Cite as: J. Hawks, *Science*
10.1126/science.abh1878 (2021).

Comment on “A global environmental crisis 42,000 years ago”

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Cooper *et al.* (Research Articles, 19 February 2021, p. 811) propose that a weakening geomagnetic field prior to the Laschamps Excursion explains megafaunal extinctions and human cultural changes that they claim happened 42,000 years ago. However, these authors misrepresent both the data and interpretations of cited work on extinctions and human cultural changes, so the specific claims they make about extinctions and cultural changes are false.

Cooper *et al.* (*1*) claim that a weaker geomagnetic field starting at 42 thousand years ago (ka) triggered a “global environmental crisis.” To support this idea, they examine Australian and Eurasian megafauna, Neanderthals, and human cultural transitions, claiming that many happened at or immediately after 42 ka. What they describe as a repeated occurrence of the number “42” for ancient extinctions prompted them to name the geomagnetic transition after the author Douglas Adams (*1*). I examined the work that they cite, finding that Cooper *et al.* exaggerate or misrepresent the importance of 42 ka in this prior work.

For example, Cooper *et al.* claim that thylacine mitochondrial diversity “indicates a bottleneck around 42 ka” [supplement of (*1*)]. The cited work (*2*) actually states that “the timing of bottleneck and recovery in Tasmania are estimated to be 20,400 (6,440-36,520 95% CI) and 3,160 (192.8-16,960 95% CI) year BP respectively.” Cooper *et al.* claim that Australian megafaunal extinctions happened around 42 ka, citing two sources. One cited paper (*3*) developed a Bayesian model that does show a “peak in extinction events at 42.1 ka.” However, this “peak” is the mode of a distribution, and it is a misrepresentation to take this as evidence of a pulse of extinctions at 42 ka. Instead, that cited work demonstrates extinctions of five genera “between 61 and 51 kyr” and 10 others “between 44 and 35 kyr.” The conclusion of (*3*) is that the climate during the broad time interval represented by megafaunal extinctions is not different from earlier or later intervals, hence its title: “Climate change not to blame for late Quaternary megafauna extinctions in Australia.” The second cited work (*4*) documents that Australian extinctions followed a regional pattern influenced by human activity and climate, which began by 48 ka and concluded after 41 ka. Together these studies demonstrate that megafaunal extinctions were a long process initiated long before 42 ka, and do not support the claim that climate change at 42 ka caused a pulse of extinctions.

Cooper *et al.* take a different approach toward Eurasian faunal and archaeological data, which show no extinctions or significant impacts at 42 ka. They instead suggest that “a cluster of megafaunal genetic transitions (woolly rhino, mammoth, bison) were previously observed around the timing of the Mono Lake geomagnetic excursion” [supplement of (*1*)], citing earlier work by Cooper *et al.* (*5*). This is a misrepresentation of the data in (*5*), in which extinction times for Eurasian *Bison priscus*, *Mammuthus primigenius*, and *Coelodonta antiquitatis* are modeled from 36 to 27 ka, not a “cluster” near the Mono Lake excursion at 34 ka. Nor are these three genera representative of the 19 taxa with extinctions between 56 and 20 ka included in that paper (*5*). This Northern Hemisphere evidence does not suggest any pulse of faunal extinctions at 42 ka.

The decline of Neanderthal biogeographic range began before 46 ka in Europe and earlier in southwest Asia. The recalibration of ^{14}C dates for Neanderthals in (*1*) shows that they survived well past 42 ka. Cooper *et al.* instead suggest that not the Adams event but the “Laschamps in general” [supplement of (*1*)] was contemporaneous with the final Neanderthals, around GS 10. In support of this idea, they claim that “the Uluzzian in Italy also appears to end contemporaneously at this point,” citing (*6*). Here again the paper misrepresents the cited work (*6*), which discusses the beginning of the Uluzzian, not its end, noting a cultural hiatus coincident with GS 12 (at ~44 ka), not GS 10. The most comprehensive recent review (*7*), not cited by (*1*), suggests that the latest Uluzzian was roughly coincident with the Campanian Ignimbrite, around 39.8 ka, although even more recent dates have been obtained from some Uluzzian contexts. Hence, the Uluzzian persisted through both the Laschamps and proposed Adams events. Cooper *et al.* also cite work on the early Aurignacian at Bajondillo Cave, Spain (*8*), acknowledging that it is "potentially slightly earlier" than "the severe cold and dry conditions of GS-9/Heinrich event 4" [supplement of (*1*)]. This is also a misrepresentation of (*8*), which shows that the transition at Bajondillo occurred between 45 and 43 ka; this precedes both the Laschamps and proposed Adams events.

Hominins have used deep cave environments from early Middle Pleistocene times, and the sensationalized claim that geomagnetic events caused "more intense utilization of cave environments" by hominins [supplement of (*1*)] ignores evidence from hundreds of caves worldwide showing both long-term and short-term hominin utilization in the period between 48 and 42 ka. Knowledge of the age of pigment markings on rock walls has indeed been transformed by U-series dating of thin calcite laminae [e.g., (*9*, *10*)]. But this method provides minimum ages, with a small known sample that is not suitable for any claim of "more intense" marking at 42 ka. What the evidence does demonstrate is that marking on cave walls had a long history prior to 43 ka in southwestern Europe (*9*), and a figurative art tradition occurred at multiple sites in Sulawesi prior to 43 ka (*10*). These data cannot be explained by geomagnetism at 42 ka.

Biological extinctions and human cultural transitions are complex processes. Price *et al.* (*11*) point to the problems inherent in meta-analysis approaches to extinction, calling instead for close examination of the data for each individual species. The same is necessary for hominin populations and cultural events, about which we still have much to learn. Megafaunal extinction in Australia, Neanderthal extinction in Eurasia, and the beginnings of pigment marking in caves all involved factors that began thousands of years before the Laschamps excursion or associated geomagnetic field changes. We will not get closer to understanding these processes by misrepresenting data, making exaggerated claims about the "clustering" of events, or minimizing observations that do not match a magic number. Any reader of Douglas Adams should understand that the importance of "42" is that no one knows what the question is.

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21 February 2021; accepted 2 November 2021
Published online 19 November 2021
10.1126/science.abh1878

Cite as: A. Cooper *et al.*, *Science*
10.1126/science.abh3655 (2021).

Response to Comment on "A global environmental crisis 42,000 years ago"

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Our paper about the impacts of the Laschamps Geomagnetic Excursion 42,000 years ago has provoked considerable scientific and public interest, particularly in the so-called Adams Event associated with the initial transition of the magnetic poles. Although we welcome the opportunity to discuss our new ideas, Hawks' assertions of misrepresentation are especially disappointing given his limited examination of the material.

Our study (*1*) identifies multiple synchronous environmental and archaeological shifts consistent with a global event around 42 thousand years ago (ka), something not previously possible given the uncertainties in the radiocarbon time scale prior to this work. In addition, recent refinements of the radiocarbon calibration curve will compress the dates of many other events around this time even closer to the Laschamps (*2*). Although a common driver behind this set of observations is consistent with our chemistry-climate model predictions of the impacts of a collapsed magnetic field, solar minima, and solar energetic particle events, they remain only temporally associated and further study is required to reveal exact mechanisms. In this regard, Hawks (*3*) provides no evidence that challenges our model, and indeed nearly all his contentions are directly contradicted by the quoted references.

For example, in the thylacine study (*4*), Hawks has confused the date for the mitochondrial genetic bottleneck within the remnant Tasmanian population (3 to 20 ka) with that for thylacine populations across the whole of Australia [ancestral divergence, 42 ka; table 3 and figure 7 of (*4*)]. Mitochondrial diversity started accumulating within the Australian-wide population around 42 ka, leading us to propose a population bottleneck caused by the Adams Event.

Similarly, we do not claim that Australian megafaunal extinctions occurred only at 42 ka and not earlier, as Hawks suggests, although the Signor-Lipps effect ensures that the last observation of poorly sampled taxa (which include the oldest apparent Australian extinctions) will occur well before the actual extinction. Although more detailed dating is required, Australian-wide compilations indicate a concentration of extinction events around 42 ka, contemporaneous with major climatic and vegetation shifts in paleoenvironmental records across Australia (*1*). As expected, regional studies differ slightly on the estimated timing of the final megafaunal extinction phase [figure 1 of (*5*)] and reflect the amount of accurate dating available, but have been explicitly linked to the Laschamps Excursion at Lake Mungo (*6*). Recent studies, including those referenced by Hawks (*7*), have concluded that climate change around this time was indeed the likely driver of Australian megafaunal extinctions, with humans a key additional stressor relative to previous glacial cycles.

Hawks also did not take into account that our study of Eurasian megafaunal extinctions (*8*) explicitly highlighted a cluster around Greenland Interstadials 7 to 5 (35 to 32 ka) overlapping the date of Mono Lake [(*1*); figure 1 of (*5*)] that included bison, mammoth, and woolly rhino [figure 1 of (*8*)]. Although Eurasian megafaunal extinctions were broadly distributed through time, very few datasets have covered the 42-ka period in any detail (*8*), severely limiting the ability to detect any pulse of megafaunal genetic transitions during the Laschamps. Humans are the only megafaunal group with large amounts of dating and genetic data around this time, and they clearly show marked genetic extinctions [(*1*); figure 1 of (*5*)].

Our observation that the recalibrated extinction date for Neanderthals at 41 to 40.5 ka is contemporaneous with the end of the Laschamps Excursion [(*1*, *2*); figure 1 of (*5*)] has drawn much attention. As with the Australian megafauna, although we highlighted that the final extinction phase occurred during the Laschamps, we noted that this represented the end of a much longer process. For European Neanderthals, we discussed the archaeological evidence for a spatiotemporally staggered replacement process by anatomically modern humans, as well as the fact that sterile layers separating the two groups within individual sites have been associated with cold Greenland Stadials 12 to 10 (*9*). Our new kauri-based radiocarbon calibration allows us to reveal that both GS-11 and GS-10 are closely aligned to the transition phases of the geomagnetic reversal, when we expect the weak field strength to produce pronounced cooling effects over the North Atlantic [(*1*); figure 1 of (*5*)].

As we stated, the most comprehensive dating study of the Neanderthal extinction/replacement process (*10*) had indeed identified that the ends of the Uluzzian and Neanderthal cultures in Italy were near-contemporaneous [figure 2 of (*10*)], whereas recent work shows that the Uluzzian ended more than a millennium before the 39.9-ka Campanian Ignimbrite (*11*). Similarly, the Bajondillo Cave study noted that the most reliable radiocarbon dates (from short-lived taxa) dated the Proto–Early Aurignacian at 42.15 to 41.2 ka (*12*), consistent with other sites across Europe [figure 1 of (*5*)].

Hawks also disputes the evidence that cave art becomes more intense from 42 ka. However, we present data showing a marked increase in the appearance and/or frequency of figurative cave art globally around 42 ka (*1*). As we noted, the increased preservation of art and the synchronous global change in artistic behavior around this time has previously been observed by archaeologists (*13*), along with the altered use of caves and ochre (*1*). Indeed, the puzzling observation that "similar cave art traditions appear to arise near-contemporaneously in the extreme west and extreme east of Eurasia" around this time has been noted (*13*) but the "cause remains unknown." We explicitly proposed that previously extant artistic practices were shifted into caves during the Laschamps, enhancing preservation potential and generating an apparent marked change in anatomically modern human behavior (*1*). This is entirely consistent with earlier but relatively rare cave wall pigment markings (some potentially by Neanderthals). Hawks similarly neglects to mention that the dating of calcite layers situated above and below cave art has allowed tightly bracketed dating, such as the Mono Lake–aged red circle series in El Castillo, which itself parallels the maximum age–dated Laschamps red circle series (*1*).

In our paper we presented a range of data showing marked global and long-term environmental and climate changes around 42 ka, which Hawks appears to have misunderstood or missed entirely. We clearly stated that the Laschamps represented the common endpoint of processes such as the Neanderthal and megafaunal extinctions, and marked changes in the occurrence of cave art, and it is a clear misrepresentation to suggest otherwise. Our study proposes a geomagnetic mechanism that can explain these and many other paleoclimatic and archaeological observations through a common forcing. As a result, despite the need for further work, 42 does indeed appear to provide an answer to many current mysteries concerning Life, the role of the Universe (cosmic radiation), and a growing number of other things.

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18 March 2021; accepted 2 November 2021
Published online 19 November 2021
10.1126/science.abh3655

Cite as: A. Picin *et al.*, *Science* 10.1126/science.abi8330 (2021).

Comment on “A global environmental crisis 42,000 years ago”

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Cooper *et al.* (Research Articles, 19 February 2021, p. 811) propose that the Laschamps geomagnetic inversion ~42,000 years ago drove global climatic shifts, causing major behavioral changes within prehistoric groups, as well as events of human and megafaunal extinction. Other scientific studies indicate that this proposition is unproven from the current archaeological, paleoanthropological, and genetic records.

Cooper *et al.* recently reported a tree ring–based ^{14}C dataset (42 to 36 ka ^{14}C BP) based on four kauri trees, achieving high-precision data (±107 to 180 years, 1σ), ideal for reconstructing the increase of ^{14}C production during the Laschamps excursion and creating a detailed kauri-Hulu calibration curve (*1*). These data allowed the authors to model statistically possible variations of the global climate during the geomagnetic inversion. Although we appreciate the scientific advances accomplished in (*1*), we note with concern several statements relating the supposed impacts of the Laschamps on hominin and faunal extinctions and human behavioral changes, which misconstrue the current paleontological, archaeological, and genetic data. Geomagnetic reversals were frequent during the Pliocene and Pleistocene (*2*), and mass extinctions at the time of these inversions have not been documented in the paleontological and archaeological record so far. For example, the Blake excursion (~114 ± 1 ka BP) (*3*) occurred without apparent serious effects on the subsistence of Neanderthals in Eurasia, *Homo sapiens* in Africa, and megafauna in Australia. In our view, Cooper *et al.* have used the archaeological and paleontological data selectively in order to create a narrative that could support the Laschamps as the main driver of a global environmental crisis. Here, we contextualize the evidence at ~45 to 40 ka BP to show that the claimed huge impacts of the geomagnetic inversion on humans and megafauna go far beyond the available data. We observe three main issues in (*1*) that include the extinction of megafauna in Australia, the demise of Neanderthals and early groups of *Homo sapiens* in Europe, and the emergence of figurative art in caves.

In our view, the Greenland ice cores and marine records do not document any notable effects of the Laschamps excursion on the global climate (*4*). However, Cooper *et al.* argue that Laschamps-associated changes in climate can be linked to megafaunal extinctions, especially in Australia, which they suggest peaked at 42.1 ka. Recent research now suggests that much of Australia's megafauna survived beyond 40.1 ka BP (*5*). Although ancestry replacements frequently occurred during the last glacial period in Eurasian megafauna, synchronous bottlenecks or extinctions around 45 to 40 ka BP have not been noted (*6*). Most of these taxa, despite turnovers, survived the Last Glacial Maximum (e.g., *Coelodonta antiquitatis*) and even the Pleistocene-Holocene transition (e.g., *Mammuthus primigenius*).

The second main issue of (*1*) is the presumed relation between the climatic impact of the Laschamps and the extinction of Neanderthals and contemporaneous European *H. sapiens*. We clarify that during their evolutionary history, Neanderthals survived glaciation events and climatic fluctuations harsher than the stadials GS-11 and GS-10 (*7*). During Marine Isotope Stage (MIS) 6 and MIS 4, the Scandinavian ice sheet reached central Germany and the coast of Poland, respectively. Therefore, climate change may have played only a minor role in the fate of the Neanderthals (*8*). A more likely factor is gradual competitive exclusion, caused by the dispersals of *H. sapiens* in Europe after ~46 ka BP (*9*), which disrupted the Neanderthal niche structure and food web.

Additionally, the radiocarbon dataset used by Cooper *et al.* [see figure S31 of (*1*)] for establishing the temporal range of Neanderthals' demise is arbitrary in the selection of ^{14}C dates. A better solution would have been to compare the chronological boundaries of key sites or the direct dates of human fossils (Fig. 1 and Table 1). In Iberia, Neanderthals may have persisted after a threshold of ~40 ka BP [(*10*) and references therein], whereas the chronology of the last Neanderthals in central and western Asia is still virtually unknown. Moreover, we note that the end of the Middle Paleolithic at one or a group of sites does not necessarily reflect the end of Neanderthals as a species, and current scenarios may change with further research in less investigated areas.

The claim that the Laschamps event had a negative impact on some early European *H. sapiens* populations is also problematic. If the weakened geomagnetic field allowed a rise in ultraviolet radiation in equatorial and low latitudes, *H. sapiens* in Africa should have been even more affected than groups living in temperate environments. Hence, the Laschamps should have slowed the dispersal out of Africa and beyond, whereas data suggest that it had no such effect. Similarly, no large-scale impact at ~42 ka BP is observed in the known African archaeological, paleoanthropological, or genetic records (*11*).

Furthermore, if we consider both the short (Uluzzian, 45/43 to 40 ka cal BP; Protoaurignacian, 41.5 to 39.9 ka cal BP; Early Aurignacian, 39.8 to 37.9 ka cal BP) and the long (Early Aurignacian, 42.5 to 37.9 ka cal BP) chronology for the cultural succession of the Early Upper Paleolithic (*12*), we note that *H. sapiens* certainly survived the climatic consequences of the Laschamps. This evidence makes it unclear how ultraviolet radiation affected only some European inhabitants when no data currently support the greater use of ochre as sunscreen in the Aurignacian or any other Upper Paleolithic culture. In addition, although the end of the Uluzzian temporally overlapped with the Protoaurignacian in northern Italy (*13*), the lamellar technologies of the Aurignacian may have originated in western Asia rather than developing from previous technical behaviors of *H. sapiens* in Europe (*12*).

Lastly, in the archaeological record, a large increase in the use of caves at 42 to 40 ka BP is not apparent in the data. Since the Lower Paleolithic, the occupations of these natural shelters were the results of complex settlement dynamics and subsistence strategies (*14*). Figurative cave paintings may have emerged as an artistic expression that tried to imitate and transfer natural patterns in new contexts. These behaviors had appeared in eastern Borneo by 52 to 40 ka BP, in Sulawesi by at least 45.5 ka BP, and possibly in Europe before 64 ka BP [(*15*) and references therein], a time period well before the increase in the ultraviolet radiation caused by the Laschamps event.

All in all, not only have Cooper *et al.* failed to provide convincing explanatory mechanisms relating the Laschamps excursion to cultural and biological changes, but their chronological coincidence with this geomagnetic reversal is highly questionable.

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ACKNOWLEDGMENTS

Funding: A.P. and J.-J.H. are supported by the Max Planck Society. A.P. is supported by the German Research Foundation (DFG; project 429271700-STONE). S.B. is supported by ERC n. 724046 SUCCESS (www.erc-success.eu/). R.B. is supported by a Ramón y Cajal research contract by the Ministry of Economy and Competitiveness (RYC2019-026386-I). J.R. and R.B. develop their work within the Spanish AEI/FEDER projects PGC2018-093925-BC32 (J.R.), CGL2016-80000-P (J.R.), and PID2019-104949GB-I00 (R.B.), and Generalitat de Catalunya–AGAUR projects 2017 SGR 836 and CLT009/18/00055. The IPHES-CERCA has received financial support from the Spanish Ministry of Science and Innovation through the "María de Maeztu" program for Units of Excellence (CEX2019-000945-M). M.H. was supported by Marie Sklodowska Curie Actions (grant no. 844014). M.H. and P.S. were supported by Francis Crick Institute core funding (FC001595) from Cancer Research UK, the UK Medical Research Council, and the Wellcome Trust. P.S. was supported by the Vallee Foundation, the European Research Council (grant no. 852558), and the Wellcome Trust (217223/Z/19/Z). C.S.'s research is supported by the Calleva Foundation and the Human Origins Research Fund. S.T. has received funding from the European Research Council under the European Union's Horizon 2020 Research and Innovation Programme (grant agreement 803147 RESOLUTION, https://site.unibo.it/resolution-erc/en). For the purpose of open access, the authors have applied a CC BY public copyright license to any author accepted manuscript version arising from this submission. **Author contributions:** All authors contributed equally to this paper. **Competing interests:** The authors have no competing interests to declare. **Data and materials availability:** Table 1 can be downloaded from Zenodo (https://zenodo.org/record/5303753#.YSpCuY4zY2w).

3 April 2021; accepted 2 November 2021
Published online 19 November 2021
10.1126/science.abi8330

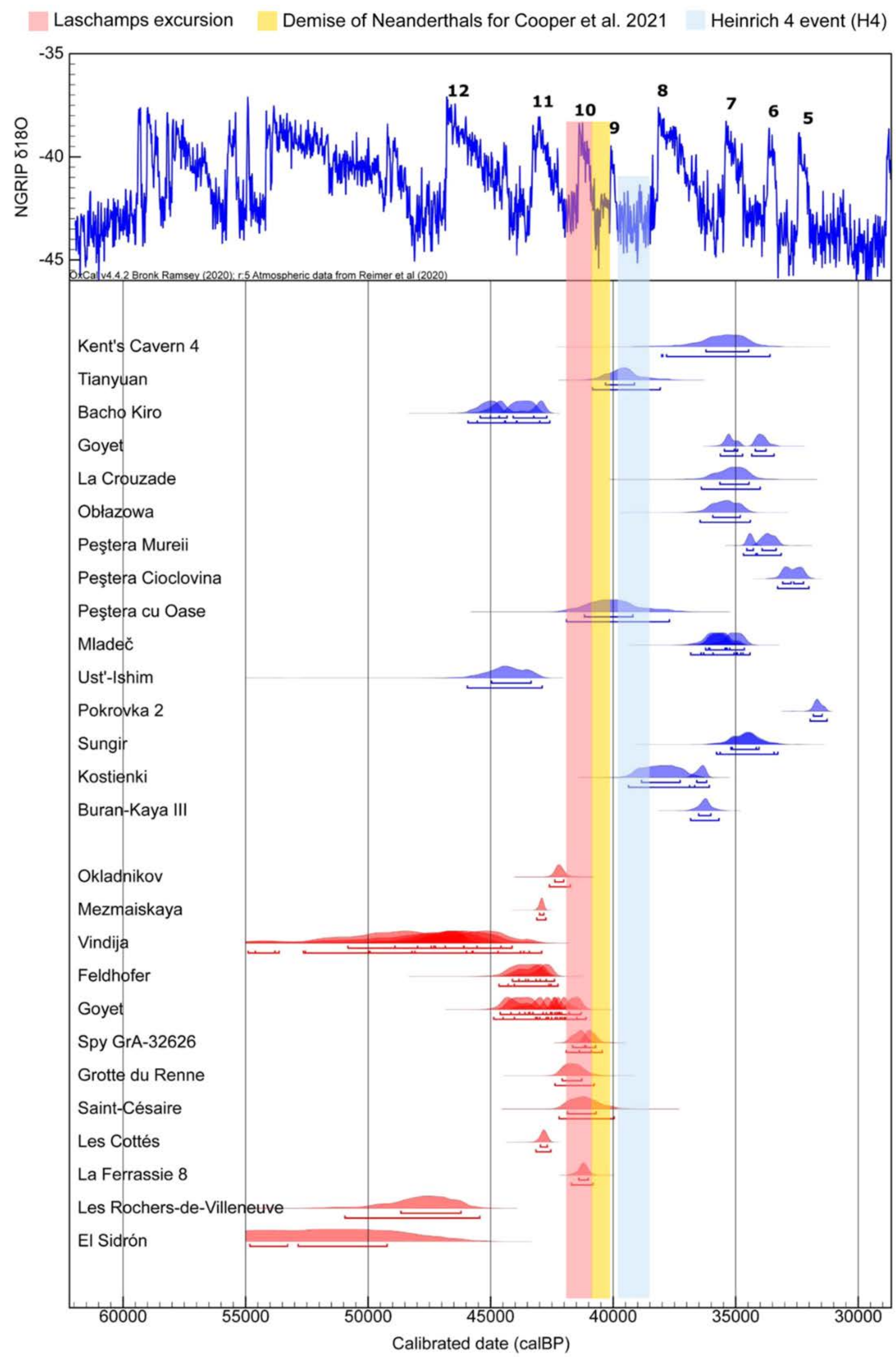

Fig. 1. Neanderthals and *Homo sapiens*' direct dates published before the Cooper *et al.* 2021 paper. Some hominins have more than one date (Spy, Goyet, Kleine Feldhofer, Vindija, Kostienki, Sungir, Peştera Mureii, Mladeč, and Bacho Kiro) and are merged together in one single line in the graph. The calibrated ranges are produced using IntCal 20 in the OxCal 4.4 program (*16*, *17*).

Cite as: A. Cooper *et al.*, *Science* 10.1126/science.abi9756 (2021).

Response to Comment on "A global environmental crisis 42,000 years ago"

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Our study on the exact timing and the potential climatic, environmental, and evolutionary consequences of the Laschamps Geomagnetic Excursion has generated the hypothesis that geomagnetism represents an unrecognized driver in environmental and evolutionary change. It is important for this hypothesis to be tested with new data, and encouragingly, none of the studies presented by Picin *et al.* undermine our model.

Numerous geomagnetic excursions have occurred throughout geological time, but currently we know very little about their potential impacts (*1*). During the late Quaternary, ancient DNA records have demonstrated that major population (and even species) extinction and replacement events have occurred relatively frequently, but often remain invisible within the fossil record (*2*). As a result, it is unclear what impact many earlier geomagnetic excursions, such as the Blake (~114 ka) and post-Blake (~109 ka), may have had on Neanderthal populations as mentioned by Picin *et al.* (*3*). However, recent studies on European Neanderthal populations around this time (*4*) suggest that environmental changes caused population fragmentation around 115 to 100 ka, while Spanish Neanderthal populations underwent a major population replacement around ~112 to 107 ka, similar to the Laschamps observations.

As we noted (*1*), the environmental changes at 42 ka are more obvious in sediment and glacial records in the Pacific region, whereas the pronounced Dansgaard-Oeschger cycles in the North Atlantic potentially obscure similar impacts. In this regard, it is important to recognize that the Greenland ice records do not represent global climate, but preserve northern Atlantic regional environmental changes. Nonetheless, the refined timing created via the kauri record reveals that the periods of collapsed magnetic field strength and implied cooling impacts during the Laschamps align very closely to Greenland Stadial GS-11 and the climatically anomalous GS-10 (*1*, *5*) (Fig. 1).

The staggered spatiotemporal pattern of European Neanderthal extinctions during the repeated (cold) stadials GS-12 to GS-10 has been explained as competitive exclusion from invading anatomically modern human (AMH) populations reexpanding more rapidly after each cycle (*6*). Neanderthal population sizes and genetic diversity were decreasing throughout the Late Pleistocene, but their survival through multiple glacial-interglacial cycles makes it seem unlikely that a standard Greenland Stadial (i.e., GS-10) alone could have caused their extinction. However, we know very little about the nature or rate of change of geomagnetic-caused environmental changes during GS-10, which arguably could have been much faster or had more severe impacts (Fig. 1). We used the most comprehensive available compilation of high-quality radiocarbon dates (*7*) to show that the final ages of western European Neanderthal populations were coincident with the Laschamps excursion. This conclusion has been further reaffirmed by studies redating anomalously young dates such as from the site Spy (*8*), by the impacts of the latest radiocarbon calibration curve (IntCal20) for this period (*9*), and seemingly by the additional data and figure presented by Picin *et al.* (Fig. 1).

Picin *et al.* point out that in Europe "*H. sapiens* certainly survived the climatic consequences of the Laschamps" (*3*); however, a recent study (led by one of the co-authors) demonstrated that the AMH populations before and after the Laschamps represent two genetically different populations (*10*), separated by a complete replacement around the Laschamps (Fig. 1). Specifically, Initial Upper Paleolithic AMH populations were replaced sometime after 45.3 to 42.6 ka, immediately before Laschamps, whereas the subsequent Aurignacian populations appear during or shortly after the Laschamps. Indeed, both the (alternative) short and long Early Upper Paleolithic chronologies presented by Picin *et al.* indicate a major transition associated with the Laschamps (Fig. 1), while the start of the Early Aurignacian is contemporaneous when calibrated with IntCal20 (*9*) or kauri-Hulu (*1*). More remarkably, the Aurignacian itself appears to end during the next major geomagnetic excursion, Mono Lake at 35 ka (*11*) (Fig. 1), after which it is genetically replaced by Gravettian populations that first appear in eastern Europe at that time (*12*). The AMH record is important because there are few other detailed European megafaunal genetic records around Laschamps, making it challenging to detect local extinction events. However, a cluster of megafaunal genetic extinction events is apparent around Mono Lake, where records are more detailed (*1*, *3*).

We specifically stated that high ultraviolet levels during the Laschamps seem unlikely to have caused major negative impacts on early AMH populations, such as extinctions or altered migration patterns (*1*). However, our climatic and solar physics models suggested that the intense ultraviolet light radiation and other associated phenomena during short (1- to 2-day) solar energetic particle (SEP) events during the Laschamps would be consistent with a sudden increase in global cave use, including a clear intensification in the appearance and diversification of early figurative cave art, as well as the use of red ochre including hand stencils (*1*). As we suggested, the sudden increase in figurative art in disparate locations across Europe and southeast Asia probably represented a preservation bias associated with the increased use of caves (potentially as short-term shelter during SEP events). We also clearly stated that the quality and diversity of cave art at ~42 ka implied that figurative art was already well established, likely in the external environment such as rockshelter and cliff walls.

In the Southern Hemisphere, the peak of megafaunal extinction events in Australia has previously been estimated at 42 ka (*13*), whereas recent work in northeast Australia (*14*) referred to by Picin *et al.* reveals that the youngest megafaunal layers (dated between 41.8 and 38.4 ka, 1 SD) appear to be associated with environmental deterioration starting around this period (Fig. 1). Similarly, the youngest radiocarbon-dated megafaunal remains in Tasmania are 41.9 to 40.9 ka (*1*) when calibrated using the new kauri-Hulu curve. Within southern Africa, spatiotemporally staggered patterns of cultural transitions complicate interpretation, although we noted that the fully developed expression of Late Stone Age technologies at ~42 ka (Fig. 1) recorded at Border Cave matched parallel megafaunal changes at Boomplaas Cave. We had overlooked equatorial African palynological records that also detail major changes in vegetation patterns and moisture levels at 43 to 40 ka (*15*), parallel to those we report in the Pacific (*1*).

Our hypothesis that the Adams Transitional Geomagnetic Event and Laschamps excursion caused major global environmental (and climatic) impacts is based on precisely aligned records and global chemistry-climate modeling. We do not claim to have resolved the full details of the mechanisms that drove global change or contemporaneous evolutionary events, as this will require further testing and analysis. However, Picin *et al.* (or Hawks) do not present any data that challenge our hypothesis, such that geomagnetic excursions remain a potentially important new environmental and evolutionary driver that has been previously overlooked.

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29 April 2021; accepted 2 November 2021
Published online 19 November 2021
10.1126/science.abi9756

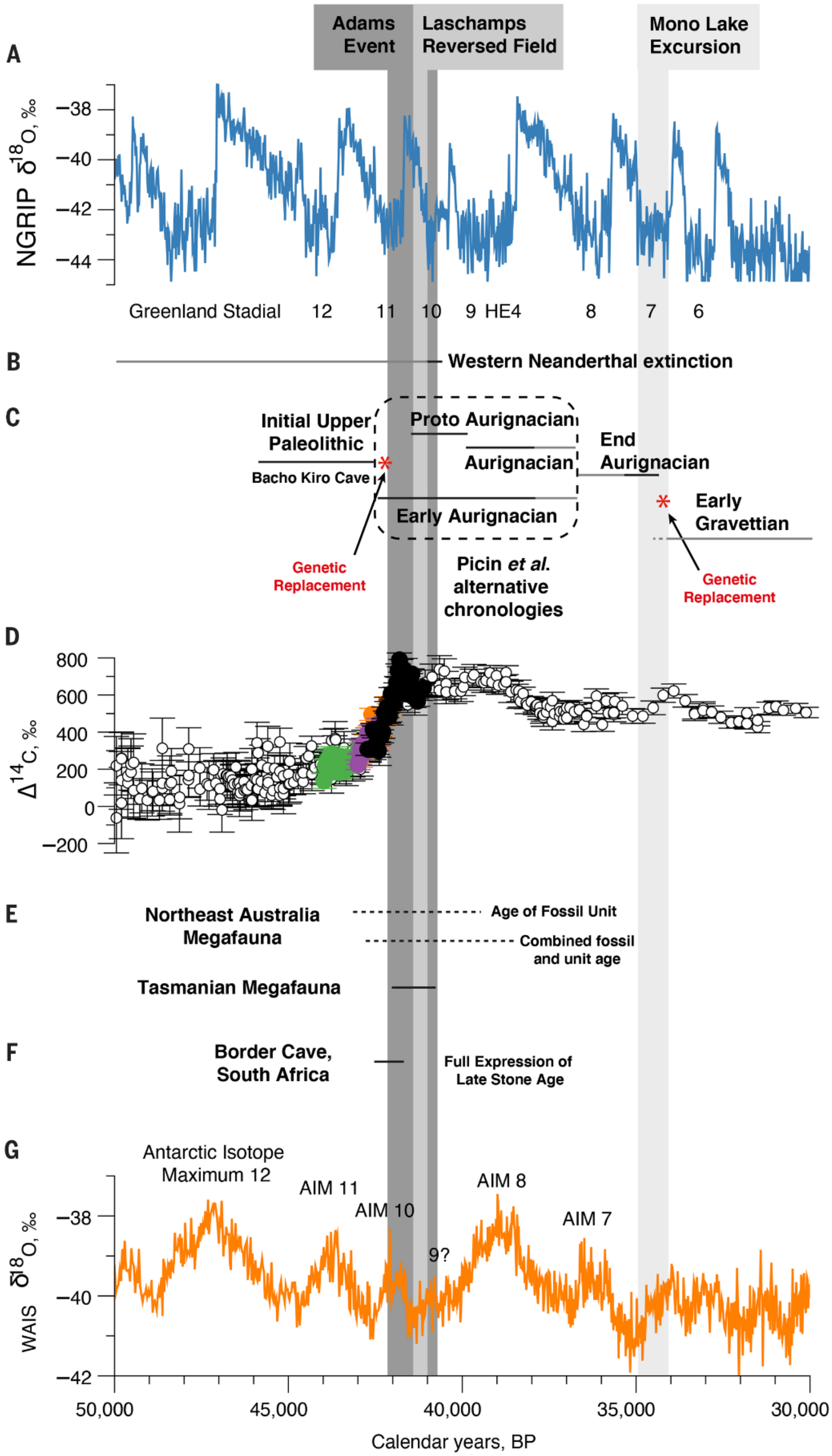

Fig. 1. Alignment of climatic, radiocarbon, anthropological, and paleontological data against the Laschamps and Mono Lake geomagnetic excursions. (**A**) NGRIP $\delta^{18}O$ with Greenland stadials (*5*). (**B**) Neanderthal extinction in western Europe recalibrated with kauri-Hulu calibration curve (*1*). (**C**) Early anatomically modern human (AMH) cultures in Europe, with genetic replacements of populations indicated with red asterisks. Initial Upper Paleolithic data are from Bacho Kiro cave (*10*). Alternative Aurignacian chronologies are from Picin *et al.* (*3*), with the End Aurignacian dated via the high-resolution record at Abri Pataud Cave, France (*11*). Gravettian genetic groups appear across Europe from 34 to 35 ka [dashed line (*12*)]. (**D**) Kauri and Hulu cave ^{14}C values from (*1*). (**E**) Youngest megafaunal layers and fossils in northeastern Australia (*14*) and Tasmania (*1*). (**F**) Full expression of Late Stone Age cultural adaptations at Border Cave, South Africa (layer 1WA transition to 1BS lower-BC) recalibrated with kauri-Hulu calibration curve (*1*). (**G**) West Antarctic (WAIS) $\delta^{18}O$ with Antarctic Isotope Maximum events.