Dusty Dark Matter Bubbles of a New Vacuum stopped in Earth and Radiating 3.5 keV X-rays.

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We continue our work on a proposal for what dark matter could be, namely that the dark matter consists of essentially macorscopic objects built from ordinary matter. The only element of "new physics" is that there should exist several types or phases of vacuum. Then the dark matter particles are bubbles of a new type of vacuum filled with ordinary matter - say diamond - under high pressure and the whole bubble is supposedly contaminated by the materials in the extragalactic or intragalactic space able to form dust. The dust has a lower than dimension 3 structure and may well be long chains of atoms.

We begin speculations on identifying the phase transition between the vacua, which we require in our model, with a (second order?) transition revealed in the Columbia plot with quark masses as axes. In the corner of small quark masses there is a true phase transition as temperature is raised, while outside this region there is instead no genuine phase transition under variation of the temperature but rather only a "crossover".

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1. Introduction

Concerning its gravitational force the existence of dark matter is incorporated in the standard cosmological model, but the non-gravitational properties of the dark matter is much less well-established and even connected with seeming contradictions or mysteries.

Many physicists still believe in WIMPs being the dark matter, while we ourselves go for a model hopefully incorporable into the Standard Model, in which the dark matter is more like macroscopic structures of ordinary matter (only with one new vacuum story added). But let us start by looking at a few questions:

1.1 Mysteries concerning Dark Matter

- Why do the Xenon experiments *not* "see" the dark matter ?

  The answer of our model: The dark matter particles get stopped down to too low speed by the atmosphere and the shielding. Then they do not have enough speed to bring the nuclei in the detector up to a speed that gives visible scintillation in the counters.

- But how can then DAMA "see" the dark matter?

  Our answer: Dark matter radiates electrons. DAMA only tests that it is dark matter by the seasonal variation [1, 2], while the Xenon-experiments exclude (or can separate) the electron induced signal. So DAMA would accept as possible dark matter a signal with sufficiently high energy electrons. However such high energy electrons would not be produced by simple collisions of a few hundred km/s dark matter particles; so special radiation would be needed.

- Could the Xenon experiments then not look for electrons also?

  Our answer: Yes, and indeed Xenon1T "saw" a little excess of "electron recoil events" of energy about 3.5 keV [3].

  Unfortunately this little electron-recoil effect was retested and it turned out, as reported in a paper published shortly after this workshop [4], to probably have been due to the presence of radon gas. So now the situation is that the Xenon-experiments saw nothing in electron recoil events either.

- But recoil electrons from 300 km/s collisions only have about 1 eV energy, not keV's!

  Our model answer: Our dark matter particles can be excited so as to radiate 3.5 keV X-rays or electrons.

- How does the dark matter get excited so as to radiate electrons in DAMA?

  Our answer: The dark matter particles get heated up and excited by the interaction with the atmosphere while being stopped.

- But if they get so easily stopped and slowed down, does it not mean that the dark matter is not truly dark?

Answer: It has an "inverse darkness"

$$\frac{\sigma}{M} = 15 m^2/kg \text{ (for velocity } v \to 0. \text{)} \tag{1}$$

enough for stopping, but only little noticed in astronomy.

In fact Correa made a fit of dwarf galaxy star velocities in a model with self interacting dark matter, SIDM, and obtained the value $15 m^2/kg$ for the low velocity limit of the ratio of the cross section relative to the mass of a dark matter particle [5]. At higher velocities the cross section falls off. Her results are displayed in Figure 1.

1.2 Our only moderately dark Dark Matter

In our model the dark matter particles or pearls consist of a tiny bubble of a new speculated vacuum filled with highly compressed ordinary matter, say carbon, surrounded by an approximately 100 times larger dust grain. This dust grain can be washed off in the Earth's atmosphere, leaving behind a cleaned vacuum bubble with a cross section say 10000 times smaller than that of the dusty pearl. The cleaned dark matter pearl gets decelerated to a much slower speed in the atmosphere and can then penetrate slowly through the shielding of the earth down to say DAMA.

Thus we have for the dusty pearls (at low velocity and at 1000 km/s in big galaxy clusters) and cleaned pearls the following values for the "inverse darkness " $\frac{\sigma}{M}$ (where σ is the cross section of the pearl and M its mass):

$$\frac{\sigma}{M}\Big|_{v \to 0} = 15 m^2/kg \text{ ("observed", dusty)} \tag{2}$$

$$\frac{\sigma}{M}\Big|_{clean} = 10^{-3} m^2/kg \text{ (cleaned, vacuum-bubble)} \tag{3}$$

$$\frac{\sigma}{M}\Big|_{v=1000km/s} = 10^{-2} m^2/kg \text{ ("observed", dusty, big clusters)} \tag{4}$$

Note that even our dusty dark matter is dark compared to atoms, but conventional WIMP dark matter is much darker than ours:

$$\text{Carbon C: } \frac{\sigma}{M}\Big|_C = \frac{\sigma_C}{12u * 1.66 * 10^{-27} kg/u} = 7.73 * 10^5 m^2/kg$$

$$\text{WIMP say: } \frac{m_W^{-2}}{m_W} \sim \frac{(0.2 * 10^{-17})^2 m^2}{2 * 10^{-27} kg} \sim 10^{-8} m^2/kg$$

Figure 2 shows that dark matter with only gravitational interactions does not function so well in simulations on dwarf galaxies [5].

2.   Our Model of Dark Matter in principle inside the Standard Model

Provided we can invent some theoretical story like that QCD, instead of being simply confined and having the Gellman $SU(3)$ symmetry of rotating the light quarks into each other or better the chiral part of it being spontaneously broken, could have another phase where the diagonal subgroup
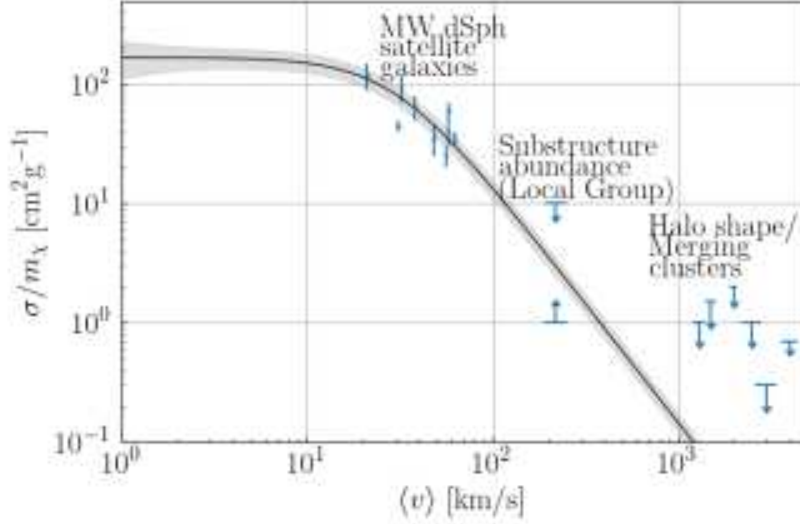
Figure 7. Same as Fig. 6, but extended to cover the range of MW-
(~200 km/s) and cluster-size (~1000 – 5000 km/s) haloes' veloc-
ities. The figure shows upper and lower limits for σ/m_χ taken
for substructure abundance studies (e.g. Volgelsberger et al. 2012
and Zavala et al. 2013), as well as based on halo shape/ellipticity
studies and cluster lensing surveys (see text).

Figure 1: By fitting to various dwarf galaxies Correa [5] has obtained the ratio of the cross section for one
dark particle hitting another one divided by the mass of such a particle, $\frac{\sigma}{M}$, also called the inverse darkness,
as a function of the velocity in the collision. Since varying the mass and the cross section by the same factor
would not change any effect of the dark matter, one can of course never obtain anything but this ratio from
the dark matter effects on the ordinary matter.

of the two $SU(3)$s survives spontaneous breaking [6]. Then we could speculate on the existence of
two phases of the QCD-part of the vacuum-structure. Really QCD and the usual Nambu-JonaLasinio
spontaneous breaking is sufficiently complicated that a slightly *different QCD-part* of the vacuum
structure can *not be excluded*. If such a possibility had just been overlooked so far then, due to the
QCD-physics, there could be two phases of the vacuum, and our speculation about an extra vacuum
inside of the dark matter bubbles could be realized completely inside the Standard Model. This
could of course explain why LHC did not see any new physics in spite of it usually being strongly
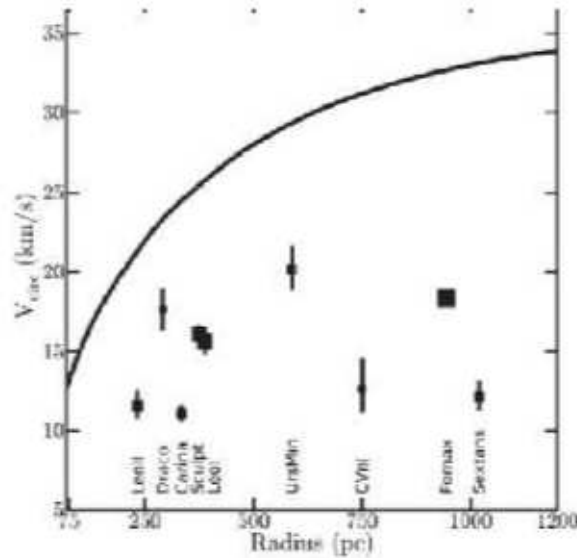expected from considering dark matter.

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Figure 2: This figure should illustrate that when Correa simulated the dark matter distribution, under the assumption of a purely gravity interaction, and regained a prediction for the star velocities it was *not* successful. So there is a call for e.g. interaction of the dark matter with itself.

- Why did LHC not see any dark matter?

  Our answer: In our model the dark matter is composed from ordinary stuff like nuclei and electrons being caught into a bubble of a second phase of the vacuum.

  There is no "new physics" in our model, except that we do not know how the two (or more) types of vacua come about.

  But we speculate that they can appear inside the Standard Model without genuine new physics; only with fine tunings of couplings.

  Presumably: *One vacuum with confinement; another one with QCD color Higgsed to be aligned with a Gellman SU(3). Another idea is that Nambu-JonaLasinio Goldstone boson fields (the pseudoscalar meson fields) could be correlated a little differently in the different vacuum-phases.* We shall show some "Columbia-plots" at the end that might give hope for this latter "different correlations in Nambu-JonaLasinio" idea.

There is another difficult question

- If DAMA can observe dark matter particles emitting fast electrons with energies of the order of 3.5 keV, then why can the Xenon-experiments not see them?

Our model answer: *This is because the Xenon experiments have a fluid and when the dark matter particles come to the fluid they fall much faster than in the solid NaI in the DAMA experiment.* So the dark matter particles spend much less time in one kg of xenon than in one kg of NaI.

This problem is very hard to solve with a WIMP-type model except if mysteriously the nuclear physics is very different for xenon versus the other elements Na and I, which sounds almost like fine-tuning the xenon interaction with the WIMP to have a special cancellation! The fluid solid difference between the two scintillators is the almost only proper qualitative difference between them. (Remember that LUX and other xenon experiment have looked so accurately that had there even been the amount of WIMPs that would give the seasonal excess in DAMA, they should have been able to see it.)

A related question is:

- Is there a way to check our dark matter model?

Our answer: One good check of our model would be to confirm that the DAMA signal for dark matter is due to the emission of fast electrons rather than nuclear recoils. In fact the COSINUS experiment [7] is presently being set up in Gran Sasso using NaI scintillating crystals as a target to cross-check the DAMA results. It is capable of disentangling e^-/γ events from nuclear recoils on an event-by-event basis, which should provide a good test of our model.

3. Our picture of the Dark Matter Pearls

In our model [8–19] the dark matter consists of macroscopic massive pearls, which in the interior has a little piece - very exactly a perfect sphere - of a vacuum in phase 2 so to speak filled with some ordinary material, such as say carbon, under high pressure. Then this little bubble of new vacuum is surrounded by a bigger but not so heavy grain of dust. The point is that, even though the ordinary material inside the bubble is in the new vacuum and highly compressed, it still interacts chemically and mechanically with the dust and thus presumably does not stay clean in the Universe for 13.6 milliards years even if it should have been created clean, in the sense that at first there was plasma around it rather than material that could contaminate it.

The dark matter particles or pearls are composed of:

- A nm-size bubble of a new speculated vacuum filled with highly compressed atomic stuff, say carbon. (We really have only very weak constraints on the size of the pearls.)

Let us remark that there is not so much to observe that can give us a good estimate of the mass of the dark matter particles. Therefore our estimate of the size of the dark matter pearls is very uncertain. If we use the idea to be found in our talk on "Tensions in Cosmology" [20] that the cosmological constant might be replaced by a network of domain walls, a surface tension of the dark matter bubbles of the order of $(30 \text{ MeV})^3$ would be called for. Then dark
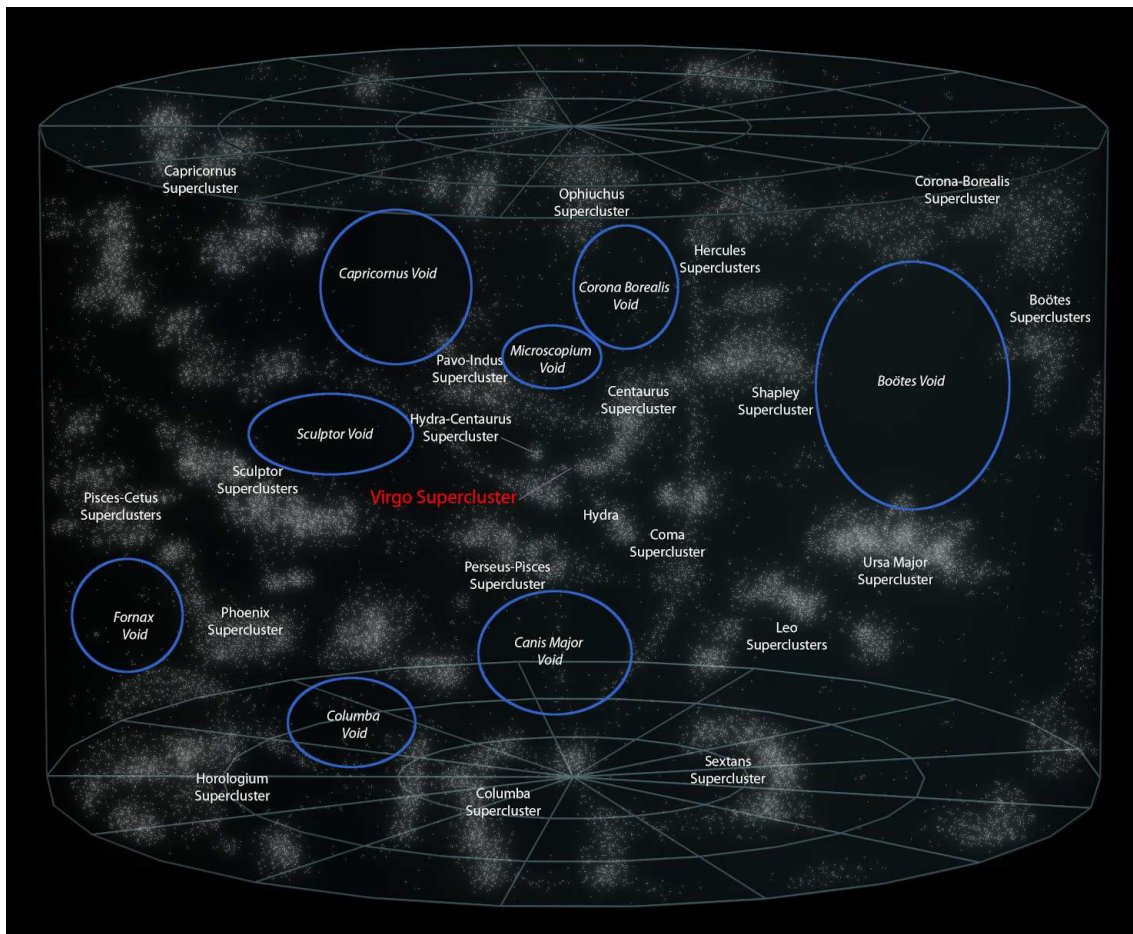
Figure 3: This picture (from Wikipedia) is an attempt to draw the distribution of galaxies in perspective as 3-dimensional. It shows several voids, regions with only a few galaxies, and by accident has rings around these voids. You could roughly take these rings to suggestively represent domain walls, in a speculation that the voids were of a different type (phase) of vacuum than the galaxy rich regions (clusters etc.).

matter bubbles would be of $10^{-8}m$ size, an order of magnitude larger than the here mentioned nanometre size. But, as stressed above, the mass is not well determined.

- A surrounding dust particle of "metallicity" material such as C, O, Si, Fe, ..., presumably of some non-integer Hausdorff dimension about 2. This atomic matter is influenced by the electrons being in a superposition partly inside the bubble of the new vacuum, where there is a very high gap between filled and unfilled electron states.

The pearls interact:

- with other dark matter particles,

- with atomic matter.

4. Huge New Vacuum Bubbles possible, if really there are different Vacua

If really the idea - our main new idea - that there are several phases of vacuum were true, as well as our assumption that the different phases have the same energy density, then a priori one could expect huge, astronomically large, regions with a different vacuum phase from that of another large region. If so, however, there would still be the surfaces - the domain walls - in between these different regions.

Now if these surfaces in between the regions would have energy per area densities as expected by dimensional arguments for new physics beyond the Standard Model, then these densities of energy on the domain wall would be so huge that astronomical size domain walls would upset our usual cosmological picture very strongly. Only because the domain wall energy density needed to fit our dark matter turns out to be surprisingly small from the new physics expectation point of view, does it become possible to speculate seriously that the domain walls could really exist out in space - and e.g. surround the voids (the big regions in space with rather few galaxies) - and only contribute tolerably to the cosmological parameters. This is illustrated in Figure 3.

The idea of having huge astronomical size vacuum bubbles will be taken up in our contribution to the Corfu workshop on "Tensions in Cosmology" just after this workshop [20].

5. Multiple Point (Criticality) Principle

As mentioned above our main new idea which we incorporate into the Standard Model is the Multiple Point Principle (MPP) [21–24], according to which there should be several phases of the vacuum and that they should be degenerate in the sense of having the same energy density. This principle can be used to fine-tune and hence predict the value of coupling constants. It was applied some time ago at the Planck scale in a somewhat complicated model to correctly predict the number of families in the Standard Model [25, 26], prior to the LEP measurement of the number of light neutrino species.

Later we used MPP to PREdict the mass of the Higgs particle before this particle was found experimentally [27, 28]. In addition to the usual vacuum with a Higgs vacuum expectation value of 246 GeV, we obtained another vacuum degenerate with it but having a very large Higgs field expectation value of order the Planck scale $\sim 10^{18}$ GeV. In Figure 4 we reproduce a copy of a painting including one of us, in which the Higgs mass prediction $135\,GeV \pm 10\,GeV$ is on the black board (although the 1 in the 135 is hidden behind the member of the cabinet Mogens Lykketoft's head).

There may not exist any true derivation of our "Multiple Point Criticality Principle", because it is basically an assumption. A good argument for it is very similar to the argument for having the melting point temperature when you have both say ice and water together. It occurs often and even has a name "slush", and having slush one knows that the temperature is 0^0 Celsius (see Figure 5).

6. The 3.5 keV X-ray from Dark Matter

The most important support for our model may be that we find the energy 3.5 keV in *two* different places as a possible characteristic level transition energy difference for dark matter:

Figure 4: This painting of one of the authors and the Danish finance minister was painted long before the Higgs particle was observed at LHC. Nevertheless due to our "Multiple Point Criticality Principle", we predicted the mass value for the Higgs particle $135\,GeV \pm 10\,GeV$ as with the 1 hidden by Mogens Lykketoft's head is seen on the painting. The much later measured value is $125\,GeV$.

- The energy of the X-ray line from galaxy clusters, galaxies and strangely the Tycho supernova remnant long suspected as coming from dark matter.

- As average of the energy of the DAMA dark matter events.

In section 12 we report on some progress made since the workshop on our understanding of the observed intensity of the 3.5 keV X-ray radiation. Our picture now is that most of the sources are well understood by the fit of Cline and Frey [29], in which the rate of this line emission goes as the square of the dark matter density. This corresponds to the dominating process being a collision or perhaps annihilation of two dark matter particles, which get some excitation emitting the 3.5 keV line. However, of course the emission in a visible amount from the Tycho supernova remnant cannot be dominantly due to this dark + dark collision [30], but must involve some ordinary matter colliding with the dark matter. Also the outskirts of the Perseus Cluster, where the dark matter density has fallen, and the centre of the Milky Way are two further sources of the 3.5 keV line, where we now think that it is collision of ordinary matter - expected to be hot atoms with energy of the order of X-rays - with the dark matter that excites the latter to emit the 3.5 keV line.

In our model we have long supposed that the dark matter bubbles of new vacuum contain matter in which the electron spectrum has a gap, a homolumo gap between the filled levels and the

Figure 5: Slush.

empty levels. It is this homolumo gap which, because of the very high pressure in the ordinary matter contained inside the bubble, has the unusually high value (compared to ordinary chemistry) of 3.5 keV for the energy difference between the highest(H) occupied(O) level (molecular orbit = MO) and the lowest(L) unoccupied(U) molecular orbit. This should then explain the tendency for the dark matter bubble to emit an X-ray of just this frequency. The excited electrons should go to the lowest unoccupied states and from there jump, under 3.5 keV X-ray line emission, down to a hole in the band of normally occupied states.

7. The Dust sitting on the Dark Matter Pearls/Bubbles

Since our bubbles of new vacuum contain - are pumped up with - ordinary matter (under pressure) it is not surprising, but rather expected, that a chemical interaction could be formed between the ordinary matter inside the bubble and the ordinary matter outside. In fact we expect that, due to the high pressure, some electrons will already by the Fermi statistics flow a bit over and actually be present outside the proper skin (= domain wall). So the bubbles have a high chance of getting contaminated by dust or other matter in the outer space where they move along. So we should imagine that the true dark matter particles are probably much like dust grains with a bubble of new vacuum filled with say carbon sitting in it somewhere. Or, if the bubbles are very large, they may literally be dirty bubbles.

Simulations of the growth of a dust grain, in which the atoms get attached to the dirt rather few at a time [31], show that the dust grain easily develops to have a lower Hausdorff dimension than a compact dust ball would have. The dust could easily be more like a little surface or some stringy network structure. The growth of a dust grain and the development of its fractal dimension in such
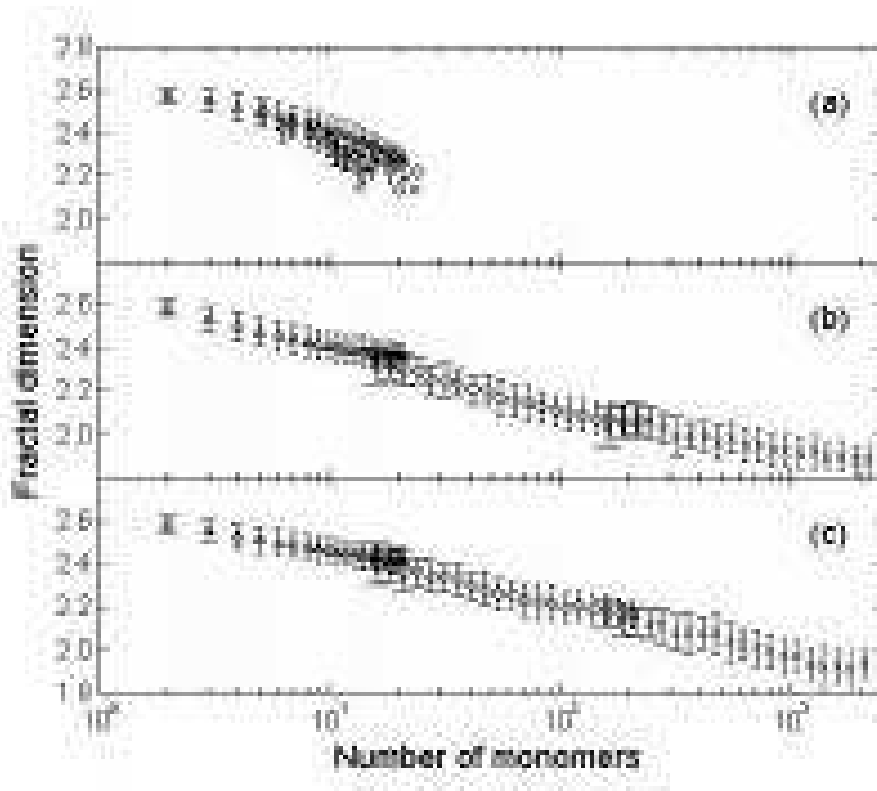
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Figure 6: Results of simulations of dust grains growing by adding single atoms or molecules [31] suggest that the Hausdorff dimension can become low of the order 1 or 2.

a simulation is given in Figure 6 . An example of such a fractal cosmic dust grain built up from 1024 monomers [32] is given in Figure 7.

We expect that such a dust grain would collect on top of one of our dark matter pearls, which in itself is very much like a seed atom. We may illustrate that in Figure 8 by drawing our little pearl as a bubble of new vacuum inside the dust grain. If the grain size is $0.1\mu m$ and the bubble size is $1nm = 0.001\mu m$, then the bubble is about 100 times smaller than the dust grain. But now if we should seek to implement the ideas of adjusting the tension in the domain walls to make it possible for the domain walls to take over the role of the cosmological constant, we should take somewhat larger bubbles in the middle and the dust grain would not be so much larger than the bubble of the second vacuum.

8. Achievements

Important achievements of our model:

- Explains that only DAMA "see" the dark matter by the particles interacting so strongly as to be quite slow and unable to knock nuclei hard enough to make observable signals. Instead
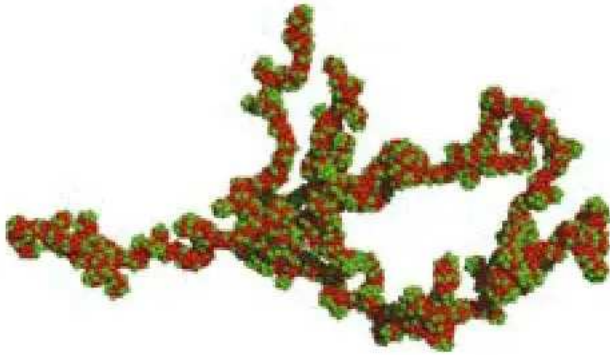
Рис. 3. Фрактальная модель космической пылинки [5]

Figure 7: Picture of a fractal cosmic dust grain constructed from 1024 monomers [32]. The mentioned lower Hausdorff dimensionality of the dust grains - if say one dimensional - would mean that the dust grain is really more like some knot of strings of molecules than a pearl.
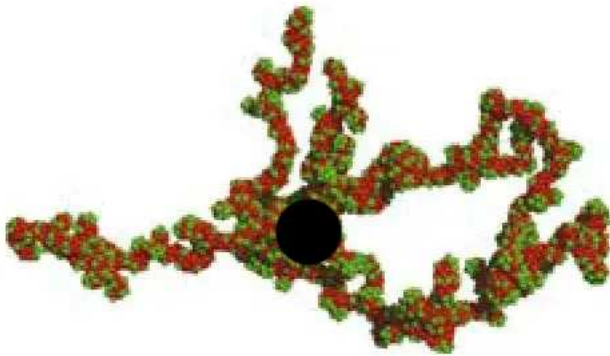

Рис. 3. Фрактальная модель космической пылинки [5]

Figure 8: Our dark matter particle is a bubble with a dust grain round it. The bubble is supposedly much heavier than the dust grain.

the DAMA signal is explained as due to emission of electrons with the "remarkable energy of 3.5 keV" from pearls in an excited state.

- The characteristic frequency of electron or photon emission by the dark matter particles is due to a homolumo gap in the material inside the bubble of the new vacuum. This gap should be equal to the 3.5 keV.

- We have made a rather complicated calculation of what happens when the bubbles - making up the main part of the dark matter particle - hit each other and the surface/skin/domain wall contracts and how one gets out a part of the energy as 3.5 keV X-rays [14]. We fit with one parameter both the very frequency 3.5 keV, and the overall intensity of the corresponding
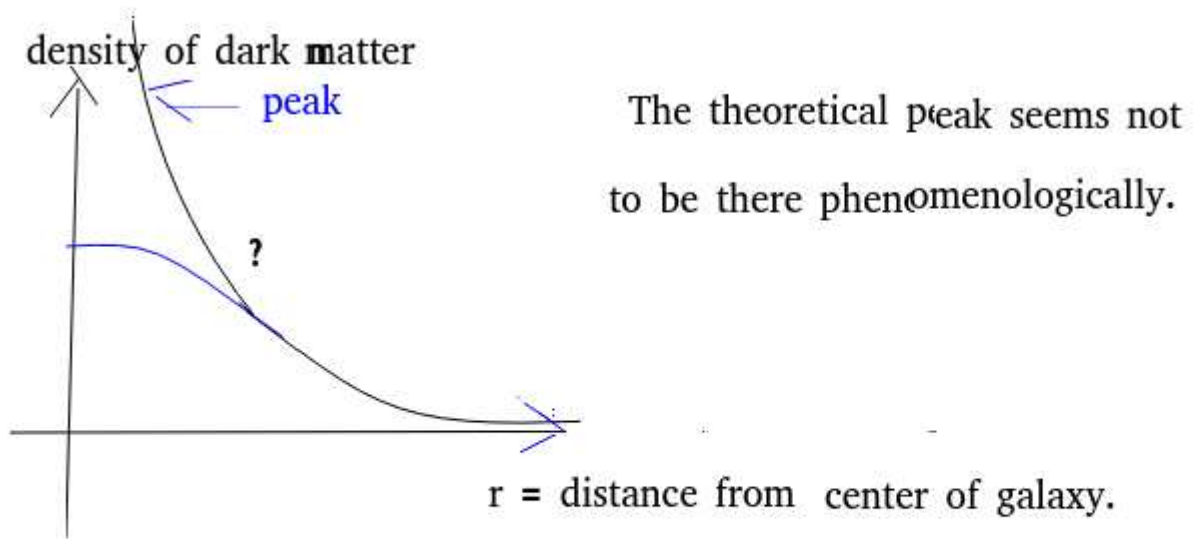
Figure 9: Illustration stressing that the pole peak in the ideal NFW-distribution at the centre of a galaxy, which is what truly only gravitationally interacting dark matter should form, is phenomenologically not quite as sharp as it should be. This could reveal self interaction of dark matter SIDM as in Correa's fits.

X-ray line observed from galaxy clusters etc. The production mechanism gives an intensity proportional to the dark matter density squared and we use the results of the analysis of Cline and Frey [29] whose model shares this property.

- We explain why - otherwise mysteriously - the 3.5 keV line was seen by Jeltema and Profumo [30] from the Tycho supernova remnant and probably also explain problems with the Perseus galaxy cluster 3.5 keV observations. This is by claiming the excitation of the bubbles comes from cosmic radiation in the supernova remnant. After the workshop we now tend to think that it is not the cosmic rays, but rather hot atoms that are most important. Cosmic rays would survive so long that they would make embarrassingly high intensities for the 3.5 keV line from say the supernovae in the Milky Way Center.

- According to expectations from ideal dark matter that only interacts essentially by gravity, there should be e.g in a dwarf galaxy a concentrated peak or cusp of dark matter (the NFW distribution [33]), but that seems not to be true. The inner density profile rather seems to be flat as expected for self-interacting dark matter [34], as illustrated in Figure 9. Correa [5] can fit the dwarf galaxy star velocities by the hypothesis that dark matter particles interact with each other with a cross section over mass ratio increasing for lower velocity, as shown in Figure 1. We fit the cross section over mass velocity dependence of hers. But we need a "hardening " of the dust around the bubbles.

We have already seen in Figure 1 how the inverse darkness $\frac{\sigma}{M}$ of the dark matter varies with
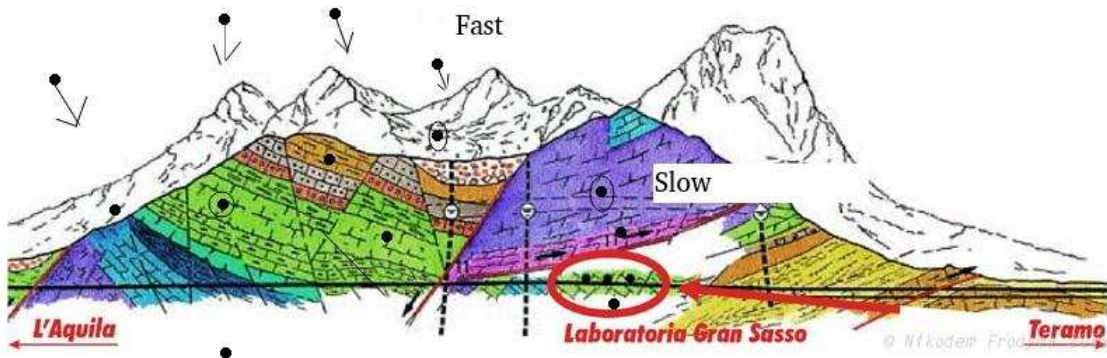
Figure 10: The mountains above the Gran Sasso laboratories.

velocity roughly in the way that it stands at about $15m^2/kg$ up to velocities of the order of 220 km/s. For higher velocity it begins to fall and becomes so small that one mainly has upper bounds for $\frac{\sigma}{M}$ for velocities present in the interior of big galactic clusters.

9. Impact

We imagine that the dark matter pearls lose their dust grain in the atmosphere or at least, if not before, by the penetration into the earth shielding and that they at the same time get excited by means of the energy of the braking of the pearls. For a very small number of the pearls this excitation energy gets radiated first much later when the pearl has passed through the earth shielding to the underground detectors (see Figure 10), so as to deliver X-ray radiation with just the characteristic 3.5 keV energy per photon. The energy is delivered we guess by electrons or photons. Thus experiments like the xenon experiments do not "see" it when looking for nucleus-caused events. Only DAMA, which does not notice if it is from nuclei or from electrons, does not throw electron-caused events away as something else.

The dark matter pearls come in with high speed (galactic velocity), but get stopped down to a much lower speed by interaction with the atmosphere and the shielding mountains, whereby they also get excited to emit 3.5 keV X-rays or *electrons*.

9.1 The Xenon experiments versus DAMA Contradiction

The really most mysterious result is that the xenon-based experiments do not "see" the dark matter, while DAMA "sees" it[1]. We want to explain the seemingly severe contradiction on Figure 11 of 5 orders of magnitude say: the DAMA-LIBRA experiment see per kg roughly 10^5 times more than the upper limits for the best xenon experiments. Compared to LUX it may only be a factor 10^3 say, but even that is a severe contradiction.

Our explanation should be that our dark matter bubble or pearl falls through the xenon experiment containers with liquid xenon essentially by free fall while they move much slower in the solid materials, especially the sodium iodide NaI. But in order to avoid the seasonal variation being

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[1] We note that the ANAIS experiment has failed to see an annual modulation with NAI(Tl) scintillators and their results [35] are incompatible with the DAMA-LIBRA results at 3σ .
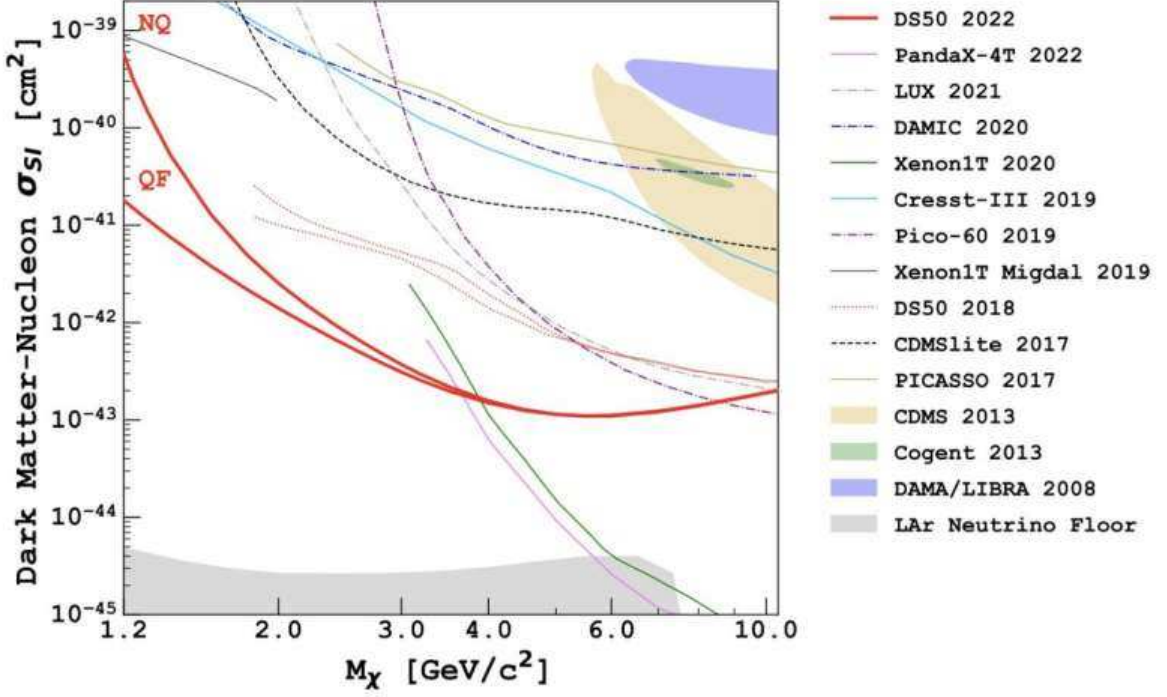
Figure 11: Upper limits on the dark matter nucleon cross section as a function of the dark matter mass from various direct detection experiments. The lilac region in the top right of the plot corresponds to the DAMA data interpreted as due to WIMPS, with a cross section of $\sigma = 10^{-40} cm^2$. However in the same mass region of order 10 GeV the limits from some of the xenon experiments go down to $10^{-44} cm^2$ or $10^{-45} cm^2$, i.e. about 5 orders of magnitude in contradiction with DAMA.

smeared away, the pearls have to come the 1400 m down to the experiments in less than a year. So the velocity on the average down through the mountain has to be at least

$$\text{Sinking velocity } v_{sink} \quad \geq \quad \frac{1400m}{year} \tag{5}$$

$$= \quad \frac{1400m}{31556926s} \tag{6}$$

$$= \quad 4.4 * 10^{-5} m/s. \tag{7}$$

This is to be compared with the velocity, which a pearl of dark matter achieves in free fall inside the tank with the fluid xenon making up the typical xenon experiment. Since the acceleration at the Earth's surface is $9.8m/s^2$, the velocity reached in a tank of depth d is given as

$$v_{fall} \quad \approx \quad \sqrt{d * 9.8m/s^2} \tag{8}$$

$$= \quad 3m/s \quad (\text{for e.g } d = 1m \text{ big tank}) \tag{9}$$

This velocity in the essentially free fall in the fluid can reach up to be of order 10^5 times larger than the $4.4 * 10^{-5} m/s$ needed to ensure the pearls come down within a year.

It must though be said here that if we want the pearls to pass through the shielding somewhat faster than in a year then one should expect to see something soon in the xenon experiments. Now,

however, what the xenon experiments looked for was a nuclear collision, and they at first sorted away the electron events. Their limits for electron events are much less strong and thus there is indeed no contradiction as yet, provided that we believe the story of pearls being stopped by the shielding and released again when coming to the fluid.

This means that indeed the slowed down particle idea could solve the otherwise extremely difficult problem of resolving the apparent contradiction between the DAMA-LIBRA experiment and the xenon ones!

In article [4] the XenonnT collaboration rechecked the "electron recoil excess" previously observed in the Xenon1T experiment, and found that there was no effect signalling anything strange any more. Compared to the old results [3] we can roughly say that the number of events in one bin went down so that a previous excess of $30\,Events/(t*y*keV)$ becomes an upper limit of say $10\,Events/(t*y*keV)$ and another bin went even less down. With the original - now to be considered wrong - measurement we found [18] that there was a need for the faster passage through the liquid xenon than through the DAMA NaI by a factor 250 in order to diminish the rate of electron observation per kg. In other words we needed that the pearls of dark matter spend per kg a factor 250 shorter time in the liquid xenon than in the NaI. Now we see that this factor 250 is not enough but should be increased by a factor corresponding to the decrease from the $30\,Events/(t*y*keV)$ to the $10\,Events/(t*y*keV)$ in one bin. Already the next most important bin is much less significant, and we shall crudely estimate that adding the two bins would mean the effect went down by a factor of 4 just to be on what is now the upper limit. So the upper limit on the signal in XenonnT is $4*250=1000$ times smaller than the signal in the DAMA-LIBRA experiment.

If we say, for illustration, that the free fall velocity in the xenon experiments is 3m/s, then the speed through the NaI in DAMA-LIBRA needs to be 1000 times slower, so that the time spent in a region of a kg in DAMA-LIBRA becomes 1000 or more times longer than the corresponding time spent in a region of a kg in the liquid xenon experiments. In order to achieve this the velocity through the NaI or similar solids should be $\frac{3m/s}{1000}=3mm/s$. In this case the time taken to pass down through the earth shielding will be

$$\text{"Passage time"}_{on\ limit} \approx \frac{1400m}{3mm/s} \tag{10}$$

$$= 4.2*10^6 s = \frac{4.2*10^6 s}{3.1*10^7 y/s} \tag{11}$$

$$= 1.3*10^{-1} y \tag{12}$$

$$= 1.5\,month \tag{13}$$

So our model is a bit in tension with the DAMA results. Namely it suggests that the time of year for the maximal signal from the dark matter observation in DAMA should be shifted to be a bit later - by 1.5 month - than the time of year estimated from the astronomical expectation of the motion of the rest system of the dark matter in the neighbourhood of our solar system.

10.   How much available dust?

We would like to get an estimate from the various types of matter available in the Universe as to how much dust can be afforded to settle on the dark matter bubbles. This will provide a check

of our ideas by comparing with the inverse darkness ratio $\frac{\sigma}{M}$ in the limit of low velocity, where one would expect the dust to play the dominant role in the case that the dust grain is larger than the proper bubble.

Let us begin by reviewing the amounts of matter of the different types available in the Universe:

- 27% dark matter (while 68% of a form of energy known as dark energy, and 5 % ordinary matter).

- The elements heavier than hydrogen and helium make up of order 2% of ordinary matter and are known as "metals". Oxygen is the most abundant "metal" making up about 1%, carbon about 0.5% and iron down to 0.1% The comoving density of these "metals" together [36] is

$$\text{"metal" density} \quad \cong \quad 5.0 * 10^6 M_\odot Mpc^{-3} \tag{14}$$
$$= \quad 3.7 * 10^{-31} kg/m^3. \tag{15}$$

10.1 Inverse Darkness $\frac{\sigma}{M}$

Using the atomic radii we can calculate the cross sections for the following atoms:

$$\text{Hydrogen H: } r_H \quad = \quad 25pm \Rightarrow \sigma_H = \pi r_H^2 = 1963pm^2 \tag{16}$$
$$\text{Helium He: } r_{He} \quad = \quad 30pm \Rightarrow \sigma_{He} = \pi * r_{He}^2 = 2827pm^2 \tag{17}$$
$$\text{Carbon C: } r_C \quad = \quad 70pm \Rightarrow \sigma_C = \pi * r_C^2 = 15394pm^2 \tag{18}$$
$$\text{Silicon Si: } r_{Si} \quad = \quad 110pm \Rightarrow \sigma_{Si} = \pi * r_{Si}^2 = 38013pm^2 \tag{19}$$

Using that one atomic unit $1u = 1.66 * 10^{-27}kg$ we get for the inverse darkness ratios $\frac{\sigma}{M}$ for the atoms mentioned:

$$\text{Hydrogen H: } \frac{\sigma_H}{1u * 1.66 * 10^{-27}kg/u} \quad = \quad 1.18 * 10^6 m^2/kg \tag{20}$$
$$\text{Helium He: } \frac{\sigma_{He}}{4u * 1.66 * 10^{-27}kg/u} \quad = \quad 4.26 * 10^5 m^2/kg \tag{21}$$
$$\text{Carbon C: } \frac{\sigma_C}{12u * 1.66 * 10^{-27}kg/u} \quad = \quad 7.73 * 10^5 m^2/kg \tag{22}$$
$$\text{Silicon Si: } \frac{\sigma_{Si}}{28u * 1.66 * 10^{-27}kg/u} \quad = \quad 8.18 * 10^5 m^2/kg \tag{23}$$

In a dust grain the atoms will typically shadow each other and thus this ratio "the inverse darkness" will be smaller than if the atoms were all exposed to the collision considered. If we denote the average number of atoms lying in the shadow of one atom by "numberthickness" we will have for the ratio for the full grain say

$$\frac{\sigma}{M}\Big|_{grain} \quad = \quad \frac{\frac{\sigma}{M}\big|_{atom}}{\text{"numberthickness"}} \tag{24}$$

If the dust grain has a fractal dimension 2 or less there is no shadowing and the parameter "numberthickness" = 1.

If we insert in the grain a mass-wise dominating bubble, the whole object will of course get a smaller ratio due to the higher mass,

$$\frac{\sigma}{M}|_{composed} = \frac{\sigma}{M}|_{grain} * \frac{M_{grain}}{M}, \tag{25}$$

where M is the mass of the bubble or, if it dominates the whole composite object, the dark matter particle.

On the average of course the mass ratio $\frac{M_{grain}}{M}$ of the dust around the bubble and the bubble itself can never be bigger than the ratio of the amount of dust-suitable mass to that of the dark matter in the Universe. So noting that the grain should largely be made up of the elements heavier than helium, the so-called "metals", and that these make up only of the order of 1% of the ordinary matter which again is only about 1/6 of the mass of the dark matter, we must have

$$\frac{M_{grain}}{M} \leq 1\%/6 = 1/600. \tag{26}$$

But really of course not all the "metal" has even reached out to the intergalactic medium, let alone been caught up by the dark matter. So we expect an appreciably smaller value for this ratio of dust caught by dark matter relative to the dark matter itself. Taking $7 * 10^5 m^2/kg$ as the typical $\frac{\sigma}{M}|_{atom}$ for dust-suitable atoms and using the so to speak simplest "equilibrium" value for $\frac{M_{grain}}{M}$ by combining equations (25, 26) and using "numberthickness" = 1, we get

$$\text{First estimate:} \quad \frac{\sigma}{M} \approx \frac{7 * 10^5 m^2/kg}{600} \tag{27}$$

$$= 1.2 * 10^3 m^2/kg = 1200 m^2/kg. \tag{28}$$

In earlier papers we have already used the dark matter self-interaction in the low velocity limit extracted from Correa's fit to the dwarf galaxy data shown in Figure 1 to give

$$\frac{\sigma}{M}|_{v-->0} = 15 m^2/kg. \tag{29}$$

So our first estimate comes out about a factor 100 over the observed value. However the dust on the dark matter was collected in a much earlier era than today, at least at first.

We now wish to use a crude estimate of the amount of dust that might pile up around a dark matter bubble with a given velocity during the evolution of the Universe. There are two important effects to be taken into account. First of all the metal density was higher in the past due to the reduction in the "radius" of the Universe by a factor $(1 + z)^{-1}$ where z is the red shift. Secondly the metallicity was lower in the past and we use the linear fits of De Cia et al. [37] to its z dependence in our estimate of the rate of collection of metals by our pearls. We hence find that the most important time for the rate of collection of metals corresponds to $z = 3.3$, when the age of the Universe was 1.52 milliard years. At this time the rate of collecting metals for a given velocity was about 8.4 times bigger than if using the present metallicity and density. So we might crudely estimate the amount of dust then being collected by using an *effective metal density* of

$$\text{"metal density"}_{eff} = 3.71 * 10^{-31} kg/m^3 * 8.4 \tag{30}$$

$$= 3.1 * 10^{-30} kg/m^3 \tag{31}$$

$$= 1.7 * 10^{-3} GeV/c^2/m^3. \tag{32}$$

The metallicity at that time [37] was a factor 10^{-1} times the one today. So the factor $1/600$ in equation (26) for the "metals" accessible to be caught by the composite dark matter particle becomes

$$\frac{M_{grain}}{M} = 1\%/6/10 = \frac{1}{6000}. \tag{33}$$

So taking $\frac{\sigma}{M}|_{atom} = 7 * 10^5 m^2/kg$ for the atoms of dust and assuming all the accessible "metals" are caught by our dark matter pearls, we obtain our estimate for the inverse darkness of the dark matter particle composed with a dust grain of dimension 2 or less:

$$\frac{\sigma}{M}|_{composed} = \frac{\sigma}{M}|_{grain} * \frac{M_{grain}}{M} \tag{34}$$

$$= 7 * 10^5 m^2/kg/6000 \tag{35}$$

$$= 1.2 * 10^2 m^2/kg. \tag{36}$$

This is of course really an upper limit for the inverse darkness, as not all of the "metal" will have been caught up by the dark matter.

Our estimated ratio

$$\frac{\sigma}{M}|_{composed} = 120 m^2/kg, \tag{37}$$

is actually one order of magnitude larger than the value extracted from the dwarf galaxy data

$$\frac{\sigma}{M}|_{Correa, v \to 0} = 15 m^2/kg. \tag{38}$$

This can be considered as a success for our model.

We now consider whether there is enough time to collect up so much dust. For orientation we could first ask how much metal-matter at all could be collected by a dust grain while already of the order of $10^{-7} m$ in size, meaning a cross section of $10^{-14} m^2$, and with a velocity of say 300 km/s = $3 * 10^5 m/s$ during an effective age of the universe of $1.52\, milliard$ years = $4.8 * 10^{16} s$. We obtain

$$\text{"available "metals" "}_{for\, 10^{-14} m^2, 300 km/s} = 3 * 10^5 m/s * 4.8 * 10^{16} s * 10^{-14} m^2 * 3.1 * 10^{-30} kg/m^3$$

$$= 4.4 * 10^{-22} kg \tag{39}$$

$$= 2.4 * 10^5 GeV, \tag{40}$$

which is to be compared to what the mass of a $(10^7 m)^3$ large dust particle with say specific weight $1000 kg/m^3$ would be, namely $10^{-18} kg$. So such a "normal" size $0.1 \mu m$ dust grain could not collect itself in the average conditions in the Universe.

However, if the grain to be constructed had lower dimension than 3, it would help because then the cross section could be larger for the same hoped for volume and thus mass. Decreasing say the thickness in one of the dimensions from the $10^{-7} m$ to atomic size $10^{-10} m$ would for the same collection of matter give a 1000 times smaller mass. This would bring such a "normal size" grain close to being just collectable in the average conditions in the Universe.

Our speculated stronger forces than usual due to the big homolumo gap would not help much, because the grain cannot catch the atoms in intergalactic space which it does not come near enough to touch.

10.2 Size of Individual Dark Matter Particles

In the approximation of dark matter having only a gravitational interaction it is well-known that only the *mass density* matters, whereas the number density or the *mass per particle is not observable.*

With other than gravitational interactions one could hope that it would be possible to extract from the fits in say our model, what the particle size should be. But the possibility for that in our model is remarkably bad! The Correa measurement yields just the "inverse darkness" ratio

$$\frac{\sigma}{M} \quad = \quad \frac{\text{"cross section"}}{\text{mass}} \tag{41}$$

Our earlier very crude estimate [18] for the rate of 3.5 keV radiation from dark matter seen by DAMA was based on:

- The total kinetic energy of the dark matter hitting the Earth per m^2 per s (but not on how many particles).

- The main part of that energy goes into 3.5 keV radiation of electrons.

- Estimate of a "suppression" factor for how small a part of this electron radiation comes from sufficiently long living excitations to survive down to 1400 m into the Earth.

None of this depends in our estimate on the size of the dark matter particles (provided it lies inside a very broad range)!

If the dark matter particles were so heavy that the number density is so low that the observation over an area of about $1m^2$ would not get an event through every year, then it would contradict the DAMA data. The rate of dark matter mass hitting a square meter of the Earth is

$$\begin{aligned}
\text{Rate} \quad &= \quad 300km/s * 0.3 GeV/cm^3 \tag{42} \\
&= \quad 3 * 10^5 m/s * 5.34 * 10^{-22} kg/m^3 \tag{43} \\
&= \quad 1.6 * 10^{-16} kg/m^2/s \tag{44} \\
&= \quad 5 * 10^{-9} kg/m^2/y \tag{45}
\end{aligned}$$

Taking the DAMA area of observation $\sim 1m^2$ we need to get more than one passage per year and thus

$$\begin{aligned}
M \quad &\leq \quad 5 * 10^{-9} kg \tag{46} \\
&= \quad 3 * 10^{18} GeV. \tag{47}
\end{aligned}$$

Using the bubble internal mass density as estimated from the 3.5 keV homolumo gap [18], this upper bound implies that the bubble radius $R \leq 10^{-7}m$.

If the bubble is small compared to the surrounding dust grain, then we would not expect the development of the dust grain around the dark matter bubble to be so different from the dust grains out in space not having any dark matter bubble in them. In Figure 12 we present the size distribution for dust grains from a simulation for ordinary dust particles of small dust grain production in galaxies
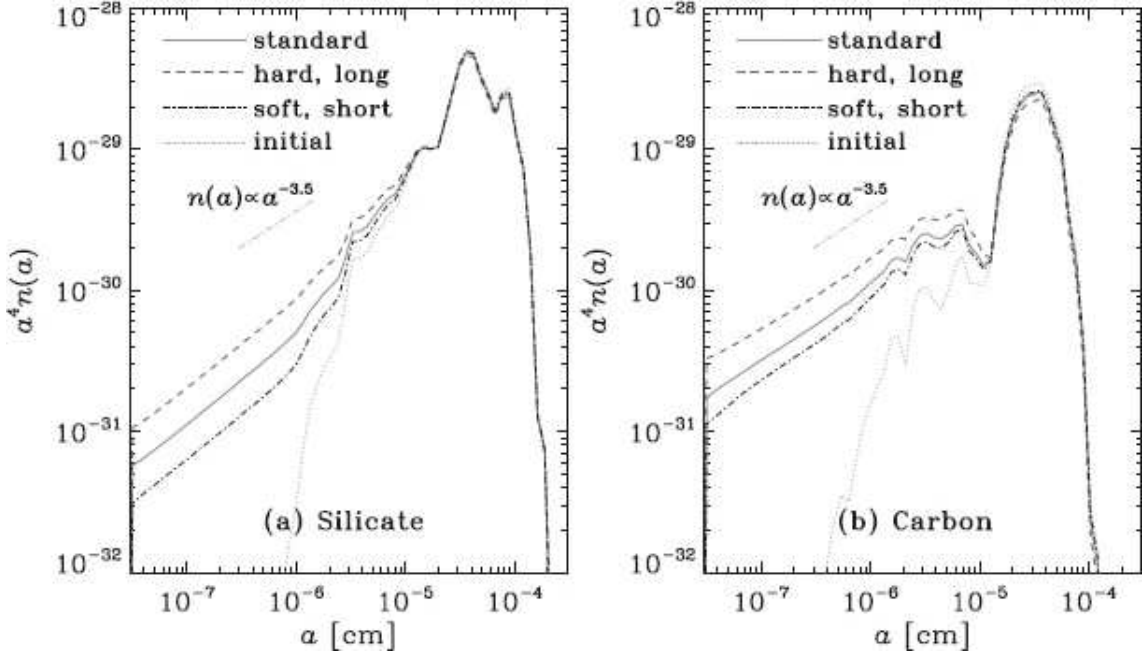
Figure 12: Simulated size distribution for dust grains.

[38]. We take a typical grain size of $10^{-7}m$ say. Then using the low velocity limit $\frac{\sigma}{M} = 15m^2/kg$ gives

$$M = (10^{-7}m)^2/(15m^2/kg) \tag{48}$$
$$= 7*10^{-16}kg. \tag{49}$$

Such a 3 dimensional compact grain of dust has "numberthickness" $\simeq 1000$ atoms behind each other. But if now the dust grain is 2 or lower dimensional, but keeping the mass of the compact grain combined with $\frac{\sigma}{M} = 15m^2/kg$, there is no shadowing and we obtain a 1000 times bigger estimate for the total or say bubble mass:

$$M = 1000*7*10^{-16}kg = 7*10^{-13}kg \tag{50}$$

(for low dimensional dust of $10^{-7}m$ size).

11. Summary Tables

In Table 1 we summarize the successes of our model and give a brief explanation of each item below.

- 1. Dwarf Galaxies, inverse darkness: Assuming the dust grain around the second vacuum bubble has a Hausdorff dimension of 2 or less and the ratio of the dust grain mass to that of the whole dark matter particle to be given by the total amount of metals in the gases in the space available relative to dark matter, we obtain (see equation 33)

$$\frac{M_{grain}}{M} = 1.6*10^{-4}. \tag{51}$$

Table 1: Successes

# & exp/th	Quantity	value	related Q.	value
1.	Dwarf Galaxies			
exp	inv. darkness =	$15 m^2/kg$	$\frac{M_{grain}}{M}$	$2*10^{-5}$
th	$= \frac{\sigma}{M}\|_{v\to 0}$	$120 m^2/kg$		$1.6*10^{-4}$
2.	Dwarf Galaxies			
exp	Velocity par. v_0	$220 km/s$	$4 r_{dust} E$	$8.1*10^{13} kg/s^2$
th.	with hardening	$77 km/s$	$4 r_{dust} E$	$1*10^{13} kg/s^2$
th.	without hard.	$0.7 cm/s$	$4 r_{dust} E$	$400 kg/s^2$
3.	DAMA-LIBRA			
exp		$0.041 cpd/kg$	suppression	$1.6*10^{-10}$
th	air	$0.16 cpd/kg$		$6*10^{-10}$
th	stone	$1.6*10^{-5} cpd/kg$		$6*10^{-14}$
4.	Jeltema & P.			
exp	counting rate	$2.2*10^{-5} phs/cm^2/s$	$\frac{\sigma}{M}\|_{Tycho}$	$5.6*10^{-3} cm^2/kg$
th		$3*10^{-6} phs/s/cm^2$	$1\% * \alpha * \frac{\sigma}{M}\|_{nuclear}$	$8*10^{-4} cm^2/kg$
5.	Intensity 3.5 kev			
exp	$\frac{N\sigma}{M^2}$	$10^{23} cm^2/kg^2$	$\frac{\xi^{1/4}}{\Delta V}$	$0.6 MeV^{-1}$
th		$3.6*10^{22} cm^2/kg^2$		$0.5 MeV^{-1}$
6.	Two Energies			
ast	line	3.5 keV		
DAMA	av. en.	3.4 keV		

This leads to our estimate of the low velocity inverse darkness for our pearls

$$\frac{\sigma}{M}\Big|_{v=0,th} \quad = \quad 120 m^2/kg, \tag{52}$$

and should be compared to Correa's value from her analysis of dwarf galaxies [5]

$$\frac{\sigma}{M}\Big|_{v=0,ex} \quad = \quad 15 m^2/kg, \tag{53}$$

which would correspond to $\qquad \dfrac{M_{grain}}{M}\Big|_{fitted} \quad = \quad 2*10^{-5}. \tag{54}$

- **2. Dwarf galaxies, velocity parameter:** We seek to estimate the velocity scale at which the inverse darkness $\frac{\sigma}{M}$ as a function of velocity falls significantly. One seeks to estimate the velocity v_0 at which the colliding pearls pass so undisturbed through each other that the bending of their paths would not disturb the motion of the pearls enough to influence the effective interaction seen by say Correa. The first theoretical line marked "with hardening" has assumed that the dust around the pearl has been influenced by the exceptionally large homolumo gap in the bubble to become extremely much harder than normal dust. It therefore keeps a large cross section up to a much higher velocity, $77 km/s$. The second theoretical line has just used a more normal elastic modulus for the dust, and even at rather small velocities, $0.7 cm/s$ and higher, the dust is just deformed and makes no effective bending of the motion of the pearl.

- **3. DAMA-LIBRA** We estimate crudely the amount of kinetic energy in the dark matter pearls being converted, assumed mostly into the excitation of the 3.5 keV electron mode, during the stopping of the pearls in the atmosphere "air" or in the solid part of the earth "stone". Next one asks how much there would be per kg of matter in the earth if this energy were smoothly distributed over a range of depths large enough to include the 1400 m deep Gran Sasso laboratory. The amount of energy observed relative to this estimated available amount is denoted "suppression" and taken to be small because there are several different excitations (although with mainly 3.5 kev) of different life times. However the long life time ones require a longer time to be excited, so that the "suppression" crudely becomes the ratio of the excitation time available to the passage time down to the measurement place.

- **4. Jeltema and Profumo** This item estimates the amount of 3.5 keV X-rays from the Tycho supernova remnant, from which it was rather surprisingly observed by Jeltema and Profumo. We estimate the amount of energy in the supernova remnant e.g. in the form of cosmic rays and then believing that part of it hits the dark matter pearls and mainly goes into emission of electrons. However a fraction of order the fine structure constant α of the excitation energy is emitted as X-rays, which like the electrons is supposed to be mainly of the preferred energy per particle 3.5 keV. We give a more detailed discussion of the Jeltma and Profumo results in reference [15].

  After the workshop we decided that it is probably collisions with *hot atoms* rather than cosmic rays that are predominant in making the dark matter produce the 3.5 keV radiation. This is because the cosmic rays would stay around so long as to make star formation regions like the centre of our galaxy produce more 3.5 kev X-rays than are seen.

- **5. Intensity 3.5 keV** In the model picture, that the bubbles of dark matter collide with one another and unite under a common skin, which contracts and thereby delivers energy of which an appreciable part is emitted as 3.5 keV X-rays, we estimate the overall intensity of the expected 3.5 keV radiation. Cline and Frey [29] have already fitted the observed intensity from various astronomical objects of this 3.5 keV line as being proportional to the *square D^2* of the density of dark matter D, from which one can extract what in our model is $\frac{N\sigma}{M^2}$. Here N is the number of 3.5 keV photons expected in one dark matter dark matter collision, σ the cross section, and M the mass of a dark matter particle. It turns out that our intensity quantity $\frac{N\sigma}{M^2}$ and the very energy per photon (3.5 keV) are both obtained as functions of the same parameter $\frac{\xi^{1/4}}{\Delta V}$ - essentially the Fermi momentum of the electrons in the bubble. So indeed the two quantities "intensity" and "the 3.5 keV" are related and the values of the parameter $\frac{\xi^{1/4}}{\Delta V}$ given in column 5 for the two quantities turn out to agree. ΔV is the binding energy of a nucleon into the inside-phase of the vacuum, and ξ is the typical size of a dark matter pearl relative to the "critical size" below which it would collapse.

- **6. Two Energies** By this item we call attention to the remarkable fact that the 3.5 keV X-ray line observed in astronomy, presumably from dark matter, has the same energy per particle as the average energy of the events in the DAMA-LIBRA experiment having the seasonal variation signalling that they are from dark matter.

12.   Addendum Since Workshop Held

We would like to pre-announce some of the progress we have made since the workshop and which we hope to publish shortly:

- We have had some success assuming that the 3.5 keV X-ray radiation is not only produced in collisions between two dark matter particles, but also when a dark matter pearl collides with an appropriate piece of ordinary matter. Actually our speculation at present takes the direction that, in the latter case, the major production of 3.5 keV X-rays should occur when atoms of ordinary matter hit the dark matter. Then, namely, the atom can come with more than 3.5 keV energy while the energy of the electron is still under this value, so that the electron cannot penetrate into the bubble or even the hardened dust because its energy is below the homolumo gap value. This should then mean that the electron would effectively be strongly interacting with the dark matter pearl, while the atom still has sufficient energy to excite the 3.5 keV line.

  The contribution of the dark matter ordinary matter interaction dominates in three cases:

  – The observation of the outskirts of the Perseus Cluster, which we previously dropped out of our fit because it produced a couple of orders of magnitude more 3.5 keV X-rays than estimated from the dark matter density squared. One shall have in mind that the dark matter density in the Perseus Cluster falls off with radius faster than the ordinary matter density, which is dominated by the so-called "X-ray gas", consisting of intra-cluster hot gas or plasma revealing itself by its X-ray emission. This X-ray gas is a very large component of the ordinary matter.

  – The Center of the Milky Way: Actually Jeltema and Profumo [30] claim that the distribution of the 3.5 keV line from the Milky Way Center does not look at all like coming from dark matter. If it reflects the distribution of both dark matter and ordinary matter, the chance that it would vary in the way found observationally should be better, since the ordinary matter is distributed in a somewhat complicated way.

  – Of course from the dark matter theory point of view the mysterious observation of the 3.5 keV line from the Tycho supernova remnant can only be understood if some atoms of ordinary matter with X-ray temperatures are present in the remnant and interact with the dark matter.

  We found that the ratios of these three different observations of 3.5 keV line production can very crudely be compatible with a model of our type, having both dark + dark production and dark + ordinary production.

12.1 Physics of the Vacuum Phases?

In 1998 Alford, Rajagopal and Wilczek proposed a new phase of QCD with "Color-Flavour Locking" [6]. It was further argued that in matter with high baryon density [39, 40] there should be a phase pattern with among other phases this color-flavour-locking one. In particular they found that, for a density of the order of that in neutron stars, there was a tetra-critical phase meeting point

which in reality would probably be shifted into a couple of triple points. Remarkably this critical point occurred just for values of the strange quark mass and a common light quark mass (the heavy quarks being ignored) close to the phenomenologically known ones! Provided this phase diagram could be extrapolated to zero baryon number density, we could claim that these authors have already found the phase(s) we hope for to produce our dark matter bubbles.

The phase diagram involving also the quark masses as parameters is the most important for us, because we would like to claim that Nature via MPP would have fine-tuned the parameters, the quark masses in this case, to just let the vacuum be on the borderline among several phases. In the literature this phase diagram is known as the Columbia-plot [41], in which the abscissa is the mass, assumed to be the same, for the two light quarks *u* and *d*, while the ordinate is the strange quark mass, the heavy quarks being ignored. The main property investigated in this plot is how raising the temperature can cause phase transitions. In the lower left corner of the plot one has spontaneous symmetry breaking of the chiral symmetry and a first order phase transition occurs as temperature is raised. For larger quark masses, there is no true corresponding phase transition as the temperature is raised, but instead just a rapid variation of thermodynamical quantities. Such a situation is called a "crossover". It is our dream to realize our MPP by the experimental quark masses lying just on the curve separating off the mentioned lower left corner. This curve represents in the vacuum - i.e. zero temperature - a second order phase transition. The Columbia plot from some time ago [42], which we reproduce in Figure 13, has the physical point - meaning the experimental quark mass combination - inside the region in the lower left corner as limited off by the phase transition curve. However, Columbia plots from later lattice calculations mostly obtain this physical point lying in the region with the "crossover" as in Figure 14 from reference [43]. However an article using a technique of Ads/CFT correspondence type [44] also got the physical point inside the lower left corner region, in spite of the lattice calculations putting it on the bulk side (i.e. with the crossover). We are tempted to take this disagreement in the literature, as to even on which side of the (second order) phase transition curve the physical point lies, as saying that the uncertainties are such that one does not really know on what side this physical point lies. In fact that means then of course that it is, within the errors, possible that the physical point - as we dream - lies just on the phase transition curve.

12.1.1 What physics distinguishes the phases?

From the just mentioned hope for having a phase transition just at the physical quark mass values, we would come to think that the phases meeting at the experimental couplings are phases distinguished from each other just very little by the precise correlations between the Goldstone boson (the pions and the other pseudoscalar mesons) fields in the different phases. In fact we think one should imagine that in the phase in the lower left corner there is a significant correlation between the Goldstone fields at neighbouring places more than just that the fields are lined up corresponding to the chiral symmetry breaking direction; while in the phase in the region marked "crossover" the correlations are closer to be only given by the quark masses. There will of course still be correlations in the "crossover" phase, also between neighbouring regions, but they will be smaller correlations of that type than in the left lower corner phase.

In later work we would hope to estimate the scale of distance at which the Nambu-JonaLasinio spontaneous breakdown sets in, presumably it is order of magnitudewise given by $f_\pi = 93 MeV$.
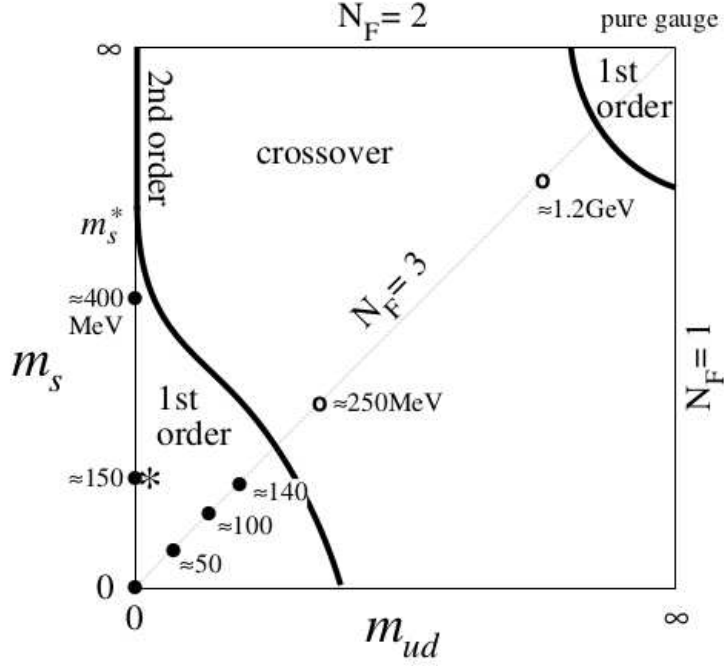
Figure 23: Order of the finite temperature QCD transition in the (m_{ud}, m_s) plane. First order signals are observed at the points marked with filled circle, while no clear two state signals are found at the points with open circle. The second order transition line is suggested [12] to deviate from the vertical axis as $m_{ud} \propto (m_s^* - m_s)^{5/2}$ below m_s^*. The values of quark mass in physical units are computed using a^{-1} determined from m_ρ: $a^{-1} \sim 0.8$ GeV for $\beta \leq 4.7$ and $\sim 1.0(1.8)$ GeV for $\beta = 5.0(5.5)$. See Sec. 8 for more detailed discussion on the values of the quark mass in physical units. The real world determined by the value of m_ϕ/m_ρ and m_π/m_ρ corresponds to the point marked with star.

70

Figure 13: This plot is taken from reference [42], which used lattice calculations to find the phase transition temperatures, and whether at this temperature there was a true phase transition or just a crossover. The phase transition temperatures are associated to the points in the quark mass plane at which the temperature was found by their lattice calculations. The plot has the common light quark mass on the abscissa and the strange quark mass on the ordinate. They determined the physical point by looking for the correct meson masses, and interestingly for us the * denoting this physical quark mass combination is on the small quark mass side of the second order phase transition curve, contrary to the next figure 14.
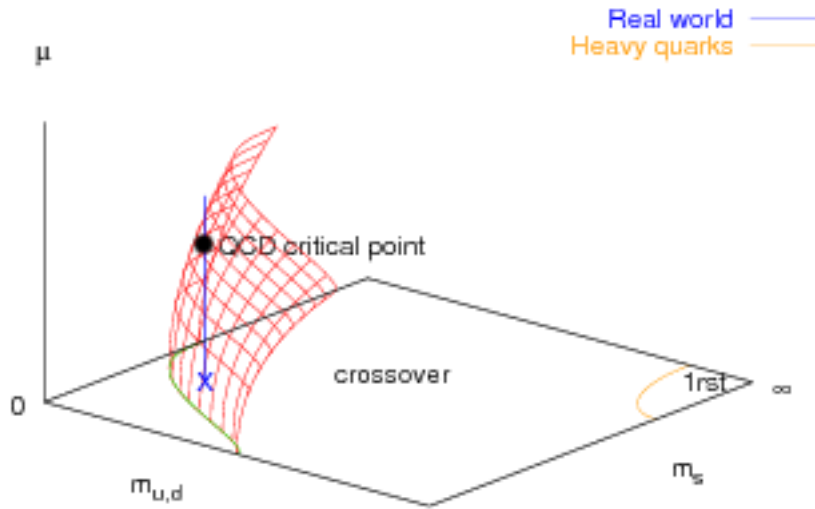
Figure 14: Here is a 3-dimensional phase diagram [43] in which there is imposed a chemical potential μ for baryon number along the vertical axis, while at the bottom in perspective we see the usual Columbia plot with the common u and d quark mass and the strange quark mass. The figure is based on the result that the physical masses for the quarks are to the large quark mass side of the second order phase transition. If however, as we hope for, the physical quark mass combination would be exactly on the second order phase transition curve, then the QCD critical point on this figure would have moved down to the curve on the vacuum surface at $\mu = 0$.

Then we can understand that, when the Compton wavelengths of the pion and kaon are short compared to the scale for the spontaneous breakdown, the sigma model fields will be specified effectively alone by the quark masses at a short distance scale. When on the other hand the Compton wavelengths for the quarks are long, then in first approximation we have a true spontaneous breakdown and the quark masses only provide a weak force determining the direction of the breaking of the chiral symmetry. In the latter case we expect a first order phase transition to a situation where say due to higher temperature the spontaneous breakdown has disappeared. In the short Compton wavelength situation, however, there is no true spontaneous breaking, because there is all the time a state kept with the same orientation of the breaking even rather locally, and thus we only expect the crossover phase. As f_π and say the average mass for the three light quarks are not much different, our speculation of the phase transition along the second order curve just coinciding with the physical quark masses is not excluded.

In early work by Learmann and Philipsen [45], they directly admit that they do not know on what side of the second order phase transition the physical point lies by putting question marks on their Columbia plot; see Figure 15. So we believe that it is not overly optimistic to suggest that some different phases in QCD really can exist if the quark masses just take the appropriate values, and that these values are indeed very close to the experimental quark masses.
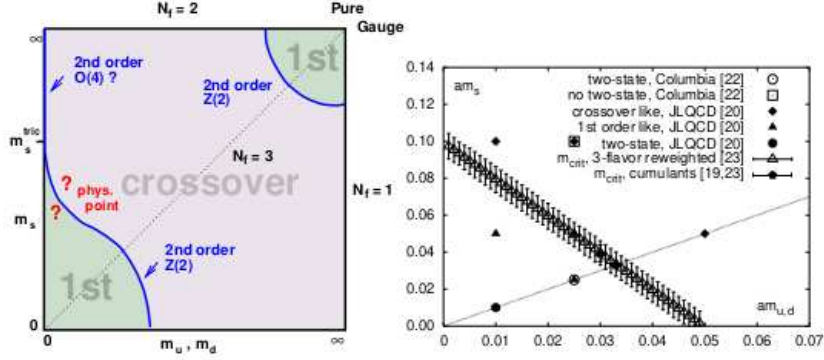
Figure 1: The phase diagram, expected (left) and lattice data (right), in the plane of strange and degenerate u,d quark masses.

Figure 15: Here Learmann and Philipsen have left question marks to tell that they did not know on what side of the second order phase transition the physical combination of quark masses lie. The right hand figure shows the second order phase transition determined from their lattice simulations with the lattice constant multiplied by the relevant quark mass along the axes.

If this is how our speculated phases come about then the scale of this physics is surely the strong interaction scale, say 0.4 GeV or so. However, we should probably take into account the very small difference in the correlations between the different phases which we suggested above. We would then expect that compared to a simple dimensionality argument - giving say 0.4 GeV as the scale - the tension S will be exceptionally small. So instead of expecting the cubic root $S^{1/3}$ to be 0.4 GeV, we expect it to be somewhat smaller.

12.1.2 What Tension did we get in our Dark Matter Fitting?

Now partly because, for dimensional reasons, we must consider the cubic root $S^{1/3}$ and partly because the mass of course goes as the cube of the linear distance scale, the mass M of our dark matter pearls depend on the ninth power of this cubic root $S^{1/3}$ of the tension. Thus putting in cubic roots of the tension only deviating by one order of magnitude we get masses deviating by 9 orders of magnitude. Thus our prediction of the mass M from the order of magnitude estimate of $S^{1/3}$ taken to be of the strong interaction energy scale allows a rather large range of masses; for example

$$S^{1/3} = 1\,GeV \quad \Rightarrow \quad M = 24\,kg \tag{55}$$

$$\text{while} \quad S^{1/3} = 100\,MeV \quad \Rightarrow \quad M = 2.4*10^{-8}\,kg \tag{56}$$

$$\text{and} \quad S^{1/3} = 10\,MeV \quad \Rightarrow \quad M = 2.4*10^{-17}\,kg = 1.4*10^{10}\,u. \tag{57}$$

Here u ~ GeV is the atomic unit.

The $M = 2.4 * 10^{-8} \, kg$ value would correspond to about 3000 km between the pearls in the solar system region, while $M = 24 \, kg$ would lead to a 1000 times longer distance, i.e. 3 million km between the pearls. To reach the mass required for making the DAMA experiment see enough separate particles, given above as the mass $M \leq 5 * 10^{-9} kg = 5 \, \mu g$, requires an $S^{1/3}$ value less than the 100 MeV in equation (56) by a factor of the ninth root of 4.8, which means $84 \, MeV$. This $84 \, MeV$ is thus the upper limit to the "strong interaction scale" allowed for our model to work. However, as already suggested, the weakness of the phase transition probably leads to a somewhat low tension and reaching down below 84 MeV should be possible.

12.1.3 Getting Rid of Cosmological Constant and Replacing by Domain Walls

In the article about our dark matter in the next workshop [20] on " Tensions in Cosmology", we calculate that one has the possibility of getting rid of the cosmological constant and effectively replacing it by domain walls. To achieve this modification of cosmology we need roughly

$$S^{1/3} \quad \sim \quad 30 \, MeV, \tag{58}$$

which fits well as a diminished strong interaction scale less than the more conventional 0.4 GeV, as well as with the requirement of it being less than 84 MeV.

This tension corresponds to a mass of our dark matter bubbles of $M \sim 10^{-12} \, kg \sim 10^{15} \, GeV$.

13. Conclusion

We have again presented and developed our long-standing model for dark matter as macroscopic composites of ordinary matter kept together and concentrated by means of a new type of vacuum - another phase of the vacuum. We think that our model solves some problems that are very difficult for other models and, in addition, has some good order of magnitude agreements suggesting that our model could be on the right track. For example, the most mysterious fact that DAMA-LIBRA have seemingly seen the dark matter while several Xenon based experiments do not - even with significantly more sensitivity - see it. We suppose dark matter is something moving through the apparatuses with a speed quite different for a solid NaI detector as in DAMA-LIBRA, where the dark matter pearls can get stopped and thus spend more time in the apparatus, than in the fluid xenon apparatuses, where they will fall quickly through. Another achievement of our model is that, because it is so difficult e.g. to see new vacua, we have essentially no new physics and can thus cope with the fact that LHC has seen nothing of the dark matter. Since the workshop we have even speculated about the so-called Columbia plots, which suggest some phase transitions as a function of the quark masses. If our speculations were established, we would really have the chance to avoid LHC having had to see anything concerning the dark matter - our model can so to speak live with *no new physics.*

We now list a series of comments about our model:

- We have put forward a model for dark matter consisting of nm size bubbles of a *new vacuum* with a mass inside of $2 * 10^{-15} kg \sim 10^{12} \, GeV$ and, apart from this vacuum speculation, using *only the Standard Model.* (But recently we got the idea that, if one wants to change cosmology by avoiding the dark energy and thus putting the cosmological constant to zero, there is a

chance of getting approximately the same effects from domain walls on the borderlines of the different vacua. This requires though that the pearls become bigger. In such a case the size of the bubble should be of the order of 10^{-8} m, rather than the nm size we believed at the time of the workshop in Corfu 2022.)

- The low velocity interaction of the dark matter particles in outer space - especially in dwarf galaxies, where Correa estimated it - is given by a *dust grain* sitting around the pearl of the new vacuum. Using the relative amount of "metals" to dark matter as also giving the ratio of the masses of the grain of dust to the dark matter in the dark matter particles, we get only an order of magnitude deviation from the low energy "inverse darkness" estimated by Correa:

$$\frac{\sigma}{M}_{v-->0} = 120 m^2/kg \quad \text{against Correa:} \quad \frac{\sigma}{M}_{v-->0} = 15 m^2/kg. \tag{59}$$

- Because of having lesser darkness than ideal dark matter (which has only gravitational interactions) - i.e. larger inverse darkness $\frac{\sigma}{M} \sim 10^{-3} m^2/kg$, even after blowing off the attached dust grain, than the "usual" WIMPs - our dark matter particles get slowed down in the atmosphere. This explains why the Xenon-experiments, which only look for nuclei recoil events when expecting dark matter, do not see any dark matter giving nuclei.

- The highly compressed "ordinary matter " (in the new vacuum) inside the bubble has, compared to usual chemistry, a very high energy gap - homolumo gap - between the highest filled state, *HOMO*, and the lowest unoccupied state, *LUMO*, speculated to be just $3.5\,keV$. This leads to the dark matter bubble having a "preferred" *emission energy for photons and electrons given by the gap height 3.5 kev*.

- It is this emission of 3.5 keV electrons (and photons) after excitation of the "ordinary" material inside the bubble, which we suppose is observed by DAMA.

- It is a remarkable accident supporting our model that the direct observation at DAMA-LIBRA and the X-ray radiation observed from galaxy clusters and galaxies supposedly coming from dark matter both have the average energy per event of 3.5 keV.

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