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Analytical study of the radio signals propagation in planetary atmospheres

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The ESA JUICE (JUpiter ICy moons Explorer) mission is planned for launch in 2022 and arrival at Jupiter around 2030. The mission is dedicated to the study of the giant gaseous and its largest moons. While the spacecraft will probe the Jovian system it will be occulted by the atmosphere of Jupiter or its satellites as seen from antennas on Earth. Such a configuration offers a great opportunity to study remotely the physical properties of the occulting atmosphere using radio links as the probe is being occulted. Indeed, non-unity index of refraction causes the electromagnetic waves to depart from the straight line and also impacts the propagation speed of the waves. Both changes modify the wave frequency and conversely, from the time variation of the Doppler measurements the index of refraction profile can be retrieved. In the literature, there are different approaches devoted to the retrieval of the refractive profile from these observables. Let mention, i) the analytic formulation of the Abel inversion which is employed for spherically symmetric atmospheres, and ii) the ray tracing method which is a numerical integration of the fundamental equations of optics and which is well suited for atmospheres with more complicated shapes. Both possess their own advantages and inconveniences. For instance, to invert a complete set of data, the ray tracing method requires more computational time than the Abel transformation. In return, the Abel inversion is based on the spherical symmetry assumption while the ray tracing technique can handle non-radial gradient in the refractive profile.

In the context of the future occultations of JUICE by Jupiter, we discuss the benefit of a new formalism based on a full reformulation of the fundamental equations of optics. This new approach let to provide a very comprehensive description of the light trajectory inside a planetary atmosphere with no assumption on the refractive profile. In the special case where the departure from the spherical symmetry is small, we present an analytic solution which is well suited for the data processing of radio occultation experiments. Indeed, this solution can handle the effect of a non-spherically symmetric atmosphere with a low computational cost. We use this solution to process the Cassini Doppler data acquired during an occultation by the oblate atmosphere of Saturn. The validity of the proposed approach is assessed comparing the results with other studies available in the literature.