PLANETARY SCIENCE EXPLORATION THROUGH 2050: STRATEGIC GAPS IN COMMERCIAL AND INTERNATIONAL PARTNERSHIPS. A. Ghosh[1]. [1]JPL/Tharisis Inc, amitabghosh@gmail.com.

Introduction: Planetary Science has emerged from a symbol of the cold war Space Race to a platform for cooperation between Nations. In the coming decades, Planetary Science will see greater participation from the Commerial Sector and International Space Agencies. Thus, NASA is likely to find partners in certain activities, but there might be either a lack of business case or a lack of capability for others tasks. Strategic investments by NASA in selected capabilities and services can facilitate the entry of Commercial Space players and smaller space agencies.

Commercial Space Companies: Though the present generation of Commercial Space Companies depend primarily on federal contracts for survival, it is conceivable that in future, that such companies will be able to access the market: either the B2B market (e.g. Asteroid mining) or the B2C market (Space Tourism). Large strides in Planetary Science can be made when such a market is created, driven, not just by vision and philantrophy, but by expectation of returns on investment. Though such a scenario appears unlikely in the present decade, it might be a reality in the 2040s: if some of the ongoing initiatives aimed at lowering the cost of space (like reusable launch vehicles and ISRU initiatives on Mars) will be successful. Although Elon Musk's stated goal[1] of reducing the cost per ton by five million percent might not be successful, cost of access to space is expected to decline significantly if not precipitiously.

Nations with emerging space capabilities: Planetary Science exploration delivers multiple objectives for a nation: from brand building, development of technology capability and national pride. Countries which have adequate resources but no significant capability in Space Exploration are trying to participate in planetary exploration.Thus, the UAE is planning a mission to Mars: whereas Saudi Arabia, Singapore, South Korea, Nigeria and Brazil are considering developing a capability to launch satellites.

Low Cost Space Industry: The Google Lunar X-Prize and the increasing use of cubesats are in very different ways developing the capability of low cost space exporation. The long term financial viability of the Companies participating for the Google Lunar X-Prize is far from certain: there might be market delivering payloads to the Moon, for example. But, there is a likelihood that this industry will find support from their respective government programs in their own countries and will help develop a class of low cost planetary missions.

What most international players or private players will not undertake: In 2030, it is conceivable that countries like India or UAE, might develop the capability of landing rovers on Mars or the Moon: thus, NASA could collaborate with such entities if there was a need for locatized data. However, there is an array of tasks that require a higher degree of technology capability and/or are >$1 billion in cost that will not be a strategic fit given the risk profile as well as the financials of most non-NASA entities. A prime example of such a task is the development of a propellant plant for generation of rocket fuel on Mars as outlined by Musk. For Musk's plan to come to fruition, NASA has to demonstrate the technology viability of ISRU, the logistical viability of large scale extraction, liquification and storage of rocket fuel at a specific location on Mars.

NASA as an enabler of the next generation of the Solar System: A generation of small companies and space agencies will appear in the next two decades: that are financially capable to share some of NASA's goals of Planetary Science exploration. However, such entities will face a learning curve of a decade or two, since there is a significant barrier to entry in Planetary Exploration. If NASA could facilitate the entry of the commercial sector and of smaller space agencies, a mutually beneficial scenario will be created. Thus, NASA could provide a select technology package, either as a paid service or as a contribution, the likelihood of success of new entities will increase. For example, if NASA is able to provide assistance in Navigation, Communication, help in flight qualification of earth based technology and Landing Systems for Mars, the new entrants will be able to successfully conduct, in 5 – 10 years, a science campaign on another planet or satellite.

Timeline of development of capability of non-NASA entities : It is conceivable that in the 2030s, India, UAE and a commercial entity like SpaceX or a Google X-Prize competitor, will be able to conduct a surface mobility mission on Mars, Martian satellites or the Moon. It is conceivable that by 2025, entities like Virgin Galactic will be able to launch their first flight to space as a cost <$1 million per passenger. By 2045, it is conceivable that such flights will extend to the Moon, and that a small market for Space tourism and development of better reusability and better technology

capability, will drive the per passenger cost to <$100,000. It is conceivable that a payload for technology demonstration of asteroid mining, will be launched in the 2030s. If there was a business case for return of a category of mined materials to earth (driven either by a scarcity of such materials on Earth and/or the cheaper cost of access to space at the time), commercial space mining might become a reality by 2050.

References: [1] Musk E. (2016) Making Humans an Interplanetary Species, *International Astronautical Congress*, *Guadalajara, Mexico.*