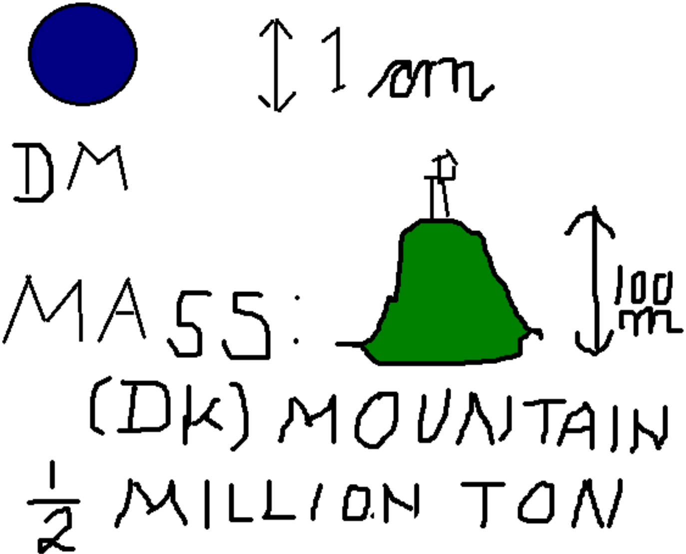
X-ray Line 3.55 keV from Dark Matter, Our Glass Pearls

Mainly work with **Colin D. Froggatt, Glasgow** but also work with **Ivan Andric, Larisa Jonke** and especially **Danijel Jurman** from Rudjer Boskovic is mentioned, major basics for our picture goes to also **Larisa Laperashvili, Don Bennett, ...**
Talk is presented by **Holger Bech Nielsen**.


1 cm
DM
MASS:
100 m
(Dk) MOUNTAIN
½ MILLION TON

Forming a Picture of Our Dark Matter Model, Pearls

- They are really bubles - with the vacuum being in two different phases, the normal vacuum outside the pearl, and a "condensate vacuum" inside. Like water-droplets have water inside and air outside.
- The surface tension - being of weak interaction scale 100 GeV - is exceedingly high from dayly life scale point of view.

$$\text{"surface tension"} = 10^{11} kg/m^2 = 10^{28} N/m \qquad (1)$$

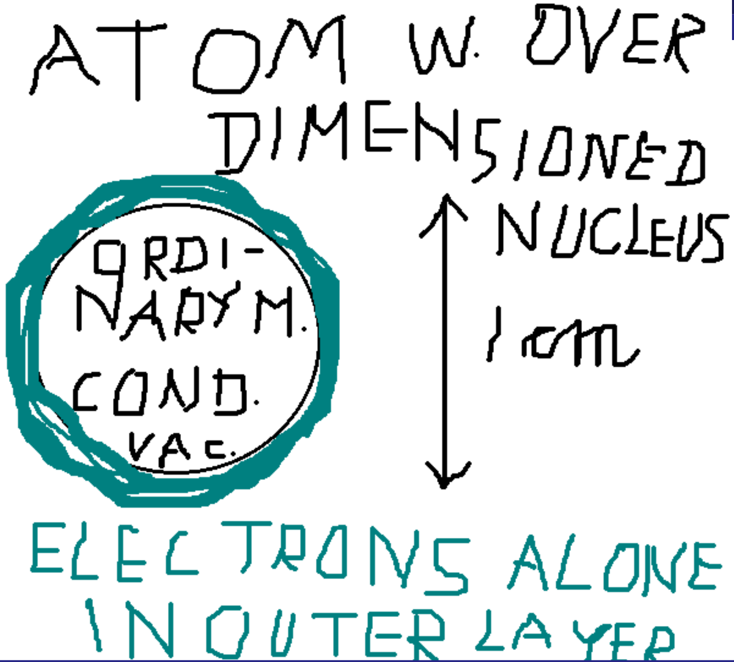
An atom-broad strip provides $10^{18} N \sim$ the weight of $10^{17} kg = 10^{14} ton$.

Picturing Our Pearls (continued)

- To keep the extremely strong surface tension from collapsing the pearl away, it must be filled with, say, ordinary matter, under extreme pressure. **So there is ordinary matter inside the dark matter in our model.** Like in a white dwarf say.
- If you feed a pearl with neutrons it can take them up under release of about 10 MeV energy per neutron. Protons would have to be shot in with big speed.

Picturing Our Pearls (continued)

- In the inside phase, "condensate vacuum", we have in our model estimated that the Higgs field expectation value is about half the outside value and the quarks and the nucleons therefore lighter inside than outside by about 10 MeV. Nucleons are atrackted towards the inside phase by a ca 10 MeV potential. For electrons this attracktion is less.
- Some electrons are bound electrically, but some a bit outside the surface with the strong tension.
- Over-dimensioned "nucleus" is not a nucleus but rather ordniary matter compressed.


ATOM W. OVER DIMENSIONED
ORDI- NARY M. COND. VAC.
NUCLEUS
1 cm
ELECTRONS ALONE IN OUTER LAYER

Pearl Picture, Hope for the 3.5 keV Line

For the purpose of explaining the unidentified X-ray line with energy 3.5 keV in our dark matter model we hope that the matter inside the pearl - where the vacuum is in the "condensate vacuum" phase - is an insulator with a gap between the filled and empty electron levels being of order 3.5 keV, since then:

- After excitation and some relaxation we could have a lot of electrons in the states which should be empty(in ground state) - especially the lowest enrgy ones among these -, and a lot of holes -especially also close to the fermi surface.
- This really means a lot of excitons(=pairs of hole and electron) in their low energy state.
- Finally the excitons decay under emmission of light of the energy corresponding to the energy released by the electron falling into the hole. The gap hoped to be 3.5 keV.

Order of Magnitude of the Gap (Homolumo-gap)

- That the gap (homolumo-gap) should be of order a few keV is not so unreasonable, because the ordinary matter inside the "condensate vacuum phase" in our dark matter according to our fits is compressed to to a density of the order $10^{14} kg/m^3$, meaning a compression in each of the three dimensions by a factor $(10^{11})^{\frac{1}{3}} \sim 5000$, and we expect the homolumo gap to be crudely proportional to the inverse of the distance of neighboring atoms.
- We shall argue for a homolumo-gap $\approx p_{fermi}\alpha^2$, which with $p_{fermi} \sim 10MeV$ can give "$homolumo - gap'' \sim 1keV$.


EMPTY
HOMO-
-LUMO-
GAP
3.5KEV
FILLED

3.5 keV line.

Two groups reported an identified feature in the X-ray spectra of dark matter-dominated objets

DETECTION OF AN UNIDENTIFIED EMISSION LINE IN THE STACKED X-RAY SPECTRUM OF GALAXY CLUSTERS

Esra Bulbul[1,2], Maxim Markevitch[2], Adam Foster[1], Randall K. Smith[1] Michael Loewenstein[2], and Scott W. Randall[1]

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Submitted to ApJ, 2014 February 10

ApJ (2014) [1402.2301]

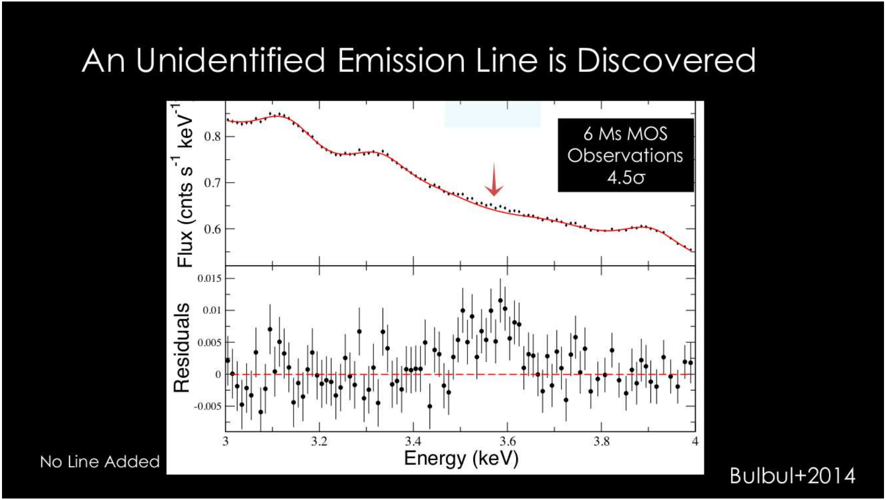
An unidentified line in X-ray spectra of the Andromeda galaxy and Perseus galaxy cluster

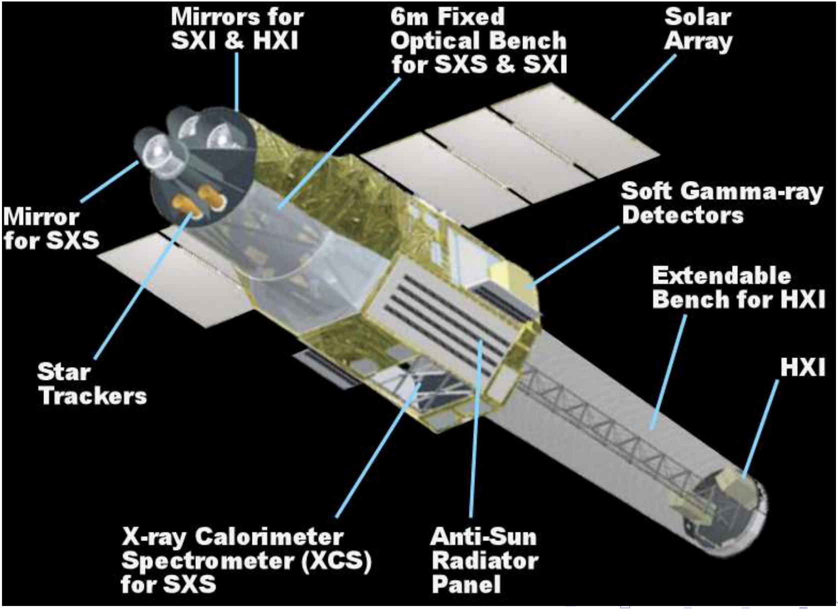
A. Boyarsky[1], O. Ruchayskiy[2], D. Iakubovskyi[3,4] and J. Franse[1,5]

[1] Instituut-Lorentz for Theoretical Physics, Universiteit Leiden, Niels Bohrweg 2, Leiden, The Netherlands
[2] Ecole Polytechnique Fédérale de Lausanne, FSB/ITP/LPPC, BSP, CH-1015, Lausanne, Switzerland

PRL (2014) [1402.4119]

- **Energy:** 3.5 keV. Statistical error for line position $\sim 30 - 50$ eV.
- **Lifetime:** $\sim 10^{28}$ sec (uncertainty: factor ~ 3)
- **Possible origin:** decay DM $\to \gamma + \nu$ (fermion) or DM $\to \gamma + \gamma$ (boson)


An Unidentified Emission Line is Discovered
6 Ms MOS
Observations
4.5σ
Flux (cnts s-1 keV-1)
0.8
0.7
0.6
Residuals
0.015
0.01
0.005
0
-0.005
3
3.2
3.4
3.6
3.8
4
Energy (keV)
No Line Added
Bulbul+2014


Mirrors for SXI & HXI
6m Fixed Optical Bench for SXS & SXI
Solar Array
Mirror for SXS
Soft Gamma-ray Detectors
Extendable Bench for HXI
Star Trackers
HXI
X-ray Calorimeter Spectrometer (XCS) for SXS
Anti-Sun Radiator Panel

"Pedagogical Model" Merle and Schneider.

Merle and Schneider propose the simple model that the dark matter consists of "sterile neutrinoes" (or other particles) with mass 7.1 keV decaying then very slowly

$$\nu_{st} \quad \rightarrow \quad \nu + \gamma \tag{2}$$

Since this is into two massless particles, a neutrino ν and a γ they each get the half energy 3.55 keV.
We may represent the rate information by fitting the lifetime of this model -which I mainly consider pedagogical to describe e.g. the rate of radiation -:

$$\text{"life time"} = 10^{-28} s \tag{3}$$

About the rate of 3.5 keV

The energy release into the 3.5 keV line corresponding to the Merle Schneider model fit of life time $10^{28}s$ means

$$
\begin{aligned}
\text{“Radiation per mass”} &= \frac{(3*10^8 m/s)^2}{2*10^{28} skg} && (4)\\
&= 0.5*10^{-11} W/kg && (5)\\
\text{With } \rho_{DM} &= \frac{m_p}{3m^3} && (6)\\
&= 10^{-27} kg/m^3, && (7)\\
\text{“Radiation per vol.”} &= 10^{-38} W/m^3 && (8)\\
\text{For cube 8kpc sides} \quad & \mathit{having} \quad (8*3*10^{16})^3 m^3 && (9)\\
&= 10^{52} m^3, && (10)\\
\text{“From “galaxy cube””} \quad & \mathit{comes} \quad 10^{25} W (3.55 \text{ radiation}) && (11)\\
\text{Compare: “luminocity Galaxy”} &= 5*10^{36} W && (12)
\end{aligned}
$$

K. J. H. Phillips , B. Sylwester , J. Sylwester criticize: In Solar flare can be 9 to 11 times higher K abundance.

Recent work by Bulbul et al. and Boyarsky et al. has suggested that a line feature at 3.5 keV in the X-ray spectra of galaxy clusters and individual galax- ies seen with XMM-Newton is due to the decay of sterile neutrinos, a dark matter candidate. This identification has been criticized by Jeltema and Profumo on the grounds that model spectra suggest that atomic transitions in helium-like potas- sium (K xviii) and chlorine (Cl xvi) are more likely to be the emitters. Here it is pointed out that the K xviii lines have been observed in numerous solar flare spectra at high spectral resolution with the RESIK crystal spectrometer and also appear in Chandra HETG spectra of the coronally active star σ Gem.

Continue of Critisism: Due to K-line from Higher Abundace

In addition, the solar flare spectra at least indicate a mean coronal potassium abundance which is a factor of between 9 and 11 higher than the solar photo- spheric abundance. This fact, together with the low statistical quality of the XMM-Newton spectra, completely accounts for the 3.5 keV feature and there is therefore no need to invoke a sterile neutrino interpretation of the observed line feature at 3.5 keV.

Hitomi does NOT find the 3.5 keV

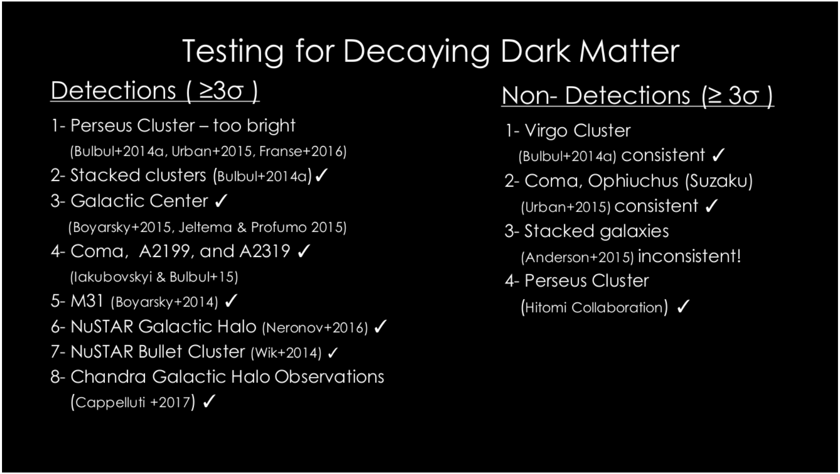
Hitomi malfunctioned just over a month after launch in February last year, but managed to collect enough data to **disprove a previously claimed sighting of the 3.5 keV line in the Perseus galaxy cluster.**

Draco Dwarf Only has Upper Limit for 3.5 keV Line

In spite of the fact that the Draco Dwarf (galaxy) $80 \pm 10 kpc$ away holds so much dark matter that its ratio of mass to luminocity is $440 M_{sun}/L_{sun}$ it was found that it has no 3.5 keV line with a 90 % confidence 20 times smaller than expected, if it were radiation simply from dark matter decay.

Any Hope for Rescuing a Connection to Dark Matter??

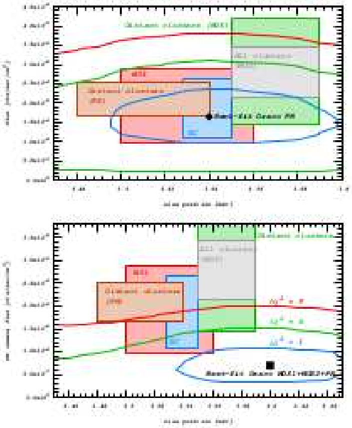
If there should be any hope for that the line 3.5 keV should come from dark matter it looks needed that it is **produced by some interaction** so that the line signal gets produced mostly from regions with bf lots of e.g. ordinary **matter**, that e.g. could throw some radiation on the dark matter (or perhaps interaction with dark matter itself).

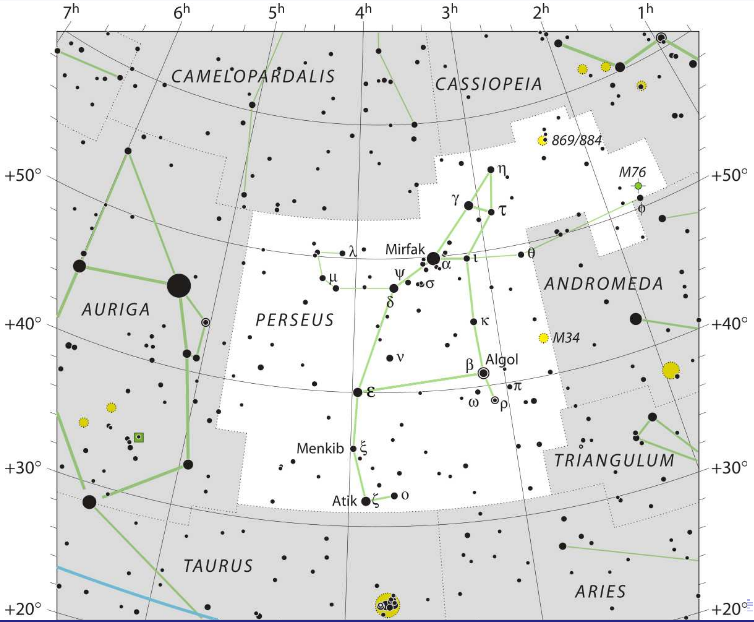

Testing for Decaying Dark Matter
Detections (≥3σ)
1- Perseus Cluster – too bright
(Bulbul+2014a, Urban+2015, Franse+2016)
2- Stacked clusters (Bulbul+2014a) ✓
3- Galactic Center ✓
(Boyarsky+2015, Jeltema & Profumo 2015)
4- Coma, A2199, and A2319 ✓
(Iakubovskyi & Bulbul+15)
5- M31 (Boyarsky+2014) ✓
6- NuSTAR Galactic Halo (Neronov+2016) ✓
7- NuSTAR Bullet Cluster (Wik+2014) ✓
8- Chandra Galactic Halo Observations
(Cappelluti +2017) ✓
Non- Detections (≥ 3σ)
1- Virgo Cluster
(Bulbul+2014a) consistent ✓
2- Coma, Ophiuchus (Suzaku)
(Urban+2015) consistent ✓
3- Stacked galaxies
(Anderson+2015) inconsistent!
4- Perseus Cluster
(Hitomi Collaboration) ✓

Analysis of Draco dSph

[1512.07217]

- The line is detected in the spectrum of Draco dSph with low (2σ) significance
- Line flux/position are consistent with previous observations
- There is a shift in position ($\sim 1\sigma$) between two XMM-Newton detectors (which happens for weak lines)
- The data is consistent with DM interpretation for lifetime $\tau > (7-9) \times 10^{27}$ sec
- Compared to [1512.01239] we do data processing differently and use a more sophisticated background model.



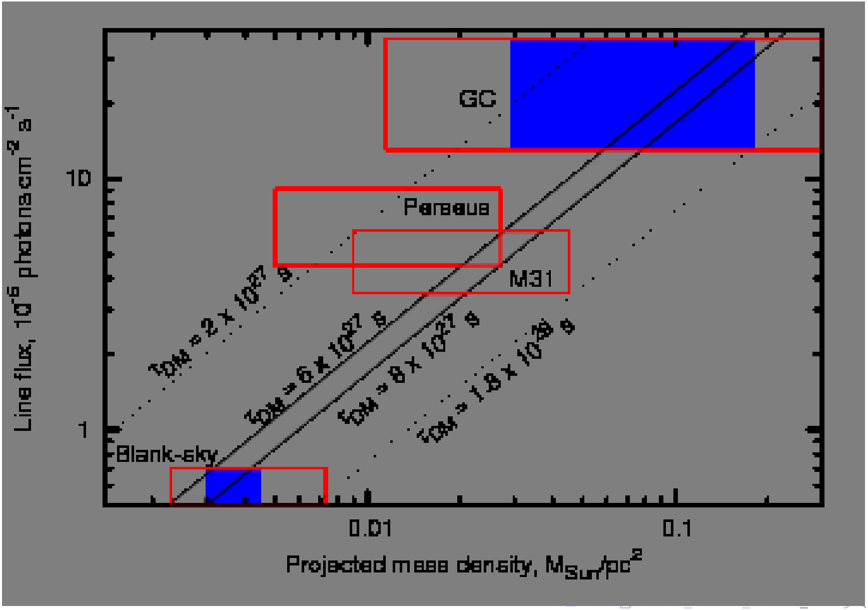

7h 6h 5h 4h 3h 2h 1h
+50° +40° +30° +20°
CAMELOPARDALIS
CASSIOPEIA
869/884
M76
η
γ
τ
ϕ
θ
λ
Mirfak
α
ι
μ
ψ
σ
ANDROMEDA
AURIGA
δ
PERSEUS
κ
M34
ν
β
Algol
π
ε
ω
ρ
Menkib
ξ
TRIANGULUM
Atik
ζ
o
TAURUS
ARIES

Searching for the 3.5 keV Line in the Deep Fields with Chandra: the 10 Ms observations Nico Cappelluti, Esra Bulbul, Adam Foster, Priyamvada Natarajan, Megan C. Urry, Mark W. Bautz, Francesca Civano, Eric Miller, Randall K. Smith

(Submitted on 27 Jan 2017)
In this paper we report a 3 detection of an emission line at 3.5 keV in the spectrum of the Cosmic X-ray Background using a total of 10 Ms Chandra observations towards the COSMOS Legacy and CDFS survey fields.

Deep Fields (Continued)

The line is detected with an intensity is $(8.8 \pm 2.9)10^{-7} phcm^2 s^1$. Based on our knowledge of Chandra, and the reported detection of the line by other instruments, we can rule out an instrumental origin for the line. We cannot though rule out a background fluctuation, in that case, with the current data, we place a 3σ upper limit at $10^{-6} ph\ cm^{-2} s^{-1}$. We discuss the interpretation of this observed line in terms of the iron line background, S XVI charge exchange, as well as arising from sterile neutrino decay. We note that our detection is consistent with previous measurements of this line toward the Galactic center, and can be modeled as the result of sterile neutrino decay from the Milky Way when the dark matter distribution is modeled with an NFW profile. In this event, we estimate a mass $m_s \sim 7.02$ keV and a mixing angle $sin^2(2\theta) = (0.69 \text{ to } 2.29) * 10^{-10}$. These derived values of the neutrino mass are in agreement with independent measurements


GC
Perseus
M31
Blank-sky
10
1
0.01
0.1
Line flux, 10^-6 photons cm^-2 s^-1
Projected mass density, M_Sun/pc^2

SEARCHING FOR THE 3.5 keV LINE IN THE STACKED SUZAKU OBSERVATIONS OF GALAXY CLUSTERS

Esra Bulbul, Maxim Markevitch, Adam Foster, Eric Miller, Mark Bautz, Mike Loewenstein, Scott W. Randall, and Randall K. Smith

Published 2016 October 26 The Astrophysical Journal, Volume 831, Number 1

 Abstract

We perform a detailed study of the stacked Suzaku observations of 47 galaxy clusters, spanning a redshift range of 0.010.45, to search for the unidentified 3.5 keV line. This sample provides an independent test for the previously detected line. We detect a 2σ-significant spectral feature at 3.5 keV in the spectrum of the

7.1 keV sterile neutrino constraints from X-ray observations of 33 clusters of galaxies with Chandra ACIS

F. Hofmann, J. S. Sanders, K. Nandra, N. Clerc and M. Gaspari
1 Max-Planck-Institut fr extraterrestrische Physik, Giessenbachstrae, 85748 Garching, Germany e-mail: fhofmann@mpe.mpg.de 2 Department of Astrophysical Sciences, Princeton University, Princeton, NJ 08544, USA 3 Einstein and Spitzer Fellow

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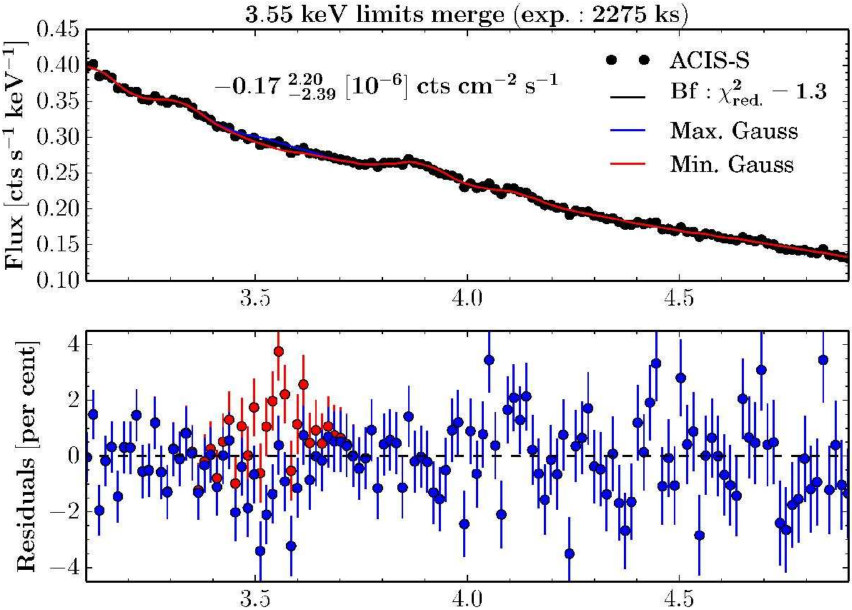
Abstract

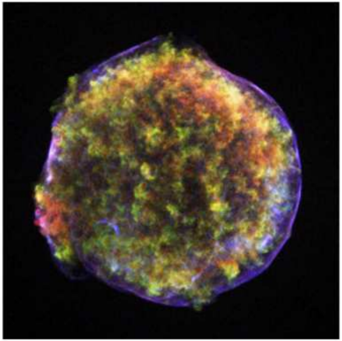
Context. Recently an unidentified emission line at 3.55 keV has been detected in X-ray spectra of clusters of galaxies. The line has been discussed as a possible decay signature of 7.1 keV sterile neutrinos, which have been proposed as a dark matter (DM) candidate.

Aims. We aim to put constraints on the proposed line emission in a large sample of Chandra-observed clusters and obtain limits on


3.55 keV limits merge (exp. : 2275 ks)
Flux [cts s^{-1} keV^{-1}]
$-0.17\,^{2.20}_{-2.39}$ [10^{-6}] cts cm^{-2} s^{-1}
ACIS-S
Bf : $\chi^2_{red.}$ − 1.3
Max. Gauss
Min. Gauss
Residuals [per cent]
3.5
4.0
4.5

Systematics?

Tycho Supernova Remnant



Credit: NASA/CXC/Rutgers/Warren, Hughes et al.

175 ksec XMM observations

Line at 3.55 keV detected:

- potassium with high abundance?
- systematics in line flux?
- *NOT dark matter*

Jeltema & Profumo 2015

Is Dark Matter the Source of a Mysterious X-ray Emission Line? April 01, 2016 The nature of dark matter is still unknown, but one potential candidate is a theoretical particle known as the sterile neutrino. In 2014, two independent groups of astronomers detected an unknown X-ray emission line around an energy of 3.5 keV in stacked X-ray spectra of galaxy clusters and in the centre of the Andromeda galaxy. The properties of this emission line are consistent with many of the expectations for the decay of sterile neutrino dark matter. However, if this hypothesis is correct, all massive objects in the Universe should exhibit this spectral feature. To test this intriguing possibility, scientists at MPA and the University of Michigan examined two large samples of galaxies, finding no evidence for the line in their stacked galaxy spectra. This strongly suggests that the mysterious 3.5 keV emission line does not originate from decaying dark matter. The nature of dark matter, and the origin of this emission line, both remain unknown.

For MOS, the flux in the 3.57 keV line was $4.0^{+0.8}_{0.8}(1.2) \times 10^{6} photonscm^{2}s^{1}$, where the errors are 68% (90%). For PN, at the best-fit energy of 3.51 keV, the line flux is $+1.0$ 6 3.9 $+0.6$ photons $cm^{2}s^{1}$. If we fix the line 1.0 (1.6) 10 energy from the MOS fit, for PN we obtain the flux $2.5 + 0.6 to 0.7$ 6 $(+1.0 photonscm^{2}s^{1}.1.1) \times 10$

...The best-fit flux at +3.7 5 3.57 keV was 5.2 +2.4 photons cm 2 s 1 . 1.5 (2.1) 10 This flux corresponds to a mixing angle of sin 2 (2) = +3.9 10 5.5 +2.6 . This angle not only is an outlier in our 1.6 (2.3) 10 measurements from the other samples but is also not co

A 3.55 keV Line from Exciting Dark Matter without a Hidden Sector Asher Berlin, Anthony DiFranzo, Dan Hooper

(Submitted on 14 Jan 2015)
Models in which dark matter particles can scatter into a slightly heavier state which promptly decays to the lighter state and a photon (known as eXciting Dark Matter, or XDM) have been shown to be capable of generating the 3.55 keV line observed from galaxy clusters, while suppressing the flux of such a line from smaller halos, including dwarf galaxies. In most of the XDM models discussed in the literature, this up-scattering is mediated by a new light particle, and dark matter annihilations proceed into pairs of this same light state. In these models, the dark matter and mediator effectively reside within a hidden sector, without sizable couplings to the Standard Model. In this paper, we explore a

Carlson Jeltena Profumo :

The clumped nature of this residual is difficult to reconcile with the much smoother distribution expected from dark matter as is the radial profile which has a much sharper gradient at the edge of the core than what expected from a decaying dark matter profile .

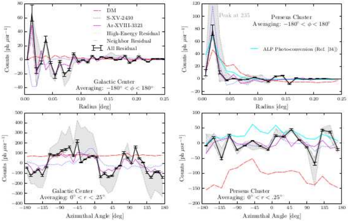


Figure 6. Radial and azimuthal profiles for the Galactic center (left panels) and for the Perseus cluster's (right panels) un-smoothed residual maps shown in Fig 5. The shaded regions bracket alternative continuum models along with the best fitting NFW template (red), S XV Line (light blue), and Ar XVIII line (magenta). Poisson error bars are shown for our 'All' model. Azimuthal profiles rotate clockwise from the line pointing from the center (Sgr A* in the GC) to positive longitudes. In the top-right panel, we also show the steepest radial profile expected from photo-conversion of axion-like-particles (solid blue), calculated using formulae in Ref. [37] and convolved with the relevant masks and instrument response.

azimuthal profile is also reasonably compatible, though much less so than for the profiles corresponding to elemental lines. However, here we have used an idealized model for the magnetic field structure which in reality will be much more complicated and could follow an azimuthal profile similar to that of emission lines. While the steepest ALP-conversion profile morphologically traces the cluster's core, the excess emission is much better fit by adding a continuum or low energy line template (after which there is no preference for ALPs). We discuss this aspect on more quantitative grounds in the next section.

Recently, Ref. [39] also calculated the morphology expected in the Milky Way's center where the signal is expected to roughly trace the projected free electron density (see also Ref. [40]). Based on the NE2001 model for the free electron distribution [41, 42], the expected signal is (i) highly elliptical with an axis ratio of nearly 4:1 elongated in the Galactic plane, and (ii) has a peak intensity offset from the center ≈ 20′ toward Galactic north. Neither of these features are remotely compatible with the observed excess. In

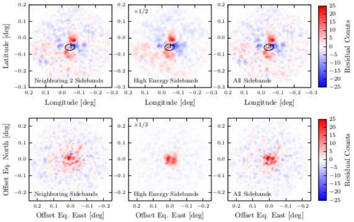


Figure 5. Comparisons between 3.45-3.6 keV residuals after subtracting the best fit continuum+isotropic templates for different models of the continuum near the Galactc Center (top row) and the Perseus cluster (bottom row). Black '+'s in the top row indicate Sgr A* while the shell of SNR Sgr A East is shown by the black ellipse [26]. Maps have been smoothed by a Gaussian kernel with $\sigma = 20''$. For the high-energy continuum model, the GC and Perseus cluster maps have been rescaled by a factor 1/2 and 1/3, respectively, in order to maintain visibility on a common scale.

satisfactory spatial morphology. These questions will be answered quantitatively in the following sections.

For Perseus, we also overlay the steepest of the radial profiles expected from photoconversion of axion-like-particles (ALPs) in Perseus' large scale magnetic field as calculated using Eqns. (3.1) and (3.3) of Ref. [37], with a free electron density n_e taken from Ref. [38], and using the NFW parameters specified in our subsec 2.6. The three dimensional profile for the axion signal is then proportional to $\rho(r) \times n_e(r)^{2\eta}$ and is always steeper than the decaying DM case for a radially decaying magnetic field, as is measured in Perseus. The case shown corresponds to the steepest magnetic field profile, $\eta = 1$, while smaller values of η lead to a significant flattening. The projected skymap was then convolved with the relevant masks.

The ALP scenario is significantly steeper than the decaying DM case due to the magnetic field falloff and it visually appears marginally compatible with the morphology of the residual emission. As $\eta \to 0$, this profile asymptotes to the decaying DM case. The

The Power in the Unidentified Line 3.5 keV

Object	Counts	$4\pi * dist^2$	Power	Per galaxy
Unit:	ph $s^{-1}cm^{-2}$	m^2	W	W
Galactic Center	2.2*10^{-5}	6*10^{41}	7*10^{25}	7*10^{25}
Perseus cluster	(6 to 7)10^{-6}	0.6*10^{50}	2*10^{29}	<2*10^{26}

$3.5keV = 3500 * 1.6 * 10^{-19} J = 6 * 10^{-16} J$

Typical Value for σ/m for Dark Matter ?

	σ/m	
Our model	10^{-12} to $^{-13} m^2/kg$	
Bound from Lux...	$10^{-13} m^2/kg$	
Atom	$10^6 m^2/kg$	(not good for dark matter!)

Any Hope for Florescence-type Dark Matter ? Perseus cl.:

Formula	$P_{3.5}$	$=$	"eff"	$\left(\frac{\sigma}{m}\right)$	ρ_{DM}	t_{sp}	P_{rad}
Our p.'s:	$10^{32}W$	$>$	0.2	$\frac{10^{-12}m^2}{kg}$	$\frac{5*10^{-28}kg}{m^3}$	$10^{16}s$	$10^{37}W$
Hope	$10^{31}W$	$=$	0.5	$\frac{10^{2}m^2}{kg}$	$\frac{10^{-26}kg}{m^3}$	$10^{17}s$	$10^{38}W$
Bounds	$10^{31}W$	;	<1	$\frac{<<10^{6}m^2}{kg}$	$\frac{10^{-26}kg}{m^3}$	$<10^{17}s$	$10^{38}W$
Other	$10^{31}W$	$>$	low	$\frac{<<10^{6}m^2}{kg}$	$\frac{10^{-26}kg}{m^3}$	$10^{17}s$	$10^{38}W$
Lux-big	$10^{31}W$	$>$	low	$\frac{10^{-13}m^2}{kg}$	$\frac{10^{-26}kg}{m^3}$	$10^{17}s$	$10^{38}W$

The radiation in the line 3.5 keV from Perseus cluster $P_{3.5}$.
The radiation of say cosmic ray hope to provide the energy P_{rad}.
The effectivity of a piece of darkmatter to convert the energy "eff".
Density of dark matter in the region where this convertion goes on ρ_{DM}.
The ratio of the cross-section to the mass of the dark matter $\frac{\sigma}{m}$.

New Law of Nature: Multiple Point Principle.

There are several phases of vacuum(having relativity principles) **and they all have very very small energy densities**(like the astronomically determined one for our present vacuum).

This principle is analogous to the having a specific temperature - in a microcanonical ensemble - when there are say both water and ice present.

The Analogy:

The analogy between the triplepoint in the vapor- water-ice combination at $(T, p) =$ "$tripelpoint$" $= (273.16K, 0.6117kPa)$ and "Multipel Point Principle" is:

- The intensive quantities, temperature T and pressure p are analogous to the kobling constants and the parameters, such as g_t , $\alpha = \frac{e^2}{4\pi}$,etc.
- The extensive quantities such as energy of the content of the bottle E, the amount (measured in mol e.g.) of water-molekyles N, the volume V are analogous to some integrals, which could include
  - space-time-volume = lifetime of universe multiplied by its volume
  - E.g. an integral over the square of the Higgs-field = the average value of the Higgsfield squared and multiplied with the just mentioned spacetime volume.
  - But it could be something similar but based on other fields.

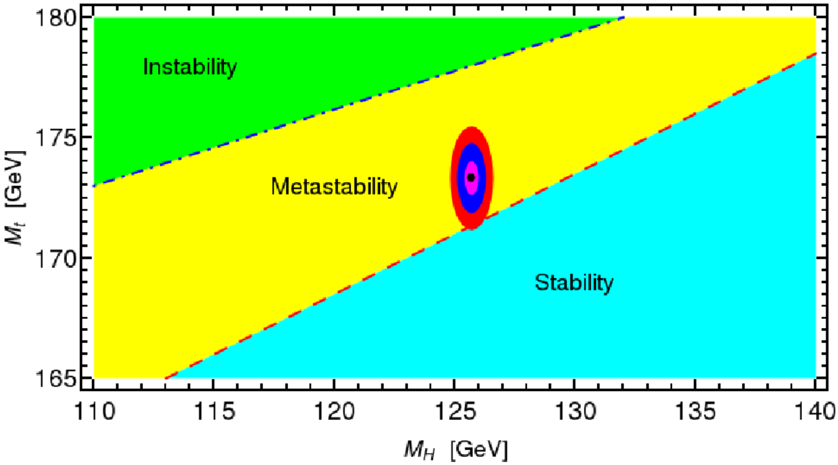
Må fortælle om at:
Vi forudsagde Higgs-Massen

Vi brugte, hvad vi kalder **Multiple Point Principle** (med Don Bennett,...), hvilket betyder, at vi antager, at koblings-konstanterne - som f. eks. top-Yukawa-koblingen relaterede til top-quark massen - og andre parametre i felt-teorien (lad os sige Standard-Modellen) - sådan som Higgsens massekvadrat - **er finindstillede** til at have just sådanne værdier at der sikres: **Flere Vacua med Samme Energi- tæthed** eller tilnærmelsesvis sådan.
Det foreslog vi (C.D.Froggatt og jeg under brug af Bennetts og min MPP) og dermed **FORudsagde** vi - længe før Higgsen blev fundet - **massen af Higgsen**.
I et papir (med Froggatt and Takanishi, Meta-MPP) 121.8 GeV $\pm$ 10 GeV; jeg er blevet malet med Mogens Lykketoft med 135 GeV $\pm$ 10 GeV(bag Lykketofts hoved). Higgs nyligt bekræftet med massen $125.09 \pm 0.21(stat.) \pm 0.11$ (syst.) GeV$/c^2$.

kunstmaler lars andersen http://www.23.dk/skak.htm

Lars Andersen

Historiemaler Portrætmaler Provokunstner Om Lars Andersen CV/omtale Kontakt


180
175
170
165
M_t [GeV]
110
115
120
125
130
135
140
M_H [GeV]
Instability
Metastability
Stability

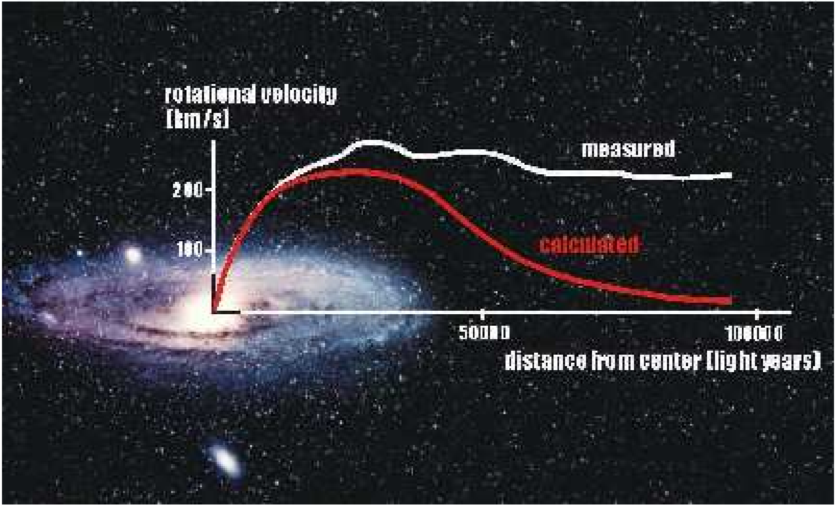
Three Agreeing Fits of the Bound State Mass:

In this way we got even two calculations for the bound state mass - using in addition crude estimation -

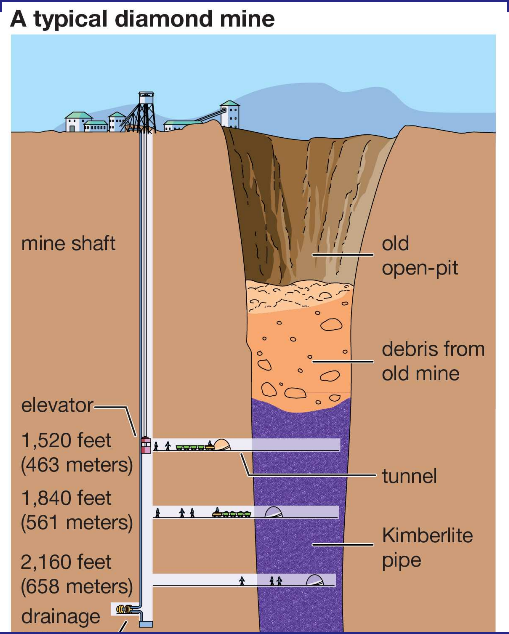
$$
\begin{aligned}
m_F(\text{from “high field vacuum”}) &\approx 850 GeV \pm 30\% \text{with} \sim 2 && (13)\\
m_F(\text{from “high field vacuum”}) &\approx 710 GeV \pm 30\% \text{without} \sim 2 && (14)\\
m_F(\text{“condensate vac.”}) &\approx 692 GeV \pm 40\% && (15)\\
m_F(\text{“bag estimate”}) &\approx 5 m_t = 865 GeV (veryuncertain) && (16)
\end{aligned}
$$

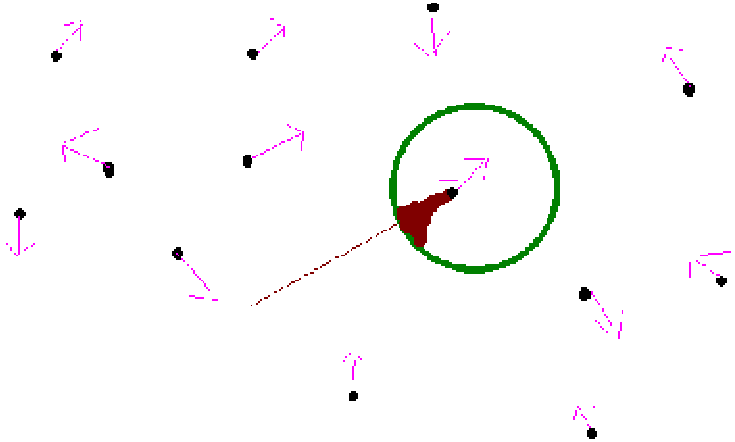
Det Kolde Mørke/sorte stof ude i rummet mellem stjernerne

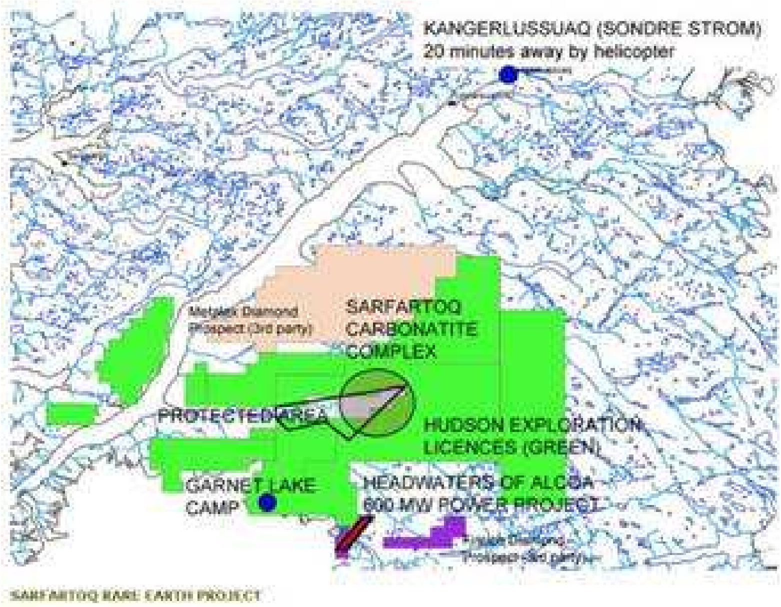
Mine kollegaer mener, at det sorte stof, som er nødvendigt at have mellem stjernerne, for at disse kan løbe så hurtigt rundt om galaksen, som de måles at løbe, ikke kan fås, hvis Standard Modellen er den endelige teori. Man har brug for mindst en anden slags partikel, som kan udgøre det sorte stof! Kun Colin Froggatt og jeg har en teori, efter hvilken, det er muligt - om end lidt kompliceret - at få det sorte stof ud af Standard Modellen alene! Lad mig dog tilstå at *vi* dog har brug for et særligt finindstillingss-princip, som sørger for at koblings-konstanterne i Standard Modellen tager værdier, som sørger for at der bliver flere vacua/tomrumstilstande med samme energitæthed. Koblingerne har altså meget specielle værdier, eller rettere relationer mellem deres værdier.

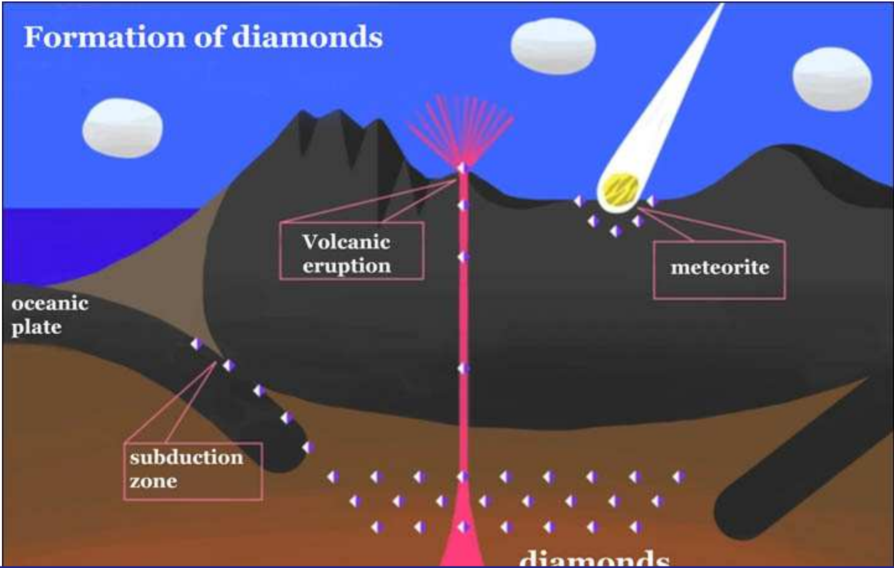

rotational velocity
[km/s]
200
100
measured
calculated
50000
100000
distance from center [light years]

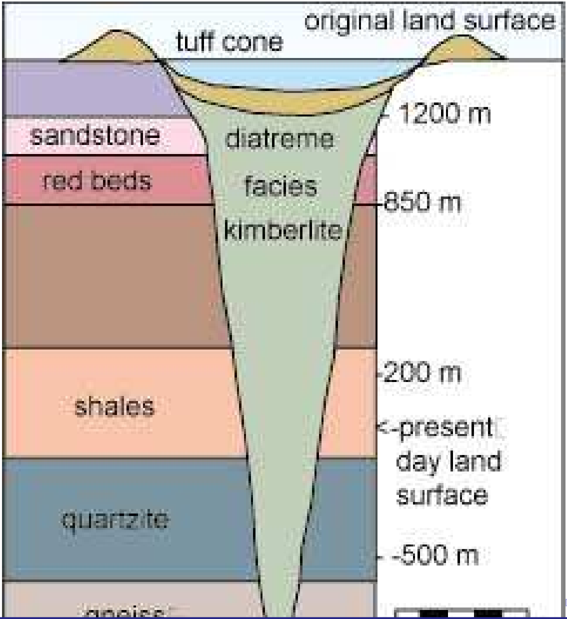
Fritz Zwicky, Opdager af Mørkt Stof


A typical diamond mine
mine shaft
old
open-pit
debris from
old mine
elevator
1,520 feet
(463 meters)
tunnel
1,840 feet
(561 meters)
Kimberlite
pipe
2,160 feet
(658 meters)
drainage

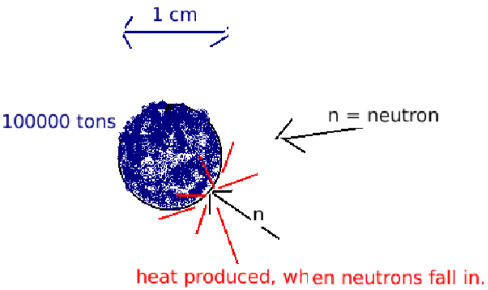



KANGERLUSSUAQ (SONDRE STROM)
20 minutes away by helicopter
SARFARTOQ
CARBONATITE
COMPLEX
PROTECTED AREA
HUDSON EXPLORATION
LICENCES (GREEN)
GARNET LAKE
CAMP
HEADWATERS OF ALCOA
600 MW POWER PROJECT
SARFARTOQ RARE EARTH PROJECT

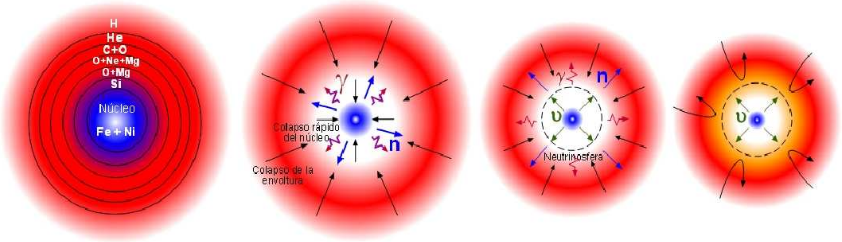

Formation of diamonds
Volcanic eruption
meteorite
oceanic plate
subduction zone


original land surface
tuff cone
1200 m
sandstone
diatreme
facies
kimberlite
red beds
850 m
200 m
shales
<-present
day land
surface
quartzite
-500 m

Pearl produce about 10 MeV energy per neutron caught

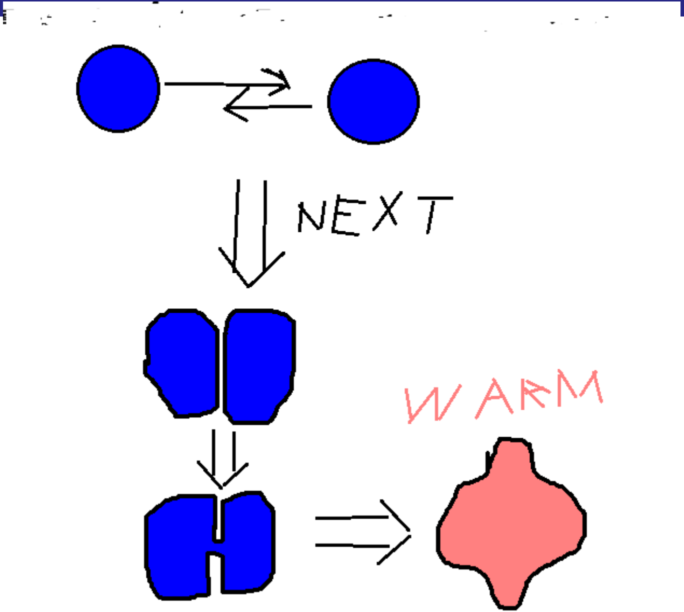


Supernova development



Collissions of Our Pearls as Source of Energy for e.g. the 3.5 keV line.

Somewhat analogous to annihilation there can in our pearl model be released a lot of energy when the dark matter particles meet/collide:
We expect them to unite and then the surface / the **skin** (can) **contract** and thereby **release energy**, in fact a lot, about the Einstein energy of a tenth of the mass of the pearl.


NEXT
WARM

Self Interaction of Our Pearls

We fitted our model parameters to match that the rate of the earth being hit by one of our dark-matter pearls was about once every 100 years or 200 years.
Now the ratio of the radius of our pearl $0.6cm$ to the radius of the earth is

$$\frac{r_{pearl}}{r_{earth}} = \frac{0.6cm}{6000km} \quad (17)$$

$$= 10^{-9} \quad (18)$$

$$\text{giving} \quad (19)$$

$$\frac{area_{pearl}}{area_{earth}} = \left(10^{-9}\right)^2 = 10^{-18} \quad (20)$$

Estimating Rate of 3.5-line from Pearl Colissions

Becase the area for hitting another pearl is 10^{-18} times that for th earth, a pearl -a selected one, we think of - will hit another pearl every:

$$\text{“hitting interval”} = 100 years * 10^{18} = 10^{20} years = 3 * 10^{27} s. \quad (21)$$

When a colission between two our pearls occurs an energy of the order of the energy in **buble surface** is released, and likely a large fraction of that becomes **excitons** and thereby gives the **3.5 keV radiation**.

Ratio of Surface to Bulk Energy

The surface tension of our pearls was supposed to be of the order of magnitude as given by the weak interaction physics, say given in terms of W-masses by dimensional arguments. By the unification after colission of two pearls the total surface area for the uniting bubles get reduced by of order unity. Taking crudely the weak interaction length scale to be 10^{-18} m $= 10^{-16}$ cm and the energy to be $100 GeV = 100 * 10^9 * 1.6 * 10^{-19} J \sim 10^{-8} J$ the energy in the tension of the pearl surface becomes

$$\text{"surface energy"} = \left(10^{16}\right)^2 * 10^{-8} J \quad (22)$$

$$= 10^{24} J \quad (23)$$

$$\sim 10^{24}/10^{17} kg = 10^7 kg \quad (24)$$

This is about $\frac{1}{10}$ of the mass of the whole pearl 10^8 kg.

Simulated Life- time $10^{28}s$.

Since about one tenth of the Einstein energy of the pearl sits in the surface tension and gets released by colission of two balls, the life time of a simulating sterile neutrino model particle would be 10 times the “hitting time” $=10^{27}s$, i.e $10^{28}s$ simulated life time. agreeing fine with the earlier fits!

The Energy Comes in Bunches of $\sim 10^7$ kg $*c^2$

With our story that the dark matter consists of pearls with a surface energy getting released when two of them collide and unite to one we have got the dark matter pearls function as **bombs** releasing 10^5 **times more energy than the one from just colliding.**

By the pure collission one only gets the energy of the event in Tunguska, which lead down the trees in a region of order of 70 km, but with the unification of droplets we get with the enormous surface tension about 100000 times as much energy release !

The temperature may raise to $\sim$ 50 MeV and corresponding γ-rays would be emitted, a candidate for a gamma-ray burst?

That the radiation from the dark matter in this way comes in **pulses**, may be **experimentally accessible**.

Homolumo-gap-effect

What we here call homolumo-gap-effect is the effect of increasing or producing the gap between the highest occupied (ho) single electron state (=molecular orbit=mo) and the lowest unoccupied (lu) single electron state (mo) originating from the elctrons **acting back** on say the positions of the ions in the material considered. One shall have in mind that increasing the homolumo-gap lowers the energy of the system of single electrons, and thus the ions are **driven** in the direction by which they can **increase this gap**.

Crude Ideas about Homolumo gap Effect in Very Dense Mater (inside our pearls)

Expectations for very highly compressed matter:

- We expect that the kinetic energy of the electrons will dominate over the potential energy. (The inverse lattice momentum scales inversely with lattice constant a,i.e. as $1/a$, and thus the kinetic energy with the inverse square **kinetic energy** $\propto 1/a^2$, while the **potential energy** $\propto \mathbf{1/a}$.
- Still if the material is a glas say, a homolumo gap effect could be there, close to the fermisurface.
- Shall argue for the homolumo gap to be crudely of the order $p_{fermi}\alpha^2$, where α is the fine structure constant and p_{fermi} is some characteristic momentum for the electrons, the fermi momentum say

Statistical Simple Calculation of Homolumo-gap in Matrix Model

I. Andric, L. Jonke, D. Jurman, and myself calculated the homolumo gap in a relativly simple matrix model, although it has **both quenched random and quantum mechanical adjustable contributions to the single fermion hamiltonian.**

Our - Andric, Jonke, Jurman, HBN - Matrix Model for Homolumo-gap Effect

Ivan Andri et al, Int. J. Mod. Phys. A 32, 1750046 (2017) [16 pages] https://doi.org/10.1142/S0217751X17500464

Adjusting the ω's of Our Matrix Model to Realistic Materials

There is one little problem with our general calculation in the work Ivan Andri et al, Int. J. Mod. Phys. A 32, 1750046 (2017) [16 pages] https://doi.org/10.1142/S0217751X17500464, namely that for a macroscopic piece of material the number of single eletron states N say in a specified set of bands will grow with the volume V proportionally and thus the number of matrix elements will grow like $N^2 \propto V^2$; but now there cannot reasonable be a number of degrees of freedom of the material growing like this square. Any number of degrees of freedom in the material should grow only as $N \propto V$ and NOT like the square!

How to Approximate Functions of Some Variables by Harmonic Oscillators

In the work by Andric et al. we calculated as if the matrix elements of the single fermion Hamiltonian were independent harmonic oscillators - each matric element $(M - M_0)_{ij}$ was an independent degree of freedom variable $q_I^{(A)}$, where then of course the index I run over $N^{(A)} = N^2$ values, where N is the order of the matrix M_{ij} for the single fermion (say electrons in case of ordinary matterials) states relevant (we imagine the very highest energy electron states twrown out as an ultraviolet cut off, say).
But now these $N^{(A)}$ dynamical variables are all described in terms of the "fundamental"/true variables of the say crystal ions, of which there are only $N^{(F)}$.

Approximate Description of Only $N^{(F)}$ True Variables as a Larger Number $N^{(A)} >> N^{(F)}$ of Formal Variables

We want to **approximate statistically** a system of $N^{(F)}$ hamonic oscillators with Hamiltonian

$$H^{(F)} = \sum_n \left(\frac{1}{2} p_n^{(F)\,2} + \frac{1}{2}\omega^2 q_n^{(F)\,2} \right) \quad (25)$$

$$\left[q_m^{(F)}, p_n^{(F)} \right] = i\hbar^{(F)} \delta_{nm} \quad (26)$$

by a system of $N^{(A)} >> N(F)$ harmonic oscillators, with variables $\left(q_l^{(A)}, p_l^{(A)} \right)$ that are in reality just functions - say linear functions - of the set of $N^{(F)}$ variables, as if this "formal system" of $N^{(A)}$ variables $q_l^{(A)}$ formed an indepent set of $N^{(A)}$ harmonic oscillators.

Identifying a Couple of Sets of Harmonic Oscillators

We want to approximate the "fundamental":

$$H^{(F)} = \sum_{n}^{N^{(F)}} \left(\frac{1}{2} p_n^{(F)\,2} + \frac{1}{2}\omega^2 q_n^{(F)\,2} \right) \quad (27)$$

$$\left[q_m^{(F)}, p_n^{(F)} \right] = i\hbar^{(F)} \delta_{nm} \quad (28)$$

by the "formal approximation"

$$H^{(A)} = \sum_{l}^{N^{(A)}} \left(\frac{1}{2} p_l^{(A)\,2} + \frac{1}{2}\omega^2 q_l^{(A)\,2} \right) \quad (29)$$

$$\left[q_k^{(A)}, p_l^{(A)} \right] = i\hbar^{(A)} \delta_{kl} \quad (30)$$

where we have relations of the form

$$q_l^{(A)} = \sum^{N^{(F)}} B_{ln}^{(q)} q_n^{(F)} \quad (31)$$

Our Relation between Two Systems of Degrees of Freedom of Different Numbers (Continued)

We have two systems of d.o.f. $\left(q_n^{(F)}, p_n^{(F)}\right)$ and $\left(q_l^{(A)}, p_l^{(A)}\right)$ which we want to treat as harmonic oscillators connected by relations of the form

$$q_l^{(A)} = \sum_n^{N^{(F)}} B_{ln}^{(q)} q_n^{(F)} \tag{33}$$

$$p_l^{(A)} = \sum_n^{N^{(F)}} B_{ln}^{(p)} p_n^{(F)} \tag{34}$$

where the non-diagonal matrices $B_{ln}^{(q)}$ and $B_{ln}^{(p)}$ are transition matrices between the two diffent systems of oscillators; they will be treated only statistically as being for our purpose random.

Our Relation between Two Systems of Degrees of Freedom of Different Numbers (Continued)

If we simply played the game, that our two sets of degrees of freedom each had only one single mass for all the d.o.f. in the set, so that

$$p_l^{(A)} = m^{(A)}\dot{q}_l^{(A)} \quad (35)$$

$$p_l^{(F)} = m^{(F)}\dot{q}_l^{(F)}, \quad (36)$$

we would obtain the relation

$$B_{ln}^{(p)} = \frac{m^{(A)}}{m^{(F)}} B_{ln}^{(q)} \quad (37)$$

But if wants the kinetic term form simply $\frac{1}{2}\sum_{l=1}^{N^{(A)}} p_l^{(A)\,2}$ for the "formal" set of systems, say the matrix elements, and $\frac{1}{2}\sum_{n=1}^{N^{(F)}} p_n^{(F)\,2}$ for the "fundamental" set, we must take $m^{(A)} = m^{(F)} = 1$.

Relations between the ω-Parameters

That the two systems of sets of harmonic oscillator related by

$$q_l^{(A)} = \sum_n^{N^{(F)}} B_{ln}^{(q)} q_n^{(F)} \tag{38}$$

$$p_l^{(A)} = \sum_n^{N^{(F)}} B_{ln}^{(p)} p_n^{(F)} \tag{39}$$

shall represent the same physics, we take to at least imply, that they have the same total kinetic and the same total potential energies.

Identifying Potential and Kinetic Energies for the Two Systems:

$$\frac{1}{2}\sum_{l=1}^{N^{(A)}} p_l^{(A)\,2} = \frac{1}{2}\sum_{n=1}^{N^{(F)}} p_n^{(F)\,2} \quad (40)$$

$$\frac{1}{2}\omega^{(A)\,2}\sum_{l=1}^{N^{(A)}} q_l^{(A)\,2} = \frac{1}{2}\omega^{(F)\,2}\sum_{n=1}^{N^{(F)}} q_n^{(F)\,2}, \text{which implies} \quad (41)$$

$$\sum_{l=1}^{N^{(A)}} B_{ln}^{(p)} B_{lm}^{(p)} = \delta_{nm}\text{and} \quad (42)$$

$$\omega^{(A)\,2}\sum_{l=1}^{N^{(A)}} B_{ln}^{(q)} B_{lm}^{(q)} = \omega^{(f)\,2}\delta_{nm} \quad (43)$$

We get a Normalized B_{ln}

Taken this we obtain especially that $\sum_{l=1}^{N^{(A)}} B_{ln}^{(p)} B_{lm}^{(p)}$ is zero for $n \neq m$, while it for all cases of $n = m$ (but fixed) has the same value, so that we can call it $B = \sum_{l=1}^{N^{(A)}} B_{ln}^{(p)} B_{ln}^{(p)}$(no summation over n). Actually we find from identical kinetic energies that B=1.

Relations to Approximately Identify Two Systems with Different Numbers of Degrees of Freedom.

Using the definition $B = \sum_{l=1}^{N^{(A)}} B_{ln}^{(p)} B_{ln}^{(p)}$(no summation over n) we get:

$$\begin{aligned} \text{From same kinetic energies:} B &= 1 && (44) \\ \text{From same potential energies:} \omega^{(A)\,2} B &= \omega^{(F)\,2} && (45) \end{aligned}$$

or simply the ω's must be the same.

How are the Commutators Connected?

The commutators for a $q_l^{(a)}$ and a $p_k^{(A)}$ is evaluated as

$$\left[q_l^{(A)}, p_k^{(A)}\right] = \sum_{n,m=1}^{N^{(F)}} B_{ln}^{(q)} B_{km}^{(p)} \approx \quad (46)$$

$$\approx \frac{BN^{(F)}}{N^{(A)}}, \quad (47)$$

which is very small if $N^{(F)} << N^{(A)}$!

$$\hbar^{(A)} = \hbar^{(F)} * \frac{N^{(F)}}{N^{(A)}}. \quad (48)$$

Effective Classical Approximation for Homolumo-gap-effect.

The result

$$\hbar^{(A)} = \hbar^{(F)} * \frac{N^{(F)}}{N^{(A)}}. \tag{49}$$

is very welcome/useful for justifying the calculational technology in our Homolumo gap paper with Andric, Jonke Jurman and HBN, because we effectively in order to come through the calculation have to use what corresponds to ignoring the quantum fluctuations and so using a classical approximation. In this article we take all matrix elements in a somehow chopped off matrix single particle Hamiltonian for the electron/fermion as independent Harmonic oscillator variables.

Our Homolumo-gap Paper uses Too Many Variables, Thus goes to Classical

But that is far too many variables in a genuine macroscopic piece of matter, which should have only a number of bosonic d.o.f. going up with increasing the size of the piece of matter only as proportional to the volume (to the first power, NOT to the second!)

Conclusion

- Our “old” model, in which dark matter consists of cm-big pearls with masses of the order of 100 thausend ton to half a million ton was suggested to be able to provide the “unidentified” **X-ray line of 3.5 keV** in fact by:
- Providing the line as a result of **excititons** (= a pair of an electron and a hole) annihilating, the homolumo-gap should then be essentially 3.5 keV.
- The distribution of the 3.5 keV signal over the sky did not fit exactly the distribution of dark matter, but rather is more **concentrated around the centers** of big galaxies or galaxy clusters.This suggests that the 3.5keV-radiation does not simply come equally strongly from all dark matter!
- For instance a production of the 3.5 keV radiation in connection with collision(e.g. annihilation) of dark matter with itself would be more favoured as the source

Other Achievements of Our Dark Matter Model

In addition to the wellfitting of the 3.5 keV-line, we claim a good fitting when we identify our pearl with the object that fell in Tunguska in 1908 and made the trees fell in an 70 km extended region and produced huge "fire" on the sky...:

- The **rate** of there falling one on earth about **once every 100 years** fit well with the surface tension being of the order given - by dimensional arguments - from the weak interaction scale$\sim$ **100GeV**.
- And with it producing **Kimberlite Pipes**, of which one found $\sim$ 6500 on the earth. (You find them on old cratoins, where you have the oldest geological layers.)

Multiple Point Principle among other saying: Inside pearl and Outside Pearl Phases have Same Energy Density, if no matter

This new law of Nature - a fine tuning model - has its own successes:

- We - Froggatt and me - PREdicted the Higgs mass to 135 GeV $\pm$ 10 GeV long before the Higgs was found experimentally.
- It "solves" the hierarchy problem in the sense that it says **Let us fine tune! Make a finetuning theory** and then an exponentially low Higgs or weak scale comes out relative to say the Planck scale.

Conclusion onSuccesses of the Multiple Point Principle(continued)

- We could get three independent estimates for the mass of the bound state of 6 top + 6 anti top, which we expect, and which fill the vacuum inside the dark matter, and they all turned out order of magnitudewise to be 750 GeV.