# A hybrid numerical approach to model pulsar magnetosphere.

Adrien Soudais • Supervisor: Benoît Cerutti

adrien.soudais@univ-grenoble-alpes.fr

Institut de Planétologie et d'Astrophysique de Grenoble

## Introduction

The study of pulsar magnetospheres has developed quickly in recent years thanks to the development of high-performance computing. Two complementary numerical methods have been used to model these objects thus far: the magnetohydrodynamic (MHD) and the particle-in-cell (PIC) techniques. Our objective is to combine the strengths of both approaches into the same numerical framework in order to achieve a larger scale separation and magnetic field strength. This approach will allow us to make realistic predictions of particle and electromagnetic spectra for pulsar, therefore bridging the gap between observations and ab-initio models. To do so we have implemented a time-dependent force-free electrodynamics (FFE) [2] module in the *Zeltron* [1] PIC-code. We show here preliminary results of this new hybrid method.

## Motivations

**Why ?**

↳ complementarity PIC/FFE

↳ multi-scales simulations

↳ reduce numerical cost

| Method | PIC | FFE |
|---|---|---|
| Particles acceleration | + | - |
| Large scales | - | + |
| Microphysics | + | - |
| Computational time | - | + |
| Energy dissipation | + | - |

## Numerical setup

**Code**

↳ *Zeltron* [1] + time-dependent FFE module

**2D axisymmetric**

↳ aligned dipole pulsar

**Magnetic flux function $\psi$**

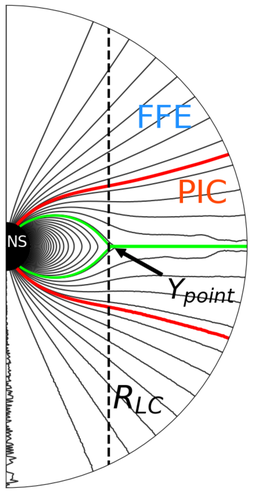
↳ criterion for the domain separation

↳ if: $\psi \in [\psi_1, \psi_2] \longrightarrow$ PIC

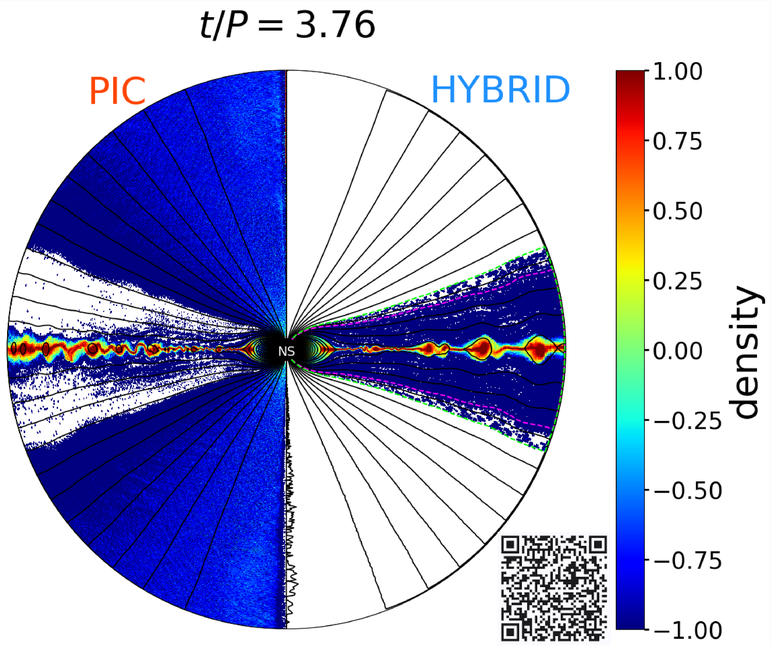
↳ else: FFE

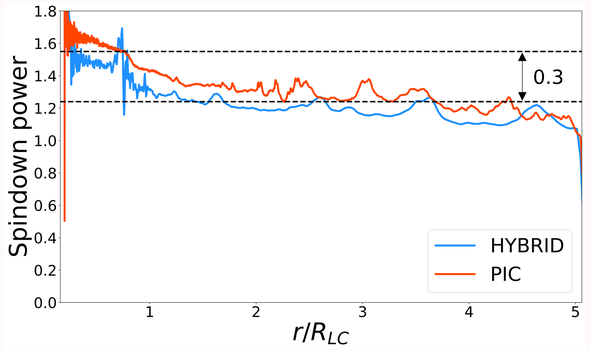
**Magnetosphere of an aligned pulsar**

↳ Fig.: Magnetic field lines in black, light cylinder ($R_{LC}$) in dashed lines. Seperation between FFE and PIC in red. The separatrix is in green with the Y-point. [3], [4]




## Results




**Snapshot**

↳ reconnecting field lines desbribed by PIC

↳ recover open field lines in FFE

↳ recover current sheet + plasmoids

**Spindown power**

↳ instantaneous spindown power of the snapshot

↳ Similar spindown power with both methods

## Conclusion & perspectives

The hybrid method presented here shows encouraging results. We are able to retrieve the behaviour of the current sheet with the formation of plasmoids. This method does not provide additional dissipation and we recover the one from the PIC simulation. In the upcoming runs at high resolution and larger scales we will be able to give predictions of particle and radiation spectra.

## References

[1] B. Cerutti, G. R. Werner, D. A. Uzdensky & M. C. Begelman (2013)
[2] Spitkovsky, Anatoly (2006)
[3] A. Y. Chen and A. M. Beloborodov (2014)
[4] Cerutti, B., Philippov, A., Parfrey, K., & Spitkovsky, A. (2015)

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