LUNAR FARSIDE RADIO ASTRONOMY BASE FACILITATED BY LUNAR ELEVATOR: T. M. Eubanks[1], C. Maccone[2] and C. F. Radley[3], [1]Asteroid Initiatives LLC, (7243 Archlaw Drive, Clifton, VA 20124; U.S.A. tme@asteroidinitiatives.com), [2]International Academy of Astronautics (IAA) and Istituto Nazionale di Astrofisica (INAF, Italy) (Via Martorelli 43, 10155 Torino (TO), Italy); clmaccon@libero.it), [3]Lunar Lift Alliance (P.O. Box 21244, Orlando, FL, 32815-0244, U.S.A.; charles@ava.st).

Introduction: On 29th April 2015 Dr Johann-Dietrich Wörner, former head of DLR, announced his intention to align the European Space Agency (ESA) to develop a "Moon Village" on the far side of the Moon for radio astronomy and other purposes. On 1st July 2015 Dr. Wörner assumed office as Director General of ESA. This Moon Village would afford the opportunity to establish new infrastructure reducing transport costs. This in turn would enable greatly increased opportunities for lunar science of all kinds.

A lunar elevator can greatly facilitate this vision. Space Elevators are not commonly considered in near-term plans for space exploration, primarily due to a lack of suitable materials for the construction of a Terrestrial space elevator. However, a Lunar Space Elevator (LSE) [1] could be constructed with existing technology and materials, such as Dyneema, Zylon or Magellan-M5. A 48 ton LSE could deployed with a single direct injection launch of SLS or 3 launches of Falcon Heavy [2]. Alternatively, using electric propulsion a single Ariane or Atlas would suffice. An LSE at Earth-Moon Lagrange Point 2 (EML2), above the Lunar Farside, offers several advantages over the previously considered LSE at EML1, and could considerably advance the exploration and development of the Farside, supporting Radio Astronomy, providing a communications platform for locations with no line-of-sight to the Earth and a means of early sample return from the Farside. The LSE can most efficiently attach to the lunar surface at the equatorial farside location at 180 degrees longitude, and reduce the cost of soft landing sixfold versus chemical rockets. A lunar elevator investment of $1B pays for itself after twenty payload landing cycles. Throughput will be at least 100 kg every six days. Theoretically throughput could be much higher, perhaps as much as 100 kg every ten hours, however, more detailed engineering analysis is required to verify that maximum capability

Lunar Space Elevators: Unlike the terrestrial space elevator, which would be kept aloft by the Earth's rotational acceleration, for an LSE the Lunar gravitational force is counterbalanced by the Earth's tidal acceleration. The low tidal gradient at a distance of 384,000 km means that Lunar space elevators are thus very long. The Lunar Space Elevator (LSE) is an extremely long tether extending from the lunar surface through the Earth-Moon L1 or L2 Lagrange gravity balance point (EML1/2). The major components of the LSE prototype include the Ribbon, the Anchor Platform on the lunar surface, the Supply Depot at EML1/2, and the Counterweight (CW) at the far end. This revolutionary space lift structure can be built from existing polymer materials and can be launched on a single vehicle. The LSE prototype would be able to lift at least 2 tons of lunar samples per year [perhaps much more], and deploy a similar quantity of equipment onto the lunar surface, revolutionizing the transport of material to and from the Moon. Table 1 shows some details of the baseline LSE for EML1 presented at LEAG in 2011 [2], together with information about the analogous elevator for EML2 (with the same fiber material, Zylon[3], mass, etc.). While the Moon's gravity is roughly spherical, the Earth's tidal gradient is slightly weaker on the Farside of the Moon, and so an EML2 LSE will be about 7% longer with a 14% reduction in surface lift capacity compared to an EML1 LSE of the same mass.

Liftetime of the LSE Current data suggests that the system life is limited by UV degradation of the tether material. Dyneema has better UV resistance than Zylon. More testing is needed but informal data from marine sailing indicates that Dyneema retains 90% of its strength after >10 years under load while exposed to diurnal UV. Some users claim even better performance. We posit that a micro-thin protective coating might be sufficient to provide indefinite protection from UV. Then the material could potentially be effective for decades.

Micrometeorites will sever tether strands on average every six months. A multi-stranded configuration is envisaged, for example the patented Hoytether. Multiple redundant strands would provide residual sufficient strength after one strand has been severed. A robot will promptly repair each severed strand. MEMS strain gauges could be used to detect and locate the lost strand.

Cost of the LSE: Space tethers and their deployment systems are inherently simple and inexpensive compared with typical spacecraft. For example, at 31.7 km, the longest tether deployed in space to date [2006] was YES2, of ESA. That project involved a cash outlay of only EU2.5M. Accounting for free student labor and in kind services, full contract price would have been about EU15M. It is reasonable to extrapolate from this that a 48 ton LSE could cost less than $1B. Pearson et al [1] analyzed an LSE design weighing over 6,100 tons and claimed a development cost of $1B-10B. Therefore the cost of the 48 ton LSE proposed here would likely be more than an order of magnitude cheaper, which reinforces the conclusion that the $1B TCO estimate is realistic, including launch. The launch cost dominates the system TCO. More analysis is needed to determine a high confidence cost number.

Technical Challenges and Future Work: The basic efficacy and feasibility of LSE is well established. Nevertheless, there are several aspects of LSE which are technically challenging with low TRL and will need more analysis, e.g.: initial deployment and stabilization; management of Coriolis forces during ascent/descent; Earthbound payload transfer to re-entry vehicle; UV protection; splicing; orbital disturbances [station-keeping]; supply of power to the climber; management of standing waves, maximizing system throughput.

The Landing Site and Sample Return from the Lunar Farside: To date, all Lunar sample returns have been from 10 sites on the Lunar Nearside. The LSE in Table 1 assumes "natural" elevator landing sites (i.e., directly beneath the Lagrange Point). An EML2 LSE could thus provide an immediate sample return from a previously unsampled region and a previously unsampled hemisphere. The EML2 landing site is near Lipskiy Crater, just North of Daedalus Crater in very rugged and heavily cratered terrain in the Lunar Highlands. Landing there with conventional chemical rockets would be hazardous, but much easier with LSE.

Radio Astronomy: The Lunar Farside radio astronomy base would be located near the lunar equator at the 180 degree longitude point, which is an ideal location for anchoring a LSE tether. The Earth is a major source of radio noise and interference. The far side of the Moon is permanently shielded from human radio transmissions, and is the best place in the solar system for a radio astronomy base. The far side is recommended as a radio quiet zone by the International Telecommunications Union under ITU-R RA.479. A high priority is for the international community to legally adopt the ITU recommendation to protect the radio environment of the far side of the Moon.

Maccone [5][6] has proposed a more extensive protection zone than the ITU. He advocates the creation of a Protected Antipode Circle [PAC], centered around the antipode on the Farside spanning an angle of 30° in longitude and latitude in all radial directions from the antipode. He claims sound scientific reasons: 1) PAC is the only area on the Farside that will never be exposed to radiation from future human space bases at the L4 and L5 Lagrangian points of the Earth-Moon system; 2) PAC is the most shielded area of the Farside, with an expected attenuation of man-made RFI of 100 dB or higher; 3) PAC does not overlap with other areas of interest to human activity except for a minor common area with the South Pole Aitken Basin. He proposes the PAC to be officially recognized by the United Nations as an International Protected Area, where no radio contamination by humans will take place.

Other Farside Science: An EML2 LSE would greatly facilitate other Farside science, including the monitoring of particles and fields at EML2, and along the Earth magnetotail at full Moon. Also monitoring of the Farside for meteor impacts, as is already being done for the Nearside[3]. The monitoring of the time of Farside impacts will be especially important if a global Lunar seismological network is established.

References:

[1] Pearson, J., Levin, E., Oldson, J. & Wykes, H. (2005) Lunar Space Elevators for Cislunar Space Development. NIAC Phase I Final Technical Report, Star Technology and Research, Inc. (2005).
[2] Eubanks, T. M. & Laine, M. (2011), LEAG, LPI Contributions 1646, 15.
[3] *Zylon Fiber PBO Technical Information* (2001) Toyobo Corporation, Ltd, available from http://www.toyobo.co.jp/seihin/kc/pbo/technical.pdf
[4] Oberst, J. *et al.* (2012) Planetary and Space Science 74, 179–193.
[5] Maccone, C. (2008) Acta Astronautica 63 (2008) 110 – 118 Protected antipode circle on the Farside of the Moon
[6] Maccone, C. (2010) Presentation to United Nations COPUOS, Vienna, Austria, June 9th–11th, 2010 Proposing a new radio-quiet zone on the Farside of the moon

Table 1: Lunar Elevator Parameters

Lunar Elevator	LSE-EM1 NearSide	LSE-EML2 FarSide
String Material	Zylon PBO	Zylon PBO
Length	278544 km	297308 km
Total Mass	48,700 kg	48,700 kg
Surface Lift Capacity	128 kg	110 kg
Total Taper (in area)	2.49	2.49
Max Force	517 N	446 N
Landing Site	0° E 0°N	180° E 0°N

Figure 1: Apollo 11 image of Daedalus Crater.

The EML2 LSE Landing site would be just below the bottom of this image; this view would be available ascending the elevator roughly an hour after leaving the surface.