**INTERNATIONAL SPACE UNIVERSITY**
**TEAM PROJECT PROPOSAL FORM**

**Project Title: Astronauts and Asteroids**

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**Date: November 2011**

**One-paragraph description:** The project involves development and comparison of two scenarios for astronaut missions to asteroids. The first mission, dubbed astronauts-to-asteroid, is similar to what NASA has been charged with; send astronauts to an asteroid for a short exploratory stay and return them to Earth. Such missions will take about six months, most of it spent in transit with no abort options. The second, called asteroids-to-astronauts, is to return one or more small asteroids to High Earth Orbit (HEO) using very efficient, low-thrust propulsion and lunar gravity assist(s) or other techniques. Astronaut missions are thus to asteroids in HEO and involve not just exploration, but setting up mining operations to deliver products to cis-lunar space. Mission transit times are measured in days and stay times are arbitrary with abort to Earth within a few days. The third part of the project is a comparison of these two options in terms of cost, risk, planetary protection, commercialization potential, international opportunities and other value realized.

**Background rationale:** NASA is planning an astronaut visit to an asteroid (or other Near Earth Object, NEO) around 2025. This astronaut-to-asteroid option is expected to involve a nominal six month mission with a short stay at the asteroid. The six month limit is due to the risks involved in human exposure to spaceflight, particularly radiation and the effects of weightlessness. Note that a typical tour on the International Space Station (ISS) is six months long, although the ISS is in Low Earth Orbit (LEO) and is thus partially protected from radiation by the Earth's magnetic field. Astronauts en route to an asteroid will have no such protection. The short stay time at the asteroid is dictated by orbital mechanics and depends a great deal on exactly which asteroid is chosen.

For either option, the astronauts are expected to examine the asteroid, characterize it, gather samples, and test In-Situ Research Utilization (ISRU) equipment. A search of the known asteroids indicates that there is at least one viable astronauts-to-asteroid target, asteroid, 1999 AO10, which has a closest approach to Earth in February of 2026 bringing it to within 0.026 AU (about four million km). There may be other, better, options. There are a number of proposals for in-space telescopes to search for asteroids with better properties for human exploration. Such telescopes are expected to be designed to find asteroids down to the 100m meter range, and would also be quite useful for meeting the planetary defense goal established by the U.S. Congress of finding 90% of NEOs 140m diameter and greater by 2020.

A recent workshop sponsored by the Keck Institute at JPL investigated the possibility of returning small asteroids whole into Earth orbit (www.kiss.caltech.edu/workshops/asteroid2011). This followed an in-house JPL study suggesting that it is possible to return a small asteroid to the ISS for study. A large fraction of the delta-v for this mission is consumed spiraling down from HEO to LEO. Leaving the asteroid in HEO would make this mission significantly easier. Indeed, Damon Landau's, JPL, presentation at the workshop suggested that it may be possible to bring a 500 ton asteroid into HEO with a near-term solar electric propulsion (SEP) vehicle and a lunar gravity assist. Assuming a 40 KW

Solar Electric Propulsion (SEP) system, the mission requires eight tons of Xe for fuel. No particular asteroid has been identified for such a mission.

Bringing an asteroid into HEO opens another path to human asteroid exploration, and enables human-assisted asteroid exploitation in the relatively near term. Asteroids in HEO could be visited by missions with transit times of only three days each way. Thus, a six-month asteroids-to-astronauts mission would spend almost the entire time at the asteroid rather than traveling through space to get there. This also means that if anything goes wrong, it is possible to abort back to Earth within a few days. Furthermore, launch windows are frequent whereas for any particular astronauts-to-asteroid target the launch windows are quite small.

Human missions to the asteroids are justified as exploration. But bringing asteroids to HEO provides an additional, economic, rationale for human missions. Terrestrial mining operations have become more and more automated, to the point that some mines have no human operators underground under normal circumstances. If the same could be accomplished with asteroids, asteroidal products could become available in cis-lunar space. However, setting up mining operations, even on Earth, is far from being automated. If astronauts can install ISRU (aka mining) equipment on asteroids in HEO, then the products can be made available for operations throughout cis-lunar space. Products might include radiation shielding mass, water, oxygen for breathing and rocket oxidizer, other volatiles, and metals. There may even be a market for asteroidal metals on Earth, although transportation costs will make this difficult to exploit initially.

It should be noted that while the human part of the asteroid-to-astronaut mission is easier, other portions are much harder. In particular, the telescope needed to find asteroids of a few meters diameter must be much more capable than that for the astronauts-to-asteroid missions, for which there is no size constraint on the asteroid selected to visit. Of course, the asteroids-to-astronauts mission requires a whole additional vehicle to attach to an asteroid and guide it into HEO; a difficult task.

**Main issue(s) to be addressed:** The primary issue is whether it is better to send astronauts to an asteroid, or bring asteroids to the astronauts. There are a wide variety of execution issues to address and the benefits are quite different, making for an interesting trade study.

**Main tasks to be accomplished**: There are three main tasks:

- Design the astronaut-to-asteroid mission, including, potentially, a telescope to find better candidate asteroids and perhaps a radar telescope to characterize them. While infra-red or optical telescopes are best for finding asteroids, determining size and rotation rate often require radar.
- Design the asteroid-to-astronaut mission, definitely including a telescope(s) to find and characterize candidates, means to find suitable low-thrust, high-exhaust velocity trajectories that result in Earth capture, asteroid tug-boats, and the astronaut mission itself.
- Perform the comparison between the two, considering not only risk, cost, and knowledge gained, but also the practical benefit to those on Earth paying for the mission: planetary defense benefits, commercialization potential and advances in international cooperation.

**International/Intercultural Scope of the Project:** Both missions have potential for international cooperation, but that potential is not equal. Both missions have opportunities for different international players to provide significant pieces with clear interfaces: for example, the detection and characterization telescopes, the tug, astronaut accommodations, mining (ISRU) equipment, and so on. There are even some small, independent pieces such as finding lunar-assist trajectories accessible via low-thrust trajectories that are suitable for a technically capable developing country with limited funds. Furthermore, each mission has different international implications in terms of planetary defense benefits which has major international implications. Evaluation of these differences is a key part of the project.

**Interdisciplinary Scope**
Expected level of involvement by disciplinary area:

| | Business Management | Life Science | Policy & Law | Physical Science | Satellite Applications | Systems Engineering | Space & Society |
|---|---|---|---|---|---|---|---|
| **Major** | ☒ | ☒ | ☒ | ☒ | ☒ | ☒ | ☒ |
| **Minor** | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Brief explanation of expected involvement by discipline:

Space Business & Management: The two missions have significantly different business and management challenges. Astronauts-to-asteroid will probably be a purely governmental program as NEOs are too far from Earth to easily deliver materials to market. The mission breaks into at least two pieces, a detection telescope and the human mission, that can be easily worked on internationally in parallel. Asteroids-to-astronauts is unlikely to be a purely commercial mission, but could have significant commercial implications if ISRU installation is successful and markets can be found for the products in cis-lunar space. Also, the project naturally breaks up into at least three major pieces: the telescope(s), asteroid return vehicle, and human mission, making it easier to coordinate a larger number of international partners.

Space Life Sciences: Both options require effective life support systems for long-term human missions beyond the protection of the Earth's magnetic field. This requires the resolution of important life sciences issues related to radiation exposure. The asteroids-to-astronauts scenario can be executed with much shorter exposure times but is more efficient if long stay times are allowed. Thus, a key issue to address in mission development is the response of biological systems to space radiation, both cosmic rays and solar flares. In the case of solar flares, a key scenario to address is whether the asteroid itself can be used for protection, in which case the asteroid-to-astronaut scenario has protection for a much larger fraction of the mission. While there are also issues related to weightlessness, these are nearly identical as those for current ISS missions.

Space Policy & Law: There is one major space policy issue, and a major space law question to answer. The policy issue resolves around the weight potential practical benefit, e.g., space mining, should be given vs adventurous exploration – sending astronauts much further from Earth than has been done before. I.e., what is more important, inspiration or industry? The space law issue revolves around the legality of a company or country tearing an asteroid apart for materials. In the astronauts-to-asteroid case one expects sample returns, which are clearly legal. However, in the asteroid-to-astronauts case there is the real possibility of consuming the entire asteroid for materials. For example, consider selling asteroid materials to Bigelow Aerospace, Inc. for shielding materials for an inflatable habitat in a lunar orbit. Would this be legal under existing space law? If not, how should the legal regime be modified to accommodate it?

Space Physical Sciences: Both mission concepts will gain a great deal of information about the distribution and composition of asteroids; however, not for the same classes of asteroids or to the same depth. In the asteroids-to-astronauts case we are limited to very small asteroids, perhaps only few meters in diameter. However, it may be possible to visit multiple asteroids, analysis can continue indefinitely (with multiple human missions) and the telescope developed for asteroid search must be much more capable (to see such small objects) and thus find a larger fraction of dangerous objects. The astronauts-to-asteroids option only requires examination of much larger objects, although visit time is limited so analysis is severely limited.

Satellite Applications: The asteroids-to-astronauts option opens up a new space application, namely, asteroid mining. If successful, this opens up opportunities for a wide variety of other applications through the use of materials already in Earth orbit, not requiring launch from Earth.

Space Systems Engineering: Both missions require careful systems analysis. In particular, the trade offs involve differing telescope requirements. Also, the asteroids-to-astronauts option involves finding small asteroids, of which there are vast numbers (hundreds of thousands or even millions). Thus, even once discovered, analysing suitability is a major task.

Space & Society: Human space exploration, as exemplified by the proposed astronauts-to-asteroid mission, has traditionally been a sink for tax dollars, justified by prestige, inspiration, leadership, and knowledge. The lion's share of the government funding for most major space programs has gone towards these goals, and relatively small amounts to activities that can generate commercial and industrial return. Space development has been largely about spending tax dollars, not generating tax revenue. The classic example is the Apollo program vs communication satellite development. Both were part of the space program of the 1960s. Apollo cost many orders of magnitude more, and today lives on in museums whereas the much less expensive (in terms of tax dollars) commercial satellite industry now generates $180 billion/year or more of revenue and pays taxes vastly in excess of the subsidies it once received. This TP is an opportunity to revisit our major priorities. Should the human space program be focussed on spectacular, inspirational firsts, allowing the participants to claim leadership, or should it be focussed on potentially delivering products and services commercially to generate economic return?

**Proposed ISU program (MSc, SSP, other) :** All

**Window of opportunity in terms of potential relevance of and interest in the project topic:** The window of opportunity is indefinite, lasting at least a few decades or more. It will continue to be relevant at least until astronauts have made a trip to an asteroid. Even then, depending on the approach taken for the first visit, the work will have relevance to follow on missions.

**Potential external interest in or sponsorship of the TP topic:** Major aerospace primes and/or mining companies. For example, there is some interest in asteroid mining in the Australian mining community.

**Prospective impact of the TP:** The TP has the potential to radically change the human space flight program of the major nations. Currently, NASA intends to send astronauts to an asteroid around 2025. This TP is essentially a comparison of two significantly different paths to that goal, with very different potential outcomes for humanity. For example, if the astronauts-to-asteroid option is judged significantly superior and adopted, the path to asteroid mining will be considerably shortened and our ability to defend the planet significantly enhanced (i.e., asteroid deflection will be demonstrated), with potentially enormous consequence.

**Additional comments:**