CAPABILITIES OF GAMMA RAY AND NEUTRON SPECTROMETERS FOR STUDYING TROJAN ASTEROID COMPOSITION. A. M. Parsons[1], L. Evans[1,2], L. Lim[1],and R. Starr[1,3]. , [1]NASA Goddard Space Flight Center, Ann.M.Parsons@nasa.gov, [2]Computer Sciences Corporation, [3]Catholic University of America

Introduction: A Trojan Tour and Rendezvous mission was specifically targeted by the 2011 Planetary Decadal Survey Committee as a high priority mission for the New Frontiers program.

Trapped in stable orbits around Jupiter's L4 and L5 Lagrange points, the Trojan asteroids are positioned right at the boundary between the inner and the outer solar system. The history of these bodies is unknown: were they formed at the outer edges of the main asteroid belt and then migrated outwards to L4 and L5 or were they formed in the Kuiper belt and then migrated inwards before being captured at L4 and L5? Studying the compositional and physical properties of these Trojan asteroids will provide a window into the dynamical history of the early solar system. To date, no spacecraft mission has ever visited a Trojan asteroid.

As the scientific community studies different Trojan asteroid mission architectures and instrument suites, it is important that a variety of high heritage instrument technologies be considered to determine the most appropriate technologies for the highest scientific return. This presentation will discuss the unique capabilities of high heritage gamma ray and neutron spectrometers for determining the surface and subsurface composition of Trojan asteroids. Unlike IR or X-ray observations, the penetrating nature of gamma rays and high-energy neutrons allows us to probe 30-50 cm below the surface of a planetary body without making contact with it. These bulk composition measurements can thus be made using remote sensing instruments from a low altitude (~50 km) orbit above the asteroid. Similar instruments have been successfully flown on previous missions such as Mars Odyssey, NEAR, and MESSENGER, so high heritage designs are readily available.

Trojan Composition Models: If Trojan asteroids formed far out in the Kuiper belt, they may consist largely of ice covered by a thin refractory lag deposit formed after sunward migration. This hypothesis could be tested with instruments that can determine if there are indeed stable volatile species trapped below the surface.

Based on thermal infrared spectra of the largest Trojans obtained with the Spitzer space telescope, it has recently been suggested that the surfaces of these Trojans may consist of fine ground silicates suspended in an IR transparent matrix such as salt [1, 2].

A gamma ray/neutron instrument package can detect subsurface volatile reservoirs as well as surface

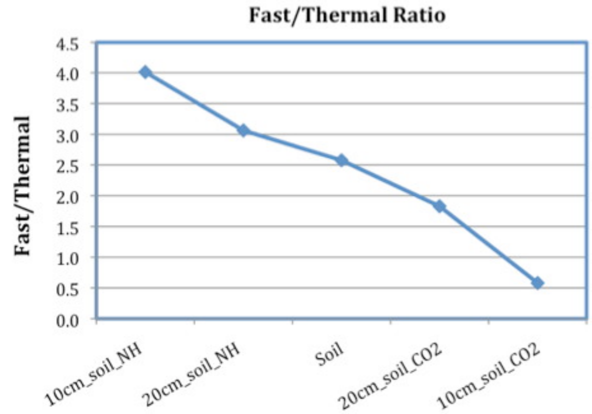

Figure 1. Fast/Thermal neutron ratio for two different ice cores, ammonia (NH_3) and carbon dioxide (CO_2), and for two different burial depths, 10 and 20 cm, compared to a pure soil composition

salt lags. We will present the results of Monte Carlo N-Particle eXtended (MCNPX) [3] computer simulations of neutron flux ratios and gamma ray count rates measured by a 6.7 cm tall, 6.7 cm dia. HPGe gamma ray spectrometer (the same size as the Mars Odyssey GRS [4]) at a 50 km altitude above a 120 km diameter spherical Trojan asteroid. For these preliminary simulations we have used a 1 particle/cm^2/s GCR flux. (Our final presentation will include simulation results scaled to the GCR flux expected at 5 AU.)

Measuring Subsurface Volatiles: As described in a recent review of Kuiper belt object composition [5], for objects the size of a Trojan asteroid, the most stable

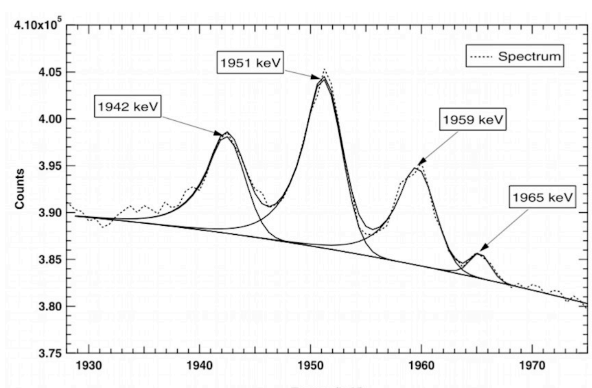

Figure 2. Gamma ray spectrometers are very sensitive to chlorine! The Mars Odyssey GRS measured Cl abundance was 0.49% ±0.3%. The GRS spectrum above shows strong Cl and Ca lines, demonstrating a gamma ray spectrometer's ability to detect salts. The peaks are from Ca(n,γ) at 1942 keV and two Cl(n, γ) lines at 1951 and 1959 keV. [6]

species besides H_2O will be CO_2, H_2S and CH_4. NH_3 may also be found if the object was formed at a sufficiently great distance (>30 AU). Only gamma ray and neutron instruments can conduct this kind of measurement remotely via subsurface detection of specific elements such as C, O, N, S and H. We will use MCNPX computer simulations to study the ability of gamma ray and neutron instruments to characterize the composition and depth of ices that may be buried beneath a thin outer layer of chondritic material.

Through computer simulations, we will demonstrate that gamma ray/neutron instruments can easily detect subsurface water ice. We will also study the ability to differentiate between water ice and other ices. For example, computer simulations were run for three elemental composition configurations for this asteroid: 1) a basic CI chondritic composition; 2) a two-layer model with NH_3 buried under 5, 10 and 20 cm thick layers of chondritic soil; and 3) another two-layer model with CO_2 buried under 10 and 20 cm thick layers of chondritic soil.

*Gamma Ray Spectrometer Results***:** Measurement of the count rates for gamma ray lines at energies characteristic of specific isotopes provides the bulk elemental composition of the asteroid material. Thus our simulation results reflect the composition of the asteroid. We also ran computer simulations to study how nitrogen and carbon gamma ray count rates would vary for CO_2 and NH_3 buried at different depths below the asteroid's surface. We find that while the gamma ray count rates from the inelastic scattering process are not very sensitive to burial depth for either element, the thermal neutron capture line count rates are quite sensitive to depth for both nitrogen and carbon.

Neutron Measurements: Neutron measurements may also provide sensitive detection of subsurface ices and identification of ice type and burial depth. The ratio of fast neutrons (E>0.1 MeV) to thermal neutrons (E<0.04 eV) is especially diagnostic. Figure 1 shows how this ratio may vary with the burial depth and the type of ice below the surface. Thermal neutrons are depressed in the presence of nitrogen because of a large resonance in the $^{14}N(n,p)^{14}C$ reaction near 3 eV. CO_2, on the other hand, thermalizes neutrons effectively, but has a low capture cross-section resulting in an enhanced thermal neutron flux. The ratios in Figure 1 reflect these differences. The fast/thermal neutron ratio, especially when used in conjunction with the gamma ray data, may prove to be very useful for detecting these trapped subsurface volatiles.

Measuring IR-Absorbing Materials in a Salt Matrix: A gamma ray spectrometer can easily detect a halite salt matrix on the surface of the Trojan asteroid, since chlorine has a very high cross-section for gamma ray-producing neutron capture reactions. To illustrate this point, Figure 2 shows strong Cl and Ca lines in Mars Odyssey GRS spectra [5]. Yang *et al.* [1] present both IR radiative transfer calculations and experimental emissivity results verifying that a ~90 wt. % salt (halite) matrix containing 2-10 wt. % IR absorber (e.g. carbon or iron) and 1-5 wt. % fine-grained silicates produces infrared emission consistent with measurements from Trojan asteroids. Compositional characterization of the absorber and silica grains suspended in it may also be possible although the high chlorine cross-section will suppress the iron and silicon signals. We will perform computer simulations of the gamma ray spectrometer's ability to measure the composition of the salt matrix and will concentrate efforts to determine the sensitivity level for detection of a small amount of iron, carbon and silicon that may be embedded in the salt.

Conclusions: Preliminary simulation results indicate that there may be effective methods for detecting subsurface CO_2 and NH_3 on Trojan asteroids using gamma ray and neutron instruments. These technologies are also effective in determining whether large salt deposits exist on Trojan asteroids.

We will continue to study the use of these instruments as we refine our simulations. The results of these refined simulations will be presented, providing quantitative estimates of expected gamma ray and neutron fluxes from a Trojan asteroid so that the required observation times can be determined for the detection of specific elements at specific altitudes and observation times. This will permit an informed evaluation of the trade space between cost/engineering feasibility and scientific return.

The potential contributions of these high energy instrument technologies to the study of Trojan asteroids is thus compelling and is worthy of greater study as the scientific community continues to develop Trojan Tour and Rendezvous Mission concepts.

References: [1] B. Yang, *et. al.,* (2012) *Icarus* http://dx.doi.org/10.1016/j.icarus.2012.11.025. [2] J. P. Emery *et. al.,* (2006) *Icarus*, 182: 496-512. [3] D. B. Pelowitz et al. (2005) *MNCPX User's Manual, Version 2.5.0*, LANL, LA-UR05-0369. [4] W. V. Boynton, *et al.* (2004) *Space Science Reviews,* 110: 37–83. [5] M. Brown (2011) *Annual Review of Earth and Planetary Sciences*, arXiv:1112.2764v1 [astro-ph.EP]. [6] L.G. Evans, et al., (2007), *JGR,* 112: 1–21.