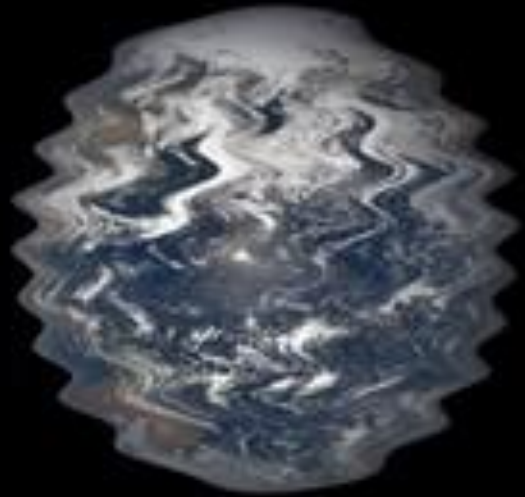
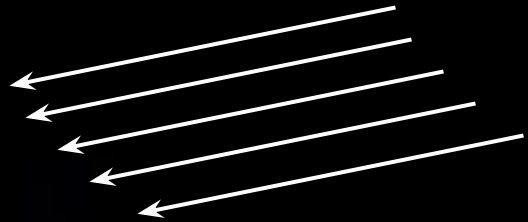
Intriguing correlation between earthquakes and cosmic radiation

J. Atmos. Sol. Terr. Phys. **247** (2023) 106068, DOI:10.1016/j.jastp.2023.106068

?





Piotr Homola

The Henryk Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences
Cosmic Ray Extremely Distributed Observatory / CREDO.science

Particle Astrophysics in Poland, Warszawa, 21.02.2025

CREDO
THE QUEST FOR THE UNEXPECTED

Graphics source: IFJ PAN / NASA / JSC

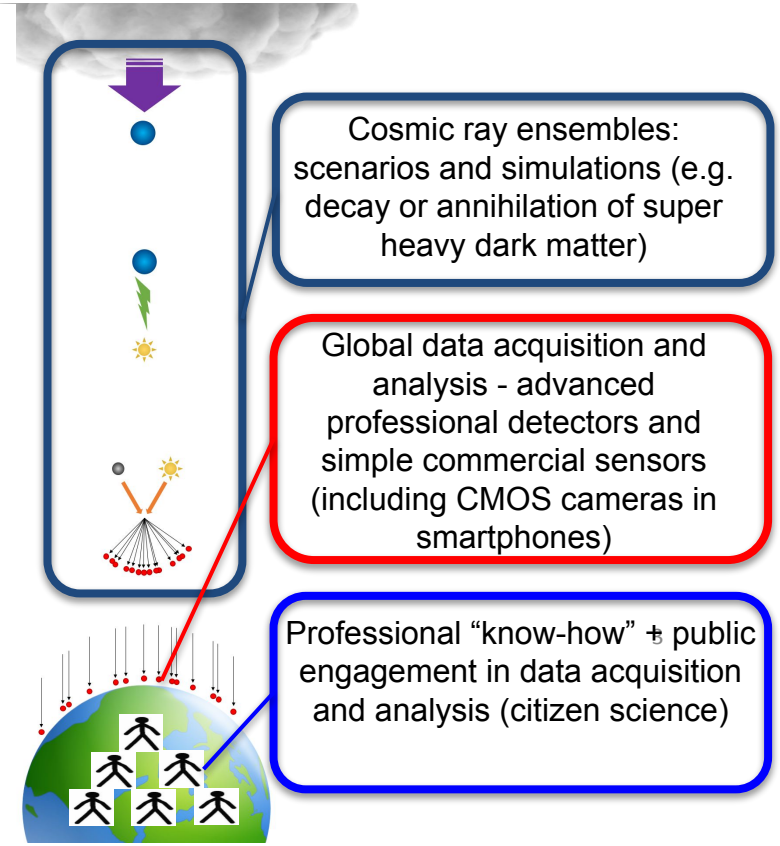

DEMOTYWATORY.PL
Correlation does not imply causation

Cosmic Ray Extremely Distributed Observatory

CREDO
THE QUEST FOR THE UNEXPECTED

study of cosmic ray correlations on a global scale: search cosmic ray ensembles

- **International collaboration**: 50 institutions from 20 countries on 5 continents
- **IFJ PAN**: founder and leader
- **Open observatory:** analyses combining data from technologically diverse devices →covering the **entire energy spectrum** of cosmic rays
- The biggest achievement to date: **observation of the cosmo-seismic correlations - a > 6σ discovery**: *J. Atmos. Sol. Terr. Phys.* 247 (2023) 106068 DOI:10.1016/j.jastp.2023.106068.



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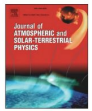

Research Paper

Observation of large scale precursor correlations between cosmic rays and earthquakes with a periodicity similar to the solar cycle

P. Homola [a,*], V. Marchenko [x], A. Napolitano [q], R. Damian [j], R. Guzik [j], D. Alvarez-Castillo [a], S. Stuglik [a], O. Ruimi [b], O. Skorenok [i], J. Zamora-Saa [c,d], J.M. Vaquero [g], T. Wibig [p], M. Knap [s], K. Dziadkowiec [j], M. Karpiel [i], O. Sushchov [a], J.W. Mietelski [a], K. Gorzkiewicz [a], N. Zabari [e], K. Almeida Cheminant [a], B. Idźkowski [h,z], T. Bulik [h,k], G. Bhatta [a], N. Budnev [r], R. Kamiński [a], M.V. Medvedev [t,u], K. Kozak [a], O. Bar [y], Ł. Bibrzycki [j], M. Bielewicz [w], M. Frontczak [l], P. Kovács [o], B. Łozowski [v], J. Miszczyk [a], M. Niedźwiecki [y], L. del Peral [n], M. Piekarczyk [j], M.D. Rodriguez Frias [n], K. Rzecki [j], K. Smelcerz [y], T. Sośnicki [j], J. Stasielak [a], A.A. Tursunov [m]

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"Astroparticle Physics Amateur"!

ARTICLE INFO

Handling Editor: Dora Pancheva

ABSTRACT

The search for correlations between secondary cosmic ray detection rates and seismic effects has long been a subject of investigation motivated by the hope of identifying a new precursor type that could feed a global early warning system against earthquakes. Here we show for the first time that the average variation of the cosmic ray detection rates correlates with the global seismic activity to be observed with a time lag of approximately two weeks, and that the significance of the effect varies with a periodicity resembling the undecenal solar cycle, with a shift in phase of around three years, exceeding 6 σ at local maxima. The precursor characteristics of the observed correlations point to a pioneer perspective of an early warning system against earthquakes.

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1364-6826/

J. Atmos. Sol. Terr. Phys. **247** (2023) 106068
DOI:10.1016/j.jastp.2023.106068

Observation of cosmo-seismic correlations: a > 6 σ discovery!

The **dychotomic** cosmo-seismic correlation

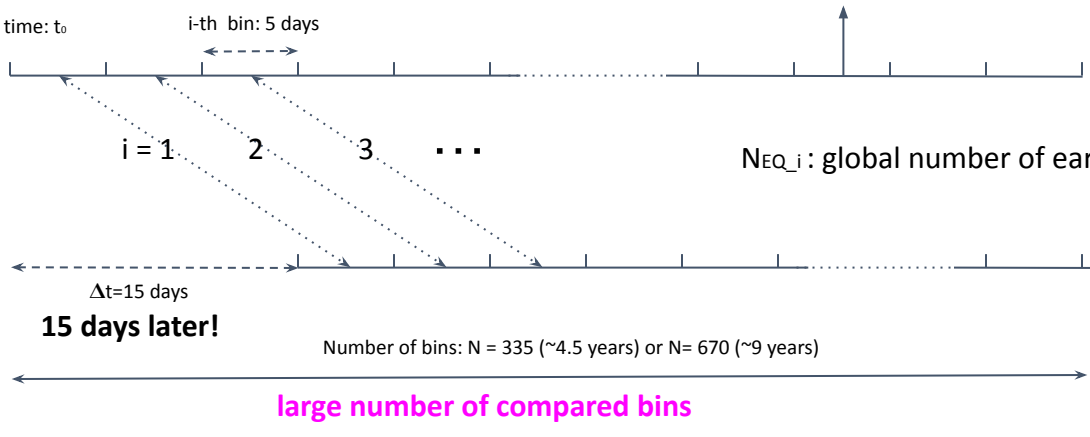
cosmic rays (**CR**):
$dCR_i = |N_{CR\_i} - N_{CR\_i-1}|$

local change in cosmic radiation

starting time matters

5-day bins

N_{CR_i} : local cosmic ray detection rate in the i-th bin



N_{EQ_i} : global number of earthquakes in the i-th bin

earthquakes (**EQ**): N_{EQ_i}

global number of earthquakes, M >= 4

large number of compared bins

M_{CR}: median of the CR data
M_{EQ}: median of the EQ data

medians: half values below, half above

N_+: (($dCR_i > M_{CR}$) and ($N_{EQ\_i} > M_{EQ}$)) or (($dCR_i < M_{CR}$) and ($N_{EQ\_i} < M_{EQ}$))
N_-: (($dCR_i > M_{CR}$) and ($N_{EQ\_i} < M_{EQ}$)) or (($dCR_i < M_{CR}$) and ($N_{EQ\_i} > M_{EQ}$))

comparison of the CR and EQ bins: signs matching or not matching?

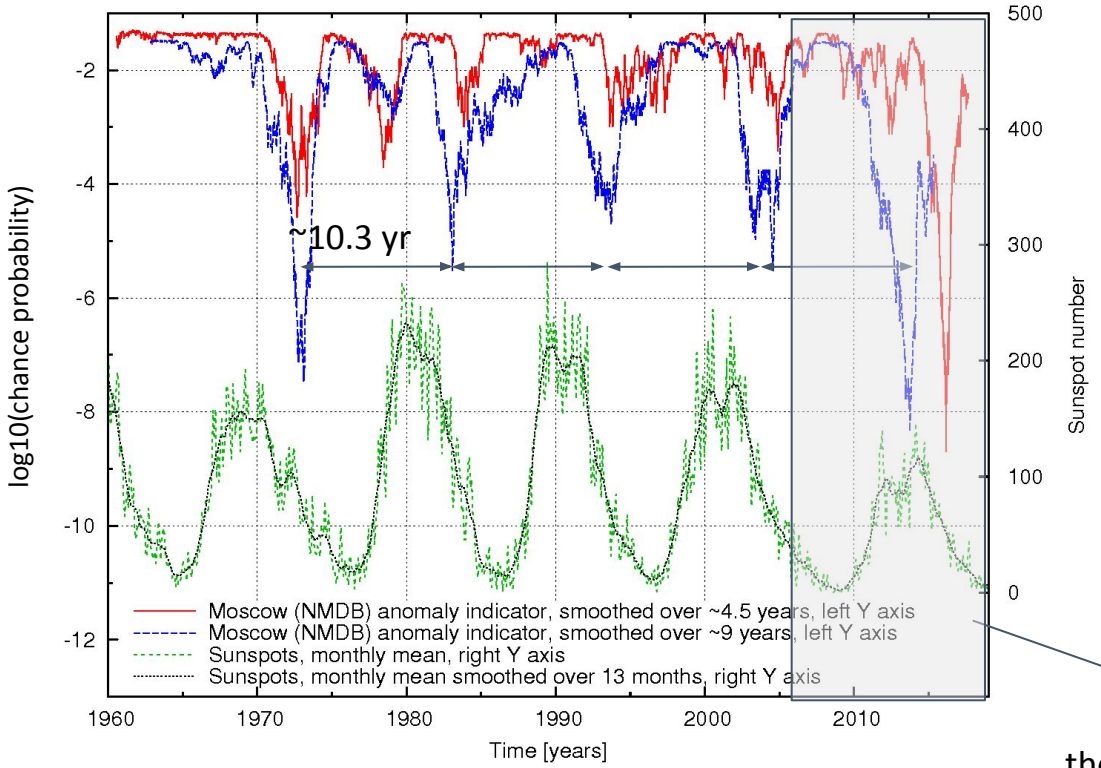
Chance probability:

$$P_{PDF}(N_{+/-} = k) = \left(\frac{n!}{k!(n-k)!}\right) p_{+/-}{}^{k} \left(1 - p_{+/-}\right)^{n-k}$$

the probability of imbalance between matching and not matching signs (binomial distribution, balance expected)

Periodicity of the effect? But not the same as solar activity…

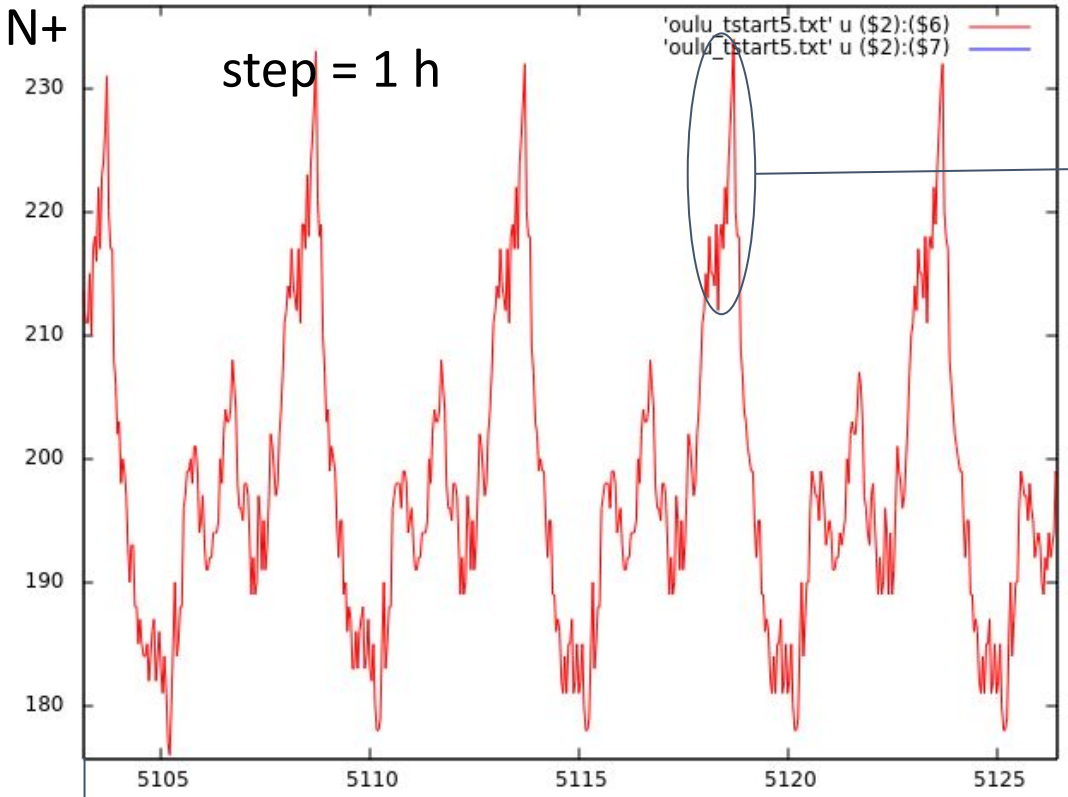
P. Homola et al., *J. Atmos. Sol. Terr. Phys.* **247** (2023) 106068, DOI:10.1016/j.jastp.2023.106068

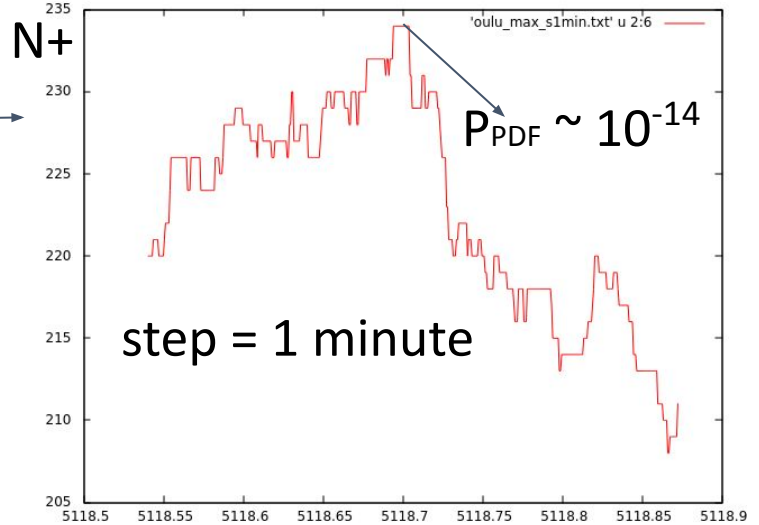


The variability of cosmo-seismic correlation for the NMDB Moscow data over time, for time windows of different widths: window **~4.5 years (1675 days, red)** and **~9 years (3350 days, blue)**. Points on the curves correspond to window centers.

the "burning" sample not considered in the final calculation of the significance

Sensitivity to small changes of t_0

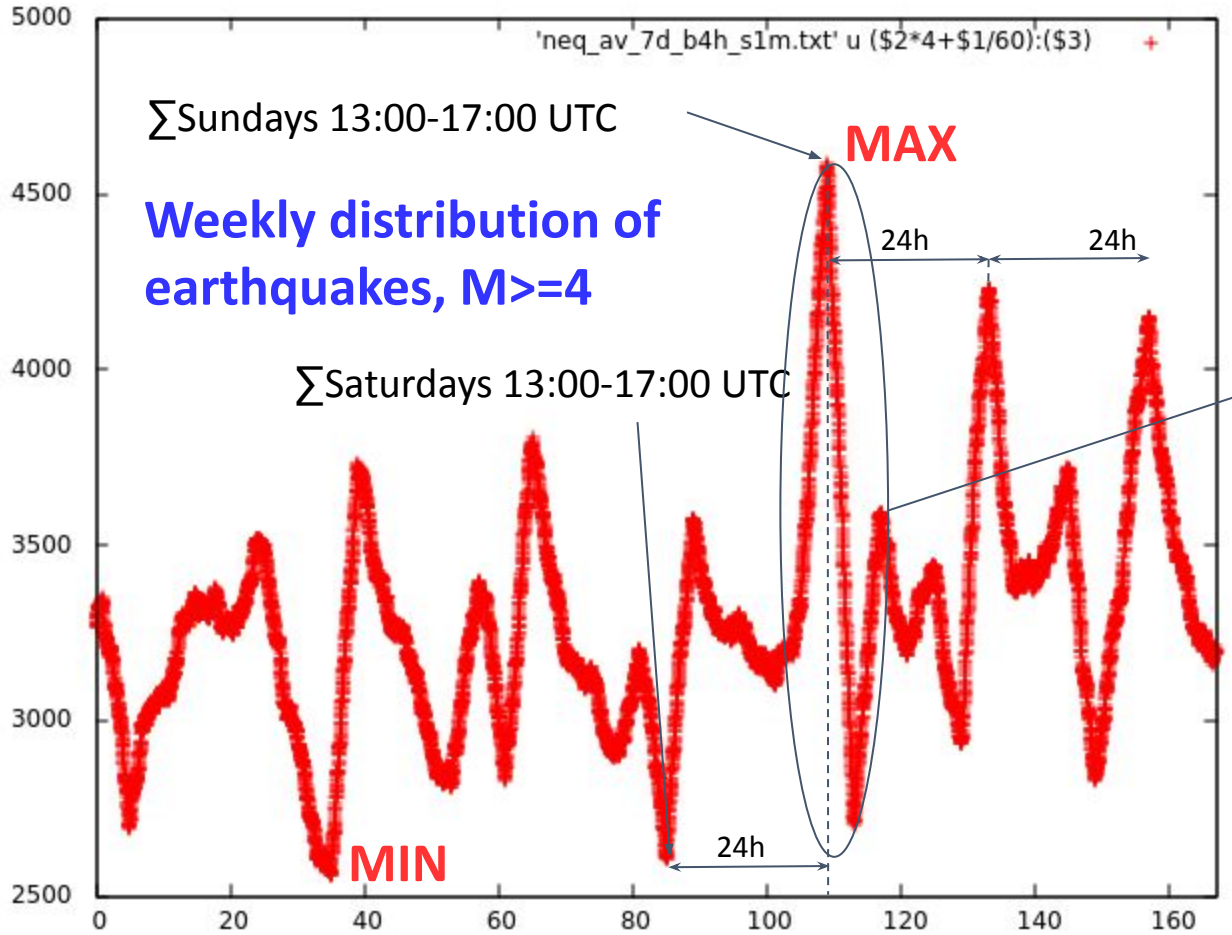


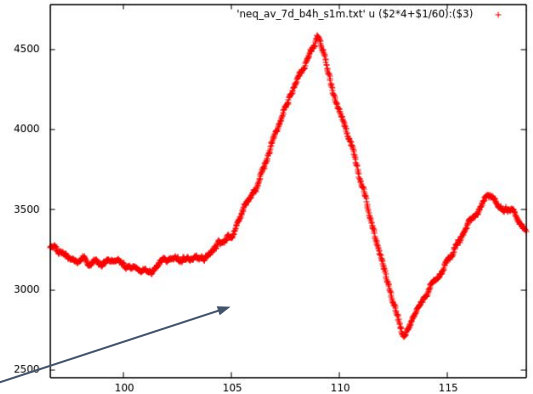


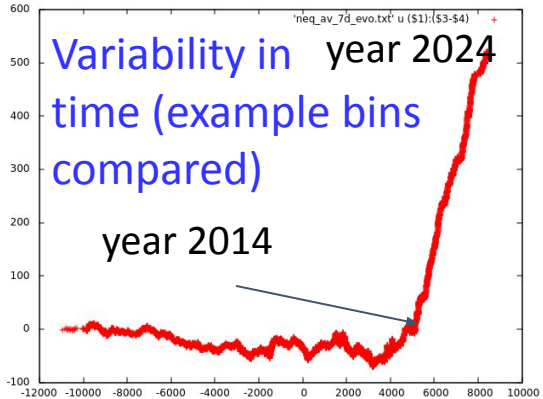
167 (50% of all the bins)

t_0 [days after year 2000]

Oulu; CR data bins: 6 hrs,
335 cosmo-seismic bins:
f x 5 days each; f=0.99915
(similar for other sites and f=1.0)

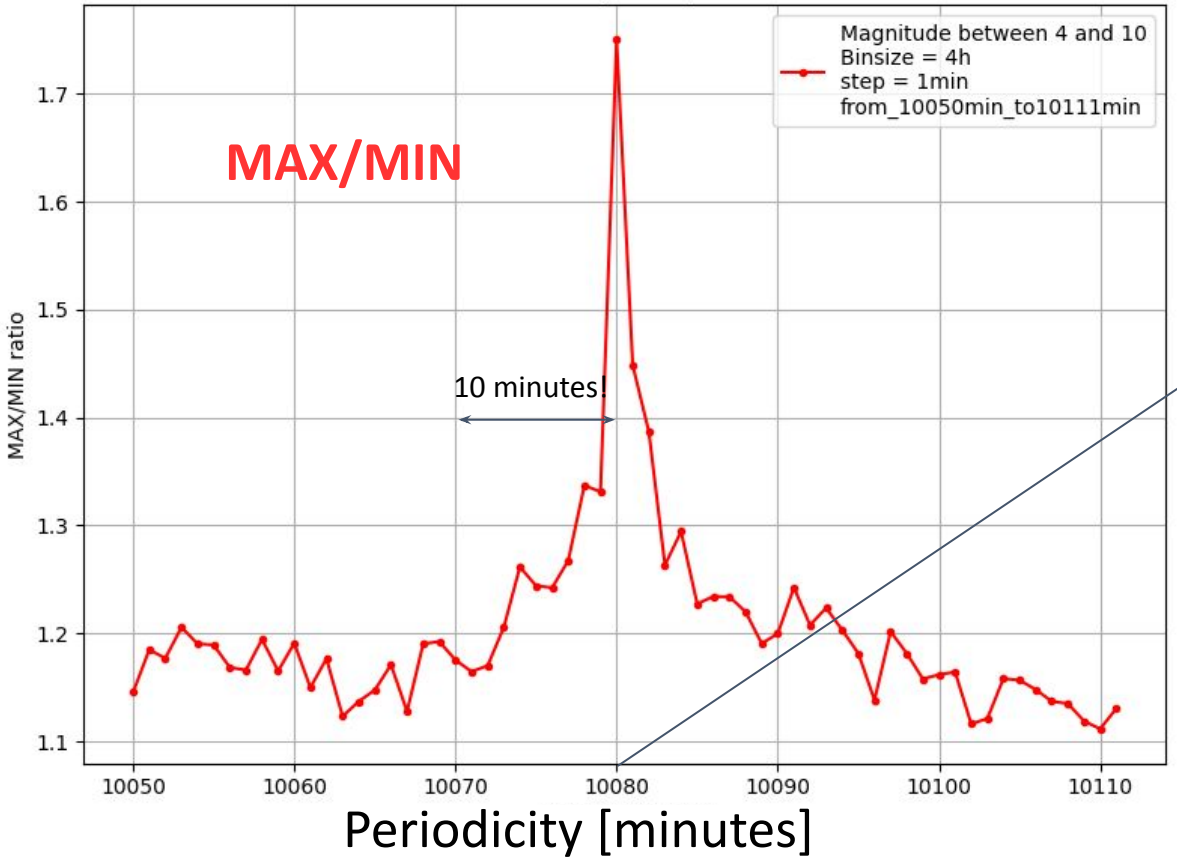






- periodicity: 7 days
- sliding window (bin): 4 h
- sliding window step: 60 s
- range of dates: ~4000 days **since 2014.01.01**

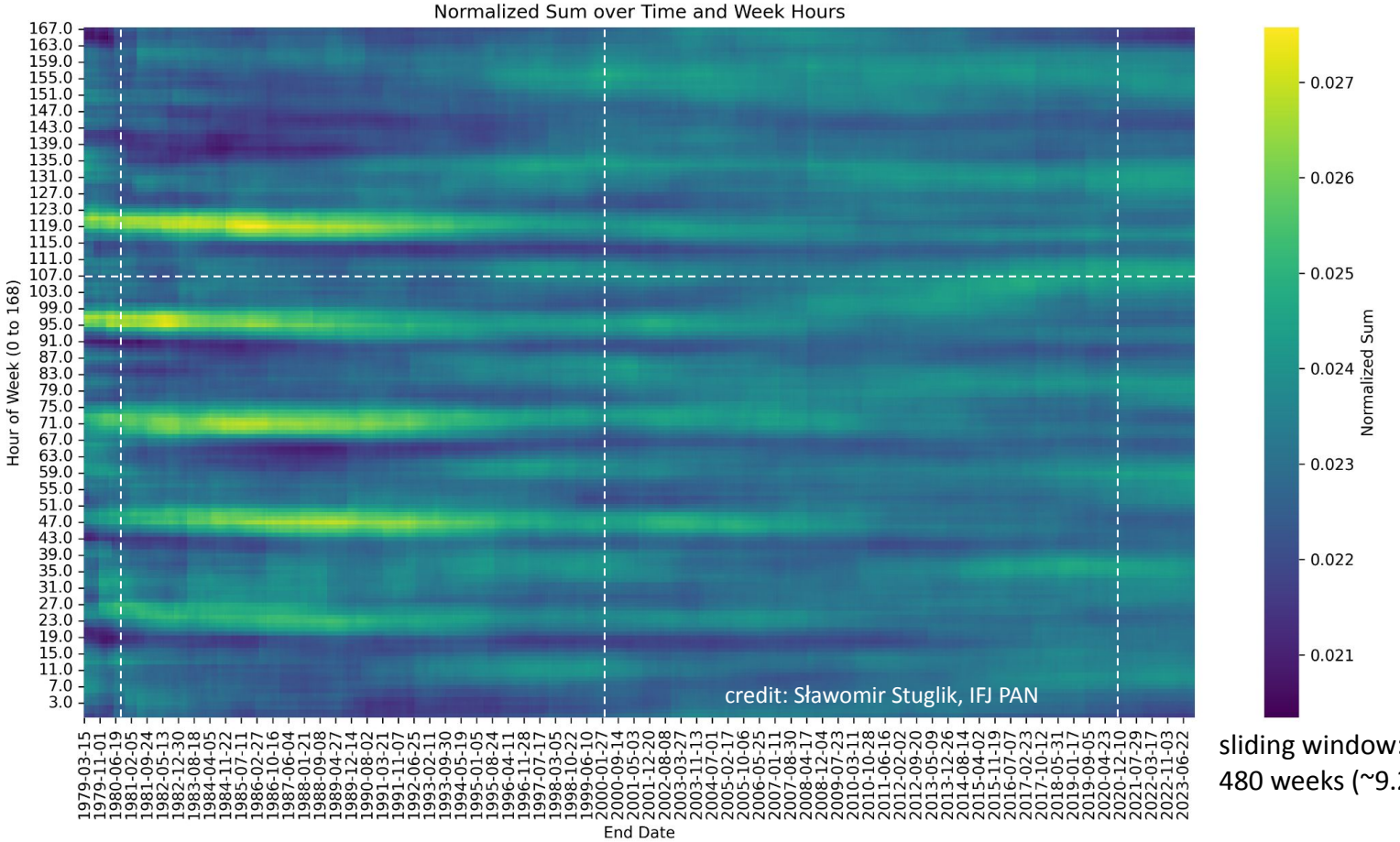
Surprising periodicity of earthquakes, M>=4



7 days exactly (+/- 1 minute)!

Credit: Tymur Kozarewski, AGH
(3rd year student., Technical Physics)

The weekly earthquake pattern varies in time



sliding window:
480 weeks (~9.2 years)

Dominating, time-dependent,
non-anthropogenic periodicity 7d
in seismic data:

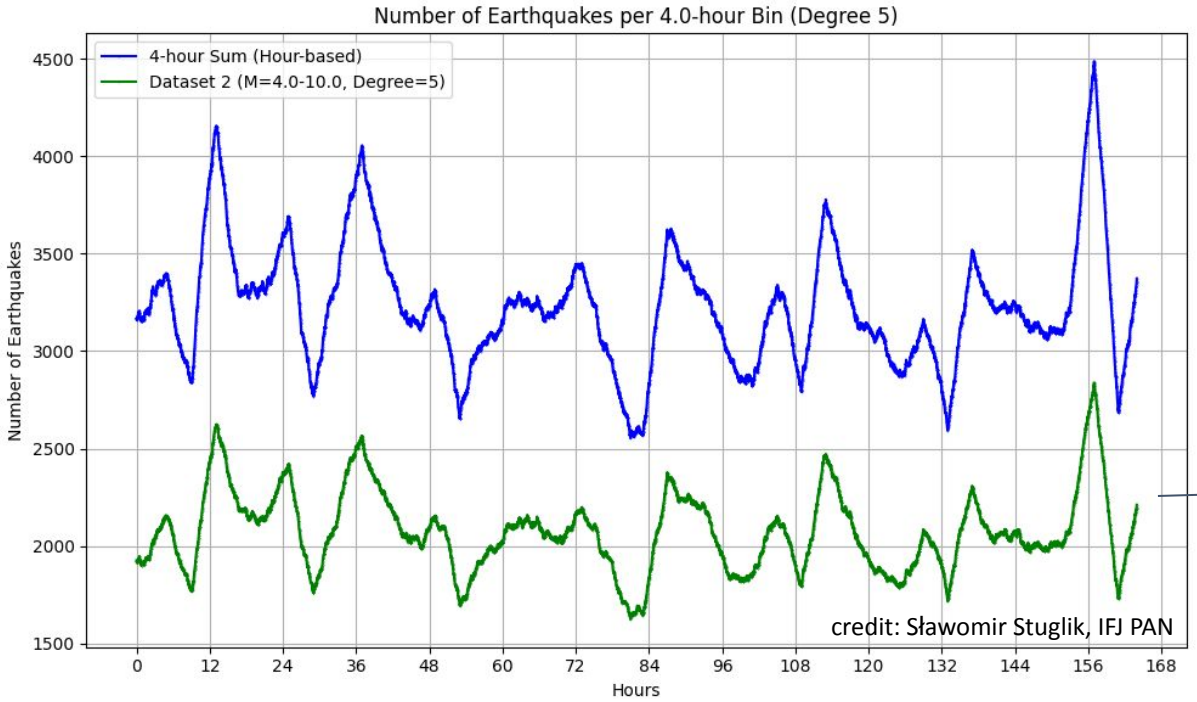
-> large fraction of strong earthquakes induced by unknown mechanism?

-> “technical” explanation of the cosmo-seismic phenomenon?

-> what are the physics process(es) behind???

Readiness for the unexpected? Important for science!

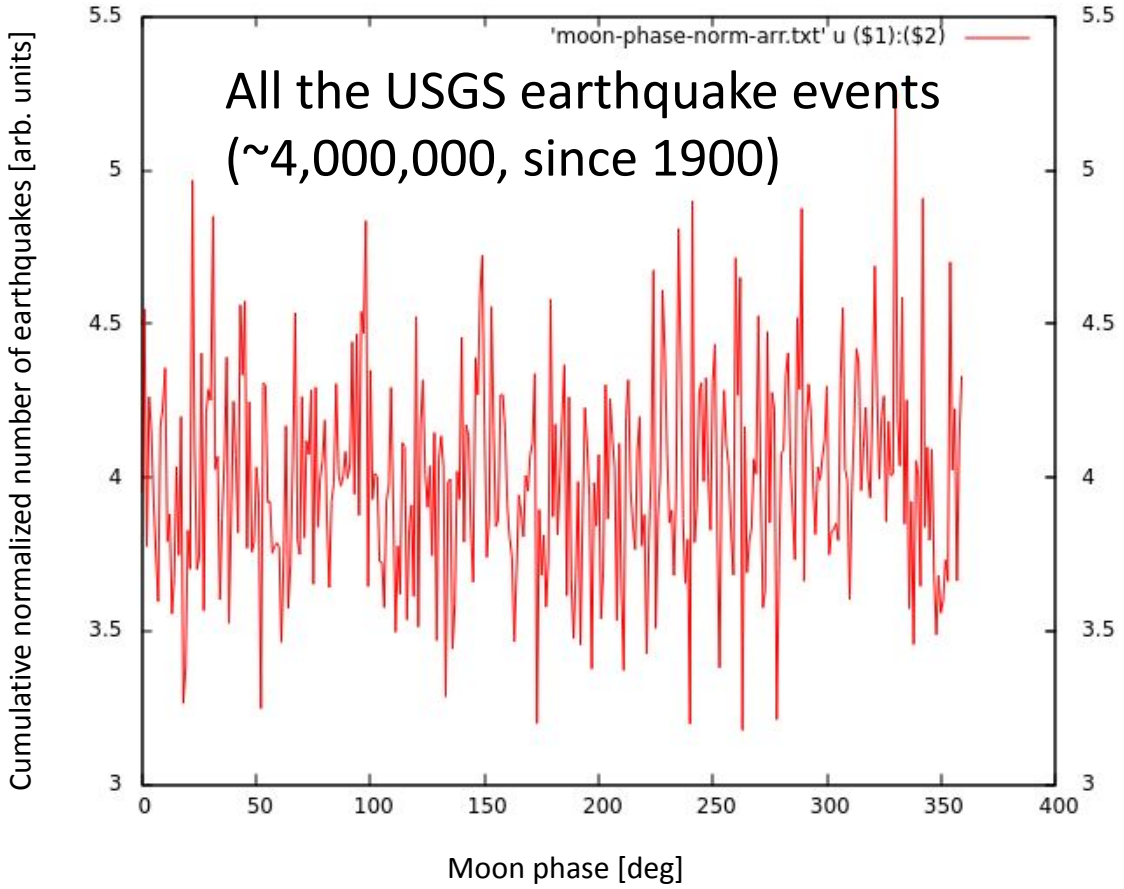
Weekly earthquake distribution: M>=4 all (blue) vs. M>=4 @ > +/- 5 deg away from the location of “industrial” earthquakes (green)



All

No locations of “industrial” earthquakes (extracted with the margin of +/- 5 deg)

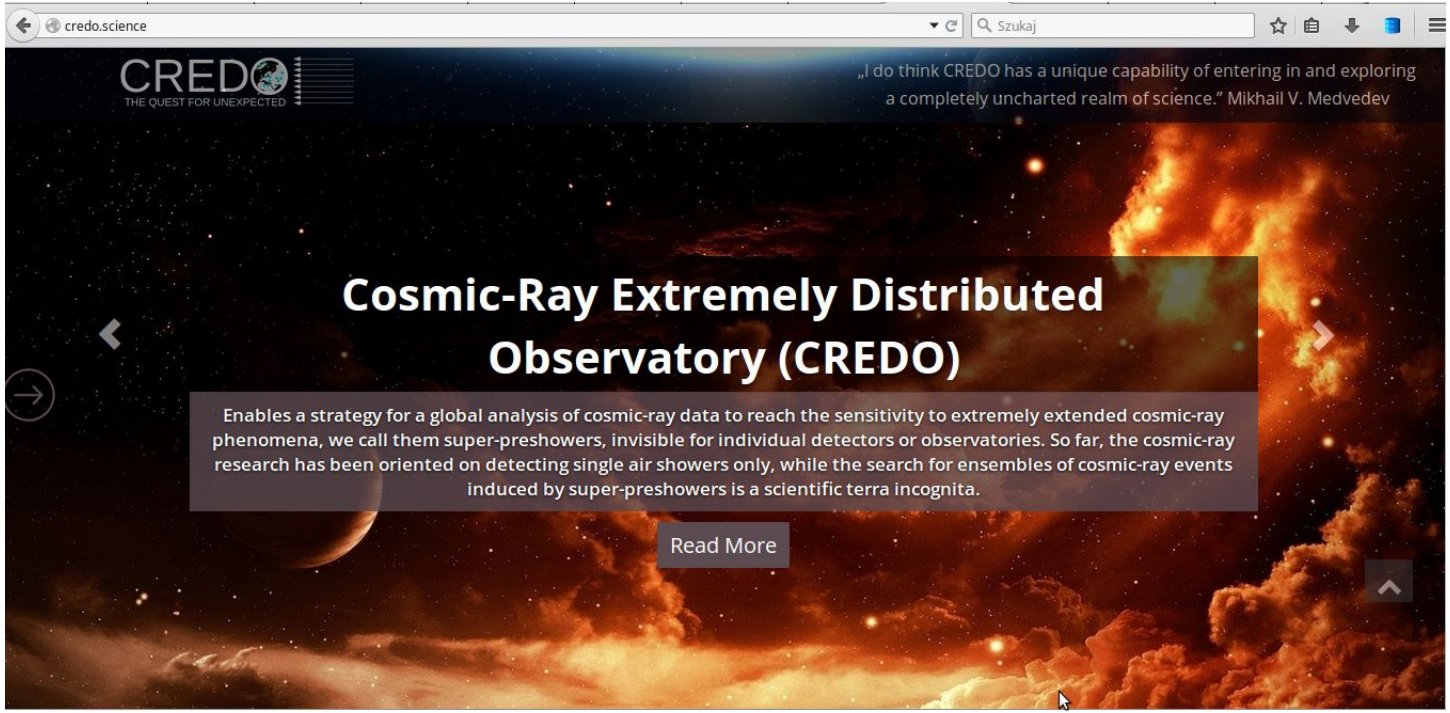
Normalized number of earthquakes vs. Moon phase



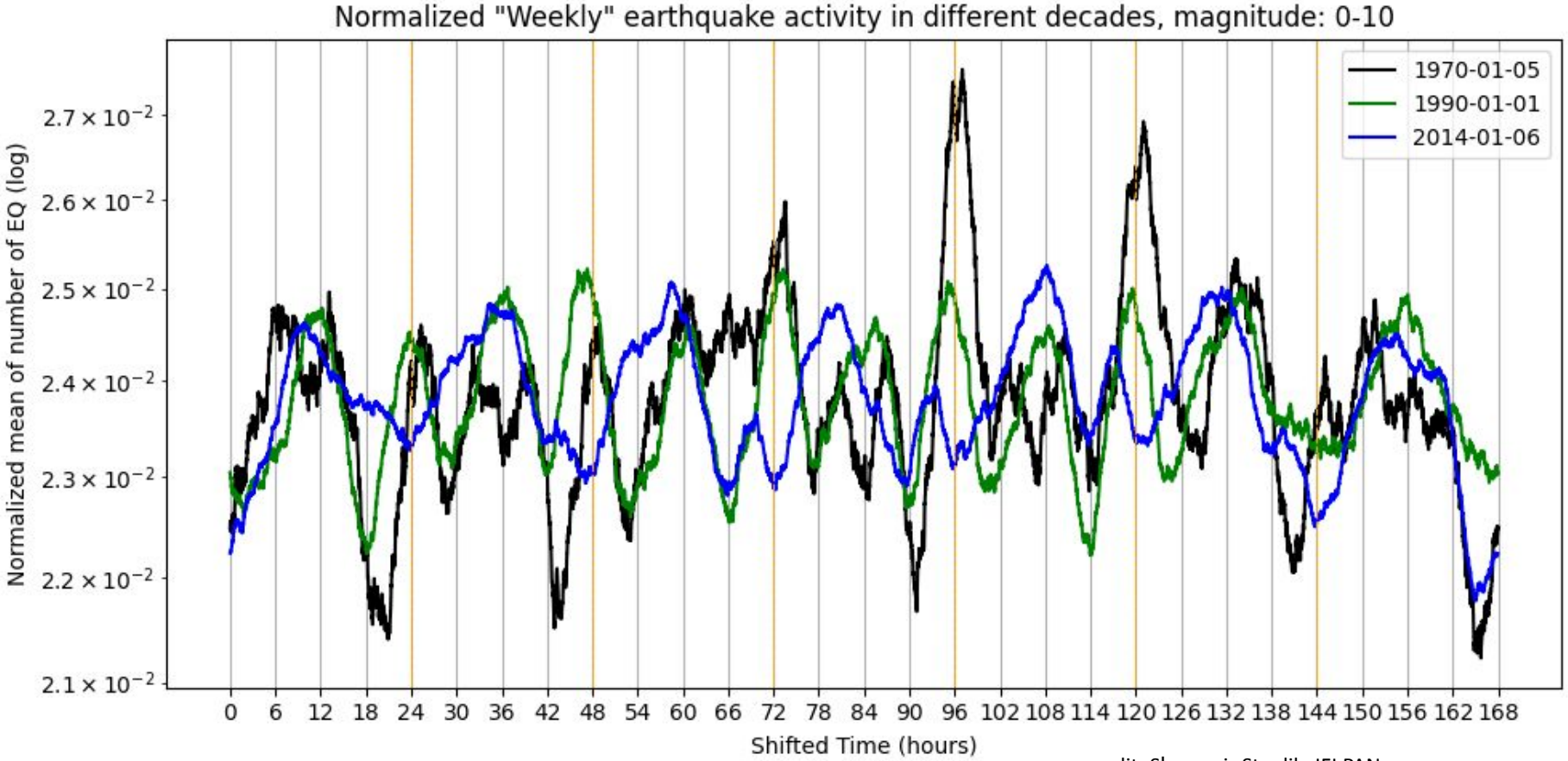
tidal forces caused by the Moon:
excluded!

BACKUP

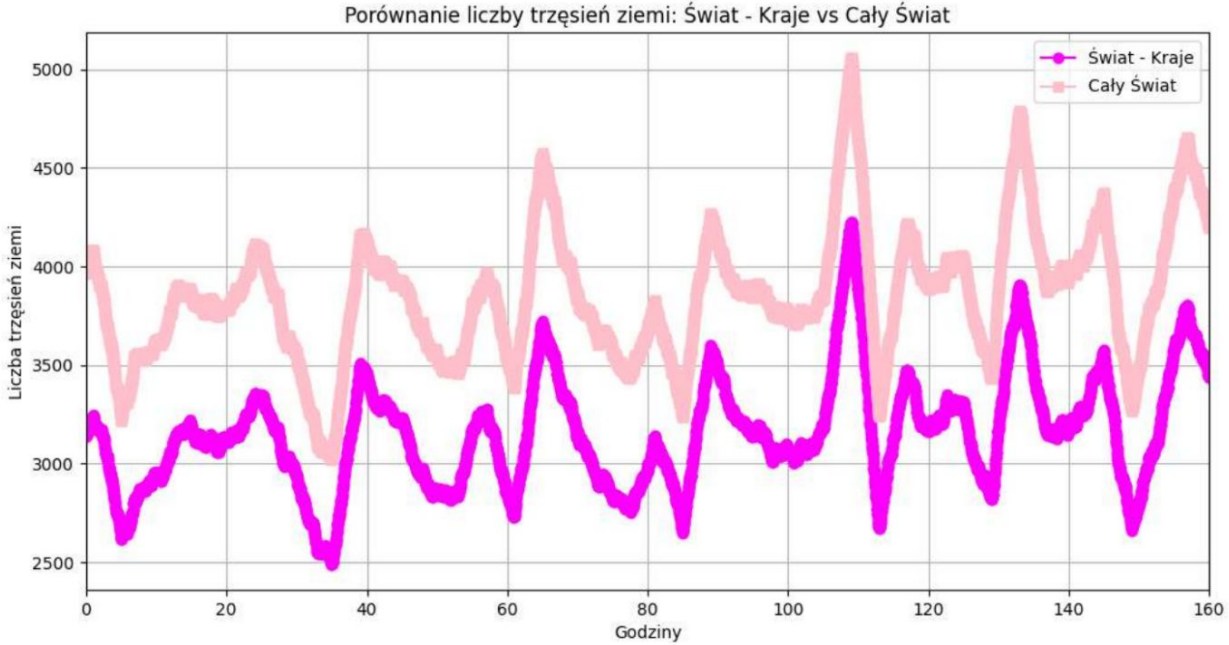
Visit credo.science...



… and help, please.

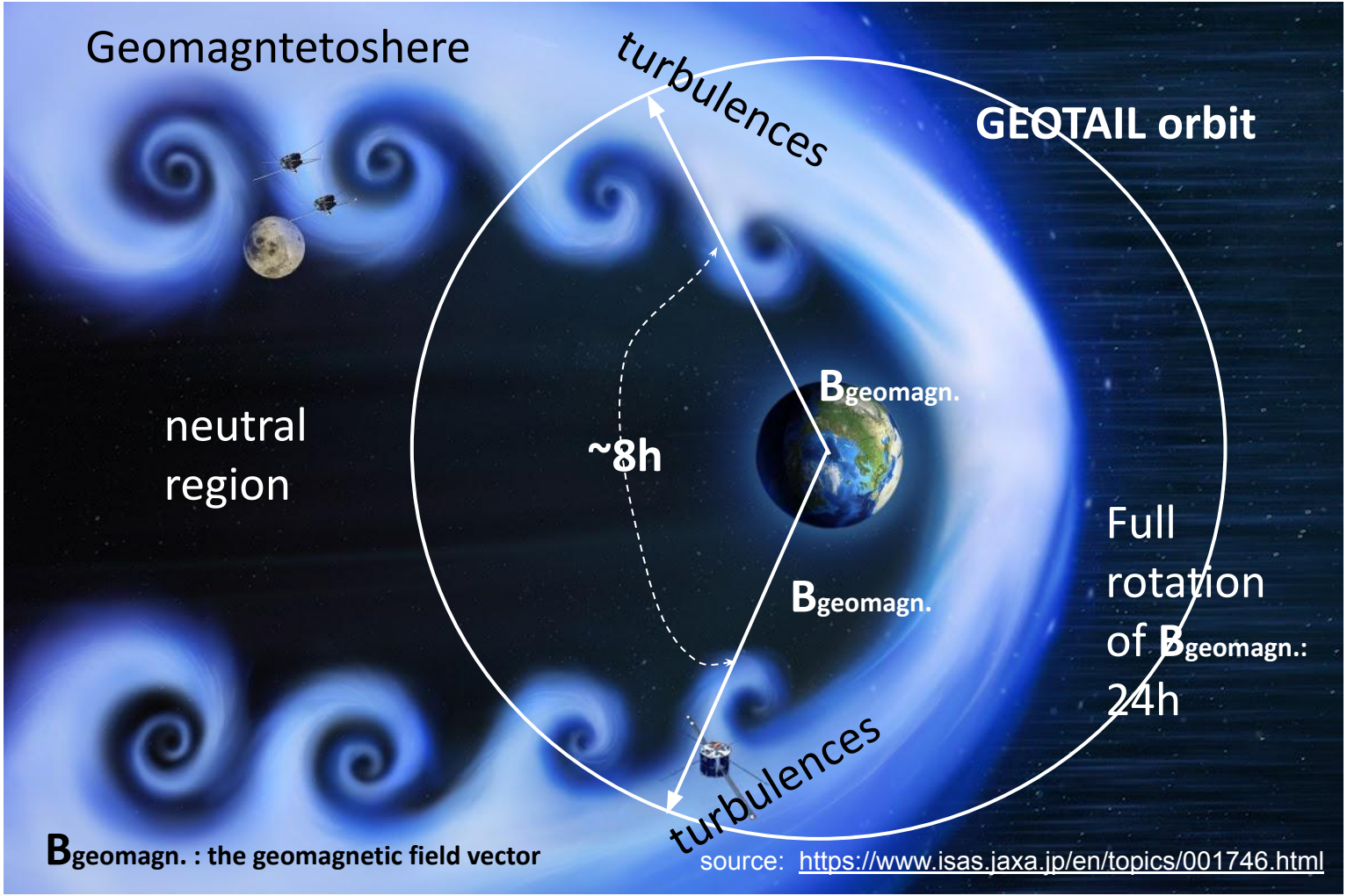


credit: Sławomir Stuglik, IFJ PAN

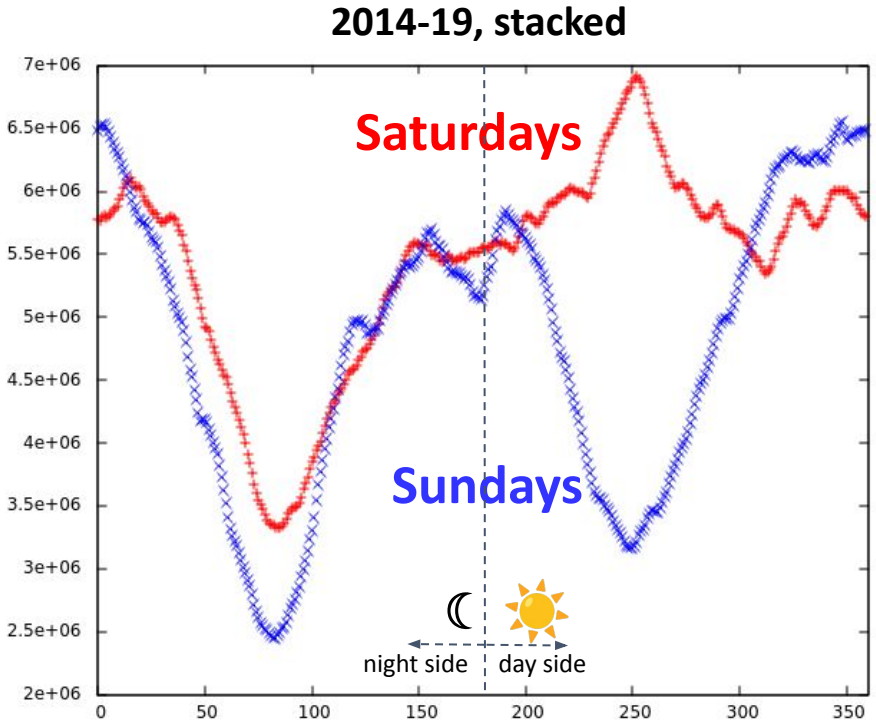


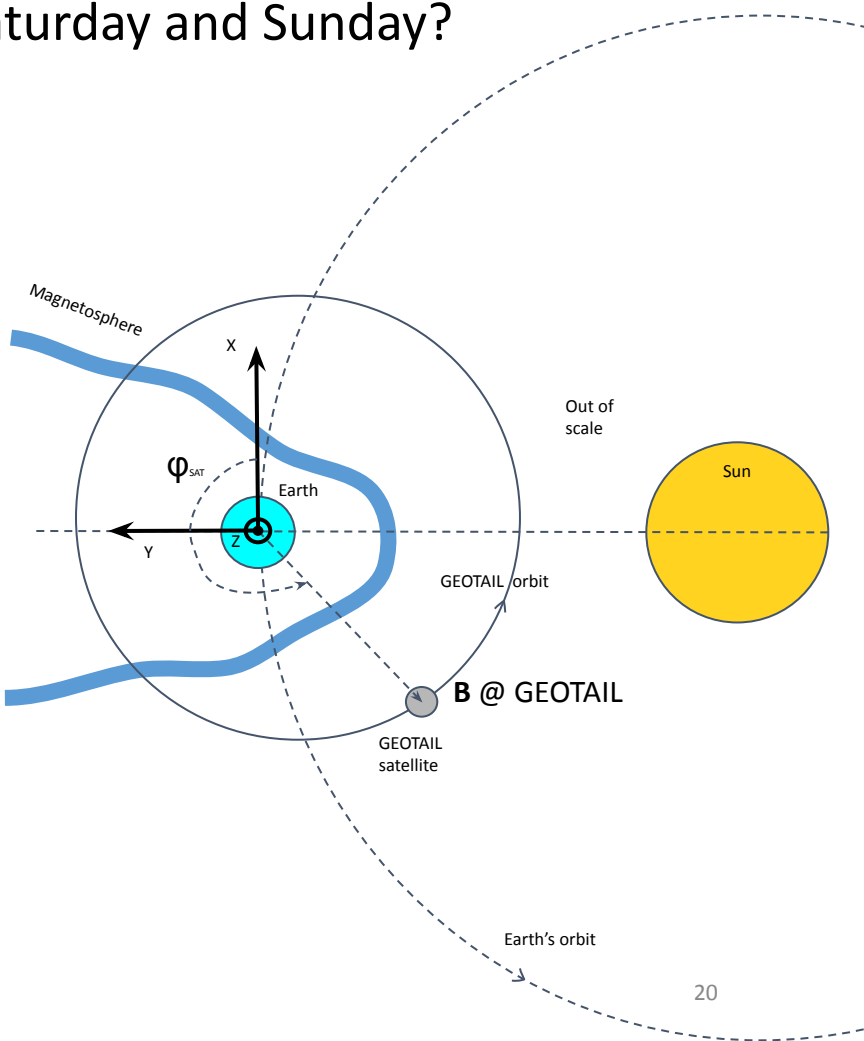
Rysunek 4.4: Skumulowany tygodniowy rozkład trzęsień ziemi na świecie dla magnitudy $\geqslant 4.0$, uwzględniający zarówno dane globalne, jak i dane z wyłączeniem USA, Japonii, Chin i Indii.

credit: Marcelina Janusiak, Cracow University of Technology


Geomagntetoshere
turbulences
GEOTAIL orbit
neutral region
~8h
Bgeomagn.
Bgeomagn.
Full rotation of Bgeomagn.: 24h
turbulences
Bgeomagn. : the geomagnetic field vector
source: https://www.isas.jaxa.jp/en/topics/001746.html

A physical difference between Saturday and Sunday?

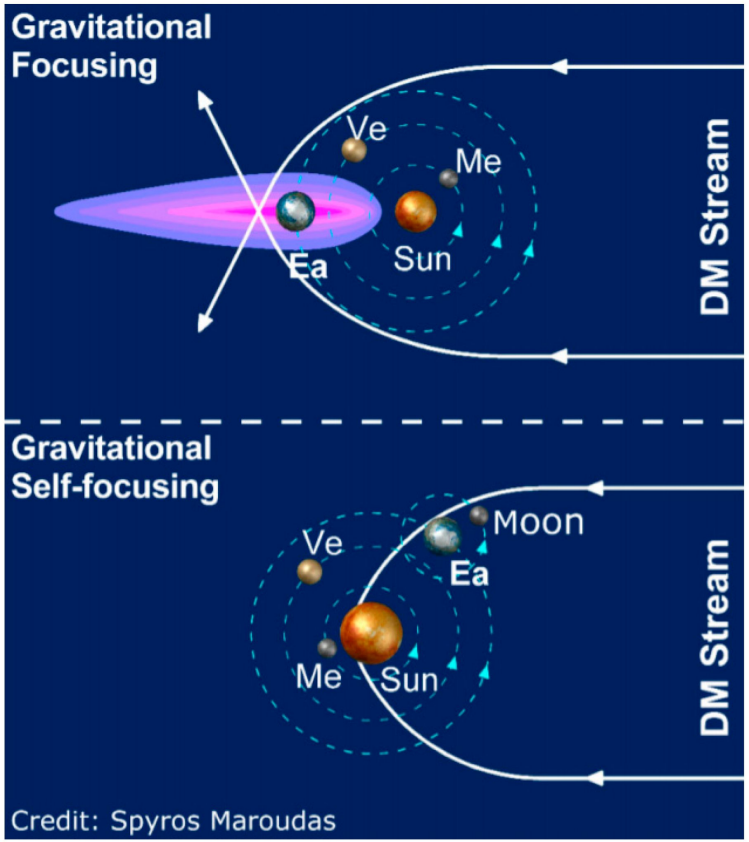




Position on the GEOTAIL orbit: φ_{SAT} [deg]

Interpretation: role of the Sun, or … Dark Matter stream?

K. Zioutas et al., 2021
Phys. Sci. Forum **2021**, *2*(1), 10; https://doi.org/10.3390/ECU2021-09313



KZ:
-> sidereal day periodicities (Earth rotation with respect to the stars, 24h-236s)
-> sidereal month (Moon orbit with respect to the stars: 27.32d)

PH: **(SH)DM overdensities:**
-> periodic (yearly?) CR variations?
-> delayed gravitational shocks?

RESEARCH ARTICLE

National Science Review
6: 1016–1023, 2019
doi: 10.1093/nsr/nwy117
Advance access publication 8 October 2018

2018

GEOSCIENCES

Evidence for diurnal periodicity of earthquakes from midnight to daybreak

Jinlai Hao, Jinhai Zhang* and Zhenxing Yao

https://doi.org/10.1093/nsr/nwy117

"Our work suggests that the earthquakes have a **dominant diurnal period**, at least from mid-night to daybreak, which could be helpful to opening a **new window to explore the physical mechanism of earthquakes**."

Bulletin of the Seismological Society of America, Vol. 99, No. 4, pp. 2273–2279, August 2009, doi: 10.1785/0120080217

Apparent Weekly and Daily Earthquake Periodicities in the Western United States

by Ali H. Atef, Kelly H. Liu, and Stephen S. Gao

Abstract Analysis of apparent seismicity rate (ASR) using magnitude ≥1 earthquakes located in the western United States confirmed the existence of prominent spectral peaks with periods of 1 and 7 days. The number of recorded earthquakes on Sundays for the duration of 1963–2008 is about 5% higher than that on weekdays, and, more significantly, there is a 9% increase of ASR in the early morning compared with that in the middle of the days. Significant similarities in the spatial distributions of the weekly and daily variations suggest that the two types of variations have the same sources and both originate from periodic variations in cultural noise that lead to periodic variations in the detectability of the seismic networks. Comparisons with freeway traffic flow data suggest that traffic flow on the freeways is not the only significant factor in the observed periodicities. Instead, ambient noise from all the ground traffic, operating machineries, and building shaking is probably the major cause of the observed apparent periodicities. The observed temporal variations in ambient noise as reflected by the ASR can be used as objective guidelines for choosing the best time/day for noise-sensitive scientific experiments.

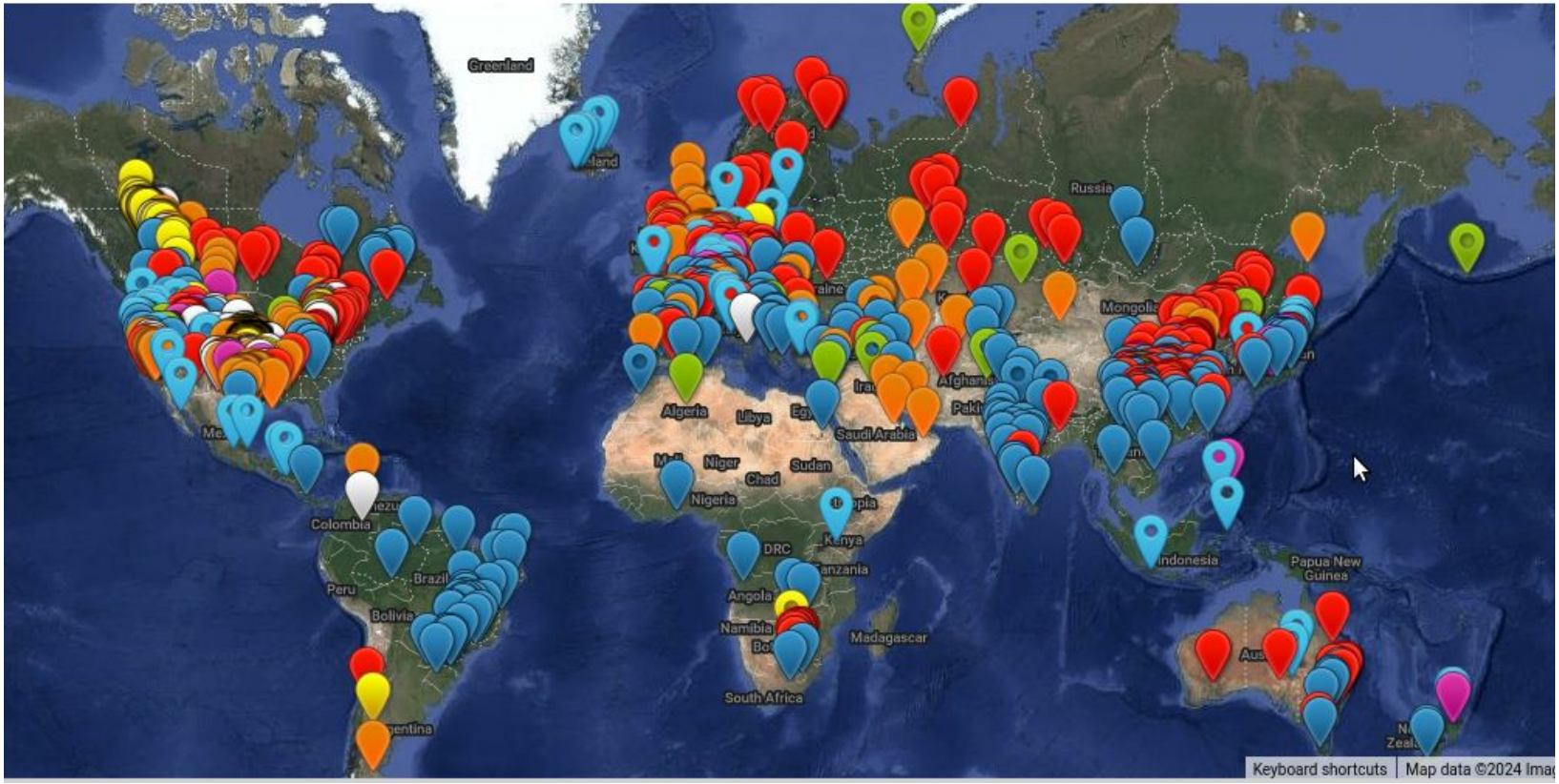
7d anthropogenic?

Western United States, magnitude >=1, conclusion: cultural & industrial noise (anthropogenic)

https://inducedearthquakes.org

The Database | About Induced Seismicity | Resources | Contribute | Research Profiles | Citation and Disclaimer | Funding and Acknowled

THE HUMAN-INDUCED EARTHQUAKE DATABASE



https://inducedearthquakes.org

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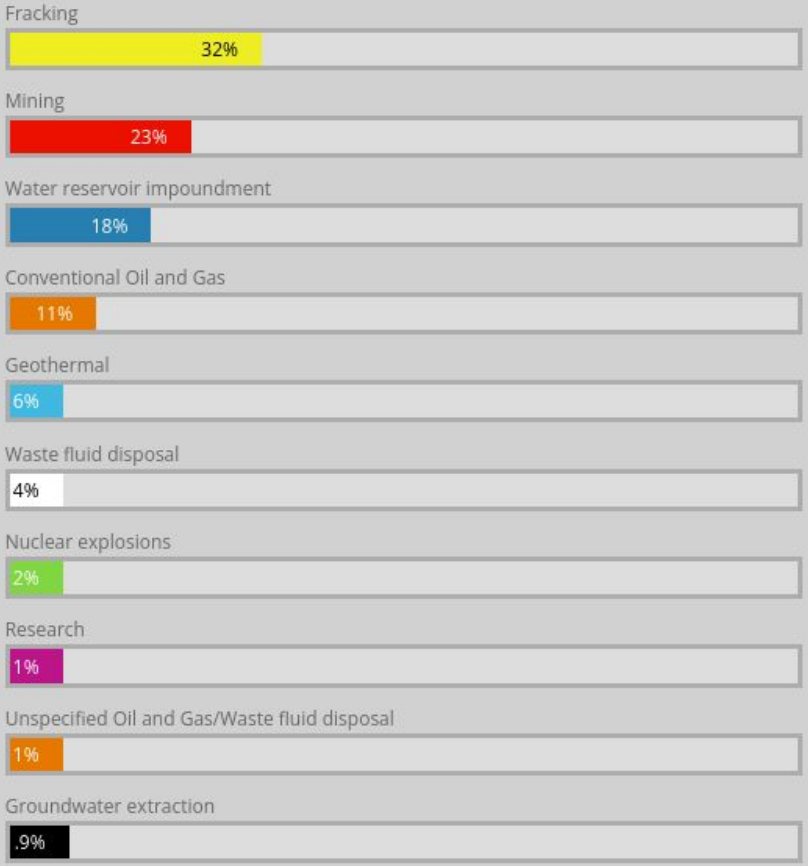
1315

Projects proposed to have induced earthquakes



The Human-Induced Earthquake Database (*HiQuake*)

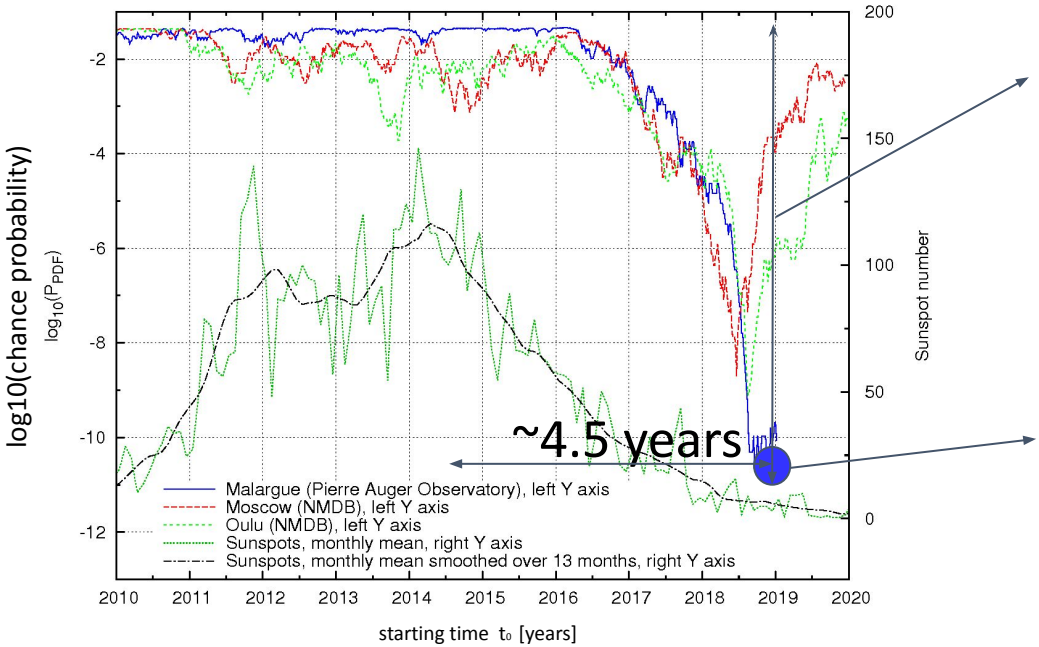
The Human-Induced Earthquake Database (*HiQuake*) is the largest and most up-to-date database of industrial projects proposed to have induced or triggered earthquakes. *HiQuake* lists all industrial projects claimed, on scientific grounds, to have induced earthquakes. The database does not filter, rank or discriminate on the basis of the strength of the claims.

The data are freely available to download in Microsoft Excel format for your own analysis. Depending on your browser, you may need to copy the link address to a new tab and/or enable pop ups to initiate the download.

We endeavour to keep the database up to date and accurate. If you have additional cases to add to the database, more information regarding existing entries, or corrections, please contact us.

HiQuake was last updated on the 16th August 2024.

The clear cosmo-seismic correlation!



Low chance probability (10^{-10})

The effect occurs from ~2014 until 2019 (335 bins of 5-day each), i.e. **during the decrease of the solar activity**

~6 σ significance of the effect in three technically independent CR data sets collected by the Moscow and Oulu NMDB stations, and by the Pierre Auger Observatory, compared to sunspot numbers. **Each point** illustrates the correlation effect during **the last ~4.5 years** (335 **five-day intervals**). All the significance curves were obtained after fine tuning of the parameter t_0 performed by applying 20 small shifts in time between 0 and 5 days.

The effect only appears if we look at the seismic data 15 days later. Could cosmic rays warn of earthquakes?

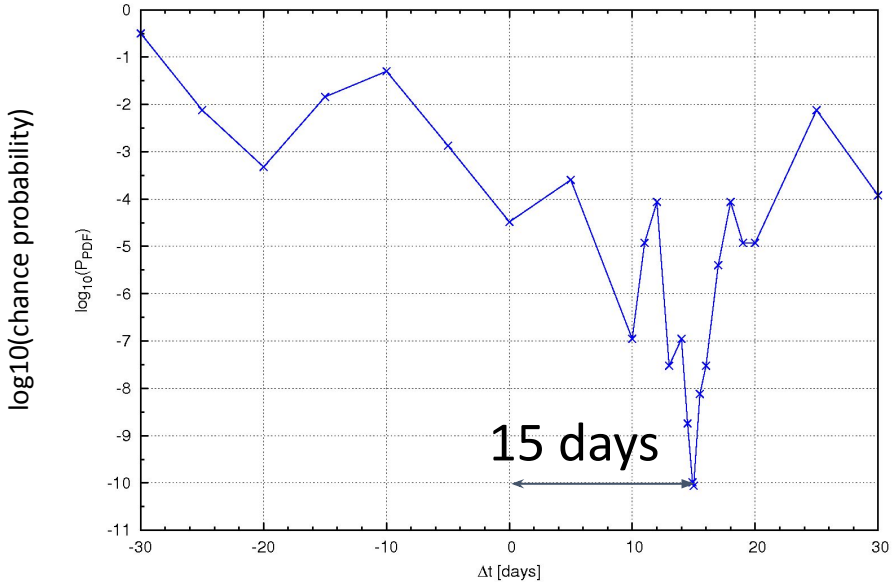
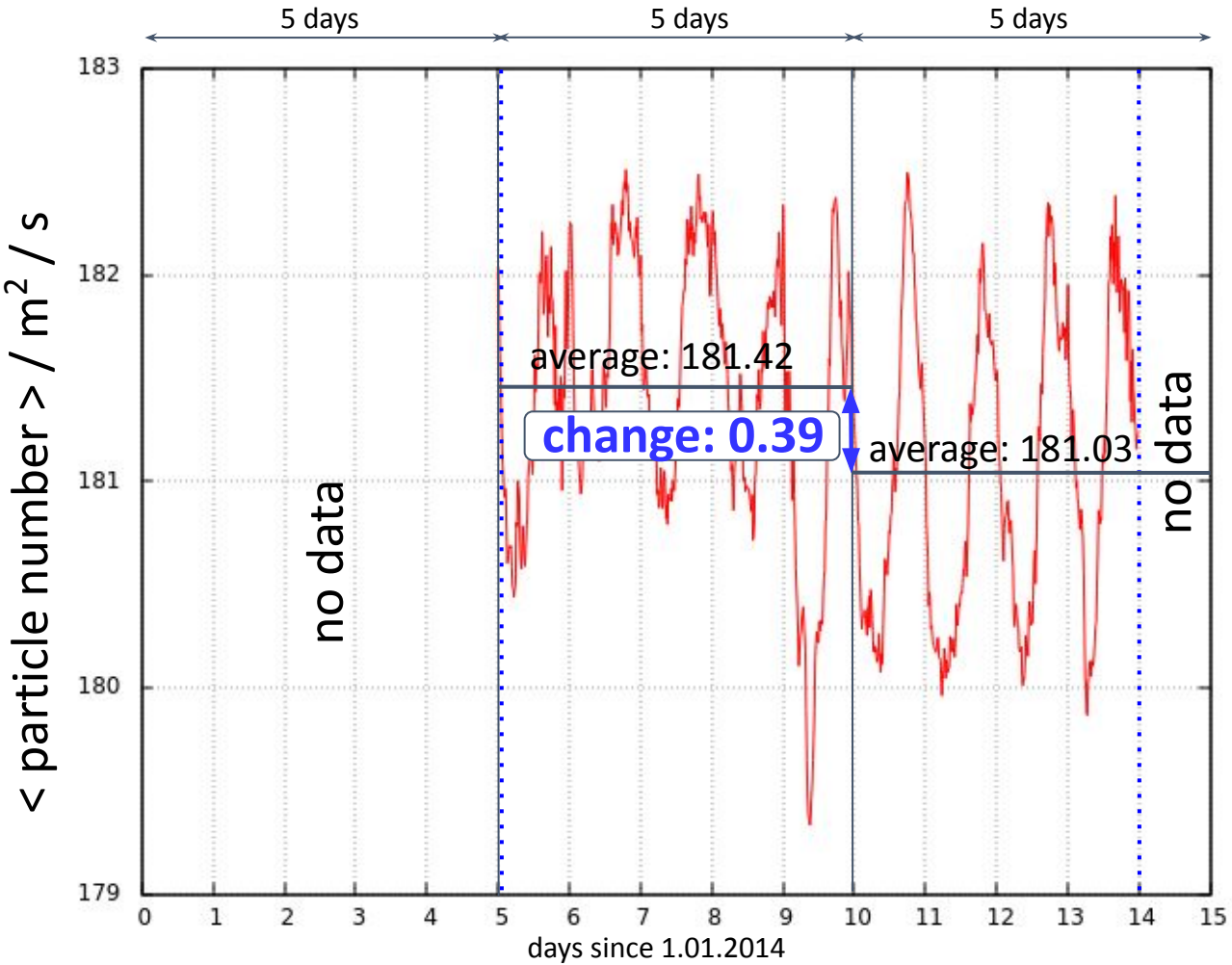


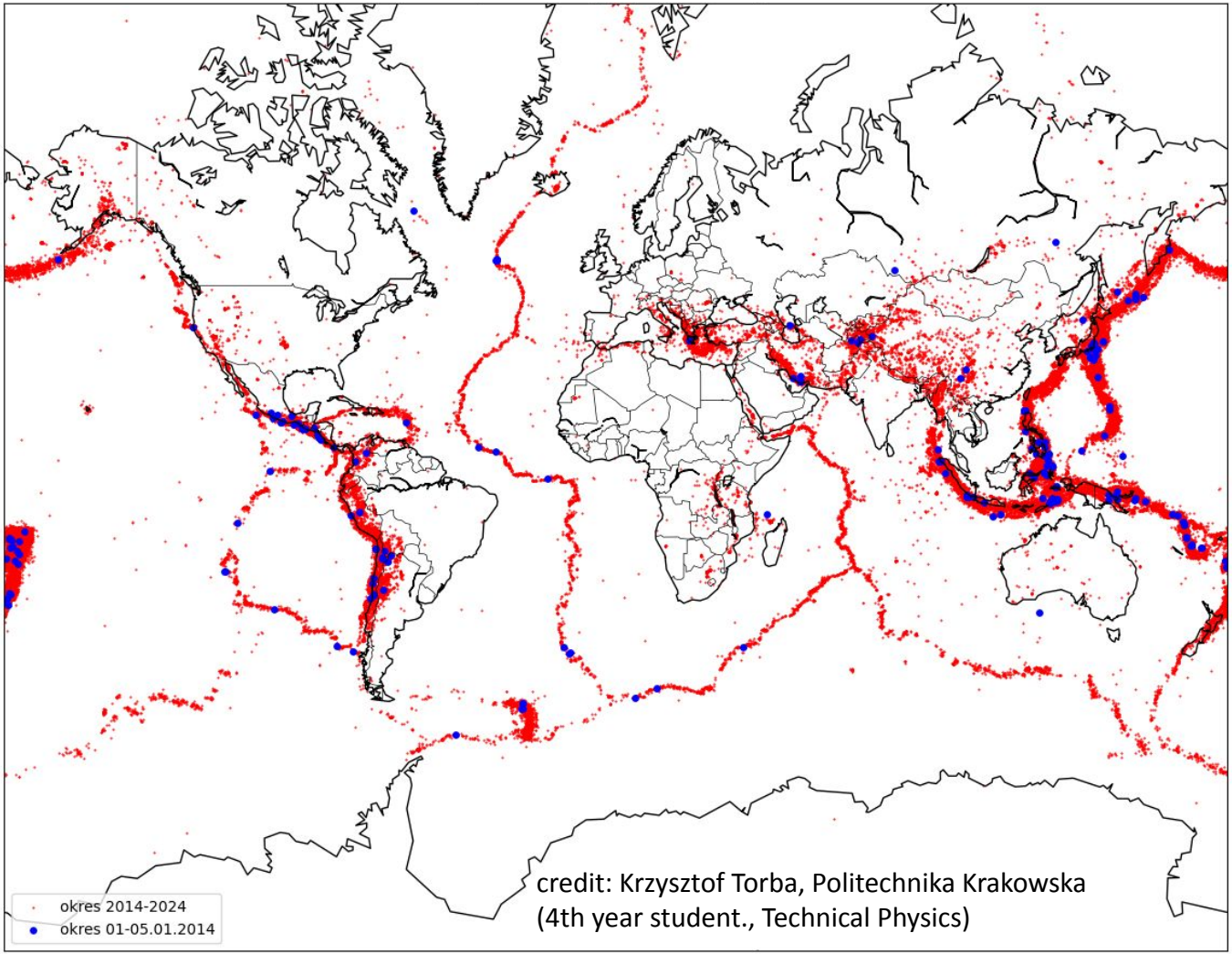
Fig. 3: The dependence of the significance of the *cosmo-seismic* correlations on the time shift t of the EQ data with respect to the Auger CR data, for the optimum free parameter set defined in Eq. 1. The positive or negative values of t correspond to the situations in which one compares the secondary cosmic ray data in a given time interval to the seismic data recorded in time intervals in the future or in the past, respectively.



Example data:
The Pierre Auger Observatory,
1-15.01.2014

Local change of the secondary cosmic radiation detection rate [<particle number>/m²/s]:

|181.03-181.42| = **0.39**



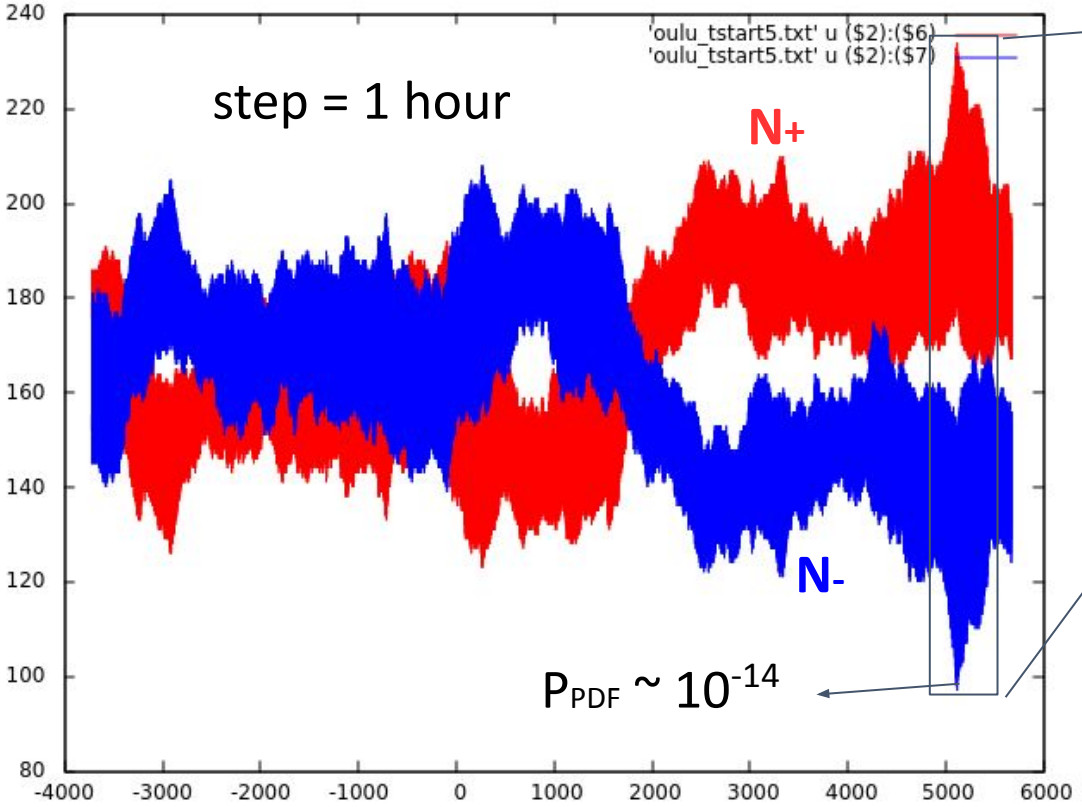
credit: Krzysztof Torba, Politechnika Krakowska
(4th year student., Technical Physics)

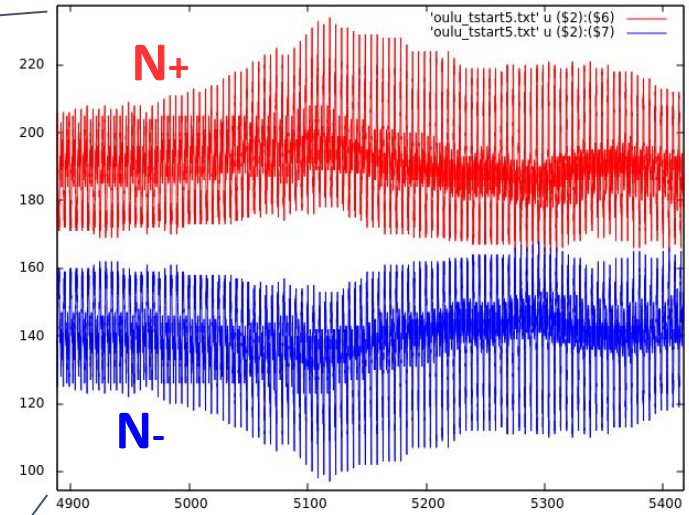
Earthquakes
magnitude >=4

example statistics:

- period: 2014-2024
  (~160 000 events)
- period: 1-5.01.2014
  (209 events)

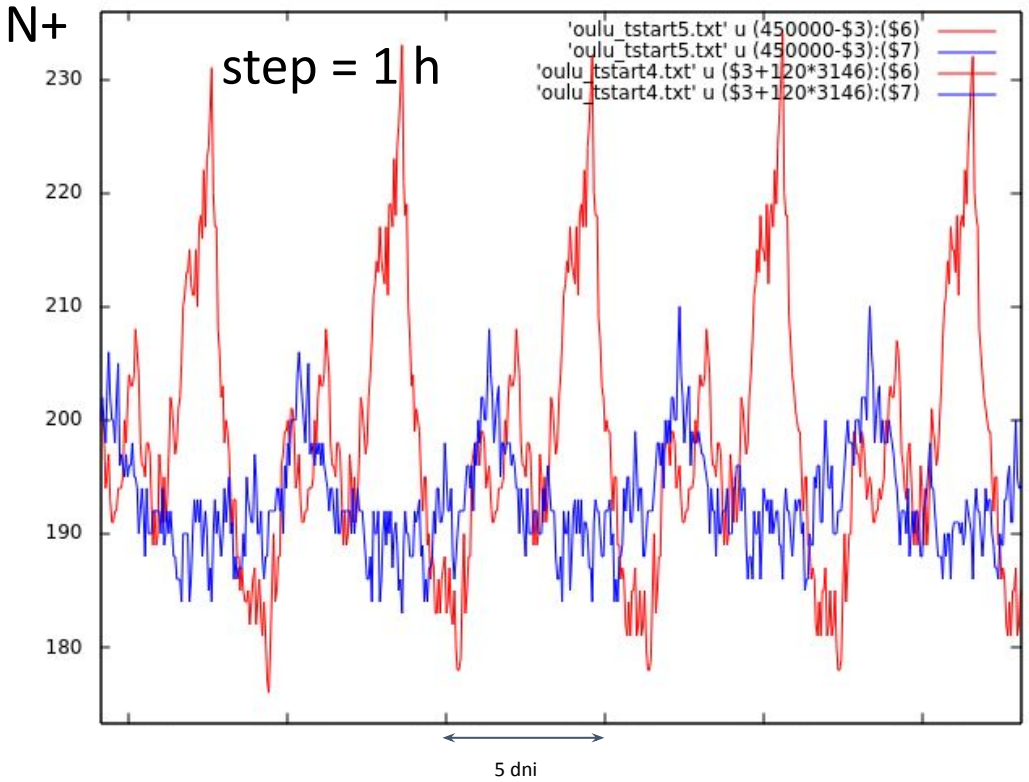
Sensitivity to small changes of t_0





Oulu; CR data bins: 6 hrs,
cosmo-seismic bin: f x 5 days;
f=0.99915

Sensitivity to small changes of t_0



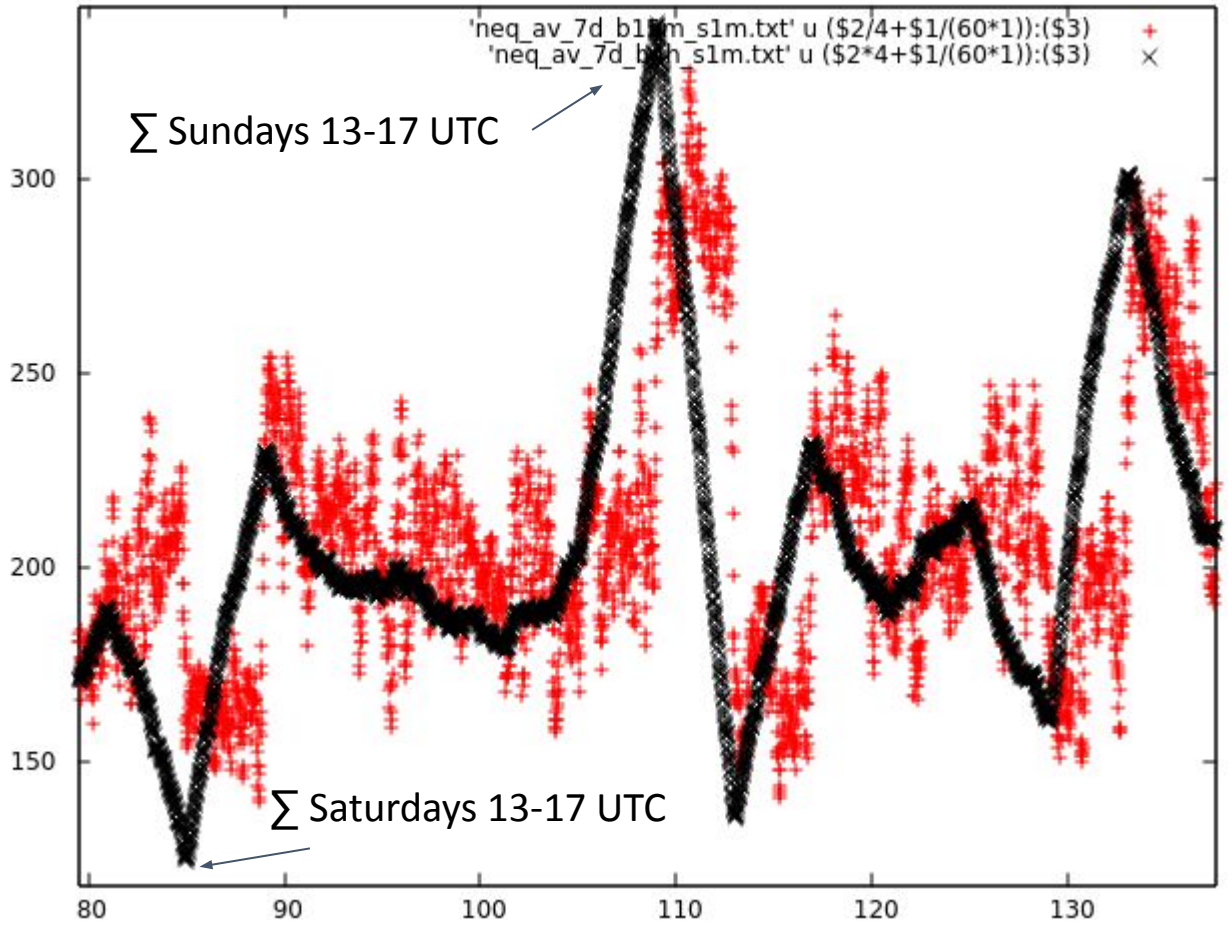
red: t_0=~2014

blue: t_0=~2006

-> optimum t_0 changes in time!

-> the seismic data "responsible" for the need of fine tuning t_0?

Oulu; CR data bins: 6hrs,
cosmo-seismic bin: f x 5 days;
f=0.99915



4h sliding window (black)

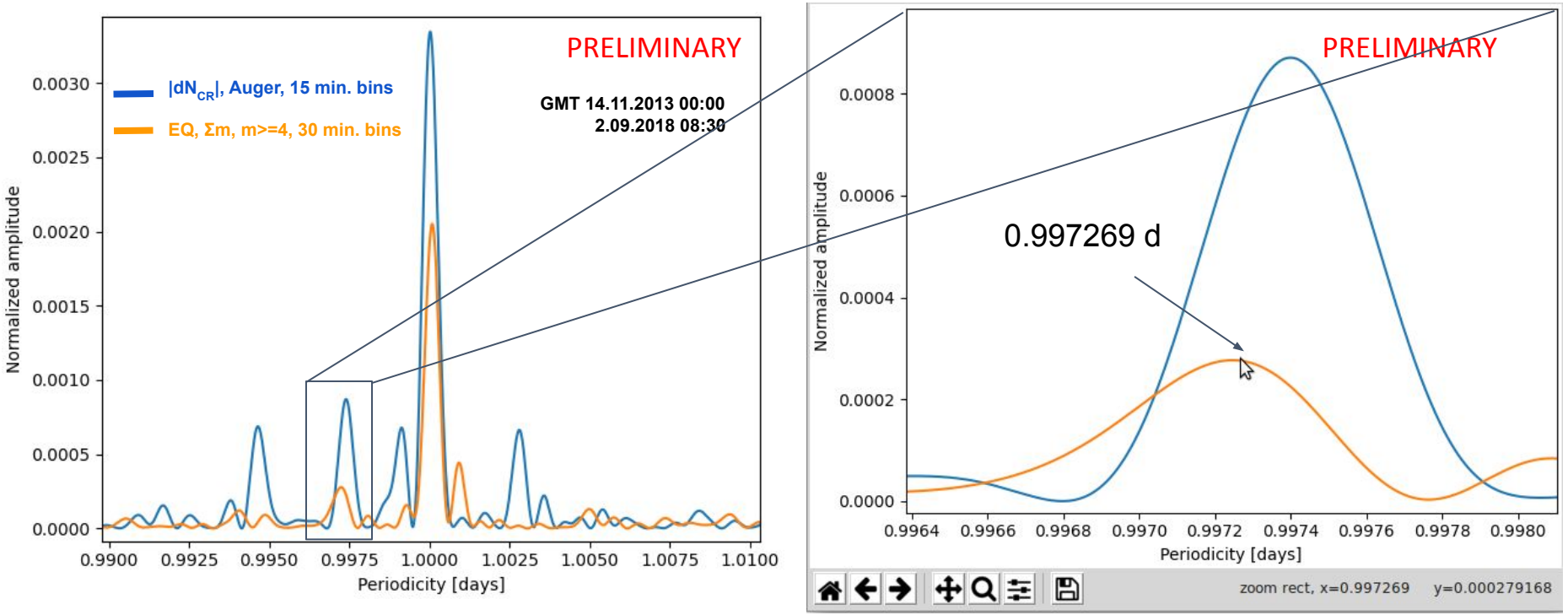
vs.

15 minutes sliding window (red)

-> plateaus at maxima and minima, lasting ~4 hours?

24h and sidereal day (SD) periodicities in $|dN_{CR}|$ and Σm_{EQ}

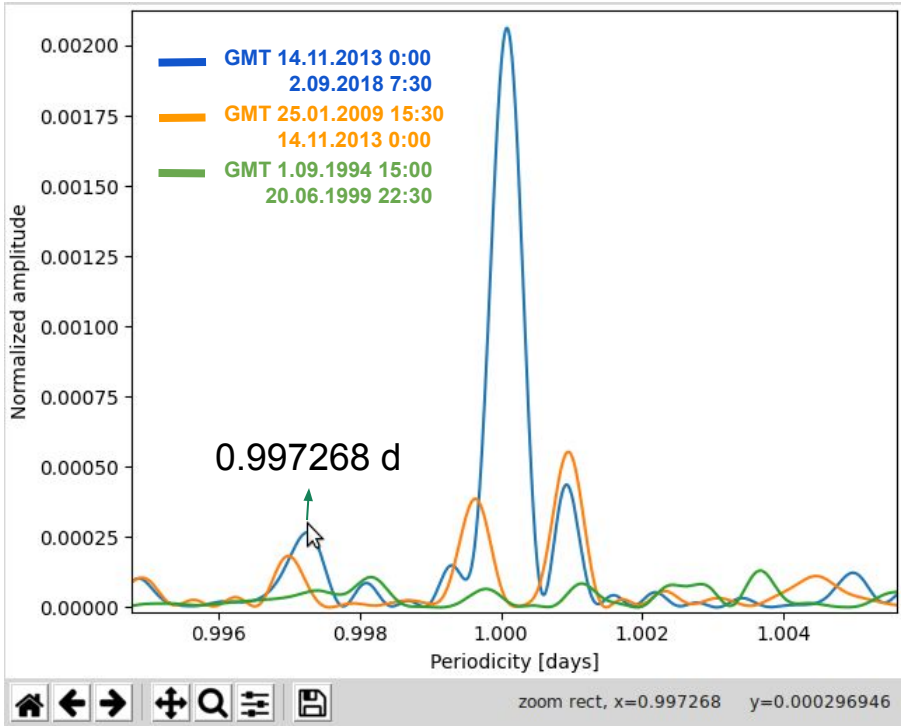
1 sidereal day = 23.9344696 hours -> 0.997269567 day; Lomb-Scargle periodograms



Clear ~24h and sidereal day periodicities both in CR and EQ data, appearing only during the cosmo-seismic correlation maximum? Responsible for the periodicity of the effect? Does the exact 0.99727 d periodicity in (part of) EQ data confirm the “external impact”?

24h and sidereal day evolution in the EQ data (m>=4), 30min. bins

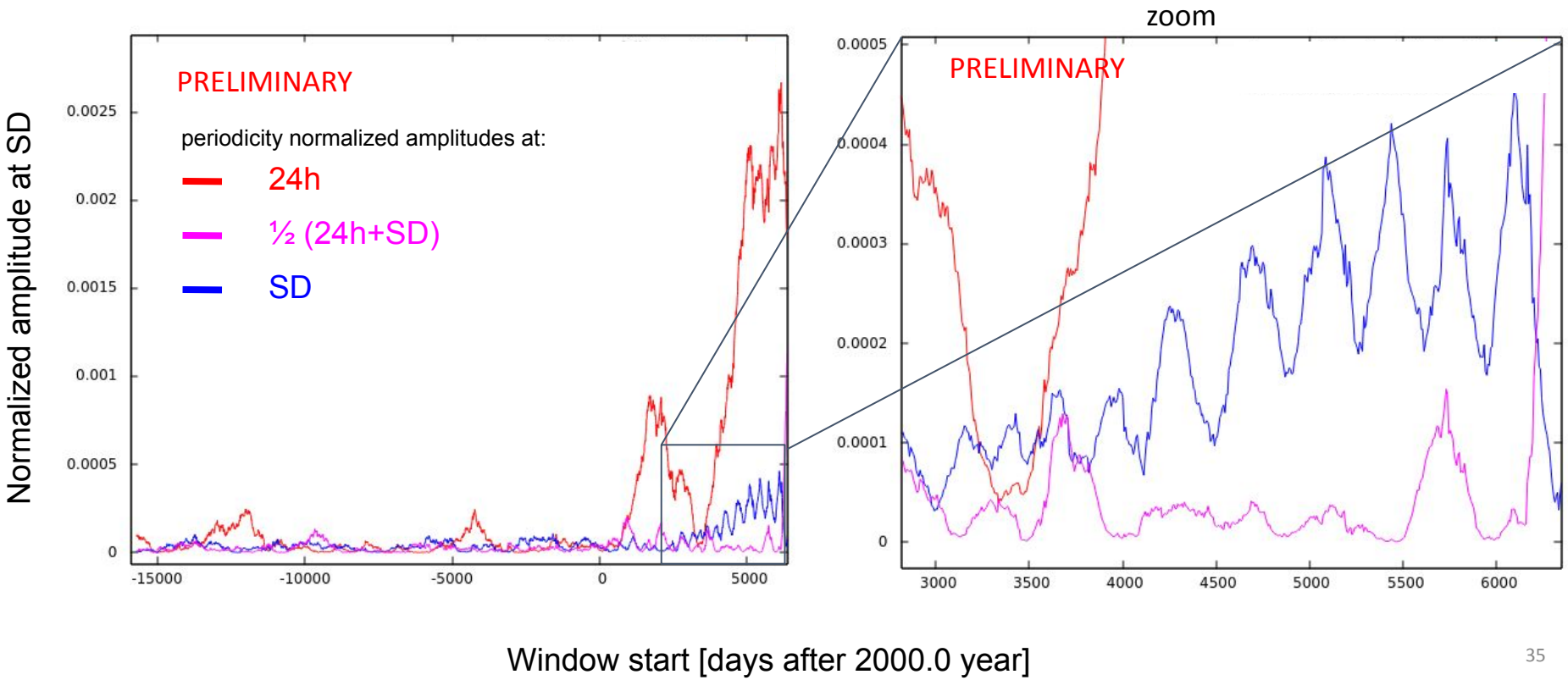
1 sidereal day = 23.9344696 hours -> 0.997269567 day



Clear 24h and sidereal day periodicities, both strongly time dependent!

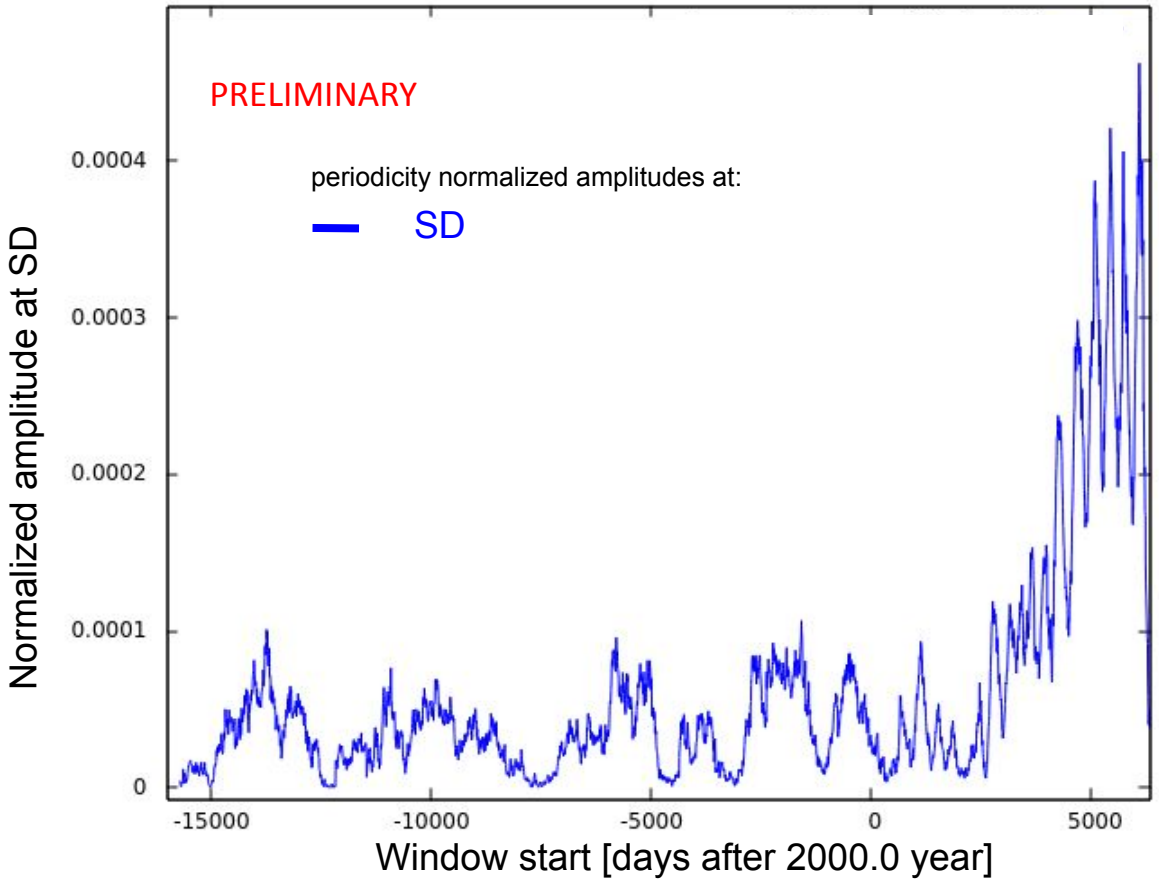
Time evolution of the 24h & sidereal day (SD) periodicities:

EQ data, N_{EQ}, 30min. bins, m >= 4, time window width: 4.5 yrs, step: 1 week



Time evolution of the sidereal day (SD) periodicity:

EQ data, N_{EQ}, 30 min. bins, m >= 4, time window width: 4.5 yrs, step: 1 week



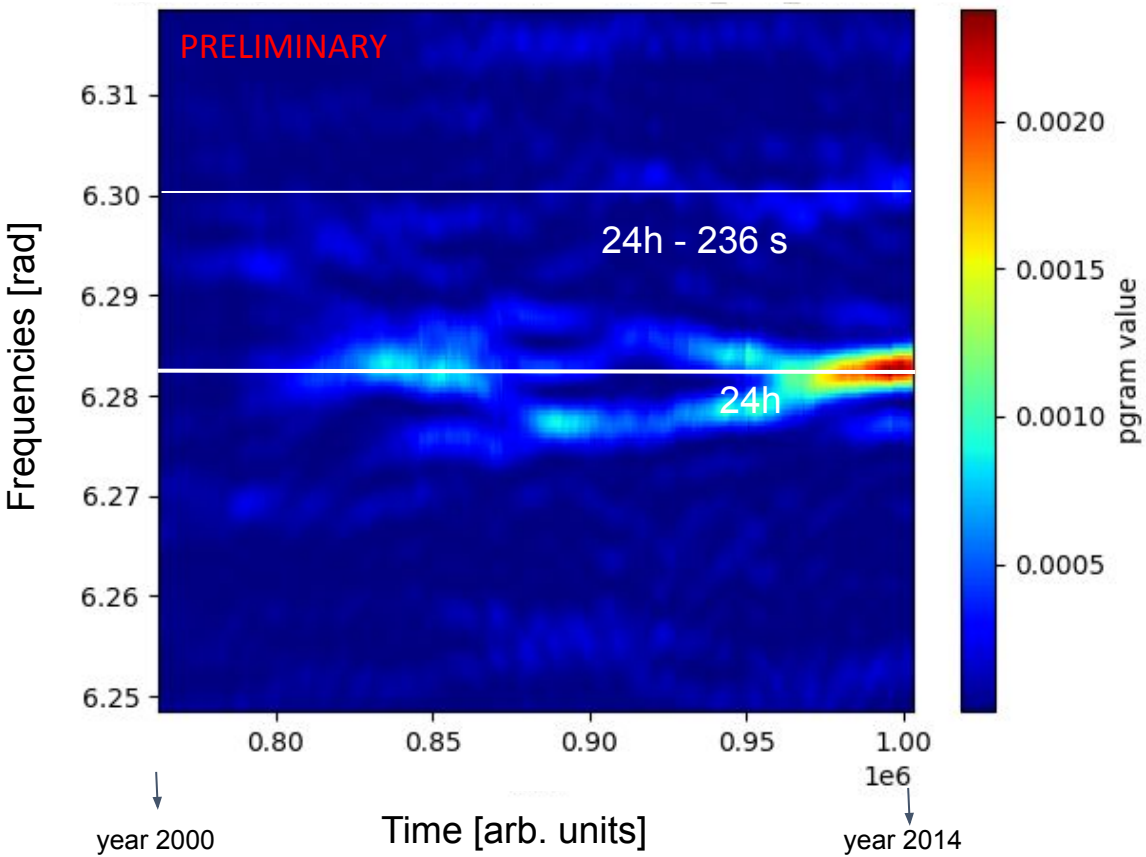
First fits (credit Maria Pycior):

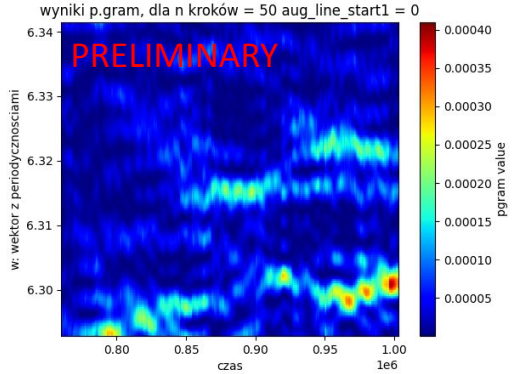
- ~390 d of the right part
- ~11 y of the left

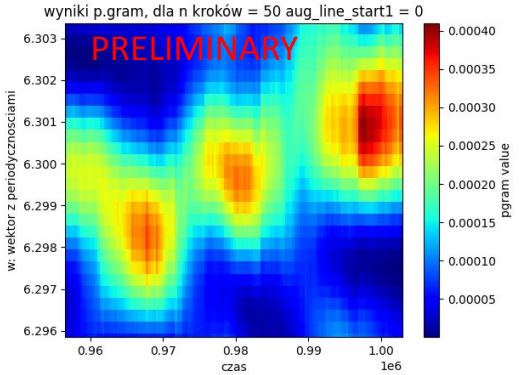
398.85d: period of the Earth & Jupiter synod

What could be the final experimental confirmation of the DM stream? Similar subthreshold "behavior" in various channels / datasets?

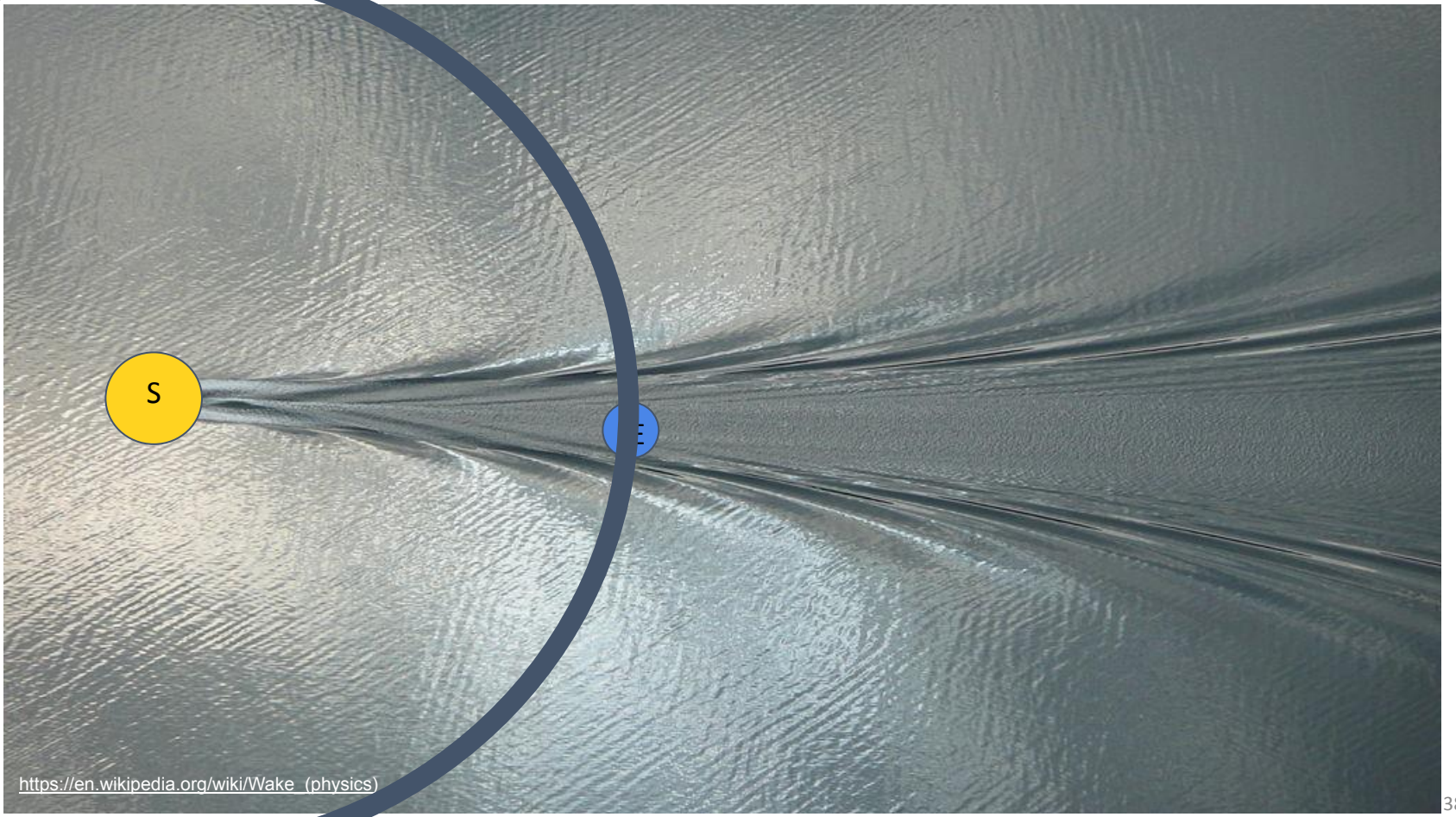
3d time evolution of periodicities in the EQ data: N_{EQ}, 30 min. bins, m >= 4, time window width: 4.5 yrs, step: 1 week



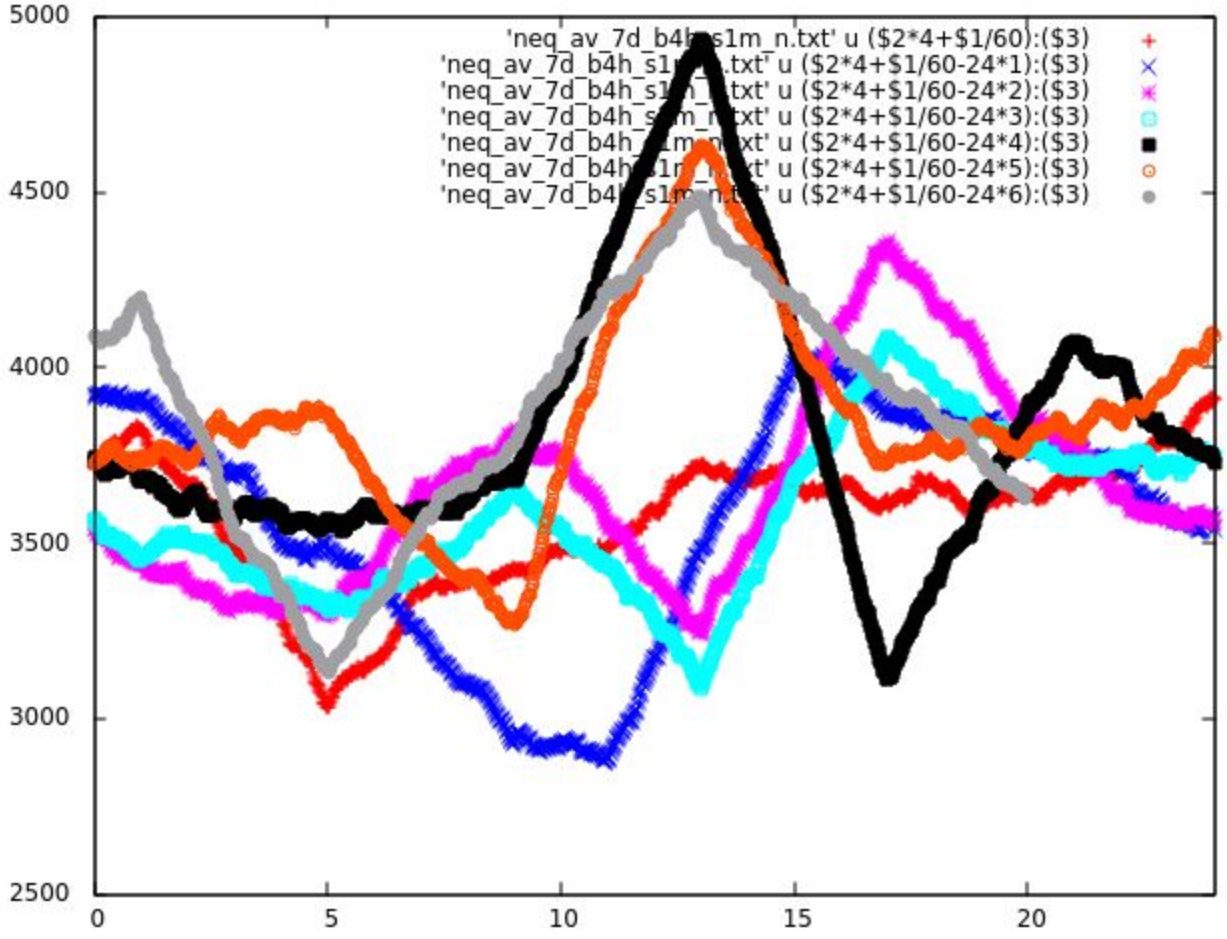




… or Dark Fluid -> dark wake(s)?



https://en.wikipedia.org/wiki/Wake_(physics)


5000
4500
4000
3500
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2500
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20
'neq_av_7d_b4h_s1m_n.txt' u ($2*4+$1/60):($3)
'neq_av_7d_b4h_s1m_n.txt' u ($2*4+$1/60-24*1):($3)
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'neq_av_7d_b4h_s1m_n.txt' u ($2*4+$1/60-24*6):($3)

https://arxiv.org/abs/2210.07367

"For **streaming dark matter**, the **gravitational focusing** gives rise to spatiotemporal **flux enhancements of orders of magnitude** above the nominal DM density. Remarkably, due to Earth's rotation the derived flux enhancements appear as transient signals lasting about 10 seconds repeating daily for days or weeks."

credit to Brian McBreen for pointing to the article

PHYSICAL REVIEW D **100,** 035001 (2019)

Planck mass charged gravitino dark matter

Krzysztof A. Meissner[1] and Hermann Nicolai[2]

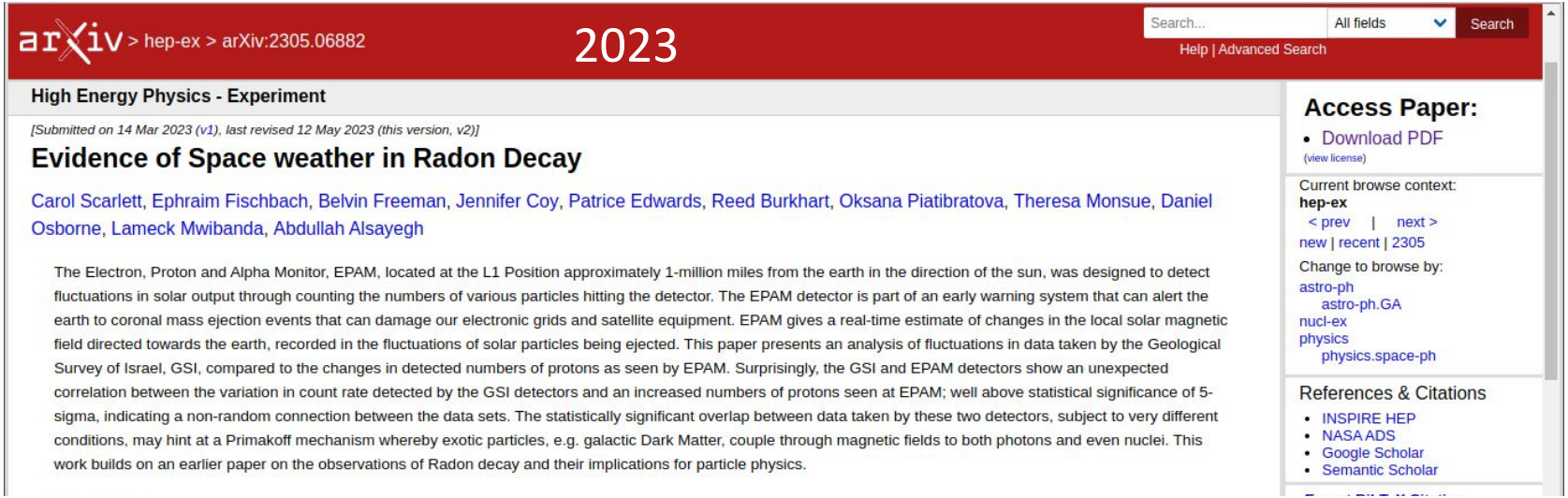
[1]*Faculty of Physics, University of Warsaw Pasteura 5, 02-093 Warsaw, Poland*
[2]*Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut) Mühlenberg 1, D-14476 Potsdam, Germany*

(Received 19 April 2019; published 2 August 2019)

Following up on our earlier work predicting fractionally charged supermassive gravitinos, we explain their potential relevance as novel candidates for dark matter and discuss possible signatures and ways to detect them.

DOI: 10.1103/PhysRevD.100.035001

https://journals.aps.org/prd/pdf/10.1103/PhysRevD.100.035001 / https://arxiv.org/abs/1809.01441



arXiv > hep-ex > arXiv:2305.06882

2023

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High Energy Physics - Experiment

[Submitted on 14 Mar 2023 (v1), last revised 12 May 2023 (this version, v2)]

Evidence of Space weather in Radon Decay

Carol Scarlett, Ephraim Fischbach, Belvin Freeman, Jennifer Coy, Patrice Edwards, Reed Burkhart, Oksana Piatibratova, Theresa Monsue, Daniel Osborne, Lameck Mwibanda, Abdullah Alsayegh

The Electron, Proton and Alpha Monitor, EPAM, located at the L1 Position approximately 1-million miles from the earth in the direction of the sun, was designed to detect fluctuations in solar output through counting the numbers of various particles hitting the detector. The EPAM detector is part of an early warning system that can alert the earth to coronal mass ejection events that can damage our electronic grids and satellite equipment. EPAM gives a real-time estimate of changes in the local solar magnetic field directed towards the earth, recorded in the fluctuations of solar particles being ejected. This paper presents an analysis of fluctuations in data taken by the Geological Survey of Israel, GSI, compared to the changes in detected numbers of protons as seen by EPAM. Surprisingly, the GSI and EPAM detectors show an unexpected correlation between the variation in count rate detected by the GSI detectors and an increased numbers of protons seen at EPAM; well above statistical significance of 5-sigma, indicating a non-random connection between the data sets. The statistically significant overlap between data taken by these two detectors, subject to very different conditions, may hint at a Primakoff mechanism whereby exotic particles, e.g. galactic Dark Matter, couple through magnetic fields to both photons and even nuclei. This work builds on an earlier paper on the observations of Radon decay and their implications for particle physics.

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References & Citations

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spaceweather (solar cycle) 1 million km above Earth

What is most fascinating and unexpected in this analysis, **the EPAM proton count rate** data shows a **strong correlation** with the count rate for gammas emitted from a chain **decay process of 222 Rn**, as seen by the GSI instruments.

radon (earthquake precursor) @ Earth

credit to Brian McBreen for pointing to the article

Heliospheric Current Sheet (- like?) behavior?

~10000 km thickness

~heavier particles required?

~periodicities close to 27 days, ½ x 27 days.

~opposite directions possible if both positive and negative charges involved?

3D time evolution of the promising periodicities (example: no. of earthquakes)