PIANOS:

Plasma Induced

Antenna Noise Spectroscopy

for Space Weather Plasma Measurements

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Executive summary

Ambient space plasma can induce electrostatic noise in a linear antenna onboard a spacecraft. The resulting quasi-thermal noise (QTN) intensity spectrum as a function of frequency depends on the plasma parameters. The phenomenon can be utilised for inferring the plasma parameters if one measures the induced noise by a sensitive radio receiver. This is called QTN spectroscopy and it has been demonstrated and validated in several space missions that the technique is able to uncover the correct plasma parameters. In PIANOS project we assess to what extent the noise measurement technique could be used to monitor key parameters of space weather in various relevant regions at low cost. We review the properties of the target plasmas, consider different antenna geometries and their deployment strategies as well as data analysis methods and algorithms. To enable low-cost space weather monitoring by the QTN method, we recommend a roadmap of technology developments activities including CubeSat demonstrations.

In Task 1 (Definition of measurement requirements) we review average and disturbed properties of key parameters of space plasmas in different plasma regions that are relevant to space weather monitoring. We cover the solar wind at different solar distances and at 1 au, Earth's magnetosheath, magnetospheric tail lobes, the magnetospheric plasma sheet, Earth's plasmasphere and Earth's ionosphere. In all cases we review density, temperature and Debye length as well as discuss presence of typical wave activity. Task 1 was made by BIRA-IASB and it is based on review of existing literature.

In Task 2.1 (Piggyback noise spectroscopy instruments) we present and analyse concepts for low-cost plasma noise spectroscopy instrument configurations that could fly as piggybacks of other missions. We cover different kinds of rigid booms for three-axis stabilised spacecraft and thin tether booms for spinning spacecraft. We also briefly explore possibilities of using existing solar panels and magnetometer booms as attachment points for lightweight antennas. We present the list of forthcoming space missions and assess their suitability as plasma noise measurements mother platforms.

In Task 2.2 (Performance analysis of usual configurations) we analyse the performance and behaviour of plasma noise spectroscopy in previously flown missions (ISEE3/ICE, Ulysses, WIND and Cassini) where noise spectroscopic measurements were performed. We also discuss implementation of noise spectroscopy measurements on future missions: CIRCUS CubeSat mission, BepiColombo Mercury mission and Solar Orbiter sun mission.

Task 3 (Definition of instrument requirements and analysis method) is about how to design proper plasma noise spectroscopy instruments and what kind of requirements it sets on the spacecraft, using the Solar Probe Plus NASA mission as an example. We also analyse noise spectroscopy plasma parameter retrieval algorithm implementation issues by using the BepiColombo mission design as an example, and discuss specifics of noise spectroscopy in strongly magnetised plasmas where natural Bernstein waves are typically excited.

In Task 4 (Identification of technology developments and roadmap) we give prioritised and motivated recommendations for selected experiments, technology developments and demonstrations that serves the purpose of yielding cost-effective and robust space weather plasma Key Parameter monitoring for the Space Situational Awareness (SSA) programme by QTN. For achieving low cost, one can use either add-on QTN spectroscopy instruments placed on legacy platforms or CubeSats dedicated to QTN. Because space weather is highly variable, an ideal space weather monitoring instrument would be able to measure the plasma correctly in a relatively wide range of Debye lengths. For the roadmap, we recommend performing QTN (onboard a CubeSat or a bigger legacy platform) in geostationary transfer orbit (GTO) or other highly eccentric Earth orbit. Such experiment would naturally traverse different plasma conditions relevant to space weather and it would serve as a prototype low-cost instrument at the same time.

Summarising different plasma regions, in the ionosphere implementing QTN on a legacy platform or in a nanosatellite is in principle straightforward, because the required antenna length is short. The geostationary orbit and the plasma sheet present the biggest challenges because the plasma is so tenuous that only spinning platforms with wire or tether booms can achieve the long up to 1 km antennas required. Such platforms could conceivably be CubeSat based and hence low cost in the future. In the solar wind, the optimal antenna length is ~ 20 m. This length is possible to achieve by a fixed boom on a three-axis stabilised platform, although achieving low cost is not self-evident. On a spinning platform the task is easier.

QTN has been successfully used and its correctness validated on several space missions. This has been possible despite the fact that in most cases the antennas were optimised for different purposes, which speaks about the robustness of the method. Predicting quantitative performance of QTN on a given hardware and in given plasma remains a nontrivial problem, however, especially in cases where the antenna or spacecraft geometries are not simple. To remedy the situation we recommend GTO or other highly eccentric Earth orbit test mission, either a dedicated intrinsically low-cost CubeSat mission or an add-on instrument on a legacy platform.