DOSE SPECTRA FROM ENERGETIC PARTICLES AND NEUTRONS (DoSEN)

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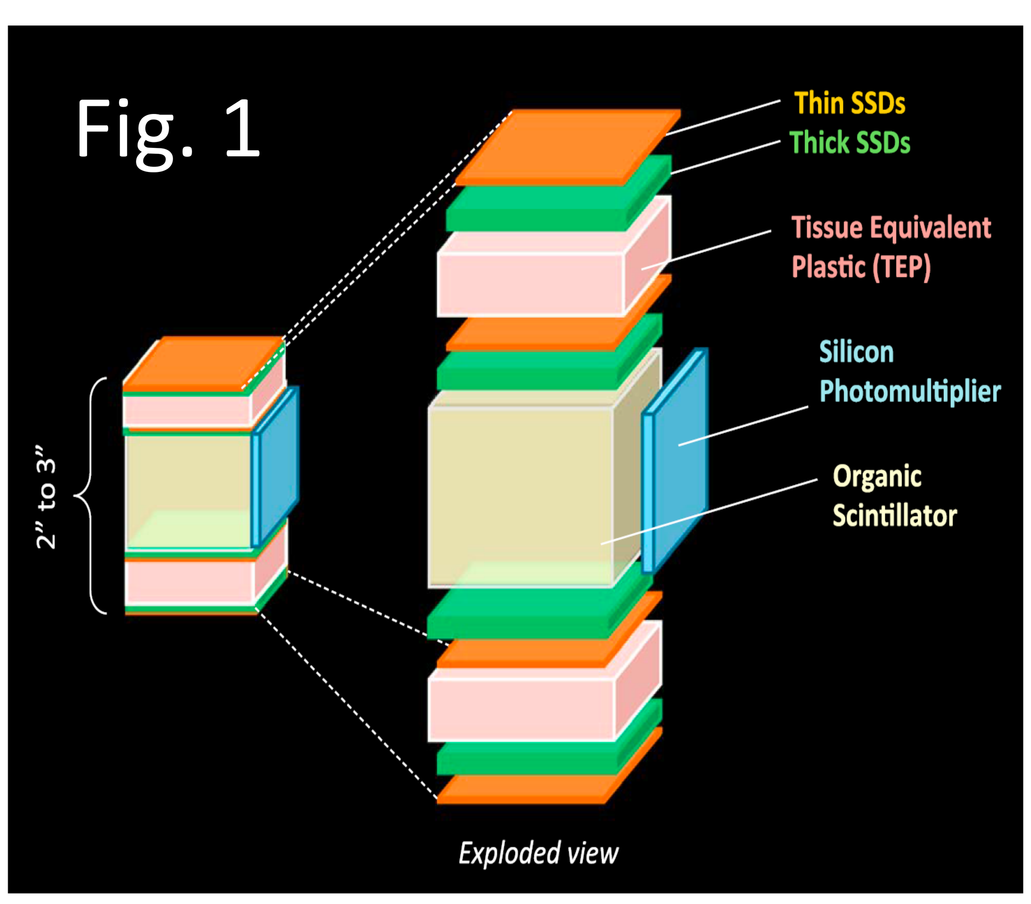
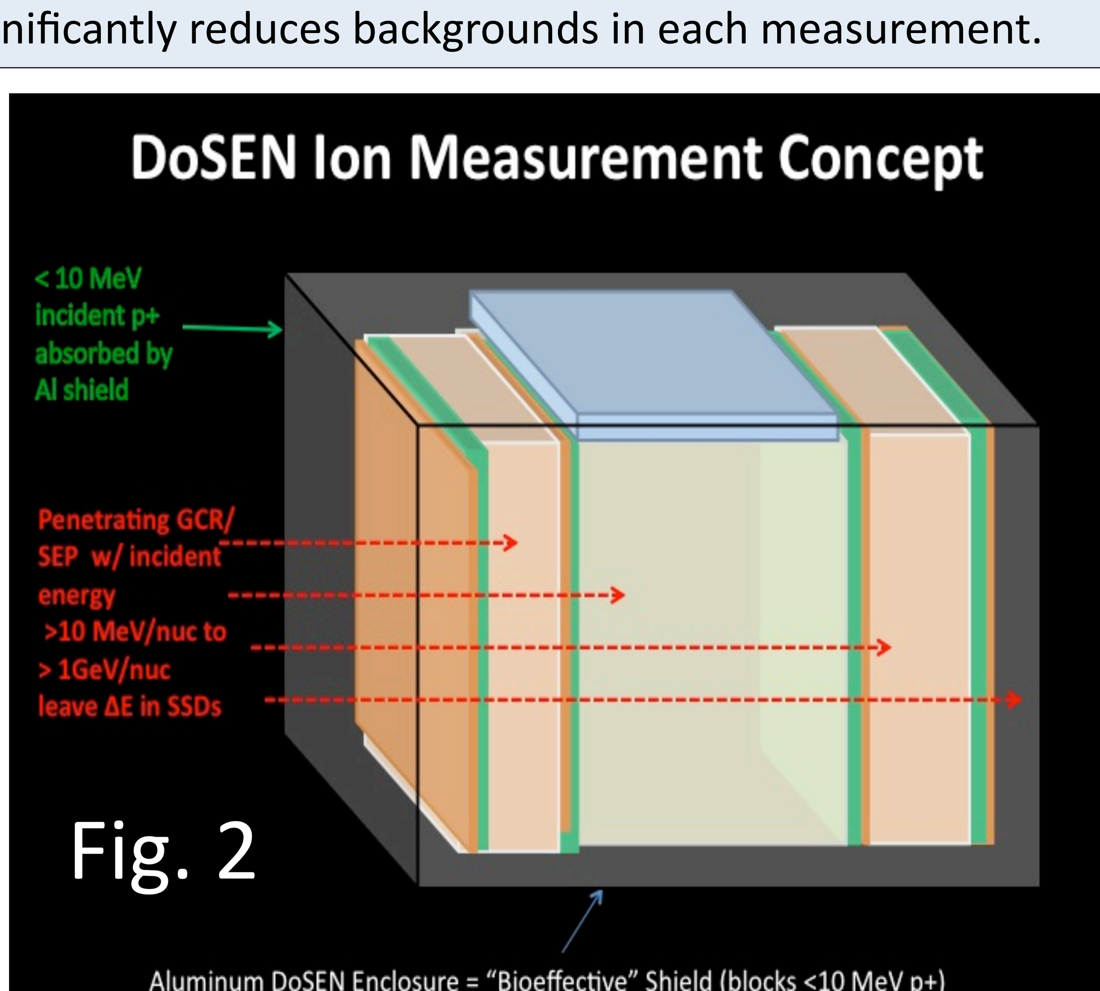
Introduction: DoSEN is an early-stage technology research project that combines two advanced complementary radiation detection concepts with fundamental advantages over traditional dosimetry. DoSEN not only measures the energy but also the charge distribution (including neutrons) of energetic particles that affect human (and robotic) health in a way not presently possible with current dosimeters. For heavy ions and protons, DoSEN provides a direct measurement of the Lineal Energy Transfer (LET) spectra behind relevant shielding material (tissue equivalent plastic), based on a successful design with rich spaceflight heritage.

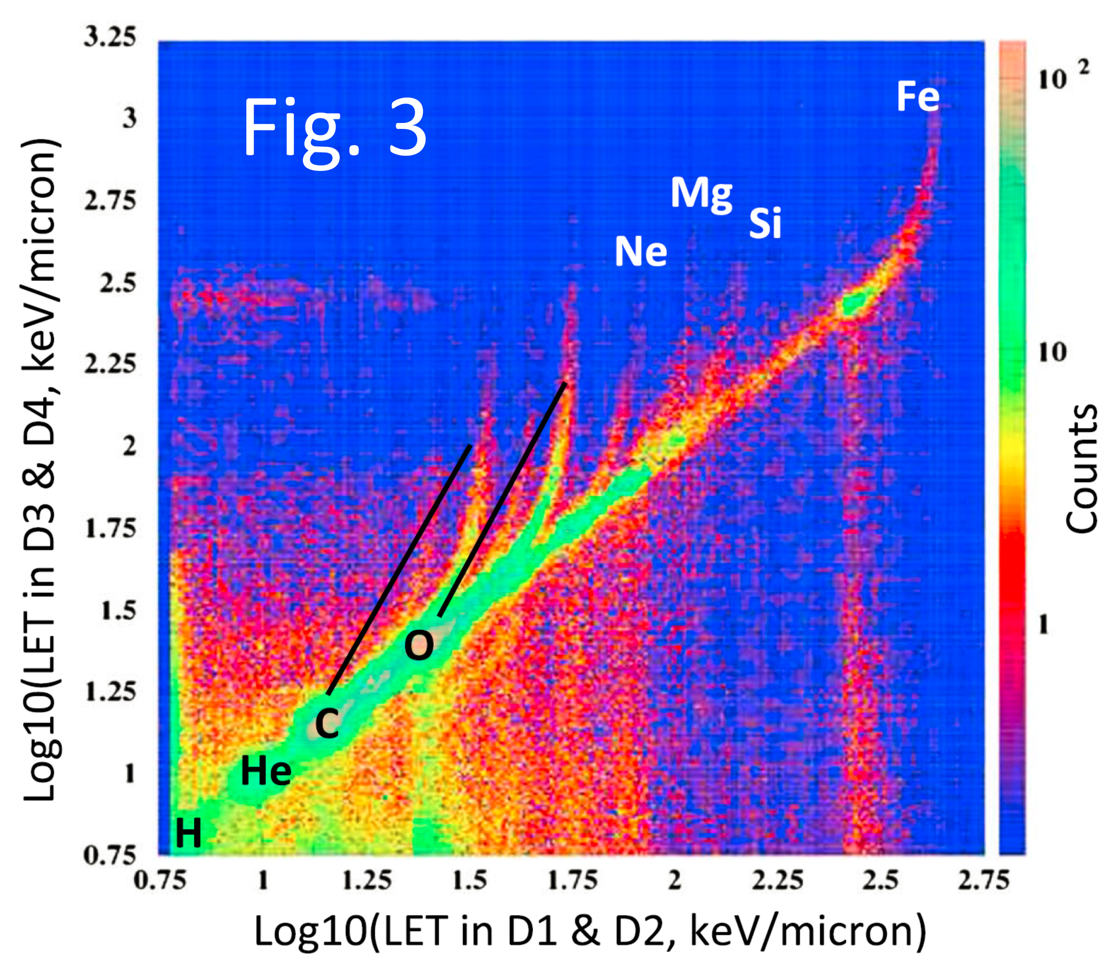
Motivation and Background: As human explorers prepare to leave the safety of near-Earth orbit, the need for assessment of the radiation environment in deep space is more important than ever. For long journeys to anticipated exploration destinations (such as the Moon, Mars, asteroids, or beyond), radiation risk reduction depends on accurate knowledge of the many sources of ionizing radiation facing manned and robotic missions, including galactic cosmic ray (GCR) ions and solar energetic particles (SEP). Pioneering work in understanding and quantifying these effects is ongoing with the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) [*Spence et al., 2010*] on the NASA Lunar Reconnaissance Orbiter (LRO) mission [*Chin et al., 2007*]. DoSEN is a prototype instrument development program that miniaturizes the CRaTER instrument , adds a neutron measurement capability, and provides for prompt reporting of dose, dose rate, and dose equivalent [*Schwadron et al., 2013*]. **Such a compact instrument could be flown on future planetary mission orbiters to characterize the radiation environment (GCR, SEP, and planetary neutrons) throughout the solar system.**



DoSEN – A Miniaturized CRaTER : DoSEN's design is based on that of CRaTER [*Spence et al., 2010*], but miniaturized for all future planetary and exploration missions. DoSEN extends CRaTER's capability by including neutron detection and dosimetry (Fig. 1). DoSEN direct lineal energy transfer (LET) measurements provide fast, active readout of dose, dose rate, dose equivalent rate from GCR, SEP, and secondary particles, all with sufficient energy to penetrate the thin housing and thus be of interest for exploration. As in CRaTER, DoSEN's multiple particle detection coincidence allows GCR ion species to be identified, from which measured LET and biological impact can be estimated through an LET-dependent quality factor. Using the coincidence of LET measurements and neutron detection significantly reduces backgrounds in each measurement.

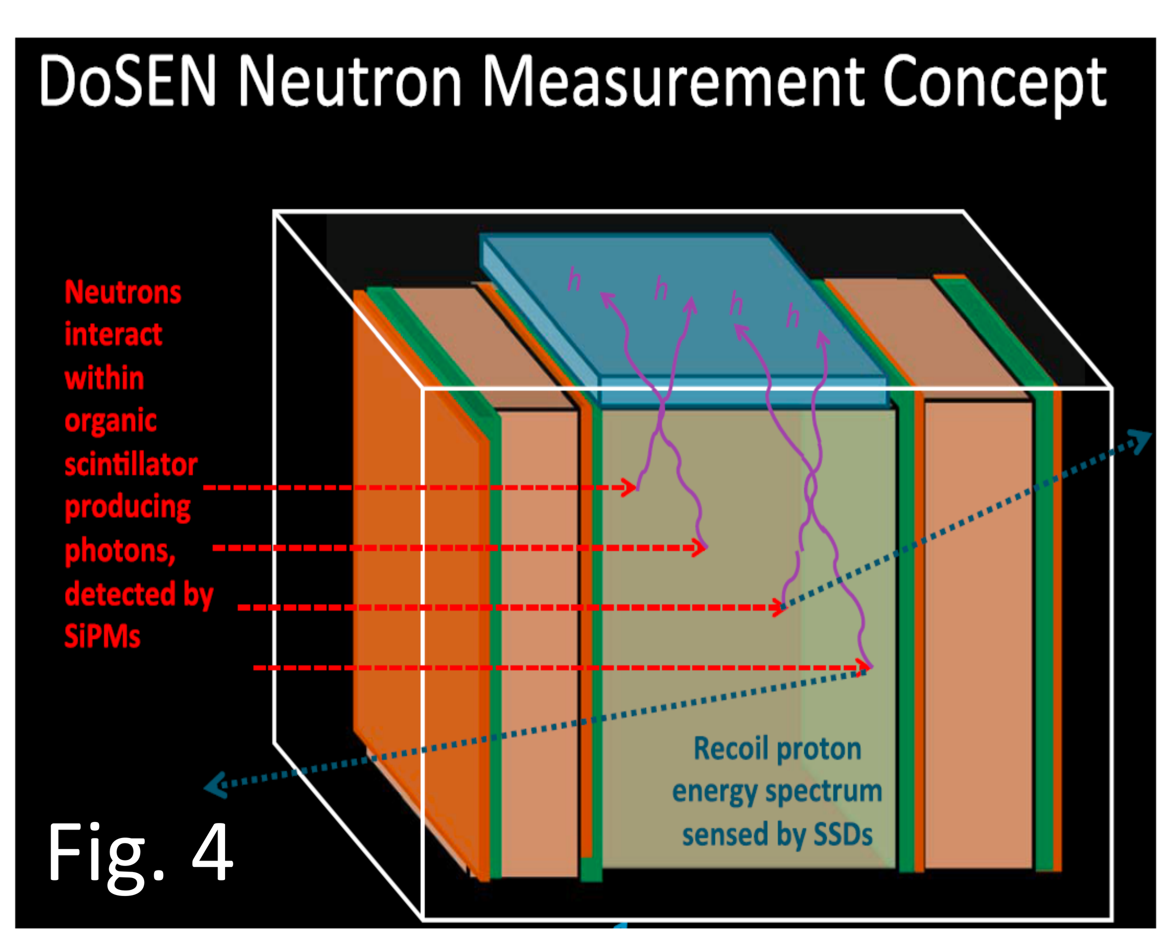


Ion Measurement Principle: For heavy ions and protons, DoSEN provides a direct measurement of the LET spectra behind shielding material (Fig. 2). For LET measurements, DoSEN contains stacks of thin-thick Si solid-state detectors (SSDs) similar in design to those used for CRaTER (Fig. 1). The thicknesses are 150 μm (thin) and 1000 μm (thick).



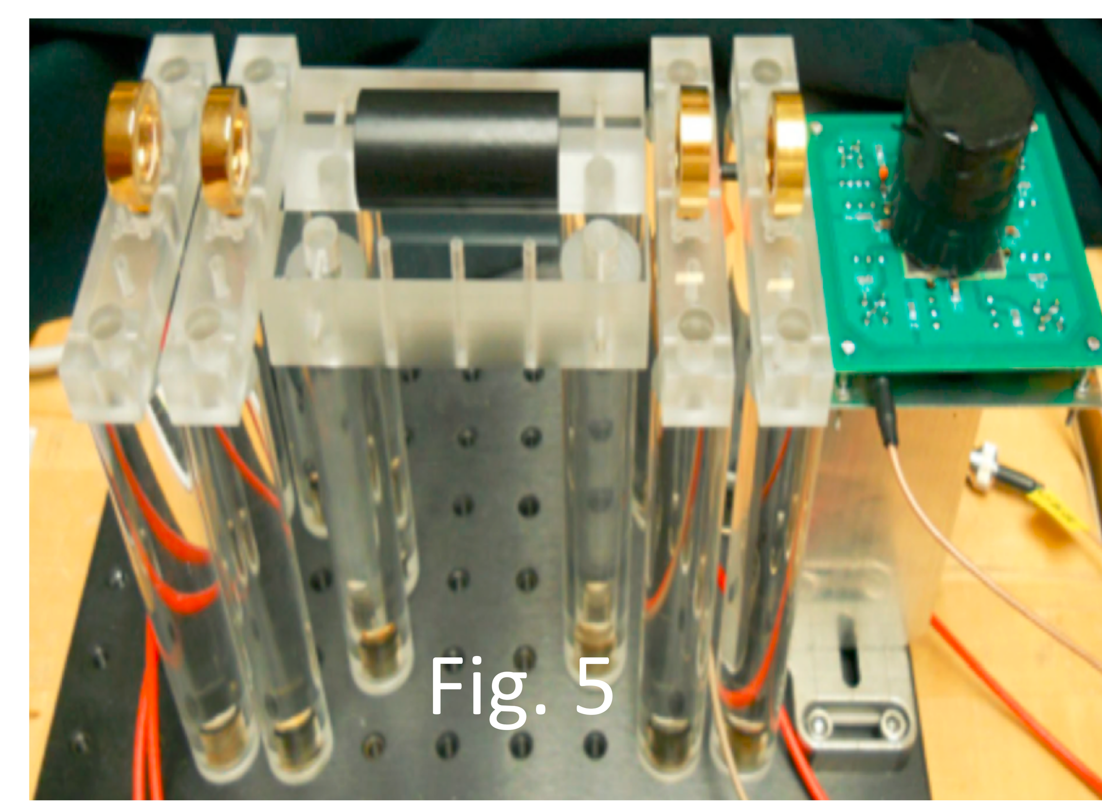
CRaTER/DoSEN Technique for Species Identification: Fig. 3 shows a CRaTER "cross plot," the LET spectra from the D1/D2 detectors versus the LET spectra from the D3/D4 detectors, measured in Lunar orbit. D1/D2 and D3/D4 refer to the thin/ thick SSD pairs; each detector pair is separated by tissue equivalent plastic (TEP). CRaTER cleanly resolves the different GCR ion species (H, He, C, O, Ne, Mg, Si, & Fe) that contribute to the radiation dose and dose equivalent.

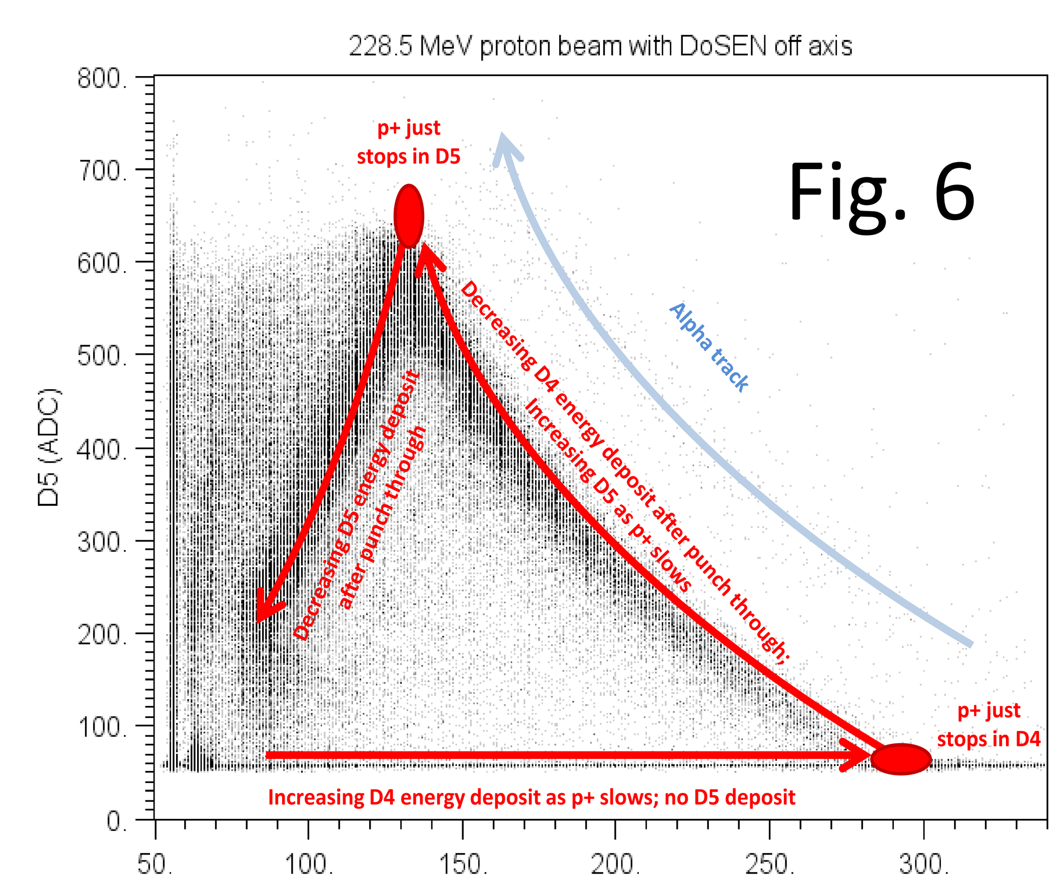
With LET spectra, we can now directly break down the observed spectrum of radiation into its constituent heavy-ion components and through biologically based quality factors that provide not only doses and dose rates but also dose equivalents, associated rates, and even organ doses.



Neutron Measurement Principle: DoSEN also measures neutrons from 10 to 100 MeV, which requires enough sensitive mass to fully absorb recoil particles that the neutrons produce (Fig. 4). Organic stilbene scintillator is used to record neutron interactions, which can be distinguished from gamma-ray interactions via pulse shape discrimination (PSD). The scintillator light is recorded using com- pact, low-voltage silicon photomultipliers (SiPMs) [*Bloser et al. 2013*]

DoSEN Laboratory Prototype: The DoSEN measurement principles have been demonstrated through the construction and testing of a laboratory benchtop prototype (Fig. 5). The prototype consists of four Si SSDs, TEP plastic, a 1-inch cylindrical stilbene crystal wrapped in white Teflon tape, and a 2 × 2 array of multi-pixel photon counter SiPMs purchased from Hamamatsu Corp. The prototype was successfully tested using the 230 MeV proton beam at the Francis H. Burr Proton Therapy Center at Massachusetts General Hospital. Fig. 6 shows a cross plot between the stilbene (D5) and an SSD (D4) for particle produced in an Al target.





DoSEN Engineering Model: The next step in the development of DoSEN is the construction and testing of an engineering model (EM) using a more realistic, compact configuration (Fig. 7) and custom electronics. At the core of the EM is a new, more rugged organic crystal, p-terphenyl, that is sensitive to gamma, neutron, and charged particle radiation. The EM will have a plastic scintillator that has its center machined out to fit the p-terphenyl crystal and will pro- vide an anti-coincidence signal. Tightly packed above and below the p-terphenyl are SSDs that have been purchased from Micron Semiconductor. We are currently exploring opportunities to test the EM with the FAA on a high-altitude aircraft.

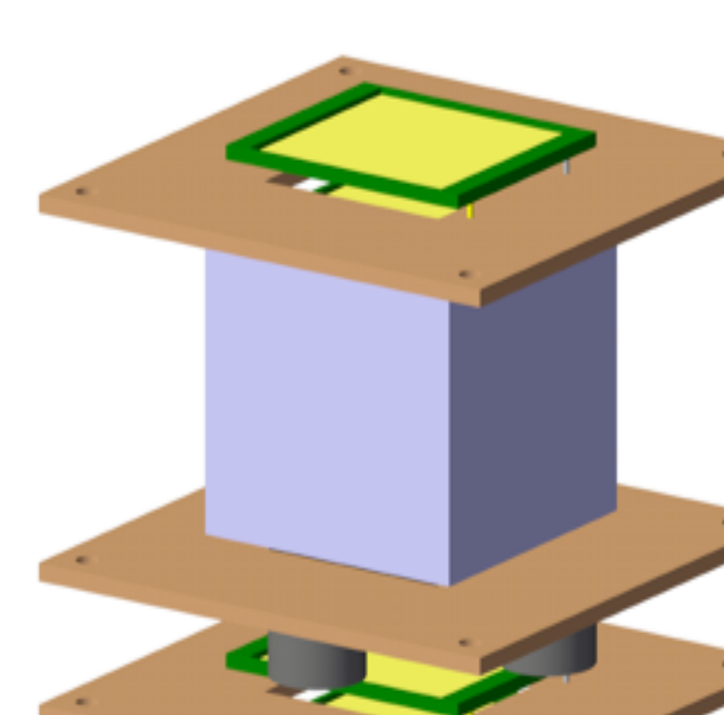


Fig. 7

References: Case, A., et al., (2013) *Space Weather*, *11*, 361-368; Chin G. S. et al. (2007) *Space Sci. Rev., 129(4)*, 391-419; Schwadron N. et al. (2013) *Space Weather*, *11*, 1-10; Spence H. E.. et al. (2010) *Space Sci. Rev., 150(1-4)*, 243-284; Bloser, P. F., et al., (2013) *Proc. SPIE, 8859*, 885909

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