

Time-domain radio aurorae and radiation-belt emission from a benchmark UCD star



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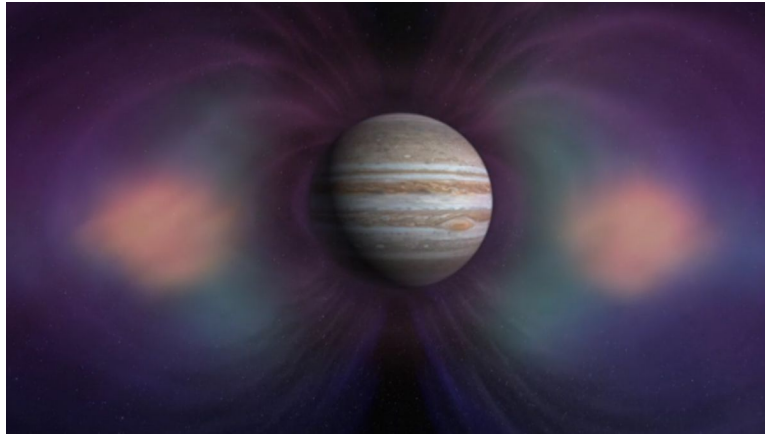


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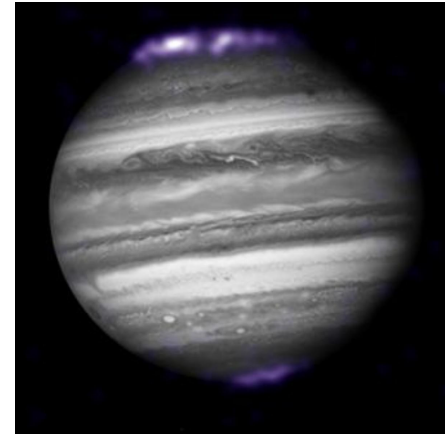
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Background and context

RADIO \longleftrightarrow MAGNETIC FIELD



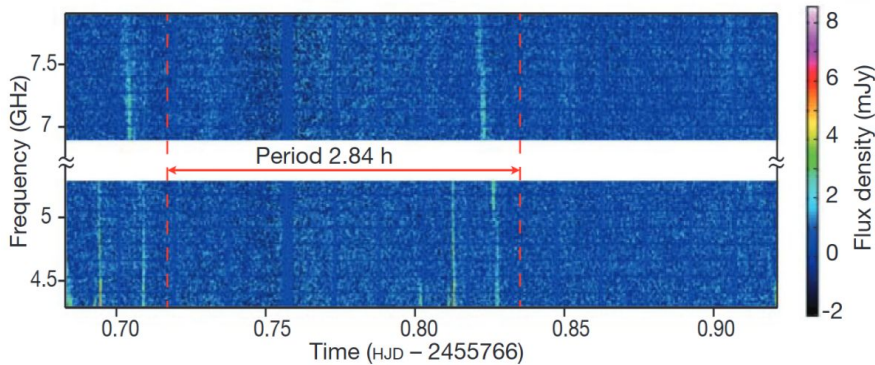
Radiation belt: synchrotron
(incoherent)



Aurora: ECMI
(coherent)

Radio emission from UCD

Circularly polarized emission



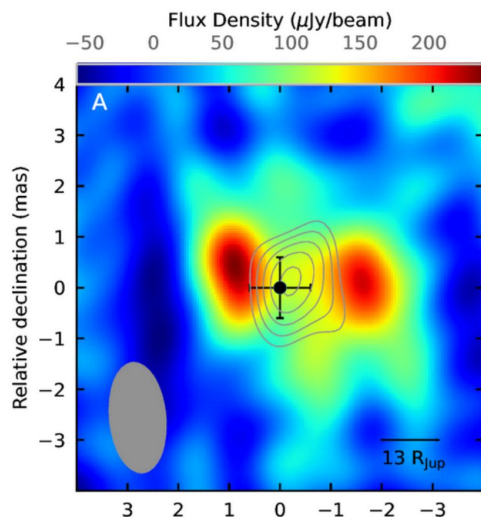
Hallinan et al. 2015

- Applicable to UCDs?
- Some UCD unexpectedly radio loud.
- Radio emission probes magnetism. Circularly polarized emission modulated by the object's rotational period.
- Unpolarized: Quiescent, slowly varying emission

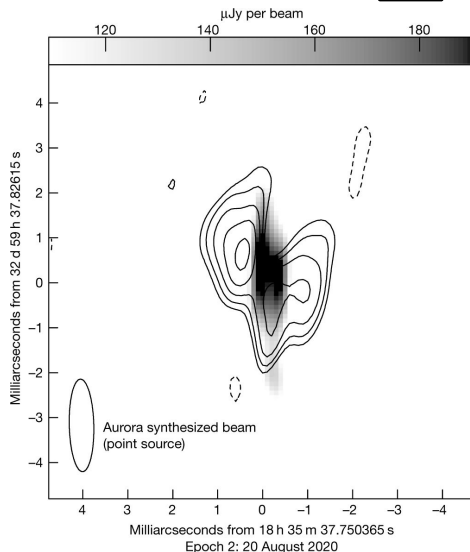
Our target: LSR J1835+3259

Table 1: Properties of the UCD LSR J1835+3259

Spectral Type	D [pc]	M [M_{Jup}]	R [R_{Jup}]	Age [Myr]	P_{rot} [h]	B [kG]	i^\heartsuit [deg]	$F_{8.5\text{GHz}}^\diamond$ [μJy]	$F_{5\text{GHz}}^\clubsuit$ [μJy]
M8.5 V	5.7	77 ± 10	1.1	$\gtrsim 500$	2.84	$\gtrsim 3$	$90^\dagger / (120-140)^\ddagger$	460–720	250–4000



Climent+23 (Science)



Kao+23(Nature)

LSR J1835+3259 showed auroral and quiescent radio emission.

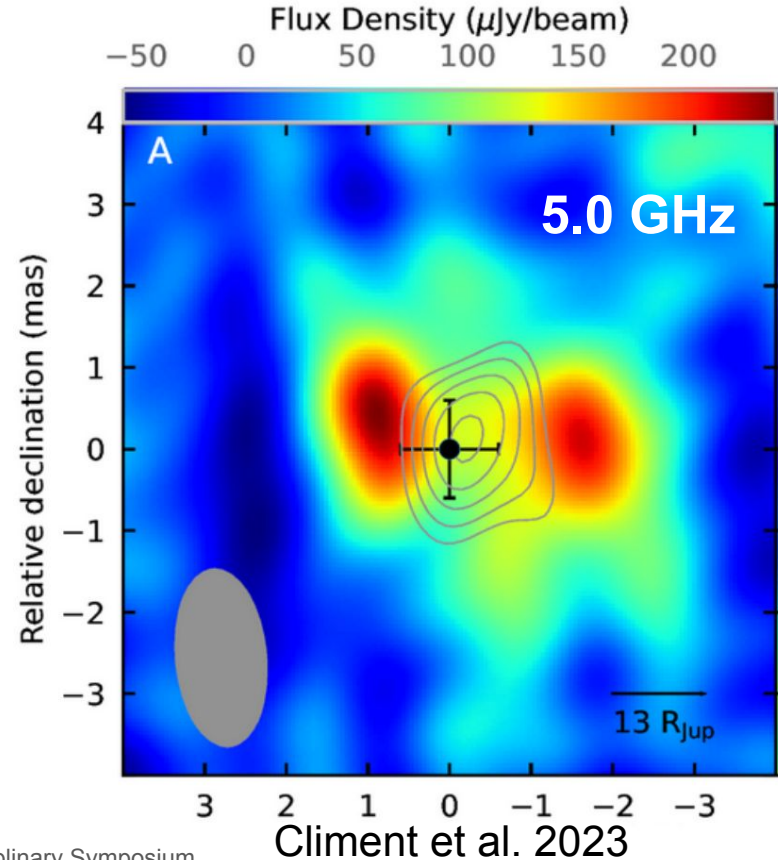
First extrasolar radiation belt ever discovered(!)

Time-resolved detections of the radiation belt

EVN observations at 5GHz provided unique insights.

Two emitting regions:

- Star-centred emission in Stokes V (grey level curves): auroral emission
- Double-lobed structure in Stokes I (red): radiation belt



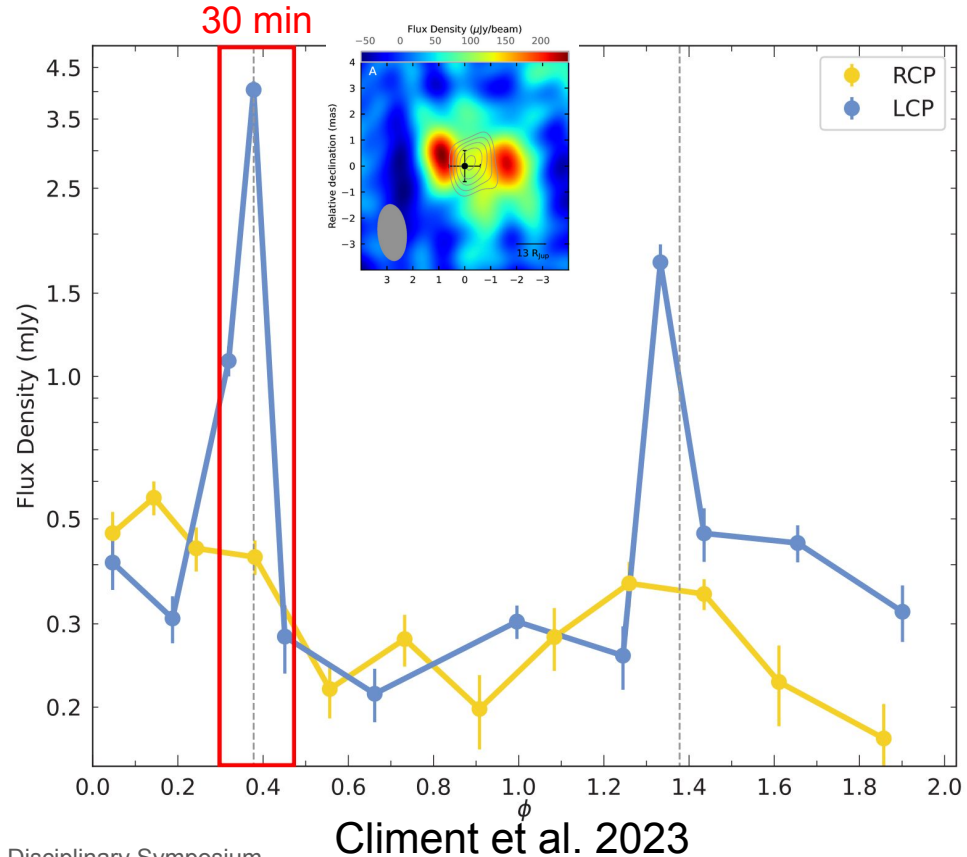
Time-resolved detections of the radiation belt

Auroral emission **only** detected at the **bursts**. (30 min, 18%)

Peaks separated by ~ 2.70 hr

Rotation period: ~ 2.84 hr

Emission much stronger than Jupiter (>50 times)

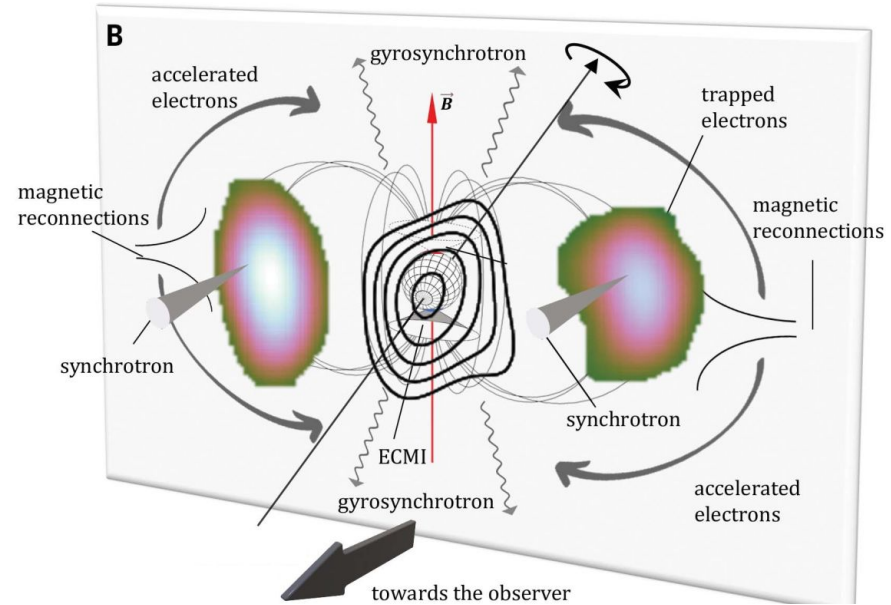


Time-resolved detections of the radiation belt

First ever geometric constraints of this UCD system:

Inclination angle $\sim 130^\circ$

Magnetic obliquity: $\sim 40^\circ$



Climent et al. 2023

Characterizing the radio emission from LSR with the VLA



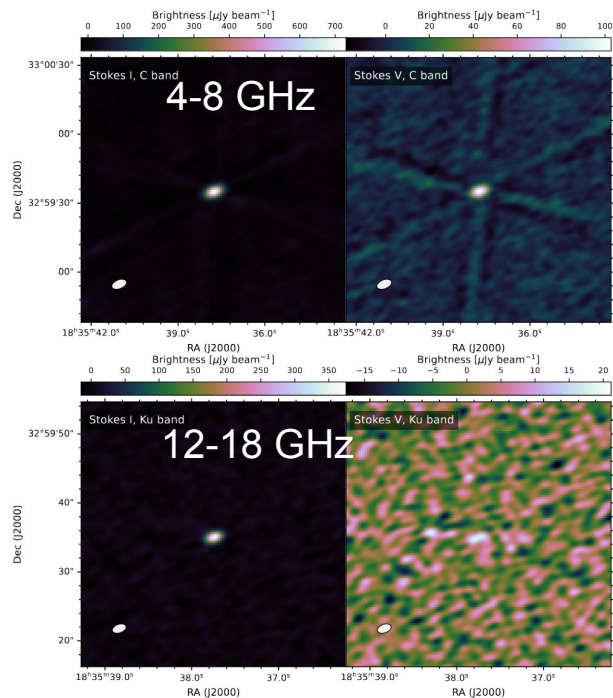
Goal: Characterize time and frequency evolution from 1 to 50 GHz with VLA

Contemporaneous observations

Shed light on the dominant mechanisms behind the observed radio emission:

- Gyrosynchrotron / Synchrotron - incoherent emission
- Electron-cyclotron maser - coherent emission

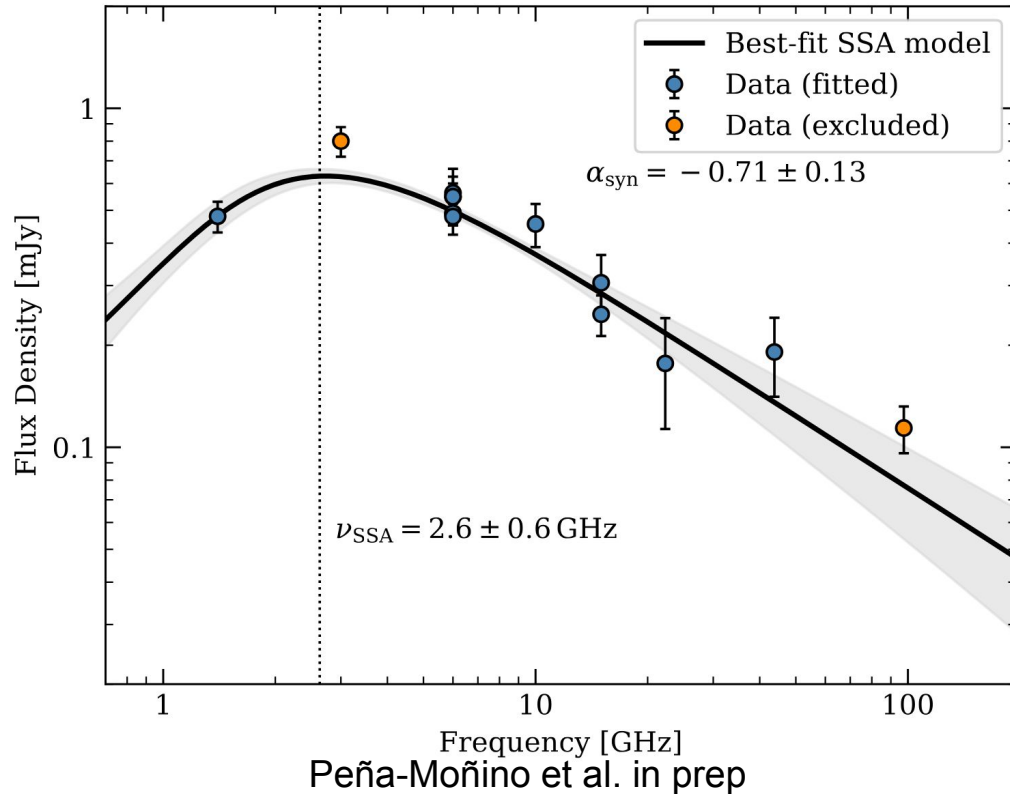
Results



- LSR J1835+3259 detected in all epochs, in all bands and Stokes I and V
- Both quiescent and bursty emission.
- Auroral emission up to 22.3 GHz
 - Cyclotron: $\nu = 2.8 B$
 - **$B \geq 8 \text{ kG} (!!)$**

Peña-Moñino et al. in prep

Quiescent, synchrotron emission



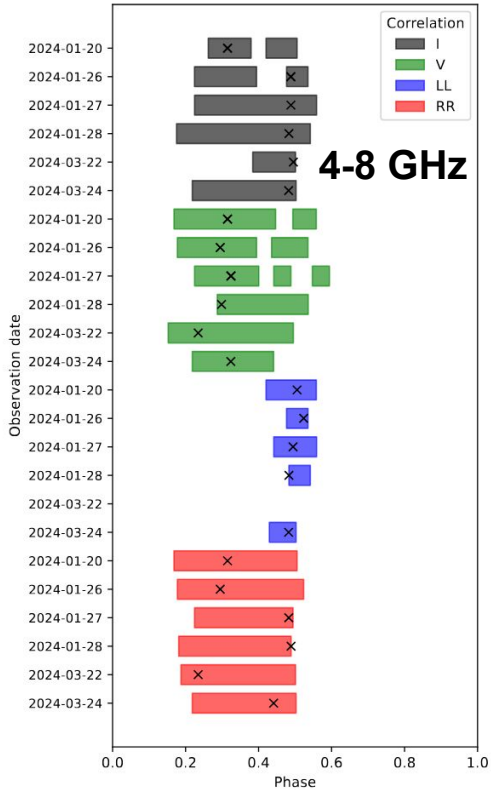
Self-absorbed synchrotron power-law:

$$\alpha = -0.71 \pm 0.13$$

$$\nu_{\text{SSA}} = 2.6 \pm 0.6 \text{ GHz}$$

- **Belt fed by a population of ultra-relativistic electrons** with $p = 2.42$ ($p = 1 - 2\alpha$; $N(E) \sim E^{-p}$ (consistent with Jupiter))
- **E(ultra-relativistic e-) ~ 15 MeV**

Auroral emission



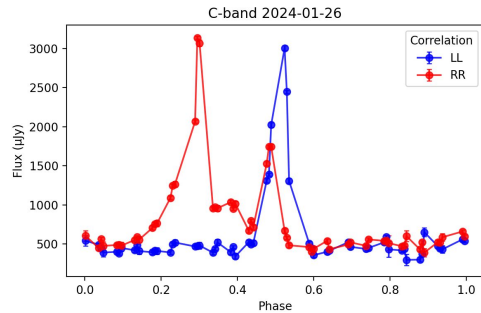
Circularly polarized radio emission dominates over 30 % of the total rotation phase, ~ 0.84 hr (50 min).

Remaining 70%: quiescent non-polarized emission.

LL: Narrow range

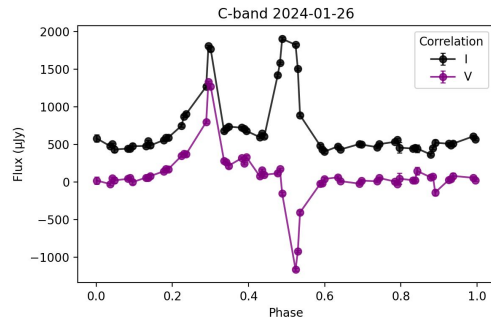
RR: Wider range

Auroral emission (light curves)



LL: One, well-defined, consistent peak at $\phi \approx 0.55$

RR: One or two, less defined, peaks distributed in the range $\phi \approx 0.2 - 0.5$



Stokes I & V: Auroral emission extends across a wider phase interval

Stokes V: Frequent polarity reversals

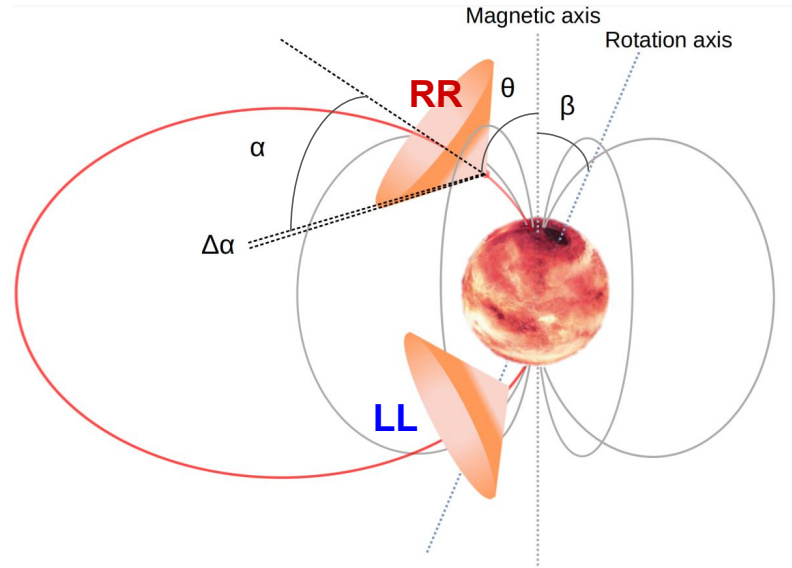
Peña-Moñino et al. in prep

Single active field line model

Emission on a hollow cone over the poles

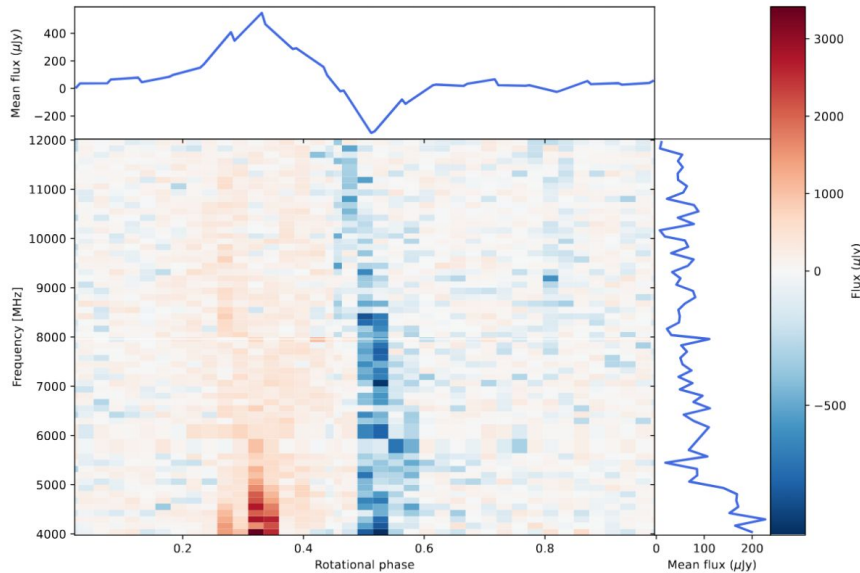
Only 1 active field line

Different polarization from each hemisphere



Peña-Moñino et al. in prep

Dynamic Spectra



Framework: CHARM:

<https://github.com/robkavanagh/charm>

- Amplitude modulated by the emission height along a dipolar magnetic field

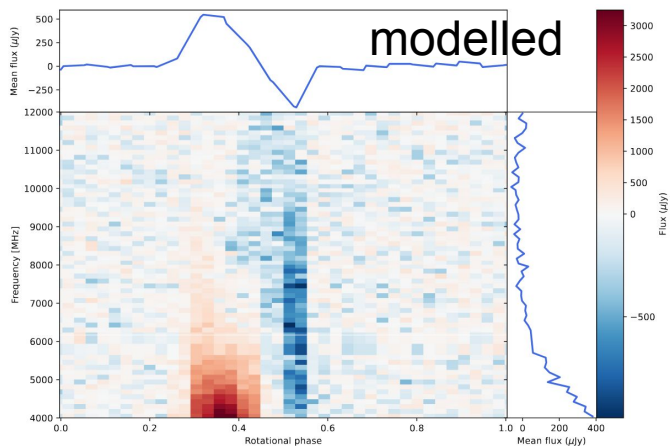
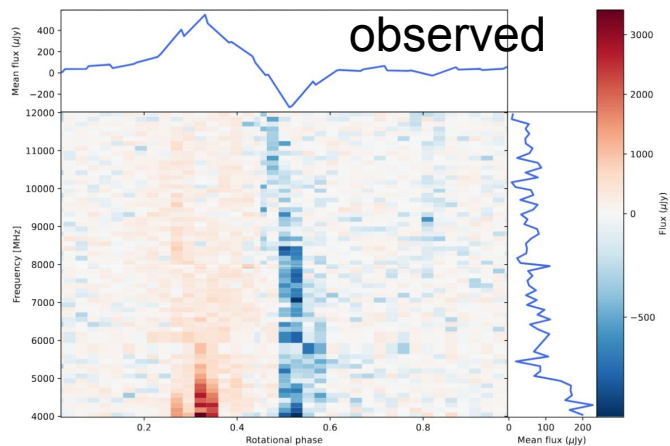
$$a(\phi, r) = \exp\left(\frac{[r - r_0(\phi)]^2}{\Delta r^2(\phi)}\right)$$

- Cone opening angle

$$\cos \alpha = \frac{v/c}{\sqrt{1 - \frac{v_c}{v_{c,max}}}}$$

Peña-Moñino et al. in prep

Dynamic Spectra



Fitting:

1. **Single-AFL** auroral emission fit for geometric parameters
2. MCMC fit for beaming parameters

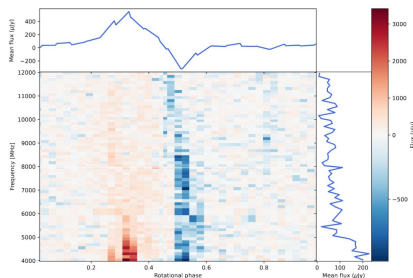
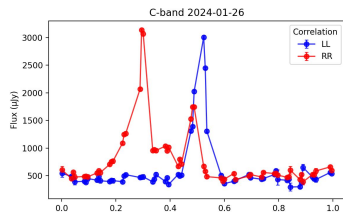
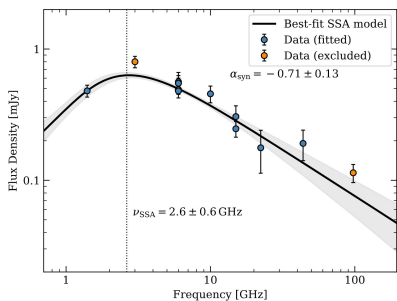
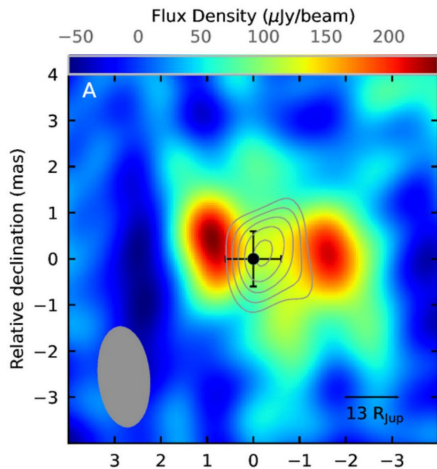
Our results place constraints on the magnetic and emission properties of LSR J1835.

Parameter	1 AFL
i	110.5
β ($^\circ$)	20.4
ϕ_0	0.57
α ($^\circ$)	80.0
$\Delta\alpha$ ($^\circ$)	1.8
θ ($^\circ$)	6.5
ϕ ($^\circ$)	329.1
h_S	1.8
h_N	1.5
Δh_S	0.3
Δh_N	0.3
v (c)	0.079

- Strong misalignment of magnetic and rotation axis needed to explain the auroral behaviour
- Properties of emission cone similar to, e.g., Jupiter values
- Characterization of physical scale of the aurora: Height above UCD surface, width
- Radio emission due to a population of very mildly relativistic electrons



$$E_{\text{kin}} \sim 1.6 \text{ keV}$$



Summary

- LSR J1835: First UCD with radiation belts
- VLA obs from 1 to 50 GHz to study emission mechanisms
- **Quiescent** emission: belt radiation of **synchrotron** origin
- Auroral emission:
 - ECMI powered by electrons with $E \sim 1.6$ keV
 - Explained by **ONE** single **active** field **line**.
 - New constraints on magnetic and emission properties of LSR J1835.
- LSR J1835+ Scaled up **Jupiter-like** emission

THANK YOU!!!

Let me know of any opportunities!

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Searching for star-planet interactions in GJ 486 at radio wavelengths with the uGMRT



Modelling magnetic star-planet interaction in the iconic M dwarfs Proxima Centauri, YZ Ceti, and GJ 1151