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DOES AN ACTIVE SUN BRING SATELLITES DOWN SOONER? SOLAR ACTIVITY AND THE RE-ENTRY OF UNCONTROLLED OBJECTS IN LOW EARTH ORBIT, 1990-2025

Abstract: When the Sun is active, the upper atmosphere heats up and expands, and objects in low Earth orbit meet more drag. This study asks whether that effect is visible in the public catalogue of all tracked objects: do uncontrolled objects re-enter the atmosphere more often in years of high solar activity? Using the CelesTrak satellite catalogue and the yearly sunspot number of the Royal Observatory of Belgium (SILSO), the share of rocket bodies in low Earth orbit that re-entered in each year from 1990 to 2025 was compared with solar activity. Rocket bodies were chosen because nobody steers them down and they are rarely created in large bursts. The yearly re-entry share of rocket bodies was strongly correlated with the sunspot number (Pearson $r = 0.80$, Spearman $\rho = 0.76$, 36 years). On average it was 4.83% in the 11 years with a sunspot number of at least 100 and 2.10% in the 13 years below 30; an increase of 100 in the sunspot number was associated with a 1.76 times higher re-entry share (95% block-bootstrap interval 1.43-2.08). The raw number of re-entries followed solar activity more closely than the number of objects in orbit. For debris the link was weaker, because large break-ups dominate some years. Starlink satellites, which are controlled and can be lowered on purpose, re-entered at a median age of 2.5-4 years. The results agree with the physical picture of solar-driven drag and show that it can be seen in a simple yearly count.

Keywords: solar activity, sunspot number, atmospheric drag, orbital decay, re-entry, rocket bodies, space debris, Starlink

Introduction

Every object in low Earth orbit slowly loses height because the thin upper atmosphere still slows it down. How fast this happens depends strongly on the density of the thermosphere, the layer of the atmosphere above about 90 km, and that density changes with the Sun. When the Sun is active, its ultraviolet radiation heats and expands the thermosphere, so the density at a given height can be many times higher than when the Sun is quiet [1]. Solar storms add short bursts: in February 2022, 38 of 49 newly launched Starlink satellites were lost after a geomagnetic storm increased the drag at their very low initial altitude [2].

Solar activity is usually measured by the sunspot number, a series kept for centuries and recalibrated in 2015 by the Royal Observatory of Belgium [3, 4]. It rises and falls in cycles of about eleven years: the period studied here includes the maxima around 1990-1991, 2000-2002, 2014 and 2024 and the deep minima around 1996, 2008-2009 and 2019.

Most studies of this effect use precise orbits of a few objects and models of the atmosphere [1, 2]. This study asks a simpler question that anyone can check with public data: is the effect visible in the whole catalogue of tracked objects, as more uncontrolled objects falling out of orbit in years when the Sun is active? The question matters because uncontrolled

re-entries of rocket bodies and debris are not planned, and because the number of objects in low Earth orbit is now growing fast [5].

The author's first study looked at how long landers survive on other worlds [8]; for this second study he chose the direction "the Sun and satellites" from three options proposed by his mentor on 4 October 2026. Before seeing the numbers for the whole catalogue, he wrote on 13 October 2026 that the Sun does influence when satellites leave orbit, but that for Starlink other factors matter more: the number of satellites in orbit, because "if there are 10 satellites and 2 come down, then with 100 satellites 20 will come down", and their age, because a Starlink satellite is designed to work for about five to seven years, so those launched in 2019-2020 reach the end of their life around 2025. Both points are tested below.

Materials and Methods

Data on objects. The satellite catalogue (SATCAT) published by CelesTrak lists every object tracked in Earth orbit since 1957 with its type (payload, rocket body, debris), launch date, re-entry ("decay") date and orbital period [6, 7]. The file was downloaded on 27 October 2026 and contained 71,149 records.

Data on the Sun. The yearly mean total sunspot number (version 2.0) was taken from the World Data Center SILSO of the Royal Observatory of Belgium [4], downloaded on 27 October 2026.

Sample. Only objects orbiting the Earth with an orbital period below 128 minutes were kept, a common threshold for low Earth orbit. For each year from 1990 to 2025, two numbers were counted for each object type: the number of objects in orbit on 1 January (launched before that date and not yet re-entered) and the number of those objects that re-entered during the year. Their ratio, in percent, is called the re-entry share. Using a share rather than a raw count answers the author's point that more objects in orbit give more re-entries.

Why rocket bodies. The main test uses rocket bodies, the spent upper stages left in orbit. Nobody steers them down, so their re-entry is set by drag, and unlike debris they are not created in hundreds at once by explosions or collisions. Debris was analysed separately. Payloads were not used for the main test, because many of them are lowered on purpose at the end of their mission.

Analysis. The re-entry share was compared with the sunspot number by the Pearson and Spearman correlation coefficients over the 36 years. To give the size of the effect, the logarithm of the re-entry share was regressed on the sunspot number; the slope is reported as the factor by which the share changes when the sunspot number rises by 100. Because neighbouring years are not independent (the solar cycle changes slowly), the 95% interval of this factor was estimated by a moving-block bootstrap with blocks of five years (4,000 resamples). As a further check, the year-to-year changes of the two series were also correlated, which removes slow trends. Finally, years with a sunspot number of at least 100 were compared with years below 30. All calculations were done in Python; the script is kept with the data.

Starlink. For Starlink satellites, the yearly re-entries from 2023 to 2025 were counted together with the satellites' age at re-entry and their launch year, to test the author's point about age.

Results

Rocket bodies. The number of rocket bodies in low Earth orbit changed little over the period, from 772 on 1 January 1990 to 999 on 1 January 2025, while the number re-entering

each year ranged from 10 (2010) to 66 (2024). The yearly re-entry share followed the solar cycle closely (Figure 1). Its correlation with the sunspot number was r = 0.80 (Spearman ρ = 0.76). The year-to-year changes were also correlated (r = 0.63), so the link is not just a slow trend shared by both series.

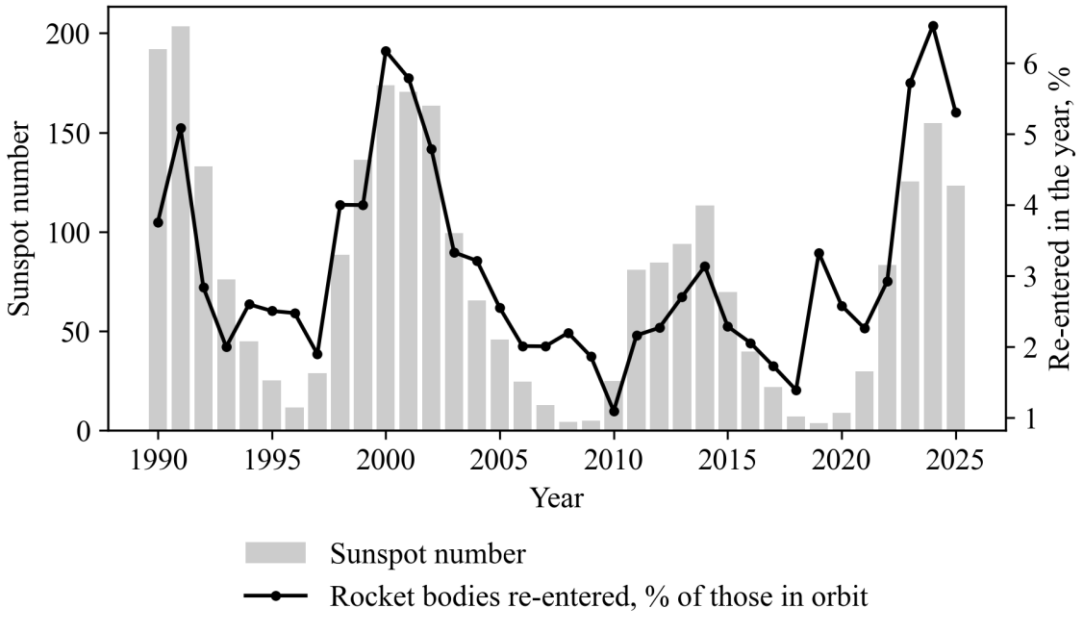


Figure 1 - Yearly mean sunspot number (bars, left axis) and the share of rocket bodies in low Earth orbit on 1 January that re-entered during the year (line, right axis), 1990-2025. Data: SILSO [4], CelesTrak SATCAT [6]

In the 11 years with a sunspot number of at least 100 the average re-entry share was 4.83%, against 2.10% in the 13 years with a sunspot number below 30. An increase of 100 in the sunspot number was associated with a 1.76 times higher re-entry share (95% interval 1.43-2.08). The highest shares were in the solar maxima: 6.17% in 2000 and 6.52% in 2024; the lowest, 1.10%, in 2010, after the deep minimum of 2008-2009.

Table 1 - Solar activity and the yearly re-entry of rocket bodies and debris in low Earth orbit, 1990-2025

Measure	Rocket bodies	Debris
Correlation of re-entry share with sunspot number, Pearson r	0.80	0.36
Correlation of re-entry share with sunspot number, Spearman ρ	0.76	0.56
Correlation of year-to-year changes (log share vs sunspot number)	0.63	0.43
Correlation of the raw number of re-entries with sunspot number	0.73	0.28
Correlation of the raw number of re-entries with the number in orbit	0.44	0.00
Re-entry share, mean of years with sunspot number ≥ 100 (11 years), %	4.83	4.10
Re-entry share, mean of years with sunspot number < 30 (13 years), %	2.10	1.45
Factor per +100 sunspot number (95% block-bootstrap interval)	1.76 (1.43-2.08)	2.11 (1.28-4.26)

The author's point about numbers. For rocket bodies, the raw number of re-entries was more closely related to the sunspot number (r = 0.73) than to the number of rocket bodies in orbit (r = 0.44). Over these 36 years the population of rocket bodies grew by less than a third (772 to 999), so its size could not explain why the yearly count rose and fell by a factor of more than six (10 to 66).

Debris. For debris the link was in the same direction but weaker (r = 0.36, Spearman ρ = 0.56), and its interval was wide (1.28-4.26). Single events dominate some years: in 2008, a year of almost no sunspots, 666 pieces of debris re-entered, and in 2022 the re-entries jumped to 1,896, while in neighbouring years they were in the hundreds. Such jumps are typical after an object breaks up at low altitude and its fragments decay within a few years whatever the Sun does; which events caused these particular years was not studied here. This is why rocket bodies are the cleaner test.

Starlink. Starlink re-entries grew from 90 in 2023 to 334 in 2024 and 671 in 2025. The median age at re-entry rose over the same years from 2.5 to 3.2 and 4.0 years, and 455 of the 671 satellites that re-entered in 2025 had been launched in 2019-2021. Of the 833 Starlink satellites launched in 2020, 668 had re-entered by the time the catalogue was downloaded.

Discussion

The main result is that the share of uncontrolled rocket bodies leaving low Earth orbit rises and falls with the solar cycle, roughly doubling between quiet and active years. This agrees with the physical explanation: an active Sun heats and expands the thermosphere,

raising the density at satellite altitudes [1], so objects lose height faster. The effect is strong enough to be seen in a simple yearly count of a whole catalogue, without precise orbits or atmospheric models.

The author's first point, that more satellites in orbit means more re-entries, is true in general and is the reason the share and not the raw count was used. For rocket bodies, however, the population changed little, and the solar cycle explained the ups and downs better than the population did. For Starlink, the population grew very fast, so the growth in re-entries cannot be split between the Sun and the number of satellites from these data alone.

His second point, about age, fits the Starlink data: re-entries rose as the satellites launched in 2019-2021 reached an age of about four years, and most of the 2020 launches had already re-entered. Starlink satellites are controlled and can be lowered on purpose, so their re-entries may say more about the operator's plans than about the Sun. In 2023-2025 their ageing coincided with a solar maximum, so for Starlink the two causes cannot be separated, which is why the effect of the Sun was measured on rocket bodies.

Limitations. The catalogue lists only objects large enough to be tracked, and the orbital period of an object that has already re-entered is its last known value, so the division into low and higher orbits is approximate. A yearly count is coarse: within a year, re-entries depend on the height of each object, and storms such as the one in February 2022 act within days [2]. The year 2019 does not fit the pattern: at the solar minimum, 32 rocket bodies re-entered (3.32%), the cause of which was not studied here. Finally, a correlation over 36 years shows that the two series move together; the physical mechanism comes from earlier work [1], not from this study.

Conclusion

In the public CelesTrak catalogue, the yearly share of rocket bodies in low Earth orbit that re-entered the atmosphere followed the solar cycle closely from 1990 to 2025 ($r = 0.80$): it averaged 4.83% in years with a sunspot number of at least 100 and 2.10% in quiet years, and an increase of 100 in the sunspot number was associated with a 1.76 times higher share. The number of rocket bodies in orbit changed too little to explain this. For debris the link was weaker because of large break-ups, and for Starlink, which can be lowered on purpose, re-entries tracked the satellites' age. An active Sun does bring uncontrolled objects down sooner, and the effect is visible in a simple yearly count. A next step would be to count re-entries by month around strong geomagnetic storms.

Data availability. The CelesTrak satellite catalogue and the SILSO sunspot number are publicly available at the addresses in references [4] and [6]. The yearly table and the analysis script are kept by the author's research mentor and are available on request.

Author contributions and use of AI tools. The author chose the research direction from options prepared by his mentor and wrote the expectation about the number and the age of satellites tested in this paper (13 October 2026). The data were downloaded and analysed, and the English text was drafted, by his mentor with the help of an AI assistant (Claude); the author read the final text and confirmed that it describes his part correctly.

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Conflict of interest. The author declares no conflict of interest.

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МАЗМҰНЫ – СОДЕРЖАНИЕ – CONTENT

ӘЛЕУМЕТТІК-ЭКОНОМИКАЛЫҚ ЖӘНЕ ҚҰҚЫҚ ҒЫЛЫМДАРЫ - СОЦИАЛЬНО-ЭКОНОМИЧЕСКИЕ И ЮРИДИЧЕСКИЕ НАУКИ - SOCIO-ECONOMIC AND LEGAL SCIENCES

Төлегенов Тимур Сейфуллаулы
ДИНАМИКА ТУРИСТСКИХ ПОТОКОВ И ЭФФЕКТИВНОСТЬ ИНФРАСТРУКТУРЫ ТУРКЕСТАНА: ОТ ЭКСТЕНСИВНОГО РОСТА К СМАРТ-УПРАВЛЕНИЮ 12

Alexander Gorevoy
WHICH INEQUALITY STATISTICS SURVIVE AN ADMINISTRATIVE BOUNDARY CHANGE? EVIDENCE FROM KAZAKHSTAN, 2010–2023 16

Rakhimov Djalil
DOES THE SHIFT TO CASHLESS PAYMENTS GO TOGETHER WITH FASTER GROWTH IN HOUSEHOLD CREDIT? EVIDENCE FROM THE REGIONS OF KAZAKHSTAN, 2023-2025 28

Kazhgerey Asan
HOW MANY FOOD BASKETS DOES AN AVERAGE WAGE BUY? WAGES AND FOOD PRICES IN THE 20 REGIONS OF KAZAKHSTAN, 2024-2026 39

Tagimova Alua
WHO WAS LEFT BEHIND? EDUCATION AND FINANCIAL INCLUSION IN KAZAKHSTAN AND THREE CENTRAL ASIAN NEIGHBOURS, 2021-2024 46

Wei Wei, Mynzhanova Gulzhakan, Niyetalina Gaukhar
DIGITAL–PHYSICAL INTEGRATION AND ECONOMIC PERFORMANCE IN INDUSTRIAL INTEGRATED ENERGY SYSTEMS: A SCENARIO-BASED ANALYSIS OF SMART GRID CONTROL, BATTERY ENERGY STORAGE, AND DIGITAL TWINS 53

Xu Fumin, Wei Wei, Ruziyeva Elvira, Moldabekova A.
FROM CULTURAL RESOURCES TO GLOBAL CONSUMER VALUE: THE BRIDGE–IMC MODEL AND THE INTERNATIONALIZATION OF BLACK MYTH: WUKONG UNDER THE BELT AND ROAD INITIATIVE 66

Ibraimkhan Alikhan
WHICH CRIMES CAN A 14-YEAR-OLD BE TRIED FOR? THE LIST IN ARTICLE 15 OF KAZAKHSTAN'S CRIMINAL CODE COMPARED WITH 30 OTHER JURISDICTIONS 82

Yerboluly Madi
DID IMPORTED CARS REALLY GET CHEAPER? CHINESE CARS AND THE AVERAGE CUSTOMS VALUE OF PASSENGER CARS IMPORTED INTO KAZAKHSTAN, 2015-2025 93

Салимбаев Ербол Аманжолович
АНАЛИЗ ИНВЕСТИЦИОННОЙ АКТИВНОСТИ КАК ИНДИКАТОР ИЗМЕНЕНИЙ ПОТЕНЦИАЛЬНОГО СПРОСА НА КОНСАЛТИНГОВЫЕ УСЛУГИ 101

Rambergenov Ramil
REGIONAL NEW-FIRM FORMATION IN UZBEKISTAN AFTER THE 2017 REFORMS: PERSISTENCE IN SCALE, CONVERGENCE IN INTENSITY, AND RECOMPOSITION TOWARD TRADE 109

Abdesh Dinara
FROM A WOMEN'S LEAD TO A MEN'S LEAD: THE GENDER GAP IN DIGITAL PAYMENTS IN KAZAKHSTAN AND THREE CENTRAL ASIAN NEIGHBOURS, 2021-2024 118

Amangeldi Aidana
DID SMALL BUSINESS IN KAZAKHSTAN REALLY SHRINK IN 2026? THE NEW TAX CODE, REGIONAL TAX RATES AND THE FALL IN THE NUMBER OF INDIVIDUAL ENTREPRENEURS 126

Cheng Che
BUILD, BUY, OR PARTNER? ENTRY MODE SELECTION AND RISK GOVERNANCE FOR WIND POWER INVESTMENT IN KAZAKHSTAN **135**

Wang Liang
FROM CAPACITY EXPANSION TO SYSTEM VALUE: COORDINATED DEVELOPMENT OF RENEWABLE ENERGY, GRID FLEXIBILITY AND ENERGY STORAGE IN KAZAKHSTAN **148**

Chen Jun
CONSTRUCTION-PERIOD CREDIT RISK MANAGEMENT FOR LARGE INFRASTRUCTURE PROJECT FINANCE IN KAZAKHSTAN **161**

Alniyaz Danial
HOW MUCH FUEL DOES A HYBRID REALLY SAVE? A SAME-MODEL COMPARISON OF HYBRID AND GASOLINE CARS IN US FUEL ECONOMY **175**

Assem Yergali, Maral Assanova
DIGITAL TRANSFORMATION AND SUSTAINABLE BUSINESS MODEL INNOVATION IN SMALL AND MEDIUM-SIZED ENTERPRISES: A SYSTEMATIC REVIEW OF DYNAMIC CAPABILITIES, VALUE CREATION, AND THE CREDIBILITY GAP IN EMERGING ECONOMIES **182**

Бейбіт Инара Алибекқызы, Едилов Саназар
ВОДА ИЗ ТУМАНА ИЛИ ВОДА ИЗ МОРЯ: ПОРОГОВАЯ СТОИМОСТЬ, ПРИ КОТОРОЙ ТУМАНОУЛОВИТЕЛИ КОНКУРЕНТОСПОСОБНЫ В МАНГИСТАУСКОЙ ОБЛАСТИ **195**

Zhenisbekova Aknur
DID A TENGE DEPOSIT OR THREE KAZAKHSTANI SHARES PROTECT SAVINGS FROM INFLATION? REAL RETURNS OF BANK DEPOSITS, KAZATOMPROM, KEGOC AND KASPI.KZ, 2020-2025 ..... **207**

Абилдаева Аселя
ОРГАНИЗАЦИОННАЯ ГОТОВНОСТЬ ВУЗОВ КАЗАХСТАНА К ВНЕДРЕНИЮ ЭНДАУМЕНТ-ФОНДОВ: КОНЦЕПТУАЛЬНАЯ РАМКА НА ОСНОВЕ ОБЗОРА ЛИТЕРАТУРЫ И АНАЛИЗА ДОКУМЕНТОВ **215**

Yang Juntao
DIGITAL ESG GOVERNANCE AND NEXT-GENERATION DIGITAL COMPETENCY AS DRIVERS OF SUCCESSION IN FAMILY AGRICULTURAL ENTERPRISES: A CONCEPTUAL FRAMEWORK ... **229**

Kairbek Mariya Islamkyzy, Kylbaev Erlan Serikovich
STATE SUPPORT FOR THE DIGITALIZATION OF MANUFACTURING IN THE REPUBLIC OF KAZAKHSTAN: AN ANALYSIS OF ITS COVERAGE OF MARKETING AND SALES ACTIVITIES **242**

Tilep Aiaru
WHEN DID IT EXPORTS TAKE OFF? ICT SERVICE EXPORTS OF KAZAKHSTAN, ARMENIA, GEORGIA AND THREE NEIGHBOURS, 2015-2024 ..... **255**

Anuarbek Murager
DID THE TENGE STOP FOLLOWING OIL? BRENT PRICES AND THE TENGE-DOLLAR RATE BEFORE AND AFTER FEBRUARY 2022 ..... **266**

Kaiyrbek Zhanadil
HOW ACCURATELY CAN OBSERVABLE LISTING DATA ESTIMATE FAIR PRICES FOR USED CARS IN KAZAKHSTAN? A HEDONIC MODEL OF 2,546 ONLINE LISTINGS **276**

Wen Yali
PERCEIVED ORGANIZATIONAL SUPPORT AND TURNOVER INTENTION AMONG KNOWLEDGE WORKERS IN A CHINESE PRIVATE TRAINING INSTITUTION: THE MEDIATING ROLE OF AFFECTIVE ORGANIZATIONAL COMMITMENT **289**

Құрманалиева Дана
ИСТОЧНИКИ ФИНАНСИРОВАНИЯ ИННОВАЦИОННЫХ ПРОЕКТОВ И КРИТЕРИИ ВЫБОРА ФИНАНСОВОЙ МОДЕЛИ **300**

ТЕХНИКАЛЫҚ ҒЫЛЫМДАР - ТЕХНИЧЕСКИЕ НАУКИ - TECHNICAL SCIENCE

Nurmakhan Almira
ADVANTAGES OF FIBER OPTIC COMMUNICATION OVER TRADITIONAL COPPER CABLES **307**

Kozhabai Bereke
SECURITY CHALLENGES IN IOT-BASED TELECOMMUNICATION NETWORKS **315**

Azamatuly Yerassyl
WHY AI-GENERATED CODE FAILS A BENCHMARK: A FAILURE ANALYSIS OF THREE OPEN LANGUAGE MODELS ON 30 HUMANEVAL+ TASKS **324**

Nurzhan Sanzhar
A FEW SHELLS, A FEW OPERATORS: WHERE LOW EARTH ORBIT IS CROWDED IN AN ALTITUDE-INCLINATION MAP OF 16,620 ACTIVE SATELLITES **333**

Askarbek Nurislam
CAN THE WEATHER TELL WHICH DAYS IN ASTANA WILL BE POLLUTED? CLASSIFYING PM2.5 EXCEEDANCE DAYS WITH MACHINE LEARNING AND CHECKING THE DATA AGAINST A GROUND MONITOR **339**

Iliyas Arman
SHOOTING ON THE MOVE: HOW MUCH AIM A ROBOT LOSES BY IGNORING ITS OWN VELOCITY, AND WHETHER A VIRTUAL-TARGET CORRECTION RECOVERS IT **350**

Ануар Әлімжан Бахытжанұлы, Сексенбаева Айша Курманбековна
СРАВНИТЕЛЬНЫЙ АНАЛИЗ СТАНДАРТОВ И МЕТОДИК ОБУЧЕНИЯ КИБЕРБЕЗОПАСНОСТИ: NICE FRAMEWORK, ECSF И ПРАКТИКО- ОРИЕНТИРОВАННЫЕ ТЕХНОЛОГИИ **356**

Mukhamedzhan Yerganat
GROWTH OF GITHUB DEVELOPER COMMUNITIES IN KAZAKHSTAN, UZBEKISTAN AND KYRGYZSTAN, 2020-2026: EVIDENCE FROM THE GITHUB INNOVATION GRAPH **366**

Kashkinov Alden
WHAT DECIDES HOW LONG A LANDER WORKS ON ANOTHER WORLD? SURFACE LIFETIMES OF 55 LANDERS ON THE MOON, VENUS, MARS, TITAN AND SMALL BODIES IN THE GCAT CATALOGUE, 1966-2025 ..... **378**

Kenesbek Miras
HOW MANY HERONIAN TRIANGLES HAVE A GIVEN LONGEST SIDE? A COMPLETE COUNT UP TO 2000 AND THE RIGHT TRIANGLES HIDDEN INSIDE **390**

Amirlan Seitkadyrov, Akezhan Omashev
AUTOMATIC MULTIPLE-CHOICE QUESTION GENERATION USING ARTIFICIAL INTELLIGENCE **401**

Idrissov Amirzhan
WHERE DO SMALL OPEN LANGUAGE MODELS BREAK ON OLYMPIAD MATHEMATICS? DOMAIN, DIFFICULTY AND MODEL SIZE ON OMNI-MATH **410**

Маматаева Рамина Адилгазыевна, Бидуәлі Алмат Алматұлы
ОБЗОР И СРАВНЕНИЕ ПОПУЛЯРНЫХ КРОССПЛАТФОРМЕННЫХ ФРЕЙМВОРКОВ ДЛЯ РАЗРАБОТКИ МОБИЛЬНЫХ ПРИЛОЖЕНИЙ **415**

Қасен Ғауһар Ғалымжанқызы, Алкеева Дана Мирасовна
КОМПЬЮТЕРЛІК КӨРУДІ ПАЙДАЛАНЫП,МЕХАНИКАЛЫҚ ДЕНЕ ЗАҢЫН АНЫҚТАУ АЛГОРИТМДЕРІН ӘЗІРЛЕУ **421**

Khalilzade Seymur Fazil oglu
ASSESSING THE IMPACT OF ELECTRIC VEHICLES ON ENERGY DEMAND IN HIGH-RISE RESIDENTIAL BUILDINGS **434**

Igilikov Adilkhan Igilikovich
PRE-TRAINED REPRESENTATIONS OF PRIOR-ADMISSION HISTORY IMPROVE ONE-YEAR, BUT NOT IN-HOSPITAL, MORTALITY PREDICTION IN ICU PATIENTS WITH CHRONIC DISEASE: A MIMIC-IV STUDY **449**

Nurgali Dias, Nurgali Miras, Akashov Aslan
PREDICTIVE TRAFFIC MANAGEMENT: EXPLORING SOLUTIONS TO TRAFFIC CONGESTION IN ASTANA, KAZAKHSTAN **461**

ПӘНДЕР АРАЛЫҚ ҒЫЛЫМДАР – МЕЖДИСЦИПЛИНАРНЫЕ НАУКИ – INTERDISCIPLINARY SCIENCES

Albiyev Asser
HOW MUCH OF AN ARTICLE COUNT IS HUMAN WORK? DECOMPOSING THE CREATION OF FIVE WIKIPEDIAS, 2010–2025 ..... **467**

Amangeldy Nurbolat
HOW MUCH OF KAZAKHSTAN'S URBAN BUILT STOCK PREDATES ITS SEISMIC CODES, AND WHERE DOES THAT STOCK SIT RELATIVE TO HAZARD? **477**

Torekhan Sabrina
WHERE ALMATY WALKS ITS OWN WAY: INFORMAL SHORTCUTS IN OPENSTREETMAP AND THE DETOURS THEY AVOID **483**

Ailan Salybekova
PARENTAL SUPPORT, PARENTAL CONTROL, STRESS AND EARLY ALCOHOL USE IN ADOLESCENT GIRLS: A NARRATIVE REVIEW WITH A FOCUS ON KAZAKHSTAN **488**

Yerboluly Madi
WHY IS KAZAKHSTAN'S GENDER GAP AT THE TOP OF CHESS SO SMALL? A BIRTH-COHORT COMPARISON ON THE FIDE RATING LIST **496**

Omashev Akezhan
REGIONAL HEALTH AND SOCIAL INDICATOR PATTERNS AND PCA- BASED MORTALITY MODELING IN KAZAKHSTAN, 2011–2024. A TWO- PART EXPLORATORY ECOLOGICAL ANALYSIS **501**

Мадиярова Жанел Биржановна
ДИПФЕЙК ТЕХНОЛОГИЯСЫНЫҢ ҚОҒАМДЫҚ ПІКІРГЕ ЫҚПАЛЫ ЖӘНЕ ОНЫ ҚҰҚЫҚТЫҚ РЕТТЕУ ТӘЖІРИБЕСІ **511**

Bolatov Sanzhar
HOW MUCH DOES KAZAKH SPEECH RECOGNITION LOSE WHEN THE MODEL GETS SMALLER? KAZAKH AGAINST 82 LANGUAGES IN THE PUBLISHED WHISPER RESULTS **521**

Ilya Tsoy
WHO PAYS MORE TOKENS FOR THE SAME SENTENCE? RUSSIAN, KOREAN AND ENGLISH IN FOUR LANGUAGE MODEL TOKENIZERS ON 1,012 FLORES-200 SENTENCES **530**

Assan Ramazan
WHICH NAME DO READERS STILL USE? FORMER NAMES OF RENAMED KAZAKHSTANI CITIES IN RUSSIAN AND KAZAKH WIKIPEDIA PAGE VIEWS, 2015–2026 ..... **543**

Nigmadilova Zhasmin
WHAT REPLACES PARABENS? THE PARABEN-FREE LABEL ACROSS PRODUCT CATEGORIES IN THE OPEN BEAUTY FACTS DATABASE **556**

ӘЛЕУМЕТТІК ЖӘНЕ ГУМАНИТАРЛЫҚ ҒЫЛЫМДАР - СОЦИАЛЬНО-ГУМАНИТАРНЫЕ НАУКИ - SOCIAL SCIENCES AND HUMANITIES

Мұқатаева Айзат Амантайқызы, Стамбекова Жанат Байғазықызы, Слямханова Гүлім Болатқызы, Қызырбек Аяулым Ерболқызы
ЖАСАНДЫ ИНТЕЛЛЕКТ ДӘУІРІНДЕГІ ҒЫЛЫМИ ТАНЫМ: ПОППЕР, КУН ЖӘНЕ ЛАКАТОС ИДЕЯЛАРЫ ТҰРҒЫСЫНАН ТАЛДАУ **561**

Мұқатаева Айзат Амантайқызы, Сапарханова Мадина Төлегенқызы, Окенова Аружан Муратхановна, Тұрсынғазыева Ақерке Ерболатқызы
ШӘКӘРІМ ФИЛОСОФИЯСЫНДАҒЫ ЕРКІНДІК ЖӘНЕ МОРАЛЬДЫҚ ТАҢДАУ МӘСЕЛЕСІ **571**

Komekova Saida
DO UNHAPPY REVIEWERS MIX IN MORE RUSSIAN? STAR RATINGS AND KAZAKH-RUSSIAN CODE-SWITCHING IN 175,002 ONLINE REVIEWS **580**

Zhumagali Yerbol
DOES A BIGGER MODEL CLOSE THE GAP? KAZAKH-LANGUAGE ACCURACY ON KAZAKHSTAN-SPECIFIC VERSUS UNIVERSAL SCHOOL SUBJECTS IN SMALL OPEN-WEIGHT LANGUAGE MODELS **593**

Abdrakhmanova Madina
DOES A MEDAL BUY ATTENTION? WIKIPEDIA VIEWS OF KAZAKHSTAN'S ATHLETES BEFORE AND AFTER THE PARIS 2024 OLYMPIC **597**

ПЕДАГОГИКАЛЫҚ ЖӘНЕ ПСИХОЛОГИЯЛЫҚ ҒЫЛЫМДАР – ПЕДАГОГИЧЕСКИЕ И ПСИХОЛОГИЧЕСКИЕ НАУКИ – PEDAGOGICAL AND PSYCHOLOGICAL SCIENCES

Kaldarbek Mergen
FAMILY OR SCHOOL? SOCIOECONOMIC COMPOSITION AND MATHEMATICS ACHIEVEMENT IN KAZAKHSTAN, PISA 2022 AND 2025 ..... **605**

Zhenis Adilzhan
WHICH OLYMPIAD PROBLEMS DO STUDENTS TAKE TO THE BOARD? CHOICES AND DEFENCES IN THE 8TH-GRADE LEAGUE OF KARAGANDY MATHBATTLES 2026 ..... **612**

Базарбаева Айнур Бектуровна
ДЕТСКИЙ ФОЛЬКЛОР И ПОДВИЖНЫЕ ИГРЫ КАК ИНСТРУМЕНТЫ ФОРМИРОВАНИЯ ОСНОВ ПРАВОВОЙ КУЛЬТУРЫ У ДЕТЕЙ СТАРШЕГО ДОШКОЛЬНОГО ВОЗРАСТА **619**

БИОЛОГИЯ ҒЫЛЫМДАР - БИОЛОГИЧЕСКИЕ НАУКИ - BIOLOGICAL SCIENCES

Bazhenova Diana
GROWTH DYNAMICS OF STERLET (Acipenser ruthenus L.) REARED IN A RECIRCULATING AQUACULTURE SYSTEM **622**

ТУРИСТИЧЕСКИЕ И СПОРТИВНЫЕ НАУКИ - ТУРИСТІК ЖӘНЕ СПОРТ ҒЫЛЫМДАРЫ - TOURISM AND SPORTS SCIENCES

Төлеп Жазира Маратқызы
ГАСТРОНОМИЯЛЫҚ ФЕСТИВАЛЬДЕРДІҢ ТУРИСТІК ДЕСТИНАЦИЯ ТАРТЫМДЫЛЫҒЫН ҚАЛЫПТАСТЫРУДАҒЫ РӨЛІ МЕН ДАМУ ҮРДІСТЕРІ **629**

ЕСТЕСТВЕННЫЕ НАУКИ - ЖАРАТЫЛЫСТАНУ ҒЫЛЫМДАРЫ - NATURAL SCIENCES

Нургельдина Асель Ермековна, Серикбаева Жанерке Алимжановна
ШЕКАРАСЫЗ ФИЗИКА: ӘР ЕЛДЕГІ ФИЗИКАЛЫҚ БІЛІМДІ САЛЫСТЫРУ **636**

Torekhan Sabrina
IS ALMATY A 15-MINUTE CITY? WALKING ACCESS TO SIX EVERYDAY PLACES FROM 170,838 BUILDINGS IN THE CITY'S EIGHT DISTRICTS **643**

Онгарбек Махабат Саятқызы
CU-PT ЖӘНЕ NI-PT ҚОРЫТПАЛАРЫНЫҢ ФИЗИКАЛЫҚ ҚАСИЕТТЕРІНЕ РЕТТЕЛУ ҮДЕРІСІНІҢ ЖӘНЕ ҚҰРЫЛЫМДЫҚ ӨЗГЕРІСІНІҢ ӘСЕРІН РЕТТЕУ **651**

Нургельдина Асель Ермековна, Әбдуәлі Мерей Ералықызы
ҮЙКЕЛІС КҮШІНІҢ ТАБИҒАТТАҒЫ РӨЛІ **659**

Ossipov Vladislav
MANY REPORTS, WEAK EVIDENCE? EVIDENCE LEVELS FOR MICROBIAL PLASTIC DEGRADATION IN THE 2,535 RECORDS OF PLASTICDB **664**

Нургельдина Асель Ермековна, Кабдулаева Жанель Батырбековна
РАДИОАКТИВТІЛІК. АЛЬФА, БЕТА, ГАММА СӘУЛЕЛЕРІНІҢ ТЕГІ МЕН ЗАҢДЫЛЫҚТАРЫ. ЯДРОЛЫҚ РЕАКЦИЯ ЖӘНЕ ЖАРТЫЛАЙ ЫДЫРАУ ПЕРИОДЫ **673**

Kashkinov Alden
DOES AN ACTIVE SUN BRING SATELLITES DOWN SOONER? SOLAR ACTIVITY AND THE RE-ENTRY OF UNCONTROLLED OBJECTS IN LOW EARTH ORBIT, 1990-2025 ..... **678**

Demin Mark
HOW MUCH LESS OXYGEN CAN THE WARMING CASPIAN SEA HOLD? THE LOSS OF OXYGEN SOLUBILITY IN THE NORTHERN, MIDDLE AND SOUTHERN CASPIAN, 1982-2022 ..... **684**