RESULTS OF A HUBBLE SPACE TELESCOPE SEARCH FOR NATURAL SATELLITES OF DWARF PLANET 1 CERES. B.E. DeMario[1], B.E. Schmidt[1], M. Mutchler[2], J.-Y. Li[3], L. McFadden[4], B. McLean[2], C. T. Russell[5], [2]Georgia Institute of Technology, School of Earth and Atmospheric Sciences, 311 Ferst Drive, Atlanta, GA 30312 , [2]STSCI, [3]PSI, [4]Goddard, [5]UCLA (bdemario3@gatech.edu; britneys@eas.gatech.edu).

Introduction: Ceres was the first object to be discovered in the asteroid belt between Mars and Jupiter. In many ways, it is a unique object, being the largest object in the asteroid belt, the only one to assume a spherical shape, and possessing the spectral signature of water vapor [1]. The IAU in 2006 elevated Ceres to the position of 'Dwarf Planet' alongside other objects such as Pluto and Eris. Ceres with many distinctive characteristics, may also have satellites. Though none have been found to date, it is nevertheless, worth continued search because of Ceres' importance among small bodies. However, the similarly large asteroid Vesta possesses no substantial satellites [2], so Ceres may in fact not have a satellite. Either result would be of scientific value.

The spacecraft Dawn will arrive at Ceres in April 2015. As preparatory work in anticipation of this arrival, an investigation was carried out to determine the presence or absence of a companion object orbiting Ceres. Long exposure images of Ceres were taken by the Hubble Space Telescope during April 2014 and analyzed by the search team. The observations included short exposures to search near Ceres for close-in satellites missed by previous surveys, and mid and long exposures with Ceres overexposed to search most of Ceres' Hill sphere for objects much smaller in size.

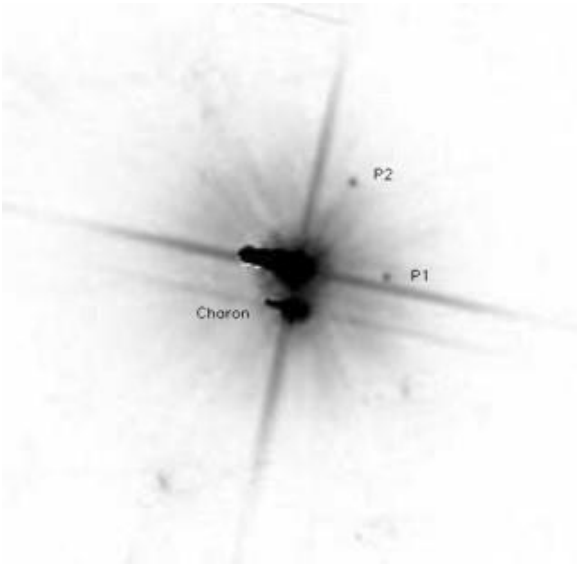

Figure 1: Dwarf Planet Pluto with additional satellites discovered by Mutchler et. al. [3]

Background: Similar investigations have been conducted by other researchers. Mutchler et. al. discovered four additional satellites surrounding the Pluto-Charon system. [3] In addition, McFadden et al. [4] using similar techniques studied asteroid Vesta's neighborhood prior to Dawn's arrival. Their investigation concluded that no satellites existed that were larger than 22 m radius, a result which was confirmed and improved upon when Dawn arrived at Vesta. [2, 4] Previously, Li et. al.[5] have photometrically analyzed Ceres at a resolution of 30 km using the Hubble Space Telescopes and failed to locate any moons at that sensitivity.

Methodology: Data collected by the Hubble Space Telescope were processed according to three different methods. These methods generated .comb, .unsharp, and .sum files, and the raw files were also retained. Researchers examined the files using a program called SAOImage DS9, which is able to display and compare the raw data according to many different interpolations(linear, logarithmic, etc). The color of the representation may also be changed to aid in scanning the images by eye.

Candidate objects were identified based on a Gaussian point-spread brightness function, not being overly bright (indicative of cosmic ray interference), and appearing in the raw files as well as the combined images. The locations of objects fitting these three criteria were recorded so that further analysis could be done to either confirm or rule out these objects.

The data files were searched starting with the widest-field, longest-exposure, 180 second files. These exposures represent the deepest look taken by the Hubble Space Telescope, and as such would have the greatest likelihood of containing satellites. These images contain approximately the inner 1/3 of the Hill Sphere of Ceres, meaning any objects found in these images are likely to have stable orbits around Ceres. However, if the objects were too close to Ceres, the additional noise contributed by the proximity of Ceres would have rendered them impossible to detect.

Following the analysis of data from all 180 second exposures, attention turned to the shorter 30-second exposures. This exposure length allows the area closer to Ceres to be observed with less noise from Ceres. In this way, by focusing search efforts on the area closer to Ceres, we have a greater chance of finding any satel-

lites which may have orbited much closer to Ceres than would be detectable in the longer exposures.

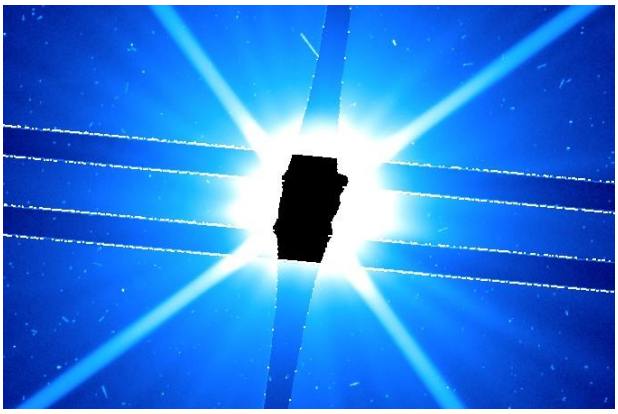

Figure 2: Overexposed image of Ceres taken by the Hubble Space Telescope.

Finally, there also existed shorter 3-second and 5-second exposures. These images were studied well because there are many circumstances that may hide moons. It is distinctly possible that cosmic rays, diffraction spikes, and poor viewing angles may have hidden moons from all previous exposures. By studying data taken at different time intervals and different exposure times, the likelihood of these objects being missed will be minimized.

In the event that no satellites were definitively detected by these approaches, a means was devised to test the limiting magnitude of the search and hence to set limits on the size of satellites that may have been too dim to observe. False objects of known magnitude were inserted into the data, some of which mimic moons and some of which mimic background objects, and the new data were studied as indicated above. Based on whether or not false objects of known magnitude were detected or not, an upper limit on the brightness, and hence the size, of satellites may be set.

We will present the results of our search for satellites or Ceres, and place limits on the size of objects to which our search has been sensitive.

References: [1] Kuippers, M. et. al. (2014) ”Localized sources of water vapour on the dwarf planet (1) Ceres”. Nature 505 (7484): 525527. [2] Memarsadeghi, N. et. al. ”Moon Search Algorithms for NASAs Dawn Mission to Asteroid Vesta.” (2011) [3] H. A. Weaver et. al. (2006). ”Discovery of two new satellites of Pluto”. Nature 439 (7079) [4] McFadden, L.A. et al. 2012 “Upper Limits on the size of Satellites of Asteroid (4) Vesta from 2007 Hubble Space Telescope observations. Icarus, 220, 305-310. doi:10.1016/j.icarus.2012.05.002 [5] Li, J.-Y. et. al. (2010). ”Hubble Space Telescope observation of Asteroid 1 Ceres in 2003/04.” Astrobiology Science Conference 2010, Abstract no. 1538.