Atomic Size Dark Matter Pearls, Electron Signal, IMP or SIDM, not WIMP

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"Korfu" , September , 2021

IMP=" Interacting Massive Particles ".
SIDM = "Self-Interacting Dark Matter".

[2]Speaker at the Korfu-meeting "The Standard Model and Beyond"

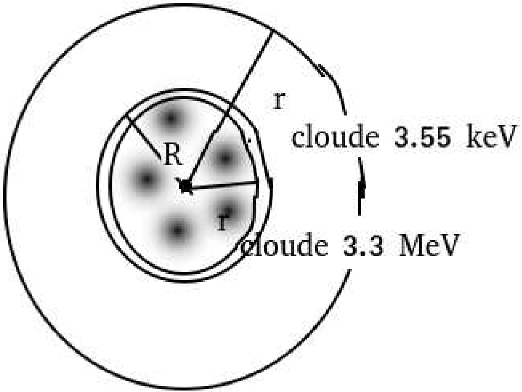
IMP or SIDM, not WIMP, most important

A bit similar to Khlopov's model of doubled negative charged particles leading to zero charged He, that can be stopped, our model assumes:

- **The dark matter particles interact so strongly as to get stopped in the earth shielding before reaching the direct dark matter searches like DAMA, LUX, Xenon1T,...**
- **They can get excited and emit energy as electrons or photons, say hours after hitting the Earth..**

Thus DAMA-LIBRA may see them as dark matter, but experiments needing recoil nuclei will not accept them as dark matter.

"Dark Matter Atomic Size Pearls, Electronic 3.55 keV Signal, IMP or SIDM, not WIMP



(About $2 * 10^5/12 \approx 2 * 10^4$ carbon "atoms" inside the bubble.)

The figure illustrates the a bit smaller than atom-size complicated/macroscopic object from which dark matter consists in our model, a pearl

- In the midle is a spherical bubble of radius

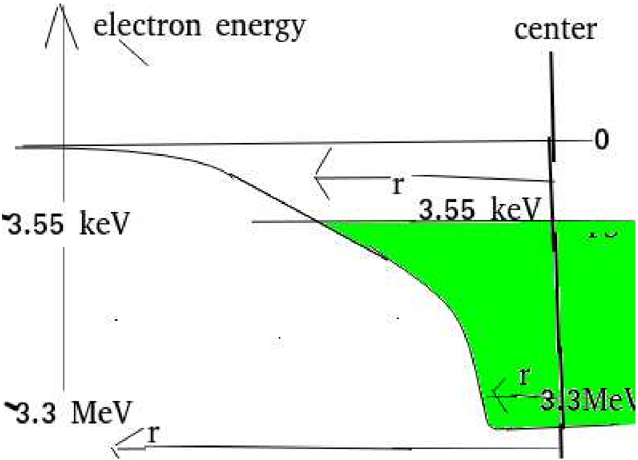
$$R \approx r_{cloude\ 3.3MeV} \approx 4 * 10^{-12} m \quad (1)$$

$$\text{where } r_{cloude\ 3.3MeV} = \text{“where potential for electron is } 3.3MeV\text{”}$$

We have namely estimated in fitting the overall rate of the intensity of the 3.55 keV radiation and the very number 3.55 keV, that in the bulk of the pearl - i.e. inside the radius R, which is the bubble region, the fermi-energy E_f supposed equal to the electron potential should be $3.3MeV$.

- The radius $r_{cloude\ 3.55keV}$ is where the electron potential is 3.55 keV. By our story of “homolumo gap”: the electron density crudely goes to zero at this radius. (It falls gradually a lot in the range between $r_{cloude\ 3.3MeV}$ and $r_{cloude\ 3.55keV}$).

The electron density and potential in the pearls



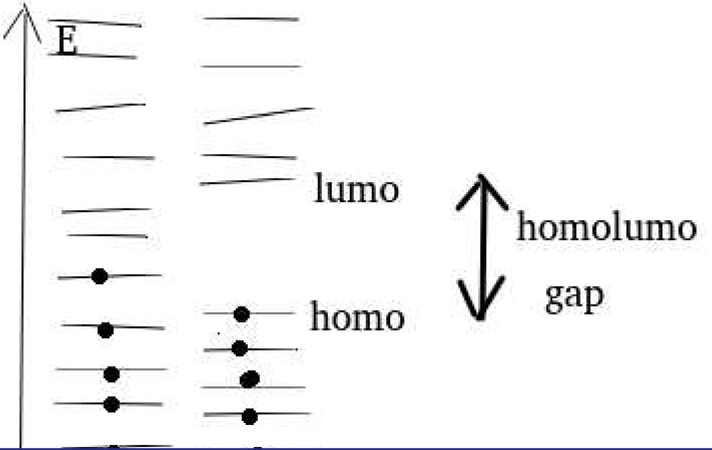
Explaining the Electron density and potential Pearl description

- Due to an effect, we call **homolumo-gap effect**, the nuclei in the bubble region and the electrons themselves become arranged in such a way as to prevent there from being any levels in an interval of width 3.55 keV. So outside the distance $r_{3.55keV} = r_{cloude\ 3.55keV}$ from the center of the pearl at which the Coulomb potential is $\sim 3.55keV$ deep there are essentially ($\sim$ in the Thomas-Fermi approximation) no more electrons in the pearl-object.
- The radius $r_{3.3MeV} = r_{cloude\ 3.3MeV}$ at which the potential felt by an electron is $3.3MeV$ deep, is supposed to be just the radius to which the many nuclei replacing the only one nucleus in ordinary atoms reach out. So inside it the potential is much more flat.

Explanation of Electron Density and Potential Figure Continued.

- The energy difference between the zero energy line and the effective Fermisurface above which there are no more electrons is of order of the in our work so crucial number 3.55 keV.
- Since in Thomas Fermi approximation there are no electrons outside roughly the radius $r_{3.55keV} = r_{cloude\ 3.5keV}$, this radius will give the maximal cross section, even for very low velocity, $\sigma_{v \to 0}$.

We cannot avoid saying what homolumo gap effect is.



Homolumo-gap effect explanation

Think first of the spectrum of energy levels for the electrons by assuming at the start the positions or distributions of the charged particles in the piece of material studied, e.g. one of our pearls, as fixed.
Then the ground state is just a state built e.g. as a Slater determinant for the electrons being in the lowest single electron states, so many as are needed to have the right number of electrons.
But now if the charged particles can be moved, a bit or much, the ground state energy could be lowered by moving them so that the filled electron state levels get lowered.
So we expect introducing such "back reaction" will lower the filled states.

Why the name "homolumo"

When the filled levels get moved downwards, then the homo= "**h**ighest **o**ccupied **m**olecular **o**rbit" level will be lowered and its distance to the lumo= "**l**owest **u**noccupied **m**olecular **o**rbit" increased by the effect of the back reaction, and so an exceptionally large region, the "homlumo-gap" with no single particle electron levels will appear on the energy axis.

Believe we can estimate the homolumo-gap E_H

Using Thomas Fermi approximation - or crudely just some dimensional argument where the finestructure constant had dimension of velocity - we got the homolumo gap in highly compressed ordinary matter, for relativistic electrons,

$$E_H \sim (\frac{\alpha}{c})^{3/2}\sqrt{2}p_f \quad (2)$$

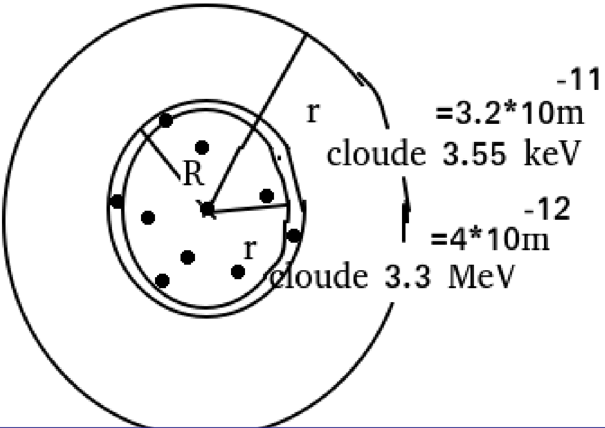
$$\text{where } p_f = \text{“}Fermimomentum\text{''} \quad (3)$$

$$\frac{\alpha}{c} = \frac{1}{137.03...} \quad (4)$$

(the $\sqrt{2}$ comes from our Thomas fermi).

It is fitting this homolumo-gap to be the energy per photon of the X-ray radiation mysteriously observed by sattelites astronomically, from clusters of galaxies or even e.g. Andromeda, that gives us the Fermi-energy $E_f \approx p_f = 3.3MeV$ assumed in the interior bulk of the pearl.

Dark Matter Pearls, Sizes Fitted to $\frac{\sigma}{M}|_{v\to 0} = 150cm^2/g$



Our Picture of Dark Matter Pearls:

- Principle Nothing but Standard Model! (seriously would mean not in a BSM-workshop)
- New Assumption Several Phases of Vacuum with Same Energy Density.
- Central Part Bubble of New Phase of Vacuum with E.g. carbon under very High Pressure, surrounded by a surface with tension S (=domaine wall) providing the pessure.
- Outer part Cloude of Elctrons much like an ordinary Atom with nucleus charge of order ten to hundred thousands. ($Z = 4 * 10^4$ effectively).

Main Achievements (first), Fitting Low velocity Interaction.

- **Low velocity $\frac{\sigma}{M}|_{v\to 0}$ cross section to mass ratio.** The a priori story that dark matter has only gravitational interactions seems not to work perfectly: Especially in dwarf galaxies (around our Milky Way) where dark matter moves slowly an apreciable cross section to mass ratio $\frac{\sigma}{M}$ going in the limit of low velocity according to the fits to $150 cm^2/g$. We may say our pearl-model "predicts" this ratio to say $314 cm^2/g$.

Name	Final profile			Preferred cross section
	M_{200} [10^9 M$_\odot$]	c_{200}	r_{core} [pc]	σ/m_χ [cm^{2}g^{-1}]
UM	0.13	34.2	180.8	40 – 50
Draco	1.17	26.8	472.9	20 – 30
Carina	1.09	19.1	648.4	40 – 50
Sextans	0.32	20.8	395.5	70 – 120
CVnI	0.46	25.7	356.8	50 – 80
Sculptor	1.65	25.8	553.2	30 – 40
Fornax	2.29	15.3	1036.7	30 – 50
LeoII	0.05	30.6	148.8	90 – 150
LeoI	1.17	31.1	410.8	50 – 70

Table 2. Form left to right: name of the dSph galaxy, present-time virial mass, concentration parameter and core size of the subhalo hosting the dSph and range of preferred cross section values that reproduce the observed DM central densities.

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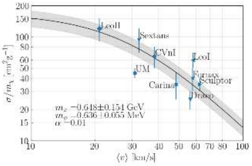
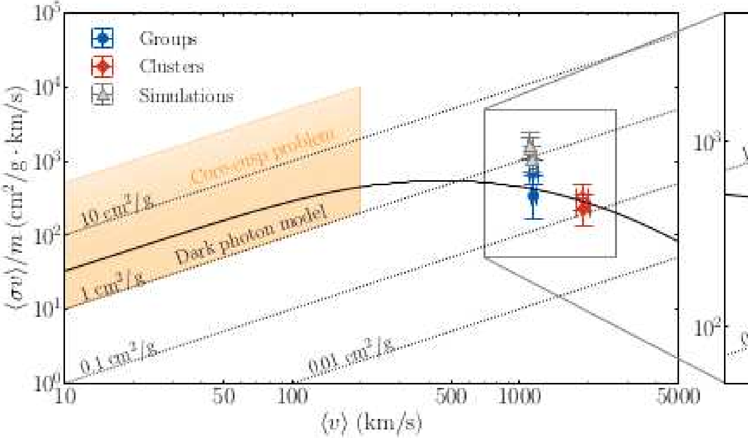
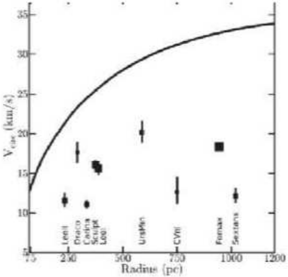
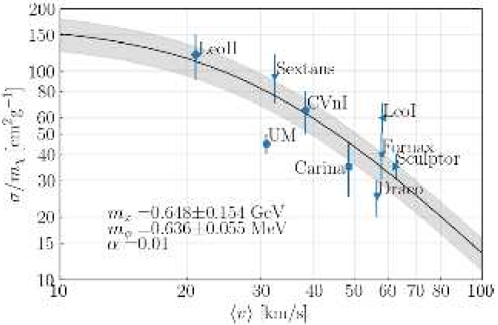


Figure 6. Cross section per unit mass, σ/m_χ, as a function of the average collision velocity, $\langle v \rangle$, of DM particles within each subhalo's core. Symbols show the range of σ/m_χ needed for the SIDM model to reproduce the central DM densities reported by Kaplinghat et al. (2019). The solid line corresponds to the best-fit relation given by eq. (15) to the MW dSph data.


Groups
Clusters
Simulations
Coresmp problem
Dark photon model
10 cm²/g
1 cm²/g
0.1 cm²/g
0.01 cm²/g
⟨σv⟩/m (cm²/g · km/s)
⟨v⟩ (km/s)
10
50
100
500
1000
5000



V_{circ} (km/s)
Radius (pc)
35
30
25
20
15
10
5
75
250
500
750
1000
1200
LeoII
Draco
Carina
Sculpt
LeoI
UrsMin
CVnI
Fornax
Sextans



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Velocity dependence of cross section over mass $\frac{\sigma}{M}$

Self-interacting d

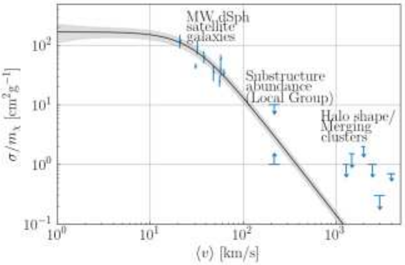


Figure 7. Same as Fig. 6, but extended to cover the range of MW- (~200 km/s) and cluster-size (~1000 – 5000 km/s) haloes' velocities. The figure shows upper and lower limits for σ/m_χ taken for substructure abundance studies (e.g. Volgelsberger et al. 2012 and Zavala et al. 2013), as well as based on halo shape/ellipticity studies and cluster lensing surveys (see text).

Main Achievements (continued), Resolving Disagreement Semingly of DAMA and Xenon-experiments.

- **Can make the Dark Matter Underground Searches get Electron Recoil Events** Most underground experiments are designed to look for dark matter particles hitting the nuclei in the experimental apparatus, which is then scintillating so that such hits on nuclei presumed can be seen. But our pearls are excited in such a way that they send out energetic **electrons** (rather than nuclei), and thus does not match with what is looked for, except in the DAMA-LIBRA experiment, in which the only signal for events comming from dark matter is a seasonal variation due to the Earth running towards or away from the dark matter flow.

Main Acievement (yet continued), The 3.55 keV X-ray Radiation

- **The Intensity of 3.55 keV X-rays from Clusters etc.** We fit the very photon-energy 3.55 keV and the overall intensity from a series clusters, a galaxy, and the Milky Way Center with one parameter $\frac{\xi_{fS}^{1/4}}{\Delta V} = 0.6 MeV^{-1}$.
- **3.55 keV Raditation from the Tycho Super Nova Remnant**Jeltema et Profumo discovered the X-ray radiation of 3.55 keV from the supernova remnant after Tycho Brahes supernova. We have a story giving the correct order of magnitude in our pearl model.

Even though we can use $\frac{\xi_{fS}^{1/4}}{\Delta V} = \frac{2}{p_f}$ only, nice to know the notation.

$$\begin{aligned}
\Delta V &= \text{`` difference in potential for a nucleon} \\
&\quad \text{between inside and outside the central part of the pearl''} \\
&\approx 2.5 MeV \qquad (5) \\
\xi_{fS} &= \frac{R}{R_{crit}} \text{estimated } \approx 5 \qquad (6) \\
\text{where } R &= \text{``actual radius of the new vacuum part''} \\
&\approx r_{cloude\ 3.3MeV} \qquad (7) \\
\text{and } R_{crit} &= \text{`` Radius when pressure so high} \\
&\quad \text{that nucleons are just about being spit out''} \qquad (8)
\end{aligned}$$

Main calculational Achievements (yet yet contiued), Energy Consideration

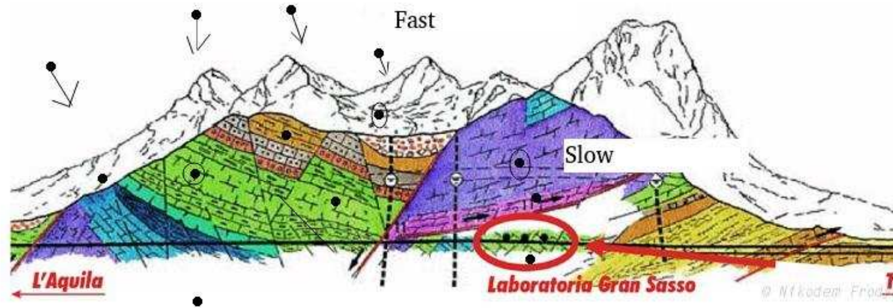
- DAMA-rate Estimating Observaion rate of DAMA-LIBRA from kinetic energy of the incoming dark matter as known from astronomy.
- Xenon1T Electron recoil rate Same for the **Electron recoil excess** observed by the Xenon1T experiment.

To explain these last calculational estimates we need to how we imagine the dark matter to interact and get slowed down in the earth shielding, and that the dark matter particles get excited and emit 3.55 keV radiation or electrons.

About the Xenon1T and DAMA-rates:

- Absolute rates very crudely The absolute rates for the two experiments are very very crude because we assume that the dark matter particles - in our model small macroscopic systems with ten thousends of nuclei inside them - can have exceedingly on a logarithmic scale smoothly distributed life times. We get **mysteriously well** order of magnitude agreement.
- The ratio of rates The ratio of the rates in the two experiments - Xenon1T electron recoil excess and DAMA - should in principle be very accurately predicted in our model, because it is supposed to see exactly the same effect just in two different experiments! We get **only** order of magnitude agreement

Illustration of Interacting and Excitable Dark Matter Pearls



The dark matter pearls come in with high speed (galactic velocity), but get stopped down to much lower speed by interaction with the shielding mountains, whereby they also get excited to emit 3.55 keV X-ray or **electrons**.

Pearls Stopping and getting Excited in Earth Shield

What happens when the dark matter pearls in our model of less than atomic size pearls hit the earth shielding above the experimental halls of e.g. DAMA?:

- Stopping The pearls are stopped in about $5 * 10^{-6}s$ (or $3.3 * 10^{-8}s$) from their galactic speed of about $300km/s$ down to a speed where the hitting nuclei no longer can excite the $3.55keV$ excitations, at a velocity $49km/s$. The stopping length is modulo a logarithmic factor $\frac{1}{4}m$ (or 1.6 mm if we use a bigger crossection over mass $\frac{\sigma}{M} = 2cm^2/g$).

Pearls stopping and getting excited in Earth shileding.(continued)

- Excitation As long as the velocity is yet over the ca. 49km/s hitting nuclei in the shielding can excite the electrons inside the pearl by 3.55 kev or more and make pairs of quasi electrons and holes say. We expect that often the creation of as well as the deacy of such excitations requires electrons to pass a (quantum) tunnel and that thus there will be deacy half lives of very different sizes. We hope even up to many hours or days...

Stopping and Exciting Pearls (yet continued)

- Slowly sinking: After being stopped in the of the order of $\frac{1}{4}m$ (or $1.6mm$?) of the shielding that pearls continue with much lower velocity driven by the gravitational attracktion of the Earth. After say about 18 hours a pearl reach the 1400 m down to the laboratories. Most of the pearls have returned to their ground states, but some exceptionally long living excitations survive.

Note that the slowly sinking velocity is so low that the hit of nuclei cannot give such nuclei enough speed to excite the scintilation counting neither in DAMA nor in Xenon-experiments

Stopping and Exciting (yet, yet continued)

- Electron or γ emission Typically the decay of an excitation could be, that a hole in the Fermi sea of the electron cloude of the pearl gets filled by an outside electron under emission of another electron by an Auger-effect. The electron must tunnel into the pearl center. This can make the decay life time become very long and very different from case to case.

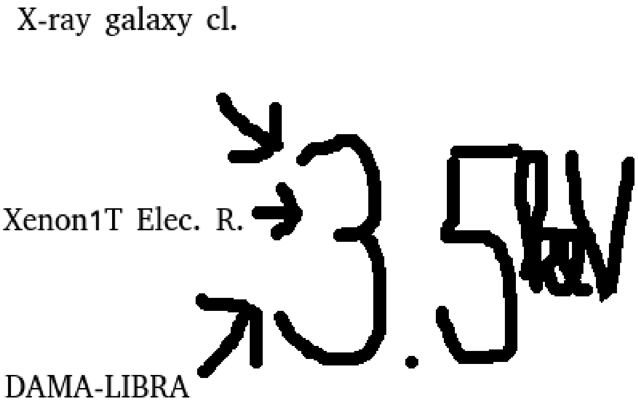
Emission as electrons or photons makes Xenon-experiments not see, except...

That the decay energy is released most often as electron energy makes it be discarded by most of the Xenon-experiments, which only expect the nucleus recoils to be dark matter events. This explains the long standing controversy consisting in DAMA seeing dark matter with much bigger rate than the upper limits for the other experiments.

Rather recently though Xenon1T looked for potential excess events among the **electron recoil events** and found with a background $(76 \pm 2) events/year/tonne/keV$ an excess $\sim 16 events/year/tonne/keV$ in the low energy region up to about 7 keV.

It is one of our main estimates to see that this rate could be of just the corresponding one to the observation of DAMA-LIBRA!

Order of magnitudewise we see $3.5keV$ in 3 different places.



The 3.55 keV crude Coincidence

The energy level difference about 3.55 keV occuring in 3 different place is a major source suggesting our model of dark matter particles being excitable by 3.55 keV:

- The line From places in outer space with much dark matter, galaxy clusters, Andromeda, Milky way Center, a non-expected line of X-ray with photon energies 3.55 keV (to be corrected for Hubble expansion...) was seen.
- Xenon1T The Dark matter searching Xenon1T, not finding usual nuclei-recoil dark matter, found an excess of **electron-recoil** events with energies in the low end, where it gets impossible to measure below 2 keV, in fact with concentration crudely around the 3.5 keV.
- DAMA The seasonally varying component is in energy between 2 keV and 6 keV, not far from centering around 3.55 keV.

Decay Observation in DAMA and Xenon1T almost a Must

Taking it seriously and not as an accident that both DAMA and Xenon1T see events with energies of the order of the astromically "famous" X-ray line 3.55 keV, we are driven towards the hypotesis, that the energies in the underground experiments for the events is determined rather from a decay of an excited particle than from a collision with a particle in the scintillator material. It would namely be pure accident, if a collision energy should just coincide with the dark matter excitation energy obseved astronomically.
So we ought to have decays rather than collisions!

How can the dark matter particles get excited ?

You can think of the dark matter pearls in our model hitting electrons and/or nuclei on their way into the shieding:

- Electrons Electrons moving with the speed of the dark matter of the order of 300 km/s toward the pearls in the pearl frame will have kinetic energy of the order

$$E_e \approx \frac{1}{2} * 0.5MeV * (\frac{300km/s}{3 * 10^5 km/s})^2 = 0.25eV. \quad (9)$$

- Nuclei If nuclei are, say Silicium, the energy in the collision will be 28*1900 times larger $\sim 5 * 10^4$ * $0.25eV \approx 10$ keV. That would allow a 3.55 keV excitation.
  To deliver such $\approx 10keV$ energy the nucleus should hit something harder than just an electron inside the pearls. It should preferably hit a nucleus, e.g. C, inside the pearl.

Conclusion, Model description

- **We have described a seemingly very viable model for dark matter consisting of atomic size but macroscopic pearls, consisting of a bubble of a new speculated type of vacuum containing some usual material - presumably carbon - under the high pressure of the skin (surface tension) can contain about ten thousend(s) of nucleons in the bubble of radius about $4 * 10^{-12} m$.**
- **The electrons have partly been pushed out of the genuine bubble of the new vacuum phase.**

Conclusion on Observations considered relative to the Model

We have compared the model or attempted to fit:

- **Astronomical suggestions for self interaction of dark matter in addition to pure gravity**
- **The sattelite found 3.55 keV X-ray line, supposedly from dark matter.**
- **The underground dark matter searches.**

Listing Counting the numbers crudely estimated:

- 1. The low velocity cross section divided by mass.
- 2. That the signal from Xenon1T and Dama should agree except for different scintillation efficiencies and notation, ... (**not working so well!**)
- 3. The absolute rate of the two underground experiments.
- 4. The rate of the Jeltema et al. Tycho SN remnant 3.55 keV
- 5. Relation between the frequency 3.55 keV and the over all rate of this X-ray from galaxy clusters etc.

Resume of our Well Fitting / Predictions

# & exp/th	Quantity	value	related Q.	value
1.	Dwarf Galaxies			
exp	$\frac{\sigma}{M}\|_{v \to 0}$	$150 cm^2/g$	$r_{cloude\ 3.3MeV\ via\ mass}$	$4.9 * 10^{-12} m$
th.		$314 cm^2/g$	$r_{cloude\ 3.3MeV\ TF}$	$3.82 * 10^{-12} m$
2.	DAMA-LIBRA			
exp	eff. cor. $rate_{summed}$	$0.216 cpd/kg$	supression	$7 * 10^{-10}$
th	$(\frac{\sigma}{M} = 0.0125 cm^2/g)$	$0.13 cpd/kg$		$4.19 * 10^{-10}$
th	$(\frac{\sigma}{M} = 2 cm^2/g)$	$0.0013 cpd/kg$		$4.2 * 10^{-12}$
3.	Xenon1T			
exp	eff. cor. $rate_{summed}$	$2.12 * 10^{-4} cpd/kg$	supression	$0.5 * 10^{-10}$
th	$(\frac{\sigma}{M} = 0.0125 cm^2/g)$	$0.002 cpd/kg$		$4.19 * 10^{-10}$
th	$(\frac{\sigma}{M} = 2 cm^2/g)$	$0.00002 cpd/kg$		$4.2 * 10^{-12}$
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.	Intesity 3.5 kev			
exp	$\frac{N\sigma}{M^2}$	$10^{23} cm^2/kg^2$	$\frac{\xi_{fS}^{1/4}}{\Delta V}$	$0.6 MeV^{-1}$
th		$3.6 * 10^{22} cm^2/kg^2$		$0.5 MeV^{-1}$
6.	Three Energies			
ast	line	3.55 keV		
DAMA	av. en.	3.1 keV		
DAMA	raw	3.4 keV		
Xen.	av. en.	3.4 keV		
Xen.	raw	3.7 keV		

Table explanation:

In the just above table, we have used the column number 2 called "Qunatity" not only for the name of the experiment involved, but also in bracket "()" the value of the ratio of cross section to mass of the dark matter pearl taken for the nucleus on dark particle (the mass is the M for the dark particle). You may take the difference between using the two values of this ratio for which we calculated as a kind of uncertainty. The truth being likely in beteen the two values presented.

In the item 6. in the second column we use the short hand "av. en." to denote our best estimate of the average energy for the supposedly dark matter caused (extra in the Xenon1t case) events, while "raw" denotes the numbers by just averaging over the observed dark matter caused events not taking care of that below 2 keV such events are invisible in the scintillation technique used.