# Study of the anisotropy of cosmic rays during the periods of the minima of the 24th solar cycle using the muonography method according to the data of the URAGAN muon hodoscope

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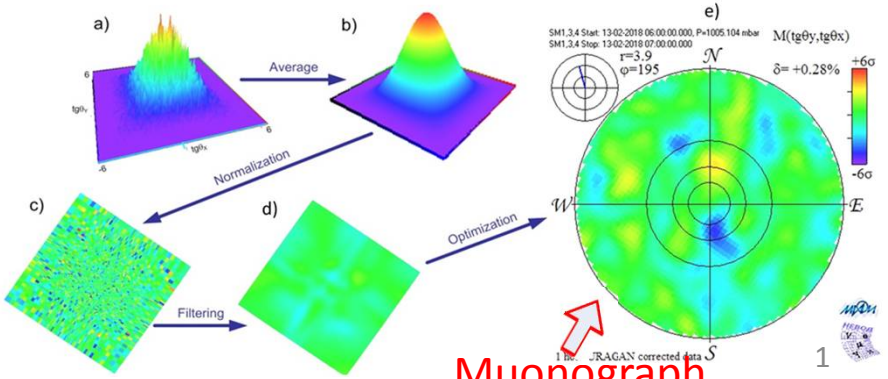
➢ Muon hodoscope URAGAN (MEPhI, Moscow) with an area of 45 sq. m is capable of real time detection of all muons arriving from the upper celestial hemisphere with a high spatial and angular accuracy.


- 4 independent **supermodules** (SM)
- **SM** - 8 planes of streamer tubes(8×[320-X & 288-Y]).
- **SM** area ~11 m$^2$.
- **SM** trigger: ≥ 4 X-planes within time gate 250 ns.
- Resolution: angular ~**0.8°**; spatial ~**1 cm**

**Muonograph** is an hourly matrix of track parameters normalized to the number of events, smoothed with respect to slow trends and daily fluctuations in the intensity, and corrected for the shape of the angular distribution of the muon flux.

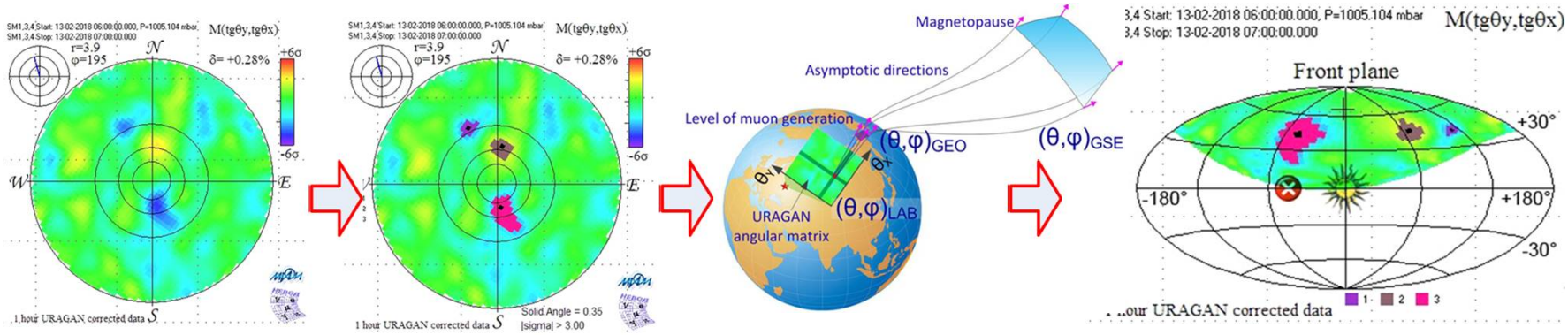
➢ **Variations in the counting rate in units of R.M.S.:**

$$\delta_\sigma(\mathrm{tg}\theta_Y, \mathrm{tg}\theta_X) = \frac{M(\mathrm{tg}\theta_Y, \mathrm{tg}\theta_X) - M_{24h}(\mathrm{tg}\theta_Y, \mathrm{tg}\theta_X)\cdot T_{live}/T_{24h}}{\sqrt{M_{24h}(\mathrm{tg}\theta_Y, \mathrm{tg}\theta_X)\cdot T_{live}/T_{24h}}}$$

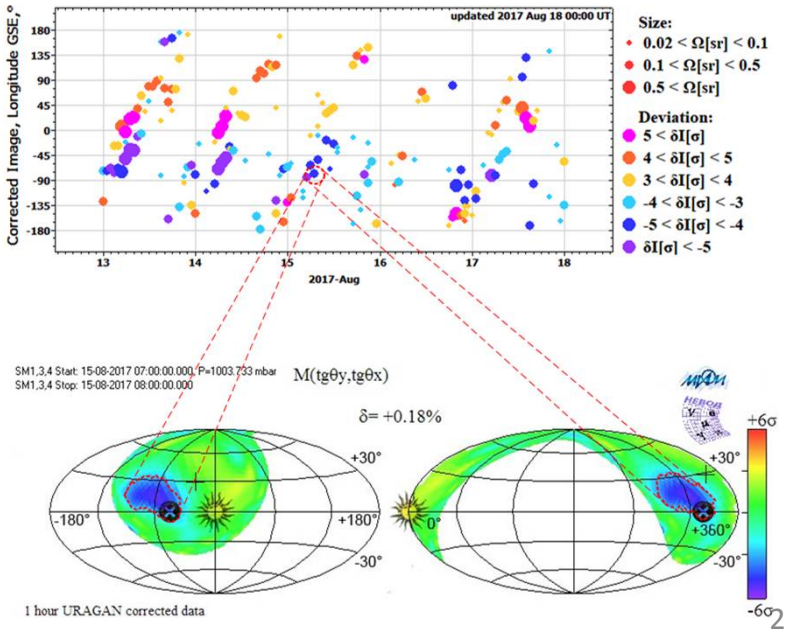


# GSE-mapping

Using asymptotic directions, **muonographs** from the Laboratory Coordinate System are transformed into the angular distribution of parent CR at the magnetopause in the GSE system.




- On the ***GSE muonographs***, regions ( ≤10) are selected with deviation ***δ >3σ***.
- These areas are referred to as ***deformation areas***. For each deformation area following values are calculated:
- ***solid angle*** of deformation and ***pitch angle*** of peak deviation in the GSE system;
- ***peak value in percentages*** *and its angular coordinates* ***(ϑ, φ)*** *in the Lab. Coordinate System.*



# Muonography the periods of the minima of 23rd and 24th Solar cycles

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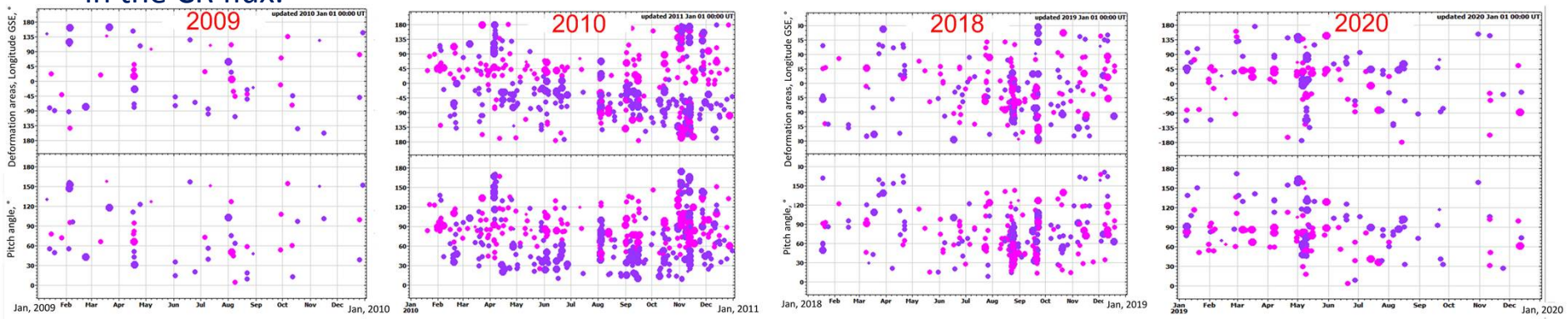
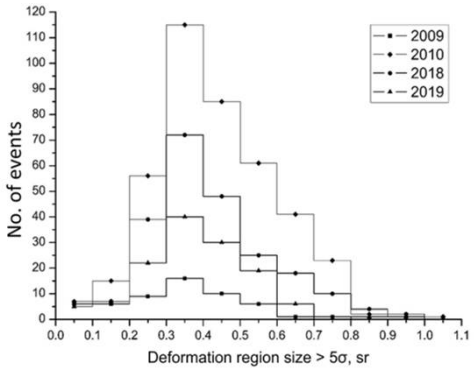
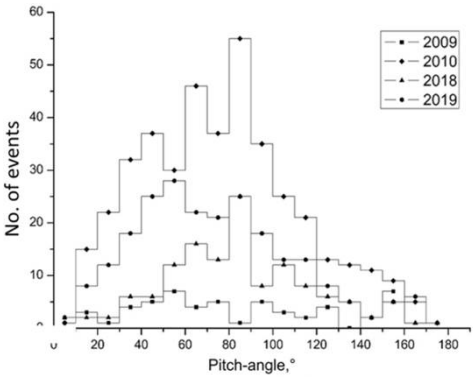
- OMNI database: periods 2009 – 2010 and 2018 -2019 → 81 geomagnetic storms as a result of the impact of the high-speed SW generated by coronal holes.
- Distributions of anisotropy areas (≥ 5σ, both increase (pink) and decrease (violet)) and pitch angles in the CR flux.




During these periods, deformation regions with sizes ranging from 0.1 to 0.8 sr were observed. The most frequently recorded areas were 0.4 sr, regardless of the year.




**2009** - particles most often detected by URAGAN with a pitch angle of **50°**,
**2010** with an angle of **90°**,
**2018** - **50°**, and in **2019** - **80°**.
Particles with pitch angles of **180°** and **0° did not enter the magnetosphere**.

**Conclusion.** The proposed approach of mapping the anisotropy area in the angular distribution in matrix form:

- Estimation of degree of deformation, the zenith and azimuthal angles of the center of an anisotropy area in the local coordinate system, and its GSE longitude and latitude.
- The use of the muonography method made it possible to estimate some of the features of the dynamics of the anisotropy of cosmic rays during periods of minimum solar activity and different polarity of the Interplanetary magnetic field.

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