SKA: Economic & Social Benefits

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Introduction

Basic science is increasingly being considered in terms of its economic and societal benefits as well as the pursuit of scientific knowledge for its own sake. Astronomy is generally perceived to be at the 'pure' end of the spectrum which runs from curiosity driven 'basic science' through 'strategic science', directed to a general field, but with no specific application in mind, to applied science. Nonetheless, a strong case can be made for astronomy, which brings together its inspirational power and its accessibility in helping to improve scientific literacy as well as some notable technological developments, especially in detectors. Radio astronomy has often brought together astronomers and engineers in productive ways and there is a strong legacy of innovations resulting from these collaborations ranging from the first computer controlled large machines (the Mk2 telescope at Jodrell Bank), several generations of low-noise amplifiers, to the ubiquitous wi-fi chips in almost every computer and hand-held device today. The demands of the Square Kilometre Array, in terms of the volume and speed of digital signal transport and processing and the numbers of low-noise receivers will stimulate developments on a different scale to other astronomy projects, simply by virtue of their volume and the pressure to reduce the unit cost. Novel digital signal processing technologies will be required both at the array stations and at the central processor. The combination of its remote, distributed location and its power requirements have led to a growing commitment to making the SKA the first major infrastructure powered by renewable energy.

This paper starts with a summary of some of the current ideas on the economic benefits of basic science in general, and especially big science facilities. This includes some of the methods used to quantify these benefits and the different ways in which these benefits arise. Following a summary of the arguments which are being made for astronomy in particular, the requirements and technologies for SKA which may provide particular opportunities for future developments are considered.

The economic benefits of science

As scientists, we have our own motivations to do basic science and we don't need to be convinced of its importance. But the question 'what is the economic benefit of publicly funded research' can be asked, and indeed is increasing being asked by policy makers. Various attempts over the years have been made to address this question. A widely quoted US survey (Mansfield 1991) quantified the annual return on investment of academic research as 28% and it is still quoted in the 2009 US science stimulus package. Such clear cut answers should be and are being questioned: some studies are commissioned by parties with a vested interest; others are in very restricted fields (especially agriculture and pharmaceuticals). CERN have commissioned some of their own studies and The University of Sussex Science Policy Research Unit has conducted a series of reviews of current literature.

The traditional argument invoked a linear model in which basic research led to technical developments and new innovations which had direct economic benefits. Public funding of such research is justified because it addresses a 'market failure': basic research generates new knowledge, which is freely available and such knowledge is a 'public good'.

However, there is an important difference between information being available and actually having the capacity to make use of it. Building this so-called 'absorptive capacity', the ability to assimilate and exploit external knowledge is an important aspect of having a strong research base. It can apply to an individual firm's private R&D or national publicly-funded research.

The linear 'science-push' model is undoubtedly unrealistic, there are various feedbacks and two-way flows; there is 'demand pull' as well as 'science push'.

Other issues with this approach include the traceability of particular benefits to particular research activities; the long time lags between the original research and the benefits; the relative importance of research outputs available in the literature (codified knowledge) and in skilled people (tacit knowledge).

Notwithstanding these problems in the basic model, many attempts have been made to quantify the economic benefits of basic research, from econometric studies to surveys and case studies. Typically these studies indicate rates of return to society as a whole of around 50%, from industrial and publicly funded research. A much quoted survey of 76 US firms covering 7 industries indicated a rate of return of 28% (Mansfield 1991). European studies have shown similar results (Beise & Stahl 1999). In the UK, a recent study claims a direct correlation of productivity growth and research council spending (lagged by only one year) (Haskel & Wallis 2010) while OECD studies show generally positive correlations of productivity growth with R&D spending and a long-term elasticity of productivity on public R&D of 0.17. (Guellec & van Pottelsberghe 2001).

The significance of these correlations and their methodologies of these studies are open to scrutiny but these numbers inceasingly find their way from reports to ministerial speeched and ultimately science policy. But such correlations tell us nothing about the *mechanisms* by which research benefits society or what sort of research has the most benefit.

Many studies have listed the potential ways in which basic science research can have added benefits to society and there have been various attempts to formally classify these (Salter & Martin 2001; Godin & Dore 2003), but broadly they are

(1) new knowledge ('know-what')

This is the traditional information output of science: codified knowledge
(2) training skilled people (‘know-how’)
Tacit knowledge – a primary output
(3) new networks and interactions (‘know who’)
Increasingly important: explicitly recognized – eg Knowledge Transfer Networks supported by UK government.
(4) new products
Spin-off products
(5) new firms
Spin-out companies; often significant regional effects

Benefits of Astronomy

Few economists have attempted to quantify the economic impacts of astronomy. In the US, the decadal review regularly points out generic benefits of astronomy and has also listed in some detail technological spin-offs and given examples of spin-out companies. In the UK, Fabian has presented a Presidential Address to the Royal Astronomical Society on ‘The Impact of Astronomy’ and the RAS have recently published a booket on ‘Big Science for a Big Society’. Astronomy does have some unique benefits, briefly

(1) The power of astronomy to inspire people of all ages into science, increasing the scientific and technical literacy of society. This is largely because of the accessibility of science, its visual nature –producing some of the most iconic and powerful images, the existence of a vast amateur community, the ability of dedicated amateurs to make real and lasting contributions to the science and now new modes of participation in ‘citizen science’ such as GalaxyZoo, SETI@Home etc. We know from university admissions that astronomy and particle physics are the two main attractors for students into physics.

(2) The technical demands of astronomy, especially in the development of the most sensitive detectors at all wavelengths, precision timekeeping and signal processing. Astronomers made significant inputs into the development of imaging CCDs, X-ray, IR, UV detectors etc.

Particle physicists make a similar case for attracting students, wide public interest, (often appealing to cosmology), technical demands for detectors and electronics.

Benefits of Big Science

The big-science aspect of particle physics and astronomy has its own benefits. The combination of purchasing power, technical demands and collaboration with scientists, means that the significant sums of money spent by these projects in industry is a significant boost to these industries. CERN studies indicate that for every €1 spent in industry those industries generate €3 additional utility (increased turnover plus any cost savings). This figure is based on studies covering the period 1955-1982 (Schmied et al 1977, Bianchi-Streit et al 1984) but the number appears to be robust and is consistent with findings by ESA in the space sector.

A more recent study by Autio et al (2003) used interviews with companies with whom CERN had placed contracts to attempt to understand how these companies benefitted. Significant numbers (35% and 17% respectively) developed new products or opened a new market.

Benefits of Radio Astronomy

Radio astronomy has its own benefits, not surprising given its development by collaborations between astronomers and radio engineers, and it went from small scale experiments to big science in a very short period. In the UK, Jodrell Bank worked closely with engineering companies on big dishes, their computer control, the development of digital computers, the development of low noise amplifiers; at Cambridge, the techniques of radio interferometry were exploited for novel software-based positioning systems (the Matrix System) by a profitable spin-out company Cambridge Positioning Systems and deconvolution techniques developed for radio astronomy have been used for a wide range of applications again by a successful spin-out company (MaxEnt). In the US, radio astronomy requirements and applications were important in the commercialization of hydrogen masers for precise timekeeping. Microwave thermography, whether for diagnosis of deep tumours (longer wavelengths penetrate further than infra-red thermograpy) or for security applications has roots in radio astronomy imaging

The most successful and ubiquitous spin-off from radio astronomy has been the development of the signal processing algorithms and their implementation on custom chipsets by John O'Sullivan and colleagues at CSIRO [can expand…]

The Square Kilometre Array

SKA is a unique project in a number of ways: it was born as a global collaboration bringing together essentially all the technical experts in radio astronomy; it is a huge leap in capabilities, in the science it will deliver, the technology it will use, and its sheer scale. Because of this scale, the production volumes involved and the pressure to reduce unit cost (both in capital terms and operations/maintenance costs over the longer term) it requires a new way of working together with industrial partners.

Many of the technologies which will be part of SKA have potential applications outside SKA and in many cases the development of existing technologies for SKA will provide significant utility to the companies involved.

Dishes, antennas and receivers

The dishes themselves represent one of the major costs and in a fixed budget the sensitivity (at the mid or high frequencies) will be significantly determined by the cost per unit area of these dishes. The precursor instruments MeerKAT and ASKAP are giving an indication of developments in dish manufacture. ASKAP have contracted

CETC54 in China to supply 36 x 12-m dishes and novel low-cost techniques for moulded composite antennas are being pursued by South African and Canadian groups.

Achieving the wide field of view required for SKA at its mid-frequencies will require the development of novel antenna arrays. These may be focal-plane arrays at the focus of dishes or aperture arrays on the ground. For focal plane arrays, the drivers include a lightweight and compact structure; for aperture arrays the pressure is on cost per unit area. Some novel designs have already emerged including the Octagon Ring Antenna developed by Zhang, Brown and colleagues in Manchester, which is already generating interest from other communities.

The numbers of individual receivers required is stimulating development of highly integrated receivers – a whole receiver, or even a whole system including digital signal processing on a chip. A collaboration between CSIRO and Sapphicon in Australia is developing such chips using a novel silicon on sapphire process. Other groups, including Manchester, UK, have developed designs for low-cost, low-noise wideband amplifiers, stimulated by SKA which could find a wide variety of applications.

Digitial signal processing and transport

Aperture array stations require substantial digital signal processing at each station to carry out beamforming and calibration. LOFAR has already pioneered the approach at low frequencies, with SKA the challenge is to do this with much higher bandwidths, many more beams and >100x the number of elements, while minimizing the cost and power consumption.

Each dish will generate ~ 100 Gb/s and mid-frequency aperture array stations will generate ~10 Tb/s each, so total data rates will be measured in Pb/s. A substantial part of this will need to be transported over hundreds of kilometers and some over 1000's of kilometers. This is several hundred times larger than say the total data flow through any of the worlds largest internet exchanges; indeed its much more than the total data flow in the world. The LHC data flow from CERN to the Tier-1 processing centres is currently 10 x 10 Gb/s (ie 0.1 Tb/s); this may increase to 1 Tb/s over the next 5 years. Radio arrays are already transporting larger volumes over privately owned fibre networks: EVLA transports >3 Tb/s over ~20km while e-MERLIN in the UK has a total data flow of 0.2 Gb/s with a longest link of more than 400km. So we already have some experience of low-cost Tb/s self-managed networks at the national level. Scaling this up to SKA will require close collaboration with industry and clearly represents a challenge and an opportunity for innovation, possibly in new techniques for high bandwidths (>= 100Gb/s per channel) but also in low cost and reliable installations of many 10Gb/s channels. The transmission equipment itself will need to be closely integrated with the digital electronics at each telescope (perhaps at the chip level – another opportunity for 'system on a chip' integration).

Power Generation

Power generation for SKA is a significant issue – the requirement is of order 100MW, similar to the average requirement for CERN/LHC or one of Google's larger US data centres. For SKA this is roughly equally split between centralized processing and the remote dishes and aperture arrays.

As with data centres, it is the electronics and the cooling that uses the power, so the prime focus is to reduce the requirement. Much of the digital signal processing may be on custom-designed chips so there are real opportunities to develop low-power devices as well as efficient processing architectures all of which will have wider implications.

SKA offers real opportunity to lead the way in terms of renewable power – the ambition is to power SKA entirely from renewable resources – and as a high-profile, global project this could have a lasting political impact.

The sites in Australia and South Africa lend themselves to solar power and options for photovoltaic (PV) and concentrated solar thermal power (CSP) have been considered in some detail. Currently CSP is cheaper to install, has higher capacity (there are several 100-150 MW systems in operation or under construction), and has cheaper options for thermal energy storage (molten salt;.the first CSP system which uses molten salt directly has just opened in Sicily). Portugal has led the way with photovoltaic systems; currently they are more expensive to install, but the price is falling fast; they are cheaper to operate, but require batteries to store the energy. Although the plant required for SKA would not greatly exceed those already being constructed, the global nature of the project and its high profile may lead to some decisive breakthroughs.

In Australia, the commitment to renewable energy for SKA has already stimulated €40m funding for research into solar and geothermal energy supplies.

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