Ber. Wissenschaftsgesch. 45 (2022): 1 – 21 www.bwg.wiley-vch.de

doi.org/10.1002/bewi.202100040

In the Shadow of the 1919 Total Solar Eclipse: The Two British Expeditions and the Politics of Invisibility**

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Summary: This paper addresses the legendary total solar eclipse of 29 May 1919. Two British teams confirmed the light bending prediction by Albert Einstein: Charles R. Davidson and Andrew C. C. Crommelin in Sobral, Brazil and Arthur S. Eddington and Edwin T. Cottingham on the African island of Príncipe, then part of the Portuguese empire.
By jointly analyzing the two astronomical expeditions supported by written and visual sources, I show how, despite extensive scholarship on this famous historical episode and the historiographical emphasis on the plural dimensions of knowledge construction, many human and non-human actors have been kept in the shadow of the eclipse. I do so by focusing on what I call knowledge from the periphery together with knowledge from below, grounded literally on how localities (sites) affect choices and events, and growing outward to encompass a wide range of participants. I show how the geopolitical status of the two nations where the observational sites were located, and specifically Portugal's condition of colonial power, affected main decisions and events, while highlighting the active role of participants, ranging from experts from the peripheries and those involved in the travels to local elites and anonymous peoples, some of whom contributed to the observation of totality.

Keywords: 1919 solar eclipse, light bending prediction, British expeditions, knowledge from the periphery, knowledge from below, invisibility, comparative study, Brazil and Portugal, plurality of actors

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** I thank the guest editors, Charles Wolfe and Gerardo Jenna, for inviting me to contribute to this issue and for their criticisms and suggestions. I extend my thanks to Clara Florensa, Luís Tirapicos, the anonymous referees, and the editor Marieke Hendriksen. Research for this paper was funded by the Foundation for Science and Technology (FCT) under projects UIDB/00286/2020 and PTDC/FER-HFC/3491/2021 (Einstein, Eddington and the Eclipse. A Global History of the Total Solar Eclipse of 1919, E3GLOBAL).

1. Introduction

The now famous total solar eclipse of 29 May 1919 was observed by four teams, including two British teams with astronomical aims very different from those that were common practice among astronomers at the beginning of the twentieth century. One of the British teams included the director of the Cambridge Observatory and astrophysicist, Arthur S. Eddington, and the expert clockmaker Edwin T. Cottingham: they went to Príncipe, an island on the west coast of Africa, then a Portuguese colony, now part of the Republic of São Tomé e Príncipe. The other British team, which included Charles R. Davidson and Andrew C. C. Crommelin, two reputed astronomers from the Greenwich Observatory, headed towards the north-eastern city of Sobral, Brazil: they intended to test the bending of light rays as they passed close to large gravitational masses, one of the predictions of Einstein's theory of gravitation, published in 1915–1916.[1]

The British expeditions were mathematical in a variety of ways. Mathematics, which was irrevocably intertwined with astronomy and physics, was dominant at both ends of the spectrum; that is, as an integral part of Einstein's prediction of light bending, which the expeditions set out to verify, and as a vital component of the process of data analysis which proved Einstein right.[2] Mathematics was instrumental to the expeditions' success, and so far these aspects have been of particular concern for historians.

Especially from the 1980s onwards doubts about the rigor of observations and data analysis were put forward by both physicists and philosophers of science alike.[3] Criticisms encompassed accusations of elimination of data that favored Newton's theory based on Eddington's early advocacy of Einstein's theory. However, inclination towards a result is not equivalent to data manipulation. Moreover, important decisions concerning the initial elimination of plates were done by the astronomer Royal Frank W. Dyson—himself neutral concerning relativity theory—given that the main telescope with an astrographic lens at Sobral lost focus during the eclipse due to heating of the coelostat.[4] The historian of science, Daniel Kennefick, has addressed the question of scientific malpractice for over a decade now, discussing thoroughly

[1] Royal Astronomical Society Archives, London [henceforth RAS], Joint Permanent Eclipse Committee Minutes [henceforth JPEC minutes]. A meeting of the Joint Permanent Eclipse Committee on 10 November 1917 launched the discussion on the preparation of the expeditions, followed by subcommittee meetings held on 10 May, 14 June, 8 November, and 14 December 1918, and on 10 January, and 14 February 1919.

[2] For the impact of Einstein's initial prediction among astronomers before 1919, see Crelinsten 2006; Stachel 2002. For the publication of the expeditions' results and the discussion of decisions taken, see Dyson et al. 1920. For the acceptance of Einstein's ideas in what has been recently dubbed as the "Einstein War," see Stanley 2019; Gates and Pelletier 2019.

[3] Hawking 1988, on 32; Earman and Glymour 1980.

[4] Stars presented streaks that made it very difficult to correctly calculate their displacement relative to the positions on the comparison plates taken two months later with the instrument back in focus. Even before this eclipse there were doubts about the performance of the coelostat of the astrographic telescope. See Kennefick 2019, on 201.

the steps taken by British astronomers, and arguing in their favor. His detailed analysis has recently come out in a book aptly titled, *No Shadow of a Doubt.*[5]

In this paper, I change the focus of analysis from the mathematical, astronomical, and physical pillars of Einstein's prediction, and the expeditions' impact in proving general relativity theory, already discussed at length in the literature.[6] I de-center my analysis from Einstein to the four British expeditioners and comparatively analyze the two astronomical expeditions supported by written and visual sources. I rely on printed sources—scientific communications, discussions, and publications, including Crommelin's short description of the Sobral expedition—and the detailed travel account of Eddington, sent to his mother and sister. Authored by experienced expeditioners, they offer a glimpse into landscapes, places, peoples, and experiences unrelated to their authors' daily routine. They are revealing both for what they refer to and for what they omit. I also rely on printed and manuscript sources related to the two localities visited, which include their correspondence with the Astronomical Observatory of Lisbon and the National Observatory of Rio de Janeiro, as well as newspaper news and visual sources, which exist in abundance in the case of Brazil but are surprisingly meagre, or altogether non-existent, in the case of Portugal. Based on all these sources, I show that the expeditions' scientific consequences were grounded on several sites, people, events, and decisions whose characteristics and contributions are repeatedly bypassed, forgotten, or made invisible in standard narratives, despite having been essential to the twisted process of knowledge construction.

In the wake of feminist, post-colonial, and subaltern studies, historical and political epistemology have been paying increasing attention to the plurality of actors, sites, and events that have contributed to the scientific enterprise broadly conceived.[7]

In this paper, I focus on what I call knowledge from the periphery, stemming from national/local communities, together with knowledge from below[8]—in the sense of being grounded literally on how localities (sites) affect choices and events, besides encompassing a wide range of participants—in order to show how despite extensive scholarship on this famous historical episode and the historiographical emphasis on the plural dimensions of knowledge construction, many relevant participants, sites, and events—including those involved in the preparation of the travels, in the travels themselves and in the observation of totality—have thus far remained marginal or altogether absent in standard narratives. That is, they have been kept in the shadow of the eclipse. I argue that their double invisibility—by contemporary

[5] Kennefick 2009; Kennefick 2019.

[6] See references in notes 2, 3, and 5.

[7] Omodeo 2019; Badino and Omodeo 2020; Conner 2005; Cooter and Pumfrey 1994; Harding 2008; Schaffer et al. 2009; Nieto-Galan 2011; Nieto-Galan 2016.

[8] For the role of periphery, see Gavroglu et al. 2008; Diogo et al. 2016. For the broad sense in which I am using knowledge *from below*, see Mawhinney 2018, who discusses how the historical specificities of geographies act as shapers of knowledge. See also: Conner 2005; Cooter and Pumfrey 1994; Nieto-Galan 2011.

and historians of science alike—must be eradicated to produce a global narrative of this momentous historical episode.[9]

To do so, first I consider the geopolitical asymmetries of the two selected sites of observation located in two different Portuguese-speaking nations (Portugal and Brazil) and offer some plausible considerations on how they relate to the decision on who went where, continuously taken for granted in the current scholarship. Second, I show how the geopolitical status of the two nations, and specifically Portugal's status as colonial power and related accusations of slave labor in Príncipe, account for Portugal's invisibility vis-à-vis Brazil, in the sense of its suppression from the written records that were reporting on these expeditions. Third, I show how various participants—from experts from the periphery and those involved in the travels to local elites and anonymous people, some participating in the observation of totality—played a role in the twisted process of knowledge construction. In particular, the discussion of successive degrees of invisibility in the published accounts by expeditioners (e.g., from manuscript to printed sources addressed to increasingly broader audiences) reveals how the active role of local peoples during the observation of totality has been suppressed; that is, how knowledge from below has been rendered invisible in sequential narratives of the eclipse observations. Finally, I reflect on the meaning of the existence of photographs of the experimental apparatus and of travelers in Sobral, contrary to Príncipe. By reflecting on this contrast, we see how the existence of pictures from Sobral functioned as another instance of a strategy to render visible many participants from the periphery as well as participants from below.

2. Expeditioners and Observation Places: The Politics of Location

Voyages have always been central to the construction and consolidation of science. Among them, expeditions hold a prominent place: traversing science and power, economics and politics, expeditions displace people, instruments, and objects in movements dominated by unexpected adventures. And despite the surgical care put into their preparation, expeditions are always subject to uncertainties that test the tenacity of the most stubborn expeditioners.[10]

Despite vast literature on the British expeditions addressed in this paper, which include references to their preparation, discussions of observation sites, and the composition of expedition teams, there is never any discussion on the final decision on who went where in the extant scholarship—Eddington and Cottingham went to Príncipe, Davidson and Crommelin headed for Sobral. And yet, *this division of labor was certainly not a chance event.* Even during wartime, everything was planned with minute detail. There is no certainty about this choice, but plausible justifications may be advanced. At first glance,

[9] On the politics of invisibility, see Kuchinskaya 2012 and Kuchinskaya 2014.

[10] For astronomical expeditions, see Pang 2002. For scientific expeditions, see Klemmum 2016; Mayhew and Withers 2020.

this was a multiple-choice problem as all travelers were experienced experts and even had prior experience working together, as when Davidson and Eddington failed at Passa Quatro, Brazil back in 1912.[11]

Of the four expeditioners only two—Eddington and Crommelin—were graduated astronomers. Eddington's unusual, yet characteristic, ability for combining an expertise in astronomy, physics, and mathematics, is fundamental for understanding the contributing factors for the "unlikely" virtual encounter between Eddington and Einstein during the Great War.[12] While Crommelin was an astronomer who specialized in comets, he maintained a keen interest in both lunar and solar eclipses, including his own participation in solar eclipse observations in 1896, 1900, and 1905. Davidson was an astronomer recognized for his instrumental expertise and longstanding experience with eclipse observations, and Cottingham was an accomplished clockmaker technician, an art that he practiced with recognized precision and an aptitude for innovation: he was ranked among the best of the *métier*.[13] Thus, given the characteristics of the observations and measurements to be taken to verify light's deflection, all team members were highly qualified professionals.

Of the four expeditioners, three were in their forties, and therefore not at risk of conscription at the very moment when the military was enlisting most of Great Britain's scientists for the war effort. While Eddington was in his early thirties when the war began and therefore subject to possible conscription, he was exempted from service due to his unusual combination of scientific characteristics and religious convictions.

As the historian of science, Matthew Stanley, has noted, Eddington was a devout Christian and a member of the Society of Friends (i. e., Quakers), a Protestant pacifist religious denomination.[14] Therefore, Eddington was a conscientious objector on religious grounds, an attitude difficult to understand by most British citizens who confounded it with anti-patriotism. If Eddington was conscripted, but refused, to participate in military service, his scientific reputation would be damaged while also raising the possibility of negative implications for the British scientific community at large. Frank W. Dyson, who knew Eddington well and admired his work, wanted to avoid this situation at all costs. Thus, with the onset of the war, Dyson negotiated an exemption from military service for Eddington on the grounds that he ran the Cambridge Observatory—one of Britain's most distinguished observatories—

[11] Eddington 1913; Eddington and Davidson 1912–1913.

[12] See Stachel 2002; Crelinsten 2006; and for Eddington's biography, Stanley 2007. In early 1915, even before Einstein completed the general relativity theory, Eddington published an article denoting familiarity with special relativity, in which he referred to the deflection of light predicted in the context of attempts at its generalization. See Eddington 1915. In 1916, he became acquainted with Einstein's complete theory of gravitation through the mediation of Dutch astronomer Willem de Sitter.

[13] Davidson 1940; Woolley 1971; "Cottingham, Edwin Turner (1869–1940). Modern Times," online: http://ringstead.squarespace.com/ringstead-people/2010/10/14/cottingham-edwin-turner-1869-1940-modern-times.html (accessed 14 December 2021).

[14] Stanley 2003; Stanley 2007. The importance of Eddington's Quakerism was initially pointed by Earman and Glymour 1980, on 72.

and hence his work was of "national importance."[15] However, as the war progressed and recruitment continued, with the increase to the age of conscription followed an increase in the likelihood of the revocation of Eddington's exemption. In this context, Dyson managed to negotiate the expedition's leadership as an alternative to military service. As with previous historical periods, science, astronomy, and religion joined hands once more. However, Eddington's exemption was due not to religious arguments supporting scientific theses, but because religious options guided the planning and pursuit of scientific activities.

At this point, it is important to stress that extant sources do not add any justification for the division of labor among the four observers and the two different expedition locations. The importance of Eddington's Quakerism for understanding some of the contours of the expeditions offers a hint worth pursuing. Being one of the two main architects behind the expeditions (the other being Dyson), Eddington self-interestedly chose the place that offered the most difficult conditions of accessibility and observation. Moreover, a deep geopolitical asymmetry existed between Sobral and Príncipe.

Sobral was the second most important city of the north-eastern state of Ceará in Brazil – a massive country, which was-then preparing to celebrate the 100th anniversary of its independence from Portugal—roughly located around 150 miles from Ceará's capital, Fortaleza. A drought-ravaged city of about 35,000 inhabitants, Sobral was a cosmopolitan city. By contrast, Príncipe was a small island far away from the Portuguese imperial metropole (Lisbon) in the Gulf of Guinea in Africa. Portuguese colonizers first arrived in the islands of São Tomé and of Príncipe in 1470, followed by centuries of settler-colonial efforts; particularly with the introduction of sugar cane in the fifteenth century. By the seventeenth century, the culture of these islands was in rapid decline for domestic reasons, local riots and competition from Brazil, eventually becoming mere *entrepôts* in the Portuguese slave trade. Achieving administrative unification by 1753, the colonies of São Tomé and Príncipe became significant global producers of cocoa and coffee by the beginning of the twentieth century. Although Portugal officially abolished slavery in 1875, the flow of natives from Angola, Cape Verde, Mozambique, and other Portuguese African colonies, searching for work on the plantations of São Tomé and Príncipe was tantamount to forced labor, much akin to the conditions of slavery. At the time of the expeditions to Sobral and Príncipe, it is estimated that Príncipe's population totaled no more than 6,000 inhabitants, no more than 3 percent of whom were Portuguese or European. Therefore, most of the population were comprised of plantation workers.[16]

[15] Stanley 2007, on 104, note 118.

[16] On working conditions at the plantations and the conflict over slave labor opposing the two European colonial powers, see Macedo 2016; Jerónimo 2009; Jerónimo 2015; Nascimento 2002. Systematic and exact data on the island's population are hard to find. My estimative results from crossing the following sources: Seibert 2016; *Boletim da Agência Geral das Colónias* 1929. I thank Duarte Pape for indicating this last source to me.

Moreover, the British team in Sobral was accompanied by two additional expedition teams from Brazil and North America. While the former represented the Observatory of Rio de Janeiro (directed since 1908 by the prestigious astronomer Henrique Carlos Morize) the latter team represented the Carnegie Institution of Washington, USA, whose interest was in magnetic, not astronomical, observations.[17] Despite the exploration of various possibilities, archival material held at the Astronomical Observatory of Lisbon makes it clear why in the end there were not any other astronomers accompanying the expeditioners in Príncipe. For example, the astronomer Manuel Peres, the director of the Observatory Campos Rodrigues (OCR) in Lourenço Marques (now Maputo) in Mozambique, tried his best to join the British team.[18] So, it is likely that Eddington chose Príncipe with the spirit of extreme dedication and accrued risk of Quaker missions organized throughout Europe to help suffering populations, regardless of their nationality.[19]

Moreover, and in my estimation, there are other additional religious reasons which may have reinforced or at least facilitated this choice. Davidson and Crommelin were portrayed as "practicing Catholics"[20] by local Brazilian newspapers, which suggests a factor of proximity and communion with the local population in a country whose official religion was Catholicism. Additionally, it was for this reason that Father Aloysius Laurence Cortie, an experienced Jesuit astronomer, was initially assigned to Sobral: the Jesuit connection involving the Portuguese and Brazilian nodes of the network was explicitly mentioned in one of the sub-committee meetings of the Joint Permanent Eclipse Committee, which discussed the preparation of the expeditions in question.[21] Finally, in the case of Eddington who was accompanied by Cottingham, his religious background may have drawn him to a place familiar to other Quakers, e. g., the influential industrialist Cadbury family. As Príncipe's largest international cocoa buyers, the Cadbury's were behind the confrontation between the British and Portuguese governments over covert practice of enslaved and/or forced labor in the plantations leading up to the establishment of the Portuguese republic in the first decade of the twentieth century.[22]

[17] Dyson et al. 1920, on 296–297.

[18] Correspondence Manuel Peres (OCR)/Oom (OAL), Arquivo Histórico dos Museus da Universidade de Lisboa, Observatório Astronómico de Lisboa (OAL), Universidade de Lisboa„ PT/MUL/OAL/C/463. Other factors concerned the old age of the director Campos Rodrigues, who relied on his deputy director Frederico Oom for running the observatory, and the reduced number of astronomers, one of which (Melo e Simas) was participating in the war in France. Discussed in detail in Mota et al. 2009.

[19] Stanley 2003; Stanley 2007.

[20] Rodrigues 2012, on 70. The fact that astronomers were presented as practicing Catholics was indicated to me by Emerson Ferreira de Almeida, whom I thank. Crommelin's Catholicism is explicitly mentioned in his obituary authored by Davidson 1940, on 236.

[21] RAS, JPEC minutes, 14 February 1919. A letter sent by Father Cortie was read in which he announced that the supervisors in Brazil of the Portuguese Provincial Father Pinto were contacted to secure help for the team heading for Sobral.

[22] Macedo 2016; Jerónimo 2009; Jerónimo 2015; Nascimento 2002.

Given the humanitarian concerns stemming from the Cadbury's religious affiliation—a position that Eddington also shared—they opposed any business transactions involving "slave cocoa,"[23] the expression used in the meeting of the Royal Astronomical Society of 9 March 1917 in which Dyson called attention to the importance of observing the total solar eclipse of 29 May 1919. Given the Cadbury's influence, it is hard to imagine that Eddington was not aware of the pressure exerted, a few years earlier, by Cadbury on local producers to ensure decent working conditions in the plantations. However, these issues are not referred to in the correspondence between Eddington and the Astronomical Observatory of Lisbon, which concerned mostly logistical questions, and involved colonial institutions and steamship companies despite the fact that all its correspondents were likely aware of such concerns.[24] Eddington even omitted the labor problem in private letters addressed to his mother. While Eddington made brief references to the use of local work in baggage transport and in the installation of the observatories facilities,[25] his descriptions largely highlighted lush landscapes, island tours, social gatherings, recreational activities, soirées, and other events.[26] One finds a similar phenomenon in the joint publication by Dyson and Davidson, which detailed the expeditions and their findings while only briefly mentioning the recourse to native labor during the transport of equipment to the plantation—particularly those sections where no railways existed—and in the construction of the telescope′s base.[27] All astronomers probably shared the naïve idea of separation between the scientific and political realms, a construction as useful for eclipsing dangerous liaisons in both the past and the present. In sum, by stressing the equivalent expertise of astronomers and the historical and political asymmetry regarding the geographical conditions proper to each observation location, I suggest that both factors, alongside religious considerations, informed the division of experts between sites *from below.*

3. Brazil's Presence, Portugal's Absence: Decoupling Astronomy from Colonialism

The conclusion of the former section is reinforced by another peculiarity in the written records related to Portugal's role as a colonial power and the accusations of using slave labor in the acquisition of wealth originating from its

[23] Dyson 1917, on 155.

[24] Correspondence from Arthur Stanley Eddington to the Direction of OAL, Arquivo Histórico dos Museus da Universidade de Lisboa, OAL, Universidade de Lisboa, PT/MUL/OAL/C/240

[25] Letter to mother Sarah Ann, 29 April–2 May 1919, Trinity College Library, Cambridge [henceforth TCL], Papers of Sir Arthur Eddington, Correspondence 1899–1943, EDDN/A/4/7. https://archives.trin.cam.ac.uk/index.php/letters-from-a-s-eddington-to-sarah-ann-eddington-madeira-and-the-eclipse-at-principe!

[26] Ibid.; letter to mother Sarah Ann, 21 June and 2 July 1919, TCL, EDDN/A/4/9. See also Weszkalnys 2009. For a detailed narrative and visual rendition of the daily impressions of travelers along their journey, see Simões and Sousa 2019.

[27] Dyson et al. 1920, on 313.

African colonies. With few exceptions, the invisibility of Portugal in most written reports is indeed striking. This results from the identification of Príncipe by its geographical location on the west coast of Africa, thereby undercutting its colonial status and obscuring otherwise undesirable political connections associated with the practice of slavery.

Among the written records, the account of the Royal Astronomical Society meeting of 9 March 1917 (referred to above) is a rare exception as it documents Dyson discussing the possibilities afforded by the 1919 eclipse and his presentation of Príncipe as "a well-developed Portuguese island, which became celebrated a short time ago owing to the politicians' interest in 'slave cocoa.'"[28] In the meeting's minutes—restricted to the astronomical circle of readers of the journal *The Observatory*—there is explicit mention of Príncipe's colonial status and existing labor conflicts. Relatedly, the other exception is the more widely disseminated article jointly authored by Dyson, Eddington, and Davidson and published in early 1920, which relays the results of the two expeditions and specifies that "Príncipe is a small island belonging to Portugal, that lies just north of the equator in the Gulf of Guinea, about 120 miles from the African coast."[29] The reference to Portugal, perhaps deliberately omitting "slave cocoa," is particularly brief. Lastly, in the article's acknowledgments, the support and hospitality of the Brazilian government is widely recognized. Contrary to Sobral, there are no thanks to the Portuguese government or its scientific institutions, save the mention of Jerónimo Carneiro—the owner of the plantation ("*roça*") Sundy, where the observations took place—and the plantation's manager, Atalaia, who established a close relationship with Eddington by virtue of his rudimentary knowledge of French.[30] That is, acknowledgements are addressed on a personal level and not as members of the institutions of a European colonial power known for practicing forced labor. When it comes to acknowledging the help of astronomers from the periphery, credit is given to Morize in his capacity as a representative of the Brazilian government, while reference to the help of Campos Rodrigues and Frederico Oom, respectively the director and deputy director of the Astronomical Observatory of Lisbon, is mentioned, not in the article's acknowledgements, but just in the section on Príncipe.[31]

Without the help of Rodrigues and Oom and of national and colonial institutions, the expeditions would not have been possible: this much is clear given the extensive correspondence between Eddington and Oom held at the archives of the Astronomical Observatory of Lisbon, and the subsequent

[28] Dyson 1917, on 155.

[29] Dyson et al. 1920, on 312.

[30] Letter to mother Sarah Ann, 29 April–2 May 1919, TCL, EDDN/A/4/7 CORRECT; letter to sister Winifred, 5 May 1919, TCL, EDDN/A/4/8

[31] RAS, JPEC minutes, Annual meeting, 14 November 1919. The same omission occurred in these minutes. It is proposed a note of thanks to the "Brazilian government" and to the "Administrator of Principe." It is further added that: "The chairman was requested to send letters of thanks to Dr. Morize, Director of the National Observatory at Rio, Dr. Jacome de Oliveira, Prefect of Sobral, and Sr. Jeronymo Carneiro, of Principe." No reference is made to the director and deputy director of the Astronomical Observatory of Lisbon.

exchange between Oom, steamship companies, and colonial institutions such as the Colonial Centre, the representative of the Colonial Agricultural Society, and the plantation landowner and president of the Planters Association, Carneiro, who secured support for Eddington and Cottingham's subsistence, material, and human needs during their stay in Príncipe.[32]

Eddington and Oom's correspondence began on 11 November 1918, the day the armistice was signed.[33] In his first letter, Eddington referred to the geographer and astronomer Arthur Robert Hinks, who, in his capacity of secretary of the Royal Geographical Society, previously contacted with the Society of Geography of Lisbon and requested additional information about Príncipe. The letter concluded by stating that Dyson fondly remembers the welcome he and his British team received when they travelled to Portugal to observe the total solar eclipse of 28 May 1900. The Lisbon astronomers and Oom excelled in providing logistical, material, and scientific support to all foreign astronomers' teams, whether professional or amateur, and skillfully seized the opportunity to claim greater scientific and social relevance for astronomy.[34]

During their stay in Príncipe, Eddington wrote to Oom on 4 May 1919 acknowledging all the support they received on the island:

> We are being most kindly entertained by Mr. Carneiro; and have everything we could possibly desire. Everyone has received us most kindly and has given us every assistance. […] This is a beautiful island, and besides making good progress with our work we are thoroughly enjoying our experiences.[35]

Eddington's unfailing optimism is clear when he writes "All we need now is a fine day for the eclipse." On 3 August 1919, and already back in London, Eddington wrote a letter thanking both the director and Oom and included "paper enlargements from three of our negatives," adding "They do not show all the fine detail of the original; but the prominence is very remarkable."[36]

[32] Correspondence from Arthur Stanley Eddington to the Direction of OAL, Arquivo Histórico dos Museus da Universidade de Lisboa, OAL, Universidade de Lisboa, PT/MUL/OAL/C/240. The correspondence from Eddington to the direction of OAL (mostly addressed to F. T. Oom) comprises the following letters: 11 November 1918, 21 December 1918, 14 January 1919, 8 February 1919, 26 February 1919, 25 March 1919, 4 May 1919, and 3 August 1919. The analysis of the impact of Príncipe's expedition on the practice of Portuguese astronomers at the Astronomical Observatory of Lisbon was analyzed in Mota et al. 2009.

[33] Letter from Eddington to Campos Rodrigues, 11 November 1918, Correspondence from Arthur Stanley Eddington to the Direction of OAL, Arquivo Histórico dos Museus da Universidade de Lisboa, OAL, Universidade de Lisboa, PT/MUL/OAL/C/240. The graphic novel Simões and Sousa 2019 begins precisely with a rendition of this letter.

[34] Carolino and Simões 2012; Carolino and Simões 2019.

[35] Letter from Eddington to Oom, 4 May 1919, Correspondence from Arthur Stanley Eddington to the Direction of OAL, Arquivo Histórico dos Museus da Universidade de Lisboa, OAL, Universidade de Lisboa, PT/MUL/OAL/C/240. The graphic novel Simões and Sousa 2019 includes a rendition of this letter.

[36] Letter from Eddington to Oom, 3 August 1919, Correspondence from Arthur Stanley Eddington to the Direction of OAL, Arquivo Histórico dos Museus da Universidade de Lisboa, OAL, Universidade de Lisboa, PT/MUL/OAL/C/240. The graphic novel Simões and Sousa 2019 ends with a rendition of this letter.

As stated above, Eddington's letters and publications omit the working conditions in the plantations and never refer to "slave cocoa." Given the common religious convictions of both Eddington and the Cadbury family; and given the conflict opposing Britain's government and Portuguese authorities one-decade prior, whose tenacious echoes still reverberated; Eddington's silence appears strange at first glance. The ethical values instilled in Eddington by an education in Britain's markedly class-based society, as well as the behavioral expectations in host-guest relationships may explain the absence of this subject in both private and public accounts.

This view is complemented by the image of science and its *métier* crafted by scientists themselves ever since the seventeenth century, which placed scientists at the antipode of the real society in which they worked. This was, moreover, the vision that undergirded Eddington's strategy, which constituted an instance of what we might call informal scientific diplomacy:[37] Eddington endeavored to present the expeditions as the quintessential instance of scientific internationalism, an image all the more captivating since it took place in a situation of warfare between the countries of the astronomers who measured deflection and the physicist who predicted it.[38] Eddington's narrative clearly highlights the attractive contours of this vision and its role in building a community of scientists committed to affirming their cultural significance and socio-professional status.

With all these aspects in mind, the invisibility of "slave cocoa" remains an uncomfortable, though perhaps unsurprising, omission. As a sign of its time, such an omission reflects the mythologies constructed by the scientific community itself. The second invisibility—its absence from narratives by historians of science—is startling and obliges our immediate redress. Historians of science must deconstruct scientists' mythologies, clarifying the entanglements between science, society, and politics in the context of scientific discovery as much as that of scientific justification.

4. To Be or Not to Be: The Hidden Faces behind Totality

The British expeditions to Príncipe and Sobral involved nearly two years of wartime preparations, culminating in five minutes (exactly 302 seconds) of eclipse observations of totality, and subject to the uncertainties of weather conditions. Despite financial support from the British government, no equipment was acquired and the accuracy of measurements depended on instruments adapted from pre-existing parts, housed in various British observatories and collected at the Royal Greenwich Observatory for the final preparations. The expedition teams moved two tons of material to tropical

[37] Studies on science diplomacy are blossoming. Among various references, see for example Lloyd and Patman 2015. I will address this aspect of British expeditions in a future publication.

[38] Stanley 2003. The plea for internationalism is also discussed in Earman and Glymour 1980, on 82–84. The historical construction of scientific internationalism is discussed in Lettevall et al. 2012.

regions near the equator—roughly 7200 km for Sobral and 5800 km for Príncipe—traveling from Liverpool to Lisbon and eventually parting ways at Madeira, with one team heading for Sobral via Belém, Manaus and Camocim, and the other heading for Príncipe via the Cape Verde islands.[39] Their success depended on knowledge from the periphery. In other words, the success of the expeditions depended upon the participation of astronomers from the countries (Portugal and Brazil) where observations were made *and* the logistical support of members of the local elites alongside workers who remained forever anonymous, thus revealing how knowledge from below and invisibility are often intertwined. In the end, several months of uncertainties and expectations converged, affording scientists 302 seconds of eclipse observations. Thus, it is no wonder that the bustle, excitement, and expectation regarding the outcome of the observations made during totality—especially if produced in the private sphere—offer spontaneous and thrilling testimonies, which often contrast with the restrained style of public accounts.

To the best of my knowledge, only Eddington produced private accounts complementing the public records related to the expeditions that observed the eclipse of 29 May 1919. Of these, the 1920 article co-authored with Dyson and Davidson provides a thorough analysis of the observations[40]—including detailed descriptions of the characteristic features of the observation sites, the experimental setup (of which there is only one photographic record in the case of Sobral and none in the case of Príncipe), and the results obtained and the calculation of the deflection value. While the account reflects the style of Eddington, who excelled as a communicator, it also conveys the need for a simple and precise explanation of the measurements made; particularly given the undesirable weather that caused several plates to show a spectacular prominence as if British astronomers wanted to observe the solar corona rather than the star background.

There are significant differences between the description included in the joint article and Eddington's private account contained in a letter to his mother upon his return to Europe:

> On the morning of the eclipse Mr Carneiro [the owner of plantation Sundy], the Curador [the man in charge of "imported forced labour"], Judge, Mr Wright [one of the two British black men who worked at the cable station], and three doctors came over. Just as they arrived a tremendous rainstorm came on, the heaviest we have seen. It was most unusual at that time of the year; but it was favorable for the eclipse as it helped to clear the sky. The rain stopped about no[o]n (the eclipse was at 2·15[41]). There were a few gleams of sunshine after the rain, but it soon clouded over again. About 1·30 when the partial phase was well advanced, we began to get glimpses of the sun, at 1·55 we could see the crescent

[39] Besides information offered in Dyson et al. 1920, the detailed reconstruction of the travel to Príncipe is possible due to Eddington's correspondence with his mother and sister (TCL, EDDN A4/2) as well as with the Observatory of Lisbon (PT/MUL/OAL/C/240). For Sobral, Crommelin's account offers a summarized rendition of the journey. Crommelin 1919. See Simões and Sousa 2019 for the travel impressions of expeditioners in a graphic novel format centered on the travel to Príncipe, including its various stops.

[40] Dyson et al. 1920, on 314.

[41] Approximate time in Greenwich Mean Time, one hour less than local time.

> (through cloud) almost continuously, and there were large patches of clear sky appearing. *We had to carry out our program of photographs in faith. I did not see the eclipse, being too busy changing plates, except for one glance to make sure it had begun, and another half-way through to see how much cloud there was.* We took 16 photographs (of which 4 are not yet developed). They are all good pictures of the sun, showing a very remarkable prominence; but the cloud has interfered very much with the star-images. The first 10 photographs show practically no stars. The last 6 show a few images which I hope will give us what we need; but it is very disappointing. Everything shows that our arrangements were quite satisfactory, and with a little clearer weather we should have got splendid results. Ten minutes after the eclipse the sky was beautifully clear, but it soon clouded again.
>
> We developed the photographs 2 each night for 6 nights after the eclipse, and I spent the whole day measuring. The cloudy weather upset my plans and I had to treat the measures in a different way from what I had intended; consequently I have not been able to make any preliminary announcements of the result. *But the one good plate that I measured gave a result agreeing with Einstein and I think I have got a little confirmation from a second plate.*[42]

This long quotation not only begins with precious details about the witnesses who observed the eclipse in the expeditioners' company but also offers a first assessment of works in view of the obstacles caused by bad weather conditions. The last sentence leaves no doubt regarding Eddington's scientific inclinations.

While different accounts are presented in the 1920 paper and this private letter, one concludes that the information provided is roughly the same. Moreover, the 1920 article differs from Eddington's letter by virtue of a refined precision regarding the identification of the moments of totality,[43] and its exclusion of references to *both* the observers' emotions *and* the local people witnessing the eclipse in the company of the observers. The public description mentioned the excellence of photographs and the notability of the solar prominence but omitted references to the disappointment caused by bad weather, the faith in the program's successful execution, and the hope of discovering evidentiary proof, and thereby corroborating Einstein's predictions regarding the existence of light's gravitational deflection as implied by the theory of general relativity.

Additionally, significant is how Eddington refers to the eclipse when, still in 1920, he published *Space, Time and Gravitation*; a non-technical book that introduces the lay public to the mathematical formalism and conceptual apparatus of relativity. The volume included two chapters on the predictions of general relativity and one chapter—aptly titled "Weighing Light"—dedicated to the results, and description, of the expeditions. Apologizing to the reader for the chapter's experimental subject despite the book's fundamentally theoretical focus, Eddington poetically described the magical moment of totality, of enormous beauty, of expectation and bustle:

> Our shadowbox takes all our attention. There is a marvelous spectacle above, and, as the photographs afterwards revealed, a wonderful prominence-flame is poised a hundred thousand miles above the surface of the sun. We have no time to snatch a glance at it. We

[42] Letter to mother Sarah Ann, 21 June and 2 July 1919, TCL, EDDN/A/4/9. Emphasis mine.
[43] In the paper it is stated that totality occurred from 2 h, 13 m, 5 s to 2 h, 18 m, 7 s TMG. Dyson et al. 1920, on 314.

> are conscious only of the weird half-light of the landscape and the hush of nature, *broke by the call of the observers*, and the beat of the metronome ticking out the 302 seconds of totality.[44]

Regarding the content of these written accounts, there is a noticeable decrease in the clarity of emotion, from the richness of the private communication, which exposes the astronomer's feelings, to the popularization of the science book rich with descriptions of landscapes and environments while omitting references to the astronomer's feelings, and, finally, to the scientific paper, centered on factual, detailed, and technical information.

In the 1920 article, the authors state that "exposures were made according to the prepared program foreseen, and sixteen plates were obtained. Mr. Cottingham gave the exposures and attended to the driving mechanism, Prof. Eddington changed the dark slides."[45] The article, therefore, omits reference to the local witnesses who accompanied the work of the expeditioners, but which are included in Eddington's letter to his mother, which lists all participants in the eclipse observation. They were Carneiro, the Curador, Judge, Wright and three doctors. While in Príncipe there was just a telescope and a coelostat and so the two expeditionaries could in principle take care of the instruments by themselves, the attentive reader of the popularization of science book encounters references to the "observers," who might have assisted them. One of the witnesses, probably the British specialist of the cable station was likely to have issued at appropriate times the final decision regarding plate changes or might have overseen taking notes of exposure times. The participation of observers in the construction of knowledge *from below* becomes clearer when comparing this statement with what transpired in Sobral—descriptions of the Sobral expedition are provided in Crommelin's short article, "The Eclipse Expedition to Sobral,"[46] and were partially transcribed in a similarly titled section of Dyson, Eddington, and Davidson's jointly authored article.[47]

Regarding descriptions of totality, both articles stated that British astronomers were accompanied by Leocádio Araújo, a civil servant from the Ministry of Agriculture who helped the British team since the very beginning; especially due to his command of English—unusual for Brazilians—and his role as the team's most proficient interpreter. As revealed in the jointly authored paper, Araújo took care of the metronome, thereby providing the necessary indications for the full compliance of stipulated exposition times for photographic plates:

> When the crescent disappeared the word "go" was called and a metronome was started by Dr. Leocádio, who called out every tenth beat after totality, and the exposure times were recorded in terms of these beats. It beat 320 times in 310 seconds; allowance has been made for this rate in the recorded times.[48]

[44] Eddington 1920, on 115. Emphasis mine.

[45] Dyson et al. 1920, on 314.

[46] Crommelin 1919.

[47] In fact, several paragraphs are the same, although this article was not signed by Crommelin, but only by his colleague Davidson.

[48] Dyson et al., on 299.

In Crommelin's account, the help provided by Araújo is not mentioned, while acknowledging that their success depended on "his [Araújo] never-failing interest and kindness."[49] Having in mind that in Sobral, contrary to Príncipe, the equipment included two telescopes and two coelostats, one wonders if the help of Araújo might have been complemented by that of another assistant.[50] In any case, help from below, from preparation works to the observation of totality, was crucial to the team's scientific accomplishments.

The following nights, plates were developed by Davidson using typical local clay pots to ensure adequate water temperature,[51] then dipped in containers with a solution that guaranteed proper conditions. In Príncipe, as in Sobral, the astronomers relied on local aid and products, in this case on ice supplied by Grageira, the manager of the Colonial Agriculture Society, to ensure adequate temperature conditions for plates' development.[52] Thus, not only did expeditioners bring instruments built with pre-existing components adapted in wartime to the conditions of the observational sites, but also local, everyday objects and materials (clay pots in Sobral, ice in Príncipe) were temporarily promoted to auxiliary scientific instruments. Therefore, the accuracy of measurements was not the outcome of state-of-the-art technologies, but resulted from the combination of technologies-of-use and household items.

With the help of different sources, it becomes clear that expeditioners in Príncipe and in Sobral observed totality in the company of other participants, some of whom held prominent functions. Thus, despite their invisibility, two types of local actors from below directly participated in the experiments at Sobral and Príncipe: workers who provided the manpower to transport equipment, to build supports for the instruments or protective structures of the whole apparatus and the members of the local elite who participated in the observations of totality or offered them the materials—clay pots and ice—necessary for the success of revelation of plates. Finally, these local actors were joined by national astronomers, and colonial authorities and individuals who, in both cases, ensured the success of the travels as well as their stop in Lisbon and Funchal, Madeira, where Eddington and Cottingham stayed for twenty-six days, the stop at Cape Verde, then also a Portuguese colony, on the way towards Príncipe, and finally the stay and work of the British observers in Sobral and in Príncipe. Making visible all these active participants who made the observations possible, some of whom also played a crucial role in the very observation of totality signals how much knowledge from below is crucial to a fair reconstruction of this historical episode.

[49] Crommelin 1919, on 369.

[50] In a discussion with Luís Tirapicos concerning the invisible assistants of the expeditionaries during the observation of totality both at Príncipe and at Sobral the possibility came to the fore that at Sobral helpers, other than Araújo, might have played a role, while at Príncipe of all witnesses the British telegrapher was especially trained at quick note taking.

[51] Rodrigues 2012.

[52] Dyson et al. 1920, on 316.

5. To Depict or Not to Depict: The Politics of Visual Representation

The invisibility of participants in the observations is further corroborated by the absence of any photographs from Príncipe, including the experimental apparatus and its exact location, the two travelers, the local elite or the participants who observed totality, which were identified in Eddington's letter to his mother.[53] This is in stark contrast with the Sobral expedition, whose photograph of the experimental equipment taken by Davidson serve as identifying marker of its make-up, alongside additional photographs of the expeditioners themselves. The existence of visual records from Sobral, and their absence in Príncipe, were likely due to the asymmetry of geographical, material and human conditions in both places. Moreover, while three expeditionary teams observed in the north-eastern Brazil only two observers moved to the equatorial island of Príncipe.[54]

Despite the absence of any visual record of the apparatus at Príncipe, and given that the wood and canvas structures built to protect the instruments were prepared in Greenwich, it is plausible that the equipment at both locations were similar save the omission of Cortie's telescope and accompanying 9-inch coelostat which was sent to Sobral.[55]

As for the extant photographs from the expeditions, Davidson and Crommelin appear in group pictures of the Brazilian team, often including women (relatives of team members). The British contingent occupy prominent positions dressed in white suits unlike their Brazilian counterparts. Moreover, this visual record shows that Morize, director of the National Observatory insisted on a detailed photographic coverage of his team of 17 people—including two assistants, a calculator, a meteorological assistant, a mechanic assistant, an assistant carpenter, and a chemist from the Geological and Mineralogical Service of Brazil (*Serviço Geológico e Mineralógico do Brasil*),[56]—in different situations and moments of observation.

This visual record was part of a consistent strategy of national and international affirmation of Brazilian astronomy and was reinforced by the presence of reputable British astronomers among Brazilian peers. In fact, as

[53] The exact location where Eddington, Cottingham and their local partners observed totality was finally clarified in 2019 through the joint work of a mathematician, an architect, and a historian of science. See Latas et al. 2020.

[54] There is also an extensive and valuable photographic record produced by the North American team recently reviewed in Crispino and Lima 2018. Epistemological questions on the various meanings of production of invisibilities are discussed in Kuchinskaya 2012 and Kuchinskaya 2014.

[55] I thank Richard Dunn for confirming the credibility of these assumptions and for pointing that this tent design, which became standard, was first used on an expedition to observe an eclipse in Japan in 1896.

[56] Morize's team included Domingos Fernandes Costa and Allyrio Hugueney de Matos, assistants, Lélio Gama, calculator, Luiz Rodrigues, meteorological assistant, Arthur de Castro Almeida, mechanics assistant, Primo Flores, assistant, Theofilo Lee, chemist. Crispino and Lima 2016. Besides their wives, three team members brought other family members.

early as 1917, Morize took the initiative of relaying detailed information concerning the conditions in Sobral to British astronomers.[57] Morize was certain that the 1919 eclipse afforded an opportunity to assert the international role of the Brazilian scientific community, and was not to be missed. Already undertaking a similar endeavor in 1912, Morize did everything within his power to transform the 1919 eclipse into a success for astronomy in general, and for Brazilian scientists in particular. Everything was, thus, carefully prepared by Morize, who travelled to Sobral beforehand to secure the support of both the Brazilian government and the local, civil, and ecclesiastical authorities. Morize's team, specialized in astrophysical observations, arrived at Sobral on 9 May 1919 and joined the British team. The North American team —the two magnetic observers Daniel Wise and Andrew Thomson—also arrived at Sobral roughly at the same time as the Brazilian team.[58]

In addition to being the director of the National Observatory, Morize was the first president of the Brazilian Academy of Sciences, established in 1916. The creation of this institution was part of a movement that emerged during the early decades of the twentieth century and gained momentum with the upcoming centenary of Brazil's independence (1922). Together with other colleagues, Morize worked to realize a scientific research ethos that recognized the centrality of science within society independent of its practical applications and consolidate a cohesive and autonomous scientific community. Moreover, Morize's willingness to support British astronomers, while developing an observational program in astrophysics, was a full demonstration of his eagerness to secure science's centrality in Brazil society, both nationally and abroad. Thus, his insistence on a detailed photographic record of the Sobral expedition —including several photographs of his team alongside Crommelin, Davidson, and the two North American observers. Through his actions, Morize rendered the role of expert knowledge from the periphery visible.

By securing the support of local authorities and Leocádio Araújo—thereby guaranteeing ample journalistic coverage of all activities associated with eclipse observations and the presence of foreign travelers—Morize rendered the role of knowledge from below visible. Local newspapers from the states of Pará and Ceará published many news, which, after all, made known Einstein's theories in Amazonia and in North-eastern Brazil for the first time.[59] With complimentary coverage in Brazil′s then-capital of Rio de Janeiro and neighboring states, Einstein was presented to the Brazilian public at the very moment that Brazilian astronomy was projected into the public sphere with increasing recognition and visibility.[60]

[57] Dyson et al. 1920, on 295; Eisenstadt and Videira 1995, on 93. For more information on the stay at Sobral, see Rodrigues 2012; Videira 2012; Crispino and Lima 2016a and b.

[58] Crispino and Lima 2018, on 2.

[59] Crispino and Lima 2016a and b.

[60] Crispino and Lima 2016a and b; Moreira 1995, on 179.

6. Concluding Remarks

By comparing the two British expeditions pertinent historical questions emerge concerning the politics of invisibility namely, the implications of the geopolitical asymmetries of the two observational sites for the choice of expeditioners among them and the meaning of asymmetries in the photographic records stemming from both observational sites; the consequences of Portugal's condition of colonial power and the accusations of slave labor in Príncipe for Portugal's invisibility in the written records; and finally the relevance of knowledge from the periphery and of knowledge from below in the complex process of knowledge construction.

The answers to these questions traverse scientific disciplines—astronomy, physics, mathematics—and technology, geography and colonial empires, as well as politics, diplomacy and religion. This paper illustrates the real and complex liaisons between science, society, and politics, showing how networks of scientific actors, local elites, and anonymous participants were all fundamental to their preparation and execution. Through the expertise of Portuguese and Brazilian astronomers the input of knowledge from the periphery secured the expeditions' success. Similarly, the input of actors and objects from below played a crucial role in the observation of totality, as seen in the "observers" who called at appropriate times to ensure the change of plates, and the means of securing the proper physical conditions for the subsequent revelation of plates via the use of clay pots and ice.

Counteracting the double invisibility of knowledge from below in most contemporary and historical accounts, this joint analysis of the two British expeditions evidences how power asymmetries between sites, countries, and actors were the conditions of possibility for the invisibilization of actors, the erasure of institutions or countries, or the use of visual representations in asserting a national astronomical community agenda in the international landscape. Concomitantly, this comparative exercise demonstrates how historical narratives about the expeditions often perpetuate asymmetries in contemporary accounts and continue to give prominence to certain actors, institutions, and places at the expense of others.

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