CERES: A PRIME TARGET FOR ROBOTIC SAMPLE RETURN AND FUTURE HUMAN EXPLORATION. K. R. Fisher[1] and L. D. Graham[1], [1]Astromaterials Research and Exploration Science (ARES) Division, NASA Johnson Space Center 2101 E NASA Pkwy, Houston Texas, 77058. Kenton.r.fisher@nasa.gov and Lee.d.graham@nasa.gov

Introduction: NASA's Dawn spacecraft was recently deactivated in November after spending three years orbiting Ceres gathering data through its remote sensing instrument suite. The Dawn mission served as a crucial step in furthering our understanding of small bodies within the Solar System and provided a wealth of new information about Vesta and Ceres during the eleven year mission.

The conclusion of Dawn should not be the conclusion of exploration at Ceres. A logical follow-on mission would be to return samples from the surface to provide ground truth for the orbiter data. Ceres sample return is highly feasible and would benefit directly from engineering developments and lessons learned from the on-going OSIRIS-REx mission.

Ceres should also be considered a prime target for long-term human missions. NASA's current human exploration architecture includes the Moon as a near-term target with Mars as the follow-on destination. Transitioning directly from the Moon to Mars requires significant advances in multiple fields including long-duration habitation, crew autonomy, and entry/descent/landing at Mars. An architecture that includes Ceres as the middle step between lunar and Martian missions would allow a phased development of the previously-mentioned technologies while accomplishing high-value scientific goals.

Dawn Science Results: Research into the data returned from the Dawn mission is underway. Early results depict a body with low bulk density which suggests significant water content [1]. NH_4 and Mg-phyllosilicates and carbonates are globally distributed and some locations feature water-ice and salt exposed on the surface [1]. The surface composition and internal structures suggests an aqueous history and there is evidence for recent cryovolcanic features [2,3,4]. These are only a few of the recent findings which confirm Ceres is a unique and scientifically significant body which should be a priority for future missions.

Sample Return: Returning samples from a planetary surface is the best way we can learn about the parent body without sending humans. Currently there are two on-going sample return missions to small bodies, OSIRIS-REx and Hayabusa 2, while a potential third is in the final stage of the *New Frontiers* competition. A Ceres sample return mission could be performed with a lower cost cap and reduced development risk by utilizing the systems previously developed for the OSIRIS-REx spacecraft.

A major component that could be re-used is the OSIRIS-REx sampling system. OSIRIS-REx will utilize the Touch-and-Go Sample Acquisition Mechanism (TAGSAM) to acquire up to hundreds of grams of surface material. TAGSAM includes a large collector head mounted to the end of an 11 foot robotic arm. The collector head has multiple gas nozzles which will dispense a burst of nitrogen gas to stir up loose regolith on the surface under the collector head [5]. A portion of this regolith will be captured in the TAGSAM collectors and stored for return [5]. This process can be repeated at up to three sampling locations. The TAGSAM system should function well on the surface of Ceres as it is a small airless body with low gravity.

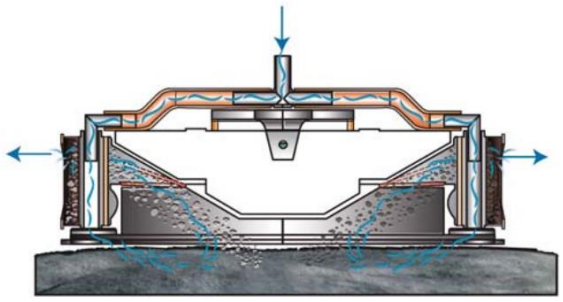

Figure 1: TAGSAM collector head. Blue lines represent the path of the nitrogen gas when dispensed to stir up loose regolith which is then trapped by the collector filters. Reusing this design for a Ceres sample return mission would be cost effective while providing valuable samples. [1]

The OSIRIS-REx design would require a few changes to operate at Ceres. Ceres is a larger gravity well than Bennu and would require more capable thrusters with a larger fuel reserve to allow the spacecraft to operate. This mass increase could be offset by removing the remote sensing instrument payload from the spacecraft. The primary purpose of the instrument suite on OSIRIS-REx was to survey the surface of Bennu to identify the best locations for sampling. Bennu had never previously been visited by a spacecraft and therefore very little was known about it. Ceres has been extensively studied and mapped by the Dawn team which would allow for removing the remote sensing instruments from a follow-on sample return mission.

Human Exploration: Human exploration should be a long-term, multi-phase process that involves building up experience at sequentially more difficult loca-

tions. Each destination should be used, in conjunction with research goals, to develop and test technologies that are needed for future missions. Ceres is an ideal location to use as an intermediate stepping stone for human exploration from the Moon to Mars.

Jumping directly from lunar missions to Mars requires closing large development gaps in two major areas: lengthy in-space transit times and difficult entry, descent, and landing (EDL) problems. Both issues are nontrivial and will require years of research and billions of dollars in investment to overcome. A human mission to Ceres would be of comparable duration as a Mars mission with vastly simpler EDL [6]. A more logical approach would be to separate these development pushes so that they are no longer required to be performed simultaneously (such as would be needed if going from Moon directly to Mars). Inserting Ceres into the human exploration architecture would allow a natural progression in the development efforts while providing a meaningful destination for astronauts.

Development could be phased in the following way:

Moon	Ceres	Mars
EVA/Surface Ops	Micro-g proximity ops/EVA	Atmospheric EDL/ascent
Long-stay surface habitation	Long-duration transit	Atmospheric EVA
Airless body EDL/ascent	Crew autonomy	

The technologies in each column would be developed while missions are on-going at the previous location. Therefore while we are operating lunar missions, development would be done on long-duration transit habitation for a future Ceres mission. Those technologies for the long transit to Ceres could be directly carried over to a future Mars mission. Then while we are testing those capabilities on trips to Ceres, development would be underway on Martian EDL.

Conclusion: In conclusion, Ceres is an ideal destination for robotic sample return and future human missions. A low-cost sample return mission could be accomplished by utilizing the technologies developed for OSIRIS-REx. Returned samples from the surface would provide ground truth for the Dawn mission results and would move us one step closer to understanding the early Solar System. Ceres is also a logical intermediate stepping stone from the Moon to Mars for human missions. It can serve as a testbed for long-duration in-space transit and provide an opportunity for crew autonomy both of which will be vital for successful Mars missions.

References: [1] McCord, T. B. and Zambon, F. (2019) *Icarus, Vol. 318,* pg 2-13. [2] Carrozzo, F. G. et al. (2018) *Science Advances. Vol. 4, No. 3.* [3] Castillo-Rogez, J. et al. (2018). 42nd COSPAR Assembly, abs B5.3-4-18. [4] Raponi, A. et al. (2018) *Science Advances, Vol. 4, No. 3.* [5] Beshore, E. et al. (2015). IEEE Aerospace Conference, abs 7118989. [6] Fisher, K. R. (2015). *Ceres as a Potential Target for Human and Robotic Exploration* white paper.