Mic25-0107

Problem Areas
Risks
Education

USC ASTE 523, Spring 2025

Design of Low-Cost Space Missions

Selene: A Near-Term, Income-Generating, Lunar Settlement

Part 4

Living on the Moon in the next decade

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Topics

- Artistic Representation of a Lunar Colony
- New book on *Lunar Commerce*
- 11. Problem areas
  - What's available and not available on the Moon
    - The nitrogen problem
  - Lunar transportation
  - Microgravity
- 12. Risk
- 13 and 14. Education
  - Public Education
  - International Lunar University

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Artistic Representation of Lunar Colony

Created by Grace and Lucy Wellman for their grandfather

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New Book on *Lunar Commerce* by Derek Webber

- Appears to be an excellent, well documented volume
- Table of Contents distributed separately
- Includes 4 main parts
  1. Why we go
  2. How we go
  3. Paving the Way
  3. Framing the Way
- Includes discussions of Revenue Potential, Risks, and Uncertainties

This appears to be an excellent volume directly addressing many of the issues addressed in class.

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Topic 11: Problem Areas -- What's Available and Not Available on the Moon

- What's available to us?
- What's missing?
- The Transportation Problem
- Gravitational Biology

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Basic Properties of the Moon Relevant to Lunar Settlements

- **Properties of the Moon and Earth**

Property	Earth	Moon	Moon/Earth Ratio
Mass	6.0×10^{24} kg	7.4×10^{22} kg	1.2%
Equatorial Radius	6,378 km	1,738 km	27.3%
Surface Area	5.1×10^{8} km^2	3.8×10^{7} km^2*	7.4% (26.6% of land area)
Gravity at the Equator	9.8 m/s^2	1.6 m/s^2	16.5%
Orbital Velocity	7.9 km/s	1.7 km/s **	21.3%
Escape Velocity	11.2 km/s	2.4 km/s	21.3%

* Equals the combined area of North and South America
** Equals 3,800 mph = Mach 5 at Earth sea level

- Orbit Properties of the Moon

Property	Value
Mean Distance from Earth	384,000 km
Synodic Period (= time from local noon to local noon)	29.5 days
Orbit Transfer Time (Hohmann Transfer)	5.0 days
Brightness of the Full Earth	80 × the Full Moon

- **Mean surface temperature of the Moon ranges from 107ºC (= 225ºF) to –153ºC (= –243ºF); however, temperature means very little without an atmosphere; 30 cm into the lunar soil the temperature is essentially constant**

In some respects, the lunar environment is very harsh and unforgiving. On the other hand, floods, tornadoes, hurricanes, and tsunamis don't exist. (There are very small Moonquakes.) There are no poisonous snakes or plants, no lizards, no indigenous folks who would strongly prefer that you go back where you came from, and nothing in the environment regards you as lunch—that's pretty good.

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Resources (Building Supplies) Available on the Lunar Surface

- The regolith (lunar soil) is typically 5 m to 15 m thick and consists of a fine grain, compact dust. It supports weight very well, but has sharp edges and is easily charged with static electricity and is a major contaminant of equipment
- Average composition of the lunar regolith by weight:
  - Oxygen 45%
  - Aluminum 5% to 13%
  - Iron 6% to 15%
  - Titanium 1% to 5%
  - Silicon 21%
  - Calcium 9%
  - Magnesium 5%
- 1% to 25% of the regolith consists of lunar glass formed largely from impacts
- Biogenic gases (carbon, nitrogen, and hydrogen) are present in the regolith with concentrations of approximately 0.01% by weight. These can be released by heating the soil to 700ºC
- The regolith is also rich in ^{3}He from long term exposure to the solar wind which could be an excellent source of nuclear power for the Moon and the Earth
- There is strong evidence for large quantities of H_2O in polar craters for which the bottoms are never in sunlight—but we don't know how easy it is to get at or how much there is

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Materials on the Lunar Surface Appropriate for Use in the Lunar Colony

- **Oxygen** is readily available in large quantities
  - Oxygen is also the heaviest part (89%) of the propellants needed for a hydrogen/oxygen rocket engine
- **Aluminum** for structural material and **silicate** for glass are available in large quantities and should be the basic building materials for a colony
  - **Iron** is somewhat less plentiful, but easier to mine --- may be a good alternative for construction
- **Water** appears to be available in the polar regions
- Both **silicon** for solar cells and **^{3}He** for nuclear power are also available
- **The principal raw materials that are available only in small quantities are nitrogen and carbon**
- The regolith itself (after removing whatever minerals are wanted) is excellent for radiation shielding, thermal insulation, and micrometeroids

The basic bulk raw materials are readily available on the Moon.
The biggest problem is nitrogen for the atmosphere.

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The Nitrogen Problem

- Nitrogen is required for plant growth and makes up 80% of Earth's atmosphere
- Unfortunately, air is remarkably heavy (~1 kg/m^3) and, at $1,600/kg, expensive to ship (irrespective of whether it's in gas, liquid, or solid form — the weight's the problem)
  - In most rooms, the air weighs more than the people
- Potential sources of nitrogen in large quantities:
  - Brought from the Earth's surface—major source to start
  - Recoverable by product from the air around goods and people brought to the Moon
  - Scooped by satellite from the Earth's upper atmosphere
  - Extraction by heating from the lunar soil
  - Brought from a carbonaceous chondrite asteroid — 9% of all asteroids are this type and typically have up to 20% bound water and 6% organic matter (C, N, H)
  - Brought from one of the comets or gas giants (CH_4 and NH_3 atmospheres)
- For working purposes we will assume a colony interior height of 35 m, composed of 3 psi O_2 and 10 psi N_2
  - Assume initially that all of the nitrogen comes from the Earth's surface
  - Gives us a "Nitrogen Tax" of $40,000/m^2 of colony area

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The Carbon Problem

- **Carbon is also required for plant growth but is not a significant constituent of the atmosphere**
  - **Carbon dioxide is only about 0.04% of the atmosphere**
  - **Carbon is needed for both plants and animals, but not in the large quantities that nitrogen is needed**
  - **Carbon and nitrogen can be brought up in methane (CH_4) and ammonia (NH_3)**
- **Potential sources of carbon in moderate quantities:**
  - **Brought from the Earth's surface—most likely source**
  - **Recoverable by product from the air around goods and people brought to the Moon**
  - **Scooped by satellite from the Earth's upper atmosphere {won't be particularly effective)**
  - **Extraction by heating from the lunar soil**
  - **Brought from a carbonaceous chondrite asteroid — 9% of all asteroids are this type and typically have up to 20% bound water and 6% organic matter (C, N, H)**
  - **Brought from one of the comets or gas giants (CH_4 and NH_3 atmospheres)**
- **Carbon will need to be brought to the Moon, but it's not aa major problem area**

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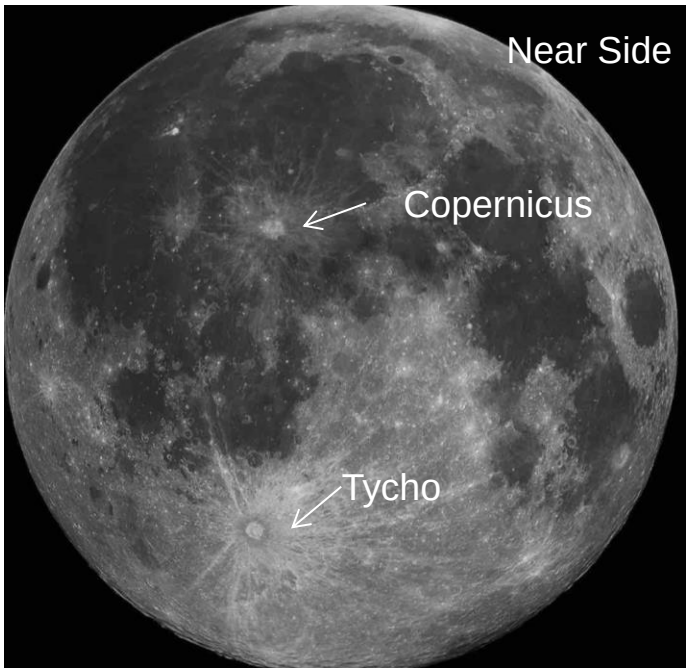
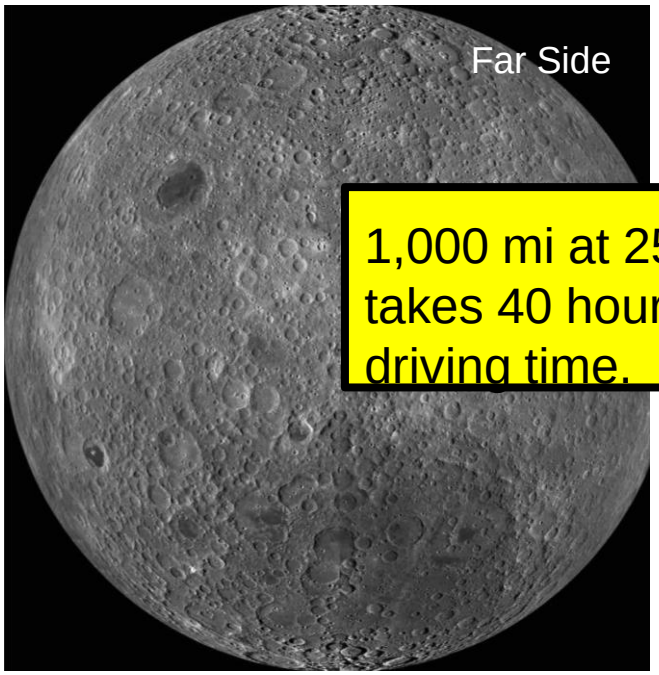
The Transportation Problem: The Moon is Big and Lunar Transportation is Hard





1,000 mi at 25 mph takes 40 hours of driving time.

- **The surface is firm and driving around locally shouldn't cause problems**
- **But, the Moon has as much area as North America plus South America combined -- it's 1,000 miles (1,600 km) from Copernicus to Tycho**
- **Airplanes and ships don't work well on the Moon**
- **"Rocket hoppers" might work, but need lots of fuel and careful design**

It will take more engineering, but it looks like moving large distances to explore the Moon's most interesting features will be challenging.

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Microgravity and the Environment

- **The good part**
  - On the Moon, we don't need the construction requirements of Earth – there is no wind, rain, storms, hurricanes, or large earthquakes, and everything (including buildings) weighs 1/6th as much as on Earth
  - Makes both construction and action easier and more fun (How high can you jump on the Moon?)
    - A pole stuck in the ground can stay there for thousands of years
- **The bad part**
  - It's not clear what continuous low gravity does to people, particularly to growing kids
  - Astronauts have returned safely to Earth after a year in 0 g
    - We should be able to spend at least 2-3 years in lunar gravity
    - It's not known what long-term low gravity will do for adults or kids

As we begin to move into the solar system, it isn't known what different levels of gravity will do to people. Will individuals become weaker or stronger? Can we live in the solar system? Can we return to Earth?
The biology of varying gravity levels is an entirely new area of science that needs substantial exploration.

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Gravitational Biology

- **We know that adults can live and work in 0-g for a year**
  - **What about babies or 5-year olds in 1/6th g?**
  - **Can a person come back to Earth after 10 years in 1/6th g? Can a child spend their first 5 years on the Moon and then come down to Earth?**
  - **The bottom line is that we simply don't know – we've never done it !**
- **The Lunar Gravitational Biology Wheel would be sitting flat on the lunar surface and rotating at a few rpm to provide long-term artificial gravity from roughly 0.2g to 1.2g, depending on how close you are to the axis**

See the description of the Lunar Gravitational Biology Wheel in the discussion of the International Lunar University below.

If we're going to explore the solar system, a lot of low-gravity (and maybe high-gravity) science needs to be done. The Moon is the place to do it.

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Topic 12 -- Risk Mitigation and Safety – Critical for a Lunar Settlement

- **Risk Areas**
  - **Radiation**
  - **Micro-meteoroid or asteroid hit**
  - **Medical emergency**
  - **Loss of air**
  - **Loss of critical resources**
  - **Fire and pollution**
- **Areas of Reduced Risk**
  - **Weather – hurricanes, tornadoes, wind, floods, forest fires, tsunamis**
  - **People that really don't want you on their land**
  - **Poisonous reptiles**
  - **Animals that regard you as lunch**

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Risk Mitigation and Safety 1: Radiation and Micro-Meteoroids

- **Radiation inside the settlement**
  - **Lunar regolith around the settlement provide mass equivalent of Earth's atmosphere between the people and space**
  - **15 psi Earth equivalent shielding = 2 to 4 m of lunar regolith on top**
    - **Regolith on roof weighs 2–3 lbs/in^2 -- Less is probably OK**
    - **More air pressure from inside than weight from the regolith**
- **Radiation outside the settlement**
  - **Monitor and limit the amount of time spent outside the settlement**
  - **Principal protection for people who are outside is adequate warning to go inside in case of solar storms**
  - **Warning comes from existing sats at Earth/Sun L1 Lagrange Point**
- **Micro-meteoroid hit**
  - **Basically same as Earth—Micro-meteoroids are stopped by the regolith on the roof, just as they are by the Earth's atmosphere**
  - **Different mechanism (on Earth they burn up; on the Moon they're stopped by the regolith), but the result is the same**

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Risk Mitigation and Safety 2: Larger Meteoroids and Loss of Air

- **Large meteoroid or Asteroid Hit**
  - — **Danger no different than on Earth — asteroid not significantly slowed by Earth's atmosphere and the consequences of a direct or nearby hit are similar (worse on Earth – remember the dinosaurs)**
- **Loss of Inside Atmosphere (leaks, meteoroids, Bob left the door open)**
  - — **Asteroids/meteoroids remarkably unlikely to happen**
  - — **In a large volume like the colony, air loss through even a large hole is slow, allowing time to find and fix the problem**
    - **Need warning system to immediately detect any pressure loss**
    - **Will want to be able to seal off some interior areas and have O_2 available to provide back-up in case of a catastrophe**
    - **Want back-up place to go (rovers, rooms, other settlements)**
- **Loss of air supply outside on the surface (leaks, lost or injured)**
  - — **While outside, maintain continuous communication with colony**
  - — **Major roads should have a supply line with air, power, and comm**
  - — **Carry back-up supply of air, power, and communications equip**
  - — **Similar to safety on ships**

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Risk Mitigation and Safety 3: Lack of Critical Supplies

- **Lack of critical supplies or major catastrophe**
  - **Biggest safety factors:**
    - **Multiple colonies**
    - **Multiple transportation systems,**
    - **Multiple communications links (on the Moon and to Earth)**
  - **In today's world, continuous communications is critical and not hard**
    - **Cell towers, lunar satellites, or direct to Earth (as was done for Apollo)**

The key issues are having multiple ways to communicate and back-ups for all critical infrastructure.

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Risk Mitigation and Safety 4: Fire and Pollution

- Fire and pollution—likely the biggest threats
  - Fires in any confined region are always a problem
    - Use fire extinguisher for small fire
    - Use oxygen control for large fire—cut the fire off, supply it to people
  - Most substantial threat may be pollution—there is no ocean or atmosphere to dump stuff into (may not be the solution on Earth for too much longer)
    - Safety comes from careful monitoring and maintenance as needed
    - "CA Department of Water and Power" becomes "Settlement Department of Air, Water, and Power."
      - They monitor, filter, and, of course, charge taxes

The lunar environment is harsh, but benign. In many respects, building a colony on the Moon is much easier and less threatening than building a town on the Amazon.

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Risk of Settling the Moon vs. Settling North and South America

- **Will people be killed in settling the Moon?**
  - Seems very likely, although numbers killed will probably be very small
- **Were people killed in the settlement of North and South America?**
  - Of course, at times in very large numbers
    - Hurricanes, storms, violent and extreme weather
    - Snakes, alligators, insects, and animals that think you're tasty
    - People that would have preferred that you not be there
- **In both cases, the major risk may be in getting there**
  - Travel to the Americas was neither easy nor safe
  - Travel to and from the Moon appears to be the largest risk area

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Key Differences in Settling the Moon vs. Settling North and South America

- **The major difference is that in settling the Moon with today's technology there is essentially continuous communications among the settlers, between the settlements, and with the Earth**
- **The other key issue is that lunar settlement involves a only few hundred or a few thousand people initially, perhaps advancing to a few million over time**
  - **The Earth's population is over 8 billion people**
  - **We really don't want all of those folks wanting to come to the Moon**

We will not convince everybody, possibly not even a majority, that living on the Moon is safe, fun, and profitable.

That's OK.

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Topics 13 and 14. Education

- 13. Public Education
  - Teaching people about the Moon and Expansion into the Universe
- 14. International Lunar University
  - Research and Education
  - Unique research areas
    - Gravitational Biology
    - History of the Solar System
    - Fermi Paradox

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Topic 13. Public Education

- The goal is to tell people worldwide about people living on the Moon and expanding into the solar system
  - Key point is that the entire population of the world, 8.2 billion people, knows about and understands the Moon
    - Essentially all of them want to know about, see, and understand people living on the Moon
    - No one wants to be left out of this conversation
- Who tells the people of the world about living on the Moon?
  - Diplomats from countries around the world
  - Educators talking to schools worldwide
  - Speakers talking in public forums in all languages
  - News crews from around the world (CNN and the London Times)
- Fortunately, modern communications technology will allow this to happen

The whole world sees and understands people living on the Moon. They may or may not want to be there, but they want their segment of society (country, race, religion) to be a part of that expansion.

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What Does the Portuguese Ambassador to the Moon (PAM) Do to Keep Busy?

- Like all ambassadors, the first job is to take care of the problems and concerns of wealthy (and likely fussy) Portuguese tourists
- Talk in real time (with a 2 sec round-trip delay) to every middle school and high school class in Portugal, telling them what living on the Moon is like
  - In Portuguese, NOT in English or Spanish
  - Compare it to locations or scenes in Portugal
  - Watch a ball tossed in the air at the same time as the classroom kids
  - Show them what Portugal looks like as seen from the Moon
  - Convince the schoolkids that they want to help make Portugal a part of the expansion of humankind into the solar system
- Show others back on Earth the view out the window or, at night, the surface of the Moon in Earthlight
- In the evening, he or she runs the Portuguese restaurant to convince wealthy tourists from elsewhere in world to visit beautiful Portugal

The Portuguese Ambassador to the Moon has one of the most sought-after jobs in the Portuguese government and stays remarkably busy.

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Topic 14. The International Lunar University (ILU)

- ILU provides undergraduate and graduate education on the surface of the Moon and education on Earth about the Moon
  - Has branches in some locations on Earth
  - Will probably have a branch on the far side of the Moon
- Most ILU students spend some time on the Moon (1 to 3 semesters) and likely more time on Earth
- What do they do on the Moon?
  - Some normal classroom activity with labs and experiments inside or outside in 1/6th g
  - Extensive setting up, monitoring, running, and adjusting lunar experiments where the PI may be at an Earth university
    - Monitoring and running the Gravitational Biology Wheel
    - Probably predominantly graduate students
  - Talking to university classes back on Earth
- Funded primarily by association with an experiment run by a PI at an Earth-based university
  - Some funding by various nations (i.e., a Portuguese scholarship)

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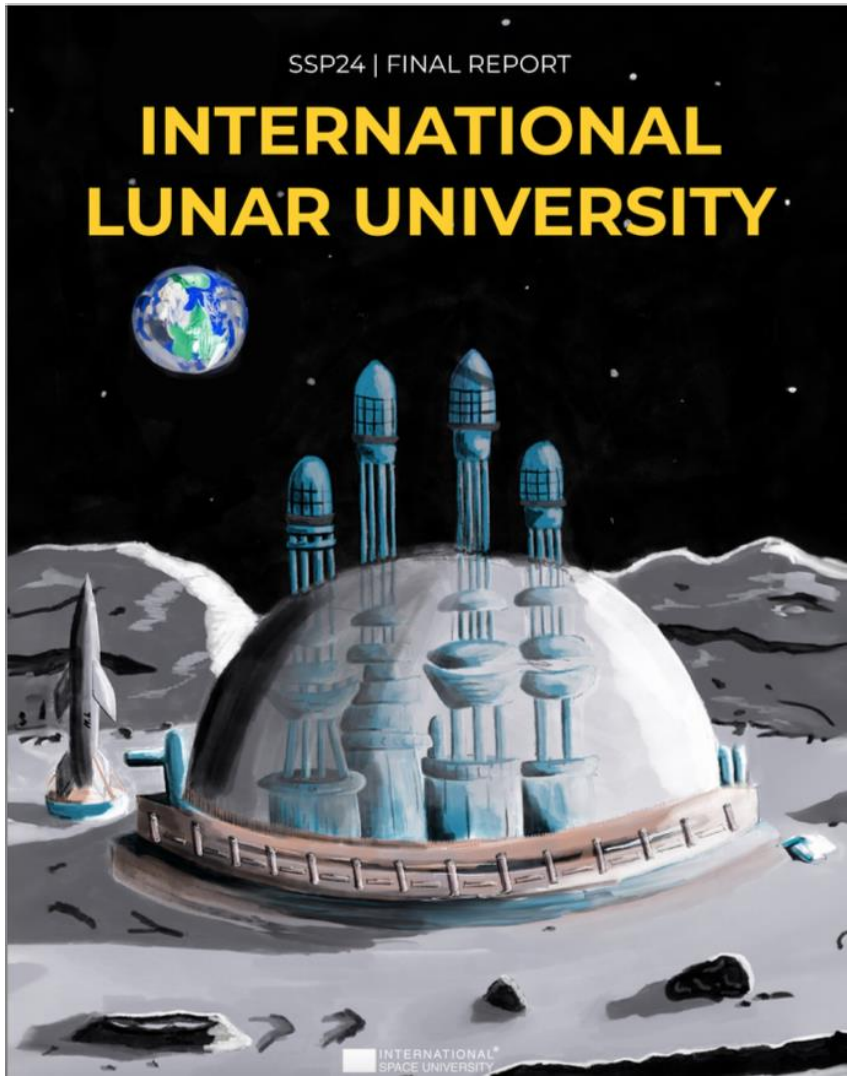
ISU 2024 study on an International Lunar University

- Intent is to establish a state-of-the-art educational and research institution focused on the Moon
- Three primary locations
  - Earth
  - Space stations
  - The Moon
- Pave the way for lunar settlers (selenauts)
- Intended to be international in scope with participants at multiple universities
- Study led by Dr. Jacob Cohen and Dr. Dan Rasky, both at NASA Ames Research Center
- For a copy go to

https://isulibrary.isunet.edu/doc_num.php?explnum_id=2263



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What Research and Education does the ILU do?

- ILU (students known as the “Lunatics”) provides undergraduate and graduate education on the surface of the Moon and education on Earth about the Moon
  - Main research areas
    - Gravitational Biology – key for human expansion into the solar system
    - History of the Earth and the solar system
    - Optical and rf exploration of the rest of the Universe from the far side of the Moon
      - Search for extraterrestrial intelligence
  - There may be work in significant other areas, such as art, architecture, geology, and ecology

The International Lunar University is largely an international science university, but also brings together a wide range of social and artistic activity and interaction. It should create a wide range of new science, social, and artistic ideas and projects.

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The Lunar Gravitational Biology Wheel

- We know that adults can live and work in 0-g for a year
  - What about babies or 5-year olds in 1/6th g?
  - Can a person come back to Earth after 10 years in 1/6th g? Can a child spend their first 5 years on the Moon and then come down to Earth?
  - The bottom line is that we simply don't know – we've never done it !
- The Lunar Gravitational Biology Wheel would be sitting flat on the lunar surface and rotating at a few rpm to provide long-term artificial gravity from roughly 0.2g to 1.2g, depending on how close you are to the axis
  - A Biology Wheel 100 m (330 ft) in diameter would have to rotate at 4.2 rpm to create an acceleration at the rim of 1.2g
    - If living at 0.16g makes us weaker, does living at 1.2g make us stronger?
    - How much low g is reasonable for good health?
    - Can old people, like me, live and work better on the Moon?

If we're going to explore the solar system, a lot of low-gravity (and maybe high-gravity) science needs to be done. The Moon is the place to do it.

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The History of the Solar System

- The Milky Way galaxy is 13.6 billion years old
- The solar system is 4.6 billion years old
- The Earth is 4.54 billion years old
- The Moon is 4.35 billion years old
- Ages of some of the key features on the Moon
  - Kepler Crater , one of the youngest features = 108 M yrs old
  - Copernicus Crater = 93 km diameter, 800 M yrs old
  - Giordano Bruno Crater, very young feature = 4 M to 10 M yrs old
  - Lunar maria = 3.3 to 3.8 B yrs old
  - Lunar highlands = 4 B yrs old

Bottom line – the surface of the Moon is a remarkable location to study the history and evolution of the solar system

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The Far Side Observatory (FSO)

- **The FSO is probably the best location in or near the Earth to observe the rest of the solar system and the Universe as a whole**
  - **Fully stable environment**
  - **Avoids interference from the Earth in both optical and radio wavelengths**
  - **Can build very large optical and radio telescopes**
- **What does the FSO observe**
  - **Solar system objects (planets, moons, asteroids, other stuff)**
  - **Nearby stars and nebulae**
  - **Other parts of the Milky Way**
  - **Distant parts of the Universe**
- **What is the FSO searching for?**
  - **Dark matter that makes up most of the Universe**
  - **Solution to the Fermi Paradox – Where is everybody?**

The FSO could also be a convenient location for exploring the Moon's far side.

The Far Side Observatory can help us find solutions to some of the most intriguing questions in science – the history of the Earth and the solar system and the existence of extraterrestrial intelligence.

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