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Impact of an extraterrestrial object at the Earth's surface. Credit: Don Davis/NASA

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CONTENTS

company of indigenous Brazilians such as the Guaraní nation; practised Venus- and solar yoga for years; and was an indomitable philosemite, a bibliophile, a committed vegetarian and a prophet *soi-disant*. A polyglot and self-styled 'Europoet', he composed scores of Persian quatrains in 7 languages, always in the style of Omar Khayyám and the *poètes maudits*.

Han seemed to defy the gods, surviving 28 cases of malaria, 6 bouts of amoebic dysentery, leishmaniasis and bilharzia, a crash in a Cessna aircraft over Amazonia while stricken with malaria (1969) and throat cancer (1993). Regarding the latter, he would flippantly remark that he had 'already died'.

People close to him often described Han as a 'man of coincidences'. I myself was introduced to him by two people in different countries who did not know each other. Weeks after my first meeting with him (2004), my wife and I bumped into him in the Louvre, although we had at no point discussed each other's travelling plans. It seems only fitting, then, that Han died on the day of the closest supermoon since 1948, while a double rainbow was photographed over the funeral building just before his final send-off.

I am grateful for the many years I was able to compare notes with Han and have no doubt that posterity will recognise his intellectual legacy.

Marinus Anthony van der Sluijs

ARTICLES

A Geomagnetic Approach to Traditions of *Axes Mundi*

Marinus Anthony van der Sluijs

Part III

Part I of this article was published in C&C Review 2016:2, pp. 13-27, and Part II in 2016:3, pp. 12-23

Solar Eruptions

The Sun releases its energy into space both in the form of electromagnetic radiation, which includes its heat and visible light, and charged particles constituting the solar corona and wind. Geomagnetic storms and substorms are due to short-lived outbursts in both categories.

A solar flare is a relatively small-scale but violent explosion in any layer of the Sun's atmosphere, often in the vicinity of sunspots. It is powered by the release of electromagnetic energy stored in the corona, which heats and accelerates the plasma contained in it. When a continuum of radiation is produced across the electromagnetic spectrum at all wavelengths, rather than in certain spectral lines only, the event is referred to as a white-light flare. The latter is far rarer than an ordinary flare, illuminates only a small portion of the disc of the Sun and lasts less than half an hour.

A coronal mass ejection (CME), formerly called a 'coronal transient', is a closely related phenomenon in which matter is emitted instead of only electromagnetic energy. It occurs when the Sun's corona forcefully ejects a huge bubble of plasma, with its own magnetic field structure, into the solar wind – typically from an eruptive prominence. The eruption is frequently accompanied by a flare and lasts several hours. If the plasma is directed towards the Earth and hence 'geoeffective', it provokes a geomagnetic storm or substorm.

While these are common events, on the order of one or more a week, an estimated 1% of coronal mass ejections involve an invisible but intense outburst of solar energetic particles (SEPs), particles accelerated to very high energies which produce exceptionally powerful aurorae when striking the Earth. In the case of protons, these occasions are referred to as 'solar proton events' (SPEs) or 'proton streams', potentially triggering rare 'proton aurorae'. Solar protons are usually largely deflected by the Earth's magnetic field, but can penetrate it more effectively when the magnetosphere is impaired or during a solar flare or a coronal mass ejection [1].

Gold's Intense Solar Outburst

For a possible cause for his magnified aurora, Peratt invoked the notion of an intense solar outburst as hypothesised by Thomas Gold [2]. The starting-point for Gold's hypothesis was that solar output may not always be as stable and predictable as it has apparently been in historical times, but that truly exceptional solar outbursts may have occurred in the past. These could have provoked severe magnetic 'superstorms' on the Earth that "would be a totally different kind of phenomenon from the usual one" [3].

Speculating on the occurrence of "one big outburst every ten thousand years", Gold reasoned that – in modern terminology – the augmented solar wind will press the Earth's magnetosphere tightly against the ionosphere and force an electrical breakdown of the latter:

> The earth's magnetic field could clearly not hold up the incoming gas, and it would indeed drive down to the atmospheric level where the gas pressure can resist the further flow. At that level the atmosphere is dense and the ionization that could be maintained would not result in a good conductivity. The incoming gas bringing its strong field into the virtually insulating atmosphere would then result in very large electric fields so directed that the resulting currents would maintain those fields. But in the atmosphere this can be done only by electrical breakdown. Since the ground is a good conductor such a breakdown is likely to take a path of breakdown through the entire thickness of the atmosphere on each side of the magnetic cloud being pressed in, and through the body of the earth from one site of breakdown to the other … This breakdown would be in the form of a series of sparks, burning for extended periods of time and carrying currents of hundreds of millions of amperes. [4]

The compression of the magnetosphere onto the ionosphere will extend over the entire Sun-facing hemisphere. The higher solar wind pressure will drive the incoming plasma down to the denser and insulating lower atmosphere, where it is resisted by gas pressure; the magnetosphere is effectively squeezed flat and the magnetopause then runs in the upper atmosphere or ionosphere. Because the atmosphere is a fairly efficient insulator, the current j – which normally closes

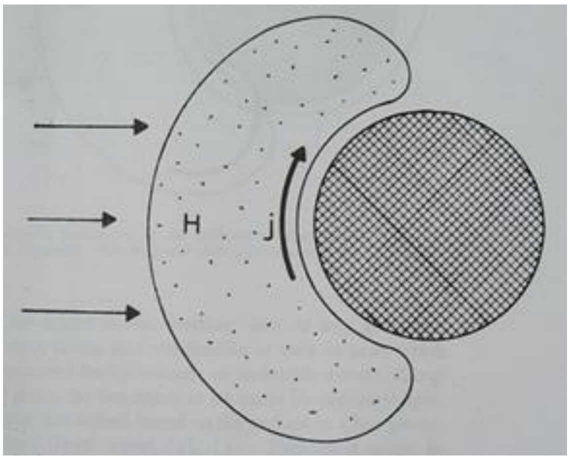

Figure 1. Magnetised plasma approaching Earth, showing the current above the insulating atmosphere.

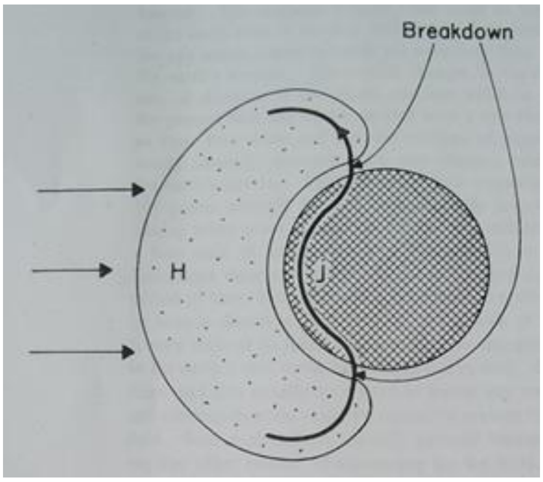

Figure 2. Magnetised plasma causing electrical breakdown of the atmosphere, showing the current short-circuiting through the crust.

through the ionosphere, diverting the incoming stream from the surface (figure 1) – will prefer an alternative path of less overall resistance: it will 'short' through the atmosphere down to the conducting solid or liquid surface, travel through the Earth to the opposite hemisphere and 'short' back up again through the atmosphere to the compressed ionosphere and magnetopause (figure 2) [5]. The momentary reduction of the Earth's native magnetosphere is tantamount to what would now be called an 'induced magnetosphere': "In an induced magnetosphere, the solar wind interacts directly with the planetary ionosphere. The fields and plasmas that are observed are generally of solar wind or ionospheric origin." [6]

Telluric currents or earth currents are – usually very weak – electric currents moving through the Earth's crust. The ionospheric currents channelling the aurora have been known to boost telluric currents enough to disrupt telegraph communications during intense magnetic storms such as those in 1848, 1859, 1882, 1892 and 1921. Gold's model implies that the auroral electrojet, which currently flows horizontally above the Earth through the ionosphere, itself transforms into a telluric current. For convenience, this hypothetical current system induced by extreme solar weather, including both its ionospheric and telluric components, may be referred to as 'Gold's current' or 'a Gold current'.

Solar Superstorms

Evidence in favour of the reality of solar superflares is mounting [7]. Superflares are defined as flares with an energy exceeding roughly 10^{33} erg, occurring on Sun-like stars [8]. In 2000, Schaefer's team announced their discovery of "nine cases of superflares involving 10^{33}-10^{38} ergs on normal solar-type stars." [9] And in 2012, Japanese astronomers reported on "365 superflares … on 148 solar-type stars" [10]. On such stars, superflares with an energy output of 10^{34} erg – a hundred times more than estimated for the 'Carrington event' of 1859 – are believed to "occur once every 800 yr" and those with one of 10^{35} erg, exceeding the Carrington event a thousand times, "once every 5,000 yr" [11].

These findings reveal that superflares are possible and common on stars which are similar to the Sun. If the Sun were to emit one, the Earth might be parched for months, while the radiation would destroy the ozone layer and ultimately contribute to mass extinctions. The superflare might be accompanied by coronal mass ejections and solar proton events to match, a combination of events – not always carefully distinguished – which one might refer to as electromagnetic or stellar 'superstorms'. Did superflares occur on the Sun itself, even within human memory? A period of doubt ended in 2007, when two scientists deemed it "reasonable to infer that much more energetic solar flares have occurred in the past" [12]. Since then, evidence has surfaced for "the greatest solar event on a multi-millennial time scale", responsible for a powerful radiation storm on the Earth in 774 or 775 CE [13].

Other studies confirm Gold's expectations regarding the response of the Earth's magnetosphere to a solar superstorm. Under quiescent conditions, the circuitry linking the magnetosphere and the ionosphere is a low-current system, but this is susceptible to perturbations. Plasma physicists speculate that "time variations in the electric field or the particle spectra will create complex structure within the Alfvén layer." [14] Theoretically, "for monoenergetic electrons and ions" the thickness of the Alfvén layer varies from several Earth radii for a highly conductive ionosphere to 100 metres for a non-conducting ionosphere. In extreme cases, "when the Alfvén layer moves inward into the plasma trough, transient electric fields aligned parallel to the magnetic field should be created. At such times, especially intense Birkeland currents would be generated." [15]

In 1993, a group of plasma scientists successfully simulated "the solar wind interaction with a planetary magnetic field" using a technique known as particle-in-cell (PIC) simulation. The simulation showed shrinkage of the magnetosphere "with great particle entry into the cusps and nightside magnetosphere" in response to a southward interplanetary magnetic field [16]. The first laboratory simulation of a supersized coronal mass ejection, with an energy exceeding 10^{33} erg, acting on an "intense magnetic dipole" such as the Earth, resulted in "the extreme (three fold) compression of the Earth's magnetopause", in which case "a conducting cover" such as the Earth's surface "would generate telluric currents". The researchers found that the plasma overpressure creates "a new quasi-stationary magnetopause that is much more closer [*sic*] to the Earth than in quiescent solar wind." [17]

Analysis of the magnetic 'Hallowe'en storm' of 2003 revealed that "the outer Van Allen belt was compressed dramatically", distorted and displaced inwards, while the plasmasphere inside it likewise underwent "a major reduction", contracting from a normal radius of 25,000-30,000 km to 9,500-12,700 km in a matter of days – even on the nightside, beyond Gold's restriction to the dayside [18]. The group concluded that "Such an extremely small plasmasphere only occurs during the strongest geomagnetic storms …" [19] And it transpires that, during the second blast of the Carrington event, the magnetopause was slammed into the ionosphere, thousands of kilometres down:

> Such was its violence that it compressed Earth's magnetosphere (which usually extends about 60,000 kilometers) to 7,000 kilometers or perhaps even into the upper stratosphere itself. The Van Allen radiation belts that encircle our planet were temporarily eliminated, and huge numbers of protons and electrons were dumped into the upper atmosphere. [20]

These simulated and empirical observations of supercompression of the magnetosphere are consistent with Gold's intuition. Apparently, an increase of Carrington-sized events by just one or two orders of magnitude would suffice to produce the type of scenario Gold envisioned. The correlation between a compressed, non-conducting state of the ionosphere and intensification of the Birkeland currents makes perfect sense of the widespread mythological traditions of a 'low' sky combined with *axes mundi*.

How do solar superstorms relate to geomagnetic reversals and excursions? As seen, the magnetopause is also thought to be capable of descending to a mere 10,000 km during reversals and excursions – but for a much longer period of time. At a minimum, the occurrence of solar superstorms or increased solar wind pressure during a geomagnetic reversal or excursion could intensify the aurora, counteracting the dwindling effect on the strength of the aurora exercised by the weakening of the field itself. But there may also be a more direct, causative link between solar superstorms and prolonged impairment of the geomagnetic dipole field.

It seems likely *a priori* that an induced magnetosphere on the Earth would involve geomagnetic reversals or excursions, because "the external field strengthens as the internal field weakens" [21]. Gold specifically related his hypothesis to geomagnetic reversals [22]. Unaware of this, LaViolette, in a departure from mainstream thought but in line with Gold's sentiments, submitted the radical proposition that overloading of the Earth's radiation belts with trapped solar flare particles can kickstart a geomagnetic reversal in a matter of days to weeks by reinforcement of the ring current [23]. The task would be even easier to accomplish if the magnetosphere had already been impaired or if solar superstorms – not considered by LaViolette – were involved. Later researchers reached similar conclusions, but did not recognise Gold's or LaViolette's priority or add solar superstorms and the geomagnetic multipole to the equation [24]. In March 2012, Robert J. Johnson independently realised that a dominant geomagnetic multipole, whether related to creation mythology or not, invites a revisitation of Gold's scenario, as both conditions involve severe magnetospheric crisis. Similarly to LaViolette, Johnson argued that a solar superstorm, such as Gold imagined, would weaken the geomagnetic dipole field through enhancement of the equatorial ring current, enabling predominance of the multipole field [25]. A potential solar explanation for geomagnetic reversals and excursions thus arises [26].

Solar Superstorms and Lightning

The aurora and lightning constitute two different modes of atmospheric discharge, which can be viewed as related plasma phenomena – respectively a 'slow' and gentle glow discharge in the ionosphere and a 'fast' and aggressive arc discharge in the lower atmosphere. On a strong dipole field, the aurorae concentrate around the north and south magnetic poles, as they are caused by relativistic electrons flowing from the magnetosphere into the ionosphere along the lines of the Earth's magnetic field. Lightning, by contrast, discharges via a direct breakdown path between the atmosphere and the surface and may occur anywhere, but predominates in the tropics.

Accordingly, it should not be surprising that, on the present model of diminished geomagnetism during a mythical 'age of creation', the Earth would have been the recipient of intense versions of both modes of atmospheric discharge [27]. The Earth's surface and the ionosphere would have functioned as conductors in a capacitor. The compressed atmosphere – due to its poor conductivity – served as a dielectric medium, polarising particles in the two conductors: cations in the ionosphere – sourced both from the solar wind and the auroral wind – and electrons in the Earth's surface. Impinging electrons with sufficient energy will penetrate the surface and excite electrons within it, thus producing a secondary emission of electrons from the ground and so enhancing the dielectric effect [28]. Aided by the weakness of the geomagnetic field, the voltage differential between the two electrodes – the surface and the ionosphere – would alone have encouraged the stripping of electrons from silicates and other minerals on the ground, generating plasma discharges as they flow upwards. The balance between the density of ions and electrons in the ionosphere would have regulated the type and intensity of discharge that would occur at any place and time – such as aurorae and lightning. Introduction of particles from various terrestrial processes, such as volcanism, would further modify the conductivity of the air and hence the dielectric discharge processes.

Earlier, a process was outlined by which multiple auroral rings, patches and hollow filamentary columns, generally confined to the ionosphere and above, could form on occasion of geomagnetic reversals and excursions. Dielectric breakdown, arguably triggered by solar superstorms, would involve a step change to far more energetic plasma-physical regimes, in which these relatively low-energy and innocuous aurorae are replaced or complemented by dramatic 'intense aurorae' accompanying Gold currents discharging at great intensity. Discharges which would be very extreme under today's arrangement of a distant magnetosphere and ionosphere are to be expected frequently and globally if the whole sunward side of the magnetosphere is compressed down to the point of forcing the magnetopause into the dense atmosphere.

Because, under these conditions, the Birkeland currents close through the Earth's surface instead of the ionosphere, the discharge channels become unidirectional *z*-pinches structured as magnetic flux ropes. Accordingly, they can be treated as direct analogues to Peratt's Column, much more so than the auroral funnels discussed earlier. Gold's estimated current strengths of "hundreds of millions of amperes" fall in the same league as Peratt's measurement of the intense aurora in giga-Ampères. Presumably, it was in response to Gold's model that Peratt – from 2005 onwards, as seen – posited a unidirectional current flow for the column, entering the Earth at one pole and exiting at the opposite one, in contrast to the circuitry of the familiar aurora though still assuming a dipole field. The discharges would switch from glow current to the much more intense arcing mode, constituting a highly intense form of lightning, perhaps an order of magnitude more powerful. The returning particles can no longer complete the solar-terrestrial circuit above the same magnetic pole as the incoming particles, as they do in the ordinary aurora, but either they produce a telluric current and depart from another pole or the circuit is not completed and net charge is delivered to the surface, as in a lightning strike. The voltages required to form these plasma columns would be greatly reduced compared to current circumstances, as the distances would be smaller than in today's situation. The discharges may not be continuously visible, but could flicker or pulse, depending on fluctuations in current densities.

If a Gold current through the Earth occurs, where will it enter and exit the surface? At any time, the structure of the geomagnetic field dictates the discharge path between the solar wind and the Earth. As long as the dipole component of the field remains dominant, the path will continue to concentrate on the north and south magnetic poles. Guided by the magnetic field direction, the current will tend to follow the magnetic meridian between the points of entry from and exit to the compressed magnetosphere. These points will preferentially be at higher latitudes, because that will maximise the 'advantage' to the current of shorting to the surface by omitting the maximum length of path through the atmosphere. Yet they will not necessarily be located at the magnetic poles themselves, unless these are favourably located at the instant of shorting.

During the transitional stage of a reversal or excursion, the prominent minor poles may all serve as discharge channels between the solar wind and the atmosphere, either singly or in pairs for in- and outgoing currents. Due to their geographic distribution, the intense discharges will no longer be confined to the circumpolar regions, but occur globally. With the ongoing energy input provided by this altered electrical circuitry, a combination or alternation of intense lightning and aurora – often presenting highly discrete forms – can occur intermittently for days to months at a time, whenever optimal conditions prevail and with morphologies and intensities that vary from occasion to occasion.

Yet direct discharges between the ionosphere and the surface need not be confined to the magnetic poles, whether dipole or multipole. While the geomagnetic field may guide the discharges towards the magnetic poles as long as it retains sufficient strength, its collapse may allow the current to short out via any local path of low resistance. Under these circumstances, actual breakdown paths through the atmosphere can in theory happen anywhere along the Sun-facing side of the Earth, depending on the instantaneous values of resistance of the atmosphere and ground – or ocean. Individual shorting events might not be all that rare, within the context of an extreme solar wind. Numerous current paths can form to the Earth's surface, especially to high terrain. On mountain peaks, these may effectively represent a form of coronal discharge.

With an eventual reduction in solar wind pressure and the consequent separation of the magnetopause from the ionosphere, the current would no longer require 'shorting' to the surface. The telluric discharge current would retreat into the ionosphere, restoring the auroral electrojets. From a human perspective, the lower parts of the discharge columns, joining the ionosphere to the surface, would appear to 'collapse' as the circuitry returned to stable conditions, reducing the displays to ionospheric rings of field-aligned filaments and finally the familiar auroral ovals.

Solar superstorms will usually have been intermittent and relatively brief, as ordinary solar storms are today, corresponding in geological records such as ice cores and tree rings to bursts in radiocarbon and radioactive beryllium levels. If the Earth's magnetosphere was already weak due to a geomagnetic reversal or excursion, coronal mass ejections with their magnetic fields may even have hit harder and more frequently than they normally do. Nor is it ruled out that an induced magnetosphere would effectively be tantamount to a continuous solar superstorm.

Solar Superstorms and *Axes Mundi*

The discharge geometries expected for solar superstorms match aspects of global creation mythology. When seen within human memory, intense lightning-like discharges between the surface and the ionosphere will have contributed to traditions of *axes mundi*. The latter require that the stable forms of the column, such as a cosmic tree or mountain, were visible for longer periods of time than isolated intervals of only a few days. This might suggest that the discharges between the ionosphere and the surface were ongoing for longer periods at a time, inconsistently with the occasionality of supersized coronal mass ejections. One possibility is that the Sun itself was more active for a prolonged period, perhaps triggering the geomagnetic excursion in the first place and flaring more frequently than it has done in recent millennia. Alternatively, the perceived permanence of many *axes mundi* may have been due to a combination of the brevity of *z*-pinch discharges with the greater stability of auroral columns at the same polar locations. Conceivably, the transitional geomagnetic field ordinarily generated relatively steady columns above the magnetic poles, but the uneventful periods were punctuated by the effects of occasional solar superstorms, which temporarily intensified the discharges.

Especially fitting descriptions of the formidable lightning phenomena seem to be the mythological associations of the base of an *axis mundi* with fire, a collection of snakes (§105) and the network of 'roots' of a cosmic tree or – if the latter is perceived as inverted – its branches (§262). In systems where the column is articulated into two or three superimposed segments (§§81-82), the *z*-pinch will correspond to the bottom section, which is typically related to the 'earth' or 'underworld'. If a flux rope at any time happened to span between a pair of magnetic poles, following geomagnetic field lines, human observers may have reported arc-like imagery, such as 'bridges' and 'rainbows'. And the disconnection of an *axis mundi*, widely reported in myth, could have specifically referred to the dramatic collapse of a column's lowest and most energetic segment, occurring when the magnetopause separated from the ionosphere to the point where the current intensity was insufficient to maintain a *z*-pinch discharge at the magnetic poles. Some traditions expressly relate that the lower part of the column was severed prior to the upper part or that the column broke in the middle. As noted, the hollow upper parts defined by the field-aligned currents between the ionosphere and the magnetopause survived above the north and south magnetic poles, albeit in 'dark mode' and with the loss of highly discrete filaments.

Meanwhile, it is possible that lightning-like discharges away from any magnetic poles relate to traditions of short-lived *axes mundi*. These lack associations of stability or permanence and are usually mythologised as ropes, spider's threads, strands of hair or indeed lightning, along which one or more mythical beings may traverse the layers of the cosmos.

All discharges, whether lightning-like or auroral, may have provided ancient man with a reason to mark the sacred places where they occurred, with a striking predilection for mountain peaks, as special, spiritually charged, taboo and often eventually a place of worship.

Plasma Instabilities in Atmospheric *Z*-Pinches

Responding to Gold's hypothesis, Biermann pointed out that collisions of the Earth's magnetosphere and its ionosphere on short timescales must have ramifications relevant to "theoretical and experimental work in plasma physics": "It has been found, I think, furthermore, that nearly all experiments in this field have been plagued by a great variety of instabilities. … It is now somewhat difficult to see how, under the circumstances which you describe, one of these instabilities would not arise just automatically." [29]

In addition to the types of instabilities discussed above in connection with the quotidian aurora and Peratt's intense aurora, it may be surmised that transient modifications of the Earth's polar funnels involved other plasma instabilities analogous to those observed in laboratory *z*-pinches, revealing additional aspects of the complex anatomy of individual sky pillars. As Peratt indicated, strengthening the field-aligned currents above a magnetic pole – as in Gold's scenario – would intensify the pinch effect, compressing the currents into a bundle with a smaller diameter than that of the current auroral ovals. The pinching would facilitate the occurrence of a range of "fiery plasma instability figures usually in association with the incoming plasma current column" [30]. These would be similar to the phenomena Bostick and his successors observed in plasma beams: funnels of parallel filaments, kinks, localised pinches and plasmoids. The instabilities would continue until 'shorting out' to the surface of the Earth led to electrical stability. The physics of the evolving *z*-pinch column as modelled by Peratt are partially confirmed in recent work [31].

Down to a level of fine detail, the morphology of Peratt's Column displays a remarkable similarity with the *axis mundi* of human traditions. Thus, the study of instabilities in plasma *z*-pinches can potentially fill in many of the details concerning the way the *axes mundi* and related features of the 'ancient sky' may have looked.

Part IV

The Gothenburg Excursion

In the preceding pages, I spelled out a geomagnetic hypothesis for traditions of *axes mundi* and related themes in creation mythology. The million-dollar question is, of course, whether there is any evidence for a geomagnetic excursion which occurred recently enough to be remembered in such remarkable detail by human populations across the globe, but early enough to antedate the earliest references to 'creation' or *axes mundi* [32].

As stated, the Laschamp excursion (40,000 BP) is the youngest excursion whose reality presently enjoys unanimous endorsement. As for any more recent excursions, a deep rift runs through the palaeomagnetist community, separating several dozens of researchers who have published evidence in favour from a 'mainstream' group ignoring these findings or rejecting them as unreliable.

On 14 October 1970, Nils-Axel Mörner retrieved a core of marine deposits from the Botanical Garden of Göteborg (Sweden). Upon analysis, he discovered that it contained evidence of what he accordingly labelled the 'Gothenburg excursion' [33]. Combining this with findings from other cores from Sweden, the north Atlantic Ocean and Lake Erie (Canada) [34], Mörner dated the event to 13,750-12,350 BP, just a couple of millennia before the end of the last glacial period. This included a period of "irregular (but not fully reversed) magnetism" at 13,750-12,400 BP, "including at least one rapid 'flip' (the Port Dover Excursion)", and the concluding Gothenburg 'flip' at 12,400-12,350 BP, during which the VGP crossed the equator into the southern hemisphere [35]. From its confinement to a very brief Swedish stratum, the Fjärås stadial, Mörner gathered that the magnetic 'flip' "only covered some tens of years and that the polarity switches probably only took some years." [36] Perhaps the flip lasted "only a few years" [37]. Thus, it appeared to be "the shortest excursion and the most rapid polar change known at present." [38] As seen through a geologist's lens, it must have been near-instantaneous. Though the claimed extreme rapidity of the Gothenburg flip was extraordinary for its day, on current knowledge it falls squarely within the realm of possibilities, as illustrated by the Steens Mountain reversal and the Laschamp excursion.

In terms of comparative stratigraphy, Mörner related the Gothenburg excursion and flip to the final stages of the cold Oldest Dryas stadial, marking the transition between pollen zones Ia and Ib [39]. On a modern scheme, the excursion began during Heinrich event I and lasted throughout the Oldest Dryas and the Bølling oscillation. The flip occurred within the colder interval of the Older Dryas in areas where the latter was discernible, but within the Bølling elsewhere. Finally, during the 'recovery' stage the north magnetic pole appears to have migrated back towards the northeast for more than a millennium, until 10,950 BP – the end of the Allerød oscillation [40].

The copious evidence Mörner marshalled forth was reinforced by many other palaeo- and archaeomagnetic studies never heretofore collated [41], and supportive material continues to pour in. Those who accept the reality of the Gothenburg excursion currently view it as a global event with an overall date range of 13,500-11,500 BP or 13,000-11,000 BP [42]. However, it appears that "the Gothenburg geomagnetic excursion could develop during different periods in different regions of the globe since the main geomagnetic field drifted westward." [43]

Mörner's samples enabled him to calculate the position of the VGP during the Gothenburg excursion (figure 3). They testify to "the VGP migrating in the Pacific region (in opposition to the periods before and after)" [44] and cluster around two low-latitude regions. For the so-called Port Dover Excursion indicated by Canadian data for *c.* 13,300 or 13,250 BP, the VGP was "in the southeast Pacific Ocean" [45]. From other cores, Mörner determined that the VGP then returned to high northern Pacific latitudes, where it stayed until 12,90 0BP [46]. The second low-latitude cluster concerns "a Mid-Pacific centre at 12,900-12,350 BP" up to 55º-60º N, but with "a fully reversed position" at 50º-70º S for the 'flip' of the final 50 years [47]. In a French set of cores, "the Gothenburg Flip consists of a rapid inclination flip immediately followed by a 180º declination switch", implying "a rapid switch between two opposed equatorial VGP positions." [48] Equatorial latitudes were also obtained from the Russian samples cited above [49]. The period 12,350-10,000 BP, according to the Swedish cores, is "characterized by generally normal magnetism" [50]. However, between 11,900 and 11,750 BP the VGP briefly reverted to mid-northern latitudes (*c.* 40º N) [51]. Another group inferred from a Canadian core a return path of the VGP from northwest India towards Siberia; the dating was imprecise, but fell within the period 12,000-7500 BP [52].

In some places, Mörner stated that the Gothenburg excursion and flip do not appear to have been associated with any significant changes in the intensity of the geomagnetic field [53]. On other occasions, however, he observed that one core recorded drastic intensity swings at the time, while in another core the intensity swung up and down and was often very low [54]. Data from lake Escondido (Argentina), combined with data stacks from other areas, showed a low intensity at 13,000-12,500 BP, which was not commented on [55]. Furthermore, throughout most of the late Pleistocene epoch the overall strength of the field was far lower than the current value, with the virtual axial dipole moment (VADM) generally remaining well below the current value of 7.78 x 10^{22} Am^2 [56] Moreover, the period 12,300-11,000

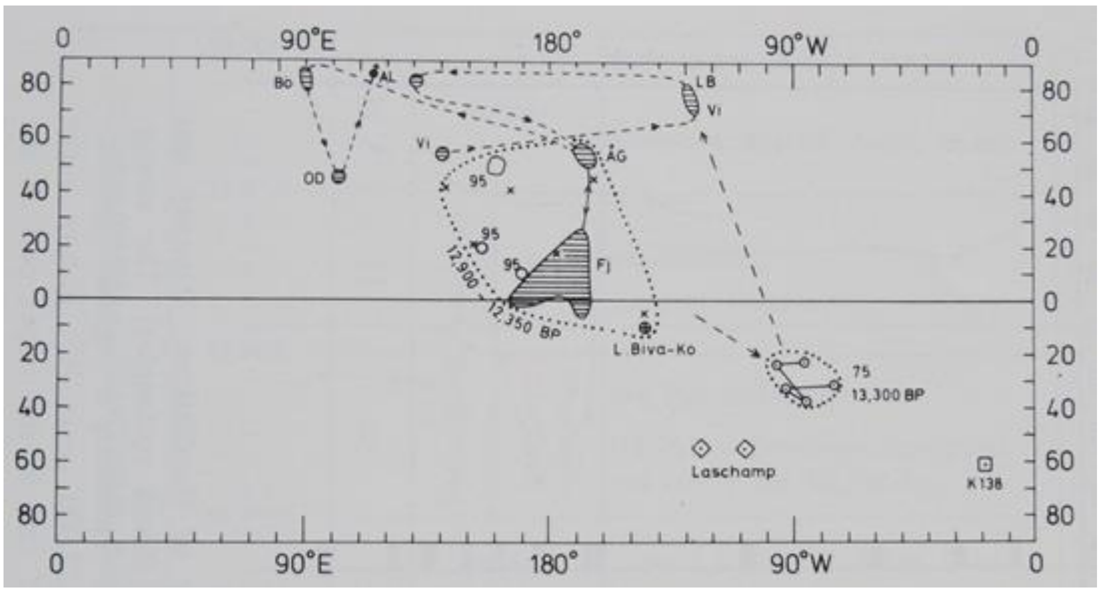

Fig. 3. Migrations of the virtual geomagnetic pole (VGP) from 13,750 BP to 11,500 BP

BP was associated with a series of spurts in the concentration of atmospheric radiocarbon [57] and radioactive beryllium [58], which exceeded any levels seen since. Such spurts are reliable diagnostic markers for geomagnetic reversals or excursions, changes in the strength of the heliomagnetic field or both [59].

The work of Mörner and others also suggests episodes of severe geomagnetic instability during the Younger Dryas and the early Holocene [60]. For his so-called Ornö Declination Departure (10,150 BP), Mörner calculated "a low-latitude

VGP in West Africa" [61]. This comports remarkably well with recent measurements taken by a different group at El Tingo (Ecuador), according to which "the majority of the reverse directions … conforms [*sic*] a patch located in southern Africa", while "a few ones [*sic*] are situated in central Africa, eastern Australia and Antarctica." [62]

Provided that it really occurred, the Gothenburg excursion emerges as a compelling candidate for the hypothesised geomagnetic event that sparked the intense aurora underlying central themes in global creation mythology [63]. As discussed earlier, the events of 'creation' that gave rise to visible intense-auroral columns must have lasted shorter than a few millennia, so that a chain of human generations would be able to string their experiences together into a single, coherent narrative; yet for the most part, any drifting magnetic poles must also have moved sufficiently slowly to give human witnesses with limited means of measuring time the impression that the columns were stationary and of a hoary antiquity. The Gothenburg excursion comfortably falls within the expected range of 200 to 2000 years. Myths concerning swift transpositions of *axes mundi*, which do exist in certain parts of the world, call for much more rapid incidents within this period, on a timescale of days to years. An actual magnetic flip with a short duration of 50 years or less, as envisioned by Mörner, might do justice to such themes.

The Gothenburg Excursion Disputed

Mörner has become an ostracised *bête noire* within academia, the Gothenburg excursion being only one bone of contention. Despite his life-long efforts to establish their reality, the Gothenburg excursion and flip remain mired in controversy – or perhaps not even that, as they are summarily dismissed by fellow palaeomagnetists. Results obtained by other groups that converged with Mörner's claims have met with a similar fate. In 1990, Russian specialists accepted the Gothenburg excursion as a palaeomagnetic reality, established with a high degree of confidence [64]. Nevertheless, others considered that the Gothenburg excursion has been "discredited" [65] or that "it is unlikely that the Gothenburg excursion actually occurred unless it was of very short duration, a circumstance probably in conflict with core dynamics. It is very unlikely that the Erieau excursion occurred." [66] Tellingly, the all-important qualifier "unless it was of very short duration" was omitted from the abstract of the latter paper [67]. Initial reports of freshly conducted fieldwork involving a limited set of samples from a few neighbouring sites often identify geomagnetic anomalies indicative of excursions, while meta-studies in the form of computerised mathematical modelling of large data sets tend to filter out such evidence.

What is unfortunate in the dismissal of the Gothenburg excursion is an apparent bias. This shows in an unwillingness to address the full spectrum of accumulated evidence and a tendency to trade concrete identification of specific errors of method or judgment for terse, sometimes condescending condemnations, coupled with cursory suggestions that large-scale computerised meta-analyses of data – in which excursions are not apparent for this period – produce more reliable results than small studies based on single sites. A recent refutation of the Gothenburg and other excursions amounted to no more than half a sentence of criticism:

> … some of these can be attributed to sedimentological and/or sampling artifacts: for example …, the Gothenburg 'flip' …, and the Lake Mungo excursion … [68]

As in the above case, opponents typically rebuke Mörner's or Noël & Tarling's original papers while ignoring the dozens of subsequent confirmative studies from places as diverse as Russia, China, Canada, Polynesia, the Pacific Ocean and South America and as recent as the present time of writing, insinuating that all scientists responsible for such work fail to grasp some of the methodological pitfalls in palaeomagnetic analysis. Yet despite private allegations to the contrary, neither naivety nor wishful thinking designed to woo the public with sensational discoveries can plausibly be cited against those accepting the Gothenburg excursion, as the responsible scientists are all qualified and credentialled, none of them amateurs, are virtually unknown to the popular media and are not known to have made any efforts to produce a popular book or documentary on the subject. In a world where 'New Age'-thinkers have done their utmost to exploit the idea of pole shifts, be they the rotational or the magnetic poles, these observations reinforce the impression of dispassionate sincerity.

With full appreciation of the complexity of palaeo- and archaeomagnetic analysis and due respect for the punctiliousness and diligence with which scientists handle this vexing discipline, the impression of a knee-jerk tendency to dispute each new piece of evidence for unstable geomagnetic conditions during the latest Pleistocene epoch with a limited arsenal of *ad hoc* objections foists itself all too easily on an unprejudiced reader. How many isolated cases of "sedimentological and/or sampling artifacts", "noise arising from the sampling procedures", "poor paleomagnetic 'recording'", "poor preservation of the core", "unsuitable palaeomagnetic conditions", "post-depositional disturbance such as sliding, slumping, bioturbation or compaction", "weathering" or "slumping rather than a real change in the magnetic field" and "fluctuations of climate" producing sediments that were "poor recorders of the direction of the ambient magnetic field" [69] will have to be assumed before sufficient critical momentum is reached to realise that a consistent pattern emerges from all over the globe? If the same intellectual rigour were applied to 'safe' measurements supporting a stable magnetic field, many such readings might equally need to be axed as untrustworthy. In view of the evidence amassed for unstable geomagnetism during the latest Pleistocene, perhaps it behooves naysayers to produce proof of cores with completely normal magnetism for this period from a large number of sites on different continents.

Absence of expected excursions in some cores has sometimes been taken as an argument against their existence [70]. It may also be objected that some purported records of the Gothenburg excursion seem to be of a different date, typically a later one, than the exact figures Mörner had specified. But are these objections necessarily damning? Was the search for alternative explanations exhaustive enough? Extremely rapid displacements of the magnetic poles – such as 'jerks', 'flips' and brief excursions – may fail to leave a 'remanent' magnetic imprint in rock or clay, escaping the radar of modern analysts entirely. Further, "paleomagnetic records of true excursions can be partially or completely obliterated or obscured due to rock magnetic viscosity, chemical changes during weathering, etc." [71] Chronometric challenges are another factor at play: "Most geomagnetic excursions have been recorded in lake or deep-sea sediments and it is extremely difficult to assess the reliability of ages assigned to them. The horizons are usually dated by assuming uniform sedimentation rates between or beyond ^{14}C dated horizons." [72] As Mörner & Lanser observed:

> Short events are only recorded occasionally in stratigraphical sequences, for example, during periods of rapid sedimentation, or if the record is continuous or samples are very closely spaced. If the chronology is not very exact, even these occasional records cannot usually be reliably correlated, making it difficult to distinguish between 'noise' and real events … [73]

In addition, excursions on a regional or continent-wide scale and ones with a time lapse between their respective expressions in different parts of the world, both mentioned earlier, might also explain why reliably dated anomalies found in some places may be absent elsewhere for the same period. Thus, some opine that excursions are "very difficult to document because they are brief (of order 10^2-10^3 years) and probably regional in nature." [74] Consequently, signals of excursions that are not matched at other locations for the same time period cannot be dismissed out of hand. Provided that sampling and analysing procedures were followed correctly, such cases may indicate non-global magnetic turbulence or rapid and short-lived displacements of the magnetic poles.

Even if the evidence remains fragmentary and controversial, the compilation of studies cited above for the first time seems to amount to a core of reliable indicators for profound and geologically short-lived alterations in the geomagnetic field during the Last Glacial Recession. The palaeomagnetism of the transitional period between the Pleistocene and the Holocene is a subject in constant flux, in which surprising discoveries continue to be made. Hence, it will be fair to conclude that the final word has not yet been said on the validity of the Gothenburg excursion. Indeed, in the wider science-historical scheme it is almost as if the extraordinary resistance of the geophysical community to the notion of any geomagnetic excursions within human memory, as opposed to those of greater antiquity, is a palaeomagnetist expression of the uniformitarian mindset, albeit it – to its credit – one with less overt mud-slinging than that displayed during the great debates surrounding, for example, the rôle of comets in the evolution of life or human history.

Non-Dipole Fluctuations – a Compromise

A synthesis between advocates and opponents of the Gothenburg excursion can probably be achieved. Bias alone is unlikely to be the sole cause of rejection. The history of science shows that when specialists – as opposed to amateurs – are quite firmly divided on an unresolved problem, the solution often turns out to be an unexpected compromise, reached not for political reasons, but because a shift to a wider perspective enables reconciliation of a kind rarely previously imagined. To the exasperation of critics, pro-excursionists have tended to blindly apply their calculations of VGPs to the geomagnetic dipole as they plotted geographic itineraries of the north or south magnetic poles on maps. However, such reconstructions "fail to correctly account for contributions from the non-dipole field and could therefore suffer from systematic errors …" [75] Though feeble, the non-dipole field appears to have been 'virtually' ignored in the analyses conducted by many practical experimenters.

The magnetism measured at any single location will depend on the counterpoise of field lines flowing through the area between different poles; most field lines terminate at one of the dipole components, but some connect with the minor poles. Any significant shift of the north or south magnetic pole may expose some locations, even at higher latitudes, to field lines associated with one of the minor poles, be it fleetingly or for a longer time.

The complexity of the intermediate field potentially resolves much of the 'excursional controversy'. Could it be that some of the anomalous signals reliably detected in palaeomagnetic data did not record the exact parameters of the dipole field, but were compromised by contributions from the multipole? In that case, sudden 'jumps' on plotted maps of VGPs will not always indicate movements of the north or south magnetic poles, but – due to counterpoise – may mean that a member of the multipole family was dominant for a time at the location from which the data were obtained. Pro-excursionists would be right in arguing that the anomalous directions or field strengths were not 'noise' generated by errors in sampling and analysis, but point to genuine irregularities in the field. Conversely, their critics would correctly observe that no actual excursion occurred, if the oscillation of the dipole members remained within 45º or 90º of the magnetic axis, depending on definitions. The compromise consists in the suggestion that the geomagnetic field was in a very early stage of an excursion, during which the dipole component was sufficiently weakened or displaced for some areas to come under momentary control of a minor pole. The effects of minor poles may often have been restricted to limited areas, so that chronostratigraphical discrepancies may sometimes be due to different minor poles prevailing locally at different times.

This insight may also explain the puzzling difference between plotted VGPs for what is supposedly the same geomagnetic excursion. "If nondipole fields were dominant, one should observe widely different VGP paths at the different sites …" [76] For the peak of a reversal, influences from the non-dipole field should strongly affect the calculated pole positions. Presumably, instances of this kind will meet the following criteria: anomalous values for magnetic variables occur consistently at a cluster of sites within the same region, but not globally; different areas may experience anomalies at the same time or a few decades or centuries apart from each other; the VGPs calculated for the irregularities can theoretically be resolved as the combined effects of all poles. In this vein, some of the 'noise' filtered out from large meta-analyses may be meaningfully explained without the need for actual excursions.

Reassuringly, proponents of the 'geocentric dipole tilt' model are exploring similar avenues of thought. They associate extremes in polar oscillation with "growing dipole moments" or "higher geomagnetic field intensities", but concede that unacknowledged contributions from the non-dipole part of the geomagnetic field may artificially boost the figures for the intensity. For example, referring to two other occasions than the Gothenburg excursion, they wrote that "it could also be argued that the high VADM values … are due to an inability to average out contributions from the equatorial dipole (i. e. the dipole tilt) and the non-dipole field. In favour of this argument, we note that alternative regional … or global … palaeomagnetic reconstructions show little or no change, or even negative peaks, during the same time period. … the larger amplitude variations in the record from western Eurasia are likely related to non-dipole field contributions." [77]

The data adduced in support of the Gothenburg excursion seem amenable to such an explanation, too. Mörner recognised as much in 1986:

> The fact that some records have a reversed inclination (with VGP in central equatorial Pacific) whilst others have a reversed declination (with VGP in eastern equatorial Africa) has, until recently, been puzzling. However, in a French set of cores the Gothenburg Flip consists of a rapid inclination flip immediately followed by a 180º declination switch. This means a rapid switch between two opposed equatorial VGP positions. This geometry and change is hard to explain in terms of mechanical disturbance or secondary processes; but is tempting to explain in terms of quadrupole forces. [78]

Accordingly, Mörner suggested that the Gothenburg excursion was an excursion of the type "sudden destruction of the dipole field into a quadrupole field" [79]. What he did not remark on is that some of the VGPs he detected coincide geographically with known minor poles; the ones in the mid-Pacific Ocean correspond to the central Pacific anomaly mentioned earlier, while the drifting African anomaly may represent the VGP he found indicated off the coast of West Africa. Nami observed that the VGPs across Africa, reported in South American and European data, are "coincident with the theoretical model … that beneath the South Atlantic Ocean, there is a 'reverse flux' patch which is a source of magnetic anomalies, particularly in Africa …" [80] And, according to another group, the return path of the VGP from northwest India towards Siberia, mentioned above, "should be attributed to the continued dominance throughout a large part of postglacial time of a different set of geomagnetic sources in the Great Lakes region on the one hand and in Europe on the other":

> Therefore geomagnetic field models with fixed but oscillating or pulsating nondipole field foci are to be preferred to models with drifting foci. [81]

That is to say, members of the multipole family appear to have dominated this period, thus accounting for discordant measurements at different locations. Presumably, the Canadian sediments in question were at the time controlled by the 'North American anomaly' discussed earlier. Meanwhile, cores from the Central Russian Upland suggested very different trajectories, focussed on northern Africa, the Atlantic Ocean and the Indian Ocean [82]. Pro-excursionists do not seem to address this problem, but solutions appear to be available. Unless the plots are erroneous or refer to different periods, it is perhaps conceivable that field lines over Russia registered influences from the West African anomaly, which is known to drift, or the Mongolian anomaly. At any rate, the unintentional agreement of VGPs calculated by Mörner and Creer's team with foci of the non-dipole field seems to vouch independently and quite powerfully for the reliability of their findings.

This revised take on palaeo- and archaeomagnetic data does not significantly affect the thesis developed here for the mythology of *axes mundi*, but – if anything – suits it even better. Direct accounts of the displacement of one or more columns are exceedingly rare in the traditions, an observation explained above by the assumption that intense-auroral columns associated with drifting poles must have moved at a slow pace almost imperceptible to human witnesses. The traditional sources are perfectly intelligible on the hypothesis that the movement of the north and south magnetic poles was limited for the most part to latitudes above 60º, while at lower latitudes auroral columns formed above prominent minor poles.

Consequently, it may be assumed at a minimum that considerable geomagnetic turbulence did indeed characterise the period associated with the Gothenburg excursion, including dwindling of the field, some modest displacement of the north and south magnetic poles and episodes of predominance of the minor poles. While a full-blown excursion may well have occurred and future research should be able to establish this unequivocally, it is not required for the multipole hypothesis of creation myths to work.

Finally, the 'polar columns' theory of myth is supported by an impressive array of climatological, geological, biological, sociological and psychological changes accompanying the geomagnetic crisis, but the extensive evidence for these is reserved for future discussion.

Summary

The field-aligned currents in the Earth's magnetosphere are responsible for the aurora. Using a plasma-physical approach, they can be modelled in terms of electron beams exhibiting various types of plasma instabilities. This understanding allows a compelling theoretical explanation for the collective human traditions concerning *axes mundi* or 'world axes' in the vagaries of the geomagnetic field at times of disruption. An episode during which the geomagnetic multipole prevailed over the dipole, such as the 'Gothenburg excursion' of 13,000-11,000 BP, may account for the apparent formation and morphology of multiple 'intense-auroral columns' in the upper atmosphere.

To further this interdisciplinary hypothesis, today's limited understanding of geomagnetic excursions is supplemented with Gold's scenario of solar superstorms compressing the Earth's magnetopause into the ionosphere. This would have resulted in a temporary transformation of ionospheric into telluric currents, featuring intense lightning-like discharges between the ionosphere and the surface, especially the magnetic poles. Plasma instabilities in hollow filamented beams and *z*-pinches, such as those studied by Bostick and Peratt, will have characterised these transformations of the aurora.

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Figures: sources

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