

# STUDY TOWARDS CONSTRUCTION AND OPERATIONS OF LARGE LUNAR TELESCOPES

P. J. Van Susante<sup>1</sup>

<sup>1</sup> *Colorado School of Mines, Department of Engineering Systems, 1500 Illinois street, Golden, Co 80401, USA*

## ABSTRACT

In this paper the construction of a large lunar south pole infrared telescope will be discussed and analyzed. The important issues that arose during this study will be addressed and the devised construction strategy will be shown, starting with the foundation and ending with the operation of the telescope with possible expansion, upgrading, and maintenance. The roles of humans and robots in the different construction phases will be discussed and briefly described. Finally an overview of the most important unsolved issues is given, including the temperature environment in permanently shadowed craters, dust contamination and mitigation, and human-robot interactions. It appears possible to construct a 25-meter segmented single aperture infrared telescope on the lunar south pole, advances in many technology areas and the filling of certain gaps of data are necessary before this telescope can become a reality.

## RATIONALE AND LOCATION

For observations in the infrared region of the spectrum from 5 to 25 microns it is necessary to observe from space where there is no atmosphere to absorb wavelengths that are of interest. For the generation of future telescopes that are to succeed the James Web Space Telescope from about 2020, the expectations and demands are great. The search for and study of extra-solar planets, as well as life and its building blocks, will continue using spectroscopy. Imaging of the earliest galaxies beyond the Hubble Deep Field will also be a very high priority on the lists of astronomers. (NASA, 2003) This next telescope in 2020 should be an improvement of an order of magnitude over previous telescopes and should complement observations in other wavelengths. A large aperture size is required to increase the sensitivity and resolution to required levels. For several reasons, including lunar gravity, a 25-meter size primary mirror was selected for the telescope. As a location, one of the permanent shadowed craters on the lunar south pole was chosen. This crater, Shackleton Crater, has some unique features, like permanent shadow and proximity of almost perpetual lit areas on its crater rim. For more information on these issues see “design and construction of a lunar south pole infrared telescope, possibilities, requirements and other issues” by this author (van Susante, 2002) at the same congress.

## REQUIRED INFRASTRUCTURE

For such a large telescope on the lunar surface, some infrastructure is required. The transportation to and from the Moon could use infrastructure envisioned by the NASA Exploration Team. (Martin, 2002)(Cooke, 2002) An outpost in Earth-Moon Lagrange point 1 would provide easy access to any location on the lunar surface. Further, a communication relay station would be required since the telescope location is not in view of Earth directly. Also, power generation would be required to operate the facility. Since an infrastructure is being generated for the construction, expansion, repair, maintenance, and upgrading of the facility is possible. Because the telescope is sensitive to dust contamination, the landing and launching operations should take place far away from the telescope (>10 km). This requires a surface transportation infrastructure, which can be used for construction elements, robots, and humans. Such an investment can be used for many years after the initial construction is completed. In Figure 1, it is shown (not to scale) where the infrastructure elements would be located and in what sequence they would be placed. An explanation of the numbers will be given here for use with Figure 1.

- 1) The landing and deployment of the communication relay station on Malapert Mountain, located approximately 120 km from the south pole on the front side of the Moon.
- 2) Landing and deployment of the second communication relay and power generation station on the rim of Shackleton Crater. This tower will also function as a pylon in the “ski”-lift transportation system. The landing will also bring the two required Rolling Cable Distributors (RoCaDi).
- 3) The landing pad and lunar base will be constructed and the cable laid down to the base by RoCaDi 1. Then the first half of the lift system will be made operational.
- 4) After RoCaDi 2 rolls down into the crater, it will become a beacon to mark the landing site for the construction shack. Then the second part of the ski-lift system can be made operational; and power, communication, and transport is guaranteed.
- 5) Finally, the elements and equipment for the telescope construction can be delivered to the landing pad near the lunar base and transported to the construction site without generating dust.

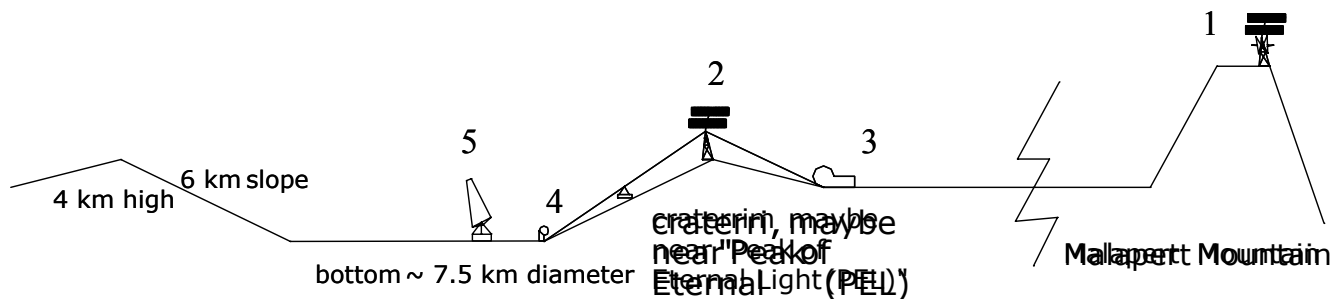


Fig. 1 Schematic cross section (not to scale) of the required lunar infrastructure

With this infrastructure in place, an era of fruitful science and exploration discoveries can start that allows for maintenance, repair, and upgrading.

## ENVIRONMENTAL ISSUES

Avoiding dust generation and contamination of telescope elements during and after construction was one of the driving requirements for the chosen concepts and the infrastructure configuration. The lunar dust is extremely fine (average 70 micron) and abrasive (Heiken, 1991). In addition, the dust is electro-statically charged, which means that it will cling to many surfaces and cannot be removed easily. The temperature which is very low inside the permanently shadowed craters can pose problems for construction but is exactly the reason why the telescope has to be built there since infrared telescopes require very low temperatures to be able to detect anything without being overwhelmed by heat radiation from the surroundings or the telescope itself. More (or any) data is required to be able to make better models and verify the models to the actual temperatures and fluctuations. This is a major issue that requires more research and perhaps a precursor mission. Seismicity was a minor issue since the seismicity on the Moon is orders of magnitudes less than on Earth. For expansion from a single telescope to an interferometer array, seismicity becomes more important since the required knowledge of the element separation distance is on the order of tens of nanometers for an interferometer (Mendell, 1998). The local terrain should be used to advantage if possible. Examples of this are to use the slopes to help save energy on transportation, use tops of hills and mountains to place communication relay stations and power generation equipment.

## PROJECT PHILOSOPHY

During the project, all choices were made in such a way that they would mitigate dust generation. If possible, the terrain should be used to the advantage of the project, or in other words, see the terrain as a resource instead as an obstacle. Another point was that robots and humans should be working together to reinforce their strong points and complement their weak points where possible. This led to a certain way of construction and assembly that will be described next. There are many important factors in the design of the telescope as it is

described here. Element size is relevant because its transportation issues, as well from Earth to the Moon as well as on the Lunar surface itself. The material of which each element is made has to meet many criteria like it has to be light, very strong, it has to have a very low coefficient of thermal expansion and has to be able to withstand very low temperatures (down to 30K) and of course it has to be able to withstand transportation by a rocket. The material that was thought of was carbon fiber / resin and silicon carbide. For this telescope the use of super conducting magnets was chosen because it has many advantages. There is no friction between the halves. They are impervious to dust and thus there is no wear and tear. There are no lubricants involved and they are energy efficient. The accuracy is also sufficient.

### TELESCOPE CONSTRUCTION SEQUENCE

First the infrastructure as described earlier will be installed after which the start of the telescope construction can begin. The first step is the foundation construction, which consists of the digging of the foundation holes and the placement of the poles. After the application and removal of the pre-load (so settlements will occur then, not during the other parts of the lifetime of the telescope), the arms will be deployed and the first ring segments will be placed as depicted in Figure 2. Then, as shown in Figure 3, the second ring and main struts will be placed on top of the first ring. After installment of the temporary axis, the main axis, counterweight, and instrument housing will be assembled as shown in Figure 4. The main-mirror support structure will be next as shown in Figure 5. The next elements will form the secondary mirror supports as shown in Figure 6. Finally the delicate elements will be placed: the secondary mirror, the instruments and the main-mirror segments as shown in Figure 7. The telescope construction is then finished and the commissioning phase can begin.

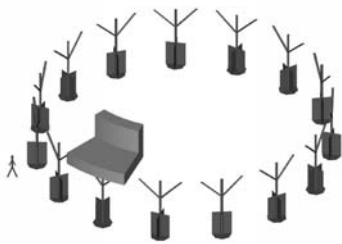


Fig.2 foundation elements and first ring element in place.

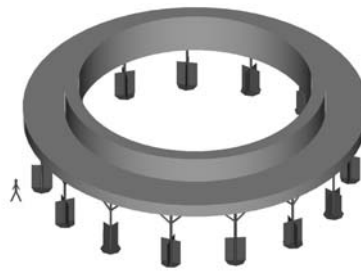


Fig.3 first super conducting magnetic ring in place

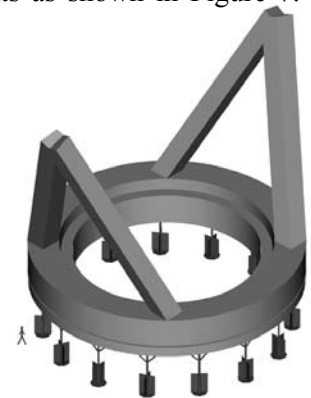


Fig.4 second ring and main support struts ready

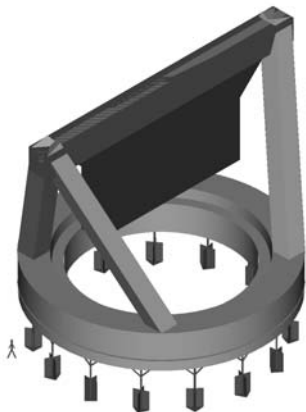


Fig.5 main axis, counter weight and instrument housing finished

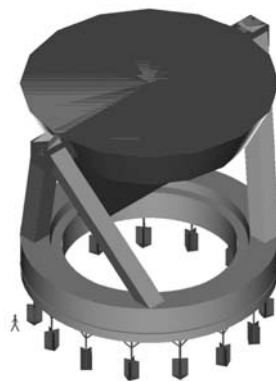


Fig.6 main mirror support structure

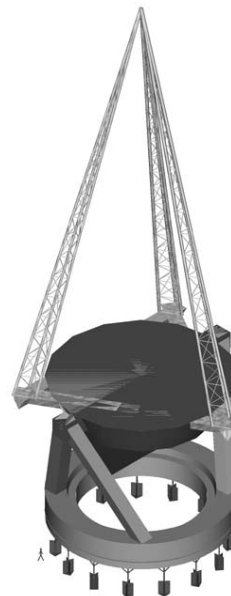


Fig. 7 secondary support struts in place



Fig. 8 telescope in finished state

## PROJECT PHASES

In total, five major project phases exist that can be divided in sub phases. The major phases are

- I) Support infrastructure outside the crater
- II) Support infrastructure inside the crater
- III) Telescope construction and assembly
- IV) Commissioning phase and operations
- V) Expansion, maintenance, and upgrading

For the sub-phases see Figure 9.

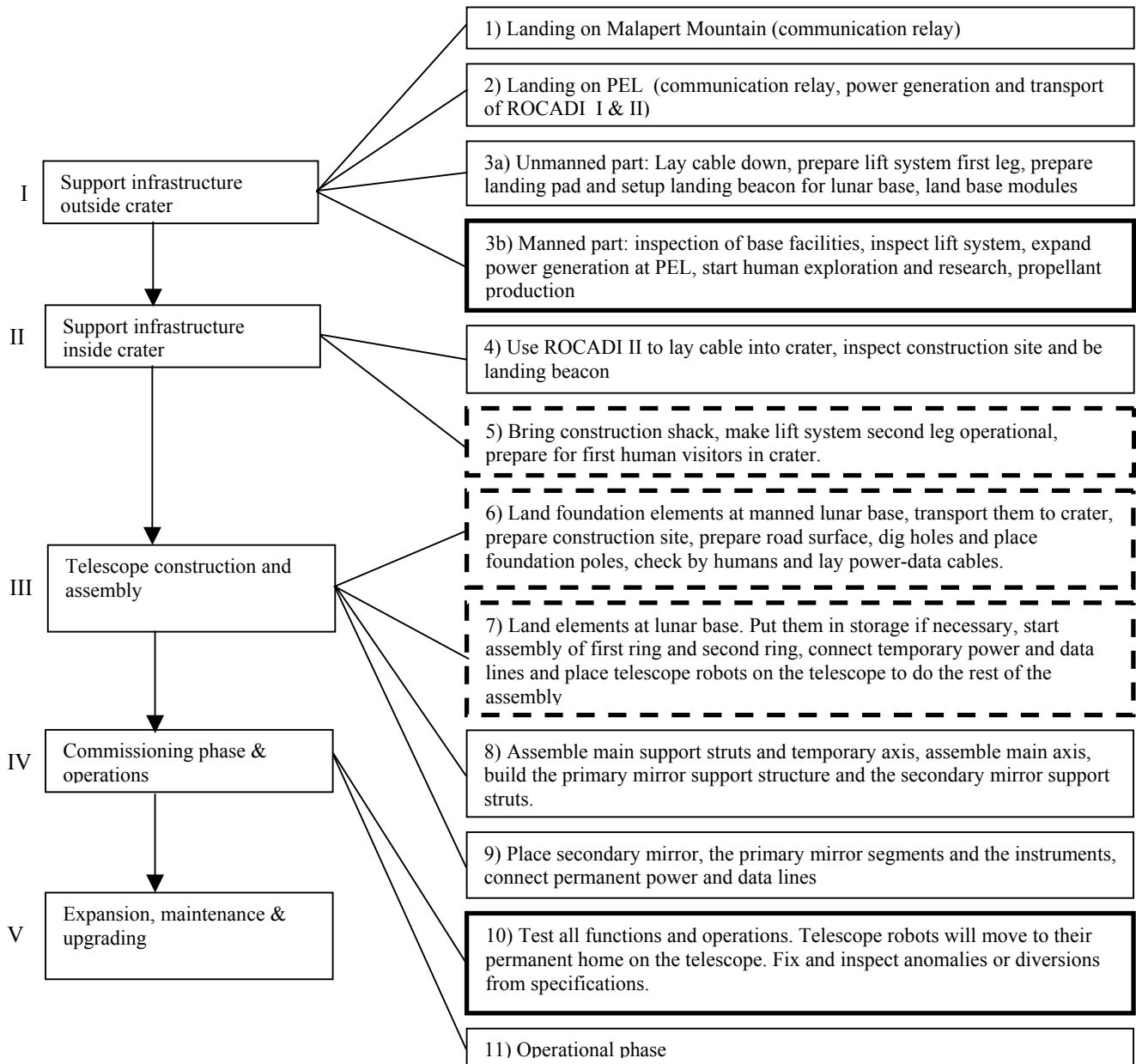


Fig. 9 : project phases

## ROLES OF HUMANS AND ROBOTS

In total for this project four different robots are needed. They can be defined as follows:

RoCaDi: Needed two times. The Rolling Cable Distributor, whose function it is to deploy the cable for communication and power transport and to function as a load bearing structural element in the ski-lift. RoCaDi will also function as a landing beacon once it arrived at its end-position. It will roll down mainly using gravity as its driver. It is maneuverable because the halves of this spherical shaped robot can rotate separately.

Ground work robot: This one is needed to perform “dirty” operations which includes the preparation of the landing pad, the digging of the foundation poles and other operations that require working with the regolith directly.

Transportation robot: This robot will transport elements and/or humans from the landing pad to the lunar base/outpost and can use the ski-lift to travel into the crater where it can deliver cargo to the construction shack or the telescope construction site. This robot needs to be equipped with a dust-free cargo space where sensitive telescope elements can be transported in safely.

On-telescope robot: Two of these robots will be placed on the telescope after both super-conducting magnetic rings are complete. Then they will construct the rest of the telescope while never leaving the structure. This is to avoid dust contamination. After the telescope is complete they will move to their garages on the telescope where they will remain until needed for maintenance, repair, or other tasks.

Human tasks in the crater concerning the telescope construction are limited to certain sub-phases as shown in Figure 9 with the dotted (activities mainly in crater) and thick lines (activities mainly near the lunar base) in phases 3b, 5, 6, 7 where they remotely control or supervise the robots.

## IMPORTANT ISSUES THAT AROSE

During the project several important issues came up that need more research, modeling, or data. One of the more important issues is the stability of temperature in the crater and of the telescope. These are closely linked and the quality of the telescope depends on the stability of the temperature and the highest occurring absolute temperature. The variations in temperature are expected to be small because changes are only due to the slow rotation of the Moon. However, there is no data available about the temperatures in the permanently shadowed craters so the existing models cannot be verified. The temperature is also important for the operations in permanent shadow since heating may be required for the robots or other moving and electronic parts.

Another area where more data is required is topography since the resolutions that are presently available are not sufficient for detailed planning and engineering. A resolution of better than one meter would be a good starting point. Very important during the entire project was the attention to dust generation and mitigation issues. It appears that most of it can be avoided or kept very local so it does not influence telescope construction and operations if carefully planned. More research on dust levitation and migration processes is necessary to determine if indeed this does not occur in the permanently shadowed areas.

The super-conducting magnetic bearings are specially designed to operate under those cold conditions but these magnets have so far only been proven to work in the lab and certainly not on a scale like this. So more research in that direction is definitely required because it also has very useful other applications in space and on Earth. (University of Houston, website references www-1 to www-4)

In this project the abilities of robots and humans play a very important role. However the development of the two working together as a team is only just beginning. This is a crucial development for exploration but could also come in very handy for construction purposes like this telescope or on Earth construction. More research needs to be done towards how they can work together and how the humans can interact easily with the robots without being overwhelmed with information flows.

Since humans are involved, the infrastructure necessary for support of humans on site was a point of attention. This needs more thought and especially more thought should be given to synergies with other scenarios and activities such as ice-mining, exploration, in situ resource utilization, and other science on and of the Moon. For cost sharing and planning in the long term this is extremely important.

The present philosophy of building a spacecraft and using it for a few years and then discarding it needs to change. Once the scale gets so large it becomes better to invest in a permanent infrastructure that can be used over several decades instead of years and for purposes other than astronomy, which is good for overall cost sharing between science, exploration, and commerce. Most of this design is based on the sharing investments philosophy.

## CONCLUSIONS

The Moon should not be forgotten as a suitable location to perform high quality infrared astronomy from the polar regions and radio astronomy from the far-side. Most issues that have been thought of as possible problems can be engineered for. It appears possible with careful integrated engineering of all involved elements to build one or more large telescopes on the Lunar surface using robots and humans. The roles of the humans are important but do not require much actual construction, but more inspection and supervision on a complex construction site. The robots will do most of the construction but many advances are still needed to make this a reality, mainly in the area of advanced sensors, flexibility and precision of operations in a location that can not be totally predicted and modeled. The interaction between humans on site and robots on site is also of crucial importance to ensure easy cooperation and to prevent accidents. A large project like this benefits greatly from sharing infrastructure with other projects. This saves costs and increases the usage of the infrastructure. It also increases the options and lowers the costs for upgrading, maintenance and expansion of the facilities.

## ACKNOWLEDGEMENTS

This work has been based on the masters thesis done at the Delft University of Technology in the Netherlands by the author in the department of civil engineering.(van Susante,2001) Partly as an internship with the education office at the European Space Research and Technology Center (ESTEC) of the European Space Agency. This work was done at the Colorado School of Mines in the Department of Engineering and sponsored by NASA's Revolutionary Aerospace System Concepts (RASC) program through former ICASE, based at NASA Langley Research Center.

## REFERENCES

- Cooke, D.R., et.al., Innovations in mission architectures for human and robotic exploration beyond low Earth orbit, IAC-02-Q.6.04, Proceedings of the 53<sup>rd</sup> International Astronautical Congress, Houston, Texas, October2002.
- Heiken, G., et.al., The Lunar Source Book, Cambridge University Press, 1991.
- Martin, G.L., The NASA Exploration Team: Recent Accomplishments, IAC-02-Q.6.03, Proceedings of the 53<sup>rd</sup> International Astronautical Congress, Houston, Texas, October 2002.
- Mendell, W., Effects of the Lunar Seismic Environment on a Moon-based Optical Interferometer, NASA/JSC/NS2, Houston, Texas, 1998.
- NASA, Office of Space Science Strategic Plan, 2003.
- van Susante, P.J., Design and Construction of a lunar south pole infrared telescope (LSPIRT), Masters thesis, TU-Delft, The Netherlands, 2001.
- van Susante, P.J., Design and construction of a lunar south pole infrared telescope, possibilities, requirements and other issues, Adv. Space Res. (COSPAR02-A-00113), this issue, 2002.
- www-1            <http://www.issu.uh.edu/publications/A9697/9697-5.html>
- www-2            <http://www.issu.uh.edu/publications/A9798/chu1.htm>
- www-3            <http://www.issu.uh.edu/publications/A9798/chu2.htm>
- www-4            <http://www.issu.uh.edu/publications/A2001/pdf/402-403-chu.pdf>

e-mail address of P.J. van Susante            paulvans@mines.edu

Manuscript received    1 December 2002            ;revised    23 February 2003            ;accepted 8 July 2003