Anti-Nuggets as Dark Matter

Ariel Zhitnitsky
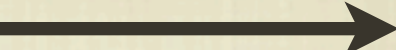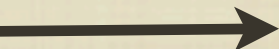
University
of British Columbia,
Vancouver, Canada

Cosmic Frontiers Workshop (CF-6),   *SLAC, March 6-8, 2013*

1. Two (naively unrelated) problems: DM and Baryogenesis.

- "Naive" Moral: Dark matter requires New (unknown) Fields

- 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" (colour superconductor) of ``Old Fields (quarks and gluons)''

- Instead of "Baryogenesis" ⟶ "separation of charges" of conventional fields (quarks and gluons).

- WE PROPOSE THAT ON THE GLOBAL LEVEL THE UNIVERSE IS <u>SYMMETRIC</u>. THE SEPARATION OF BARYON CHARGES IS ORIGINATED AT THE QCD SCALE. SOME CHARGES ARE LOCKED IN FORM OF LARGE DENSE QUARK MATTER NUGGETS (AND ANTI-NUGGETS), SIMILAR TO WITTEN'S STRANGELETS.

- THE NUGGETS REMAIN STABLE OVER COSMOLOGICAL TIMESCALES AND SERVE AS DM.

- WE TAKE THE ADVANTAGE OF STRONG CP VIOLATION RESULTING FROM $\theta \neq 0$ DURING THE QCD PHASE TRANSITION. THIS SOURCE OF CP VIOLATION IS <u>NOT AVAILABLE</u> ANYMORE TODAY.

- STRONG CP VIOLATION IN QCD: FROM A "FUNDAMENTAL PROBLEM" IT BECOMES A "FUNDAMENTAL KEY ELEMENT" IN RESOLUTION OF "MATTER-ANTIMATTER ASYMMETRY PUZZLE" IN OUR UNIVERSE.
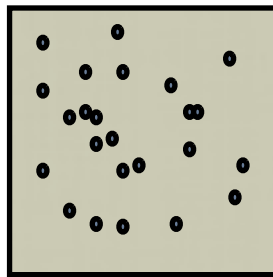
Matter in the Universe
A model which explains both the matter-antimatter asymmetry and the observed ratio of visible matter to DM
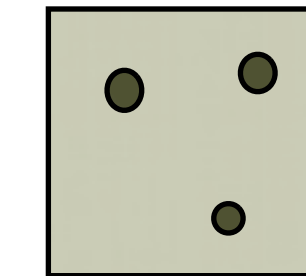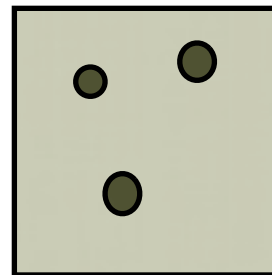
$$B_{tot} = 0 = B_{nugget} + B_{visible} - \bar{B}_{antinugget}$$

$$B_{DM} = B_{nugget} + \bar{B}_{antinugget} \simeq 5\, B_{visible}$$
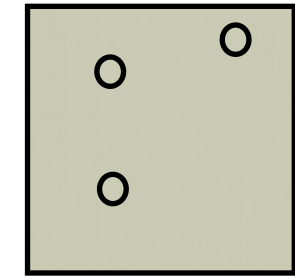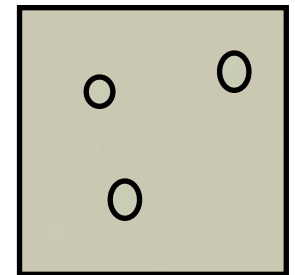
The ratio $B_{nugget}/\bar{B}_{antinaget} \simeq 2/3$ *is determined by CP violating parameter* $\theta \sim 1$

One part:
visible matter

Two parts:
matter nuggets
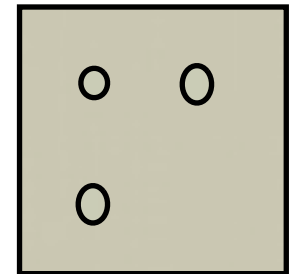
Three parts:
anti-matter nuggets

- INSTEAD OF CONVENTIONAL LOCAL FIELDS THE DM IN THIS FRAMEWORK IS A COMPOSITE OBJECT (LIKE SOLITONS IN CONDENSED MATTER PHYSICS)

- IF THE NUGGETS ARE SUFFICIENTLY MASSIVE THE OBSERVATIONAL CONSEQUENCES OF THESE OBJECTS WILL BE SUPPRESSED BY SMALL NUMBER DENSITY

- A SMALL GEOMETRICAL FACTOR REPLACES A WEAK COUPLING CONSTANT FOR LARGE NUGGETS

$$\epsilon \sim S/V \sim B^{-1/3} << 1$$

$$B \sim 10^{25}, \quad R \sim 10^{-5} \ cm, \quad M \sim 10 \ g$$

(TO BE COMPARED WITH THE AXION CORRELATION LENGTH $m_a^{-1} \sim 10^{-5} cm$)

Source of Emissions

p,n

e

511 keV

e⁺

1-20 MeV

e

$\bar{q}q \rightarrow 2 \text{ GeV}$
energy

thermalization

e⁺

X rays ~10 keV
(~ 10% of energy)

γ~ 100 MeV - 1 GeV
(rare events)

Fermi Pressure
$R \sim 10^{-5} \; cm, \quad B \sim 10^{25}$

e⁻

axion
domain
wall
pressure

**Antimatter
color superconductor**

e⁺

$(10^{-4} - 1)\text{eV}$
bremsstrahlung radiation
(~90% of energy)

e⁺

electro-spere
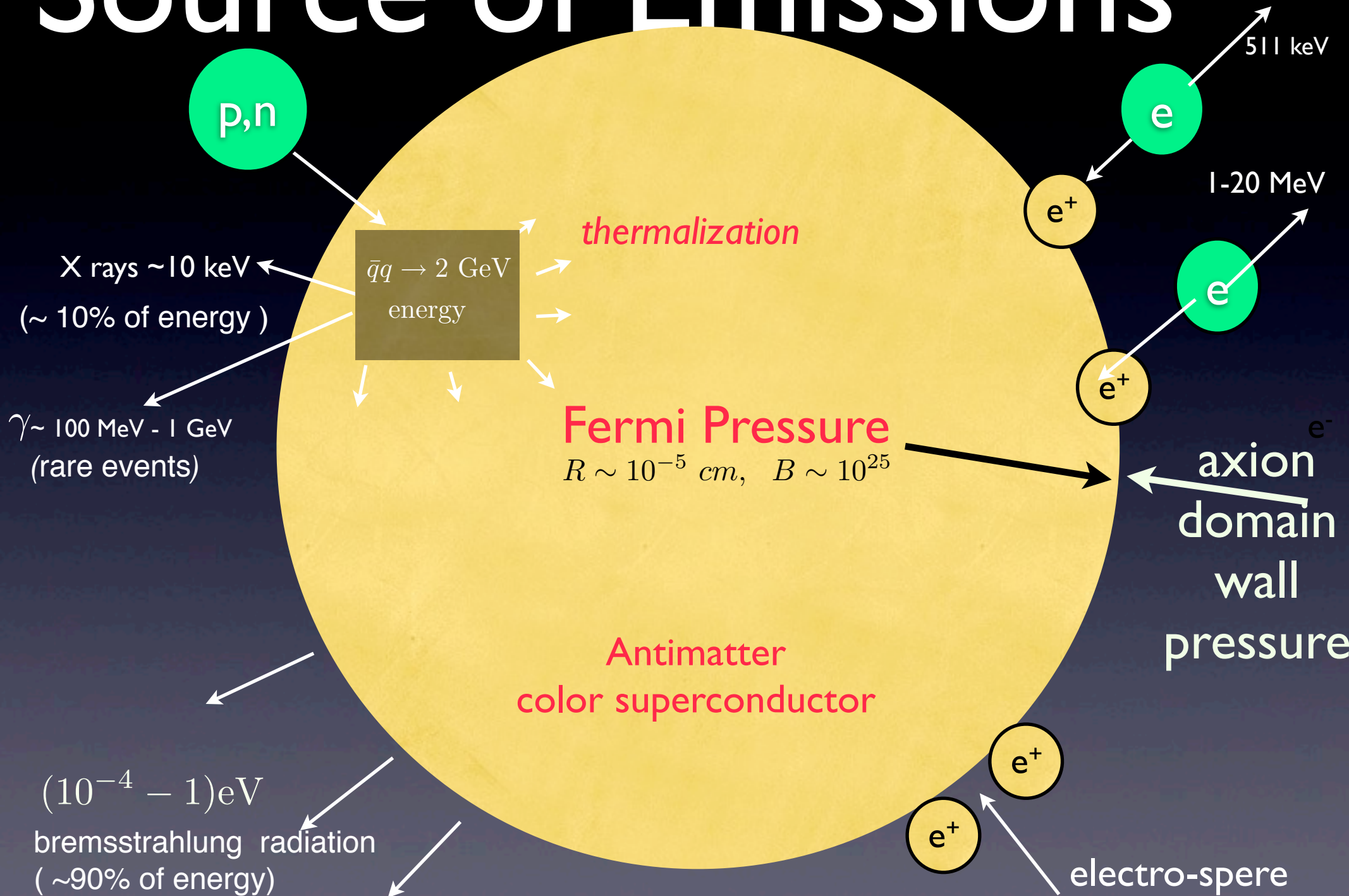
- Mechanisms of formation and properties of quark nuggets (in colour superconducting phase) and Witten's strangelets are very different.

- Difficulties to study the formation: unknown the QCD phase diagram at $\theta \neq 0$, formation of the soliton-like object is a general hard problem...

- Excess of antimatter is locked away in antimatter nuggets requiring no fundamental baryon asymmetry to explain the observed matter/antimatter asymmetry.

- The nuggets have a large binding energy (~100 MeV) such that large baryon charge in the nuggets is not available to participate in BBN at T~MeV.

2. Observational Cosmological Puzzles
(naively unrelated story)

- Several independent observations of the galactic core suggest unexplained sources of energy:

- The most known case is the 511 keV line (<u>INTEGRAL</u>) which has proven very difficult to explain with conventional astrophysical positron sources.

- A similar, but less known mystery is the excess of gamma-ray photons detected by <u>COMPTEL</u> across a broad energy range 1-20 MeV. Such photons have been found to be very difficult to produce via known astrophysical sources

- Detection by the <u>CHANDRA</u> satellite of diffuse X-ray emission from across the galactic bulge provides a puzzling picture: after subtracting known X-ray sources one finds a residual diffuse thermal X-ray emission consistent with very hot plasma (T= 10 keV). Source of energy fuelling this plasma is a mystery.

- The <u>WMAP</u> experiment has revealed an excess of microwave emission, $23 < w < 61$ GHz from the center of our Galaxy. This excess, which is uncorrelated to the known foregrounds, is known as the ``<u>WMAP haze</u>''.

- Recent measurements by the <u>ARCADE2</u> experiment unambiguously show an excess in the <u>isotropic radio</u> background at frequencies below the GHz scale.

- Origin of these excesses remains a mystery as all conventional sources for these diffuse emissions are not capable to describe the observations.

3. Immediate (generic) consequences:

- If DM is originated from the QCD scale the relation $\Omega_{DM} \sim \Omega_B$ may come naturally as both contributions are originated from the same QCD physics.

- The DM nuggets made of quarks/antiquarks do interact with visible matter. However, the interaction is strongly suppressed: a small geometrical factor $\sigma/M \simeq 10^{-10} \mathrm{cm}^2/\mathrm{g}$ replaces the standard requirement for the coupling constant to be weak. It is well below typical cosmological limits
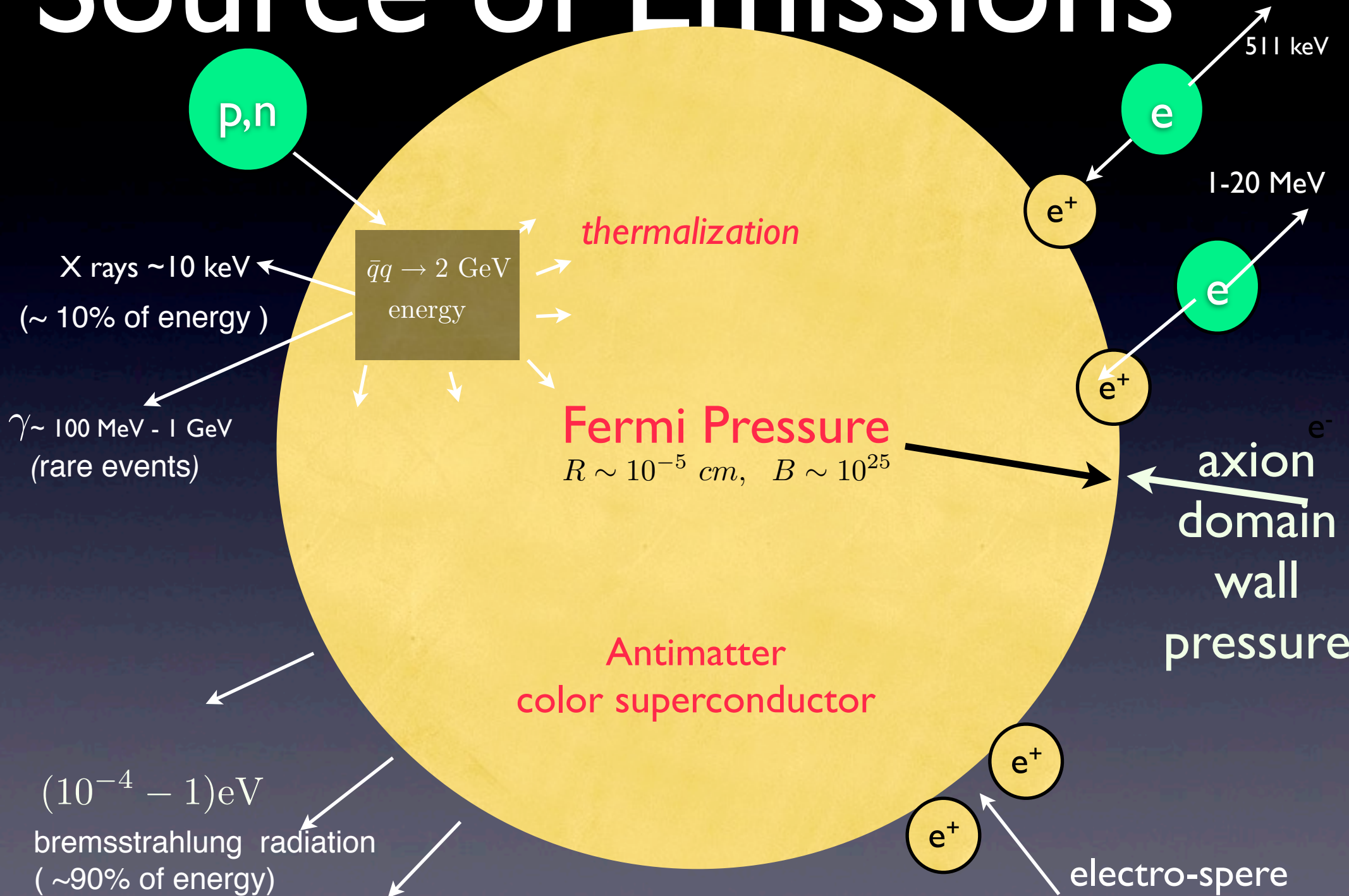
$$\sigma/M \leq 1\mathrm{cm}^2/\mathrm{g}$$

- All effects are proportional to a single unknown parameter computed along the line of sight

$$B^{-1/3} \int dr \, \rho_{visible}(r) \cdot \rho_{DM}(r)$$

- Standard tight constraint on antimatter presence in our universe does not apply here as it does not radiate/ annihilate as conventional <u>matter</u>.

- Rare events of annihilation of the visible matter with antimatter nuggets provide an excess of radiation which apparently have been observed in different frequency bands: 511 keV, 1-20 MeV, X -rays, microwaves (WMAP haze),....

- on large scales, the nuggets behave as standard collisionless cold dark matter. However: some modifications are expected in dense regions (galaxies), where DM does interact strongly with visible matter.

- The idea of the charge separation during the QCD phase transition at $\theta \neq 0$ (the key element of the proposal) can be tested at RHIC and LHC. Recent Experimental results (STAR, ALICE collaborations) support charge separation effect (local P, CP violation in heavy ion collisions has been observed).

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Antimatter
color superconductor

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(~90% of energy)

e⁺

e⁺

electro-spere

Relevant Literature

- DM-Baryogenesis   JCAP 2003; PRD. 2005

- 511 keV line (INTEGRAL)   PRL. 2005

- 1-20 MeV excess (COMPTEL)   JCAP 2008; PRD. 2010

- X-ray emission (CHANDRA)   JCAP 2008

- $23 < w < 61$ GHz (WMAP haze)   PRD. 2008

- $w < 1$ GHz (ARCADE 2)   arxiv 1210.2400

Conclusion: galactic excess emissions

- " Non- baryonic Dark matter" could be ordinary baryonic matter which is not in the ``normal hadronic phase", but rather, in the exotic colour superconducting phase.

- In this phase the baryon charge is not available for BB Nucleosynthesis

- A small geometrical factor $\epsilon \sim S/V \sim B^{-1/3} \ll 1$ replaces a weak coupling const.

- Conventional killing problem (for other models) of insufficient CP violation is automatically resolved here: CP violation is <u>large</u> at the QCD phase transition; it is <u>diminished</u> by now as a result of the axion dynamics.

- **All effects are proportional to one and the same asymmetric normalization factor (which is a single unknown parameter in the entire framework).**

$$B^{-1/3} \int dr \, \rho_{visible}(r) \cdot \rho_{DM}(r)$$

- **This is very different (e.g. morphologically) from conventional DM models where effect is proportional to**

$$\int dr \, \rho_{DM}^2(r) \text{ (annihilating DM)} \quad or \quad \int dr \, \rho_{DM}(r) \text{ (decaying DM)}$$

- **All relative intensities are fixed by conventional physics. It covers 11 orders of magnitude:**

$$\omega \sim 10^{-4} \text{ eV for WMAP haze } to \ \omega \sim 10 \text{ MeV for COMPTEL}$$

Recent development. Prospects for ground based (suborbital) detection.

- K.Lawson, PRD 83 (2011), 103520

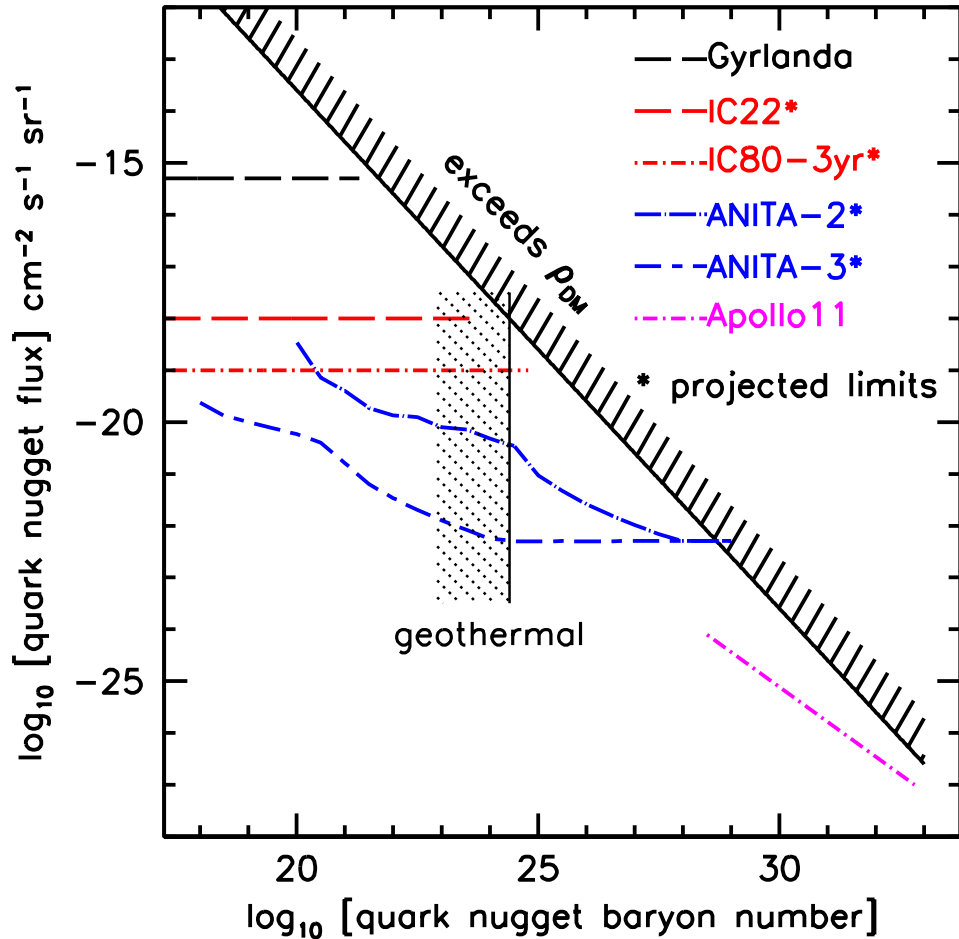- P. Gorham, PRD 86 (2012), 123005

- K.Lawson, arxiv 1208.0042

- Expected flux at the earth's surface

$$\frac{dN}{dA\ dt} = nv \approx \left(\frac{10^{25}}{B}\right) km^{-2} yr^{-1}$$

- This flux is well below the sensitivity of any conventional WIMP DM searches. The flux of nuggets is similar to that of cosmic rays near GZK limit.

- An extensive air shower will be developed around the primary particle.

- The shower is driven not by kinetic energy of the primary, but by energy released in matter-antimatter annihilation.

- There are many <u>similarities</u> (in terms of spectrum) with conventional <u>air shower</u> produced by a single ultrahigh energy primary.

- However, there are some important differences (<u>see Lawson's presentation</u>).

- Generally, the nuggets carry sufficient momentum to travel through the earth and emerge from opposite side.

Plot from P. Gorham, PRD 86 (2012) 123005

Existing and projected limits on anti-quark nugget fluxes

CONCLUSION (detection prospects):

1. *Radio emission of anti-quark nuggets with $B = 10^{24} - 10^{28}$ can be studied by balloon -borne instruments such as ANITA.*

2. *Analysis of existing ANITA-2 data for these event signatures has begun, and results may be expected within the next year.*