VAILDATION AND CHARACTERIZATION OF A SPACECRAFT THERMAL ION SENSOR

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Abstract

As humans come to rely more and more on satellites, an understanding of the environment in which they operate becomes invaluable. The neutrals and ions that make up Earth's upper atmosphere interact and transport energy in many complex ways. In-situ measurements of gas properties add data to the models and inform theories describing the region. Before collecting data in space, spacecraft instruments are tested in vacuum chambers on Earth to verify their operation. GRIDS is a spacecraft sensor combining two instruments: a Retarding Potential Analyzer (RPA) and an Ion Drift Meter (IDM). In this paper, we describe these instruments and present vacuum chamber test results characterizing the sensor.

Introduction

The Earth's atmosphere consists of many types of particles and understanding how they all interact is an interesting area of research. Many satellites, including the International Space Station, operate within this environment. Signals from all satellites must travel through the atmosphere to reach users on Earth. Thus, besides for the sake of science, it is important to study the properties and interactions of the neutrals and ions that comprise the atmosphere.

There are many ground-based and satellite-based techniques used to gather information about the atmosphere. Below we describe two satellite-based thermal ion instruments and present test results characterizing a sensor that combines these two instruments.

Retarding Potential Analyzers

Retarding Potential Analyzers (RPAs) are a useful thermal ion instrument developed in the 1960's (Knudsen, 1966) (Fanelli, et al., 2015). They consist of several biased conductive mesh grids placed perpendicular to incoming ions, and an ion collector to measure the current due to these ions. As energetic particles flow into the instrument, they encounter the electric field created by biases on the grids. In the simplest case, there are a few grounded shielding grids and a biased retarding grid. A particle with an energy greater than the bias on this retarding grid will be able to pass though the grid to the collector at the back of the instrument. A particle with a lower energy will not. As the bias on the grid is changed, particles of different energies will be barred from the collector.

The plot of collected particles vs. the voltage on the retarding grid is called an I-V curve; it is the integral of the distribution function of the particles. If all the particles have an energy higher than the highest voltage on the grid, the I-V curve will be flat as none of the particles will be stopped at any of the voltages. If all the particles have the same energy, the I-V curve will resemble a step function because all the particles will pass the retarding grid, until the retarding grid voltage is higher than the particle energy, then none of the particles will reach the collector. If the particles have a Maxwellian distribution, all the particles will pass the retarding grid when the voltage is low. As the retarding grid voltage rises, fewer and fewer particles will reach the collector, until all of them are stopped. By analyzing the I-V curve, the particle mass and species, temperature, and average energy can be found. Figure 1 shows a side view of the grids in an RPA, along with associated circuitry.

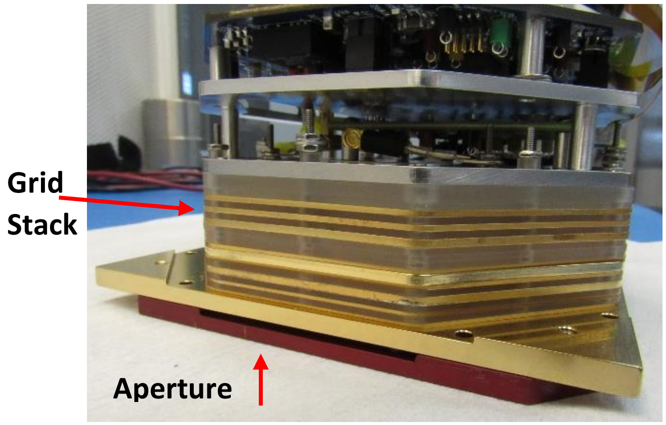

Figure 1 - Photograph on a RPA from the side showing the grid stack and associated electronics.

On a spacecraft, an RPA is placed on the ram facing side so it sees particles entering the aperture at the spacecraft speed. At typical Low Earth Orbit (LEO) altitudes, spacecraft move at 8 km/s. If the RPA sweeps through all its voltages in one second, it will be able to take a measurement every ~8 km. The faster the RPA sweeps, the better spatial resolution it will have. However, faster sweeps require fewer retarding grid voltages and/or shorter collection time at each voltage. These consequences combine to make the data noisy.

<u>Ion Drift Meter</u>

An Ion Drift Meter (IDM) consists of an aperture and four ion collecting plates. (Heelis & Hanson, 1998) The four plates are arranged such that each covers a quadrant of the back collecting area of the instrument. A stream of charged particles entering the aperture straight-on will hit each collector evenly. However, if particles are coming in at an angle, the aperture will shadow some of the collector area and some of the collectors will receive more particles than others. This ratio of currents to the different collectors allows the entry angle of the particles to be determined. Figures 2 and 3 show a simple schematic of an IDM to illustrate how the ratio of currents to the collectors changes as the particle entry angle changes.

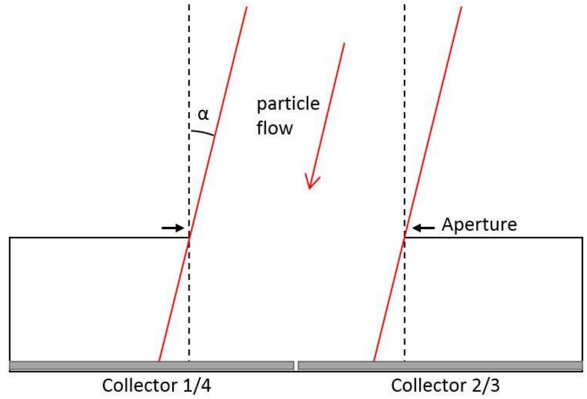

Figure 2 - Schematic of and Ion Drift Meter showing how the collected current changes with entry angle.

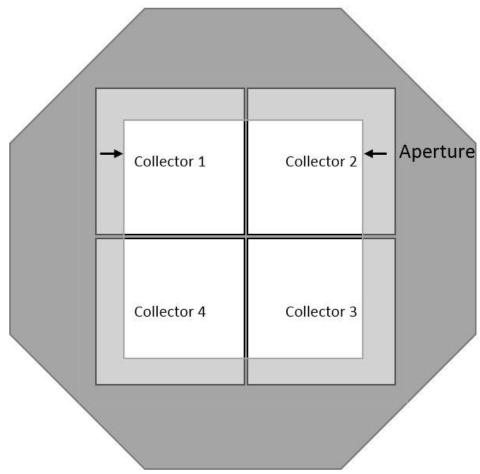

Figure 3 - Schematic of the collectors in an Ion Drift Meter showing the aperture overlapping the edges of the collectors.

Using the ratio of currents on the right half (collectors 1 and 4) to the currents on the left half (collectors 2 and 3) allows the alpha angle to be calculated (as illustrated in Figure 2). Taking the ratio of the top half (collectors 1 and 2) to the bottom half (collectors 3 and 4) allows the beta angle to be calculated. Alpha is a measure of how the particles are coming in from the left or right sides while beta is a measure of how the particles are coming in from the top or bottom.

Testing

The GRounded Ion Distribution Sensor (GRIDS), shown in figure 4, is an innovative new sensor that combines a RPA and IDM in one housing. It was designed and built at Utah State University and sent to Virginia Tech for testing. Validation in a vacuum chamber with a source of charged particles is necessary for any such instrument before flight.

We have developed a configurable ion source that produces a beam of ions to use in testing instruments like GRIDS (Robertson, Earle, & Green, 2019). This source uses filaments as an electron source. Neutral particles near the filaments get ionized by the energetic electrons emitted from the filaments, and are subsequently accelerated out of the device due to the internal electric field. For our tests, this ion source was set aperture-to-aperture with GRIDS, as shown in Figure 5, and put in the vacuum chamber. Figure 6 shows the ion source and GRIDS under test. For IDM testing, GRIDS was set on a rotary table, so its aperture could be rotated with respect to the ion source thereby changing the angle of particle entry.

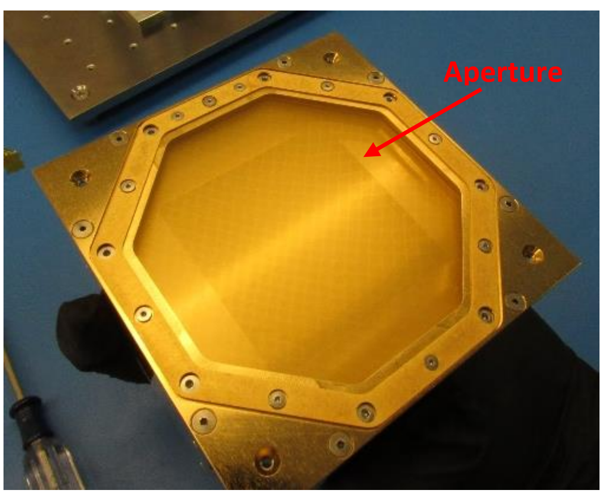

Figure 4 - The GRIDS sensor showing the aperture and grids.

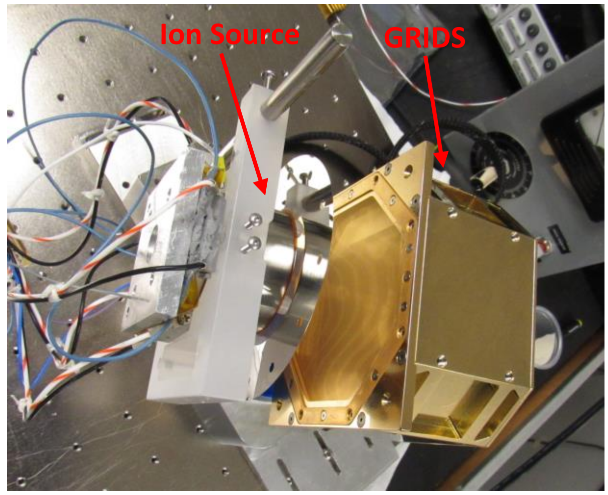

Figure 5 - The GRIDS sensor set aperture-to-aperture with the Ion Source.

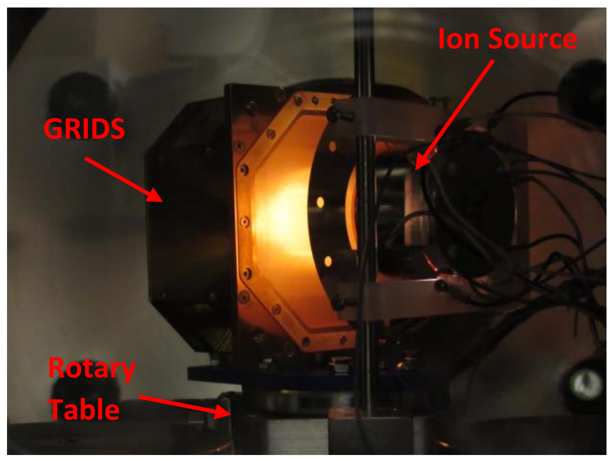

Figure 6 - The GRIDS sensor in vacuum under test. The light comes from the filaments that are used to drive the Ion Source.

Results

Two versions of GRIDS were tested. The difference between the two versions is the cadence at which the voltage on the retarding grid changes. In one version, the voltage swept from low to high every two seconds (1/2 Hz). This allows more voltages to be obtained in each sweep, giving a smoother curve. In the other version, the voltage sweep happens ten times each second (10 Hz) resulting in higher spatial resolution at the expense of noisier data. Figures 7 and 8 show I-V curves for both versions.

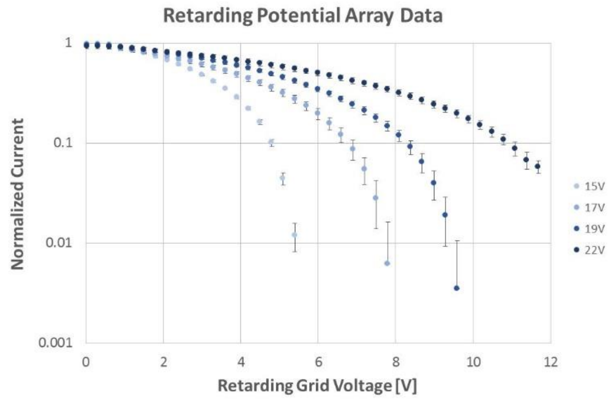

Figure 7 - Plot of RPA data from GRIDS with four energies shown. This is the ½ Hz mode.

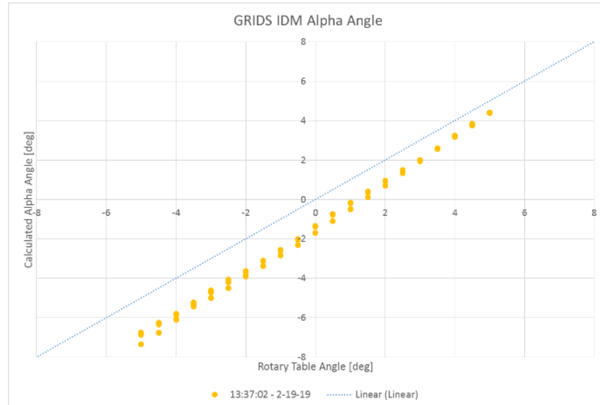

Figure 9 - Plot of IDM data from GRIDS showing calculated angle vs. actual angle.

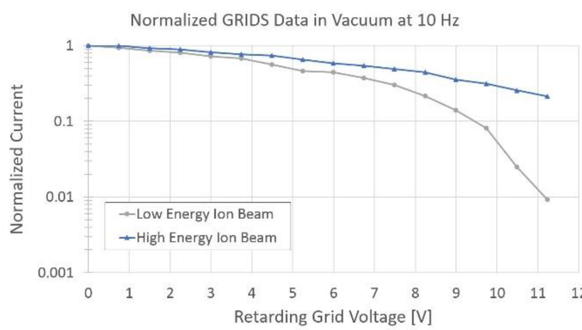

Figure 8 - Plot of the RPA data from GRIDS with two energies shown. This is the 10 Hz mode.

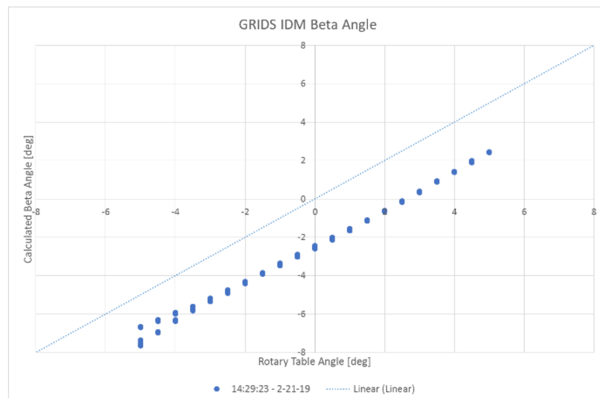

Figure 10 - More GRIDS IDM data

Figures 9 and 10 show the results for the IDM testing. GRIDS was turned from +5 deg to -5 deg in 0.5 deg steps and held at each step for several data points. The particle entry angle is calculated from the ratio of the currents to the right half to left half (or top to bottom half) of the collecting surface in GRIDS. The straight light blue line in Figures 9 and 10 is what the calculated angle should be in the ideal case and the yellow (or blue) points are the calculated angles. As, the rotary table only allows rotation in one dimension. GRIDS was rotated 90 deg, in order to repeat the test for the other angle (beta) (Figure 10).

GRIDS' response to the total ion density was also tested. Figure 11 shows how the magnitude of the first several points of the RPA sweep change with pressure. At higher pressures, the magnitude of the collected current is higher and at lower pressures, the magnitude of the collected current is lower. Careful calibration allows these initial points of each RPA sweep to serve as a measure of the total ion density along the satellite's orbit path.

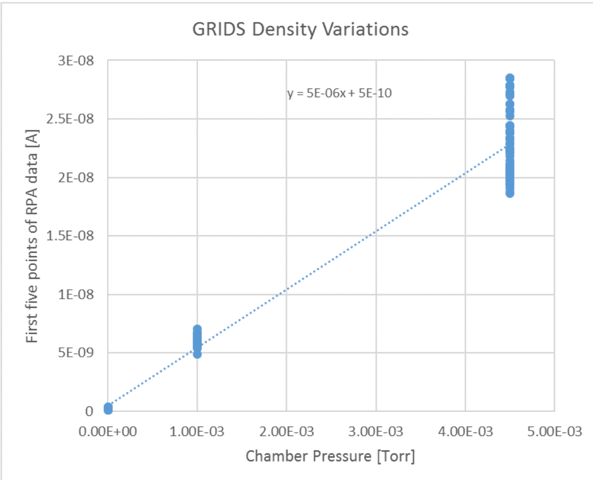

Figure 11 - Plot of GRIDS collected current vs. pressure showing linearity of GRIDS' sensitivity to density variations.

Discussion

Comparing the ½ Hz and 10 Hz I-V curves shows that while the 10 Hz version is not as smooth, it still behaves as expected and can be interpreted to find characteristics of the ions (Figures 7 and 8). This fast cadence leads to a higher spatial resolution than any RPA yet flown. Thus this instrument will provide higher resolution measurements that may reveal new results.

In the angle testing, the ideal and calculated angles do not match exactly (Figures 9 and 10). This is due to asymmetries in the ion beam and misalignment of the apertures. However, the data show that GRIDS is sensitive to changes in the incoming particle angle and that the calculated angles trend in the correct direction.

Figure 11 shows that GRIDS' response to density is approximately linear. As the background pressure in the chamber rises, there are more neutrals for the ion source to ionize. This creates a denser ion beam which means more ions are collected in GRIDS.

Performing the above tests shows that GRIDS works as expected in a space-like environment and raises the instrument's Technical Readiness Level (TRL). A high TRL is often a requirement before NASA will fly a sensor. While there are still some issues to work out, the sensor concept is validated. Especially exciting is the 10 Hz data showing that the electronics in GRIDS are sensitive enough to take measurements at spatial resolutions much shorter than any previously flown instrument.

In the future, we will work on ion source beam uniformity and better alignment with the GRIDS aperture. We will also fill in more pressures on the density variation plot to confirm linearity.

Acknowledgements

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