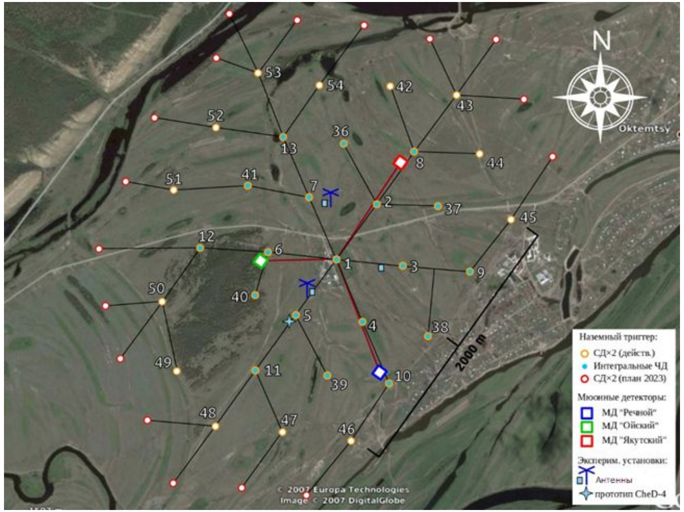
The study of cosmic rays with energies greater than 5 EeV by radio method

Presenter: Igor Petrov

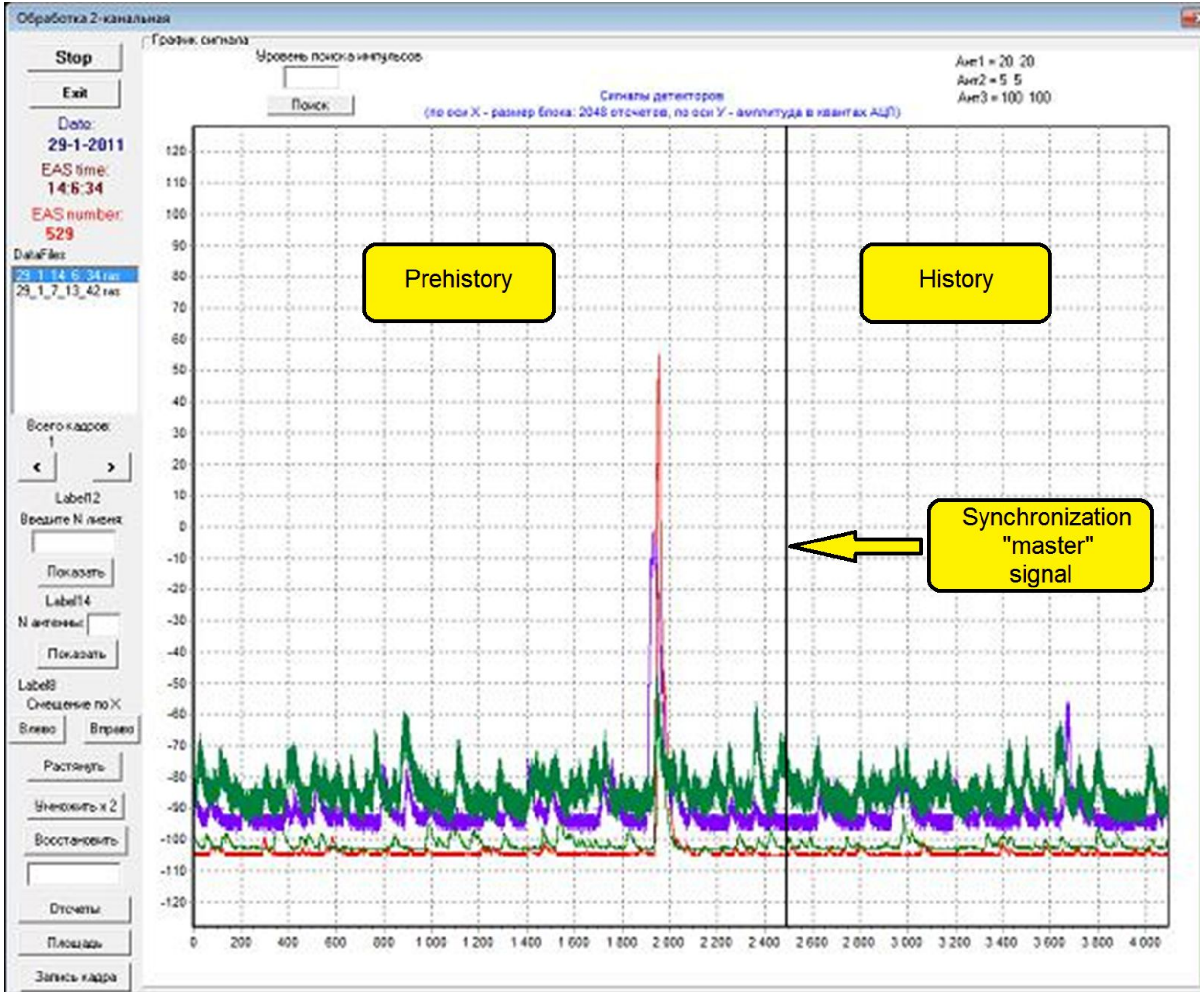
Yu.G. Shafer Institute of Cosmophysical Research and Aeronomy.

The Yakutsk array

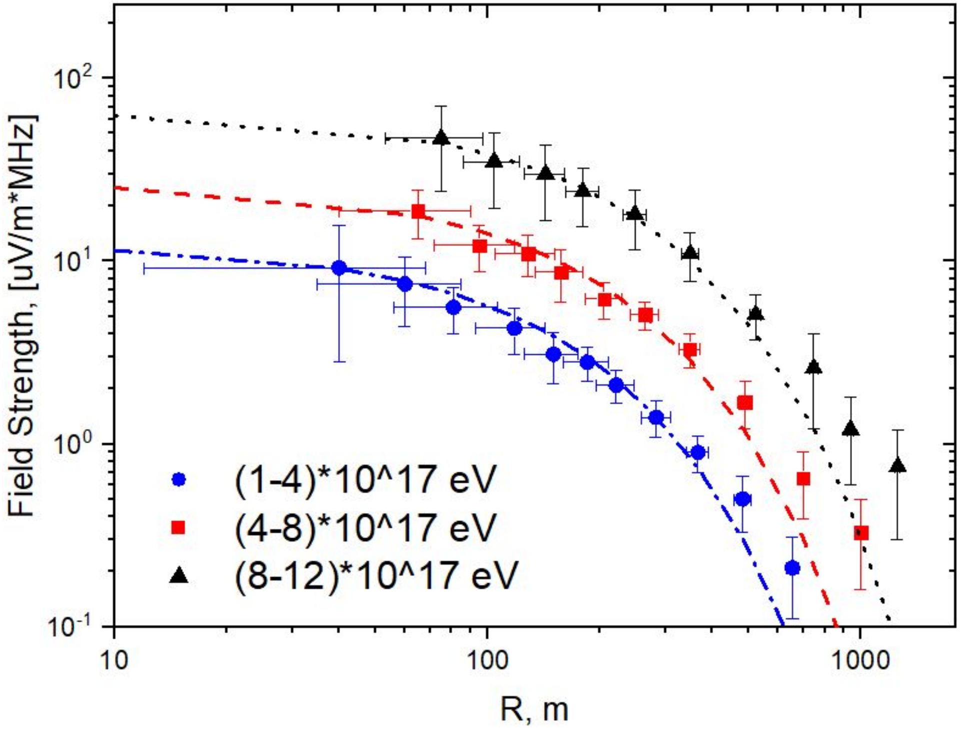


58 stations with scintillation detectors;
27 integral 3 track Cherenkov detectors;
5 muon detectors;
6 antennas

Energy range: $10^{15} - 10^{20}$ *eV*
Area of the array: *~8 km*^{2}.
The array operates from September to April


Обработка 2-канальная
График сигнала
Stop
Exit
Date:
29-1-2011
EAS time:
14:6:34
EAS number:
529
DataFiles:
Уровень поиска импульсов
Поиск
Сигналы детекторов
(по оси X - размер блока: 2048 отсчетов, по оси У - амплитуда в квантах АЦП)
Ант1 = 20 20
Ант2 = 5 5
Ант3 = 100 100
Всего кадров:
Label12
Введите N ливня
Показать
Label14
N антенны:
Показать
Label8
Смещение по X
Влево
Вправо
Растянуть
Умножить x 2
Восстановить
Отсчеты
Площадь
Запись кадра
Prehistory
History
Synchronization
"master"
signal

LDF of Air Shower Radio Emission E≥10^{17} eV



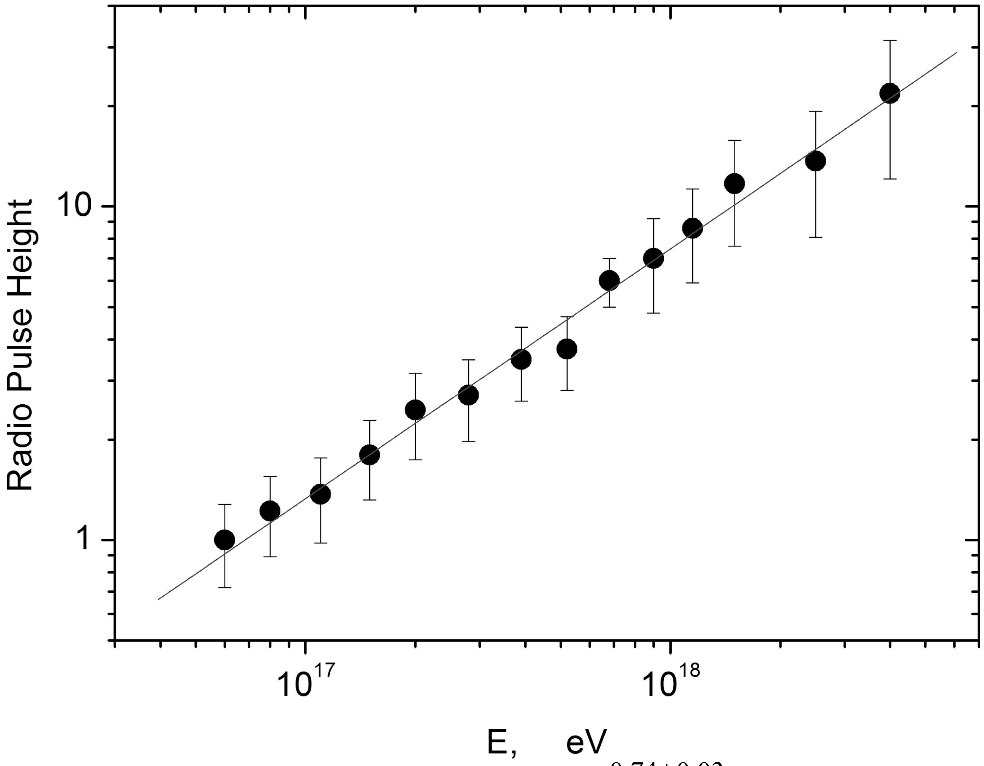
Average LDF for three energies:

θ ≤ 45°;

Axii of showers within 500 m;

SNR ≥ 5.

Radio emission amplitude dependence on energy of the shower



$$\varepsilon_{EW} = (1{,}35 \pm 0.06) \cdot \left(\frac{E}{10^{17}} \right)^{0.74 \pm 0.03} \qquad \frac{\chi^2}{dof} = 0.13$$

Air Shower Event with Energy E > 10^{19} eV

Date:

22. 01. 2014

Time:

21:49:08

Zenith angle:

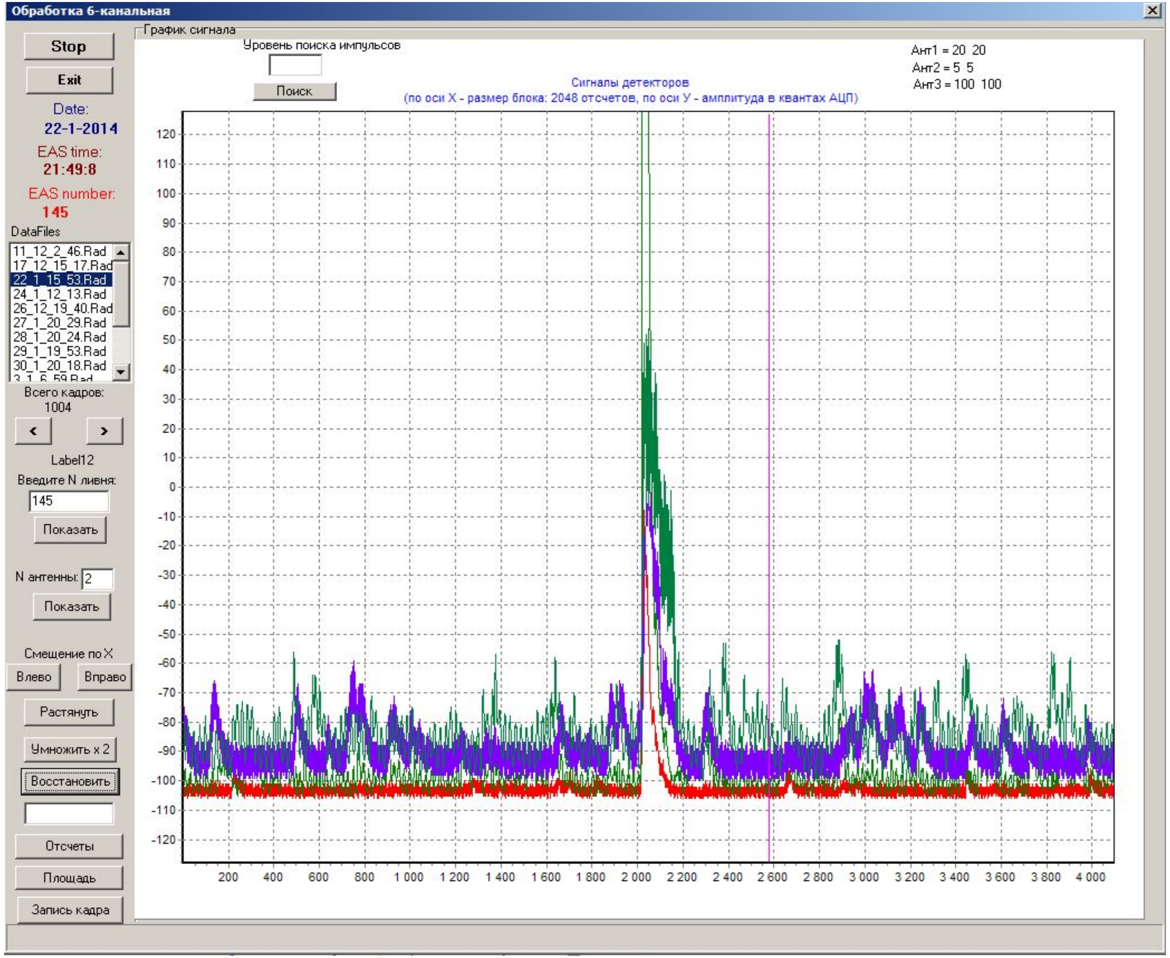
θ = 47°

Azimuth angle:

Ψ = 189°

Energy:

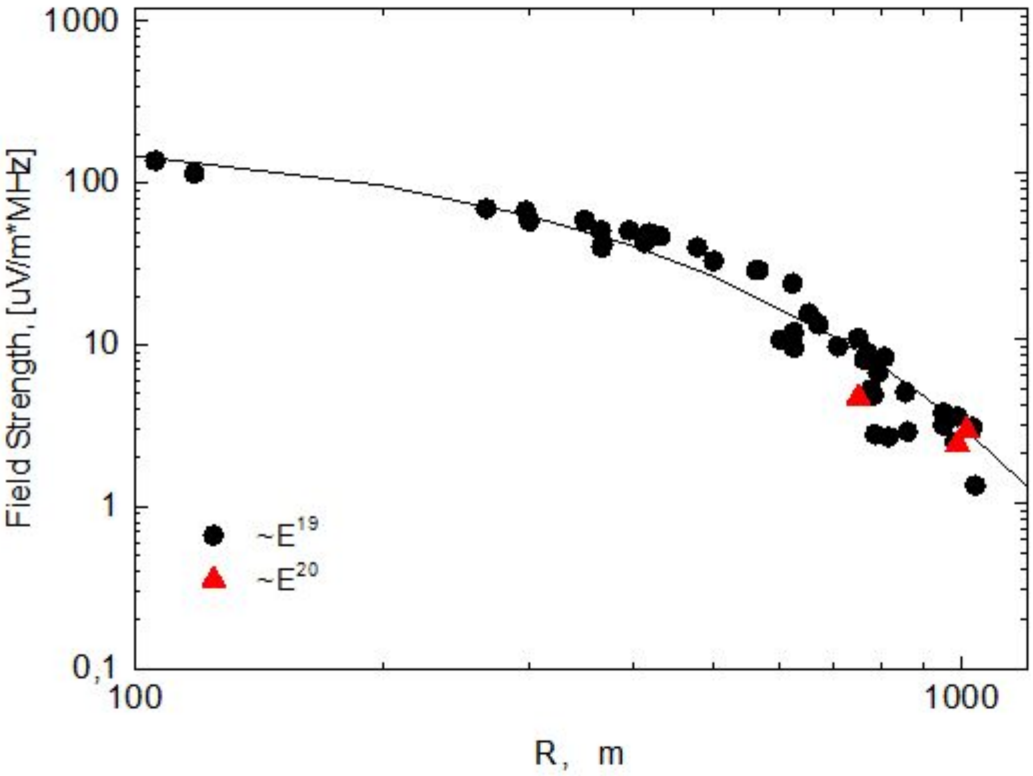
$E_0 = 1{,}11 \cdot 10^{19}$ eV



List of Air Showers with Energy ≥10^{19} eV Registered by Yakutsk array Antennas

Data	θ, deg	ψ, deg	E_0, eV	A_ν, $\mu V \cdot m^{-1} \cdot MHz^{-1}$	R, m
16.11.86	74	180	$3.1 \cdot 10^{19}$	58.0	300
16.12.87	71	178	$3 \cdot 10^{19}$	40.0	367
21.02.88	70	210	10^{19}	3.1, 3.8	1030, 950
09.03.88	36	125	$9 \cdot 10^{18}$	6.2	792
07.05.89	59	168	$1 \cdot 10^{20}$	62.5	750
10.03.11	51	239	$1.1 \cdot 10^{19}$	89, 43, 5.8	350, 413, 604
16.05.11	69	99	$1.6 \cdot 10^{19}$	33, 29, 40	501, 564, 479
31.12.11	15	165	$1.1 \cdot 10^{19}$	1.2, 1.0, 2.9	950, 980, 860
12.04.12	8	222	$1.3 \cdot 10^{19}$	4.1, 2.8, 6.0	762, 785, 626
04.05.13	46	295	$1.1 \cdot 10^{19}$	5.3, 6.0, 12	776, 768, 368
12.12.13	15	297	$1.2 \cdot 10^{19}$	5.1, 8.4, 3.6	855, 806, 988
03.10.13	21	21	$1.1 \cdot 10^{19}$	9.1, 11, 2.7	419, 396, 815
22.03.13	46	4	$1.8 \cdot 10^{19}$	41, 48, 78	418, 432, 366
02.01.14	48	207	$7.9 \cdot 10^{19}$	16.3, 19.4	1013, 988
22.01.14	47	189	$1.1 \cdot 10^{19}$	107.6, 119.6	297, 266
05.02.14	26	343	$3.5 \cdot 10^{19}$	3.4, 5.6	671, 627
02.03.14	30	217	$1.2 \cdot 10^{19}$	4.9, 6.0, 7.8	782, 749, 708
04.01.18	26	211	$1.6 \cdot 10^{19}$	1.3	1038
05.01.18	45	303	$2.1 \cdot 10^{19}$	180, 150	106, 118

LDF of Air Shower Radio Emission E≥10^{19} eV



Normalized to
E= 1.5*10^{19} eV
<θ> = 43°

X_{max} estimation

Depth of X_{max} is estimated by

$$X_{max} = (8 \pm 28) + P_1 \cdot (217 \pm 11) \quad (1)$$

$$X_{max} = (281 \pm 9) + P_2 \cdot (33 \pm 2) \quad (2)$$

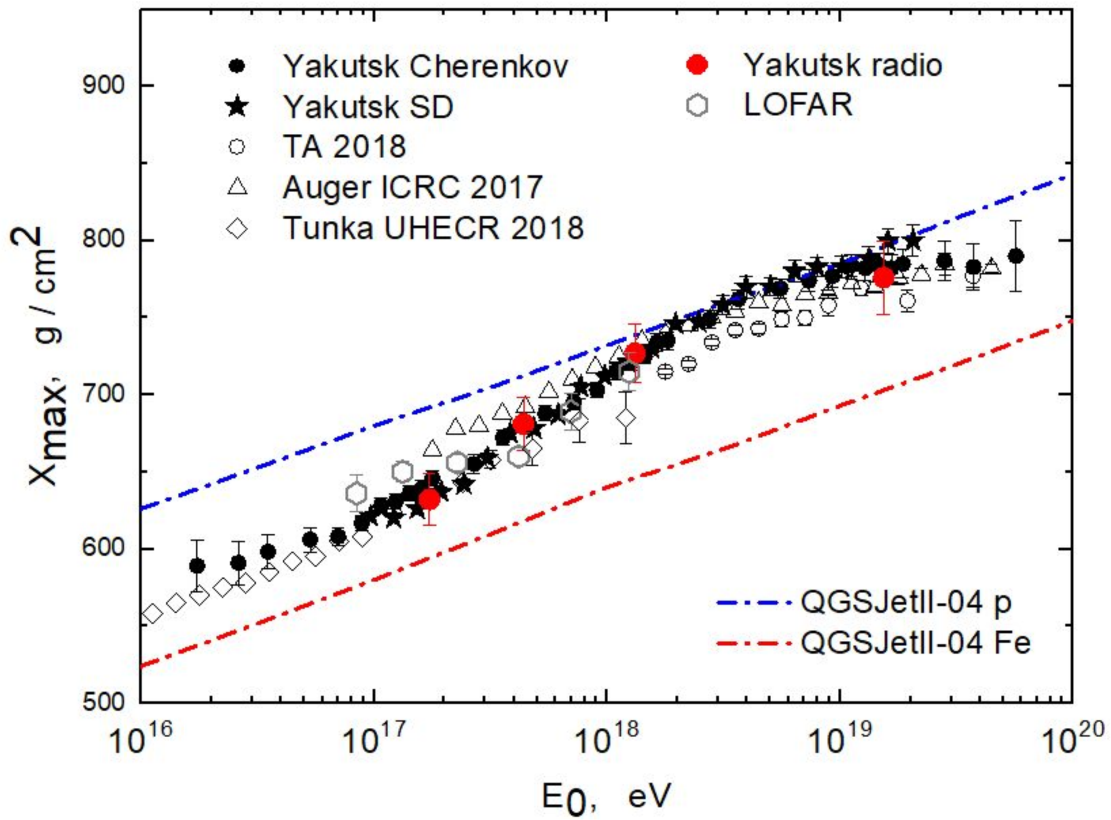
$P_1 = A(80)/A(200)$

$P_2 = A(175)/A(725)$

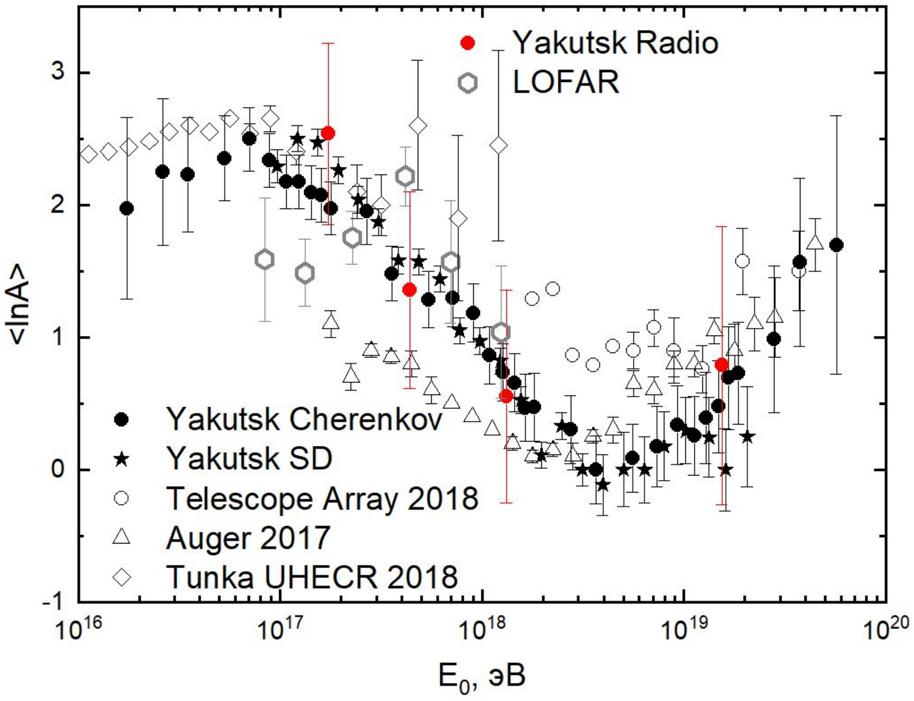
Eq. (1) is used for air showers with energy $<3*10^{18}$ eV

Eq. (2) is used for air showers with energy $\geq3*10^{18}$ eV

$<X_{max}>$ vs E_0


Yakutsk Cherenkov
Yakutsk SD
TA 2018
Auger ICRC 2017
Tunka UHECR 2018
Yakutsk radio
LOFAR
QGSJetII-04 p
QGSJetII-04 Fe
900
800
700
600
500
Xmax, g / cm2
10^16
10^17
10^18
10^19
10^20
E0, eV

Mass composition



$$\langle \ln A \rangle = \left(\frac{X_{\max}^{\exp} - X_{\max}^{p}}{X_{\max}^{Fe} - X_{\max}^{p}} \right) \cdot \ln A_{Fe}$$

Conclusion

- Radio experiments expands the possibilities of experimentally studying the characteristics of air showers;

- Energy of the showers was determined by radio emission signal amplitude and depth of maximum by ratio of amplitudes at different distances;

- Depths of maximum development estimated for 4 different energies by radio measurements are in agreement with depths of maximum development estimated by optical methods;

Thank you for your attention!