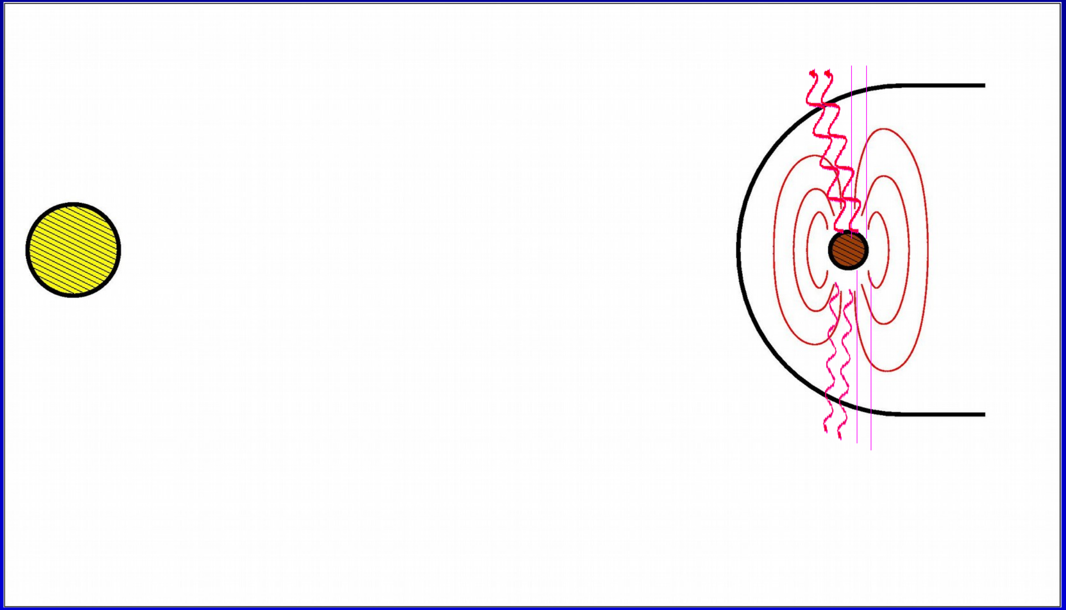
The search for exoplanetary radio emission: Jupiter as an exoplanet + LOFAR beamformed observations



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Philippe Zarka, Iaroslavna Vasylieva

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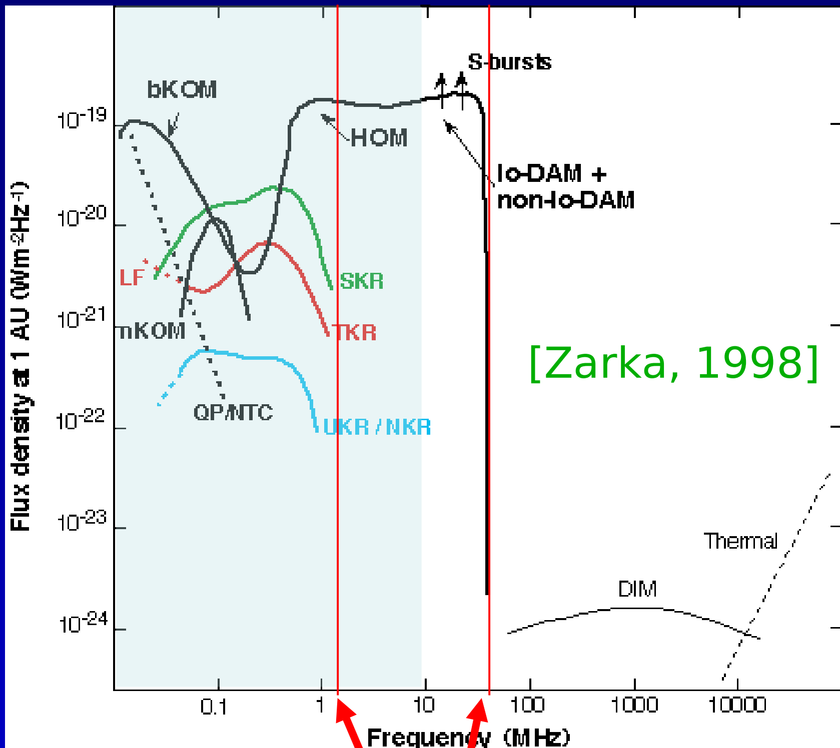
Solar system wisdom (Jupiter)



$$f_c \propto \frac{eB}{m_e}$$

radio emission

→ detect magnetic field!

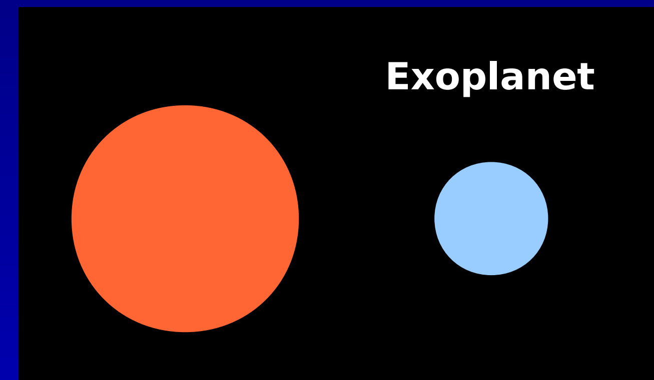
→ calculate magnetic field!

[Grießmeier 2015]

Beyond the solar system

distance = 10^{17} m
rel. signal = 10^{-10}

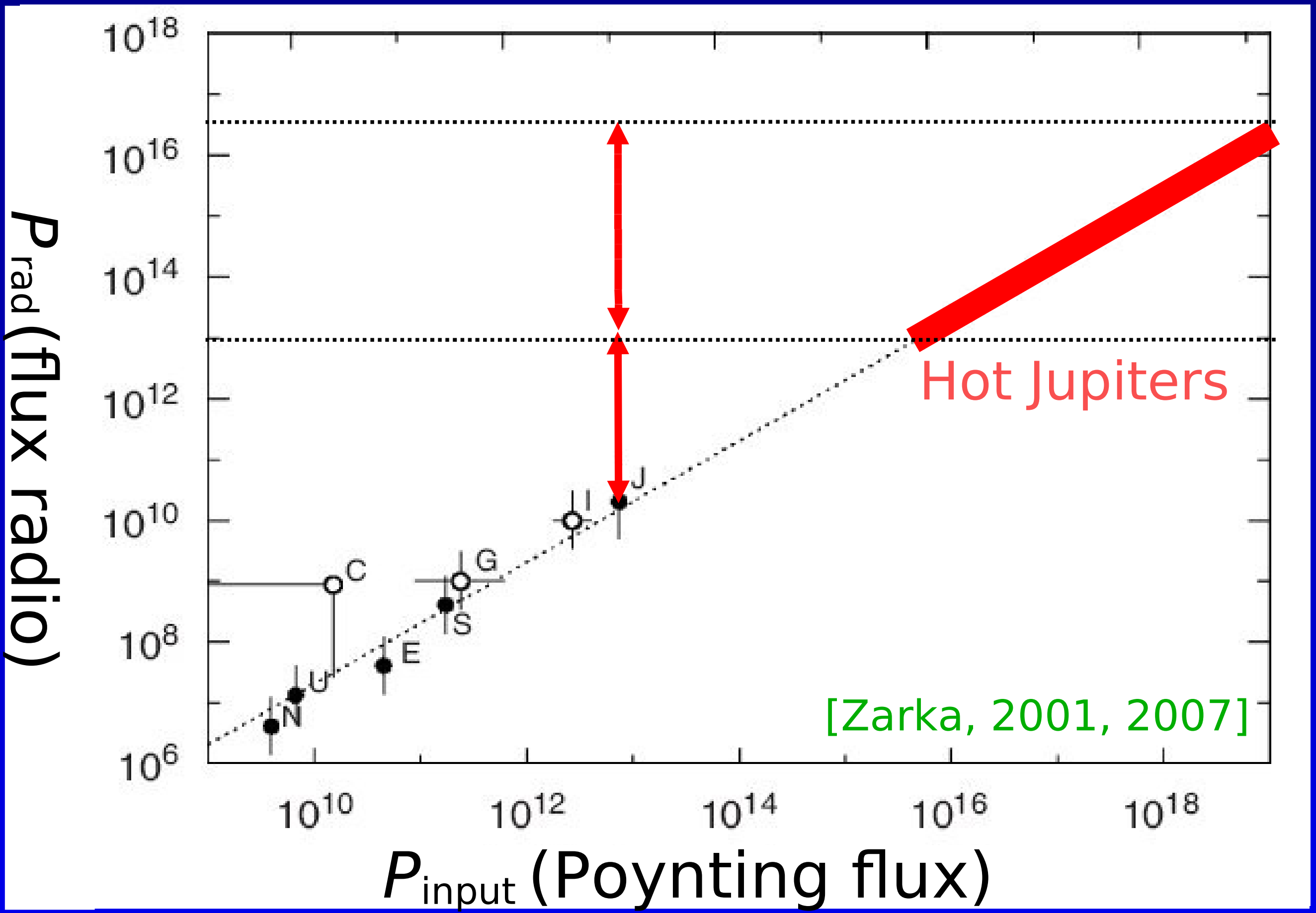
no (firm) detection yet



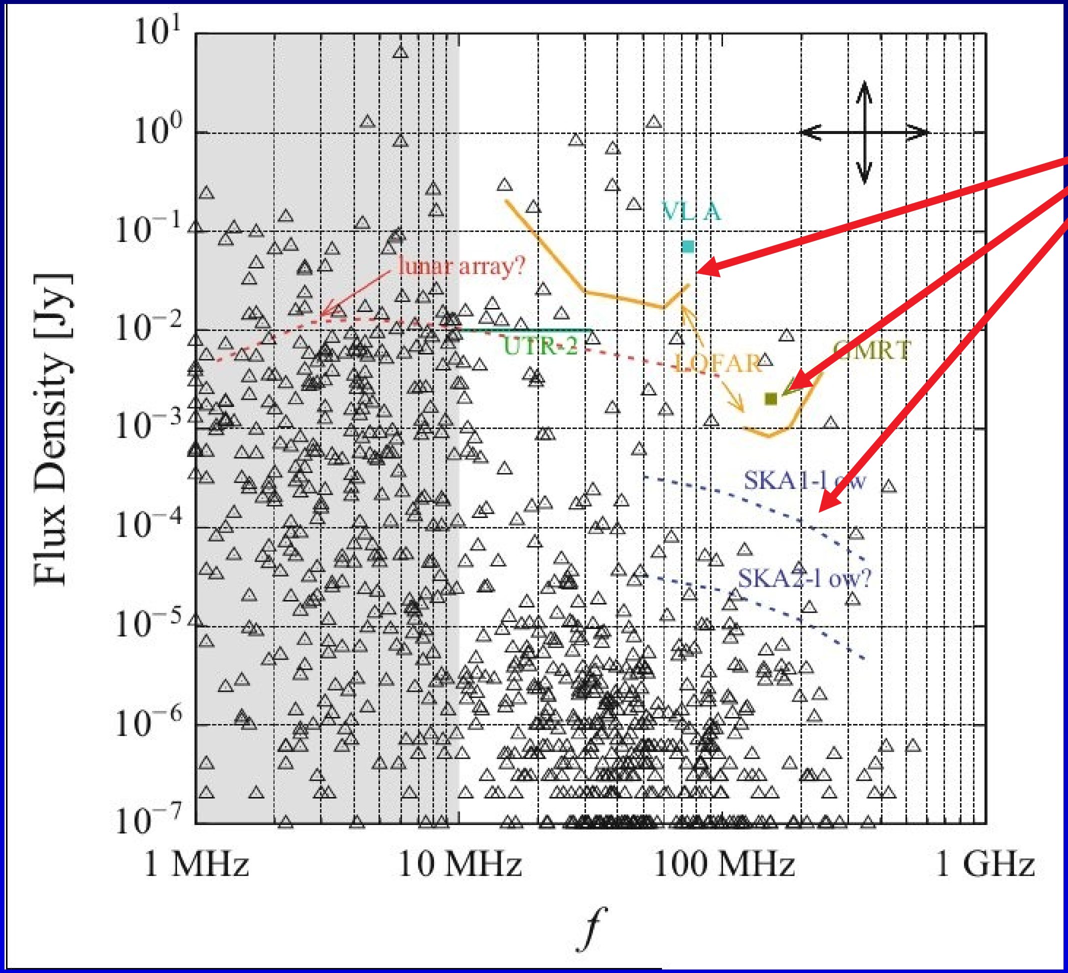
distance = 10^{12} m
rel. signal = 1

Beyond the solar system

theoretical studies: intense emission is possible
(Jupiter x10^3...10^7)



Theoretical sensitivity limit



simple estimates:
- detection possible

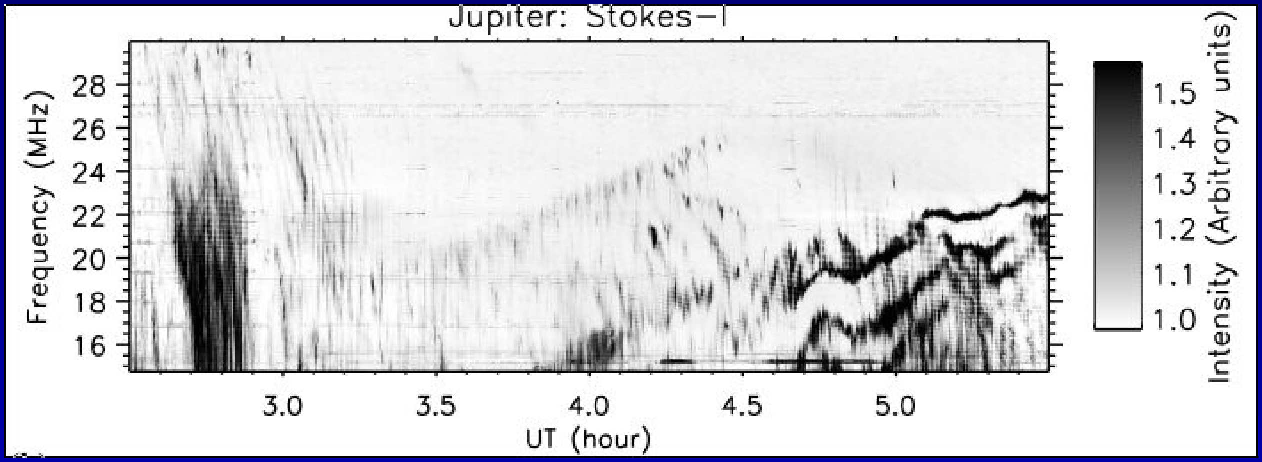
[Grießmeier et al. 2007, 2011, 2018]

LOFAR beamformed observations

- observe well-known exoplanets
- target selection based on predictions
- fine control over RFI mitigation
- need good orbital coverage
- multiple beams (ON + OFF)
- data processing (cleaning) [Turner et al. 2017]

LOFAR cycle	time	target	observation
LC5	18h	55 Cnc	beamformed
LC6	47h	Ups And	beamformed
LC7	28h	Tau Boo	beamformed
	10h	V830 Tau	bf+img
LC8	7h	Corot-7	beamformed

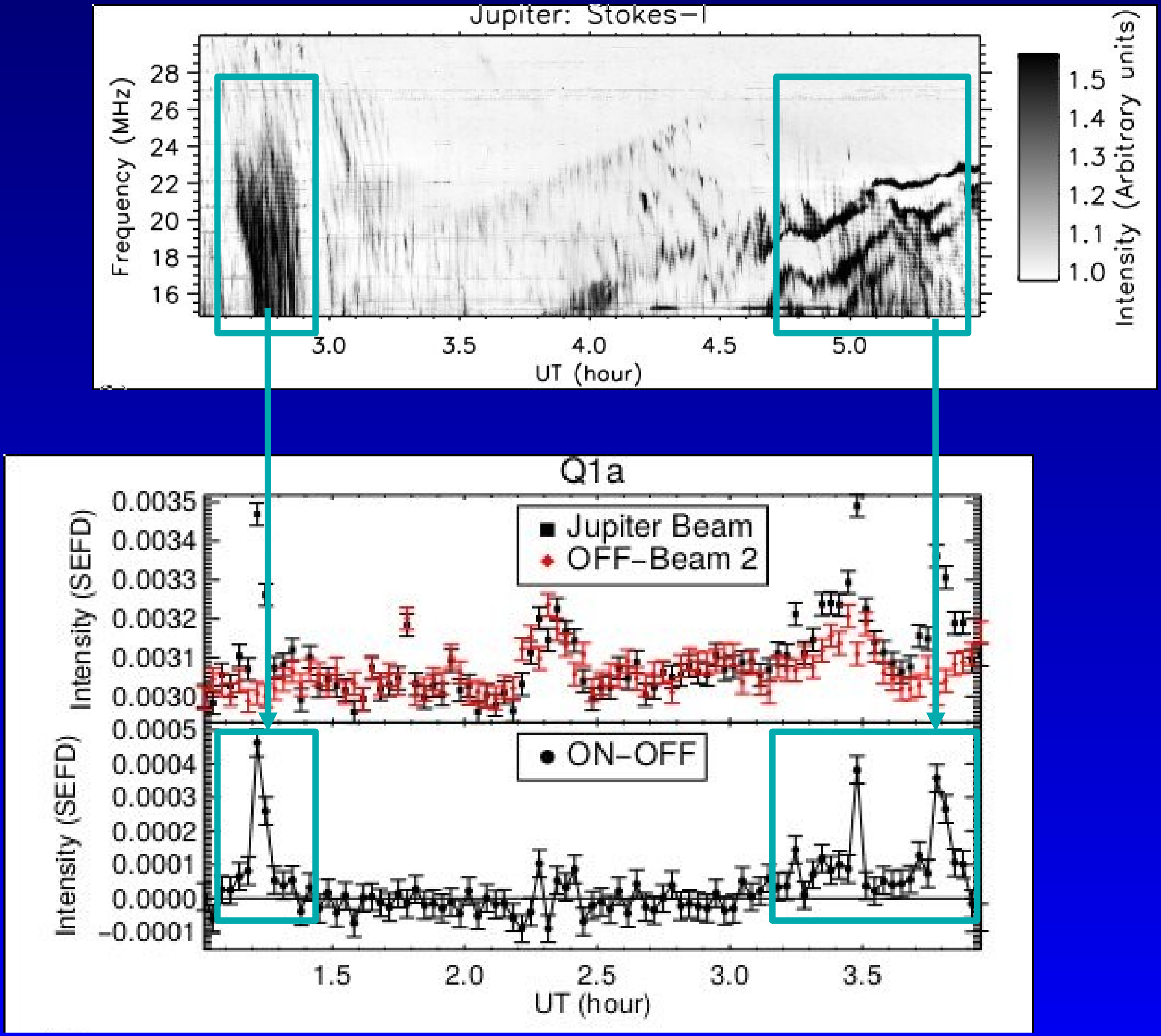
Dynamic spectra & diagnostics



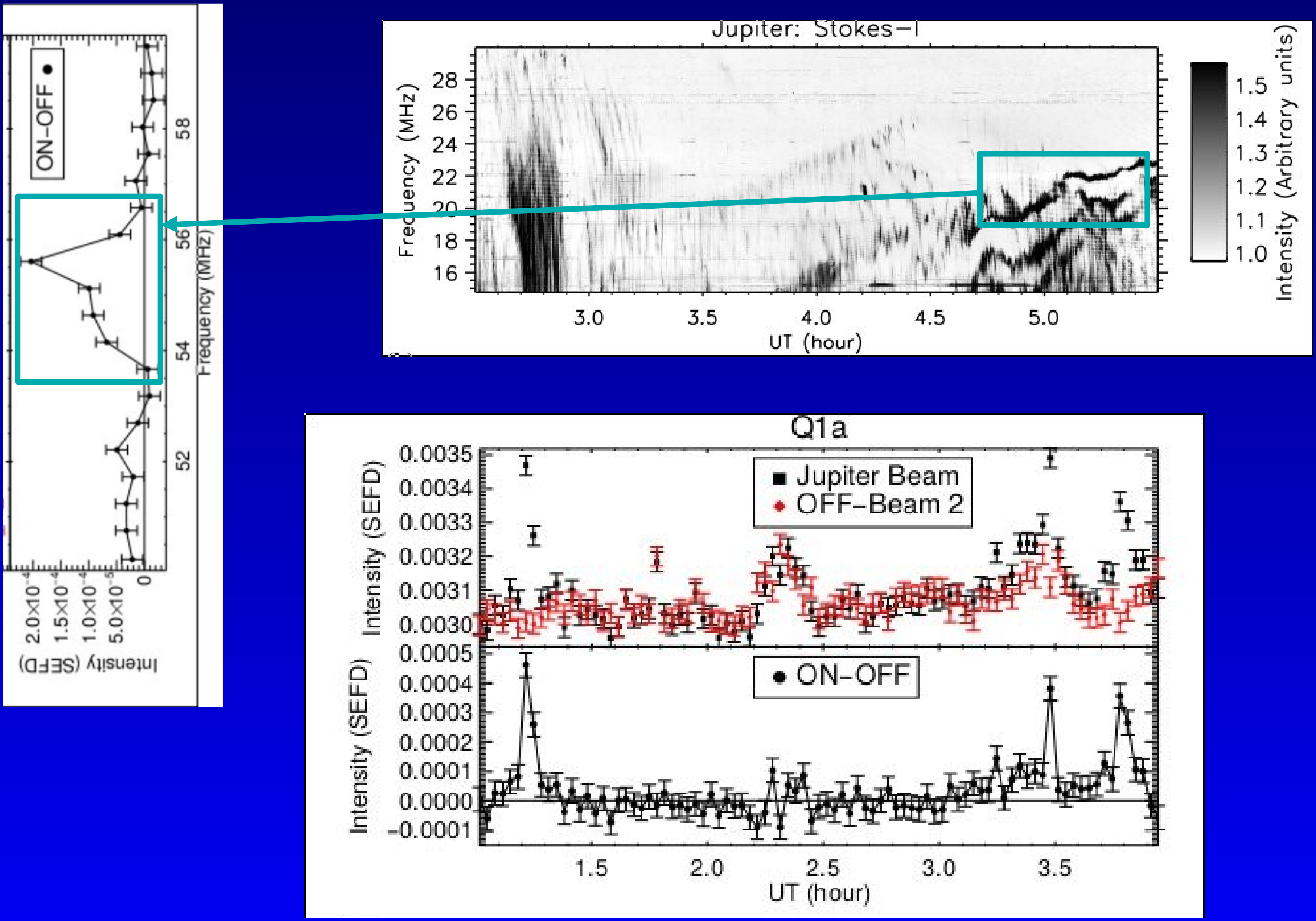
slow emission

bursty emission

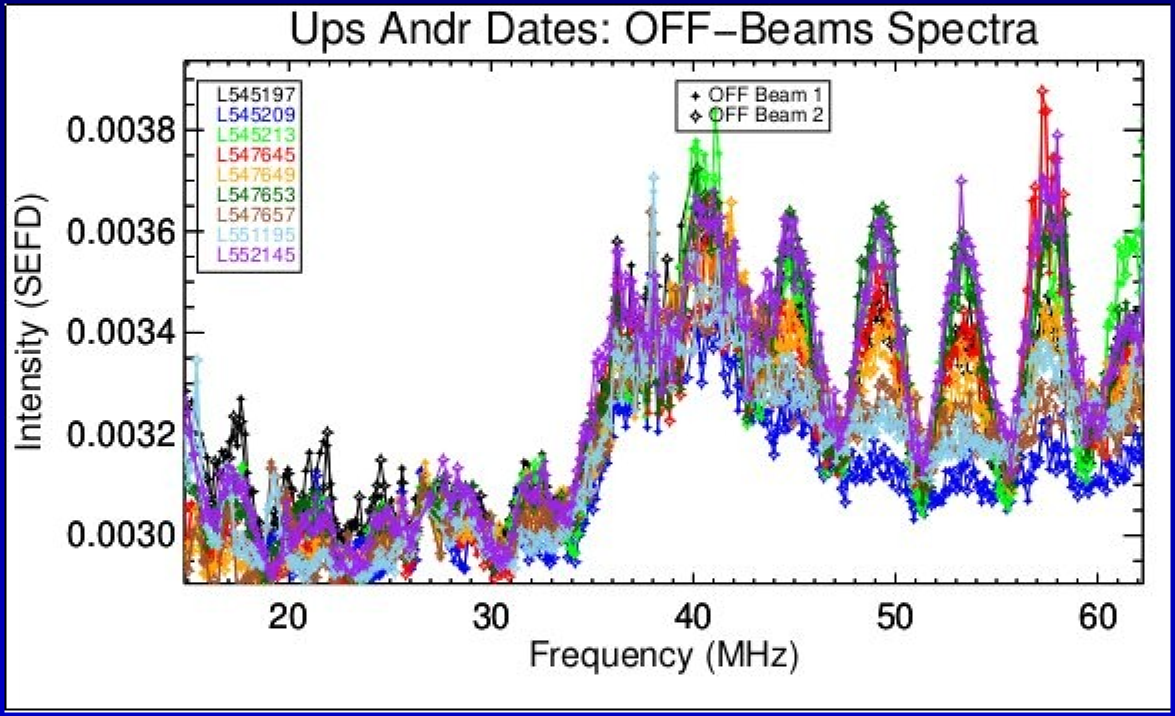
Slow emission: Jupiter



Slow emission: Jupiter

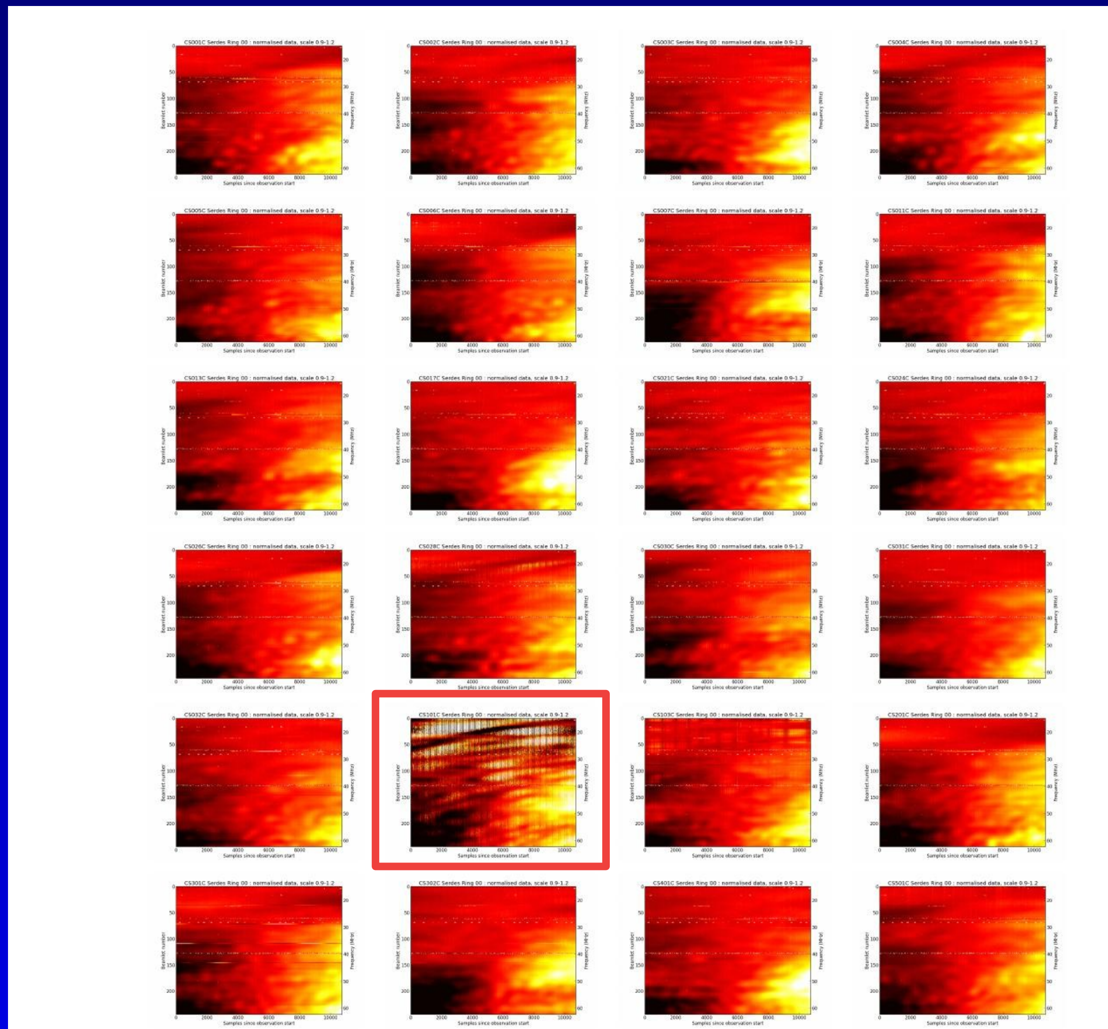


Slow emission: exoplanet



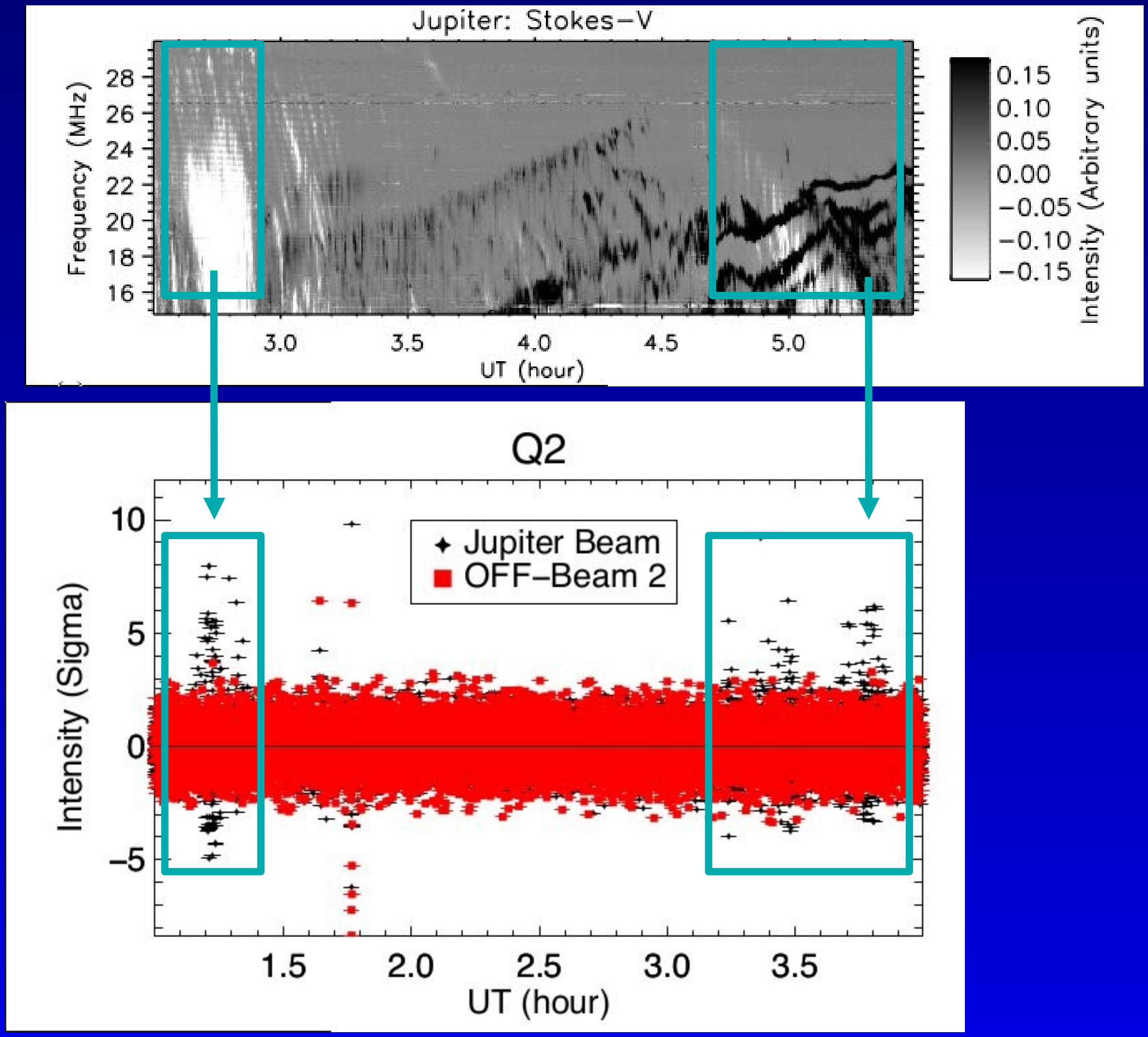
- apparent ‘ripples’ in OFF-beam data
- cleaning not yet perfect
- data quality problem (bad stations)!

Data quality & bad stations



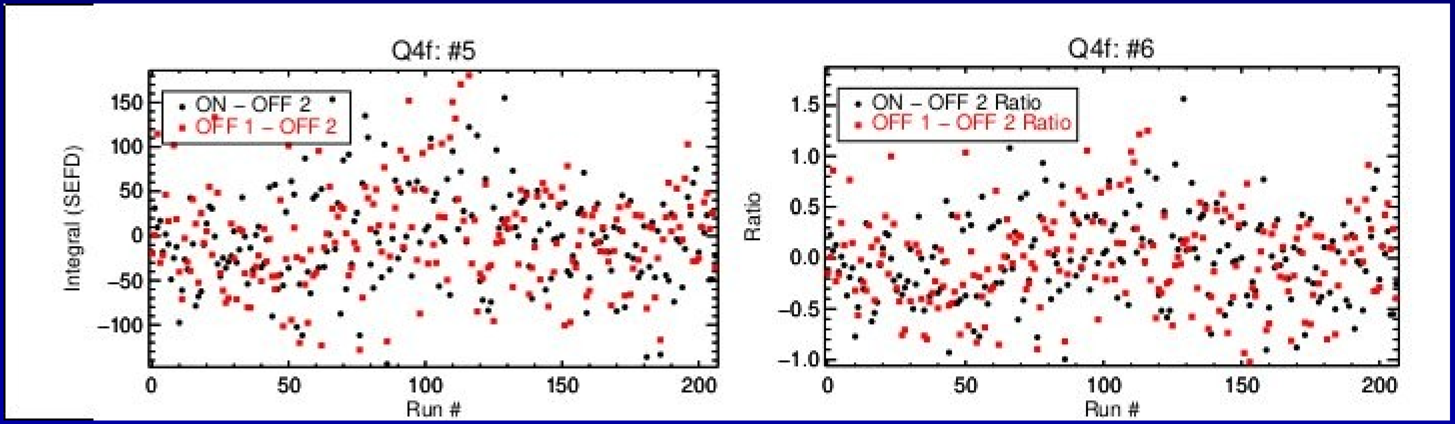
- including bad stations is... bad!

Bursty emission: Jupiter



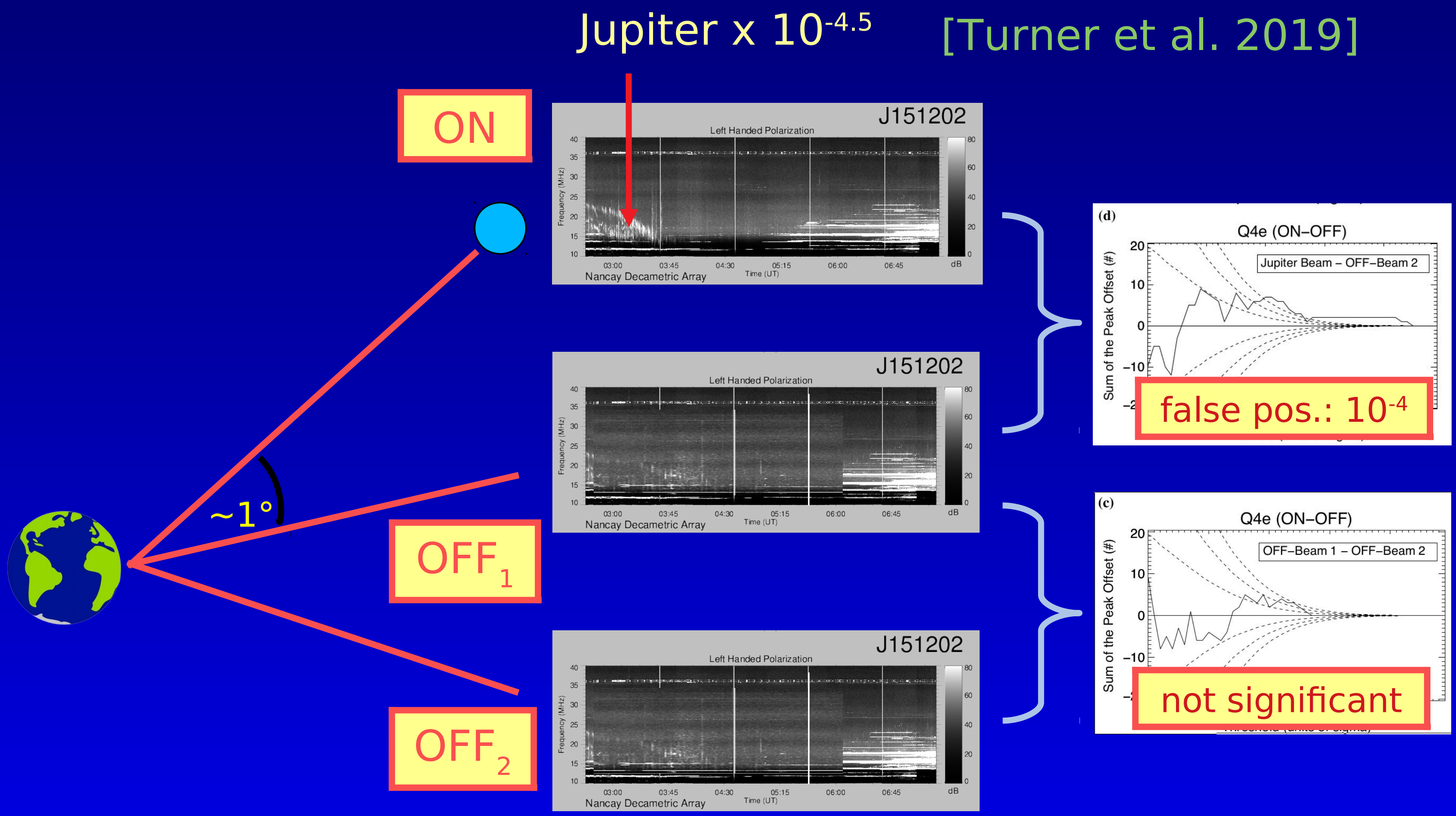
- Jupiter's emission is bursty
- search bursts of 1-10 s duration

Bursty emission: Exoplanet



- exoplanets: no bursts detected
- go through data again
- nondetection → upper limits

Dynamic spectra



- bursts of Jupiter x $10^{-4.5}$ would have been detected
- → upper limit to bursty emission [Turner et al. in prep.]

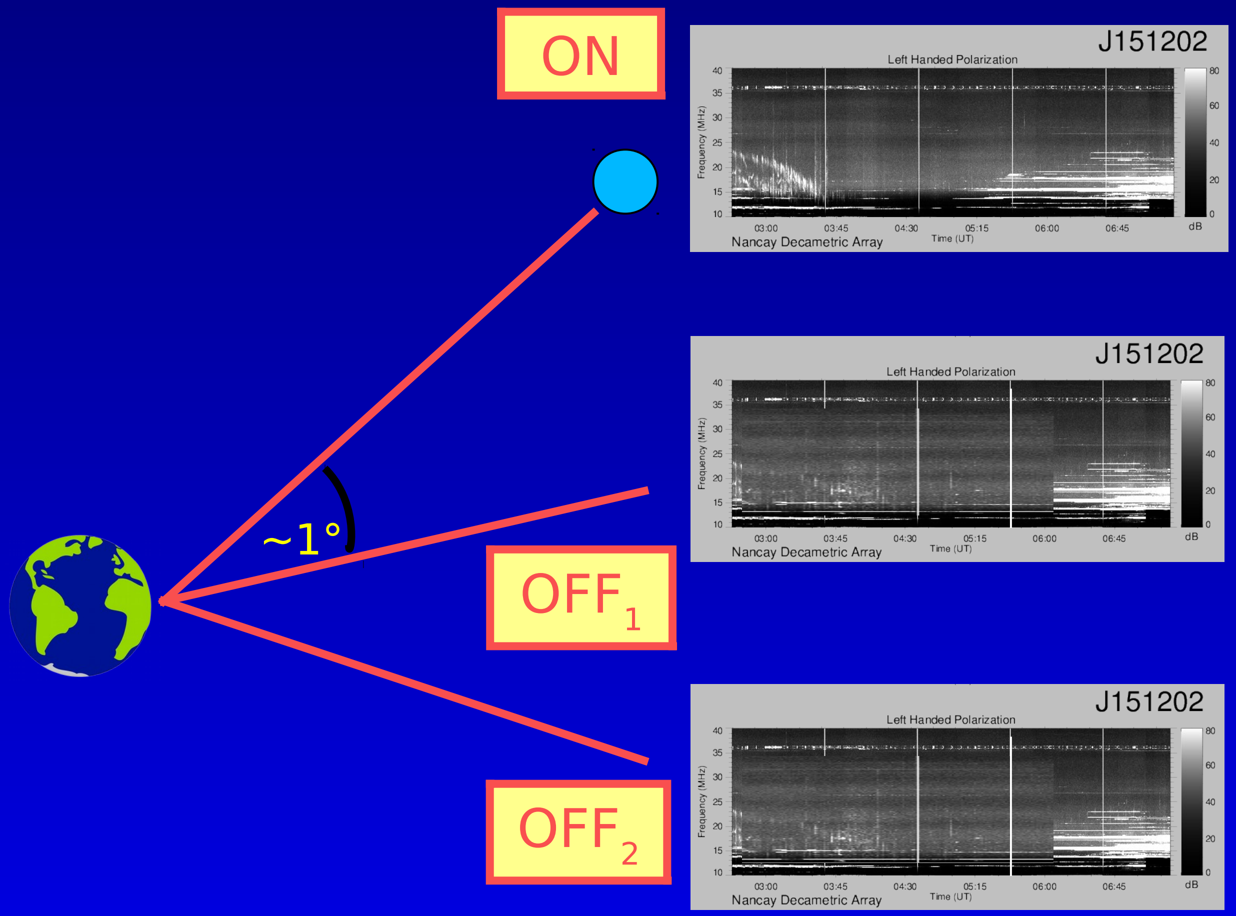
Lessons learned

- beamformed data → good time-frequency resolution
- → powerful RFI cleaning
- need (at least!) 3 beams
- Stokes V > Stokes I
- need orbital coverage (→ observing time)
- 1 bad station can corrupt the sum!
  → have to exclude bad stations

- slow emission:
  combine with imaging (DynSpecMS; A. Loh, C. Tasse, ...)
- bursty emission:
  beamformed observations, but with quality control

- best test: simultaneous observations
  → UTR-2, NenuFAR (science operations start 07/2019!)

Multibeam setup

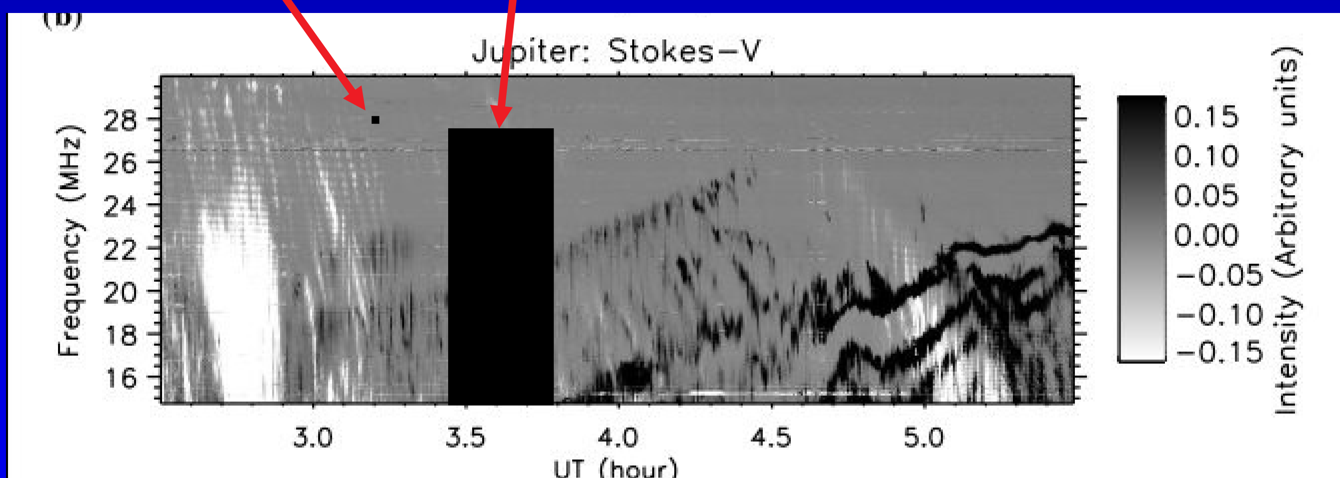


Theoretical sensitivity limit

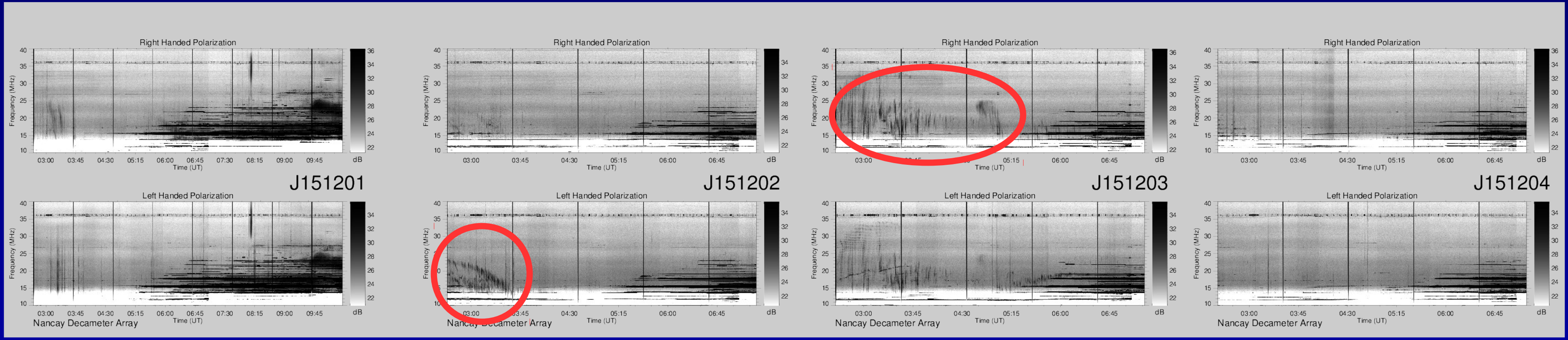
- observe well-known exoplanets
- beamformed observations

$$\Delta S = S_{sys} / (N \sqrt{n_{pol} \tau_r b})$$

→ ΔS=200 Jy (per t-f "pixel" of 10 ms x 3 kHz) ...but...
→ ΔS= 5 Jy (rebinned "pixel" of 1 s x 45 kHz) ...but...
→ ΔS=0.01 Jy (20 min x 12 MHz) ...but...

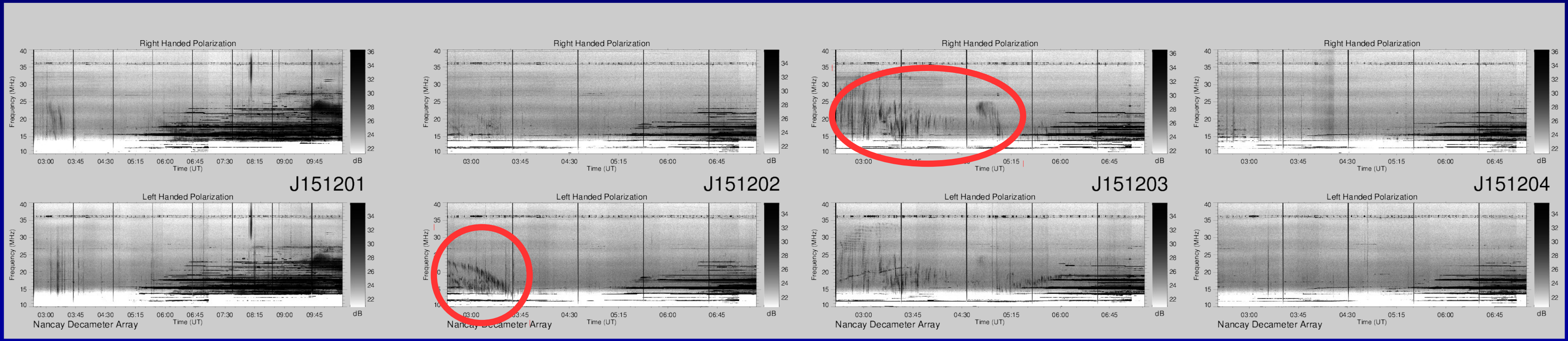


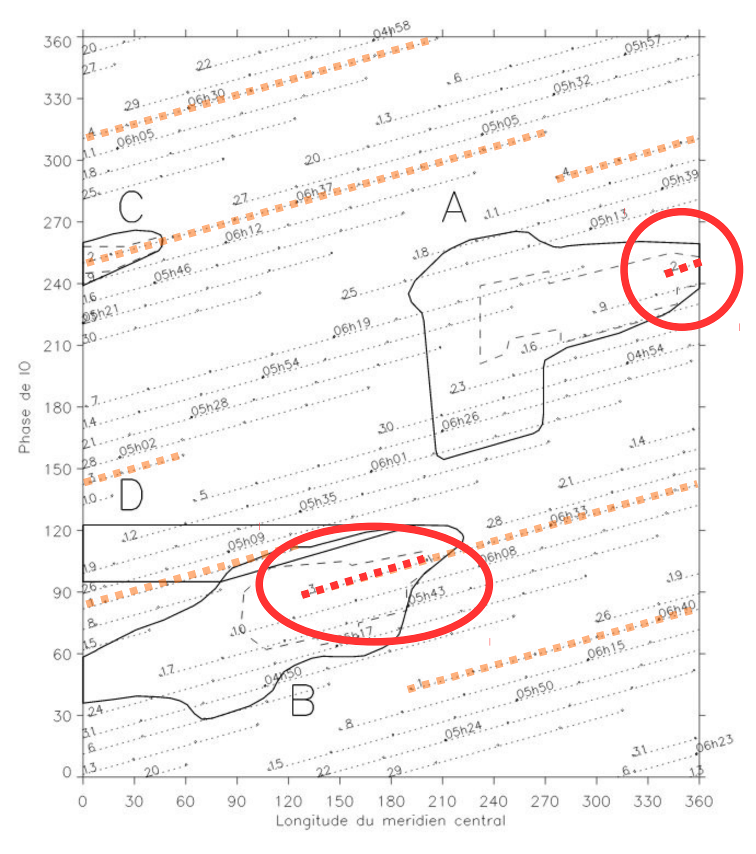
Orbital phase



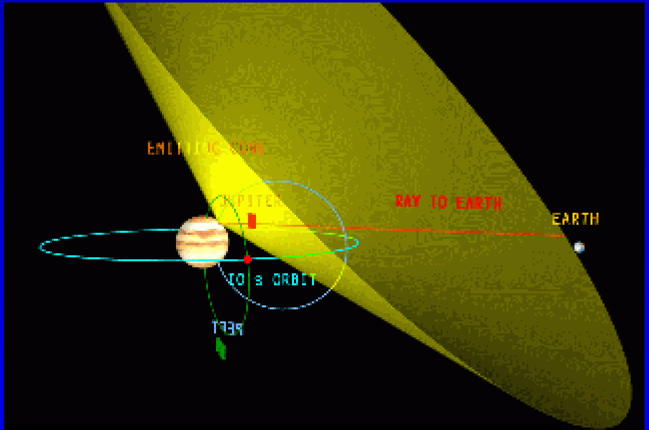
- for Jupiter, random observations only give 10-20% detections!

Orbital phase



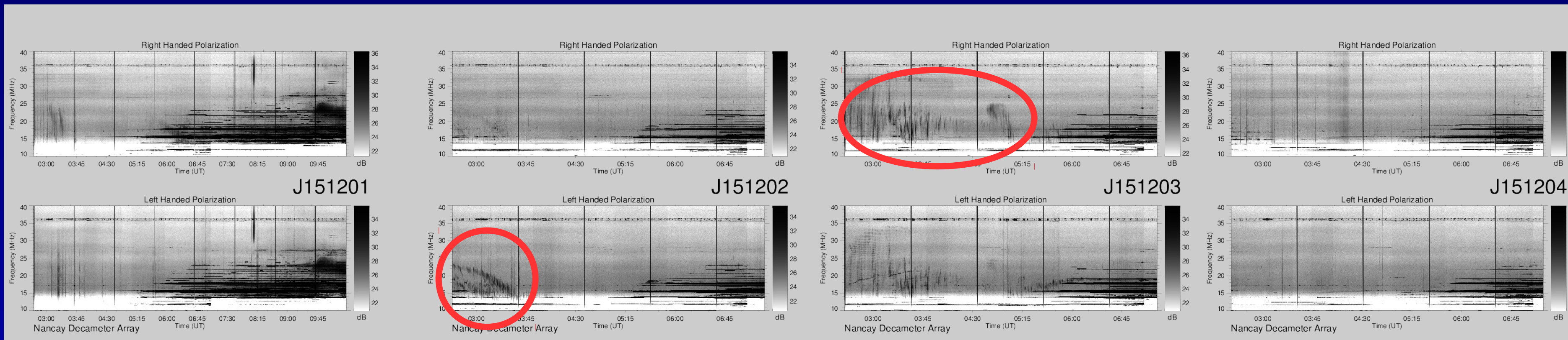


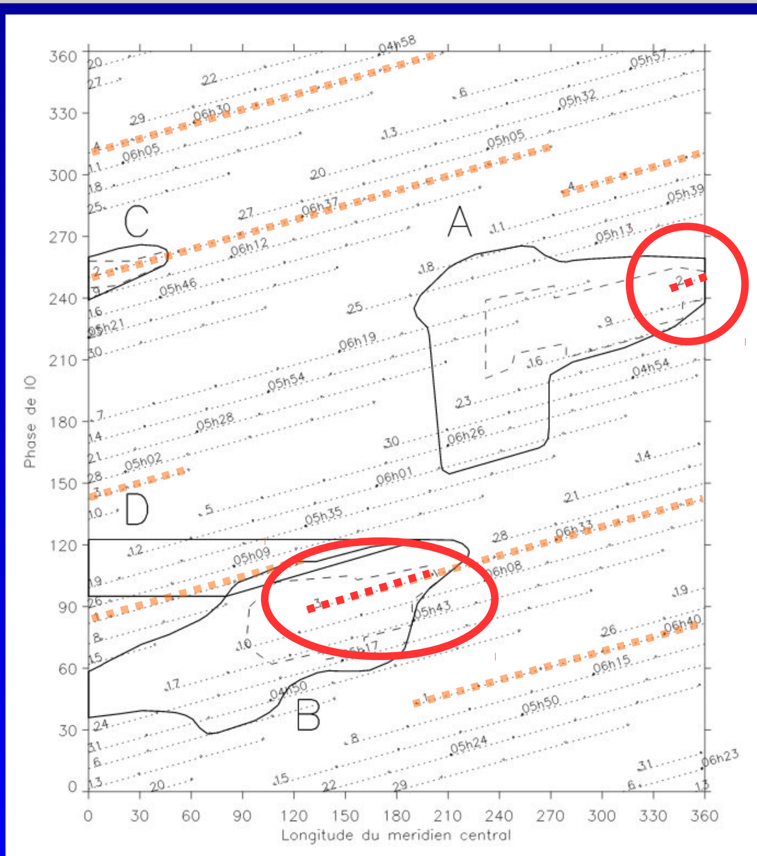
- for Jupiter, random observations only give 10-20% detections!
- emission is always on
- emission is strongly beamed



[Imai Lab., Kochi National College of Technology]

Orbital phase





- for Jupiter, random observations only give 10-20% detections!
- emission is always on
- emission is strongly beamed

- for exoplanets: have to cover orbit
- else: non-detections meaningless

Orbital phase