Roadmap of Dark Matter models for Run 3

Search for Axion-antiquark-Nuggets via their interaction with LHC:

A reanalysis of stored data from the ~4000 LHC beam monitors

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based on **[A.Z.]** Ariel R. Zhitnitsky, https://arxiv.org/abs/2105.08719 + https://arxiv.org/pdf/2405.04635 *p.t.o.* →

&) On behalf of: D. Budker (Mainz/Germany), G. Cantatore (Trieste/Italy), S. Cetin (Istanbul/Turkije), A. Gougas (Athens/Greece), D. Horns (Hamburg/Germany), M. Maroudas (Hamburg/Germany), M. Karuza (Rijeka/Croatia), A. Kryemadhi (Messiah/USA), K. Ozbozduman (Istanbul/Turkije), O.M. Ruimi (Jerusalem-Mainz/Israel-Germany), Y.K. Semertzidis (Daejeon/Korea), C. Zamantzas (CERN), A. Zhitnitsky (Vancouver/Canada), K. Z. **Further reading**: https://arxiv.org/abs/2403.05608 **March 2024**

AQN high dense anti-quark matter

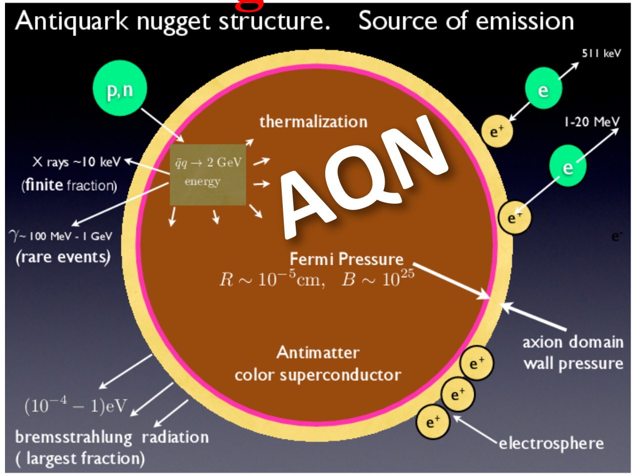
→ DM problem + charge asymmetry in cosmos. + explanation of local mysteries / anomalies → work in progress ←

CERN **13-17 May 2024**

Axion-Quark-Nuggets (AQNs) **A. Zhitnitsky, JCAP 2003 [A.Z.]**

=> ***Color superconductivity in QCD*** => T. Schäfer, F.**Wilczek**, P.R.D 1999

Original motivation: heavy ions & application: NS core => extract a signal?



Baryon number → $\sim 10^{23:28}$

size ~ 0.1 to 1 μm

ρ ≈ nuclear density ≈ 10^{15} gr/cm^3

[A.Z.]: $\rho_{\text{normal matter}} \approx \rho_{\text{DM}}$ => random cosmic coincidence**?**

AQNs: DM problem + charge asymmetry in cosmos + more p.t.o.→

review paper (**Rev Mod Phys,** https://arxiv.org/abs/0709.4635) **on colour superconductors**. cited all original papers Alford Rajagopal **Wilczek** (1998), also (Schäfer and **Wilczek,** 1999) and (Rajagopal **Wilczek** 2000) & Rapp, Schäfer Shuryak Velkowsky

Interaction of AQNs with normal matter: **q-qbar annihilation** → **~2 GeV**

By contrast the maximum energy transfer from the **Witten's nuggets** to surrounding material is $\sim$ $\mathbf{10^{-6} m_p c^2}$ per baryon charge of the nugget

[Submitted on 16 Mar 2020 (v1), last revised 11 Oct 2020 (this version, v2)]

Infrasonic, acoustic and seismic waves produced by the Axion Quark Nuggets

2022

1yr later:

Dmitry Budker , Victor V. Flambaum , Ariel Zhitnitsky

View PDF

We advocate an idea that the Axion Quark Nuggets (AQN) hitting the Earth can be detected by analysing the infrasound, acoustic and seismic waves which always accompany the AQN's passage in the atmosphere and underground. Our estimates for the infrasonic frequency $\nu \simeq 5$ ~Hz and overpressure $\delta p \sim 0.3$ Pa for relatively large size dark matter (DM) nuggets suggest that sensitivity of presently available instruments is already sufficient to detect very intense (but very rare) events today with existing technology. A study of much more frequent but less intense events requires a new type of instruments. We propose a detection strategy for a systematic study to search for such relatively weak and frequent events by using Distributed Acoustic Sensing and briefly mention other possible detection methods.

Comments: Paper is restructured, title is changed. All technical results remain identically the same published May 13, 2023

Mysterious, ultra low-frequency noises detected in Earth's atmosphere + **scientists can't explain them**

NewsBy Ben Turner **from Live Science** **may 2023**

Solar-powered balloons detected strange rumblings at … 70000 feet above Earth's surface. Scientists can't identify them.

https://www.livescience.com/space/astronomy/mysterious-ultra-low-frequency-noises-detected-in-earths-atmosphere-and-scientists-cant-explain-them

DM STREAMS:

grav focusing by solar system bodies. Lens performance => 1/speed^2 & v_{DM} ~ 0.001c

PLUS

Gravitational self-focusing by the inner Earth

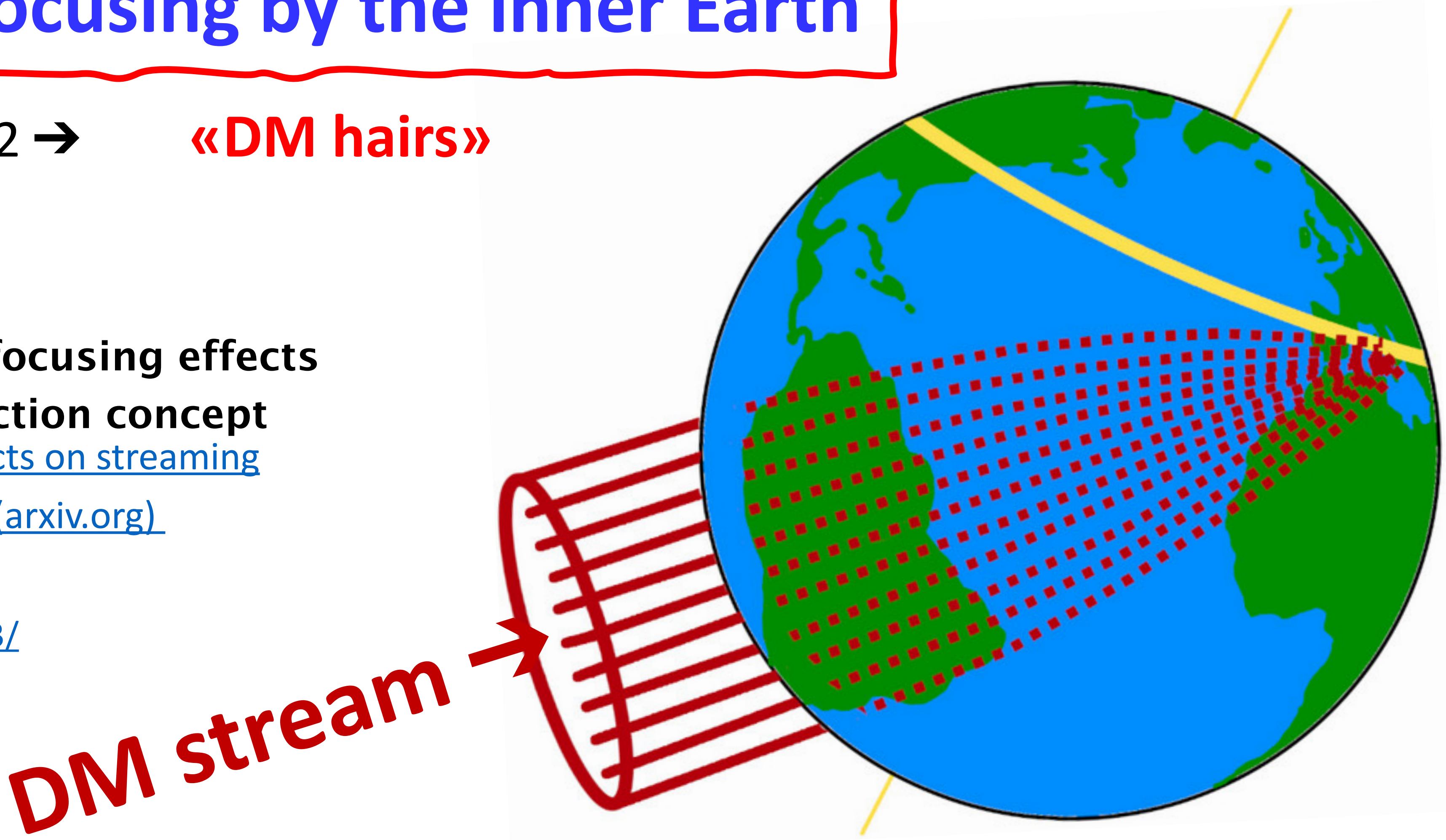
G. **Prezeau**, ApJ. 814 (**2015**) 122 ➔ «DM hairs»

Y. **Sofue**, Galaxies, 8 (**2020**) 42

A. Kryemadhi, M. Maroudas,
A. Mastronikolis, K. Z., **Gravitational focusing effects on streaming DM as a new detection concept**
[2210.07367] Gravitational focusing effects on streaming dark matter as a new detection concept (arxiv.org)

P.R. D108 (**2023**) 123043

https://journals.aps.org/prd/abstract/10.1103/PhysRevD.108.123043



Abaz Kryemadhi

Signal candidate ID:

NOVEL PLANETARY SIGNATURES FROM THE DARK UNIVERSE

p.t.o. ➔

K. Z., V. Anastassopoulos, A. Argiriou, G. Cantatore, S. Cetin, A. Gardikiotis, H. Haralambous, M. Karuza, A.Kryemadhi , M. Maroudas, A. Mastronikolis, C. Oikonomou, K. Ozbozduman, Y.K. Semertzidis, M. Tsagri, I. Tsagris

Astrophysics, 66 (#4), December, **2023;** ASYS(4)_2023.pmd (springer.com)

From the **abstract:**

Local?

DM ⇔ unexpected cosmological observations. ✓ ✓

➔ within our solar system, diverse obs's also defy conventional explanations, like the main physical process(es) underlying the heating of the different solar atmospheric layers, etc.

➔ **Streaming DM ⇔ viable common scenario** : due to gravitational focusing + selffocusing by the solar system bodies. **This fits in as underlying process behind a large Nr of unexplained diverse obs's.** ✓

In short: an unexpected local obs' fits streaming DM origin ⇔ planetary dependency[&)] **no way out**

&) **NO strong remote planetary force**

Results of UFO dynamics studies with beam in the LHC – IOPscience **<= SURPRISE!**

UFOs @ LHC **U**nidentified **F**alling **O**bjects size + exper. ID

similar for AQN ➔ ***first step:*** **Re-analysis - scrutiny**

Some UFOs ➔ AQNs?

AQNs much different than **UFO**s **=>** **ρ:** ≈ gr/cm^3 vs. 10^{15} gr/cm^3

pico-gram => grams / kg.

➔ technique similar / signature **->** extreme e.g. saturation effects

due to many γ's ? =>beam detectors threshold effects**!?**

TBInvestigated

Of note! Over- ⇔ **under**-estimate

DM is.. ‘ *interacts only gravitationally,*

+ widespread: it does not emit or absorb radiation’ …→ **`misleading`**

e.g.: → p.t.o.

"Floating dark matter in celestial bodies," JCAP 10 (**2023**) 057, arXiv:2209.09834 [hep-ph].

Floating DM in celestial bodies Rebecca**K.Leane**+Juri**Smirnov** https://iopscience.iop.org/article/10.1088/1475-7516/2023/10/057 **…**we show that a significant DM population can thermalize **and sit towards the celestial-body surface.** This surface-enhanced DM distribution allows for new phenomenology for DM searches in a wide range of celestial bodies, including the Sun, Earth, Jupiter, Brown Dwarfs, and Exoplanets. … In reality, **a constant stream of DM particles are colliding with stars and planets** at every moment, some of which are not yet in their equilibrium position. The fact that an additional non-equilibrium DM component can exist was considered for the Earth in [89],+extended for Earth further in [90–95]. …>>>> see also:

++

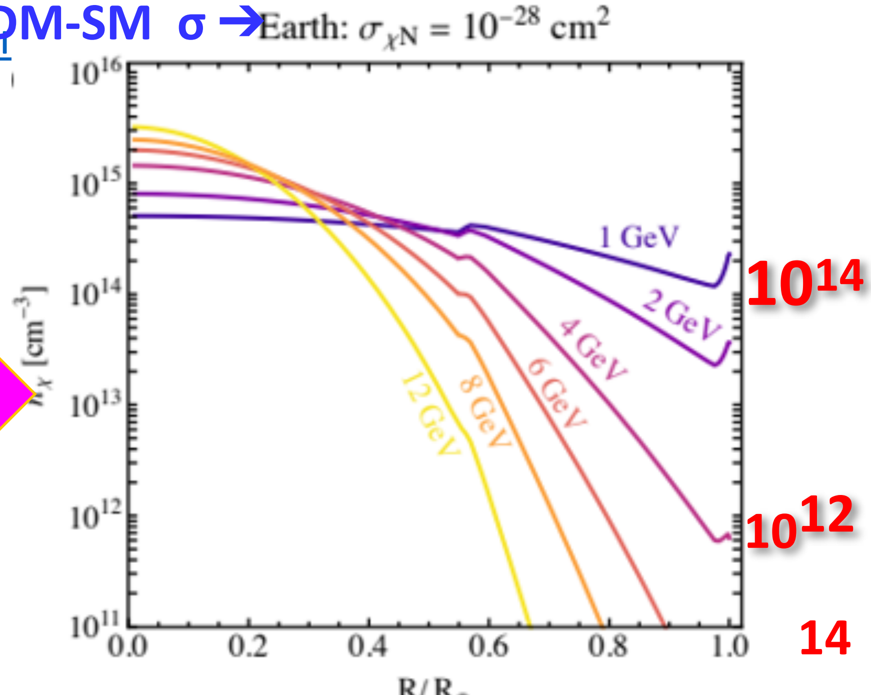
https://doi.org/10.32388/0XHYID **Planetary relationship as a key signature from the dark sector**

Konstantin Zioutas[1], Giovanni Cantatore[2], Serkant Cetin[3], Antonios Gardikiotis[1], Eleni Georgiopoulou[1], Sebastian Hofmann, Marin Karuza[4], Abaz Kryemadhi[5], Marios Maroudas[1], Andreas Mastronikolis[6], Kaan Özbozduf Tsagris[1], Mary Tsagri[1]

For fixed DM-SM σ →

$$\rho_{DM} \approx 0.45\ \text{GeV/cm}^3 \rightarrow \rho_{DM} \approx> 10^{14}\ \text{GeV/cm}^3$$

@ Earth's surface



Direct detection of AQN DM:

for 0.001c→ 3 mm/10 nsec

1. Protons X AQN → via the ¬4000 beam monitors (wire chambers)

   antenna area about 400 m^2 → ~ 1 event / month (grav. Self-focusing ~10^5x

   So far, ∑(LHC ON) ~26 months.

2. Magnets as AQN detectors

   a) bulk cryo magnets as Calorimeters for AQNs → ~ 12000 m^2 => 1 event /d (30kJ)

   b) AQN X SC coils → antenna area about 800 m^2 , BUT priority LHC physics (~1-10 mJ/cm^3)

>> DM = flagship of CERN <<

LHC cryo-magnets as calorimeter for AQNs?

*"The LHC cryogenics system can be used as **a large calorimeter** of 21 km long (8 cold ARC of 2.7 km each). The LHC ARC magnets are regulated at **1.95 K** with superfluid helium + are equipped with about **1500 thermometers** having a resolution of **~1mK**. When SC magnets are at their nominal temperature without powering or special ongoing operation for a long time (few days/weeks per year), the magnets are regulated at ± 5 mK + an extra energy deposition could be detected above **~30kJ.***

SC coils: 1-10 mJ

➔***spatial resolution of 100 m."*** **=>AQNs:5x10^7J/m [A.Z.] Sensitivity margin ~1000x.**

"About the spatial and time resolution in detecting an event:

- *The metal mass is playing a negligible role, because the heat capacity of stainless steel + Iron at 2 K is almost null. The superfluid helium is the dominant component.*
- *Because of superfluidity, the heat propagates almost instantaneously in the superfluid bath over the 100 m. Consequently, it is impossible to figure out where the heat is deposited along the 100m, so **100 m** is the spatial resolution that one can obtain.*
- *About the timing, it takes some time to observe the helium rising in temperature due to the very high heat capacity of superfluid helium. Typically, one should expect a time resolution with precision of about **2 min**."*

THANKS

for the invitation and your attention!

Back-up slides

arXiv:2108.11647 [pdf]

The Dark Universe is not invisible

Phys. Sci. Forum 2021, 2(1), 10 Febr. 2021

Trillions of DM particles may lurk in Earth's crust

https://doi-org.ezproxy.cern.ch/10.1016/S0262-4079(22)01808-5 Oct. 2022

Dunkle Materie weniger dunkel?

= **Is DM less dark?**

https://www.scinexx.de/news/kosmos/dunkle-materie-wer-enigdunkel/ Febr. 2023

Seminar at CERN 28/3/2023, M. Hostert. **Semi-Visible Dark Photons**

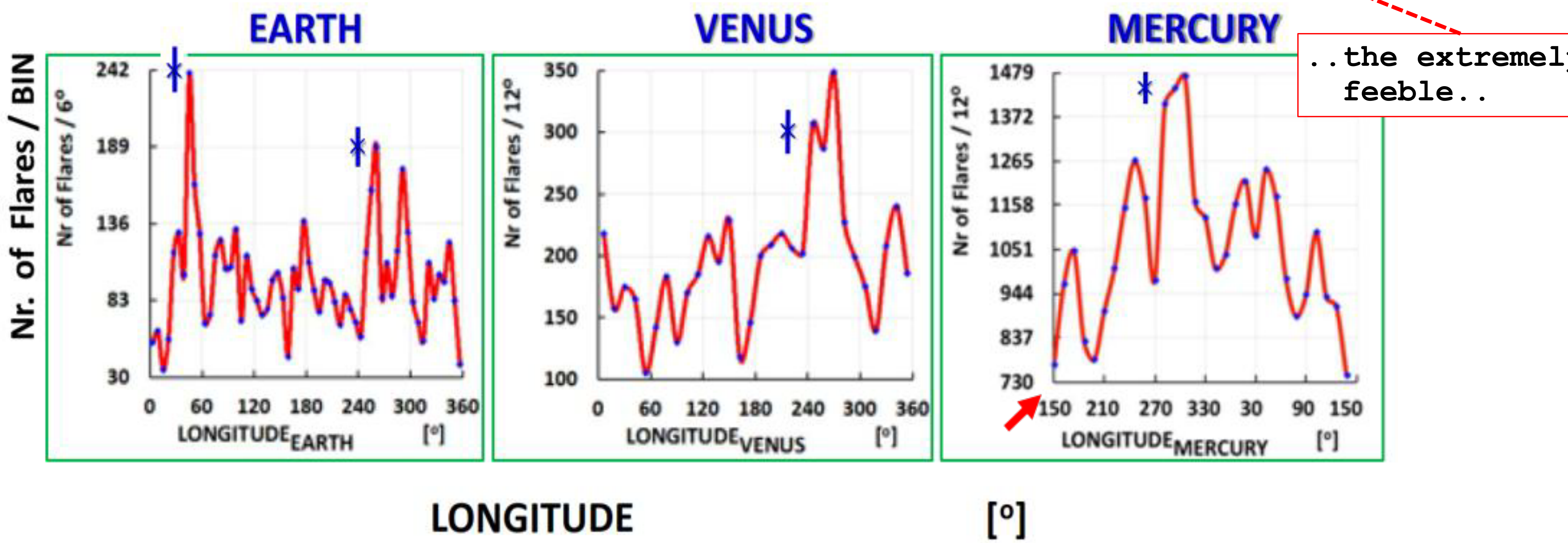
https://arxiv.org/abs/2302.05410 self-interacting DM? Febr. 2023

Solar Flares

Biggest + unpredictable solar system "***explosions***"

Peaking *planetary relationship,*

excludes remote planetary interaction, like: tidal forces



We briefly overview the main differences between AQN model and Witten's quark nuggets [12–14] in next section II A. However, we want to emphasize here that the main distinct feature of the AQN model in comparison with Witten's quark nuggets is that AQNs can be made of matter as well as antimatter during the QCD transition as a result of this charge segregation process

….

We remind the readers that **the antimatter in this framework appears as natural resolution of the long standing puzzle on similarity between visible and DM components, $\Omega_{DM} \sim \Omega_{visible}$ irrespective to the parameters of the model. This feature is a result of the dynamics of the CP violating axion field during the QCD formation period.**

$$\frac{\langle \dot{N} \rangle}{4\pi R_{\oplus}^2} = \frac{0.4}{\mathrm{km}^2\mathrm{yr}} \left(\frac{10^{24}}{\langle B \rangle}\right) \left(\frac{\rho_{\mathrm{DM}}}{0.3\,\frac{\mathrm{GeV}}{\mathrm{cm}^3}}\right) \left(\frac{\langle v_{\mathrm{AQN}} \rangle}{220\ \mathrm{km\ s}^{-1}}\right). \quad (5)$$

https://journals.aps.org/prd/pdf/10.1103/PhysRevD.101.043512 **PRD 101** **2020**

https://indico.cern.ch/event/1336733/contributions/5631509/attachments/2762863/4811858/LHCDM24%20workshop-3.pdf

WORKSHOP AT CERN

13-17 May 2024

Session: Unexplored signatures & wildcard ideas
(Monika Blanke, Alexander Grohsjean, Giuliano Gustavino)

AQNs high dense anti-quark matter
→ DM problem + charge asymmetry in cosmos.
+ explanation of local **mysteries / anomalies**
→ **work in progress**
←

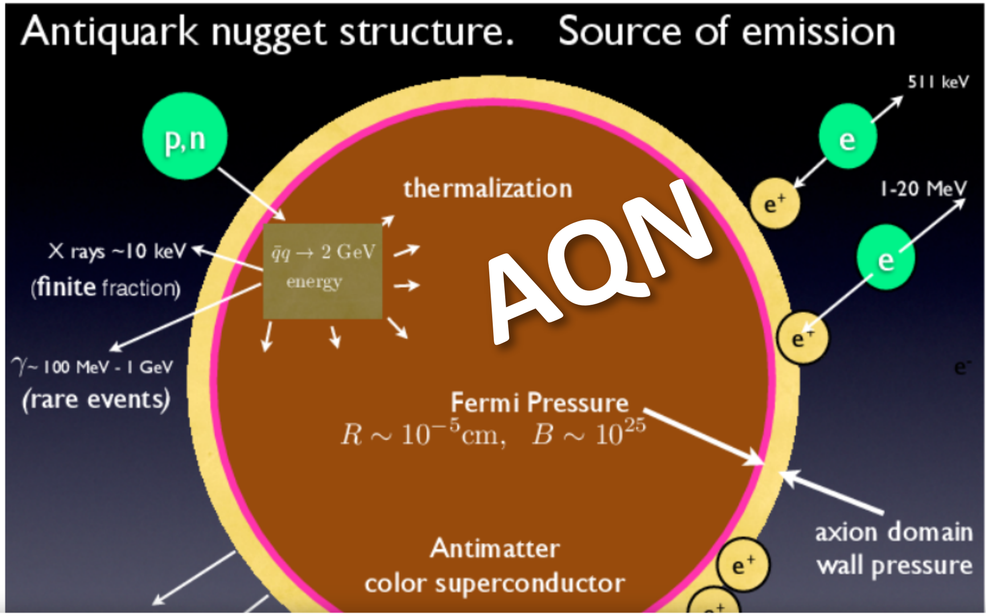


FIG. 2. (Anti)nugget internal structure and sources of emission from the core of the galaxy.

Floating DM in celestial bodies

RebeccaK.**Leane**+Juri**Smirnov** https://iopscience.iop.org/article/10.1088/1475-7516/**2023**/10/057

…we show that a significant DM population can thermalize **and sit towards the celestial-body surface.** This surface-enhanced DM distribution allows for new phenomenology for DM searches in a wide range of celestial bodies, including the Sun, Earth, Jupiter, Brown Dwarfs, and Exoplanets. … In reality, **a constant stream of DM particles are colliding with stars and planets** at every moment, some of which are not yet in their equilibrium position. The fact that an additional non-equilibrium DM component can exist was considered for the Earth in [89],+extended for Earth further in [90–95].

R. K. Leane and J. Smirnov, "Floating dark matter in celestial bodies," JCAP 10 (**2023**) 057, arXiv:2209.09834 [hep-ph].

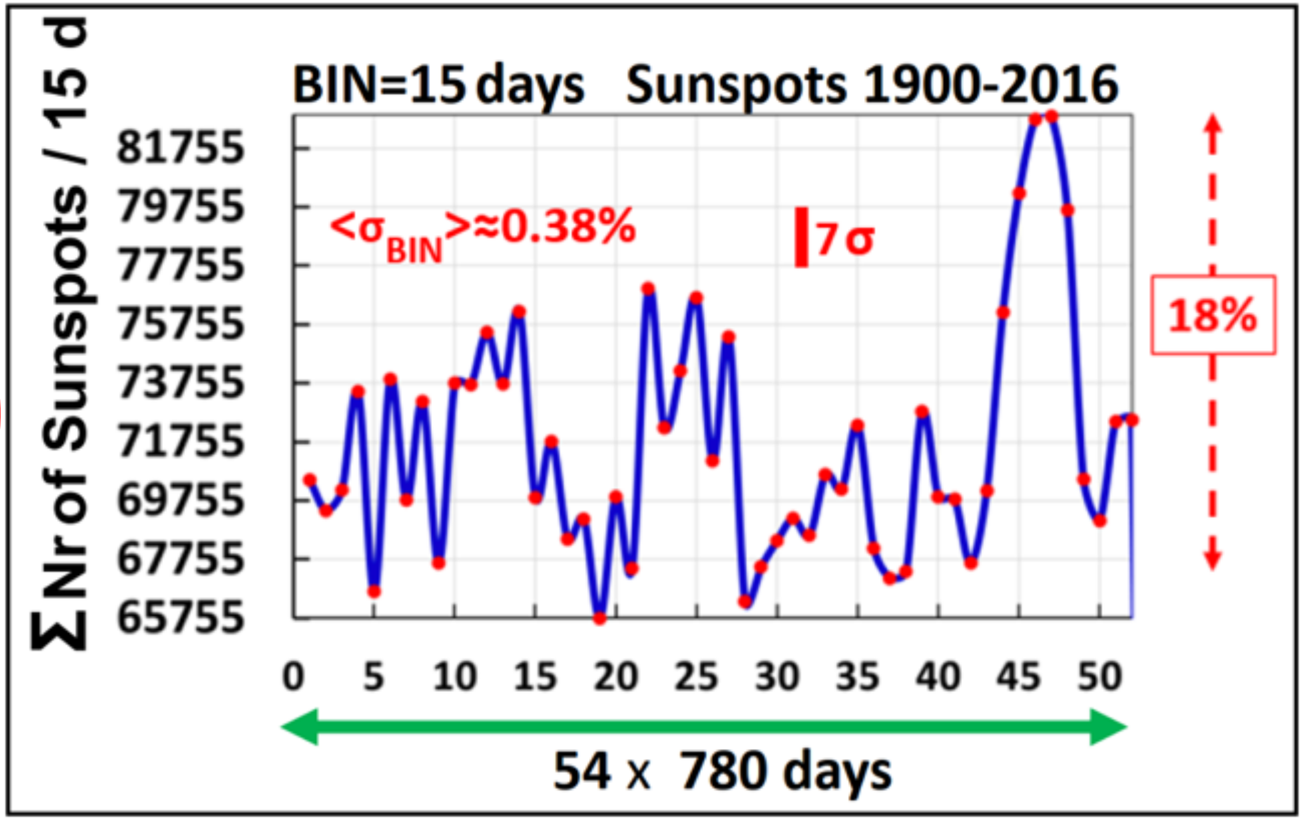


Figure 1. Summing up 54 consecutive Mars-Earth synods of 780 days. The statistical significance of the various peaks is (far) above 5σ. The 780-day periodicity is not recovered by the Lomb-Scargle periodogram (.

https://www.qeios.com/read/0XHYID

Bertolucci et al./Phys.Dark Universe17(**2017**)13

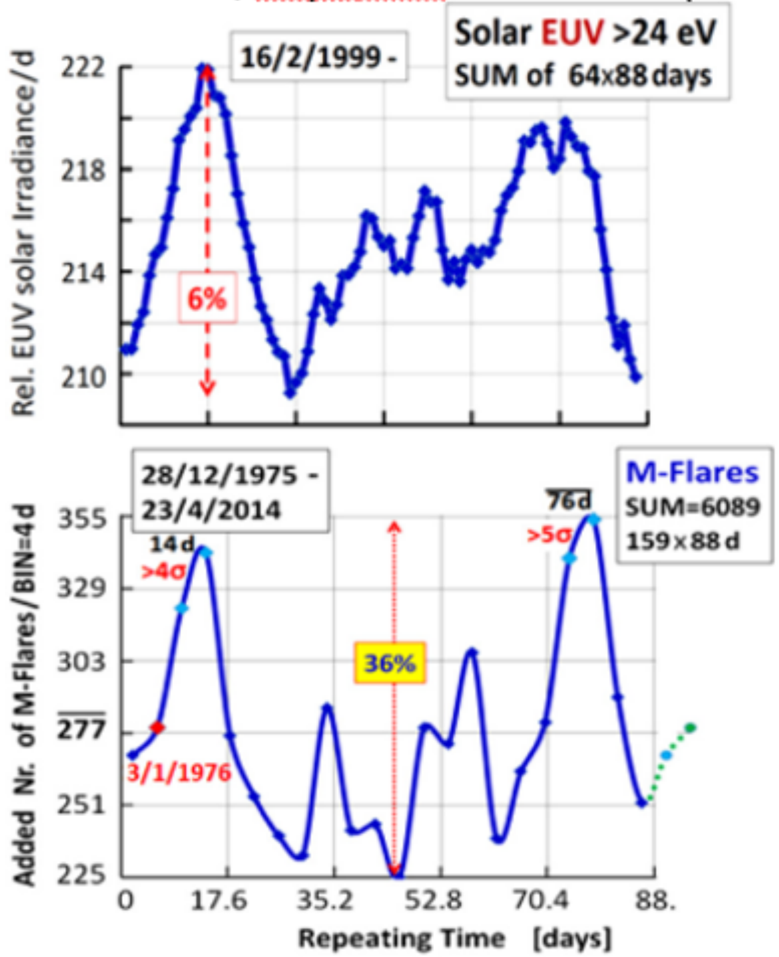
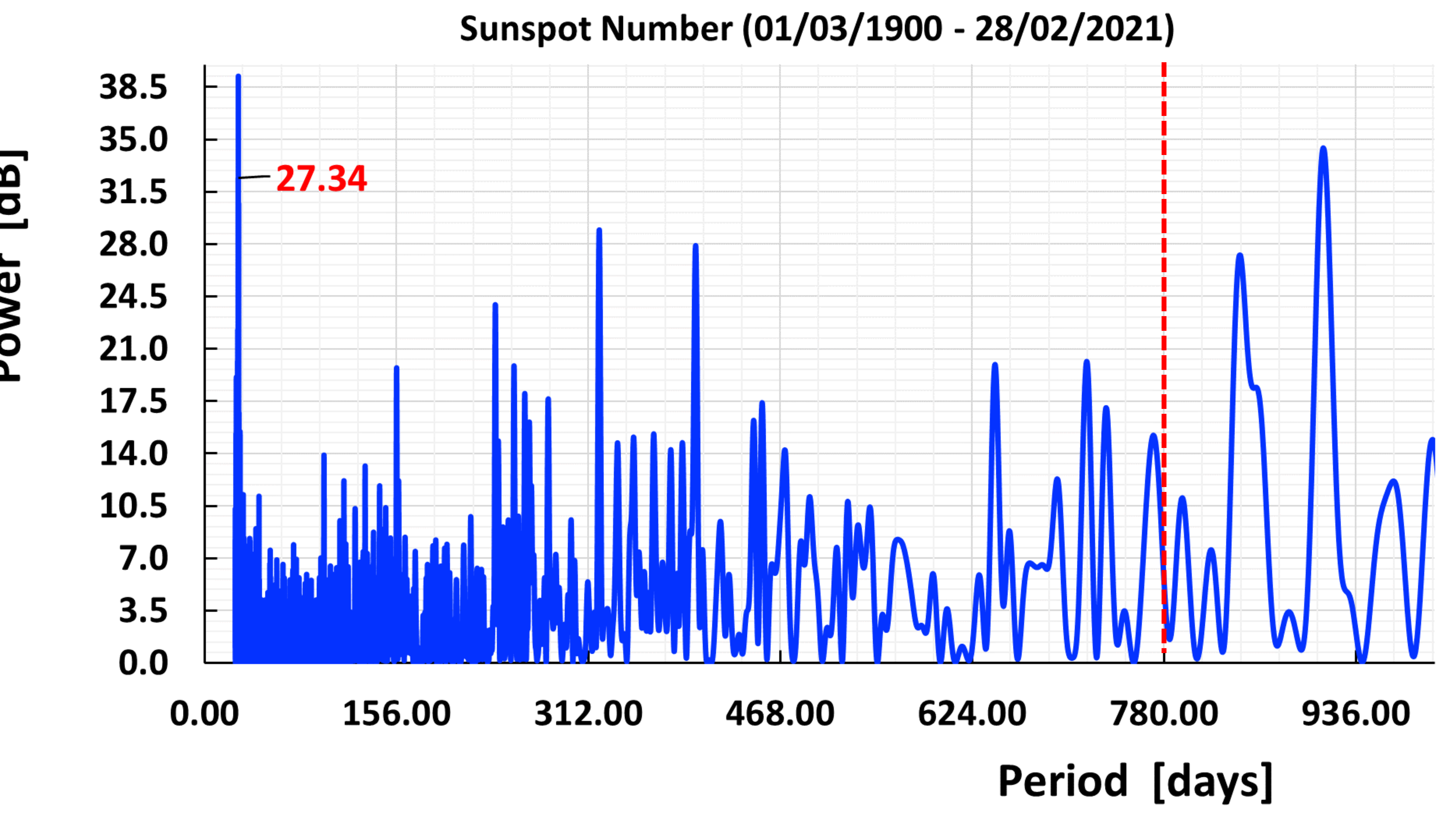


Fig. 10. The sum of consecutive time intervals of 88 days for solar EUV (UP) and M-Flares (BOTTOM). The fluctuations of the upper plot show that the measured EUV values are accurate below the ~1% level, which is sufficient for the purpose of this work. The zero point in the *X*-coordinate coincides (within 1 bin) with Mercury's heliocentric longitude $\Theta = 0°$. The BIN size is equal to 1 day and 4 days, for EUV and M-flares, respectively.

http://dx.doi.org/10.1016/j.dark.2017.06.001



Sunspot Number (01/03/1900 - 28/02/2021)
Power [dB]
38.5
35.0
31.5
28.0
24.5
21.0
17.5
14.0
10.5
7.0
3.5
0.0
27.34
0.00
156.00
312.00
468.00
624.00
780.00
936.00
Period [days]

Physics

Rebecca Leane Stanford University & Juri Smirnov University of Liverpool

Trillions of dark matter particles may lurk in Earth's crust

DARK matter can be trapped inside massive objects, and much of it may be closer to the surface of stars and planets than we realised. On Earth, there may be more than 10 trillion dark matter particles in each cubic centimetre of the planet's crust.

Dark matter is a hypothetical form of matter that isn't visible because it doesn't seem to interact with light. However, it does interact with regular, or baryonic, matter via gravity, and particles of dark matter may occasionally smash into particles of baryonic matter.

Rebecca Leane at Stanford University in California and Juri Smirnov at the University of Liverpool in the UK calculated how these collisions would affect the distribution of dark matter inside celestial bodies. Our galaxy and most others are in huge clouds of dark matter, so a constant stream of these particles is probably entering every planet and star in the galaxy.

Leane and Smirnov found that this dark matter doesn't simply sink to the centres of planets and stars as some past research has assumed. "If you're a dark matter particle, you have gravity pulling you towards the centre of the star or the planet, but as you head down you're bouncing off of all the matter on the way to the core," says Leane. "It turns out that even if you give the dark matter as much time as it likes, some of it still ends up near the surface because of all this bouncing."

They calculated that, in the sun, this would result in 100 trillion particles of dark matter or more in each cubic centimetre of the surface.

"If there's a bunch of dark matter at the surface of the Earth, that could make it easier to detect"

While current detectors aren't built to search for this trapped dark matter – it is expected to move slower than dark matter hurtling in from space, so it would carry less energy and be harder to detect – a high concentration near the surface could help future experiments.

"If there's a bunch of dark matter just sitting at the surface of the Earth, that could make it easier to detect," says Leane. ■

Leah Crane