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.

"Exploration of the Heavens"
Astronomy in Colonial America and the Early Republic

Astronomy had prestige within the early Colonial elite
- John Winthrop Jr., first telescope
- Early college presidents often observers
- Religious motivations often predominant

Transits of Venus of 1761 and 1769
- 1761, Prof. John Winthrop, St. John's, Nfld
- 1769, American Philosophical Society
- Pennsylvania Provincial Assembly provides £200
- "New stage of maturity in the development of America"
- Declaration of Independence read July 8, 1776 from observing platform built in Philadelphia

David Rittenhouse, first great American astronomer
- Builds three orreries £300 each (normal £93)
- Jefferson names him as one of three great intellects that signaled the nation's coming of age (along with Washington and Franklin)
- 'Astronomer to the State of Pennsylvania'

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

The Early "Observatory Movement"
The First College and High School Observatories

Yale University, 1828

- Sheldon Clark gift, 10-inch refractor, finest telescope in the Americas, first sighting of Halley's Comet in 1835

University of North Carolina, 1832

-Initiative of President Joseph Caldwell, most expensive until Naval Observatory

Williams College, 1836

-Initiative of President's brother, Albert Hopkins, religious motivations, oldest extant observatory in the U.S.

Philadelphia High School Observatory, 1837 -

-The American Philosophical Society uses redistributed surplus funds from the federal government to build a research observatory at the Central High School

-Project included first imported German refractor, first planned with wide range of input from members of U.S. scientific community

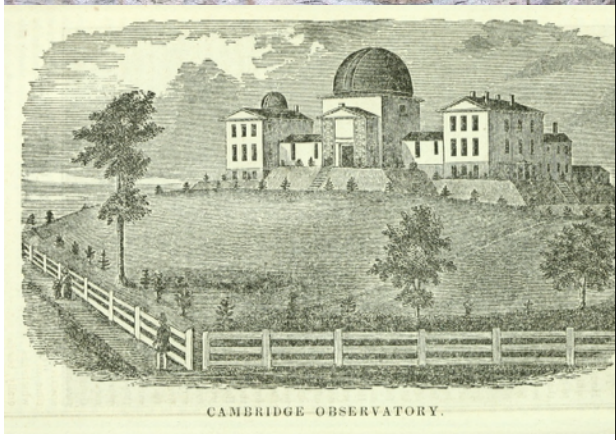
The Civic Observatories
Astronomy by Public Subscription in Cincinnati and Boston

Cincinnati Observatory, 1843

- -Economic boomtown, 6th largest city in the U.S.,
- -Ormsby Macknight Mitchel gave public lecture series on 'The Planetary and Stellar Worlds'
- -Casts astronomy as competition with Russia.
- -"Realizing the truth, that in our own country, and under a republican form of government, the people must hold, with respect to all great scientific enterprises, that position of patrons, which in monarchical governments is held by Kings and Emperors."
- -Cincinnati Astronomical Society, $25 per membership
- -3rd largest refractor in the world, no funds for research

Harvard College Observatory, 1844

- -Benjamin Pierce addressed a crowd of a thousand on the Great Comet of 1843 and need for an observatory
- -Textile tycoon Abbott Lawrence chaired a subscription committee that raised funds from the Boston elite.
- -Refractor tied for largest in the world, equal to Pulkovo
- -As at Cincinnati, no salaries until 1848 Phillips bequest



The Civic Observatories II
Conflict Between Scientists and Donors, North and South

Dudley Observatory, 1854

-Albany elite planned new university with world-class observatory as centerpiece, worked with Mitchel

-Built building first, scientists consulted after

-Science council disagreed with instrument choice

-Conflict with trustees continues, Benjamin Gould and Benjamin Pierce barricade themselves in the observatory

Barnard Observatory, 1856

-First president of University of Mississippi plans to make 'Pulkovo'-style observatory center of new university

-Large appropriation by State legislature allows order of new 'largest refractor in the world' from Alvan Clark

-Civil War results in reappropriation, unclaimed lens

Dearborn Observatory, 1865

-1862 lecture leads to Chicago Astronomical Society

-Society later learn about the availability of 18.5-inch Clark refractor and the society's secretary rushes to Boston to purchase it before Harvard can.

Founder Observatories
The Gilded Age of American Astronomy Begins

Gilded Age wealth leads to a new era of big astronomy projects

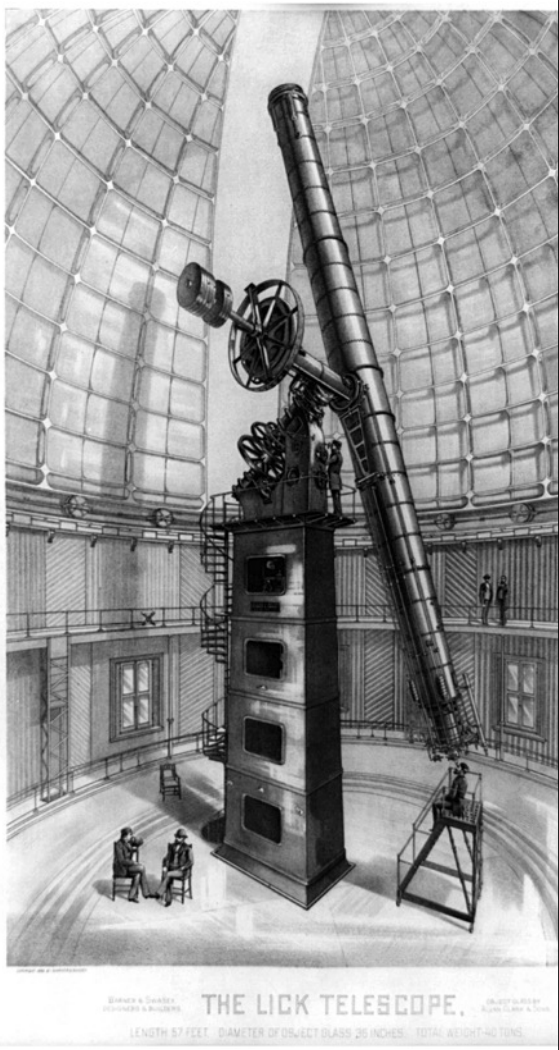
- -1892 survey reported over 4,047 'millionaires' (billionaire equivalent in 2015 GDP-ratio terms), ~540 equivalent today

McCormick Observatory, 1870

- -Leander McCormick, youngest of the three brothers responsible for McCormick Harvesting Machine Company
- -Southerner in Chicago, plans to donate own 26.5 inch 'world's largest telescope' to University of Virginia.
- -Personal wealth collapse means provides less than half of total funds, project not completed until 1885

Lick Observatory, 1876

- -Richest man in California in the 1870s.
- -Leaves 17.5% of his entire estate to to build the world's first mountain-top observatory with the world's largest telescope, provided that he is buried under it.
- -Equivalent share for richest Californian today ~$9B
- -First billion-dollar equivalent U.S. space project



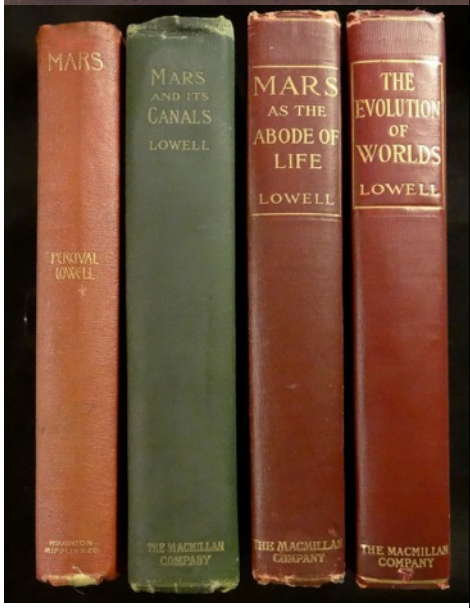
Founder Observatories II
The American Grand Amateurs

Lewis Morris Rutherford (1816-1892)

- -Fortunate enough to be born into a wealthy New York family and to marry into an even wealthier one.
- -Pioneering astrophotography (1865) and stellar spectroscopy
- -Personal observatory on 2nd Ave and East Eleventh Street was one of the best equipped in the nation.
- -Donated his equipment and plates to Columbia University

Percival Lowell (1855-1916)

- -Son of wealthy Boston family, returning from travels in Asia, commits to undertake a life exploring Mars by telescope.
- -Built largest personal observatory in America, the Lowell Observatory, which in time would become a major scientific institution with the discovery of Pluto.
- -Popular writings, *Mars and Its Canals*, *Mars as the Abode of Life* major contributor to American enthusiasm for Mars
- -Spent 25% of annual income on observatory, though decreased share to 10% with greater inheritance, showing income inelasticity.



George Ellery Hale (1868-1938)
America's Great Astronomical Entrepreneur

Son of an elevator magnate, had extensive personal observatory built at his home in Chicago.

-Was first person to photograph a solar flare at age 24.

Yerkes Observatory, 1895

-Funds from Charles Yerkes, despised Chicago financier

-40-inch Clark USC refractor available after Los Angeles real estate crash, pitches with William Rainey Harper

-Hale's first 'world's largest telescope' at age 27

Mount Wilson Observatory, 1910

-Hale joins Advisory Committee of Carnegie Institution of Washington and builds support for new, large reflector

-First astronomical observatory established by a major philanthropic organization.

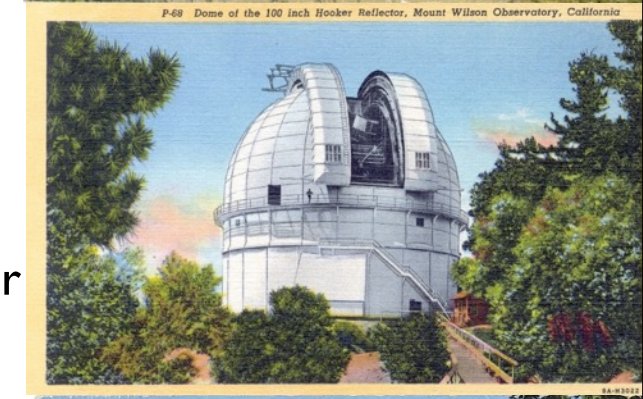
-Builds personal relationships with Carnegie, Hooker

Palomar Observatory, 1928

-Funded by Rockefeller Foundation, via Wickliffe Rose

-Hale's 2nd 'billion-dollar'-equivalent class observatory

-Completed in 1948, 200-inch reflector largest until 1976



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:**

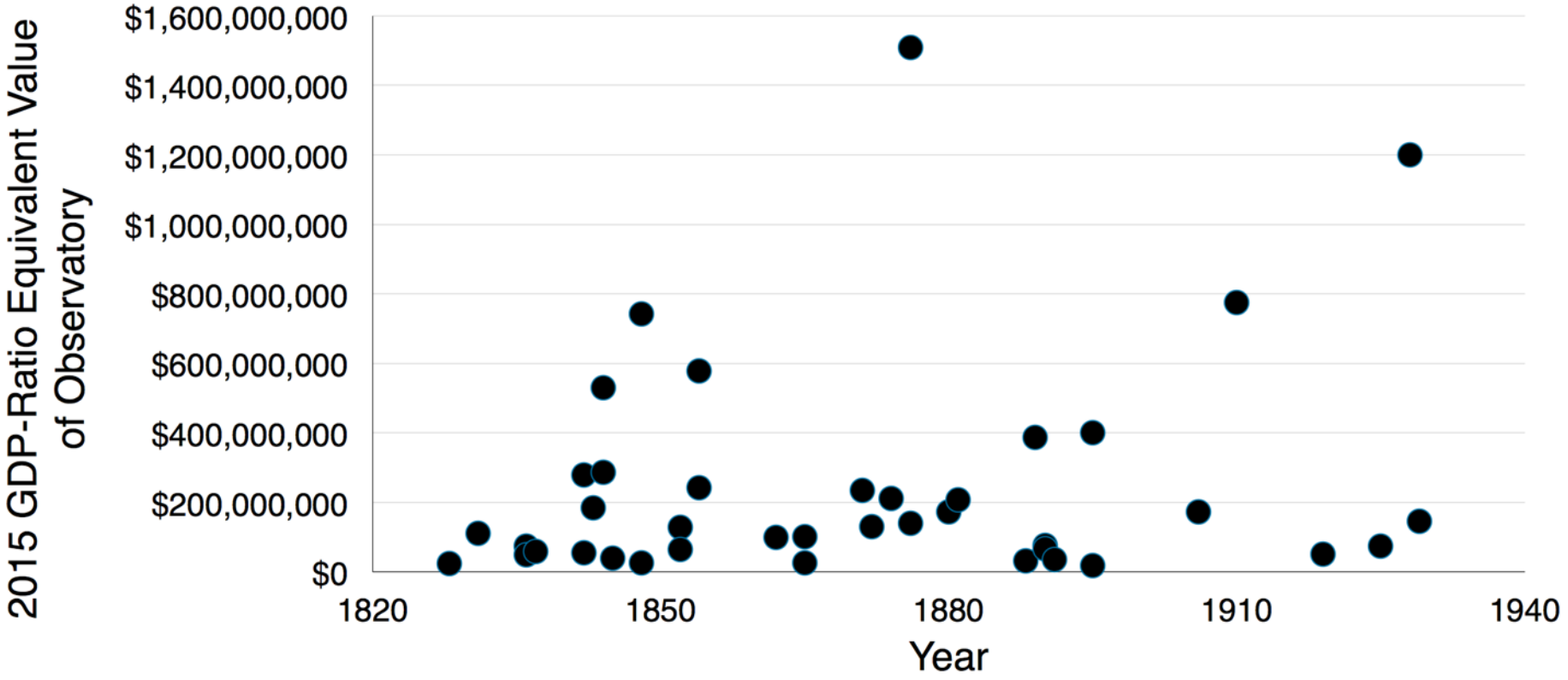
1) Production Worker Compensation (PWC) - adjust for cost of principle input of space exploration, which is skilled labor.

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

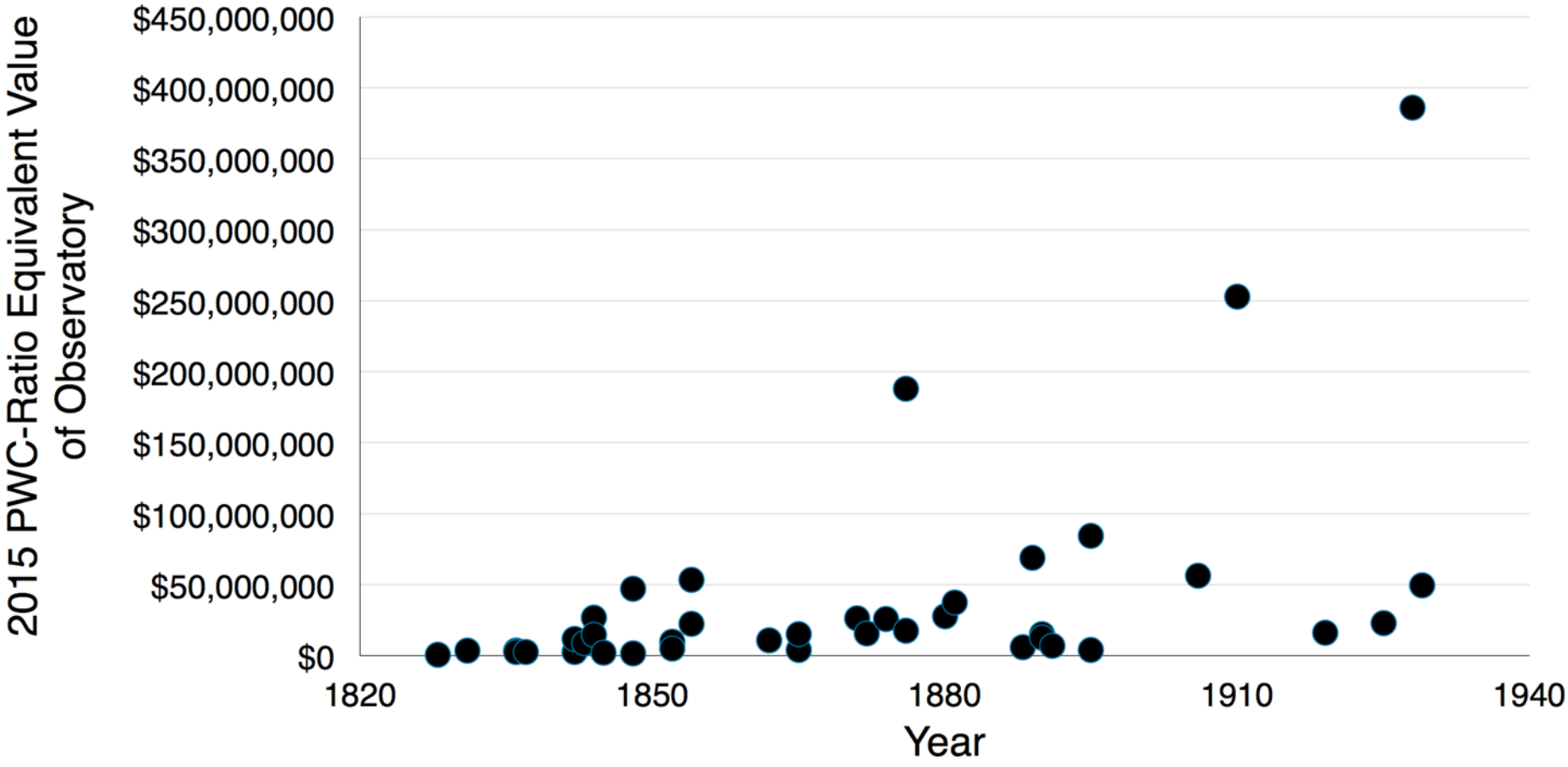
Project	Year	Nominal Prices in U.S. Dollars ($)	Constant Prices in 2015 PWC-adjusted U.S. Dollars ($)	GDP-ratio Equivalent Value in 2015 U.S. Dollars ($)
Yale College Observatory	1828	1,200	764,000	24,100,000
University of North Carolina Observatory	1831	6,400	3,490,000	110,000,000
Hopkins Observatory	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

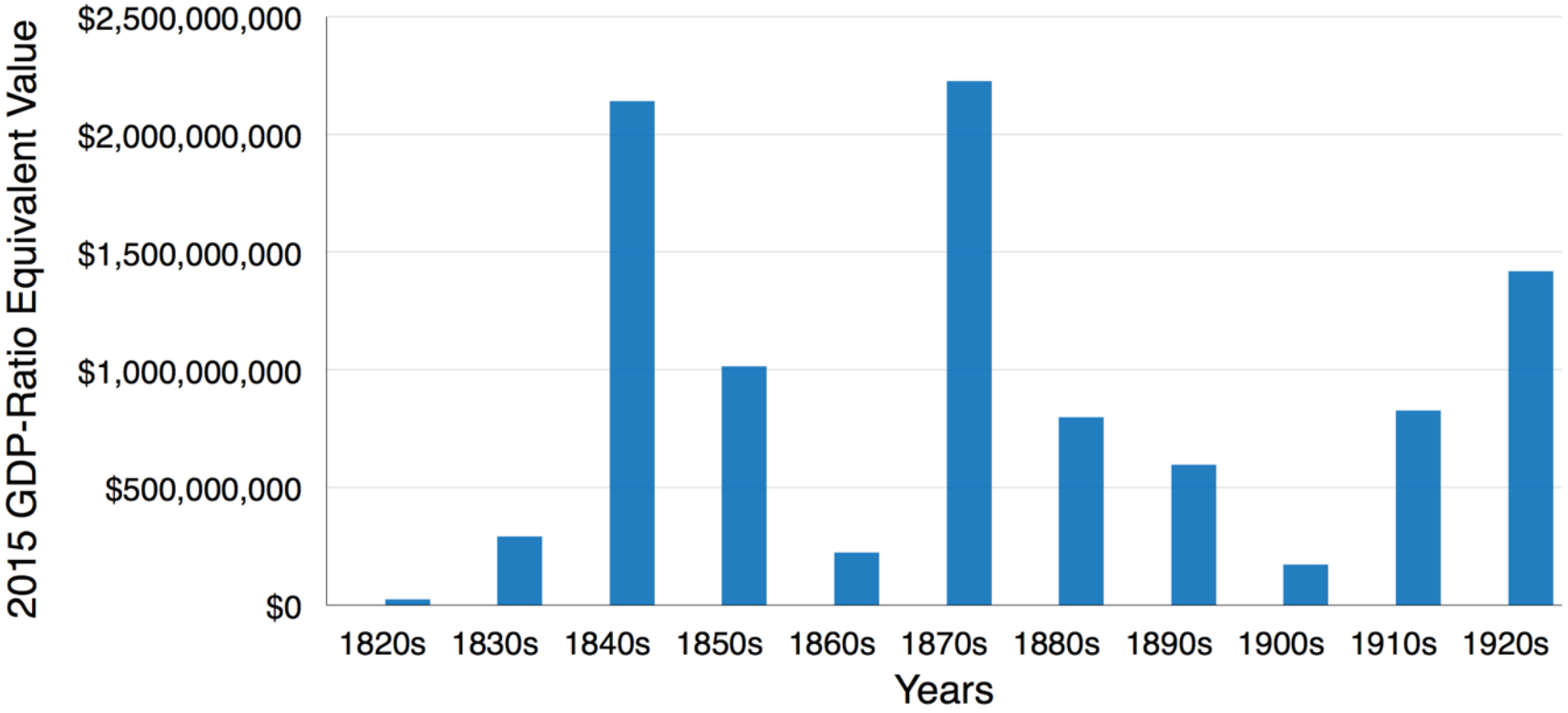
Value of U.S. Observatories, 1820s to 1920s: GDP-ratio adjusted equivalent value in 2015 dollars



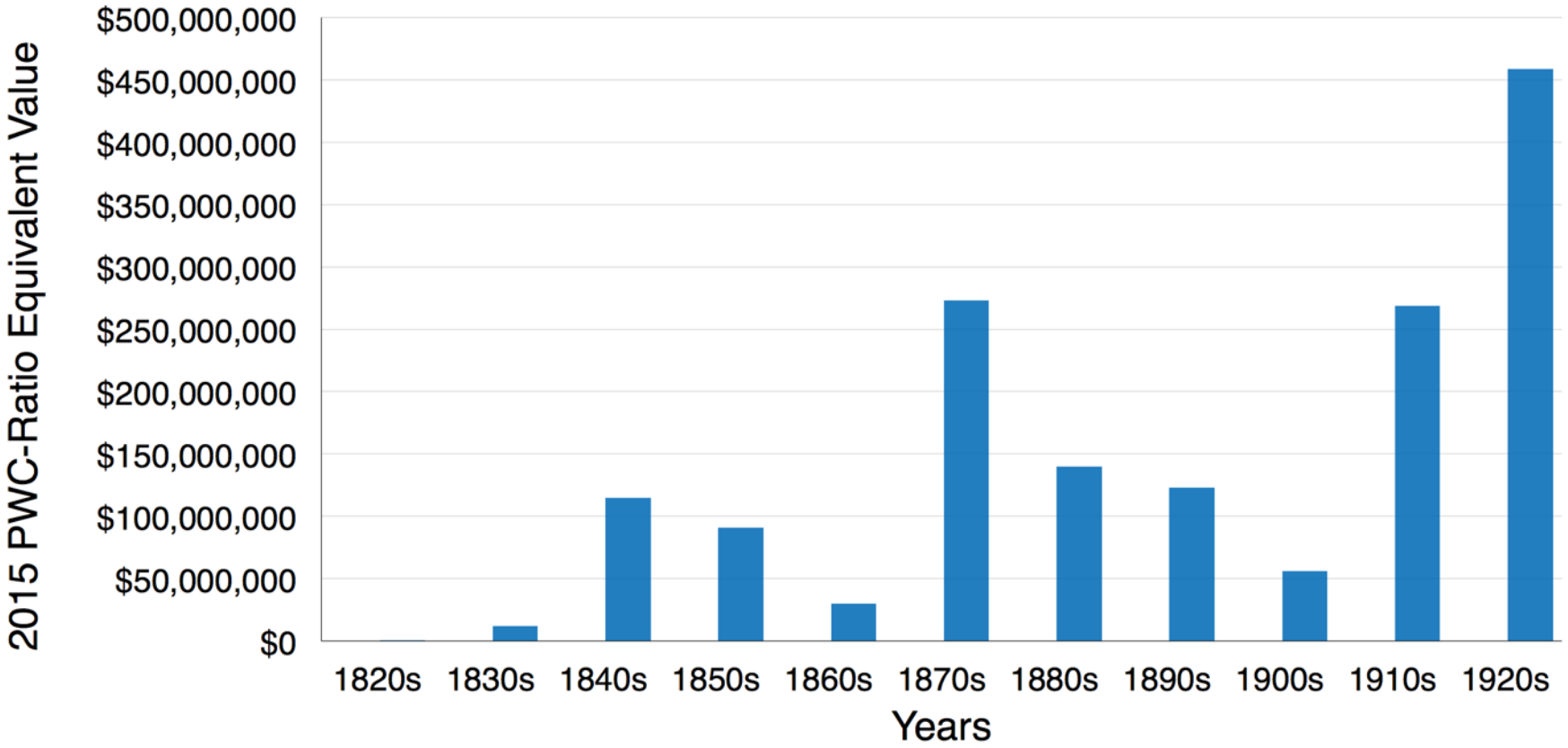
Value of Expenditures on U.S. Observatories, 1820s to 1920s: PWC-ratio adjusted equivalent value in 2015 dollars



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.

Early Life and Early Career (1885-1918)

Born into middle-class family, father inventor of small machines
- Boyhood notebooks include plans for artificial diamond manufacturing and a large-scale frog hatchery
-'Aerial Navigation Department' contained space travel ideas

Education at Worcester Polytechnic, Clark University, Princeton
-Student Notebooks incl. 'Navigability of Interplanetary Space' and concepts for solar energy for in-space transportation, ion propulsion, production of hydrogen and oxygen from the Moon, and liquid-fuel propulsion.

Teaches physics at Clark, instructor in 1914, full professor by 1920
-Begins experimental work using his salary in 1914 focused on high-altitude multiple-charge solid-fuel rocket.
-Receives first grant from Smithsonian of $5,000 in 1916.

Goddard cultivated major military relationships during WWI
-Funded by Maj. Gen. George Squier, chief of Signal Corps, who had the single largest appropriation in US history.
-After failed industry partnership efforts with Rockwood Sprinkler, sequestered at Mt. Wilson for duration of WWI

SCIENCE MAY SEND ROCKET TO THE MOON

Smithonian Institution Plans First Contact Between Two Planets

APPARATUS IS PERFECT

Jules Verne Rivaled in Fact by Invention of "Shot" Into Wide Space

From Publicity to Private Funding (1919-1930)

Smithsonian publishes 'A Method for Reaching Extreme Altitudes'

-Worldwide public interest, significant enthusiastic incl. multiple volunteers for trips to the Moon and Mars.

-Attempts public fundraising but inexperienced in the public sphere, over-promises, and the attention dies down.

Returns to work on liquid-fuel rockets at Clark University

-Hermann Oberth's *Die Rakete zu den Planetenräumen* in 1923, perception of competition, more Smithsonian support.

-March 16, 1926, first flight of a liquid-fuel rocket.

-1927 visited by Lt. Edwin E. Aldrin.

-Rocket explosion results in new media interest in 1929

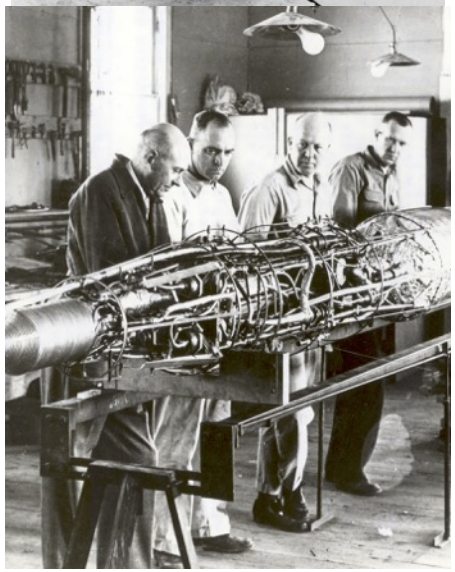
Enter Charles Lindbergh and the Guggenheims

-Lindbergh visits Goddard, flight back from DuPont labs

-Connects with Carnegie Institution, Guggenheims

-D.C. apartment meeting with John Merriam (Carnegie), Charles Abbot (Smithsonian), chief of U.S. weather bureau, Walter Adams and Horace Babcock from Mt. Wilson

-Lindbergh visits Daniel Guggenheim on Goddard's behalf, secures major funding ($3M PWC-ratio / $12M GDP-ratio)



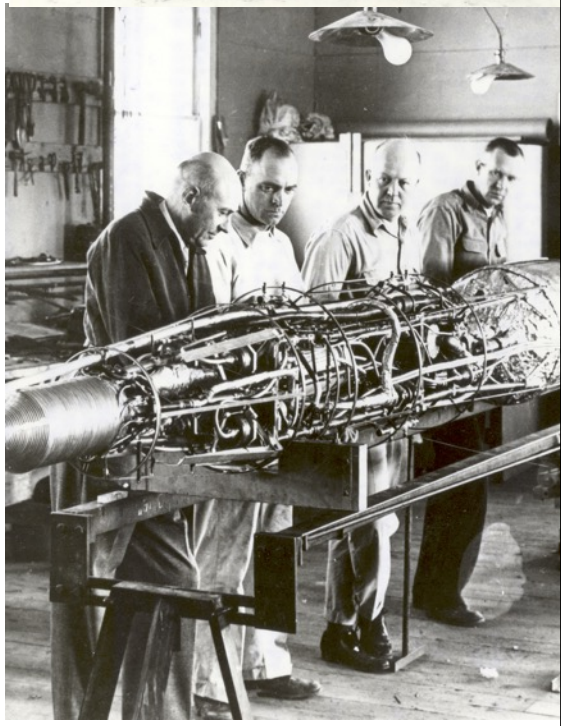
The Roswell and Annapolis Years (1930-1943)

Goddard moves with team to Roswell, NM 1930

- -Over 11 years and 48 flight tests, develops core liquid-fuel rocketry technologies including curtain cooling, gyroscopic stabilization, turbo pumps.
- -Continued support from Harry Guggenheim
- -Limitations of private funding with 2.3km flight leading only to encouragements to go higher on the same budget
- -Meanwhile, Von Braun's A-1 flight of 1.7km in1934 led to the massive military support that founded Peenemünde.

Goddard never abandoned his pursuit of military funding

- -Corresponded widely with military supporters, including Vannevar Bush and General Henry 'Hap' Arnold
- -George Lewis's (NACA) support lead to JATO Navy contract, his largest single year contract
- -Worked 2 years on a liquid-fuel JATO, but health declined



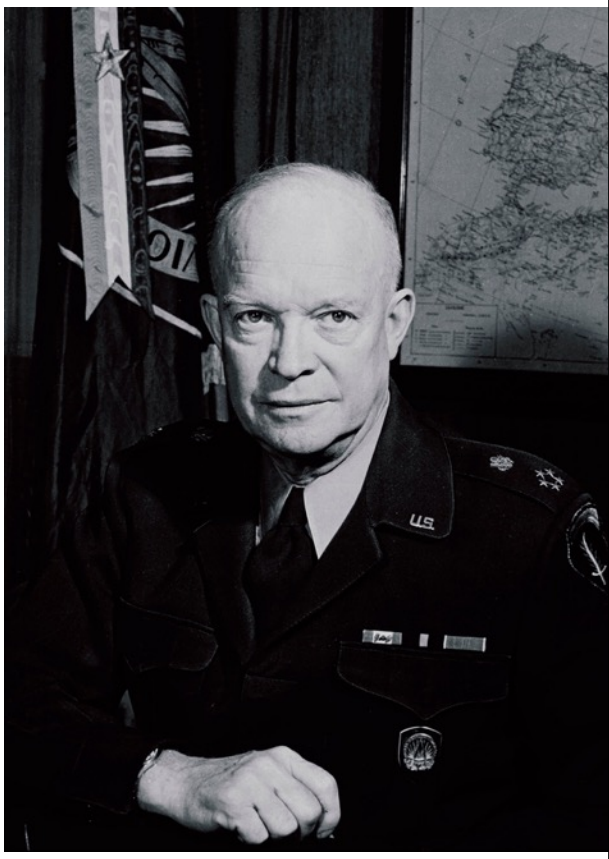
Robert Goddard's Funding History

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	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

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, April 21, 1961
"Brief Analysis of Department of Defense Space Program Effects"

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

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.