Natural radio emission of Jupiter as interferences for radar investigations of the icy satellites of Jupiter

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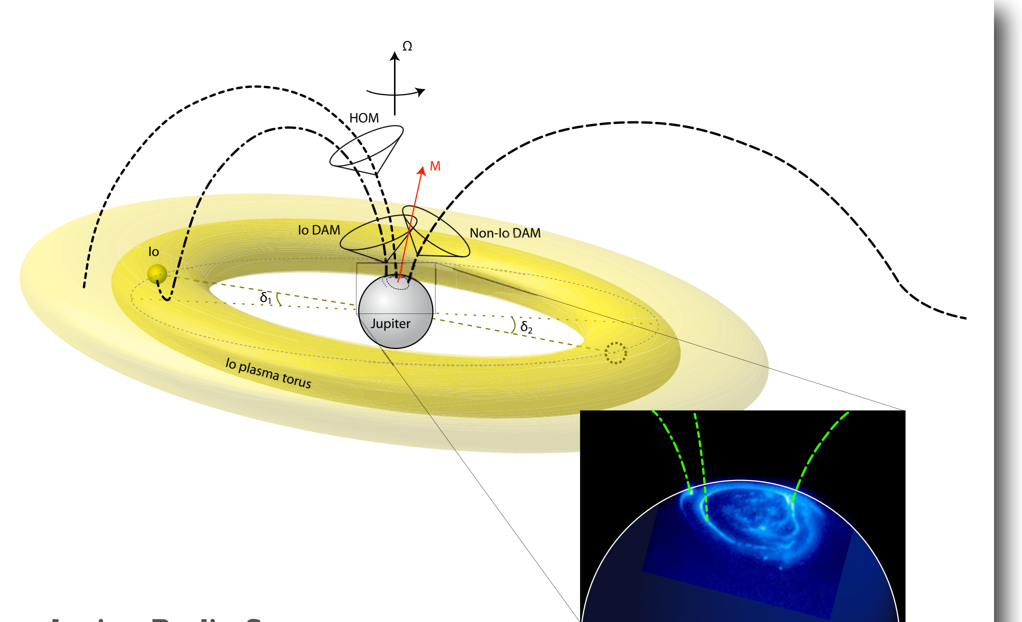
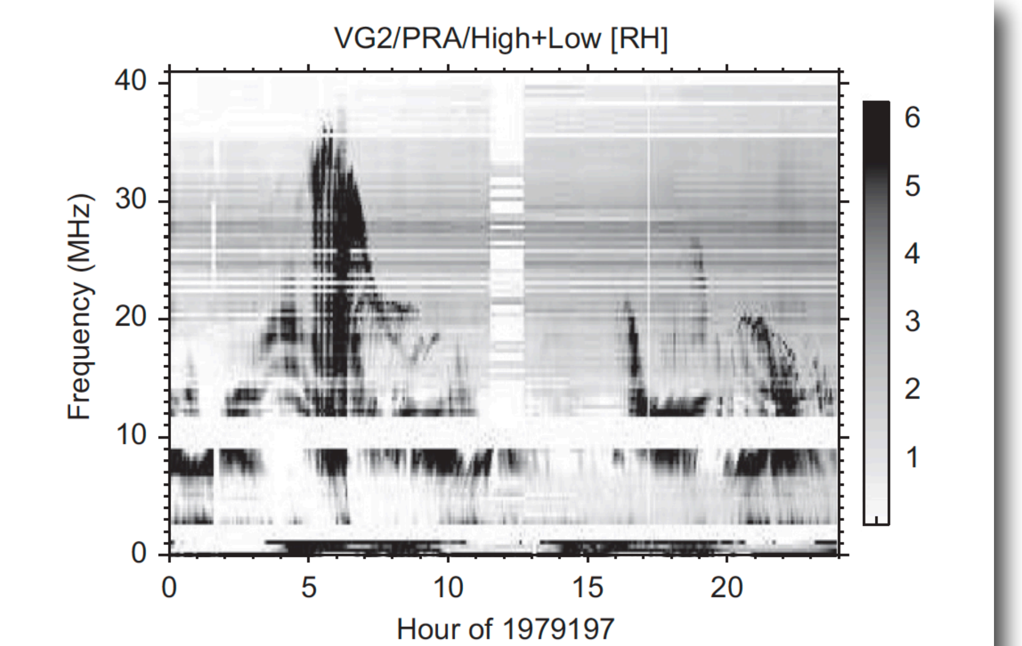
abstract

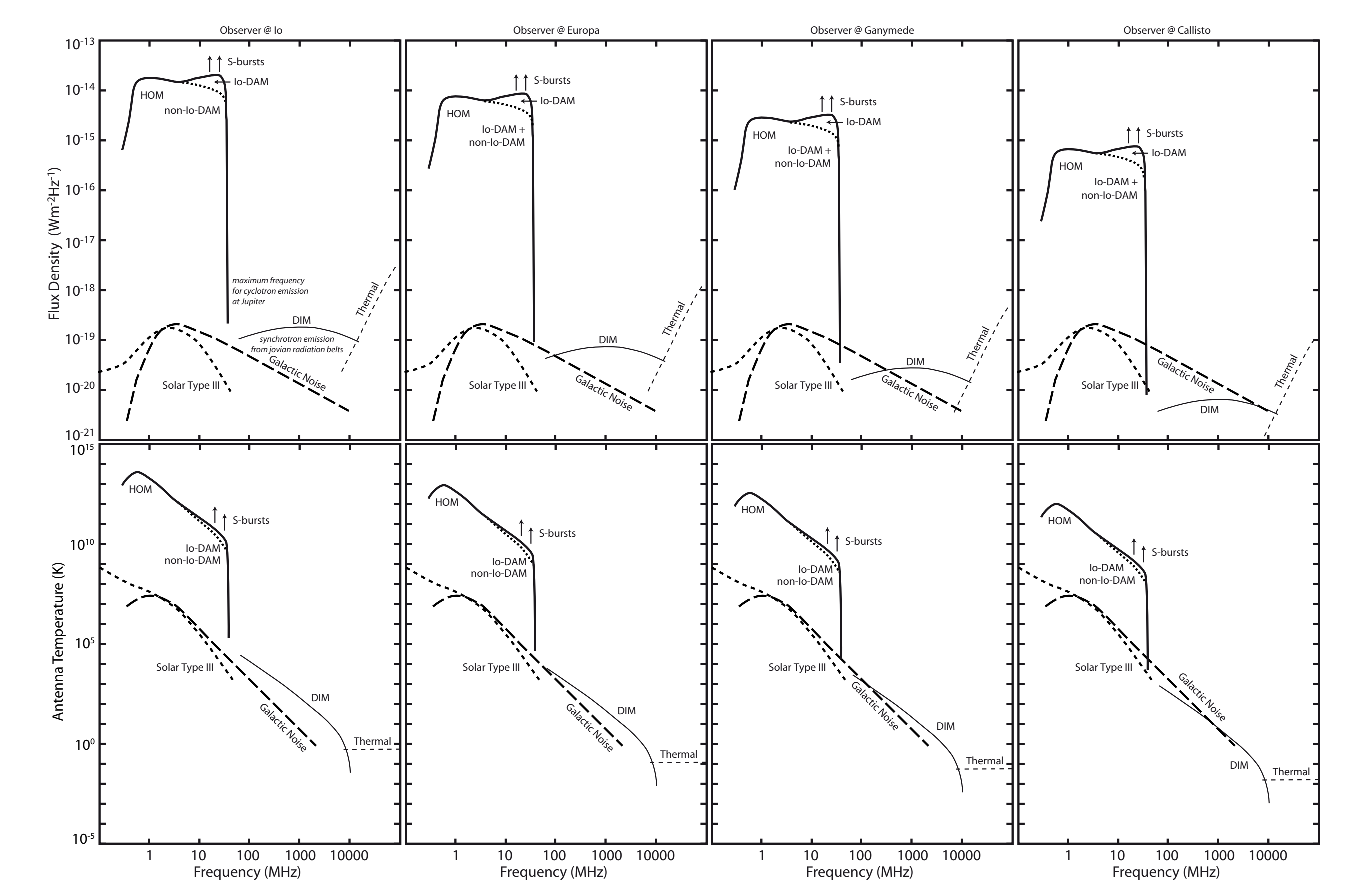
Radar instruments are part of the core payload of the two Europa Jupiter System Mission (EJSM) spacecraft: NASA-led Jupiter Europa Orbiter (JEO) and ESA-led Jupiter Ganymede Orbiter (JGO). At this point of the project, several frequency bands are under study for radar, which ranges between 5 and 50 MHz. Part of this frequency range overlaps with that of the natural jovian radio emissions, which are very intense in the decametric range, below 40 MHz. Radio observations above 40 MHz are free of interferences, whereas below this threshold, careful observation strategies have to be investigated. We present a review of spectral intensity, variability and sources of these radio emissions. As the radio emissions are strongly beamed, it is possible to model the visibility of the radio emissions, as seen from the vicinity of Europa or Ganymede. We have investigated Io-related radio emissions as well as radio emissions related to the auroral oval. We also review the radiation belts synchrotron emission characteristics. We present radio sources visibility products (dynamic spectra and radio source location maps, on still frames or movies), which can be used for operation planning. This study clearly shows that a deep understanding of the natural radio emissions at Jupiter is necessary to prepare the future EJSM radar instrumentation. We show that this radio noise has to be taken into account very early in the observation planning and strategies for both JGO and JEO.We also point out possible synergies with RPW (Radio and Plasma Waves) instrumentations.



Jovian Radio Sources



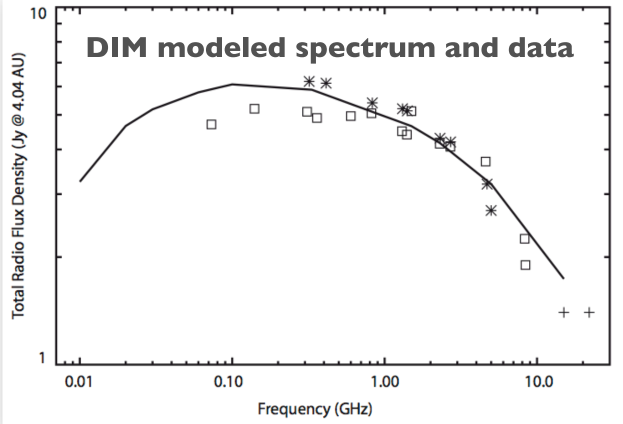
High Latitude DAM radio emission observed by Voyager2



Jovian Radio Environment: Flux Densities and Antenna Temperatures

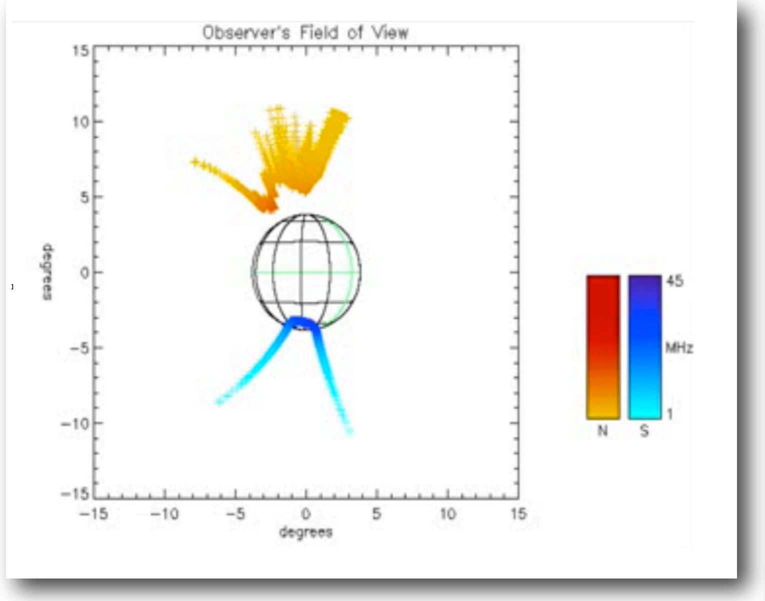
Natural radio emissions in the jovian environment:
- Non-thermal jovian radio emissions emitted on high latitude magnetic field lines (HOM, Io-DAM, non-Io-DAM and S-bursts). These emissions are polarized, sporadic and strongly beamed. They display fine structures negative frequency drifts between *–15* and *–25 MHz/s*
- Synchrotron radiation from the radiation belts (DIM).
- Solar radio emissions (Solar Type III bursts)
- Galactic background emission resulting from the free-free interactions of the electrons in the Galactic magnetic field.

DIM modeled spectrum and data

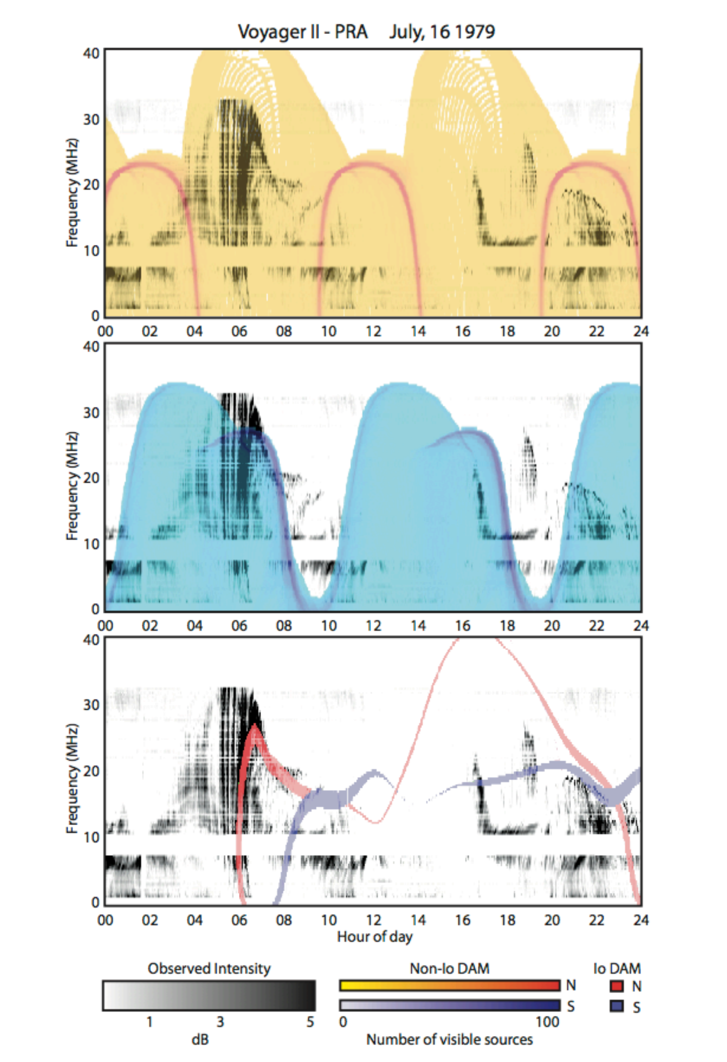


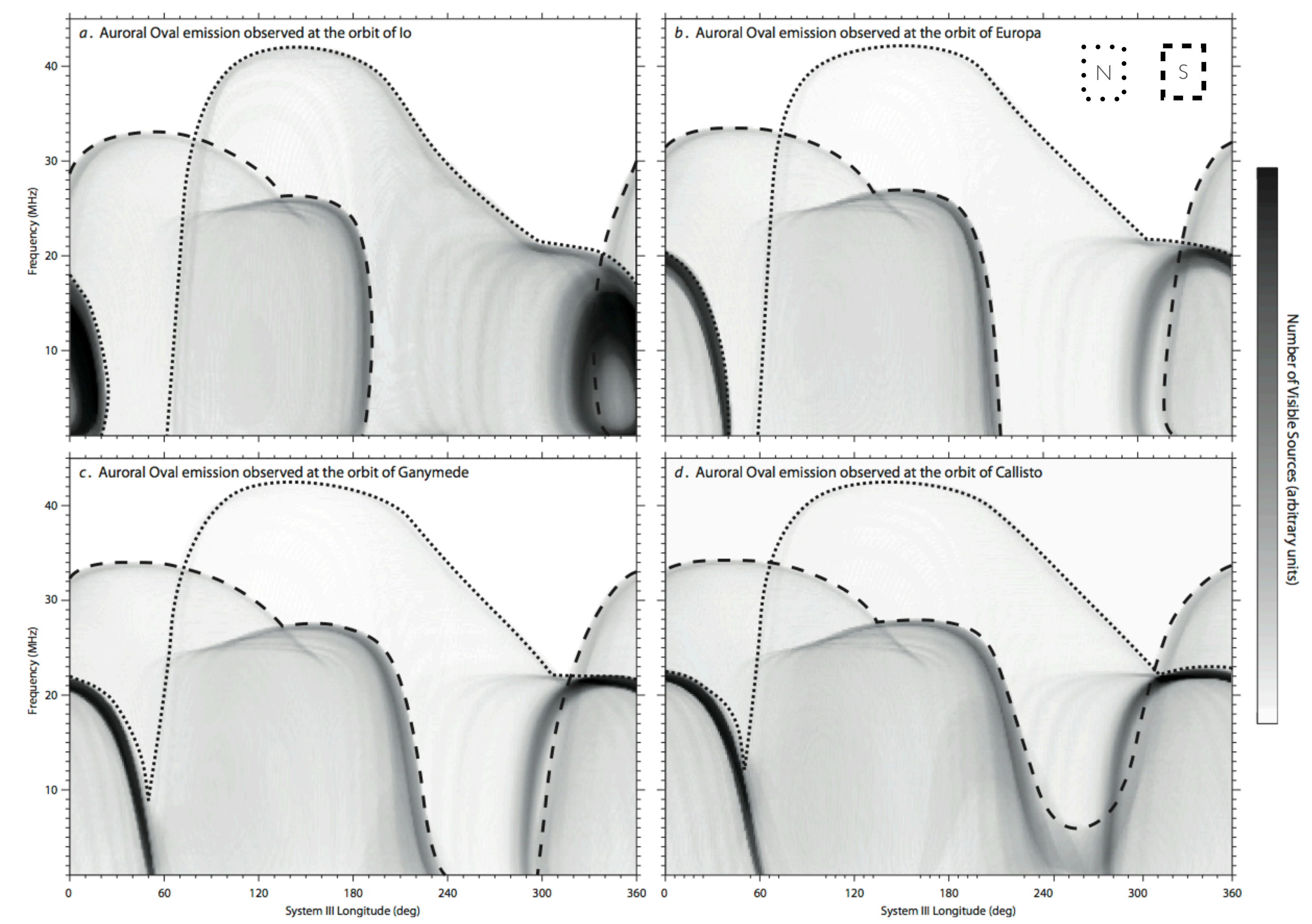
Parameters R (km)	z (km)	α (dB/km)	r_{layer}	Antenna Temperature (short antenna: $G = 3/2$) (K) 20 MHz	30 MHz	40 MHz	50 MHz	Antenna Temperature (adapted antenna: $G = 3.3$) (K) 20 MHz	30 MHz	40 MHz	50 MHz
200	1	5	0.68	2.51×10^8	1.12×10^8	6.29×10^7	4.02×10^7	1.22×10^9	5.41×10^8	3.04×10^8	1.95×10^8
200	1	5	0.21	2.40×10^7	1.07×10^7	6.00×10^6	3.84×10^6	1.16×10^8	5.16×10^7	2.90×10^7	1.86×10^7
200	1	10	0.68	7.95×10^7	3.53×10^7	1.99×10^7	1.27×10^7	3.85×10^8	1.71×10^8	9.62×10^7	6.16×10^7
200	1	10	0.21	7.58×10^6	3.37×10^6	1.90×10^6	1.21×10^6	3.67×10^7	1.63×10^7	9.18×10^6	5.87×10^6
200	2	5	0.68	7.87×10^7	3.50×10^7	1.97×10^7	1.26×10^7	3.81×10^8	1.69×10^8	9.53×10^7	6.10×10^7
200	2	5	0.21	7.51×10^6	3.34×10^6	1.88×10^6	1.20×10^6	3.63×10^7	1.62×10^7	9.09×10^6	5.81×10^6
200	2	10	0.68	7.87×10^6	3.50×10^6	1.97×10^6	1.26×10^6	3.81×10^7	1.69×10^7	9.53×10^6	6.10×10^6
200	2	10	0.21	7.51×10^5	3.34×10^5	1.88×10^5	1.20×10^5	3.63×10^6	1.62×10^6	9.09×10^5	5.81×10^5
200	5	5	0.68	2.42×10^6	1.07×10^6	6.04×10^5	3.87×10^5	1.17×10^7	5.20×10^6	2.92×10^6	1.87×10^6
200	5	5	0.21	2.31×10^5	1.02×10^5	5.76×10^4	3.69×10^4	1.12×10^6	4.96×10^5	2.79×10^5	1.79×10^5
200	5	10	0.68	7.64×10^3	3.40×10^3	1.91×10^3	1.22×10^3	3.70×10^4	1.64×10^4	9.25×10^3	5.92×10^3
200	5	10	0.21	7.29×10^2	3.24×10^2	1.82×10^2	1.17×10^2	3.53×10^3	1.57×10^3	8.82×10^2	5.65×10^2
500	1	5	0.68	4.05×10^7	1.80×10^7	1.01×10^7	6.48×10^6	1.96×10^8	8.71×10^7	4.90×10^7	3.13×10^7
500	1	5	0.21	3.86×10^6	1.72×10^6	9.65×10^5	6.18×10^5	1.87×10^7	8.30×10^6	4.67×10^6	2.99×10^6
500	1	10	0.68	1.28×10^7	5.69×10^6	3.20×10^6	2.05×10^6	6.19×10^7	2.75×10^7	1.55×10^7	9.91×10^6
500	1	10	0.21	1.22×10^6	5.43×10^5	3.05×10^5	1.95×10^5	5.91×10^6	2.63×10^6	1.48×10^6	9.45×10^5
500	2	5	0.68	1.27×10^7	5.67×10^6	3.19×10^6	2.04×10^6	6.17×10^7	2.74×10^7	1.54×10^7	9.87×10^6
500	2	5	0.21	1.22×10^6	5.40×10^5	3.04×10^5	1.95×10^5	5.88×10^6	2.62×10^6	1.47×10^6	9.42×10^5
500	2	10	0.68	1.27×10^6	5.67×10^5	3.19×10^5	2.04×10^5	6.17×10^6	2.74×10^6	1.54×10^6	9.87×10^5
500	2	10	0.21	1.22×10^5	5.40×10^4	3.04×10^4	1.95×10^4	5.88×10^5	2.62×10^5	1.47×10^5	9.42×10^4
500	5	5	0.68	3.98×10^5	1.77×10^5	9.96×10^4	6.37×10^4	1.93×10^6	8.57×10^5	4.82×10^5	3.08×10^5
500	5	5	0.21	3.80×10^4	1.69×10^4	9.50×10^3	6.08×10^3	1.84×10^5	8.17×10^4	4.60×10^4	2.94×10^4
500	5	10	0.68	1.26×10^3	5.60×10^2	3.15×10^2	2.02×10^2	6.10×10^3	2.71×10^3	1.52×10^3	9.76×10^2
500	5	10	0.21	1.20×10^2	5.34×10^1	3.00×10^1	1.92×10^1	5.81×10^2	2.58×10^2	1.45×10^2	9.30×10^1

Simulated radar echo signal strength at Ganymede



Radio emission visibility modeling:
The ExPRES tool (Hess et al., 2008) allows us to predict the CMI (Cyclotron Maser Instability) induced radio emissions visibility for various observation geometries (source location and observer location), and various emission pattern parameters (emission cone aperture, thickness, with possible variation with frequency).
We use this tool to predict operational clean periods for radar observations in the DAM range.
An exemple is given with the reanalysis of Voyager II data, where we identify auroral oval DAM emission, as well as Io-controlled DAM.





Simulated auroral radio emission visibility at the various Galilean satellites, using the EXPRES (*EXoplanetary and Planetary Radio Emissions Simulator*) tool. Study of Voyager and future JUNO observations will refine input parameters.

EJSM/JGO Radar Characteristics

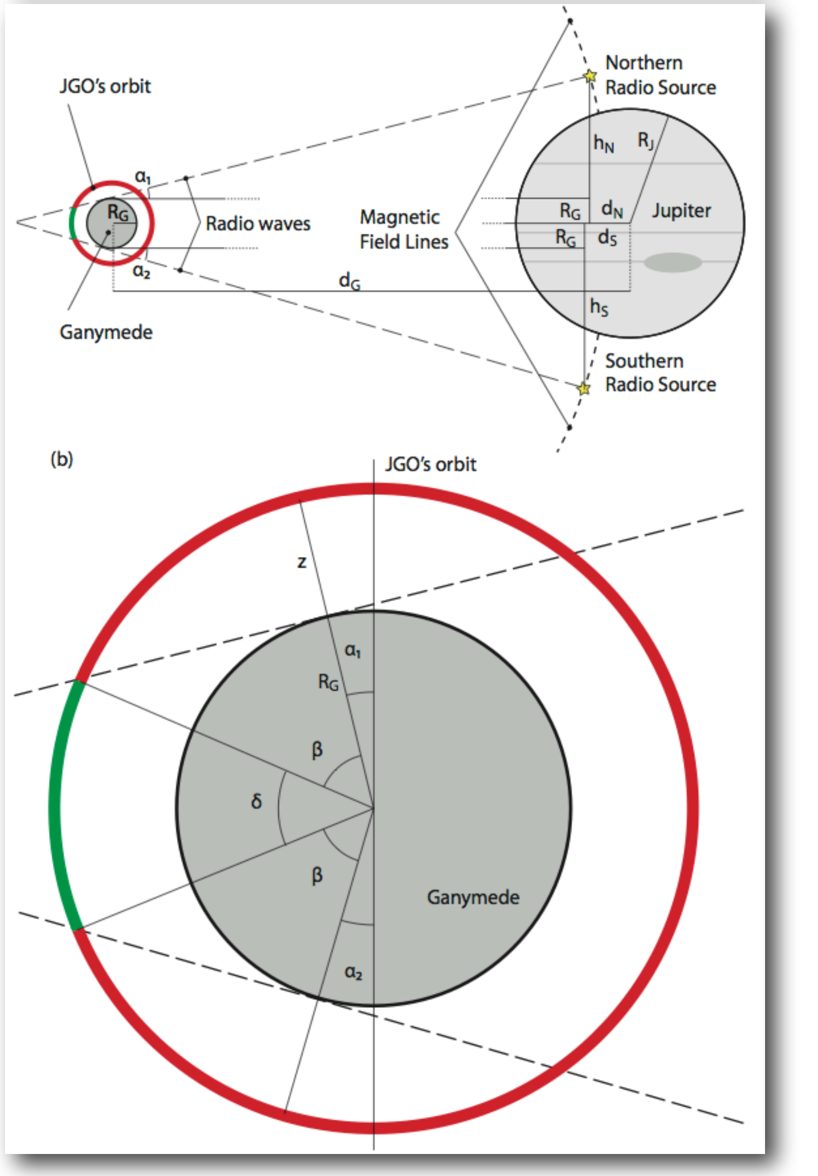
Parameter	Value(s)
$\mathcal{P}_{TX}$	$20\,W$
ν	20 to 50 MHz
L_D	5 to 10 m
λ	c/ν
G	1.5 ($L_D \ll \lambda$) up to ~3.3 ($L_D = 1.26\lambda$)
τ_p	$150\,\mu s$
δ_ν	$10\,MHz$
$\lvert r_{surface}\rvert$	~ 0.27
$\lvert r_{layer}\rvert$	$\sim$ 0.21 to 0.68
α	$\sim$ 6 to 16 dB/km
L_{sys}	0.5
R	200 to 500 km
z	up to 5 km

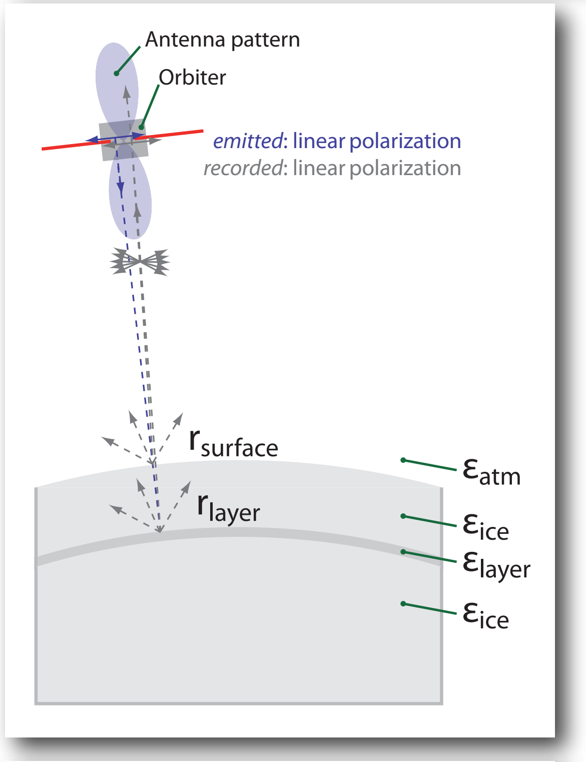
Radar Equation

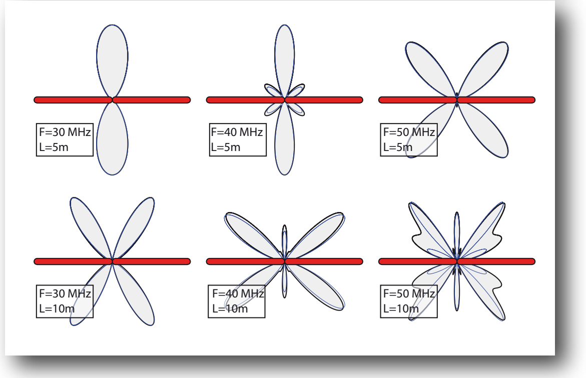
$$\mathcal{P}_{RX} = \frac{\mathcal{P}_{TX}\lambda^2 G^2 \tau_p b (1 - |r_{ice}|^2) r_{layer}^2 10^{-\alpha z/10} L_{sys}}{(4\pi)^2 (2(R+z))^2}$$

Radio Measurement Essentials

Quantity		Unit
Operating frequency	ν	Hz
Operating wavelength	λ	m
Speed of light	c	m/s
Antenna effective area	A_{eff}	m^2
Antenna main lobe solid angle	Ω_A	sr
Antenna gain	G	–
Spectral Power Density	$P(\nu)$	W/Hz
Spectral Flux Density	$S(\nu)$	$W/m^2/Hz$
Brightness density	$B(\nu)$	$W/m^2/Hz/sr$
Brightness temperature	T_B	K
Antenna Temperature	T_A	K
Source solid angle	ω_s	sr







Radar science constraints:
- The natural radio emissions are much stronger than the radar echoes, so they must be taken into account in the operation planning.
- From ExPRES simulations, we show the clean periods occur every jovian rotations above 22 MHz. Below this frequency, icy satellite shadowing is necessary: we computed that 30 to 40% of the final orbital phase would be in a clean radio environment.
NB: Surface roughness (causing signal clutter) has not been studied here, but this effect increases with frequency, hence favoring lower frequencies.
- Antenna pattern nulling can also be used to reduce the noise coming from Jupiter. However, the natural radio waves reflected by the surface will also interfere with radar echoes.

Science Synergies and Support:
- RPWS instrumentation could be used to support radar observations: natural fine structures are drifting much slower than the radar chirp signals, the radio observations can be used as a temporal context information. Similarly, the natural radio emissions are wide band emissions, hence a frequency context information could also be provided.
- Polarization and wave vector direction measurements capabilities could also be used to discriminate radar from natural radio waves.
- The radar pulses are very intense compared to the natural radio emissions, so the possible impact on the radio instruments preamplifiers must be studied!

Main References:
- ***Jovian Radio Emission Review*, Zarka, J. Geophys. Res. (1998)**
- ***Radar signal and propagation through ice*, W. Kofman, et al. Space Sci. Rev. (2010)**
- ***EXPRES code*, S. Hess, et al. Geophys. Res. Lett. (2008)**
- ***Jovian Radiation Belt radio modeling*, D. Santos-Costa, & S. Bolton, Planet. Space Sci. (2008)**