

FUTURE OF SPACE TRAVEL



Chris Impey

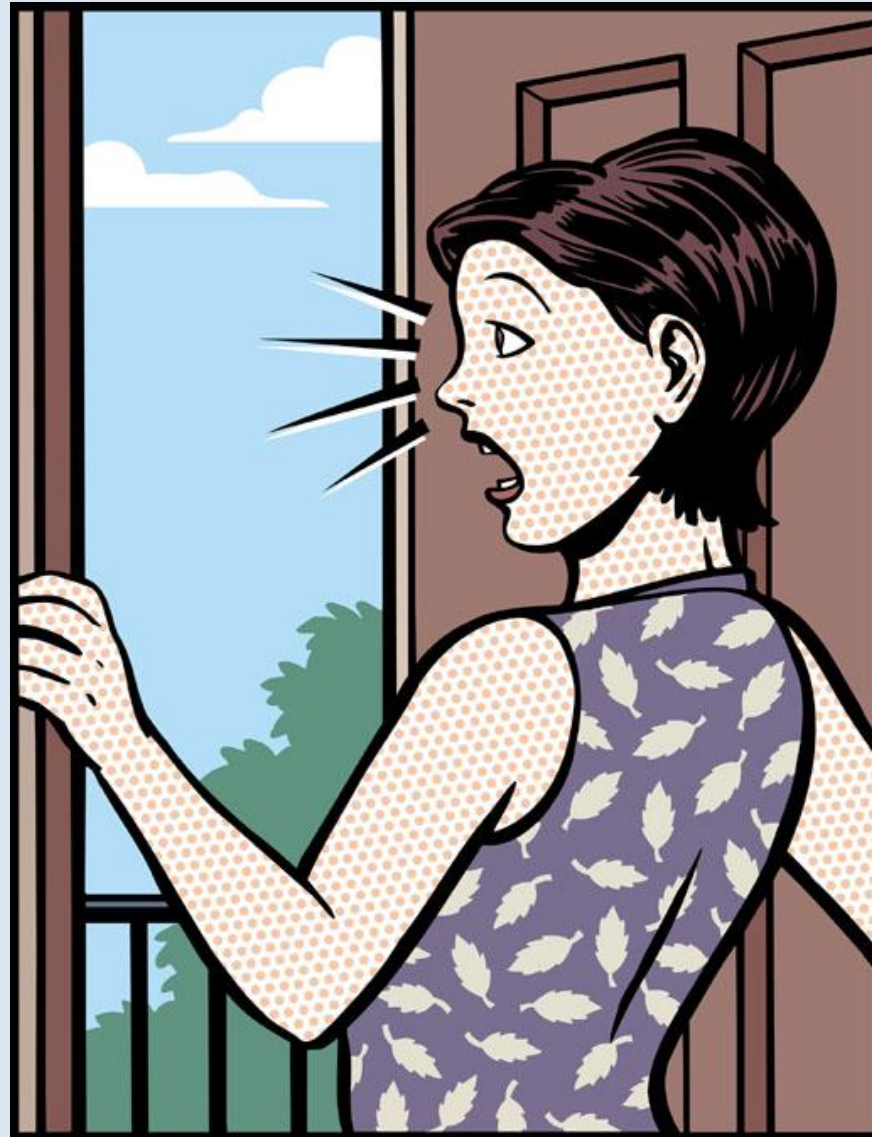
BEYOND

A person in a white space suit with a blue visor and a life-support backpack stands in a doorway. The doorway is set into a metallic wall. Above the doorway is a small yellow and grey arrow pointing up and down. The view through the doorway is a black space filled with white stars and a few faint nebulae. The text 'OUR FUTURE IN SPACE' is overlaid on this space scene in yellow capital letters.

OUR
FUTURE
IN
SPACE

CHRIS IMPEY

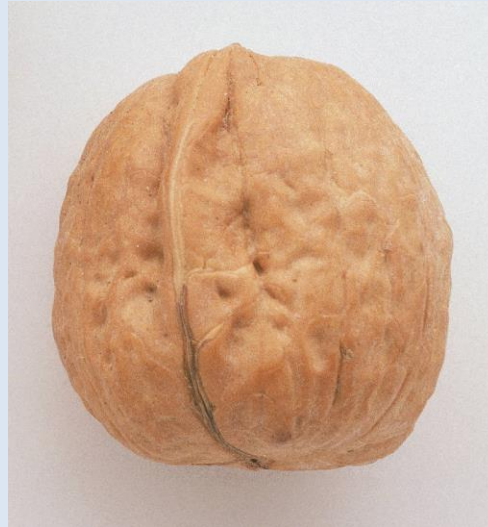
Space is Big



A Scale Model



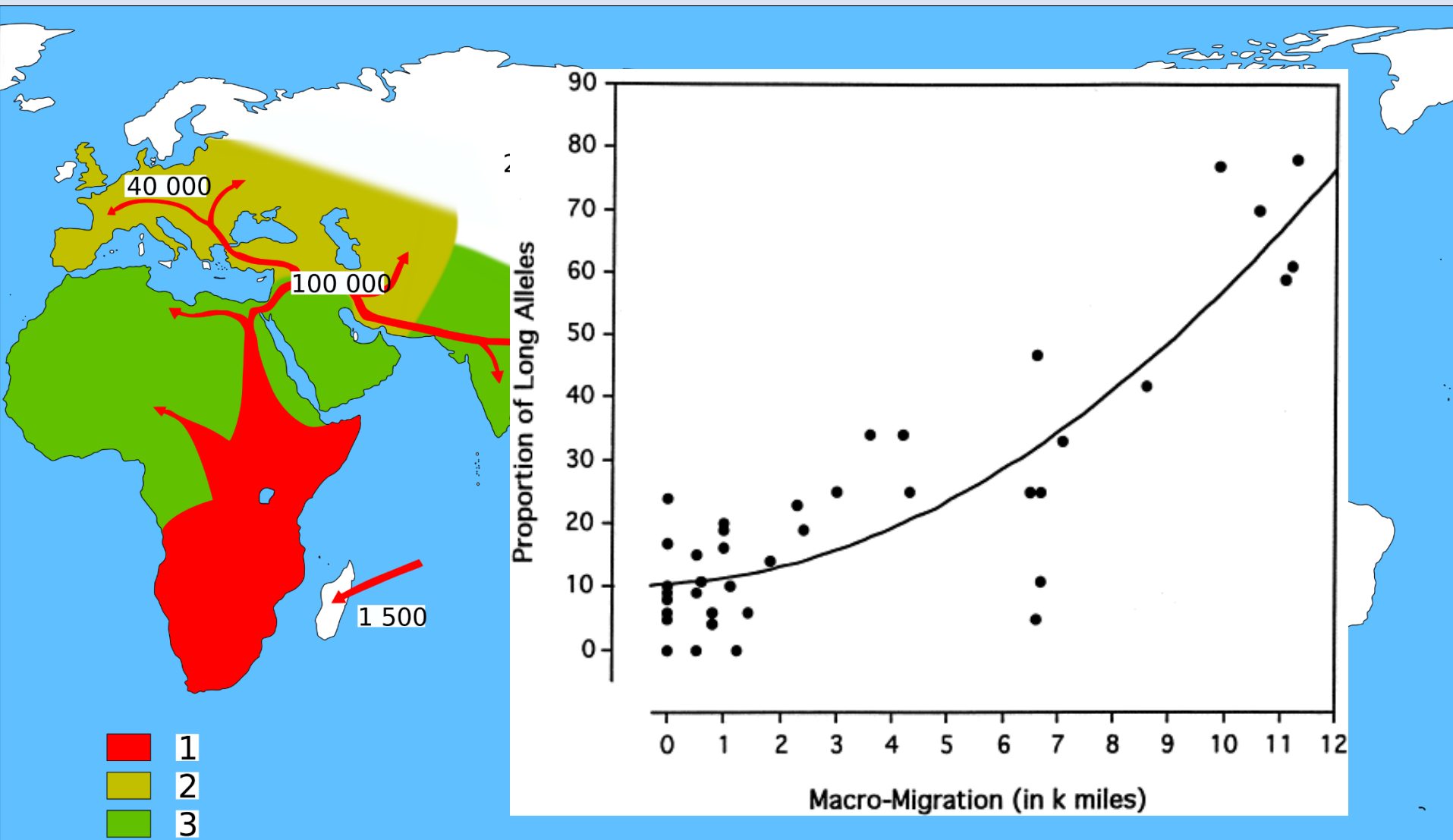
=



Set the Earth
to the size of
a walnut, or a
1:10,000,000
scale model

- The Moon is a pea at arm's length
- The Sun is a 3 m ball 100 m away
- Neptune is another pea 2 km away
- The nearest star is 50,000 km away

Early History





Wan Hu (~1550)



Robert Goddard (1926)



Miss Baker (1959)



Yuri Gagarin (1961)

Leonov Space Walk

Leonov Space Walk

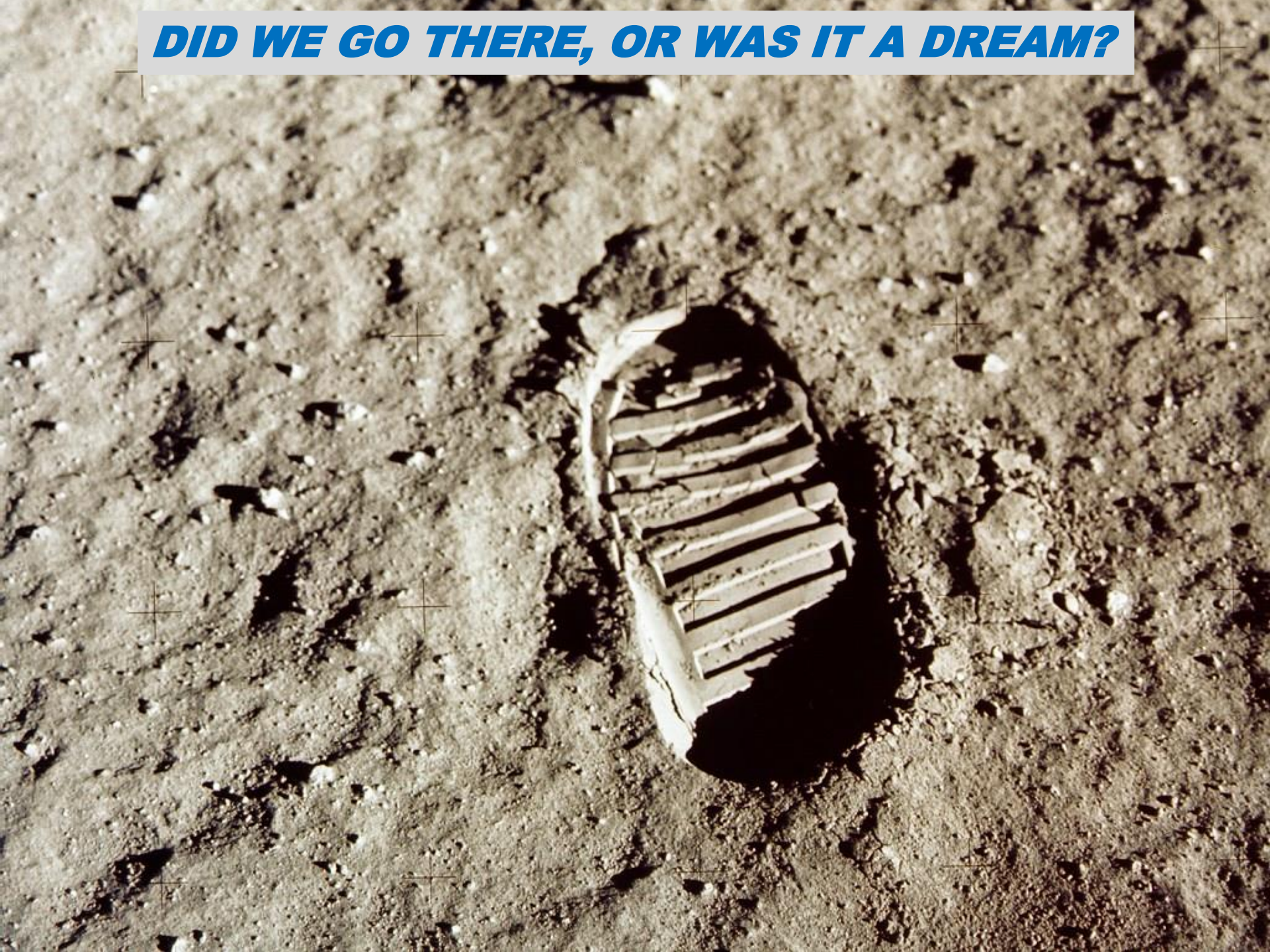


Apollo 13

Apollo 13



DID WE GO THERE, OR WAS IT A DREAM?



Flag



Apollo 17 Lunar Module
Challenger Descent Stage
LROC NAC 4x Enlargement
M109032389LE

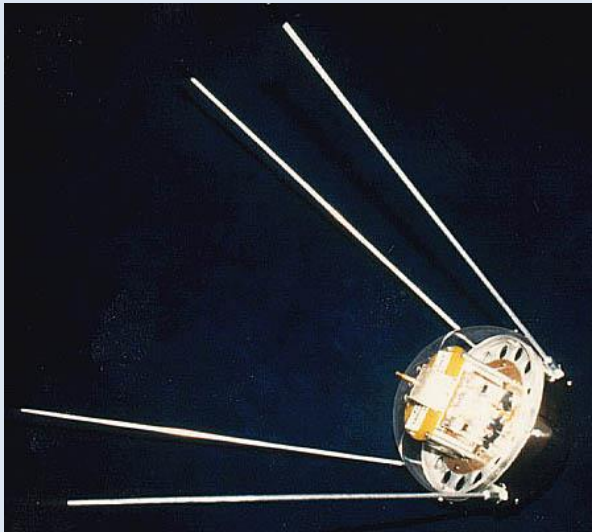
Buzz Aldrin's Payback

Buzz Aldrin's Payback





The State of Space



The space age is a little over 55 years old. The activity has mostly been the work of 2 countries, often driven by military or geopolitical motives.



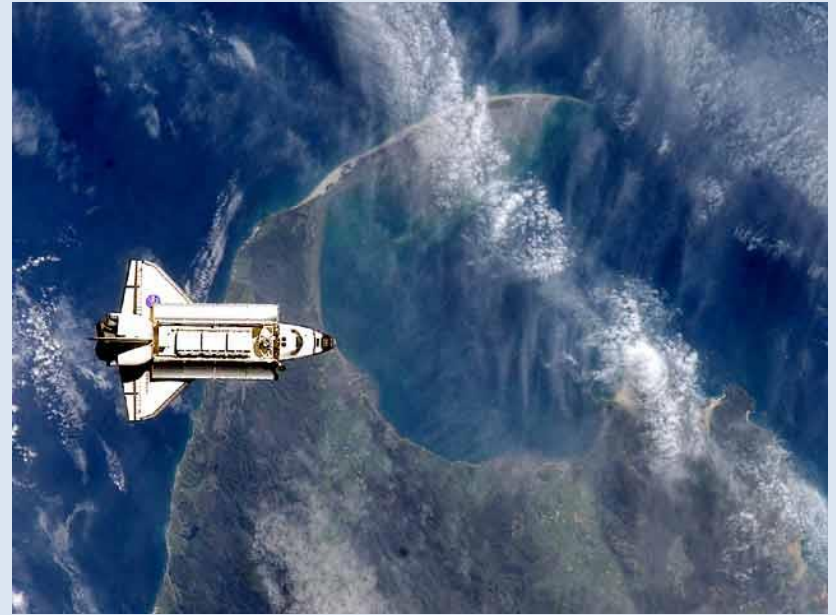
About 560 people have been in orbit. A dozen have set foot on the Moon and it is 40+ years since we have been there. Space travel is very exciting and very dangerous.



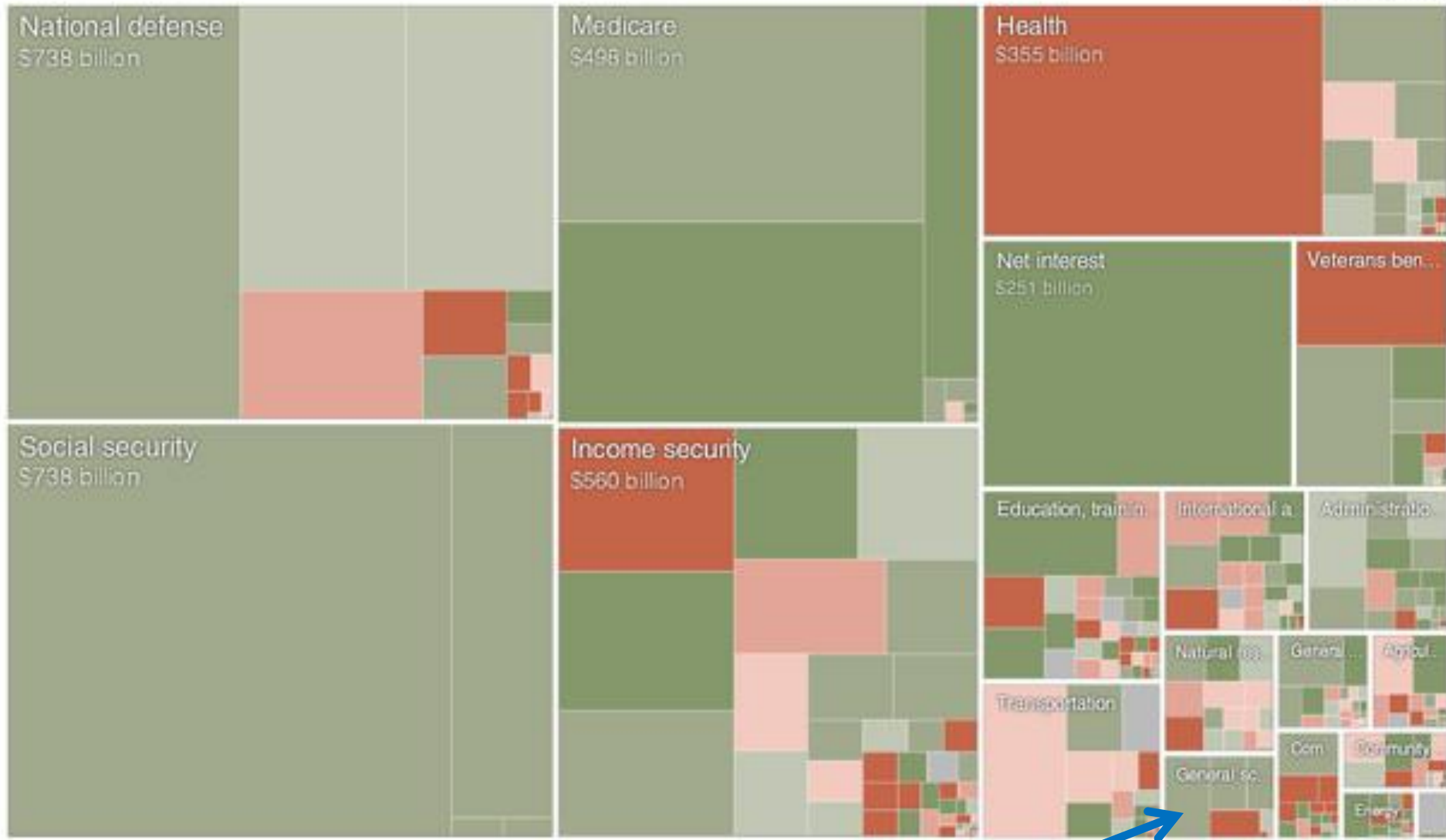
It's important to realize the space program is still in its very early phases...

A Cloudy Vision

The Space Shuttle represents 40 year old technology. Two of five were lost, a catastrophic failure rate of 1 in 50. The military gave up on it and built their own launch capability and the telecom industry uses rockets from Europe and China. Progress on the successor has been slow and halting.



The space station was supposed to cost \$8 billion back in 1984. It's heading for \$120 billion yet it has few users among industry and science clients, though it is the station for experimentation on technology for deep space.



Color shows percent change from 2010

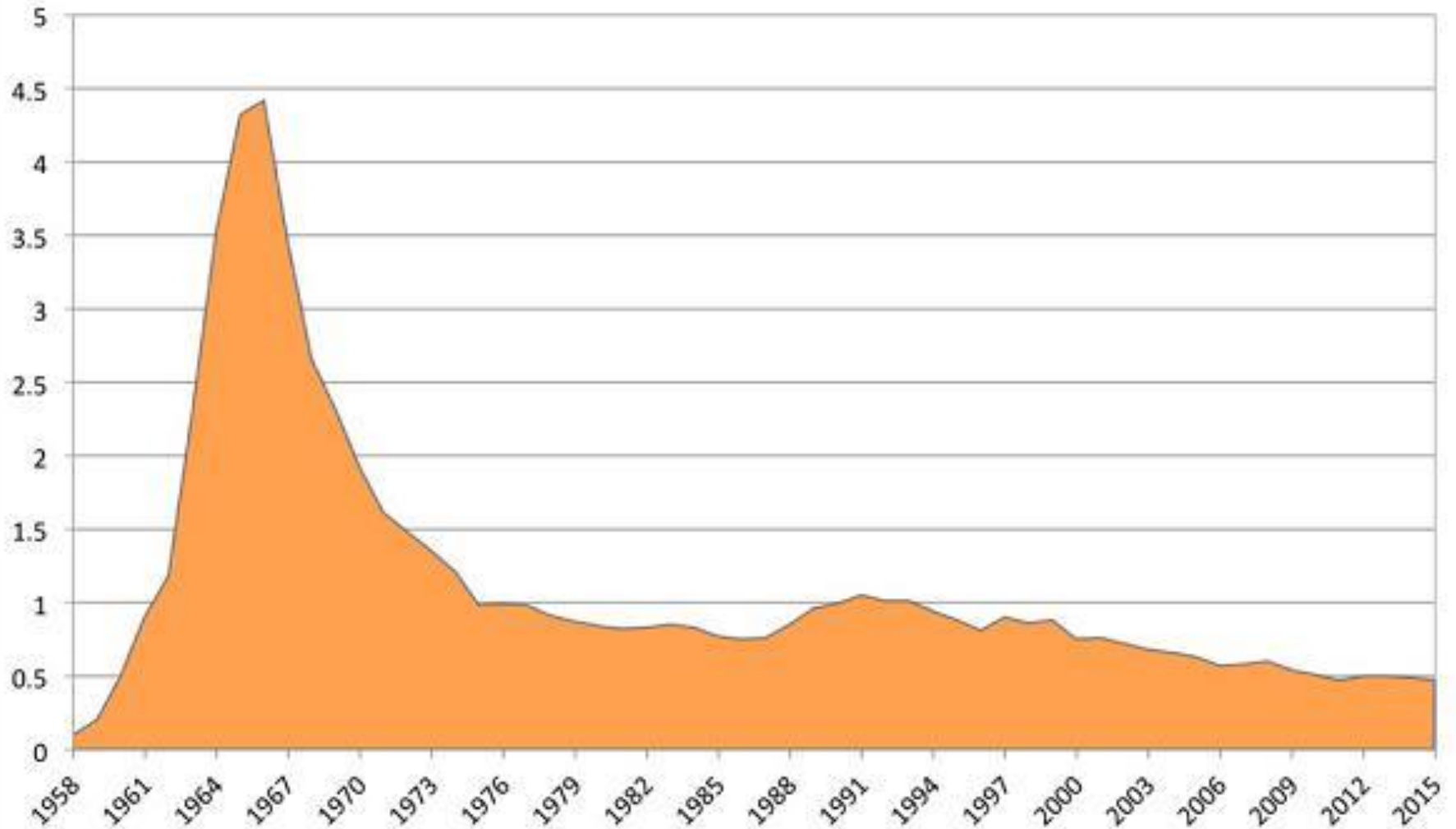
-10% -3% 0 +3% +10%



NASA Lives Here

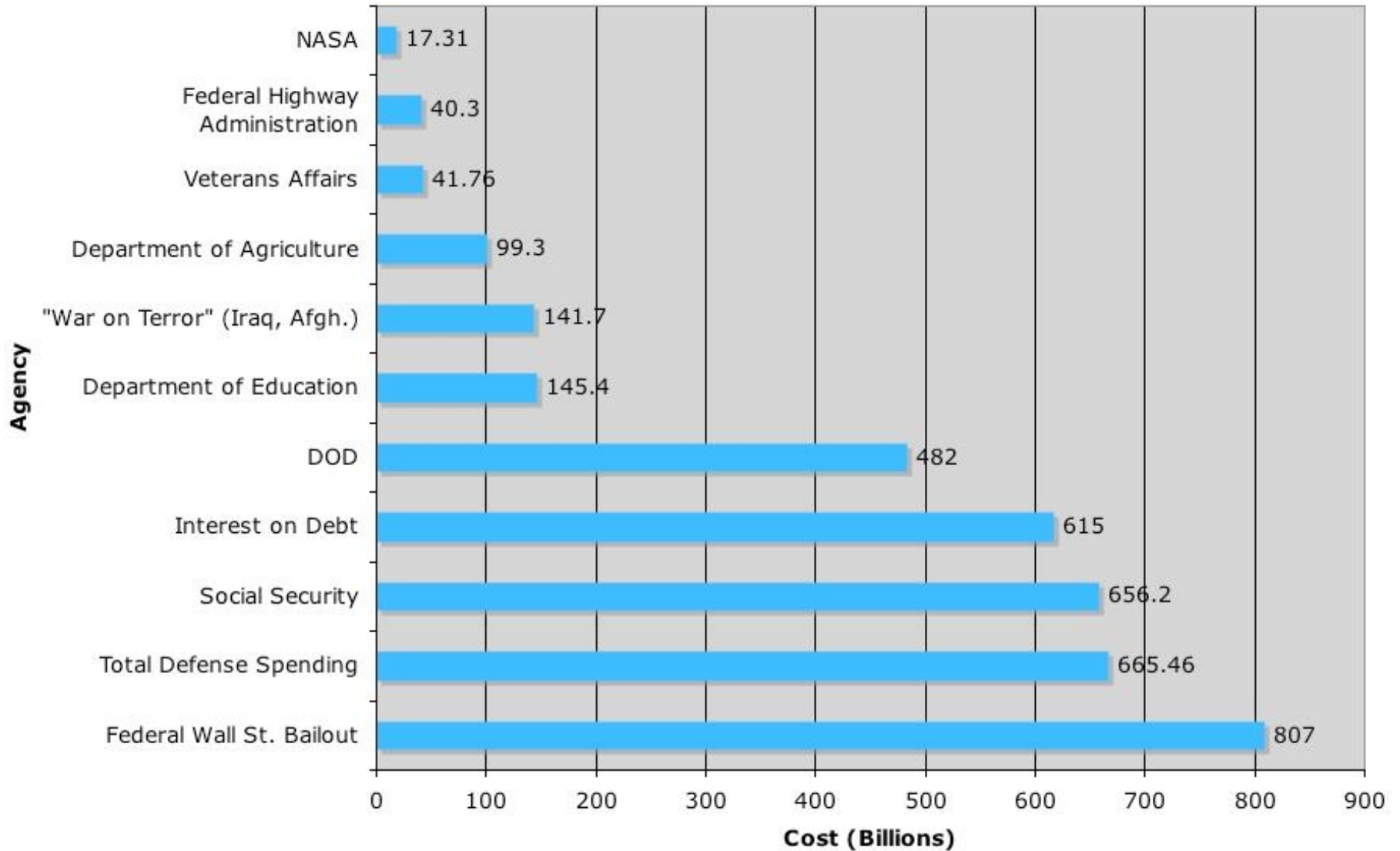
That sinking feeling...

Percentage of Federal Budget allocated for NASA



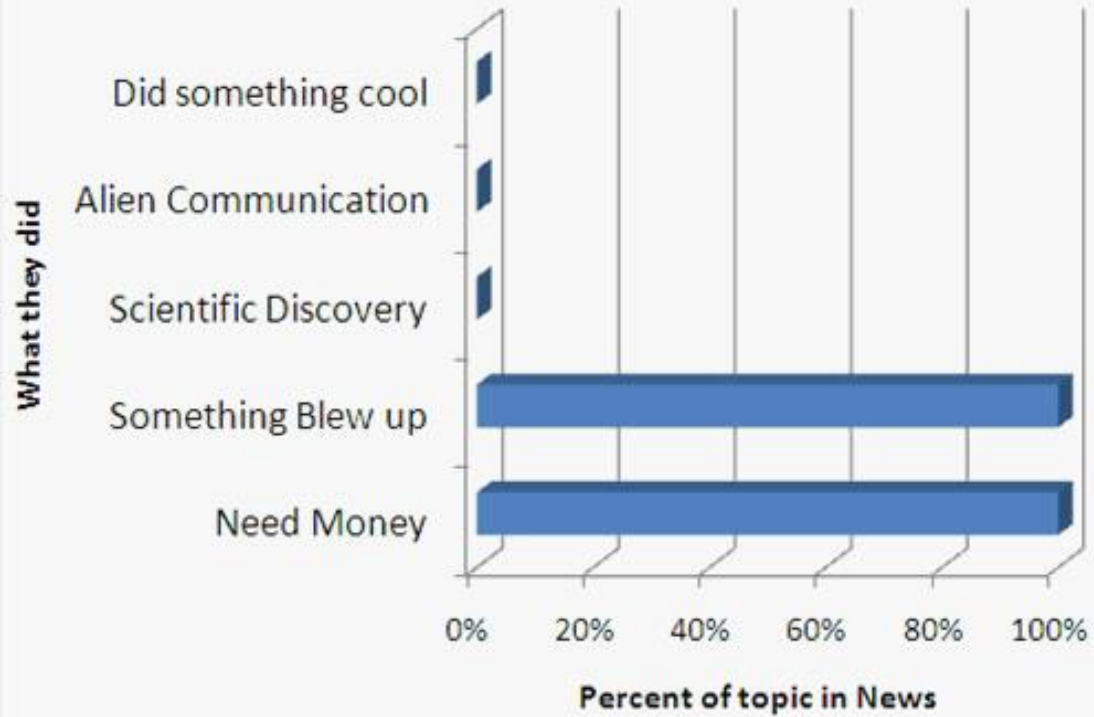
2008 Federal Budget Allocation

(not inclusive; just comparative)



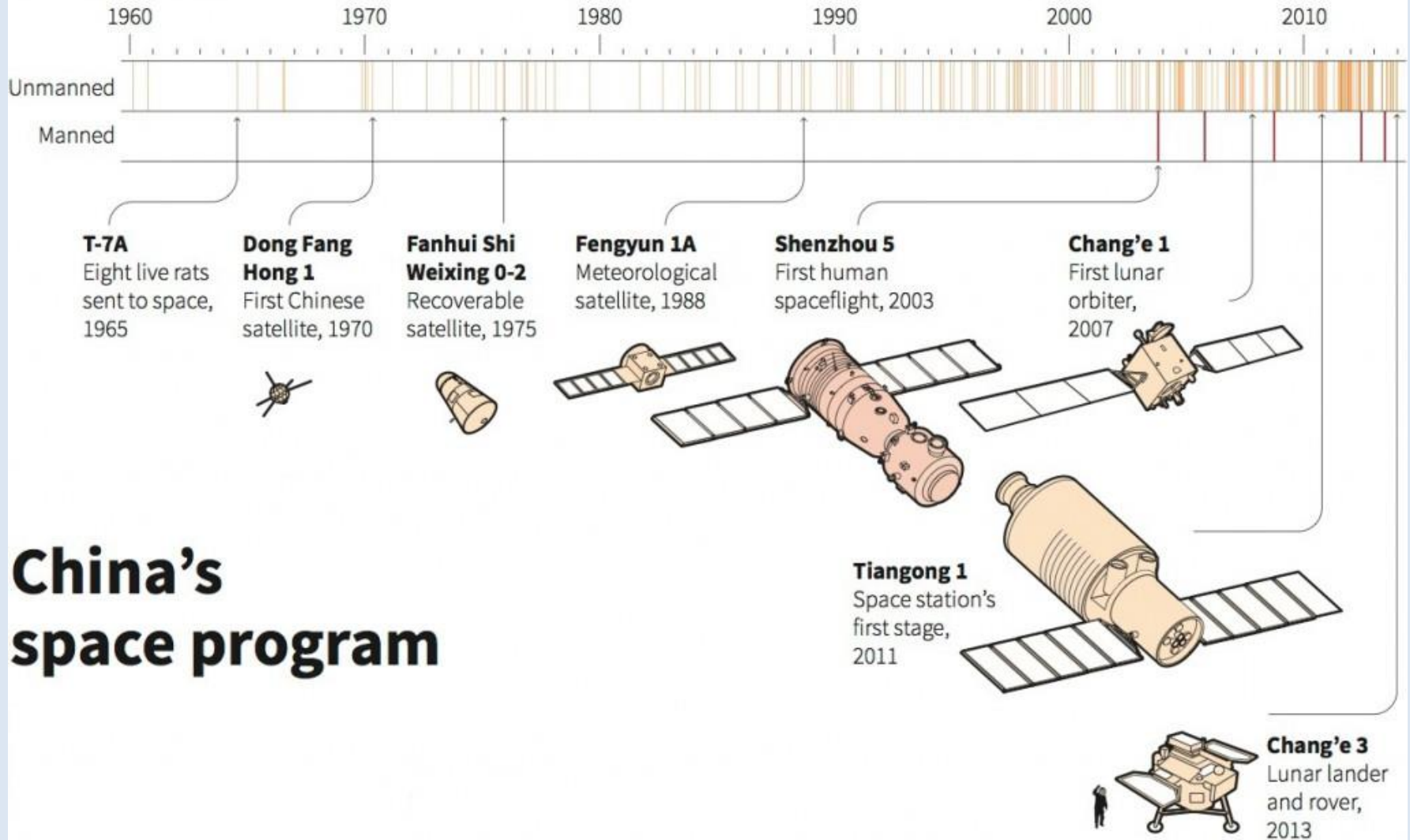
- * "Total Defense Spending" includes DOD, VA and War on Terror monies
- * Interest on debt does not include interest on bailout debt
- * This chart compares a few agencies and excludes many others.

NASA in the News



Meanwhile in China...

Timeline of launches



China's space program

Private Sector

Billionaire Dennis Tito paid \$20 million to ride a Russian Soyuz spacecraft for a week's vacation to the Space Station. Charles Simonyi went twice (and space-walked the second time) for a "cool" \$35 million.

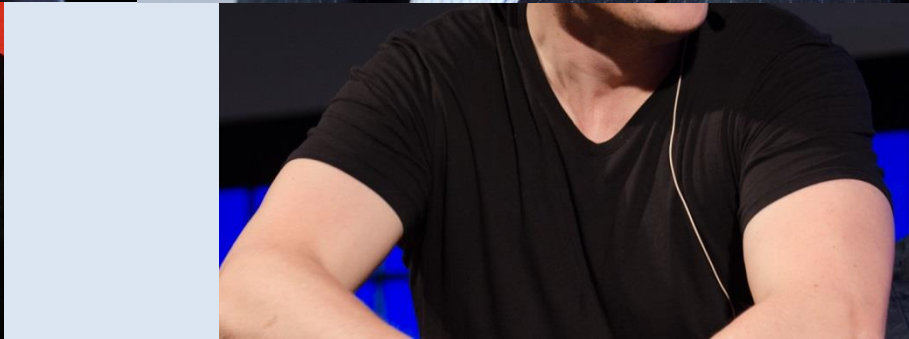
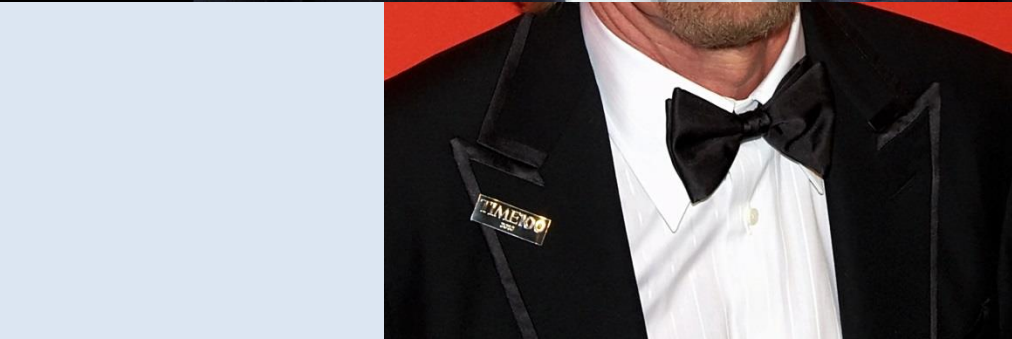


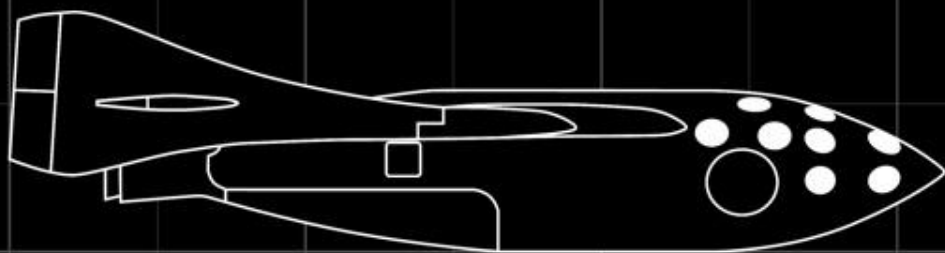
Inspired by the \$25,000 prize won by Lindbergh in 1927, the \$10 million X-prize was won by Burt Rutan for a repeated sub-orbital flight reaching 100 km. Google now has a Moon prize.

Billionaire entrepreneur Richard Branson (Virgin Group) partnered with Burt Rutan to form The Spaceship Company. There are 15 private space outfits worldwide.

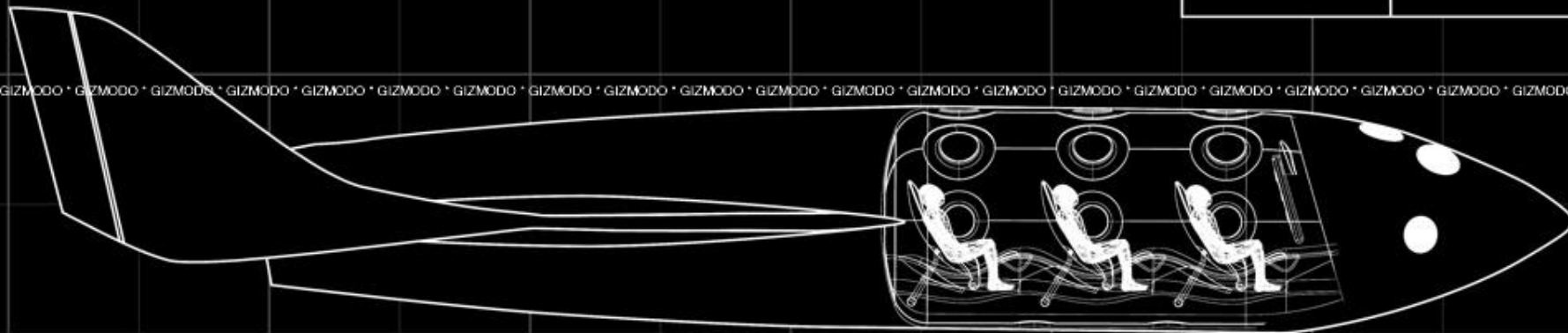


SpaceShipTwo just had a disaster but plans paying flights in ~2017. Tickets are \$250,000. They have \$40 million in deposits and 20,000 expressions of interest. Note: there are 1800 billionaires in the world, and growing.





↑ SpaceShipOne 28ft



↑ SpaceShipTwo 60ft

FEET 10 20 30 40 50 60



SCALE COMPARISON CHART

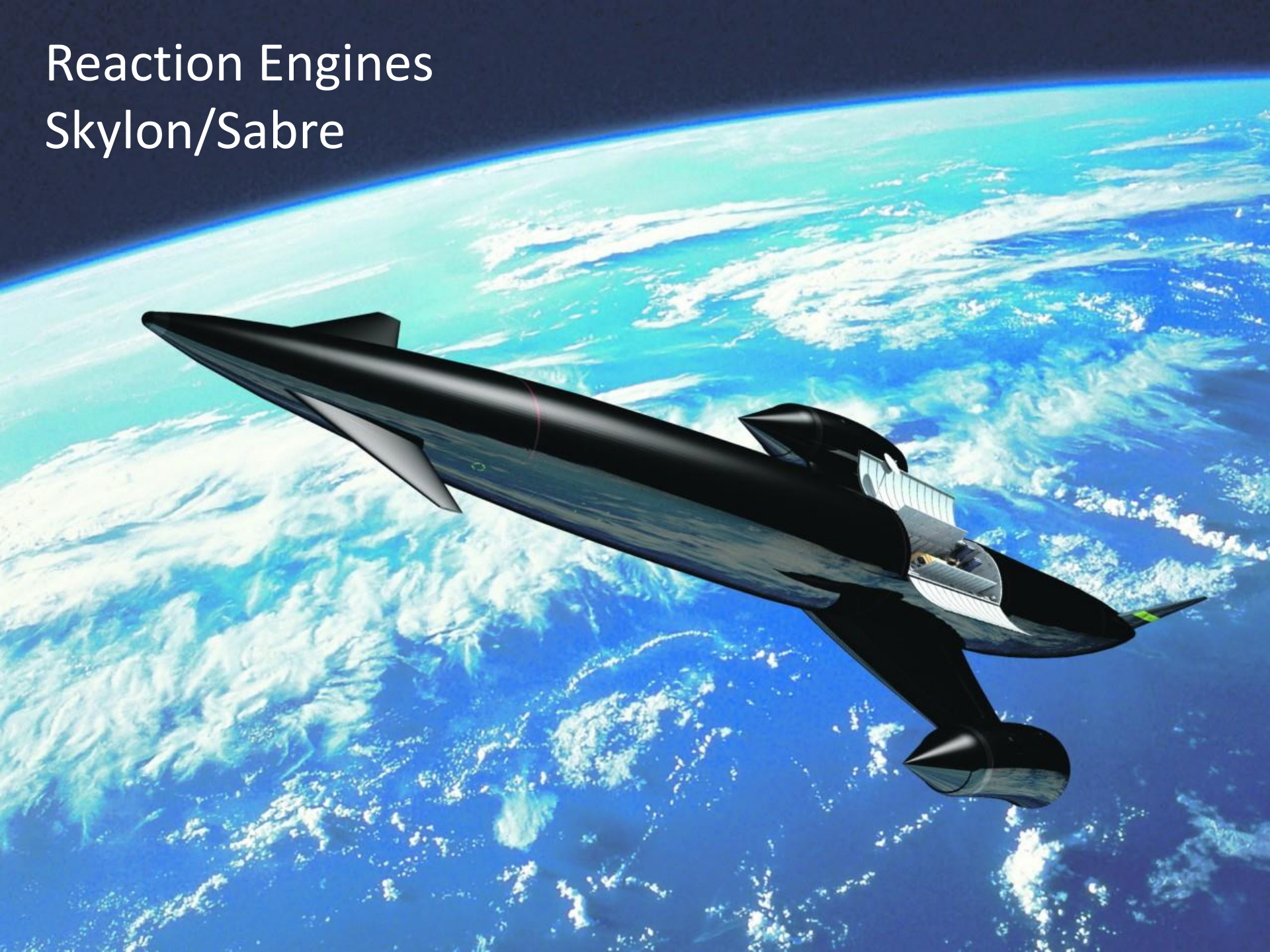
SPACESHIPONE. SPACESHIPTWO

DATE: 28.09.06

SCALE 1:68

Due to US Government regulations regarding technology transfer and commercial confidentiality, this is a conceptual representation of the exterior of SpaceShipTwo. SpaceShipTwo is currently under construction for Virgin Galactic at Scaled Composites in Mojave, California and is planned to be revealed for the first time in the second half of 2007. She will be named Virgin SpaceShip (VSS) Enterprise.

Reaction Engines Skylon/Sabre



Lunar X Prize

Land a robot safely on the Moon, travel 500 meters, send back data and images for a prize of \$30 million.



SPACEPORT AMERICA





Space is Hard



Space is Hard



T+ 00:08:17

STAGE 2 TELEMETRY

SPEED

ALTITUDE



UPCOMING

SECO

STAGE 1 LANDING

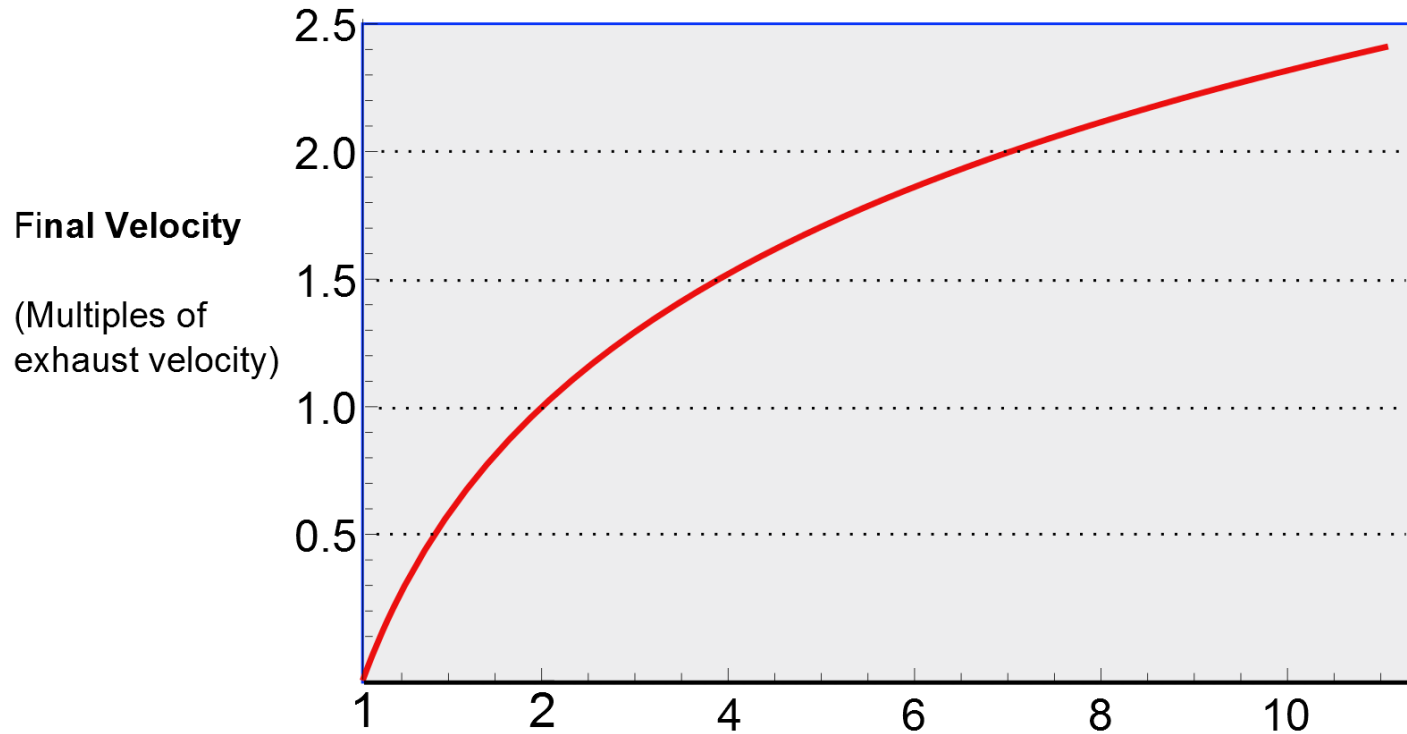
THE FIRST STAGE OF FALCON 9 IS ATTEMPTING AN EXPERIMENTAL LANDING ON THE AUTONOMOUS SPACEPORT DRONE SHIP

LAUNCH: CRS-8



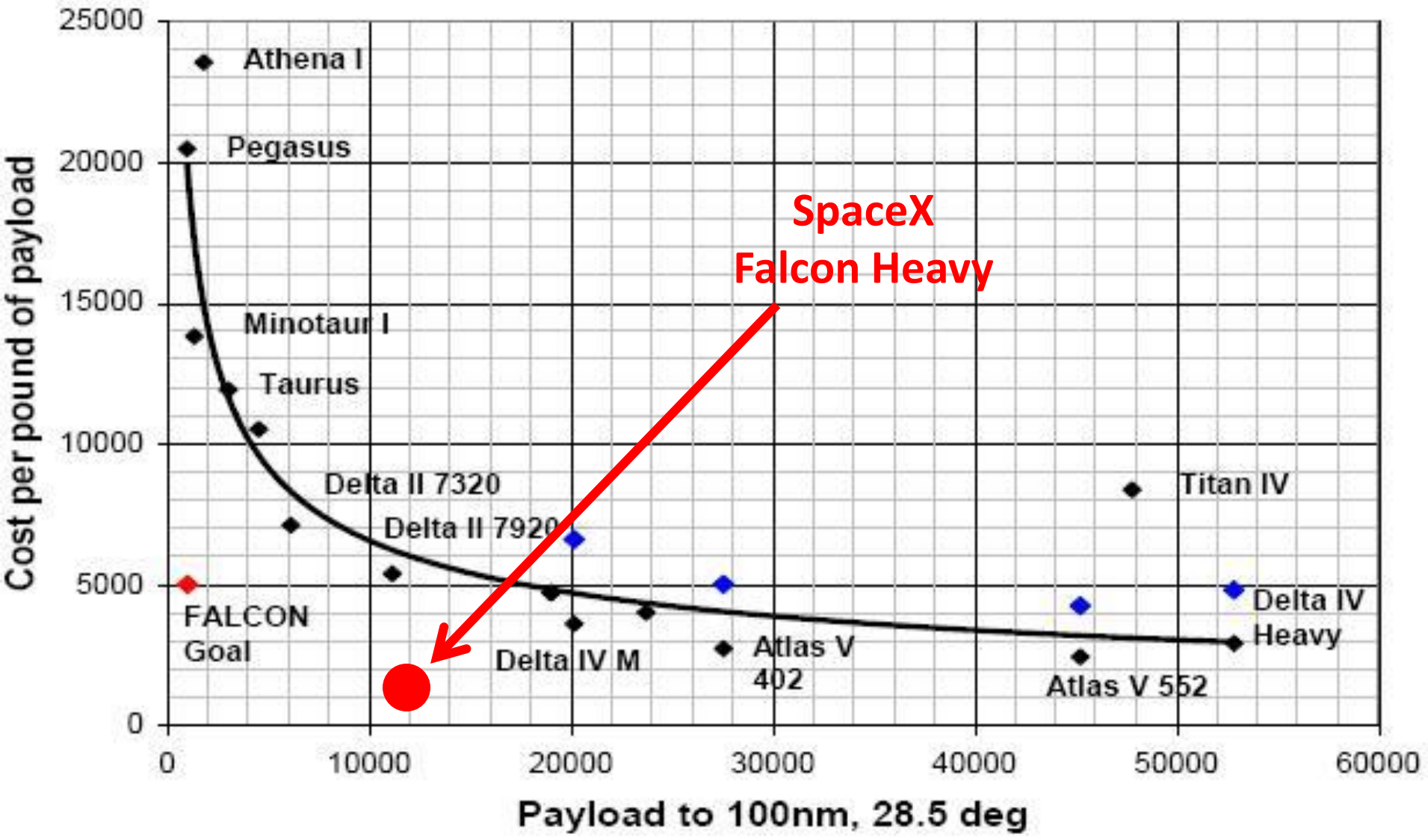
Two brutal curves...

The Rocket Equation



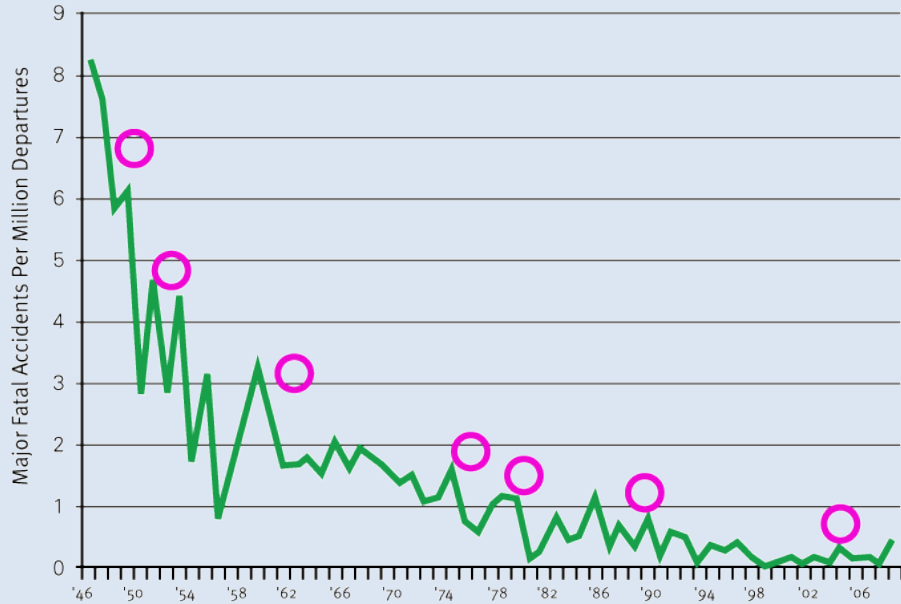
$$\Delta v = v_{ex} \ln \left(\frac{m_0}{m_1} \right)$$

$$\text{Mass Ratio} = \frac{\text{Rocket + fuel}}{\text{Rocket}}$$

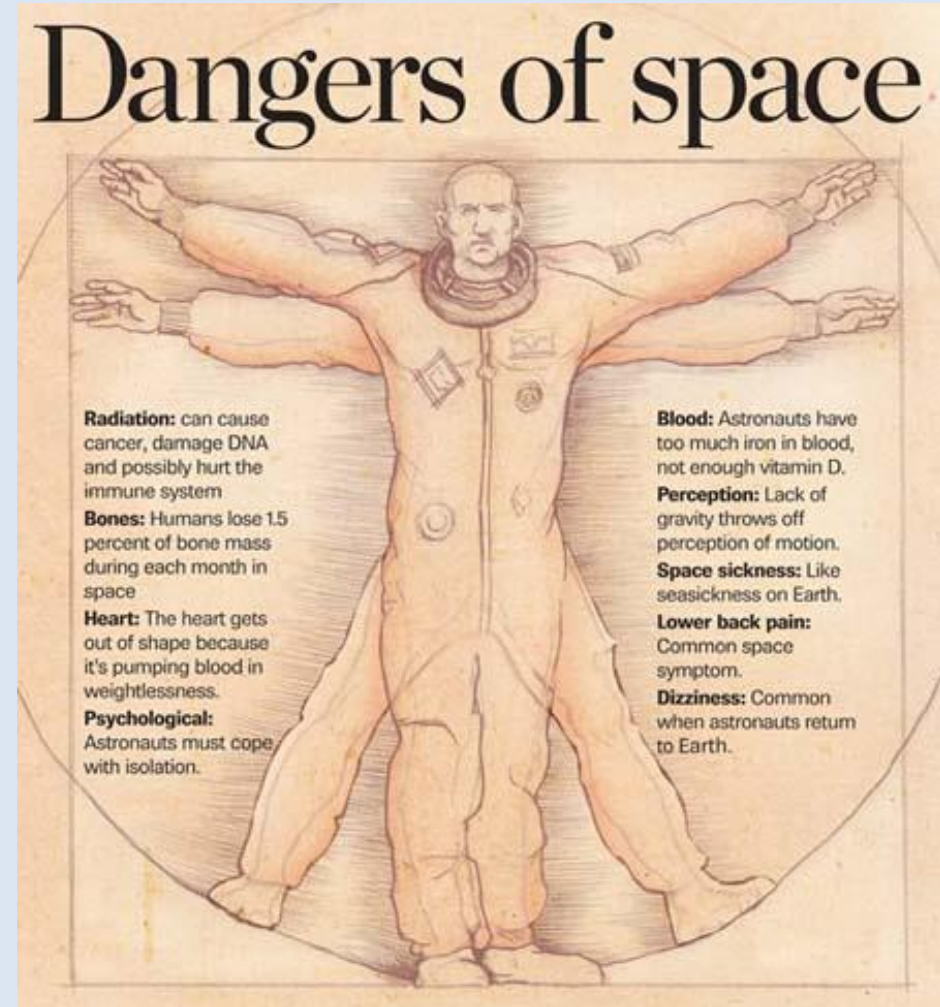


Launch Costs of Common Space Launch Systems

People will die...



The fatality rate in civil aviation has declined by a factor of 100. Higher risk can be accepted in the pioneering phase, within a viable space business model.



Space Hazards

Space Hazards

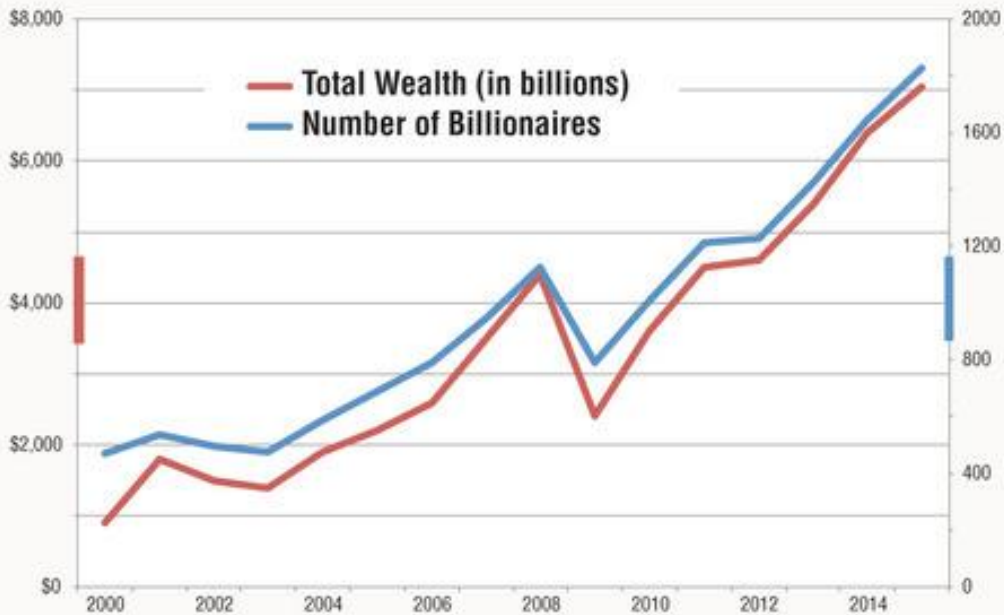


Worst Case Scenario

Worst Case Scenario



■ Growth in World's Billionaires



Source: Forbes

Simonyi spent ~\$35m on two space junkets.

R. Branson has spent \$300m on space so far.

E. Musk has also spent \$400m on space so far.

There are 1800 people worth 10^9 worldwide.

Collectively, they are worth over \$7 trillion.

Economic Model



Trip in the next 40 years (or once in a lifetime):

8% would pay 1 month salary.

13% would pay 3 months salary.

12% would pay 6 months salary.

49% would pay a year's salary.

Mean salary: \$80k

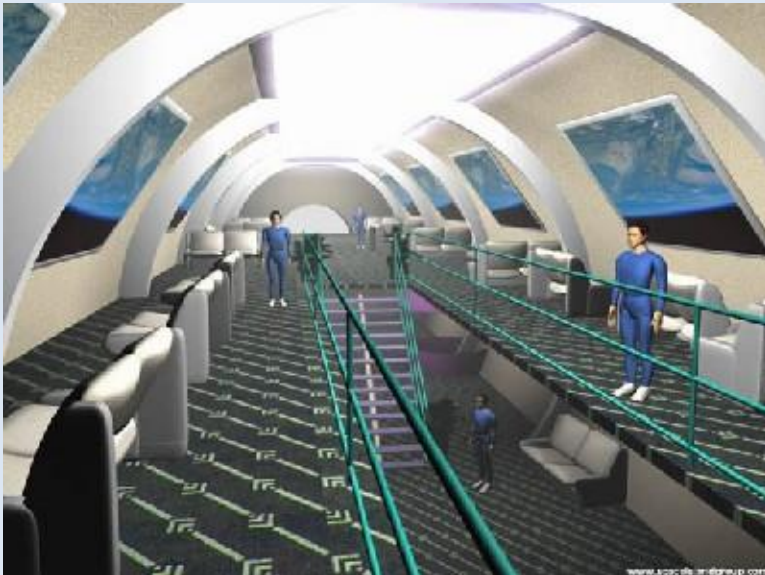
30 million college grads

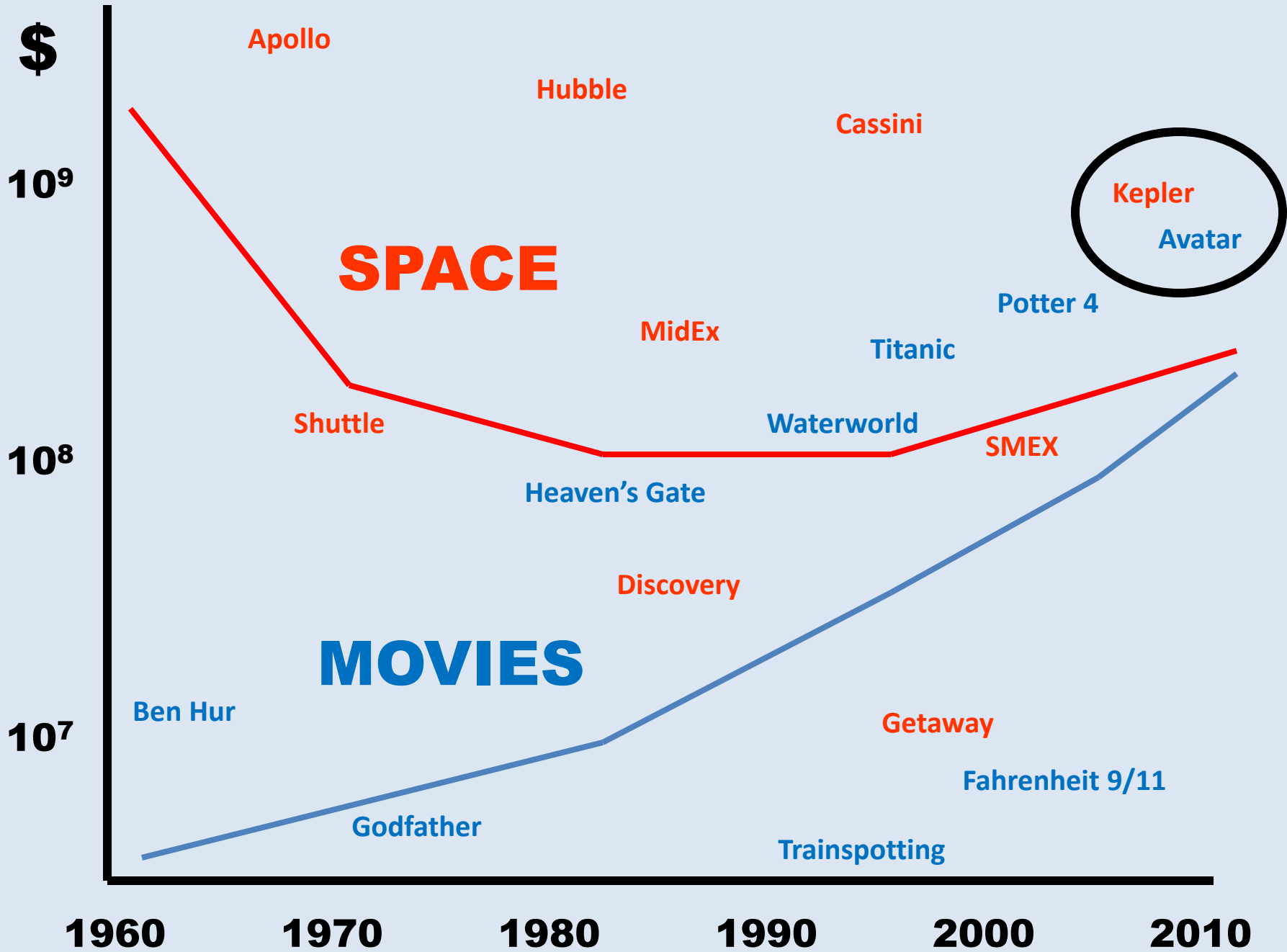
Not in the market

Not in the market

If price 5x lower:
Yield = \$20 billion

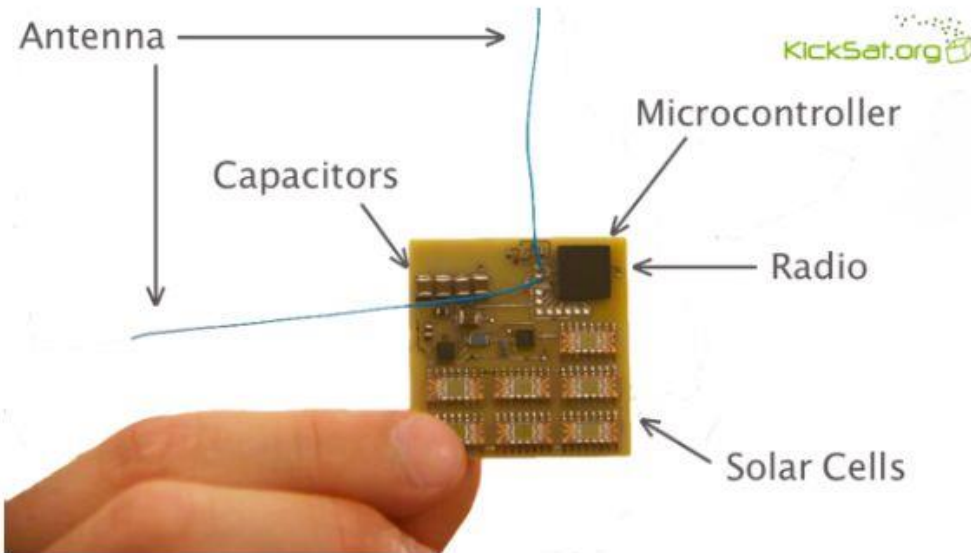
If price 2.5x lower:
Yield = \$110 billion





Room at the Bottom

The Sprite Spacecraft

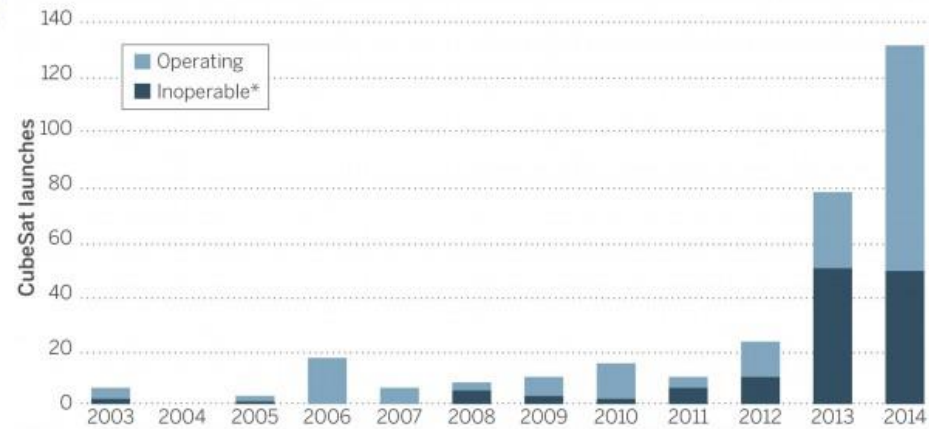


Sprites are the size of a couple of postage stamps but have solar cells, a radio transceiver, and a microcontroller (tiny computer) with memory and sensors -

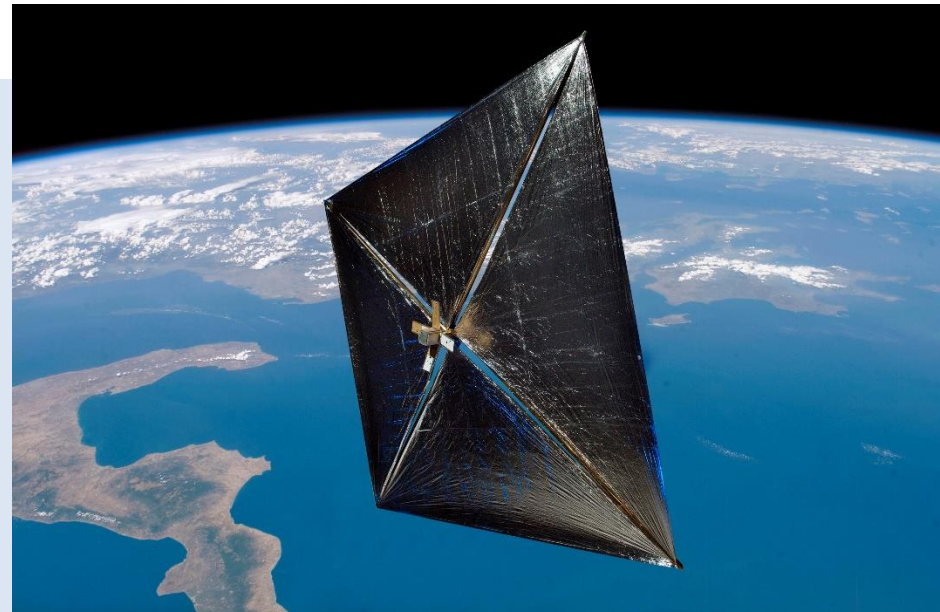
Cubesats and other miniature technologies are dramatically lowering the bar for achieving Earth orbit. Solar sails put all the Solar System within reach.

The swarm cometh

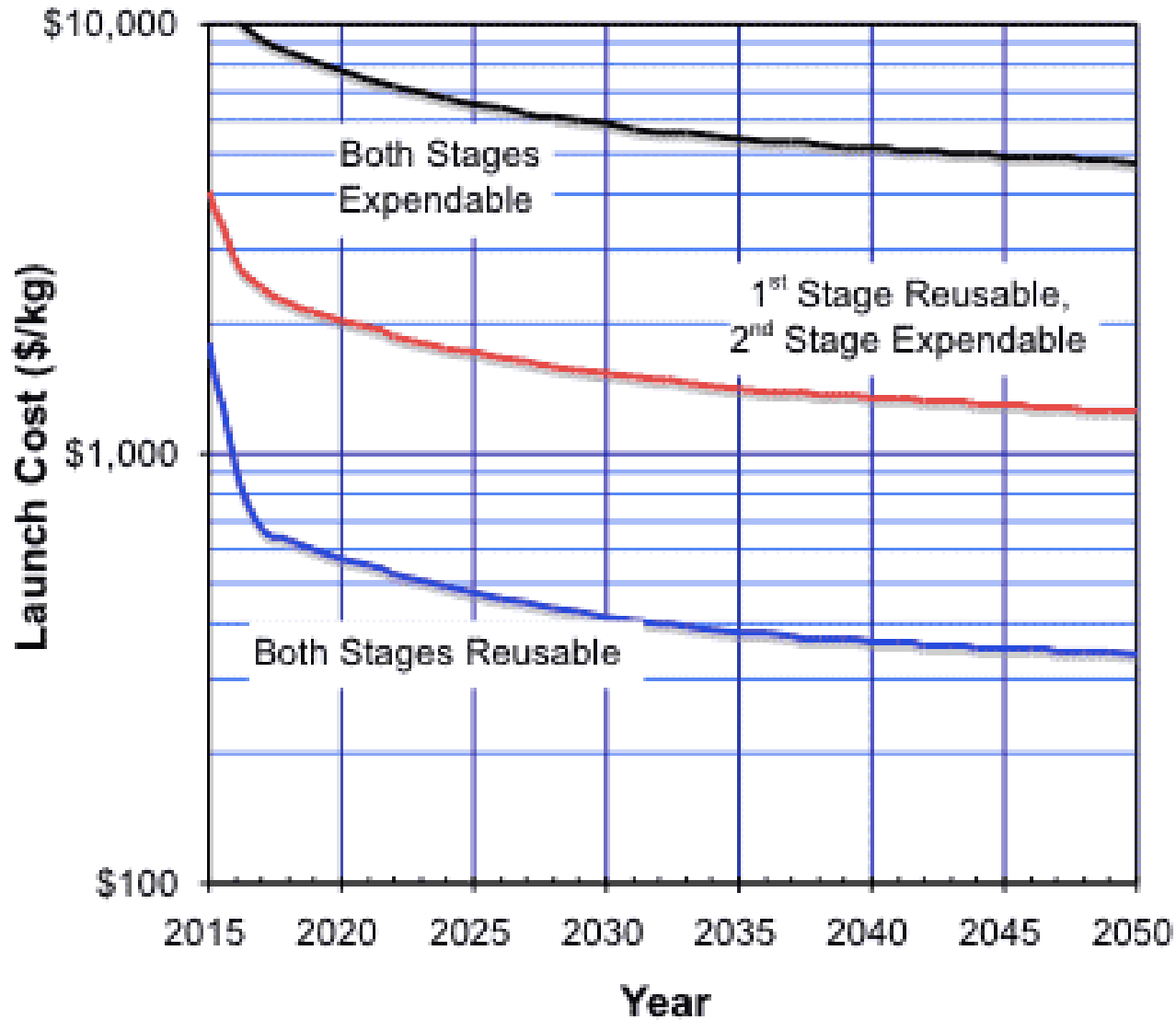
In 2014, a record 132 CubeSats were launched—more than in their first decade.



*CubeSats that have reentered the atmosphere, are dead in orbit, or failed to launch. As of 10 March 2015.



Cost per Person



2010: \$2M

2015: \$250k

2020: \$40k

2050: \$20k

THE INTERNET

COMMERCIAL

RESEARCH

MILITARY

PIONEER

Google



1960

1970

1980

1990

2000

SPACE TRAVEL

COMMERCIAL

RESEARCH

MILITARY

PIONEER



1920



1950



1980

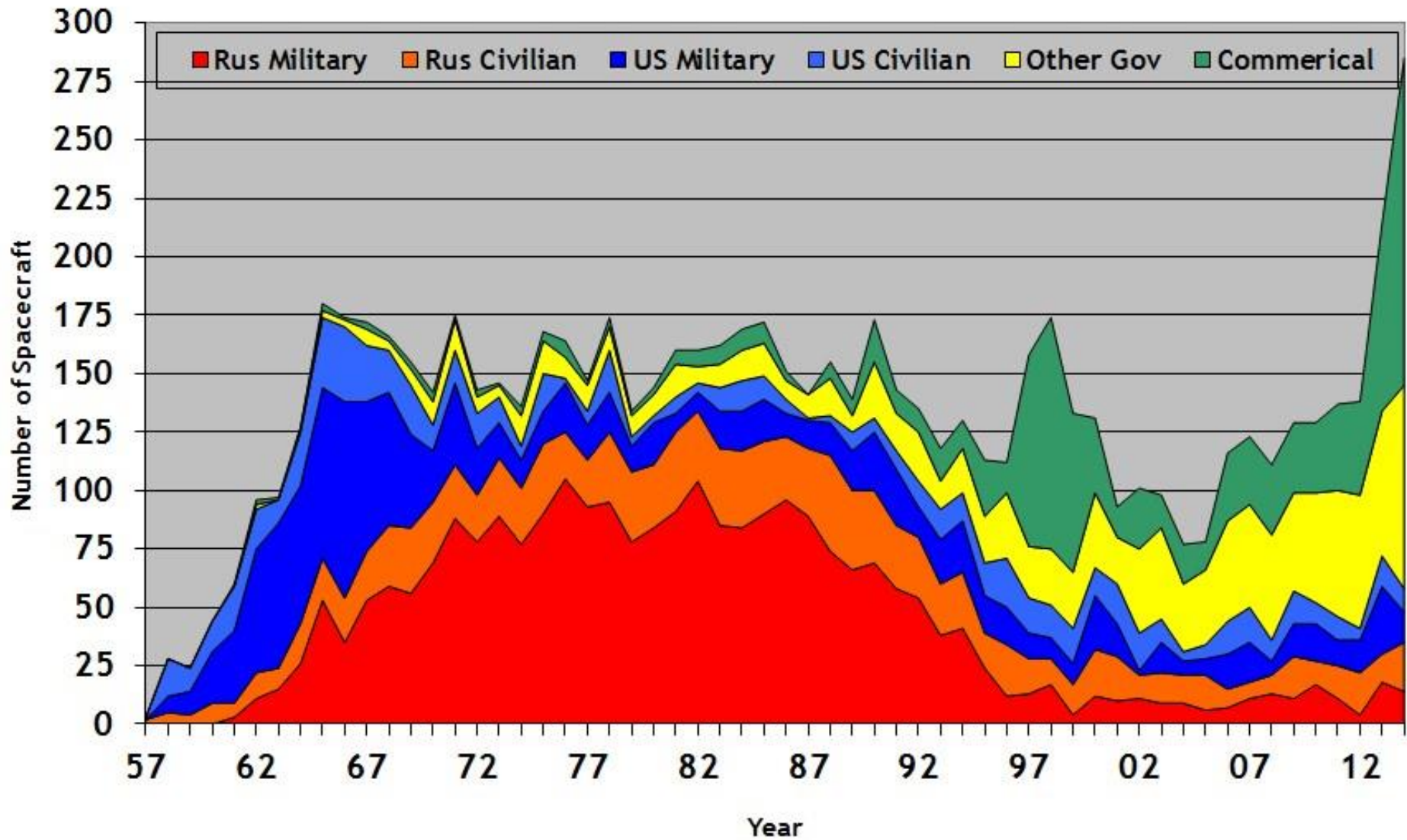
2010



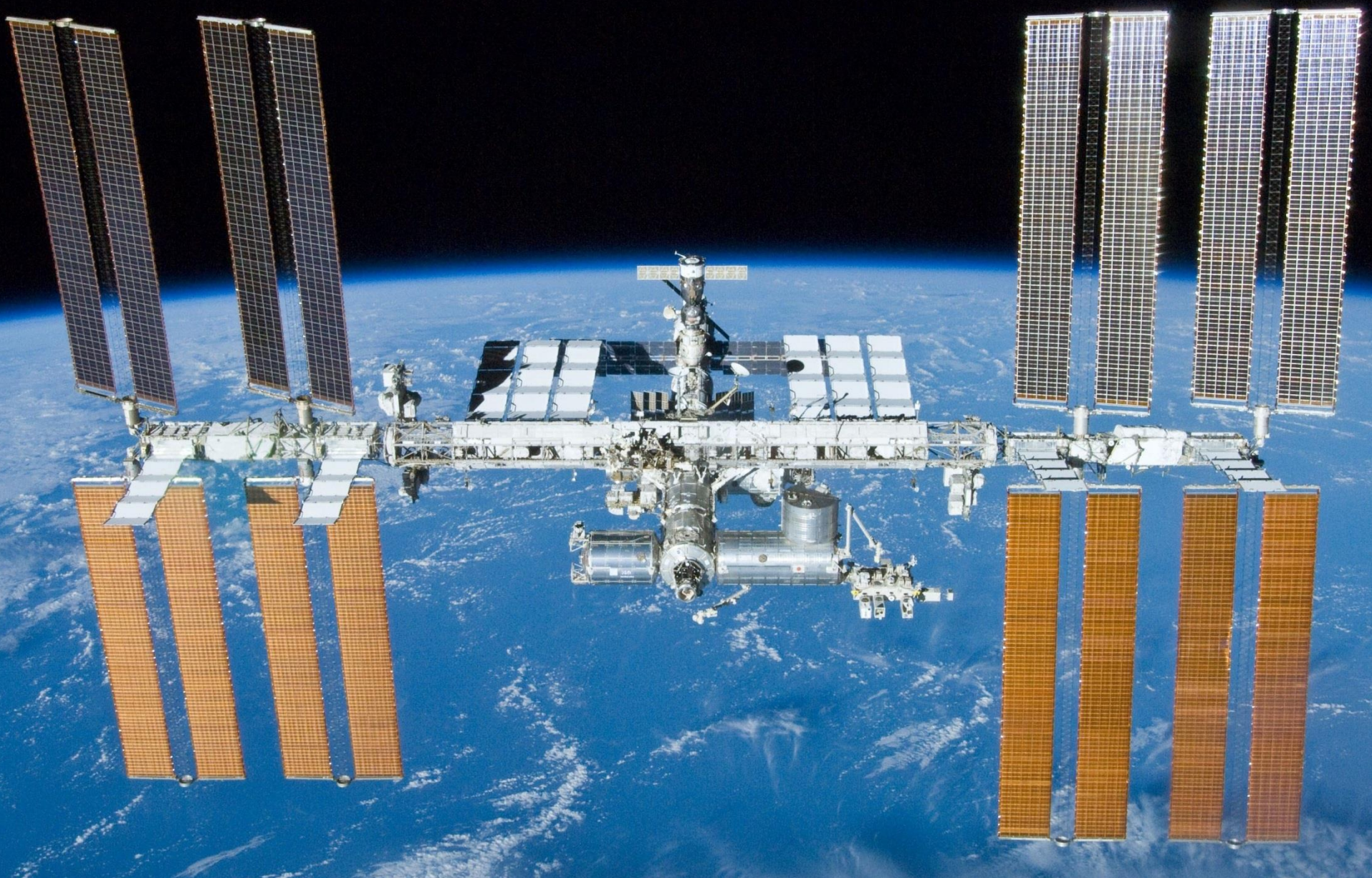
2040



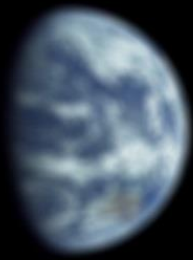
Number of Spacecraft Launched, 1957-2014



On the Horizon



Margie Lawson



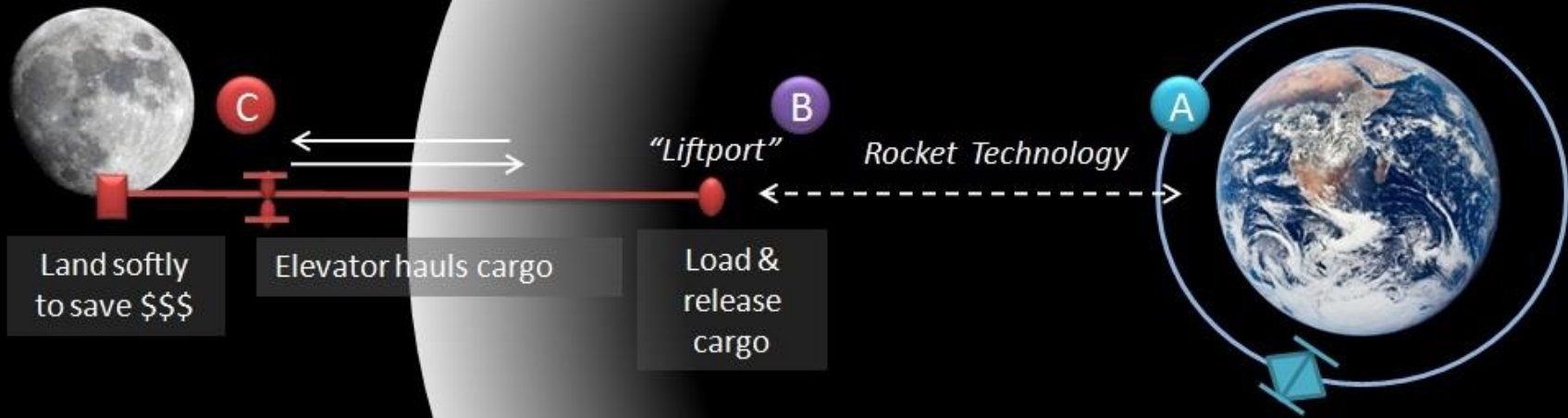
Stairway to heaven...



SPACE ELEVATOR

www.planet46.com
© 2014 Glenn Davis

Not drawn to scale



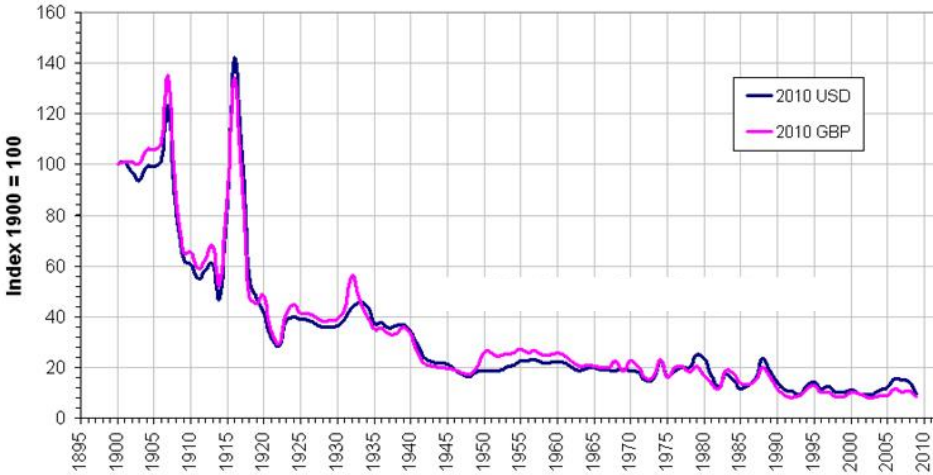
Getting to the moon

- A** Reach Earth's Orbit
 - Travel by current rocket technology at \$5K - \$20K per pound
- B** Reach "Liftport"
 - Move cargo by rocket at modest cost
- C** Reach the Moon
 - Cheap & reliable long-haul to and from the moon with a solar powered elevator; built with a ribbon anchored in earth's gravity well.

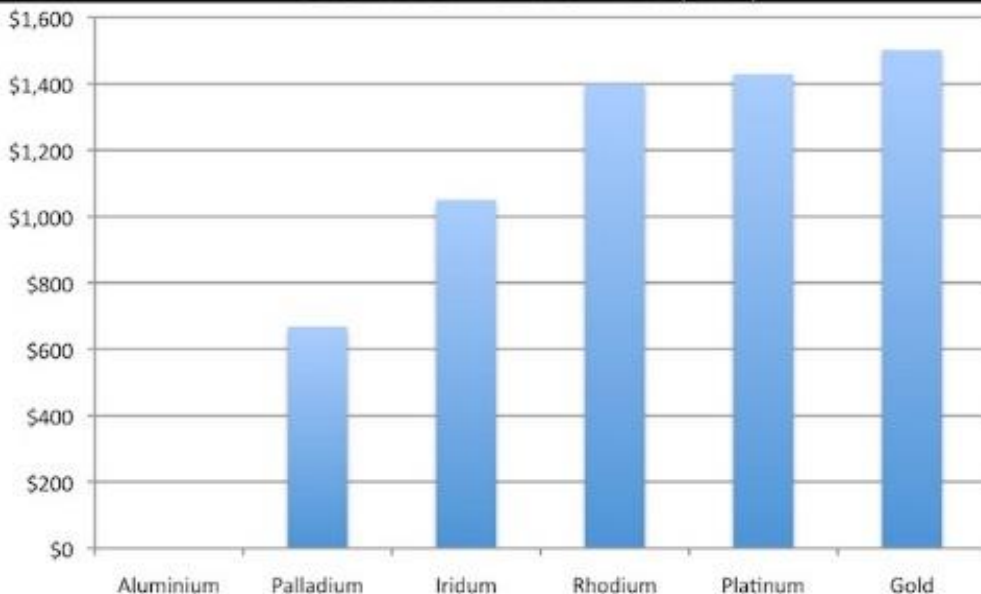
Lunar elevator provides cheap and reliable access to the moon. This is because it eliminates the vast rocket fuel costs involved in braking on the way to the moon, and lifting off on the way back.

...and mining asteroids.

Inflation Adjusted Aluminium Price in US Dollars and GB Pounds



Current Commodities Prices (\$/oz.)



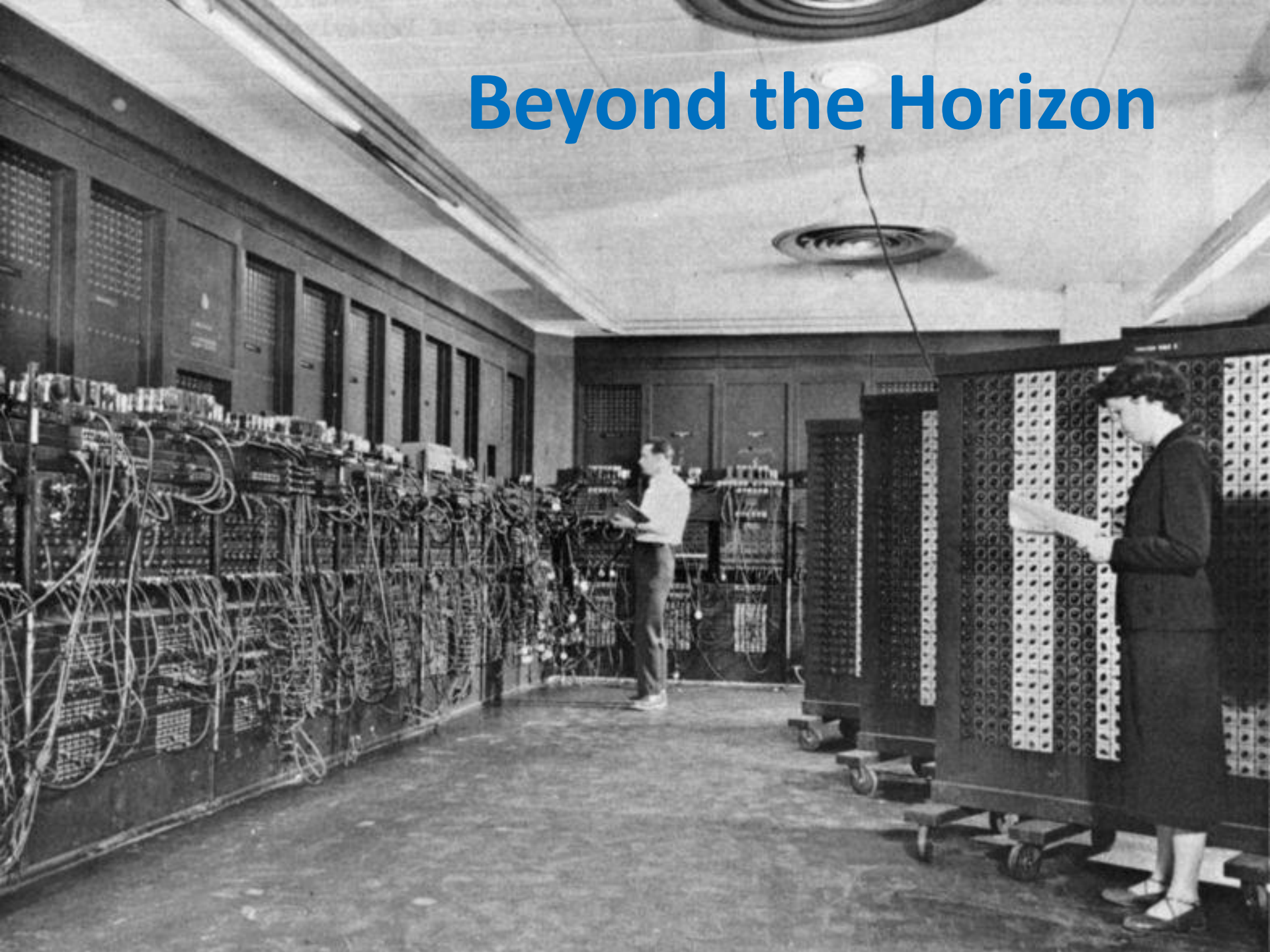
Economic progress on Earth has been fueled by access to cheap metals and minerals. Aluminum provides a historical example.

There are over 100 near-Earth asteroids over 500m diameter. A single one could provide:

Platinum group metals alone are worth about \$2 trillion.

Water for all conceivable space travel vs. \$20,000/liter shipped from Earth.

Beyond the Horizon



“Never make predictions, especially about the future.”

Casey Stengel, Baseball Manager

(ENIAC, from 1944, weighed 30 tons, dimmed Philly when it was running, and was a million times slower than a PC)

“I think there is a world market for maybe 5 computers”

Thomas Watson, IBM Chairman, 1943

“Computers in the future may weigh less than 1.5 tons”

Popular Mechanics Magazine, 1949

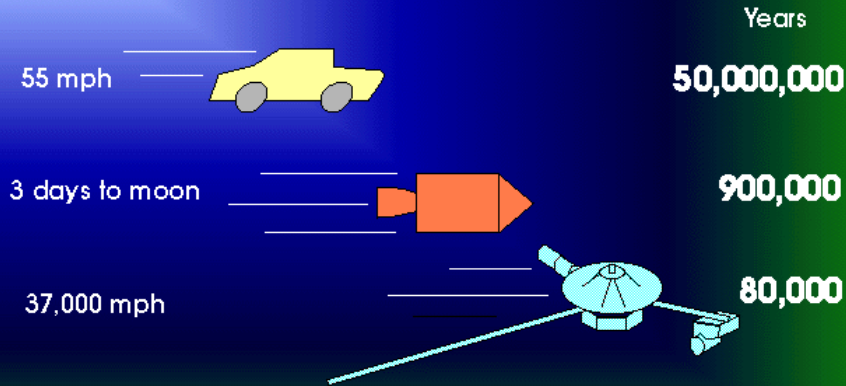
“There’s no reason anyone would want a home computer”

Ken Olsen, CEO, Digital Equipment, 1977

Current speeds are too slow...

Enormous Journeys

Examples of trip times to reach Centauri Cluster...



Conclusion: we need a
Light Speed Breakthrough

CD-94-68481

So the fastest spacecraft would take **10,000** years to reach the nearest stars since it can only travel at **0.2%** of the speed of light. This is far too slow for a realistic interstellar transport.

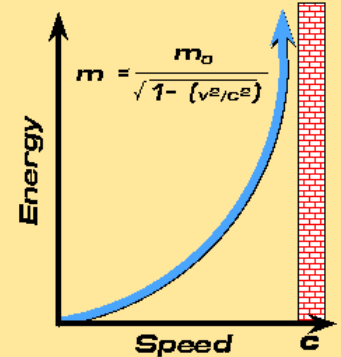
Fundamental physics imposes a limitation. As light speed is approached the energy from propulsion goes into increased mass, via $E = mc^2$, rather than increased speed. Energy costs are formidable above 10% of c .

Special Relativity

The basics

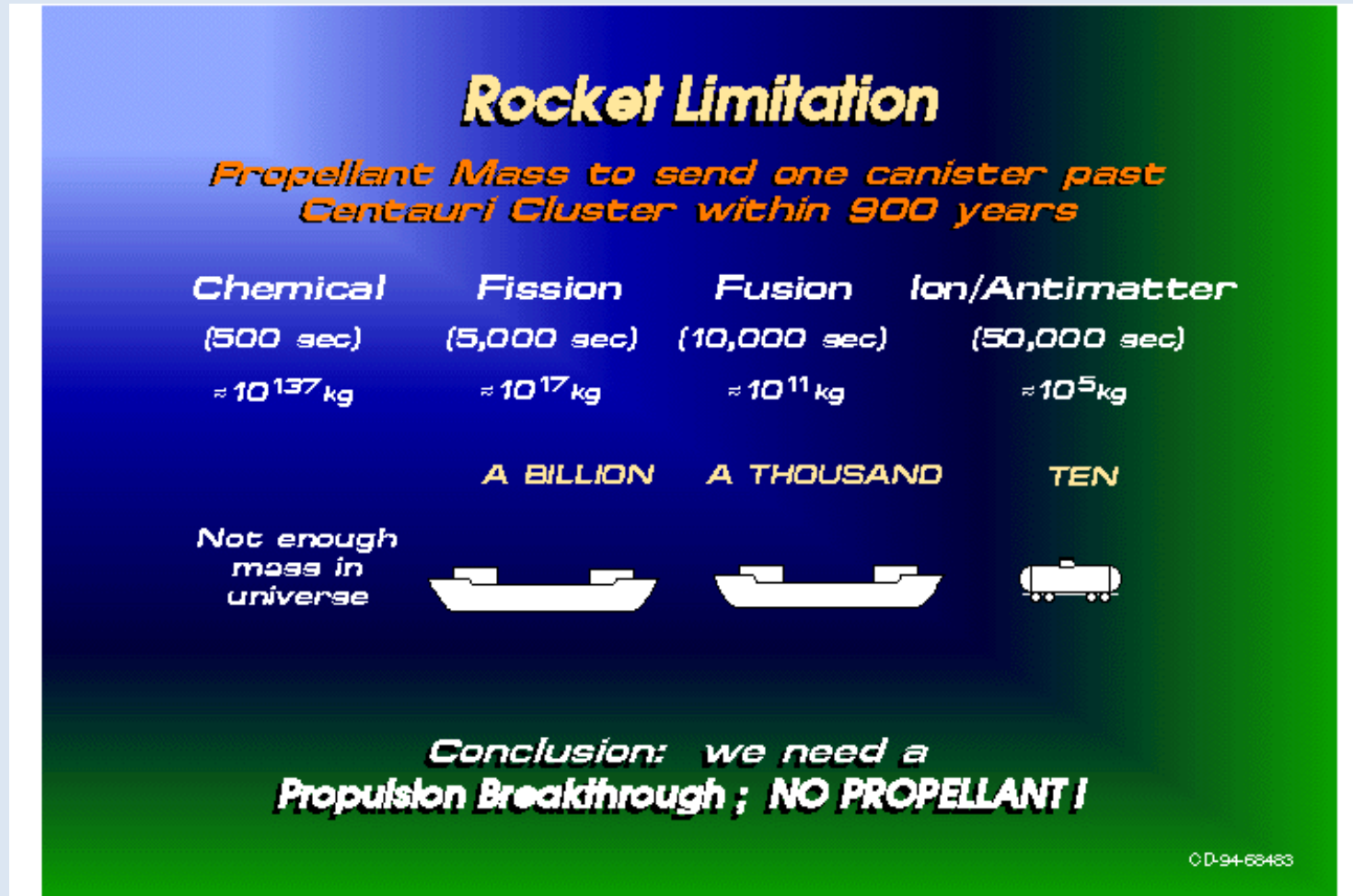
$$d = v \times t$$

$$c = c'$$



CD-94-68903

...and fuels are not good enough...



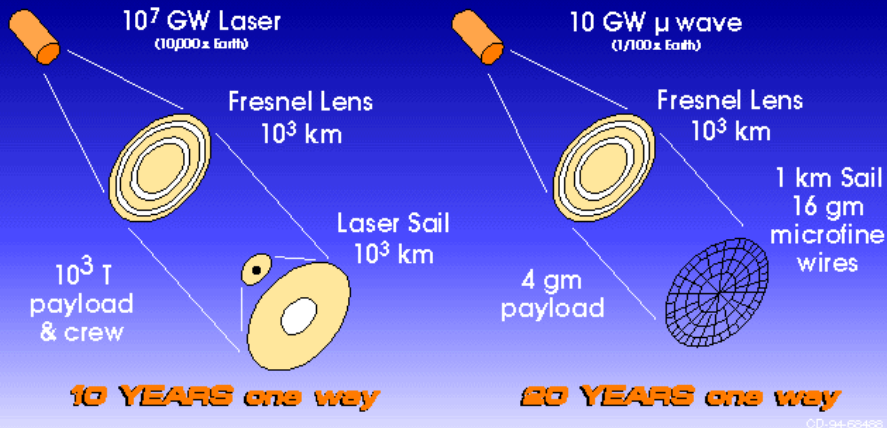
Chemical and even nuclear fuel is not the way to go, because too much fuel must be carried on board. So what's the answer?

Ideas for the Future

Beamed Propulsion Concepts

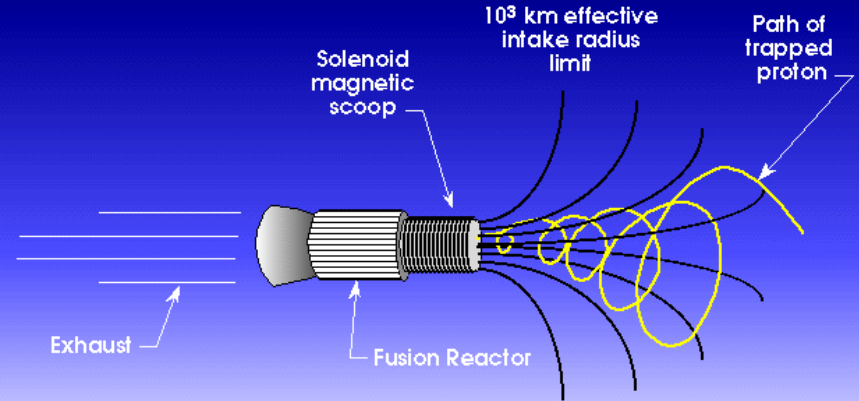
Laser Light Sail
1984...
R. Forward, et al

Star Wisp
1985
R. Forward

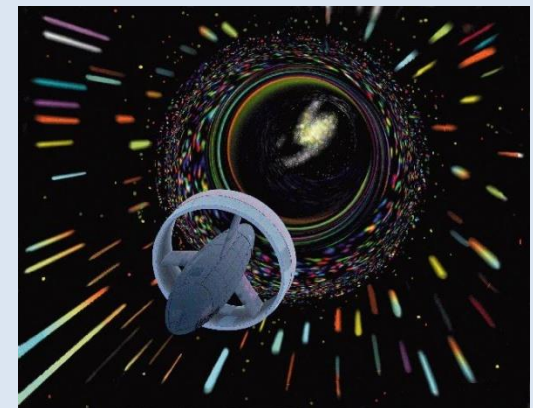


Fuel from Space

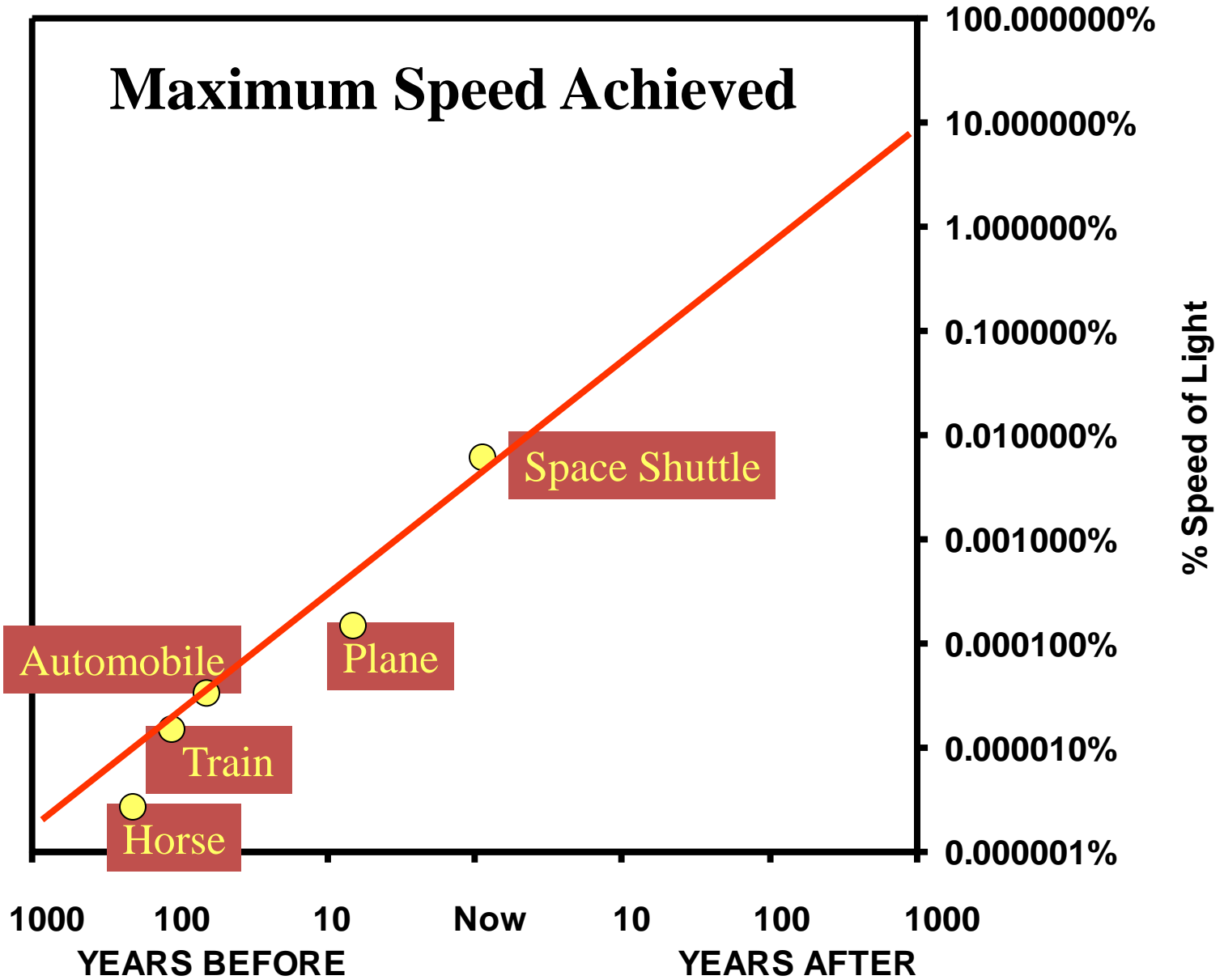
Interstellar Ramjet
1960, R. Bussard, et al.



They are very plausible ideas to work on, but **warp drive and worm holes** may have to wait.



Maximum Speed Achieved



How long to colonize?

Assume 10,000 years
per 20 parsec hop

30,000 pc



Total time to span the
Galaxy:

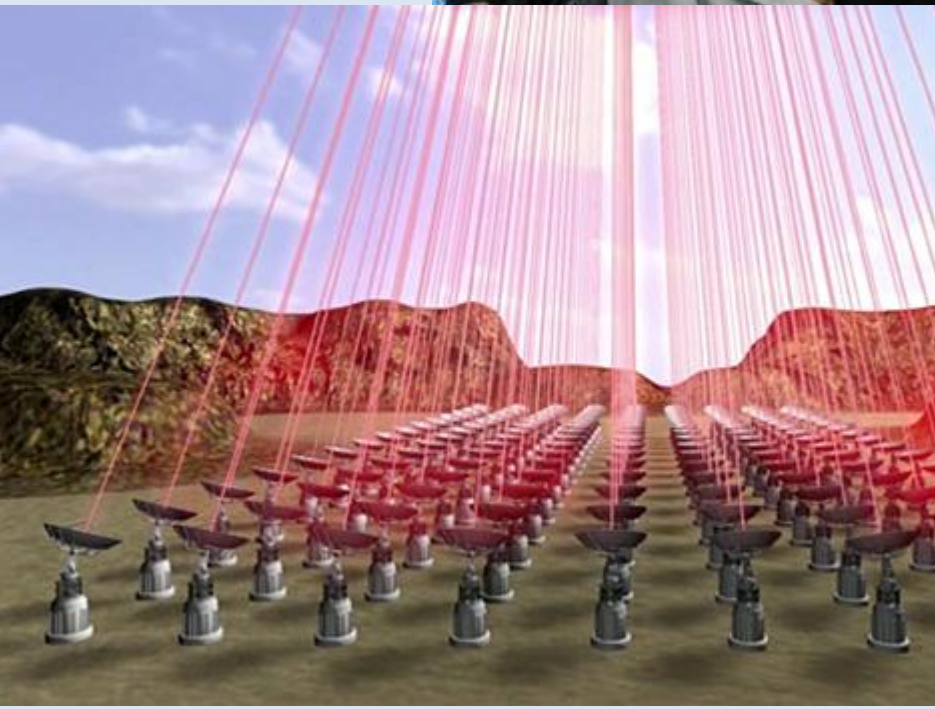
1500 hops \times 10,000 years
= 15,000,000 years

Reaching for the Stars

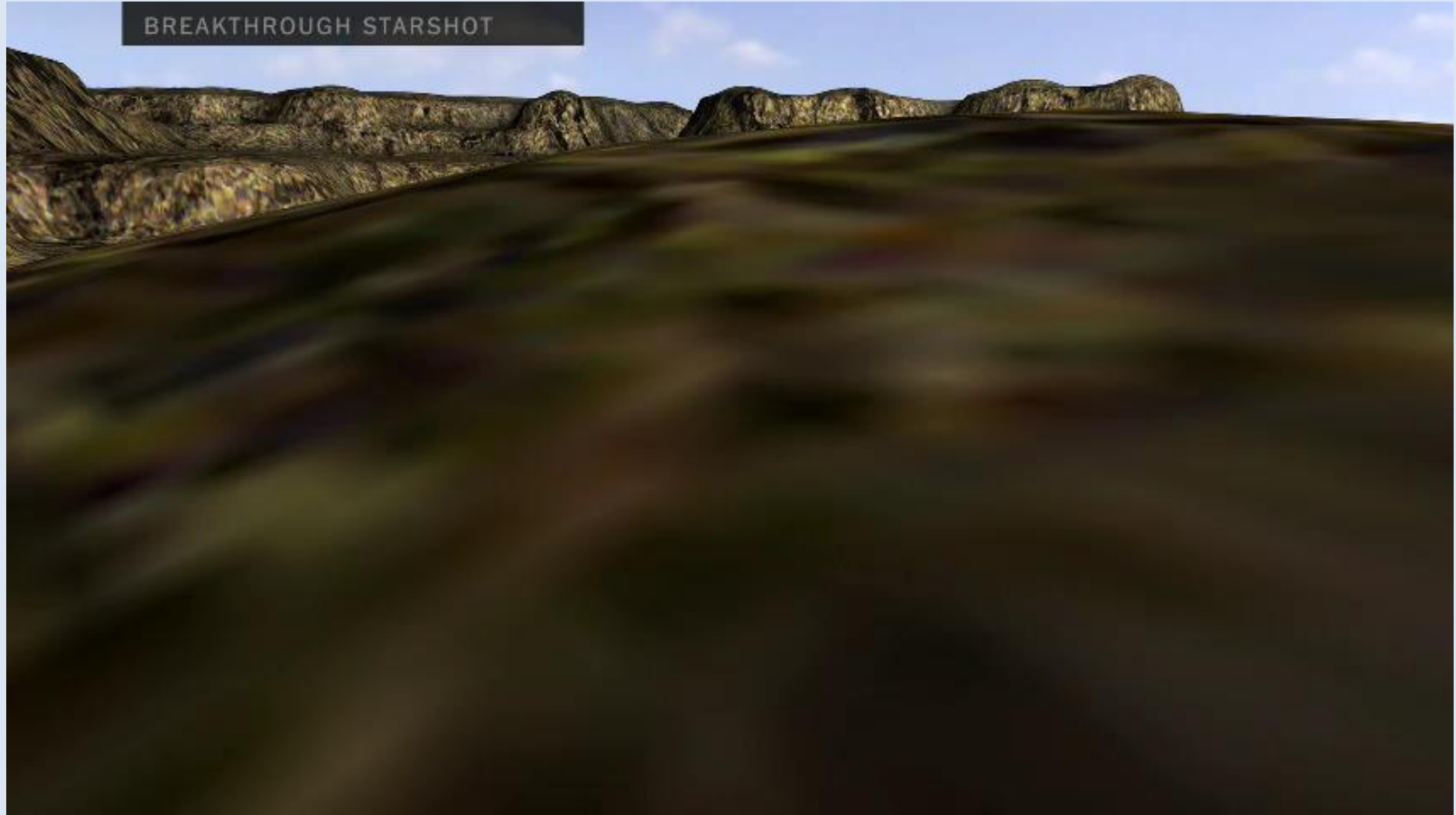
Powerful
Lasers:
100 TW



Small
Spacecraft:
1 gram



BREAKTHROUGH STARSHOT





THE GREEN MARS

Terraforming of Mars

Building up the atmosphere

- Increasing the pressure
- Changing air chemical composition
 - Importing ammonia
 - Importing hydrocarbons
 - Importing hydrogen
 - Using fluorine compounds



Building up water content

- Water sources
 - Melted ice
 - From nearby asteroids
 - Artificial rains (after heating up the planet)



Heating up the planet

- Enhancing greenhouse effect
 - Orbiting space mirrors
 - Nuclear weapons
 - Imported fossil fuels
 - Guided asteroids to hit Mars



Planting Mars

- By importing
 - Synthetic microbes
 - Genetically engineered seeds



Mars colonization

- Megascall engineering
- Laser-propelled spaceships
- Building cities on Mars
- 3D printed homes

DURATION

90 Years

120 Years

150 Years

50 Years

70 Year

COST

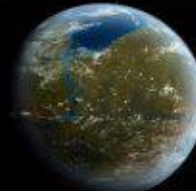
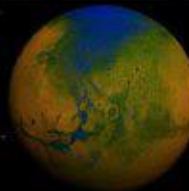
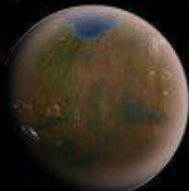
500 Billion USD

700 Billion USD

900 Billion USD

300 Billion USD

1.5 Trillion USD





2020

Neighborhood Earth



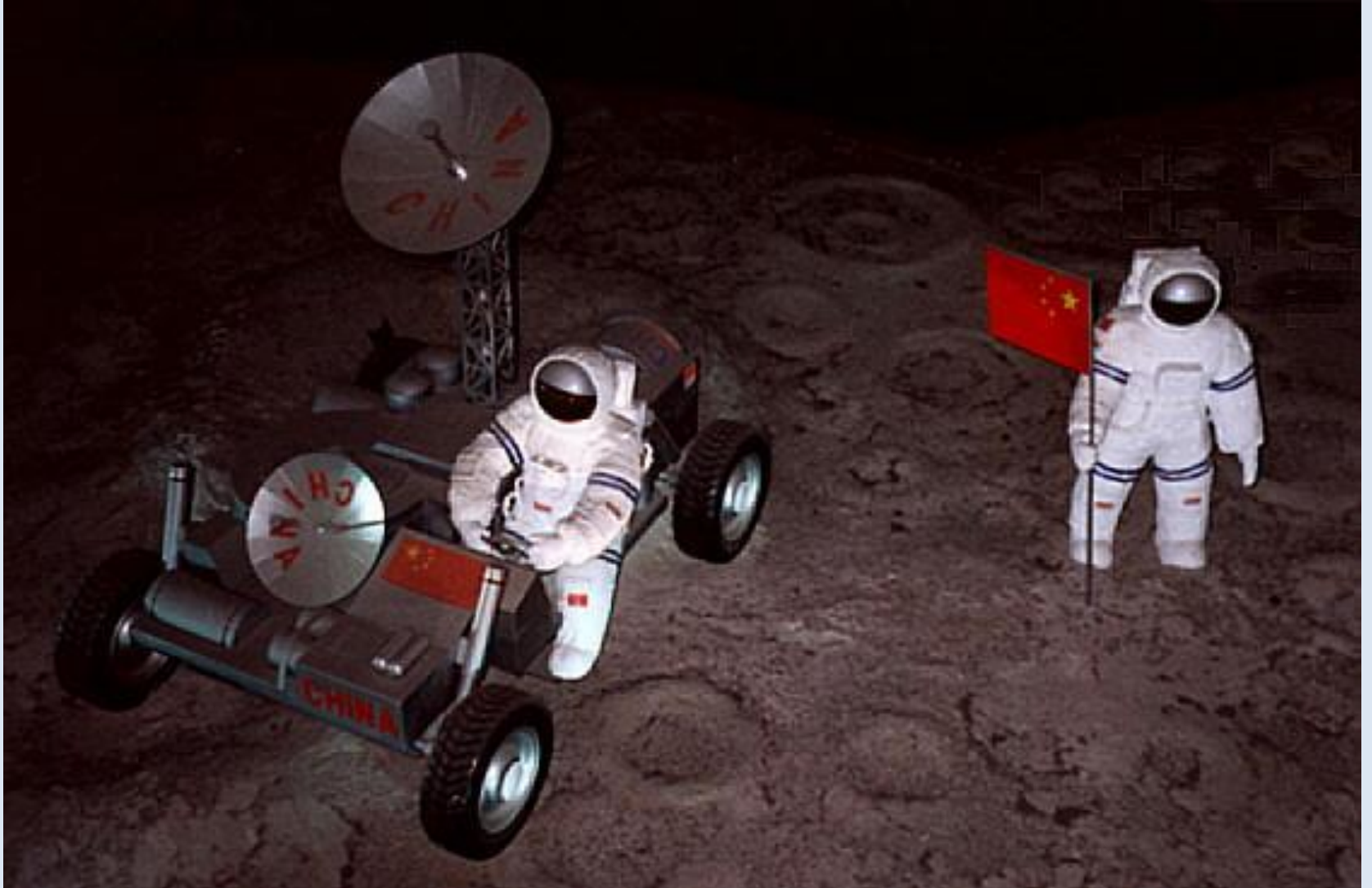
2025

Suspended Animation



2030

Chinese Moon Base



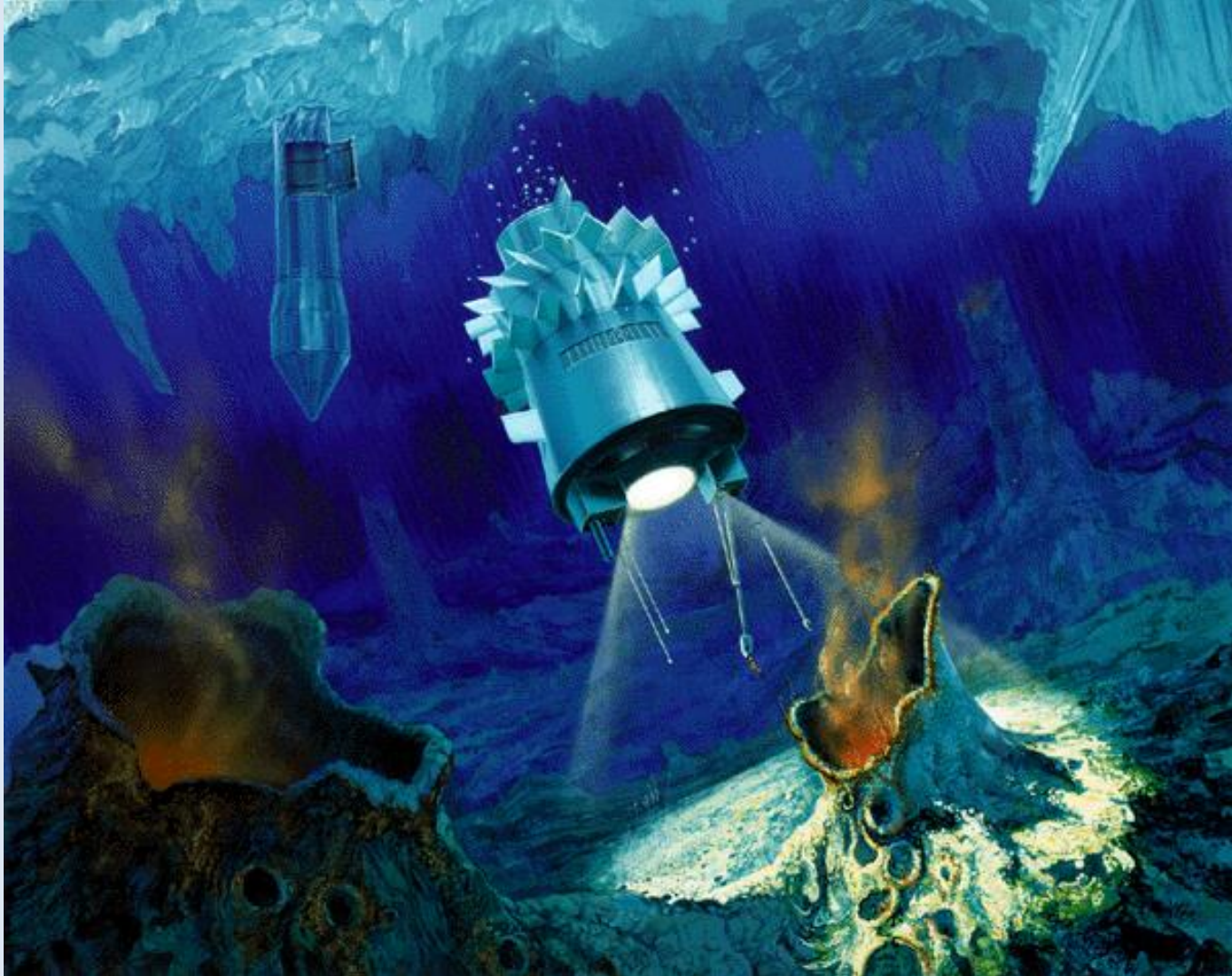
2035

1000th Space Tourist



2040

Virgin Europa



2045

Off-Earth Baby



2050

Mars Colonists



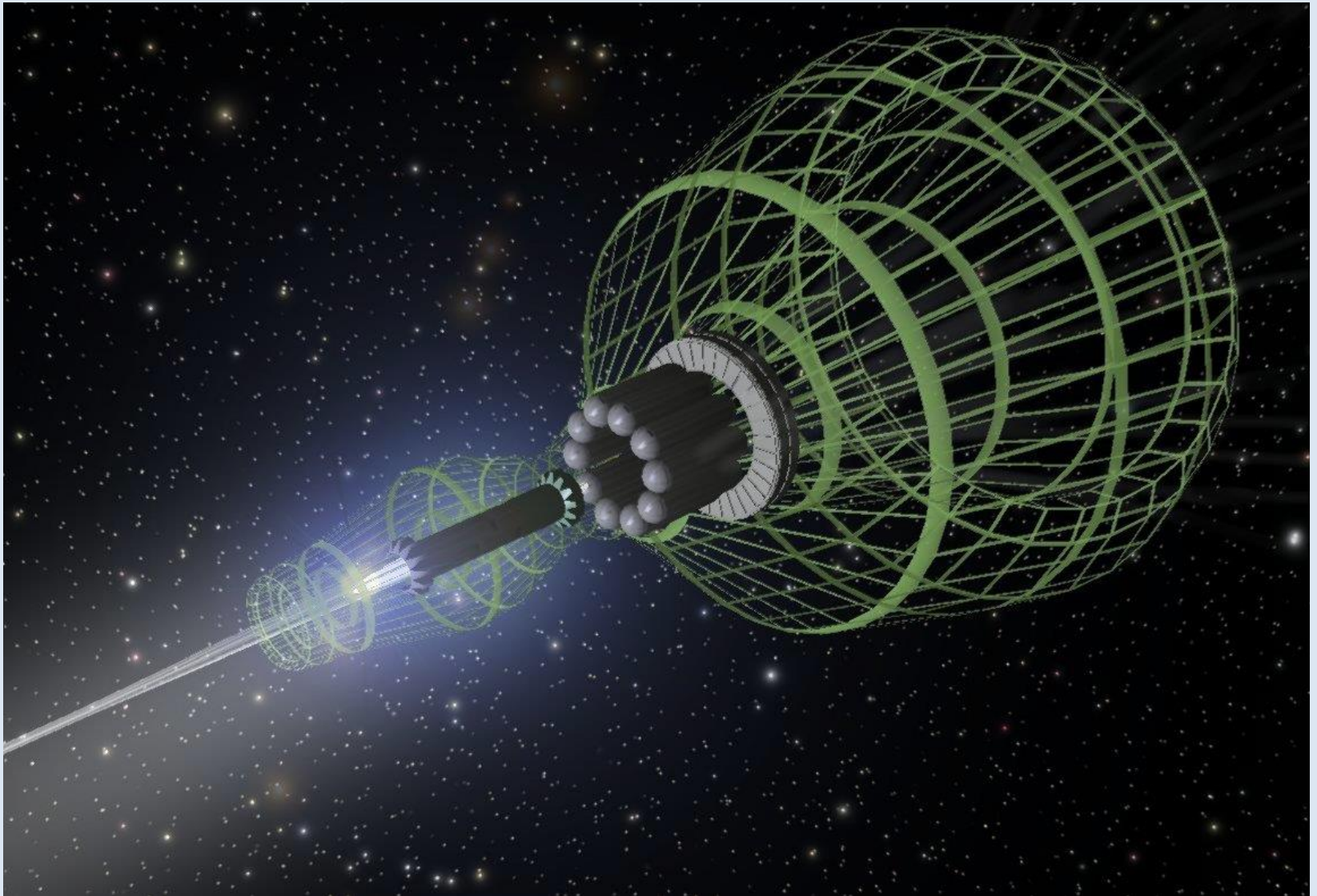
2055

Google BotNet



2060

Exploring Alpha Centauri



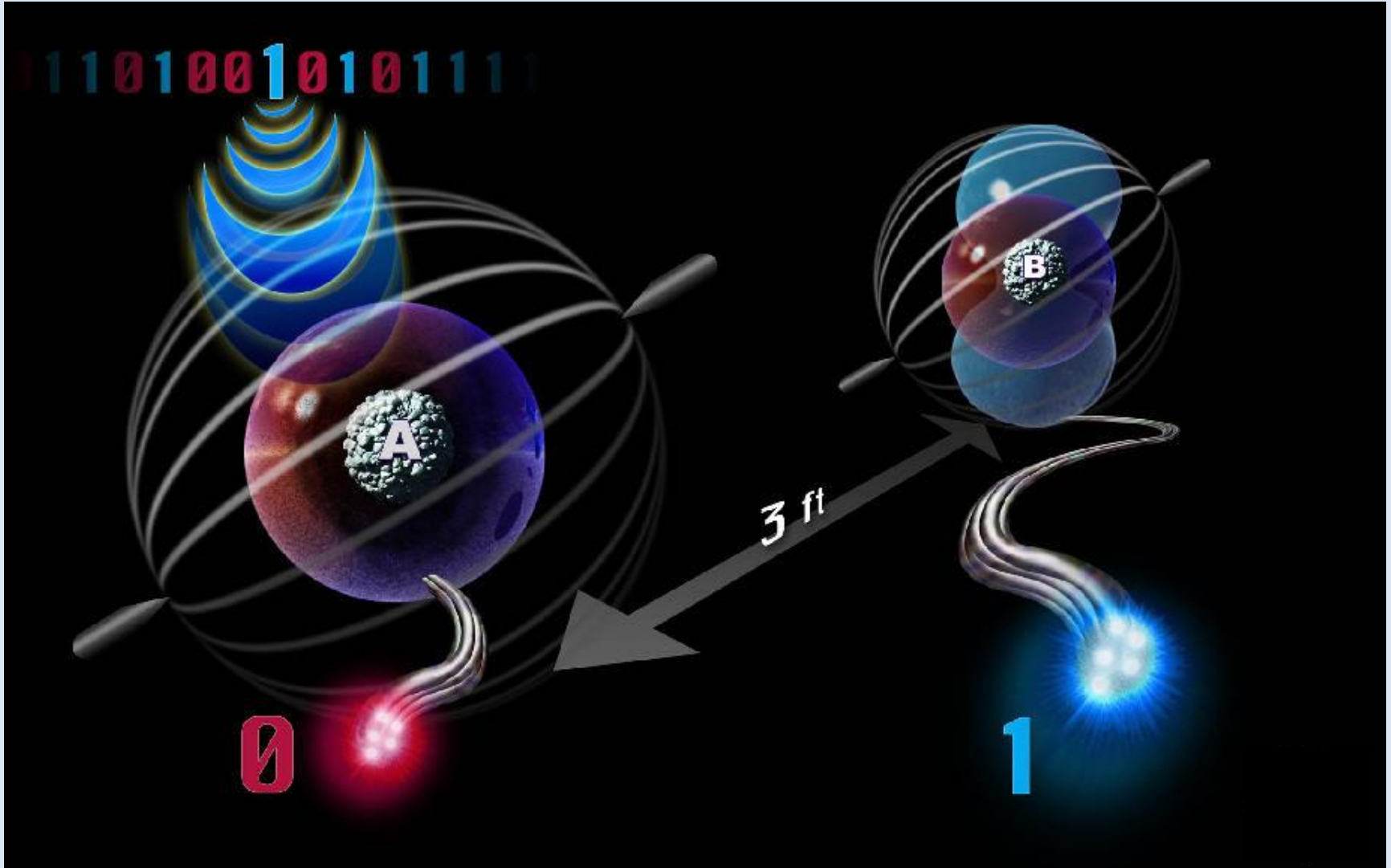
2080

Von Neumann Probes



2100

Teleportation Test



2120

Mastery of the Solar System





THE END...

...OF THE BEGINNING