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| **Institution:** The University of Manchester | | |
| **Unit of Assessment:** 9 (Physics and Astronomy) | | |
| **Title of case study:** Radio astronomy and big data - bringing STEM training to the developing world | | |
| **Period when the underpinning research was undertaken:** January 2000 – December 2020 | | |
| **Details of staff conducting the underpinning research from the submitting unit:** | | |
| **Name(s):** | **Role(s) (*e.g.* job title):** | **Period(s) employed by submitting HEI:** |
| Robert Beswick | Reader, Head of Science Operations and Support, UK's National Radio Astronomy Facility, e-MERLIN/VLBI | 2002 – present |
| Anna Scaife | Professor | 2015 – present |
| Benjamin Stappers | Professor | 2007 – present |
| Peter Wilkinson | Emeritus Professor (2014 onwards, Professor (1993 – 2014) | 1993 – present |
| Rene Breton | Professor (2020 onwards), Reader (2017 – 2020), Lecturer (2016 – 2017), Marie Curie Fellow (2014 – 2016) | 2014 – present |
| Anita M S Richards | Hon. Senior Research Fellow (2020 onwards), Postdoctoral Research Associate (2004 – 2020) | 1998 – present |
| **Period when the claimed impact occurred:** 2015 – 2020 | | |
| **Is this case study continued from a case study submitted in 2014?** N | | |

## 1. Summary of the impact

The Jodrell Bank Centre for Astrophysics (JBCA) is a leading contributor to human capital development (HCD) around STEM training and infrastructure development in Africa and across the developing world. JBCA established the 'Development in Africa with Radio Astronomy with Big Data' (DARA Big Data) programme, and is a leading institute in the precursor DARA project, which deliver comprehensive programmes of STEM training and advancement opportunities across sub-Saharan Africa. These are underpinned by JBCA's research in radio astronomy, including Very Long Baseline Interferometry (VLBI) and the Square Kilometre Array (SKA), and data science. The impact is global, with JBCA programmes working from Africa and the Americas (Colombia, Mexico) to Europe (Latvia) and Southeast Asia (Indonesia, Thailand). These have expanded STEM education and data science skills, thus helping to lay the foundations for these developing regions to thrive as future data and science-driven economies.

## 2. Underpinning research

VLBI synchronises multiple radio telescopes, often thousands of kilometres apart, allowing them to operate in concert as single entities, greatly increasing their angular resolution, sensitivity and scientific capabilities. The planned African VLBI Network will span sub-Saharan Africa using repurposed large (32-m diameter) ex-telecoms dishes alongside new telescopes. This distributed facility will work with South African and European/UK research infrastructures, enabling new radio astronomy projects to be conducted with greater resolution and capability, and is paving the way to the final continental-scale phase of the Square Kilometre Array (SKA).

JBCA (including Jodrell Bank Observatory) is a leading centre for research in radio astronomy and associated big data, operational infrastructure and technology development. This wide body of research underpins a network of multiple STEM training and development activities.

**Development and operations of radio telescopes infrastructures:** UoM developed and operates e-MERLIN, the UK's National Radio Astronomy facility, and coordinates the UK's involvement in VLBI collaborations around the world. In 2010, a consortium of researchers, including from UoM, published a research article containing modelling experiments that demonstrated the potential benefits of converting the Goonhilly telecommunications antennas into radio-telescopes for use in e-MERLIN and VLBI **[1]**. These new simulations quantified the research benefits that could come from the antenna conversion, and served as an exemplar for similar projects around the world. Accompanying this, a team including UoM researchers,

documented the conversion of a 30-m telecommunications antenna in New Zealand into a radio telescope **[2],** with an emphasis on the mechanical and electrical challenges. These research papers **[1, 2]** inform the principles, practicalities and benefits of converting redundant telecommunication antennas into radio-astronomy facilities, including the newly converted 32-m radio telescope at the Ghana Radio Astronomy Observatory (GRAO) – the first operational African VLBI Network telescope outside of South Africa.

**Instrumentation and big-data:** In 2010, UoM researchers presented experimental data and technical descriptions of the European Pulsar Timing Array, designed to detect long-wavelength gravitational waves **[3]**. Notably, this describes UoM-led research in pulsar timing, acquisition and analysis systems involved, and demonstrated new upper limits to the amplitude of a gravitational background. This directly evolved into the UoM-developed 'Hebe' systems deployed as the early-science instrument at GRAO, as described in **[4]**. These papers aided the successful repurposing of the GRAO telescope, creating local research opportunities, and is used in DARA human capital development training.

In 2019, the researchers published big data research developing cloud-based open-source processing software for real-time pulsar candidate identification and characterisation **[5]**. This resource-efficient algorithm and optimised selection methods enabled accurate, high-throughput pulsar filtering using limited resources. Prototyping work demonstrated that key pulsar processing can be scaled to SKA data using present-day commercially available hardware. The protocols developed for data acquisition and characterisations **[3, 4, 5]** informed the DARA/DARA Big Data training programme and hackathons. Furthermore, data collected from GRAO with Hebe**,** and analysed with derived techniques, is used in practical training **[5]**.

**Astrophysics to HCD training:** DARA and DARA Big Data training material was developed by UoM staff, based upon UoM VLBI and big data (including above) research. Examples include **[6]**, in which the UoM researchers developed state-of-the-art calibration techniques for VLBI data. Data, analysis techniques and science from **[6]** have been directly used for advanced training, curriculum design and online content; key parts of the DARA programme.

## 3. References to the research

Researchers from the University of Manchester are in bold.


[1] Woodburn, L., Natusch, T., Weston, S., **Thomasson, P.**, Godwin, M., Granet, C., Gulyaev, S., "Conversion of a New Zealand 30-Meter Telecommunication Antenna into a Radio Telescope", 2015, *PASA*, 32, 17. DOI: 10.1017/pasa.2015.13

[2] Klockner, H-R., Rawlings, S., Heywood, I., **Beswick, R. J.**, **Muxlow, T. W. B.**, **Garrington, S. T.**, Hatchell, J., Hoare, M. G., Jarvis, M. G., Jones, I., van Langevelde, H. J., "Goonhilly a new side for e-MERLIN" 2010, *Proceedings of Science*, 10th European VLBI Network Symposium, 22. DOI: 10.22323/1.125.0022

[3] **Ferdman, R. D.**, *et al.*, "The European Pulsar Timing Array: Current efforts and a LEAP toward the Future", 2010, *Classical & Quantum Gravity*, 27, 8. DOI: 10.1088/0264-9381/27/8/084014

[4] **Scragg, T.**, **Stappers, B. W.**, **Breton, R. P.**, Smith, J. N., Adomako, D, Duah Asabere, B, Chibueze, J. O, Cloete K., "Pulsar Observations at the Ghana Radio Astronomy Observatory" 2017, *Proceedings of the International Astronomical Union*, 13, 410. DOI: 10.1017/S1743921317009152

[5] **Lyon, R.**, **Stappers, B. W.**, **Levin, L.**, **Mickaliger, M. B.**, **Scaife, A.**, "A processing pipeline for high volume pulsar candidate data streams" 2019, *Astronomy & Computing*, 28. DOI: 10.1016/j.ascom.2019.100291

[6] **Radcliffe, J. F.**, **Garrett, M. A.**, **Beswick, R. J.**, **Muxlow, T. W. B.**, Barthel, P. D., Deller, A. T., Middelberg, E., "Multi-source self-calibration: Unveiling the microJy population of compact radio sources", 2016, *A&A*, 587, 85. DOI: 10.1051/0004-6361/201527980


## 4. Details of the impact

Just a decade ago the few astronomers in African VLBI Network partner country universities outside South Africa faced difficulties of isolation and lack of access to facilities. Likewise, these countries also suffered from a dearth of opportunities and skills training in computational and data-science techniques vital for the development of competitive and sustainable research communities. These skills and opportunity gaps threatened the sustainability of new research infrastructures being built in Africa, such as the SKA, and severely reduced the benefits for hosting countries. However, the largest impact of these skills deficits is that they impede developing countries' ability to compete and thrive as data driven economies **[A, B]**.

To help address this in multiple low income and developing countries the UoM has been at the forefront of a global network of projects, established between 2015-17, delivering advanced STEM and data science human capital development training inspired by radio astronomy. These include the UoM-led DARA Big Data, EC JUMPING JIVE 'VLBI in Africa' programmes, DARA (led by the University of Leeds with the Universities of Manchester, Oxford, Hertfordshire, Bristol, and UCLAN) and parallel initiatives in Latin America (UoM-led 'Radio Astronomy for Development in the Americas' RADA, Colombia), and south-east Asia (Thailand) **[A].** These programmes have been shown by independent reviews **[A, B]**, and the African Governments **[C, D, E, F],** to be *"building self-sustaining research communities"* across Africa, and *"using Big Data challenges… to develop, promote and encourage the translation of data intensive methodologies between diverse research fields such as astrophysics, health data, and sustainable agriculture, and providing science communication training essential for data-informed policy engagement"* (**[F]**, Deputy Director-General, Department of Science and Technology, South African Government).

Upskilling the local workforce in data intensive science and STEM skills aids economic growth; supports development and investment in new research infrastructures like the African VLBI Network, and is providing the foundation for African partner countries to realise the benefits from major research infrastructure investment such as the SKA. These programmes have provided STEM outreach, training, and advanced postgraduate opportunities for African trainees, which translate into skills and opportunities for African communities. This impact is further corroborated by the South African Commissioner for the 4IR ('Fourth Industrial Revolution', and former SKA South Africa Director, who describes the work of DARA/DARA Big Data as *"an important catalyst in South Africa and its African partner countries (and beyond) in developing readiness for the 4IR"* **[E]**.

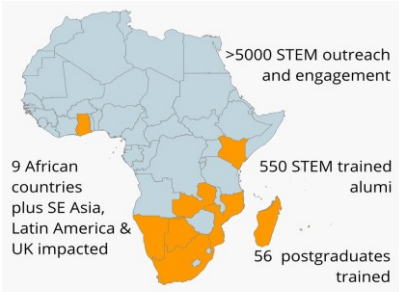


***Figure 1**: Training by numbers. Globally these programmes have reached thousands of young individuals with direct involvement of UoM staff spanning multiple continents. JBCA, UoM, is the largest UK provider of expert trainers and staff time to these projects.*

**Pathways:** So far over 550 people have received up to 8 weeks of intensive training, hackathons and workshops delivered by programmes across 8 African countries (Botswana, Kenya, Ghana, Namibia, Zambia, Madagascar, Mozambique and Mauritius – see Figure 1), plus South Africa and Colombia, Thailand, Mexico and Indonesia. These programmes bring together academics and their research, alongside industry and space agency experts, professional outreach and development partners, and experts in international science policy advocacy to provide a full spectrum of training. Using this wide array of expertise and a tiered approach these projects have, to date, reached 1000s of school-aged children, community leaders and policy makers through STEM outreach, science promotion and science policy training. The projects have provided STEM and data-science training for young adults, advanced science and technology internships in Europe, and hosted postgraduate positions for 56 students to date, along with soft-skills and business/entrepreneurial mentoring **[A, C, F, G].**

**Human Capital Development:** Our programmes focus on STEM training, and computational data-driven techniques and skills, which enhance capacity across these countries. UoM research **[1-6]** has informed and been widely incorporated into the syllabus content and activities. The DARA Big Data hackathon format uses relevant local real-life datasets and issues, from crop development and drought management in Kenya, to machine learning

analysis of social media's role in influencing attitudes to the COVID-19 pandemic such as public perceptions of schools reopening in Zambia or the tendency for people to see COVID-19 as a hoax. This format has gone on to inspire hackathons run by the International Astronomical Union's Office of Astronomy for Development, the Inter-university Institute for Data Intensive Astronomy and the Big Data Africa initiative reaching an even large international audience **[B, E]**.

DARA graduates receive "*high-quality training helping to develop the first generation of astronomers and operational scientists within these developing nations*" **[A].** In many cases similar opportunities were not available prior to DARA/DARA Big Data, and essentially no professional astronomers previously worked in many of the countries where these projects run. The returning DARA/DARA Big Data postgraduate alumni are amongst these countries' first research astronomers. They are role models for the next generation, and are fostering a self-sustaining pipeline of talent and interest in science **[C, D, H, G]**. Furthermore, several businesses and outreach programmes have been set up by DARA/DARA Big Data alumni, benefiting from the skills and guidance provided. Examples include; ethical astro-tourism businesses, such as Sayari and M87 founded in 2018-19 in the Maasai Mara, Kenya; start-up businesses in Zambia, and schemes promoting STEM subjects and supporting gender equality in science education in Ghanaian and Kenyan schools reaching 1,000s of students.

DARA/DARA Big Data projects are internationally recognised to have solidified research infrastructure investment in Africa through skills enhancement and influencing the views of leaders and politicians **[D, E, F]**. A 2019 Ministerial Joint SKA Africa partner meeting highlighted the *"significant advances in (a) human capacity development initiatives, (b) the strengthening of relevant institutional capacities, (c) the formulation of new academic programmes around physics and astronomy, (d) the roll-out of high-performance computing capability and big data training interventions and (e) science engagement and outreach",* and expressed *"unanimous appreciation of the DARA and DARA-BD* [DARA Big Data]" **[C]**.

**Data-informed policy:** Wide engagement in data-informed policy is more prescient than ever. A central theme of DARA Big Data is science communication and advocacy for policy engagement. Six UK-based policy fellowships and two MScRs have been created for African students, providing rigorous science policy development and communication training. This has fed into high level discussions, resulting in the development of white papers with the Kenyan government on Food Security and Drought Management, and contributed to UK Government briefing notes detailing environmental remote sensing and machine learning **[I]**; helping to inform and shape future government policy both in Africa and the UK **[E, F]**. The UK BEIS's independent thematic impact assessment **[A]** summarised influence of these actions as: *"The success shows that the concept of development for astronomy and the DARA project, has managed to capture the imagination of policy makers and funders, and created a pipeline of interest in Africa and beyond".*

**The GRAO antenna:** UoM research, exemplified by **[1, 2, 5]**, has helped to motivate and inform the conversion of a redundant telecommunication antenna for radio astronomy and developed key components (such as, advanced receiver backend processing system **[1]**) and data handling (software *e.g.* Hebe **[2, 5]**). This has been deployed on, and essential to the success of, the former Vodafone 32 m antenna at GRAO, Ghana. The GRAO antenna was inaugurated by President Nana Addo Dankwa Akufo-Addo of Ghana **[D, J]** in 2017. At this event the Head of Africa Planning, SKA South Africa commented that **'***attaining the SDGs* [United Nations' Sustainable Development Goals] *depend very much on Africa's ability to gather data on health, education, agriculture, sanitation and the economies to make informed decision, and that was what the observatory would help in attaining'* **[J]**. Thus far over GBP4,500,000 **[J]** has been invested by the South African and Ghanaian Governments in the conversion at GRAO, benefiting communities by improving local services (*e.g.* roads and internet provision) and training essential skilled workers such as "*electrical, software, and mechanical engineers",* as stated by the Director of GRAO **[J]**. The accompanying human capital development programmes are an essential part of this, encouraging *"young people to take up science"* and *"increasing science and innovation"*, according to the Minister of

Environment, Science, Technology & Innovation, Ghana **[D]**, thus providing wide and sustained community benefits (*ibid*, **[C]**).

**5. Sources to corroborate the impact**


[A] Independent thematic Impact Study Report (July 2018) on the impact of the Newton Fund in South Africa commissioned by UK Government Department BEIS by Coffey (consultancy firm specialising in international development). https://www.newtonfund.ac.uk/files/newton-fund-evaluation-south-africa-report/

[B] Independent review of *'Big Data and Industry Skills Development Support'* in Africa on behalf of the Inter-university Institute for Data Intensive Astronomy (IDIA) in South Africa. Assessment report is authored by Prof. Carolina Odman (University of the Western Cape, SA) and outlines the role and impact of DARA Big Data in skill development across Africa. https://www.idia.ac.za/schools-hackathons-and-skills-development/

[C] Joint media statements on the outcomes of the 5th and 6th SKA Africa Partner country (Botswana, Ghana, Kenya, Madagascar, Mauritius, Mozambique, Namibia, South Africa and Zambia) Strategic/Ministerial meetings (2018 and 2019) https://www.dst.gov.za/index.php/media-room/latest-news/2933-joint-media-statement-on-the-outcomes-of-the-6th-ska-africa-partner-countries-meeting and https://www.sarao.ac.za/newsletters/sarao-news/02-2018/joint-media-statement-on-the-outcomes-of-the-5th-ministerial-meeting-of-the-square-kilometre-array-african-partner-countries/

[D] Letter from Ghanaian Minister of Environment, Science, Technology and Innovation, Prof Kwabena Frimpong-Boateng, corroborating the impact of DARA in Ghana (3 March 2020).

[E] Letter corroborating the impact of DARA-Big Data and DARA (28 January 2021) on South Africa and African partner countries from Prof. B. Franaroff (South African Commissioner for the 4th Industrial Revolution (2019-), and former Project Director for SKA South Africa (2003-2015))

[F] Letter corroborating impact of DARA and DARA-Big Data (11 February 2021) from Daan de Toit, Deputy Director-General: International Cooperation and Resources, Department of Science and Technology, South African Government (https://www.dst.gov.za)

[G] Testimony about the DARA project upon receipt of the Space & Satellite Professionals International 2018 Better Satellite World Award for 'significant contributions to global good' (https://www.sspi.org/cpages/dara)

[H] Two testimonials from Kenyan and Ghanaian DARA alumni published in NatureJobs Blog articles published in February 2018 detailing the role and impact of DARA from a participant's perspective. (http://blogs.nature.com/naturejobs/2018/02/28/african-astronomy-and-how-one-student-broke-into-the-field/ and http://blogs.nature.com/naturejobs/2018/02/26/a-student-shaping-the-future-of-african-astronomy/)

[I] POST Note - article 628, June 2020 – 'Remote sensing and machine learning'. Input into UK Government regarding the use of machine learning for the analyses of remote sensing early observations data and increasing our understanding of complex environmental systems. Key contributions by UoM Profs. A. Scaife & R. Breton. https://post.parliament.uk/research-briefings/post-pn-0628/

[J] Joint Ghanaian Ministry of Environment, Science, Technology and Innovation Government, and South African Department of Science and Technology statement on the occasion of the inauguration of the 32-m Radio Telescope in Kuntunse in 2017 (http://mesti.gov.gh/launch-ghana-radio-astronomy-observatory/).