The TUS experiment

1. Goals of the experiment:

1a. Give a short description of the goals of the experiment - limited to ½ page.

The TUS space experiment has been proposed to measure the energy spectrum, composition and angular distribution of the Ultra High Energy Cosmic Rays (UHECR) at $E = 10^{19}$-10^{20} eV, to study the region beyond the GZK cutoff. Existence of these particles is beyond the Standard Model of particle physics and is of great interest. The study from the orbit is much more effective in comparison with the ground-based detectors. The existing world statistics is assumed to be increased by a factor of 2 during 3 years of the global data taking. The TUS detector will make it possible to study UHECP neutrino Extensive Air Showers (EAS) from the space orbit.

1b. Explain what the project adds to the international scenario: limited to ½ page.

The measurements of Cosmic Ray (CR) spectrum, composition and anisotropy in the wide energy interval are an important part of the particle physics study. Ultra High Energy Cosmic Rays (UHECR) at E ~ 10^{20}eVwere discovered more than 50 years ago, but the results in the UHECR physics do not give clear answers to the most important questions. The UHECR origin and nature, the mass composition, anisotropy and possible UHECR sources are still unclear. To a large extent, the problem is due to the very low UHECR flux –the current Auger and TA experiments have ~200 UHECR events at E > 5 · 10^{19}eV and a few events at ~10^{20} eV.

The TUS project's goal is the experimental study of UHECR. The fluorescent and Cherenkov radiation of the Extensive Air Showers (EAS) generated by UHECR particles should be detected in the Earth's atmosphere on the night side of the orbit at altitudes 400–500 km. It will be possible to evaluate the EAS energy and arrival directions at energies E > 7 ·10^{19}eV that is beyond the GZK limit. An important advantage of space detector is the possibility of taking data from different arrival directions of the sky with the same apparatus and with the same systematic uncertainties.

2. Contributions of the JINR group:

2a. Give an itemized list of the specific contributions of the JINR group in hardware (including use of JINR computing resources for the project), software development and physics analyses - limited to 1 page.

1. Design, fabrication and optical parameters measurements of the focusing Fresnel mirrors that is presented in Fig.1.

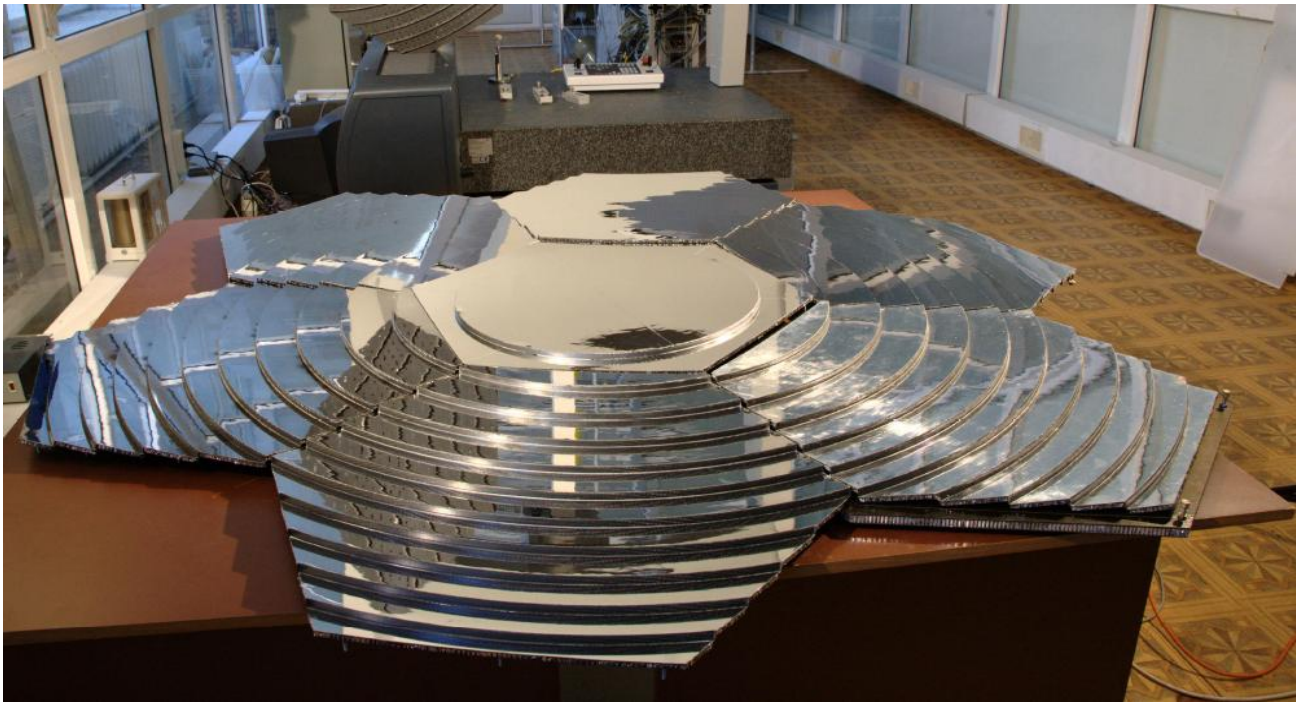

Fig.1. The focusing Fresnel mirrors of the TUS detector

2. The software package has been developed to simulate performance of the TUS detector - the TUSSIM program
- for the Fresnel mirror optical parameters,
- the light guide of the photo detector,
- the front end and trigger electronics.

3. The software package has been developed to reconstruct EAS events of TUS data. The TUS data analysis and as a result the first EAS candidates were found and analysed (Fig.2.)

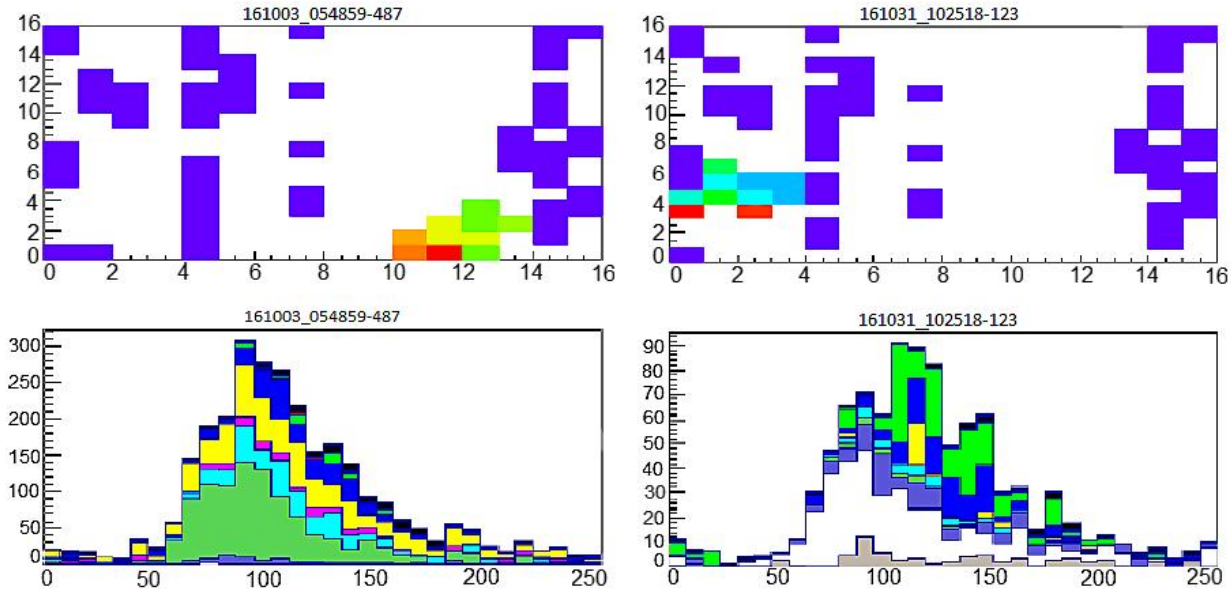

Fig.2. The first EAS candidates in the TUS experiment. Upper plots – images of events with hit pixels on the PMT matrix and not-working (blue) ones. Bottom plots – the amplitude variations of time for selected hit pixels

2b. Give a list of the responsibilities of JINR group members within the management structure of the collaboration, if any, giving the name of the JINR member, the managerial role and the appointment period.

Unfortunately there is no management structure of the TUS collaboration.

3. Plans. *Give a short description limited to ½ page of the JINR group plans (in data taking, analysis, detector R&D, upgrade activities…) till the end of the currently approved project.*

1. Relative and absolute calibration of TUS detector PMTs using TUS flight data itself
2. Complete a search and physical analysis of EAS candidates from TUS data taking into account PMT calibration.
3. Publish 2-3 papers in the refereed journals
4. Preparation PhD theses for A.Grinuyk and M.Lavrova

4. Publications: *List the papers published in 2016, 2017 and 2018 in the refereed literature (no conference proceedings) in which the JINR group had a major contribution (e.g. author of the analysis, promoter of the experiment, corresponding author, realization of a key equipment etc.). Give title of paper, reference and describe in 1-2 sentences the JINR contribution. Mention the total number of papers published by the project in the same time period.*

1. A. Grinyuk, V. Grebenyuk, B. Khrenov, et al. Astropart. Phys. 90 (2017) 93-97. The orbital TUS detector simulation. (The JINR group contribution is ~100% of the paper content).

2. First results from the TUS orbital detector in the extensive air shower mode
   B.A. Khrenov, P.A. Klimov, M.I. Panasyuk, S.A. Sharakin, L.G. Tkachev at al. Journal of Cosmology and Astroparticle Physics. Volume 2017, September 2017 (The JINR group contribution is crucial).

3. The TUS Detector of Extreme Energy Cosmic Rays on Board the Lomonosov Satellite. P. A. Klimov,M. I. at al. Space Science Reviews. Volume 212, Issue 3–4, pp 1687–1703 (The JINR group contribution is crucial).

The total number of papers published by the project ~20

5. PhD theses: *List the PhD theses completed within the last 3 years, or expected to be completed within 2019, by JINR students within the project, giving the student name, thesis title and graduation year.*

PhD theses for A.Grinuyk preliminary title: The TUS detector optical system: design, fabrication and parameter measurements. The TUS optical system simulation and data analysis.

PhD theses for M.Lavrova preliminary title: The TUS detector simulation, development of programs for EAS event search and reconstruction. The EAS candidates search in TUS data and analysis.

PhD theses for A.Grinuyk and M.Lavrova are expected to be completed within 2019

6. Talks:

6a. List the invited plenary talks given by members of the JINR group in 2016, 2017 and 2018 at international conferences, workshops…: give name and date of the Conference, title of talk and speaker name.

1. A.Grinuyk. International Symposium on Cosmic Rays and Astrophysics. 20-22 June Moscow 2017, title: Space experiment TUS
2. L.Tkachev. New Trends in High-Energy Physics, 24-30 September 2018, Montenegro, Budva, Becici, "Splendid Hotel.
   JINR activity in the NUCLEON and TUS/KLYPVE space experiments
3. V.Lavrova. International Symposium on Very High Energy Cosmic Ray Interaction, 21-25 May 2018. Nagoya University, Nagoya, Japan, title: Search and study of EXTENSIVE AIR SHOWER events with the TUS space experiment

6b. Give a similar list for parallel talks.

1. A.Grinuyk. 35thInternational Cosmic Ray Conference.
   The TUS space experiment: calibration in flight. 12-20 July 2017, Busan, Korea

7. Group size, composition and budget.

7a. Present in a Table the list of JINR personnel involved in the project, including name, status (e.g. PI, researcher, post-doc, student, engineer, technician…) and FTE. Mention the total number of people in the collaboration.

The total number of people in the TUS collaboration author list - 22 people

List of the JINR TUS project participants:

Name	employment	involvment	PhD
1. V. Grebenyuk	senior scientist	10%	yes
2. A. Grinyuk	engineer	50%	in preparation
3. M. Lavrova	engineer	60%	in preparation
4. L. Tkachev	head of sector	20%	yes
5. A. Tkachenko	scientist	10%	no
6. U.Nurtaeva	engineer	20%	no

7b. Indicate the expected changes in the group size, if any, till the end of the currently approved project.

Expected changes in the group size ±1 persons

7c. Present the JINR group budget from 2018 till the end of the currently approved project in a Table specifying the main budget items (equipment, computing, salaries, common funds, travel…)

Small ~10% of total budget

7d. Indicate the use of JINR computing resources for the group and for the project if any.

LIT computer farm