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Discovery of Jovian radio bursts related to Ganymede and the main aurora, and implications on Alfvénic electron acceleration

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Université de Paris

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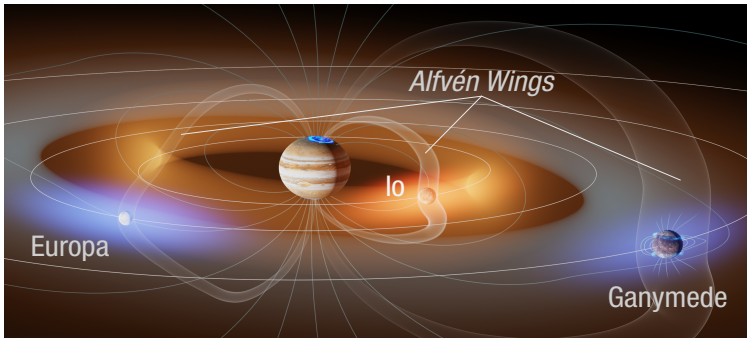
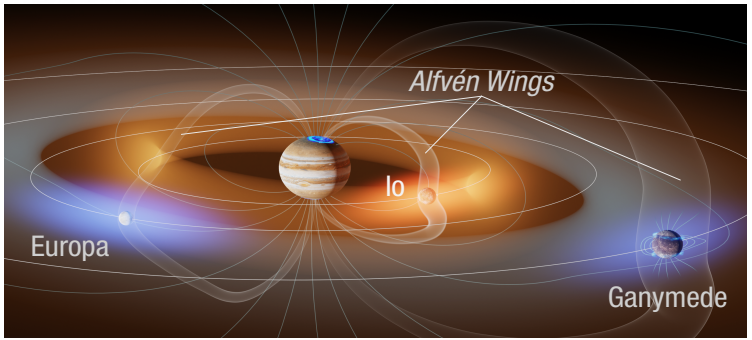


[Szalay et al., 2022]



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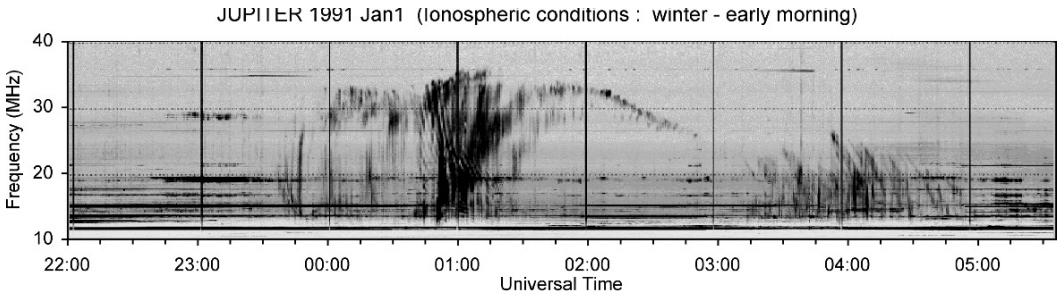
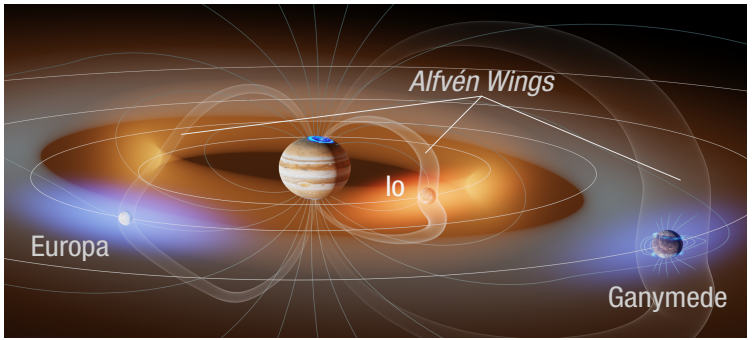
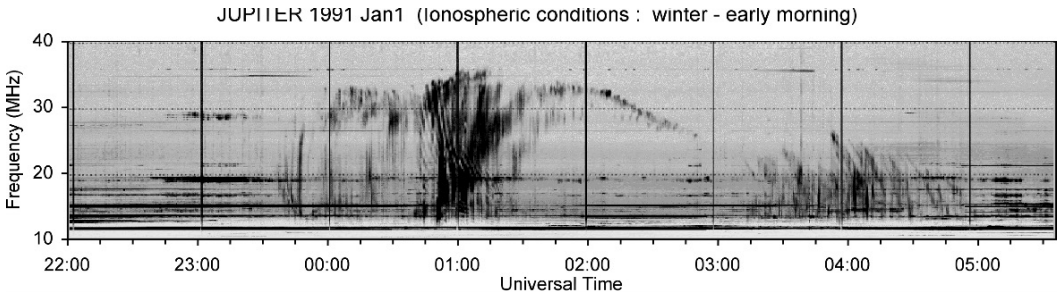
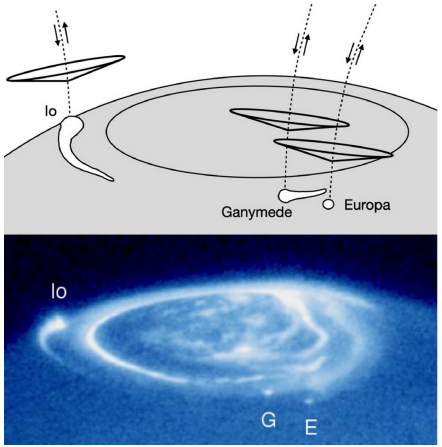


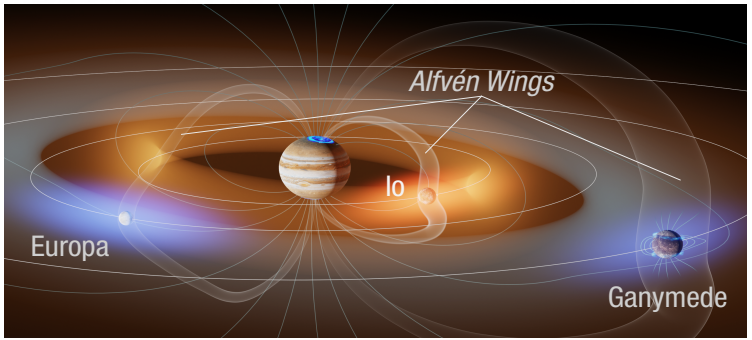


[Szalay et al., 2022]





[Clarke et al., 2002]



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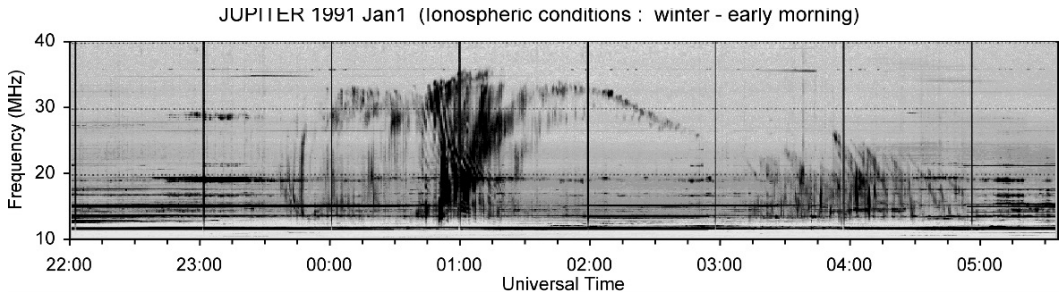

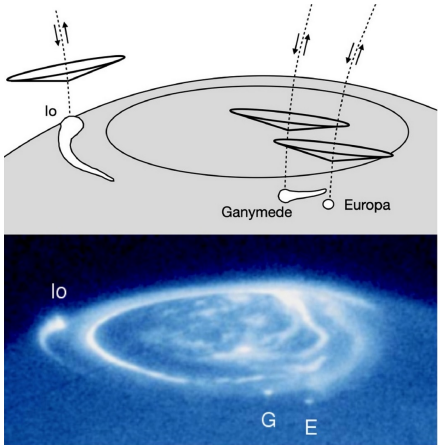

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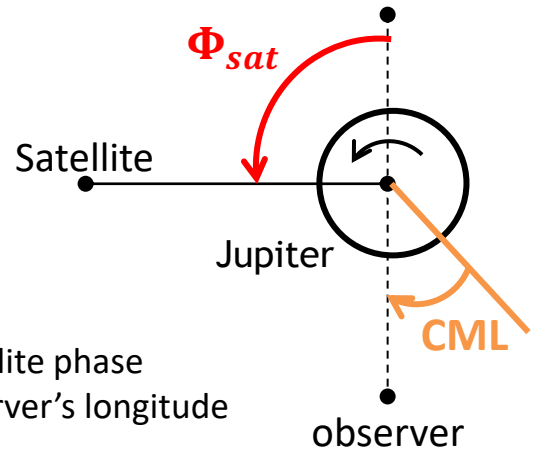
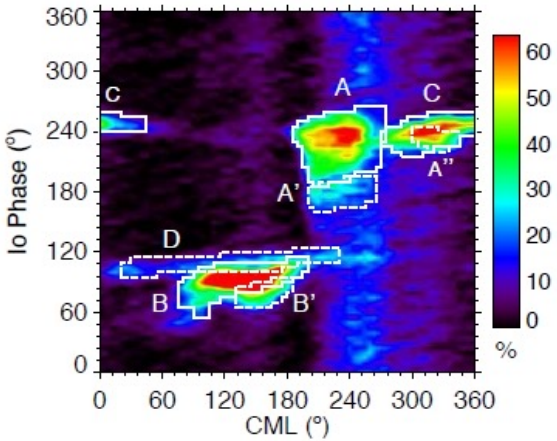
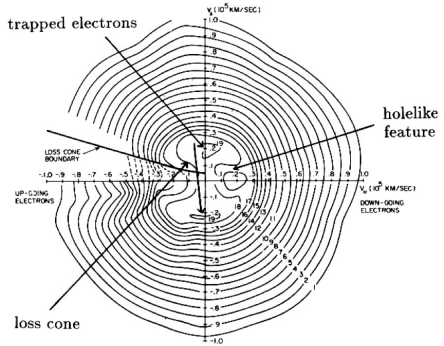


Φ_{sat} : satellite phase
CML : observer's longitude

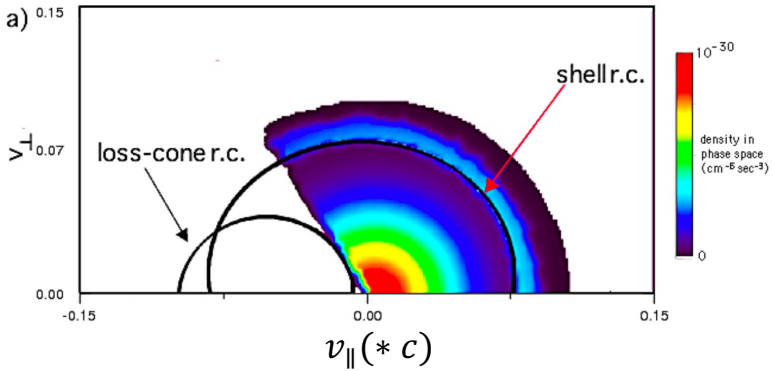


[Zarka et al., 2018]

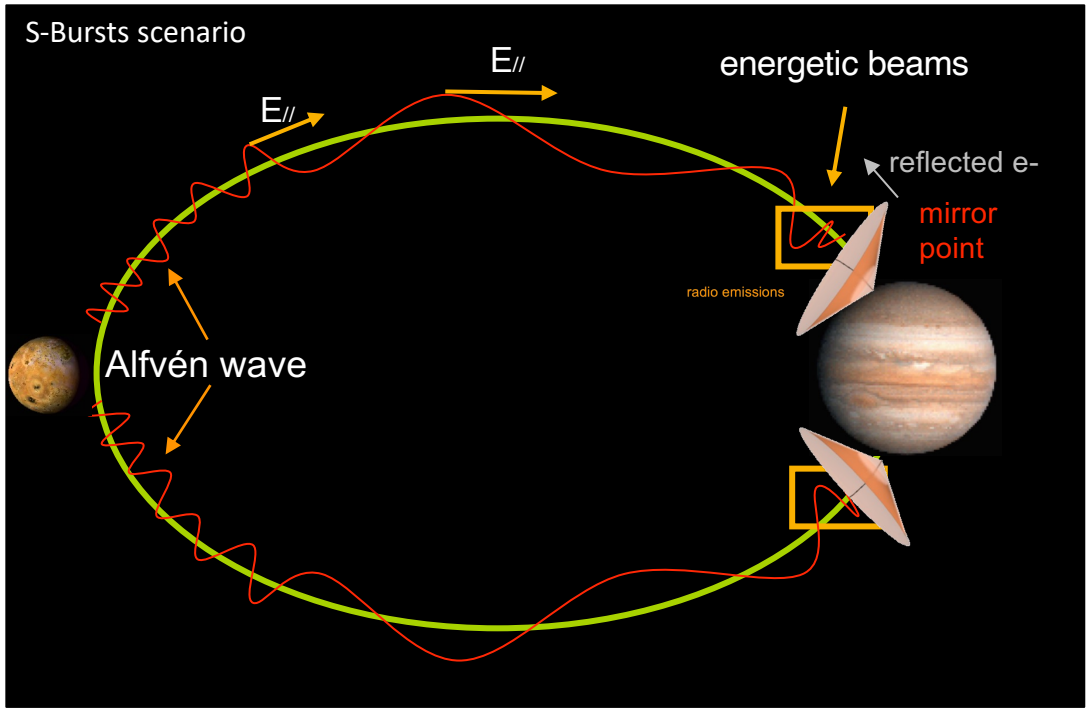
- IFT radio emissions mostly due the Cyclotron Maser Instability driven by loss-cone (mirrored) electrons



[Mizera & Fennell, 1977]



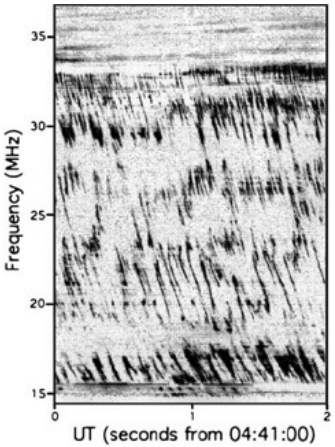
[Hess et al., 2007]



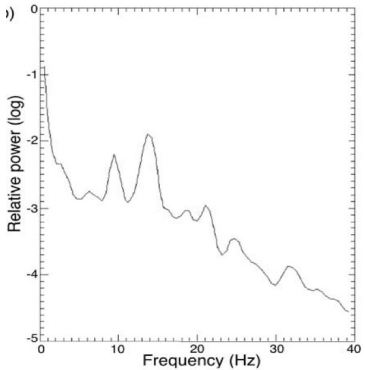
Nancay Decameter Array :

$2.6ms \times 3.05\ kHz$

- Discrete signals, quasi-periodic ~5-10 Hz, drift $\sim -20\ MHz.s^{-1}$



[Zarka, 2004]



[Hess et al., JGR, 2007]

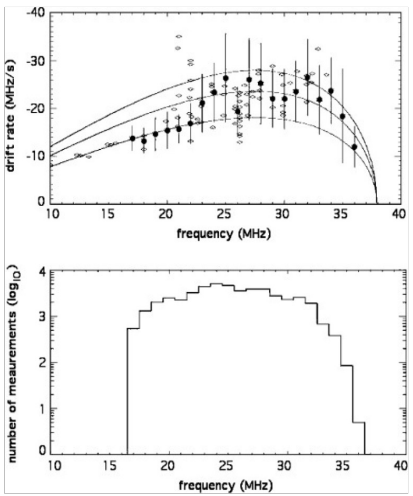
Nancay Decameter Array :

$2.6ms \times 3.05\ kHz$

- Discrete signals, quasi-periodic ~5-10 Hz, drift $\sim -20\ MHz.s^{-1}$

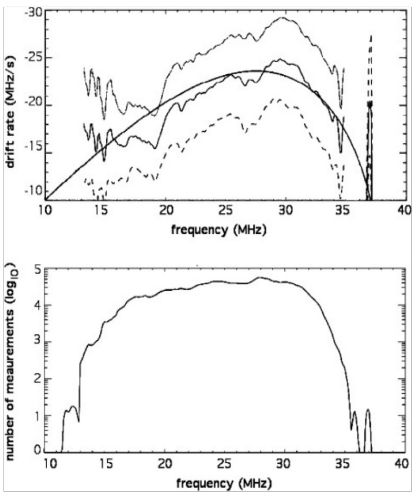
→ produced by $\sim keV$ e- with adiabatic motion

E = 5.3 ± 2.2 keV, ϕ_{eq} ~ 2.8°

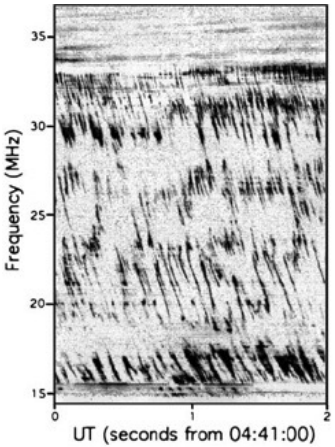


[Zarka et al., 1996]

E = 4.5 ± 1.1 keV, ϕ_{eq} ~ 2.7°



[Hess et al., PSS, 2007]



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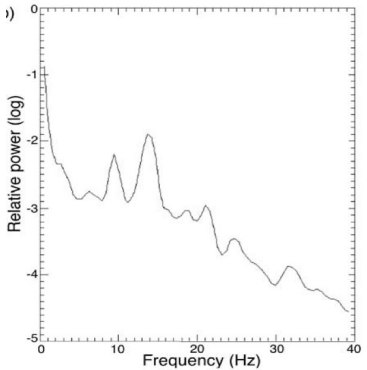


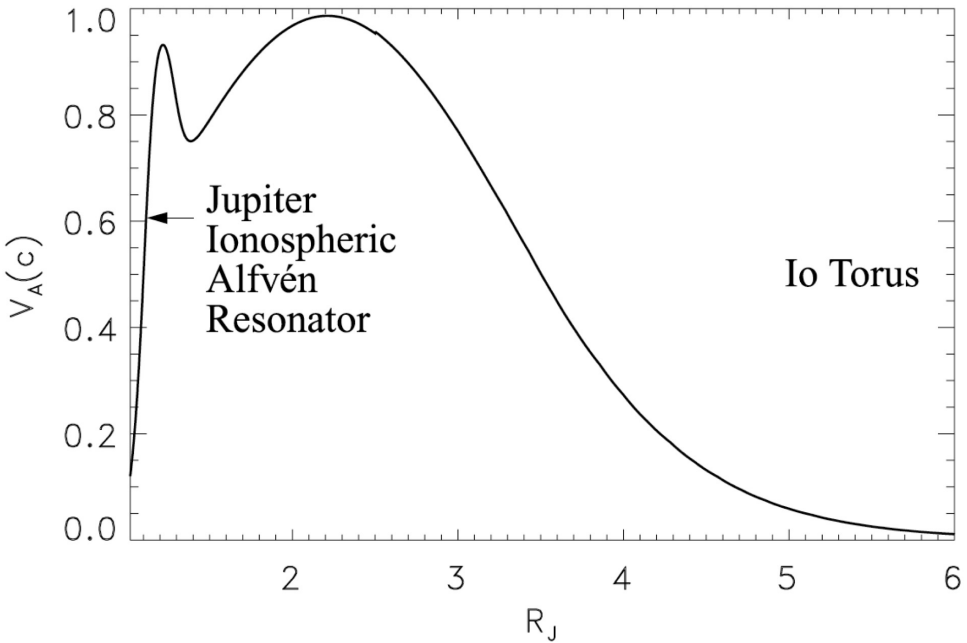
[Hess et al., JGR, 2007]

Nancay Decameter Array :

$2.6ms \times 3.05\ kHz$

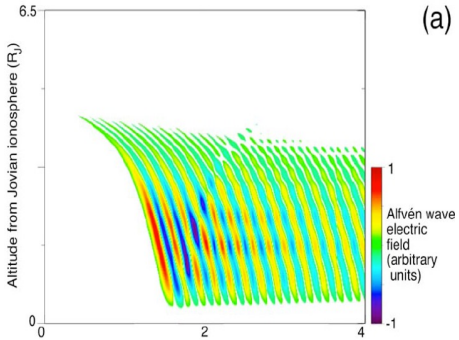
Alfvén waves resonator:

- Ergun et al. [2006] proposed that AW resonate near the Jovian ionosphere, accelerating electrons periodically
- Su et al. [2006] : AW in IAR at period ~ 20 Hz (Earth ~10 Hz)



- Modelisation and simulation [Hess et al., 2007], where a 5Hz AW train(3s, 0.01G) is injected at the outer edge if Io torus.

↳ kinetic ($\lambda_a \sim \lambda_e$) : $\delta E_{//} = \omega_A k_\perp \lambda_e^2 \delta B_\perp$



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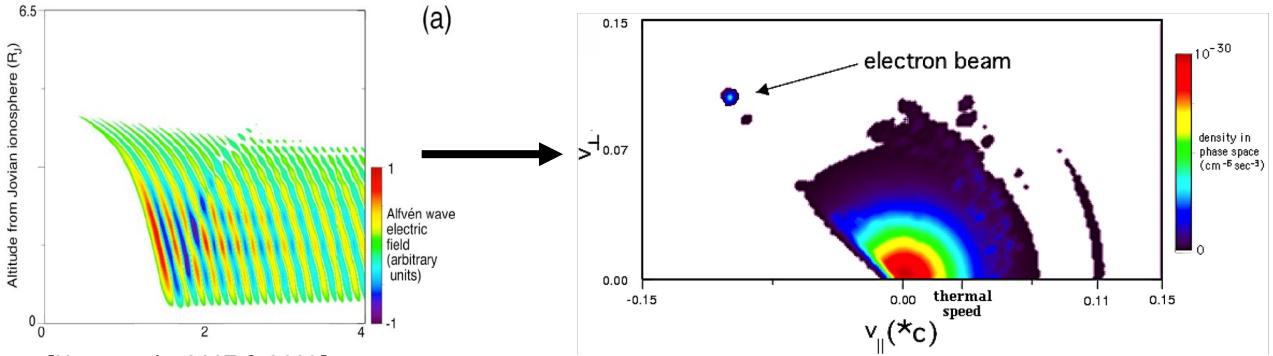
↳ acceleration (to ~keV) along IFT, by $\delta E_{//}$ of Maxwellian electrons injected at Io *(+ gravitation, cenfrifugal force, ambipolar E-field, magnetic mirroring)*



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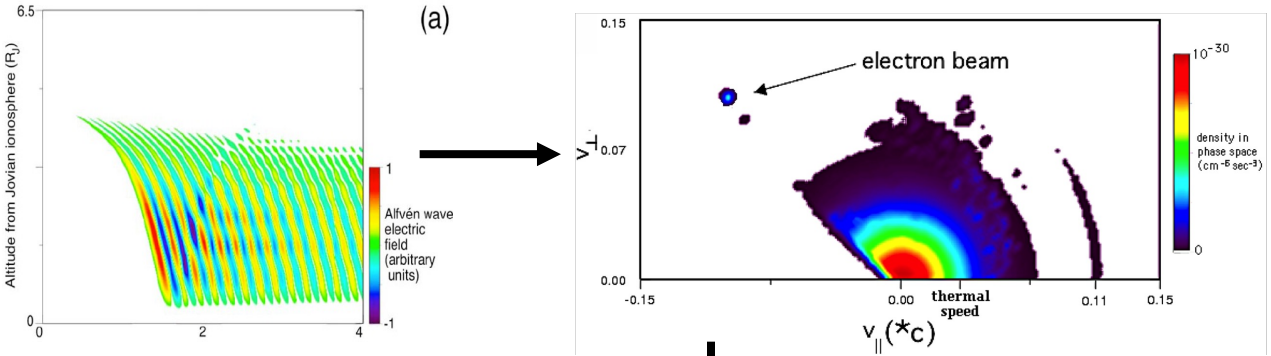
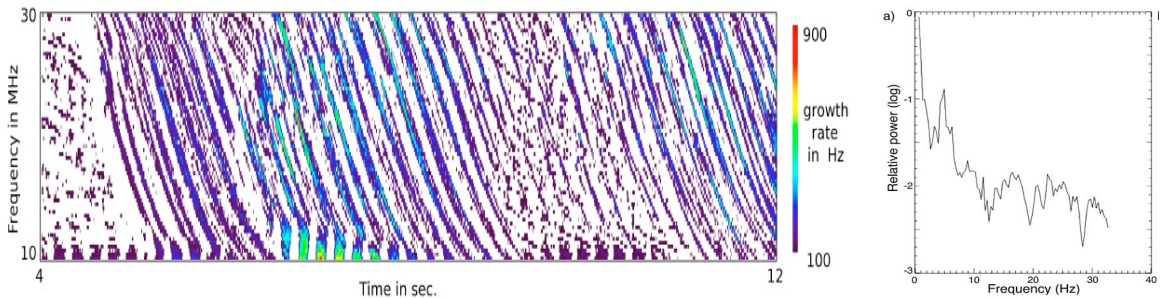
↳ electron distribution *(s,t)* → CMI growth rates → radio bursts : **all found modulated at AW period**



[Hess et al., 2007 & 2009]



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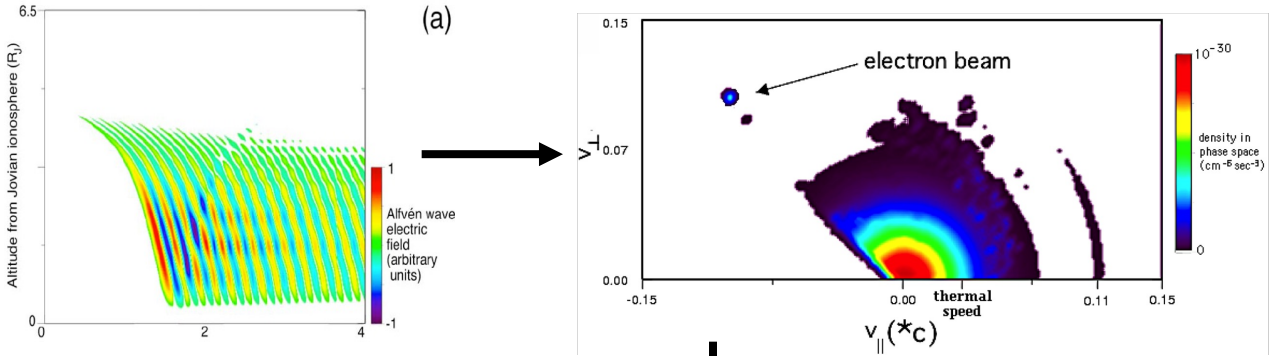
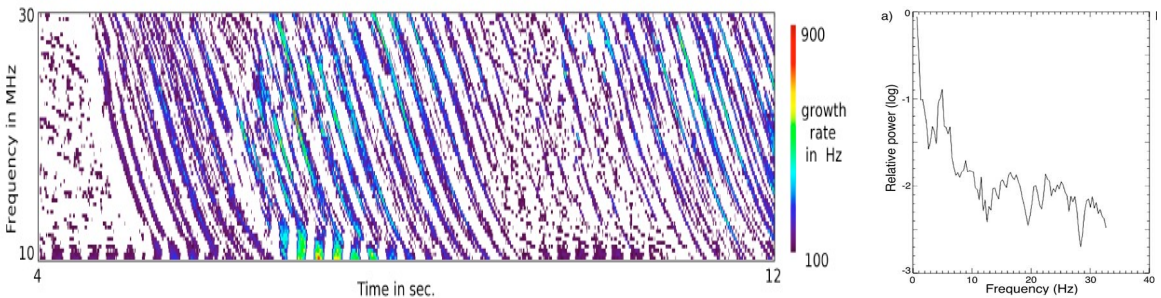


[Hess et al., 2007 & 2009]

- $v_A \gg v_{\|,e}$ → non-resonant acceleration, in both direction (independently of the direction of propagation of the AW)



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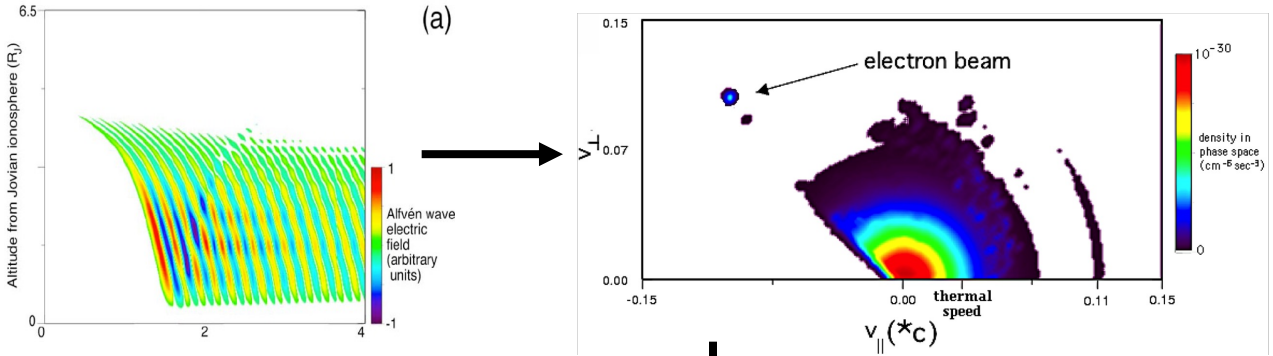
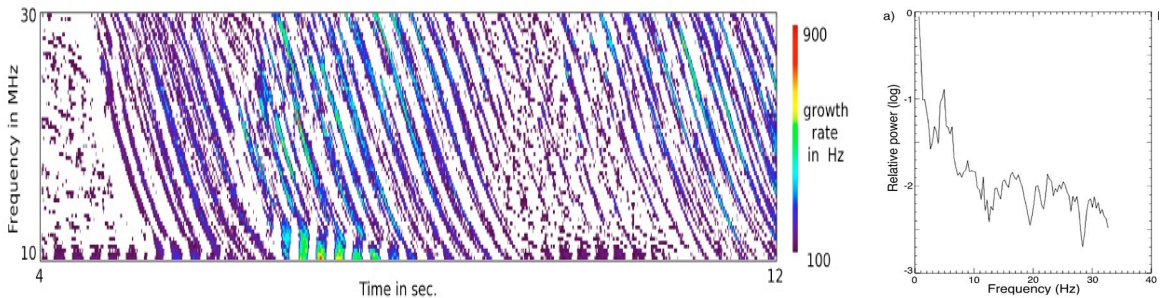
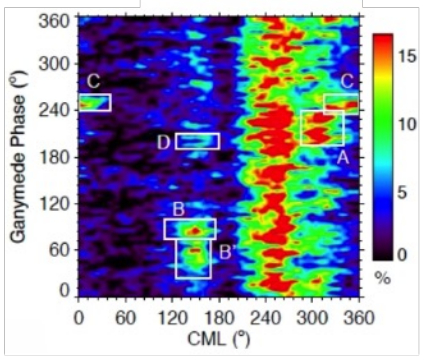


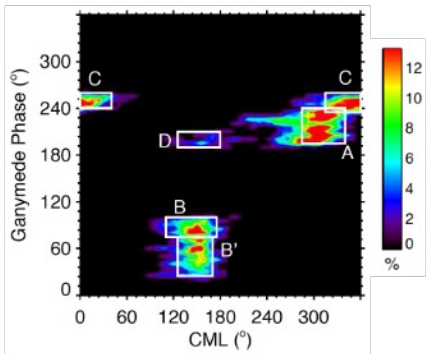
[Hess et al., 2007 & 2009]

- $v_A \gg v_{\|,e}$ → non-resonant acceleration, in both direction (independently of the direction of propagation of the AW)
- e- acceleration near lower edge of high $E_\|$ region escape downward → quasi-adiabatic motion, mirroring, radio emission
- e- beams are short lived because accelerated in a narrow δz around $z \sim 1.5 - 2\ R_J$

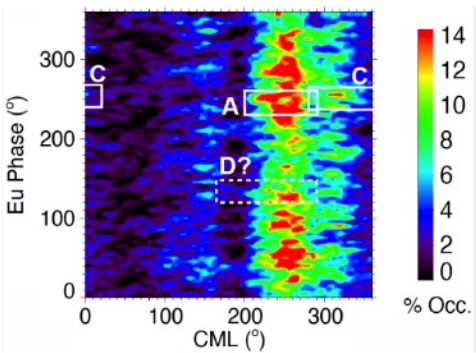


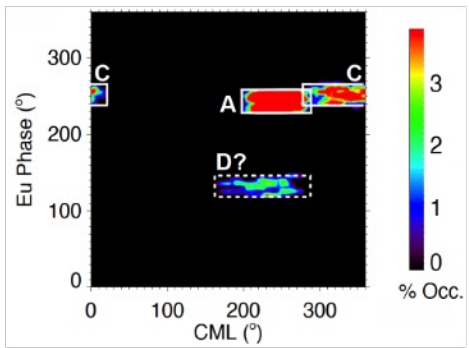
- Jovian radio emission known since 1955 [Burke & Franklin, 1955]
- Bigg [1964] : discovery of Io-induced emission
- Zarka et al. [2018] : discovery of Ganymede-induced emission
- Jacome et al. [2022] : discovery of Europa-induced emission



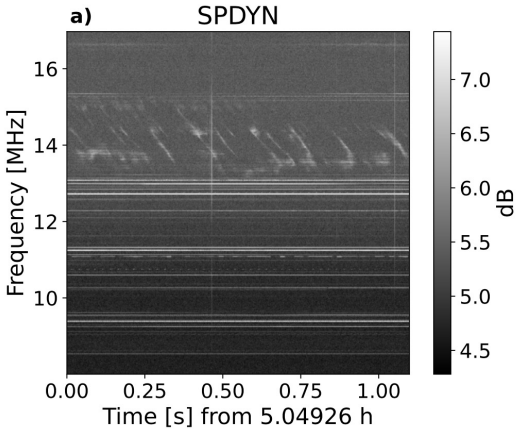


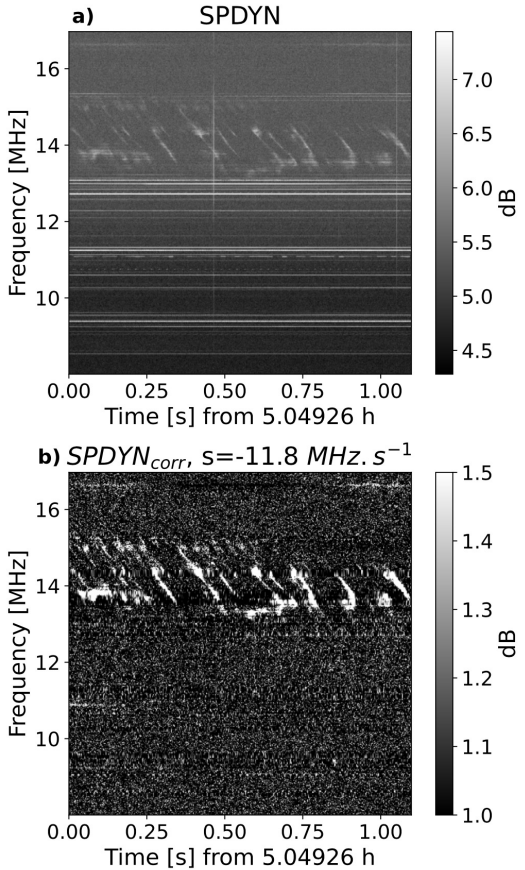
[Zarka et al., 2018]





[Jacome et al., 2022]


a)
SPDYN
Frequency [MHz]
16
14
12
10
0.00
0.25
0.50
0.75
1.00
Time [s] from 5.04926 h
7.0
6.5
6.0
5.5
5.0
4.5
dB


a)
SPDYN
Frequency [MHz]
16
14
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0.25
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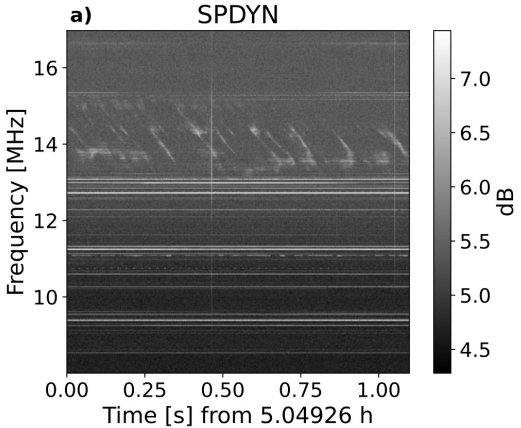
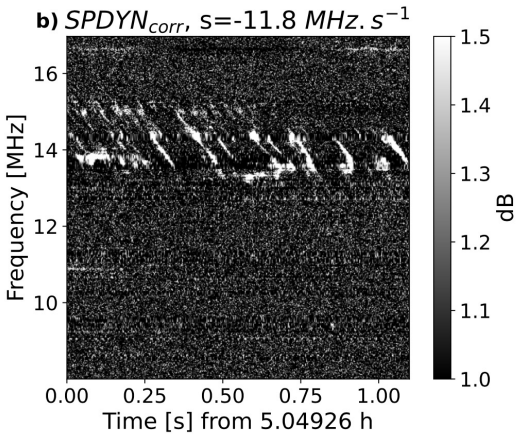
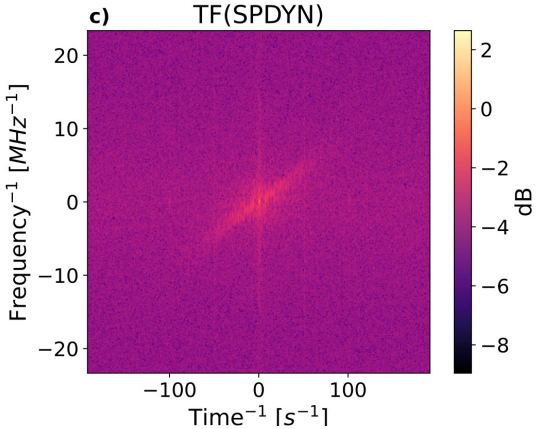
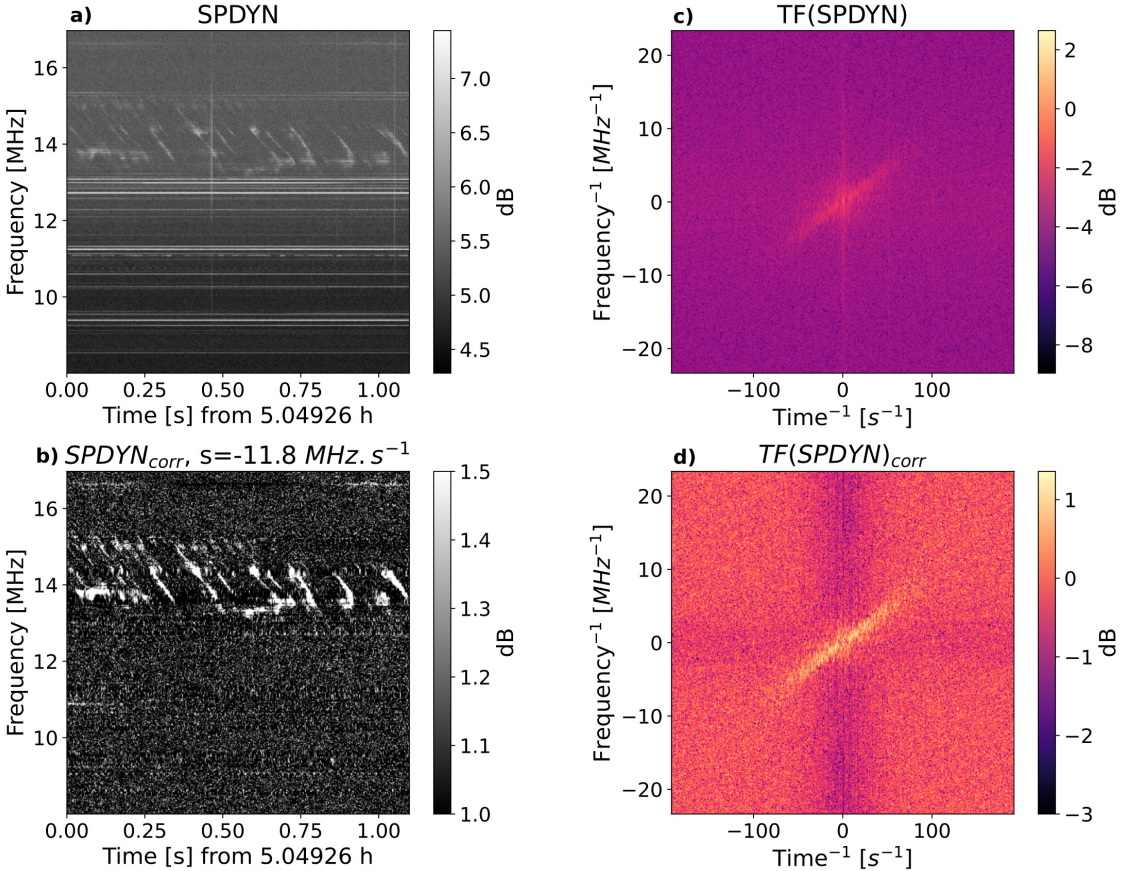
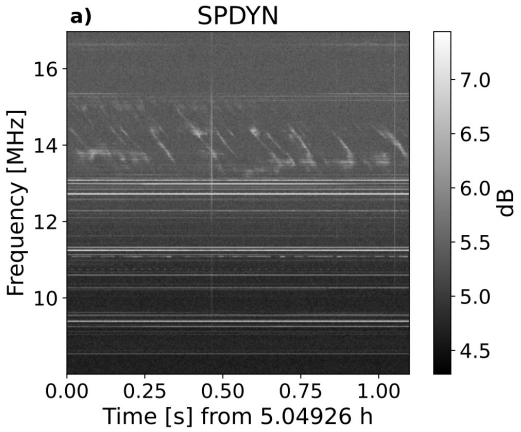
0.75
1.00
Time [s] from 5.04926 h
7.0
6.5
6.0
5.5
5.0
4.5
dB
b) $SPDYN_{corr}$, s=-11.8 $MHz.s^{-1}$
Frequency [MHz]
16
14
12
10
0.00
0.25
0.50
0.75
1.00
Time [s] from 5.04926 h
1.5
1.4
1.3
1.2
1.1
1.0
dB

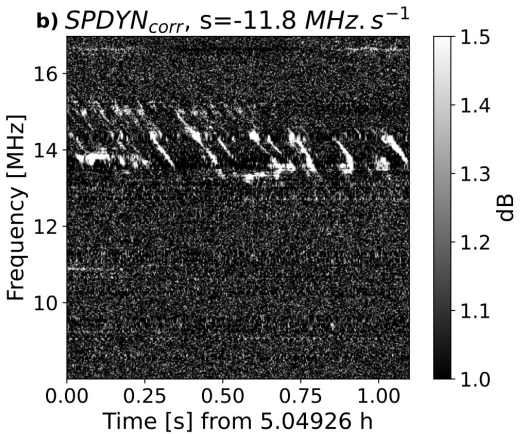

a)
SPDYN
Frequency [MHz]
Time [s] from 5.04926 h
dB

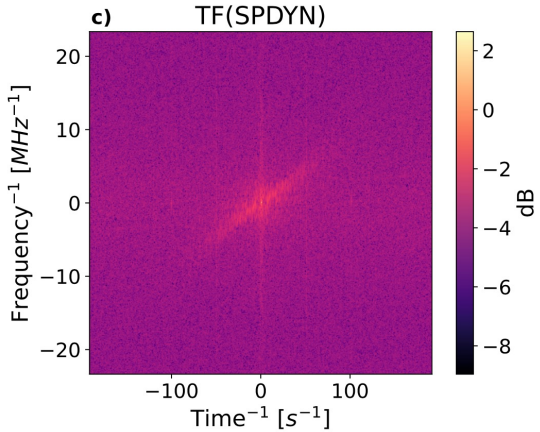

b) $SPDYN_{corr}$, s=-11.8 $MHz.s^{-1}$
Frequency [MHz]
Time [s] from 5.04926 h
dB

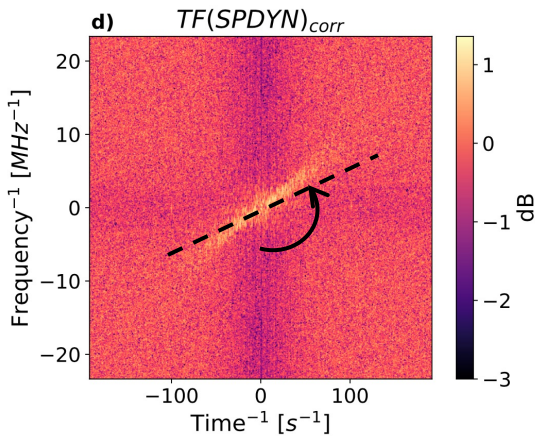

c)
TF(SPDYN)
Frequency^{-1} [MHz^{-1}]
Time^{-1} [s^{-1}]
dB

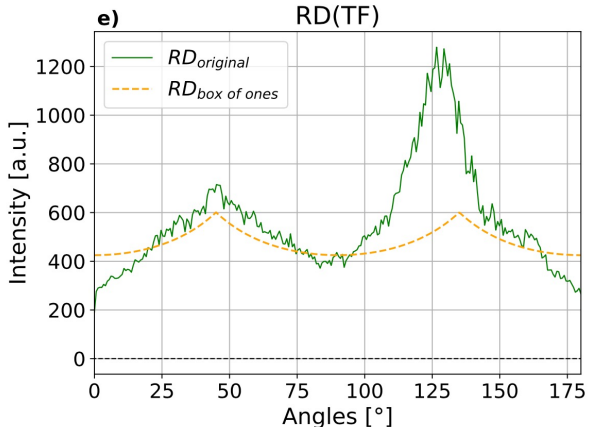

a) SPDYN
Frequency [MHz]
Time [s] from 5.04926 h
dB
b) $SPDYN_{corr}$, s=-11.8 $MHz.s^{-1}$
Frequency [MHz]
Time [s] from 5.04926 h
dB
c) TF(SPDYN)
Frequency^{-1} [MHz^{-1}]
Time^{-1} [s^{-1}]
dB
d) $TF(SPDYN)_{corr}$
Frequency^{-1} [MHz^{-1}]
Time^{-1} [s^{-1}]
dB

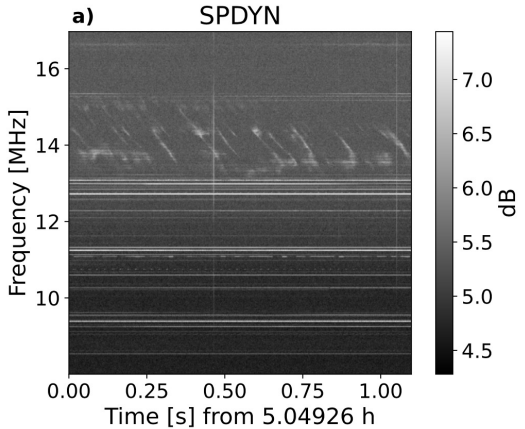

a)
SPDYN
Frequency [MHz]
Time [s] from 5.04926 h
dB

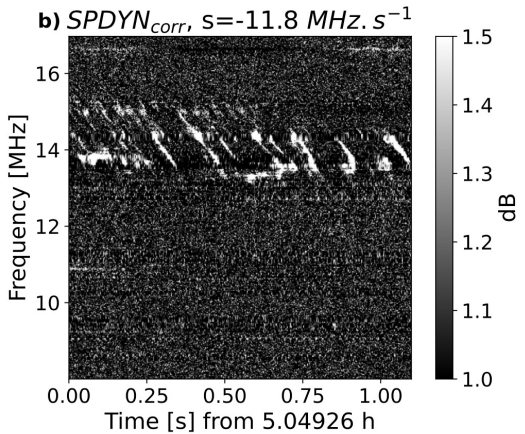

b) $SPDYN_{corr}$, s=-11.8 $MHz.s^{-1}$
Frequency [MHz]
Time [s] from 5.04926 h
dB

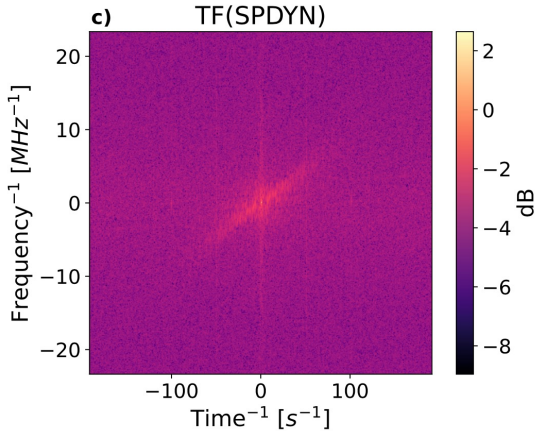

c)
TF(SPDYN)
$Frequency^{-1}$ [MHz^{-1}]
$Time^{-1}$ [s^{-1}]
dB

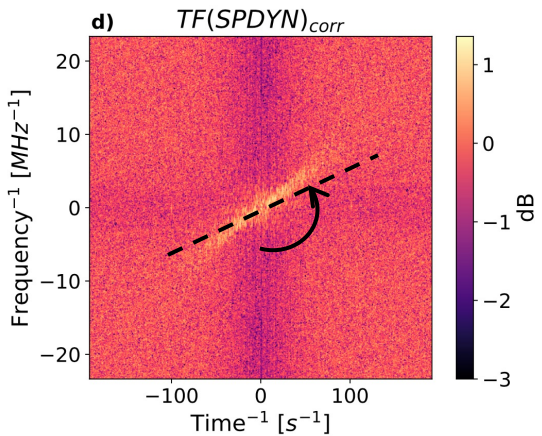

d)
$TF(SPDYN)_{corr}$
$Frequency^{-1}$ [MHz^{-1}]
$Time^{-1}$ [s^{-1}]
dB

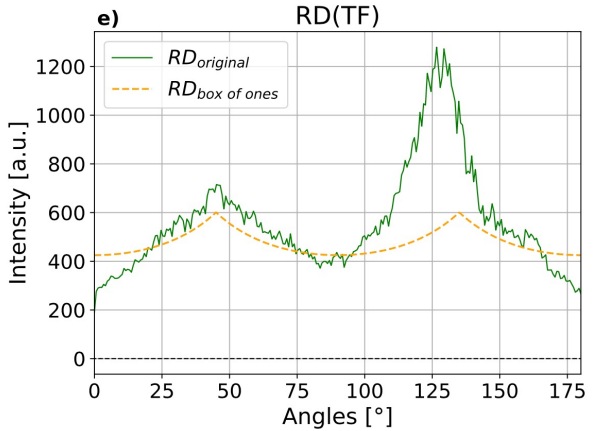

e)
RD(TF)
$RD_{original}$
$RD_{box\ of\ ones}$
Intensity [a.u.]
Angles [°]

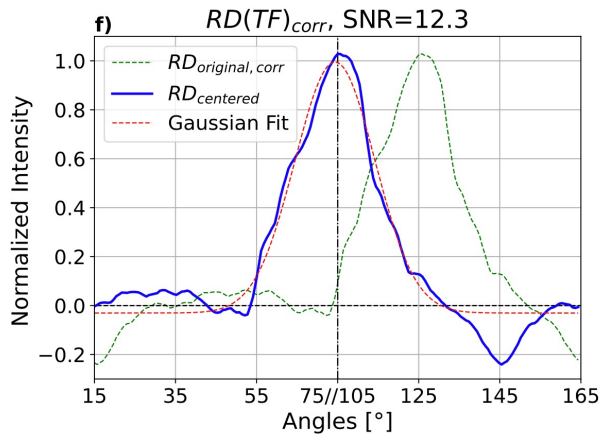

a)
SPDYN
Frequency [MHz]
Time [s] from 5.04926 h
dB


b) $SPDYN_{corr}$, s=-11.8 $MHz.s^{-1}$
Frequency [MHz]
Time [s] from 5.04926 h
dB

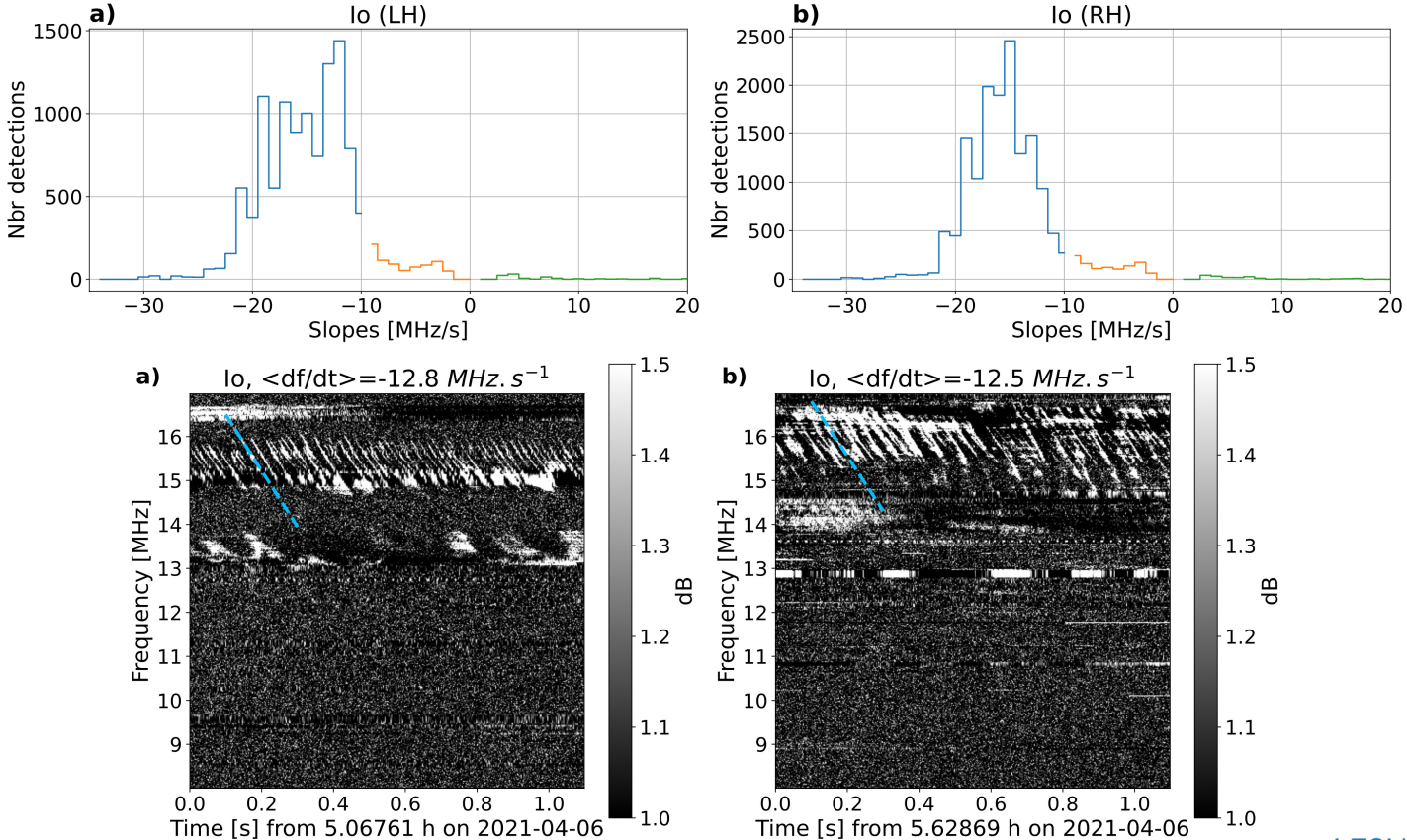

c)
TF(SPDYN)
$Frequency^{-1}$ [MHz^{-1}]
$Time^{-1}$ [s^{-1}]
dB

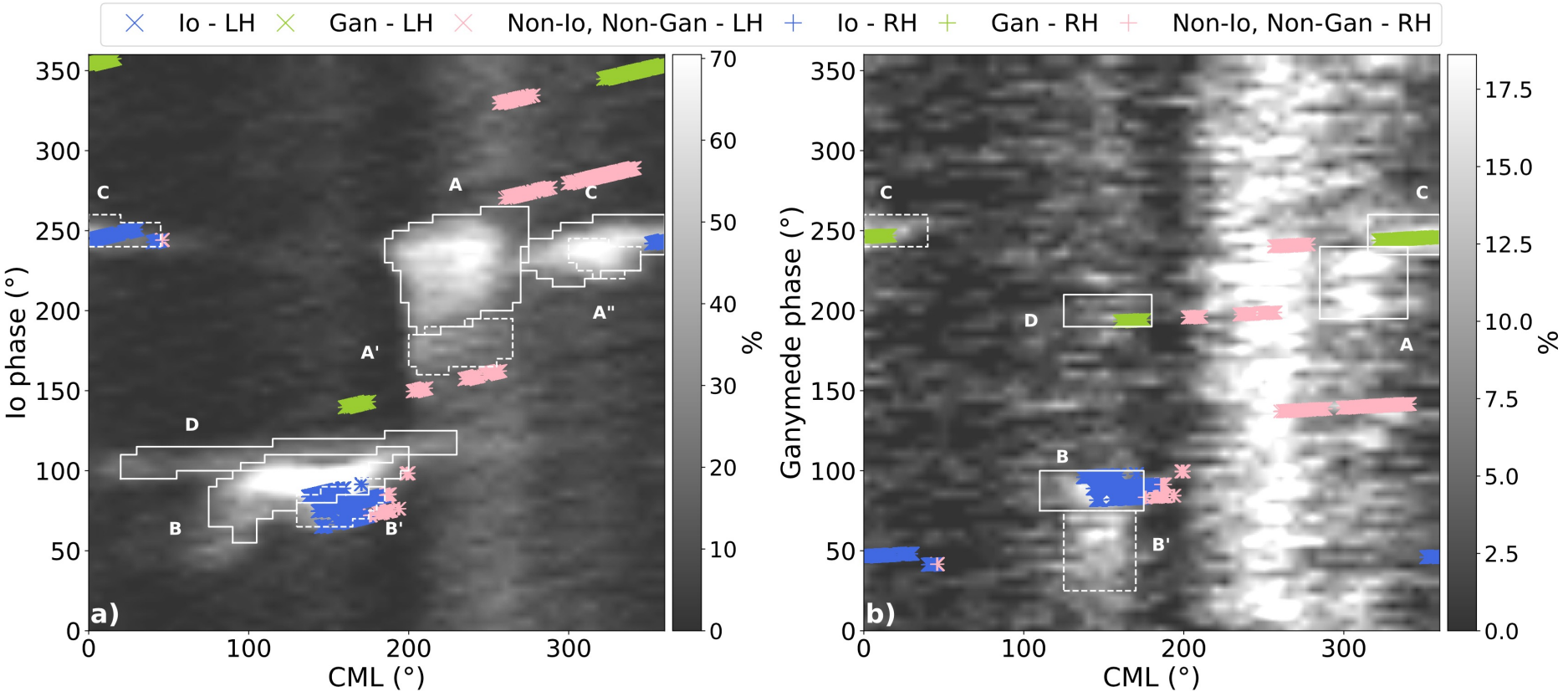

d)
$TF(SPDYN)_{corr}$
$Frequency^{-1}$ [MHz^{-1}]
$Time^{-1}$ [s^{-1}]
dB


e)
RD(TF)
$RD_{original}$
$RD_{box\ of\ ones}$
Intensity [a.u.]
Angles [°]


f)
$RD(TF)_{corr}$, SNR=12.3
$RD_{original,\ corr}$
$RD_{centered}$
Gaussian Fit
Normalized Intensity
Angles [°]

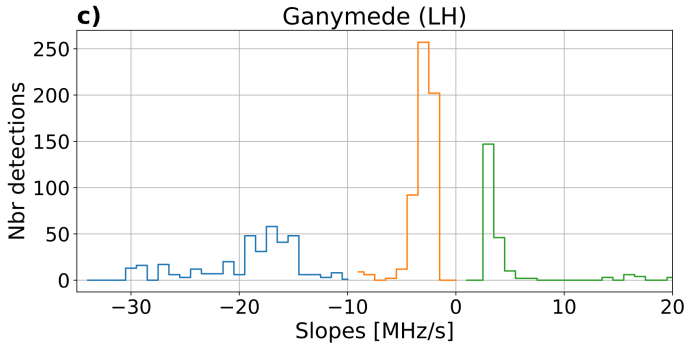
Expected detection of Io-related S-bursts with slopes mainly around $\sim -15\ MHz/s$:

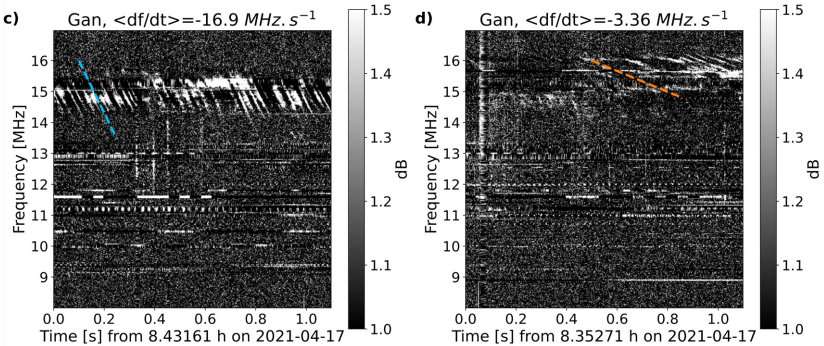




Analysis over April 2021

New detection of Ganymede and aurora-related S-bursts (slopes ~ -15 and $-5\ MHz/s$):





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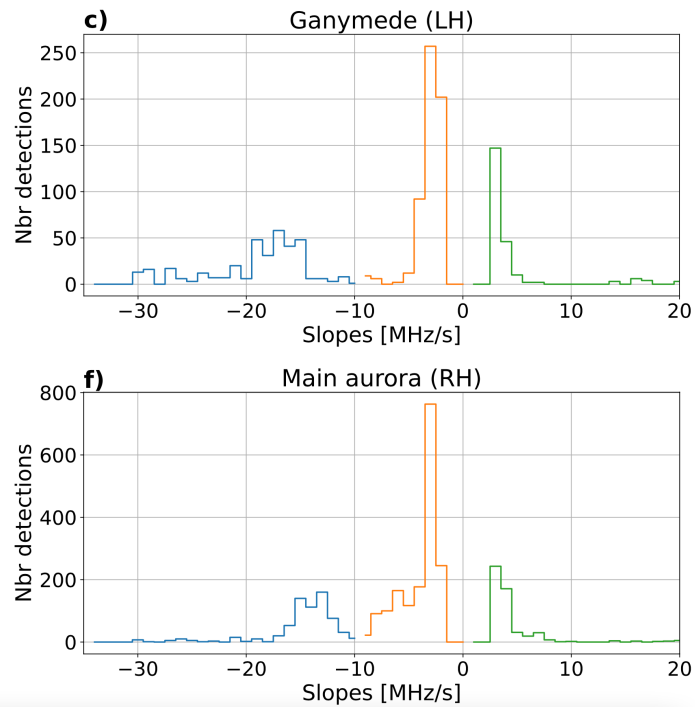
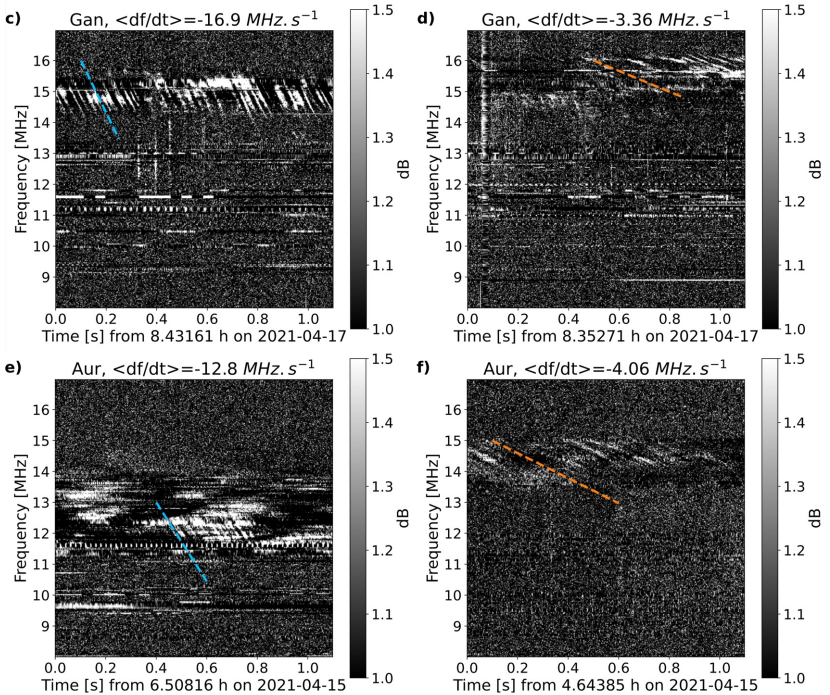
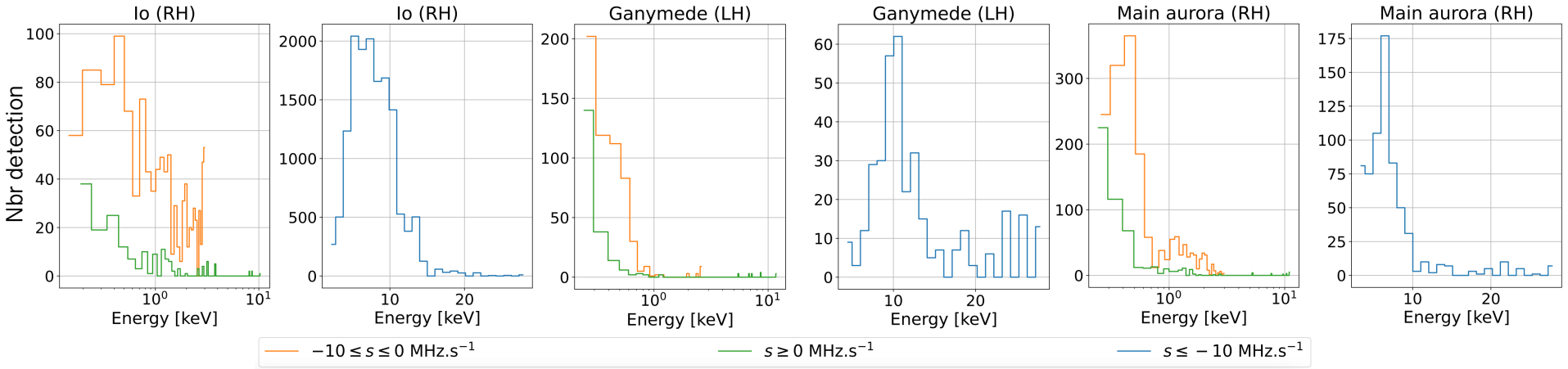




- In proportion, Ganymede-induced & auroral bursts seem to lead to more slower drift-rates with less intense bursts

Corresponding parallel kinetic energies :



- Two families of slopes : ~ -15 and $-5\ MHz/s$
  ↳ electron with energies ~ 1-10 keV & 0.1-1 keV

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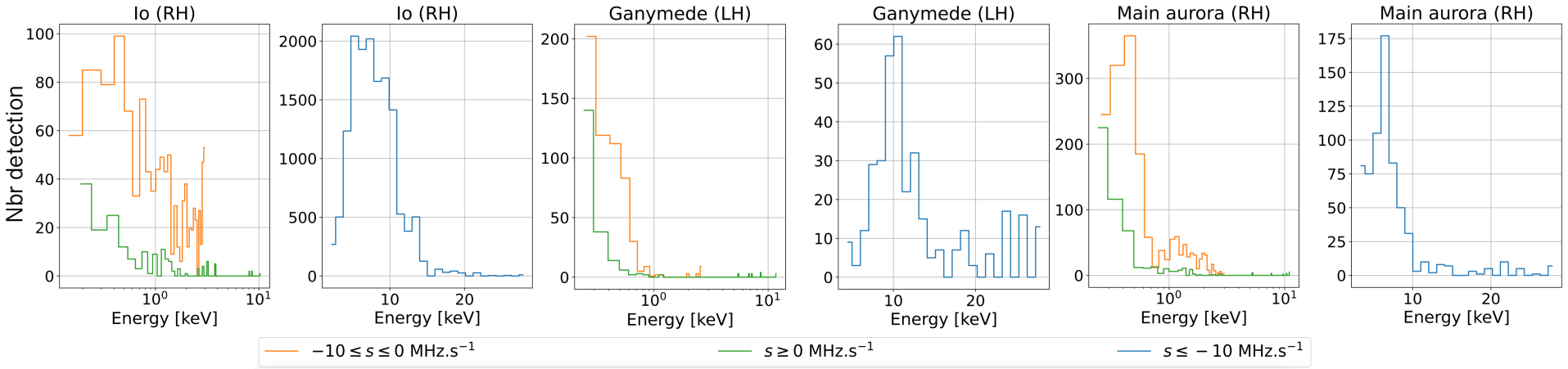

- Two families of slopes : ~ -15 and $-5\ MHz/s$
  ↳ electron with energies ~ 1-10 keV & 0.1-1 keV

⇒ How to obtain CMI with electrons of 0.1-1 keV ?
  ↳ mode X harmonic / mode O fundamental ?
  Or mode X fundamental with non-thermal plasma

Main conclusions :

- Robust method for automatic detection
- First detection of millisecond bursts related to Ganymede and the diffuse aurora
- Ubiquitous Alfvénic electron acceleration at Jupiter
- Two populations of time-frequency drifts → two populations of electrons with different energies
- Mauduit et al., 2023, Nature Communications (doi : 10.1038/s41467-023-41617-8)

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Perspectives :

- Process all data available : $\sim 100\ Tb$ since 2017
- Statistical study of drifts distribution, frequencies of the emissions, etc.`
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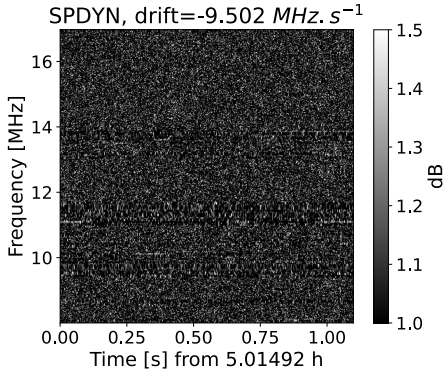
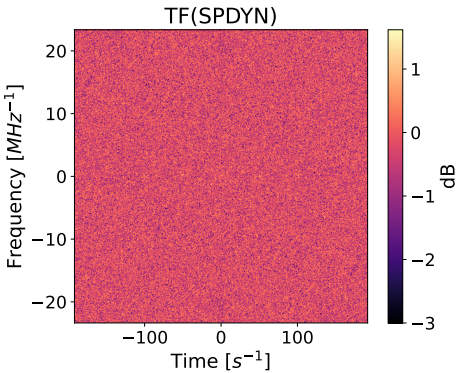
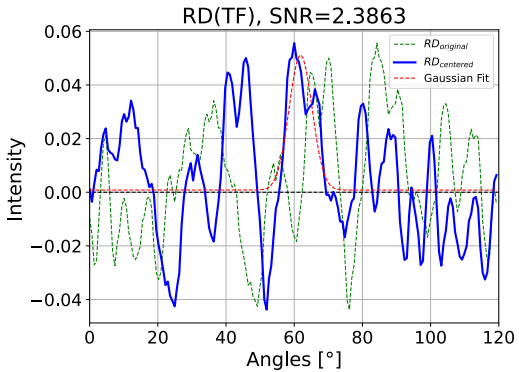
Thank you for your attention !

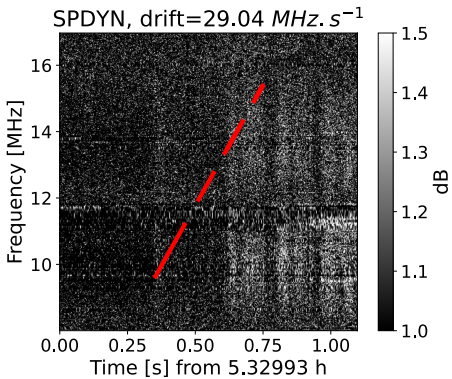
Example of non-detection:

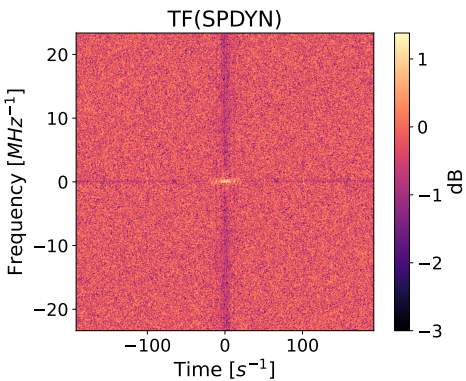


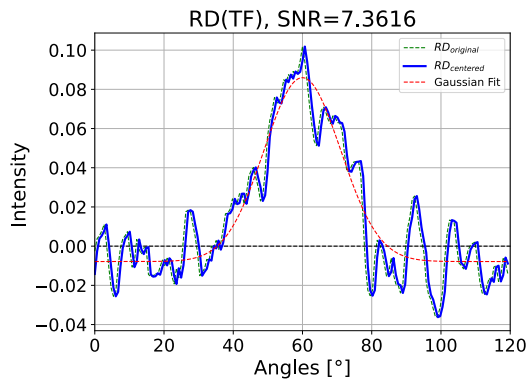


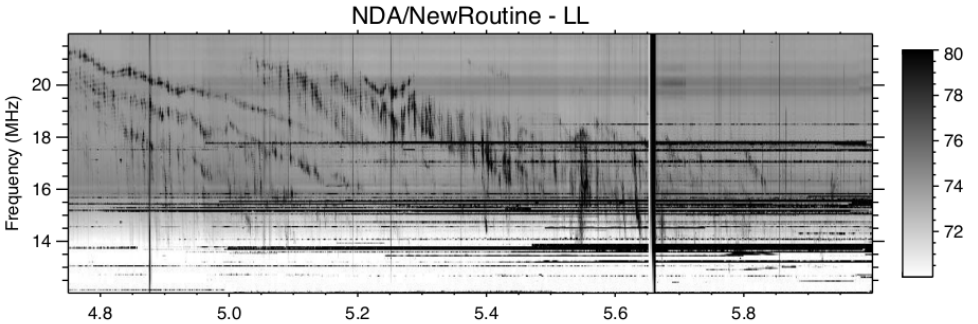


Example of positive slope :



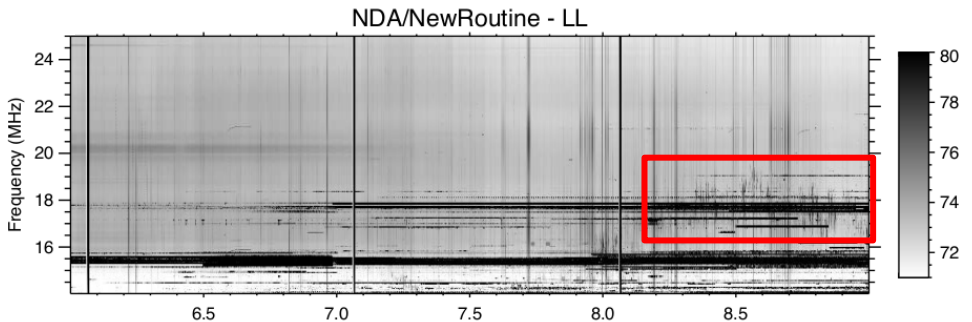


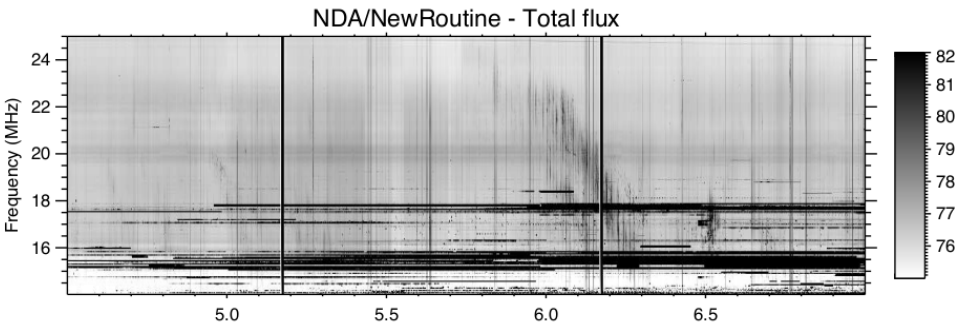




Io related emissions

Ganymede related emissions





Diffuse aurora related emissions