

Stars and exoplanets with LOFAR

Sanne Bloot

LOFAR Data School
21-09-2026

What is the brightest source in the sky?

Optical

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Optical



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Optical



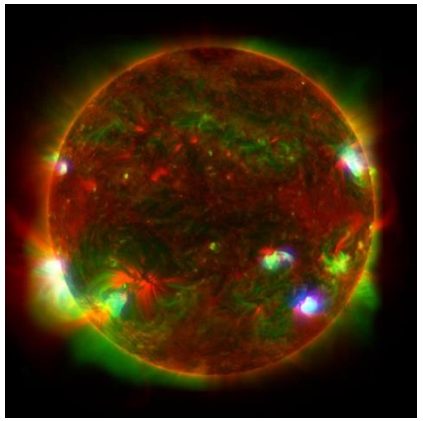
X-ray

What is the brightest source in the sky?

Optical



X-ray



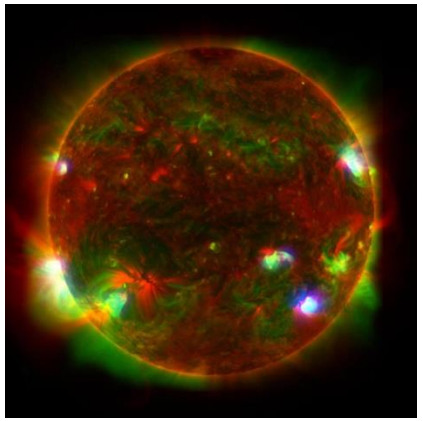
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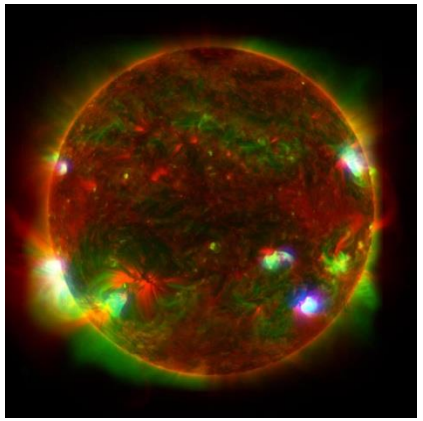
UV

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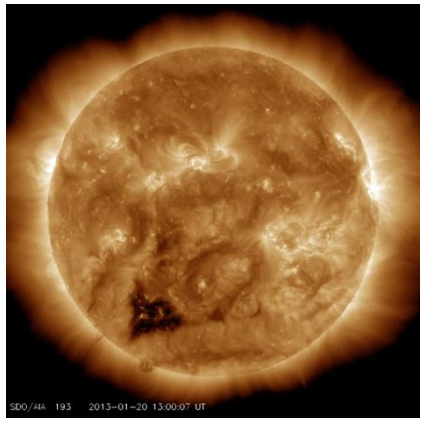
Optical



X-ray



UV



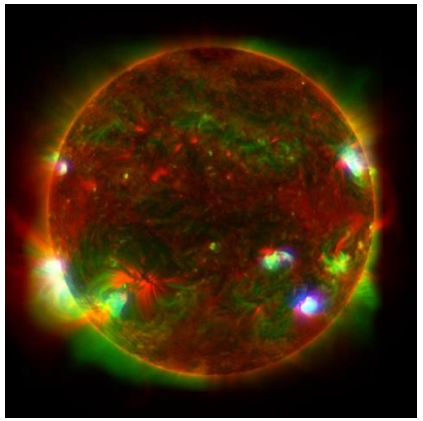
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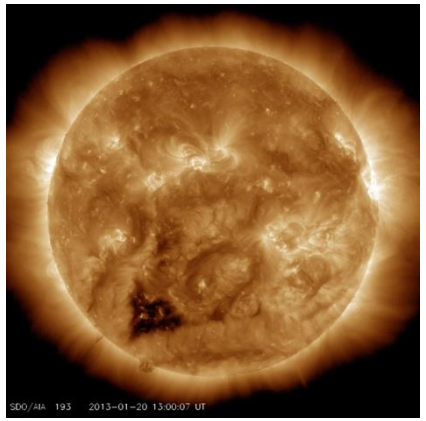
Optical



X-ray



UV



Radio

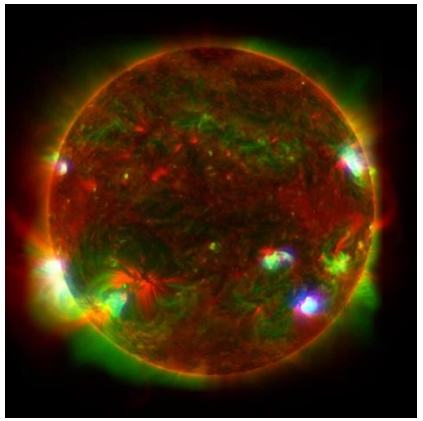
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What is the brightest source in the sky?

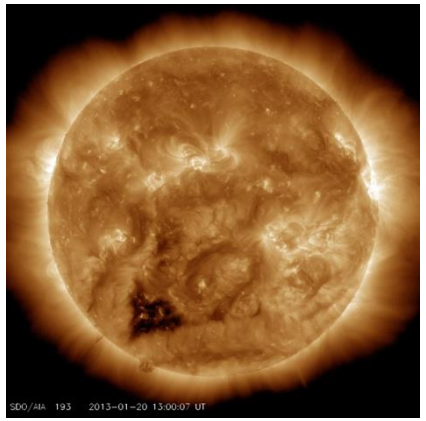
Optical



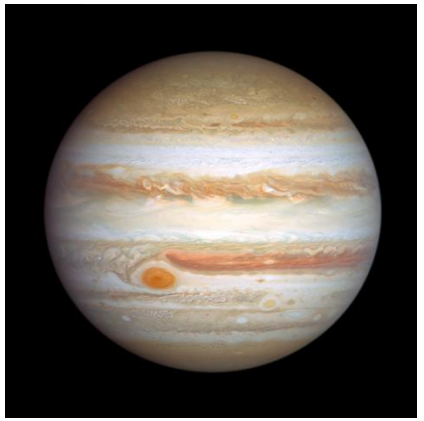
X-ray



UV



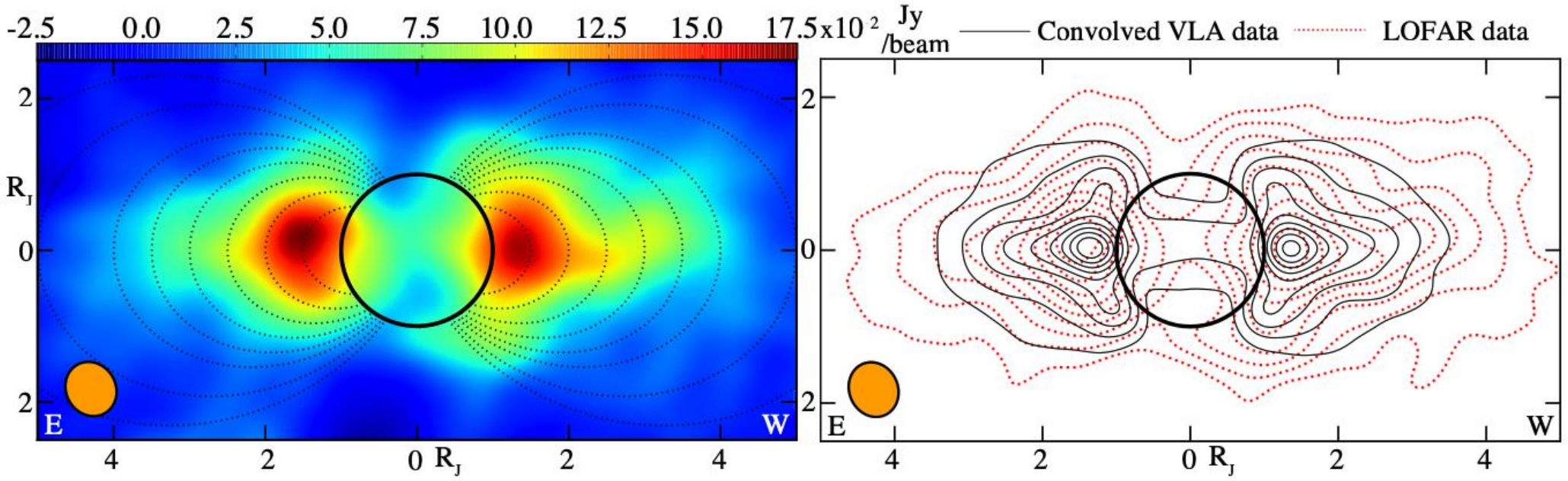
Radio



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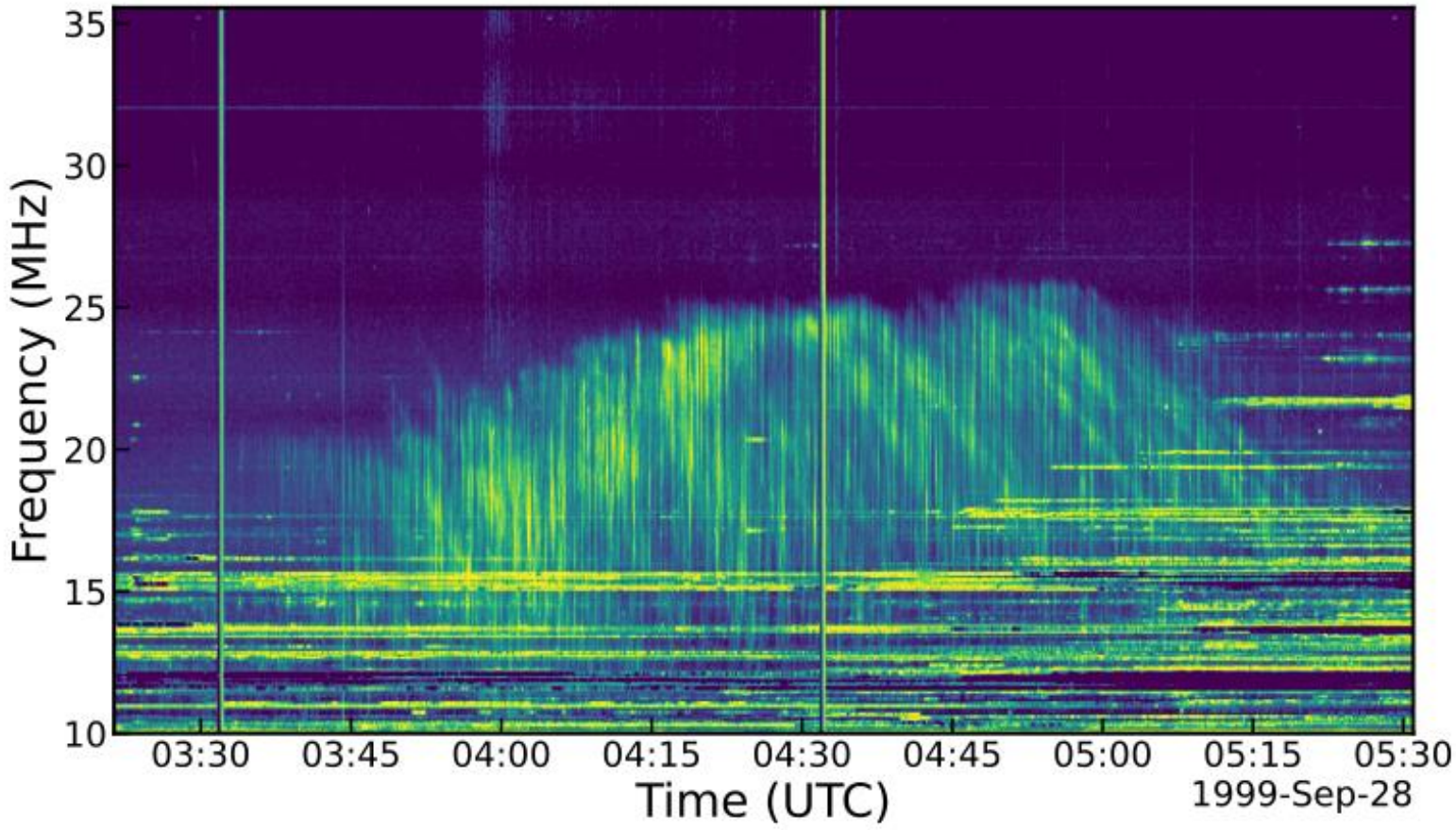
Jupiter at gigahertz frequencies

- Synchrotron radiation belts
- Particles trapped in the magnetic field



Jupiter at lower frequencies

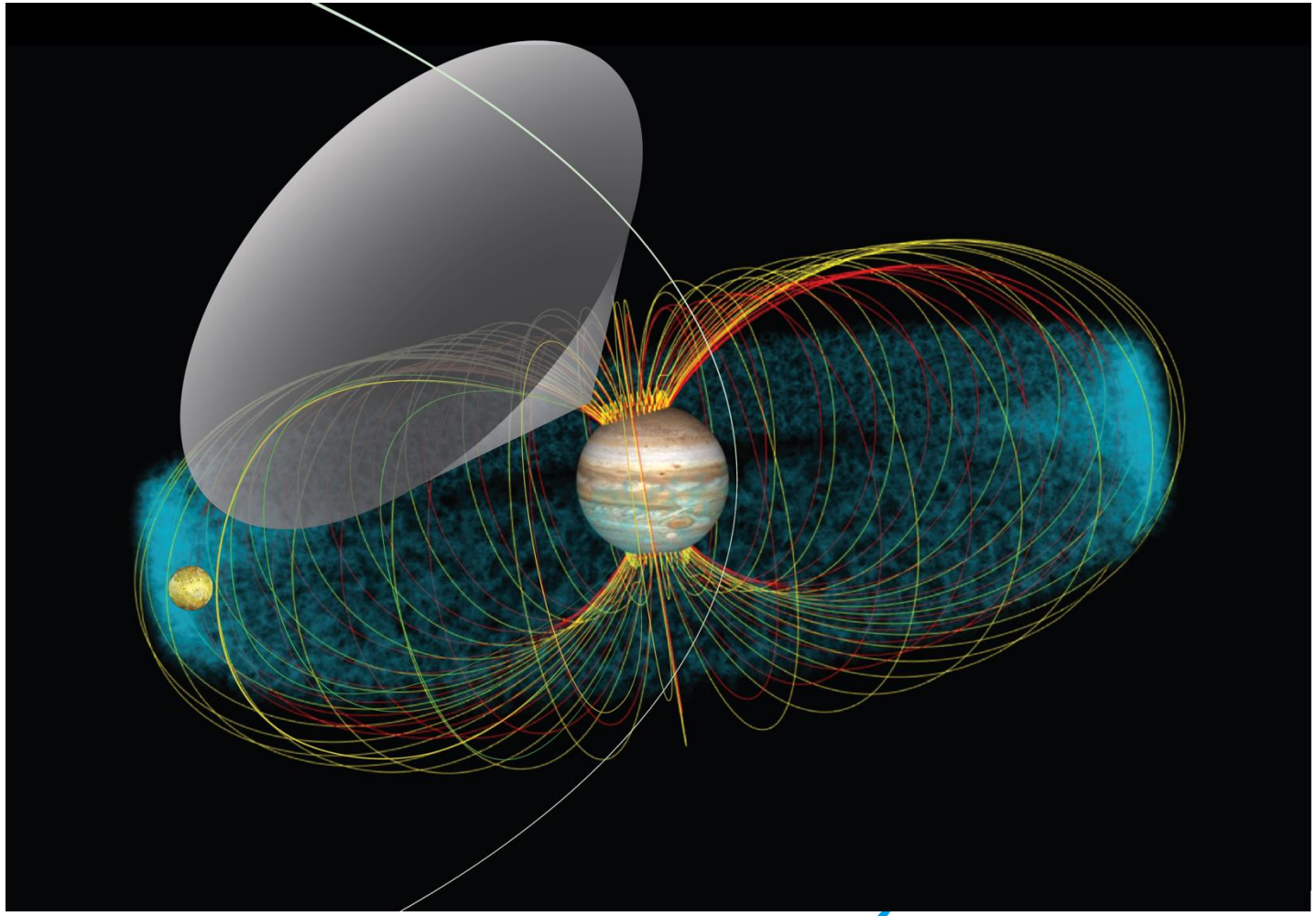
- Strong bursts
- Highly circularly polarised
- Periodic



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Electron cyclotron maser instability

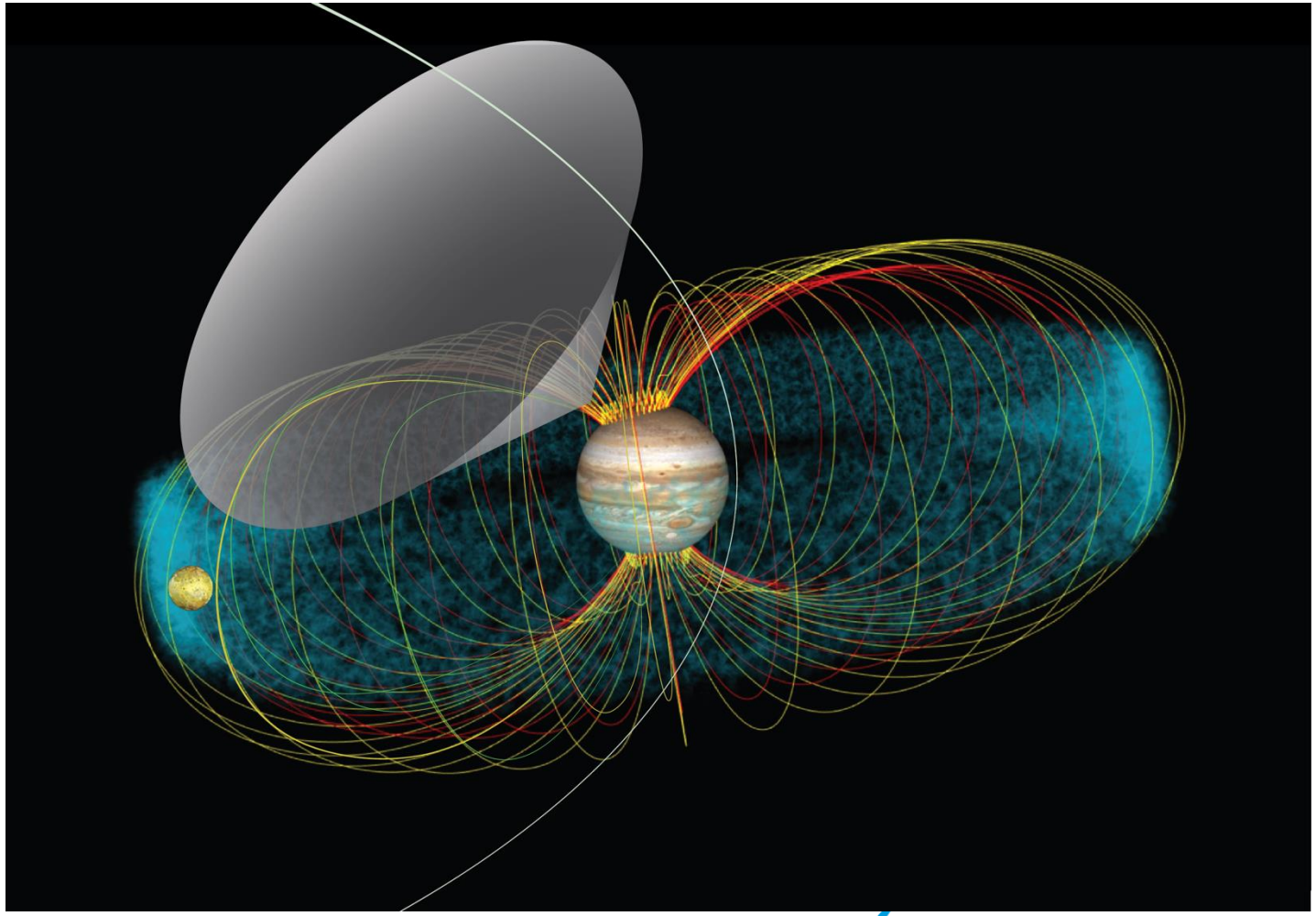
- Cyclotron emission
- $\nu_B \approx 2.8 \times 10^6 B$
- Strongly elliptically or circularly polarised
- Beamed on the surface of a wide cone



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Periodicity

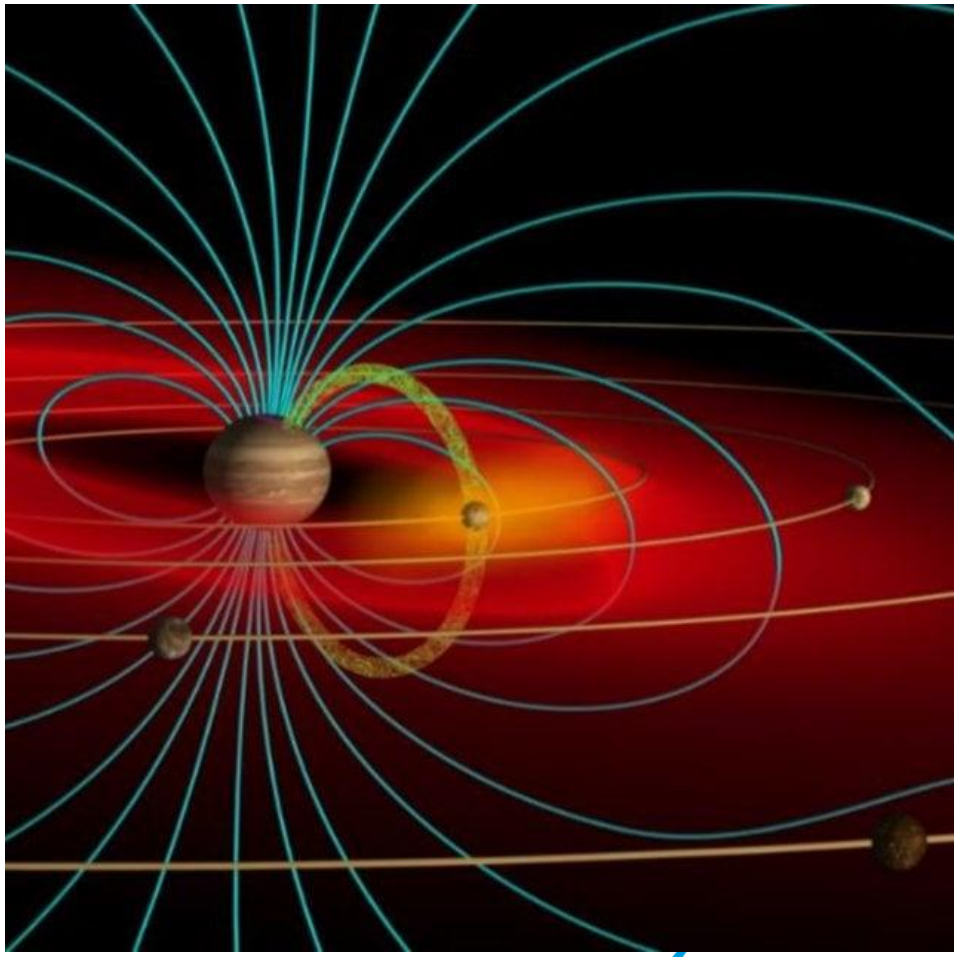
- ECMI is beamed
- Rotation modulates the visibility
- Exact periodicity depends on what powers the bursts



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Breakdown of corotation

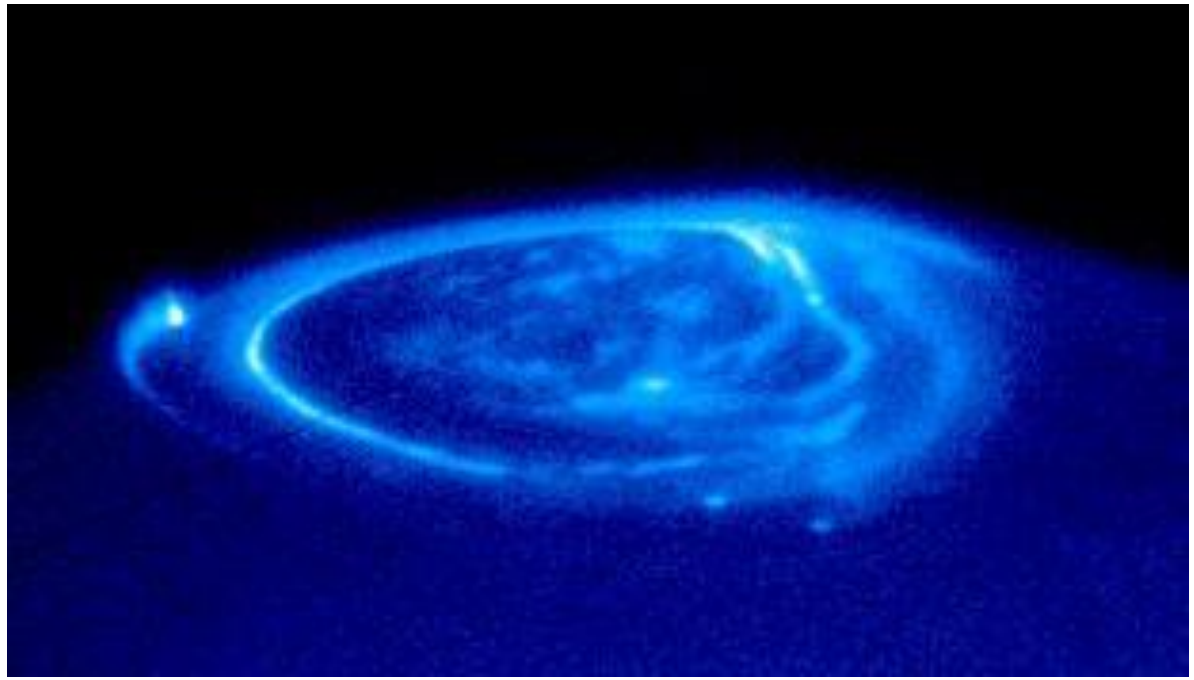
- Jupiter has a plasma torus mostly caused by Io's volcanism
- Charges moving relative to the magnetic field activates the magnetic field
- Radio emission periodic with the rotation



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Breakdown of corotation

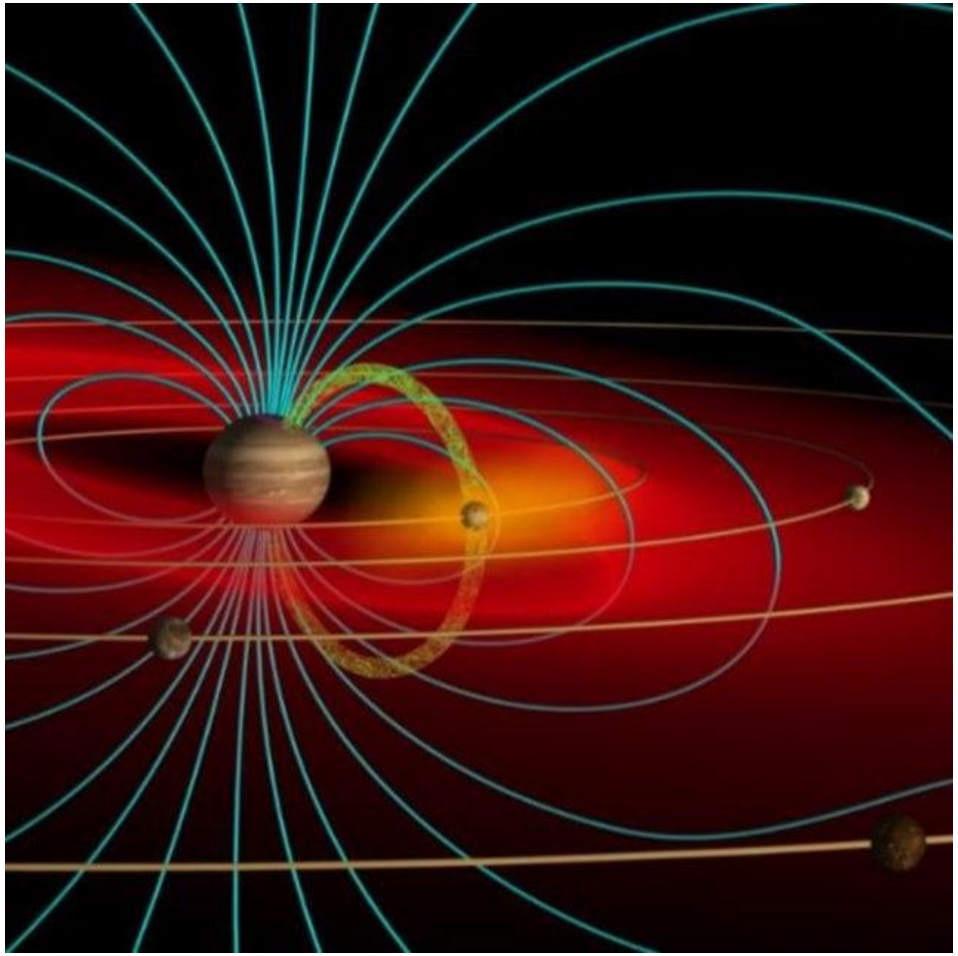
- Jupiter has a plasma torus mostly caused by Io's volcanism
- Charges moving relative to the magnetic field activates the magnetic field
- Radio emission periodic with the rotation
- This process causes the aurorae



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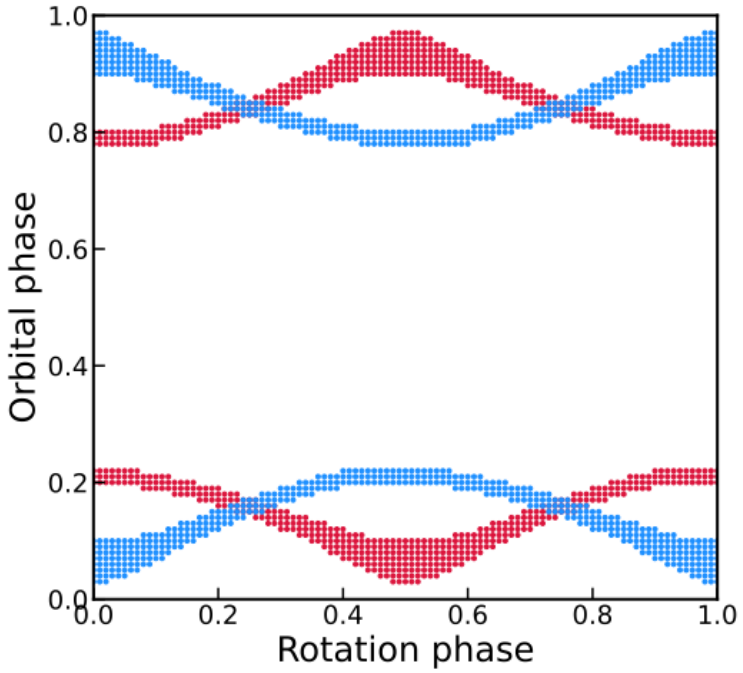
Jupiter-Io interaction

- Io activates the field lines it connects to
- Only activates a small section of the magnetic field at a time
- Emission periodic with Io's orbit *and* the rotation of Jupiter

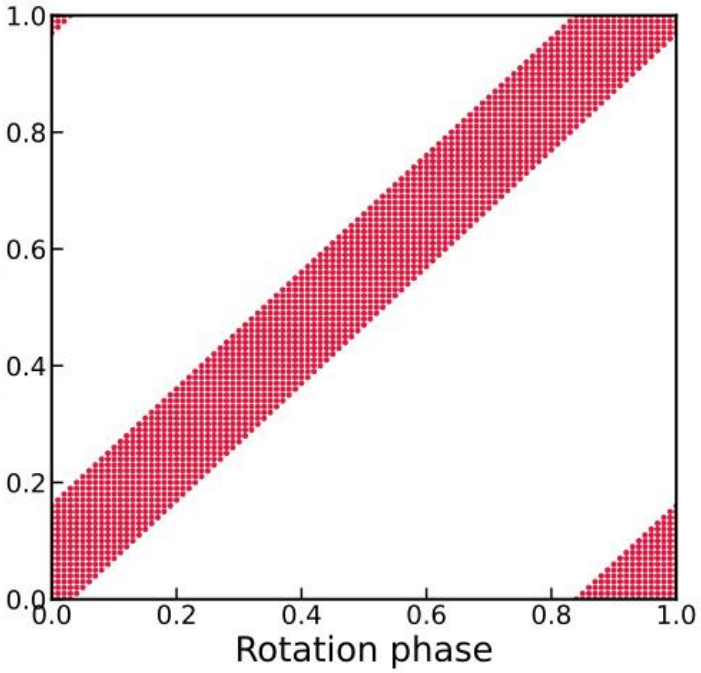


Interaction emission patterns

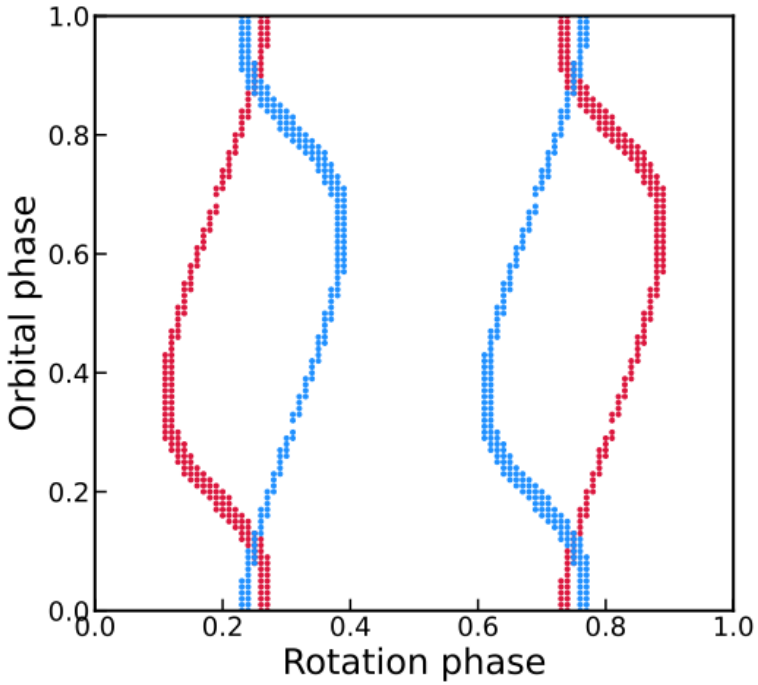
Small magnetic obliquity



Some magnetic obliquity

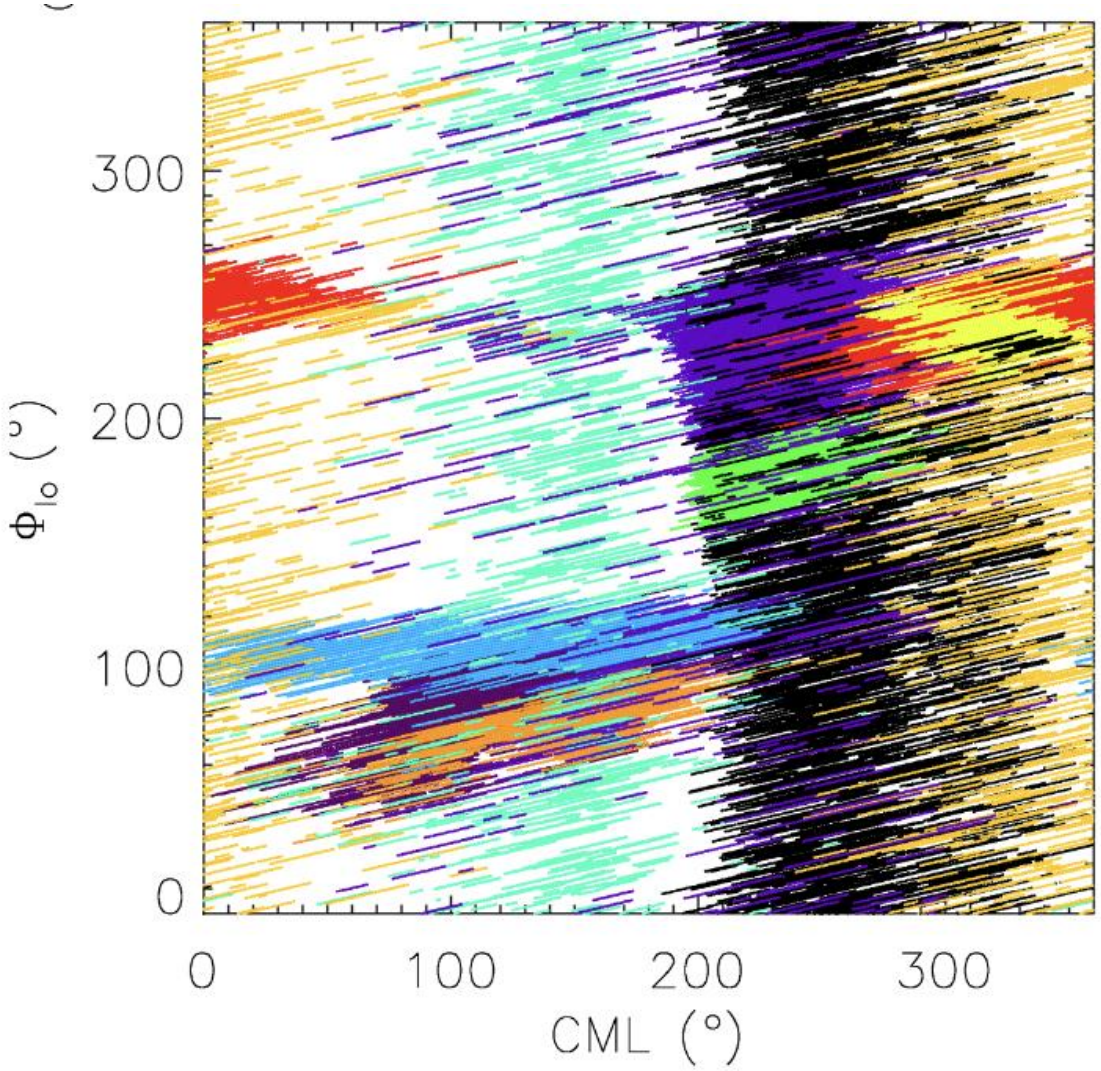


Large magnetic obliquity



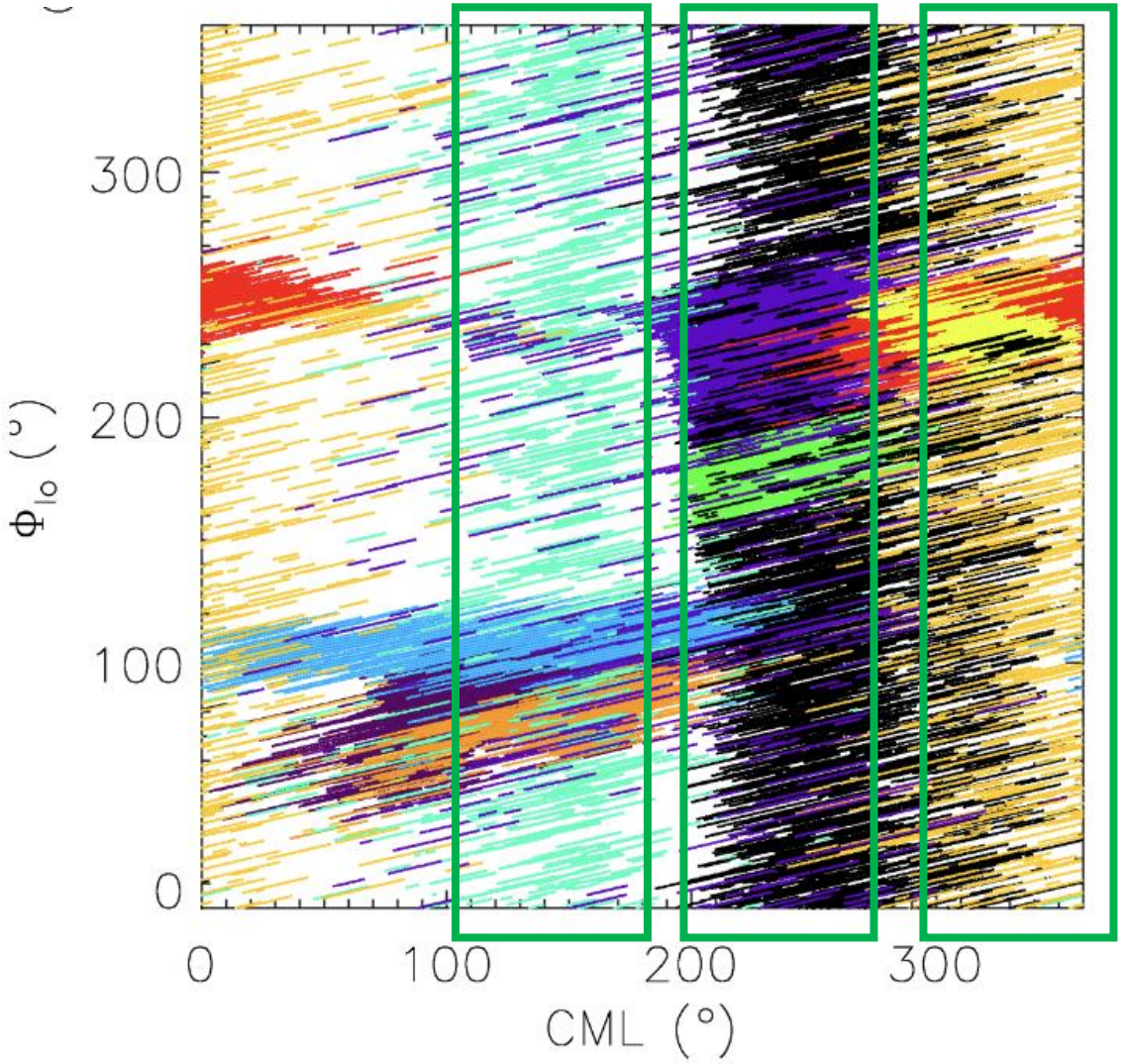
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Jupiter-Io interaction



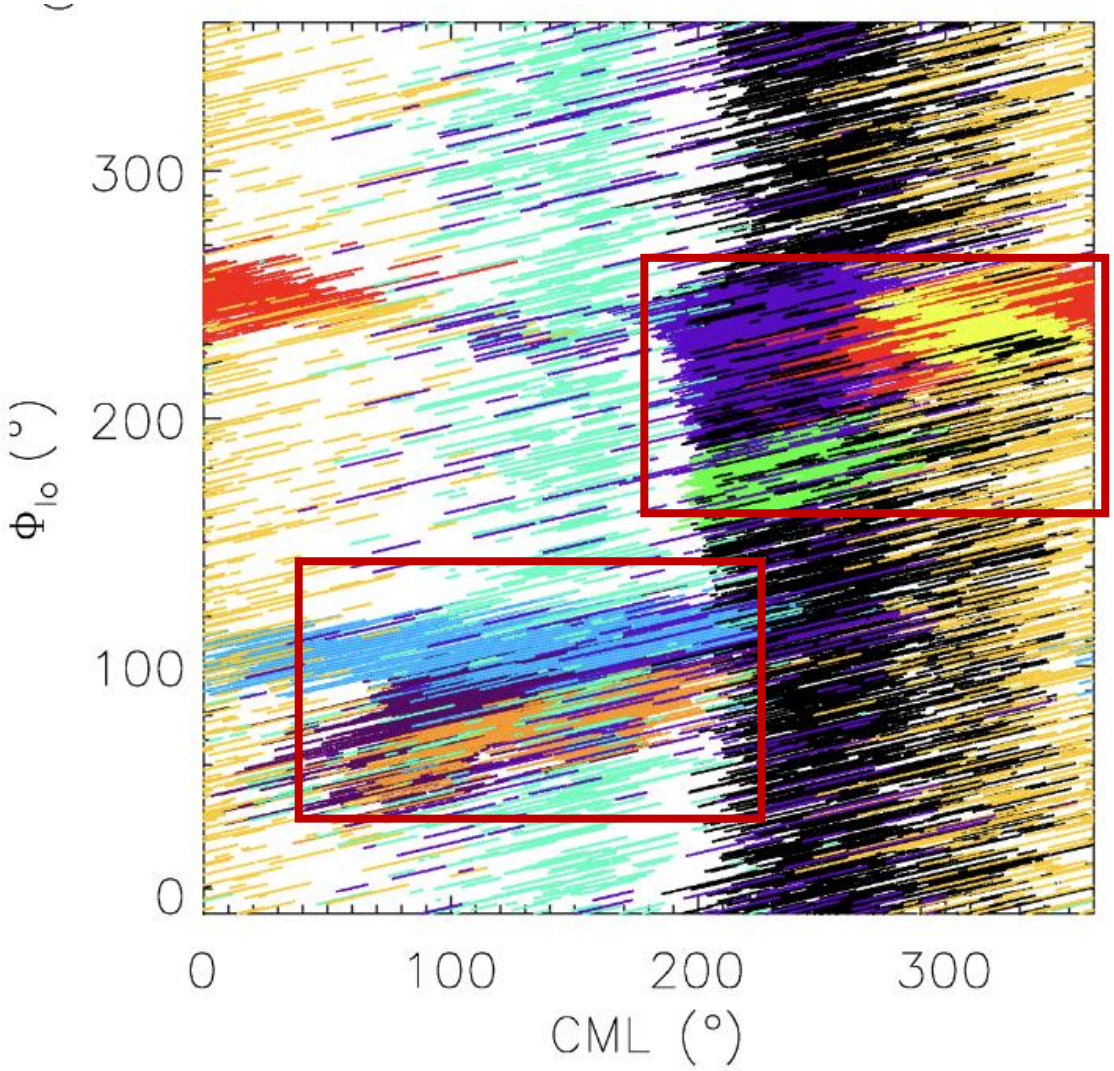
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Jupiter-Io interaction



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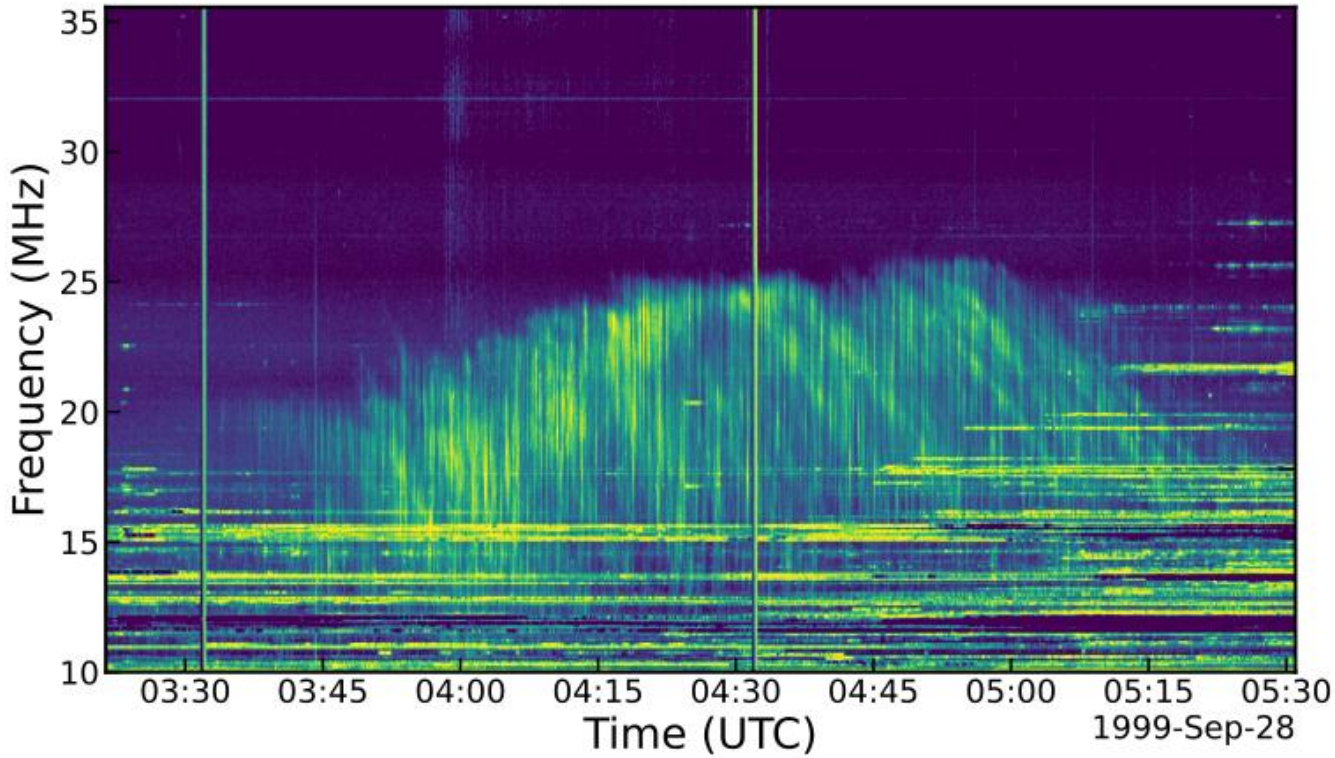
Jupiter-Io interaction



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Jupiter

- Synchrotron radiation belts
- ECMI bursts
- Breakdown of corotation
- Interaction with Io



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Exoplanets

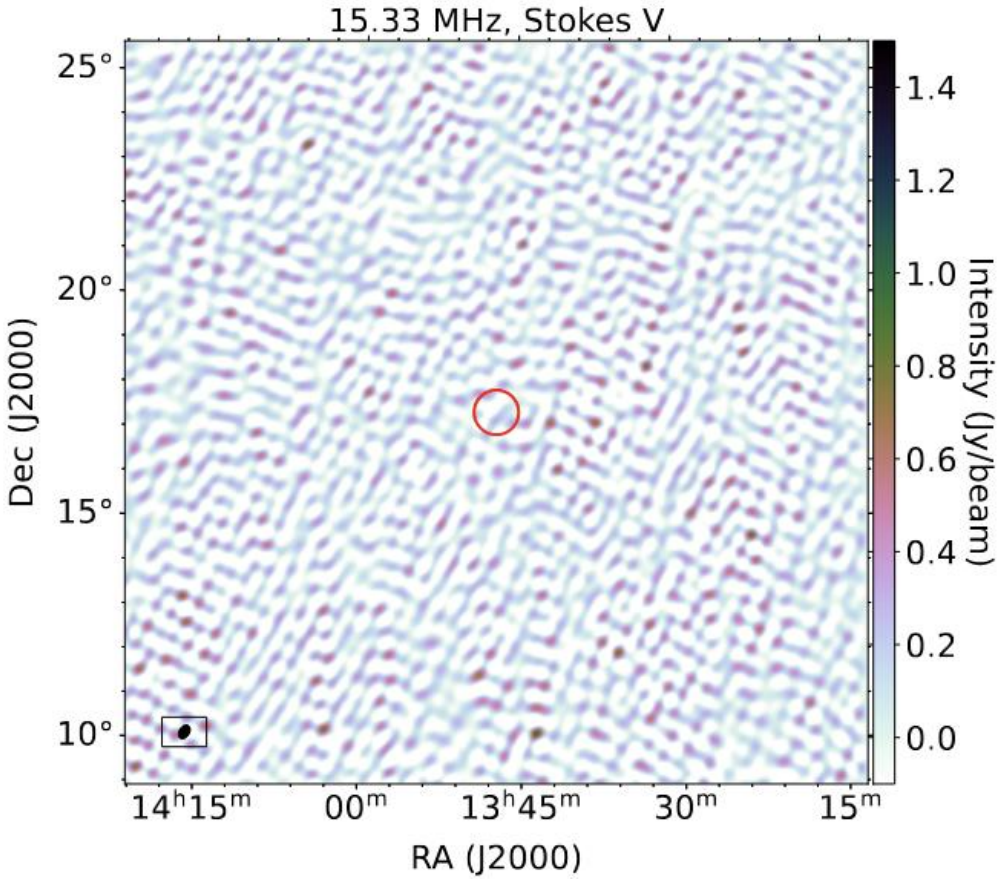
- ECMI gives the magnetic field
- Habilitability
- Detect exomoons?
- Faint
- Extremely low frequencies



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Exoplanets with LOFAR

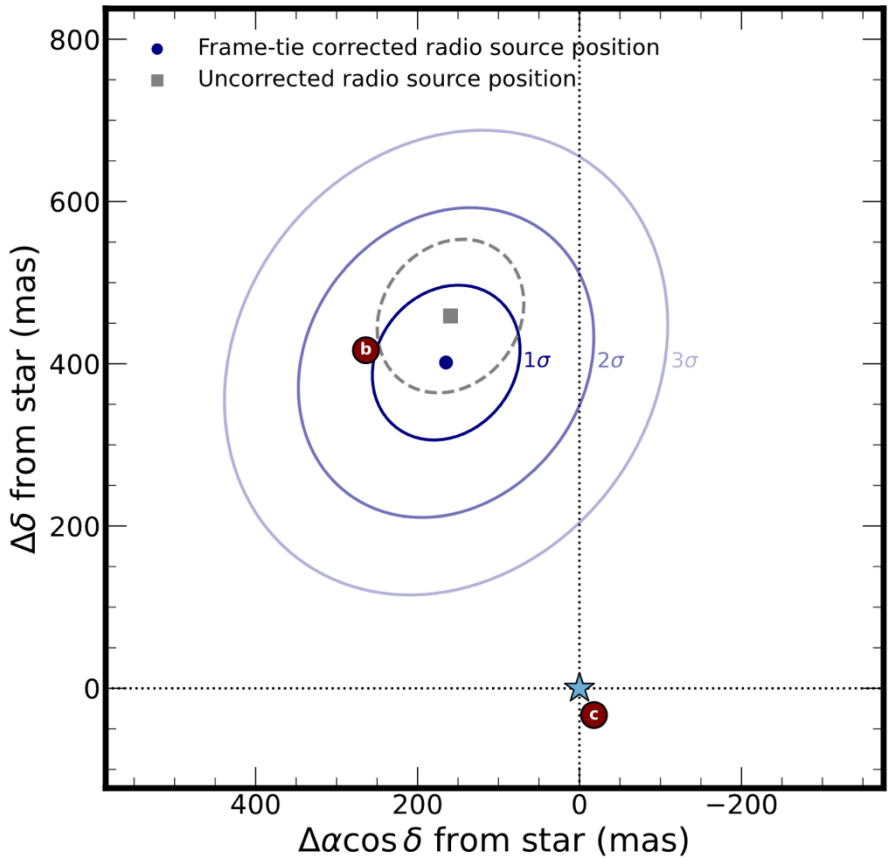
- Potential detection of Tau Bootis (Turner et al. 2021)
- Follow-up could not confirm the detection (Turner et al. 2024, Cordun et al. 2025)



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Exoplanets with MeerKAT

- MeerKAT detection at L and S band
- Position matches beta Pictoris b
- Ortiz Ceballos et al. (in review)



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Brown dwarfs

- Less massive than stars, more massive than planets
- Strong magnetic fields
- Rotate in a few hours
- Behave like Jupiter at radio frequencies

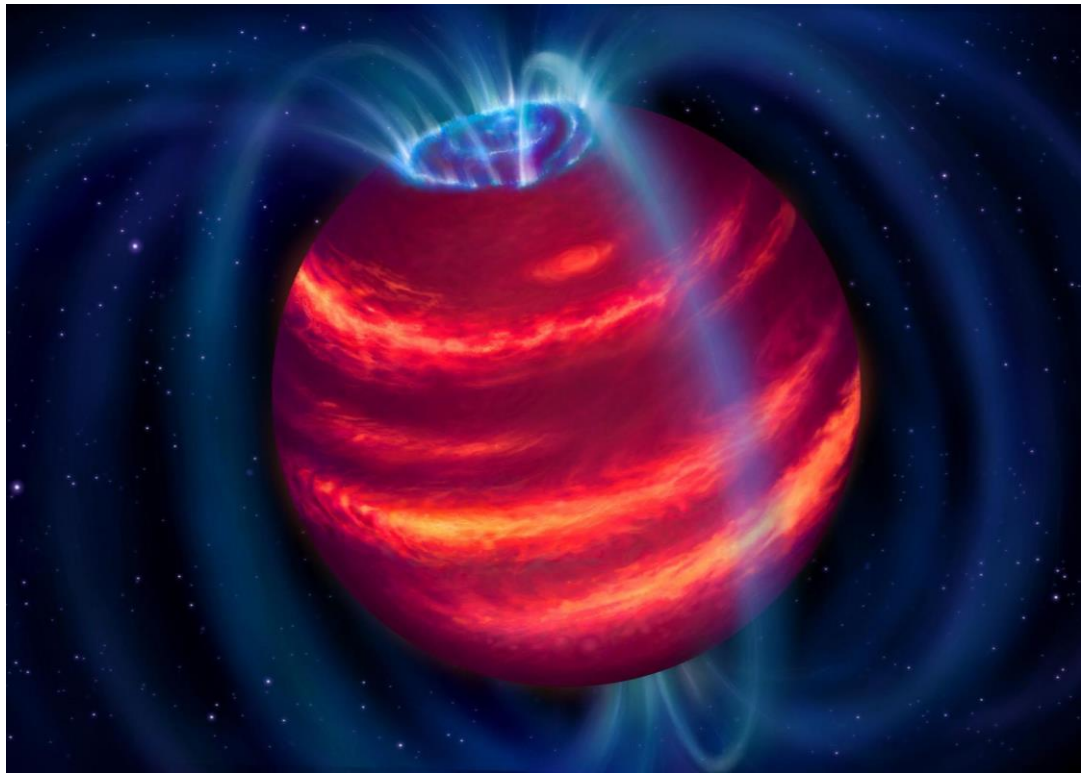
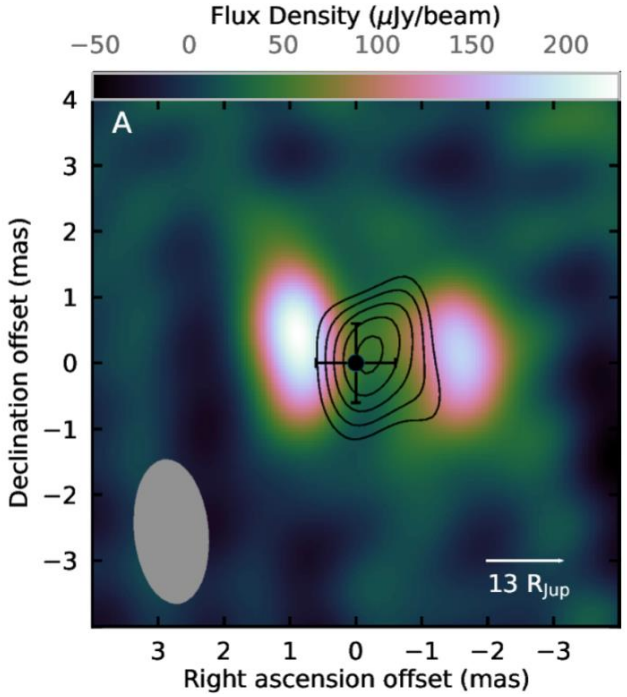


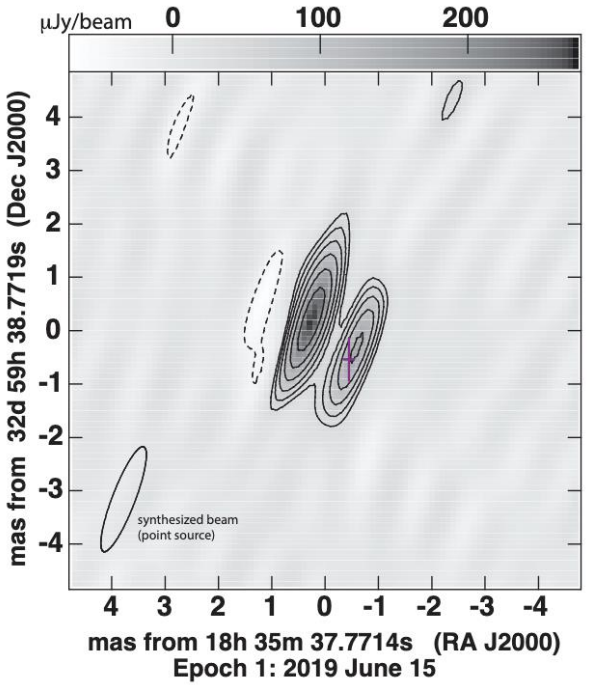
Image credit: Danielle Futselaar

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Brown dwarfs in radio

- Radiation belts
- Climent et al. (2023), Kao et al. (2023)

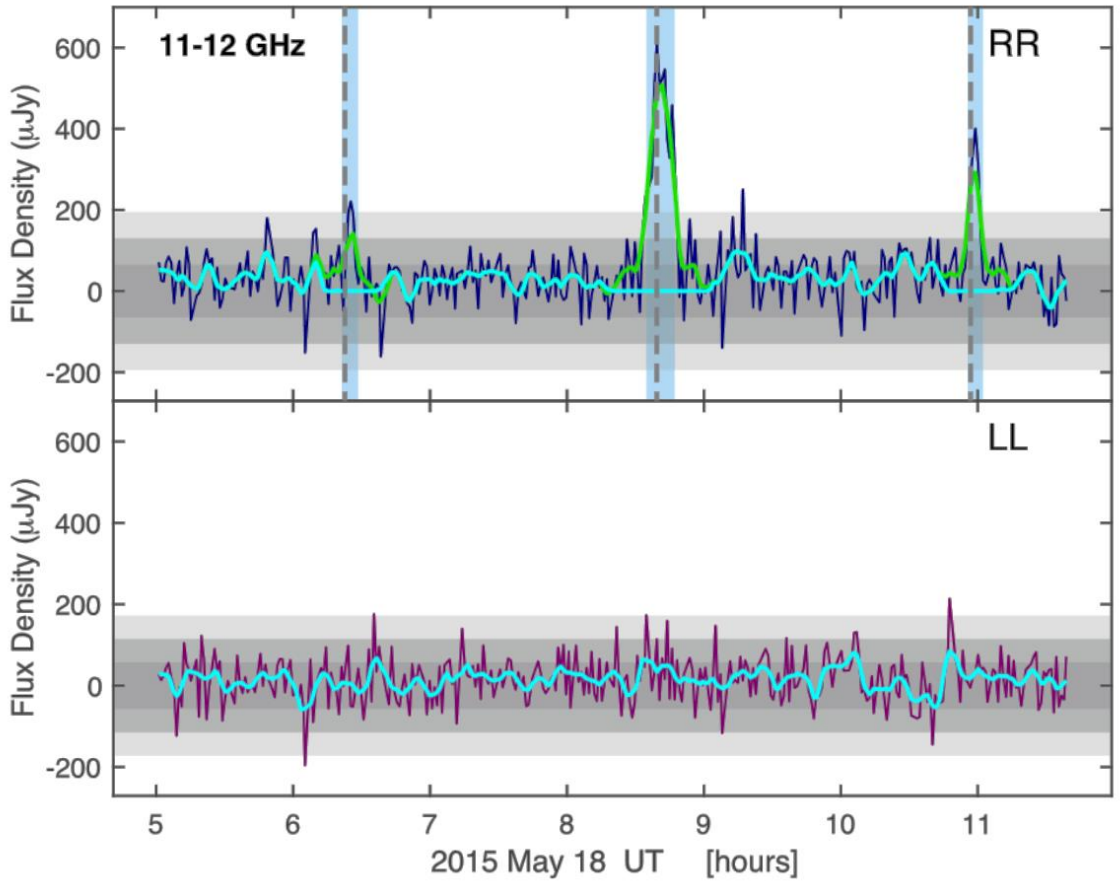




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Brown dwarf bursts

- Short pulses
- Strongly circularly polarised
- Periodic

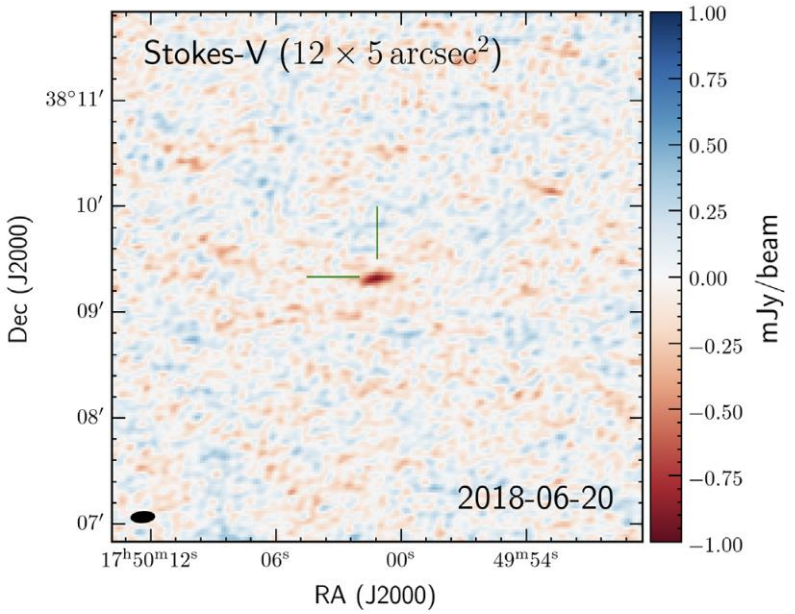


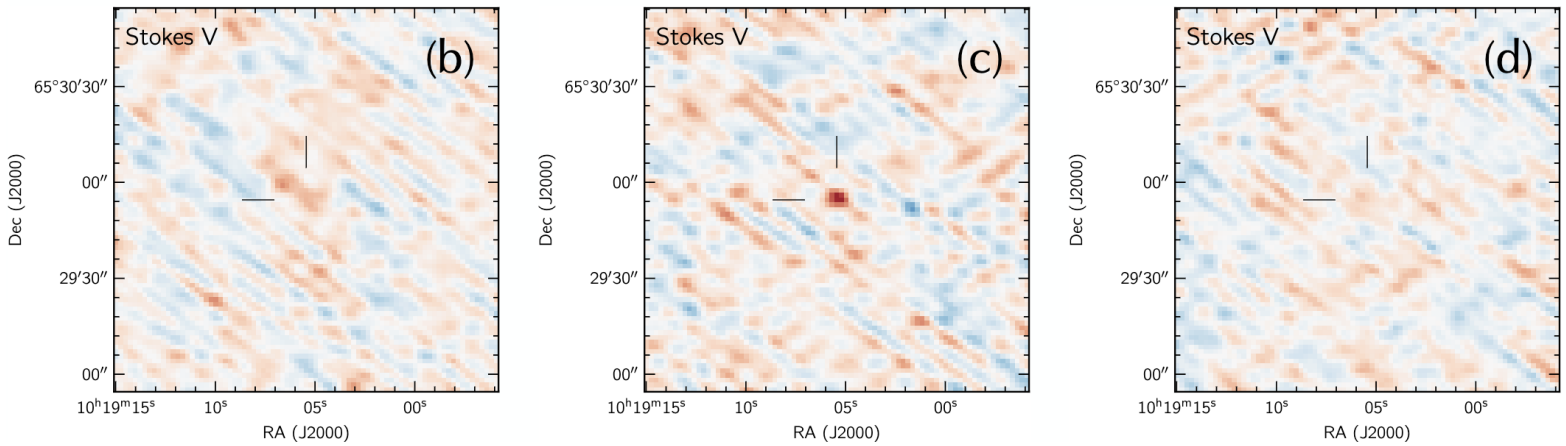
Kao et al. (2018)

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Brown dwarfs with LOFAR

- Elegast
  - Vedantham et al. (2020)
  - Continuous emission for 8 hours
- WISEP J1019+65
  - Vedantham et al. (2023)
  - Typical pulse emission

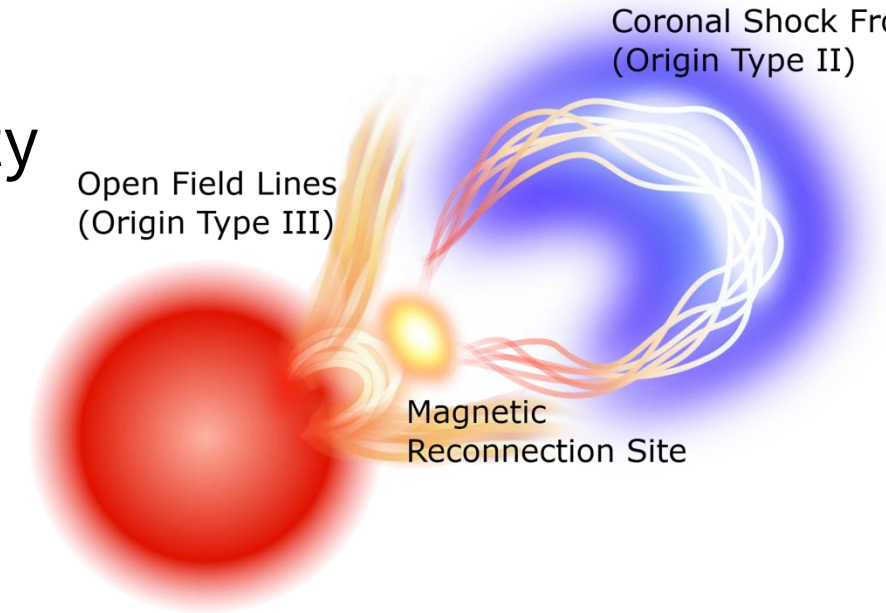


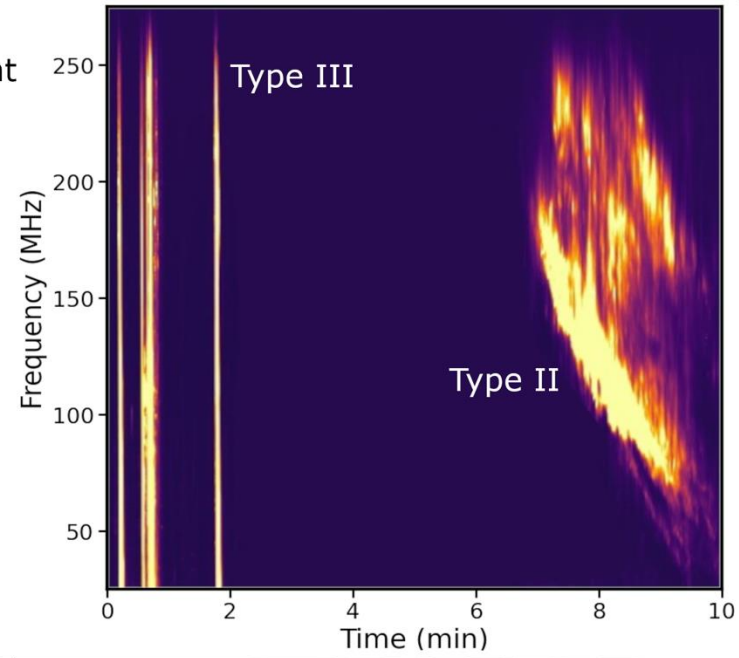


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Stars at radio frequencies

- Solar type bursts
- Plasma emission
- $\nu_p \approx 9000\, n_e^{1/2}$;
- Traces stellar activity

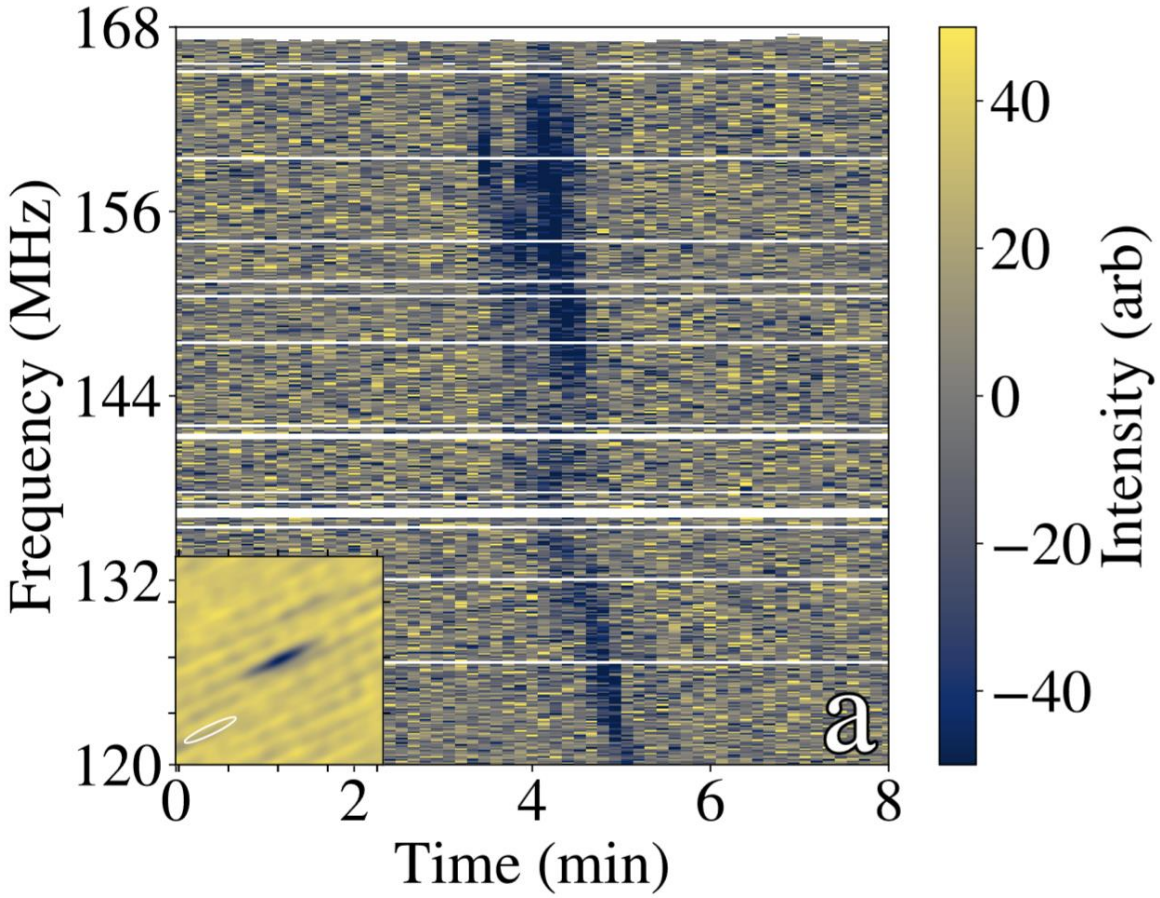




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Type II bursts

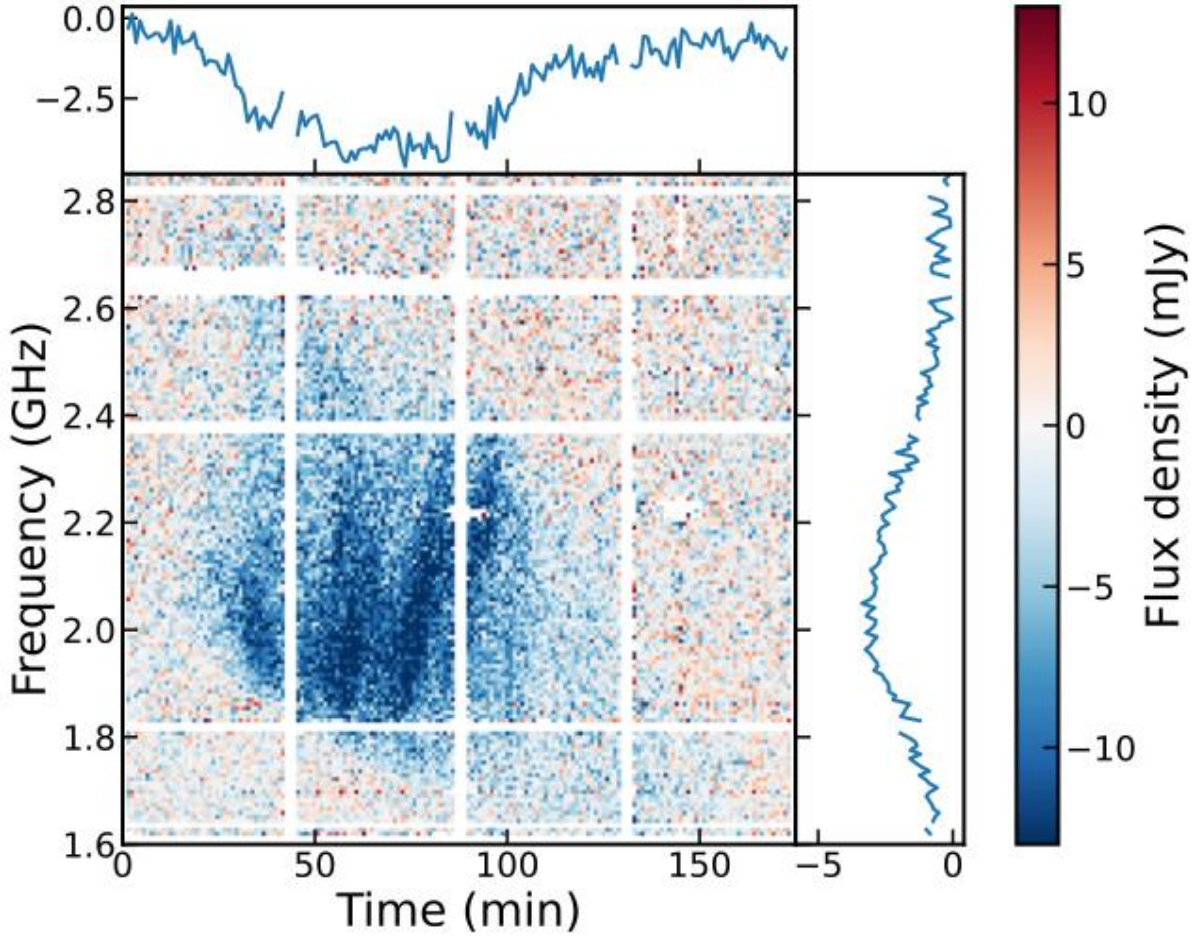
- Caused by coronal mass ejections
- Characteristic time-frequency drift
- Detected with LOFAR (Callingham et al. 2025, Konijn et al. 2025)



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ECMI from stars

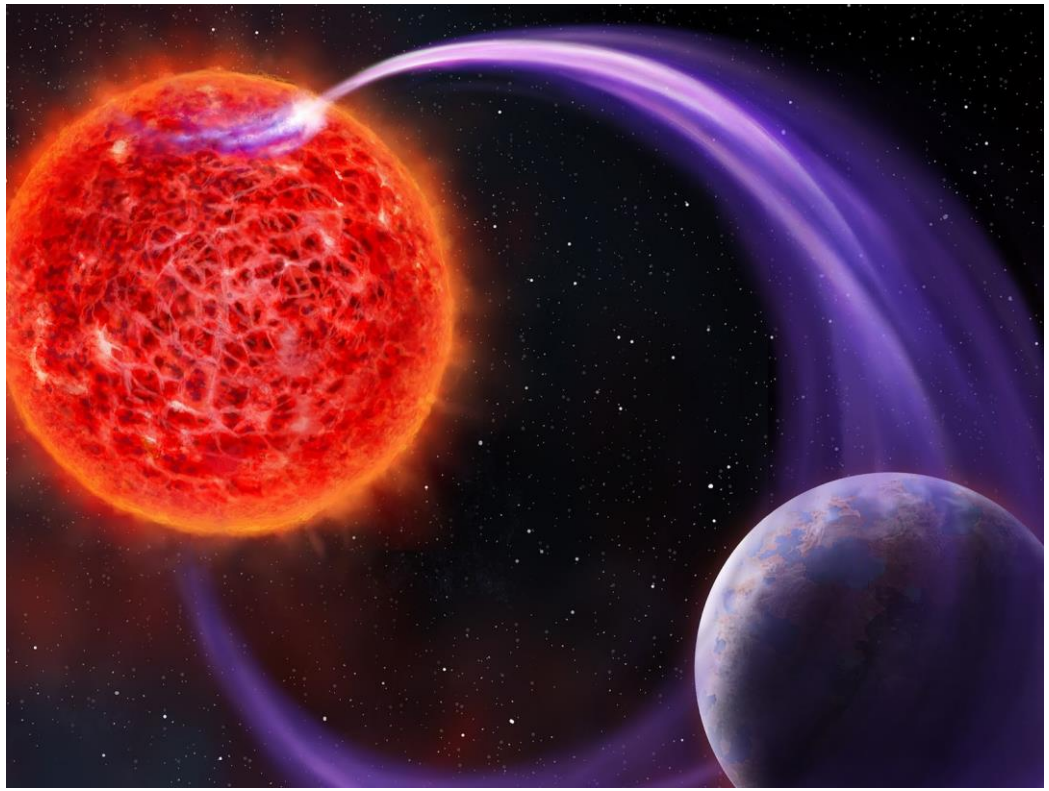
- Bright, circularly polarised bursts
- Breakdown of corotation
- Periodic with the rotation of the star



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Star-planet interactions

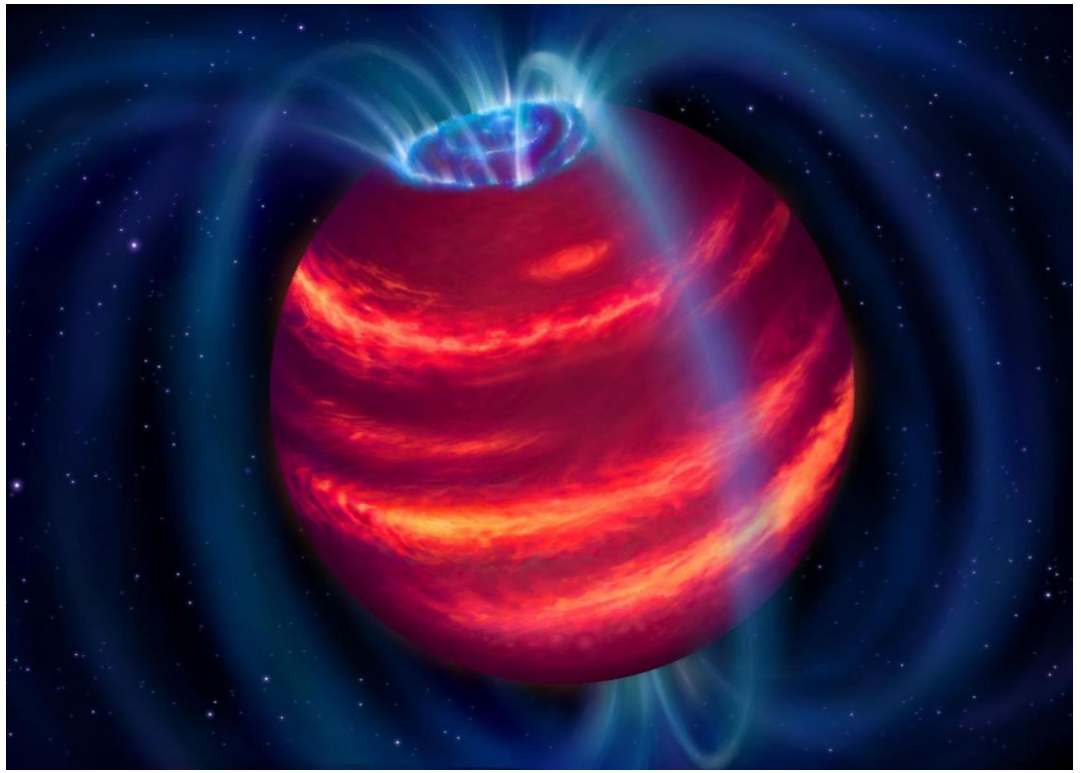
- Scaled-up version of Jupiter-Io
- Periodic
- Can be used to
  - Measure planetary magnetic fields
  - Study space weather
  - Detect new exoplanets?
- Tentative detections (e.g. Perez-Torres et al. 2019, Vedantham et al. 2020, Pineda & Villadsen 2023, Trigilio et al. 2023)



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Observational strategies

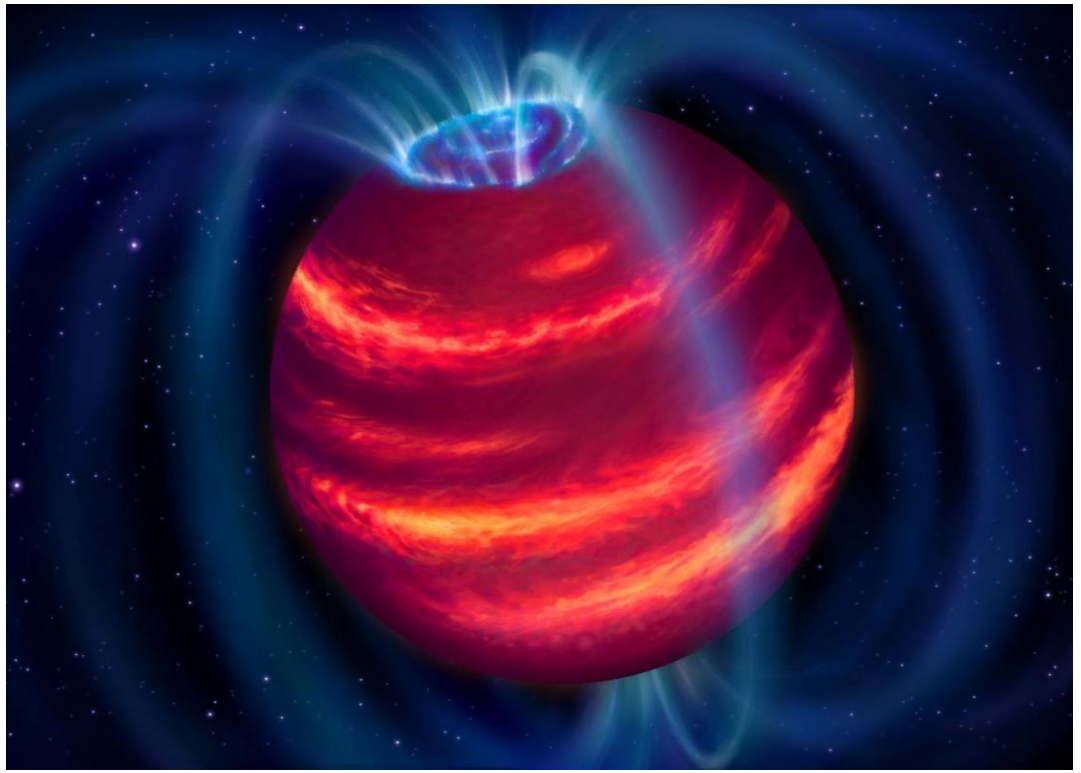
- How do we find these objects?
- Crossmatching



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Observational strategies

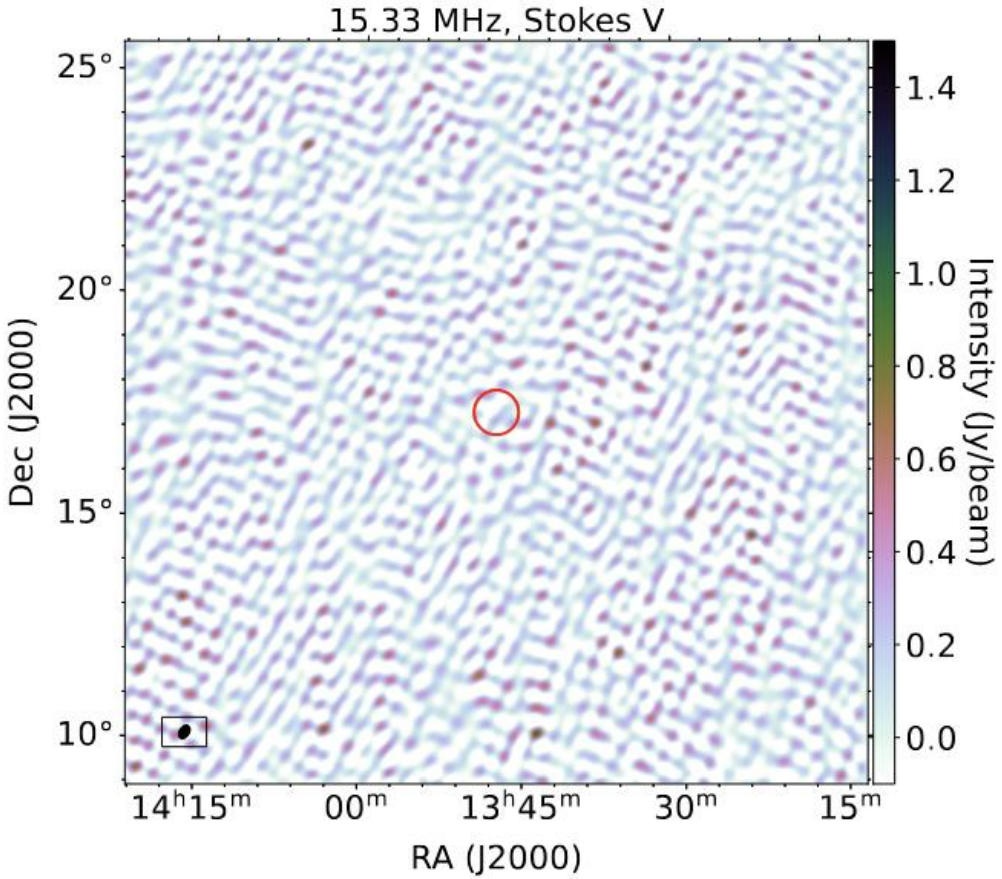
- How do we find these objects?
- ~~Crossmatching~~
- Low-frequency search



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Observational strategies

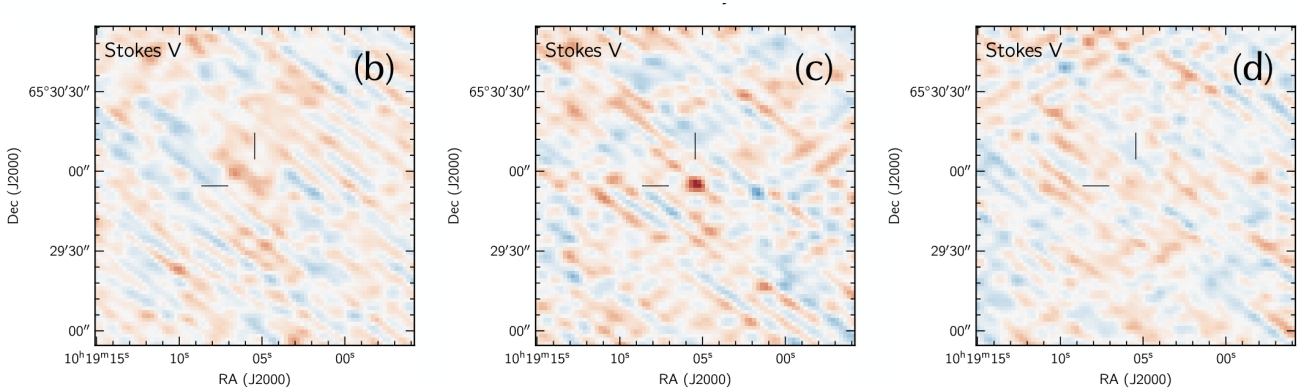
- How do we find these objects?
- ~~Crossmatching~~
- Low-frequency search
  - Possible, but hard
  - LOFAR LBA
  - Ionospheric cutoff – telescope on the moon?



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Observational strategies

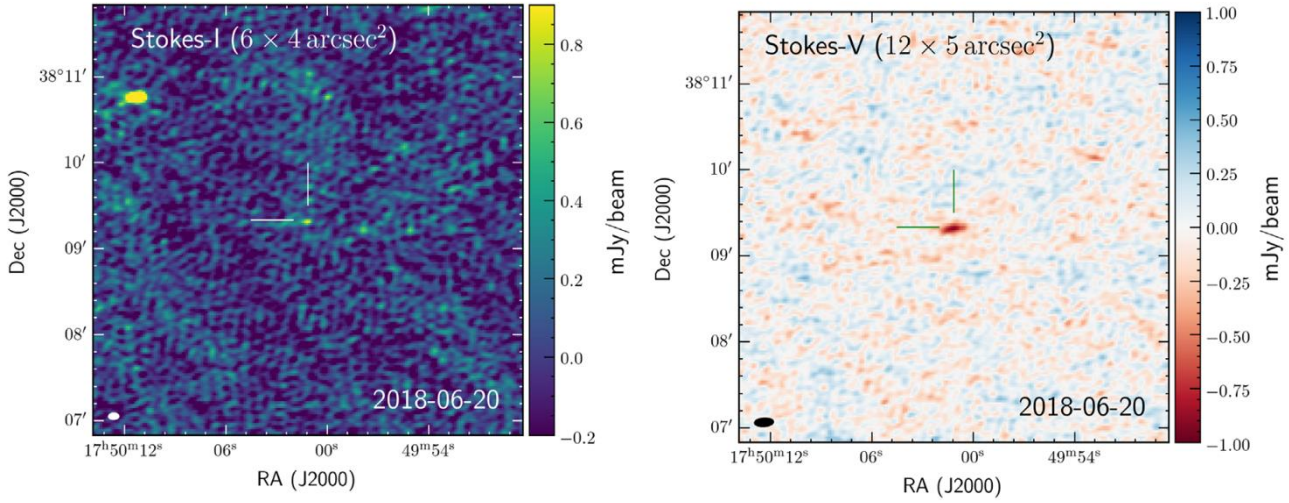
- How do we find these objects?
- ~~Crossmatching~~
- Low-frequency search
  - Possible, but hard
  - LOFAR LBA
  - Ionospheric cutoff – telescope on the moon?
- Transient search



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Observational strategies

- How do we find these objects?
- ~~Crossmatching~~
- Low-frequency search
  - Possible, but hard
  - LOFAR LBA
  - Ionospheric cutoff – telescope on the moon?
- Transient search
- Circular polarisation



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