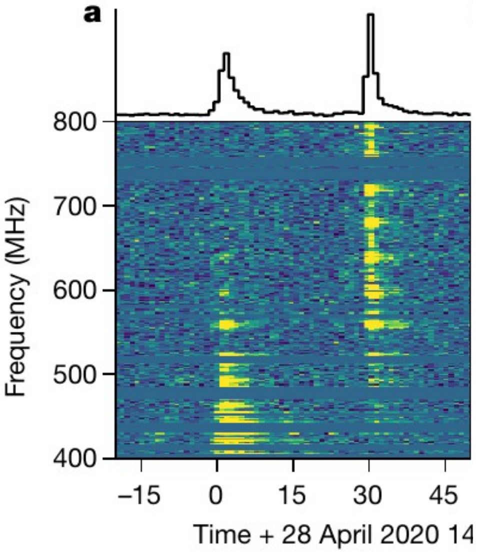
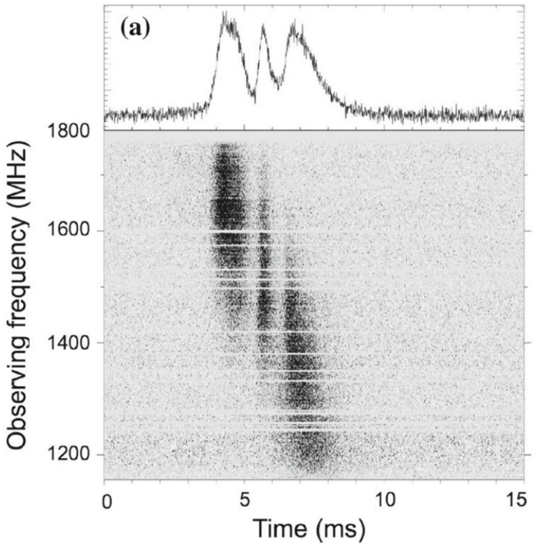
-
Journées Théories PNHE 11/2024

LUTH Observatoire de Paris | PSL cnrs

Image credit: ESO/L. Calçada (Creative commons)

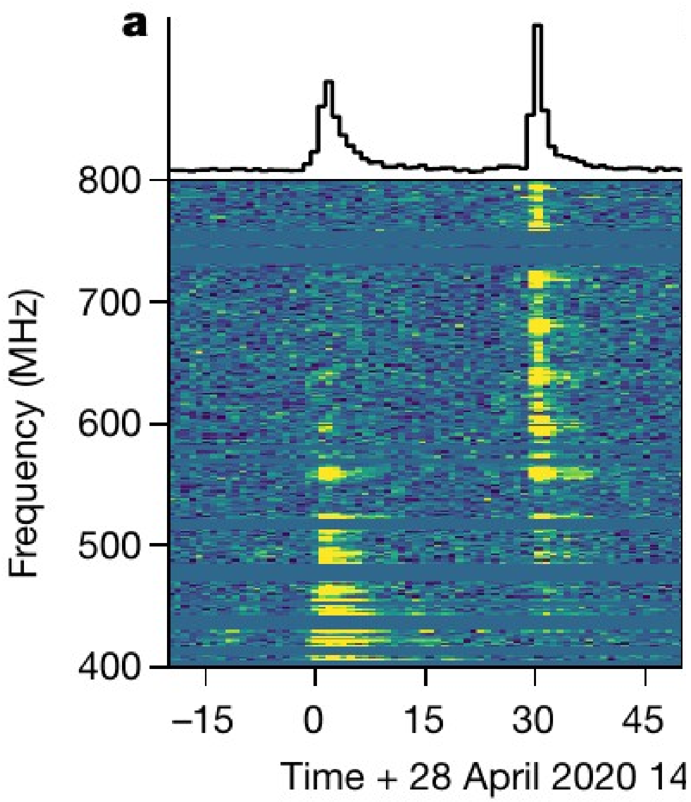
Introduction to Fast Radio Bursts and their models





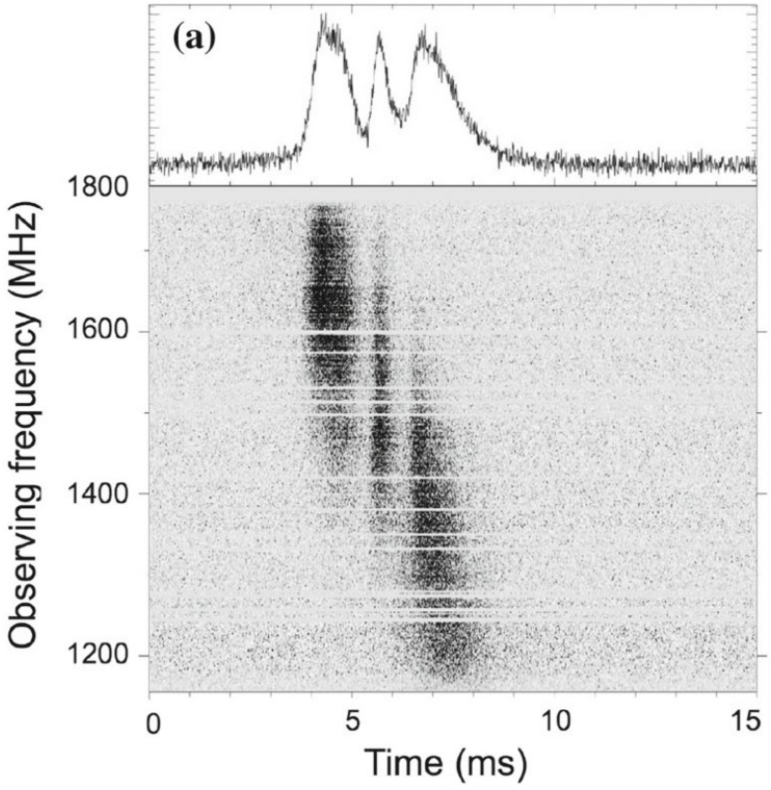
Fast radio bursts

One-off : broad-band and shorter



FRB200428, (Chime/FRB 2020b)

Repeaters : narrow-band, longer, downward-drifting sub-bursts



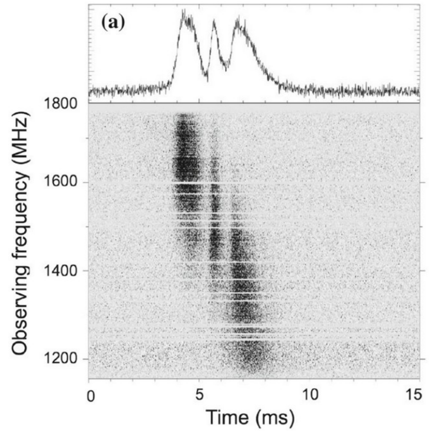
FRB121102, Hessels+18

Celebrities

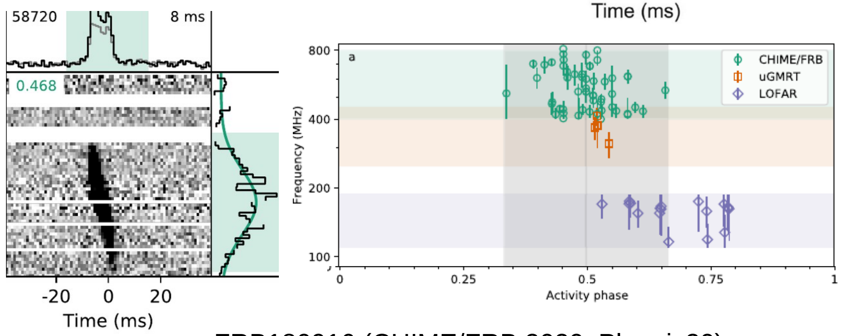
- **FRB121102** : the <u>loud</u> one
  - Up to 30 bursts/hour
  - 1 Gpc
  - Very high RM (10^5 rad/m^2)
  - Persistent radio counterpart
  - Periodic acitvity window with period 160 days

- **FRB180916.J0158+65** : the <u>periodic</u> one
  - 16 days periodicity
    - 5 day activity window
    - Higher freq come earlier (and narrower)
  - Star-forming region

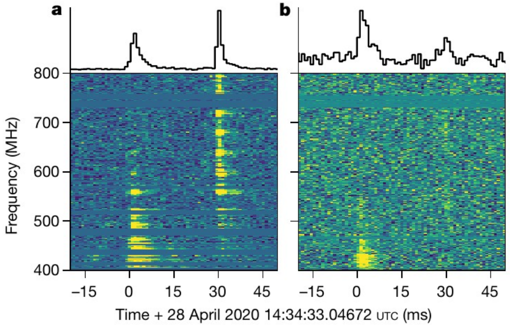
- **FRB200824.SGR1935+2154** : the <u>Galactic</u> one
  - Low luminosity
  - (but 10^3 brighter than other magnetars)
  - X-ray counterpart (Magnetar flare)



FRB121102, (Hessels18)

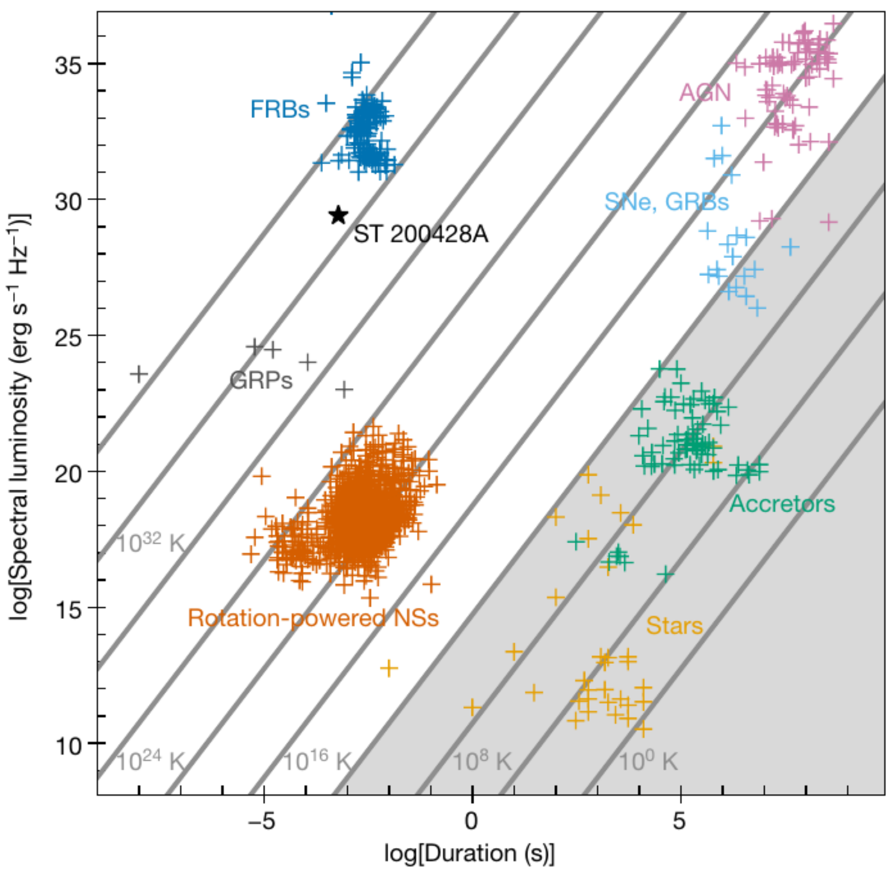


FRB180916 (CHIME/FRB 2020, Pleunis20)



FRB200428, (Chime/FRB 2020b)

Comparison to other radio transients



Radio transients in 1-2 GHz band, Bochenek+2020

Overview of the model maze

- Asteroids + Neutron star (NS)
- White dwarf – Neutron star (NS)
- Giant pulses (Young pulsars)
- Magnetar
  - Shock wave
  - Magnetospheric
- Pulsar – O/B star close binary (or combed NS)
- Flare stars
- Catastrophic events (mergers...)
- Plasma lensing
- Blitzars
- Cavitons (AGNs)
- (Even more) exotic :
  - Quark novae
  - Axion stars
  - Light sails (aliens)
  - ...

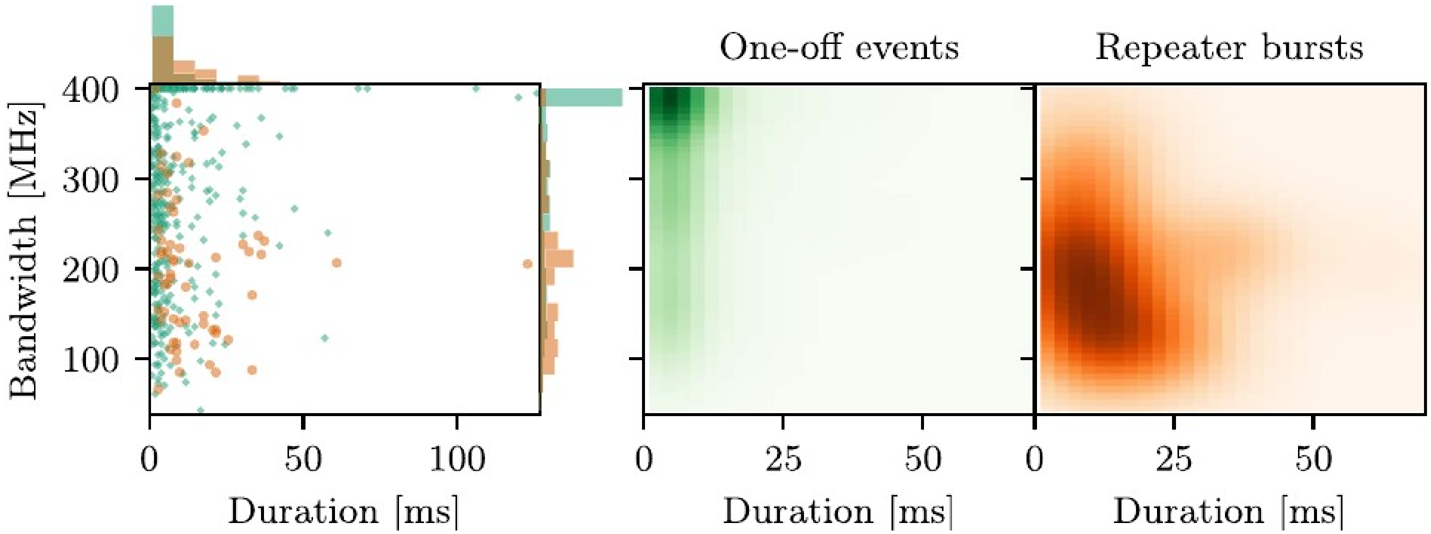
Overview of the model maze

- **Asteroids + Neutron star (NS)**
- **White dwarf – Neutron star (NS)**
- **Giant pulses (Young pulsars)**
- **Magnetar**
  - **Shock wave**
  - **Magnetospheric**
- **Pulsar – O/B star close binary (or combed NS)**

- ~~Flare stars~~
- ~~Catastrophic events (mergers...)~~
- Plasma lensing
- Blitzars
- Cavitons (AGNs)
- (Even more) exotic :
  - Quark novae
  - Axion stars
  - Light sails (aliens)
  - ...

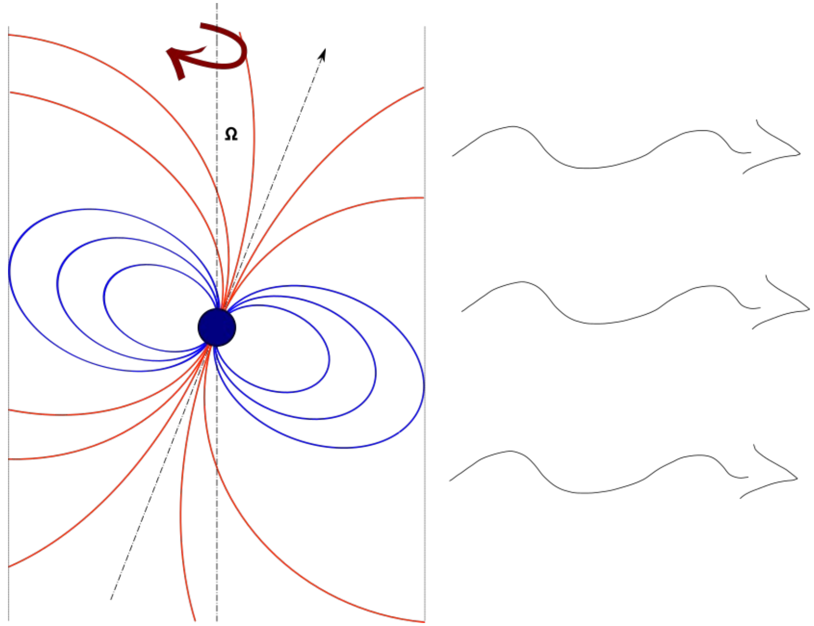
State of the art of modelling (more or less)

- Statistical distributions: occurrence times, bandwidth/duration correlations...
- Physical constraints on observables are broadly averaged quantities: flux, duration, bandwidth, frequency drift…
- Burst morphology fitted with empirical functions (e.g. Gaussian).

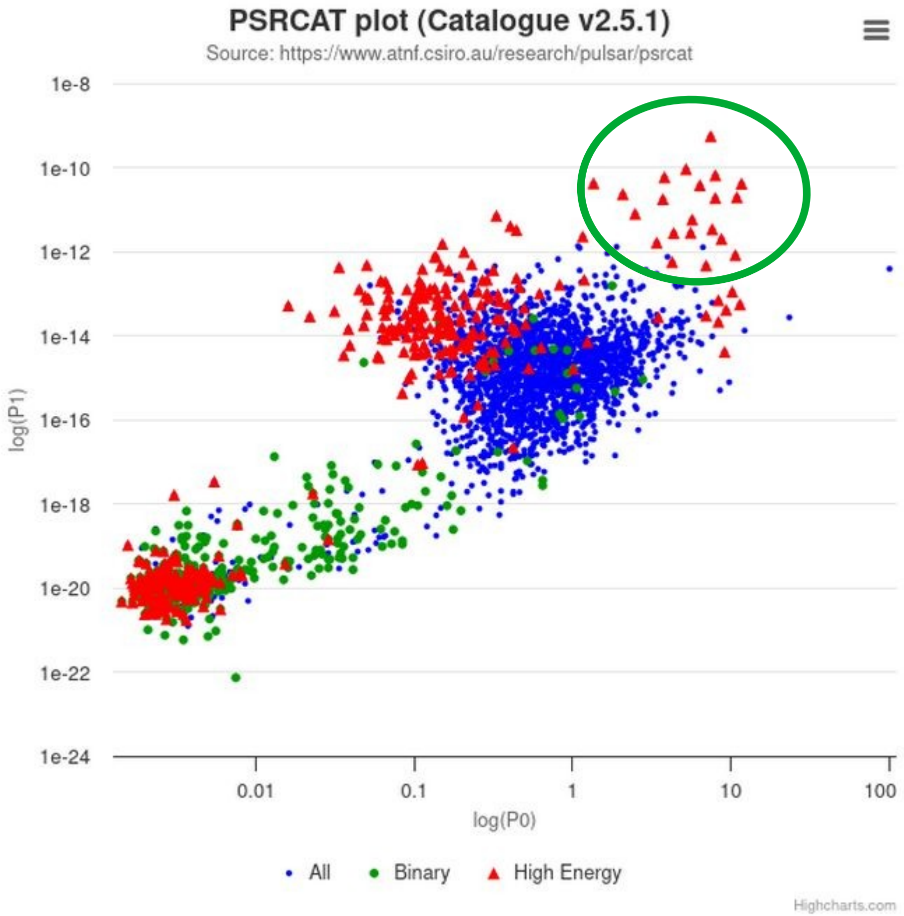


Pleunis+ 2021

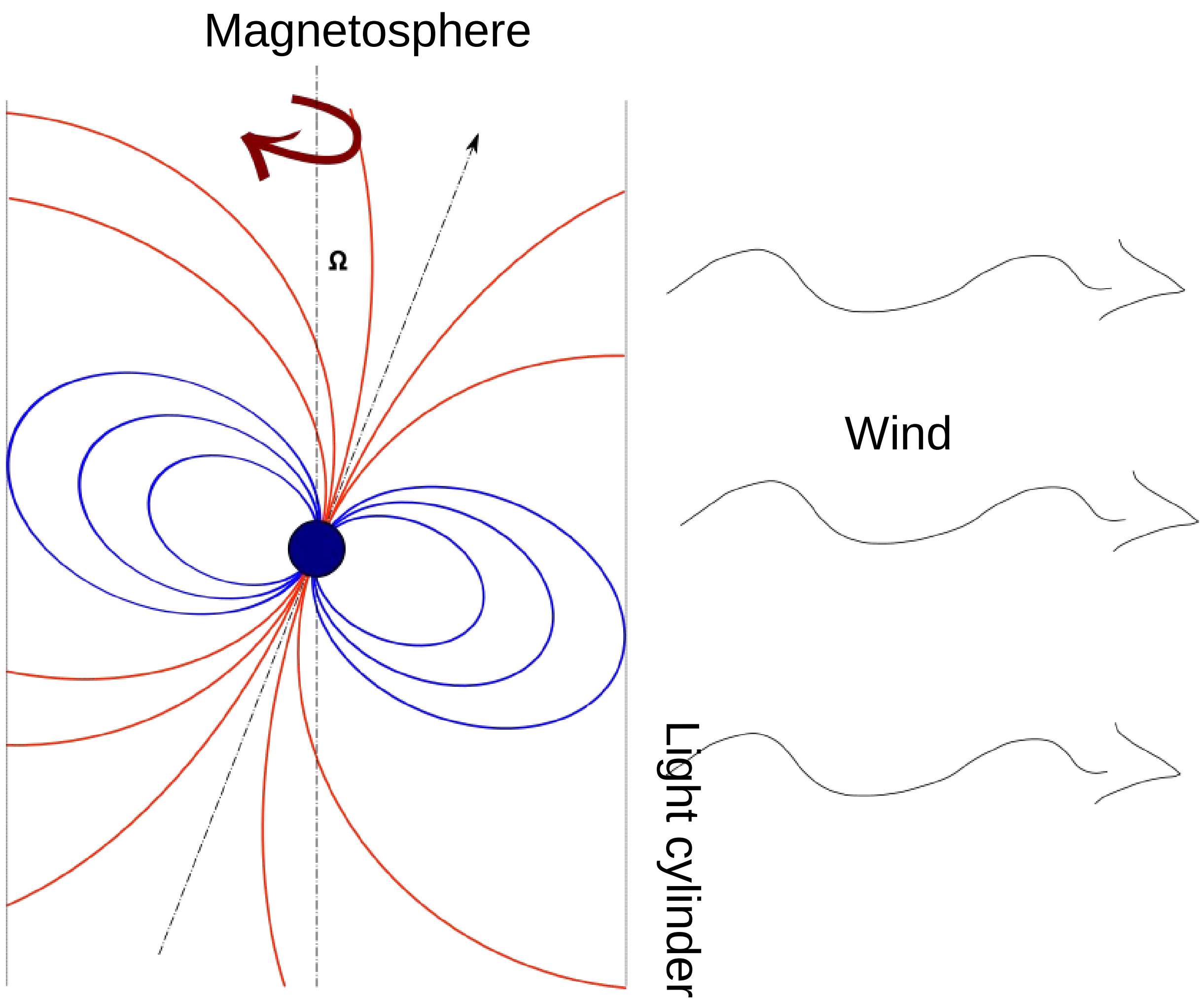
Preliminary theoretical elements



Magnetars : P ~ 2 – 10 s, large Pdot



Neutron star magnetosphere/wind



In magnetars:

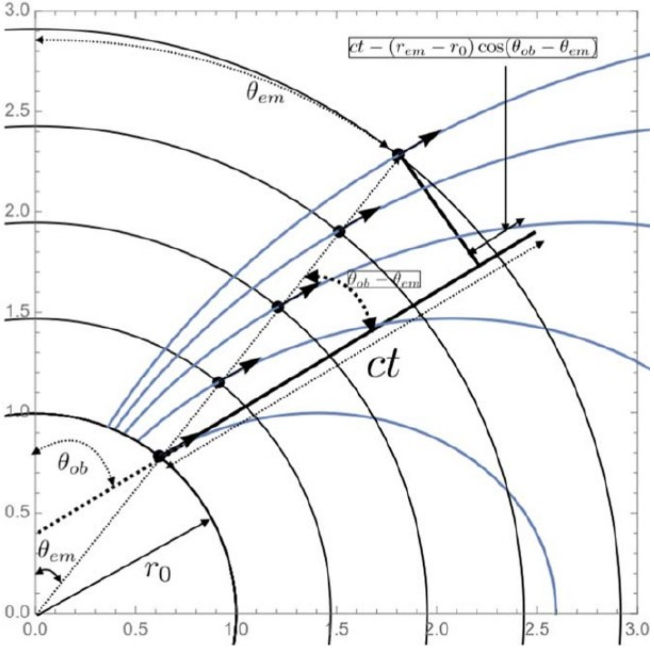
- "*Twisted magnetosphere*" : toroidal magnetic field
- Magnetic field : $10^{12} – 10^{16}$ G
- *Star quakes* (responsible for magnetar flares)
- Magnetically-powered emission (vs rotation-powered for pulsars)
- Rotation period ~ few seconds for "normal" magnetars

Radius-to-frequency mapping

- **Idea** : emission frequency $\omega \propto 1/r^{\alpha}$

  where r = distance from central engine

  - Emitting plasma is propagating outwards
  - Emission is relativistically beamed

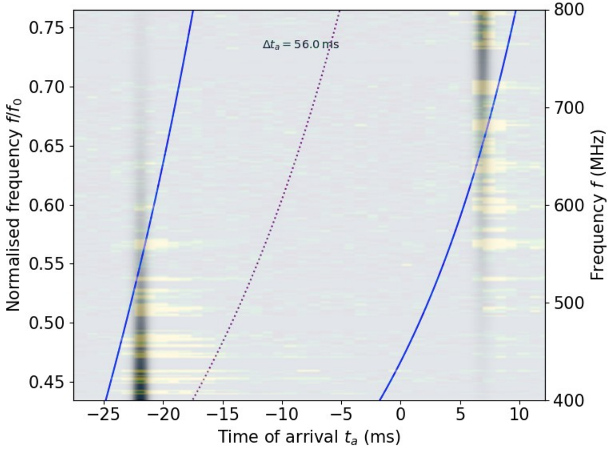


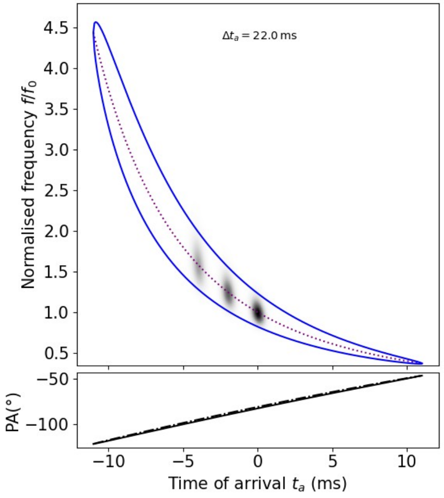
Lyutikov20

- **Emission mechanisms:**
  - Synchrotron Maser : $\omega_{\text{peak}} \propto B$
  - Curvature radiation : $\omega_c \propto 1/r_c$
  - Plasma frequencie<u>s</u> : $\propto B^{\beta}$

- **Interesting result :**
  - ➔ If NS magnetosphere rotating slow / burst duration then *linear frequency drift*

A geometrical model of burst morphologies



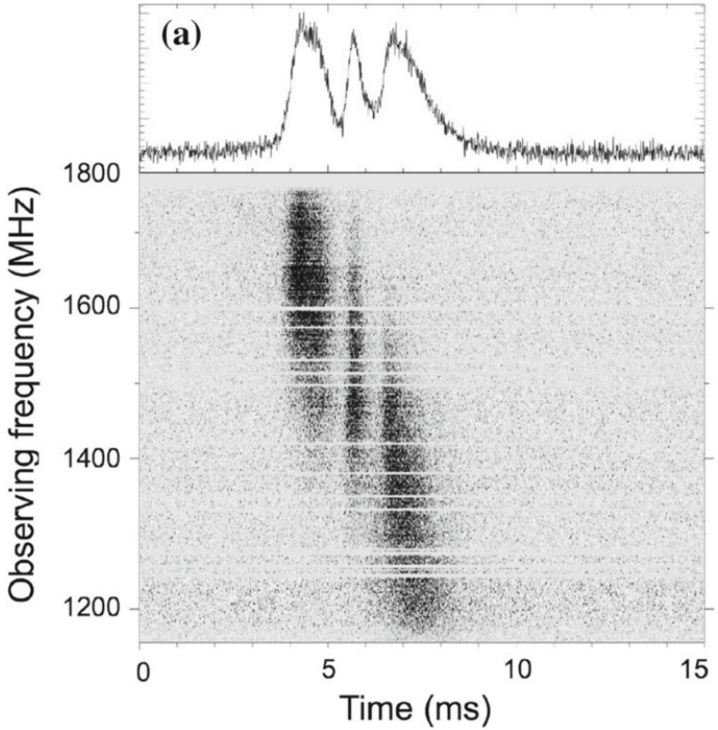


Spoiler

Voisin24 ; Voisin in prep.

Burst morphology in the dynamic spectrum encodes quantities such as

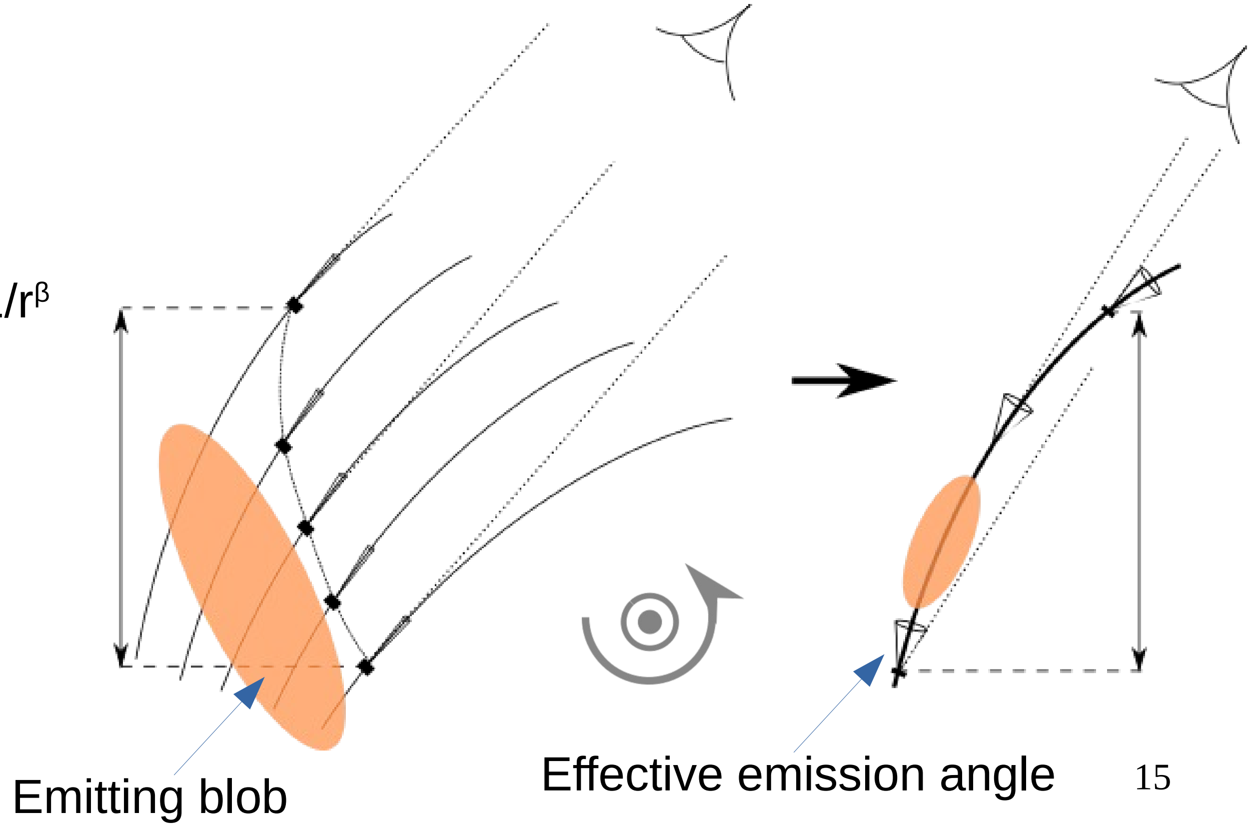
- Spin period
- Magnetic geometry



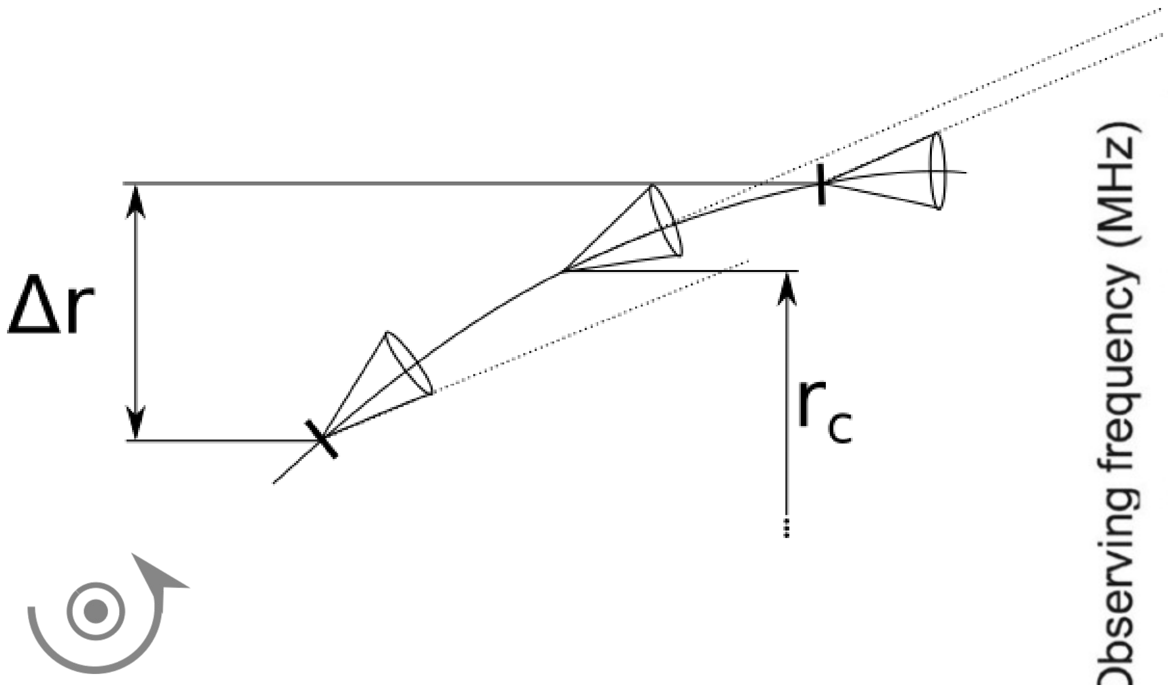
Geometrical assumptions

Hypothesis :

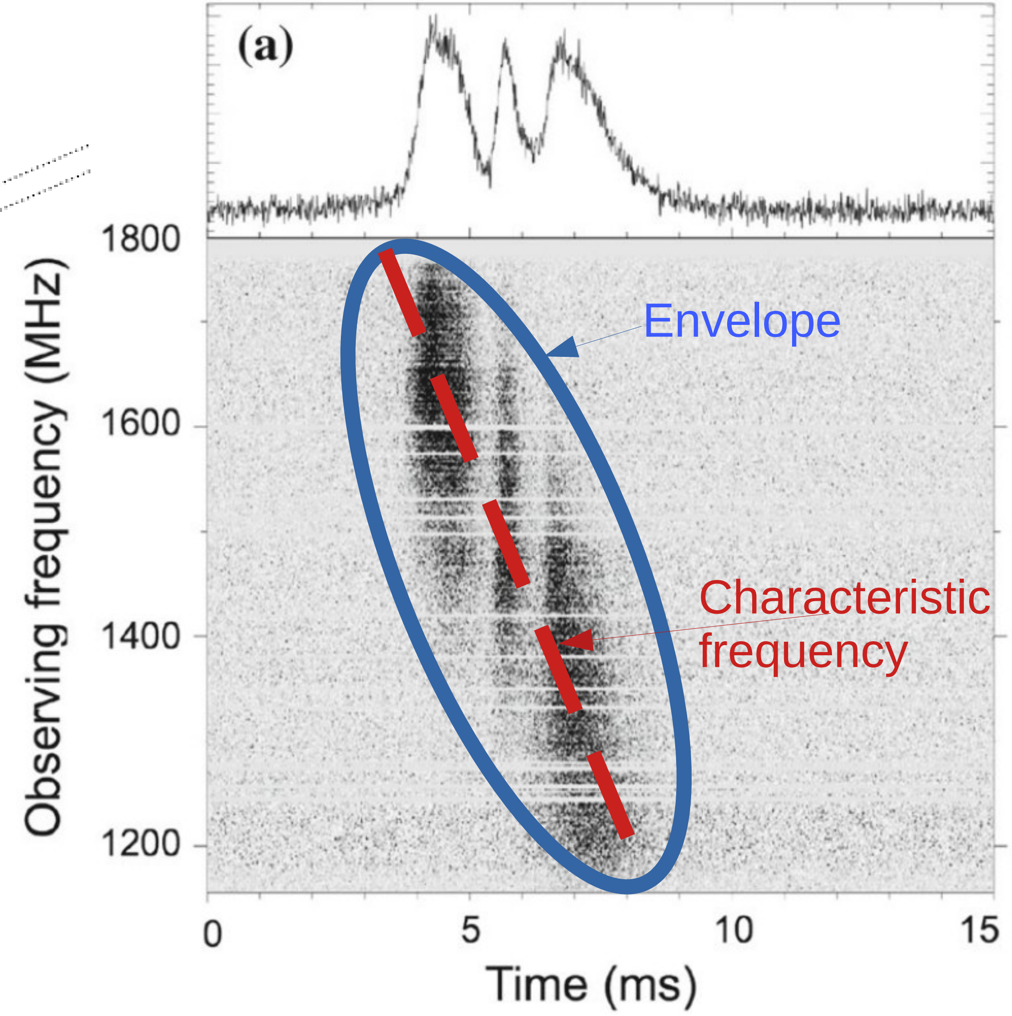
- Emission region very localized in space & time
- Emitting plasma propagating at ~c
- Source in rotating frame
- Radius-to-frequency mapping : $f \sim 1/r^{\beta}$
- Polarisation: Rotating vector model



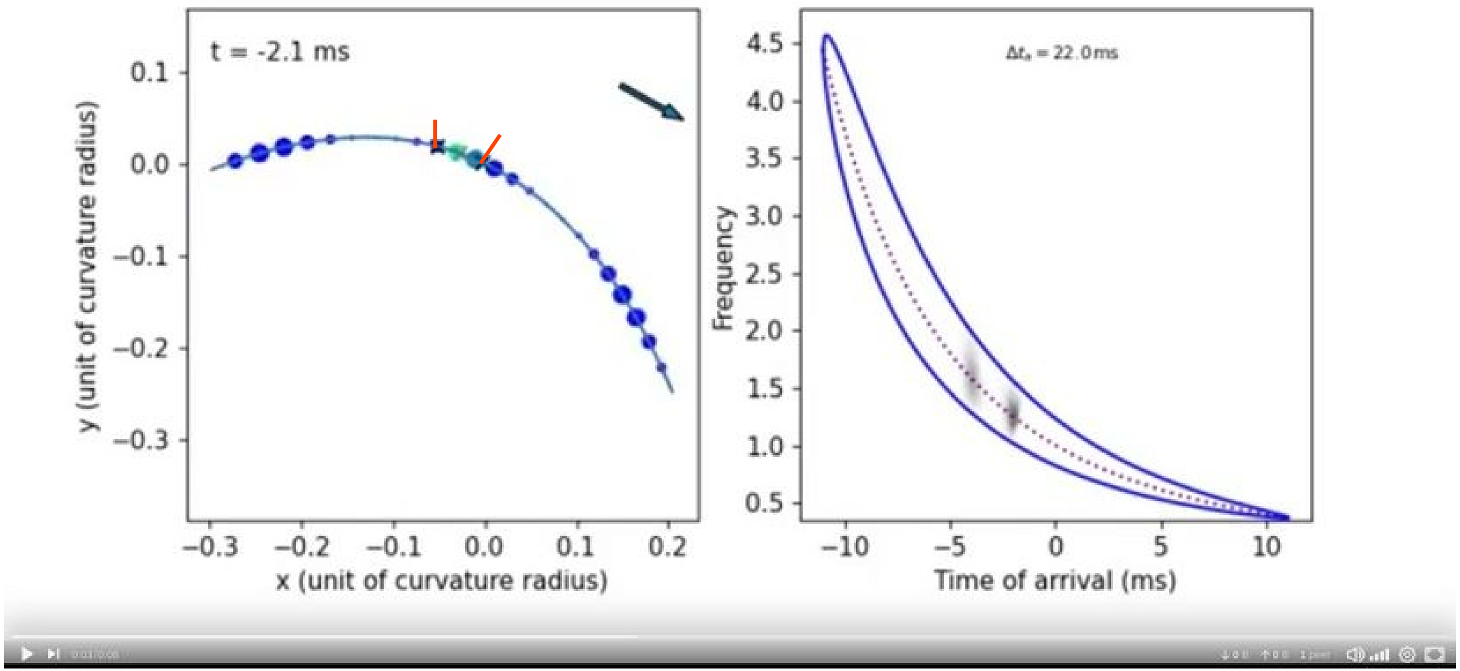
Geometric envelope



FRB121102, Hessels+18



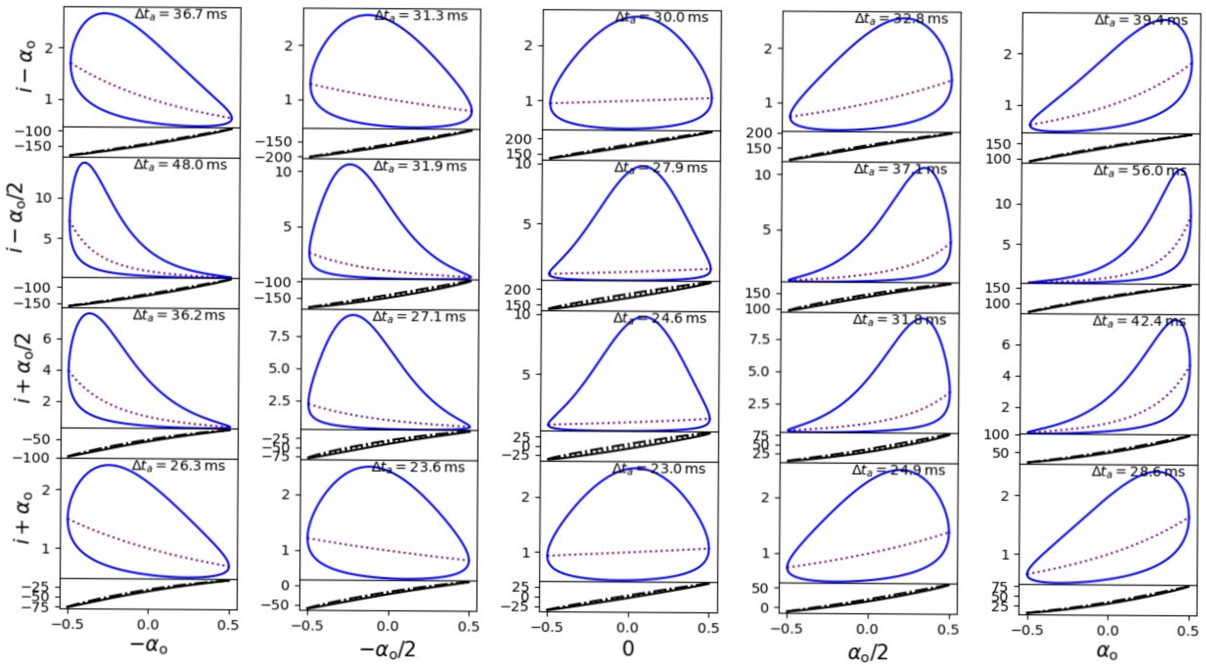
Pseudo-Gaussian bursts



See animation on Astrotube of Obs. Paris

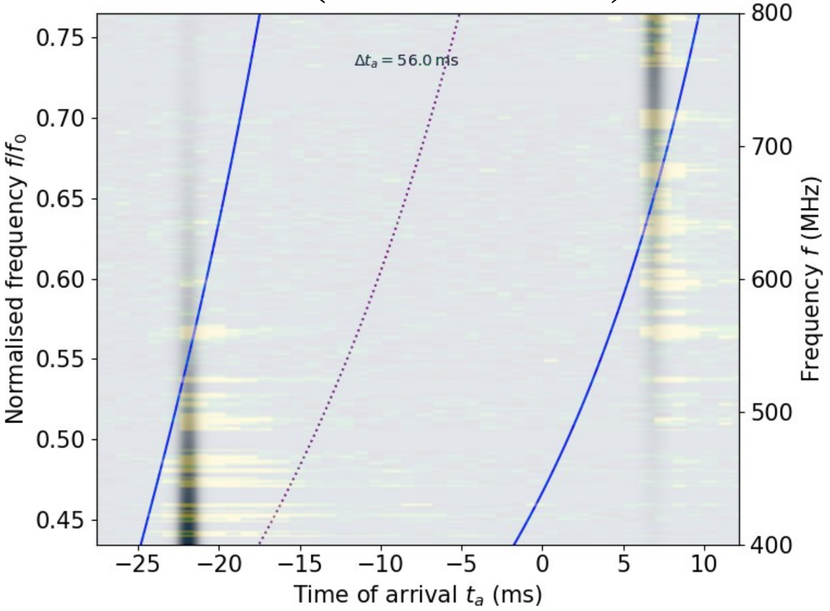
Dipole magnetic field, Pspin=3.2sec

Voisin, A&A 2023



Envelopes in the polar cap region at r = 100R$_*$, Voisin2023

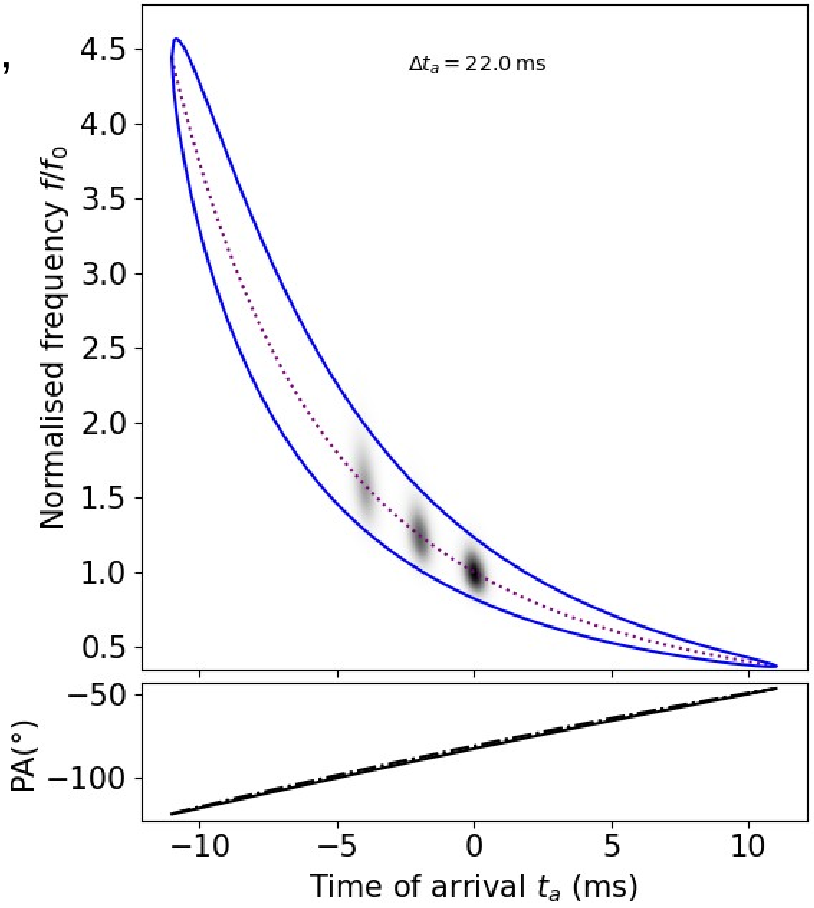
Modelled envelope+bursts overlaid with FRB200428 (Chime/FRB 2020b)



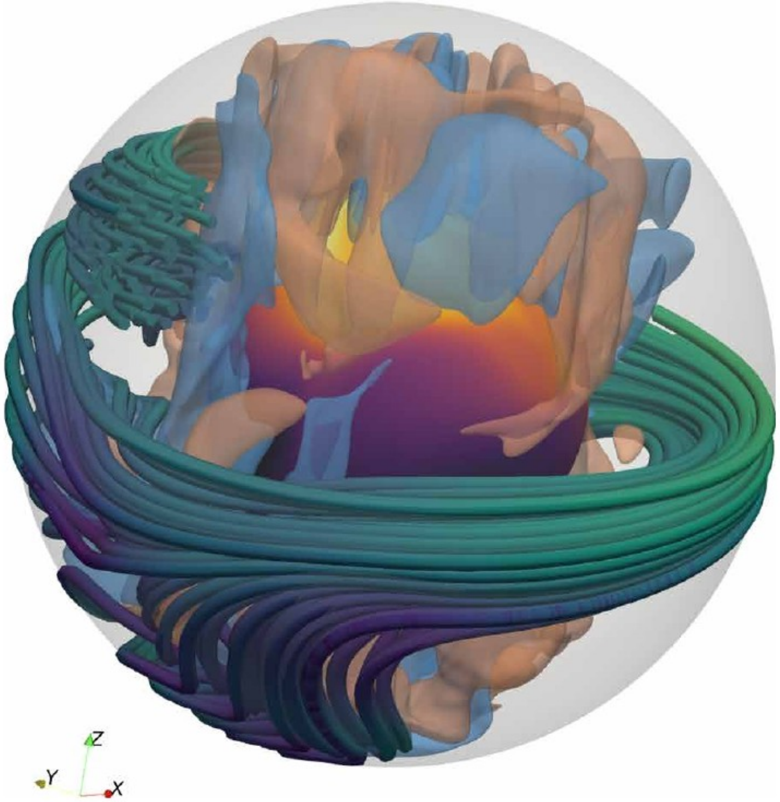
Dipole+toroidal magnetic field : P_*=250ms

Voisin, A&A 2023

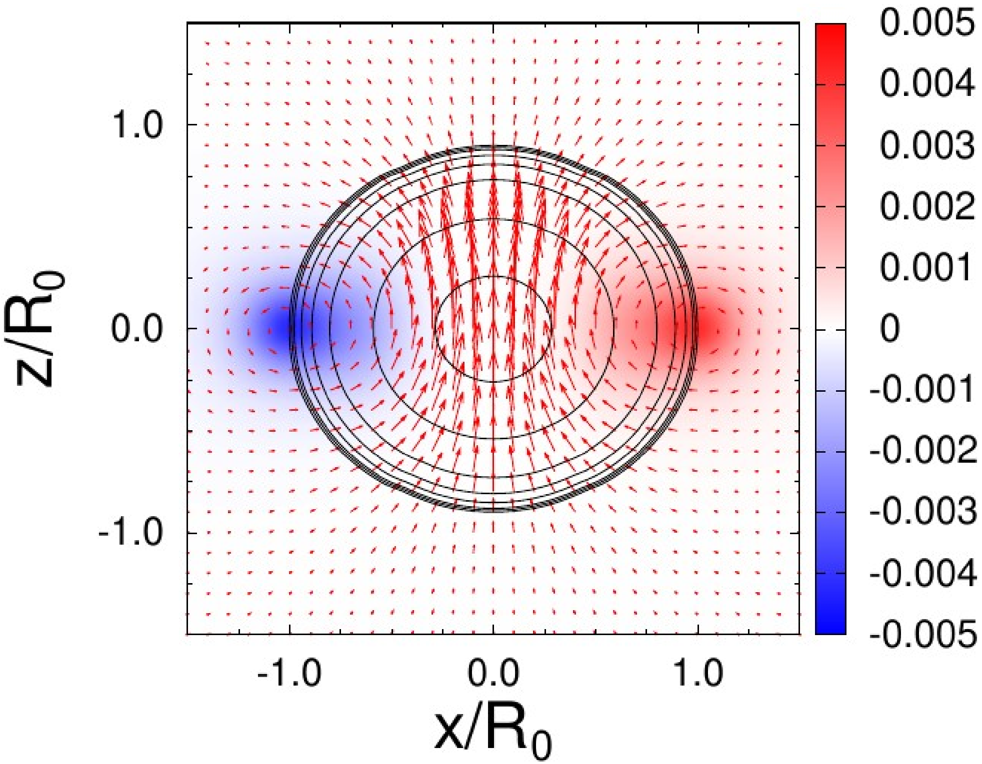
- Three bursts in envelope with Btoro = 0.5 Bdipole, (Voisin2023)
- Relative frequency drift: fdot/f ~ 110s^{-1}
- **Toroidal component generically produces:**
  - **Downward drifting sub-pulses**
  - **Narrow-band emission**



Toroidal field in young magnetars



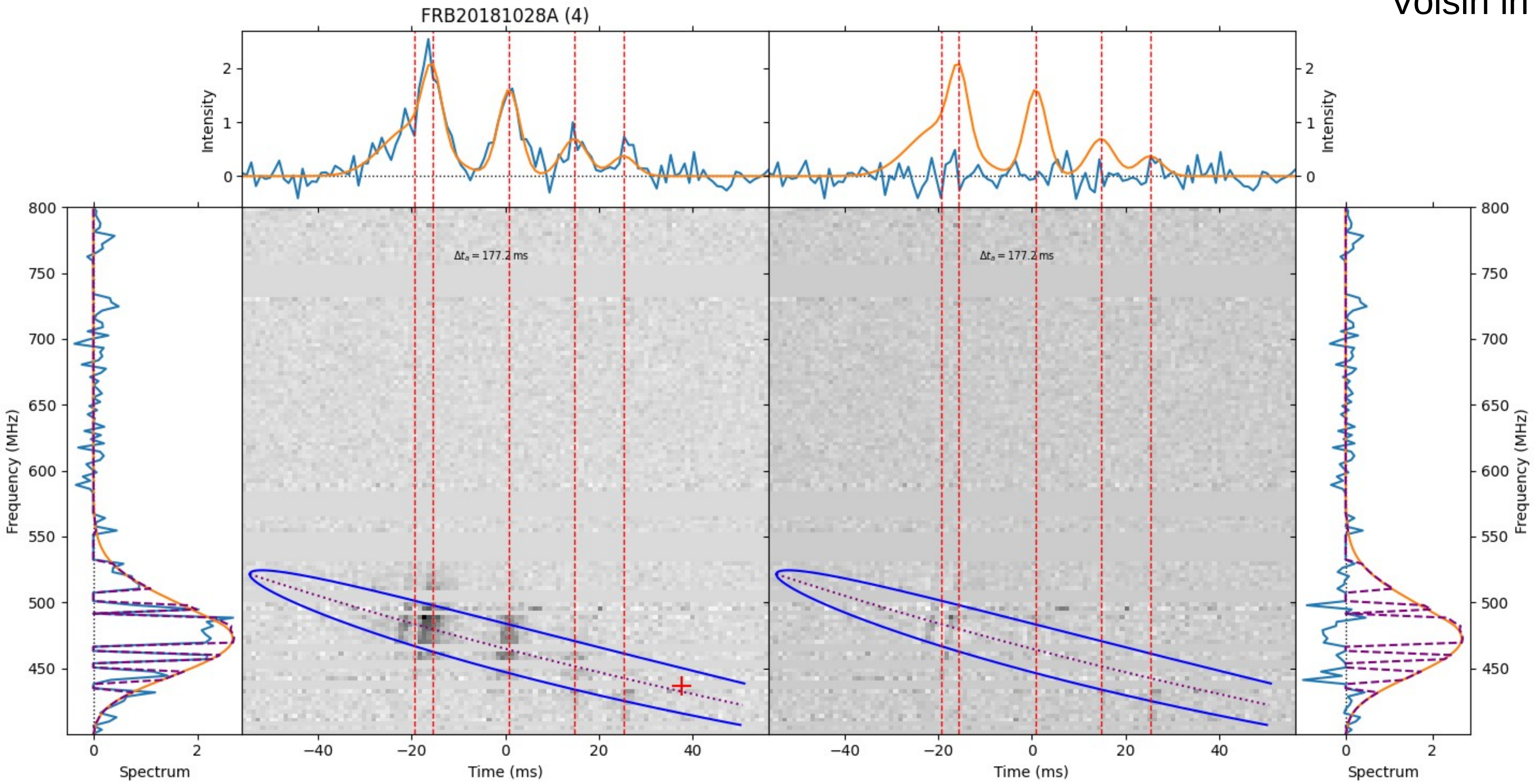
Raynaud+2020 : toroidal B field ~ 200x dipole inside the star



Uryū+2023 : toroidal B field ~ 4x dipole <u>outside</u> the star (at the surface)

Application to CHIME/FRB data

Voisin in prep.

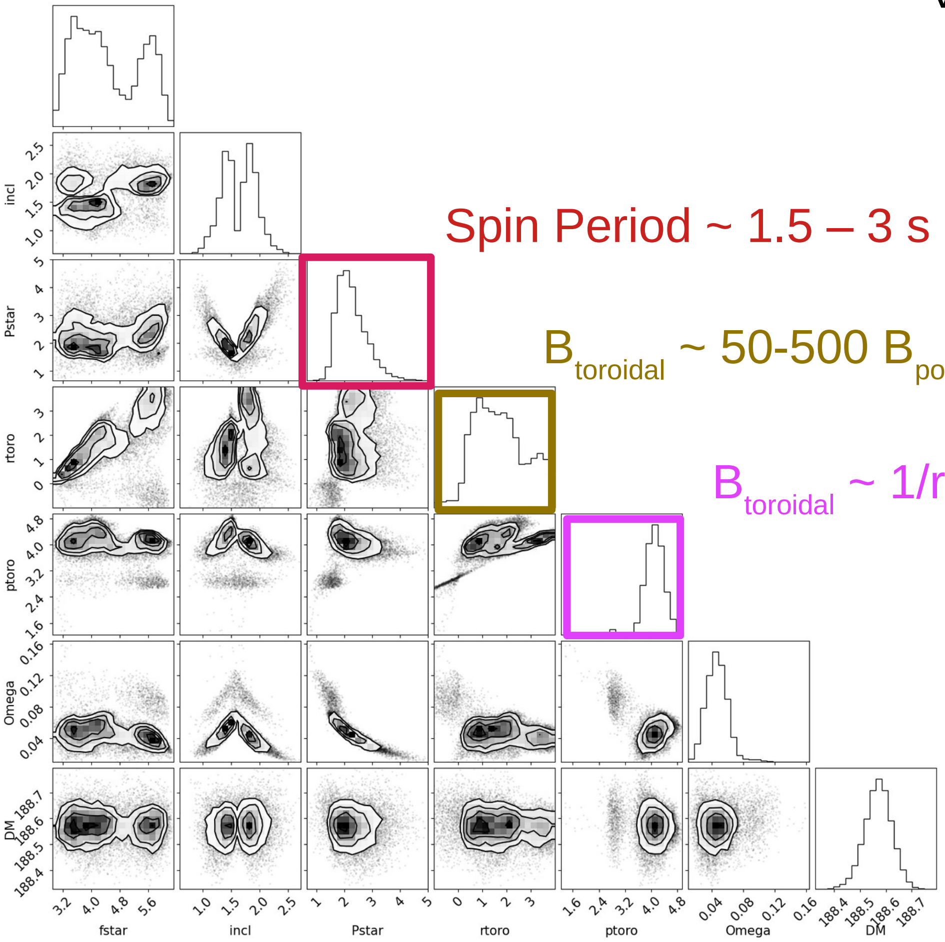


FRB20180814A: moderately fast magnetar with strong toroidal magnetic field

Voisin in prep.

- Repeater FRB20180814A

- Assuming :
  - « Curvature radiation » : f ~ 1/r
  - Axi-symmetric magnetic field



Spin Period ~ 1.5 – 3 s

$B_{toroidal}$ ~ 50-500 $B_{poloidal}$ @ surface

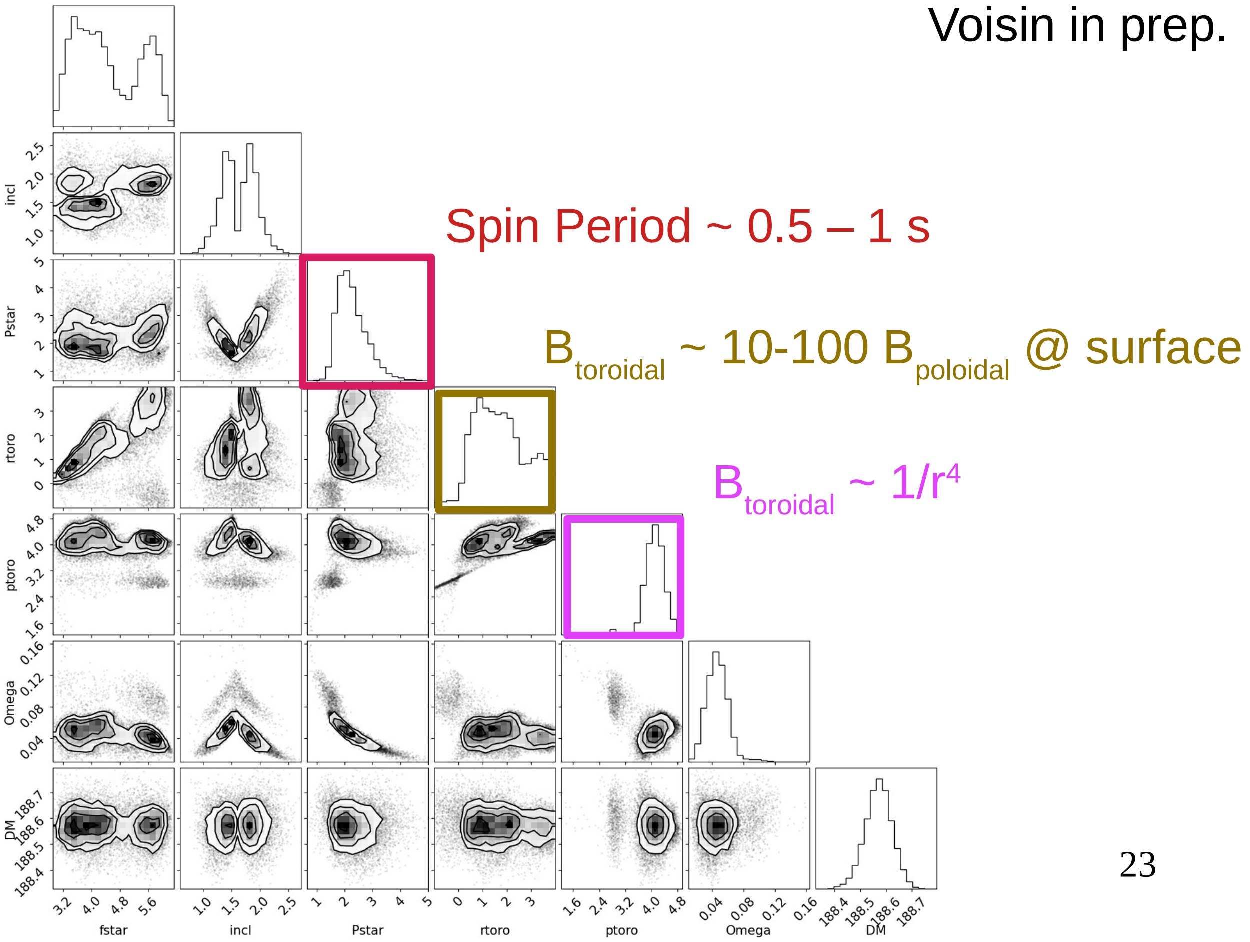
$B_{toroidal} \sim 1/r^4$

FRB20180916B : ~~Moderately~~ fast magnetar with <u>less</u> strong toroidal magnetic field

Voisin in prep.

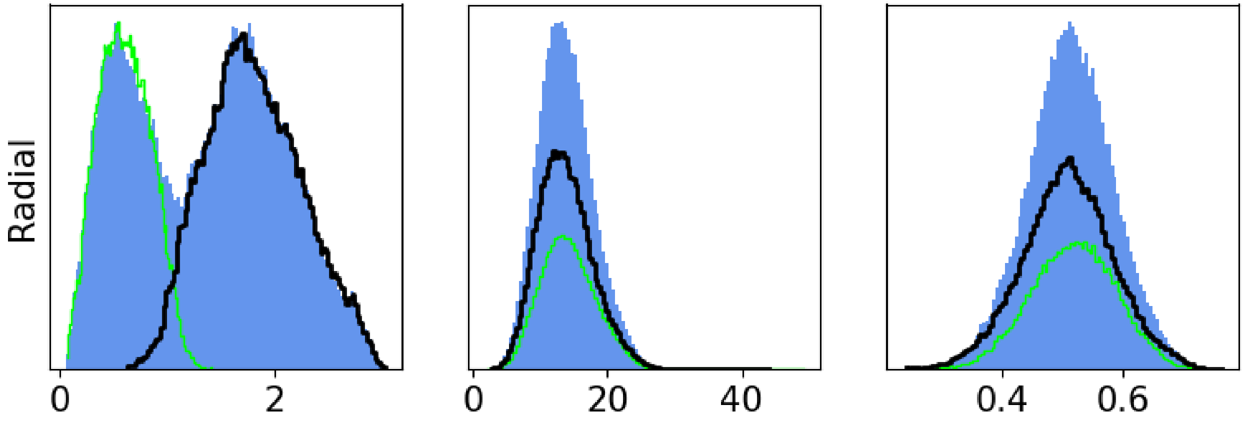
Assuming :

- « Curvature radiation » : f ~ 1/r
- Axi-symmetric magnetic field

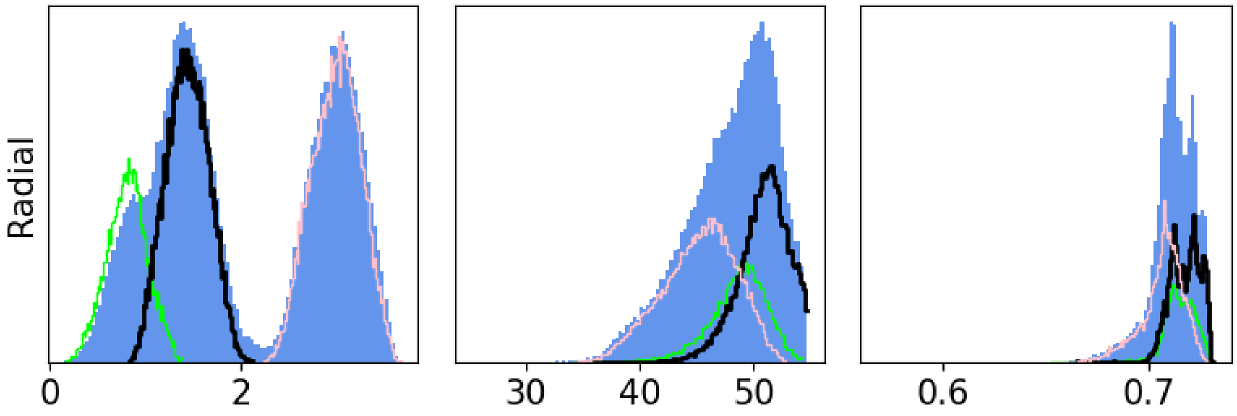


Positions in the magnetosphere

FRB 20180916B



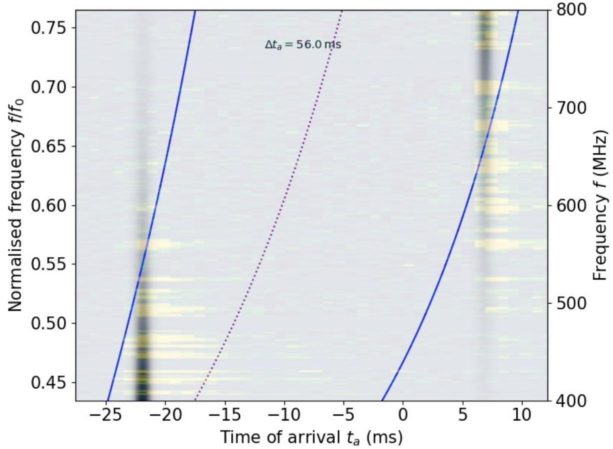
FRB 20180814A



The Message and a « nice story »

- Burst morphology may encode important parameters such as :
  - Spin period
  - Magnetic geometry

- The nice story :
  - Repeaters ~ high toroidal-field magnetars ~ very active ~ « young »
  - One-off ~ lower toroidal field (dissipated?) ~ less active ~ « older »



Voisin, A&A 2023