

Axion Quark Nuggets DM and Matter-Antimatter asymmetry: theory, observations and future searches

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*19-th PATRAS workshop on Axions, WIMPs and WISPs,
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- The main goal of this talk is to overview a novel paradigm when the DM behaves as a **strongly** interacting object instead of **weakly** interacting object in old canonical paradigm. The new paradigm is based on the so-called Axion Quark Nugget (AQN) DM framework
- A number of talks of this workshop are based on this new ideas. This talk is a brief Introduction to the AQN framework:
- Ophir Ruimi, Sept 17, 5:35pm, “Search for AQN at LHC”
- Jinsu Kim, Sept 18, 10:25am, “ Search for AQN at CAPP”
- Mihaela Parvu, Sept 19, 4:05pm, “Detection of Axion Anti-Quark Nuggets via their interaction in kt liquid detectors”

1. THE DM AND BARYOGENESIS AS TWO SIDES OF THE SAME COIN

- THERE ARE TWO (APPARENTLY UNRELATED) PHENOMENA:
 - 1. 80-YEARS OLD MYSTERY: THE NATURE OF DARK MATTER (ZWICKY 1937)
 - 2. ANOTHER 50-YEARS OLD MYSTERY: BARYOGENESIS (SAKHAROV, 1967)
- MANY OTHER OBSERVED PUZZLES AND MYSTERIOUS EVENTS ... TO BE MENTIONED TODAY...
- WHY THE BARYONIC MATTER DENSITY Ω_{visible} AND THE DARK MATTER DENSITY Ω_{dark} ARE SIMILAR IN VALUES AS OBSERVATIONS SUGGEST, $\Omega_{\text{dark}} \simeq 5 \Omega_{\text{visible}}$? THEY COULD ASSUME DRAMATICALLY DIFFERENT SCALES IF THEY ARE ORIGINATED FROM DIFFERENT PHYSICS.

Fritz Zwicky and Vera Rubin



The DM side of the coin



Sakharov

Sakharov formulated precise criteria when such baryogenesis is possible:

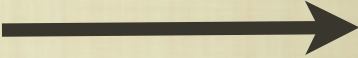
1. There must be B-violation;
2. There must be C and CP violation;
3. There must be out-of-equilibrium dynamics

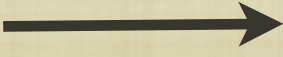
The Baryogenesis side of the coin

2. OLD PARADIGM VS NEW PARADIGM

■ 1. “NAIVE, OLD PARADIGM” MORAL: DM REQUIRES NEW FIELDS SUCH AS WEAKLY INTERACTING MASSIVE PARTICLES (WIMP)S. NOTHING IS FOUND SO FAR, SEE NEXT SLIDE

■ 2. “NAIVE, OLD PARADIGM” MORAL: NEW FIELDS MUST BE NONBARYONIC. ARGUMENTS COME FROM STRUCTURE FORMATION REQUIREMENTS, BIG BANG NUCLEAR SYNTHESIS (BBN), ETC, SEE A SLIDE FROM CERN PAGE

■ NEW PARADIGM: INSTEAD OF “NEW FIELDS”  “NEW PHASES” OF “OLD FIELDS” (QUARKS AND GLUONS)

■ INSTEAD OF “BARYOGENESIS”  “SEGREGATION OF CHARGES” OF CONVENTIONAL FIELDS (QUARKS) AT $\theta \neq 0$

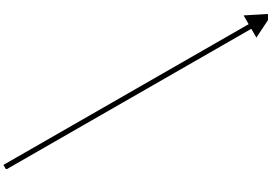
Dark matter

Invisible dark matter makes up most of the universe – but we can only detect it from its gravitational effects

Galaxies in our universe seem to be achieving an impossible feat. They are rotating with such speed that the gravity generated by their observable matter could not possibly hold them together; they should have torn themselves apart long ago. The same is true of galaxies in clusters, which leads scientists to believe that something we cannot see is at work. They think something we have yet to detect directly is giving these galaxies extra mass, generating the extra gravity they need to stay intact. This strange and unknown matter was called "dark matter" since it is not visible.

Dark matter

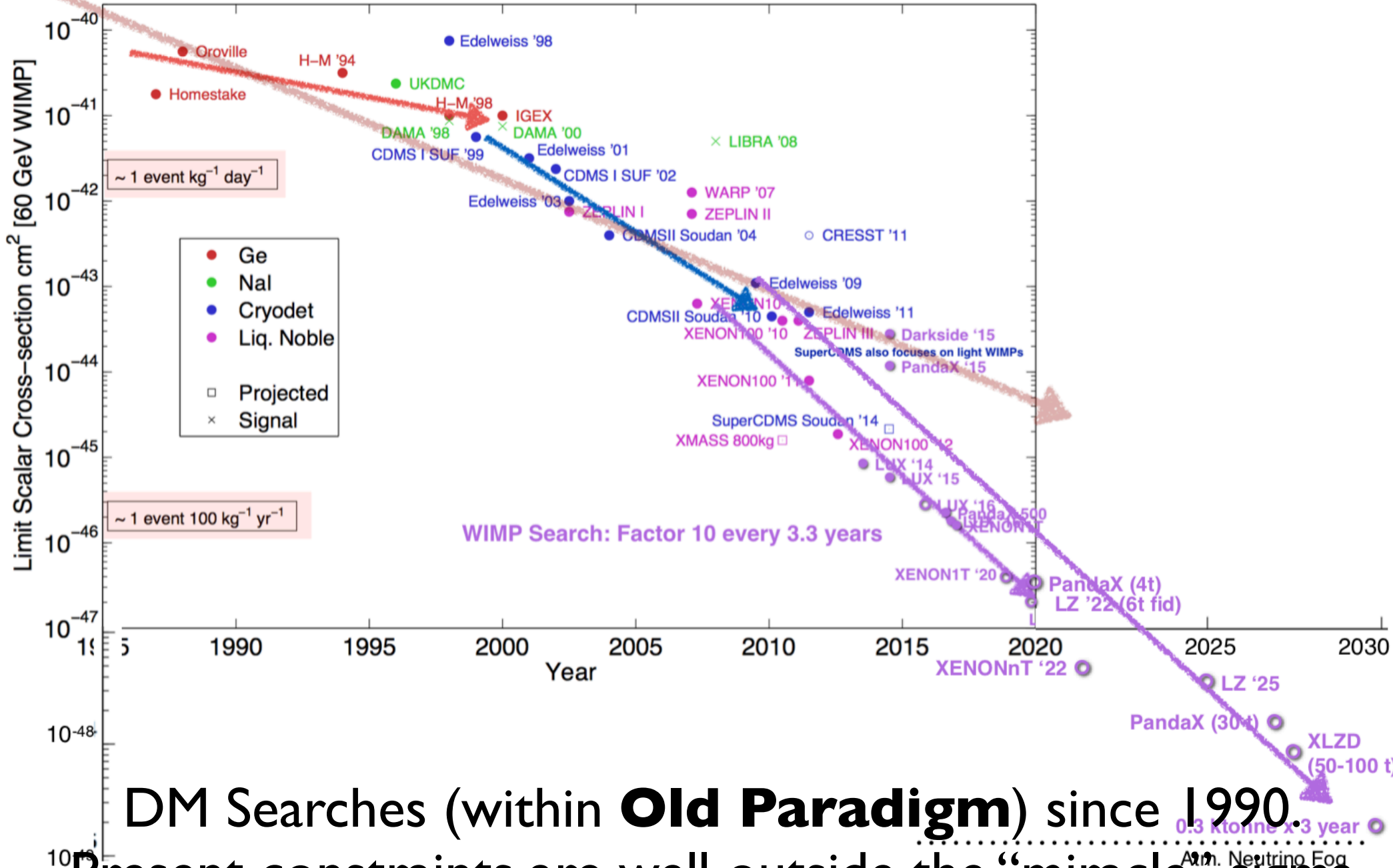
Unlike normal matter, dark matter does not interact with the electromagnetic force. This means it does not absorb, reflect or emit light, making it extremely hard to spot. In fact, researchers have been able to infer the existence of dark matter only from the gravitational effect it seems to have on visible matter. Dark matter seems to outweigh visible matter roughly six to one, making up about 27% of the universe. Here's a sobering fact: The matter we know and that makes up all stars and galaxies only accounts for 5% of the content of the universe! But what is dark matter? One idea is that it could contain "supersymmetric particles" – hypothesized particles that are partners to those already known in the [Standard Model](#). Experiments at the [Large Hadron Collider](#) (LHC) may provide more direct clues about dark matter.



Unlike normal matter, dark matter does not interact with electromagnetic force. This means it does not absorb, reflect or emit light, making it extremely hard to spot...

Moore: Factor 10 every 6.5 years

Dark Matter Searches: Past, Present & Future



DM Searches (within **Old Paradigm**) since 1990.

Present constraints are well outside the “miracle” sigma

■ FURTHERMORE, OUR CLAIM IS THAT WE HAVE BEEN WITNESSING (INDIRECTLY) THE MANIFESTATIONS OF THE DM (BEYOND GRAVITY) FOR YEARS WITH MANY PUZZLING OBSERVATIONS AT ALL SCALES (BBN, GALACTIC, SUN, EARTH)

■ TODAY I SPECIFICALLY FOCUS ON SEVERAL OBSERVED PUZZLES AND ANOMALIES WHICH COULD BE THE MANIFESTATIONS OF THIS NEW PARADIGM DM :

1. MYSTERIOUS DIFFUSE GALACTIC UV RADIATION;
2. SOLAR CORONA HEATING MYSTERY (SINCE 1939)
3. FUTURE SEARCHES: BROADBAND DETECTION STRATEGY -THE DAILY MODULATIONS (CAST/CAPP ANALYSIS) AND NEW BROADBAND INSTRUMENTS SUCH AS BREAD

■ THE IDEA THAT THE DM COULD BE IN FORM OF VERY DENSE QUARK NUGGETS (QN) OF STANDARD MODEL FIELDS IS NOT NEW AND HAS BEEN ADVOCATED BY **WITTEN IN 1984**

■ THE CRUCIAL (FOR COSMOLOGY) PARAMETER σ/M IS SMALL. THEREFORE, THE NUGGETS ARE QUALIFIED AS DM CANDIDATES

$$\frac{\sigma}{M} \ll 1 \left(\frac{\text{cm}^2}{\text{gram}} \right)$$

E. Witten



THERE WERE MANY PROBLEMS WITH THE ORIGINAL 1984- WITTEN'S IDEA:

1. THERE IS NO FIRST ORDER PHASE TRANSITION IN QCD
2. FAST EVAPORATION
3. HARD TO ACHIEVE STABILITY
4. E.T.C.

AS A RESULT THE IDEA WAS DROPPED IN 90-S

NEW ELEMENT TO RESCUE THE NUGGET'S IDEA: THE AXION

■ THERE ARE TWO NEW ELEMENTS (IN COMPARISON WITH OLD WITTEN'S CONSTRUCTION):

1. THERE IS EXTRA CP ODD AXION FIELD. PRECISELY THIS CP ODD FIELD $\theta \neq 0$ IS RESPONSIBLE FOR CHARGE SEGREGATION OF THE CHARGE (REPLACING BARYOGENESIS)

2. AS A CONSEQUENCE: THERE ARE TWO SPECIES, THE NUGGETS AND ANTI-NUGGETS (REPRESENTING THE DM).

THE CONSTRUCTION LEADS TO THE SIMILARITY BETWEEN DARK AND VISIBLE SECTORS: $\Omega_{\text{dark}} \approx \Omega_{\text{visible}} \sim \Lambda_{\text{QCD}}$

■ THE NUGGETS AND ANTI-NUGGETS ARE ABSOLUTELY STABLE OBJECTS ON THE COSMOLOGICAL TIME SCALE. ONLY SMALL PORTION OF THE BARYON CHARGE GET ANNIHILATED DURING BBN, CMB, POST-RECOMBINATION EPOCHS.

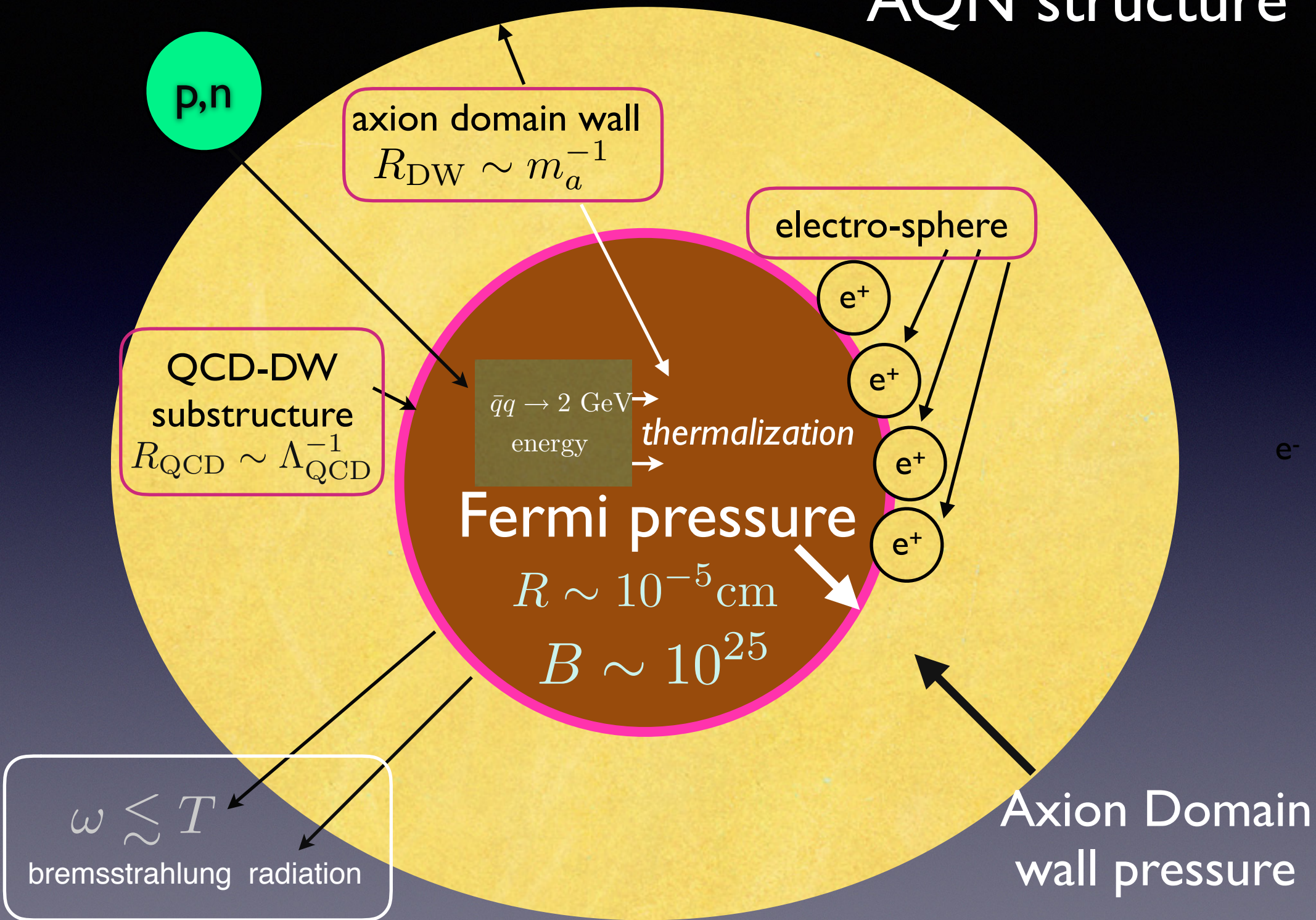
■ THEREFORE, THE AQNS SURVIVE THE LONG EVOLUTION IN UNFRIENDLY ENVIRONMENT UNTIL PRESENT DAY.


Disclaimer:

- In the applications to be discussed below I take agnostic viewpoint regarding the formation mechanism- I assume that such antimatter nuggets do exist. It is consistent with all cosmological, astrophysical, satellite, and terrestrial observations as long as

$$\langle B \rangle \geq 3 \cdot 10^{24} \quad [\text{direct IceCub constraint}]$$

AQN structure



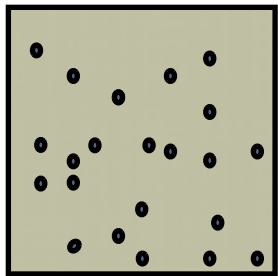
- The **New Paradigm** is: the DM could be in form of very dense and heavy quark nuggets, called the Axion Quark Nugget (AQN) which **strongly** interact with SM particles, quarks and gluons.
- Why don't we see these strongly interacting AQNs in everyday life?
- The answer is: conventional WIMP's density is $\frac{1 \text{ WIMP}}{(\text{litre})}$
- while typical AQN density is $\frac{1 \text{ AQN}}{(1000 \text{ km})^3}$  very rare events
- Nevertheless, I want to argue that we have been witnessing of such **rare** events of **strongly interacting objects** for years and even centuries. My arguments today are based exclusively on well-recorded events by modern physics laboratories.
- These events are usually called “mysterious”, “puzzling”, “anomalous”, “exotic” etc events without given any explanations

MATTER IN THE UNIVERSE

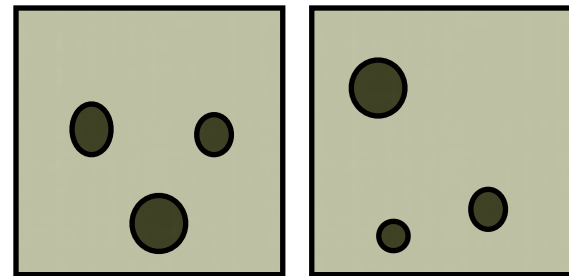
1. CP violating parameter $\theta \sim 1$ generates the difference between number of nuggets and antinuggets which must be order of one effect (observations: $B_{nugget}/\bar{B}_{antinugget} \simeq 2/3$)
2. The annihilation processes continue until visible anti-baryons get annihilated and baryons remain;
3. The final result: $\Omega_{\text{dark}} \approx \Omega_{\text{visible}}$ as observed irrespective to any parameters of the model

$$B_{tot} = 0 = B_{nugget} + B_{visible} - \bar{B}_{antinugget}$$

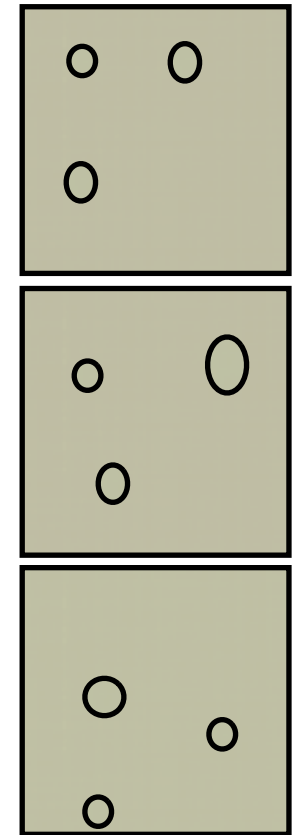
$$B_{DM} = B_{nugget} + \bar{B}_{antinugget} \simeq 5 B_{visible}$$



One part:
visible matter
(hadronic phase)



Two parts:
matter nuggets
(CS phase)



Three parts:
anti-matter nuggets
(CS phase)

Applications. Observed mysterious emissions: from the galaxy to the Sun

- galaxy:



Physics Letters B
Volume 828, 10 May 2022, 137015



The mysterious diffuse UV radiation and axion
quark nugget dark matter model

[Ariel Zhitnitsky](#) ✉

- Sun:

Solar corona heating by axion quark nugget dark matter

Nayer Raza, Ludovic Van Waerbeke, and Ariel Zhitnitsky
Phys. Rev. D **98**, 103527 – Published 26 November 2018

3. MYSTERIOUS COSMIC DIFFUSE UV RADIATION

RECENT STUDIES OF THE DIFFUSE FAR UV BACKGROUND BY GALEX (GALAXY EVOLUTION EXPLORER) SHOW HUGE INCONSISTENCY OF THE CONVENTIONAL PICTURE WHEN UV BACKGROUND IS A RESULT OF DUST SCATTER FROM THE UV EMITTING STARS, [HENRY ET AL, 2015]:

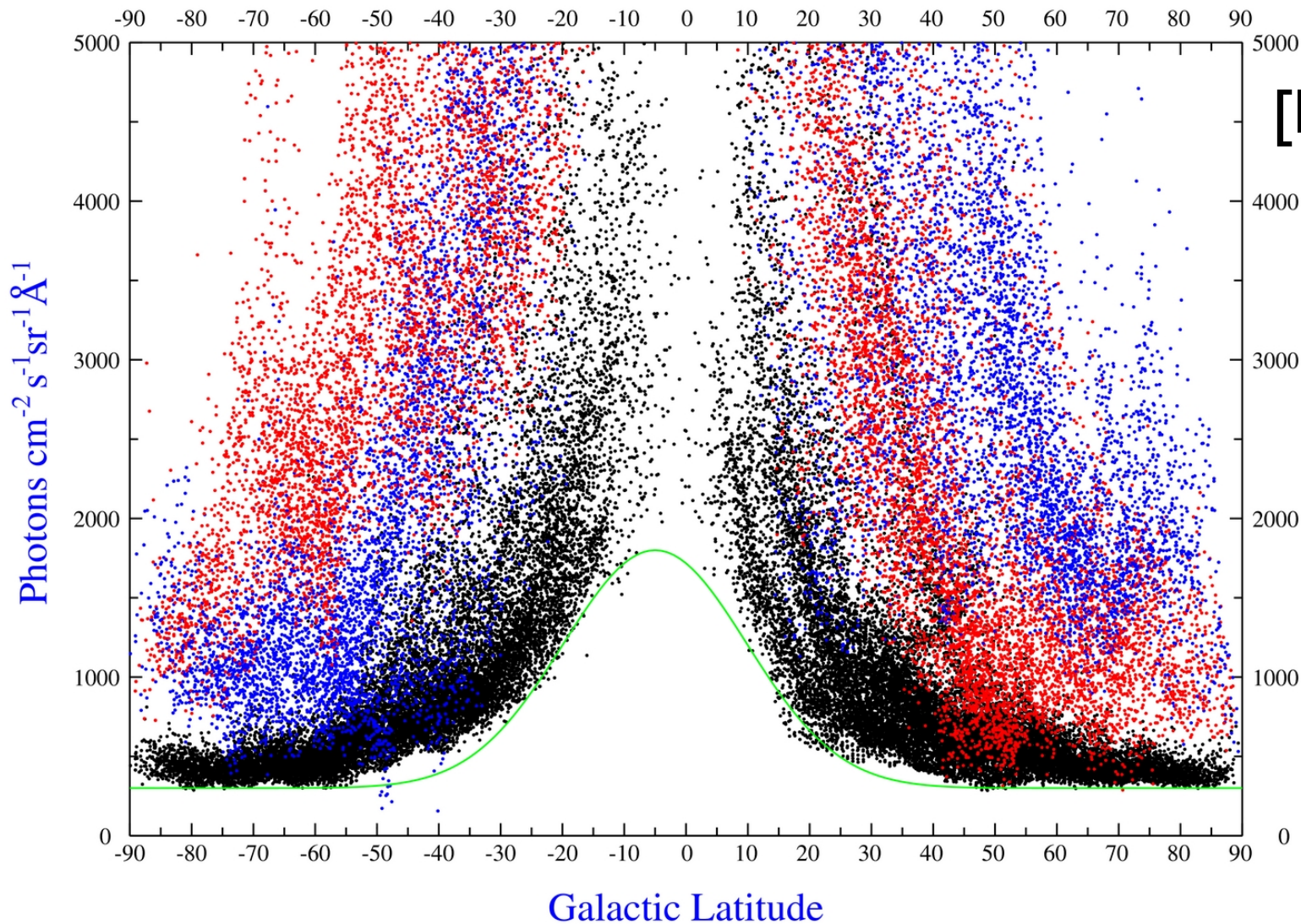
1. “*uniformity puzzle*” -THE DIFFUSE FUV $[(1300 - 1700)\text{\AA}]$ RADIATION IS VERY UNIFORM IN BOTH HEMISPHERES, IN CONTRAST WITH STRONG NON-UNIFORMITY IN DISTRIBUTION OF THE UV EMITTING STARS (SEE NEXT SLIDE);

2. “*galactic longitude puzzle*” - THE DIFFUSE FUV RADIATION IS ALMOST INDEPENDENT OF GALACTIC LONGITUDE. IT MUST BE CONTRASTED WITH LOCALIZATION OF THE UV EMITTING STARS WHICH ARE MOSTLY CONFINED TO THE LONGITUDE RANGE $(180^0 - 360^0)$ (SEE NEXT SLIDE);

■ 3. “*galactic latitude puzzle*”- THE DIFFUSE RADIATION INCREASES IN BRIGHTNESS TOWARD LOWER GALACTIC LATITUDE. THIS SHOULD BE CONTRASTED WITH CONVENTIONAL MODELLING WHICH PREDICTS VERY LOW BRIGHTNESS AT LOW GALACTIC LATITUDES $\in (-20^0, +20^0)$

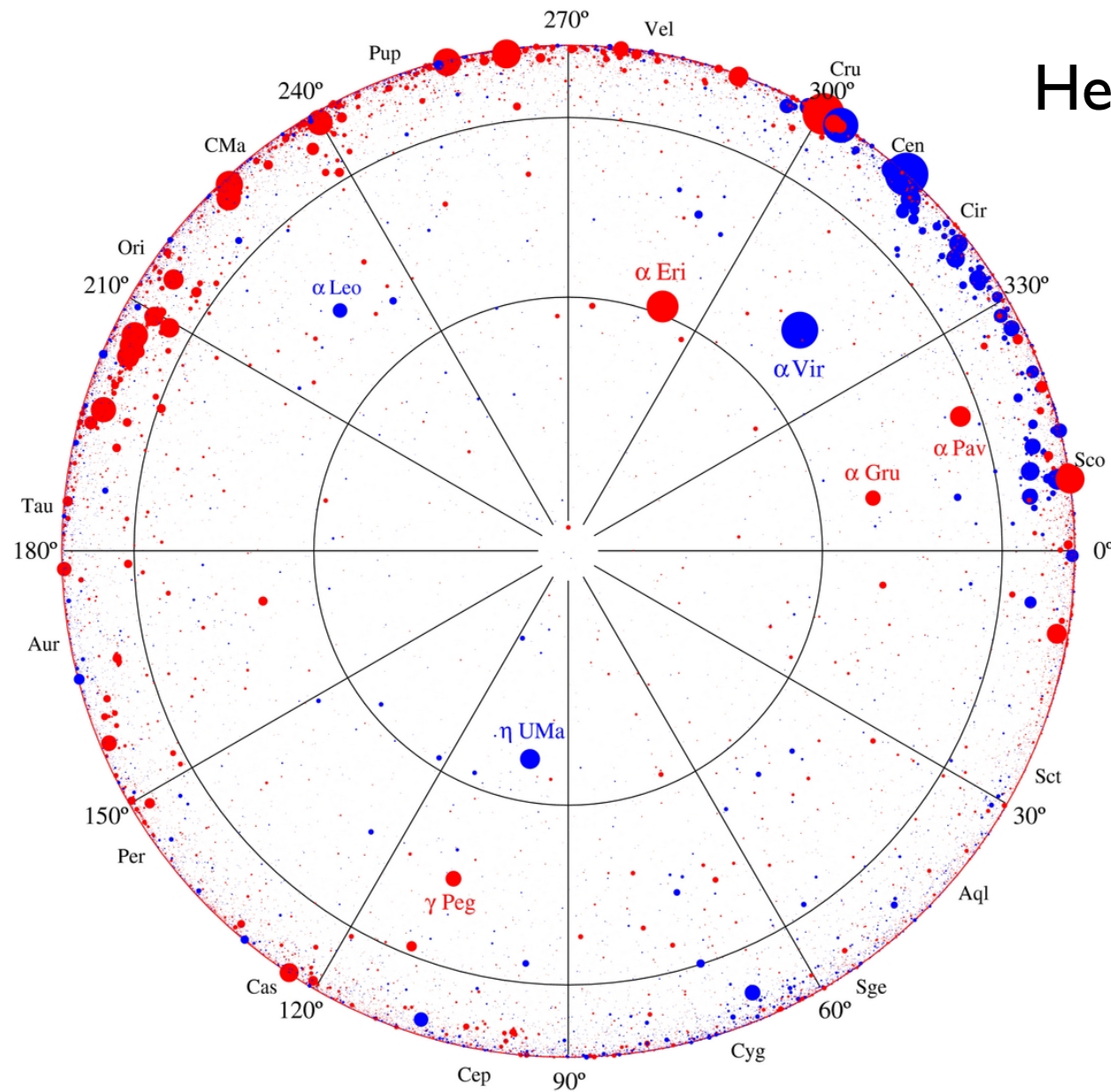
■ 4. “*non-correlation puzzle*” CONVENTIONAL PICTURE FOR THE FUV SUGGESTS THAT IT MUST BE CORRELATED WITH THE THERMAL ($100\mu m$) EMISSION AS BOTH RADIATIONS ARE ASSUMED TO BE RELATED TO THE DUST AND ITS DISTRIBUTION IN THE GALAXY.

■ THIS PICTURE DRAMATICALLY FAILS AS THERMAL ($100\mu m$) EMISSION IS HIGHLY ASYMMETRIC AND STRONGLY CORRELATED WITH LOCATIONS OF THE UV EMITTING STARS, WHILE FUV DIFFUSE EMISSION IS HIGHLY SYMMETRIC AND UNIFORM, SEE SLIDES BELOW. IT ALSO SUGGESTS THAT FUV HAS GALACTIC (NOT EXTRA GALACTIC, NOR TERRESTRIAL) ORIGIN.



[Henry et al, 2015]

FUV (black), thermal ($100 \mu\text{m}$) emission at different longitudes (red-southern, and blue-northern). Dramatic difference between the thermal and FUV emissions, which must have independent origin. There is no connection between thermal (asymmetric) and FUV (symmetric) emissions,



Locations of the UV bright stars are shown (blue-northern, red-southern galactic latitudes). The sky is dramatically different in FUV as most of the bright stars concentrated on galactic plane and half of the galactic longitudes ($180^0 - 360^0$)

■ **TOTAL LUMINOSITY L_{AQN} FROM A SINGLE AQN IS**

$$L_{\text{AQN}} \approx 4\pi R^2 \cdot F_{\text{tot}}(T) \approx 4.7 \left(\frac{T}{5 \text{ eV}} \right)^{\frac{17}{4}} \frac{\text{erg}}{\text{s}}$$

■ **TO ESTIMATE TOTAL FUV INTENSITY $\Phi_{\text{AQN}}^{\text{FUV}}$ PRODUCED BY ALL NUGGETS ALONG THE LINE OF SIGHT ONE SHOULD MULTIPLY L_{AQN} TO THE AQN'S DENSITY AND MEAN FREE PATH $\mathcal{R} \sim 0.6 \text{ kpc}$ AND FRACTION $\chi \simeq 0.2$ TO FUV EMISSION**

$$\Phi_{\text{AQN}}^{\text{FUV}} \sim L_{\text{AQN}} n_{\text{AQN}} \mathcal{R} \chi \sim 5 \cdot 10^{-5} \left(\frac{T}{5 \text{ eV}} \right)^{\frac{17}{4}} \frac{\text{erg}}{\text{s} \cdot \text{cm}^2}$$

■ **THIS ESTIMATE SHOULD BE COMPARED WITH INTENSITY OF EXCESS FUV DETECTED BY GALEX OVER ITS BANDPASS**

$$10^{-5} \text{ erg cm}^{-2} \text{ s}^{-1} \quad \text{in band } (1380 - 2500) \text{ \AA}$$

■ IT SHOULD BE ALSO COMPARED WITH FUV INTENSITY PRODUCED BY WIMP-LIKE MODELS $< 10^{-17} \text{ erg}/(\text{s} \cdot \text{cm}^2)$ THIS MECHANISM NATURALLY EXPLAINS 1-4 PUZZLES MENTIONED ABOVE:

■ “*uniformity puzzle*” IS RESOLVED AS DM IN FORM OF THE AQN UNIFORMLY DISTRIBUTED IN THE GALAXY;

■ “*galactic longitude puzzle*” IS RESOLVED AS DM PARTICLES ARE NOT SENSITIVE TO GALACTIC LONGITUDE;

■ “*galactic latitude puzzle*” IS RESOLVED AS THE INTENSITY MUST INCREASE TOWARD LOWER LATITUDES BECAUSE IT IS PROPORTIONAL TO VISIBLE DENSITY $\Phi_{\Gamma} \propto \int_{\Gamma} dl n(l)n_{\text{DM}}(l)$

■ “*non-correlation puzzle*” WITH IS THERMAL EMISSION IS ALSO RESOLVED AS DM DOES NOT FOLLOW THE LOCATIONS OF STARS.

4. SOLAR EXTREME UV (EUV) RADIATION

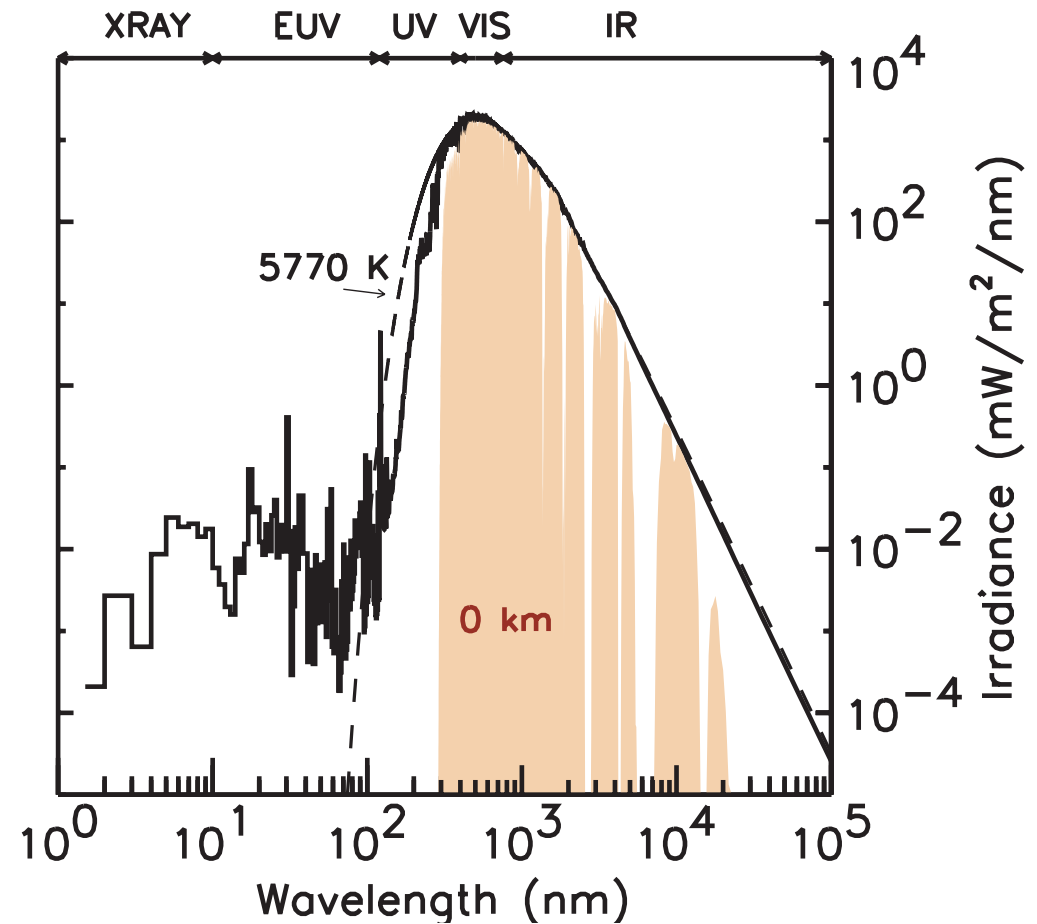
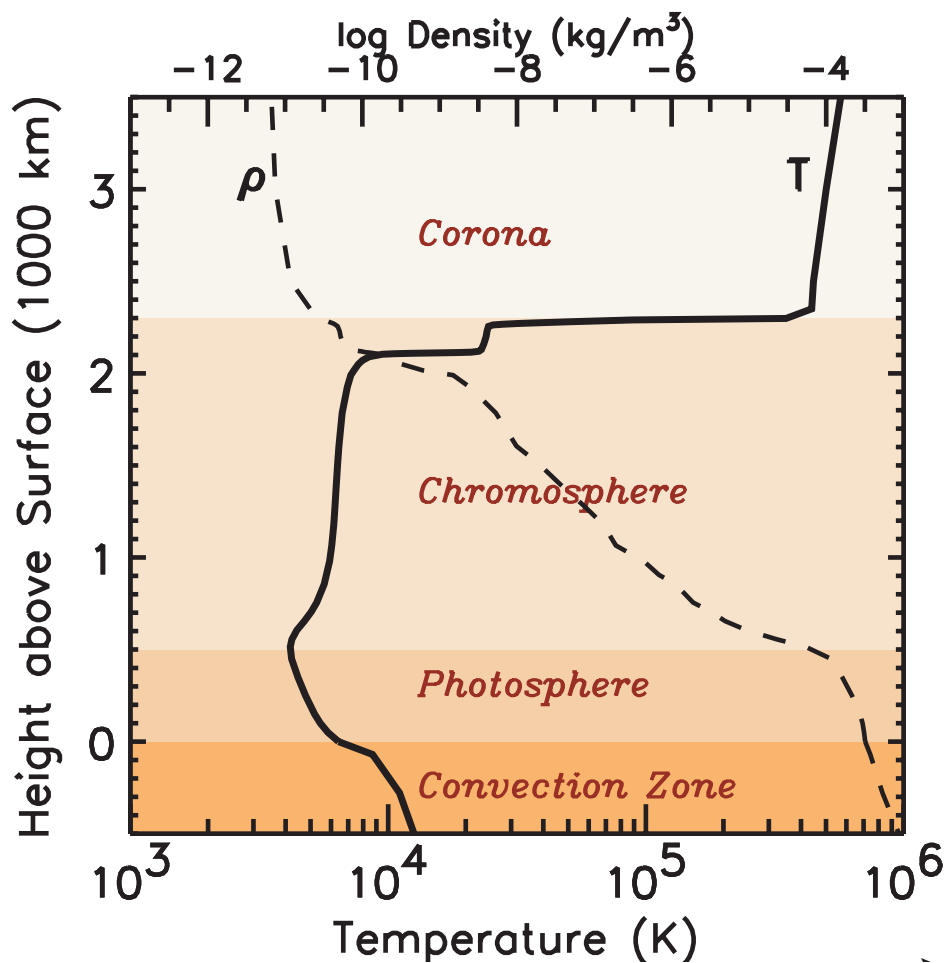
■ THE QUIET SUN EMITS EUV RADIATION WITH THE ENERGY OF ORDER 100 eV WHICH CANNOT BE EXPLAINED IN TERMS OF ANY CONVENTIONAL ASTRO-PHENOMENA.

$$L_{\odot} \text{ (EUV from Corona)} \sim 10^{30} \cdot \frac{\text{GeV}}{\text{s}} \sim 10^{27} \cdot \frac{\text{erg}}{\text{s}}.$$

■ APPARENT VIOLATION OF THERMODYNAMICS. CAN BE ONLY RESOLVED WITH NON-THERMAL INJECTION OF ENERGY THAT HEATS UP THE CORONA. THE EUV EMISSION OCCURS ABOUT 2000 KM ABOVE THE SURFACE WHERE THE TEMPERATURE SUDDENLY JUMPS:

$$T \simeq 10^4 \text{ K} \Rightarrow T \simeq 10^6 \text{ K}$$

■ “EVERYTHING ABOVE THE PHOTOSPHERE (ABOUT 10^{-6} OF THE TOTAL SOLAR LUMINOSITY) IS NOT SUPPOSED TO BE THERE AT ALL” (*Solar Corona Mystery*, W.Grotrian, 1939)



Left: the temperature distribution in outer Sun: the drastic changes occur in vicinity of 2000km. The transition region is about 200 km wide.

Right: the unexpected deviation from the thermal distribution in EUV and soft x rays from corona

- **PUZZLES: THE TRANSITION HAPPENS ON SCALE 200 KM, WHILE TYPICAL SCALES (MEAN FREE PATHS) ARE $(10^3 - 10^4)$ km**
- **THIS APPARENT VIOLATION OF THE SECOND LAW OF THERMODYNAMICS (TEMPERATURE INCREASES WHEN DENSITY DECREASES) CAN ONLY BE RESOLVED IF THERE IS SOME UNKNOWN NON-THERMAL SOURCE OF ENERGY**
- **THE SOURCE SHOULD SUSTAIN POWER OF ORDER 10^{27} erg/s WHICH REPRESENTS $(10^{-6} - 10^{-7})$ OF THE TOTAL LUMINOSITY**
- **THIS EMISSION IS VERY UNIFORM OVER SURFACE, AND OCCURS EVEN IN THE QUIET SUN WHERE MAGNETIC FIELD IS SMALL ~ 1 G**
- **THIS EUV EMISSION DOES NOT DEPEND ON SOLAR ACTIVITY**
- **THE OBSERVED DOPPLER SHIFTS OF EMITTING IONS: ~ 300 KM/S, FAR EXCEED THERMAL VELOCITY 11 KM/S.**

■ **THIS PROPOSAL:** WE ADVOCATE A SCENARIO WHEN THE ENERGY DEPOSITION IS ORIGINATED FROM OUTSIDE THE SYSTEM (NOT FROM DEEP DENSE REGIONS OF THE SUN, WHICH IS A CONVENTIONAL EXPLANATION, SEE COMMENTS BELOW)

■ THE EXTRA SOURCE OF THE ENERGY IS ASSOCIATED WITH THE **DARK MATTER ANTI-NUGGETS** CONTINUOUSLY ENTERING THE SUN FROM OUTER SPACE.

■ THE IMPACT PARAMETER FOR CAPTURE OF THE NUGGETS BY THE SUN

$$b_{\text{cap}} \simeq R_{\odot} \sqrt{1 + \gamma_{\odot}}, \quad \gamma_{\odot} \equiv \frac{2GM_{\odot}}{R_{\odot}v^2},$$

■ THE TOTAL ENERGY FLUX DUE TO THE COMPLETE ANNIHILATION OF THE AQN (AXION QUARK NUGGETS) IS ESTIMATED AS

$$L_{\odot} \text{ (AQN)} \sim (\pi b_{\text{cap}}^2) \cdot v \cdot \rho_{\text{DM}} \simeq 10^{27} \frac{\text{erg}}{\text{s}},$$

■ IT NICELY AND MYSTERIOUSLY **COINCIDES** WITH THE TOTAL (OBSERVED) EUV ENERGY OUTPUT FROM CORONA WHICH IS HARD TO EXPLAIN IN TERMS OF CONVENTIONAL ASTROPHYSICAL SOURCES (CORONA HEATING PUZZLE)

5. WHEN THE AQN HITS THE EARTH...

■ NUMBER OF AQNS HITTING THE EARTH SURFACE IS TINY.

$$\frac{\langle \dot{N} \rangle}{4\pi R_{\oplus}^2} \simeq \frac{4 \cdot 10^{-2}}{\text{km}^2 \text{ yr}} \left(\frac{\rho_{\text{DM}}}{0.3 \frac{\text{GeV}}{\text{cm}^3}} \right) \left(\frac{\langle v_{\text{AQN}} \rangle}{220 \frac{\text{km}}{\text{s}}} \right) \left(\frac{10^{25}}{\langle B \rangle} \right) \left(\frac{\langle B \rangle}{B} \right)^{\alpha}, \quad \alpha \approx (2 - 2.5)$$

■ CORRESPONDING AXION FLUX VERY LOCAL, IN CONTRAST WITH COSMIC AXION BACKGROUND (CAB) FLUX

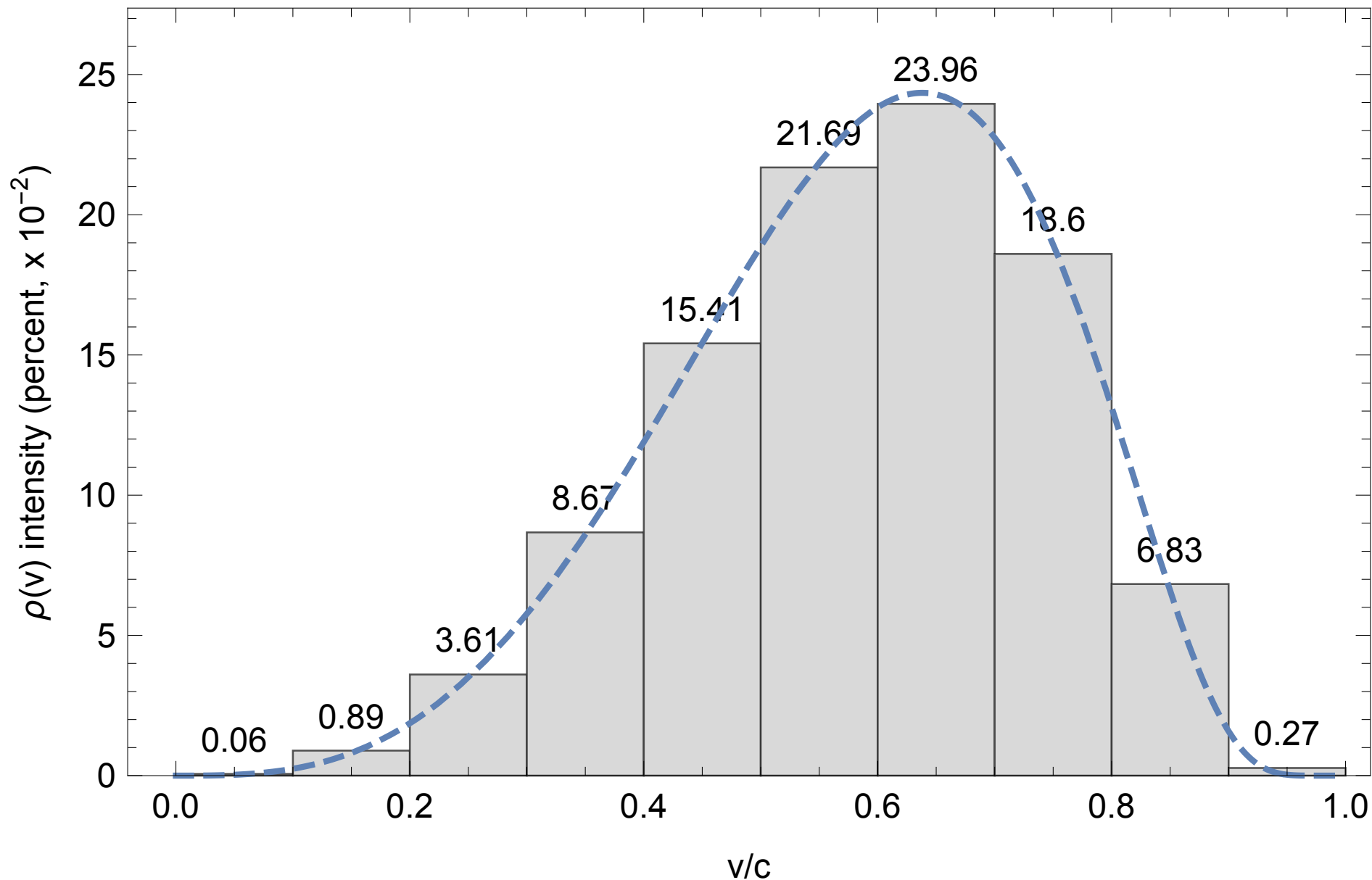
$$m_a \langle \Phi_a^{\text{AQN}} \rangle \sim 10^{14} \frac{\text{eV}}{\text{cm}^2 \text{ s}}, \quad v_a \simeq 0.6c.$$

■ IT IS INSTRUCTIVE TO COMPARE WITH CONVENTIONAL GALACTIC AXIONS (MISALIGNMENT MECHANISM, DW DECAYS)

$$m_a \Phi_a^{(\text{galactic})} \sim \rho_{\text{DM}} v_{\text{DM}} \simeq 10^{16} \left(\frac{\rho_{\text{DM}}}{0.3 \text{ GeV}} \right) \frac{\text{eV}}{\text{cm}^2 \text{ s}}, \quad v_a \simeq 10^{-3} c$$

■ IT IS ALSO INSTRUCTIVE TO COMPARE WITH (COSMOLOGICAL) ENERGY DENSITY OF THE CAB FLUX

$$\rho_{\gamma} < \rho_{\text{CMB}} \sim 10^{10} \frac{\text{eV}}{\text{cm}^2 \cdot \text{s}}, \quad v_a \sim c$$



The main result of these computations is that the typical velocity is very large $\langle v_a \rangle \approx 0.6c$ which should be contrasted with galactic axions $\langle v_a \rangle \approx 10^{-3}c$

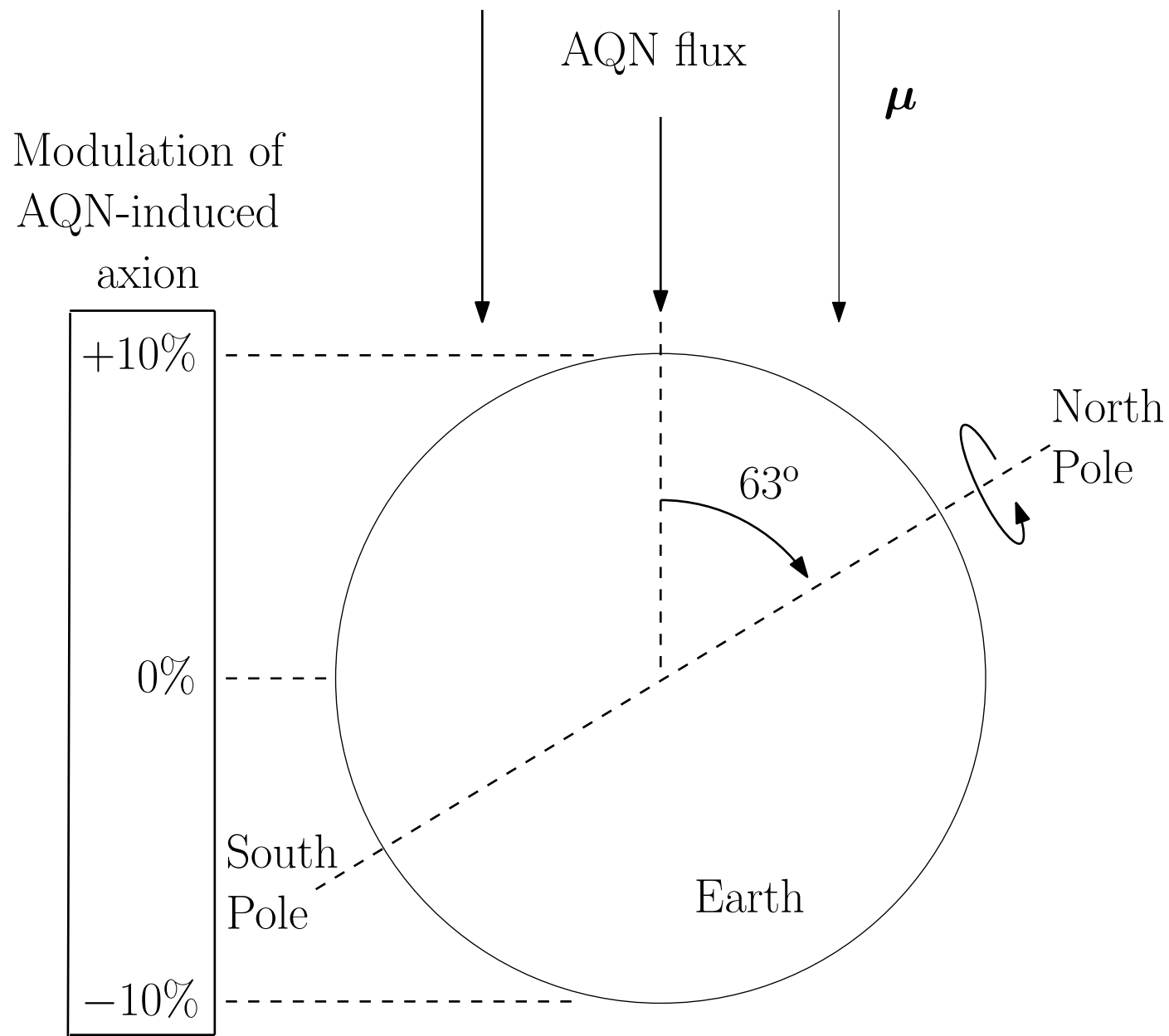
6. BROADBAND DETECTION STRATEGY

- **AVERAGE VELOCITY OF THE AQN-INDUCED AXIONS IS VERY LARGE $\langle v_a \rangle \simeq 0.6c$. THE CORRESPONDING EM SIGNAL IS EXPECTED TO BE VERY BROAD WITH $\Delta\nu \sim \nu$.**
- **FOR EXAMPLE: IF $m_a \approx 1.25 \cdot 10^{-5} \text{eV} \approx 3 \text{ GHz}$ THE EM BAND CORRESPONDS TO $\nu \in (3 - 5.4) \text{GHz}$. IT SHOULD BE CONTRASTED WITH CONVENTIONAL CASE $\Delta\nu/\nu \sim 10^{-6}$.**
- **IT IS OBVIOUS: A NEW BROADBAND DETECTION STRATEGY MUST BE IMPLEMENTED IN ONE WAY OR ANOTHER.**
- **THE DM FLUX SHOWS THE ANNUAL (AND DAILY) MODULATIONS DUE TO THE PRESENCE OF RELATIVE ORIENTATION OF THE EARTH'S VELOCITY AND AXIS OF ROTATION AND DM GALACTIC WIND (EFFECT~ 10%):**

$$\langle E_a \rangle \Phi_a^{\text{AQN}}(t) \simeq 10^{14} A(t) \left[\frac{\text{eV}}{\text{cm}^2 \text{s}} \right] \quad A_{(a)}(t) \equiv [1 + \kappa_{(a)} \cos \Omega_a(t - t_0)],$$

7. DAILY MODULATIONS

- THE DAILY MODULATIONS FOR WIMPS OR ANY OTHER FUNDAMENTAL PARTICLES (INCLUDING GALACTIC AXIONS) ARE VERY TINY BECAUSE ADDITIONAL VELOCITY IS 0.5 km/s TO BE COMPARED WITH VELOCITY OF GALACTIC WIND 220 km/s
- CONVENTIONAL INSTRUMENTS ARE NOT DESIGNED TO MEASURE THE DIRECTIONALITY WHICH WAS THE MAIN REASON WHY THE DAILY MODULATIONS WERE LARGELY IGNORED IN THE PAST
- THERE ARE TWO NOVEL SOURCES FOR THE DAILY MODULATIONS: 1. THE AQN-INDUCED AXION IS A RELATIVISTIC PARTICLE, AND 2. THE AQN'S SIZES AT THE MOMENT OF ENTRY AND EXIT OF THE EARTH'S SURFACE ARE DIFFERENT BECAUSE THE AQN IS A COMPOSITE OBJECT



- 1. THE IDEA IS TO FIT THE TIME DEPENDENT SIGNAL

$$A_{(a)}(t) \equiv [1 + \kappa_{(a)} \cos \Omega_a(t - t_0)], \quad A_{(d)}(t) \equiv [1 + \kappa_{(d)} \cos(\Omega_d t - \phi_0)]$$

- 2. THE SAME FIT COULD BE CARRIED OUT BY PERFORMING THE FOURIER TRANSFORM

- 3. LET US ASSUME THAT THE SIGNAL WITH $\Omega_d = 24 \text{ h}$ IS RECORDED. IS IT A TRUE SIGNAL OR A NOISE?

- 4. ONE SHOULD CHECK THAT NO MODULATIONS APPEAR FOR ZERO MAGNETIC FIELD $B=0$ (SUCH TEST EXCLUDES TEMPERATURE FLUCTUATIONS, HUMAN-RELATED SOURCES, TIDES, ETC)

- 5. ONE SHOULD ALSO CHECK A PROPER DRIFT OF THE PHASE ϕ_0 WITH THE SEASONS (TO EXCLUDE ANY SPURIOUS SIGNALS)

- 6. THERE ARE FEW OTHERS (MORE SOPHISTICATED CONSISTENCY CHECKS) THAT THE SIGNAL IS NOT A SPURIOUS SIGNAL BUT A TRULY GENUINE SIGNAL SUCH AS NETWORK OF DETECTORS

- We incorporated these ideas to search for the daily modulations by using CAST-CAPP previously recorded data, see recent preprint arxiv 2405.10972, see talk by Kaan Ozbozduman at the Cosmic WISPers meeting (Istanbul, Turkey, Sept 3-6 2024)
- We conclude with wording “We have observed daily variations at vanishing and non-vanishing B . We could not conclusively determine an axion-related signal.”
- “Additional tests to discriminate a true genuine signal from the noise or spurious signals cannot be carried out as the CAST-CAPP detector is no longer operational”
- We advocate to search for the daily modulations with broadband instruments such as “BREAD” see Sonnenschein and Hoshino talks, or single photon detector such as “RAY”, see Maruyama talk at this meeting

The daily modulations and broadband strategy in axion searches. An application with CAST-CAPP detector

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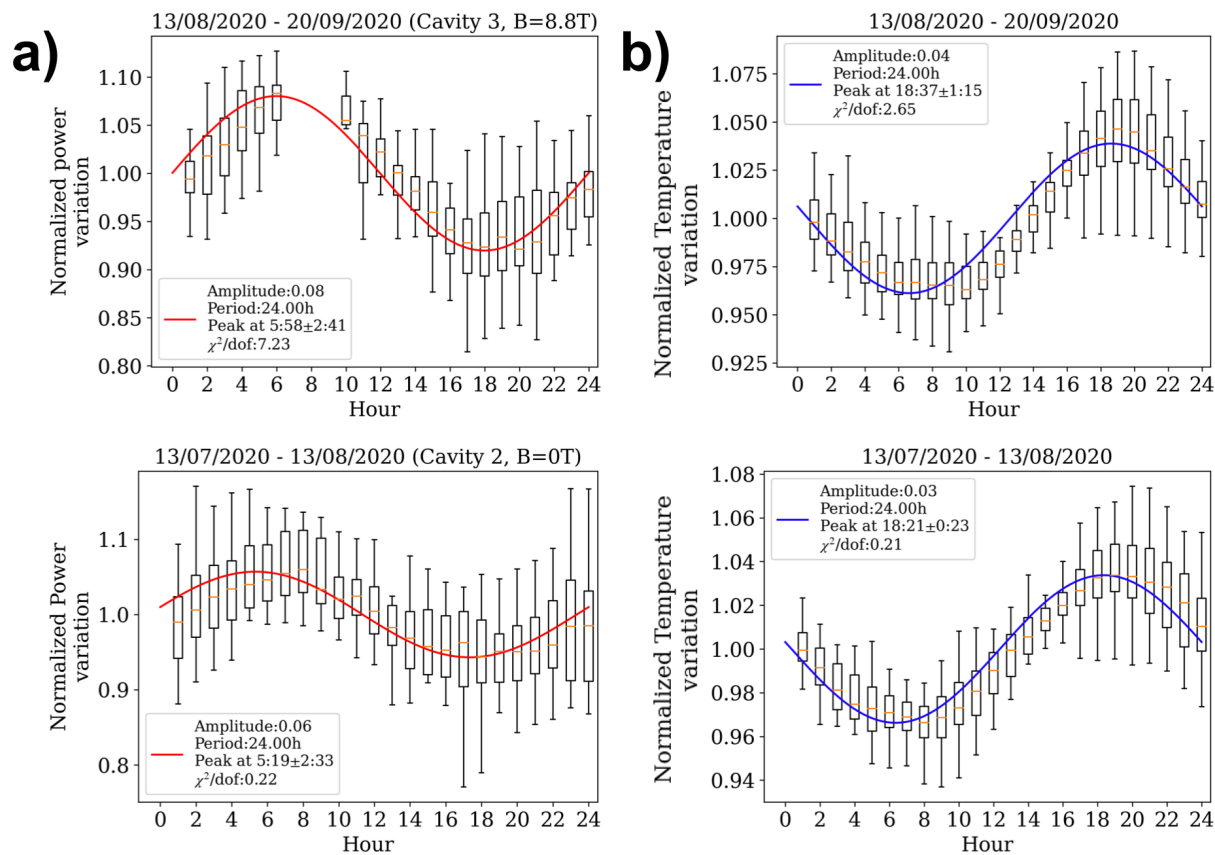


FIG. 7. Box plots showing the hourly distributions of the normalized power variation (left) and normalized environmental temperature variation (right) for $B = 8.8\text{ T}$ (top) and $B = 0\text{ T}$ (bottom). A sine function with a daily periodicity is fitted to the data. The gap in the upper left plot is due to the CAST-CAPP data acquisition schedule in that time interval of data taken.

CONCLUSION

- "NON- BARYONIC DARK MATTER" COULD BE ORDINARY BARYONIC MATTER (WE KNOW AND LOVE) WHICH IS IN NON-HADRONIC PHASE (COMPOSITE OBJECT), THE AQN
- RATIO: $\Omega_{\text{dark}} \sim \Omega_{\text{visible}}$ IS VERY GENERIC CONSEQUENCE OF THIS FRAMEWORK (NO SENSITIVITY TO AXION MASS m_a , NOR TO THE MISALIGNMENT ANGLE θ_{initial}). THIS IS BECAUSE BOTH COMPONENTS ARE PROPORTIONAL TO ONE AND THE SAME FUNDAMENTAL Λ_{QCD} SCALE OF NATURE.
- THIS MODEL OFFERS A SIMULTANEOUS RESOLUTION OF A NUMBER (NAIVELY UNRELATED) OLD MYSTERIES: DM, BARYOGENESIS,...
- THE AQN FRAMEWORK CHANGES ENTIRE PARADIGM OF THE DM- FROM A NON-INTERACTING (IN GALAXIES) TO STRONGLY-INTERACTING (IN STARS+PLANETS) SYSTEM

■ IN PARTICULAR, THERE ARE MANY HINTS (IN MANY FREQUENCY BANDS) SUGGESTING THAT THE ENERGY INJECTION TO SPACE DID OCCUR DURING THE UNIVERSE EVOLUTION.

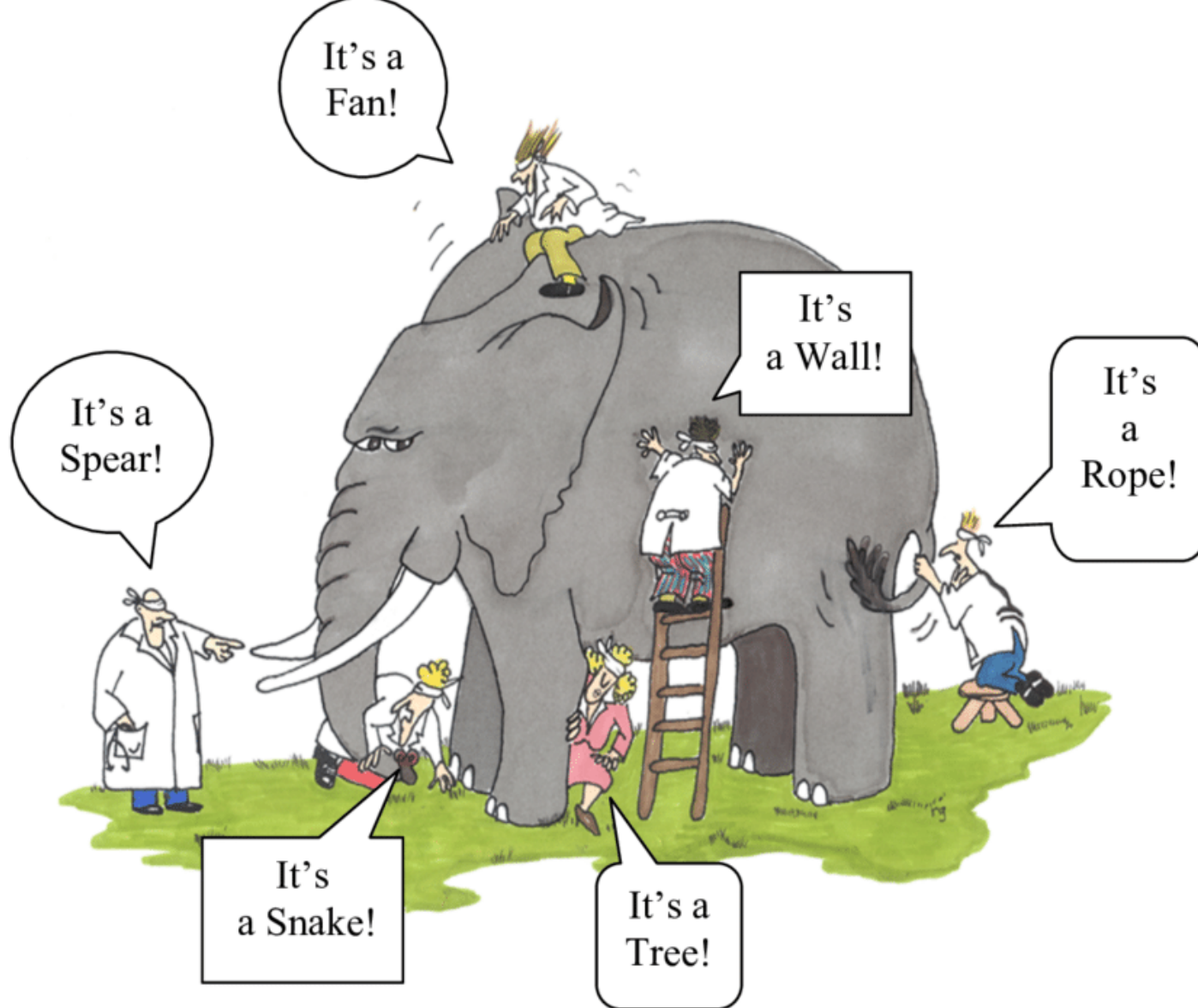
■ 1. MANY OBSERVED EXCESSES OF RADIATION ON GALACTIC SCALE. IT INCLUDES UV, OPTICAL , RADIO FREQUENCY BANDS

■ 2. LONG STANDING PROBLEM ON PRIMORDIAL LITHIUM PUZZLE

■ 3. MANY OBSERVED PUZZLES DURING THE STRUCTURE FORMATION AT SMALL GALACTIC SCALES (SUCH AS CORE-CUSP PROBLEM, TOO BIG TO FAIL, ETC)

■ 4. IN FACT THE AQNs BEHAVE AS CHAMELEON-LIKE COMPOSITE PARTICLES. THEY BEHAVE AS CONVENTIONAL DM COMPONENTS ON LARGE GALACTIC SCALES, BUT INTERACT VERY STRONGLY IN DENSE ENVIRONMENTS

- **Question:** Why these strongly interacting objects have never been observed in numerous DM laboratories around the globe?
- **Answer:** All designated DM laboratories are built to detect the WIMPs with mass $M_{\text{WIMP}} \sim 10^2 \text{ GeV}$, while $M_{\text{AQN}} \sim 10^{25} \text{ GeV}$. Therefore, it takes million of years before a single event occurs in a small DM detectors measured in meters.
- Large Cosmic Rays (CR) detectors with size 100 km are appropriate to study these objects. However, hardware and software of these labs are designed (from the start) to study the ultra-relativistic CR, while AQN is a non- relativistic object.
- In their analysis they automatically remove any correlations with long time scales
- Pure sociological problem: people prefer to stay within the old WIMP-mainstream, which has been dominating paradigm for 40 years



The main essence of my talk: different people (from different fields conducting different experiments around the Globe), in fact, observe and study **different** parts of a body of the **same** elephant

■ DO WE HAVE AN EXTRAORDINARY EVIDENCE TO MAKE OUR EXTRAORDINARY CLAIM?

■ TIME WILL TELL...



In Other Words...



“Extraordinary claims
require
extraordinary
evidence.”

-Carl Sagan