LARGE LUNAR TELESCOPE CONSTRUCTION, AN EXAMPLE

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Summary

This paper will sketch a scenario and describe the infrastructure required for the construction and operation of a 25 m infrared telescope in Shackleton Crater at the South Pole of the Moon. It will describe the humans and robots required to build it and what possibilities it will offer. Required technology development and possible precursors will be discussed. This paper will address where we could go with focused efforts to develop the lunar surface for multiple purposes like mining, science and exploration. The focus of this paper will be the astronomical observatory to be erected, it will, however, show an infrastructure that can be used for much more. The study was done at the Colorado School of Mines and conducted for NASA's Revolutionary Aero Space Concepts program.

Introduction

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 at least 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. One of the permanent shadowed craters on the lunar South Pole was chosen as the location. This crater, Shackleton Crater, has some unique features, like permanent shadow and proximity of almost perpetual lit areas on its crater rim.

Infrastructure required

A project such as constructing a large infrared telescope on the lunar surface requires the building of an extensive but multipurpose infrastructure. This infrastructure consists of many elements such as:

- space transportation infrastructure
- a manned lunar base
- ground transportation infrastructure
- communications infrastructure
- power generation and transmission infrastructure

The space transportation infrastructure would consist of several elements as have been described by Martin (2002), Cooke (2002), Duke (2003) and Blair (2003). This space transportation infrastructure would take care of the delivery of the required robots, humans and construction elements to the required locations on the lunar surface.

A small (temporary) manned lunar base is required for the construction supervision and maintenance on-site and trouble-shooting in general. Of course once the base is established it can also be used for exploration, science and mining operations other than the telescope construction. To prevent contamination of the sensitive telescope elements by landing and launching and other activities, the construction elements will have to be landed at least 10 km away from the telescope site and all other activities will have to take place also more than 10 km away from the site. This means that the elements for the telescope will be landed a considerable distance away from the construction site and will have to be transported via ground transportation.

This ground transportation will have to minimize dust generation or it would defeat the purpose of siting the landing pad far away. The ground transportation will consist of a "clean" transportation robot and a cable-lift system (comparable to a ski-lift). There also will have to be two storage areas for telescope elements. Some telescope elements may have to be temporarily stored till the construction process has reached their point of installation. Since these elements contain electronics and such, some will need a partially climate-controlled storage area so different temperatures will not damage elements and there is time for outgassing and time to acclimatize to the different temperatures.

The floor of Shackleton Crater is not visible from Earth and parts of the rim will obscure the Earth from time to time so communication links will be required. A combination of two communication links has been researched by de Weerd 1998. He concluded that a relay station on Malapert Mountain, ~120 km away from the rim of Shackleton Crater, and a second relay station on that crater rim would allow for 24/7 communication with Earth.

The floor of Shackleton Crater is also in permanent shadow (Margot et. al 1990) and hence has limited options for power generation. For this study, the use of solar power was assumed because the total amount of power required for the robots and telescope operation is in the order of 5-10 KW. Some part of the rim of Shackleton Crater receives sunlight for more than 80% of the lunar cycle (Bussey 1998) with periods not exceeding 3 Earth days in winter. If the communication station is placed in that position it could also function as a power generation station. The lift system could use the same location as its top-tower and its cable could be used for power transmission to the telescope site and if power generation capacity would be increased it could also supply the lunar base with electricity.

Short Scenario Description

Before construction can begin the infrastructure needs to be established in a certain order. Assumed is that the space transportation infrastructure is in place. First there is the installation of the communication relay on Malapert Mountain which can be done by a single lander. Second there is the landing of the communication relay station and power generation station on the rim of Shackleton Crater (See Figure 1). Then the assembly of the lunar base and landing pad can begin and all further landings can take place using a landing beacon. After the first leg of the lift system is operational, the landing in Shackleton Crater can take place and assembly of the second leg of the lift system and construction outpost can start (See Figure 2). Once the construction outpost and the second leg of the lift system are operational, telescope construction can commence.

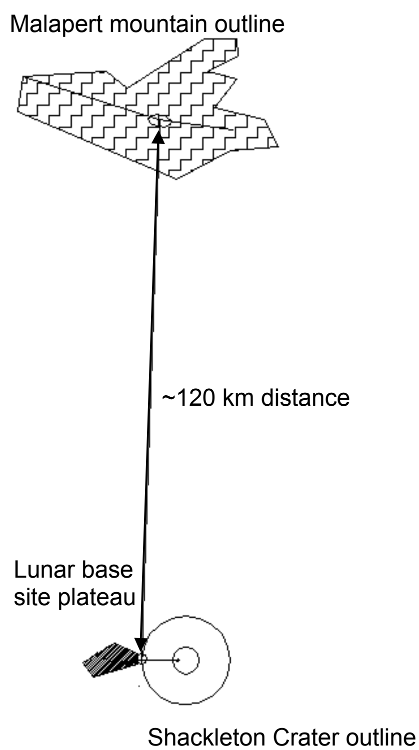

Figure 1: Scale representation of the important lunar features for this project.

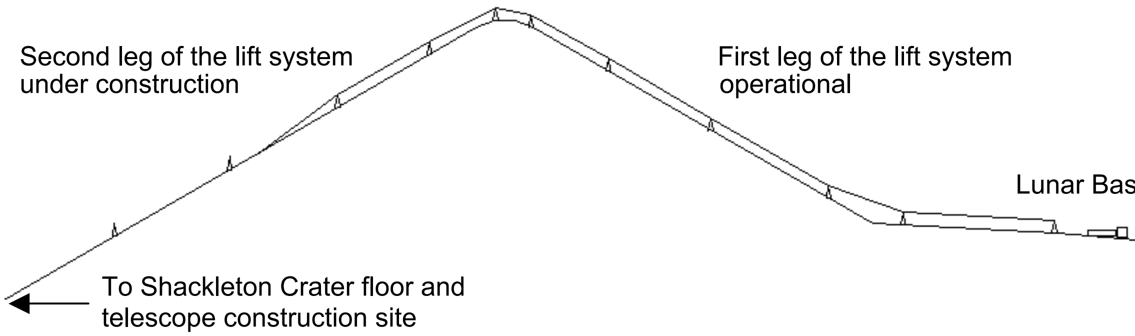

Figure 2: a sketch of the lift system as envisioned over a cross section of the rim of Shackleton Crater.

Lift system

Once the communication infrastructure and power generation is in place, the first part of the lift system will be deployed. It will start with the deployment of the first Rolling Cable Distributor (RoCaDi) that was transported there with the lander on the rim of Shackleton Crater. RoCaDi I will roll down to the lunar base site and while rolling down it will identify suitable locations for the lift towers. Once down, RoCaDi I can connect to the modules of the lunar base that have arrived shortly after RoCaDi I and so hook up the power that will be generated at the top of the crater rim. Once down, the lift towers can be delivered and placed by a different specialized "tower" robot. That robot will also place the cable on the wheels that will support the cable once lifted to its desired height. Once all the poles have been placed and the cable is in position everywhere it can be lifted to the desired height and the first leg of the lift system can be tested. The first leg would give access to the rim of Shackleton Crater from the lunar base and would allow maintenance and expansion of the power generation capacity. The second leg from the top of the crater rim to the bottom of the crater will be done in the same way. The only difference is that RoCaDi II will have to be transported to the lunar base first and then brought up to the crater rim by using the first leg of the lift system. Once the cable is hooked up on the top the deployment of the second part can start.

Construction sequence

When the lift system is operational, the actual construction of the telescope can begin. The construction sequence is described in van Susante (2002). It consists of:

-foundation pole placement (See Figure 3)
-installation of the first half of the super conducting magnetic ring (See Figure 4)
-installation of the second ring half and the main support struts (See Figure 5)
-installation of the main axis, counter weight & instrument housing (See Figure 6)

-main mirror support structure installation (See Figure 7)
-installation of the secondary mirror support struts (See Figure 8)
-installation of the instruments and mirror segments (See Figure 9)
-once construction is finished the commissioning phase can start where all elements and the telescope as a whole will be aligned and tested.

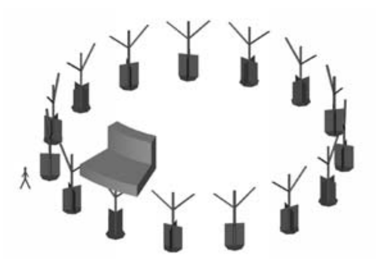

Fig.3 foundation elements and first ring element in place.

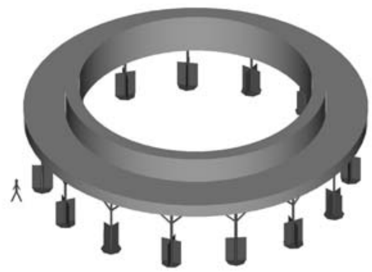

Fig.4 first super conducting magnetic ring in place

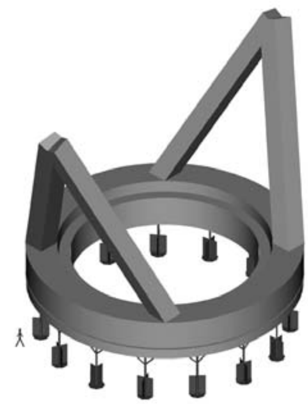

Fig.5 second ring and main support struts ready

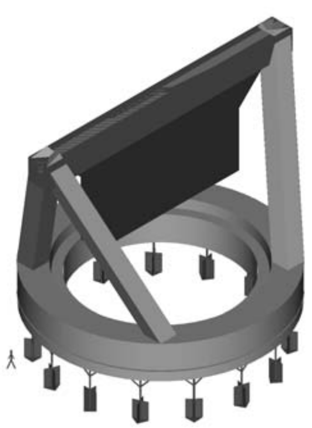

Fig.6 main axis, counter weight and instrument housing finished

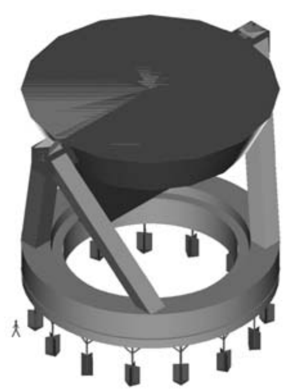

Fig.7 main mirror support structure

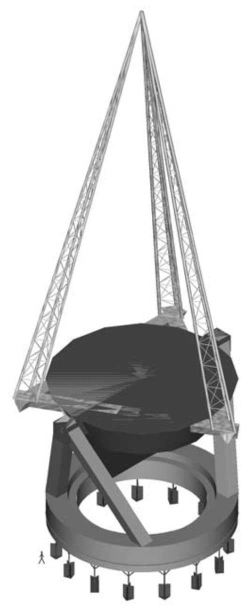

Fig. 8 secondary support struts in place

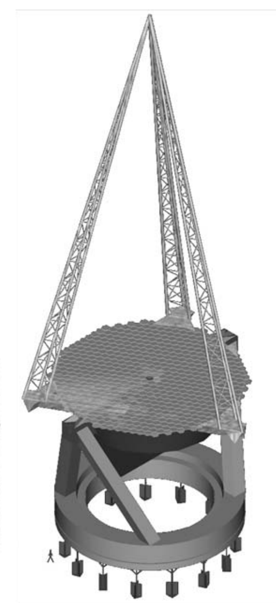

Fig. 9 telescope in finished state

Humans and robots required

The assembly and construction of this telescope and its infrastructure will require the use of humans and robots working together. Next to humans on Earth it will be necessary to have 4 humans on the lunar surface close to the telescope construction site. The lunar base will house the astronauts and provide the ability to remotely control and perform maintenance on the construction robots working in Shackleton Crater. During certain phases of the project as described in van Susante (2002), two astronauts will stay in the crater for a maximum duration of two weeks to supervise and assist the construction first-hand. A total of seven robots of five types will be required for this project. *Two RoCaDi's* as described before, *a "dirty" work robot* to perform operations with regolith such as digging, landing pad and road preparation, *a tower placing robot* that will have to pick-up and transport the lift-towers to their positions and place them, a *"clean"-transport robot* for the transportation of the telescope elements in a clean and dust-free environment, and finally, *two on-telescope robots* that will do most of the telescope construction once the second half of the super conducting magnetic azimuth bearing is complete. The on-telescope robots will not come into contact with the lunar surface and will only accept the elements that are brought by the clean-transport robot. This procedure prevents any dust from contaminating the elements before or while being placed. The same two on-telescope robots will stay forever on the telescope in special garages and perform maintenance once the telescope is completed.

Lunar Environment positive and negative factors

The environment on the Moon is the main reason for choosing that location in the first place, but some environmental characteristics could ruin the otherwise perfect location. The Moon has gravity, one sixth of the gravity of Earth, and that is a positive factor. Constructing telescopes in a gravity field has been done many times on Earth and the structural deformations generated by this gravity field can be compensated for by designing the telescope keeping this deformation in mind. At the same time the telescope will be on a large stable body with seismic activity that is several orders of magnitude less than on Earth (Heiken 1991, ESA 1996, Mendell 1998). On Earth, the largest collection of world-class telescopes is located on the Big island of Hawaii with an active volcano on it.

The Vacuum on the Moon is of a very high quality and care must be taken not to contaminate it by high volumes of landings and launches. Each Apollo landing roughly doubled the existing lunar atmosphere briefly. Many atoms quickly will escape the lunar gravity well and thus such contaminations will not last, but they could temporarily disturb local measurements.

Dust is another contaminant. Not of the atmosphere but of the telescope sensitive instruments and mirror segments. To prevent this contamination, all activities taking place on the lunar surface must be carefully monitored and transportation that generates dust must be minimized. Once the lift system is operational, there will be no dust generation for most of the traverse from the lunar base to the construction site. Local, short distance transport by the robots is still required and mitigation measurements such as driving slow, using fenders and dust deflecting shields must be taken such that the dust does not travel high and far. These are easy measurements to take and make sure that surface activity can still take place after sensitive elements have been installed.

Another environmental characteristic of Shackleton Crater is the stable, extremely low temperature that is calculated to be as low as 70 K or 30 K in locations that are not in view of the parts of the crater rim that are lit by the sun (Vasavada 1999, Carruba 1999). This can be artificially achieved by using appropriate shielding of a few layers of multi-layer-insulation (MLI). The temperature fluctuations are expected to be in the order of 10 K and are expected to happen very slow. The cold temperature is an issue that has influence on the quality of the functioning of the telescope (the colder, the better), but also influences the functioning of machinery and electronics. Moving parts will need some form of lubrication to prevent unnecessary wear and tear and the cold temperatures in combination with the vacuum environment do not allow regular means of lubrication. A diamond coated surface may prove effective in such circumstances. Magnetic bearings that do not need lubrication could be another option. Electronics mostly will need to be warmed to operating temperature.

Another issue during construction is the amount of lighting available for construction. Because of the permanent shadow it will be necessary to bring lights to make sure that every location where activities take place will be sufficiently visible for the planned activity. What wavelength and power will be most efficient will have to be researched.

Opening of possibilities

Once the telescope is constructed and operational, several capabilities and possibilities have been generated. First there is the infrastructure generation that can be used for many other purposes such as exploration, mining and science, but also can be used to maintain, upgrade and expand the telescope facility. The telescope itself will have great capabilities with its 25 meter diameter main mirror that is passively cooled to a very stable temperature (~30-40 K). It can perform observations of, in theory, infinite duration for the part of the universe it can see. This infrared telescope would be so sensitive that it could, in theory, perform in just 17 days, all observations that the James Webb Space Telescope (JWST) makes in 10 years. By making it relatively easy to maintain and upgrade the telescope, its life-expectancy can be almost unlimited. By expanding the facilities with more telescopes in the crater, the observations will be able to remain state-of-the-art for decades (>50 years) after completion.

Technology development required

Before this unique instrument can be built, technology developments are necessary. An integrated design is required for the telescope such that the capabilities of humans and robots are used to their best abilities and the weight and size of all elements is optimized. An important aspect where technology development is required is the required precision. How to reach the micrometer or better precision when robots only can achieve a precision in the order of half a millimeter or worse. The tolerances during construction are also much larger in general than the required telescope precision. Special care must be taken to develop and test the connections of telescope parts such that the expected tolerances can be met while still being able to achieve the required precision after construction is done. This will require actuators inside some elements so the position can be adjusted at different scale levels. It also will require sensors to detect the positions at the same scale as the functioning of the actuators.

The technology for the lift system needs to be developed and tested. The lift system will be a factor of 3 longer than the longest on Earth and will have to operate under more severe environmental circumstances than on Earth. No part of the lift technology has been tested in space so in essence everything still needs to be developed and tested.

Other technology 'only' needs to be improved by expanding the operational constraints of it. A good example of this are some of the robot mechanisms. They have been tested and operated successfully in space and its environment. The lunar South Pole environment is similar in some respects (vacuum) and different from the space environment in others (temperature is lower, but there is less variation, there is dust, it is not only cold, but also dark all the time in the crater).

Robot systems must be tested and qualified for operations under the specific lunar South Pole environmental conditions. Next to that, it is necessary to develop the cooperation between robots, astronauts and tele-operators of the robots. On a construction site, safety is important, especially if a small mistake not only damages the work but also can kill the workers. So, awareness of the positions of all active people and machines, as well as what they will do next is important. Ease of communication between the active people and machines is required so quick and accurate decisions can be made.

Research to be done and possible precursors

Much research is still required and many tests will need to be performed on Earth as well as on the lunar surface before the final design can be made. Some examples of research to be done are: testing of new cable materials for the lift-system that will be able to function on the lunar surface, the further development of super conducting magnetic bearings for telescope-use of the size described in this paper, element connection techniques and mechanisms with the required tolerances and precision need to be developed, operations tests for human-robot interaction and construction need to be tested on Earth, tele-operation and its limits need to be researched in more detail, laser range-finder technology needs to be adapted for use on the moon, and operations procedures for the dark, cold areas need to be developed and tested. Some precursor missions, that will be required before any final decisions can be made, are a topography mapping mission of the lunar South Pole with a resolution better than 1 meter and actual measurements of the temperature environment because at present only models exist of the permanently shaded areas.

Synergies between other functions

The required infrastructure and operational capabilities for a project such as this telescope can be used for many other functions as well. Synergies with possible operations in exploration / prospecting, mining, other fields of science on, of and from the Moon and even commercial development are all possible and very important to share costs and investments. By sharing and building an infrastructure much more can be achieved for the same costs while opening up and making accessible the lunar surface for all kinds of operations. Once this is achieved it will speed up the access into the solar system because a space station with resources will have been established.

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