The Long Space Age

The Economic Origins of Space Exploration from Colonial America to the Cold War

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Questions

- Who has funded space exploration over time?
- How often has the private-sector funded projects of equivalent size to SpaceShipOne (~$30M) or Elon Musk's founding of SpaceX (~$100M) or Jeff Bezos's funding of Blue Origin (~$1B)?
- Are there patterns and trends in the motivations that have driven the funding of space exploration projects in the U.S. going back to the Colonial Era?
- What can the past tell us about how we might best advance space exploration and space development today?

Key Concepts

- Intrinsic Motivation: behavior driven by internal interest and enjoyment that is sustainable without regard to external incentive or reward.

- Signaling: behavior where one party credibly conveys some information about itself to other parties through costly action.

John Quincy Adams (1767-1848)
6th U.S. President (1825-1829) and 1st American Space Advocate

Firm believer in science and astronomy

- "The science of astronomy is the intercourse of immortal man with the universe"

First Annual Address to Congress in 1825

- Proposed a major astronomical observatory
- "If we reflect a moment upon the discoveries which, in the last four centuries, have been made in the physical constitution of the universe by the means of these buildings, and of observers stationed in them, shall we doubt of their usefulness to every nation?"
- Congress strongly opposed the project

House of Representatives 1831-1848

- Smithson bequest in 1836 ($300M/$6B today)
- Chair of the House Committee on the Smithsonian, proposes plan with observatory
- Compares U.S. efforts unfavorably with Russia's
- Overall plan accepted, minus the observatory

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

Total number of observatories and endowments in data set	**40**
Total PWC-ratio adjusted value of expenditures in 2015 U.S. dollars	**$1,568,764,000**
Total GDP-ratio adjusted value of expenditures in 2015 U.S. dollars	**$9,737,400,000**
Percentage of GDP-ratio equivalent expenditures from government funds	**3.4%**
Percentage of GDP-ratio equivalent expenditures from private-sector funds	**96.6%**

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

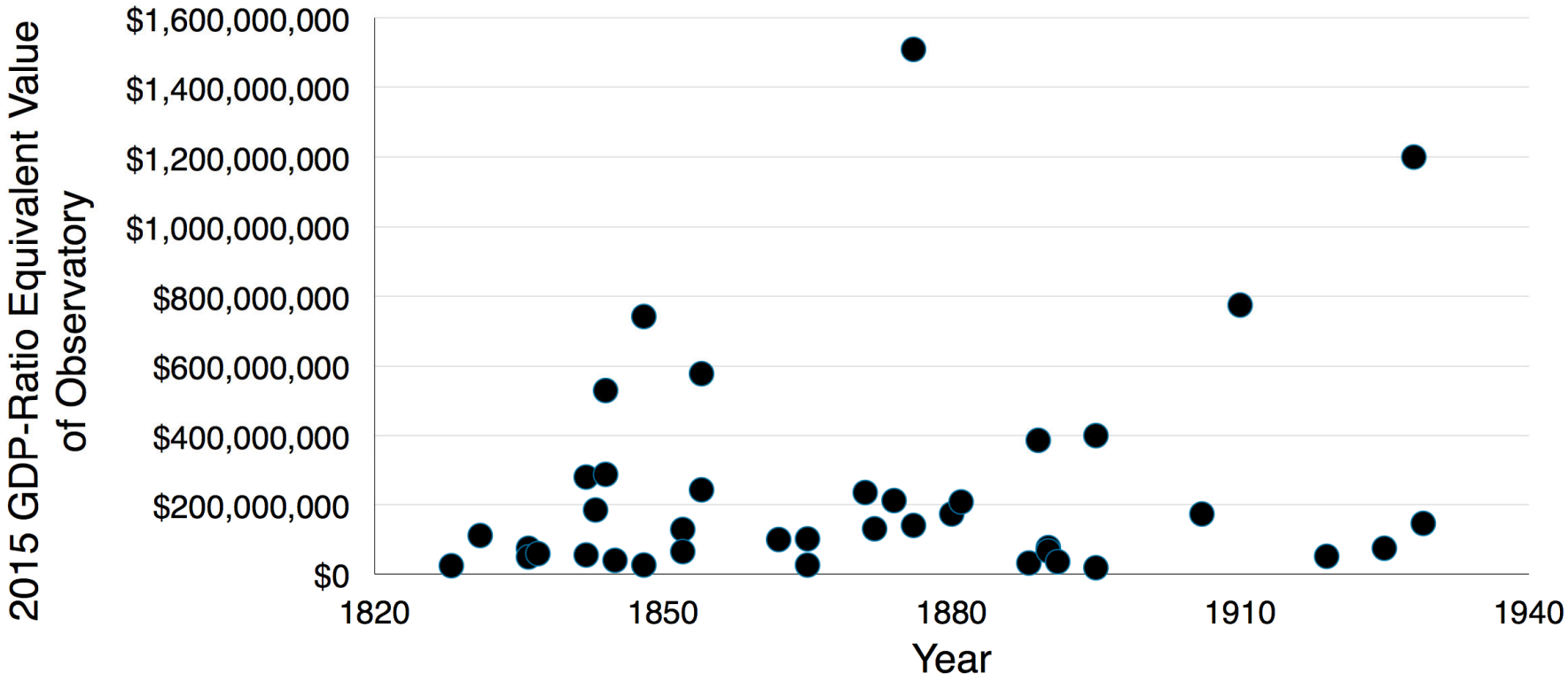
1) Production Worker Compensation (PWC) - adjust for cost of principle input of space exploration, which is skilled labor.

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

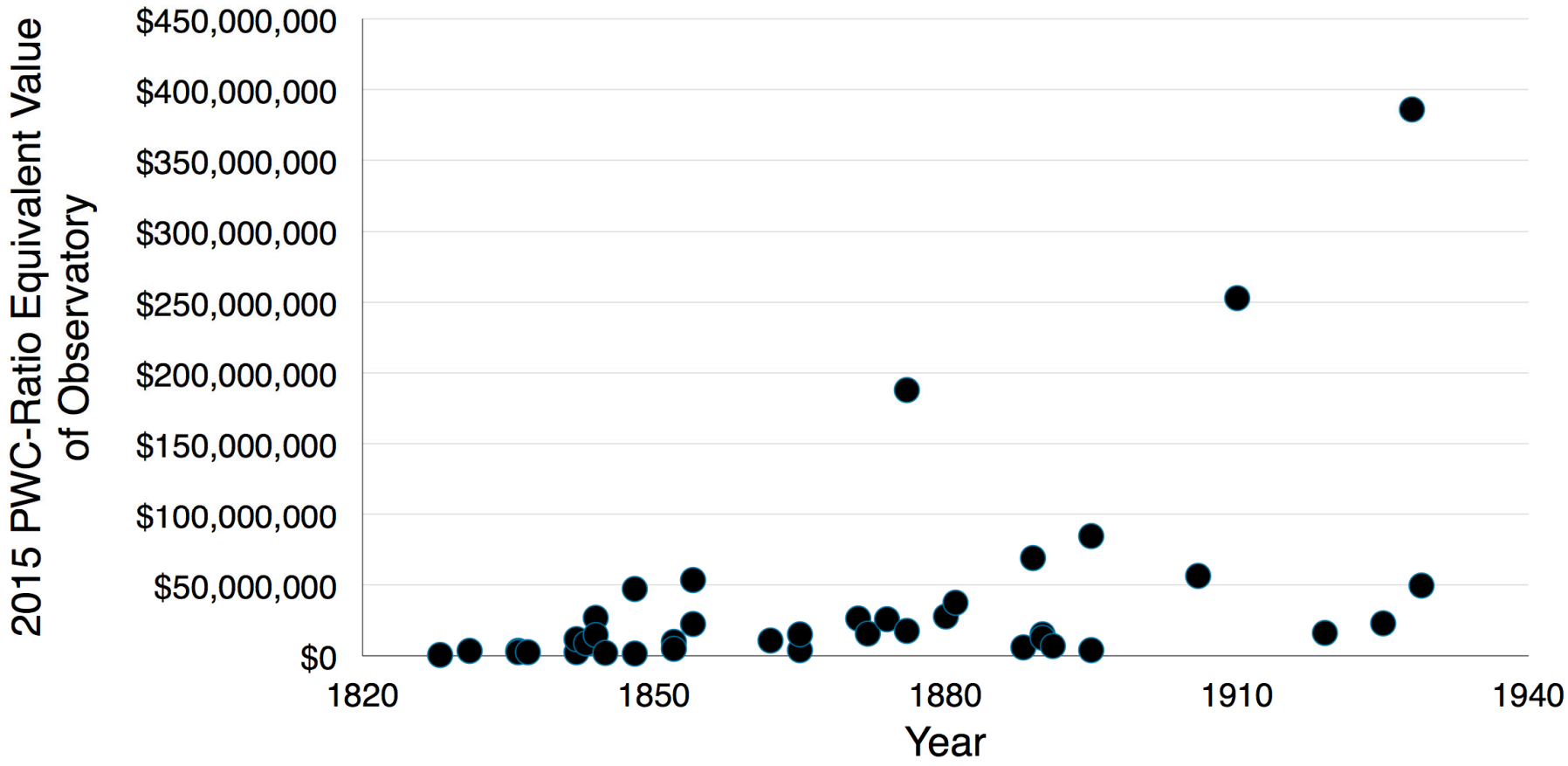
Project	Year	Nominal Prices in U.S. Dollars ($)	Constant Prices in 2015 PWC-adjusted U.S. Dollars ($)	GDP-ratio Equivalent Value in 2015 U.S. Dollars ($)
Yale College Observatory	1828	1,200	764,000	24,100,000
University of North Carolina Observatory	1831	6,400	3,490,000	110,000,000
Hopkins Observatory	1836	6,100	3,580,000	74,400,000
Western Reserve College Observatory	1836	4,000	2,350,000	48,800,000
Philadelphia High-School Observatory	1837	5,000	2,500,000	58,000,000
West Point Academy	1842	5,000	2,390,000	55,700,000
U.S. Naval Observatory	1842	25,000	11,900,000	279,000,000
Cincinnati Observatory	1843	16,000	8,730,000	184,000,000
Harvard College Observatory	1844	50,000	26,800,000	530,000,000
Georgetown Observatory	1844	27,000	14,500,000	286,000,000
Jackson Observatory	1845	4,000	2,140,000	38,800,000
Edward Philips Endowment – Harvard	1848	100,000	47,000,000	743,000,000
Shelby College Observatory	1848	3,500	1,640,000	26,000,000
Detroit Observatory	1852	22,000	10,000,000	129,000,000
Shattuck Observatory	1852	11,000	5,020,000	64,700,000
Litchfield Observatory	1854	50,000	22,500,000	243,000,000
Dudley Observatory	1854	119,000	53,500,000	578,000,000
Allegheny Observatory	1862	32,000	10,700,000	98,800,000
Vassar College Observatory	1865	14,000	3,820,000	25,300,000

Project	Year	Nominal Prices in U.S. Dollars ($)	Constant Prices in 2015 PWC-adjusted U.S. Dollars ($)	GDP-ratio Equivalent Value in 2015 U.S. Dollars ($)
Dearborn Observatory	1865	56,000	15,300,000	101,000,000
Winchester Observatory	1871	100,000	26,300,000	235,000,000
Halsted Observatory	1872	60,000	15,700,000	130,000,000
Morrison Observatory	1874	100,000	25,900,000	211,000,000
Lick Observatory	1876	700,000	188,000,000	1,510,000,000
Washburn Observatory	1876	65,000	17,400,000	140,000,000
Warner Observatory	1880	100,000	27,500,000	172,000,000
McCormick Observatory	1881	135,000	37,500,000	207,000,000
Kenwood Physical Observatory	1888	25,000	5,970,000	32,200,000
Elias Loomis Endowment – Yale	1889	300,000	68,900,000	387,000,000
Goodsell Observatory	1890	65,000	14,900,000	77,000,000
Chamberlin Observatory	1890	56,000	12,900,000	66,400,000
Ladd Observatory	1891	30,000	6,890,000	34,800,000
Yerkes Observatory	1895	349,000	84,600,000	400,000,000
McMillan Observatory	1895	16,000	3,880,000	18,300,000
New Allegheny Observatory	1906	300,000	56,200,000	173,000,000
Mount Wilson Observatory	1910	1,450,000	253,000,000	775,000,000
Griffith Observatory	1919	225,000	15,900,000	51,300,000
Perkins Observatory	1925	379,000	23,000,000	74,800,000
Mount Palomar Observatory	1928	6,550,000	386,000,000	1,200,000,000
McDonald Observatory	1929	840,000	49,700,000	145,000,000

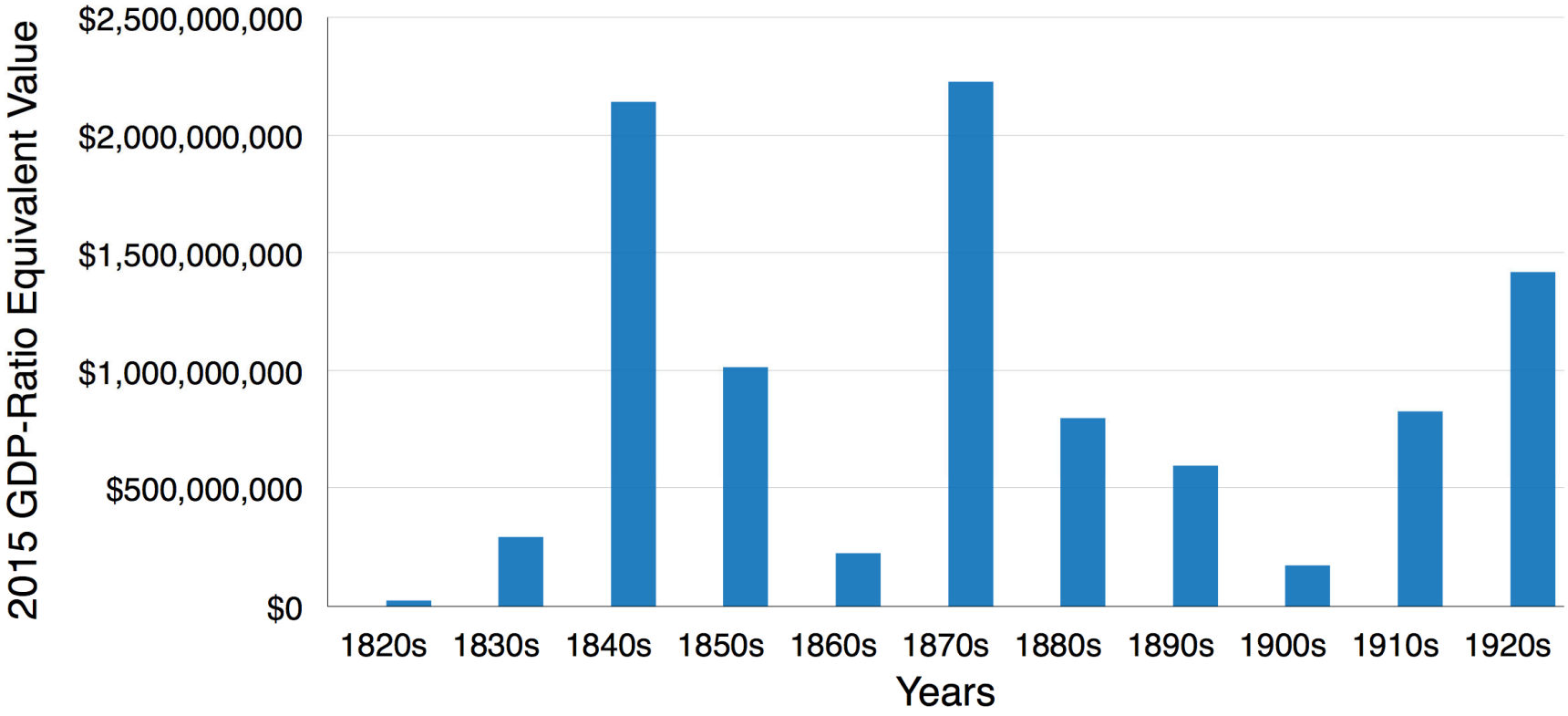
Value of U.S. Observatories, 1820s to 1920s:
GDP-ratio adjusted equivalent value in 2015 dollars



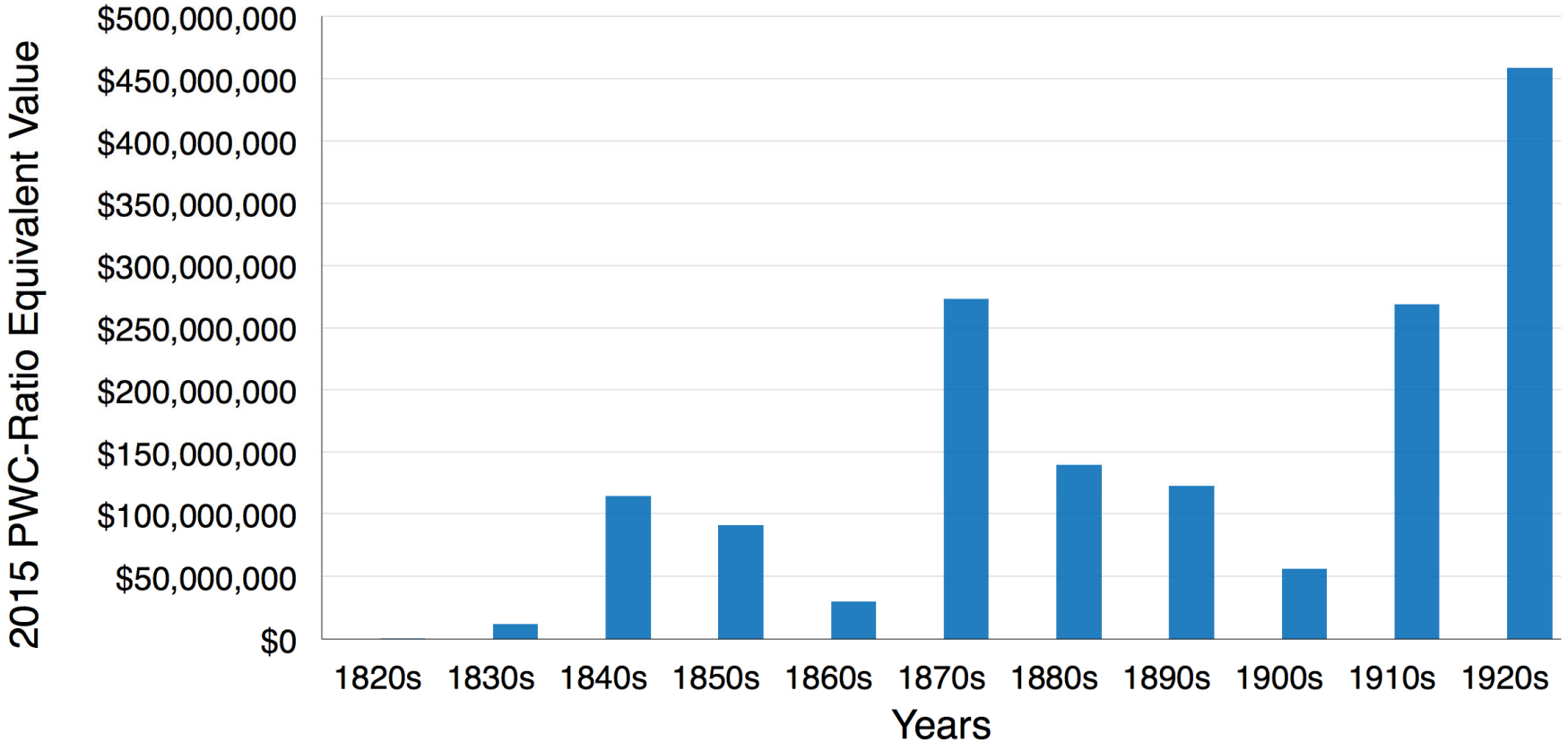
Value of Expenditures on U.S. Observatories, 1820s to 1920s:
PWC-ratio adjusted equivalent value in 2015 dollars



Decadal Expenditures on U.S. Observatories, 1820s to 1920s:
GDP-ratio adjusted equivalent value in 2015 dollars



Decadal Expenditures on U.S. Observatories, 1820s to 1920s: PWC-ratio adjusted equivalent value in 2015 dollars



Robert Goddard (1882-1945): 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

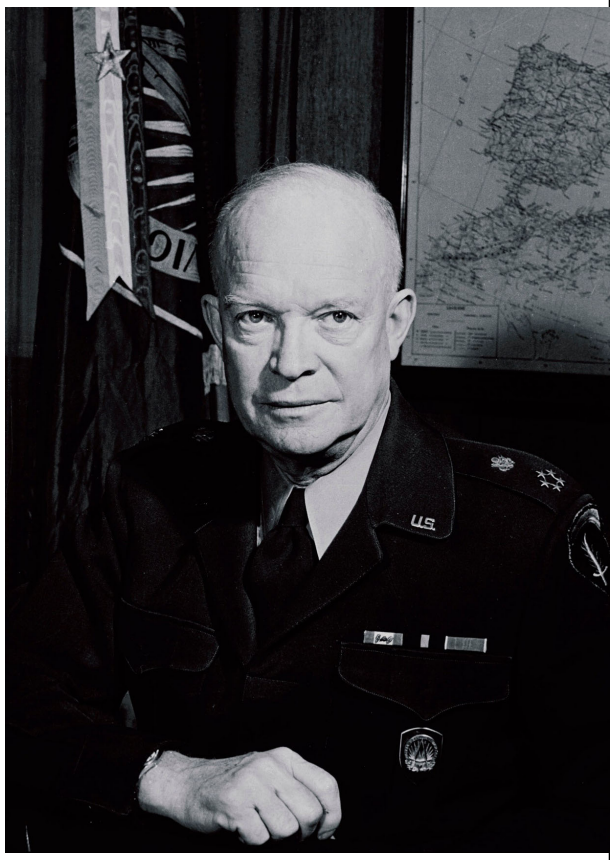
Intrinsic motivations drive his supply of (virtuoso) labor.

Year	Source	Nominal Value in U.S. Dollars ($)	Constant-Price Value in 2015 PWC U.S. Dollars ($)	GDP-Ratio Equivalent Value in 2015 U.S. Dollars ($)
1917	Smithsonian (Hodgkins Fund)	5,000	536,000	1,500,000
1918	U.S. Army Signal Corp	25,000	2,130,000	5,890,000
1921	Clark University	2,500	158,000	607,000
1922	Clark University	1,000	68,800	243,000
1924	Smithsonian (Cottrell Fund)	5,000	301,000	1,030,000
1924	AAAS	190	11,400	39,000
1928	Smithsonian (Operations)	1,750	103,000	321,000
1929	Smithsonian (Research Corporation)	2,500	148,000	431,000
1929	Smithsonian (Operations)	2,500	148,000	431,000
1930	Carnegie Institute of Washington	5,000	290,000	978,000
1931	Daniel Guggenheim	50,000	2,980,000	11,700,000
1932	Smithsonian (Hodgkins Fund)	250	17,100	75,800
1933	Guggenheim Foundation	2,500	173,000	788,000
1934	Guggenheim Foundation	18,000	1,040,000	4,860,000
1935	Guggenheim Foundation	18,000	1,010,000	4,370,000
1936	Guggenheim Foundation	20,000	1,110,000	4,250,000
1937	Guggenheim Foundation	20,000	970,000	3,880,000
1938	Guggenheim Foundation	20,000	955,000	4,130,000
1939	Guggenheim Foundation	20,000	955,000	3,860,000
1940	Guggenheim Foundation	20,000	912,000	3,510,000
1941	Guggenheim Foundation	3,000	124,000	418,000
1942	Army Air Force	13,000	462,000	1,410,000
1942	Navy Bureau of Aeronautics	87,267	3,100,000	9,480,000
1943	Navy Bureau of Aeronautics	104,600	3,260,000	9,290,000
	Private Sources	217,190	**12,010,300**	**47,421,800**
	Military	229,867	**8,952,000**	**26,070,000**
	Total	447,057	**20,962,300**	**73,491,800**

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, 1946

'Preliminary Design of an Experimental World-Circling SpaceShip'

The Apollo Anomaly

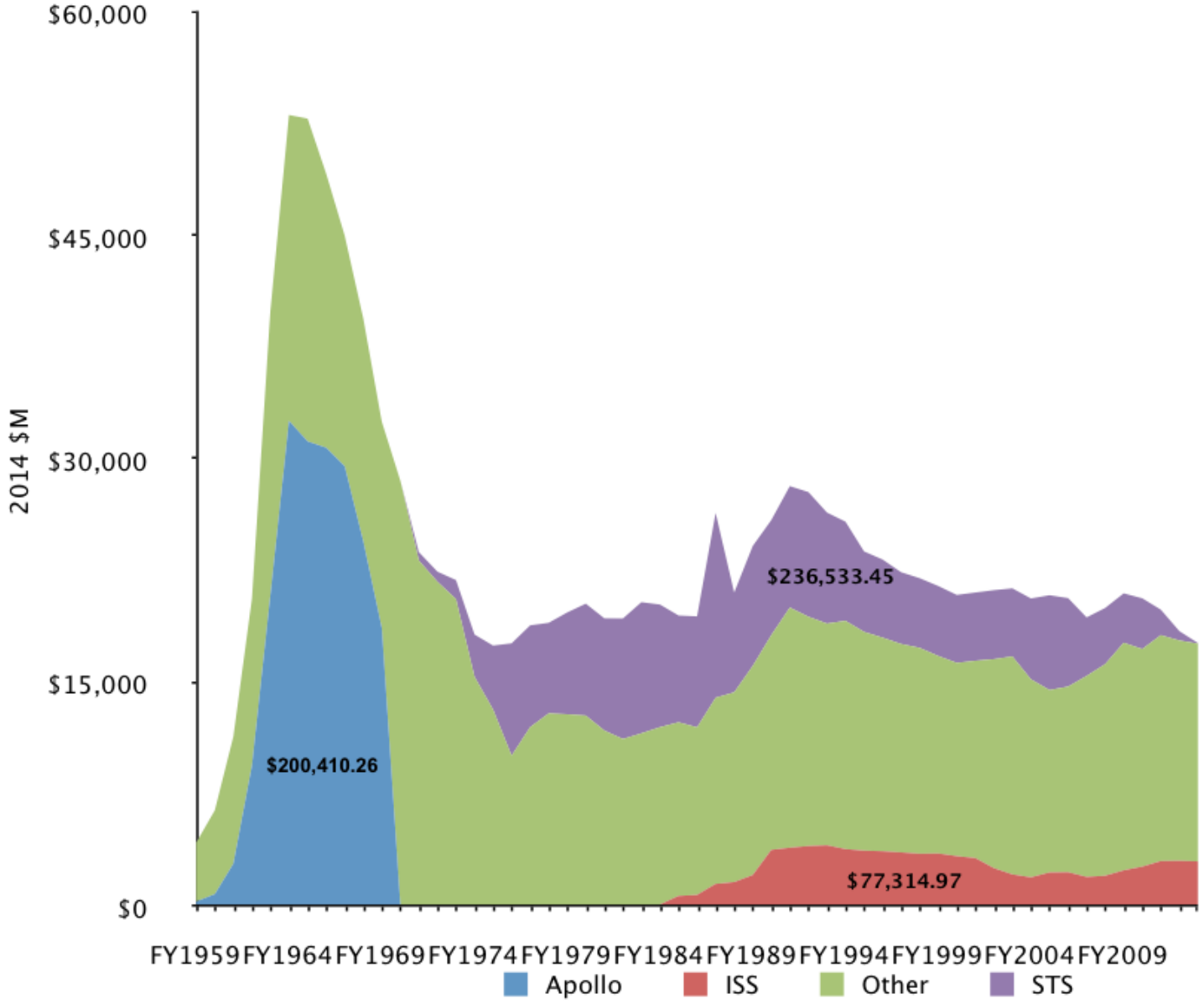
President Kennedy had no particular enthusiasm for space exploration

- -1961, Cold War, Yuri Gagarin, Bay of Pigs in Cuba
- -Space achievements became, briefly, a matter of existential geo-political importance for the nation

But by June of 1961, Kennedy proposed a lunar landing as a partnership with the Soviet Union to Khrushchev

- -First 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
- -Congress not willing to support this shift in signal, added bill language that prohibited work with communist countries, reduced support

Total Cost of Apollo, $25B in 1969 dollars, equivalent to $205B in 2015-PWC-terms, $440B in 2015 GDP-ratio-terms


$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

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;

-Cancellation of Apollo missions 18-20

Human spaceflight continues and is reborn with the Space Shuttle and the ‘re-useable spaceplane’ vision

-Caspar Weinberger, Deputy Director of OMB, 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

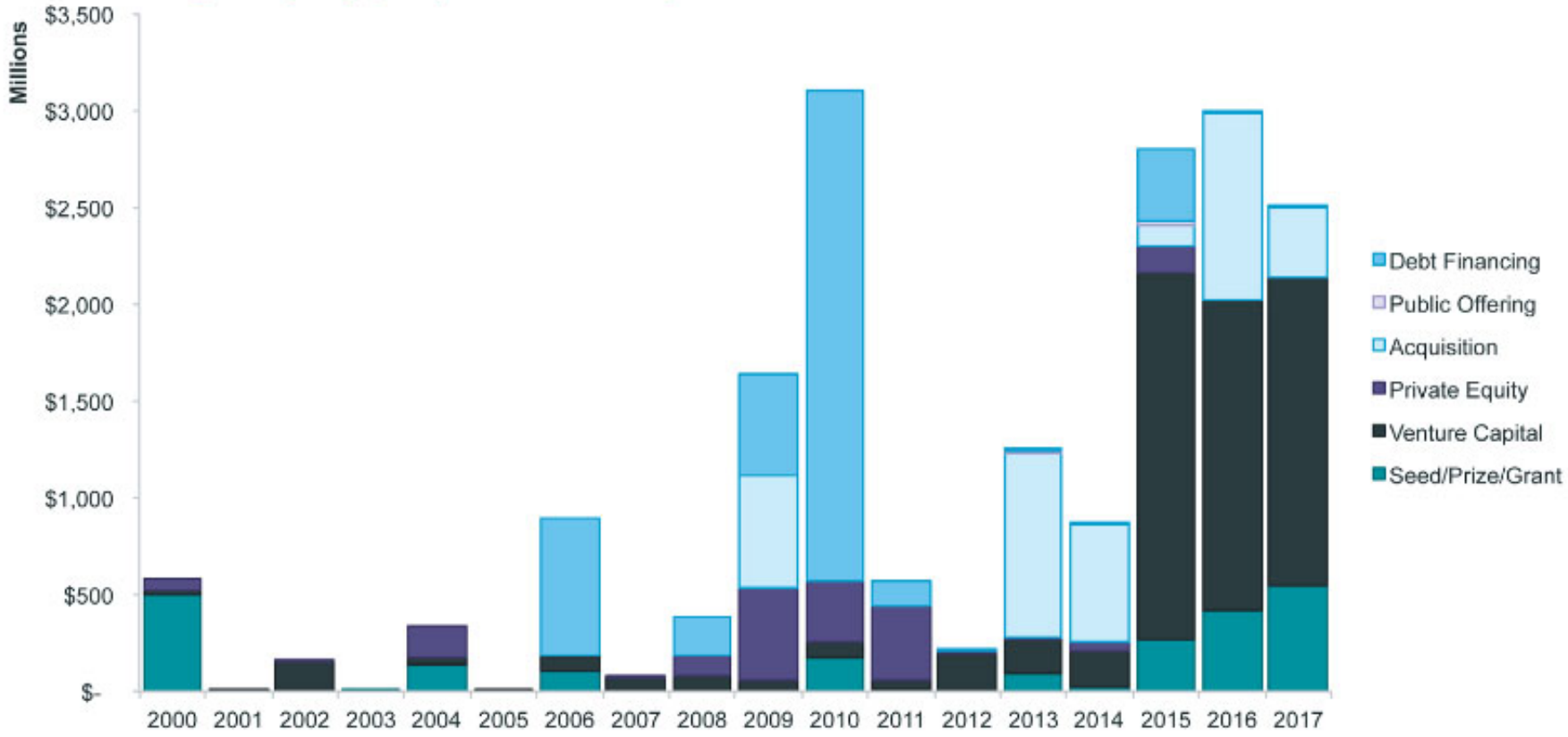
- -Space Station Freedom at ‘$8 billion’, for a high-visibility, technology-investment program, was a low-cost signal
- -Official Reagan-Bush 1984 Campaign Brochure, Goal #2: “Develop space, America’s Next Frontier

With 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

ISS has served as a credible (i.e. costly) signal of the willingness of diverse nations to work together and of a commitment to continued human spaceflight activities

Magnitude of Investment, Including Debt, Acquisitions, and Offerings, by Type (2000-2017)



>20 Billionaires with Significant Space Investments

Forbes Rank	Name	2015 Net Worth (billions)	Source of Wealth	Notable Space Affiliation
1	Bill Gates	$79.2	Microsoft, self-made	Kymeta
15	Jeff Bezos	$34.8	Amazon.com, self-made	Blue Origin
19	Larry Page	$29.7	Google	Planetary Resources
43	Charles Ergen	$20.1	Satellite TV, self-made	DISH Network
51	Paul G. Allen	$17.5	Microsoft, investments	Scaled Composites, Stratolaunch Systems, Vulcan Aerospace
56	Ma Huateng	$16.1	Internet, self-made	Satellogic, Moon Express
81	Sheldon Adelson	$31.4	Casinos, self-made	SpaceIL
100	Elon Musk	$12.0	PayPal, Tesla Motors, Solar City, self-made	SpaceX
137	Eric Schmidt	$9.1	Google, self-made	Planetary Resources
168	Ricardo B. Salinas	$8.0	Retail, media	OneWeb
330	Richard Branson	$4.8	Virgin, self-made	OneWeb, Virgin Galactic
393	Subhash Chandra	$4.2	Media, self-made	Teledesic, ICO
462	Lynn Schusterman	$3.7	Oil and gas, investments	SpaceIL
557	Yuri Milner	$3.2	Facebook	Planet Labs, SETI
847	Peter Thiel	$2.2	Facebook, Palantir, self-made	SpaceX
1006	Kavitark Ram Shriram	$1.9	Venture capital, Google	Planetary Resources
1054	Craig McCaw	$1.8	Telecommunications	Teledesic, ICO
1105	H. Ross Perot Jr.	$1.8	Computer services, real estate	Planetary Resources
1324	Charles Simonyi	$1.4	Microsoft, self-made	Planetary Resources
1324	Kenji Kasahara	$1.4	Social networking website, self-made	Astroscale
1741	Morris Kahn	$1.0	Software, self-made	SpaceIL

Historical Lessons Learned:

1.Space exploration has been an important part of national identity since Independence

2. Private funding and intrinsic motivations for space exploration in America have a robust history and have, at times, been the primary source of support

3. Signaling motivations are another primary source of demand, particularly now that space exploration has become an embedded goal of a national agency

4. Expenditure on space exploration has been volatile on a per-decade basis for almost two centuries

5. Institutional transitions and the regular creation of new institutions have been important features of the evolution of American space exploration capabilities over time

6. 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

Thoughts on the next phase of our ‘Long Space Age’

1. Important to recognize private-sector origins and public-sector predominance. Although the intrinsic motivation and private funding of individuals is a vital historical force in American space exploration, it was not until public funding was made available for space exploration that we developed the capability for robotic space exploration and human spaceflight and the public funds provided were, and remain, at least an order of magnitude or two larger than that provided for by the private sector.

2.Worthwhile to encourage high-net-wealth individuals to fund space science missions and establish foundations for space development. Numerous individuals have been encouraged to fund and endow space research institutions in the past and can be again.

3. Important to recognize signaling value of spaceflight, including ‘flags and footprints’. Missions that provide ‘firsts’ are more effective signals than repeated achievements. Human Mars orbital missions and other deep space ‘firsts' should be seen in this light.

4. Remember that American space exploration is product of a network of hundreds of public and private institutions, and hundreds of thousands of people, over the course of centuries. We should prepare for the long run rather than the short sprint and develop patient long-term strategies that are resilient to change.