The Long Space Age: An Economic History of American Space Exploration

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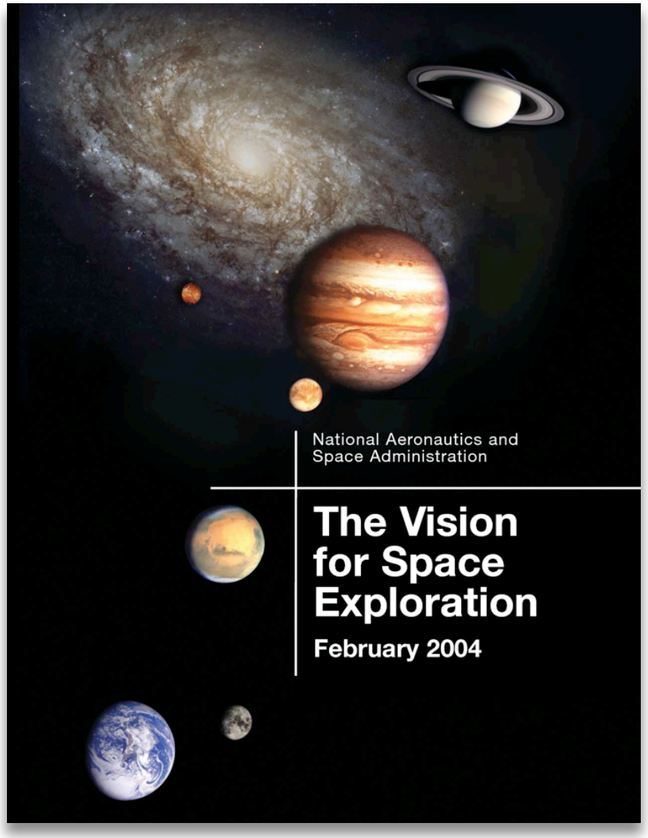
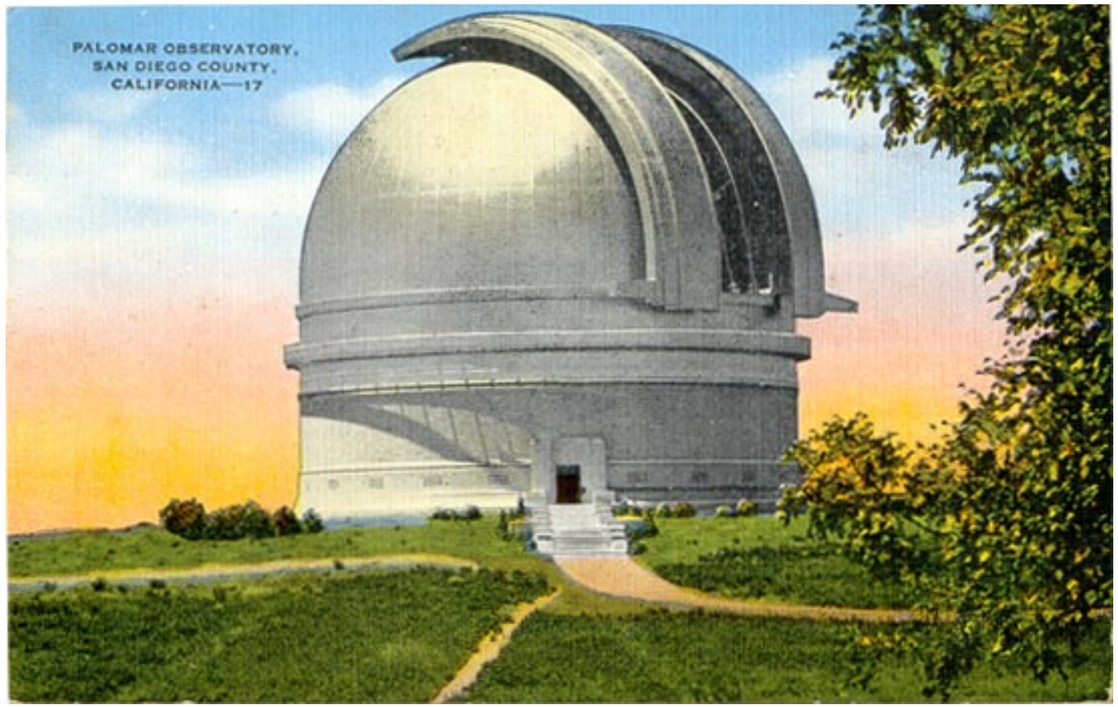
Keck Institute for Space Studies Lecture
California Institute of Technology
Guggenheim Building
May 27, 2014

Questions

- Who has funded space exploration over time?
- How often has the private-sector funded projects of equivalent size to SpaceShipOne (~$28M) or Elon Musk's founding of SpaceX (~$100M)?
- Are there patterns and trends in the motivations that drive the funding of large space exploration projects?
- What can the past tell us about our options for the future of space exploration and space development?





“Like buried treasures, the outposts of the universe have beckoned to the adventurous from immemorial times. Princes and potentates, political or industrial, equally with men of science, have felt the lure of the uncharted seas of space, and through their provision of instrumental means the sphere of exploration has rapidly widened.”

George Ellery Hale, ‘The Possibilities of Large Telescopes’, *Harper’s*, 1928

Expenditure on U.S. Observatories, 1820-1940: Summary

Total Number of Observatories and Endowments in Data Set	42
Total PWC Adjusted Value of Expenditures in 2010 U.S. Dollars	$2,141,831,040
Total GDP-Ratio Adjusted Value of Expenditures in 2010 U.S. Dollars	$7,912,600,000
Percentage of Total GDP-Ratio Equivalent Expenditures Supplied by Government Funds	3.4%
Percentage of Total GDP-Ratio Equivalent Expenditures Supplied by Private-Sector Funds	96.6%

***Methods for Converting to Current-Year Dollar Equivalents:**

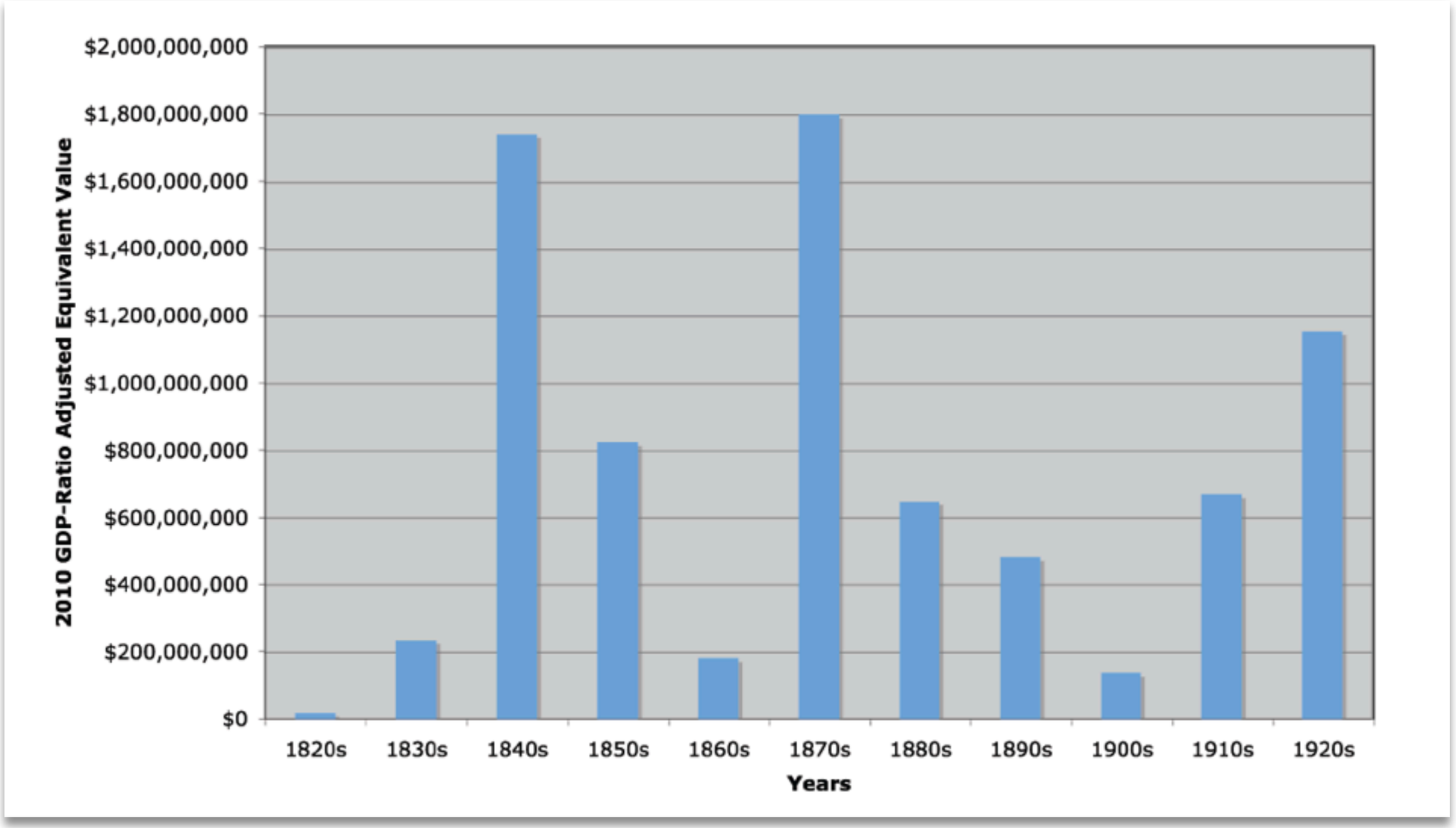
1) Production Worker Compensation (PWC) - adjust for cost of principle input of space exploration, which is skilled labor.

2) Gross Domestic Product (GDP) - adjust for size of the economy as a whole.

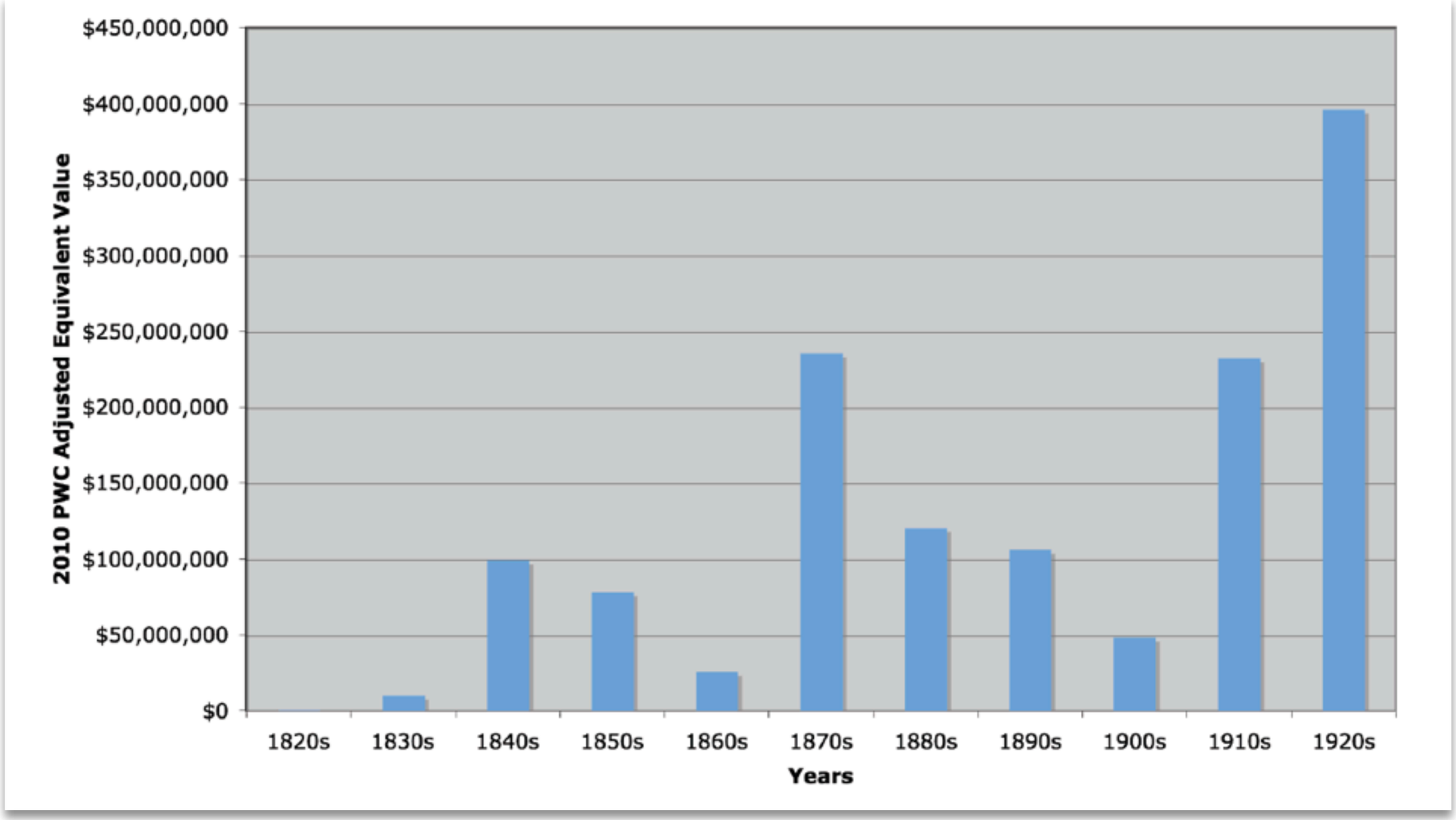
Project	Year	Current Prices in U.S Dollars ($)	Constant Prices in U.S. Dollars ($) adjusted by PWC index, base year 2010*	GDP-ratio Equivalent Value in U.S. Dollars ($) adjusted by ratio to GDP, base year 2010**
Yale College Observatory	1828	1,200	661,000	19,600,000
University of North Carolina Observatory	1831	6,400	3,020,000	89,200,000
Hopkins Observatory	1836	6,100	3,100,000	60,500,000
Western Reserve College Observatory	1836	4,000	2,030,000	39,700,000
Philadelphia High-School Observatory	1837	5,000	2,170,000	47,200,000
West Point Academy	1842	5,000	2,070,000	45,300,000
U.S. Naval Observatory	1842	25,000	10,300,000	227,000,000
Cincinnati Observatory	1843	16,000	7,550,000	150,000,000
Harvard College Observatory	1844	50,000	23,200,000	431,000,000
Georgetown Observatory	1844	27,000	12,500,000	233,000,000
Jackson Observatory	1845	4,000	1,860,000	31,600,000
Edward Philips Endowment - Harvard	1848	100,000	40,700,000	604,000,000
Shelby College Observatory	1848	3,500	1,420,000	21,200,000
Detroit Observatory	1852	22,000	8,680,000	105,000,000
Shattuck Observatory	1852	11,000	4,340,000	52,600,000
Litchfield Observatory	1854	50,000	19,400,000	198,000,000
Dudley Observatory	1854	119,000	46,300,000	470,000,000
Allegheny Observatory	1862	32,000	9,300,000	80,300,000
Vassar College Observatory	1865	14,000	3,310,000	20,600,000

Project	Year	Current Prices in U.S Dollars ($)	Constant Prices in U.S. Dollars ($) adjusted by PWC index, base year 2010*	Equivalent Value in U.S. Dollars ($) adjusted by ratio to GDP, base year 2010**
Dearborn Observatory	1865	56,000	13,200,000	82,300,000
Winchester Observatory	1871	100,000	22,800,000	191,000,000
Halsted Observatory	1872	60,000	13,600,000	106,000,000
Morrison Observatory	1874	100,000	22,400,000	171,000,000
Lick Observatory	1876	700,000	162,000,000	1,220,000,000
Washburn Observatory	1876	65,000	15,100,000	114,000,000
Warner Observatory	1880	100,000	23,800,000	140,000,000
McCormick Observatory	1881	135,000	32,400,000	169,000,000
Kenwood Physical Observatory	1888	25,000	5,160,000	26,200,000
Elias Loomis Endowment - Yale	1889	300,000	59,600,000	315,000,000
Goodsell Observatory	1890	65,000	12,900,000	62,600,000
Chamberlin Observatory	1890	56,000	11,110,000	54,000,000
Ladd Observatory	1891	30,000	5,960,000	28,300,000
Yerkes Observatory	1895	349,000	73,200,000	325,000,000
McMillan Observatory	1895	16,000	3,360,000	14,900,000
New Allegheny Observatory	1906	300,000	48,700,000	140,000,000
Mount Wilson Observatory	1910	1,450,000	219,000,000	630,000,000
Griffith Observatory	1919	225,000	13,800,000	41,700,000
Perkins Observatory	1925	379,000	19,900,000	60,800,000
Mount Palomar Observatory	1928	6,550,000	334,000,000	977,000,000
McDonald Observatory	1929	840,000	43,000,000	118,000,000

Decadal Expenditures on U.S. Observatories, 1820s to 1920s: GDP-ratio adjusted equivalent value in 2010 dollars



Decadal Expenditures on U.S. Observatories, 1820s to 1920s: PWC-ratio adjusted equivalent value in 2010 dollars



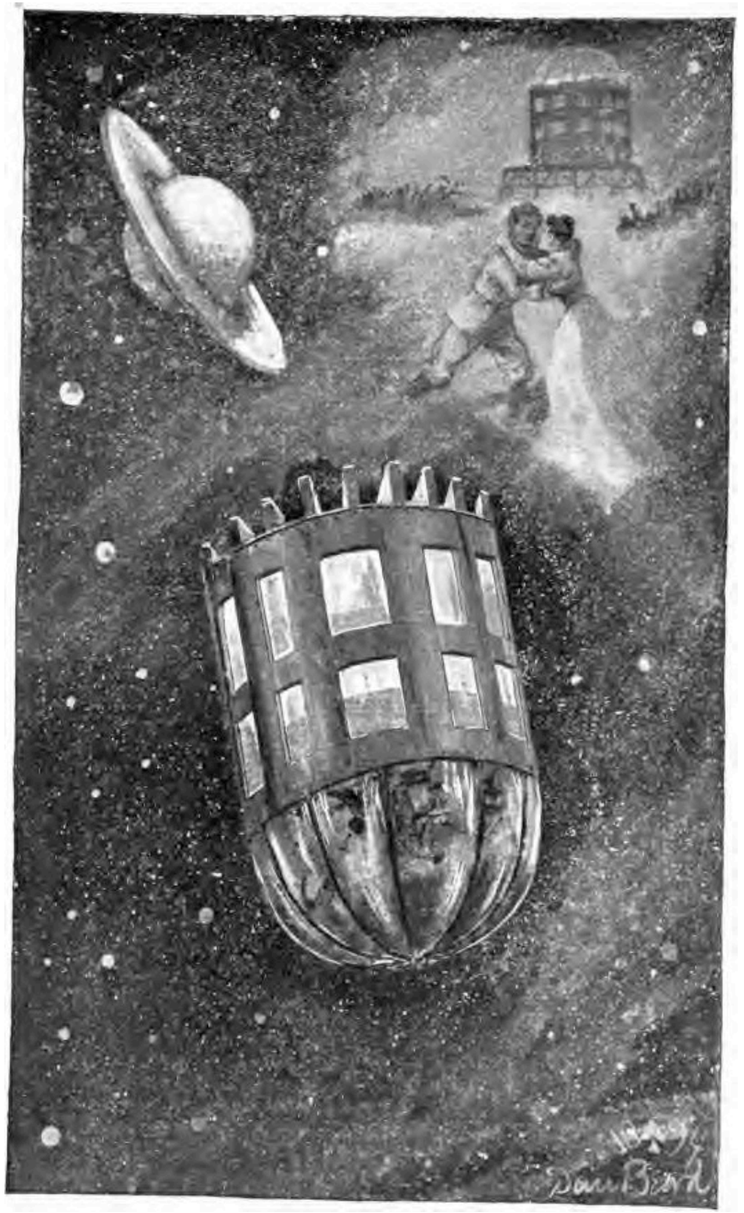
The Development of American Spaceflight Concepts in the 1800s:

- Three individuals independently develop concepts for human spaceflight in the U.S. in the 1830s:
  1) Edgar Allan Poe
  2) John Leonard Riddell
  3) Edward Everett Hale

- Jules Verne's *From the Earth to the Moon* (1865) depicts three passengers departing from Florida on a three-day voyage to the Moon with first known spaceflight cost-estimate $4,000,000 ($8 billion GDP-adjusted / $1.3 billion PWC-adjusted), privately-funded by voluntary contribution

- Edward Hale's 'The Brick Moon' (1869-1870) space station concept, with 37 inhabitants, introduces utopian themes for space habitation that are carried even further in *Man Abroad* (1877) which depicts the United States of America expanding to encompass the solar system

- John Jacob Astor IV's *A Journey in Other Worlds* (1894) first to describe a role for government, though minor, in the development of spaceflight



Robert Goddard (1885-1945): The First American Spaceflight Entrepreneur

"In the history of rocketry, Dr. Robert H. Goddard has no peers. He was first. He was ahead of everyone in the design, construction, and launching of liquid-fuel rockets which eventually paved the way into space"

Werner Von Braun, 1970

First to achieve flight with a liquid-fuel rocket

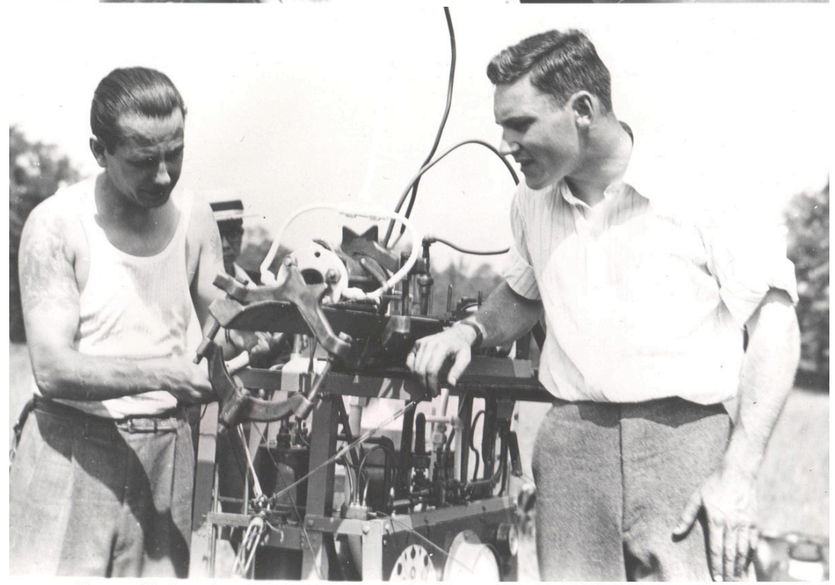
First to raise significant funds for spaceflight technology

- Age 16 reads *War of the Worlds* and *Edison's Conquest of Mars,* and commits himself to spaceflight
- Intrinsic motivations drive his supply of (virtuoso) labor.

Year	Source	Nominal Value in U.S dollars ($)	Constant-Price Value in U.S. Dollars ($) adjusted by PWC index, base year 2010*	GDP-Ratio Equivalent Value in U.S. dollars ($) adjusted by ratio to GDP, base year 2010**
1917	Smithsonian (Hodgkins Fund)	5,000	464,000	1,220,000
1918	U.S. Army Signal Corp	25,000	1,850,000	4,790,000
1921	Clark University	2,500	137,000	493,000
1922	Clark University	1,000	59,500	198,000
1924	Smithsonian (Cottrell Fund)	5,000	261,000	835,000
1924	AAAS	190	9,910	31,700
1928	Smithsonian (Operations)	1,750	89,200	261,000
1929	Smithsonian (Research Corporation)	2,500	128,000	351,000
1929	Smithsonian (Operations)	2,500	128,000	351,000
1930	Carnegie Institute of Washington	5,000	251,000	796,000
1931	Daniel Guggenheim	50,000	2,580,000	9,490,000
1932	Smithsonian (Hodgkins Fund)	250	14,800	61,900
1933	Guggenheim Foundation	2,500	150,000	644,000
1934	Guggenheim Foundation	18,000	903,000	3,960,000
1935	Guggenheim Foundation	18,000	878,000	3,570,000
1936	Guggenheim Foundation	20,000	961,000	3,470,000
1937	Guggenheim Foundation	20,000	839,000	3,160,000
1938	Guggenheim Foundation	20,000	826,000	3,370,000
1939	Guggenheim Foundation	20,000	826,000	3,150,000
1940	Guggenheim Foundation	20,000	789,000	2,870,000
1941	Guggenheim Foundation	3,000	107,000	344,000
1942	Army Air Force	13,000	400,000	1,170,000
1942	Navy Bureau of Aeronautics	87,267	2,680,000	7,830,000
1943	Navy Bureau of Aeronautics	104,600	2,820,000	7,650,000
	Private Sources	217,190	10,401,410	38,626,600
	Military	229,867	7,750,000	21,440,000
	Total	447,057	18,151,410	60,066,600

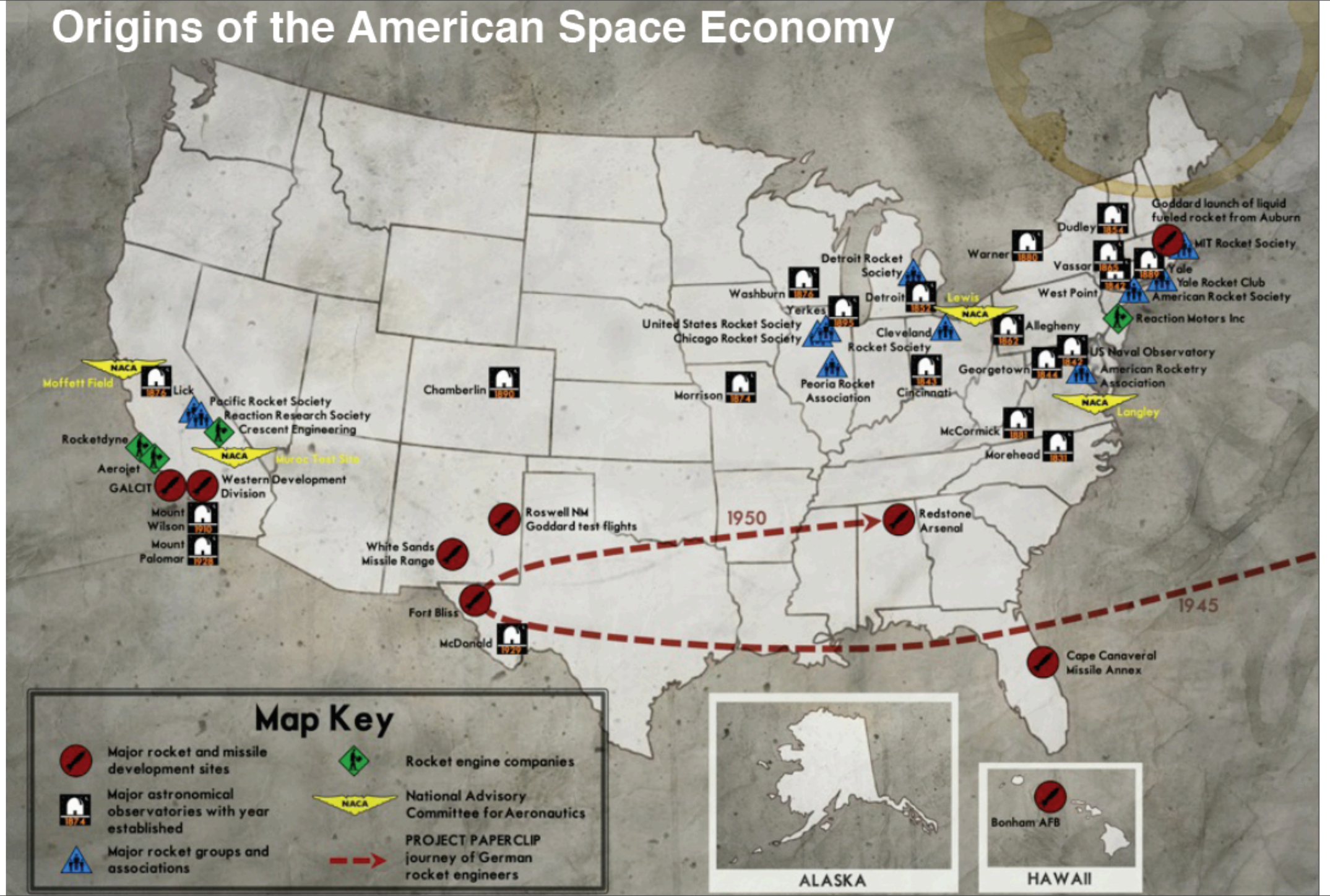
American Rocket Society (1930-1963) and Reaction Motors Incorporated (1941-1958)

- American Interplanetary Society, New York; Hugo Gernsback, David Lasser, Edward Pendray; sci-fi writers and rocket hackers; evolves into American Rocket Society (ARS); evolves into AIAA
- Reaction Motors Incorporated, 1941; New Jersey; members from ARS; *first company formed dedicated to the pursuit of spaceflight*
- Laurance Rockefeller, one of the first 'Venture Capitalists', invests $500,000 for 21% of company in 1947



James Wyld's engine, "the first rocket engine to use regenerative cooling in America," according to author Gregory Kennedy, is tested on June 8, 1941, in New Jersey. The motor "operated successfully and for long periods without burnout," information with the photograph said. From left are American Rocket Society members Hugh Franklin Pierce, and Robert Youngquist. - Image Credit: Smithsonian Institution/NMMSH Archives

Origins of the American Space Economy




4 ОКТЯБРЯ
1957 г.
Первый в мире
советский
искусственный
спутник Земли
40
коп. ПОЧТА СССР

NASA


NASA


USA

Sputnik, the Cold War, and Signaling

"One can predict with confidence that failure to master space means being second-best in the crucial arena of our Cold War world.
In the eyes of the world, first in space means first, period;
second in space is second in everything." Vice-President Johnson, 1961

- Signals are costly actions that can credibly transmit information; 'difficult to make and difficult to fake'; particularly useful in conditions of asymmetric information (imagine yourself in Ghana or Vietnam in 1957)
- Sputnik shocked the U.S. and the world because it provided new information about the state of Soviet technical capabilities that were not widely known

"Since mastery of the elements is a reliable index of material progress, the nation which first makes significant achievements in space travel will be acknowledged as the world leader in both military and scientific techniques. To visualize the impact on the world, one can imagine the consternation and admiration that would be felt here if the United States were we to discover suddenly, that some other nation had already put up a successful satellite"
RAND Corporation, 'Preliminary Design of an Experimental World-Circling SpaceShip, 1946

The Apollo Anomaly

- John Logsdon's work has made it apparent that President Kennedy had no particular enthusiasm for space exploration
- 1961: Yuri Gagarin, Bay of Pigs Fiasco in Cuba
- Space achievements became, briefly, a matter of existential geo-political importance
- But by June of 1961, Kennedy proposed a lunar landing as a partnership with the Soviet Union to Khrushchev in their meeting in Vienna, and then again in 1963 at the U.N.; as willing to sacrifice an American lunar landing to signal peace as to conduct it to signal American leadership

Secret of Defense, Robert McNamara on Apollo

“All large scale space programs require the mobilization of resources on a national scale. They require the development and successful application of the most advanced technologies. Dramatic achievements in space, therefore, symbolize the technological power and organizing capacity of a nation. It is for reasons such as these that major achievements in space contribute to national prestige. This is true even though the scientific, commercial or military value of the undertaking may, by ordinary standards, be marginal or economically unjustified.”

Robert McNamara, “Brief Analysis of Department of Defense Space Program Effects”, April 21, 1961

The Space Shuttle - ‘Because space flight was here to stay”

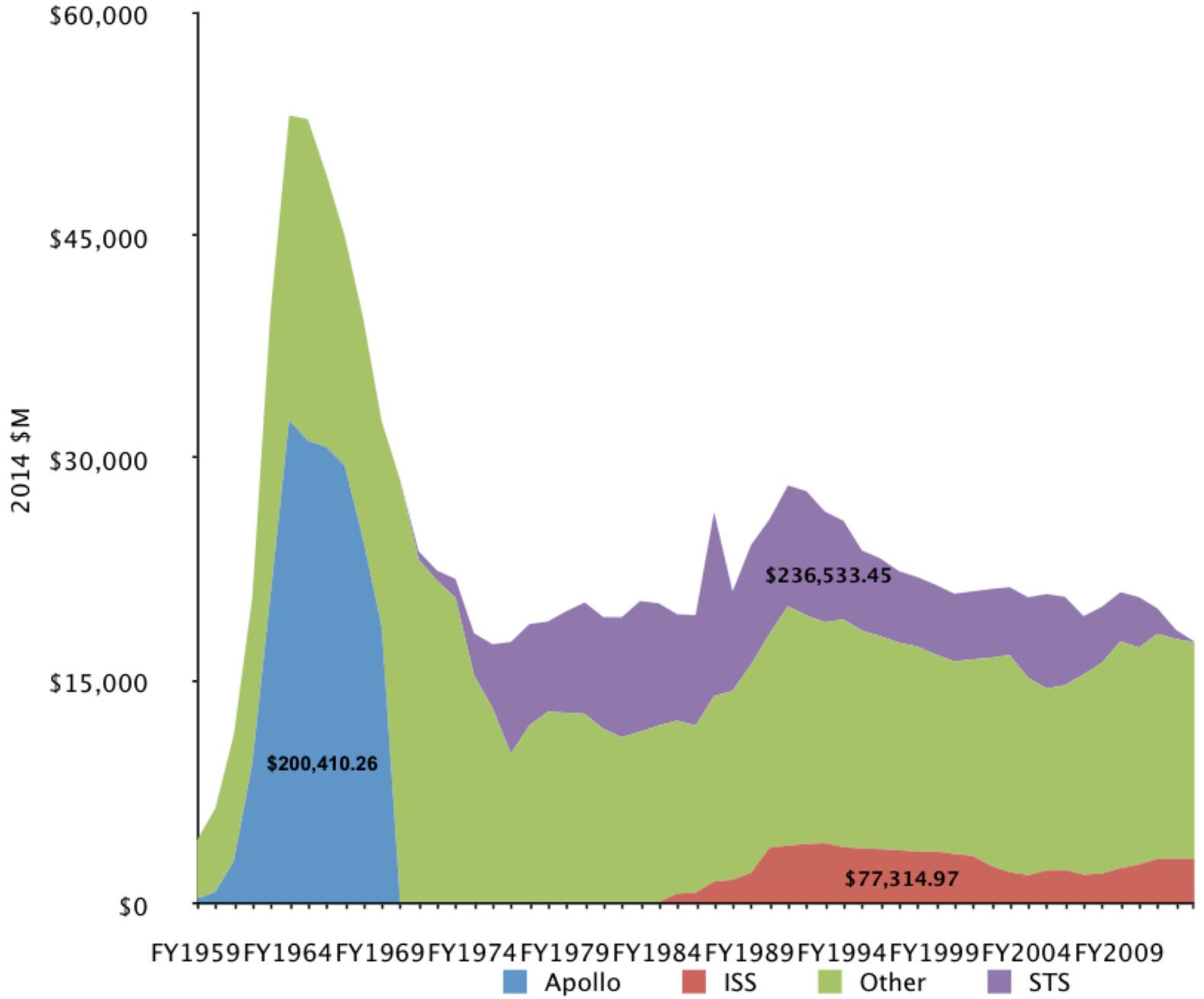
“It is much more difficult to recede from a scale of expenditure once adopted than it is to extend the accustomed scale in response to an accession of wealth” Thorstein Veblen, 1899

- Starting in 1965, Congress reduces support for human spaceflight; Nixon cancels Apollo missions 18-20
- Human spaceflight continues and is reborn with the Space Shuttle and the ‘re-useable spaceplane’ vision
- Nixon’s Deputy Director of OMB, Caspar Weinberger, wrote that he believed it would be a negative signal to fail to commit to a new spaceflight program; didn’t care what it was; Nixon, ‘Ok, I agree with Cap’;

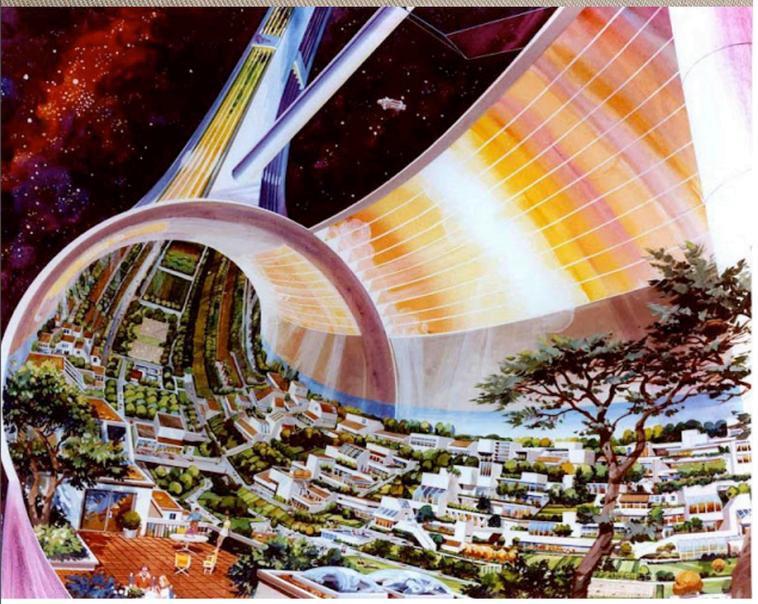
“*Even if it was not a good investment, the nation would have to do it anyways, because space flight was here to stay. Men are flying in space now and will continue to fly in space, and we’d best be part of it*”
NASA Deputy Administration quoting President Nixon in1972

The Space Station - “Freedom” to “International”

- ‘Space Station Freedom’ was the first, and thus far only, major NASA initiative to have been integrated at a high-level into a Presidential campaign
- 1984 State of the Union; incumbent President Reagan talking about ‘Morning in America’, but has a large deficit to deal with
- Space Station Freedom at ‘$8 billion’, for a high-visibility, technology-investment program, was a low-cost signal
- Official Reagan-Bush 1984 Campaign Brochure, Goal #2: “Develop space, America’s Next Frontier
- *...then the Challenger Disaster in 1986, End of the Cold War in 1991*
- President Clinton wanted to signal his willingness to work with Russia and to reduce government spending; ISS redesign savings accounted for 2% of Clinton’s 1993 spending cuts


$60,000
$45,000
$30,000
$15,000
$0
2014 $M
$200,410.26
$236,533.45
$77,314.97
FY1959
FY1964
FY1969
FY1974
FY1979
FY1984
FY1989
FY1994
FY1999
FY2004
FY2009
Apollo
ISS
Other
STS

Meanwhile, in the private-sector...



- Harvest Moon Project: 1970-1972, 'The Committee for the Future', supported by Barbara Marx Hubbard, heiress to the Marx Toy fortune, proposed to use cancelled Apollo hardware for a privately-financed venture to the Moon to deploy;
  1) prototype lunar garden under a plastic dome
  2) a robot lunar rover
  3) a laser communications relay system
  4) a small telescope, 'First Lunar Observatory'

- Olin Teague, (D-Texas), Chair of House Science Committee's Manned Spaceflight Subcommittee, introduced House resolution in 1972, calling for NASA to donate hardware to CFF

- Gerald O'Neill's 'space colonies' vision for space settlement had spurred the L5 Society to ~10,000 members by 1986

- First Era of 'New-Space' 1980-99: Space Industries Incorporated; SpaceHab; MirCorp; SpaceDev; BlastOff!; Bigelow Aerospace

The New Millennium: The Return of the Private-Sector to Space

- Internet produces ‘tech-billionaires’ who start space companies
  - Jeff Bezos, Amazon.com, Blue Origin (2000)
  - John Carmack, Doom/Quake, Armadillo Aerospace (2000)
  - Elon Musk, PayPal.com, SpaceX (2002)
  - Paul Allen, Microsoft, “SpaceShipOne” (2004)
  - Richard Branson, Virgin Group, Virgin Galactic (2004)
  - Larry Page & Sergey Brin, Google, Google Lunar X Prize (2007)

- 2004-2014: Commercial Spaceflight Federation estimates that these and other ‘commercial space companies’ have had private investment of $2.5B; comparable to $1.8B for private observatories in 1870s;

National Aeronautics and Space Administration

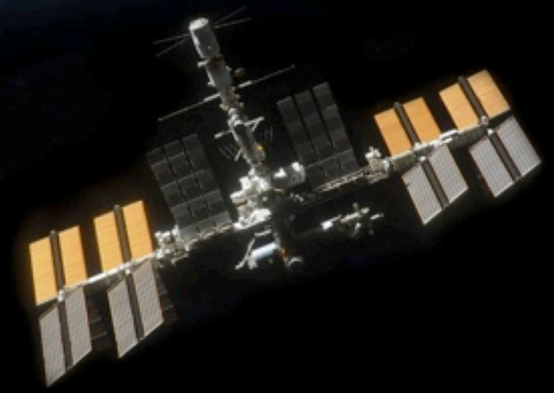
Commercial Crew Program


Blue Origin


Boeing


Sierra Nevada


Space X




ATK


Excalibur


ULA

HUMAN EXPLORATION

NASA's Path to Mars

EARTH RELIANT

MISSION: 6 TO 12 MONTHS
RETURN TO EARTH: HOURS

Mastering fundamentals aboard the International Space Station

U.S. companies provide access to low-Earth orbit

PROVING GROUND

MISSION: 1 TO 12 MONTHS
RETURN TO EARTH: DAYS

Expanding capabilities by visiting an asteroid redirected to a lunar distant retrograde orbit

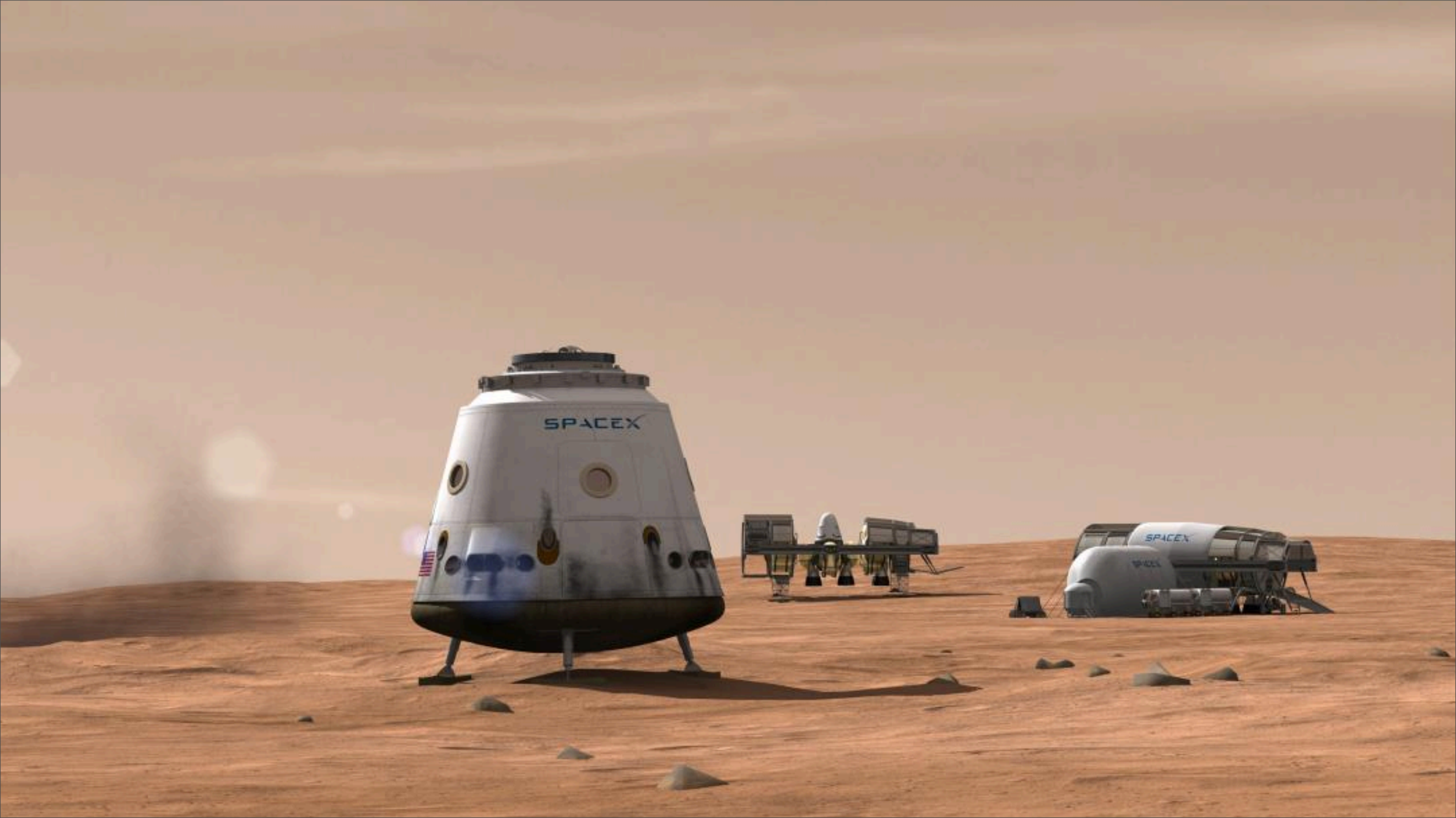
The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion spacecraft

MARS READY

MISSION: 2 TO 3 YEARS
RETURN TO EARTH: MONTHS

Developing planetary independence by exploring Mars, its moons and other deep space destinations

www.nasa.gov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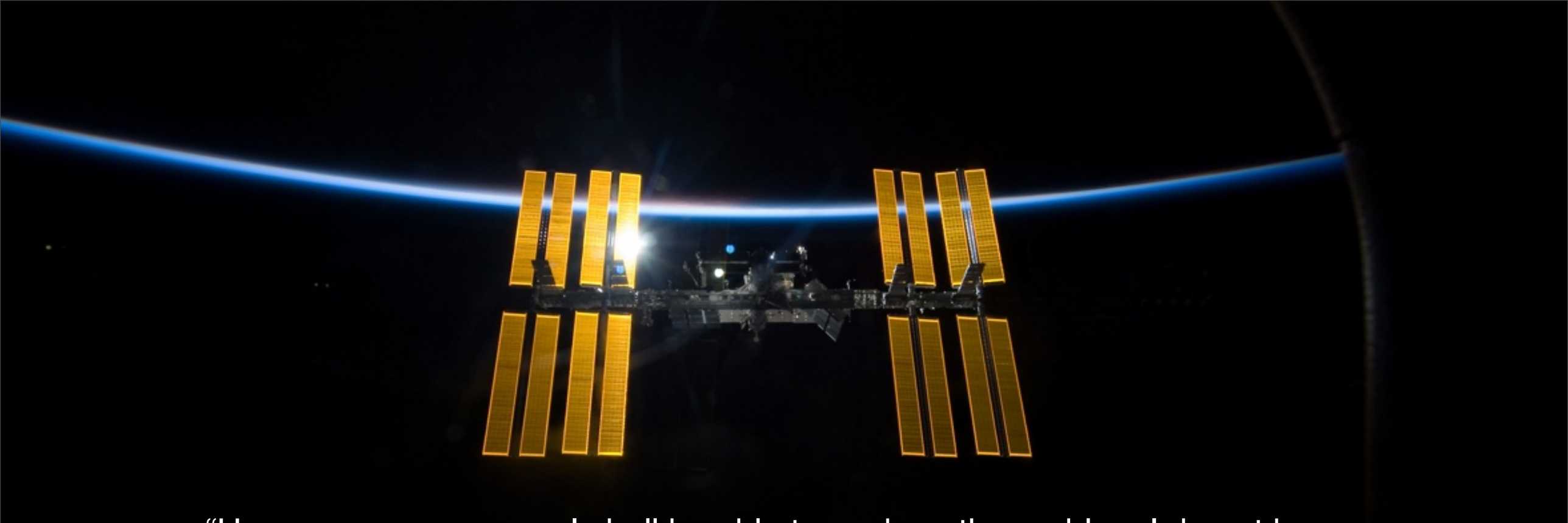
Lessons Learned:

1. Private funding and intrinsic motivations for space exploration in America have a robust history and have, at times, been the primary source of support
2. Signaling motivations are another strong source of demand, and have proven especially so now that space exploration has been firmly been embedded in a federal agency
3. Expenditure on space exploration has been volatile on a per-decade basis for almost two centuries and there is no reason to expect this to change
4. Institutional transitions and the regular creation of new institutions have been important features of the evolution of American space exploration capabilities over time
5. Space exploration as an economic outcome can be thought of as the result of the interaction of actors with a 'taste' for space exploration (intrinsically motivated - although this taste can be transmitted) either self-supporting or entering into exchange with others (political, military, commercial, philanthropic, etc.) on some basis for resources



“How many more years I shall be able to work on the problem I do not know;
I hope, as long as I live.
There can be no thought of finishing, for ‘aiming at the stars’ both literally and figuratively, is a problem to occupy generations, so that no matter how much progress one makes, there is always the thrill of just beginning”

Robert Goddard, in personal letter to H.G. Wells, 1932