Detection of Jovian Kilometric and Hectometric auroral radio harmonic with Juno/Waves

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Introduction

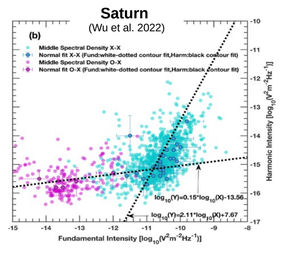
Jovian radio auroral emissions:

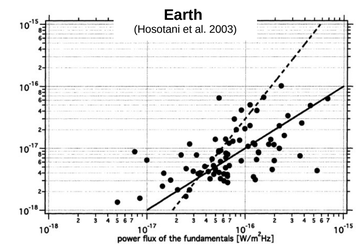
- Generated by wave-particle instability (CMI):
  - Close to fce
  - Perpendicular to B
  - Requires fpe/fce<<1 & inversion population (keV)
- Jupiter's auroral acceleration region

Harmonics

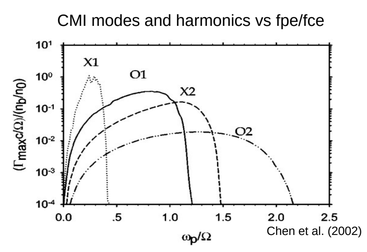
- Never clearly identified at Jupiter
- Opportunity for remote sensing
- Fundamental energy transfer in magnetosphere
- Comparative Planetology

	Earth AKR	**Saturn** SKR	**Jupiter** bKOM, HOM, DAM, Moon-DAM
Generation mechanism	CMI verified Viking Ergun et al. 2003	CMI verified Cassini Mutel et al. 2010	CMI verified Juno Louarn+ 2017, Louis+ 2023, Collet+ 2025
Detection harmonics	**1st and 2nd (X/O mode) harmonics regularly observed** (Benson 1982)	**1st and 2nd (X/O mode) harmonics regularly observed** (Wu+ 2022)	**Unconfirmed unclear reports of Io-DAM and HOM harmonics** (Menietti 1995, Menietti et al. 1998)





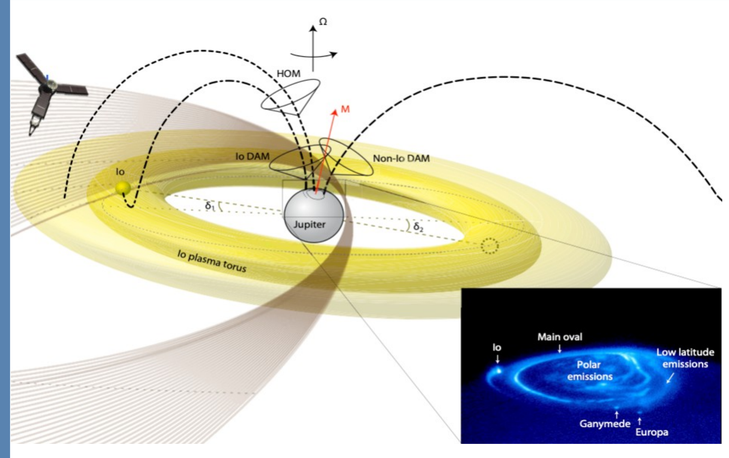
Never verified
probably at least 2 coexisting



Harmonics generation mechanism?

3 possible mechanisms:

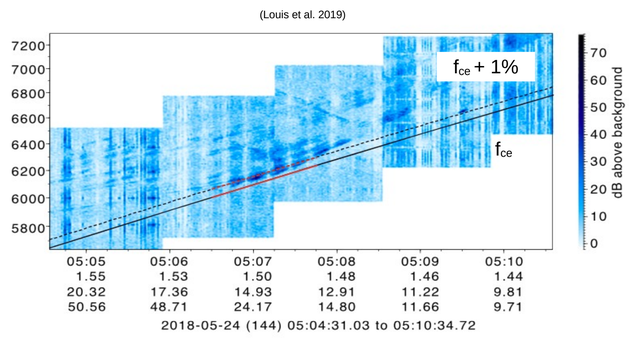
- Direct CMI at n fce (Melrose et al. 1982)
- Inverse Landau instability driven by the electron beam (Oya & Morioka 1983)
- Coalescence of X mode with Z mode emissions (Melrose 1991)



Juno mission

- 77 Orbits Jupiter since 2016
- Designed to study auroral regions
- 2-3 hours in the auroral regions (high res)
- Radio (1 antenna), plasma and magnetic instruments

Methods

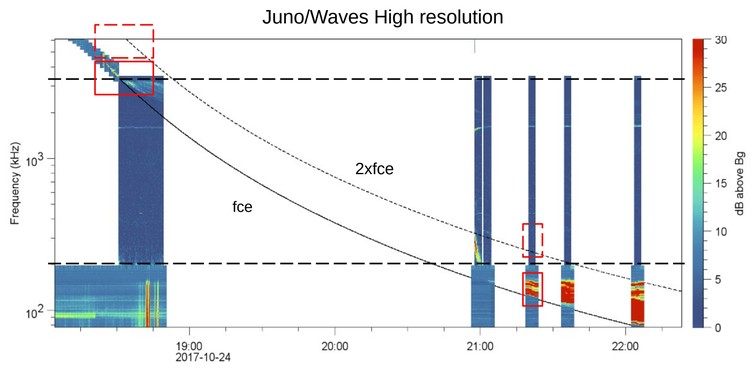


Survey radio sources

Harmonics probably weak: need to be in radio **sources**

- Identified from radio measurements where **f<fce+1%**
- Requires high resolution (LR df/f=7%)
- Survey 77 Juno orbits (2016-2025) for sources
- Identify harmonics close to 2 fce in these sources

Out of 77 orbits: we identified 124 sources

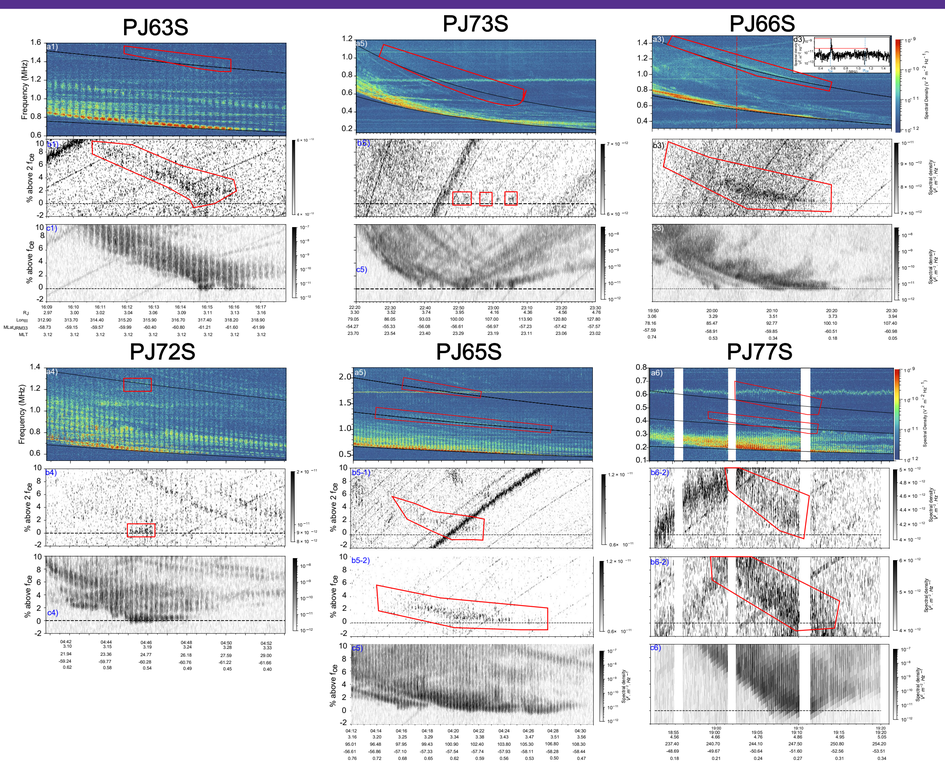


Instrumental constraints

High resolution radio not always available
4 sub receivers: We need to have fce and 2fce on the same
For fce>3MHz only 1 MHz band: no harmonic detection possible.
Frequency criteria:

- $10\,kHz < f_{ce} < 75\,kHz$
- $150\,kHz < f_{ce} < 1500\,kHz$

Out of 124 sources: 42 validate the criteria



Results

Out of these 42 source crossings,
We found **6 cases** with harmonics:

- Fundamental from 200 to 700 kHz
- fpe/fce ~ 10^{-2} (one order of magnitude larger that usual)
- Associated with e- **monoenergetic** signatures
- Intensity is 2 to 3 orders of magnitude lower (close to instrument noise)
- 2 cases with **2nd harmonics**

PJ	Source crossing interval	f_F(kHz)	R (R_J)	M-SHELL (R_J)	Zone	f_{pe}/f_{ce}	I_{H1}/I_F ($\times 10^{-3}$)	I_F ($V^2\,m^{-2}\,Hz^{-1}$)
PJ63S	2024-07-16 16:08 to 16:18	700	3.1	25	Diff. A.	10^{-2}	3	3×10^{-8}
PJ65S	2024-09-20 04:09 to 04:31	450-600	3.4	32	ZI/Diff. A.	10^{-2}	5	2×10^{-8}
PJ66S	2024-10-22 19:50 to 20:30	400-600	3.3.3-3.6	23	ZI/Diff. A.	10^{-2}	17	1×10^{-8}
PJ72S	2025-05-07 04:40:47 to 04:53:05	600	3.2	23	N/A	10^{-2}	4	2×10^{-8}
PJ73S	2025-06-08 22:20 to 23:30	300	3.6-4.2	50	N/A	$5 \cdot 10^{-2}$	2	2×10^{-8}
PJ77S	2025-10-17 19:06 to 19:15	200	4.7-5.0	20-40	ZI/Diff. A.	$1\text{-}3\times10^{-2}$	2	1×10^{-8}

Open Questions

- Source identified at relatively low **fpe/fce**: necessary condition?
- Compared to fundamental: different **modes**? **Beaming angle**?
- Jovian harmonics: very **rare** or too **weak**?
- **Generation mechanism** still unknown but direct CMI seems unlikely
- SKR harmonics were observed 30-40 dB weaker than fundamental: comparable to our result
- What about **DAM** (up to 40 MHz)?
  - If harmonics: up to 80 MHz (1st harmonic) or up to 120 MHz (2nd)
  - But fpe/fce even lower

Conclusion

- Harmonic identified for only **6 bKOM/HOM** cases out of 77 orbits
- Confirms previous detection with Voyager
- Confirms **universality** of Auroral Radio Harmonics
- **Generation mechanism** remains to be studied
- Opens possibility of Jovian Auroral Radio Emissions **up to 120 MHz** (frequency range of **SKA**)

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Also on brieucco.github.io

More (DAM) cases?