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ABSTRACT If they are successfully to carry out a research programme, astronomers need two crucial resources – access to telescopes, and sufficient time allocated on them to make observations and collect data. This paper employs the concept of the 'moral economy' – the unwritten expectations and traditions that regulate and structure a community – as an analytical model to examine how astronomers and science managers allocate resources. I use the example of the Gemini 8-Meter Telescopes Project, a recently completed pair of large telescopes in Hawaii and Chile, as a vehicle to explore the moral economy of contemporary astronomy. Paying particular attention to the early years of the project (1987–92), I describe plans to build a new telescope facility for the entire US astronomy community, against the backdrop of the institutional, political and financial forces that shape national and international astronomy. By focusing on the process through which astronomers moved the Gemini telescope project from abstract blueprints and budgets into glass and steel, I examine themes such as access, equity, control and authority in contemporary science.

Keywords funding, Gemini, instruments, resource allocation, science policy

Large Telescopes and the Moral Economy of Recent Astronomy

W. Patrick McCray

All scientists need resources – equipment, funding, time – to carry out their research. For optical astronomers, two of the most important assets are access to telescopes and sufficient time allocated on them to make observations and collect data.[1] Astronomers are critically affected by the availability and distribution of these, and they describe the sociology of their community in dialectical terms based on resource allocation. The community makes a fundamental and long-standing distinction between those who have access to telescopes through their institutional affiliation and those who do not, and must instead compete for time at one of the federally-funded national centres. A former observatory director explained the situation:

> There are the independent observatories which some people call the 'haves'. And there are the 'have nots!' . . . The people who are the 'have nots' still have to rely on the National Observatory to get time.[c, 2]

A key difference separating postwar optical astronomy from other physical sciences in the United States is its long tradition of private and

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philanthropic support. Historically, private institutions or state-supported universities have funded and managed most large American telescope facilities. The largest and best telescopes have been available, therefore, to only a small fraction of the entire astronomical community. There were not nearly enough telescopes or observing time to meet the demands of the rapidly growing postwar astronomy community.

In 1957, the US National Science Foundation (NSF) responded to the need for more telescopes and observing time by establishing a system of national observatories. While the participation of the federal government provided extensive funding and telescope facilities for the entire astronomy community, it created ever-increasing competition and divisiveness in that community about how such resources should be used and distributed. Should funding go to cutting-edge instrumentation and long-term observing programmes at institutions run by the 'haves', or to build and operate facilities for the larger community of 'have nots?'. Goetz Oertel, former president of the corporation that manages prominent national facilities such as the National Optical Astronomy Observatories (NOAO) and the Hubble Space Telescope, described this tension as . .

> . . a natural tug of war between those who have and those that have not, in terms of access to their own telescopes. The national observatories have always been controversial. With the 'haves' being reluctant or negative and the 'have nots' being enthusiastically in favor of them.[g]

E.P. Thompson's concept of the *moral economy*, introduced in his essay on food riots in 18th-century England, is used here as an analytical model to describe how the essential resources for doing astronomy are allocated, and access to them negotiated.[3] For Thompson, a moral economy refers to the *mentalité* – the expectations and traditions – that structured and mediated interactions between the consumers and producers of life's basic needs. The moral economy is concerned with the rights people have to the necessities of living; it also addresses the manner in which non-economic relations are regulated according to tradition and non-monetary social norms. Robert Kohler later modified Thompson's concept to include the activities of experimental scientists; he wrote that 'unstated moral rules define the mutual expectations and obligations of the various participants in the production process', and that these '[m]oral conventions regulate access to tools of the trade. . .'.[4]

The moral economy of astronomy functions through negotiations and compromises. It shapes how access to resources – telescopes, funding, and observing time – is acquired. What is accepted as an equitable distribution of resources is contested frequently and in different ways by astronomers and science administrators. The historical tradition with regard to resources in postwar American astronomy is a divide between the 'haves' and the 'have nots'. This pattern of resource distribution creates strong emotions among both groups of astronomers. Moreover, debates over the authority to divide resources and set priorities have been, and continue to be, a traditional part of astronomy's moral economy. For example, since the 1950s, the National Academy of Sciences, the NSF, and NASA all convene formal committees of prominent astronomers which are influential in shaping long-term resource allocation.

In 1975, a small fraction of the American astronomy community, led by America's national observatory, initiated exploratory plans for a new and larger national telescope facility. For over a decade, astronomers and engineers proposed building a new telescope that would be significantly bigger than any operated by private institutions. Yet, by 1987, nothing had been funded or built. Moreover, there was persistent and contentious debate in the community about the future rôle of the national observatory as a resource provider. Astronomers knew that several new telescopes larger than the Hale 200-inch, the biggest (and privately operated) telescope, were going to be built by private American and international institutions in the next decade.[5] Many astronomers debated the purpose the national optical astronomy centre should have in this new world of larger and more powerful instruments, and asked how their community, as a whole, could remain competitive without access to the independent private facilities. Between 1987 and 1993, there was a crisis in the American optical astronomy community. In this period, astronomers and science managers thrashed out plans for a new and larger national observing facility, eventually named the 'Gemini 8-Meter Telescopes Project' (hereafter, 'Gemini'). However, political and financial forces determined that the United States build Gemini as a partnership with six other countries – the United Kingdom, Canada, Australia, Chile, Brazil and Argentina. In June 1999, on the barren, windswept summit of Mauna Kea in Hawaii, the first Gemini telescope, one of the largest in the world, was dedicated. With a twin companion telescope in Chile scheduled for completion in 2000, the Gemini Project was the culmination of a 25-year effort to build new observing facilities that the entire American astronomy community could access. The total cost of the two telescopes was $184,000,000; operations each year are roughly another $20m; the US pays half these costs.

Since 1990, Gemini's cost and scale have been exceeded by more elaborate and expensive technoscientific endeavours. The telescopes are well on the way to becoming a 'black box' (but with 24-ton, 8.1-meter primary mirrors). However, in 1990 Gemini was a controversial science project, especially for ground-based optical astronomy. Its future was far from assured, and many in the astronomy community expressed great concern that the telescope would not (or would) be built.

The Gemini telescopes are only two of several new, very large telescopes completed in the past decade; others will see 'first light' in the next few years. Any astronomer in the United States or one of the Gemini partner countries can apply for observing time on any of these new instruments. At the dedication ceremony on 25 June 1999, Rita Colwell, Director of the National Science Foundation, remarked: 'This observatory represents the journey by scientists, engineers, and administrators to a symbolic summit'.[6] What exactly was the journey that Colwell referred to?

This paper is, in part, an exploration of Gemini's early history, and of how the people who advocated it overcame obstacles that threatened the nascent project. I will describe plans to build a new national telescope facility against the backdrop of the institutional, political, and managerial actors that shape the moral economy of national and international astronomy.

By examining the unwritten rules, interests and historical traditions that are inherent to the astronomy community, we can discern more clearly the processes and negotiations through which its members allocate and distribute commodities, tangible and otherwise. We must also consider the motivations behind these processes, and whether and when an individual or institution is acting primarily out of a concern for fairness and equity, or in self-interest. By focusing on the people and institutions who brought the Gemini telescopes from the abstractions of blueprints and budgets into the messy and imperfect real world, I explore important themes such as access, equity, control and authority in contemporary science. The questions I ask here are simply put: What is the historical basis for the allocation of resources within optical astronomy? How did Gemini get approval and funding? What was the process and what forces and people influenced it?

Drawing on Thompson's insightful development of the moral economy concept, I examine the values and social processes that exist in contemporary astronomy and, in particular, in the early history of the Gemini telescopes. At the same time, I adapt and extend the idea of a moral economy to examine the traditions, assumptions, rules and relationships that exist in late 20th-century astronomy. What are the essential features of a moral economy as it is used in this paper?

A moral economy, like any economy, involves objects of value.[7] The most important commodities for the astronomers and science policy administrators whose story I tell here are an adequate amount of observing time, resources to build and operate new telescope facilities, and funding for one's own research. Other less tangible goods, such as the power to control resource distribution, the authority to set astronomy's priorities, and the prestige (and jealousy) accorded to an institution or individual having a rich supply of resources, are also part of astronomy's moral economy.

A moral economy certainly is not apolitical. The process through which the Gemini telescopes were approved and funded clearly required the mediation of American and international politicians. Some astronomers also became politically involved within their community and at the national level, and attempted to influence aspects of the Gemini telescope project.

A moral economy, as considered in this paper, is founded on certain principles of fairness and means of control regarding access to the resources astronomers need. These standards are not defined explicitly by members of the community. However, they are understood tacitly and frequently reconsidered, redefined and renegotiated. Indeed, it will be seen by the paper's end that one of the factors determining whether an individual or institution is able to secure access successfully to resources is the ability to understand and use the unwritten conventions, traditions and rules of astronomy to best advantage.

Contemporary Optical Astronomy and Its Moral Economy

One feature of moral economies is that they are historically created, changed, and destroyed.[8] Between 1957 and 1987, there were several developments that altered optical astronomy's moral economy. It may seem, at first, that American astronomy after World War II simply experienced many of the same changes historians have noted in other physical sciences, with the influx and influence of government funding and the construction of new and elaborate facilities.[9] But the extensive private and state investment that defined and shaped American astronomy before World War II did not die out after the introduction of generous federal funding.

Before World War II, American astronomy was a relatively coherent discipline.[10] The community was small, observations were made almost entirely at visible wavelengths, and, despite the use of large and expensive instruments, astronomy was practised mostly as 'small science'.[11] While teams of pre-war astronomers worked on research projects at institutions such as the Harvard College Observatory, the romantic image of the lone astronomer on a mountain patiently guiding a telescope through the cold night had a degree of truth to it. But, after World War II, practices changed dramatically. Astronomers began to use new technology, such as rockets, electronic detectors, and radar, to make observations at other wavelengths. New technologies also had a synergistic relation with astronomy, stimulating and requiring bigger funding sources and collaborative research efforts, and creating many sub-disciplines of research such as radio and x-ray astronomy.

After World War II, American optical astronomers were slow to take advantage of federal patronage. They certainly did not respond as quickly or enthusiastically as did the American physics community. Before the advent of the national observatory system, the directors of private observatories wielded considerable power, and controlled access to the nation's largest telescopes.[12] David DeVorkin attributes the initial tepid response of astronomers to federal funding to 'an élite infrastructure that was more concerned about preserving authority and control than it was in increasing its size or introducing new technologies'.[13] Gradually, these attitudes changed. A key development was the emergence of a national observatory system for optical astronomy.

Throughout the mid-third of the 20th century, larger and better private telescopes continued to be built in the southwestern United States, where the climate and observing conditions were better. By 1960, the nation's largest telescopes were concentrated mostly in California, and there were no nationally available facilities that were competitive.[14] A dichotomy developed in American observational astronomy as the balance of power, in terms of access to the best instruments, shifted away from older observatories such as Harvard and Yerkes (Chicago). Astronomers without access to the large, private telescopes were understandably concerned about their limited resources and lack of time on the largest telescopes. Many of these astronomers were from institutions in the Midwest and the East, where observing conditions were poor and easy travel to California was not possible. In 1953, at a special conference at the Lowell Observatory in Flagstaff, Arizona, Leo Goldberg, then chair of astronomy at the University of Michigan, spoke up: 'I think what this country needs is a truly National Observatory to which each astronomer with ability and a first-class problem can come on leave from his university'. Goldberg's suggestion got a favourable response from the NSF, and that agency began to explore possible sites for the observatory.[15] In 1957, representatives from seven universities – California, Chicago, Harvard, Indiana, Michigan, Ohio State and Wisconsin – met and soon formed the Association of Universities for Research in Astronomy, Inc. (AURA). AURA's charge was to operate the new national observatory for the NSF. In 1958, AURA selected Kitt Peak, near Tucson, Arizona, as the observatory's site. A solar observatory and an optical facility in Chile soon followed. In 1984, to consolidate facilities, the three national observatories – Kitt Peak, the Cerro-Tololo Inter-American Observatory in Chile, as well as National Solar Observatory in Sunspot, New Mexico – were merged into the 'National Optical Astronomy Observatories' (NOAO) and managed, as before, by AURA.

Formal evidence is scant that the American astronomy community had a sense of entitlement – that is, that the federal government owed them telescope time and other resources – or that this is the case today. However, the moral economy is about unwritten but commonly shared values and traditions. The *mentalité* among postwar astronomers – as evidenced by extensive reports, correspondence and oral histories – shifted, and the federal government, via the NSF and NASA, became seen as a generous and essential provider of resources. The nationally available telescopes were built and operated with the NSF's support, and their presence greatly increased the light-collecting area available to the overall astronomy community.[16] American astronomers not affiliated with privately-run observatories soon had access to two national 4-meter telescopes, numerous smaller ones, and could observe in both the Northern and Southern hemispheres. By 1980, about two-thirds of the NSF's support for astronomy went to the national observatories.[17]

Helmut Abt, who edited *The Astrophysical Journal* – one of the most important publications in astronomy – for 28 years, recalled that the national observatory's most important effect on astronomy was providing competition with the private observatories, and the tools to evaluate other astronomers' research results.[a] In a 1978 interview, influential Caltech astronomer Jesse Greenstein described the national observatory system as having a profound effect, offering a place where astronomers, regardless of affiliation, could carry out research. He went on to note:

> The main problem for the AURA management is the question of democratic choice versus elitist, snobby concentration of effort . . . How to choose the select few, how to do this without ruining their position as the national observing facility?[18]

Astronomers' emotional reactions toward nationally-available telescopes depend on whether one is a 'have' or a 'have not'. In 1998, I asked a prominent (but anonymous) astronomer at a large Midwestern school without its own large observing facilities how people in the community without private telescopes feel. He replied:

> Thoughts toward the National Observatory are in the vein that they are your support. That's how we get our observing time around here.

But how do people who have access to their own telescope facilities feel about the existence of the National Optical Astronomy Observatories? This astronomer responded with anger and resignation:

> They don't give a flying fuck about the rest of us. They'd just as soon as take it all. In fact, not too long ago some of them [astronomers from private institutions] proposed we gut the national observatories and, more or less, give it all to them. The people who proposed this said that the people who wouldn't have access to telescopes anymore were minor players in astronomy and so they wouldn't be missed.

On the other side, some astronomers whose access to facilities mark them as 'haves' believe that the national centres have not always operated at the cutting edge of technology development, and that the considerable federal money spent on them would be better used as grants to individuals or private institutions. For example, in 1993, in a letter widely circulated throughout the scientific community, Sandra Faber of the University of California (which has considerable access to private facilities) described an American astronomy community that was deeply divided over the rôle NOAO should have, and suggested a radical re-organization of the national observatory. She noted that the national observatories are a source of jealousy in that they compete with private and university groups for funding, and that it might be better to give away NOAO facilities to private or university consortia. These groups would operate the telescopes and reduce the services and support offered by the national observatory.[19]

With its establishment, the national observatory system altered the balance of resources, and brought about a new and tacitly understood social contract with the astronomy community. The availability of large telescopes outside the private observatory system came to be seen by some 'haves' as a challenge and a threat to their own resource base and prestige. Demand for observing time with the Kitt Peak and Cerro-Tololo telescopes soon outpaced availability.[20] This shortage was accentuated by the fact that scientists from institutions with their own private facilities could also apply to use the national telescopes. The allocation of observing time at the national facilities, and their management, became sensitive and politically charged. In time, the dearth of adequate and available observing time would play an important factor in plans to build a new national telescope bigger than those at Kitt Peak or Cerro-Tololo.

American Astronomers Debate a New National Telescope

In the late 1970s and early 1980s, the US astronomy community clearly articulated the scientific advances that telescopes bigger than the Hale 200-inch could make.[21] Also, in the 1980s, the National Science Foundation, in cooperation with NOAO, was funding plans for a new, much larger national telescope that would be available to the entire American astronomy community. The technical design and scientific agenda for the new telescope provoked impassioned discussions; they were matched in intensity by debate over the future of the national observatory and priorities for astronomy in the next decade. Between 1975 and 1987, the long and continuing tension between private and federal patronage for American astronomy affected plans to build a new national telescope.

In the summer of 1975, Kitt Peak astronomers and engineers began working on concepts for a telescope with a 25-meter aperture. The new telescope programme at Kitt Peak was called the 'Next Generation Telescope Project'. If built, it would have a collecting area 125 times that of the Hale 200-inch, the largest operating telescope in the world at that time. Between 1977 and 1980, the Next Generation Telescope programme became somewhat unfocussed, as engineers and astronomers advocated and explored several different design concepts. Soon, Kitt Peak management scaled back their ambitions and initiated the 15-meter 'National New Technology Telescope' (NNTT) Project as an extension of their earlier programme.

Kitt Peak, as the national centre for optical astronomy, took the lead rôle in the organizing efforts. Funding for the NNTT programme originally came from the operating budget of Kitt Peak. A year later, the National Science Foundation demonstrated support for the effort by funding a proposal for telescope technology development.[22] In January 1982, the NNTT project received another major boost when the National Academy of Sciences published the third decadal survey of astronomy.[23] These reports describe the health of the discipline, summarize important scientific advances of the decade, and set research goals for the next ten years. More importantly, through a process of debate and negotiation that is closed to the public and the general astronomy community, the decadal survey committees present a prioritized and influential list of instruments and facilities for federal funding. The 1982 survey, chaired by George Field of the Harvard-Smithsonian Center for Astrophysics, listed a 'New Technology Telescope of the 15-meter class' among its recommended priorities for new facilities.

In 1984, shortly after the national observatories were consolidated to form NOAO, a committee of high-ranking astronomers chose a design concept for the NNTT that was later endorsed by the AURA Board. The overall NNTT design was based on concepts advocated by astronomers from the University of Arizona. At its heart, the telescope would also use four 7.5-meter mirrors on a single common mount to achieve the light-collecting power of a 15-meter telescope.[24] The mirrors were to be made by a team led by astronomer Roger Angel at Arizona's Steward Observatory. In 1984, as part of its NNTT development programme, NOAO established an Advanced Development Program, led by Jacques Beckers.

Following the 1984 decision to use the Arizona design, there were instances of personality clashes and institutional competition between Steward Observatory and NOAO.[25] Arizona had its own large-telescope ambitions. During this time, the NSF was also heavily committed to building the Very Long Baseline Array, a national radio-astronomy facility given the highest priority in the decadal survey chaired by George Field. Partly because of its commitment to this facility, the NSF's funding for NOAO decreased steadily by about 21% between 1984 and 1990, while staff numbers dropped by 15%.[d, 26]

With the support of the NSF, the Steward Mirror Laboratory and NOAO continued developing NNTT-related technology at a modest level. However, at the National Science Foundation's Astronomy Division, there were growing concerns with the slow progress in scaling up mirror-making technology.[27] Meanwhile, Jacques Beckers and others at NOAO tried to create community support for the project which varied:

> Some were very skeptical. It was mixed . . . There was a big disagreement in the community about large telescopes . . . a big fear in the community at smaller universities that this grandiose telescope project would push the little guy out of the way.[c]

By the end of 1986, the NNTT Project had become unstable, and its future uncertain. Community support for the project was not overwhelming. Other institutions in the United States, including Caltech and the Carnegie Institution of Washington, had plans to build their own large telescopes in the next ten years. While the 15-meter NNTT was clearly bigger than any of these, astronomers and administrators had questions about the scientific justification for a national facility at a time when private or international groups were building a new generation of instruments. At the same time, community doubts were growing about the future of NOAO as an institution in the coming era of large-telescope optical astronomy and the Hubble Space Telescope.

The Future Directions Committee

E.P. Thompson's concept of a moral economy suggests that when people's needs are not being met, they will act in proscribed manners mediated by customs and values. 1987 was a watershed year for the national observatory; there was a crisis in the American astronomy community over the future of the NNTT project and, more significantly, of the national observatory system. Differing visions of the national observatory represented conflicting views of astronomy's moral economy. Some astronomers valued reducing the rôle of the national observatory, and leaving the allocation of resources to private and state-operated institutions. Others favoured a stronger and more prominent position for NOAO as the flagship of American astronomy. Each path would re-shape the means and degree to which astronomers had access to necessary resources. What does the community's response to the crisis in 1987 tell us about the moral economy of astronomy, and its values?

In September 1986, the AURA Board selected Goetz Oertel as their new President. Previously, he had held top-level management positions at NASA and the Department of Energy. In the Spring of 1987, Sidney C. Wolff took over management of NOAO as its first woman Director. The two of them took a hard look at the NNTT project and the future of NOAO in US astronomy. Oertel recalls that the community and political support for the NNTT seemed limited, and he had personal doubts about the plan to build any large telescope requiring four 7.5-meter mirrors.[g] His conversations with Washington politicians added to his unease. Richard Malow was the Congressional staffer for the House Appropriations committee that oversees the NSF's and, therefore, NOAO's budget. He remembers having concern over the rising national debt and doubts about beginning another large-scale astronomy project.[f]

Soon after taking office, Oertel commissioned the 'Future Directions for NOAO' Committee. AURA asked the Committee to examine the appropriate rôle for the national observatory, and to determine the best way for NOAO to complement and cooperate with other astronomical research facilities. Steve Strom, then an astronomer at the University of Massachusetts, chaired the Committee, which included prominent astronomers from private, state and federal institutions. Strom described the NNTT programme as coming under pressure simultaneously from different factions in the discipline's moral economy:

> . . . there were two competitions. Between the élitist institutions who . . . didn't want NOAO to succeed and the smaller institutions that didn't want NOAO to succeed, but for very different reasons.[h]

Strom's comment brings out an important and longstanding debate in the astronomy community, both in the United States and abroad: Is it better to provide many small telescopes so that more researchers can get some share of observing time, or is the optimal strategy to provide a few larger and more powerful telescopes that will allow a smaller part of the community to do research on fainter and more distant objects?[28]

In August 1987, the AURA Board convened a retreat for its members in the mountain resort of Keystone, Colorado. Members of Strom's Committee attended, along with representatives from the NSF. Major topics on the agenda were the future rôle of NOAO, the needs of the

American astronomy community, and the types of facilities that the national observatory should develop.

Meeting participants discussed options for NOAO's future; each gave the national observatory a different responsibility in terms of supplying resources for optical astronomers.[29] One was for NOAO to have a flagship rôle in American astronomy. In this case, NOAO would be the premier institution in ground-based optical and infrared astronomy, analogous to the United Kingdom's Royal Observatories at Greenwich and Edinburgh. To achieve a flagship NOAO, building the 15-meter class NNTT would have a high priority. According to Strom, some argued that this path would presumably increase the programmatic coherence, political unity and competitive strength of American astronomy; others countered that it would be difficult if not impossible to implement, given the federal funding realities of the time *versus* the level of support available for privately-run astronomical institutions. Those at the meeting also did not anticipate that private and state-funded observatories would cede the leadership rôle and accompanying federal funding to NOAO voluntarily.

At the other extreme, Strom's Committee considered the possibility that NOAO should provide only service and support to enhance the research programmes of privately-run United States observatories. Envisioned thus, NOAO's rôle in this model was analogous to the NSF's Antarctic Program, which operates and supports facilities for scientists to use. This model of NOAO would require a minimal amount of federal funds, leaving the lion's share of money to private and state-run observatories. NOAO's scientists and engineers would not be expected to make major contributions to United States astronomy on their own and a new, large, and national facility would not be built. While favoured by some members of the private-observatory community, this option was unfavourable to those with greater plans for the national observatory.

In the end, a third option was chosen that lay between the two extremes. In this strategy, which Strom later described as 'a first among equals' approach, NOAO would be complementary to the private observatory system, leading in some areas and providing support in others. NOAO, as it was argued by members of Strom's Committee, would develop leadership and unique facilities in certain areas where there were 'scientific deficiencies and unexploited opportunities [by] directing resources toward their remedy'.[30] NOAO would develop facilities to the extent that they were not being pursued by other private groups, concentrate on unique areas of instrumentation and research, and still continue to provide support for American astronomers lacking their own resources.

At the Keystone meeting, astronomers proposed several different plans for a new national telescope facility. All of these centred around building telescopes in the 8-meter class. While the astronomers debated whether it would be better to build one or two 8-meter telescopes, where to build them – Hawaii or Chile – and what their scientific capabilities should be, few participants advocated building the 15-meter NNTT.

A vote was never taken at Keystone on whether to kill the 7-year-old NNTT Project. However, as Goetz Oertel recalled in 1999, after the August Keystone meeting 'it faded away like MacArthur, an old soldier'.[g] In September 1987, Steve Strom and the Future Directions Committee released their final report.[31] Its executive summary described a rôle for NOAO that was most consistent with the complementary, 'first among equals' model discussed at the Keystone retreat. The report recommended that NOAO's first priority should be to 'build as rapidly as feasible two 8-meter class telescopes (one in each the Northern and Southern hemispheres) with superlative image quality and located at excellent sites'. Shortly after the Keystone meeting, the AURA Board resolved that it intended ' . . . to construct and operate 8-meter telescopes to provide outstanding research facilities for the US optical and infrared astronomy program during the early 1990s'.[32]

After the Keystone retreat, NOAO staff – demoralized, by some accounts – went back to the drawing board and submitted a proposal, entitled 'The NOAO 8-meter Telescopes', to the NSF in September 1989. The four-volume proposal describes the scientific programmes for the two telescopes, a technical description of the facilities and instruments, along with detailed management and budget information.[33] If funded, it would be one of the largest and most expensive projects undertaken by the NSF, and would represent a major federal commitment to ground-based optical astronomy and the national observatory system.

The choice the Future Directions Committee and the AURA Board selected was a compromise between two extremes. It did not resolve the community debate over NOAO's rôle. At this point, it is worth asking why astronomers perceived it was important for the national observatory to build two new, large, and cutting-edge telescopes. Part of the answer is that, given the new telescope facilities under development by private institutions, without a similar programme NOAO would find itself operating much smaller telescopes. It would, therefore, have been outpaced by developments in the private sector, and unable to offer the overall astronomy community access to large, competitive facilities. In the end, a select group of American astronomers decided that having fewer but more powerful telescopes would be more beneficial to the overall community than the health and continued existence of NOAO.

Science Politics and the Birth of Gemini

At its heart, the moral economy, as I am using the concept here, is about how people obtain resources and address questions of equity. In addition, the question of who has the authority to decide the distribution of resources looms large. Between 1987 and 1993, astronomers and science managers transformed the plan to build two 8-meter telescopes as a nationally accessible telescope facility. When this was done, the Gemini Telescopes Project was an international collaboration, the US astronomy community had a 50% share in it, and infrared optimization of the telescopes was a guiding design goal. These events and developments are too complex to fully describe here. Instead, I wish to present key events with an eye toward the people and institutions who played key rôles in shaping the community's access to resources, and the process of how Gemini was approved.

In the late 1980s, the United States was not the only country pursuing plans for new, very large telescopes. The United Kingdom and Canada were also considering how to build an 8-meter class telescope. Unlike the situation in the USA, astronomy in both the UK and Canada is almost solely supported by government funding, and does not have a history of private support. Because of this tradition, and an understanding that British or Canadian governments would not fully fund telescopes solely for their astronomers, international collaboration was necessary. Beginning in 1987, UK and, later, Canadian astronomers discussed plans with NOAO staff to build a new observing facility together.[34]

In the United States, the possibility of a collaborative American-British-Canadian effort attracted the attention of Erich Bloch, the NSF Director. Bloch advocated industrial competitiveness and, at times, seemed to direct the NSF on a path that deviated from the agency's traditional mission of supporting basic research. As a result, astronomers saw Bloch as not especially supportive of their discipline. However, Bloch strongly favoured international collaboration, and used astronomy as a convenient vehicle to pursue this goal.[35]

In July 1989, astronomers from the USA, the UK and Canada met formally for the first time to discuss potential collaboration. This was followed by a series of meetings throughout 1990. In April 1990, the AURA Board recognized 'the opportunity for scientific excellence and the pool of technical expertise', and unanimously passed a resolution to 'enthusiastically endorse the international collaboration to build two 8-meter telescopes'.[36]

The plans to build the two 8-meter telescopes, and the possibility of an international effort, were reported by Ann Gibbons in the 18 May 1990 issue of *Science*.[37] Gibbons' article drew attention to what would be one of the controversies surrounding the telescope project in its formative years – that of international collaboration. While describing the powerful capabilities of the new instruments, she also reported that the NSF would not commit to building the telescopes, now estimated to cost $176m, without foreign contributors paying half the cost. American astronomers began to complain about the direction the project seemed likely to take: the two national telescopes might be built as an international facility in which American astronomers would have only a 50% share. Gibbons said that some astronomers were angry that the United States could not (or would not) provide all of the funding, and worried that an international effort would take longer to fund and build, and be harder to manage. Some noted that the last decadal survey had advocated a new, national telescope 8 years before, with no clear progress visible. Gibbons went on to report how the United States astronomy community was split over whether it would be better to build only one national telescope in Hawaii or share half of two international telescopes giving full-sky coverage: she quoted Ed Stone (a Caltech astronomer and, later, Director of the mission-oriented Jet Propulsion Laboratory) as summarizing some opinions when he said: 'Half a telescope is better than none'.

Building the two 8-meter telescopes as an international effort was not explicitly envisioned at the 1987 AURA meeting at Keystone, or in the 'Future Directions for NOAO' report that came out shortly after. Even as late as 1989, it was not at all certain that the international route would be chosen. But, by 1990, AURA had endorsed an international effort, and plans for an American-British-Canadian partnership were well under way.

There were several reasons for this transformation. Interest in an international effort existed at two levels in the worldwide astronomy community. In the United States, it was largely from the top down, via the NSF and the policies of Erich Bloch. American astronomers, in general, certainly wanted new facilities, but ones funded and operated by the United States: as Gibbons' article makes clear, Bloch was adamant that any new large telescope be built as a collaborative venture, despite resistance from astronomy's rank and file. British and Canadian governments were reluctant or unable to fully fund separate national telescopes, creating a favourable environment for collaboration. British and Canadian astronomers took advantage of United States interest in international collaboration that came from the top down. Science policymakers and administrators (such as Bloch) favoured international efforts in general, and saw astronomy as a convenient vehicle to pursue them. The opportunity to build two new large telescopes as an international effort was a timely match between science and politics of which astronomers and policymakers took advantage.

By 1990, the planned two-telescope project had the firm support of the NSF's upper management and science agencies abroad, and the approval of AURA (who expected to manage the project). Although American astronomers continued to debate the rôle of the national observatory and its participation in an international effort, there was some satisfaction that a course of action had been selected both for NOAO and for the telescope project. If it was to receive the necessary funding, the telescope project now had to build support and attract additional advocates in the larger world of science policy, as well as in the US political arena.

In early 1989, the National Academy of Sciences was preparing to conduct its fourth decadal survey of astronomy and astrophysics. The National Academy asked John N. Bahcall, a theoretical astrophysicist at the Institute for Advanced Study in Princeton, to chair the survey and set the discipline's priorities for the coming decade.[b, 38] Bahcall immediately began selecting his Committee. Shortly after being asked to chair the decadal survey, Bahcall was also elected President of the American Astronomical Society. This raised his profile in the science community, and gave him an additional base from which to call upon his astronomer colleagues. By the end of 1989, Bahcall had selected a Committee including six members of the National Academy of Sciences, two Nobel laureates, and two directors of national observatories. Fifteen different panels reported to the main Committee on topics ranging from optical astronomy to computing and data processing. In 1989, an article in *Physics Today* quoted Bahcall explaining the size of his Committee, and noting: 'We want to make sure we don't miss anything. In the end, the strength of the report we issue will depend on consensus'.[39]

Bahcall knew that one of his thorniest jobs was to form a consensus for priorities within the optical astronomy community. In a 1999 interview, he explained features of what amounts to the community's moral economy:

> It was not a community used to working in groups and used to getting along and used to helping each other achieve their priorities . . . We worried about it more than any other group. The intensity of it, the feelings, were much higher, among the individuals involved with the discussions in those groups.[b]

Steve Strom, who chaired the 1987 'Future Directions for NOAO' Committee, headed the panel that addressed ground-based optical and infrared astronomy for the decadal survey. Members of Strom's panel were keenly aware that at least eight other telescopes larger than six meters would be built within the next ten years. Several of these would be operated by groups outside the United States. Bahcall and his Committee interpreted this trend as a serious erosion of American leadership in astronomy, where dominance is often measured by the amount of available telescope collecting area.[40]

Strom organized forums in different parts of the country where astronomers could meet and discuss their perceptions and wishes for the next decade. Each regional group of astronomers viewed the situation differently, depending on their access to resources. Strom recalls that the scientists from the Midwest felt very disenfranchised, and the least blessed with resources; as a result, they felt most in need of the national observatory that would provide telescope access, but not necessarily new or larger facilities. On the other hand, astronomers from places such as Caltech and the University of Arizona had plans for their own facilities; they were less concerned about having a big, new national facility, and wanted federal funds allocated to help build instruments and operate their own telescopes.[i]

Bahcall was also aware that several new ground-based facilities were going to come on-line in the 1990s. He knew it was going to be difficult to advocate another large general-purpose telescope, even if it was open to the national community. As a result, he was in favour of a new facility with unrivaled capabilities, and believed that a national telescope project without some unique rôle would not fare well: 'I would not personally have supported a telescope which was not special . . . I wanted the US to have some unique facilities'.[b] A unique rôle was essential to the continuing future of the NOAO/international 8-meter telescope project. It was also, not coincidentally, one of the suggestions of the Future Directions Committee in 1987.

A key person who helped advocate a unique rôle for a new national or international telescope project necessary to ensure that it ranked high on Bahcall's recommendations was Frank J. Low. Low was a prominent infrared astronomer at the University of Arizona. He had served on Strom's Future Directions Committee, and was also on the optical/infrared panel in the Bahcall decadal survey. Low suggested optimizing at least one of the planned 8-meter telescopes for infrared observing. This would give it a unique capability that no other telescope facility of that size in the world could offer.[e, 41] Bahcall recalled meeting with Low in January 1990, at a meeting of the American Astronomical Society, and hearing about Low's idea for an infrared optimized telescope. As he recalls:

> [I]t was clear that the scientific frontiers [for this type of telescope] were virgin and vast! I was thrilled by the idea. I think that, within half an hour, I said 'That's something we really have to do'.[b]

The next political hurdle for the telescope project was actually to receive money from Congressional Appropriations Committees. Funding for the National Science Foundation, the ultimate source of money for the telescope project, is controlled by the House and Senate Subcommittees for the Departments of Veterans Affairs, Housing and Urban Development, and Independent Agencies (VA/HUD/IND). The telescope project appeared in the NSF's budget for fiscal year 1991 as a request for $4m.[42]

On 27 February 1990, Robert Traxler, the chair of the VA/HUD/IND Appropriations Committee quizzed Bloch about the use of the money and the need for any new telescope, when the much-heralded and very expensive Hubble Space Telescope would soon be operational.[43] Traxler and other committee members asked probing and sometimes critical questions about new large-scale science projects in the NSF's budget, including a request for funds to begin building a gravitational-wave detector, and they expressed concern that the NSF's 'big science' projects might be squeezing out its grants programme to individual investigators. He chided Bloch: 'We know they are all your children, you love them equally, and you want every one of them'.[44]

In May 1990, Richard Malow, the House clerk for the VA/HUD/IND Appropriations Committee and Traxler's right-hand man, visited NOAO headquarters in Tucson to meet with staff, and to discuss the telescope project. Finally, in October 1990, Congress passed House Resolution 5158.[45] In effect, the resolution said that the American astronomy community had $88m; they could either build two telescopes with it and have half of each, or build a single telescope solely for use by the US community. However, Erich Bloch and other high-ranking officials had made international collaboration a *sine qua non* for the Gemini Project, and negotiations were well under way with the UK and Canada.

Prospects for the 8-meter telescope project were much improved now that substantial money had been appropriated. However, it still needed the blessing of the astronomy community to ensure community support and future funding. In the Spring of 1991, the Bahcall Committee released its report – this informally referred to the 1990s as the 'decade of the infrared' – which made an infrared optimized 8-meter telescope on Mauna Kea, the highest priority for ground-based astronomy.[46] The fourth priority overall was an 8-meter telescope in the southern hemisphere, a twin of the one on Mauna Kea. The southern telescope would operate both at optical and infrared wavelengths. The twin 8-meter telescopes had thus received a major boost of official community support.

The issue of international collaboration remained unresolved and uncertain for several more months. On 19 December 1990, as Bahcall and his Committee were preparing their final report, the UK Science and Engineering Research Council voted formally to join the United States and Canada on a collaborative effort. The USA would provide 50% of the funding, while the UK and Canada would each contribute 25%.[47] When it released its report, the Bahcall Committee did not specify an international partnership, and the language of the optical/infrared panel's report is somewhat vague, referring to 'a pair of nationally accessible 8-meter telescopes'. Bahcall was personally opposed to the international arrangement, favouring American-owned telescopes.[48] However, the mandate from the Congress was one US telescope, or two done as an international effort with the American astronomy community getting half. The American astronomy community gradually accepted the international option. The plan did have the advantage of providing new and very large telescopes to observe the night skies in the Northern and Southern hemispheres. By the summer of 1993, the financial and organizational framework for building the Gemini 8-Meter Telescope Project was largely in place.

Gemini and the Moral Economy of Astronomy

This paper has extended E.P. Thompson's (and others') use of the moral economy idea to the processes, values and traditions that astronomers employ to allocate their resources – in this case, access to telescopes and funding for new facilities. What do the plans for a new national telescope and its early history tell us about the workings of astronomy's moral economy?

The American astronomy community has often debated how its resources should be allocated, and how the national observatory should serve the community. Historically, some in the community have advocated building more small telescopes, while others have pushed for a few new telescopes much larger than those currently available. This was central to the debate at the 1987 AURA retreat in Keystone. Part of the desire for larger telescopes comes from the need to compete with forefront research done by astronomers at large private facilities, such as the two Keck 10-meter telescopes. Fewer nationally available telescopes means, however, a smaller number of available observing nights, and telescopes that will serve a more limited group of users. The type of facilities American astronomers selected was connected intimately with NOAO's potential rôles in providing resources to the community – one that was more service-oriented, or one that gave the national observatory leadership in select areas of the discipline. In choosing to build the two Gemini telescopes, the American astronomy community opted for bigger, more modern and cutting-edge facilities that would serve fewer users and create a more prominent rôle for NOAO.

The decadal reviews prepared by the National Academy of Sciences play a powerful rôle in shaping astronomy's moral economy. Through these reports, astronomers recommend how resources should be allocated, what facilities will best serve the community, and what the community's priorities are to be. Not surprisingly, the committees' demographics have historically tended to favour senior astronomers from more prestigious universities. Despite the participation of a large number of astronomers in these surveys, the debates they engender are kept largely opaque to the overall community. In short, the allocation of resources is not a democratic process. Despite this, the astronomy community is frequently held as an exemplar of a science that makes tough choices about its priorities, offers recommendations to funding agencies, and generally follows them.[49] Given the historical disparity between the 'haves' and 'have nots' and the increasing fragmentation of astronomy into sub-disciplines, it is not at all clear how another, more participatory mechanism would work more effectively.

Consider the different rôles the National Academy of Sciences decadal surveys have played in the historical development of two large-scale astronomy facilities: the Hubble Space Telescope and Gemini. In 1971, the decadal survey chaired by Jesse Greenstein did not explicitly recommend the Large Space Telescope, as it was then called. Instead, Greenstein's report strongly endorsed the construction of the Very Large Array, a series of 27 radio telescopes. This was in spite of Greenstein's personal reservations of having so much of the federal funding for astronomy go to support national centres at the expense of university programmes.[50] Later, Congressional opponents to the project used the lack of formal community support to attack the Space Telescope Project. It fell to astronomers such as Lyman Spitzer and John Bahcall to offer a different interpretation of the Greenstein report, and to lobby members of the survey committee retrospectively to back the Space Telescope Project.[51] The space telescope, later re-named after Edwin Hubble, barely survived its Congressional battles.

Advocates of the Gemini Telescope Project avoided this potential trap by emerging with strong and explicit official recommendations for the twin 8-meter telescopes. From 1987 onwards, several different committees in the United States and abroad, including the Bahcall panel, gave support to a twin 8-meter telescope project. Even Bahcall himself, who opposed international collaboration, was swept along by the force of his Committee's support for the project, and its place in the larger context of the 'decade of the infrared'.[b] Gemini had the strong support of astronomers from both Canada and the United Kingdom. When a project such as

Gemini is international, it may become more difficult unilaterally to withdraw without embarrassment, or casting doubt on future collaborative possibilities. The possibility of an international project excited some American astronomers who looked to a time when other collaborations would result in more telescopes available to the community.[52] Moreover, having two telescopes, one in Hawaii and one in Chile, guaranteed American astronomers full-sky coverage at nationally-available facilities. This helped bolster broader support for the project among American astronomers who may not have been as supportive of a single infrared-optimized telescope in Hawaii.

Another strategy that proponents of Gemini followed was to sell the project as a niche facility. The Hubble Space Telescope was faced with many of the same challenges as Gemini and its earlier precursors, lacking a solid base of community support.[53] Astronomers knew that both Hubble and Gemini would be national facilities open to all members of the American science community. However, the Hubble Space Telescope was going to be absolutely unique. There would be no other large space telescopes with which it had to compete. The same could not be said for Gemini – astronomers and science administrators expected the completion of several other large ground-based telescopes during the 1990s.

Securing community support for Hubble required a diverse coalition of stellar and planetary astronomers who all had use for the space telescope. It also meant that space-based astronomy could not be seen as being promoted at the expense of traditional ground-based facilities. Whereas the design for Hubble was incrementally altered to make it appeal to a broad group of astronomers, a different tack was taken with Gemini. John Bahcall and the other members of his Committee recognized that getting community support and federal funding for a general-purpose national facility, even if it had international partners, was not going to be easy. Therefore, acting on the suggestion of Frank Low and others, Bahcall's Committee endorsed the Gemini Telescope Project as an instrument with unique capabilities. By insisting that one of the telescopes be optimized for infrared observation, astronomers established a clear and special 'discovery space' for the project. Infrared optimization gave the Gemini telescopes a defence against potential opponents in the community who might question why the NSF's research dollars should go to build 'more of the same' with regard to large telescope facilities. American astronomers accomplished this task without alienating international partners who, lacking access to similar telescopes, were understandably less enthusiastic about having what seemed to them an overly specialized telescope facility.

The success of getting Gemini approved, funded and built required much negotiation and compromise. Goetz Oertel, when talking informally with me about Gemini, used Bismarck's familiar saying: 'Politics is the art of the possible'. From the standpoint of American astronomers, a major compromise was building two telescopes as an international effort rather than holding out for a single national telescope in Hawaii or, even more boldly, two national telescopes. What was the cost of compromise to the American astronomy community?

One obvious result of the international collaboration was the loss of observing time that American astronomers might have had if they had gambled and held out for two telescopes fully funded by the United States. Also, while an infrared-optimized telescope project is arguably important to a balanced scientific research agenda, discussions continued well into the 1990s about how to achieve this goal, and about the impact it would have on other observers not that interested in the infrared. For example, astronomers and project managers within the Gemini Project later debated for months about the reflective coating that the primary mirrors should have.[54] Some astronomers argued that silver, which is better for infrared observing but not as useful for optical and ultraviolet research, should be used. Others pushed for a standard aluminum coating which permits ultraviolet observations at the expense of infrared sensitivity. Such disputes may seem trivial and technical. However, they are at the heart of how different factions of astronomers determine whose interests will take priority.

Why did American astronomers sacrifice managerial control and observing time? To a large degree, they had no real choice other than to have no telescopes at all. Erich Bloch and Congress made international collaboration a prerequisite for the project. Perhaps the community, by forming a united front, could have overridden this. But a united front is not, historically, a feature of the American optical astronomy community when it comes to resource allocation. Also, prior to Gemini, there were no plans to build a new large telescope in the Southern Hemisphere that would be readily available to the American astronomy community. By opting for two telescopes, the American astronomy community as a whole gained the ability to observe with very large telescopes in both hemispheres. Meanwhile, the European Southern Observatory was preparing to construct a suite of four 8-meter telescopes in Chile. Gemini offered American astronomers the opportunity to compete with foreign astronomers in the Southern Hemisphere.

The compromises necessary to have the Gemini telescopes approved and funded also affected institutions such as NOAO, AURA and the NSF. While the United States was the dominant partner and best-represented on the different Boards governing Gemini, there was some loss in administrative control by building the project as an international effort. What did the American institutions who managed and funded Gemini gain as a result? The NSF gained the experience and prestige of being the executive agency for a very large and expensive international project. The NSF, acting as the executive agency, selected AURA to manage the construction and commissioning of the telescopes, thereby providing it with another prominent national observatory facility to manage, in addition to the NOAO telescopes and the Hubble Space Telescope.

But it was the national observatory which was most affected when the Gemini telescopes were approved and funded. Throughout the 1980s, NOAO was a beleaguered institution. A stagnant budget, inflation and staff cuts had depressed morale and diminished NOAO's position in the scientific community. Concomitantly, NOAO was pulled in several directions by 'haves' and 'have nots' in the astronomy community. Some astronomers wanted NOAO to provide large and cutting-edge facilities; some wanted more access to smaller telescopes; and others simply wished that NOAO would be dissolved and its funding used to support individual researchers and private observatories. The decision to build the Gemini telescopes did not resolve community conflicts about the rôle of the national observatory and what its mission should be. While Gemini gave new life to NOAO, it came at a price.

In the early 1990s, the international partners of Gemini organized the management of the Gemini project. The Gemini Board was formed under the agreement signed by the United States, the United Kingdom, and Canada.[55] The NSF and other international science agencies gave ultimate authority to the Gemini Board and effectively took direct control away from NOAO and AURA. These actions eliminated any direct managerial control that NOAO might have, and reduced its participation and influence in the project.

Why was this done? A letter from Goetz Oertel to AURA Board members in 1991 provides some clues. It asks what the relation should be between the Gemini Project and NOAO. Oertel notes that AURA expected to rely heavily on NOAO in the coming months for engineering, scientific and administrative support. However, he added that it is important that it did not appear that the United States has 'disproportionate control over the international Gemini project'.[56] NOAO's rôle was a delicate issue, and it was forced to cede control so as to avoid alienating the international partners whose cooperation, support and funding were critical.

Despite the loss of direct control, American astronomers continued to associate NOAO – for better or for worse – with Gemini, reflecting the organization's long-standing attempts to build a new national facility.[57] NOAO remained associated with Gemini when the NSF established the 'United States Gemini Project Office' as a separate division of NOAO. Through this project office, NOAO serves as the American 'door' to the internationally-run telescopes. This association gave NOAO the opportunity to be a player in the game of very large telescopes. It also helped strengthen NOAO's position in the moral economy of astronomy as a provider of telescope observing time for the entire community. NOAO's compromises strengthened its position in the astronomy community, at least in the short term. But, in reality, NOAO was weakened by having Gemini removed from its direct control.

Contemporary American optical astronomy, unlike its counterpart in the Canada or the United Kingdom, has an inherent tension built into its moral economy due to a postwar legacy of privately-funded telescopes competing with the national system. Even after the Gemini Project was well under way, considerable disagreement continued (and still does) within the astronomy community on long-standing issues such the rôle of the national observatory, the types of facilities it should operate, and how access to national telescopes should be granted. These issues are part of long-standing historical conflict over resources within the American optical astronomy community between 'haves' and 'have nots'. Whereas radio astronomers in the United States have remained united and put their faith largely in resources provided by a federally-funded system of facilities, optical astronomers have hedged their bets. Indeed, one of the most common institutional arrangements for astronomy in general is the increase in the number of facilities run by consortia. Some of the collaborations even have NOAO as a partner in an interesting hybrid of private-public cooperation.[58]

The process of negotiations and consensus building through which Gemini emerged as a viable project took place over several years and in many different countries. It required the participation of an international *mélange* of astronomers, engineers, politicians and managers. Building the Gemini telescopes was partly an effort to maintain a fair distribution of resources within the community. It helped expand the community, who had access to some of the world's largest telescopes. The building of the Gemini telescopes may be seen as a reaction against the growing number of large telescope facilities operated by the traditional 'haves' in the community. In an era when almost all the biggest telescopes were being built as private facilities for the 'haves', Gemini helped preserve the ideal that all American astronomers could compete for access at two of the world's most modern telescopes. But it would be naïve to think that the persons and committees who determined the direction American astronomy would take did so solely out of altruism. Ideals of equity and fairness with respect to telescope access were also used to serve broader institutional needs, such as the health of the national observatory system, and as justification for its continued existence. Gemini's early history is not simply a story about how scientists prevailed over bureaucratic and financial hurdles in their quest for a bigger and better telescope. Through the political and institutional machinations that took place as the design, support and funding for the Gemini telescopes were stabilized, members of the American astronomy community played an active rôle in shaping their moral economy.

Interviews

In this paper, I draw on a number of interviews with astronomers and administrators who were involved in the events I analyze. With one exception (see note 18), I conducted these interviews myself; transcripts are in my personal working files. I use alphabetic superscripts in the main text to indicate the sources of information and quotations from these interviews. With one exception, my interviewees waived anonymity.

The interviews are coded as follows:

a **Helmut Abt**, Tucson, AZ, 20 January 1999.
b **John N. Bahcall**, Princeton, NJ, 2 December 1999.
c **Jacques Beckers**, Chicago, IL, 1 June 1999.
d **John T. Jefferies**, Tucson, AZ, 26 February 1999.

e **Frank J. Low**, Tucson, AZ, 23 February 1999.
f **Richard Malow**, Washington, DC, 24 September 1999.
g **Goetz Oertel**, Washington, DC, 24 September 1999.
h **Steve Strom**, Tucson, AZ, 19 January 1999.
i **Steve Strom**, Tucson, AZ, 19 February 1999.

Notes

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1. In this paper, 'astronomy', unless noted otherwise, is restricted to traditional ground-based astronomy in which scientists make observations in the visible or near-ultraviolet or infrared parts of the spectrum. There are many types of telescopes for observing different regions of the spectrum: 'telescope', unless noted otherwise, means telescopes as they are traditionally thought of – ground-based instruments with mirrors to collect and reflect light to detectors and other devices.
2. Beckers' terms were repeated frequently by the other astronomers and science managers I interviewed.
3. See E.P. Thompson, 'The Moral Economy of the English Crowd in the Eighteenth Century', *Past and Present*, Vol. 50 (1971), 76–136. This essay was later reprinted in Thompson's *Customs in Common* (New York: New Press, 1991), 185–258, along with a review essay entitled 'The Moral Economy Reviewed', 259–315. The term itself dates back to the 19th century. Thompson's interpretation of the concept has been adapted by historians of science, most notably by Robert Kohler in his book *Lords of the Fly: Drosophilia Genetics and the Experimental Life* (Chicago, IL: The University of Chicago Press, 1994), esp. Chapter 1; Kohler builds on Thompson's term to discuss the practices of 20th-century biologists and geneticists. Lorraine Daston's essay, 'The Moral Economy of Science', *Osiris*, Vol. 10 (1995), 3–24, also presents a helpful discussion of the term.
4. Kohler, op. cit. note 3, 12.
5. For example, the University of California and Caltech had funding for two 10-meter telescopes on Mauna Kea in Hawaii, and the European Southern Observatory was going to build a facility with four new 8-meter telescopes in Chile. Also, a 6-meter Russian telescope, reputed to be hampered by a poor site and technical flaws, was completed in the 1970s, but was not available to Western astronomers. I have adopted the convention of astronomers in this paper, and refer to some telescopes in English units and some in metric. For example, the Palomar telescope is often referred to just as the '200-inch' (about 5 meters), and the Mt Wilson is the '100-inch', whereas other telescopes built later are referred to in metric units – such as the Kitt Peak '4-meter'.
6. NOAO Press Release (NOAO 99–08, 25 June 1999).
7. In Thompson's presentation of the moral economy, the object of value was food. In Kohler's work, the commodities were the exchange of *Drosophila* stock, and distribution of prestige and credit among biologists and geneticists.
8. Daston, op. cit. note 3, 7.
9. See, for example, Daniel J. Kevles, *The Physicists: The History of a Scientific Community in Modern America* (New York: Knopf, 1978; Vintage, 1995), papers in Peter Galison and Bruce Hevly (eds), *Big Science: The Growth of Large-Scale Research* (Stanford, CA: Stanford University Press, 1992), and Chandra Mukerji's *A Fragile Power: Scientists and the State* (Princeton, NJ: Princeton University Press, 1989).
10. John Lankford's *American Astronomy: Community, Careers, and Power, 1859–1940* (Chicago, IL: The University of Chicago Press, 1997) presents a comprehensive sociological picture of United States astronomy before World War II.

11. Peter Galison and Bruce Hevly, 'Introduction: The Many Faces of Big Science', in Galison & Hevly (eds), op. cit. note 9, 1–17, at 9.
12. Chapter 7 of Lankford's *American Astronomy* (op. cit. note 10) is especially relevant here, as it describes the considerable power observatory directors had over the careers of astronomers, their institutions' research agendas, and the distribution of observing time and funding.
13. This quotation is from David DeVorkin's unpublished draft paper, 'Who Speaks for Astronomy?: How Astronomers Responded to Government Funding after World War II', *Historical Studies in the Physical and Biological Sciences* (forthcoming, 2000), which discusses the response of astronomers to federal funding after 1945. My thanks to Dr DeVorkin for sharing an advance copy of this paper with me. For comparison, physicists' response to funding is presented in Kevles' *The Physicists* (op. cit. note 9, esp. Chapter 23, 'The Physicists Established') and Paul Forman's 'Beyond Quantum Electronics: National Security as Basis for Physical Research in the United States, 1940–1960', *Historical Studies in the Physical and Biological Sciences*, Vol. 18 (1987), 149–229.
14. For example, private large telescopes were built at the Mount Wilson and Lick Observatories in California, and the McDonald Observatory in Texas. This trend culminated in 1948 with the dedication of the famous 200-inch Hale telescope on California's Palomar Mountain. Lankford (op. cit. note 9, 199) notes that by the 1930s there was already distrust and intense competition between observatories on the East and West coasts.
15. Copies of the original correspondence between the NSF and astronomers working to create a national observatory is preserved at NOAO's library in Tucson, Arizona. The call for a National Optical Observatory occurred at a time when other disciplines in American science were developing large facilities. For example, Brookhaven National Laboratory, financed with money from the Atomic Energy Commission and operated by Associated Universities Incorporated (AUI), a nine-university consortium, opened in 1947. In 1956, AUI received a contract from the NSF to operate the National Radio Astronomy Observatory (NRAO) for the growing sub-discipline of radio astronomy. The NSF's move into big science by funding and building national centres of science coincided generally with the launching of Sputnik and the International Geophysical Year.
16. By the end of 1961, AURA operated the fifth largest telescope in the United States, the 84-inch at Kitt Peak. This was followed in 1973 with a four-meter telescope, second in size only to the Palomar 200-inch. A year later, AURA commissioned a twin to the Kitt Peak four-meter at the Cerro-Tololo Inter-American Observatory in Chile. These telescopes were open to the entire astronomy community, including international visitors. A time allocation committee selected users on the basis of peer-reviewed proposals.
17. The information on government support for United States astronomy is taken from Jesse Greenstein (ed.), *Astronomy and Astrophysics for the 1970s; Reports of the Panels*, Vol. 2 (Washington, DC: National Academy of Sciences, 1973), 350–408, and 'Astronomy and Astrophysics for the 1980s (Vol. 2): Reports of the Panels' (Washington, DC: National Academy of Sciences 1983), 403–14.
18. Jesse Greenstein, interviewed by Spencer Weart (19 May 1978), American Institute of Physics Collection; quote at 243–44.
19. Sandra Faber to the NSF Committee on Astronomy and Astrophysics (19 April 1993): Working Files; Astronomy Division, National Science Foundation; Arlington, VA. These files are hereafter referred to as 'NSF-AST'. I wish to thank the National Science Foundation for permitting me to examine these materials.
20. By the end of the 1970s, requests for prime observing time at Kitt Peak's two largest telescopes outnumbered available nights by a factor of three.
21. 'The Scientific Case for a Very Large Aperture Ground-Based Telescope' (Tucson, AZ: Kitt Peak National Observatory, January 1980); Sandra M. Faber, 'The Scientific Case

for a 10-Meter Telescope', in Adelaide Hewitt (ed.), *Optical and Infrared Telescopes for the 1990s* (Tucson, AZ: Kitt Peak National Observatory, 1980), 304–28.
22. This gave Kitt Peak an additional $600,000 for fiscal years 1981 to 1983: 'A Technology Development Program for a National 15-Meter Telescope', A Joint Proposal by KPNO, and the Universities of Arizona, California and Texas (1981). This was funded by NSF under the contract number AST 78–27800.
23. 'Astronomy and Astrophysics for the 1980s (Vol. 1): Report of the Astronomy Survey Committee' (Washington, DC: National Academy of Sciences, 1982).
24. The competing design, which was later used to build the two 10-meter Keck telescopes, was a segmented mirror telescope championed by physicist Jerry Nelson at the University of California. The developmental work and selection of a design for the national telescope is presented in W. Patrick McCray, 'Designing a New National Telescope: Technological Possibilities and Scientific Priorities, 1975–1984' (forthcoming).
25. An NSF memo from 23 September 1985 notes: 'There is little evidence of a sense of cooperative collaboration in the actions of the UA-Steward group toward NOAO', before listing specific problem areas: NSF-AST files.
26. Also: 'Astronomy and Astrophysics Panel Reports: Working Papers' (Washington, DC: National Academy of Sciences, 1991), XII–6.
27. Letter from Wayne Van Citters to Sidney Wolff (26 October 1987): Peter Strittmatter Personal Files; Steward Observatory, The University of Arizona. My thanks to Dr Strittmatter for permitting me to examine materials in his working files.
28. For example, papers in Hewitt (ed.), *Optical and Infrared Telescopes for the 1990s*, op. cit. note 21, present cases for several options.
29. These are summarized in documents from the meeting, including a memo from Goetz Oertel to AURA Board Retreat Participants, 'Agenda and Issues for Board Retreat' (31 July 1987): from Peter Strittmatter, Personal Files.
30. Ibid., 5.
31. Steve Strom (chair), 'Report of the Future Directions for NOAO Committee' (AURA: 15 September 1987): NSF-AST files.
32. Reported in *NOAO Newsletter* #12 (1 December 1987), 1.
33. 'The NOAO 8-m Telescopes Proposal to the National Science Foundation' (Washington, DC: Association of Universities for Research in Astronomy, Inc., September 1989). The total costs (in 1989 dollars) estimated by NOAO and AURA staff were $85.6m for the first telescope and $58m for the second.
34. Letters from: John Jefferies to Richard Ellis (12 March 1987); Richard Ellis to John Jefferies (11 May 1987); Sidney Wolff to Richard Ellis (28 May 1987); Goetz Oertel to Richard Ellis (3 September 1987); E.W.J. Mitchell to Goetz Oertel (2 November 1987): all in NSF-AST files.
35. Letter from Erich Bloch to Tor Hagfors (25 August 1988): NSF-AST files.
36. Reported in the June 1990 edition of the *NOAO Newsletter.*
37. Ann Gibbons, 'Astronomers Want New Optical Telescopes, but. . .', *Science*, Vol. 248 (18 May 1990), 806–07.
38. Bahcall played a key rôle in securing federal funding for the Hubble Space Telescope in the 1970s, when it ran into serious obstacles in Congress. According to Bahcall, these experiences helped him as he assumed the chairman's rôle of the most influential committee in astronomical science policy.
39. Irwin Goodwin, 'Academy Group Observes Astronomy in Cloudy Period of Budget Cuts', *Physics Today*, Vol. 42 (August 1989), 45–46.
40. 'Astronomy and Astrophysics Panel Reports: Working Papers' (Washington, DC: National Academy of Sciences, 1991), XIV: 10–11.
41. Electromagnetic radiation from stars and galaxies exists at all wavelengths, from gamma rays to radio waves. Visible light, which our eyes can detect, makes up only a fraction of the entire electromagnetic spectrum, and has wavelengths in the range of about 0.3 microns (μm) to 0.8 μm. Infrared radiation exists at longer wavelengths, from about 1 to 40 μm.

42. This money was to carry out engineering design studies and to purchase the glass needed to fabricate the first of two 8-meter mirrors.
43. Reported in 'Hearings for the House Appropriations Committee for VA/HUD/IND, National Science Foundation Hearings' (27 February 1990).
44. Ibid., 116. The Laser Interferometer Gravitational Wave Observatory (LIGO) was a cooperative effort between Caltech and the Massachusetts Institute of Technology. LIGO was commissioned in 1999, the same year as the first Gemini telescope. Its final cost (as of 1999) was over $370m, well over what was originally estimated. Harry Collins has written extensively about the science and technology of gravitational wave detection. His paper, H.M. Collins, 'The Meaning of Data: Open and Closed Evidential Cultures in the Search for Gravitational Waves', *American Journal of Sociology*, Vol. 104, No. 2 (September 1998), 293–338, contains some discussion of LIGO's history.
45. This gave $4m to purchase glass for the mirrors and design studies. The language of the resolution states: 'The conferees have included $4,000,000 requested for engineering studies and the purchase of glass for two new eight meter optical telescopes. The conferees expect that the US share of the project will not exceed $88 million – or one–half the cost of the project as estimated by the NSF. The conferees direct the NSF to obligate fiscal year 1991 funds solely for work on the US eight meter telescope until a firm, fixed, cost-sharing arrangement has been concluded with all foreign partners. If no foreign participation is ultimately agreed to, the cost of a single telescope may not exceed $88 million'.
46. 'The Decade of Discovery in Astronomy and Astrophysics' (Washington, DC: National Academy of Sciences, 1991).
47. The Canadians also suggested the name 'Gemini' for the telescope project, at a steering committee meeting in January 1991.
48. In a letter, Bahcall revealed that a vote by fax was taken on 15 November 1990 to approve language in the final report stating that '... we would prefer one whole IR optimized 8-m telescope rather than two shared (international) telescopes...', wording which was ultimately not included: letter from John Bahcall to Sidney Wolff (4 December 1991): NSF-AST files.
49. Anon., 'Powerful Visions for Astronomy', *Nature*, Vol. 405 (25 May 2000), 379.
50. Greenstein interview, loc. cit. note 18, 235.
51. Paul Hanle, 'Astronomers, Congress, and the Large Space Telescope', *Sky & Telescope*, Vol. 70 (April 1985), 300–05.
52. Letter from Alan Dressler to Wayne Van Citters (4 December 1992): NSF-AST files.
53. See, especially, Robert W. Smith, 'The Biggest Kind of Big Science', in Galison & Hevly (eds), op. cit. note 9, 184–211. Much more detail can be found in the book by Robert W. Smith, with contributions by Paul A. Hanle, Robert H. Kargon and Joseph N. Tatarewicz, *The Space Telescope: A Study of NASA, Science, Technology, and Politics* (Cambridge: Cambridge University Press, 1989).
54. This dispute can be seen in project updates that appeared in the *Gemini Project Newsletter* between 1994 and 1996. The project initiated a research and development programme to compare the performance of aluminum and silver coatings, and to determine which best met the performance requirements determined by the Gemini Science Committee.
55. 'Memorandum of Understanding Between the National Science Foundation of the United States of America and the National Research Council of Canada and the Science and Engineering Research Council of the United Kingdom concerning the construction and operation of an 8m telescope on Mauna Kea, Hawaii and an 8m telescope on Cerro Pachon, Chile, to be known as the Gemini Project' (5 August 1992): NSF-AST files.
56. Letter from Goetz Oertel to the AURA Board (5 November 1991): NSF-AST files.
57. The continual blurring of the distinction between NOAO and the actual Gemini Project repeatedly manifested itself in interviews I conducted with American astronomers who were not directly associated with the project.

58. For example, the 3.5-meter WIYN telescope on Kitt Peak, built as a collaboration between the Universities of Wisconsin, Indiana and Yale, in conjunction with NOAO, was dedicated in 1994.

W. Patrick McCray received his doctorate in 1996 for research in the history of glassmaking technology in Renaissance Europe: this work was published as *Glassmaking in Renaissance Venice: The Fragile Craft* (Ashgate Press, 1999). For the past three years he has been researching historical and sociological aspects of postwar optical/infrared astronomy and telescope design, partly as an NSF postdoctoral fellow at the University of Arizona, and more recently as a research fellow at the Center for History of Recent Science at the George Washington University. He is currently at work on a book for Harvard University Press, tentatively entitled *Exploring Instruments: Large Telescopes and Postwar Astronomy*, and is a historian at the Center for History of Physics.

Address: Center for History of Physics, American Institute of Physics, One Physics Ellipse, College Park, Maryland 20740-3843, USA; fax: +1 301 209 0882; email: wpmccray@erols.com