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

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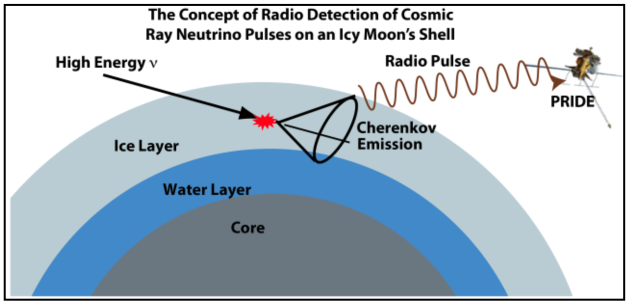
Overview: We describe the concept for an instrument, PRIDE (Passive Radio Ice Depth Experiment), to measure the thickness of the ice shell on an outer planet ice moon. This is an update to our presentation at the first IPM workshop [1], including analyses presented in our subsequent publication [2] and results from the first quarter of a 2014 NIAC Phase 1 grant. Unlike a high powered and massive device such as an ice-penetrating radar, PRIDE is a passive receiver of a naturally occurring signal generated by interactions of deep penetrating cosmic ray neutrinos. We discuss the basic concept and consider the instrument design requirements from the perspective of a NASA Outer Planet Orbiter Mission. We show results of new simulations and examine updated configurations for the antenna, receiver, and electronics, and present results on issues we are now stuydying to produce a more concrete design.

Abstract: We are exploring a concept for a novel and innovative low cost, low power, low mass passive instrument to measure ice depth on outer planet moons, such as Europa, Ganymede, and Enceladus. Indirect measurements indicate that liquid water oceans are likely present beneath the icy shells of such moons. This has important astrobiological implications, and their exploration is a high priority. However, determining the thickness of these icy shells is challenging given spacecraft SWaP (Size, Weight and Power) resources. The current approach uses a suite of instruments, including an ice penetrating radar, to provide constraints on ice thickness. The proposed instrument, which uses experimental techniques adapted from high energy physics, is a passive receiver of a naturally occurring signal generated by interactions of deep penetrating cosmic ray neutrinos. It could measure ice thickness directly, and at a significant savings to spacecraft resources. In addition to getting the global average ice thickness this instrument can potentially be configured to make low resolution global maps of the ice shell. Such maps would be invaluable for understanding planetary features and finding the best places for future landers to explore. We describe the instrument concept, consider design requirements for an outer planet orbiter mission, and describe steps undertaken to determine feasibility.



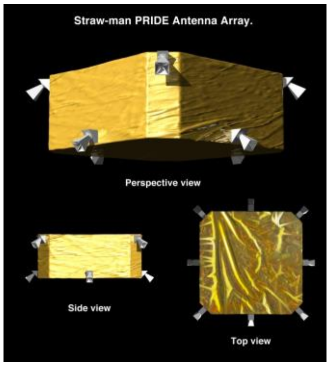
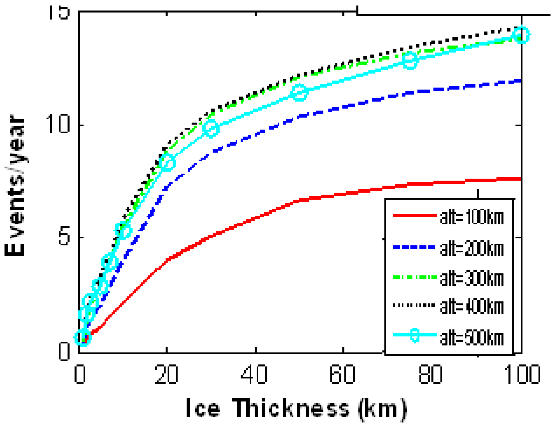


Figure 1. Top: Illustration of the PRIDE concept. A high energy cosmic ray neutrino penetrates the ice at a grazing angle. The neutrino initiates a shower of secondary charged particles that emit a conical pulse of Cerenkov radiation that can be detected at satellite altitude. The distributions of the characteristics of detected pulses will indicate the thickness of the ice layer. Bottom: Strawman PRIDE antenna array for full 360-degree azimuthal coverage. The two rings of antennas enable reconstruction of event direction via timing differences in neighboring receivers.

The basic idea, illustrated in Figure 1, is to use radio receiver technology to detect cosmic ray neutrinos passing through the ice and generating Cerenkov radio pulses. EHE (> 10^{18} eV) cosmic ray neutrinos are produced from the interaction of cosmic ray protons with cosmic background radiation [3], and can penetrate deep into the ice before interacting with nuclei. 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. The direction can be determined via arrival time differences in multiple antennas. This technology has already been demonstrated on Antarctic long duration balloon flights [4]. This concept is useful because the remote sensor is passive and does not have high requirements for power, weight, or size, as illustrated in Table 1.

In an initial analysis [1,2], oriented toward demonstrating basic utility and potential feasibility, a Monte Carlo simulation of the detection process was developed and used to examine basic ice depth resolution capabilities. We found that the event rate, and zenith angle and signal size distributions all correlate with ice thickness for satellite observations, indicating that PRIDE may have depth resolution up to considerable thicknesses (tens of km for the case of pure very cold ice, and ~10-20 km for briny ice), which would add value to any ice moon instrument suite. An example is shown in Figure 2, which shows the simulated event rate vs ice sheet thickess for a satellite orbiting Europa for cases of pure cold ice and ice containing brine [7]. The event rate is strongly dependent upon ice sheet thickness, indicating that PRIDE may have the potential to resolve thickness, and that the capability depends upon ice purity. Shoji et al. [5] have also examined this concept, finding that event rate is sensitive to ice depths of up to 6-8 km for ice containing a basic model of impurities.



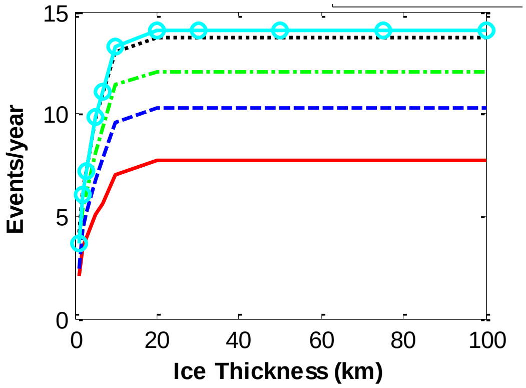


Figure 2. Events/year (X 10^4) detected vs. ice sheet depth, assuming a Waxman-Bahcall normalized E^{-2} spectrum. Upper: pure ice. Lower: briny ice model from [7]. Depths up to tens of km, in the case of pure ice, and up to 10-20 km, in the caseof briny ice, can be measured if the incident neutrino flux is known.

In our current work, being performed under an FY15 Phase 1 NIAC grant, we are extending the scope of the original work in several aspects in order to investigate feasibility in more detail. One primary goal is to implement and analyze more realistic and higher fidelity models of ice impurities, as neither briny ice or the simple impurity model in [5] reflect expected impurities to be found in Europan ice. Cases will be analyzed for a variety of temperature vs depth and ice impurity models in order to improve the estimation of ice transparency vs depth and the resulting event detection rates. In addition, we will address several issues arising from oversimplifications in our initial Monte Carlo simulation due to lack of resources, include the following efforts:

- Integrate higher fidelity simulation software used by other high energy neutrino experiments. This will provide an important check on our previous results for absolute event rate vs ice sheet thickness, using higher fidelity and more esatablished tools. In addition, we will modify the software to simulate additional ice moons (Ganymede, Callistro, Titan, and Enceladus).
- Simulate additional background signals, including nucleonic cosmic ray impacts upon the ice surface. High energy cosmic ray events have been observed by the ANITA experiment during Antarctic balloon flights.
- Investigate approaches for including surface ice roughness effects, which will affect the allowable geometry of events that can be detected within the ice.
- Explore the possibility of making low resolution global maps of the ice shells - instead of simply getting a global average ice thickness, including investigating resolution limits for detecting local ice thickness

changes and large water pockets. Shoji *et al* have recently analyzed the possibility of detecting local water inclusions beneath the surface of Enceladus [6].

- Investigate the potential measurement of signals reflected from the ice/water interface. For certain geometries and ice thicknesses, down going signals can reflect off of the ice/water boundary and also be detected in orbit. It is therefore possible that we could detect the direct signal and some microseconds later the reflected signal. The time difference between the signals would yield an independent measure of the ice depth on a single event.

We will present the current status of our ice transparency, surface roughness modeling, and event rate vs ice sheet model analyses and results.

Table 1: PRIDE Parameters

Parameter	PRIDE
Dimensions (m)	- 0.3 by 0.2 by 0.7 horn antennas (3 to 8) - 0.25 by 0.25 by 0.25 (600 MHz tripoles)
Mass (kg)	5-10 for horn antenna array (ROM), less for dipoles/tripoles
Power (W)	O(10) (ROM)
Frequency (MHz)	~200–2000
Passive/ Active	Passive
Notes	No moving parts. Antennas placed at open locations on spacecraft body.

References:

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