university of groningen / faculty of mathematics and natural sciences / kapteyn astronomical institute

Search for a spectral cutoff and periodic signal from a radio brown dwarf binary

or (the unexpected virtue of non-detections)

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ASTRON
Netherlands Institute for Radio Astronomy

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Why study brown dwarfs in radio?

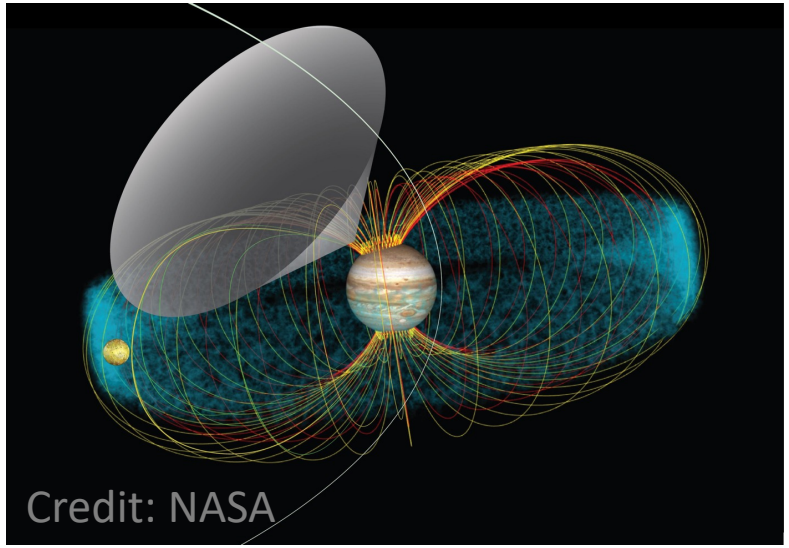
“cuz it’s cool.”

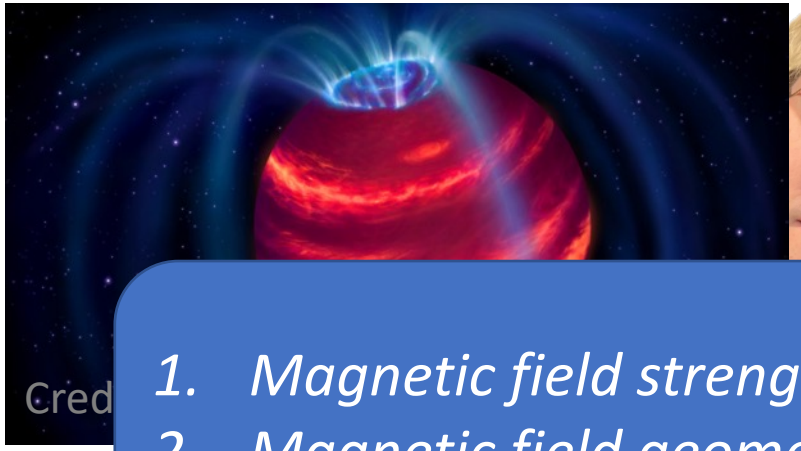
Check out my poster in the library!

- Charges moving in magnetic fields emit in radio wave

  $\Longrightarrow$Excellent probe of magnetospheric acceleration mechanis

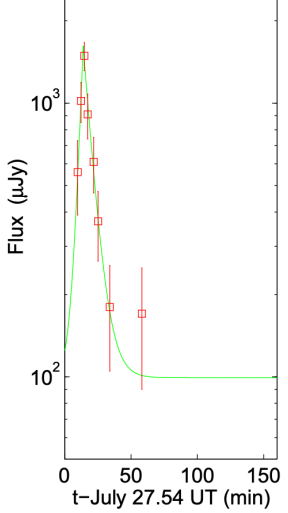
- Allow us to study magnetospheres of brown dwarfs and gas-giant plane



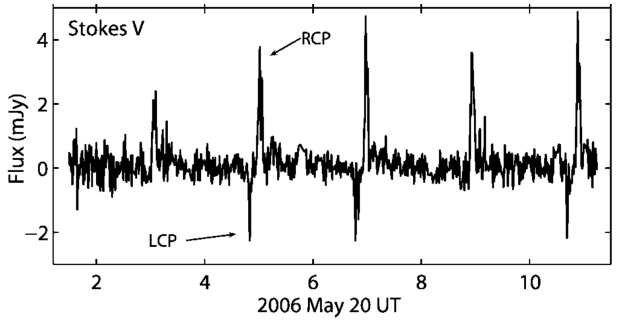


1. *Magnetic field strength of brown dwarfs*
2. *Magnetic field geometry*
3. *“Star”-planet interactions*

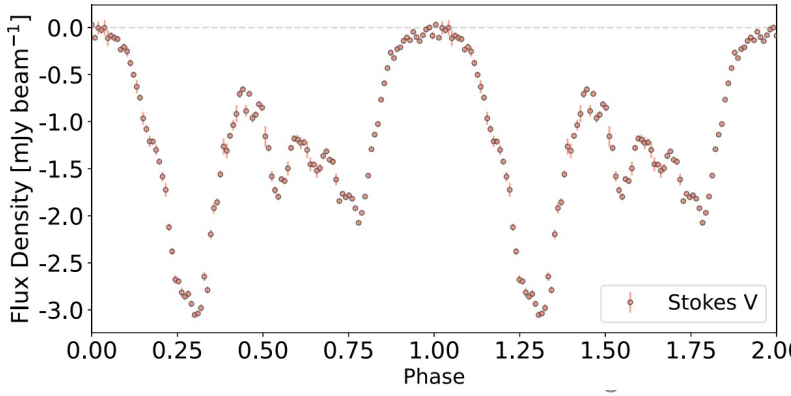
History of radio brown dwarf



- First radio brown dwarf discovered by Berger+ 2001
- Jupiter-like radio pulses (Hallinan+ 2007, 2008, 2015; Route & Wolszczan 2012, 2016; Williams+ 2017)



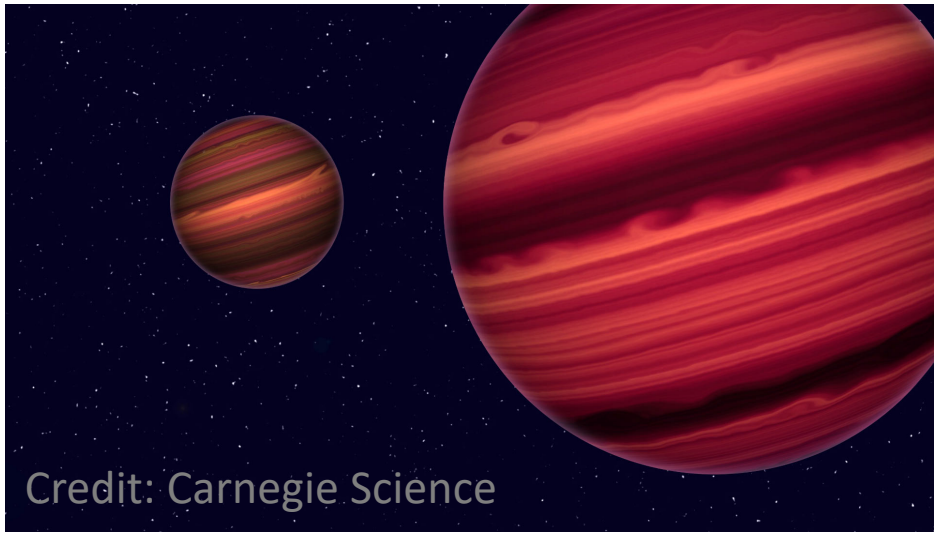
- kG-field in brown dwarfs (Kao+ 2016, 2018)
- Coldest (T8) radio brown dwarf to date (Rose+ 2023)

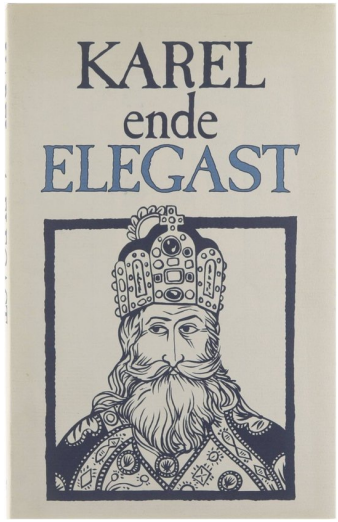


- I hope I can be on here someday…

What is J1019? Fact sheet

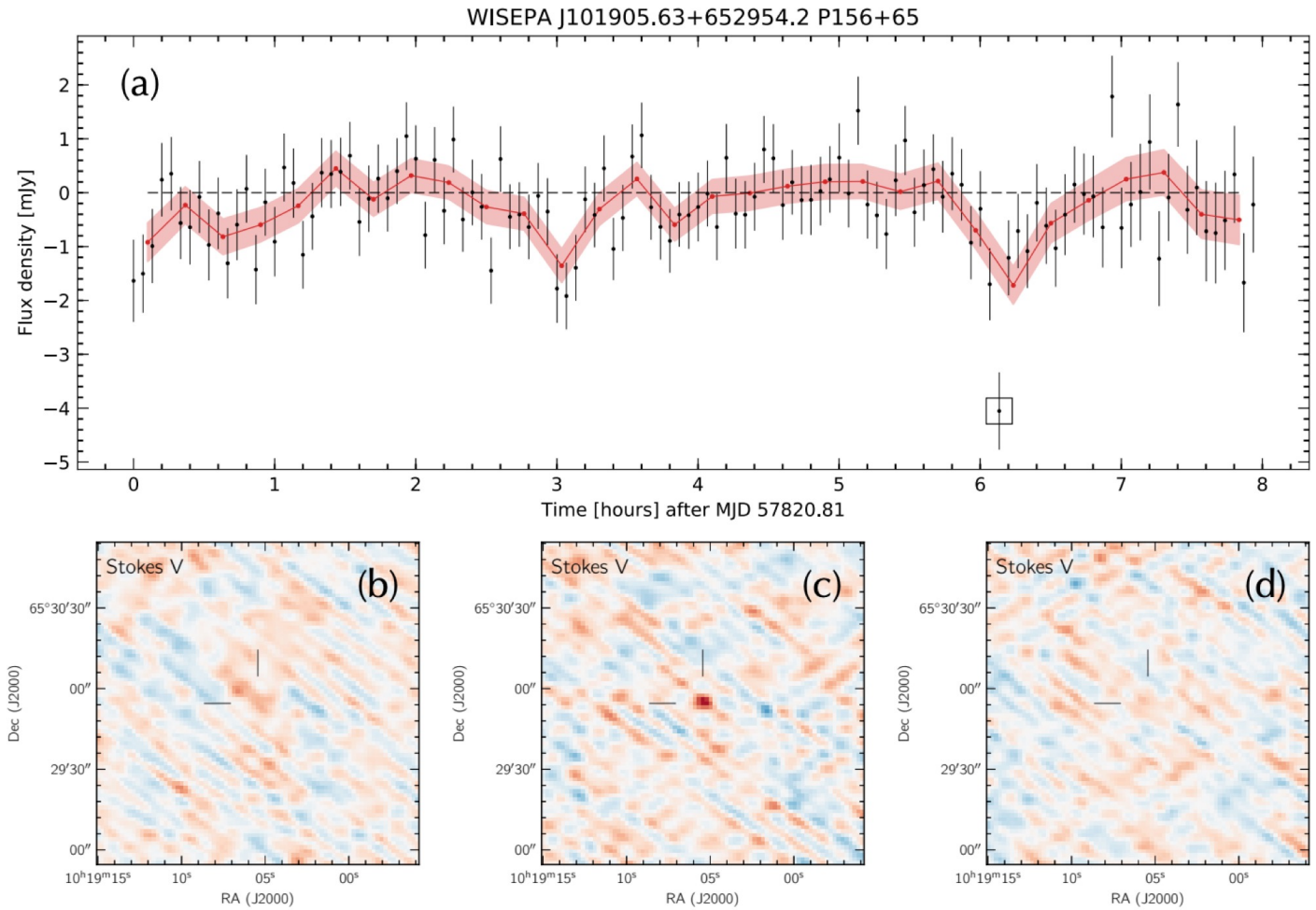
- Full name: WISEP J101905.63+652984.2
- Brown dwarf binary
- Both T dwarfs (T5.5 and T7.0)
- Not too far away: ~23pc
- Second LOFAR-detected brown dwarf, with the first being

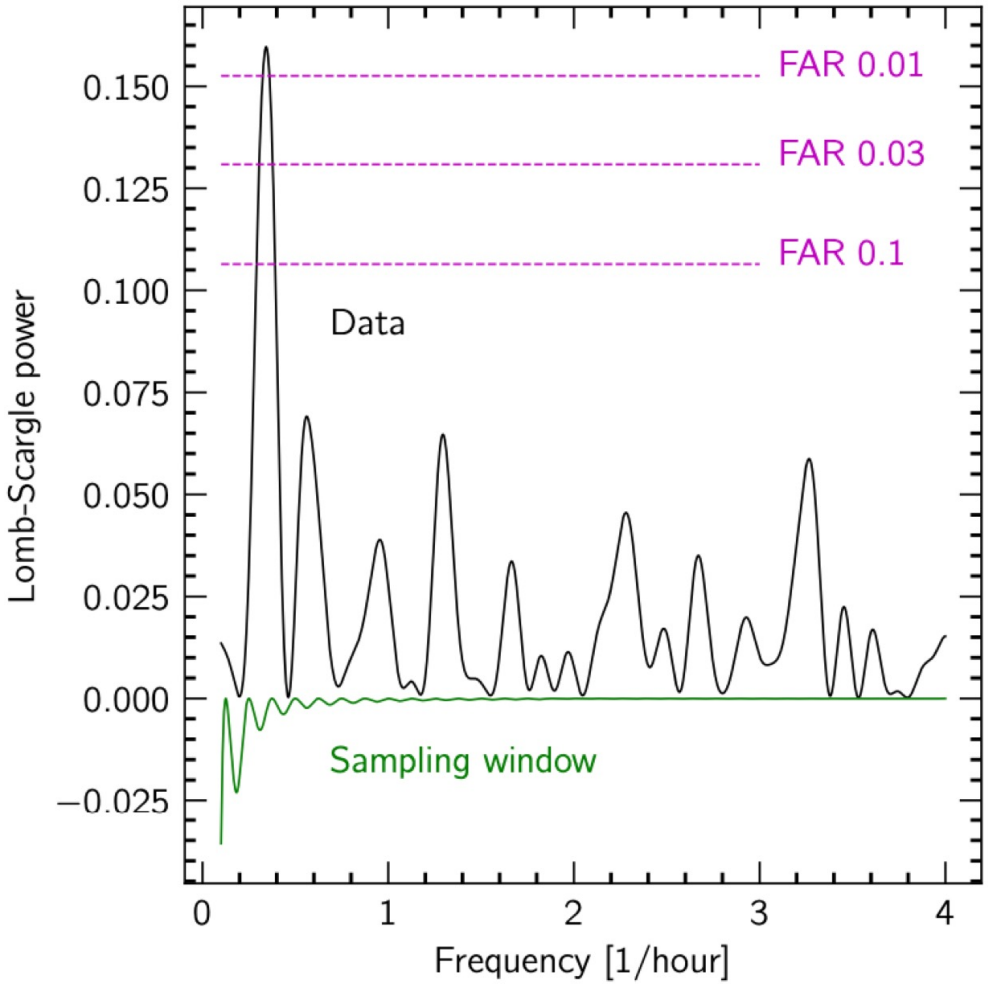




Vedantham+ 2020, 2023

Original paper: Vedantham+2023



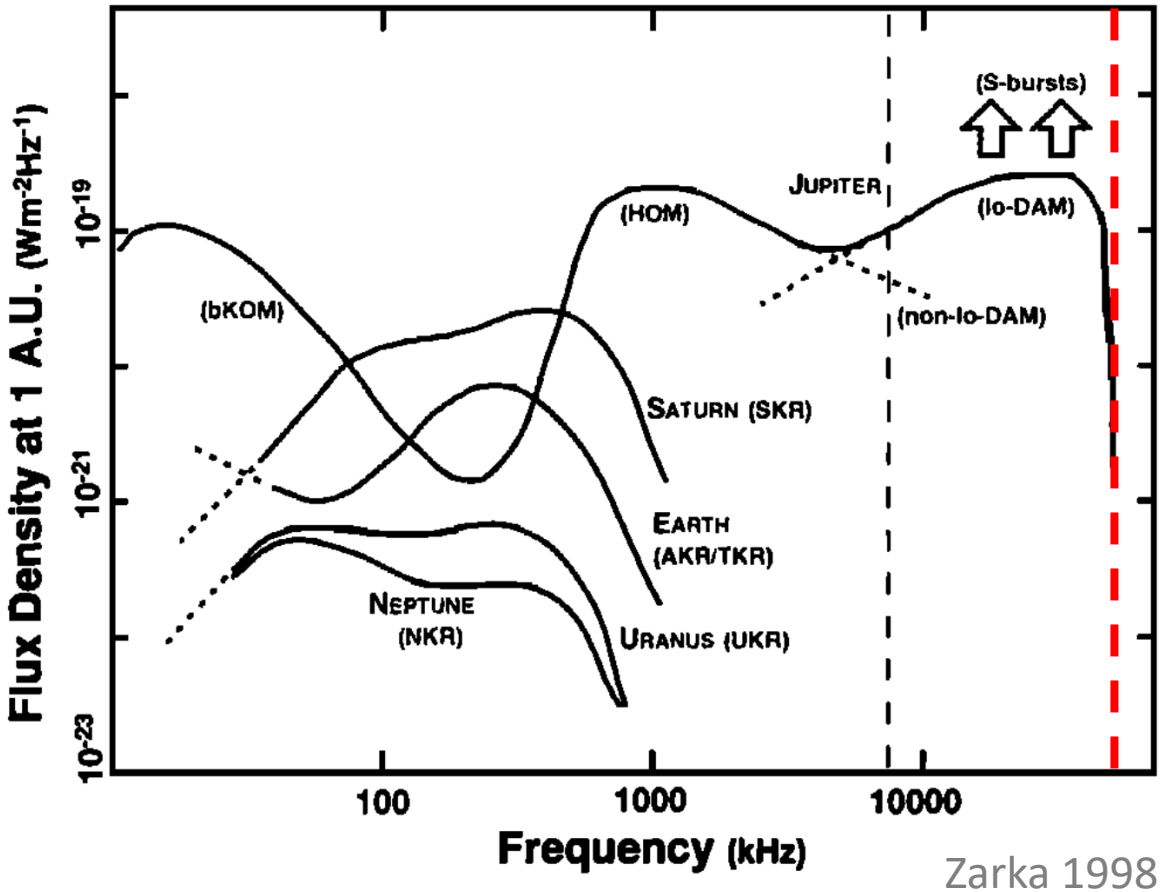


- Strongly circularly polarised (V/I~100%)! Also repeating at ~3h.

What makes J1019 special?

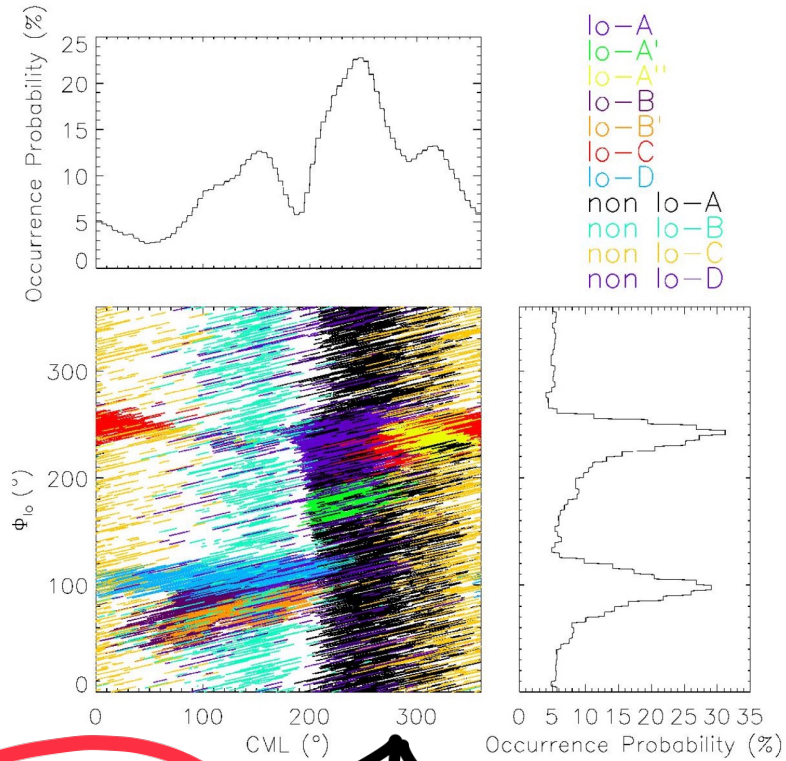
- Untargeted radio sky survey ⇒ unbiased!
- Binary ⇒ mass constraints!
- Highly circularly polarised ⇒ ECME
- ECME cuts off at $f_B = 2.8\ B_{\max}\ \mathrm{MHz}$
- Cutoff ⇒ B-field strength ⇒ Validating full-convective dynamo models!

~40 MHz



Zarka 1998

Big ide



Marques+ 2017

Spectral cutoff & Pulse tracking

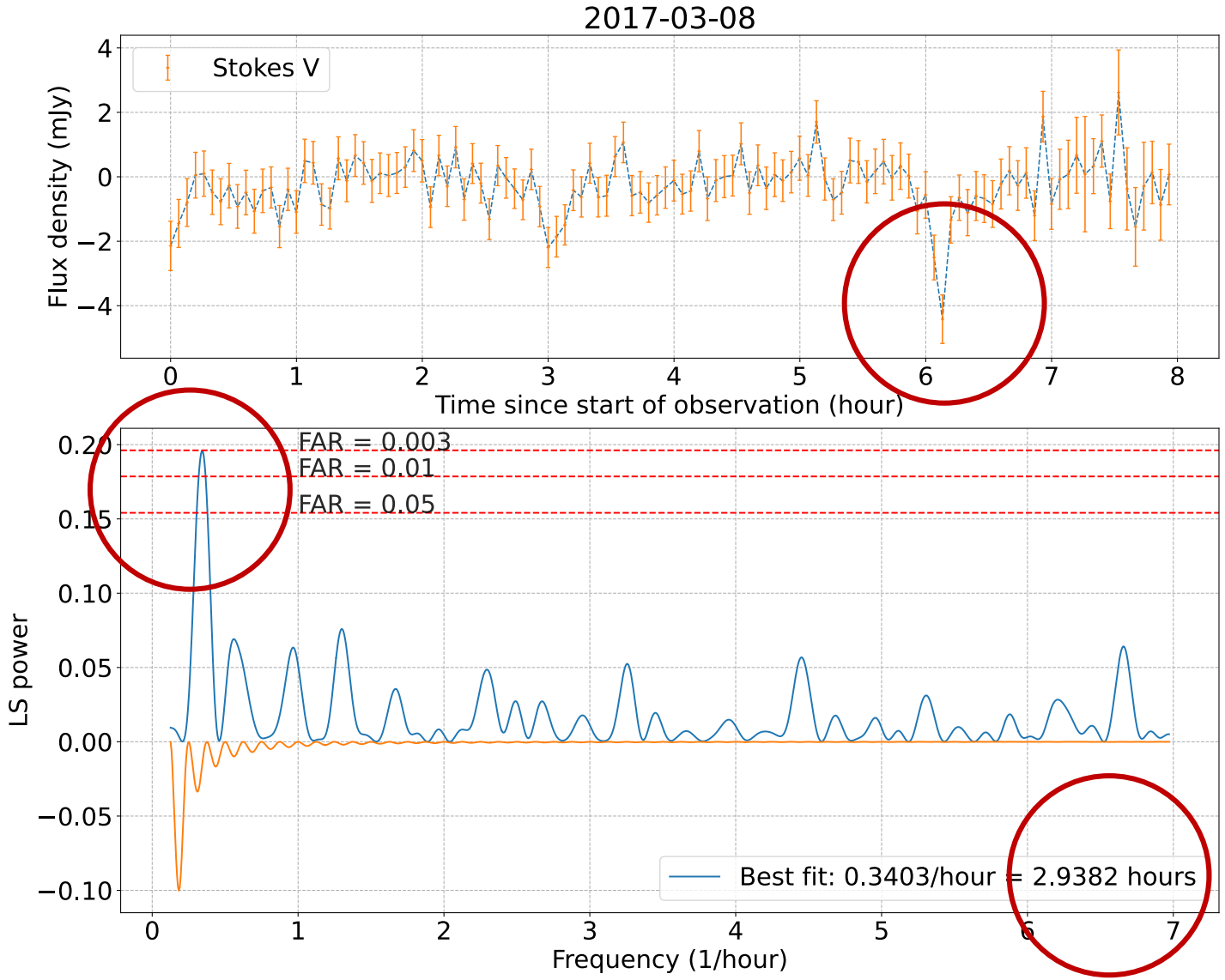
- Dynamo models (Baraffe+ 2003, Christensen+ 2009) predict a cutoff at L-band (1-2 GHz): VLA!
- Spectral cutoff: GMRT+LOFAR (near-)simultaneous observation
- Pulse tracking: Additional LOFAR observations

Me back then:

Data, data, and more data

- Original LoTSS DR2 epoch: 2017-03-08
- Now, we have 10 LOFAR follow-up observations (mainly between December 2022 – March 2023)
- Two of which has GMRT observing (near-)simultaneously
  - Band-4 (550 – 850 MHz) on 2023-01-24
  - Band-3 (250 – 500 MHz) on 2023-03-08
- VLA epoch: 2023-04-22

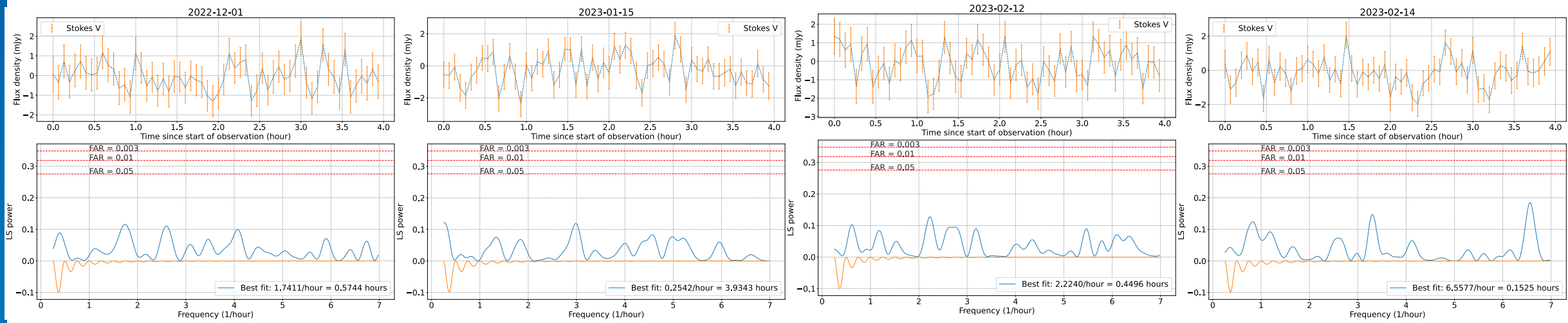
Before results: recap



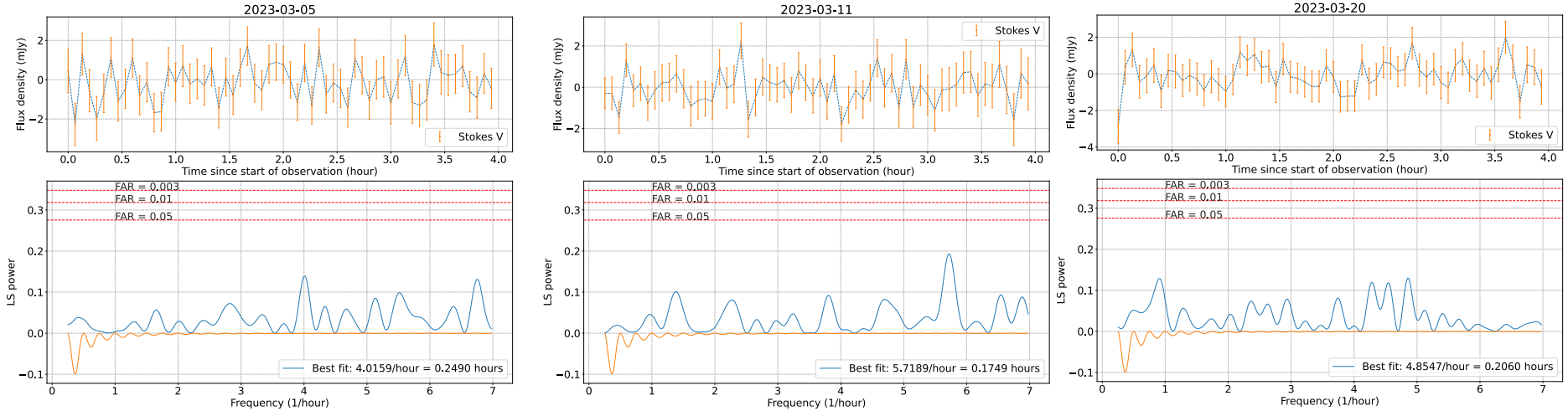
Results: analysing every epoch

“This is fun.”

Yiu+ in prep. × 13



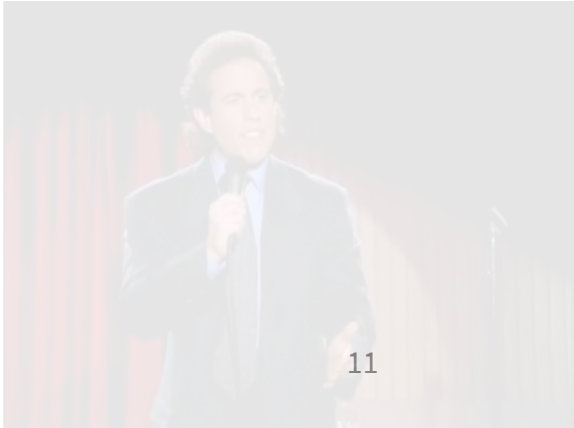
I will spare you the pain.



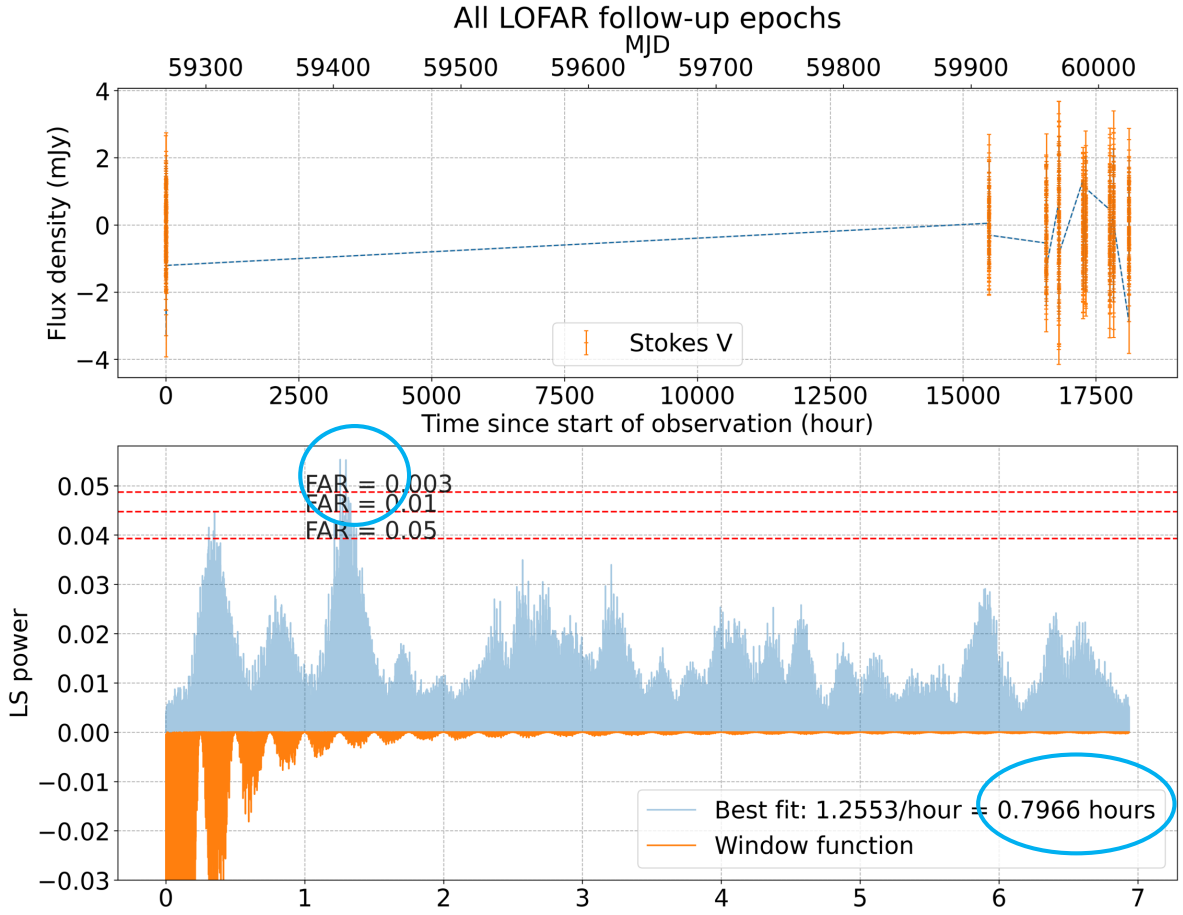
Non-detections galore

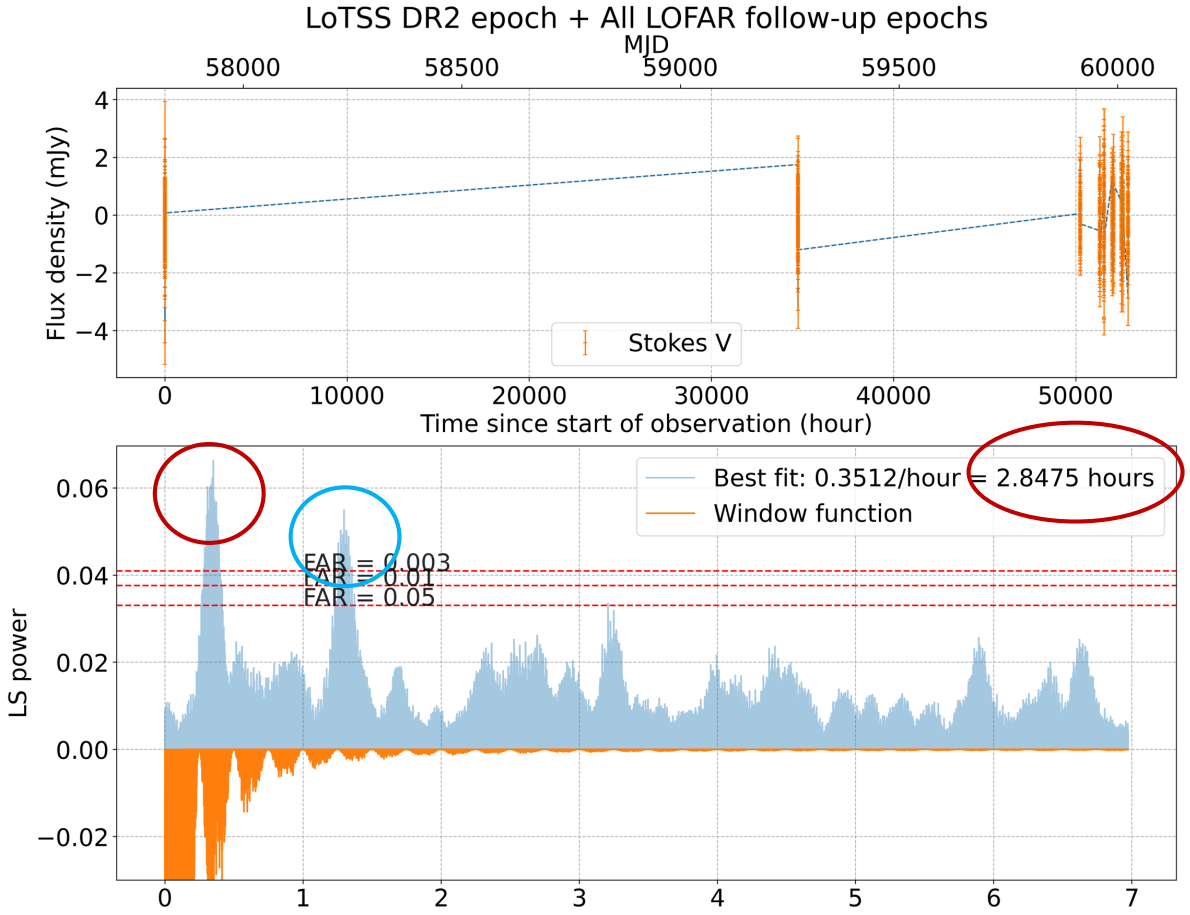
- No pulse as strong as the original 4-mJy pulse in all 10 LOFAR follow-up observations.
- Same with GMRT and VLA: no detections.
- Period signature not strong enough to be confident (FAR too high)
- “What’s the deal w

Cross-epoch analysis



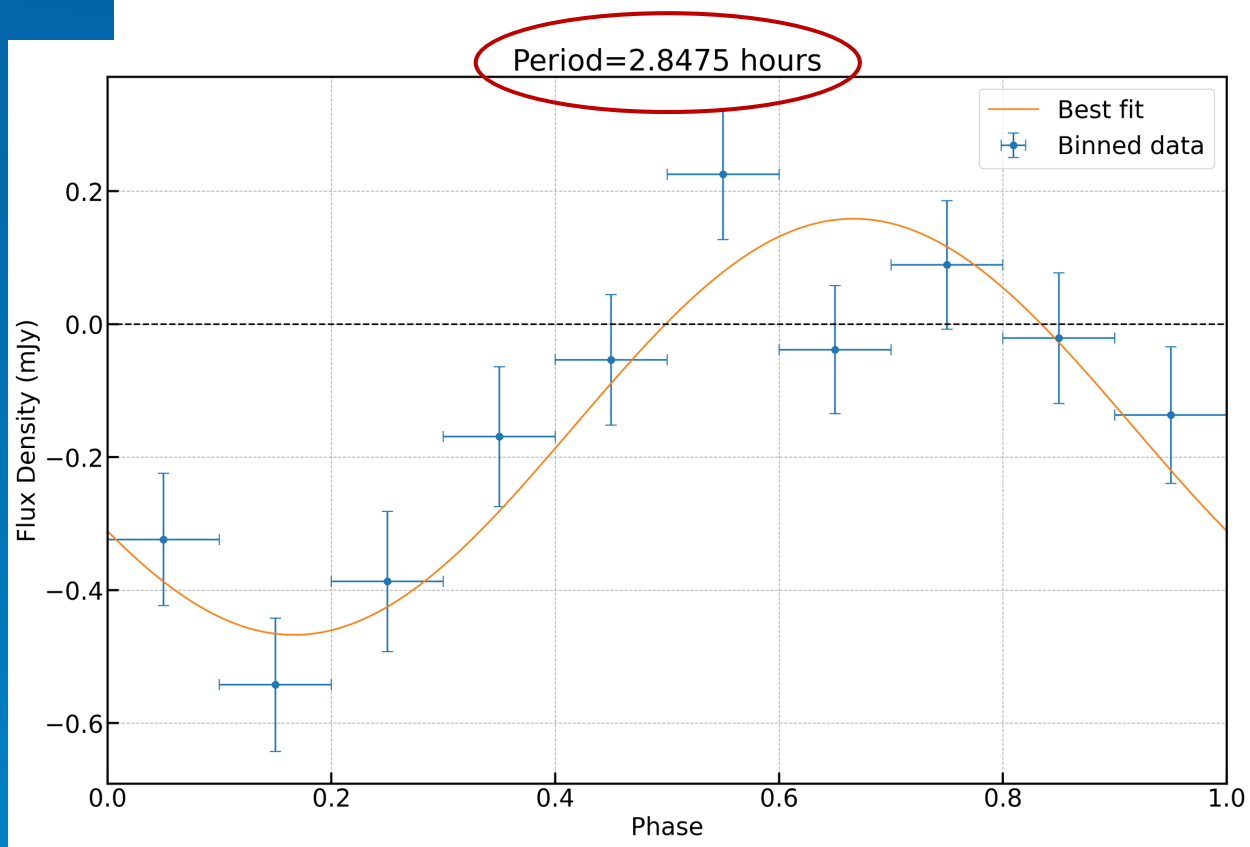
Cross-epoch analysis

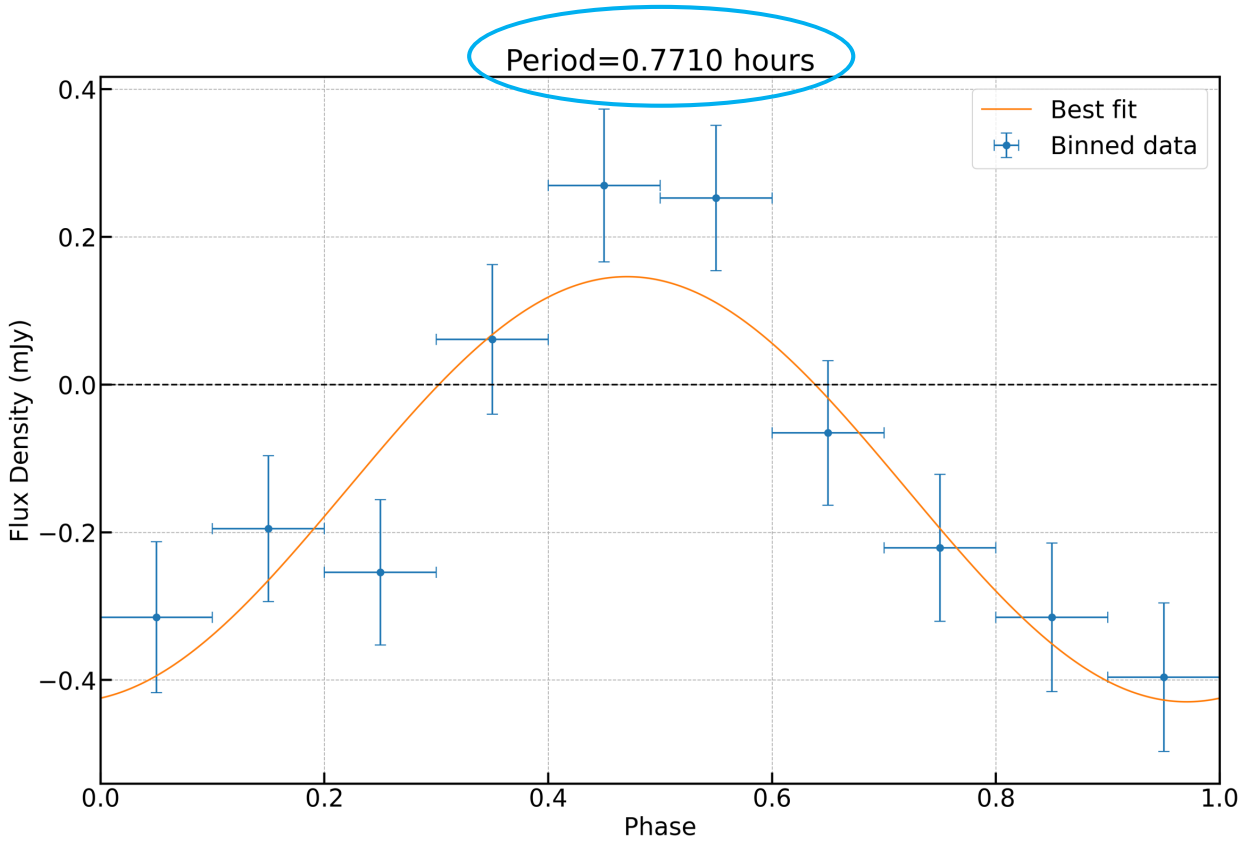




Besides the original 3h period, a new 0.8h period appeared!

Phasefolded light curve



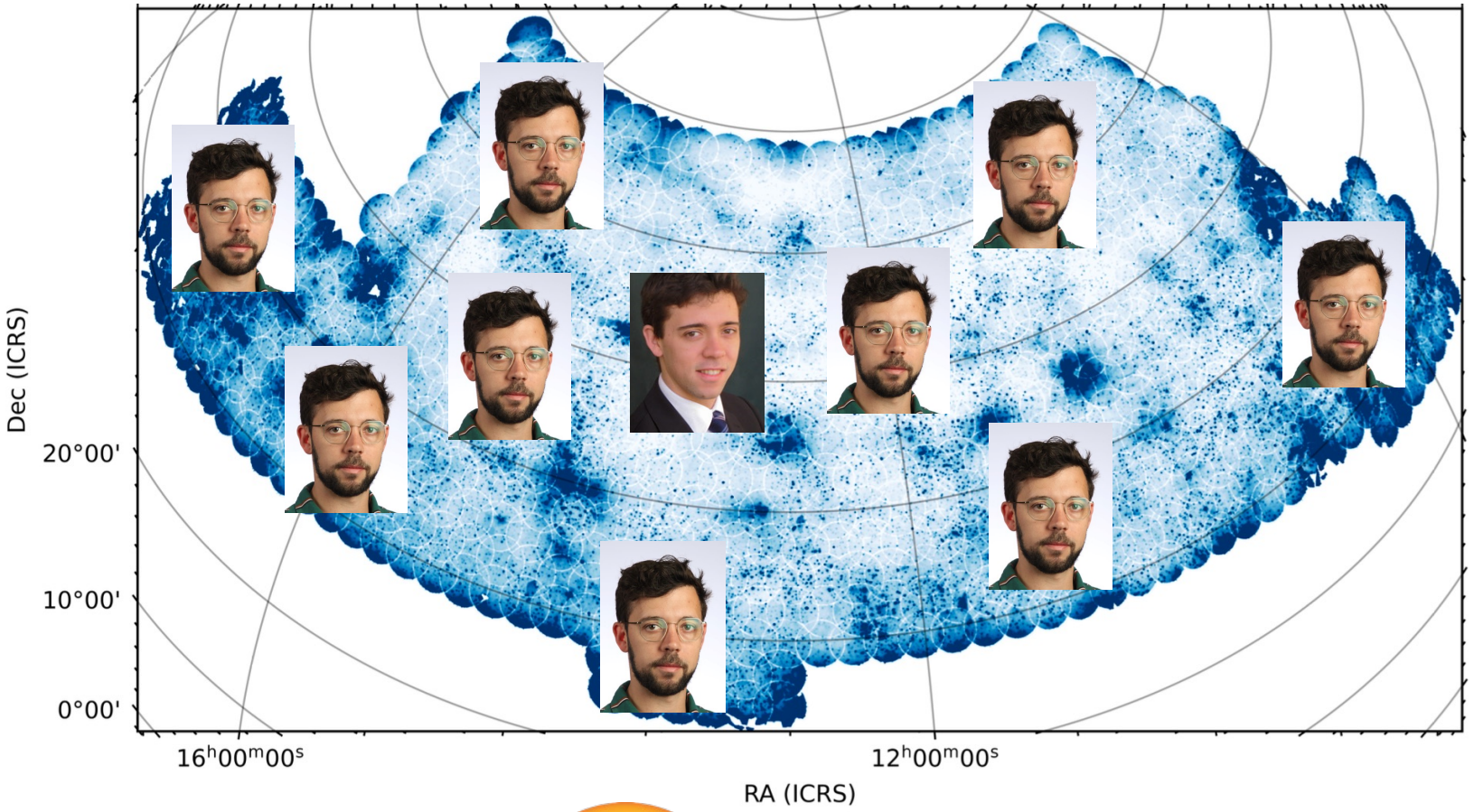


The unexpected virtue of non-detections

- There are 106 brown dwarfs within 25pc in LoTSS DR2 footprint (Best+ 2024)
- Beaming ⇒ Only ~10% of them are ever visible to us (Zarka+ 2004)
- Only 1 brown dwarf (J1019) detected from LoTSS DR2

How “special” is J1019 really?

The unexpected virtue of non-detections




= detected


= not detected

Poisson:

$$P(F,R) = \frac{\lambda^k e^{-\lambda}}{k!}$$

$$\lambda = 10.6 \times F \times R$$

F = Fraction of radio-loud brown dwarfs

R = Activity of a brown dwarf

The unexpected virtue of non-detections

- From LoTSS DR2: $k = 1$

$$P(F, R) = \frac{\lambda^k e^{-\lambda}}{k!}$$

$$\lambda = 10.6 \times F \times R$$

- 10 LOFAR follow-ups all yield non-detections

High F, low R
⟹ J1019 is not special

The unexpected virtue of non-detections

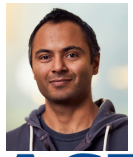
Our target can either be detected or not detected in these 11 observations:

Observer:

Binomial:

$$P(R) = \binom{n}{x} R^x (1-R)^{n-x}$$

= detected



= not detected

R = Duty ratio of a brown dwarf

The unexpected virtue of non-detections

- From LoTSS DR2: $k = 1$

$$P(F, R) = \frac{\lambda^k e^{-\lambda}}{k!}$$

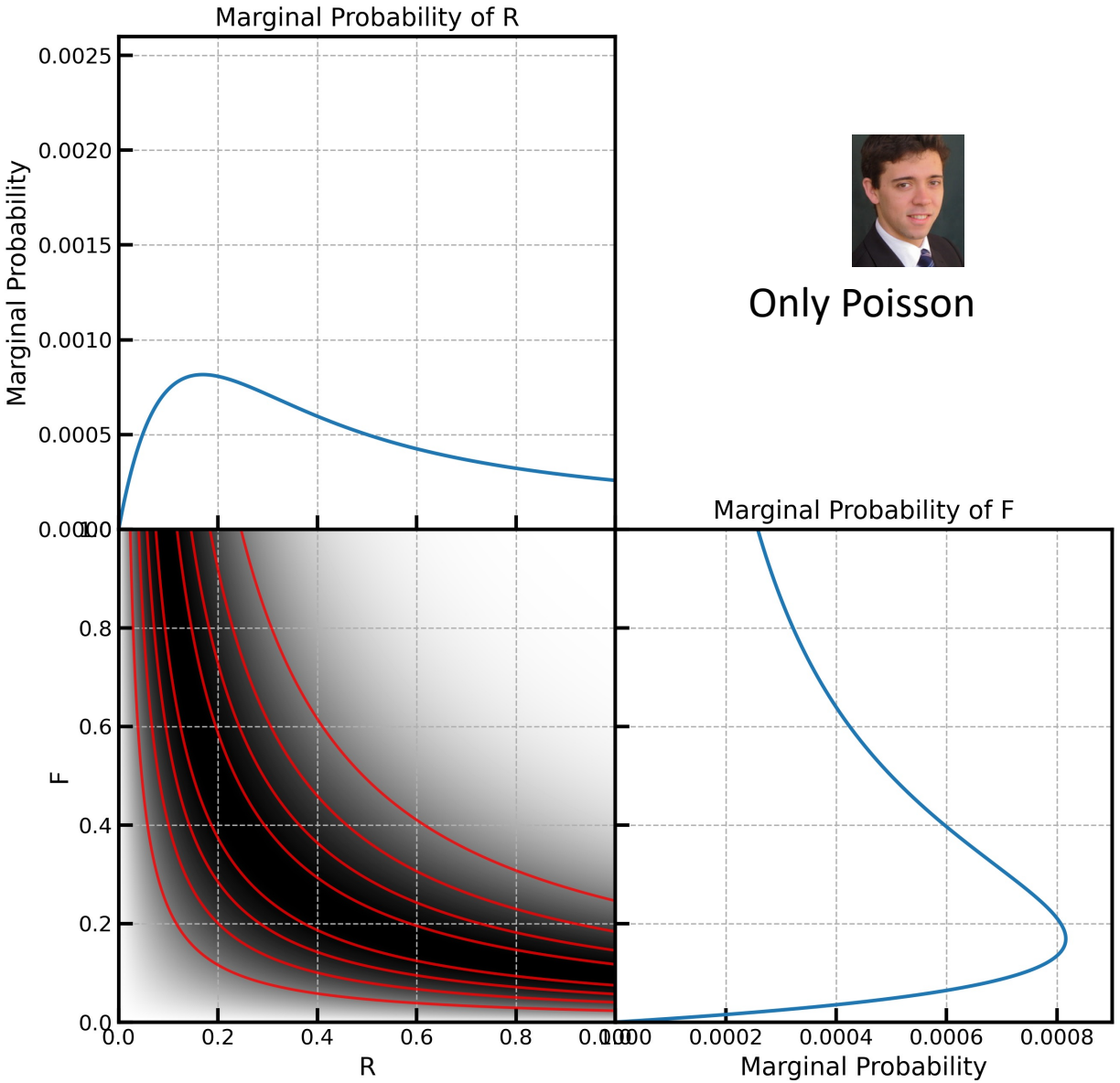
$$\lambda = 10.6 \times F \times R$$

- From follow-up observations: $n = 11, x = 1$

$$P(R) = \binom{n}{x} R^x (1 - R)^{n-x}$$

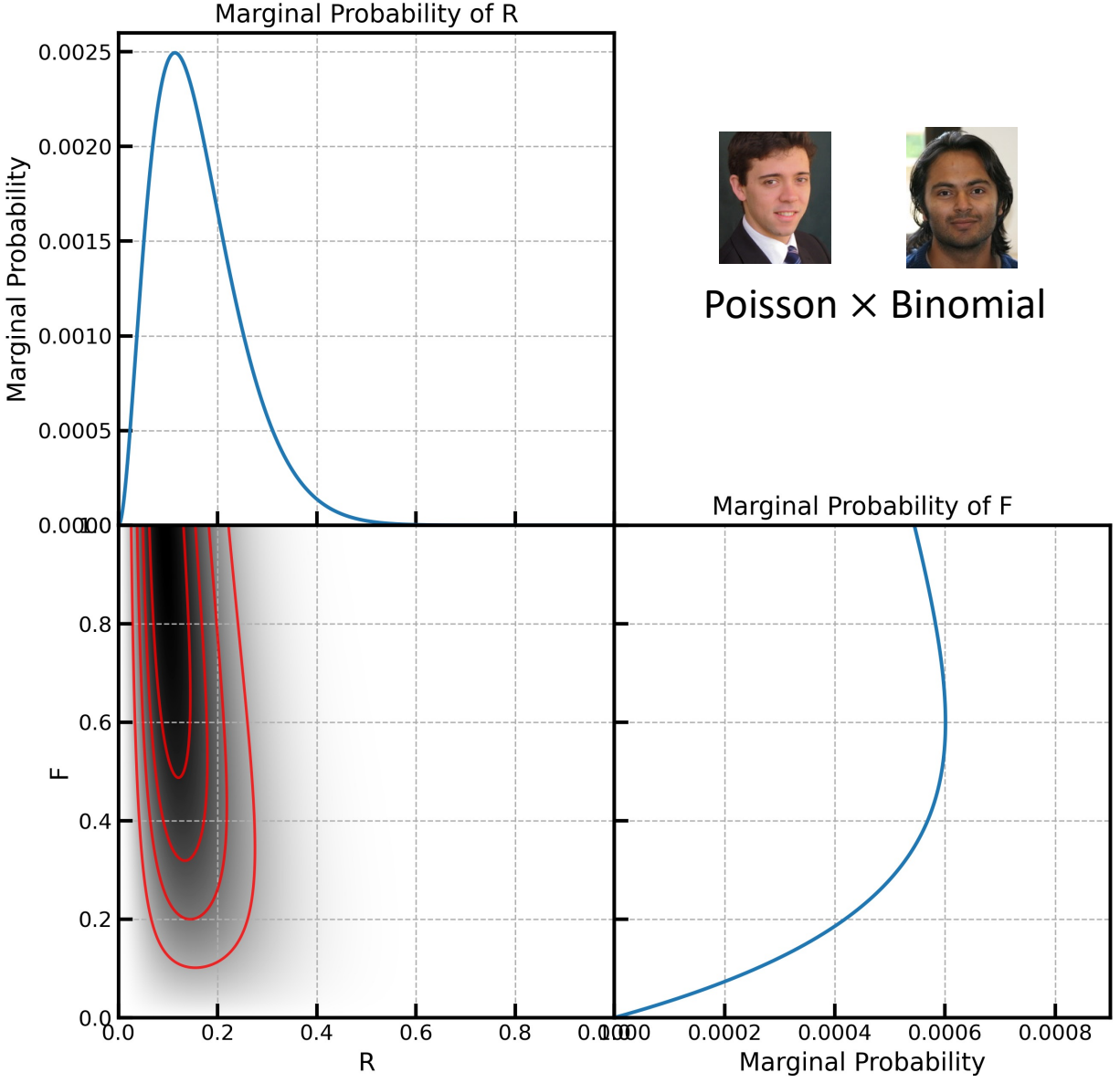
With these, we can constrain F and R quite well!

With only DR2



Only Poisson

With both DR2 and follow-ups

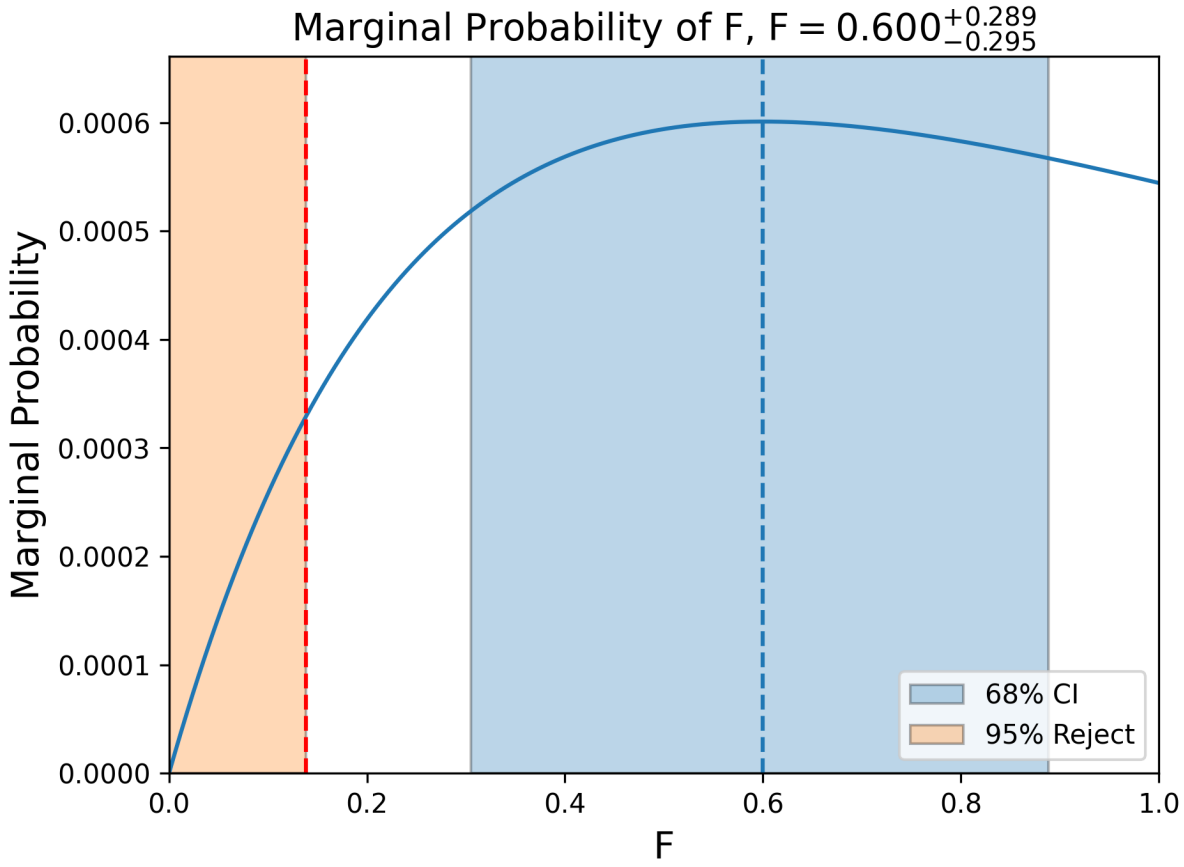


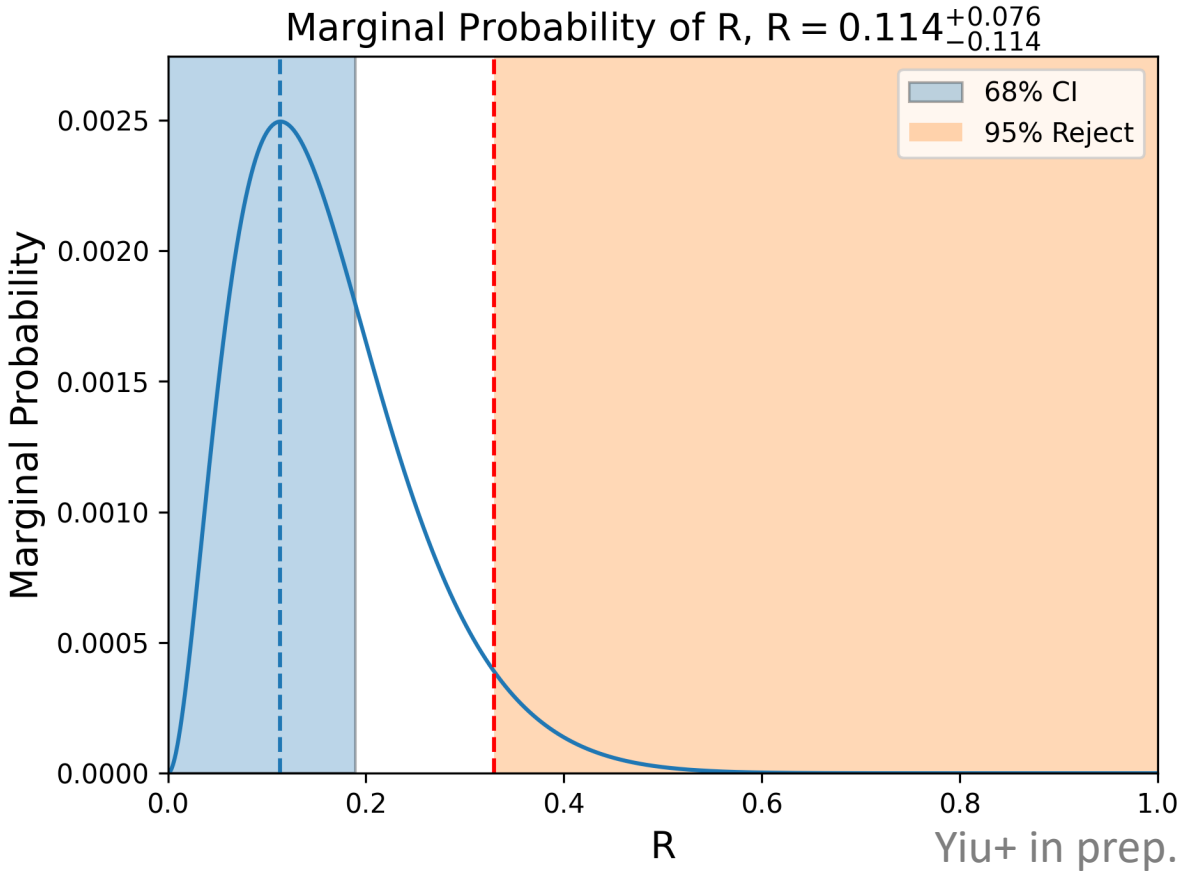
Poisson × Binomial

Yiu+ in prep.

F = “Specialness”
F = Fraction of radio-loud brown dwarfs

R = “Activeness”
R = Duty ratio of a brown dwarf





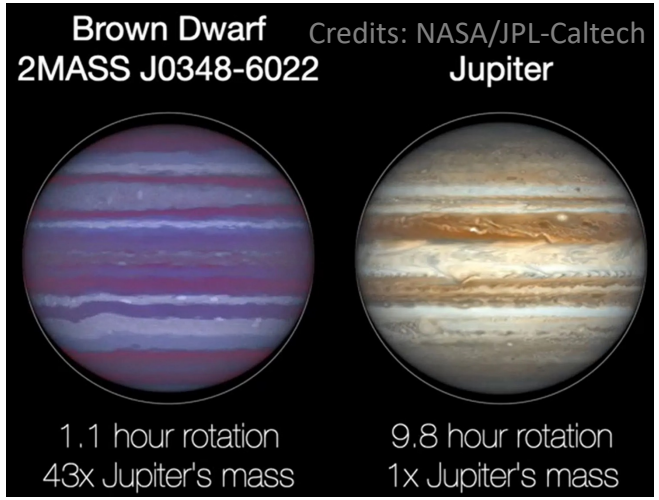
Yiu+ in prep.

We can reject F < 0.14 and R > 0.33 with 95% confidence!

Conclusion

- Each follow-up observation of J1019 by itself: non-detection ☹

⟹ ❌ Search for spectral cutoff or track pulses ☹ ☹ ☹



- Combining all epochs revealed a new 0.8h period! ☺

⟹ Reaching the rotational break-up limit (Tannock+ 2021)

- The non-detections allow us to constrain F and R

⟹ High value of F implies J1019 is most likely not too “special”

Who’s ready for clam bake?