Rapid monitoring of the state of Jupiter radiation belts with LOFAR

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Giant gaseous planet

Fast rotation $P \sim 10h$

Highly magnetized $|\vec{\mathcal{M}}| \sim 4.2\ G$

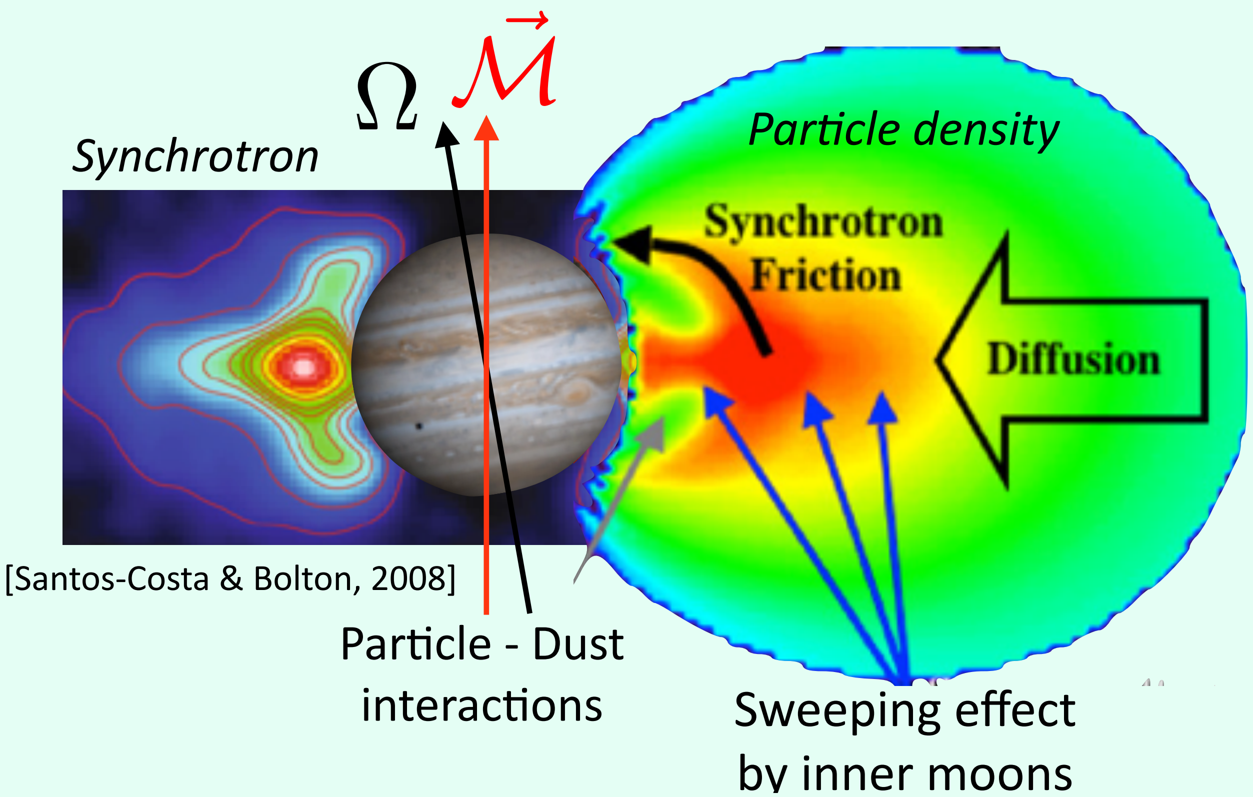
$\rightarrow$

One of the biggest magnetosphere (MS) in the Solar System

One of the most energetic radio transient at $\lambda \sim \mathrm{Dm}$

Source of many radio signals at various timescales, frequencies and locations in the MS

What are radiation belts ?



Nature: synchrotron radiation from

- relativistic electrons E > 1 MeV
- trapped in a ~dipolar magnetic field $|B| \sim r^{-3}$

Projected structure in the sky: Arrow-shaped < 3 R_J due to emission, dust, moons and rings

Critical synchrotron frequency $\boxed{\nu_c \propto E^2 B}$

Motivations

- **Where** and **what** are the sources ?
- How to link the **morphology of the radiation** to the **distribution of electrons** ?
- **What mechanisms** for the particles ? ***losses*** ***transport***
- What are the various **temporal variabilities** ? *from hours to years*
- How it connects to outer regions in the MS ?

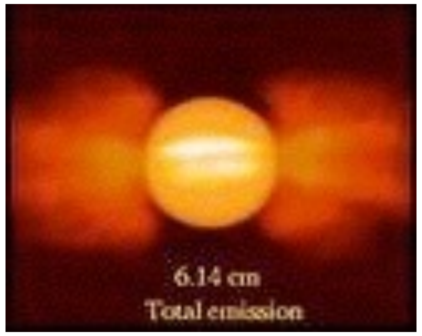
How to address these questions?

Multi-frequency & resolved imaging of the synchrotron emission in

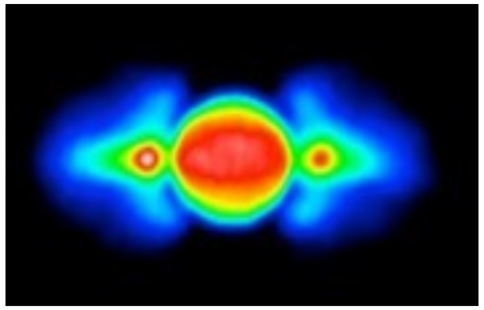
$$\overset{?}{\leq} 40\ \mathrm{MHz} - \sim 10\ \mathrm{GHz}$$

How LOFAR can help ?

poor angular resolution
poor signal-to-noise ratio
} Below 300 MHz

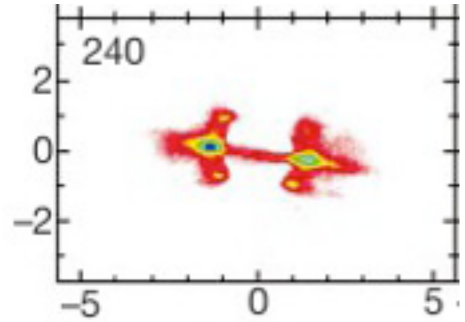


5 GHz / 6 cm

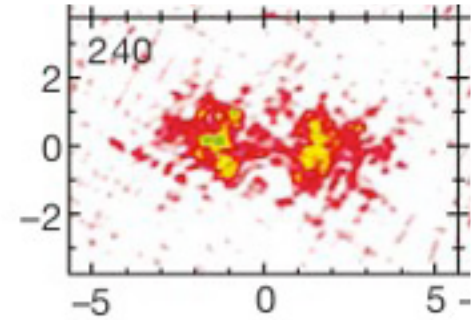


2.3 GHz / 13 cm

ATCA

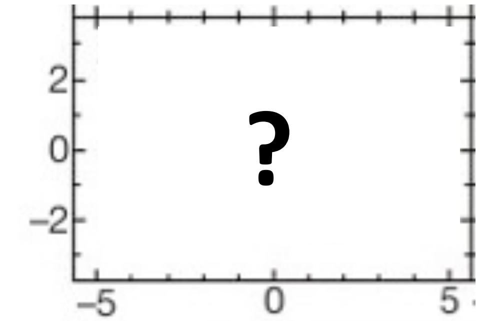


1.4 GHz / 20 cm



333 MHz / 90 cm

VLA



<300 MHz / >1 m

LOFAR

LOFAR (LOw Frequency ARray)

SKA Precursor for SKA-LOW

Giant digital Phased Array Interferometer

N_{ant} = ~50 antennas distributed in NL + Europe

1 antenna = 1 phased array = 1 « station »

Frequency coverage: 30-250 MHz

Resolutions: 1 µs / 1 Hz / 1''   Sensitivity: 1 mJy

Multi-beam capabilities

Observing modes:

- **Interferometer** — **N_{beams} x NxN pixels Imaging**
- Tied-Array beam — N_{beams} x 1 sensitive pixel

Dedicated planetary pipeline

Flagging/Averaging

Direction-independent calibration

Requires specific reduction due to :
- **large FoV at LF**
- **moving target**

+ Wide-field imaging

+ Source finding

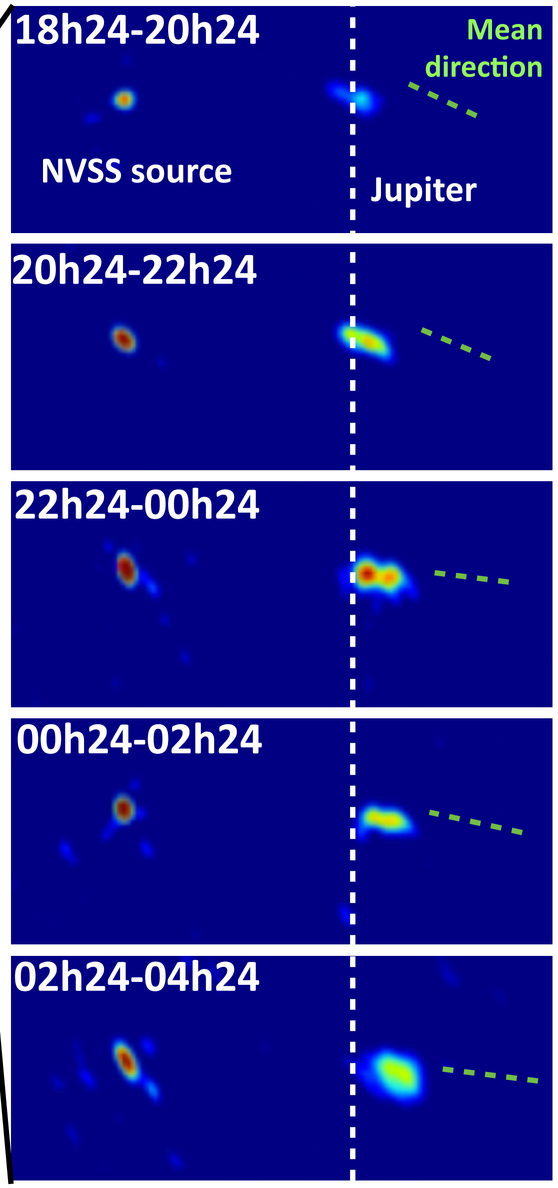
+ Direction-dependent Calibration

+ Correction for planetary sources
- **Apparent (Earth revolution)**
- **Intrinsic (Jupiter fast rotation)**

+ Multi-frequency imaging

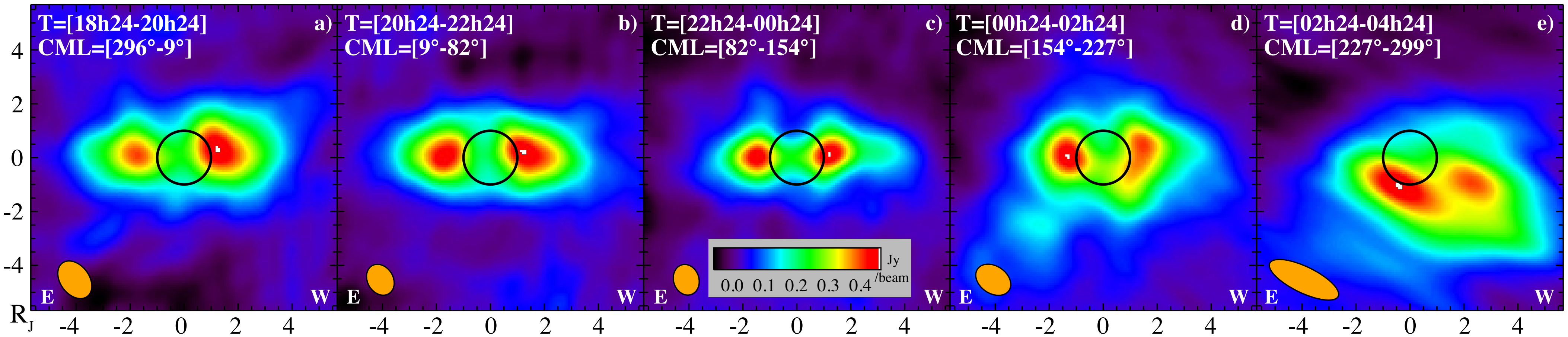
Jupiter centered image cubes

Classic reduction and imaging

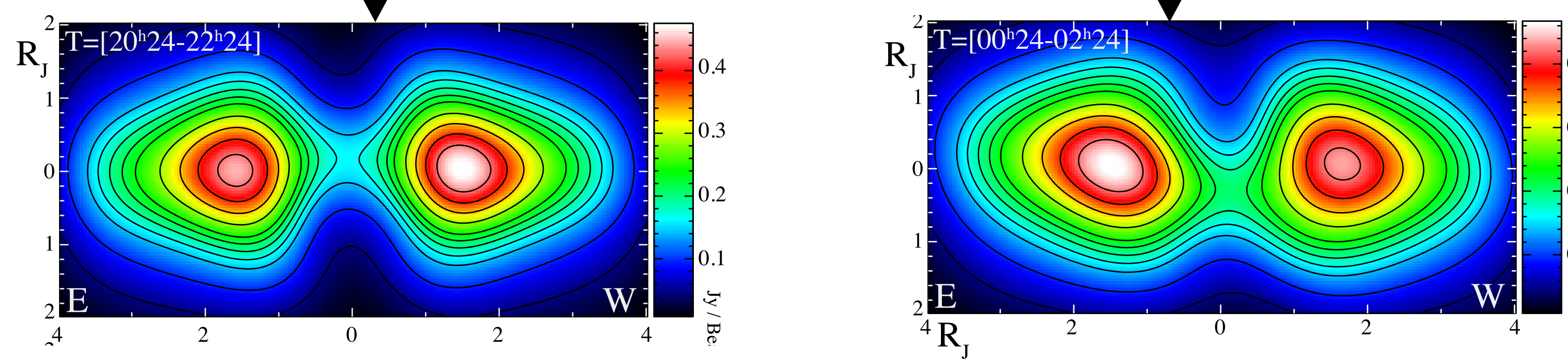


Results

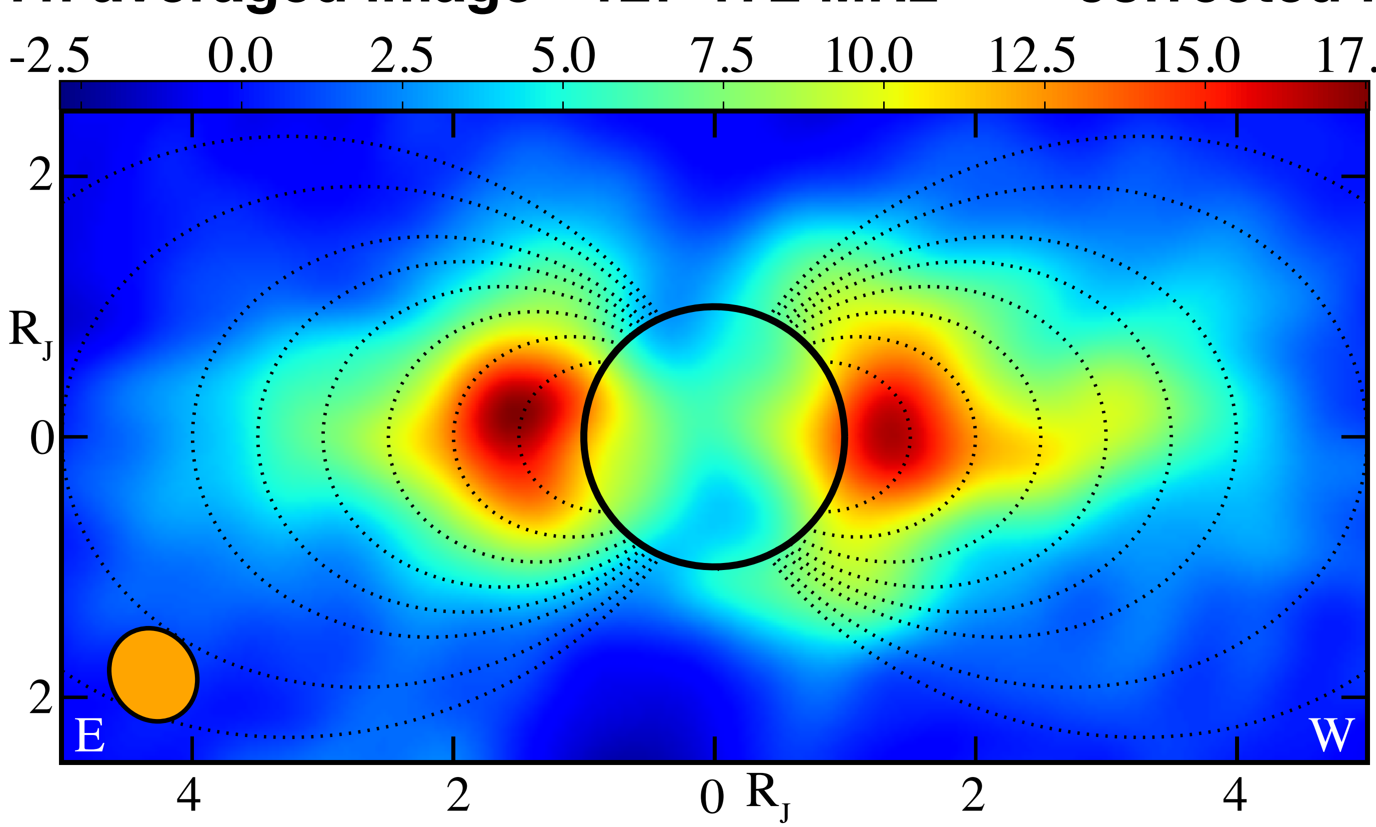
2h averaged image - 127-172 MHz corrected for intrinsic & apparent motion

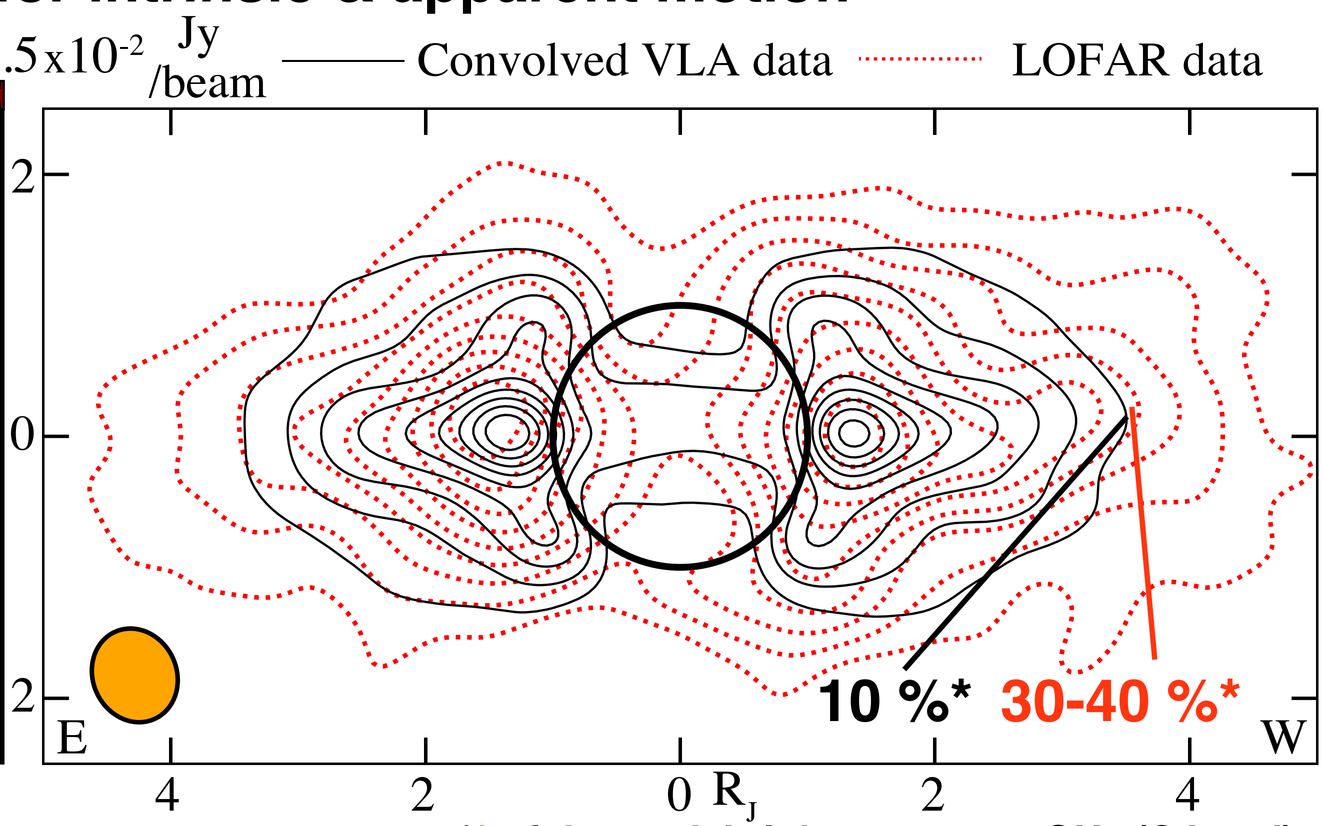


Simulation of synchrotron maps (Nenon, Sicard)



7h averaged image - 127-172 MHz corrected for intrinsic & apparent motion



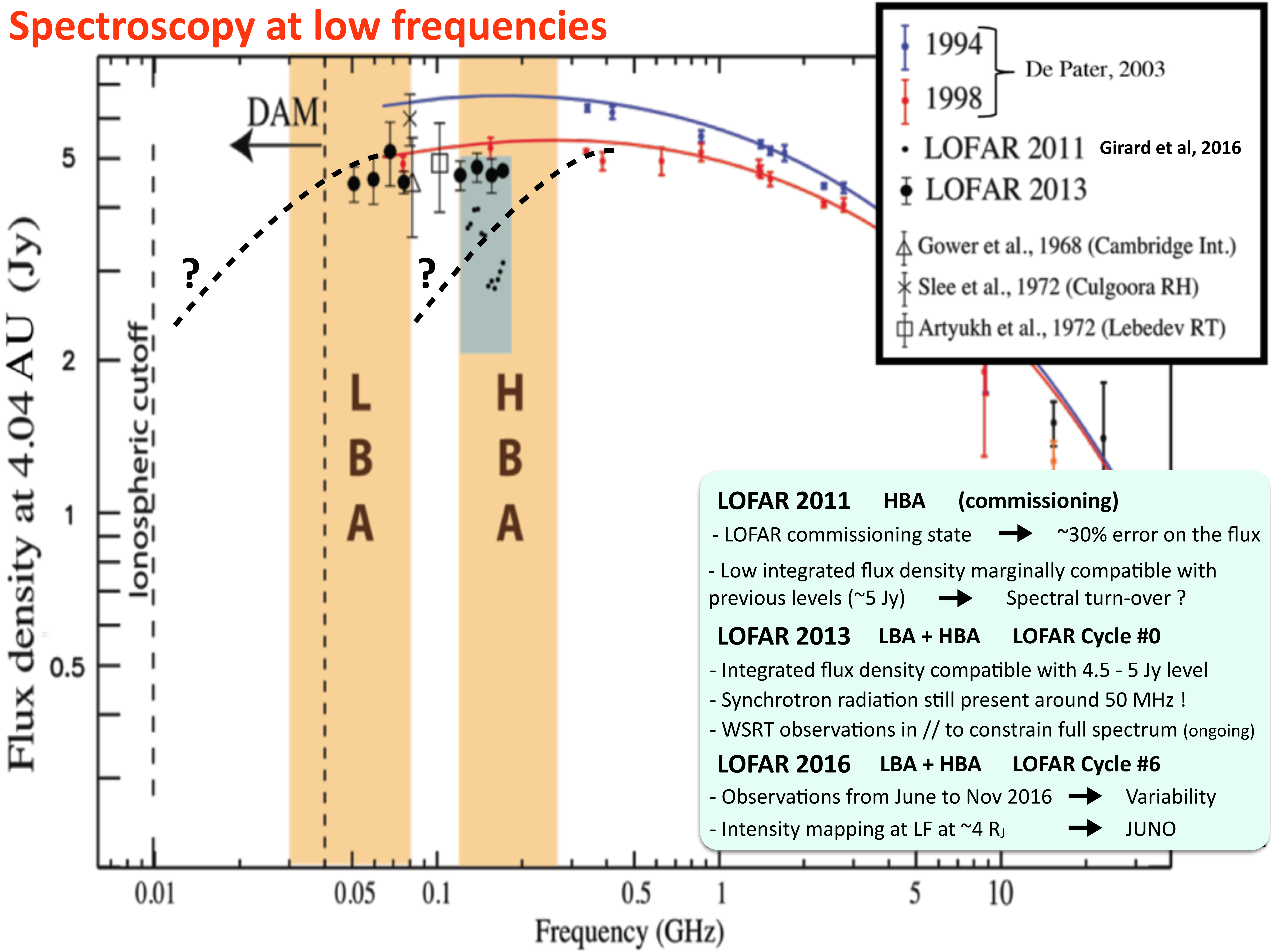


** of the peak brightness at ~5 GHz (C band)

at ~150 MHz (HBA)

Larger extension of the synchrotron emission > 3 R_J probing low energy electrons

Spectroscopy at low frequencies



LOFAR 2011 **HBA** **(commissioning)**

- LOFAR commissioning state → ~30% error on the flux
- Low integrated flux density marginally compatible with previous levels (~5 Jy) → Spectral turn-over ?

LOFAR 2013 **LBA + HBA** **LOFAR Cycle #0**

- Integrated flux density compatible with 4.5 - 5 Jy level
- Synchrotron radiation still present around 50 MHz !
- WSRT observations in // to constrain full spectrum (ongoing)

LOFAR 2016 **LBA + HBA** **LOFAR Cycle #6**

- Observations from June to Nov 2016 → Variability
- Intensity mapping at LF at ~4 R_J → JUNO

Coordinated JUNO / Ground-based LOFAR observations