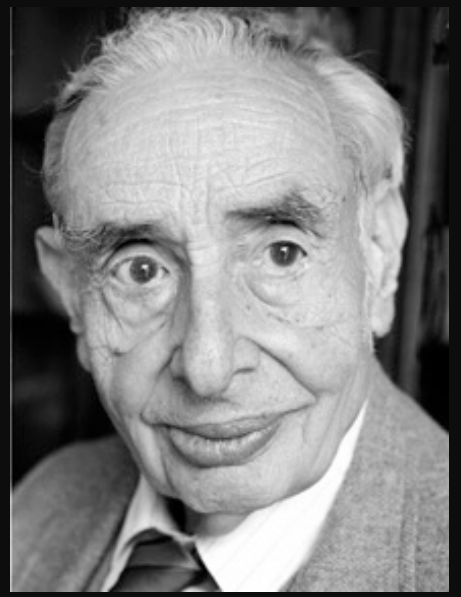
The Earth’s magnetic field

Contents

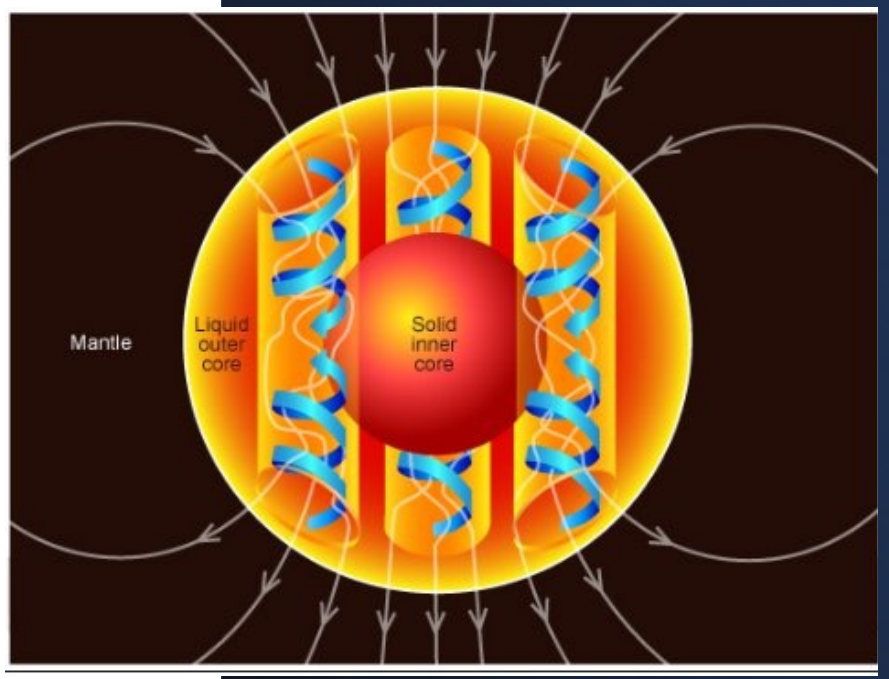
History

- (1600) William Gilbert (de Magnete): the Earth is magnetic, originates from permanent magnetism, the internal part of the Earth is made out of iron
- (1832) Carl Friedrich Gauss: was the first who made observatory recording of the magnetic field
- (1919) Joseph Larmor: a dynamo is generating the magnetic field
- Patrick Blackett: searched relation between the angular and magnetic moments of the Earth, but found nothing
- (1945-47) Walter M. Elsasser: proposed the presently accepted dynamo theory, magnetic field is resulted from electric current induced in the outer core of the Earth



Dynamo theory

- Three requisities for the dynamo to operate
  - Electrically conductive fluid medium
  - Kinetic energy provided by planetary rotation
  - Internal energy source, to drive convective motions within the fluid
- the outer core contains conducting metal in liquid state (mainly iron)
- Convection is caused by the heat difference between the solid inner core and the core-mantle boundary
- The convection is deflected by the Coriolis-effect, therefore the flow organizes to columns
- The stream of the conducting matter produce the poloidal magnetic field

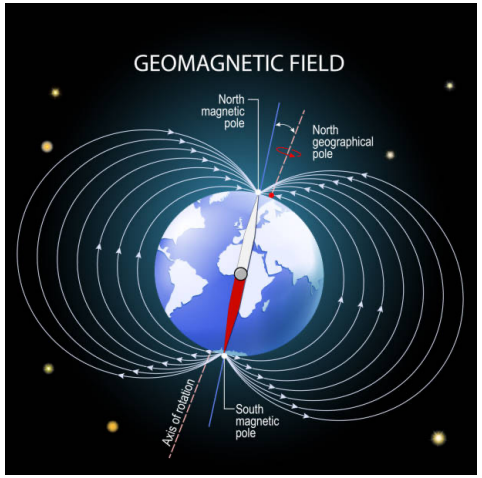


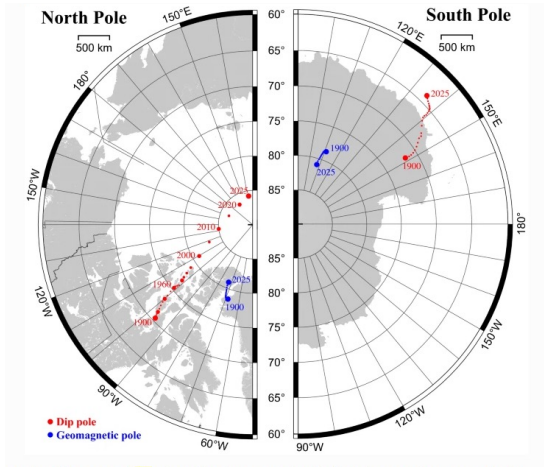
Time evolution of the magnetic field

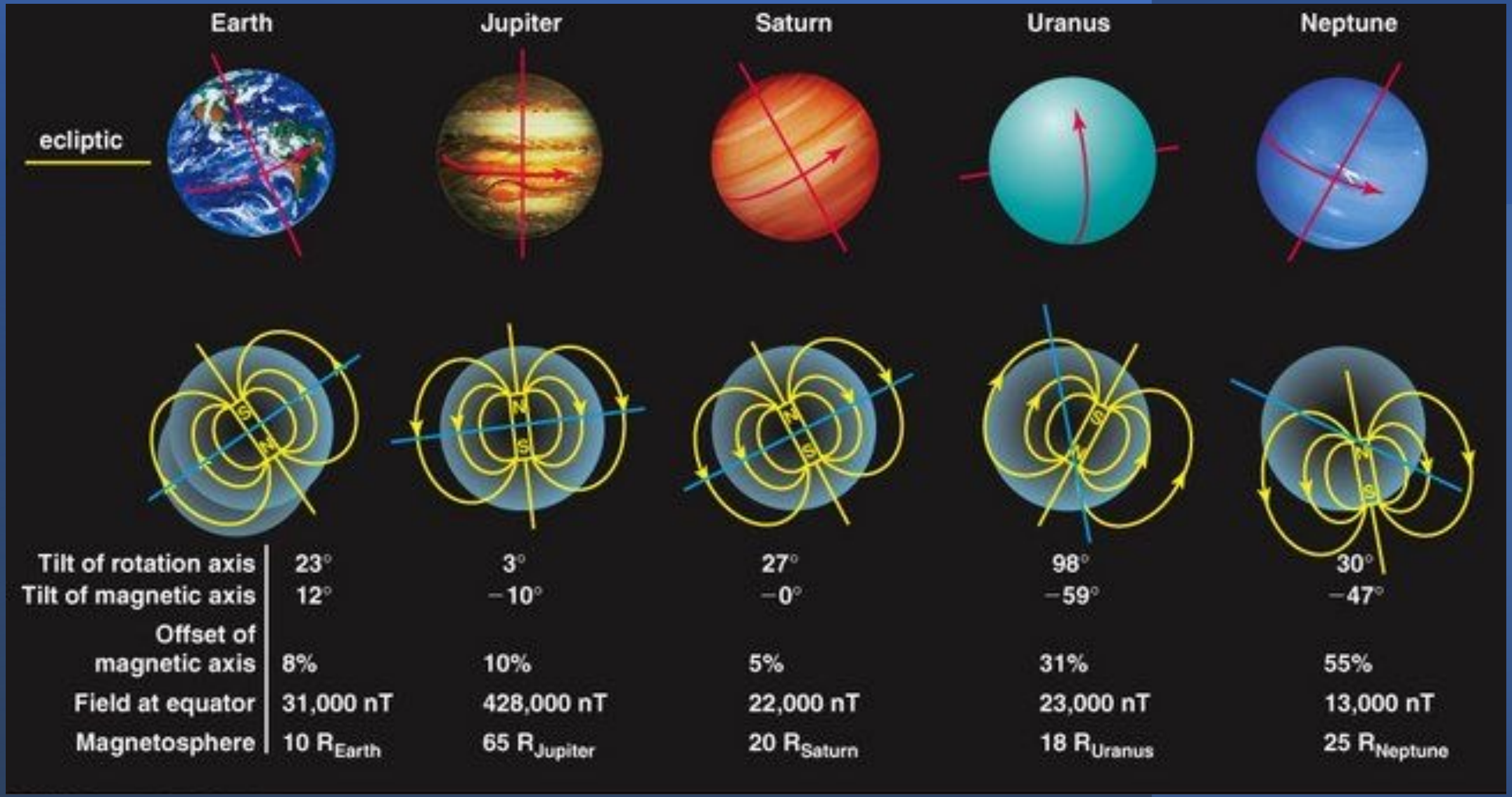
- The induction equation:
- $\frac{\partial \mathbf{B}}{\partial t} = \eta \nabla^2 \mathbf{B} + \nabla \times (\mathbf{u} \times \mathbf{B})$
- $\eta = \frac{1}{\sigma \mu}$ — magnetic diffusivity
- Magnetic Reynolds number: $\mathrm{R_m} \sim \frac{\mathrm{induction}}{\mathrm{diffusion}}$
- For a functioning geodynamo: $R_m > 40$
- Magnitude of the magnetic field on the surface is ranges between 25 and 65 μT (or 0,25-0,65 G (gauss)), for comparison a fridge magnet is about 10 000 μT

Shape of the magnetic field

- The magnetic field of the Earth is approximated by a magnetic dipole
- Therefore, the simplest way to represent the magnetic field is to imagine it as a bar magnet at the center of the Earth
- But the north and the south poles do not align with the rotational axis, so the magnetic axis is tilted at an angle of about 11°, but it is continuously changing
- If we investigate further, we can find out, that is the dipole is not Earth centred, so the magnetic north- and south poles are not exactly on the opposite sides of the Earth



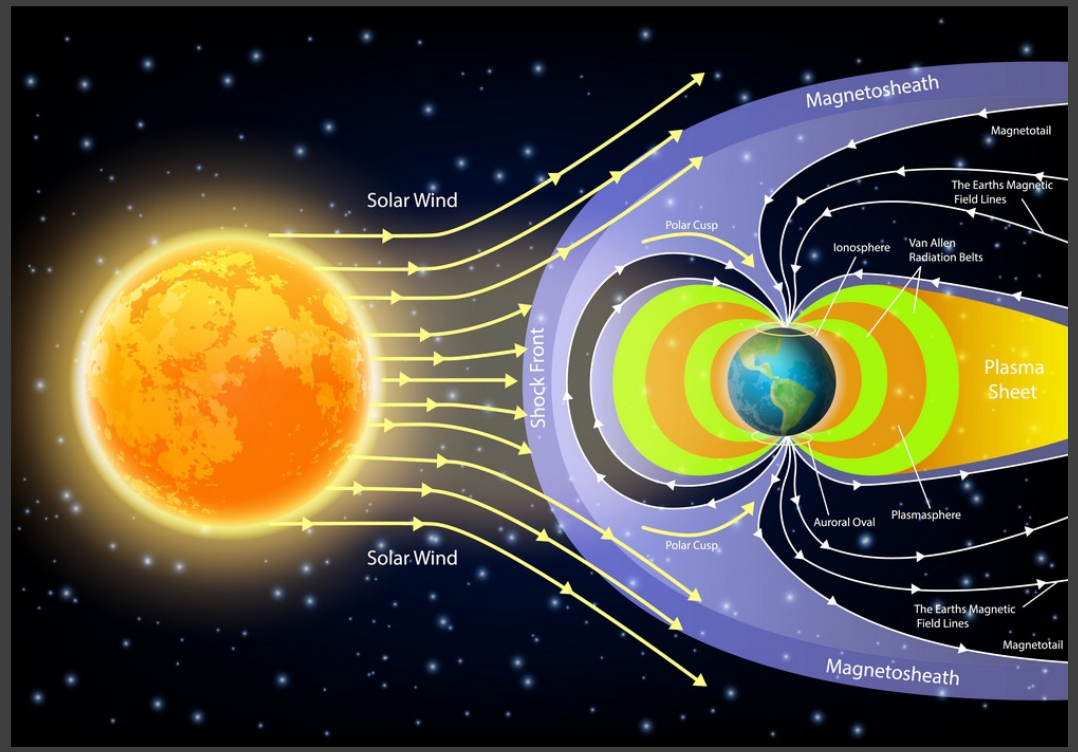




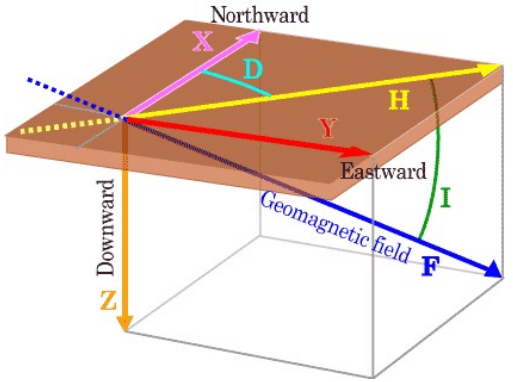
	Earth	Jupiter	Saturn	Uranus	Neptune
Tilt of rotation axis	23°	3°	27°	98°	30°
Tilt of magnetic axis	12°	−10°	−0°	−59°	−47°
Offset of magnetic axis	8%	10%	5%	31%	55%
Field at equator	31,000 nT	428,000 nT	22,000 nT	23,000 nT	13,000 nT
Magnetosphere	10 R_{Earth}	65 $R_{Jupiter}$	20 R_{Saturn}	18 R_{Uranus}	25 $R_{Neptune}$

Shape of the magnetic field

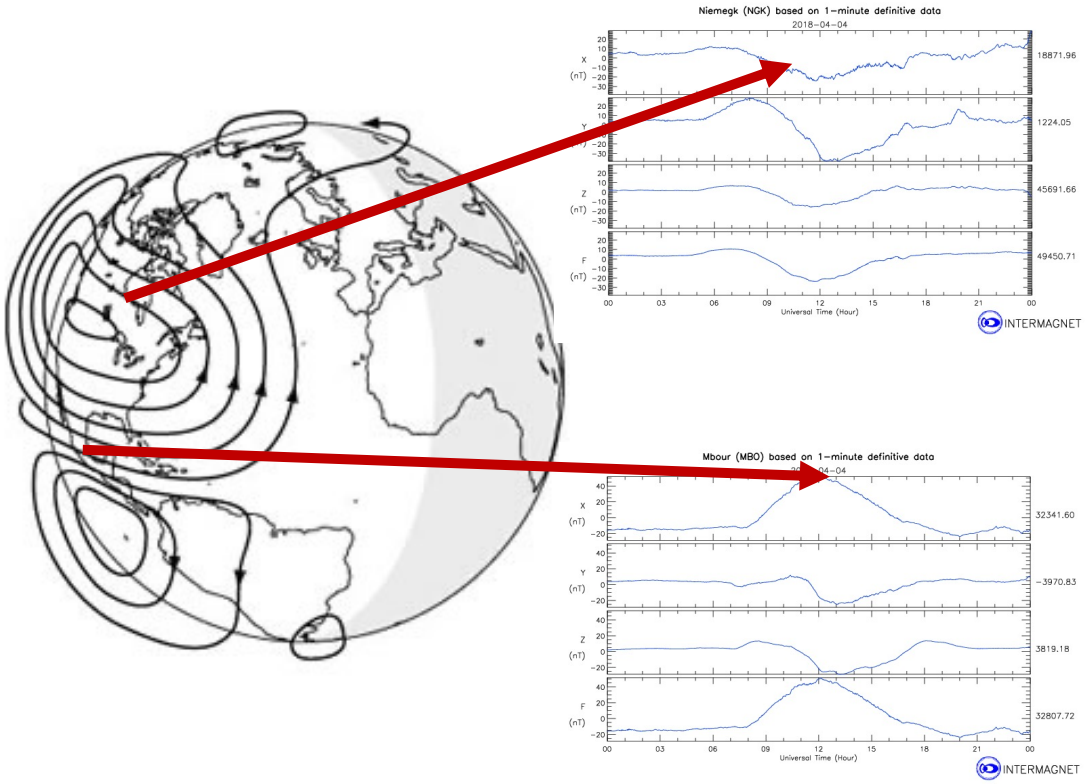
- The charged particles which come from the Sun (known as solar wind) are causing an asymmetrical shape to the magnetic field
- The magnetic field deflects most of these particles, preventing them to reach the atmosphere
- The solar wind could strip away the upper atmosphere, where the ozone layer is located, which is protecting the Earth from the harmful UV radiation



The Solar quiet (Sq) variation of the magnetic field

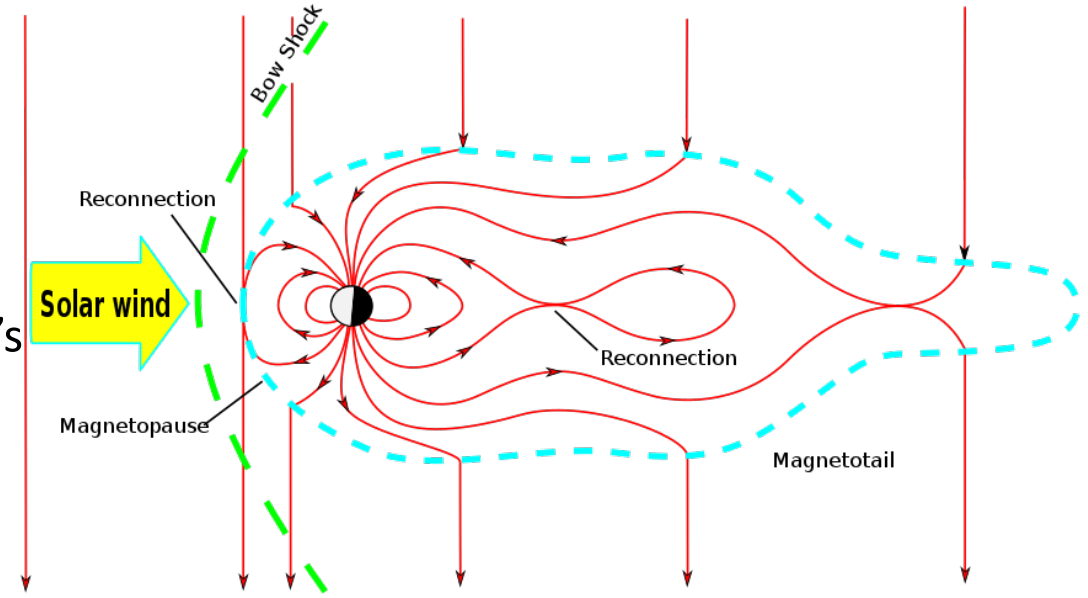


- The locally measurable magnetic field is changing during a day
- The EUV radiation of the sun produces extra ionization in the ionosphere
- Due to the streaming of the particles, an electric current emerges in the ionosphere, which can weaken or strengthen the magnetic field on the surface of the Earth



Geomagnetic storm

- In most severe cases, storms are caused by solar coronal mass ejection
- The solar wind carries the Sun's magnetic field
- If this field is pointing southwards, then a geomagnetic storm can be expected
- The two magnetic fields are reconnecting
- In the anti-sunward part of the magnetosphere, another reconnection takes place, when the Sun's and Earth's magnetic fields detache from each other. The geomagnetic field lines bounce back towards the Earth
- Several current systems build up in the magnetosphere, which cause drastic variation in the geomagnetic field.

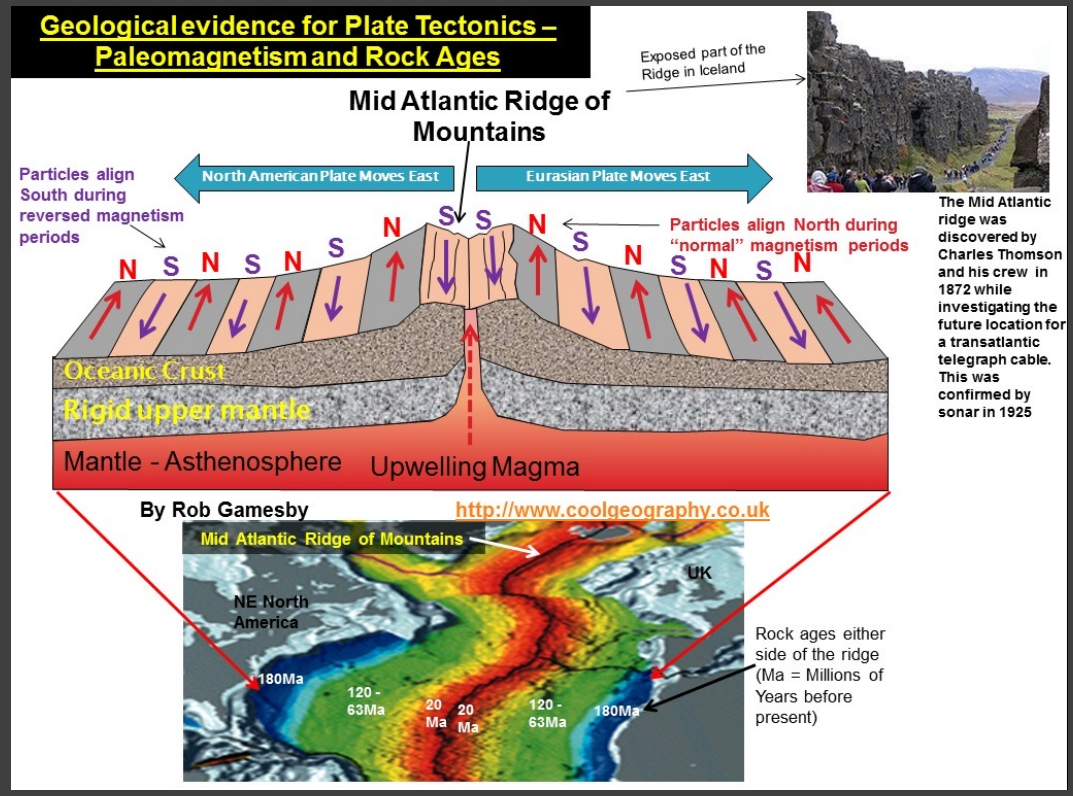


Aurora

- During these magnetic storms, the famous aurora borealis is observable
- At the poles the geomagnetic field is at its weakest, therefore the charged particles can reach the atmosphere
- When this happens the particles can interact, with the air molecules, the consequence of these interactions can be ionization or excitation
- When a molecule or an atom is in the exited state, deexcitation can happen, as the electron jumps down to a lower energy level, as a consequence of it the energy difference is taken away by an emitted photon
- This is what we can see as polar light
- The geomagnetic field lines turn visible

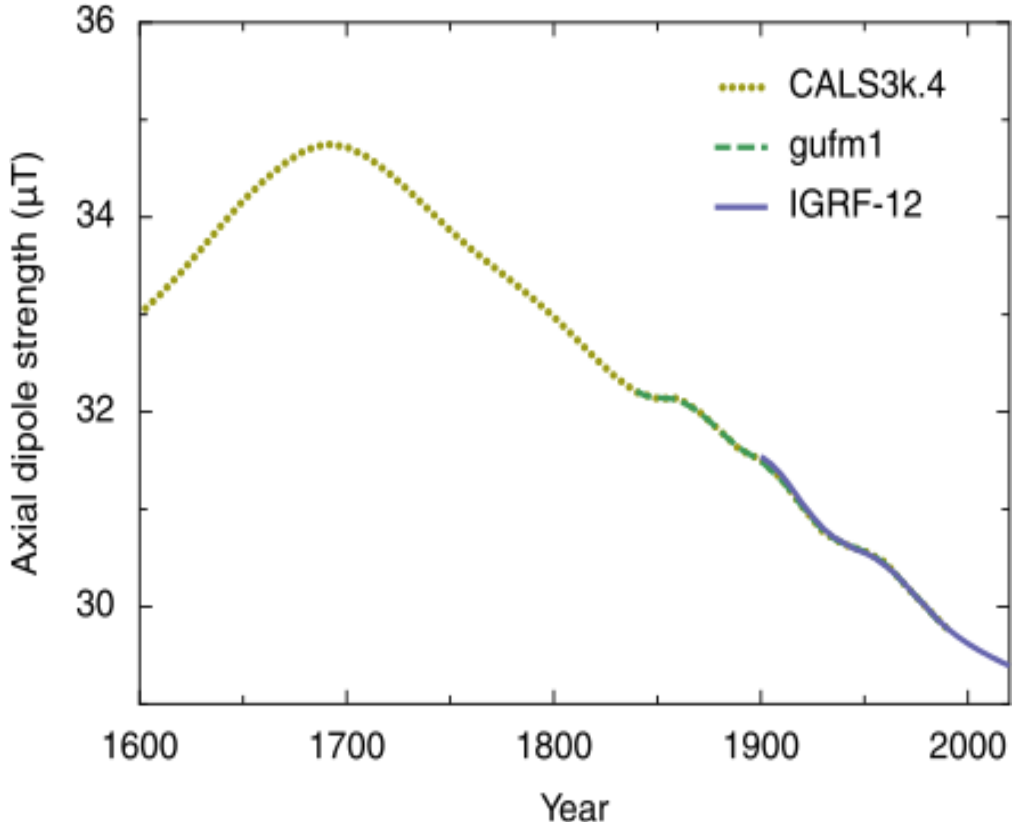
Paleomagnetism

- Studying lava flows, the past orientation of the magnetic field can be revealed
- The direction of the magnetic field is recorded in magmatic rocks. As the flowing lava cools down and solidifies, the actual magnetic field freezes in the rocks
- Because of this we know that the poles of the geomagnetic field is wondering, and, in extreme cases, the north and the south poles can also switch places
- The latter is called polarity reversal. The reversals occur near randomly with intervals ranging from 0,1 million to 50 million years, the last event happened about 780 000 thousand years ago



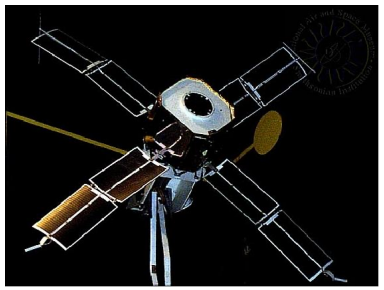
Future

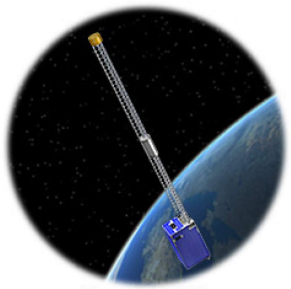
- At present, the geomagnetic field is weakening
- During the last 150 years it has declined by 10-15%, and the rate of the decay has been accelerating over the last several years, but it is in the normal range of variation
- The measurements of the last couple of hundred years are not enough to extrapolate an overall trend

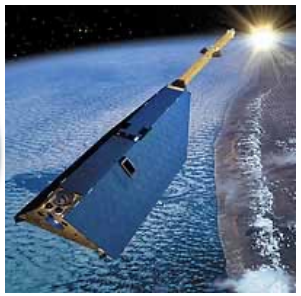


Measurement of the geomagnetic field

- Measurements can be made on the Earth, in observatories
- Field measurements
- In the magnetosphere by satellites
- With the measurements, we can map the Earth's magnetic field







Spacecraft missions (from the middle of the 20. century)

MagSat, Oersted, CHAMP, Swarm

Biomagnetism

- The geomagnetic field is used to navigate on the Earth
- Humans use a compass to help them orient
- But many species have a “built-in” compass
- Numerous animals which use the geomagnetic field, such as birds, whales, sharks or turtles

Thank you for your attention!

Sources

- https://researchoutreach.org/articles/earths-magnetic-field-changes-through-time/?cn-reloaded=1
- https://www.quora.com/How-does-the-outer-core-influence-the-Earth-magnetic-field
- https://en.wikipedia.org/wiki/Earth%27s_magnetic_field#Geographical_variation
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