

90 years on – the 1919 ecli



Richard Ellis, Pedro G Ferreira, Richard Massey and Gisa Wozniak return to Príncipe in the International Year of Astronomy to celebrate the 1919 RAS expedition led by Sir Arthur Eddington.

The first experiment to observationally confirm Einstein's General Theory of Relativity was carried out in May 1919, on a Royal Astronomical Society expedition to observe a total solar eclipse. Sir Arthur Eddington travelled to Príncipe, a small island off the west coast of Africa, and sent another team to Sobral, Brazil, from where the eclipse would also be visible. This year, in a new RAS-funded expedition organized for the International Year of Astronomy, we returned to Príncipe to celebrate this key experiment that shook the foundations of 20th-century science.

Since 1687, Sir Isaac Newton's law of gravity had been the workhorse of celestial mechanics. Newtonian gravity could be used to explain the motions of a host of celestial bodies and the heavens were reliable and predictable. There was one small discrepancy: accurate measurements of Mercury's orbit did not quite fit the Newtonian paradigm. Mercury was observed to precess around the Sun slightly too quickly, by an extra degree for every 8400 years. By the end of the 19th century, attempts to explain the anomaly with classical solutions, such as unseen moons or interplanetary dust, had failed.

Einstein's new idea

New theories were suggested in which gravity, rather than acting instantaneously, is transmitted only at the speed of light. The most elegant of these was Einstein's General Theory of Relativity. Einstein proposed that the fabric of both space and time is warped, and that the speed at which these warps can propagate is limited. The precession of Mercury can then be explained: it is always being attracted towards the place where the Sun was three minutes earlier. Warped space-time around massive bodies implies that passing rays of light should be deflected. Arguments can be made for the gravitational deflection of light by treating it as corpuscular within Newtonian theory; however, if space and time are distorted, Einstein calculated that the deflection should be exactly twice that predicted in Newtonian theory. It was quickly realized that the Sun was the only local body massive enough to produce a measurable deflection and, while

stars near the Sun are not normally visible, they would be during a total solar eclipse.

Einstein attempted to convince observers to measure the gravitational deflection. He found an enthusiastic colleague in Erwin Finlay-Freundlich, whose expedition to Russia in August 1914 was scuppered by the outbreak of war in the very month of the solar eclipse: as a German national in Russia, he was arrested. William Campbell, Director of the Lick Observatory, was similarly unlucky in his attempts. His missed the 1914 eclipse and another in June 1918 in Washington State due to thick cloud. In hindsight, it was quite fortunate for Einstein that no-one between 1911 and 1918 found cloudless skies; an incorrect calculation in his early work meant that his theory would have been disproved. Einstein refined his calculations during the war and predicted that stars at the limb of the Sun would appear to move 1.7 arcseconds from their true positions.

It was Sir Frank Dyson, the Astronomer Royal, who recognized the unique opportunity of the 1919 eclipse. The Sun would be in front of the rich Hyades star cluster, the densest population of bright stars on the ecliptic plane. These would provide plenty of background sources in which to measure a deflection. However, Eddington became the driving force behind the expedition because he was personally inspired by the significance of Einstein's theory. The RAS organized two parallel teams: Eddington and Edwin Cottingham to the cocoa plantation at Roça Sundry, Príncipe; and Andrew Crommelin and Charles Davidson to Sobral, in northeastern Brazil.

At the time of Eddington's expedition, Príncipe formed part of Portuguese colonial territory, and correspondence recently unearthed at the Geographical Society of Lisbon reveals that the RAS had already begun asking for maps and permission to visit the island during the war. The eclipse would be visible across South



1: The old plantation buildings at Roça Sundry, Eddington's base in 1919.

America and Africa, but it was important to be as close as possible to the sub-solar point, where the Earth's rotation keeps observers in the Moon's shadow for longer, thereby extending the observing window.

Eddington observed the Hyades star cluster from Oxford at night time in January and February 1919. In May, heavy clouds on Príncipe cleared just in time for the eclipse and, during the six-and-a-half minutes of totality, Eddington took comparison photographs: the stars were shifted by the full Einsteinian deflection. The result was announced to the world in newspapers and then in the *Philosophic Transactions of the Royal Society*. It helped reunite a world torn apart by war. As JPMcEvoy wrote in *Eclipse*: "A new theory of the universe, the brainchild of a German Jew working in Berlin, was confirmed by an English Quaker on a small African island." Eddington considered his verification of the deflection, which he glimpsed via an early analysis of his plates while still on Príncipe, the greatest moment of his life.

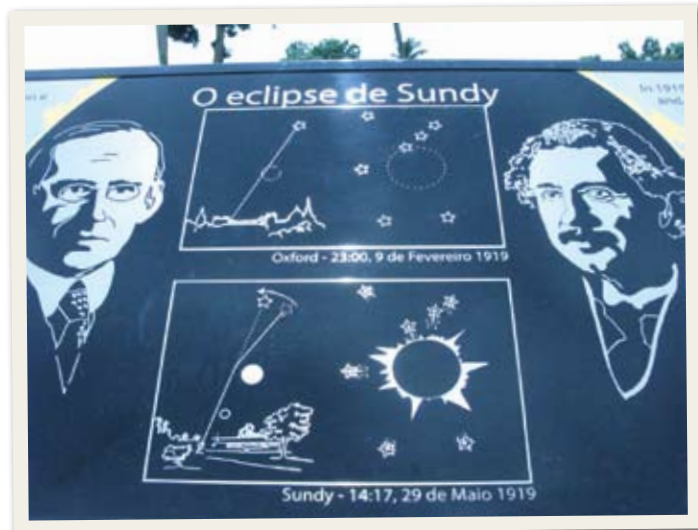
Poor weather

While some historians suggest that Eddington's faith in the General Theory of Relativity may have blinded him to contrary evidence, a recent analysis by D Kennefick has dispelled this notion. The basis of the controversy was that remaining partial cloud at Príncipe permitted only two successful astrographic plates to be taken, with five stars on each; the resulting deflection was 1.61 ± 0.30 arcseconds, while Einstein predicted 1.75 arcseconds. By contrast, several plates taken with an astrograph at Sobral,

pse expedition at Príncipe



2: Unveiling of the plaque, with President Cassandra on the right.



3: Close-up of the plaque explaining why Eddington came to Príncipe.

with 12 stars on each, yielded a deflection of only 0.93 arcseconds.

It has been claimed that Eddington dispensed with some of the Sobral data without good reason. However, the Sobral plates were out of focus, leading to great uncertainty in the plate solution. An independent Sobral telescope with a 4 inch lens gave a deflection of 1.90 ± 0.11 arcseconds, consistent with the deflection observed at Príncipe. And it was in fact Dyson who initially rejected the results from the Sobral astrograph, not Eddington. In 1979, a reanalysis of the Sobral plates using modern equipment measured a deflection of 1.55 ± 0.32 arcseconds. The expedition was the first to satisfactorily confirm Einstein's prediction, and Eddington's observations from Príncipe were a key component of that process.

Cocoa controversy

The Portuguese discovered the uninhabited islands of São Tomé and Príncipe in the 1470s. They introduced vast plantations of sugar cane, followed later by coffee and cocoa. The intensive plantation economy was initially made possible by slave labour and, from the 19th century, by the so-called service and contract labourers who were brought in primarily from Angola and Cape Verde. These labourers

sparked a brief British–Portuguese controversy a few years before Eddington's visit.

By the early 20th century, São Tomé and Príncipe had become world leaders in cocoa production. Around 1905, the young British journalist Henry Nevinson called attention to the appalling conditions in the Portuguese colonial plantations, alleging infringement of 19th-century international treaties on the abolition of slavery. These allegations indicted chocolate manufacturer Cadbury Brothers, which drew a large part of its supply from Príncipe, forcing the company to justify its use of Portuguese cocoa before an English court. Cadburys boycotted Santomean cocoa until the death rate of labourers declined, but even after the boycott had been lifted continued to import cocoa primarily from the Gold Coast, where production on locally owned land had proved more successful.

The incident remains controversial to this day, with some commentators suggesting that the slavery allegations were engineered in order to give the British colonies an advantage in the increasingly overcrowded global cocoa market. Although we can presume that Eddington was aware of the controversy – Lord Cadbury was a fellow Quaker, and the trial had been widely publicized – he does not mention it in the few letters he sent back home from his trip.

Einstein and Eddington's legacy

Einstein's theory and Eddington's experiment transformed the landscape of physics and astronomy. The General Theory of Relativity established, for the first time, a mathematical framework within which it was possible

to track through calculation the evolution of the universe as a whole. Big Bang cosmology has proved hugely successful in predicting the overall structure of the universe and many finer details. For example, it predicts that the universe is expanding and that distant galaxies are receding from us at a speed that is approximately proportional to their distance. This has been amply confirmed by redshift measurements throughout the 20th century. The Big Bang universe was hotter and denser in the past, and we have now seen exquisite evidence for the primordial fireball in the cosmic microwave background. It is in the cosmic furnace of the initially hot and dense state that we believe that the first light elements were forged, in abundances again consistent with modern measurements.

Although even Einstein saw no practical use for gravitational lensing, as the bending of light by mass has come to be known, the phenomenon has emerged as one of the most powerful probes of the cosmos. Gravitational lenses work effectively like glass lenses, focusing and magnifying light – but on a cosmic scale. They enable us to see objects otherwise too far away or too faint for even the largest telescopes on Earth. The lensing signature can also be observed around any nearby concentration of mass, regardless of whether that material is shining.

Dark matter is now known to be the most abundant gravitating material in the universe. It is thought to be mysteriously distinct from the baryonic protons, neutrons and electrons. Crucially, dark matter does not interact via the electromagnetic force, so is completely invisible: it does not emit, reflect, nor even absorb light.

“Although Einstein saw no practical use for gravitational lensing, the phenomenon has emerged as one of the most powerful probes of the cosmos.”



4: The team from Britain, São Tomé e Príncipe, Portugal and Brazil.



5: Music and dancing in Sundry: the dëxa group.

But it does create a gravitational field and can thus be revealed by gravitational lensing. In the same way that lines of text can become bent when read through a magnifying glass, images of distant galaxies can appear grossly distorted and magnified when behind a concentration of dark matter. It is possible to work out the shape and material properties of a magnifying glass from distorted images of text, even though the glass is transparent. Using the same technique to investigate dark matter, astronomy is currently leading particle physics in what may turn out to be the most important scientific investigation of the 21st century.

Our expedition

Príncipe today is an autonomous region of the micro-state of São Tomé e Príncipe (STP), which with its 170 000 or so inhabitants is the second smallest African country. Since independence in 1975, STP has undergone a phase of state socialism, followed, from the early 1990s, by a process of political opening, democratization and the privatization of previously state-owned land and property. Its prime export is still cocoa, but current output is only a small fraction of what was once extracted from the islands by Portuguese colonizers. Experiments are being made into the production of organic cocoa and spices to revitalize an agricultural sector currently geared largely towards subsistence rather than export.

Given the absence of any larger industries and STP's continuing isolation, tourism is the most promising route for economic and social development. The islands are famed for their lush rain forests, secluded beaches and biodiversity; efforts are being made to develop both conventional and eco-tourism.

Interest in the small island state has also grown in recent years because of the announcement of potential offshore oil resources, which as yet await exploration. A sophisticated oil

revenue management law, public information campaigns and similar measures are being designed to curb Santomeans' expectations of quick and easy wealth. Whether or not STP's oil is explored in the future, of prime importance will be the introduction and diversification of sustainable economic measures to help the country out of poverty.

It was in this context that the idea of celebrating the eclipse observation was first raised by one of us, Gisa Weszkalnys, who has worked as a social anthropologist in STP, in a conversation with the regional president in 2007. We discussed what could be done to improve the situation of Príncipe's barely 6000 inhabitants, who find themselves considerably disadvantaged. Everything but the most basic food stuffs has to be imported, yet there is no port. Only one small plane and some irregular ships connect Príncipe to its larger twin island. There is a small hospital, a handful of schools, and very few opportunities for young people to find employment. In collaboration with Richard Ellis, a plan was developed to install an informative plaque benefiting both locals and tourists at the Roça Sundry plantation, where Eddington made his observations. The 90th anniversary of the expedition coincided with the International Year of Astronomy 2009, and Richard and Gisa secured "Special Project" status from the International Astronomical Union. During a scouting visit to Príncipe in September 2008, they were received by the President of the Republic, Fradique de Menezes, who offered the project full support. Logistical help was provided by the Dutch eco-tourism entrepreneur Rombout Swanborn, who operates resorts on both islands.

In the UK, Richard and Gisa teamed up with Pedro G Ferreira and Richard Massey and secured the necessary funds from the RAS and IAU to proceed with the May 2009 events. Richard Massey designed and oversaw construction of the plaque; Pedro coordinated plans

with a parallel team organized by the Lisbon Geographical Society, under the stewardship of Portuguese social anthropologist Sónia Frias.

Celebrations

The official celebrations kicked off on 22 May in Lisbon, with Pedro giving a talk on the legacy of Eddington's measurements. The talk was attended by Santomean and Portuguese dignitaries and citizens, astronomers, anthropologists and journalists. The Portuguese Minister of Science closed the day's ceremonies, discussing the contemporary relevance of Einstein's General Theory of Relativity. That evening, Gisa, Richard M and Pedro, along with representatives from the Lisbon Geographical Society, flew to São Tomé for a week of celebrations. Throughout our stay, we were accommodated in Rombout Swanborn's Omali Lodge (in São Tomé) and the Bom Bom Resort (in Príncipe).

The week in STP was peppered with a series of popular talks about Eddington and astronomy. A lecture at the Portuguese Cultural Centre in downtown São Tomé was lively, and the audience – comprised mainly of academics, journalists and members of the government – were engaged and inquisitive. This atmosphere was echoed at the Instituto Superior Politécnico, the island's public institute of higher education, where a sizeable crowd of students turned out to attend a talk on amateur astronomy. We designed a series of posters on Eddington's measurements, gravitational lensing and astronomy in general, which will remain on display in the institute's physics laboratory.

The public lectures were supplemented by receptions at various embassies and interviews with the local radio, newspapers, the African branch of Portuguese public television, and the BBC Online and World Service. It became apparent in our conversations with Santomeans during the week of the trip, that Eddington and Einstein had quickly become a popular topic of



6: A new issue of stamps celebrate Príncipe's place in astronomical history.



7: Trying out a telescope at Roça Sundry.

conversation in São Tomé.

An educational campaign organized by the Santomean Ministry of Education, which toured local schools in the run-up to the event, had been indispensable to preparing the ground and raising additional awareness.

The expedition benefited tremendously from such multiple collaborations. During our stay in São Tomé, three members of the NGO Scientists in the World flew to Príncipe and throughout the week ran workshops with the teachers and children in the island's only secondary school. The children engaged enthusiastically in the various sessions, learning about modern physics and astronomy for the first time. The teachers saw the visit as an opportunity to access new and interesting material with which to engage their students. The unique connection that Príncipe has with this major scientific event proved to be a true source of excitement.

On the morning of 28 May we were flown over to Príncipe on a small Dornier aeroplane to meet our hosts, Regional President José Cassandra and members of the Príncipe government. That afternoon we gave two public talks after which we were invited for dinner at the Sundry plantation where the local villagers celebrated our arrival. In the middle of drumming, singing and dancing, we brought out some telescopes and observed the clear night sky with enthusiastic children, young people and adults, and later ate a delicious meal of traditional dishes in the dining hall of the central building of the former plantation, hosted by President Cassandra.

The formal celebration began on 29 May at the island's post office: a new issue of stamps commemorating Eddington's visit sold out

within an hour. The centrepiece of the celebrations then took place in the forecourt of the Sundry Plantation, where President José Cassandra unveiled the plaque. The local community turned out en masse, and a number of flights had been chartered to fly in more diplomats, government ministers, civil servants, academics and journalists. Almost 100 people attended the subsequent speeches and talks by, among others, the Santomean Minister of Education, President Cassandra, and Pedro representing the RAS and IAU. The formal events were followed by a lunch with open-air entertainment, a session of dance and *dêxa*, a traditional form of music from the island. That afternoon, we flew back to São Tomé and the following morning we returned to Europe.

The future

Eddington's 1919 measurement of the bending of light was used to determine the nature of gravity, and this research continues to this day. For the past decade, scientists have been confronted with the peculiar observation that the expansion of the universe seems to be accelerating away from the Big Bang, rather than slowing down as expected under the force of gravity. The acceleration can be explained by postulating a strange new form of energy, dark energy, which is repulsive under gravity and drives space-time apart. An alternative possibility, preferred by some theorists, is that the apparent acceleration is due to deviations from the General Theory of Relativity on the largest scales.

Whether Einstein's theory requires slight adjustments is now the overriding question in cosmology, and is driving international research in the field. The geometric nature of gravitational light deflection makes it ideally suited to trace the geometry and size of the universe at different epochs, and to test small inconsistencies in General Relativity. Up and coming experiments incorporate gravitational lensing

in their observational programmes and, in the same way that Eddington used lensing in his test of Newtonian gravity, we will do so again, on larger, more distant scales.

Our visit to Príncipe was met with great enthusiasm and interest. Throughout our stay, our hosts repeatedly suggested that similar events should happen regularly and more often. The regional and national governments are keen on establishing annual workshops for teachers and students, or a permanent centre on Príncipe to celebrate the experiment. Some of STP's international diplomatic partners have also shown interest in financially supporting the endeavours. It is clear that Eddington's trip to Príncipe is recognized as an important part of Santomean cultural heritage and can be an anchor for initiatives through which the population of these remote islands may, in the future, take part in scientific knowledge and discovery. ●

Richard Ellis, California Institute of Technology, rse@astro.caltech.edu; Pedro G Ferreira, University of Oxford, p.ferreira1@physics.ox.ac.uk; Richard Massey, Royal Observatory Edinburgh, rm@roe.ac.uk; and Gisa Weszkalnys, University of Oxford, g.weszkalnys.97@cantab.net.

More information

<http://www.1919eclipse.org>

Further reading

Grant K 2005 *A Civilised Savagery: Britain and the New Slavery in Africa, 1884–1926* (Routledge, London).

Kennefick D 2009 *Physics Today* **62** 37–42.

McEvoy J P 1999 *Eclipse* (Fourth Estate, London).

Mendes Ferrão J E 2008 in Instituto Marquês de Valle Flôr (ed.) *São Tomé, Ponto de Partida* (Chaves Ferreira, Lisbon).

Satre L J 2005 *Chocolate on Trial: Slavery, Politics and the Ethics of Business* (Ohio University Press, Athens).

Seibert G 2006 *Comrades, Clients and Cousins: Colonialism, Socialism and Democratization in São Tomé e Príncipe* (Brill, Leiden and Boston).

Waller J 2002 *Fabulous Science: Fact and Fiction in the History of Scientific Discovery* (Oxford University Press).

"It is clear that Eddington's trip to Príncipe is recognized as an important part of Santomean cultural heritage."