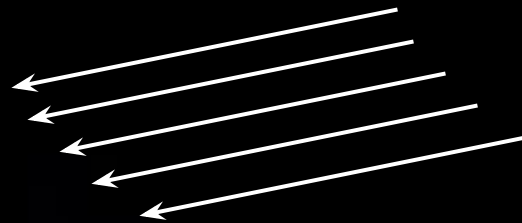
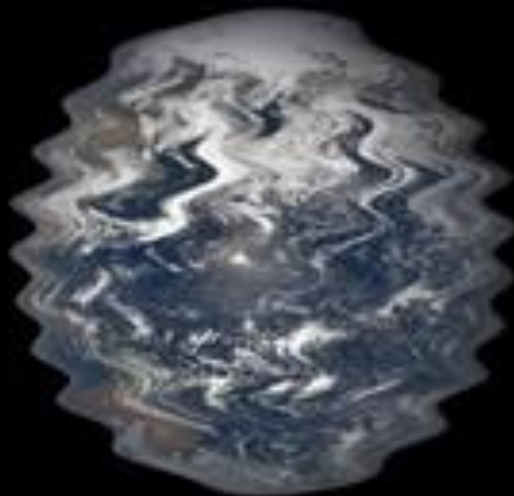


What is behind the cosmo-seismic effect?

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



Graphics source: IFJ PAN / NASA / JSC

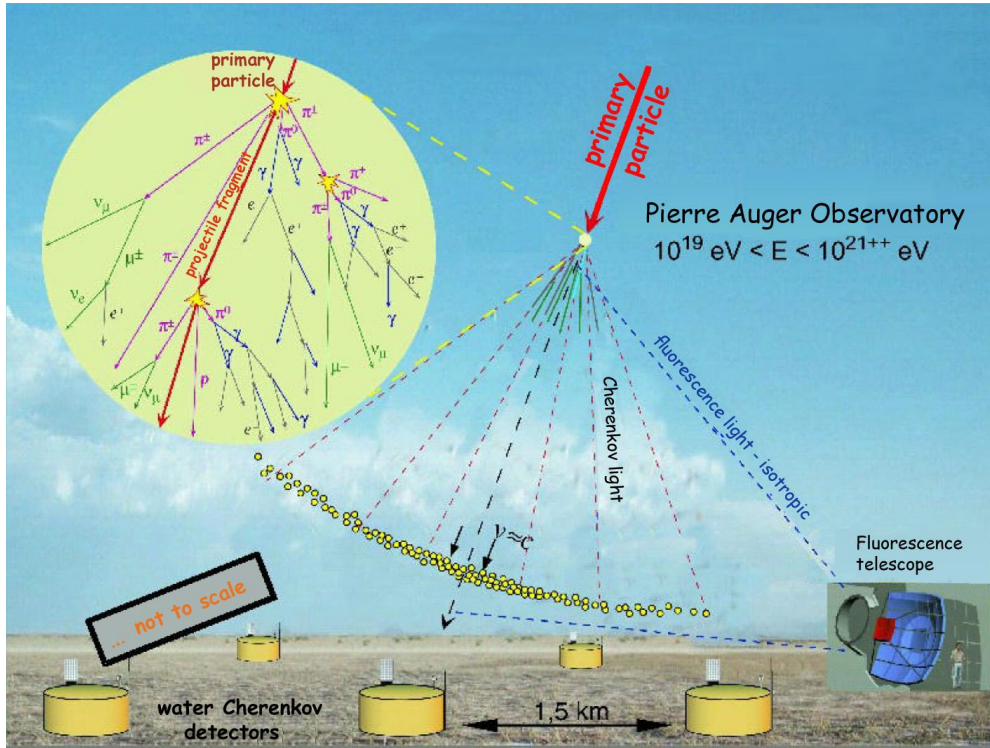
Piotr Homola
The Henryk Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences
Cosmic Ray Extremely Distributed Observatory / [CREDO.science](https://credo.science)

FuSe Training School, Tihany, 11.09.2026



**Correlation does not
imply causation**

The Pierre Auger Observatory and extensive air showers



location: **Argentina**

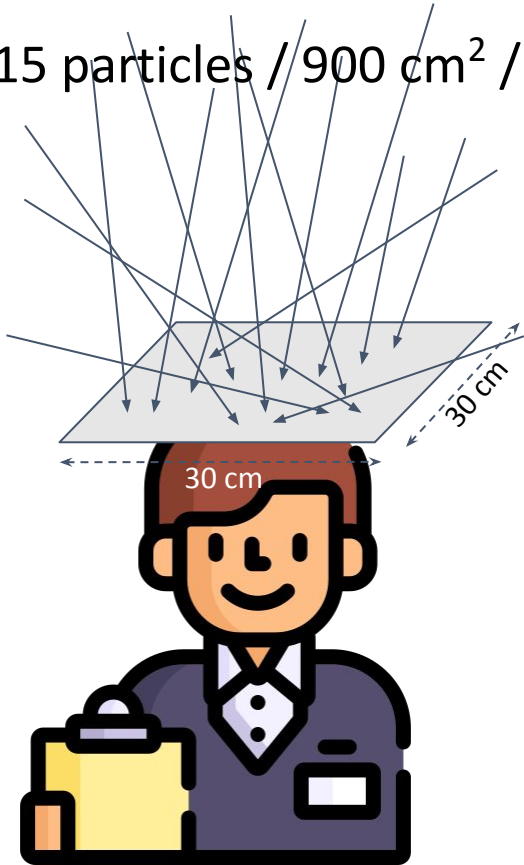
particle counters:
1600 detectors

single detector surface: **10 m²**

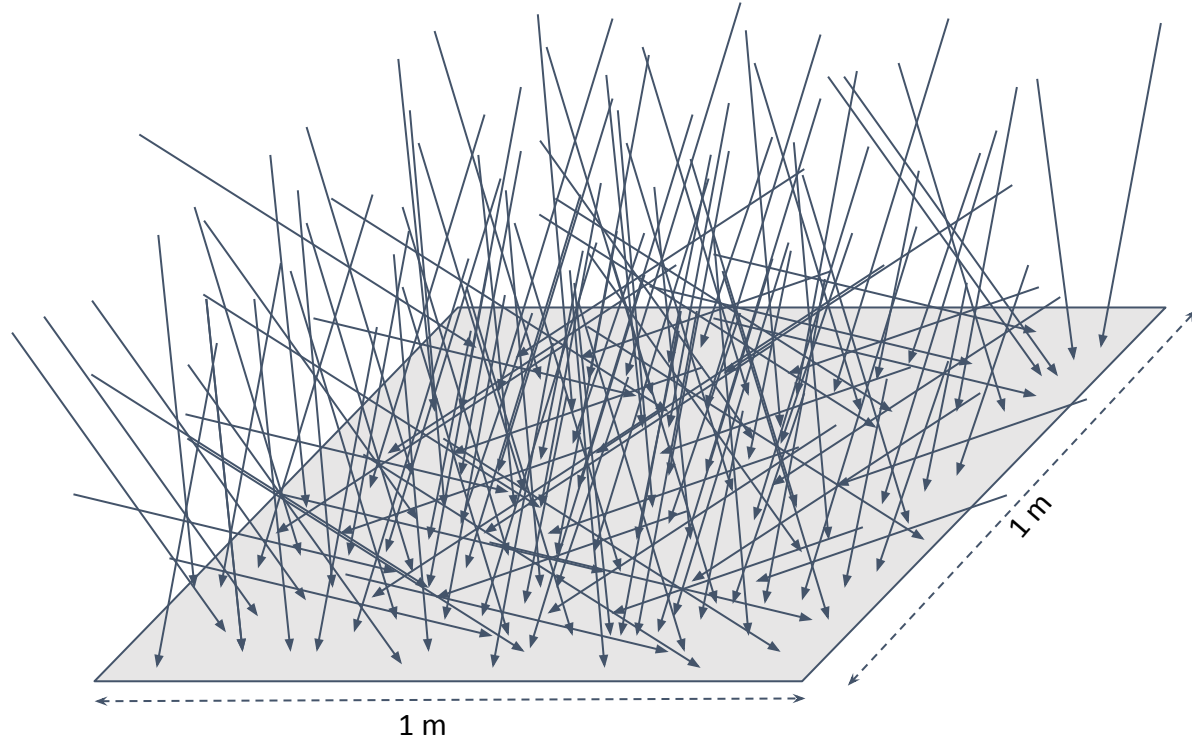
total surface of the detector
array: **3000 km²**

Secondary cosmic radiation

$\sim 15 \text{ particles} / 900 \text{ cm}^2 / 1 \text{ second}$



$\sim 150 \text{ particles} / 1 \text{ m}^2 / 1 \text{ second}$



Global cosmic ray studies make sense!



**DID YOU KNOW THAT YOU HAVE
AN INTERGALACTIC
PARTICLE DETECTOR
RIGHT IN YOUR
POCKET?**

Install CREDO Detector app for Android
and hunt for the deeply hidden
treasures of the Universe.

Find CREDO Detector on  **Google Play**

or scan QR 



The Cosmic Ray Extremely Distributed Observatory

key reference: *Symmetry* 2020, 12(11), 1835, <https://doi.org/10.3390/sym12111835>

CREDO
THE QUEST FOR THE UNEXPECTED

+ you =
smarter
together

CREDO
JOURNEY

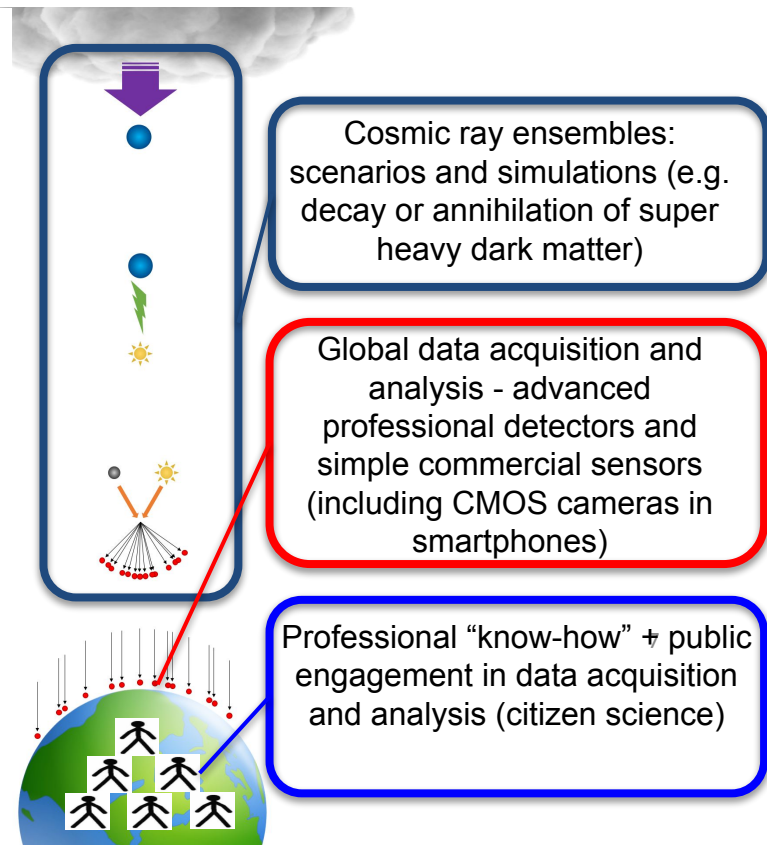


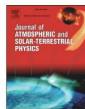
Cosmic Ray Extremely Distributed Observatory



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 $> 6\sigma$ discovery:**
J. Atmos. Sol. Terr. Phys. 247 (2023) 106068
[DOI:10.1016/j.jastp.2023.106068](https://doi.org/10.1016/j.jastp.2023.106068).





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^a, R. Damian^j, R. Guzik^j, D. Alvarez-Castillo^a, S. Stuglik^b, O. Ruimi^b, O. Skorenok^j, J. Zamora-Saa^{c,d}, J.M. Vaquero^e, T. Wibig^f, M. Knap^g, K. Dziadkowiec^j, M. Karpel^h, O. Sushchovⁱ, J.W. Mieltski^a, K. Gorzkiewicz^a, N. Zabari^e, K. Almeida Cheminant^a, B. Idzkowski^{h,k}, T. Bulik^{h,k}, G. Bhatta^a, N. Budnev^l, R. Kamiński^a, M.V. Medvedev^{l,m}, K. Kozak^a, O. Bar^y, Ł. Bibrzycki^j, M. Bielewicz^w, M. Frontczak^j, P. Kovács^o, B. Łozowski^j, J. Miszczyk^j, M. Niedźwiecki^j, L. del Peral^l, M. Piekarczyk^j, M.D. Rodríguez Friasⁿ, K. Rzecki^j, K. Smelcerz^y, T. Sośnicki^j, J. Stasielak^j, A.A. Tursunov^m

^a Institute of Nuclear Physics Polish Academy of Sciences, 31-342, Kraków, Poland^b Racah Institute of Physics, Hebrew University of Jerusalem, Jerusalem, IL, 91904, Israel^c Departamento de Ciencias Físicas, Universidad Andres Bello, Fernández Concha 700, Las Condes, Santiago, Chile^d Millennium Institute for Subatomic Physics at High Energy Frontier - SAPHIR, Fernández Concha 700, Las Condes, Santiago, Chile^e Astronómico Ltd., Juliusz Słowackiego 24, 35-069, Rzeszów, Poland^f Astrophysics Physics Amateur, 34-500, Zakopane, Poland^g Departamento de Física, Universidad de Extremadura, Avda. de Elvas s/n, 06006, Badajoz, Spain^h Astronomical Observatory University of Warsaw, Al. Ujazdowski 4, 00-478, Warsaw, Polandⁱ Taras Shevchenko National University of Kyiv, 01601, Kyiv, Ukraine^j AGH University of Krakow, al. Mickiewicza 30, 30-059, Kraków, Poland^k Astronomical Nicolaus Copernicus Astronomical Center, Rebrorska 4, 00-614, Warsaw, Poland^l Pedagogical University of Krakow, Podchorążych 2, 30-084, Kraków, Poland^m Institute of Physics, Silesian University in Opava, Beethovenova nám. 13, CZ-74601, Opava, Czech Republicⁿ Space and Astroparticle Group, University of Alcalá, Ctra. Madrid-Barcelona, Km. 33,7, E-28871, Madrid, Spain^o Wigner Research Centre for Physics, Konkoly-Thege Miklós út 29-33, H-1121 Budapest, Hungary^p Department of Theoretical Physics, Faculty of Physics and Applied Informatics, University of Lodz-Panorama 149/153, PL-90-236, Lodz, Poland^q University of Napoli "Parthenope", Department of Engineering, Centro Direzionale, Isola C4, 80143, Napoli, Italy^r Irkutsk State University, Physical Department, K. Marx str., 1, Irkutsk, 664003, Russia^s Astrophysics Physics Amateur, 60470, Dobromir, Poland^t Department of Physics and Astronomy, University of Kansas, Lawrence, KS, 66045, USA^u Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, MA, 02139, USA^v Faculty of Natural Sciences, University of Silesia in Katowice, Bankowa 9, 40-007, Katowice, Poland^w National Centre for Nuclear Research (NCBJ), Solimna Str. 7, 05-400, Otwock, Swierk, Poland^x Astronomical Observatory, Jagiellonian University, Orla Str. 171, 30-244, Kraków, Poland^y Department of Computer Science, Cracow University of Technology, 31-155, Kraków, Poland^z SKA Observatory, Jodrell Bank, Lower Withington, Macclesfield Cheshire, SK11 9TT, UK

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 undecadal solar cycle, with a shift in phase of around three years, exceeding 6σ at local maxima. The precursor characteristics of the observed correlations point to a pioneer perspective of an early warning system against earthquakes.

^{*} Corresponding author.E-mail address: Piotr.Homola@ifj.edu.pl (P. Homola).*J. Atmos. Sol. Terr. Phys.* **247** (2023) 106068[DOI:10.1016/j.jastp.2023.106068](https://doi.org/10.1016/j.jastp.2023.106068)

Observation of cosmo-seismic correlations:

a $> 6\sigma$ discovery!

“Astroparticle
Physics
Amateur”!

The earthquake in Chile, 27.02.2010, M 8.8, 500 victims, losses: US\$ 30 billion

Chile earthquake



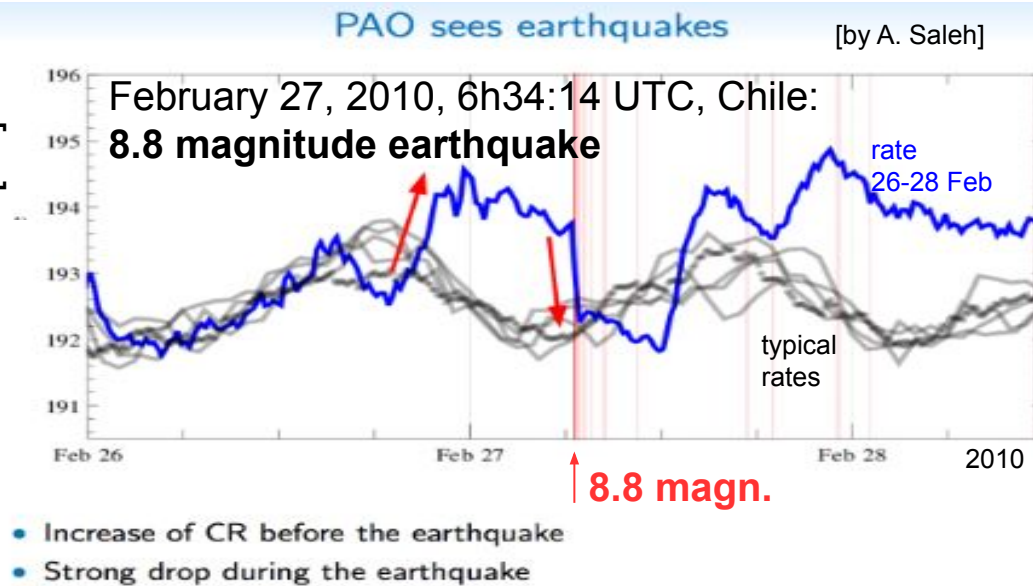
source: <http://news.bbc.co.uk>

The Pierre Auger Observatory,
3000 km²



The seismic precursor in cosmic rays: inspiration from the Pierre Auger Observatory

Pierre Auger
Observatory
scaler rate [Hz]



Inhabitants of territories
threatened by earthquakes:

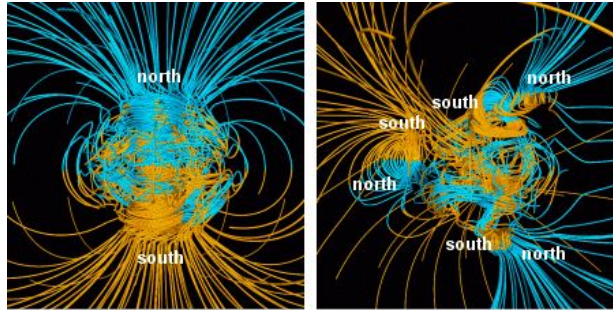
2,7 billion people

**Science as a service to
the human community?**

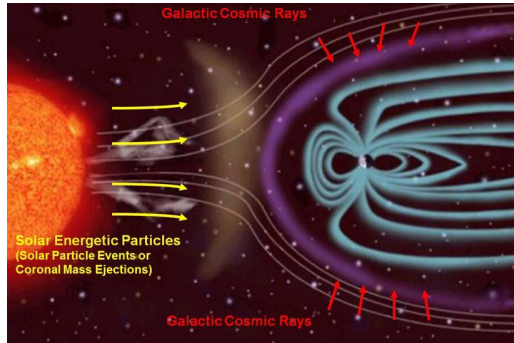
Even the smallest chance to
save lives

= a must check!

the COSMO-GEO precursor concept



between reversals during a reversal
Source: Wikipedia / „Geomagnetic reversal”



Source: Wikipedia / „Health threat from cosmic rays”

Earth outer core: Liquid (molten iron)
→ geomagnetism

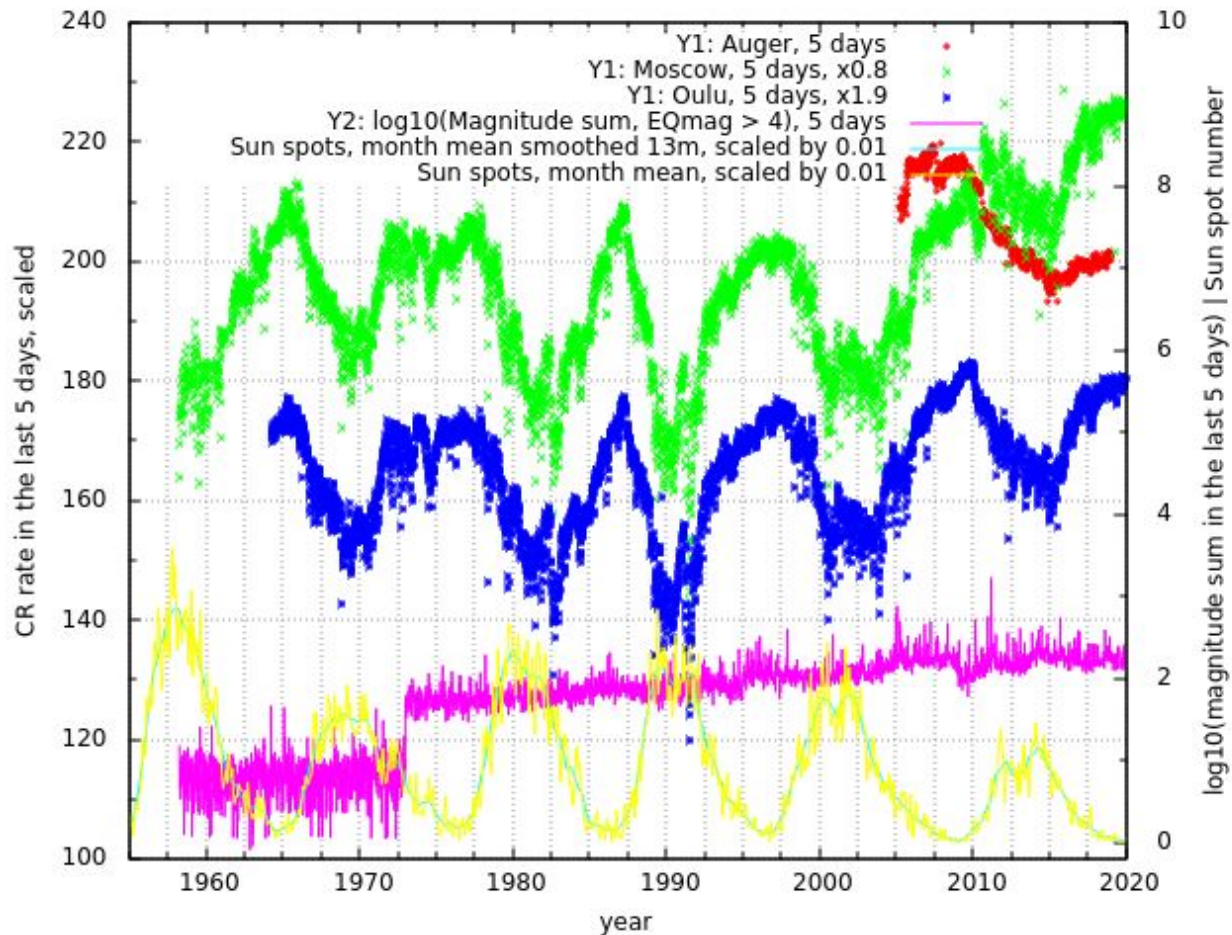
↓
Impulse (tidal forces)
→ hydrodynamics: waves

↓
→ Mechanical wave upwards (slow, hours?)
→ Electromagnetic wave („instant”, ms)

↓
Local/global geomagnetic field vector changes
AND seismic effect might occur!

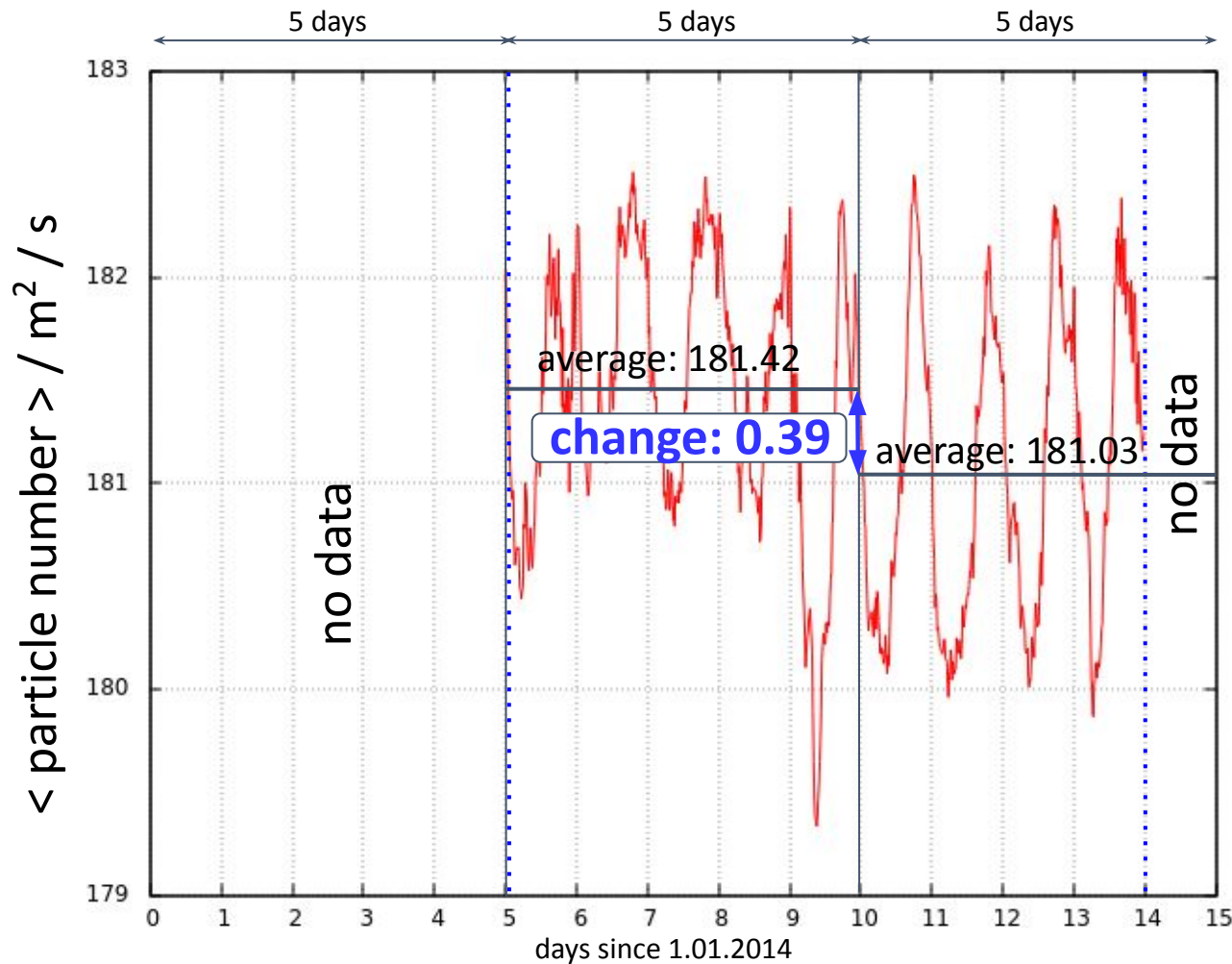
↓
Variation of the CR rate!

↓
Earthquake precursors?



Public data!

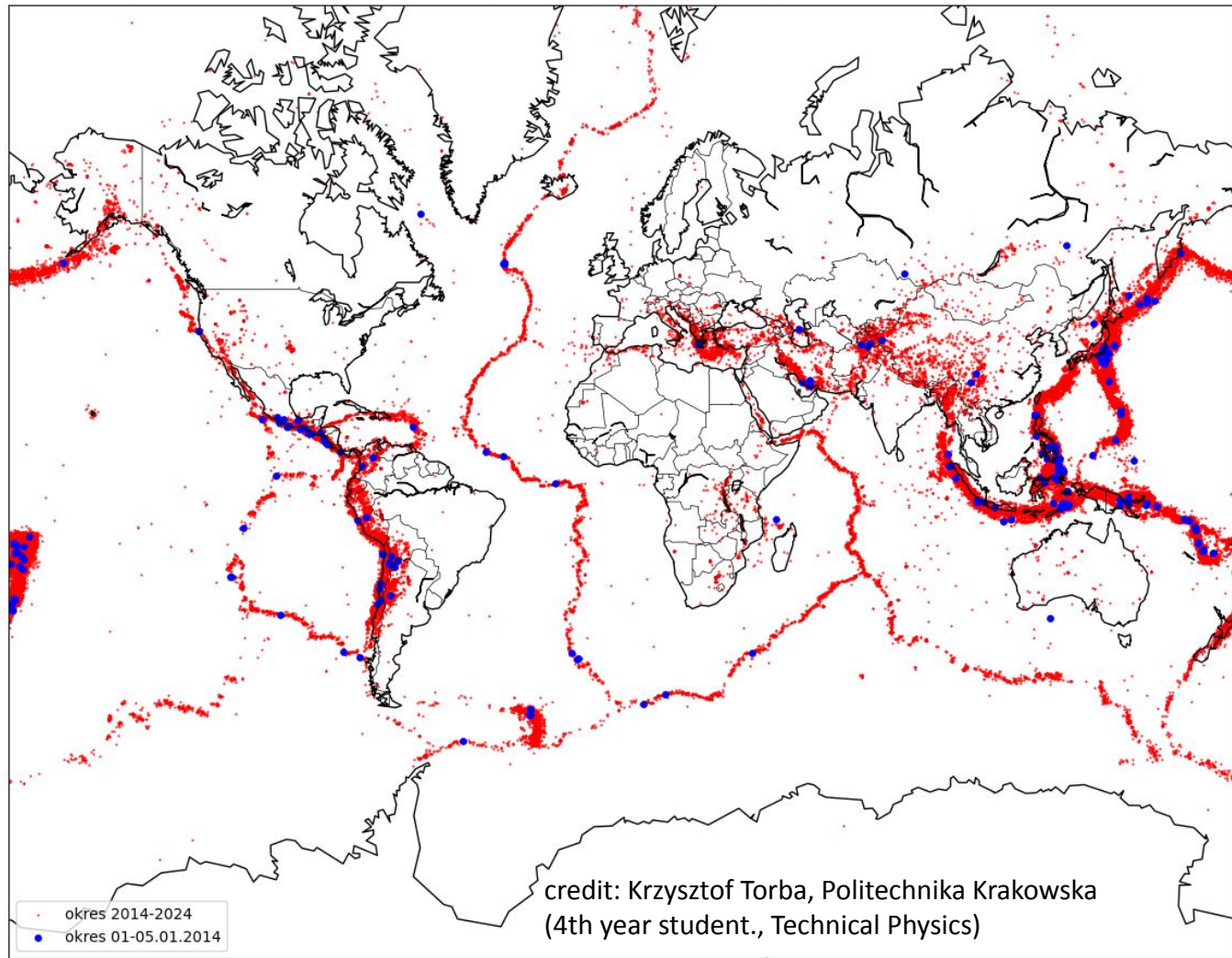
[Pierre Auger Observatory scaler data](#)
[Neutron Monitor Database](#)
[U.S. Geological Survey](#)
[Solar Influences Data analysis Center](#)



Example data:
The Pierre Auger
Observatory,
1-15.01.2014

**Local change of the
secondary cosmic
radiation detection
rate [$\langle \text{particle number} \rangle / \text{m}^2 / \text{s}$]:**

$$|181.03 - 181.42| = \mathbf{0.39}$$



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

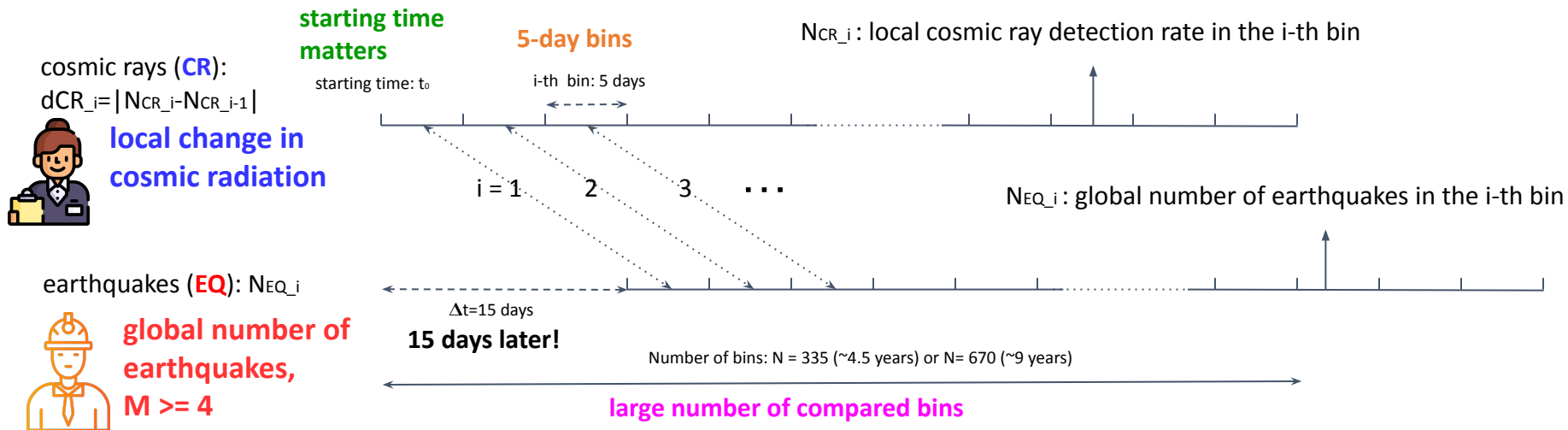
Earthquakes magnitude ≥ 4

example statistics:

● period: 2014-2024
(~160 000 events)

● period: 1-5.01.2014
(209 events)

The dychotomic cosmo-seismic correlation



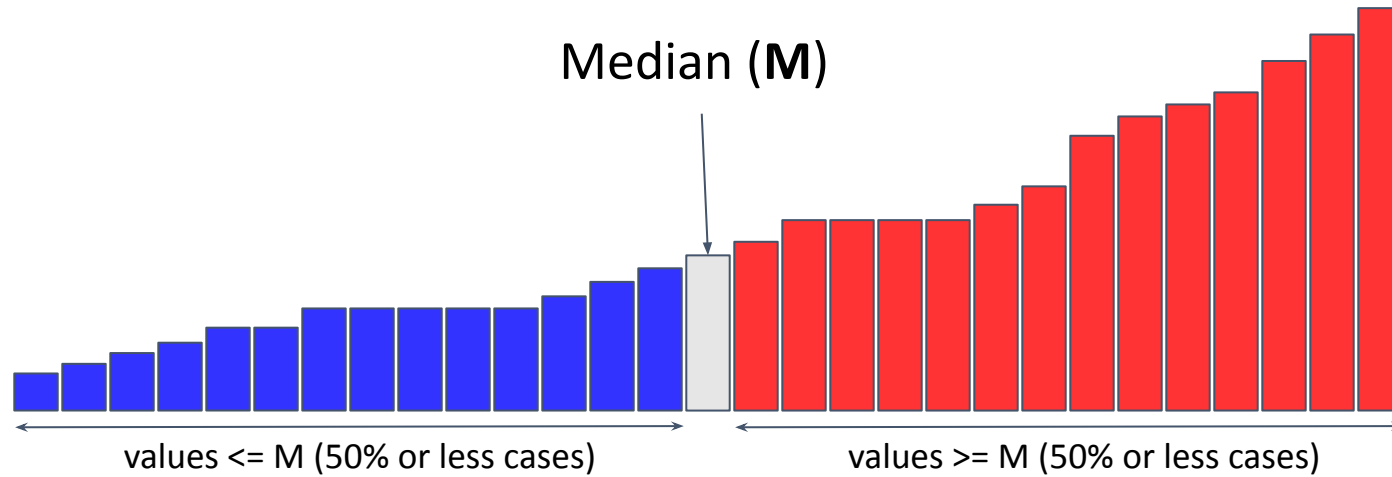
M_{CR} : median of the CR data **medians: half values below, half above**
 M_{EQ} : median of the EQ data
 N_+ : $((dCR_i > M_{CR}) \text{ and } (N_{EQ_i} > M_{EQ})) \text{ or } ((dCR_i < M_{CR}) \text{ and } (N_{EQ_i} < M_{EQ}))$
 N_- : $((dCR_i > M_{CR}) \text{ and } (N_{EQ_i} < M_{EQ})) \text{ or } ((dCR_i < M_{CR}) \text{ and } (N_{EQ_i} > M_{EQ}))$

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

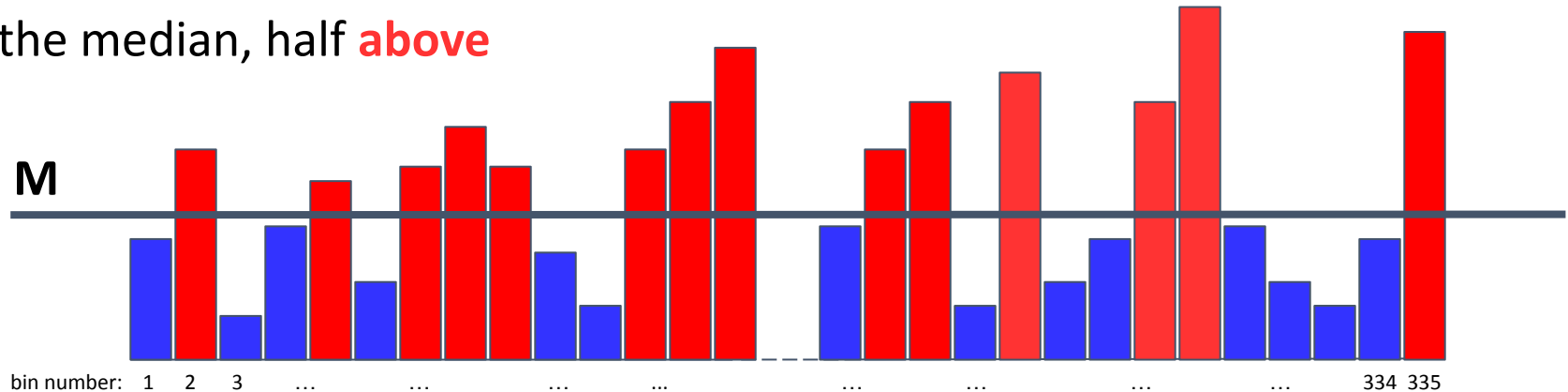
Chance probability:

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

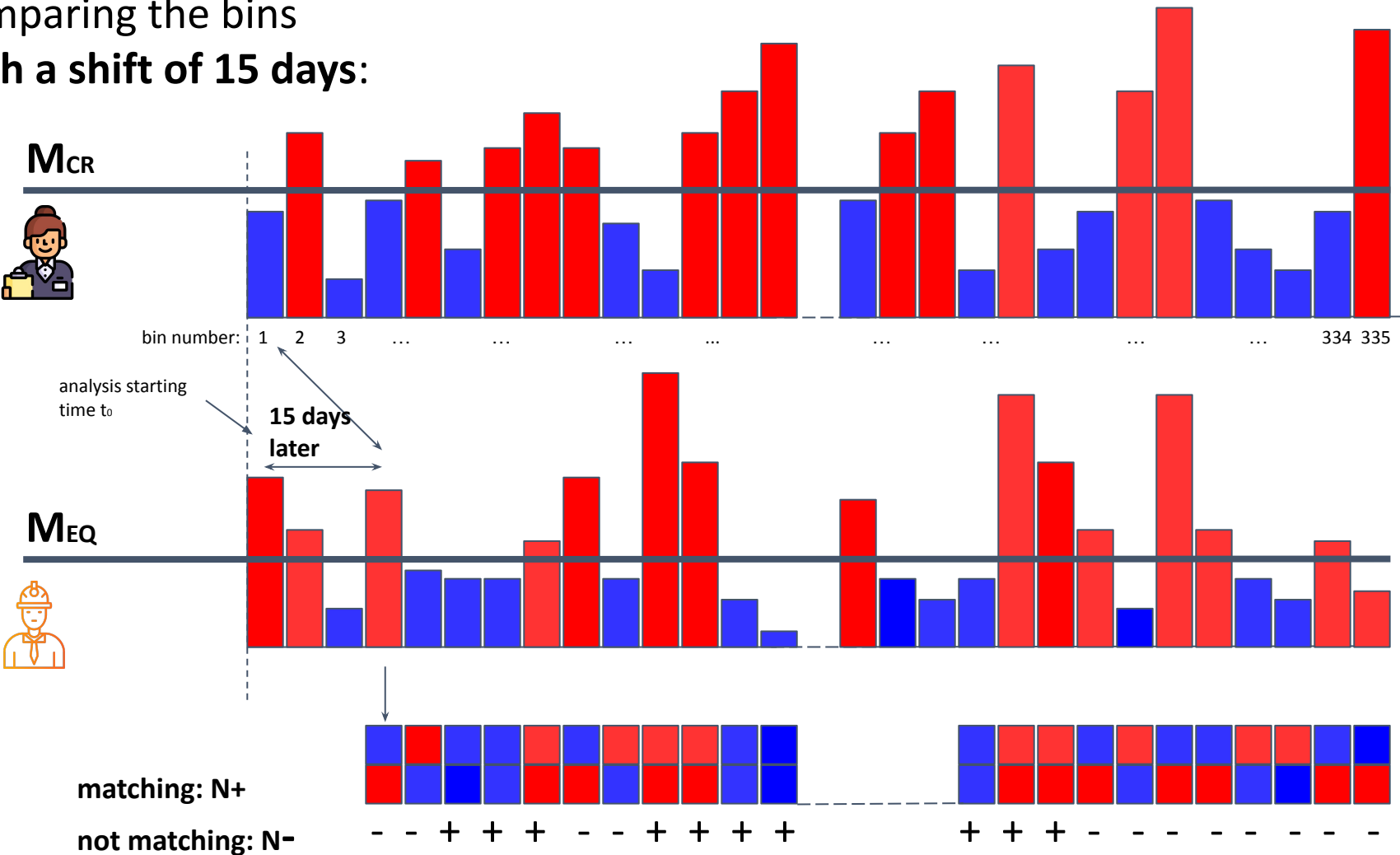
the probability of imbalance between matching and not matching signs (binomial distribution, balance expected)



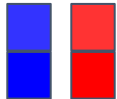
Data: half of the values **below**
the median, half **above**

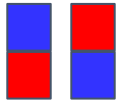


comparing the bins
with a shift of 15 days:



Outcome:

Number of
matching, **N+**  : ~200

Number of not
matching, **N-**  : ~100

We've got it! Even **twice more** matching
than not matching! How did you know?

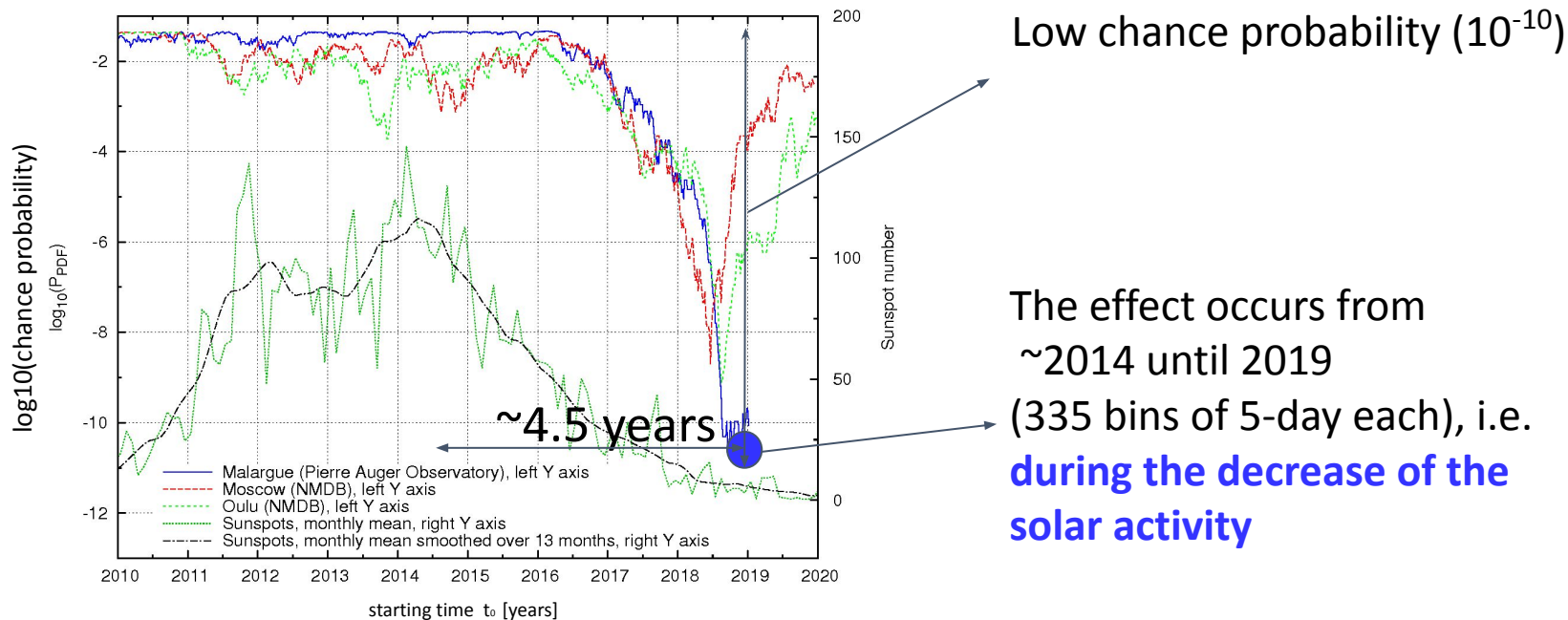


I was shooting :)
A clear **cosmo-seismic
correlation!**

Small chance probability!
Like one per billion!



The clear cosmo-seismic correlation!



$\sim 6\sigma$ 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?

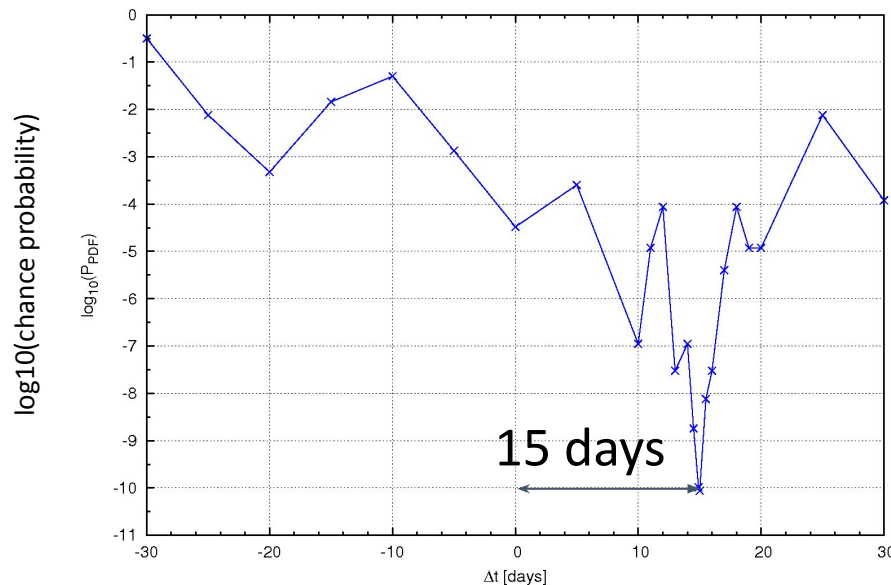
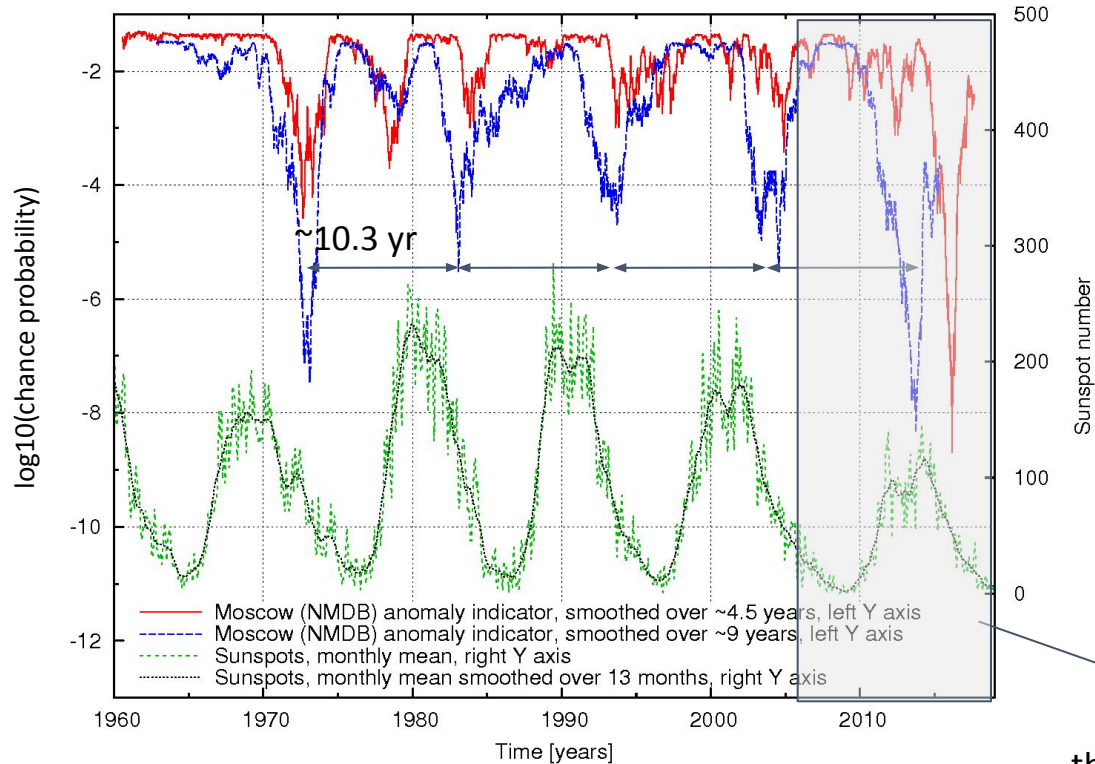


Fig. 3: The dependence of the significance of the *cosmo-seismic* correlations on the time shift t of the EQ data with respect to the Auger CR data, for the optimum free parameter set defined in Eq. 1. The positive or negative values of t correspond to the situations in which one compares the secondary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

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: t_0 , lag, bin size

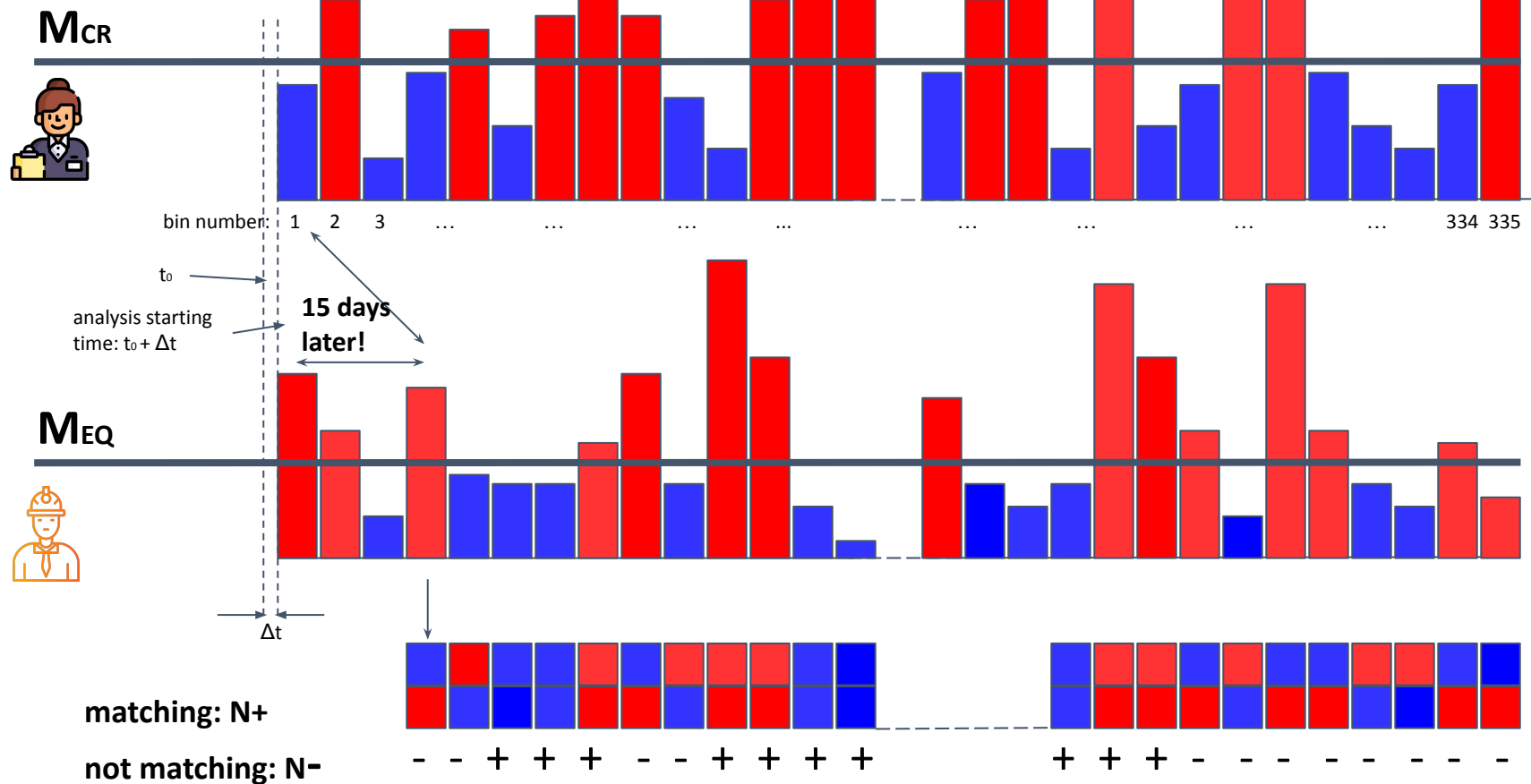
And how about changing the starting time only slightly, say one day?



Why not. It should not matter - we look at a wide period of time, many years, one day is nothing...



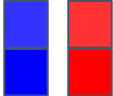
small change of the analysis
starting time: $t_0 \rightarrow t_0 + \Delta t$

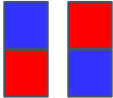


.... a bit of re-computing, and...



Outcome:

Number of
matching, **N+**  : ~150

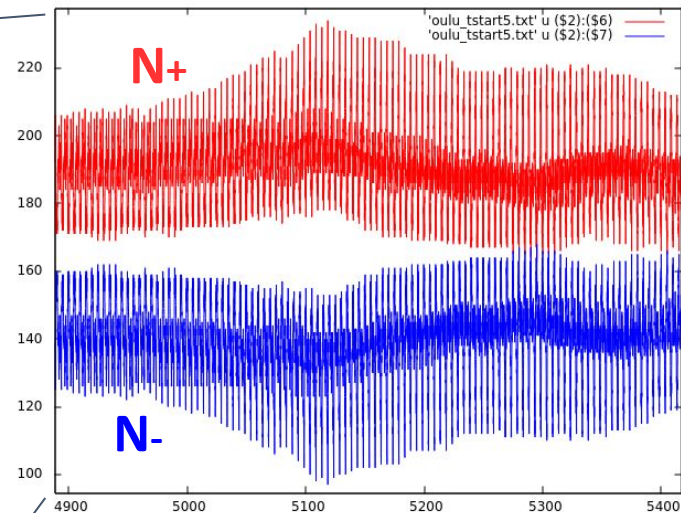
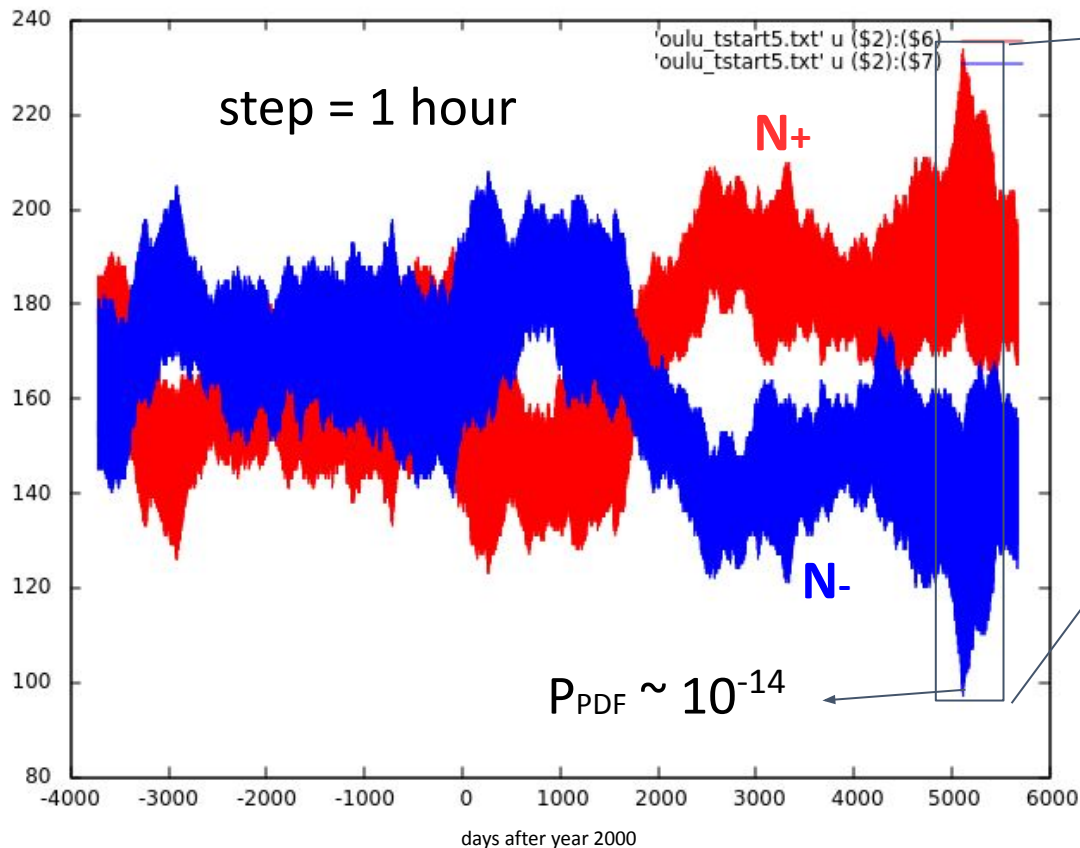
Number of not
matching, **N-**  : ~150



Oh no! The effect is
gone!

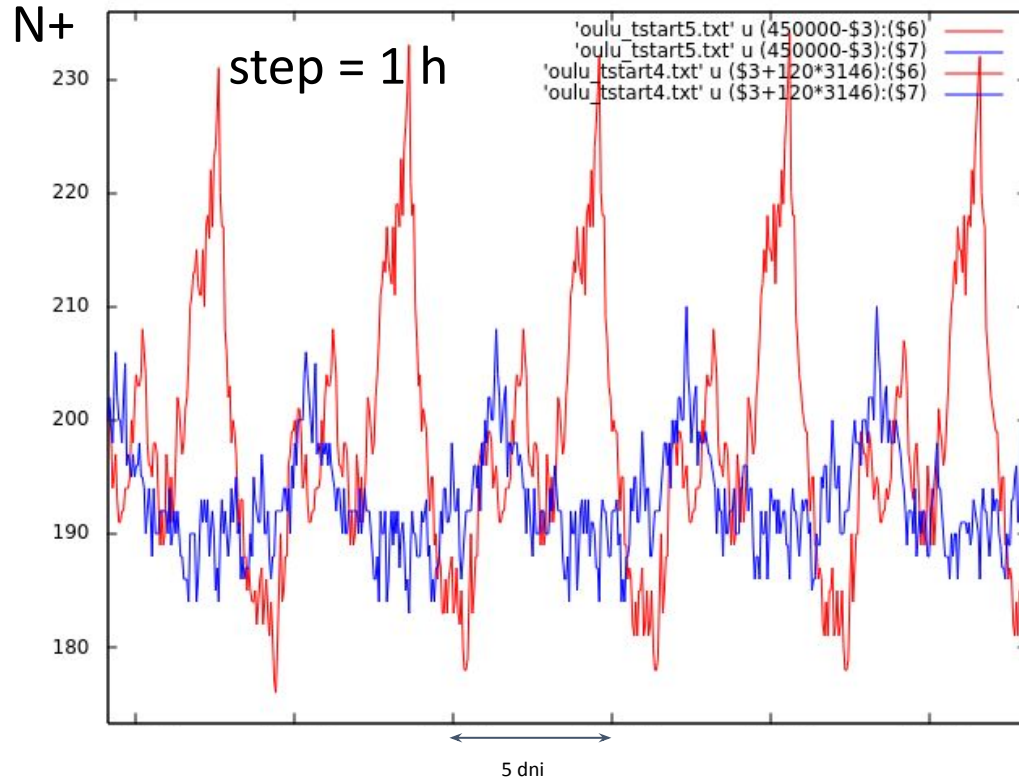


Sensitivity to small changes of t_0



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

Sensitivity to small changes of t_0



red: $t_0 \sim 2014$

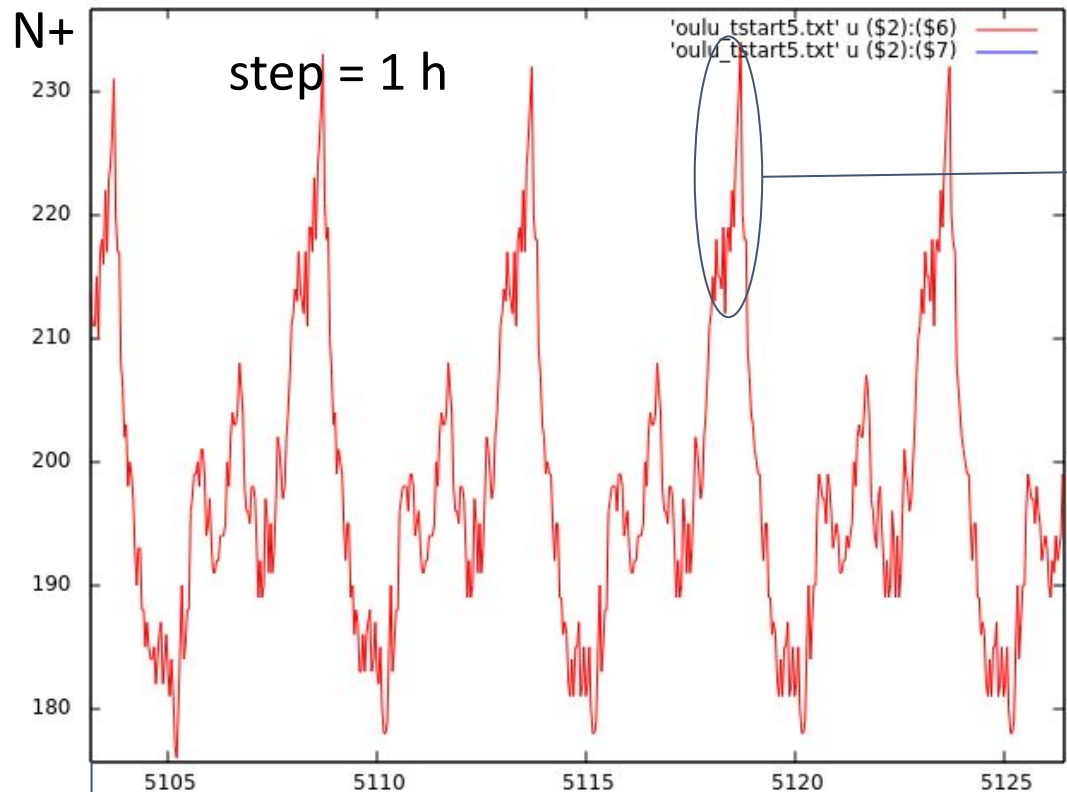
blue: $t_0 \sim 2006$

-> optimum t_0 changes in time!

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

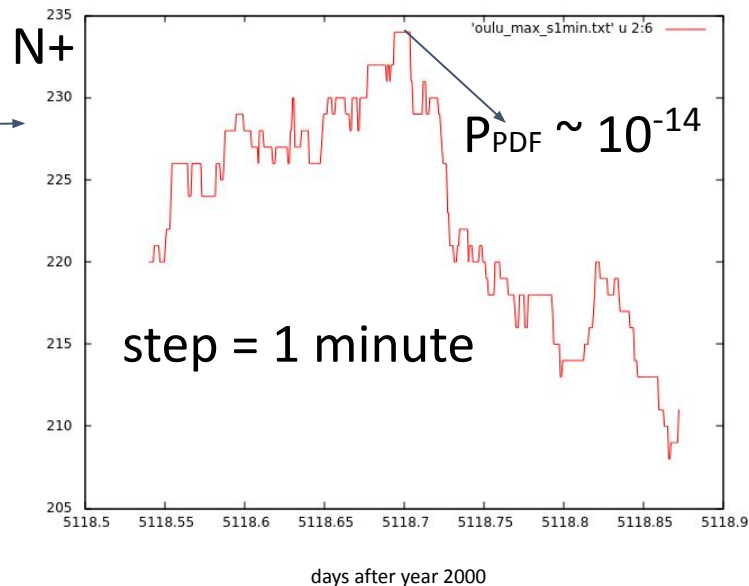
Oulu; CR data bins: 6hrs,
cosmo-seismic bin: $f \times 5$ days;
 $f=0.99915$

Sensitivity to small changes of t_0



step = 1 h

'oulu_tstart5.txt' u (\$2):(\$6)
'oulu_tstart5.txt' u (\$2):(\$7)

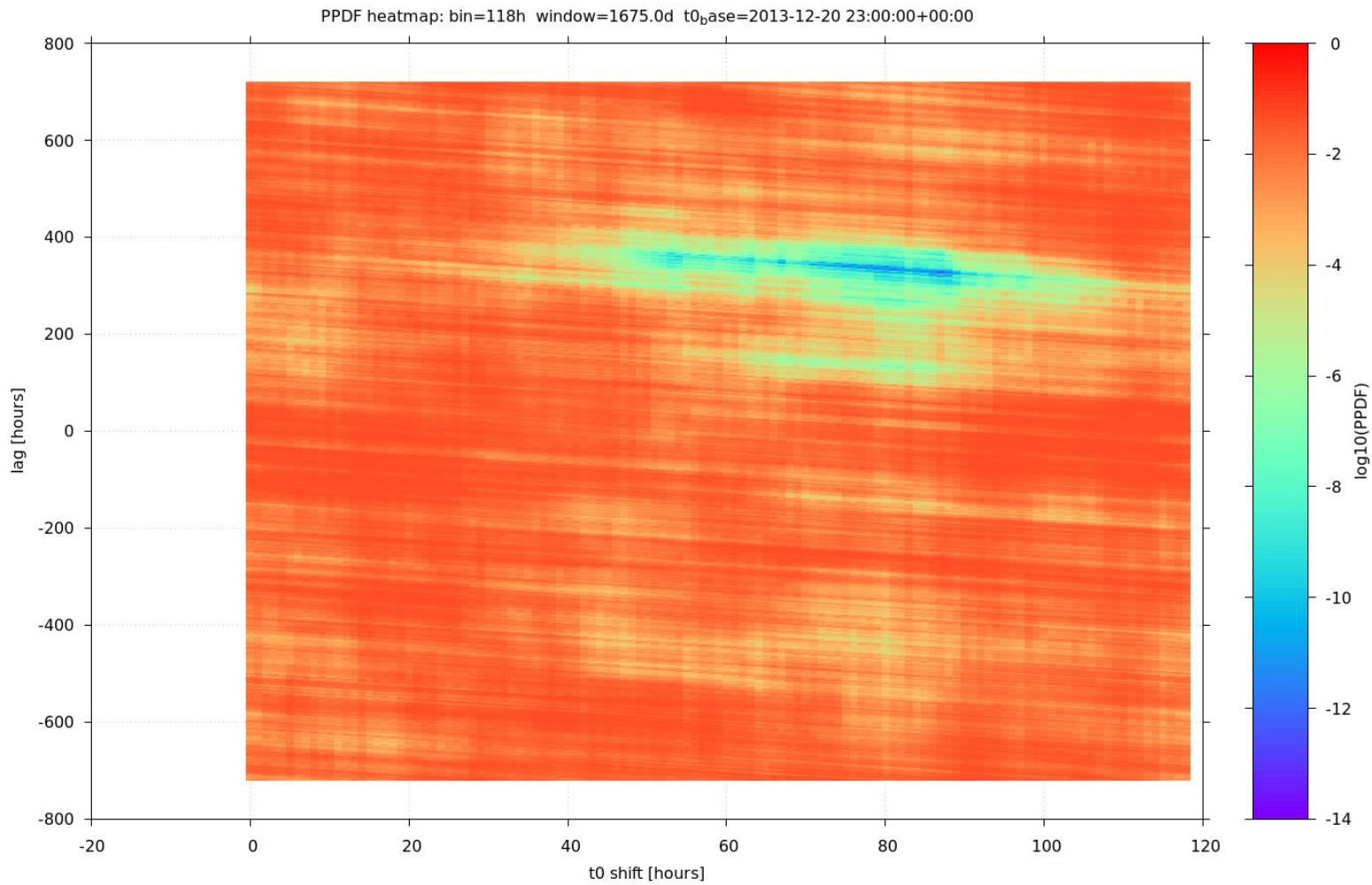


step = 1 minute

$P_{PDF} \sim 10^{-14}$

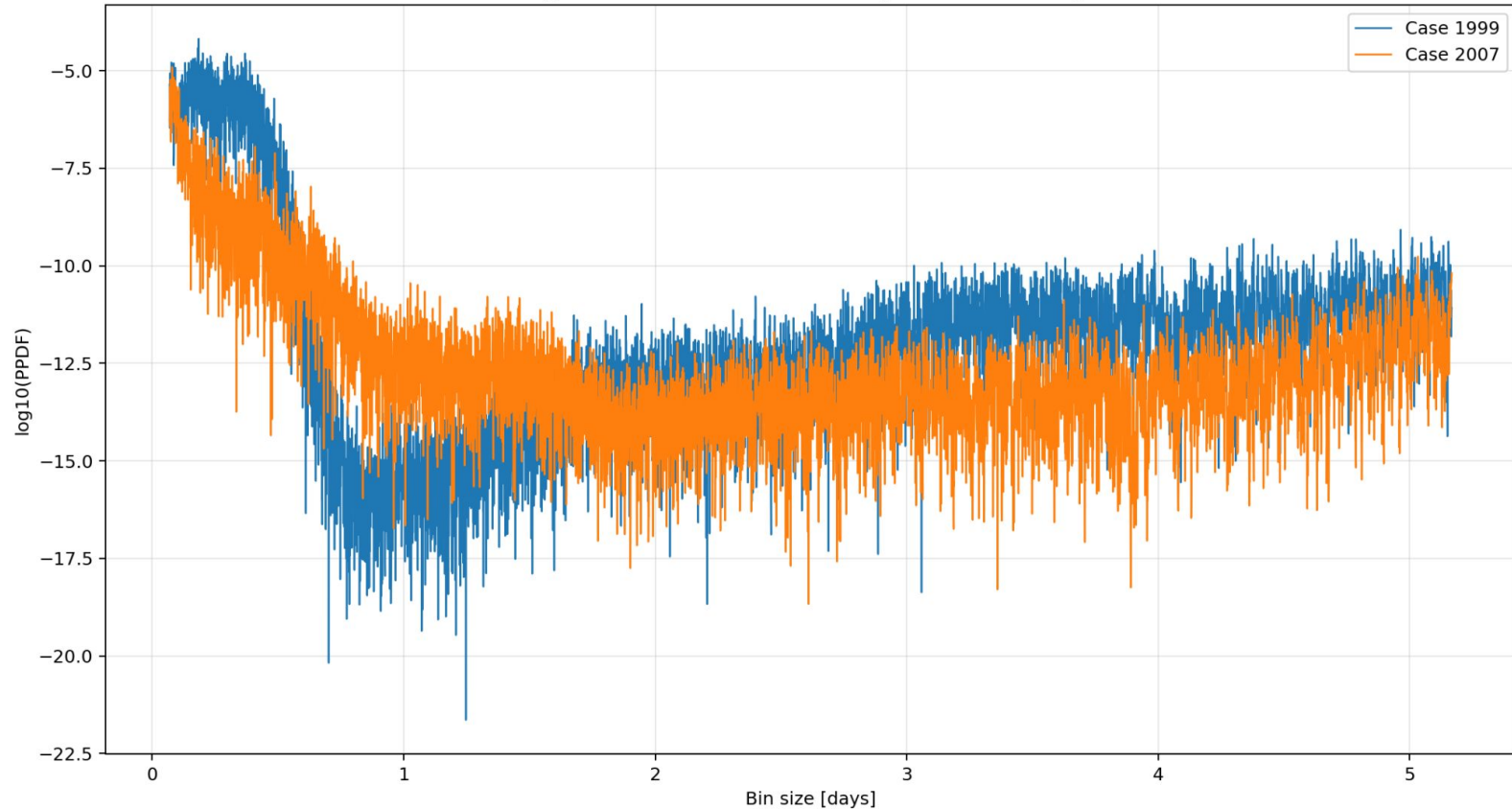
Oulu; CR data bins: 6 hrs,
335 cosmo-seismic bins:
f x 5 days each; $f=0.99915$
(similar for other sites and $f=1.0$)

The 15 days lag: real island on t_0 /lag/bin_size phase space

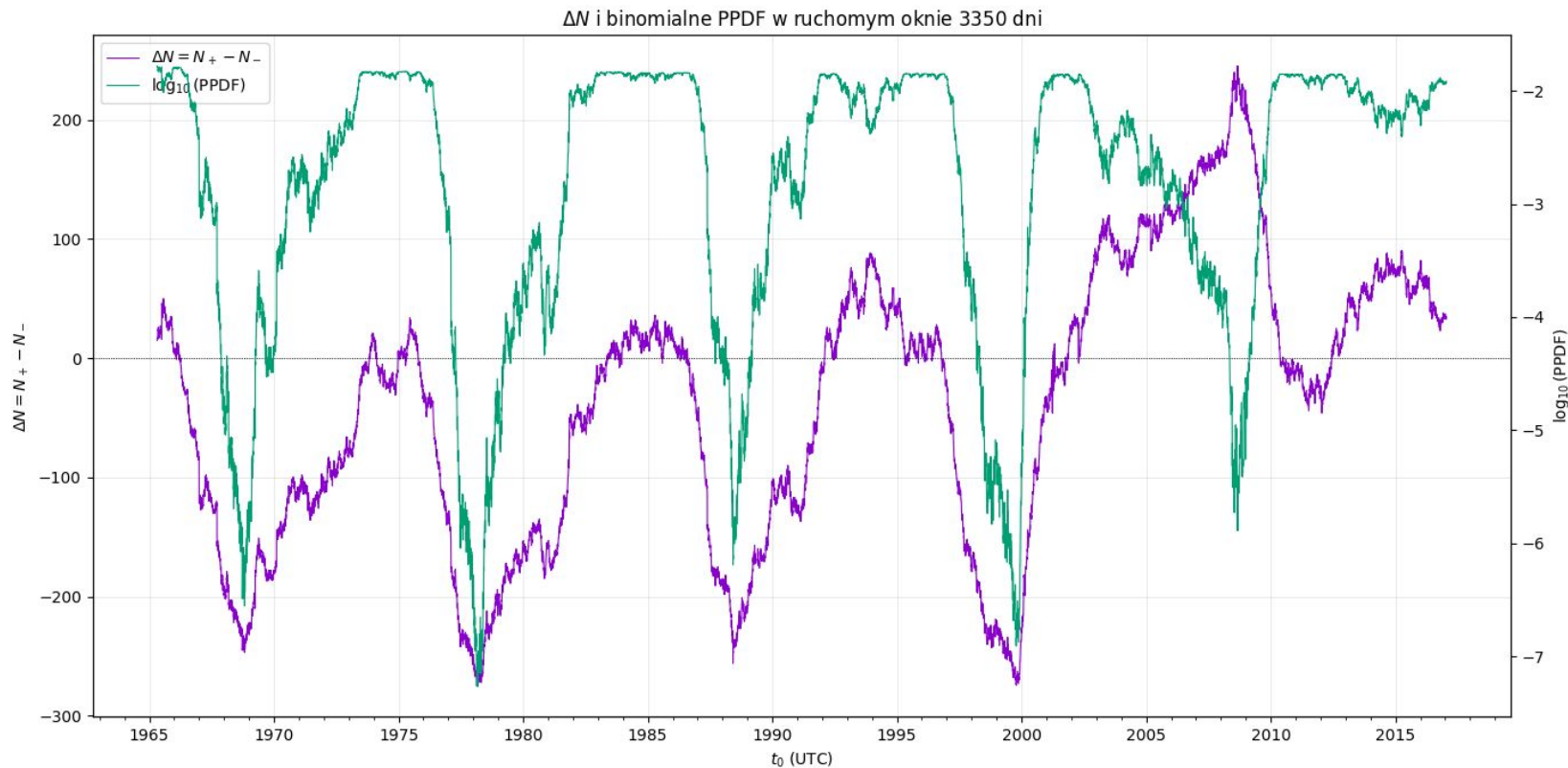


Any bin size goes (with t0/lag optimization)

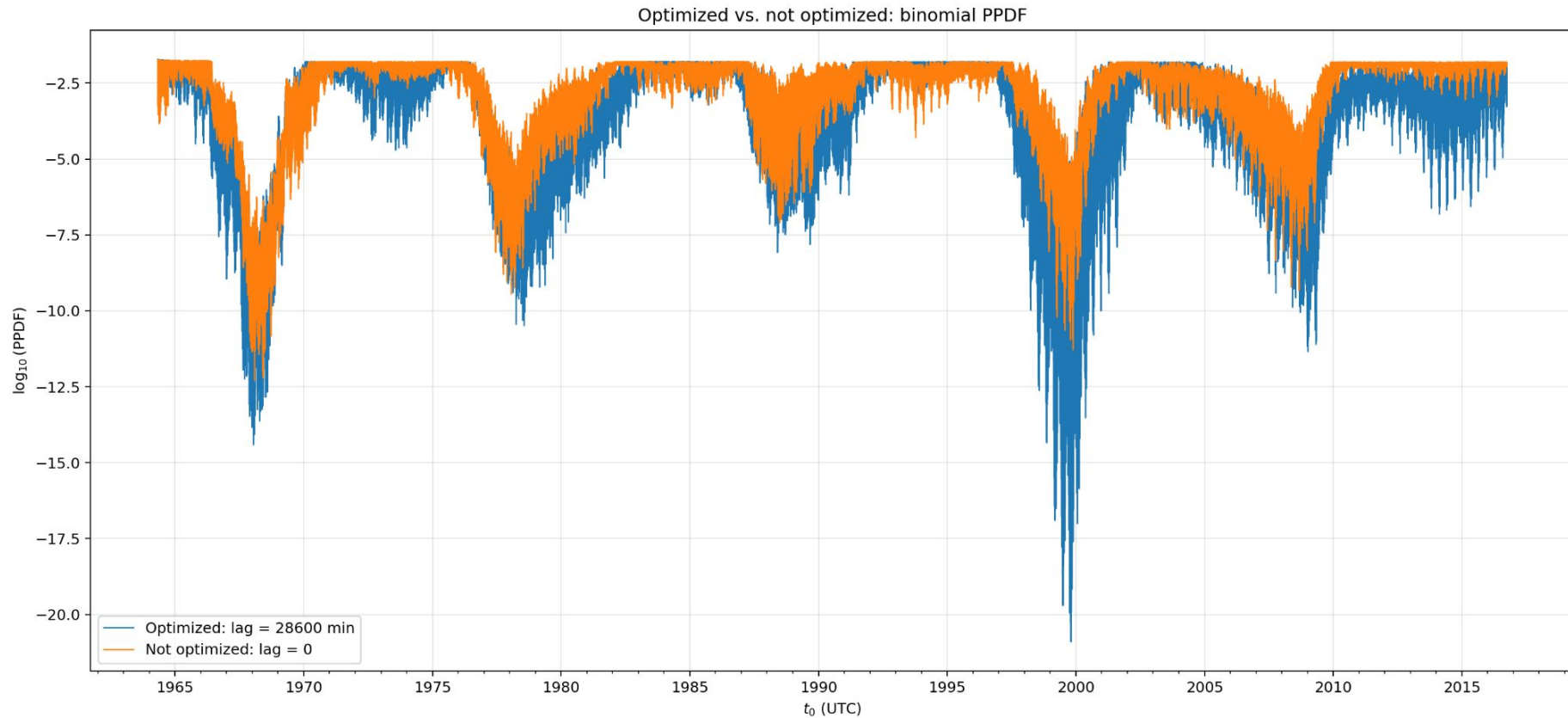
Optimized PPDF vs. bin size
(global minimum over t0 and lag for each bin size)



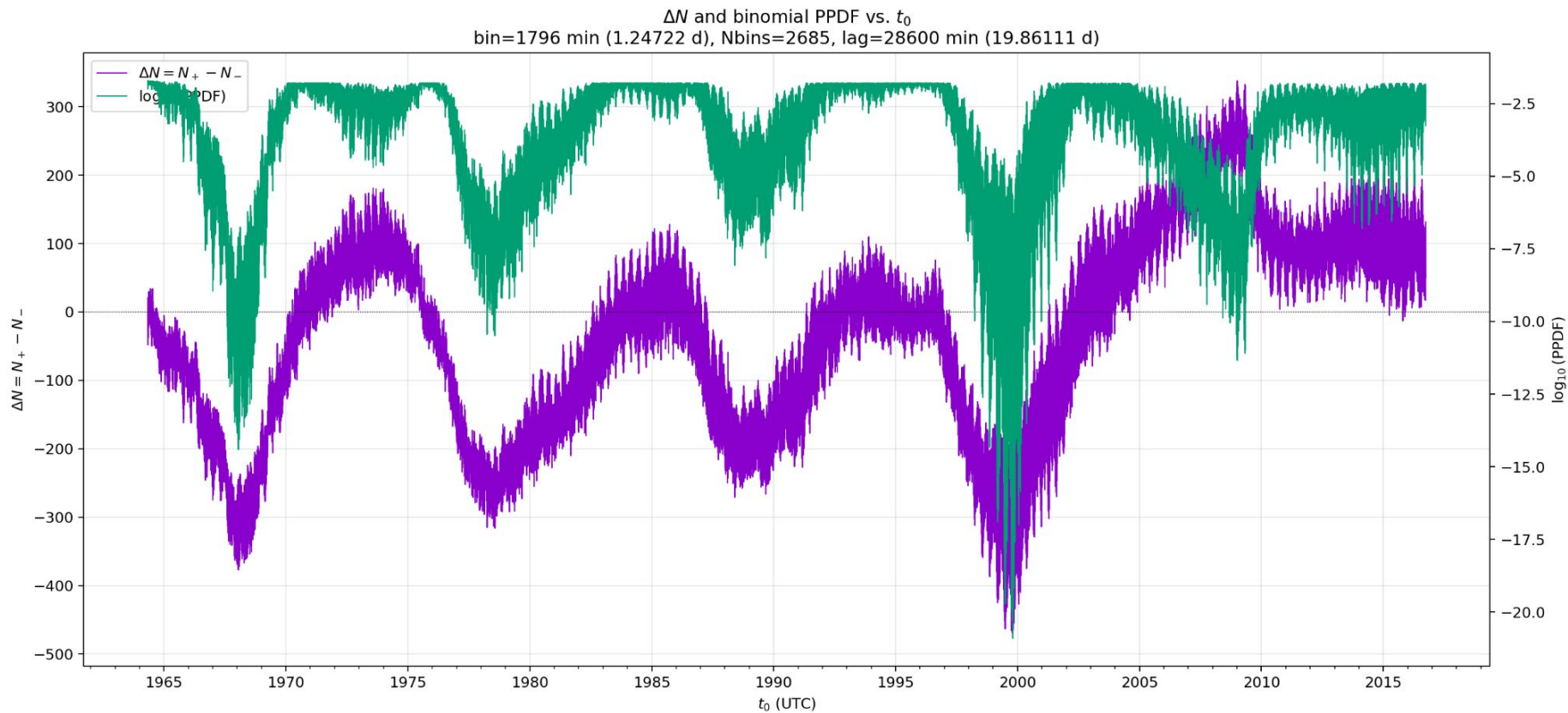
$dN = N_+ - N_-$ bin: 1 day, **no t_0 /lag optimization**, running window 3350 days (~9 years), step 1 day



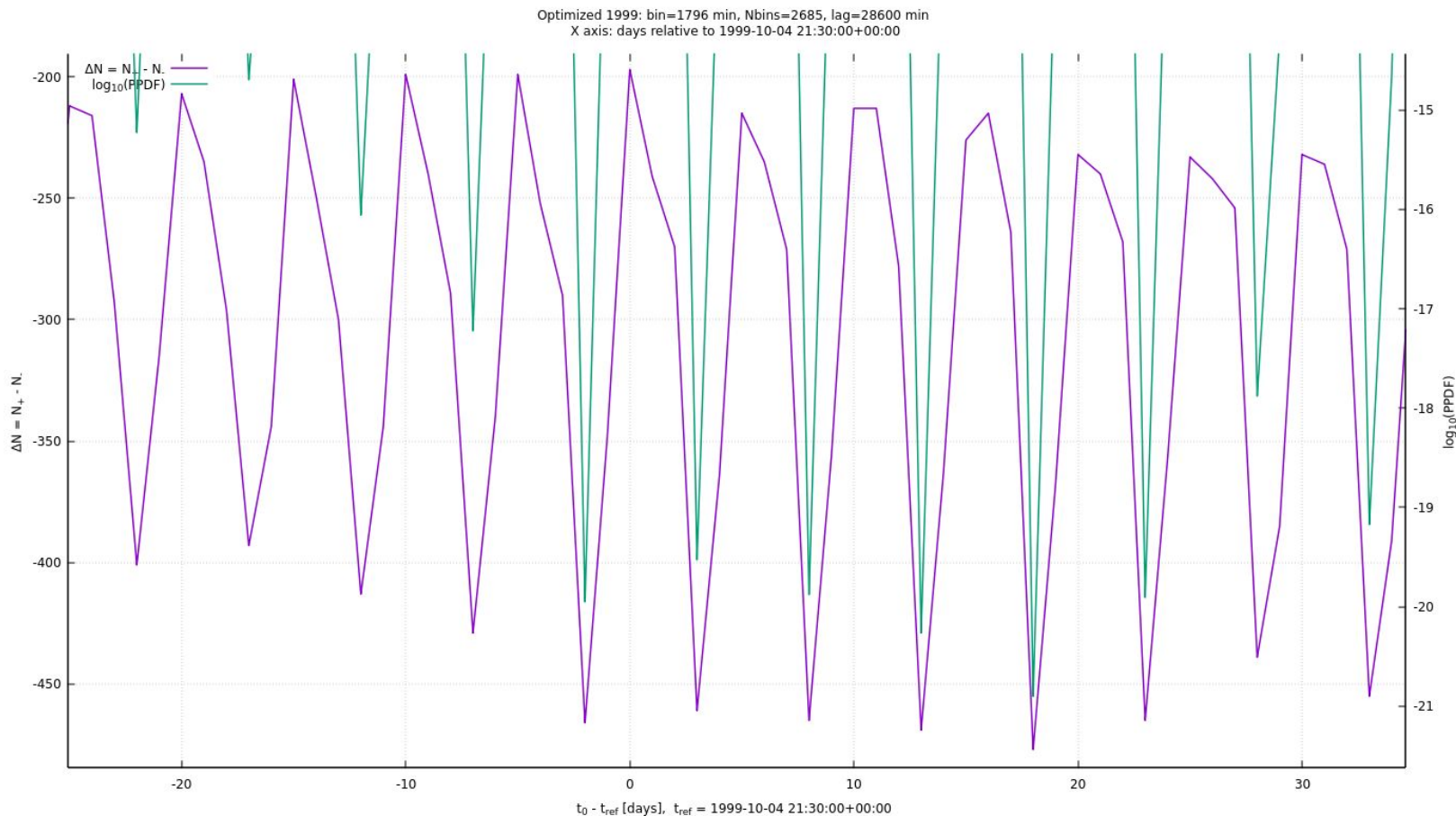
The extreme PPDF (bin size = 1796 min.): optimized vs. not optimized



The extreme PPDF: some physics scale at 110-120 days?

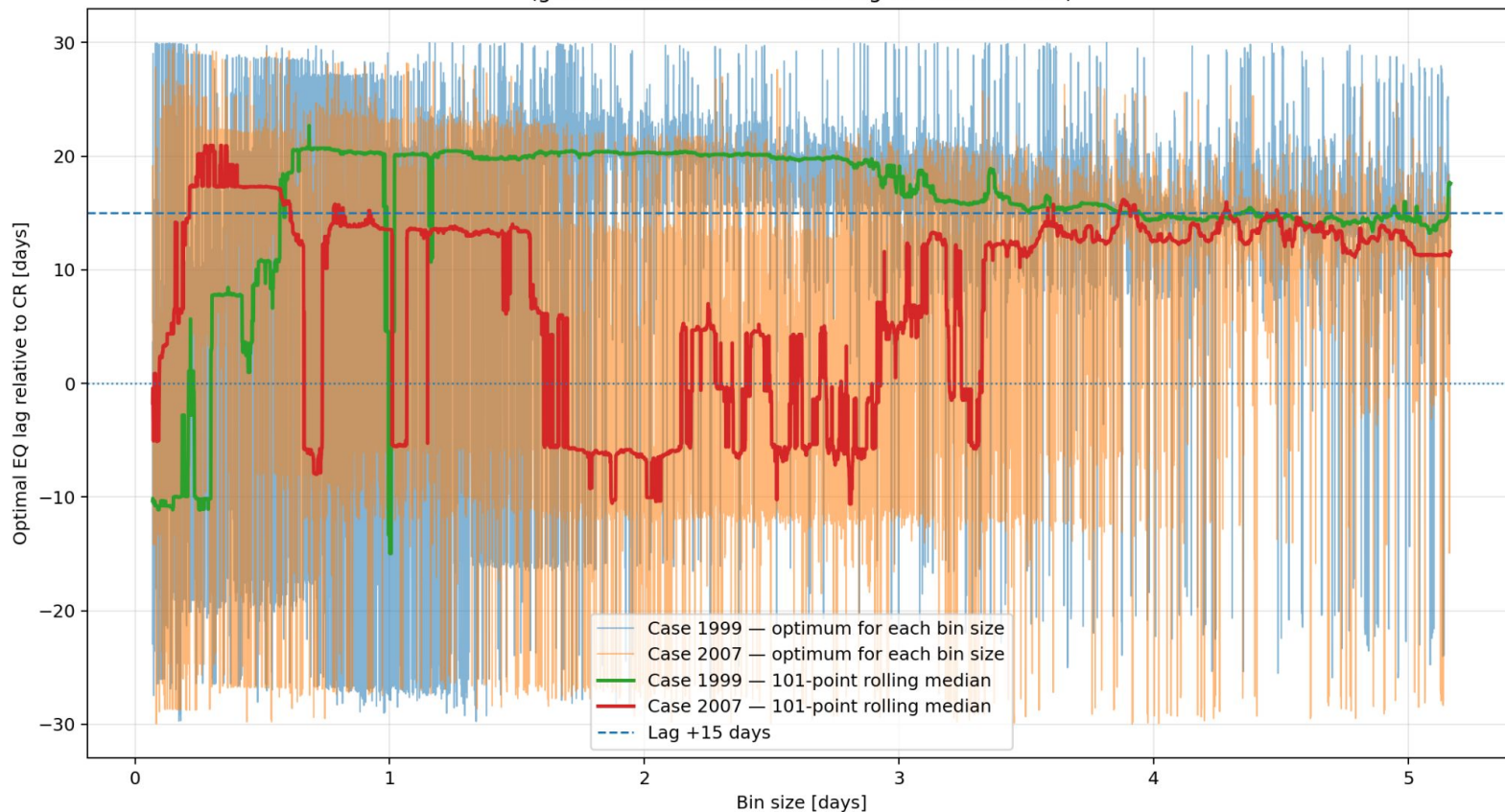


The extreme PPDF: some physics scale at 5 days?



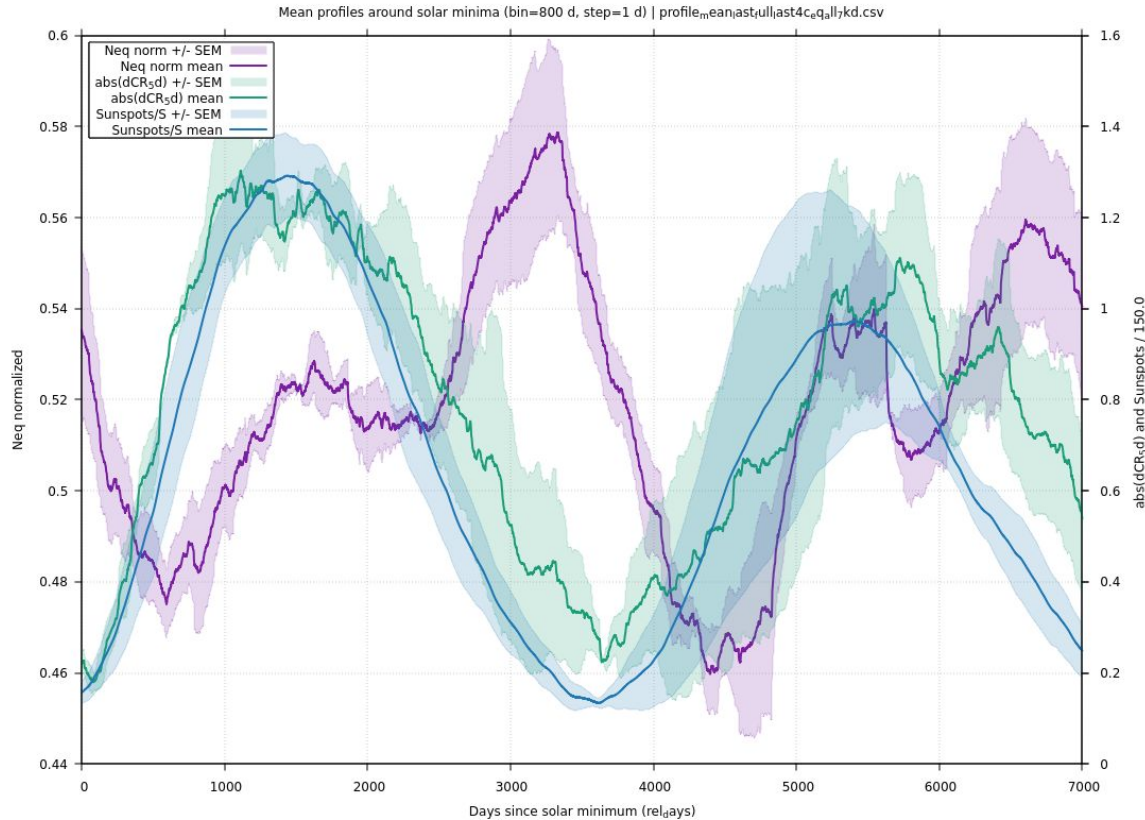
The 15 days lag: real but local (not universal)

Optimal lag vs. bin size — cases 1999 and 2007
(global minimum over t_0 and lag for each bin size)



Sensitivity to: window size / trends

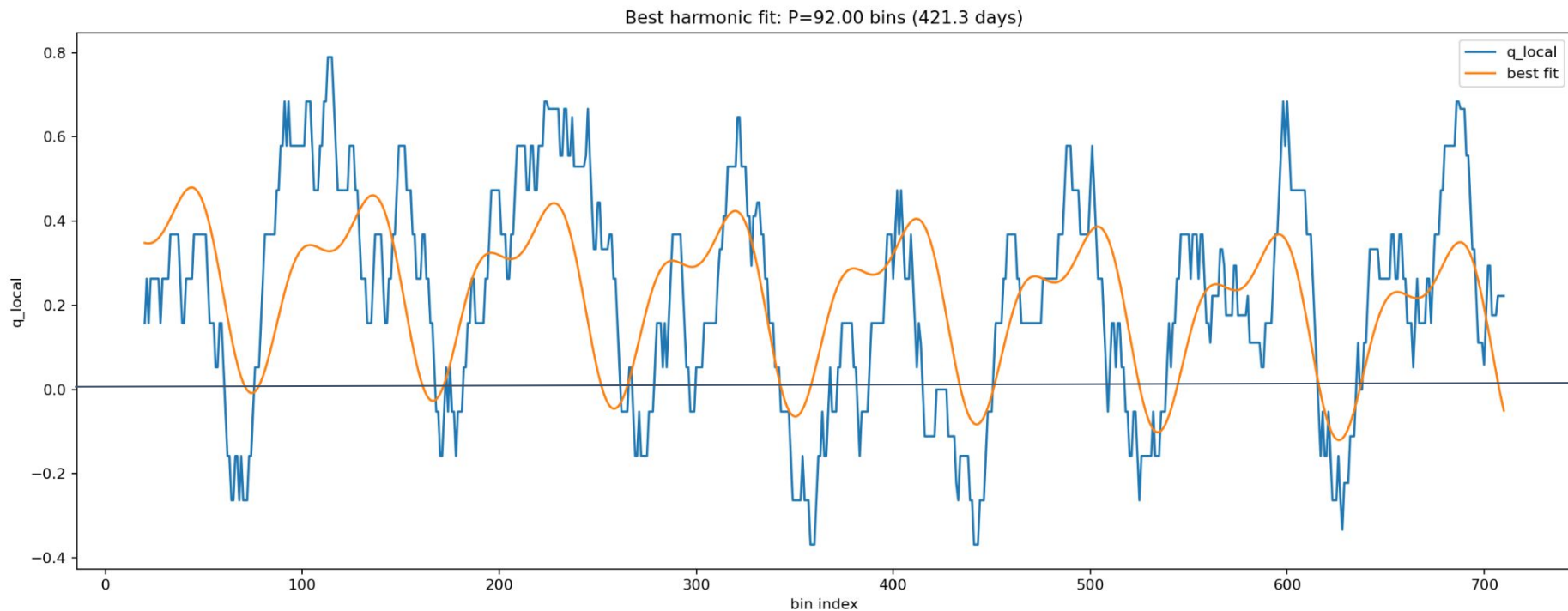
The last 4 full solar cycles: average profiles: Neq ($m \geq 4$), abs(dCR), sunspots



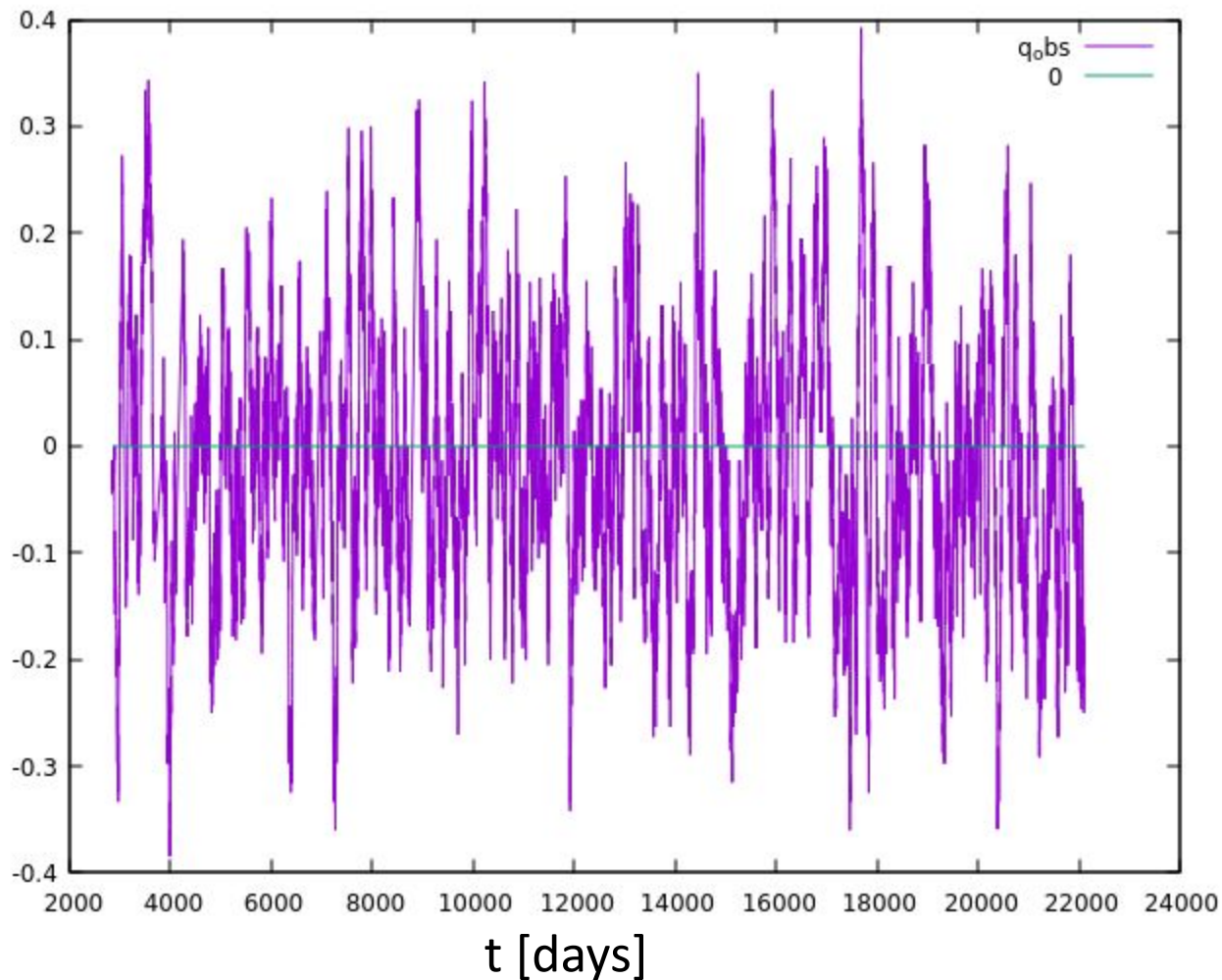
Neq normalized
 $\rightarrow \text{Neq_800d}(t) / (\text{Neq_800d}(t) + \text{Neq_800d}(t-800d))$

$|\text{dCR_5d}|_{800d}$
 $\rightarrow$ scaled to match
 min & max of the
 solar cycle

$q = (N+ - N-)/(N+ + N-)$: the local (in time) measure of bin signs matching, $t_0 = 2007$, bin size = 6595 m (~4 days) days, running window 20 bins, **global medians (for the big window)**



t [days]



$$q = (N+ - N-) / (N+ + N-)$$

running window:
width 81 days, step 1 day,

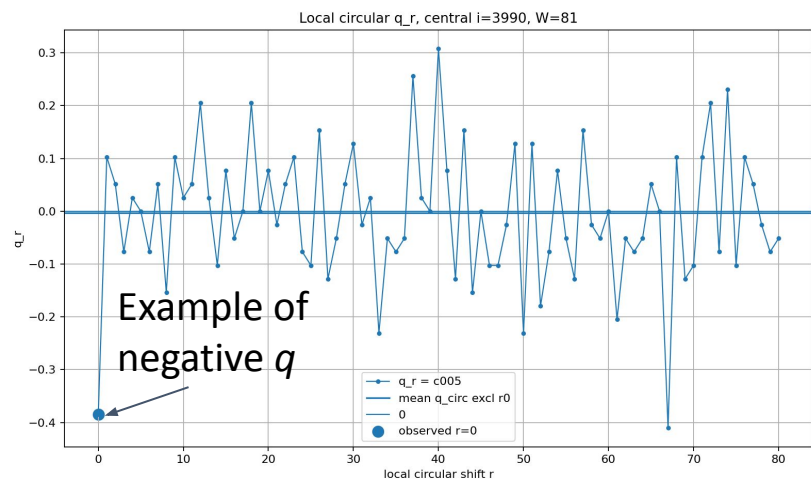
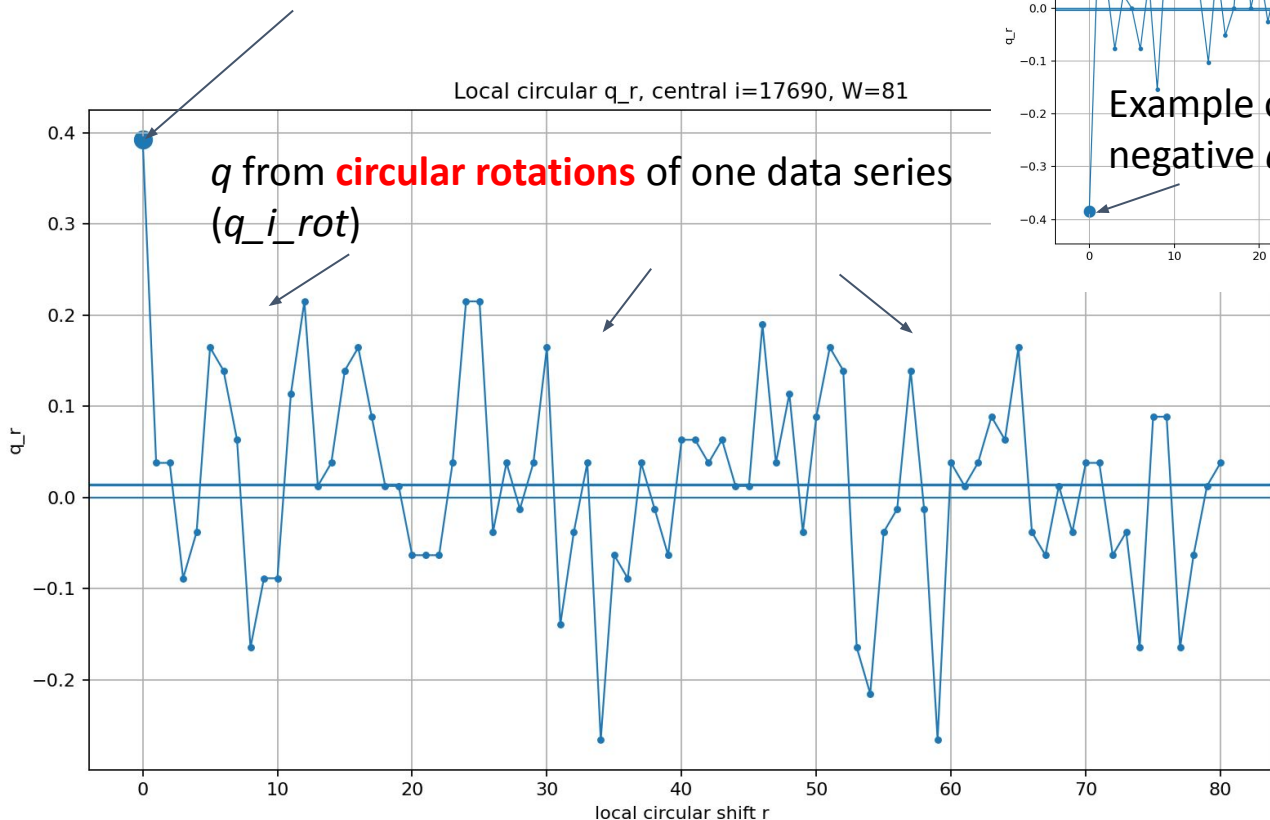
signs wrt local median:
+/-80 days

full time range

-> no clear large scale
(solar?) cycles

-> small scale matching /
not matching changes?

Example of positive q , no rotation (q_{i_0})



Comparing

observed:

$$\sum (q_{i_0} - \langle q_{i_rot} \rangle)$$

vs.

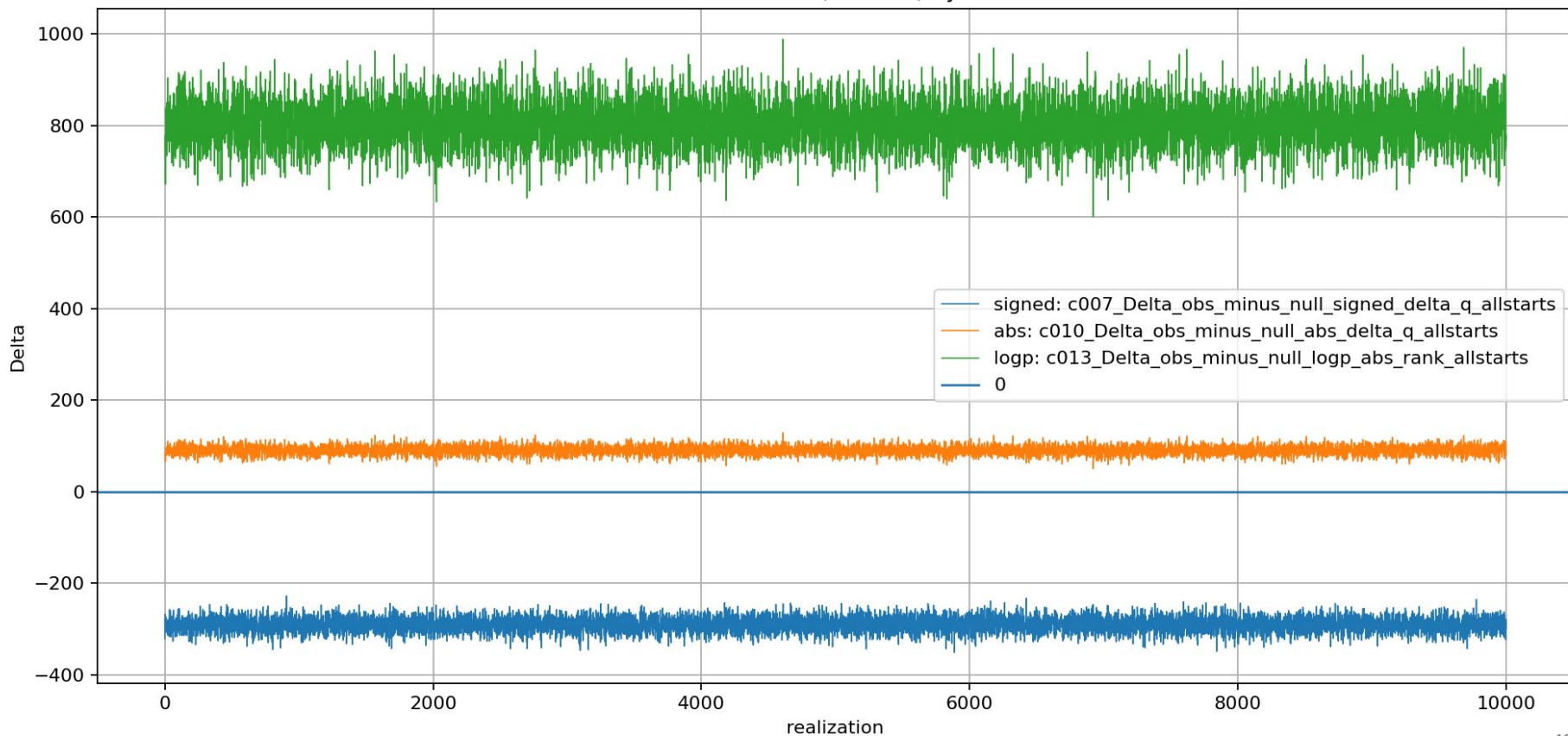
null:

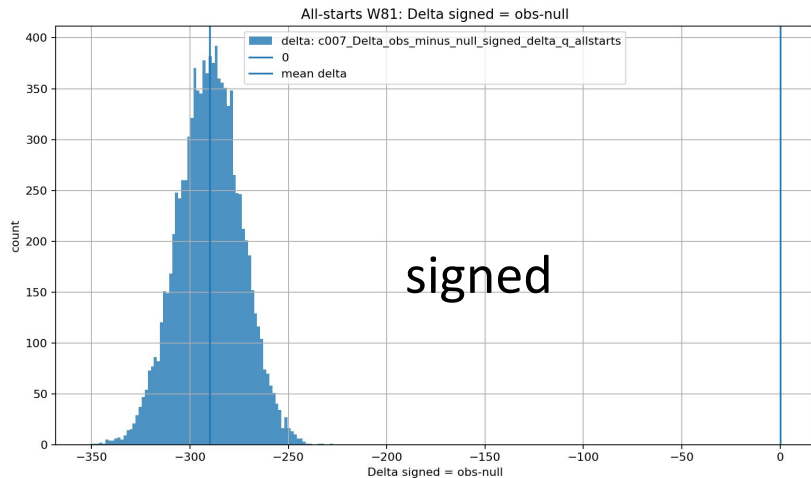
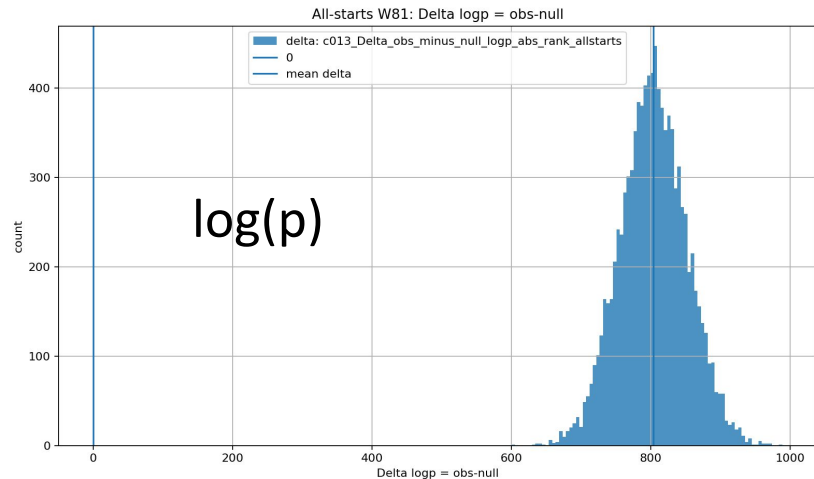
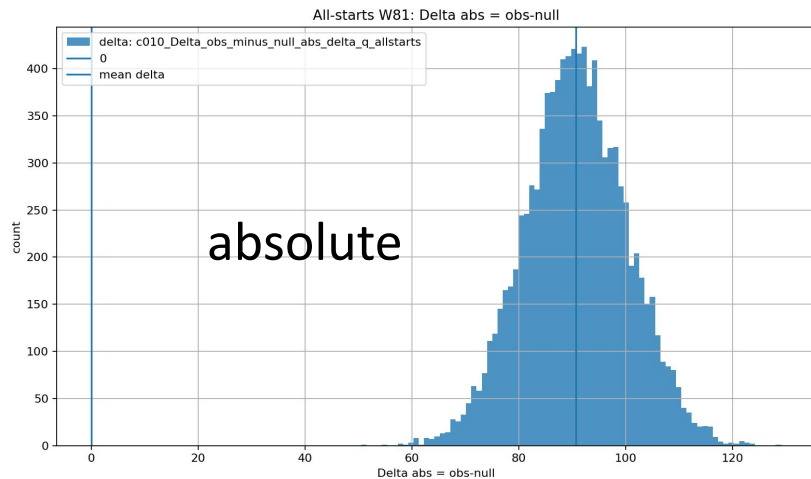
$$\sum (q_{i_random} - \langle q_{i_rot} \rangle)$$

Is q_{i_0} special?

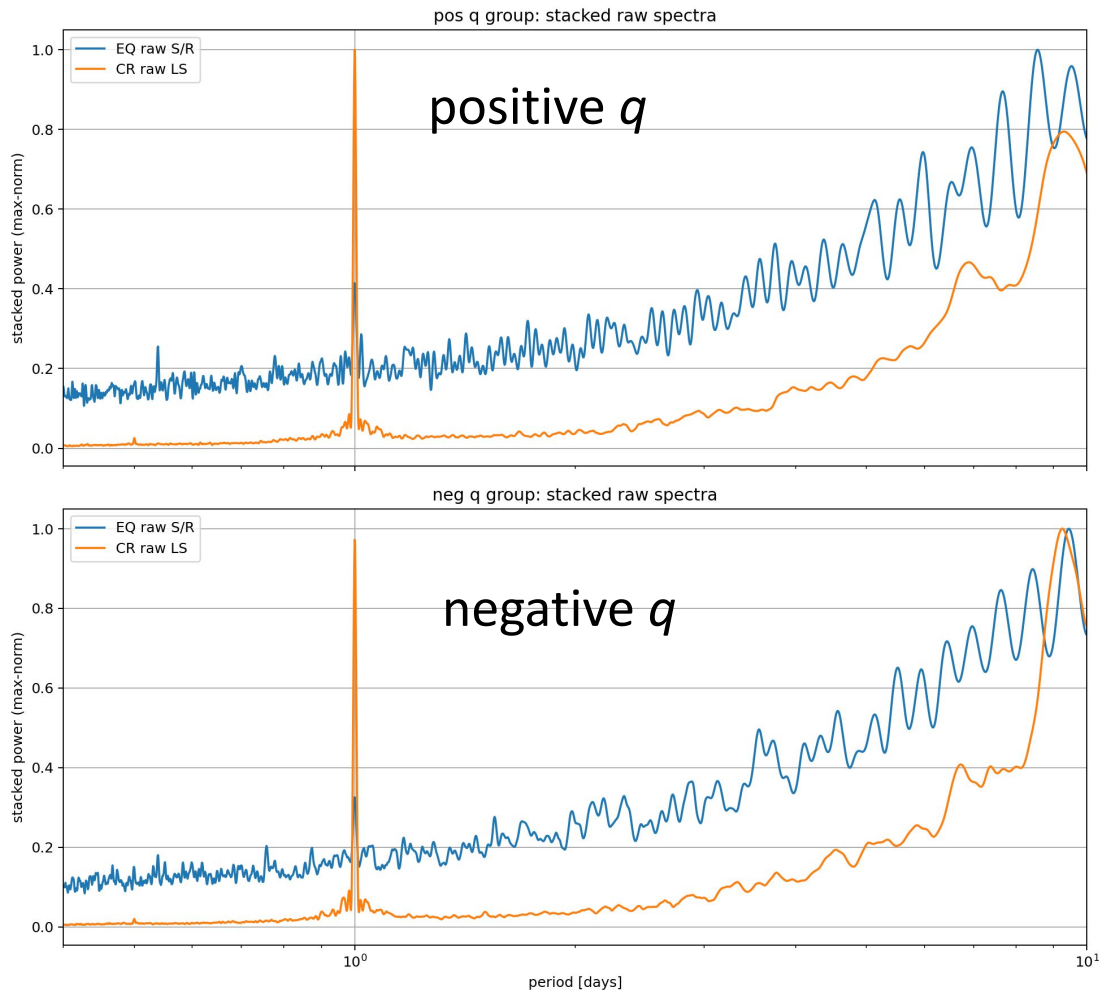
Delta = observed - null, 10M realizations

All-starts W81: Delta(obs-null) by realization





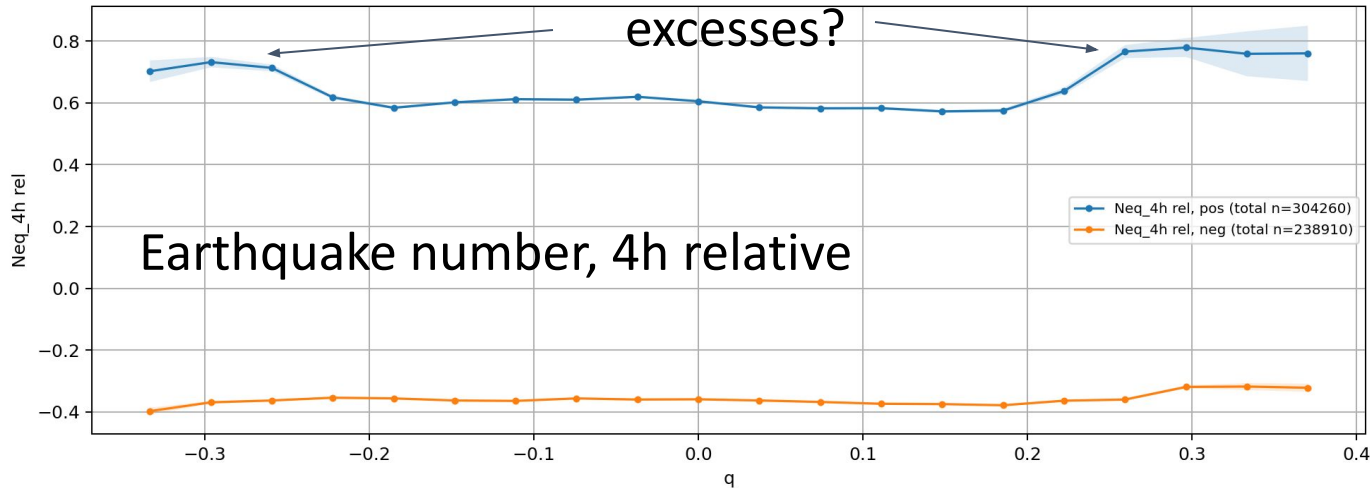
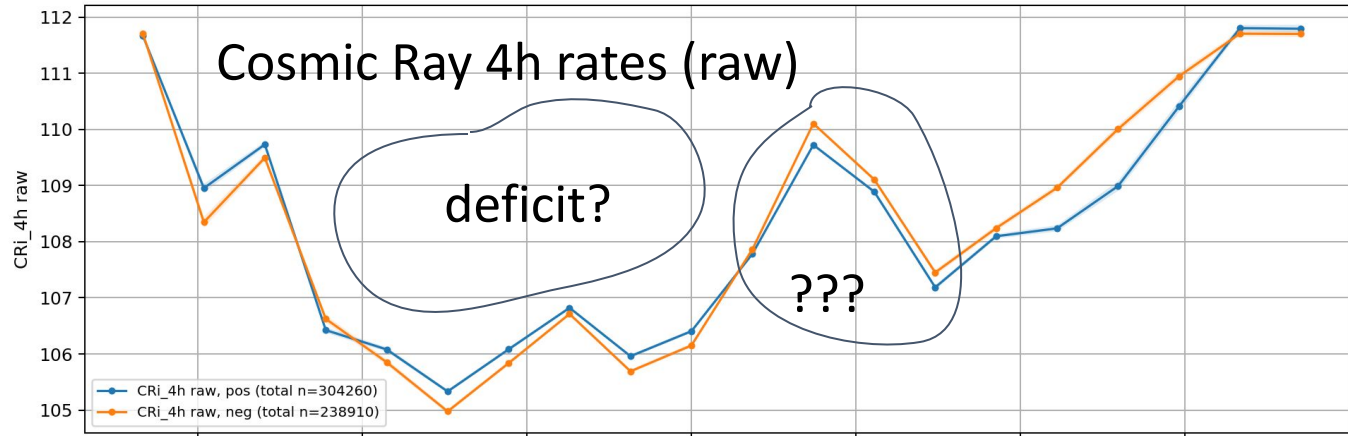
z-scores ~ 50-100, similarly for positive and negative q
 -> alternating, statistically real, **phases of order and anti-order?**
 -> ~80 days?
 -> any periodicity of alternation?



possibilities for alternating order & anti-order phases?

- beating (slightly different frequencies in the two data sets)
- same frequencies + phase drift of one series
- anti-order due to taking absolute CR rate
- unrepeatable pattern
-?

Mean bin values vs parent-window q split by sign($N_{eq_4h_rel}$)



Data split by the sign of N_{EQ} :

positive N_{EQ}

negative N_{EQ}

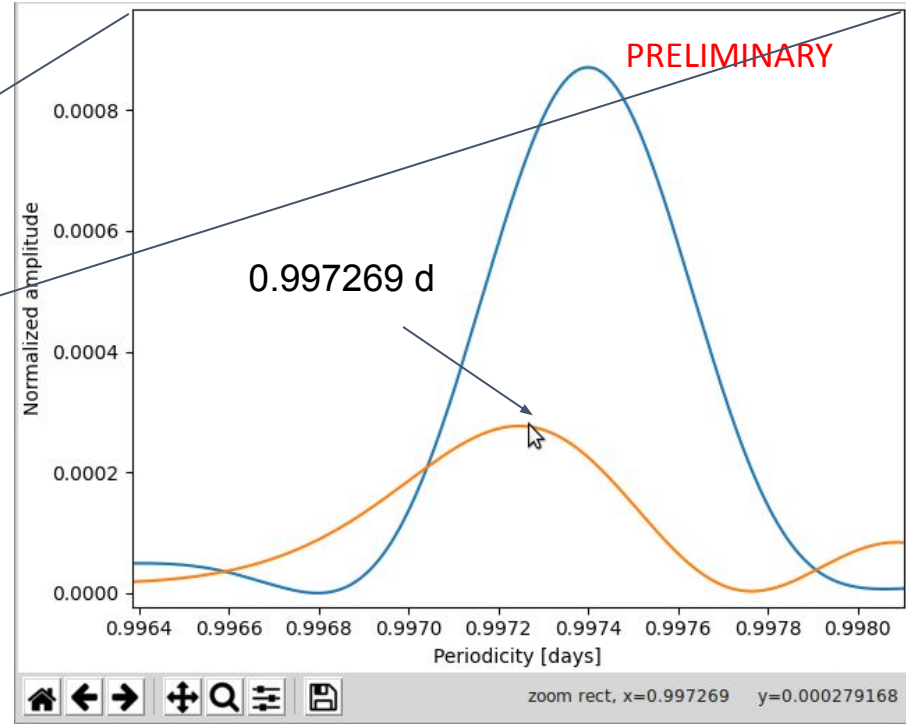
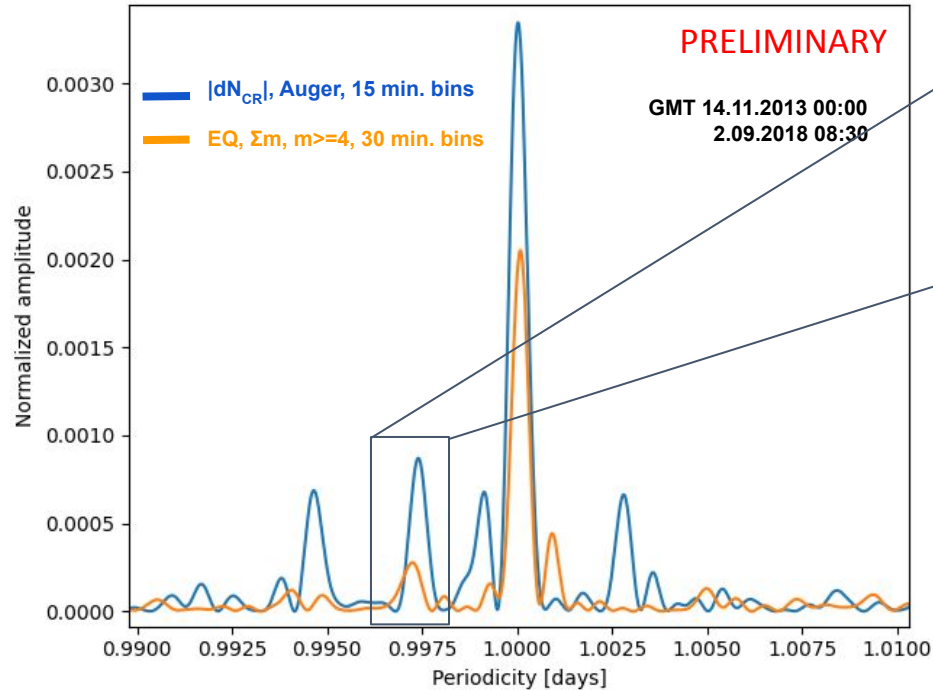
Looking for the characteristics of q

- more EQs in large $|q|$ phases?
- more intense CR emission in large $|q|$

Promising (weird) periodicities

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

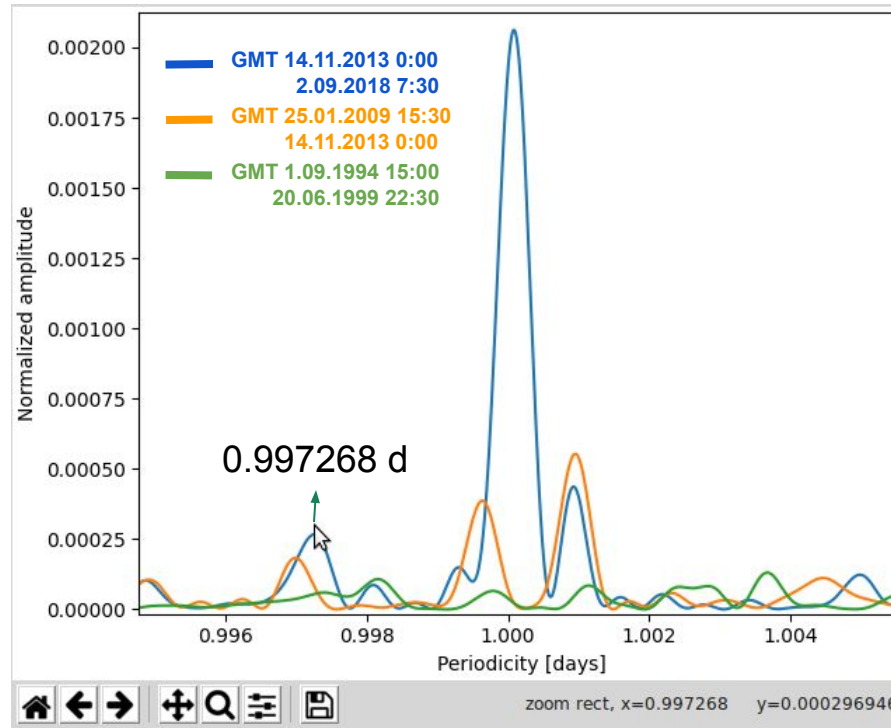
1 sidereal day = 23.9344696 hours $\rightarrow$ 0.997269567 day; Lomb-Scargle periodograms



Clear ~ 24 h 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 ($m \geq 4$), 30min. bins

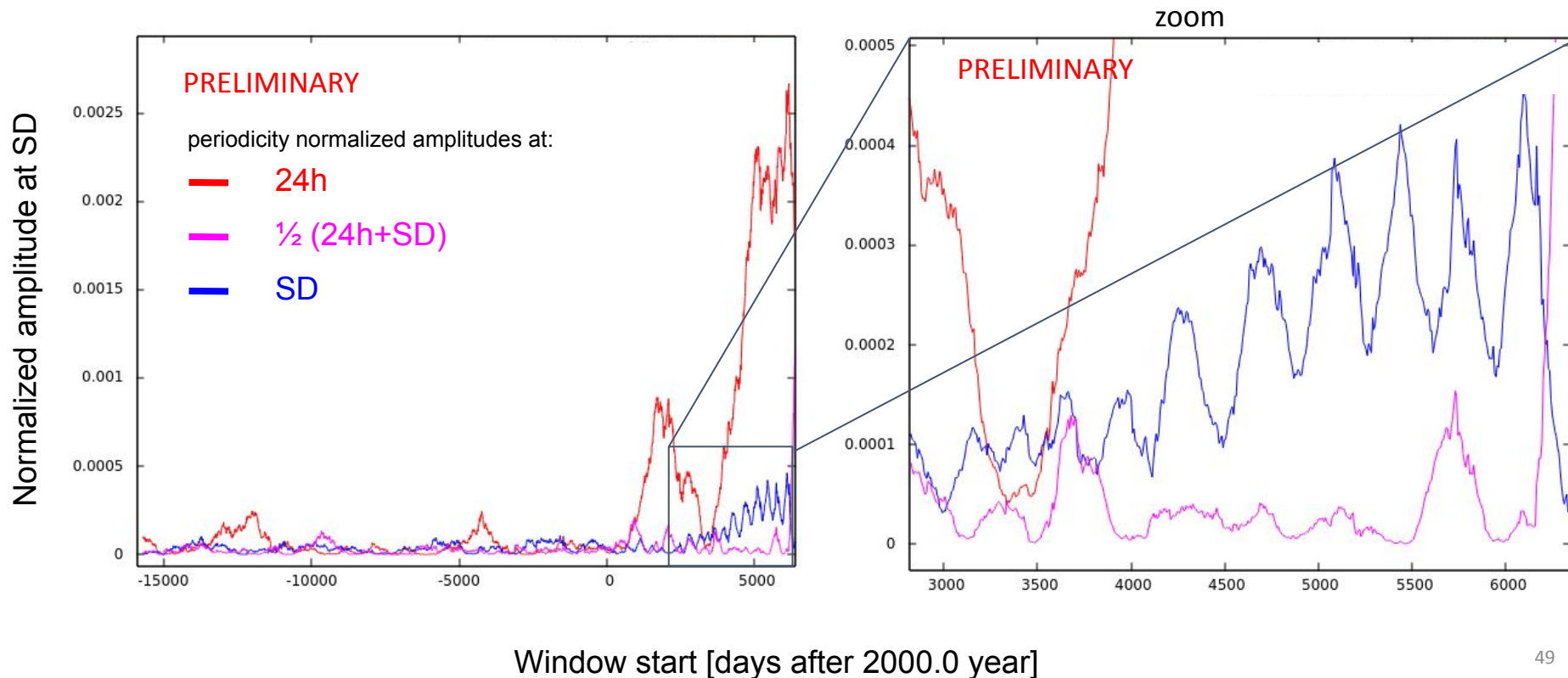
1 sidereal day = 23.9344696 hours $\rightarrow$ 0.997269567 day



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

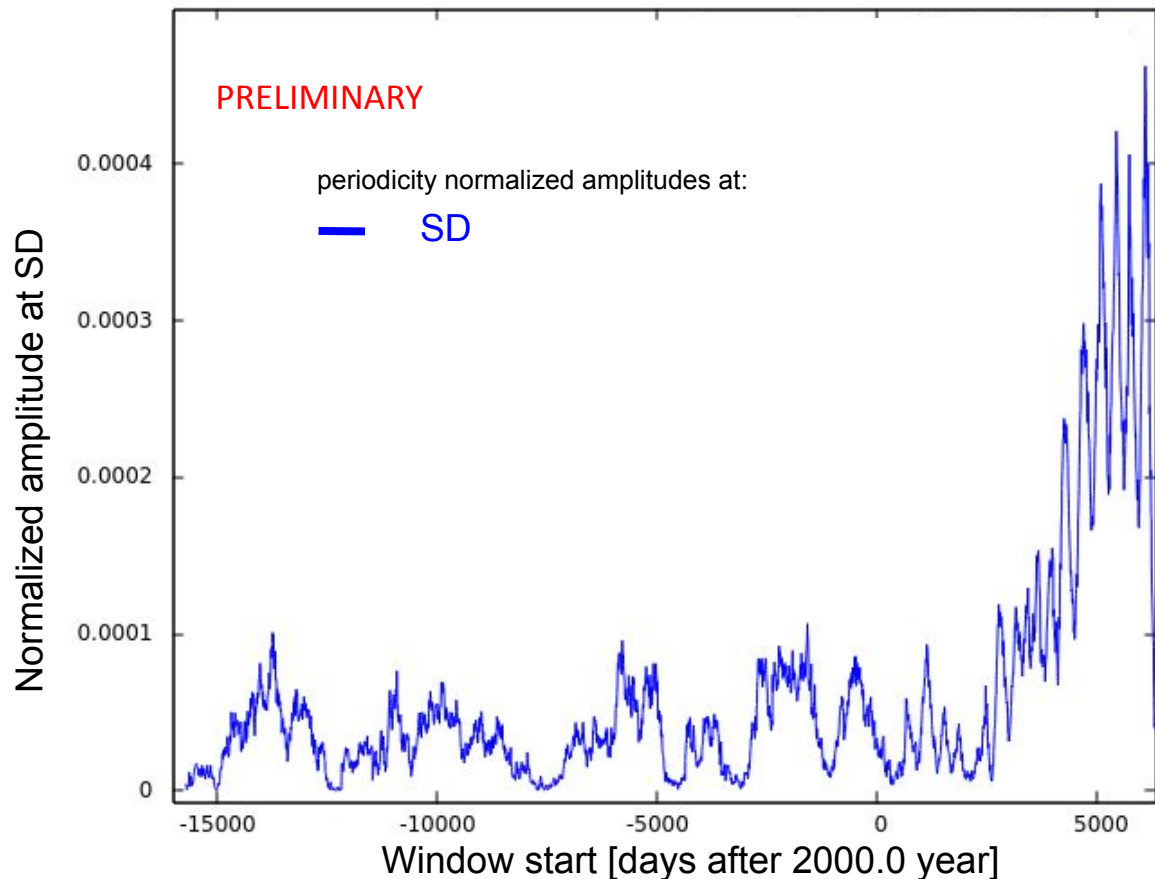
Time evolution of the 24h & sidereal day (SD) periodicities:

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



Time evolution of the sidereal day (SD) periodicity:

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

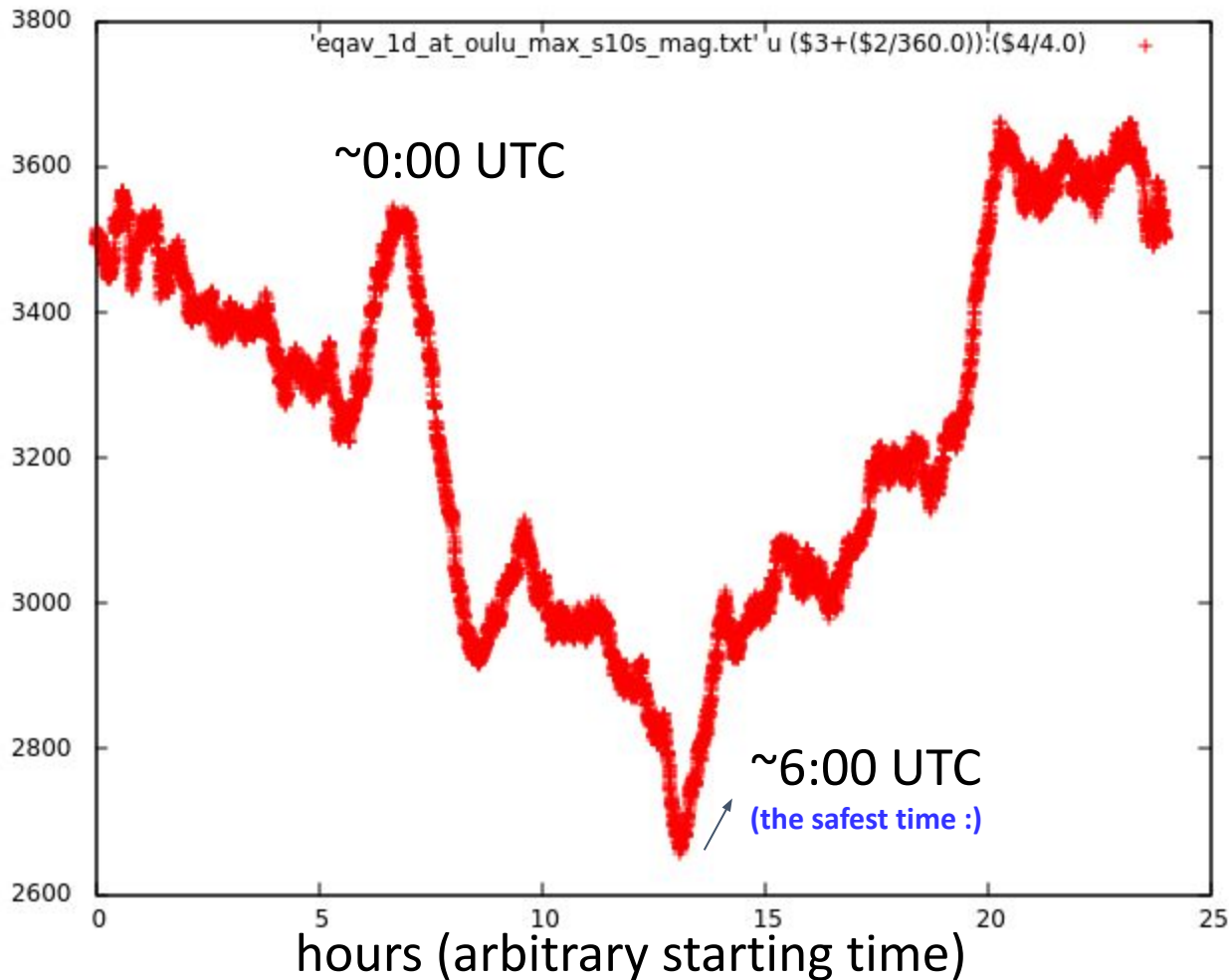


First fits (credit Maria Pycior):

- ~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?

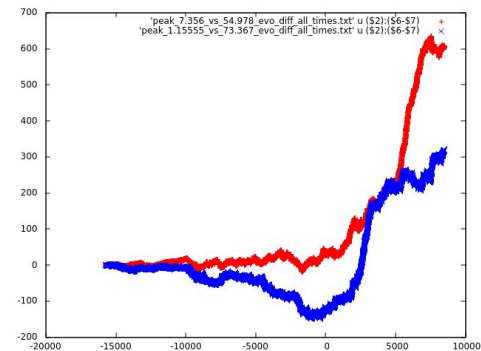
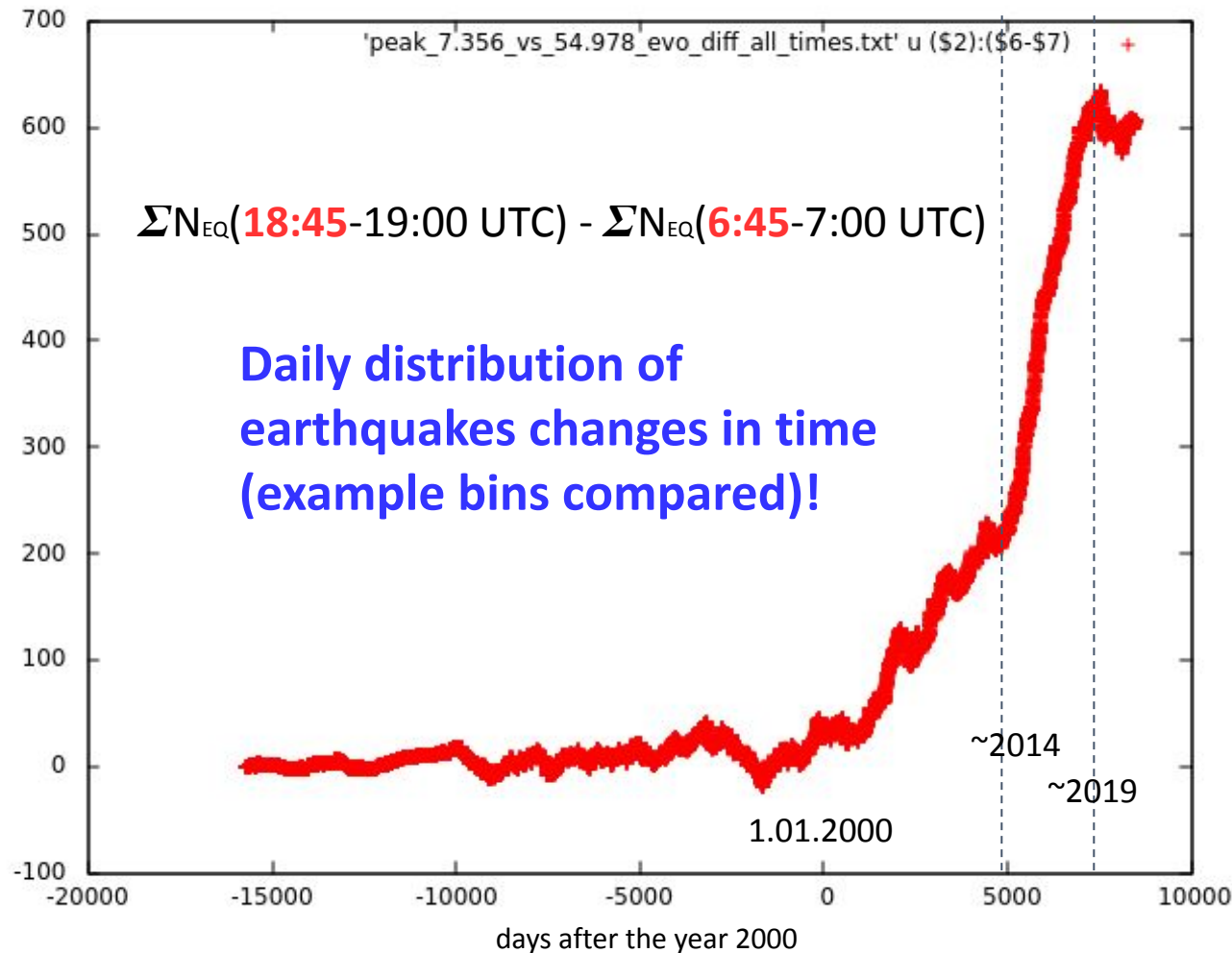


24 hour stacked N_{EQ}

- average 1 h bins
- 10 s sliding step
- ~2000 days since 2014
- **no or much weaker lunar day (24h 50 m) periodicity**

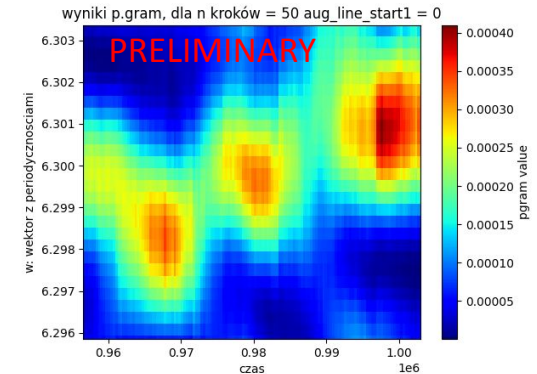
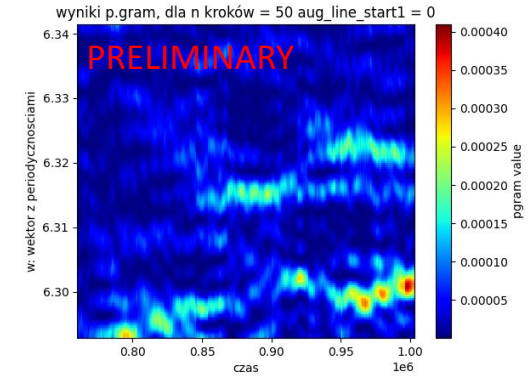
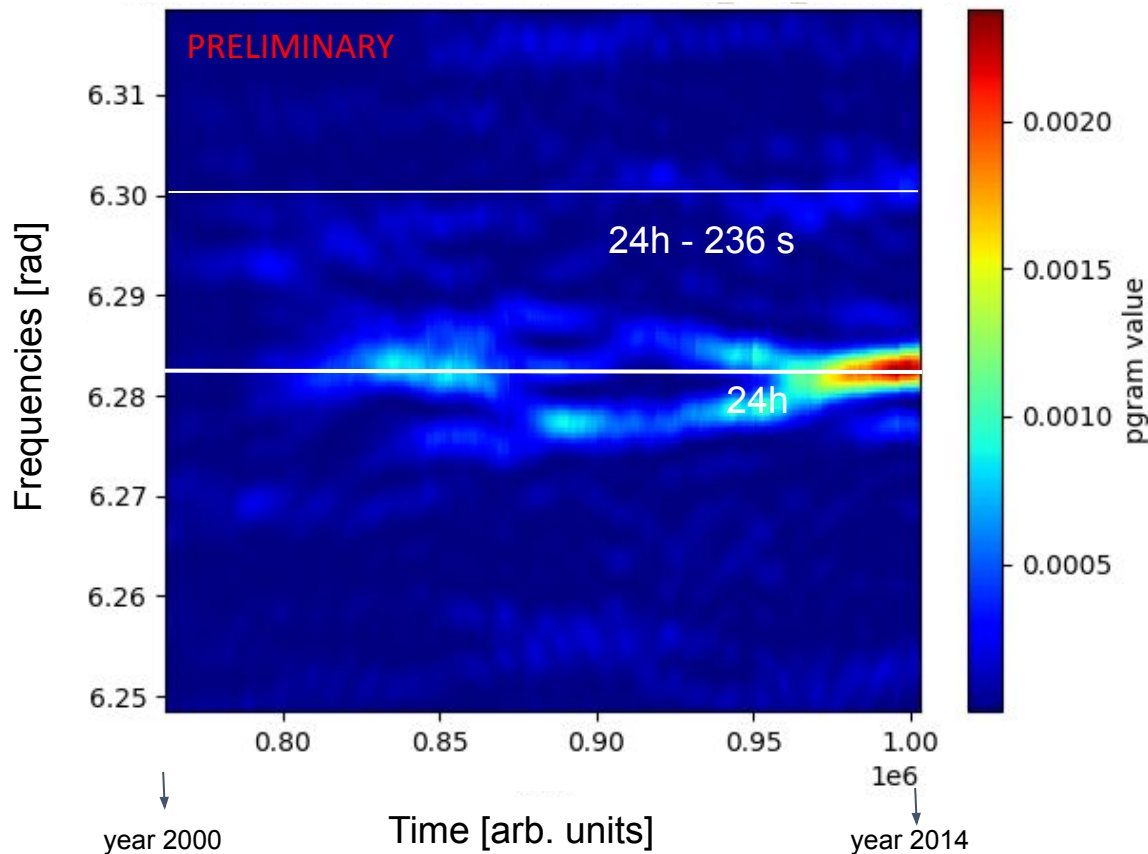
24 h periodicity -> **role of the Sun**

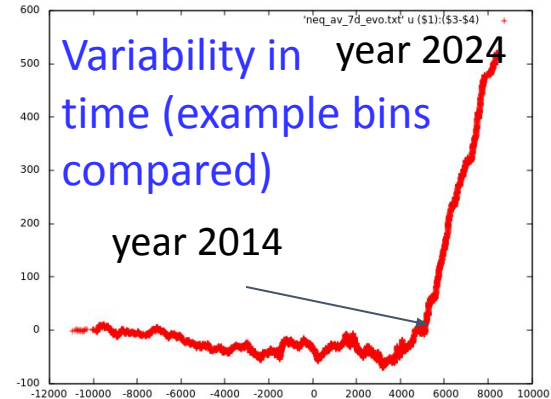
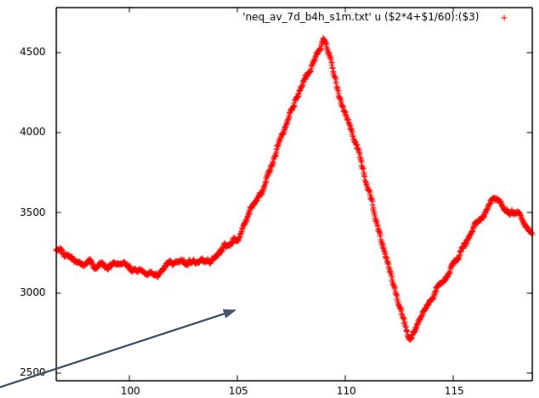
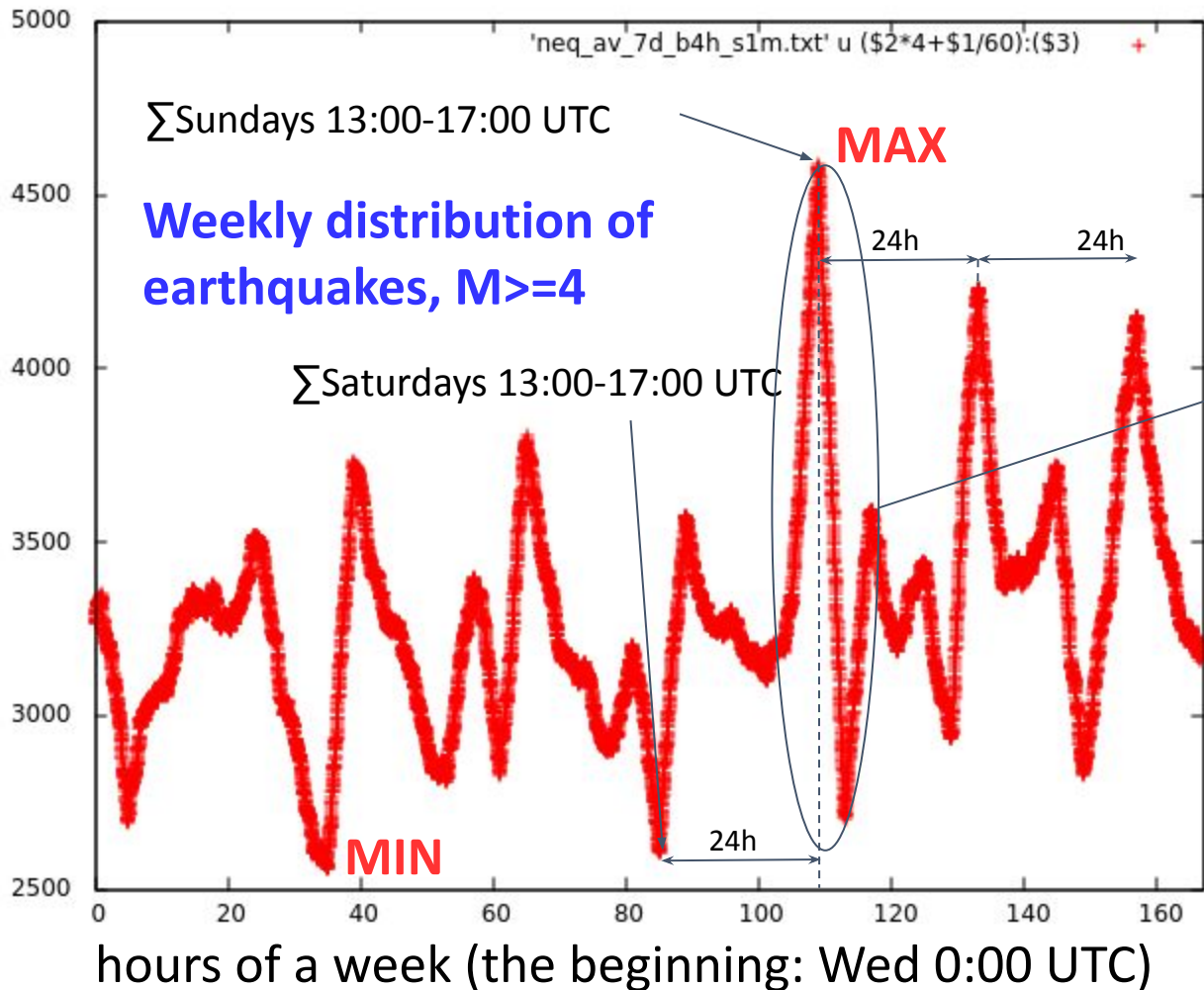
no lunar day periodicity
-> **“third factor”**
sensitive to magnetism?



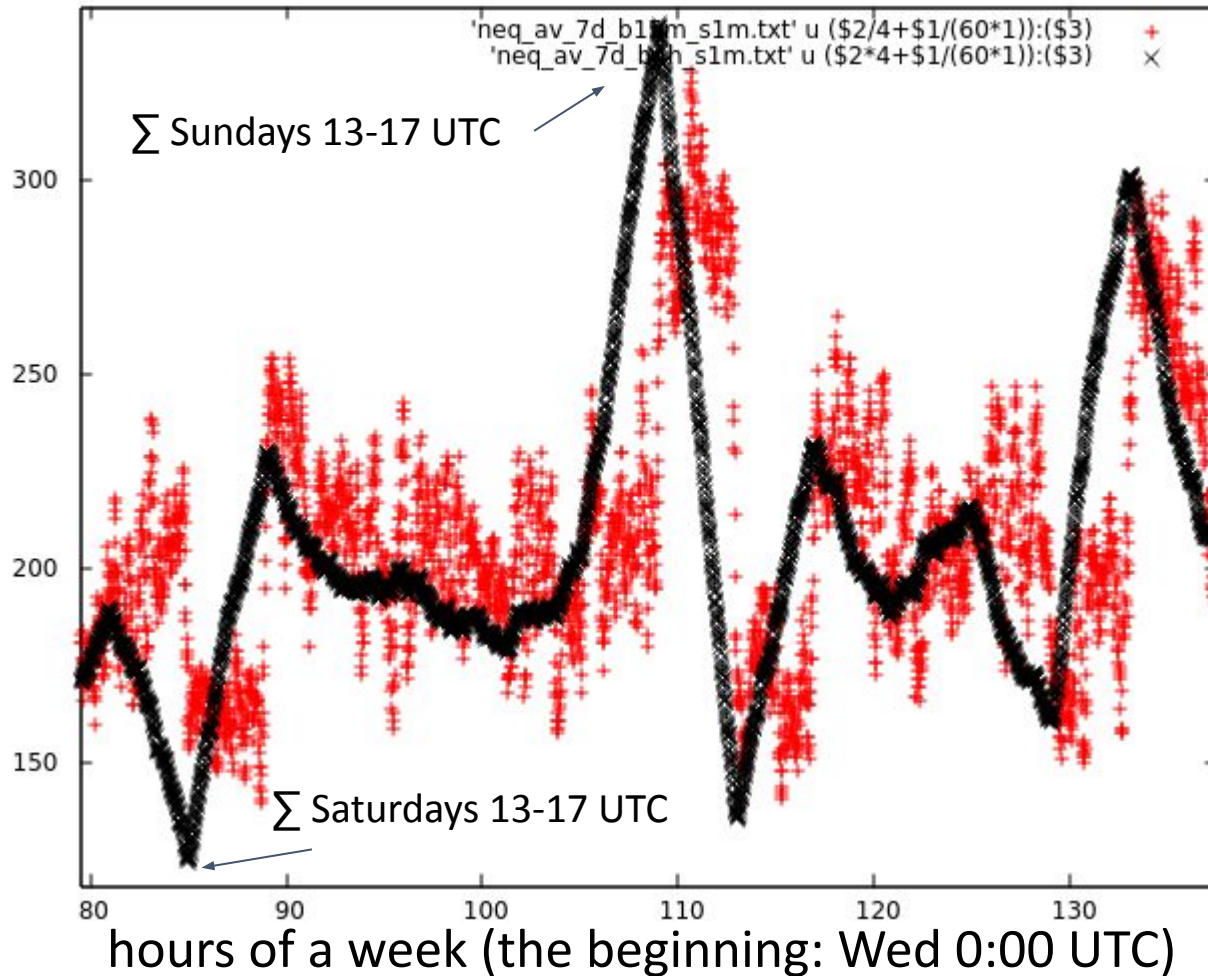
- > **“dramatic” 5 years** of increasing asymmetry of the daily distribution of earthquakes
- > **different times of day: different variability in time (different “dramatic” period)**

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





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

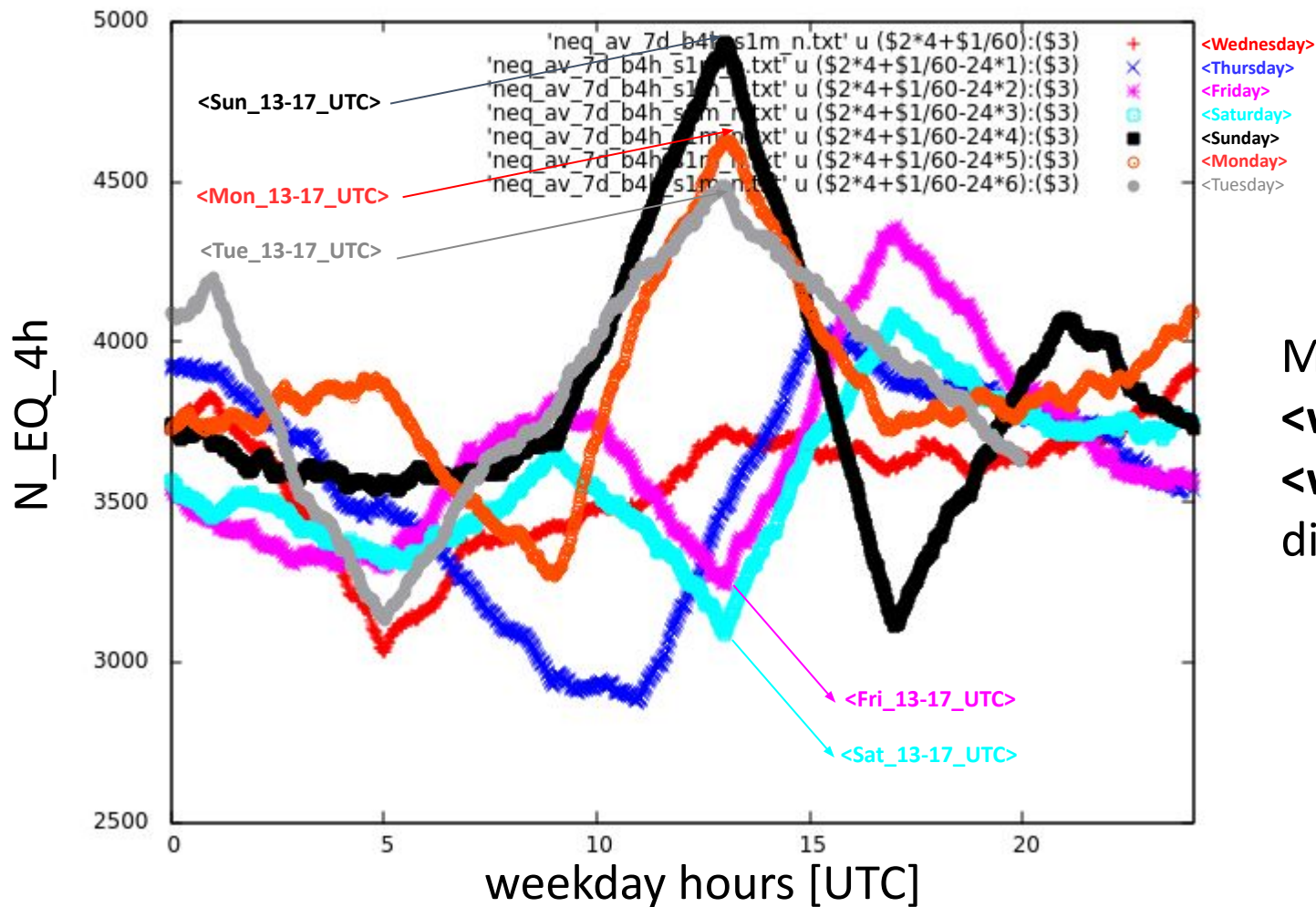


**4h sliding window
(black)**

vs.

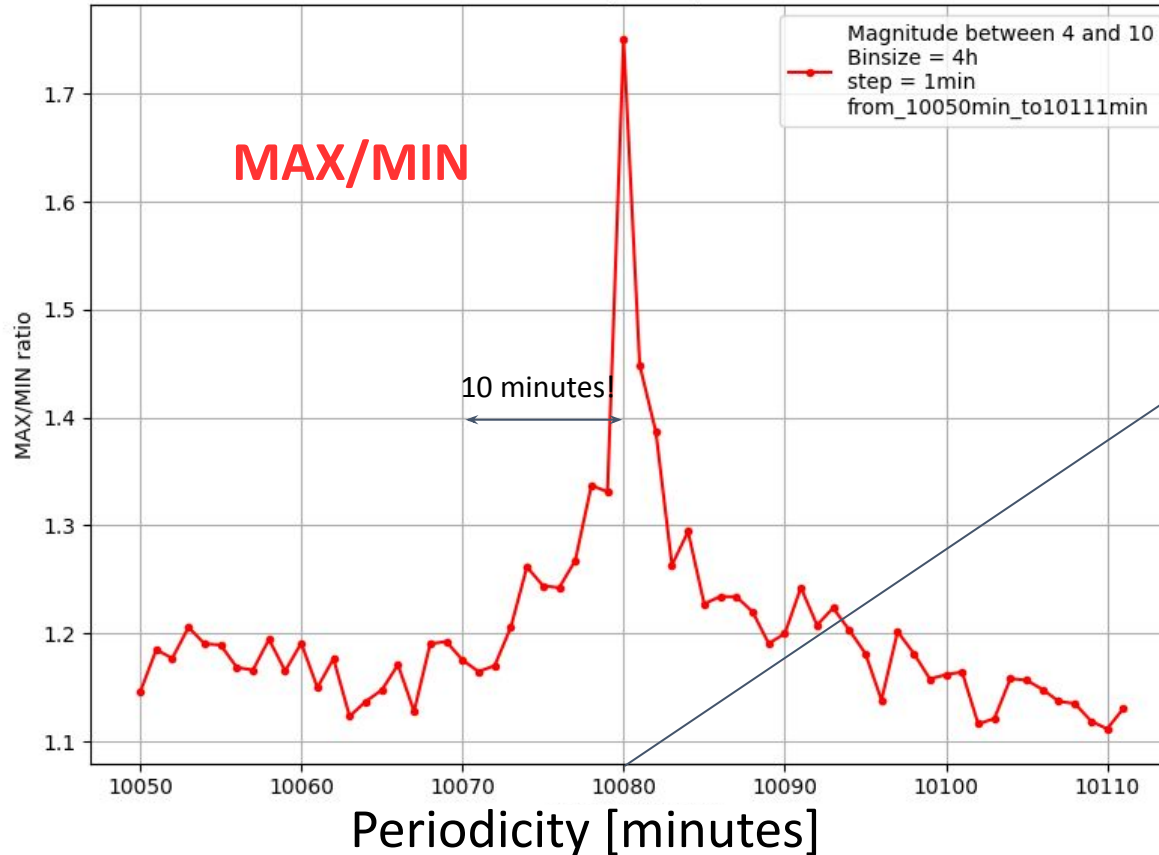
**15 minutes sliding
window (red)**

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



Major
<weekday> to
<weekday>
 differences!?

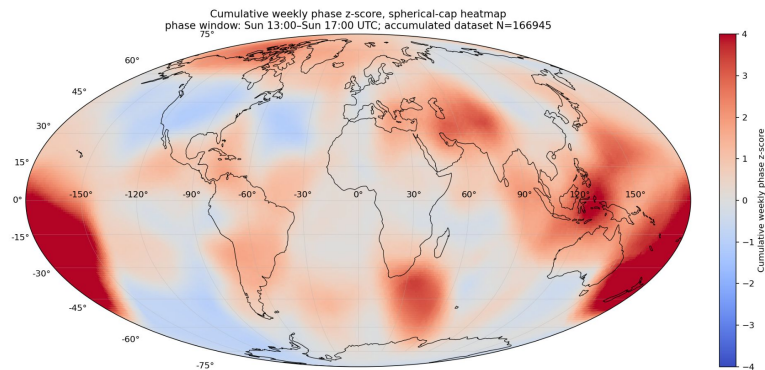
Surprising periodicity of earthquakes, $M \geq 4$



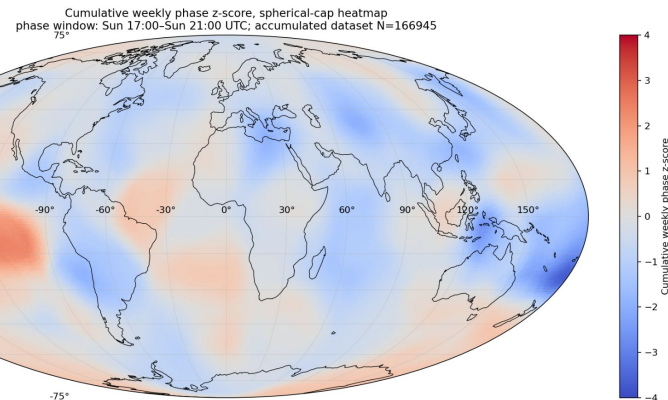
**7 days exactly
(+/- 1 minute)!**

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

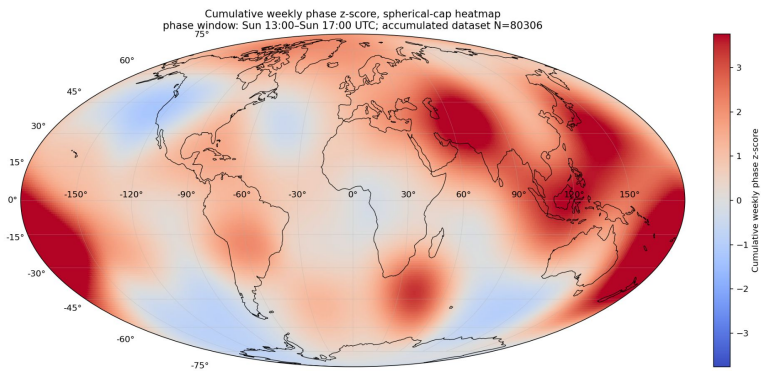
<N_EQ_rel_Sun_13_17 UTC>



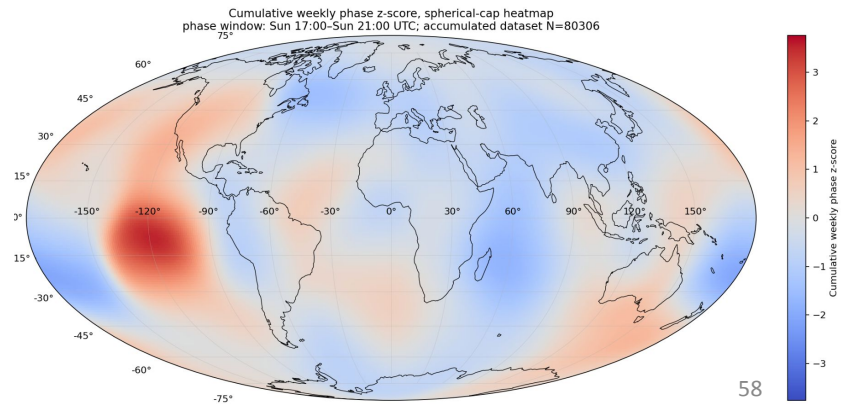
<N_EQ_rel_Sun_17_21 UTC>



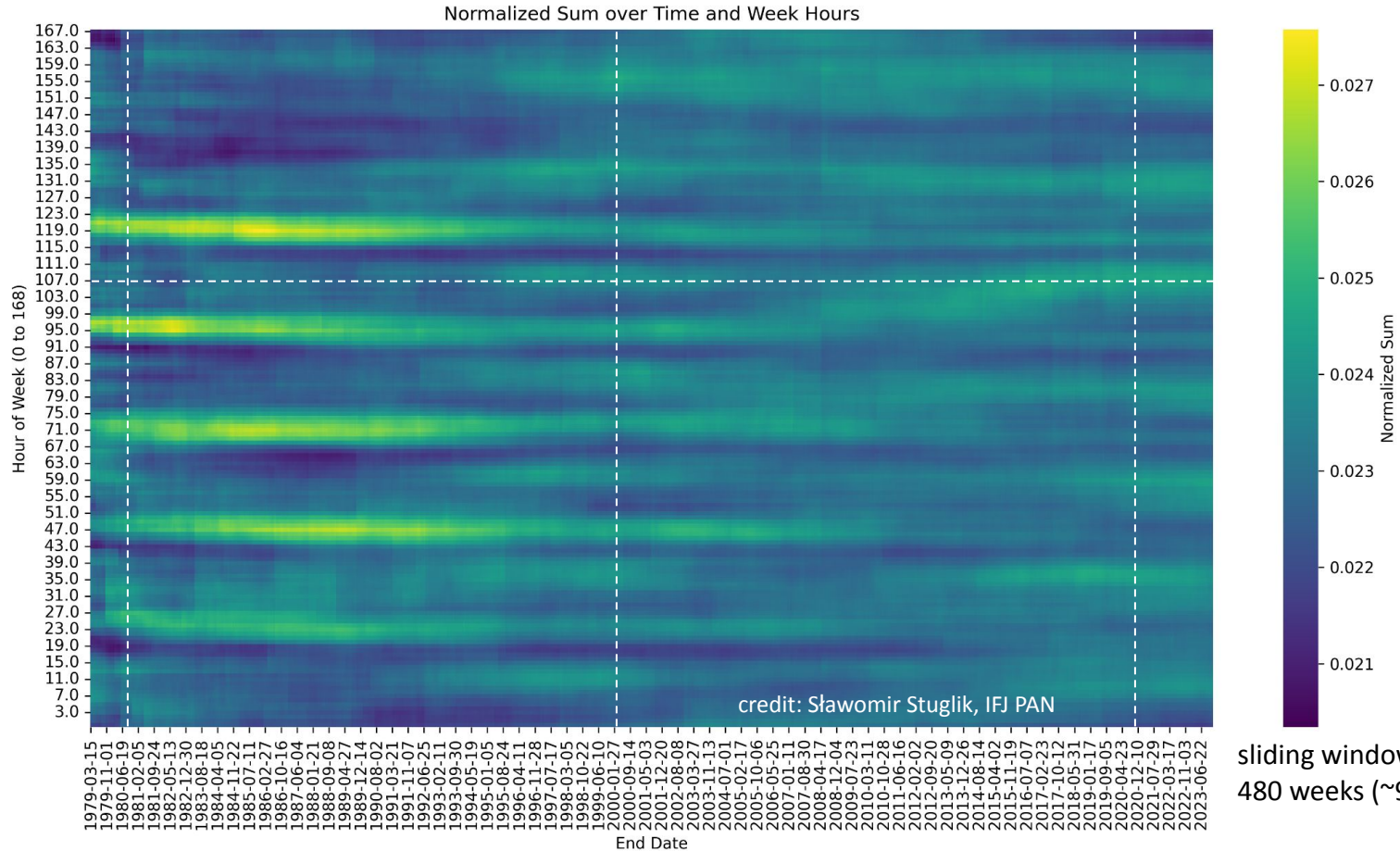
$m \geq 4$



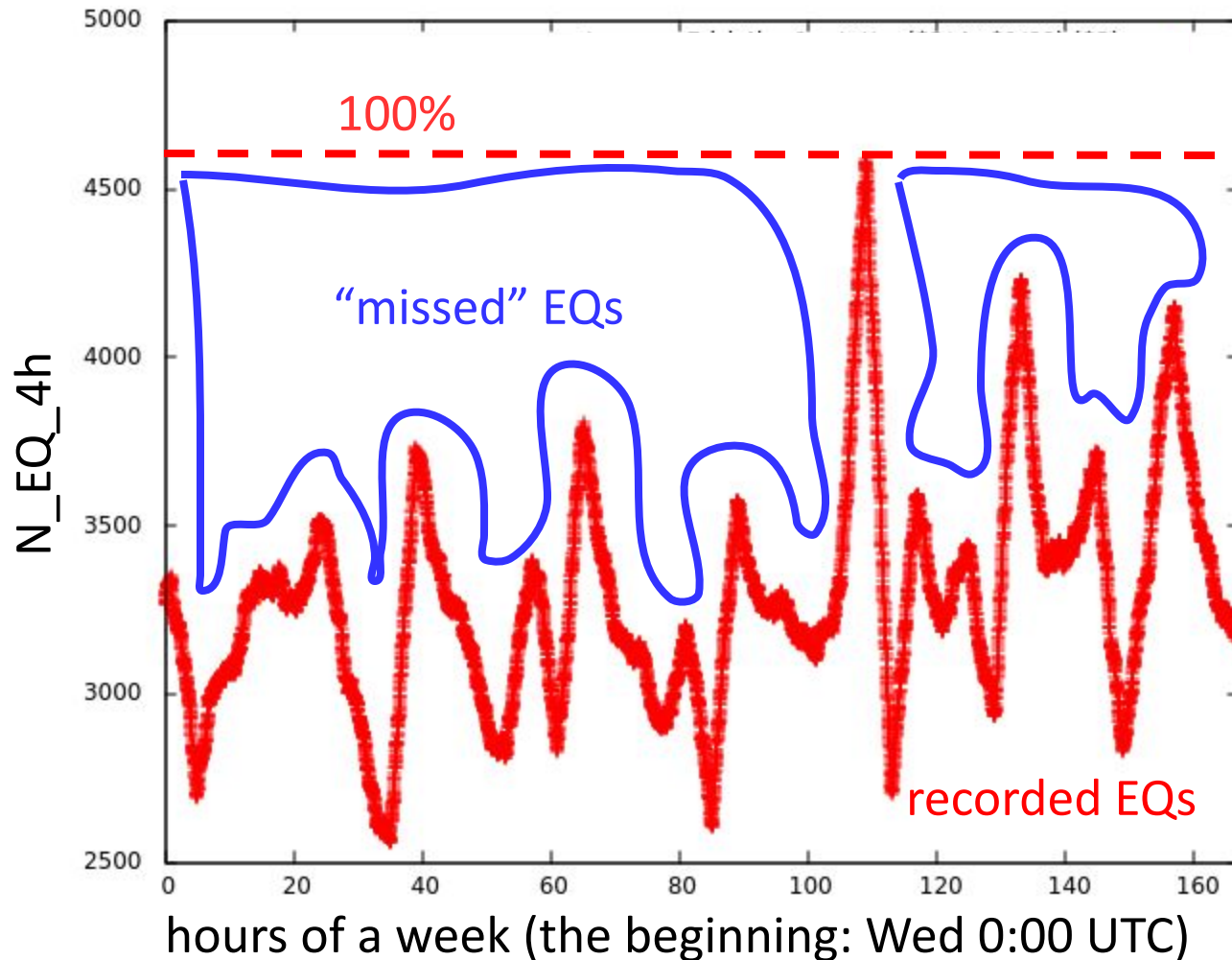
$m \geq 4.5$



The weekly earthquake pattern varies in time



Example “NOs”:



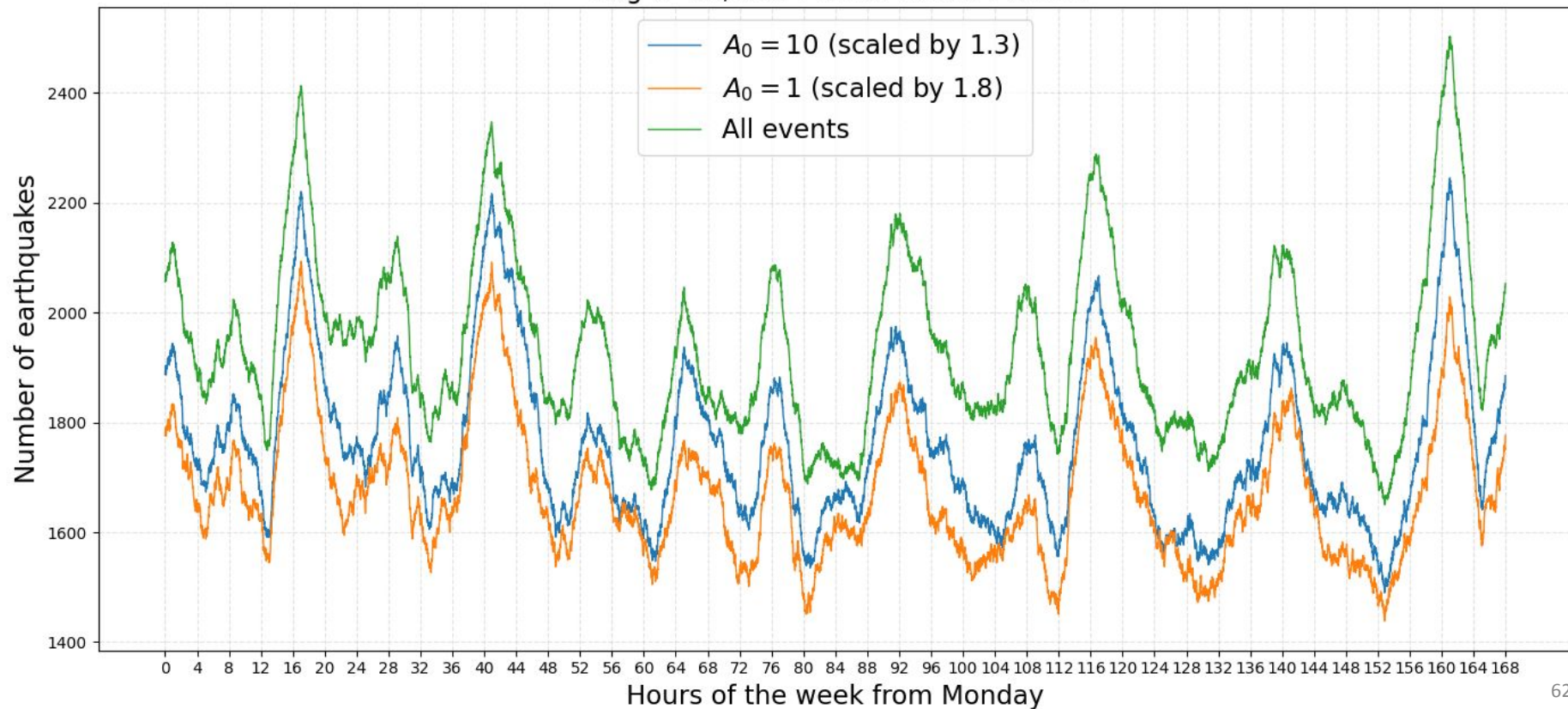
Civilisation noise
(earthquakes not detected due to noise induced human activity - **only deficit possible**)?

"missed" EQs: $\sim 30\%$,
only $\frac{1}{6}$ ($\sim 5\%$) could be missed given the geometry of the sensor network
-> **deficit rejected at $> 5\sigma$ (preliminary)**

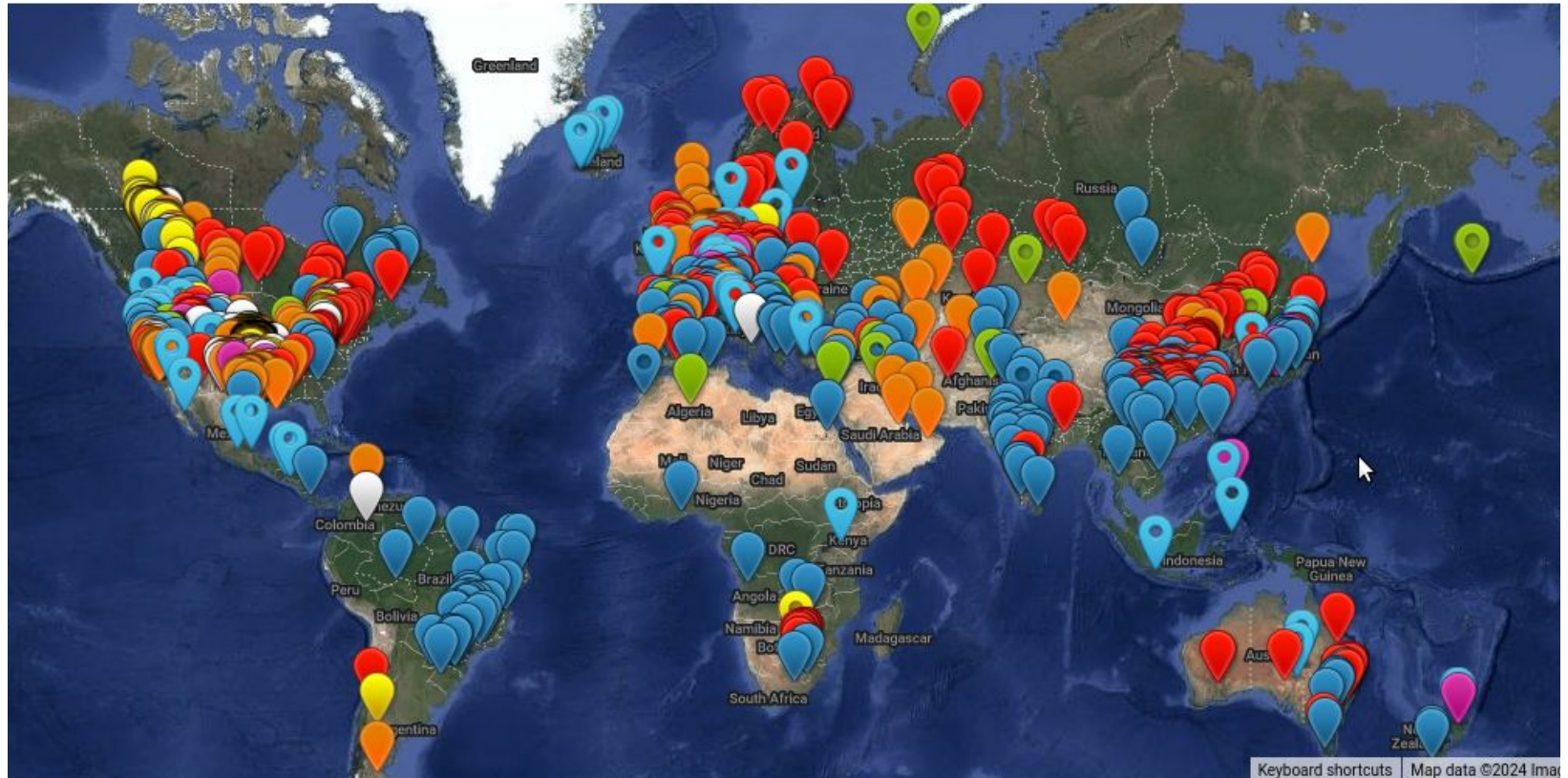
The weekly pattern with declustered EQ data (analysis and plot by Magdalena Bochnak)

Weekly Earthquake Plot (background, 4h window, step 1 minute)

Mag ≥ 4.5 , 2014-01-01 to 2024-12-31



THE HUMAN-INDUCED EARTHQUAKE DATABASE



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.

Fracking

32%

Mining

23%

Water reservoir impoundment

18%

Conventional Oil and Gas

11%

Geothermal

6%

Waste fluid disposal

4%

Nuclear explosions

2%

Research

1%

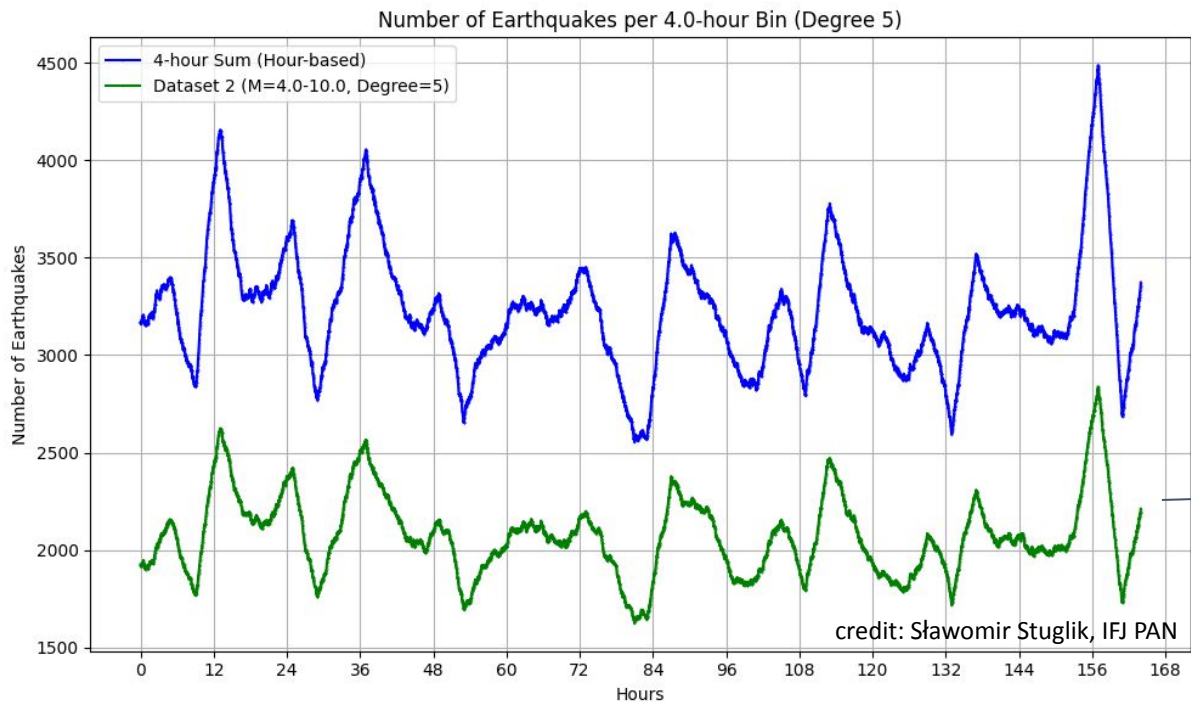
Unspecified Oil and Gas/Waste fluid disposal

1%

Groundwater extraction

.9%

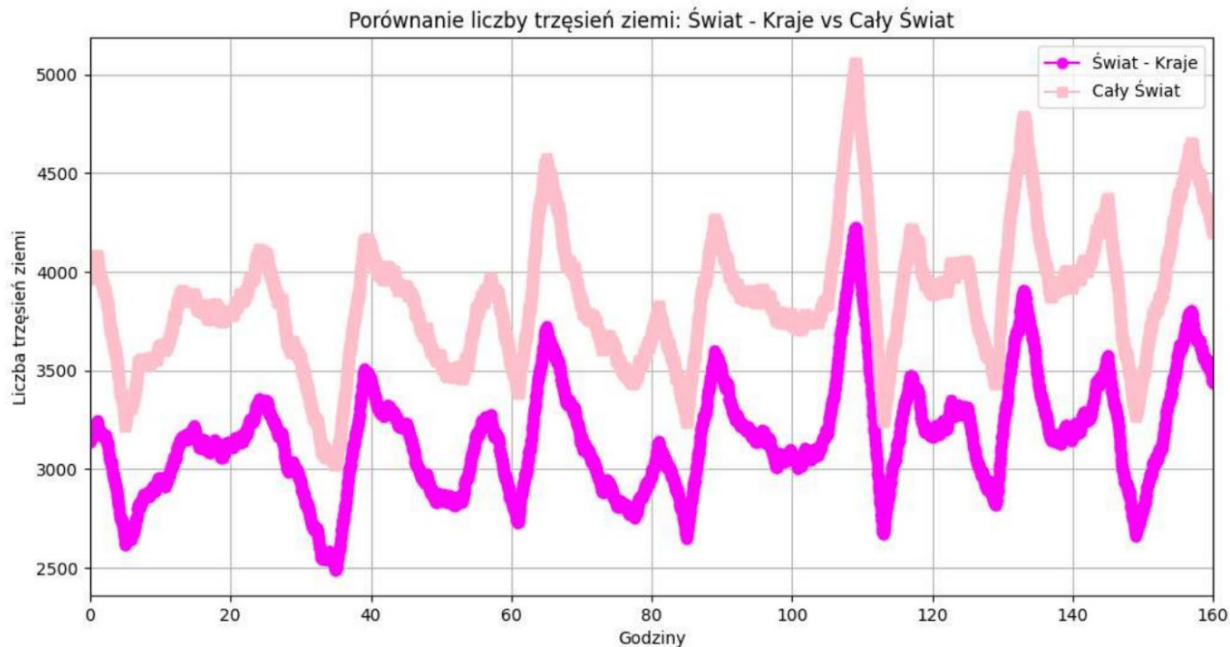
Weekly earthquake distribution: $M \geq 4$ all (blue) vs. $M \geq 4$ @ ± 5 deg away from the location of “industrial” earthquakes (green)



→ All

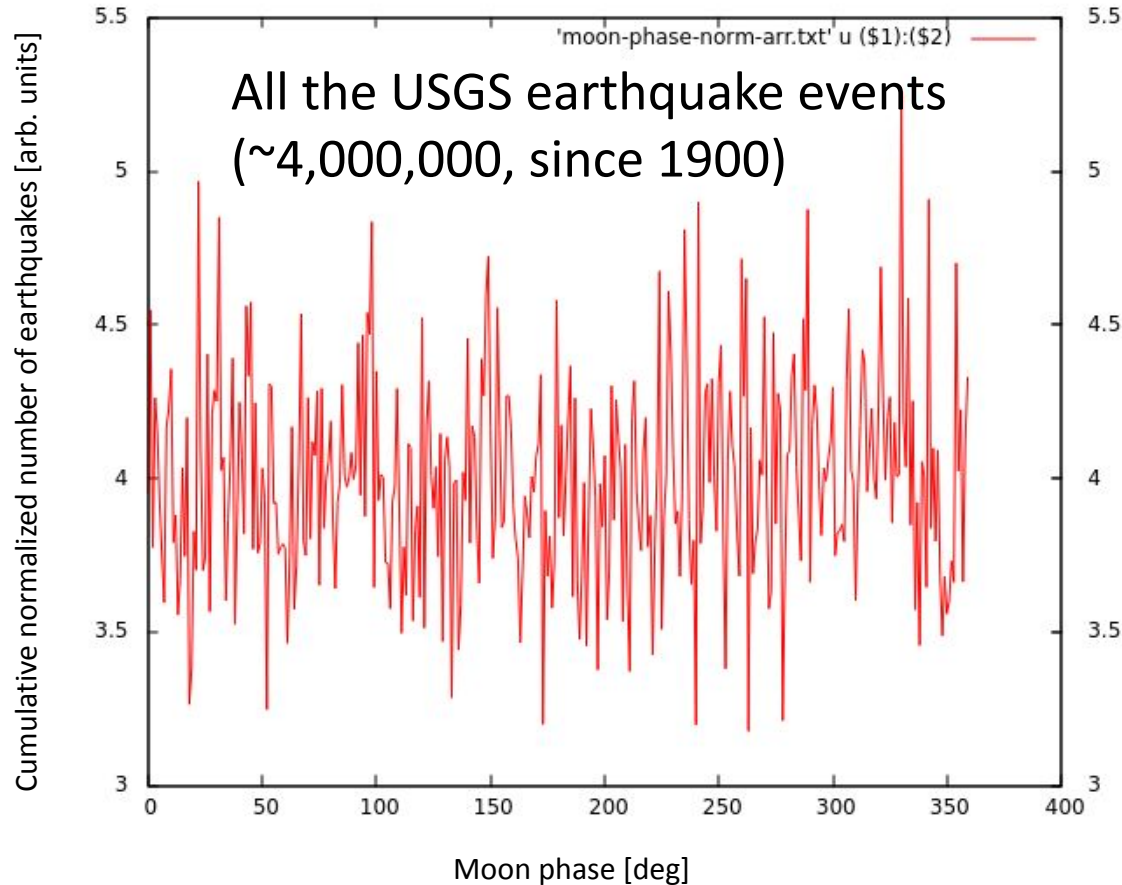
No locations of
“industrial”
earthquakes
(extracted with the
margin of ± 5 deg)

Cutting out populated/industrialized countries: the effect stays there



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

Normalized number of earthquakes vs. Moon phase



tidal forces caused by
the Moon:
excluded!

Inspiring literature (examples):

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 midnight to daybreak, which could be helpful to opening a **new window to explore the physical mechanism of earthquakes.**”

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)

arXiv > astro-ph > arXiv:2210.07367
2023

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Search
Help | Advanced Search

Astrophysics > Instrumentation and Methods for Astrophysics

[Submitted on 13 Oct 2022 (v1), last revised 5 Dec 2023 (this version, v3)]

Gravitational focusing effects on streaming dark matter as a new detection concept

Abaz Kryemadhi, Marios Maroudas, Andreas Mastronikolis, Konstantin Zioutas

Cosmological simulations for cold dark matter (DM) indicate that a large number of streams might exist in our Galaxy. The present work incorporates gravitational focusing (GF) effects on streaming DM constituents by the Sun and the Earth preceding their encounter with Earth bound detectors. For streaming DM, the GF 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. This work presents a novel opportunity for DM signal detection and identification, and the present simulation can be applied to any kind of invisible matter entering the solar system.

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astro-ph
astro-ph.CO

<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.”

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.

Access Paper:

- Download PDF (view license)

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new | recent | 2305

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- physics.space-ph

References & Citations

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- NASA ADS
- Google Scholar
- Semantic Scholar

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

Planck mass charged gravitino dark matter

Krzysztof A. Meissner¹ and Hermann Nicolai²

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*



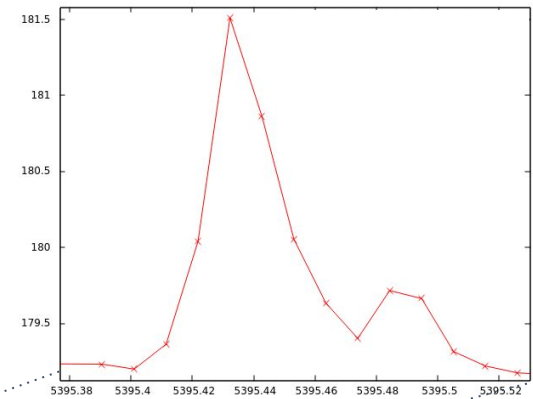
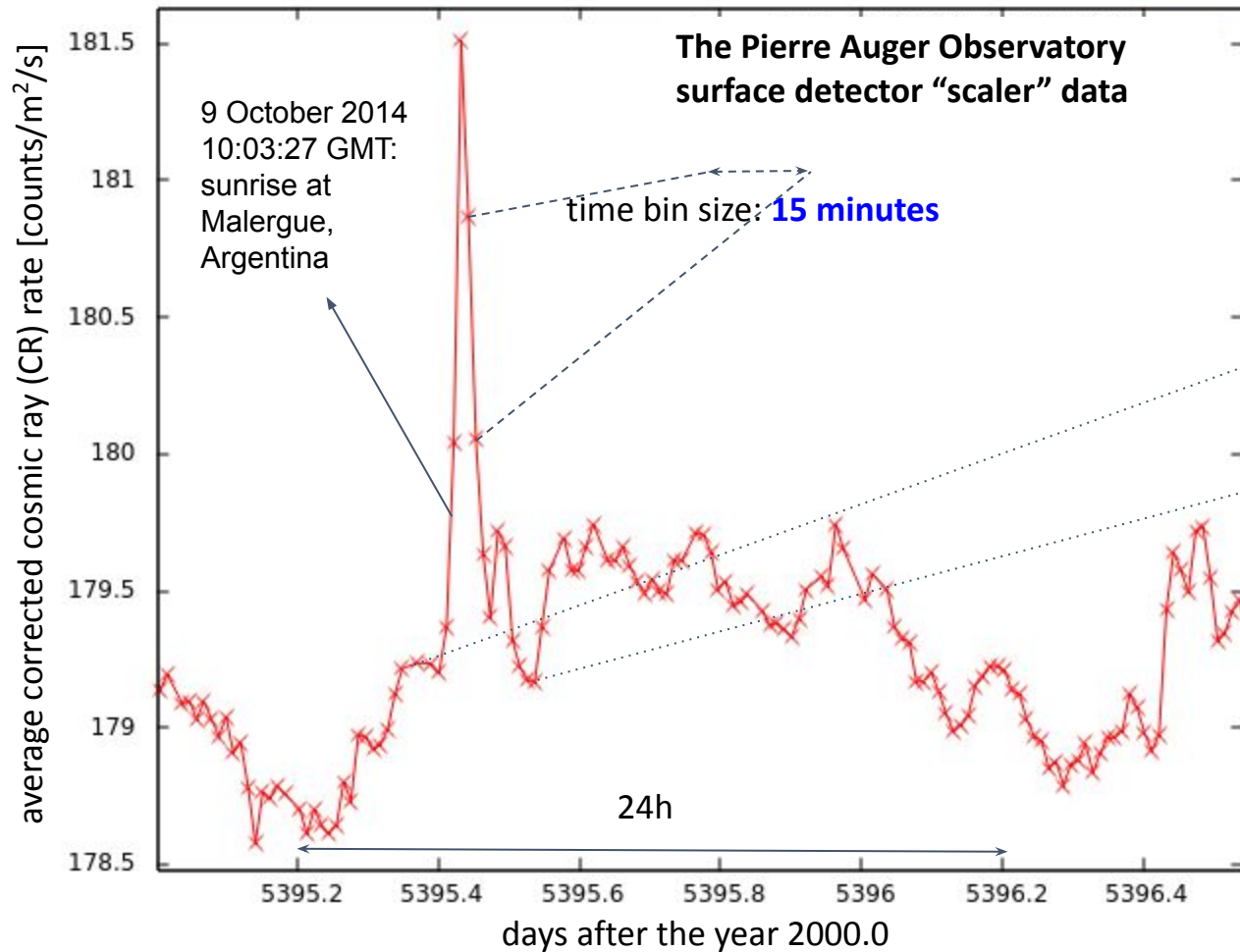
(Received 19 April 2019; published 2 August 2019)

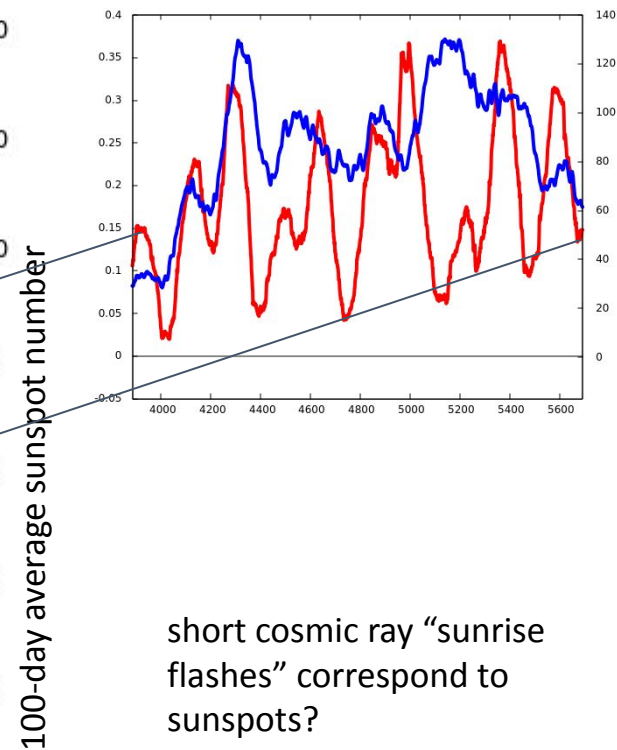
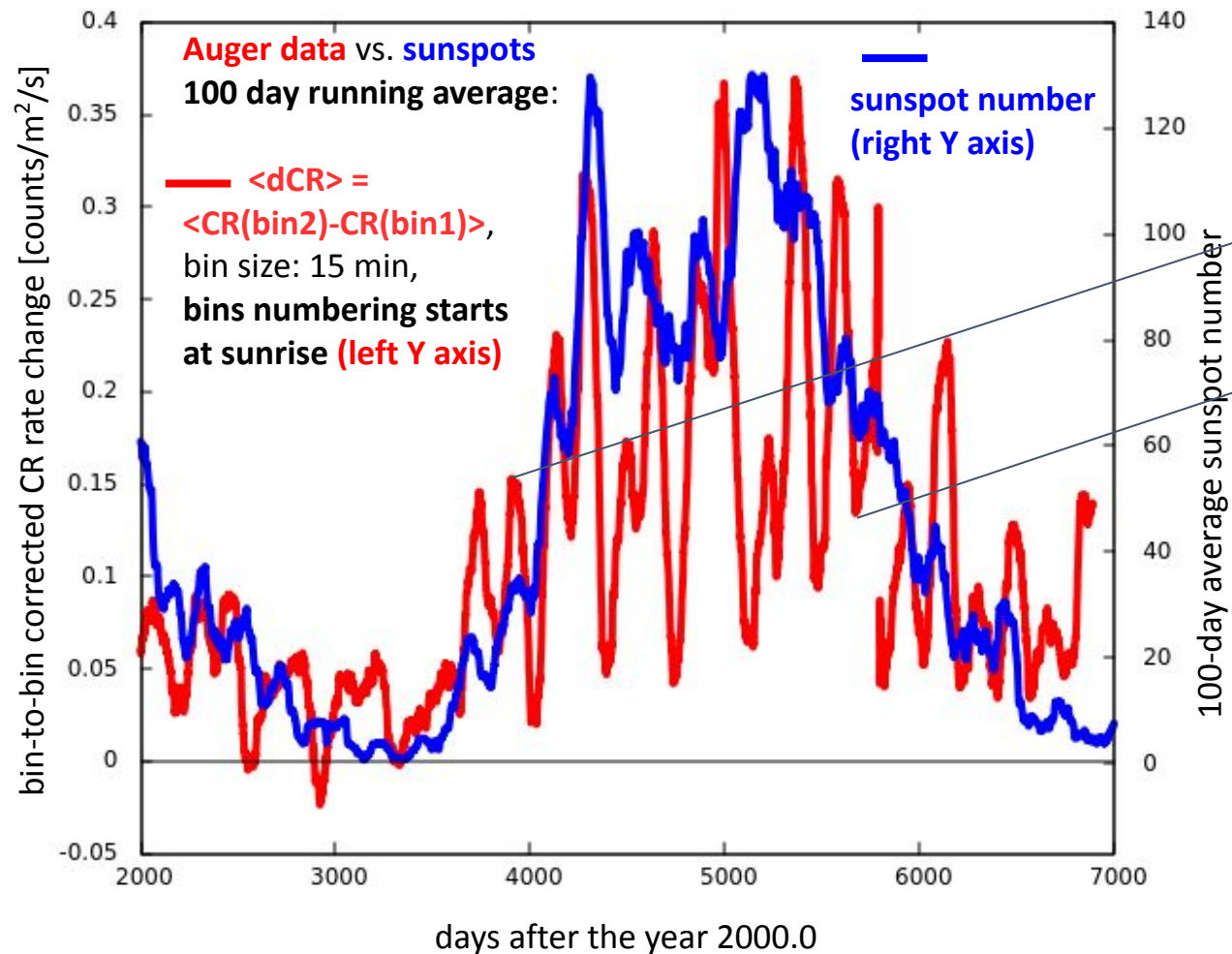
Following up on our earlier work predicting fractionally charged supermassive gravitinos, we explain their potential relevance as novel candidates for dark matter and discuss possible signatures and ways to detect them.

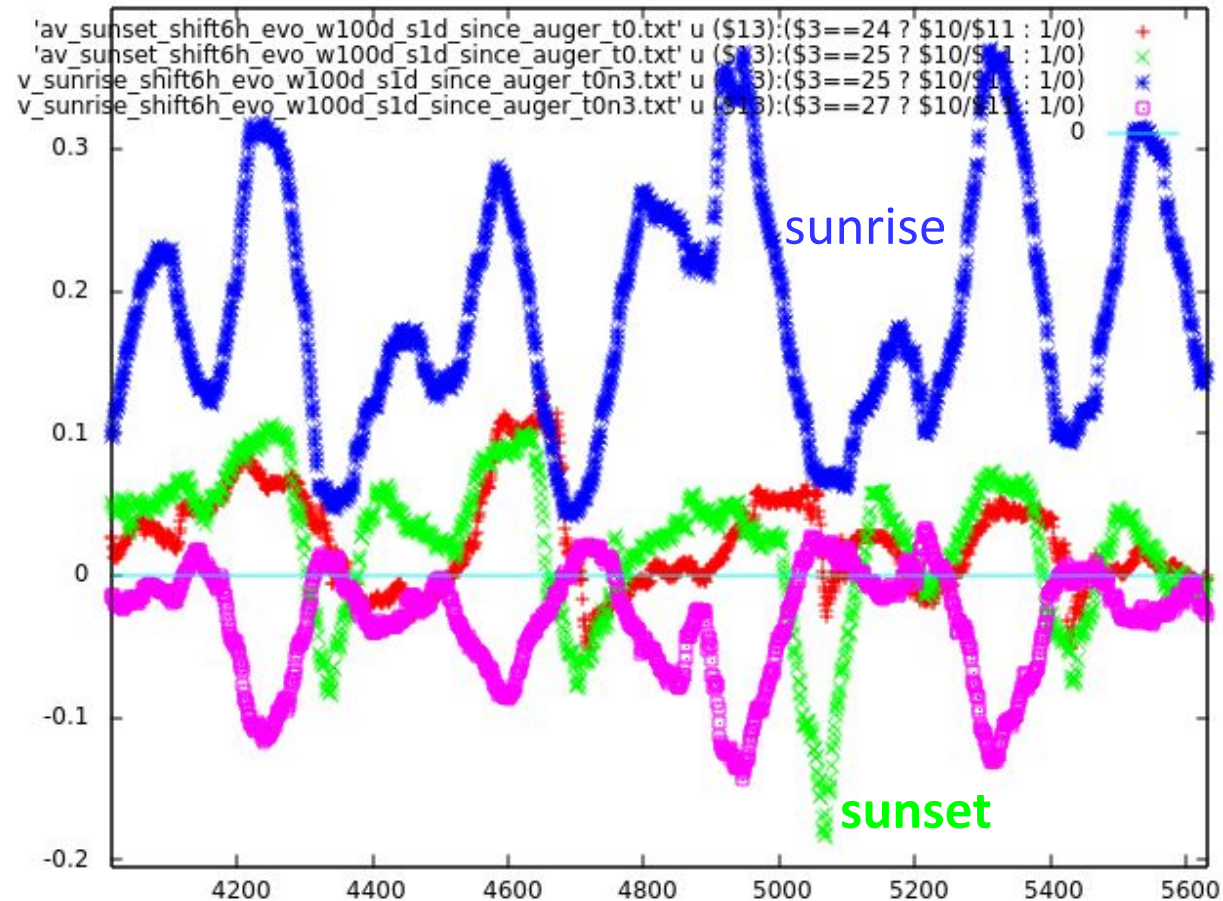
DOI: 10.1103/PhysRevD.100.035001

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

Openness to the unexplained CR/EQ
phenomena (examples):







Sunrise vs Sunset @ Auger

- peak on sunrise?
- deep on sunset?
- shifted by ~3 months?

The tension in the UHECR energy spectrum

From: Deligny, O.; for the Pierre Auger and Telescope Array Collaborations. The energy spectrum of ultra-high energy cosmic rays measured at the Pierre Auger Observatory and at the Telescope Array. [PoS 2020, ICRC2019, 234](#).

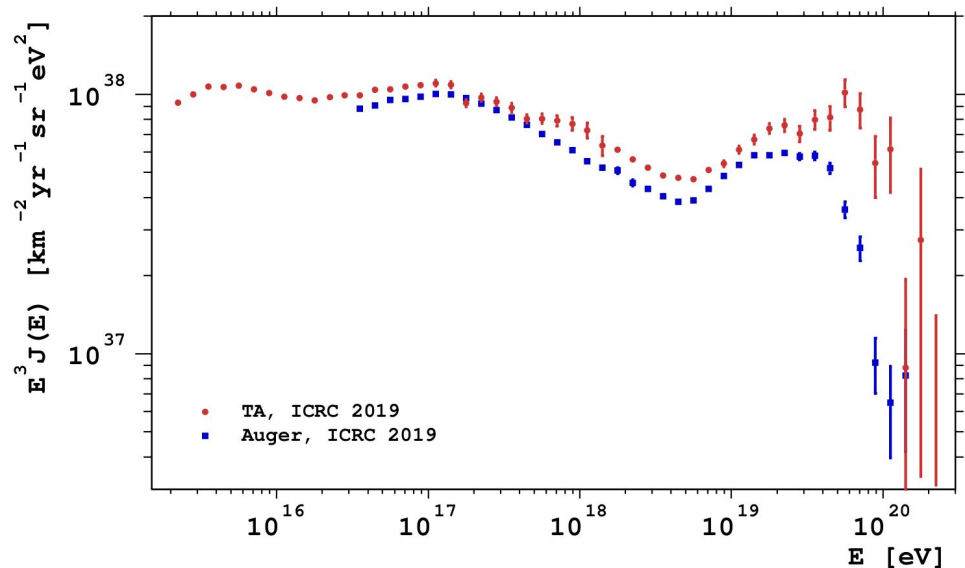
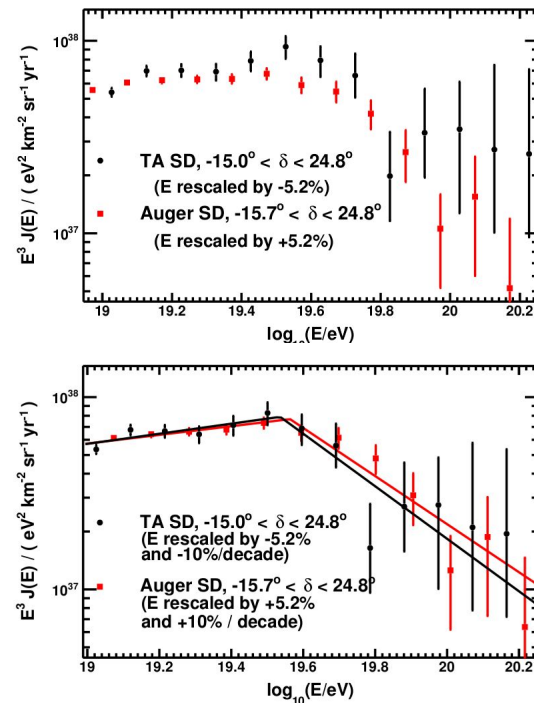
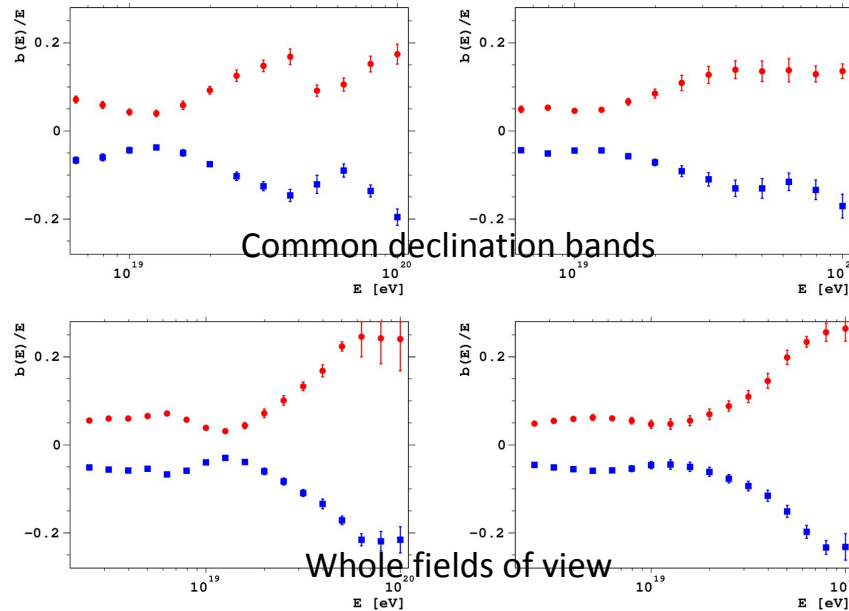


Figure 1: ICRC 2019 energy spectra of the Pierre Auger Observatory and the Telescope Array scaled by E^3 . In each experiment, data of different detection techniques are combined to obtain the spectrum over a wide energy range.



The tension: energy dependent reconciliation

From: Deligny, O.; for the Pierre Auger and Telescope Array Collaborations. The energy spectrum of ultra-high energy cosmic rays measured at the Pierre Auger Observatory and at the Telescope Array. [PoS 2020, ICRC2019, 234](#).



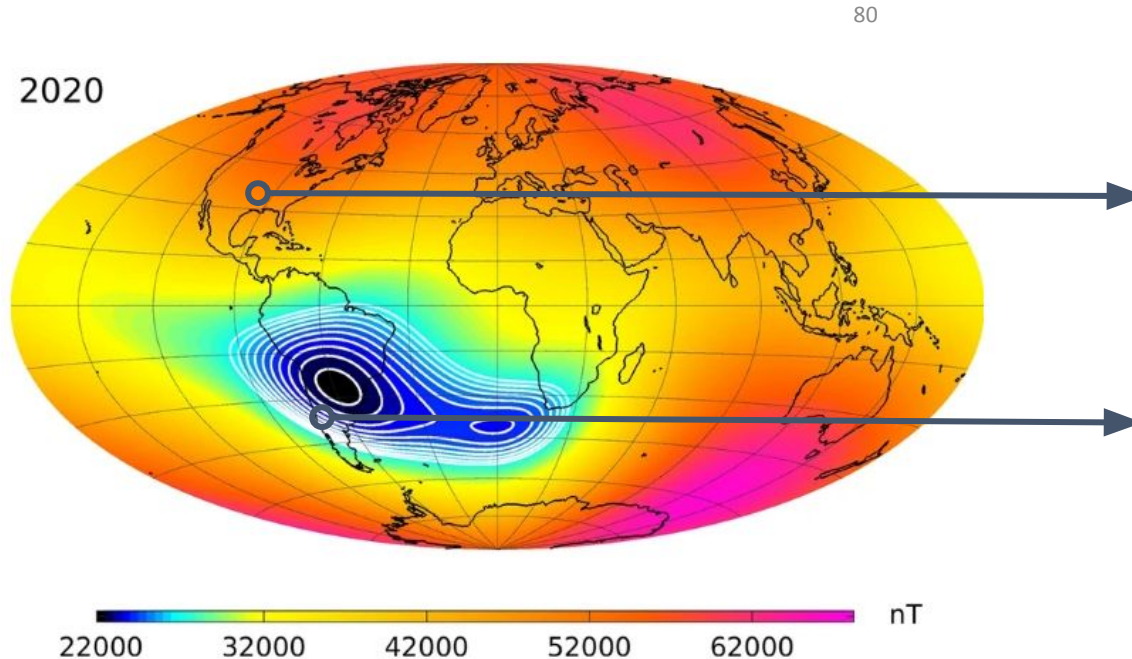
“On top of a global rescaling of energies, a **non-linearity is needed** to bring spectra in agreement in the **range of common declinations**

...

The **sources** of the non-linearity **have not been identified, yet.**”

Figure 3: Energy shift term needed to bring the fitted differential spectra in agreement. Left: single broken power law for the underlying spectrum. Right: double broken power law for the underlying spectrum. Top: analysis in the common declination band, using an energy spectrum estimator free of directional-exposure distortions of anisotropies. Bottom: analysis in the whole fields of view of each observatory.

Ideas: technology, mistakes, or physics?



If physics:

Telescope Array:

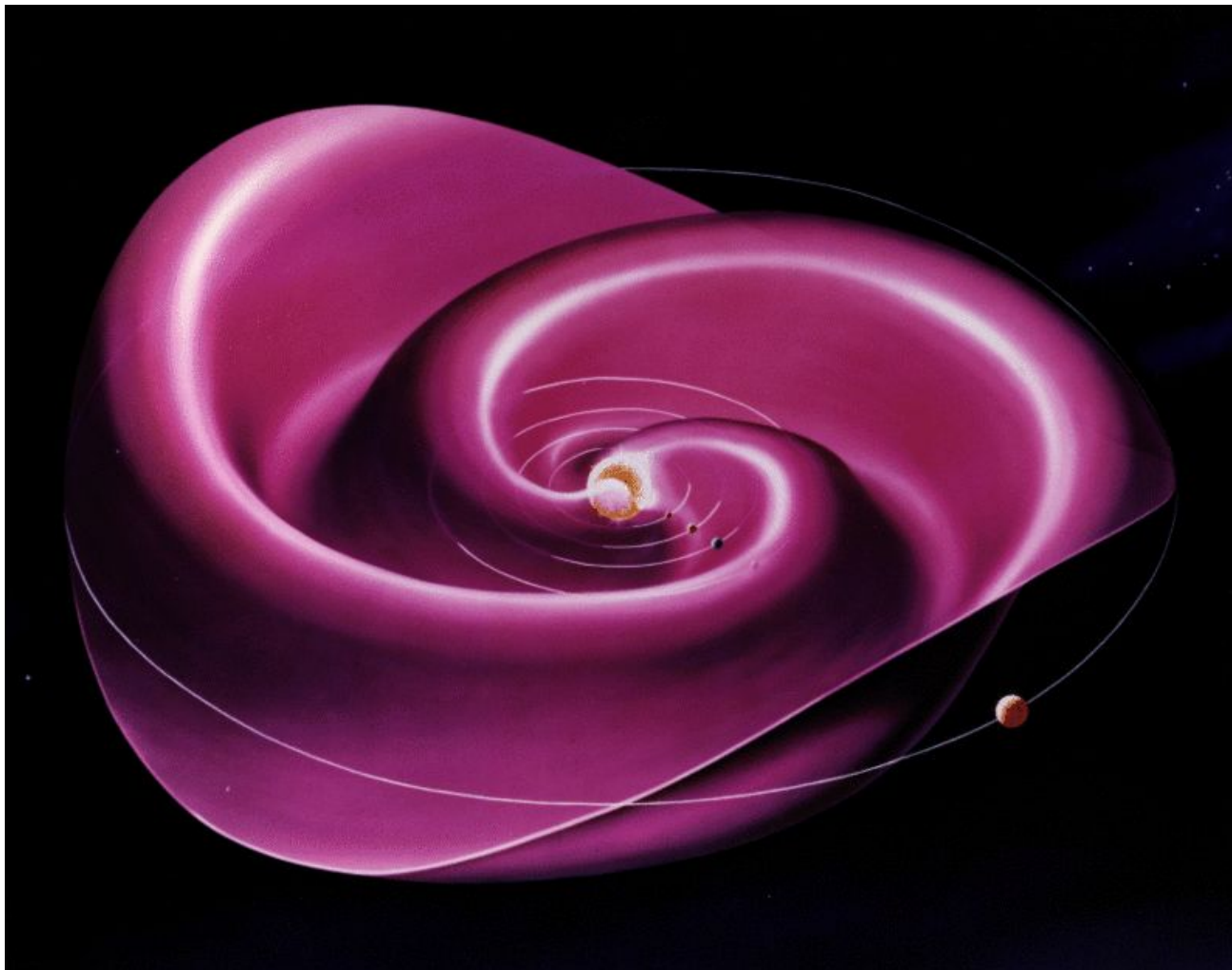
$$|\vec{B}| \sim 55 \mu\text{T}$$

Pierre Auger Observatory:

$$|\vec{B}| \sim 25 \mu\text{T}$$

Factor ~ 2 difference
in the strength of
the geomagnetic field

Candidate speculations:



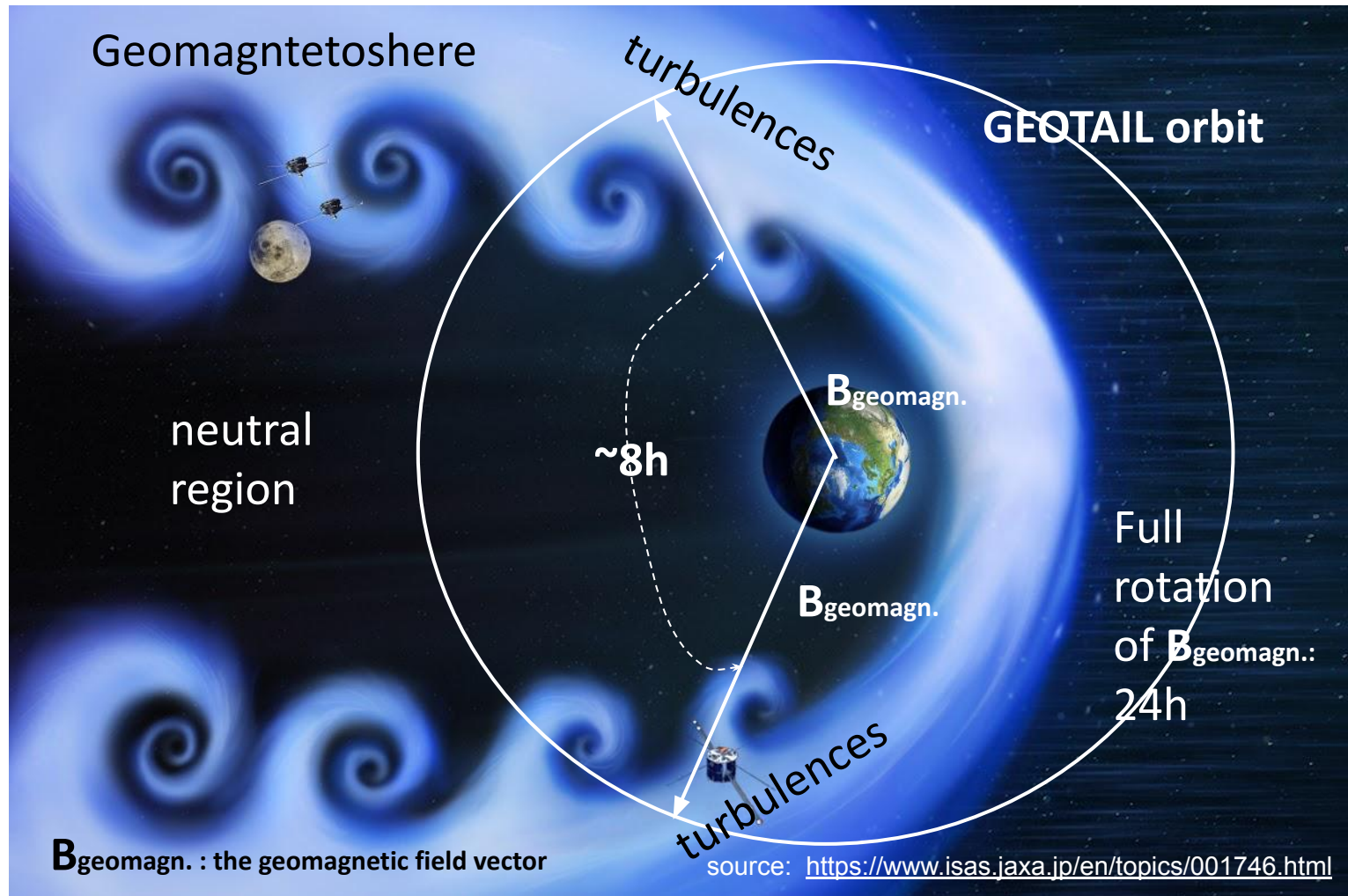
Heliospheric Current
Sheet (- like?)
behavior?

~10000 km thickness

~heavier particles
required?

~periodicities close to
27 days, $\frac{1}{2} \times 27$ days.

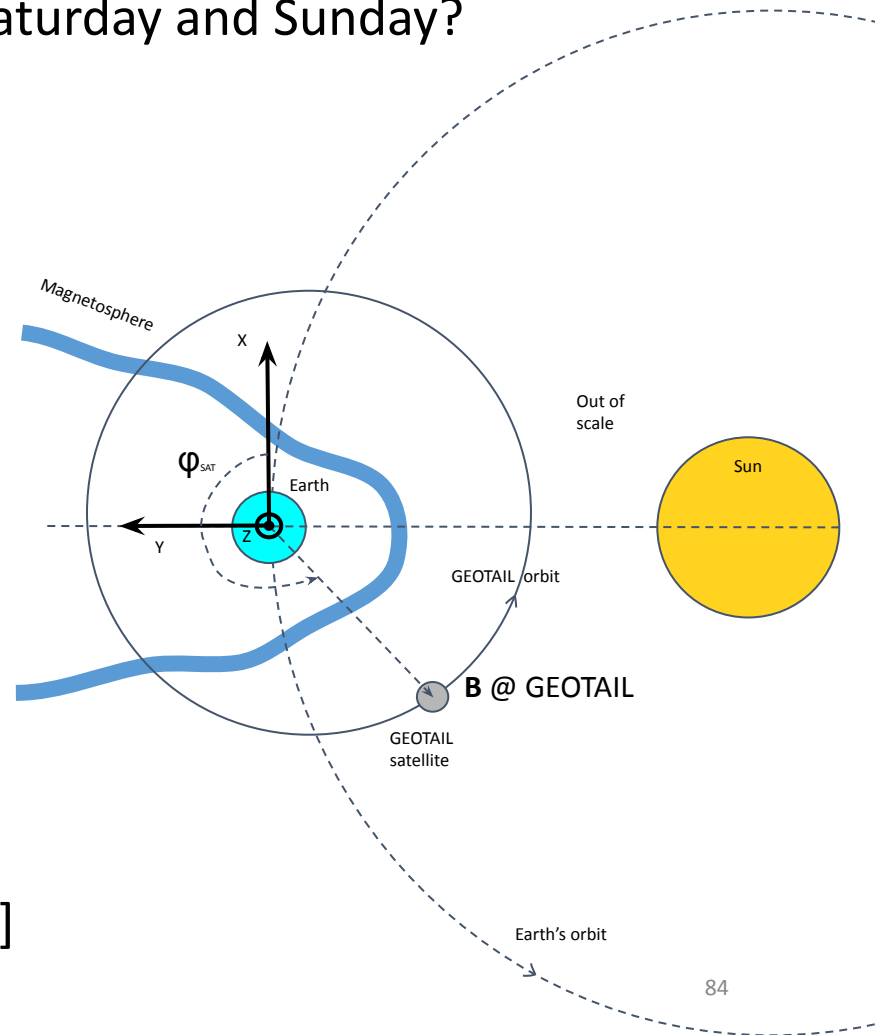
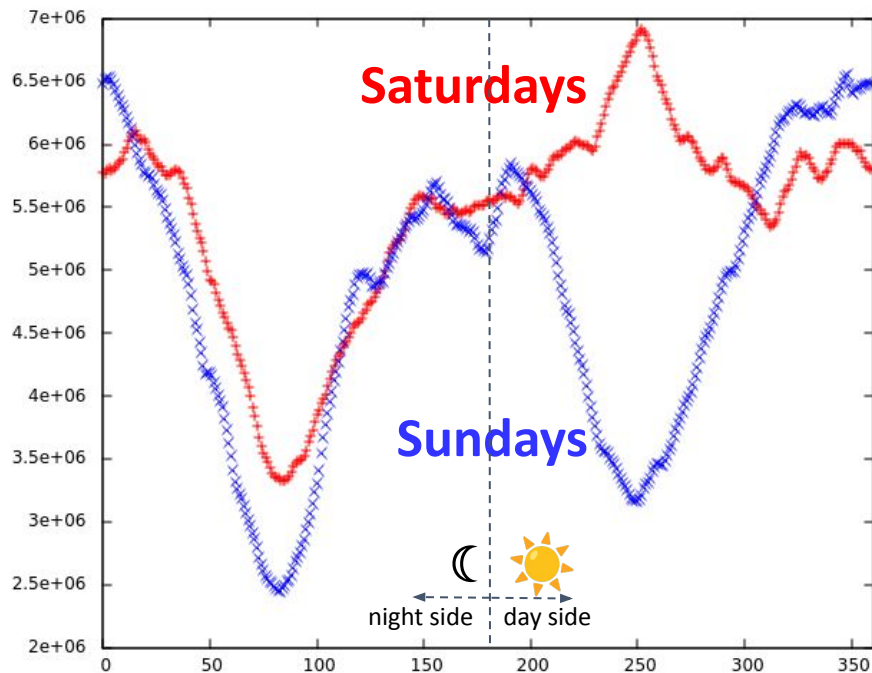
~opposite directions
possible if both
positive and negative
charges involved?



A physical difference between Saturday and Sunday?

ΣB_z @ GEOTAIL

2014-19, stacked

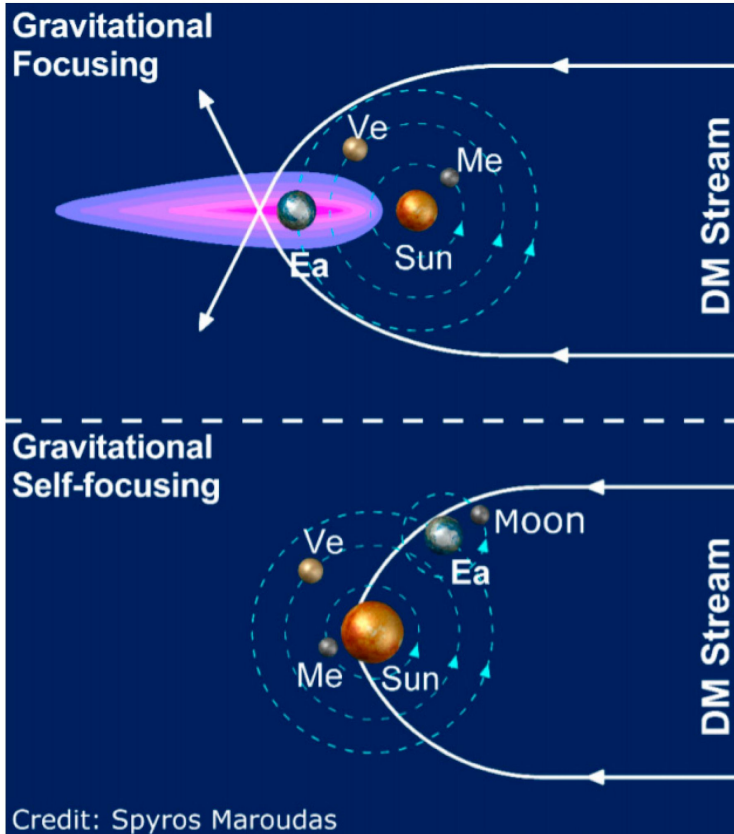


Position on the GEOTAIL orbit: ϕ_{SAT} [deg]

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?

Non anthropogenic 7.0 days imaginable in physics

Rossby waves = rotational modes = r-modes

observed in:

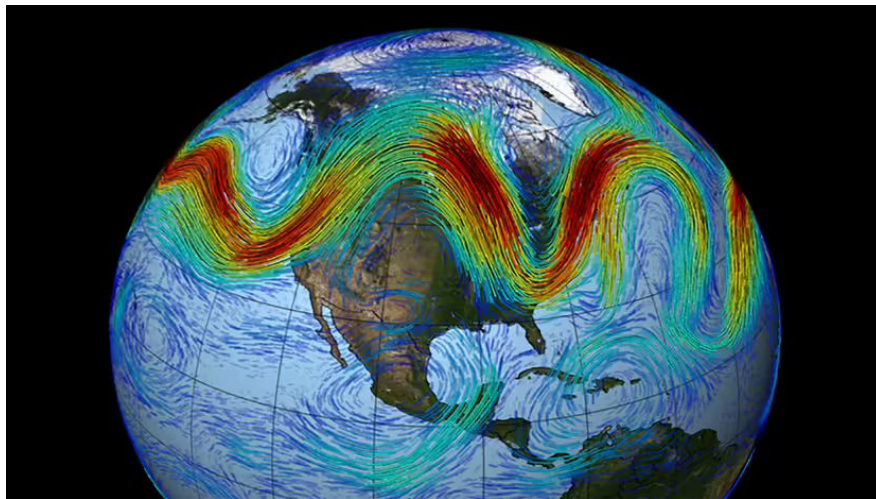
- Earth atmosphere
- Earth oceans
- planets: Mars, Jupiter, Saturn
- the Sun
- stars

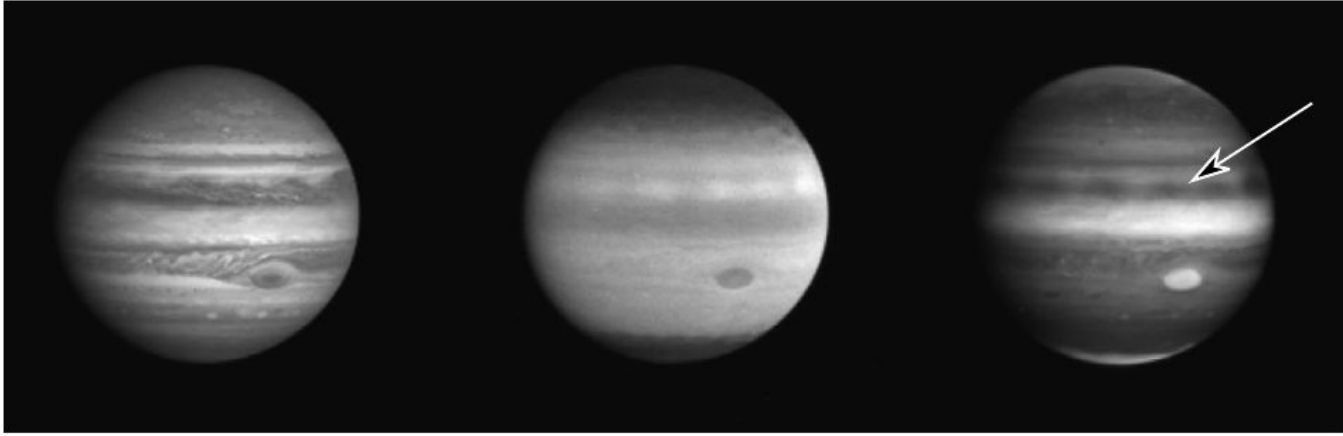
expectations:

- neutron star (GW emission by CFS-instability)

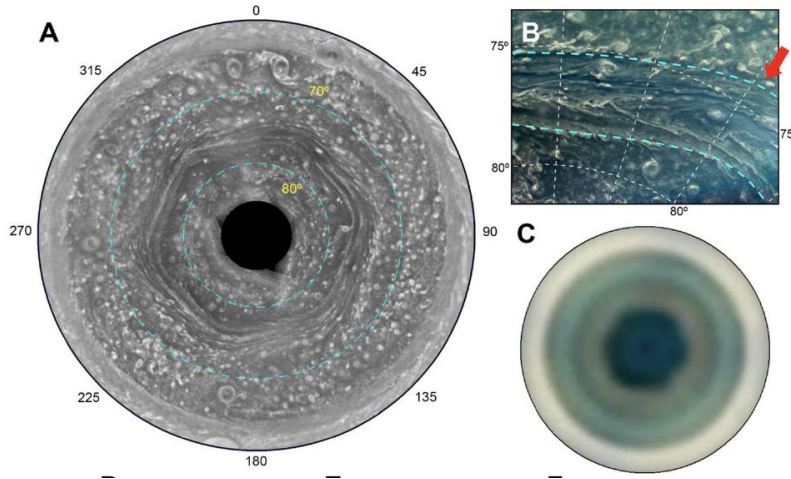
speculations:

- Earth core ??
- exotic near-ideal medium, e.g. DM co-rotating with the Earth (*idea by PH*)





Jupiter



Saturn

Rossby waves - basics

for more details, see a
review:

[Space Sci Rev 217,15 \(2021\)](#)

in rotating frame, Coriolis force


$$\rho \left[\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} + 2\mathbf{\Omega} \times \mathbf{v} \right] = -\nabla p + \rho \nabla \Phi,$$

linearization:

$$\frac{d\mathbf{v}}{dt} + (\mathbf{v} \cdot \nabla) \mathbf{U} + 2\mathbf{\Omega} \times \mathbf{v} = -\frac{1}{\rho_0} \nabla p' + \frac{\rho'}{\rho_0^2} \nabla p_0,$$

thin layer approximation: no gravity, no pressure gradients

$$u_\theta = -\frac{1}{\sin \theta} \frac{\partial \chi}{\partial \phi}, \quad u_\phi = \frac{\partial \chi}{\partial \theta},$$

only tangential components of $\mathbf{v}$
expressed by *stream function* $\chi(\theta, \phi)$

$$\frac{\partial}{\partial t} \left[\frac{1}{\sin \theta} \frac{\partial}{\partial \theta} \left(\sin \theta \frac{\partial \chi}{\partial \theta} \right) + \frac{1}{\sin^2 \theta} \frac{\partial^2 \chi}{\partial \phi^2} \right] + 2\Omega \frac{\partial \chi}{\partial \phi} = 0.$$

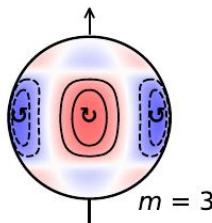
$$\chi = \cos(-\sigma t + m\phi) \chi_1(\theta), \quad \text{spherical harmonics} \quad Y_n^m(\theta, \phi), \quad -n < m < n$$

Rossby wave frequencies:

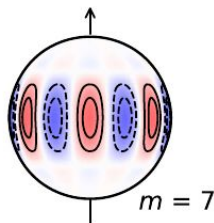
$$\sigma = -\frac{2m\Omega}{n(n+1)}.$$

submultiples of Ω

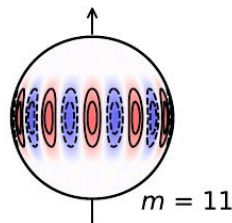
the Sun



$m = 3$



$m = 7$



$m = 11$

$m=n$, sectorial (equatorial) modes

$$\sigma = -\frac{2\Omega}{m+1}$$

$$\Omega/2\pi = 453 \text{ nHz}$$

Mode m	Frequencies		Linewidth observed (nHz)	SNR	Dates
	Theory (nHz)	Observed (nHz)			
2	-302	missing	—	—	1996–2017
3	-227	-253 ± 2	7^{+4}_{-3}	9.2	1996–2017
4	-181	-194^{+5}_{-4}	18^{+14}_{-7}	10.8	2010–2016
5	-151	-157 ± 4	11^{+14}_{-6}	14.3	2010–2016
6	-129	-129 ± 8	47^{+28}_{-16}	2.7	2010–2016
7	-113	-112 ± 4	17^{+10}_{-7}	6.6	2010–2016
8	-101	-90 ± 3	12^{+7}_{-5}	7.5	2010–2016
9	-91	-86 ± 6	37^{+21}_{-11}	2.3	2010–2016
10	-82	-75 ± 5	28^{+12}_{-10}	2.7	2010–2016
11	-76	-75 ± 7	43^{+23}_{-13}	1.7	2010–2016
12	-70	-59 ± 6	42^{+20}_{-12}	1.4	2010–2016

earthquakes occurrences:
exact 7-day periodicity !

$$\sigma = \frac{1}{7}\Omega$$

$$(n, m) = (6, 3); (7, 4); \dots$$

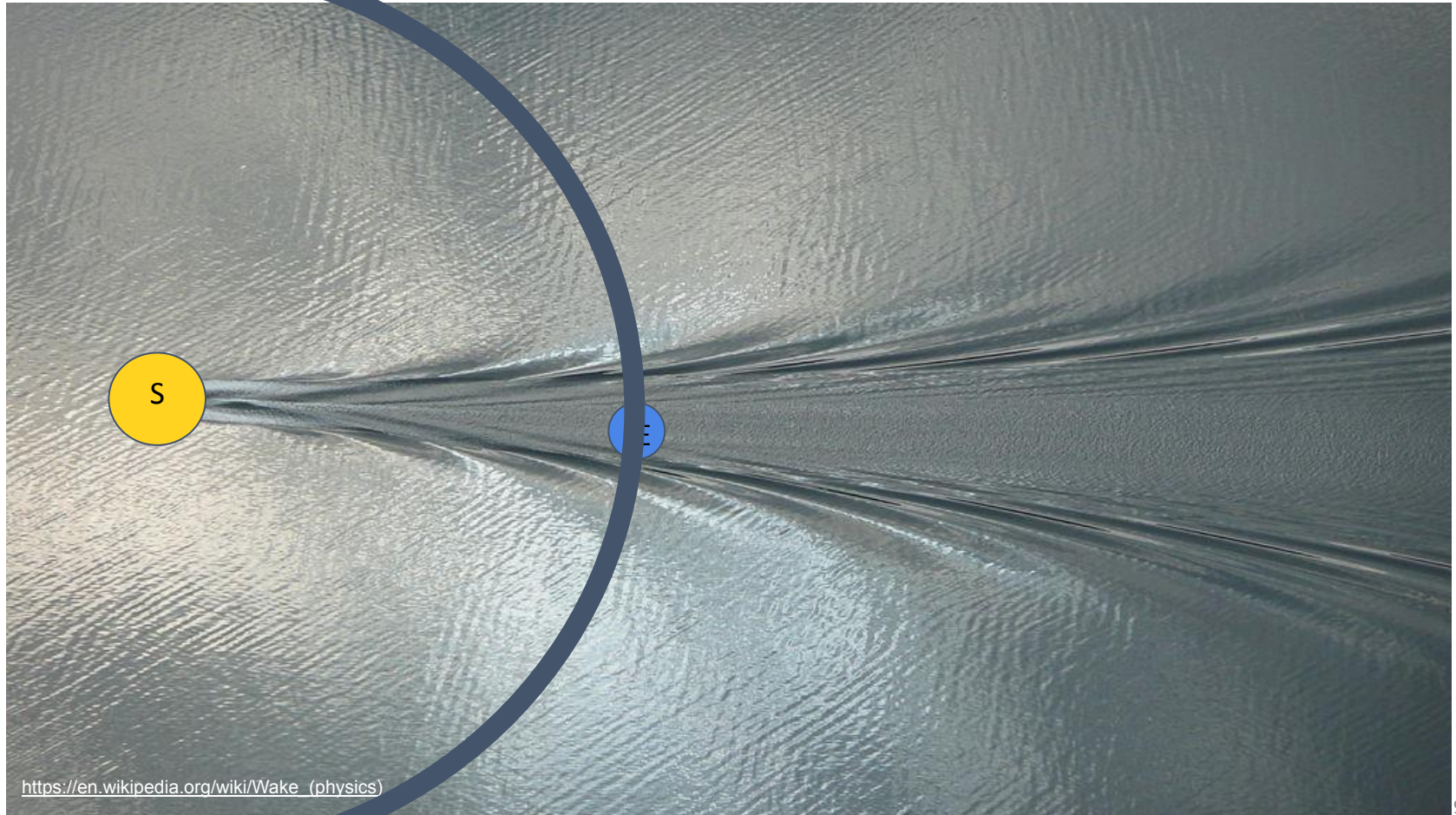
Issues [PH]:

- $T_{\text{Earth}} = 24 \text{ h} - 236 \text{ s}$ (sidereal day),
solar (day-like) forcing factor needed
- how about the other r-modes?

$$\sigma = -\frac{2m\Omega}{n(n+1)}.$$

n↓ m→	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1														
2	$\frac{1}{3}$	$\frac{2}{3}$													
3	$\frac{1}{6}$	$\frac{1}{3}$	$\frac{1}{2}$												
4	$\frac{1}{10}$	$\frac{1}{5}$	$\frac{3}{10}$	$\frac{2}{5}$											
5	$\frac{1}{15}$	$\frac{2}{15}$	$\frac{1}{5}$	$\frac{4}{15}$	$\frac{1}{3}$										
6	$\frac{1}{21}$	$\frac{2}{21}$	$\frac{1}{7}$	$\frac{4}{21}$	$\frac{5}{21}$	$\frac{2}{7}$									
7	$\frac{1}{28}$	$\frac{1}{14}$	$\frac{3}{28}$	$\frac{1}{7}$	$\frac{5}{28}$	$\frac{3}{14}$	$\frac{1}{4}$								
8	$\frac{1}{36}$	$\frac{1}{18}$	$\frac{1}{12}$	$\frac{1}{9}$	$\frac{5}{36}$	$\frac{1}{6}$	$\frac{7}{36}$	$\frac{2}{9}$							
9	$\frac{1}{45}$	$\frac{2}{45}$	$\frac{1}{15}$	$\frac{4}{45}$	$\frac{1}{9}$	$\frac{2}{15}$	$\frac{7}{45}$	$\frac{8}{45}$	$\frac{1}{5}$						
10	$\frac{1}{55}$	$\frac{2}{55}$	$\frac{3}{55}$	$\frac{4}{55}$	$\frac{1}{11}$	$\frac{6}{55}$	$\frac{7}{55}$	$\frac{8}{55}$	$\frac{9}{55}$	$\frac{2}{11}$					
11	$\frac{1}{66}$	$\frac{1}{33}$	$\frac{1}{22}$	$\frac{2}{33}$	$\frac{5}{66}$	$\frac{1}{11}$	$\frac{7}{66}$	$\frac{4}{33}$	$\frac{3}{22}$	$\frac{5}{33}$	$\frac{1}{6}$				
12	$\frac{1}{78}$	$\frac{1}{39}$	$\frac{1}{26}$	$\frac{2}{39}$	$\frac{5}{78}$	$\frac{1}{13}$	$\frac{7}{78}$	$\frac{4}{39}$	$\frac{3}{26}$	$\frac{5}{39}$	$\frac{11}{78}$	$\frac{2}{13}$			
13	$\frac{1}{91}$	$\frac{2}{91}$	$\frac{3}{91}$	$\frac{4}{91}$	$\frac{5}{91}$	$\frac{6}{91}$	$\frac{1}{13}$	$\frac{8}{91}$	$\frac{9}{91}$	$\frac{10}{91}$	$\frac{11}{91}$	$\frac{12}{91}$	$\frac{1}{7}$		
14	$\frac{1}{105}$	$\frac{2}{105}$	$\frac{1}{35}$	$\frac{4}{105}$	$\frac{1}{21}$	$\frac{2}{35}$	$\frac{1}{15}$	$\frac{8}{105}$	$\frac{3}{35}$	$\frac{2}{21}$	$\frac{11}{105}$	$\frac{4}{35}$	$\frac{13}{105}$	$\frac{2}{15}$	
15	$\frac{1}{120}$	$\frac{1}{60}$	$\frac{1}{40}$	$\frac{1}{30}$	$\frac{1}{24}$	$\frac{1}{20}$	$\frac{1}{120}$	$\frac{1}{15}$	$\frac{3}{40}$	$\frac{1}{12}$	$\frac{11}{120}$	$\frac{1}{10}$	$\frac{13}{120}$	$\frac{7}{60}$	$\frac{1}{8}$

... or Dark Fluid -> dark wake(s)?



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!



exact 7-day periodicity:

$$\sigma = -\frac{2m\Omega}{n(n+1)}.$$

$$\sigma = \frac{1}{7}\Omega \quad (n, m) = (6, 3); (7, 4); \dots$$

BUT when gravity included :

Lamb parameter $\epsilon = \frac{E_{kin}^{rot}}{E_{grav}} \quad \epsilon = \frac{4\Omega_{\oplus}^2 R_{\oplus}^2}{gH}$

$$\sigma = -2m\Omega \left[n(n+1) + \frac{\epsilon}{2} \left(1 - \frac{(2m-1)(2m+1)}{(2n-1)(2n+3)} \right) \right]^{-1}$$

BUT when magnetic field included:

$$\mathbf{V}_A = \mathbf{B} / \sqrt{\mu_0 \rho} \quad \text{Alfven waves velocity}$$

$$\frac{\sigma_+}{m} = -\frac{2\Omega}{n(n+1)} - \frac{V_A^2}{2\Omega R^2} [n(n+1) - 2], \quad \text{prograde modes}$$

$$\frac{\sigma_-}{m} = \frac{V_A^2}{2\Omega R^2} [n(n+1) - 2]. \quad \text{retrograde modes}$$