Robotic, Self-Sustaining Architecture to Utilize Resources and Enable Human Expansion throughout the Solar System

SRR / PTMSS

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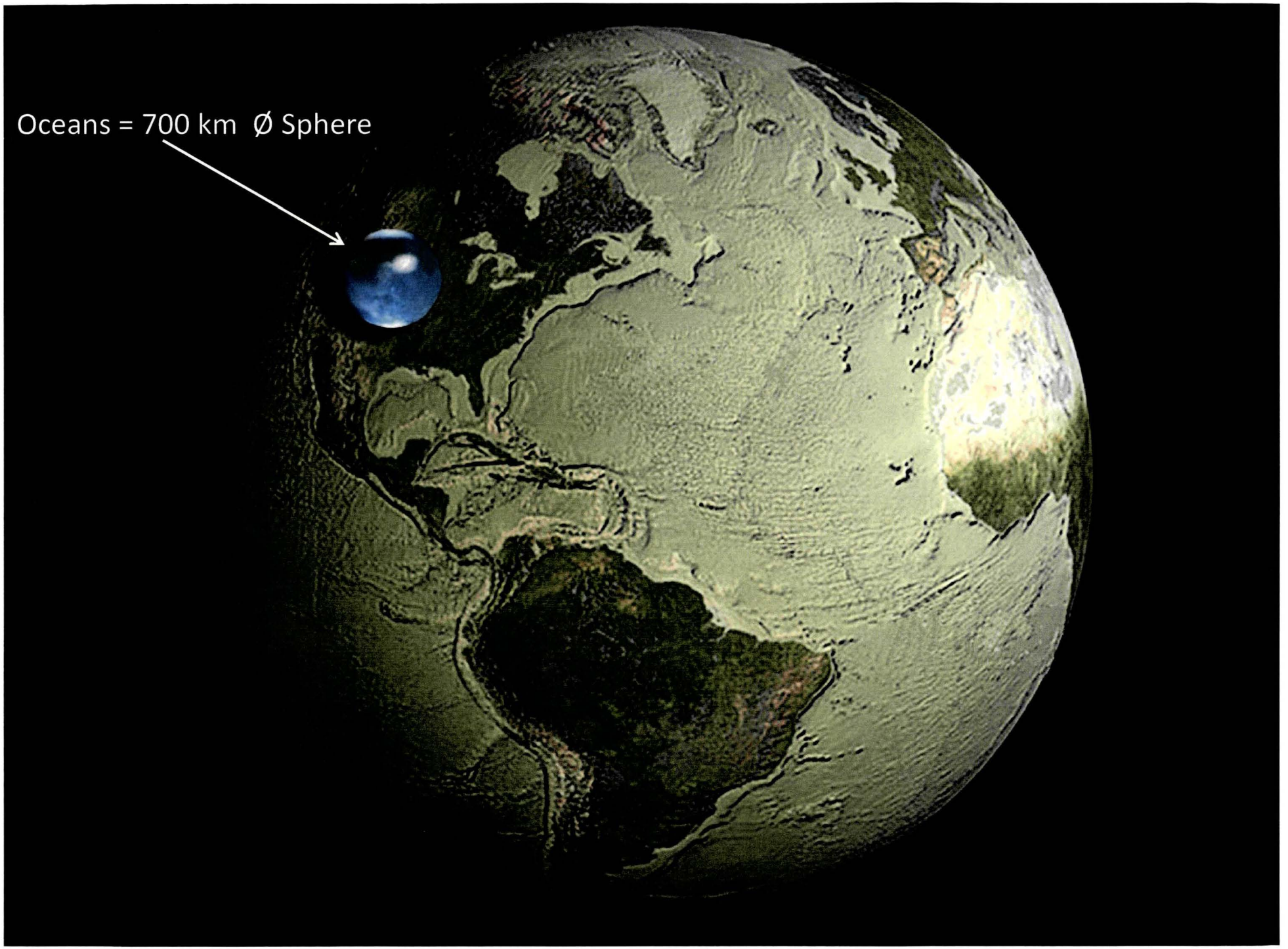
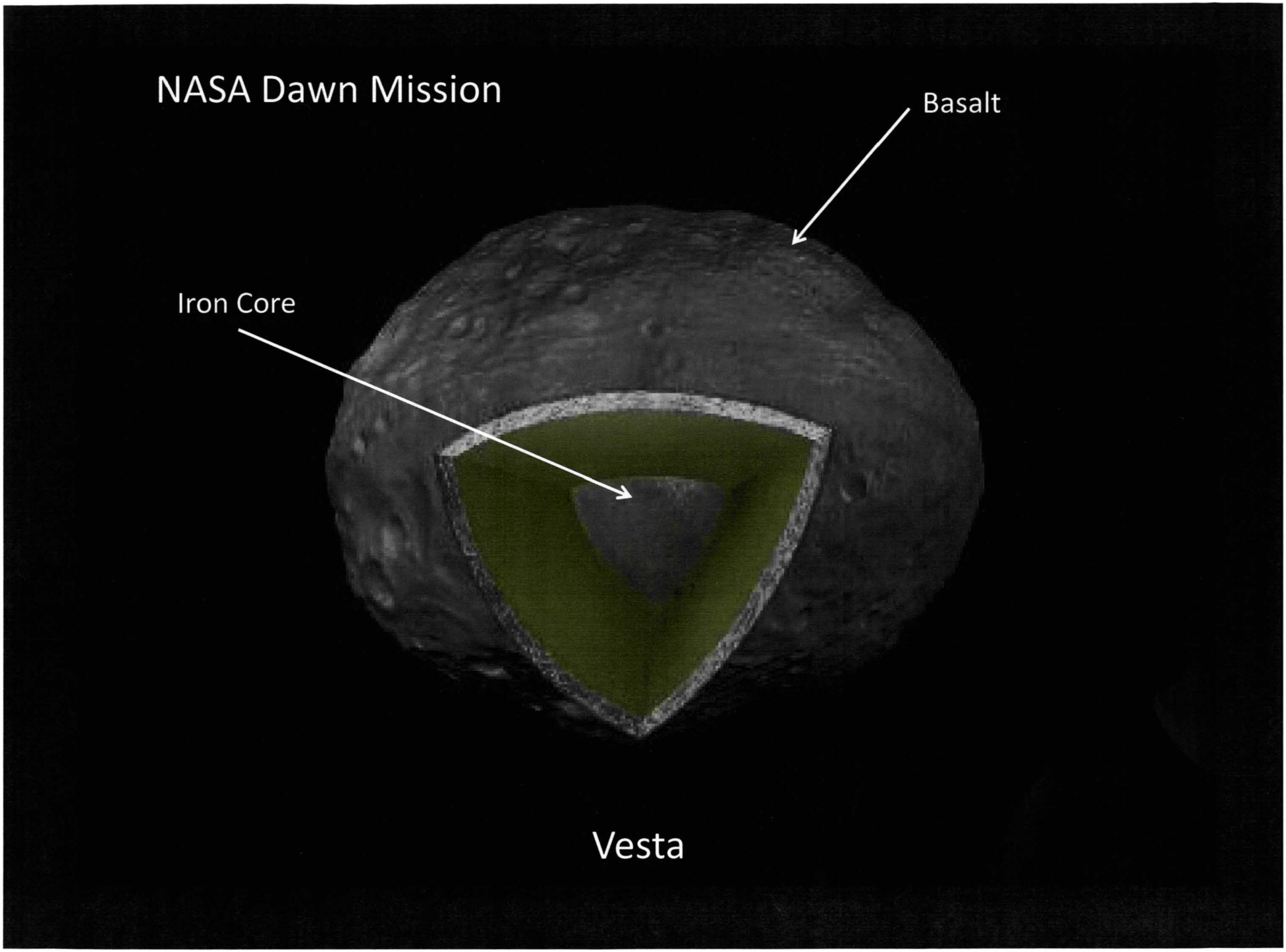
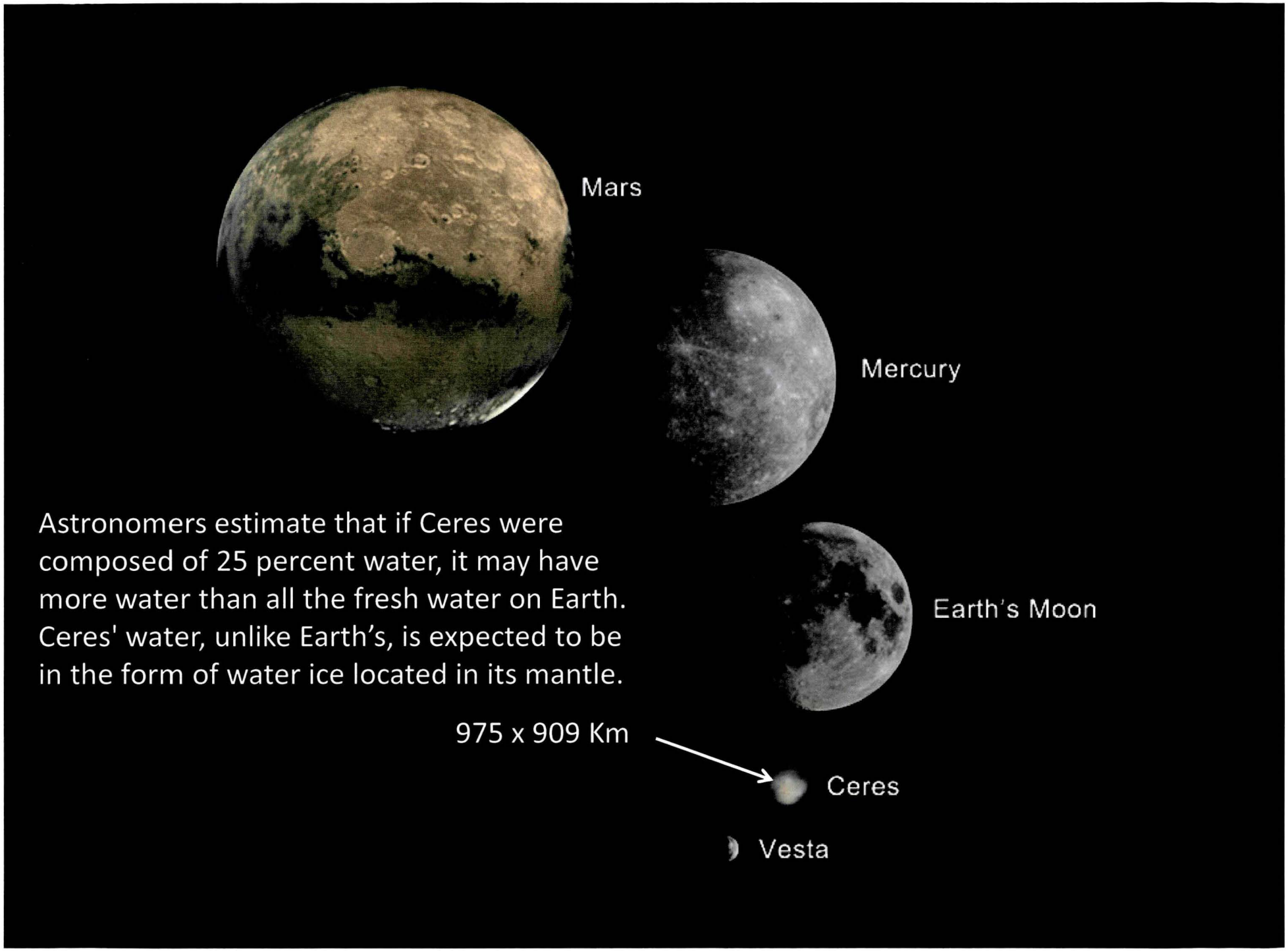
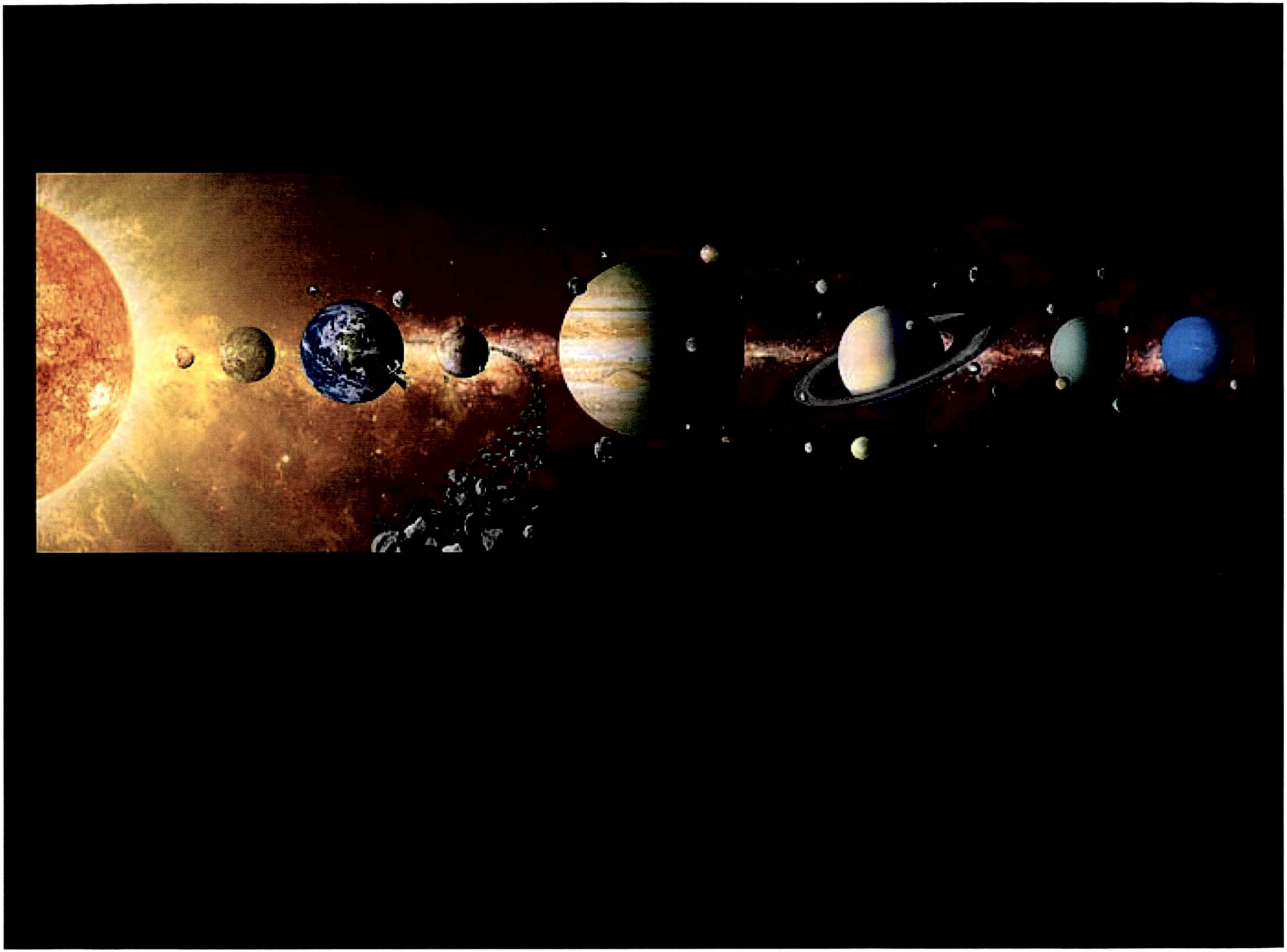
Granular Mechanics & Regolith Operations (GMRO) Lab

NASA/Kennedy Space Center

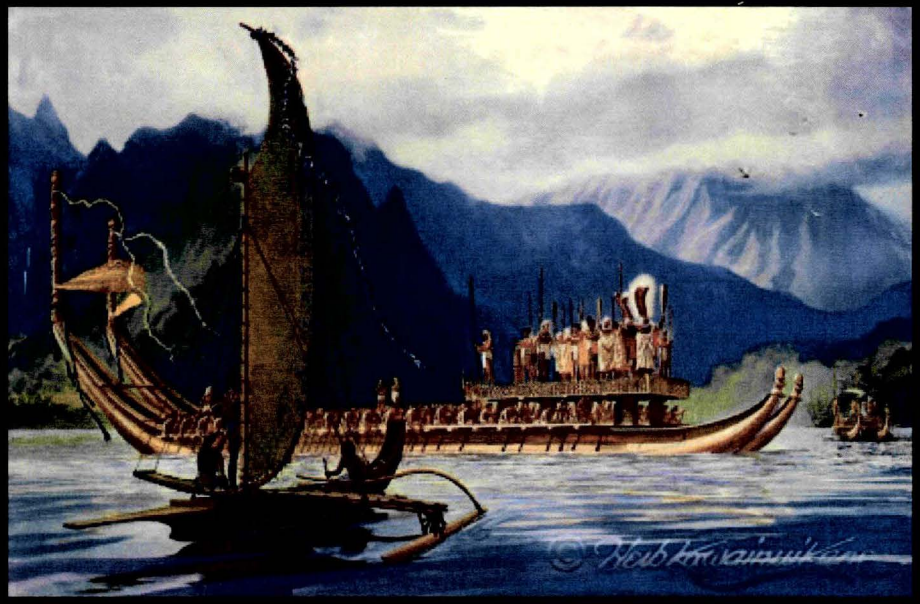

Oceans = 700 km Ø Sphere

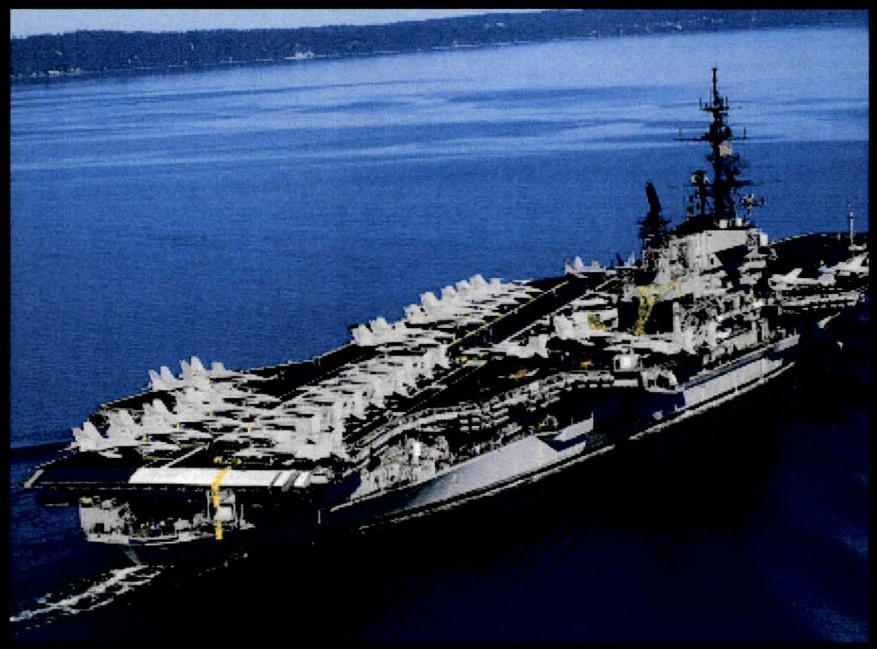

NASA Dawn Mission
Basalt
Iron Core
Vesta

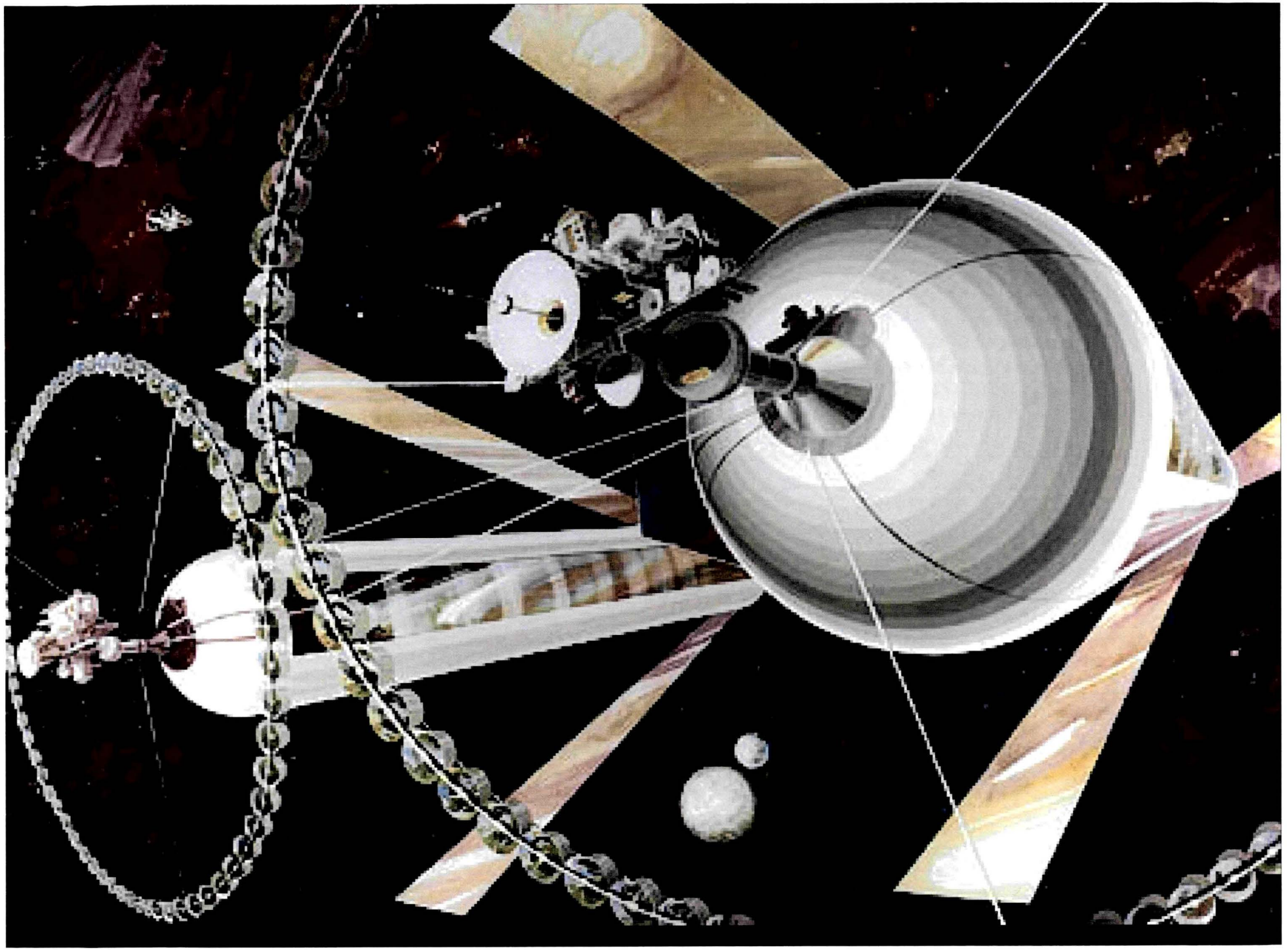

Mars
Mercury
Earth's Moon
Astronomers estimate that if Ceres were composed of 25 percent water, it may have more water than all the fresh water on Earth. Ceres' water, unlike Earth's, is expected to be in the form of water ice located in its mantle.
975 x 909 Km
Ceres
Vesta

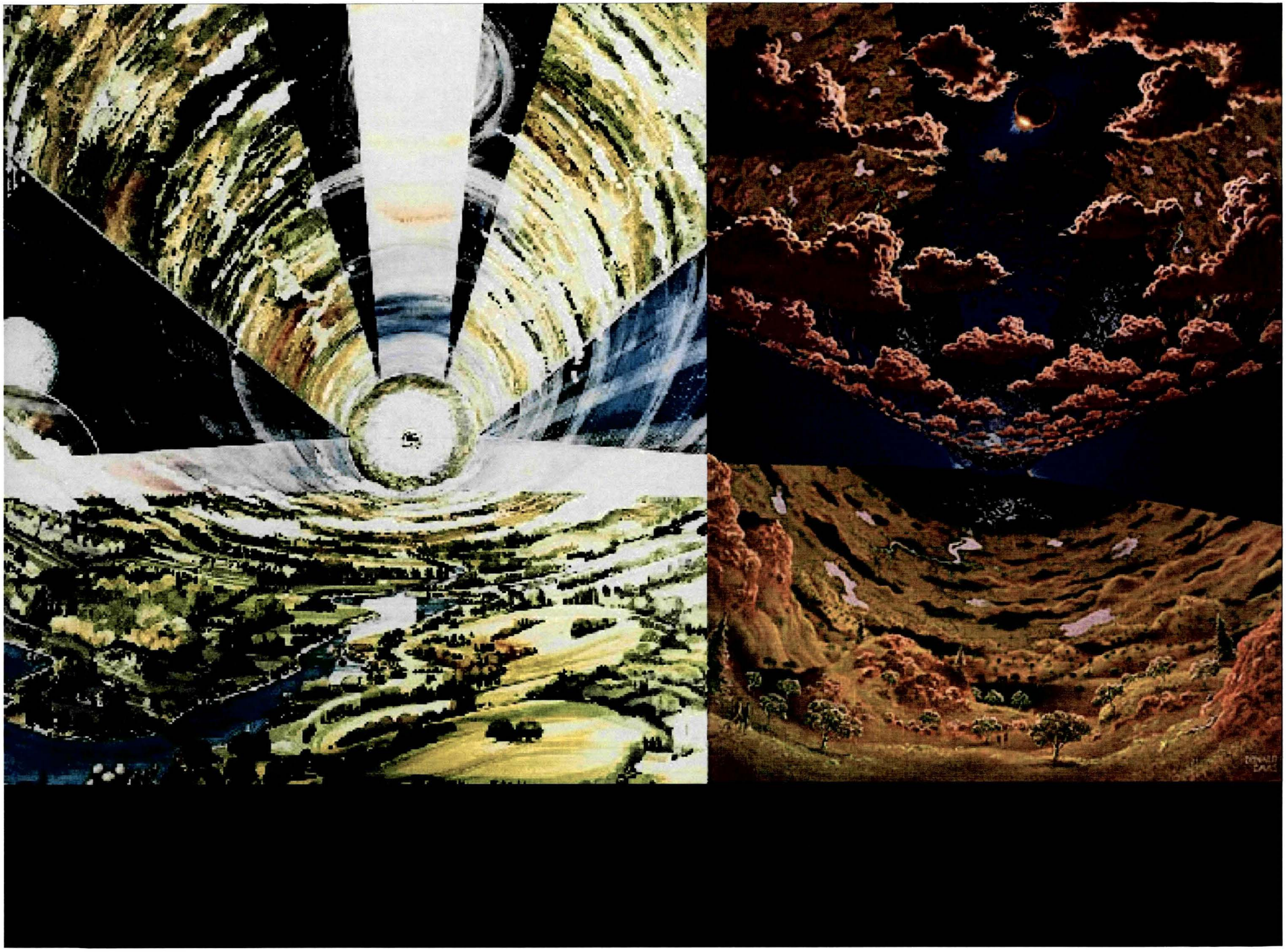


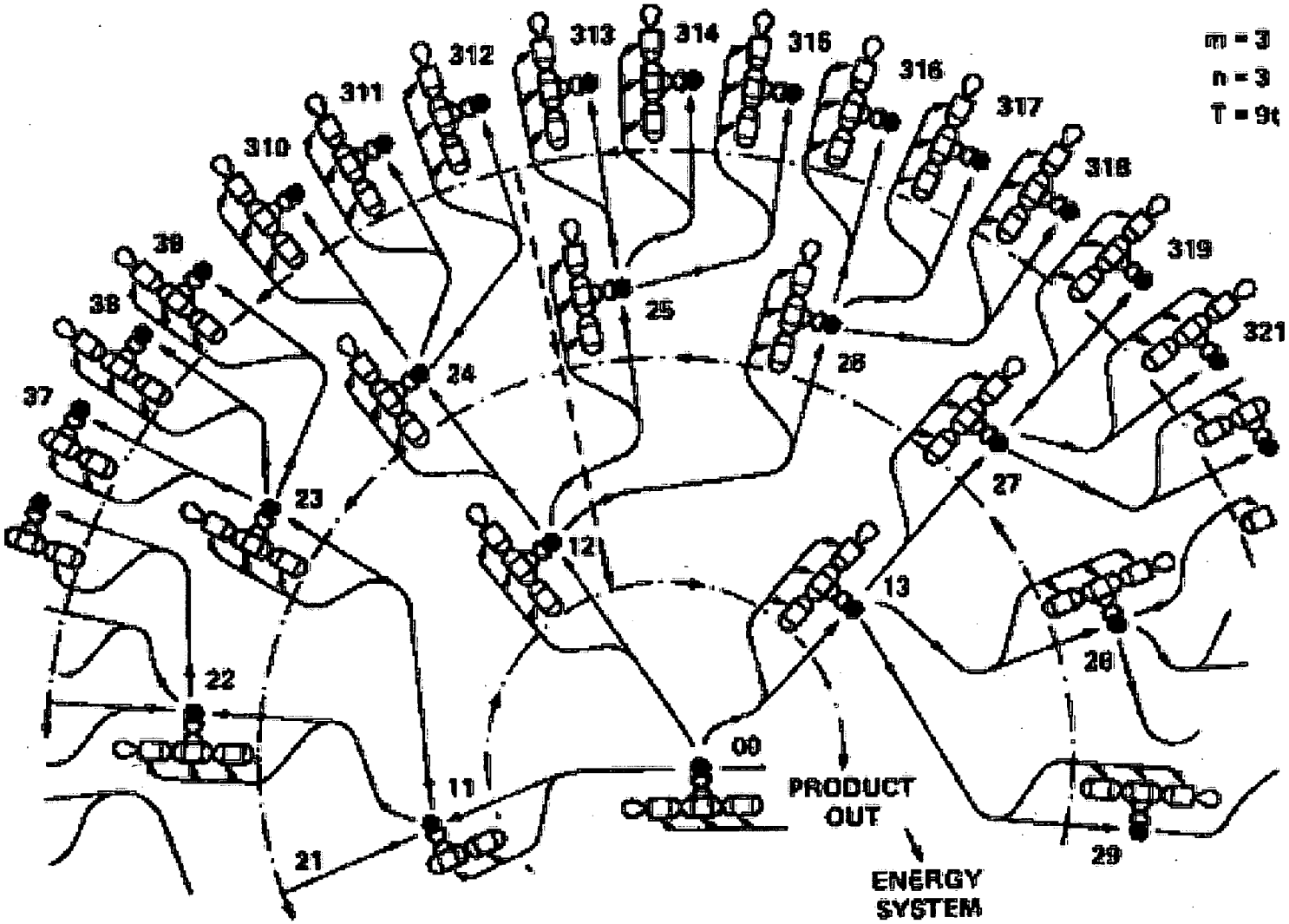
A New Level of Civilization

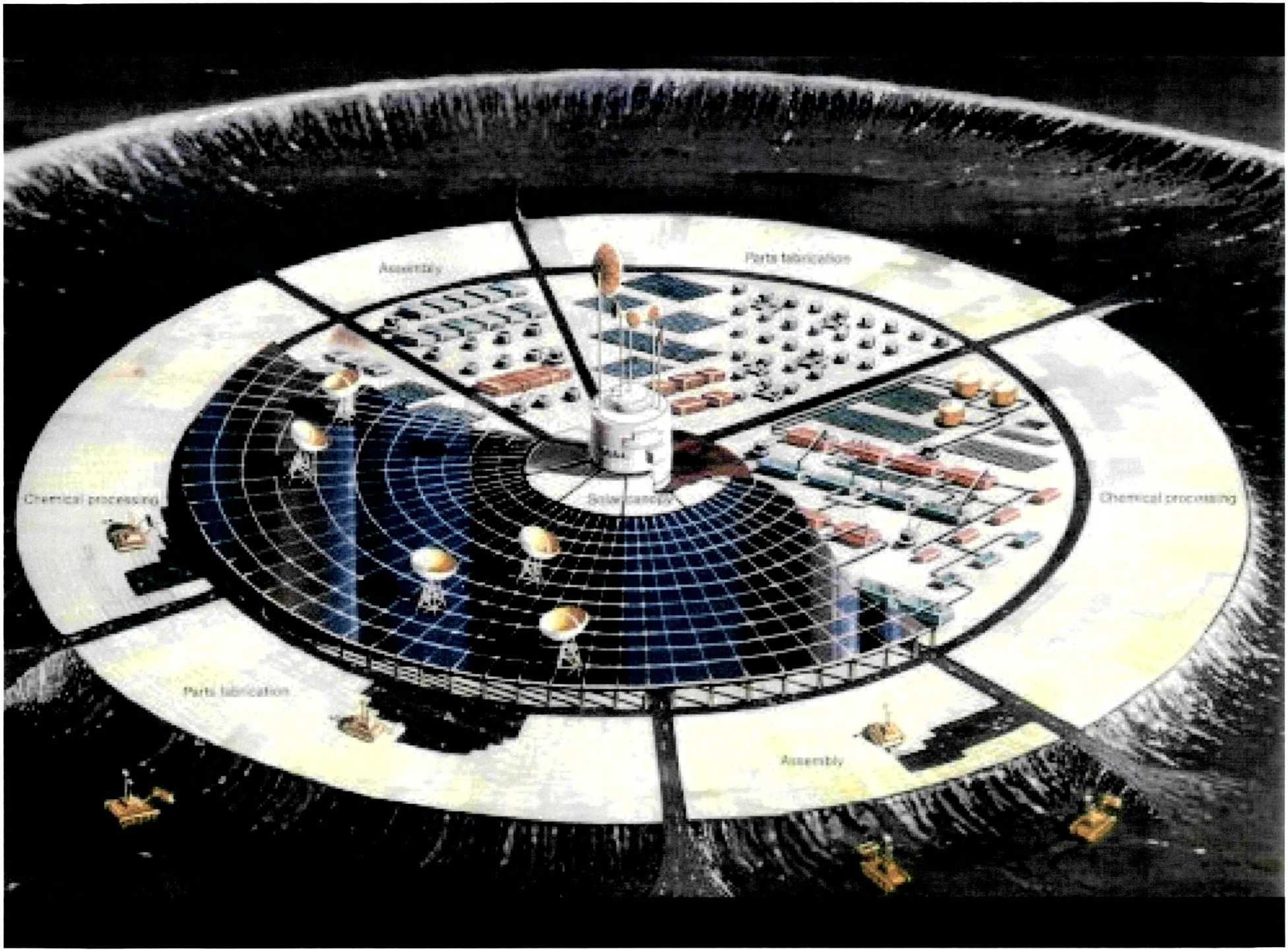






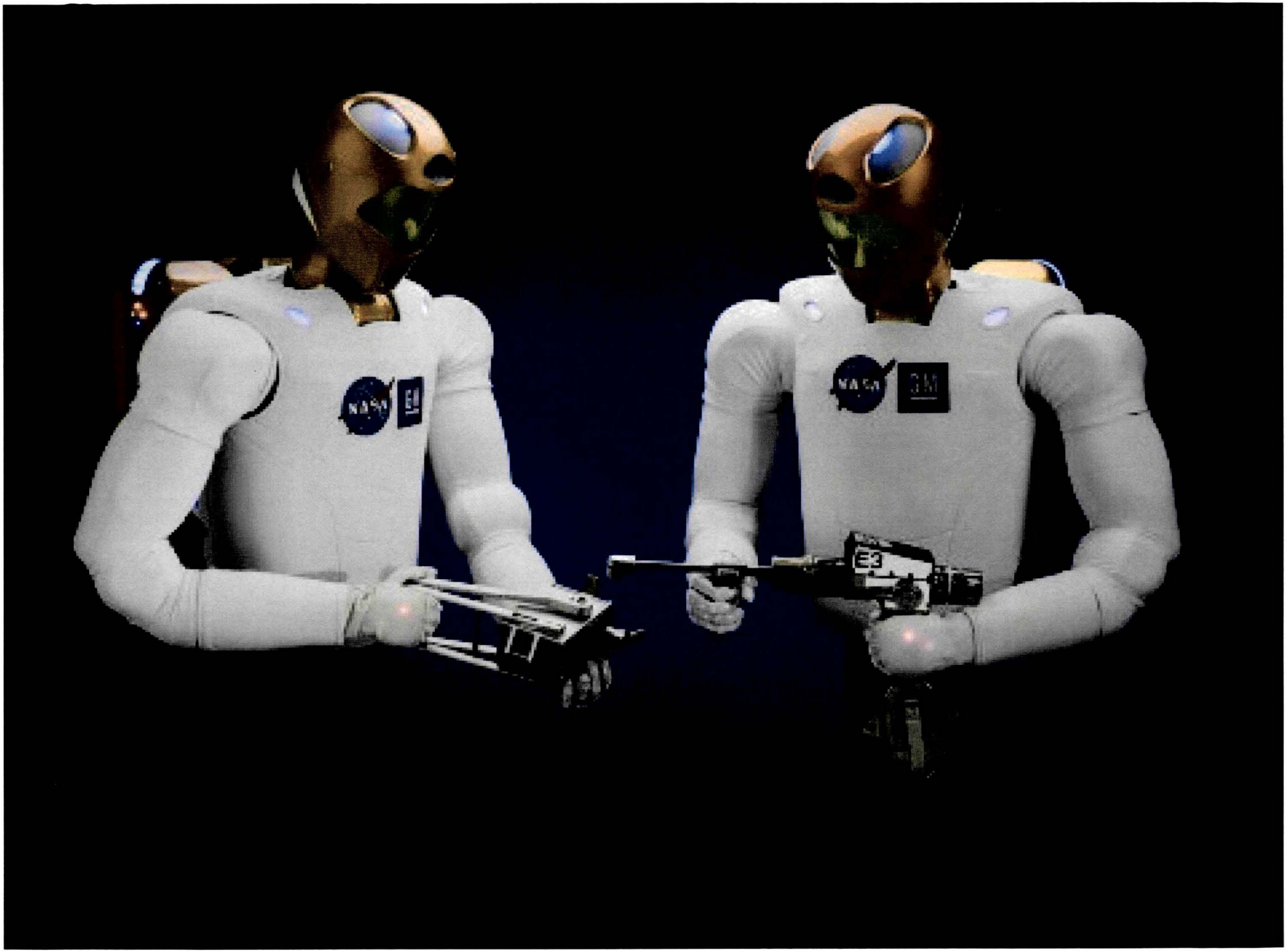



m = 3
n = 3
T = 9t
312
313
314
315
316
317
318
319
321
311
310
39
38
37
25
26
24
23
27
12
13
22
28
00
11
21
29
PRODUCT
OUT
ENERGY
SYSTEM


Assembly
Parts fabrication
Chemical processing
Chemical processing
Parts fabrication
Assembly

But it hasn't happened.....yet

GAME CHANGERS


NASA
NASA

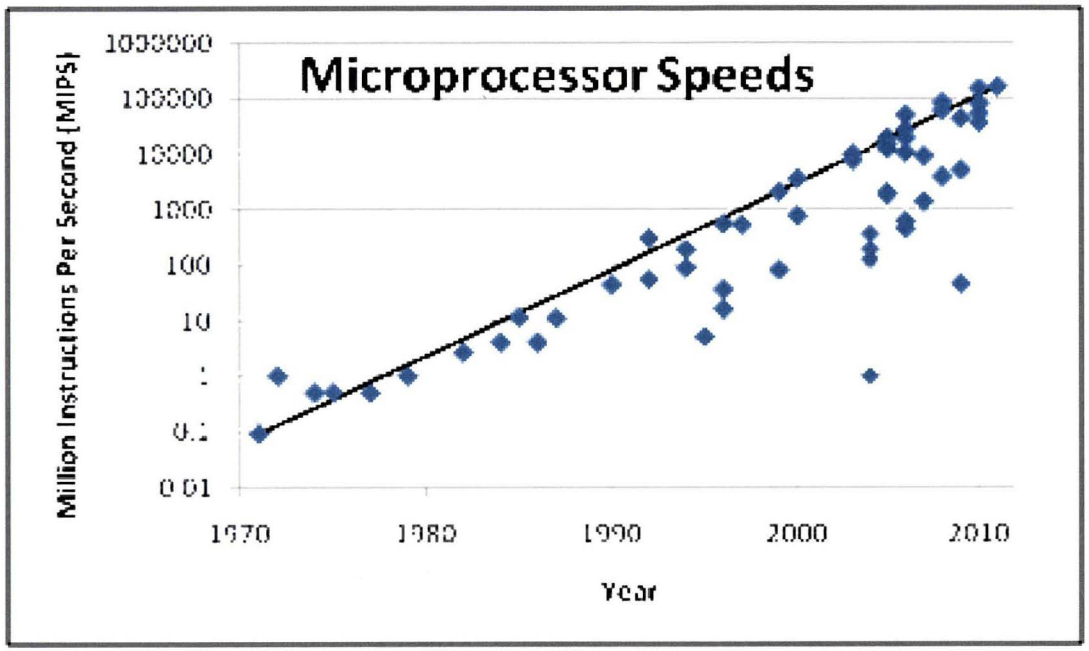
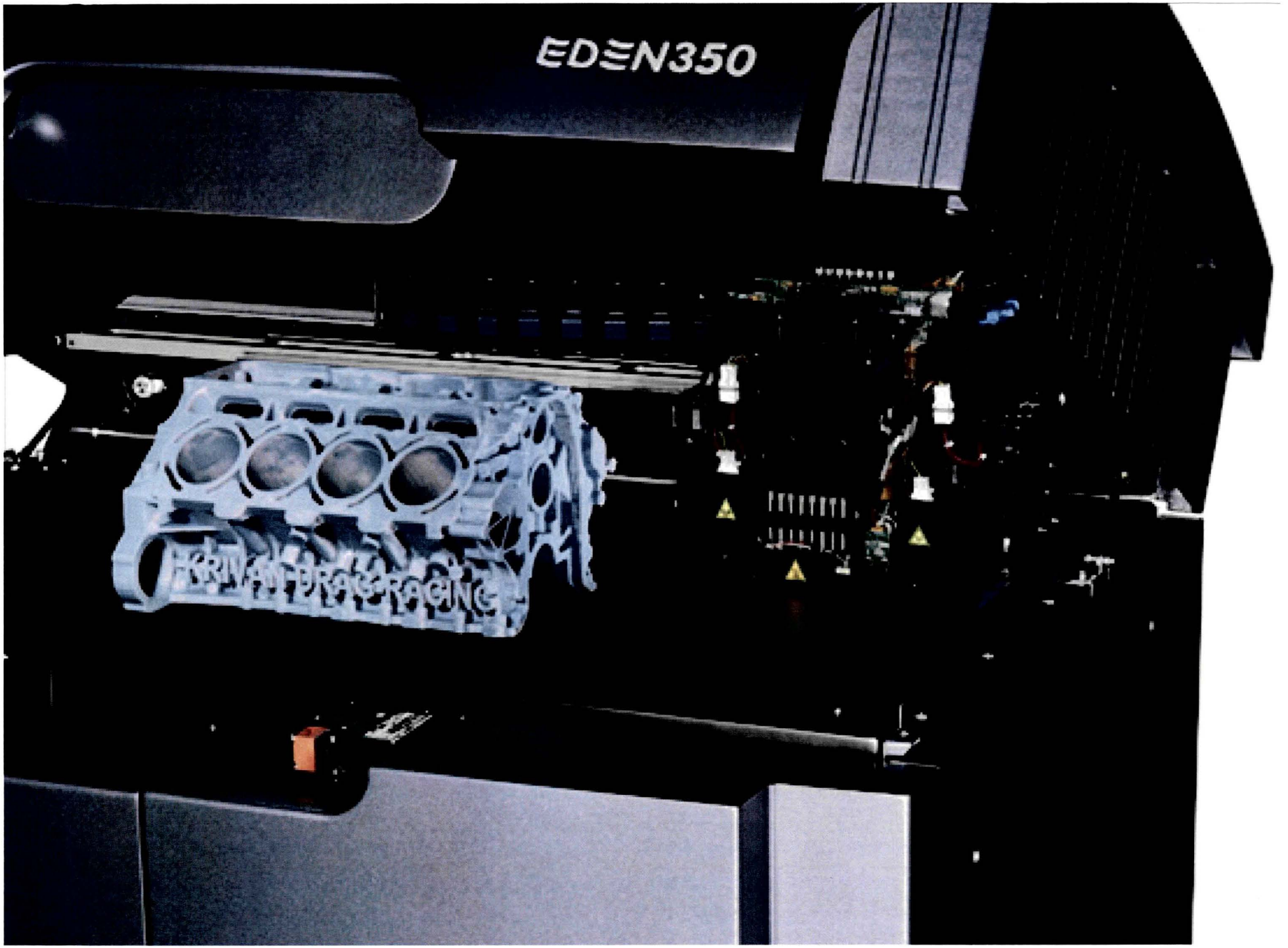
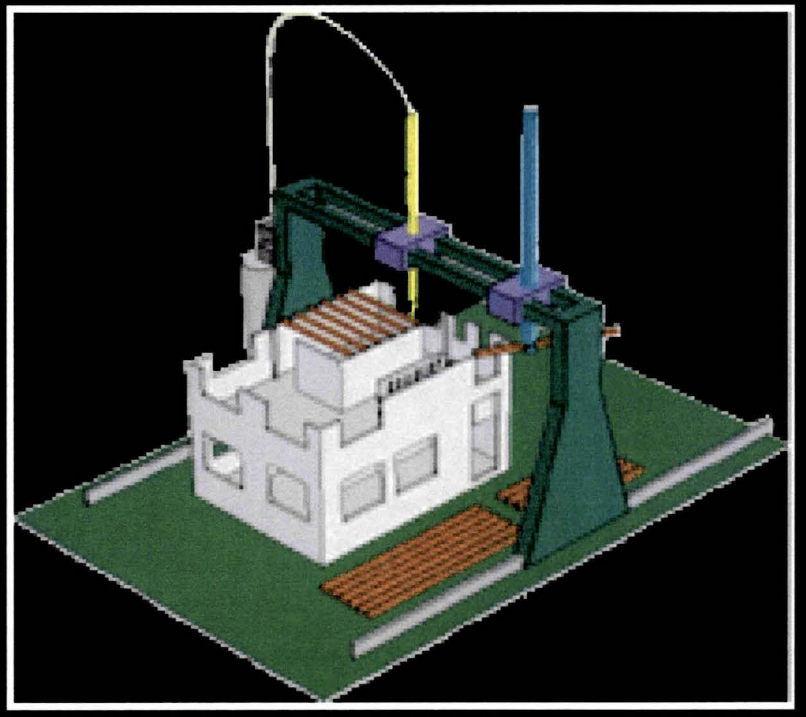
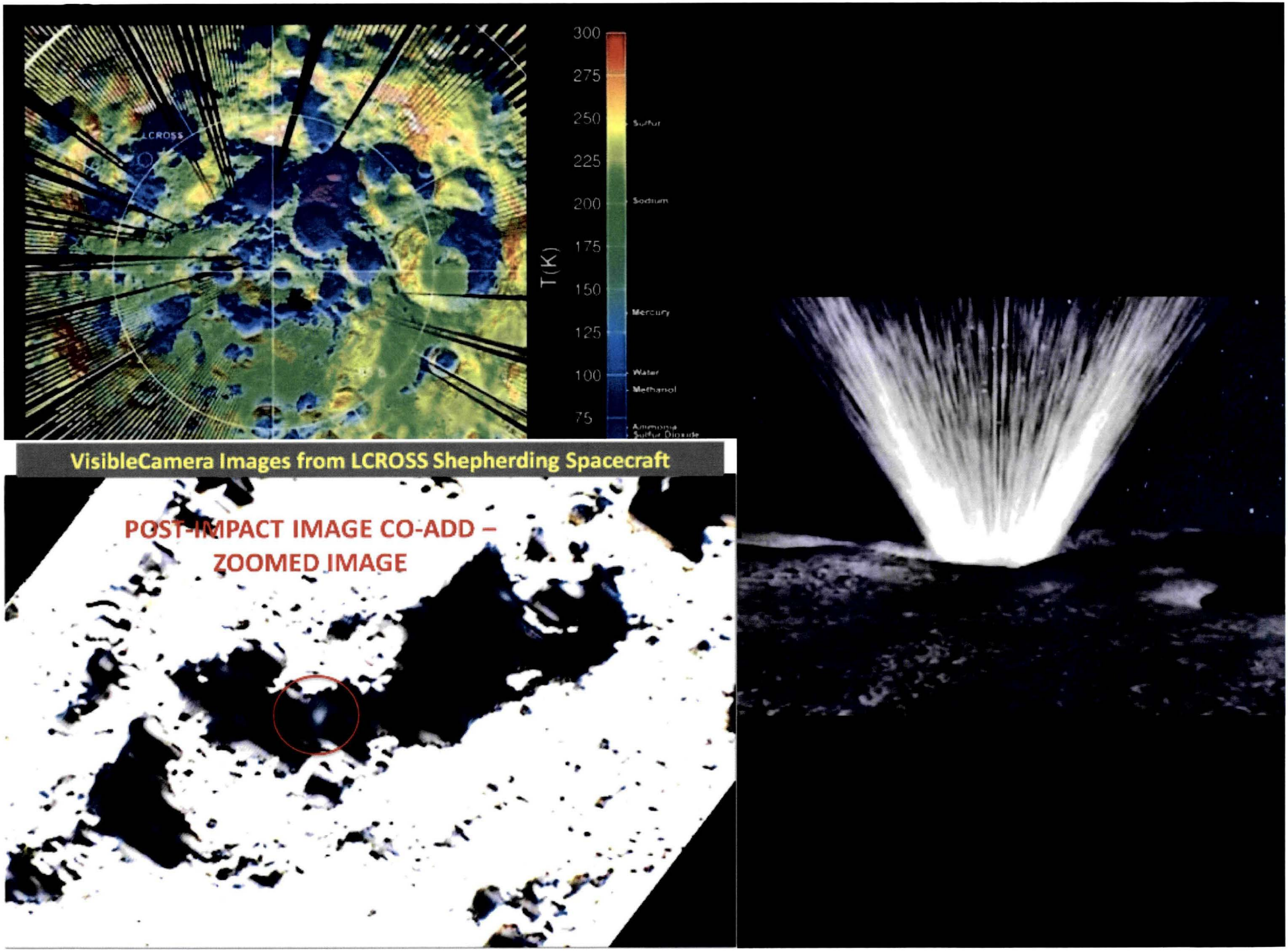


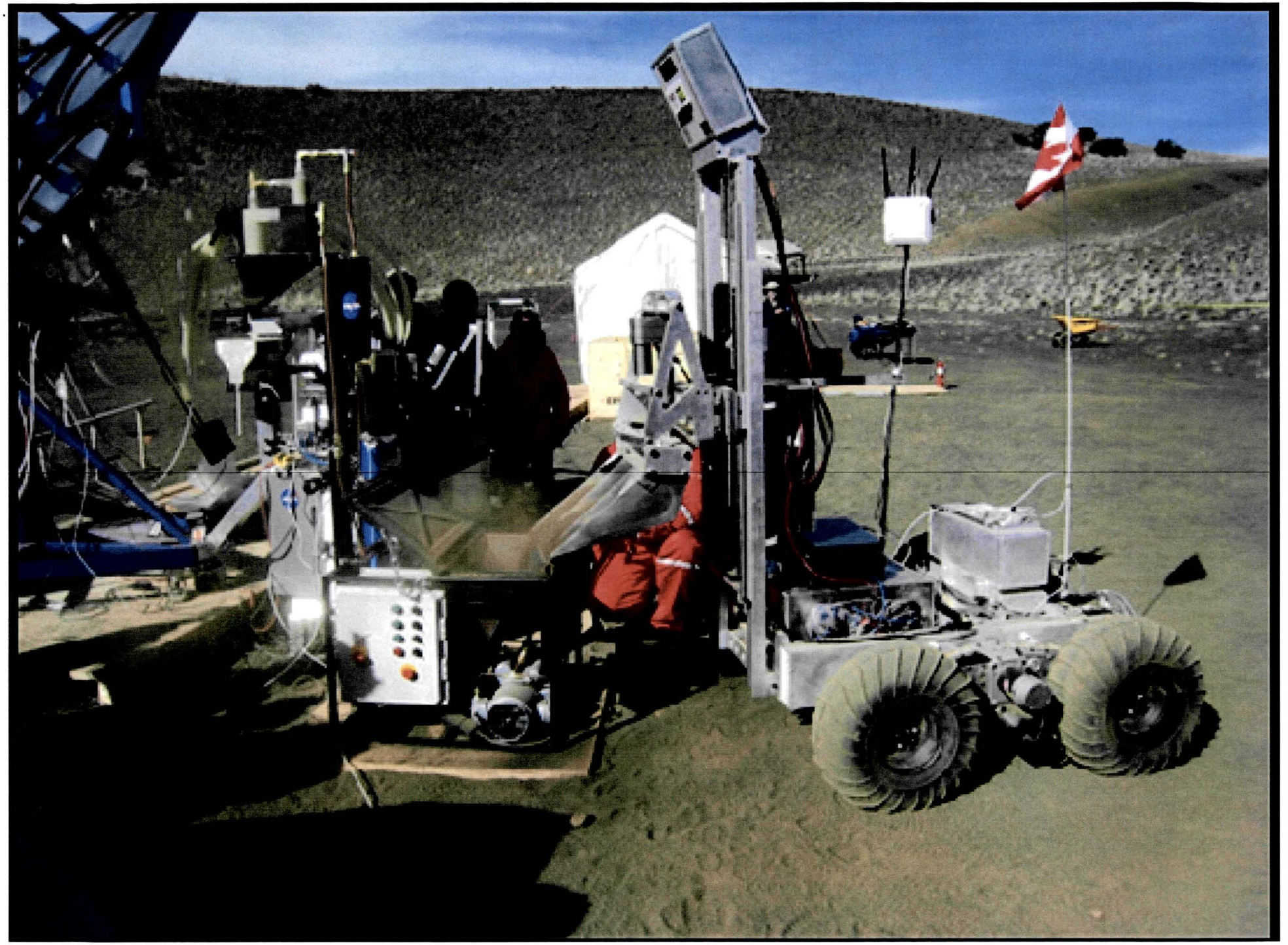
Fig. 1: Progress in Microprocessor Instruction Processing Speeds by Year


EDEN350

Direct Metal Laser Sintering (DMLS)




LCROSS
300
275
250
225
200
175
150
125
100
75
T(K)
Sulfur
Sodium
Mercury
Water
Methanol
Ammonia
Sulfur Dioxide
VisibleCamera Images from LCROSS Shepherding Spacecraft
POST-IMPACT IMAGE CO-ADD –
ZOOMED IMAGE



PROPOSED NEW APPROACH

Key Ideas

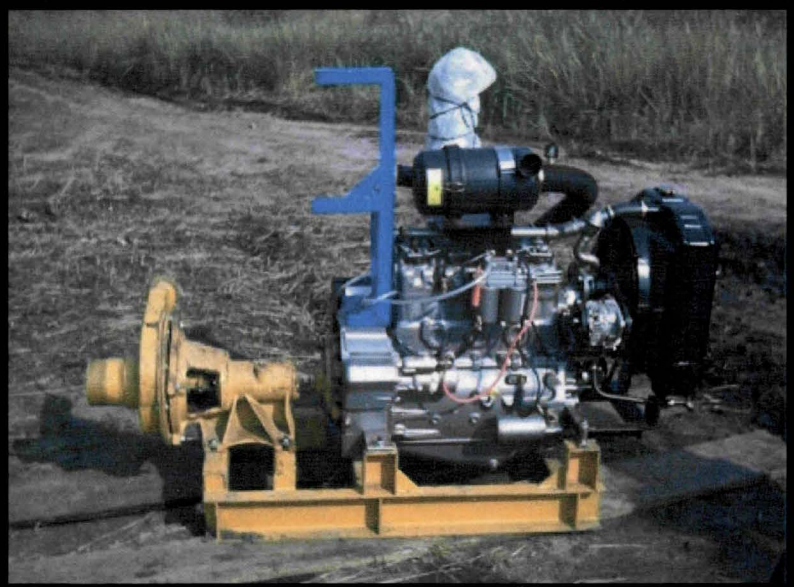
- Don't launch it; evolve it
- Not a simplistic "self-replicator"
  - The biosphere and industry are not self-replicators
- Use "Appropriate Technology" at each step
  - It doesn't need to be low mass or high tech
  - It needs to be easy to make in space
- The technologies are already being developed
  - Simply "spin them in"
- The technologies are advancing exponentially

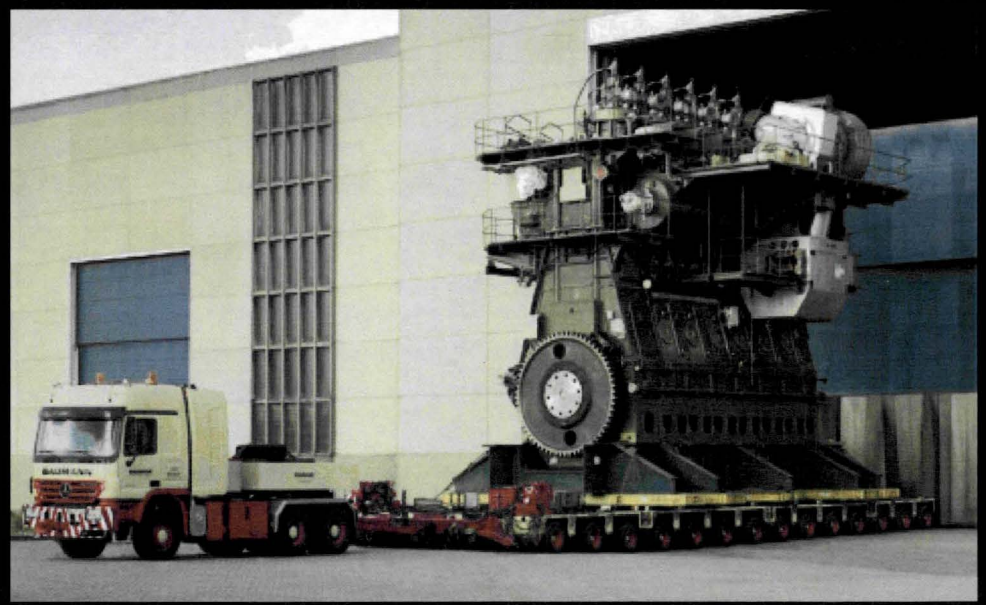
Example of Appropriate Technology

Europe, 1620

America, 1620

Appropriate Technology Water Pumps

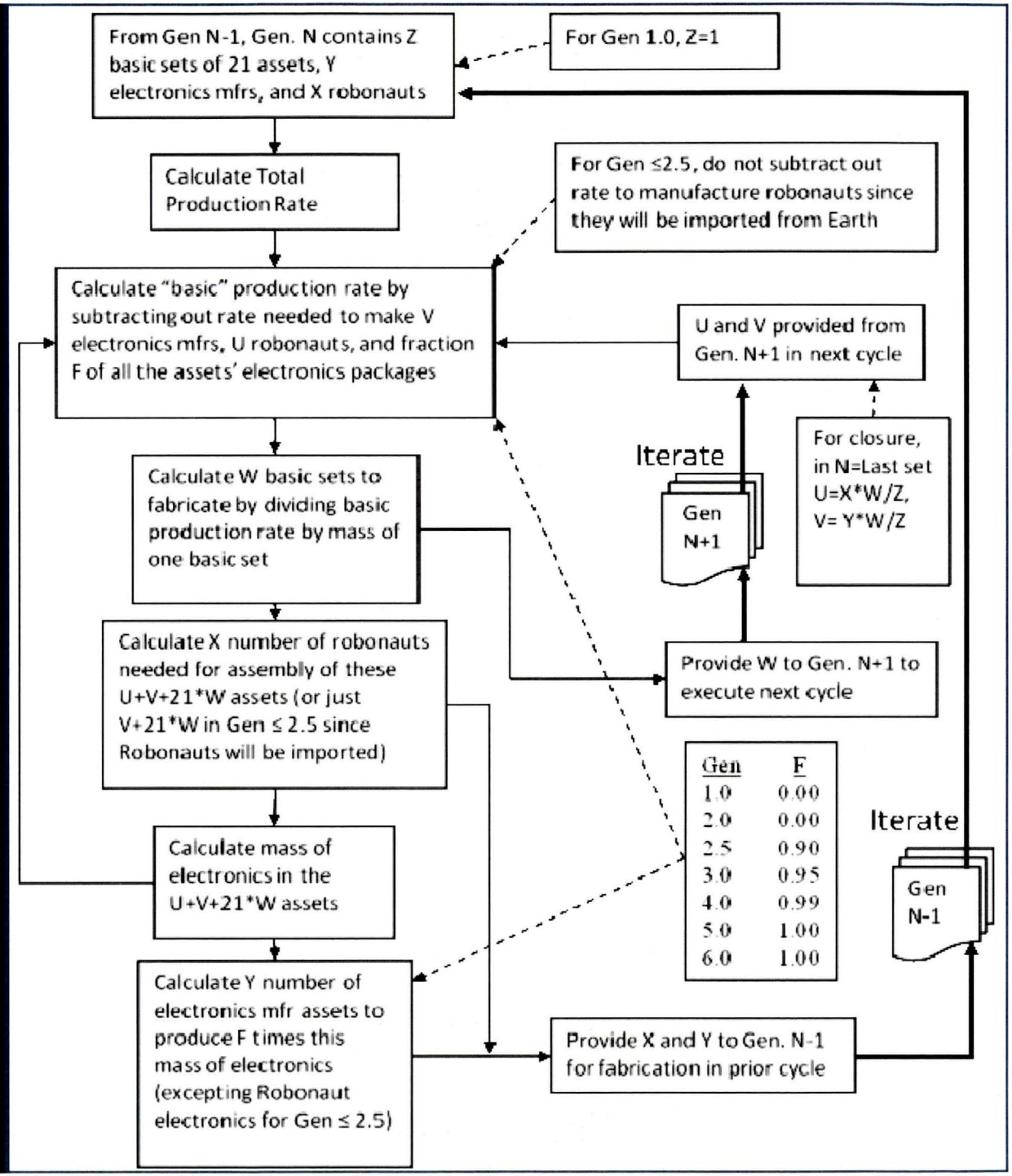




Generations of Space Industry (Notional)

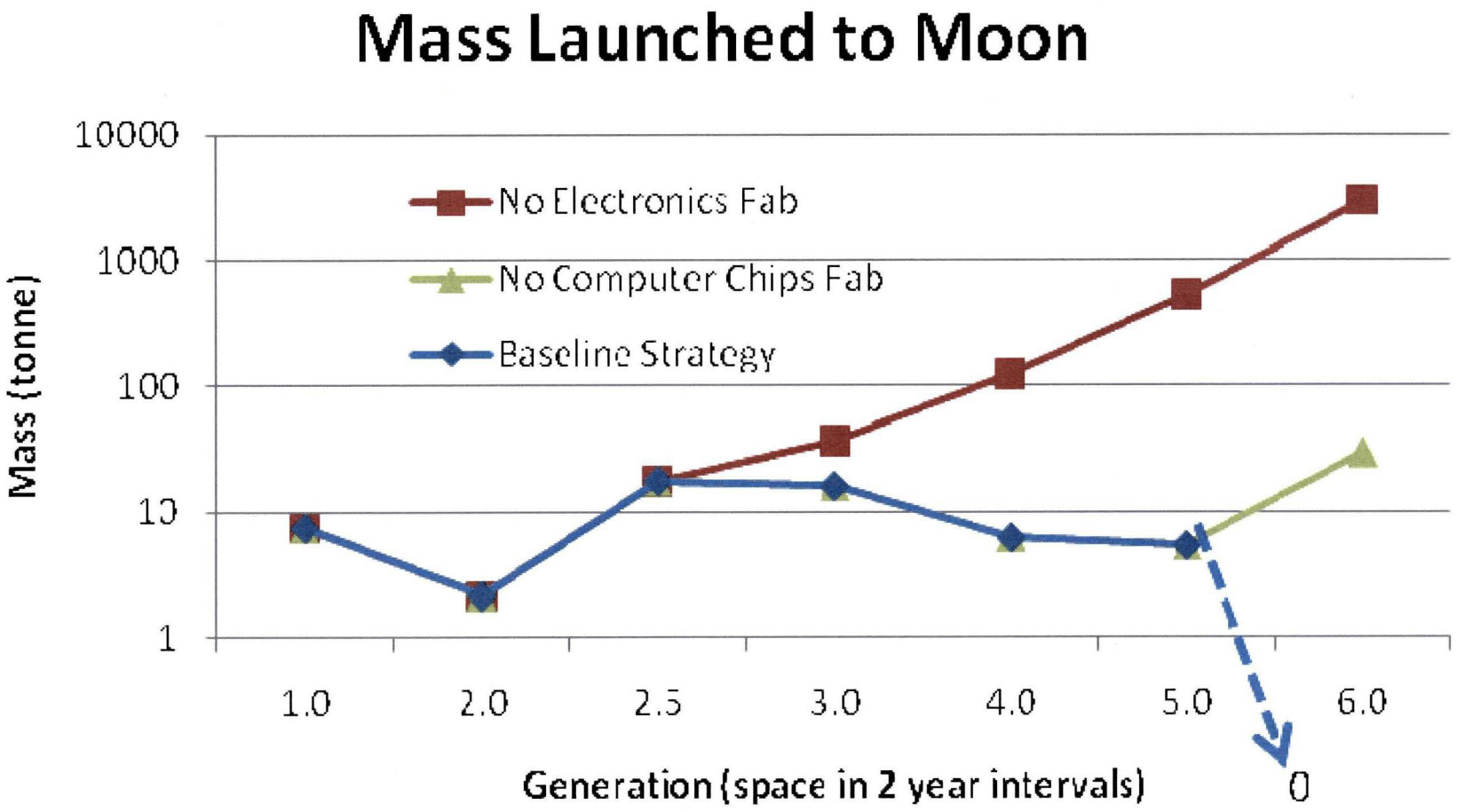
Gen	Human/Robotic Interaction	Artificial Intelligence	Scale of Industry	Materials Manufactured	Source of Electronics
1	Teleoperated and/or locally-operated by a human outpost	Insect-like	Imported, small-scale, limited diversity	Gases, water, crude alloys, ceramics, solar cells	Import fully integrated machines
2	Teleoperated	Lizard-like	Crude fabrication, inefficient, but greater throughput than 1.0	(Same)	Import electronics boxes
2.5	Teleoperated	Lizard-like	Diversifying processes, especially volatiles and metals	Plastics, rubbers, some chemicals	Fabricate crude components plus import electronics boxes
3	Teleoperated with experiments in autonomy	Lizard-like	Larger, more complex processing plants	Diversify chemicals, Simple fabrics, eventually polymers.	Locally build PC cards, chassis and simple components, but import the chips
4	Closely supervised autonomy with some teleoperation	Mouse-like	Large plants for chemicals, fabrics, metals	Sandwiched and other advanced material processes	Building large assets such as lithography machines
5	Loosely supervised autonomy	Mouse-like	Labs and factories for electronics and robotics. Shipyards to support main belt	Large scale production	Make chips locally. Make bots in situ for export to asteroid belt
6	Nearly full autonomy	Monkey-like	Large-scale, self-supporting industry, exporting industry to asteroid main belt	Makes all necessary materials, increasing sophistication	Makes everything locally, increasing sophistication
X.0	Autonomous robotics pervasive throughout solar system enabling human presence	Human-like	Robust exports/imports through zones of solar system	Material factories specialized by zone of the solar system	Electronics factories in various locations

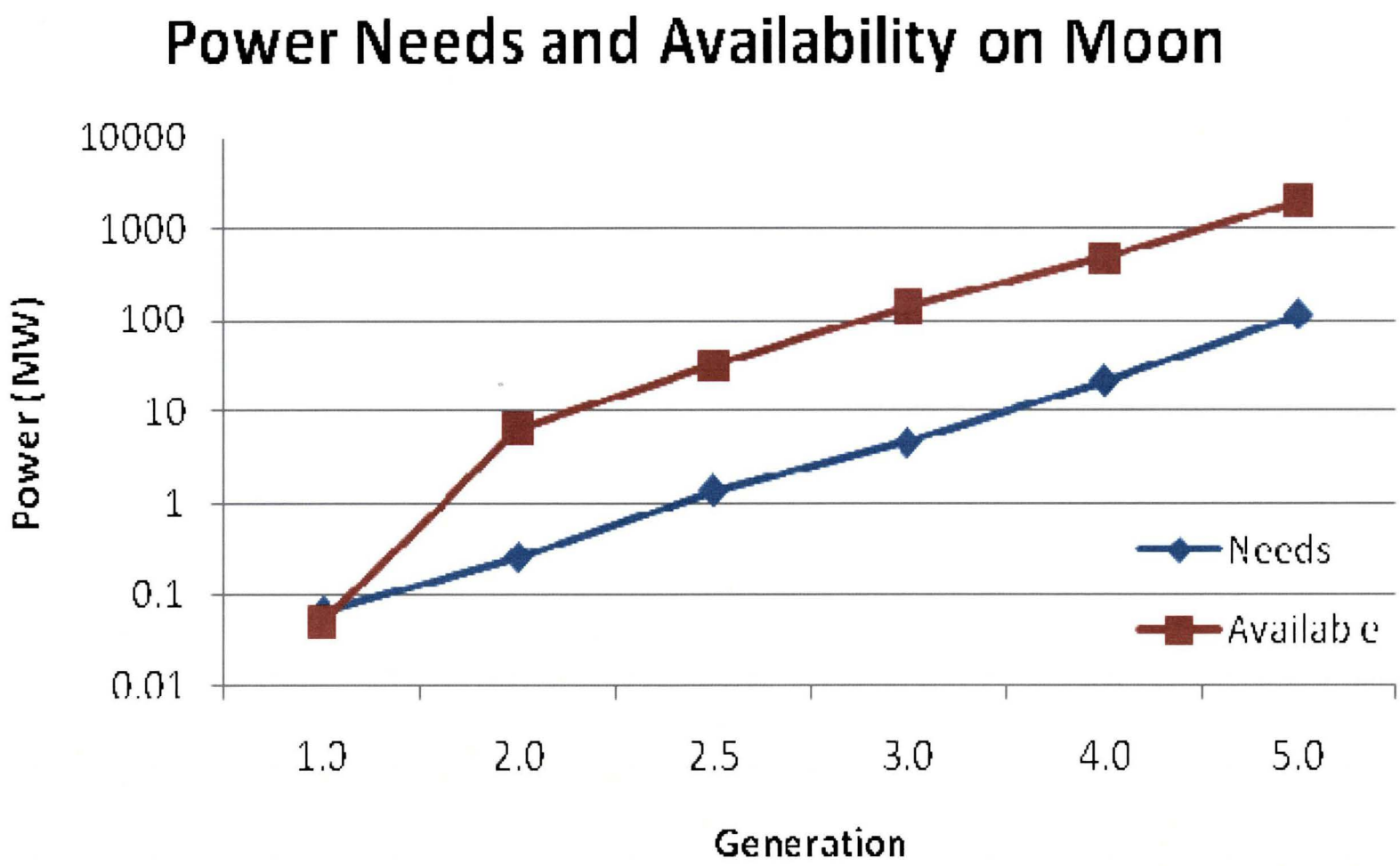
- **Simplistic Modeling**
- Not intended to be definitive
- Explores some of the key parameters
- Attempt to demonstrate basic feasibility
- Intends to generate interest and further investigation
- Needs a much larger study with a much larger group of contributors

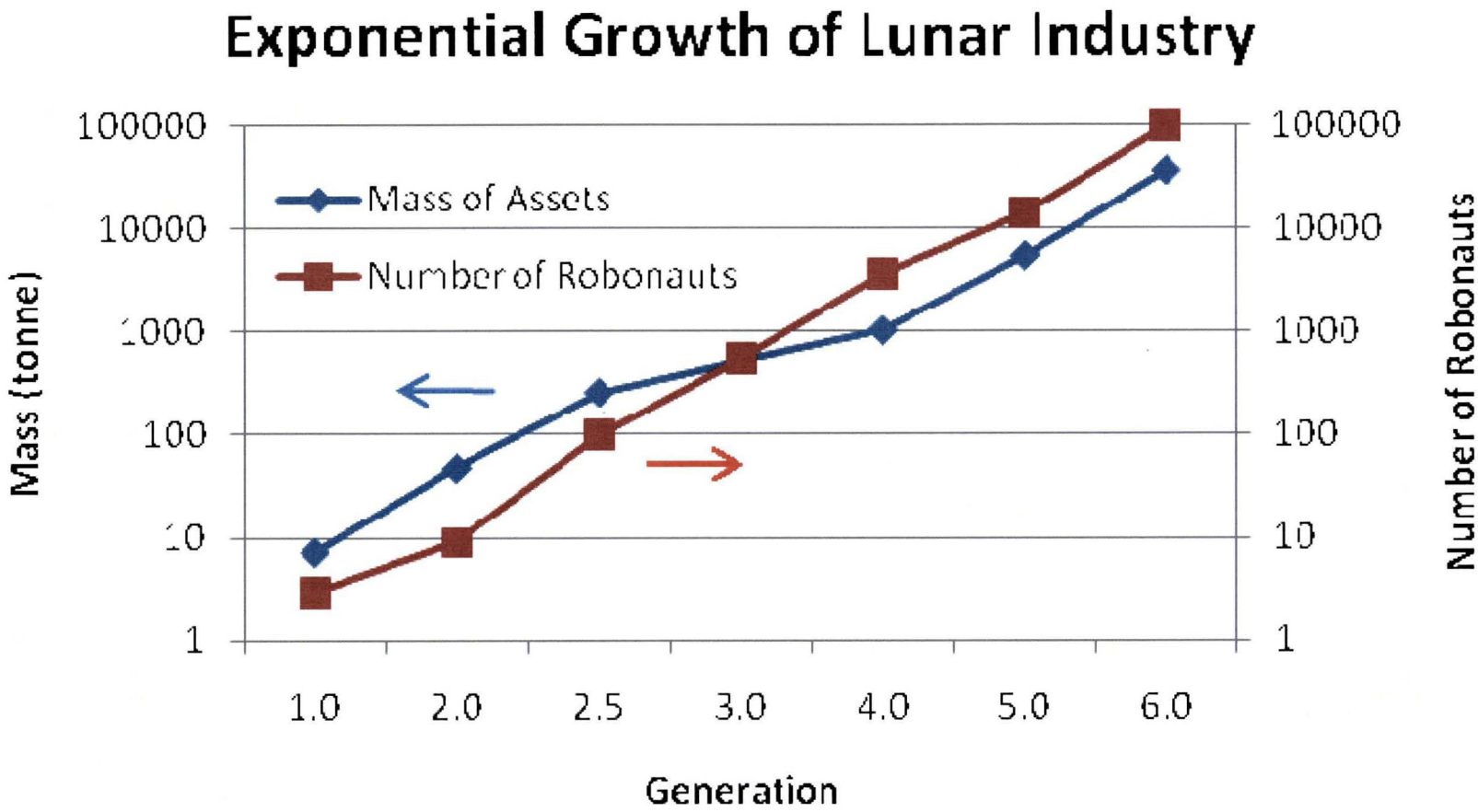


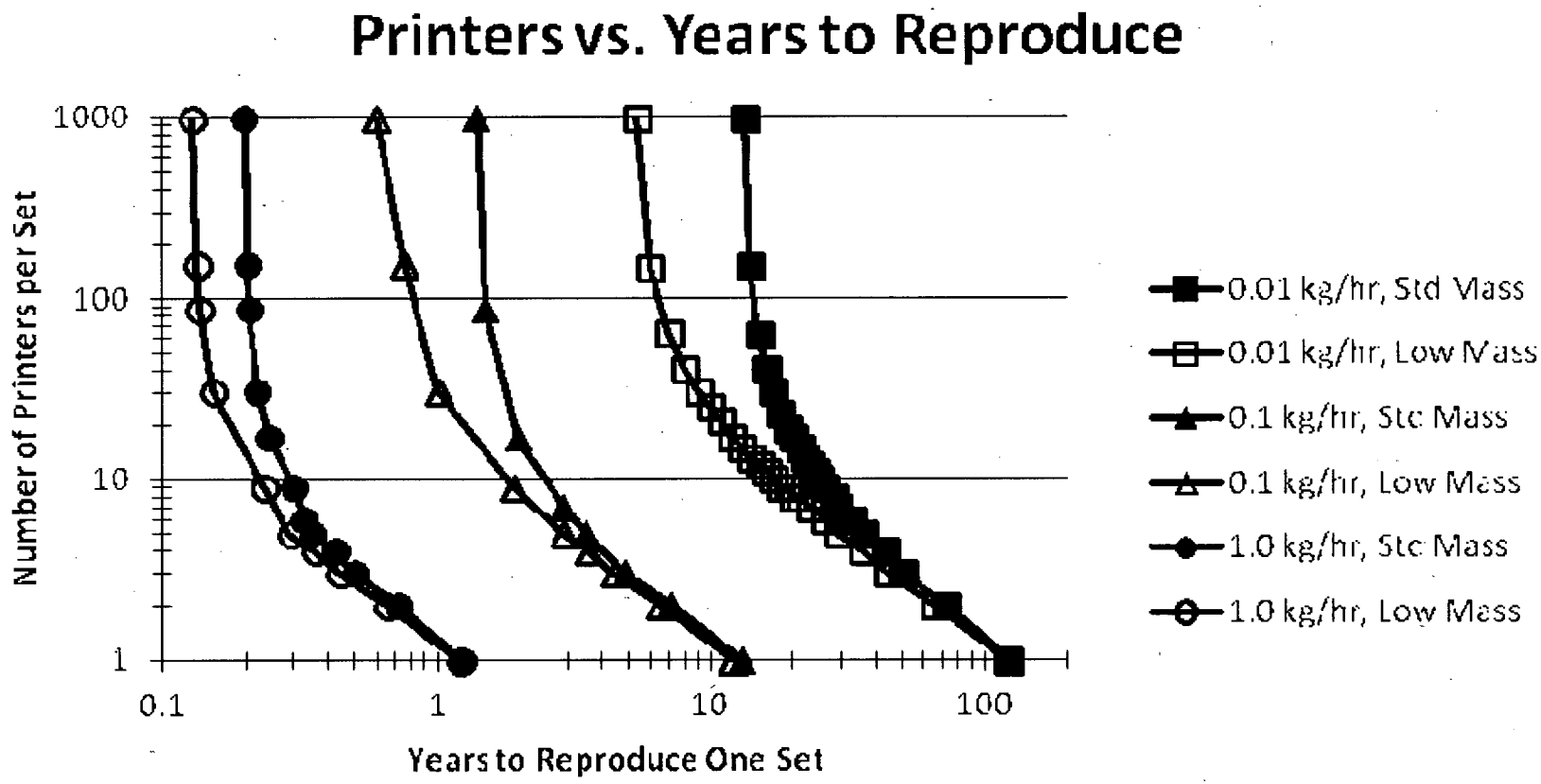
Additional Production

- Gen 3.0
  - 80 MT construction equipment
- Gen 4.0
  - Dust Free Laboratory Facilities
- Gen 5.0
  - 120 MT materials stockpiled to send industry to asteroid main belt
- Gen 6.0
  - Fleet of 6 spacecraft (20 MT plus 12 MT payload, each plus propellants)
  - Takes industry to Main Belt

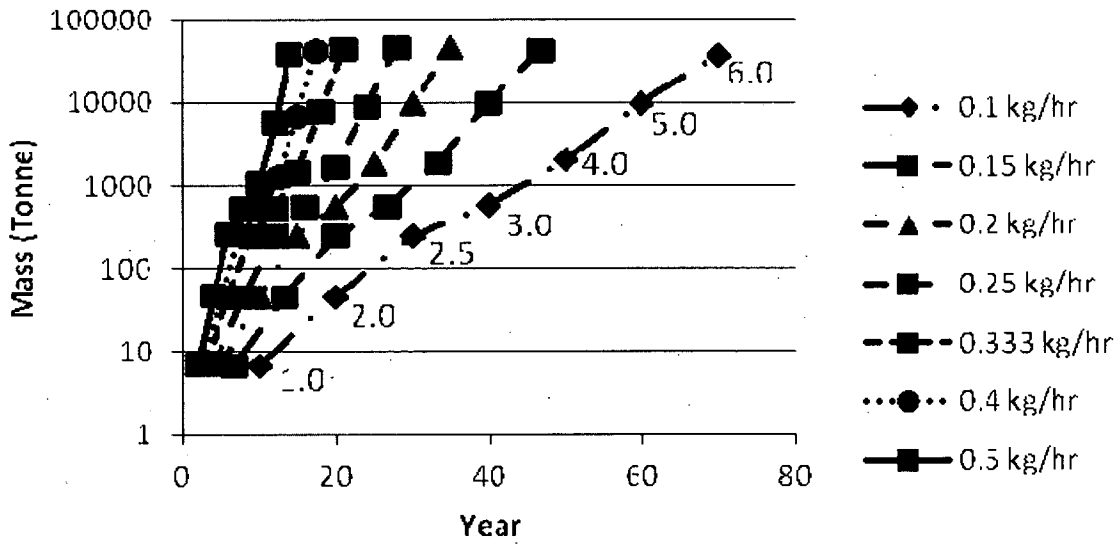

Mass Launched to Moon
10000
1000
100
10
1
Mass (tonne)
No Electronics Fab
No Computer Chips Fab
Baseline Strategy
1.0
2.0
2.5
3.0
4.0
5.0
6.0
0
Generation (space in 2 year intervals)


Power Needs and Availability on Moon
10000
1000
100
10
1
0.1
0.01
Power (MW)
Needs
Availab e
1.0
2.0
2.5
3.0
4.0
5.0
Generation

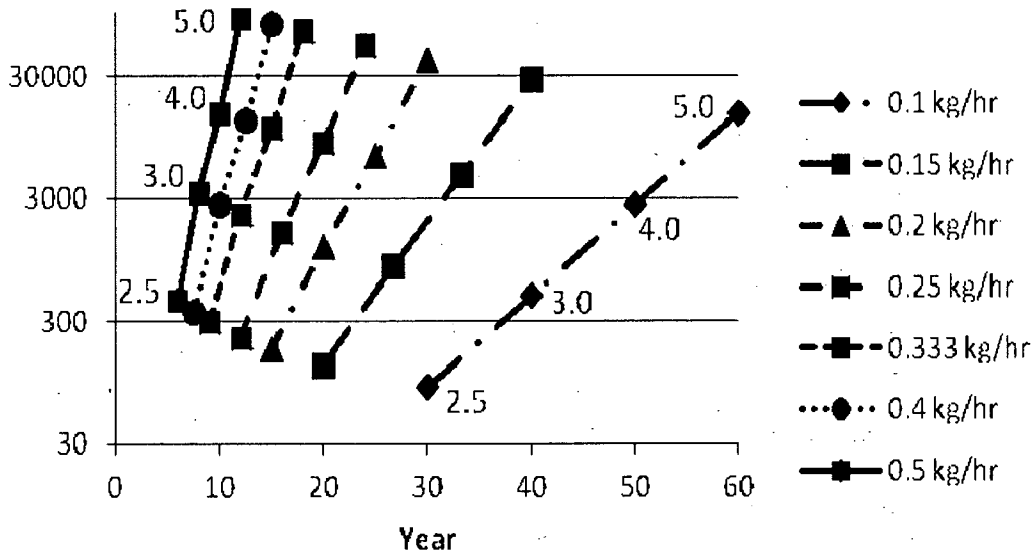

Exponential Growth of Lunar Industry
100000
10000
1000
100
10
1
Mass (tonne)
Mass of Assets
Number of Robonauts
100000
10000
1000
100
10
1
Number of Robonauts
1.0
2.0
2.5
3.0
4.0
5.0
6.0
Generation


Printers vs. Years to Reproduce
Number of Printers per Set
1000
100
10
1
0.1
1
10
100
Years to Reproduce One Set
0.01 kg/hr, Std Mass
0.01 kg/hr, Low Mass
0.1 kg/hr, Std Mass
0.1 kg/hr, Low Mass
1.0 kg/hr, Std Mass
1.0 kg/hr, Low Mass

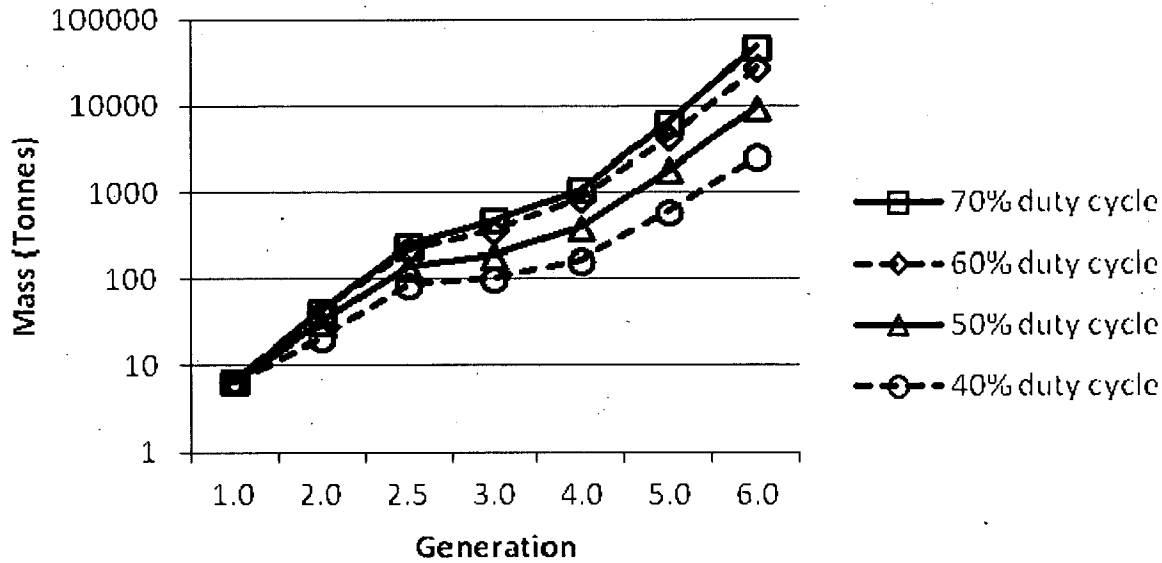
Mass of Assets



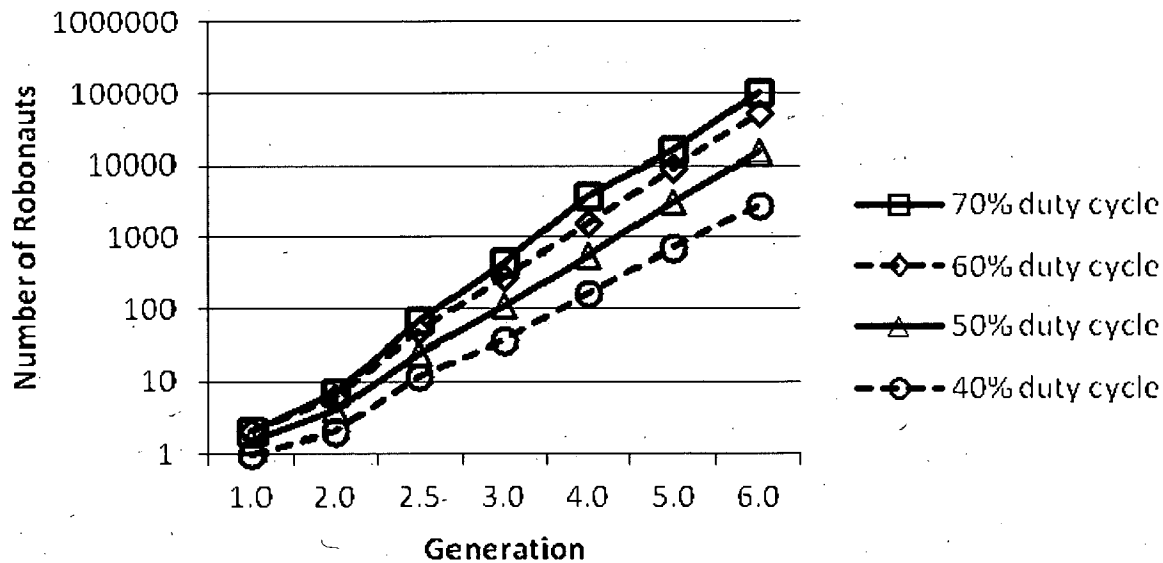
Number of Robonauts Made



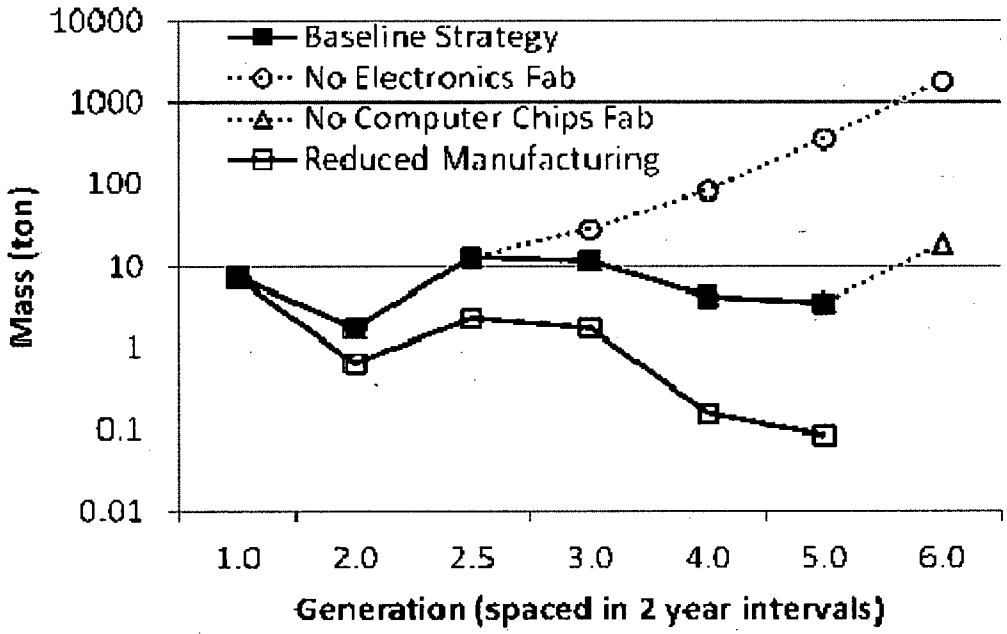
Mass of Assets on Moon

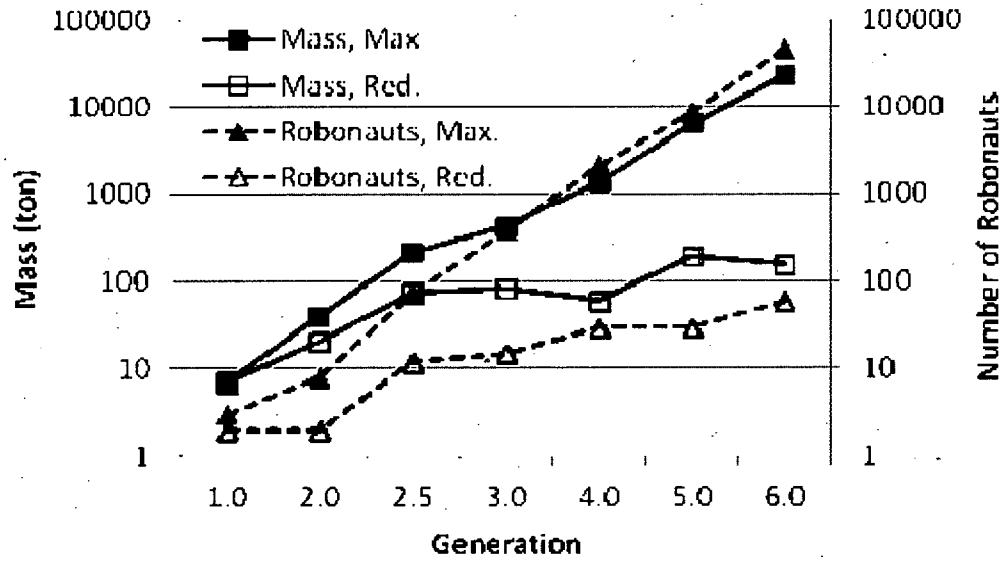


Robonauts on Moon



Minimizing Launch Mass





Scenarios

- Global Relief Effort
- The Great Migration
- The Foundation
- The Space Endowment
- Anti Virus
- National Defense

The Robosphere

- Like an Ecosphere
- Like a living cell
- Beautifies the solar system
- Allows us to live at the top of a food chain
- Enables us to do great things
  - Terraforming, colonies
  - Science, arts
  - Interstellar travel

Cost/Benefit

- Cost:
  - Develop and launch 12 to 60 tons to Moon and operate it for 20 years
  - Launch costs will be negligible using newer capabilities
  - Comparing to cost and mass of ISS, this will be less expensive than ISS
    - Most mass will be redundant hardware, not unique items
- Benefit
  - Move from being a Type-1 to a Type-2 civilization
    - Solve world economic problems
    - Make our existence safe in the solar system
    - Brilliant possibilities for the future
  - Move toward a Type-3 civilization
    - Extend human presence through the Milky Way