Searching for large dark matter clumps using the Galileo Satnav clock variations

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Abstract

The search of transient space variations of fundamental constant, like the fine structure constant or the proton-to-electron mass ratio in the neighborhood of the Earth, has known considerable interest this last decade. The main motivation comes from recent models describing DM as macroscopic objects weakly interacting with ordinary matter (through a generic *scalar coupling*). Some models for Dark Matter (DM) suggest possible encounters with a period
tau of macroscopic dark structures with the Earth, implying transient variations of fundamental constants. Such variations should leave signatures on clocks onboard GNSS satellites (1). In (2), we present an original study dedicated to the search for such 'DM transients' using the network of passive H-Maser onboard Galileo satellites. Our first results are based on a fast method, the maximum reach analysis (MRA). We excludes a large range of coupling strength with ordinary matter for transient sizes from 10ˆ5 to 10ˆ9 km, never explored before. However, this analysis is not suited for the detection of potential events.
In this talk, we present a rigorous statistical method, based on the match filtering technique (MFT) (3), to directly detect large transient transits using data mining on Galileo clock data. In order to mitigate the possible impact on satellite clock data from mismodeled satellite orbits, we furthermore introduce Satellite Laser Ranging (SLR) measurements in the analysis. In principle, our phenomenological approach is quite general in the sense that it is possible to test any geometrical configuration of large DM transients and interactions with ordinary

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matter. However, we address only the case of a square hyperbolic tangent profile for an effective transient variation of the fundamental constants. This work provides the first direct detection of transient DM objects using a match filtering technique with probes in space.

We first developed a theoretical modeling of transient event signature, considering the spacecraft motion, encompassing large values for d (from 0.1 to 10ˆ9 km). The present signature is a periodic variation of the frequency between clock satellite pairs at the satellite orbital period. This variation is modulated by an envelope depending on the DM transient size. Considering the statistical MFT approach (3), we construct a correlation matrix between pairs of Galileo clocks at different epochs and a large template of events with period
tau, size d and velocity of the transient object. According to the usual methodology (3), we quantify how well a given template matches the signal within the data series via a signal-to-noise ratio (SNR) statistic. A statistic of maximum SNR is then obtained by simulating 10,000 data series of clocks products based on the Galileo clock noise. This leads to a numerical calculation of a threshold value corresponding to the minimum value above which any SNR-max value is due to a genuine physical effect and not to randomness with a confidence level of 95%. Hence, a potential event is denoted as *candidate event* when the SNR from a specific template exceeds this threshold. The results obtained from this statistical analysis show evidence of several statistically significant candidate events. In parallel, our analysis of Galileo satellite orbit residuals from SLR data allowed to decorrelate clock and orbit products and to conclude that the observed events are indeed an effect on the clock and not an artefact from mismodeled orbits.

The exploration of possible origins for these large SNR, including temperature and magnetic effects on the satellite clocks, is still ongoing. If all the candidate events can be explained by such systematic effects, the lack of DM transient observation will provide the best constraints obtained in space for this model of coupling of DM clumps with ordinary matter. Otherwise, we could have discovered a novel effect on clock, possibly due to new physics or an unknown natural effect.

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