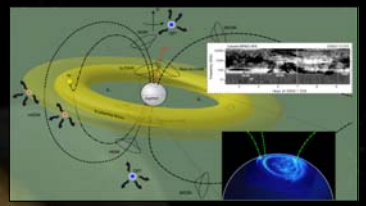
Radio and Plasma Wave Investigations (RPWI) in Japan --- NOW: Engineering Model Development

Radio: first Direction/Polarization, Subsurface (80kHz – 45MHz)
Wave: first Wave-Particle interaction (few – 1MHz/20kHz)
E-field: first DC E-field measurement (Langmuir probe)
Plasma: first Low-T plasma measurement (Langmuir probe)

Y. Kasaba (Tohoku Univ.) + RPWI-Japan



(1) Jovian system: Structure & Variation ～Fast rotating Giant magnetosphere～
(2) Jovian system: Energy release ～System filled with energetic particles～
(3) Satellite – Jupiter system ～Electrical coupling of Satellite - Jupiter～
(4) Satellite environment ～Atmosphere, Magnetosphere, and Interiors～

みんなでふたたび木星へ，そして氷衛星へ その4 ～電波・プラズマ波動観測器RPWIの飛翔へ～

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尾崎 光紀[3]，石坂 圭吾[7]，垰 千尋[8]，三好 由純[9]，阿部 琢美[10]，
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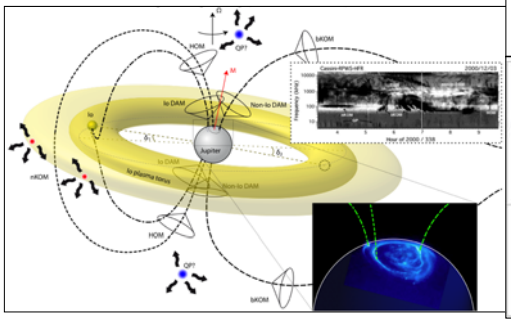
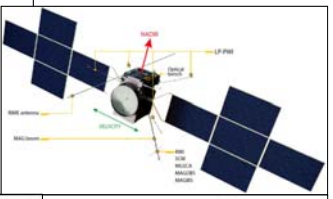
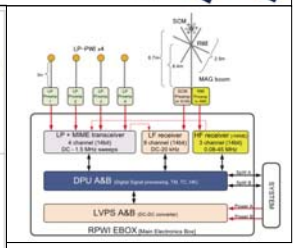
JUICE-RPWI日本チーム

（要旨）欧州宇宙機関（ESA）木星探査機JUICEに搭載される電波・プラズマ波動観測器RPWI（Radio Plasma Wave Instruments）は，欧州チームにより氷土星探査機カッシーニ搭載のRPWS，日本チームにより月探査機かぐや・ジオスペース探査衛星ERG・日欧水星探査機BepiColombo搭載の電波・プラズマ波動・レーダー観測器群からの発展展開となる，木星・衛星周回軌道への初投入となる低温電子・イオンおよびDC電場観測機能，電磁場三成分のプラズマ波動観測機能，電波の方向探知・偏波観測機能，および高度オンボード処理によるバッシブ表層・地下探査レーダー機能や波動-粒子相互作用検出機能により，木星総気圏の構造・ダイナミクスおよびガリレオ衛星群との相互作用，氷衛星の大気・電離圏および氷地殻・地下海へのアクセスを狙う．2016年7月に仙台で行われた「RPWIチーム会合」での最新状況を踏まえ，1970年代に遡る本チームの経緯・目標・展望を述べる．

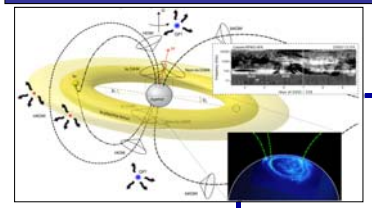






ref. 笠羽他，日本惑星科学会誌，25, 3, 96-107, 2016.

RPWI: Contribution from Japan ---- TEAM structure



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[Tohoku Univ.]

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[Kanazawa Univ.]

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Scientist (SWPIA / model)

Atsushi Kumamoto
Co-I (HF: Passive Radar)
[Tohoku Univ.]

Meisei Elec.
H/W development

H/W:
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(Tohoku Univ., Meisei Elec. Co.)

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Science (Obs / Model)

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Masato Kagitani	Sci. (Obs)	Tomoyuki Nakajo *[Fukui Univ. Tech.]*	Sci. (Obs)
Hajime Kita	Sci. (Obs)	Kazumasa Imai *[Kochi National Coll. Tech.]*	Sci. (Obs)
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Hiromu Nakagawa	Sci. (Obs)		
Shoichi Okano	Sci. (Obs)		
Hiroshi Oya	Sci. (Obs)		
Takeshi Sakanoi	Sci. (Obs)		
Naoki Terada [Tohoku Univ]	Sci. (Model)		
Satoshi Kurita	Sci. (Obs)		
Shoya Matsuda *[Nagoya Univ.]*	Sci. (Obs)		

Radio and Plasma Wave Investigations (RPWI)

(2) Jovian system: Energy
～System filled with Relativistic particles～
Particle accelerations along the field lines ?
MEV accerelation by Wave ?
Injection of plasmas into the inner region ?

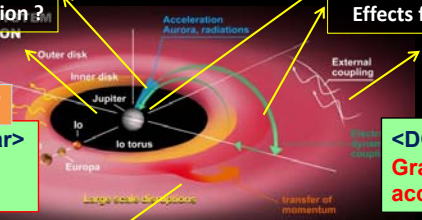
(1) Jovian system: Structure
Fast rotating Giant magnetosphere～
MIT Couplings ?
Retraction of rot. Energy to outside?
Effects from outside? SW / EUV

first Direction/Polarization/Refl HF section

first detection !

<Radio: Remote with UV/IR & Radar>
Global high-Energy activities !
Remote sounding of Satellites !

<DC E-field: In-situ>
Grasp the plasma motion & acceleration E-field !



<Wave: In-situ>
Direct detection of Electromagnetic energy exchanges !

<Low-T plasmas: In-situ>
Grasp the plasmas around/from satellites !

first detection !

[first Wave-Particle interaction]

S-WPIA

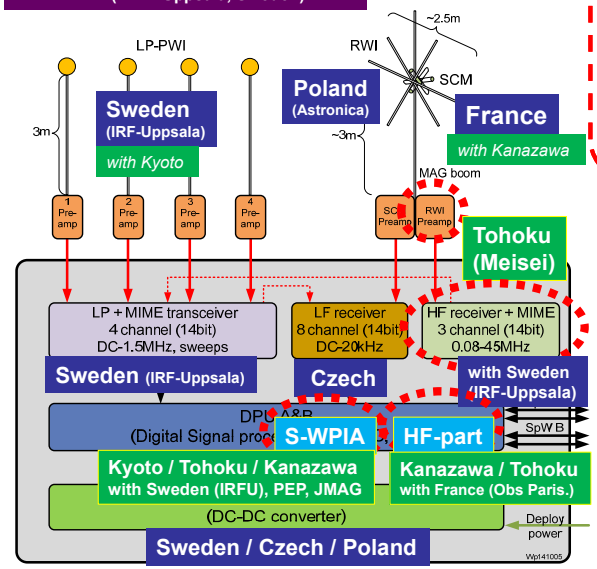
Passive Radar

(3) Satellite – Jupiter system
～Electrical coupling of Satellite - Jupiter～
Current connections between them ?
Enhancement by plasma from satellites ?

(4) Satellite: Environment & Crust
～Electrical sounding of Atmosphere / Interior～
Plasma production: Volcano, Water, … ?
Conductivity of Surface & Subsurface ?

Radio and Plasma Wave Investigations (RPWI)

[PI] Jan-Erik Wahlund
(IRF – Uppsala, Sweden)



Sweden (x2), Austria (x1) Czech(x1), France (x4), Japan (x6+α), USA (x5), Poland (x1), UK (x2)

<Remote sensing: Radio>

[HF-System]

* Ex3(80kHz – 45MHz)

first Direction & Polarization →
Remote sensing of Plasma with IR/UV/ENA
Surface & subsurface with Radar & submm

HF | Passive Radar

<In-situ: Waves, DC E-field, Low-T plasma>

[LF-System]

* Ex3 & Bx3 (few – 20kHz) — S-WPIA
* Wave-Particle correction

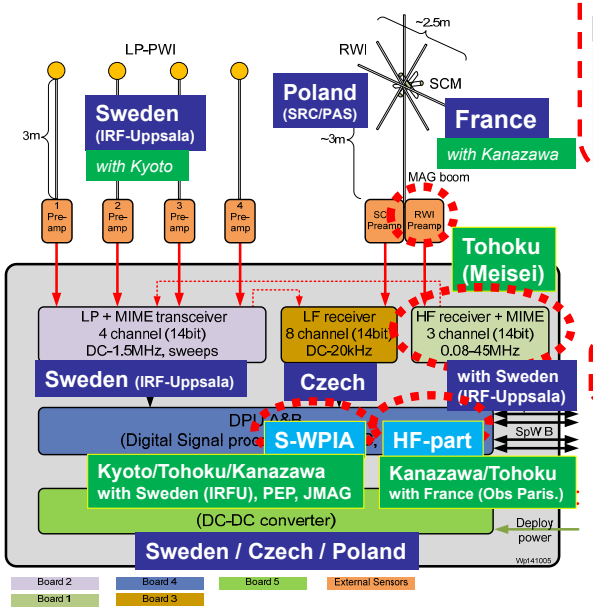
[LP-System]

* Electron / Ion (Langmuir probe)

first Wave-Particle interaction
first DC-E field detection
first low-T plasma detection

RPWI: Contribution from Japan

[Co-PI] Y. Kasaba (Tohoku Univ.)



<Remote sensing: Radio>

[HF-System]

* RWI Preamp (Tohoku / Meisei)
* HF – Receiver (Tohoku / Meisei + IRF-Uppsala)
* DPU: HF - Software (Tohoku / Kanazawa)

HF | Passive Radar

<In-situ: Wave, DC-field, Low-T plasma>

[LF & LP-System] — S-WPIA

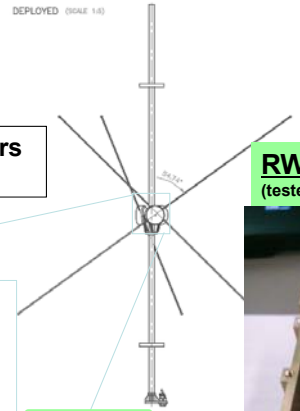
* Software-type WPIA (Tohoku/Kyoto/Kanazawa)
* Contribution to design: E/B sensor, Langmuir Probe (Kyoto/Kanazawa/Tohoku)

[Science]
Hokkaido, Hakodate FU, Tohoku, Nagoya, Toyama PU, Kanazawa, Fukui IT, Kyoto, Kouchi NCT, RIKEN

RPWI: Contribution from Japan ---- H/W

[Critical] Radiation, Low-T, Long harness | (80k-45MHz) x X/Y/Z

RWI-ANT
Poland (Astronika)



2.5m tip to tip x 3 pairs
(8m from S/C)

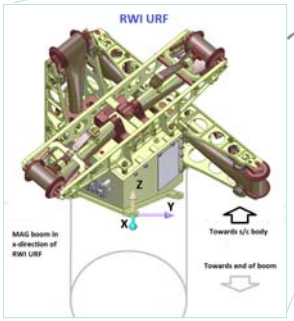
HF
Tohoku U
Meisei

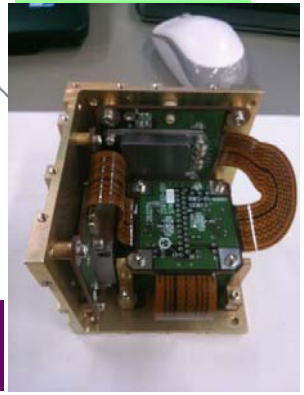
[Heritage]
Kaguya/LRS
ERG/HFA

with HF-FPGA
by IRF-Uppsala

RWI-Pre EM1
(tested in 2016)

HFA: EM1
(tested in 2016)





RWI-Pre
Tohoku U
Meisei

[Heritage]
MMO/WPT-Pre
Kaguya/PWS-Pre

RPWI: Contribution from Japan ---- H/W

High Radiation (Mrad ??)

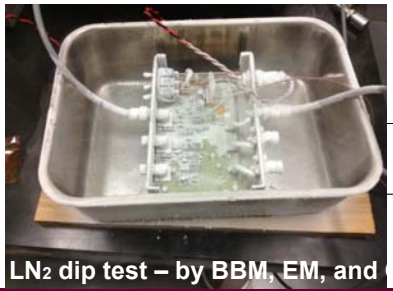
"Al 3.0mm + Ta 1.3mm"
→ <100krad

Long Harness (10.5m for 50MHz)

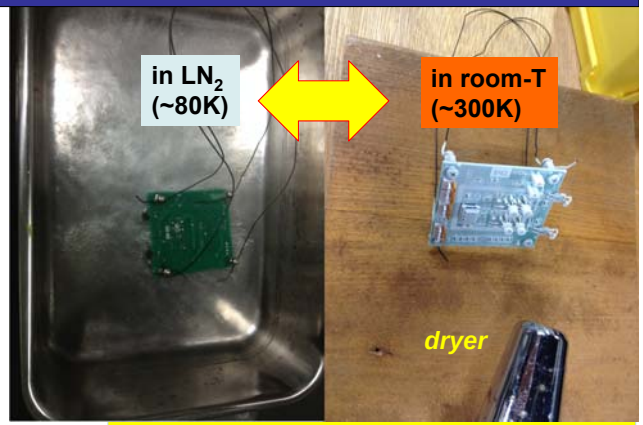
- Tested & revised to 'Co-axial', well covered by Rad-shield

Low Temperature (30-40 K ??)

- LN_2 (-77K) test
  → Ok above 145K!
- Low-TEMP chamber
  → in TU & Meisei + ESTEC



LN_2 dip test – by BBM, EM, and



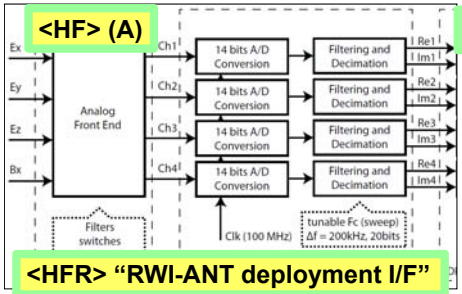
LN_2 low temperature Shock-cycle test
'300K <> 80K' x 20 (BBM#4 in 2015, EM1 in 2016)

LN_2 -- low temperature function and performance test

Thermal Vacuum Test: +120 ~ -170degC
… succeeded by BBM#4 / EM1

RPWI: from Japan DPU software

A. DPU – HF data reduction (Kanazawa U / Tohoku U)

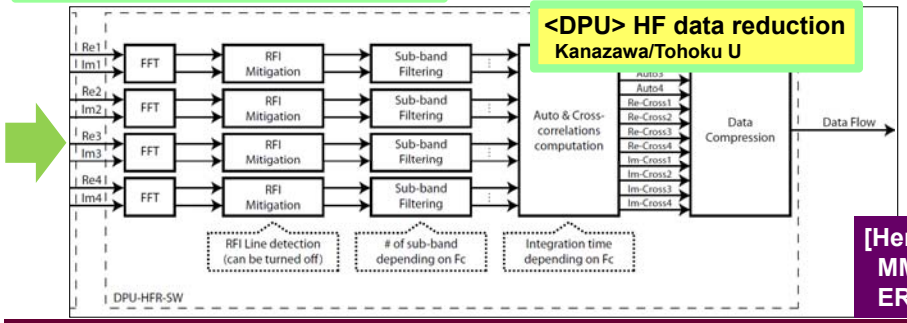


<HF> (D)

<HF output>
"330kHz x 3ch x2(real / imaginary) "
down-converted waveform

<TLM output> *** SOFTWARE in DPU! ***
80kHz~45MHz x 1~3ch、1-64s resolution
Spectrum data: 0.2 – 1.6kbps

<HFR> "RWI-ANT deployment I/F"



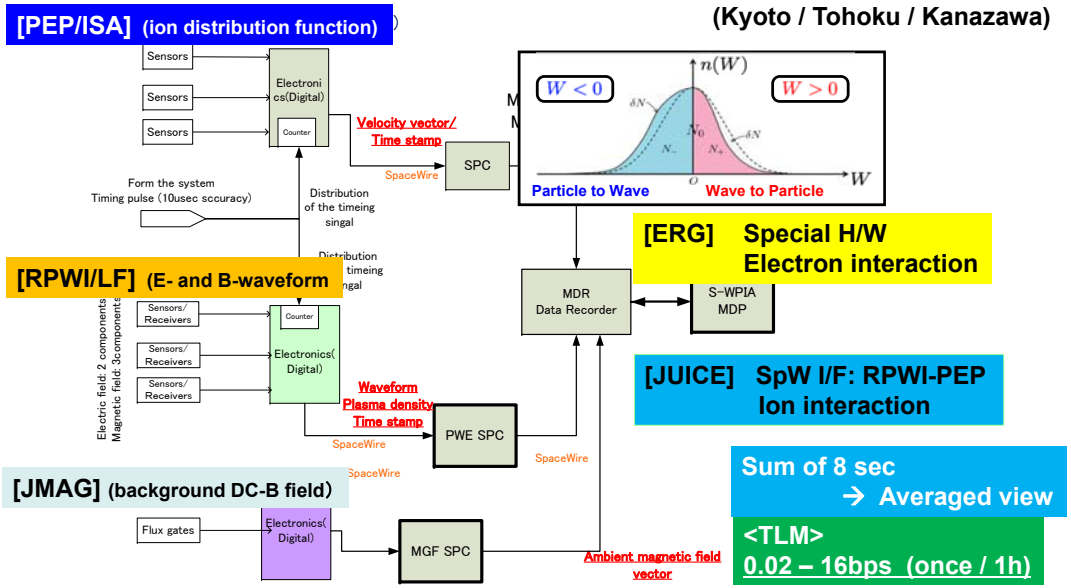
<DPU> HF data reduction
Kanazawa/Tohoku U

[Heritage]
MMO/MDP - PWI
ERG/PWE - HFA

[DPU: Software-type Wave Particle Interaction Analyzer (SWPIA)]

[Heritage] ERG/S-WPIA

(Kyoto / Tohoku / Kanazawa)



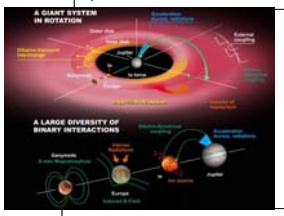
[DPU: Software-type Wave Particle Interaction Analyzer (SWPIA)]

[Heritage] ERG/S-WPIA

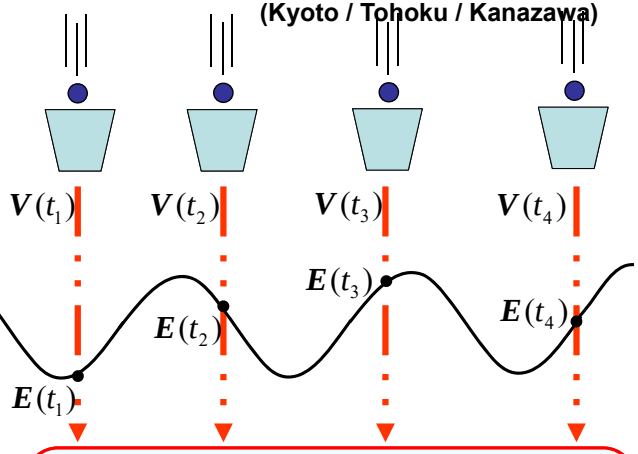
JUI-IRFU-RPWI-TN-026_i1.0_Wave_Particle_Interaction_Analyzer

(Kyoto / Tohoku / Kanazawa)

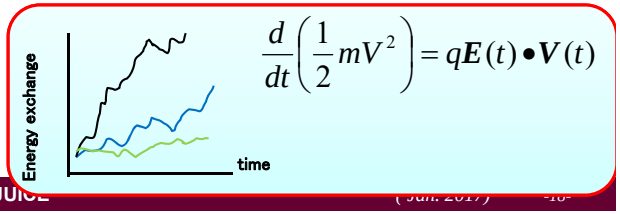
Plasma particle sensor (Plasma measurement)



Plasma wave receiver (Waveform observation)



Direct measurement of energy flow by Wave – Electron/Ion interaction

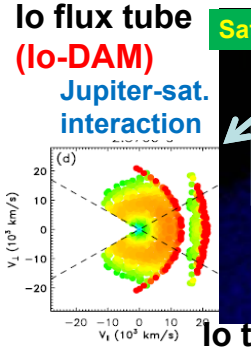


It is larger demand for the low-TLM missions!

(1) Jovian system: Structure & Variation ～Fast rotating Giant magnetosphere～
(2) Jovian system: Energy release ～System filled with Relativistic particles～
(3) Satellite – Jupiter system ～Electrical coupling of Satellite - Jupiter～

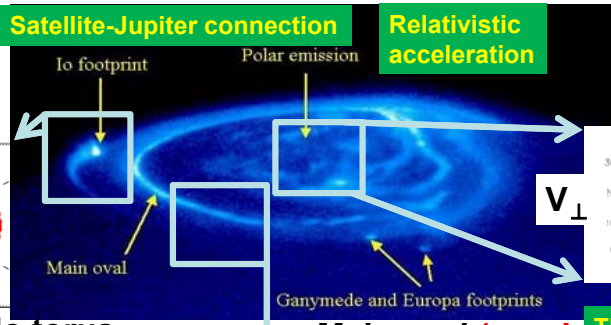
Io flux tube (Io-DAM)

Jupiter-sat. interaction



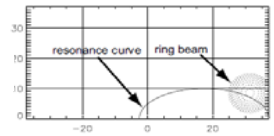
Satellite-Jupiter connection

Relativistic acceleration



Polar cap (QPB)

Quasi-Periodic Emission

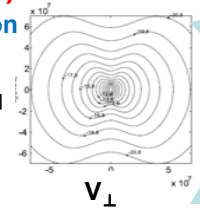


$V_\perp$

$V_{//}$

Io torus (nKOM)

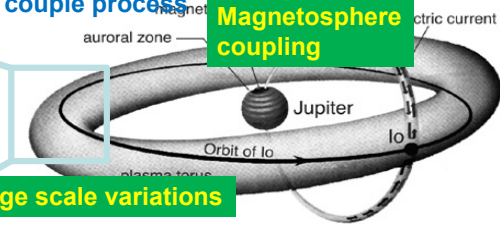
injection



$V_\perp$

Main oval (non-Io)

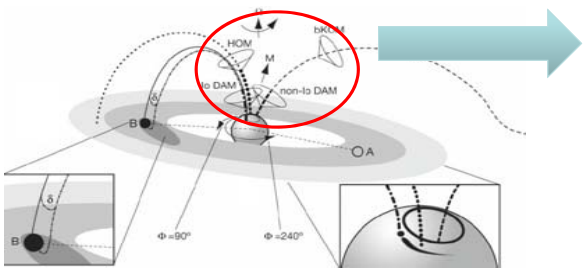
M-I-T couple process



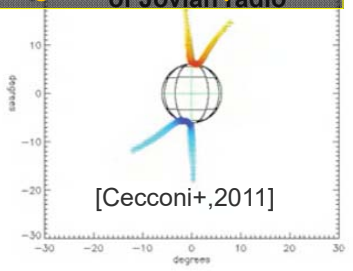
Themosphere – Ionosphere – Magnetosphere coupling

Large scale variations

Accelerations were rarely observed by in-situ. They can be remotely sensed by radio emissions.

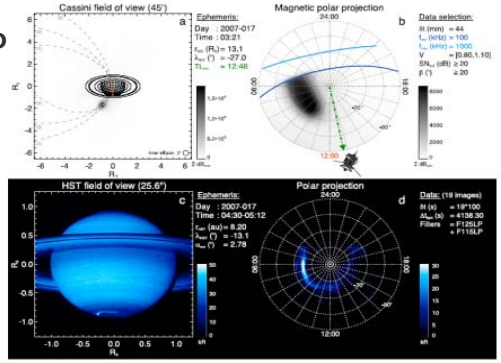


Simulated source direction of Jovian radio



[Cecconi+,2011]

Saturn's auroral radio imaged by Cassini
[Lamy+09]

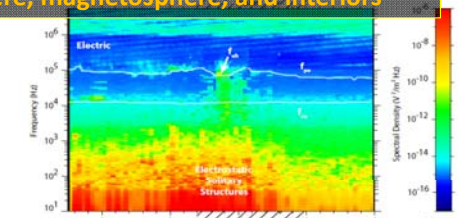


'Imaging of particle accelerations' can be achieved by
Goniopolarimetry

first Direction & Polarization
→ plasma remote sensing package with IR/UV/EUV

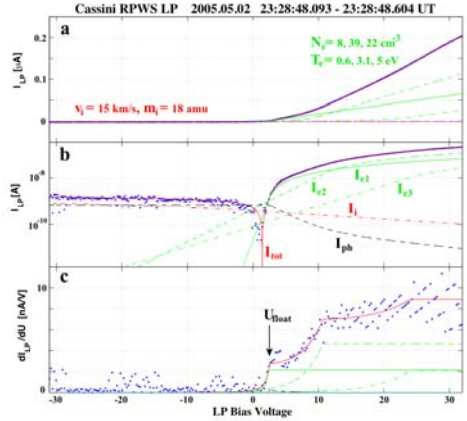
Plasma Density

first DC-E field detection
first low-T plasma detection
by In-situ & Remote [radio occultation])



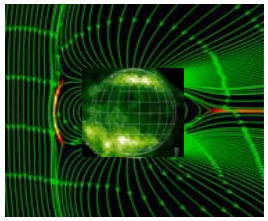
The number density is determined through several techniques:

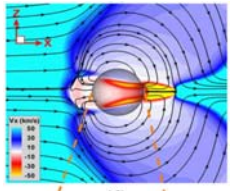
- LP-PWI bias voltage sweeps (for densities > 10 cm^{-3})
- Monitoring the upper hybrid emissions (f_{uh})
- Monitoring the spacecraft potential (U_{SC}) and calibrating toward f_{uh} (or possibly an electron spectrometer on board S/C).
- Continuous sampling of the probe current (allows ms time resolution).
- Active mutual impedance measurements (MIME)

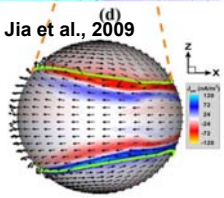


Icy Moon Conductivities & Electric Currents

first DC-E field detection
first low-T plasma detection
with Surface & subsurface Remote [radio reflection])







Jia et al., 2009

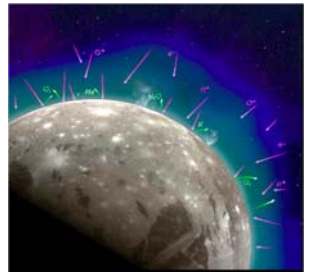
Upward/Downward
$j \approx 0.05\text{-}0.1\ \mu A/m^2$

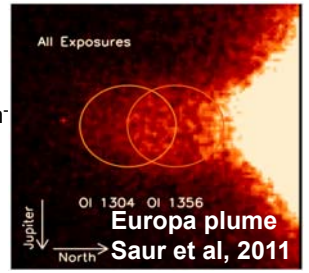
- Determine the electric conductivity
  - Assess their role in supporting MHD-dynamo generated current systems induced by the rotating and variable Jovian magnetosphere
  - Assess how these currents may couple inductively to sub-surface oceans
- Monitor electric acceleration structures at magnetic flux tubes connected to Ganymede's auroral regions.
  - $\sigma_H \approx -\sigma_P \sim en_e/(2B) \sim 10^{-4}\text{-}10^{-3}$ mho near surface
  - $j \geq \sigma E \sim 0.1\ \mu A/m^2$ $I \geq 100$ kA through ionosphere?
  - Or through salty sub-surface ocean?

Ionization, heating and dynamics of exospheres

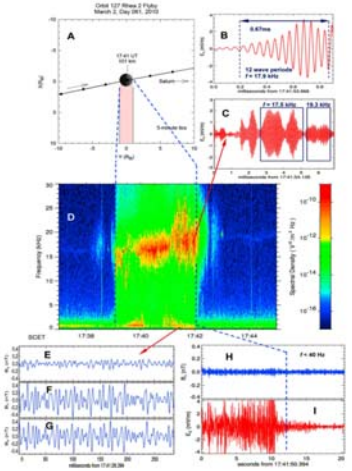
- H_2O-products released fr. surface:
  - Magnetospheric particle sputtering
  - Sub-surface breaching of oceanic material
  - Diffusion from interior
  - Meteoritic impact evaporation
  - Solar radiation decomposition
- Leads to
  - **O & O_2-rich atmospheres** (10^8 cm^{-3})
  - **O_2^+-rich ionospheres** (500-20000 cm^{-3})
  - **Electrically conducting** layers
- RPWI will:
  - Monitor plasma densities 10^{-4} – 10^5 cm^{-3} (ms resolution)
  - Locate (electron) heating regions in the dense plasma (>0.1 cm^{-3})
  - Determine **ExB** convection and bulk ion drift speed
  - Monitor the size and mass distribution of a possibly existing charged dust component
  - Monitor **dust-plasma** interactions

first low-T plasma detection

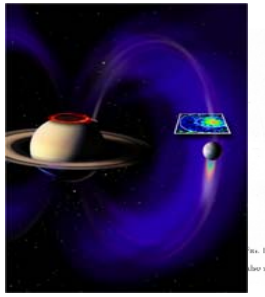


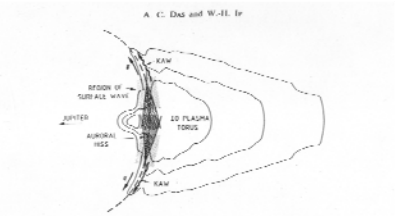


Whistlers



Dispersive Alfvén Waves

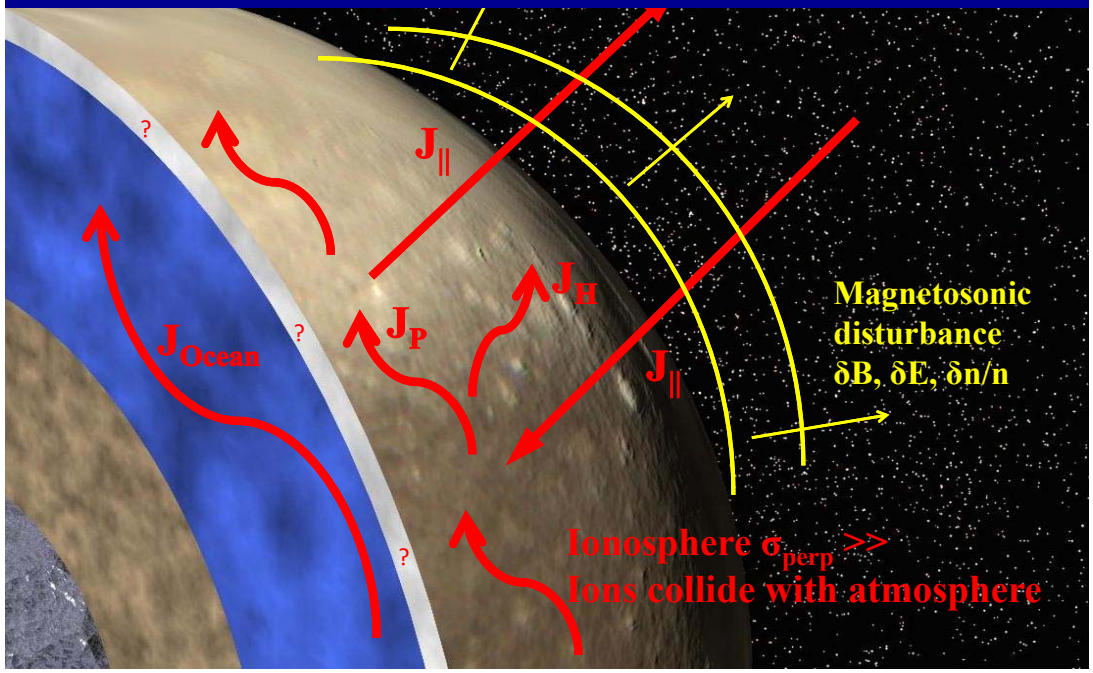




[first Wave-Particle interaction]
first DC-E field detection
first low-T plasma detection

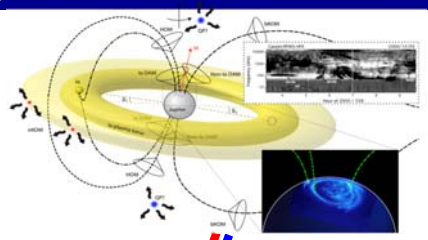
[DPU: Passive SubSurface Radar (PSSR)]

JUI-IRFU-RPWI-TN-026_i1.0_Passive_Subsurface_Radar



[DPU: Passive SubSurface Radar (PSSR)]

[Heritage] Kaguya/LRS



Pros

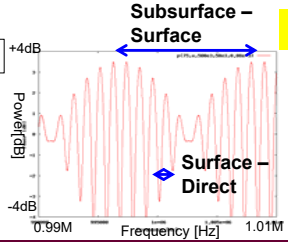
Radio Source: Low-Frequency (& Wide-band) radio waves from Jupiter which continuously emitted.

Less attenuation ($\propto 1/f$) in the subsurface media is expected in ~1MHz.
(Long antenna & PWR is needed if we emit it.)

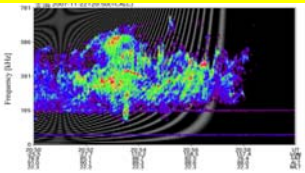
ref. **RIME** = Active Radar @ 9MHz

Cons

Jupiter-side area of the moons only
(Ganymede: 7.15 day orbit around Jupiter)



Lunar case: AKR by Kaguya LRS



[DPU: Passive SubSurface Radar (PSSR)]

JUI-IRFU-RPWI-TN-026_i1.0_Passive_Subsurface_Radar

<Reflectance> Space(ε_r=1) ⇔Ice(ε_r=3) ⇔ Liquid ocean (ε_r=87)

Surface echo (Space ⇔ Ice)

R_S ~ 0.27

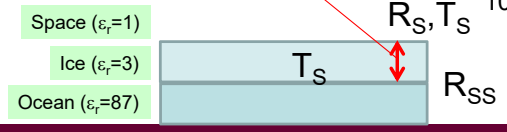
Subsurface echo (Ice ⇔ Ocean)

R_{SS} ~ (1-0.27) x 0.69 x T_{ice}
~ 0.50 x T_{ice}

<Transmission in ice ~150 km>

T_{ice} ~ 0.25 – 0.06 @ 50MHz
[$f_{TiO2,FeO}$ = 1 - 10%]

Ice thickness: D>150km
(suggested in prev. studies)
[kivelson et al. 2002; Spohn and Schubert, 2003]



PSSR (passive radar) @ 1MHz [up to ~90km ??]