An update on the cosmo-seismic correlations: a manifestation of a charged dark matter stream?

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Cosmic Ray Extremely Distributed Observatory / CREDO.science

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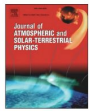

Research Paper

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

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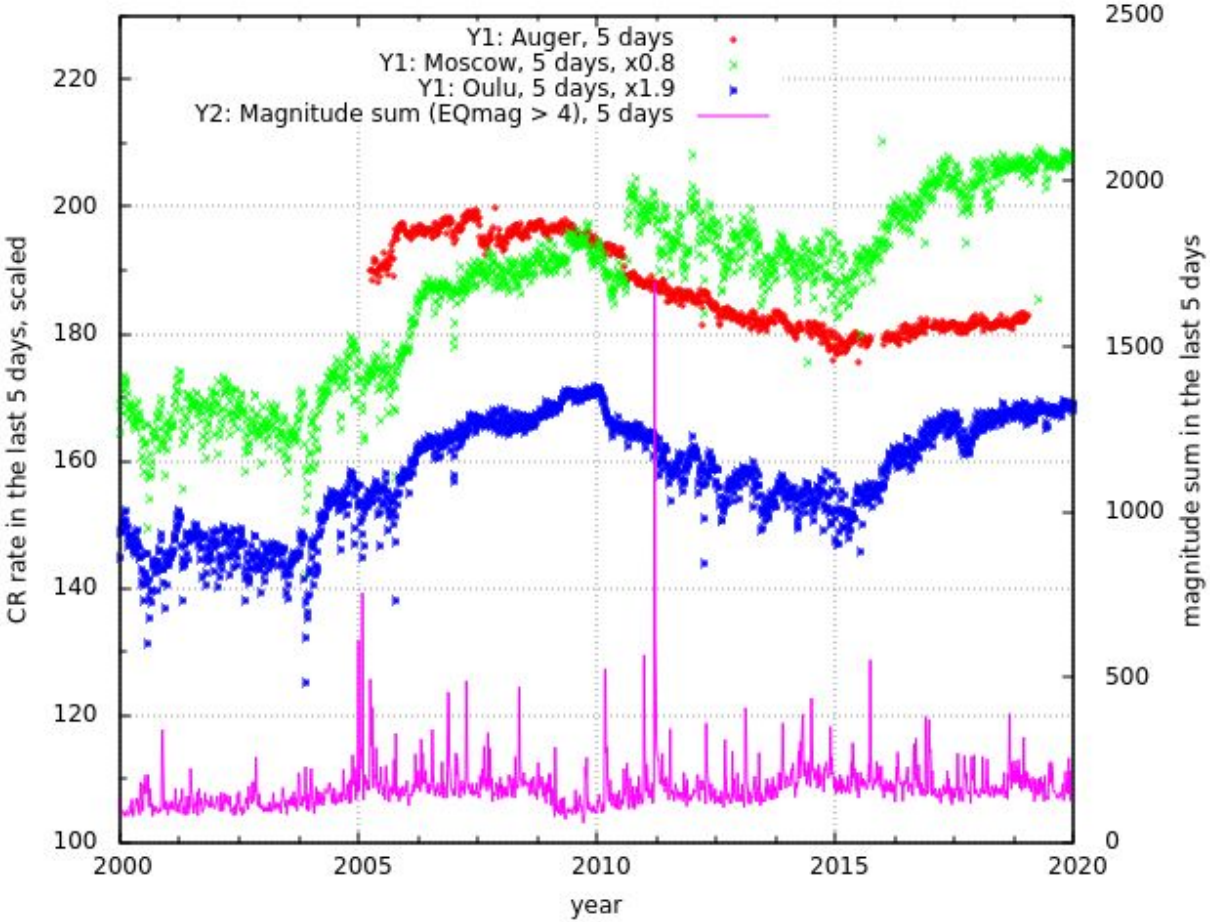
Observation of cosmo-seismic correlations: discovery > 6 σ!

"Astroparticle Physics Amateur"!

The data



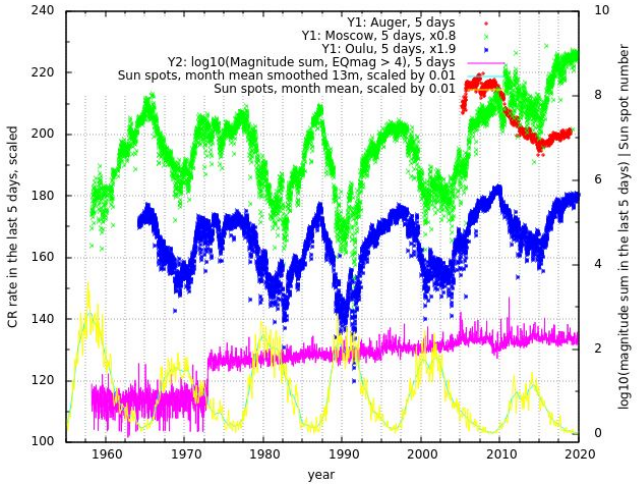
public resources of:

[Pierre Auger Observatory scaler data]

[Neutron Monitor Database]

[U.S. Geological Survey]

[Solar Influences Data analysis Center]

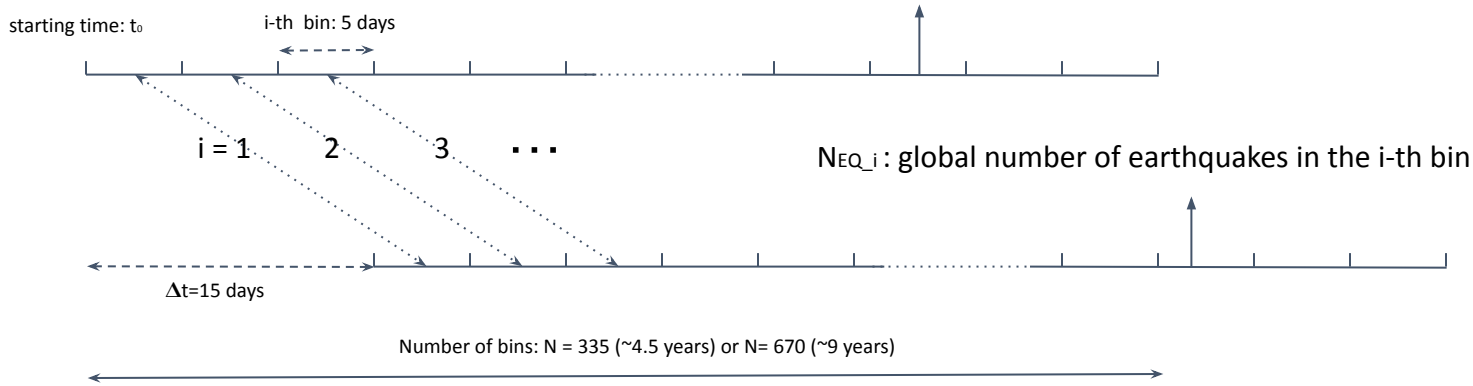


Checking for a correlation $|dN_{CR}|$ vs. $\Sigma magnitude_{EQ}$ using **5-day bins** over ~**4.5 yr windows**

Dichotomic correlation

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

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



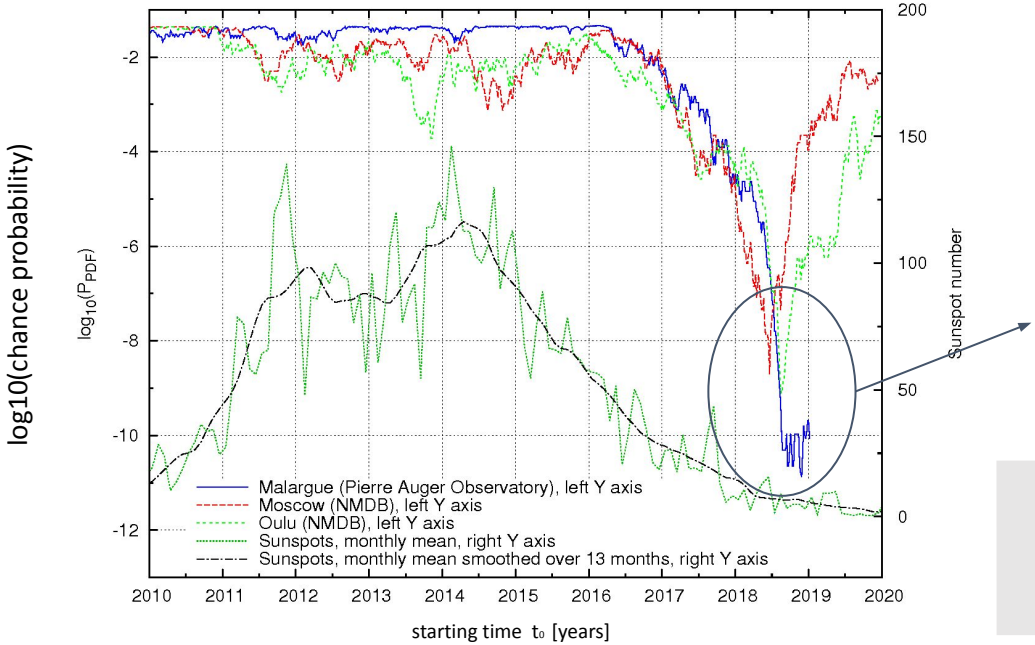
N_{EQ_i} : global number of earthquakes in the i-th bin

M_{CR}: median of the CR data
M_{EQ}: median of the EQ data
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 ($N_{EQ\_i} > M_{EQ}$))

Chance probability:

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

Local cosmic dynamics vs. global seismicity: dependence on geographical location?



different cosmic ray sites see the **dichotomic** correlation effect differently? Need for more detectors?

analysis performed on "burning" data sample!

~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.

Cosmic ray variation 15 days before the corresponding change in seismic activity!

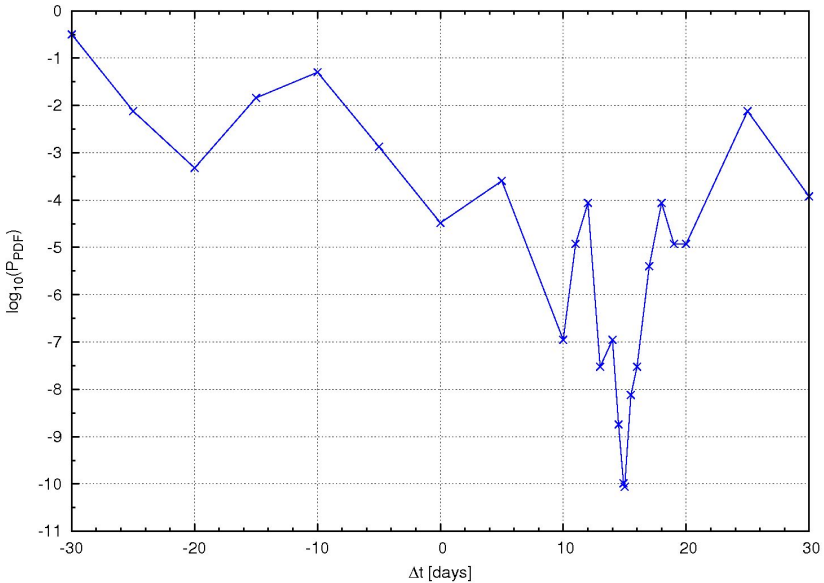
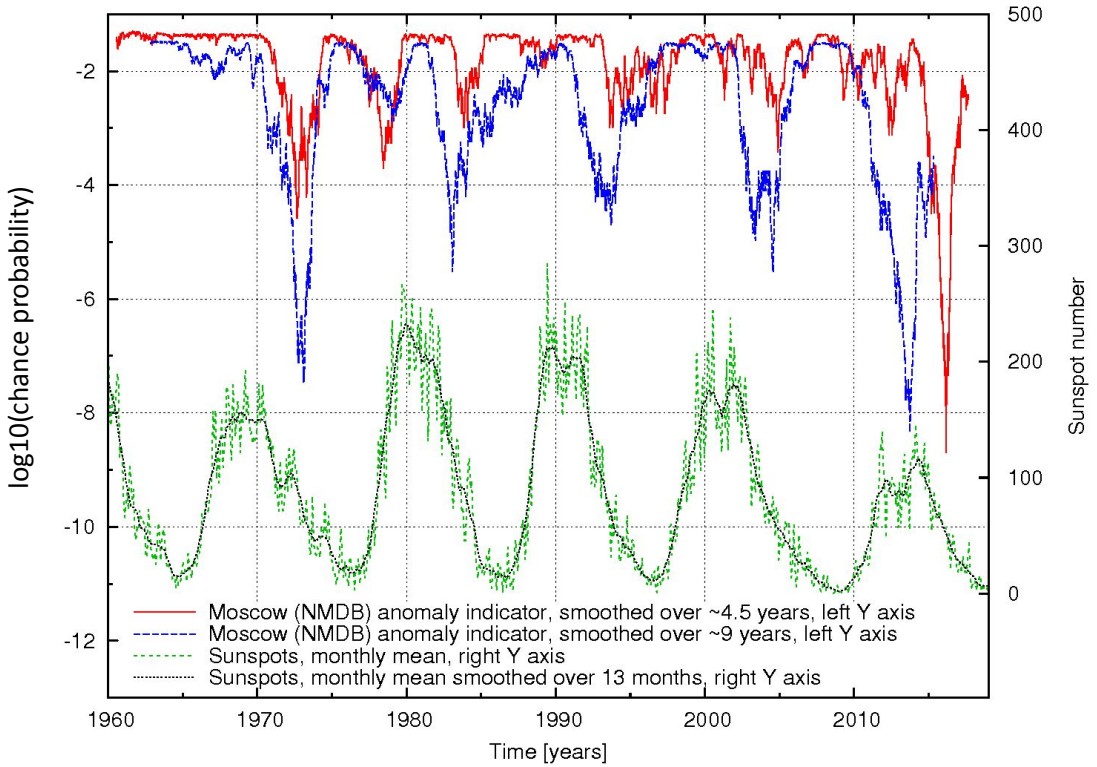


Fig. 3: The dependence of the significance of the *cosmo-seismic* correlations on the time shift t of the EQ data with respect to the Auger CR data, for the optimum free parameter set defined in Eq. 1. The positive or negative values of t correspond to the situations in which one compares the secondary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

Interpretation: Role of the Sun or….?

P. Homola et al., 2022: https://arxiv.org/abs/2204.12310



The anomaly indicator in the Moscow NMDB data set compared to the sunspot number. Each point on the correlation significance curves corresponds to the effect found over the smoothing window length of **~4.5 years (1675 days, in red)** and ~9 years (3350 days, in blue), with the curve points located at the centers of the windows.

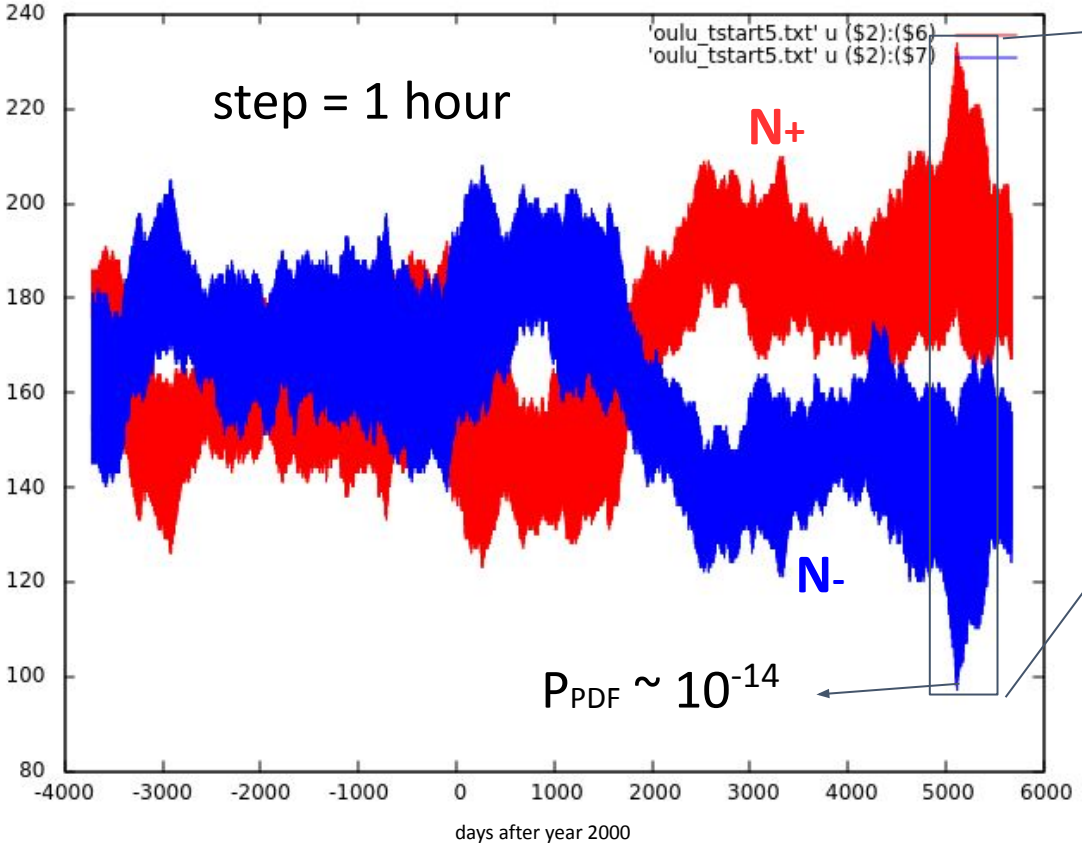
The key “peculiar” properties of the cosmo-seismic effect

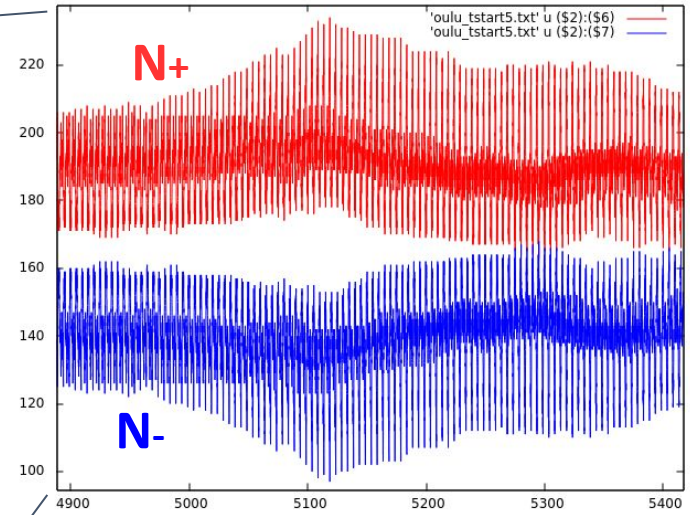
1. to sensitivity -> common periodicities & specific signal shape
2. dominant 24 h periodicity in EQs varying in time -> new EQ mechanism, Sun engaged magnetically!
3. EQs and non-tidal role of the Moon -> implies “third factor” active gravitationally
4. sidereal day periodicity in both EQ and CR data varying in time -> external stream + sensitivity to local conditions (or variations of the “third factor”?)
5. hemispherical / semiday EQ differences: external impact?
6. a special EQ week of the year at ~mid November: a specific external arrival direction?
7. radiation precedes earthquakes: a slower than light “third factor” capable of inducing radiation?

-> **charged dark matter stream** as the leading (only?) candidate physic scenario?

1. Sensitivity to very small t_0 shifts: a uniquely characteristic signal behind?

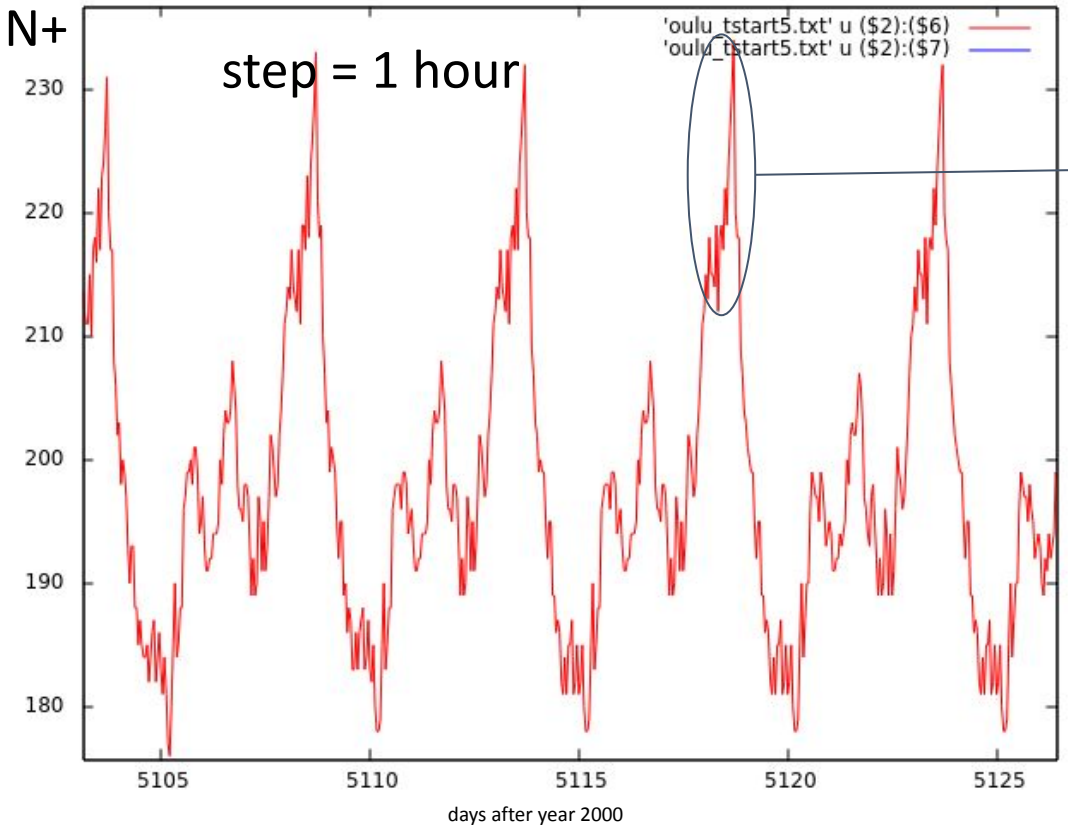
Sensitivity to very small to shifts

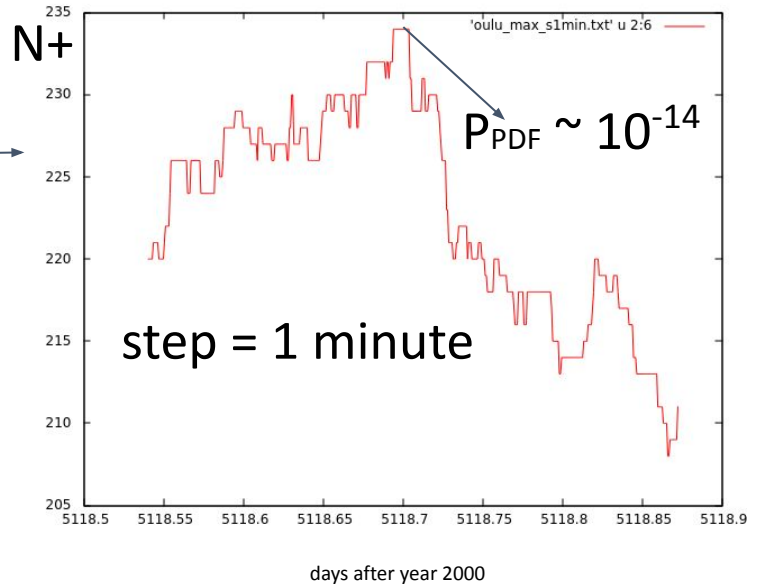




Oulu; CR data bins: 6hrs,
cosmo-seismic bin: f x 5 days;
f=0.999915

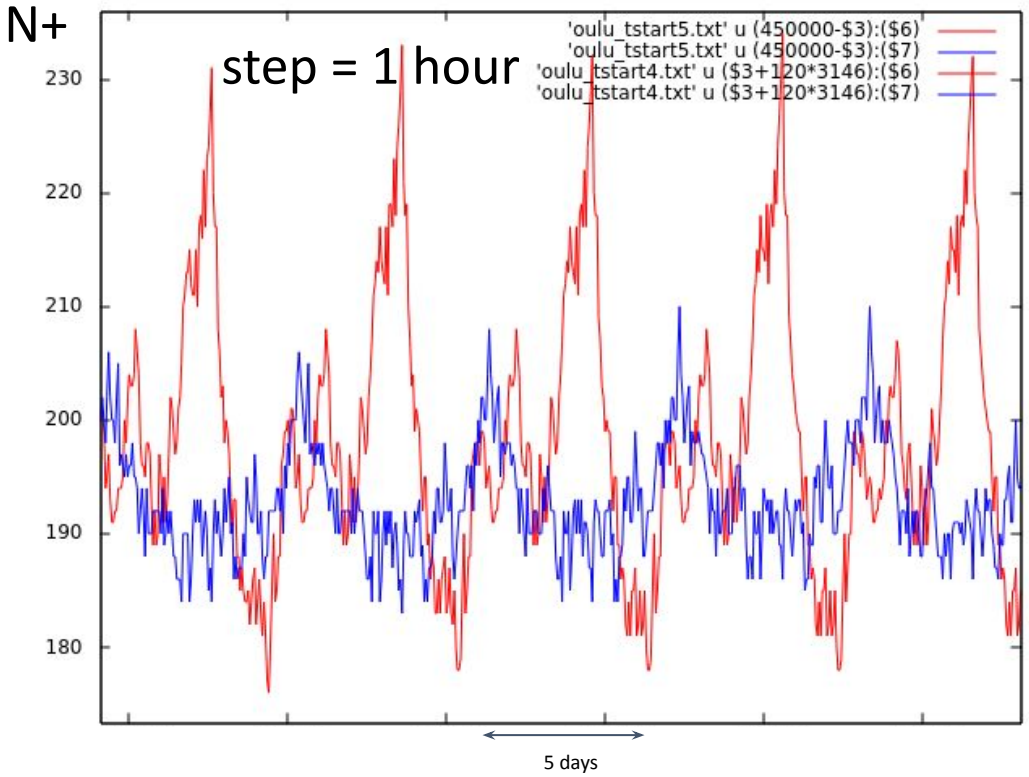
Sensitivity to very small t0 shifts





Oulu; CR data bins: 6hrs,
cosmo-seismic bin: f x 5 days;
f=0.999915
(similar for other sites and f=1.0)

Sensitivity to very small t_0 shifts



red: t_0=~2014

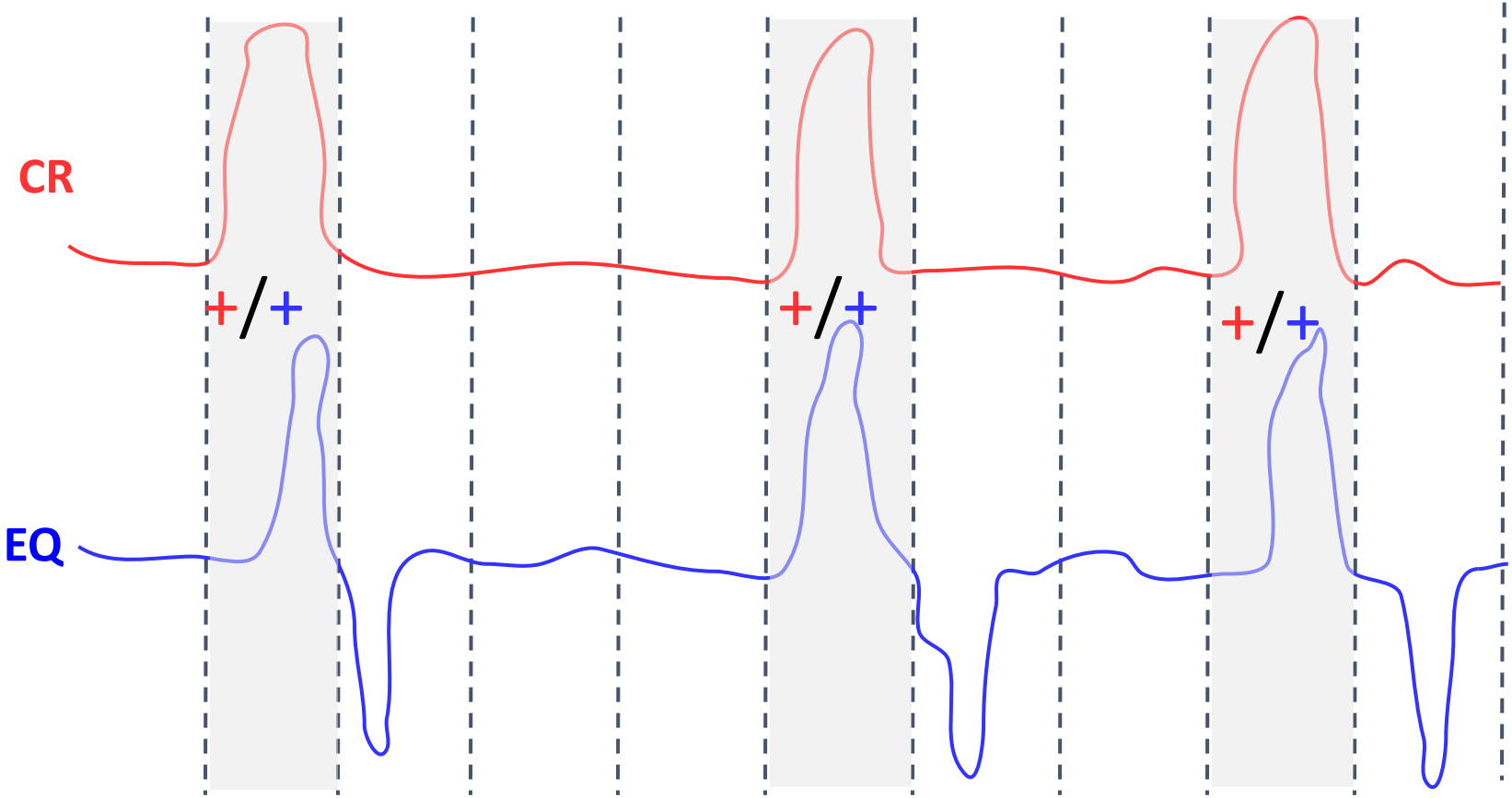
blue: t_0=~2006

-> optimum t_0 evolves in time!

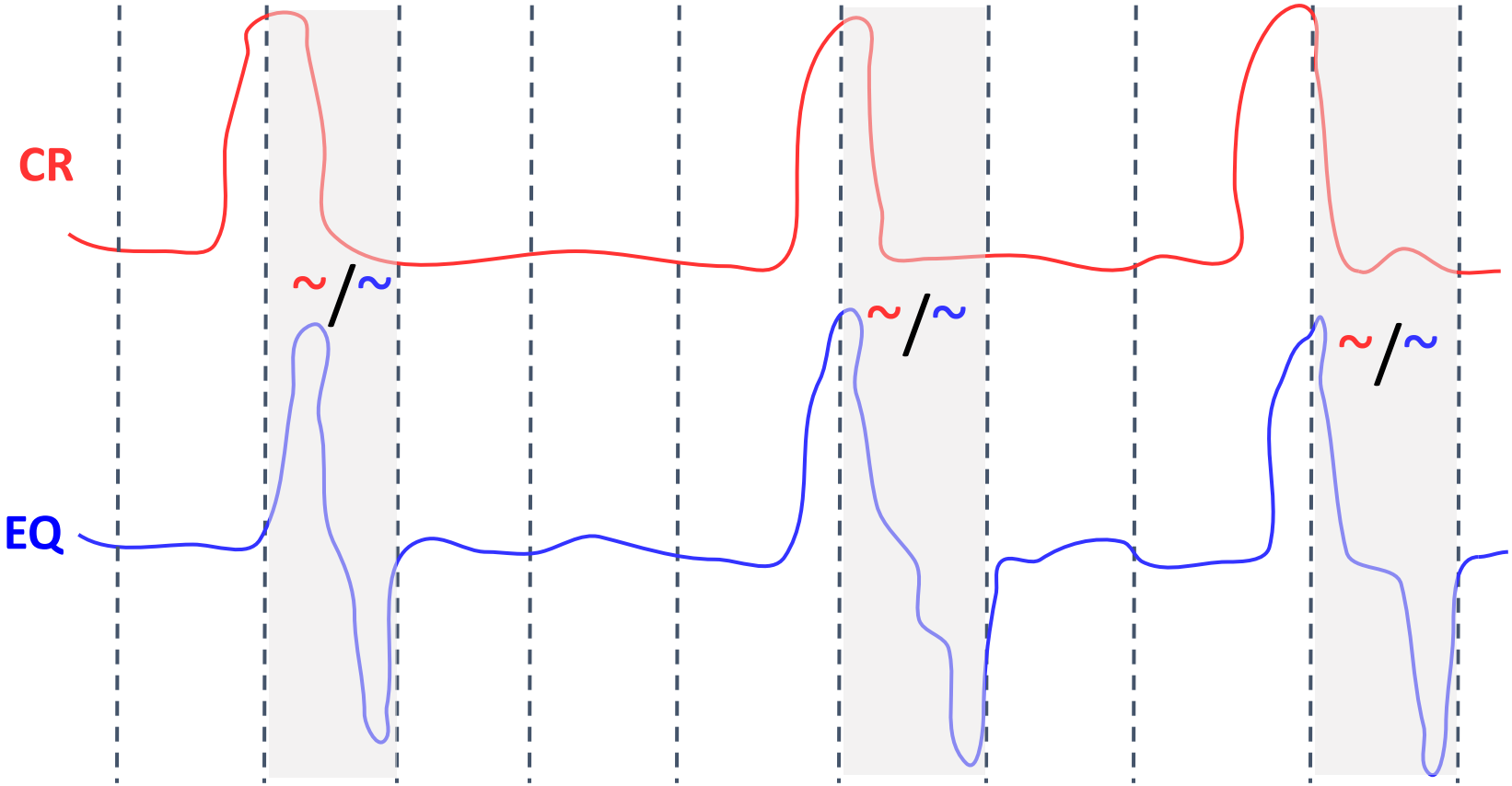
-> EQ data responsible for the t_0 fine tuning effect?

Oulu; CR data bins: 6hrs,
cosmo-seismic bin: f x 5 days;
f=0.999915

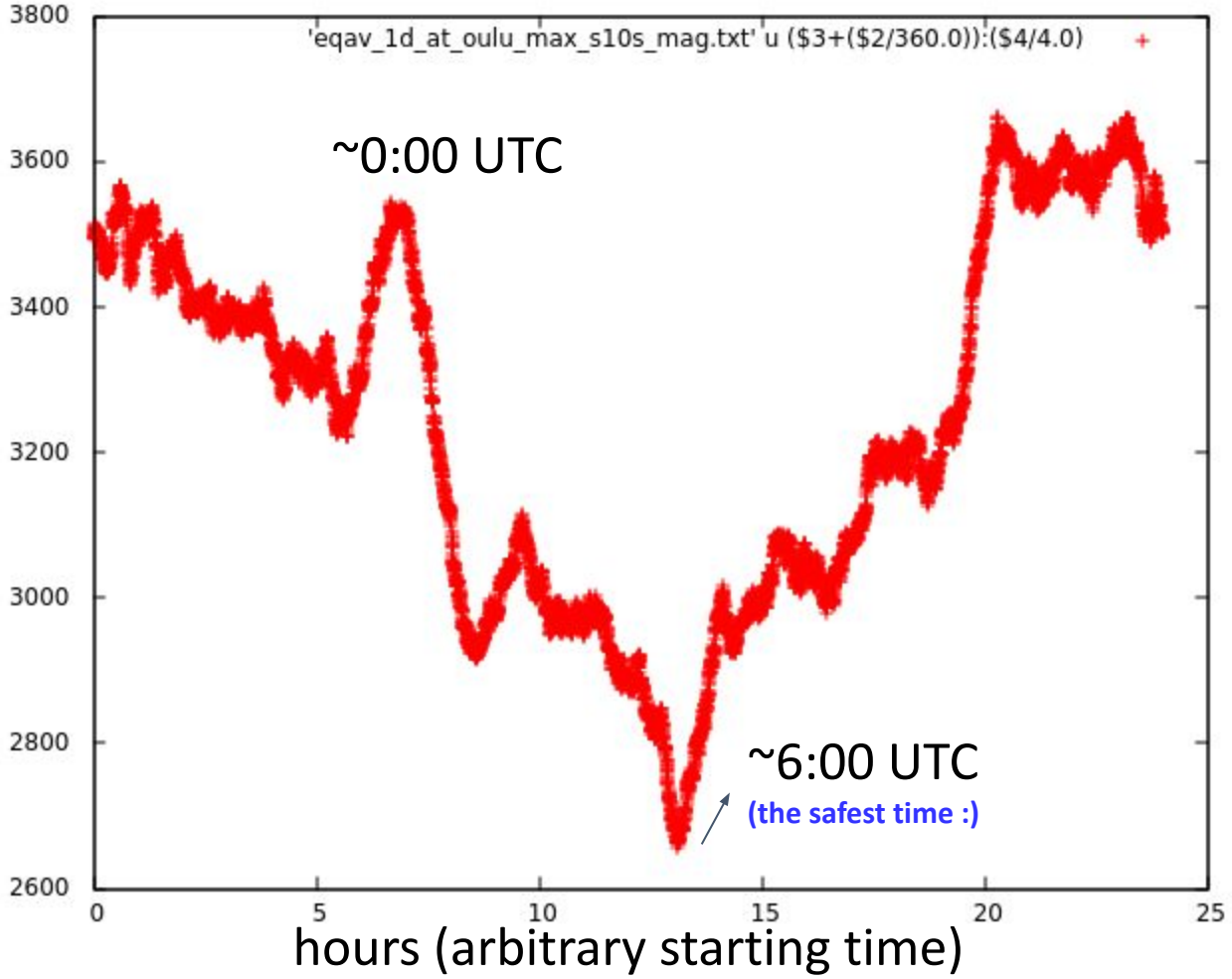
“clicks” @ many points with just a small t0 shift?



“clicks” @ many points with just a small t0 shift?



2. Dominant, time-dependent 24 hour periodicity in the EQ data: new EQ mechanism?

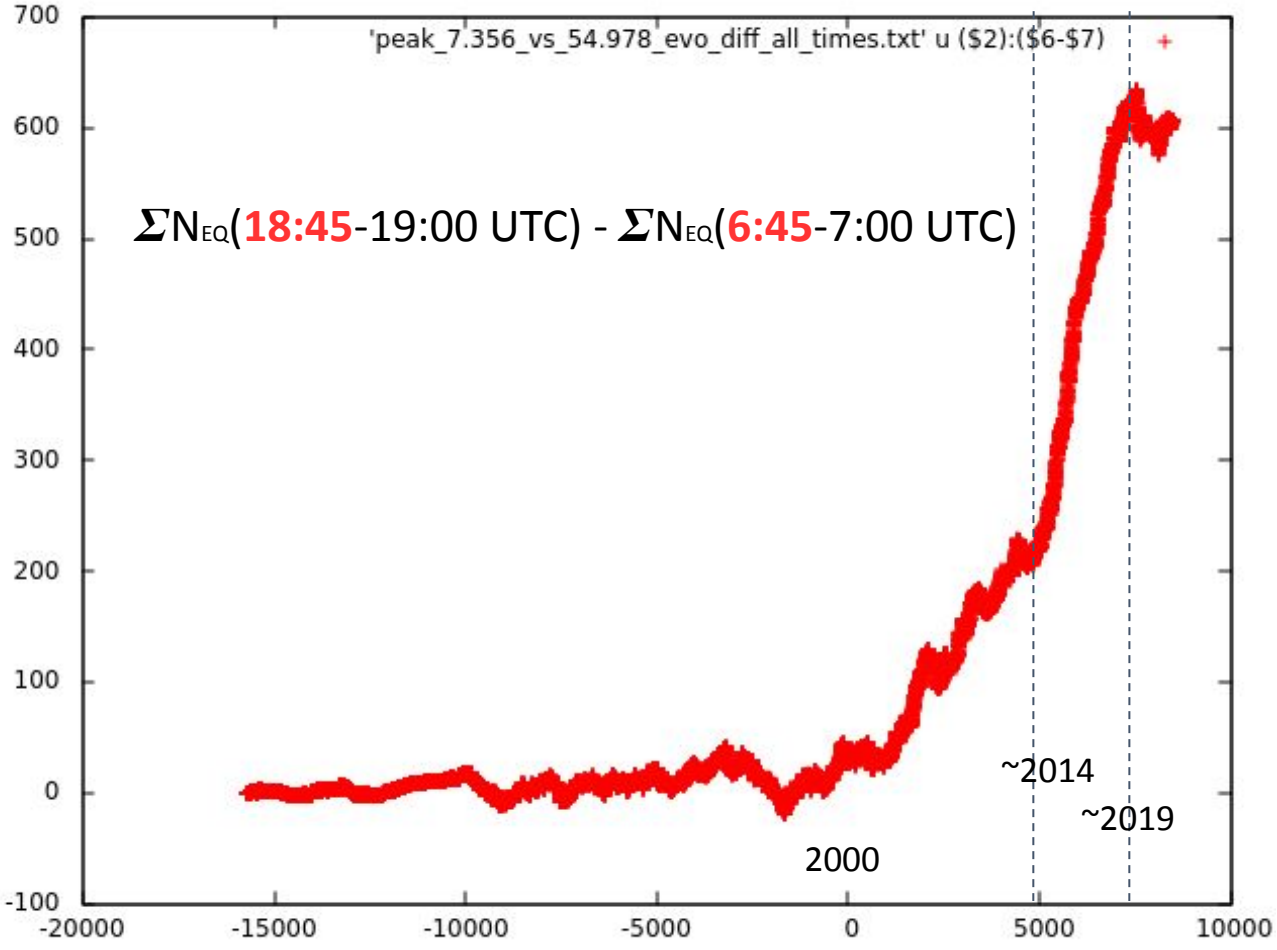


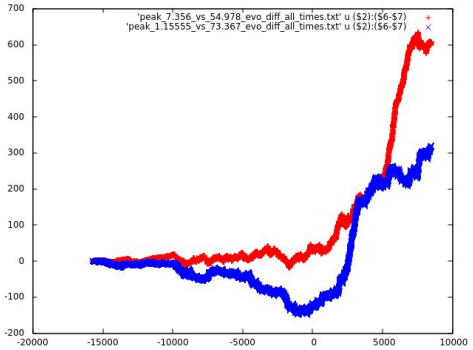
24 hour stacked N_{EQ}

- 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**

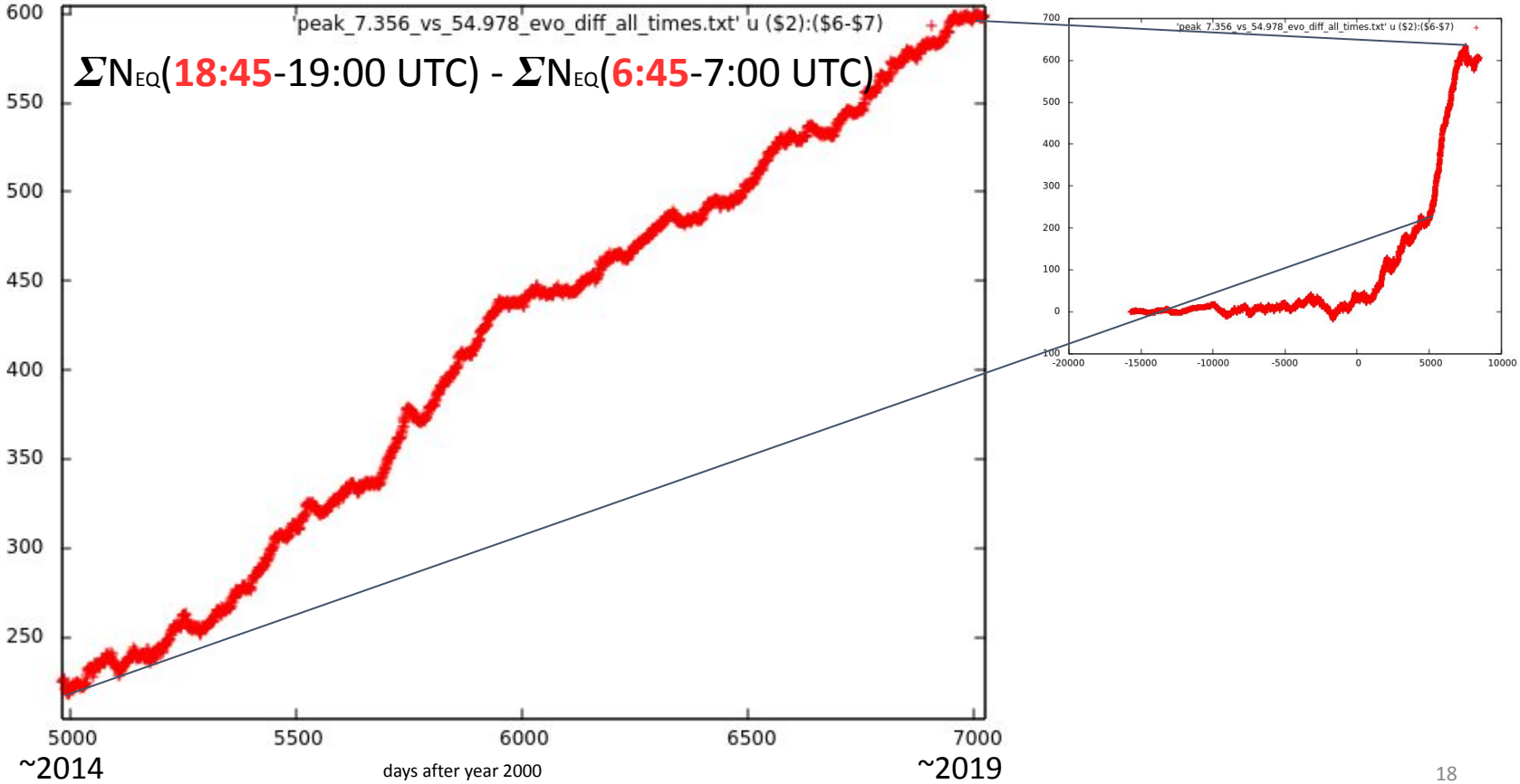


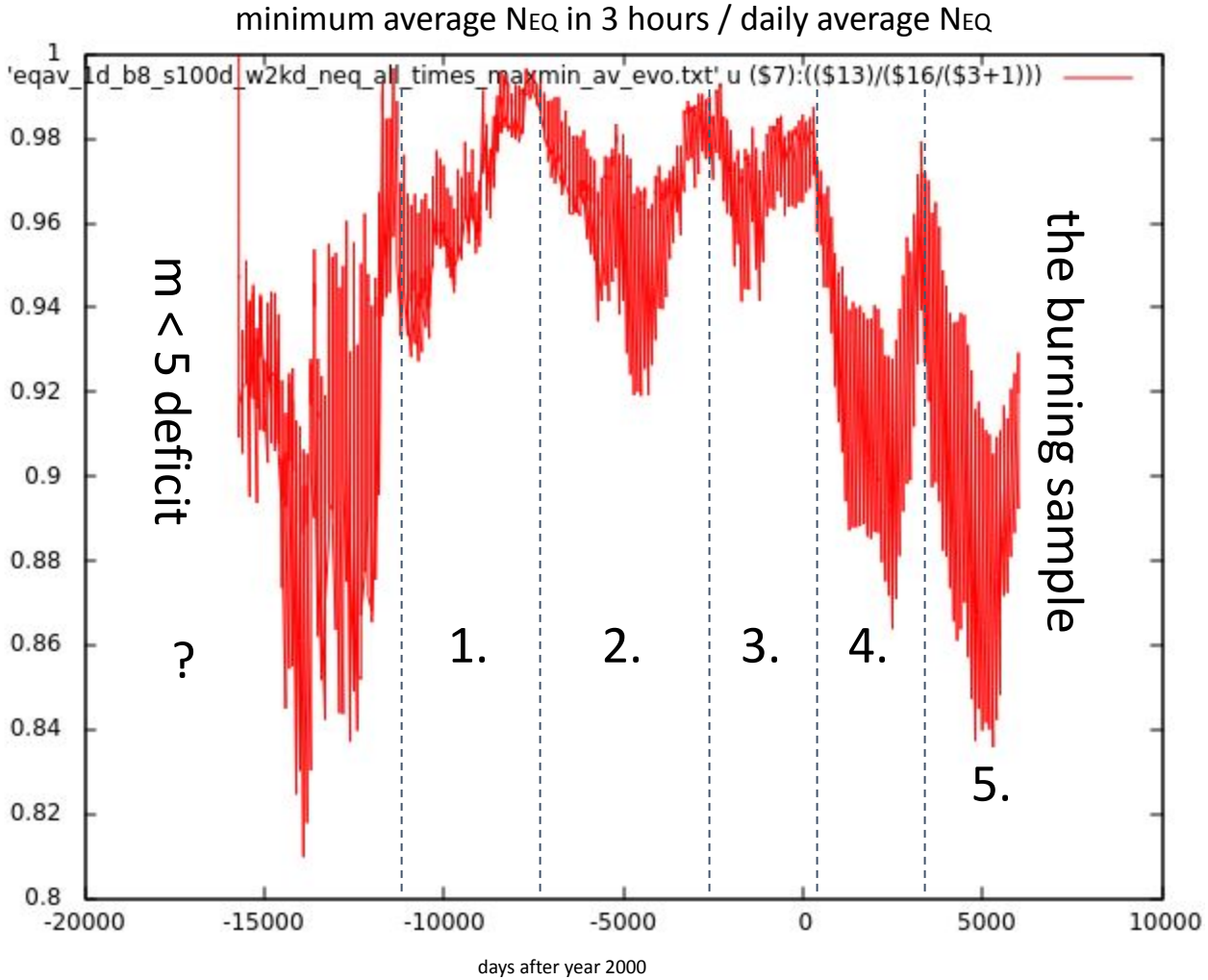


-> **"dramatic" 5 years** of increasing daily asymmetry for special time bins

-> **different bins: different time evolution** & "dramatic" time

~ uniform daily N_{EQ} asymmetry increase during the “dramatic” time





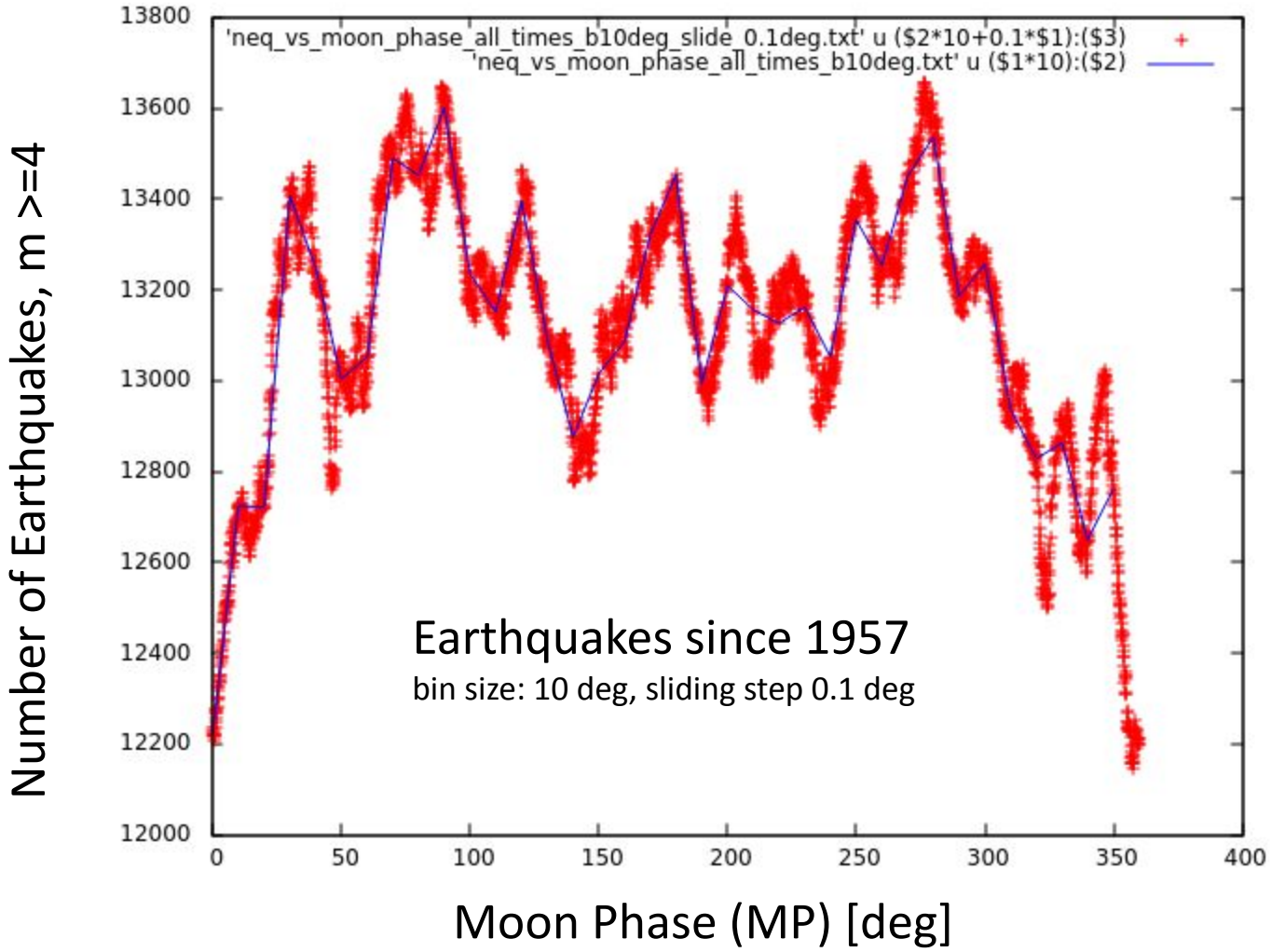
24 hour asymmetry of N_{EQ} evolves with time!

average 3 h bins.
averaged over time window of:
~2000 days
sliding step: 100 days

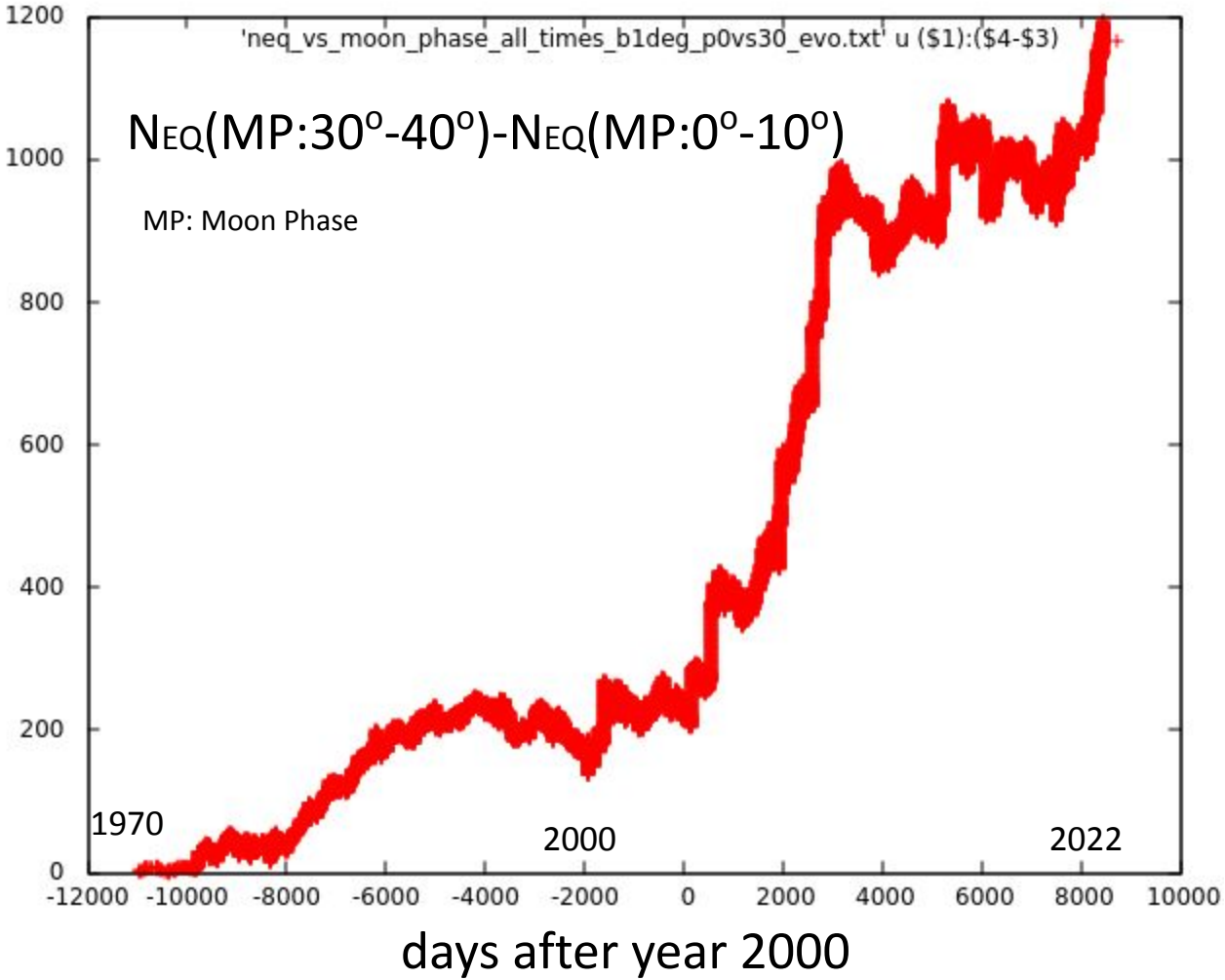
-> **different "eras" of 24h asymmetry?**
-> like Fig 4 (cosmo-seismic article)

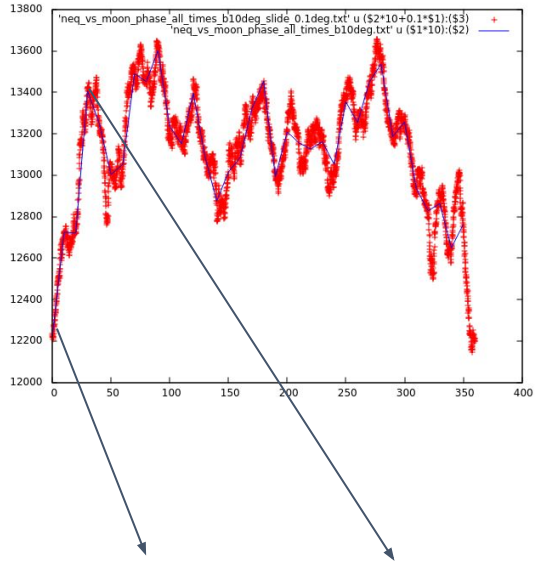
-> **variations of the "third factor" or its sensitivity to magnetism**

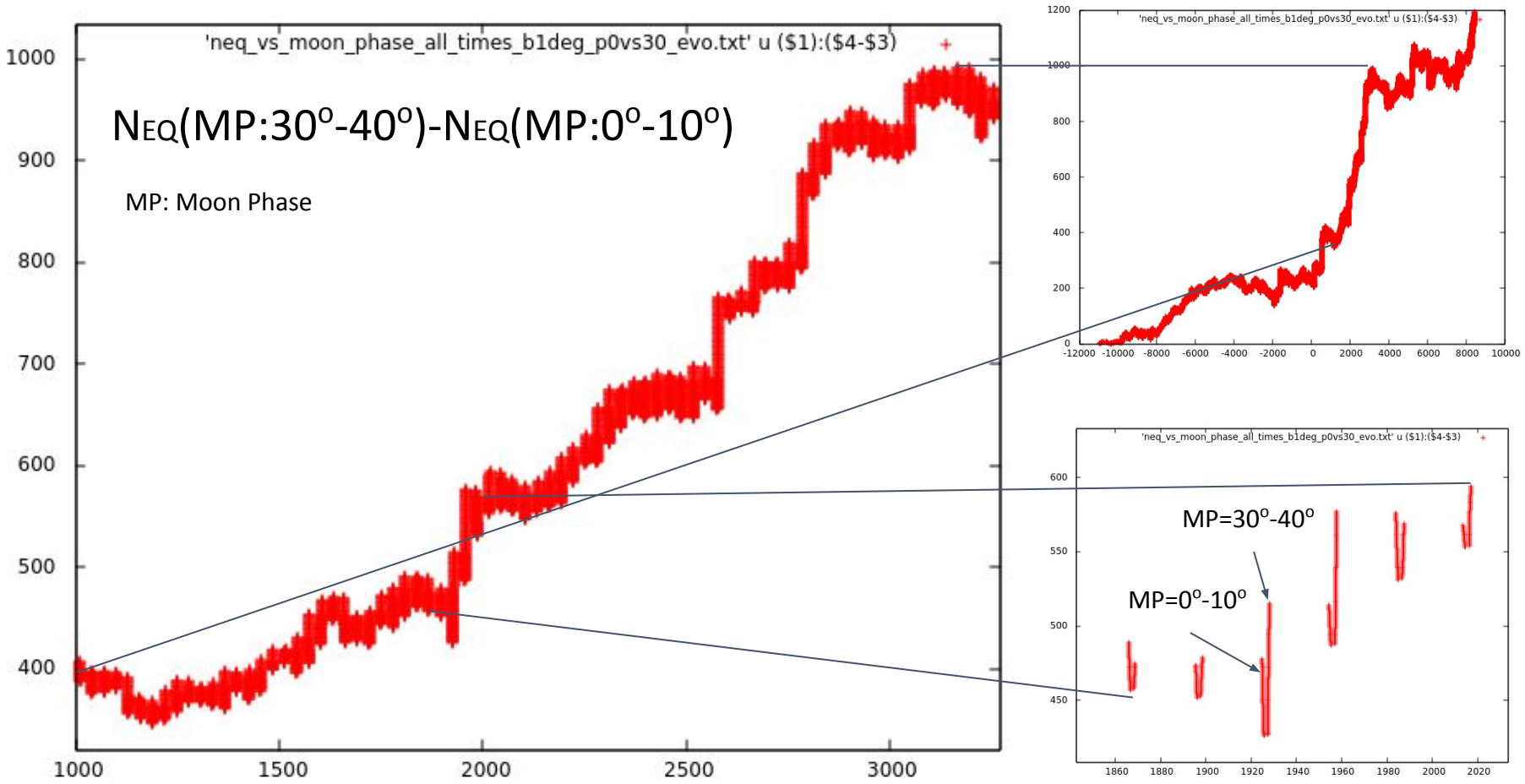
3. Non-tidal role of the Moon in triggering earthquakes? -> “third factor” active gravitationally



clear minimum @ New Moon??


'neq_vs_moon_phase_all_times_b1deg_p0vs30_evo.txt' u ($1):($4-$3)
NEQ(MP:30°-40°)-NEQ(MP:0°-10°)
MP: Moon Phase
1970
2000
2022
days after year 2000

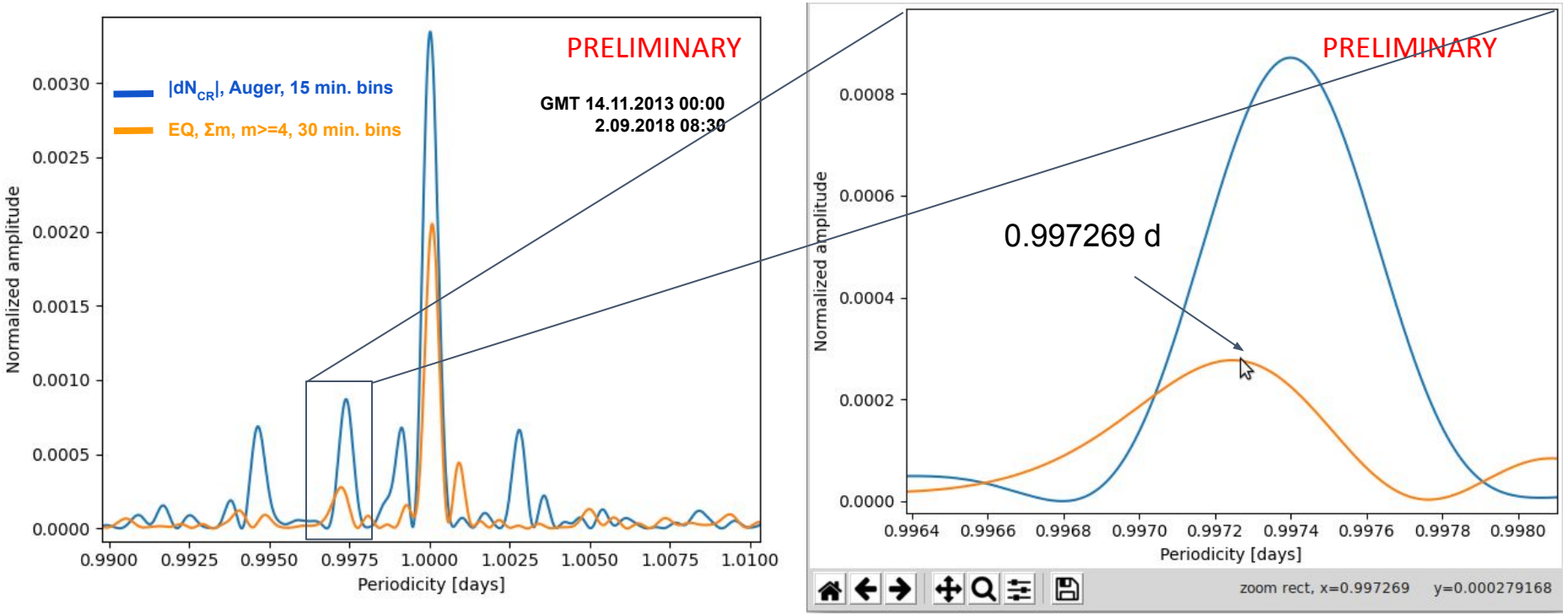

'neq_vs_moon_phase_all_times_b10deg_slide_0.1deg.txt' u ($2*10+0.1*$1):($3)
'neq_vs_moon_phase_all_times_b10deg.txt' u ($1*10):($2)
MP: 0°-10°
30°-40°


'neq_vs_moon_phase_all_times_b1deg_p0vs30_evo.txt' u ($1):($4-$3)
NEQ(MP:30°-40°)-NEQ(MP:0°-10°)
MP: Moon Phase
MP=30°-40°
MP=0°-10°
days after year 2000

4. time dependent sidereal day periodicity in both EQ and CR data -> exosolar origin of the “third factor” + its inherent variations or sensitivity to local conditions

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

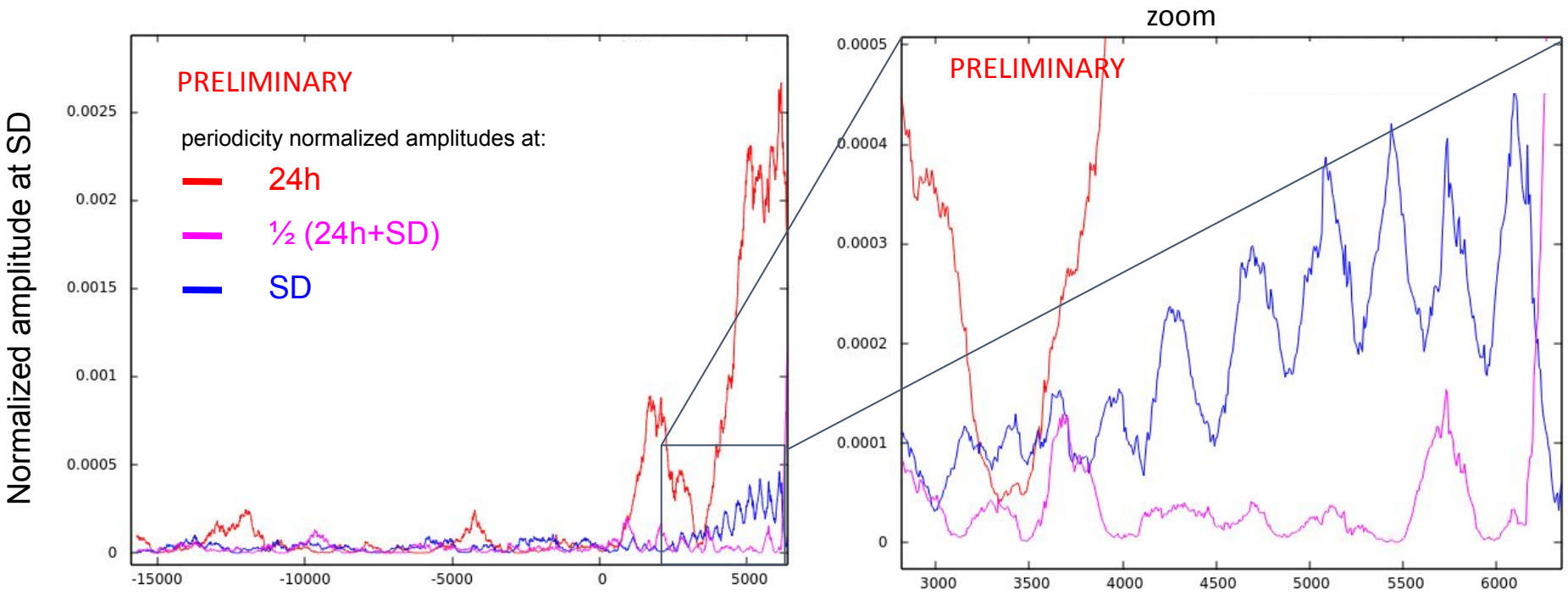
1 sidereal day = 23.9344696 hours -> 0.997269567 day; Lomb-Scargle periodograms



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”?

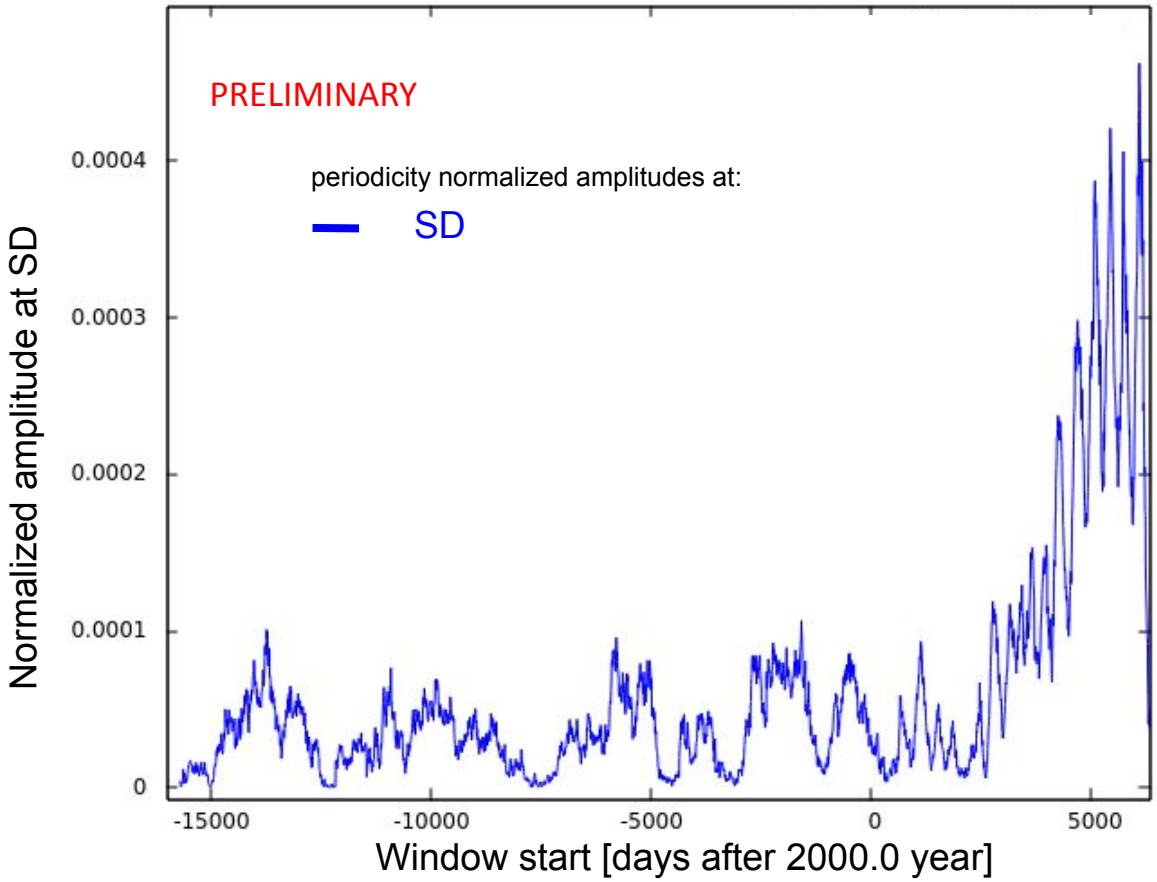
Time evolution of the 24h & sidereal day (SD) periodicities:

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



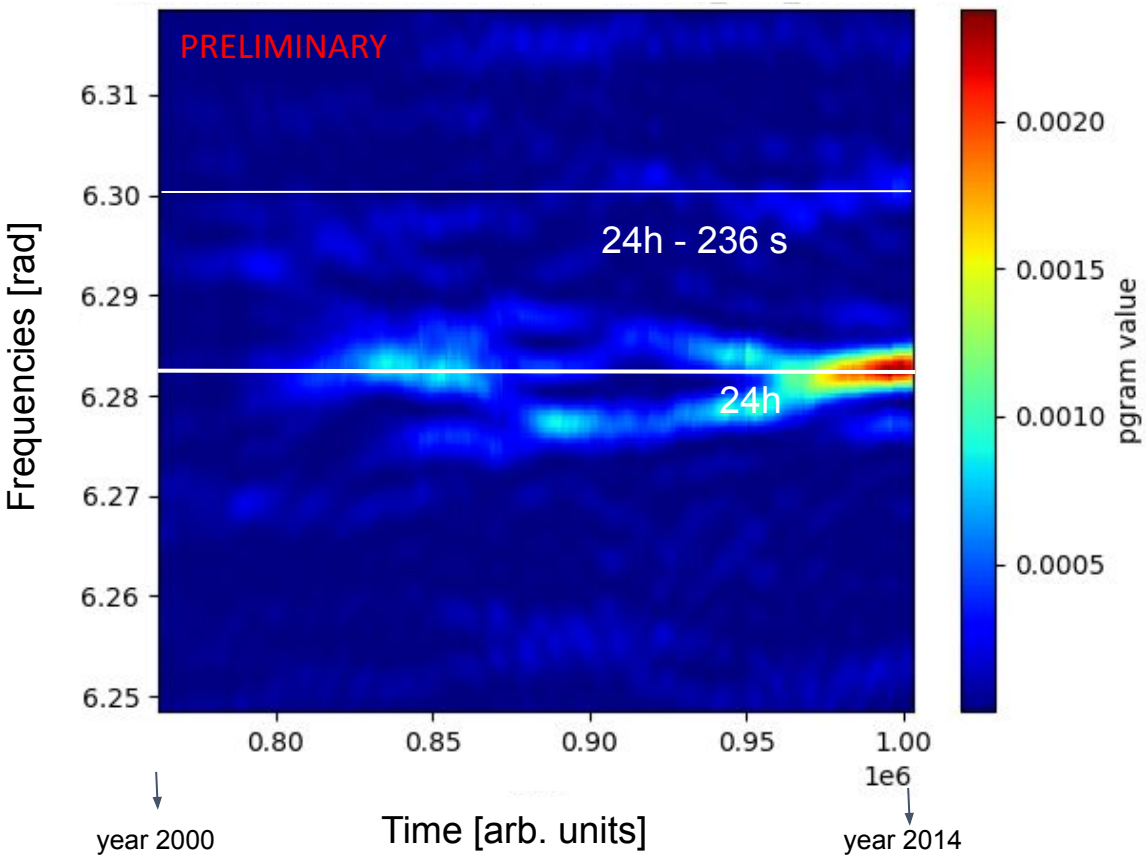
First fits (credit Maria Pycior):

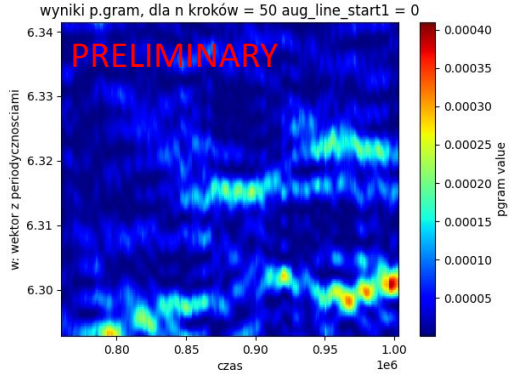
- ~390 d of the right part
- ~11 y of the left

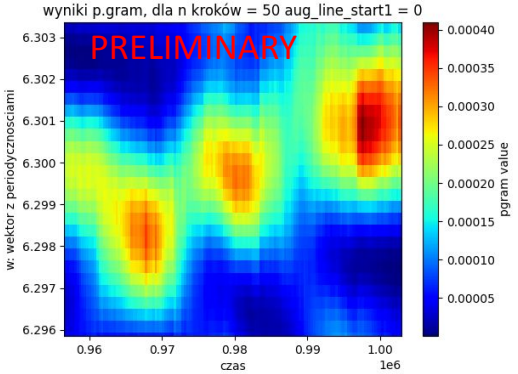
398.85d: period of the Earth & Jupiter synod

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





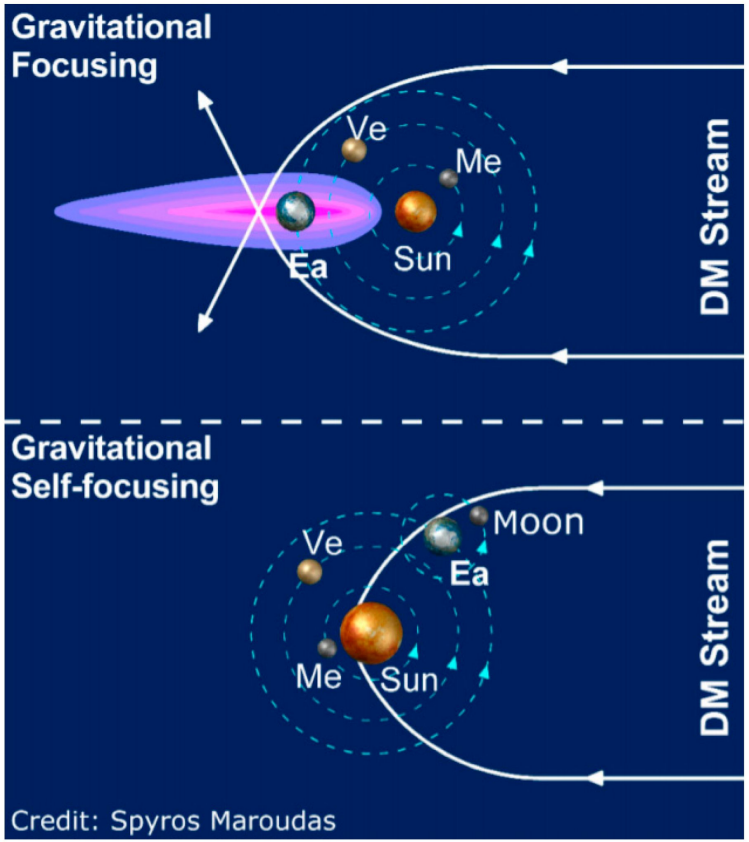


Literature Support

- DM streams + focusing ~orders of magnitude
- super-heavy charged dark matter
- 24h Japan: “new EQ mechanism”, 2018
- spaceweather @ Radon (credit Brian)
- books: heliospheric current sheet, rotation of the Sun

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



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

30

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]

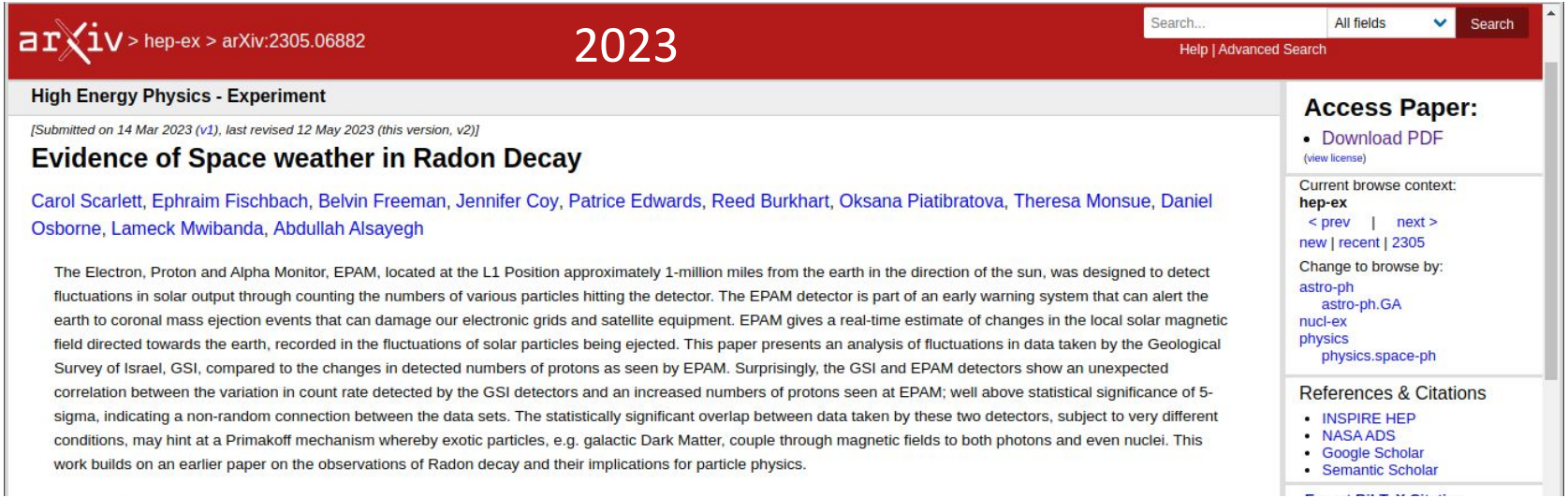
[1]*Faculty of Physics, University of Warsaw Pasteura 5, 02-093 Warsaw, Poland*
[2]*Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut) Mühlenberg 1, D-14476 Potsdam, Germany*

(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

- INSPIRE HEP
- 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

credit to Brian McBreen for pointing to the article

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**."

Heliospheric Current Sheet (- like?) behavior?

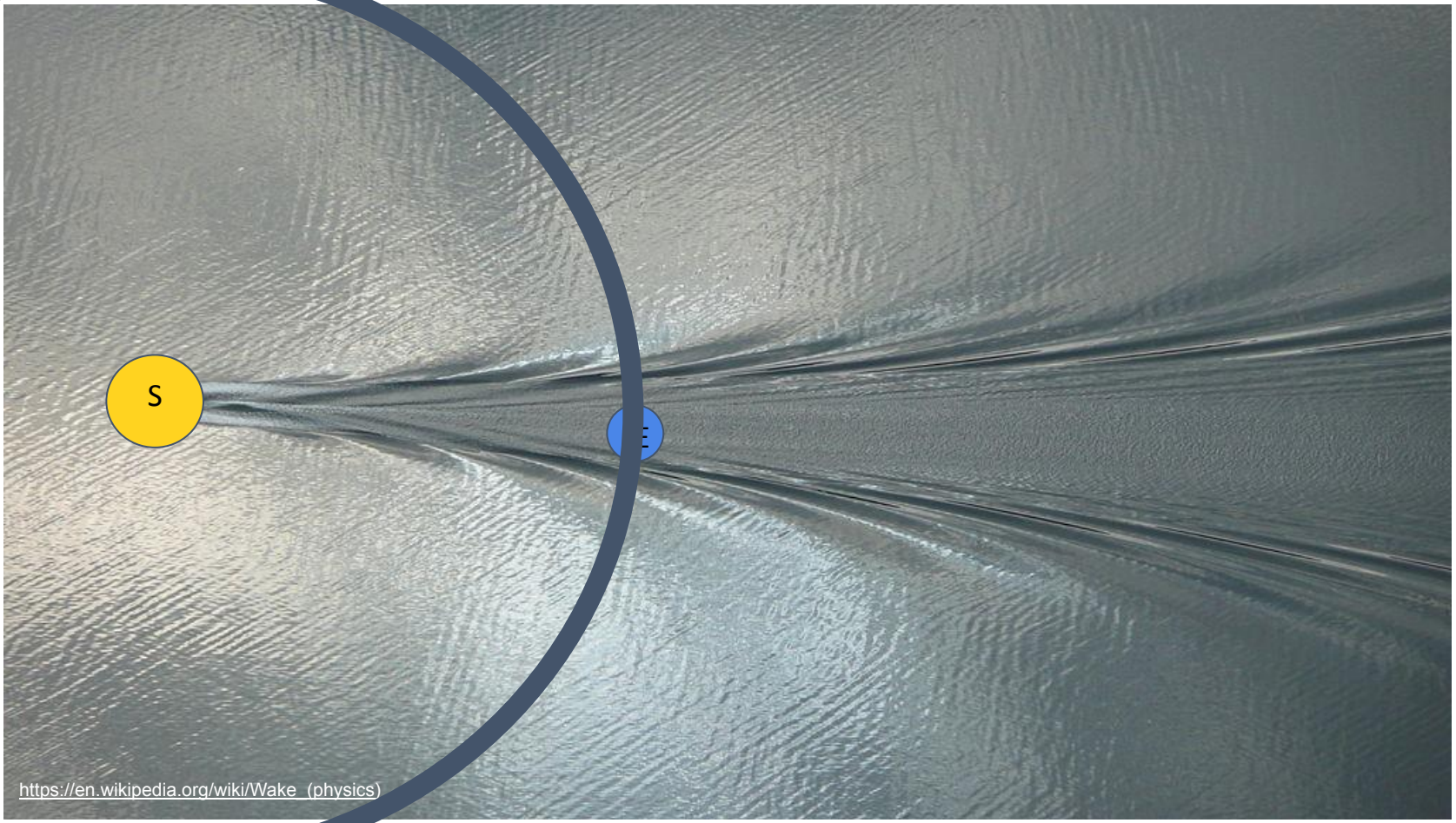
~10000 km thickness

~heavier particles required?

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

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

… or Dark Fluid -> dark wake(s)?

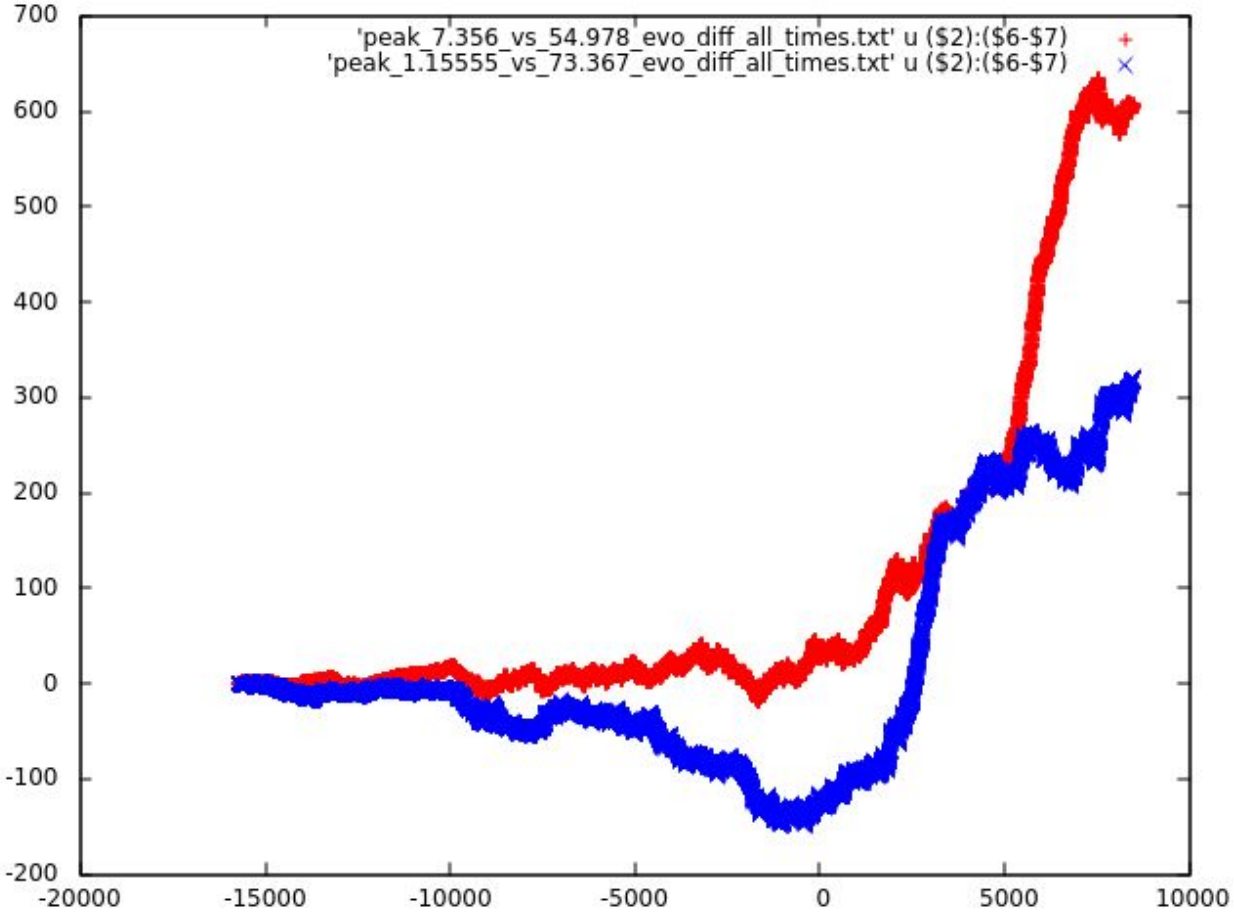


https://en.wikipedia.org/wiki/Wake_(physics)

Observable charged dark matter stream around?

- foundations of physics!
- predicting some earthquakes by monitoring cosmic ray sources moving within the Solar System!
- revisiting climate change models by considering the new external factor!

BACKUP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200
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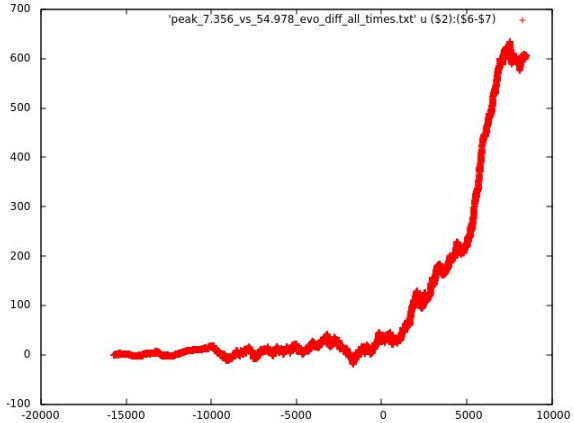
0
-100
-200
-20000
-15000
-10000
-5000
0
5000
10000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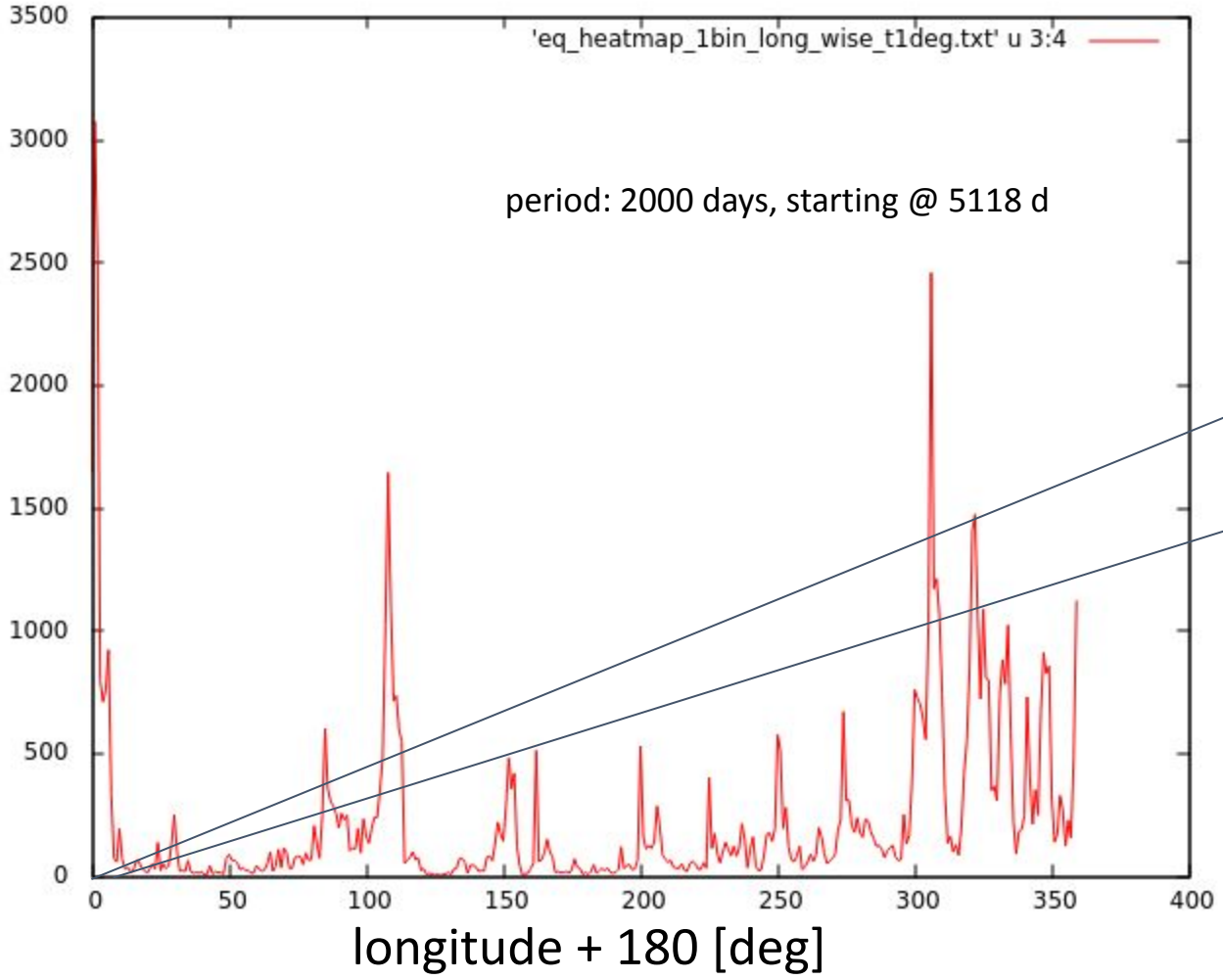
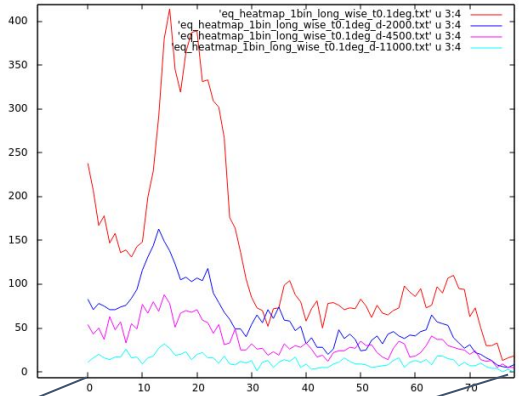
700
600
500
400
300
200
100
0
-100
-20000
-15000
-10000
-5000
0
5000
10000

5. hemispherical & semiday differences in EQ data: external impact?

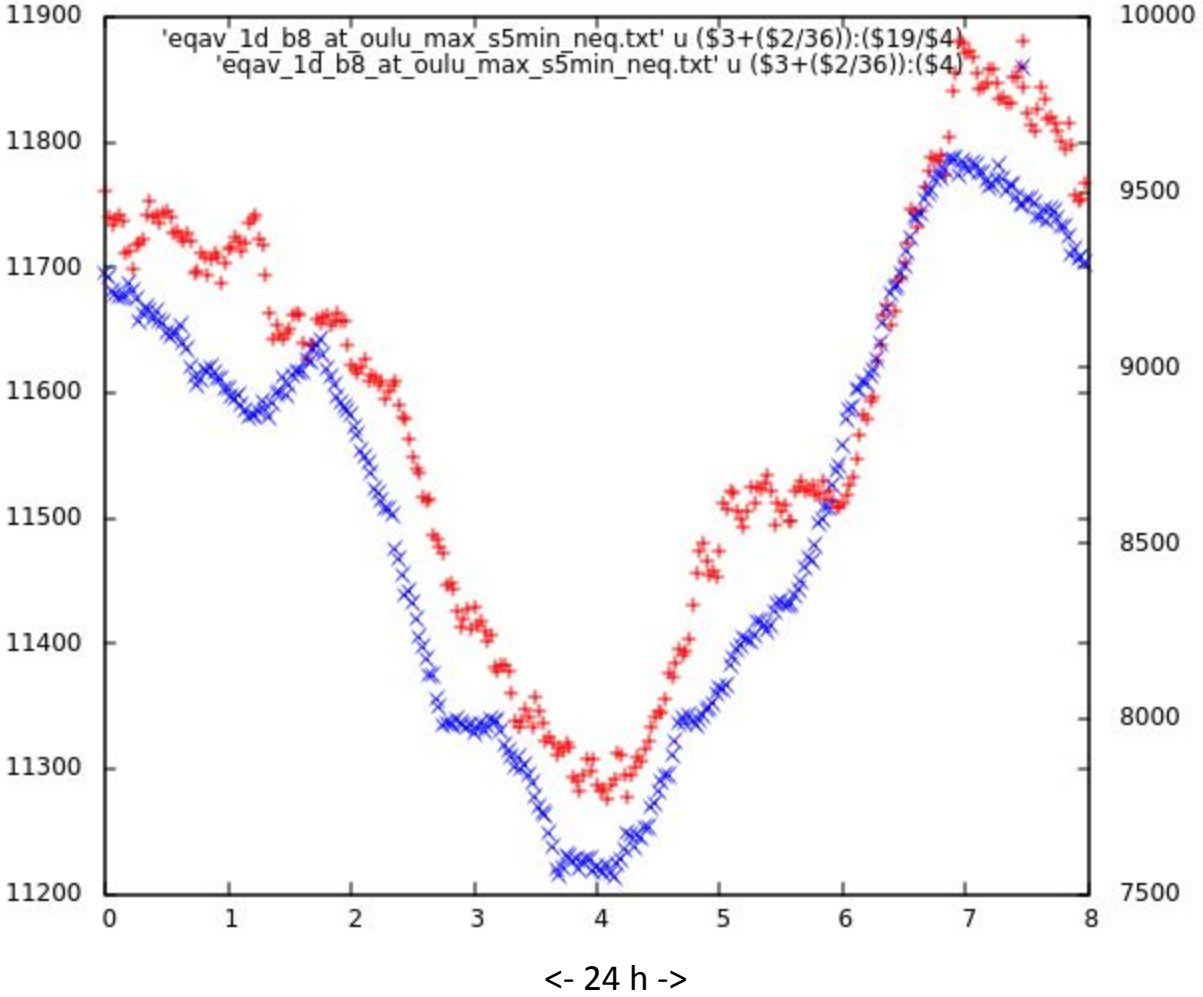


period: 2000 days, starting @ 5118 d



(longitude + 180 [deg])*10

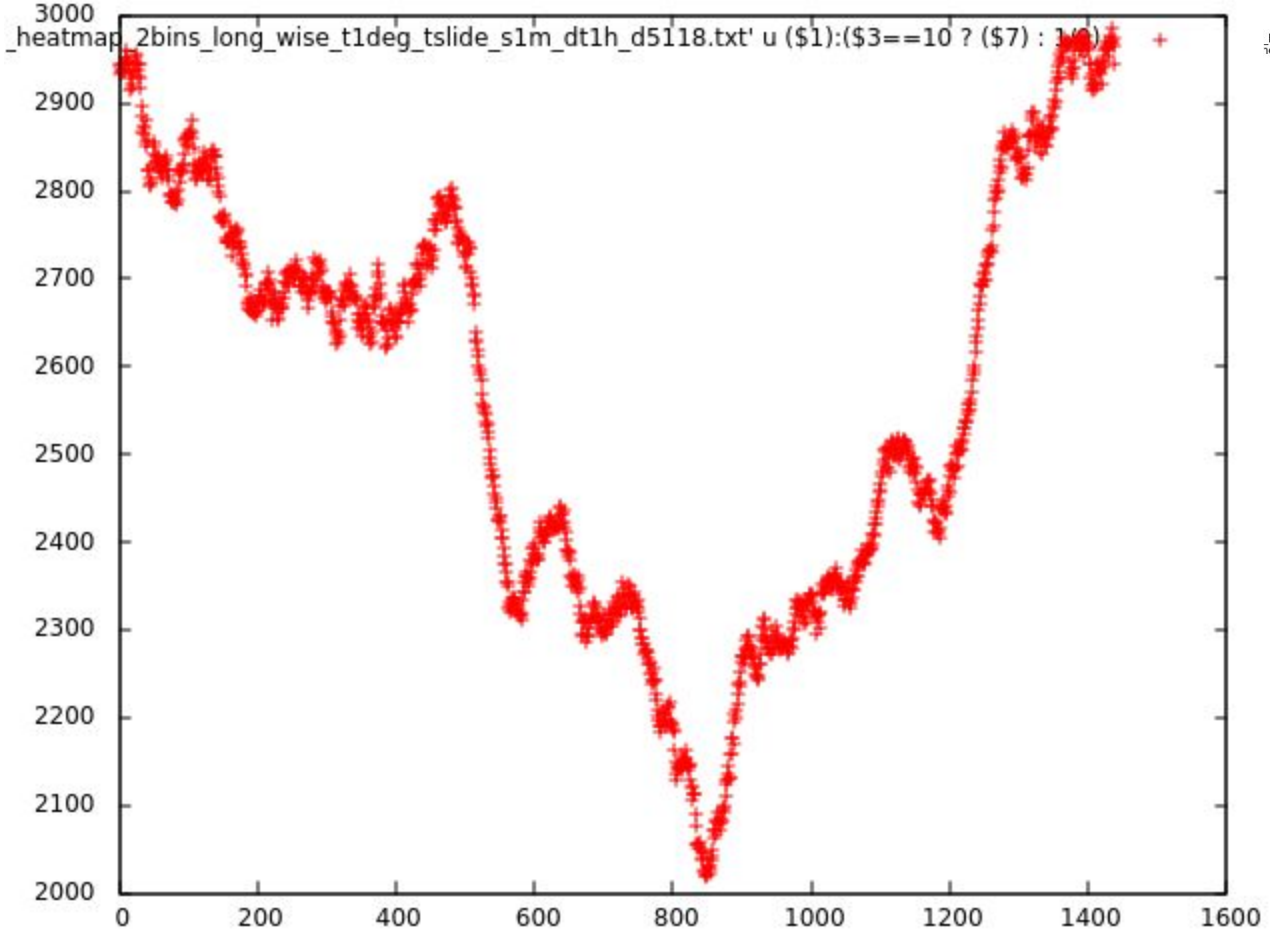
average EQ activity significantly changes with time!

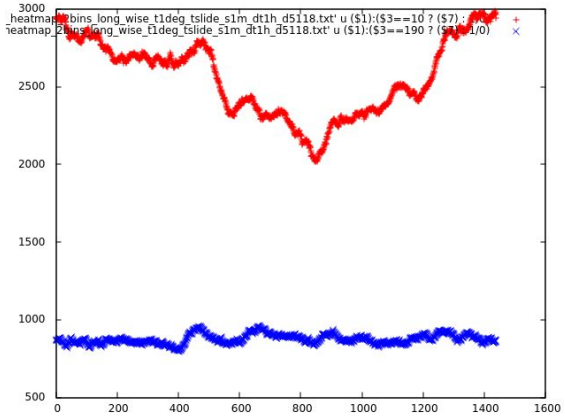


blue: N_{EQ}

red: <EQ distance from Auger>

N_{EQ} (t) connected to EQ locations?



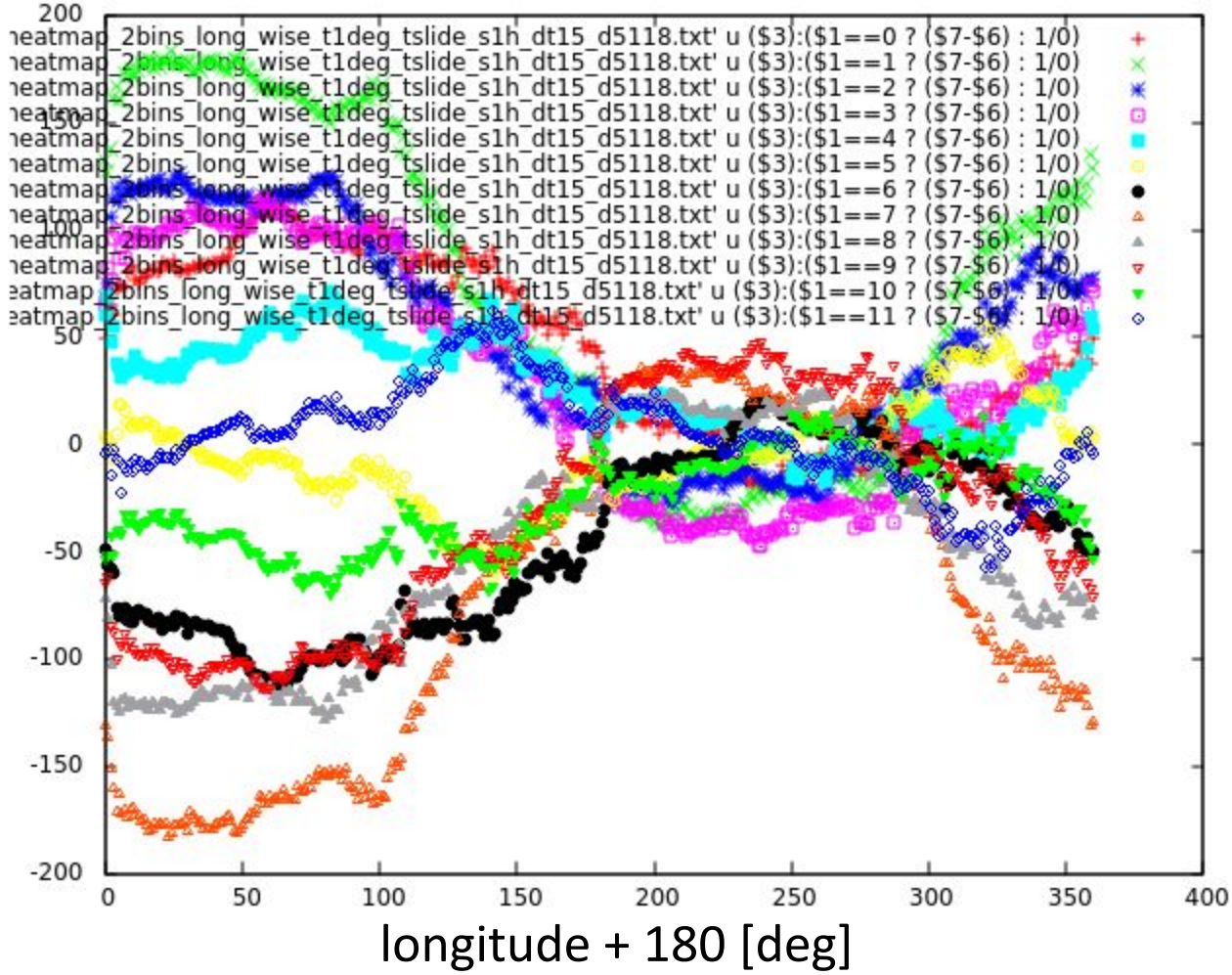


Daily NEQ asymmetry dictated by the most active regions:

long: 10°E - 170°W

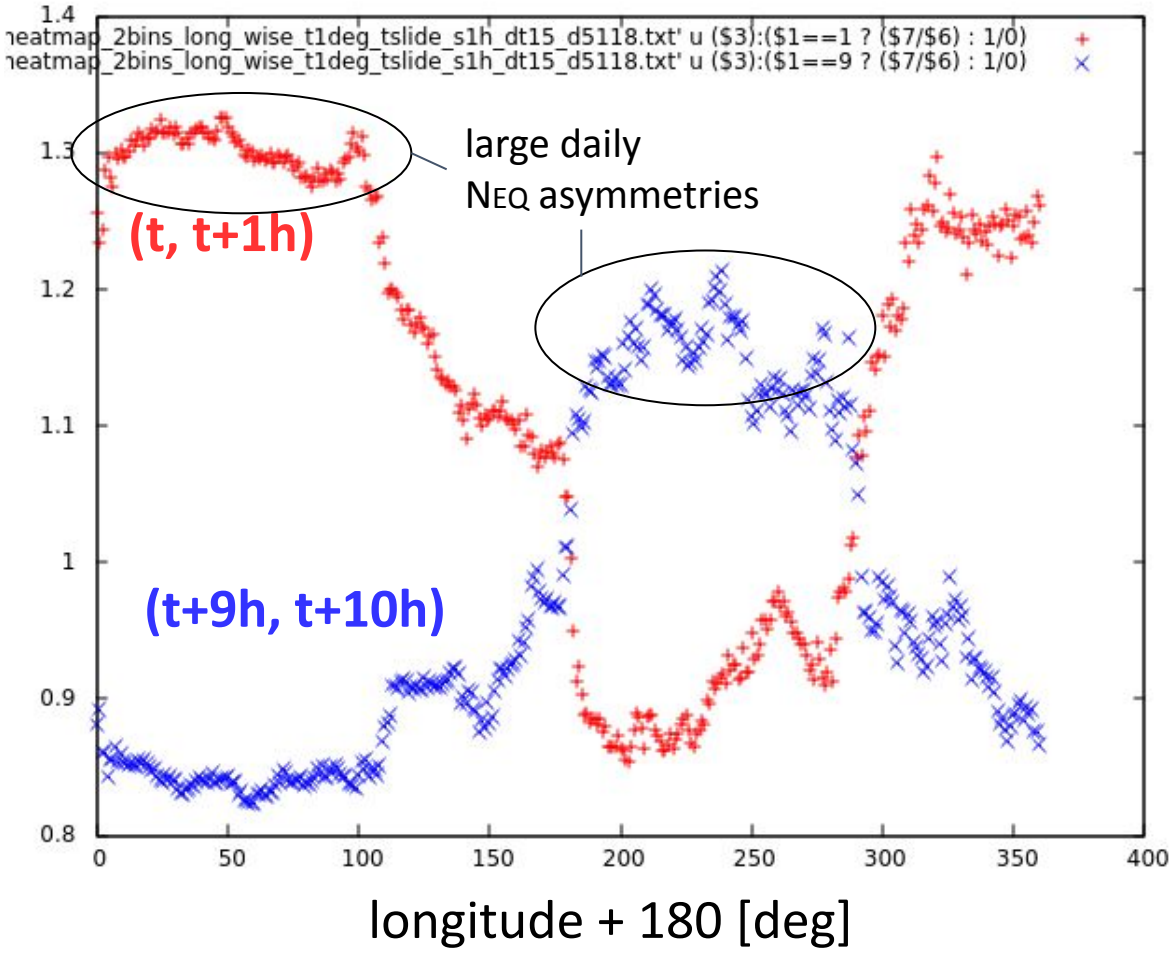
vs.

long: 170°W - 10°E

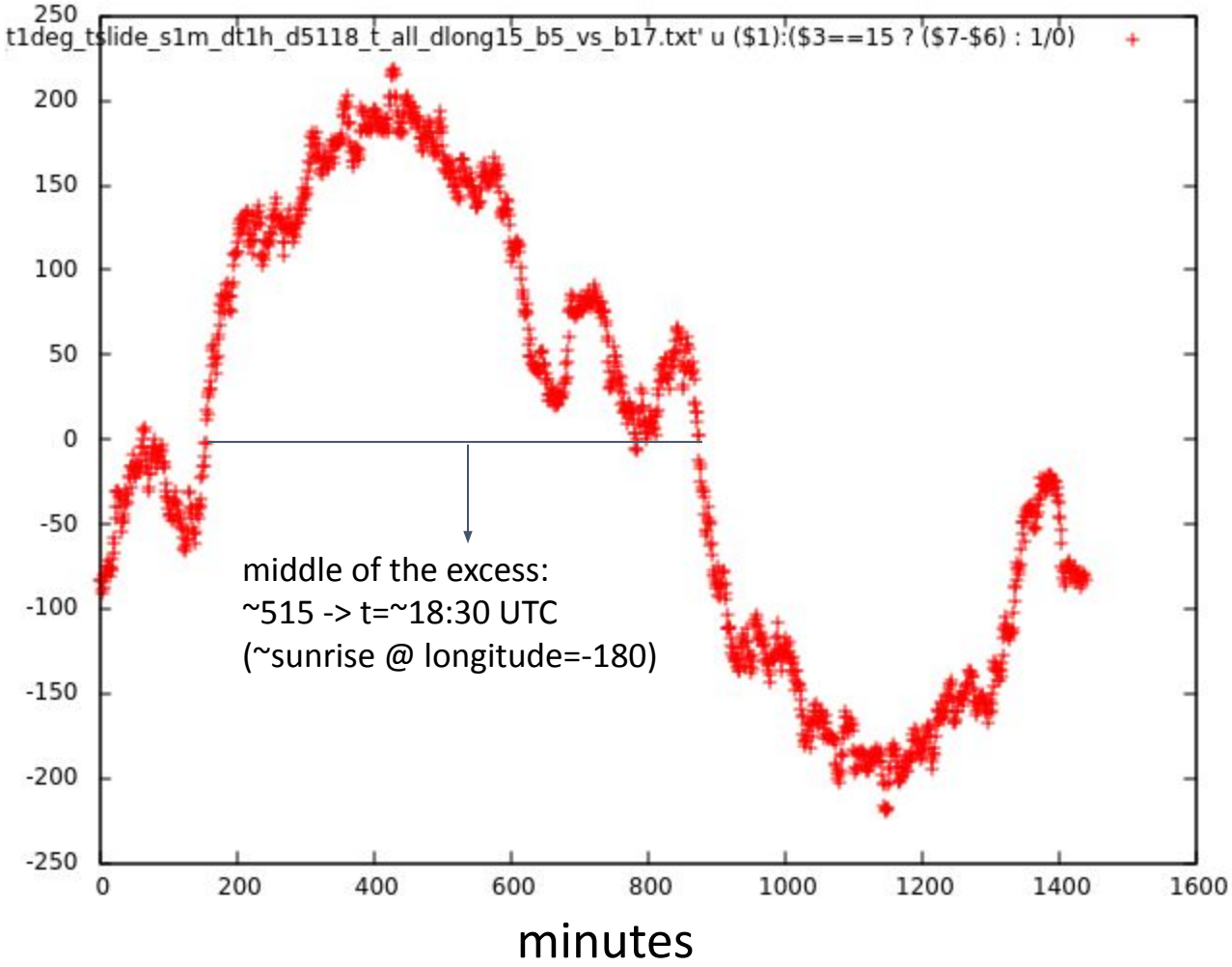


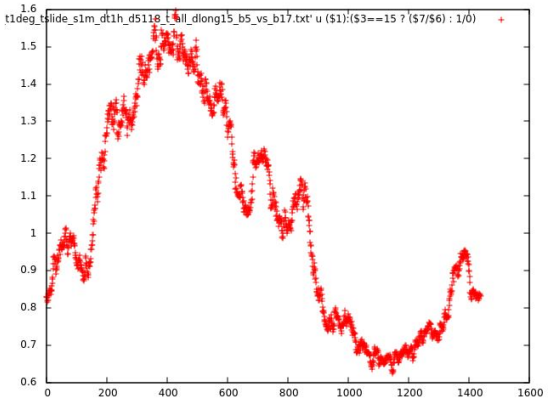
hemispheric asymmetries:
NEQ(t)-NEQ(t+12h)
longitude range: 180 deg
time range: 1h

colors: different time of the day, every 1 hour (the other half antisymmetric)



selected hemispheric asymmetries:
NEQ(t)/NEQ(t+12h)
longitude range: 180 deg
time range: 1h



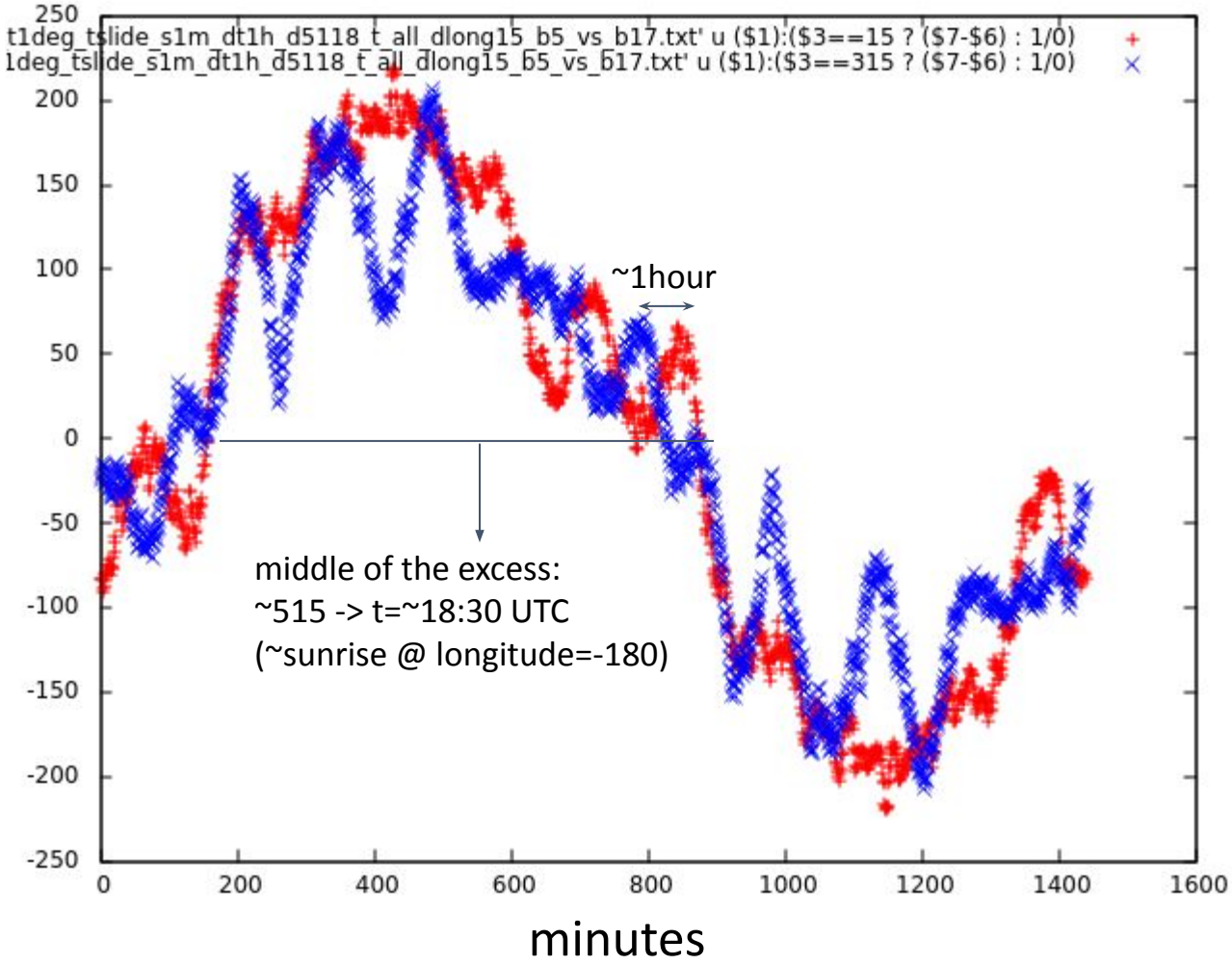


relative (up):
NEQ(t)/NEQ(t+12h)

and

differential (left):
NEQ(t) - NEQ(t+12h)

longitudes: (-180,-165)
dt=1 hour
max @ ~18:30 UTC



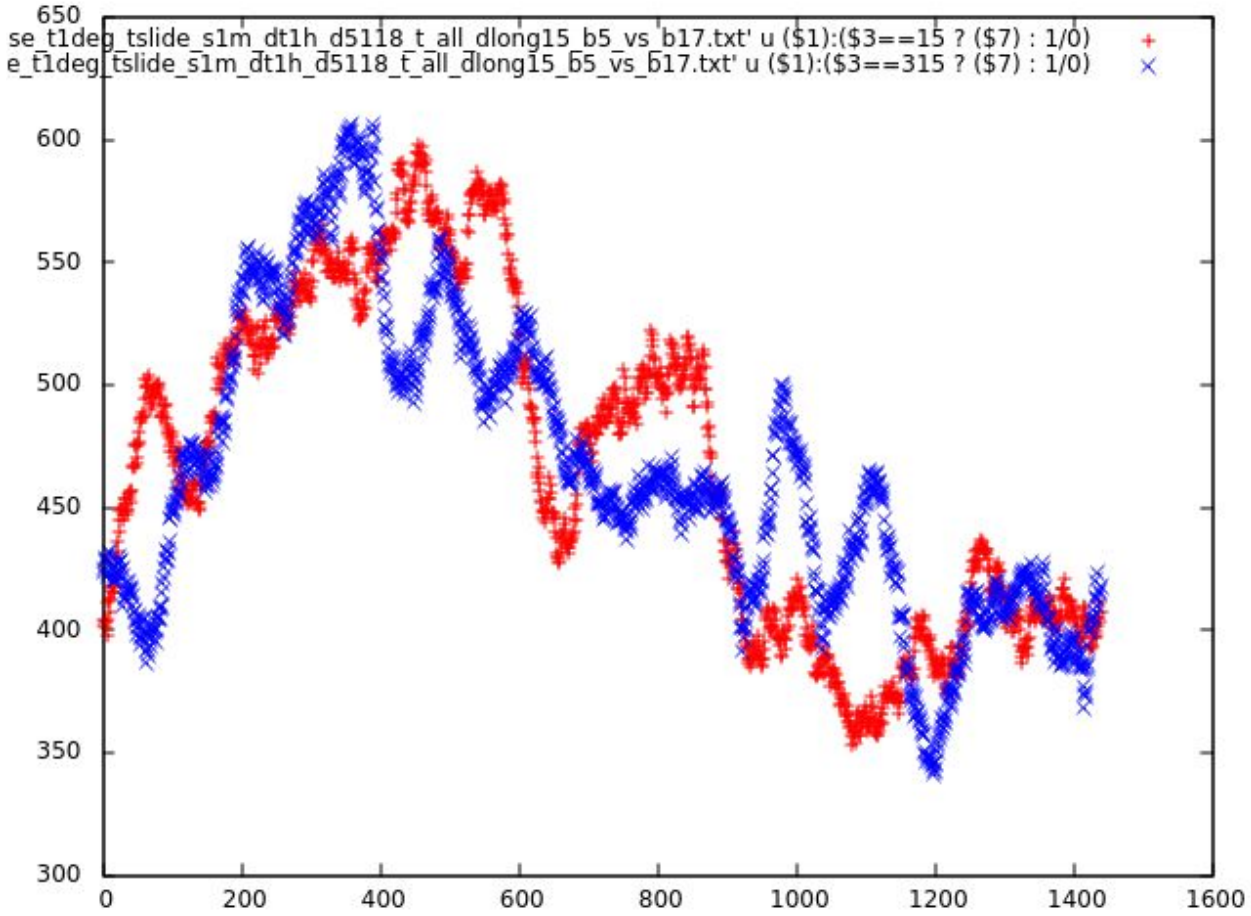
differential (left):
NEQ(t) - NEQ(t+12h)

longitudes:
(-180,-165) RED
vs
(120,135) BLUE

dt=1 hour, window: 2000 days
max @ ~18:30 UTC

similar asymmetry shape
for distant (by ~60 deg in long)
regions?

- what are the peaks in blue?
- blue “later” than red by 1hr? But 60 deg difference?



minutes

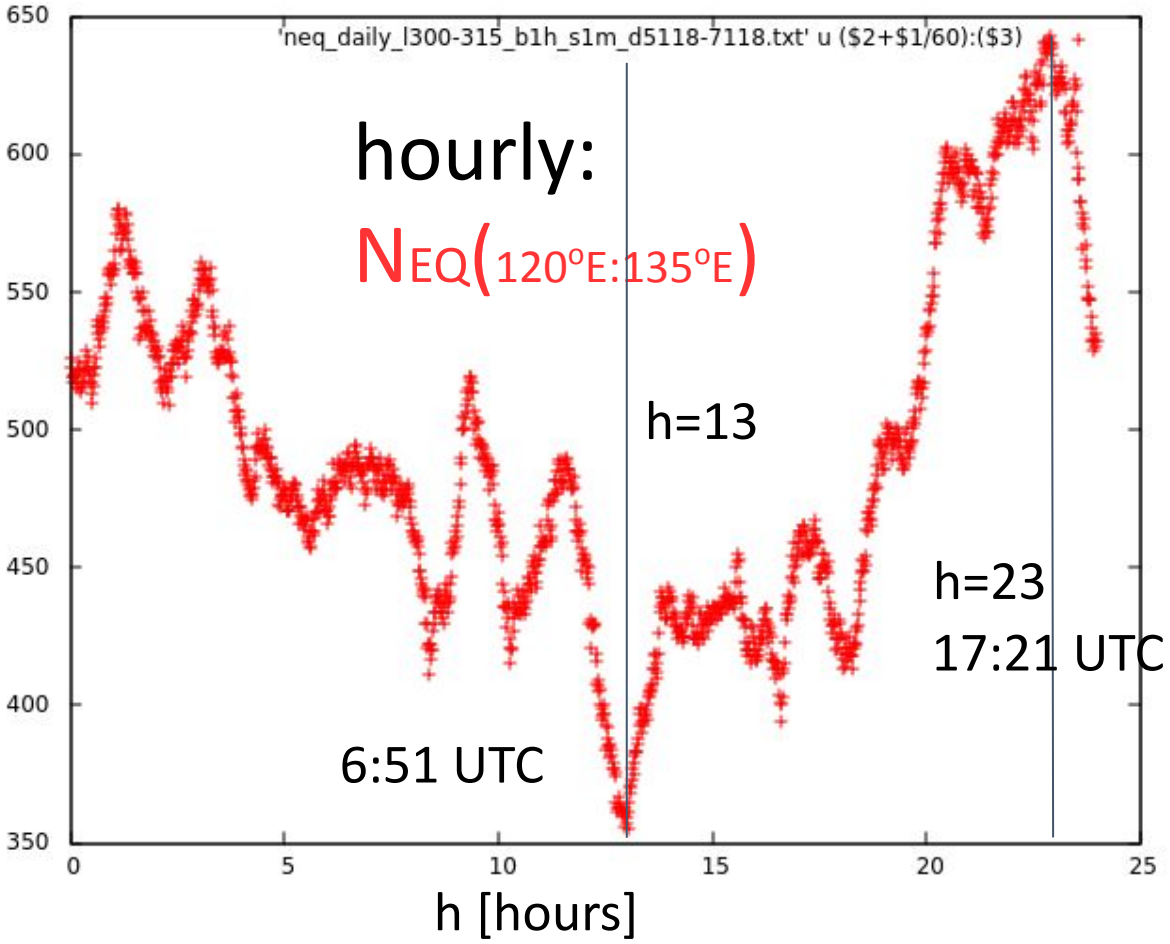
hourly:

$N_{EQ}(180^{o}W:165^{o}W)$

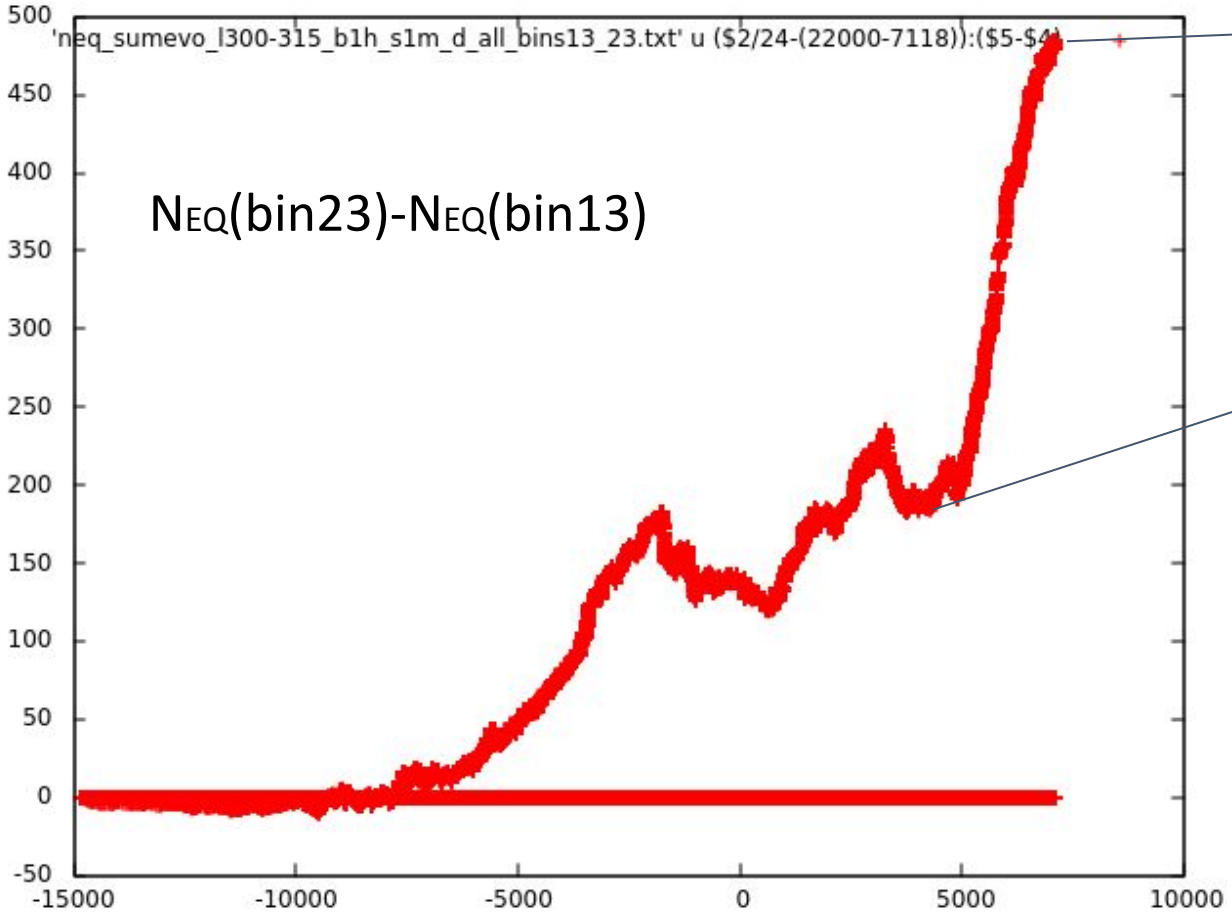
vs.

$N_{EQ}(120^{o}E:135^{o}E)$

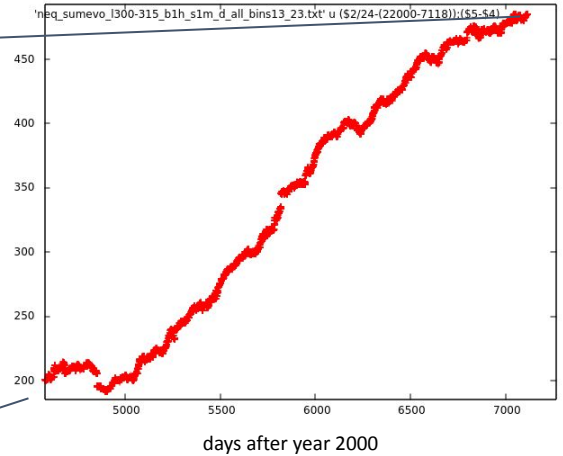
-> distant locations but similar average daily asymmetry?



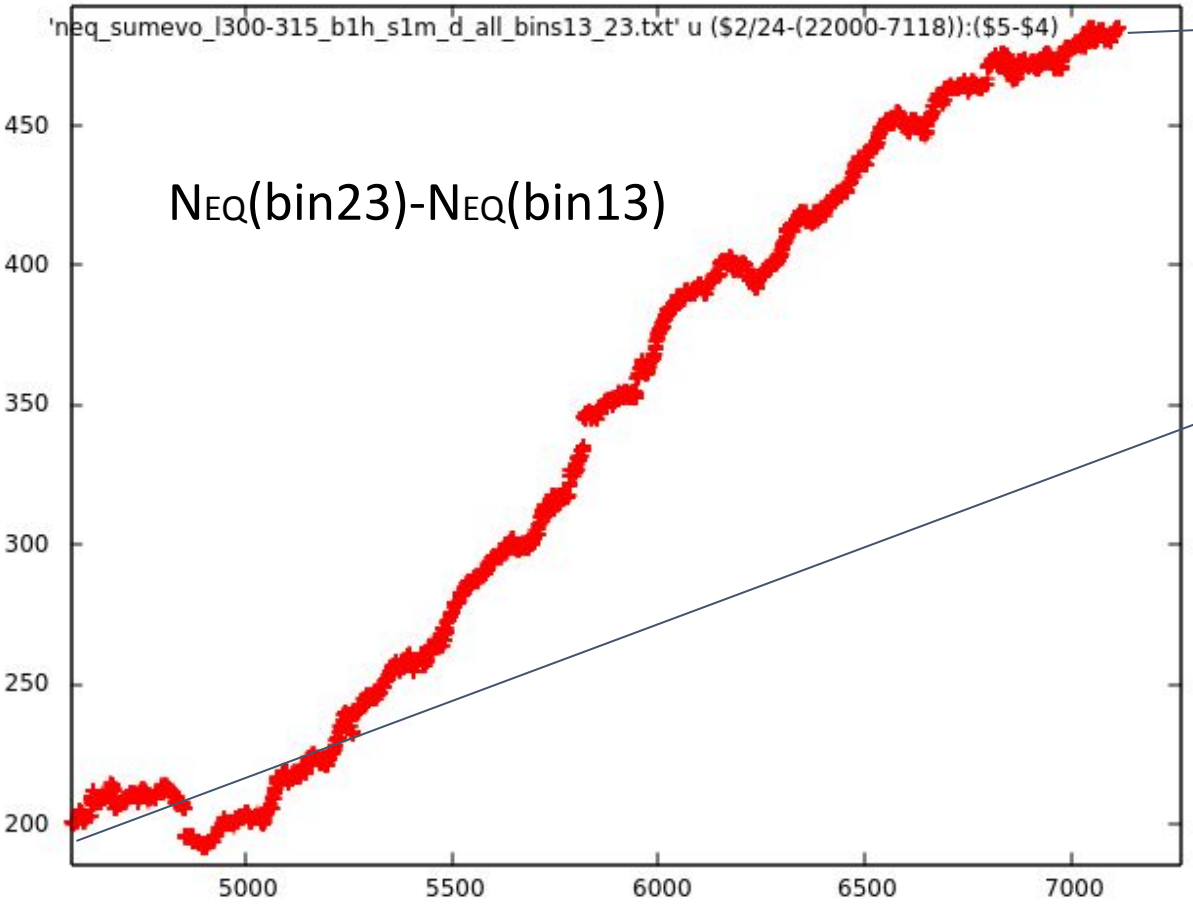
Let's focus on some region…

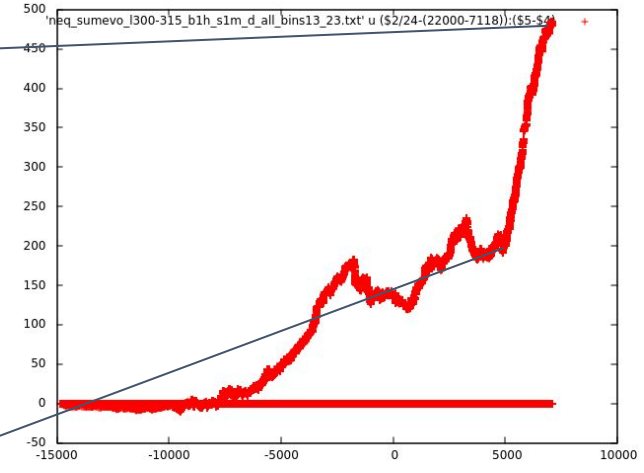


N_{EQ}(bin23)-N_{EQ}(bin13)



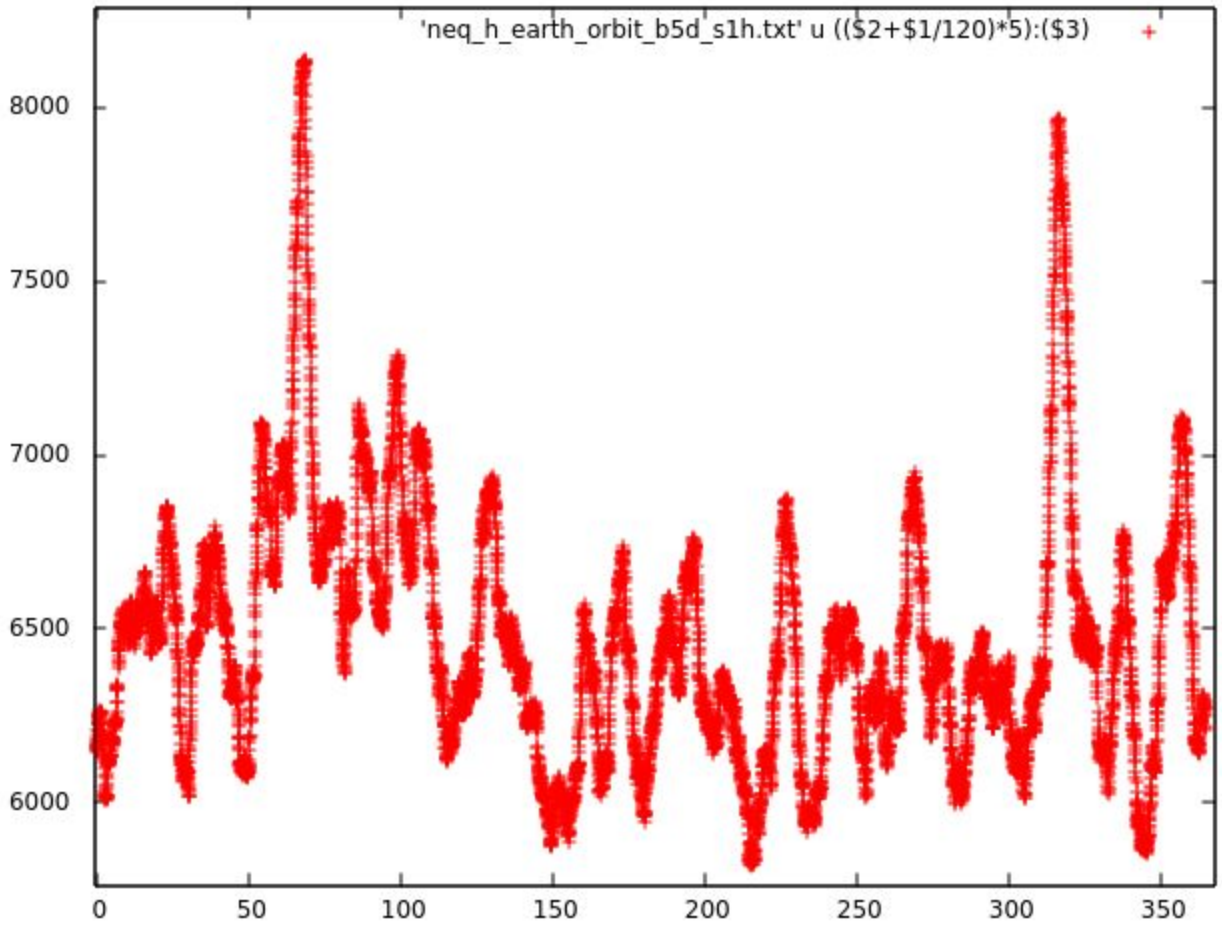
- any (semi)yearly behavior? (external stream)
- relation to solar magnetic field?
- tidal forces? But why so dynamic in time?
- no lunar day or synodic month in EQ data… but how about Moon quarters?





- any (semi)yearly behavior? (external stream)
- relation to solar magnetic field (cycles)?
- tidal forces? But why so dynamic in time, why no lunar day or synodic month in EQ data?
- … but how about Moon quarters?

6. a special EQ week of the year at ~mid November: a specific external arrival direction?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6500
6000
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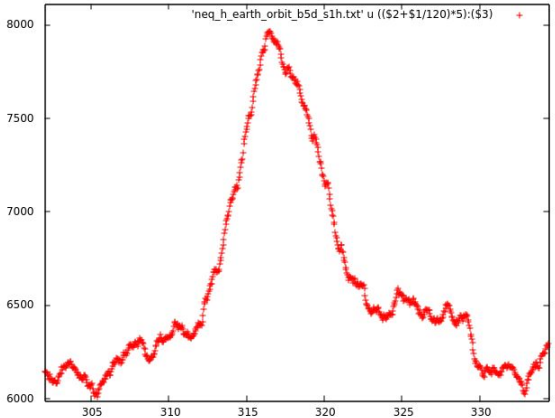
100
150
200
250
300
350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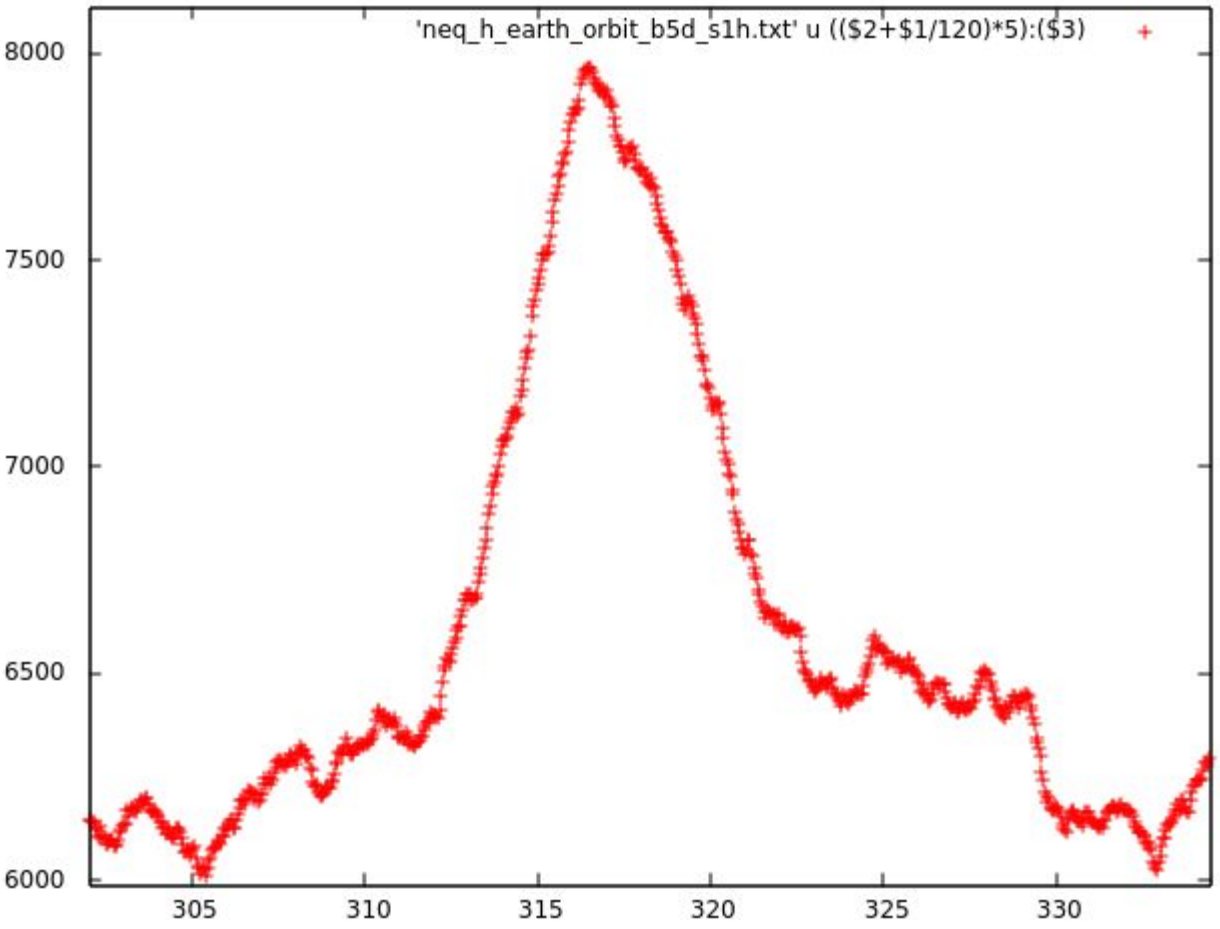
315
320
325
330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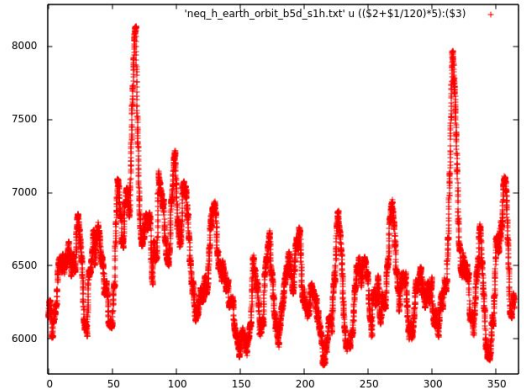
7000
6500
6000
305
310
315
320
325
330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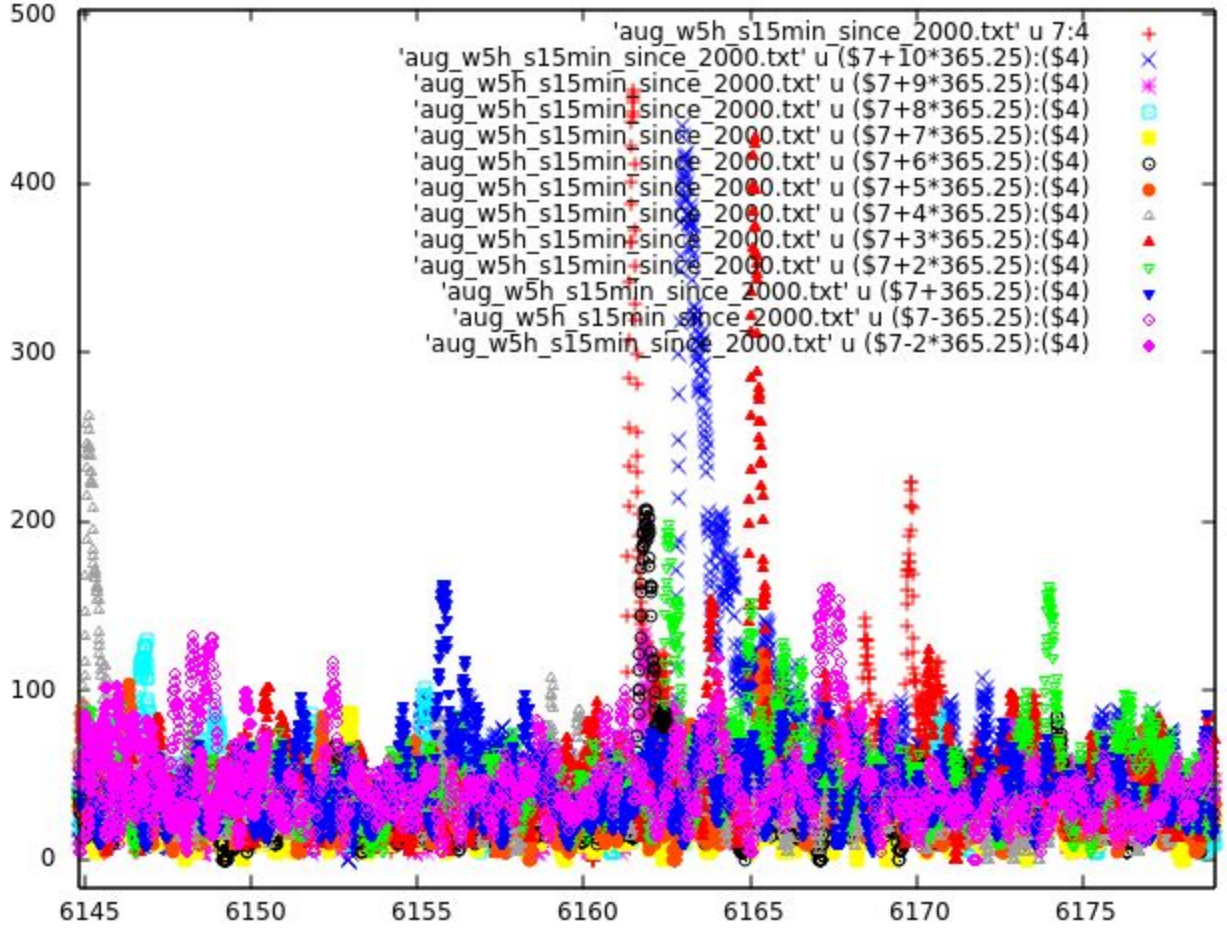
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'aug_w5h_s15min_since_2000.txt' u ($7+10*365.25):($4)
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'aug_w5h_s15min_since_2000.txt' u ($7+8*365.25):($4)
'aug_w5h_s15min_since_2000.txt' u ($7+7*365.25):($4)
'aug_w5h_s15min_since_2000.txt' u ($7+6*365.25):($4)
'aug_w5h_s15min_since_2000.txt' u ($7+5*365.25):($4)
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'aug_w5h_s15min_since_2000.txt' u ($7+3*365.25):($4)
'aug_w5h_s15min_since_2000.txt' u ($7+2*365.25):($4)
'aug_w5h_s15min_since_2000.txt' u ($7+365.25):($4)
'aug_w5h_s15min_since_2000.txt' u ($7-365.25):($4)
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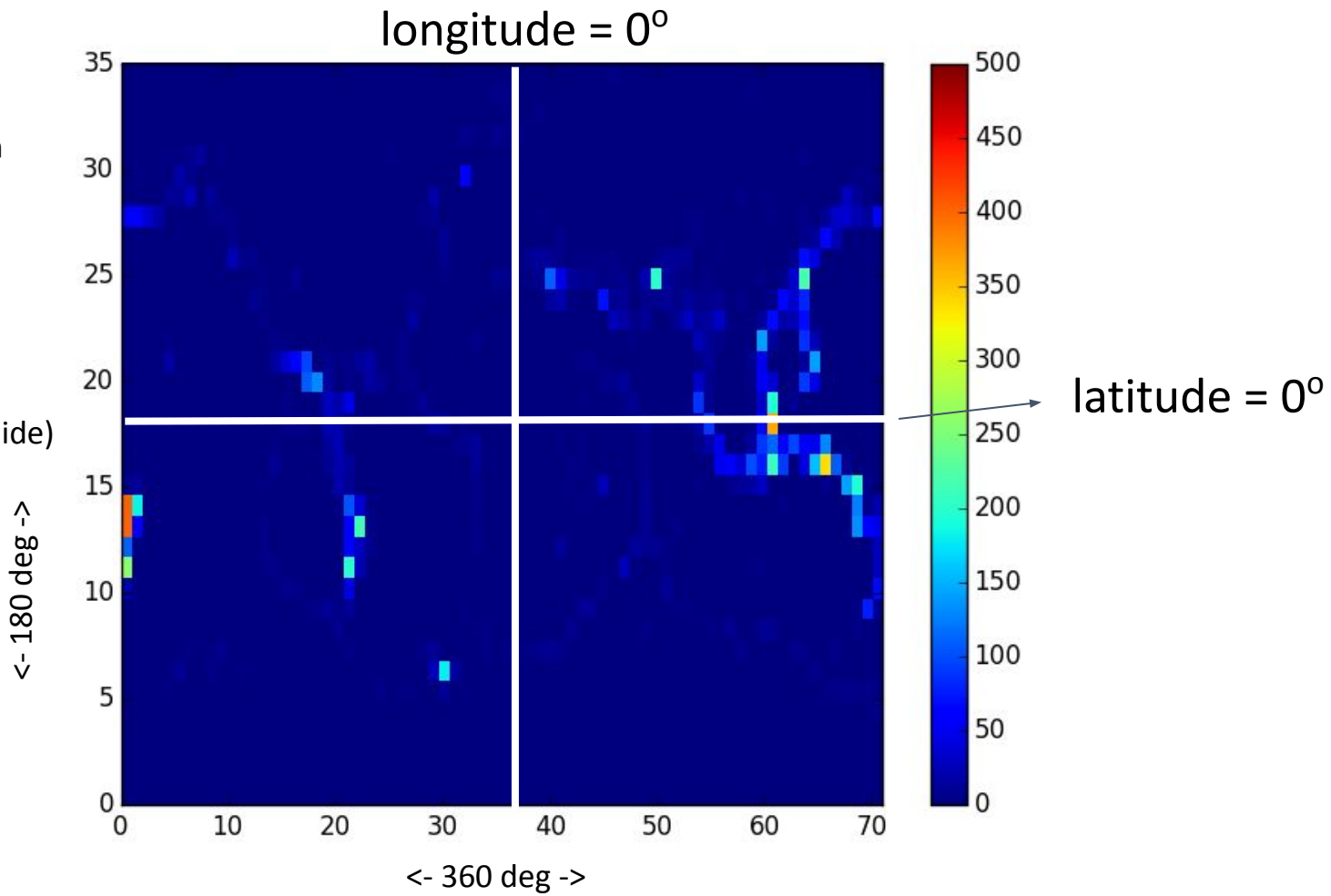
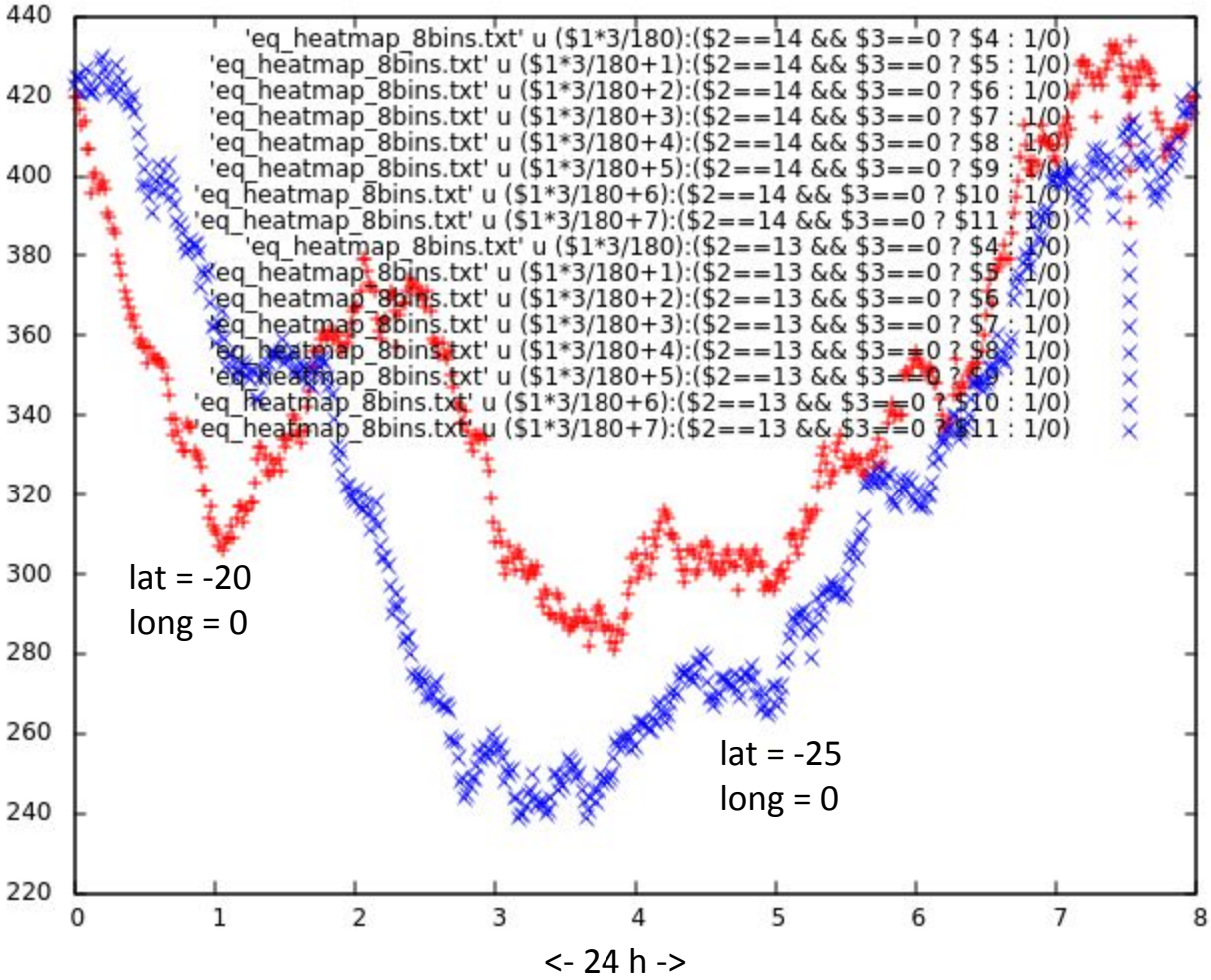
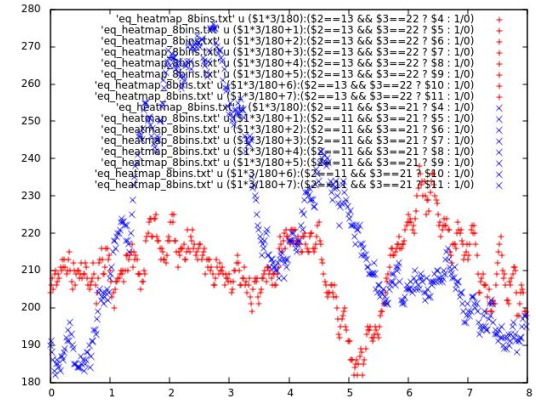
500
400
300
200
100
0
6145
6150
6155
6160
6165
6170
6175

Average daily N_{EQ},
bin: 3h, 8 bins / 24h
tile: 5 deg x 5 deg
lat = 0 deg -> 18
long = 0 deg -> 36

time:
bin 7 (cf. previous slide)



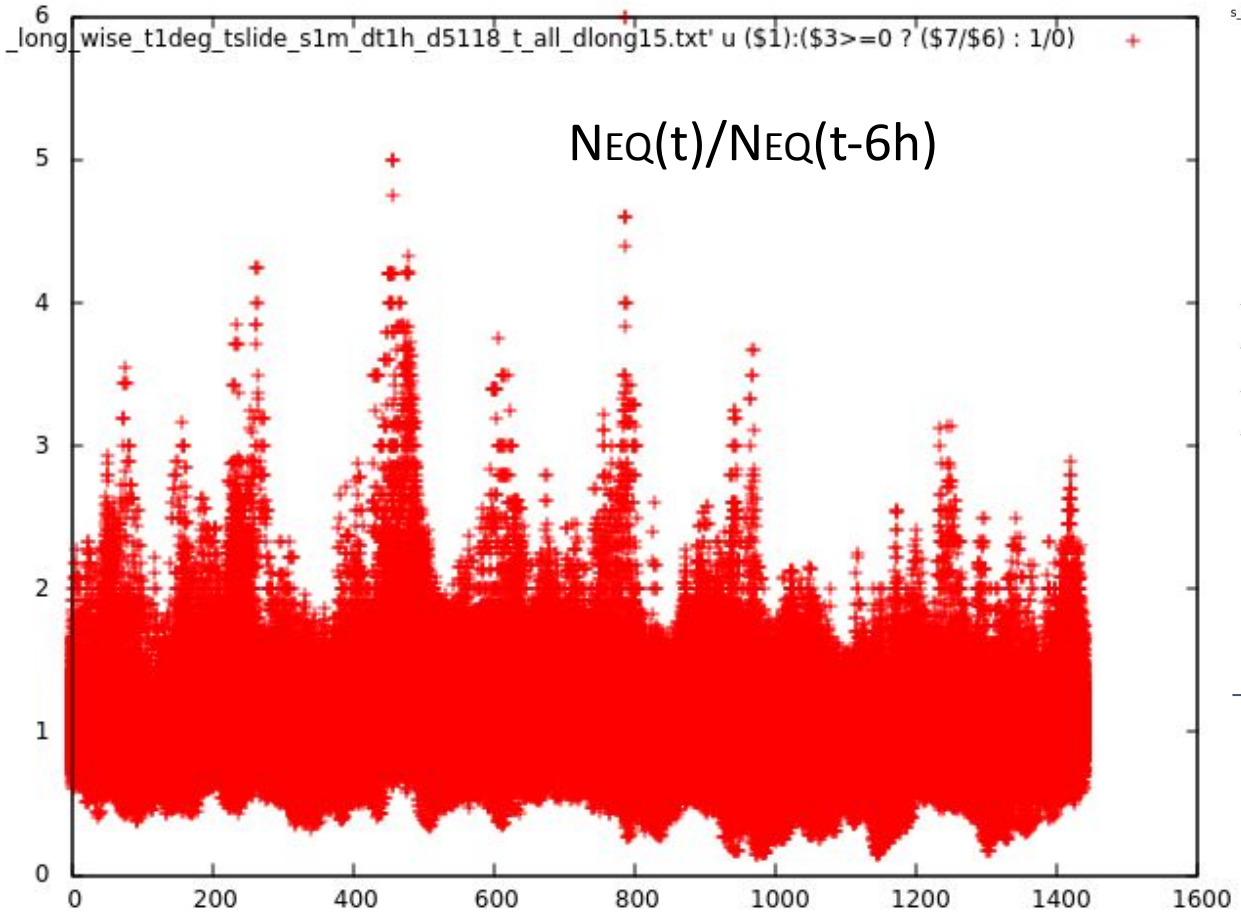


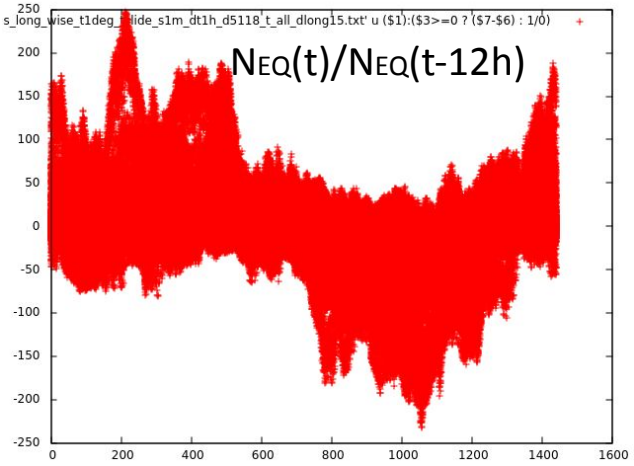


lat = -35
long = -75

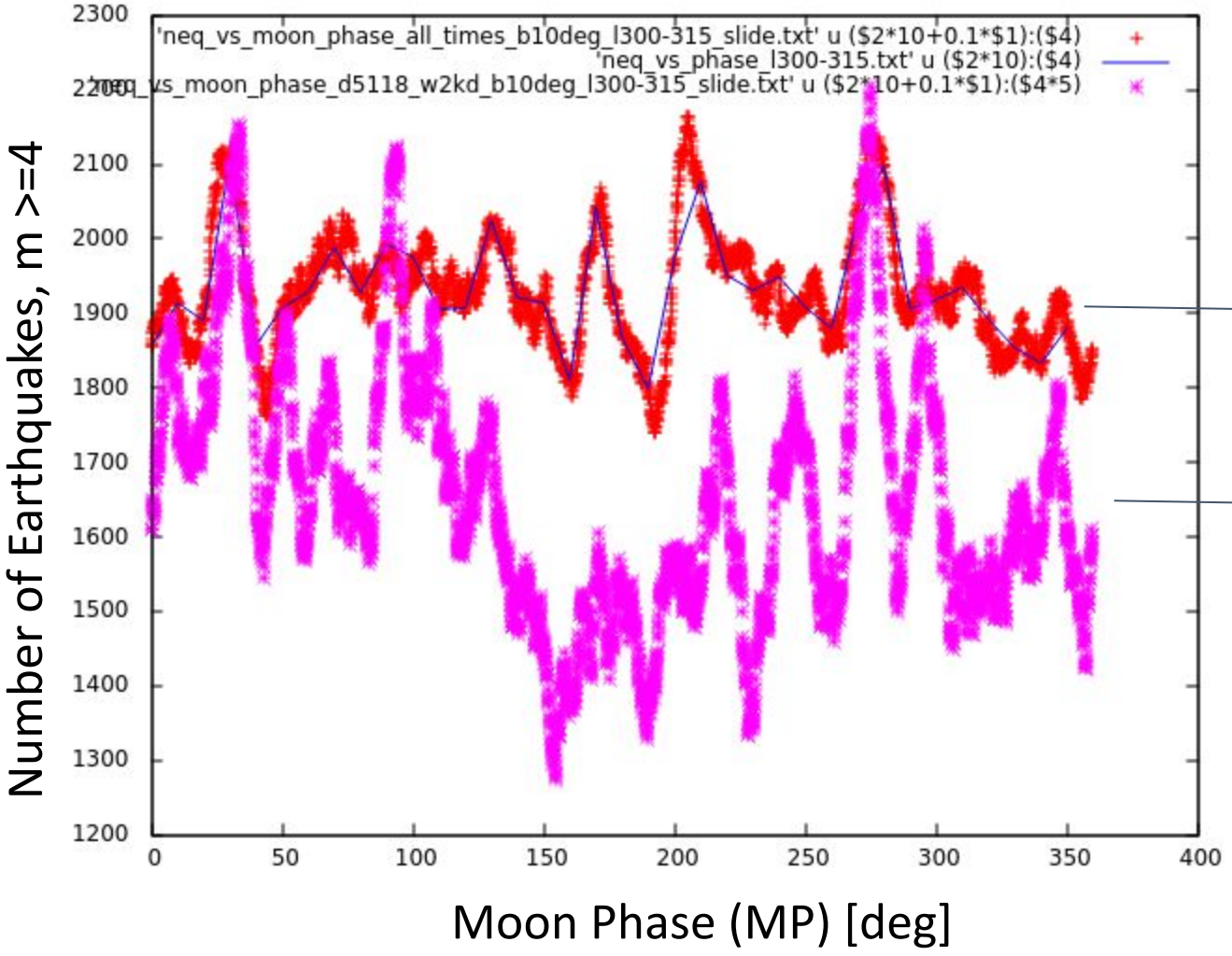
lat = -25
long = -70

local N_{EQ}
(5 deg x 5 deg)





→ “discreteness” of NEQ @ 6 hrs difference?



longitude cut:
120^{o}<= long <=135^{o}

since 1957

~2014-19
(scaled)

Cosmic rays do not trigger earthquakes or how media support science

After the cosmo-seismic press release:

2023

- [abcactionnews.com] Why scientists say earthquakes feel powerful after cosmic rays strike
- [bollyinside.com] Is it possible to predict earthquakes using cosmic radiation? An unconventional idea with scientific basis
- [downtoearth.org.in] Scientists find link between surges of cosmic radiation from space and earthquakes
- [earth.com] Breakthrough: Surges of cosmic radiation from space directly linked to earthquakes
- [easternherald.com] Scientists have noticed jumps in cosmic radiation before powerful earthquakes
- [edukemy.com] Link between surges of cosmic radiation from space and earthquakes
- [gigazine.net] It turns out that there is a remarkable correlation between the intensity of earthquakes and cosmic rays, and there is also the possibility that it can be applied to predict the occurrence of earthquakes
- [gktoday.in] The Link between Earthquakes and Cosmic Radiation
- [greatgameindia.com] Scientists Find Link Between Surges Of Cosmic Radiation From Space And Earthquakes
- [iastoppers.com] Link between surges of cosmic radiation from space and earthquakes
- [mesonstars.com] Earthquakes would be related to solar activity according to a study by physicists
- [natureworldnews.com] Cosmic Rays Possibly Connect with Earthquakes on Earth [Study]
- [naukawpolsce.pl] Intrygująca korelacja między trzęsieniami ziemi a promieniowaniem kosmicznym
- [newsbeezer.com] Scientists find link between cosmic ray waves from space and earthquakes
- [newsweek.com] Scientists Link Cosmic Radiation to Earthquakes for the First Time
- [o2.pl] Sensacja w Krakowie. Odkrycie, które może zmienić cały świat
- [phys.org] The intriguing correlation between earthquakes and cosmic radiation
- [popularmechanics.com] There's a Surprising Connection Between Earthquakes and Cosmic Rays.
- [pk.edu.pl] Korelacja między trzęsieniami ziemi a promieniowaniem kosmicznym – ważne odkrycie z politechnicznym udziałem
- [prepp.in] Scientists Find Link Between Surges Of Cosmic Radiation From Space and Earthquakes
- [projektpulsar.pl] Czy promieniowanie kosmiczne powoduje trzęsienia ziemi?
- [rmf24.pl] Czy badania promieniowania kosmicznego pomogą przewidywać trzęsienia Ziemi?
- [scienceblog.com] Intriguing Correlation Found Between Earthquakes and Cosmic Radiation
- [space.com] Earthquakes seem more intense after cosmic ray strikes. Scientists say this is why.
- [space24.pl] Korelacja między trzęsieniami ziemi a promieniowaniem kosmicznym
- [spaceref.com] Intriguing Correlation Between Earthquakes And Cosmic Radiation.
- [time.news] The enigmatic relationship between cosmic radiation and earthquakes on Earth
- [wattsupwiththat.com] Do Cosmic Rays Precede Earthquakes?
- [world-today-news.com] Discovering the Link: Cosmic Radiation and Seismic Activity for Earthquake Prediction
- [zmescience.com] Could cosmic radiation predict earthquakes? A wild idea, but still rooted in science
- CREDO - Astronarium 155

whattsupwiththat.com / Willis Eschenbach:

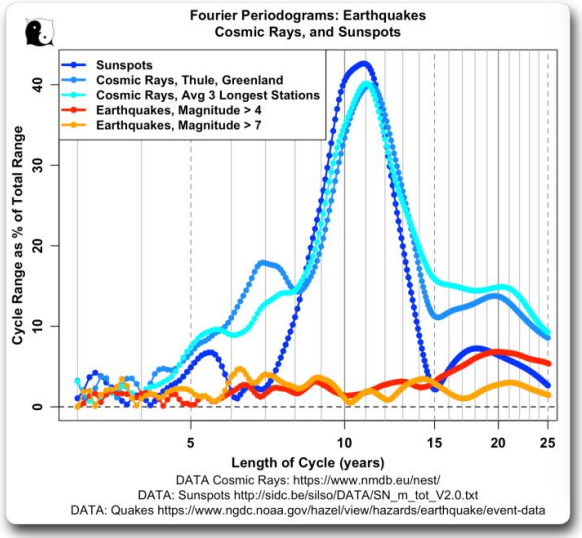


Figure 1. Fourier Periodograms of monthly sunspots, earthquake average magnitudes, and cosmic rays. The three longest records of cosmic rays are from Thule, Greenland; Jungfraujoch, Switzerland; and Newark, NJ USA. In addition to the earthquakes of magnitude greater than 4 studied by the authors, I also looked at earthquakes of magnitude greater than 7.

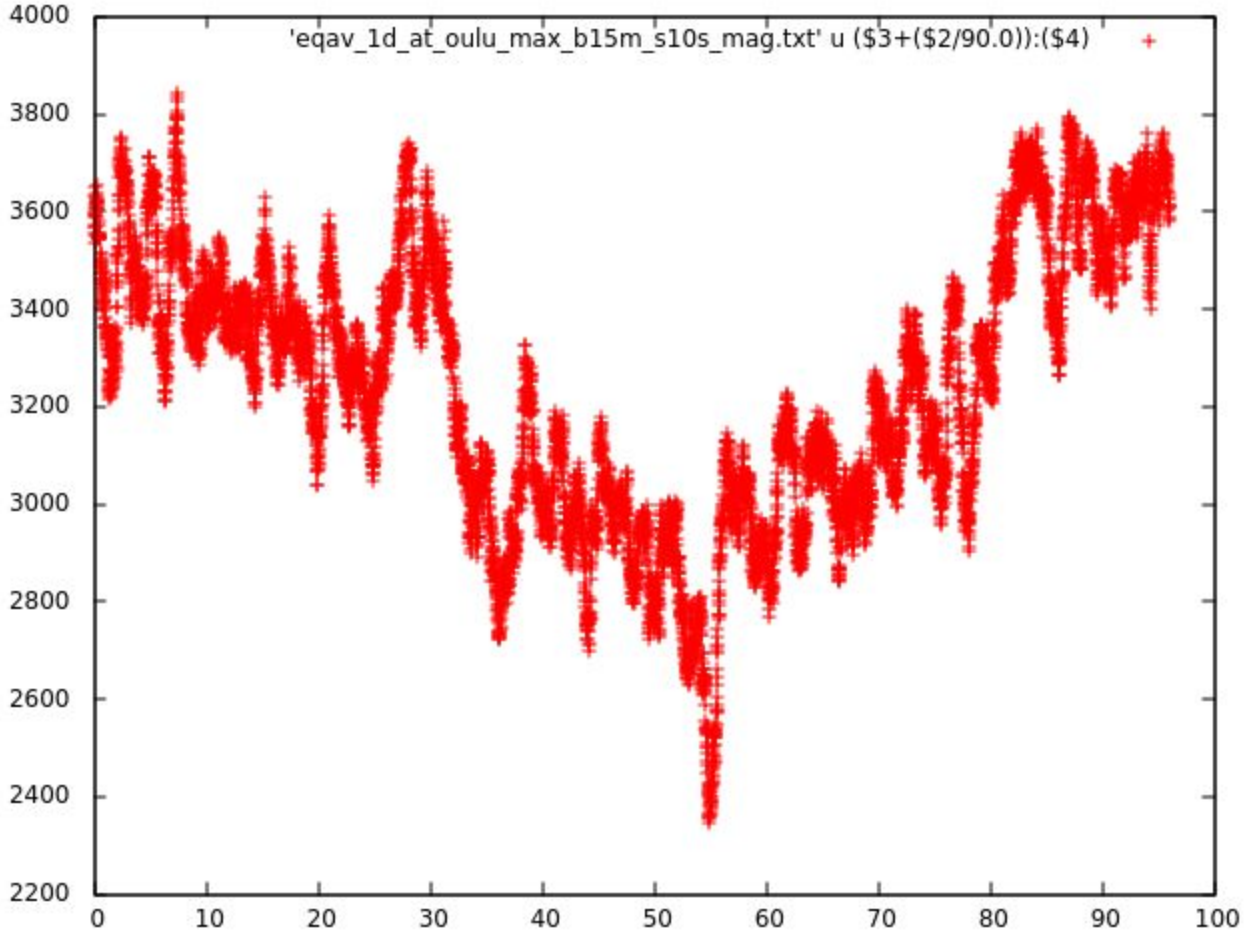
no solar activity cycle seen in the earthquake data

↓

galactic cosmic rays / solar emission less likely to trigger earthquakes

↓

non-conventional explanation of the cosmo-seismic correlation more likely!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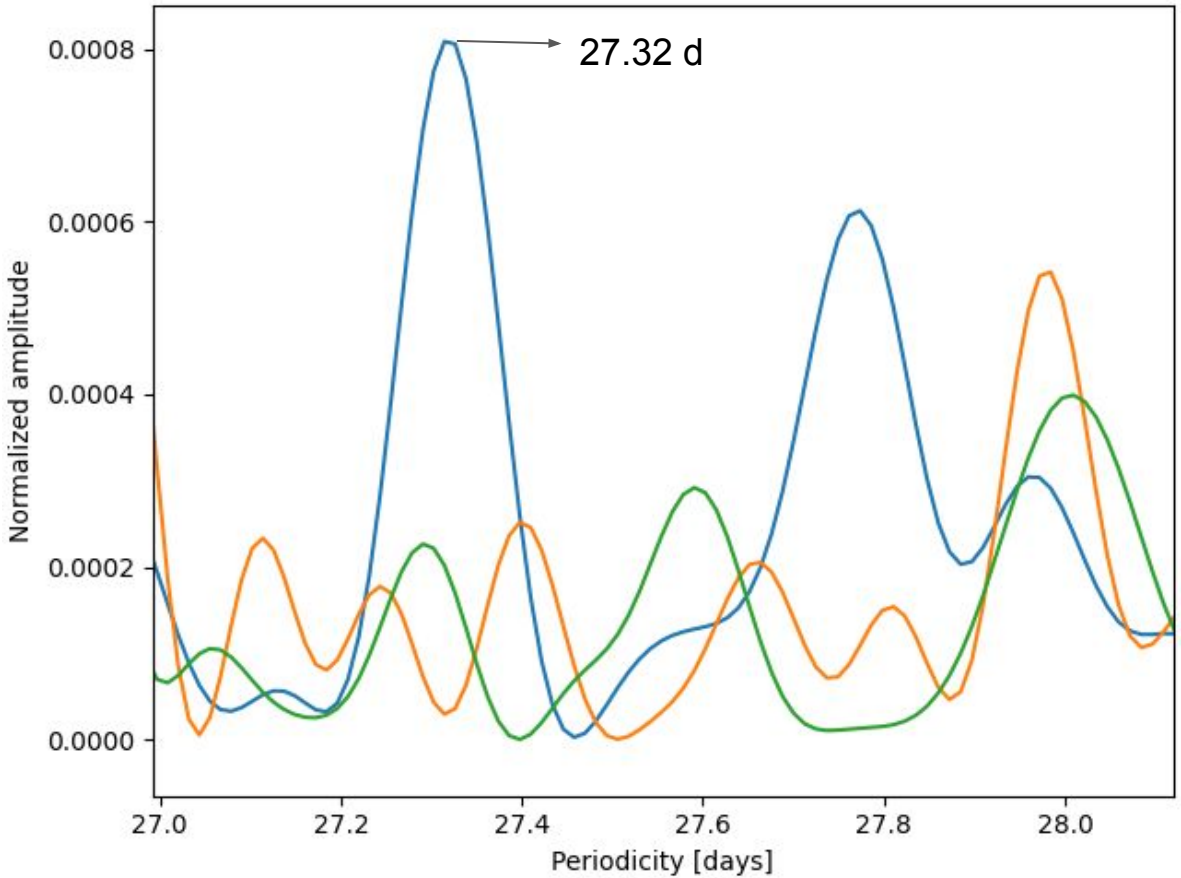
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
0
10
20
30
40
50
60
70
80
90
100

27.32 day periodicity in Earthquake data? Zoom a)



2001-2015
1986-2000
1971-1985

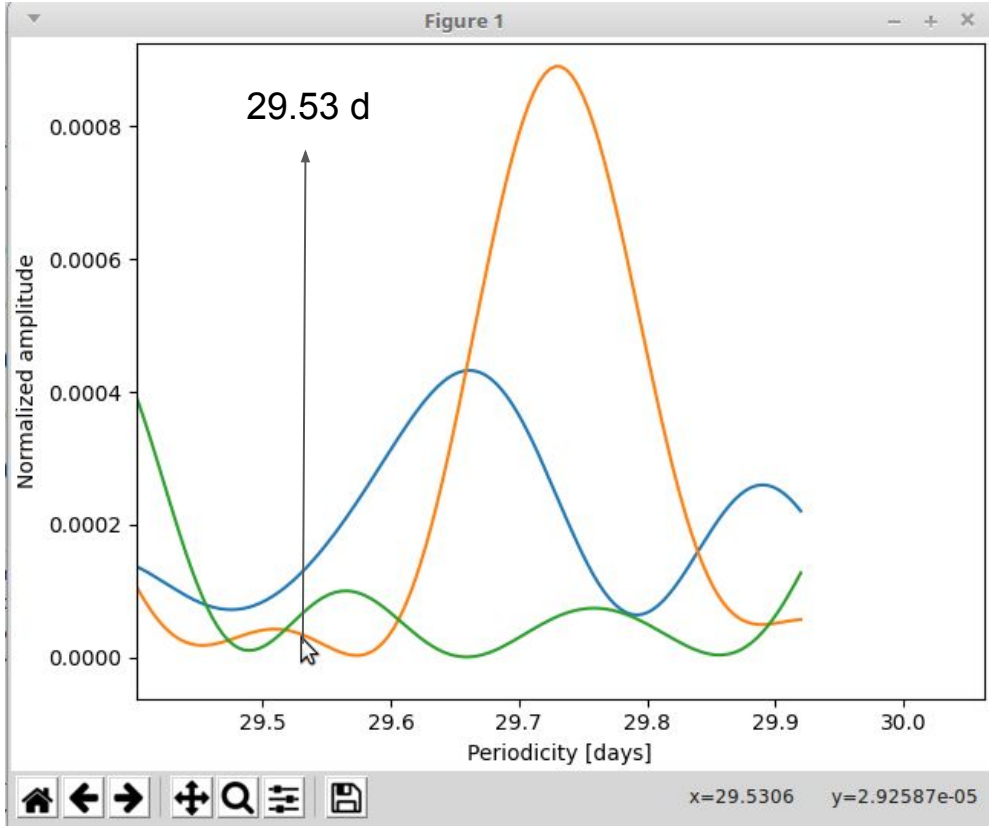
[independent bins]

parameters:

- Lomb-Scargle periodogram
- EQ magnitude: m > 5.2
- number of EQs / day
- max 25 EQs / day

conclusion:
if yes, it's presence and strength varies with time (solar activity?)

29.53 day periodicity in Earthquake data? No



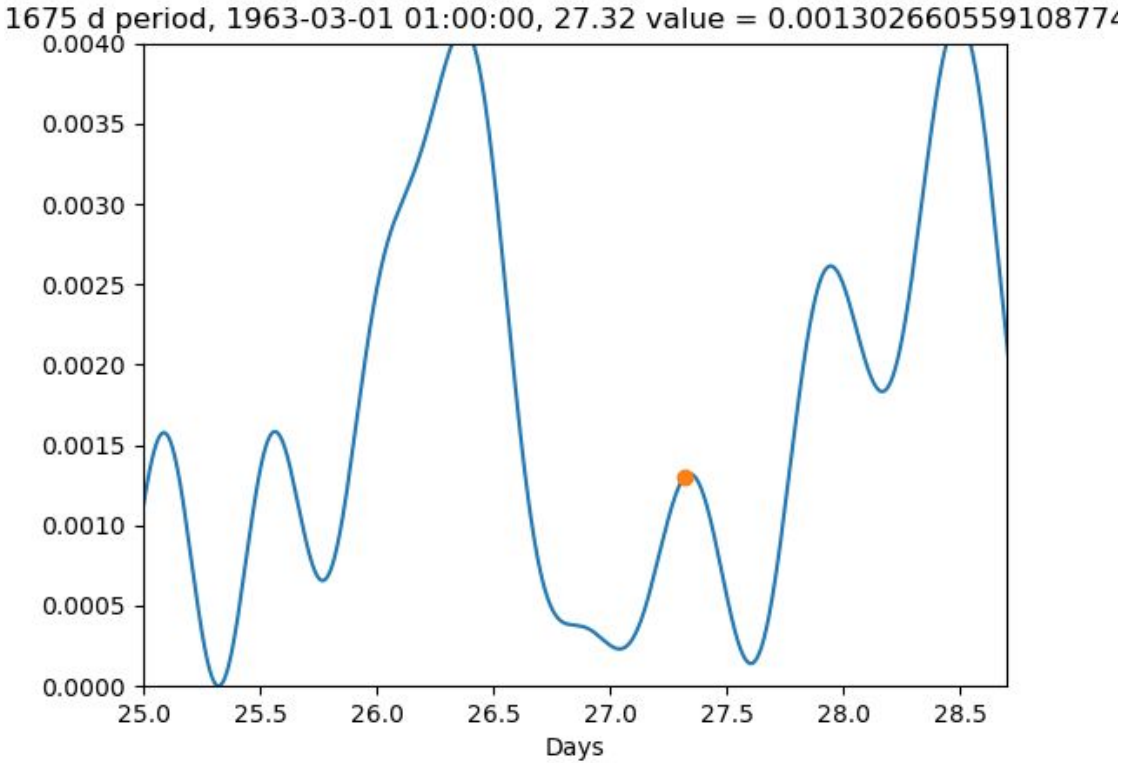
2001-2015
1986-2000
1971-1985

parameters:

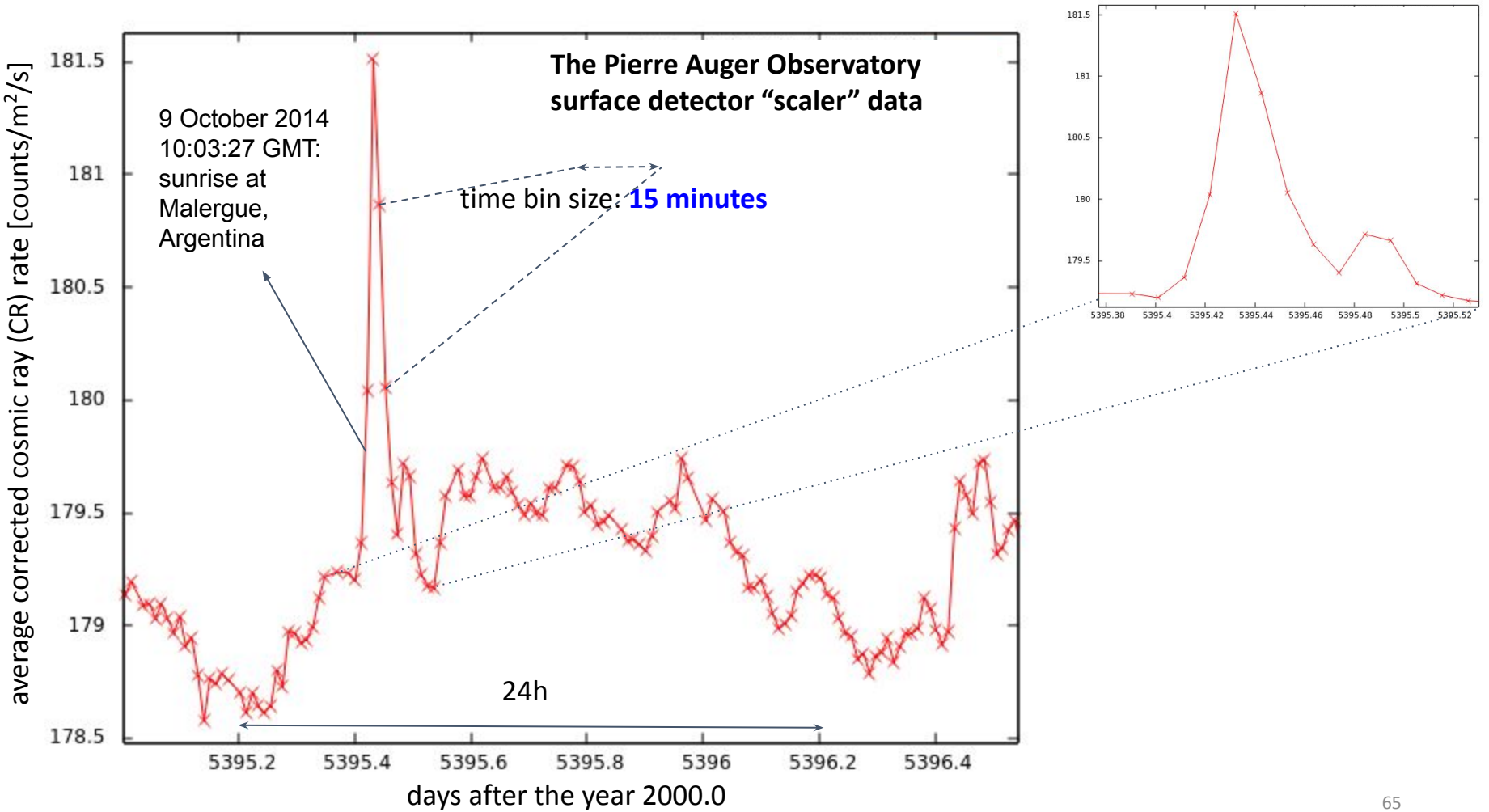
- Lomb-Scargle periodogram
- EQ magnitude: m > 5.2
- number of EQs / day
- max 25 EQs / day

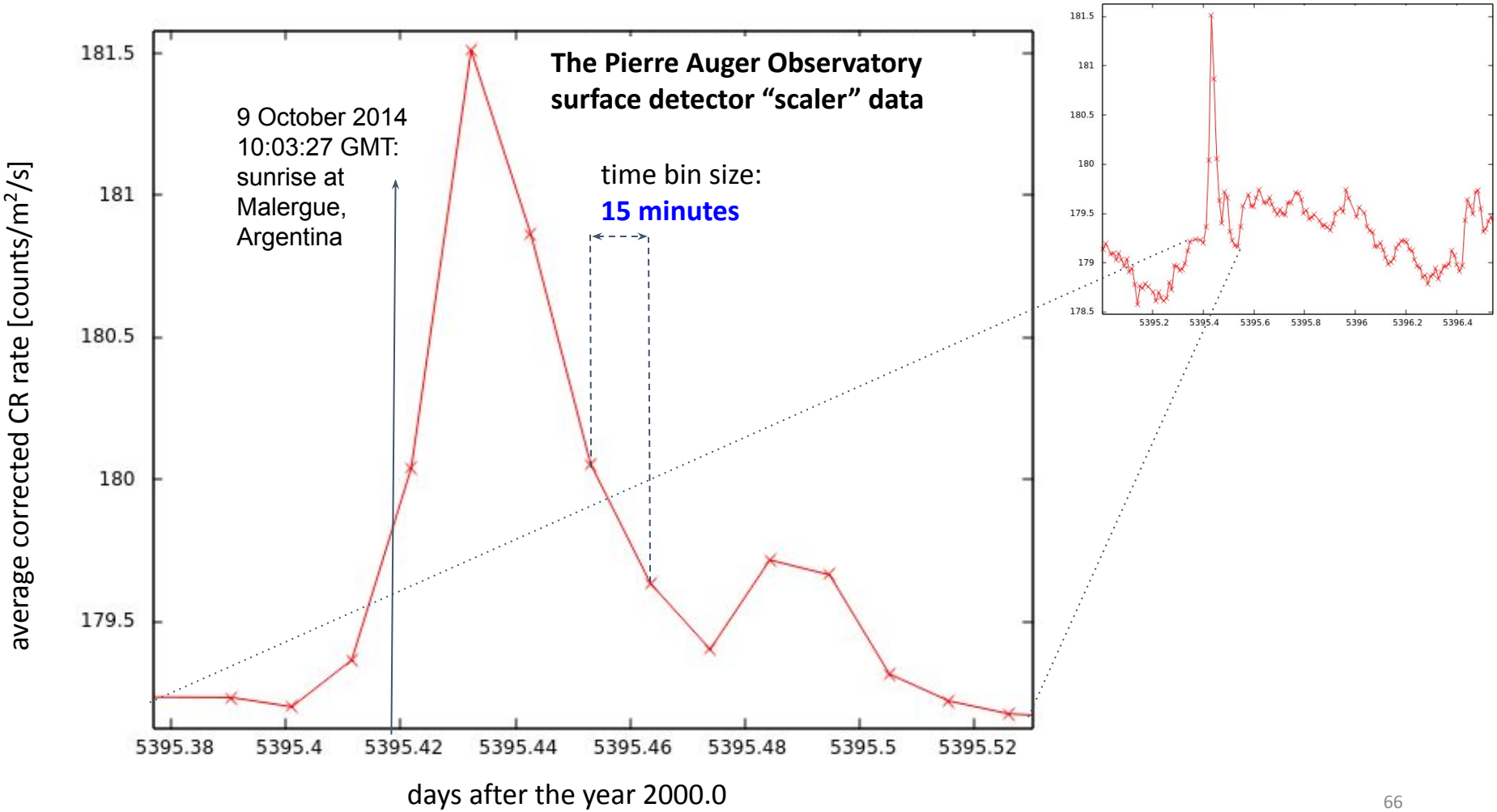
conclusion:
Nothing at 29.53d

Time evolution of the 27.32 d line [gif]



credit: Maria Pycior, AGH UST


The Pierre Auger Observatory
surface detector "scaler" data
9 October 2014
10:03:27 GMT:
sunrise at
Malergue,
Argentina
time bin size: 15 minutes
24h
average corrected cosmic ray (CR) rate [counts/m²/s]
days after the year 2000.0
181.5
181
180.5
180
179.5
179
178.5
5395.2
5395.4
5395.6
5395.8
5396
5396.2
5396.4
181.5
181
180.5
180
179.5
5395.38
5395.4
5395.42
5395.44
5395.46
5395.48
5395.5
5395.52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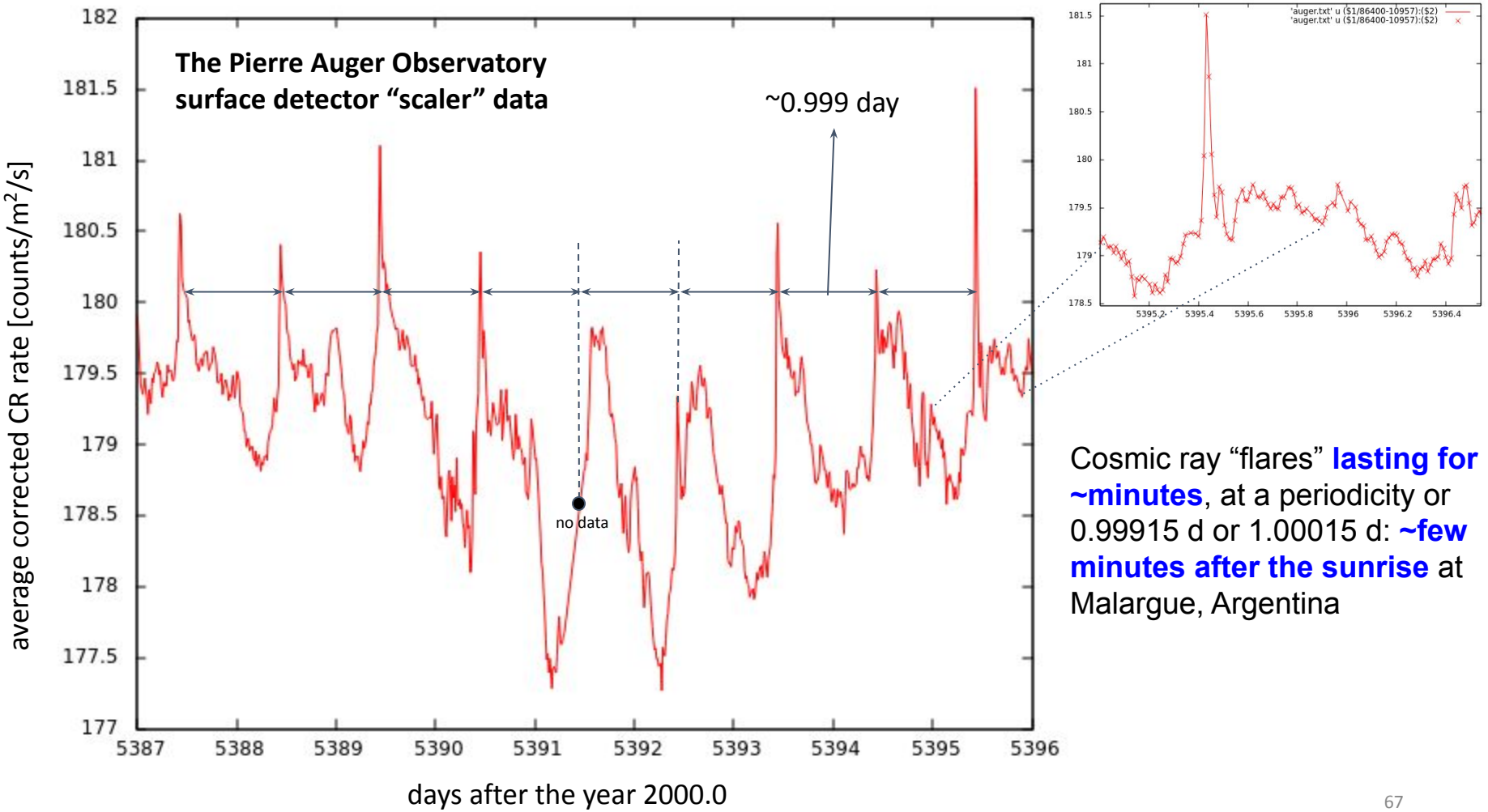
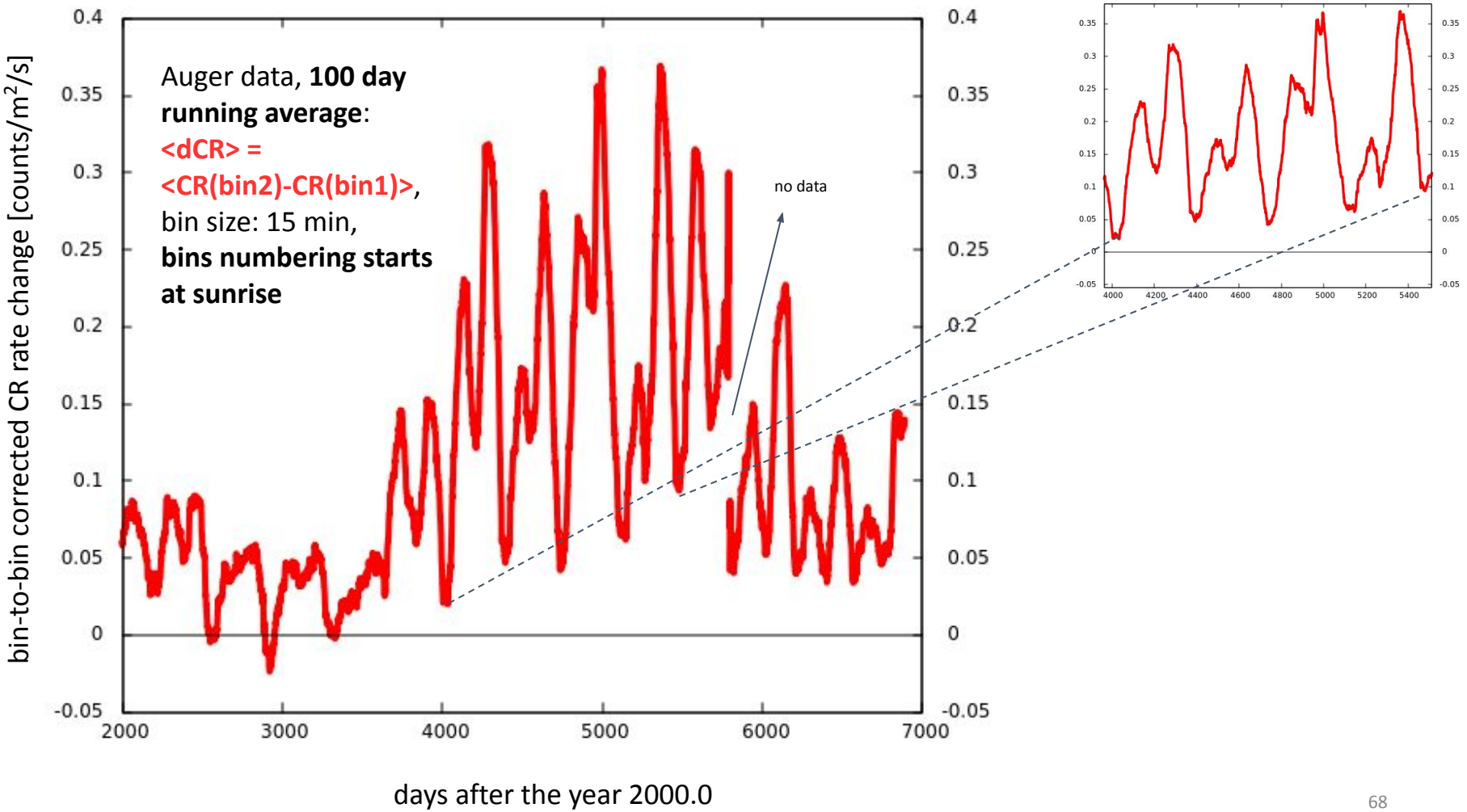
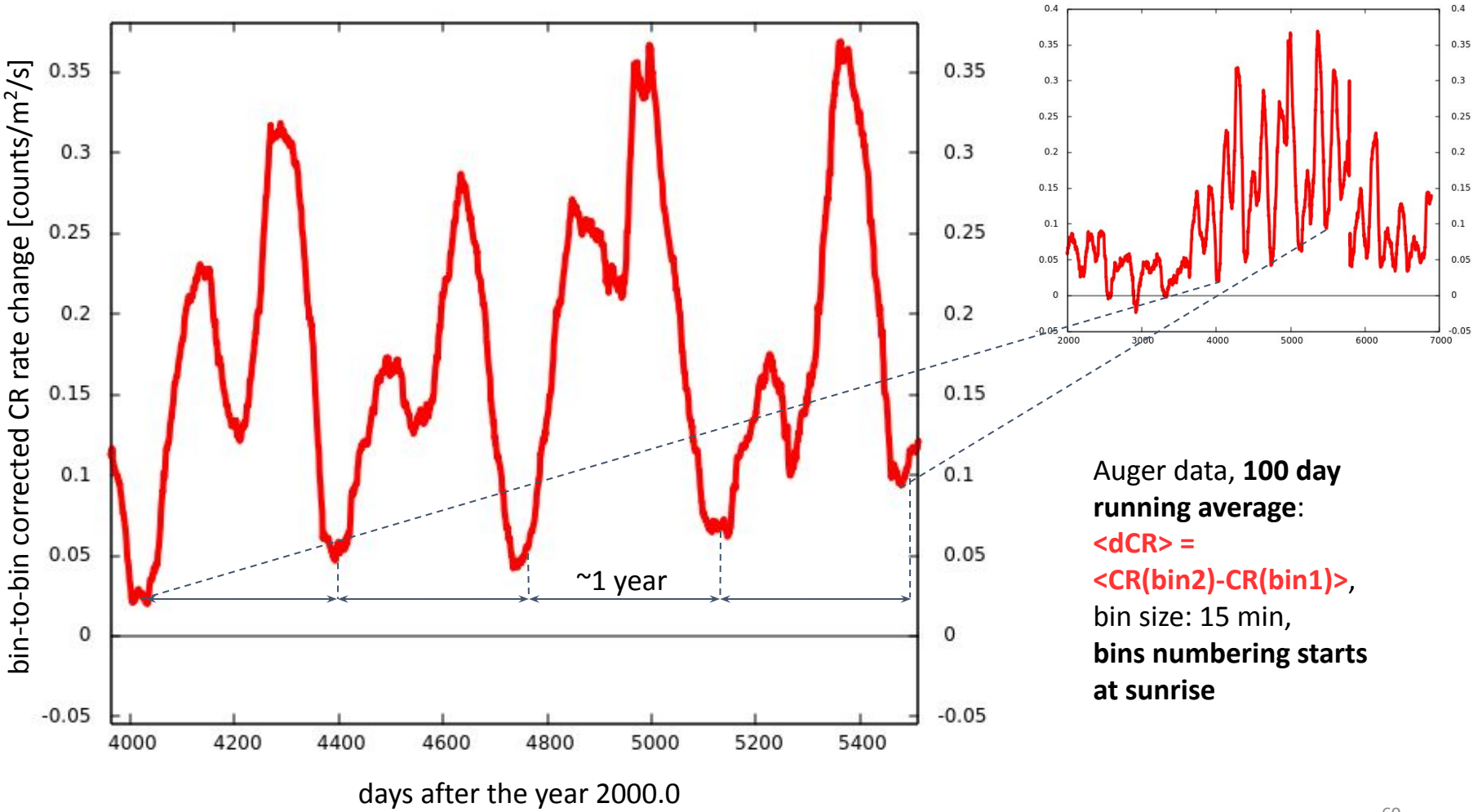
5395.4
5395.6
5395.8
5396
5396.2
5396.4

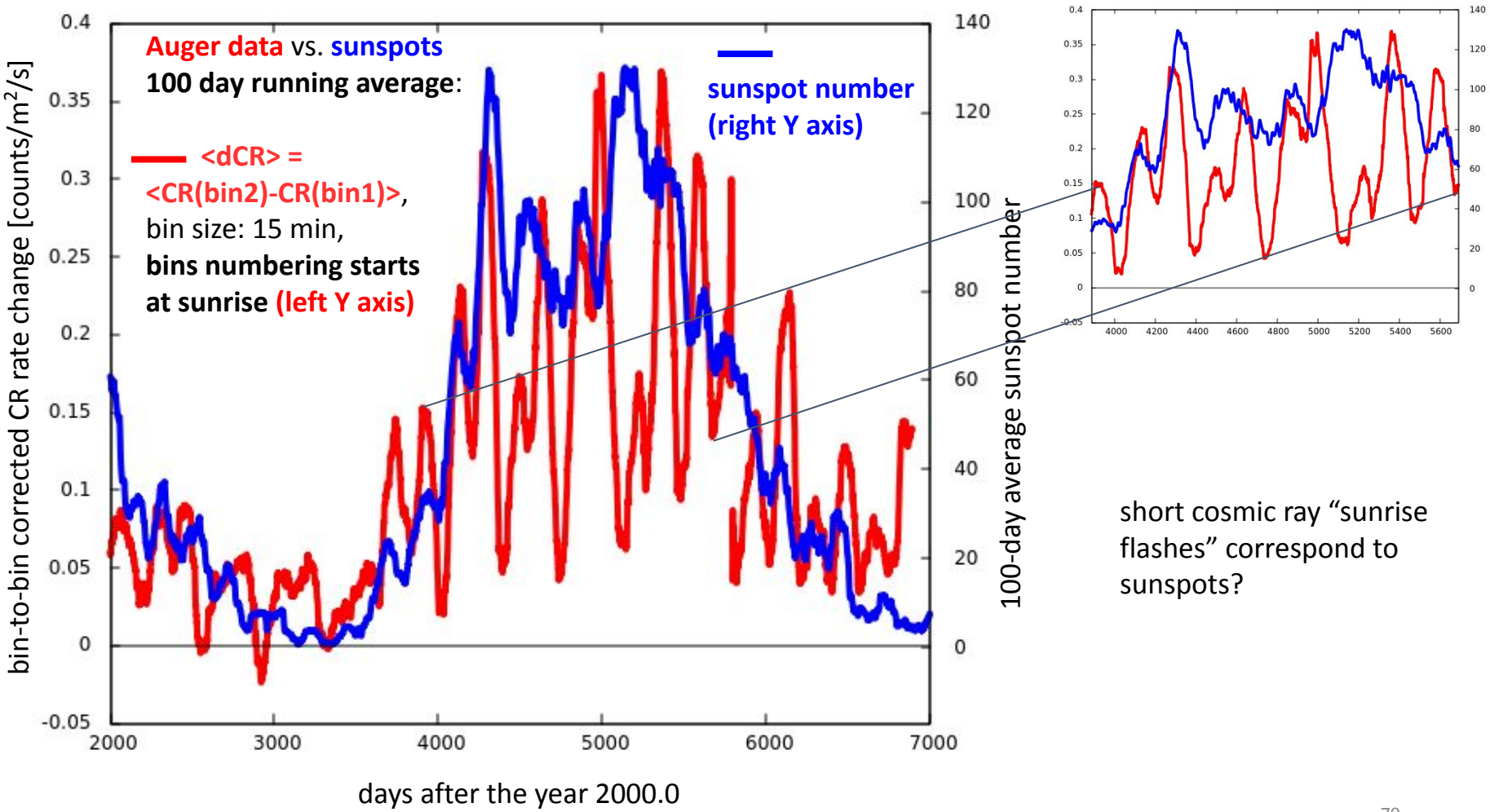


Cosmic ray "flares" **lasting for ~minutes**, at a periodicity or 0.99915 d or 1.00015 d: **~few minutes after the sunrise** at Malargue, Argentina


Auger data, **100 day running average**:
<dCR> = <CR(bin2)-CR(bin1)>,
bin size: 15 min,
bins numbering starts at sunrise
no data
bin-to-bin corrected CR rate change [counts/m²/s]
days after the year 2000.0



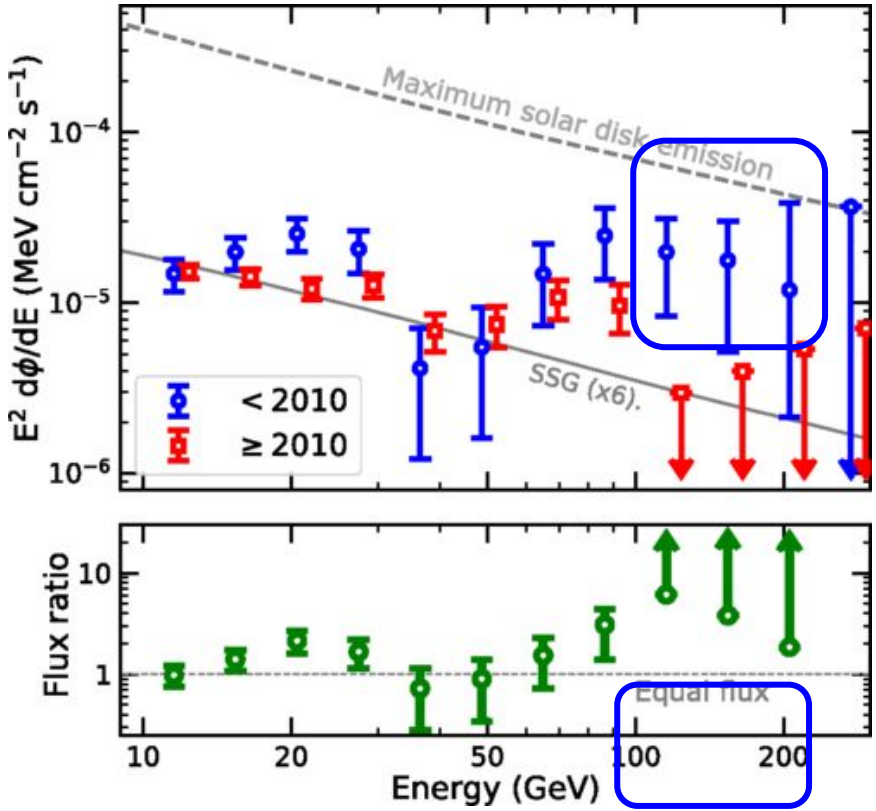
Auger data, **100 day running average**:
<dCR> = <CR(bin2)-CR(bin1)>,
bin size: 15 min,
bins numbering starts at sunrise



short cosmic ray “sunrise flashes” correspond to sunspots?

Hard gamma emission from the solar disk seen only during the solar minimum (Fermi-LAT)

Fermi-LAT: “a New Component of High-Energy Solar Gamma-Ray Production”, observed only during the solar minimum



(Top panel) The solar disk γ-ray spectrum during solar minimum (**before January 1, 2010; blue circles**) and after it (red squares). Small shifts along the x axis improve readability. The gray lines show the SSG model renormalized by a factor of 6 to fit the lowest-energy data point (solid line), and the maximum γ-ray flux that could be produced by hadronic cosmic rays (dashed line). (Bottom panel) The ratio of the γ-ray flux observed during and after solar minimum. All upper and lower limits are based on 2σ Poisson fluctuations in the photon count.

“These **observations** provide important new clues about the mechanisms behind solar disk γ-ray emission, which **remains mysterious**.”

[T. Linden, et al., Phys. Rev. Lett. 121, 131103, https://doi.org/10.1103/PhysRevLett.121.131103]

Journal of Cosmology and Astroparticle Physics

PAPER

Cosmic ray ensembles as signatures of ultra-high energy photons interacting with the solar magnetic field

The CREDO collaboration, N. Dhital[1,2], P. Homola[2], D. Alvarez-Castillo[2,3], D. Góra[2], H. Wilczyński[2], K. Almeida Cheminant[2], B. Poncyljusz[4], J. Mędrala[5], G. Opiła[5], A. Bhatt[1], B. Łozowski[6], G. Bhatta[2], Ł. Bibrzycki[7], T. Bretz[8], A. Ćwikła[9], L. Del Peral[10], A.R. Duffy[11], A.C. Gupta[12], B. Hnatyk[13], P. Jagoda[5,2], M. Kasztelan[14], K. Kopański[2], P. Kovacs[15], M. Krupinski[2], M. Medvedev[16,17], V. Nazari[3], M. Niedźwiecki[18], D. Ostrogórski[5], M. Piekarczyk[7], M.D. Rodríguez Frías[10], K. Rzecki[5], K. Smelcerz[9], K. Smolek[19], J. Stasielak[2], O. Sushchov[2], T. Wibig[20], K. Wozniak[2], J. Zamora-Saa[21,22], Z. Zimborás[15] and A. Tursunov[23] – Hide full author list

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Journal of Cosmology and Astroparticle Physics, Volume 2022, March 2022

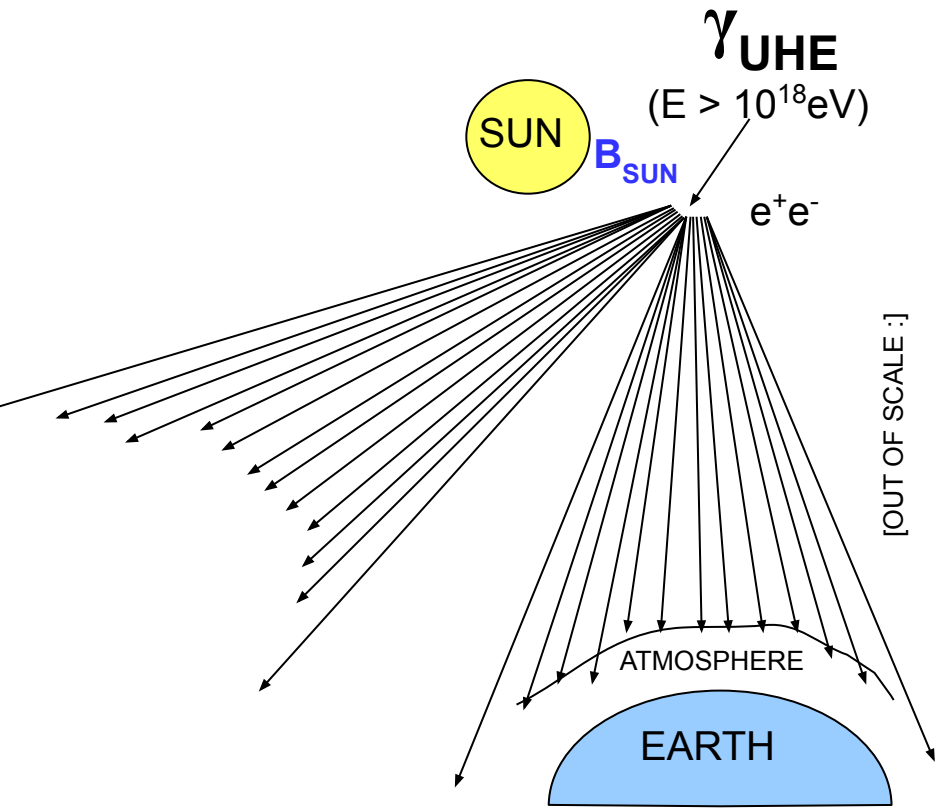
universe

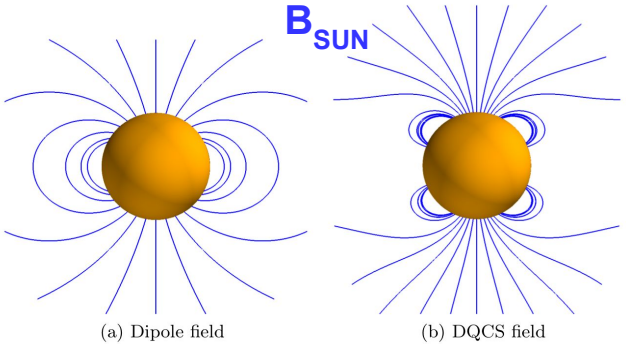
Open Access Article

Simulation of the Isotropic Ultra-High Energy Photon Flux in the Solar Magnetic Field

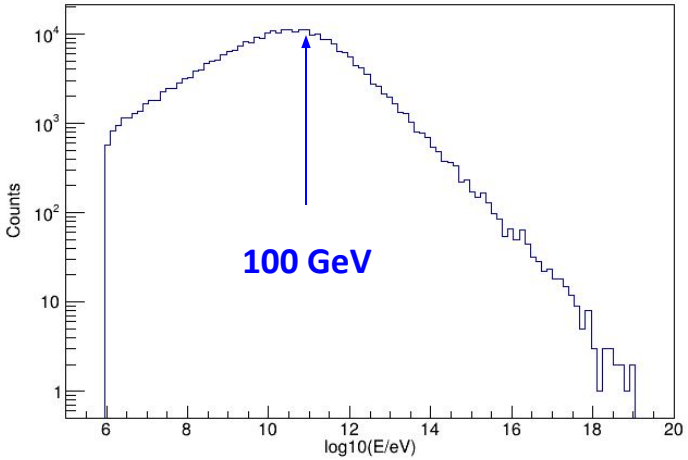
by Bożena Poncyljusz [1,*], Tomasz Bulik [1], Niraj Dhital [2], Oleksandr Sushchov [3], Sławomir Stuglik [3], Piotr Homola [3], David Alvarez-Castillo [3], Marcin Piekarczyk [4], Tadeusz Wibig [5], Jaroslaw Stasielak [3], Péter Kovács [6], Katarzyna Smelcerz [7], Maria Dolores Rodriguez Frias [8], Michał Niedźwiecki [9], Justyna Miszczyk [3], Tomasz Sośnicki [10], Łukasz Bibrzycki [4], Arman Tursunov [11], Luis Del Peral [8] and Krzysztof Rzecki [10]

>=EeV photons nearby the Sun⟶ air shower walls

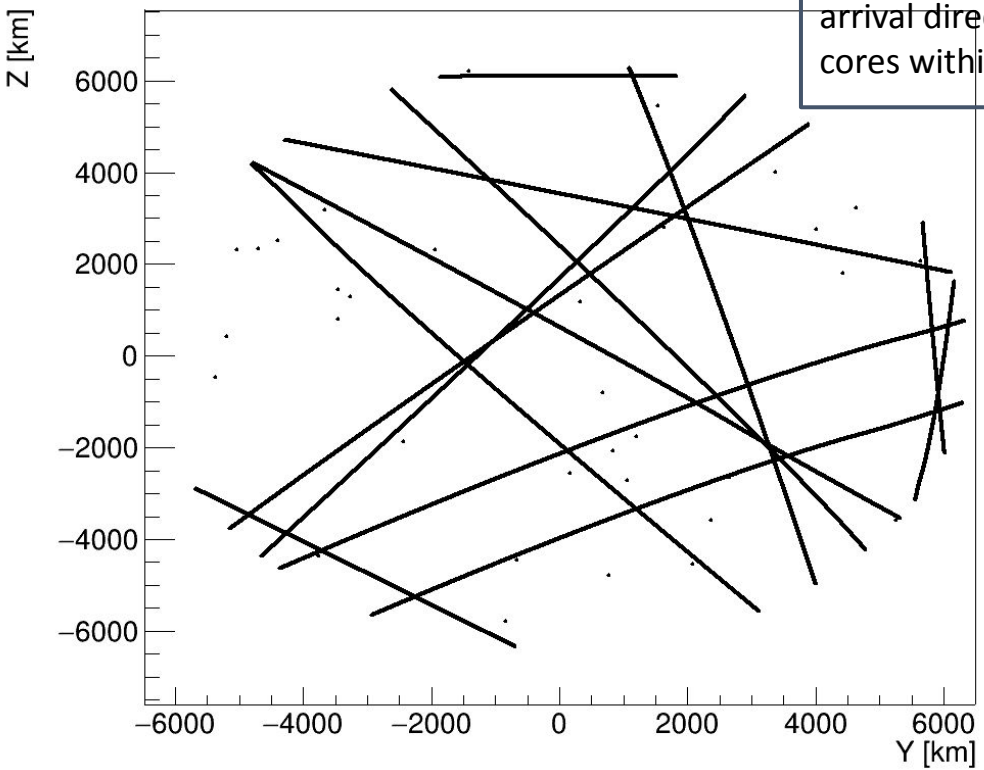




entire photon spectrum engaged



Air shower walls & new astrophysical constraints



Air shower walls simulations: $E_\gamma=10^{20}$ eV, 100 random arrival directions passing near the Sun, CRE footprint cores within 10,000 km from the Earth center

(!) Comparable with the existing observations of the Sun in gamma rays, e.g. Fermi-LAT [T. Linden, et al., Phys. Rev. Lett. 121, 131103; 10.1103/PhysRevLett.121.131103], HAWC [A. Albert et al. (HAWC Collaboration), Phys. Rev. D 98, 123011 (2018); 10.1103/PhysRevD.98.123011

->

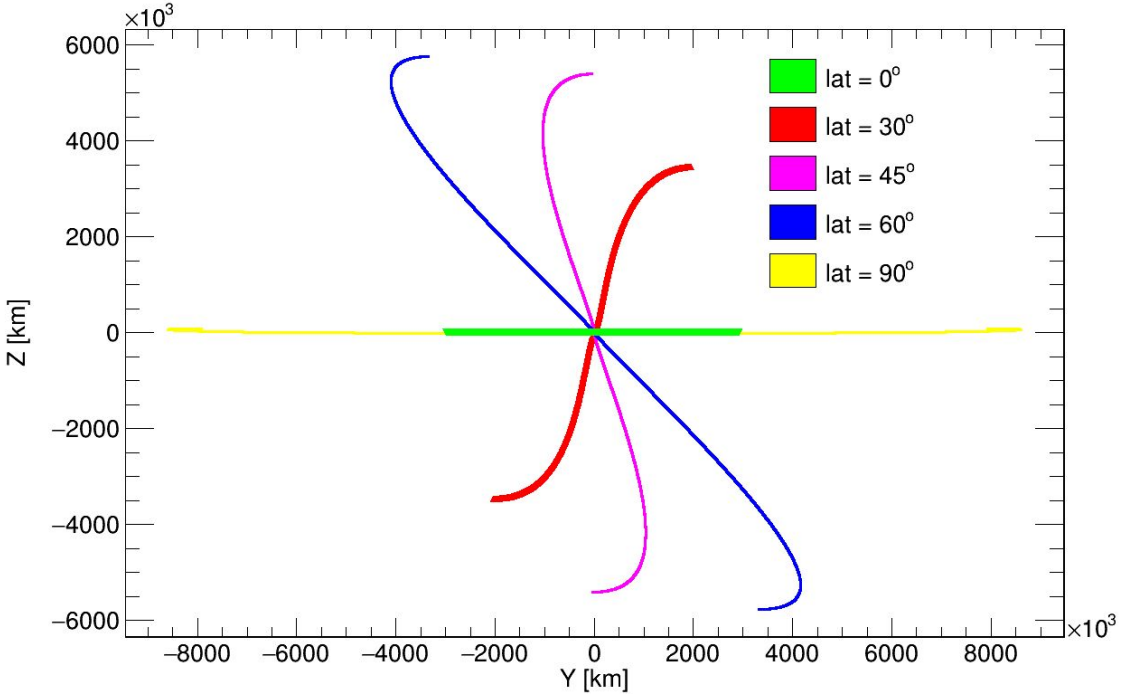
B. Poncyljusz et al. (CREDO Collaboration), *Universe* **2022**, *8*(10), 498; https://doi.org/10.3390/universe8100498

\+ work in progress

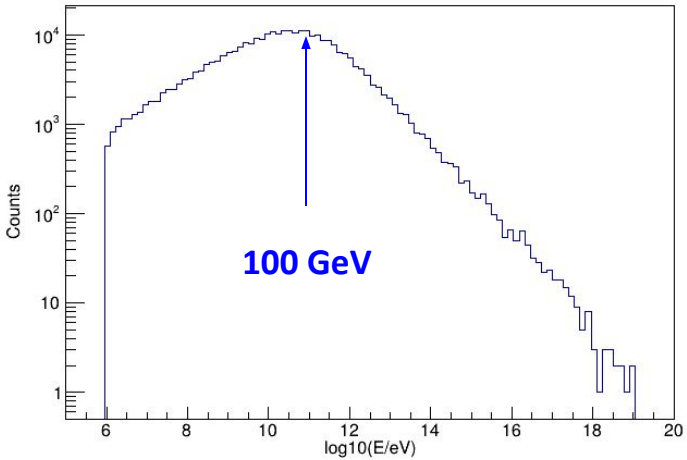
From: BSc project of B. Poncyljusz (UW) with PH and Tomasz Bulik (UW) as supervisors, 2021

Air shower walls: footprints up to 1AU, all photon energies

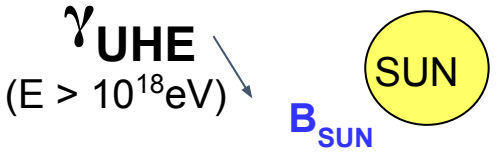
footprints very thin (~1m), up to 1 AU long, non-trivial shapes, dependent on incidence angle and impact parameter

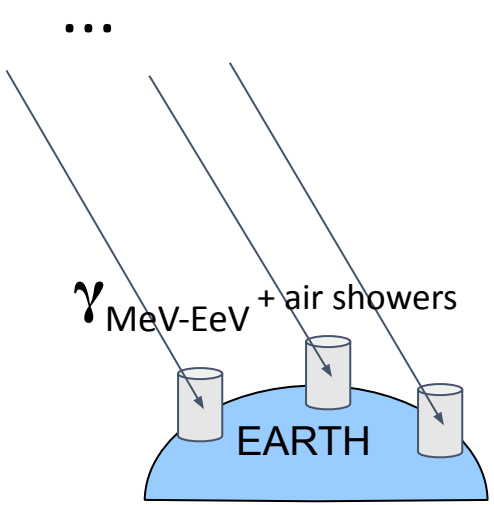


entire photon spectrum engaged

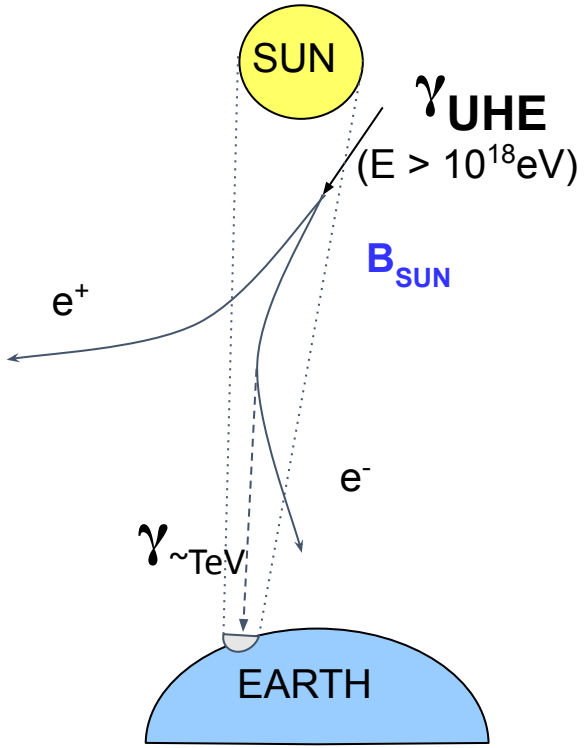


Air shower walls: observe or constrain UHE photons





- displacement > ~100 km
- similar arrival directions
- consistent timing



- γ_{TeV} from the direction of the Sun
- characteristic E spectrum excess towards TeV