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Original Paper

War and Science: The Century-Long Transformation of Caltech's Physics Discipline (1891-2026)

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Abstract

Caltech's physics discipline offers an unusually complete record of what happens to a science when its patron changes. Between 1891 and 2026 it passed through four funding regimes: private endowment, wartime contract, federal sponsorship, and the mixed order loosening since 1991. Each transition left traces in one archive. Reading that record requires two literatures that seldom meet. Big Science theory accounts for the scale of research; the Triple Helix accounts for who pays for that scale, and so who names the problems. Their model describes a peacetime arrangement. The Caltech record shows the wartime version that preceded it. Once the NDRC and then the OSRD began buying research in 1940-41, the industry pole did not disappear. It was absorbed into military demand. Caltech took more than eighty million dollars in federal contracts, second only to MIT, and about ninety-five percent of its war work went to rockets and guided missiles. What grew at the junctions—NOTS at China Lake, JPL, RAND—belonged to no single sphere, and their permanence made the substitution stick. Two features of that arrangement matter later. The arrangement was elastic, since patrons could be exchanged while the university stayed put: JPL passed from the Army to NASA in 1958, Owens Valley from the Navy to the NSF in 1970. It was also unequal, since costs fell first on the exposed: Tsien Hsue-shen, stripped of his clearance in 1955, and Margaret Burbidge, barred from the dome under her own name. After 1991 the security premise expired, and these institutions had to argue for themselves before publics, before Native Hawaiian communities at Mauna Kea, and before a Congress that refused the 47 percent cut proposed for NASA science. The closing section asks what the record implies for data access and siting, where the case is for defaults that can be reopened rather than settled once.

Keywords

Triple Helix Model, Big Science, California Institute of Technology, Astrophysics, Science and Technology Studies, Data Justice

1. Introduction

1.1 Science in a Turbulent Era

Contemporary fundamental physics is undergoing a public crisis of meaning. Four decades have passed since the completion of the Standard Model without a comparable advance in fundamental theory; the Higgs boson, found in 2012, confirmed that framework rather than extending it. Experimental probes have meanwhile become extraordinarily expensive: collaborations of several thousand people operate machines costing billions of dollars, and the room for accidental discovery narrows as the price of each experiment rises. The result is a cycle in which costlier instruments yield fewer surprises, and each generation of instruments must therefore be justified more elaborately than the last.

The material basis of Big Science is straining under this burden. The Superconducting Super Collider was cancelled in 1993 after roughly two billion dollars had been spent, ending four decades of American leadership in high-energy physics [1] The Thirty Meter Telescope has been stalled for more than a decade by protest and litigation, and in 2025 the National Science Foundation declined to advance it toward construction. In both cases the obstacle was not the physics but the terms on which the physics could be paid for.

Knowledge production is polarizing at the same time. Between 1980 and 2022 the American share of global research papers fell from about 40 percent to about 15 percent, while China's share rose from near zero to 32 percent [2]. The National Science Board [3] records the same shift. Volume, however, is not access. For researchers excluded from flagship facilities and from data rights, the question is not who publishes most but who is licensed to produce knowledge about the universe at all. Whitehead [4] observed that the trajectory of a scientific discipline reflects the intellectual and institutional matrix of its moment. The observation applies with unusual force to a field that now depends on instruments no university can buy alone.

1.2 Literature Review: Historiography of War and Science

Historians have long asked how war reshapes science. Kevles followed the American physics community as it grew alongside the nation, asking what remains of expert detachment once physicists accept the patronage of corporations, universities, and federal agencies. [5] Forman sharpened the question into his distortion thesis: between 1940 and 1960 the direction of American physical research rested on national security rather than on problems internal to the discipline.[6] Leslie gave the claim institutional form in his study of the military-industrial-academic complex at MIT and Stanford. [7] Lowen added the administrators, showing how actively universities solicited military and foundation patrons[8] , and Wolfe (2018) traced the ideological work that kept Cold War science presenting itself as free inquiry.[9] Daniels and Krige (2022) have reconstructed the regulatory machinery through which the postwar state decided what knowledge could cross its borders.[10]

Astronomy has its own branch of this historiography. Lankford closed his account of the American astronomical community at 1940, exactly where the Big Science era begins, [11]and Doel stopped on the eve of the space age. [12]DeVorkin took up the military's role in creating the space sciences directly,

[13]a story he later extended through the Smithsonian Astrophysical Observatory [14]. Tyson and Langsurveyed the whole arc of astrophysics' alliance with war[15], while McCray supplied the archival analysis of Project Vista on which parts of this paper rely.[16]

Two gaps remain, and they structure what follows. The first is empirical. This literature clusters on East Coast establishments such as MIT, Harvard, and Stanford, or on single wartime episodes; few studies follow one small West Coast institute across an entire century. The second gap is analytical, and it matters more. Historians of science usually treat war as the background against which science unfolds, whereas the innovation-studies literature behind the Triple Helix model describes a civilian arrangement and says little about how war formed it. What falls between these two bodies of work is the causal chain this paper pursues: how war, by rerouting money and reorganization, repeatedly redrew the boundary of a discipline.

1.3 Analytical Framework: Wartime Evolution of the Triple Helix

The framework joins two bodies of theory. The first is the Triple Helix model, formulated by Etzkowitz and Leydesdorff to describe the interaction of university, industry, and government in knowledge-based economies. Its empirical prototype is MIT and the firms around it, and its central claim is that the three spheres take over one another's functions, so that hybrid organizations appear at their interfaces. [17]The second is Big Science theory. De Solla Price described the change in scale of research as a change in the state of the system, [18]and Galison and Hevly treated large-scale research as a distinct organizational form defined by expensive instruments, large teams, and deep state involvement.[19]

This paper combines them because each answers a question the other leaves open. Big Science theory explains the scale at which research is organized. The Triple Helix explains who pays for that scale, and therefore who acquires authority over the research agenda. Their intersection supplies the argument: a change in the funding regime moves the boundary of the problems a discipline can pose, and organizational innovation converts that move into a durable institutional fact.

The wartime variant is a specific claim about the middle term (Figure 1). Under the conditions of the Second World War and the Cold War, the industry pole was displaced by the military, and the university-industry-government triad became a tightly coupled university-military-government one. The helix then produced not commercial technology transfer but hybrid institutions and national science policy. The claim is not that industry vanished. It is that military demand became the operative content of the industry pole for the institutions examined here, and that this substitution is what allowed patronage to redraw disciplinary boundaries so quickly.

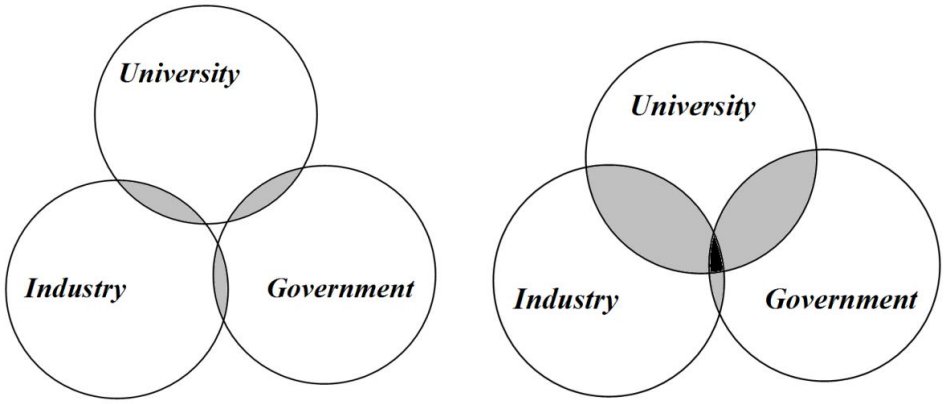


Figure 1. The wartime Evolution of the Triple Helix. The Industry Pole is Displaced by the Military, and Hybrid Institutions Appear where the Three Spheres overlap. Author's diagram

1.4 Case Selection: Why Caltech

Caltech is a theoretical rather than a statistical sample, chosen for four reasons. The first is completeness: an institution founded in 1891 passed through philanthropic, wartime contract, and federal civilian funding regimes, and all three transitions left continuous records in one archive. The second is extremity: the institute received more than eighty million dollars in wartime contracts, second only to MIT, with about 95 percent of its war work concentrated in rocketry and guided missiles [20,16]. One participant recalled that most of Caltech had become a branch of the Bureau of Ordnance.

The third reason is the density of hybrid institutions. The Jet Propulsion Laboratory, the Naval Ordnance Test Station, and the RAND Corporation all took shape within a few dozen miles of Pasadena, which makes the region an unusually clear window onto the wartime helix. The fourth is contemporaneity. Between 2024 and 2026 the laboratory lost a third of its staff, and NASA announced in May 2026 that its management contract, held by Caltech since 1958, would be opened to competition. A single campus thus contains a century of regime change and the crisis of the present one.

2. Philanthropic Capitalism and the Emergence of Astrophysics (1891-1941)

2.1 From a Vocational School to a Research Institute

Caltech began obscurely. In November 1891 the Pasadena philanthropist Amos Throop founded a vocational school with thirty-one students and six teachers, offering practical subjects from carpentry to domestic science [22]. The transformation came from outside the curriculum, through George Ellery Hale, who had built the Mount Wilson solar observatory nearby and joined the board of trustees in 1907. Hale set out to convert a local school into a research university: he removed the preparatory department and the commercial course, recruited Arthur Noyes from MIT to lead chemistry, and in 1917 brought Robert Millikan from Chicago on a part-time arrangement that soon became permanent.

Between 1919 and 1921 the institute secured large private endowments, restated its purpose, and took

its present name in 1920. Millikan directed the Norman Bridge Laboratory of Physics while leading the institution, on terms that gave him the largest share of its income and the smallest share of its administration. The arrangement was a trade of private wealth for agenda autonomy. Millikan deliberately avoided federal money and relied on foundations and donors instead, and by the early 1930s visits from Dirac, Schrödinger, Heisenberg, Lorentz, and Einstein had made a suburban vocational school into one of the capitals of world physics.

2.2 1917: The Hooker Telescope and the Birth of Astrophysics

The institutional change ran parallel to a change in what astronomy was. Classical astronomy was a science of position: it measured angles, timed transits, and published catalogues. From the middle of the nineteenth century, spectrographs, photographic plates, and silvered reflectors made starlight itself available for analysis, and the governing question shifted from where a body is to what it is made of and how it changes. Hale institutionalized the shift through a sequence of instruments on Mount Wilson, culminating in the 100-inch Hooker telescope of 1917. The Hooker remained the largest telescope in the world for three decades, and Hubble used it in 1923 and 1924 to establish that the nebulae lie outside the Galaxy; the expansion itself was established in 1929.

The epistemic change had an organizational counterpart that is easy to overlook. Hale co-founded the Astrophysical Journal in 1895, giving the emerging field a certifying organ independent of the positional astronomy establishment. Name, instrument, and publication infrastructure moved together. That combination, rather than the addition of a subfield, is what marks the redrawing of a disciplinary boundary. It also established the funding pattern that would govern the next two decades: a single donor, a single instrument, and a research agenda set by the scientists who used it.

2.3 1928: Palomar and the Ceiling of Private Capital

In 1928 Hale obtained six million dollars from the Rockefeller Foundation for a 200-inch telescope [21], and the project was entrusted to Caltech for execution. The instrument, completed at Palomar in 1948, remained the most effective telescope in the world until 1993. The sum mattered less than what it bought. The 200-inch program was the moonshot of its decade, and its list of problems was drawn up entirely by astronomers rather than by the state. Philanthropic capital thus purchased not only glass and steel but the right to decide what questions the instrument would answer.

The regime had a ceiling, and the ceiling was structural. A donor could fund one instrument and, at the outer limit, one observatory. Donors could not fund a class of instruments, and they could not commit for the thirty years an observational program required. The point is visible in the prewar rocketry group, where the institute's industrial and military ties first appeared. Theodore von Kármán took over the Guggenheim Aeronautical Laboratory in 1930, and in 1936 Frank Malina, Jack Parsons, Edward Forman, and Tsien Hsue-shen conducted the first rocket tests in the Arroyo Seco. In 1942 the group founded Aerojet to mass-produce Jet-Assisted Take-Off boosters. A classic university-industry-government triad was already forming in Pasadena, financed by small grants and private capital.

What that arrangement could not do was scale. When the capital intensity of an instrument exceeded what private wealth could supply, the choice was to abandon the instrument or to change the patron. The war resolved the choice before the institute had to make it. The direction of causation, however, deserves care. Nothing in this account suggests that money chose the problems. The 200-inch programme was proposed by astronomers because the questions they had already chosen, the distance scale, the structure of galaxies, the physics of stellar atmospheres, could not be answered with the instruments they had. Capital did not set that agenda; it set the scale at which the agenda could be pursued, and the scale in turn changed what the agenda could contain. Instrumental ambition was internal to the discipline, and it was that ambition, pressing against the limits of private wealth, that made the institute available to a new patron.

3. War as Catalyst: World War II and Organizational Restructuring (1941-1945)

3.1 1940-1941: The OSRD and the Contract Form

The machinery of mobilization took shape in 1940 and 1941, when the Roosevelt administration created the National Defense Research Committee and then the Office of Scientific Research and Development under Vannevar Bush. The scale had no precedent. The OSRD signed more than 2,200 research contracts worth about 462 million dollars, exceeding earlier federal research spending by one to two orders of magnitude [20]. The budget read like a list of national needs: radar led with 129.6 million dollars and rocket ordnance followed with 82.9 million. Contractors specialized to an extraordinary degree. About 94 percent of MIT's wartime funds went to radar at the Radiation Laboratory, and about 95 percent of Caltech's went to rockets and guided missiles (Figure 2).

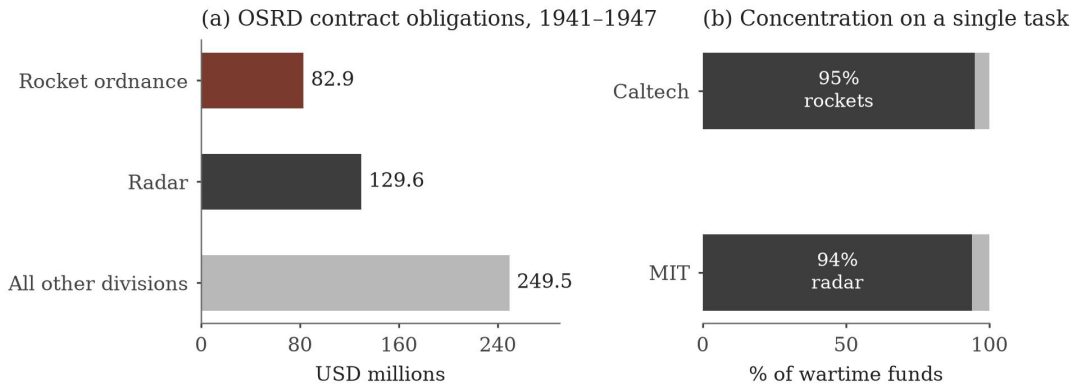


Figure 2. Wartime obligations and institutional concentration. (a) OSRD contract obligations by category, where the residual category is calculated from the reported total; (b) share of each institution's wartime funds committed to a single task. Compiled by the author from Gross and Sampat (2020) and McCray (2004).

For Caltech the conversion was total. The institute took in more than eighty million dollars in

government contracts, second among American universities only to MIT, and its several thousand employees produced over a million artillery rockets. The contracts also introduced a new accounting object into university life, the overhead rate. Indirect costs recovered from federal sponsors turned buildings, utilities, and administrative staff into chargeable items, and the institutional budget began to be written in the grammar of the contract rather than in the ledger of the endowment. One participant recalled that most of Caltech had become a branch of the Bureau of Ordnance [16] Nearly every senior physicist moved onto the war track. Charles Lauritsen directed the rocket ordnance program, and William Fowler worked on proximity fuses and solid rockets with a posting to Los Alamos, where the nuclear experiments that had been his real ambition were interrupted until after the war.

The asymmetry of the mobilization is worth recording. Lee DuBridge left the faculty to direct the Radiation Laboratory, and Robert Bacher became head of experimental physics at Los Alamos. University talent functioned as a strategic reserve that the state could call up wholesale. In personnel terms the war also previewed the postwar distribution of power, since the merit network formed under contract supplied the academic leadership of the next decade.

3.2 1943: NOTS and the Weapons Station Run by Civilians

The war's most instructive new institution was the Naval Ordnance Test Station. Caltech needed open desert to test rockets, and the Navy needed an aviation ordnance proving ground. Lauritsen and Commander Sherman Burroughs surveyed sites together and settled on China Lake in the Mojave, where the Navy established the station in November 1943 with a mission defined by the Secretary of the Navy as the research, development, and testing of weapons. The station also hosted Project Camel, in which Caltech personnel drop-tested atomic bomb shapes from B-29 bombers, and its three ten-thousand-foot runways, funded by the Manhattan District, opened in June 1945.

The institutional novelty lay in the blurred identity. The station was a Navy facility, yet civilian scientists set its research agenda, and fundamental research was written into its core mission. The Navy was buying more than finished weapons; it was buying continuing scientific capacity. Lauritsen's own trajectory is emblematic. The founder of the Kellogg Radiation Laboratory turned himself from an accelerator physicist into the organizer of an ordnance program, and after the war he sat on more than sixty government committees as a defense adviser courted by all three services[22] .

In helix terms, NOTS is the first complete specimen of an institution grown in the overlap of the three spheres: site and funds from the Navy, scientific authority and personnel from Caltech, mission and legitimacy from the government. No party could have built it alone. That is what distinguishes a hybrid institution from a sponsored one.

3.3 1943-1944: JPL and the Contract That Came First

The second institutional line ran through the Arroyo Seco. After the first successful JATO flights in 1941, intelligence about the German V-2 reached the United States in 1943. Von Kármán analyzed the German program for the Army Air Forces and submitted a missile proposal to the Army Ordnance Department on 20 November 1943. The contract followed early in 1944, and the rocket group was

formally constituted as the Jet Propulsion Laboratory. From its first day the laboratory was a legal hybrid, managed by a university, financed by an armed service, and dedicated to national needs. It was the prototype of what would later be called a federally funded research and development center.

By 1945 it employed nearly three hundred people and had moved from the Private sounding rocket toward the Corporal, the first American generation of ballistic missiles. The founding reveals the wartime mechanism at its clearest: demand first, organization second. Under the philanthropic regime a scientific problem came first and money followed. The service contract reversed the sequence. The funder defined the mission, and the university converted that mission, in the course of executing it, into disciplinary resources.

Von Kármán's departure for Washington at the end of 1944, to organize the Air Force's scientific advisory structure, announced a further change in the scientist's role. Physicists were ceasing to be suppliers of technology and were entering the making of national strategy.

3.4 Mechanism: The Wartime Substitution

The catalytic effect of the war compresses into three mechanisms. The first is financial: contracts displaced endowments. Philanthropic capital ran on ten-year cycles and respected the community's agenda; OSRD contracts ran on the war's clock and took the task order as their charter. Caltech went overnight from Millikan's fortress of government avoidance into the nation's second-largest war contractor.

The second is organizational: boundaries blurred. NOTS was a Navy base directed by civilians, JPL a university laboratory executing Army contracts, and men such as DuBridge and Bacher held university and national laboratory posts at once. The partial assumption of one another's functions, which the helix literature describes in measured tones, happened here in its most radical form.

The third is personal: scientists became strategists. Lauritsen and von Kármán moved into the inner circle of national strategy and, after the war, never left it.

The three mechanisms describe where resources went. They do not yet explain why the movement of resources should redraw a boundary of knowledge. The answer lies in where the decision about problems is taken. Under the philanthropic regime the unit of production was an individual investigator and an instrument he could build, so the choice of problem remained with the person who would pursue it. Big Science changed the unit. When an instrument costs more than any single institution can raise, the decision to build it passes to whoever can pay, and the decision to build carries with it the decision about what the instrument is for. The contract bought not answers but the right to name the question. That is why the substitution could redraw a discipline within four years, and why it left the cheaper parts of physics, theory and small-scale experiment, comparatively untouched.

What the three mechanisms establish is that the war was not a temporary borrowing of university science but a permanent rewriting of its financial and organizational form. In 1945 Bush published Science, the Endless Frontier, which elevated the contract regime into a peacetime creed and led to the National Science Foundation in 1950 [23] . The irony is historical: before a democratically accountable

system of federal science could take root, the Cold War had already made the wartime helix into the everyday structure of American research.

4. Institutionalizing the Cold War: The University-Military-Government Complex (1946-1991)

4.1 1946: DuBridge and the Federal Grant University

Postwar Caltech did not return to Millikan's philanthropic regime. It could not, and it did not want to. DuBridge made federal sponsorship of peacetime science a central aim of his presidency from 1946, and he brought Bacher in to head the division of physics, mathematics, and astronomy. Under Bacher the physics faculty rose to the first rank in the country, with Anderson, Feynman, Gell-Mann, and Fowler on its staff. The division was also a bargain between two institutions that had learned to need each other: the university supplied the intellectual authority, and the state supplied the instruments that authority now required. Kevles [5]coined the precise name for this arrangement: the federal grant university, in which budgets, facilities, and even research agendas rest on federal contracts, and the university purchases unprecedented scale and prestige within that frame.

Millikan's resistance is the more revealing because it failed. The old president never reconciled himself to peacetime federal money, since the philanthropic order he had guarded, with its agenda autonomy, had been irreversibly breached by the war. The disagreement between the two presidents was less a clash of temperament than a time lag between two regimes of science. Millikan mourned an era in which patrons leaned in to hear what scientists wanted. DuBridge managed an era in which scientists learned the language of congressional hearings.

The change is visible in the smallest details of institutional life. Appointment letters began to cite project accounts rather than endowed chairs, and departmental planning began to follow the federal budget cycle rather than the donor's intentions. Astronomy made the same move more dramatically than physics, since it had been financed almost entirely by private money. In the 1950s the Owens Valley Radio Observatory became one of the first astronomical facilities to accept federal funds, specifically from the Office of Naval Research. Only in 1970, when the Mansfield Amendment restricted defense money to projects with military uses, did the Navy withdraw and the National Science Foundation take over. Even stargazing, in the early Cold War, was paid for by the Navy.

4.2 1945-1948: RAND and the Interface Organization

The highest organizational achievement of the military-academic interaction was a new species, the think tank. In October 1945, over lunch at Hamilton Field near San Francisco, General Henry Arnold told executives of Douglas Aircraft that he had thirty million dollars left in his wartime research budget and wanted to spend it on an independent organization of civilian scientists who would study future weapons and strategy for the Air Force. The result was Project RAND, established inside Douglas in early 1946, whose first report, Preliminary Design of an Experimental World-Circling Spaceship, anticipated Sputnik by eleven years.

In 1948, with seed capital from the Ford Foundation, RAND left Douglas and incorporated as an

independent nonprofit. Both the military and the manufacturer had come to see that an intellectual contractor housed inside a hardware contractor carried an unavoidable conflict of interest. The separation was therefore not a retreat from the arrangement but its refinement.

RAND's significance for the helix is that it made the wartime improvisation permanent. Summer studies such as Vista, which assembled a quarter of the institute's faculty in 1951 to examine tactical nuclear weapons and whose report the Air Force suppressed, convened scientists during academic breaks and disbanded when the project ended. RAND kept scientists continuously at work on strategy, and game theory, systems analysis, and the doctrine of mutual assured destruction all issued from that arrangement. Systems analysis gave the services a way to compare weapons that had no common metric, and it gave civilians a technical language in which to argue with officers without disputing their authority. The summer-study network of the early 1950s, including MIT's Lexington, Hartwell, and Charles projects, Caltech's Vista, and Princeton's East River, formed a revolving-door ecology in which the same physicists circulated among campuses, with RAND as the hub and the permanent exit. The helix thereby acquired a fourth kind of component: the interface organization, belonging fully to none of the three spheres yet selling certainty to all of them.

4.3 1955: Tsien and the Price of Trust

The helix's erosion of academic freedom reached its climax in the case of Tsien Hsue-shen. Von Kármán's most brilliant student, a founding member of the GALCIT rocket group, and director of the Guggenheim Jet Propulsion Center, he had his security clearance revoked at the height of McCarthyism, spent five years under house arrest, and was deported to China in 1955 as part of a prisoner exchange from the Korean War. In China he founded that country's missile and space programs. DuBridge's oral history still treats the deportation with visible discomfort.

The episode matters to the argument for two reasons. The first is scale. A security review conducted inside one institution amplified along a chain that ran from personal trust to the community's structure of trust to national immigration and security policy, and it ended with the United States having trained, with its own hands, the chief designer of a strategic rival. The second is distribution. The costs of the helix were not borne evenly. They fell first and hardest on the people standing at its edge, and the institution that had built its postwar standing on federal contracts had no mechanism for pricing that loss.

Self-reflection from inside the system came almost at the same moment. In his farewell address of 17 January 1961, Eisenhower coined the term military-industrial complex, but a less-quoted passage of the same speech addressed this paper's subject directly. The free university, he observed, had experienced a revolution in the conduct of research, and a government contract had become virtually a substitute for intellectual curiosity. He went on to warn that public policy could itself become the captive of a scientific-technological elite[24] . A five-star president's anxiety over the federalization of the university, and Lowen's account of administrators eagerly developing their opportunity, are two faces of the same coin.[8]

4.4 1957: B²FH and the Return of Pure Science

The Cold War helix produced more than weapons and missions. It also produced basic science of the purest kind, though the sources of its nourishment must be recorded honestly. Fowler's nuclear physics had been interrupted by ordnance work and Los Alamos, and after the war he returned to Kellogg and deliberately ran the laboratory's accelerators as instruments of astrophysics, measuring nuclear reaction rates as astronomical data. In 1954 Hoyle predicted from elemental abundances that carbon-12 must possess a resonance near 7.65 MeV (Hoyle, 1954).[25] In 1957 the Kellogg group confirmed the Hoyle state experimentally, a rare case of astronomers driving a discovery in nuclear physics.

That same year Margaret Burbidge, Geoffrey Burbidge, Fowler, and Hoyle published the 104-page B²FH paper on the synthesis of the elements in stars[26]. They argued that nearly every element from carbon to uranium is made by nuclear processes in stellar interiors and supernova explosions. The resonance Hoyle had predicted was the hinge of the argument, since without a level near 7.65 MeV above the carbon-12 ground state the triple-alpha process could not proceed fast enough to produce the carbon on which the rest of the sequence depends. The paper founded nuclear astrophysics and brought Fowler the 1983 Nobel Prize in Physics [27].

The episode cuts two ways for the analysis. On one side, B²FH shows that the human and instrumental stock accumulated under the wartime regime could flow back into pure science: the accelerator culture of Kellogg, the experimental craft Fowler had honed on munitions, and the research freedom bought by federal money together produced one of the century's most durable results in astrophysics. On the other side, the same campus reproduced its own exclusions. Margaret Burbidge was denied a Carnegie fellowship because of her sex and reached the Mount Wilson telescopes in 1955 only as her husband's assistant. The first author of B²FH could not obtain an observing permit in her own name. Big Science concentrated resources and, at the same time, reproduced the community's internal structure of exclusion.

4.5 1958: JPL to NASA and the Substitutable Patron

Sputnik turned the helix toward space. On 31 January 1958, JPL's Explorer 1 put the first American satellite into orbit. NASA was founded that October, and on 3 December JPL was transferred intact from the Army Ballistic Missile Agency to the new agency, remaining under Caltech management as NASA's only federally funded research and development center. The transfer was an elegant rearrangement of the helix: the military pole was swapped for a civilian space agency while the university-government contract structure stayed in place.

JPL then deliberately abandoned the fields where it would have competed with industry and the military, making robotic planetary exploration its core mission. Mariner, Voyager, Galileo, and Cassini all came from this laboratory, and planetary science as a discipline was organizationally created along this mission pipeline[13] . The Apollo years measured the regime's peak scale. In 1966 NASA took 4.41 percent of the federal budget, a share that would not be matched again.

The campus changed shape in step. In the 1960s Caltech's geology division, exploiting the mission

resources next door, moved into planetary science and renamed itself the Division of Geological and Planetary Sciences, a title it keeps today[12] A low-cost renaming ratified the birth of a new disciplinary territory. The redrawing of boundaries here owed nothing to paradigm debate; it was done by mission orders from the laboratory next door.

4.6 Mechanism: Three Propositions

Three propositions follow from this chapter. The first is institutionalization through permanized temporariness. Summer study groups were improvised, and RAND made their function permanent; service contracts were provisional, and the federally funded center gave them durable form; Navy support for radio astronomy never had a proper mandate, and when the Mansfield Amendment drew the boundary in 1970, the National Science Foundation simply took over.

The second proposition is that the helix owed its elasticity to the substitutability of patrons. JPL moved from the Army to NASA in 1958, and Owens Valley moved from the Navy to the National Science Foundation in 1970, while the university did not move at all. The stability of the Cold War helix lay less in a fixed triangle than in the university's learned capacity to migrate among sponsors.

The third proposition is that the costs of the structure were prepaid by its most exposed members. Tsien lost his clearance, Burbidge could not enter the telescope dome under her own name, and the authors of the Vista report watched it disappear into Air Force drawers. Those standing at the edge of the helix absorbed its friction first. Chapter IV tests all three propositions against the contemporary crisis.

4. The Post-Cold War Era: Loosening and Reconfiguration (1991-2026)

5.1 1993: The Death of the SSC

The Cold War helix rested on an ontological premise called the Soviet Union. When the Berlin Wall fell in 1989 and the Union dissolved in 1991, the premise disappeared, and the largest scientific machine paid first. In October 1993 Congress voted to terminate the Superconducting Super Collider, an 87-kilometer ring whose budget had swollen from 4.4 billion dollars to more than 11 billion. More than twenty kilometres of tunnel had already been bored in Texas at a cost of about two billion dollars when the House killed the project 282 to 143[1] .

The cancellation is usually blamed on mismanagement and overruns, and the project was in fact badly managed. But the deeper signal concerned pricing. Once winning the Cold War could no longer justify Big Science, Big Science had to learn to justify itself. American particle physics never again obtained a comparable domestic facility. CERN took over global leadership in high-energy physics, and the discovery of the Higgs boson in 2012 happened in Geneva, not in Texas. The discovery was also not the paradigm rupture that the field had awaited, which is itself evidence for the argument: a confirmation can be first-rate physics and still leave a research programme without its former political warrant.

The legacy survived in another form. Some of the physicists displaced by the cancellation moved into gravitational-wave research at the Laser Interferometer Gravitational-Wave Observatory, a facility led

jointly by Caltech and MIT under National Science Foundation sponsorship. On 14 September 2015 LIGO made the first direct detection of a gravitational wave, GW150914 from a binary black-hole merger[28], and the 2017 Nobel Prize went to Caltech's Kip Thorne and Barry Barish together with MIT's Rainer Weiss. LIGO displays a different organizational form of Big Science. It was born from the civilian funding system, as a decades-long international collaboration whose thousand-member team publishes under collective authorship. If the fuel of Cold War Big Science was fear, the fuel of its successor had to be consensus, and consensus is built far more slowly.

5.2 2014-2019: The Thirty Meter Telescope and the Social Ground

The fragility of consensus is on full display in the standoff over the Thirty Meter Telescope. The project is promoted by Caltech and the University of California with partners in Canada, Japan, China, and India. It calls for a thirty-meter primary mirror, a budget of about 2.6 billion dollars, and a site on Mauna Kea, a dormant volcano sacred in Native Hawaiian culture. Protesters interrupted the groundbreaking in 2014, and mass protests blockaded the site in 2015. That December the Hawaii Supreme Court invalidated the construction permit, holding that the board had approved it before holding the contested case hearing it owed the objectors[29] . The board issued a new permit in 2017, and the court affirmed it a year later[30]. Protests returned in July 2019, and thousands of kia'i, or protectors, camped on the access road while images of arrested elders circulated worldwide. The governor then withdrew his emergency proclamation, and the state extended the construction deadline by two years, to September 2021[31].

The project never substantively resumed. In 2025 the National Science Foundation declined to advance the telescope to final design, on the ground that two multibillion-dollar telescopes could not both be funded, and committed no further money to it [32] A Spanish-financed alternative on La Palma was then explored. Two distinct causes are often conflated here. Protest explains why construction stopped in 2019; budget explains why the federal application was withdrawn in 2025. The first is a crisis of consent, the second a crisis of appropriation, and the project suffered both.

In the vocabulary of this paper, the impasse marks the irruption of a fourth actor. The triangle of university, government, and capital, philanthropic and foreign-governmental in this case, remained intact, but it had left out the claims of local communities and cultural heritage, and in the age of social media those claims could organize the paralysis of a construction site. For a community habituated to the Cold War helix, the lesson arrived late: the foundation of Big Science has never been concrete and steel alone. Thirteen telescopes already stood on Mauna Kea, and what the protectors asked was why their mountain again. That question could not be asked under philanthropic capital, when the land belonged to the forest service and the money to a steel magnate, and it could not be asked under contract science, when China Lake lay deep inside a Navy base.

5.3 2025-2026: The Federal Pole Contracts

This section concerns events still in progress, and what follows should be read as contemporary history: a record of positions taken, not of outcomes settled. The share of the federal budget that the space

agency commanded had already fallen from 4.41 percent at the Apollo peak to about 0.35 percent (The Planetary Society, 2025; see Figure 3). In 2025, at the start of the second Trump administration, NASA absorbed the sharpest fiscal shock since the Cold War helix was consolidated. The budget request for fiscal 2026 proposed cutting the Science Mission Directorate by 47 percent, from about 7.3 billion dollars to 3.9 billion, and terminating nineteen science missions in operation or development, including the long-lived and healthy Chandra X-ray Observatory. More than four thousand civil servants left through buyouts and layoffs (The Planetary Society, 2025; see Figure 3).

JPL took the brunt. The laboratory cut 530 positions in February 2024, another 325 that November, and 550 more in October 2025, reducing its workforce from about 6,500 to about 4,500, roughly the level of the early 1960s [33]. The deeper change came in May 2026, when NASA announced that the management contract held by Caltech since 1958 would be opened to competitive bidding before it expires in 2028 [34]. A stewardship that had survived every previous reorganization was placed on the market. No request for proposals had been issued and no competing bidder had been named at the time of writing, so whether the laboratory changes hands, and on what terms, is not yet knowable. What can be recorded is the decision itself and the conditions under which it was taken.

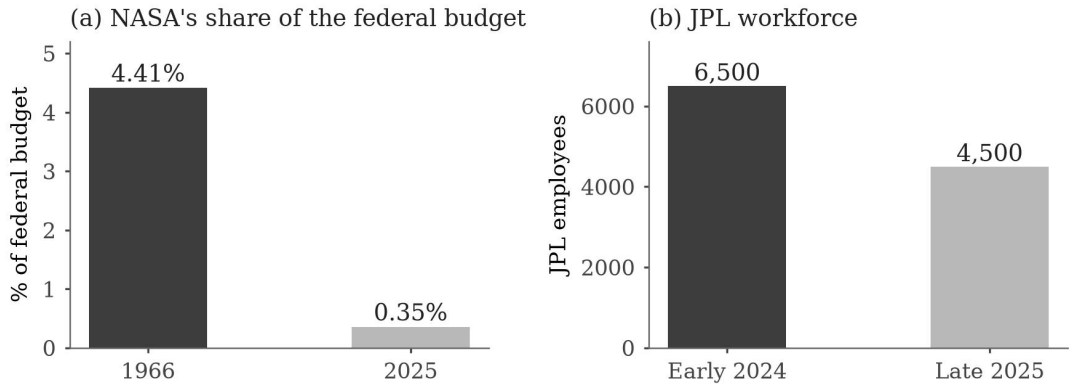


Figure 3. Contraction at the federal pole. (a) NASA's share of the federal budget in 1966 and 2025; (b) JPL workforce before the 2024-2025 reductions and after them, layoffs and attrition together. Compiled by the author from The Planetary Society (2025) and Los Angeles Times (2025)

Congress rejected the proposal. The House bill held NASA's top line steady but cut about 1.3 billion dollars from the science directorate, the Senate bill maintained science funding at the previous level, and both positions drew support from advocacy groups and from bipartisan concern for local employment[33] . The figures above describe the position at the time of writing; appropriations of this kind are reopened every year, and they should be read as a snapshot rather than a settled baseline. The rejection should be read less as self-repair than as an exposure of fragility. When the funding will of the federal pole becomes a variable of electoral politics, the whole ecology attached to it, from

management contracts to graduate fellowships, enters periodic shock. One detail deserves recording. During the 2025 layoffs, JPL engineers and scientists organized public protests and a unionization drive in Pasadena. The identity of science worker as a political category is growing precisely where the helix is loosening.

5.4 Data Justice

Running alongside the budget crisis is a structural rearrangement of who produces astronomical knowledge. The figures cited earlier come from Nagaraj and Yao [2], who geocoded the author affiliations of 44 million publications between 1980 and 2022 and found the American share falling from about 40 percent to 15 percent while China's rose from near zero to 32 percent (Figure 4). The National Science Board[3] records the same trend. The concern here is not the league table but the access structure underneath it. In an era of flagship surveys, the right to publish increasingly depends on membership in a small circle of facilities and data streams. LSST data at the Vera Rubin Observatory are gated by data-rights agreements, with the American and Chilean communities holding immediate access while astronomers elsewhere must purchase or negotiate access, and proprietary periods at the Space Telescope Science Institute have concentrated Hubble and James Webb data in a few teams.

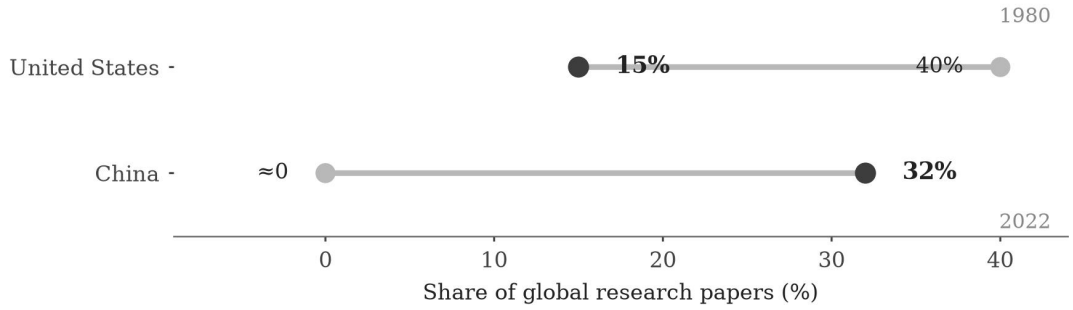


Figure 4. National shares of global research papers, 1980 and 2022. Compiled by the author from data in Nagaraj and Yao (2026)

Marginal communities have begun to answer back, as African astronomy associations press for FAIR data principles to become default infrastructure rather than conference slogans. When data mean papers and papers mean careers, unequal access converts directly into unequal opportunity. That is what data justice means in astronomy: not whether data are true, but who is licensed to produce data that count as knowledge. Artificial intelligence adds a second gate, since training astronomical foundation models requires computing capacity concentrated in a handful of institutions and corporate laboratories. The gating logic itself is old. In the 1930s, Rockefeller's six million dollars decided who could see the universe from Palomar; today data-rights protocols decide who can see it in the LSST database. The form of capital changed; the gate did not.

5.5 Mechanism: Reconfiguration Where the Helix Loosens

Read together, the cases of this chapter suggest three paths of reconfiguration. The first is the

legitimation vacuum left by the military pole. The SSC showed that a pure-science facility without a national-security narrative lacks defenders in Congress proportionate to its cost; LIGO showed the alternative, since a project with a Nobel-level goal and international cost-sharing can find a new stability. The helix has shifted from security-driven to prestige-driven.

The second path is the entry of a fourth actor. The telescope standoff demonstrates that indigenous communities, public opinion, and social-media mobilization now hold effective veto power over the siting and governance of Big Science, and a triangular model no longer suffices where civil society occupies a fourth corner.

The third is the periodic instability of the federal pole. The 2025-2026 crisis saw executive proposals contemplate cuts on the order of 47 percent for NASA science within a single year, with Congress and advocacy groups absorbing the shock, and the decision to re-bid the laboratory's management contract injects market logic into what had been the oldest and steadiest link between university and government. Together the three paths support one judgment: the Cold War helix was built historically and is dissolving historically, not with a crash but contract by contract, facility by facility, election by election.

6. Conclusion

Read against a century of evidence, the argument comes down to four claims.

First, Caltech's history is the history of two substitutions of the Triple Helix. Between 1917 and 1945 a prewar order built on philanthropic capital and scientific self-governance was replaced wholesale by a university-military-government triangle, as OSRD contracts displaced endowments. Between 1946 and 1970 the wartime improvisations were given permanent form in the federally funded center, the standing think tank, the summer-study network, and the federal grant system. The standard narrative, modelled on MIT, describes a benign intertwining of university, industry, and government. The Caltech record suggests something the standard model misses: its classic form was born in war, and the industry pole has been, since the 1940s, largely a proxy for military demand. The three spheres are not constants; they switch with the state of national security. The reverse arrow holds as well. Astronomers and physicists did not wait to be recruited. The problems they had chosen generated instrument requirements that no single donor could meet, and those requirements made the search for a new patron a scientific necessity rather than a political accident. Patronage set the scale; the discipline set the questions, and the questions kept redefining what counted as an adequate scale.

Second, war's reshaping of science runs deeper than money and organization. Chapter I showed how the shift from positional astronomy to astrophysics depended on instrument clusters and agenda autonomy. After 1945 agenda autonomy itself was renegotiated. Scientists did enter the inner rooms of strategy, and the military did fund the purest research, but entry and funding were never symmetric: the Air Force could bury the Vista report, and a single amendment could strip the Navy's astronomy budget. The same regime also produced B²FH. Cold War science was neither a golden age of free inquiry nor a

transmission belt for military will. It was a negotiating arena in which the boundaries of autonomy were continuously and unequally drawn.

Third, the post-Cold War crises are at root crises of legitimation. The cancellation of the collider, the telescope standoff, and the budget shock differ in form, but they pose one question. When national security can no longer underwrite Big Science, the community must justify its machines before the public, before indigenous communities, and before global colleagues. If the fruits of Big Science remain reserved for a few institutions, a few countries, and a few holders of data rights, the public support it now requires is morally unstable. Data justice belongs at the centre of Big Science's post-Cold War legitimacy, not at its margins.

Fourth, the history yields a normative consequence, and the derivation matters as much as the rule. If a funding regime is legitimate only when those who carry its costs have standing in its decisions, then three commitments follow. Data should be open by default, because the default is the only setting under which access does not depend on belonging to the right institution; the exception must therefore be argued case by case, and it must be narrow, time-limited, and appealable. Siting should require the substantive consent of affected communities before the decision rather than compensation after it, since a community that can only be compensated has already been overruled. And flagship facilities should carry statutory funding that outlasts an election cycle, because an instrument that takes twenty years to build cannot be governed by a budget that turns over every two.

The strongest objections are that each rule removes an incentive. Proprietary periods repay construction, and some communities may want restriction rather than openness. The first objection is answered by the time limit, which preserves the incentive without converting it into a permanent property right. The second is answered by locating the exception with the community rather than with the observatory, so that restriction becomes a right that can be exercised and withdrawn rather than a discretion that can be granted. Every gate erected in the name of efficiency or security, from donors' preferences to military secrecy to data-rights protocols, was eventually re-examined by history, and every time the cost fell on the most vulnerable members of the community. The rules proposed here are reverse-engineered from that record, and they keep the exceptions narrow for the same reason: the record shows how easily an exception becomes a gate.

The observation that opened this paper claimed that a science's fate is never the product of its internal logic alone, and the record confirms that much. Yet institutions and ideas do not have the final word either. From the five young men called the suicide squad in the Arroyo Seco, to the elders camped on the Mauna Kea access road, to the engineers protesting layoffs in Pasadena, the same scene recurs: people shaped by structures stand up and reshape them. The helix keeps turning, and who turns it next remains an open political question.

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