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1
variables of the geomagnetic field

fabled magnetic mountain

> There was no doubt that we were in the vicinity of a magnet, whose power produced these effects as terrible as they were natural.
>
> – Jeorling, in Jules Gabriel Verne, *Le Sphinx des glaces*[10]

The cosmic 'navel' (*omphalós*) and the world axis (*axis mundi*) are universal themes in traditional cosmologies. In some cases, these putative centres were identified with a known geographical location, such as Delphi (Greece); in others, they remained imaginary, mythical places.

The scientific discovery first made in Greece that the earth is spherical and has poles set in motion an intellectual trend to associate these traditional midpoints with the pole, one way or another.[11] Familiar local centres could be claimed by some contrived logic to be situated directly under the celestial pole or to have been so in the past, while ones as yet unlocalised could be fixed at the pole without special pleading. Some mythical entities without previous connotations of centrality, such as the sky-bearing giant Atlas of Greek myth, were also transferred to the astronomical axis.[12] Where this conceptual 'polarisation' happened, its timing varied from culture to culture but always followed exposure to Hellenistic or Western cosmology; generally, it preceded the first successful expeditions to the poles in 1909 and 1911, which put a definitive end to all such fancies (fig. 1).

It can be argued that the European science of magnetism was drawn into this broader process at the time of its budding in the Late Middle Ages. Since antiquity, rumours had circulated of perilous island-mountains composed of magnetic material that would pull the iron nails

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[10] Verne 1897: 435 (•).
[11] The spherical theory of the earth enabled others to identify the equator or the inaccessible core with equal rights as the centre of the earth or cosmos even without having reached these locations.
[12] van der Sluijs 2011b: 125-127, 129; 2019a: 148-149, 161, 165-170, 175, 178, 284, 305.

out of approaching ships.[13] In the 13th century, a tendency arose to locate such a magnetic insular mountain at the north geographical pole. The rationale must have been that only a giant magnet positioned in the far north could explain the north-pointing tendency of the freely suspended magnetised needle, which had been introduced to Europe not long before – probably in the late 12th century.[14] Before the scientific measurement of magnetic variables, when magnetic variation and dip angle were not yet observed, Europeans assumed that the magnetised iron needle points to true north, seeking the celestial pole more than the terrestrial one. The former was still regarded as the pivot around which the heavenly bodies completed actual revolutions, the earth being central and stationary. Because the celestial pole was not yet distinguished from the pole star (Polaris or α Ursae Minoris), the magnet's presumed orientation towards it could be regarded as validating the basic astrological principle of heavenly bodies governing earthly ones.[15]

The oldest surviving textual witness to the motif of the polar magnetic mountain is a love poem composed in an unknown year by the Italian Guido Guinizzelli (*c*1225-1276):

> In that part below the north wind
> are the mountains of the magnet,
> which give the air the virtue
> to draw iron; but because it is far away
> it wants to have help from a like stone,
> to make use of it
> so that the needle directs itself towards the star.[16]

One gathers that Guinizzelli supposed the magnetic mass at the geographical pole to be too remote to propel an iron object towards itself, but capable of at least making it turn towards the pole star directly above it in the sky with the help of a small magnet, which magnetises the needle. The poet seems to have stood at the crossroads of one of the earliest advances in the study of geomagnetism: the realisation that the

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[13] *e.g.*, Ptolemy, *Geography*, 7. 2. 31, trs. Stückelberger & Graßhoff 2017: 730-731, where the magnetic stone is called 'Herakles' stone' (*Hērakleías líthou*), *cf.* Pliny the Elder, *Natural History*, 2. 98 (211); 36. 25 (127). See further Yamamoto 2018: 317-325.

[14] Yamamoto 2018: 325.

[15] Yamamoto 2018: 135, 164, 186-194.

[16] Guido Guinizzelli, *Madonna, il fino amor* (*My Lady, the Fine Love*), 49-55, ed. Contini 1960: 455 (•). Modernised Italian spelling was used in the version in anonymous 1828: 119. Turner (2010: 14) cited the translation given by Benjamin (1898: 155), but although this conveyed the spirit it was too fanciful. 'Virtue' means 'force' in historical contexts of physics.

Attracting little to no interest at first, this theoretical foundation stone lay long forgotten; the breakthrough occurred only in the wake of two 19th-century developments, when methods of scientific analysis were more advanced and the birth of systematic archaeology from earlier antiquarian interests created great potential for the discovery. During the 1860s, Silvestro Gherardi (1802-1879), who was an Italian physicist, independently proved that some archaeological objects, notably bricks, can acquire magnetisation upon heating and subsequent cooling, which they then preserve in a stable state – so-called 'remanent magnetism'.[142] A few decades later, his younger compatriot and colleague Giuseppe Folgheraiter (1856-1913; fig. 26) realised that the orientations of this immanent magnetism can then be used to determine the geomagnetic field at the times the objects were fired, known from the archaeological contexts, and so establish a chronological reconstruction of the field's history.[143]

For earlier periods than the time span covered by archaeological finds, *palaeomagnetists* analyse crustal rocks, including cooled volcanic lava flows on land, mostly consisting of basalt, and sequences of consolidated sediments on the floors of lakes and oceans; the latter provide continuous data sets, often over long periods of time. The inception of palaeomagnetic research proper is usually credited to the French geologist Achille Delesse (1817-1881), beginning in 1849.[144]

Well before that, in 1753, the Italian physicist Giovanni Battista Beccaria (1716-1781) had first suggested that lightning strikes can produce magnetism in objects that diverges from the ambient magnetism:

> Not only the iron objects, but all bodies susceptible to the magnetic virtue I find to be magnetised by lightning. I already spoke to you about the piece of brick magnetised by lightning, which struck in this Tower of Asinelli. ... This brick now is magnetised, and has its poles, or rather two series of poles, southern and northern ones ...[145]

On a later occasion, he wrote to a correspondent:

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[142] Turner 2010: 153; Principe & Malfatti 2020: 308, 313-316.
[143] Folgheraiter 1896a-e; 1897a-b; 1899; *cf.* Principe & Malfatti 2020: 305-306, 319-328, 330; Turner 2010: 152-153; Courtillot & Le Mouël 2007: 11, 19; Oddone 1914: 74-84; Brunhes 1906: 705-706.
[144] Turner 2010: 152; Courtillot & Le Mouël 2007: 18.
[145] Giovanni B. Beccaria to Charles Emmanuel III (1701-1773), king of Sardinia, ed. Beccaria 1758 (1753): 260-261 (•), *cf.* 262; 1772: 305, tr. 1776: 307. These observations are absent from Beccaria 1753.

> I will add this, what I have observed in Iceland with these eyes, that this meteor certainly does not always present a spectacle in the way of the leader of a dance, but in a continuous brightness, sometimes an enemy even to itself, repeatedly batters itself with a great and terrible force; I was very little, but I remember that men, too, were aghast at its ferocious appearance.[260]

This was just before the Maunder Minimum (*c*1645-*c*1715) set in, during which auroral activity waned. Elsewhere, individual death was especially feared as the outcome of exposure to the aurora. Equalaq (fig. 38), an old Inuit woman from Churchill (Manitoba), evinced the former conviction of her nation that the aurora is able to kill people:

> ... a long time ago they used to believe it, but the younger people nowadays don't believe it ... even the older people like me don't believe it anymore ... but it's true.[261]

Another Inuit lady, from Nunavut, expressed similar embarrassment about the belief she had come to view as childish:

> When we were children ... I used to see different coloured *aqsarniit* – some were bright pink in colour. I had heard it said that the *aqsarniit* cut peoples' heads off. I tended to believe this because I was also aware of the saying that the *aqsarniit* used walrus heads for footballs, and so I was scared of them! I think it has something to do with the speed they go at: if they touch your head then it will be cut off. Although I never heard of anyone losing their head because of the *aqsarniit*, they still feel frightening.
>
> The other thing was that when we whistled at them they would make swishing sounds and would pick up speed. Seeing this made me really terrified thinking that they would indeed cut off my head. Of course that was a child's way of thinking about them. It was at Avvajjaq, when we used to play outside a lot, dressed in our caribou-skin clothing.[262]

The Iñupiat of North Slope Borough (northern Alaska) perceived the same threat in the northern lights: "The knife also serves as a protection against the aurora, which most of them agree is bad, and when bright

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[260] Torfaeus 1715 (1706): 103-104 (•). The term 'meteor' was long used in the classical sense of any luminous atmospheric phenomenon.
[261] Equalaq, recorded 1972 at Churchill, in Eather 1980: 107 figure, left part.
[262] Catherine Aaluluuk Arnatsiaq, of the Amitturmiut, recorded January 1990 at Igloolik, in MacDonald 1998: 149, 151. Avvajjaq is a small island near Igloolik.

6
primordial 'spots'

Although most of the studies cited above were not concerned with events within human memory, there is no theoretical reason why their results could not also apply to geologically recent occasions and thus be potentially reflected in ancient traditions.

One prominent theme in creation mythology on which geomagnetic excursions may shed light is that of one or more relatively small stable structures in the fledgling cosmos – often rounded and variously located in the sky, on the earth or in an indeterminate place around which the earth is to be formed. These 'spots' were frequently regarded as the first discrete form of matter, the locus of beginnings and the only source of light then available. Luminous or not, each was typically portrayed as a primordial particle, speck, blob, cone, disc, spiral or enclosure, metaphorically described as a solitary deity, a sun, a rock, a seed, a heart, the first land, an island, a mound, an egg, a shell, a chest, a womb, a serpent and so forth (§§2, 13-29, 31-32, 46, 48-51, 64, 67-69, 93-94).[449]

Traditions of this type could have referred to auroral rings, crescents or discs surrounding magnetic poles. In addition to wandering north and south geomagnetic poles, perhaps the minor poles developed such features, too, upon acquiring enough magnetic intensity. As noted, if these auroral foci possessed a much smaller true or apparent diameter than today's ovals, human witnesses could have perceived them in their entirety as complete circles or ovals.

polar-cap aurorae

To bring some order into the bewildering variety of metaphors used in myth for the primordial 'spots', it will help to take a closer look at the types of aurorae that occur inside the auroral ovals. Under ordinary circumstances, visible aurorae are almost completely confined to the discrete auroral ovals and are produced by the precipitation of both electrons and protons, with high-energy electrons dominating on the nightside. But aside from the ovals, the polar caps they encircle host

[449] See van der Sluijs 2019a: 290-291.

> ... when God commanded, a tree arose from the water and began to grow, but the devil's pine would not stand erect but tottered from one side to the other.[550]

In the fog and the first land or island of these traditions, one recognises the primordial 'spot'; the darkness will be investigated below (pp. 146-154). In myth, all such dynamic behaviour – including the other categories – does not derogate from the overall apparent immobility of each column. Indeed, it could well have contributed to the belief that the column was alive (§§146-147).

A stationary position to a human observer is natural for poles belonging to the standing part of the geomagnetic field, but also places a constraint on the rapidity with which drifting poles and their correlated aurorae may move in the course of excursions.

Supposing that a column would move at a constant rate of 0.08° of latitude or 8.88 km on the surface each year, equalling 4° or 444 km in a human lifespan of 50 years, a complete migration from the rotational pole to the equator and back would last 2250 years. This figure is compatible with the estimated duration of a 'classic' excursion, ranging from perhaps 200 to 5000 years – 10,000 at the very most. When viewed from a considerable distance, the shift might escape the attention of an individual observer or community. At the much higher historical rates of 0.18° to 0.7° of latitude per year calculated for the westward or eastward drift of minor poles,[551] which need not be constant at all, a human being would observe a drift of 9° to 35° or 999 to 3885 km on the surface in 50 years. This might still be just about slow enough, from certain angles, to sustain an impression of near-fixation should one of these drifting poles facilitate a columnar aurora viewed from far away. Applying the rate recently determined for the Laschamps excursion (40,000 BP), of "half a degree in latitude per year during the transitional phase between the clear normal (N) polarity ... and the clear reversed (R) polarity",[552] someone living in the same place for 50 years could see an auroral focus move over the distance of 25° of latitude or 2775 km on the surface. Poles of both types may, therefore, have contributed to the mythical image of stationary columns.

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[550] Spassky 1822: 33-34 (135-136), paraphrased in Holmberg 1927: 329.
[551] Lowrie 2007: 314; Pesonen *et al.* 1994: 65.
[552] "The whole duration of these complex directional variations lasted [*sic*] some 3000 yr ..., with about a total of 1200 yr characterized by transitional directions ..." Nowaczyk *et al.* 2012: 63, *cf.* 68.

Münkü (Mato Grosso, Brazil), 'a smoky mist' is released and apparently produces a sort of lasting twilight – a direct succession of dawn and dusk – at a time when all people live in a rock and the sun does not yet shine.[642] According to the Marind (southeastern Papua, Indonesia), such limited light was restricted to what would be the 'day', in the time when the sun (*Katané*) was still living towards the west 'in a deep pit under the earth' (§§430, 435):

> So it was that there was neither light nor warmth at that time, only a faint twilight differentiated day from night.[643]

The sun in this last tale reminds one of that in the |Xam myth cited above (pp. 146-147) and, like that, may or may not have been a primordial 'spot'. Widely reported, too, is an age prior to the regular alternation of day and night in which periods of light and darkness followed each other, but were of unpredictable, erratic lengths.[644]

Some sources link the fledgling light to the 'low sky'. For example, traditional writings of the Nakhi people (northwestern Yúnnán, south-central China) associate a greenish hue with the sky when it was still close to or mixed with the earth, which was unsteady (§32). One version, the details of which are hard to fathom, reads:

> In ancient times, when the sky and the earth were in primal chaos, ... there appeared a beautiful sound above, from underneath beautiful air appeared. Those two changed and a bright sky, which looked like green turquoise, appeared. The bright sky changed and a beautiful voice that could shout appeared. ...
>
> The turquoise green *Zibubanyu*-sky was not clean. The sky changed. ... The black and very brilliant turquoise changed into a dark sky ...[645]

Another version, not much more lucid, appears to claim that greenness was applied to the sky with some difficulty, at a time when the sky was still too close for comfort and before the sun and moon were in it to produce the regular alternation of day and night:

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642 recorded December 1959 - February 1960, in de Moura 1960: 46 (•).
643 recorded 1920-1925, in Wirz 1925: 76 (•).
644 van der Sluijs 2018a: 65-71.
645 Nakhi manuscript 1946.34.12, Hanna Asp Collection, National Museum of Ethnography, Stockholm (Sweden), tr. Anna Fäldt, in Fäldt 2001: 87-90. The manuscript was probably authored by Ä-dzhi, a *dongba* or priest from Chángshuǐ, west of Lìjiāng.

between the traditional poles of uniformitarianism and catastrophism, linking ancient conceptions to stunning but non-violent and only moderately rare phenomena.[706]

Astute though it may have been of d'Ortous de Mairan and his few late followers to equate Olympian or Semitic gods with auroral apparitions of familiar types, an even bolder suggestion is put forward here – that the traditional sanctity of some spots, including mountains, traced to auroral activity that actually played out above them at times of severe geomagnetic instability. If the scenes of observed lightning strikes and lithoplasma were tabooed or sacralised, should not those of 'intense aurorae' in the setting of a geomagnetic excursion have been so *a fortiori*? Could the intense aurorae of a hoary past, including polar 'spots' and columns, have constituted just another category of transient light phenomena tied to cult sites, be they man-made monuments or natural features such as mountain peaks?

It was already noted above (pp. 101-102, 120) that traditional societies widely perceived primordial 'spots' and columns in the sky as cosmic 'navels' or 'centres' – hallowed spots deemed to facilitate communication between heaven and earth or between immortals and mortals, where the 'creation' of the world had taken its origin. Such *omphaloí* were frequently situated in the local landscape, with or without an obvious geological landmark (§134), on grounds that elude scholars. Perhaps some acquired their status because they were formerly crowned or thought to have been crowned by imposing auroral rings, crescents, discs or columns, which unbeknownst to the viewers manifested above magnetic poles. Did any of the places traditionally identified as an *axis mundi*, such as Delphi (Greece), Mount Zion (Israel), Mount Kailāśā (Tibet; fig. 72), the region of Mount Belukha in the Altai range (fig. 73; southwest Siberia) or – wherever it was located exactly – Mount Kūnlún (northwest China), perchance correspond to locations that were electromagnetically active during geomagnetic excursions?

As seen (pp. 45-47), much of the structure of the non-dipole geomagnetic field is thought to remain stationary over time, changing in magnitude only, on timescales of decades to centuries. Perhaps such stable minor poles were in the same positions as they are now even during reversals and excursions. Intriguingly, the location of the 'Mongolian anomaly' (figs. 19-23), a standing part of the non-dipole field, corre-

[706] In van der Sluijs 2019a: 73, the perhaps unwieldy term 'ephnidiontomythology' was suggested for the study of transient but not necessarily dangerous natural events in myth.

17
the Gothenburg excursion

> … given time, the rare event becomes a probability and given enough time, it becomes a certainty.
>
> – Derek Victor Ager, *The Nature of the Stratigraphical Record*[792]

Since the 1970s, a large number of palaeomagnetists have adduced evidence for a geomagnetic excursion associated with the very tail end of the last glacial period. Before this can be reviewed, a few words need to be said regarding the complex chronological framework in which it is set.

In geological terms, the earth has been in an ice age for the past 2,580,000 years – the so-called 'Quaternary glaciation' or 'Pleistocene glaciation'.[793] Ice ages are divided into successions of glacial and interglacial periods. The Last Glacial Period (LGP) preceding the current interglacial period roughly corresponds to the final part of the Pleistocene epoch – the Tarantian stage or Upper Pleistocene (126,000-10,000 BP). Towards the end of this period, between 22,000 and 18,500 BP, occurred the Tardiglacial, Late Glacial or Last Glacial Maximum (LGM), when the ice cover reached its maximum extent (fig. 86). The ensuing millennia (18,500-10,000 BP), during which the earth tended to warm up and the ice to retreat, are variously referred to as the Tardiglacial, Late Glacial or Last Glacial Recession or the Last Glacial-Interglacial Transition (LGIT).[794] The events in the discussion below all relate to the latter period.

This most recent process of deglaciation was not uniform, but involved repeated swings in climate. Accordingly, the Last Glacial Recession is subdivided into alternating periods of lower temperatures, called stadials, and higher temperatures, called interstadials. 'Heinrich events' are episodes for which the cores retrieved from ocean sediments show a high concentration of rock grains of continental origin and low levels of plankton shells. This is usually taken to indicate that armadas of icebergs

[792] Ager 1993: 75.
[793] Krüger (2013) provided an excellent overview of the early history of ice-age theory.
[794] A similar term, the Last Glacial Termination, is sometimes extended from 20,000 to 8000 BP, into the Holocene epoch.

end of the Oldest Dryas. Perhaps in other parts of the world the same geomagnetic event – if it even occurred at the same absolute time – fell at the very end of the Bølling or during the Older Dryas. Some workers distinguish between the Bølling *sensu lato* and the Bølling *sensu stricto*, the former of which includes years that other stratigraphers treat as precedent to the Bølling.

In the system followed here, Mörner's dates are maintained for the Gothenburg excursion in northern Europe, but assigned to different stratigraphic zones. The stage of anomalous but generally normal magnetism begins during Heinrich event 1 and lasts throughout the Oldest Dryas and the Bølling oscillation. The flip occurs within the colder interval of the Older Dryas in areas in northwestern Europe where the Older Dryas is discernible, but within the Bølling and perhaps even the Oldest Dryas elsewhere. Finally, during the recovery stage the north geomagnetic pole migrates back towards the northeast for more than a millennium, until 10,950 BP – the end of the Allerød oscillation.[809]

Mörner supplemented the results of his own fieldwork with copious evidence for the Gothenburg excursion from the work of peers (fig. 89). Supportive palaeo- and archaeomagnetic studies have continued to pour in since. This wealth of data has never heretofore been collated. A selection, the most complete published to date, is tabulated below. As with the Solovki excursion, entries that identify the Gothenburg excursion expressly are listed alongside less explicit evidence for an excursion in the relevant time frame.

Table 3. Select palaeo- and archaeomagnetic evidence for the Gothenburg excursion (14,800-11,000 BP).

	site:	**core(s):**	**date(s):**	**observations:**
•	Botanical Garden, Göteborg, Sweden (57°41′6″ N, 11°57′18″ E) (figs. 90-92)	B873 (layers ?-14)	13,750-12,400 BP	"a millennium of irregular (but not fully reversed) magnetism"[810]
		(layers 13-12)	12,400-12,350 BP	"polarity ... was reversed through 180°",[811] "reversely magnetized",[812] "a fully reversed position at 50-70° S [*sic*]",[813] "generally

[809] Mörner 1976a: 241; Mörner & Lanser 1975: 122.
[810] Mörner & Lanser 1974: 408; *cf.* Mörner 1976b: 252 figure 16. 4; 1977b: 413.
[811] Mörner *et al.* 1971: 173, *cf.* 174.
[812] Hospers *et al.* 1973: 122 (*cf.* 125) = 1976: 235 (*cf.* 240).
[813] Mörner 1976a: 240.

Certainly, the observations on Uranus support the expectation expressed earlier (p. 94) that aurorae will still focus above magnetic poles if the latter are heavily inclined relative to the rotational axis. Uranus' "bright spots of activity" bring to mind the compact patches or enclosures associated in myth with the early stages of 'creation', often stationary, luminous and preceding the formation of cosmic axes, which were explained as a combination of auroral rings and polar-cap aurorae.[1138]

Venus

A second instructive 'space laboratory' of auroral distribution is Venus. Atomic oxygen dominates Venus' neutral atmosphere at altitudes between 140 and 190 km,[1139] thus creating the potential for auroral light similar to that of the earth. However, the current system is rather different. Venus' intrinsic magnetic field, which is a dipole field, is of negligible strength compared to that of the earth.[1140] Therefore, "the atmosphere exerts an overwhelming control over plasma and magnetic structures. This is a special and perhaps unique condition in the solar system."[1141] The solar wind interacts directly with Venus' ionosphere, without the intervention of a dipolar magnetosphere to speak of. This interaction induces a magnetic field with a non-dipolar morphology.[1142] Consequently, Venerian aurorae are not expected to form along rings in the vicinity of the rotational poles, but wherever Venus' induced magnetic field guides electrons flowing in from the solar wind:

> The draping of solar wind magnetic field lines passing the obstacle of Venus is thought to be the mechanism by which those electrons are channeled into the Venusian atmosphere.[1143]

[1138] The structure of Uranus' magnetosphere is complicated further by the passage of the planet's moons through it: "The large tilt of the magnetic dipole axis leads to a dynamic situation in which the moons traverse a wide range of magnetic latitudes and longitudes. In so doing, the moons can effectively sweep up the trapped energetic particles from the magnetosphere. ... The moons sweep through the magnetosphere in a complex way and can absorb radiation belt particles ..., creating a dynamic magnetospheric structure." Ness *et al.* 1986: 87. This condition is less applicable to a terrestrial situation, as the earth's moon orbits well above the bulk of the magnetosphere, crossing only the magnetotail once a month, whereas Uranus' largest moons reside permanently inside that planet's magnetosphere.

[1139] Phillips *et al.* 1986: 1048.

[1140] *e.g.*, Breuer & Moore 2009: 324; Singhal 2009: 47.

[1141] Siscoe 1979: 325.

[1142] Birk *et al.* 2004: L15, L17; Hartle & Grebowsky 1995: 117.

[1143] Slanger *et al.* 2008: 291; *cf.* Price 2000: 122.

Pupin

It will be recalled (p. 296) that von Reichenbach created a thin envelope of light around his terrella, which he called a 'photosphere'. He only did so in passing and nothing suggests that he ever consciously regarded the instrument as a suitable model for the sun. To do that, and thereby turn the terrella into a solculus, may have been an innovation on the part of the Serbian-American physicist and chemist Mihajlo Idvorski Pupin (1858-1935).

Pupin's device consisted of a brass sphere, serving as one electrode, placed inside a large glass bulb coated with tinfoil and wired so that it could serve as the other electrode (fig. 127). This could be the earliest instance of a terrella, or rather a solculus, completely immersed in the vacuum of a surrounding chamber, as opposed to the older practices of vacua produced inside a terrella or only over the poles of one.

In 1892, Pupin reported that a series of 'coronoidal electrical discharges' he had produced with this apparatus, using a poor vacuum at "various degrees of rarification", "resemble in many characteristic details the appearance and behavior of the solar corona" (fig. 128):

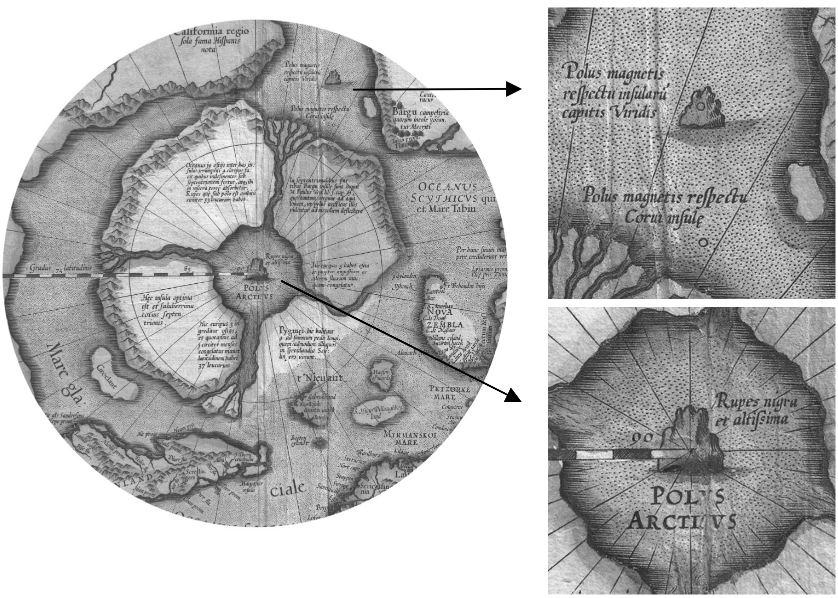
> All these phenomena suggested to my mind a very strong similarity between the streamers of an electrical discharge through poor vacua and those of the solar corona ...[1345]

The discharge started "in the form of four large streamers, together with a very large number of short luminous jets which were more or less uniformly distributed over the sphere" and "rotated rapidly."[1346] This result reminded Pupin of the granular structure seen on the sun, while "luminous spots" which "appeared from time to time at several points of the surface" resembled the sun's faculae. These are the bright spots in the photosphere formed by concentrations of magnetic field lines in the canyons between the granules. Often appearing in conjunction with sunspots, they are brighter, smaller and more short-lived than them. One "discharge between the brass sphere and the tinfoil ... looked like a black-faced Medusa with fiery serpents dancing all around her head."[1347]

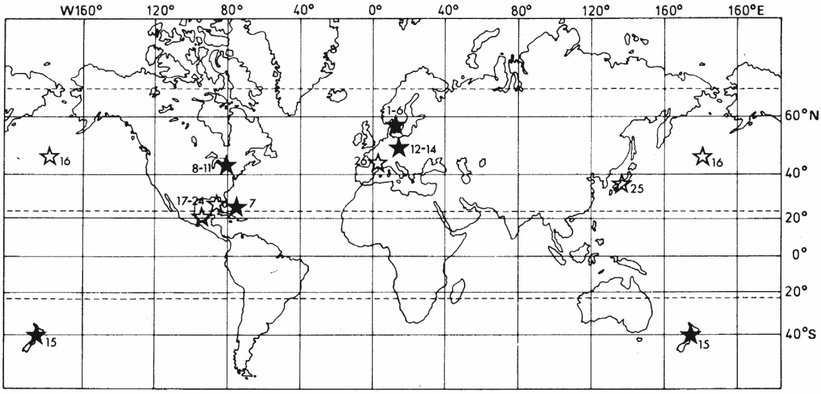
[1345] Pupin 1892a: 482/483 figures 1 to 6, 483, 495.
[1346] Pupin 1892a: 492.
[1347] Pupin 1892a: 495.

1901-1913	Birkeland	two circumpolar rings (auroral ovals); point discharges (sunspots), which can be the focus of 'stars' with straight or vortical arms (solar prominences; spiral nebulae) and of 'pencils', including polar ones and spherically radial ones (solar prominences; 'cathode rays'); polar cones; equatorial ring, possibly rayed (Saturn's rings); equatorial plane of rays (zodiacal light); corona (solar corona); spherical striation (cometary comae); with much attention to degree of magnetisation, strength of electric current, quality of vacuum, and diode polarity	brass, aluminium	electro-magnetic
1946	Malmfors	electrodes on opposite sides of the sphere (charge separation at Earth's morning and evening sides); ionisation (Earth's ionosphere); circumpolar rings (auroral ovals); arcs; equatorial bright spots; polar rays	magnetised steel	electro-magnetic
1955-1958	Block	electrodes on opposite sides of the sphere (charge separation at Earth's morning and evening sides); ionisation (Earth's ionosphere); hemispherical 'corona' transitioning to paired eccentric circumpolar rings (auroral ovals) with increasing magnetism and stable Voltage; bright spots	?	electro-magnetic
1965	Hänsel	various electrode arrangements; a spectrum from multiple 'auroral zones' to an equatorial ring on an unmagnetised sphere	fluxball	electro-magnetic
1967	Quinn & Fiorito	plasma-physical terminology; equatorial belt; arcs, usually transequatorial; polar streamers; latitudinal and intensity variation with Voltage and pressure; fixed magnetism	Alnico 5	electro-magnetic

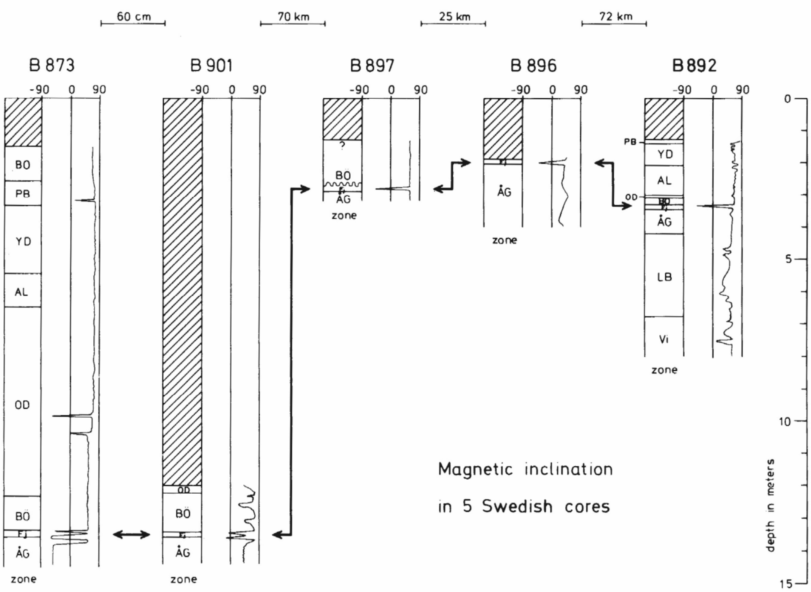
3. Geert **Kremer** (Gerardus **Mercator**; 1512-1594), indicating the position of the magnetic pole on a globe: the magnetic pole is offset from the geographical pole. *Engraved by Frans Hogenberg (1535-1590) in 1574.*



4. Detail from Kremer's map of the Arctic (1595), showing two possible locations of the magnetic pole not far from each other, based on measured meridians of zero declination. The captions read *Polus magnetis respectu insularũ capitis Viridis* (*Magnet's pole with respect to the islands of Cape Verde*) and *Polus magnetis respectu Corui insulę* (*Magnet's pole with respect to the island of Corvo*). Kremer regarded the former, depicted as a mountain, to be the correct one. A *Rupes nigra et altissima* ('black and very high Rock'), not explicitly designated as magnetic, occupies the geographical pole, surrounded by four large islands, as described by the anonymous 14th-century English Franciscan friar. *Cropped from the 1620 edition produced by Joost de Hondt (Iudocus Hondius; 1563-1612). An earlier, almost identical version appeared as an inset in Kremer's world map of 1569.*



89. Localities at which the Gothenburg flip was established and well dated (black stars) or tentatively recognised (open stars), as of 1974. The tentative identifications for Lake Biwa (25) and the Laschamps excursion (26) have since been assigned much earlier dates, while that for New Zealand (15) has been refuted (Sukroo *et al.* 1978). 1-6: six Swedish cores; 7: deep-sea core A179-15; 8-11: four Canadian clay sections; 12-14: three Czechoslovakian löss sections; 15: the Okupata Tephra on North Island, New Zealand; 16: deep-sea core V20-108 from the northern Pacific; 17-24: eight deep-sea cores from the Gulf of Mexico. *Courtesy Nils-Axel Mörner (1938-2020).*



92. Zonation and magnetic inclination of the Swedish cores B873, B901, B897, B896 and B892, with at the top the distances between the cores. The Gothenburg excursion is indicated by the arrows. Hatched areas represent parts of the cores that were not analysed. 'ÅG' = Ågård, 'Fj' = 'Fjärås', 'BÖ' = 'Bølling', 'OD' = 'Older Dryas', 'AL' = 'Allerød', 'YD' = 'Younger Dryas', 'PB' = 'Preboreal', 'BO' = 'Boreal'. *Courtesy Nils-Axel Mörner (1938-2020).*

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