THE DECISION TO BUILD THE VERY LARGE ARRAY

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Introduction

The idea of building a large array of radio telescopes developed about 1960. Some twelve years later Congress authorized the construction of the Very Large Array, an assemblage of 27 dishes, arranged in the shape of a Y, in which each arm is 21 km long. This enormous instrument is expected to be capable of a resolution of 1 second of arc, making its resolution comparable to that of optical telescopes. Its authorization marked the end of a lengthy confrontation between advocates of other instruments, whose relative merits were weighed by several committees and government agencies. When the decision was finally made, it was essentially a consensus choice of the country's most influential astronomers, whose unanimity convinced the government that the VLA was worth building.

The Whitford Panel

About 1960 the National Science Foundation established a committee of radio astronomers, headed by John Pierce of Bell Telephone Laboratories, to consider the future of radio astronomy. Their report, which appeared about 1962, recommended,[1] among other things, the construction of an array of radio telescopes with 1 minute of arc angular resolution. Meanwhile the National Radio Astronomy Observatory at Green Bank, W. Va. was being established. When its director, Otto Struve, retired, he interested Joseph Pawsey in coming to Green Bank to assume the job. While still in Australia Pawsey spoke and wrote privately[1] on the need for a large, high-resolution array to be built at NRAO. Before he was able to take over, Pawsey died and David Heeschen was appointed first interim director and then director. In September 1962 Heeschen issued a memo to NRAO staff assigning responsibilities

for the VLA.

Late in 1961 the Committee on Science and Public Policy of the National Academy of Sciences established a Panel on Astronomical Facilities,[2] headed by A.E. Whitford, who was then director of the Lick Observatory of the University of California. During the Panel's deliberations, the members met with Heeschen in October 1963. The Whitford report, issued in 1964, made recommendations in optical astronomy, radio astronomy and auxiliary instruments and automation. The committee's highest recommendation for radio astronomy was that a very large, high-resolution pencil-beam array with low sidelobes be constructed as a national facility. Such an array, the Panel said, might consist, for example, of about 100 individual parabolic dishes, each about 85 feet in diameter. The estimated cost was $40 million. The array meant was presumably the VLA, then being studied at NRAO.

The Whitford committee's second recommendation was for a high-resolution array consisting of about eight antennas, to be built at the Owens Valley Observatory, at a cost of $10 million. Thirdly, the Panel recommended the construction of two fully steerable 300-foot paraboloids at a cost of $16 million.

VLA Proposal

In Fall 1964, George Swenson took a leave of absence from the University of Illinois to go to Green Bank, where he became chairman of the VLA design group in 1966.[3] He worked there until the end of 1967.[1] Funds for the design work were initially provided by NRAO itself. Later the NSF provided support.

The first NRAO report on the VLA appeared in December 1965. Then in January 1967 NRAO submitted a two-volume proposal to NSF, calling for an array with 36 antennas. Each arm of the Y was to be 21 km long, and the dishes were to be 25 meters in diameter. Its cost was to be $51.9 million.

Two years later a third volume was added to the proposal (January 1969), and by this time the number of antennas had been reduced to 27. NRAO had decided to reduce the scale, Heeschen says,[4] because the design studies had shown that the extra bit of capability was too expensive. The reduction saved millions of dollars.

Owens Valley Proposal

The Owens Valley Radio Observatory proposed to the NSF in 1964 that a four-element array be built, each element to be 40 meters in diameter.[5] Shortly afterward, in the spring of 1965, OVRO was given funds to build a prototype dish. Then in April 1966 the California Institute of Technology, which operates OVRO, sent a proposal to NSF asking that seven more antennas be built, each 130 feet in diameter (40 meters). Its cost was to be $14.9 million.[3] The advantage of the OVA proposal, according to Alan Moffett of OVRO, is that it could have been built in only three years, using existing technology.

CAMROC-NEROC Proposal

One of the recommendations of the Whitford committee had been for two 300-foot paraboloids. While the committee was meeting, another committee was being formed--the Cambridge Radio Observatory Committee (CAMROC). This group consisted of representatives from Harvard University, the Massachusetts Institute of Technology, the MIT Lincoln Laboratory and the Smithsonian Astrophysical Observatory. These organizations contributed seed money to

design a larger, more precise antenna.[6] In late 1965 CAMROC issued a two-volume preliminary report with design objectives[3] and then requested $1.1 million for a detailed study of design and feasibility. This was forthcoming in November 1966.[3] The original CAMROC concept was to build a 400-foot steerable antenna inside a radome at a cost of $33 million. In the middle of the following year the CAMROC group decided to form a corporation, at the same time expanding its affiliated institutions to 13. (These were Boston University, Brandeis University, Brown University, Dartmouth College, Harvard University, University of Massachusetts, MIT, University of New Hampshire, State University of New York at Buffalo, State University of New York at Stony Brook, Polytechnic Institute of Brooklyn, Smithsonian Astrophysical Observatory and Yale University.)

At about the same time, in July 1967, an Ad-Hoc Scientific Panel for Large Radio Astronomy Facilities, headed by Robert Dicke of Princeton University, was formed. NEROC submitted[7] a proposal to the committee for a radome-enclosed 440-foot steerable antenna, operable to a wavelength of 5 cm with a spatial resolution of about 10^{-3} arc sec. Its cost would be $27.8 million.[8] In June 1970 a new NEROC proposal was submitted to the NSF. The final design called for a 440-foot fully steerable, filled-aperture paraboloid with Gregorian optics. It was to be enclosed in a radome to minimize environmental effects. A pointing precision of 5 arc seconds was expected, adequate for operation at wavelengths as short as 1.2 cm.

Other Proposals

When the Dicke panel met in July 1967, in addition to the VLA, OVA and CAMROC-NEROC dish, they had to consider[3] several other proposals. One was made by the Associates in Radio Astronomy (consisting of Stanford University,

California Institute of Technology, University of California and University of Michigan) for a 100-meter-diameter antenna to be built in Owens Valley. According to Moffett,[5] this concept was never seriously considered. There was a study of the Largest Feasible Steerable Telescope, headed by John Findlay of NRAO. NSF had rejected a $2-million proposal from the Naval Research Laboratory for a 300-foot transit telescope. The University of Maryland had submitted an informal proposal, from Gart Westerhout, for a 300-foot steerable paraboloid. Sidney Bowhill at the University of Illinois had submitted a proposal for a 100-meter-diameter antenna to be used primarily for aeronomy, but secondarily for radio and radar astronomy (at a cost of $12 million). Finally it was estimated that at a cost of $2-3 million, the 1000-foot-diameter telescope of the Arecibo Ionospheric Observatory could be resurfaced to increase its surface accuracy from 70 cm to 10 cm.

First Dicke Panel

Before the decision to form the Dicke panel on radio astronomy facilities, there was a movement afoot to produce a new survey of astronomy as a whole, including space astronomy. For example, in January 1967, Bengt Stromgren, president of the American Astronomical Society, wrote[9] to Harvey Brooks, chairman of the National Academy's Committee on Science and Public Policy, asking that the Whitford report be updated. In April a group of leading astronomers was invited[10] to a COSPUP meeting.[11] At the meeting an ad-hoc committee, headed by Whitford, was established to formulate the ground rules for a new study of both space and ground-based astronomy.

That same month, the NSF Astronomy Advisory Panel recommended[12] the

formation of an ad-hoc scientific advisory panel for large radio-astronomy facilities.

The Dicke panel consisted[13] of two optical astronomers, three radio astronomers, and three who were neither. They were, in addition to Dicke, Bart J. Bok (University of Arizona), Stirling A. Colgate (New Mexico Institute of Mining and Technology), Rudolph Kompfner (Bell Telephone Laboratories), William W. Morgan (Yerkes Observatory), Eugene N. Parker (University of Chicago), Merle A. Tuve (Carnegie Institution of Washington) and Gart Westerhout (University of Maryland). They met in Washington, DC, 24-28 July with representatives from Cal Tech (OVA), the Associates in Radio Astronomy (100-meter dish at Owens Valley), NRAO (VLA), NEROC((440-feet dish in radome), Cornell University (upgrading Arecibo 1000-meter spherical dish) and the Committee on Institutional Cooperation (100-meter dish for aeronomy).

Each day the panel held[14] an open session for five or six hours and then met in closed session for the remainder of the day. The last half day was an executive session.

The panel's report, dated 14 August 1967, discusses the relative merits of antennas with fully filled apertures (single dishes) and incompletely filled apertures (arrays). In either case, a large receiving area is required to detect a weak point source.

If one desires high-resolution radio pictures, the report explains, the receiving aperture has to be effectively spread over a very large region, many miles across. Such an incompletely filled aperture has penalties: reduced sensitivity to surface brightness, undesirable side lobes, inflexibility and electronic complexity. A large correlation array cannot be used

effectively, the report notes, for spectroscopic work of radar astronomy, nor for studies needing rapid changes in frequency coverage, unless the electronic system is extremely complicated. Nevertheless the large array is the only type of instrument that can obtain the many high-resolution pictures needed.

The report goes on to say that a large filled aperture in the form of a single dish is needed to provide complementary information not readily obtainable from the large array. These needs are for: surveys at low resolution, high sensitivity to surface brightness, line spectroscopy, broad-band observations at many wavelengths, and planetary radar.

So, the panelists concluded, both large dishes and large arrays were needed. Accordingly, they made the following recommendations:

1. The Proposal by Cal Tech "for an array of eight dishes be funded as soon as possible, with an adequate operating budget, and with the proviso that at least 50% of the observing time be made nationally available."

2. The proposal by Cornell University to upgrade the 1000-foot spherical dish in Arecibo, Puerto Rico to permit observations at 10-cm wavelength or shorter be accepted and funded as soon as possible, "with an adequate operating budget, and with the proviso that at least 50% of the observing time for astronomy be made nationally available."

3. Definitive studies are needed to assess the potential of large, fixed, spherical dishes with multiple feeds (the Arecibo type) because the approach may lead to instruments of the largest collecting area.

4. A large array and ultimately a very large array are needed. The OVA

will take care of the immediate needs for a large array. It is too soon to decide on the exact form a very large array should take. The VLA proposal made by NRAO for a 36-dish array is promising. In the next few years NRAO should concentrate "extensively on phase-coherent radio astronomical research at a resolution of 1 sec of arc or better to show conclusively the expected tremendous stride forward that should result from a very large array with this resolution."

5. NEROC has had success in studies of a new type of vertical-truss, lightweight, fully steerable dish in a radome. But the NEROC proposal should be deferred until more is known of the capabilities of an Arecibo-type spherical dish as a large precision instrument, operating at short wavelengths. The panel asked that the NEROC group assist[15] in making comparisons between the potentialities of these two types of antennas.

6. The ARA proposal should be declined because the Arecibo and NEROC concepts have more revolutionary possibilities.

7. Very large radio telescopes should be made nationally available to qualified visitors at least 50% of the time.

There was no immediate reaction from NSF.

Origins of the Greenstein Committee

The ad-hoc committee to formulate ground rules for an updating of the Whitford report had been formed in April 1967. Harvey Brooks recalls[16] that he spent a year in conversations between Hugh Loweth of the Bureau of the Budget and Leland Haworth, director of NSF, formulating the ground rules for an update. This time it was felt, by Loweth, by the astronomical community and by NASA, Brooks says, that space and ground-based astronomy should be

considered as one entity. At the same time the NAS Division of Physical Sciences, in parallel with COSPUP, had been discussing[17] a broad survey of astronomy.

The following year the Bureau of the Budget produced[18] a "Prospectus for Study of Priorities in Astronomy." This document notes that in the next five years, several astronomy projects would be competing for funds, each costing $50-100 million. These were: satellites in the Orbiting Astronomical Observatory series and in the Orbiting Solar Observatory series; the OVA and VLA; Astra (manned astronomy satellite); large, steerable filled-aperture antennas (such as NEROC), and other new starts in manned astronomy. A new effort was needed, according to the prospectus, to evaluate these needs.

Brooks then prepared a proposal for the update, which he circulated[19] for comments to Lewis Branscomb, headeof the Joint Institute for Laberatery Astrophysics, Jesse Greenstein (Cal Tech optical astronomer) and Leo Goldberg (director, Harvard College Observatory). In the fall of 1968 Sidney Reed Jr, head of the NSF Office of Planning and Policy Studies, sent the draft[20] of a letter to COSPUP (asking for the update) to Brooks for his comments. Then in January 1969 the formal invitation[21] was finally sent, at least two full years after the movement to update the Whitford report had begun. It came in the form of a letter from Haworth to Brooks, asking that COSPUP submit a proposal to NSF to study astronomy in cooperation with NASA. He asked that COSPUP provide a rationale that would assist in choosing among the many possible projects before NSF and NASA, "so that the actual choices

to be made can be made at whatever budget levels may eventuate in future years." NSF and NASA were to review the proposed study-group membership and make suggestions for additional members.

An ad-hoc group headed by Geoffrey Keller, formerly with the NSF astronomy section and then at Ohio State, was formed[22] to draft the proposal and suggest panel members.[23] At the urging of NASA, which needed guidance, the final proposal[24] promised an interim report by March or April 1970 to assist in planning the FY 1972 budget. The amount requested was $168 000.

Second Dicke Panel

Two years after its first meeting, the Dicke panel was reconvened in Washington from 9-11 June 1969. The same panelists met, except for Merle Tuve. In its report the Panel noted[25] that two years earlier it had felt that the NEROC and NRAO proposals were both excellent but that the design studies needed further work on specific questions. Now, in 1969, the Panel found that both groups had demonstrated the engineering feasibility of their respective instruments. The report of the second Dicke panel recommends the following items (in which the order is not on the basis of priority):

1. The Arecibo resurfacing should be done and the facility be made nationally available.

2. The OVA should be built as soon as possible and made nationally available.

3. The Panel recommended with equal urgency that the fully steerable 440-foot dish enclosed by a radome be built now, and made nationally available.

4. A start should be made on constructing the VLA; this construction should proceed in stages over a several-year period. At the completion of each stage, that portion of the array should be operational and available

for observations.

5. Studies should be continued of methods for building very large steerable dishes, particularly in the application of the principle of homologous structure deformation; the studies should be oriented toward design of an antenna usable to 3-6 millimeters.

6, In parallel with support of the major facilities, support of radio astronomy in the universities should be substantially improved.

7. At least 50% of the observing time at these unique radio-astronomy facilities should be made available to visitors.

Response of NSF

The response of the NSF to the second Dicke panel was almost immediate, according[26] to William Wright, head of the Division of Mathematical and Physical Sciences. In October 1969 NSF requested that the Bureau of the Budget include in the budget $2 million to initiate construction of the VLA. However, it was late in the budget cycle, Wright remarked, and was therefore not included. Why the VLA and not OVA or the NEROC dish? The argument that convinced Wright to go for the VLA, he says,[27] is that the NEROC studies did not demonstrate that we could do particularly better with big dishes than could be done in Western Europe. On the other hand, the VLA seemed to be just as well engineered and would be vastly more capable than the Westerbork array in the Netherlands. As for the OVA, Wright says, it was a problem of scale. Once it was decided to build the VLA, one should not waver. A smaller observatory such as the OVA could have been done piecemeal (although this was not done). And if NSF had opted for the OVA and did not get it, then there

would be no telescope at all. Wright notes that the above argument, which convinced him, may not have convinced William McElroy, the NSF director, or Randal Robertson, the associate director for research. "It may just have been done by osmosis," he concludes.

Thus, by the time the COSPUP committee that was to update the Whitford report was just getting underway, the NSF had already made up its mind that it wanted to build the VLA.

Smithsonian Legislation

Between the meetings of the first and second Dicke panels, a new method of funding the NEROC dish was attempted. One of the NEROC members, the Smithsonian Astrophysical Observatory, was funded by the Smithsonian Institution, whose funds are handled by legislation independent of NSF. In the summer of 1968 James Bradley of the Smithsonian Institution asked[16] Edward Lilley of SAO what was stalling the NEROC dish. Bradley suggested that the Smithsonian Institution might be interested in sponsoring legislation to build the 440-foot dish.

To evaluate the need for a large filled-aperture radio-radar telescope a meeting was held at the Smithsonian Institution in Washington on 30 November and 1 December, to which about 25 active radio astronomers were invited. John Findlay of NRAO was chairman of the meeting. In its report[28] the group noted that both large arrays and large dishes were needed and expressed the hope that the Arecibo telescope would be upgraded. The group recommended that the Smithsonian Institution should seek Federal funding to build the NEROC-designed dish. Accordingly, Senate bill 705 was introduced in the Senate by Senator Clinton P. Anderson, and another bill was introduced in the

House.

Greenstein Committee--Early Period

In July 1969 COSPUP asked Jesse Greenstein of Cal Tech to accept the chairmanship of the Astronomy Survey Committee. After some discussion and correspondence, Greenstein accepted and started forming his committee, which met for the first time on 11, 12 October. The committee's work was administered by the Division of Physical Sciences of the National Research Council.

(The final membership of the committee was: Jesse Greenstein, Cal Tech, chairman; Helmut A. Abt, Kitt Peak National Observatory; Jacques Beckers, Sacramento Park Observatory; Geoffrey Burbidge, University of California, San Diego; Bernard F. Burke, MIT; A.G.W. Cameron, Yeshiva University; Frank D. Drake, Cornell University; Ray L. Duncombe, US Naval Observatory; George Field, University of California, Berkeley; Herbert Friedman, Naval Research Laboratory; John E. Gaustad, University of California, Berkeley; Leo Goldberg, Kitt Peak National Observatory; David Heeschen, NRAO; Geoffrey Keller, Ohio State University; Robert P. Kraft, University of California, Santa Cruz; Robert B. Leighton, Cal Tech; Donald C. Morton, Princeton University Observatory; Robert Noyes, Smithsonian Astrophysical Observatory; Charles R. O'Dell, Yerkes Observatory; Jeremiah P. Ostriker, Princeton University; Bruno B. Rossi, MIT; Harlan J. Smith, University of Texas; Lyman Spitzer, Princeton University Observatory. Bruce N. Gregory was executive secretary.)

As the Committee began operating, panels were formed on various topics, such as radio astronomy, optical astronomy, infrared astronomy, space astronomy, and so on. In choosing the chairman of the radio astronomy panel,

the Greenstein committee wound up selecting David Heeschen, director of NRAO, which had proposed the VLA. At the time some committee members raised the question[29] of bias--that putting Heeschen in charge made it inevitable that the VLA would achieve top priority from the panel. Greenstein argued in favor of Heeschen, pointing out[29] that he was a member of the National Academy of Sciences and that he had high integrity. Furthermore, he argued, all first-rate radio astronomers would be biased in favor of a particular instrument.

(The radio-astronomy panel members were: David S. Heeschen, NRAO, chairman; Geoffrey Burbidge, University of California, San Diego; Bernard F. Burke, MIT; Marshall H. Cohen, Cal Tech; Frank D. Drake, Cornell University; George B. Field, University of California, Berkeley; Gordon H. Pettengill, MIT; James W. Warwick, University of Colorado, and Gart Westerhout, University of Maryland.)

By December 1969 the radio-astronomy panel had prepared a preliminary report.[30] It endorsed the recommendations of the second Dicke panel, that is, for the Arecibo resurfacing, the 440-foot radome-enclosed telescope, the OVA and the VLA. It also recommended that a millimeter-wave telescope be included in the total radio-astronomy program, advocating that starts on all these projects be made in FY 1971. There was apparently some hope[31] that at least the VLA would appear in the FY 1971 budget, aided and abetted by a COSPUP endorsement. William Wright had written to the NSF director in October, saying he believed the Greenstein committee would endorse the Dicke panel recommendations at its next meeting, 5 December. He went on to say that although the

meeting was late, "it should be adequate, provided that both we and COSPUP are prepared to move quickly after that date." But as we have already seen, the Bureau of the Budget did not include the VLA (or any other major radio astronomy facility) in the FY 1971 budget.

Greenstein Committee Report in Spring 1970

The Committee had committed itself to issuing a preliminary report in spring 1970 to aid NASA in preparing its budget. COSPUP had told[32] the Committee to limit its funding requests to $6 million each year for FY 1972 and 1973. After taking into consideration the deliberations of the panels on infrared, optical and radio astronomy, the Committee reaffirmed[33] its support of the Dicke panel recommendations but noted that none were within the budgetary limitations (except for the Arecibo project, which had already been included in NSF's FY 1971 program). Accordingly the Committee recommended that NRAO complete the design of a 65-meter-diameter radio telescope for use as a millimeter-wave dish. In addition it recommended that the remainder of the funds be used to pick up operating costs of major projects dropped by the Department of Defense.

In preparing his transmittal letter for the report, which was to be sent to Academy president, Philip Handler, Harvey Brooks sent a draft to Greenstein, in which he said[32] that further delays on building the big dish programs would mean that it might no longer be worthwhile to build them, if the German, Dutch and Swedish projects for dishes without radomes were successful. This comment drew complaints[34,35] from Committee and panel members; for example, Bernard Burke (a radio-astronomy panel member and participant in NEROC), regarded the remark as giving the "kiss of death" to the big dish. So Brooks

softened[34] the comment in the final version of his letter to Handler.

Despite the eagerness of NSF and NASA to receive the preliminary report, little apparently came of it.[36] However, NSF says that it did take the report into account in preparing its FY 1972 budget estimates.

Writing[36] to the members of the National Science Board in November 1970, director McElroy said, "In spite of the present fiscal stringencies, I am convinced that the US must start on the VLA and initiate engineering studies for the High Precision Antenna (presumably the millimeter-wave dish) if it is to maintain a strong position in astronomy....The US is in the unfortunate position of not having started any new radio-astronomy facilities in about ten years."

Although NSF was clearly committed to the VLA, it chose not to include it in its FY 1972 budget request, even though it had done so the preceding year. It is not clear why. Perhaps McElroy thought that he would hurt[26] the rest of the budget if he asked for the VLA.

Radio-Astronomy Panel

Meanwhile the radio-astronomy panelists were meeting from the autumn of 1969 to the latter part of 1970. Brooks, speaking for COSPUP, urged the panel members to establish priorities. One point of view[37] among the panelists was that two urgent projects should be selected without priority ordering. A second point of view was that there should be no ordering of priority. A third point of view, held by Burbidge, was that a single instrument should be given highest priority. Heeschen had[38] mixed feelings. At times during the discussion, it appeared that the VLA and the millimeter-wave telescope would both be given top priority; this embarassed Heeschen,

according to Burke, because both instruments were designed by NRAO. Burke and Cohen were opposed[37] to having two high-priority items because Burke was protecting NEROC and Cohen was protecting OVA. Eventually Burke came to believe that a single instrument had to be selected, and he had felt from the beginning of the deliberations that if it were to be one item, it would have to be the VLA. He feels that NSF had somehow conveyed the message to them that the VLA would be built first. Cohen then joined with Burke in advocating one item. A vote was taken, and the VLA won.[38] Greenstein was notified informally that the radio astronomers had opted for the VLA.

A few weeks later, most of the radio-astronomy panel met[37,39] with Carl York, staff member for physical science of the White House Office of Science and Technology. They told OST of their desire to build the VLA, and then they prepared an informal report to that effect for Edward David, the President's Science Adviser. Later the panel members met with David himself.[38] Burke recalls[37] David saying, "It looks like you're going to get your project."

In its final report,[40] the Radio Astronomy Panel recommended three instruments, in order of priority: a large aperture-synthesis array, a fully steerable parabola for centimeter-wavelength observations, and a large telescope for millimeter-wavelength observations.

Greenstein Committee--Later Period

All through its deliberations the Greenstein Committee was being urged by Brooks to make priority judgements.[41] Writing to Greenstein in April 1970, for example, Brooks said that the Bureau of the Budget could not make necessary selections between projects without scientific guidance. He pointed out that Batavia was funded in a tight budgetary year because the entire high-energy

physics community was united behind it. Similar unanimity in the astronomical community might do the same for a single major astronomical facility in the next two years, but Brooks doubted it.

Throughout the Committee's deliberations, a representative from NSF, Robert Fleischer, head of the astronomy section, attended.

By October 1970, the Greenstein Committee had met[42] with representatives of NASA, NSF, the Bureau of the Budget and representatives of Congressional staffs interested in astronomy and space science. Panel reports had been completed and were to be discussed the following month by the Committee. It was not yet clear, in October, whether the Committee would provide a unique priority list or whether they would choose to provide lists of desired programs at various funding levels.

Within the Committee, there were debates[29] for several months over the proposals for infrared astronomy, optical astronomy and solar astronomy. Other big contenders were[37] the Large Space Telescope, another 200-inch optical telescope, the VLA, and the High Energy Astronomical Observatory for x-ray observations. Burke recalls[37] pointing out to the Committee that the VLA would be unique in the world, and that the time was ripe for another major radio telescope. The optical instrument would not be unique. And x-ray astronomy already had a lot to do with small satellites. He feels that the only other serious contender was an instrument for infrared astronomy, but the development of techniques in that field was more primitive, and the infrared astronomers did not have a completely worked-out design.

Greenstein points out[43] that for many years he and other astronomers had felt that we were accumulating a deficit--each year we were losing $5 million

that should have been invested in radio astronomy. The deficit had been accumulating for 20 years, Greenstein feels.

Field recalls[29] that the VLA was regarded by the Committee as primarily an instrument for studying cosmology. They debated where the primary thrust in research should be made. The VLA's primary competitor in doing cosmological studies was HEAO. Optical astronomy already had many instruments, some just coming into operation, whereas radio-astronomy facilities had been sorely lacking.

Finally in late 1970 and early 1971, it was decided to take straw votes, with Greenstein alone seeing the results. He says[43] that roughly 80% of the people involved voted for the VLA each time. In a report to COSPUP from the Committee[44] in April 1971, it was described that, in "an exhausting April 1971 session at MIT, two test ballots proved to give remarkable agreement on major recommendations."

Meanwhile in February 1971, OST contacted[39] NSF, telling Wright and Fleischer that Science Adviser David would ask for an initiative in astronomy, which he anticipated would be the VLA.

At the May meeting of the President's Science Advisory Committee[44] the VLA was discussed, with the idea of including it in the FY 1973 budget. Present at the meeting were[39] budget examiners from the Office of Management and Budget and representatives from NASA, NSF and the Defense Department. Throughout the summer the VLA was discussed[44] informally by PSAC.

The Committee's final report[45] was written late in the spring of 1971. It recommended four programs with the highest priority. These, in order of importance were:

1. "A very large radio array, designed to attain resolution equivalent to that of a single radio telescope 26 miles in diameter; this should be accompanied by increased support of smaller radio programs and facilities at the universities or other smaller research laboratory."

2. An optical program to vastly increase efficiency of existing telescopes by use of modern electronic auxiliaries. At the same time new large telescopes should be created.

3. There should be a significant increase in support of infrared astronomy.

4. A program for x-ray and gamma-ray astronomy from a series of large orbiting High Energy Astronomical Observatories should be funded, supported by construction of ground-based optical and infrared telescopes.

The following items were also felt to be of high scientific importance, but their funding, although urgent, should not create a delay in funding the above items:

5. Construction of a very large millimeter-wavelength antenna.

6. Doubling of support for astrophysical observations from aircraft, balloons and rockets.

7. Continuation of the Orbiting Solar Observatories through OSO-L, M and N.

8. A sizable increase of support for theoretical investigations.

9. An expanded program of optical space astronomy, leading to the launch of a large space telescope at the beginning of the next decade.

10. Construction of a large, steerable radio telescope designed to operate efficiently at wavelengths of 1 cm and longer.

11. Construction of several modern astrometric instruments.

In discussing the VLA, the report points out that many astronomical problems require a radio resolving power that approaches that of ground-based optical telescopes--about 1 sec of arc. NRAO had carried out extensive and detailed studies of aperture-synthesis systems to achieve this goal. Its final design, the report says, can achieve high-quality radio pictures of the required resolution at a rate of about two pictures of new regions per day. The design calls for 27 antennas of 85-foot aperture, deployed in a carefully calculated pattern over an area 26 miles in diameter. The rotation of the earth over periods of hours causes the geometric separation of the antennas (as seen from the sky) to be changed so as to produce the required antenna orientations and separations. A large, central computer system controls the antennas and processes the information from them. The VLA will produce the equivalent of a radio "eye" 20 miles in diameter at a cost of $62 million and five years in construction time.

At about the same time as the final Greenstein Committee deliberations were under way, Bernard Burke, formerly a proponent of the NEROC design, contacted[27] Edward Lilley, who was head of the CAMROC and NEROC project office, asking that the Smithsonian Institution withdraw its proposal to build the NEROC-designed dish. The following month, in May 1971, a letter was sent by the Smithsonian Institution to the participants in the 1968 Smithsonian-sponsored meeting, announcing that SAO and SI were suspending further action on the large telescope.

Greenstein's Point of View

At the June sessions of the Greenstein Committee, the chairman himself felt impelled to resign. "I said that I was seeing the death of everything I held dear," he told[43] us. Writing to Brooks the following month, Greenstein said,[46] "You know that I wished to resign as Chairman and even from membership in the Survey. The major recommendations so clearly required management by NASA Centers, or by National Observatories and therefore by the NSF; the report was personally antithetical to my style of research and management. I have, by fortunate chance, always worked in prosperous endowed institutions. The style of these institutions has been excellent; some questions you raised concerning judgement for 'peer group' have been answered successfully only in these private institutions. I do not know how that style can be extended in future nationally-funded and managed centers, even when consortia of universities are nominally in charge. I was persuaded that my attempt to withdraw would seriously damage the cause of astronomy."

Once he had made up his mind not to resign, Greenstein fully supported the recommendations of the Committee. Looking back,[43] he feels that the VLA was a wise choice, particularly since further improvements to the design have made the VLA more flexible. However, he regrets that the other half of the Committee's first recommendation was not followed--universities are suffering. "If death is suffering, then we are suffering." Since the Mansfield amendment cut back Defense Department support of astronomy, NSF has not picked up all projects previously support. The result has been a 20-30% decrease in expenditure for astronomy, Greenstein says.

OMB and Congress Act

What finally put the VLA over? William Wright of NSF feels[47] that it was a question of accumulated momentum. There was the assurance by the Dicke panel that the VLA was a sound device and then the assurance by the Greenstein Committee that it was an astronomically desirable instrument. In October 1971 NSF requested $3 million for initial steps to build the VLA in FY 1973.

A crossout hearing was held[48] at the Office of Management and Budget that same month; through maneuvers[39] of OST, the choice was to be made between ground-based astronomy (the VLA) and space astronomy (the High Energy Astronomical Observatory[48]). York, who worked on physical science for OST and Russell Drew, who worked on space science for OST, had agreed to play for the middle ground: Drew would not shoot down the VLA and York would not shoot down HEAO. In hearings before Caspar Weinberger, OMB director, and the assistant directors (Donald Rice served as assistant director for science), Hugh Loweth of OMB argued the various sets of alternatives. The VLA would cost $60-70 million, whereas HEAO would cost $450 million. Alternative scenarios were considered:[39] The VLA alone could be built, or HEAO alone, or parts of both. It was decided, Loweth recalls,[48] to fund the VLA piece by piece, year by year. And HEAO was to go ahead on a scaled-down basis.

The following January the President's budget carried a line item to initiate construction of the VLA. And in August 1972, Congress appropriated the funds to start building the VLA.

Conclusion

There is no single, obvious point at which it became clear the VLA would be built--no single decision was made that put it over the top. Rather, it was the influence of many that finally made the difference--the NRAO group that persisted in design studies, the NSF staff that kept in close contact

with the rival telescope designers, the Whitford Committee, the Dicke panels, the radio-astronomy panel of the Greenstein Committee, the Greenstein Committee itself, the National Academy of Sciences COSPUP, and in the latter stages, the Office of Science and Technology and the President's Science Advisory Committee. In the end, the decision came about because a consensus was finally reached among many of the country's most influential astronomers; this convinced OST, PSAC and OMB that the VLA was wanted and needed.

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References

1. Interview with George Swenson, 19 March 1975.

2. "Ground-Based Astronomy: a Ten-Year Program," National Academy of Sciences-National Research Council, 1964.

3. NSF Memo to members of National Science Board, 2 March 1967, by E.H. Hurlburt, NSF program director for radio astronomy.

4. Interview with David Heeschen, 19 May 1975.

5. Interview with Alan Moffett, 21 May 1975.

6. Interview with Edward Lilley, 2 May 1975.

7. NEROC Proposal for a Radio-Radar Astronomy Telescope, July 1967.

8. "A Large Radio-Radar Telescope: Proposal for a Research Facility," 30 June 1970, Northeast Radio Observatory Corporation, 4 vols.

9. Letter from Bengt Stromgren to Harvey Brooks, 30 January 1967.

10. Letter from Harvey Brooks to David Heeschen, E.M. Purcell, Nicholas Mayall, A.E. Whitford, Jesse Greenstein, Lyman Spitzer, Leo Goldberg, W.W. Morgan and Gart Westerhout, 6 April 1967.

11. Those who attended were Nicholas Mayall, A.E. Whitford, Jesse Greenstein, David Heeschen, Leo Goldberg, Frank Edmondson, Lyman Spitzer and Edward Purcell, according to a letter from Harvey Brooks to Lewis Branscomb, 1 June 1967.

12. Memo from Gerald F.W. Mulders, head, NSF astronomy section to Randal M. Robertson, associate director (research), 14 April 1967.

13. "Report of the Ad-Hoc Advisory Panel for Large Radio Astronomy Facilities," National Science Foundation, 14 August 1967.

14. Interview with Robert H. Dicke, 20 May 1975.
15. This comparison was carried out and led to a NEROC report, "Comparison of Large Spherical and Parabolic Radio Telescopes," March 1968.
16. Interview with Harvey Brooks, 7 May 1975.
17. Letter from Edwin L. Goldwasser to Harvey Brooks, 13 March 1969.
18. Letter from John D. Young, director, Economics, Science and Technology Division, Bureau of the Budget, to James Webb, administrator, NASA and Leland Haworth, director, NSF, 30 April 1968; memorandum attached called "Prospectus for Study of Priorities in Astronomy."
19. Letters from Harvey Brooks to Lewis Branscomb, Jesse Greenstein and Leo Goldberg, 2 May 1968.
20. Draft of letter to COSPUP, sent by Sidney Reed Jr to Harvey Brooks, 21 November 1968.
21. Letter from Leland Haworth to Harvey Brooks, 22 January 1969.
22. Letter from Geoffrey Keller to 10 persons, 27 February 1969.
23. Memo to Harvey Brooks, presumably from a secretary, 22 May 1969, reporting conversation with Robert Green of COSPUP, who said that Sidney Reed wanted the interim report by April 1970; Letter from Leland Haworth to Harvey Brooks, 26 May 1969.
24. Letter from John S. Coleman, executive officer, NAS, to Leland Haworth, 23 May 1969.
25. "Report of the Second Meeting of the Ad Hoc Advisory Panel for Large Radio Astronomy Facilities," National Science Foundation, 15 August 1969.
26. Interview with William Wright, 12 May 1975.
27. Interview with William Wright, 21 May 1975.

28. "Summary of a meeting to consider a large filled-aperture radio-radar telescope," J.W. Findlay, 1 December 1968.

29. Interview with George Field, 30 April 1975.

30. Letter from Jesse Greenstein to Harvey Brooks and Philip Handler, 6 December 1969. Attached is report from panel, dated 1 December 1969.

31. Memo from William E. Wright to Director, NSF, 13 October 1969.

32. Letter from Harvey Brooks to Jesse Greenstein, 12 May 1970.

33. Report to COSPUP from Astronomy Survey Committee, 26 April 1970.

34. Letter from Harvey Brooks to E.M. Purcell, 3 June 1970.

35. Letter from Jesse Greenstein to Harvey Brooks, 26 May 1970.

36. Memo from William McElroy to members of the National Science Board, 19 November 1970.

37. Interview with Bernard Burke, 12 May 1975.

38. Interview with David Heeschen, 19 May 1975.

39. Interview with Carl York, 16 May 1975.

40. "Astronomy and Astrophysics for the 1970's, Volume 2, Reports of the Panels," chapter 1, National Academy of Sciences, Washington, DC, 1973.

41. Letter from Harvey Brooks to Jesse Greenstein, 10 April 1970.

42. Letter from Jesse Greenstein to Hugh Odishaw, 16 October 1970.

43. Interview with Jesse Greenstein, 21 May 1975.

44. Draft report to COSPUP, presumably from Greenstein, 25 April 1971.

45. "Astronomy and Astrophysics for the 1970's, Volume 1, Report of the Astronomy Survey Committee," National Academy of Sciences, Washington, DC, 1972.

46. Letter from Jesse Greenstein to Harvey Brooks, 23 July 1971.

47. Interview with William Wright, 6 May 1975.

48. Interview with Hugh Loweth, 20 May 1975.