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Laboratory Demonstration on Remote Sensing of Neutral Particles in the Upper Atmosphere using Artificial Ion Beam

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Neutral particles play an important role in the physics of the upper atmosphere, which expands and shrinks depending on solar activity. The density of neutral particles in the upper atmosphere below 1,000 km altitude have been estimated conventionally using statistical analysis on satellite orbital decay and point-wise measurements by vacuum gauges and mass spectrometers onboard satellites. These methods enable us to comprehend the structure of the upper atmosphere, but do not clear the real-time situation in space. It is very difficult to measure neutral particle distribution by remote sensing using an RF wave. A set of in-situ observations with multiple satellites at various regions may supply real-time global data useful for space weather forecasts, but it requires an impractically large number of satellites to accomplish its purpose. This paper proposes another solution, that is the remote sensing of the neutral particle distribution using energetic neutral atoms (ENAs) excited by artificial ion beams, as shown in Figure.

This system consists of an ion source and a detector onboard independent satellites. First, the ion source in the given point ejects the fast beam ions at the given time (Figure [a]). As soon as being ejected from the ion source, the ions are restricted by the geomagnetic field and gyrate along the magnetic lines (Figure [b]). On the way of the longitudinal travel along it, the ions experience the charge exchange collision (CEX) with ambient cold neutral atoms in the upper atmosphere and are converted to ENAs (Figure [c]). Because of a lack of response on the magnetic and electric fields ENAs draw ballistic trajectories holding the information of the production regions, such as the density and composition, and are caught by the detector at a separate position (Figure [d]). The production rate of ENAs is associated with the flux of the exciter ion beam, the CEX cross-section, the scattering cross-section and the density of neutral particles, only the last of which is unknown. Therefore the ENA images give us the neutral particle distribution along the magnetic line on which the ion source stays. A single scanning for the measurement is accomplished in the time duration of several thousands seconds in which the exciter ions and the resultant ENAs travel the distance in the order of 10,000 km from the ion source to the detector. As a satellite with an ion source sweeping the Low Earth Orbit (LEO), the detector onboard another satellite in the Medium Earth Orbit (MEO) gathers the global data on the neutral particles. The neutral particle composition is specified by means of analyzing the response of ENA dependent on the species of the ion beam such as xenon, krypton, argon, etc. Krypton and argon ions selectively react with atomic oxygen and nitrogen molecules, respectively, which are the main components in the upper atmosphere. Assuming a well-collimated 1 keV krypton ion beam with 1A beam current and 1 second pulse duration on the equator in 500km altitude, a simple estimation shows the proposed remote-sensing sends 15,000 particles of ENAs to the detector, with 0.01 m2 sensing area, locating 5,000km apart from an ENA production region and reveals density profile of atomic oxygen along the magnetic line with 20km spatial resolution. This method might give us another feature of Earth atmosphere time-dependent and local fluctuating.

In order to investigate the feasibility of the proposed diagnostics the laboratory experiment was demonstrated using the ion source, the CEX cell and the Quartz Crystal Microbalance with grid. The xenon ion beam generated ENA from CEX with an oxygen molecule in the mixture gas of oxygen and nitrogen. The particle density of oxygen based on the proposed diagnostics was in good agreement with the data of the vacuum gage.