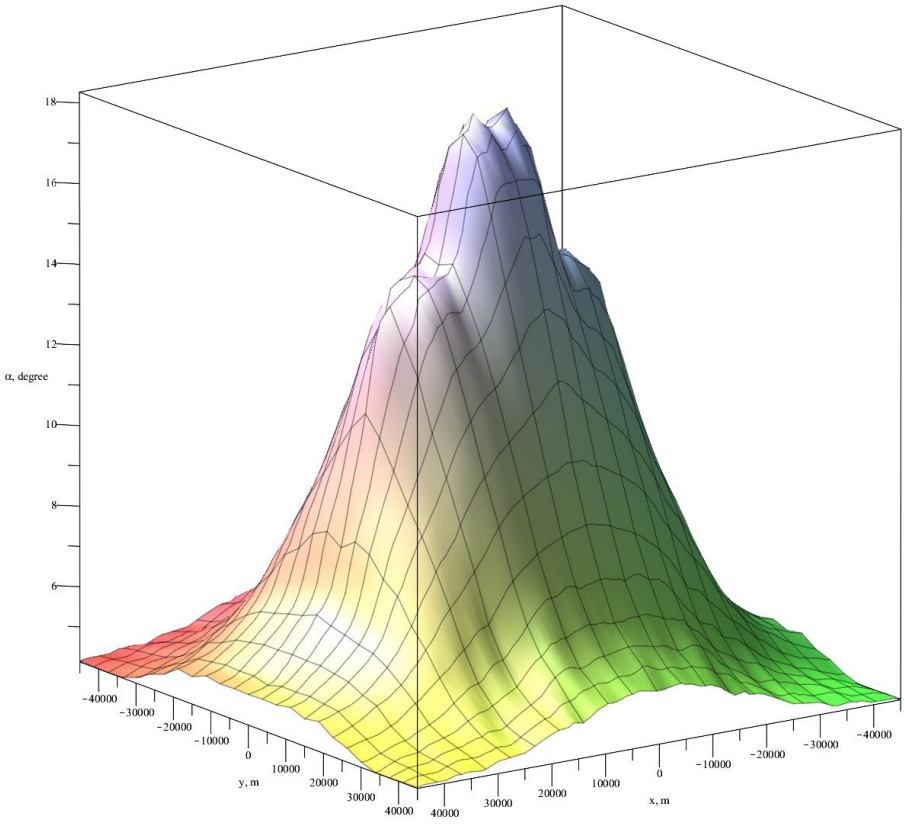
Brief information about the project

Name of the project	AP14869524 «Effects of Nonlinear Vacuum Electrodynamics and General Relativity on Magnetars»
Relevance	The project proposes a research that will be carried out on the study of the passage of electromagnetic waves through a Magnetar within the framework of nonlinear vacuum electrodynamics and general relativity (GR), namely, the phenomenon of nonlinear magnetic lensing of a plane front of an electromagnetic wave (gamma radiation from gamma-ray bursts) when it passes a dipole and quadrupole magnetic field in curved spacetime of the neutron star (Magnetar). The experienced researchers from Kazakhstan in the field of relativistic compact astrophysical objects will participate in the project. The Project manager is Dr Medeu Abishev, Doctor of Physical and Mathematical Sciences. This research group includes young researchers in the field of GR, astrophysics, and cosmology from Kazakhstan.
Purpose	Investigation of the passage of the front of electromagnetic waves through a Magnetar in the framework of nonlinear electrodynamics of vacuum and general theory of relativity.
Objectives	1. to investigate various static and stationary metrics with dipole and quadrupole magnetic fields considering the rotational and quadrupole parameters; and obtain spherically symmetric and axially symmetric external solutions of the Einstein equations by using various models of nonlinear vacuum electrodynamics. 2. to investigate the passage of a plane front of an electromagnetic wave through dipole and quadrupole magnetic fields in curved spacetime with the metrics obtained earlier in the project and solve the field equations of nonlinear vacuum electrodynamics considering the curvature of space around the magnetar. 3. to analyze the possibility of detecting nonlinear magnetic lensing based on observational data from space telescopes operating in a wide energy range;
Expected and achieved results	The results obtained during the implementation of this Project will be published in 2 articles in peer-reviewed scientific publications in the scientific direction of the project, listed in the 1 (first), 2 (second) quartiles in the Web of Science database and(or) with a CiteScore percentile in the Scopus database of at least 65, and in 1 more article in domestic editions included in CCSES MES RK. Results achieved: ***for 2022*** ***For Problem 1*** Solution of Einstein's equations for magnetars taking into account the magnetic field, rotation and quadrupole moment. Development of computer codes in Maple and

	Mathematica for numerical study of the problem and for performing analytical calculations The Einstein equations for magnetars are solved taking into account the magnetic field, rotation and quadrupole moment. Computer codes have been developed in Maple and Mathematica for the numerical study of the problem and for performing analytical calculations. ***For Task 1.1*** Development of computer codes in Maple and Mathematica for numerical study of the problem and for performing analytical calculations Computer codes were written in Maple and Mathematica for the numerical study of the problem and for performing analytical calculations. ***For Problem 1.2*** Solution of Einstein's equations for magnetars, taking into account the dipole and quadrupole magnetic field, rotation and quadrupole moment of the magnetar. An approximate metric for magnetars is obtained taking into account the dipole and quadrupole magnetic field, rotation and quadrupole moment of the magnetar. ***for 2023*** ***For Task 2*** Study of the passage of the electromagnetic wave front of the dipole and quadrupole magnetic field of a magnetar in curved space-time Analytical and numerical solutions are obtained for model problems of the passage of the electromagnetic wave front of the dipole and quadrupole magnetic field of a magnetar in curved space-time. A numerical calculation of the passage of the front of an electromagnetic wave of the dipole and quadrupole magnetic field of a magnetar in Schwarzschild space-time in harmonic coordinates has been carried out ***For Problem 2.1*** Study of the passage of the electromagnetic wave front of the dipole magnetic field of a magnetar in curved space-time with a quadrupole source The parameters of the wave transmitted through the dipole magnetic field of a magnetar in curved space-time with a quadrupole source are determined. A numerical calculation of the passage of the electromagnetic wave front of the dipole and quadrupole magnetic field of a magnetar in the space-time of a quadrupole source has been carried out.

	For Problem 2.2 Study of the passage of the electromagnetic wave front of the quadrupole magnetic field of a magnetar in curved space-time with a quadrupole source The parameters of the wave transmitted through the quadrupole magnetic field of a magnetar in curved space-time with a quadrupole source are determined
Research team members with their identifiers (Scopus Author ID, Researcher ID, ORCID, if available) and links to relevant profiles	1. Dr. Medeu Abishev. ScopusID AuthorID (h-index=6): https://www.scopus.com/authid/detail.uri?authorId=26530759900. WoS ResearcherID (h-index=5): https://www.webofscience.com/wos/author/record/1556025. ORCID: https://orcid.org/0000-0003-3602-6934. 2. Dr. Saken Toktarbay. ScopusID AuthorID (h-index=5): https://www.scopus.com/authid/detail.uri?authorId=56336189300; WoS ResearcherID (h-index=5): https://www.webofscience.com/wos/author/record/1379146; ORCID: https://orcid.org/0000-0002-5699-4476/. 3. Dr. Yerlan Aimuratov. ScopusID AuthorID (h-index=8): https://www.scopus.com/authid/detail.uri?authorId=56743315700. WoS ResearcherID (h-index=7): https://www.webofscience.com/wos/author/record/1258987. ORCID: https://orcid.org/0000-0001-5717-6523. 4. Tursynbek Yernazarov. ScopusID AuthorID (h-index=1): https://www.scopus.com/authid/detail.uri?authorId=58508797700. WoS ResearcherID (h-index=0): https://www.webofscience.com/wos/author/record/51788571. ORCID: https://orcid.org/0000-0001-8411-4942. 5. Adel Umirbayeva. ScopusID AuthorID (h-index=1): https://www.scopus.com/authid/detail.uri?authorId=57776936900 WoS ResearcherID (h-index=1): https://www.webofscience.com/wos/author/record/47262848. ORCID: https://orcid.org/0000-0001-9339-4990. 6. Nurzat Kenzhebayev. Scopus AuthorID (h-index=0): https://www.scopus.com/authid/detail.uri?authorId=57212102197. WoS ResearcherID (h-index=0): https://www.webofscience.com/wos/author/record/23870703. ORCID: https://orcid.org/0000-0002-9505-3492.
List of publications with links to them	- *two oral talks on conference «New trends in theoretical physics» National University of Uzbekistan, October 23 (Monday) – October 28 (Saturday), 2023.* 1 **Abishev M.** Propagation of gravitational and electromagnetic waves through the magnetic field of the magnetar in Nonlinear vacuum electrodynamics 2 **Yernazarov T.** Nonlinear electrodynamical lensing of electromagnetic waves in the dipole magnetic field of the magnetar - *two oral talks on conference «XV International Conference on Gravitation, Astrophysics and Cosmology» (ICGAC15) July 3 – 7, 2023 Kolon Hotel, Gyeongju, Korea* 1 **Abishev M.** Nonlinear Vacuum Electrodynamic effects on magnetars

	2 **Yernazarov T.** Nonlinear electrodynamical lensing of electromagnetic waves on the dipole magnetic field of the magnetar. - *one oral talks on conference «Third Annual Meeting of Kazakh Physical Society» National Nuclear Center of the Republic of Kazakhstan, June 7–11, 2023, Kurchatov* 1 Abishev M. More On Gravitational Waves From Double Monodromy Inflation - *two oral talks on conference «Abdildin Readings 2023»* 1 **Abishev M.** Propagation of gravitational and electromagnetic waves through the magnetic field of the magnetar // 30 min oral talk 15.04.2023, «Abdildin Readings 2023», 12-15 April 2023, Al-Farabi KazNU, Almaty, Kazakhstan 2 **Yernazarov T.** Effects of nonlinear vacuum electrodynamics during the passage of the beam front through the magnetar magnetosphere // 15 min oral talk 15.04.2023, «Abdildin Readings 2023», 12-15 April 2023, Al-Farabi KazNU, Almaty, Kazakhstan - *one conference proceedings published:* 1 **Yernazarov T., Abishev M., Aimuratov Y.** Correspondence of gamma radiation coming from GRBs and magnetars based on the effects of nonlinear vacuum electrodynamics // The Sixteenth Marcel Grossmann Meeting. Conference Proceedings, pp. 4401–4409, February 2023. https://doi.org/10.1142/9789811269776_0371. - *one research article is accepted for publication in the journal ranked Q2 in Scopus database:* 1 Beissen N., **Abishev M., Toktarbay S., Yernazarov T., Aimuratov Y.**, Khassanov M. Nonlinear electrodynamical lensing of electromagnetic waves on the dipole magnetic field of the magnetar // 2023 (*Принята к публикации в журнале International Journal of Modern Physics D*). https://doi.org/10.1142/S0218271823501067
Patents	-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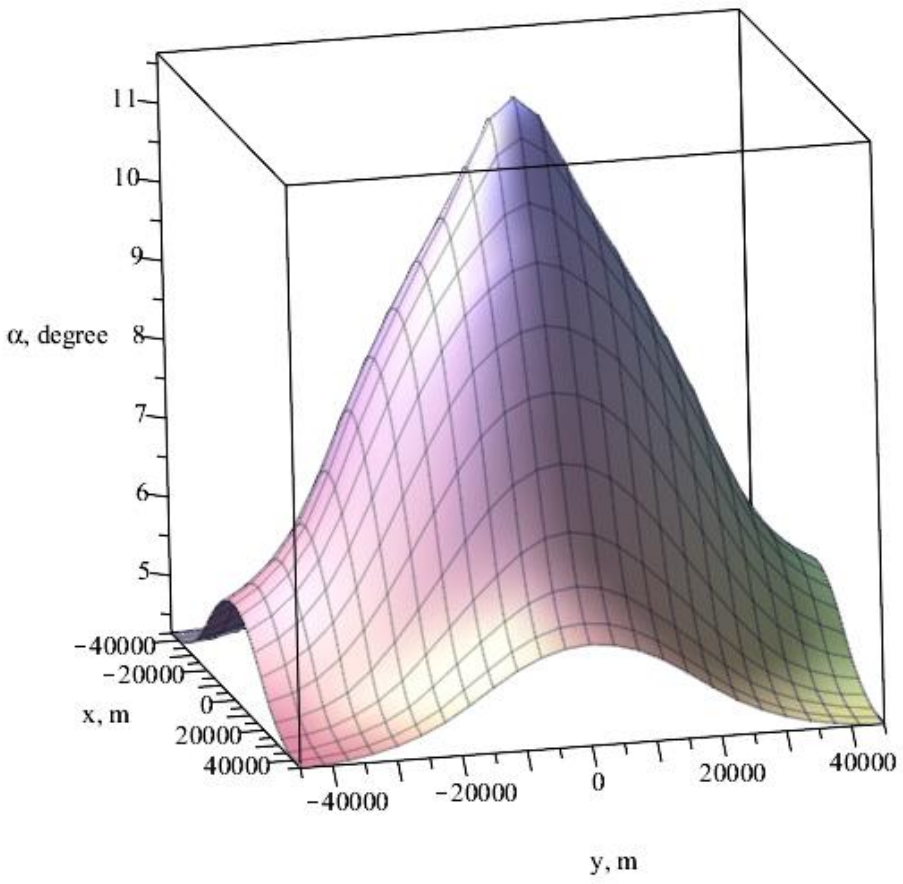
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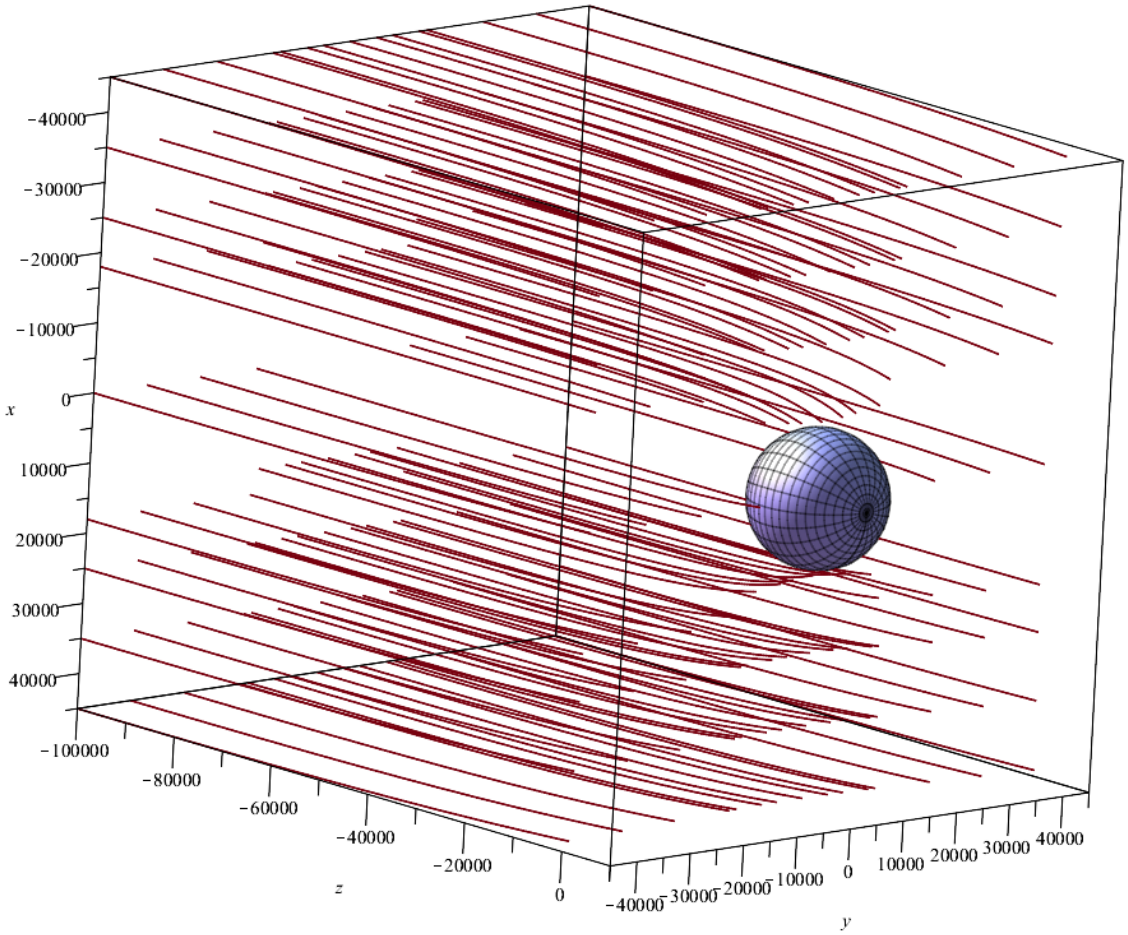
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