CHAPTER 11

The momentum of maturity

What to do with ageing Big Science facilities

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The legacy of largesse

This text grew out of a curiosity of mine. Given that so much of the rhetoric surrounding Big Science is either about large scientific facilities that are new and shiny and therefore at the cutting edge of what technology can produce and the tax-payer can cope with, or about future projections of even grander, though non-existent, large-scale science facilities, what about the fate of older Big Science machinery? What happens to Big Science infrastructure once it is not that new any more?

If we turn to the scholarly literature on science and technology, and fields such as the history of science and technology or science and technology studies, we will not find that many answers. In fact, these fields have been criticized for placing their emphasis on new and emerging technologies, rather than analysing technologies that are, relatively speaking, mature, even old. Why study things, people, institutions, and artefacts that have found widespread use and might be regarded 'out-of-date, obsolete, and merely persisting', when you can study innovation, invention, pioneers? As David Edgerton noted, 'the vast majority of historical studies of technology continue to be studies of invention, innovation, the new, novelty and of change' (Edgerton, 1999, 112 & 113–14; Edgerton 2007). In a similar discussion of the neophilic tendency in histories of science and technology, Svante Lindqvist has pointed out the dearth of discussion about the phases in which a technology gradually disappears (Lindqvist, 1994).

Lindqvist has also suggested that we should view science and technology through Fernand Braudel's vision of historical time flowing at different speeds. In Braudel's model, an upper layer of events and people moves faster than more slowly moving temporal layers underpinning such events. Lindqvist, however, exchanges Braudel's slower geographical and climatological factors with technological systems—the semi-permanent features of our modern world that move at slower speeds than the events and discoveries happening in the uppermost layer (Lindqvist 1998; Braudel 1980). The popular and political discourse about Big Science is—perhaps not surprisingly—focused on the new, the shiny, the things that are seen as cutting edge. Often, public interest is fired up about facilities that do not even yet exist. They are projections into the future. Much of the building-up of public interest and political acceptance of Big Science facilities uses an idiom of expectation; of promissory notes handed out containing future products, innovations, or discoveries. Following Lindqvist's take on Braudel, Big Science facilities can be said to exist in a layer of expectations, floating above the fast-paced world of events, and the historical processes that flow even more slowly (Brown & Michael 2003; Borup et al. 2006). It is arguable that, for Big Science to take concrete shape, this future-oriented layer of expectation is a necessary precondition.

Leaving the realms of expectation, it is the aim of this chapter to identify and explore some of the processes that are underway in the lower and slower temporal layer of large-scale scientific infrastructure. It seems particularly apt to be able to do this—admittedly in essay form—in a research project devoted to a facility that emphatically does not exist, namely the European Spallation Source. We do not know yet whether the ESS will join the American Super Conducting Supercollider (SSC) in the graveyard of failed Big Science projects with three-letter acronyms. In doing so, I will inevitably look at other facilities than the ESS. The cases are mostly picked from modern astronomy. It is the hope that this contribution to the developing literature on the ESS and MAX IV will provide some food for thought for future generations of ESS-related activities, should the dreams of the neutron community ever take on solid form in Lund.

This chapter explores a number of research questions. (*i*) What happens to large-scale scientific instruments once they have reached a mature age? What happens with research infrastructure that has seen some action and might even be regarded as dated by some actors, but not by others? (*ii*) What are the problems associated with large, mature research instruments? What are thus the challenges they pose to the people and organizations (funding bodies, research councils, universities) running the science? Are there conflicts? (*iii*) What are the environmental aspects of large-scale research infrastructure about to be shut down?

One element in the futuristic idiom of the discourses of politics and policy of large-scale research infrastructure is creative destruction, sometimes as a vague undertone, often spelled out. In order to take the next step, we need to build even bigger machinery capable of reaching higher energies or farther out into space, and the way to do that is to close down existing instrumentation, so as to concentrate resources on the next generation of facilities—or so the rhetoric claims. The success of large-scale scientific infrastructure is not only about making the installation work in a technical sense, but also about making it viable in a political sense. Technical problems need to be overcome, but politics have to be made palatable. And what could be more alluring—whether you are the minister of science, technology and innovation, or the leader of a large private foundation—than financing something that is bigger than anything else on the planet by relegating older machinery to the scrap-heap of history? There is research policy logic in closing facilities down, and the average life expectancy of Big Science facilities in operation between the 1940s and the 1980s seems to be of the order of a decade (Congressional Research Service 1987).

All the facilities that are closed down, does that just happen without opposition? Surely not, and the aim here is to look at the politics and practice of shutting down large-scale scientific infrastructure and discuss a number of examples of debates that have surfaced just as Big Science facilities reach maturity; they, like new and future machinery, are contested sites, facing debates about their funding and environmental impact. By dint of having existed and functioned for years, they can be said to have a sociological momentum in that they support user bases that are non-trivial in weight. They most certainly have momentum in the material sense: they are big, and dismantling them is not a trivial exercise, involving as it does environmental impact assessments as well as costly decommissioning work estimated by some commentators to be of the same order of magnitude as for their construction in the first place. Large-scale research infrastructure projects dot the landscape of all of the countries that were significant actors in the post-war expansion of research systems: an archipelago of installations, remnants of a period when the industrialized nations in East and West spent money on Big Science like there was no tomorrow. Now we are living in Tomorrow's World, we have to live with the material legacy of that largesse. The archipelago needs to be handled, governed, decided upon. The lightness of expectations meets the momentum of existing installations, as it were.

Uses for mature instrumentation

At time of writing, European astronomers are about to decide whether to construct a truly impressive telescope. The European Extremely Large Telescope (E-ELT), will, if everything works out—and the chances have improved since Brazil joined the European Southern Observatory (ESO), thereby providing a stabilizing force that balances out some of the problems that might arise given the current European economic crisis—be built by European countries and placed on a mountain-top in a desert in Chile. It will, as the superlative-laden name of the installation so proudly proclaims, give European astronomers access to a cutting-edge large-scale facility when it starts observing the cosmos about the same time as the ESS is supposed to start producing neutrons in Lund.

In order to finance Sweden's membership of this European endeavour, the representative from the National Swedish Research Council made it very clear at a hearing with leaders of the Swedish astronomy community that Swedish astronomy would have to agree to cuts in the funding of other facilities in order to release money for the E-ELT (Cumming 2010). Funding for the Nordic Optical Telescope (NOT), constructed in the 1980s, or perhaps Swedish membership of the Square Kilometre Array (SKA), which will be the world's largest radio telescope when built by a consortium of 67 organizations in 20 countries, might be dropped in order to fund the E-ELT. And the Swedish National Committee of Astronomy clearly stated in a position paper drafted at a meeting in Gothenburg in April 2010 that it would prioritize E-ELT over SKA or NOT (Svenska nationalkommittén för astronomi 2010).

The decision to go ahead with funding new and costly facilities can introduce tensions in the scientific community. A scientific discipline is not homogeneous, but is made up of various scientific subcultures, each with its own array of instrumentation, ways of experimenting, observing, and communicating, and so on (Galison 1999). This has implications not only for the theory of knowledge, but also for research policy. If the funding of a new facility is found by diverting funds from other existing facilities, rather than by increasing the funding available to the discipline, there will in all likelihood be conflicts brewing. Resource reallocation in a zero-sum research policy game can be a recipe for infighting, especially if some subcultures' use for the new facility is small, whereas they might instead prefer the continued operation of older, more mature scientific technologies. Different machinery caters to different scientific subcultures, and the construction of a specific type of instrumentation can be a cause for conflict, and thus involves significant political work in order to build up coalitions in support of the instrument. Just such a conflict arose in Swedish physics after the decision to join CERN-II without increasing government funding to the field (Widmalm 1993). In the case of the Hubble Space Telescope, one part of the process of making the telescope a reality involved developing a political consensus within the American astronomical community that the Hubble Space Telescope was the instrument to go for (Smith 1992). In this case, optical astronomy using very large telescopes seems to trump radio astronomy using very large radio telescopes (SKA) or the continuing use of medium-size telescopes (NOT).

The Swedish astronomical community's choice whether to pool their resources and throw themselves behind membership of the E-ELT illustrates a common process in the politics of Big Science facilities. In astronomy, the move from telescopes in the 2–4 metre class, typically constructed during the 1970s and 1980s, to telescopes in the 10–15 metre class has led to debates about astronomy's resource allocations. Looking at the various arguments made, it is evident that proponents of the more mature and, relatively speaking, smaller instrumentation might not have the upper hand, but neither are they going to give up without a fight. Bigger is not generally better; there are types of astronomical observation that are better done on small- and medium-sized telescopes than on big ones. A single very large telescope will be tremendously oversubscribed so users would only get access to the facility for short periods, whereas some astronomical phenomena require observations over longer periods of time. An obvious case is the first discovery of an exo-planet orbiting a sun-like star made in 1995 with a telescope from the 1950s operated at the Observatoire de Haute-Provence, and the list of examples can go on and on. The discoverers, Mayor and Queloz of the Geneva observatory, apparently valued their ability to have regular and non-bureaucratic access to this nearby small telescope. One important factor in the discovery was the fine-tuning of a new type of detector, tinkering which would have been more or less impossible if it had had to be done under the aegis of time-allocation committees like those that manage access at larger telescopes. Observations would have been time-consuming, would have had to be planned long in advance—no tinkering then—and the amount of telescope time available (a scarce resource at large facilities) would have been much less. The fact that the telescope at the Haute Provence observatory used by Mayor and Queloz was a lowly 1.93 metre reflector dating from 1958—a type of telescope that is regularly being shut down—mattered less for these kind of measurements than did regular and ample access to the facility (Mayor & Queloz 1995; D. Dravins personal communication).

This process of activism in favour of keeping older facilities going instead of decommissioning or mothballing them is visible in US astronomy. Instrumentation priorities for the US astronomy and astrophysics community are set by decadal surveys. Confronted with the closure of mature medium-sized telescopes, the ReSTAR committee (Renewing Small Telescopes for Astronomical Research) has argued for several years for the continuing use of some installations (ReSTAR 2007). The ReSTAR committee is an example of intra-scientific argument in favour of the continued use of telescopes that were once large, but have progressively become smaller relative to other facilities. It argues, among other things, that aging telescopes, having become relatively smaller as newer and bigger installations are built, still continue to produce useful scientific results. They can also contribute to science through training and education. Small telescopes make it possible to gain experience in the practice of astronomical observation, unlike large telescopes, where students typically do not have the opportunity to gain experience in the technical intricacies of scientific practice. Smaller and older telescopes, the report claims, also can serve as test-beds for new astronomical technologies such as detectors and spectrographs. Bigger is not necessarily better, according to the report, which uses the metaphor of 'workhorse instruments' to describe the role of telescopes in the 2–4 metre range. 'Time domain astronomy' and surveys are important parts of modern astronomy, and normally they cannot be done at a unique and uniquely oversubscribed behemoth; the single Leviathan collecting light from the universe needs to be complemented by an astronomical Argus with many lesser lenses. These types of arguments also surface in other contexts. The Kitt Peak National Observatory in Arizona, with a number of telescopes that used to be large, but are now old and medium-sized, has been made available to the astronomical community since the 1970s. Facing the shutdown of telescopes on Kitt Peak, astronomers voiced concerns similar to the ReSTAR committee (National Optical Astronomy Observatory 2012).

Outreach and heritage

Arguments for the continued use of ageing scientific installations can come not only from within the disciplinary politics of science, where sizeable communities of users for various reasons might be content with what they already have. Extra-mural interest groups sometimes voice arguments against the shutdown of once-large facilities. Successful outreach activities can therefore have policy implications. When a facility has been able to muster support—on the level of the local community, or on a national level—these groups can mount organized resistance to the policy of shutting down research infrastructure.

One example is the David Dunlap Observatory at the University of Toronto, where a local community protested against a decision to close the observatory (Deans 2007). This instrument was the second largest telescope in the world when it was constructed in the 1930s using a donation from the family of the local mining magnate, David Dunlap, who became hooked on astronomy after hearing a popular lecture in 1921 by the astronomer C. A. Chant on the close encounter between Comet Pons-Winnecke and the Earth (Fernie 1979). It is still the largest telescope on Canadian soil (although Canadian astronomers have the use of larger instrumentation abroad, such as the Canada–France–Hawaii facility atop Mauna Kea in Hawaii). When the plans to shut the observatory became public, a petition was started that eventually ran to thousands of signatures. Demonstrators gathered outside the observatory, forming human chains and marching to the skirl of bagpipes. 'It's not just about science—though that is important—it's about place, people and community', one activist argued (Potter 2008). They claimed that the observatory played a role in educating and inspiring people to learn about science. It was apparent that they felt proud of 'their' observatory and anger at a research policy process that could lead to the decommissioning of an observatory and, they claimed, showed how little science mattered in Canada.

Outreach activities at some large astronomical observatories have been very popular, sometimes almost too popular in that they have attracted such crowds of visitors that their popularization has risked disturbing the measurements at the observatory (Agar 1998). There can be local, regional, and national pride invested in the sites of Big Science facilities, hence the protests at the shutdown of the David Dunlap Observatory.

When scientific activities have come to an end, observatories, laboratories, and accelerators can live on as sites of scientific heritage or museums—science museums where the triumphs of yesteryear are celebrated through the display of scientific hardware, and elderly laboratories and observatories can find a second or third century of life as heritage. They become parts of the commemorative practices of science (Abir-Am & Elliott 2000). The Greenwich Observatory in London, the old Stockholm observatory, and the Mount Stromlo observatory in Australia are just three examples from astronomy, and there are many others to be studied in astronomy and other disciplines. Witness, for example, the fate of the Bevatron, constructed in the mid-1950s and used in the discovery of the antiproton (which brought a Nobel Prize in 1959) and the antineutron. Attempts were made later to upgrade the facility. The user community shifted gradually from high-energy physicists to scientists from the life sciences, but eventually the scientific uses of the facility petered out, and it was shut down in 1993. When the question of demolition and decommissioning was raised, local activists protested. Instead of decommissioning it, they wanted to turn the facility into a science museum: 'we haven't had a lot of Nobel prizes up there lately … There's nothing wrong with paying a tribute', one of the activists argued (Brumfiel 2006). Besides the heritage function, local activists were also alarmed at the environmental impact of a shutdown. Eventually the activists lost, and at time of writing the decommissioning process is almost finished (Bevatron Landmark & Demolition News 2005).

One can only speculate about what will happen once NASA decides to mothball the Hubble Space Telescope in Earth orbit or, as the case might very well be, to de-orbit the Hubble, making the decommissioning exercise into a bright meteor hurtling down through the sky, a very visible sign of the priorities of modern astronomy. The Hubble Space Telescope, defective upon launch but soon optically restored, has periodically been refurbished by servicing missions that have installed new detectors and electronics in what otherwise would be a piece of early-1980s space debris orbiting the Earth. Now, with the Space Shuttle grounded, no future servicing missions to the Hubble are planned, and, as the relentless march of technological progress moves on, the telescope will become even more dated with each passing year. Yet in the public's eye, the Hubble Space Telescope is still high-tech. What will the response be to the Hubble's demise, either as slow mothballing or spectacular celestial event?

At the time when servicing missions—to the tune of $1 billion dollars a throw—were still being pursued, before the grounding of the Space Shuttle fleet, the decision to go ahead with these costly upgrades to the Hubble Space Telescope was sometimes debated, as not all astronomers thought this was a good way to spend money. Andrew Jaffe, professor of astronomy and cosmology at Imperial College and a regular participant in astronomy policy debates, publicly voiced concerns at these costly upgrades on his blog, the platform from which he often discusses the policy of space technologies and astronomy: 'it's between $1 billion for Hubble and all the other ways NASA could spend that money—or all the ways it would be spending it if it weren't for Hubble or Mars (not to mention the more or less useless—and dangerous—International Space Station). In particular, it could be for the sputtering Origins Program which could still produce a series of unmanned missions over the coming decades to find planets, image the early universe, and trace the evolution of Black Holes. I'd rather see these missions go forward than eke a few more years out of Hubble, frankly.' Martin Rees (who, at the time, besides being a leading astronomer, was president of the Royal Society), also voiced concerns that the costs involved in keeping Hubble going would have too severe an impact on other science projects and NASA missions (Jaffe 2005; Thomas 2006).

The obduracy of science

The decision to shut down a scientific facility actualizes a set of environmental issues. The very bigness of Big Science can become a problem as the organizations responsible for building and running large facilities become responsible for handling the residue of their activities. Now, when the cold war is over, a large number of aging accelerators and reactors is reaching retirement age. This has spawned a new field, complete with journals, specialist engineers, and a business sector, solely for the decommissioning of Big Science facilities.

One tactic is to plan for the dismantling and decommissioning of the facility from the very outset. In the case of the ESS, planning is already underway to prepare for the dismantling of the facility (Agrell 2012). The ESS consortium has bought decommissioning plans from Studsvik Nuclear AB, a company specializing in the decommissioning and dismantling of large facilities in the nuclear sector, as well as in nuclear waste treatment. According to one study, the cost of dismantling the ESS in an environmentally safe way will be in the order of SEK500 million or about €60 million.

In what might be seen as a changing trend, it can be noted that the ESS organization is already running a decommissioning study parallel with the planning stages of the facility. A 1999 report from the European Union on the problem of decommissioning particle accelerators claimed that the issue is of increasing importance since the European accelerator park is ageing, and warning that the 'existence of a decommissioning plan or provision for dismantling costs is an exception' and that 'the awareness of the dismantling and long-term waste problem is almost nonexistent' (European Commission 1999, 134). It can also be noted that Studsvik's report on the cost of decommissioning the ESS is much lower than the estimated costs for decommissioning particle accelerators, which are estimated to be some 50–100 per cent of the investment costs of such accelerators (Bergström & Eriksson 2005).

The environmental ramifications of dismantling large facilities are not limited to facilities with materials contaminated with radiation. Sites of a sensitive nature when it comes to culture and cultural heritage can also be a problem for those who want to dismantle very large facilities as best as possible. The ESS argues that after forty years' use it will return its site to the pristine, fertile farmland it is now. Critics have argued that it will be impossible once the land has been 'dug up, filled with concrete, asphalted, mixed, transported and built on' as a local activist put it (*Lund* 2008).[1] The debate mirrors the problem of obduracy in city planning and the difficulty of 'unbuilding' city structures (Hommels 2005).

Skåne's rich loam takes on something of a mythic quality when used as an argument by some of the ESS-protestors; equally, sublime sensibilities of a more heavenly order are sometimes wounded by the presence of Big Astronomy facilities. Modern telescopes are placed on mountains, and many of these sites were chosen at a time when respect for non-Western traditions was not allowed to stand in the way of technoscientific advances. The Kitt Peak Mountain, home to the eponymous observatory, was selected as a site for the national optical observatory in 1958, at the dawn of the space age, after an agreement had been signed with the Tohono O'odham nation on whose land the mountain stands. In the last ten years, however, tensions have been developing between the National Science Foundation and the Tohono O'odham. A similar situation pertains at Mauna Kea on Hawaii. Here, decommissioning plans will have to balance an ensemble of telescopes owned by several countries, a mix of US state universities, and privately funded telescopes. This sensitive ecology is further complicated by a long history of non-US presence and sometimes strong opposition to Big Science facilities from environmental activists and Hawaiians protesting at the presence of large-scale technology in this 'sacred landscape'. The telescope site was first leased in 1968. The decommissioning plans calls for physical as well as ecological restoration (there are endangered species of insect on the mountain), and for cultural considerations to be taken into account, involving the native Hawaiians' ideas about the divine nature of the mountains (Office of Mauna Kea Management 2010).

Concluding remarks

Sometimes, Big Science seems to live in an illusive and illusory temporal dimension. The public discourse surrounding these large-scale facilities is often formulated in a futuristic idiom. Upcoming facilities are presented as roads to the future in order to sell them, and newly constructed facilities are hailed as simply the best. Academic writing on Big Science, just like much of the history of science and technology, is often given over to innovation, discovery, the new. Lindqvist has noted that mature technologies, right up until their disappearance, have at the very least been somewhat under-studied by historians, and he might very well be right in his talk of a blind spot; certainly, this essay has been an attempt to point out some of the processes involved when facilities reach maturity and face shutdown.

One of these processes has its origin in the fact that closure may very well be viewed with alarm by some members of the academic community, sometimes even going as far as to argue for the continued operation of some installations. Opposition to closure may also come from outside the scientific community: large-scale natural science is viewed by many as a hallmark of modern society, a visible accomplishment on the local and national levels, and thus the phasing-out of such installations can in some instances lead to protests from non-scientists. Lastly, the economic and environmental dimensions of dismantling large-scale infrastructures are not to be sniffed at. Dismantling is perhaps not as exciting as the research futurology of the design phase, when expectations of future innovations and discoveries are dangled before the public and the taxpayers, but it is very important since it deals with the real here and now, and not the future.

Notes

1 In Swedish original: 'ESS-konsortiet påstår att åkermarken ska återställas i sitt ursprungliga skick efter den 40-åriga driften. Skitsnack, på ren skånska. Mark som är uppgrävd, betongfylld, asfalterad, uppblandad, bortforslad, bebyggd går inte att återställa i sitt ursprungliga skick.' download/18.5adac704126af4b4be2800018128/1271307680819/MAX-lab5.2010.pdf>, accessed 18 August 2012.

References

Abir-Am, Pnina G. & Clark A. Elliott (2000) (eds.), *Commemorative Practices in Science: Historical Perspectives on the Politics of Collective Memory* (*Osiris, 2nd series* 14).

Agar, Jon (1998), *Science and Spectacle: The work of Jodrell Bank in post-war British culture* (London: Routledge).

Agrell, Wilhelm (2012), 'Framing prospects and risk in the public promotion of ESS-Scandinavia', *Science and Public Policy* 61, 429–38.

Bergström, Ulla, & Evert Eriksson (2005), *Overview of decommissioning of the European Spallation Source, located in Sweden* (Studsvik: Studsvik Nuclear AB).

Bevatron Landmark & Demolition News (2005), web page available at <http://www.berkeleycitizen.org/bevatron/bevatron14.htm>, accessed 18 August 2012.

Borup, Mads, Nik Brown, Kornelia Konrad & Harro Van Lente (2006), 'The sociology of expectations in science and technology', *Technology Analysis and Strategic Management* 18, 285–98.

Braudel, Fernand (1980), 'History and the Social Sciences: The Longue Durée', in *On History* (Chicago: University of Chicago Press).

Brown, Nik, & Mike Michael (2003), 'A Sociology of Expectations: Retrospecting Prospects and Prospecting Retrospects', *Technology Analysis and Strategic Management* 15, 3–18.

Brumfiel, Geoff (2006), 'Views Collide over Fate of Accelerator', *Nature* 442, 612.

Committee for Renewing Small Telescopes for Astronomical Research (2007), *Renewing Small Telescopes for Astronomical Research: Report of the Committee for Renewing Small Telescopes for Astronomical Research*, December.

Congressional Research Service (1987), *World inventory of 'big science' research instru-*

ments and facilities, Library of Congress Congressional Research Service transmitted to the task force on science policy (Science policy study background report no 4; Washington DC: US Government Printing Office).

Cumming, Robert (2010), <https://twitter.com/maltesk/status/13305242580> and <https://twitter.com/maltesk/status/13304458088>, accessed 18 August 2012.

Deans, Paul (2007), 'Dunlap Observatory, RIP', *Sky & Telescope*, available at <http://www.skyandtelescope.com/news/10259442.html>, accessed 18 August, 2012.

Edgerton, David (1999), 'From innovation to use: Ten eclectic theses on the historiography of technology', *History and Technology* 16, 111–36.

— (2007), *The shock of the old: Technology and global history since 1900* (New York: OUP).

European Commission (1999), 'Evaluation of the Radiological and Economic Consequences of Decommissioning Particle Accelerators', Nuclear Safety and the Environment, Report EUR 19151, available at <http://ec.europa.eu/energy/nuclear/studies/doc/other/eur19151.pdf>, accessed 18 August 2012.

Fernie, J. D. (1979), 'People and Places: Collected Reminiscences of John Frederick Heard', *Journal of the Royal Astronomical Society of Canada* 73, 53–73.

Galison, Peter L. (1997), *Image and Logic: A Material Culture of Microphysics* (Chicago: University of Chicago Press).

Jaffe, Andrew (2005), 'Hubble redux (not)', available at <http://www.andrewjaffe.net/blog/science/000044.html>, 18 August 2012.

Lindqvist, Svante (1994), 'Changes in the Technological Landscape: The Temporal Dimension in the Growth and Decline of Large Technological Systems', in Ove Granstrand (ed.), *Economics of Technology*, pp. 271–88 (Amsterdam: North-Holland).

— (1998), 'La lagom longue durée: Tidsanda och struktur i en studie kring Hannes Alfvén', in Evert Baudou (ed.), *Forskarbiografin: Föredrag vid ett symposium i Stockholm 12–13 maj 1997*, pp. 143–57 (Stockholm: Kungl. Vitterhets-, historie- och antikvitetsakademien). Lund (2008), [Letter to the editor], *Lund*, 5 November.

Mayor, Michel, & Didier Queloz (1995), 'A Jupiter-mass companion to a solar-type star'. *Nature* 378, 355–59.

National Optical Astronomy Observatory (2012), web page, available at <http://ast.noao.edu/node/168>, accessed 18 August 2012.

Potter, Rod (2008), Comment to 'Activism against shutdown: The case of DDO', available at <http://www.gustavholmberg.com/magnitude/2008/12/03/activism-against-shutdown-the-case-of-ddo/#comment-56142>, accessed 18 August 2012.

Smith, Robert W. (1992), 'The Biggest Kind of Big Science: Astronomers and the Space Telescope', in Peter Galison & Bruce Hevly (eds.), *Big Science: The Growth of Large-scale Research*, pp. 184–211 (Stanford: SUP).

Svenska nationalkommittén för astronomi (2010), 'Svar på frågor från RFI vad gäller strategi och prioriteringar av infrastruktur för astronomin i Sverige fram till 2020'.

Thomas, Gavin (2006), 'Hubble Mission is "wonderful news" ', *BBC News*, 31 October 2006, available at <http://news.bbc.co.uk/2/hi/science/nature/6103866.stm>, accessed 18 August 2012.

Widmalm, Sven (1993), 'Big Science in a Small Country: Sweden and CERN II', in Svante Lindqvist (ed.), *Center on the Periphery: Historical Aspects of 20th-Century Swedish Physics*, pp. 107–40 (Canton, Mass: Science History Publications).