The Science and Technical Developments of a Neutrino Detector Spacecraft

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The idea of new Science of interest to NASA and DOE elementary particle physics that could be done with a neutrino detector spacecraft was introduced by Nick Solomey in 2015 with various publications and presentations behind the idea in 2016-2019 [1-3]. These ideas are summarized here in this short write-up for the Snowmass 2020 review of particle physics.

The detection of solar neutrinos from the Sun here on Earth are limited by our distance from the source, modifications by neutrino oscillations and nuclear matter effect on the way to the Earth, add to this that the Earth is a fixed unchanging distance from the Sun which limits our abilities to do more science; nevertheless solar neutrinos have been detected on Earth and were the first evidence for neutrino oscillations and continue to be studied by large detectors. However, it is possible to detect far more solar neutrinos by going closer to the Sun and at 7 solar radii distance the solar neutrino flux would be 1000x that on Earth and at 3 solar radii 10,000x that on Earth. This would result in the need for a smaller detector to do the same things that large detectors on earth do and a 1 ton detector need only be 1 kg at 7 solar radii. A spacecraft with a neutrino detector on board that can operate unshielded in space would allow for new science including unique elementary particle physics. For example the transition between coherent and de-coherent oscillations for 10 MeV neutrinos occurs when a space craft reaches 35 solar radii away from the Sun, and for 5 MeV neutrinos at 8 solar radii; just studying where this coherent/de-coherent transition in neutrino oscillations are would tell us a lot about the theory underlying neutrino oscillation physics. Since the nuclear furnace of our Sun is not a point at the central core of the Sun but is more shaped like a toroid some 0.1 solar radii from the center and that the pp cycle is on the outside and the CNO, F and heavier element fusion cycles closer inside then a space craft going out of the ecliptic plane and viewing the nuclear core from the higher polar latitudes could allow neutrinos from rare fusion process to be more easily detected, and since our Sun is not a sphere but is flattened due to rotation then there is less nuclear matter effects on neutrinos exiting the Sun through the polar regions and the difference between equatorial and polar neutrino oscillations could be observed and studied for Nuclear effects. Clearly NASA's goal of better understanding our Sun can be achieved with such improved studies but elementary particle and nuclear physics could also benefit from such a new spacecraft idea.

Other science that can be done with a spacecraft capable of detecting neutrinos in space are that solar neutrino backgrounds in dark matter searches go down as the detector goes away from the Sun and at Jupiter a 10x reduction is expected and 100x reduction at Uranus. By measuring the solar neutrino flux as a space craft goes further away from the Sun the solar neutrino rate expected would be well known and a neutron flux which falls off even faster equally well known, any deviations from this expected decrease with distance could then be attributed to possible detection of dark matter and this might dramatically increase the sensitivity to dark matter direct observation.

The Sun itself could also be used as a concentrator lens, and NASA currently has a program of study to use the light from a distant exoplanet as focused by the Sun at the Gravitational Focuses for light to image an exoplanet's surface. One of the main limitations to such an instrument is that the gravitational focus for light by our Sun is 500 to 700 AU away and the furthest spacecraft man has sent out of our solar system is presently only 165 AU away from the Sun after almost 50 years of traveling.

However because the neutrino has a non-zero mass a neutrino gravitational focus would be much closer at 20 to 40 AU, about the distance of Uranus to Pluto. The light collection power of a gravitational lens is enormous about 10^13 but when using light a ocular disk has to be used to block the direct light from the surface of the Sun, solar-type neutrinos are low energy and the Sun itself is transparent to low energy neutrinos so its neutrino collection power could be 100 to 1000x more than that using light giving a 10^15 neutrino collection power. The galactic core of our galaxy is only 25,000 light-years away and although this large distance diminishes the solar neutrinos form the many stars in the galactic core the galactic core is the largest concentration of solar-type neutrinos in the sky other than our Sun due to the immense number of stars there (most are hidden from view due to galactic clouds) and it is fairly well concentrated in that the Galactic core as viewed form the Earth is only 2 times larger than the solid angle of our moon. A rough estimate is that the neutrino gravitational focus of neutrino from the galactic core at the focus point could be as large as 800x that of solar neutrinos from our sun at Earth. The distance of 20 to 40 AU is possible to reach with current space craft technology and that as a neutrino detector moves across the neutrino gravitational focus it would be like a single pixel camera imaging the unseen structure of the galactic core and is of interest to NASA. Of interest to DOE is that just measuring where the neutrino gravitational focus is of our Sun from a source like the galactic core would be a new way to measure the mass of the neutrino hence this could be of interest to the elementary particle physics community.

All of these ideas relies upon the ability of a neutrino detector to operate unshielded in space. This appears to be possible by using the technique of a delayed timing pulse coincidence. A neutrino could interact on Ga and produce a conversion electron and 60% of the time produce a nuclear exited state of Ge, the Ge (69 or 71) would then decay with 2.5 microsecond half-life or 20 millisecond half-life with a fixed well known gamma ray energy signature and the two observed pulses in the detector in the correct time window would allow the elimination of backgrounds from Galactic gamma rays, Cosmic Rays and random radioactive decays. This neutrino detector development funded since 2017 by NASA through the NIAC NASA Space Technology Mission Director is underway [4,5]. Furthermore the planets Uranus and Neptune will be going through the point in space opposite the Sun and Galactic core in 2035 and 2065 and it might be possible to use their atmosphere on the dark side of the planet to look for neutrino interaction changes caused by the neutrino gravitational focus of the Sun. A spacecraft orbiting Uranus or Neptune would make use of the imaging camera when the orbit takes it on the night-time side of the planet.

[1] N. Solomey, Studying the Sun's Nuclear Furnace with a Neutrino Detector Spacecraft in Close Solar Orbit, AAS/Solar Physics Division, Abstracts# 47 Presentation and poster P7-26, Boulder Colorado, June 2016.

[2] N. Solomey (PI), NASA Innovation and Advanced Concept 2018 Grant "Astrophysics and Technical Study of a Solar Neutrino Spacecraft", May 15, 2018 to Feb. 14, 2019.

[3] N. Solomey, M. Christl, C. Gimar, A. Nelsen, R. McTaggart and H. Meyer, Astrophysics, Technical and Mission Study of a Solar Neutrino Spacecraft, 27 Sept. 2018 presented at the NASA NIAC symposium, Boston, MA, see the online video link at: https://livestream.com/viewnow/NIAC2018/videos/180892751

[4] N. Solomey et al., Science Mission of a Neutrino Space-craft, AAS 234, 126.04 (2019).

[5] N. Solomey et al., Astrophysics and Technical Study of a Solar Neutrino Spacecraft. NASA 2019-Phase-2; NIAC (NASA Innovative Advanced Concepts) Grant