# NRT discovery of the eclipsing black widow pulsar PSR J2055+3829

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**MODE-SNR-PWN 2019 workshop**

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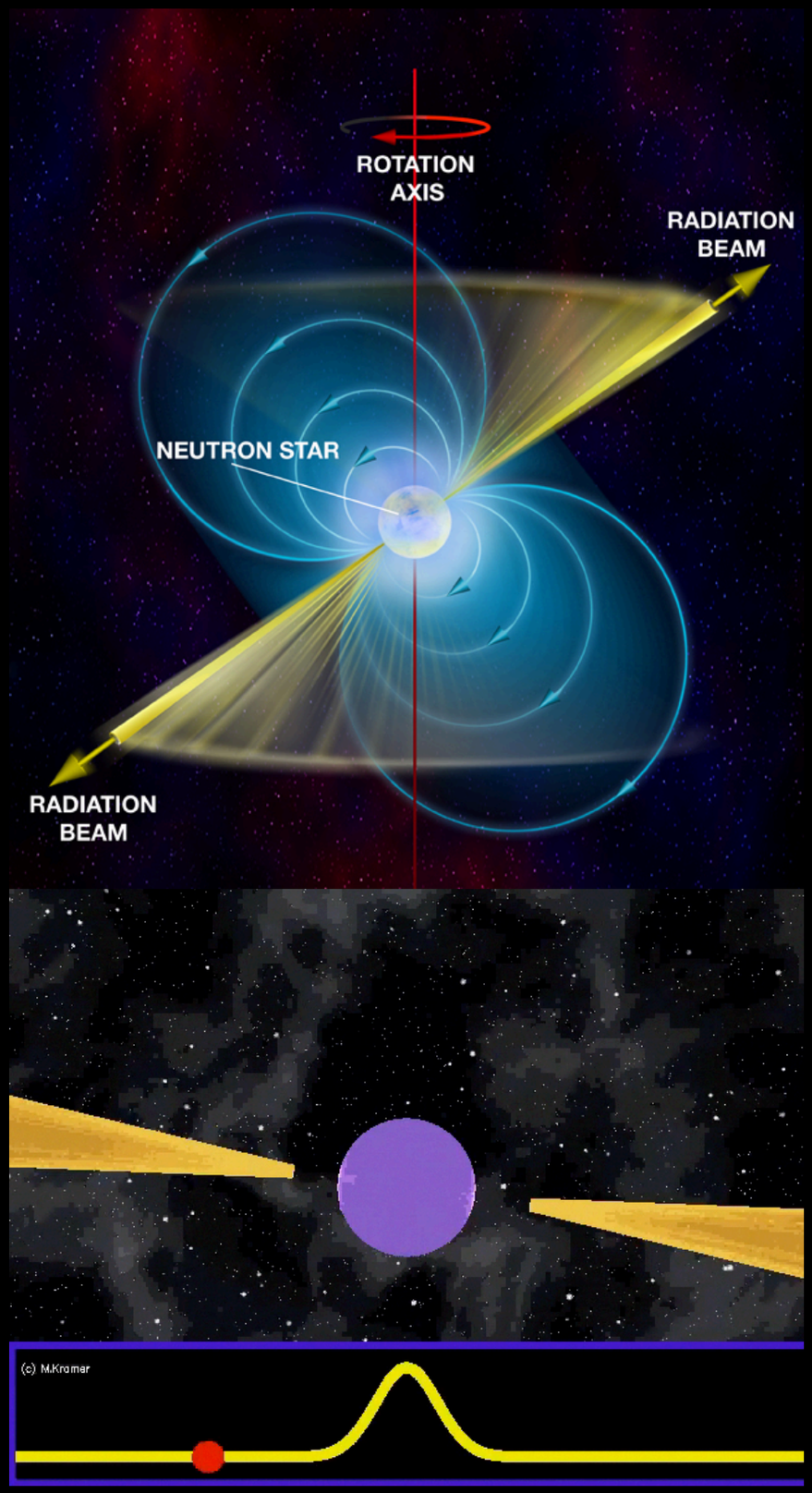
# Pulsars




Pulsars are rapidly rotating highly magnetized neutron stars, born in supernova explosions of massive stars.

Masses: 1.2 - 2 $M_\odot$, Radii ~ 13 km.

Emission (radio, optical, X-ray, gamma rays…) produced in beams around the star.

**Pulsars are cosmic lighthouses!**

**Extreme objects:**

- Luminosities up to $10^4$ $L_\odot$
- Surface temperature ~ $10^6$ K
- Surface gravity ~ $10^{11}$ Earth's
- Surface magnetic fields: $10^8$ - $10^{15}$ G

# The Nançay Radio Telescope (NRT)

~94-m equivalent meridian telescope, located in Sologne, 70 km South of Orléans.

Minimum declination: -39°

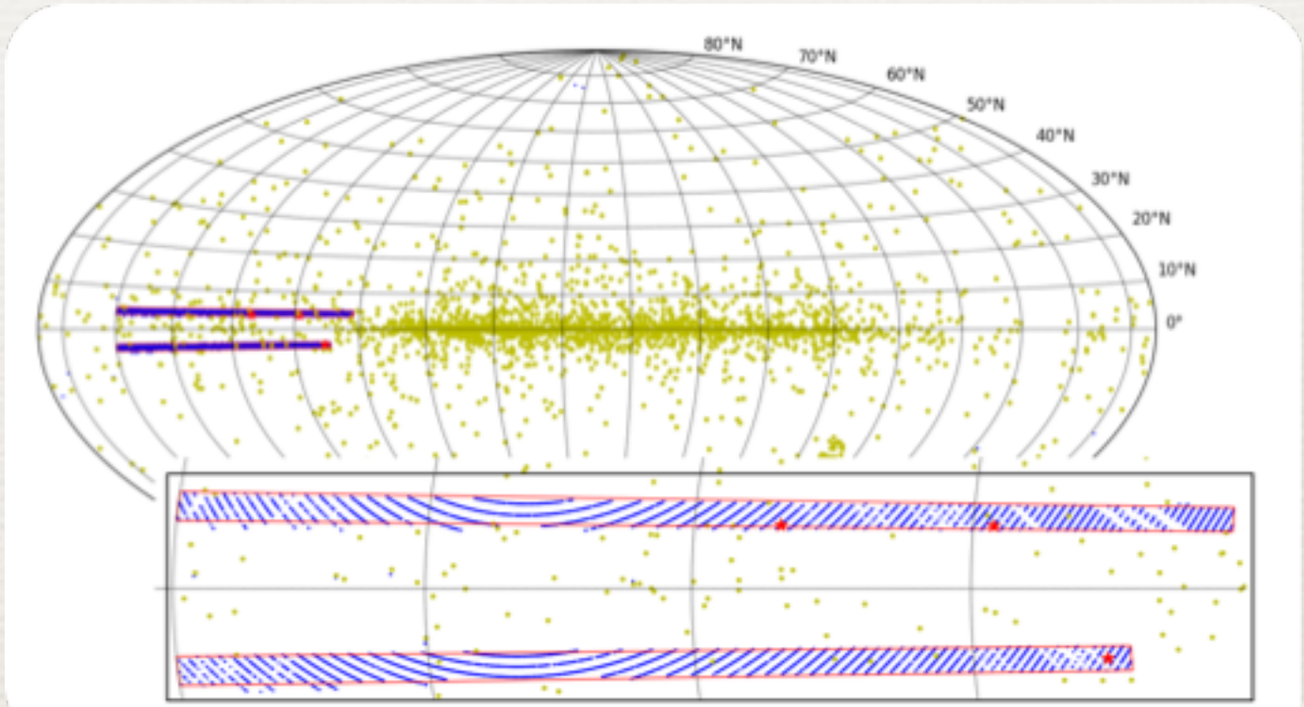
# The SPAN512 survey

Franck Octau, PhD thesis (2017)

SPAN512: pulsar survey at 1.4 GHz conducted with the NRT between 2012 and 2018.

Goal: find stable MSPs (e.g. suitable for PTA experiments) and exotic systems.

~5800 18-min pointings, in the following sky regions: 74° ≤ l < 150° and 3.5° ≤ |b| < 5°.




Two independent analyses done by Grégory Desvignes (MPIfR) and Franck Octau (LPC2E).

3 pulsars discovered, two MSPs and one « normal » pulsar.

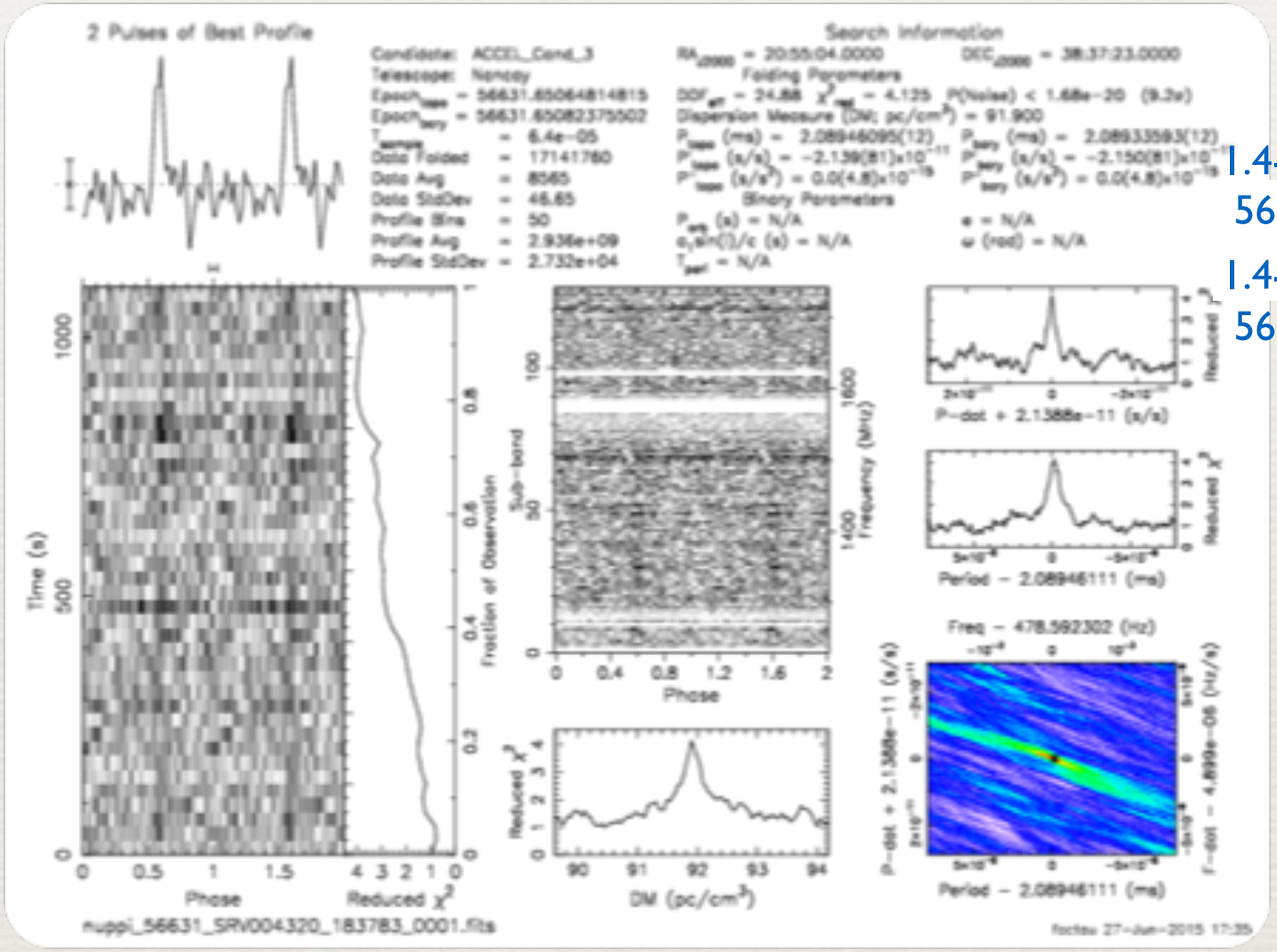
Survey description & pulsar discoveries: see Desvignes et al., in prep.

**Table 1.** Parameters of the SPAN survey

| | |
|---|---|
| Sampling time | 64 μs |
| Total bandwidth | 512 MHz |
| Number of channels | 1024 |
| Center frequency | 1486 MHz |
| Integration time | 18 min |
| Final quantization | 4 bits |
| Gain | 1.4 K/Jy |
| System temperature | 35 K |
| Nominal sensitivity | 0.055 mJy |
| Total observing time | 1740 hours |

From Desvignes et al. (2013)

# Discovery of PSR J2055+3829




1.4-GHz obs. at MJD 56631 (5 Dec 2013)

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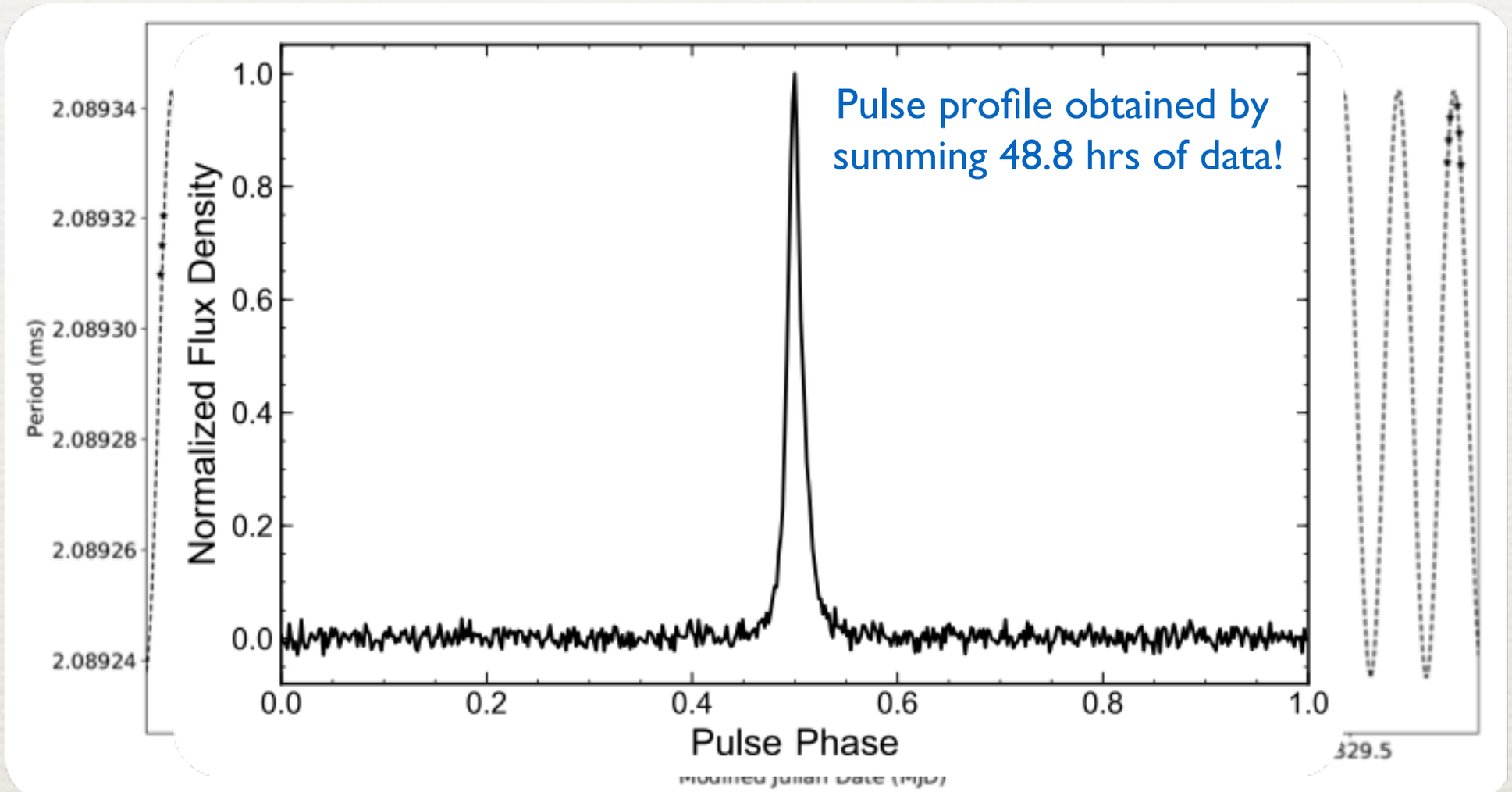
Franck Octau: re-analysis of the SPAN512 data using AI-based algorithms to rank pulsar candidates.

New good pulsar candidate found, with a period P ~ 2.089 ms, and DM ~ 91.9 pc cm$^{-3}$.

Re-observations of the candidate on 19 & 20 Oct. 2015: >10-sigma detections!

# Initial observations




Fits of the apparent pulsar period measured during observations made closely in time (see plot above) led to: $P_0 \sim 2.089$ ms, $P_b \sim 0.130$ d (~ 3.1 hours), $x \sim 0.046$ lt-s,

and thus a $0.02 < m_c < 0.05\ M_{sun}$. Black widow pulsar?

Single peaked pulse profile at 1.4 GHz.

Also detected at >2 GHz, albeit with much weaker flux density.

# Radio timing

Timing observations done with the NUPPI backend (512 MHz of bandwidth, coherently de-dispersed), mostly at 1.4 GHz.

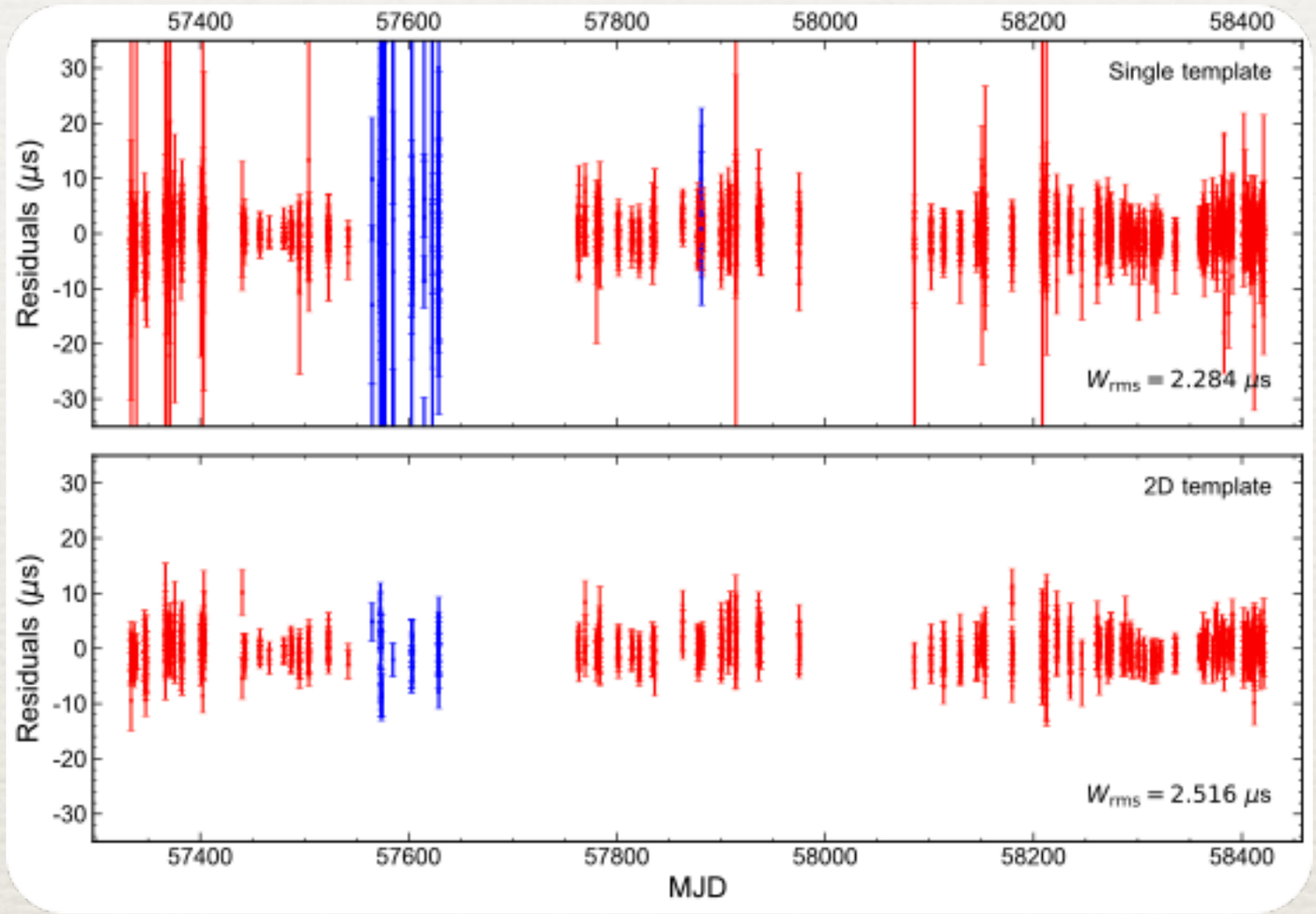
TOAs extracted using a single template & with a 2D template with freq. resolution. Consistent timing results.

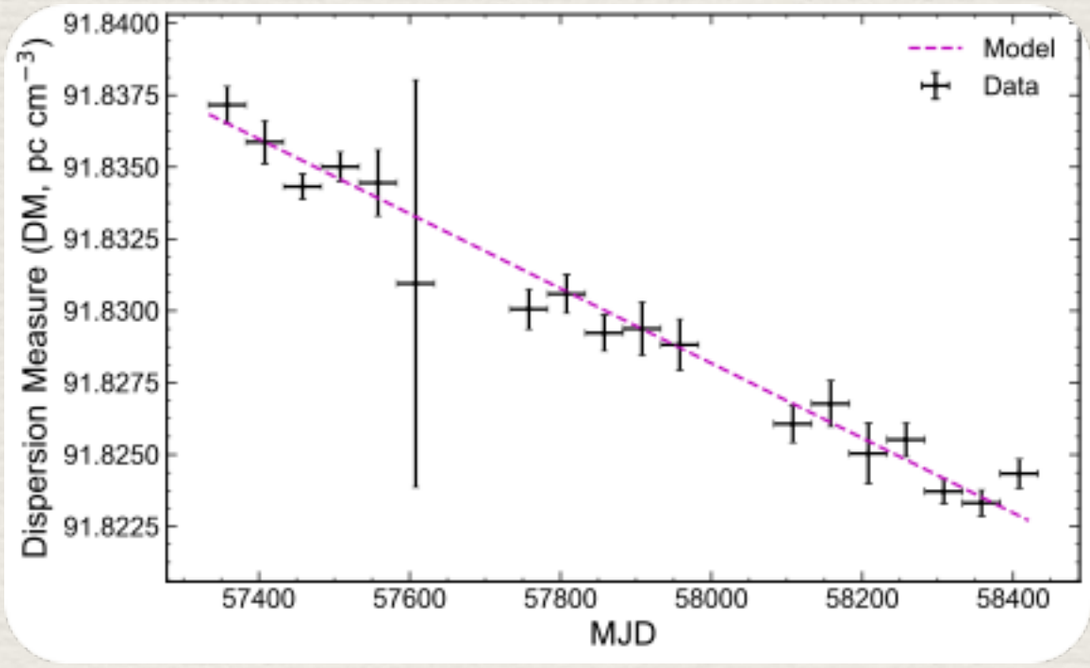
~2.3 μs rms residual achieved with 4 freq. sub-bands & 1 TOA / 10 min.

DM variations & modest orbital period variations detected (-2.0(1)e-12 s/s).

**Black widow pulsar!**

Radio eclipses seen at 1.4 GHz (next slide).

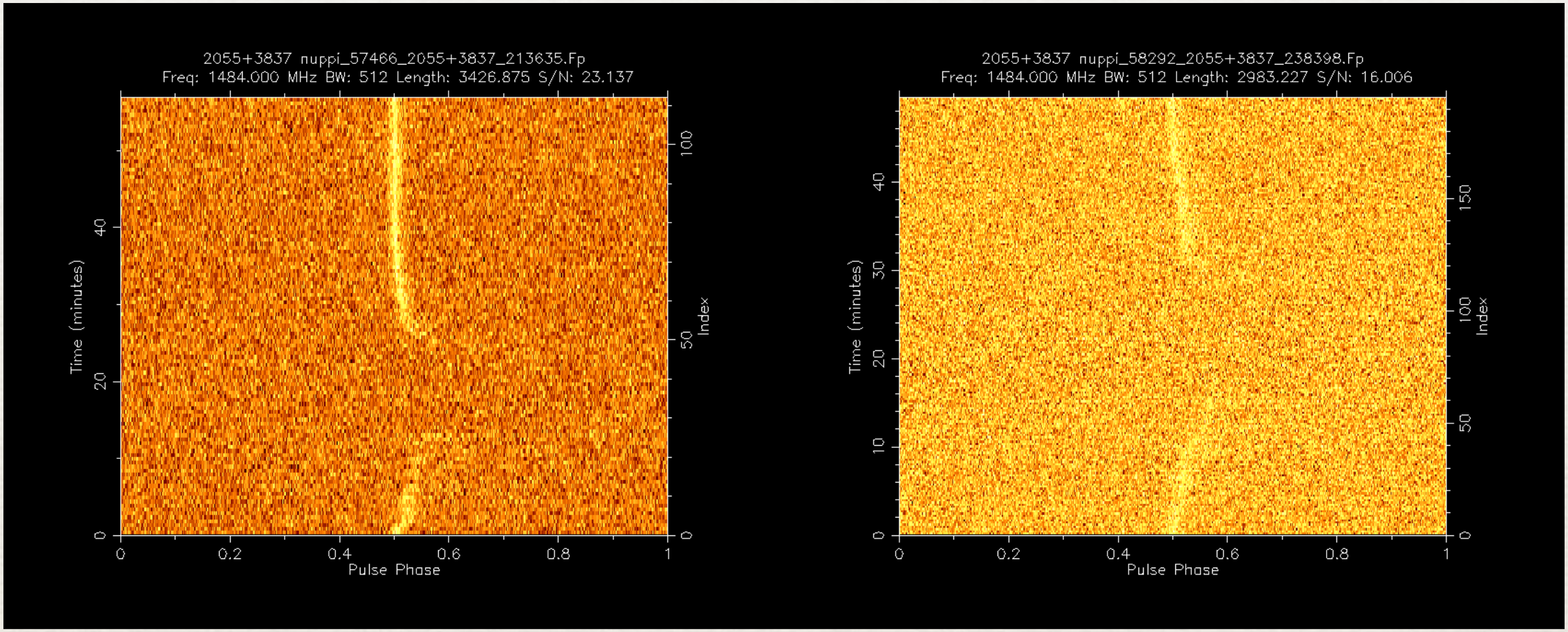


# Radio eclipses

MJD 57466

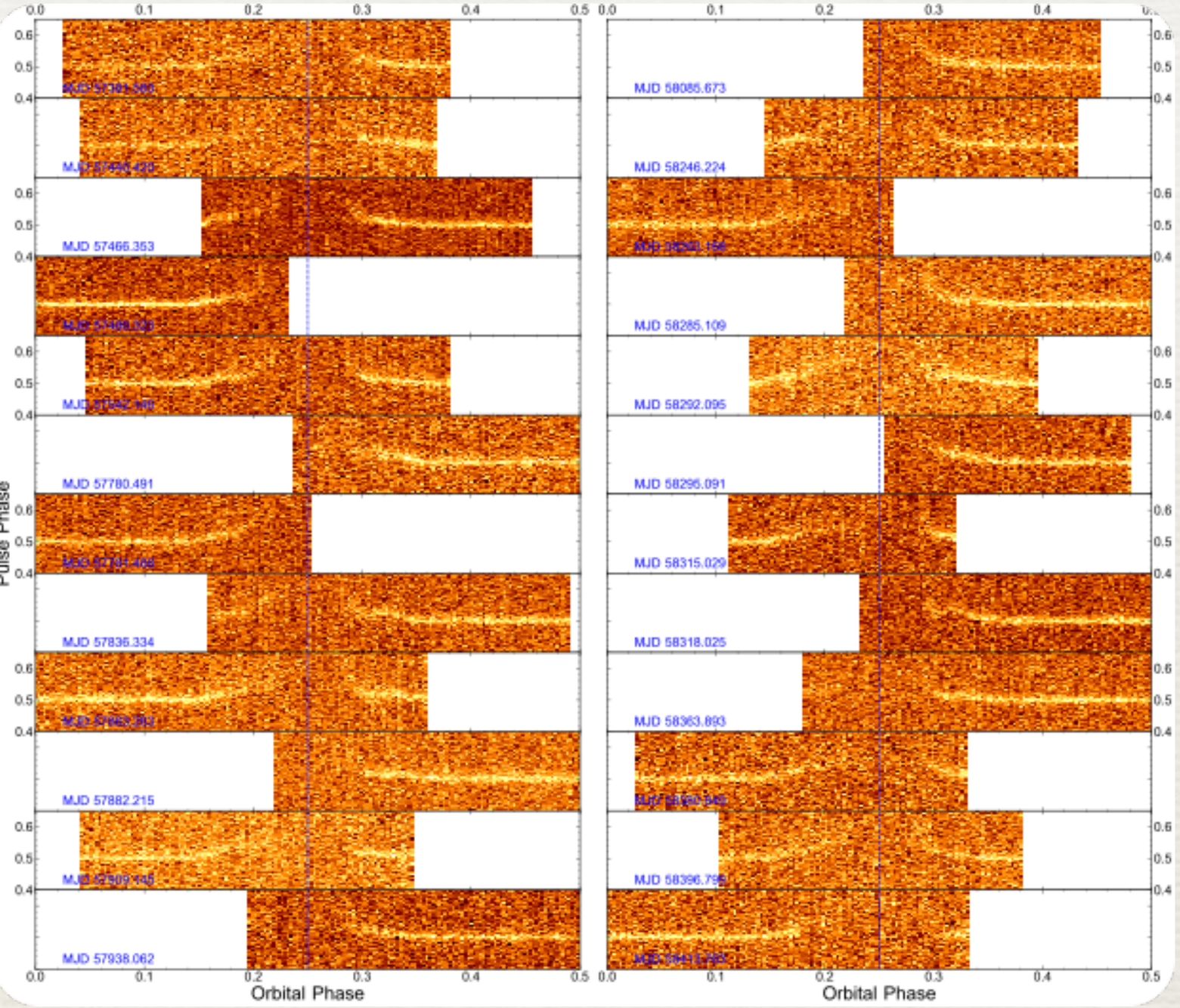
MJD 58292




Examples of 1.4-GHz observations of PSR J2055+3829 at Nançay, around superior conjunction, i.e., when the companion passes between the observer and the pulsar.

Radio eclipses caused by outflowing material from the companion star are observed (as is also commonly observed in other similar systems).

# Radio eclipses (continued)




Left: radio flux density (at 1.4 GHz) as a function of orbital & pulse phase, for a selection of bright detections containing partial or complete eclipse traverses.

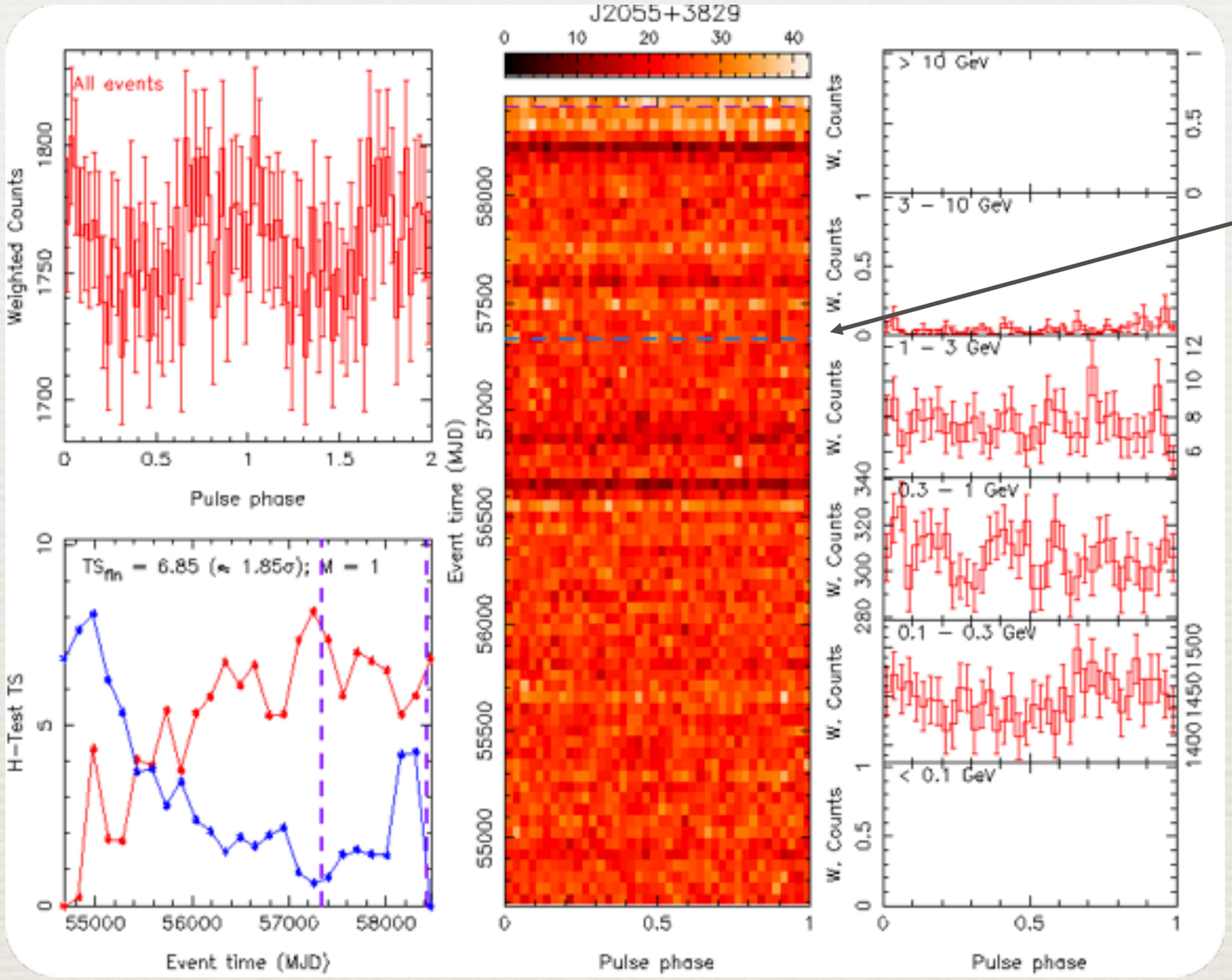
Radio emission completely obscured for a few (~19) minutes around superior conjunction.

Asymmetry of ingress and egress phases, as commonly observed in other eclipsing BW pulsars. Eclipse-to-eclipse variability observed.

Properties of PSR J2055+3829 (Roche lobe radius, orbital period, $\dot{E}/a^2$, etc.) consistent with those of other eclipsing black widows.

Observations at lower frequencies, where dispersive effects are more acute, would be very useful!

# Can we see J2055+3829 in gamma rays?




Start of ephemeris validity interval

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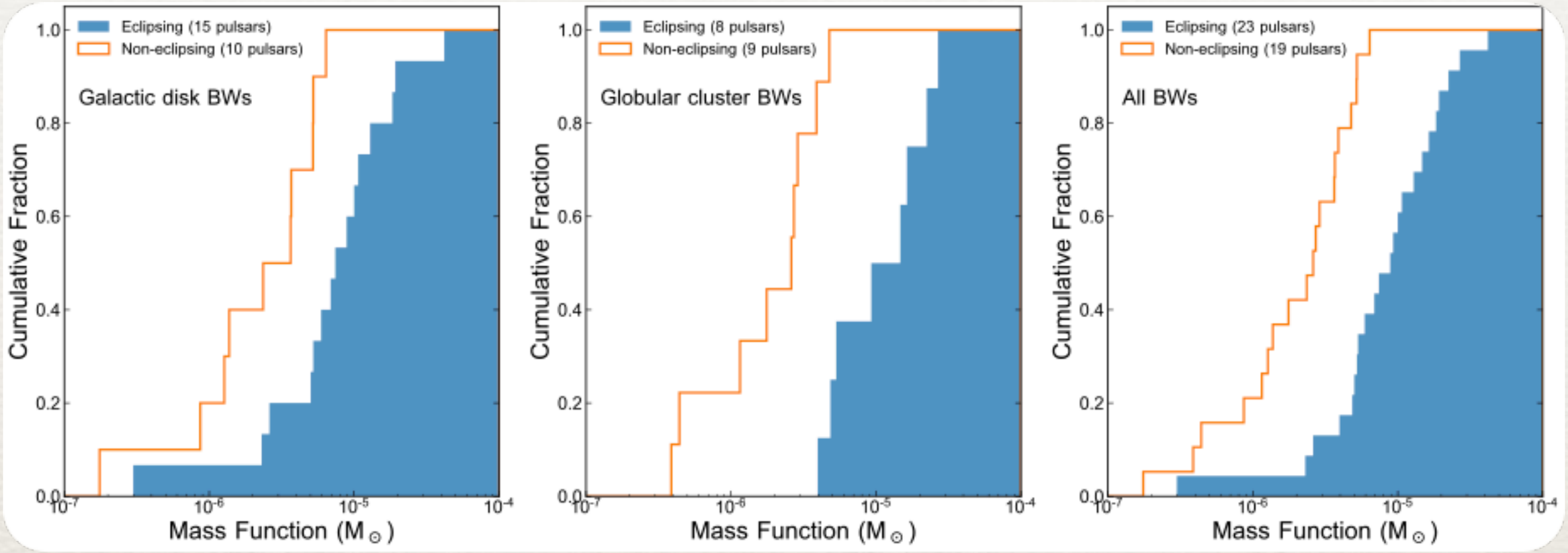
Fermi Gamma-ray Space Telescope

We searched for pulsations in Pass 8 LAT data, using the weighting scheme presented in Bruel et al. (2019) and the search strategy from Smith et al. (2019). No pulsations found!

The Ė of ~3.6e33 erg/s makes J2055 a good gamma-ray candidate. However, DM-derived distances are quite large (4.6 kpc for YMW16, 4.4 kpc for NE2001). Note: no 4FGL source within ~2 deg of the pulsar.

# Mass function of eclipsing & non-eclipsing BWs




$$f(m_p, m_c) = \frac{(m_c \sin i)^3}{(m_p + m_c)^2} = \frac{4\pi}{T_\odot} \frac{(a_p \sin i)^3}{P_b^2}$$

Freire (2005): do eclipsing BWs have larger mass functions?

Many BW discoveries since then! KS tests indicate that mass function distributions are drawn from distinct distributions, with p-values of resp. 1.5%, 0.08% & 0.007%.

Higher (sin i) could explain the larger mass functions of eclipsing BWs. However, non-eclipsing objects seen under low inclinations could have heavier companion.

# Conclusions / Summary

- PSR J2055+3829 is a 2.089-ms pulsar in a tight 3.1-hr orbit around a very low mass companion, discovered in the SPAN512 survey conducted with the Nançay radio telescope. PSR J2055+3829 is a member of the black widow class of pulsars.

- As commonly observed in other black widows with high inclinations, J2055+3829 displays radio eclipses around superior conjunction.

- No pulsations are detected in the LAT data. The Ė parameter makes it a good candidate for a LAT detection but the distance is likely large. Nevertheless, the current timing solution only covers the last ~3 yrs of LAT data.

- Discovery paper to be submitted very soon.

**Thank you!**