Spider pulsar binaries with the Nançay Radio Telescope

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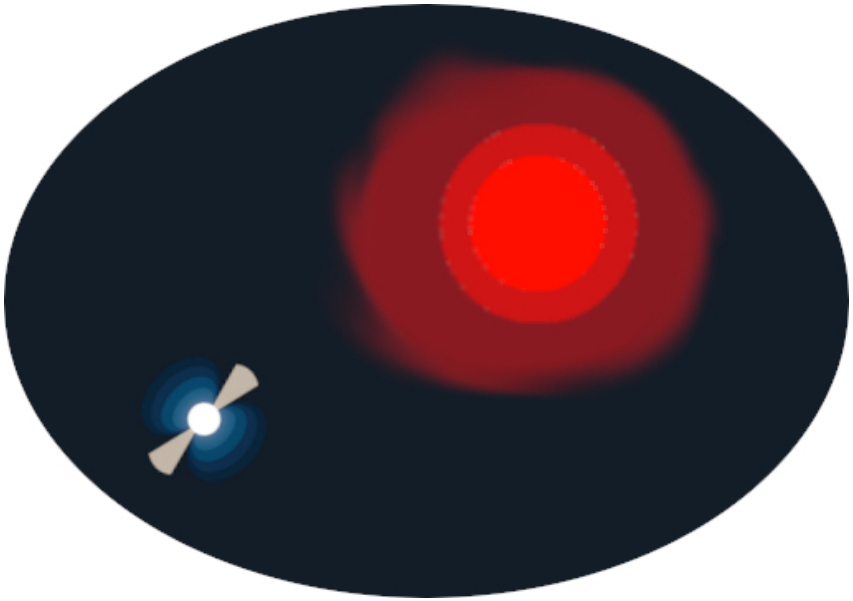
Spider pulsar binaries



- $P_{spin} < 20$ ms
- $10^{-4} < M_c < 0.5\ M_\odot$
- Orbital periods < 2 days
- No more accretion but gas from the companion forming a large cloud that might delay or even eclipse the pulsar beam.
- 77 spiders in the ATNF pulsar catalogue with those criteria.

Why are spiders interesting ?

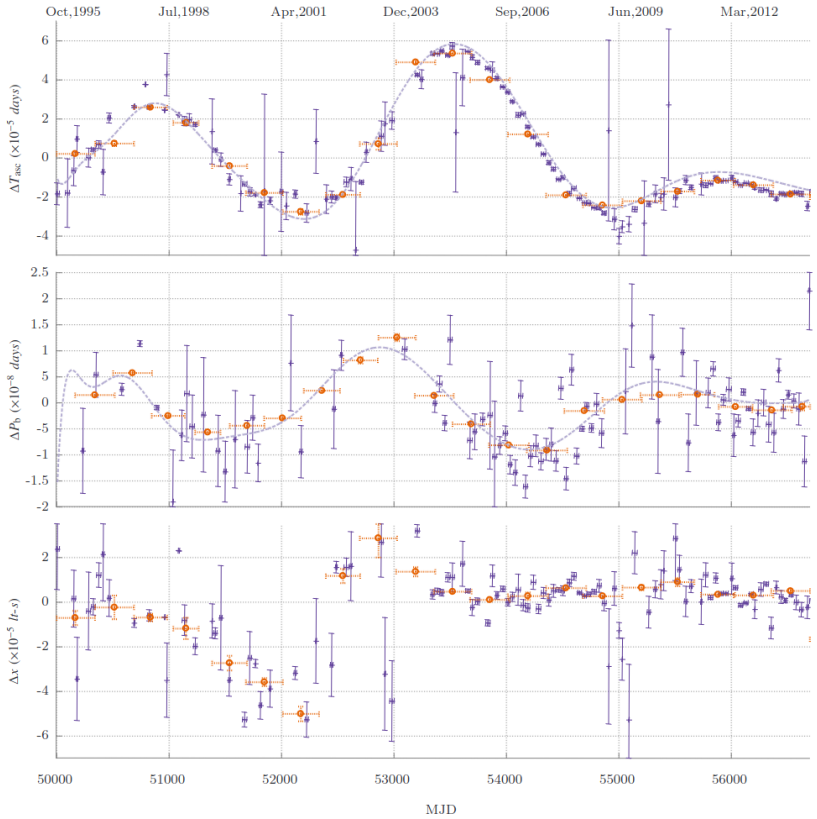
Spiders binaries are useful to study different topics:

- Neutron star properties : equation of state, mass distribution.
- Wind interactions and high-energy radiation.
- Evolution process of millisecond pulsars.
- Eclipse phenomenology :
  - How do they work ?
  - Under which conditions do we see them ?
  - Do they share common characteristics ?

Spiders orbital (in)stability

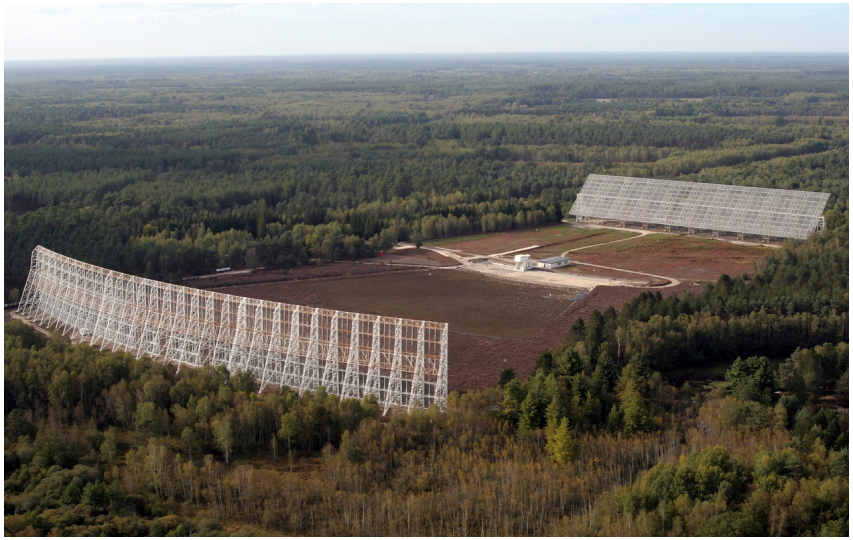
Timing stability of spiders is very different from one spider to another.

- Some are very stable, easy to model and are used in PTAs (see Bak Nielsen et al. 2020).
- Some are very unstable and require multiple orbital period derivatives (see figure at the right).
- But studies of this instability can help probe companion nature (see Voisin et al. 2020).



Variations of several timing parameters of PSR J2051-0827; Shaifullah et al (2015)

Spiders in the NRT sky



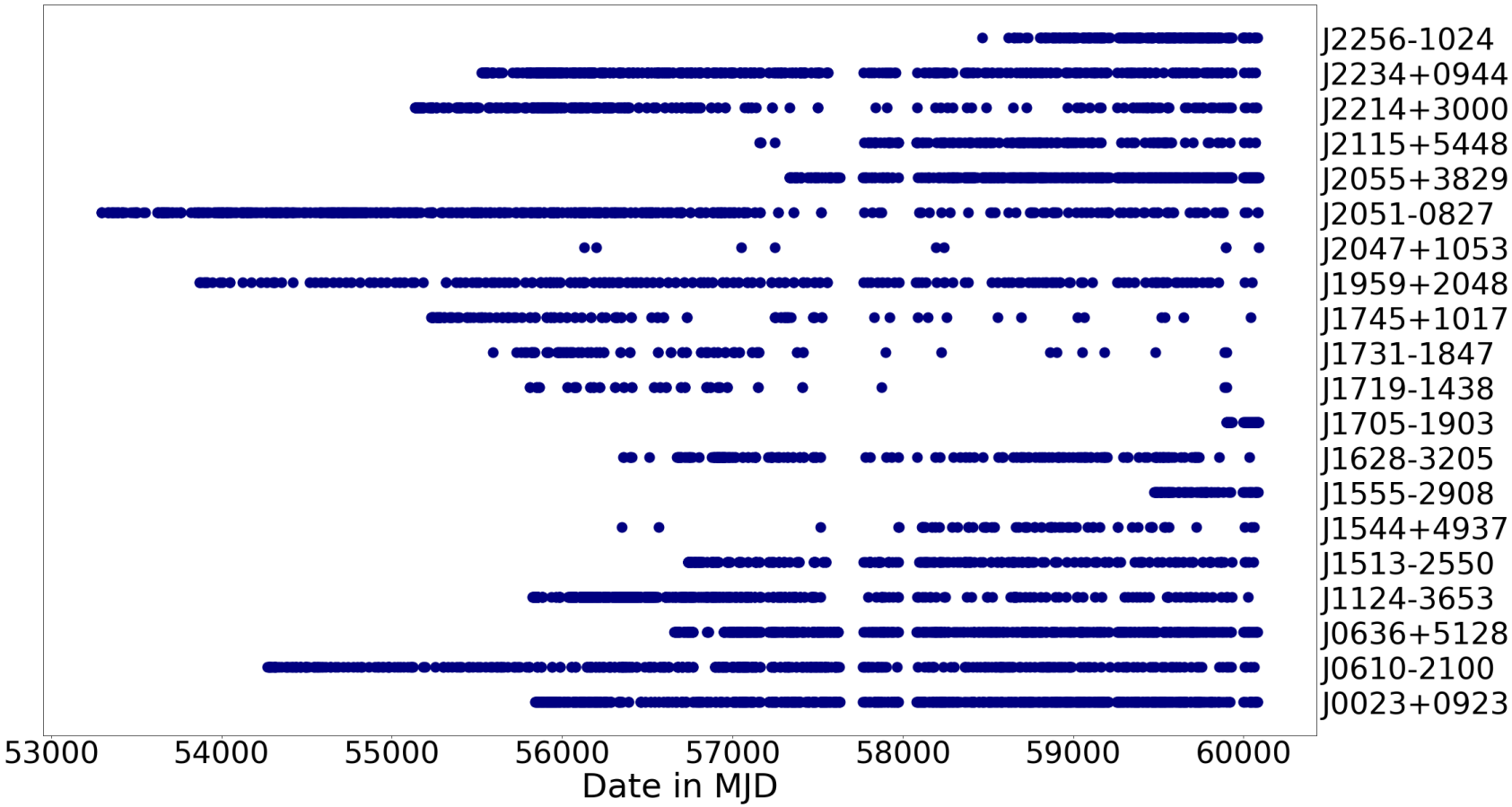
The Nançay Radio Telescope (NRT) has a pulsar observation program, and is observing spiders since 2004:

- $P_{spin} < 20$ ms
- $10^{-4} < M_c < 0.5\ M_\odot$
- Orbital periods < 2 days
- Declination > -39°

We use the NUPPI coherent dedispersion backend, 128 x 4MHz channels, L or S band receiver, 1.4 K/Jy.

Spiders in the NRT sky

NRT is currently monitoring 19 spiders:



Scientific objectives (1/2) : review of the NRT spiders

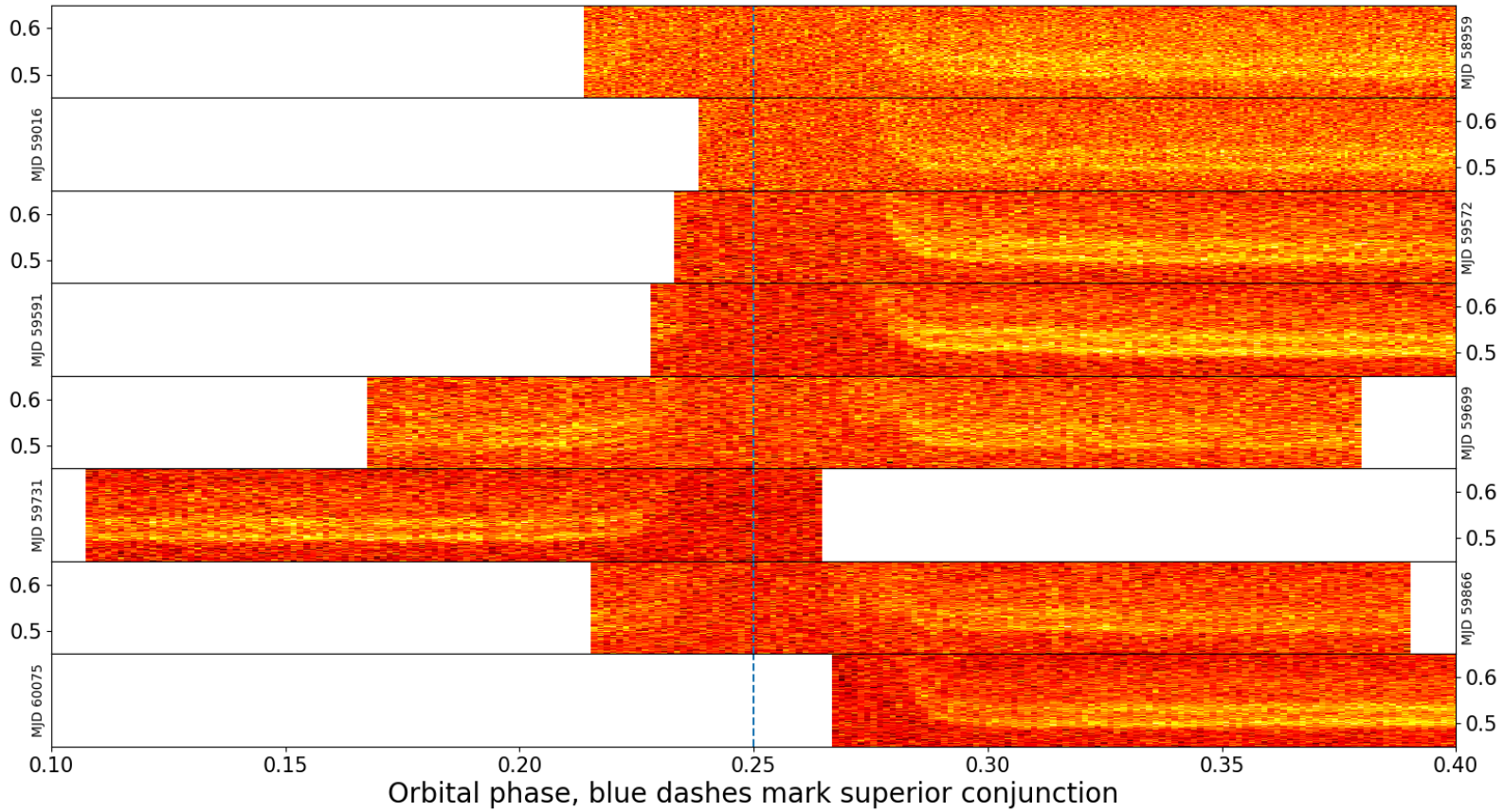
For the 19 observed by NRT, since I am interested in orbital stability, I did a systematic review of :

- amount of NRT data to determine if more observations are needed.
- eccentricity of the orbit.
- number of orbital period/frequency derivatives, if any.
- presence or absence of eclipse or delay at superior conjunction (at the typical central frequency of 1.484 GHz).

And a systematic literature review on:

- presence or absence of eclipse or delay below 1.4 GHz.
- if already measured, the Roche-lobe filling factor.

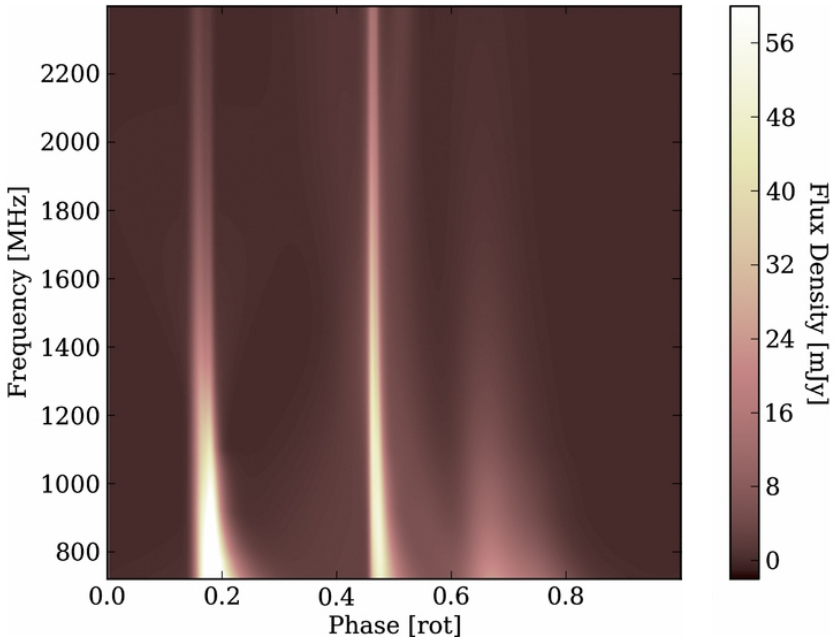
Eclipses : the example of J2256-1024 (Hessels et al. 2011)



8 best NUPPI observations during eclipses for J2256, rotational phase vs orbital phase.

Scientific objectives (2/2) : systematic study of eclipses

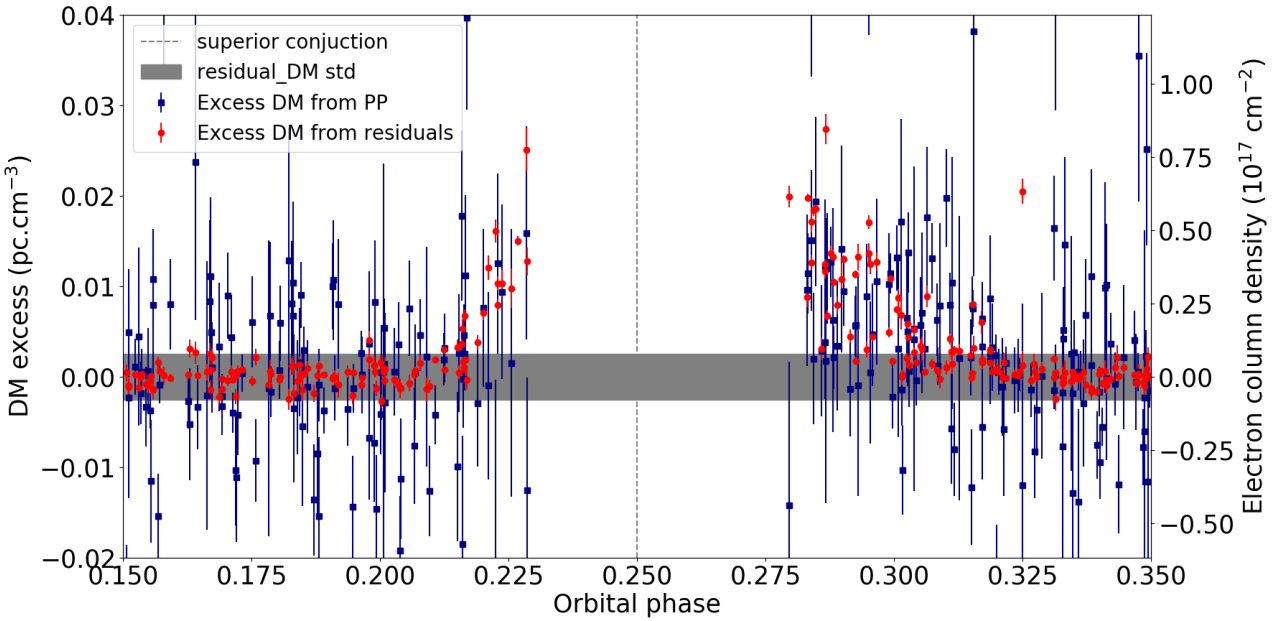
- DM measurement during eclipses with the PulsePortraiture 2D (intensity VS rotational phase VS frequency) template matching suite (Penucci et al. 2014).
- Timing analysis and investigation of spiders with unstable orbits using the model from Voisin et al. (2020).
- (Eventually) polarimetry of spiders around eclipses.



2D profile of M28A from Penucci et al. (2014)

DM studies : the example of J2256-1024

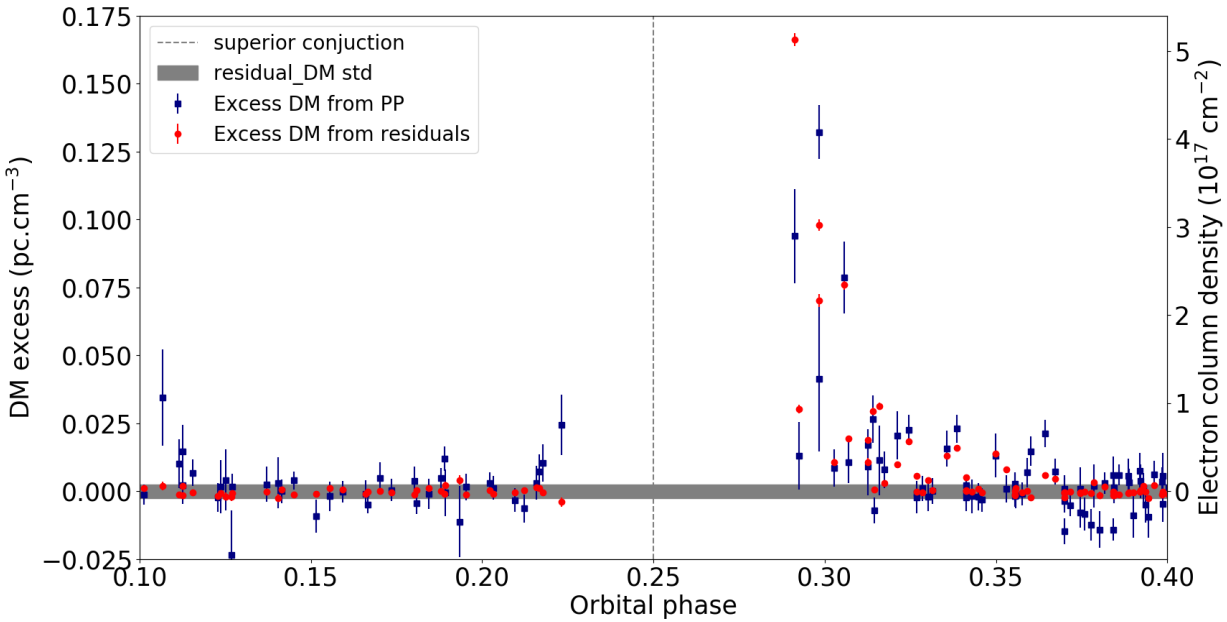
Eclipse lasts 5.1 % of the orbit, which is 15.7 minutes. It is 0.58 $R_\odot$ wide, while the companion Roche lobe radius is 0.23 $R_\odot$. Therefore, the occultating cloud is not gravitationally bound to the companion.



NUPPI TOAs with 1 TOA / 5 min. TOA SNRs > 15, zoomed on superior conjunction.

Another example : J1555-2908 (Ray et al. 2022)

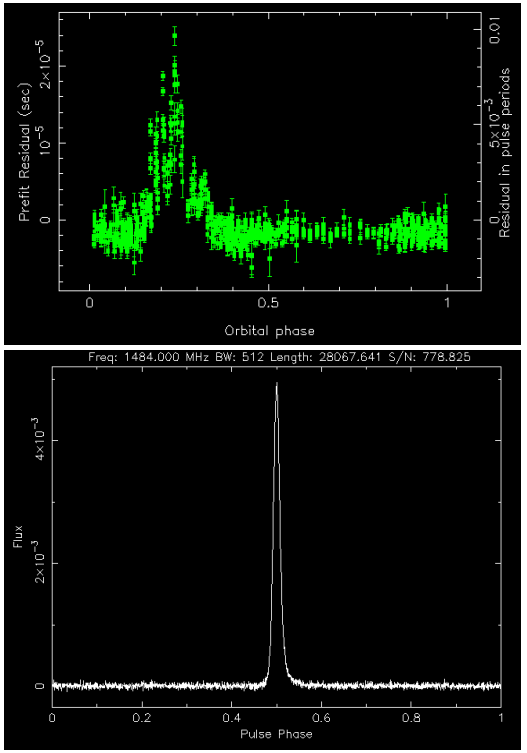
J1555 is eclipsing in gamma rays, hence seen nearly edge-on (i>83° according to Clark+2023). In radio the eclipse is dramatically asymmetrical.



NUPPI TOAs with 1 TOA / 5 min. TOA SNRs > 8, zoomed on superior conjunction.

A new target : J1705-1903 (Morello et al. 2019)

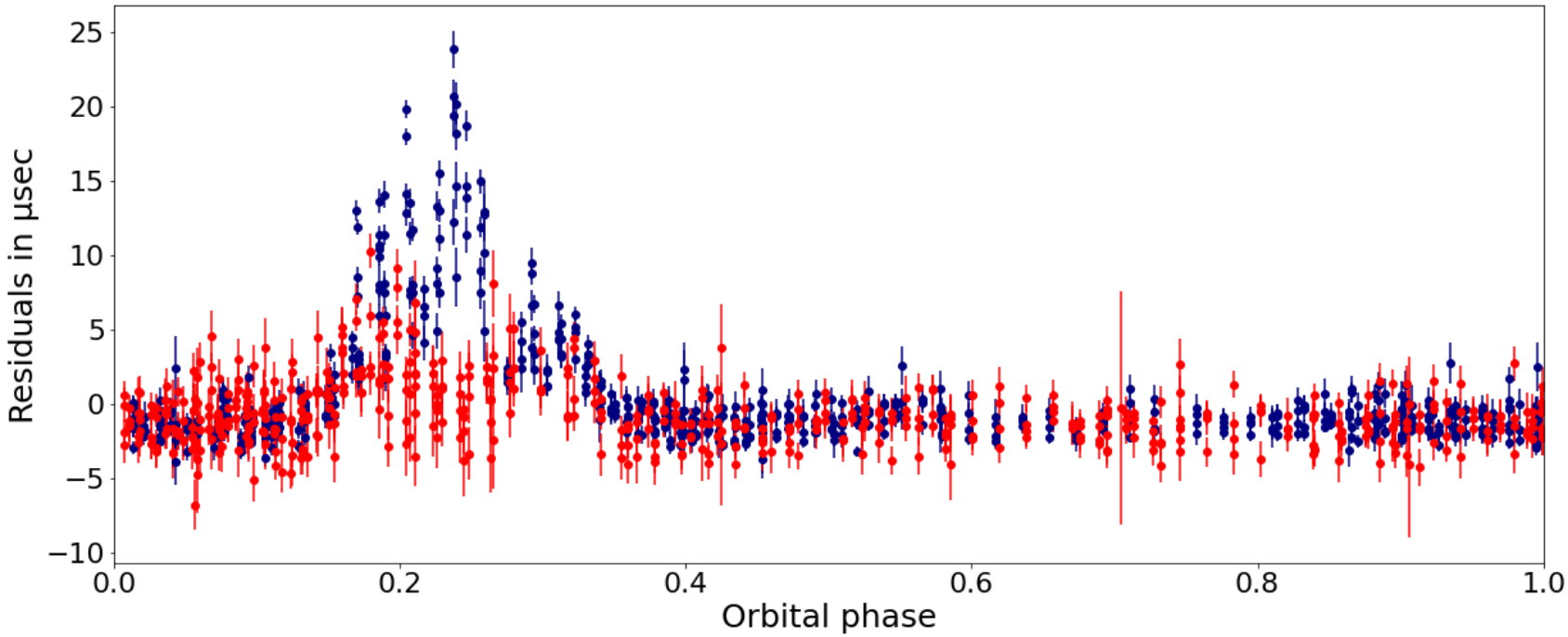
- Observed with NRT since 15/11/22
- 27 observations of $\lesssim$ 1 hour for an orbital period of 4.4 hours including 11 during the eclipse $\longrightarrow$ good coverage of the orbit
- TOA median uncertainty of 670 ns (MeerKAT: 340 ns, with 256s integrations and 50 MHz sub-bands; Miles et al. 2023)



(Top) Timing with 4 frequency bands of 128 MHz, TOAs every 5 minutes, and no cleaning. (Bottom) Fully integrated profile.

On/off eclipses of J1705-1903

A good example of the typical spider variability actually occurred at the beginning of this year :



NUPPI TOAs for J1705-1903, 2022 data in blue, 2023 data in orange

Summary and prospects

Spider pulsars are very interesting objects in themselves, but also as tools for other science. The eclipse phenomenon and the orbital instability are investigated with different approaches as understanding these features is crucial to grasp a complete picture of the nature of these objects.

The NRT is observing spiders for a long time and the accumulated data are a gold mine for spiders study, with a sample of 19 spiders.

My current goal is to develop a pipeline to systematically analyse the eclipses of the pulsars in our sample, as opposed to studying them individually.