Mystery of Cape Agulhas

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Abstract

Which physics experiments yield different results on northern and southern hemisphere? The paper describes several experiments conducted (or observed) in Cape Town and surrounding area that relate to Sun's apparent movement, seasons of the year, behaviour of the compass and natural background radiation.

Sun's apparent movement

You can see two photographs in fig. 1, both of which were taken around the time when the sun was highest above the horizon (about 13 o'clock of summer time). Can you tell the difference? What is the reason for the difference?

Fig. 1: Photos of shadows heading north and south.

The shadow in the upper photo is pointing southward and in the lower one northward. This suggests that the upper photograph was taken in the southern hemisphere and the lower one in the northern hemisphere. The situation is illustrated in Figure 2.

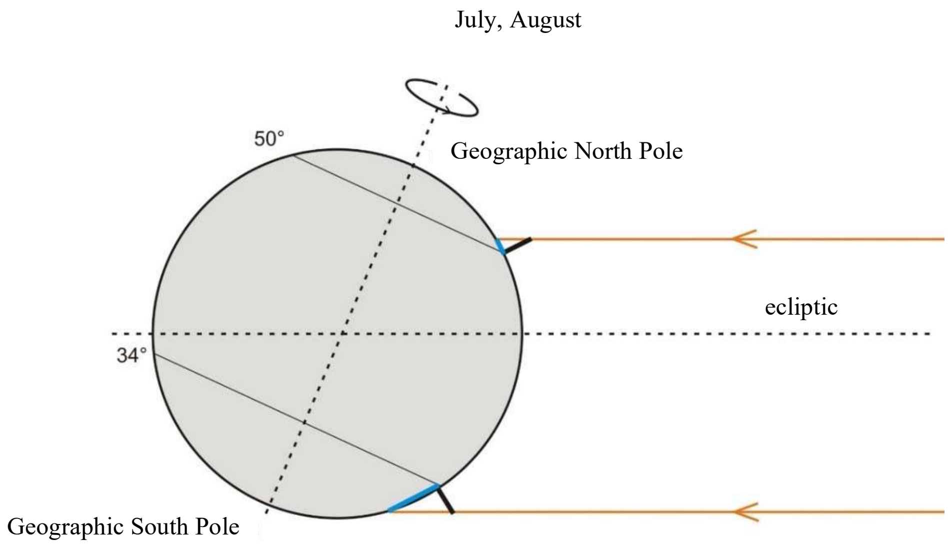

Fig 2: Directions of shadows are opposite to each other on the Northern hemisphere (Pardubice 50° N) and on the Southern hemisphere (Cape Town 34° S).

While looking towards the Sun at noon on the Northern Hemisphere, we are facing south. East is to our left and west to our right. Thus, the Sun apparently moves from left to right. Whilst looking at the Sun at noon on the Southern Hemisphere, we are facing north. East is to our right and west to our left. Therefore, Sun apparently moves from right to left.

Hot here and cold in Africa?

We associate the African continent with the hot Sahara or tropical forests. However, when you go to Cape Town in July, it is wise to pack a sweater, a jacket, and even a beanie. During the northern hemisphere summer, it's cold in the Southern Hemisphere. The primary causes are geometrical – functions of the cosine and the arc length (amount of time the Sun resides) above the horizon.

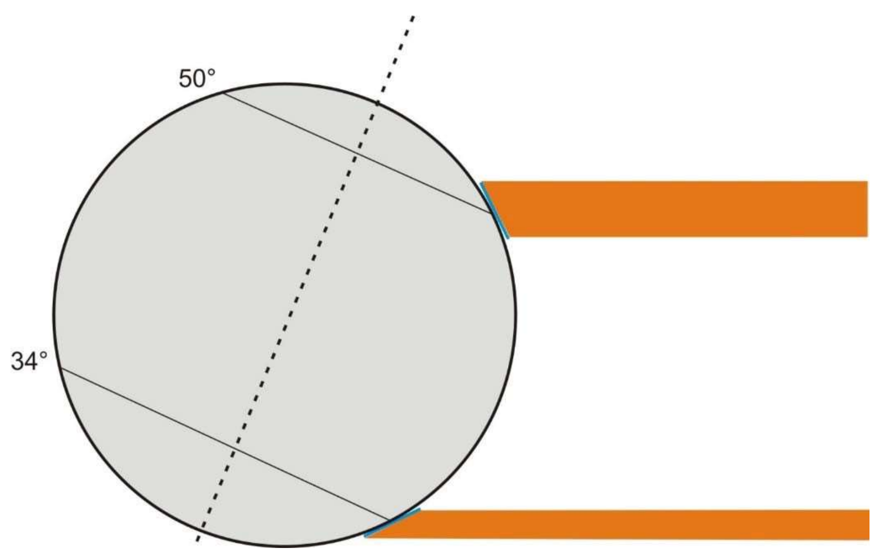

Fig. 3: Number of rays (energy) impacting chosen area per a time unit depends on the angle of incidence.

It is apparent from fig. 3, that there is a bigger number of rays impacting chosen area per time unit on the Northern Hemisphere (higher radiant flux) than equally large area on the Southern Hemisphere. This situation corresponds to our main holiday season. The lower radiant flux and shorter day length leads to less heated surface and therefore colder weather, e.g. in Cape Town. It is winter season there, nonetheless it is not as cold as it gets here.

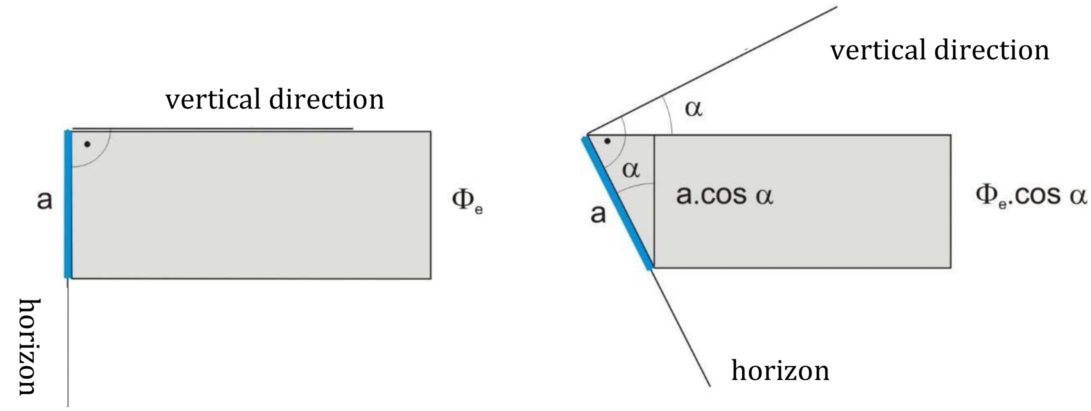

Fig. 4: Area's projection perpendicular to the rays varies according to the cosine function.

On the left in fig. 4 the rays impact the area perpendicularly to the surface that can be thought of as a square of area $a \times a$. Angle of incidence is measured between the ray and a line perpendicular to surface (vertical direction) and is equal to 0° in this case, the incoming radiant flux is Φ_e. The area on the right in fig. 4 is slanted and the angle of incidence is α. As seen from the Sun, the size of the area has decreased because it is no longer a square but a rectangle with sides $a \times a \cdot \cos\alpha$. The radiant flux is $\Phi_e \cdot \cos\alpha$ in this situation, which is lower than before. The number of photons impacting the area each second varies during the day according to the angle of incidence. The overall amount for 24 hours depends on the amount of time the Sun spends over the horizon radiating on the area. In winter, this means shorter time and fewer photons.

Compass attraction towards vertical bars

The article [1] describes experiment conducted in the Northern hemisphere (in Pardubice). We can see in the pictures that when the compass is brought close to a cast iron radiator, the south pole of the compass needle is attracted to the upper part of the radiator, whilst the north pole of the needle is attracted to the lower part of the radiator. Iron (cast iron, steel) bars and objects prolonged in vertical direction are in the Northern Hemisphere magnetised by the vertical component of the geomagnetic field in such a way that the north pole is facing downward and south pole upward. This is reversed in the Southern Hemisphere (fig. 5).

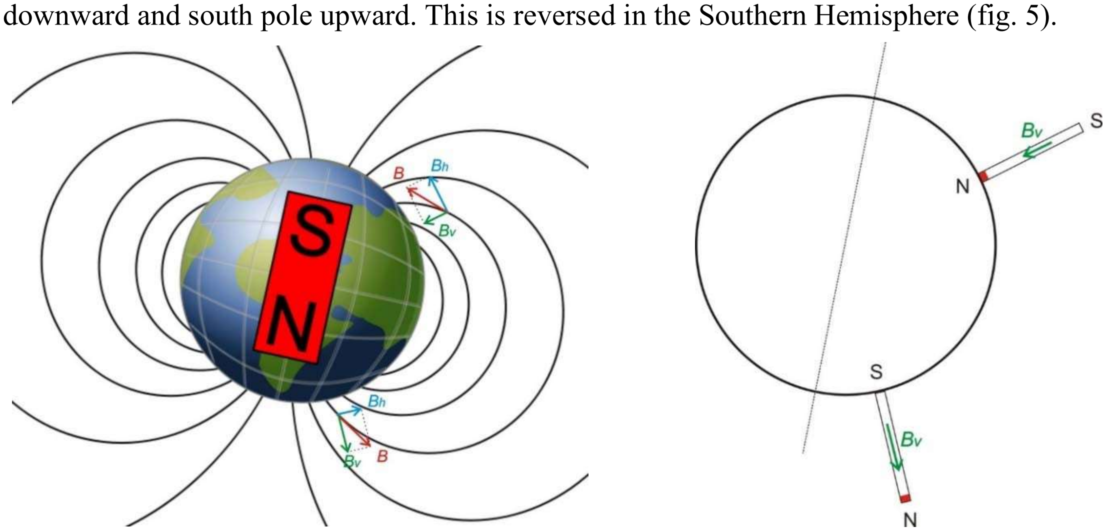

Fig. 5: On the left – Earth's magnetic field (https://cs.wikipedia.org/wiki/Magnetick%C3%A9_pole_Zem%C4%9B#/media/File:Earth%27s_magnetic_field,_schematic.svg). Direction of magnetic induction is tangent to the magnetic field line. Its vertical component magnetizes iron bars with opposite polarity on the Norther and Southern hemisphere.

To verify the theory about magnetised bars an experiment was conducted in Pardubice and in Cape Town. Its results are shown in fig. 6.

Fig. 6: On the left – attraction of the compass needle to a vertical iron bar on the Northern Hemisphere; on the right – on the Southern Hemisphere.

Mystery of Cape Agulhas

Cape Agulhas is southernmost point of Africa, where the Atlantic and Indian Oceans meet. It is a place of fierce storms and high waves. It is clear from the Czech name (English translation would be Cape of Needles) that it is somehow connected to the compass. We have conducted an experiment here using a SILVA compass fabricated in Sweden, i.e. designed to be used in the Northern Hemisphere. The matter at hand is the tilt of the compass around an axis perpendicular to the needle. Such tilting causes only slight jiggling of the needle in different parts of the Czech Republic. Yet a negligible tilt of the northern part of the compass towards the ground on Cape Agulhas forced the needle to rotate 180° (fig. 7).

Have north and south swapped?

Fig. 7: When lowering the north end of the needle towards the ground the needle rotates 180°.

The explanation is related to the direction of geomagnetic field lines according to fig. 5. Fig. 8A to 8F explain needle's behaviour.

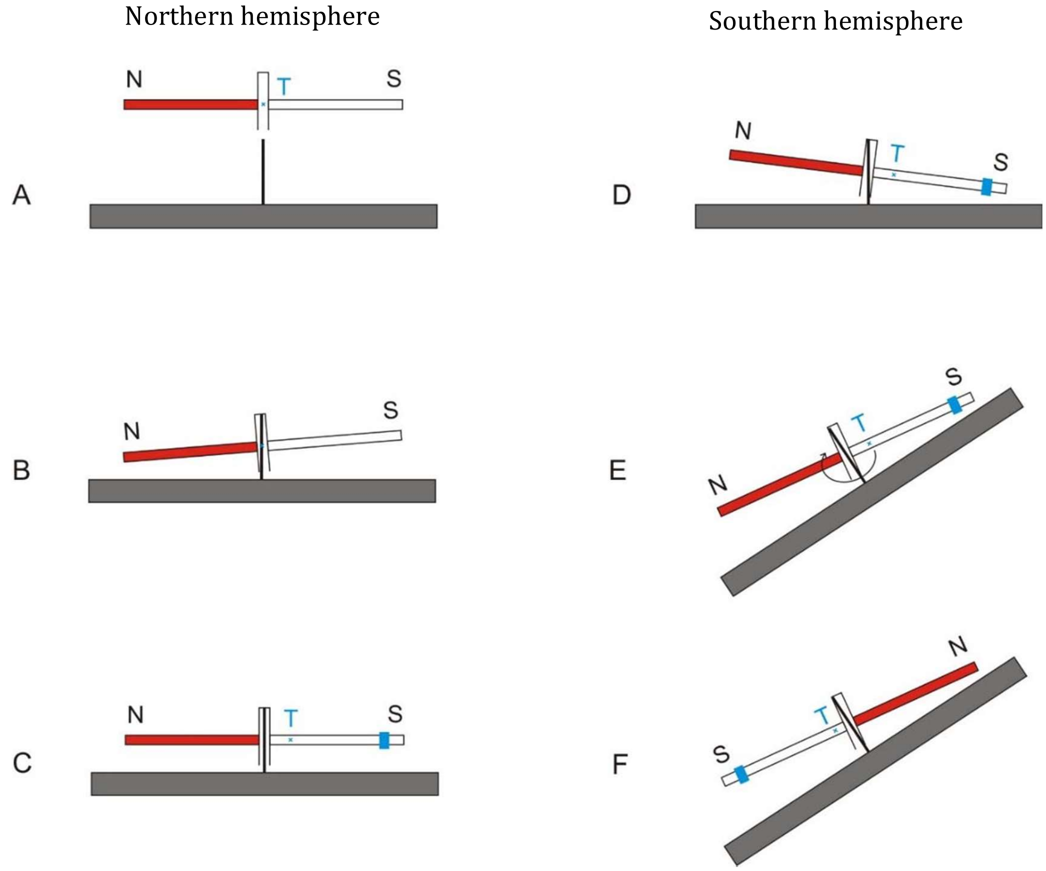

Fig. 8: Behaviour of the magnetic needle designed for the northern hemisphere.

Fig. 8A shows a compass needle that would have its gravity centre in the middle. Due to the vertical component of magnetic induction that points toward the ground on the northern hemisphere this needle would tilt when fitted onto the tip (fig. 8B). Its rotation on the tip would be impaired. To maintain balance the gravity centre must be shifted to the right (fig. 8C). When such a compass is brought to the southern hemisphere its needle tilts to the right while placed horizontally (fig. 8D). This is caused by two reasons. Firstly, the left side is lifted by the magnetic force due to the changed direction of the magnetic induction and secondly, the right side is subjected to a downward moment of gravitational force. When the compass is tilted the needle's gravity centre is placed above the rotational axis (unstable equilibrium in fig. 8E) and the needle rotates into stable equilibrium (fig. 8F). Placing the compass horizontally causes the needle to return to the proper position facing north.

The situation can be demonstrated using a created model in fig. 9. A wooden "needle" contains a magnet taped to the red end (the right one) and is balanced on the tip (a nail) without implementing any other magnet. By placing magnet's poles in such way that the right end of the needle is attracted to it we can break the balance. The needle can be (approximately) re-balanced attaching a small weight to the left side of the needle (lower part of fig. 9). Afterward replace the magnet on the right with a less powerful magnet that repulses the needle. When the right side is lifted the needle just jiggles. When the left side is lifted the needle rotates 180°.

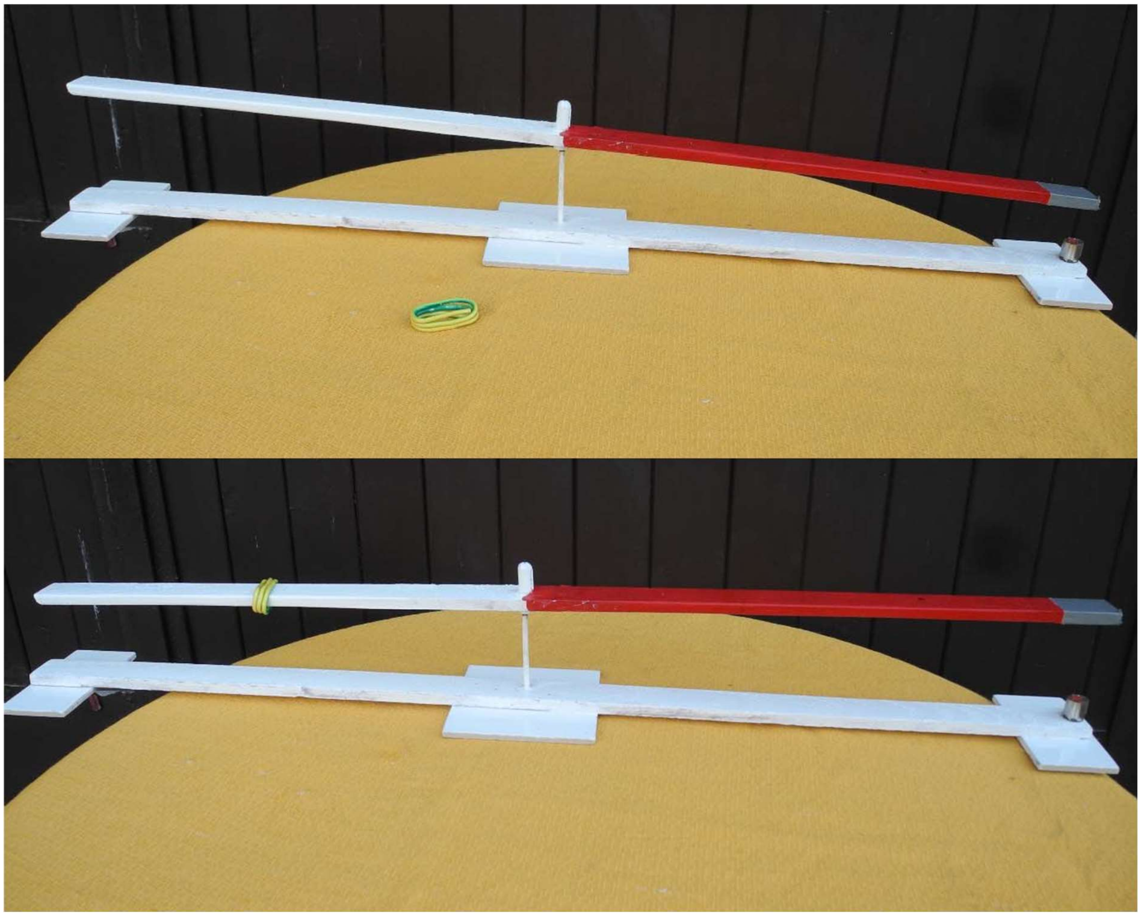

Fig. 9: Wooden model of the needle and board to demonstrate its rotation.

Mystery of Cape Agulhas solved. Obviously, this phenomenon doesn't occur solely on Cape Agulhas, but generally anywhere on the Southern Hemisphere. A compass designed for the Southern Hemisphere would display similar behaviour on the Northern Hemisphere, but it would be the southern end of the needle that requires tilting.

Radon in the environment

Radon is created in all naturally occurring decay chains – of uranium ^{235}U, ^{238}U and thorium ^{232}Th. Uranium and thorium had been present in Earth's crust since its creation and that is where radon is created as well. It reaches the surface with groundwater or directly diffuses through the soil. Uranium had been mined in several areas of the Czech Republic and several radon spas are located here as well. Comparing concentrations of radon in Cape Town and in the Czech Republic proved to be interesting.

A viable method of detecting products of radon decay is based on filtering larger amounts of air. Radon passes through the filter, while its radioactive decay products (polonium, bismuth, lead) can get caught on the filter. Alfa and beta radioactivity of those product is measured.

The experiment employs a vacuum cleaner and a paper tissue as a filter. Air was being sucked for 5 minutes and afterwards the used tissue was placed onto the pixel detector MX-10 for 10 minutes. In fig. 10 you can compare measurement from iThemba LABS (RSA)(on the left) and from a detached house in Pardubice (on the right).

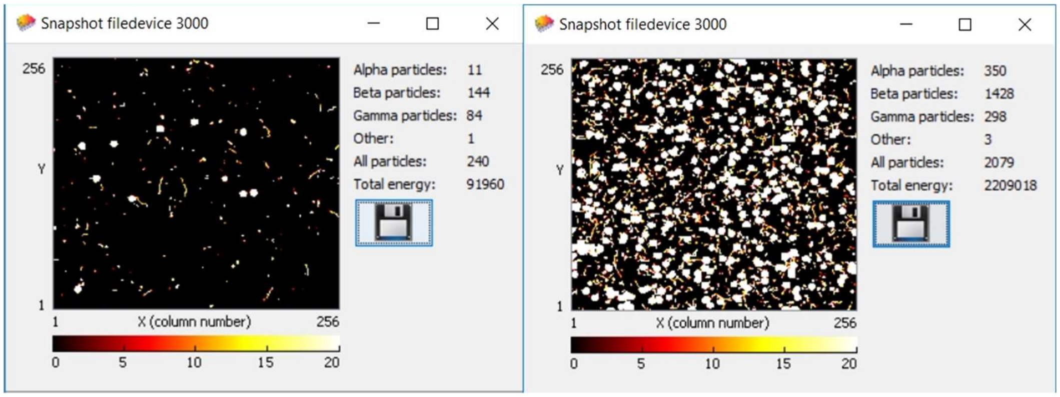

Fig. 10: The background radiation in iThemba LABS (RSA)(on the left) and in Pardubice (on the right).

The difference is visible at first glance. The radioactivity in the detached house in Pardubice is significantly higher. For the sake of objectivity, it needs to be said that the used vacuum cleaners can differ in volumetric flow rate and therefore the overall amount of air sucked through the filter during measured 5 minutes can differ. This clearly relates to the number of captured atoms.

Muons

Muons, created when primary cosmic rays interact with gas atoms in the atmosphere, can be discovered in the background radiation. Muons leave a characteristic trace in the pixel detector MX-10 – a line segments varying in length. To leave a straight line on a chip as thin (300 μm) as MX-10, muons must impact it almost entirely in the plane of the chip. This phenomenon is quite rare, and it is necessary to wait for it for a couple of minutes or dozens of minutes.

The detector was placed vertically (only a few muons arrive from directions low above the horizon [2]) and an hour-long measurement was conducted in Somerset West (RSA) and in Pardubice. A comparison of three measurements from RSA and CZE can be seen in fig. 11.

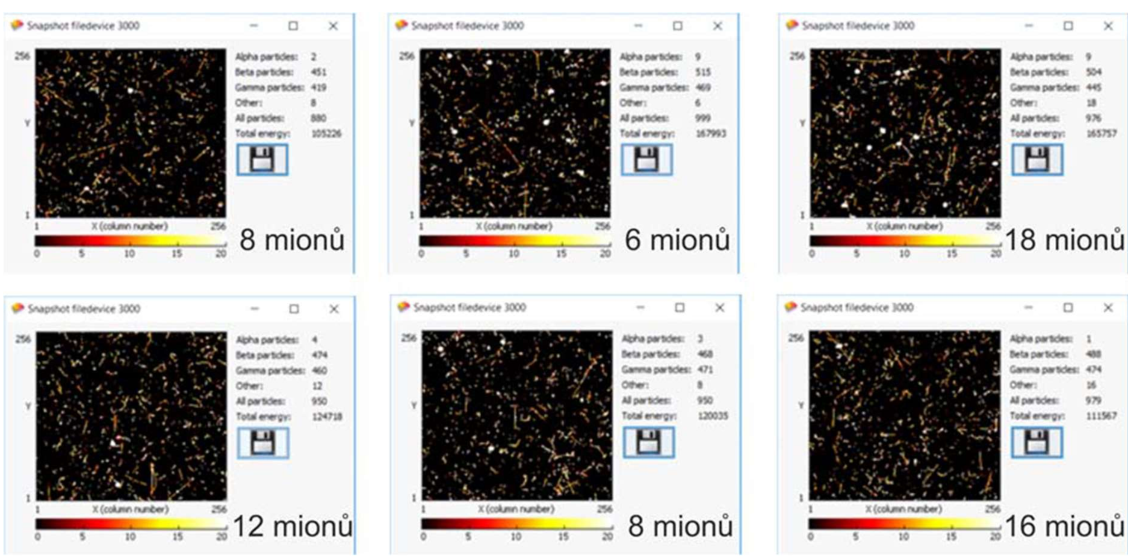

Fig. 11: Muons in the background radiation in RSA (upper pictures) and in CZE (lower pictures). The chip was placed vertically, exposure time is one hour in each measurement.

Muon traces including at least 20 pixels are classified as “other” by the program. The number of muons per hour in RSA were 8, 6 and 18. The number of muons in CZE were 12, 8 and 16. Based on the six mentioned measurements a conclusion can be made – the number of muons measured doesn’t significantly differ on Southern and Northern Hemispheres. This fits well with the idea that the primary cosmic radiation of higher energies is isotropic and comes from all over the galaxy.

References

[1] Vícha V., Jurica J.: *Mapujeme geomagnetické pole*. In: Sborník konference Veletrh nápadů učitelů fyziky. Ed.: Miléř T., Válek J. Masarykova univerzita Brno, 2016. s. 218-219

[2] Vícha V.: *Experimenty s pixelovým detektorem pro výuku jaderné a částicové fyziky*. ČVUT Praha, 2016.