THE UNIVERSE IN A MIRROR

The Saga of the Hubble Telescope and the Visionaries Who Built It

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Oh, I have slipped the surly bonds of earth,
And danced the skies on laughter-silvered wings;
Sunward I've climbed and joined the tumbling mirth
Of sun-split clouds—and done a hundred things
You have not dreamed of—wheeled and soared and swung
High in the sunlit silence. Hov'ing there,
I've chased the shouting wind along and flung
My eager craft through footless halls of air.
Up, up the long, delirious, burning blue
I've topped the wind-swept heights with easy grace,
Where never lark, or even eagle flew;
The high, untrespassed sanctity of space,
Put out my hand, and touched the face of God.

JOHN GILLESPIE MAGEE, JR.

astronomy during my lifetime, and the chance to be a key part of that was very attractive."

O'Dell was also restless in his position as head of the astronomy department at the University of Chicago. He was only thirty-four, and was looking for a change. His wife wasn't happy living at the Yerkes Observatory. Like the Burbidges before her, she found the place too isolating.[55]

Once Jesse Mitchell knew that a scientist of O'Dell's prestige was willing to consider moving to Marshall to head the space telescope project, he felt free to recommend Marshall for the lead position in building the telescope, with Goddard as support. On May 5, 1972, the decision was announced. The Marshall Space Flight Center was to be the "lead" center, designing the telescope structure and supervising its construction. Goddard in turn was put in charge of building the scientific instruments that would go inside the telescope body.[56]

By the end of that summer Bob O'Dell had taken a three-year leave of absence from the University of Chicago and moved to Marshall to become the project scientist for the Large Space Telescope. If all went well, he hoped to get the project funded, under construction, and launched by 1977.

What he didn't know was that it wasn't going to take three years, or even six, to do this. In fact, O'Dell's time in Huntsville was to last more than a decade. And even then it would be another nine years before the telescope was launched.

Meanwhile, for Lyman Spitzer, the decision to pass on the space telescope job was the first of several crucial events that would seal his own fate relating to the Hubble Space Telescope. By choosing the easier path of staying in Princeton, he had unwittingly begun the process that would eventually make him an outsider looking in.

3

Getting Money

The climber was tall, thin, and wiry. He moved smoothly, carefully, and methodically, working his way up the wall without pause. Two hundred and fifty feet below him stretched the green and shimmering meadows of the Yosemite Valley.

On a ledge beneath him, forty-three-year-old astronomer Ralph Bohlin fed out the safety line, watching intently to make sure he was ready to catch the man should he fall. Bohlin was especially concerned because the climber was not merely another human being, he was sixty-six-year-old Lyman Spitzer, director of Princeton University's Department of Astrophysical Sciences, one of the country's most eminent scientists and considered by many the father of the Hubble Space Telescope.

"I felt a little guilty [since] I usually let him lead on the harder parts," remembered Bohlin.

Spitzer's mountain climbing hobby had become exceedingly more sophisticated since the 1950s. In the 1960s Don Morton introduced him to more modern technical climbing techniques, and they as well as fellow Princeton professor Ted Cox would go on regular weekend trips to climb the cliffs in upstate New York. Morton and Spitzer also took part in several major mountain-climbing expeditions to some of the more remote places on Earth.

For example, in 1965 they were members of the second Canadian expedition to Baffin Island, where they climbed two mountain peaks, including the first ascent of 5,500-foot-high Mount Thor. At one point Spitzer hesitated, daunted by the "vertical rock face above us." Morton wanted to go on, however. As Spitzer wrote later, "He had sort of counted on getting me to the top, and after eating a little supper of

cheese, apricots and chocolate I felt more daring and decided to go on up. I am very glad I did, since the climbing was really not so terribly difficult. We got to the top at midnight and had a fine view of the entire range, with the sun only just a bit below the horizon."

Since Spitzer had to return home sooner than the others, his plan had been to leave Morton after a second climb and hike solo twenty miles to the coast to meet a local Eskimo with a boat.

Unfortunately, the two missed each other. If Spitzer didn't get 20 miles further down the coast to the village of Pangnirtung by the next day, he would be left stranded on Baffin Island. With no spare food or supplies and no way to contact anyone if something should go wrong, Spitzer started out, fording several roaring and freezing streams along the way. "In retrospect we had taken an awful risk," Morton wrote years later. "Nothing serious happened thanks to Lyman's stamina and skills in wilderness travel."[1]

Another time—in a more offbeat adventure—the two astronomers decided to climb the Gothic tower of the Princeton Graduate College. This ornate structure had been climbed by students and teachers in the past, but Spitzer had never done it and wanted to. One of Spitzer's graduate students provided the key for the building, and early one Sunday morning Spitzer, Morton, John Wrigley, and Michael Shull proceeded to set up a top rope so that they could be safetied as they climbed.

Unfortunately, no one had told the campus security people, who showed up as Spitzer was about two-thirds of the way up the side of the tower. "[They] demanded that we cease and desist, threatening to call the town police," wrote Morton years later.[2]

Now, in 1981, Spitzer was in Yosemite with Bohlin, and—fearless as usual—he had climbed too far above his protection. Unable to rest, he got tired, lost his grip, and fell.

Below, Bohlin reacted immediately. "I started to pulling in the slack." Then the chockstone protection that was lowest and nearest to Bohlin came loose, which frightened him and made him hold off, letting Spitzer's fall take the slack to avoid putting more stress on the remaining chocks.

This was a mistake. The slack in the line allowed Spitzer to drop enough to hit the ledge where Bohlin was sitting, about twenty feet to the side. "To me it looked like [I] hadn't really broken his fall that much.

I was greatly relieved to see him move and greatly relieved to find that it was only a broken arm."

Even with a broken right arm Spitzer was unperturbed. Carefully they worked their way down the mountain, with Bohlin first lowering Spitzer and then following. When they reached the ground Bohlin suggested they head to the hospital. "No," said Spitzer in his genteel way. "We're going to have dinner first." They put his arm in a sling, made a nice dinner at camp, and then went to the hospital.

This accident was in many ways the swan song of sixty-six-year-old Spitzer's rock-climbing career. Though he was climbing again in about a year, "he didn't climb a whole lot after that," noted Bohlin.[3]

Spitzer's fearless and adventurous spirit was not unusual among American astronomers in the postwar era. For example, in 1967 when Bob O'Dell was director at Yerkes, he had joined Spitzer on a climbing expedition to central British Columbia. Unlike Spitzer, Bob O'Dell didn't find mountain climbing to his taste. "I was never a good rock-climber." (His strongest memory of this trip was how the expedition ran out of food early.) Then, in 1976, when the space telescope project was in full swing, the two men had arranged to go diving together in the giant tank at the Marshall Space Flight Center where astronauts were simulating a spacewalk using mock-ups of the shuttle and the space telescope.

Flying remained O'Dell's first love. Since moving to Huntsville he had gotten passionately involved in competitive aerobatic flying. He purchased a small plane in 1973, and modified it so much himself that the FAA considered him the builder. By 1980 he knew so much about the sport that he even penned the book *Aerobatics Today*, considered for many years the sport's textbook.

Meanwhile, the space telescope project was slowly inching forward. When O'Dell arrived at Marshall on September 1, 1972, to take over as project scientist, he immediately found himself embroiled in a turf war between Marshall and Goddard, a situation that was to be repeated innumerable times in the years to follow.

The working relationship between the two centers had supposedly been worked out earlier that summer, with Goddard handling the science instruments under Marshall's leadership. O'Dell discovered that this agreement was so vaguely worded that it was causing confusion and discord. Moreover, the deep resentment felt by Goddard managers because

Fig. 3.1. Bob O'Dell and his airplane, c1979. (Photo courtesy of C. Robert O'Dell)

the center had lost the space telescope project to Marshall caused them to give it a low priority. "I think it's fair to say that they did not put their very best people on the program," noted Robert Bless, principal investigator for the telescope's High Speed Photometer being built by the University of Wisconsin.[4]

Goddard managers also resisted giving up control of the project. For example, the Goddard manager in charge of science instrument development, Ken Hallam, wanted all scientific work, including all contacts with the scientific community, to go through him, not O'Dell. On top of that, Hallam was still insisting on using Goddard's design for the telescope, something that neither Marshall nor O'Dell wanted.

In a series of brutal meetings throughout the fall of 1972, dubbed by O'Dell "war councils" in his diary, O'Dell had Hallam removed as instrument scientist and negotiated a new working arrangement with Goddard. O'Dell got full control, and would work with George Levin, whose job would be limited to managing construction of the science instruments as designed under O'Dell's leadership.[5]

The telescope project was hardly in O'Dell's control, however. Unbeknownst to him, shortly thereafter an event much more significant to the future of the space telescope took place at NASA headquarters. The occasion was a December 21, 1972, meeting with NASA administrator James Fletcher. One of the disagreements between the Marshall and Goddard managers at the time had to do with the use of contractors to build the telescope. Marshall managers wanted to hire two associate

contractors and manage them as equals. One would build the telescope itself, essentially a frame with two mirrors precisely positioned. The other would build the telescope's support systems module, containing the power supply, pointing system, communications equipment, and other equipment for keeping the telescope operating. Goddard managers instead advocated hiring a single prime contractor to build everything, who would in turn hire subcontractors to build whatever sections the prime contractor couldn't handle.

The December 1972 meeting with Fletcher, to which O'Dell was not invited, was to review the cost benefits of these two approaches. After almost two hours of detailed and tedious cost analysis, John Naugle, the head of the space science and applications department at headquarters (having taken over that position when Homer Newell was promoted to associate administrator of all of NASA in 1967), recommended that NASA go with Marshall's associate contractor approach.

As the meeting was winding down, Fletcher suddenly changed the subject entirely, using the last fifteen minutes to force a rethinking of the very nature of the space telescope project. As George Levin noted in his minutes of the meeting, "Fletcher went on to redesign the LST."[6]

To understand the context of Fletcher's actions, as well as much of the history of the Hubble Space Telescope, it is necessary to also understand the annual and cyclical nature of NASA's budget negotiations. These negotiations last two years: one year for NASA and the executive branch to work up their proposed numbers, and one year for Congress to review these numbers and to approve or change them.

Take the 1974 NASA budget as an example. The negotiations for this budget began inside NASA headquarters in 1972, with NASA headquarters bureaucrats meeting repeatedly with NASA center bureaucrats and White House bureaucrats to argue about how to divide up the money. Then, at the beginning of 1973, the 1974 budget was finalized and presented with great fanfare to Congress. Congress then reviewed and debated this budget for the better part of 1973, holding hearings, writing reports, and arguing its substance on the floor of the Senate and House before finally giving its approval.

Each year, this cycle is repeated, and each year, it influences how projects live or die.

Because the space telescope was not yet an official NASA project, its place in the 1974 budget was not significant. Yet, everyone knew that once it got under way it was going to quickly become one of NASA's most expensive projects. Thus, Fletcher's main concerns during that December 1972 meeting centered not so much on how many contractors NASA hired to build the space telescope but on the future 1974 congressional budget negotiations and how an expensive LST project was going to affect them. As he listened to his managers debate the pros and cons of these two contractor approaches, Fletcher was startled by the total proposed cost numbers. Goddard's proposal estimated a price for LST through launch and one year of operation at $500 million. Marshall in turn figured the telescope would cost about $900 million.

Fletcher waited until the main business of the meeting was finished before raising his concerns. He pointed out that it was unrealistic to plan on building a billion-dollar program, considering the political atmosphere in Congress at the time. He insisted instead on a budget limit of $300 million for construction, launch, and the first year of operation. He also demanded that the LST be simplified, reducing the number of science instruments as well as the number of shuttle flights to maintain it.

Immediately afterward and for years to follow, Fletcher's magical $300 million number, picked out of the air with no connection to actual cost, was the bottom line for the Large Space Telescope. As headquarters bureaucrats went ahead with Marshall's two-contractor arrangement and began actual construction, they did so using Fletcher's number, limiting the cost through launch to between $290 and $340 million.

What they did not do, however, was simplify the project as Fletcher had stipulated. By the end of 1972 the basic audacious design for the Large Space Telescope was essentially complete. No one wanted to change it significantly. For the astronomers, a significantly smaller telescope wouldn't be worth building. For the engineers, a simpler telescope wouldn't be as challenging to build.

Thus, not only would the Large Space Telescope have a mirror 120 inches across, making it for the time the third largest telescope ever made, NASA was going to put it in orbit, using the shuttle and astronauts to maintain and update it periodically, as recommended by Spitzer's astronomy committee at the 1965 Woods Hole meeting. All the design studies, by Goddard, Marshall, Boeing, and others, had conceived the space telescope for a time when space travel was routine, ambitious, and continuous, with the space shuttle making anywhere from 25 to 60 flights per year. It had therefore been planned as an automated and permanent observatory, operated remotely from the ground but with the capability to add, remove, and change out instruments, just as is done with any telescope on the ground.

The heart of the telescope would be its mirror and structure, but behind that mirror the telescope would have the capability of taking on any type of research instrument, from spectrographs to optical cameras to infrared or ultraviolet detectors. And as with all ground-based telescopes, as new developments made old instruments obsolete, the instruments in the telescope could be changed out as well. Moreover, the designers saw that the most efficient way to do these manned maintenance missions was with unscheduled shuttle flights. Rather than plan specific regularly scheduled upgrades, they expected shuttle missions to be so routine that whenever the telescope needed repair or upgrade, a flight could be quickly scheduled and inserted into the shuttle program.

As absurd as it seems, accepting Fletcher's lowball budget number without changing any of the telescope's design was (and remains) the normal way of doing business in Washington. Called by Beltway insiders a "buy-in," this Machiavellian approach to government funding relied on the fact that once the project was under way it would be difficult for Congress to kill it. Instead, the bureaucrats and their advocates outside the government would get Congress to approve the project at a lower number, then come back later for more money when needed.

Even as these bureaucratic machinations were taking place at NASA headquarters, O'Dell was starting development work on the space telescope's science instruments. In December 1972, he put out a call to the scientific community, asking them to propose instrument concepts. In conjunction with this call O'Dell also organized what he called a "dog and pony show," traveling the world in January 1973 to encourage astronomers to get involved. "The show opened at Harvard, right there at Harvard College Observatory, right in their library," O'Dell remembered. "Then we went to Chicago. Then we went to Caltech."[7] Eventually, O'Dell even went to Europe to press the flesh with scientists and make the case for the Large Space Telescope.

By April O'Dell was able to sift through the various concept proposals and form a number of design teams, all of which became part of what he called the Large Space Telescope Working Group. Eventually made up of seven teams—one for each of the telescope's six instruments plus a group of "interdisciplinary scientists" whose job was to take a larger view of the project—the initial working group met four times during the last half of 1973 as it determined the design of the telescope's science instruments.

By late 1973 when Naugle submitted his 1975 science budget, the project had advanced enough that he listed the telescope as a separate item, $6.2 million to fund the continuing design work. No one objected, and the item was included in the budget proposal that was presented to Congress on February 4, 1974.

Throughout the early part of 1974 the budget floated through Congress with little comment and no objection. During the February hearings in front of both the Senate Aeronautical and Space Sciences Committee and the House Science and Astronautics Committee, there were few fireworks, with most of the questions centering on the just completed Skylab program and the ongoing construction of the space shuttle fleet. Though there were some skeptics of NASA, the majority of the elected officials on these committees were very supportive of NASA. As Senator Frank Moss (D-Utah) noted at the opening of the Senate hearings, "I am pleased to see the NASA budget request for next year at a higher dollar level, albeit only slightly higher."[8]

Meanwhile, O'Dell found that the bulk of his in-NASA budget discussions with Naugle centered on whether to officially introduce the telescope as a major new project with full funding in next year's 1976 budget, or wait one more year.

Things changed, however, when Fletcher and Naugle gave testimony before the House Subcommittee on Appropriations in late March. Here they found that the winds of change were blowing hard, in their face.

NASA's budget for 1975 was part of an omnibus bill that also included funds for the Veterans Administration, the Department of Housing and Urban Development, the National Science Foundation, the Federal Communications Commission, and a handful of other smaller agencies. With the last U.S. troops only recently out of Vietnam, the congressmen on the Appropriations Subcommittee that handled these agencies were

far more interested in getting money to help disabled veterans than they were for funding a new NASA project. Moreover, the increasing U.S. dependence on foreign oil made energy programs significantly more appealing to them than space, since "people are starting to think about more earthly problems," noted subcommittee chairman Edward Boland (D-Massachusetts). "We have a pretty good problem on Earth with respect to energy, and so there has been some concern about the money we are spending in space, and whether we ought to continue that."[9]

This subcommittee then devoted three days of hearings to painstakingly dissecting the NASA budget, going over every detail and budget item, searching for things to cut as well as ways to make NASA shift the focus of its research toward Earth-based environment work, such as energy conservation, solar power, or even hydrogen-powered cars.

When the subject of the Large Space Telescope came up on day one, Naugle was asked how much the project, once started, would eventually cost. At this point he made his first tactical error, stating the cost would be "$400 to $500 million," based upon the full fifteen-year mission, instead of Fletcher's $300 million figure through the first year of operations. As Fletcher had expected, this number was immediately noticed by the congressmen. Fletcher promptly tried to deemphasize it by adding that Naugle's figure was to "be phased over quite a number of years."[10]

Things got worse on the second day of hearings. In the morning session, congressmen George Shipley (D-Illinois) and Burt Talcott (R-California) expressed strong reluctance to fund more space telescope studies. Both noted how the National Science Foundation had recently asked for and gotten funding to build the Very Large Array radio telescope in New Mexico. As Talcott said, "We are exploding with telescopes."

Shipley also worried about the possibility of a buy-in. "The thing that bothers me again is that this is more or less a new program. You are talking about a possible estimate of $400 million." He then added, "It would be very unusual if you asked for the $6.2 million for a definition study and did not come in next year for development funds."

Naugle then made his second tactical error, noting how a major review by the National Academy of Sciences of the future of astronomy had been completed in April 1972. Chaired by Dr. Jesse Greenstein from the California Institute of Technology, the report, dubbed *Astronomy and Astrophysics for the 1970s*, had been the result of four years of discussions

among almost all the important astronomers in the country. The report was also the first of what was to become regular decadal planning surveys by astronomers of their future priorities. In describing this report, Naugle explained how it had "looked at all of astronomy, ground-based and space-based, and [had] recommended an order of priority." He then added, "We have been following the guidelines in that report. We moved through the sequence that they recommended. The Large Space Telescope was recommended as an effort we should do."[11]

What Naugle didn't mention, however, was that though the Greenstein report had listed LST as a priority, it had given it a much lower priority than a lot of other projects, placing it ninth on a list of eleven.[12] Having now made the congressmen aware of the report, Naugle should have known that they would immediately get a staffer to find and review it.

By the afternoon session of the second day, support for the space telescope continued to deteriorate. As the congressmen made their way point by point through the NASA budget, they discovered that the agency was also planning to build a ground-based 120-inch infrared telescope on the top of Mauna Kea in Hawaii for $6 million. Because ground-based telescopes were normally funded out of the National Science Foundation, Boland immediately asked, "Why do you have this in your budget? Why should not this be funded by the National Science Foundation?"

Fletcher tried to explain, saying that the infrared telescope was being built to support NASA's planetary missions.

At this point Congressman Robert Tiernan (D-Rhode Island) brought up the Greenstein report again. Having now reviewed it, he pointed out that the infrared telescope was listed third among the report's four top priorities, none of which included an optical space telescope. Naugle was then forced to agree to provide for the record the Greenstein report's full recommendations, thereby making sure that everyone on the subcommittee would read it.[13]

Thus, when the Appropriations Subcommittee submitted its final report to Congress on June 21, it wasn't surprising that they recommended cutting *all* funding for the space telescope. As their report noted, "The LST is not among the top four priority telescope projects selected by the National Academy of Sciences, and suggests that a less expensive and less ambitious project be considered as a possible alternative." Moreover, the subcommittee also recommended a total of $39 million of cuts in NASA, while also including a comparable $39 million increase for the Veterans Administration. These cost-cutting congressmen, focused on spending money on "earthly problems," had found with the Greenstein report the justification they needed for cutting both NASA and the space telescope.[14]

In the House debate five days later, these changes met with general approval. If anything, there was concern from many members of Congress that the increases for veterans were insufficient. Though a few representatives questioned the NASA cuts, including James Symington (D-Missouri), who made a speech decrying the deletion of LST and noting that Jesse Greenstein actually supported the telescope, the budget passed by 407 to 7. Even Symington voted for it.[15]

Once again, despite years of effort, Lyman Spitzer's dream seemed about to evaporate.

In Huntsville, Bob O'Dell wasted little time. He had heard about the House report on June 20, the day before it was released, and had immediately started a campaign to get the money restored. O'Dell quickly recognized that the main justification used by the subcommittee for rejecting the space telescope was the low priority given to it by the *Astronomy and Astrophysics for the 1970s* report. He surveyed the report's members, and discovered that of its twenty-three members, fourteen were already working on the space telescope in some capacity.[16] It was obvious that he had to get these people to tell Congress that they considered the space telescope more important than indicated by their report.

For O'Dell the situation was delicate. His three-year leave of absence from his tenured position at the University of Chicago would end in 1974. He didn't want the project to die, but he also needed to know if there would be a project at all in order to decide whether to hold on to his position in Chicago. More importantly, as a civil servant he was legally forbidden from lobbying Congress. "I couldn't call, but I could pick up the phone," O'Dell explained.[17] And he could work to get others to do his work for him.

O'Dell began contacting every important astronomer he could think of for help. In the five days between the release of the House subcommittee report and the House vote, O'Dell worked the phone aggressively.

He did this despite being specifically instructed by his administrative boss at NASA headquarters, Bland Norris, to do nothing.[18]

First on his list was Jesse Greenstein. Of all the members of the 1972 report, Greenstein—the report's chairman and the man who had organized and edited it—was known to have decidedly ambivalent feelings toward space astronomy, beginning at the very dawn of the space age. In the late 1940s the Army was learning how to build and launch missiles by flying the German V2 rockets that they had captured at the end of World War II. Rather than fly them empty, however, they offered the bomb chambers to scientists, letting them fly scientific experiments at almost no cost. The result of this collaboration had produced Richard Tousey's first ultraviolet spectrums of the Sun as well as James van Allen's first detailed mappings of the Earth's magnetosphere.

Greenstein, then a thirty-eight-year-old astronomer working at the Yerkes Observatory, decided to give it a try. He built and installed a spectrograph on one V2 rocket, and watched it blast off from the White Sands test range.

All he got from the experiment was blank film. The shutter of the spectrograph never opened.[19]

This failure turned him off from space astronomy, and made him for decades one of the most steadfast opponents to the idea of spending large sums of money for the building of space telescopes. Though he repeated said that he did not specifically oppose all spending on space, he always treated any space proposal with great skepticism. As he once told Lyman Spitzer after Spitzer had started work in 1961 on the Copernicus satellite, "Lyman, you're young, you'll live to see it fail."[20]

In chairing the 1972 report, however, Greenstein tried very hard not to impose his personal biases on the report. "I don't make this report. I'm chairman," Greenstein explained in 1978. "And I didn't try to influence its outcome."[21]

As a result, the survey's first four recommendations included "a program for x-ray and gamma-ray astronomy from a series of large orbiting High Energy Astronomical Observatories." The report's number one priority, however, was the building a very large array radio telescope, a recommendation that Congress had accepted when it approved $80 million of funding in 1972 for the construction of the Very Large Array. And though the report advocated building the space telescope, it gave

its construction a priority below things like orbiting solar observatories and the use of balloons, airplanes, and suborbital rockets.[22]

For Greenstein, the report's emphasis on space astronomy was less distressing than its focus on funding big government science projects rather than giving money to university research. "[The report] ended up with all my business claims for a balanced program for astronomy disappearing down the maw of big science; the death of university astronomy."[23]

When O'Dell called Greenstein about Congress's rejection of the space telescope, Greenstein was surprisingly agreeable about helping. He explained that the reason the survey had placed the space telescope so low in its priorities is that NASA officials had told them to consider the telescope a shuttle-linked project which would be built in the 1980s, not the 1970s. As Greenstein noted later, "We couldn't tell them to put up the space telescope when there wouldn't be shuttles in the '70s to fly it and repair it."[24]

About this same time O'Dell also received a call from the office of Congressman James Symington (D-Missouri). Symington, a member of the House Science and Astronautics Subcommittee that only weeks before had approved NASA's request to do the telescope studies, was upset by the House Appropriations Subcommittee report. He considered the deletion of LST's funds an invasion of his turf, and intended to fight it.

In talking to Symington's office, O'Dell learned that Symington wanted to get Greenstein to clarify the position of the National Academy report, to explain why LST had been given such a low priority. O'Dell, who knew that Greenstein was attending a meeting in DC, provided them hotel contact information and suggested they arrange a meeting with Greenstein. As a result of this meeting Symington was able to cite Greenstein's name in his House speech on June 26, announcing further that Greenstein was writing a letter in support of the space telescope, and that Symington intended to read that letter into the Congressional Record as soon as he got it.

■ ■ ■

Even as O'Dell was working the phones in Huntsville, in Princeton Spitzer and others were gearing up their own campaign to save the proj-

ect. The most important person working with Spitzer was a man who just three years earlier had not even heard of the space telescope.

When O'Dell's "dog and pony show" had toured the country in January 1972 to sell the space telescope to astronomers, the buzz he created had reached the ears of John Bahcall at the Institute for Advanced Study in Princeton, New Jersey. Bahcall, a theoretical physicist whose models describing the nuclear processes within the Sun had revolutionized the field in the 1960s, had only recently become interested in the study of more distant astronomical phenomena.

Bahcall had just gotten his appointment to the institute in 1971 and was therefore ideally placed to become a crucial member of the space telescope team. For one thing, the institute—where Einstein had worked for the last twenty-two years of his life—had been conceived and designed to provide an environment where brilliant minds were left free to follow whatever research goal appealed to them. As noted by journalist Ed Regis in his book *Who Got Einstein's Office?*:

> The institute is exactly the nirvana for eggheads that it's cracked up to be. The temporary members, and the far smaller group of permanent professors—there are about twenty-five of these—work on their own projects at their own pace and have no further responsibility or accountability to anyone. . . . You don't even have to write up a report describing the work you did there, if any.

Not only did the institute pay its professors a very high salary, it provided them an office, an apartment, and breakfast and lunch five days a week as well as dinner on Wednesdays and Fridays.[25]

Bahcall thus did not have to teach, and was given no research assignments by anyone. He could follow whatever interests appealed to him.

Moreover, the institute was located walking distance from Princeton University, where Lyman Spitzer headed the astrophysical department. When Bahcall arrived he took the very informal weekly luncheons that Spitzer and Schwarzschild had been holding since the fifties and transformed them into a major social and academic event, occurring every Tuesday in a board room at the institute and attracting as many as a hundred people from all of the nearby universities. Rather than have people simply sit and chat with their neighbors, Bahcall would instead ask a number of people to describe either their research or some new

Fig. 3.2. John, Neta, and Dan Bahcall shortly after Dan's birth, 1971. (Photo courtesy of Neta Bahcall)

exciting development in their field. "Any visitors would always be called upon," remembered Neta Bahcall, astronomer as well as Bahcall's wife. "It was a wonderful opportunity—that's why it became so popular—for all of us to hear about everything that is happening in astronomy."

As the organizer of this semiformal event, Bahcall added his own personal touch, heralding each luncheon's start by standing in the stairwell just outside his office and shouting at the top of his lungs that the lunch was about to begin. "He liked to have fun," Neta Bahcall said. "We would just jump!"[26]

Surrounded by such a vibrant intellectual community, Bahcall—who was naturally enthused about the pursuit of knowledge anyway—couldn't help but be exposed to a whole range of new topics. As soon

as he heard about the space telescope he was inspired by the idea, and immediately sent off a short letter to O'Dell to express his excitement and offer his assistance should it be needed.

When O'Dell got this letter, which was by no means a formal proposal and wasn't intended as such, he instantly decided that that was what it was. "John is one of those guys with just endless enthusiasm and energy," O'Dell said in a 1985 interview. "If you're around him for too long, he's too much, because sometime you just desire quiet and sleep and rest."[27] He called Bahcall and asked him if he would like to become part of the science working group that O'Dell was forming. O'Dell wanted Bahcall to be one of the space telescope's interdisciplinary scientists, along with Spitzer, Art Code, Margaret Burbidge, and a handful of other prominent astronomers.[28]

Though Bahcall hadn't planned on getting that involved, the idea of helping design the world's first space telescope was too alluring. "It was just the greatness of the program, the potentialities of the program, independent of whether I was a theorist or an observer, which attracted me."[29] He agreed to join O'Dell's science working group, and for the next year or so was involved in the typically unexciting and complex legwork necessary to finalize the telescope's basic scientific design.

When the House subcommittee declared the project dead on June 21, however, John Bahcall's participation was suddenly pushed to a new level. He became O'Dell's lobbying voice, saying the things to members of Congress that O'Dell was forbidden to say because of legal restrictions. "No one had more conviction of the rightness and the value of [the] space telescope," noted O'Dell. "I was feeding him ammunition and he was just blasting."[30]

John Bahcall was a soft-spoken but firmly clearheaded and determined man. His journey to the world of astrophysics was strange and truly American in nature. Born and raised in a lower-class Jewish family living in Shreveport, Louisiana, he had little scientific training as he grew up. "My family and my family's friends were not intellectuals. They concentrated on making a living, a fulltime occupation."

In high school his interests were more focused on playing tennis then learning about science: his school day ended at noon rather than 3 pm so that he could practice for the school's tennis team. Only in his senior year did he discover that he had a talent for intellectual pursuits. That

year he joined the debating team and, to his glee, did so well that he quickly moved up to the school's first team. "When John set his mind to doing something he pretty much always did it," said Max Nathan, his school friend and debating partner. The two went on to win both the state and regional competitions, making them the first team from Louisiana eligible to go to the national tournament, held in Boston in 1952. They traveled to Boston on their own and beat students from some of the best schools in the country to become the national champions.

Bahcall then went to Louisiana State University, studying philosophy with the thought that he would use it toward becoming a reform rabbi. During the summer break, however, his mother and a cousin arranged for him to transfer to the University of California at Berkeley. Though he was still focused on philosophy, Berkeley required that he take at least one science course. Up until then Bahcall had studied no science, and in high school he had not progressed past elementary algebra.

His advisor told him that he would have to make up this lack by taking evening high school science classes. Bahcall, however, didn't want to go back to high school. He looked over the various available physics courses. There were three choices, one for non-scientists, one for engineers and medical students, and one for those who planned to become professional physicists. Bahcall went to the teacher of the last option and said he wanted to try it. Despite his lack of prerequisites, Bahcall was allowed to enroll, on the condition he drop the course as soon as he realized the work was beyond him.

Instead, he persevered, pulling a C in the course. "It was the most difficult thing I had ever done in my life," Bahcall remembered in 2002. It was also the most exhilarating thing he had ever done. "I fell in love with the subject."[31]

In the ensuing years Bahcall focused his interests on two subjects, the physics behind the Sun's nuclear processes and the nature and makeup of the just-discovered quasi-stellar objects, or quasars. By the 1960s he was involved in the first neutrino telescope, being built by Ray Davis of Brookhaven in the Homestake gold mine in South Dakota. Davis needed to know if his telescope would be sensitive enough to detect the predicted flux of neutrinos that the Sun produced as a by-product of its nuclear engine. Bahcall worked out the first detailed analysis of that

process, predicting that the flux would be large enough for Davis's telescope to measure it.

Bahcall was only partly right. Though Davis's telescope was successful in detecting the neutrino flux, to everyone's puzzlement the flux was significantly less than predicted by Bahcall's model. It wasn't until the 1990s that scientists realized that the difference was explainable only in terms of new physics. Neutrinos were more complicated than expected: they had mass, and would oscillate between different states as they traveled through space.[32]

In 1971 Bahcall accepted a position at the Institute for Advanced Study in Princeton. There he planned to dedicate his time to studying quasars and solar neutrinos while also strengthening astrophysical research at the institute. As Ed Regis wrote in 1987:

> When [Bahcall] became executive officer of the School of Natural Sciences [at the institute], he was not at all bashful about packing the place with astronomers. These days, when institute administrators have to scramble to find office space, or room in the housing project, for visiting members, they blame it on John Bahcall, who brings in astronomers by the dozens. The institute's astrophysicists, coupled with the university astronomers next door, have made Princeton a world center for astrophysics.[33]

Within hours of learning of the 1974 congressional vote to delete all space telescope funding, however, Bahcall and Spitzer found themselves to be lobbyists instead of scientists. As a professor, the timing was excellent for Spitzer. He had all of July to devote to the campaign. Bahcall's time was his own. His only loss—which was not trivial—was the time the lobbying took him away from his research.

While Spitzer started calling his contacts in Congress, which were many because of his work on nuclear fusion, Bahcall took out the directory for the American Astronomical Society and began calling everyone he knew to ask them to write letters to their senators and representatives.[34]

Spitzer also called O'Dell, and the two brainstormed what to do. They decided that while Spitzer and Bahcall contacted astronomers, O'Dell would call the many industry contractors working on the space telescope and get them to funnel information to Bahcall and Spitzer as well as to Congress.

First on their agenda, however, was to clarify the reasoning behind the Greenstein report's recommendation. Working together, Bahcall, Spitzer, and O'Dell solicited all twenty-three members of the Greenstein committee and got them to endorse a draft statement by Bahcall that stated, "In our view, Large Space Telescope has the leading priority among future space astronomy instruments."[35]

Then, on July 2, Congressman Symington stood on the House floor and, as he had promised on June 26, inserted into the Congressional Record a letter by Jesse Greenstein in support of the Large Space Telescope. As Greenstein wrote, "Astronomers felt then and feel now that the LST is the ultimate optical telescope and that together with a balanced ground-based program, it will open up new vistas for the human mind to contemplate."[36]

By that date Bahcall and Spitzer had already arranged a series of meetings in Washington, DC, through July, visiting with numerous elected officials and their staffs, including senators William Proxmire (D-Wisconsin) and Charles Mathias (R-Maryland). These two men were respectively the Democratic chairman and the senior Republican on the Senate Appropriations Committee that was to review the House budget bill and make its own budget recommendations to the Senate.[37]

Proxmire, well known for his Golden Fleece awards for what he believed was absurd and wasteful government spending, was of like mind with Boland in opposing spending at NASA. No one expected to get much help from him. Mathias, however, was very interested in helping. After their meetings he agreed to reinsert the space telescope's $6.2 million in the budget.

For Mathias, a liberal Republican whose willingness to oppose the Nixon administration had irritated the leadership of his party, the space telescope was a chance to show his broad-mindedness to Maryland voters. He expected a tough reelection campaign later that year, first in the primary from Republican conservatives, and then in the main election from Barbara Mikulski, a Democratic city council member in Baltimore.*[38]

For Bahcall, the lobbying experience that summer was somewhat frustrating. "It came at a large cost to me personally, in terms of not allowing

* In the end, Mathias beat Mikulski handily, 57–43 percent. She in turn would return to win the 1986 Senate campaign when Mathias retired.

me to do science during that period."[39] At times it was also nerve-racking. In one case, Bahcall had wrangled an appointment with Congressman Max Baucus (D-Montana), also a member of Boland's Appropriations Subcommittee. Bahcall had heard that Baucus had a lawyer in his office who was married to someone who worked at Goddard. Bahcall called the wife, who put him in touch with the lawyer, who arranged the interview.

Bahcall was ushered into Baucus's office, put on a stool, and told that he had 15 minutes to make his pitch. Worse, Baucus began firing questions at Bahcall, one after another. "I had the feeling that . . . if there were any questions I couldn't answer in 15 seconds, he was just going to walk out of the room in disgust."[40]

At times the effort seemed pointless. For example, Bahcall and Spitzer spent fifteen minutes trying to explain the importance of the project to Democratic congressman George Shipley. Shipley, one of the telescope's biggest skeptics in the House Appropriations Subcommittee, explained that only two years previously Congress had approved another big-budget telescope, the Very Large Array (VLA) radio telescope to be built in New Mexico. "We just approved the VLA telescope, which was going to solve the riddles of the universe," Shipley complained. "Now you want another telescope. What's wrong with you fellows?"[41]

Shipley's complaint was typical. The Greenstein decadal survey's recommendation, with VLA at the top and the space telescope down near the bottom, had given congressmen like Shipley the clear impression that the astronomers themselves believed that the space telescope could wait.

In spite of all this, the lobbying effort by Spitzer and Bahcall bore fruit. When the Senate Appropriations Committee issued its report on August 1, it not only included the money for the LST, as Mathias had promised, it also reinstated the $39 million that the House had tried to cut from NASA. The Senate was far less cost conscious than the House. They not only accepted NASA's budget numbers, they also topped the House's increased appropriations for the Veterans Administration by more than half a billion dollars.

Proxmire, who opposed these budget increases, wasn't about to give up. In bringing the budget bill to the Senate floor on August 5, he introduced an amendment to cut an additional three percent across the board from the discretionary portions of the budget bill. In the floor

fight that followed, Proxmire's amendment failed. Not only were most senators uninterested in cutting spending, they were terrified that someone might think they were in favor of reducing the budget for the Veterans Administration.

Proxmire's maneuver, did, however, succeed in getting the budget bill sent back to the Senate Appropriations Committee for review. As he announced just before the Senate made this decision, "I intend to fight and fight to the very best of my ability for at least a $160 million deduction."[42] Though the subsequent second report, issued on August 15, still included an increase for the Veterans Administration exceeding half a billion dollars, the increase was now offset by other trims. For example, even though the NASA budget still included the $6.2 million for the space telescope, the agency's budget was only increased by a total of just under $4 million. The committee had merely left the decision on what to cut to NASA. "The Committee feels that NASA is better able to apply this reduction with a minimum of disruption to its priorities."[43]

On August 16 the final conference committee negotiations between the House and Senate took place. Though Mathias was on the committee, so were Boland, Talcott, Shipley from the House, and Proxmire from the Senate, making it amazing that many of the Senate's higher figures were accepted. For NASA, however, the money for telescope studies was cut again to $3 million, a trim that meant that though work could go forward, it would be impossible to introduce the telescope as a new project in 1975. The project would have a wait at least one more year.

Moreover, the cut indicated that the project still faced strong opposition. On August 2, even as negotiations were ongoing, Spitzer called O'Dell to tell him of a recent conversation he had had with James Fletcher, NASA's administrator, in which the idea of reducing the size of the telescope had come up. As then planned, the telescope's mirror had a diameter of 3 meters, or about 120 inches. Because Spitzer had the impression that Fletcher's support of the space telescope was somewhat lukewarm, he thought it wise for the project to consider Fletcher's suggestion. O'Dell agreed. They had to do something to improve their support in both Congress and NASA. O'Dell suggested that Spitzer write him a letter outlining his thoughts on the matter. On August 7 Spitzer did so, suggesting that the science working group "consider telescopes

with an aperture ranging from 1 to 3 meters . . . The chief consideration should be given to an alternative [large space telescope] with an aperture between 2 and 2.5 meters."[44]

From O'Dell's perspective, 1.8 meters "would have been wonderful," though he believed that they could get the best compromise of good science and greatest savings by going to some middle size, say 2.4 meters. Moreover, he was aware, because of his top secret clearance, that the military space program had already built and launched high-resolution spy satellites using mirrors with a 2.4-meter diameter. Using this diameter in the space telescope would save money, since the development costs for a larger mirror would be far greater. Over the next six months he made an effort to poll every scientist involved in the project on this proposal. Most were also willing to consider reducing the mirror size, but rejected anything less than 2 meters. Even at that diameter John Bahcall told O'Dell that he would have to reassess his personal role in the project.[45]

In the end, the astronomers compromised, and at a December 13, 1974, working group meeting at Marshall they agreed to a reduction from 3 to 2.4 meters, or 120 to 94 inches. This smaller size would still allow them to achieve most of their scientific goals, while simplifying construction enormously. Though a 3-meter telescope could fit inside the shuttle cargo bay, the fit would be very tight, and carried with it a lot of difficult engineering problems that no one was sure could be solved easily or cheaply. The smaller size made these engineering problems much more manageable.[46]

After these 1974 compromises O'Dell and the other astronomers assumed that the telescope would finally be submitted for full funding in the 1977 fiscal budget and submitted to Congress in January 1976. Called a "new start" by NASA budget managers, the project's entire costs would now be listed in detail in the NASA budget.

The 1974 budget battles, however, indicated the tenuous nature of the project's future. The attitude of the Congress in the late 1970s was far from enthusiastic about space and NASA, and after the November 1974 elections, the political situation had become even worse. The Watergate scandal and Richard Nixon's resignation in August 1974 had resulted in a new Congress dominated by Democrats like Edward Boland, individuals who were much more inclined to spend government money

on social programs, not big scientific research projects involving astronauts and NASA.

For the '77 budget the agency had been planning to include two science "new starts," the space telescope and the Solar Maximum Mission, intended to study the Sun during its solar maximum in 1979–80. In 1974 John Naugle had retired, and the new associate administrator for space science, Noel Hinners, realized that he couldn't justify a new start for the space telescope in '77. Not only was the new Congress more hostile to new NASA spending, the new president, Gerald Ford, wanted to cut the federal budget as well. In October 1975, Ford had announced that he wanted to trim an additional $28 billion from the total 1977 budget, of which NASA had to shoulder $305 million in cuts. In order to meet these demands, Fletcher, still a tepid supporter of the space telescope anyway, realized that he did not have the cash to start the telescope in 1977, even at the $300 to $350 million cap he was demanding for it. Moreover, while the Solar Maximum Mission had to be in orbit in time for the solar maximum in 1980, the telescope could wait. As several congressmen had previously noted, the stars would always be there. Fletcher told Hinners to hold off.[47]

Normally, a bureaucrat in Hinners's position would have simply included a few million dollars so that the telescope's design work could go forward, pending a new start some time in the future.

Hinners, however, had a different idea. "I figured that if there were one or two million in there, that would probably keep the outside community quiet [but] wouldn't have done much." He decided to exercise what he liked to call "the Black Art." Instead of simply accepting the delay and including a small stipend to keep the program alive, he deliberately deleted the entire telescope budget. "My strategy was to put nothing in and get the outside world really antagonized. And it worked. Panic!"[48]

As part of the annual cycle of budget negotiations, the President's proposed federal budget is kept under wraps until mid- to late January. No one outside the executive branch is supposed know what's in it until it is revealed by the White House. Nonetheless, on December 22, 1975—three days before Christmas—O'Dell called John Bahcall and leaked the fact that the telescope had been deleted, thereby giving Bahcall

about a month to prepare his lobbying campaign before the official release of the budget on January 21, 1976.[49]

At the time Spitzer was on sabbatical in Paris, so it was entirely up to Bahcall to get the campaign underway. Once again he started calling and writing everyone he knew, suggesting that they draft letters to be sent the instant the budget became public knowledge. He himself drafted a letter to Fletcher, expressing his "surprise and disappointment," and his fear "that the scientific community will conclude that NASA is intent on obtaining funds to support its own institutional needs in preference over wider goals." He also got Spitzer and several other important astronomers to agree to sign a joint statement to Fletcher in which "all signatures were made by John Bahcall with the agreement of the signees so that [Fletcher] could receive this letter as soon as possible." This joint letter described "the immediate angry reaction of many scientists" to the deletion and demanded a meeting with Fletcher to discuss the issue.[50]

Unlike the 1974 lobbying effort, the 1976 effort carried risks. In 1974 the campaign had the support of the bureaucrats in NASA. In 1976 the campaign was directed *at* the bureaucrats at NASA, criticizing their decision to delete the telescope. If it should fail, the astronomers might only succeed in antagonizing the very people they had to work with at the space agency.

In this context it is unclear how much Bahcall knew about Hinners's strategy. What is known is that he did talk numerous times to Hinners immediately after finding out about the cut, working out the campaign strategy with him. Moreover, as Bahcall himself said many years later, there were many individuals at NASA, such as O'Dell, who "were willing to do courageous and illegal things" to help save the telescope. For example, O'Dell was pushing the limits of the law if not breaking it by his behind-the-scenes lobbying effort.[51]

For O'Dell, the risks were significant. Following the 1974 lobbying campaign he had written the University of Chicago to formally give up his tenured position there. As he explained in his resignation letter, "My firm belief is that the Large Space Telescope should, and eventually will, be built. My departure now would be interpreted as a loss of support for the program. . . . In light of the current difficulties, this interpretation would clearly be enough to kill this program. I cannot in good faith do

this and must, therefore, tell you that I do not intend to return to the University of Chicago next autumn."[52]

Then, only a few weeks before Hinners deleted all money for the space telescope, George Pieper at Goddard offered O'Dell the job of running the center's Optical Astronomy department. Though the two men disagreed strongly on many issues relating to the space telescope, they also respected each other. The job would give O'Dell a more secure position in space science, especially considering the space telescope's lack of funding. After taking several weeks to think about Pieper's offer, O'Dell turned it down, despite having learned in the interim of the space telescope's loss of funding. "The relocation of my family three years ago had long term effects on my children which I only now really appreciate," he explained in a letter to Pieper. Moreover, his wife liked it in Huntsville, and did not want to move.

O'Dell was now totally committed to the project. "Like Cortez burning his boats on the beach, I was going to make sure [the space telescope] succeeded." Without tenure, without funding, and without any clear future at NASA, he was left with only one choice: succeed.[53]

As soon as Fletcher officially announced NASA's budget in mid-January, the campaign began, with Bahcall acting as public point man and O'Dell providing him and others information and support. Once again there were trips to Washington, DC. Once again there were endless phone calls and letters. Once again Bahcall found himself meeting with senators and congressional representatives.

Though his 1976 trips to Washington with Spitzer and others to lobby elected officials were important, Bahcall's greatest influence in 1976 was as the campaign's lead organizer. He began issuing regular reports to the astronomy community, providing specific details about the various members of Congress on the important budget committees, including summaries of their attitude toward the space telescope and what might influence them. Under his leadership a legion of other scientists took up the banner of the space telescope and carried it wherever they went.[54]

For example, inspired by Bahcall, George Wallerstein of the University of Washington made his own lobbying visits to Congress, sitting down with the staff of two representatives and one senator. He then sent out a letter addressed to "numerous astronomers," haranguing them to write their own letters. "Do it TODAY. If you don't, I don't want to

hear one peep out of you complaining about Congress or the lack of jobs for your students in the 1980's; it will be your fault, not theirs!"[55]

Also inspired into action by Bahcall was George Field, director of the Harvard College Observatory and the Smithsonian Astrophysical Observatory and chairman of the Physical Sciences Advisory Committee that regularly provided advice to Fletcher as well as the White House. Field had been a student of Lyman Spitzer's, and had adopted the same research interests as Spitzer after his graduation, investigating the gases lurking out in the empty regions between the stars. In fact, he had specifically picked Princeton for his postgraduate education because of his admiration of Spitzer and Schwarzschild. "I learned a tremendous amount from [them], both about the specifics of astronomy, but also, the way to do science. I found them enormously stimulating people."[56]

Field, as a Massachusetts resident, had a particularly important position. Boland, as chairman of the House Appropriations Subcommittee and their chief opponent in the 1974 battles, represented Springfield, Massachusetts.

In 1976 Boland was no less of a problem. In budget hearings in February he noted that though the telescope had been dropped from the budget, his subcommittee was "under pressure from about every conceivable institution that is in astronomy in the United States" to get those funds reinstated. Nonetheless, he questioned the need for the telescope in lieu of other priorities. "What good is it going to do when you get it out there? What does it do? What does it find?" Despite attempts by Fletcher and Hinners to defend the telescope's value, Boland concluded by noting, "There are some problems here on Earth which we have to be concerned about, and they are the difficult ones. If we don't solve those, there won't be any money for space applications or space technology or space science."[57]

In his own effort to save the telescope, Field called Boland's office, wrote to him, and even talked directly to Boland at one point, all to no avail. His most interesting opportunity to influence Boland took place one day while he was at Washington's National Airport, waiting for a plane. There he saw the president of MIT, Jerome Wiesner, chatting with Democrat Thomas P. ("Tip") O'Neill, Speaker of the House, and the man who represented the congressional district in Massachusetts where Harvard was located. Field knew that Boland and O'Neill were

old friends, having shared an apartment together in DC for the last twenty-four years.

Field joined them, and turned the conversation to the space telescope, explaining to O'Neill how the project might bring as much as $50 million in government money to Massachusetts. O'Neill found the thought of such pork very appealing, and promised to "discuss it with Eddie" when he and his wife joined Boland for a Cape Cod vacation in the next few weeks.[58]

O'Dell, meanwhile, continued to skirt the edges of the law in his effort to save the telescope. He would send out regular "Dear Colleague" letters to the members of the science working group, describing to them the status of the lobbying campaign and hinting at things they could do to further the campaign. He arranged for Noel Hinners to attend several science committee meetings run by O'Dell, including the space telescope's working group as well as a session of a science working group on doing astronomy on the space shuttle. At this second meeting one whole afternoon session ended up being focused not on shuttle astronomy but on "space telescope issues." While Hinners explained the logic behind the agency's budget decision (though not mentioning his own use of "the Black Art" to get things moving), O'Dell gently warned that if the telescope project did not get a new start by the next year, it faced the possibility of never flying at all.[59]

In the meantime, Bahcall, Spitzer, Field, and O'Dell continued to push for a meeting with Fletcher, which finally occurred, after several postponements, on May 19, 1976. To their horror, they discovered that Fletcher was not only relatively uninterested in the space telescope, he knew very little about it.

"We were appalled how little Fletcher understood [about] the project at the time," remembered Field in 1986.

"Fletcher himself did not come across as a person committed to science," remembered Bahcall in 1983. "He came across as a person . . . committed to the goals of NASA, which at the time were primarily institutional . . . and not particularly science-oriented."

Nonetheless, the meeting forced Fletcher to recognize how strong and deep the support for the space telescope was among astronomers. As Field noted, "Fletcher was a skilled bureaucrat." He now had to include in his political calculations this powerful and effective group of astrono-

mers, a fact that made it far more difficult for him to oppose funding the space telescope.[60]

Despite all this campaigning, by early June the situation still appeared bleak. In his discussions with various senators and their staff, Bahcall was only able to get from them a small bone. Though no elected official was willing to reinsert the new start in the 1977 budget, a number of senators and representatives agreed to include language authorizing NASA to issue what was called a request-for-proposals (RFP). This document, which describes a project's specifications and is used by contractors to write their bids, is normally not released until after a new start is appropriated. Bahcall had gotten Congress to agree to allow the RFP's early release in anticipation of an official new start in the 1978 budget.[61]

On June 8, however, Boland stepped in to try and stop this maneuver. On that day his House Appropriations Subcommittee issued a report to the House in which they specifically prohibited NASA from releasing an early RFP or selecting a prime contractor. As the subcommittee report stated, "It felt that such a procedure established an unacceptable and highly unusual precedent."[62]

Boland's action was a serious tactical error. The chairman of the House Authorizations Committee, Don Fuqua, resented Boland's Appropriations Subcommittee interference in what he considered an Authorization Committee matter. At this same time it also appeared that Boland was getting sick and tired of the constant lobbying of astronomers. For example, in a meeting between astronomer Myron Smith and his own Texas congressman, J. J. Pickle, Smith was told by Pickle how "Boland was feeling quite harried over political lobbying by astronomers."[63]

In the House-Senate conference committee negotiations at the end of July, Boland's effort to stop the space telescope failed. The compromise went through. NASA was authorized to release its RFP early.

The battle was far from over. The compromise also stated that "this is not to be construed as an endorsement of development funding of the project."[64]

Over the next year the campaign went on unrelentingly. As one congressman noted, "[Many] of us have had our rugs and carpets worn out by astronomers." In February 1977, after NASA had released its 1978 budget with a new start for the space telescope, Bahcall was asked to

testify before Congress. For this trip he also arranged numerous meetings with more members of Congress and their staffers, accompanied by astronomers George Wallerstein, George Field, Vera Rubin, and Margaret Burbidge, trying to stave off any opposition to the new start.[65]

Burbidge and Bahcall had reserved separate rooms in the same hotel, and had agreed to meet for breakfast before heading out to Congress. To Burbidge's surprise, Bahcall was five minutes late. "He's usually extremely punctual," she remembered in 1984.

As they ate, Bahcall explained that he had spent half the night in the emergency room. When he had been getting into bed the night before he had cut his thigh on a nail that had been sticking out of the mattress. "It was bleeding rather a lot," he explained. When he called the hotel desk they insisted he go to the hospital for stitches and a tetanus shot.

Anyone who has ever walked the halls of Congress knows the distances involved. Everything is spread out, with long tunnels between buildings. Yet, off they went, walking back and forth from office to office to see as many representatives as possible. "John was limping very slightly but going at full speed," Burbidge said in 1984. "He was obviously in pain."[66]

Once again, this lobbying effort had demanded an endless amount of networking. For example, getting to see Congresswoman Lindy Boggs, Democratic representative from Bahcall's hometown district in Louisiana and a new member of Boland's subcommittee, required a long chain of contacts. The journey began when Bahcall, Spitzer, and Burbidge met with Democratic senator Bennett Johnston of Louisiana. One of Boggs's staff members happened to be there, and in talking to this staff member Bahcall learned that Boggs's own daughter, Barbara Boggs Sigmund, happened to be a local New Jersey elected official in the county where Bahcall lived. Bahcall called Sigmund, and through her was able to arrange a meeting with Boggs.

The meeting itself was interesting. Because of an important pending House vote, Boggs arranged to meet Bahcall in the ladies lounge adjacent to the House floor so that she could get away quickly to vote if necessary. "For me the setting was somewhat bizarre," Bahcall remarked in a 1985 interview.

Boggs, however, was enthusiastic about the idea of a space telescope. Also, "it was somewhat helpful in Lindy Boggs's mind that I was from

Louisiana," Bahcall noted. She not only backed the telescope during March House Appropriations hearings, she helped Bahcall get appointments with a number of other important elected officials and their staff.[67]

Bahcall and Spitzer returned to Congress twice more in April 1977. Not only did they have to contend with Boland's opposition, but on May 11 Senator William Proxmire of Wisconsin announced his opposition as well, noting his lack of faith in NASA's cost estimates. As his press release noted, "A recent General Accounting Office report shows that NASA has neglected to report the full costs of the controversial space telescope project. According to the GAO, the space telescope will have a life cycle cost of $1.4 billion, or over 200 percent more than the NASA development estimate given to Congress."[68]

Though Proxmire was eventually proven right, his opposition was too little too late. The astronomers' campaign had worked. In mid-July, Proxmire tried and failed to get the Senate Appropriations Committee to delete the telescope's funding. Despite being chairman of the committee, Proxmire was outvoted 4 to 2. When the appropriations bill came up for debate before Congress, the issue of the space telescope was not even discussed. Instead, Boland tried on the House floor to delete funds for the Jupiter Orbital Probe, later dubbed Galileo, and was voted down.[69]

By the end of July 1977 NASA had chosen its contractors. The optical telescope assembly, holding the mirror, its frame, and the fine guidance sensors that would keep the telescope locked on target, would be built by Perkin-Elmer of Danbury, Connecticut. The telescope support systems module, including the gyros and power supply and body, would be built by Lockheed Missiles and Space Company in Sunnyvale, California. The two companies had bid $69 and $83 million respectively, considerably less than the $475 million that Congress had approved. Even when the cost was added to build the six science instruments that would sit at the back of the optical telescope assembly, on the surface at least it appeared in 1977 that the space telescope's budget had plenty of reserve cash, despite William Proxmire's and the GAO's concerns.[70]

4

Building It

In the spring of 1981, astronomer Kris Davidson took a two-month sabbatical from teaching at the University of Minnesota to travel to the Cerro Tololo Inter-American Observatory in the southern hemisphere. Located on top of the 7,200-foot-high Cerro Tololo peak in the high Andes mountains about 300 miles north of Santiago, Chile, this astronomical observatory was then one of the best places to go if an astronomer wanted to take a close look at some of the more unusual objects in the southern sky.

For Davidson, one of the more interesting of these unusual objects was the star Eta Carinae. "We already knew at that time that Eta Carinae was a really special object," he remembered. In the almost twenty years since Geoffrey Burbidge had first speculated that Eta Carinae might be the galaxy's next supernova, a handful of astronomers had managed to glean some additional basic facts about it. Apparently it was one of the galaxy's most massive stars, weighing somewhere around 100 times the Sun's mass, with surface temperatures greater than 50,000 degrees Fahrenheit. Further analysis of the star's spectrum indicated that its Homunculus was made of three separate shells of dust. One astronomer thought that the Homunculus was a ring of material tilted 70 degrees from our line of sight. Another noted that the growing Homunculus was likely caused by what he called "bipolar jets," jets of material shooting out from the star's poles.

Trying to figure out exactly how this all fit together with the images available, however, remained difficult. The best some astronomers had been able to do was to meticulously make repeated spectrograph cuts through the nebula, accumulating data on the motion and velocity of