Institution: University of Oxford		
Unit of Assessment: 9 - Physics		
Title of case study: The Global Jet Watch: engaging schoolgirls in developing countries in science		
Period when the underpinning research was undertaken: 2005-present		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed:**
Professor Katherine Blundell	Professor of Astrophysics	01/10/2000 – present
Period when the claimed impact occurred: 1 August 2013 – 31 December 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

The twin goals of the Global Jet Watch observatories combine cutting edge research in astrophysics with engaging schoolgirls around the world (including South Africa and India) into science. The embedding of these observatories within residential schools, in cultures that do not traditionally think of women as scientists, has resulted in schoolgirls: (i) being eyewitness observers to authentic research, (ii) operating research-grade telescopes themselves, (iii) becoming proficient in operating sophisticated technology and control software and (iv) hearing talks about different aspects of science, engineering and being a scientist. Over 2,000 schoolgirls between Q4-2013 and Q4-2020 have been introduced to astronomy via the Global Jet Watch. Participation in the Global Jet Watch has encouraged girls to pursue STEM careers.

2. Underpinning research (indicative maximum 500 words)

The details of the causes and effects of accretion to and ejection from near a black hole are poorly understood and notoriously hard to test. One way in which such systems can potentially be studied is through the measurement of the properties of the plasma jets through which matter is expelled. However, the traditional application of the Doppler effect to this measurement problem cannot separately determine the two most useful quantities — the launch speed and launch angle of the jets, hindering studies of the astrophysical mechanisms at play. However, research undertaken by Blundell at the University of Oxford shows that these quantities can be decoupled by application of equations 2 and 3 of **[Ref-1]** which is a key part of the research that underpins the Global Jet Watch. These equations take two observables: the simultaneously measured redshift and blueshift of oppositely-directed jets of protons and electrons ejected from a black hole system, measured in a single optical spectrum, as illustrated in Fig 1. They give two separate physical quantities: the launch speed and launch angle of the plasma jets. In effect, the application of this methodology transforms a traditional spectrograph into a speedometer allowing access to two key physical properties which, when combined with information about the matter accreted towards the black hole at earlier times, enable quantitative and testable modelling. The use of these concepts was pioneered in **[Ref-2]**.

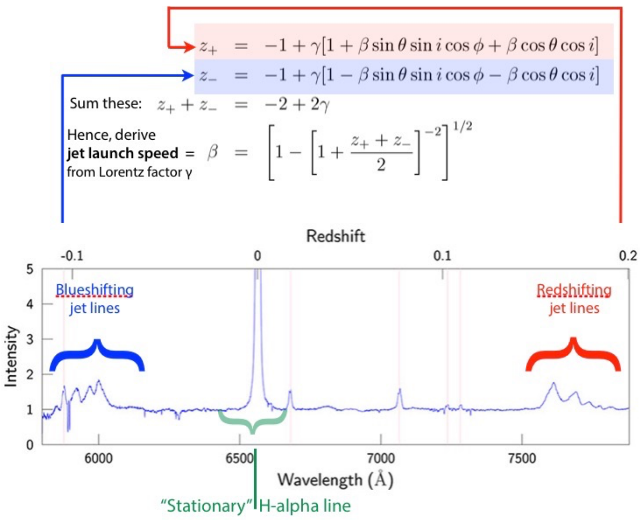

Fig 1: For the first time, a technique to simultaneously decouple the speed and the launch angle of emitted plasma jets has been developed [Ref-1]. Sequences of successive spectra reveal velocity changes resulting from an exceptional accretion event **[Ref-2]**.

The timescales over which accretion and ejection take place are hours and days, which mandates commensurate time-sampling. This is entirely possible to accomplish in principle. However, in practice it is difficult to achieve because any individual observatory located at a given longitude and latitude can only monitor a particular target, even at a typically favourable Right Ascension and Declination, with a duty cycle of at most one third in any nychthemeron. The five Global Jet Watch observatories are separated in longitude so that there is always at least one of them in darkness, enabling 24/7 monitoring of targets in the 24-hour-night sky.

High-time resolution (hours and days) is a necessary but not sufficient condition for making advances in time-domain astronomy – so too is *sustained* monitoring over the longer timescales (months and years) on which other relevant and closely related phenomena occur. For example, it is a prediction of **[Ref-3]** that circumbinary matter (i.e. matter in orbit around binary star systems) should persist on remarkably stable orbits and might therefore be relatively common in nature. **[Ref-3]** analyses and predicts the characteristics (for example, precession) of dynamic circumbinary orbits, as a function of the mass ratio of the two inner binary components and of their eccentricity, on timescales of many tens of orbital periods of the inner star in the binary (i.e., timescales of years). *Sustained, time-lapse spectroscopy* having *high-time resolution* is a rarity in astronomy, because it is not compatible with the schedules of observatories serving a diverse user community. The less resource-intensive alternative of time-lapse photometry is becoming more common but determining underlying physical processes for e.g. why a target gets brighter or fainter can be model-dependent and inconclusive if only light-curves are employed. In contrast, time-resolved *spectroscopy* is a much more powerful tool because *it can elucidate the underlying dynamical evolution*.

Motivated by the above research challenges and opportunities, the Global Jet Watch observatories were built by Professor Blundell. These round-the-world telescopes thus deliver round-the-clock spectroscopy as well as photometry on a variety of Galactic systems that evolve stochastically (such as nova explosions - exemplified by our first discovery of a circumbinary disc following a nova detonation **[Ref-4]**) and/or periodically (such as binary star systems for which we correctly disambiguated apastron and periastron **[Ref-5]**) and microquasars varying with persistent patterns, within multiple periodicities, revealing particle acceleration **[Ref-6]**).

3. References to the research (these are all articles in peer-reviewed international journals)

[Ref-1] "Jet Velocity in SS 433: Its Anticorrelation with Precession-Cone Angle and Dependence on Orbital Phase" K. M. Blundell & M. G. Bowler,
Astrophysical Journal Letters **2005**, *622*, L129-L132; doi: 10.1086/429663

[Ref-2] "SS433's accretion disc, wind and jets: before, during and after a major flare"
K. M. Blundell, L. Schmidtobreick & S. Trushkin,
MNRAS **2011**, *417*, 2401-2410; doi: 10.1111/j.1365-2966.2011.18785.x

[Ref-3] "The dynamics and stability of circumbinary orbits"
S. Doolin & K. M. Blundell,
MNRAS **2011**, *418*, 2656-2668; doi: 10.1111/j.1365-2966.2011.19657.x

[Ref-4] "Classical Nova Carinae 2018: Discovery of circumbinary iron and oxygen"
D, McLoughlin, K. M. Blundell & S. Lee,
MNRAS **2020**, *494*, 743-749; doi: 10.1093/mnras/staa651

[Ref-5] "GG Carinae: orbital parameters and accretion indicators from phase-resolved spectroscopy and photometry"
A. J. Porter, D. Grant, K. M. Blundell, S. Lee,
MNRAS **2021**, *501*, 5554-5574; doi: 10.1093/mnras/staa3749

[Ref-6] "SS433'S Jet trace from ALMA imaging and Global Jet Watch spectroscopy: evidence for post-launch particle acceleration"
K. M. Blundell, R. Laing, S. Lee, A. Richards,
Astrophysical Journal Letters **2018**, *867*, L25; doi: 10.3847/2041-8213/aae890

4. Details of the impact (indicative maximum 750 words)

The Global Jet Watch comprises a multi-longitude distribution of telescopes so there is always at least one of them in darkness which links *"astronomers at Oxford University with school children around the world in order to carry out cutting-edge research…"* says the Royal Astronomical Society **[A]**. The twin goals set at the outset of the project were to combine (1) the fundamental research aims with (2) engaging schoolgirls in developing countries into science **[Fig 2]**. Because of (2), the original four observatories were located in residential schools **[Fig 3]**, selected following a process of identifying suitable astronomical sites and personally interviewing a number of school headteachers. This process was led by Professor Blundell, who is described by the South Africa school headmistress as *"the inspiration and igniter of a love for science in the girl children of the world"* **[B]**. Much of the training of the new students takes place during servicing missions by Professor Blundell herself to the observatories **[Figs 4,5]**, but this is supplemented by interactions over Skype/WhatsApp/Zoom **[Fig 6]**.


Fig 2


Fig 3

After such training in each school observatory the students can then control the telescope for themselves and explore the night sky **[Fig 2]**. They are able to identify different objects in the night sky, use the telescopes to do target acquisition, tracking (sidereal and non-sidereal), and guiding to enable deeper observations of fainter targets. Different students enjoy various projects spanning different types of targets from catalogues of Bennett, Messier and Caldwell to different craters on the moon to the orbits of the moons of Jupiter.


Fig 4

After local bedtime, over the internet, the telescopes are remote-controlled, and the time-lapse data are relayed to Oxford. "First light" was achieved at the fourth school observatory (India) in late 2013 after which it was possible at all four schools for students to observe for themselves. Schools are fertile places in which to share scientific endeavours because each new academic year replenishes with a new cohort. More than 2,000 students have thus been introduced to astronomy between 2013 and 2020.


Fig 5

The headmistress of the South Africa school reports **[B]** that the Global Jet Watch "*captured the imagination of so many girls that [science] became seen as multi-faceted, exciting and achievable*", and the numbers of girls studying science there has grown to "*two thirds of the cohort of matriculants in the last 5-7 years*"; a cohort at this school is typically ~75. This engagement includes boarders from disadvantaged backgrounds of whom "*many have been inspired to become the next generation of scientists and have taken up the challenge to work harder… and make a difference to the world*". The first student from the South Africa school inspired to become a scientist because of her hands-on experience with the telescope since late 2013 is currently in the process of deciding which of four offers from South African universities she will accept for post-graduate work. This student writes **[C]**

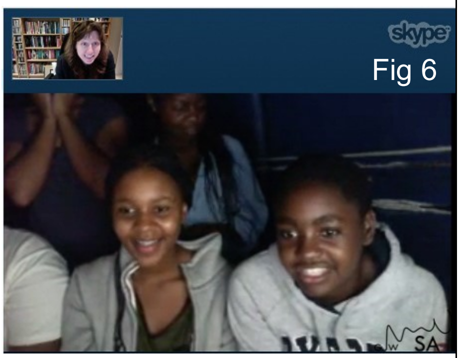
Fig 6

“*I am so, so grateful for these opportunities you gave us; these experiences led to the most growth I’ve ever had…*”

Fig 7

Fig 8

The northern-most observatory in the Global Jet Watch is hosted by a school established by the Government of India so that the bright children of rural families, who would otherwise be working on the land, can receive a formal education. The school has no library and one flushing toilet. Over half of the students are first-generation literates. This school is ethnographically diverse and includes a substantial quota for discriminated-against Dalits and Adivasi. The students rapidly attain proficiency in operating the telescope. One student wrote “*once i enter the observatory i forget everything… i feel i have entered heaven*” **[D]**; this particular student went on to study physics with engineering at a college in southern India and later reflecting on experiences at the school writes “*The experience at the observatory truly changed me as a person… it started my journey as a research student*” **[D]**.

During the pandemic lockdown of 2020, Professor Blundell was requested to give a lecture to similar Government of India schools. This lecture, entitled “Beyond our Planet”, was broadcast to a live audience of 2,500 students **[E]** and has subsequently been viewed on YouTube by a greater number still **[F]**. The lecture encouraged students to consider a career in science for themselves **[Fig 9]** and received “*tremendous appreciation from the beneficiary students*” **[E]** who “*expressed their immense happiness and gratitude*” **[G]**. During the introduction to this lecture a senior consultant in the Dept of School Education and Literacy makes reference to several students going onto Higher Education as a direct result of hands-on experience with the telescope; some such students are listed in **[H]**.

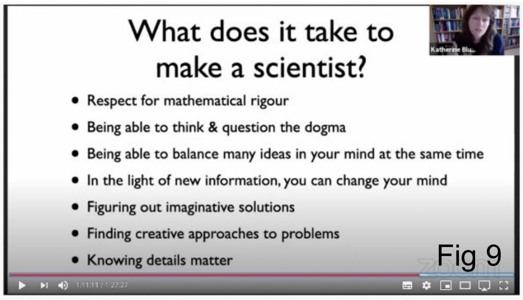

Fig 9

Under Vigyan Joshi - "Beyond Our Planet" Talk by Prof Katherine Blundell

There are numerous challenges in operating a global research/education mission in developing countries. One of these challenges concerned the lack of safe and reliable electricity, which interrupted observing; electrical spikes destroyed cameras, computers and device protectors. In order to obtain an enduring supply of safe electricity for uninterrupted operations at the India school observatory, Professor Blundell and her colleagues built a solar farm on the school roof **[Fig 7]** to enable all aspects of observatory operations to go completely off-grid **[I]**. The inquisitive and attentive audience of impressionable teenagers drawn from 300 villages across Karnataka, who watched construction, now understand that light energy is collected from our nearest star by day **[Fig 8]**, then stored as chemical energy in 2,000Ah batteries until it is needed at night to study interesting targets in the rest of the universe. But these students don’t merely *understand* this, they can *articulate* the principles – during frequent visits from other schools in the region (students and teachers from different schools who have visited now number over a thousand) – demonstrating that “*scientific trickle down*” can occur when real research meets outreach. The Physics teacher at this school in India writes of how proud he is of his students that when they have visits of “*schools from Karnataka, Andhra Pradesh, Kerala and Andaman Nicobar… these girls explain well to visiting students and visitors from outside about telescope, solar farm and Astronomy*” **[J]**.

Fig 10

The context for the students who attend (and who visit) the India school especially is very different from students at UK schools. One schoolgirl, still at the India school, said "*My parents are basically farmers. They don't know what is "Space" and "Scientists". After coming here, I was inspired from this telescope… and also from you (Prof Blundell) that I want to become a scientist."* **[K]**. The India school Principal requests that *"Prof Blundell… [continues] to be a mentor and inspiring force to our rural and talented students who in turn will become catalysts to their entire family"* **[H]**.

Opportunities for outreach have arisen for Professor Blundell as a result of the Global Jet Watch and its results, including talks in literary/science festivals, astronomical societies, schools & universities. Named lectures [with audience figures] include the 2016 Bolton Lecture at Leeds [500+], the Alfred Curtis lecture of the British Astronomical Association (BAA) [200+], the 2018 Jeremiah Horrocks Lecture UCLan [400+]. Examples of follow-up letters illustrate the effects on audiences: one schoolteacher who brought students to the Bolton Lecture wrote "*All 41 of the BGS [Bolton Grammar School] students came away excited and enthused by the talk*" **[L]**; the Global Manager of Shell Projects & Technology after the BAA talk wrote "*Your talk was the best and most interesting I have heard in a long time… for me it is back to my normal work today, but I will have an extra spring in my step!*" **[M]**.

The Global Jet Watch, together with her extensive outreach achievements **[Fig 10]**, led Professor Blundell to be appointed Gresham Professor of Astronomy in 2019. Gresham Professors are appointed "*to make new learning of contemporary relevance and academic integrity available to a wide and diverse audience*" and for having a "*record of high-level scholarship and a demonstrable ability to communicate the complexity of [their] subject to an intelligent and interested public*" **[N]**. Prior to lockdown her in-person lectures "*were filled to capacity*" **[N]** and her YouTube broadcasts reach audiences of thousands; the lecture "Cosmic Concepts: the end of Matter?", describing the Global Jet Watch, has audience figures exceeding 12,000 **[O]**.

Professor Blundell has been invited back twice for radio interviews in Australia, specifically on the Global Jet Watch, on the ABC's Science Show. This programme has been hosted by Robyn Williams for decades, and in addition to the live broadcast is downloaded as a podcast with 1,600,000 listeners. He writes **[P]** "*she has done as much to bring top-flight science to the public, young and old, as anyone I have met in 50 years of broadcasting*" and that he often uses the Global Jet Watch "*as an example of what can be done with young people, especially girls, by taking them seriously whatever their educational level or ethnic background*".

Other recognition for the Global Jet Watch was Professor Blundell's appointment to OBE in the 2017 Queen's Birthday Honours "*for services to astronomy and the education of young people*".

5. Sources to corroborate the impact

[A] Royal Astronomical Society Citation for George Darwin Lectureship 2015
[B] Letter from Headmistress of South Africa school
[C] Letter from South Africa student
[D] Email from student at India school
[E] Letter from Senior Consultant to the Dept of School Education and Literacy
[F] Screengrab of lockdown lecture "Beyond our Planet" with YouTube viewing numbers
[G] Thank you letter from Principal of one of the Indian schools (not the school that hosts our observatory) who watched the lockdown lecture, mentioning the students' reactions.
[H] Letter from India school principal
[I] Website describing the solar farm next to the observatory on the India school roof (www.GlobalJetWatch.net/solar/technology)
[J] Letter from Physics Teacher at India school
[K] 3-min movie with India schoolgirls describing their reactions to the Global Jet Watch (www.GlobalJetWatch.net/news/what-is-the-global-jet-watch)
[L] Letter from a UK teacher who brought a school party to 2016 Bolton Lecture
[M] Letter after lecture to amateur astronomers (Global Manager Shell Projects & Technology)
[N] Letter from Gresham Provost
[O] Screengrab of Gresham lecture "The End of Matter?" with YouTube viewing numbers
[P] Letter from presenter of the ABC's Science Show