Radio & Plasma Wave Instrument (RPWI) for the Jupiter Ganymede Orbiter (EJSM/JGO)

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18 Institutes from 10 Countries

Both instrument builders and theoretical groups

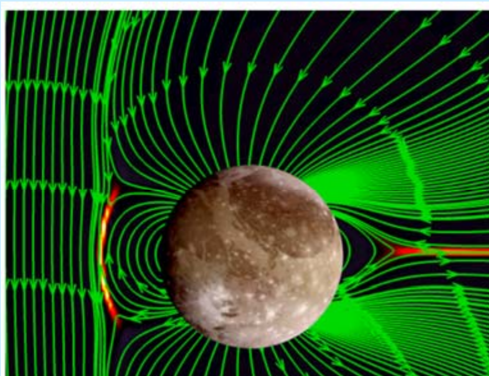
Heritage of radio, cold plasma, and plasma wave instrumentations onboard:

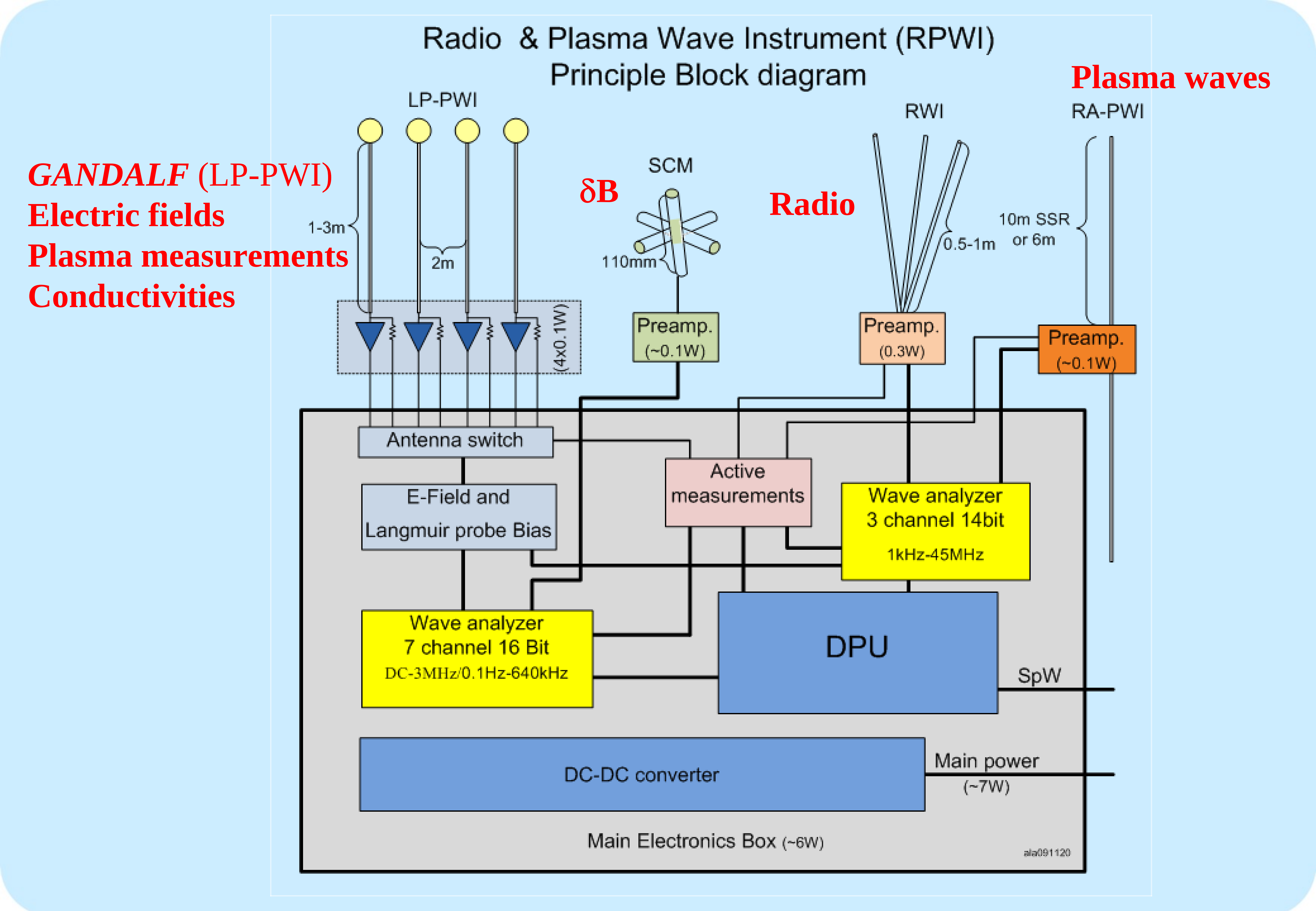
Cassini, Cluster, Rosetta, Galileo, Voyagers, BepiColombo, Swarm, Themis, Astrid II, Freja, Viking, STEREO, Juno, RBSP, Proba-2…

EJSM Instrument WS, ESTEC, Jan. 18-20, 2010

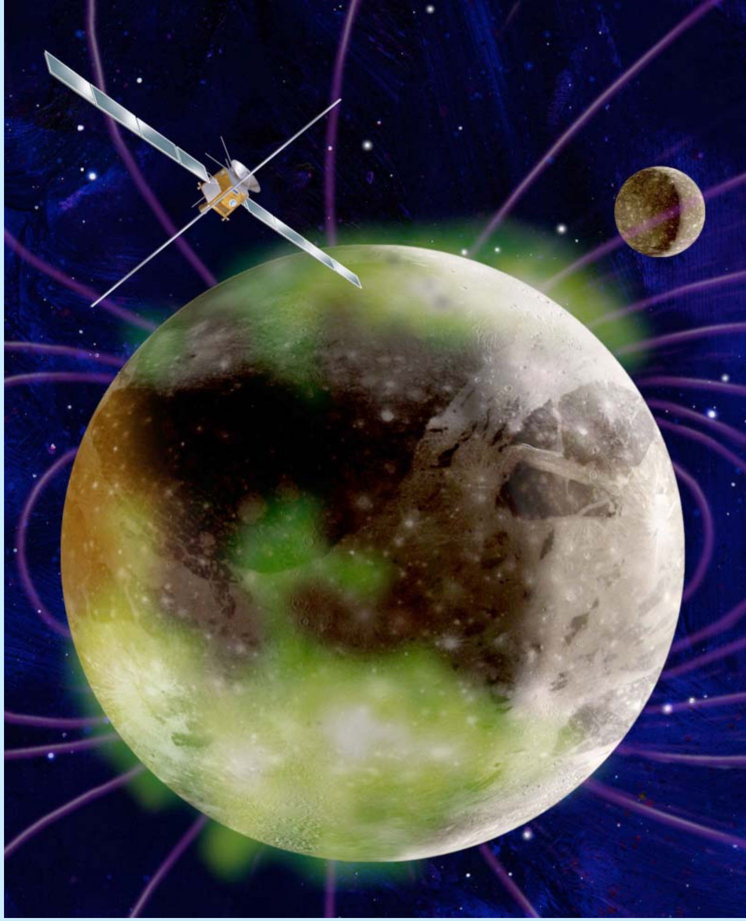
RPWI Science (some)

- Detailed investigation of moon-magnetosphere interactions (Ganymede & Callisto)
  - Plasma characteristics (n_e, n_i, T_e, v_{di}, …) of ionized exospheres & Jupiter's magnetosphere
  - Electric conductivities (σ) of ionized exospheres
  - **E**- & **B**-fields of ULF & plasma waves, and their role in energy transfer
  - Magnetospheric convection patterns (**E×B**, v_{di}), co-rotation break-down
  - Ionospheric current systems
  - Study time variability (dynamics) due to external forcing, plasma escape
- Monitor remotely generated radio waves
  - Source locations, auroral processes
- Monitor μ-sized dust
  - Dust-plasma interaction?
- Coupling processes between Jupiter's magnetosphere, ionosphere and thermosphere




Radio & Plasma Wave Instrument (RPWI)
Principle Block diagram
Plasma waves
GANDALF (LP-PWI)
Electric fields
Plasma measurements
Conductivities
LP-PWI
1-3m
2m
(4x0.1W)
δB
SCM
110mm
Preamp.
(~0.1W)
Radio
RWI
0.5-1m
Preamp.
(0.3W)
RA-PWI
10m SSR
or 6m
Preamp.
(~0.1W)
Antenna switch
E-Field and
Langmuir probe Bias
Active
measurements
Wave analyzer
3 channel 14bit
1kHz-45MHz
Wave analyzer
7 channel 16 Bit
DC-3MHz/0.1Hz-640kHz
DPU
SpW
DC-DC converter
Main power
(~7W)
Main Electronics Box (~6W)
ala091120

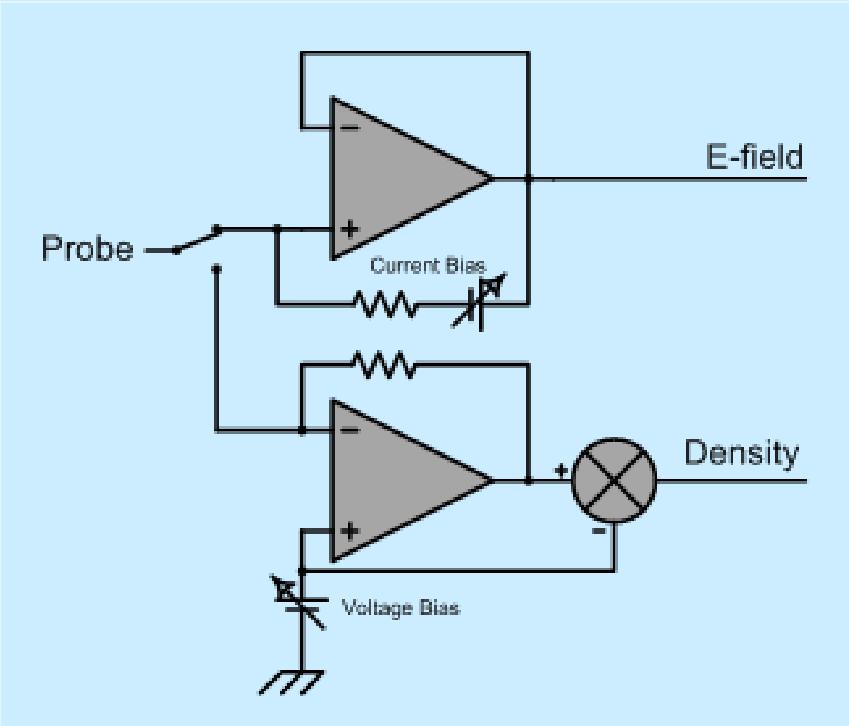
RPWI Radiation Protection



- Spot shielding
  – All exterior electronics (pre-amps)
- Box & Spot shielding
  – Main RPWI electronics box
- Use of Rad-hard components
- Radiation test facilities in Uppsala

– Co60	1-10 Rad/min	Free of charge
– Electrons, 7.5-15 MeV	High dose rate	500 €/h
– Protons, 20-180 MeV	150 Rad/min	500 €/h
– Protons, < 6 MeV	Low dose rate	100 €/h
– Heavy ions		

Example: LP-PWI Preamplifier



Specifications:

- Switchable E-field / Density
- 100mW power consumption
- 500kRad Radiation hardend (w/o shielding)
- Positive feed back current generator
- E-field:

  DC-300Hz +-100V input range

  DC to 3MHz small signal bandwidth

  Better than 10^9 input resistance

  1nA – 1µA Current Bias range

  16 nV/sqr(Hz) noise

- Density:

  DC to 10kHz bandwidth

  10pA to 1µA input current range

  +-100V Voltage Bias range

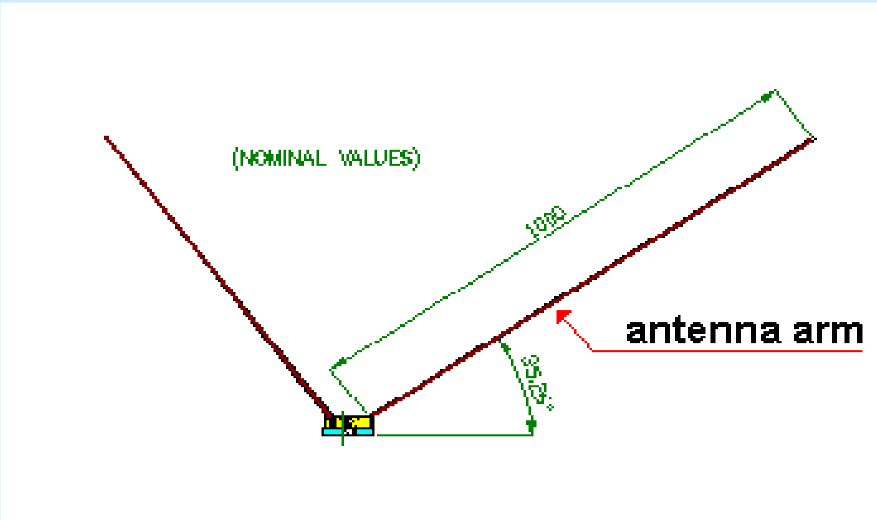
Mission heritage:.

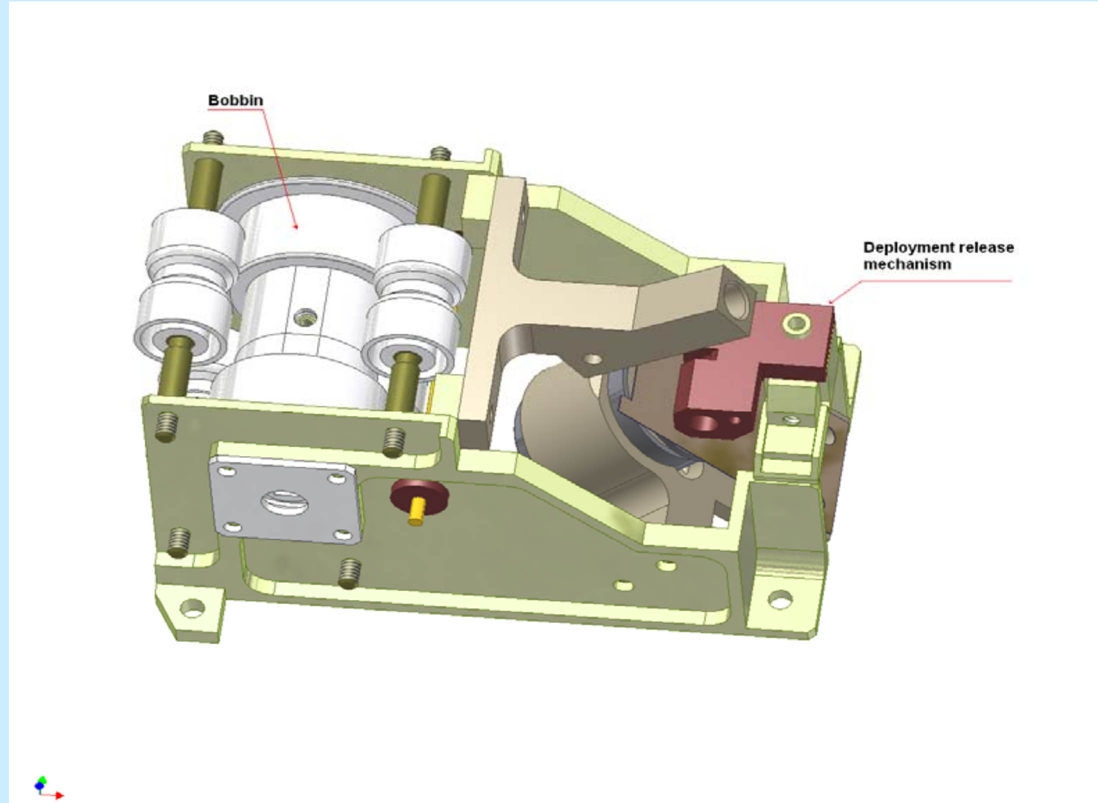
Viking: E-field/Density
Rosetta: E-field/Density
Freja: E-field/Density
Cluster: E-field/Density
Astrid: E-field/Density
Swarm: Density
Cassini: Density

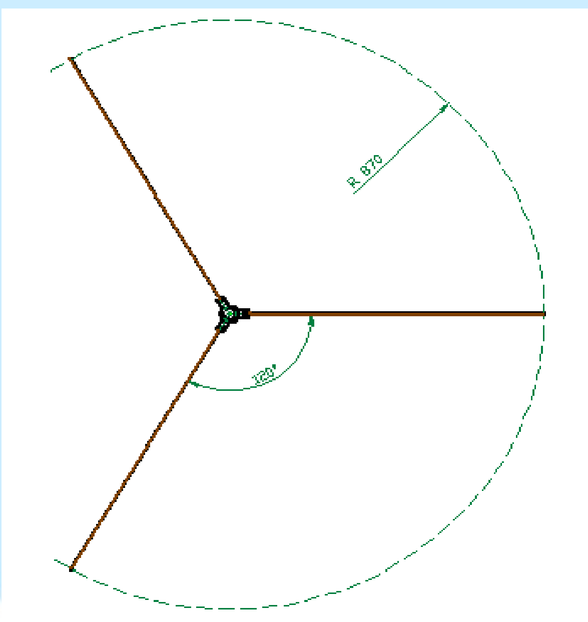
New development: New low noise Rad hard operational amplifiers

Develop a MEMS chip including nano-switches and amplifiers

RWI, Space Research Centre Design







Mechanical	
Dimensions (when stowed):	41 x 57 [mm] (H x Φ)
Dimensions (when deployed):	575 x 870 [mm] (H x Φ)
Mass:	~0.20 [kg]
Monopole length:	1.00 [m]
Tubular boom material:	Berilium Bronze 0.05x20 [mm]

RWI, Berkeley Design

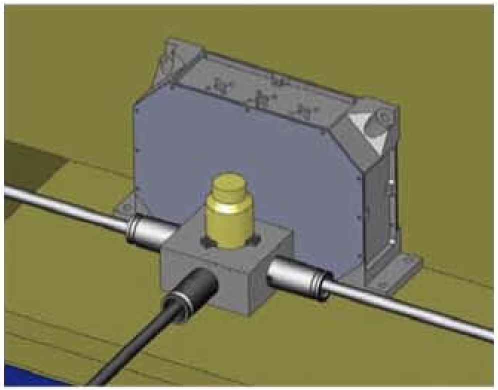


Figure E.8 Antenna deploy unit and preamp and a possible mounting configuration. The deployed configuration is designed to put two antennas near the spacecraft body, and the third antenna out into the plasma. RRR measurements will use a pair of antennas as a dipole.

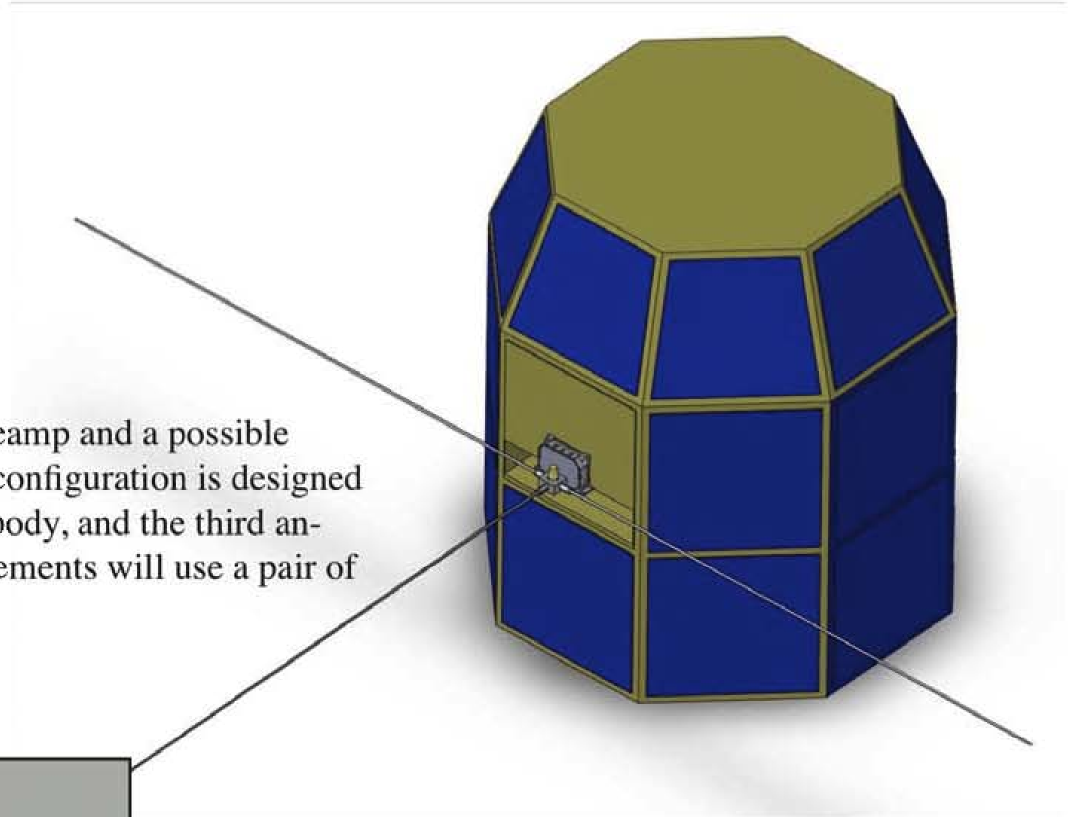


Table E.3 DEWD Resources

Subsystem	Mass (kg)	Power (W)	Form
TDS/DPU	3.6	3.5	7.5"x8.5"x4.5"
RRR	1	1.5	7.5"x8.5"x1"
Preamp	0.4	0.4	5"x3.5"x1.5"
Antennas/ Deploy	0.7	-	2"x2"x2"
Total	5.7	5.4	

3 x 1.5m monopoles
< 1.1 kg (w/ preamp)

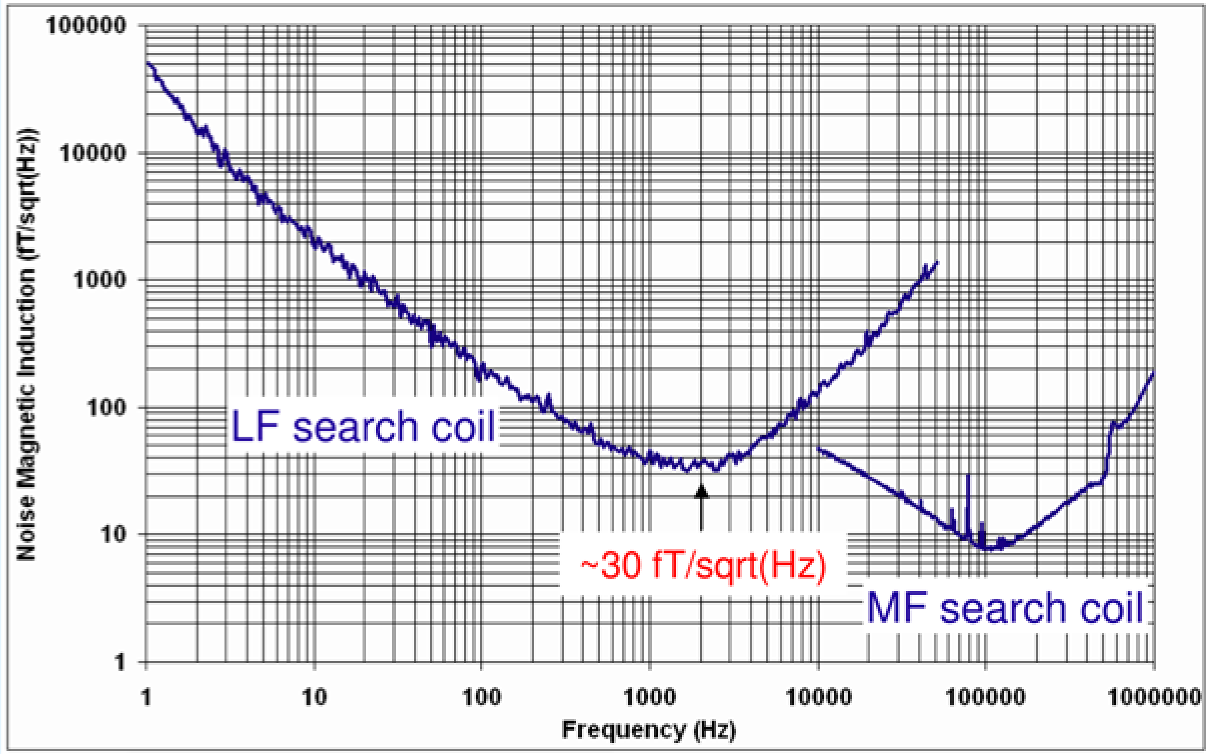
Stacer: 20 g/m up to 2.5 m
0.2-0.4 cm diameter

Dust Electric Waveform Detector
Very high TRL

'whip stacer' – Polar, THEMIS, RBSP sensors

Dual-Band Search Coil: Bepi-Colombo

Sensitivity curves:



Ketron Peek tube

+ copper sheet for ES shielding

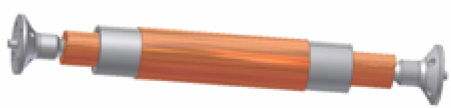
+potting inside the tube

Length=112mm,

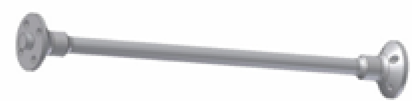
Diameter=16mm

LF & MF windings

+ Ferrite mutual reducer



Machined magnetic core



Basic structure of a Dual-Band Search Coil sensor

SCM: current status *(design with better sensitivity)*

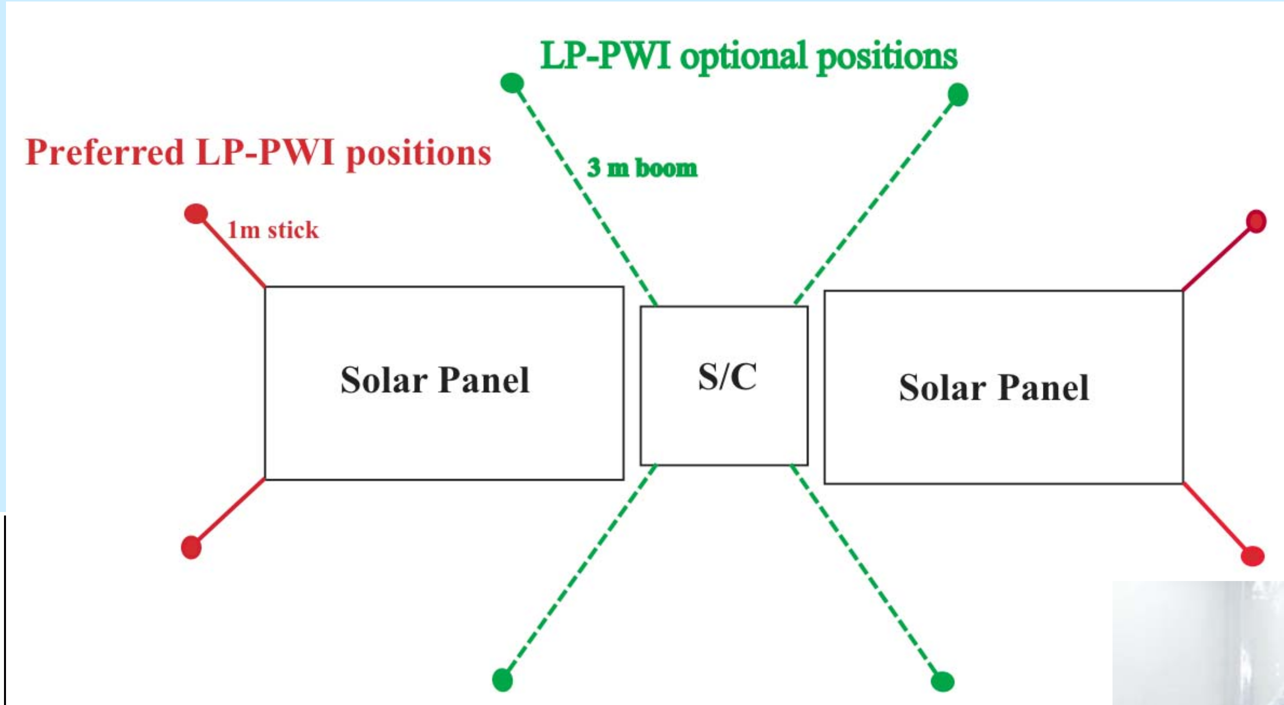
Optimized design using 20 cm Dual-Band Search Coil sensors

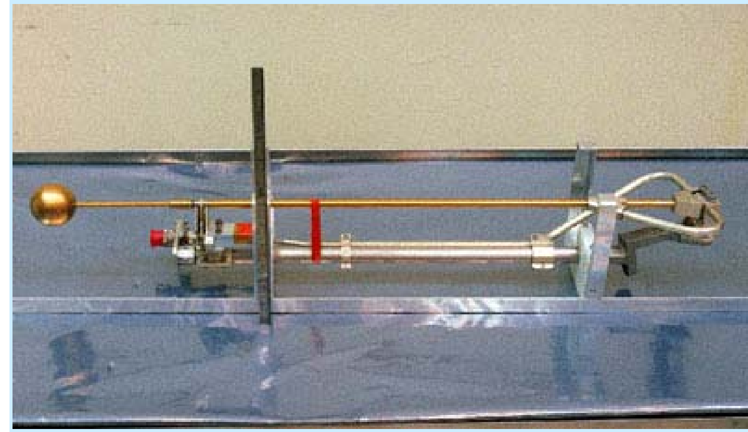
Number of DB-SC sensors	**3**
Bandwidth	**0.1 Hz to 4 kHz (LF1 band)** **1 kHz to 20 kHz (LF2 band)**
Sensitivity	**8 pT/√Hz @ 1 Hz** **0.6 pT/√Hz @ 10 Hz** **0.06 pT/√Hz @ 100 Hz** **10 fT/√Hz @ 1 kHz** **4.5 fT/√Hz @ 10 kHz**
Mass (DB-SC[a] + PA[b])	**750 g (+ cables ~120 g/m)[c]**
Power	**200 mW [d]**
Length	**20 cm**
Location	**boom (> 2 m)**
Electrical interface	**6 analog signals to LFR**

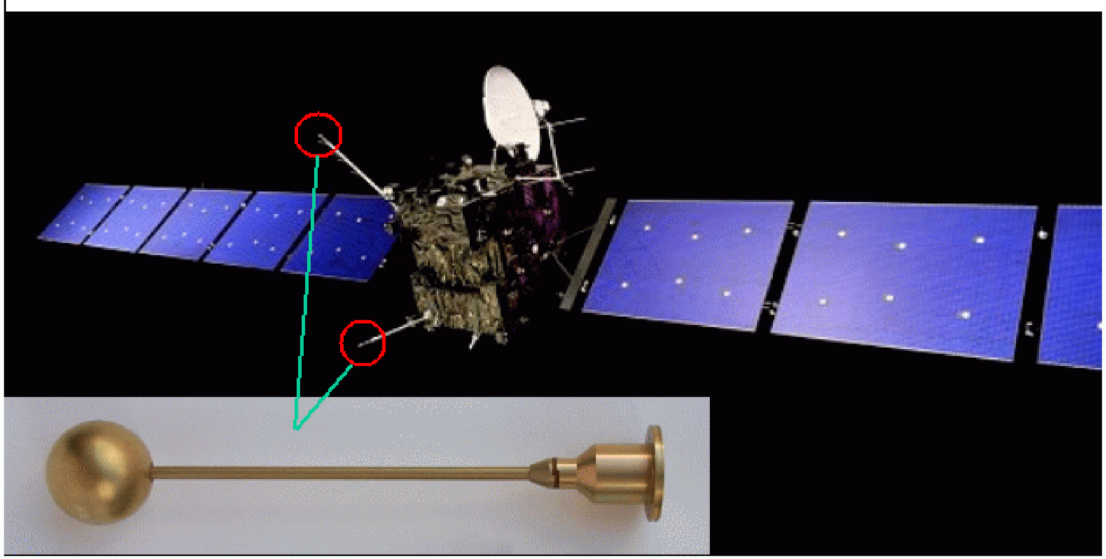
(a) 30 g less only if mono-band
(b) 1 mm Al thickness (box: ~50 g)
(c) 36 g/m less if mono-band
(d) 100 mW if mono-band

Heritage: Ulysses (ESA/NASA), Galileo & Cassini (NASA), Cluster (ESA), THEMIS (NASA). Current fabrication: MMS (NASA), Bepi Colombo (ESA/JAXA)

LP-PWI (GANDALF) sticks/booms

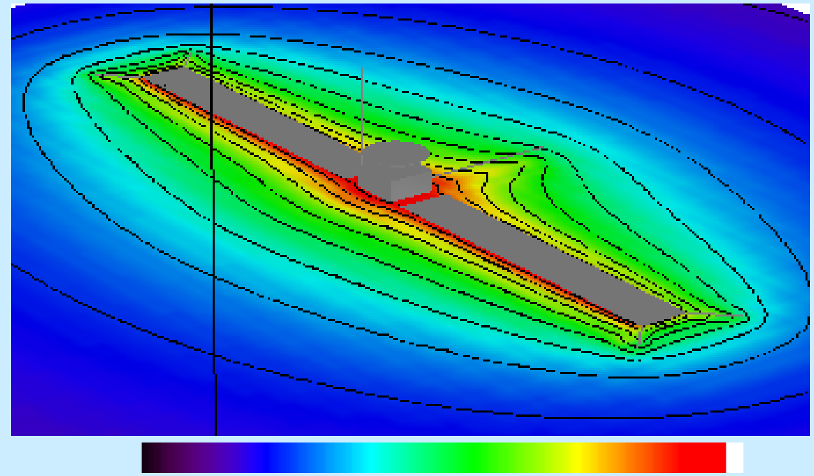






S/C Modelling support for RPWI Sensor accommodation

- Potential patterns
  - Few mV/m after correction
- Wake patterns
- S/C photo-electron distributions



Wake pattern in Solar wind

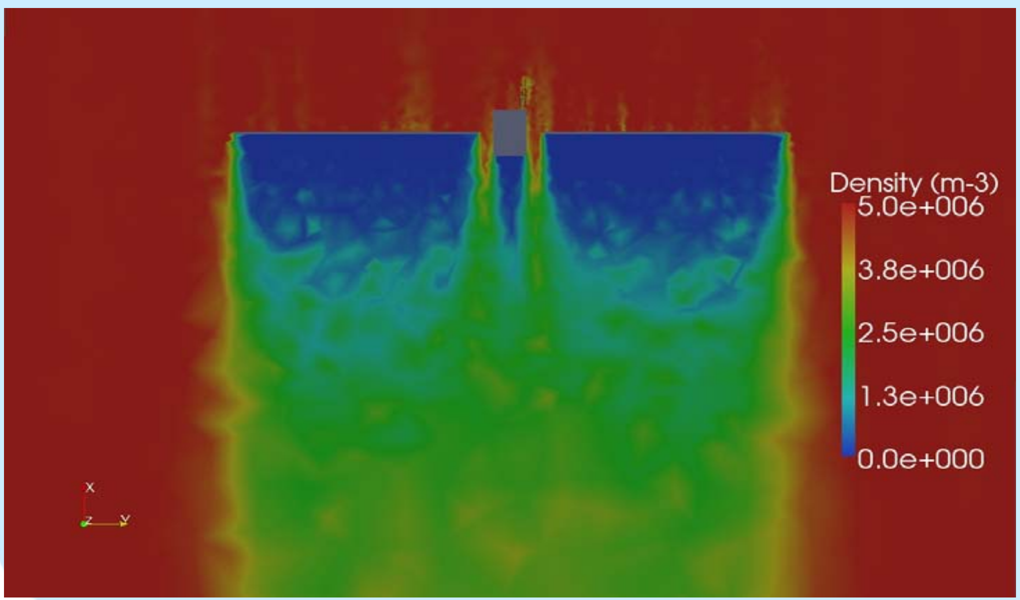
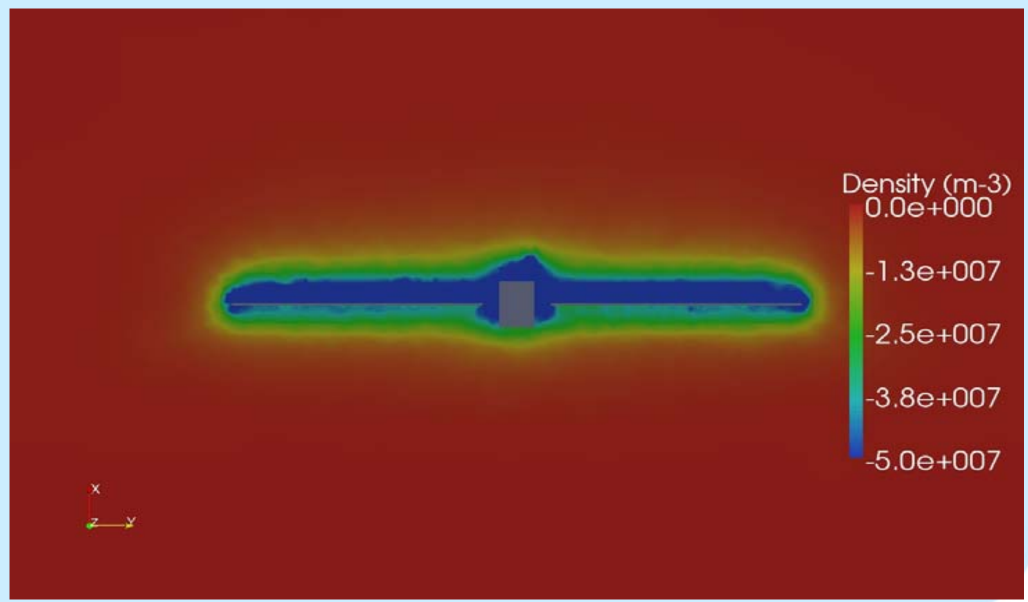
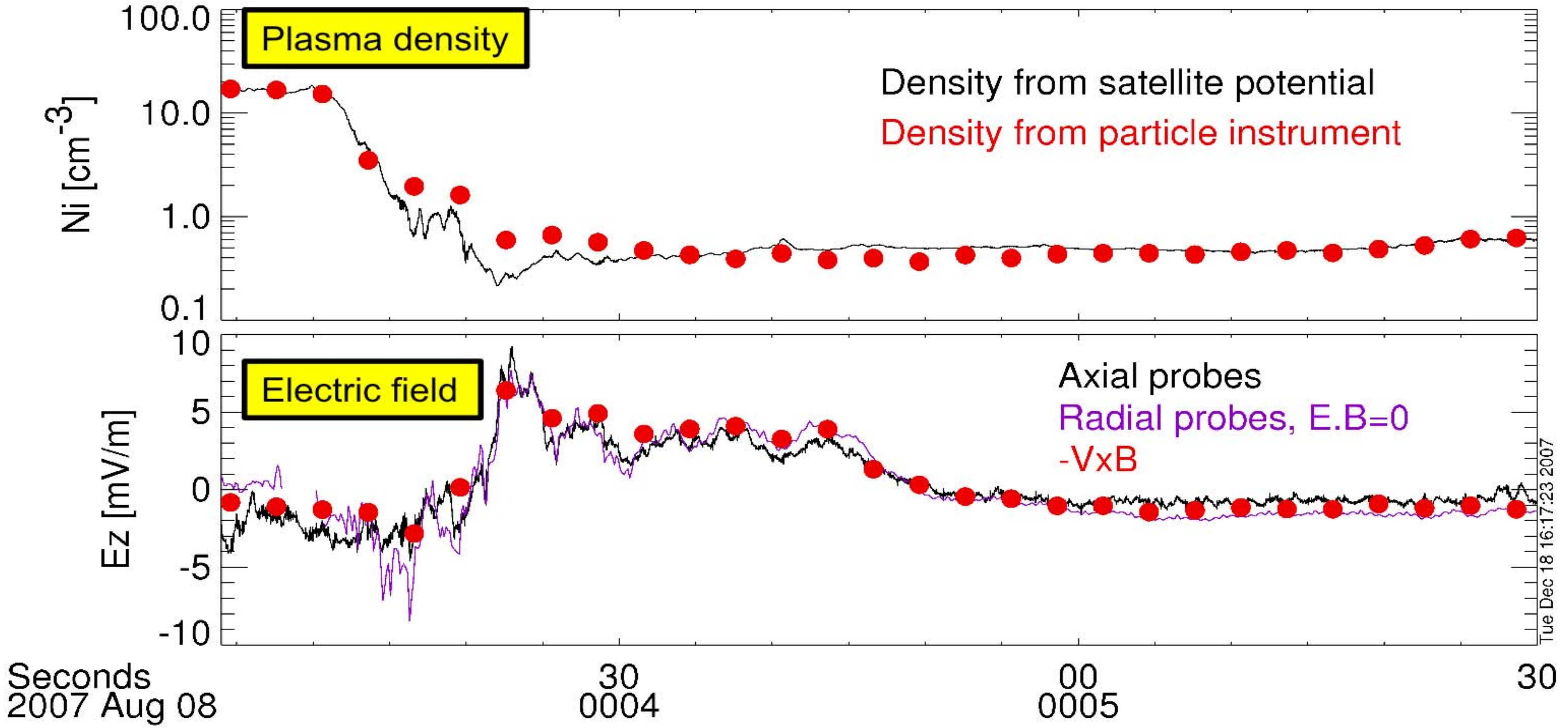


Photo-electron density in solar wind

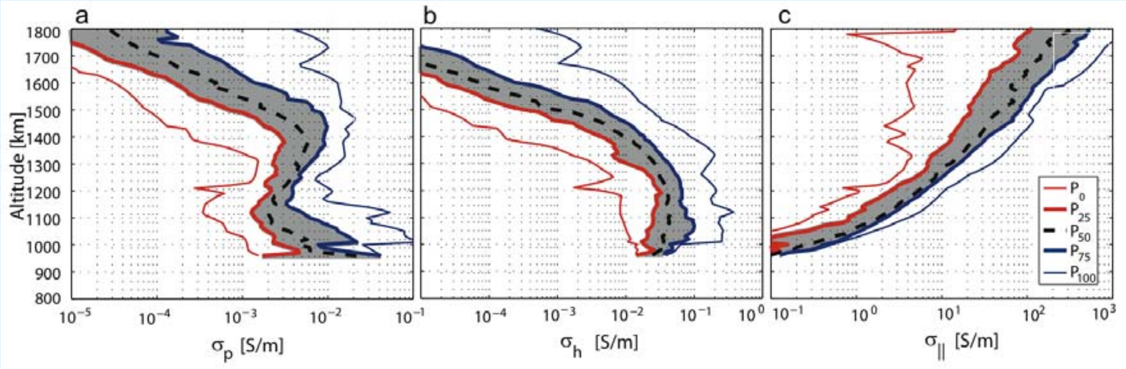


THEMIS. Symmetric booms, length 3 m.

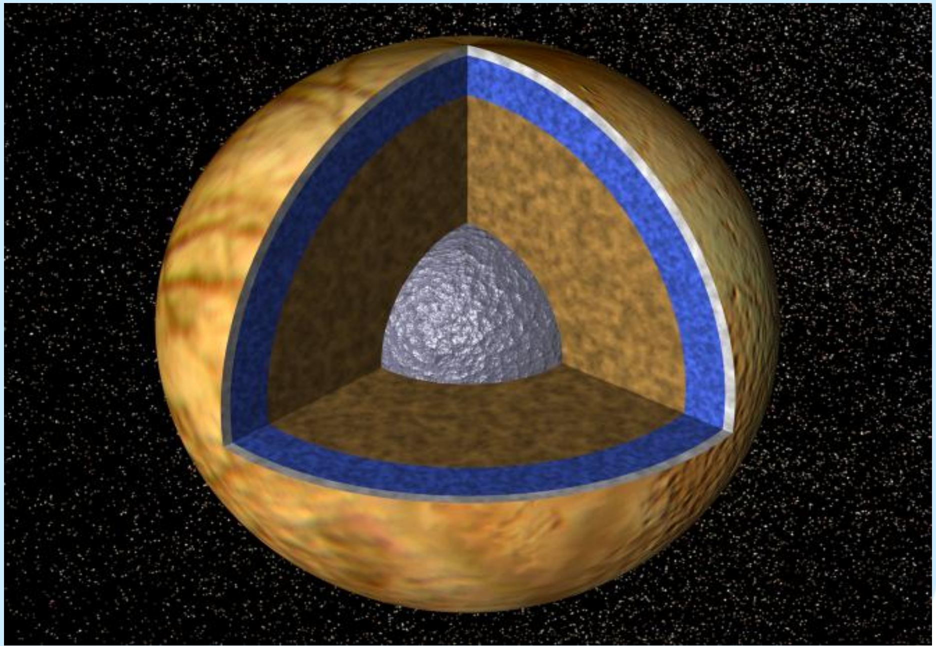


Ganymede Conductivities & Currents

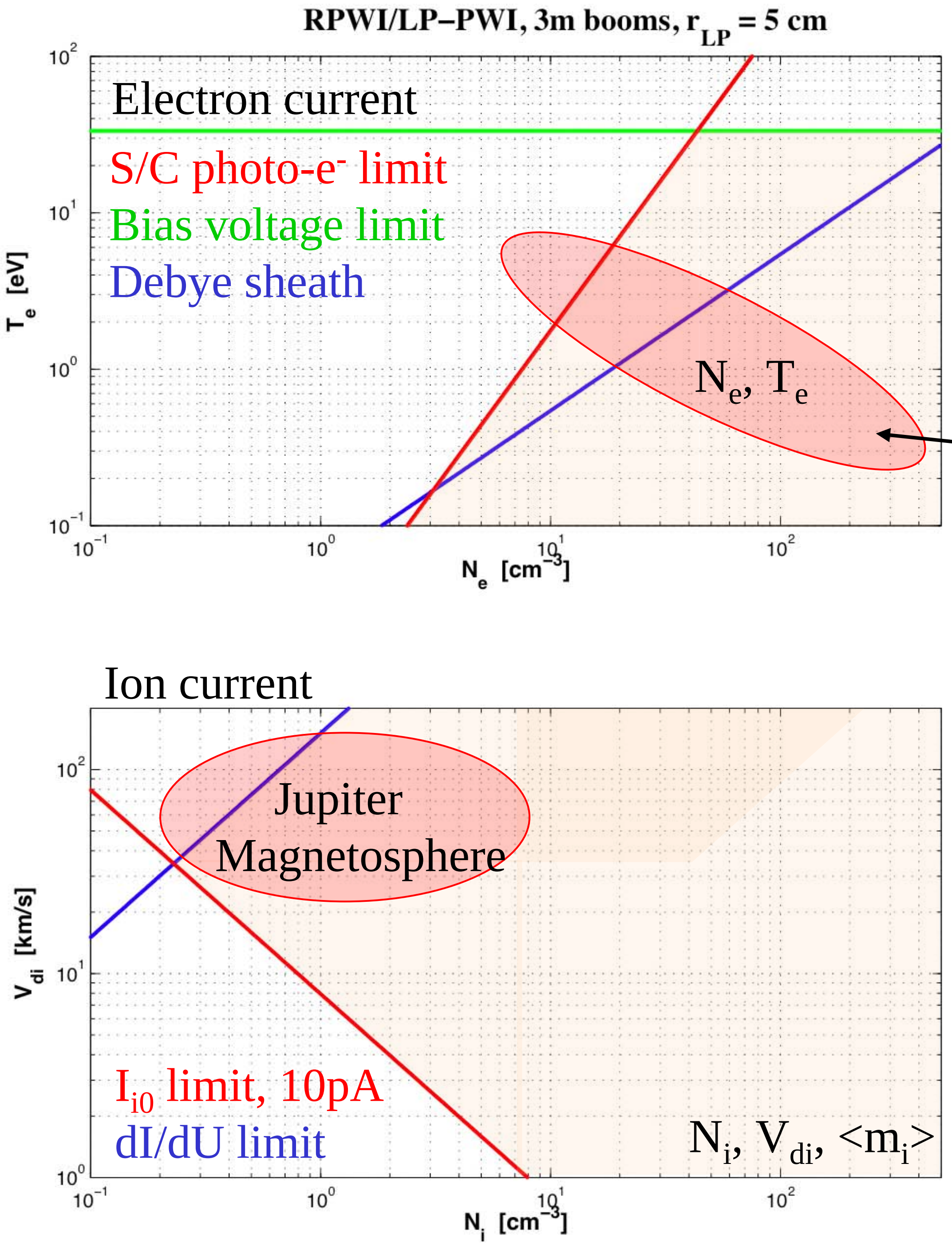
Rosenqvist et al., 2009 for Titan



- $n_{n,surf} \sim 1\text{-}3 \cdot 10^8$ cm^{-3}
- $n_e \sim 400\text{-}4000$ cm^{-3}
- O_2^+ - O_2 collisions dominate
  - $\nu_{in} = 2.59 \cdot 10^{-11} n(O_2) \mathrm{sqrt}(T)(1-0.073\log(T))^2 \sim 0.1 - 0.5$ s^{-1}
- $\nu_{in} \sim \Omega_i = 0.4$ s^{-1}, $\nu_{en} << \Omega_e$
  - $\sigma_H \approx - \sigma_P \sim en_e/(2B) \sim 10^{-4}$ mho
- Measurable currents
  - $j \geq \sigma E \sim 0.1$ μA/m^2
  - $I \geq 100$ kA through exo-ionosphere



LP-PWI Operation Domain

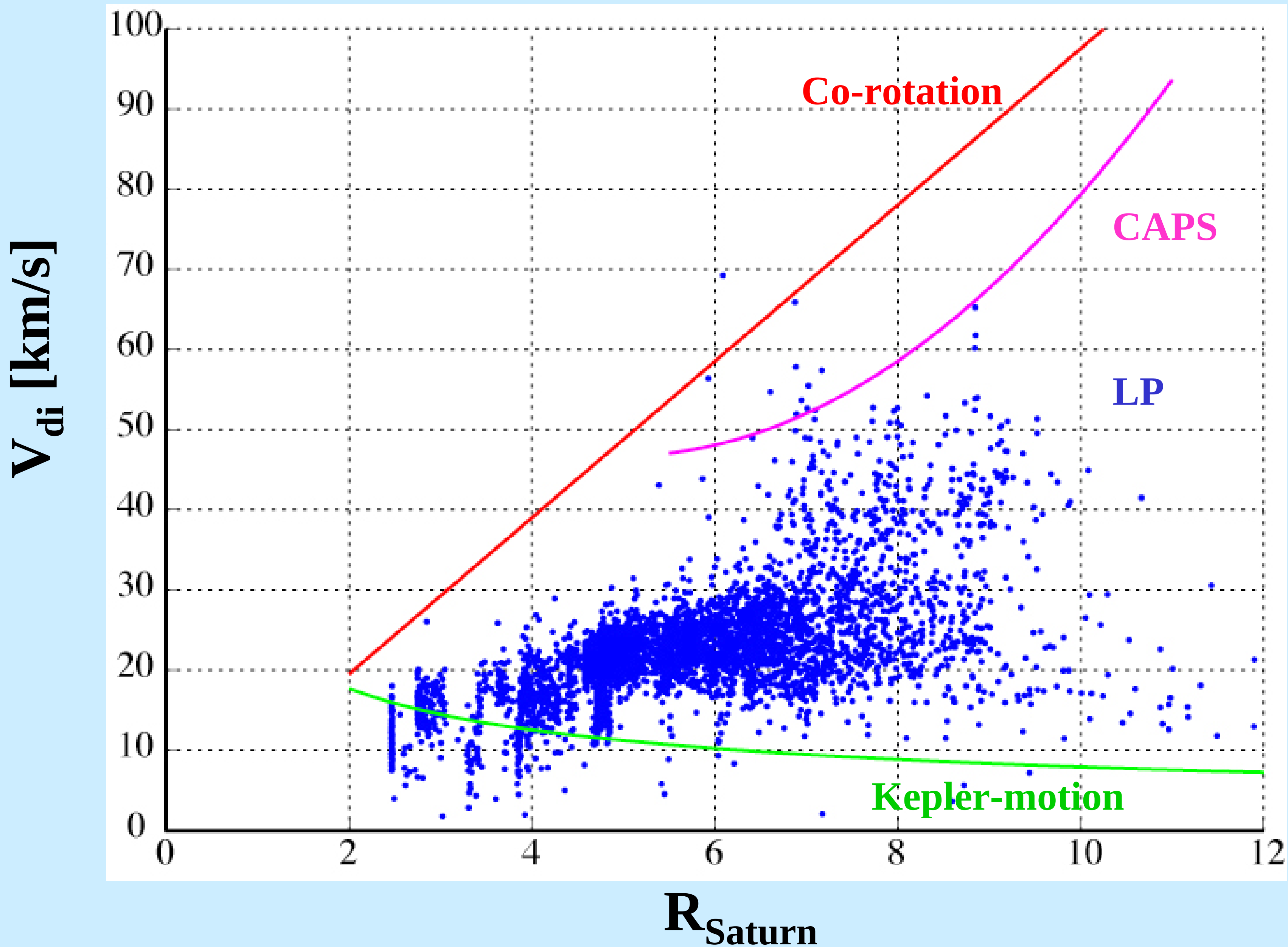


U_{float} everywhere $\Rightarrow$ $N_{e,proxy}$ possible

Assumed:
±100 V sweeps
10 pA noise level

Situation will improve if
- LP-PWI sensors on tips of solar panels
- 1 pA noise level reached

Saturn Equatorial Ion Drift Speed (preliminary)



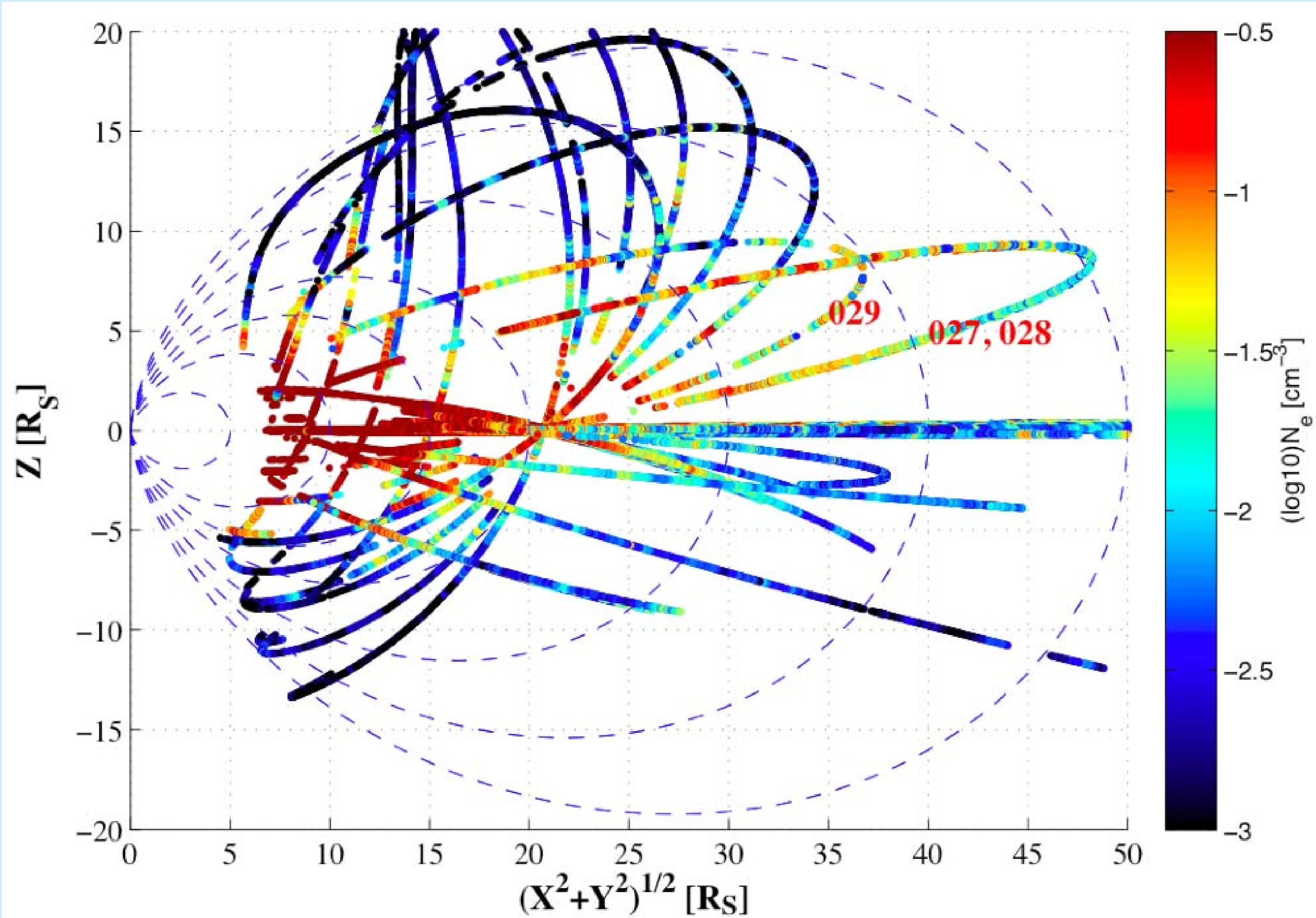
Whole Saturn magnetosphere n_e mapping

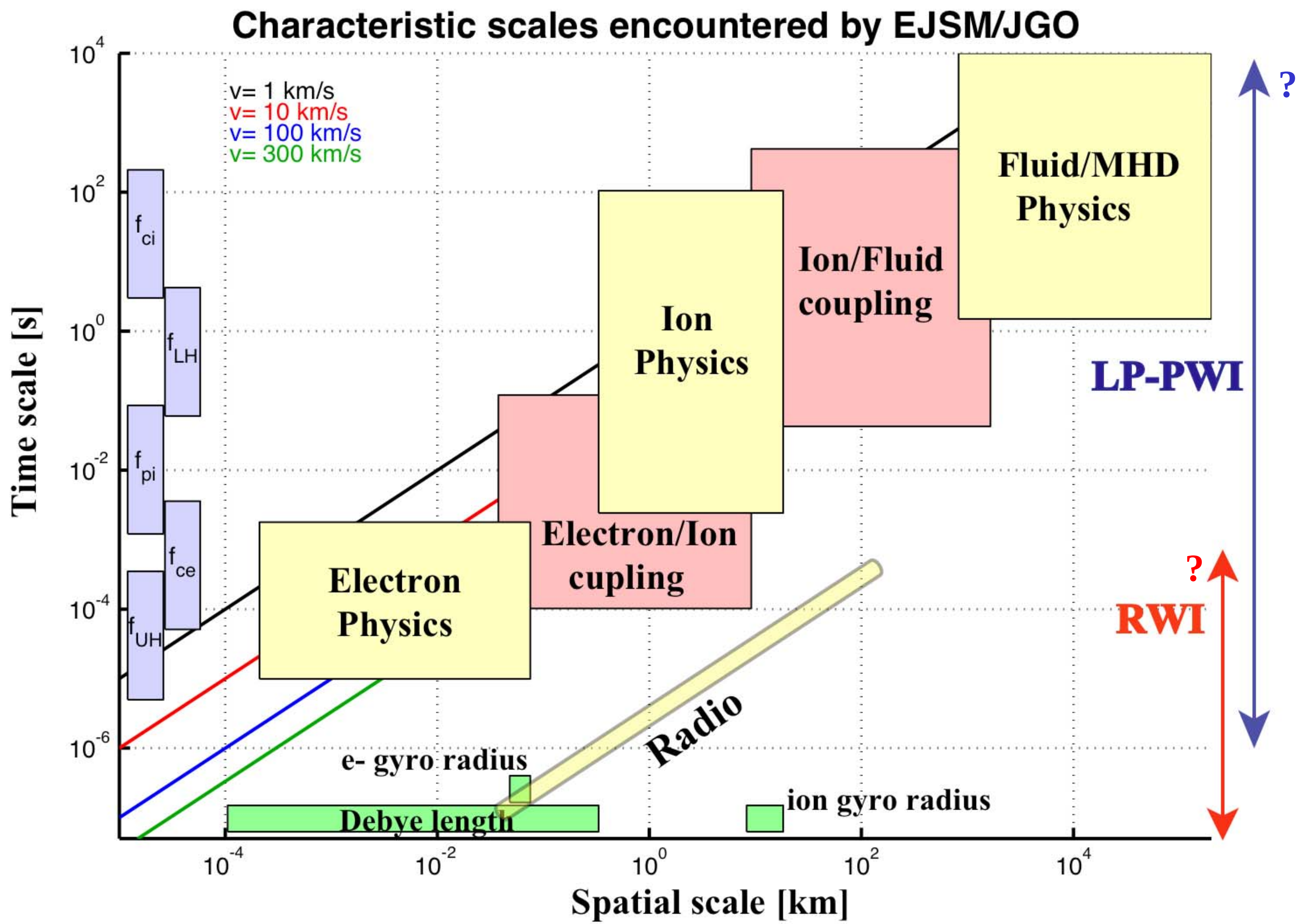
2 orders of magnitude variations

Low & high density regions

Rev 000 - 043

[Morooka et al., Ann. Geophys., 2009]





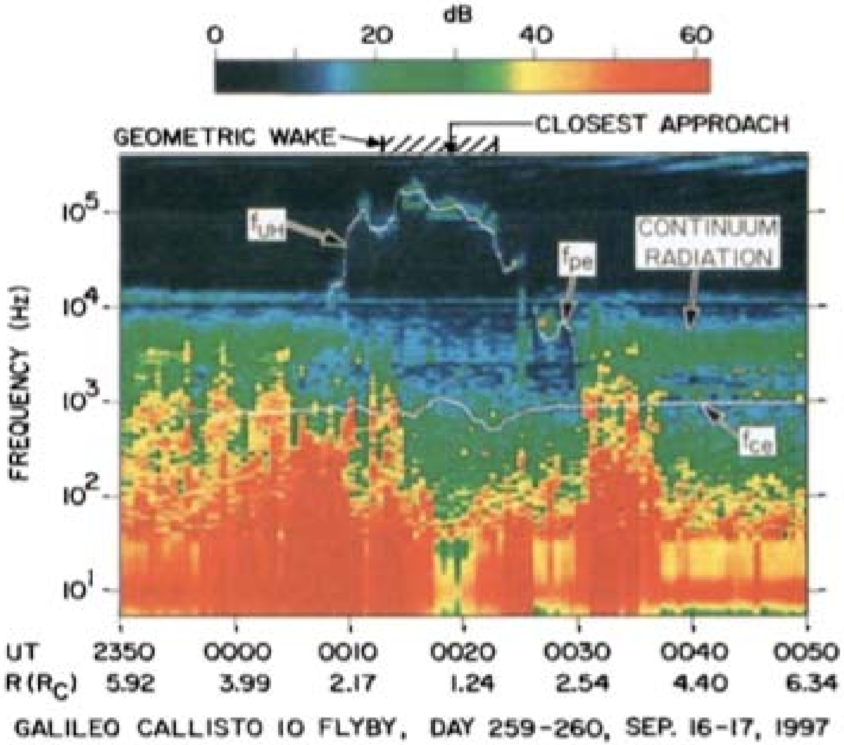
Characteristic scales encountered by EJSM/JGO
v= 1 km/s
v= 10 km/s
v= 100 km/s
v= 300 km/s
Time scale [s]
Spatial scale [km]
f ci
f LH
f pi
f ce
f UH
Electron Physics
Electron/Ion cupling
Ion Physics
Ion/Fluid coupling
Fluid/MHD Physics
Radio
e- gyro radius
Debye length
ion gyro radius
LP-PWI
RWI
?
?

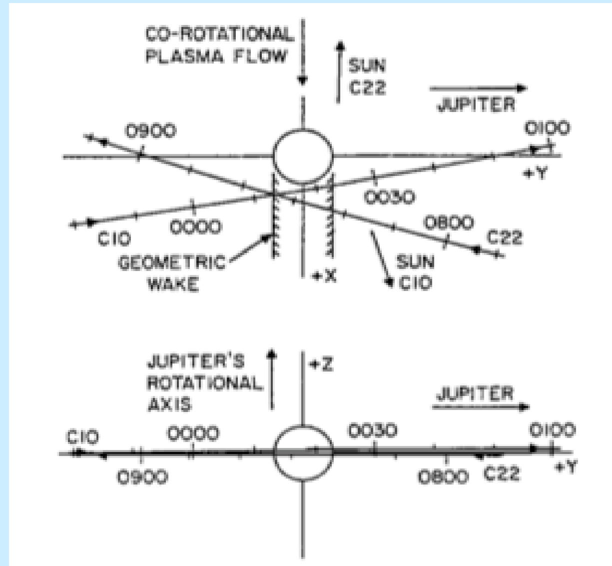
RPWI Measured Quantities

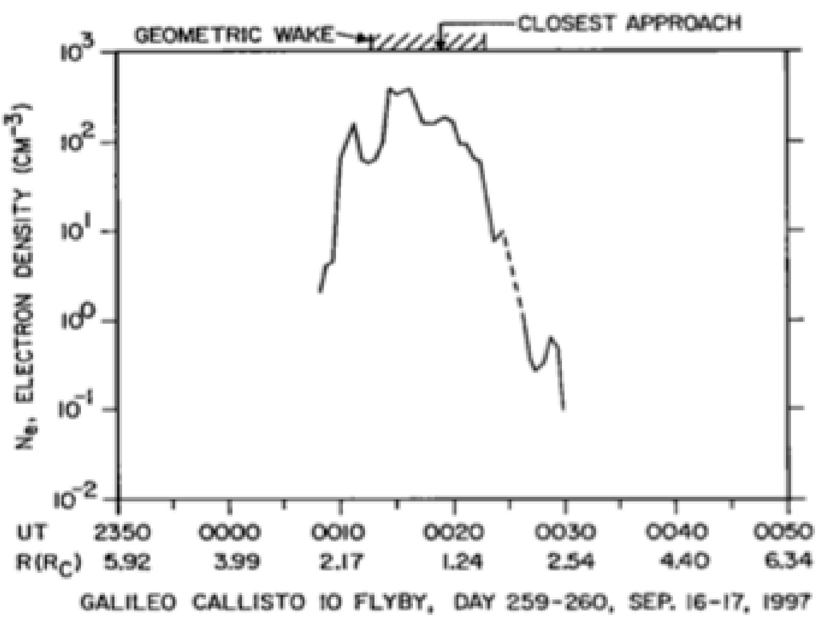
Measured Quantity	Range
LP-PWI	
Electron density (n_e, $\delta n/n$)	0.001 – 10^6 cm^{-3}, 0(dc)-10 kHz
Ion density (n_i)	1-10^6 cm^{-3}, <1 Hz
Electron temperature	0.01 – 20 eV, <100 Hz
Ion drift speed	0.1-200 km/s, <1 Hz
Ion temperature	0.01 – 20 eV, <1 Hz
Spacecraft potential	±50 V, <100 Hz
Electric field vector, δ**E**(f)	0(dc) – 3 MHz (waveform), ±1 V/m Bit resolution: 0.015 mV/m
Integrated solar EUV flux	Resolution 0.05 Gphotons/cm^2/s
Active Measurements	
Electron density (n_e)	0.001 – 1000 cm^{-3}
Electron temperature	0.1 – 100 eV
Electric sensor calibration	
Effective antenna length of sensors	
Deployment length of sensors	
RWI	
Electric field vector, δ**E**(f)	10 kHz – 45 MHz
SCM	
Magnetic field vector, δ**B**(f)	0.1 Hz – 20 kHz (one coil up to 600 kHz)
RA-PWI	
Electric field, δE(f)	1 kHz – 45 MHz

NOTE: Electron density, spacecraft potential and magnetic & electric field vectors are available for all plasma conditions encountered (also in the magnetosphere).

Callisto Ionosphere



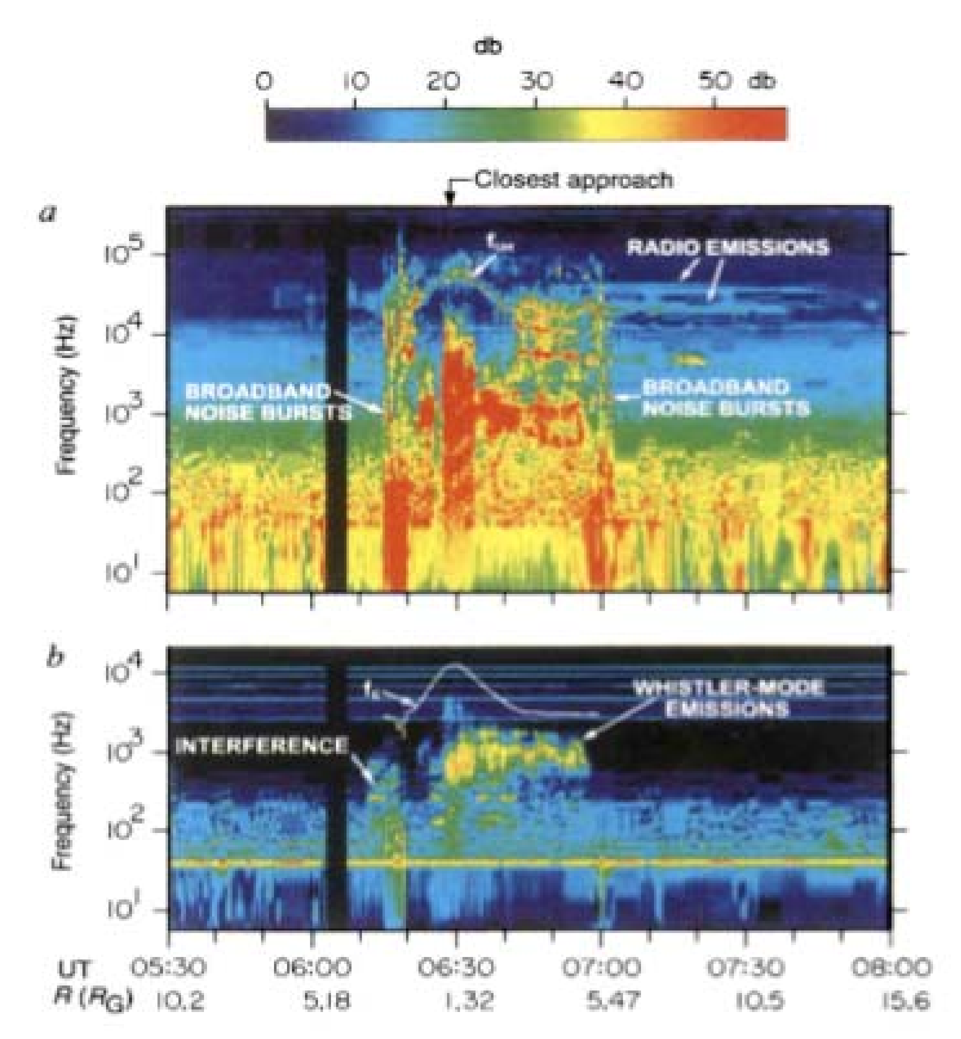


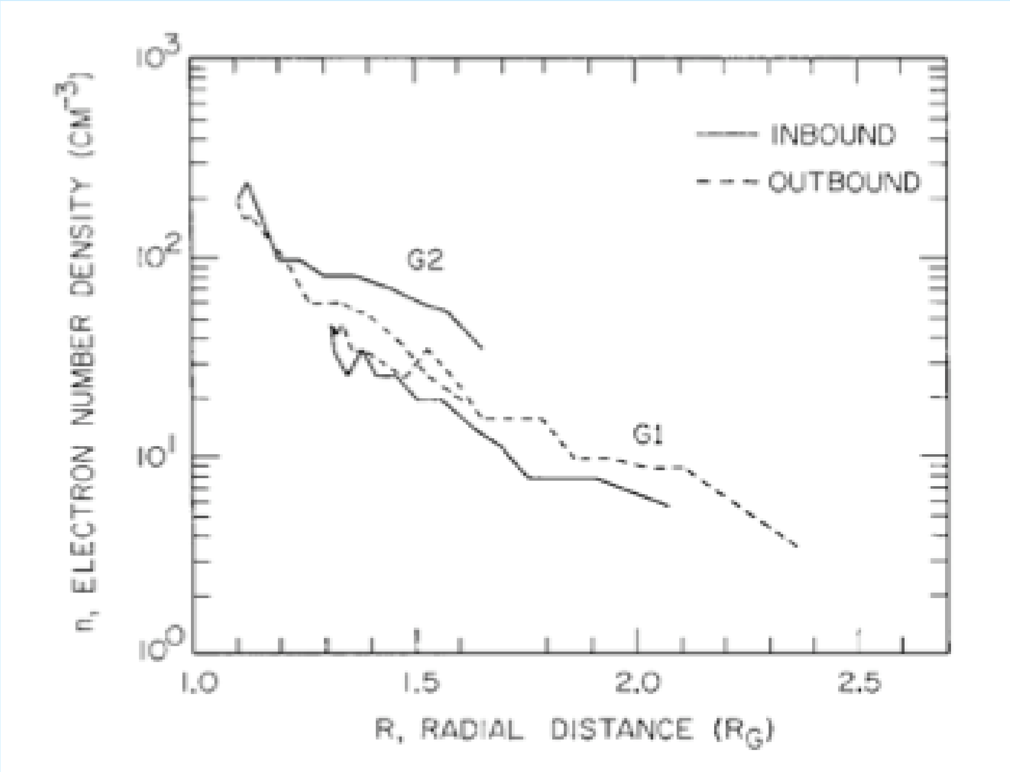


- Galileo Plasma wave instrument [Gurnett et al., GRL, 2000]
- N_e up to 400 cm^{-3} at 535 km
  > 100 cm^{-3} at 500-600 km
- Highly variable
- Ionospheric peak $N_e \approx$ 7000-17000 cm^{-3}
- $H_p \approx$ 30-50 km

- $U_{SC} < 0$ expected

Ganymede Exo-Ionosphere





Galileo Plasma wave instrument

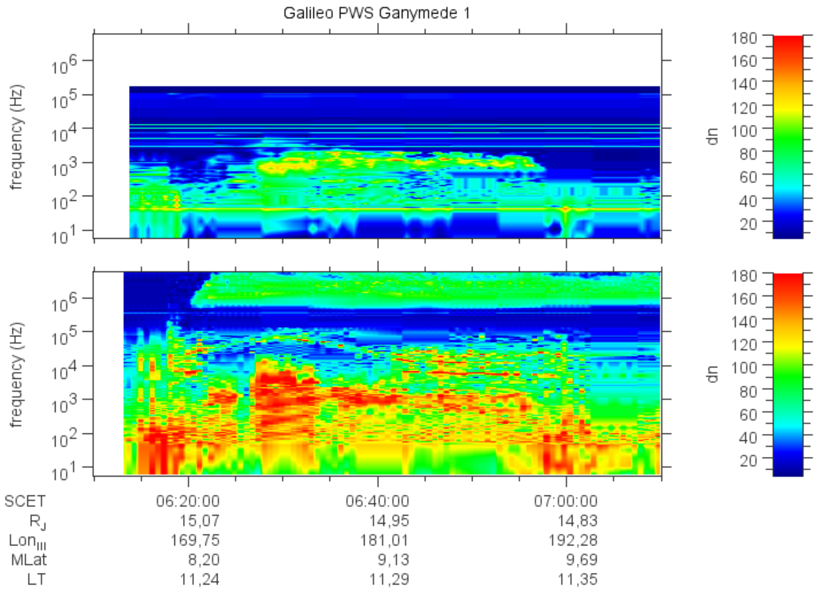
[Gurnett et al., 1996; Eviatar et al., 2001]

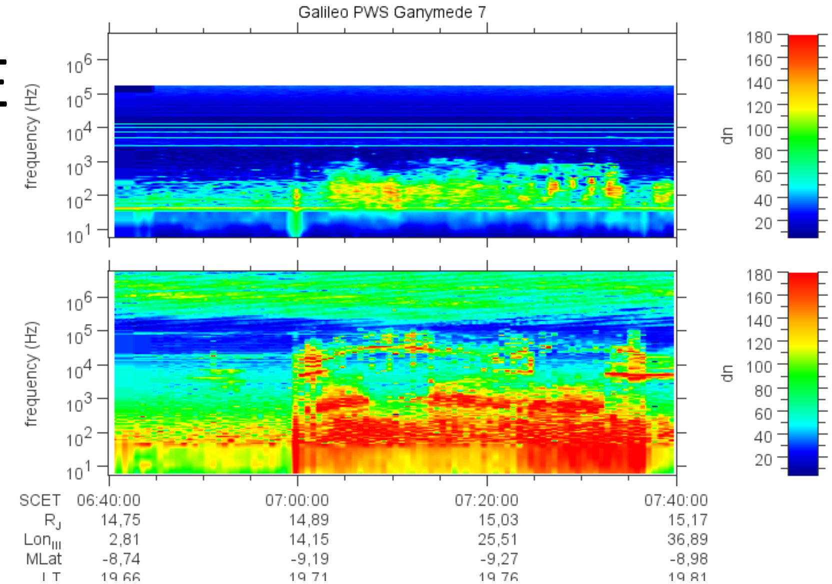
- 200-300 cm^{-3} @ 260 km

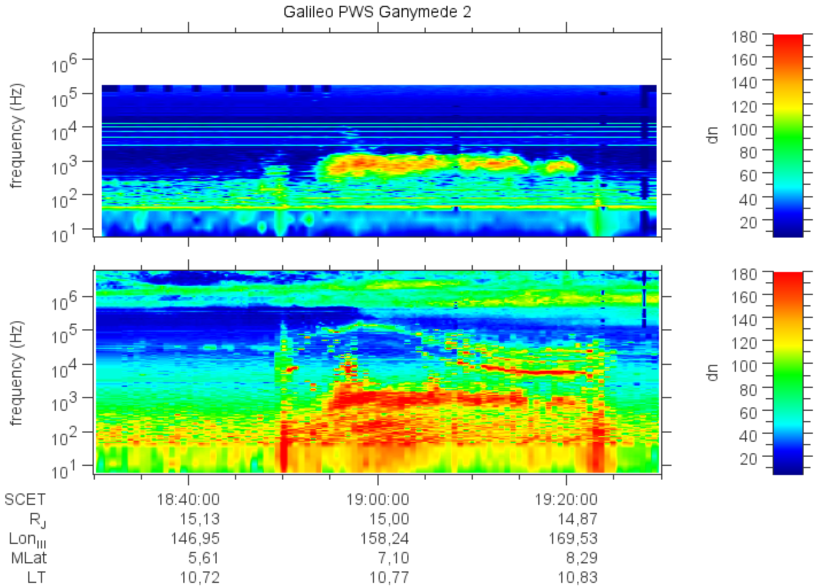
- $n_{e,surface} \approx$ 400-4000 cm^{-3} [Kliore et al., 1998]
- $T_i \approx$ 1-3 eV [Frank et al., 1997]

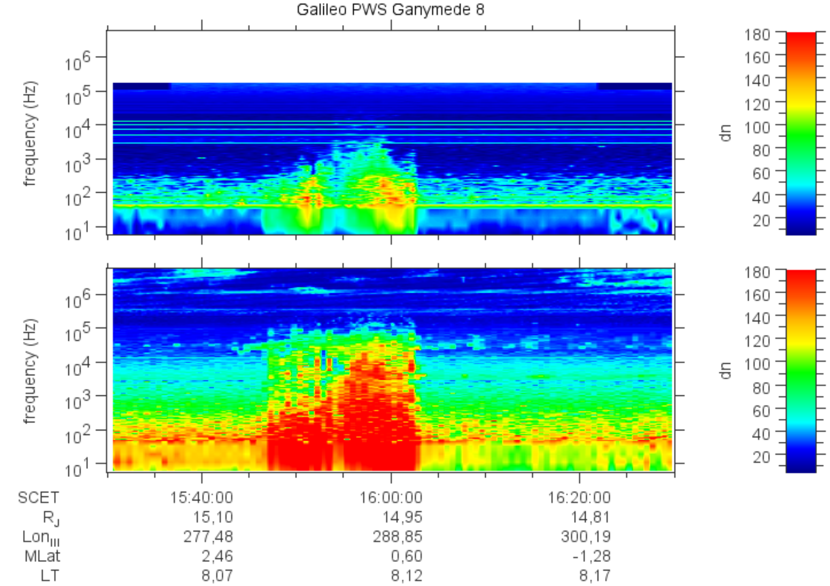
EJSM: GANYMEDE

Galileo PWS data

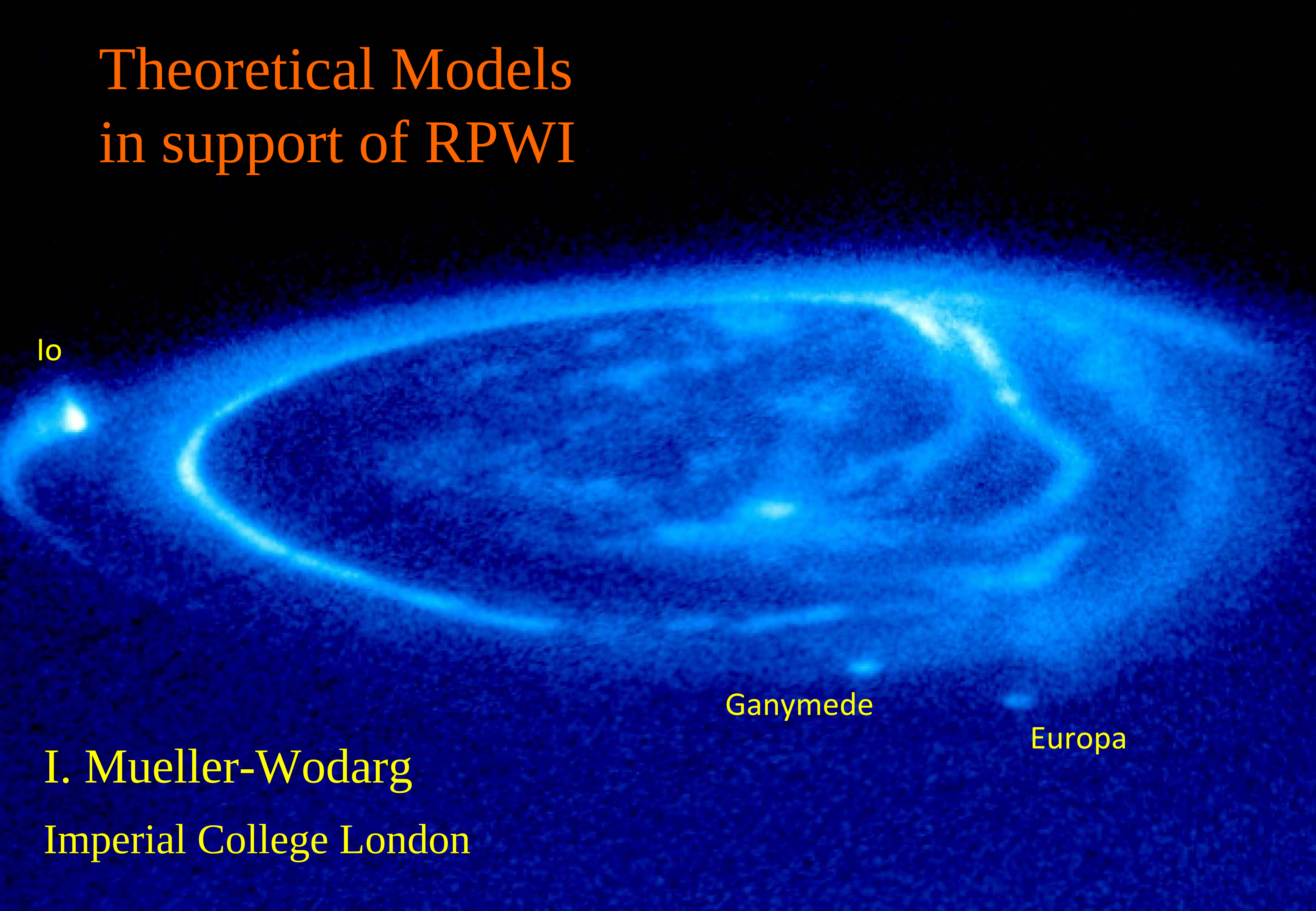








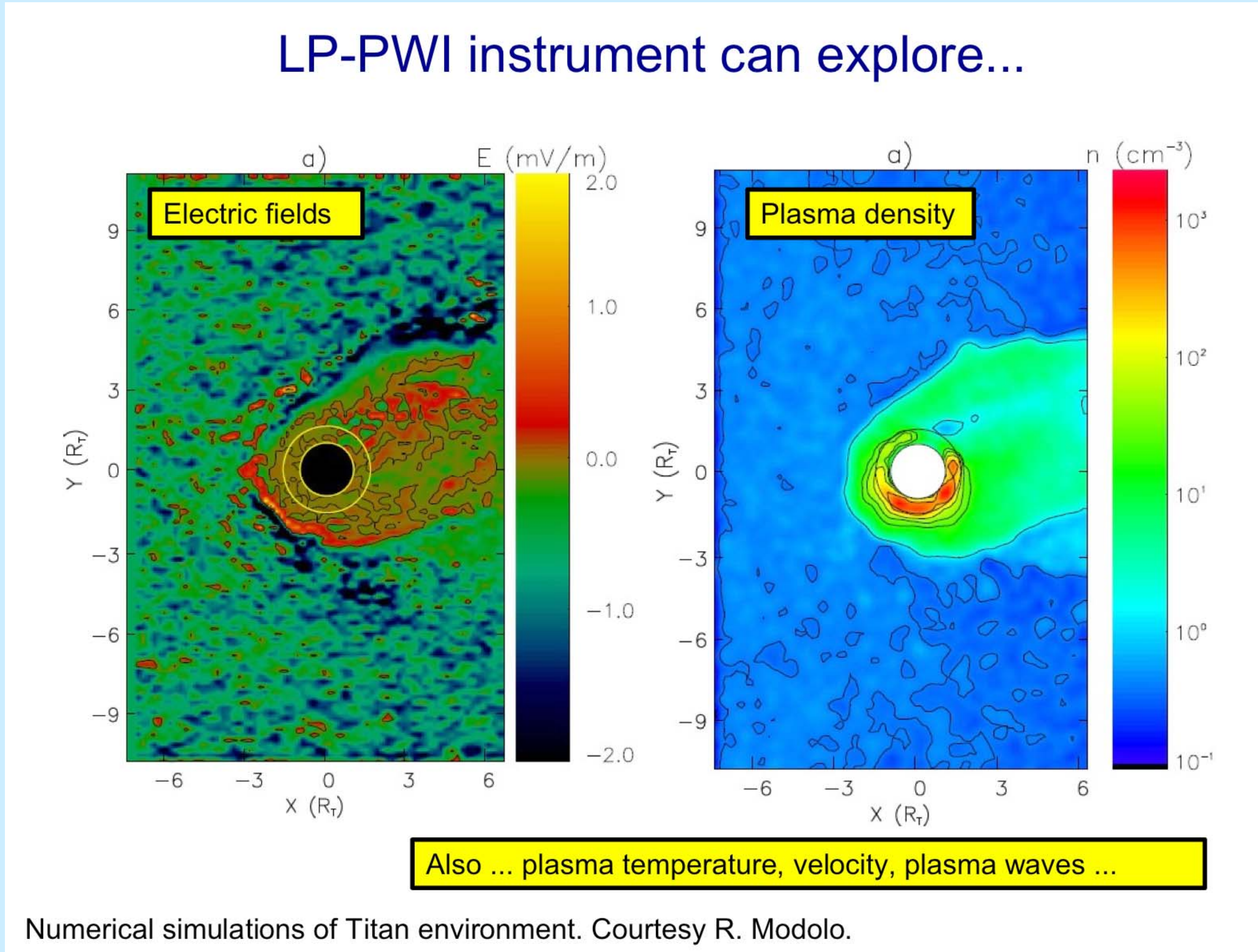
Theoretical Models in support of RPWI



I. Mueller-Wodarg
Imperial College London

Models of Moon interactions

Upcoming: Hybrid code simulations of Ganymede (2 groups)



Numerical simulations of Titan environment. Courtesy R. Modolo.

RPWI Team & Meetings

- Distribution of tasks within the team in progress
- Meetings:
  - Uppsala, November, 2009
  - Prague, February 18-19, 2010
  - May?

End

S/C Requirements

Instrument	Mass [kg]	Power [W]	TM [kbps]	TRL
RPWI Common Electronics	3.0[1]	7+3[2]		8[3]
LP-PWI (GANDALF)	2.0[4]		Min: 64 bps Max: Several kbps[5]	8
RWI	1.5[6]		1-100 kbps[5]	8
SCM	1.0[7]		See LP-PWI	8
RA-PWI	(3.7[8])		From 50 bps-2kbps[5]	8
Total:	**7.5** +(3.7[8])	**7**+(3[2])	**64 bps-100 kbps[5]**	**8**

1) Includes electronics box (1kg), DPU (400g), DC/DC converter (200g), three electronics cards (2x400g+1x600g)
2) Includes also heaters (3W, TBC)
3) Electronics design is flight proven. Interfaces to sensor elements and electronics box need be adapted. Possible update due to outcome of radiation analysis in this proposed study.
4) Includes 4x spherical sensors (50g each), booms (450g each) incl. pre-amplifiers.
5) Data rates are dependent on mode of operation choice. The duty cycle of data taking can be adjusted to comply with available TM rates at a particular time.
6) Includes antennas, pre-amplifiers and shielding
7) Includes 3 SCM-sensors. Should be accommodated on a 1-2 m boom (e.g., MAG boom).
8) Optionally it is possible to use the SSR dipole antenna, in which case no sensor mass is needed (TBD)

ESA TDAs

- Technology Development Activities (TDAs)
- Our input:
  - Development of FPGA algorithms for digital analyzers to obtain high dynamic range
  - Development of radiation hard low noise/distortion pre-amps
  - Prototyping RWI antenna designs
  - Define LP-PWI deployment sticks
  - Develop EMC requirements (interaction during S/C design)
  - Investigate S/C body effects on RPWI radio measurements
  - Investigate RPWI design imposed by S/C environment models (ESA SPIS)
  - RWI antenna prototyping [H. Rothkael application]

Ex: Sweep from Saturn Plasma Disc

$$I = I_i + I_e + I_{ph,Ly-\alpha} + I_{e*,i*} + I_{dust}$$

$$I_{ph} = const$$

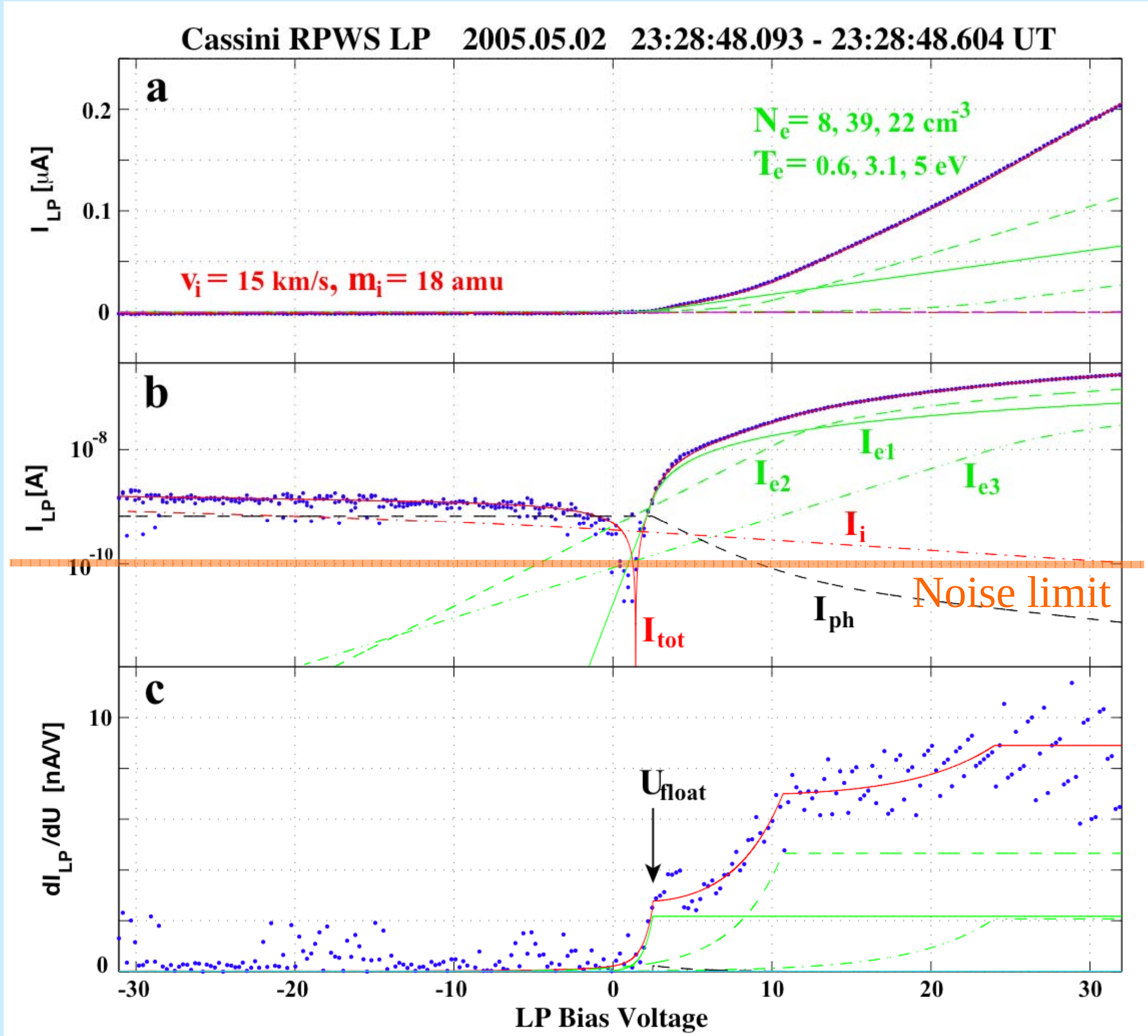
$$I_e <<$$

$$I_i = I_{i0}(1 - \chi_i)$$

where

$$I_{i0} = A_{LP} n_i q_i \sqrt{\frac{v_i^2}{16} + \frac{k_B T_i}{2\pi m_i}}$$

$$\chi_i = \frac{e(U_{bias} + U_{SC})}{\frac{m_i v_i^2}{2} + k_B T_i}$$



$$I_{ph,S/C}$$

$$I_e = I_{e0}(1 - \chi_e)$$

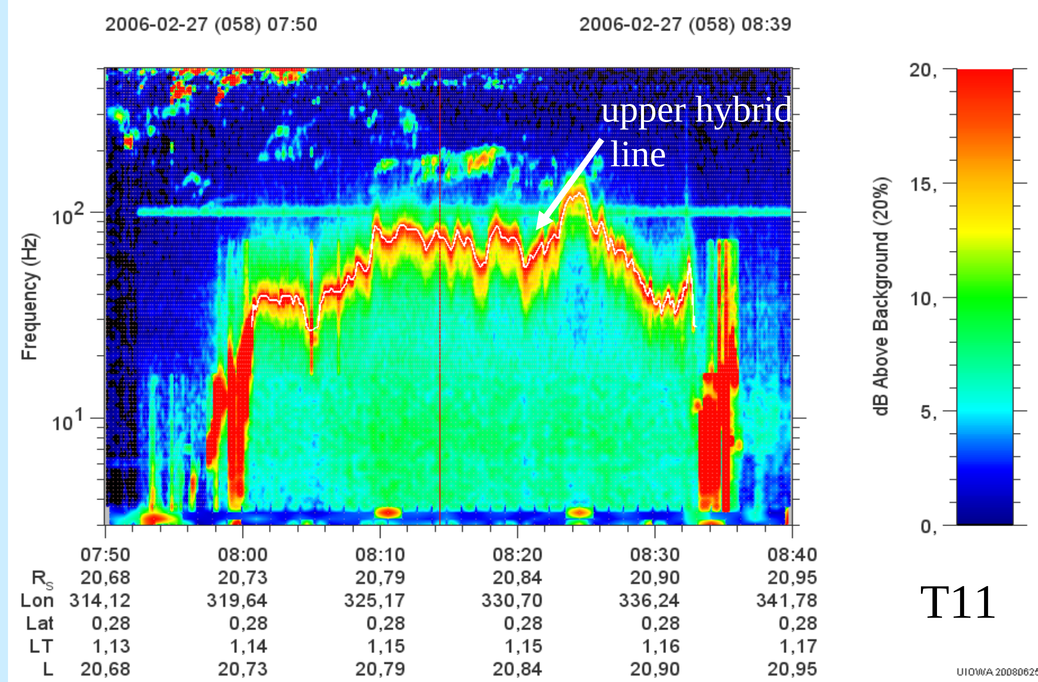
$$I_i <<$$

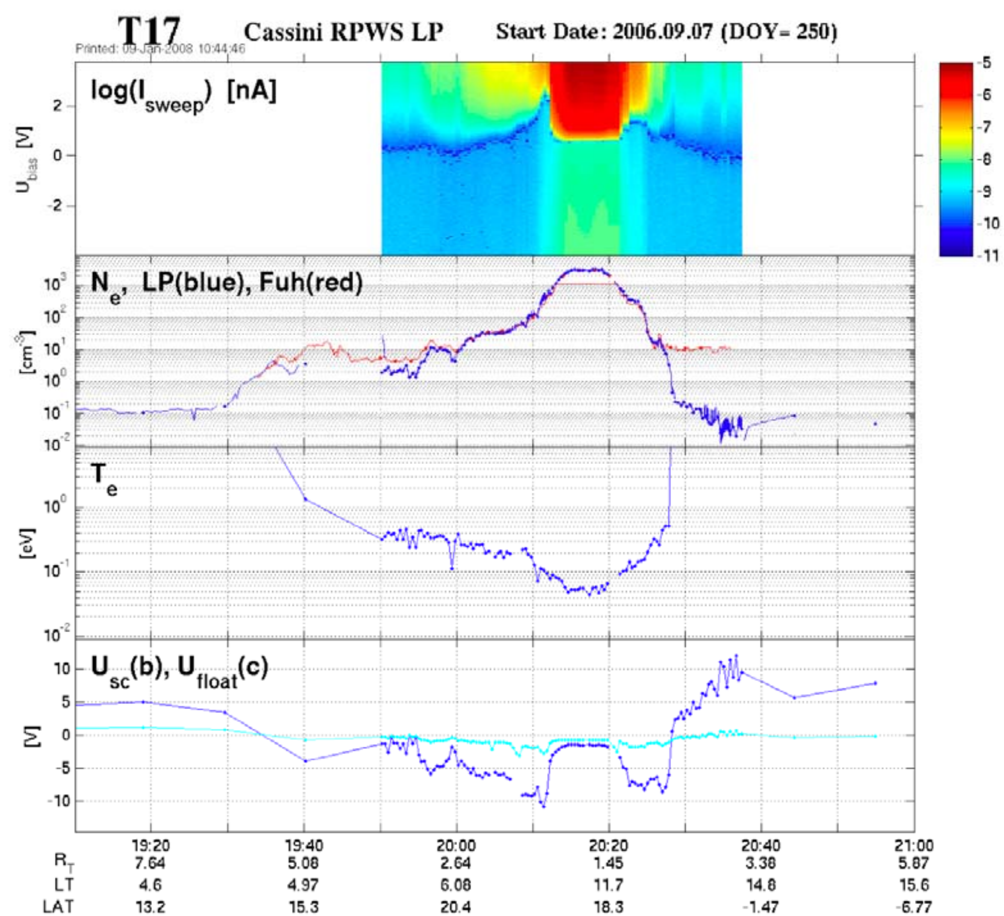
where

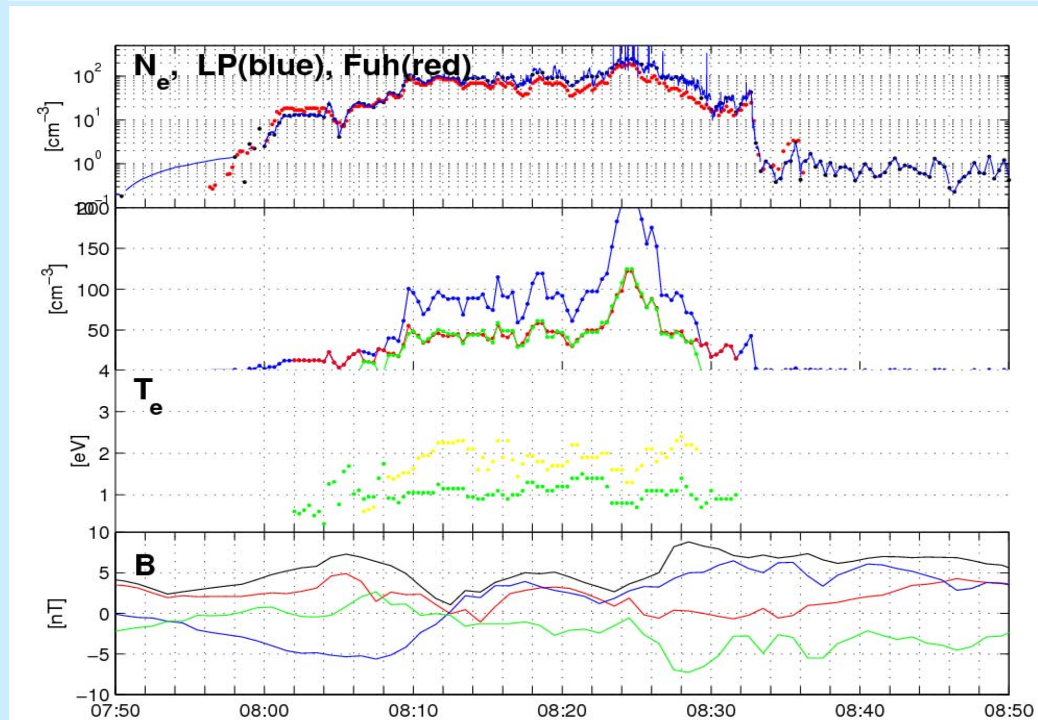
$$I_{e0} = A_{LP} n_e q_e \sqrt{\frac{k_B T_e}{2\pi m_e}}$$

$$\chi_e = \frac{e(U_{bias} + U_{SC})}{k_B T_e}$$

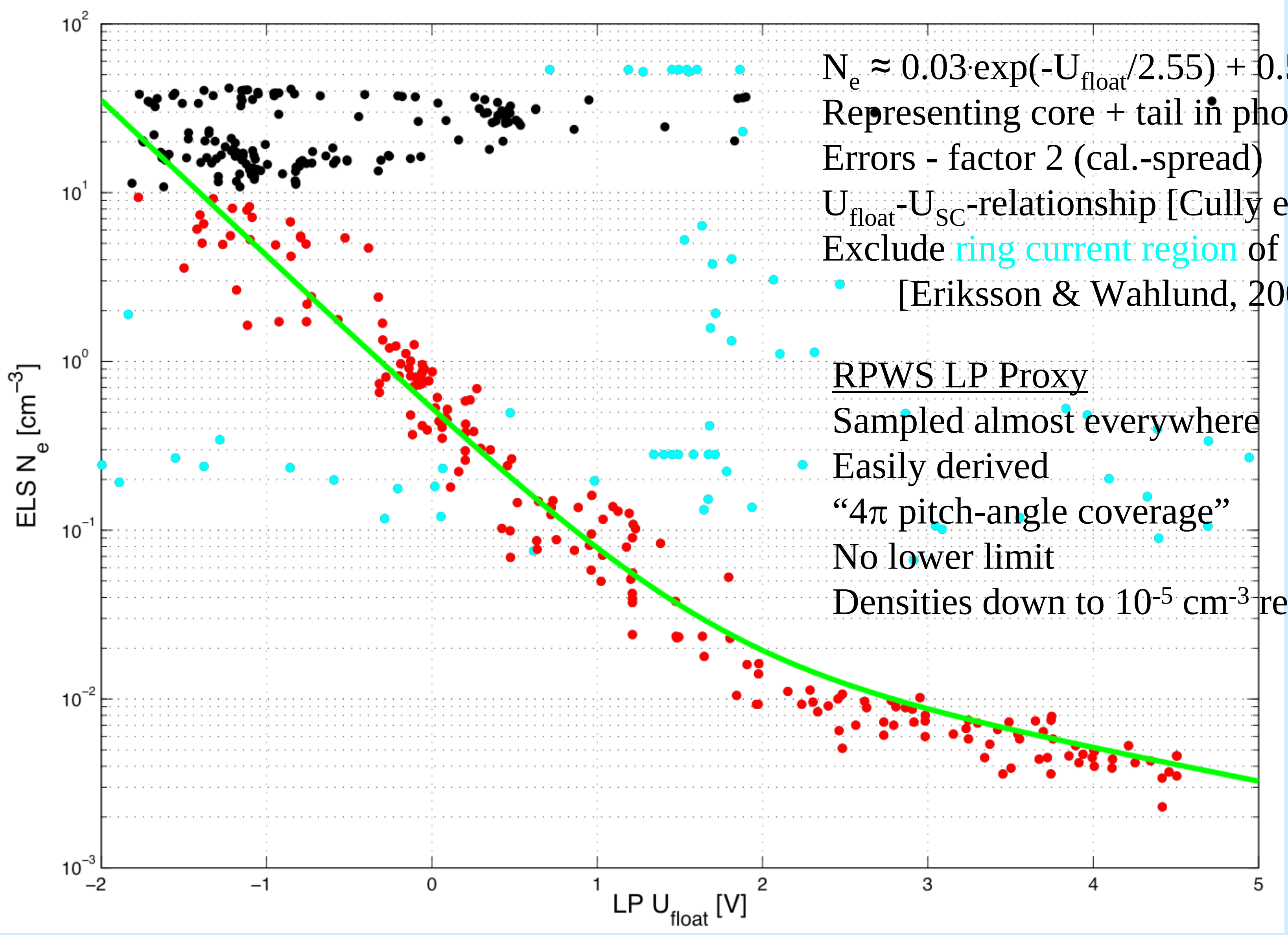
- Titan Exo-Ionosphere
  - Extend several R_{Titan}
  - Heavy cold ions
- Plasma escape
  - ~ few 10^{25} ions/s







The U_{float}-N_e-proxy (SOI)



$N_e \approx 0.03 \cdot \exp(-U_{float}/2.55) + 0.5 \cdot \exp(-U_{float}/0.45)$

Representing core + tail in photoelectrons

Errors - factor 2 (cal.-spread)

U_{float}-U_{SC}-relationship [Cully et al., 2007]

Exclude ring current region of energetic particles [Eriksson & Wahlund, 2006]

<u>RPWS LP Proxy</u>

Sampled almost everywhere

Easily derived

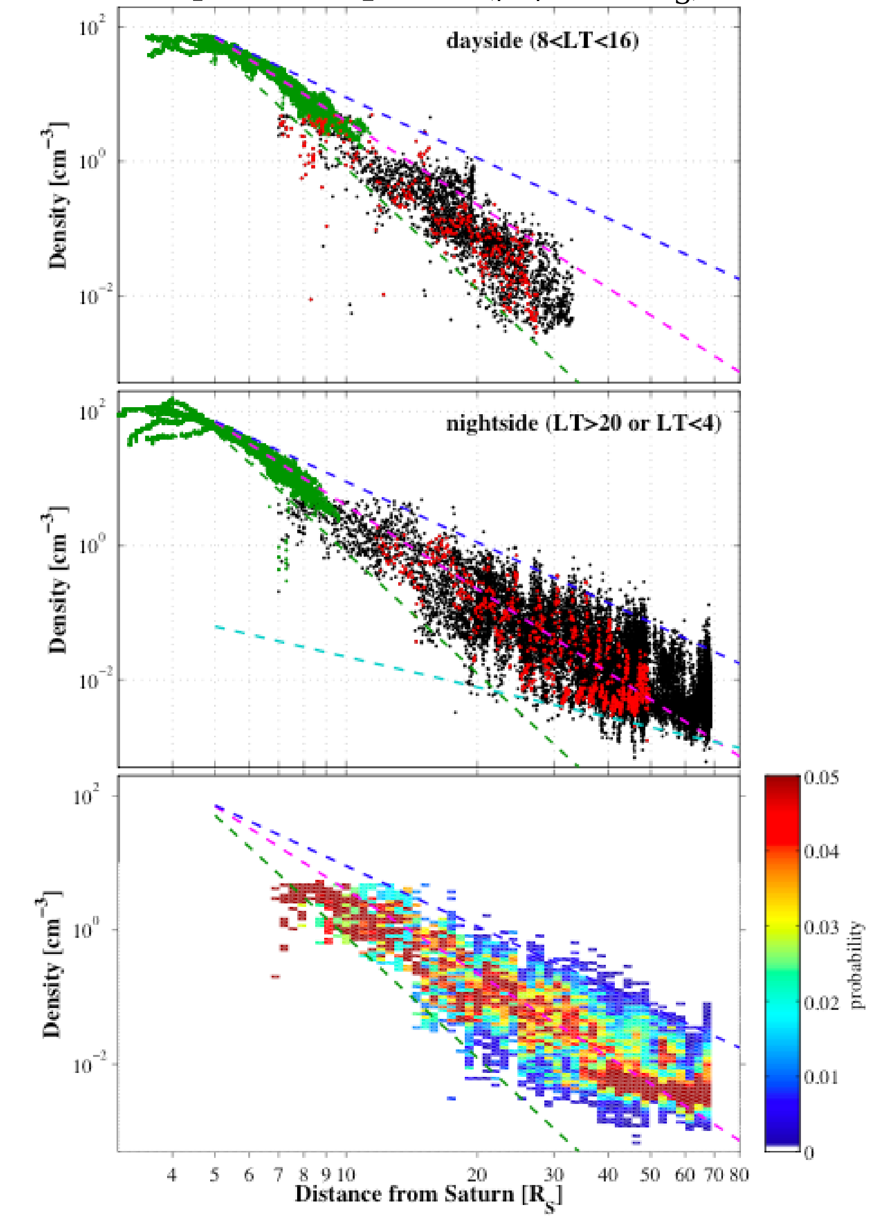
“4π pitch-angle coverage”

No lower limit

Densities down to 10^{-5} cm^{-3} reachable

Upstream magnetospheric dynamics

Equatorial plane (|Z|<0.5 R_S)

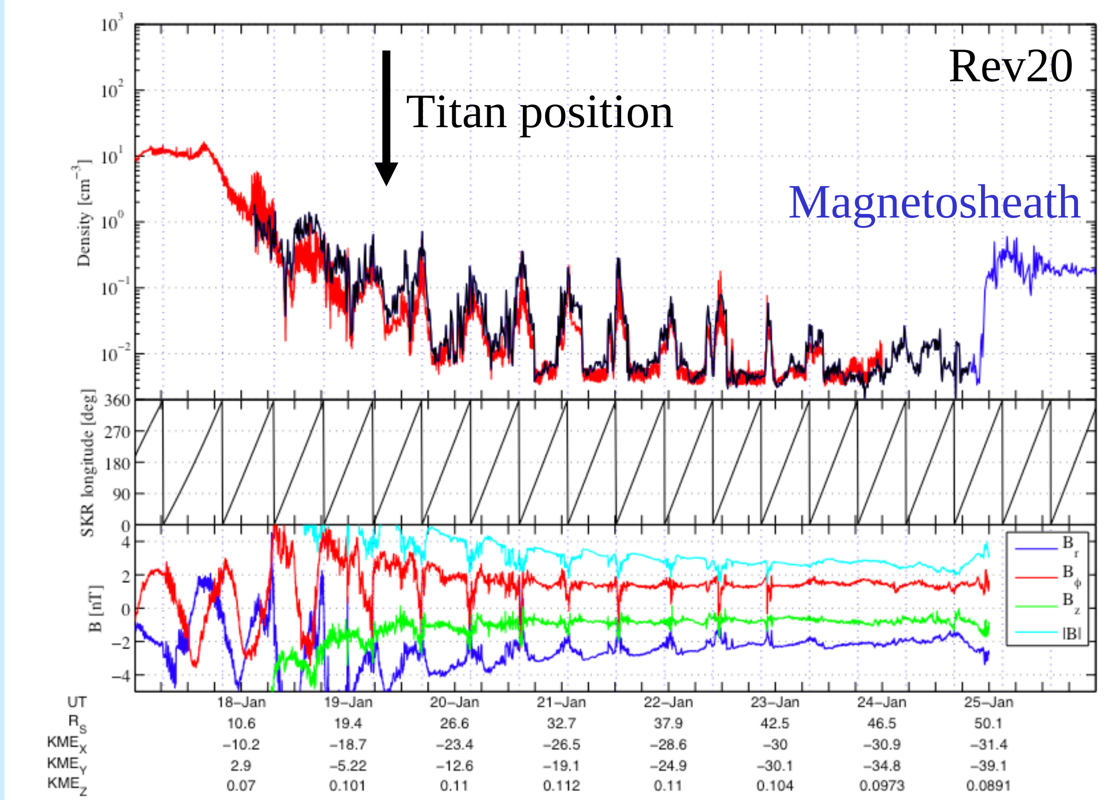


[*Morooka et al.*, Ann. Geophys., 2009]

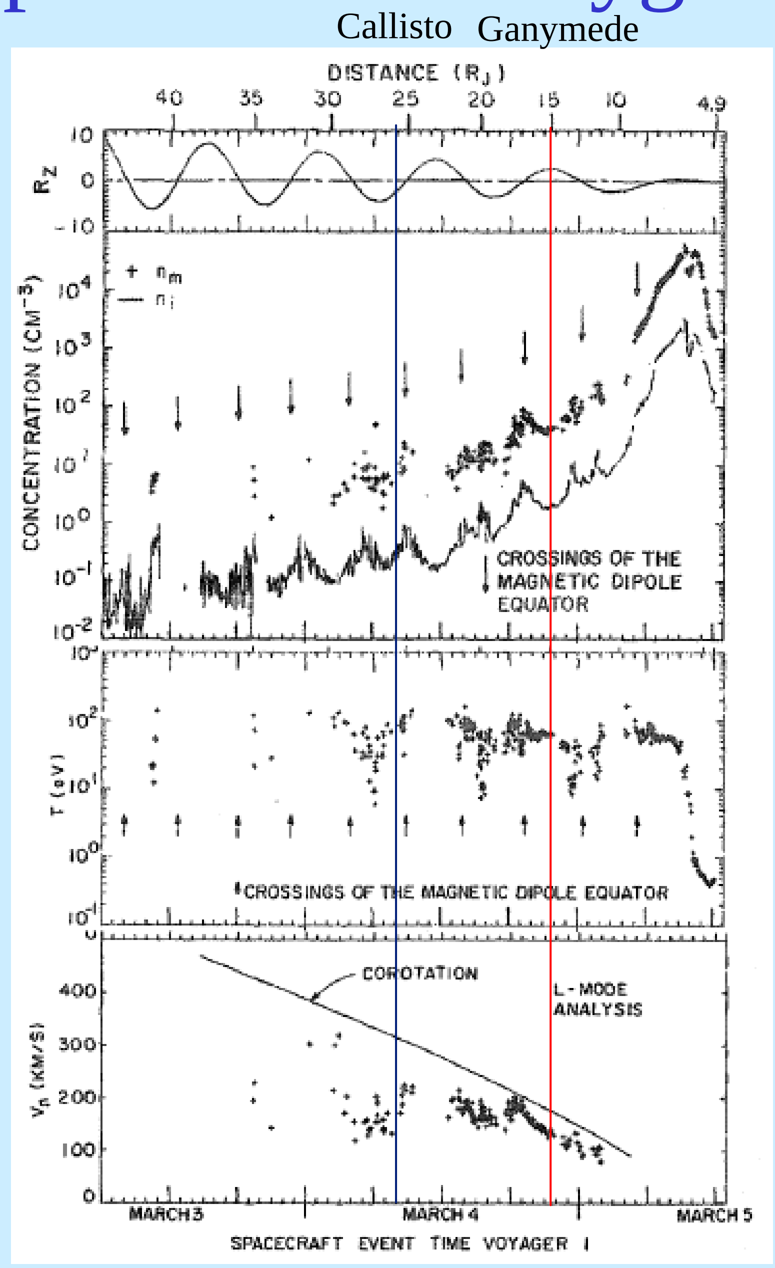
Mapped Saturn's magnetosphere using 44 orbits & identified the magnetospheric regions

2 orders of magnitude variations in n_e
Quasiperiodic ~ planetary rotation (10.7 h)

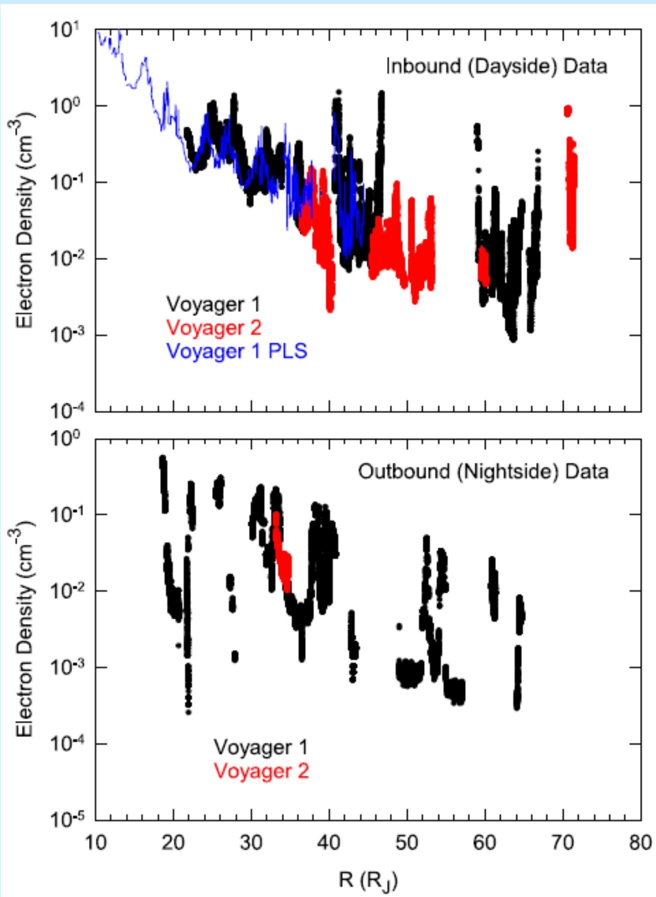
Also provides proof for that SKR longitude variations is associated with bulk plasma variations



Plasma parameters. Voyger 1 fly-by



EJSM: MAGNETOSPHERE



$4x10^3$ (Io torus)
$<10^{-3}$ (outer magnetosphere) cm^{-3}

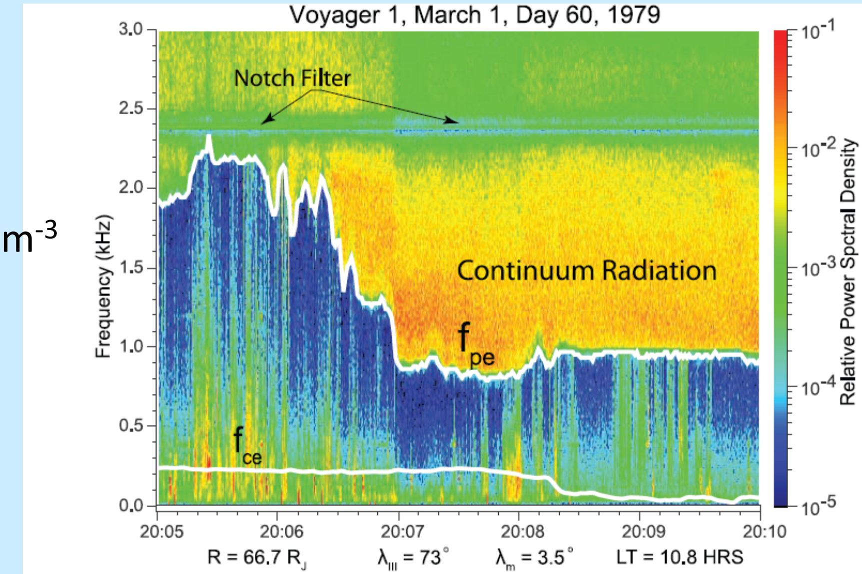
Richards et al., AGU, 2003
Galileo PWS observations
Barnhart et al., JGR, 2009

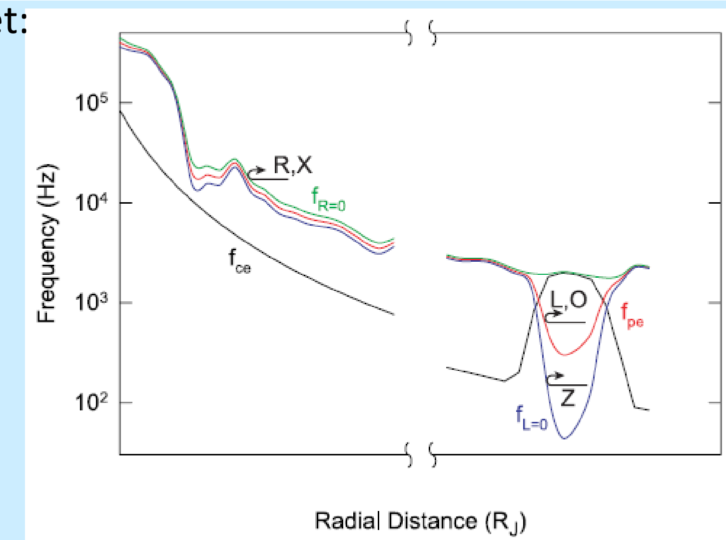
Average densities
at **the center** of the current sheet:

@20 Rj: 1 cm^{-3}
@120 Rj: 0.01 cm^{-3}

Jupiter Ganymede Orbiter:

10^{-3} (10^{-4})-10 (10^2) cm^{-3}





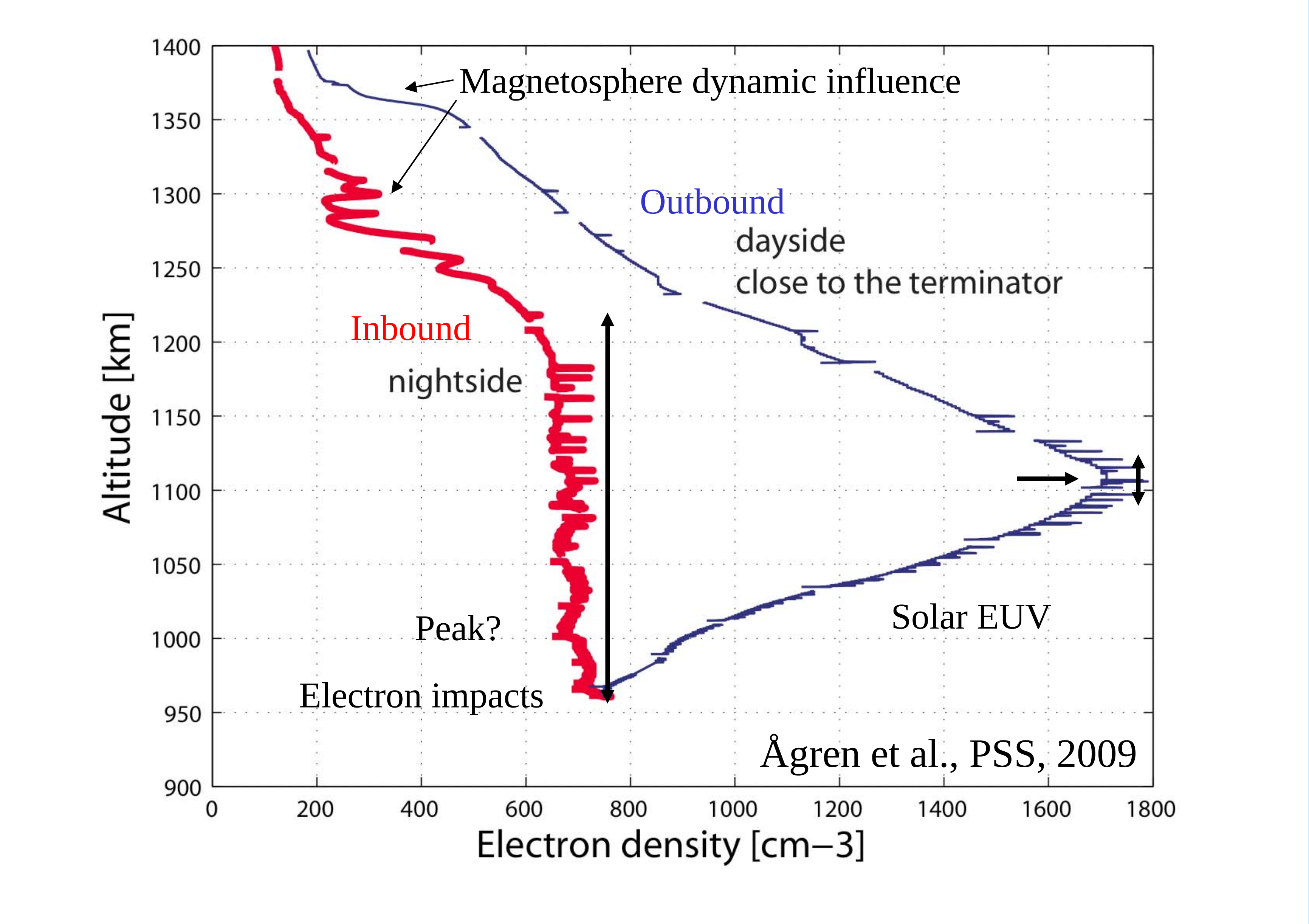
The electron number density (n_e) is determined through several independent techniques:

- Through LP-PWI potential bias sweeps (for densities > 10 cm^{-3})
- Through monitoring the upper hybrid emissions (f_{uh})
- Through monitoring the spacecraft potential (U_{SC}) and calibrating toward f_{uh} (or possibly an electron spectrometer on board S/C).
- Through continuous sampling of the LP-PWI probe current (ms time resolution).

The radio and plasma waves measurements by RPWI combined allows for determination of

- Wave polarization
- Wave Poynting flux/Radio flux
- Electric field vector determination in frequency range from near dc to 45 MHz
- Interferometry and determination of wave group speeds, plasma drift speeds, and plasma density inhomogeneities ($\delta n/n$)
- Convection electric fields ($\mathbf{E}\times\mathbf{B}$ drift)
- Waveform determination
- Electric fields of structures and waves responsible for accelerating charged particles
- Direction finding
- Dust distribution (above about 1 μm size)
- Signatures of dust-plasma interactions

Titan Ionosphere profile (20 Hz)



Cassini Lessons

- Improving LP ion ram flux measurements
  - Larger probe, e.g. 5 cm radii
  - More sensitive receiver, better than 100 pA
  - Larger U_{bias} range, e.g. ±100 V
  - Should then be possible to measure the ion flux in Jupiters co-rotating magnetosphere around Ganymede and even Callisto & enable direct V_{di} measurements thereof
- A combination of several methods for N_e and T_e measurements are essential
- Particle measurements are inadequate to measure a dense cold plasma
  - Electron Spectrometers are effected by $U_{SC} < 0$ making the core population unreachable
  - Ion Energy Spectrometers are extremely un-sensitive at low energies
- Long antenna (10 m) plasma wave measurements difficult below 1 kHz

AVAILABLE RADIO DATA AT JUPITER: SYNCHROTRON DATA

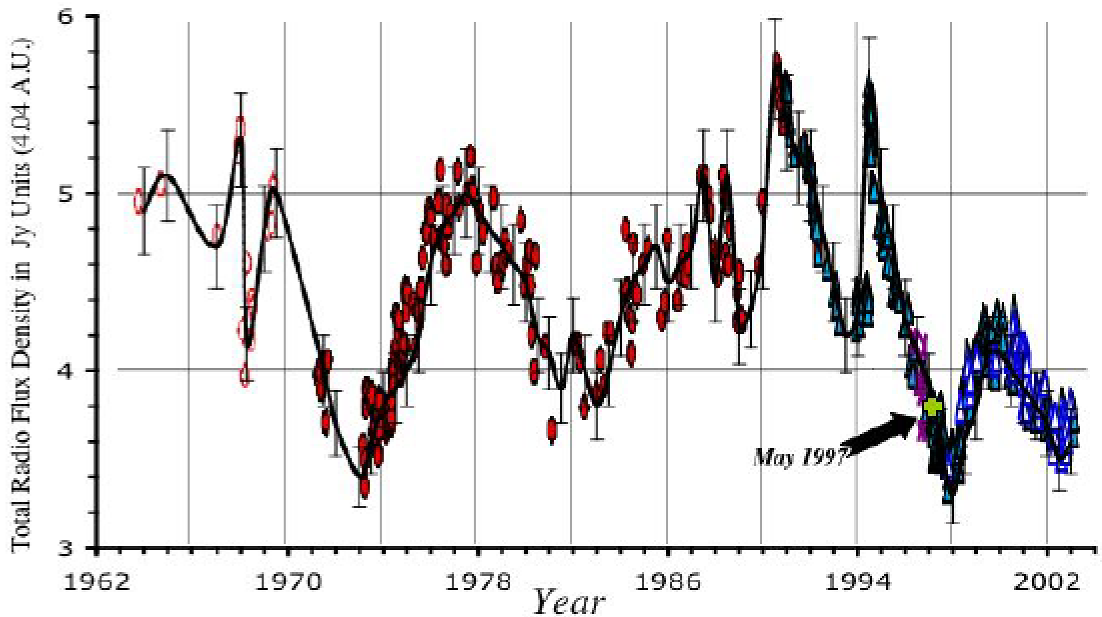


Figure 1. History of long-term variations in the flux density of Jupiter's synchrotron radio emission at 13-cm wavelength. The DSN and GAVRT data (open and filled triangles) were merged with the ongoing NASA/JPL Jupiter Patrol (filled circles), and observations made with Parkes and Nancay radio telescopes (open circles) (after *Bolton et al.* [2002]). The black curve depicts the general temporal variation of the decimetric emission.

Santos-Costa and Bolton, JGR, 2008

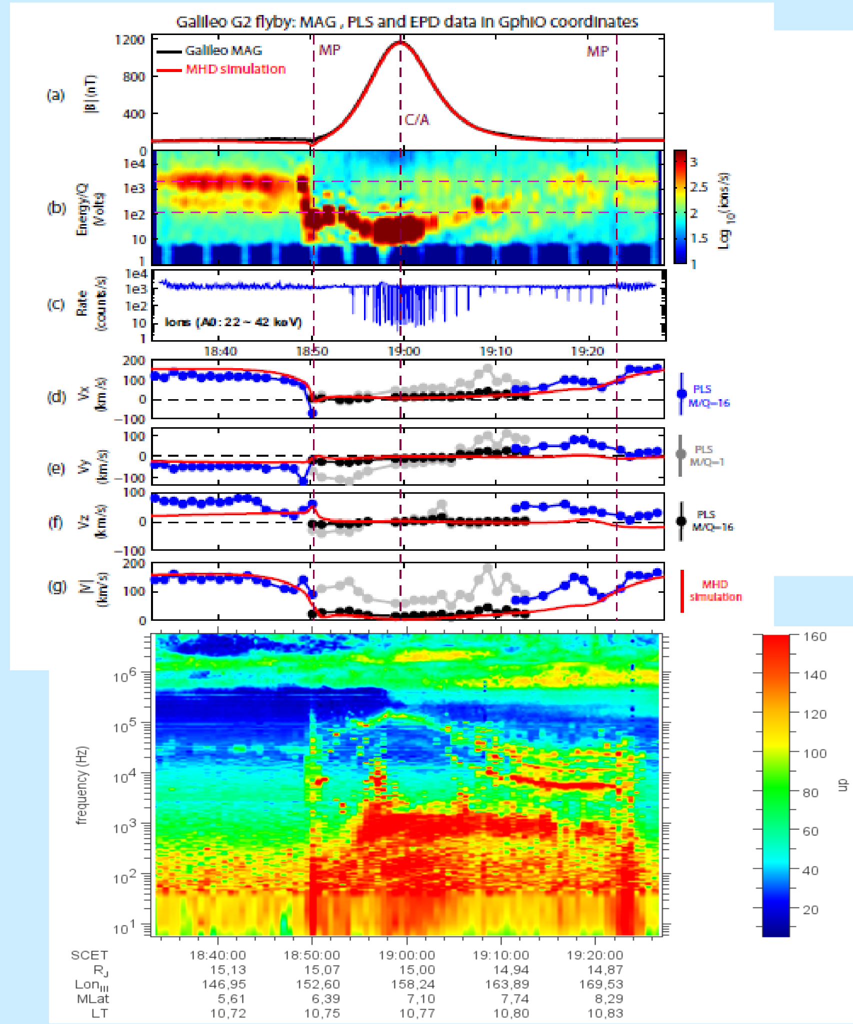
VLA observations made at various wavelengths (e.g., 20 and 6 cm) http://archive.cv.nrao.edu/

Next year:

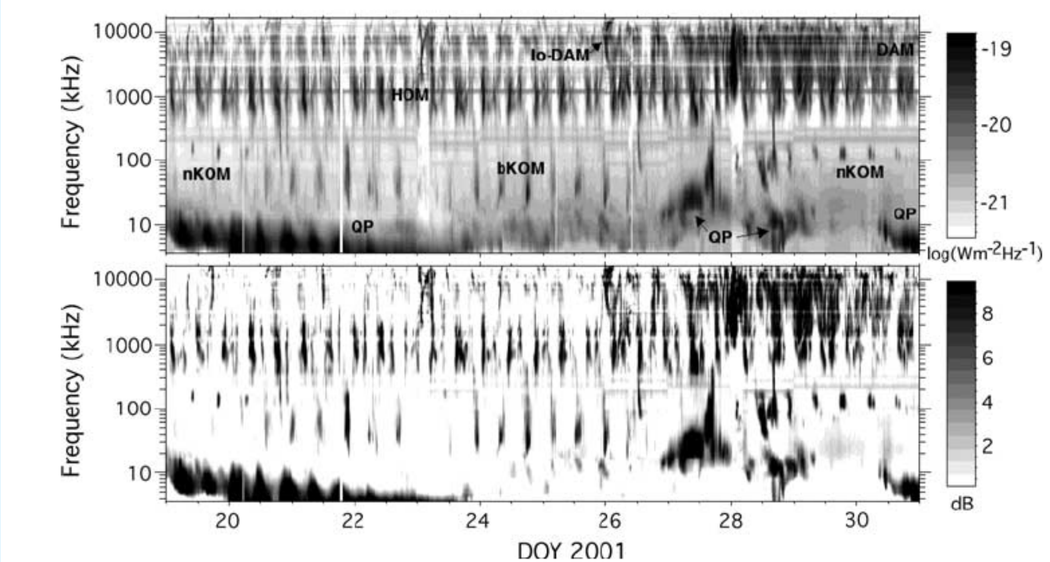
- **Proposal for a Jupiter Plasma Science Archive at CDPP**

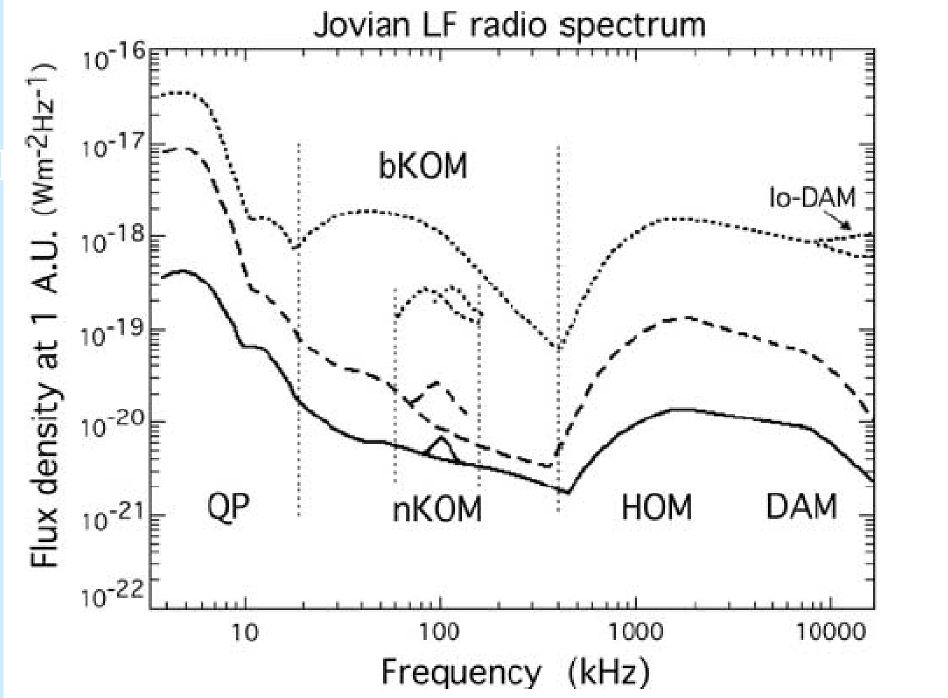
AMDA (Automated Multi-Dataset Analysis)

1. Visualization editor
2. Download data
3. Parameter editor
4. External data
5. Visual search
6. Conditional search
7. Time-Table manager



EJSM: RADIO (Zarka & Cecconi, JGR, 2004)





Cassini RPWS Data

Table 2. Average and Peak Powers of Jovian Radio Components

Component	Spectral Range, kHz	Beam Solid Angle Ω, sr	Average Power, W	Average Power (High Activity), W	Peak Power, W
QP (LF)	3.5–10	2π	2.3×10^8	4.5×10^9	5.5×10^9
QP (HF)	10–23	2π	5.6×10^7	2.9×10^8	7.0×10^8
QP (total)	3.5–23	2π[a]	2.9×10^8	4.8×10^9	6.2×10^9
nKOM	60–160	4.8[b]	5.0×10^7	2.4×10^8	7.7×10^8
bKOM (LF)	23–200	1.9	7.1×10^7	3.0×10^8	7.2×10^9
bKOM (HF)	200–400	1.9	1.0×10^8	1.8×10^8	1.9×10^9
bKOM (total)	23–400	1.9[c]	1.7×10^8	4.8×10^8	9.1×10^9
HOM (LF)	400–1000	1.6	5.1×10^8	4.0×10^9	1.5×10^{10}
HOM (HF)	1000–3000	1.6	3.8×10^9	3.5×10^{10}	1.2×10^{11}
HOM (total)	400–3000	1.6[c]	4.3×10^9	3.9×10^{10}	1.4×10^{11}
DAM	3000–16000	1.6[c]	1.3×10^{10}	8.2×10^{10}	4.5×10^{11}

EJSM: CALLISTO

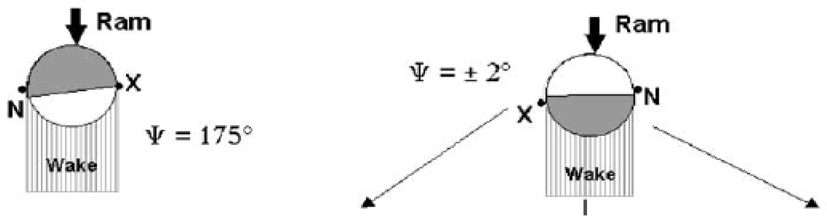
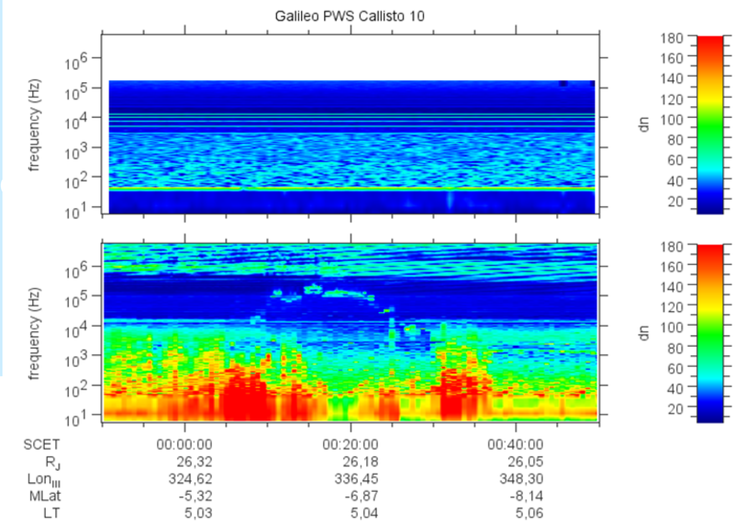


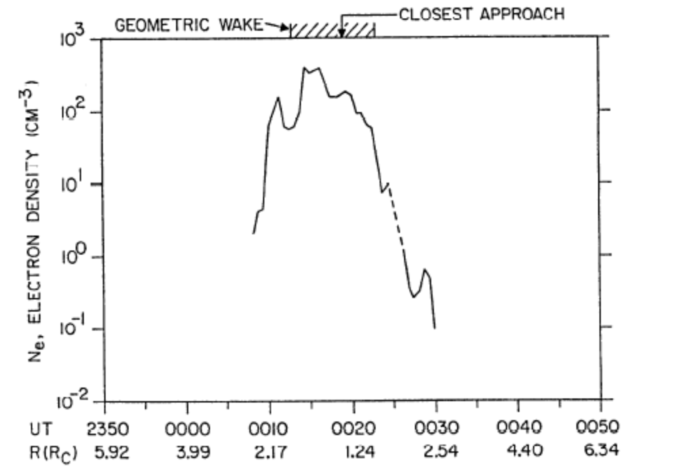
Table 2. Measured Ionospheric Properties and Inferred Atmospheric Densities for Callisto

Observation	SZA (deg)	Peak Altitude (km)	Peak Electron Density (cm^{-3})	Neutral Scale Height (km)	Inferred O_2 Density at the Surface (cm^{-3})	Inferred O_2 Column Density (cm^{-2})
C20 N	85.0	72.0	4,300 ± 4,40	–	–	–
C20 X	99.2	42.0	5,100 ± 3,300	–	–	–
C22 N	78.7	27.2 ± 1.5	15,300 ± 2,300	14.8 ± 0.2	PI - $2.14 \times 10^{10} \pm 1.28 \times 10^{10}$ EI - $1.76 \times 10^{10} \pm 2.73 \times 10^{9}$ C - $1.89 \times 10^{10} \pm 4.59 \times 10^{9}$	C - $2.80 \times 10^{16} \pm 6.81 \times 10^{15}$
C22 X	95.0	8.0	8,500 ± 17,000	–	–	–
C23 N	82.5	47.6 ± 1.5	17,400 ± 1,500	24.5 ± 0.9	PI - $1.89 \times 10^{10} \pm 2.00 \times 10^{8}$ EI - $1.49 \times 10^{10} \pm 2.81 \times 10^{9}$ C - $1.64 \times 10^{10} \pm 1.70 \times 10^{9}$	C-$4.01 \times 10^{16} \pm 4.40 \times 10^{15}$
C23 X	97.6	32.0	3,000 ± 1,600	–	–	–

PI-Photoionization EI-Electron Impact C-Combined

Figure 2. Electron density profiles derived from Galileo radio occultation observations of the Callisto ionosphere. The smoothed profiles are shown in black, and the unsmoothed ones in gray.





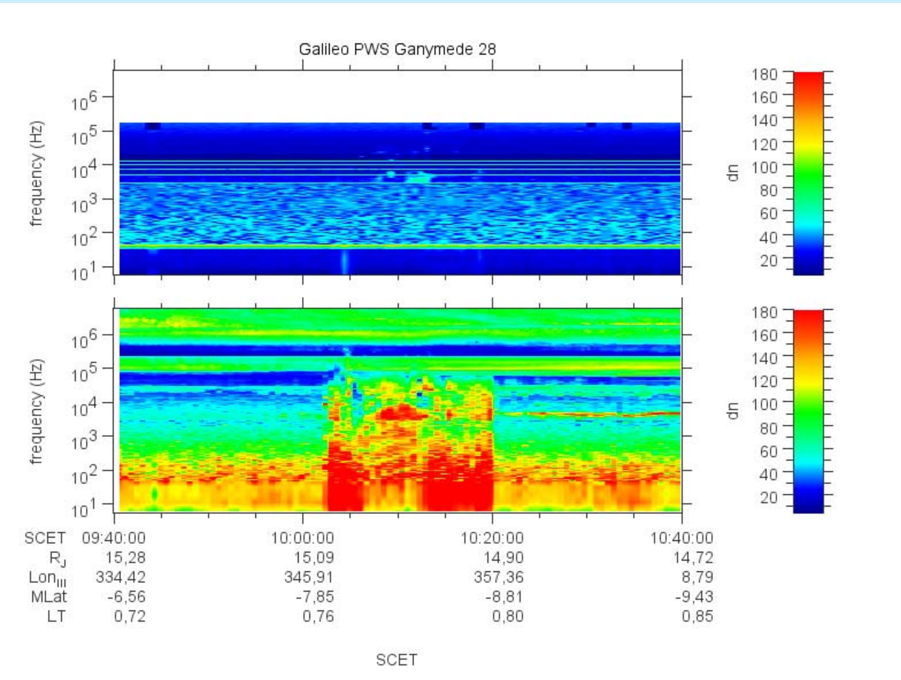
Galileo Callisto Flybys, Kliore et al., JGR, 2002
Radio occultation data (2.5 GHz, S-band)

<u>Ionospheric densities :</u>
Density above 10^4 cm^{-3}
for very close flybys (< 50 km)

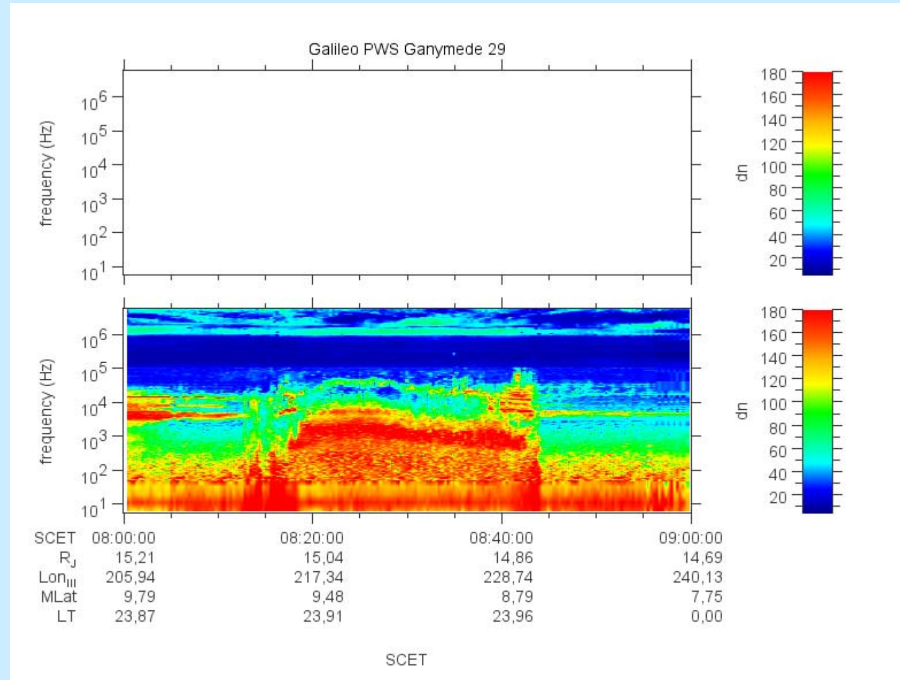
EJSM: GANYMEDE

Galileo
PWS
Data

Das2 software from Iowa



G28	below	low-latitude upstream	0.34
G29	above	midlatitude downstream	0.88

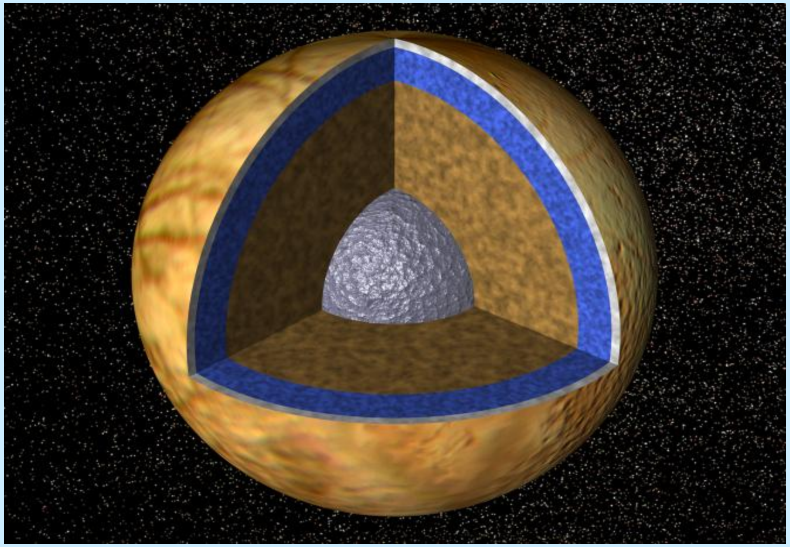


PAYLOAD SUMMARY TABLE

Instrument	Acronym	Mass [kg]	Size [cm]	Power [W]	TM [kbps]	TRL	Heritage
RPWI Common Electronics	RPWI-E	3.0[1]	15x15x8 cm	7+3[2]		8[3]	
Langmuir Probe & Plasma Waves Instrument	LP-PWI	2.0[4]	4x 5cm probes on tip of 1-3m booms[5]		Min: 64 bps Max: Several kbps[6]	8	Cassini RPWS Rosetta LAP Cluster EFW BepiColombo PWI
Radio Wave Instrument	RWI	1.5[7]	Triad of 50cm-1m antenna[8]		1-100 kbps[6]	8	Cassini RPWS STEREO Waves Juno, RBSP BepiColombo PWI
Tri-axial Search Coil Magnetometer	SCM	1.0[9]	11x11x11cm		See LP-PWI	8	BepiColombo PWI Cassini RPWS
Radar Antenna Plasma Wave Instrument	RA-PWI	(3.7)[10]	2x6m dipole, SSR antenna[10]		From 50 bps to 2kbps[6]	8	Cassini RPWS BepiColombo PWI
Total:		**7.5+(3.7)[10]**		**7+(3)[2]**	**64 bps-100 kbps**	**8**	

1) Includes electronics box (1kg), DPU (400g), DC/DC converter (200g), three electronics cards (2x400g+1x600g)
2) Includes also heaters (3W, TBC)
3) Electronics design is flight proven. Interfaces to sensor elements and electronics box need be adapted (no problem).
4) Includes 4x spherical sensors (50g each), booms (450g each) incl. pre-amplifiers.
5) Boom design depends on possible accommodation configurations on S/C. The further the sensors are from the S/C main body the better. A most suitable place would be the solar panels furthest away from the S/C main body, in which case ca: 1 m long sticks will do.
6) Data rates are dependent on mode of operation choice. The duty cycle of data taking can be adjusted to comply with available TM rates at a particular time.
7) Includes antennas, pre-amplifiers and shielding
8) Includes triad of antennas with deployment mechanism. This triad should preferably be deployed on a boom (TBC) and depends on possible S/C accommodation configuration. The 1-2 m boom not included in mass estimate. Can be MAG boom.
9) Includes 3 SCM-sensors. Should be accommodated on a 1-2 m boom (e.g., MAG boom).
10) Optionally it is possible to use the SSR dipole antenna, in which case no sensor mass is needed (TBC).

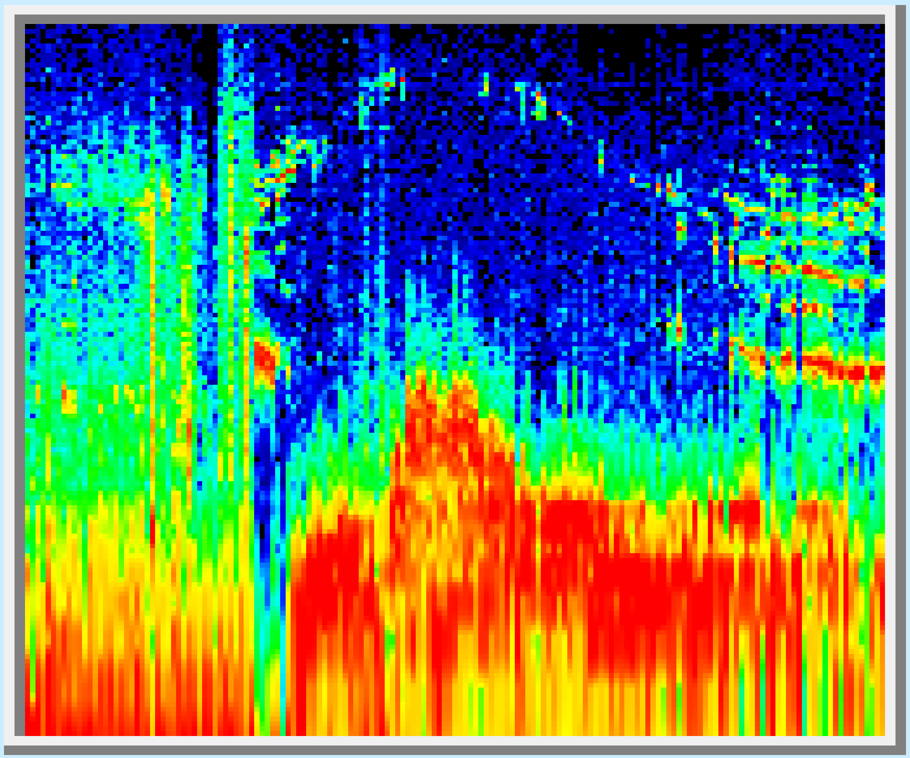
Icy Galilean Moons
(Europa), Ganymede, Callisto

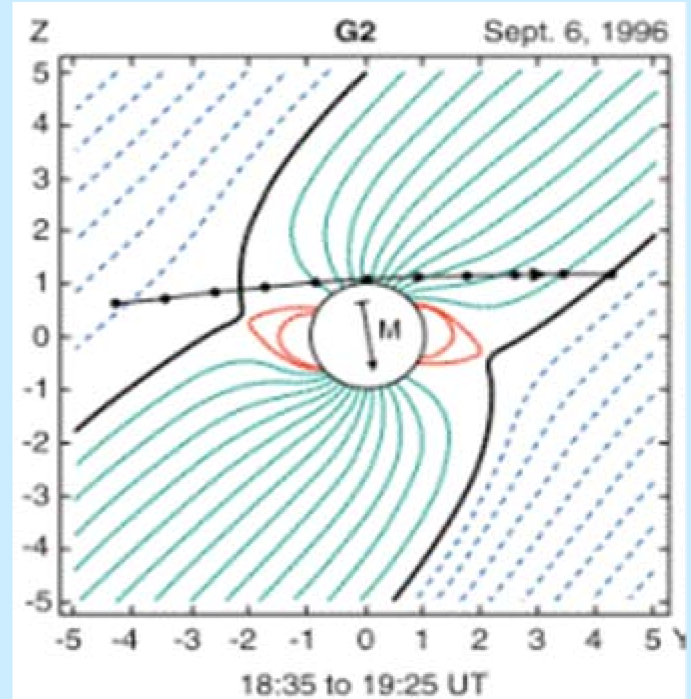


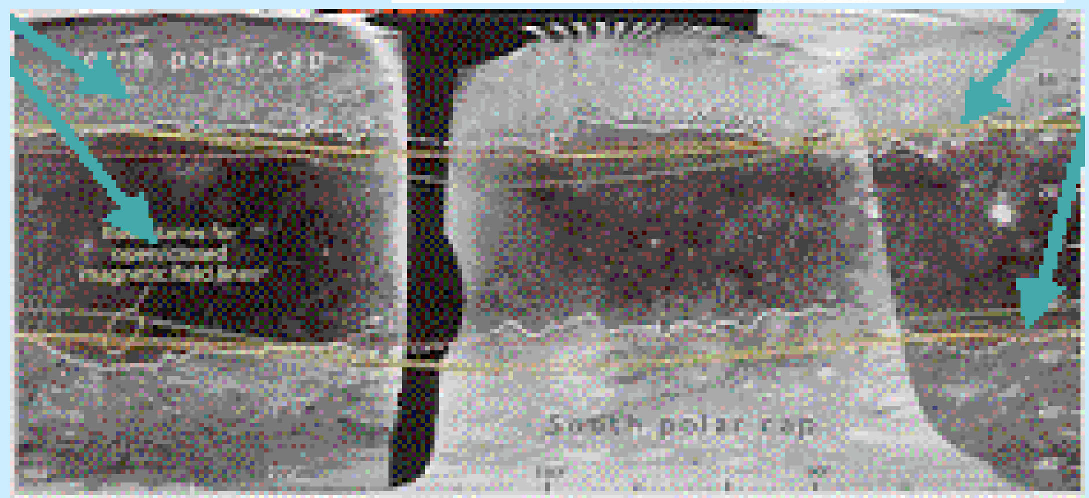
- H_2O-products released fr. surface:
  - Magnetospheric particle sputtering
  - Sub-surface breaching of oceanic material
  - Diffusion from interior
  - Meteoritic impact evaporation
  - Solar radiation decomposition
- Leads to
  - O-rich atmospheres (10^8 cm^{-3})
  - O_2^+-rich ionospheres (500-20000 cm^{-3})
  - Exospheres/exo-ionospheres studied by radio-occultation onboard Galileo & Pioneer-10 and plasma wave instrument (f_{UH}) onboard Galileo
- Interaction with Jupiters magnetosphere makes them highly variable and act as MHD dynamo current system generators
- Possible current systems also in the sub-surface oceans

Ganymede surface interactions

- Internal **B**-field (700 nT)
- Plasma wave acceleration
- Energetic particles reach surface near the poles
- Change surface ice properties







LP measurement of V_{di}

- Ion current (V_{di}) in magnetosphere near Ganymede
  - 10 cm diameter probe
  - Sensitivity = 10-50 pA to probe
  - $n_i v_{di} > (1 - 4) \cdot 10^{10}$ ions/m^2/s for 10 cm probe
  - $n_i v_{di} > (4 - 16) \cdot 10^{10}$ ions/m^2/s for 5 cm probe

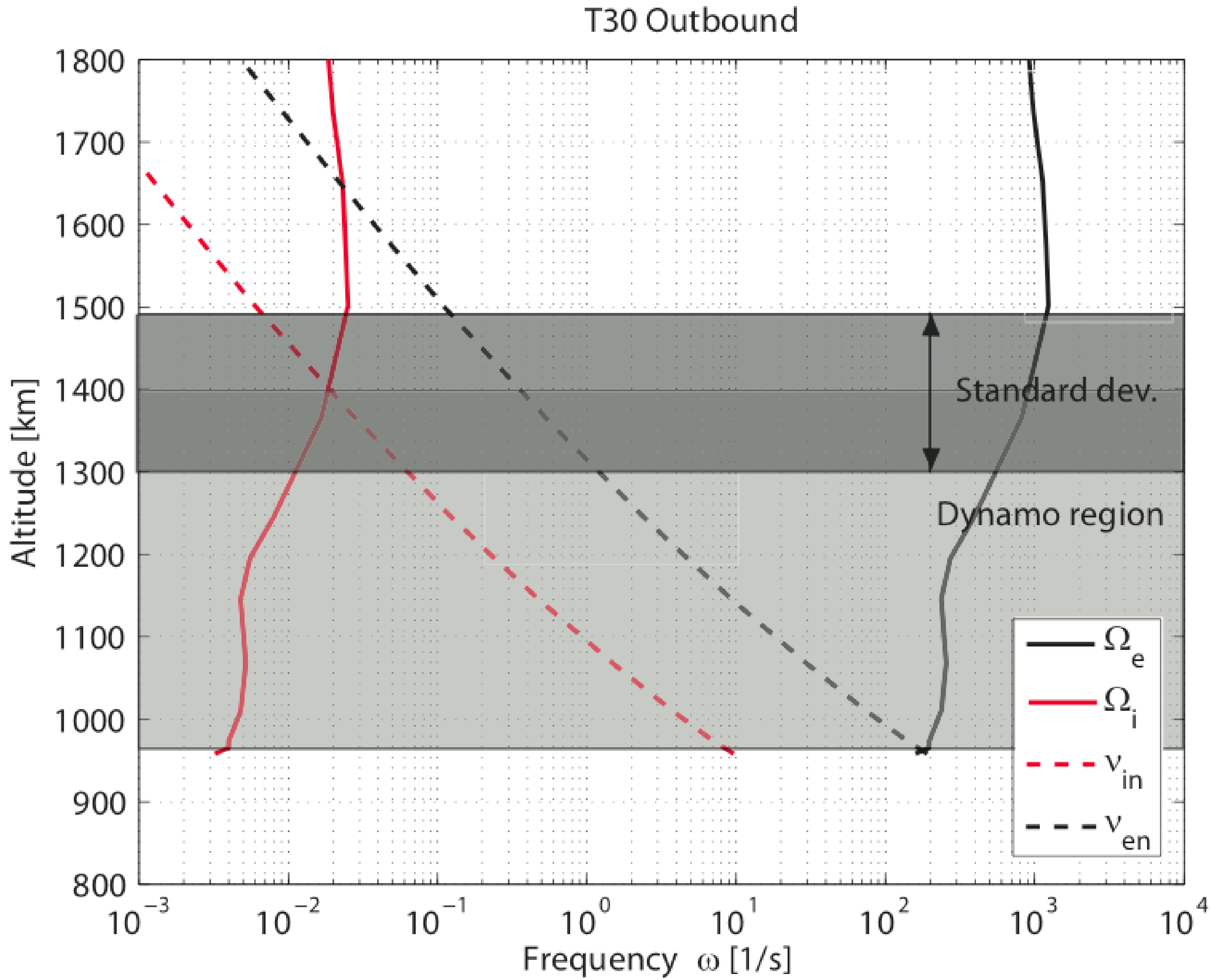
Environment [after *Blomberg et al.*, 2005]

5e11 ions/m²/s

5e10 ions/m²/s

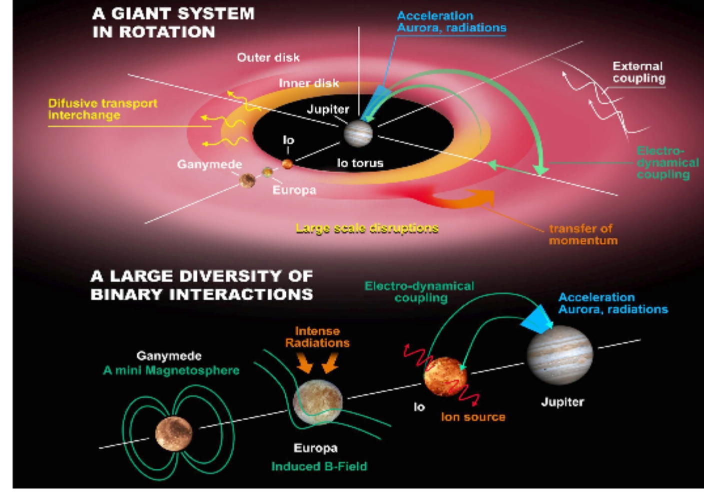
Body	Io	Europa	Ganymede	Callisto	Unit
Radius	1815	1565	2640	2420	km
Distance from Jupiter	5.9	9.4	15.0	26.4	R_J
Orbital period	1.769	3.551	7.155	16.689	days
Co-rotation velocity	75	119	180	334	km/s
Observed plasma velocity	62-74	98	138	236	km/s
Orbital velocity	17.3	13.7	10.9	8.2	km/s
Relative co-rotation velocity	45-57	84	127	228	km/s
Density, Jovian magnetosphere	4000	50	4	0.2	cm^{-3}
Co-rotational dynamic pressure	400	12	2	0.4	nPa
Electron temperature	4	43	130	130	eV
Ion temperature	43	52	60	86	eV
Thermal pressure	30	0.8	0.1	0.01	nPa
Jovian magnetic field	1800	450	100	10	nT
Intrinsic B field (eq. surface)	1300?	small	700	small	nT
Alfvén velocity	130	300	250	300	km/s
Acoustic velocity	19	26	37	40	km/s
Magnetosonic velocity	133	310	250	300	km/s
Beta	0.02	0.01	0.03	0.2	

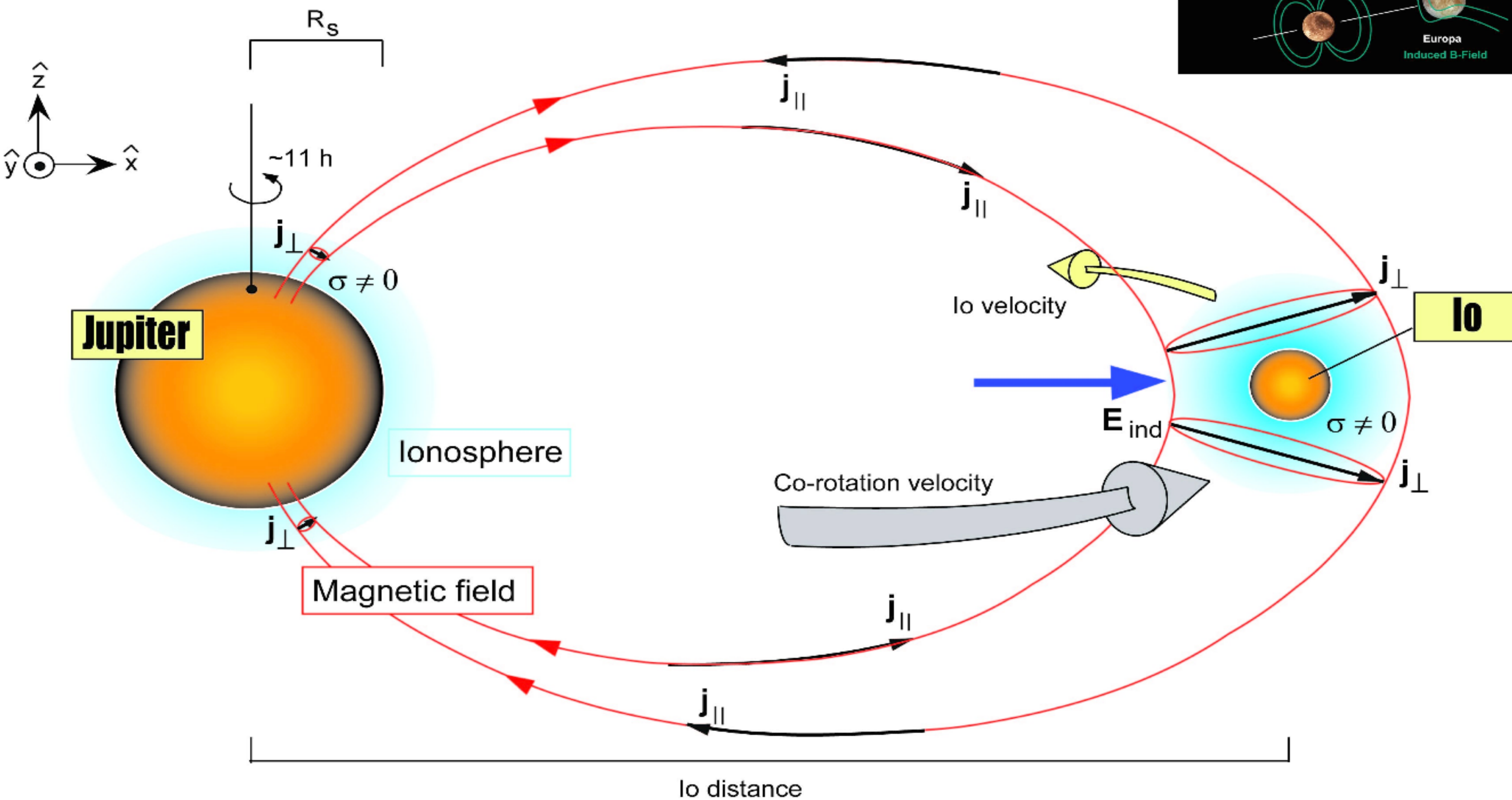
Table 1. The Galilean moons of Jupiter – properties of the moons and their plasma environment. Adapted after [8].


T30 Outbound
Altitude [km]
Frequency ω [1/s]
Standard dev.
Dynamo region
Ω_e
Ω_i
ν_{in}
ν_{en}
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}

Plasma environment

Distribution functions (cold+hot)
EM fields – DC/LF(ion)/HF(electron) frequencies

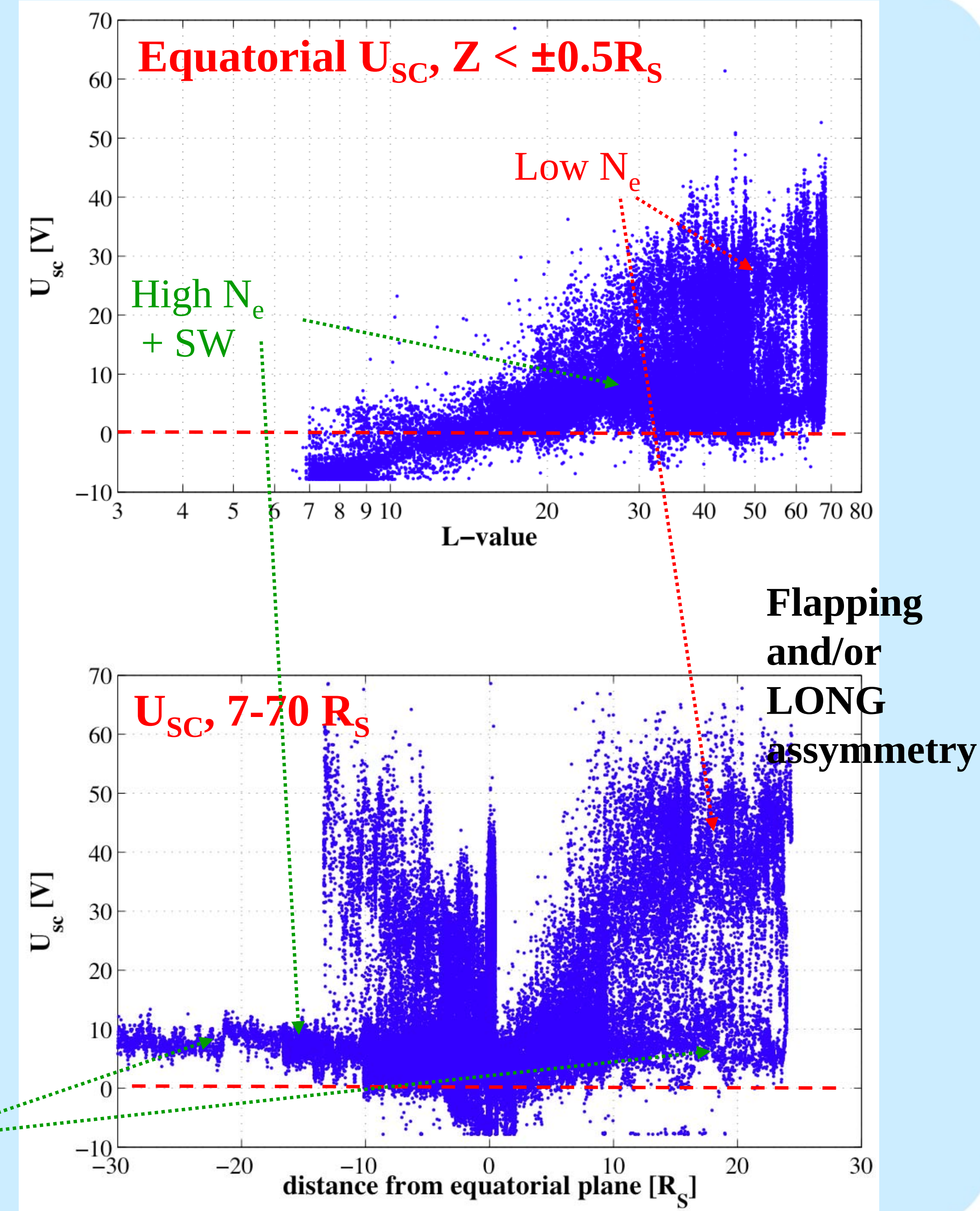




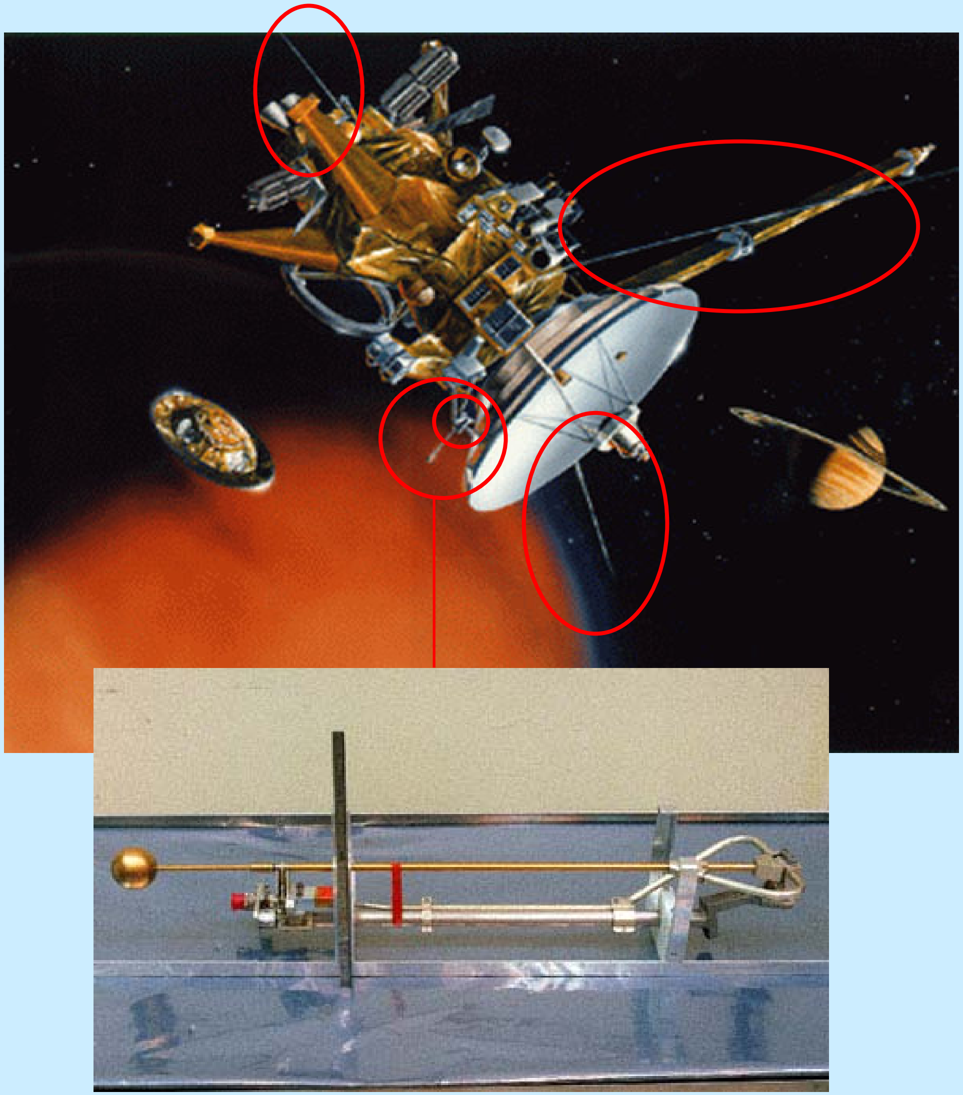
Solar system – best *in situ* laboratory to study plasma universe!

U_{SC} in Saturn's Magnetosphere

- **Equatorial U_{SC}**
  - **Plasma Disk (<11-14 R_S) : < 0V**
  - **Beyond 11-14 R_S: > 0V**
  - **High N_e: + few V**
  - **Low N_e: +15-40V**
- **Z-dependence:**
  - **Lobe regions: +25V to +60V**
  - **SW: + few V**



Cassini Experience



- **Radio & Plasma Wave Science (RPWS)**
- Antenna trio (few Hz - 16 MHz) & Sounder
- Three-axis Search-Coil (few Hz -12 kHz)
- Langmuir Probe (LP)
  - TiN coated spherical sensor (5 cm) on 1.5 m boom
  - Bias Voltage Sweeps (each 24 s)
    - $N_e > 5$ cm^{-3} (photo-e$^-$ limited)
    - $T_e < 8$ eV ($U_{bias} < \pm 32$ V limited)
    - U_{SC} within ±70 V
      - **Give $N_{e,proxy}$ fr. 0.0001 cm^{-3} to 5 cm^{-3}**
    - Ion flux, V_{di}, N_i
    - UV (Ly-α) intensity
  - Other
    - 20 Hz [~300 m res.] at Titan
    - δN/N-"interferometry" at 10 kHz