Probing Exoplanetary Magnetospheres at Low Radio Frequencies with NenuFAR

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PRE conference

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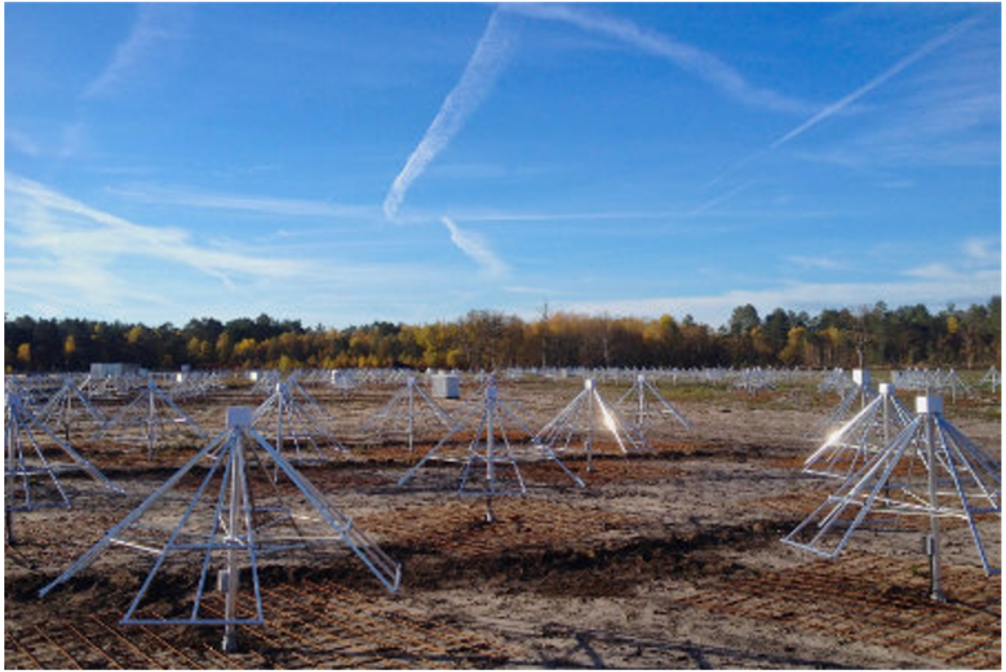
NenuFAR

Dense core (400 m) + remote antennas (~3 km)

Low-frequency (10 - 88 MHz)

High sensitivity @ 20-30 MHz

Low spatial resolution (1 deg @ 20 MHz)



Predictions for Radio-Exoplanets

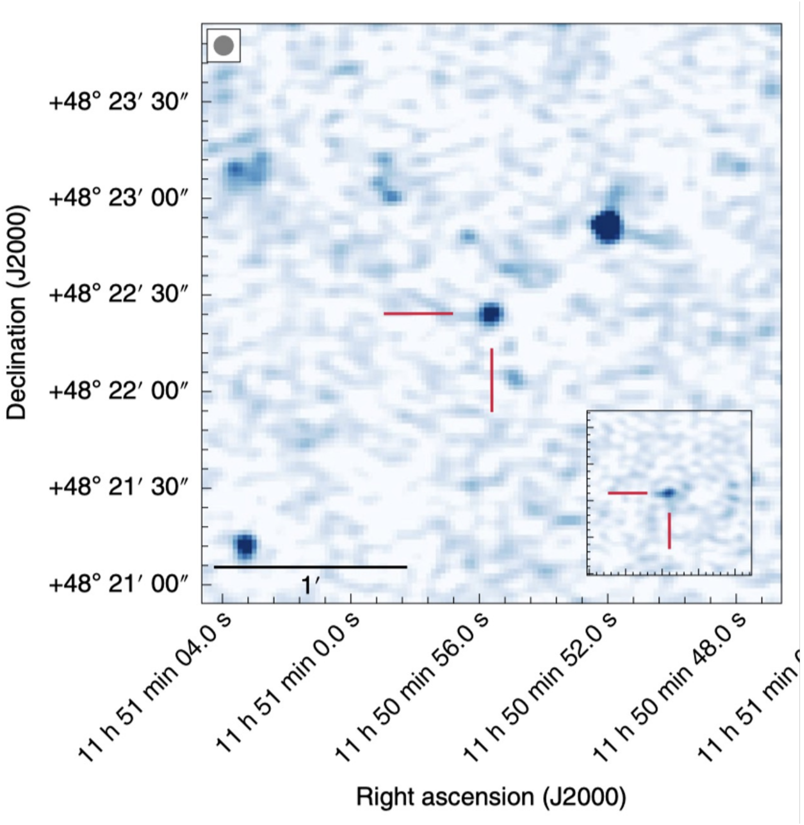
Magnetospheric → Low frequencies

Star-Planet Interactions → Low & High frequencies

Circular polarization (Cyclotron-Maser Instability)

Possible linear emission

Transients, only detectable at specific orbital phases.



Total intensity image for GJ1151, Vedantham et al. 2020

HD 189733, a case study

The system

K type primary + M dwarf companion
Hosting a hot jupiter
19 pc away
40 G magnetic field

Star-planet interaction, yes or no?

ZDI, Ca II K, X ray: yes
Radio: tentative detection (2.7 sigma)
Multiwavelength analysis: stellar activity, not SPI
Stellar wind modeling: planetary emission 21-25 MHz

Low-frequency observation is needed!

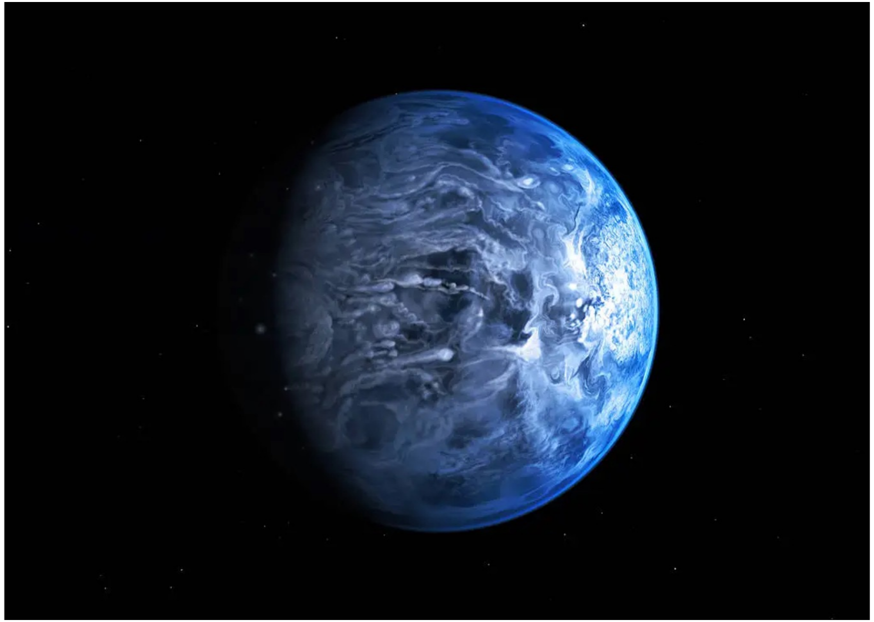


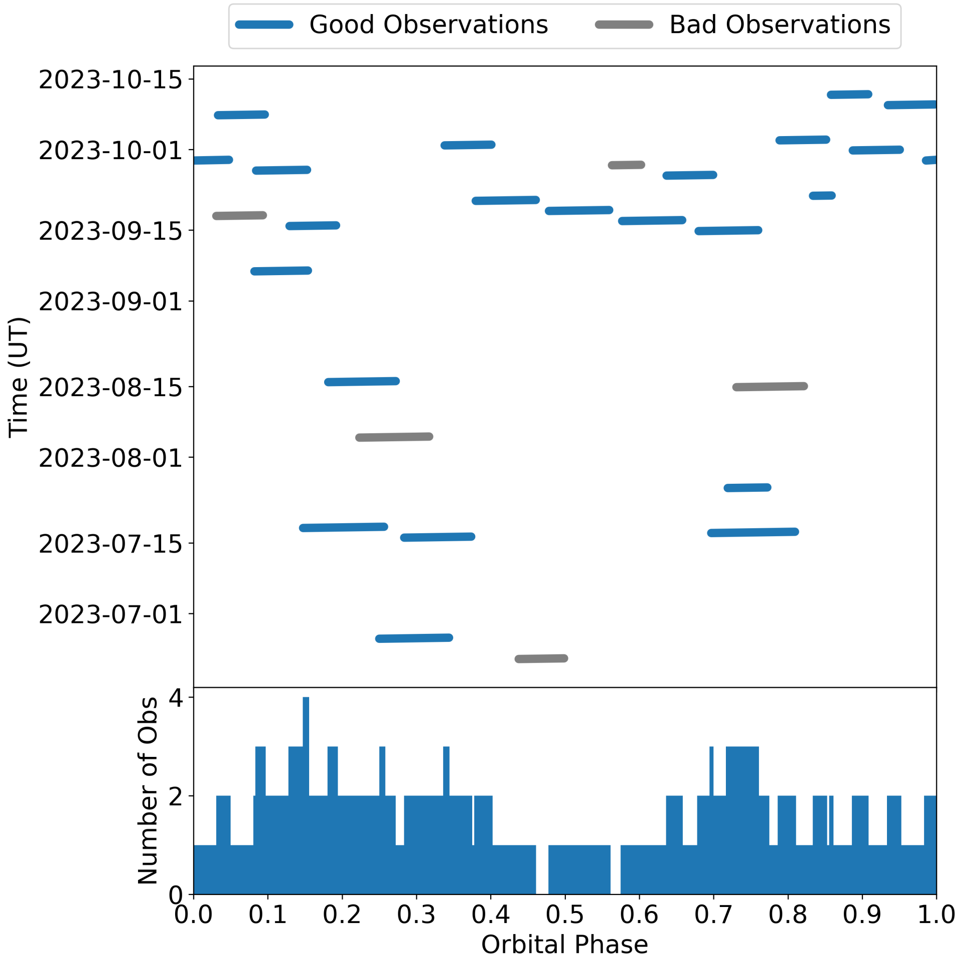
Image Credit: ESO/M. Kornmesser

Observations

NenuFAR observed the system for 103 hours (imaging), covering entire orbital phase.

Parameter	Value	Units
Array Configuration	Core + Remote MAs	
Frequency Range	15.8 to 62.5	MHz
Frequency Resolution[a]	15	kHz
Temporal Resolution	8	seconds
Field of View (FoV)[b]	20	degrees
Spatial Resolution[c]	0.5	degrees

Notes. [(a)] The frequency and temporal resolutions listed here correspond to the Level 1 data products, obtained after initial preprocessing steps that involve averaging, and thus differ from the raw data resolution. [(b)] The FoV is calculated as the full width at half maximum (FWHM) of the angular resolution corresponding to a single MA of NenuFAR at 39 MHz. [(c)] The spatial resolution is derived at 39 MHz. It is larger than the theoretical resolution of NenuFAR (0.1 degree) at the frequency, due to two of the four remote MAs being flagged during most of the observational campaign.



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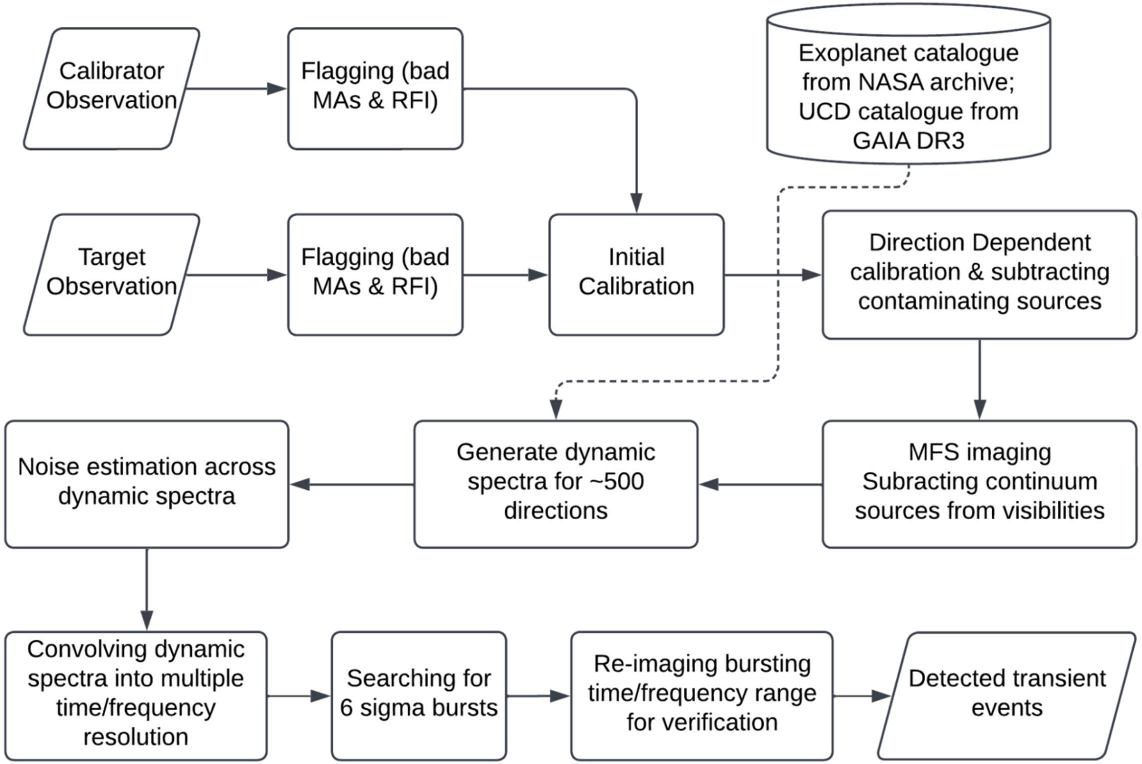
The pipeline

Pipeline optimized for transients:

1. Direction-dependent calibration
2. Remove non-variable sources from visibilities
3. Generate dynamic spectra for multiple directions



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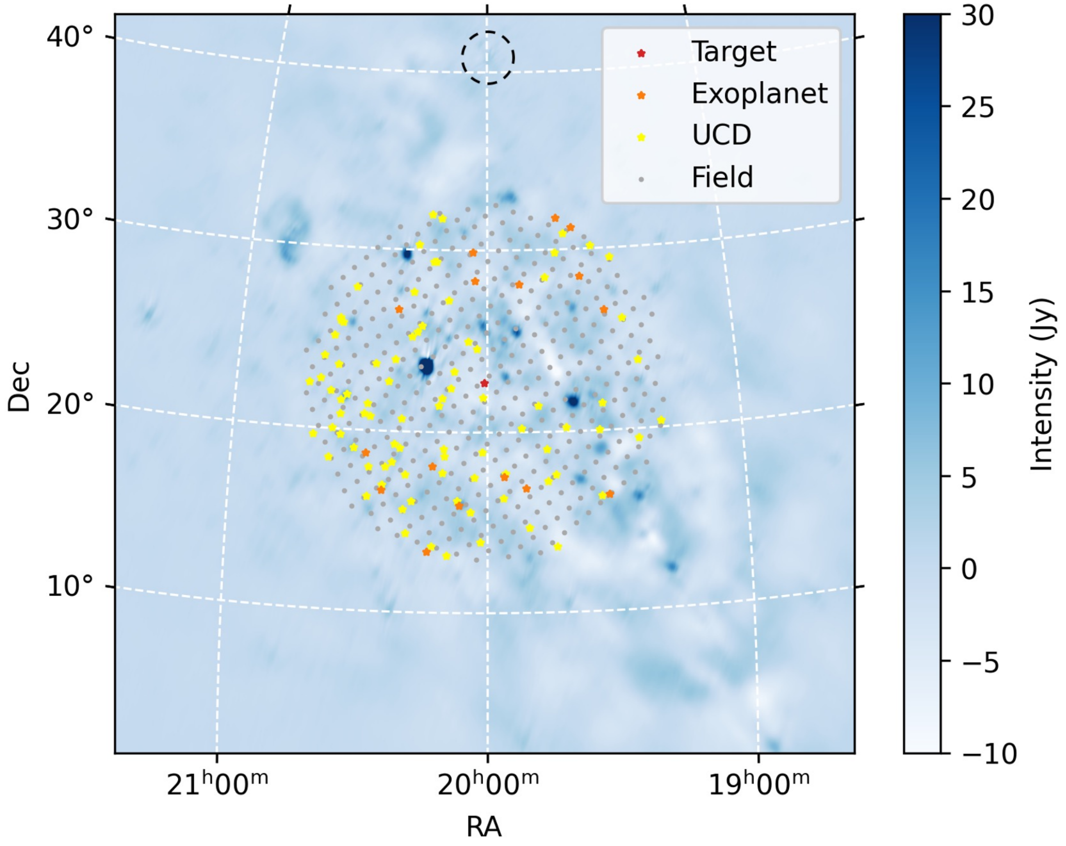
Dynamic spectra, multiple directions

500 “beams” within the FoV!

1. Primary target
2. Exoplanets (~20)
3. Brown Dwarfs (~80)
4. Field grids (~400, 1 deg separation)



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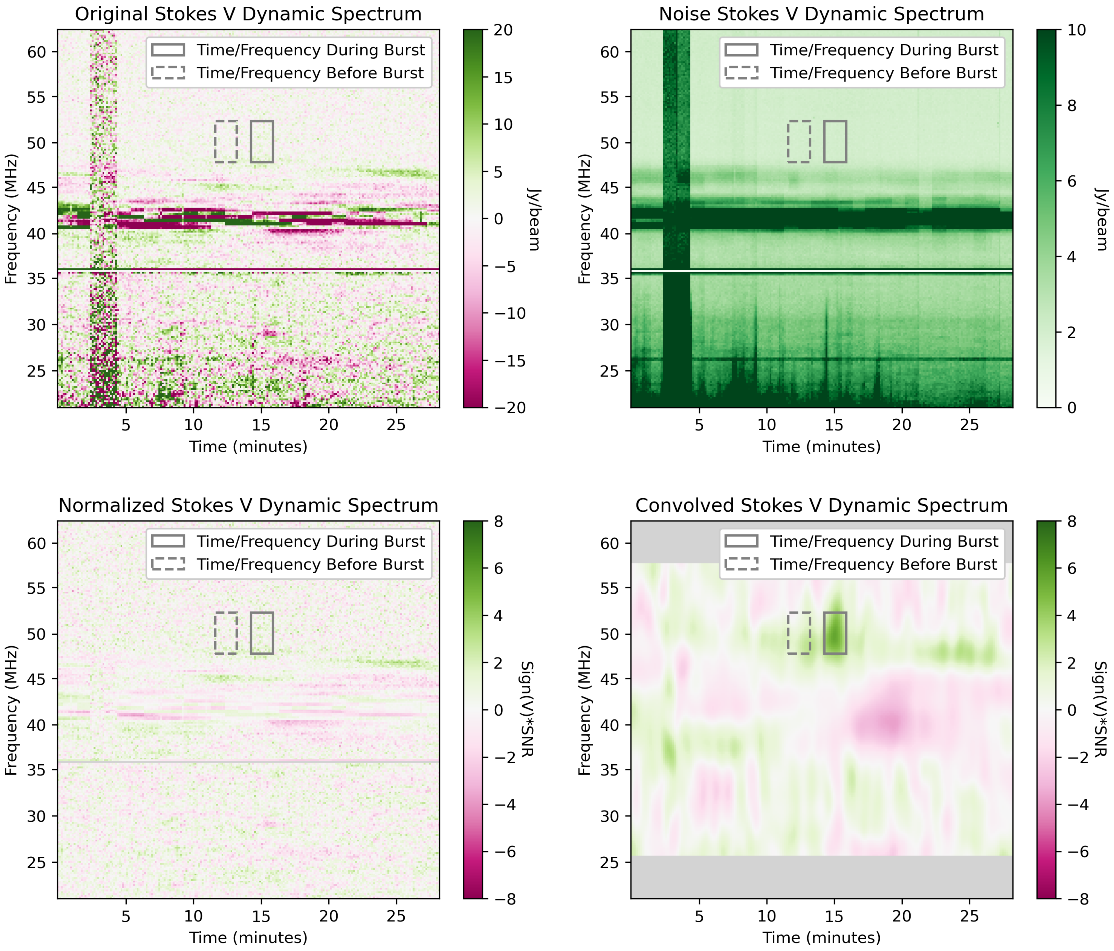
Finding transients in dynamic spectra

Normalisation: flatten the noise

Convolution: multiple time/frequency width to search for transients

Verification: Re-image the bursting time/frequency range.



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HD 189733

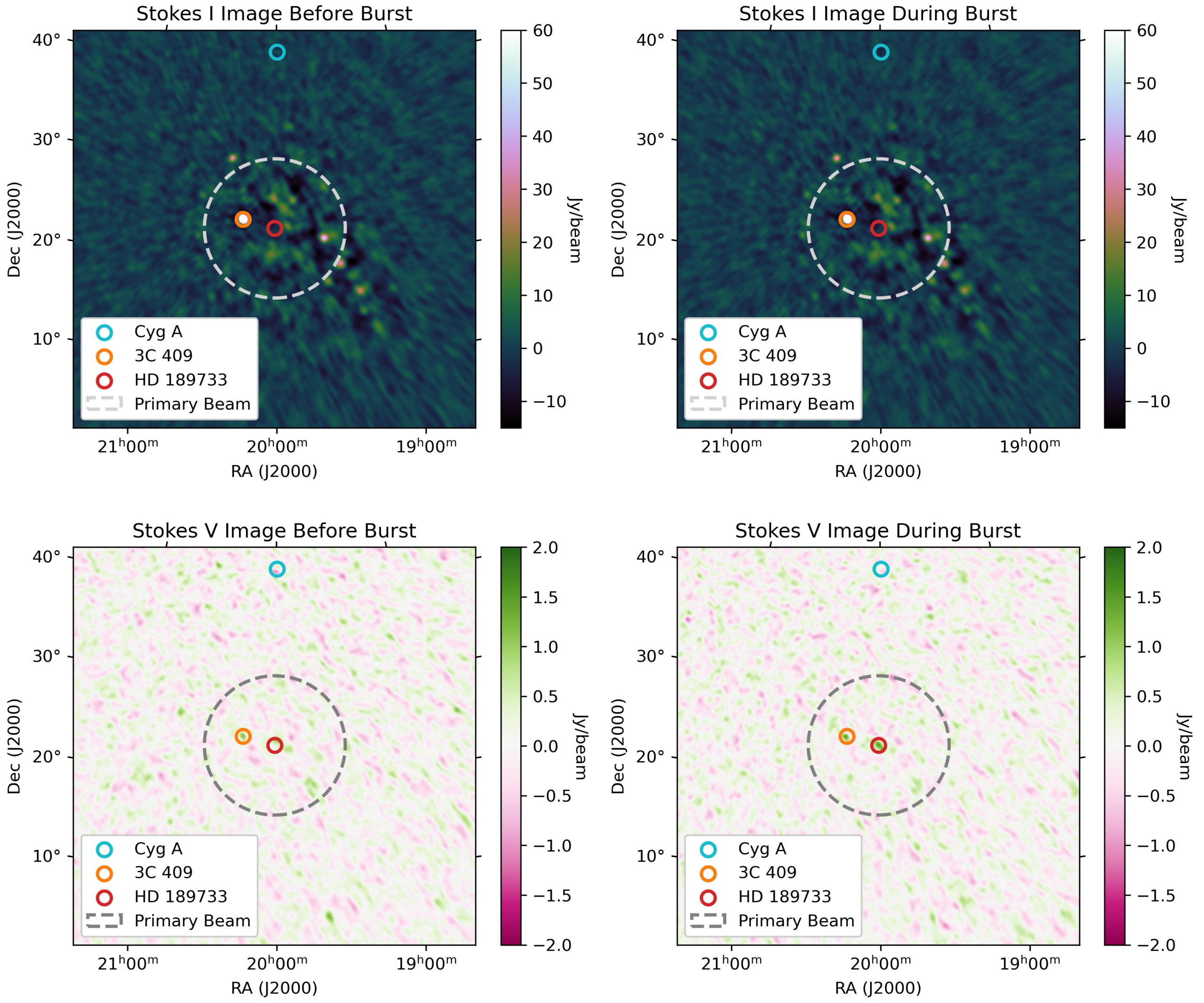
1.5 Jy (6 sigma) burst

1.5 min * 5 MHz

Fractional pol > 38%

Detected at transit of the planet

No multiwavelength observation available



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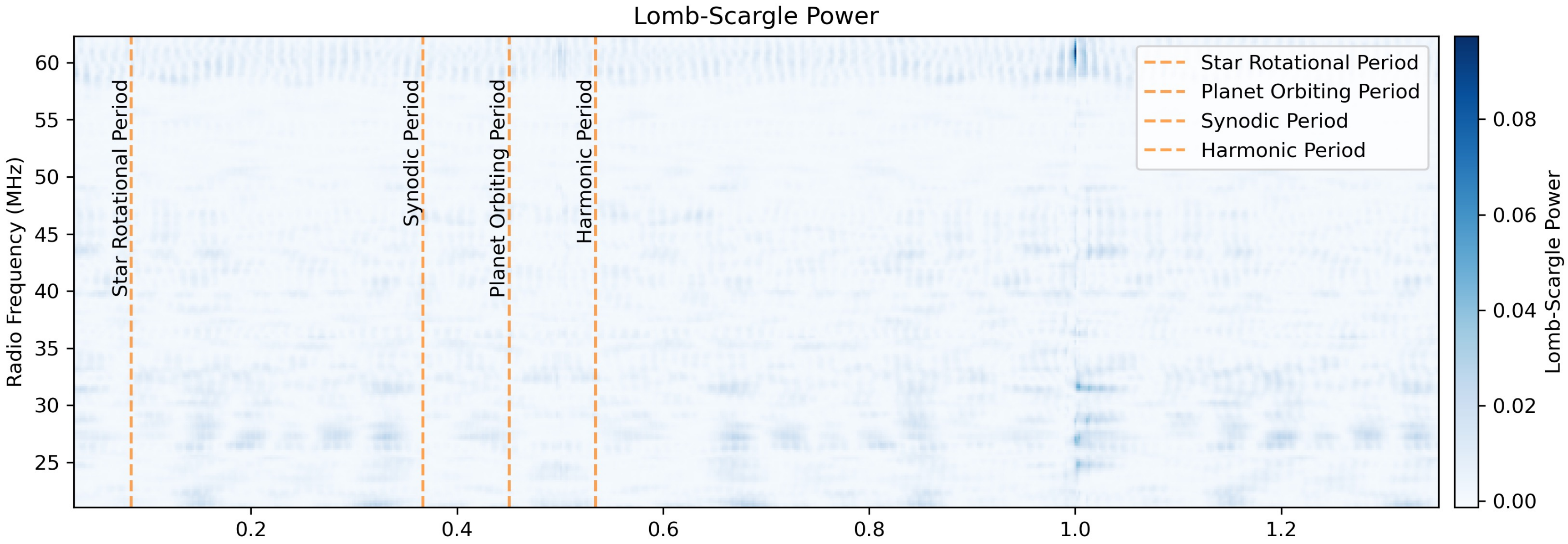
Search for periodicity

Repeating bursts => not noise peak

Lomb-Scargle method

Periods searched:

1. Star rotation
2. Planet orbiting
3. Synodic/hamonic period between the two



Four hypotheses regarding the burst

1. Star-Planet Interaction
2. Intrinsic Stellar Activity
3. Background M-dwarf (HD 189733 B)
4. Noise Peak

Image Credit: NASA Exoplanet Archive

Mechanism	Power	f_{ce}	f_{pe}/f_{ce}	Viewing angle
Sub-Alfvénic SPI	Yes	Yes	Plausible (hotspot)†	Marginal‡
Wind-magnetosphere	Plausible	Unknown	Unknown	Favorable‡
Stellar CMI	Yes	Yes	Plausible (hotspot)†	Irrelevant
Stellar plasma emission	Plausible (flare)	Irrelevant	Irrelevant	Irrelevant

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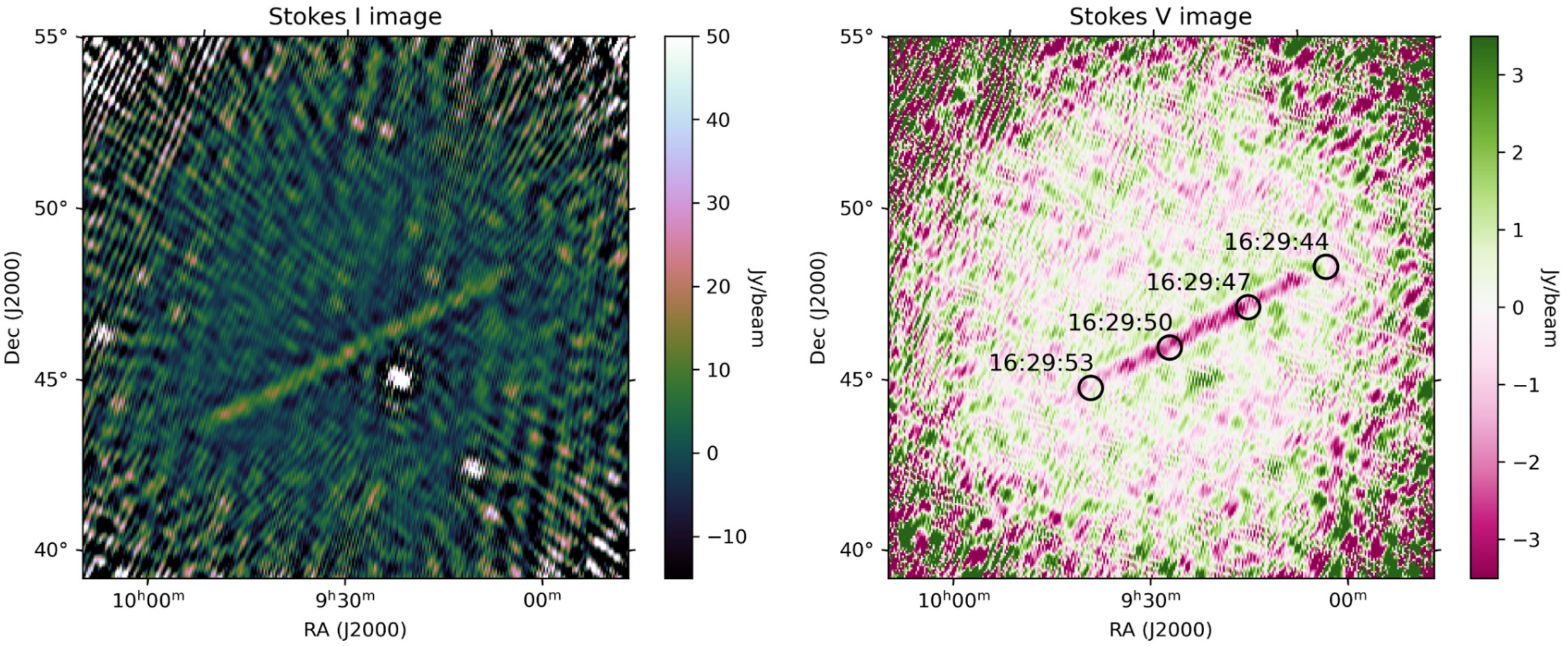
Uninvited guests in our data

Trail from Starlink: 55-65 MHz, 15 sec integration, single satellite



Take-away messages

- 103 hour campaign with NenuFAR on HD 189733
- 1.5 Jy Stokes V burst detected
- No periodicity found
- Multiple hypotheses including SPI, stellar emission, background source and noise peak
- In search for exoplanets, we detected transients caused by Starlink satellites.

Read more:
Exoplanet ☺

Read more:
Satellites ☹

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