are more likely to complete primary school (showing upward mobility) if the family is Christian than if it is Muslim or traditionalist. Conversely, if a pair of parents did complete primary school, their children are more likely to drop out before the end of primary school (showing downward mobility) if they are Muslim or traditionalist than if they are Christian.

The mobility gaps that Alesina *et al.* document across religious groups are large. For example, among Nigerian children born to parents without schooling, nearly 80% of Christian children but less than 50% of Muslim children will go on to complete primary school themselves. In Cameroon, nearly 20% of Muslim children whose parents completed primary school will not do so themselves, compared with just 4% of Christian children.

Nigeria and Cameroon exhibit some of the largest mobility gaps, but the authors found evidence for such gaps in most countries they investigated. A few countries, including Rwanda, South Africa and Uganda, show the opposite pattern, with Muslim people having higher educational mobility than Christian people – in these countries, Muslim people represent just a small percentage of the population.

What explains the widespread gaps in intergenerational educational mobility across religious groups in Africa? Alesina *et al.* persuasively discount several plausible answers: economic factors such as occupation; differences in household size and composition; geographical factors such as distance to the capital; and historical factors such as distance to colonial-era Christian missions (where many schools were established). Instead, the authors show that mobility gaps correlate with religious demographics and with differences in 'initial' literacy rates – that is, rates at the time African countries gained independence from European colonizers, which was around the 1960s in most cases. These findings corroborate my own, which show that the proportion of Muslim people at the regional and village level is a strong predictor of the Christian–Muslim gap in attendance and years of school (ref. 2 and see go.nature.com/3lbsshj).

Alesina *et al.* show that the Christian–Muslim mobility gap is larger in regions where there are proportionally more Muslim people, and where there was a large gap in literacy between religious groups during the colonial period. The authors analyse migration and patterns of segregation – whether individuals move into or out of places where people tend to share their own religion – and show that the upward mobility of Muslim people improves when they move, at a young age, to regions where upward intergenerational educational mobility is high. However, Muslim people are less likely than Christian people to move to these areas.

Why these patterns exist and persist therefore remain open questions. Alesina and colleagues acknowledge in their conclusion that "Our study begets more questions than it answers". But the work is important for at least two reasons. First, education is considered a central component of economic growth and human development (a measure of people's capabilities, see go.nature.com/41hoeso), so this work might help to explain persistent economic inequality both across and within countries.

Second, the findings invite us to consider what education has meant historically and how its meaning might vary across communities in the twenty-first century. Achieving high levels of formal education – perhaps more accurately described as mass schooling[3] – and economic growth are often considered universal goals for countries, and ones on which they are assessed, ranked and categorized by international institutions such as the United Nations and the World Bank. But if countries and communities have historically and in the present opted for different kinds of education, in part because of the religious underpinnings of education systems, our understanding of current patterns of schooling will benefit from a deeper investigation of the relationship between religion and education.

The implications are not just theoretical. Policies designed to increase schooling rates often treat education as a set of politically neutral skills and knowledge, and thus focus on reducing resource constraints – building more schools, training more teachers or removing school fees, for instance. But education is fundamentally political, and its roots in Africa are far from neutral. On the contrary, the backbone of today's education sector has its roots in widespread attempts by Christian missionaries to convert others to Christianity, and in economic exploitation and political subjugation by colonial powers. Education was not then the human right that it is considered today, but a tool for colonizers to govern and extract resources with[4]. Seen through this lens, it is not at all surprising that distribution of education during the colonial period was both uneven and systematically related to religious demographics – and that the ramifications of this continue to be felt today.

Education is the means through which we transmit not only skills such as literacy and numeracy, but also ideas, norms and values. For this reason, religion might be a key factor in explaining patterns of education. The role of education in shaping beliefs also explains why religious organizations have taken a particular interest in its provision and regulation. Only when we consider this political aspect of education will we be able to make sense of the inequalities that Alesina *et al.* have aptly demonstrated.

Melina R. Platas is in the Social Science Division, New York University Abu Dhabi, Abu Dhabi, PO Box 129188, United Arab Emirates.
e-mail: mplatas@nyu.edu

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Astronomy

Atmosphere search off to a rocky start

Laura Kreidberg

Astronomers have used observations of infrared light to measure the heat emanating from an Earth-sized exoplanet known as TRAPPIST-1b. Their findings reveal that the planet is a bare rock, devoid of any atmosphere. **See p.39**

The exploration of terrestrial, or rocky, planets beyond the Solar System has long been the domain of science fiction. But real planets have been discovered orbiting stars other than the Sun, and, with the extraordinary observing ability of the James Webb Space Telescope (JWST), astronomers are finally able to bring these distant worlds into view. On page 39, Greene *et al.*[1] used the telescope to detect heat coming from a terrestrial exoplanet called TRAPPIST-1b. The authors' observations indicate a barren wasteland of a planet, with a hot surface that bears no trace of an atmosphere. The result is a setback for scientists hoping to find planets reminiscent of Earth in the TRAPPIST-1 system, but it is an exciting

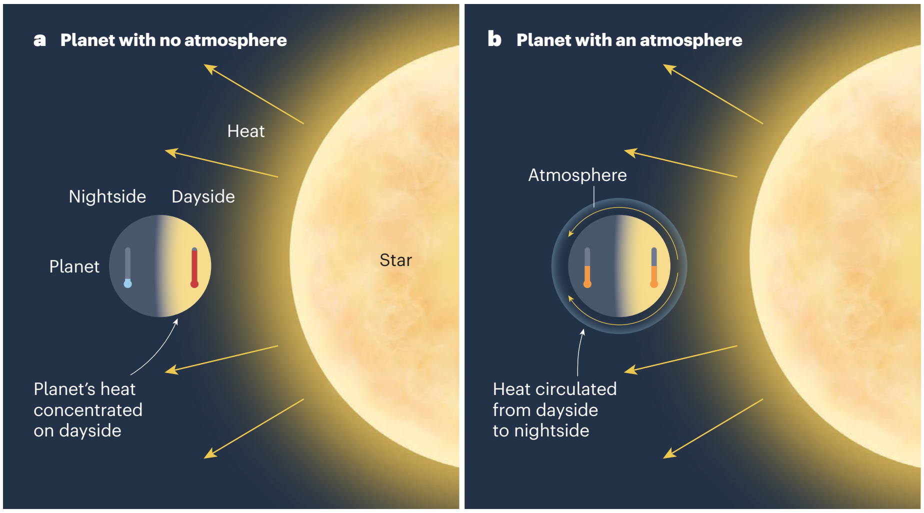

Figure 1 | Dayside heat as a signature of an atmosphere. Greene *et al.*[1] used the James Webb Space Telescope to measure the temperature of the exoplanet TRAPPIST-1b to determine whether it has an atmosphere. **a**, In the absence of an atmosphere, the heat from a star is absorbed by a planet's surface, resulting in a hot dayside (the side of the planet facing the star) and a cold nightside. **b**, By contrast, an atmosphere can circulate heat from the dayside of a planet to its nightside. The authors measured a very hot dayside temperature for TRAPPIST-1b, indicating that the planet probably doesn't have an atmosphere.

demonstration of the JWST's capabilities.

TRAPPIST-1b is one of seven terrestrial planets orbiting a small star that lies just 12 parsecs from Earth. The system was discovered[2] in 2016 by the Transiting Planets and Planetesimals Small Telescope (TRAPPIST). The planets are less creatively named b, c, d, e, f, g and h in order of their distance from their parent star, TRAPPIST-1. In cosmic terms, the system is close to Earth and, with sizes similar to or slightly smaller than that of Earth, the planets are large relative to their star, which is around the size of Jupiter. These features mean that the TRAPPIST-1 planets offer an unmatched opportunity for detailed characterization[3].

In the years since the planets' discovery, astronomers have carefully measured the masses and radii of the planets, revealing that the bodies have densities similar to that of Earth[4]. Some of the planets are a little hotter than Earth, some a little cooler, but a few might be in the right temperature range for water to exist in liquid form on their surfaces[5] – that is, if they have any water at all.

Liquid water is thought to be crucial for planetary habitability. Life as we know it depends on the presence of water and other 'volatiles' – nitrogen, carbon dioxide and methane, for example. But whether an exoplanet has a volatile-rich atmosphere is challenging to predict: it depends on a wide range of factors, including the initial delivery of water and other ices during the planet's formation; gases that leak out of the planet's mantle through volcanic activity; and how the atmosphere has been eroded by intense starlight and by impacts with other planets[6].

Compared with rocky worlds in the Solar System, the TRAPPIST-1 planets are particularly vulnerable to atmospheric loss. Small stars such as TRAPPIST-1 emit very bright light at ultraviolet frequencies during the first billion years of their lives, blasting their young planets with high-energy radiation and potentially evaporating a volume of water equivalent to many times that found in Earth's oceans[7]. The only way to discover whether these planets have been able to maintain any atmosphere is to observe them directly.

To start the search for atmospheres on the TRAPPIST-1 planets, Greene *et al.* investigated planet b – the hottest of the seven, and thus the easiest to study. The planet and the star are too close together to separate them spatially from Earth's vantage point. Instead, the authors searched for changes in the total brightness of the system as the planet moved through its orbit. The observations were timed to coincide with an eclipse during which planet b passed behind TRAPPIST-1, so its brightness was blocked by the star.

"The dayside of TRAPPIST-1b is a toasty 500 kelvin, which is a giveaway that no thick atmosphere is present there."

The exquisite observing abilities of the JWST were crucial to the study's success: the instrument enabled the detection of tiny changes in the light emitted by the exoplanet at infrared frequencies. Greene *et al.* inferred the amount of light coming from the planet by comparing observations of the star and planet together with those of the star alone. This game of peek-a-boo allowed them to measure the temperature of the planet's dayside, the part of the planet that faces its star.

The authors' measurements show that the dayside of TRAPPIST-1b is a toasty 500 kelvin, which is a giveaway that no thick atmosphere is present there (Fig. 1). Atmospheres tend to recirculate heat from a planet's irradiated dayside to its dark nightside. This heat circulation evens out the temperature difference between the two hemispheres[8]. In the absence of an atmosphere, the heat from the star is absorbed by the surface and re-radiated directly to space, resulting in the hottest possible dayside and a frigid nightside. The dayside of TRAPPIST-1b is as hot as it possibly could be, implying that the planet is probably a bare rock without any atmosphere.

The absence of an atmosphere on TRAPPIST-1b is a sobering jolt after years of speculation about what these planets might be like. But the reason for its absence is intriguing in itself. Perhaps the atmosphere simply couldn't survive the harsh irradiation of the planet's early years. Alternatively, it could have been blown off when the planet collided with another giant object. Or maybe there never was an atmosphere, and the planet formed 'dry', as a bare rock hurtling through space for billions of years, containing no carbon or oxygen.

There is no guarantee that TRAPPIST-1b is representative of the cooler planets in the system. If some of these other worlds do have atmospheres, future observations from the JWST will detect them. Evidence that all the planets are airless would instead have profound implications for other planets out there that are currently deemed suitable for life. Most of the rocky planets in the Galaxy orbit small stars similar to TRAPPIST-1 (ref. 9). If it turns out that these small stars zap the atmospheres of the planets they host, the number of potentially habitable worlds would be substantially reduced. Maybe Earth, with its large Sun, is even more special than previously thought.

Laura Kreidberg is at the Max Planck Institute for Astronomy, D-69117 Heidelberg, Germany.
e-mail: kreidberg@mpia.de

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