The Terror of History: Solar Eclipses and the Origins of Social Complexity and Complex Thinking *

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Abstract

Our research advances the hypothesis and empirically establishes that a higher incidence of solar eclipses is associated with higher social complexity and complex thinking in pre-modern societies. We construct a novel dataset of solar eclipses' incidence at the ethnic-group level, bringing together a wide range of historical, ethnic and GIS data sources. We exploit variations in the exposure to solar eclipses in a set of 1267 ethnic groups derived from Murdock's 1967 Ethnographic Atlas. Variation in the exposure to total eclipses is exogenous, as eclipses are randomly and sparsely distributed all over the globe. Moreover, unlike other natural phenomena, solar eclipses do not destroy capital —be it human or physical. We use jurisdictional hierarchy levels, political integration and class stratification to account for social complexity. Increasing levels of gods' involvement in human affairs and the play of games proxy for complex thinking. Our results are robust to a wide range of geographical and ethnic-group controls as well as to a horse race regression between solar eclipses and other natural phenomena: lunar eclipses, earthquakes and volcano eruptions. As a potential mechanism, we hypothesize that solar eclipses and the fear they instilled raise the demand for explanations. Societies that experience frequently such episodes develop more complex societal structures and become more versed in complex thinking in an attempt to comprehend and eventually control the natural environment.

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1 Introduction

"Since the cause of the fear is ignorance, is it not worth acquiring knowledge in order to remove your fear? How much more worthwhile it is to investigate causes, with your whole mind focused on this goal! For no more deserving subject can be found, and you must not simply lend your mind to it, but spend your mind on it."

Seneca (2010, Book 6.3, p. 91)

The economic literature relates economic prosperity to human capital —see Galor and Moav (2006), Barro (2001) and Hanushek and Woessmann (2012)— and social complexity, both for historical setups and in the present. The salience of human capital can be traced back to the time of the Industrial Revolution[1] —Squicciarini and Voigtländer (2015)— and even to previous institutions fostering its accumulation, see for instance Valencia Caicedo (2018) and Mokyr (2018). The latter, social complexity, is related to forms of societal and class organisation that eased the division of labour allowing for an earlier takeoff and ultimately promoting economic growth, see Bockstette et al. (2002), Borcan et al. (2017) and Depetris-Chauvin and Özak (2018).

This paper inquires about the origins of complex social structures as well as of complex thinking, natural precursors of early states and human capital. Departing from classical determinants of human capital and economic development, we propose a novel determinant that has cast its long shadow on the comparative development of countries: exposition to rare, dreadful events that trigger curiosity. We particularly focus on total solar eclipses as one unique case of rare and frightening event with an even distribution across Earth.[2] In line with Murray (2014, p. 240), we see total solar eclipses as a driver of curiousness that encourages more complex thinking.

Our research advances and empirically establishes that more frequent exposure to solar eclipses is related to higher social complexity —a proxy for development— and more complex thinking, in a sample of 1267 pre-modern ethnic groups derived from Murdock's Ethnographic Atlas (1967). In particular, for each ethnicity, we count the number of total solar eclipses visible from its homeland. Such eclipses occur when the Sun, the Moon and the Earth perfectly align on the ecliptic. To an observer on the Earth, day turns into night as parts of the latter

[1] In particular, knowledge accumulated at the upper tail of the distribution —and not that of the average worker— was decisive for economic development.

[2] Earthquakes and volcano eruptions also classify as rare events that instil terror. However, these only occur in selected locations, damage physical and human capital and societies experiencing them can grow accustomed.

enter the Moon's shadow. The darkening is very local: a strip less than 160 km wide that affects vasts swaths of the Earth in a west-east motion.[3] On average, there is one total solar eclipse approximately every 18–20 months somewhere on the Earth. For a given location, total solar eclipses are separated, on average, by four centuries. At the ethnic homeland level, the average time between two eclipses is around 60 years while the average number of eclipses is approximately 77 over a period of 4.000 years. Crucially, the societies in Murdock's Ethnographic Atlas are by the very construction of the Atlas sparsely located over the globe, which is essential in terms of exposure to eclipses; and, when surveyed, were still in early stages of development: solar eclipses would still be a trigger of awe, terror and questioning.

In our empirical analysis, we first employ the levels of jurisdictional hierarchy, political integration and class stratification to account for social complexity. Secondly, the presence of high gods and the play of strategy games serve as proxies for complex thinking. Our results positively relate the number of total solar eclipses to the aforementioned outcomes. We rationalise our findings in line with the opening quotation: rare events raise the demand for explanations, and those who experience more of such episodes develop more complex societal structures and become more versed in complex thinking in an attempt to comprehend and eventually control the natural environment.[4] The results are robust to an exhaustive set of controls regularly employed in this literature and further checks: various econometric techniques, alternative variables to account for solar eclipses and different clustering strategies. We also present evidence indicating that other events, e.g., earthquakes and volcano eruptions, that may drive curiosity and thinking do not affect our results. The same holds for other potentially confounding theories that have been advanced in the related literature. By focusing on the effects of solar eclipses, we believe that our results do not suffer from endogeneity problems and we can derive a causal relationship.

The results we present are broadly in line with the extensive literature documenting factors that promote human capital accumulation, especially in pre-modern times. There is ample evidence for religion —Becker and Woessmann (2009), Valencia Caicedo (2018), Waldinger (2017)—, the early introduction of the printing press —Baten and van Zanden (2008)—, or institutional factors —Galor et al. (2009), Bobonis and Morrow (2014). Our paper contributes to this literature by focusing on a prior stage, i.e., cognisance and complex thinking shaped early

[3] Also, temperature drops —up to 10 degrees— and wind slows down and changes direction (Gray and Harrison (2012) and Eugster et al. (2017)). In contrast, partial solar eclipses present a larger area of effect but offer a milder obscuration. This type of eclipse occurs when the Sun-Moon-Earth alignment is less precise.

[4] We are not interested in the scientific validity of the proposed explanations for solar eclipses. At any rate, proposing an explanation, even if ingenuous, represents an intellectual endeavour.

in history.

This paper is also related to the literature that explores the impact of historical shocks on long-run economic and social outcomes. Nunn and Wantchekon (2011) reviews the effects of slave trade on trust and Barro (2006, 2009) analyse the impact of natural disasters have on asset returns. Closer to our outcomes on social organisation, Cavallo et al. (2013) show that extreme natural disasters promote political revolutions, thereby affecting growth. Belloc et al. (2016) find that earthquakes slowed down the transition from autocracy to self-governance in medieval Italy. Regarding the impact of solar eclipses on socio-economic outcomes, there is not much, if anything, directly related in the economic literature. To the best of our knowledge, solar eclipses have only been explored by Boerner et al. (2019) when analysing the early adoption of mechanical clocks.

By analysing the effects of solar eclipses, which are by their own nature non-destructive events, we depart from this literature. The distinction is important as we are interested in human curiosity: destructive events may have diverted thinkers' interest away from explaining the phenomena towards more urgent reconstruction or may have even killed them. Similarly, physical capital losses retard economic growth, eroding the need for more complex social organisations.

Last, we contribute to the literature that inquires about social complexity determinants. Fenske (2014) explores the impact of ecological diversity on the state centralization, while Litina and Bertinelli (2014) argue that greater diversity in land suitability for agriculture is associated with the emergence of early states. We complement this literature by exploring one additional determinant.

The remainder of the paper is as follows. Section 2 briefly describes solar eclipses and introduces anecdotal evidence related to our mechanism. Section 3 discusses the data and empirical strategy. Section 4 presents the benchmark results, while Section 5 conducts several robustness checks. Section 6 discusses potential mechanisms and Section 7 concludes.

2 Solar Eclipses

In this section, we rely on historical, anecdotal evidence and traditional folklore to hypothesise about the intricate channels through which eclipses may have contributed towards the early emergence of social complexity and complex thinking.

2.1 Solar Eclipses and Complexity: The Mechanism

Terror and the Need to Tame Nature. As described in the subsequent section, solar eclipses are irregular phenomena, randomly scattered all over the world and not associated with physical destruction.[5] As such, celestial phenomena, in general, have been associated with awe and terror (see Park (2010)). For many, solar eclipses are bad omens and this superstition is still present even in contemporary societies (Steel (2001)). The Crow people rejoiced as the Sun rebirths more fortified after an eclipse. Others saw it simply as an sign of transformation, such as the Laguna-Acoma Pueblo.

Eclipses have long fascinated humankind. Historical records evidence the initial attempts to register them. Recorded eclipses in China go as back in time as the 2043BC solar eclipse. Later eclipses dating from 1250-1046BC and appear as bone inscriptions, see Pankenier (2014, p. 2044, 2073-2074). Other sources also highlight the lengthy records kept by the Chinese: the first entry in Kelley and Milone (2011, p. 118) corresponds to 709BC. Besides the Chinese, other ethnic groups kept accounts of eclipses: the Zapotec (Justeson (2014, p. 765)) and the Swedish in the form of rock art (Ruggles (2014, p. 357)) Section A in the Appendix explains how pre-modern societies predicted the timing of eclipses. However, local visibility was impossible to forecast until 1715.

Folklore and mythology present different explanations for the temporary vanishment of the Sun. Some are very ingenuous: Cherokee and Vietnamese people believed that a giant frog eats the Sun, a celestial dragon does so in China, mythical dogs steal the Sun in Korea and, according to the Pomo an angry bear is responsible. In contrast, some myths indicate a clear understanding of celestial mechanics and cleverly introduce the Sun and the Moon, this is, the two celestial bodies intervening in a solar eclipse. For the Battammaliba, the Sun and the Moon clash and the only way to stop them from fighting is to halt all conflict on Earth. The Diné, the Wirangu and the Warlpiri explain that during an eclipse, the Sun and Moon are mating.

The fear instilled by celestial phenomena triggered early attempts to understand nature and tame it. This is succinctly reflected in a wide range of historical quotes. To Aristotle, wisdom is the measure of one's knowledge about the natural cause of things, an assumption equally endorsed by the Romans (Carrier, 1998). Cicero (1923, Book 2.28 (60)) argued:

"*(...)whatever comes into existence, of whatever kind, must find its cause in nature; and*

[5] Appendix A provides additional details.

hence, even though it may be contrary to experience, it cannot be contrary to nature. Therefore, explore the cause, if you can, of every strange thing that the excites your astonishment. If you do not find the cause be assured, nevertheless, that nothing could have happened without a cause(...)"

One hundred years later, Seneca (2010, Book 6.3, p. 91) argues:

"*Since the cause of the fear is ignorance, is it not worth acquiring knowledge in order to remove your fear? How much more worthwhile it is to investigate causes, with your whole mind focused on this goal! For no more deserving subject can be found, and you must not simply lend your mind to it, but spend your mind on it.*"

He further extends his line of thought to eclipses by noting that only those who ignored how things work in nature viewed them as prodigies as they seemed contrary to the natural order.

Anecdotal evidence by historians suggests that, indeed, eclipses intensified the study of nature. In particular, eclipses influenced the study of astronomy and ultimately the development of scientific tools (Turner (1909) and Dohrn-van Rossum (1998)). It was not only the need to understand the phenomenon but also the special conditions that the phenomenon itself posed that triggered the development of astronomy. Approximately the year 150BC, the Greek astronomer Hipparchus of Nicaea tried to calculate the distance between the Earth and the Moon using a solar eclipse. He was informed that in northwestern Turkey the Moon and the Sun perfectly aligned. Meanwhile, for the very same eclipse, in Alexandria —about 1000 km apart—, the overlap was only 80%. Using trigonometry, he calculated the distance between Earth and the Moon.

Even in more recent years, the French astronomer Pierre Janssen noticed an unknown line in the yellow part of the Sun's spectrum during his observations of the 1868 total solar eclipse. He later showed that the line corresponded to an unknown element: helium. However, this was only a side discovery for he studied the observability of the solar corona.

Motivated by this evidence, we hypothesise that various aspects of complexity have been reinforced by ethnic groups' higher exposure to eclipses. On the one hand, the awe and fear associated with eclipses, perpetuated over centuries through folklore and written records, is a key driver in the development of complex social structures and complex thinking. On the other hand, the very presence of eclipses allowed earlier scientific discoveries, giving a first-mover advantage to societies with more frequent exposure. We thus hypothesise that the combined outcome of these two mechanisms shaped societies to be more complex in a wide range of dimensions.

3 Data and Empirical Strategy

3.1 Data

Our paper advances the hypothesis that more frequent exposure to total solar eclipses increases social complexity and urges complex thinking.[6] We rely on Murdock (1967) and Murdock and White's (1969) Ethnographic Atlas to obtain variables reflecting these outcomes. The Atlas contains a set of pre-modern societies when surveyed. For these social groups, most of them not having mastered astronomy, solar eclipses would still represent a meaningful event worth explaining. These societies are, by construction, sparsely distributed across space which reduces spatial correlation concerns. According to Chick (1997), in the context of anthropology, *complexity* has a particular meaning: "[w]hen anthropologists differentiate cultures in terms of their relative complexity, they do not use the term 'complex' in its ordinary, literal, or dictionary sense. What they imply, rather, is their status vis-à-vis one another with reference to one or more classificatory criteria which have been postulated to correlate with different levels or stages in cultural development. Examples are legion, e .g., literate as opposed to preliterate societies [...]" Data on total solar eclipses come from Espenak and Meeus (2006) and includes information about all total solar eclipses that occurred between the years 2000BC and 2000AD. In what follows, we describe our main variables of interest.

Social complexity. The Ethnographic Atlas provides three variables directly related to ethnic groups' social organisation. The first variable conveys information about the levels of hierarchy that exist beyond the local community. Five levels are possible, and more hierarchical societies score higher in this indicator. The second variable measures political integration. In this case, the indicator presents six differentiated categories: absence of local integration, autonomous local communities, peace groups transcending local communities, minimal states, little states and states. Finally, we focus on class stratification among freemen within ethnic groups. There may be no distinction among freemen, or alternatively, individuals may belong to social classes determined by wealth, elite status, dual classifications or more complex systems.[7] Following Diamond (2017), we see the variables related to social complexity as indirect indicators of economic progress. Moreover, starting from Murdock and Provost (1973), anthropologists have

[6] We remark, though, that we are interested in the intellectual effort these events represent while remaining agnostic regarding whether a conceived explanation is accurate or not. In that sense, we see these events as forcing individuals to think about the unknown. Hence, even is the final explanation is blatantly incorrect as of today standards —or even in comparison to similarly advanced societies— its ideation should increase cognitive skills.

[7] In the Ethnographic Atlas, these indicators correspond to variables 33, 90 and 66, respectively.

systematically argued that these proxies of social organization indicate cultural complexity.

Complex thinking. The Ethnographic Atlas does not record any variable directly related to complex thinking. However, it is possible to find proxy indicators that reflect deeper and more intricate reasoning. First, we use the variable Higher Gods. It presents a taxonomy of gods according to their involvement in human affairs whereby each level represents a more complex set of attributes. The possible stages are: lack of gods, the belief in gods who are nonetheless inactive in human affairs, gods that are active in human affairs but unsupportive of human morality and, finally, gods that are both active in human affairs and supportive of human morality.[8] We argue that developing a set of gods and endowing them with morality represents a more challenging mental endeavour compared to just conceiving the existence of gods. In that sense, we see progress in this scale as indicating more complex thinking. Moreover, as Schaller et al. (2011) mentions, moralizing gods (the top echelons in our scale) can extend the limited scope of human cooperation and provide the means to enforce social norms. Eventually, this process can shape the large-scale complex cooperative institutions. According to the authors, "[t]o achieve a civilization of this scale, it was necessary to invent them [high gods]".

Our second proxy variable informs us about the types of games played in the society. These can be: physical games, chance games, strategy games or a combination of the previous. We transform this variable into a dummy indicator stating whether an ethnic group plays strategy games or not. Strategic behaviour is indicative of advanced cognitive skills and societies that rely on strategic thinking develop such games to teach the next generations how to operationalise it. According to Chick (1997), these variables are also proxies for cultural complexity.

Solar Eclipses. To capture the long-lasting impact of solar eclipses we construct a novel dataset of their incidence at the ethnic-group level bringing together a wide range of historical, ethnic and GIS data sources. Among the different types of eclipses, we focus on total and annular eclipses. In these two sorts, the Moon completely obscures the Sun, effectively turning day into night. The most comprehensive dataset about solar eclipses is Espenak and Meeus (2006), which compiles all the relevant information for all solar eclipses occurring between 2000BC and 3000AD. Based on this data, Jubier (2019) computes "paths of totality" for each eclipse: all positions on Earth from which a total solar eclipse is visible. In fact, total solar eclipses are visible only within a relatively narrow area, typically not wider than 160 km.[9]

[8]The more complex systems of beliefs embed gods with considerations of what is right and wrong and capable of punishing misbehaviour.

[9]This area appears naturally as the shadow the Moon casts transverses the Earth due to the movement of

Our main independent variable is the number of total solar eclipses visible from within each ethnic homeland. We construct it by intersecting eclipse paths with ethnic homeland boundaries from Fenske (2014). We restrict the data to eclipses that took place between the years 2000BC and 2000AD. Figure 1 presents several paths of totality[10] and exemplifies the construction of our independent variable.

We argue that solar eclipses present several advantages compared to other natural phenomena. First, their occurrence is rare. Individuals can become accustomed to more common events, for instance, lightning. We thus believe that solar eclipses are more likely to have a long-lasting impact. Second, different from earthquakes and volcano eruptions, solar eclipses do not destroy physical nor human capital. Capital destruction would directly affect complex thinking and societies beyond the cognitive channel we postulate. Lastly, solar eclipses are well distributed across the Earth and the effects can be perceived by a large collectivity.

Table 15 in the Appendix indicates the average number of eclipses that have ever been visible in a homeland, which is 77, while Figure 2 illustrates the total number of eclipses for the full set of homelands over the globe. This number is large because we use the number of eclipses visible over the course of 4000 years. By doing so, we capture the actual frequency of eclipses better than if we used narrower time frames more prone to idiosyncratic variation.[11]

Other Controls. The Ethnographic Atlas provides several control variables at the ethnic-group level. Our benchmark specification follows Fenske (2014) and includes major crop types. We augment it accounting for habitat characteristics.

Furthermore, we rely on GIS solutions to compute additional variables related to economic development. First, we introduce a series of standard climatic and geographic controls: average temperature and precipitation, absolute latitude and a south dummy.[12] Following Nunn and Puga (2012), we include controls for terrain ruggedness and elevation.

We also introduce we introduce the distance to the coast and distance to the rivers because early civilizations and early state formation took place near waterways as Mann (2012) indicates. Additionally, exposure to foreign ideas is higher near major communication hubs: ports in pre-modern times. Similarly, we follow Ashraf and Galor (2013) and we control for the terrestrial distance to Addis Ababa to capture the effect of genetic diversity. We further include measures

both bodies.

[10] We draw the reader's attention to their narrow and elongated shape.

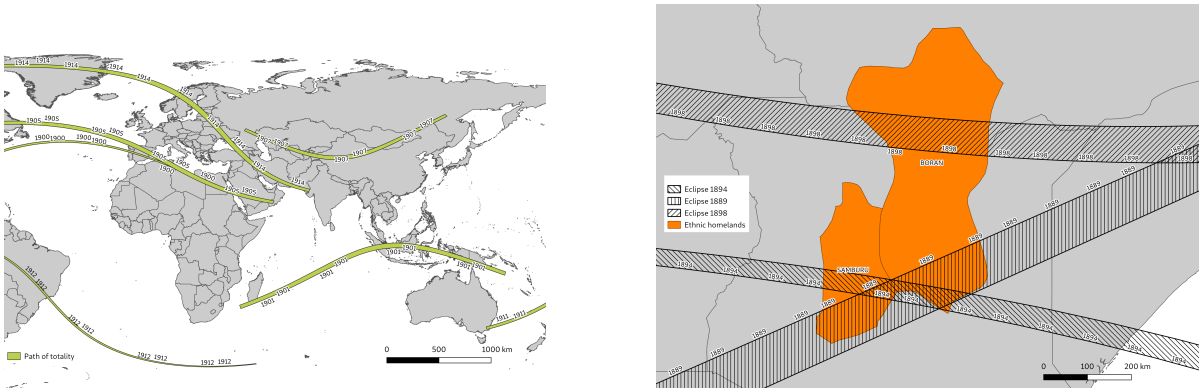
[11] Our results though are robust to introducing alternative, shorter time frames of 500 years from different epochs.

[12] Because of the tilted Earth axis, the northern hemisphere experiences more solar eclipses.

Figure 1: Paths of totality.

(a) Global coverage.

(b) Eclipses at the ethnic homeland level.



Notes: Figure 1a represents several paths of totality for selected total solar eclipses. Each path of totality covers a narrow area no wider than 160 km that stretches in the east-west direction. Figure 1b displays several ethnic homelands together with some selected paths of totality. Our main variable, the number of total solar eclipses visible from within an ethnic homeland is obtained counting the number of paths of totality that intersect a given ethnic homeland.

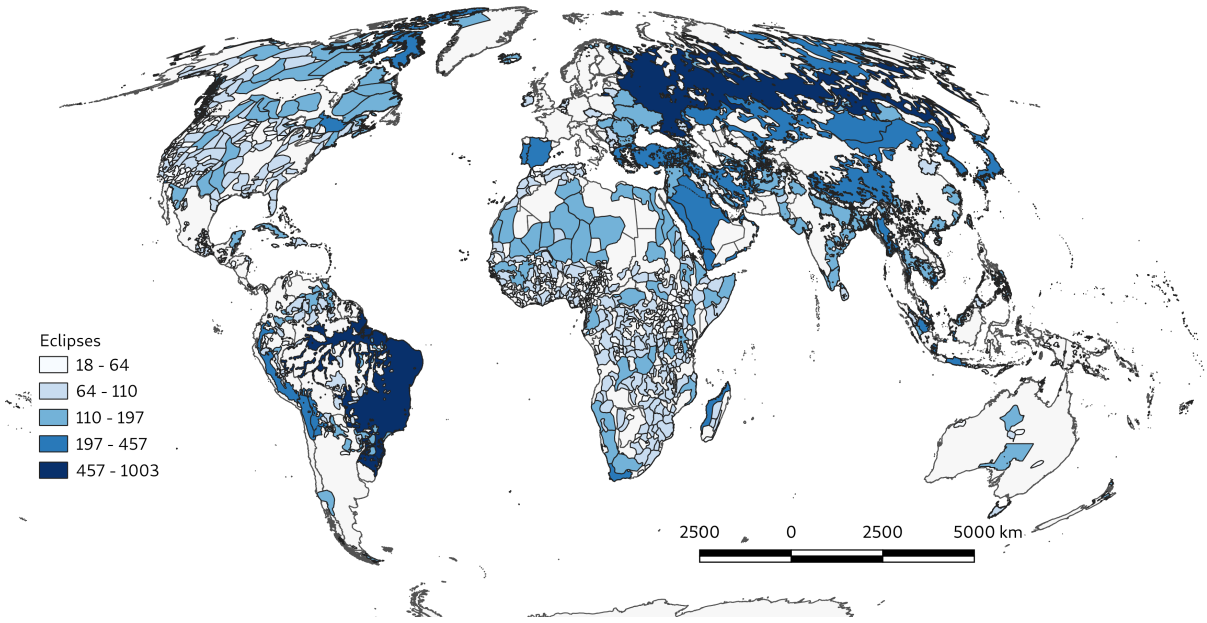
for malaria prevalence and potential caloric yield. The mortality burden posed by malaria can negatively affect the adoption of new technologies —as malaria prevalence can induce inbreeding and high mortality rates can deter technological progress through a shortened life expectancy. According to Galor and Özak (2016) and Diamond (2017), higher potential caloric yield can both directly and indirectly —through preferences— foster economic development.

In the robustness and the discussion section, we further augment the analysis with an additional set of geographical controls including the area of each ethnic homeland (larger areas are exposed to more eclipses), dependency on different modes of production and ecological diversity. Further, we also show that our results are robust to other dreadful events: volcano eruptions and earthquakes. Moreover, neither lunar eclipses or cloud coverage affect our results.

Table 15 in the Appendix reports the summary statistics for all our dependent and explanatory variables as well as for the ethnic and geographical controls. The data are all reported at the level of our unit of analysis: the ethnic group.

Moreover, running horse race regressions with other measures of eclipse prevalence —the average, maximum or minimum time between two consecutive eclipses— does not compromise our results. In all cases, these are qualitatively similar to those of the benchmark regression.

Figure 2: Distribution of total solar eclipses at the ethnic homeland level.



Notes: This Figure represents the number of total solar eclipses that occurred between the years 2000BC and 2000AD that were visible from within ethnic homeland boundaries.

3.2 Empirical Strategy

Using the aforementioned data we estimate the following equation:

$$C_i = \alpha_0 + \alpha_1 E_i + \alpha_2 \mathbf{I}_i + \alpha_3 \mathbf{G}_i + \alpha_4 \mathbf{D} + \varepsilon_i$$

where C_i denotes each of the five measures of social complexity and complex thinking at the ethnic-group level. E_i measures the number of eclipses an ethnic homeland has been exposed to. $\mathbf{I}_i$ and $\mathbf{G}_i$ are vectors of ethnic and geographical controls, respectively. $\mathbf{D}_i$ denotes continent fixed effects capturing unobservables across continents in which ethnic groups are located and ε_i is an ethnicity-specific error term. We cluster standard errors at the regional level. All our dependent variables, except for playing strategy games are ordered. Therefore, regressions follow an ordered logit model. In the case of strategy games, we rely on OLS. Our results report the obtained coefficients as well as the marginal effects.

4 Empirical Findings

This section reports the results of our benchmark analysis, relating the prevalence of total solar eclipses to increased social complexity and complex thinking. During a solar eclipse, as the Moon obscures the Sun, day turns into night. Also, temperature drops —up to 10 degrees— and wind slows down and changes direction.[13]

Columns (1)–(3) of Table 1 report the findings for the *Juristinctional Hierarchy* variable. Column (1) reports the coefficient when we control only for continental fixed effects. Column (2) augments the analysis with all the relevant geographical controls while column (3) enriches it with the addition of the ethnic-group controls. We introduce our controls gradually to follow the evolution of the coefficients. Our results indicate that, for all three cases, results are always statistically significant at the one percent level and the magnitude of the coefficient remains remarkably stable even after the addition of the full set of controls. We devote Table 2 to the implied marginal effects.

In a similar fashion, Columns (3)– (6) and (7)– (9) report the results for *Political Integration* and for *Class Statification*, correspondingly. In all cases, our findings are qualitatively significant at the one percent level and quantitatively similar and stable across specifications even after the introduction of the full set of controls. In the rest of the paper, we will always refer to the specification employed in Columns (3), (6) and (9) as the benchmark specification. This specification has the full set of basic controls that, on the one hand, captures a wide range of confounding factors and, on the other hand, maximizes the number of observations. Later, the benchmark specification is the starting point when conducting our robustness checks and when testing competing theories and other potential confounding factors. Turning to the magnitude of the results, Table 2 reports the marginal effects. Since in most cases —in all variables except for *Strategy Games*— we estimate ordered probit regressions, it makes more sense to present the marginal effects. In Columns (1)–(3) report the marginal effects for the benchmark specification. When we compute the marginal effects employ the average number of eclipses per century to have a more meaningful measure of the incidence of eclipses.[14]

For the case of *Juritinctional Hierarchy*, the marginal effect of a one-unit change in the incidence of eclipses (this is, of one additional eclipse per century) is the reduction of the probability of having no levels of jurisdictional hierarchy by 9.6 percentage points. Societies that

[13] See Gray and Harrison (2012) and Eugster et al. (2017).

[14] The average number of eclipses per century equals the total number of eclipses divided by 40.

Table 1: Benchmark results: Solar eclipses and social complexity.

	Jurisdictional Hierarchy			Political Integration			Class Stratification		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Total number of eclipses	0.014*** (0.003)	0.015*** (0.003)	0.016*** (0.002)	0.011*** (0.003)	0.014*** (0.003)	0.015*** (0.003)	0.008*** (0.003)	0.011*** (0.003)	0.011*** (0.003)
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geography	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Ethnic	No	No	Yes	No	No	Yes	No	No	Yes
R^2 Pseudo-R^2	0.148	0.218	0.228	0.093	0.188	0.223	0.082	0.145	0.147
Observations	906	906	906	251	251	251	821	821	821

Summary: This Table presents the results of ordered logit regressions relating the impact of eclipses on the measures of societal complexity at the ethnic-group level. Columns (1)–(3) report the findings for the *Juristinctional Hierarchy* variable. Columns (3)–(6) and (7)–(9) report the results for *Political Integration* and for *Class Statification* correspondingly. In all three cases, the first Column reports the coefficient when we control only for continental fixed effects. The second Column includes geographical controls while the last adds the ethnic-group controls. The results systematically report and positive and significant effect of eclipses on social complexity.

Notes: (i) "Jurisdictional Hierarchy Beyond Local Community" is an ordered variable taking values 1 (No Levels) to 5 (Four Levels); (ii) "Political Integration" takes six levels, indicating whether there is absence of political integration, autonomous local; communities, peace groups transcending local communities, minimal states, little states or states; (iii) "Class Stratification" takes 5 values from no distinction among freemen to complex strata. (iv) The measure of eclipses captures the number of total solar eclipses an ethnic homeland has been exposed to over the whole period; (v) continent fixed effect include dummies for Asia, Europe, Africa, North America, Oceania and South America; (vi) robust standard error estimates, clustered at the regional level, are reported in parentheses; (vii) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Table 2: Marginal effects: Social complexity.

Jurisdictional Hierarchy		Political Integration		Class Stratification	
No levels	-0.096^{***}	Absent	-0.033^{***}	Absent	-0.081^{***}
	(0.013)		(0.012)		(0.018)
1 level	0.012^{***}	Local com.	-0.058^{***}	Wealth	0.008^{**}
	(0.005)		(0.008)		(0.003)
2 levels	0.044^{***}	Preace groups	-0.001	Elite	0.005^{**}
	(0.007)		(0.001)		(0.002)
3 levels	0.030^{***}	Min. states	0.018^{**}	Dual	0.044^{***}
	(0.006)		(0.008)		(0.010)
4 levels	0.010^{***}	Little states	0.024^{***}	Complex	0.025^{***}
	(0.004)		(0.004)		(0.007)
		States	0.050^{***}		
			(0.012)		

Summary: This table presents the marginal effects of the results reported in Table 1 for the three measures of social complexity. The full set of controls is considered in the analysis.

Notes: (i) "Jurisdictional Hierarchy Beyond Local Community" is an ordered variable taking values 1 (No Levels) to 5 (Four Levels); (ii) "Political Integration" takes six levels, indicating whether there is absence of political integration, autonomous local; communities, peace groups transcending local communities, minimal states, little states or states; (iii) "Class Stratification" takes 5 values from no distinction among freemen to complex strata. (iv) The measure of eclipses captures the number of total solar eclipses an ethnic homeland has been exposed to over the whole period; (v) continent fixed effect include dummies for Asia, Europe, Africa, North America, Oceania and South America; (vi) robust standard error estimates, clustered at the regional level, are reported in parentheses; (vii) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

experienced one more eclipse over the course of a century have approximately 1.2 percentage points higher probability to organise in one hierarchical level, 4.4 percentage points higher probability to report two levels of hierarchy, 3 percentage points higher probability to report three levels of hierarchy and 1 percentage point higher probability to report four layers of hierarchy. Similar magnitudes are obtained for the remaining columns and indicate that e.g., one additional eclipse in the century is associated with a 5 percentage point higher probability for a society to be organised as a state —the highest political integration category— as well as with 2.5 percentage point higher probability to find itself on the highest level of class stratification.

Table 3 reports the results for *Complex Thinking*. Columns (1)–(3) present the findings for *Higher Gods*, while Columns (4)–(6) report the results for the *Strategy Games*. Column organisation mimicks Table 1. For both groups of variables, the results are again statistically significant at the one percent level and qualitatively confirm the results in Table 1, thus suggesting that higher exposure to eclipses is associated with more complex thinking. Similarly, Table

Table 3: Benchmark results: Solar eclipses and complex thinking.

	Higher Gods			Strategy Games		
	(1)	(2)	(3)	(4)	(5)	(6)
Total number of eclipses	0.008*** (0.003)	0.006*** (0.002)	0.006*** (0.002)	0.002*** (0.000)	0.001*** (0.000)	0.001*** (0.000)
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Geography	No	Yes	Yes	No	Yes	Yes
Ethnic	No	No	Yes	No	No	Yes
R^2 Pseudo-R^2	0.142	0.238	0.248	0.540	0.613	0.655
Observations	583	583	583	334	334	334

Summary: This table presents the results of ordered logit regressions relating the impact of eclipses on the measures of complex thinking at the ethnic-group level. Columns (1)–(3) report the findings for the *High Gods* variable. Columns (3)–(6) report the results for *Strategy Games*. In all cases, the first Column reports the coefficient when we control only for continental fixed effects. The second Column includes geographical controls while the last adds the ethnic-group controls. The results systematically report and positive and significant effect of eclipses on social complexity.

Notes: (i) "High Gods" is an ordered variable taking values 1 (Absent or Not Reported) to 4 (Present, active, and specifically supportive of human morality); (ii) "Strategy Games" is a binary variable taking values 0 (No strategy games) and 1(Strategy games); (iii) The measure of eclipses captures the number of total solar eclipses an ethnic homeland has been exposed to over the whole period; (iv) continent fixed effect include dummies for Asia, Europe, Africa, North America, Oceania and South America; (v) robust standard error estimates, clustered at the regional level, are reported in parentheses; (vi) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

4 reports the margninal effects. As before, the results suggest that societies that experienced an additional eclipse per century are more likely to have a more complex system of gods. In particular, the probability of having no gods at all decreases by 3.5 percentage points while it raises the probability that gods support human morality by 2.6 percentage points.

Table 4: Marginal effects: Complex thinking.

Higher Gods		Strategy Games	
No gods	-0.035^{***}	Yes	0.057^{***}
	(0.012)		(0.012)
Not active	0.004		
	(0.003)		
Active, no morality	0.005^{**}		
	(0.002)		
Morality	0.026^{***}		
	(0.010)		

Summary: This table presents the marginal effects of the results reported in Table 1 for the three measures of social complexity. The full set of controls is considered in the analysis.

Notes: (i) "High Gods" is an ordered variable taking values 1 (Absent or Not Reported) to 4 (Present, active, and specifically supportive of human morality); (ii) "Strategy Games" is a binary variable taking values 0 (No strategy games) and 1(Strategy games); (iii) The measure of eclipses captures the number of total solar eclipses an ethnic homeland has been exposed to over the whole period; (iv) continent fixed effect include dummies for Asia, Europe, Africa, North America, Oceania and South America; (v) robust standard error estimates, clustered at the regional level, are reported in parentheses; (vi) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Overall, our main analysis indicates a systematic effect of the incidence of eclipses on social complexity and complex thinking. The magnitude of our results is not trivial, especially taking into account that we consider eclipses over such long period. In the following section, we test the robustness of our benchmark findings to a series of alternative assumptions and additional controls.

5 Robustness

5.1 Validity of the Eclipses Measure

Our measure of eclipses, and in particular the choice of the time period is quite broad to capture not only the actual incidence of eclipses but also their long-lasting impact on social complexity and complex thinking through mechanisms associated with oral and written tradition such as

folklore and mythology. This assumption also reflects the fact that the incidence of an eclipse is not instantaneously associated with more complex structures. It is a long-lasting process that is being completed over the course of centuries.

Yet, we view as important to employ different time periods to explore whether the results remain for more restrictive time spans. In Table 5, Panels A to H report the results of the benchmark specification for all five measures of complexity when using alternative periods to compute the total number of eclipses. These measures consider the following periods: 2000BC-1500BC, 1500BC-1000BC, 1000BC-500BC, 500BC-0AD, 0AD-500AD, 500AD-1000AD, 1000AD-1500AD, 1500AD-2000AD.[15]

Table 5: Robustness: Alternative time frames.

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
	Panel A: 2000BC–1500BC				
Total number of eclipses 2000BC-1500BC	0.105*** (0.015)	0.107*** (0.019)	0.079*** (0.018)	0.050*** (0.014)	0.012*** (0.002)
R^2 Pseudo-R^2	0.220	0.213	0.147	0.264	0.670
Observations	878	244	796	564	321
	Panel B: 1500BC–1000BC				
Total number of eclipses 1500BC-1000BC	0.102*** (0.013)	0.097*** (0.017)	0.062*** (0.017)	0.041** (0.017)	0.009*** (0.002)
R^2 Pseudo-R^2	0.227	0.212	0.141	0.250	0.648
Observations	895	251	814	580	334
	Panel C: 1000BC–500BC				
Total number of eclipses 1000BC-500BC	0.088*** (0.013)	0.087*** (0.016)	0.065*** (0.014)	0.036** (0.016)	0.009*** (0.002)
R^2 Pseudo-R^2	0.217	0.208	0.144	0.245	0.651
Observations	898	248	813	581	333
	Panel D: 500BC–0				
Total number of eclipses 500BC-0	0.093*** (0.019)	0.120*** (0.027)	0.064*** (0.016)	0.037*** (0.013)	0.010*** (0.003)
R^2 Pseudo-R^2	0.211	0.217	0.139	0.246	0.654
Observations	896	249	812	575	331
	Panel E: 0–500				

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[15]Table 19 in the Appendix reports the correlation coefficients between our benchmark measure of eclipses and all the alternative periods that we use. In all cases, the correlation is quite high which provides a first indication that the use of different measures should not drastically change the results.

Table 5 – *Continued from previous page*

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
Total number of eclipses 0-500	0.107*** (0.018)	0.129*** (0.020)	0.088*** (0.017)	0.031** (0.013)	0.009*** (0.003)
R^2 Pseudo-R^2	0.225	0.230	0.149	0.249	0.644
Observations	892	249	809	573	329
	Panel F: 500–1000				
Total number of eclipses 500-1000	0.101*** (0.012)	0.103*** (0.020)	0.081*** (0.019)	0.033*** (0.011)	0.010*** (0.002)
R^2 Pseudo-R^2	0.226	0.223	0.154	0.243	0.651
Observations	900	248	815	580	331
	Panel G: 1000–1500				
Total number of eclipses 1000-1500	0.104*** (0.016)	0.103*** (0.017)	0.069*** (0.018)	0.055*** (0.017)	0.012*** (0.002)
R^2 Pseudo-R^2	0.222	0.218	0.142	0.258	0.659
Observations	904	249	819	581	333
	Panel H: 1500–2000				
Total number of eclipses 1500-2000	0.119*** (0.014)	0.125*** (0.023)	0.072*** (0.018)	0.037** (0.016)	0.010*** (0.002)
R^2 Pseudo-R^2	0.234	0.231	0.146	0.246	0.654
Observations	898	250	813	578	332
Controls (common to all regressions)					
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes

Summary: This table reports the results of the benchmark specification for all five measures of complexity, when using each of the alternative eight measures of eclipses. These correspond to the number of total ecplipses for the following periods: 2000BC-1500BC, 1500BC-1000BC, 1000BC-500BC, 500BC-0AD, 0AD-500AD, 500AD-1000AD, 1000AD-1500AD, 1500AD-2000AD. The full set of controls is considered in the robustness analysis.

Notes: (i) "Jurisdictional Hierarchy Beyond Local Community" is an ordered variable taking values 1 (No Levels) to 5 (Four Levels); (ii) "Political Integration" takes six levels, indicating whether there is absence of political integration, autonomous local; communities, peace groups transcending local communities, minimal states, little states or states; (iii) "Class Stratification" takes 5 values from no distinction among freemen to complex strata. (iv) "High Gods" is an ordered variable taking values 1 (Absent or Not Reported) to 4 (Present, active, and specifically supportive of human morality); (v) "Strategy Games" is a binary variable taking values 0 (No strategy games) and 1(Strategy games); (vi) The measures of eclipses capture the number of total solar eclipses an ethnic homeland has been exposed to in each of the following periods: 2000BC-1500BC, 1500BC-1000BC, 1000BC-500BC, 500BC-0AD, 0AD-500AD, 500AD-1000AD, 1000AD-1500AD, 1500AD-2000AD; (vii) continent fixed effect include dummies for Asia, Europe, Africa, North America, Oceania and South America; (viii) robust standard error estimates, clustered at the regional level, are reported in parentheses; (ix) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

As anticipated, our results in Table 5 suggest that the effect is present no matter which

measure we use. Moreover, the magnitude is also quite similar with no systematic differences across periods or measures.

5.2 Alternative Eclipse Measures

While we argue that an eclipse is an impressive event which may have a long-lasting impact on people, we highlight that an additional feature of eclipses that reinforces their impact is their rather low frequency. In Table 6 incorporates three different measures of frequency: the average time between two consecutive eclipses in Panel (A), the minimum time between consecutive eclipses in Panel (B) and the maximum time between consecutive eclipses in Panel (C). The results of this exercise are in line with our hypothesis, this is, more frequent eclipses are associated with higher complexity, except for the minimum time between consecutive eclipses. However, we believe the total number of eclipses to be a more straightforward and easy to interpret measure, hence our preference for it. At any rate, however, the total number of eclipses already embodies a frequency component: the average time between eclipses.[16] At any rate, though, all measures are highly correlated as Table 17 in the Appendix evinces.

5.3 Additional Ethnic Controls

Our benchmark analysis controls for a wide range of ethnic and geographical controls as well as various fixed effects. To further mitigate concerns about possible omitted variables, Table 7 augments the benchmark analysis with a series of additional ethnic-group controls. Panels (A) and (B) include dependence on gathering and agriculture, respectively while Panel (C) introduces agricultural intensity levels. Panel (D) includes fixed effects for the subsistence mode of production.

Table 7: Robustness: Additional ethnic controls.

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
	Panel A: Gathering				
Total number of eclipses	0.015***	0.015***	0.010***	0.005**	0.001***
	(0.002)	(0.003)	(0.003)	(0.002)	(0.000)

Continued on next page

[16]The average time between eclipses equals 4000 divided by the number of eclipses. Notice, though, that the alternative measures we propose are more finely grained: they consider the time between consecutive eclipses.

Table 7 – *Continued from previous page*

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
Dependence on gathering	−0.338***	−0.337***	−0.395***	−0.231*	−0.027*
	(0.083)	(0.056)	(0.088)	(0.123)	(0.015)
R^2 Pseudo-R^2	0.236	0.233	0.160	0.253	0.660
Observations	906	251	821	583	334
	Panel B: Agriculture				
Total number	0.016***	0.016***	0.011***	0.006***	0.001***
of eclipses	(0.002)	(0.003)	(0.002)	(0.002)	(0.000)
Dependence on agriculture	0.116*	0.182***	0.245***	−0.006	0.036***
	(0.060)	(0.053)	(0.062)	(0.077)	(0.011)
R^2 Pseudo-R^2	0.231	0.228	0.158	0.248	0.667
Observations	906	251	821	583	334
	Panel C: Agricultural intensity				
Total number	0.014***	0.014***	0.010***	0.006**	0.001***
of eclipses	(0.002)	(0.003)	(0.002)	(0.002)	(0.000)
Agricultural intensity					
No agric.	Ref.	Ref.	Ref.	Ref.	Ref.
Casual agric.	1.045	3.503***	0.749	0.623	0.340***
	(0.839)	(0.902)	(0.601)	(1.895)	(0.109)
Extensive agric.	0.850	3.260***	1.342	0.594	0.421***
	(0.958)	(1.083)	(1.124)	(1.914)	(0.093)
Horticulture	−1.827*	0.037	−0.360	0.215	0.298**
	(1.110)	(1.534)	(1.448)	(2.102)	(0.119)
Intensive agric.	1.788**	3.906***	2.496***	0.778	0.458***
	(0.866)	(1.151)	(0.871)	(1.933)	(0.133)
Intensive irrigated agric.	1.831*	4.682***	2.381**	0.615	0.497***
	(1.046)	(1.184)	(1.069)	(2.104)	(0.134)
R^2 Pseudo-R^2	0.252	0.256	0.171	0.249	0.662
Observations	906	251	821	583	334
	Panel D: Subsistence economoy				
Total number	0.015***	0.015***	0.010***	0.005***	0.001***
of eclipses	(0.002)	(0.004)	(0.003)	(0.002)	(0.000)
Subsistence					
Gathering	Ref.	Ref.	Ref.	Ref.	Ref.
Fishing	0.341	−1.106***	1.050**	0.143	0.008
	(0.454)	(0.340)	(0.429)	(0.556)	(0.057)
Hunting	0.575	0.482	−0.243	0.220	0.019
	(0.579)	(0.350)	(0.568)	(0.607)	(0.057)
Pastoralism	1.217**	0.221	0.643	1.195	0.009
	(0.555)	(0.873)	(0.583)	(0.833)	(0.166)
Int. agric.	0.518	−0.317	0.718	0.449	0.138
	(0.340)	(0.544)	(0.531)	(0.685)	(0.084)

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Table 7 – *Continued from previous page*

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
Two or more sources	1.603***	1.120	1.920***	0.537	0.187**
	(0.518)	(0.819)	(0.598)	(0.583)	(0.080)
Agric.	0.399	−0.641	0.432	0.848	−0.037
	(0.452)	(0.504)	(0.503)	(0.671)	(0.041)
Ext. agric.					
R^2 Pseudo-R^2	0.244	0.246	0.173	0.251	0.668
Observations	906	251	821	583	334
Controls (common to all regressions)					
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes

Summary: This table reports the results when we add controls for a wide range of ethnic and geographical controls as well as various fixed effects. Panels (A) and (B) include dependence on gathering and agriculture. Panel (C) introduces agricultural intensity levels. Panel (D) includes fixed effects for the subsistence mode of production. The full set of controls is considered in the robustness analysis.

Notes: (i) "Jurisdictional Hierarchy Beyond Local Community" is an ordered variable taking values 1 (No Levels) to 5 (Four Levels); (ii) "Political Integration" takes six levels, indicating whether there is absence of political integration, autonomous local; communities, peace groups transcending local communities, minimal states, little states or states; (iii) "Class Stratification" takes 5 values from no distinction among freemen to complex strata. (iv) "High Gods" is an ordered variable taking values 1 (Absent or Not Reported) to 4 (Present, active, and specifically supportive of human morality); (v) "Strategy Games" is a binary variable taking values 0 (No strategy games) and 1(Strategy games); (vi) The measure of eclipses captures the number of total solar eclipses an ethnic homeland has been exposed to over the whole period; (vii) continent fixed effect include dummies for Asia, Europe, Africa, North America, Oceania and South America; (viii) robust standard error estimates, clustered at the regional level, are reported in parentheses; (ix) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

In general, the results indicate that agriculturalists exhibit more complex social structures. This is in line with comparative development theories, namely, the impact of the Neolithic revolution (Diamond (2017)). According to Litina and Bertinelli (2014), similar findings arise for irrigation and intensive agriculture. However, the introduction of such variables does not alter our main result.

5.4 Spatial Correlation

The variables may be spatially correlated, affecting the statistical significance of our results. A first line of argument against this concern is related to the very construction of the data. The effort of Murdock to collect the data in the Ethnographic Atlas was made with the intention to

Table 6: Robustness: Alternative measures of eclipse incidence.

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
	Panel A: Avg. time				
Avg. time between eclipses	−3.293***	−2.852***	−2.026***	−1.492***	−0.170**
	(0.543)	(0.647)	(0.477)	(0.364)	(0.072)
R^2 Pseudo-R^2	0.228	0.212	0.143	0.249	0.635
Observations	906	251	821	583	334
	Panel B: Minimum time				
Minimum time between eclipses	−16.925**	−1.912	−7.112*	−6.528	0.530
	(7.086)	(5.163)	(3.830)	(5.798)	(0.438)
R^2 Pseudo-R^2	0.194	0.177	0.126	0.241	0.626
Observations	906	251	821	583	334
	Panel C: Maximum time				
Maximum time between eclipses	−0.564***	−0.459***	−0.419***	−0.266***	−0.054***
	(0.106)	(0.151)	(0.104)	(0.090)	(0.019)
R^2 Pseudo-R^2	0.213	0.194	0.141	0.246	0.643
Observations	906	251	821	583	334
Controls (common to all regressions)					
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes

Summary: This table reports the results of regressions including alternative measures of eclipse frequency as independent variable. Columns (1)–(5) report the results for all our measures of social complexity and complex thinking while controlling for the full set of controls in the benchmark specification. Panel (A) includes in the analysis the average time between consecutive between eclipses, Panel (B) the minimum time and Panel (C) the maximum time between two consecutive eclipses. The full set of controls is considered in the robustness analysis.

Notes: (i) "Jurisdictional Hierarchy Beyond Local Community" is an ordered variable taking values 1 (No Levels) to 5 (Four Levels); (ii) "Political Integration" takes six levels, indicating whether there is absence of political integration, autonomous local; communities, peace groups transcending local communities, minimal states, little states or states; (iii) "Class Stratification" takes 5 values from no distinction among freemen to complex strata. (iv) "High Gods" is an ordered variable taking values 1 (Absent or Not Reported) to 4 (Present, active, and specifically supportive of human morality); (v) "Strategy Games" is a binary variable taking values 0 (No strategy games) and 1(Strategy games); (vi) continent fixed effect include dummies for Asia, Europe, Africa, North America, Oceania and South America; (vii) robust standard error estimates, clustered at the regional level, are reported in parentheses; (viii) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

mitigate correlation across groups over space or time.[17]

We further try to empirically address this concern by conducting some additional tests in Table 8. First, Panel (A) incorporates the number of eclipses visible from the closest neighbour's homeland as an additional regressor. This variable allows us to control for potential communication between groups, especially about eclipses, which would otherwise appear as noise. Panel (B) uses an alternative level to cluster the results: ecoregions. Besides being more precise, ethnic groups within the same ecoregion face similar difficulties from the habitat, for instance, in terms of food availability, soil characteristics or building materials. Finally, Panel (C) exploits the fact that ethnic groups whose languages are siblings or closely related tend to display similar characteristics arising from a common, shared history. In that sense, we introduce language fixed effects as an additional control and cluster the standard errors at that same level. All in all, neither of these more demanding specifications challenges our previous association between eclipses and social complexity or complex thinking.

Table 8: Robustness: Spatial correlation.

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
	Panel A: Nearest neighbour				
Total number of eclipses	0.016***	0.015***	0.012***	0.007***	0.001***
	(0.002)	(0.004)	(0.003)	(0.002)	(0.000)
Total number of eclipses, neighbour	−0.002	0.002	−0.003**	0.002	0.000
	(0.002)	(0.003)	(0.002)	(0.003)	(0.000)
R^2 Pseudo-R^2	0.225	0.219	0.142	0.269	0.653
Observations	861	233	779	551	311
	Panel B: Clustering at ecoregions				
Total number of eclipses	0.016***	0.015***	0.011***	0.006***	0.001***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.000)
R^2 Pseudo-R^2	0.228	0.223	0.147	0.248	0.655
Observations	906	251	821	583	334
	Panel C: Language Fixed Effects				
Total number of eclipses		0.020***	0.011***	0.005*	0.001**
		(0.004)	(0.003)	(0.003)	(0.001)
Language FE		Yes	Yes	Yes	Yes
Controls (common to all regressions)					

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[17] In the literature, the possible correlation between cultures is known as Galton's problem. When collecting his data, Murdock sampled cultures as independent as possible to mitigate this concern (see e.g.Mace et al. (1994)).

Table 8 – *Continued from previous page*

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
Fixed effects		Yes	Yes	Yes	Yes
Geography		Yes	Yes	Yes	Yes
Ethnic		Yes	Yes	Yes	Yes
R^2 Pseudo-R^2		0.336	0.202	0.358	0.728
Observations		251	821	583	334

Summary: This table reports the results when we attempt to mitigate concerns about spatial correlation. Panel (A) controls for the total eclipses visible in neighbouring ethnic homelands. Panel (B) clusters the standard errors at the ecoregion level. Panel (C) enriches the benchmark analysis with a set of language family fixed effects and clusters the standard errors at that same level. The full set of controls is considered in the robustness analysis.

Notes: (i) "Jurisdictional Hierarchy Beyond Local Community" is an ordered variable taking values 1 (No Levels) to 5 (Four Levels); (ii) "Political Integration" takes six levels, indicating whether there is absence of political integration, autonomous local; communities, peace groups transcending local communities, minimal states, little states or states; (iii) "Class Stratification" takes 5 values from no distinction among freemen to complex strata. (iv) "High Gods" is an ordered variable taking values 1 (Absent or Not Reported) to 4 (Present, active, and specifically supportive of human morality); (v) "Strategy Games" is a binary variable taking values 0 (No strategy games) and 1(Strategy games); (vi) The measure of eclipses captures the number of total solar eclipses an ethnic homeland has been exposed to over the whole period; (vii) continent fixed effect include dummies for Asia, Europe, Africa, North America, Oceania and South America; (viii) robust standard error estimates, clustered at the regional, ecoregional and language-family level, are reported in parentheses, for Panels (A), (B) and (C), respectively; (ix) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

A final concern is related to mass migrations of ethnic groups, particularly, the Bantu expansion that occurred between 1000BC and 1AD.[18] It consisted of a series of sequential migrations, from western Africa to the east and south. In Table 9 we first exclude, in Panel (A), west, central, east and southern African regions from the regression. Panel (B) further expands the exclusion to the whole African continent. In general, the results are similar to those we obtained before, except for Higher Gods.

5.5 Location accuracy and visibility

Two final concerns we address are related to the accuracy of the location of the eclipses as this would affect their visibility of eclipses from a particular location, as well as their visibility due to climatic conditions.

First, our results may suffer from low accuracy regarding either homeland boundaries or eclipse paths. Although in general ethnic homeland boundaries are accepted as precise enough,

[18] According to Giuliano and Nunn (2017), the Bantu expansion is the only migration that could have affected ethnic homeland boundaries.

Table 9: Robustness: Bantu expansion.

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
	Panel A: Excluding south Africa				
Total number of eclipses	0.014***	0.017***	0.011***	0.003	0.002***
	(0.002)	(0.003)	(0.002)	(0.002)	(0.000)
R^2 Pseudo-R^2	0.320	0.286	0.241	0.276	0.596
Observations	528	190	506	380	280
	Panel B: Excluding Africa				
Total number of eclipses	0.015***	0.017***	0.010***	0.003	0.001***
	(0.002)	(0.003)	(0.002)	(0.002)	(0.000)
R^2 Pseudo-R^2	0.324	0.284	0.268	0.206	0.559
Observations	475	179	462	338	277
Controls (common to all regressions)					
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes

Summary: This table reports the results when we attempt to mitigate concerns about mass migrations, in particular, the Bantu expansion. Panel (A) excludes the regions transversed by the Bantu: west, central, east and southern Africa. Panel (B) excludes the entire African continent. The full set of controls is considered in the robustness analysis.

Notes: (i) "Jurisdictional Hierarchy Beyond Local Community" is an ordered variable taking values 1 (No Levels) to 5 (Four Levels); (ii) "Political Integration" takes six levels, indicating whether there is absence of political integration, autonomous local; communities, peace groups transcending local communities, minimal states, little states or states; (iii) "Class Stratification" takes 5 values from no distinction among freemen to complex strata. (iv) "High Gods" is an ordered variable taking values 1 (Absent or Not Reported) to 4 (Present, active, and specifically supportive of human morality); (v) "Strategy Games" is a binary variable taking values 0 (No strategy games) and 1(Strategy games); (vi) The measure of eclipses captures the number of total solar eclipses an ethnic homeland has been exposed to over the whole period; (vii) continent fixed effect include dummies for Asia, Europe, Africa, North America, Oceania and South America; (viii) robust standard error estimates, clustered at the regional level, are reported in parentheses; (ix) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

this could nonetheless be an issue. Regarding eclipse paths, the exact local visibility hinges upon having precise estimates of the Earth's tidal frictions. Hence, the first eclipses in the series may be slightly mislocated. We address this double concern by shifting ethnic homelands three degrees northwards —alternative directions and amounts are equally valid. This effectively represents different ethnic boundaries and paths of totality. Panel (A) of Table 10 presents the results when we compute the total number of eclipses visible from the displaced ethnic homelands. The results remain qualitatively and quantitatively the same.

Second, we also address concerns regarding diminished visibility due to cloud coverage. In this case, we introduce average cloud coverage as an additional regressor. Although this variable is contemporaneous, we believe that global cloud patterns have not changed much over the course of centuries as these mostly result from winds and mountain ranges. Hence, even though cloud visibility is affected by micro-climatic conditions, the mean value should be roughly constant over time. The results of this second exercise, displayed in Panel (B) of Table 10, are also similar to the benchmark results. In fact, even if cloudy, during a total solar eclipse obscuration is above 90%, so the darkening of the sky would still be perceived.

6 Discussion

In this section, we discuss and empirically test other competing or complementary factors that could give rise to social complexity and complex thinking.

6.1 Other Rare Events

First, we investigate to what extent other rare events may have influenced our outcomes of interest. After all, our hypothesis hinges on the fact that such episodes trigger curiosity. We know with certainty that several other types of rare events occurred during the course of thousands of years and may as well have instilled fear or may have been catastrophic. When describing solar eclipses in Section 2, we listed several characteristics that make them unique: their rare occurrence, their non-destructive nature and the partial visibility. While all the above characteristics make eclipses a significant factor in determining complexity, still we test additional events. In Table 11 we run horse race regressions between our measure of total eclipses and three other types of rare events: volcanoes —proxied by the distance to the closest one— in Panel (A), distance to tectonic faults in Panel (B) and the incidence of lunar eclipses

Table 10: Robustness: Location accuracy and visibility.

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
	Panel A: Displaced Ethnic Homelands				
Total number of eclipses	0.016***	0.015***	0.011***	0.006***	0.001***
	(0.002)	(0.003)	(0.003)	(0.002)	(0.000)
R^2 Pseudo-R^2	0.226	0.221	0.144	0.249	0.654
Observations	907	251	822	584	334
	Panel B: Cloud Coverage				
Total number of eclipses	0.016***	0.015***	0.011***	0.005**	0.001***
	(0.002)	(0.003)	(0.003)	(0.002)	(0.000)
Cloud coverage	0.000*	0.000	0.000**	−0.000**	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
R^2 Pseudo-R^2	0.231	0.223	0.149	0.256	0.657
Observations	906	251	821	583	334
Controls (common to all regressions)					
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes

Summary: This table reports the results when we attempt to mitigate concerns about location accuracy and visibility In Panel (A) we create a new measure of eclipses by displacing ethnic homelands 3 degrees northwards and replicate the benchmark regression. In Panel (B) we account for actual eclipse visibility which might be affected by clouds. We control for the average level of cloud coverage over the year. The full set of controls is considered in the robustness analysis.

Notes: (i) "Jurisdictional Hierarchy Beyond Local Community" is an ordered variable taking values 1 (No Levels) to 5 (Four Levels); (ii) "Political Integration" takes six levels, indicating whether there is absence of political integration, autonomous local; communities, peace groups transcending local communities, minimal states, little states or states; (iii) "Class Stratification" takes 5 values from no distinction among freemen to complex strata. (iv) "High Gods" is an ordered variable taking values 1 (Absent or Not Reported) to 4 (Present, active, and specifically supportive of human morality); (v) "Strategy Games" is a binary variable taking values 0 (No strategy games) and 1(Strategy games); (vi) The measure of eclipses captures the number of total solar eclipses an ethnic homeland has been exposed to over the whole period; (vii) continent fixed effect include dummies for Asia, Europe, Africa, North America, Oceania and South America; (viii) robust standard error estimates, clustered at the regional level, are reported in parentheses; (ix) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

in Panel (C). In all three cases we find, first, no significant effect of any of these events on our complexity outcomes, and second, no qualitative or quantitative impact on our eclipses variable. The non-significance of lunar eclipses was expected. After all, lunar eclipses are visible on a whole hemisphere at once, making them more frequent and less impressive. Also, they happened at nighttime and can go unnoticed by people. Distance to volcanos and tectonic faults proxies for the likelihood of observing volcano eruptions and earthquakes: both catastrophic and destructive events that nonetheless can raise awareness about the unknown. Although eruptions and earthquakes, especially the largest of them, have vanished whole civilizations from Earth, ethnic groups far enough could have perceived them, contributing towards their levels of complexity of that society.

Table 11: Discussion: Other rare events.

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
	Panel A: Volcanoes				
Total number of eclipses	0.015***	0.015***	0.012***	0.006**	0.001***
	(0.002)	(0.003)	(0.003)	(0.002)	(0.000)
Dist. Volcano	0.016	0.000	−0.064**	−0.007	0.001
	(0.022)	(0.026)	(0.031)	(0.033)	(0.004)
R^2 Pseudo-R^2	0.229	0.223	0.154	0.248	0.655
Observations	906	251	821	583	334
	Panel B: Tectonic faults				
Total number of eclipses	0.016***	0.015***	0.011***	0.006**	0.001***
	(0.002)	(0.003)	(0.003)	(0.002)	(0.000)
Dist. Tec. Fault	−0.016	−0.001	−0.029	0.021	−0.002
	(0.016)	(0.025)	(0.029)	(0.024)	(0.002)
R^2 Pseudo-R^2	0.229	0.223	0.149	0.249	0.655
Observations	906	251	821	583	334
	Panel C: Lunar Eclipses				
Total number of eclipses	0.016***	0.016***	0.011***	0.007**	0.002***
	(0.003)	(0.004)	(0.003)	(0.003)	(0.000)
Total number of lunar eclipses	−0.001	−0.001	−0.000	−0.001	−0.000
	(0.002)	(0.003)	(0.001)	(0.002)	(0.000)
R^2 Pseudo-R^2	0.229	0.223	0.147	0.248	0.655
Observations	906	251	821	583	334
Controls (common to all regressions)					
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes

Continued on next page

Table 11 – *Continued from previous page*

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
Ethnic	Yes	Yes	Yes	Yes	Yes

Summary: In this table, we run horse race regressions between our measure of total eclipses and three other types of rare events: volcanic eruptions, proxied by distance to volcanoes, in Panel (A), distance to tectonic faults in Panel (B) and the incidence of lunar eclipses Panel (C). The full set of controls is considered in the analysis.

Notes: (i) "Jurisdictional Hierarchy Beyond Local Community" is an ordered variable taking values 1 (No Levels) to 5 (Four Levels); (ii) "Political Integration" takes six levels, indicating whether there is absence of political integration, autonomous local; communities, peace groups transcending local communities, minimal states, little states or states; (iii) "Class Stratification" takes 5 values from no distinction among freemen to complex strata. (iv) "High Gods" is an ordered variable taking values 1 (Absent or Not Reported) to 4 (Present, active, and specifically supportive of human morality); (v) "Strategy Games" is a binary variable taking values 0 (No strategy games) and 1(Strategy games); (vi) The measure of eclipses captures the number of total solar eclipses an ethnic homeland has been exposed to over the whole period; (vii) continent fixed effect include dummies for Asia, Europe, Africa, North America, Oceania and South America; (viii) robust standard error estimates, clustered at the regional level, are reported in parentheses; (ix) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Finally, we also test to what extent partial eclipses may have had a similar impact. Partial solar eclipses are visible in a much wider area than their total counterparts. However, the obscuration decreases rapidly as one moves farther away from the path of totality and, according to (Hughes, 2000), 90% of the Sun must be shadowed to perceive the implied decrease in luminosity. Therefore, we construct a 100 km buffer around each path of totality to account for the area likely to be in the penumbra of the eclipse, this is, to experience a partial eclipse. Table 12 incorporates the number of total and partial eclipses as regressors. Mostly, only total eclipses predict social complexity and complex thinking while partial eclipses do not seem to be important in developing complex societies. Unnoticed partial eclipses in the area we consider may explain this lack of results.

6.2 Homeland Area

The use of ethnic homelands as a basis to compute the number of total solar eclipses implies a mechanical relationship between each homeland's area and the latter. After all, we count all eclipses visible from *anywhere* within ethnic homeland boundaries, and a larger area implies that more eclipses are visible.[19] Since controlling a larger area may require more sophisticated forms of social organisation, Table 13 proposes several tests to mitigate this concern. First,

[19]Using the entire ethnic homeland as a basis has the advantage of encompassing information exchange between group members. This is, ethnic groups dispersed over a large territory can communicate and exchange information on eclipses only seen by a fraction of the group.

Table 12: Discussion: Partial eclipses.

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
Total number of eclipses	0.013***	0.014***	0.010***	0.005*	0.001***
	(0.002)	(0.003)	(0.002)	(0.003)	(0.000)
Total number of partial eclipses	0.005**	0.003	0.002	0.001	0.000
	(0.002)	(0.003)	(0.002)	(0.004)	(0.000)
R^2 Pseudo-R^2	0.231	0.224	0.148	0.249	0.656
Observations	903	251	820	582	334
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes

Summary: In this table incorporate partial solar eclipses as an additional regressor alongside the number of total solar eclipses. The full set of controls is considered in the analysis.

Notes: (i) "Jurisdictional Hierarchy Beyond Local Community" is an ordered variable taking values 1 (No Levels) to 5 (Four Levels); (ii) "Political Integration" takes six levels, indicating whether there is absence of political integration, autonomous local; communities, peace groups transcending local communities, minimal states, little states or states; (iii) "Class Stratification" takes 5 values from no distinction among freemen to complex strata. (iv) "High Gods" is an ordered variable taking values 1 (Absent or Not Reported) to 4 (Present, active, and specifically supportive of human morality); (v) "Strategy Games" is a binary variable taking values 0 (No strategy games) and 1(Strategy games); (vi) The measure of eclipses captures the number of total solar eclipses an ethnic homeland has been exposed to over the whole period; (vii) continent fixed effect include dummies for Asia, Europe, Africa, North America, Oceania and South America; (viii) robust standard error estimates, clustered at the regional level, are reported in parentheses; (ix) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

Panel (A) introduces ethnic homelands' area as control.[20] In Panel (B), area is kept constant by considering only the number of total solar eclipses visible from within a 50 km-radius area centred around the centroid of each ethnic homeland.[21] By construction, this variable captures only exposition to solar eclipses. Finally, Voronoi polygons are used in Panel (C) to create artificial ethnic homeland boundaries that are, nonetheless, related to their actual counterparts.

Overall, these strategies do not modify our previous conclusions. The results for social complexity remain positive and highly significant throughout all the specifications. This is less the case for complex thinking, though: in Panel (B), solar eclipses are no longer significant for Strategy Games, while in Panel (C) the results for Higher Gods are impacted. However, the coefficients remain positive and the previous changes alternate between dependent variables. Finally, the lack of results for partial eclipses in Table 12 is also indicative that areas are not driving our results. In fact, larger areas experience more eclipses of *both* sorts. However, only total solar eclipses bear predictive power.

6.3 Other Driving Forces: Scalar Stress and Ecological Diversity

The literature on the formation of more complex societies, especially the empirical one, is not very extensive. A first hypothesis brought up is that of scalar stress (Johnson (1982)), i.e., societal stress that is reinforced by a growing population. The need to mitigate the concern associated with an enlarging population led societies to more complex structures. Panel (A) of Table 14 controls for population density as derived from the shorter version of the Ethnographic Atlas. Notably, the number of observations dramatically drops in all five variables. Our results remain intact for the measures of social complexity while they become insignificant when measuring complex thinking. Population density does have a direct effect on social complexity as measured by "Jurisdictional Hierarchy" and "Political integration" mostly confined to the upper echelons of population density. This is in line with the theory of scalar stress. However, as the number of observations becomes really small, we treat these findings with caution.[22] Following Fenske (2014), we further alleviate the concern of a reduced sample size introducing population density

[20] Ethnic groups reaching higher levels of complex thinking may have expanded, occupying the territory and displacing previous settlers. In that sense, area would be an outcome of total solar eclipses, and hence it should not be a control. For this reason, area is not part of the main set of independent variables.

[21] Ethnic homeland's median area is approximately equal to the 50 km-radius are we consider here.

[22] Regarding the measures of complex thinking, running the benchmark regressions on the sub-sample of ethnic groups with information on population density renders the coefficient associated with eclipses insignificant. Therefore, the lack of statistical significance in Table 14 can be partly attributed to a non-random sampling, as Panel (B) illustrates.

Table 13: Discussion: Area.

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
	Panel A: Area				
Total number of eclipses	0.016***	0.014***	0.012***	0.006***	0.001***
	(0.003)	(0.004)	(0.003)	(0.002)	(0.000)
area_degrees	−0.001	0.003	−0.006**	0.001	0.000
	(0.005)	(0.006)	(0.003)	(0.007)	(0.001)
R^2 Pseudo-R^2	0.228	0.223	0.148	0.248	0.655
Observations	906	251	821	583	334
	Panel B: 50 km buffer				
Total number of eclipses	0.019**	0.035**	0.016**	0.034*	0.000
	(0.009)	(0.017)	(0.008)	(0.018)	(0.002)
R^2 Pseudo-R^2	0.186	0.180	0.125	0.244	0.626
Observations	906	251	821	583	334
	Panel C: Voronoi polygons				
Total number of eclipses	0.009***	0.009***	0.005**	0.007	0.001*
	(0.002)	(0.003)	(0.002)	(0.006)	(0.000)
R^2 Pseudo-R^2	0.188	0.193	0.124	0.254	0.651
Observations	850	240	770	548	306
Controls (common to all regressions)					
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes

Summary: In this table we further address the fact that bigger homelands experience more eclipses. To mitigate this concern we directly control for area. The full set of controls is considered in the analysis.

Notes: (i) "Jurisdictional Hierarchy Beyond Local Community" is an ordered variable taking values 1 (No Levels) to 5 (Four Levels); (ii) "Political Integration" takes six levels, indicating whether there is absence of political integration, autonomous local; communities, peace groups transcending local communities, minimal states, little states or states; (iii) "Class Stratification" takes 5 values from no distinction among freemen to complex strata. (iv) "High Gods" is an ordered variable taking values 1 (Absent or Not Reported) to 4 (Present, active, and specifically supportive of human morality); (v) "Strategy Games" is a binary variable taking values 0 (No strategy games) and 1(Strategy games); (vi) The measure of eclipses captures the number of total solar eclipses an ethnic homeland has been exposed to over the whole period; (vii) continent fixed effect include dummies for Asia, Europe, Africa, North America, Oceania and South America; (viii) robust standard error estimates, clustered at the regional level, are reported in parentheses; (ix) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

in 1960 as a proxy for its past value in Panel (C).

Fenske (2014) proposes that ecological diversity has an effect on state centralisation. In particular, he shows that more ecologically diverse places are associated with more centralized states. His findings are based upon a sample of pre-colonial African ethnic groups, yet his insight is readily applicable to the full set of ethnic groups in Murdock's Ethnographic Atlas. In Panel (D) of Table 14 we directly take into account this theory by controlling for a measure of ecological diversity. As anticipated, ecological diversity has a positive and significant effect on all three measures of social complexity. Importantly though, our measure of total solar eclipse incidence remains intact and is qualitatively similar.

Table 14: Discussion: Scalar stress and ecological diversity.

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
	Panel A: Population density				
Total number of eclipses	0.016***	0.027**	0.016**	−0.002	0.001
	(0.003)	(0.011)	(0.006)	(0.005)	(0.001)
Population density					
< 1 p. / 1-5 sq. mile	Ref.	Ref.	Ref.	Ref.	Ref.
1 p. / 1-5 sq. mile	0.081	−2.924*	3.171***	0.580	−0.028
	(1.004)	(1.536)	(1.086)	(0.621)	(0.169)
1-5 p. / sq. mile	2.199	1.542	0.615	−0.474	0.313**
	(1.689)	(2.273)	(1.049)	(1.015)	(0.127)
1-25 p. / sq. mile	3.436*	2.250	1.262	0.481	0.278
	(1.809)	(2.098)	(0.854)	(1.246)	(0.238)
26-100 p. / sq. mile	2.527	3.394*	1.824**	0.462	0.032
	(1.924)	(2.061)	(0.757)	(0.752)	(0.141)
101-500 p. / sq. mile	3.244*	4.056*	1.964*	1.021	0.205
	(1.920)	(2.230)	(1.150)	(0.960)	(0.320)
> 500 p. / sq. mile	4.105*	9.186***	2.937*	0.016	0.475
	(2.157)	(2.152)	(1.565)	(1.272)	(0.284)
R^2 Pseudo-R^2	0.403	0.530	0.371	0.322	0.795
Observations	113	82	114	103	76
	Panel B: Subsample without Pop. Density				
Total number of eclipses	0.019***	0.019*	0.017***	−0.001	0.002***
	(0.003)	(0.010)	(0.006)	(0.005)	(0.001)
R^2 Pseudo-R^2	0.364	0.429	0.330	0.312	0.754
Observations	113	82	114	103	76
	Panel C: Population Density 1960				
Total number of eclipses	0.019***	0.019*	0.017***	−0.001	0.002***

Continued on next page

Table 14 – *Continued from previous page*

	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
	(1)	(2)	(3)	(4)	(5)
	(0.003)	(0.010)	(0.006)	(0.005)	(0.001)
Pop. Den. 1960					
R^2 Pseudo-R^2	0.364	0.429	0.330	0.312	0.754
Observations	113	82	114	103	76
	Panel D: Ecological Diversity				
Total number	0.015***	0.015***	0.010***	0.006***	0.001***
of eclipses	(0.002)	(0.003)	(0.002)	(0.002)	(0.000)
Eco. divesity	1.379***	1.219**	1.283***	−0.244	−0.039
	(0.354)	(0.597)	(0.293)	(0.428)	(0.085)
R^2 Pseudo-R^2	0.236	0.228	0.154	0.248	0.655
Observations	906	251	821	583	334
Controls (common to all regressions)					
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes

Summary: In this table we test whether scalar stress or ecological diversity are driving the results. In Panel (A) we account for scalar stress by controlling for population density. Since observations drop when we include population density, Panel (B) displays the baseline regression results for the sub-sample for which population density is available. Panel (C) introduces population density during 1960 as a proxy its past values. Finally, in Panel (D) we control for ecological diversity as suggested by Fenske (2014).

Notes: (i) "Jurisdictional Hierarchy Beyond Local Community" is an ordered variable taking values 1 (No Levels) to 5 (Four Levels); (ii) "Political Integration" takes six levels, indicating whether there is absence of political integration, autonomous local; communities, peace groups transcending local communities, minimal states, little states or states; (iii) "Class Stratification" takes 5 values from no distinction among freemen to complex strata. (iv) "High Gods" is an ordered variable taking values 1 (Absent or Not Reported) to 4 (Present, active, and specifically supportive of human morality); (v) "Strategy Games" is a binary variable taking values 0 (No strategy games) and 1(Strategy games); (vi) The measure of eclipses captures the number of total solar eclipses an ethnic homeland has been exposed to over the whole period; (vii) continent fixed effect include dummies for Asia, Europe, Africa, North America, Oceania and South America; (viii) robust standard error estimates, clustered at the regional level, are reported in parentheses; (ix) *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level, all for two-sided hypothesis tests.

7 Conclusion

This paper proposes that rare, dreadful events are powerful triggers of human curiosity in pre-modern societies through curiosity. This is also indirectly reflected in more complex social structures as economic prosperity increases. We focus on a unique case of rare and frightening effect whose effects are felt by large collectivities: total solar eclipses.

Total solar eclipses present three main characteristics that distinguish them from other

events. First, they are rare but somewhat regular. Second, setting them aside from volcanic eruptions and earthquakes, solar eclipses are harmless both in terms of human and physical capital. Finally, total solar eclipses are well distributed across Earth and their effects can be perceived by a large collectivity.

In line with our theory, we find that ethnic groups with higher exposure to solar eclipses score systematically higher in three measures of social complexity —jurisdictional hierarchy, political integration and class stratification— as well as in two measures of complex thinking —gods involvement in human affairs and the play of strategy games. Our findings suggest that solar eclipses had a persistent and systematic effect on both types of complexity examined here, this is, societal complexity and complex thinking. Our results are solid even after controlling for a wide range of geographical and ethnic controls and are robust to a series of additional tests and alternative theories. We rationalise our findings proposing that solar eclipses —and rare events in general— raise the demand for explanations, and those who experience more of such episodes develop more complex societal structures and become more versed in complex thinking in an attempt to comprehend and eventually control the natural environment.

Our research sheds light on the origins of complex societal structures and the emergence of complex thinking, complementing previous findings. Our contribution particularly highlights the importance of thinking for development, in line with theories on the importance of human capital. However, curiosity is pre-requisite of knowledge, hence our results extend further back in time.

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A Eclipse prediction in pre-modern times

One possible concern regarding the results is that eclipses were predictable and, hence, that a ruling elite may have used this private knowledge to instil fear and coerce the population. Similarly, it is also possible that ethnic groups particularly afraid or fond of eclipses might have targeted locations with more or less future eclipses as migratory destinations.

This Section addresses these concerns by explaining in detail how pre-modern societies predicted eclipses. It is important to highlight that we deal with two types of predictions: time and location.

The timing of eclipses. All eclipses —solar and lunar— occur when the Sun, the Moon and the Earth align on the ecliptic plane: the plane on which the Earth orbits the Sun. The Moon's orbit is tilted about 5 degrees with respect to the ecliptic, which implies that two intersection points exist: the nodes.

During each new moon, the Moon is situated in the day-time hemisphere. In general, though, it typically passes too high or too low on its orbit to cast any shadow on Earth. However, when the Moon is at one of its nodes during a new moon, it blocks sunlight, casting a shadow on Earth. To an observer on Earth, the Sun slowly enters into the shadowed area, effectively disappearing: a solar eclipse.[23] However, the shadow is too narrow as to affect the entire Earth: solar eclipses are very local, roughly spanning 160 km wide.[24] Figure 3 illustrates the special configuration required for eclipses, together with the more common full and new moon situations. Finally, depending on the distance between the centre of the Moon and the ecliptic, eclipses are partial —the Moon passes too high or too low— or total. The Sun–Moon distance also determines how much of the Sun is covered by the shadow, generating total or annular eclipses.

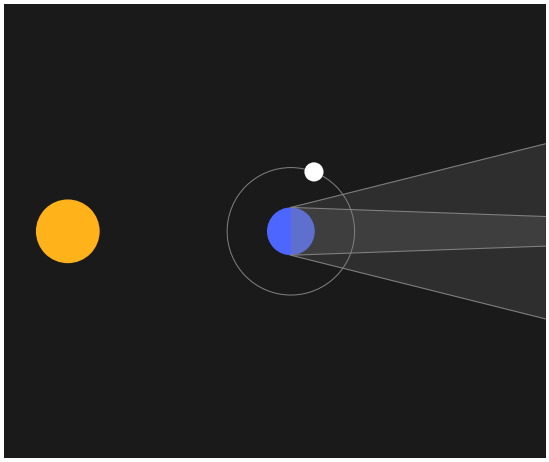
In summary, solar eclipses require a new moon and the Moon must be sufficiently close to the ecliptic. Pre-modern societies exploited the regularity inherent to these phenomena. The time between two consecutive new moons is called a *synodic month* with a length of 29.53 days. Since the orbital plane of the Moon is tilted about 5 degrees with respect to the ecliptic, eclipses are only possible whenever the Moon crosses the ecliptic. This happens each *draconic month*

[23] Another requirement is that the apparent diameter of the Moon to be roughly similar or larger than that of the Sun. This is, the Moon must appear as large as the Sun, or more, to effectively obscure it. By a fortunate coincidence, the relative distance between the Earth and Sun and the Moon and the Earth coincides with the relative size of the Sun with respect to the Moon when the Moon is closest to the Earth. As the Moon slowly drifts away from the Earth, several millennia from now eclipses will be only annular.

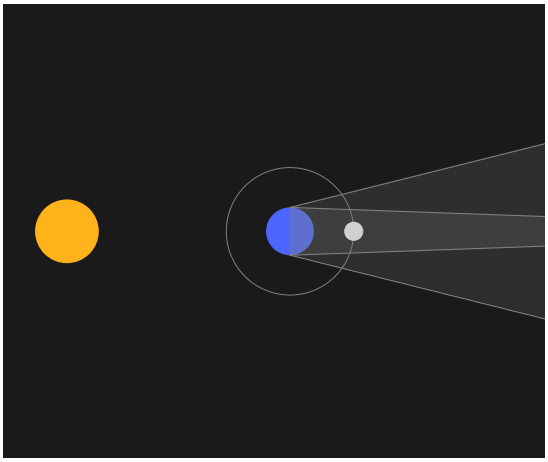
[24] During a regular full moon, the Moon is located opposite the Earth and reflects light from the Sun. However, if it is at its node —or near it—, the Earth blocks sunlight, generating the lunar eclipse. Such phenomena are visible from the entire night hemisphere.

Figure 3: Eclipses, full moon and new moon.

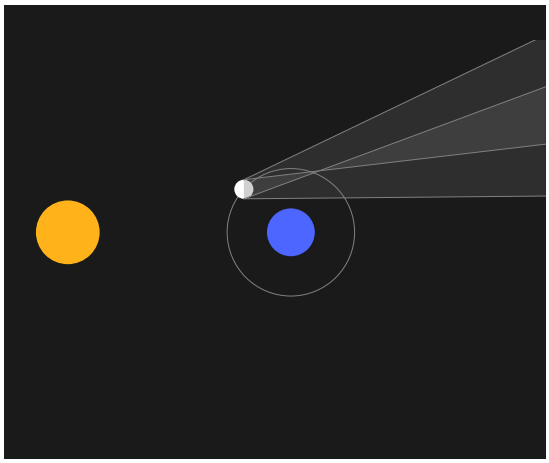
(a) Full moon.



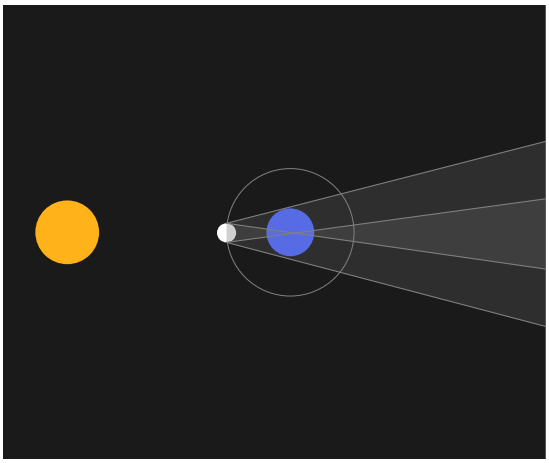
(b) Lunar eclipse.



(c) New moon.



(d) Solar eclipse.



Notes: This figure represents four combinations that produce, respectively, a full moon —3a—, a lunar eclipse —3b—, a new moon —3c— and a solar eclipse —3d. Notice that lunar eclipses are only possible during a full moon and solar eclipses during a new moon. Also, eclipses are only possible near the nodes, this is, when the moon crosses the ecliptic. *Source:* Adapted from Bryant (2011).

with a duration of about 27.2122 days. Combining both, we find that eclipses must be 173.31 days apart: half the beat period between frequencies.[25]

So far, we have been working with only two frequencies: synodic and draconic months. Steele (2000b), Kelley and Milone (2011), Freeth (2014) and others state that another cycle was added to the previous two: the *anomalistic month*. It measures the time it takes to the Moon to have the same apparent size in the sky.[26] When the three cycles coincide, the eclipses are similar: total, partial or annular, and with a similar magnitude. An anomalistic month lasts for 27.554 days, so using the triple-cycle to predict similar eclipses implies that each is separated by 18

[25]The beat period computes the time it takes to two different frequencies to come back into synchronisation. For frequencues f_1 and f_2, the beat period equals $\frac{f_1 f_2}{f_1 - f_2}$.

[26]Differences in its apparent diameter are caused by the elliptic orbit it follows around the Earth.

years, 11 days and 8 hours. The triple-cycle is known in the literature as *Saros*, and modern astronomers classify eclipses as belonging to one Saros series.[27] The problem of predicting using the Saros cycles is that two consecutive eclipses do not belong to the same series. However, it is possible to simultaneously follow several Saros cycles.

Others included alternative cycles. For instance, Mesoamericans and Arid Americ hunter-gatherers counted synodic and sidereal months, see Murray (2014, p. 666).[28] Based on similar principles, the Mayas predicted eight centuries of solar eclipses, worldwide (Murray (2014, p. 700)).

Local visibility of eclipses. The system we presented above is most useful at predicting lunar eclipses: these are visible from the entire night hemisphere. It is also capable of accurately predicting solar eclipses, but not the local visibility. In fact, solar eclipses present additional challenges. The first one is that the Saros cycle is not an integer number of days. Consider that a total solar eclipse was visible from some location. If the Saros were 18 years and 11 days, the Earth would have been exactly on the same position, and the predicted eclipse would be visible from the same location. However, the additional eight hours imply that the Earth has rotated 120 degrees, and the eclipse is visible 120 degrees away from the first one. Taking an even longer cycle of three Saros solves this problem.[29] Nevertheless, there is a second complication for solar eclipses: eclipses from a Saros series present a longitudinal drift. Therefore, even solar eclipses that are three Saros apart are not necessarily visible from the same location. Figure 4 illustrates both the east-west and north-south drifts of the Saros cycles.

The necessary knowledge to derive the timing of eclipses was available to ancient cultures, which were able to predict eclipses.[30] In fact, they were quite apt at it and, by the eighth century BC, Babylonian astronomers published *warning tables* that indicated possible eclipses. However, predicted eclipses were not always visible from Babylonia. As we explained, predicting the local visibility of solar eclipses is far more complex for solar eclipses and requires precise knowledge of the orbits of the Moon and the Earth. Steele (1997) compares solar eclipses predicted by Babylonian astronomers to actual realisations and finds that out of 61 recorded eclipses, only 28

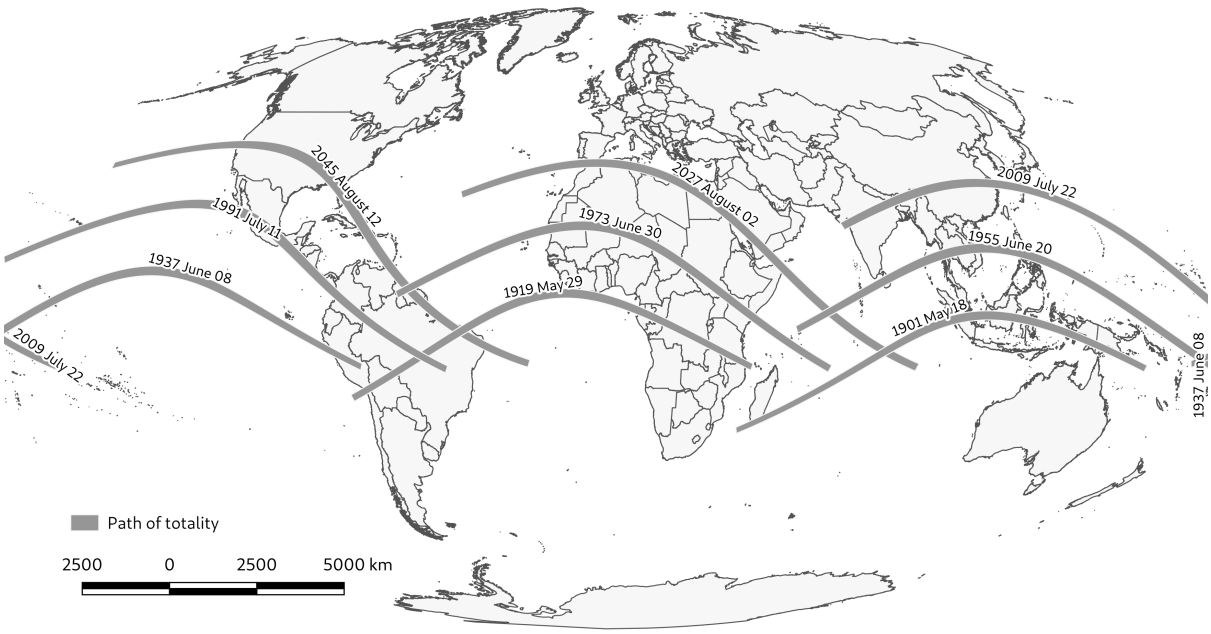
[27] The Saros cycle was already known by Chaldean (neo-Babylonian) astronomers around 600-500BC. Contrary to what it may seem, Saros cycles are finite and preclude long-term predictions. This is so because the numbers discussed before are only approximations, and errors accumulate with time. However, a Saros cycle typically contains 69 to 87 lunar eclipses covering up to 1566 years.

[28] A sidereal month lasts 27.25 days.

[29] Although less acute, the turning of the Earth also affects the local circumstances of lunar eclipses, Steele (2000a, p. 15). Using a triple-Saros cycle completely solves the issue.

[30] Steele (2000b, p. 11) discusses that, since lunar eclipses are visible from the entire night hemisphere, early astronomers based their calculations on them.

Figure 4: Eclipses from Saros 136.



Notes: This Figure represents nine solar eclipses corresponding to the 136 Saros series. Eclipses follow a west and northward shift, preventing local predictions.

were visible from Babylonia. However, all of the 61 solar eclipse predictions correspond to an actual eclipse.

Overall, the complexity associated with accurate predictions of solar eclipses, the irregularity in their location and the limited dissemination of scientific knowledge across societies and across time, reinforced the awe associated with solar eclipses versus that caused by other similar phenomena.

B Summary statistics

Table 15 below provides the summary statistics for all the variables we use in our analysis.

Table 15: Summary statistics.

	Mean	Std. Dev.	Min.	Max.
Independent Variables				
Eclipses				
Number of eclipses	77.264	61.576	17.000	1002.000
Max. Time between eclipses	2.921	1.239	0.242	8.575
Min. Time between eclipses	0.021	0.025	0.000	0.214

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Table 15 – *Continued from previous page*

	Mean	Std. Dev.	Min.	Max.
Avg. time between eclipses	0.658	0.289	0.040	2.151
Number of lunar eclipses	1584.582	106.359	1521.000	2780.000
Dependent Variables				
Jurisdictional Hierarchy				
No levels	0.447	0.497	0.000	1.000
One level	0.312	0.463	0.000	1.000
Two levels	0.149	0.356	0.000	1.000
Three levels	0.071	0.257	0.000	1.000
Four levels	0.021	0.143	0.000	1.000
Class Stratification				
Absence among freemen	0.493	0.500	0.000	1.000
Wealth distinctions	0.186	0.389	0.000	1.000
Elite	0.039	0.193	0.000	1.000
Dual	0.216	0.412	0.000	1.000
Complex	0.067	0.249	0.000	1.000
Political Integration				
Absence	0.017	0.129	0.000	1.000
Automous local comm.	0.100	0.300	0.000	1.000
Peace groups	0.008	0.087	0.000	1.000
Minimal states	0.064	0.246	0.000	1.000
Little states	0.023	0.150	0.000	1.000
States	0.031	0.174	0.000	1.000
Absent	0.354	0.478	0.000	1.000
High Gods				
Not active in hum. affairs	0.345	0.476	0.000	1.000
Active in hum. affairs, not supp. of hum. morality	0.058	0.234	0.000	1.000
Supportive of hum. morality	0.243	0.429	0.000	1.000
Strategy Games				
Strategy games	0.177	0.382	0.000	1.000
Controls				
Bioclimatic and Geography				
Annual mean temp.	196.738	85.867	−158621	301.410
Annual precipitation	1324.715	945.300	0.264	6415.639
Temp. seasonality	3504.329	3475.523	108.250	20324361
Precipitation seasonality	66.201	33.373	5.048	215.847
Avg. cloud coverage	5801.644	1661.750	801.131	9455.415
Ecological diversity	0.419	0.246	0.000	0.839
Dist. coast (degrees)	4.223	3.921	0.000	16.535
Dist. river (degrees)	2.360	7.834	0.002	77.675
Dist. Addis Ababa (degrees)	233.323	268.472	1.119	723.192
Dist. volcano (degrees)	5.769	5.913	0.014	33.347
Dist. tectonic fall (degrees)	8.120	7.635	0.000	49.380
Area (degrees)	6.912	42.707	0.000	1327.699
Ruggedness	88.099	32.506	0.000	199.000
Elevation	163.290	25.378	0.000	210.116
Malaria	0.170	0.206	0.000	0.688
Caloric yield	1252.093	892.230	0.000	4975.770

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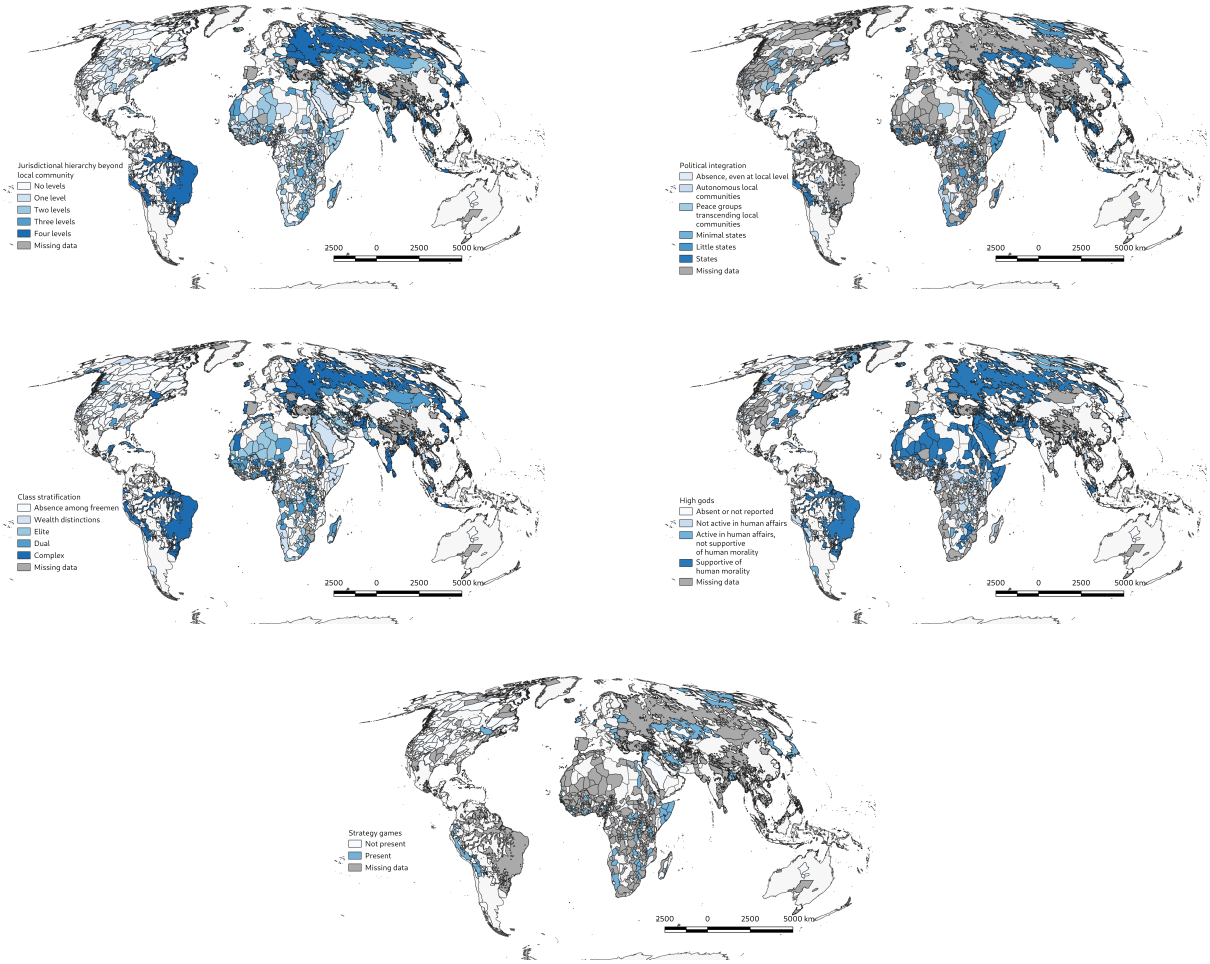
	Mean	Std. Dev.	Min.	Max.
Abs. latitude	21.111	17.447	0.017	78.070
South (0/1)	0.212	0.409	0.000	1.000
Ethnic characteristics				
Dependence on gathering (%)	11.794	15.276	2.500	80.500
Dependence on agriculture (%)	45.743	26.190	2.500	90.500
Intensity of Agriculture				
No agriculture	0.193	0.395	0.000	1.000
Casual agriculture	0.036	0.186	0.000	1.000
Extensive agriculture	0.417	0.493	0.000	1.000
Horticulture	0.084	0.277	0.000	1.000
Intensive agriculture	0.168	0.374	0.000	1.000
Intensive irrigated agriculture	0.103	0.304	0.000	1.000
Major Crop Type				
None	0.200	0.400	0.000	1.000
Non food crop	0.002	0.043	0.000	1.000
Vegetables	0.002	0.043	0.000	1.000
Tree fruits	0.070	0.255	0.000	1.000
Roots or tubers	0.201	0.401	0.000	1.000
Cereal grains	0.525	0.500	0.000	1.000
Subsistence Economy				
Gathering	0.082	0.275	0.000	1.000
Fishing	0.081	0.274	0.000	1.000
Hunting	0.059	0.237	0.000	1.000
Pastoralism	0.065	0.246	0.000	1.000
Extensive agriculture	0.388	0.487	0.000	1.000
Intensive agriculture	0.209	0.407	0.000	1.000
Two or more above	0.049	0.216	0.000	1.000
Agriculture, unknown type	0.066	0.249	0.000	1.000
Fixed Effects				
Continent				
Africa	0.453	0.498	0.000	1.000
Asia	0.159	0.365	0.000	1.000
Australia	0.009	0.096	0.000	1.000
Europe	0.023	0.150	0.000	1.000
North America	0.235	0.424	0.000	1.000
Oceania	0.057	0.232	0.000	1.000
South America	0.064	0.246	0.000	1.000
Major Habitat Type				
Boreal forest	0.020	0.141	0.000	1.000
Desert	0.103	0.305	0.000	1.000
Flooded grasslands	0.010	0.100	0.000	1.000
Mangroves	0.012	0.108	0.000	1.000
Mediterranean scrub	0.025	0.158	0.000	1.000
Montane grasslands	0.020	0.138	0.000	1.000
Snow, ice, glaciers,rock	0.003	0.050	0.000	1.000
Tempered broadleaf forests	0.044	0.205	0.000	1.000
Temperate coniferous forests	0.074	0.262	0.000	1.000

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Table 15 – *Continued from previous page*

	Mean	Std. Dev.	Min.	Max.
Temperate grasslands, savannas	0.039	0.194	0.000	1.000
Tropical coniferous forests	0.013	0.112	0.000	1.000
Tropical dry broadleaf forests	0.038	0.192	0.000	1.000
Tropical grasslands	0.283	0.451	0.000	1.000
Tropical moist broadleaf forests	0.303	0.460	0.000	1.000
Tundra	0.012	0.108	0.000	1.000
Water	0.001	0.029	0.000	1.000

Figure 5: Geographical distribution of outcomes.



C Correlations between measures

The following tables present correlation measures across several variables that we employ in our study. First, Table 16 presents the raw correlation between our measure of eclipse prevalence and the entire set of outcomes: Jurisdictional Hierarchy, Political Integration, Class Stratification, Higher Gods and Strategy Games.

Table 16: Correlation: Outcomes.

	Total eclipses	Jurisdictional Hierarchy	Political Integration	Class Stratification	Higher Gods	Strategy Games
Total Eclipses	1.000	0.388	0.325	0.267	0.245	0.281
Jurisdictional Hier.	0.388	1.000	0.835	0.640	0.258	0.530
Class Strat.	0.325	0.835	1.000	0.691	0.338	0.578
Political Int.	0.267	0.640	0.691	1.000	0.224	0.499
Higher Gods	0.245	0.258	0.338	0.224	1.000	0.281
Strategy Games	0.281	0.530	0.578	0.499	0.281	1.000

Table 17: Correlation: Eclipse measures.

	Total eclipses	Max. time	Min. time	Avg. time
Total eclipses	1.000	−0.569	−0.286	−0.662
Max. time	−0.569	1.000	0.320	0.778
Min. time	−0.286	0.320	1.000	0.536
Avg. time	−0.662	0.778	0.536	1.000

Table 17 correlates the different measures of eclipse prevalence: total number of eclipses, the maximum and minimum time between two consecutive eclipses and the average time between consecutive eclipses. In Table 18 we correlate the total number of solar eclipses with the distance to volcanoes, tectonic faults and the number of lunar eclipses: competing theories that could explain social complexity and complex thinking. Finally, Table 19 correlates eclipse prevalence across different time periods.

Table 18: Correlation: Other mechanisms.

	Total eclipses	Dist. volcano (degrees)	Dist tectonic fault (degrees)	Total lunar eclipses
Total eclipses	1.000	0.268	0.136	0.601
Dist. volcano (degrees)	0.268	1.000	0.519	0.199
Dist. tectonic fault (degrees)	0.136	0.519	1.000	0.117
Total lunar eclipses	0.601	0.199	0.117	1.000

Table 19: Correlation: Eclipse prevalence across periods of time.

	2000BC-2000AD	2000BC-1500BC	1500BC-1000BC	1000BC-500BC	500BC-0	0-500AD	500AD-1000AD	1000AD-1500AD	1500AD-2000AD
2000BC-2000AD	1.000	0.957	0.955	0.962	0.937	0.951	0.961	0.951	0.948
2000BC-1500BC	0.957	1.000	0.903	0.905	0.866	0.904	0.910	0.899	0.913
1500BC-1000BC	0.955	0.903	1.000	0.914	0.874	0.889	0.896	0.906	0.893
1000BC-500BC	0.962	0.905	0.914	1.000	0.909	0.894	0.907	0.910	0.897
500BC-0	0.937	0.866	0.874	0.909	1.000	0.889	0.894	0.880	0.850
0-500AD	0.951	0.904	0.889	0.894	0.889	1.000	0.914	0.877	0.888
500AD-1000AD	0.961	0.910	0.896	0.907	0.894	0.914	1.000	0.902	0.903
1000AD-1500AD	0.951	0.899	0.906	0.910	0.880	0.877	0.902	1.000	0.880
1500AD-2000AD	0.948	0.913	0.893	0.897	0.850	0.888	0.903	0.880	1.000