Detection and interpretation of fine structures in radio bursts from the Red Dwarf AD Leonis

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Introduction - The FAST radio-telescope

Five-hundred meter
Aperture
Spherical radio
Telescope

Guizhou province (China)

[1000—1500] MHz
Full polarization

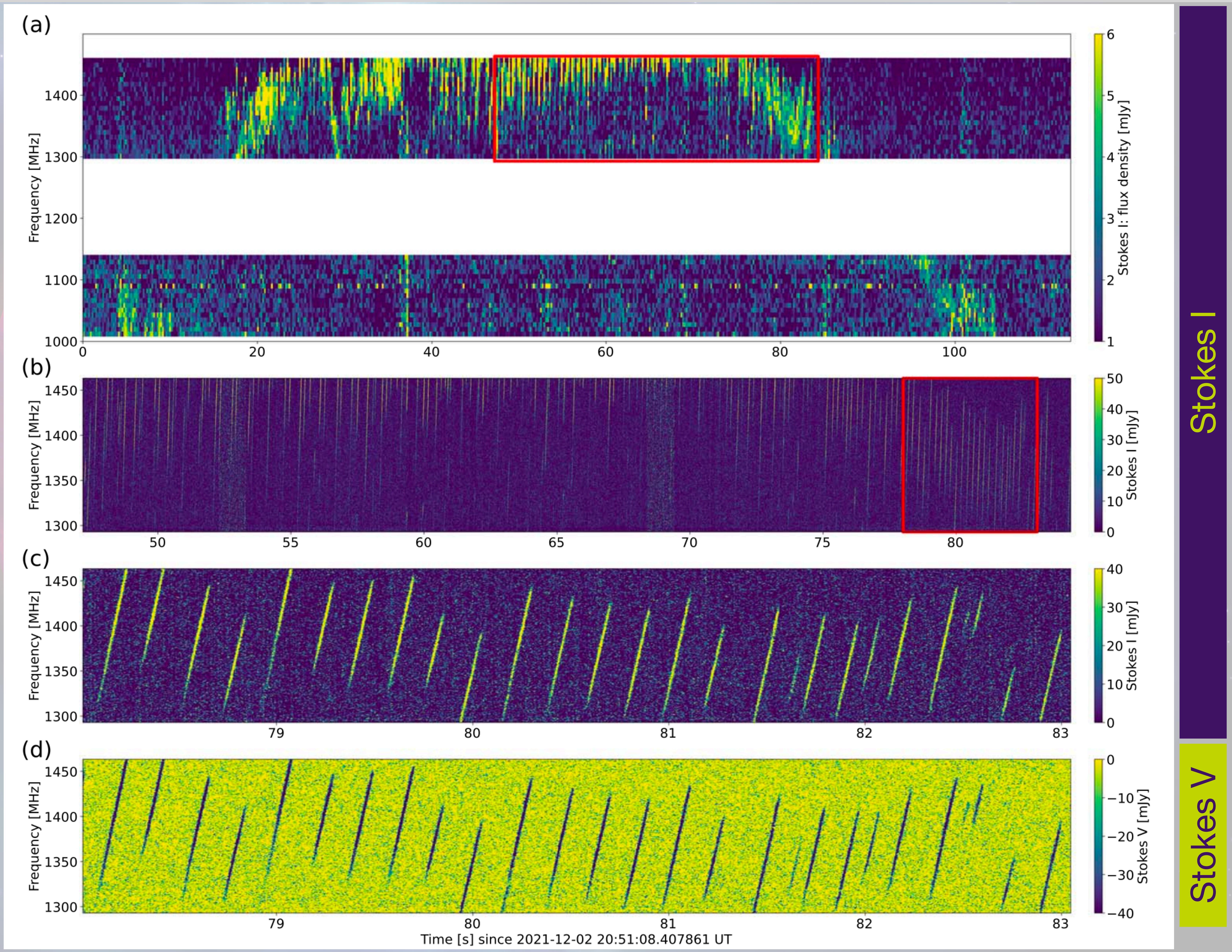
δt = 196.608 μs
δf = 0.49 MHz

Observations of AD Leonis

“Slow” drifting features
(~ minutes)

“Fast” drifting features
(~ milliseconds)

Zhang et al., 2023, APJ

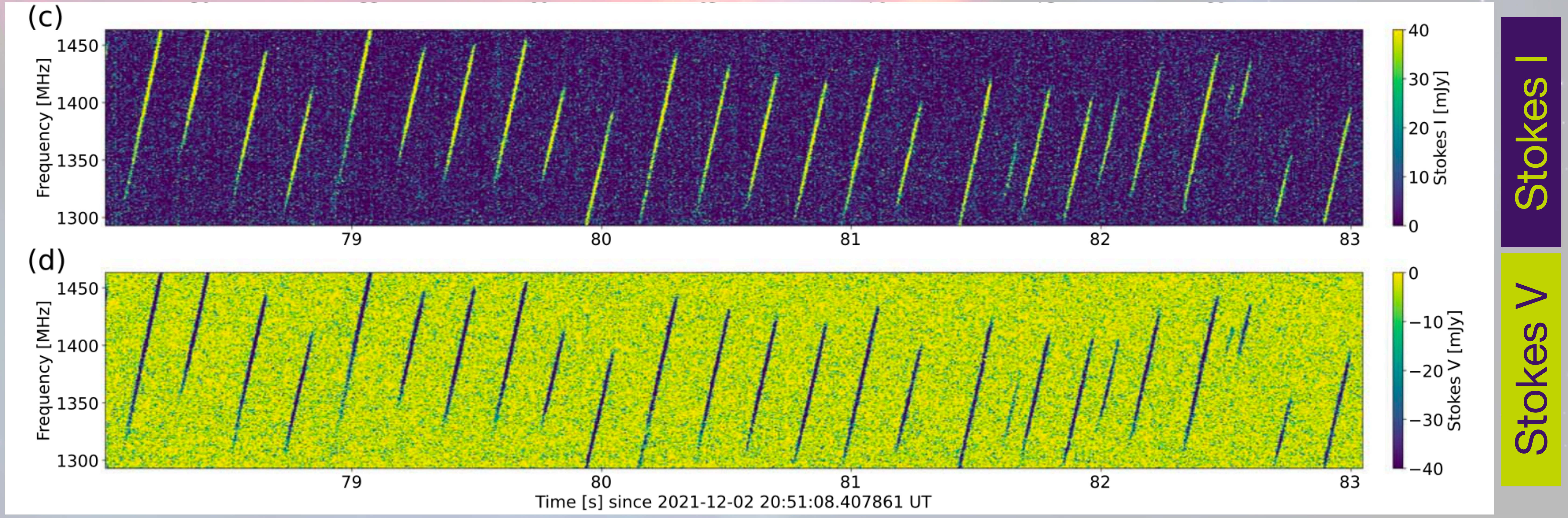


Observations of AD Leonis

Not the first observations of AD Leo, but never with such resolution

Emissions are:
- Bursty
- Right-Handed (RH) Circularly polarized ~100%

—> Cyclotron Maser Instability Mechanism
  - same as Earth, Jupiter and Saturn auroral radio emissions
  - $f_{emission}$ ~ fce ∝ B
  - drift ∝ electron energy



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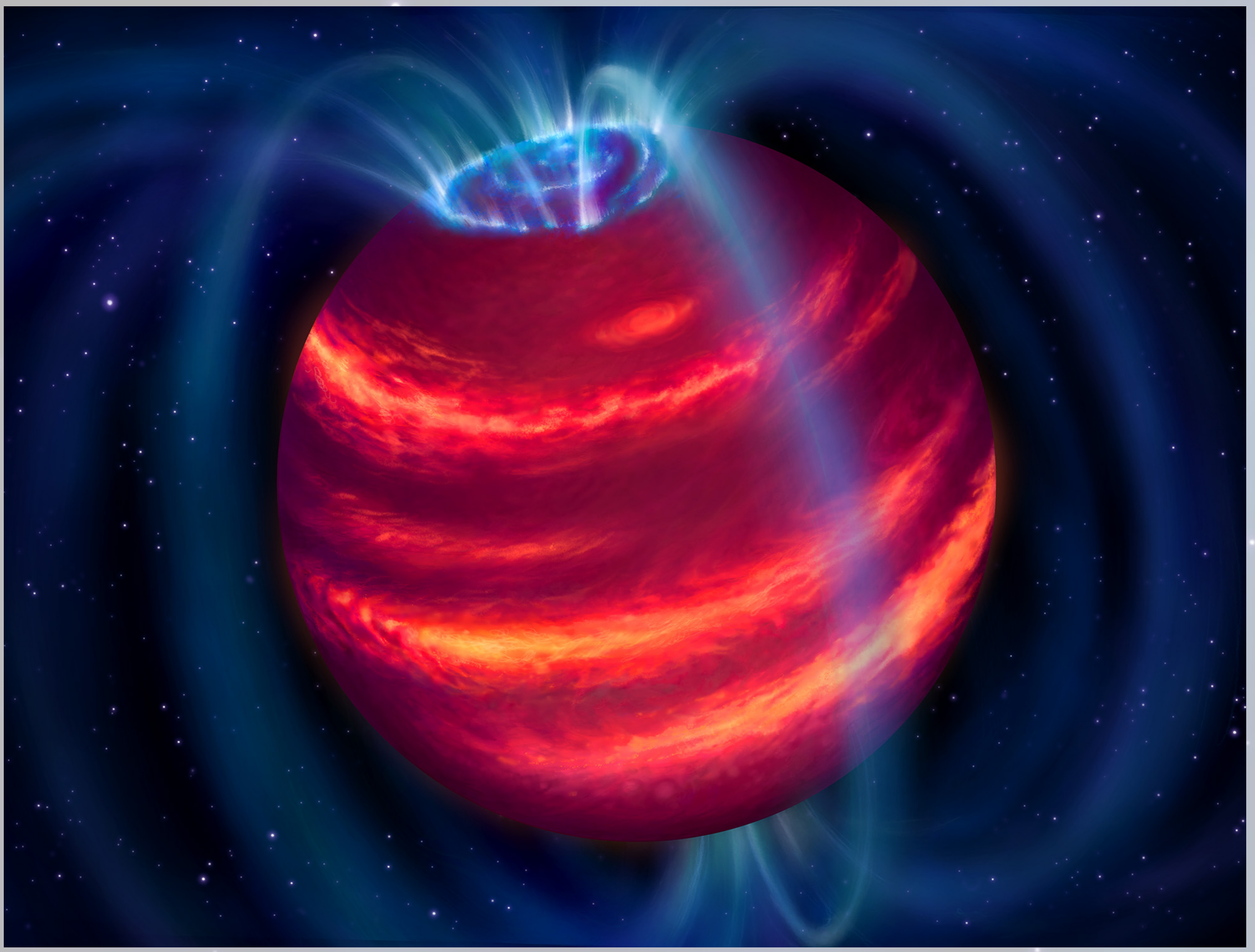
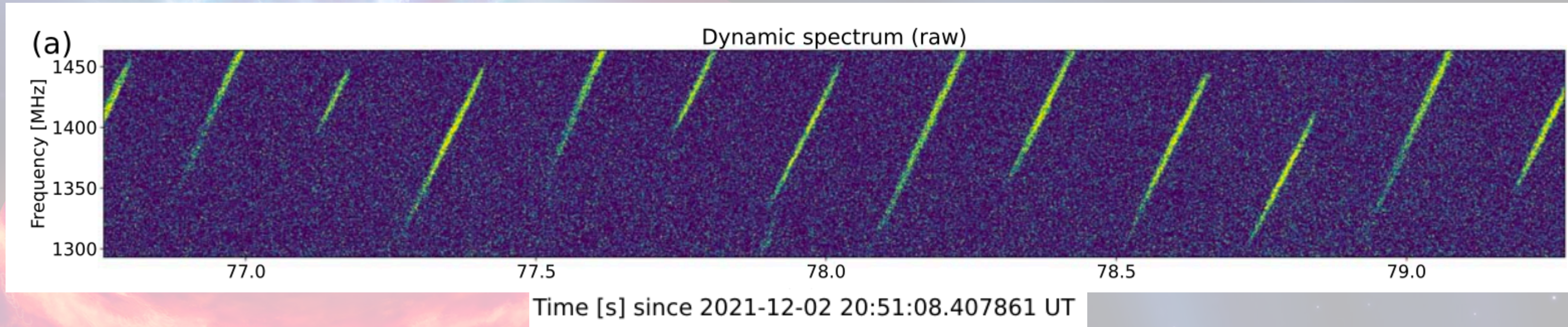
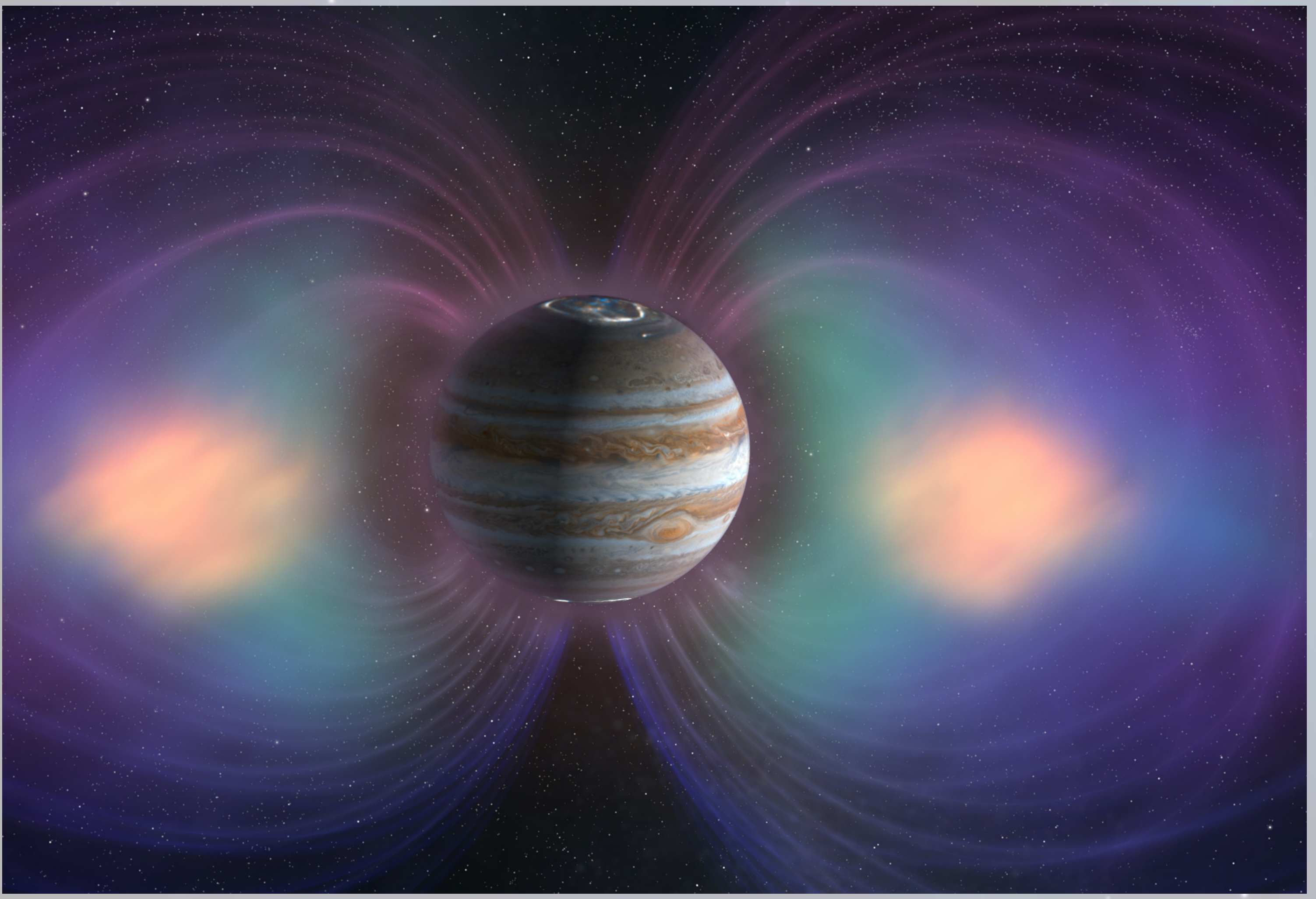
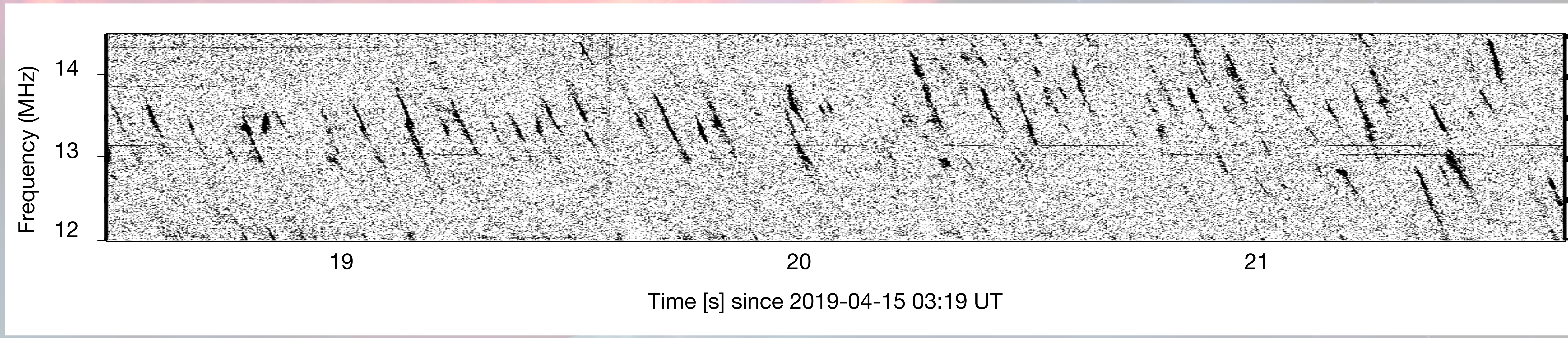
Comparison AD Leonis / Jupiter



AD Leo







Jupiter

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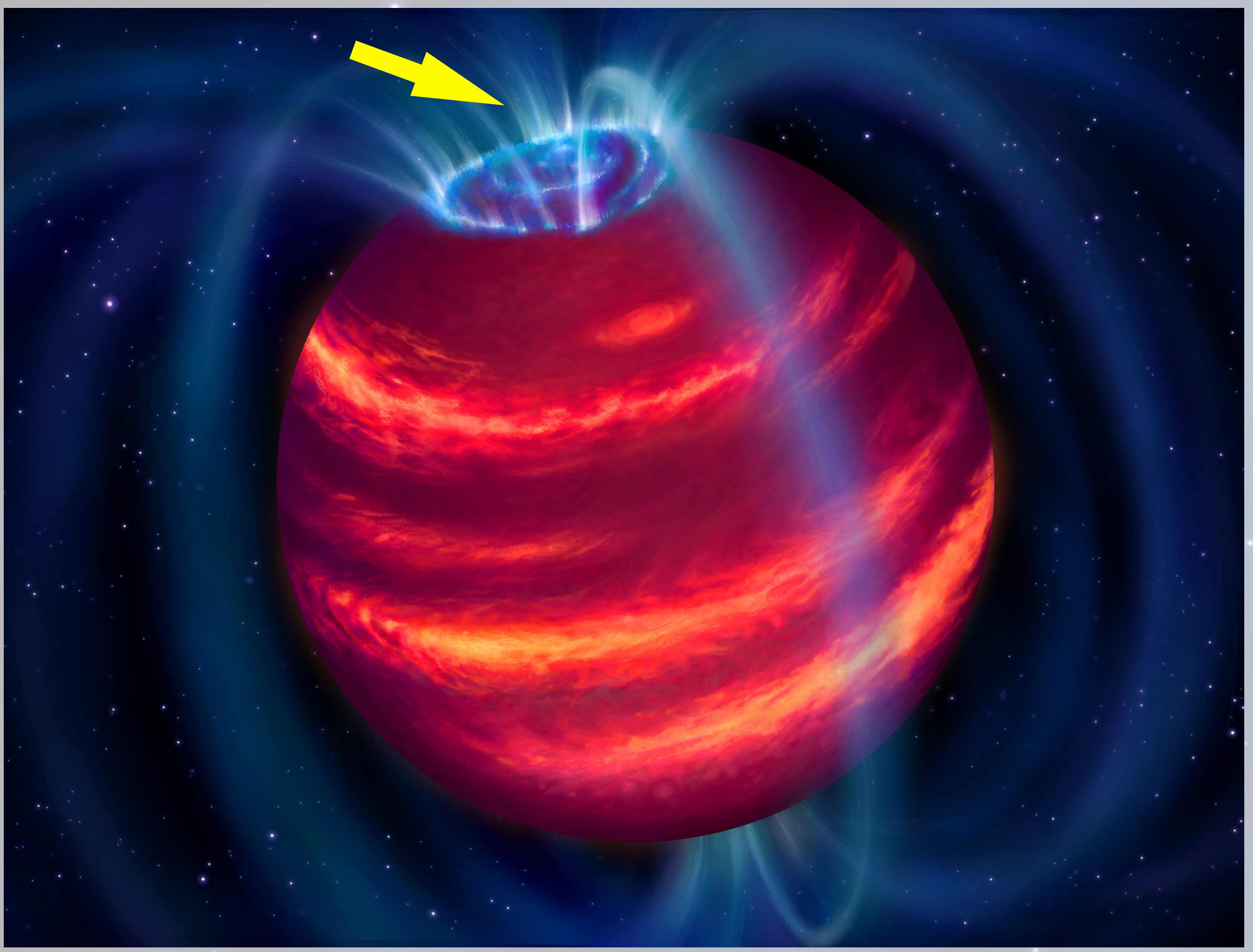
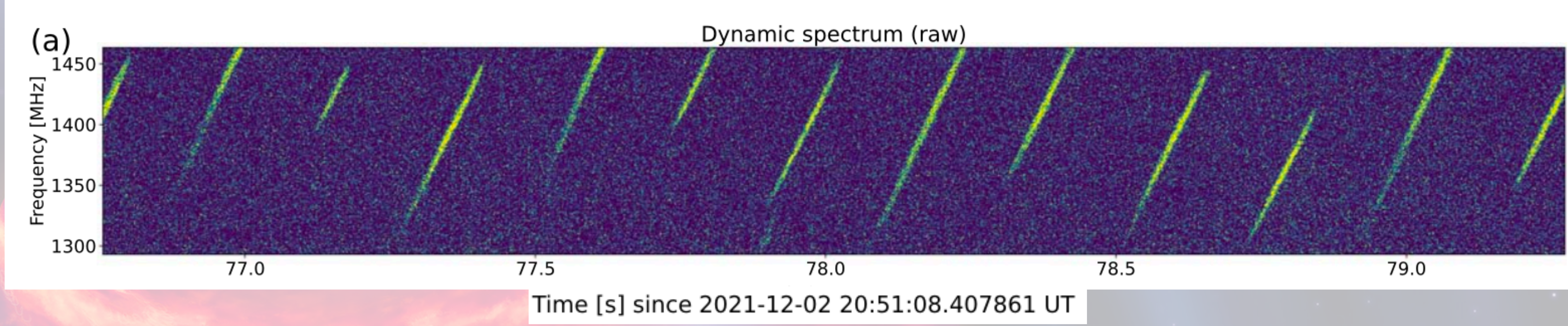


AD Leo



$$\frac{\mathrm{d}f}{\mathrm{d}t} = \frac{\mathrm{d}f_{\mathrm{ce}}}{\mathrm{d}l}\frac{\mathrm{d}l}{\mathrm{d}t} = \frac{\mathrm{d}f_{\mathrm{ce}}}{\mathrm{d}l}v_{||}(f_{\mathrm{ce}}),$$

$f_{ce} \propto B \propto 1/\text{altitude}$

↗ f (t): ↘ electrons

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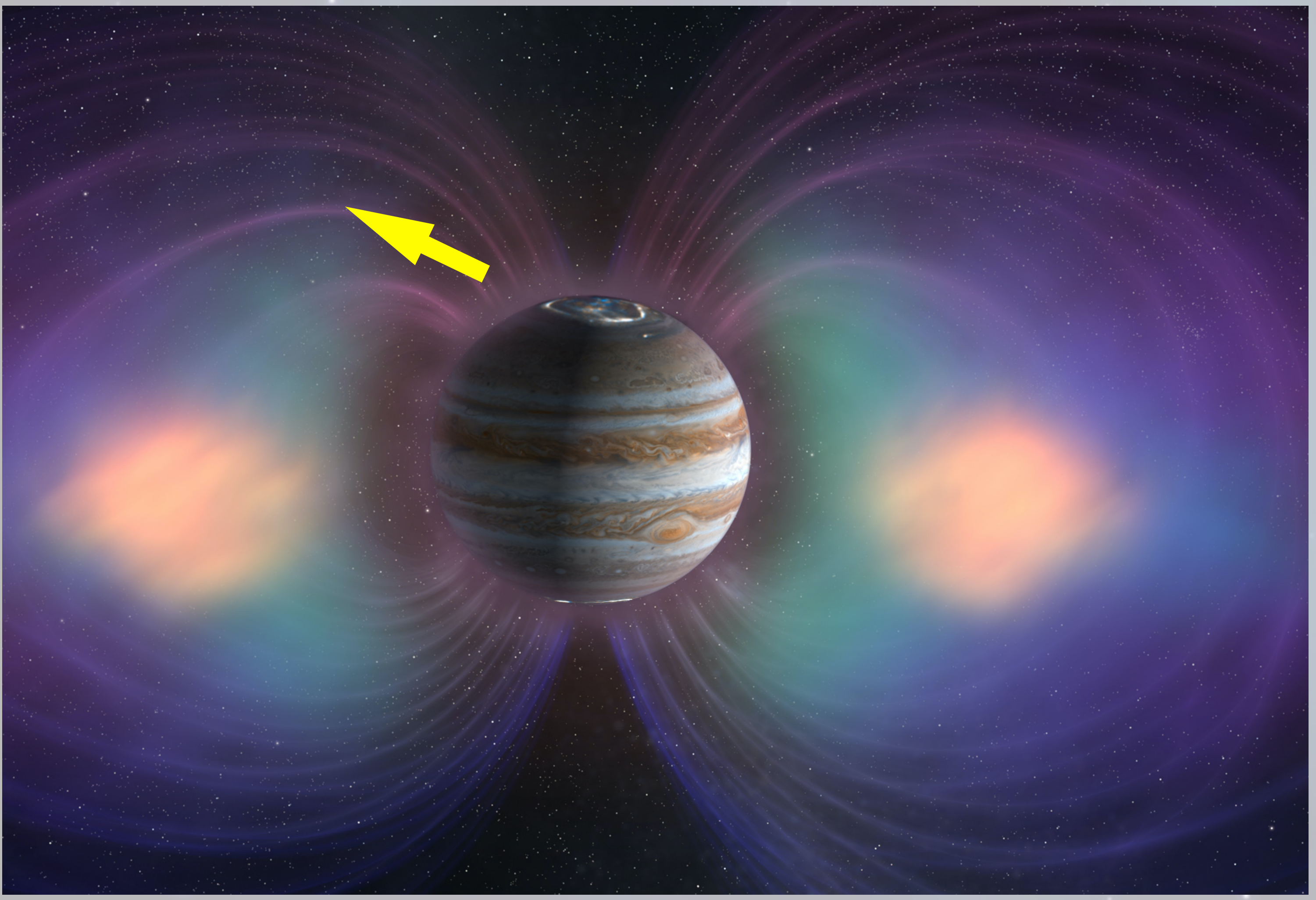
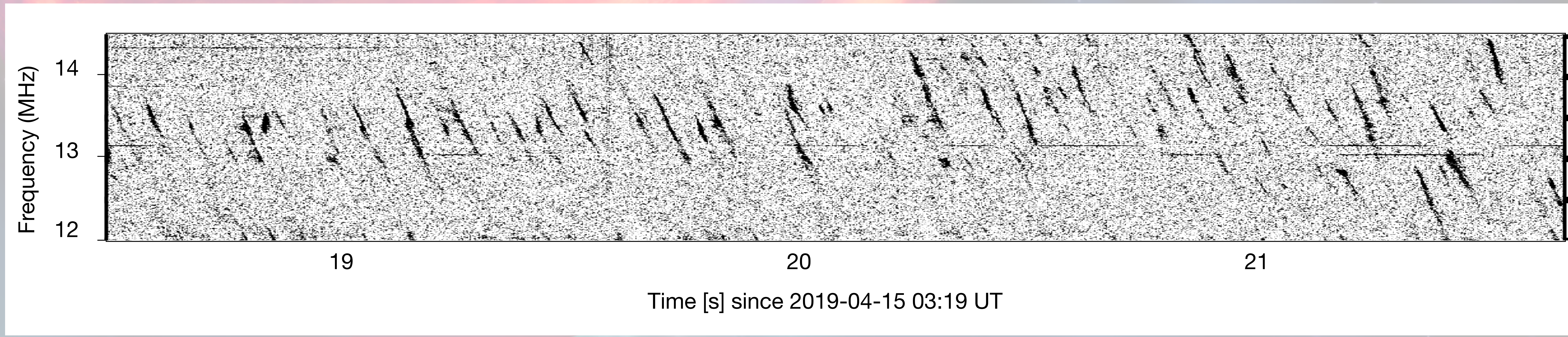




Jupiter

AD Leonis

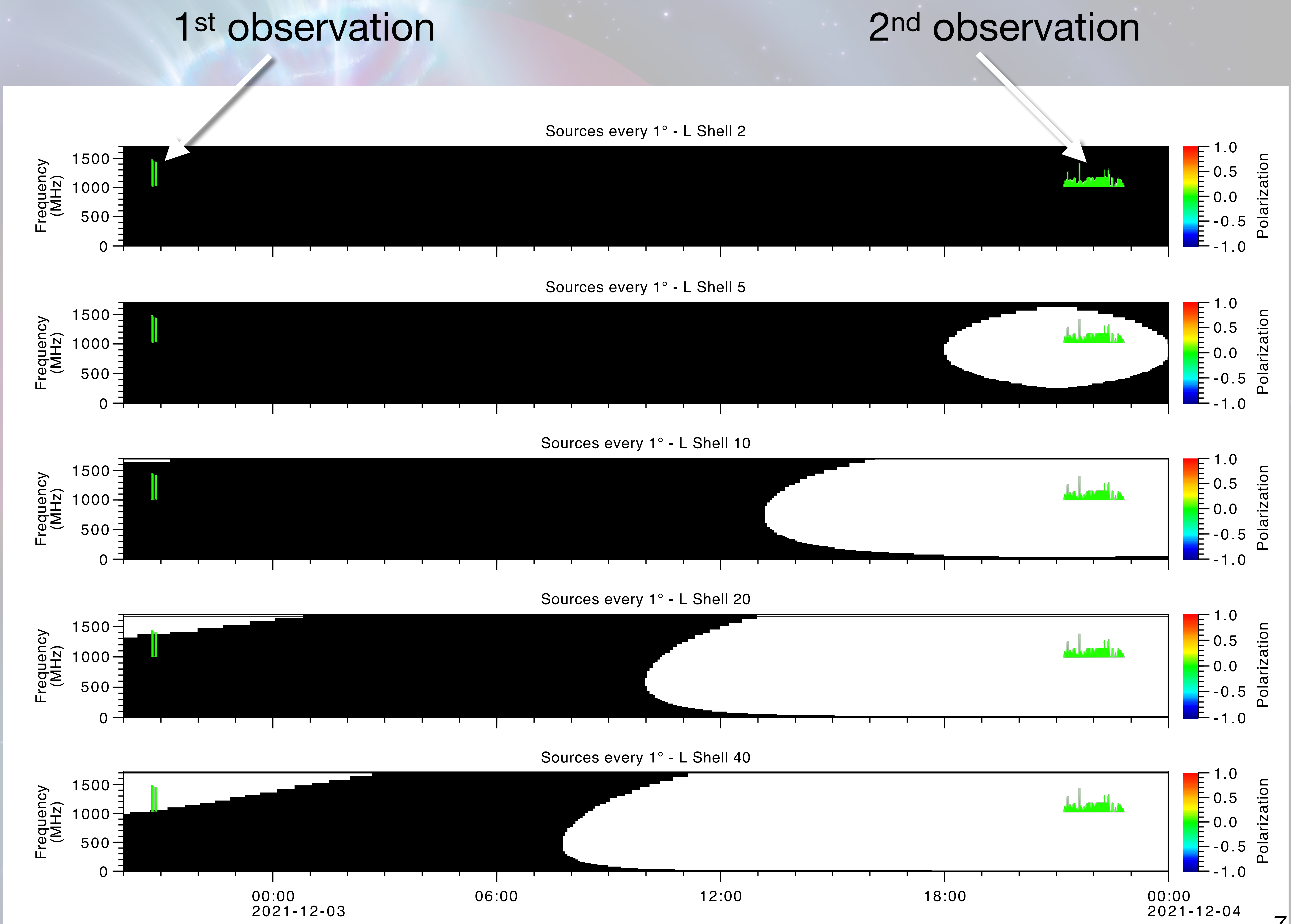
M3.5 V star
Mass: 0.45 M_{Sun} Morin et al. (2008)
Radius: 0.44 R_{Sun} Mann et al. (2015)
Distance: 4.965 pc Gaia Collaboration 2020)
Period: 2.23 ±0.001 days Fouqué et al. (2023)

Zeeman Doppler Imaging measurements:
Dipolarity: 70%
B_{Max}: 460 G
Obliquity: 59°
Bellotti et al. (2023)

Potential exoplanet in orbit (debated) (Radial Velocity) Tuomi et al. (2018), Carleo et al. (2020), Kossakowski et al. (2022)

ExPRES simulations

- AD Leonis Magnetic field model
- Mechanism:
  - Cyclotron Maser Instability
- Electron distribution function:
  - Loss cone / shell type
- Electron energy E_{e-}:
  - 5, 10, 20, 100, 200, 500 keV
- Position:
  - L shell 2, 5, 10, 20, 40
  - δlongitude: 1°
  - co-rotating w/ AD Leo
- Wave propagation mode:
  - Left-Ordinary (LO)
  - Right-eXtraordinary (RX



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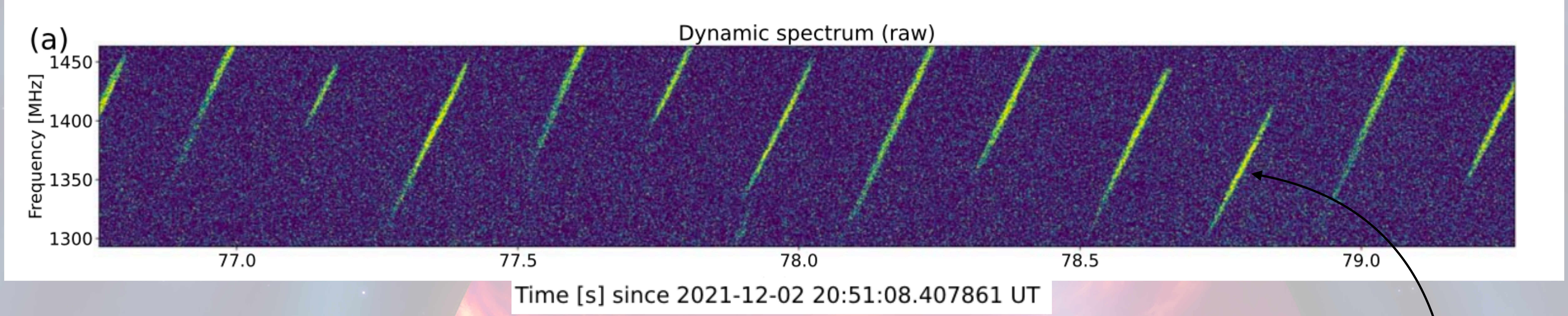
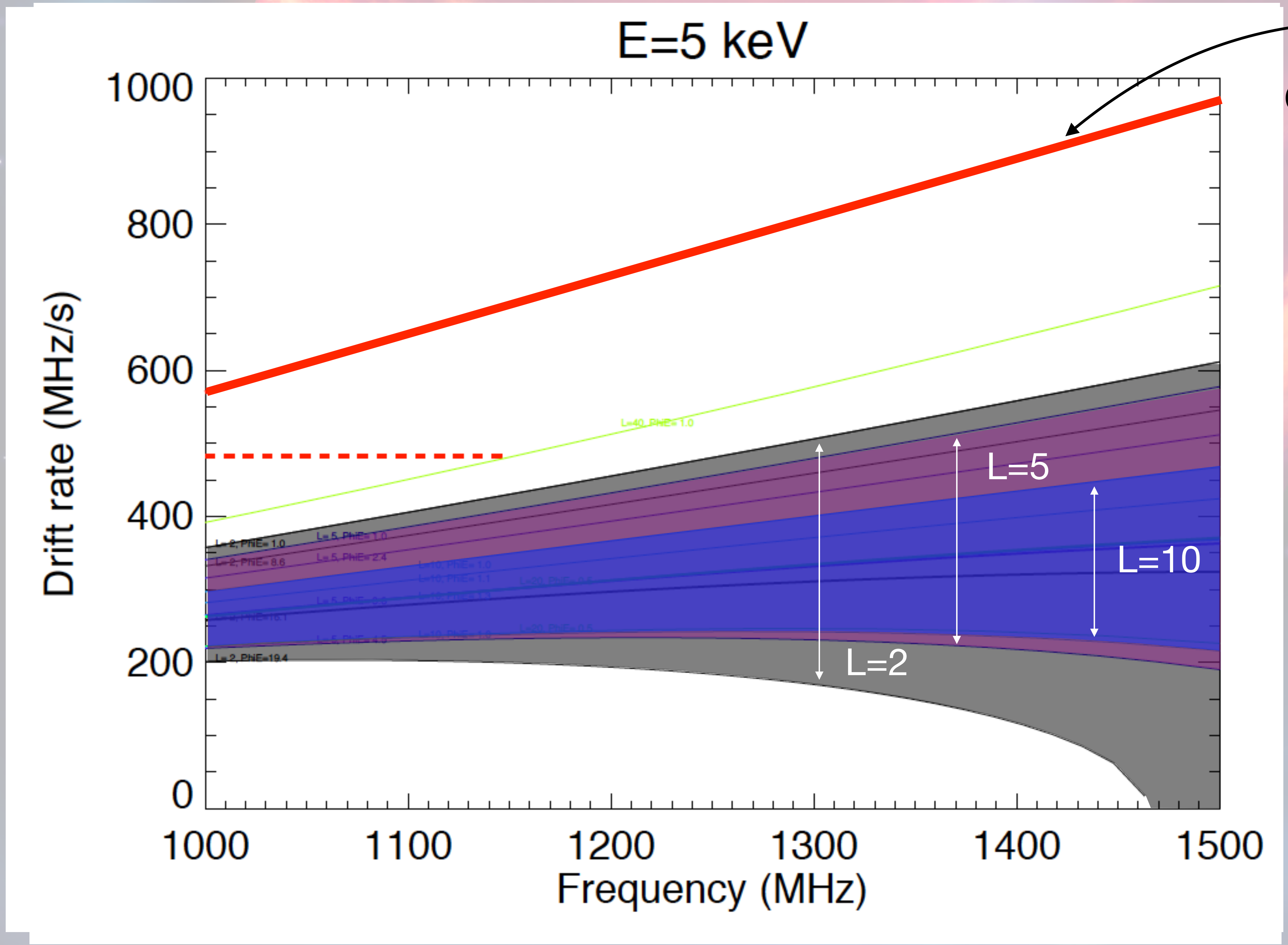
2021/12/02-03 (RH emission)				
	LO North	LO South	RX North	RX South
LC 5 keV		L=2		
LC 10 keV		L=2		
LC 20 keV		L=2		
LC 100 keV				
LC 200 keV				
LC 500 keV				
Shell 90°	L=2	L=2	L=2	L=2

Shell not excluded but no information on E_{e-}

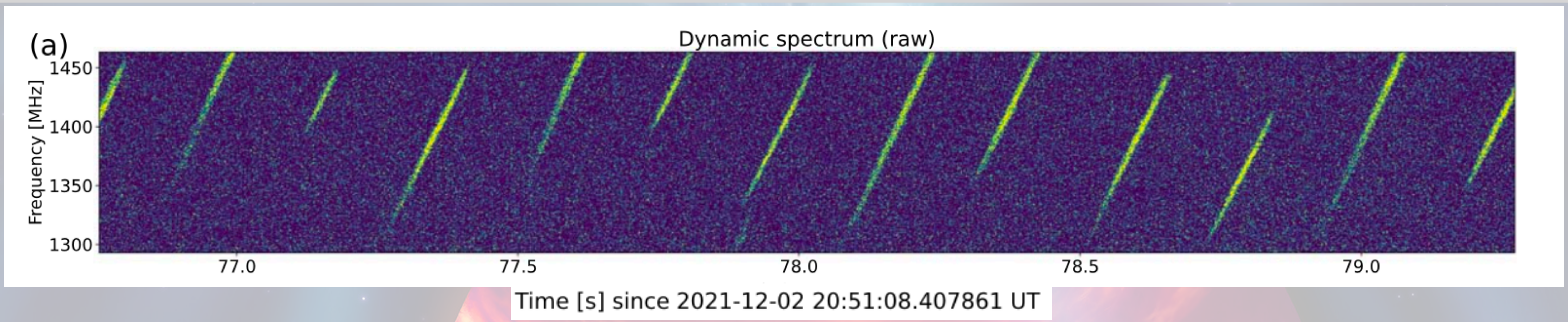
Bursts and theory

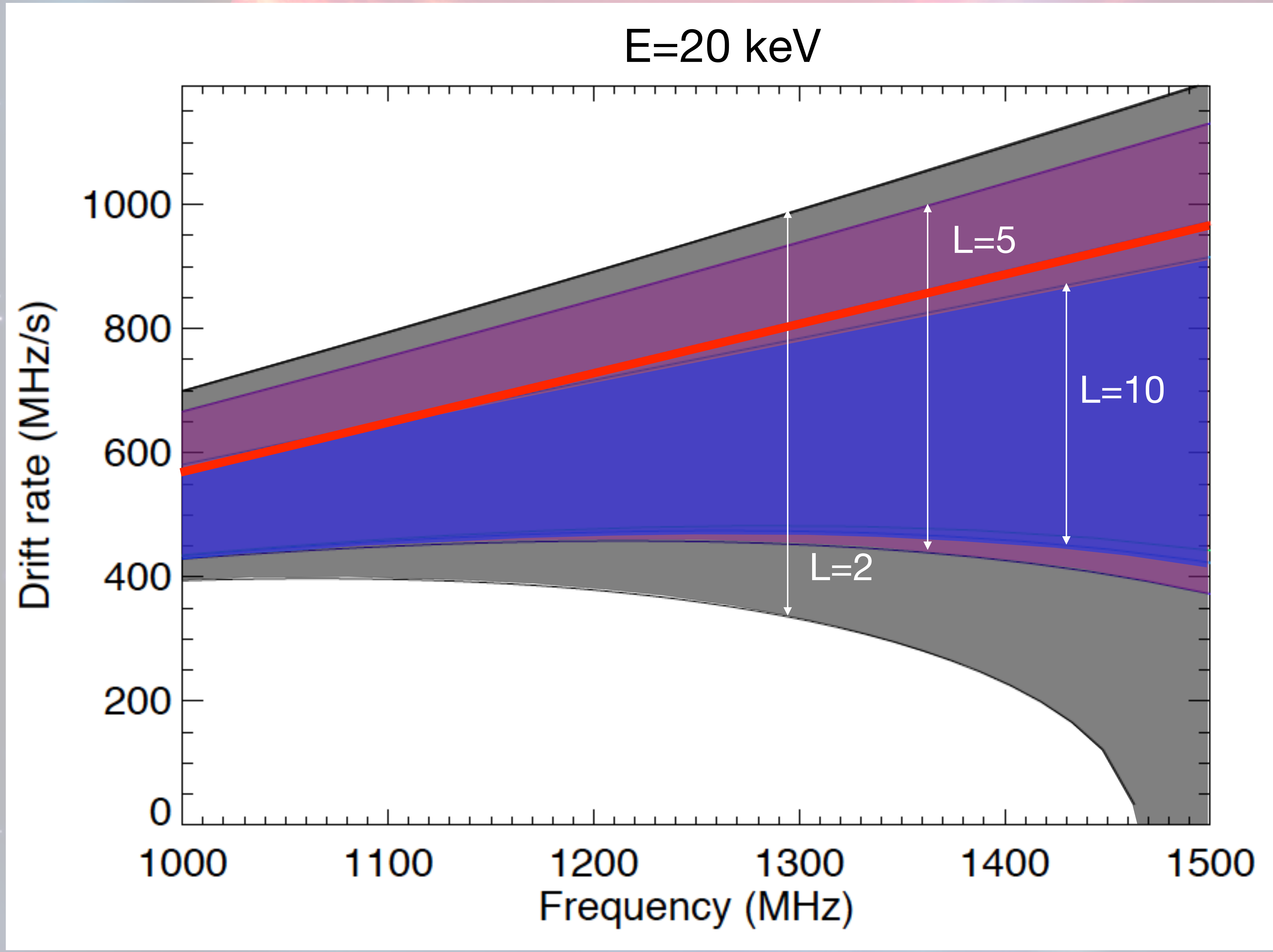


Measured drifts over the two observations



Bursts and theory





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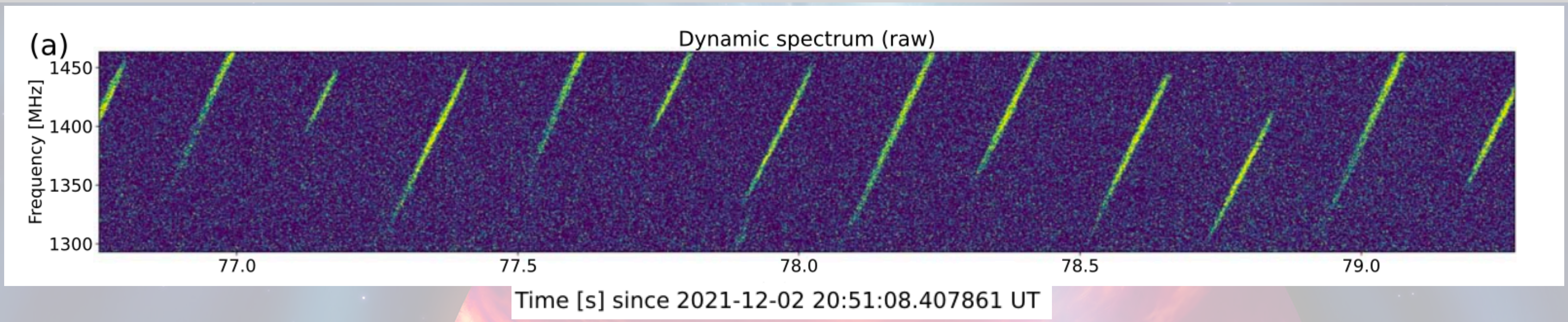
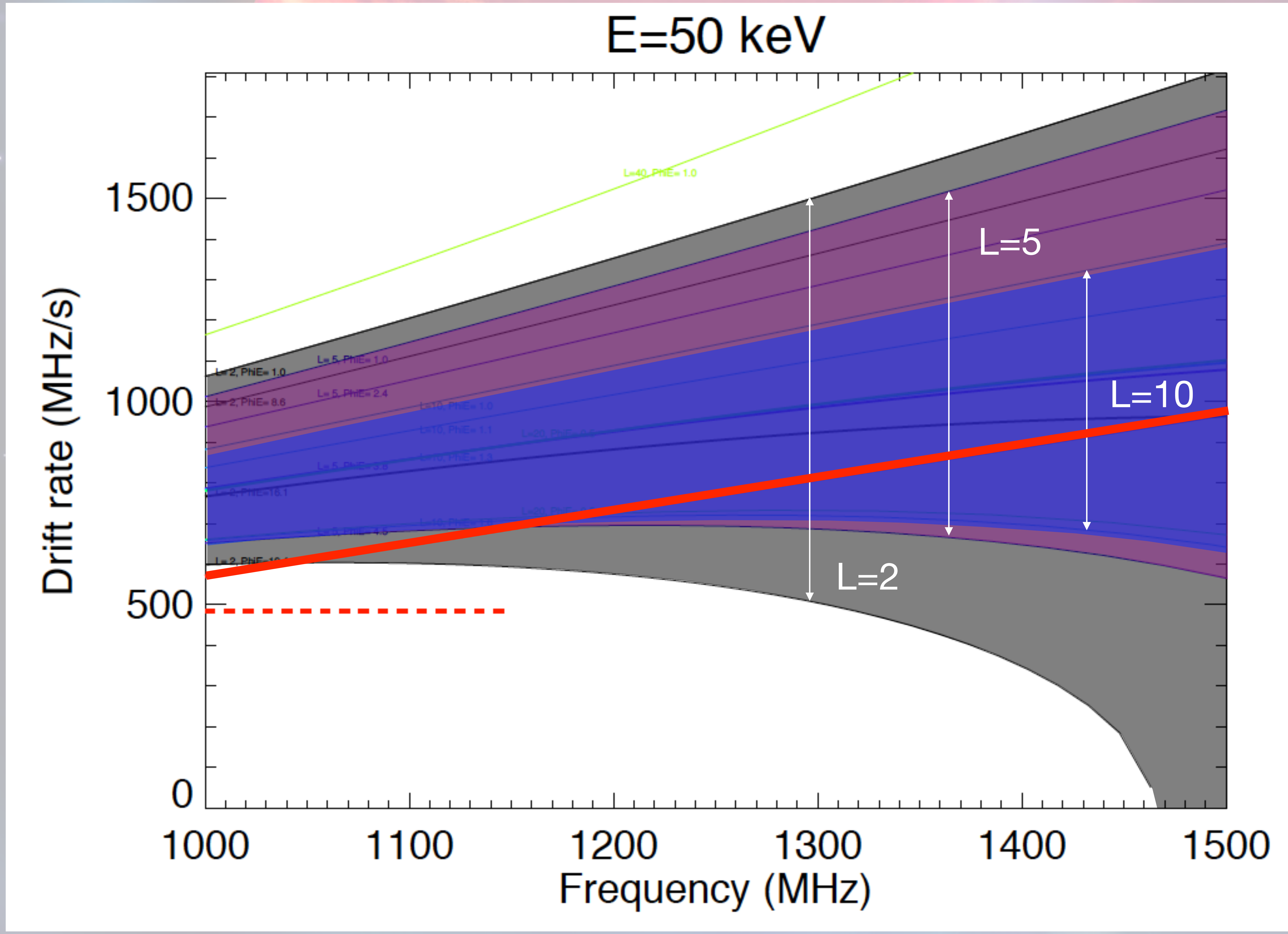
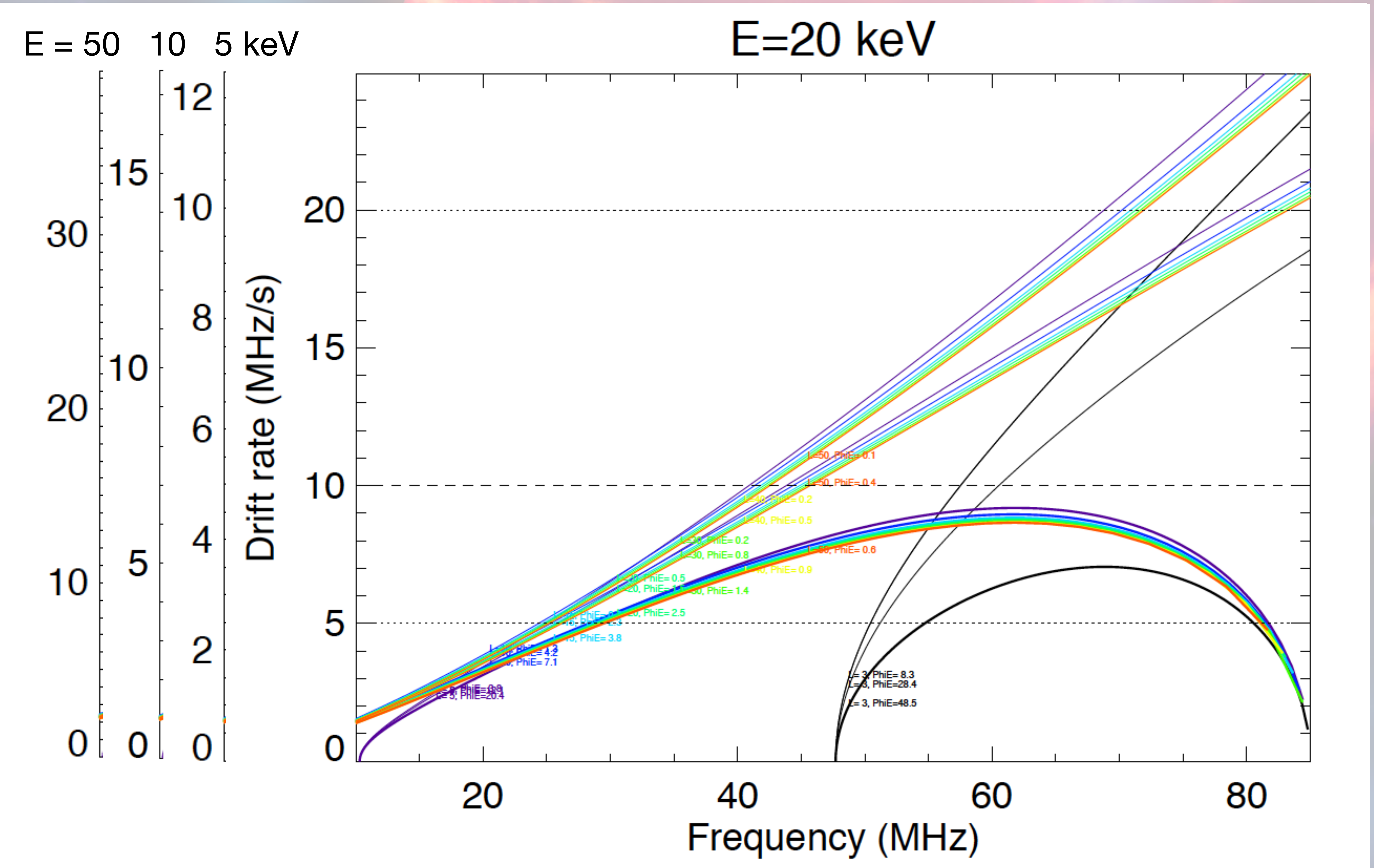




What does it mean for observations with NenuFAR frequency range?



Conclusions & Perspectives

- Coherent results between the two approaches, on:
  - “slow” drifting features (ExPRES simulations)
  - “fast” drifting features (Bursts)

—> - CMI
  - E_{e-}= [10-20] keV
  - Position: small L-shell (2-5 R_{ADLeo})

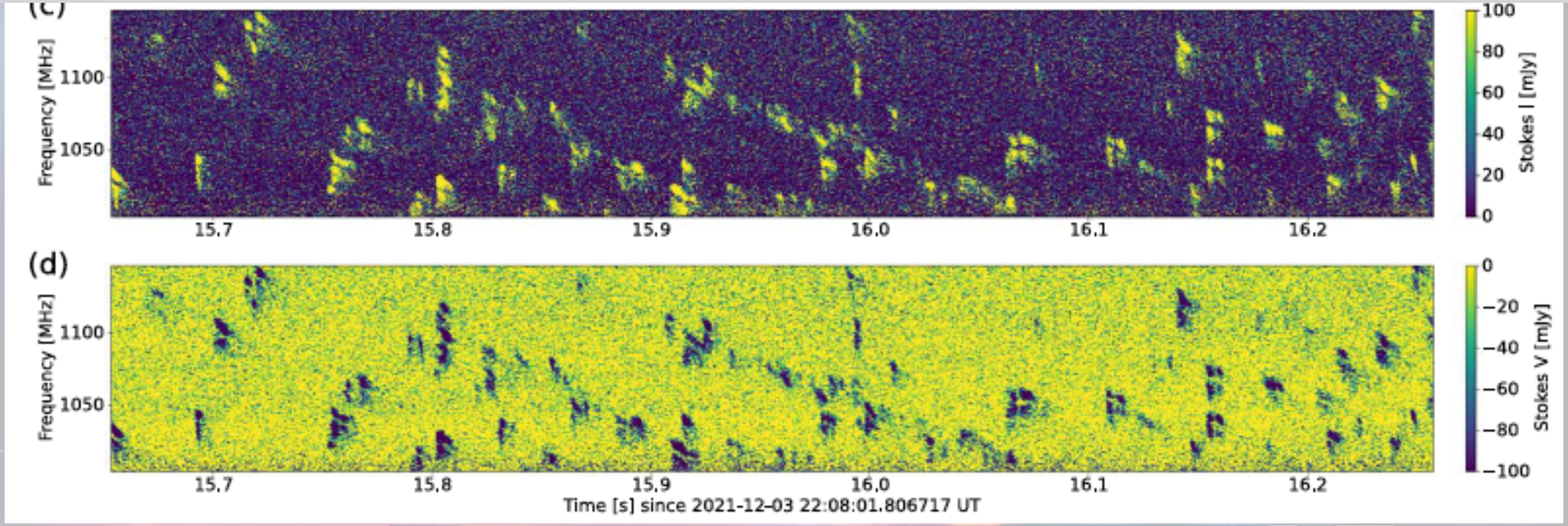
- ExPRES simulations could give constrains on:
  - Electron distribution function type (Loss cone vs. Shell)
  - Wave propagation mode

—> More observations needed

—> Should be observable with NenuFAR
  - 418 hours of observations (over 4 years)
  - Pipeline to analyse “slow” and “fast” drifting features in development

Back up
AD Leonis vs. Sun

2nd type of radio emissions



Solar observations