Making a meal of the big dish: the construction of the Jodrell Bank Mark 1 radio telescope as a stable edifice, 1946–57

Jon Agar

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Making a meal of the big dish: the construction of the Jodrell Bank Mark 1 radio telescope as a stable edifice, 1946–57†

JON AGAR*

> This ... is the story of the planning and construction of the Giant Radio Telescope at Jodrell Bank, Cheshire. What is a Radio Telescope? It is no less than man's newest instrument for probing the mysteries of the universe by the reception and analysis of radio waves coming from outer space ... Observations made with radio telescopes have opened up an entirely new field of astronomical research, in which British scientists have taken the lead. With this great new instrument at their disposal they will be still better equipped to maintain that lead, and to be pioneers in a new voyage of discovery for mankind as a whole.
>
> Script for *The Inquisitive Giant*, 1954.[1]

> this is likely to be a very troublesome child. It is becoming increasingly and unpredictably expensive ... Nor does there seem to be great confidence that [it] will be a success.
>
> Sir Keith Murray, 1955.
> Chairman of the University Grants Committee.[2]

From a distance the Mark 1 radio telescope at Jodrell Bank is an edifying sight. It is a steel structure of over 1000 tons, holding aloft a fully steerable dish of wire mesh which focuses incoming radio waves from astronomical objects. It is set in gently rolling Cheshire countryside. Its striking appearance can easily be recruited as a powerful symbol of progress and of science as the pursuit of pioneering spirits.

If historical observers move a little closer, they notice that the serene and solitary icon of the telescope is a carefully constructed image. The telescope is in fact unstable. Its superficial stillness hides a ferment of activity. To use physical metaphors, it is in a 'dynamical equilibrium' of potentially damaging and destabilizing historical 'forces'. There were several forces in the contextual equilibrium. 'Funding' was one such force: for the building of the telescope nearly ceased several times and was always uncertain. Furthermore, its backers had conflicting agendas for postwar science. The telescope exceeded its budget, and in doing so was nearly enrolled by bodies who wished to see no scientific research (beyond teaching laboratories) carried out within universities. As radio astronomy grew from wartime radio and radar work there was a 'military' force: the telescope was used as a satellite tracker and early warning system. Such connections were

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* History of Science Unit, Physics Laboratory, University of Kent at Canterbury, Kent CT2 7NR.

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1 Anvil Films Ltd, 'The giant radio telescope', script for *The Inquisitive Giant*, film treatment for the Central Office of Information, Beaconsfield, December 1954.

2 Public Record Office (PRO), UGC 7 152, minute of meeting, 31 January 1955.

useful: in return the astronomers could cite its importance for national security as an argument for continued support. There were the 'labour' and 'contract' forces: labourers took strike action and firms raised their costs, both threatening the stability and success of the telescope. Since the scale of the telescope was impressive, there was the 'media' force. To this list can be added the forces of academic politics, regional planning, peer review and radio frequency allocation.[3]

For the astronomers to speak authoritatively, their equipment had to be seen as *stable* and *successful*. However, they had only partial control over the forces determining the telescope's perceived status. Those forces they did not control were liable to be taken up by other groups with possibly conflicting concerns. Constant *activity* was therefore needed to secure the telescope's status. This activity included the invention of a discourse of research programmes within which the telescope appeared natural and necessary, mobilizing arguments and imagery on many fronts including the new televisual media, and striking alliances where possible with bodies with shared concerns.[4] I distinguish the telescope's 'status', meaning a group's reading as to whether the instrument was a success or a failure, from the telescope's 'significance' which expresses the meaning or purpose attributed to it.

In this paper I will discuss two 'forces'. The story of the funding of the telescope locates the telescope in a context of government departments and educational movements. Each could interpret the telescope differently, causing the telescope's significance to become unstable. The astronomers' reaction to this fragmentation of the telescope's meaning was to paper over it or, where necessary, to make use of it. In the account of the second force, I discuss how the astronomers were intensely concerned with 'interference'. Interference was 'noisy' and 'dirty': an 'impurity'. Its absence was held as a criterion for good astronomical work.[5] Interference was an artefact of an essential ambiguity in the

3 The discipline of radio astronomy has attracted above average attention from the science studies community, for good reason: it is recent and therefore open to sociological inquiry, it is an example of the supposedly novel genre of 'big science' with its almost inevitable mix of governmental, military and institutional components, and it is contained, both in time and (conveniently for British researchers) space. During the 1950s, sizable groups existed only at Cambridge, Manchester and Australia. It was not until the 1960s that the huge resources of the USA were turned fully onto the subject. Sociological technique was applied with success in D. O. Edge and M. Mulkay, *Astronomy Transformed: The Emergence of Radio Astronomy in Britain*, New York, 1976, and continued in S. Woolgar, 'The Emergence and Growth of Research Areas in Science with Special Reference to Research on Pulsars', unpublished Ph.D. thesis, Cambridge University, 1979. The subject is used as a case study of science policy in B. R. Martin and J. Irvine, 'Assessing basic research: some partial indicators of scientific progress in radio astronomy', *Research Policy* (1983), **12**, 61–90, and J. Irvine, B. R. Martin, J. Abraham and T. Peacock, 'Assessing basic research: reappraisal and update of an evaluation of four radio astronomy observatories', *Research Policy* (1987), **16**, 213–27. The history of British radio astronomy, in particular Jodrell Bank, is found in A. C. B. Lovell, *The Story of Jodrell Bank*, London, 1968, A. C. B. Lovell, *Out of Zenith*, New York, 1973, and contributions to *The Early Years of Radio Astronomy* (ed. W. T. Sullivan), Cambridge, 1984. For radio astronomy in the USA, see A. A. Needell, 'Berkner, Lloyd, Tuve, Merle and the federal role in radio astronomy', *Osiris* (1987), **3**, 261–88. The important Australian groups are covered in P. Robertson, *Beyond Southern Skies: Radio Astronomy and the Parkes Telescope*, Cambridge, 1992.

4 For the invention of discourses see S. Shapin, 'Pump and circumstance: Robert Boyle's literary technology', *Social Studies of Science* (1984), **14**, 481–520.

5 A similar concern over 'noise' in high energy physics has been noted by Sharon Traweek: S. Traweek, *Beamtimes and Lifetimes*, Cambridge, Mass., 1988, 50. For 'impurities' see M. Douglas, *Purity and Danger: An Analysis of Concepts of Pollution and Taboo*, London, 1966.

representational practices of the astronomers: a 'spike' on a pen-recording could be attributed either to an astronomical object or to a local source.[6] Radio interference came from the local milieux of the telescope. There were inevitable encounters with other radio users: one can talk therefore of a 'social history of interference'. The astronomers entered local disputes with radio hams, operators of the new microwave ovens, the air force, the police, tug-boat owners on the Mersey, the army, and other bodies in the North-West. These conflicts resulted in patterns of radio frequency allocation, which were built into the technology of the telescope. So the social history of interference was played out on the radio spectrum, with the outcome that both the ways of life of local inhabitants and also the research practices of the astronomers were reciprocally transformed.[7] The spectrum negotiations, and their implications for the locality of the telescope, are discussed as an example of a mechanism whereby the contextual relations can be seen integrated, inscribed and grounded into a laboratory's milieu.[8]

The emergence of radio astronomy was a result of three factors: the redundancy of a large quantity of wartime radio and radar equipment, the existence of a workforce experienced in the techniques to use the apparatus (and also with the conclusion of hostilities unemployed), and a host of institutional contacts that turned this small segment of society into a well-connected, high-status group. The group of Manchester University physicists at Jodrell Bank exemplified this development. In 1937, Patrick Blackett, the eminent left-wing scientist, transformed the Department of Physics at Manchester University, bringing in a wholly new staff and a new research direction: cosmic rays. In 1939, the staff dispersed: Blackett into naval operational research, his protégé Bernard Lovell into radio direction finding (RDF later radar) at the Telecommunications Research Establishment (TRE). The physicists returned to Manchester in 1945 and turned the ex-army radar sets (obtained through TRE contacts) to the sky to search for cosmic ray showers. However, what they found were the echoes of meteor trails. The group under

6 The parallels with Mary Douglas's work on pollution are clear: it is because the interference is seen as a threat to the astronomers' ordering of their data that it is labelled as polluting.

7 For 'form of life' applied to complex scientific organizations, see A. Pickering, 'Big science as a form of life', in *The Restructuring of the Physical Sciences in Europe and the United States, 1945–1960* (ed. M. De Maria and M. Grilli), 1988, 42–54. However, Pickering does not use 'form of life' in Wittgenstein's usage, his 'form of life' has more similarities to Bourdieu's 'habitus'. Pickering's 'Pragmatism in particle physics', *The Development of the Laboratory* (ed. F. A. J. L. James), London, 1989, 174–83 is also relevant.

8 My essay has close parallels with work foregrounding spatial aspects of laboratories in the history of science, particularly S. Forgan, 'Context, image and function: a preliminary enquiry into the architecture of scientific societies', *BJHS* (1986), **19**, 89–113; M. Williams, 'Astronomical observations as practical space: the case of Pulkowa', in F. A. J. L. James, op. cit. (7), 118–36; B. Latour, 'Give me a laboratory and I will raise the world' in *Science Observed* (ed. K. Knorr-Cetina and M. Mulkay), Beverly Hills, 1983, 141–70; R. Kargon, S. Leslie and E. Shoenberger, 'Far beyond big science: science regions and the organization of research and development', in *Big Science: The Growth of Large-Scale Research* (ed. P. Galison and B. Hevly), 1992, 334–54; S. Shapin, 'The house of experiment in seventeenth century England', *Isis* (1988), **79**, 373–404; O. Hannaway 'Laboratory design and the aim of science: Andreas Libavius versus Tycho Brahe', *Isis* (1986), **77**, 585–610. Also, on a geographical tack, T. Hagerstrand, *Innovation Diffusion as a Spatial Process*, 1967, D. Massey and D. Wield, 'Science parks: a concept in science, society and "space" (a realist tale)', *Environment and Planning D: Society and Space* (1992), **10**, 411–22; the contributions to D. Gregory and J. Urry (eds.), *Social Relations and Spatial Structures*, London, 1985, and particularly R. Shields, *Places on the Margin: Alternative Geographies of Modernity*, London, 1991.

Lovell expanded around a programme of radar investigations of meteor showers, joined by other wartime co-workers on radar. The radio astronomy group cheaply improvized a telescope consisting of a bowl of wire fixed to the ground. It was in this context that plans for a large, steerable telescope were made.

1 HOW THE FUNDING OF JODRELL BANK FRAGMENTED IT

Several factors combined to make the financial status of the telescope uncertain. These included increasing costs of raw materials, successive design changes, lack of closure as to the institutional form of the telescope, and a protracted debate over university finances originating in the Public Accounts Committee and the Treasury.

The structure, more akin to a bridge than an optical telescope, was made out of riveted and bolted steel. Increases in the cost of steel and labour necessarily meant rises in the cost of the telescope. In order to track objects across the sky it required unusual engineering specifications, including an immensely powerful but steady, controllable and *slow*, drive. Some components could be cheaply improvized (for example the elevation drive consisted of the rack and pinions from two scrapped battleships), whereas others had to be designed and built from scratch and were volatile and expensive (for instance the azimuth drive mechanism).[9]

The design changes revealed the telescope's malleability in a very real sense. They reflected efforts to mobilize support from new constituencies, the incorporation of changing commitments, and the outcome of spectrum negotiations. However, once inscribed into the designs and built into the technology of the telescope, they became difficult to change: the telescope was *malleable* but not *fluid*.[10]

The securing of the initial capital grant of £279,140 from the Department of Scientific and Industrial Research (DSIR), and accompanying recurrent grants from the DSIR and the University Grants Committee (UGC), required effective mobilizations of the diverse resources available to the astronomers. The reputation and contacts of Blackett obtained the backing of the astronomical establishment: the Royal Astronomical Society (RAS) formed a one-off sub-committee under Sir Edward Appleton specifically to endorse 'construction of the proposed paraboloid' by which 'the prestige of Science in Britain would be considerably enhanced'.[11] Lovell carefully wrote memoranda and press releases for the RAS, the Royal Society and the DSIR, locating the telescope *centrally* in national arguments (Britain could regain the lead in astronomy 'unfortunately lost to America' if radio astronomy was backed since it was 'independent of climatic conditions')[12] and wide research programmes ('investigating galactic and solar radio emission, meteoric phenomena, aurorae, lunar and planetary echoes').[13]

9 A. C. B. Lovell, *The Story of Jodrell Bank*, London, 1968, 72.

10 On possible 'conservative' implications for research strategy see Edge and Mulkay, op. cit. (3), 332.

11 PRO DSIR 2 497. Scientific Grants Committee, meeting 22 June 1950.

12 PRO DSIR 2 497. Lovell, 'A Proposal for a 250 ft Aperture Steerable Paraboloid for Use in Radio Astronomy', January 1950. Jodrell Bank Archive (hereafter JBA) 'Frequencies 1952–1963', CS7/29/1, Lovell, third draft of Royal Society memo. JBA CS1/5/8. Untitled, contains press releases.

13 PRO DSIR 2 501.

Within a year of the initial grant more money was needed. The detection in 1951 of the neutral hydrogen emission line by astronomers at Harvard, Leiden and Australia on the 21 cm wavelength allowed radio astronomers to compete with optical astronomers in galactic observations. But to adapt the Jodrell Bank telescope to receive the radiation required its reflective mesh to be finer: weighing and costing more.[14] The hydrogen frequency was *built into* the telescope, committing the astronomers to seek the exclusive allocation of emission lines, and facilitating research programmes incorporating them. Changes in the telescope's structure were reciprocated by changes in the research practices of the astronomers.

Lovell sought extra money. He attempted to marry the concerns of the radio astronomers with those of the Air Ministry.[15] Encouraged by the response of Dr Robert Cockburn, its Scientific Advisor, Lovell and the Consulting Engineer, H. C. Husband, discussed modifying the telescope to receive radar frequencies, allowing its use as an early warning system.[16] However, Air Ministry funding fell through in April 1954, and the significance of the telescope reverted to being that of an astronomical instrument, but not before the design change had been incorporated by Husband into the telescope's structure, at an extra cost of £46,000. Although the status and significance of the telescope were usefully malleable, allowing different versions to be mobilized for different audiences, the steel structure could prove expensively firmer. But the telescope was now adapted to receive even higher frequencies, and its defence interpretation could still be used by Lovell in arguments to persuade funding bodies (particularly in protecting the telescope's complex but *fully steerable* mount in negotiations with the DSIR).

Rhetoric of defence was in part persuasive to another source of funding: the Nuffield Foundation. Blackett's postwar laboratory had been partially built up on Nuffield money, and in the summer of 1951 (during the height of the Korean War), Sir Henry Tizard, secretary to both civil and military government scientific advisory committees and ex-trustee of the Foundation visited Lovell at Jodrell Bank.[17] Tizard knew that the DSIR was at this stage sympathetic to the telescope project, but that the escalating cost worried the Treasury, and he wrote a letter to the trustees of the Nuffield Foundation recommending that the Foundation should contribute if necessary. That winter, the Treasury informed the DSIR that any extra money for the telescope must come out of the DSIR's already allocated funds. The DSIR approached the Nuffield Foundation directly, and the trustees were apparently swayed by Tizard's advocacy. However, the reaction of Lord Nuffield himself[18] was far more problematic: as a believer in private enterprise he opposed the use of Foundation money to support what he saw as a speculative government project. According to the Nuffield Foundation's 'biographer' the arguments that persuaded Nuffield were first

14 PRO DSIR 2 512. The mount needed to be stronger to support the heavier dish. The weight of the structure increased from 900 to 1177 tons, the total cost to £445,046.

15 Lovell, op. cit. (9), 84.

16 The telescope's sensitivity was not surpassed until 1963, when the Fylingdales network became operational. See D. Campbell, *The Unsinkable Aircraft Carrier*, London, 1986, 84–6.

17 R. W. Clark, *A Biography of the Nuffield Foundation*, London, 1972, 102–3, forms the base of my account of the Nuffield negotiations. The Nuffield Foundation papers relating to Jodrell Bank were destroyed in 1990.

18 Lord Nuffield was originally William Morris; money for the telescope was available from the Foundation (which was set up in 1943) owing to the rise in Morris Motors stock with the postwar automobile boom.

that radar (now a device of high status and proven military value) was once 'esoteric', and secondly that 'the radio telescope might one day be directed if need be on the steppes of Russia'.[19]

The lack of closure over the institutional form of the telescope was inevitably worrying to the Manchester astronomers. The cause was the scale of the enterprise which inevitably drew comparisons with nuclear and particle physics machines:

> The capital sum is considerable, and puts the equipment into the same class... as some of the new cyclotrons... there may be much to be said in favour of having it at a central institution where it is available for all who wish to use it rather than at a particular university.[20]

A similar threat came from frequency allocation bodies, which were dominated by powerful armed service interests. These 'enquired whether the astronomers, knowing the risks of radio interference around Cambridge and Manchester, had... considered the practicability of selecting a more remote location' such as Scotland.[21] In response, Lovell no longer portrayed radio astronomy as independent of climate:

> the Cheshire plain in which Jodrell Bank is situated is particularly suitable for radio astronomy, not only as regards topography, but also... weather conditions.

However, the most impressive argument that could be used was the physical presence of the half-finished telescope. Its bearing can be seen in the way the astronomers won the support of the UGC. When, in 1955, the DSIR attempted to shift responsibility for the telescope to the UGC ('just as they expected us to take over nuclear physics research'),[22] the UGC began to question what 'is likely to be a very troublesome child': was 'this Jodrell Bank enterprise really a desirable, valuable and necessary adjunct to Manchester University?'. The UGC requested a 'private discussion' with the University,[23] but the Vice-Chancellor replied that 'it would be best if you could visit Jodrell Bank'.[24] The meeting was held under the massive half-completed structure of the telescope. The site was a powerful (visual and tangible) argument for continued funding. Murray, a UGC official 'was immensely impressed... [by the] zest and enthusiasm... and support of the university'.[25] The Committee was persuaded of the possibility of making 'an emergency addition to the Manchester block grant' from 'now almost infinitesimal reserves'.[26]

The bodies that could be brought to the telescope under the astronomers' guidance were more easily convinced of its value. However, the astronomers' presentations could not determine the response of groups further away. Where these groups were powerful, this freedom to interpret the telescope's status was a source of instability. The remit of the Public Accounts Committee (PAC), a body independent of the government, was to ensure

19 Clark, op. cit. (17), 105.

20 PRO UGC 7 152. Letter Lockspeiser (DSIR) to Trueman (UGC), 4 June 1951. Lockspeiser compared it to Brookhaven in the USA.

21 JBA CS7/29/1. Minutes meeting at GPO, 20 October 1953.

22 PRO UGC 7 152. Minute of internal meeting, 31 January 1955.

23 PRO UGC 7 152. Letter Hale to Stopford, 4 February 1955.

24 PRO UGC 7 152. Letter Stopford to Hale, 10 February 1955.

25 PRO UGC 7 152. Minute sheet, on which the chairman of the UGC, Sir Edward Hale, has pencilled 'So was I – E.H.'.

26 PRO UGC 7 152. Letter Murray to Blount, 29 March 1955.

that government departments were not wasteful with public funds. But it also pursued an agenda of its own making: through the 1950s it was concerned that there was inadequate control of finance in universities, and sought the inspection of universities' accounts by the Comptroller and Auditor-General.[27] The telescope, read as an example of a university's lack of financial control, could become enlisted as a powerful weapon in the PAC's armoury.

In 1954, the PAC summoned Sir Ben Lockspeiser, under-secretary of the DSIR, to give evidence to explain the changes in the telescope's design. After detailed questioning, he stated that there would be no further increases unless 'scientific demands... entirely new came up which would compel – literally compel us – to make the review'.[28] However, DSIR actions did not rest there. It utilized its flexibility in interpreting the status of the Jodrell Bank telescope and astronomers by commissioning a film in which the telescope was 'a tribute to the mind and spirit of Man himself'.[29] In particular, 'man in two *complementary* types... the scientist, the seeker, the dreamer of dreams, the thirster after knowledge... and his *essential* partner, the practical engineer' (my italics). The script was a carefully worded defence against a specific PAC criticism: inadequate dialogue between university scientists ('in this case Professor Lovell') and the contracted engineers ('Husband and his son').

Nevertheless, fear of the effects of PAC criticism inevitably led to the questioning of the status of the telescope within the departments that dealt directly with Jodrell Bank:

> We discussed the general question of the placing of large and expensive to run machines... we should have in the future to consider how far it was right to leave the erection and maintenance of such machines to universities, or how far they might be more directly DSIR commitments.[30]

There were doubts as to how far universities ought to house sites for research science (beyond teaching laboratories), and discussion as to how far government establishments such as Harwell were better placed financially and institutionally to carry out 'big science'.[31] The telescope's instability therefore threatened to topple over into wider issues.

In March 1957, the Comptroller and Auditor-General, Sir Frank Tribe, published a report on the escalating cost of the telescope. Its contents were widely reported (unfavourably) by the newspapers.[32] It was at this point that the telescope's troubles were made public, and the PAC's actions became open: it called Sir H. Melville, successor to Lockspeiser at the DSIR, before the Committee. Melville's answers implied that it was Husband who was at fault:

> [Q.] If this was a University project, who had changed the design without obtaining approval of the University, the engineer or Prof Lovell?

27 Asa Briggs, 'Development in higher education in the United Kingdom' in *Higher Education: Demand and Response* (ed. W. R. Niblett), London, 1969, 95–116.

28 Parl. Papers HCP (1953/54) 67-I, para. 2512.

29 Script for *The Inquisitive Giant*, op. cit. (1).

30 PRO UGC 7 152. Letter Blount (DSIR) to Murray (UGC), 25 February 1954.

31 For the birth of Harwell (concurrent with that of Jodrell Bank), see M. Gowing, *Independence and Deterrence: Britain and Atomic Energy 1945–52*, 2 vols., London, 1974. Furthermore the period contained the tangled negotiations towards European organizations of science (ELDO, ESRO, EMBO and CERN), for CERN see A. Hermann, J. Krige, U. Mersits and D. Pestre, *The History of Cern*, 2 vols., New York, 1990 and 1992.

32 Lovell, op. cit. (9), 182.

[A.] Oh, no, quite clearly the engineering consultant changed the design without concurrence of the University.[33]

However, Melville did not seem well briefed. He got the size of the telescope wrong, and believed that Lovell lived by the telescope 'in apartments',[34] and that he was 'unaware of any [design] changes until the steelwork arrived'. The PAC then linked the case of the telescope to their concerns over university finance:

(Chair) ... would you agree that the expenditure has not been properly controlled and administered by the University?
(Melville) I think we would be bound to say that in this instance Manchester University's financial administration is not without criticism.
(Chair) Of course, this does not give us very much satisfaction when we think of the Treasury Minute of January... which said that non-recurrent grants to universities are properly controlled and properly administered.[35]

The PAC report was published on 13 August 1957. Strong criticism from the press was pre-empted and dampened by a press conference organized by the Public Relations Officer of the DSIR, Col. W. Hingston, earlier in the summer, and held at Jodrell Bank. The DSIR could by this stage call upon the spectacle of the now moving and steerable telescope to impressive effect.

The UGC interpreted the PAC actions in terms of its *own* anxieties, an internal meeting in 1956 being:

perturbed by the possible consequences vis-a-vis the PAC and the Treasury if it was established that the university was to blame for this over-expenditure. Anything that could be done therefore to make it clear... that the blame lay elsewhere seemed to me highly desirable, not only from the point of view of Manchester, *but of the Universities as a whole* [my italics].[36]

The UGC perceived the instability of 'this ailing and costly infant', the root of which lay with the PAC, as a risk to the financial independence of universities. Murray recommended that the Vice-Chancellor of Manchester, Mansfield Cooper, sought further comment from the Vice-Chancellor of Bristol, Philip Morris. Filling in Morris, Murray informed him that he had not told Mansfield Cooper that 'certain people in the Treasury itself, where the issue has been discussed by DSIR, are already citing the Manchester problem as evidence supporting the PAC view'.[37] Morris's main conclusion was that the matter 'should be cleared up as far as possible by rigorous examination and by the clear establishment of actual or constructive faults on the part of any concerned'. A Committee of Inquiry set up previously to consider the telescope had 'taken Counsel's opinion twice and each [had] confirmed that there [had] been a breach of contract by the consultant [Husband]'.[38] After lengthy consideration the University decided not to sue, to the irritation of the Treasury, which opined:

33 Parl. Papers HCP (1956/7) 75-I, para. 1839.
34 Parl. Papers HCP (1956/7) 75-I, para. 1849.
35 Parl. Papers HCP (1956/7) 75-I, paras. 1945–6.
36 PRO UGC 7 152. Minute by Murray, 10 October 1956.
37 PRO UGC 7 152. Letter Murray to Morris, 11 October 1956.
38 PRO UGC 7 152. Minute by Murray, op. cit. (3).

> Manchester University seem to have failed to keep adequate supervision over the consulting engineer and have concealed from DSIR until too late the legal possibility of recovering money from him.[39]

As a result 'an unnecessary burden has been placed on the Exchequer'. The overall pattern as viewed from the Treasury was that 'financial control by DSIR over Manchester University was weak, and control by the University over Professor Lovell perhaps even weaker'.[40] Rhetoric of national and scientific prestige, of the kind wielded with success by Lovell with the DSIR and UGC, failed to impinge on and deflect the more distant Treasury.[41]

The fluctuating status of the telescope was the result of different versions of it being mobilized for different ends. It never became fixed since no group could determine its audience's reaction to a given interpretation. Such instability was unwelcome to the astronomers, the DSIR and the UGC, where it confused and lessened the significance of *their* particular presentation of the telescope, necessitating action to support and stabilize it; but the freedom to redefine the telescope was too useful an asset for the astronomers to ignore. Ironically, the instability was a resource for other groups, particularly the PAC, to use in advancing their own agendas.

The status and significance of the telescope were malleable: for example the interpretation 'defence system' was easily appended to the telescope's usual significance as an 'astronomical instrument'. But the design appeared to be more recalcitrant: astronomers could argue that funds or radio frequency allocations were 'essential because large amounts of apparatus [were] already built'.[42] However, this was a result of the telescope's technological 'momentum': its apparent inexorable growth reflecting its embodiment within social forms and organizations.[43] As the telescope became ingrained within social practices, intriguingly *concrete* and *local* formations appeared, which I discuss next in the context of frequency allocation.

2 HOW FREQUENCY ALLOCATION FOR RADIO ASTRONOMY HELPED GROUND THE TELESCOPE LOCALLY

Aeroplanes, battleships, prominent hills and amateurs' sheds all rapidly became sites for radio technology during the first half of the twentieth century. The reaction of governments was institutional regulation and management: both internationally, through the International Radiotelegraph Union (renamed the International Telecommunications Union in 1932 on merging with the International Telegraph Union), and nationally by the

39 PRO UGC 7 152. Letter Turnbull (Treasury) to Hale, 8 March 1957.

40 PRO T 218 132. Internal memo, Griffiths to Knowles, 15 October 1958.

41 To Lovell's vexation: 'I felt at the time and still feel today that these conditions were made by men whose first concern was the preservation of their own skins, who had no concept of the... consequences of their action, and whose horizon was limited by the walls of their offices.' Lovell, op. cit. (9), 150.

42 JBA CS7/29/1. Letter Ryle to Lovell, 19 July 1953.

43 'Momentum' is used here in the sense defined by T. P. Hughes, *Networks of Power: Electrification in Western Society 1880–1930,* Baltimore, 1982, and deployed by D. MacKenzie, *Inventing Accuracy*, Baltimore, 1991.

'administrations' empowered by the ITU.[44] Within Great Britain the administration was the General Post Office (GPO), then a government department.

However, the political significance of spectrum allocation and its birth in largely military contexts (in Europe), was reflected in the influence wielded by the armed services in the bodies determining spectrum strategy: a Cabinet Frequency Committee (attached to the Cabinet Office) and the Joint Frequency Planning Panel (an interdepartmental sub-committee of the British Joint Communications and Electronics Board).

The GPO regulated spectrum use by a combination of observation and application. It sought information from all services regarding the precise location and power of transmissions, the frequencies required, and the purposes to which they were to be put. It had the power to combat transgressions, resolve disputes and negotiate between services. Such regulatory activities had two implications: the spectrum became spatially reified, and the country was partitioned.

The radio frequency spectrum was spoken of in territorial terms: that is to say actors used spatial metaphors. For instance, radio frequencies came in 'bands', different services had to be 'accommodated' or 'given room' in them, and if there was no room there might have to be a 'clearance' of frequencies. The bands came in 'blocks', which might have 'reservations' or even 'squatters'. In a particularly illuminating example: 'the [armed] Services have very extensive commitments which *occupy* all the space between 235–350 Mc/s' (my italics).[45] The spatialization of the spectrum was a result of the institutional process whereby it was 'divided' and allocated. The use of spatial metaphors was not inevitable. Other alternatives were the 'highway' model, where frequencies were talked of as lines or routes of communication; the 'economic' model, where the spectrum was a 'resource' with 'stock and flow attributes'; and the 'engineers' model where there were 'stations' and 'circuits'. There was inevitably much mixing of metaphors, with the dominant metaphor determined by context. This reification is a *result* of the administration and allocation of the radio spectrum. Furthermore it has to be actively held in place by regulatory vigilance, accompanied by changes in practice by radio users.[46]

The partitioning of the country can be seen in the GPO's efforts to prevent interference between stations. Radio frequencies lower than about 25 Mc/s travelled around the earth's surface, so powerful transmitters could reach anywhere.[47] The radiation did attenuate gradually with distance, so stations using the same frequency were placed at suitable distances from each other. These frequencies were absorbed by the atmosphere and so did not concern astronomers. Frequencies higher than 25 Mc/s were only received from

44 G. A. Codding, *The International Telecommunications Union: An Experiment in International Co-operation*, Leiden, 1952.

45 JBA CS7/29/1. Minutes of meeting 'Frequencies for Radio Astronomy', held on 20 October 1953 at GPO HQ.

46 The commodification of corn provides a parallel tale of the reificatory effects of regulation, see W. Cronon, *Nature's Metropolis: Chicago and the Great West*, London, 1991, 118. For an example of organizational change transforming scientific (here therapeutic) locales, see R. Cooter 'The politics of a spatial innovation: fracture clinics in inter-war Britain', in *Medical Innovation in Historical Perspective* (ed. J. V. Pickstone), London, 1992, 146–64.

47 The Nauen radio station near Berlin was received by U-boats under the Atlantic as early as 1917. For Nauen see D. R. Headrick, *The Invisible Weapon: Telecommunications and International Politics 1851–1945*, Oxford, 1991, 164.

transmitters in 'line-of-sight'. These frequencies were useful to the radio astronomers, who were therefore intensely concerned with radio transmission within their horizons: discs of fifty mile radii around Jodrell Bank and Cambridge. The partitioning was the result of numerous negotiations, mediated by the GPO, between the radio astronomers and other local spectrum residents.[48]

Radio astronomers sought 'quiet skies', in parallel with their optical counterparts' concerns with 'dark skies'.[49] Indeed one cause for the siting of the telescope at Jodrell Bank, twenty miles from Manchester in rural Cheshire, was interference from electrical noise generated by the city's trams.[50] 'Quietness' was not located in the heavens but on the inscription devices of the telescopes. For example, Lovell graphically described one case of 'severe interference' as being so bad that it 'caused the recording mechanism to trip continuously'.[51] The astronomers' authority rested on 'clean' inscriptions: in which the link between astronomical object and representation could be seen to be direct and unproblematic. Local radio transmissions therefore were a threat to the telescope's stability, and provoked the astronomers into constant efforts in their locality to silence them, in order to control the space *within* the observatories' walls.[52]

In the years immediately after the war, the astronomers at Jodrell Bank worked with temporary assemblages of apparatus. They likewise either possessed short-term six-month licences from the GPO or opportunistically worked in gaps in the radio congestion.[53] The construction of the Mark 1 paraboloid required a more planned approach to the frequency spectrum: its design and the particular frequencies used were heavily interdependent: '[without] permanent allocations... it is difficult to plan the construction of equipment for use with the telescope'.[54]

In 1952, a new beacon at Manchester Ringway airport, transmitting on 75 Mc/s, provided the immediate cause for action. It forced the closing down of a Jodrell Bank transmitter and aroused the suspicions of the Ministry of Civil Aviation, prompting Lovell to seek 'formal authority' for the use of radio frequencies. 'I am sure you will appreciate that the question of frequency allocation... is of fundamental importance to the future of

48 Other network technologies have a strong spatial side to them: transport and the utilities, for example. For electrification see D. E. Nye, *Electrifying America: Social Meanings of a New Technology*, London, 1990; B. Luckin, *Questions of Power: Electricity and Environment in Inter-War Britain*, Manchester, 1990; and T. P. Hughes, op. cit. (43).

49 Street lighting in Greenwich was one of the factors in the move of the Royal Observatory to Herstmonceaux. See A. J. Meadows, *Greenwich Observatory*, 3 vols., London, 1975, in ii, 20. My thanks to Mari Williams for this example. Interestingly, the possible vibrations from projected train lines were also worrisome to Airy at Greenwich, for which there is a direct parallel with Jodrell Bank. It is the concern for accurate measurement (shared amongst others by metrology and astronomy) that makes the scientist intensely aware of environment.

50 Lovell, op. cit. (9), 2.

51 JBA CS7/29/1. Letter Lovell to G/C Passmore, 21 April 1956.

52 Another source of the astronomer's spatial concerns was its genealogy. Radar was explicitly concerned with distance, direction and topography. For example Robert Watson-Watt, a key figure in the development of British RDF, comments: 'The Radio Research Board had trained a team of young research workers encouraged to see and explore the wide open spaces between the Morse Key and the loudspeaker.' R. Watson-Watt, 'Radar in war and peace', in *Industrial Research in Britain* (ed. E. N. da C. Andrade), 1st edn, London, 1946, 55–65.

53 JBA CS1/4/6, contains licences.

54 JBA CS7/29/1. Letter Lovell to Sharpe, 22 December 1953.

the subject' wrote Lovell to the DSIR.[55] He provided them with an extensive list of frequencies required, noting: although these 'requirements might seem severe...general clearance is only needed for a comparatively small radius around Jodrell Bank'. Lovell concluded hoping that the DSIR would 'be able to enlist the sympathy of the Post Office authorities'. This the DSIR set about doing, with the result that the GPO organized an exploratory meeting.

Representatives from Jodrell Bank, the Cavendish Laboratory radio astronomy group at Cambridge and the GPO drew up lists and discussed frequencies. Both groups of radio astronomers stressed the importance of the hydrogen emission line to which, as we have seen, they had made technological commitments.[56] The GPO 'undertook to discuss the proposed list...with the [Joint Frequency Planning Panel]' and report back.

The radio astronomers now found that the 'formal' use of radio frequencies was beset with problems. Frequencies requested by them were already used by Ministry of Civil Aviation navigational beacons, taxis, radio dealers, tugs on the Mersey, local police services; and soon to be used by the armed services on 'military exercises' in the Pennines, and 'high power television'.[57] The high hydrogen frequency was available, but little else. The Panel regretted that not much could be protected, 'but this seems inevitable since...these frequencies fall into parts of the spectrum which are particularly valuable for radio services of many kinds', and it asked 'if it was practicable to carry out your observations in more remote locations'. The solution to exile from spectrum space could be exile in physical space!

Again, the threat to stability was countered by the mobilization of the resources available to the astronomers. First Jodrell Bank and Cambridge astronomers coordinated their requests. Secondly, they recruited a more powerful ally: the Royal Society. Lovell's letter to its Secretary, D. C. Martin, was calculated to galvanize the Society, portraying a science in crisis:

> [the GPO's] limited action is however quite insufficient to safeguard any successful future for radio astronomy in Great Britain.[58]

Lovell called for 'a progressive policy' that would 'give priority to the reasonable claims of radio astronomy', and darkly warned of the dangers to a subject that 'now formed an important part of the country's scientific effort, and might well influence the future of radio communications'.

Soon after Lovell had contacted Martin, he received a copy of the letter from the GPO to the DSIR.[59] Here were the decisions of the Joint Frequency Planning Panel again, but presented in a more 'discouraging' way: 'it would be quite impracticable to reserve a frequency that was [even] reasonably free from interference'. The technological implications were made explicit: the astronomers ought to be made aware of 'the situation right away in case they propose to spend more on equipment for a frequency which...will

55 JBA CS7/29/1. Letter Lovell to Vernon, 11 March 1952.

56 JBA CS7/29/1. Minutes of *ad hoc* meeting, 16 May 1952.

57 JBA CS7/29/1. Letter Vernon to Fryer, 22 October 1952.

58 JBA CS7/29/1. Letter Lovell to Martin, 23 April 1953.

59 JBA CS7/29/1. Letter Greenall (DSIR) to Lovell, 14 May 1953, enclosing letter Mead (GPO) to Greenall, 8 May 1953.

be subject to a lot of interference later on'. The expansion of their instrumentation was, of course, precisely what the astronomers intended to do.

Lovell lost no time in forwarding the offending letter to the Royal Society: 'I think this epitomises the point which I was trying to make... The [GPO] are perfectly willing to fit in frequencies for Radio Astronomy after other interests have first attention'.[60] To the DSIR, Lovell expanded the point: 'Unless we are given top priority for the allocation of frequency, Great Britain will have to give up the subject entirely within the next ten years.'[61]

Lovell and Jack Ratcliffe, a colleague of Martin Ryle's at the Cavendish Laboratory, wrote the memorandum for the Royal Society to take to the Lord President (the member of the Cabinet responsible for non-nuclear science) and the GPO. Out from the early drafts went details of the cost of the Jodrell Bank programme and a favourable quote from an RAS resolution ('In drafting this memo, I have had to bear in mind... that it was to be a short document which might be read by the Post Master General').[62] It used familiar national and climatic arguments and called for the Royal Society to persuade the GPO to refrain from issuing licences on certain frequencies to any service within a 'clear area [covering] a radius of 50 miles from each observatory'. Although the astronomers presented unified demands, this did not mean that they had identical interests, here revealed by the different attitudes towards transmission licences between Cambridge and Jodrell Bank. As Ratcliffe stated: 'we have no need for transmitting and do not feel that the case for granting a transmission licence is anything like so good as the case for refusing transmitting licences to others'. This disagreement was due to the different research programmes, a 'division of labour' noted elsewhere.[63] Lovell conceded 'I do not think it worth confusing the issue at this stage, since we are fighting a matter of principle.'[64]

Although the radio astronomers did not secure any specific frequency allocations, their pressure did achieve a tangible institutional outcome: the Lord President 'found that hitherto there had been no direct representation on these [interdepartmental] Committees of what I might call the "radio astronomy interest"' and recommended that this be corrected.[65] With the appointment of Robert Smith-Rose, successor of Appleton at the Radio Research Station, the astronomers had forged a strong institutional weapon against instability.

It was noted above that design changes of the telescope accompanied the stress put on emission lines in the research programmes. The following episode illustrates how the importance of the emission lines (repeatedly stated and recognized by the allocation bodies) was utilized in expansionist strategies by the radio astronomers, and how such policies were interrelated with their technology. Independently of the starting up of Royal Society machinery, there was some 'promising'[66] movement from the Joint Frequency Planning Panel about frequency allocation. As Lovell wrote to Ryle: 'I am sure that you will agree

60 JBA CS7/29/1. Letter Lovell to Martin, 15 May 1953.
61 JBA CS7/29/1. Letter Lovell to Greenall, 15 May 1953.
62 JBA CS7/29/1. Letter Lovell to Ratcliffe, 19 May 1953.
63 Edge and Mulkay, op. cit. (3), 58.
64 JBA CS7/29/1. Letter Lovell to Ratcliffe, 11 June 1953.
65 JBA CS7/29/1. Letter Marquess of Salisbury to Sir David Brunt, 29 January 1954.
66 JBA CS7/29/1. Covering letter Greenall to Lovell, 8 July 1953, for letter Mead to Greenall, 4 July 1953.

that we should correlate our answers to this letter'; radio astronomy would be best served by securing 'as many frequencies as possible'.[67] Ryle concurred: 'now the Royal Society document is in circulation, the time is ripe for a *really comprehensive* list of frequencies to be applied for'.[68] Ryle had two objectives: reopen 'the question of the lower frequencies which the GPO seems to think is settled'. This should be closed again before other interests appeared: 'I think we should move fast before commercial television gets going!' Secondly, the frequencies of emission lines should automatically be protected. With such concerns in mind, the broad band between 200 and 400 Mc/s became salient to the astronomers. The threat to the telescope on these frequencies came from 'high power television' serving the Manchester area and 'over-flying aircraft', both *local* problems. As Ryle noted:

> the best line to take is to press for something in the [RAF's] 250–400 Mc/s band, as this is symbolic of the whole problem, i.e. we only want a small fraction of the band; we know it to be used by others; we don't necessarily believe these other users to be any more vital than ourselves. This same problem occurs elsewhere, but this is an obvious focus as it is a very serious gap from our point of view.[69]

For an approach to the Air Ministry he suggested an *operational* argument: it was 'quite inconceivable that [the RAF's band] would not be able to stand pruning by 2–5%. If this is impossible the whole system would appear to be operationally too marginal to be of use.' For the Royal Society, the astronomers presented the problem as a threat to fundamental science from *commercial* television: Lovell complained that 'considerable bands were being held in reserve for commercial television, and yet radio astronomy had no priority with which to claim even a fractional part of the band'.

It is in their presentations to the DSIR and GPO, however, that the malleability of the telescope's hardware is revealed. Both groups of astronomers stated that they had planned 'expensive equipment' around the key bands[70] (the 'new large paraboloid at Jodrell Bank and...the new interference system at Cambridge'), and that the 'requirements of the radio telescopes must be regarded as having equal priority with any of the equipments used by the services'.[71] But this was not enough to protect the telescope, and a new argument was needed. Ryle's suggestion to Lovell forged the significance of emission lines (as recognized by the allocating bodies), the need for a clear frequency in the 'critical' RAF band, and the adaptability of the telescope's hardware:

> the big paraboloid may be the only instrument capable of doing worthwhile observations at [the Deuterism emission frequency]...I have not followed the literature closely enough to know how likely its detection is, or whether it is likely to prove anything that cannot be derived more easily from the Hydrogen line.[72]

Lovell took the hint. In a letter to the GPO he argued that 'as a general principle we regard it as extremely important to keep the few spectral frequency lines clear'.[73] When

67 JBA CS7/29/1. Letter Lovell to Ryle, 16 July 1953.
68 JBA CS7/29/1. Letter Ryle to Lovell, 19 July 1953.
69 JBA CS7/29/1. Letter Ryle to Lovell, 29 October 1953.
70 JBA CS7/29/1. Minutes of meeting at GPO, 20 October 1953.
71 JBA CS7/29/1. Letter Lovell to Ryle, 21 October 1953.
72 JBA CS7/29/1. Letter Ryle to Lovell, 18 March 1954.
73 JBA CS7/29/1. Letter Lovell to Sharpe, 22 March 1954.

this reasoning drew an unpromising response, Lovell called in support: 'the successful observation of the deuterium line at this frequency might become very important in radio astronomy... the Radar Research Establishment at Malvern is interested... [and] is building an equipment [*sic*] to search for this emission line. This presumably might support our case for a reservation.'[74] The frequency of 354 Mc/s was in this way negotiated and adopted onto the GPO lists of frequencies for radio astronomy. Nevertheless, the malleability of the telescope was manifest: although Lovell could argue that the paraboloid was 'ideally suited' to 354 Mc/s in order to drive a wedge in the RAF allocation, no problems were presented when the deuterium line was *subsequently* located on 322 Mc/s.

The astronomers perceived that their possession of too few frequencies put at risk the 'expensive equipment' that was under construction at Jodrell Bank and Cambridge. They therefore sought 'a place on equal terms... in the radio spectrum'.[75] Their strategy was to seek as much spectrum 'territory' as possible, since once it was occupied and built into the technology of the telescopes, the future reallocation of the frequencies became extremely difficult for the GPO.[76] The utility within such strategies of presenting the structure of the telescope as immutable is plain. However, as was revealed by the skirmish over the RAF's band, as well as the design changes discussed earlier, it was actually very adaptable. The telescope's design and significance were resources available to be used in arguments that the astronomers advance, and to win allies. A key example of this was in their seeking more institutional power: through the Royal Society and the Lord President they obtained representation on frequency allocation bodies. Later they mobilized a campaign through the international structures of allocation to secure inclusion in the ITU's tables. The important aspect to note was that these national and international allies were enrolled to solve *local* disputes.

The radio astronomers were presented with the problem of bringing the locally experienced interference to the regulatory bodies. They solved this problem by setting it in a durable and transportable form.[77] Figure 1 shows an example of the constructed pictures of interference taken to meetings with the GPO.[78] It consists of two pen recordings of the measurements of a radio source, made at different dates, aligned together. Radio astronomers had the problem of not possessing, unlike their optical cousins, readily recognizable (and aesthetically pleasant) representations of astronomical objects.[79] Three points can be made about the figure. First, the use of pen-recordings allowed the

74 JBA CS7/29/1. Letter Lovell to Sharpe, 13 May 1954.

75 JBA CS7/29/1. Letter Smith-Rose to Lovell, 6 August 1954.

76 An intriguing parallel in the history of science of territorial ambitions in an abstract space is the nineteenth-century conflict over 'stratigraphical geology', see J. A. Secord, *Controversy in Victorian Geology: The Cambrian–Silurian Dispute*, Princeton and Guildford, 1986, and M. J. Rudwick, *The Great Devonian Controversy*, London, 1985.

77 See B. Latour, 'Drawing things together', in *Representation in Scientific Practice* (ed. M. Lynch and S. Woolgar), London, 1990, 19–68, for the advantages given by the use of 'immutable mobiles'.

78 JBA CS7/29/1. Photograph composed for meeting at GPO, 20 October 1953.

79 For the use of 'pleasant' pictures in optical astronomy see M. Lynch and S. Y. Edgerton Jr, 'Aesthetics and digital image processing: representational craft in contemporary astronomy', in *Picturing Power: Visual Depiction and Social Relations*, Sociological Review Monograph 35 (ed. G. Fyfe and J. Law), London, 1988, 184–220.

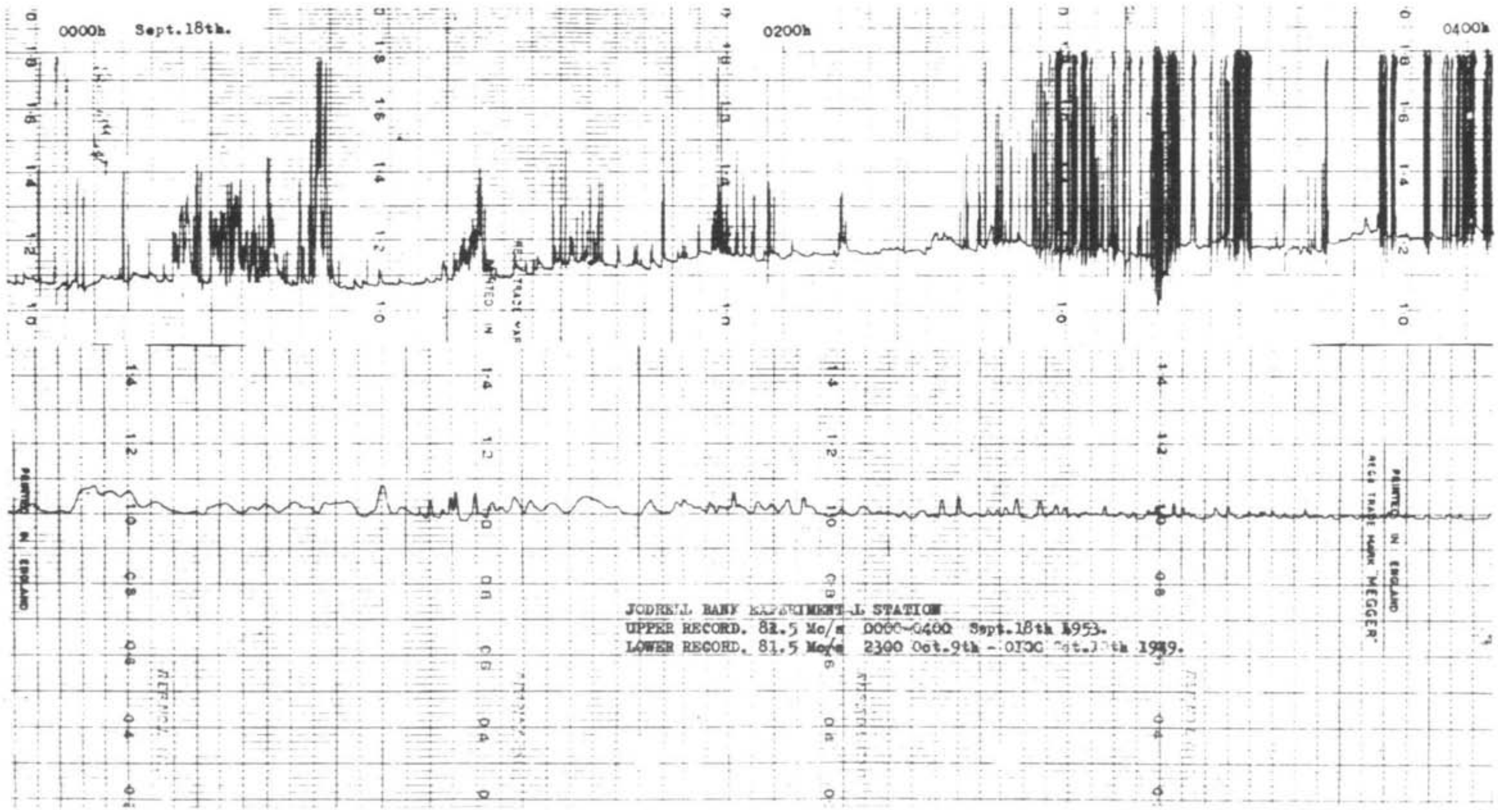

Figure 1. A 'before and after' illustration of the deleterious effects of radio interference, drawn up and deployed with success by the astronomers in their negotiations with the government frequency bodies. Radio astronomers, unlike their optical cousins, did not have the advantage of possessing readily recognizable representations of astronomical objects.

interference to appear in a form apparently *unmediated* before the regulatory body.[80] Secondly, in their construction of the figure (by aligning the pen-recordings together), the astronomers constrained the interpretations of the image to the one they wanted. Thirdly, the astronomers were making use of the very ambiguity in their representational practices that was the cause of their anxiety over interference: in the same way the fragmented significance of the telescope was mobilized in the pursuit of funds, their ambiguous data could be used to 'protect' the telescope.

The threat to stability came from the locality of the telescope: in the case of frequencies, a disc of radius fifty miles. Any source of interference produced in the telescope's environs concerned the radio astronomers, prompting them to seek that 'services be reorganised in frequency or geographically in a way [not to] increase interference to Radio Astronomy'.[81] They therefore actively opposed local television transmitters. Gee radio navigational beacons at Camphill (ten miles from Jodrell Bank) and Stenigot (within fifty miles),[82] private business radio services,[83] overflying aircraft, tugs, police, and any other service wherever they trespassed onto frequencies used by the radio telescope. As the Cabinet Frequency Committee noted, this led to 'frequency plans [being] adjusted and area limitations... accepted in order to assist Radio Astronomy'.[84] The mechanisms by which these were put into place were innumerable local 'arrangements' with services, particularly the government departments that occupied large tracts of spectrum (the Air Ministry, the War Office, the Ministry of Transport and Civil Aviation, and the Home Office).[85] One such 'arrangement' is illustrated by the following minute:

> MTCA has undertaken to avoid... the assignment of any frequency between 131.9 to 132 Mc/s within 50 miles of Jodrell Bank or Cambridge but fears that interference may arise... There are [5] air-ground-air assignments... within 50 miles of Jodrell Bank. It is hoped to reaccommodate these within the next eighteen months.

Similar local negotiations are revealed in a letter from Lovell to Ryle: 'I gave an address to the Manchester Luncheon Club last week and took the opportunity of dealing quite severely with Manchester's overspill, electricity grid lines and frequency reservations, as they affect the future of the radio telescope.'[86] The problems over the control of radio interference near Jodrell Bank can be sited in a whole range of other local conflicts. The grid lines mentioned were an attempt to lay electrical cable near to the telescopes, which would cause interference. A 275 kV supergrid line, planned to run within '7000 yards', was renegotiated in 1952.[87] The overspill referred to reflects Congleton Borough Council's

80 For a discussion of the emergence of a 'mechanical objectivity' see L. Daston and P. Galison 'The image of objectivity', *Representations* (1992), 40, 81.

81 JBA CS7/29/2. Document 'Allocation of Frequencies for Radio Astronomy' drawn by Smith-Rose for Cabinet Radio Committee.

82 JBA CS7/29/1. Letter Smith-Rose to Lovell, 30 March 1955.

83 JBA CS7/29/1. Letter Golothan to Lovell, 18 November 1957, notes services in Bebington, St Helens, Leeds, Hollinwood, Shrewsbury, Driffield and Northwich, around 183 Mc/s alone.

84 JBA CS7/29/1. Minutes of Cabinet Frequency Committee, 23 July 1954.

85 JBA CS7/29/1. Second Report by the Joint Frequency Planning Panel on the Allocation of Frequencies for Radio Astronomy, 8 January 1955.

86 JBA CS7/29/1. Letter Lovell to Ryle, 2 November 1953.

87 Lovell, op. cit. (9), 170.

scheme for expansion. The electrical activity inevitably associated with urban areas would again cause interference. The episode developed into an intense controversy with the telescope portrayed by Congleton businessmen as a threat to Cheshire's economy. The eventual resolution was the creation in 1955 of an area with a six mile radius within which existed stringent planning restrictions.[88] Hence Lovell's enquiry of Ryle: 'Do you have any worries about encroachment of population or grid lines?'[89]

CONCLUSIONS

> We end on the most impressive shot that can be obtained of the *whole* telescope.
>
> Script for *The Inquisitive Giant*, 1954[90]

We therefore see the telescope becoming enmeshed and adopted into the local environment. There existed processes whereby the Jodrell Bank telescope could not be an isolated observatory. But what functions and effects did they have? The account of the telescope's funding revealed how variable and diverse its interpretations were. This was the case even for the radio astronomers, although in their exploitation of this *instrumental* interpretive flexibility they always sought to reserve for themselves the privilege of defining the telescope.[91] But what allowed the astronomers this asymmetric position? It stemmed from the significance of the telescope being malleable but not fluid: not any reading of the telescope could be made and, by and large, its interpretation as an *astronomical* instrument was dominant. This stability was due to the colonization of the environment of the telescope with communities of practice that accepted and *made* such a reading.

I suggest that the definition of laboratories as sites for 'science' is not *only* determined by scientific practices within the lab; but (and particularly for those sciences, for example metrology and astronomy, that involve accurate measurement) it is also grounded by numerous mechanisms of 'arrangements' of the surrounding ways of life, from astronomers to town planners and aeroplane pilots.[92] The examination of the spatial setting *outside* the laboratory seems to me likely to be as fertile as the studies of the *inside* have been.[93] This was shown in the account of frequency allocations: in their actions to

88 Ibid., 168.

89 Other urban activities, such as the use of microwave ovens, could cause controversy and interference. During the 1960s and 1970s, Jodrell Bank astronomers, to keep their inscription devices clear at the observatory's centre, had to seek to control the activities within the kitchens of Cheshire.

90 Anvil Films Ltd., op. cit. (1) (my emphasis).

91 S. Schaffer, 'The Leviathan of Parsontown: Literary Technology and Scientific Representation', unpublished paper, is a parallel discussion of the slipperiness of astronomical authority, when different actors within a telescope's context conflict.

92 D. Cahan in 'The geopolitics and architectural design of a metrological laboratory: the Physikalish-Technische-Reichsanstalt in Imperial Germany', in F. A. J. L. James, op. cit. (7), 137–154, says 'The key concern in planning and designing metrological laboratories is the environmental control of both external and internal sources of disturbances.' I suggest that such concerns are more widespread.

93 For such 'internalist' study of science see, for example, B. Hillier and A. Penn, 'Visible colleges: structure and randomness in the place of knowledge', in *Science in Context, the Place of Knowledge: The Spatial Setting and its Relation to the Production of Knowledge* (ed. S. Shapin, A. Ophir and S. Schaffer) (1991), **4**, (1), 23–49.

secure the telescope, the astronomers had to concern themselves with, and transform, their environment. This resolves a methodological problem with my introductory metaphors of 'forces' keeping the telescope in 'dynamical equilibrium': that they might be platonic, idealistic and *ungrounded*. Now, it is possible to see them locally woven, by means of regulations, 'arrangements' and other social practices, into the milieux which embed the telescope.