

## ANALOGS BETWEEN ANTARCTICA AND THE MOON: A SOUTH POLE EXPERIENCE FOR PLANNING LUNAR MISSIONS

**Yuki D. Takahashi**

University of California, Berkeley, USA  
yukimoon@berkeley.edu

### ABSTRACT

In planning any human missions to the Moon, experiences in Antarctica are worth reviewing because of numerous environmental and logistical analogs. At the time of growing interest in the south pole of the Moon, analogs between Antarctica and the Moon are presented based on the experience of executing an astrophysics project at the South Pole. Since the 1950s, numerous countries have established stations in Antarctica, overcoming many challenges similar to those involved in going to the Moon. The lunar surface and Antarctica, particularly the south poles of the Moon and the Earth, have many environmental analogs that make them desirable sites especially for astronomy. One experiment is the BICEP telescope, which was installed in 2005 at the South Pole to investigate the origin of the Big Bang through the cosmic microwave background. The entire process of designing, building, transporting, deploying, and operating the telescope has involved many considerations perhaps analogous to those required in executing a human mission on the Moon.

### 1. INTRODUCTION

Being so familiar and visible to everyone, the Moon is perhaps the most inspiring target of exploration outside the Earth. Many space agencies worldwide are planning human lunar exploration, and private ventures can strive to enable personal trips to the Moon within lifetimes of much of the current generation. However, going there safely is by no means a simple feat. It is worth drawing lessons from previous efforts with similar challenges. This paper examines how lunar mission plannings could benefit from decades of experience at one of the remotest locations on Earth, the South Pole. Based on the experience of executing an astrophysics project at the South Pole, many political, environmental, and logistical analogs between Antarctica and the Moon are presented.

#### 1.1. South Pole of the Earth

Antarctica is by far the remotest continent on Earth, and has no permanent inhabitants. No part of it was

sighted until the 1820s [1]. It is a continent roughly 4000 km across, comparable to the Moon's 3500-km diameter (Fig. 1).



Fig. 1: Antarctica and the Moon, in roughly the same scale. (credit: NASA)

The first time a human reached the South Pole was in 1911; however, 45 years had elapsed before humans returned to the Pole and set up what has today become a vibrant research base. The Moon may witness a similar history after being abandoned from human presence for nearly 40 years (Table 1). Since the 1950s, numerous countries have

established stations across the continent, overcoming many challenges similar to those involved in going to the Moon. Today, there are over 100 Antarctic research facilities by 28 countries, with summer and winter populations of roughly 4000 and 1000, respectively [2].

<u>South Pole</u>	<u>Moon</u>
1911-1912: 1st human	1969-1972: 1st human
... 45 years ...	...already ~40 years...
1956: 1st return, permanent base.	20??: Human return? permanent base?
1988: 1st tourist.	20??: Tourists?

Table 1: Possible historical analog.

### 1.2. South pole of the Moon

The possibility of water ice in the permanently shadowed craters near the south pole makes it one of the most interesting destinations on the Moon. Some hilltops in the polar region could offer both a constant line-of-sight view of the Earth for communication and nearly constant Sun light for power. For this reason, this region may be an ideal site for lunar surface activities. Several types of astronomical observatories have been proposed at the lunar south pole, including very-low-frequency array [3] and infrared telescopes in permanently shadowed craters. With human visits or eventual presence, facilities on the lunar surface is serviceable and can be more permanent than those in free-space.

### 2. ASTROPHYSICS EXPERIMENT AT THE SOUTH POLE

Among the various fields of research, astrophysics finds advantages in Antarctica similar to those on the Moon. Many observatories have been set up around the continent, including neutrino detectors and telescopes at various wavelengths. This paper draws from the experience of planning and executing an astrophysics experiment at the South Pole with a modest team of ~15 since 2002.

BICEP (Background Imaging of Cosmic Extragalactic Polarization) is an experiment aiming

to study the first fraction of a second of the birth of the universe by observing the cosmic microwave background radiation left over from the Big Bang [4]. It employs an array of novel detectors cooled to 0.25 K, sensitive to mm-wave radiation at 100 and 150 GHz. The team consists of physicists from Caltech, JPL, U.C. Berkeley, and U.C. San Diego, and is funded by the U.S. National Science Foundation and private donations. The team deployed the telescope to the South Pole in November 2005 and has been operating it nearly continuously since with success. BICEP remains the first and the only operating experiment dedicated to searching signatures of gravity waves from cosmic inflation.

The author has had the privilege of working at the South Pole for 2-3 months at a time during every Antarctic summers since 2005.



Fig. 2: BICEP observatory at the South Pole (credit: D. Barkats)

### 3. ENVIRONMENTAL ANALOG

The lunar surface and Antarctica, particularly the south poles of the Moon and the Earth, have many environmental analogs that make them desirable sites especially for astronomy. Both are extremely cold and dry sites devoid of unwanted interferences. Both provide stable platforms unlike in free space. The poles present constant skies and thermally stable conditions during their long nights and days. The thin dry atmosphere over the Antarctic plateau with months of dark winter makes the South Pole the best site on Earth for an experiment like BICEP. For planning human missions to the lunar surface, it is beneficial to study the lessons from existing projects and operations in Antarctica.

<u>South Pole</u>	<u>Lunar poles</u>
Cold & stable (200~250K)	Permanent Shadows (~40K?)
Thin dry air	Vacuum
Dark winters	14-day nights
Radio quiet	Far from Earth
Constant sky, low Sun	Slower rotation, low Sun

Table 2: Summary of environmental analogs, especially those relevant to astronomy.

### 3.1. Low temperatures

First of all, both locations are subject to extremely low temperatures. The South Pole experiences temperatures lower than  $-70\text{ C}$ , not far from the freezing point of carbon dioxide ( $-78.5\text{ C}$ ). This

required designing instruments capable of operating at such low temperatures. We chose to enclose most of the instrument in a room-temperature air space, exposing on the telescope aperture and the baffle surrounding it. A flexible bellows was used as an environmental seal that permits telescope motion.

The forebaffle, which is essential for blocking or absorbing any stray radiation before entering the telescope aperture, needed to be lined with a microwave absorbing foam, which becomes brittle at low temperatures. To prevent foam pieces from depositing on the telescope aperture, we found a non-reflective polyethylene sheet to cover the absorber foam. This design has performed remarkably and has been adopted in other telescopes.

Another example is the design of a rotatable calibration device, which needed to not only work mechanically in extremely low temperatures, but also be simple to set up and operate safely by a human in the cold and the dark. The bearing for the rotation stage needed a special type of grease that

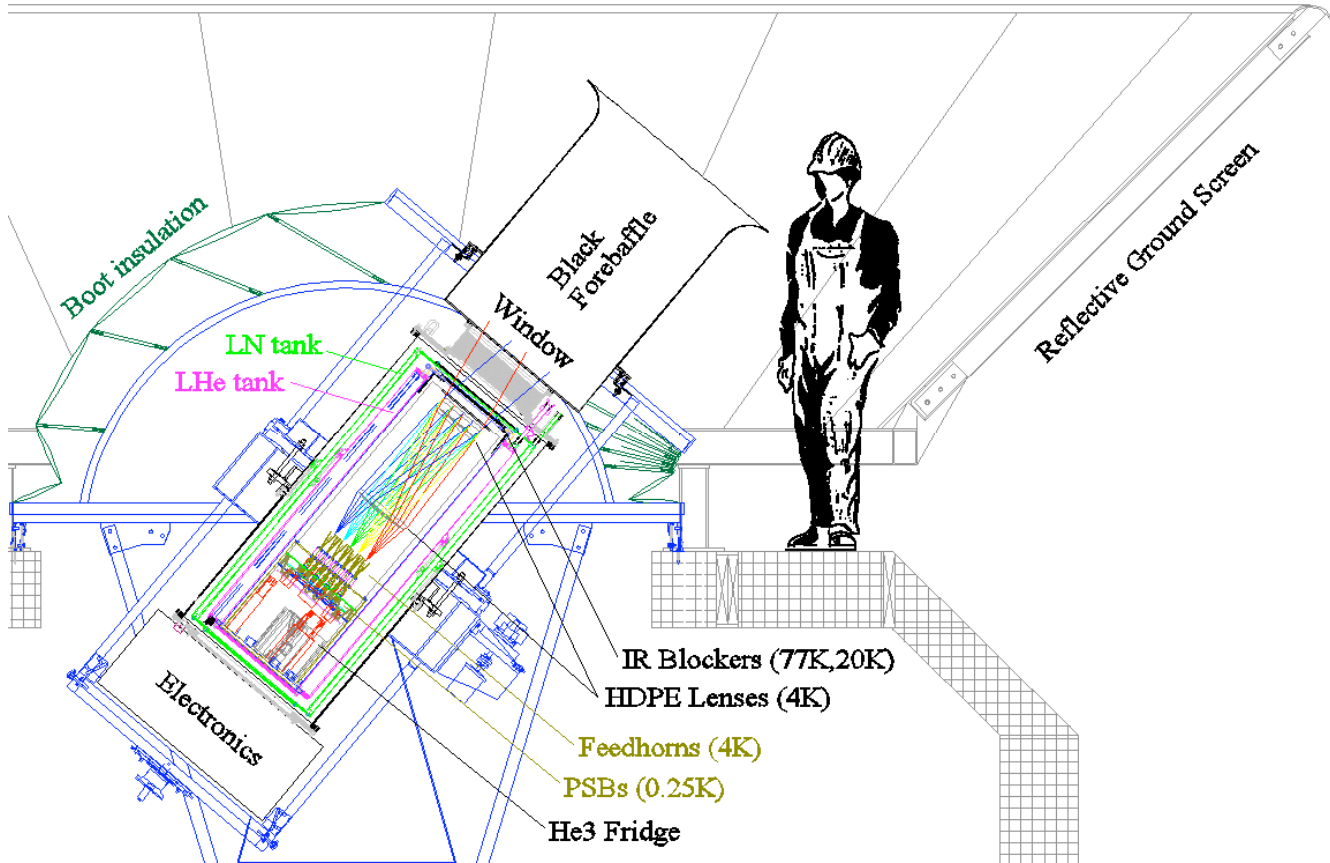


Fig. 3: BICEP telescope, with polarization sensitive bolometers (PSBs) in a cryostat with liquid helium (LHe) and liquid nitrogen (LN).

continues to perform at low temperatures. Materials needed to be chosen carefully based on their differential thermal contractions and thermal conductance. Prior to field deployment, the device was tested using a large refrigerator that cools to  $-70$  C. Also, the device was designed to be easy to handle even with thick gloves and bulky gears. Finally, calibration procedures were designed with maximal automation and minimal necessity for outdoor labor.

### 3.2. Low humidity

The low temperature at the South Pole also makes it one of the driest places on Earth, just as on the Moon or in outer space in general. The low concentration of water vapor in the atmosphere is one of the main reasons this site was chosen, since water molecules absorb and emit in our observing frequencies.

The lack of water molecules in the air allows electrostatic charges to accumulate easily, increasing the likelihood of sparks that can damage electronics and other sensitive equipment. In designing electronic cards for telescope operations, inputs and outputs were tied to electrostatic discharge protection circuits.

### 3.3. Low air density

Another factor that also affects electronic designs is the thin air due to the 2800-meter altitude. This altitude places the telescope above much of the air mass, providing an advantage similar to that in outer space.

With less air molecules, however, the ability to dissipate heat is reduced, making computers and electronics susceptible to over heating. This is an even more severe danger in the vacuum of outer space. As with space missions, we had a tight constraint on the mass and volume of electronics, forcing us to design very small circuit boards, enhancing the heat mitigation challenge. Expected heat dissipation was calculated and generous amount of heat sinking was incorporated.

### 3.4. Minimal interference and constant skies

In addition to the above analogs that pose design challenges, there are other similarities advantageous for astronomy. Being at such a remote location, the

South Pole is devoid of unwanted interference, just as on the Moon, especially where the lunar terrain blocks the Earth and the Sun. Especially during the 6-month winter, at the South Pole the Sun stays below the horizon, providing an extended period of ideal observing conditions. To fully take advantage of this unique condition, observatories like BICEP are situated in the Dark Sector, designated to be free of radio transmitters.

Being on the axis of rotation, the polar locations allow uninterrupted observation of astronomical targets in the constant sky.

## 4. LOGISTICAL ANALOG

The remoteness and harshness of both locations also mean similarities in logistics. Difficult transportation, scarce resources, limited communications, and lack of developed infrastructure have all made Antarctic operations nontrivial and risky. Lunar projects can benefit from these analogs in planning contingencies, external support, and emergency response. Examples are presented from the past 3 years of involvement in the United States Antarctic Program, which has been a valuable training experience for future work on missions to the Moon.

### 4.1. Lacking infrastructure

Just like the Moon today, the South Pole was initially an endless desolation, where going there, let alone working there, seemed daunting. However, since 1956, the United States has constructed and maintained a permanent station that today has an impressive infrastructure.

### 4.2. Difficult transportation

Today, going to the South Pole typically takes about 3 days, somewhat similar to the traditional transit time to the Moon. With the United States Antarctic Program, a passenger first goes to Christchurch, New Zealand at least a day before the Antarctic flight to prepare all the extreme cold weather gear and ensure that the total mass, including that of the passenger, is within the limit. From New Zealand, passengers typically fly to Antarctica on a jet cargo aircraft C-17 along with up to 77 tons of cargo. The flight is about 5 hours to the coastal McMurdo station, where we stay overnight for another flight to the Pole the next day. Flights between McMurdo

and the Pole are on ski-equipped LC-130 propeller aircraft, whose hydraulic fluid for landing gear is rated for temperatures of  $-50\text{ C}$  or above. This prohibits any flights in and out of the South Pole Station from mid-February to the end of October. The limited accessibility requires careful planning of all the necessary items and contingencies.



Fig. 4: Ski-equipped LC-130 aircraft taking off from the South Pole Station, with an array of observatories in the background. (credit: S. Richter)

#### 4.3. Scarce resources

Other than the Sun light and the ground, there exist no natural resources, making it crucial to conserve as much as possible. There is a comprehensive recycling system and all the waste is brought back to the main land. To provide fresh vegetables during the long dark winter, an experimental growth chamber exists to grow crops such as cucumbers, lettuce, tomatoes, zucchinis, and herbs.



Fig. 5: The hydroponics growth chamber at the South Pole Station.

#### 4.4. Limited Communication

Being at such a remote location, communication with the rest of the Earth is a major challenge. The South Pole Station uses three old geostationary satellites (TDRS, MARISAT, GOES) that have

wobbled off of their original orbits enough to be visible from the Pole for several hours a day. Together, they provide  $\sim 12$  hours a day of data link, allowing  $\sim 15$  GB/day of data transfer at 5 MB/s as well as 5~35 KB/s internet connection. Additionally, the Iridium satellites are used to transfer electronic mail throughout the day and for emergency telephone connection. BICEP telescope transfers 3.5 GB of data to California every day.



Fig. 6: Antennas for communications through relay satellites in geosynchronous orbits.

#### 4.5. Emergency response

At such a remote location with no traditional support systems, swift and well-trained emergency response is critical. At the South Pole Station, emergency response team consists of professional fire fighters, secondary fire team, medical staff, and trauma team, drawing volunteers from various sectors of the station population. We trained regularly to prepare for various scenarios and held occasional realistic drills. Drills included simulations of multiple casualty incidents with fake patients that we learned to assess, package, and transport to medical facility. Since the medical facility on the station is very limited, timely response can make a significant difference to the recovery of patients.

On 2006/12/26, there was a major emergency involving the station's main power plant. During some generator maintenance, glycol for transferring waste heat to warm the station burst out, quickly vaporizing and filling the entire power plant. Power to the entire station shut down and everyone gathered in the dining hall. Six patients were delivered to the medical office. Such incidents

could happen on the Moon and they should be studied to help plan response and contingencies.

## 5. POLITICAL ANALOG

Like the Moon, Antarctica is not owned by any nation, making it a unique common property with a model of peaceful uses among different nations. The Antarctic Treaty, signed in 1959, has been governing the activities of its 45 member nations. This was used as the model for the Outer Space Treaty in 1967, which governs the activities on the Moon as well. Currently, the International Polar Year 2007-2009 is generating many partnerships between nations. These efforts are worth studying in promoting international cooperation for the Moon. For instance, the International Lunar Observatory Association aims to establish a multifunctional facility on the Moon through multinational effort [5]. To build collaborative relationships from early on in the careers of future leaders, students and young professionals have founded the Lunar Explorers Society, an international group promoting exchanges and cooperation across boundaries. These endeavors could carry on, and try to improve, the model of cooperation established in Antarctica.



Fig. 7: The Ceremonial South Pole with flags of the 12 original signatory nations of the Antarctic Treaty.

Finally, private efforts to realize personal travels to the Moon could learn from existing tourism companies for Antarctica for their business models. The first tourist flight to Antarctica was in 1957 [6]. Today, any healthy person can fly to the South Pole for US\$35,000 through Adventure Network International [7].

## 6. CONCLUSION

Experience of working at the South Pole of the Earth can offer valuable insights into upcoming human expeditions to the Moon because of various environmental and logistical analogs between Antarctica and the Moon.

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