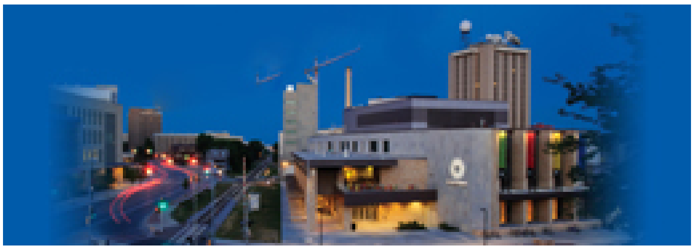

Contribution ID: **32** Type: **not specified**

PRIDE – Passive Radio Ice Depth Experiment - An Instrument to Measure Outer Planet Lunar Ice Depths from Orbit using Neutrinos

Tuesday, 14 May 2013 16:35 (20 minutes)

We describe a concept for an instrument to measure the thickness of the ice shell on a planetary body, such as Jupiter's moon Europa, by making use of the Askaryan Effect RF signal from extreme high energy neutrinos. Unlike a large high powered active device, i.e., an ice-penetrating radar, this instrument is a passive receiver of a naturally occurring signal generated by interactions of deep penetrating cosmic ray neutrinos. It is therefore potentially less massive and requires less power, making it very attractive for outer planet missions. We discuss the basic concept and consider the instrument design requirements from the perspective of a NASA Outer Planet Orbiter Mission. We show results [1] of simulations, compare signal-to-noise estimates, and examine possible components and configurations for the antenna, receiver, and electronics. We note some options that can be used to reduce mass and power. Finally, we identify issues that would need further study to produce a more concrete design.
[1] Miller, T., Schaefer, R.K., and Sequeira, H.B., Icarus, 220, 877-888, 2012.

Summary

In the world of astrophysics, difficult problems can occasionally benefit from the use of results derived from seemingly unrelated areas. In the case at hand we explore how results from the world of high energy cosmic rays could potentially help solve a difficult measurement problem in planetary geology. Europa, one of the Galilean moons of Jupiter, is believed to be covered with an ice shell of unknown thickness, likely ranging from a few kilometers to tens of kilometers. Indirect measurements imply that under the ice is an ocean, which is warmed by tidal and volcanic heating, and is thought to be one of the best locations for life to have formed in the solar system outside of Earth. It is therefore of high scientific priority to gain a better understanding of the geology and structure of Europa by measuring the ice shell thickness. The question is then: "How can we best probe ice that is tens of km thick given the stringent mass and power requirements of a Europan explorer satellite?"

The work described here and in [1] was performed to determine whether the preceding measurement question could be answered with a reasonable instrument built to use the Extreme High Energy (EHE) cosmic ray neutrino signal to extract the ice depth on a planetary-sized body. All aspects of the instrument design are covered – the expected signal, the detector configuration, the sampling electronics, etc. Our expectation was that we would encounter a "show-stopper" that would make this instrument untenable, but to our surprise we did not find any obvious major shortcomings. We present here the overall concept and suggest ways PRIDE (Passive Radio [frequency] Ice Depth Experiment) could be realized. We begin with an examination of the expected neutrino signal, then look at antenna/detector characteristics, move on to detector configuration, and end with a discussion of the signal sampling electronics. Lastly, we present conclusions and identify issues for further study.

The basic idea is to use radio receiver technology to detect cosmic ray neutrinos passing through the ice and generating Cerenkov radio pulses. Typically ice is probed with radar to determine its thickness. However, at depths of greater than 10 km the power required may be beyond the capacity of an outer planet mission. Other indirect methods, such as gravity and magnetic field measurements, can be employed to narrow the depth to a range of tens of km, but cannot be expected to provide more precision. Fortunately, nature already provides particles that penetrate deep into the ice and produce signals that can be harvested from a low orbit sensor and possibly used to accurately determine the thickness of the ice at depths of up to tens of km. EHE (> 10^18 eV) cosmic ray neutrinos are produced from the interaction of cosmic ray protons with cosmic background radiation [2], and can penetrate deep into the ice and interact with nuclei to produce a particle shower. The detection sequence begins with a neutrino penetrating through the ice sheet at a grazing angle and interacting within the ice to produce secondary charged high energy particles, which go on to interact and produce additional particles, eventually leading to a shower of charged particles moving through the ice for several meters before ranging out. The shower of particles will develop a net negative charge due to electrons from the ice being scattered into the shower. The entire shower, which moves faster than the speed of light within ice, will produce Cerenkov radiation at wavelengths greater than its physical size. For the given conditions, the resulting spectrum of emitted radiation peaks at ~0.2 to 2 GHz, and can be detected from orbit through radio transparent media. At typical Europan temperatures of ~100K, pure ice has attenuation lengths of tens of km or more. The depth of the ice sheet can then be determined from the rate, direction and magnitude of the received signals. This concept is useful because the remote sensor is passive – and does not require the power, weight, or large self-deploying antenna of ice-penetrating radar. This basic technology has already been demonstrated on Antarctic long duration balloon flights by ANITA [3].

A Monte Carlo simulation of the detection process was developed to examine basic ice depth resolution capabilities. The results indicate that the overall event rate is strongly dependent upon ice sheet thickness, indicating that PRIDE may have the potential to resolve thickness to great depth, which would add value to the any Europan (or other ice moon) instrument suite.

The NASA flagship mission concept provided the initial inspiration for us to consider the described technology [4], which was first presented in the context of planet-sized detectors for astrophysical neutrinos and cosmic rays in [5]. Shoji et al. [6] have also examined this concept, presenting results of a Monte Carlo simulation of event rate vs. ice depth up to 8 km. The present work extends the earlier efforts by presenting results for angular distribution of detected events, assuming possibly deeper and clearer ice, including higher energy events, and analyzing and presenting potential hardware and electronics concepts for the detector itself. While we were motivated by the problem of Europan ice, we anticipate this approach could be applied to any icy planetary body, e.g., Jupiter's other ice-covered moon Ganymede or possibly Saturn's Enceladus.

References:

[1] Miller, T., Schaefer, R.K., and Sequeira, H.B., Icarus, (in press), 2012. [2] Waxman, E. and Bahcall, J.N., (1998) Phys.Rev. D59, 023002. [3] Gorham, P. W., et al., (2009) Astropart. Phys. 32,10. [4] Schaefer, R. K., Miller, T.C., and Sequeira, H.B. (2009) Synergistic Science & Instrument Poster Ab-stracts, Europa Jupiter System Mission Instrument Workshop, July 15-17, 2009. p 38. [5] Gorham, P. W. (2004) Proc. NASA Advanced Planning Office's Capa-bility Roadmap Public Workshop, 38. [6] Shoji, D., Kurita, K., and Tanaka, H.K.M., (2011) Geophys. Res. Lett., 38, L08202.

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Session Classification: Neutrino Astrophysics III - Theory

Track Classification: Neutrino Theory Parallel