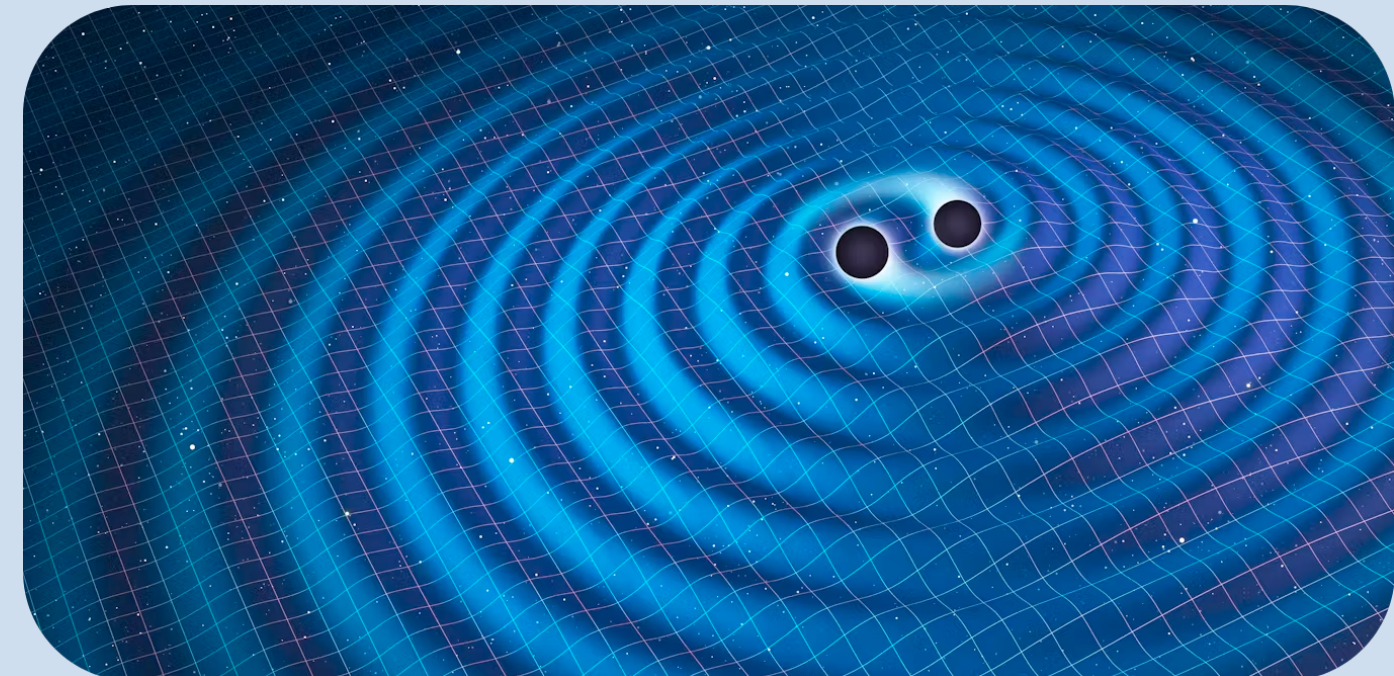


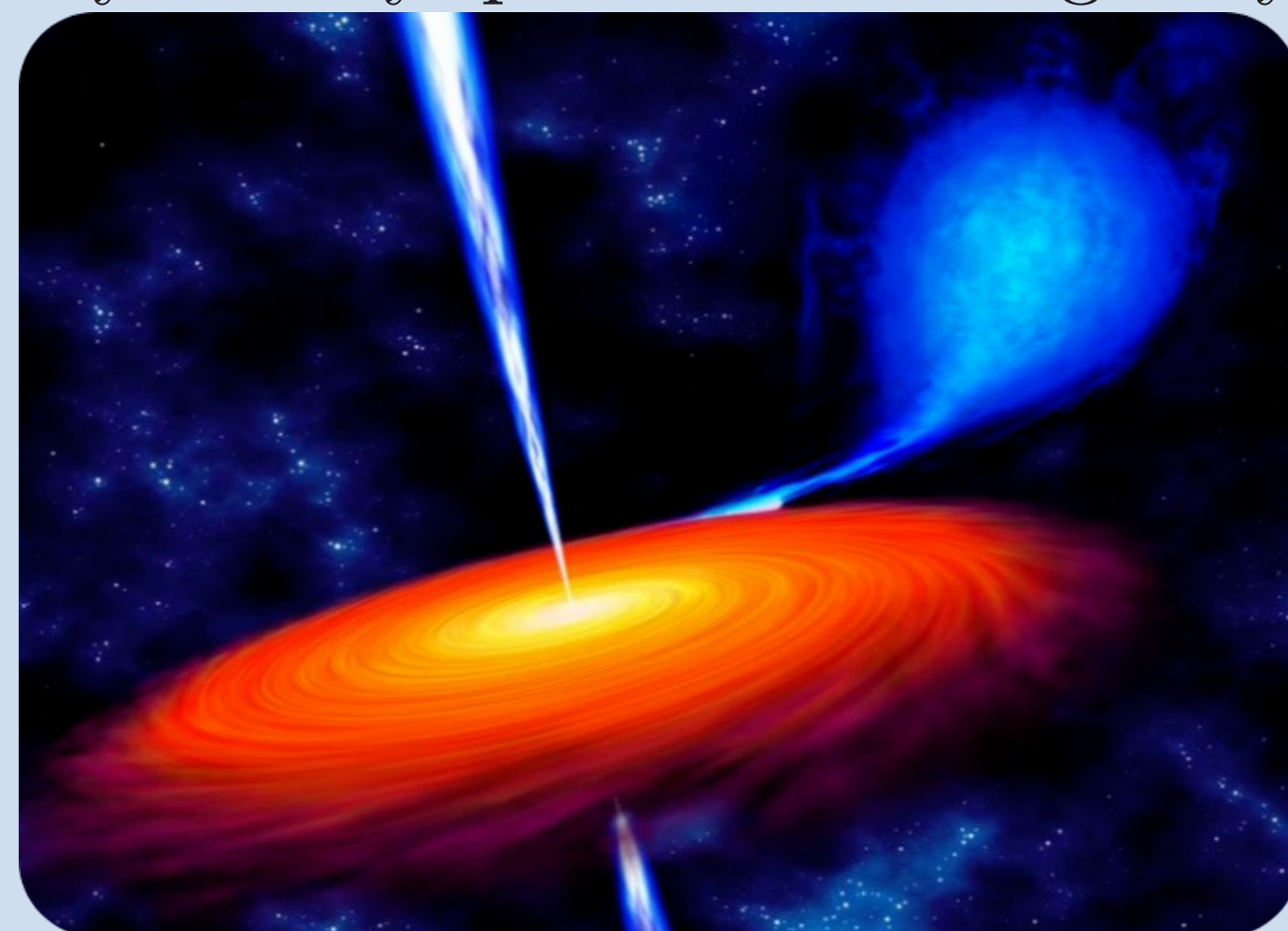
GRAVITATIONAL WAVES AND CONTINUOUS-WAVE EMISSION FROM FAST-SPINNING PULSARS

Gravitational Waves (GWs) are perturbative solutions of the Einstein equations, which propagate at speed c . They can arise from a wide variety of astrophysical and cosmological events.



Our research is focused on **continuous waves (CWs)** emitted by fast-spinning, non-axisymmetric neutron stars (pulsars) in binary systems, i.e., with an orbiting companion.

A rapidly-rotating pulsar emits a persistent, quasi-monochromatic signal: this is possible thanks to the lack of axial symmetry, i.e., deformations of the star. The main target of binary directed searches is **Scorpius-X1**, the brightest low-mass X-ray binary pulsar in our galaxy.



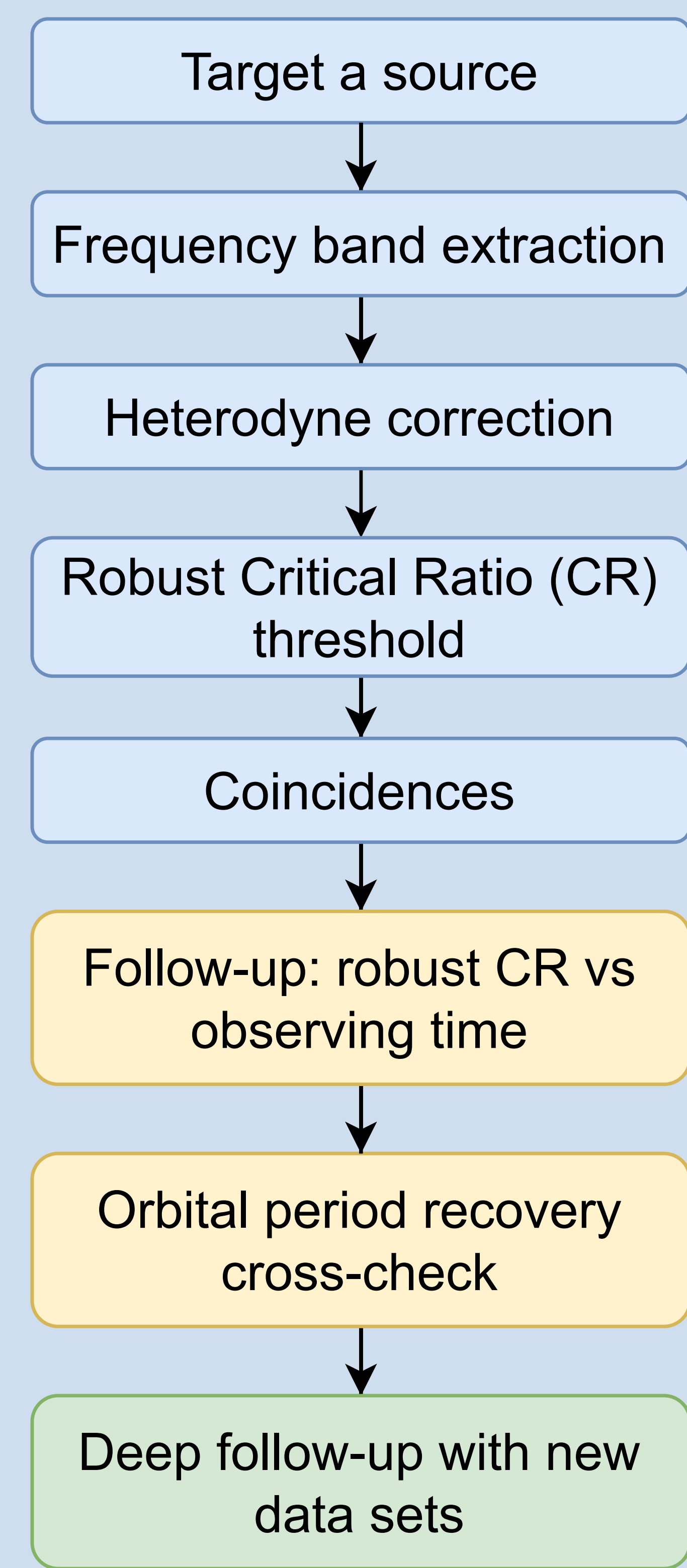
- The signal **frequency** is nearly constant (when no spin-down is present), with an **amplitude**^[1] of $h_0 = \frac{4\pi^2 G}{c^4} f_{GW}^2 \frac{I_3 \epsilon}{r}$
- Traveling from the source to the detector, the signal undergoes several modulations: the received signal is **not** expected to be monochromatic
- **Binary Doppler delay** brings a **double-horn-shaped** shift^[2,3]:

$$\Delta M = \frac{a_p \Omega}{1 - e}$$

PHASE MODEL:

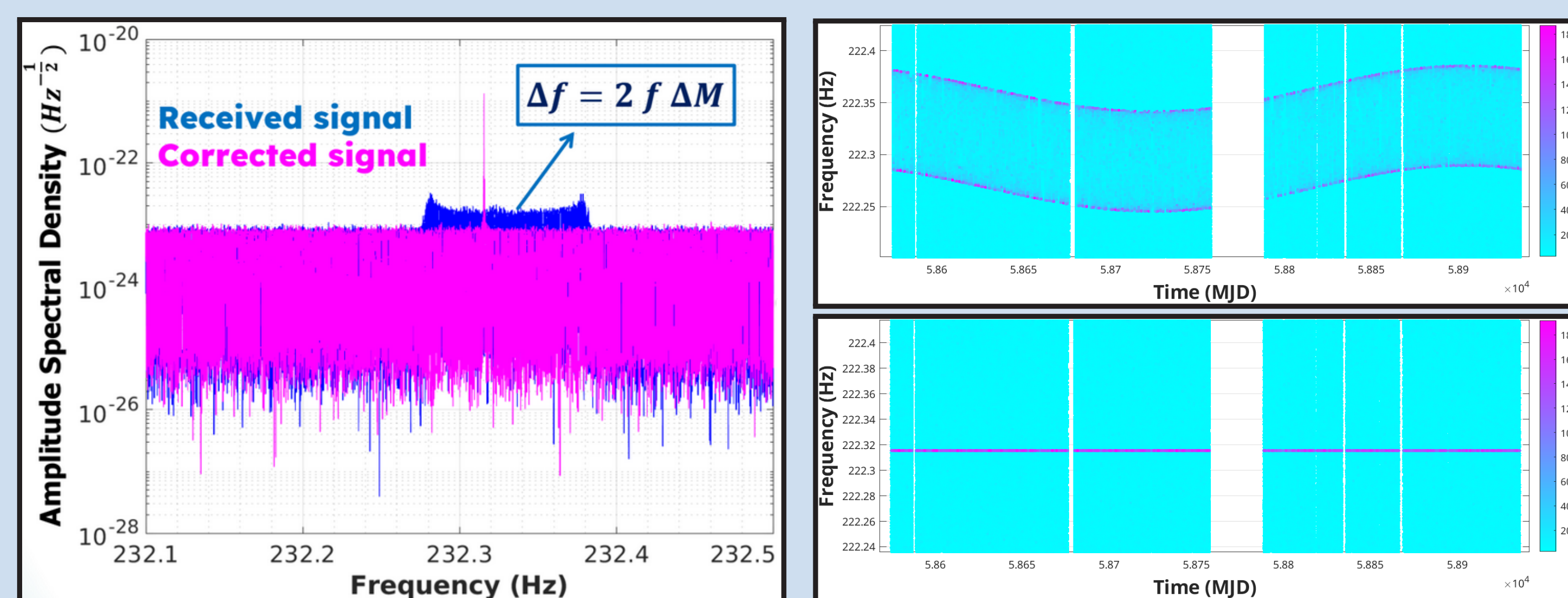
$$\phi(t) = 2\pi f \left(\Delta t - a_p [\sin\omega(\cos E - e) + \cos\omega \sin E \sqrt{1 - e^2}] \right)$$

THE PIPELINE



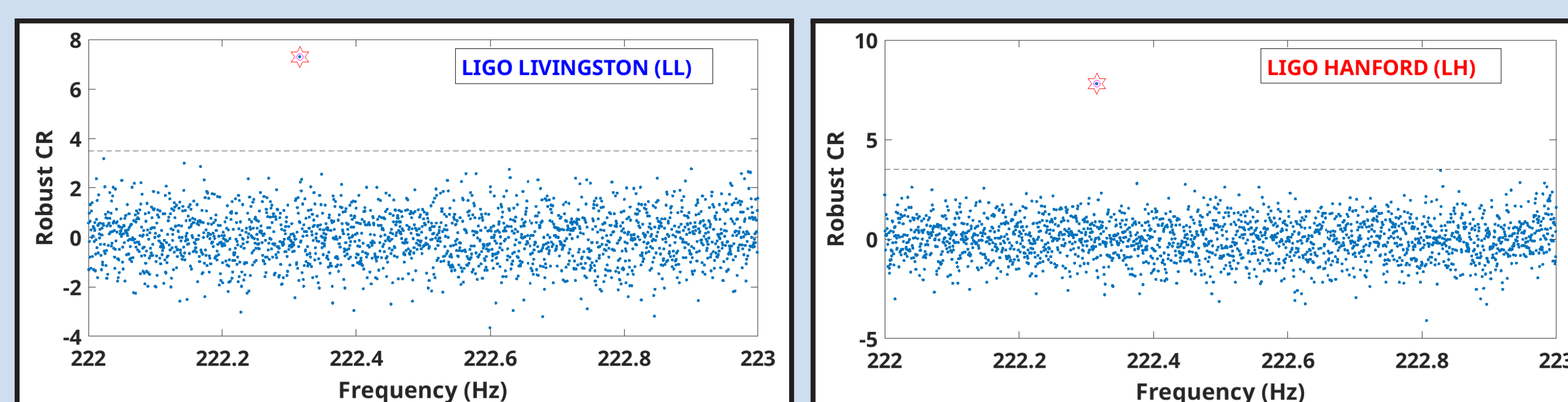
HETERODYNE CORRECTION

Time series data are multiplied for an exponential factor $e^{-i\phi(t)}$: we are removing the modulations to have a monochromatic signal. Data are analyzed in the frequency domain through the creation of time-frequency maps (**peakmaps**)^[5].



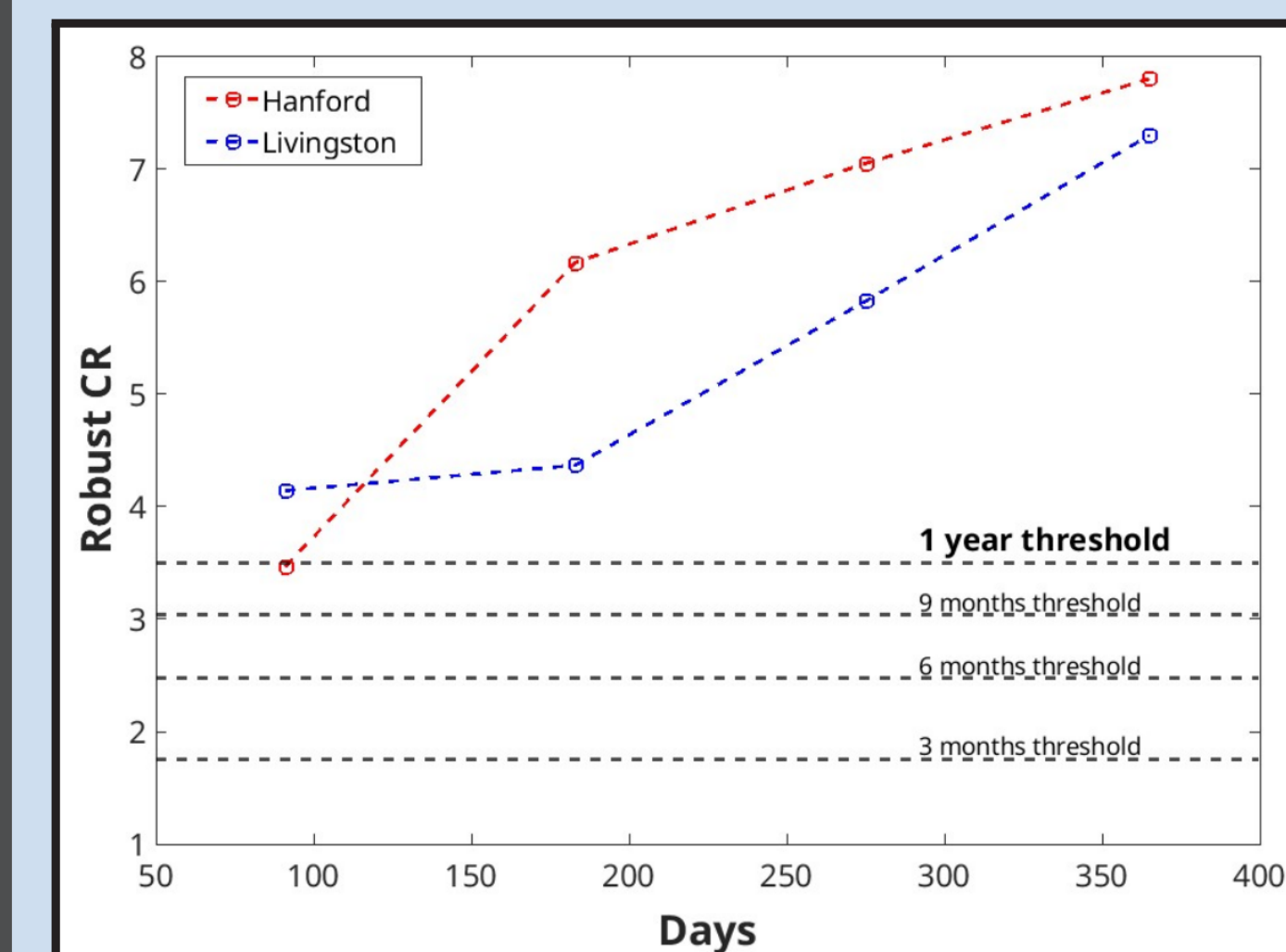
FREQUENCY-DOMAIN ANALYSIS

Peakmaps are projected over the frequency axis and for each peak a **robust CR** is computed, selecting only those crossing a fixed threshold ($\theta_{thr}=3.5$). If a peak crosses θ_{thr} in both detectors (**coincidences**), it undergoes further follow-up, otherwise it is discarded.

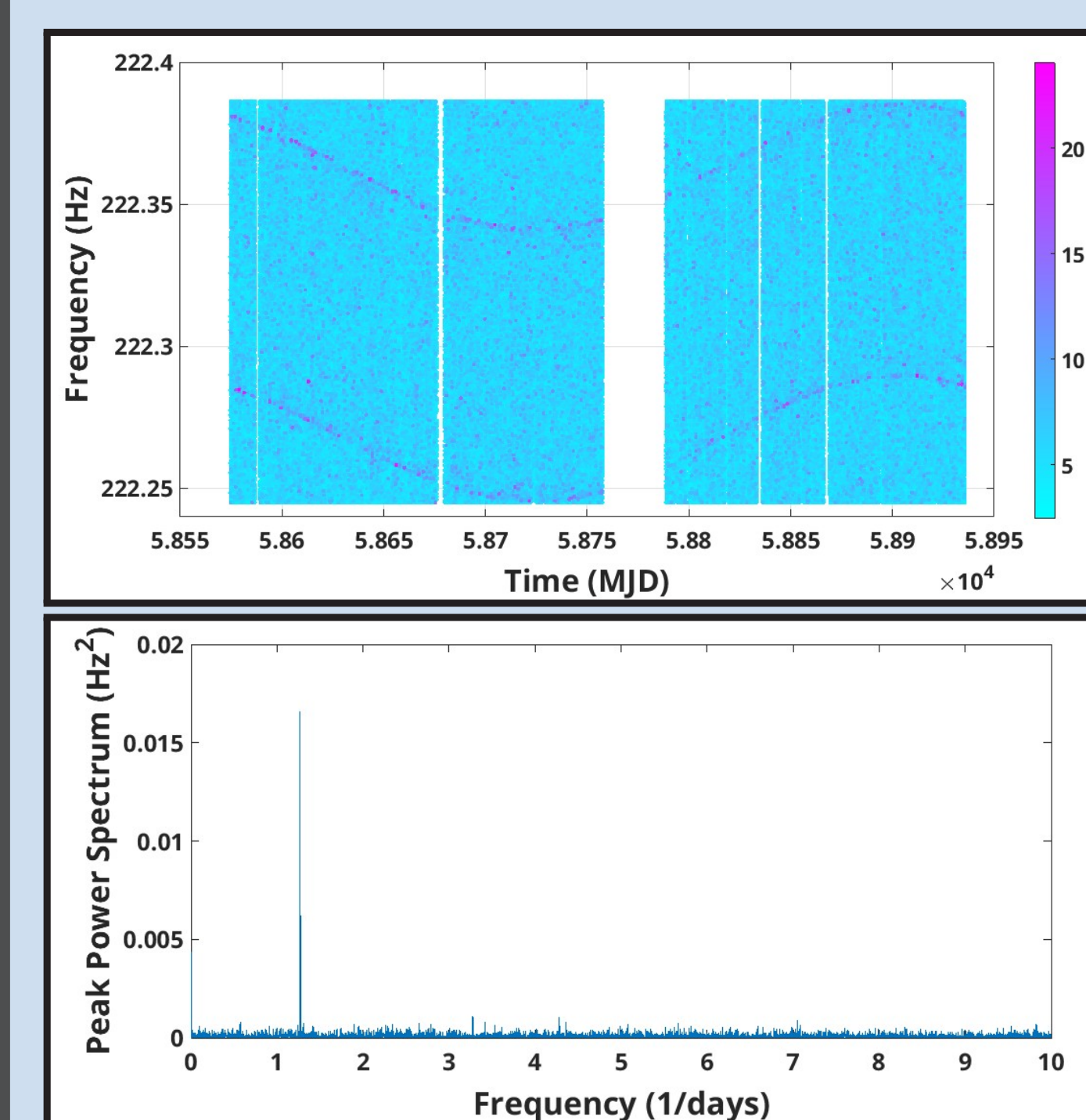


FOLLOW UP

Since robust CR \propto observing time, we exploit this feature by repeating the analysis for different time segments: we check if this trend is monotonically increasing, otherwise the candidate is discarded.



We implemented an **independent** cross-check for the computation of orbital period: starting from the modulated signal, we compute a **peak power spectrum**, whose fundamental harmonics is the inverse of source orbital period^[2].



This estimation can be compared to the targeted source orbital period to corroborate the presence of a signal.

OUTCOMES FROM REAL SEARCH IN O3 DATA

We run the analysis in the [220-230] Hz-band for Scorpius X-1 (left table: tested parameters^[4]; right table: results) and for three ATNF pulsars (J1231-1411, J1802-2124, J1514-4946); no candidates were found.

	Test 1 (central parameters)	Test 2 (‘plus’ offsets)	Test 3 (‘minus’ offsets)
Frequency	[220-230] Hz		
α (°)	244.9794		
δ (°)	-15.6400		
a_p (s)	2.34	3.24	1.44
P (s)	68023.92	68023.94	68023.90
e	0.01	0.011	0.009
t_{osc} (GPS s)	1078153676	1078153709	1078153643
ω °	45.0	45.1	44.9

	θ_{thr}	Peaks over threshold		Candidates in coincidence	First follow-up
		Livingston	Hanford		
Test 1	3.5	11	10	0	0
	2	529	544	13	0
Test 2	3.5	8	15	0	0
	2	355	479	11	0
Test 3	3.5	9	9	0	0
	2	523	519	11	0

ONGOING PROJECTS

- Real search on O4 data for Scorpius X-1 and other ATNF interesting targets;
- Scorpius X-1 sensitivity estimation.

REFERENCES

- [1] Maggiore, 2007 [4] Killestein et al., 2023
 [2] Leaci et al., 2017 [5] Astone et al., 2010
 [3] Leaci & Prix, 2015

