## **COLD PLASMA DIAGNOSTICS IN THE JOVIAN SYSTEM:**

# **BRIEF SCIENTIFIC CASE AND INSTRUMENTATION OVERVIEW**

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# ABSTRACT

he ovian magnetosphere equatorial region is filled with cold dense plasma that in a broad sense co rotate with its magnetic field he volcanic moon o which expels sodium sulphur and oxygen containing species dominates as a source for this cold plasma he three icy alilean moons allisto anymede and uropa also contribute with water group and oxygen ions

If the alilean moons have thin atmospheres with residence times of a few days at most heir ionized ionospheric components interact dynamically with the co rotating magnetosphere of upiter and for example triggers energy transfer processes that give rise to auroral signatures at upiter n these moons the surface interactions with the space environment determine their atmospheric and ionospheric properties

he range of processes associated with the ovian magnetospheric interaction with the alilean moons where the cold dense plasma expelled from these moons play a key role are not well understood onversely the volatile material expelled from their interiors is important for our understanding of the ovian magnetosphere dynamics and energy transfer

angmuir probe investigation giving *in-situ* plasma density temperatures UV intensity and plasma speed with high time resolution would be a most valuable component for future payloads to the upiter system

ecent developments in low mass instrumentation facilitate angmuir probe *in situ* measurements on such missions

# 1. SCIENTIFIC CASE IN BRIEF

### 1.1 Basic Properties of the Galilean Moons Atmospheres and Ionospheres

he atmospheres of the alilean moons of upiter are almost collision free and the atoms and molecules within them can to a large degree directly leave the weak gravitational field of these moons he residence times for their atmospheres are of the order of a few days at most hese atmospheres can therefore rightly be termed exospheres and their corresponding ionized parts can be termed exo ionospheres

bservations indicate that the exospheres of the three icy alilean moons uropa anymede and allisto everal authors have also are oxygen rich [ ] ] and the oxygen was modelled these exospheres [ thought to be water products released from the surface by the action of magnetospheric energetic charged particle bombardment Ikali atoms have been detected in the exosphere of uropa [] which has been suggested to come from sub surface oceanic material that has breached the icy surface in the past [] II the three icy moons are predicted to have sub surface oceans [] ther possibly contributing atmospheric sources are diffusion from the interior meteorite impact evaporation and solar radiation decomposition and sputtering he exosphere of allisto may also harbour significant amounts of as detected by the instrument on board alileo []

he exosphere of o has its origin from volcanic activity on the moon as well as surface sputtering by magnetospheric charged particle bombardment ulphur dioxide is released into the tenuous atmosphere by volcanoes which is then partly transformed into

and [ ] he atmosphere and ionosphere of o are highly variable given the nature of the volcanic sources Iso the night and daytime atmospheric densities may differ by several orders of magnitude due to the temperature dependence of frost on the surface he surface pressure may at times reach a nbar in which case the exobase is above the surface and may rise to an altitude of ~ km

he ionospheres of the three icy alilean moons have been observed with radio occultation techniques [

] as well as by using in situ upper hybrid emission measurements [] on the alileo spacecraft n

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allisto peak ionospheric densities of up to cm were inferred a few tens of km above the surface near the equator he allisto ionosphere seemed highly variable in time between flybys and a detectable ionosphere was only found when the ram side was in sunlight which indicates that both plasma impact ionization and photo ionization are sources for this ionosphere he ionosphere of uropa showed peak densities up to cm near the surface

he ionosphere of anymede is a special case since this moon also has a substantial internally generated magnetic field n near surface that forms a small magnetosphere inside the magnetosphere of upiter he presence of a magnetic field affects the dynamics of the ionosphere [ ] he dipole moment is aligned with the ovian magnetic field and thus the interaction at anymede's magnetopause favours reconnection he ionosphere is dominated by molecular steadily oxygen ions at polar latitudes and by atomic oxygen ions at low latitudes [] he polar wind plasma outflow along "open" polar cap field lines to upiter's magnetosphere would likely consist of atomic oxygen ions because of their greater mobility t has been suggested that the ice properties are modified by the impacts of the energetic particles entering on polar cap open field lines [ ] allisto and uropa do not have significant permanent magnetisation ather an induced magnetic field is set up through the interaction with upiter's planetary field

he ionosphere of o has been confirmed by radio occultation measurements on board ioneer and he densities vary considerably alileo [ 1 between the leading and trailing hemispheres showing the influence of changes in its atmosphere as well as in the co rotational magnetospheric flow he ionospheric peak was below km and typical plasma densities near o reach cm urprisingly o's ionosphere was found dominated by a [ ] ulphuric ion components exist but are less abundant he belief is that surface sputtering of a and a by heavy charged particle bombardment from the surrounding magnetosphere cause sodium to be the dominant ion

# 1.2 Dynamic Interaction with the Jovian Magnetosphere

he four alilean moons orbit upiter well inside the ovian magnetopause and consequently interact primarily with upiter's co rotating magnetosphere he interaction at the alilean moons is sub magnetosonic and the flow is diverted gradually without the formation of shock fronts t allisto the ach number may at times exceed unity although alileo observed no such cases [] more detailed account for the magnetospheric electrodynamics can be found in two companion papers [] he interaction of the ovian magnetospheric plasma with the cold plasma in the ionospheres of the alilean moons acts as a dynamo driving lfvén waves and field aligned currents along upiter's magnetic field that close dissipates in the ovian ionosphere [] he cold plasma variations in the neighbourhood of the dilean moons therefore play a key role for the

alilean moons therefore play a key role for the workings of this dynamo he effect is clearly seen in images of UV emissions from upiter's ionosphere at the sub auroral foot points of the alilean moons [] o far such auroral spots have been found corresponding to o uropa and anymede o's being the far most luminous

t has already been said that the plasma in the ovian magnetosphere approximately co rotates with the planet owever the co rotation is not perfect but rather the plasma lags behind co rotation by a rate that increases with distance from the planet [ ] nside

the plasma flow is close to co rotational while outside this distance the flow lags with respect to co rotation and stays around km s

o is a very important source of plasma for the ovian magnetosphere xospheric molecules escape the gravitation field of o and move into the magnetosphere of upiter in copious amounts here the neutrals are ionized and dissociated by magnetospheric electrons he total source of ions from o is ions s he newly created ions are affected by the orentz force and are picked up by the co rotating ovian magnetic field and form the o plasma torus he size of the torus large where number densities reach cm near o and decreasing outward with a scale height of the order of a upiter radius

ince the o plasma torus is slightly collisional the plasma as a whole is heated via this pickup process he detection of an extended and stagnant wake downstream of o [] indicates that the plasma takes a considerable time to accelerate to co rotation speed he o plasma torus consists of an inner cold part  $_{i}$ ~ eV and an outer hotter part  $_{i}$ ~ eV that is somewhat colder than the pickup energy

## 2. INSTRUMENTATION OVERVIEW

or future detailed investigation of the alilean moons and their interaction with the ovian magnetosphere a most valuable payload element would be a double angmuir probe instrument wo state of the art examples of such sensors are the instrument W on board on osetta [ ] and the assini uygens [] oth these examples employ titanium nitride i surface coatings on the sensors first flown on the wedish satellite strid to ensure good electrical work functions durability and chemical inertness

#### 2.1 **Principles of Measurement**

angmuir probe experiment consists of a small conducting spherical sensor of a few cm diameter mounted on a boom extending from the spacecraft he length of the booms should optimally be longer than the local ebye length  $\lambda_e$  and the probes situated in the ram plasma flow n practice the boom length and placement is often subject to considerations of what is technically feasible on the spacecraft n assini and osetta the solid boom length used was m and m

respectively n a spinning spacecraft there is the choice to have much longer wire booms



Fig. 1: The dual Langmuir probe instrument on board Rosetta that will arrive at a comet in 2014.

angmuir probe is in theory a simple experiment where the probes are set to a specific bias potential or swept in bias potential and the electrical current from the surrounding plasma is sampled When the probe is negatively biased the current is dominated by ions attracted to the probe or by photoelectrons emitted from a sunlit probe When the probe is positively biased attracted electrons dominate the current rom a controlled angmuir probe experiment it is possible to derive a fair range of information from the cold plasma component below an energy a few tens of eV as described below

he bulk ion and electron temperatures density and composition are crucial parameters for understanding any space plasma and related aeronomy or instance knowing the plasma density and temperatures is necessary to understand what chemical pathways in ionospheres and atmospheres he plasma in the ionospheres of the alilean moons as well as the surrounding magnetosphere of upiter is typically collision free mean free path  $\lambda_e$  and of low probe radius and therefore rbit density  $\lambda_{e}$ otion imited theory [ ] works well to describe the current voltage relationship of a angmuir probe in this environment

Table	1.	Basic	plasma	properties	derivable	from		
Langmuir probe operations.								

<u>nstrument</u> <u>ode</u>	<u>easured</u> <u>uantity</u>	<u>ange</u>					
Potential Sweep each s	n <sub>e</sub> <sub>e</sub> v <sub>thi</sub> ∼√ <sub>i</sub> m <sub>i</sub> φ UV ntensity	– cm – eV ± V					
<b>ð</b> n/n, interferometer	n <sub>e</sub> δn n e V <sub>plæma</sub>	– cm k z – eV k z km s					

\*) Depending on plasma density. Lower if density falls below 1,000 cm<sup>-3</sup>

\*\*) Depending on sampling frequency and probe separation

Fig 2. The RPWS Langmuir probe on board Cassini operates successfully in most regions of the Kronian magnetosphere even if its main objective is to carry out measurements in the ionosphere/upper atmosphere of Titan.

n theory the current for positive bias potential is directly proportional to density and the slope of the characteristic of the current voltage relationship is proportional to  $n_e \sqrt{e}$  rom these relations the plasma density and electron temperature can be determined from a Voltage sweep rom the negatively biased part of the characteristic one can for dense enough plasma estimate an effective ion energy consisting of a ram and a thermal part  $m_i v$  e i nowing the spacecraft

velocity this information gives an estimate of  $\sqrt{i}$  m<sub>i</sub> and by knowing the ion mass from for example ion mass spectrometers the ion temperature can be derived

onversely if the ram flow dominates some information on the ion mass can be obtained he negatively biased part of the angmuir probe voltage sweeps also give information on the y alpha UV intensity which is an important parameter for determining the surface – radiation interaction processes of the icy moons of upiter [ ]



Fig 3. Derived parameters from Cassini RPWS Langmuir probe potential sweeps during the flyby of the inner magnetosphere of Saturn [34].

## 2.2 High Time Resolution $\Delta n/n$ and T<sub>e</sub>

n previous spacecraft angmuir probes at constant bias have traditionally determined the density with high time resolution using a calibration factor and the probe current sampled at a rather high rate while the temperature was usually determined from angmuir probe potential sweeps every few minutes he relative plasma density change  $\delta n n$  is commonly sampled at k z rate and by careful calibration and by the use of receivers with large dynamic range bit or higher it is today possible to sample the absolute plasma density  $n_e$  with a similar rate his technique was used successfully on the strid mission []

ampling of the electron temperature with second to millisecond resolution with a semi active technique gives several orders of magnitude higher resolution in time and space as compared to a bias sweep [ aitt and hompson iefring et al digital waveform generator is used to make a harmonic variation of the otherwise constant bias voltage and facilitates the high time resolution temperature measurement n the ionospheres of the alilean moons millisecond time resolution correspond to a distance of only a few meters along the spacecraft trajectory his opens the possibility to study small scale heating processes which are believed to exist near the dynamic boundaries of the ionospheres of the moons and their interaction with the co rotating magnetospheric plasma of upiter

## **2.3 A**n/n Interferometry

wo angmuir probe sensors separated by a few meters allow the determination of the plasma velocity component in the probe separation direction by a "time of flight" method f plasma density fluctuations  $\delta n n$ are sampled simultaneously at two spatially separated points the signals will show a substantial degree of correlation but with a time shift corresponding to a propagation velocity his technique has successfully been used on magnetospheric satellites to study plasma flow velocities [ ] similar method can be used to monitor the atmospheric outflow erosion from the alilean moons caused by the eroding action of the co rotating magnetosphere of upiter n accuracy of a fraction of a km s is achievable for relative plasma spacecraft velocities not exceeding approximately

km s he large scale convective plasma flow in the ovian magnetosphere and its deviation from co rotation can therefore be studied with a angmuir probe instrument

#### 2.4 Probe Surface Coating

he surface coating of sensors for cold plasma measurements in space must satisfy many requirements t must be durable to sputtering micrometeorites and manufacturing procedures t must also be inert to the reactive oxygen radicals encountered around the alilean moons and it should have good electrical and thermal properties in order to give a sensitive measurement and to keep the probe at a reasonable temperature

he electrical work function adhesion and thermal stability properties have been extensively tested in the laboratory for i surface coating [ ] as well as for other coatings [ ] which have been or will soon be used for angmuir probe sensors he i coating was applied to both the assini [ ] and strid angmuir sensors [ ] with excellent performance n epi olombo we consider a  $i_x I_y$  chemically deposited surface [ ] with better thermal properties in the hot ercury environment but otherwise very similar to the i surface n the environment of the

moons of upiter the high energy particles in upiters radiation belts is of concern owever the mechanically very hard durable and chemically inert i surface is well adapted for such a radiation environment

#### 3. SUMMARY

here are several strong scientific reasons in favour of including the ability to measure the cold plasma properties and small scale plasma structures on future missions aiming to explore the alilean moons and their interaction with upiter's magnetosphere couple of state of the art instruments were described

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