ROCKS TO ROBOTS:
Concepts for Initial Robotic Lunar Resource Development

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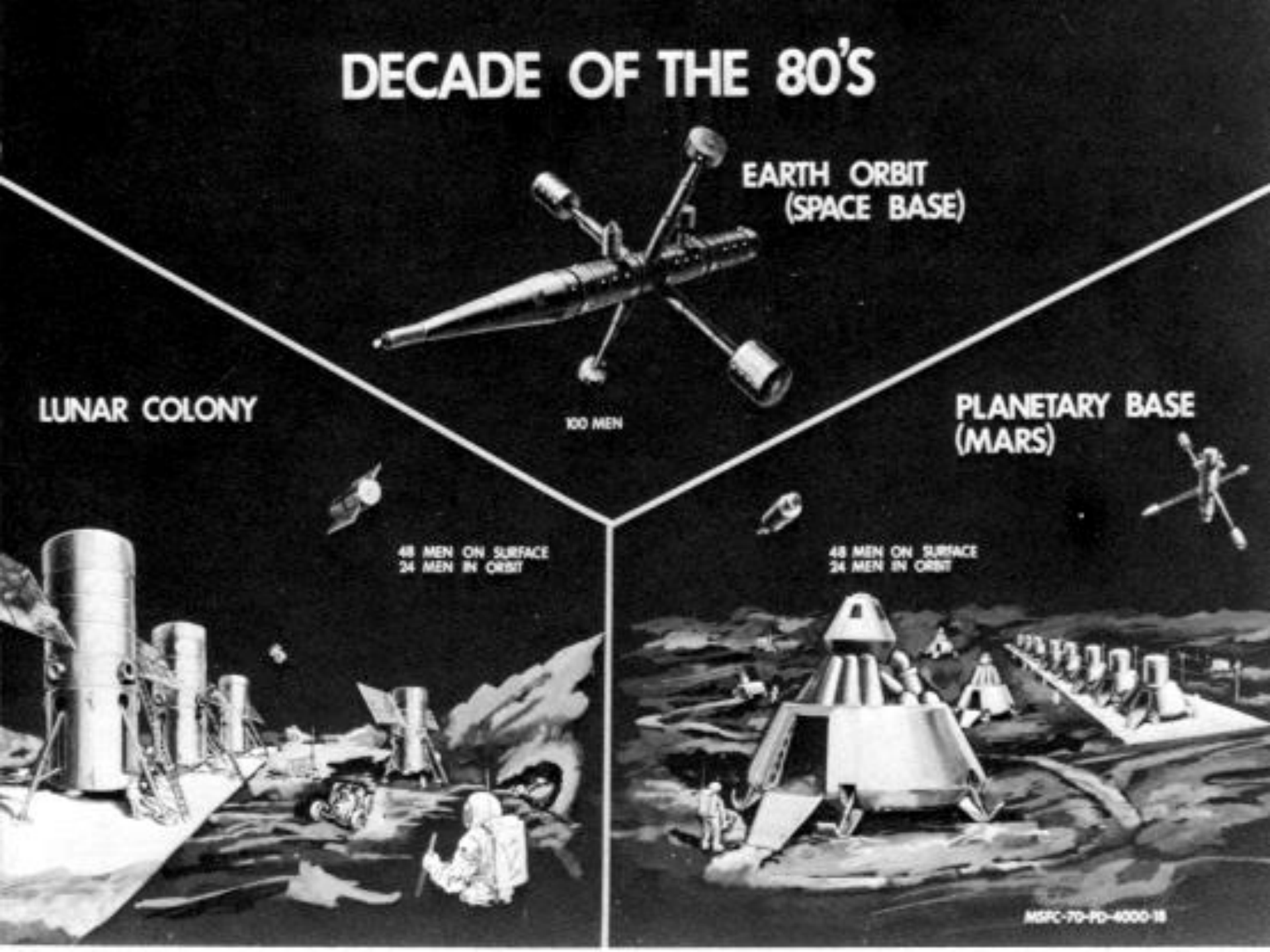
We have all grown up with space-fairing visions for humanity…

Sustained presence on the Moon was "right around the corner"…

DECADE OF THE 80'S



The FIRST MOON CITY

The first Moon explorers are not expected to stay longer than six weeks. But as other expeditions follow and more and more supplies arrive, permanent storehouses, living quarters and laboratories will be built. Men will need to stay for longer periods—perhaps for years. They will want to take their families with them.

To avoid the discomfort of moving always in space suits, the settlement will be roofed in, given its own artificial atmosphere and weather. And so the first Moon city will come into being, man's furthest outpost in space—in time to become, in its turn, a jumping-off place for journeys to the planets.

Pictured from A. C. Clarke's
"The Exploration of Space"
(Harper & Bros.)


Why haven’t these wonders materialized?

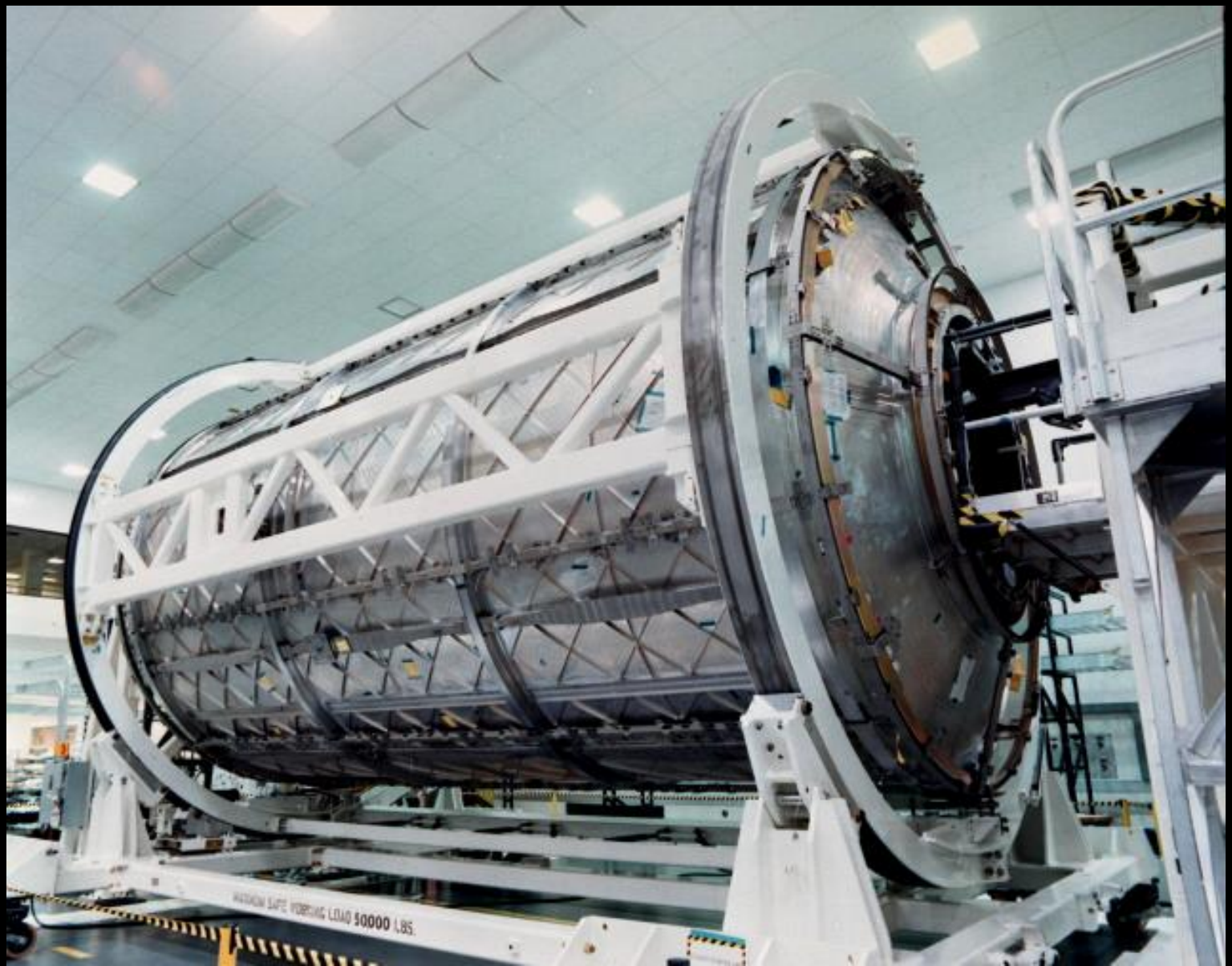
The culprit is the Rocket Equation!

$$M_{orbit} = M_{inital} / \exp(Delta\_V/(I_{sp} * g))$$

- We are restricted by an unfavorable exponential term in the rocket equation, …
- Which dictates that the net mass to orbit is <u>at best</u> only about 15% of the initial mass of our rocket.
- This severely limits the mass we can afford to bring with us from Earth into space!

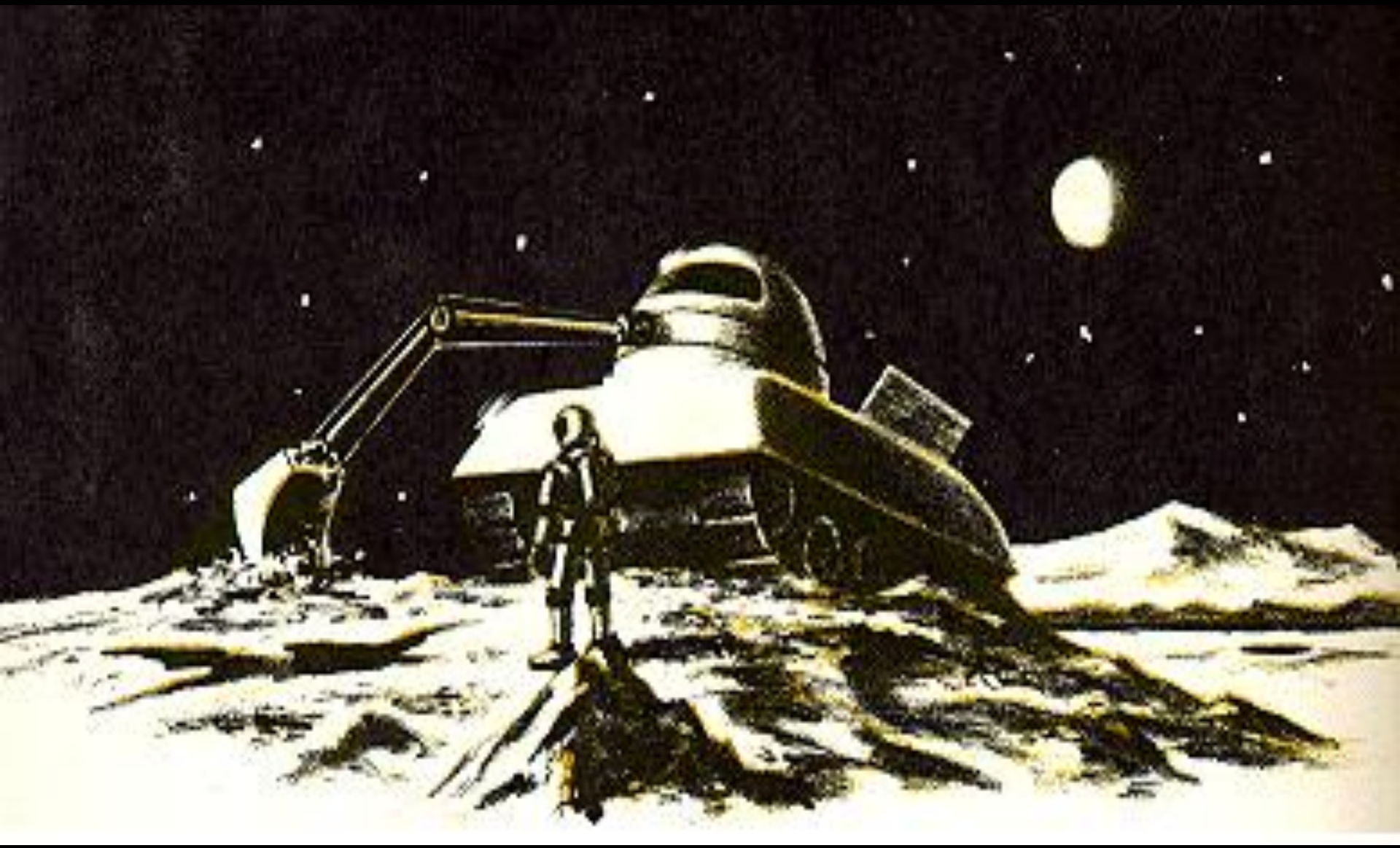

Let’s look at the mass of some
things we might like to bring with us:

A place to live and work:
like US Lab Destiny: 14,000 kg

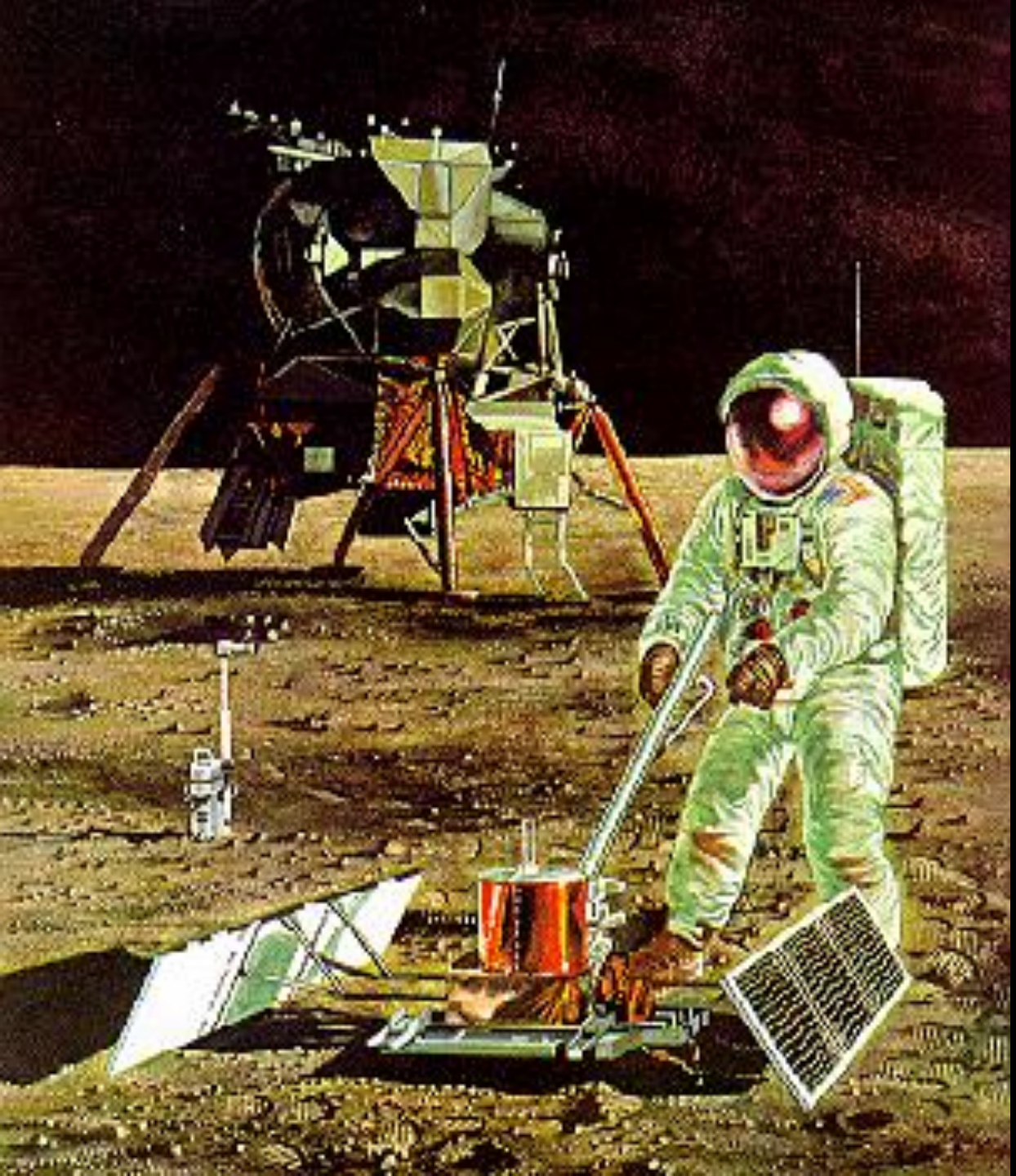


ISS at Mission 5A: 101,600 kg

How about an “earthmover”?…



Caterpillar Model 330C L Hydraulic Excavator – 35,100 kg

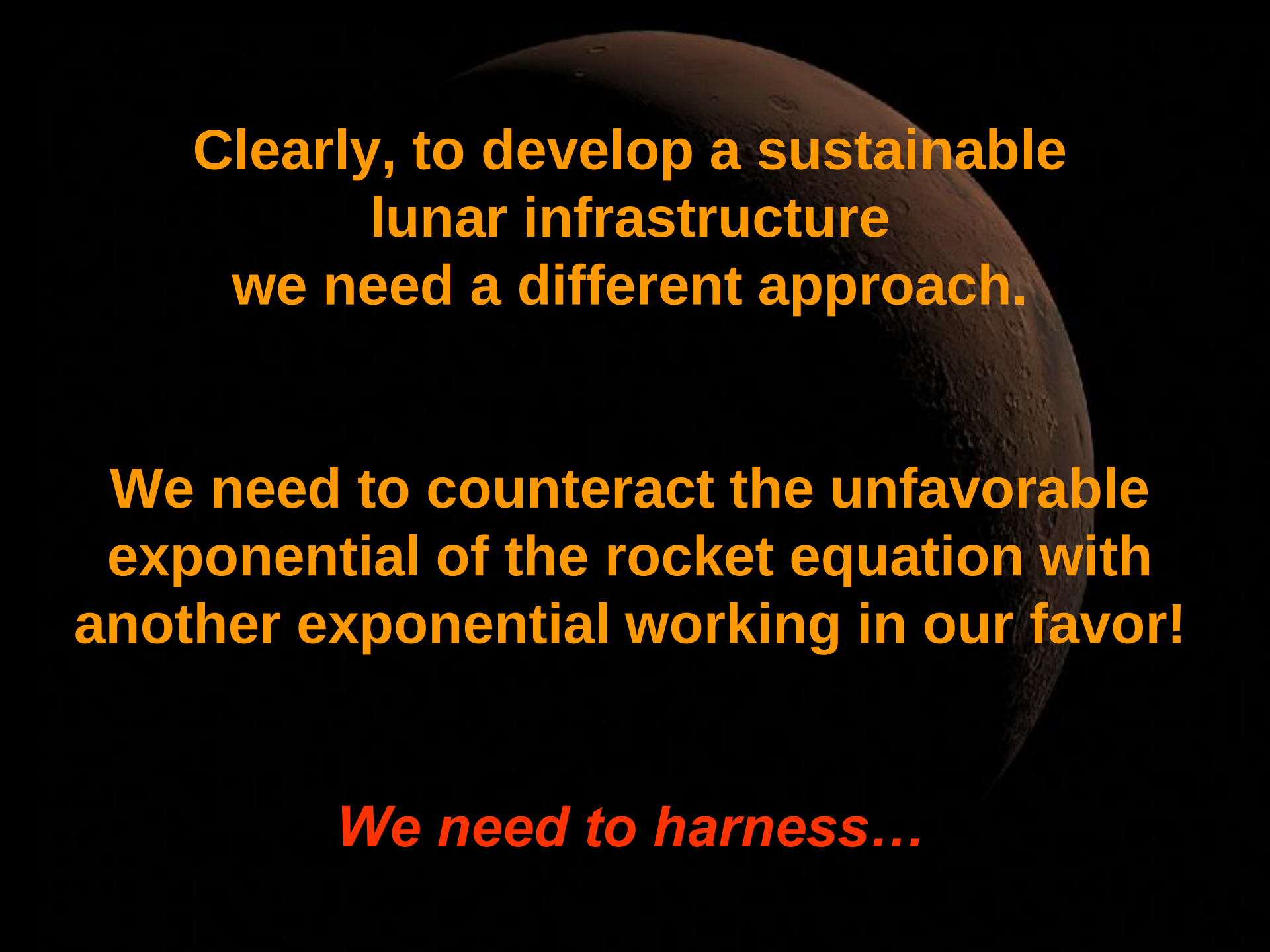


Lunar Reality

Apollo: 6900 kg delivered to the surface of the Moon…

…and required Saturn-The Largest Rocket Ever Built!

All together, the six Apollo landings only delivered the mass of about one fully loaded moving van!



Clearly, to develop a sustainable lunar infrastructure we need a different approach.

We need to counteract the unfavorable exponential of the rocket equation with another exponential working in our favor!

We need to harness…

Compound Interest!

- **P = C exp(rt)**

- Here the exponential is working in our favor instead of against us, and counteracts the unfavorable exponential of the rocket equation.

But how can we attain compound interest from a lunar mission?

We must convert resources already on the Moon to our purposes, namely:

- Regolith
- Sunlight
- Vacuum
- ~3 second communication with Earth

We can work with these resources immediately, on a small (kilogram-kilowatt) scale, by robotic remote control - “telepresence”

Telepresence

- Abundant telepresence is critical
  - Enables exponential growth rates
  - Provides flexibility to overcome obstacles
  - Allows re-direction of emerging industrial base to any desired application
  - Has tremendous intangibles:
    - Outreach
    - Commercialization
    - Internationalization
    - Entrepreneur and public participation
  - Projects the human mind onto the Moon

First Mission

- Modest Unmanned Robotic Mission
- Mission Scaled to Available Existing Launch Vehicle
  - perhaps 1000 kg to lunar surface.
- A rover that can dig and move regolith
- Telepresence “Glove Box”
  - Box on Earth, Gloves on Moon
- Regolith Material Processing Lab
  - *In Situ* Resource Utilization (ISRU)

Regolith ISRU Material Processing Lab

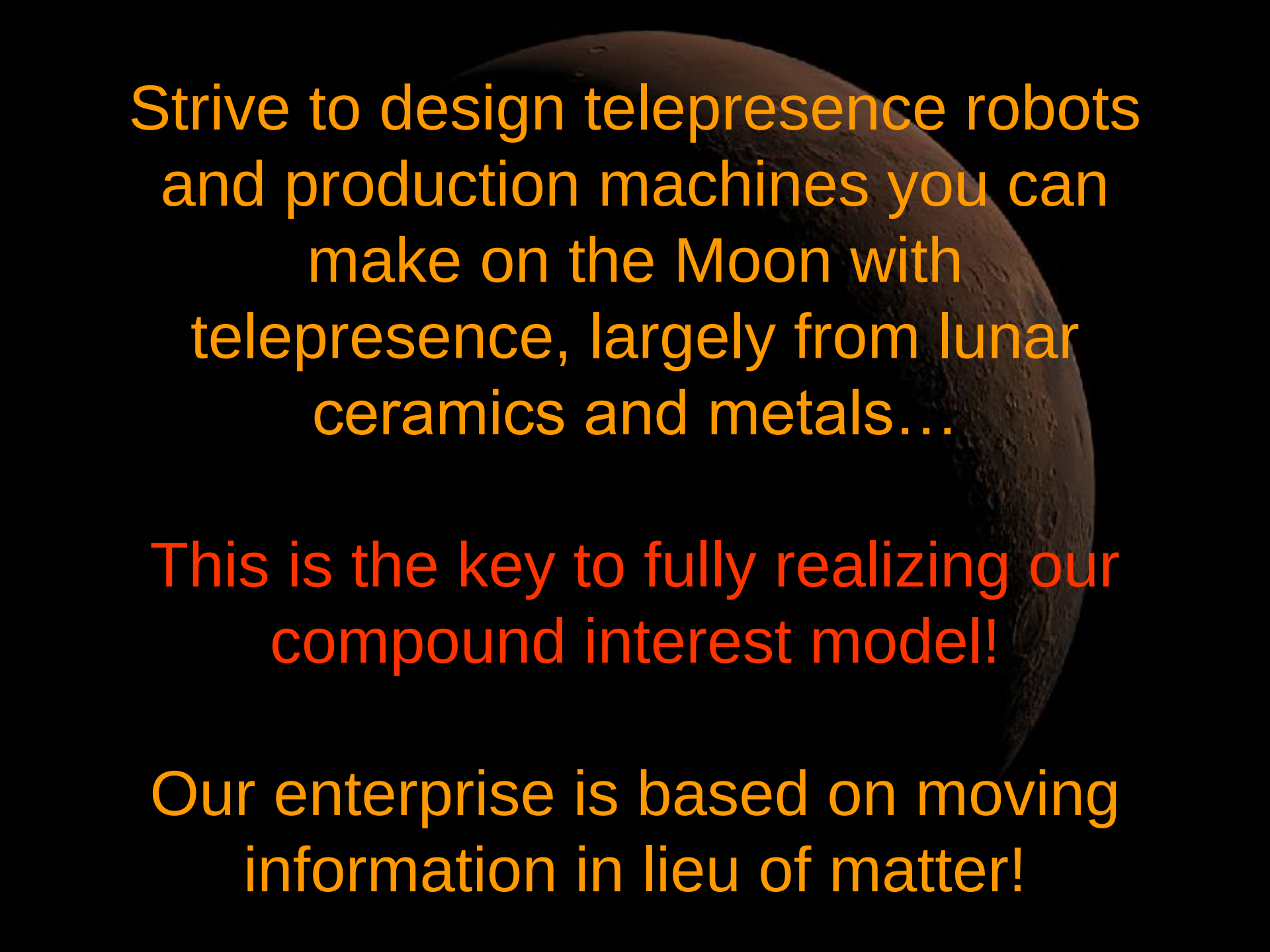
- Assemble, manipulate, repair apparatus
- Solar Furnace to bake and fuse regolith
  - Make Moon glass and ceramics
- Characterize ceramics you make
  - 50 times stronger than Earth glass?
- Microwave regolith
  - Pave regolith in place, form objects

Regolith ISRU Material Processing Lab

- Thin Film Deposition in Lunar Vacuum
  - Mirror coatings on Moon glass
    - Build another solar furnace
  - Solar cells on a regolith glass crust
- Extract metals, demonstrate oxygen
  - Electrolysis of FeO in regolith melt

Repeat Missions to Robot Outpost

- Add more telepresence stations, energy sources, & laboratory capability
- “Build stuff that helps you make more stuff”
- Reuse and adapt everything you can
- Learn how to do more
- Scale up and add more processes
  - Access more elements and volatiles



Strive to design telepresence robots and production machines you can make on the Moon with telepresence, largely from lunar ceramics and metals…

This is the key to fully realizing our compound interest model!

Our enterprise is based on moving information in lieu of matter!

Add Partners and Commercialize

- A free market based on import, export, and creation of lunar information
- Government Role is to:
  - Lower risk with first missions
  - Provide initial infrastructure
  - Generate excitement and vision
  - Get out of the way
- Cost to enter is manageable
- A space venture that is scalable and incremental
- Don’t have to wait for manned programs

Profit Centers

- Sell time on “gloveboxes” and lab facilities
- Create intellectual property of new, fundamental lunar industrial processes
- Supply the “glovebox” community
- Sell outreach experiences - tourism
- Sell monuments
  - “a brick with your name on it on the Moon”
- “YOU can participate. Telepresence puts YOU there.”

Scaling Has Vast Potential

- The Moon is about the size of Africa
- Thousands of terawatts of sunlight
- Clone outposts
- Adapt processes to rest of solar system
- Path to big projects

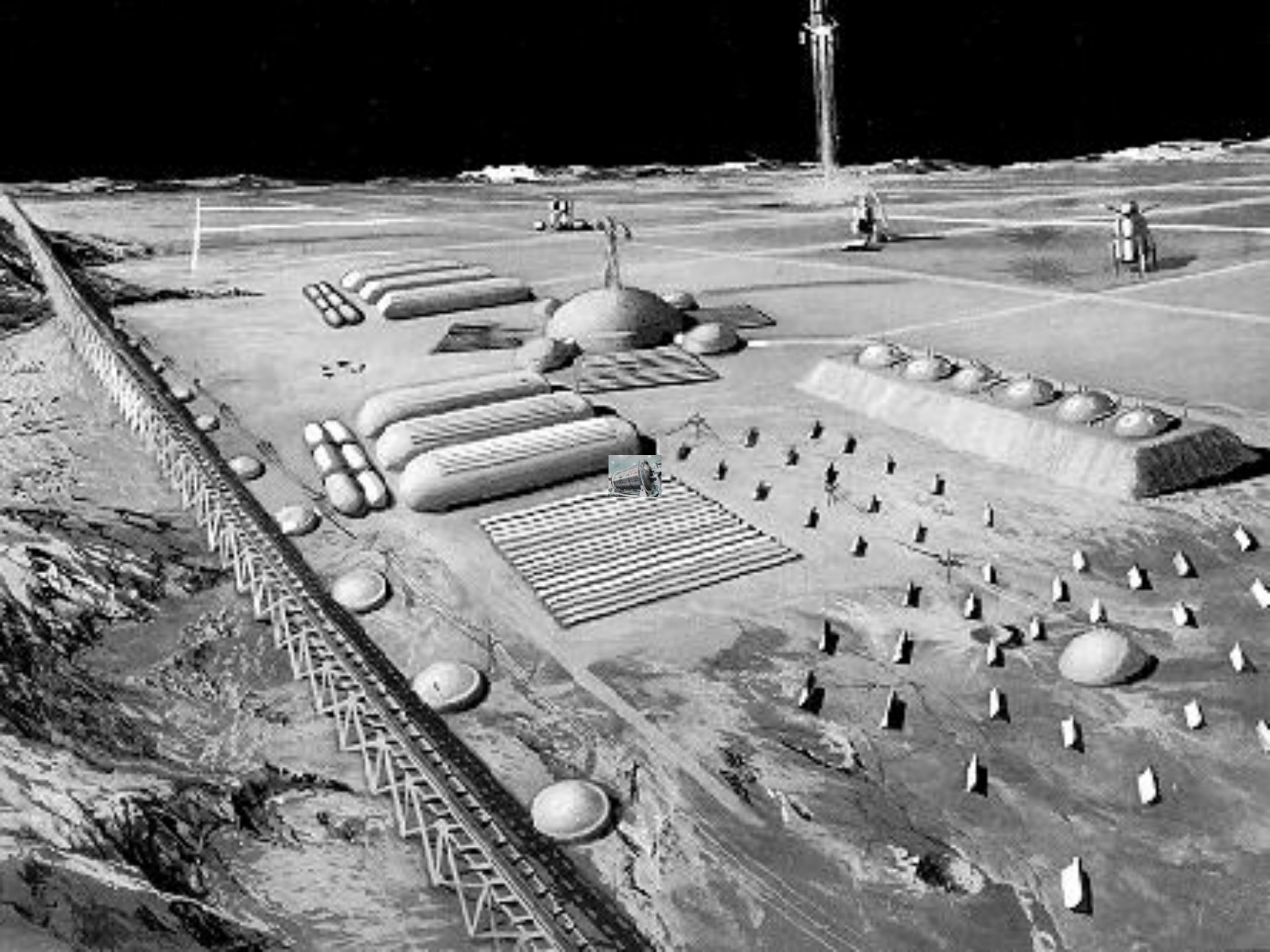
Eventually Enables “Big” Lunar Projects

- Lunar Habitats
- Oxygen and Food Production
- Rocket Fuel Production
- Large Scale Mining
- Helium Three Mining
- Observatories and Laboratories
- Mass Drivers
- Construction Materials to Orbit
- Large Scale Solar Energy
- Microwave Beaming of Energy
- Information Archive for Humanity

Let the market sort them out!

Bottom Line

- We have to master ISRU if we want more than a transient presence in space
- ISRU makes everything else possible
- Let's devise an ISRU strategy scaled to launch vehicles that are available now at funding levels we can get
- If our 1000 kg "seed" mission can replicate ~120 grams an hour, it doubles every year…
- The seed becomes a million kilograms of lunar industrial capability after ten years…



Exponential Growth

Credits

- Dreams of Space - Children's Space Art: John Sisson
  - http://sun3.lib.uci.edu/~jsisson/john.htm
- Biological Growth: Dr. Alan Cann
  - http://www-micro.msb.le.ac.uk/LabWork