Around neutron stars

- Pulsar magnetosphere and wind
- Pulsar timing and tests of gravity
- Spider binaries
- Fast radio bursts

LUTH l'Observatoire de Paris | PSL

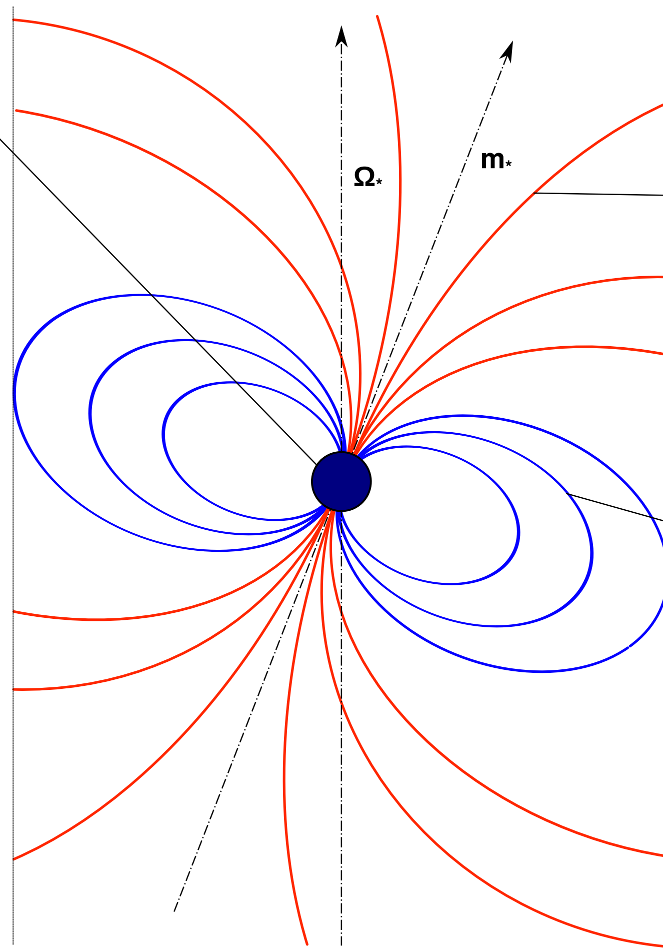
Magnetospheres

F. Mottez, G. Voisin

What's a pulsar ?

Neutron star

- "**Hot**", T~ 10^5-10^6K, can radiate 1-10keV X-rays.
- **Compact** : R_*= 10km radius, 1.4 Msol, compactness ~0.2
- **Magnetized** : B_*= 10^{4}- 10^{10}T at the pole if dipolar field assumed
- **Spinning:** Period between P_* = 1ms and 10s
- **Spinning down:** dP_*/dt ~ 10^{-21} - 10^{-12} s/s



Open magnetic field lines. Plasma escapes.

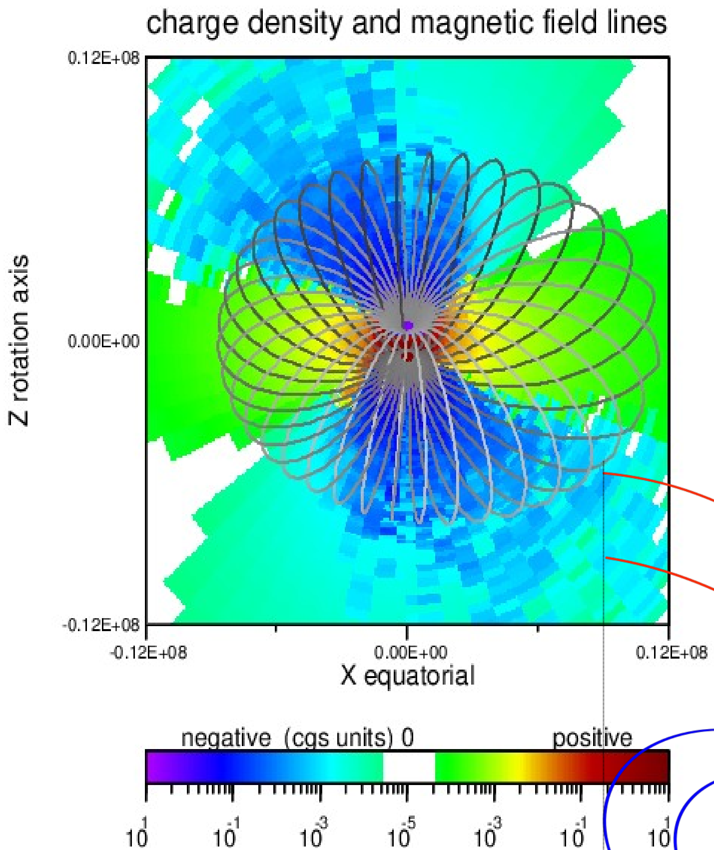
- **Plasma e+e-** is produced
- **Radiation** is produced from radio to gamma ray

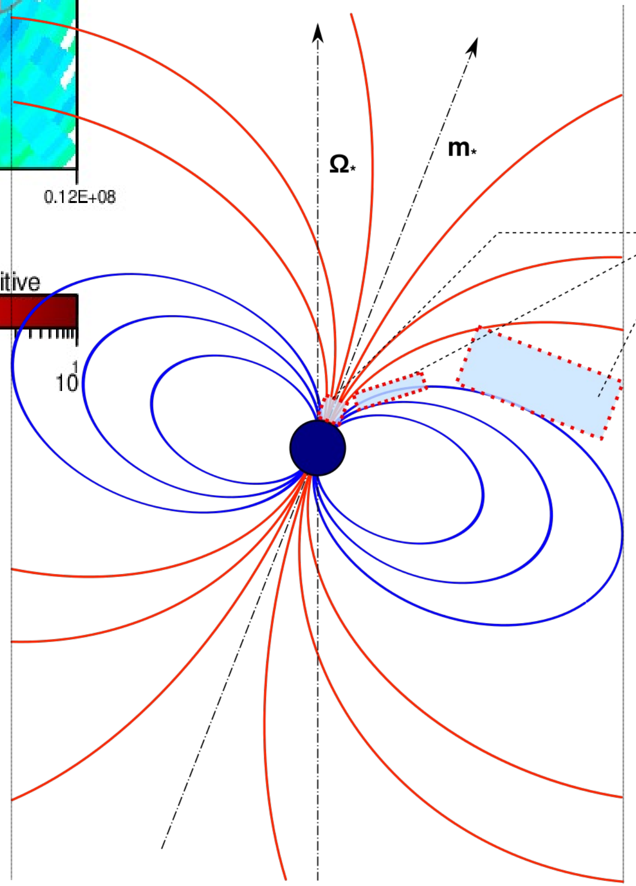
Closed magnetic fiield lines. Force free area.

Light Cylinder

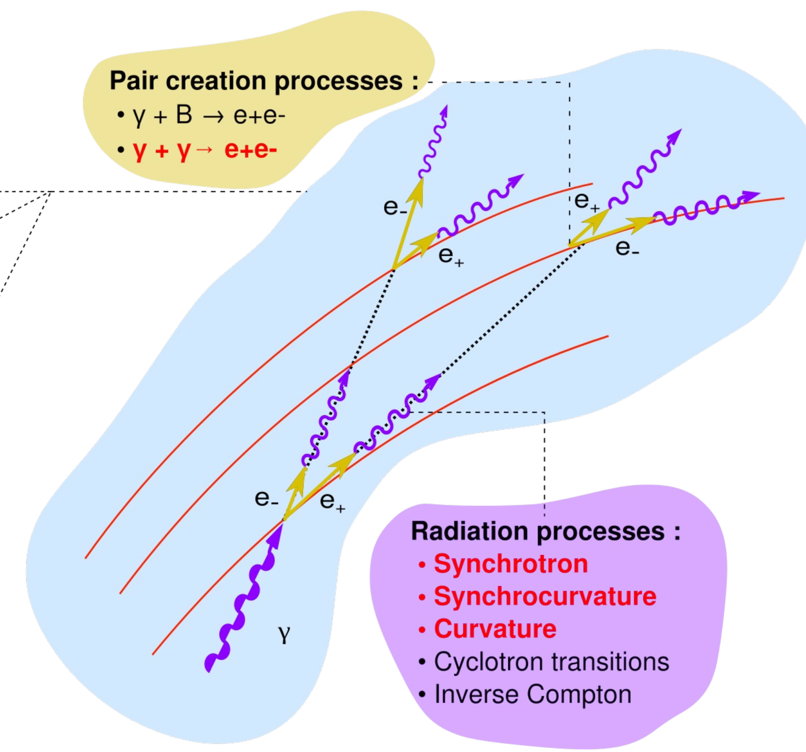
- **Where the plasma would corrotate** at c
- **Radius** from R_{LC} = 300km to 3 millions km

Magnetospheres





Global simulation: in project



Local cascade mechanism

Timing

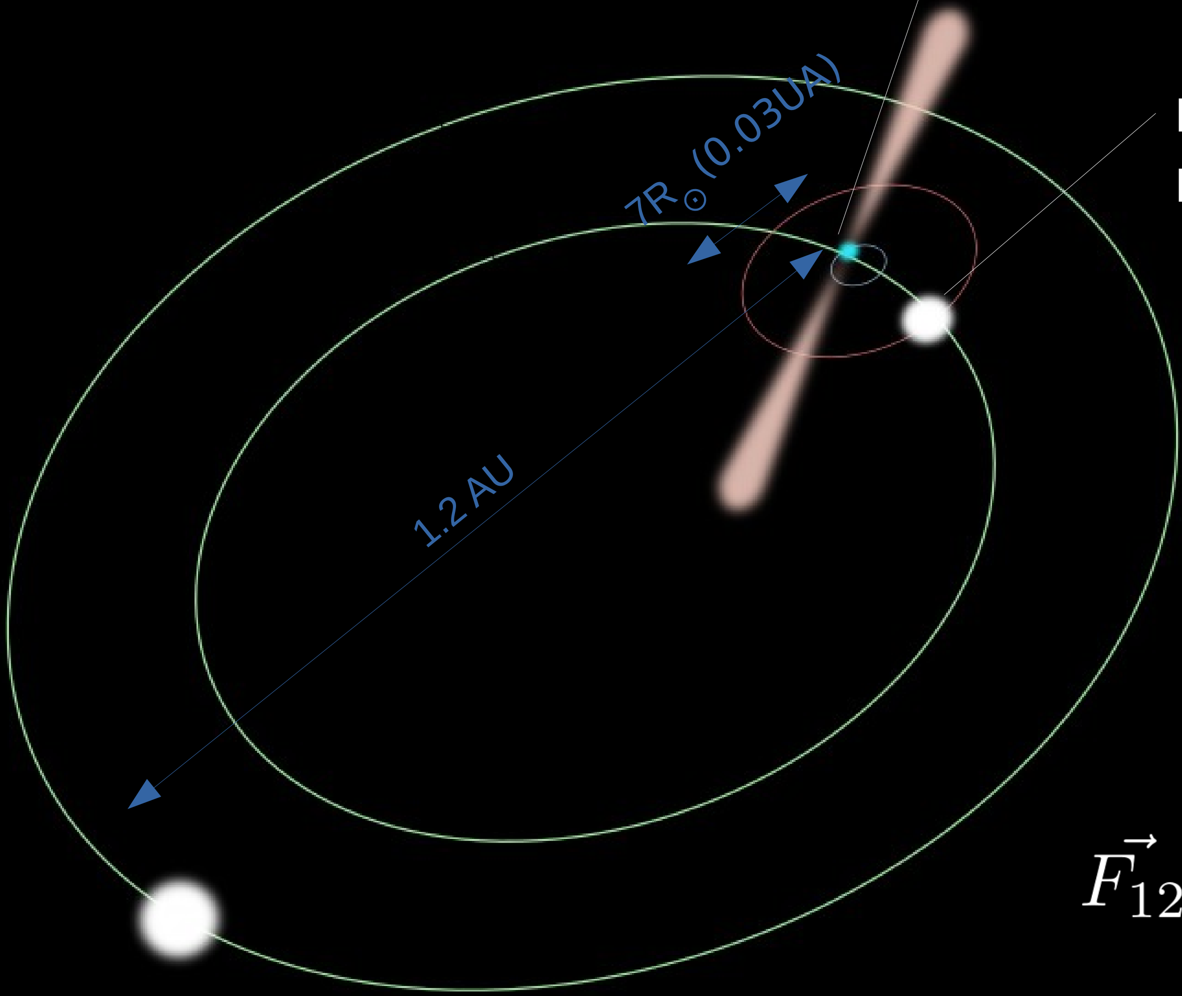
G. Voisin

The unique PSR J0337+1715: universality of free fall

Ransom+14
Archibald+18
Voisin+20

Mpsr ~ 1.4 $M_\odot$
Spin period ~ 3ms

Mi = 0.2 $M_\odot$
Pi ~ 1.6 day

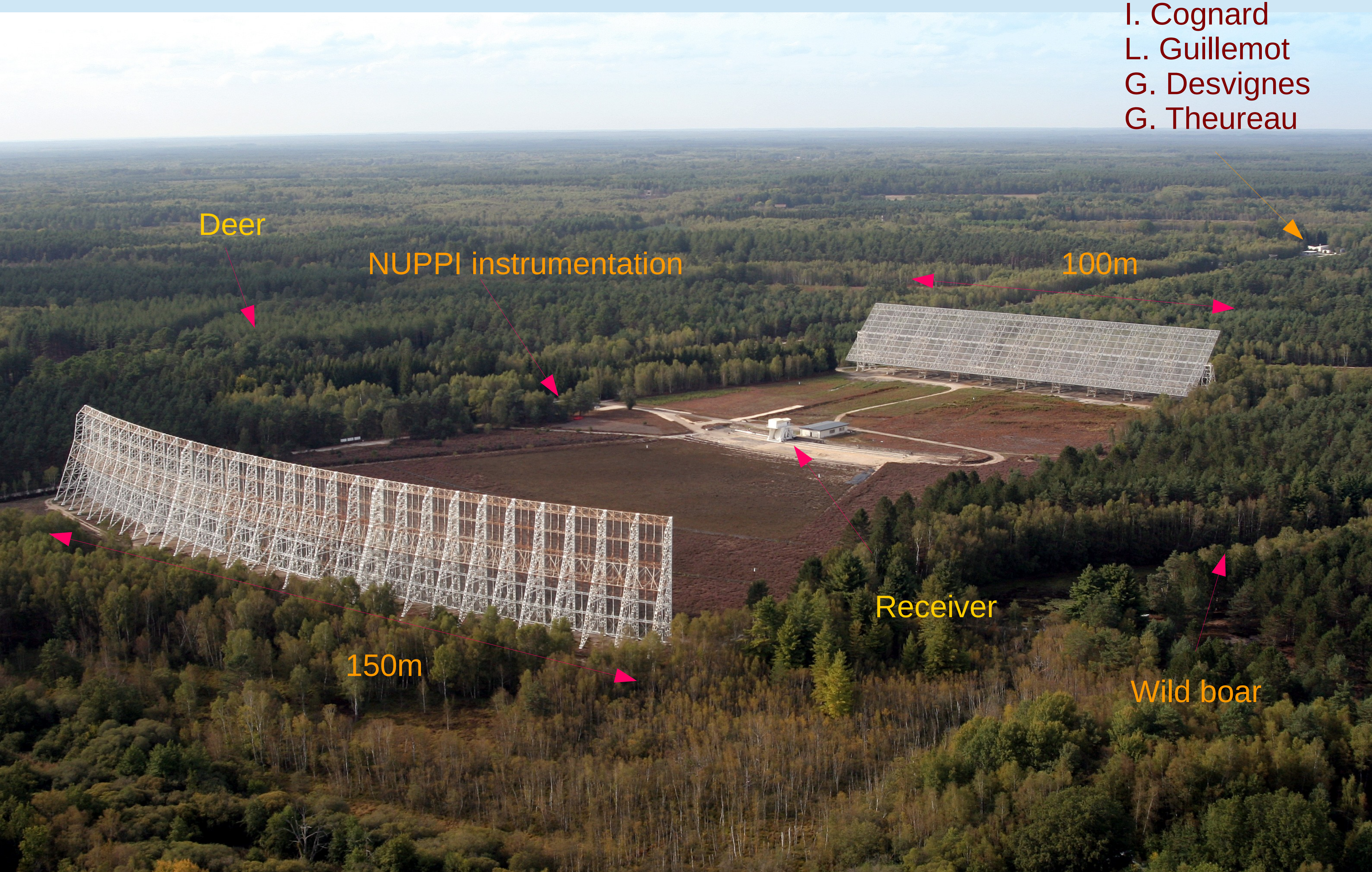


Mo ~ 0.4 $M_\odot$
Po ~ 327 days

$$\vec{F_{12}} = G(1+\Delta_{12})\frac{m_1 m_2}{r_{12}^2}$$

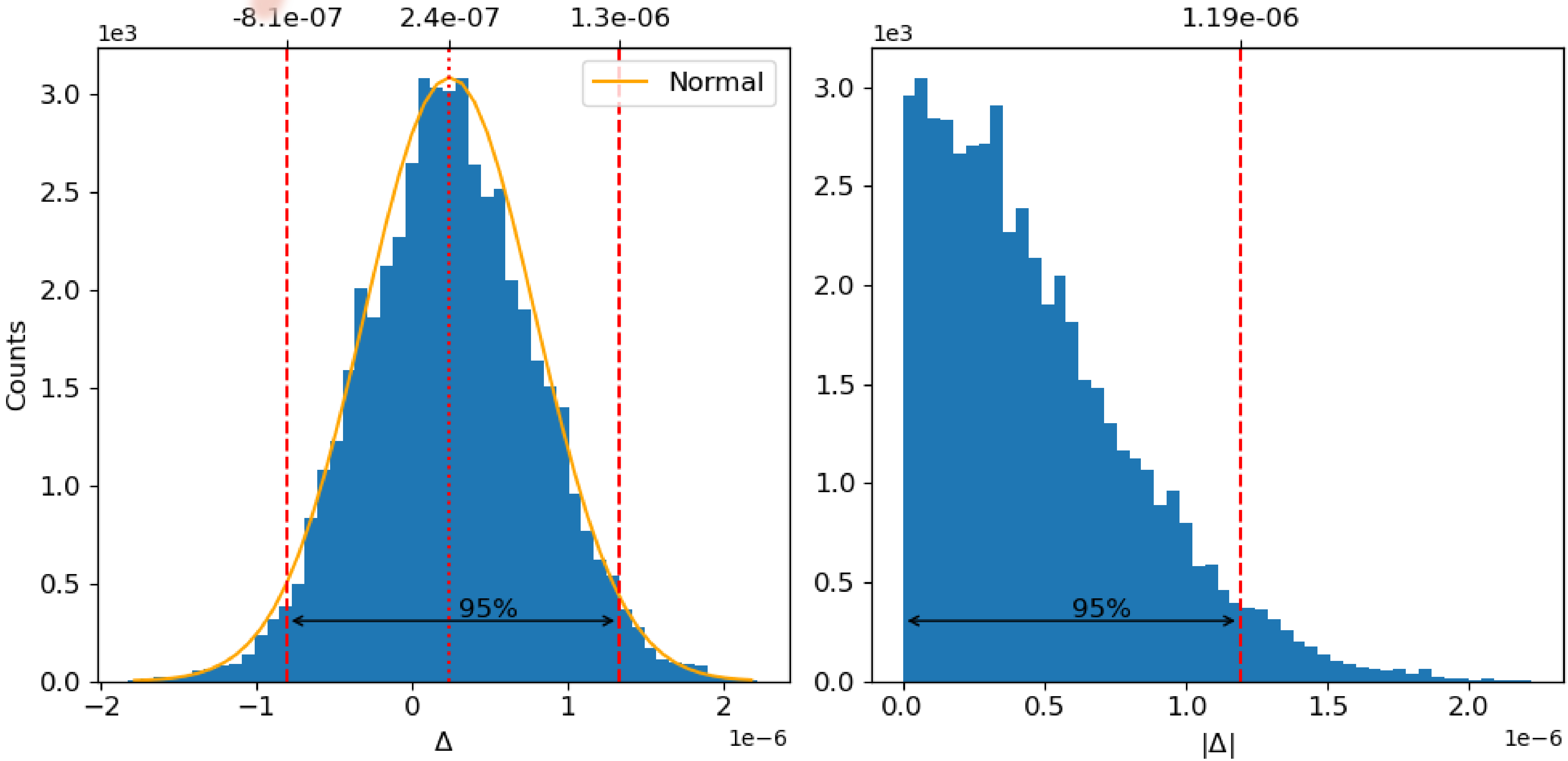
Welcome to Nançay !

I. Cognard
L. Guillemot
G. Desvignes
G. Theureau



Preliminary!

Strong Equivalence Principle: effect of assuming a planet in the system



$|\Delta| < 1.2 \times 10^{-6}$ 95% confidence

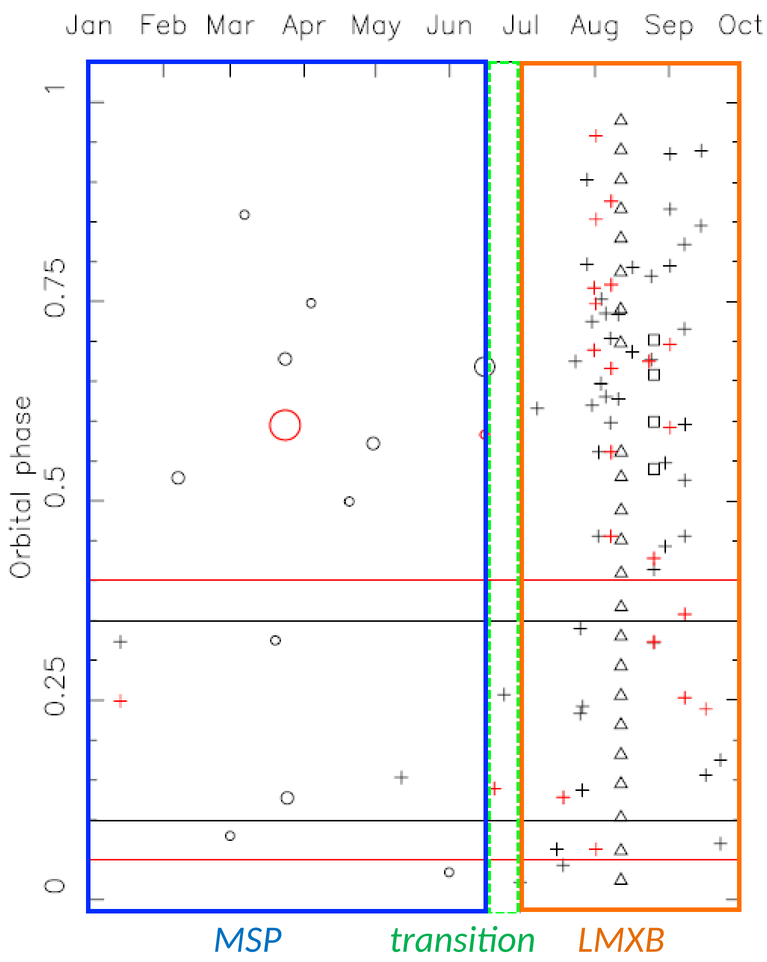
(Against $|\Delta| < 2.05 \times 10^{-6}$ in Voisin+2020)

Spider binaries

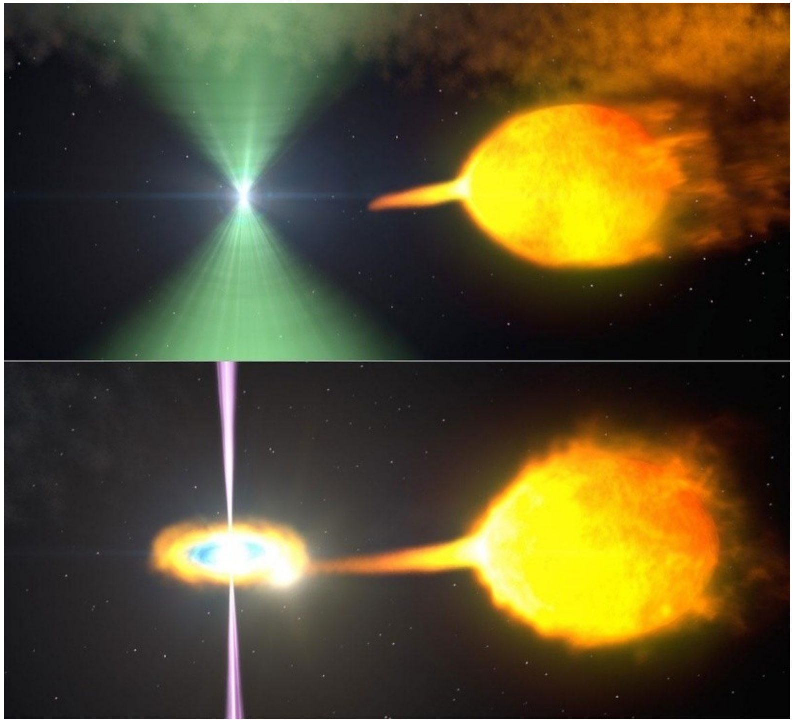
tMSP : Transitional Millisecond Pulsars

- More than *70 spiders systems*, *'Black Widow'* or *'Redback'*, discovered *over the last decade*

- *Rotation-powered millisecond pulsars* that have retained a low-mass stellar companion, where the *neutron star can swing between the radio-pulsar and accretion states* in *shorter timescales* than stellar evolution timescales



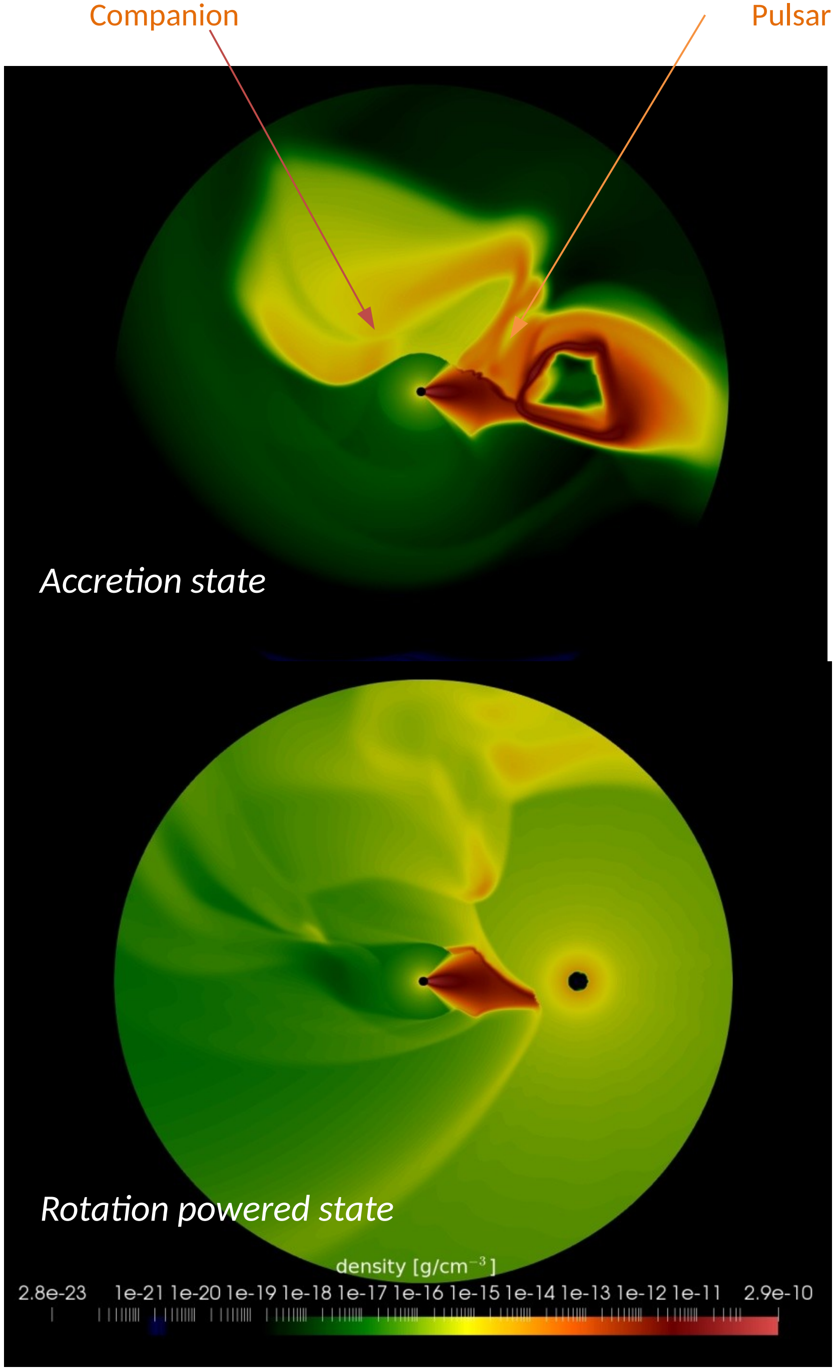
Y-ray photon flux from J1023 in June 2013, Stappers et al. 2014



First discovered – PSR J1023+0038

2001 : **LMXB** *2004 :* **MSP** *2013 :* **LMXB**

2D Hydrodynamical simulations



Using Adaptive Mesh Refinement code [AMRVAC 2.0]() we aim at :

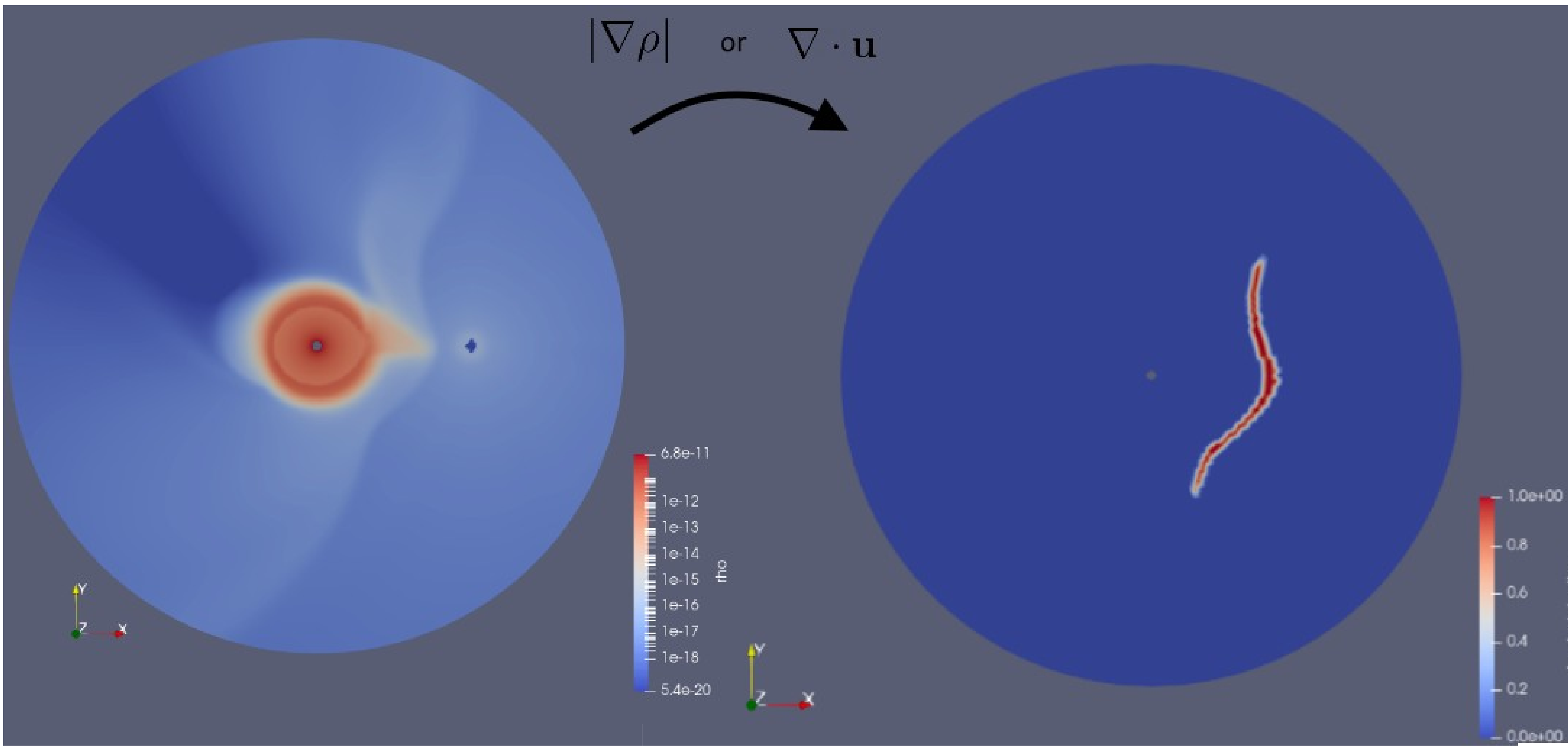
- Describing the *multi-physical interaction between the winds* of a millisecond pulsar and its stellar companion

- Understanding the *formation and evolution of an accretion disc* interacting with the pulsar wind

- Modeling the effect on the companion's atmosphere of the *irradiation flux* from the pulsar and its consequences on the *accretion flow*

Post Processing : Shock Detection

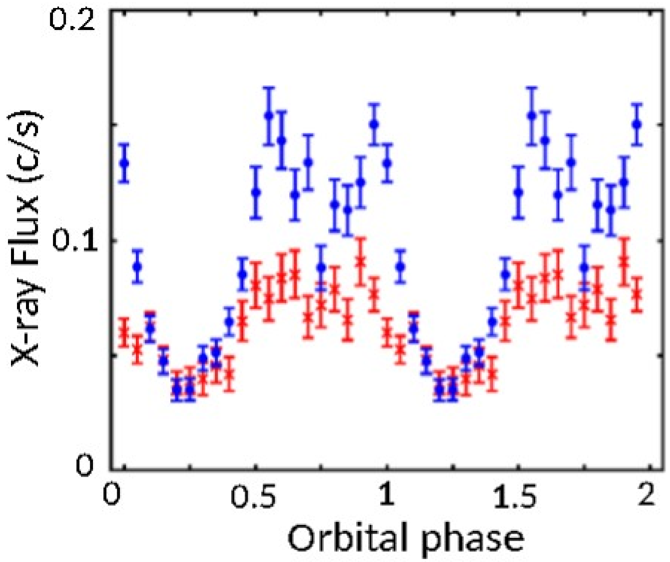
Using *user-defined threshold* on different variables to the particular simulation, we detect the *existence of a Intra-Binary Shock* *(IBS)*, result of the collision between the pulsar wind and the companion wind or its magnetosphere



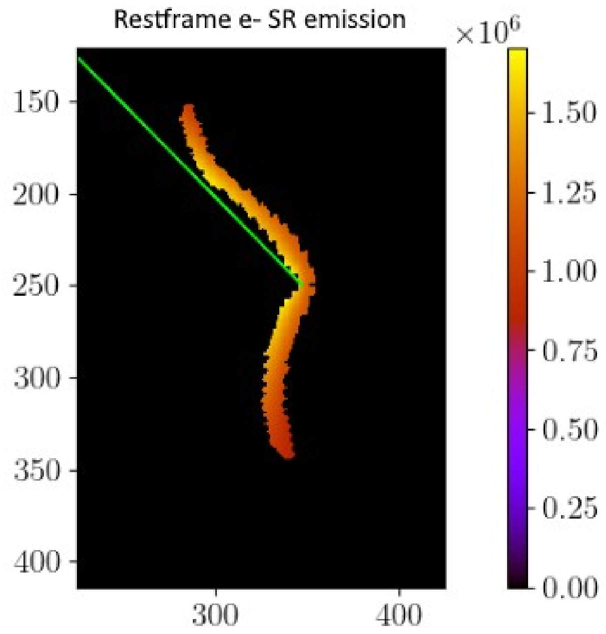
Post Processing : Orbital variability of the X-ray flux

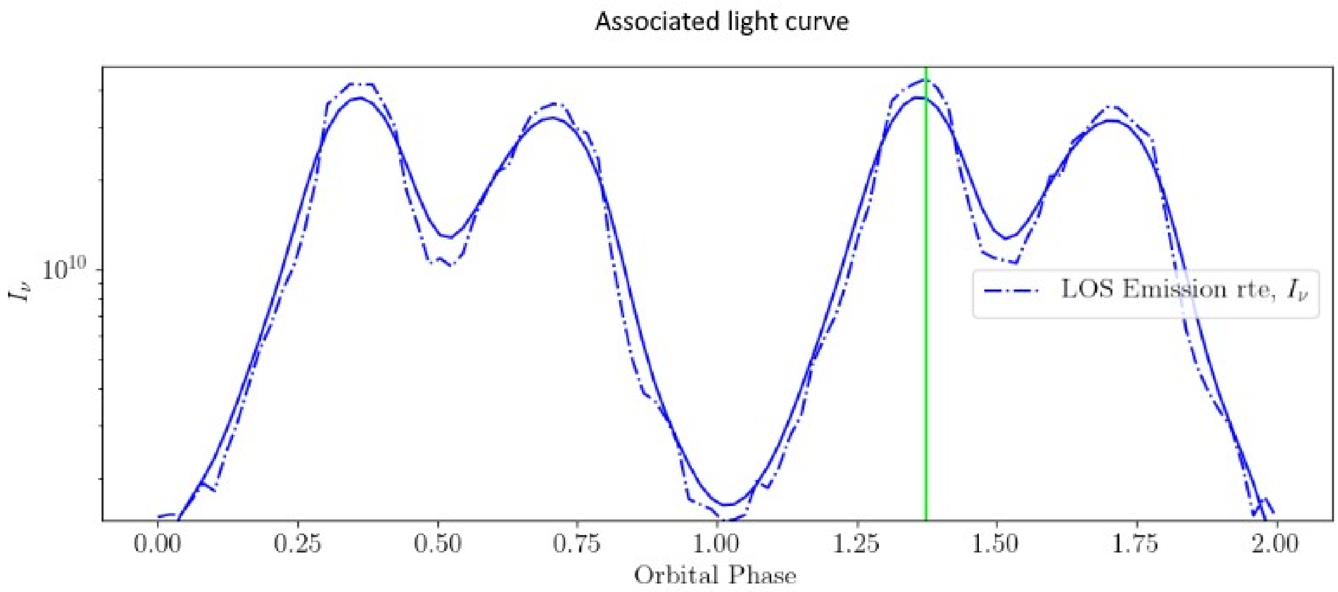
- *IBS : efficient site of particle acceleration* and *non-thermal emission* due to the *Doppler boosting, SR and IC*.

- *Wind momentum ratio* will set the *shock orientation and opening angle*, thus determining the *shape of the X-ray orbital light curve*



X-ray orbital modulation observed from PSR J1227–4853 (RB) on 2013, Dec 29 (red points) and 2014, Jun 27 (blue points), Papitto and de Martino, 2020



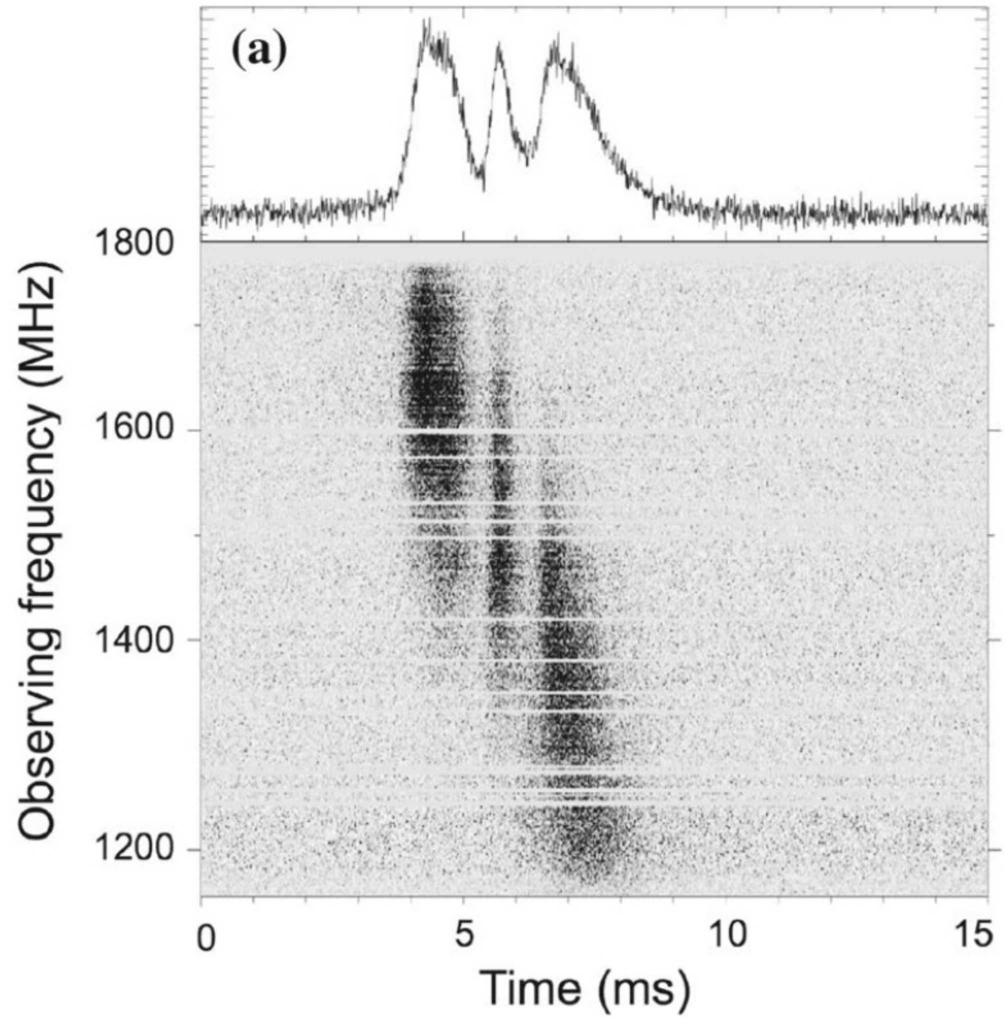


Fast Radio Bursts

Fast radio bursts

FRB121102, Hessels18

- Extragalactic DM/distance
- Intense : >> 10^{23} erg/Hz/s
- Fast : a few ms with ~10µs substructures
- Narrow bandwidth : ~1GHz
- Downward drifting subpulses
- Polarisation :
  - Mostly or totally linear
  - No clear trend on Faraday rotation (across sources)
  - Moderate or no swing



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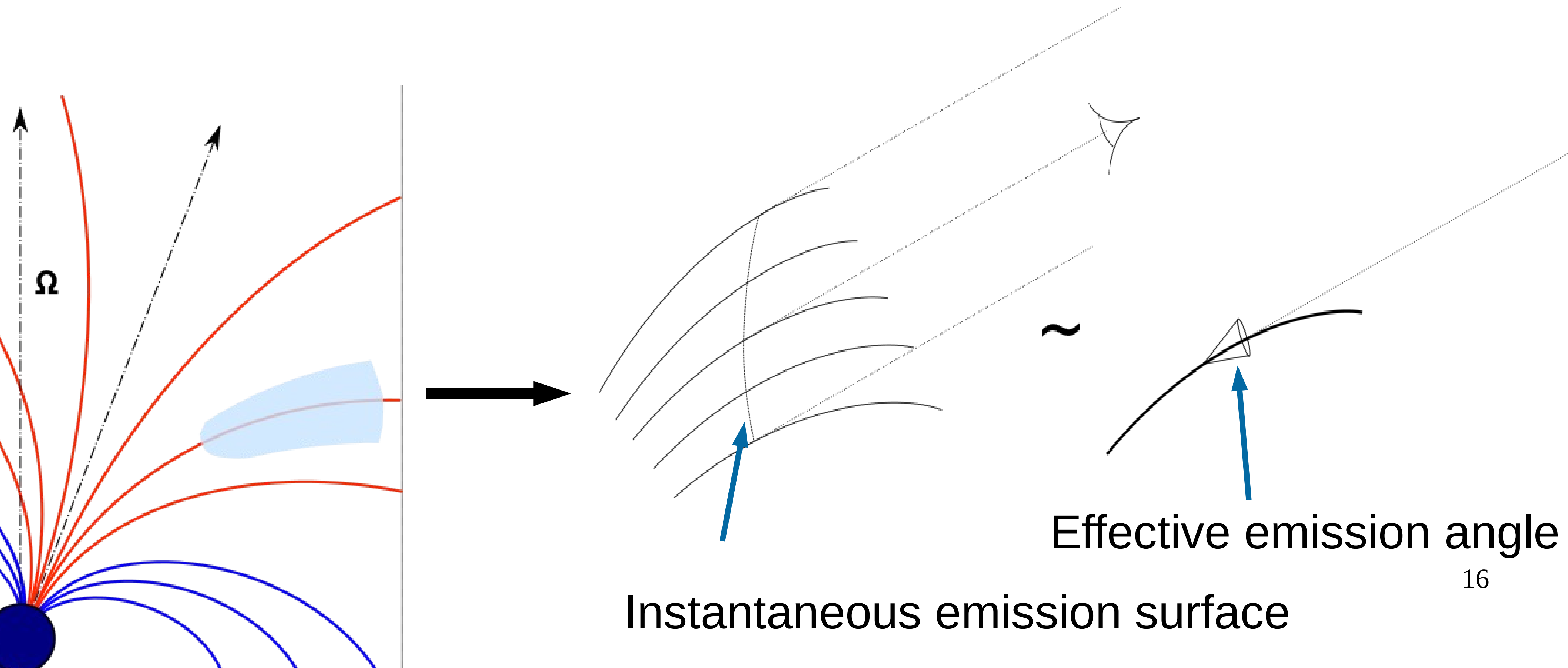
FRBs: A geometrical model

Preliminary

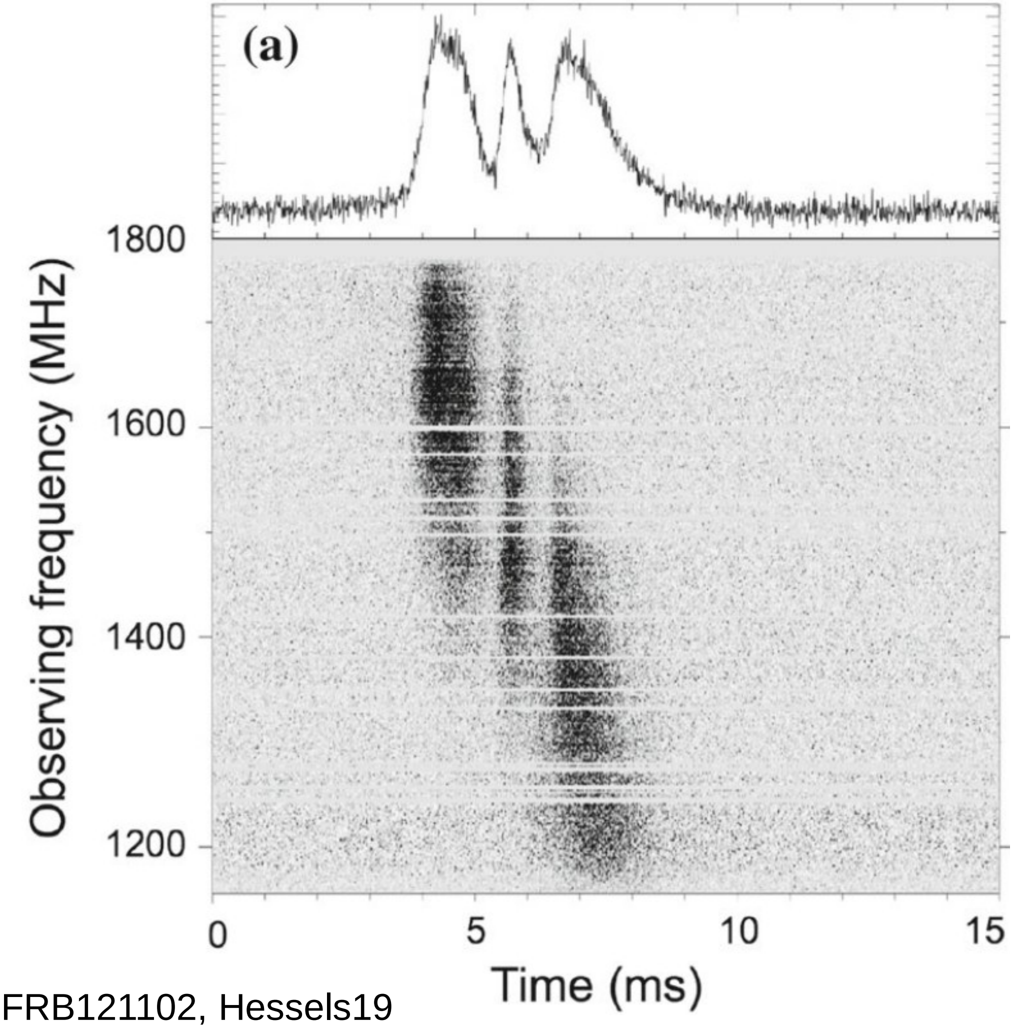
Hypothesis :

- Emission duration is trigger limited, not visibility limited (as in e.g. pulsars)
- Emission takes place on a small bundle of lines
- Propagation though bundle much shorter than trigger duration

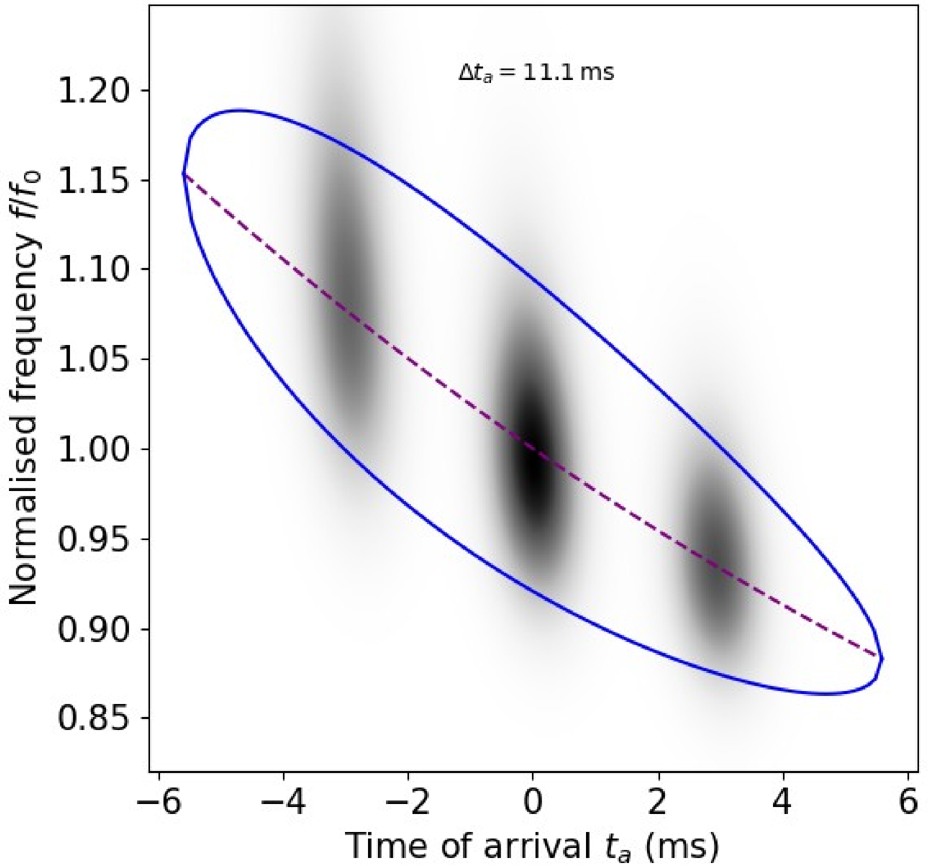


Preliminary

Down-drifting sub-bursts



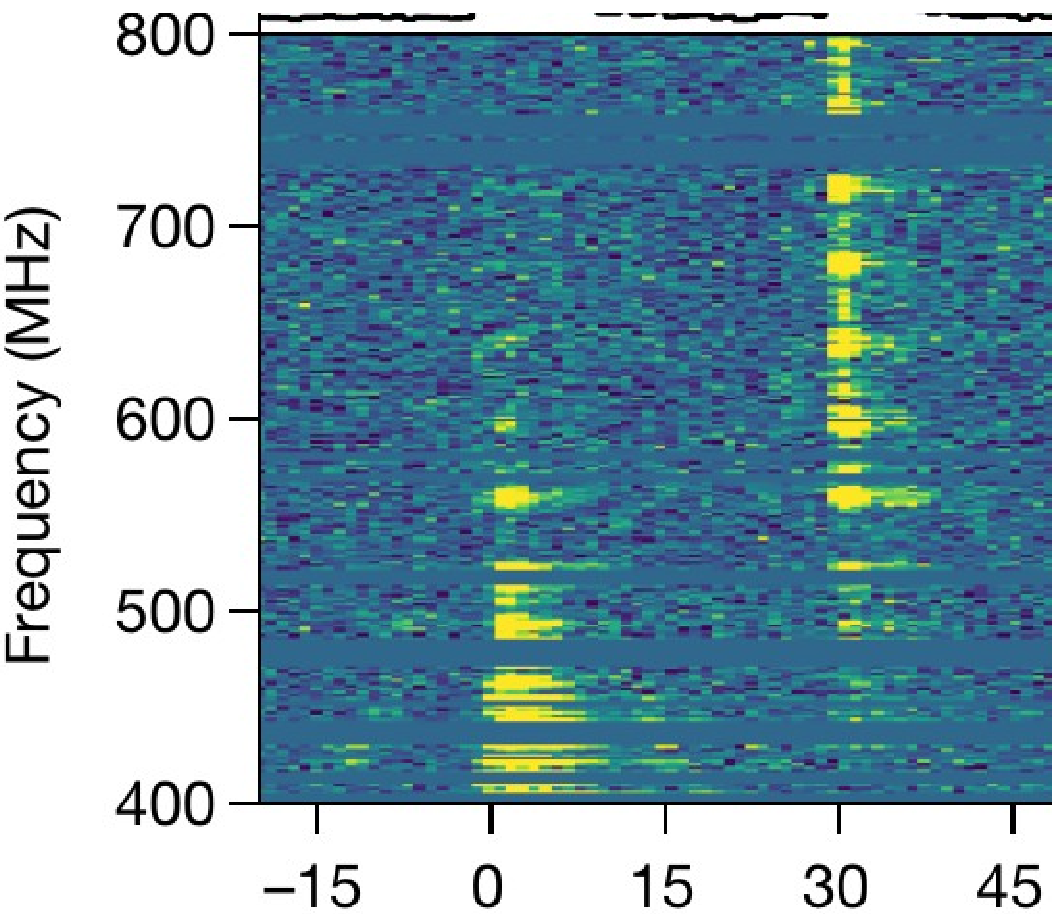
FRB121102, Hessels19



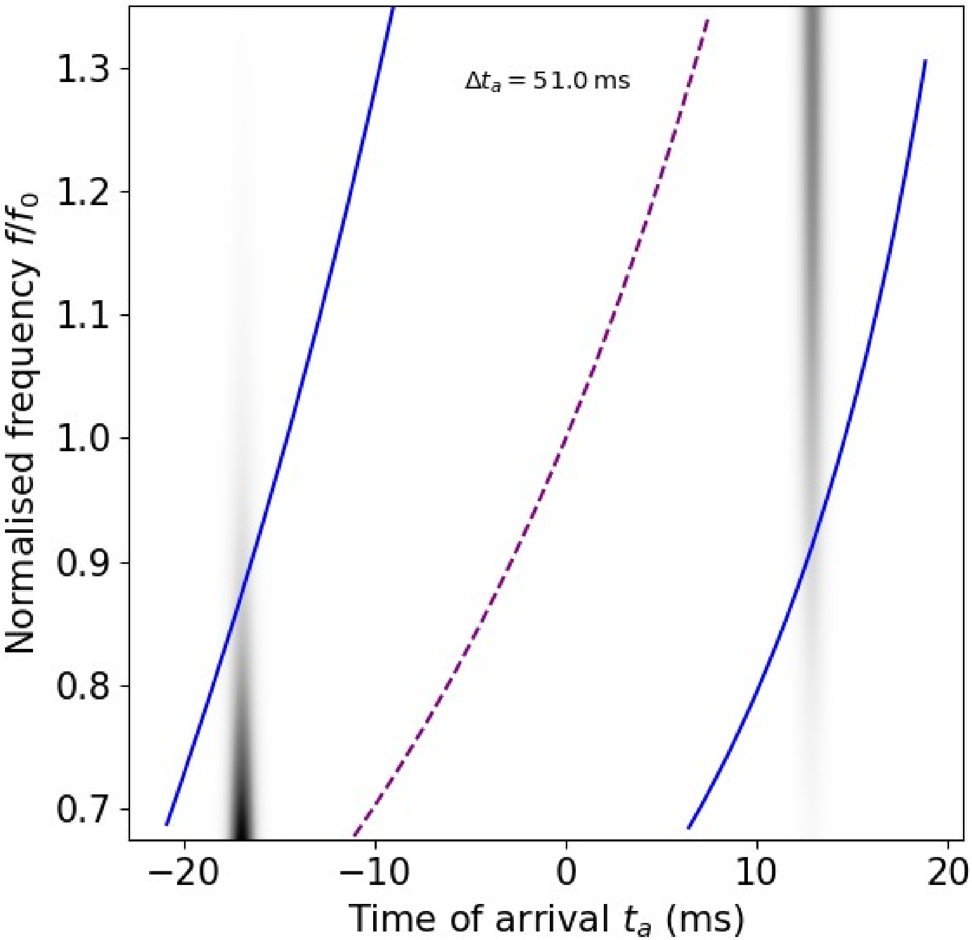
Split monopole geometry
(outer magnetosphere)

Preliminary

The Galactic magnetar bursts



J1935+2154, Andersen et al. 2020



Dipolar polar-cap geometry

Summary

- A "1st principle" kinetic code in development
- Testing gravity with a numerical timing model
- Probing interaction of pulsars with their spider companions with RMHD simulations
- Modelling Fast Radio Bursts