

Axion Quark Nuggets: theory, observations and future experimental searches

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Axions beyond Gen 2. UW, Seattle, January 25-28. 2021

This talk is based on recent papers written with astro,
particle experimentalists, and AMO-Nuclear Physics people

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**New mechanism producing axions in the AQN model
and how the CAST can discover them**

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Y. Semertzidis[§]

← will speak on Wed

Center for Axion and Precision Physics Research, Institute for Basic Science,

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Axion quark nugget dark matter: Time modulations and amplifications

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Axion quark nuggets and how a global network can discover them

Dmitry Budker^{*} ← will speak on Wed

*Johannes Gutenberg-Universität Mainz (JGU)—Helmholtz-Institut, 55128 Mainz, Germany
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Xunyu Liang[‡] and Ariel Zhitnitsky[§]

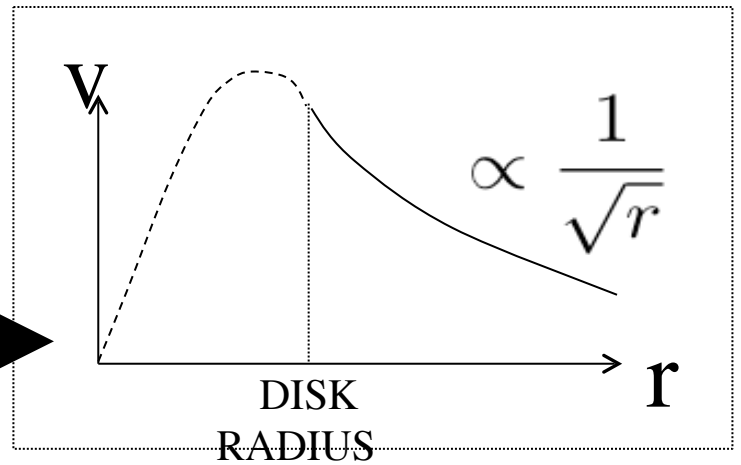
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AXION AND ITS RELATION TO A NUMBER OF OLD (AND APPARENTLY UNRELATED) MYSTERIES

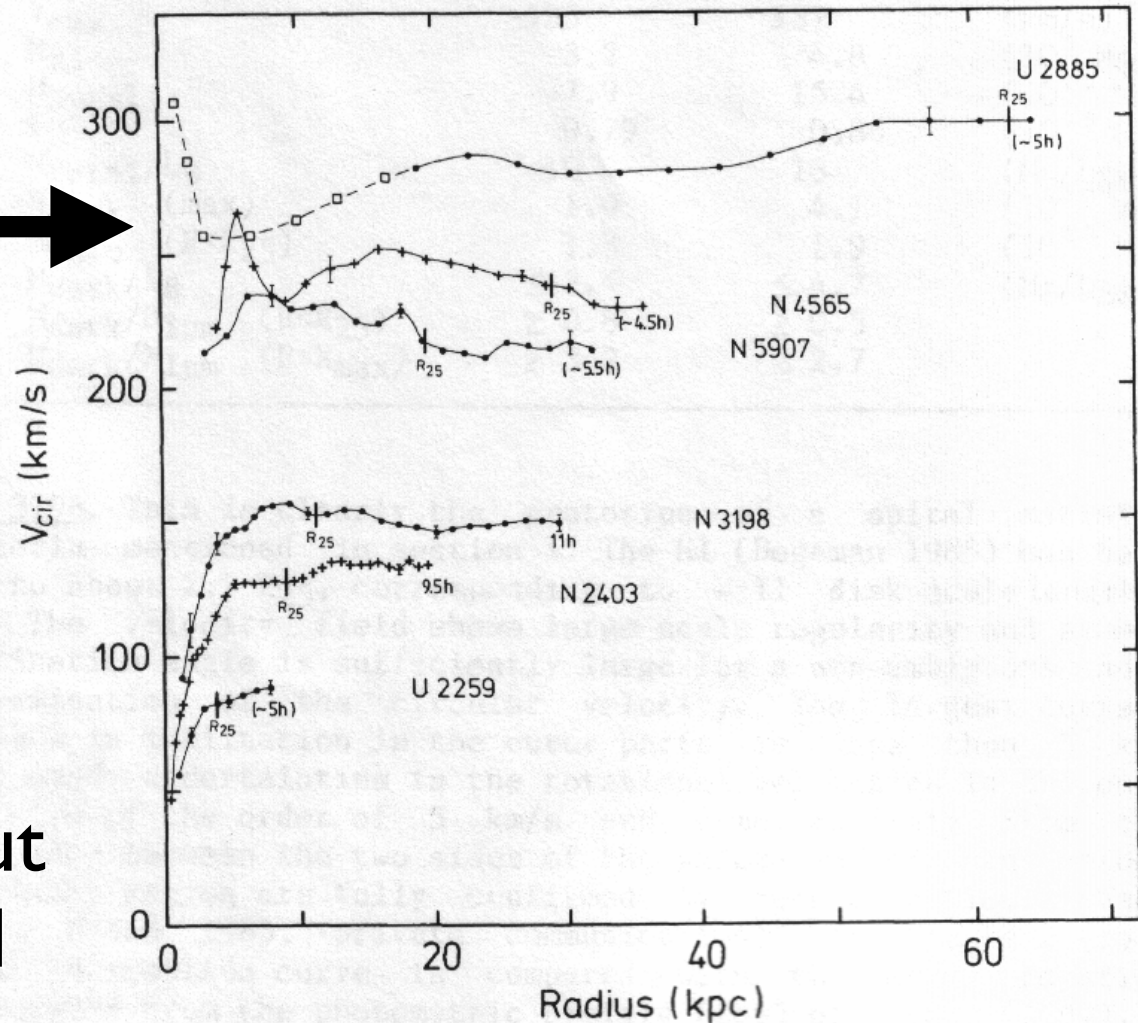
- **1. 80-YEARS OLD MYSTERY: THE NATURE OF DARK MATTER (ZWICKY 1937)**
- **2. ANOTHER 50-YEARS OLD MYSTERY: BARYOGENESIS (SAKHAROV, 1967)**
- **3. YET ANOTHER 80- YEARS OLD MYSTERY: THE SO-CALLED “SOLAR HEATING PUZZLE” (W. GROTRIAN, 1939)**
- **4. YET ANOTHER OLD MYSTERY: PRIMORDIAL LITHIUM PUZZLE (PROBLEM STAYS WITH US FOR AT LEAST TWO DECADES)**
- **5. MANY OTHER OBSERVED PUZZLES ... TO BE MENTIONED TODAY**

I. Evidence for dark matter

Expected behaviour for the velocities of stars



The observed velocity distribution



Take home lesson: there is DM in our Universe.
DM knows about gravity, but does not know about E&M

Fritz Zwicky and Vera Rubin

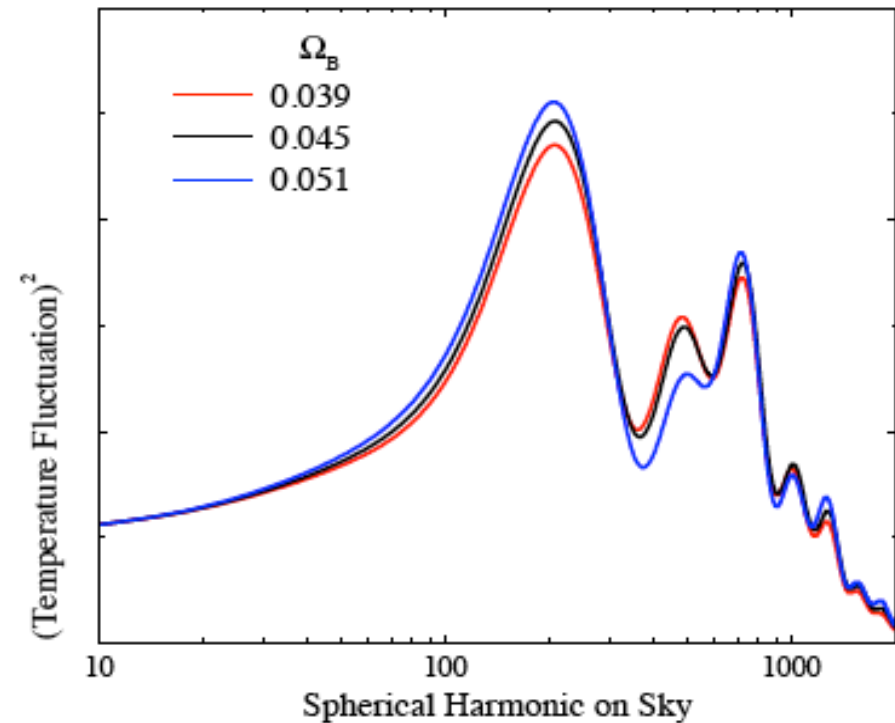


2. Short overview on Baryogenesis

The cosmic microwave background (CMB) and Big Bang Nucleosynthesis (BBN) are highly sensitive to parameter $\eta \equiv n_B/n_\gamma$, the baryon to photon ratio.

$$\eta \equiv \frac{n_B}{n_\gamma} \simeq 6 \cdot 10^{-10}$$

Take home lesson:
the parameter η is known
with very high accuracy





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

- On other hand: our fundamental equations predict that the matter and antimatter should have equal number densities, i.e. $n_B = n_{\bar{B}}$
- In this case the protons and antiprotons annihilate each other until the temperature drops to $T \simeq 20 \text{ MeV}$

- For such low temperature the parameter η is many orders of magnitude smaller than observed value:

$$\eta \text{ (naive)} \equiv \frac{n_B}{n_\gamma} \sim 10^{-19} \quad \text{for} \quad T = 20 \text{ MeV}$$

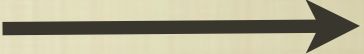
- Conventional resolution: one should have one extra baryon per $\sim 10^{10}$ particles such that the annihilation stops at $T = 40 \text{ MeV}$ when no antimatter remains

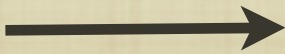
- **WE WANT TO OFFER A NEW ALTERNATIVE (UNORTHODOX) FRAMEWORK WHERE ALL THESE, NAIVELY UNRELATED, PHENOMENA COULD BE INTIMATELY CONNECTED**
- **CP-ODD AXION FIELD PLAYS THE KEY ROLE IN LINKING ALL THESE PHENOMENA.**
- **ESSENTIALLY, OUR CLAIM IS THAT WE HAVE BEEN WITNESSING (INDIRECTLY) THE MANIFESTATION OF THE DM (BEYOND GRAVITY) FOR YEARS WITH MANY PUZZLING OBSERVATIONS (20+ PUBLISHED PAPERS WITH “HINTS”)**
- **IT INCLUDES: THE EXCESS OF RADIATION FROM GALACTIC CENTRE (INCLUDING 511 KEV LINE, DIFFUSE X -RAYS, ETC), SOLAR CORONA HEATING PROBLEM, PRIMORDIAL LITHIUM PROBLEM, TELESCOPE ARRAY MYSTERIOUS BURSTS, DAMA/LIBRA OBSERVATION OF THE ANNUAL MODULATION WITH $9.5 \sigma CL$, X- RAYS SEASONAL VARIATIONS OBSERVED BY XMM-NEWTON WITH $11 \sigma CL$, TO NAME JUST FEW...**

3. TWO (NAIVELY UNRELATED) MYSTERIES: DARK MATTER AND BARYOGENESIS.

■ 1. “NAIVE” MORAL: DARK MATTER REQUIRES NEW (UNKNOWN) FIELDS SUCH AS WIMPS

■ 2. “NAIVE” MORAL: NEW FIELDS MUST BE NONBARYONIC. ARGUMENTS COME FROM STRUCTURE FORMATION REQUIREMENTS, BBN, DECOUPLING DM FROM RADIATION, ETC

■ THIS PROPOSAL: INSTEAD OF “NEW FIELDS”  “NEW PHASES” (DENSE COLOUR SUPERCONDUCTOR) OF “OLD FIELDS”

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

■ 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.

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

1. THERE IS EXTRA $N=1$ AXION DOMAIN WALL PRESSURE (ACTING ON THE CLOSED AXION DW BUBBLES). IT MAKES THE NUGGETS STABLE (FIRST ORDER PHASE TRANSITION IS NOT REQUIRED, AS IN THE WITTEN'S CASE). THEY ARE ABSOLUTELY STABLE AND CAN SERVE AS DM PARTICLES.

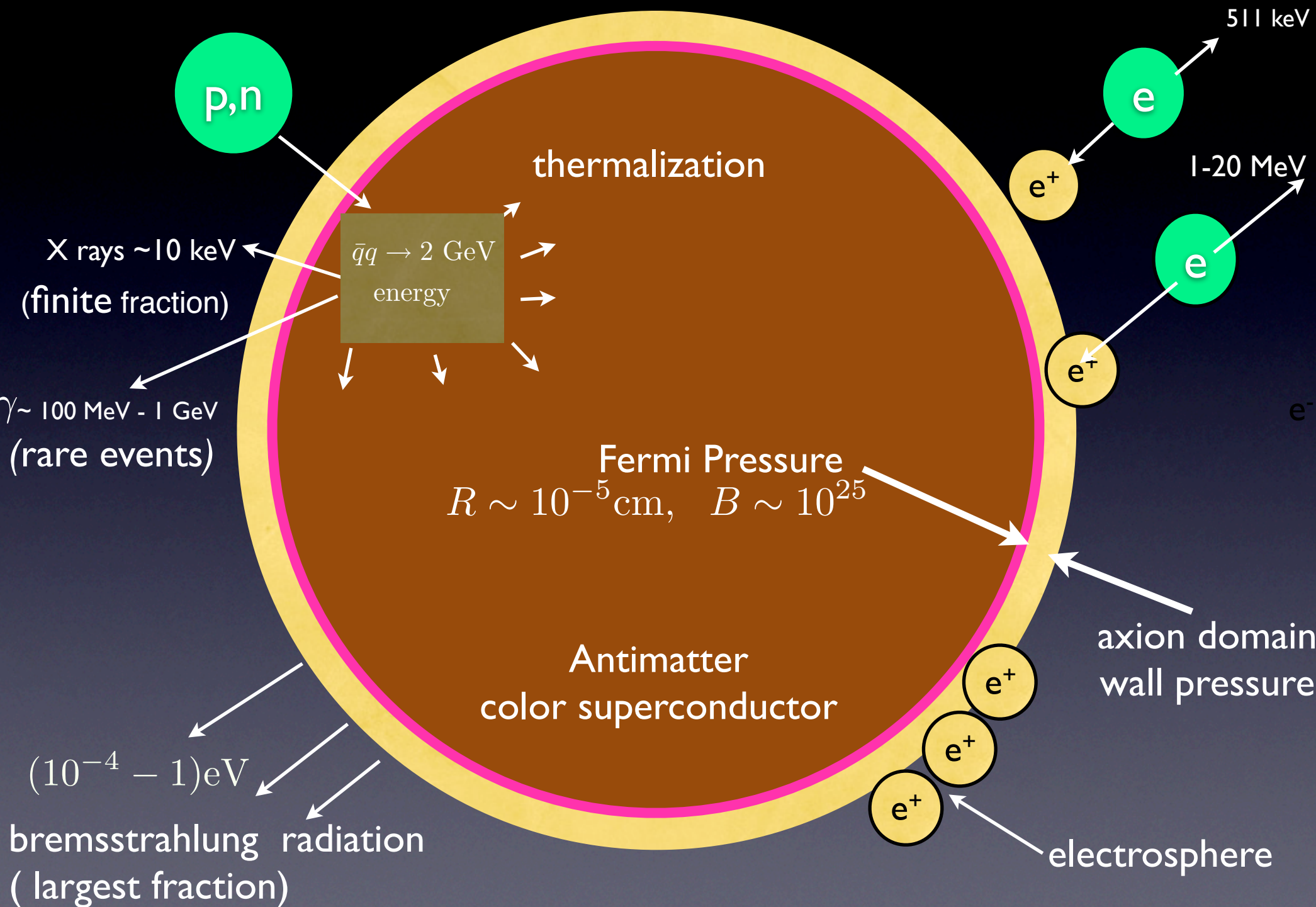
2. THERE ARE TWO SPECIES, THE NUGGETS AND ANTI-NUGGETS. THE SIZE IS DETERMINED BY m_a AS $R \sim m_a^{-1}$

A SMALL GEOMETRICAL FACTOR REPLACES A CONVENTIONAL REQUIREMENT FOR A WEAK COUPLING CONSTANT. NUGGETS ARE QUALIFIED AS THE DM CANDIDATES:

$$\epsilon \sim S/V \sim B^{-1/3} \ll 1 \quad \sigma/M \ll \text{cm}^2/\text{g}$$

COSMOLOGICAL **CP-ODD** AXION FIELD GENERATES THE DISPARITY BETWEEN TWO SPECIES AT $\theta \neq 0$ WHICH IMPLIES THE SIMILARITY BETWEEN DARK AND VISIBLE SECTORS: $\Omega_{\text{dark}} \approx \Omega_{\text{visible}} \sim \Lambda_{\text{QCD}}$

Antiquark nugget structure. Source of emission



■ THERE IS A MISCONCEPTION THAT THE TOPOLOGICAL DEFECTS (SUCH AS THE DOMAIN WALLS) CAN ONLY BE FORMED IF THE PQ PHASE TRANSITION OCCURS AFTER THE INFLATION, I.E. $H_I > f_{PQ}$.

■ HOWEVER: THE $N=1$ DOMAIN WALL INTERPOLATES BETWEEN TOPOLOGICALLY DISTINCT, BUT PHYSICALLY IDENTICAL VACUUM STATES LIKE IN SINE-GORDON MODEL $V(\theta) \sim \sin \theta$. THESE DISTINCT TOPOLOGICAL SECTORS MUST BE PRESENT INSIDE THE SAME HORIZON SUCH THAT INFLATION CANNOT SEPARATE THEM.

■ THE $N=1$ AXION DOMAIN WALLS ALWAYS EXIST WHEN θ INTERPOLATES BETWEEN ONE AND THE SAME PHYSICAL VACUUM STATE: $\theta \rightarrow \theta + 2\pi n$

■ THE $N = 1$ DW CAN BE FORMED IRRESPECTIVELY TO THE INFLATION SCALE. WE ALWAYS ASSUME $H_I < f_{PQ}$.

4. AQN FORMATION: COHERENCE ON A COSMOLOGICAL SCALE. ABUNDANCE.

IF CP VIOLATING AXION FIELD $\theta(t)$ WERE ZERO AT THE MOMENT OF FORMATION THAN AN EQUAL NUMBER OF NUGGETS AND ANTI-NUGGETS WOULD FORM.

$\theta \neq 0$ DURING THE FORMATION TIME IMPLIES THAT THE DIFFERENCE BETWEEN TOTAL BARYON CHARGE HIDDEN IN FORM OF NUGGETS AND ANTI NUGGETS IS ORDER OF ONE:

$$\Omega_{\text{dark}} \simeq \left(\frac{1+c}{1-c} \right) \Omega_{\text{visible}}, \quad c \equiv \frac{|B_{\text{nuggets}}|}{|B_{\text{antinuggets}}|}.$$

BARYON CHARGE OF THE VISIBLE MATTER IS EXPRESSED IN TERMS OF THIS PARAMETER $c(T) \sim 1$ AS THE TOTAL BARYON CHARGE IS ZERO:

$$B_{\text{tot}} = B_{\text{baryons}} + B_{\text{antibaryons}} + B_{\text{nuggets}} + B_{\text{antinuggets}} = 0$$

■ THE SAME RELATION CAN BE WRITTEN AS FOLLOWS

$$[\Omega_{\text{dark}} = \Omega_{\bar{N}} + \Omega_N] , [\Omega_{\text{visible}} = \Omega_{\bar{N}} - \Omega_N] \rightarrow \Omega_{\text{dark}} \approx \Omega_{\text{visible}} \sim \Lambda_{\text{QCD}}$$

■ THERMODYNAMICS DOES THE JOB. ABUNDANCE OF AQNS IS ALWAYS EFFECT OF ORDER OF ONE AS LONG AS EFFICIENCY OF FORMATION IS LARGER THAN $\eta \sim 10^{-10}$ AT THE MOMENT OF FORMATION.

■ IF THE EFFICIENCY IS TOO HIGH \rightarrow THE ANNIHILATION BETWEEN VISIBLE BARYONS AND AQNS CONTINUE UNTIL $\Omega_{\text{dark}} \approx \Omega_{\text{visible}}$

■ PARAMETER η HERE IS DETERMINED BY THE TEMPERATURE WHEN FORMATION ENDS $T_{\text{form}} \approx 40 \text{ MeV} \lesssim T_{\text{CS}} \approx 60 \text{ MeV}$. THERE IS NO FINE TUNING (IN TERMS OF T) IN THIS FRAMEWORK

■ IT IS ASSUMED THAT INFLATION OCCURS AFTER PQ WHEN THE SAME θ_0 OCCUPIES ENTIRE VISIBLE UNIVERSE

■ FOR $c \simeq 2/3 \Rightarrow \Omega_{\text{dark}} \simeq 5 \Omega_{\text{visible}}$ THE NUGGETS SATURATE THE PRESENT DM DENSITY TODAY.

MATTER IN THE UNIVERSE

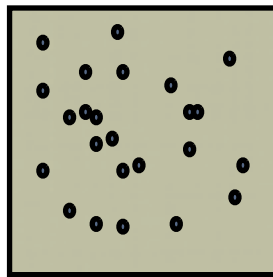
A model which explains both the matter-antimatter asymmetry and the observed ratio of visible matter to DM

$$\Omega_{\text{dark}} \sim \Omega_{\text{visible}}$$

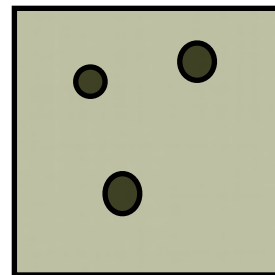
$$B_{\text{tot}} = 0 = B_{\text{nugget}} + B_{\text{visible}} - \bar{B}_{\text{antinugget}}$$

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

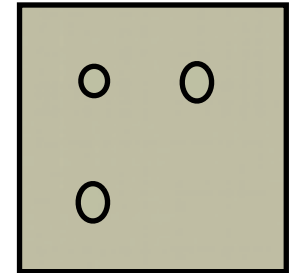
The ratio $B_{\text{nugget}}/\bar{B}_{\text{antinugget}} \simeq 2/3$ at the end of formation is determined by the sign of axion CP violating parameter θ_0



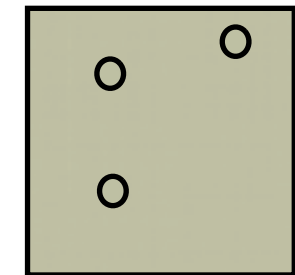
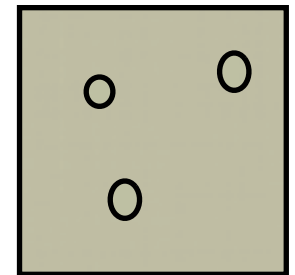
One part:
visible matter



Two parts:
matter nuggets



Three parts:
anti-matter nuggets



5. WHEN THE AQN HITS THE EARTH...

■ NUMBER OF AQNS HITTING THE EARTH SURFACE IS TINY. IT IS VERY RARE EVENT IN COMPARISON WITH WIMPS:

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

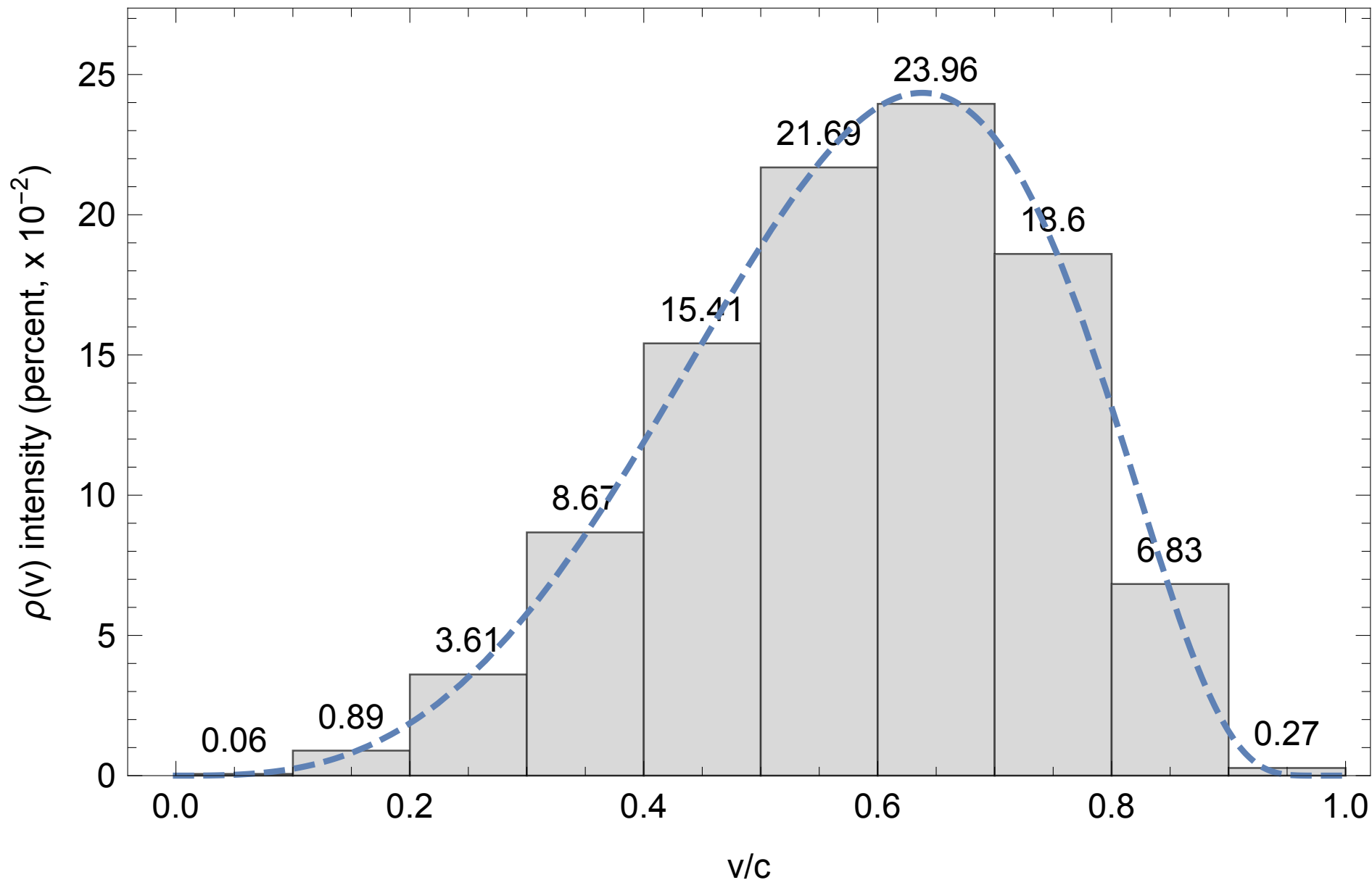
■ CORRESPONDING AXION FLUX (AS A RESULT OF ANNIHILATION)

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

■ IT SHOULD BE COMPARED WITH CONVENTIONAL GALACTIC AXIONS (MISALIGNMENT MECHANISM, DW DECAYS)

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

■ THE FLUX IS TWO ORDERS OF MAGNITUDE SMALLER... ONE SHOULD STUDY SEPARATELY: RELATIVISTIC AQN-INDUCED AXIONS AND GRAVITATIONALLY TRAPPED AQN-INDUCED AXIONS



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 $\langle v_a \rangle \approx 10^{-3}c$

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 $\Delta\nu \sim \nu$.
- IT SHOULD BE CONTRASTED WITH CONVENTIONAL CAVITY TYPE EXPERIMENTS WHEN $\Delta\nu/\nu \sim 10^{-6}$.
- A NEW BROADBAND DETECTION STRATEGY MUST BE IMPLEMENTED. IDEA CAN BE FORMULATED AS FOLLOWS:
 1. THE DM FLUX SHOWS THE ANNUAL AND DAILY AND ANNUAL MODULATIONS DUE TO THE PRESENCE OF RELATIVE ORIENTATION OF THE EARTH'S VELOCITY AND AXIS OF ROTATION AND DM GALACTIC WIND (EFFECT $\sim 10\%$):

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

■ 2. THE IDEA IS TO SEPARATE ENTIRE FREQUENCY BAND INTO A NUMBER OF SMALLER FREQUENCY BINS $\Delta\nu_i$

■ 3. THE TIME DEPENDENT SIGNAL IN EACH FREQUENCY BIN HAS TO BE FITTED ACCORDING TO THE DAILY AND/ OR ANNUAL MODULATION TO EXTRACT FITTING PARAMETERS $\kappa_{(a)}^i, \kappa_{(d)}^i$

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

■ 4. LET US ASSUME THAT THE MODULATION IS RECORDED IN SOME BIN, SAY \bar{i} : SUCH THAT $\kappa_{(d)}^{\bar{i}} \neq 0$ OR/AND $\kappa_{(a)}^{\bar{i}} \neq 0$

■ 5. ONE SHOULD CHECK THAT NO MODULATION APPEARS IN OTHER BINS $i \neq \bar{i}$ (TO EXCLUDE SPURIOUS SIGNALS)

■ 6. THERE ARE FEW OTHERS (MORE SOPHISTICATED CONSISTENCY CHECKS) THAT THE SIGNAL IS NOT A SPURIOUS SIGNAL

- **SO, THE BASIC IDEA IS TO COLLECT THE STATISTICS FOR A SPECIFIC HOUR FOR ENTIRE DATA SET. FIT THE DATA TO EXTRACT $\kappa_{(d)}^i$ ASSUMING $\kappa_{(d)} \cos(\Omega_d t - \phi_0)$]**
- **WORK IN PROGRESS BY C. ADAIR, M. HASINOFF, AZ: PRELIMINARY ANALYSIS OF THE CAST/CAPP DATA HINTS TO THE DAILY MODULATIONS (WITHOUT CLAIMING ANY PHYSICAL RESULTS).**
- **ERROR BARS ARE LARGE, STATISTICS IS SMALL. HOWEVER, THERE ARE TWO TENDENCIES: 1. DEVIATION FROM ZERO TO POSITIVE VALUES (HINTS TO NON VANISHING EFFECT). 2. HINTS TO DAILY MODULATIONS**
- **PRECISELY THIS STRATEGY HAS BEEN USED BY DAMA/ LIBRA COLLABORATION WHICH HAS BEEN OBSERVING THE ANNUAL MODULATION FOR 20 YEARS (IN SPITE OF A HUGE BACKGROUND).**

they published a story about my paper 4 days ago.

I better show few slides by myself

Cosmic-ray detector might have spotted nuggets of dark matter

21 Jan 2021



Scanning the sky: the Middle Drum facility of the [Telescope Array](#) observatory in the Utah desert. Could anomalous signals seen by the observatory be evidence for axion quark nuggets? (Courtesy: Ben Stokes/University of Utah)

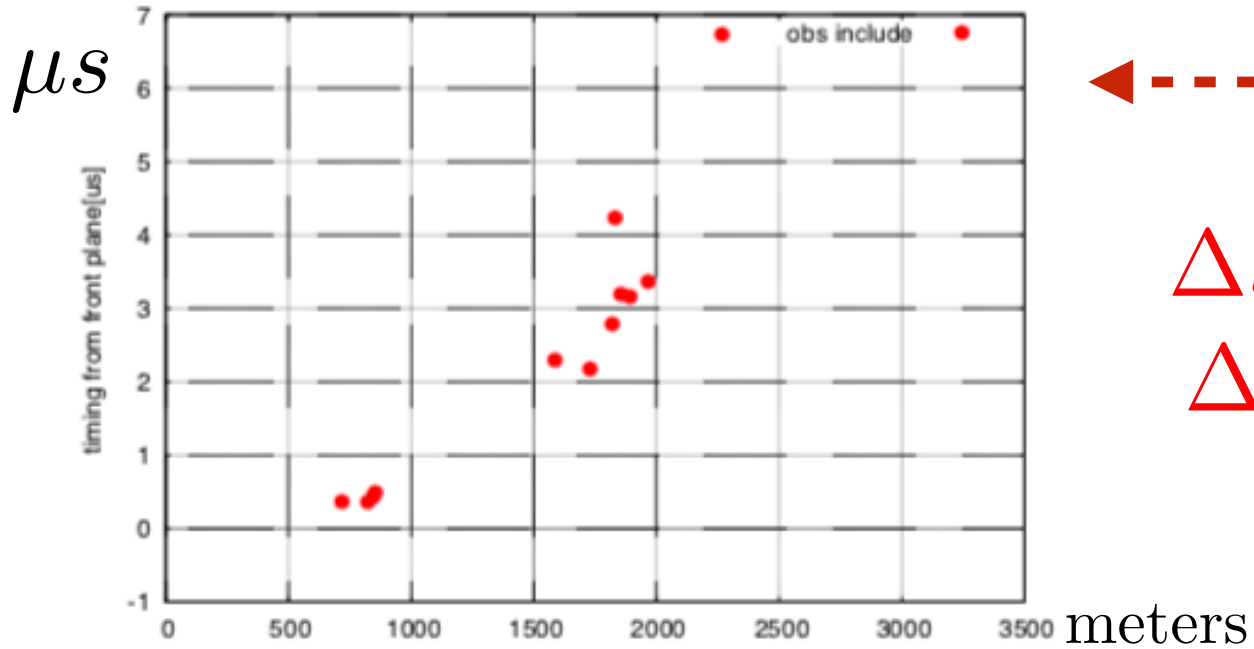
6. TELESCOPE ARRAY MYSTERIOUS BURSTS

- TELESCOPE ARRAY (TA) EXPERIMENT [ABBASI-2017] HAS RECORDED SEVERAL BURSTS OF AIR SHOWER-LIKE EVENTS. THIS BURSTS ARE VERY DISTINCT FROM CONVENTIONAL SINGLE SHOWERS, AND ARE FOUND TO BE 100% CORRELATED WITH THUNDERSTORM. THE UNUSUAL FEATURES ARE:
- “*clustering puzzle*”: BURST IS DEFINED AS 3+ CONSECUTIVE EVENTS WITHIN 1 MS, WHICH WOULD BE A HIGHLY UNLIKELY OCCURRENCE FOR 3+ CONSECUTIVE HITS IN THE SAME AREA ~ 1 KM IF INTERPRETED AS CR EVENTS
- IF ONE TRIES TO FIT THE OBSERVED BURSTS WITH CONVENTIONAL CODE FOR HE CR EVENTS ONE SHOULD EXPECT 10^{13} eV ENERGY RANGE (BASED ON FREQUENCY OF APPEARANCE), WHILE INTENSITY SUGGESTS 10^{19} eV;

- *“curvature puzzle”*: ALL BURST EVENTS ARE MUCH MORE CURVED THAN USUAL CR AIR SHOWERS. ALSO: THE EDGES IN WAVEFORMS ARE DRAMATICALLY DIFFERENT, *“edge puzzle”* (SEE TWO NEXT SLIDES);
- *“synchronization (with thunderstorm) puzzle”*: MOST OF THE BURSTS ARE SYNCHRONIZED (LESS THAN 1 MS) OR RELATED (LESS THAN 200 MS) WITH THE LIGHTNINGS/FLASHES
- SOME BURSTS ARE NOT RELATED TO LIGHTINGS → THEY CANNOT BE OUTCOME OF FLASHES. ALL OF THEM OBSERVED UNDER THUNDERSTORM. THE TOTAL 10 BURST EVENTS HAVE BEEN OBSERVED DURING 5 YEARS OF OBSERVATIONS;
- RECONSTRUCTED BURSTS START AT MUCH LOWER ALTITUDE THAN CONVENTIONAL HE CR SHOWERS (30KM).

adopted from TA collaboration [Abbasi-2017]

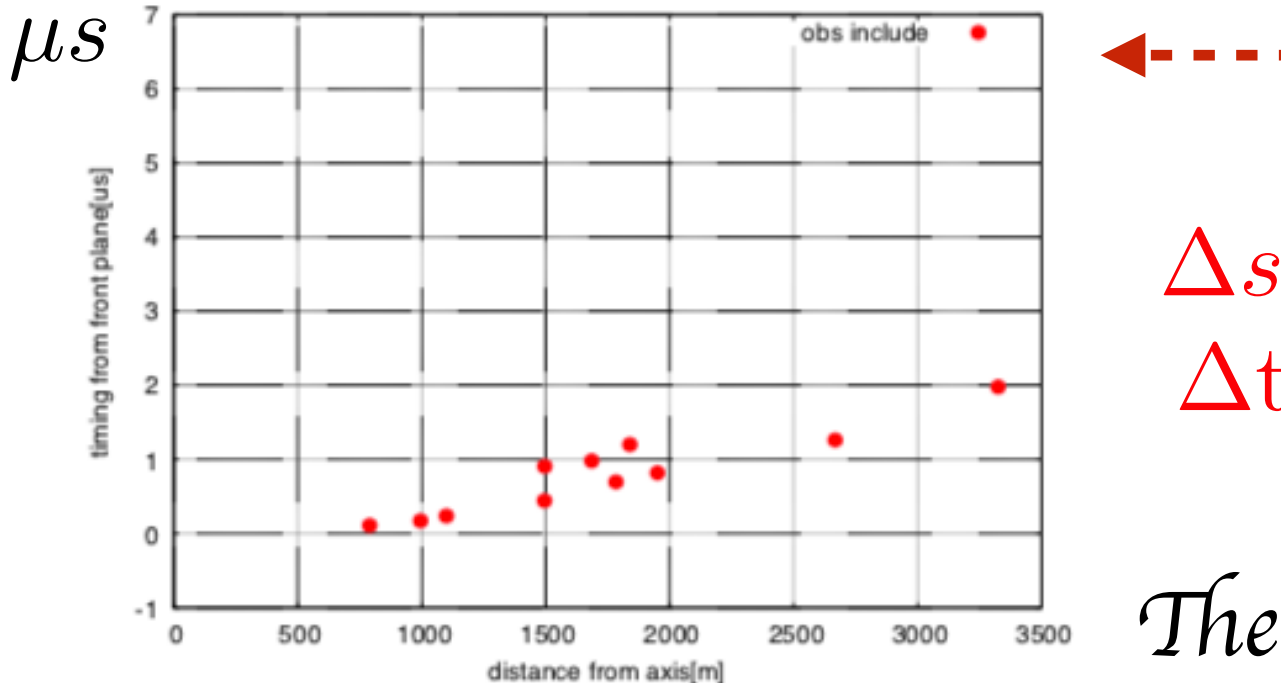
SD Event 120706 014911 184219



←----- typical burst event

$$\Delta s \in (0, 5 - 2) \text{ km},$$
$$\Delta t \in (0 - 8) \mu s$$

SD Event 080701 234921 873245

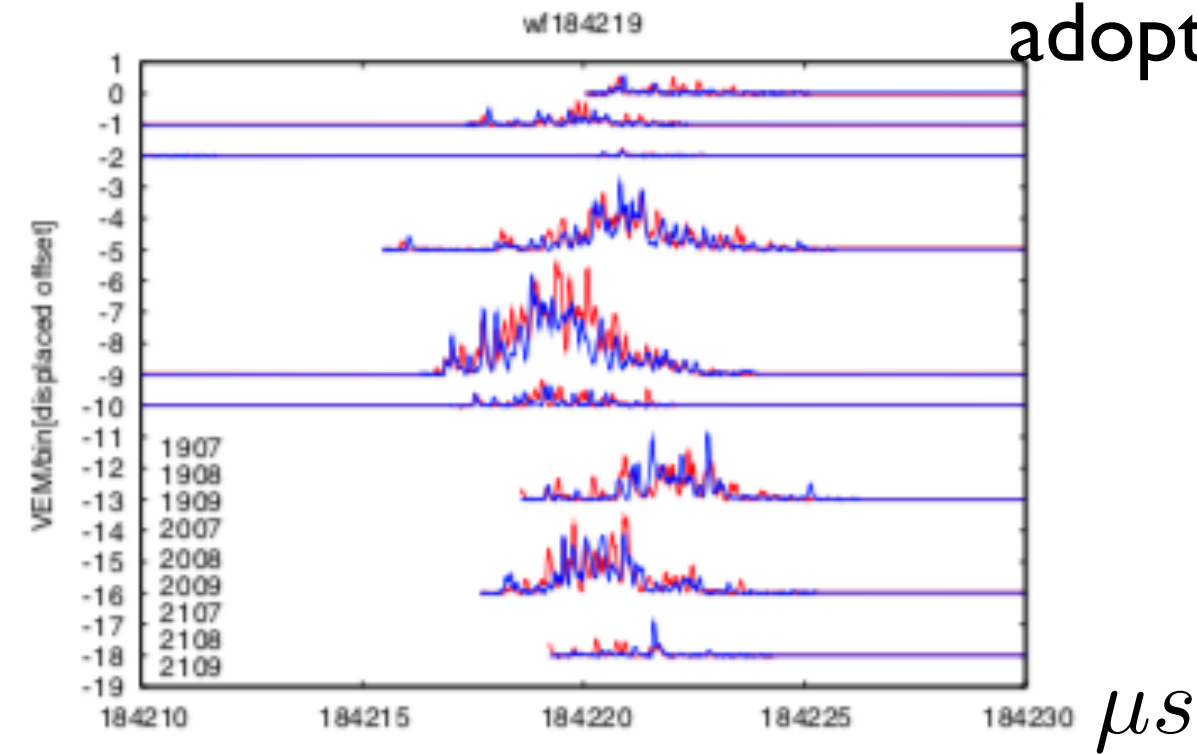


←----- typical CR event

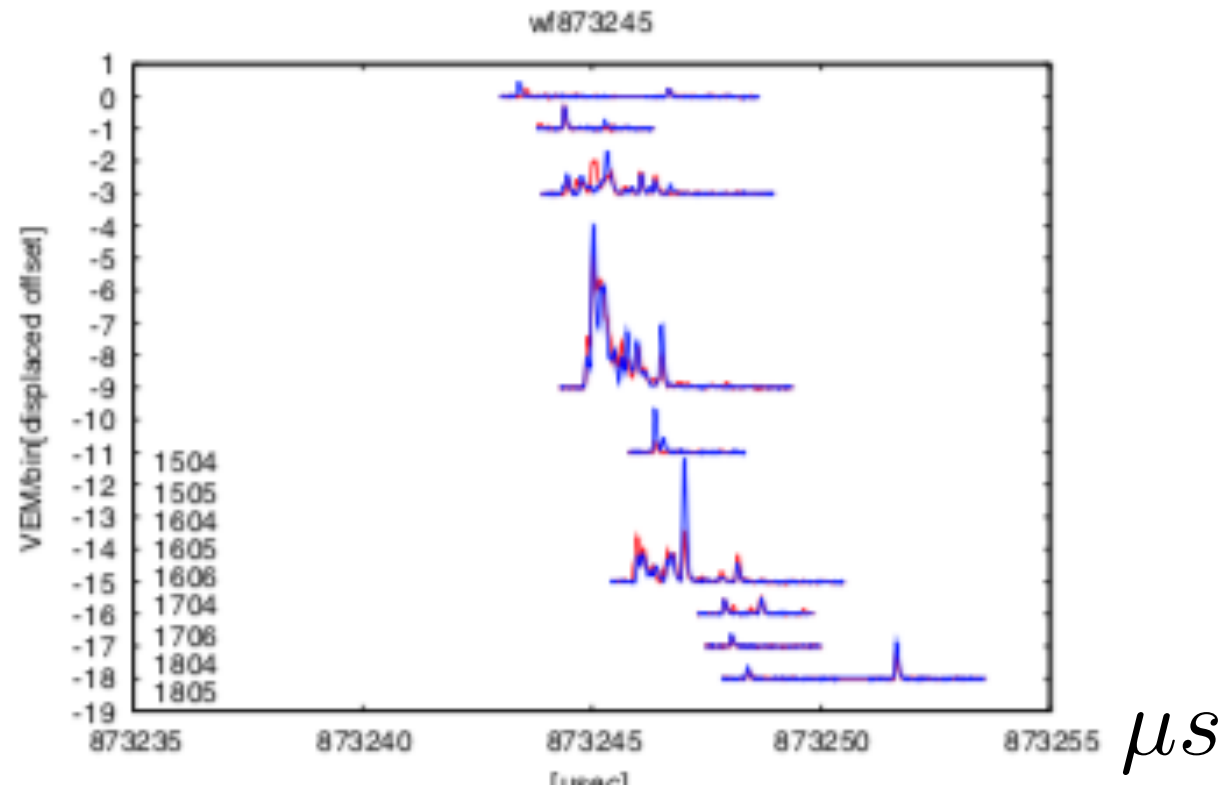
$$\Delta s \in (0, 5 - 3.5) \text{ km},$$
$$\Delta t \in (0 - 2) \mu s$$

The “curvature puzzle”

adopted from TA [Abbasi-2017]



← - - typical burst event



← - - typical CR event

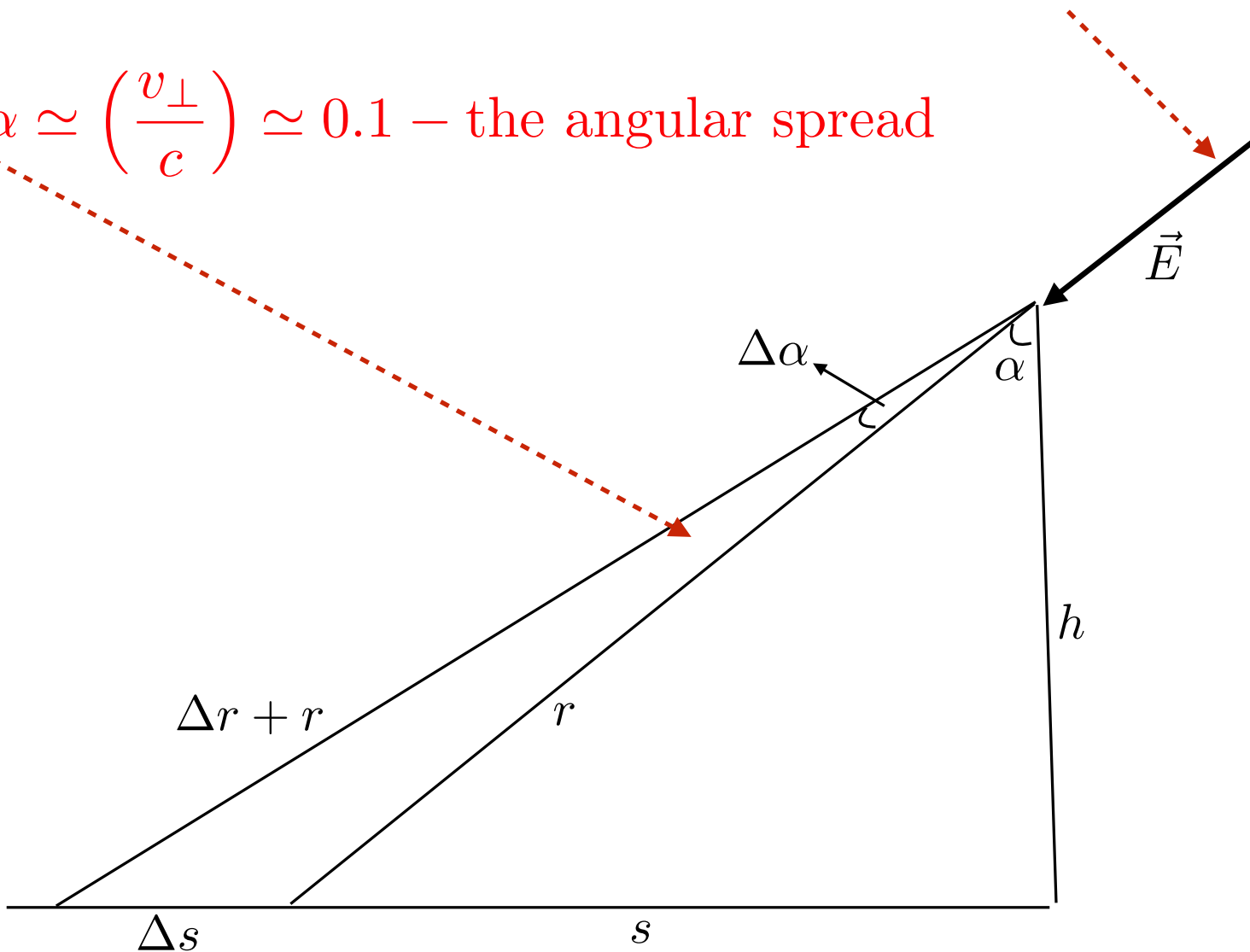
The "edge puzzle"

7. MYSTERIOUS BURSTS AS THE AQN ANNIHILATION EVENTS UNDER THUNDERSTORM

- WHEN THE AQN PROPAGATES IN ATMOSPHERE IT EXPERIENCE A LARGE NUMBER OF ANNIHILATION EVENTS WITH SURROUNDING MATERIAL
- IF THE AQN HITS THE REGION UNDER THUNDERCLOUD THE WEAKLY BOUND POSITRONS LOCALIZED AWAY FROM THE NUGGET'S CORE MAY BE LIBERATED BY PRE-EXISTING ELECTRIC FIELD $E \sim \text{KV/CM}$ WHICH IS KNOWN TO EXIST
- AS A RESULT OF STRONG ELECTRIC FIELD THE POSITRONS WILL ACCELERATE TO ENERGIES $\sim 10 \text{ MEV}$ ON SCALES OF ORDER $l_a \sim 100 \text{ m}$ (SO CALLED AVALANCHE SCALE)
- THE MEAN FREE PATH FOR SUCH ENERGETIC POSITRONS IS OF ORDER SEVERAL KM, SO THEY CAN REACH THE TA DETECTOR

Instant direction of the electric field at the moment of exit

$$\Delta\alpha \simeq \left(\frac{v_{\perp}}{c}\right) \simeq 0.1 - \text{the angular spread}$$



Δs - Spatial spread on the surface, observed by T ASD

■ THE POSITRONS TRAVELLING THE DISTANCE r THE SPATIAL SPREAD Δs IS ESTIMATED AS

$$\Delta s \simeq r \left(\frac{\Delta \alpha}{\cos \alpha} \right) \simeq \frac{1 \text{ km}}{\cos \alpha} \left(\frac{r}{10 \text{ km}} \right)$$

■ THE TIME SPREAD OF THE ARRIVING PARTICLES IS DETERMINED BY Δr AND ESTIMATED AS FOLLOWS

$$\Delta t \simeq \frac{\Delta r}{c} \simeq 3 \mu s \cdot (\tan \alpha) \cdot \left(\frac{r}{10 \text{ km}} \right) \text{ where } \Delta r \simeq r \tan \alpha \Delta \alpha$$

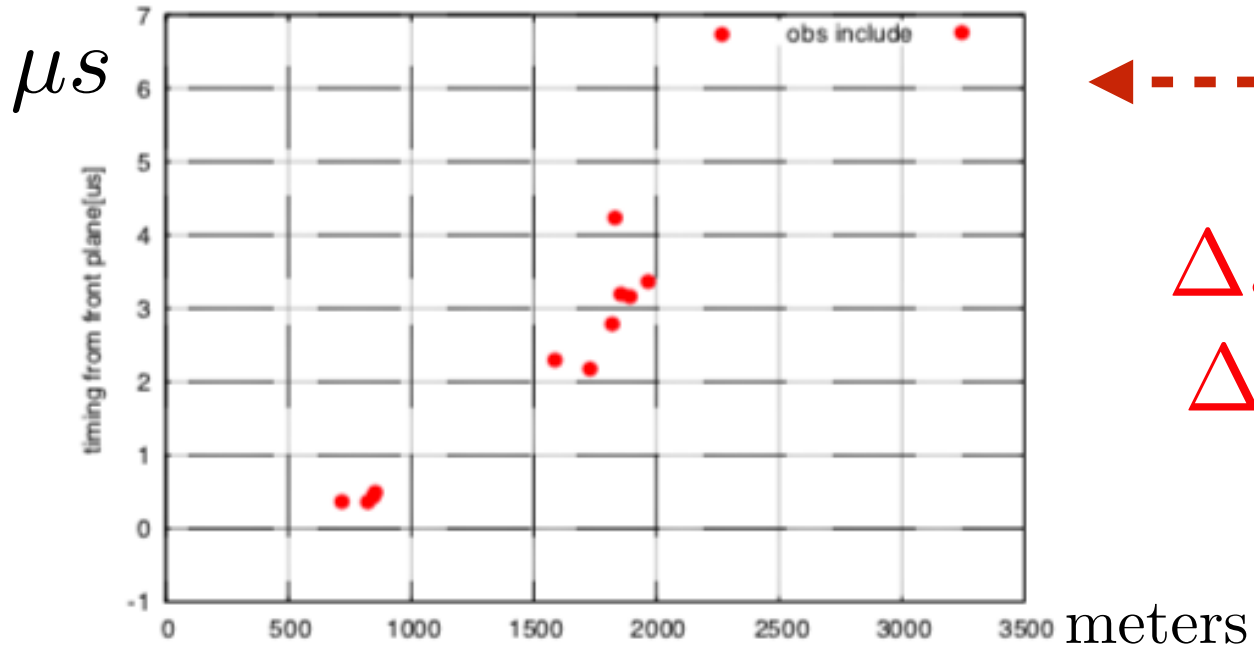
■ IMPORTANT: THE BASIC SCALE IS $v_{\perp} \simeq 0.1c$ WHICH IS NOT PRESENT IN CONVENTIONAL CR ANALYSIS

$(2\Delta t)$ varies $(0 - 8)\mu s$ when $(2\Delta s)$ changes between $(0.5 - 2)$ km

■ IT IS CONSISTENT WITH OBSERVATIONS. IT REPRESENTS RESOLUTION OF “*the curvature puzzle*” WITHIN AQN MODEL

adopted from TA collaboration [Abbasi-2017]

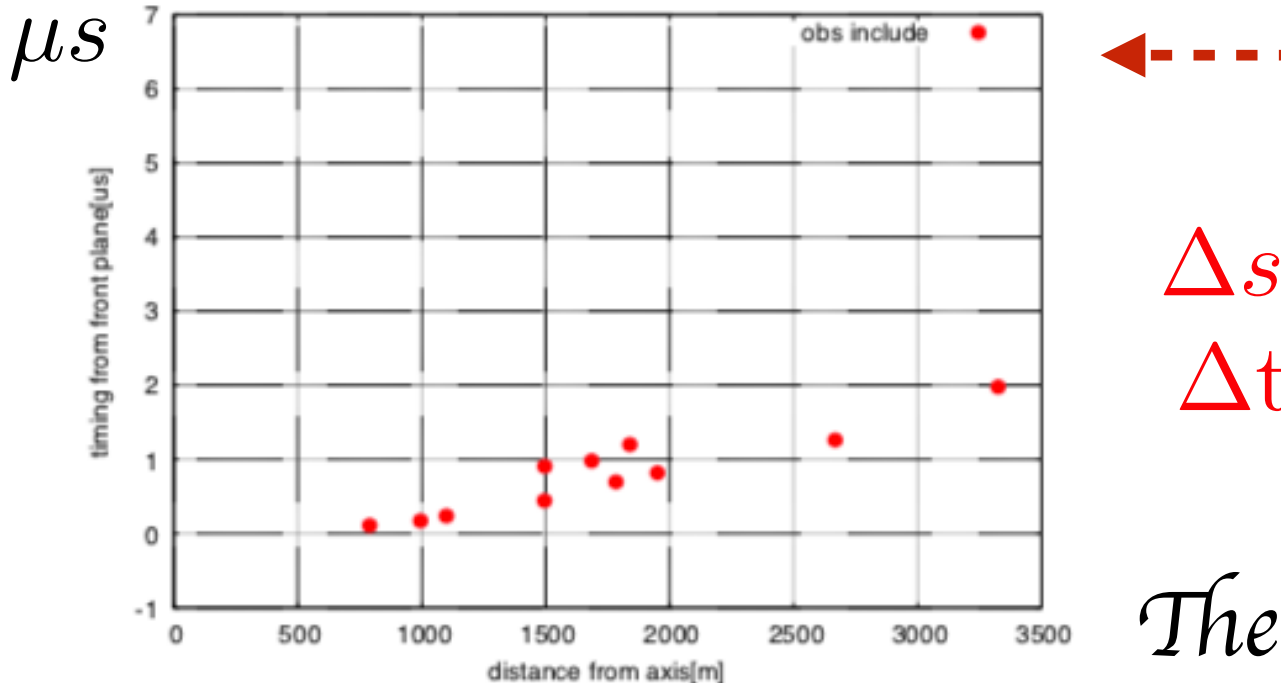
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SD Event 080701 234921 873245



←----- typical CR event

$$\Delta s \in (0, 5 - 3.5) \text{ km},$$
$$\Delta t \in (0 - 2) \mu s$$

The “curvature puzzle”

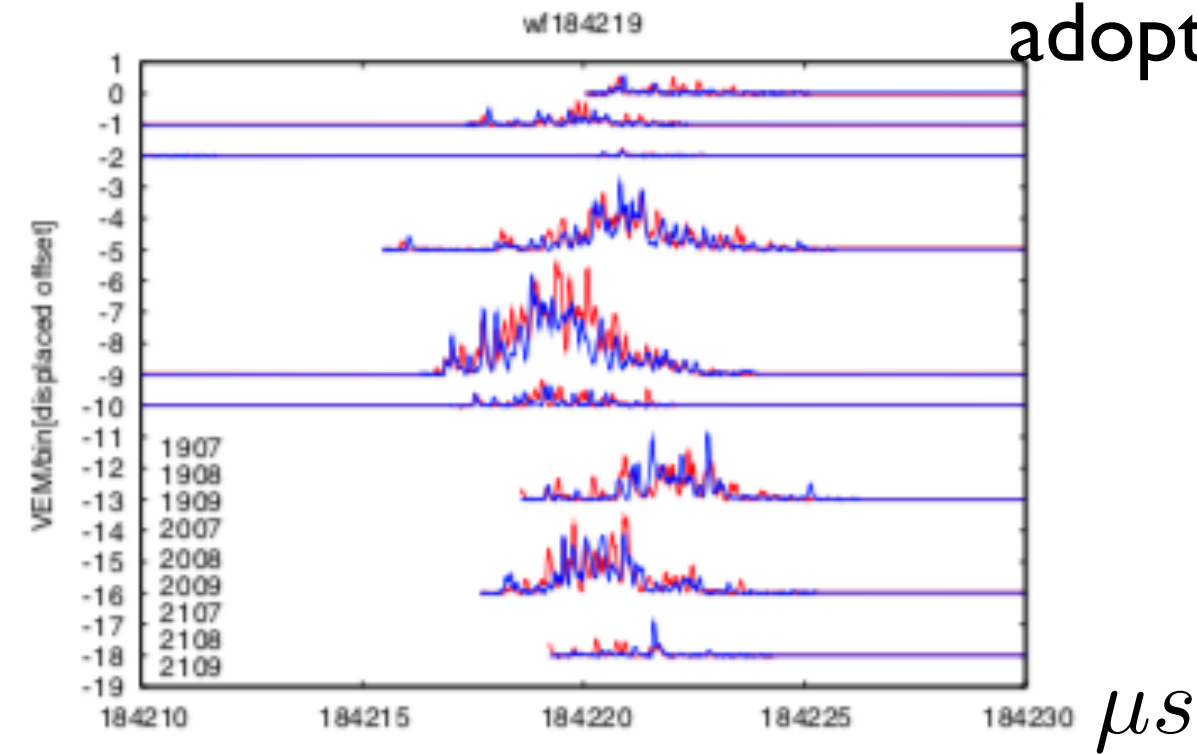
ALL BURSTS ARE OBSERVED UNDER THE THUNDERSTORM. IT IS HARD TO UNDERSTAND HOW CR MAY “KNOW” ABOUT THE THUNDERSTORMS. IN AQN FRAMEWORK THE ELECTRIC FIELD PLAYS THE KEY ROLE BY LIBERATING THE POSITRONS WHICH MIMIC THE CR EVENTS (THIS RESOLVES “*synchronization puzzle*”).

THE AQN TRAVERSES A SHORT DISTANCE $\sim 0.25\text{km}$ DURING THE BURST 10^{-3}s WHICH IS TREATED AS A CLUSTER OF EVENTS WHEN THE ELECTRIC FIELD FLUCTUATES ON THE SCALE OF ALONG THE AQN’S PATH 10^{-6}s (IT RESOLVES “*clustering puzzle*”)

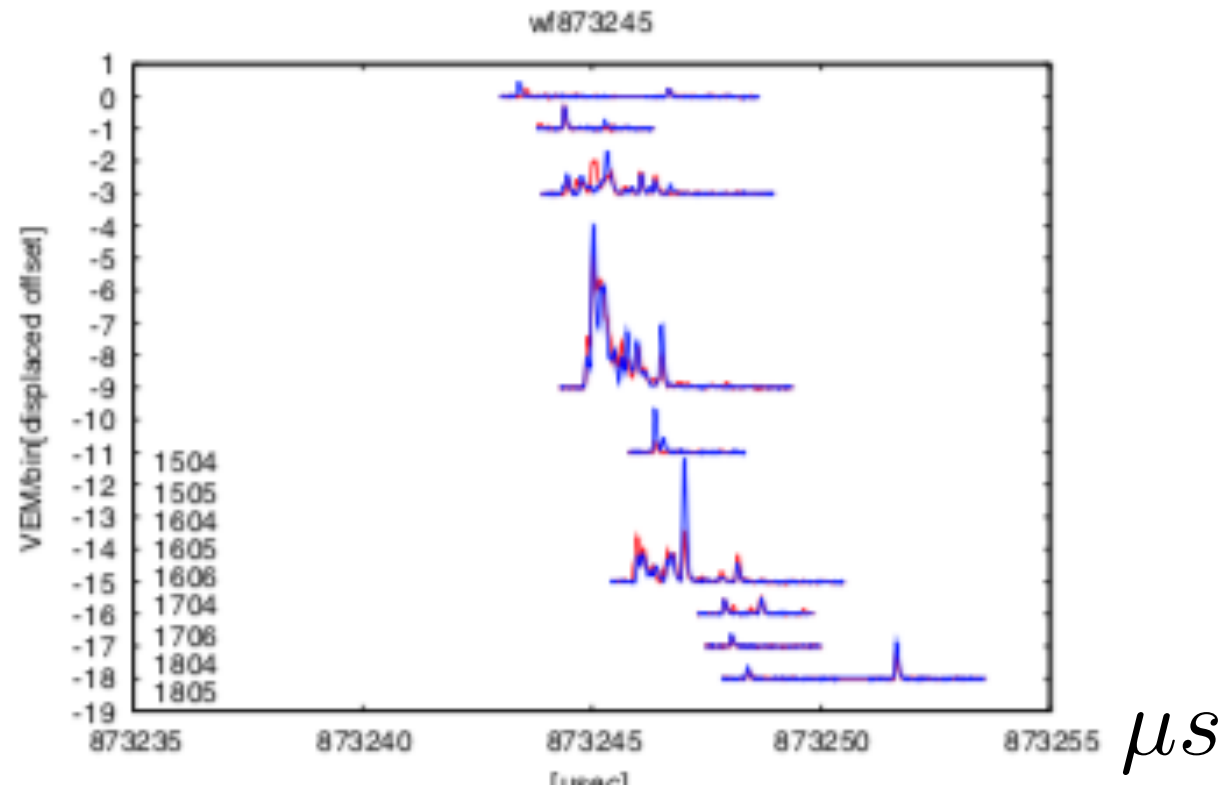
OCCURRENCE OF 3+ INTENSE EVENTS DURING 10^{-3}s IN 1KM AREA IS HARD TO EXPLAIN WITH CONVENTIONAL CR ASSUMPTION (IT RESOLVES “*clustering puzzle*”)

CONVENTIONAL CR SHOWERS HAVE AN ULTRA RELATIVISTIC PARTICLE (SHARP EDGE IN WAVEFORMS). LARGE NUMBER OF POSITRONS PRODUCE NON-SHARP EDGE, RESOLVING “*edge puzzle*”

adopted from TA [Abbasi-2017]



← - - typical burst event



← - - typical CR event

The "edge puzzle"

CONCLUSION

■ "NON- BARYONIC DARK MATTER" COULD BE ORDINARY BARYONIC MATTER (WE KNOW AND LOVE) WHICH IS IN THE EXOTIC COLOUR SUPERCONDUCTING PHASE. WE COIN THIS MODEL AS THE AXION QUARK NUGGET MODEL (AQN)

■ $\Omega_{\text{dark}} \sim \Omega_{\text{visible}}$ IS VERY GENERIC CONSEQUENCE OF THIS FRAMEWORK (NO SENSITIVITY TO AXION MASS m_a , NOR TO THE MISALIGNMENT ANGLE θ_{initial}). IT IS THE DIRECT CONSEQUENCE OF THE FRAMEWORK WHEN THE DARK MATTER AND VISIBLE COMPONENTS ARE PROPORTIONAL TO ONE AND THE SAME FUNDAMENTAL Λ_{QCD} SCALE.

■ THIS MODEL OFFERS A SIMULTANEOUS RESOLUTION OF A NUMBER (NAIVELY UNRELATED) OLD MYSTERIES: DM, BARYOGENESIS, SOLAR CORONA MYSTERY, PRIMORDIAL LITHIUM, TELESCOPE ARRAY MYSTERIOUS BURSTS, ETC

■ THE AXIONS WILL BE INEVITABLY PRODUCED EACH TIME WHEN THE ANNIHILATION EVENT HAPPENS BECAUSE THE AXION FIELD PLAYS A KEY ROLE IN CONSTRUCTION OF THE AQNS (PLAYS ROLE OF A SQUEEZER). THE TYPICAL AXIONS HAVE THE VELOCITIES $v_a \simeq 0.6 c$.

■ **BROADBAND DETECTION TECHNIQUE MUST BE IMPLEMENTED TO SEARCH FOR SUCH AXIONS. DAILY MODULATION IS A POWERFUL TOOL TO ANALYZE THE DATA TO REMOVE SPURIOUS AND NOISE SIGNALS.**

■ THE DISCOVERY OF THE AXIONS WITH $v_a \simeq 0.6 c$ WILL BE DIRECT MANIFESTATION OF THE AQN FRAMEWORK (IN CONTRAST WITH INDIRECT OBSERVATIONS SUCH AS BARYOGENESIS, LITHIUM PUZZLE, SOLAR CORONA MYSTERY, DIFFUSE X-RAYS, GALACTIC 511 KEV, XMM - NEWTON SEASONAL VARIATIONS, ETC)

$\Omega_{\text{dark}} \sim \Omega_{\text{visible}}$

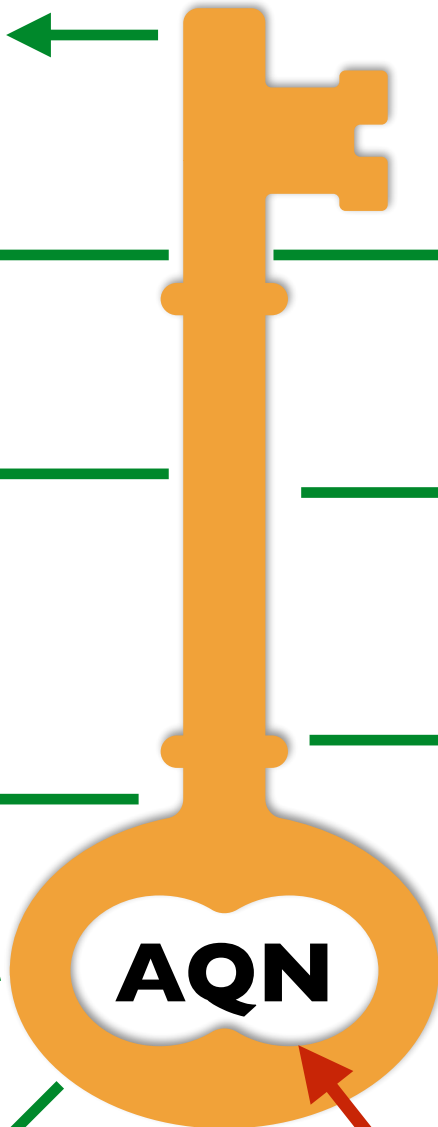
“Baryogenesis”
(charge separation)

Primordial
Lithium Puzzle

TA mysterious
bursts

sky-quakes

XMM-Newton
seasonal variations



Dark Matter

Solar corona
Mystery

DL annual
modulation

We need to discover
the **axion** to unlock
all these mysteries
(simultaneously)