A Possible New Dark Matter Detector in Space

Dr. Nick Solomey

Prof. of Physics

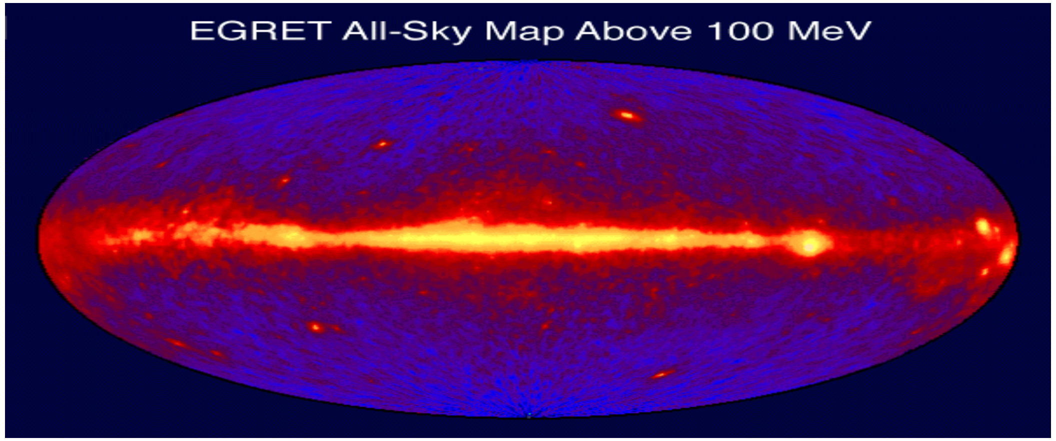
Wichita State University

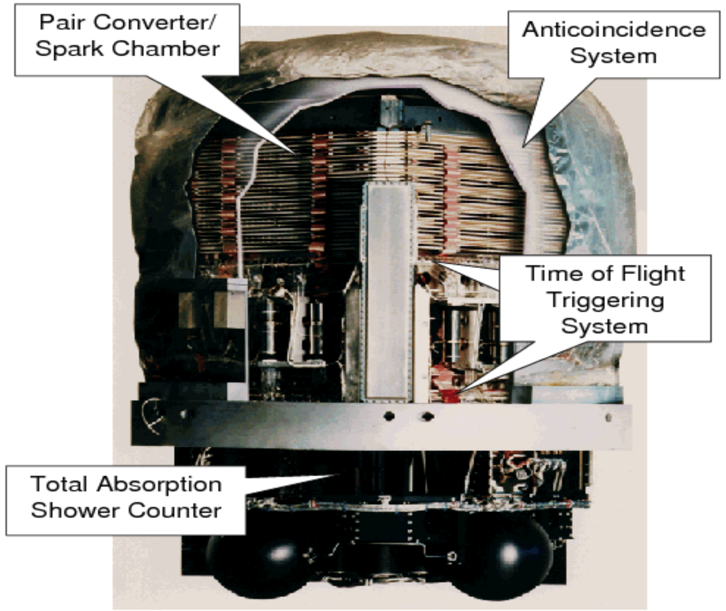
Kansas, USA

Background:

- My background is as an experimental Particle Physicists who has done experiments at CERN in Geneva Switzerland and Fermilab in Chicago, and lots of detector developments.
- Recently particle Physics is becoming an important role in Astronomy and Spacecrafts, and these new projects could be a guide for my idea:

Using a small spark-chamber particle detector in 1992 NASA launched the EGRET spacecraft, which opened our eyes to high-energy Gamma-ray Astronomy. Now a large amount of gamma ray astronomy like this is done with the Fermi Satellite.





Question:

- If we can operate a neutrino detector in Space What new Science can be done?
  - On Earth a few hundred solar neutrinos have been detector from the Sun's core. By going closer to the Sun the $1/r^2$ dependence would let us get a solar neutrino flux up to 45,000x.
  - A detector with 25 kg active target is equal to 25 T on Earth at 7 Solar Radii.
  - A detector with 25 kg active target is equal to 250 T on Earth at 3 Solar Radii.
  - Close to the Sun a collection of neutrino events would permit the internal radius structure of neutrino emitting core to be studied 900x better, so each event is equal to 900 events on earth, for internal structure.

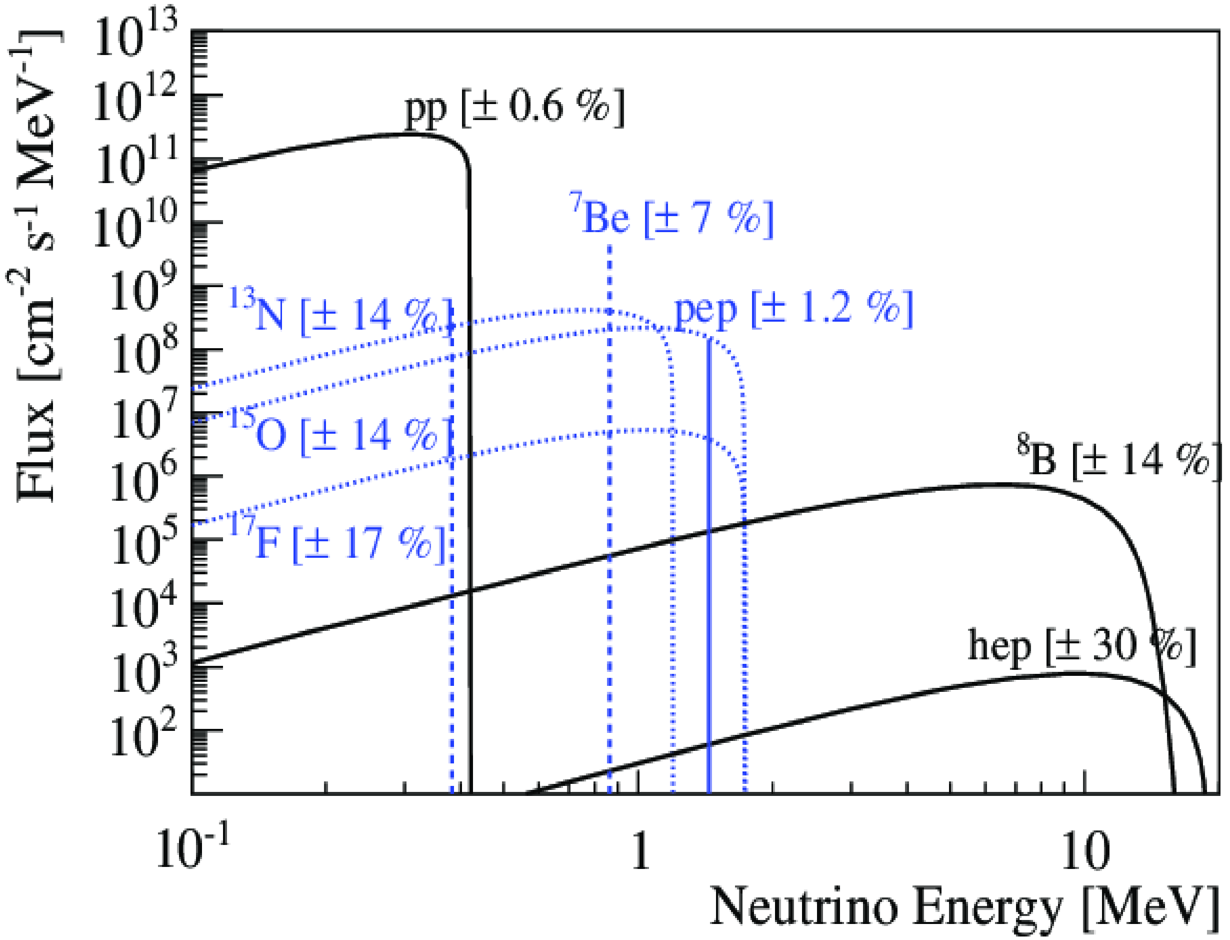
Table 1: Intensity of solar neutrinos at various distances from the Sun.

Distance from Sun	Solar Neutrino intensity relative to Earth
696342 km	46400
1500000 km (~3 Sun R)	10000
4700000 km (~7 Sun R)	1000
15000000 km	100
474340000 km	10
Mercury	6.7
Venus	1.9
Earth	1
Mars	0.4
Astroid belt	0.1
Jupiter	0.037
Saturn	0.011
Uranus	0.0027
Neptune	0.00111
Pluto	0.00064
KBP	0.0002
Voyager 1 probe 2015	0.00006

Study Solar Nuclear Core:

- By going close to the Sun it not only increases the neutrino flux and improves the signal to noise ratio, but allows a platform for new Science:
  - A spacecraft in orbit could change distance and go off the axis of the ecliptic.
  - At Earth the neutrino oscillations are coherent, but closer than 35 solar radii solar neutrino flavors are incoherent, changing their ratio to each other with distance from the sources

- Rare neutrino fusion and better understanding of currently observed fusion neutrino processes.



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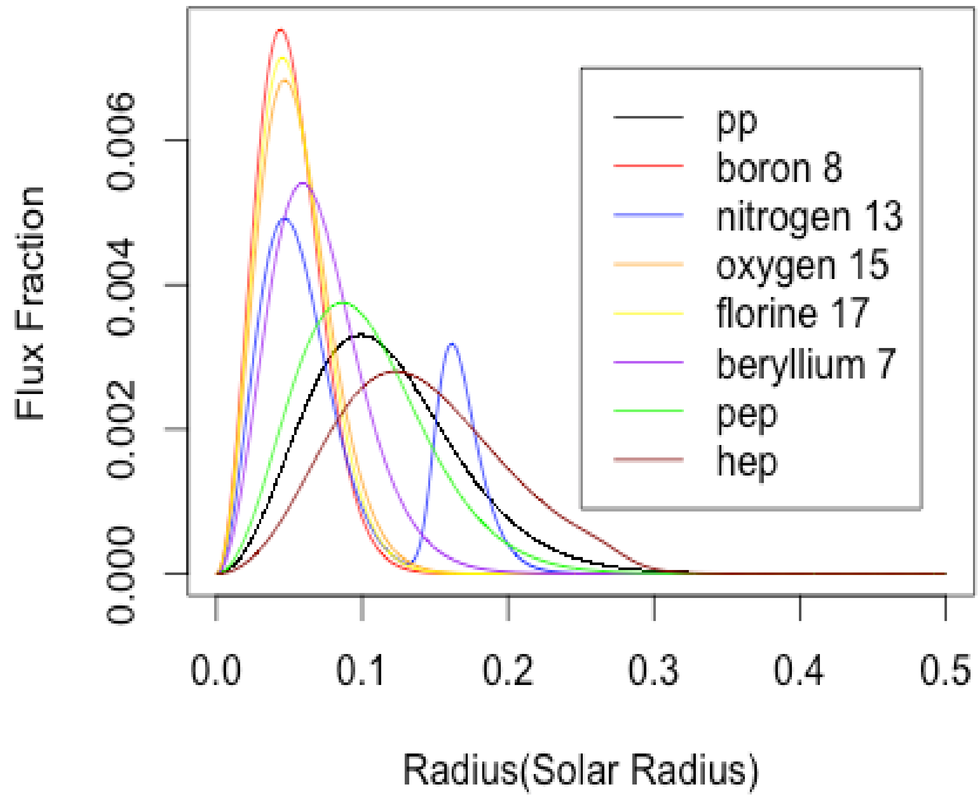
  - A spacecraft in orbit could change distance and go off the axis of the ecliptic.
  - Close to the Sue by 30x gives us 900x improvement in angular resolution but since neutrinos are not directional it would be by model matching.

- Science:
  - Image the fusion reactor core of the Sun.



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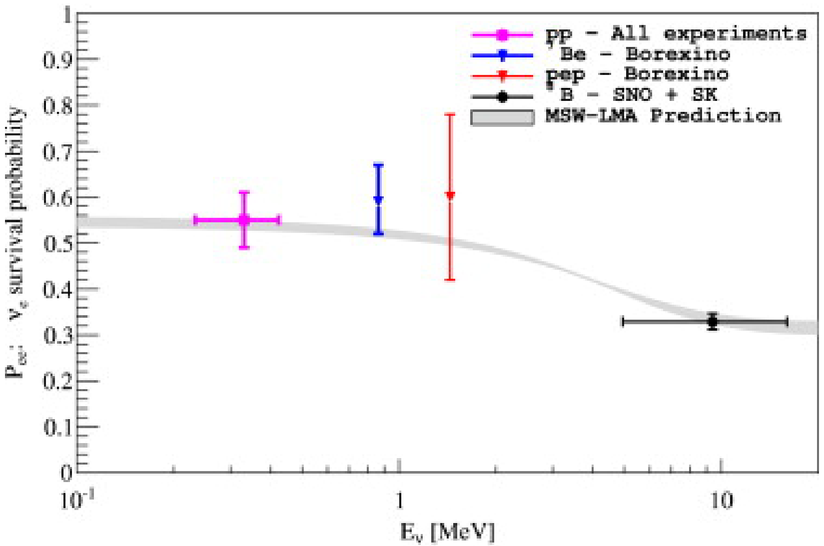
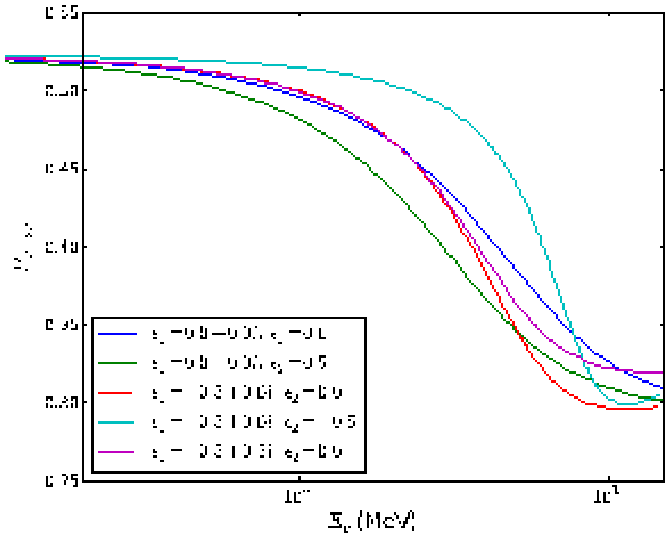
Neutrino Energy (MeV)	Oscillation length (km)	Coherence Length (km)	[illegible]$_x$ (cm)
1	34	$2.44x10^5$	$3.15x10^{-9}$
5	170	$6.10x10^6$	$3.15x10^{-9}$
10	340	$2.44x10^7$	$3.15x10^{-9}$





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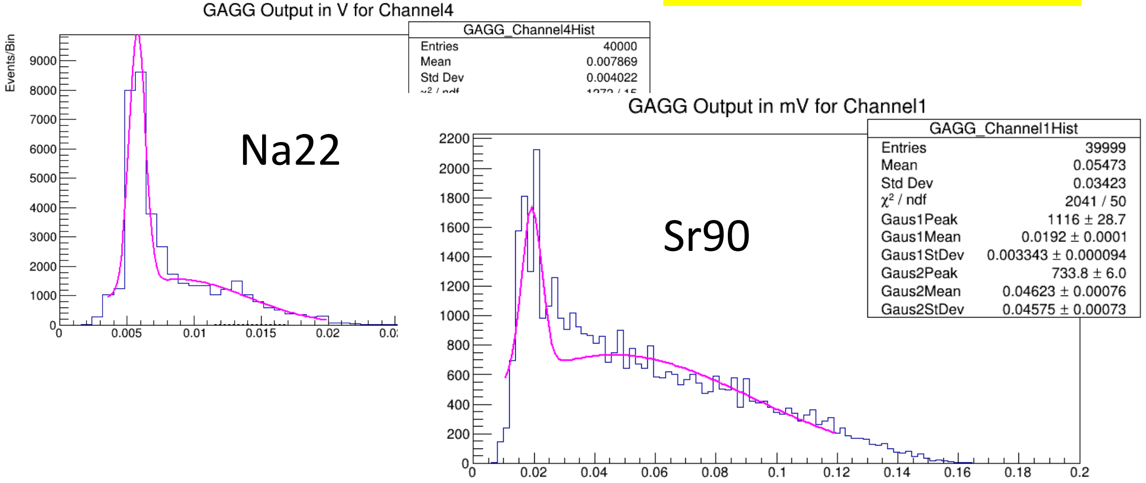
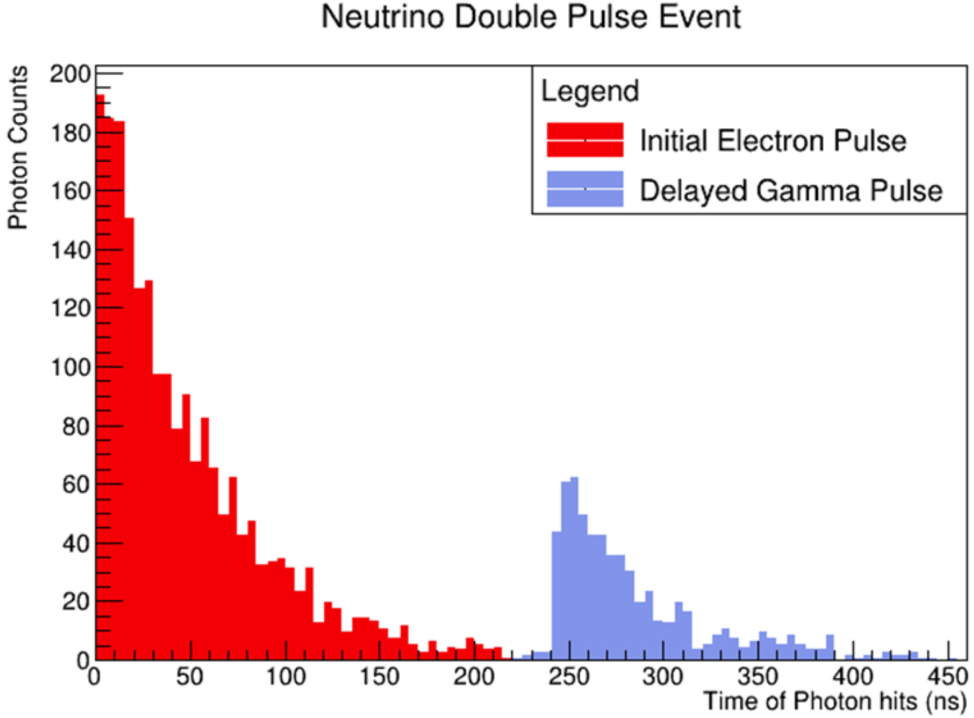
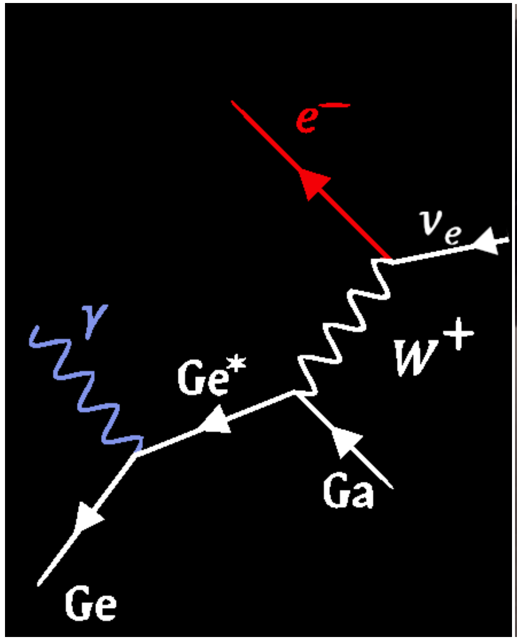


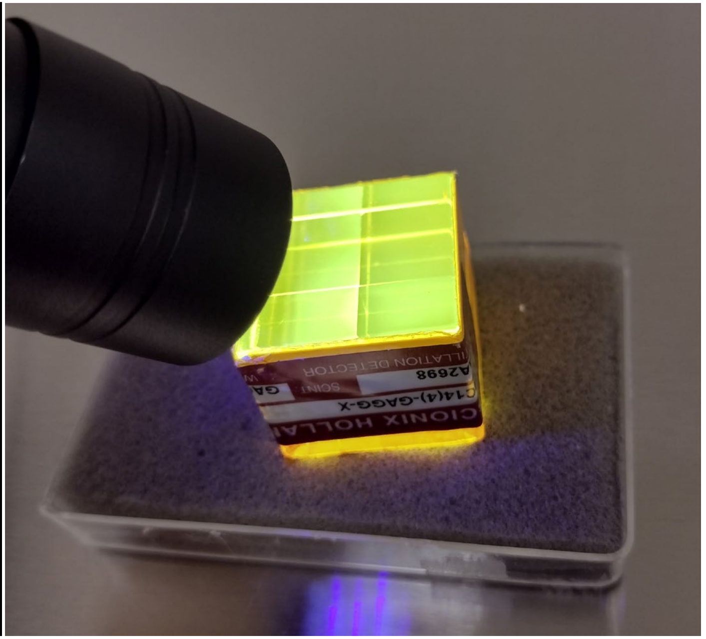


Our Technique: Double timing pulse

$^{69}Ga + \nu$ into e- ^{69}Ge m1 or m2	^{69}Ge m1 decays X-ray	5 us	86 keV
	^{69}Ge m2 decay gamma	2.8 us	397 keV
$^{71}Ga + \nu$ into e- ^{71}Ge m1	^{71}Ge m1 decay gama	20 ms	175 keV

GAGG Crystal with 20% Ga, large and fast light yield:

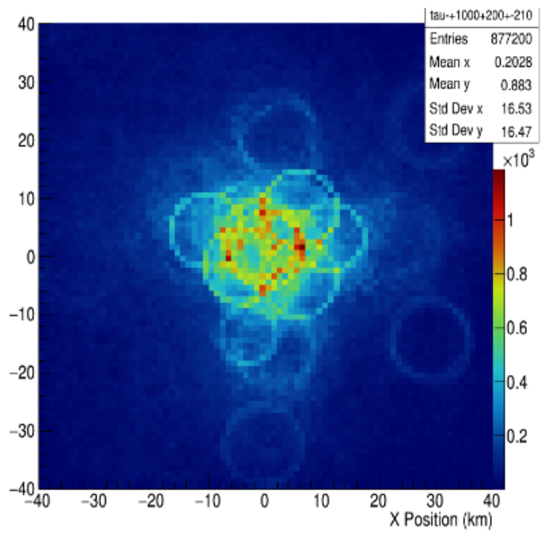


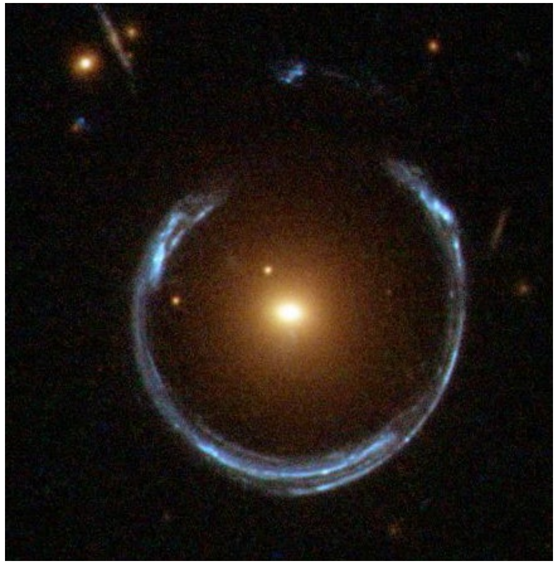


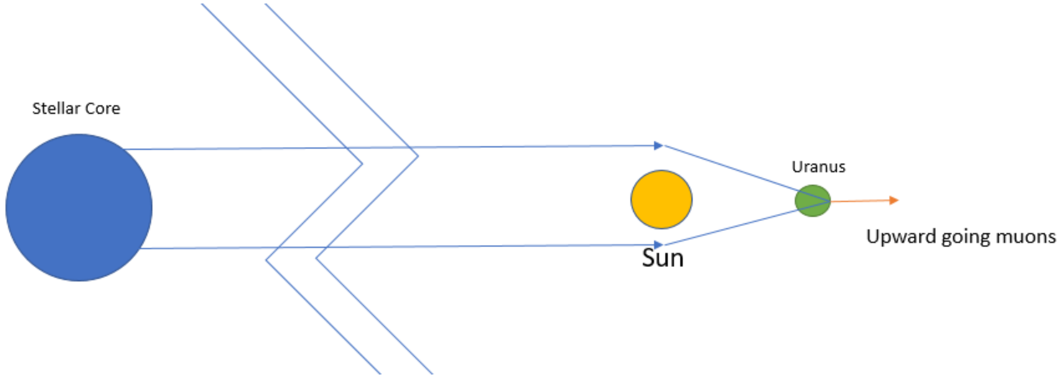
Neutrino Gravitational Focus:

- Neutrino have mass so this neutrino gravitational focus is 20 to 40 AU from Sun
- “light” collecting power is larger
- Use an Ice-Giant dark side as neutrino target
- Can study: Galactic core image, Ice-Giant tomography with neutrino and Particle Physics neutrino mass.

- First studies show nice high energy neutrino shower Cherenkov rings:







Neutrino Gravitational Focus:

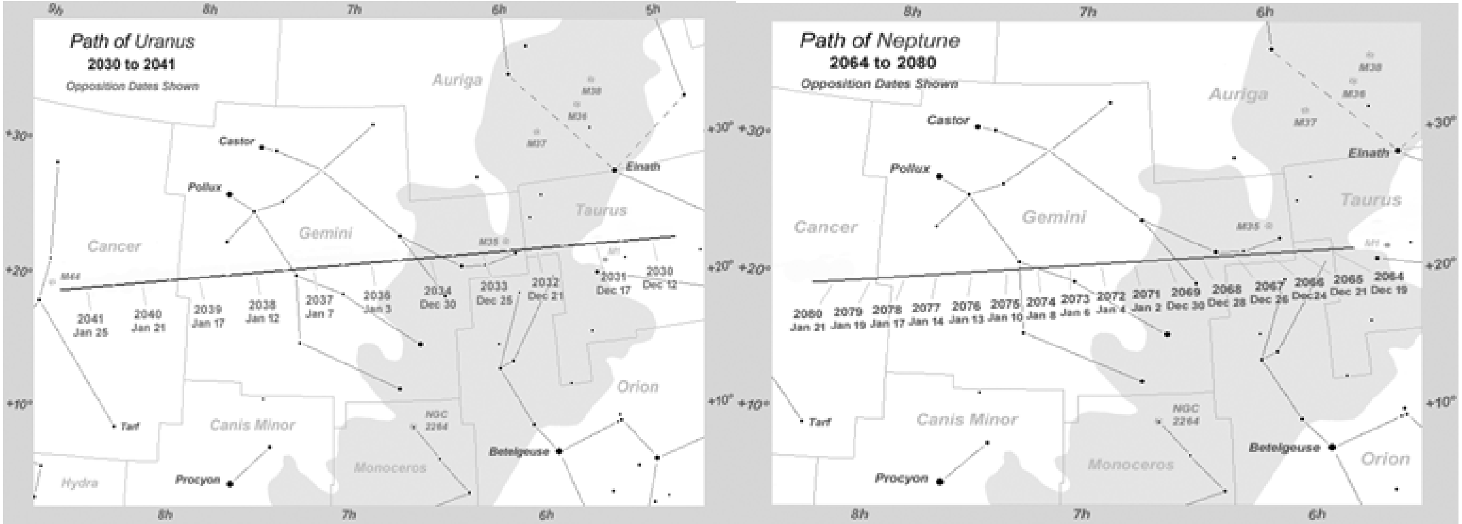
- Used model of stars in galactic core and their distribution by Kent (S.M. Kent et al. Luminosity model of Milky Way, APJ v378, p131, 1991)
- Estimate used absolute magnitude of stars to figure the number of neutrinos compared to our Sun, this is certainly wrong, but it is to low.
- Corrected for the distance to the Galactic core at 25,000 l.y.
- Used "Light" collecting power of Gravitational Lens at 10^{13}.
- Used off axis stars with "light" reduction out to 1 degree.
- Assumed a 4 m diameter 8 m long detector volume, i.e. size of space craft upper stage.

Get that the number of galactic fusion neutrinos is 800 to 8000 times more neutrinos than at the surface of the Earth directly from our own Sun. We also see that the many accretion disks produce high energy neutrinos that can be focused.

Mary Lynn Buchele and Aysia Bains (senior thesis) with N. Solomey (adviser), Galactic Neutrinos Lensed by the Sun: an Initial Estimate, Wichita State University 2018 and 2022.

Neutrino Gravitational Focus:

Uranus and Neptune will soon be passing through Neutrino Gravitational Focus of Galactic Core formed by our Sun.



Left is the track of Uranus through the night sky and on the right is the track of Neptune [13]; as can be seen from extending these graphs the two planets will be opposite the Sun from the galactic core in 2037-2038 and 2065-2067 and will provide an opportunity for using them as a large target for galactic core neutrinos being gravitationally focused by our Sun.

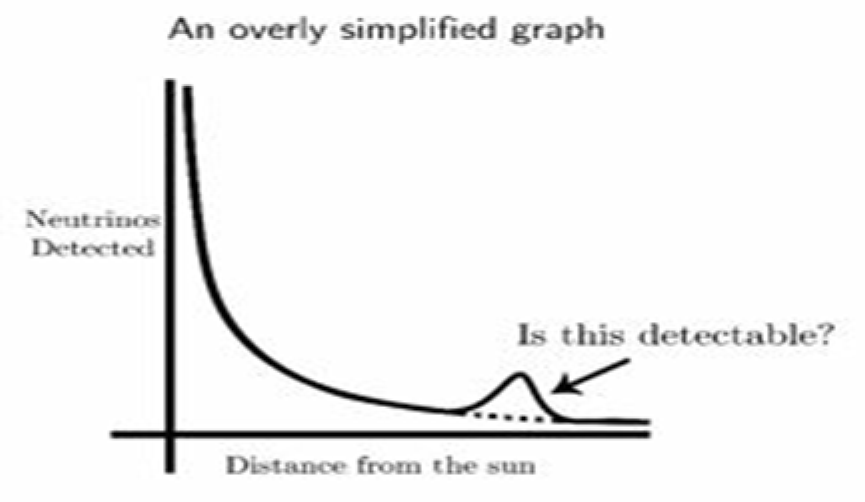
Neutrino Gravitational Focus:

Science possible:

Elementary Particle Physics:

Can we measure Mass of Neutrino

- From location of neutrino gravitational focus from the Sun.



Astrophysics:

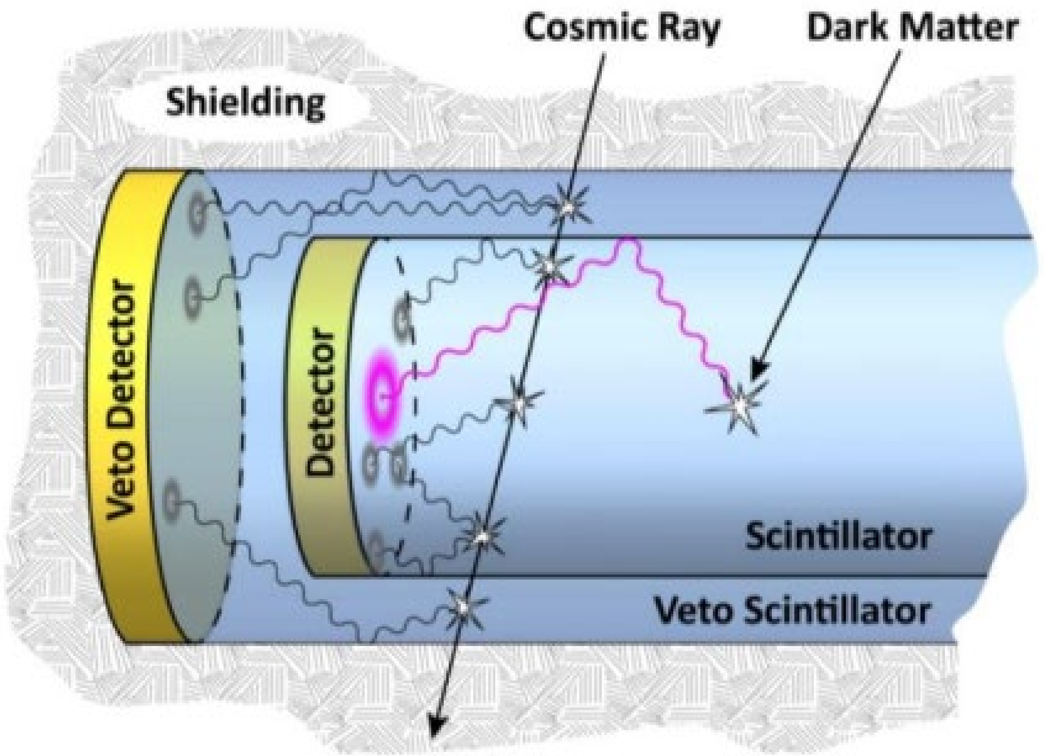
- Measure neutrino intensity of point sources like Crab and Geminga Pulsar.
- Measure number of Galactic Core Accretion disks from high energy neutrinos
- Image Galactic Core Structure

Planetary Science:

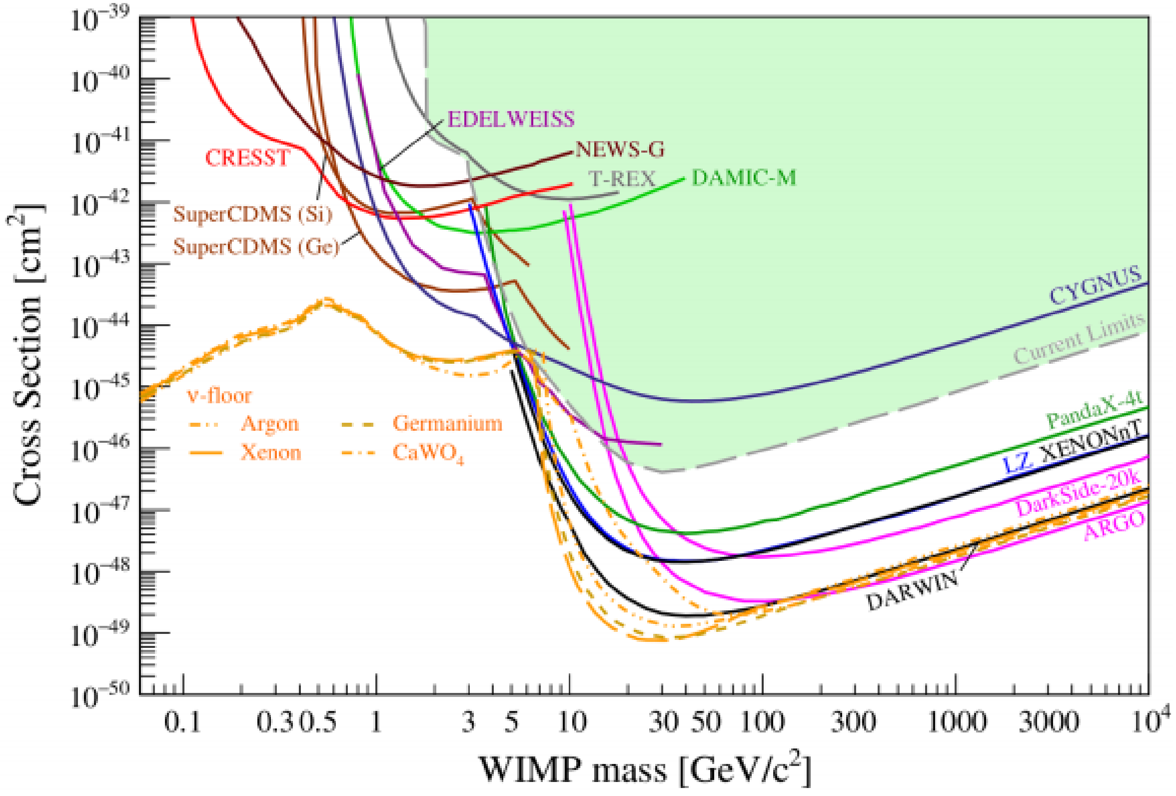
- Study the interior structure of a Gas or Ice Giant with neutrino tomography

Dark Matter Search:

Typical Detector for Neutrinos or Dark Matter:



Current worldwide dark matter experiments limited by solar neutrino background:

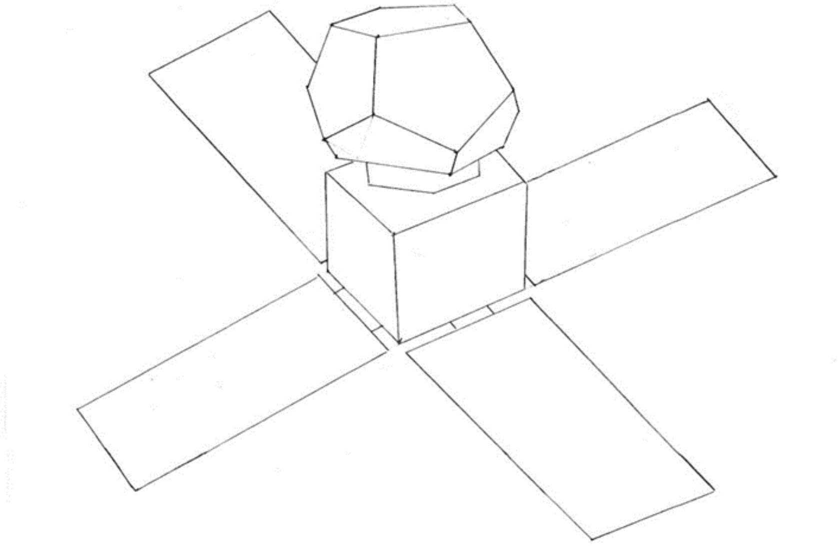


Dark Matter Search:

- By going away from the Sun we could have less solar neutrinos backgrounds.
- Dark Matter could be accumulating around the Sun and it might be higher density closer to the Sun.
- If we cannot distinguish solar neutrinos from dark matter in a detector like many Search experiments cannot, but
  - we know the solar neutrinos fall off as $1/r^2$ which can be removed, and
  - with a large difference in distance from Sun we should be able to see 1 part per thousand and maybe even 1 part per million.

Dark Matter Search:

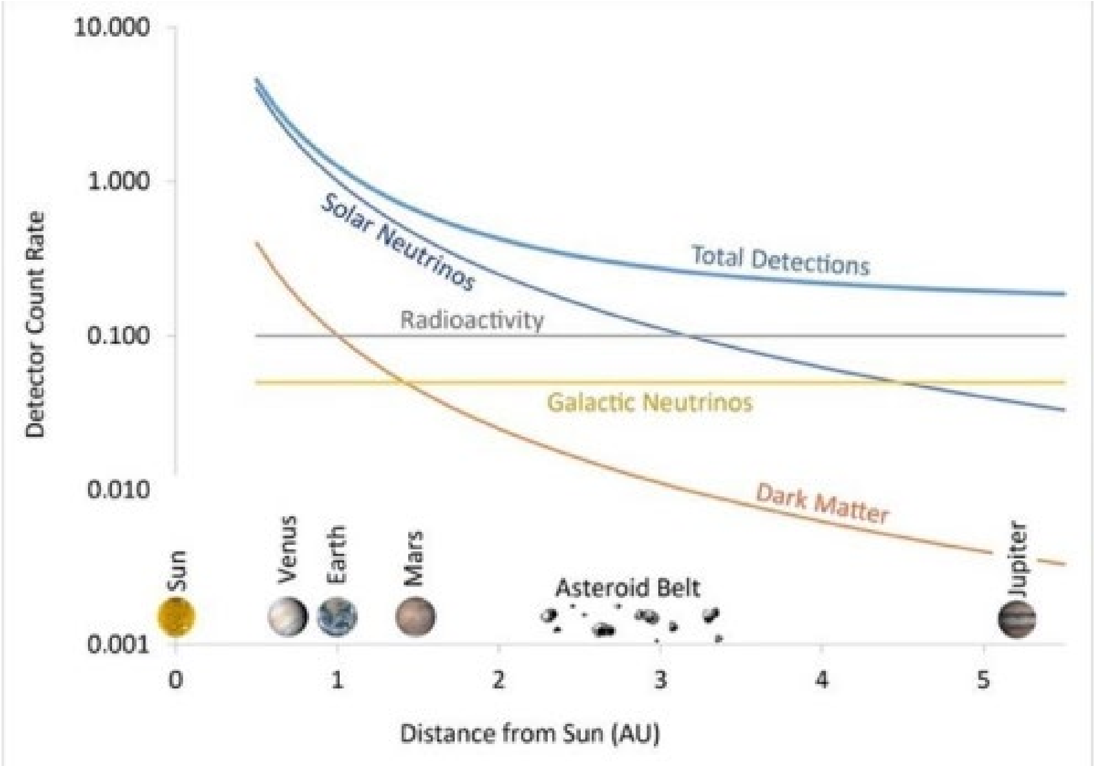
One option is a Spacecraft Dark Matter Detector



Disadvantages:

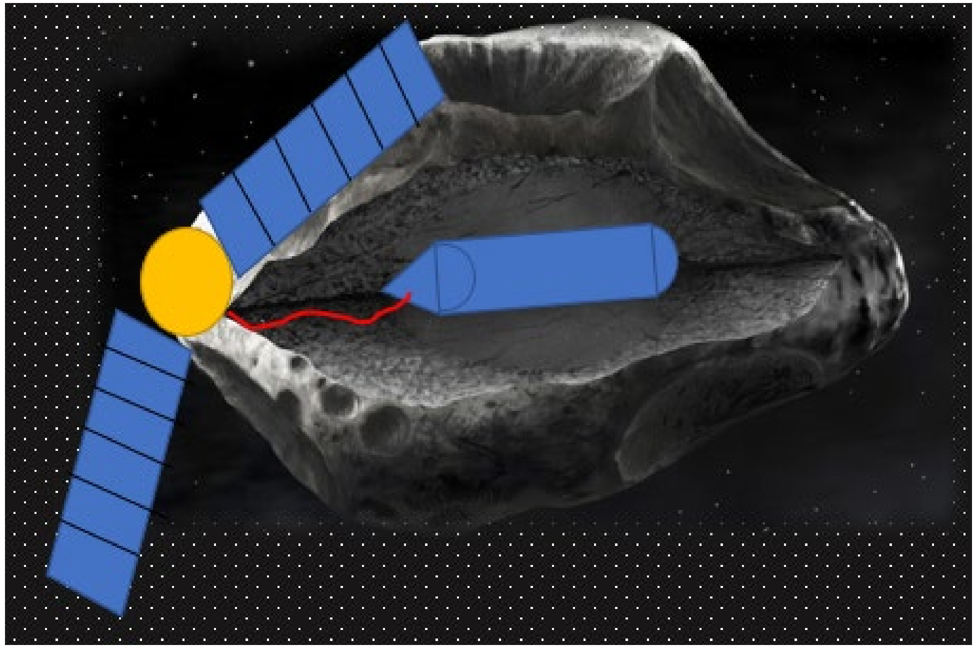
- Limited to a small mass detector
- Only able to take a small shielding

The detector signals four parts as a function of distance from Sun:



Dark Matter Search:

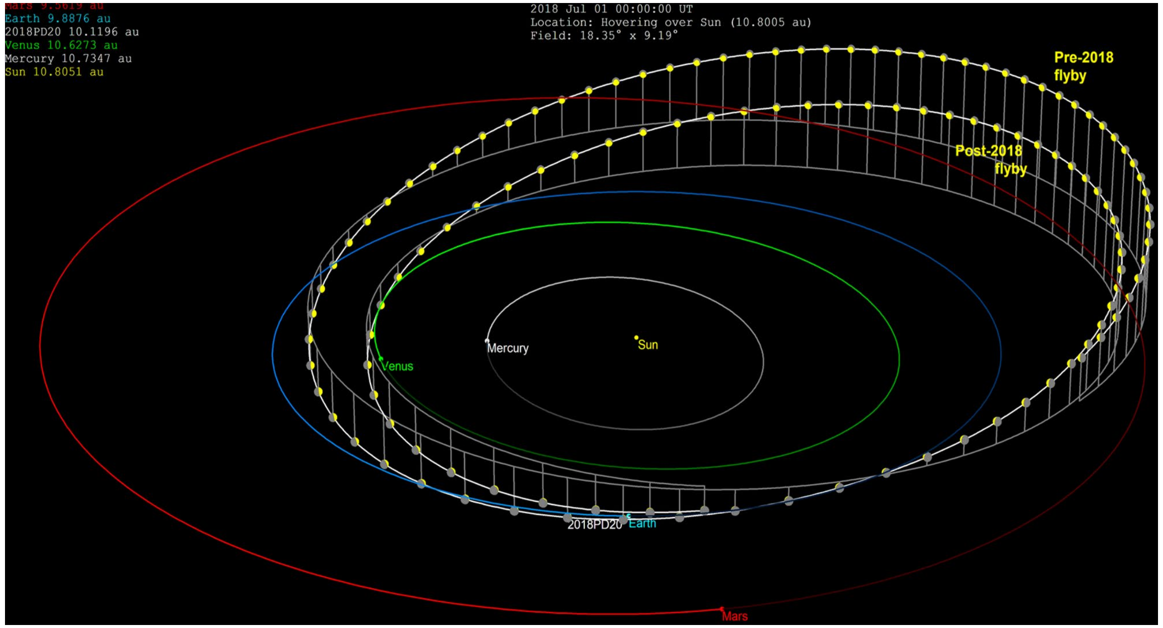
Another option is a Dark Matter Detector in an Asteroid



Advantages:

- Larger mass detector
- Shielding from being inside asteroid

There are many Asteroids that go close to Earth and into orbit of Venus and out to Jupiter:



Detector:

- Melt detector into ice-core asteroid close to sun
- Use a scintillator that is water soluable

Dark Matter Search:

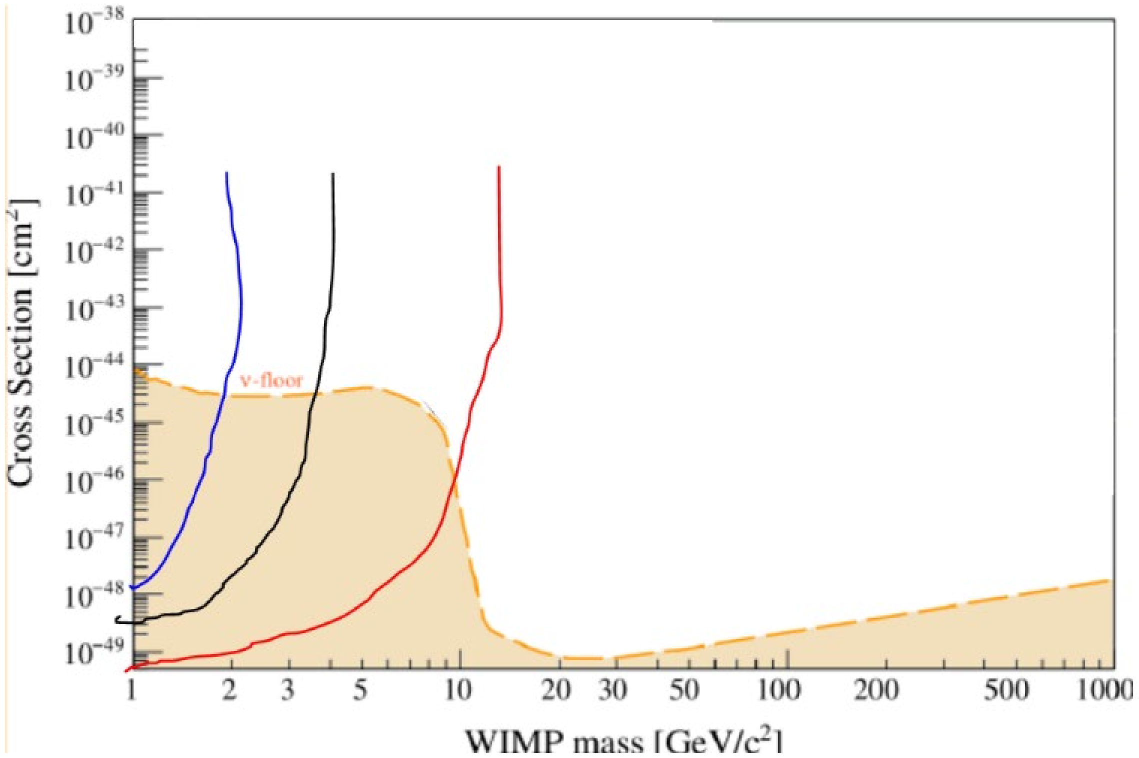
Shrey Tripathi as MS-Physics student did a detailed low mass spacecraft detector sensitivity simulation:

Mass (GeV/c^2)	R(interactions/kg/year)
10	17.19
20	8.60
30	5.73
40	4.30
50	3.44
60	2.87
70	2.46
80	2.15
90	1.91
100	1.72

For a 10 kg low mass detector rates and local WIMP density has a standard value 0.3 GeV/c^2 /cm3 and WIMP velocity is approximated at 10^{-3}c.

$$R = \frac{\rho_\chi}{m_\chi} v\, \sigma_N \frac{N_A}{A}$$

Simulations of low, medium and high mass (10, 100, 1000 kg) Dark Matter Detector masses but assuming perfect veto and shielding:



This project and its funding history started at Wichita State University in 2015.

It is now a cooperation across colleges with Aerospace and Electrical Engineering.

It is in cooperation with NASA labs and other Universities

2015
NASA EPSCOR PDG
with MSFC Les Johnson for $15200

2016
WATKINS FELLOWSHIP
with N. Schwartz for $5000

2016
WSU MURPA GRANT
with Atri Dutta (AE), for 7500

2017
NASA FELLOWSHIP
N. Solomey summer at MSFC for $31300

2018
NASA NIAC PHASE-1
Simulation study for $125000

2019
MSFC CAN GRANT
with MSFC for $138000

2019
NASA NIAC PHASE-2
Construction and Lab testing for $500000

2021
SIMON FUND
Construction of Clean Room for $6000

2021
NASA NIAC PHASE-3
CubeSat space test of detector for $2000000

Total: $2,828,000

MSFC, Huntsville AL

CubeSat Launch into Space

- A rideshare launch on either a SpaceX or RocketLab vehicle
- For our 8 kg, 3U CubeSat into Polar Low Earth Orbit
- 4.5 g maximum acceleration so a smooth ride into space
- $180,000 for the launch
- $425,000 for two years of communications
- Aiming for launch in late Summer of Fall of 2024

At Wichita State our team of Faculty (Physics, Aerospace and Electrical Engineering), along with undergraduates and graduate students (both Master and PhD in Engineering and Physics):

- [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 Phase-1 2018 Grant "Astrophysics and Technical Study of a Solar Neutrino Spacecraft", May 15, 2018 ot Feb. 14 2019 80NSSC18K0868, and NASA Innovation and Advanced Concept Phase-2 2019-2021 Grant, Astrophysics and Technical Lab Studies of a Solar Neutrino Spacecraft Detector, 80NSSC19M0971.
- [3] N. Solomey (PI), CubeSat test of a space neutrino detector, NIAC Phase-3 grant, Oct. 1, 2021 through Sept. 30, 2023, 80NSSC21K1900.
- [4] N. Solomey et al., Design of a Space-based Near-Solar Neutrino Detector for the νSOL Experiment, arXiv:2206.00703, and N. Solomey, Development of a neutrino detector capable of operating in space, arXiv:2206.12479.

We feel these ideas can develop into new ways to study solar neutrinos, Dark Matter and do other science

We welcome Questions or Discussions