

New detector to search for the Dark Matter, slightly differently

Based on my recent paper:
arXiv:1304.0833v3 [astro-ph.IM] 9 Jun 2013

J. Va'vra, SLAC

New detector to search for the Dark Matter, slightly differently



**Requires a discussion of physics
topic, which is not the main stream in
the field of the Dark Matter search**

Abstract:

Existing or soon to be approved Dark Matter experiments are well designed for heavy WIMP masses larger than $6-7 \text{ GeV}/c^2$. They are not so well designed for light Dark Matter particle masses approaching $\sim 1 \text{ GeV}/c^2$.

We will discuss two Dark Matter detectors with the smallest possible detection-reach equivalent to either a single electron or a single photon of a few eV energy.

We will also discuss a possibility that such candidate is so called "small hydrogen atom", a long-forgotten subject in physics, but hotly discussed in 1920's and 1930's. We will discuss a theoretical hint why such objects could exist, point out to searches in the astrophysics, and efforts to find such atoms in the lab in the past and future.

“There very many fragile ideas in the past, which were viewed with scepticism initially.”

- Solar neutrino flux measured by Ray Davis.
- Albert Einstein's theory of relativity never got the Nobel prize.
- Martin Perl spent ~30 years trying to answer I. Rabbi's question if there is anything else after electron & muon. This led to a discovery of the τ -meson.
- ...

Two separate detection issues requiring completely different experimental efforts

- **Determine what the Dark Matter actually is.**
- **Design a detector, sensitive to it and determine yearly modulation, even though we do not know yet what it is.**
- **The Dark Matter direction.**

What is the density of the Dark Matter ?

R. Catena and P. Ullio, arXiv:1111.3556v1 [astro-ph.CO] 15 Nov 2011 **based on high-resolution numerical simulations:**

Dark matter density near Earth:

$$\rho \sim 0.3 \text{ GeV/cm}^3$$

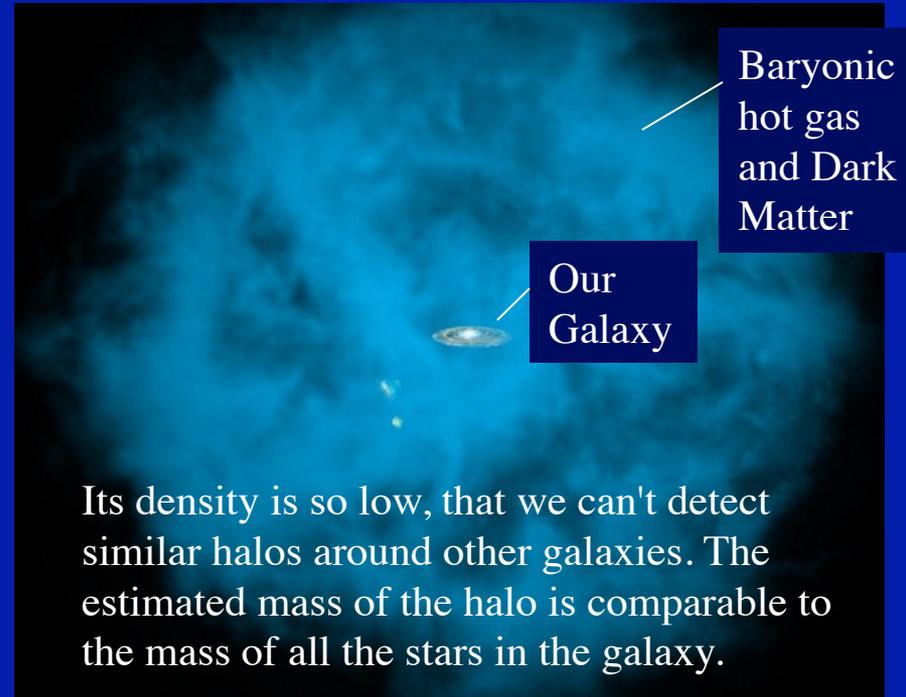
Therefore one would expect:

$$\sim 300 m_{\text{Dark Matter}} / \text{liter}$$

where

$$m_{\text{Dark Matter}} \sim 1 \text{ GeV}/c^2$$

Chandra: Our Galaxy with its baryonic hot gas halo:
(I am assuming that the Dark Matter may have a similar shape)



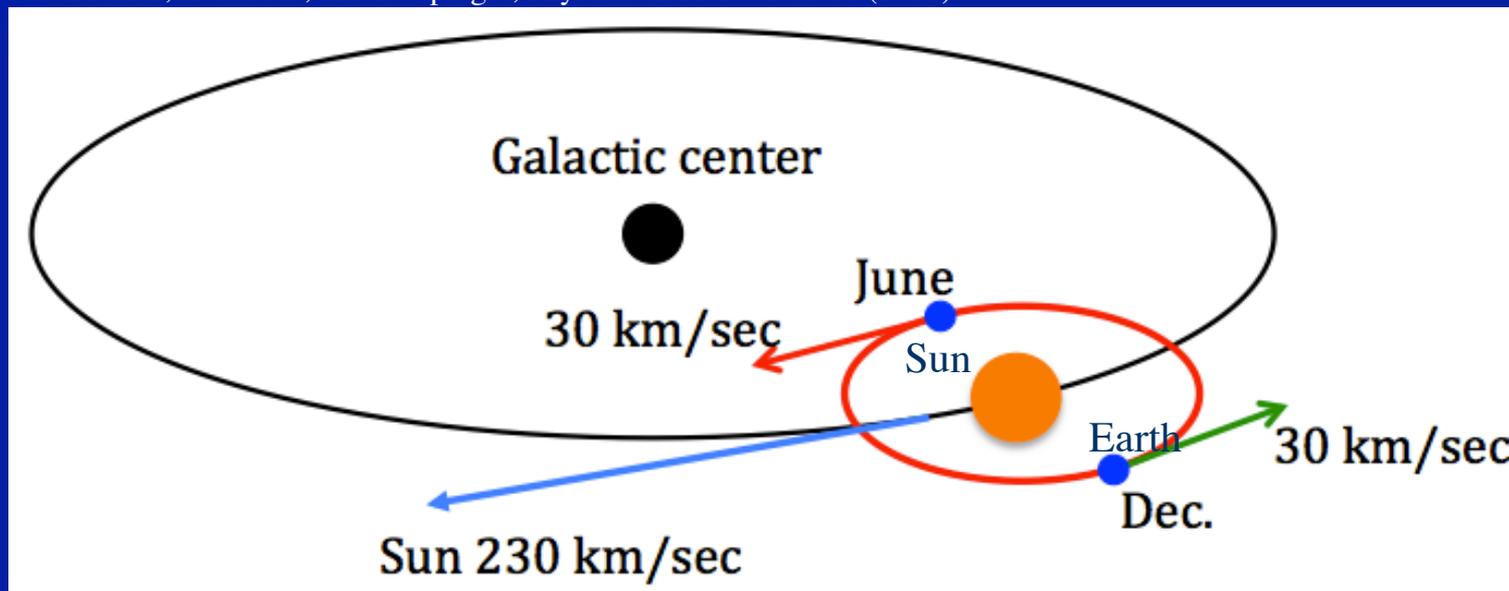
Its density is so low, that we can't detect similar halos around other galaxies. The estimated mass of the halo is comparable to the mass of all the stars in the galaxy.

They estimate this distribution from the X-ray attenuation.

- **If the Dark Matter mass is this light, there is lots of it.**
- **This fog seems to be stationary relative to the Galaxy motion.**

Relative velocity Δv of Dark Matter relative to the Earth

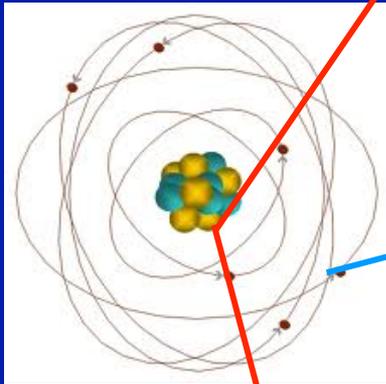
A. Drukier, K. Freese, and D. Spergel, Phys.Rev.D33:3495-3508 (1986):



- **We assume that the SUN's velocity relative to the Dark Matter is $v \sim 230 \text{ km/sec}$:**
 - $v = 230 \text{ km/sec}$ corresponds to $\beta = (v/c) \sim 0.00077$, i.e. $\sim 4 \mu\text{sec/meter}$.
 - $\Delta v = 30 \text{ km/sec}$ corresponds to $\Delta\beta = \Delta(v/c) \sim 0.0001$. There are tails though !
 - **The modulation in the kinetic energy of Dark Matter mass ΔE_{kin} for this Δv is:**
 - a) $\Delta E_{\text{kin}} \sim 5 \text{ keV}$ ($m_{\text{WIMP}} \sim 1 \text{ GeV}/c^2$),
 - b) $\sim 40 \text{ keV}$ ($m_{\text{WIMP}} \sim 8 \text{ GeV}/c^2$),
 - c) $\sim 400 \text{ keV}$ ($m_{\text{WIMP}} \sim 80 \text{ GeV}/c^2$)
- **However, one must realize that since the Dark Matter direction was not yet determined, things may end up to be different at the end.**

Two types of possible processes

WIMP interacting with nucleus:

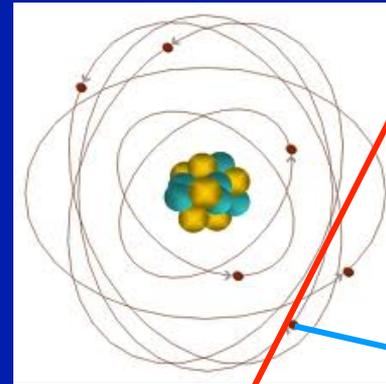


Interacts with a nucleus, shakes it and produces either a single electron or single photon release, and ion can then ionize nearby atoms

WIMP

In this case, the cross-section is very small. One wants to be in a deep mine, and build the detector from a low radioactivity materials.

Small hydrogen or other WIMP interacting with atomic shell-electrons:



Interacts electromagnetically with atomic shell via a **dipole moment**, and produces either single electron or single photon

p ••• e⁻

Small hydrogen

In this case, the cross-section is relatively large. One wants to be relatively close to Earth surface !!!

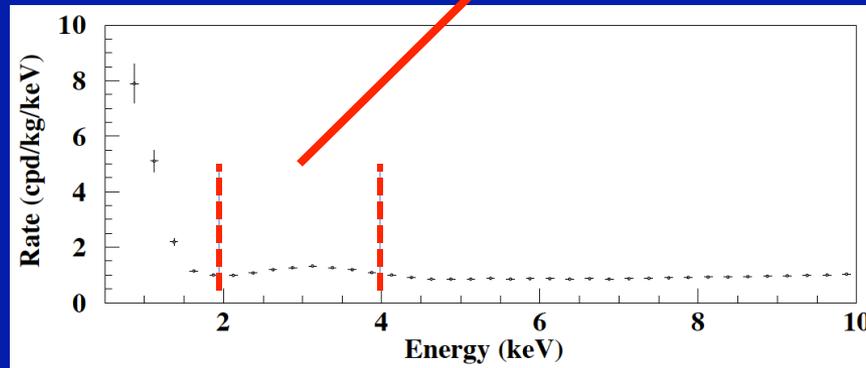
- In both cases one deals with a very small signal, and experiments are difficult.

Experiments assuming a nuclear recoil

Most assume that the WIMP mass is heavy ($\sim 80 \text{ GeV}/c^2$), recently people started to consider a moderately heavy mass ($6\text{-}10 \text{ GeV}/c^2$), but practically nobody assumes a mass close to $\sim 1 \text{ GeV}/c^2$.

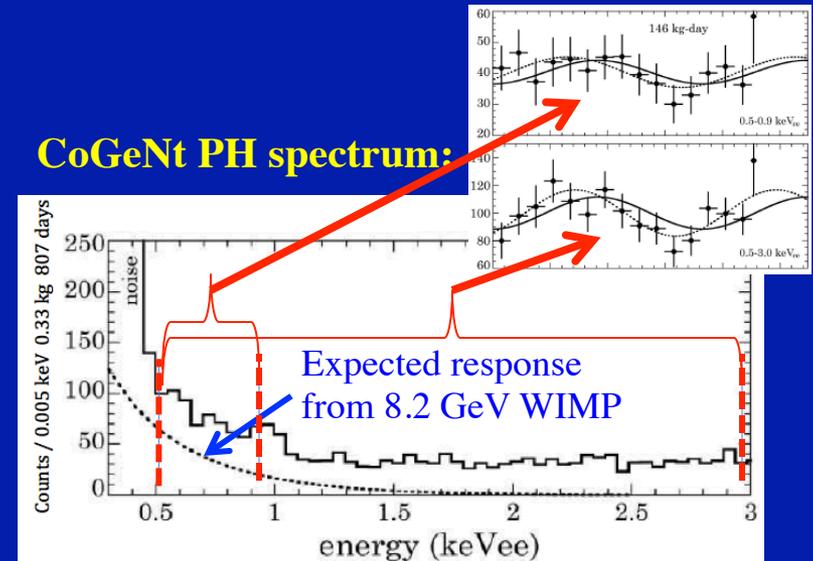
Only two experiments see a clear yearly modulation

DAMA PH spectrum:



R. Bernabei et al., arXiv:0804.2741 [astro-ph].

CoGeNT PH spectrum:



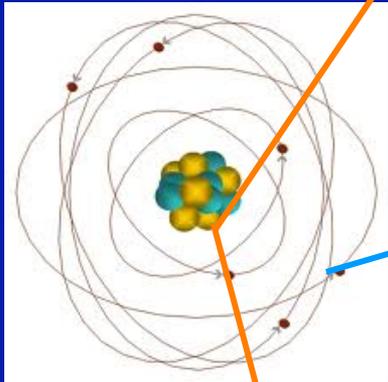
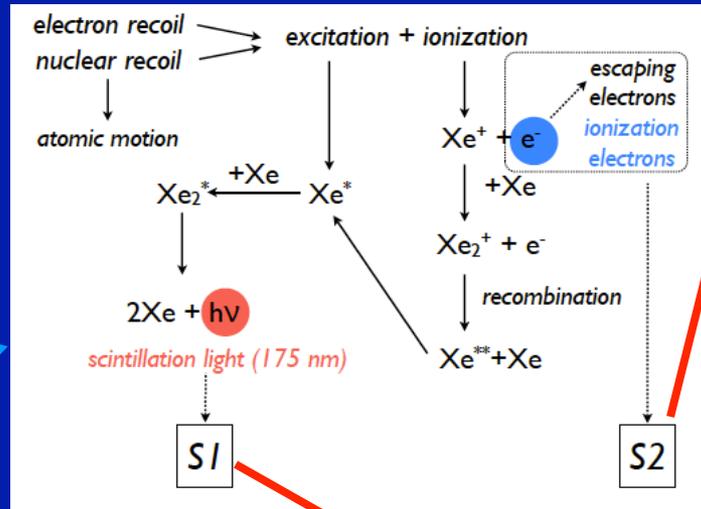
C.E. Aalseth et al., arXiv:1208.5737v2 [astro-ph].

- **Important point: DAMA and CoGeNT cannot tell that if their signal comes from a nuclear recoil or from an interaction with atomic-shell electrons !**
- **Assuming that it comes from a nuclear recoil: One can make CoGeNT and DAMA consistent if the WIMP mass is $\sim 7 \text{ GeV}/c^2$ with $\sigma \sim 2 \times 10^{-40} \text{ cm}^2$.** (D. Hooper et al., arXiv:1007.1005v3 [hep-ph] 27 Oct 2010)

Heavy Dark Matter: search using a noble liquid dual-phase TPC

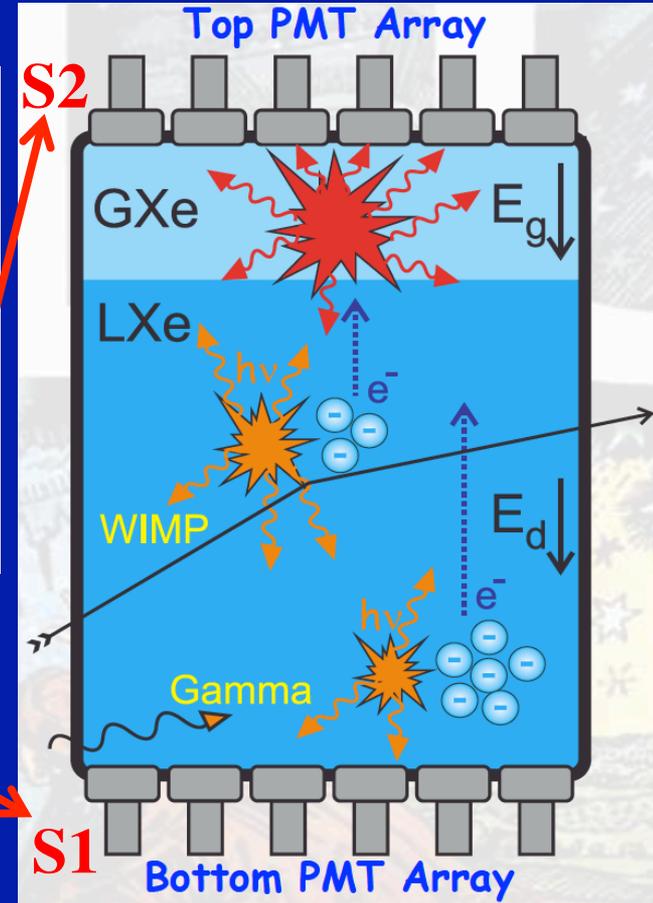
(if the Dark Matter mass is heavy, this is indeed the right detector choice)

Physics processes in LXe:



○ Heavy WIMP

WIMP interacts with a nucleus, shakes it, produces an ionization of its atom and photon excitation; the ion can subsequently ionize nearby atoms.

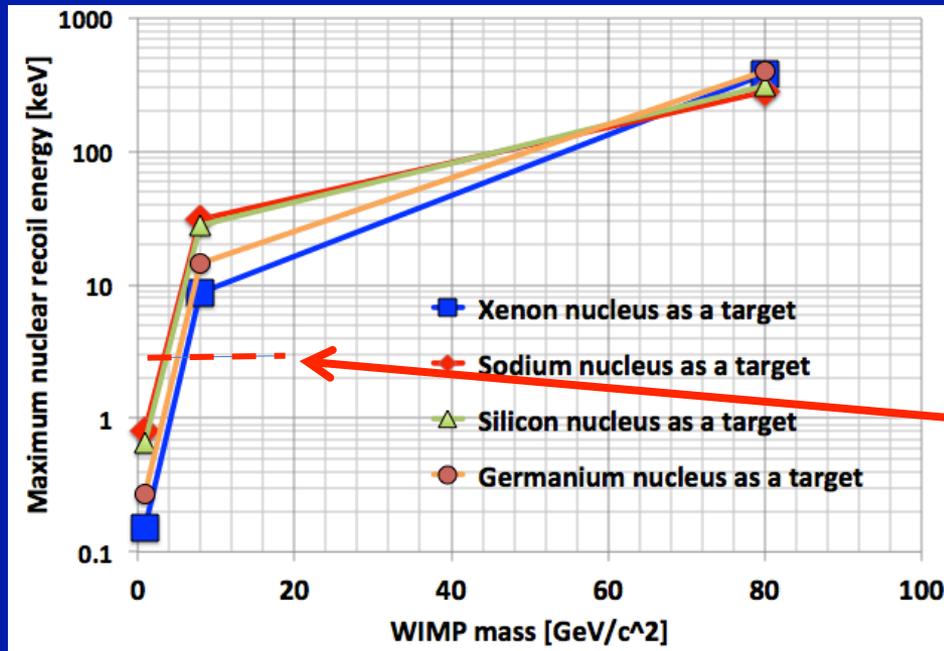


$$S2/S1_{\text{gamma}} \gg S2/S1_{\text{WIMP}}$$

- This idea is used in Xenon-10, Xenon-100, Xenon-1T, LUX, LZ, Darkside, ArDM, etc.

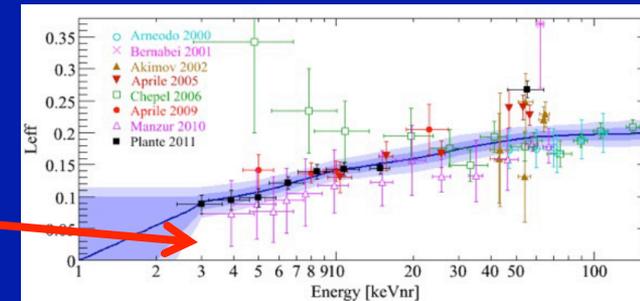
Na or Xe nuclear targets cannot see a Dark Matter mass close to $\sim 1 \text{ GeV}/c^2$ and $\Delta E_{\text{kin}} \sim 5 \text{ keV}$ energy

Assume that WIMP has a velocity modulation of $\Delta 30 \text{ km/sec}$ ($\Delta\beta \sim 0.0001$):



Xenon tests with neutrons:
The smallest recoil energy reached in LXe test was $\sim 3 \text{ keVnr}$.

$$L_{\text{eff}} \sim S2/S1$$

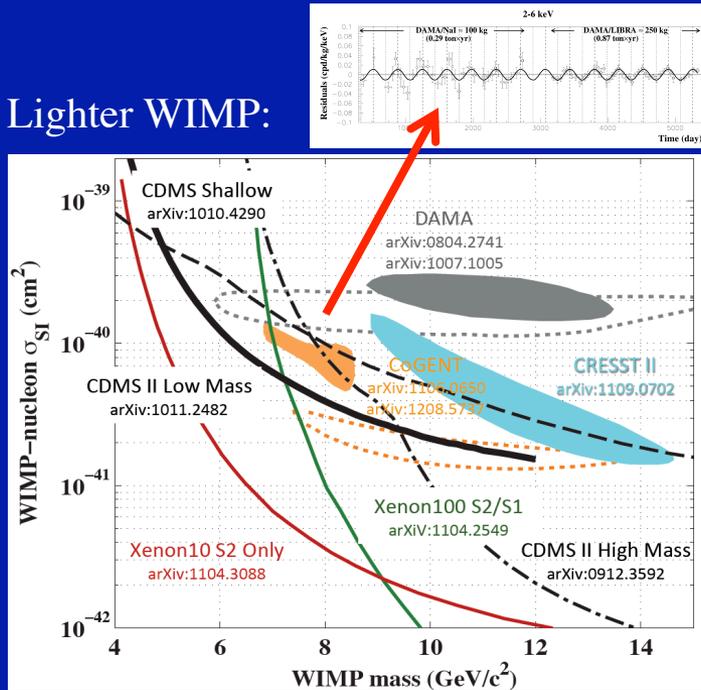


G. Plante et al., Phys. Rev. C 84, 045805 (2011).

- If the Dark Matter particle mass approaches a mass of $\sim 1 \text{ GeV}/c^2$, DAMA, CoGeNt, Xenon-100 cannot see it. However, all these experiments, should see a modulation of the signal if the WIMP mass is $7-8 \text{ GeV}/c^2$, and if it recoiling from the nucleus.

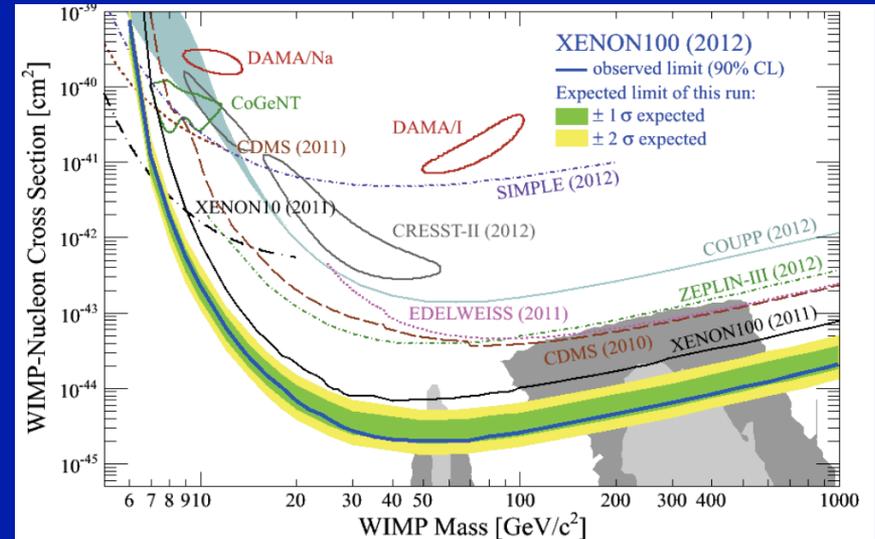
Present reach of major Dark Matter experiments

Lighter WIMP:



M. Pyle, Joint CPAD and Instrumentation Frontier Community Meeting, Argonne lab, Jan. 10, 2013.

Heavy WIMP:

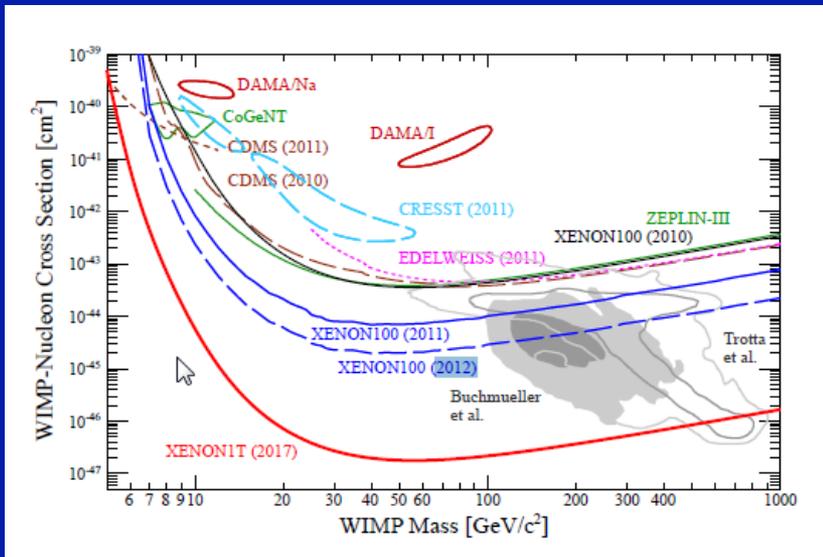


E. Aprile, "Talk at DarkAttack conference", Ascona, July 18, 2012.

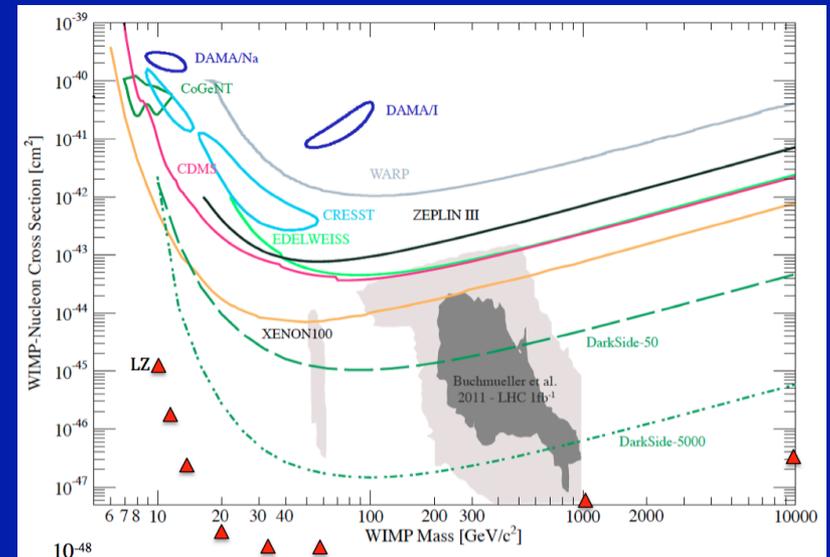
- **Xenon-100 does not see any modulation signal. Why are they missing it ? Is it because their analysis demands a nuclear recoil ?**
- **One can also ask a question if DAMA sees interactions with atomic shell electrons rather than the nuclear recoil ? DAMA analysis cannot tell if their signal comes from a nuclear recoil. CDMS and Xenon-100 can.**

Future Dark Matter experiments Xenon 1T, Darkside and LZ will push even lower limit

Heavy WIMP:

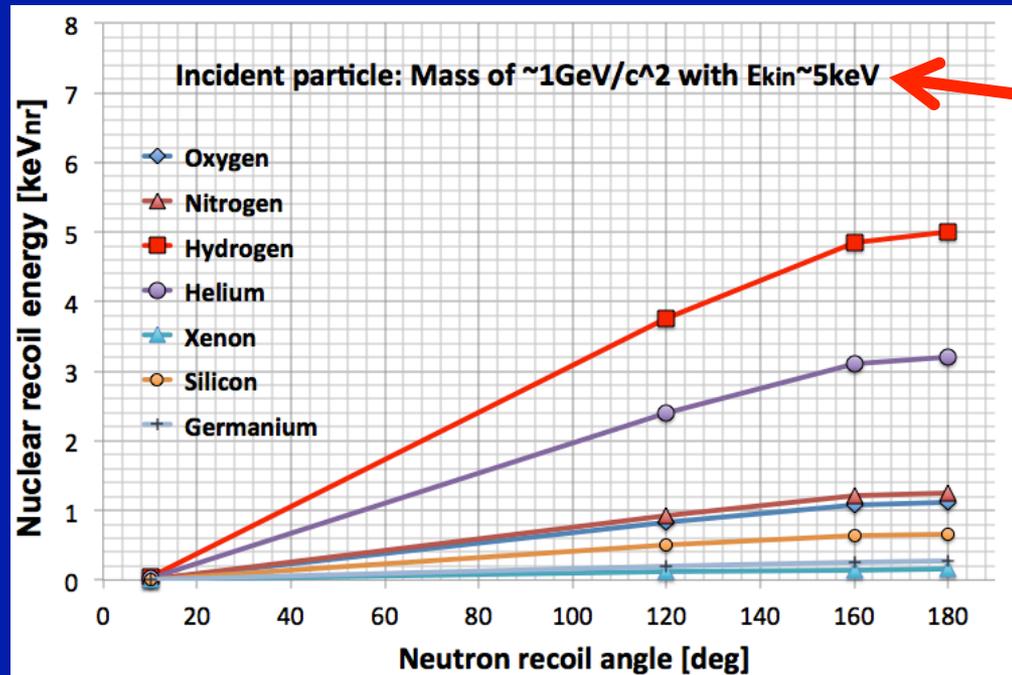


Heavy WIMP:



- Xenon-1T will reach a limit of $\sim 10^{-47}$ cm⁻², LZ is proposing to reach a level of $\sim 10^{-48}$ cm⁻², Darkside will reach $\sim 10^{-47}$ cm⁻².
- Clearly, to push forward with these two experiments, one has to ignore DAMA and CoGeNT results.

Nuclear recoil energy for a Dark Matter mass close to $\sim 1 \text{ GeV}/c^2$ and $\Delta E_{\text{kin}} \sim 5 \text{ keV}$ kinetic energy



But remember there are tails in the velocity distribution

- If the Dark Matter particle's weight approaches to a mass of a nucleon, one needs to change the target nuclei to have any appreciable recoil energy. One has to consider hydrogen, or helium. Using noble liquids would be a wrong choice, if we require a nuclear recoil.
- CDMS sees 3 events in lighter Si-detectors (none in heavier Germanium !!!), which may indicate a lighter mass WIMP (?). Not yet enough events to see a modulation. So, they cannot exclude a mass of $\sim 1 \text{ GeV}/c^2$ yet.

Experiments assuming interaction with atomic shell-electrons

An example of such Dark Matter could be “the small hydrogen”, an atom hotly debated in 1920’s and 1930’s. There are other strange atoms, where a charged Dark Matter is imbedded in atoms, but we will not discuss it here.

What is the “small hydrogen” ?

History lesson

(A. Pais, Inward bound, page 397, Clarendon press - Oxford, 1986)

- **Rutherford** suggested in 1920 that electron-proton could be bound in tight state.
- At that point neither the **Schroedinger** equation (1926) or **Dirac** equation (1928) was not known to Rutherford. Schroedinger was 33 in 1920.
- Rutherford asked his team, including **Chadwick**, to search for the small hydrogen atom.
- After Chadwick's discovery of the neutron in 1932 there was a lot of discussions whether it is an elementary particle or a hydrogen-like atom formed from electron and proton.
- **Heisenberg** (31 in 1932, when he got a Nobel prize) was among those who argued that Chadwick's particle is a small hydrogen atom.
- At the end the **Pauli**'s argument won: the neutron spin $1/2$ follows the Fermi-Dirac statistics and this decided that the neutron is indeed an elementary particle.
- **This is a well-established fact and it is not discussed here.**

However

- **However, it is a separate question to see if the Schroedinger or Dirac equations or QED would actually allow a solution corresponding to a small hydrogen, which would be a completely separate entity to the neutron discovered by Chadwick.**
- One reason that the story of small hydrogen atom was forgotten is that nobody has observed it in the lab. As we will see it is very hard.
- The story of the small hydrogen was “re-erected” in 1992-93 by **J. Maly and J. Va’vra**.
- I gave our papers to **J. Bjorken** and **S. Brodsky** a few years ago. **S. Brodsky** pointed out that one should not use the 1920 quantum mechanics to solve the problem of small hydrogen, as electron is very fast. However, he pointed out that **Spence & Vary** used QED to solve e^-p and e^-e^+ systems and found possible bound states. I will have something to say a little bit later on.
- **Only experiment can provide a hint what is the right path.**

The “1920 quantum mechanics” of the small hydrogen atom.

J. Maly and J. Va’vra, Fusion technology, 24, 307, (1993), and 27, 59, (1995).

The **relativistic Schrodinger equation** for a hydrogen-like atom (see Schiff):

$$(-\hbar^2 c^2 \nabla^2 + m^2 c^4) u(\vec{r}) = [E - e\phi(r)]^2 u(\vec{r}) \quad (1)$$

This equation can be solved exactly for the **Coulomb potential** $e\phi(r) = -\frac{Ze^2}{r}$ by separating variables: $u(r, \theta, \phi) = R(r) Y_{\ell m}(\theta, \phi)$, which yields the radial equation:

$$\frac{1}{\rho^2} \frac{d}{d\rho} \left(\rho^2 \frac{dR}{d\rho} \right) + \left[\frac{\lambda}{\rho} - \frac{1}{4} - \frac{\ell(\ell+1) - \gamma^2}{\rho^2} \right] R = 0 \quad (2)$$

where: $\rho = \alpha r$, $\gamma = \frac{Ze^2}{\hbar c}$, $\alpha^2 = \frac{4(m^2 c^4 - E^2)}{\hbar^2 c^2}$, $\lambda = \frac{2E\gamma}{\hbar c \alpha}$

The solution can be obtained by the following substitution:

$$R(\rho) = F(\rho) e^{-\frac{1}{2}\rho}, \text{ where: } F(\rho) = \rho^s (a_0 + a_1 \rho + a_2 \rho^2 + \dots) = \rho^s L(\rho)$$

This leads to differential:

$$\rho^2 \frac{d^2 L(\rho)}{d\rho^2} + \rho [2(s+1) - \rho] \frac{dL(\rho)}{d\rho} + [\rho(\lambda - s - 1) + s(s+1) - \ell(\ell+1) + \gamma^2] L(\rho) = 0 \quad (3)$$

Putting explicitly the expression for $L(\rho)$ into equation (3), we obtain:

$$[s(s+1) - \ell(\ell+1) + \gamma^2] a_0 \rho^0 + f_1(s, \ell, \gamma) \rho^1 + f_2(s, \ell, \gamma) \rho^2 + \dots = 0$$

Equating each term in front of each ρ^n with zero, we obtain from the very first term ρ^0 :

$$s(s+1) + \gamma^2 - \ell(\ell+1) = 0 \quad (4)$$

which is a quadratic equation with the following solution:

$$s = -\frac{1}{2} \pm \left[\left(\ell + \frac{1}{2} \right)^2 - \gamma^2 \right]^{\frac{1}{2}} = s(\pm), \quad (5)$$

Two solutions with two infinities:

1) for $s = s(+) > 0$: $F(\rho) \rightarrow \infty$ as $\rho \rightarrow \infty$

To keep $F(\rho)$ finite, one has to set: $\lambda = \text{integer} + s + 1$

2) for $s = s(-) < 0$: $F(\rho) \rightarrow \infty$ as $\rho \rightarrow 0$

Maly & Va’vra: To keep $F(\rho)$ finite, one has to use the Smith-Johnson or Nix potentials or other potentials at small ρ , the Coulomb potential at large ρ , and match two solutions at some boundary.

The difference between the normal and small hydrogen atom is just a sign.

J. Maly and J. Va'vra, Fusion technology, 24, 307, (1993), and 27, 59, (1995).

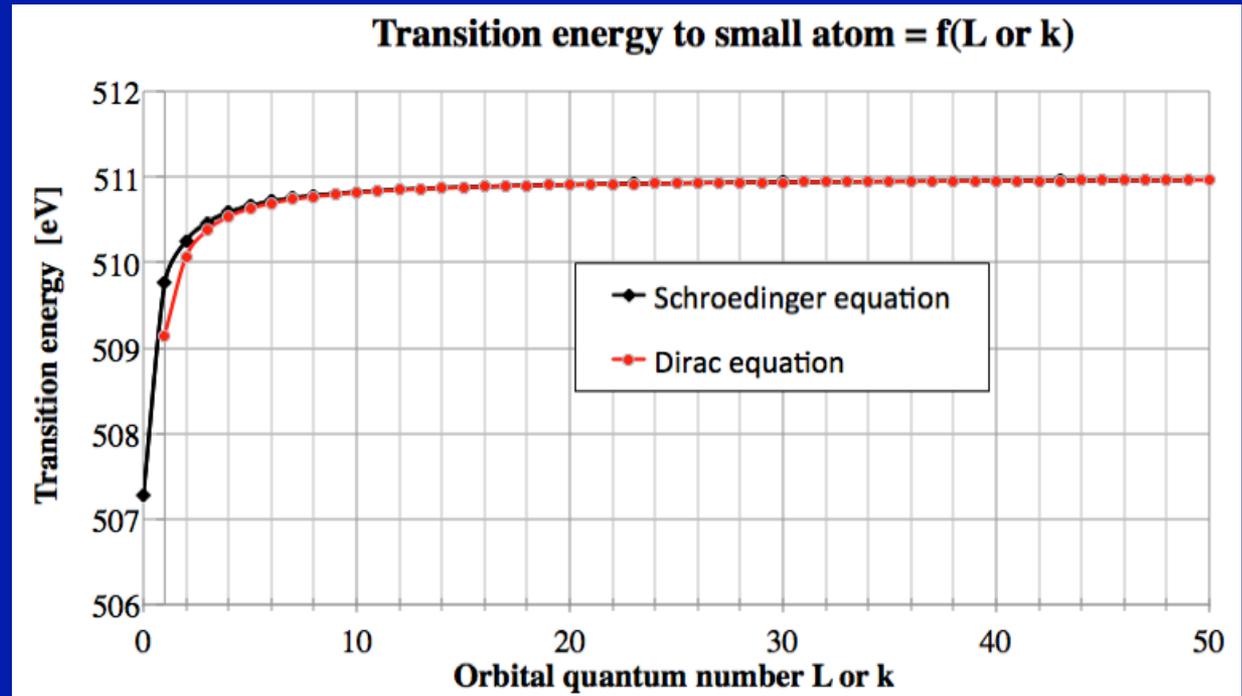
- **$s(+)$ solutions correspond to normal hydrogen.**
 - **$s(-)$ solutions correspond to a small hydrogen.**
-
- $s(-)$ solutions were neglected in Quantum Mechanics. Quoting Schiff exactly: "The boundary condition that $F(\rho)$ be finite at requires that we choose positive s ".
 - Energy levels corresponding to $s(-)$ solutions are also called "DDL levels" for "Deep Dirac Levels".

A direct consequence of allowing s(-) solutions are new energy levels.

J. Va'vra, arXiv:1304.0833v3 [astro-ph.IM] 9 Jun 2013

Table 1. Calculated energy levels and transitions between two levels, k and k+1, of the "small hydrogen atom" in the infrared wavelength region. Table also shows the nearest absorption lines measured in the solar spectra.

Orbital quantum number k	Calculated energy level E(k) [keV]	Calculated transition E(k+1) - E(k) [nm]
1	509.135	1.330
2	510.067	3.990
3	510.378	7.981
4	510.533	13.301
5	510.626	19.952
6	510.688	27.933
7	510.733	37.244
8	510.766	47.885
9	510.792	59.856
10	510.813	73.157
11	510.830	87.789
12	510.844	103.751
13	510.856	121.042
14	510.866	139.664
15	510.875	159.616
16	510.883	180.899
17	510.889	203.511
18	510.895	227.453
19	510.901	252.726
20	510.906	279.329
21	510.910	307.262
22	510.914	336.525
23	510.918	367.118
24	510.921	399.041
25	510.924	432.294
26	510.927	466.878
27	510.930	502.792
28	510.932	540.035
29	510.935	578.609
30	510.937	618.513
35	510.946	885.871
40	510.952	1145.248
50	510.962	1765.761
73	510.973	3592.703
102	510.981	6987.195
192	510.989	24644.641
326	510.993	70896.811
491	510.995	160660.437
1130	510.997	855827.765



Sommerfeld's formula:

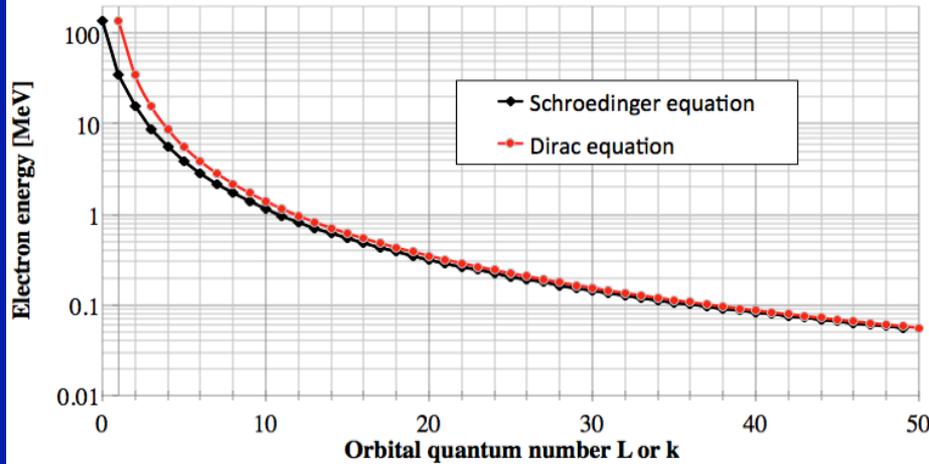
$$E = mc^2 \left(1 + \frac{\gamma^2}{\lambda^2}\right)^{-\frac{1}{2}}$$

- **For orbital quantum number k > 10, the transition energy is close to 511 keV.**

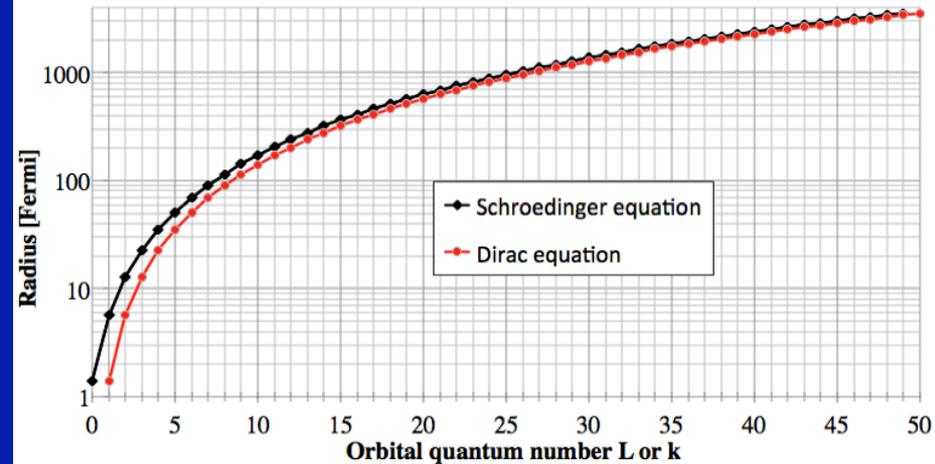
Some other dependencies.

J. Va'vra, arXiv:1304.0833v3 [astro-ph.IM] 9 Jun 2013

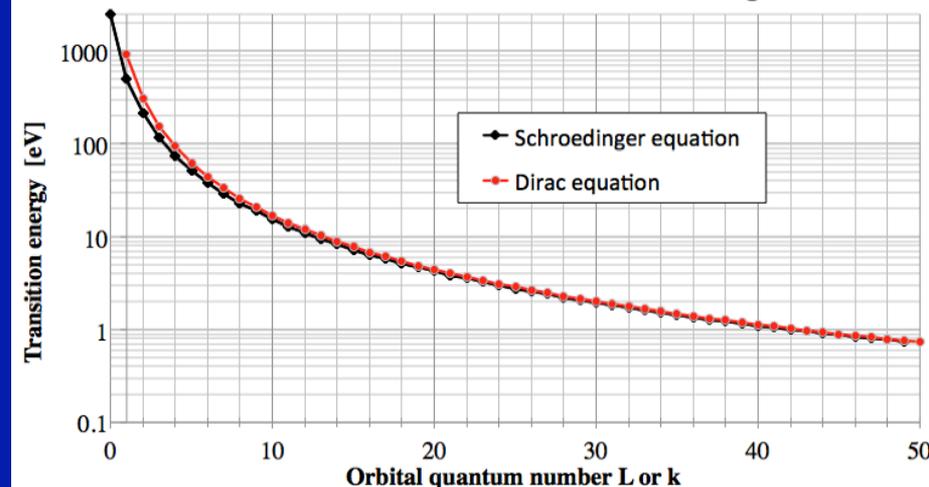
Electron energy on orbit of small atom = $f(L \text{ or } k)$



Size of small hydrogen atom = $f(L \text{ or } k)$



" $E(L) - E(L+1)$ " or " $E(k) - E(k+1)$ " transition energies = $f(L)$



- Use Bohr model and DeBroglie models to estimate these dependencies.
- The small hydrogen atom is quite large for larger orbital excitations.
- The small hydrogen can communicate via rather long wavelengths for large orbital excitations.

Is the QED calculation also finding bound states in e^+e^- , e^-p systems ?

(J.R. Spence and J. Vary, "Electron-proton resonances at low energy from a relativistic two-body wave equation", Physics Letters B 271 (1991) 27-31)

- Their QED calculation includes a spin-spin interaction, retardation and Coulomb contributions, and it assumes that the proton is point-like.
- The paper claims that the **retardation term is important for a bound state to occur**. It comes about because electrons are moving very fast around a proton in such a bound state, and potentials travel with a finite velocity of light. The classical 1920 Quantum theory does not deal with this issue at all.
- **I asked James Vary, professor of physics at Iowa State University, about the status of his QED calculation recently:**

Hi Jerry:

4.17.2013

Thank you for your email and your interesting paper.

We worked hard to find any error in our calculations and were not able to do so.

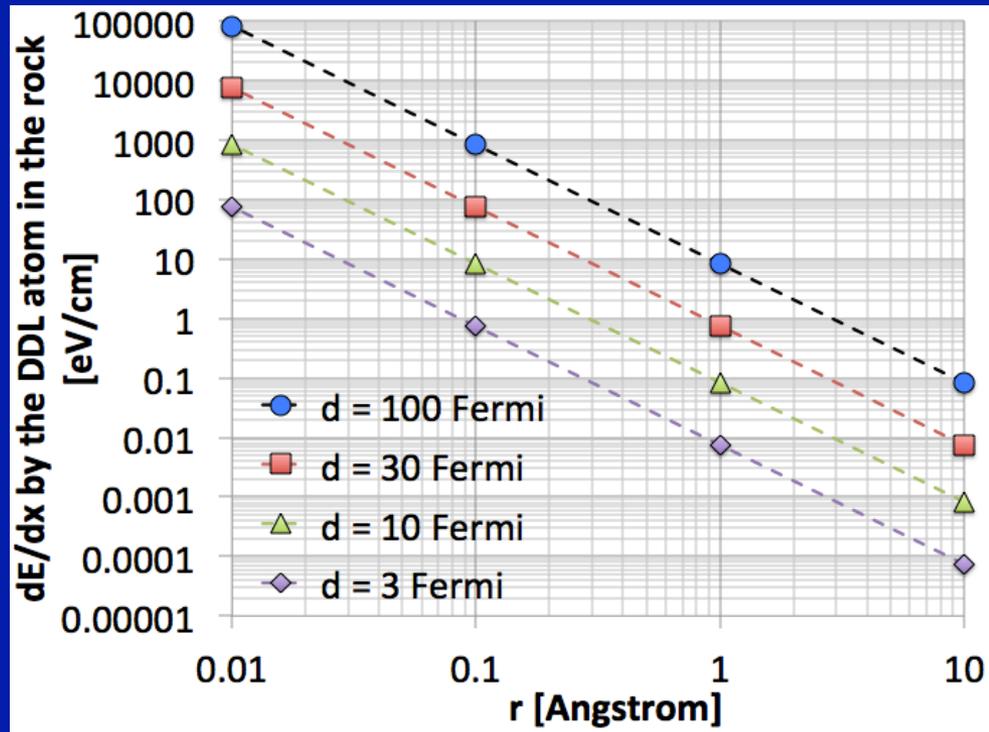
With other graduate students, we are now engaged in a more up-to-date QED calculation using light-front quantized field theory and positronium is one system we are addressing.

James

What is a dE/dx deposit of the small hydrogen as it travels through a medium ?

dE/dx deposit of small hydrogen atom in the rock

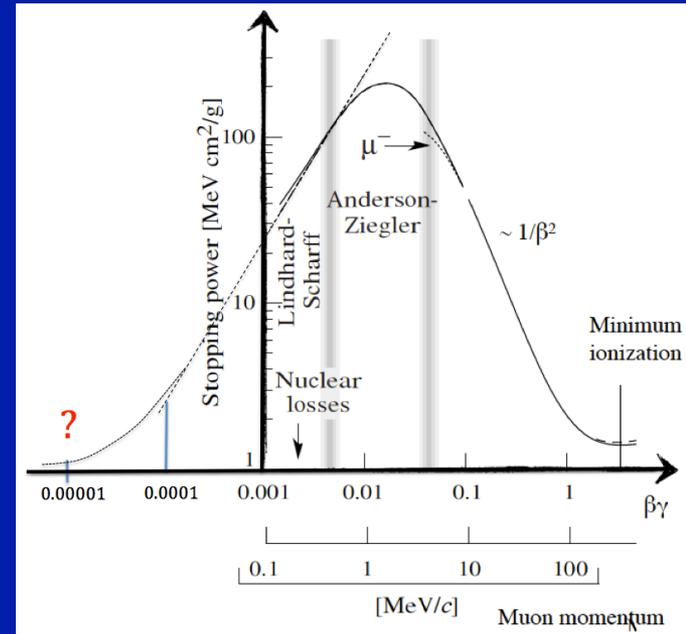
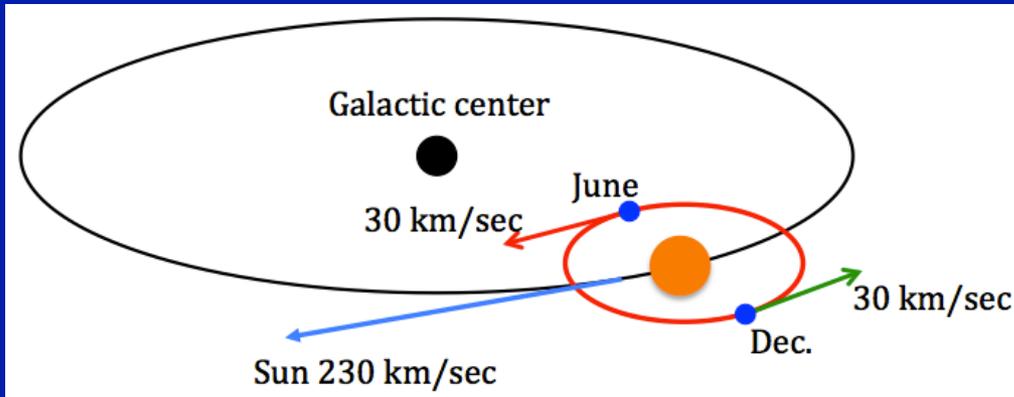
J. Va'vra, arXiv:1304.0833v3 [astro-ph.IM] 9 Jun 2013



- Introduce an effective charge in the Bethe formula, which is charge scaled down by a ratio: $E_{\text{single charge}} / E_{\text{dipole}} \sim (q / r^2) / [(q \cdot d) / r^3] \sim r / d$ for $r \gg d$, where q is a single charge, d is a distance between two charges in the dipole, r is a distance of small hydrogen to atom.
- **This ratio is close to $\sim 10^7$ for $r \sim 0.1 \text{ \AA}$, $d \sim 3 \text{ F}$ ($dE/dx \sim 1.5 \text{ MeV}/(\text{g}/\text{cm}^2)$, $\rho \sim 5.5 \text{ g}/\text{cm}^3$).**
- **The small hydrogen will deposit a very small amount of energy into the medium.**

dE/dx deposit of small hydrogen

J. Va'vra, arXiv:1304.0833v3 [astro-ph.IM] 9 Jun 2013



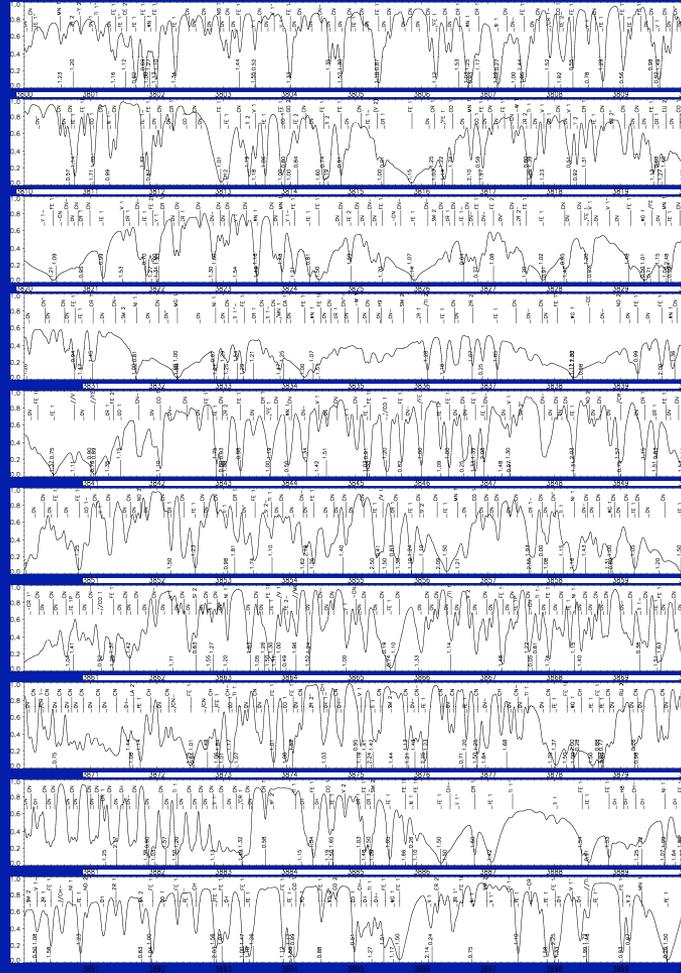
- A velocity of 230 km/sec corresponds to $\beta = v/c \sim 0.00077$. Its modulation due to the 30 km/sec variation is $\Delta\beta = \Delta(v/c) \sim 0.0001$.
- The energy loss for a value of $\beta = v/c \sim 0.00077$ is still on the "Bethe-rise" side of the dE/dx-curve. Can one see the dE/dx modulation due to $\Delta\beta$ -effect?
- Homework: estimate the energy loss more precisely. Without this one cannot design the experiment and search for some effects mentioned later. To do this one needs to know the size of the small hydrogen atom, perfferably from QED.

Search for the small hydrogen in the Universe

- Spectra from the SUN.
- Spectra from distant Galaxies.
- Spectrum from the center of our Galaxy.

Search for transitions to the small hydrogen lines in the spectra from the Sun

Absorption spectra from the Sun:

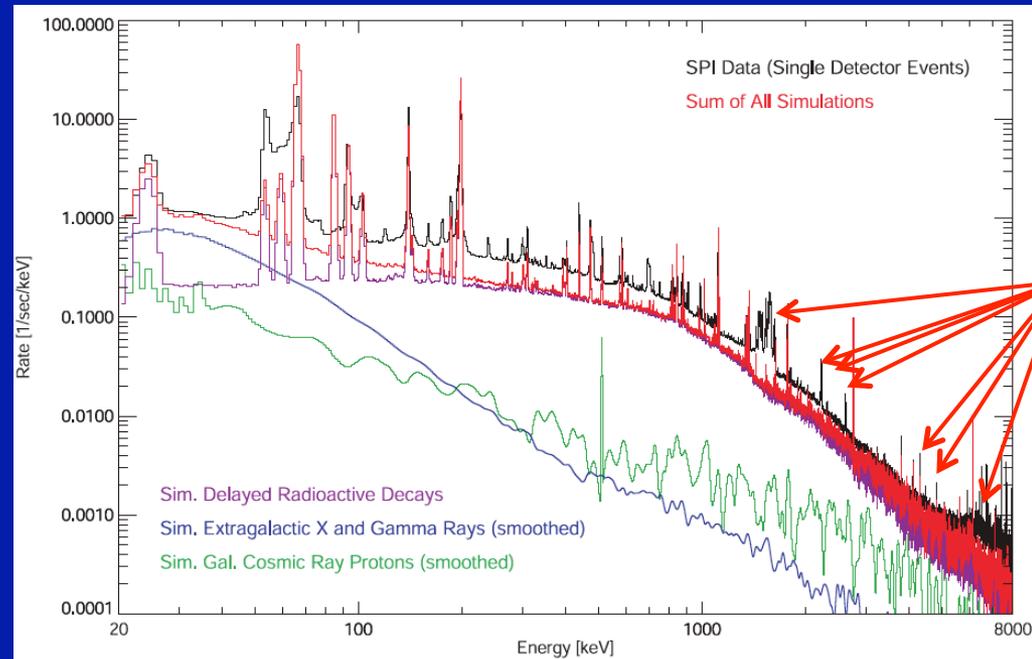


- **Too complicated. This is not the way to do it, I think.**

Neutron detection by the Integral satellite

G. Weidenspointner et al., A&A 411, L113–L116 (2003)

Comparison of data and MC simulation:



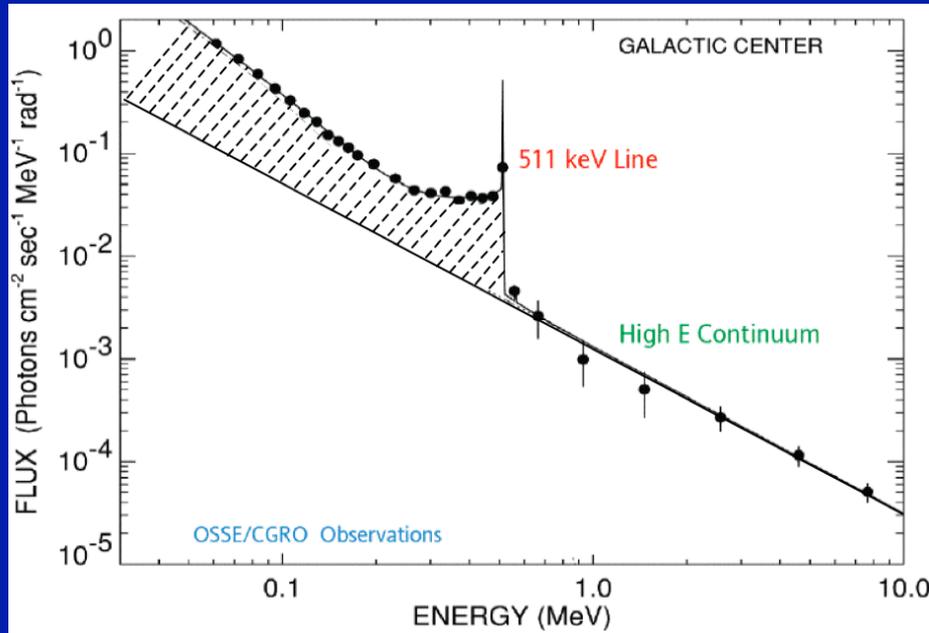
Nuclear capture peaks

- Paper says: "Thermal neutron capture is responsible for numerous and strong lines at several MeV; their **unexpected** presence poses a difficult challenge for our physical understanding of instrumental backgrounds and for Monte Carlo codes".
- **A standard explanation is that these neutron capture peaks are caused by cosmic ray proton interactions with the satellite's structure, producing neutrons, which capture and produce multi-MeV Gammas; however, the above paper did not prove it.**

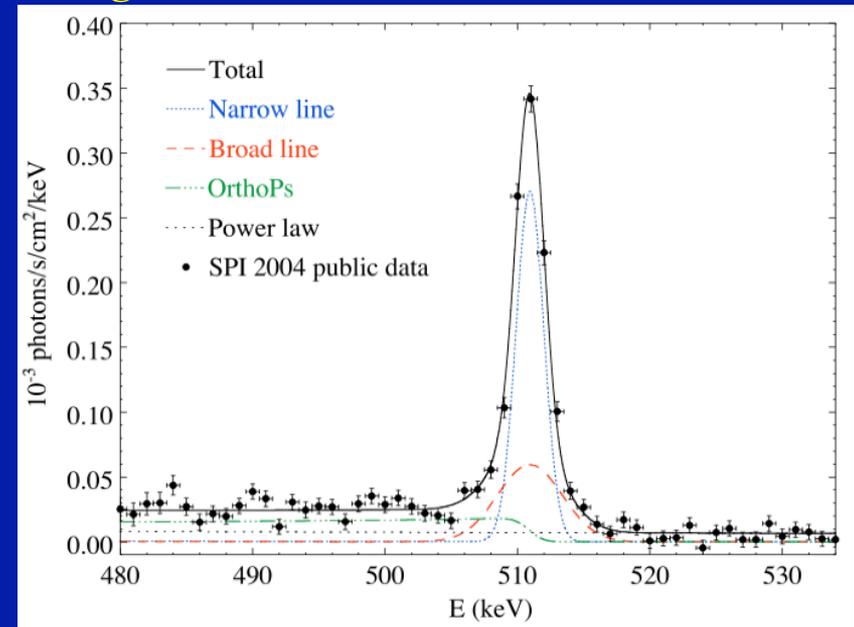
A 511 keV signal from the center of our Galaxy

J. Va'vra, arXiv:1304.0833v3 [astro-ph.IM] 9 Jun 2013

OSSE satellite:



Integral satellite:



- **The most obvious explanation of this signal is the annihilation of e^- & e^+ .**
- **The calculation indicates a total e^+ annihilation rate of more than $\sim 2 \times 10^{43} e^+ / s$.**
- Citing the Integral paper (N. Prantzos et al., arXiv:1009.4620v1, Sept. 2010):
”Despite 30 years of intense theoretical and observational investigation the main sources of positrons have not been identified up to now”.
- **Could this be a place to form the small hydrogen ?**

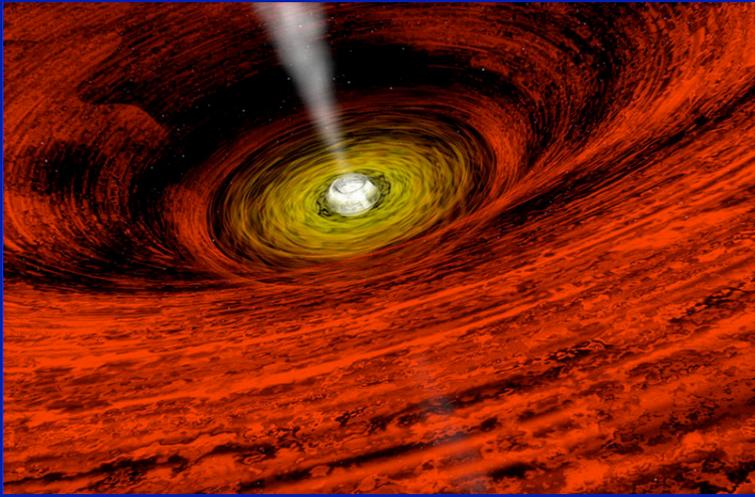
6/6/13

J. Va'vra, Dark Matter search,
differently

31

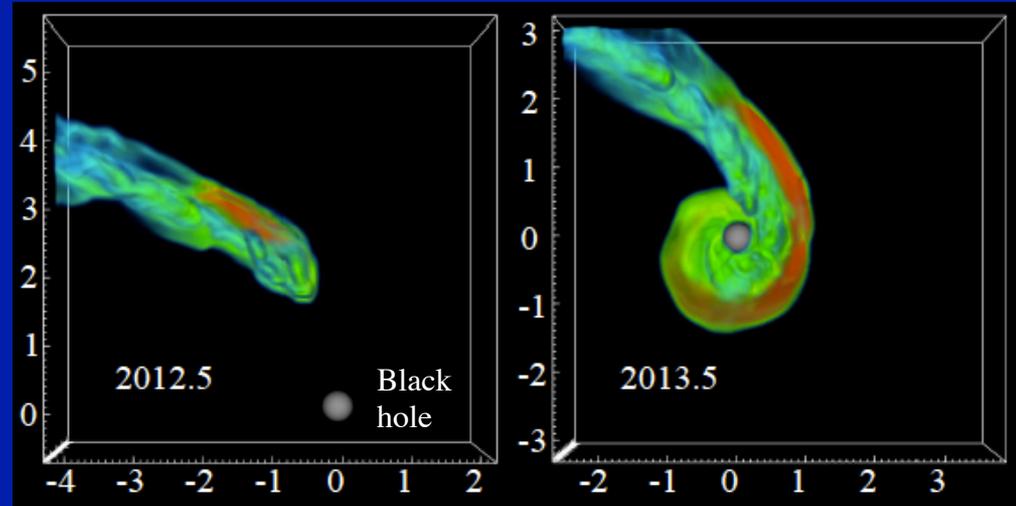
A hydrogen cloud approaching to Center of our Galaxy in the middle of 2013

Center of the Galaxy (our imagination):



At this point the hydrogen is fully ionized. The perfect condition for electrons and protons to form the small hydrogen and produce a 511 keV signal.

A real simulation of a hydrogen bubble as it approaches the galaxy center:



P. Anninos et al., arXiv:1209.1638v1 [astro-ph.GA] 7 Sep 2012)

- **A peak of collisions is expected in the middle of this year.**
- **Will the 511 keV peak increase its intensity ? I would need the Fermi satellite's data from their gamma burst monitor to determine this time dependence.**

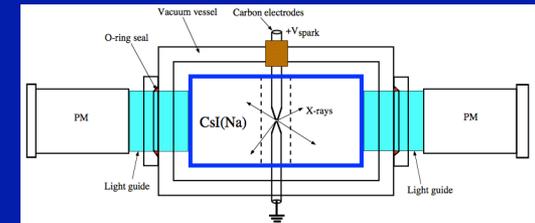
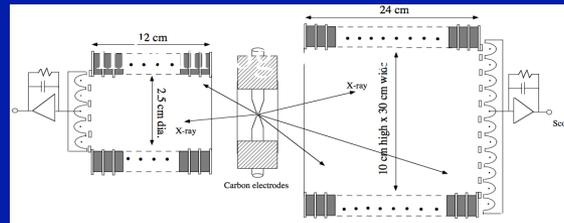
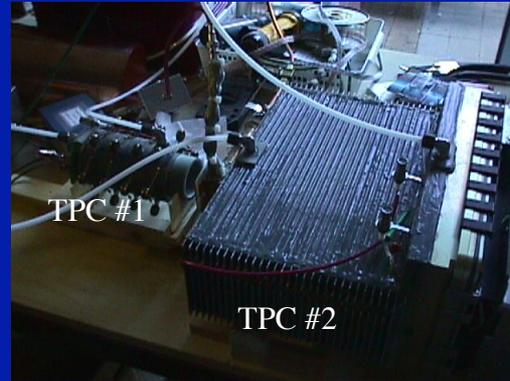
Direct search for the small hydrogen in the lab

Two examples from a search in the lab

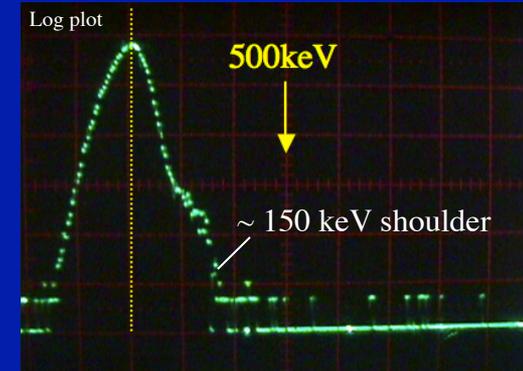
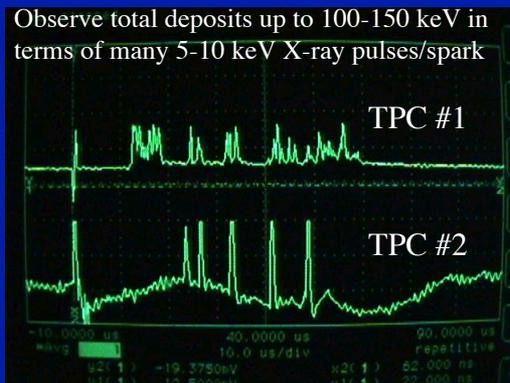
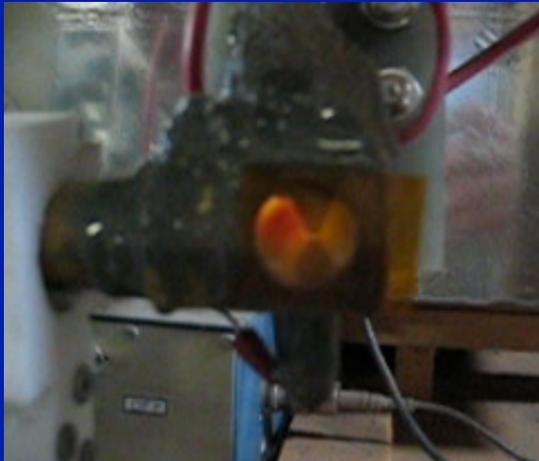
J. Va'vra et al., log books and plus also Nucl. Instr. & Meth., A 418 (1998) 405

- Sparking in hydrogen gas
- Gas pressure ~ 2 Torr
- $V_{\text{spark}} < 2.5$ kV
- 4×10^{14} electrons/spark
- Electron density $\sim 10^{17}$ el./cm³
- < 0.17 J/pulse
- See many 1-10 keV X-rays/spark

The aim of these tests: to find the 511 keV signal



Spark gap:



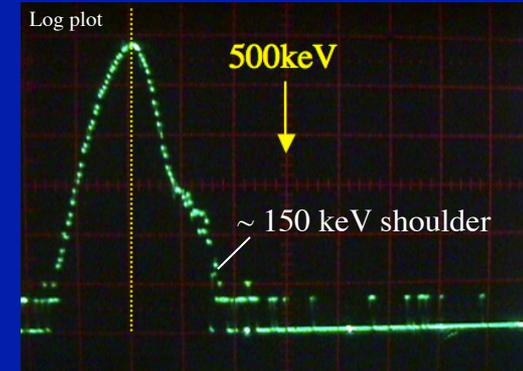
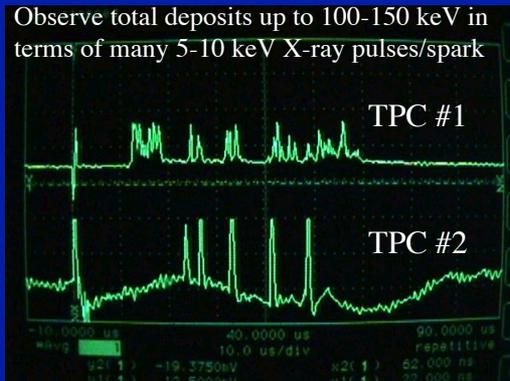
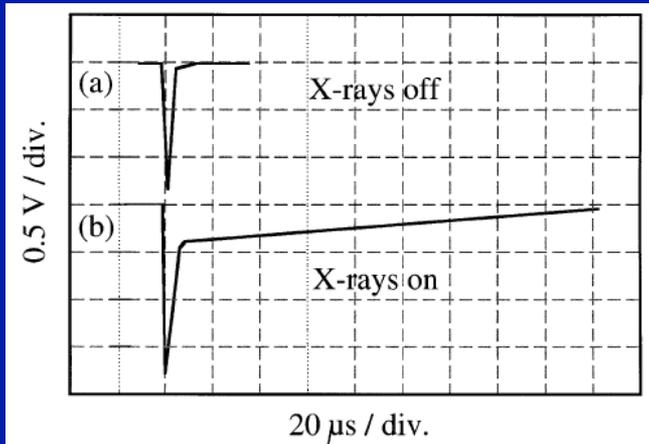
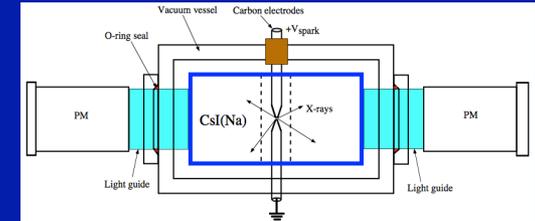
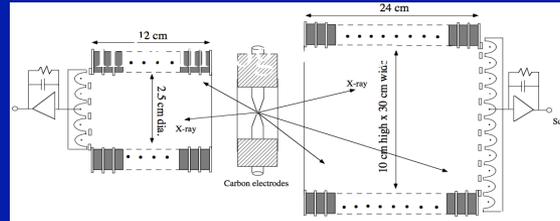
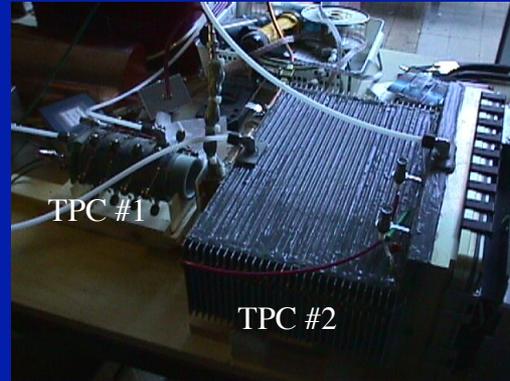
- No clear single 511 keV pulse, but many 2-10 keV pulses/ev.
- Are they from the same event ?

Two examples from a search in the lab

J. Va'vra et al., log books and plus also Nucl. Instr. & Meth., A 418 (1998) 405

- Sparking in hydrogen gas
- Gas pressure ~ 2 Torr
- $V_{\text{spark}} < 2.5$ kV
- 4×10^{14} electrons/spark
- Electron density $\sim 10^{17}$ el./cm³
- < 0.17 J/pulse
- See many 1-10 keV X-rays/spark
- X-rays produced only when H⁺ ions were produced at $V > V_{\text{th}}$:

The aim of these tests: to find the 511 keV signal



- A "classical" explanation: one is reaching a pinch effect condition

How to find the small hydrogen in the lab ?

- **The transition to small hydrogen level may go mostly via a multi-photon effect. One has to catch all photons to get a sum close to 511 keV. I think, I will go back to a sparking test in the middle of CsI crystal, using smaller electrodes, sub-ns HV pulser, smaller hole in the crystal to catch more photons and hope to get a total sum of 511 keV energy.**
- **At some depth below the surface the small hydrogen energy will become to be in a thermal equilibrium with surrounding atoms. There will be a high concentration of these atoms at this depth. Evacuate a cylinder, bring it down there. Small hydrogen will get through walls and fill up the cylinder. Measure absorption lines with an optical spectrometer. Expected lines: 307.3, 336.5, 367.1, 399.0, 432.3, 466.9, ... [nm]**
- **Will the small hydrogen do a nuclear capture ? One should check if nuclei at this depth have excess of neutrons.**
- **Initially I thought that one should use a powerful laser going through a low pressure hydrogen and produce a high density of electrons-ion pairs, and one would look for 511 keV Gammas. My preliminary check into this:**
 - SLAC has a 10 TW laser at FACET which we transport into the accelerator housing and use to ionize gas contained within a vacuum chamber in the beam line. There are plans to use ~50 Torr hydrogen in this chamber. We plan to do a test if one can generate a 511 keV signal.
 - **However, the problem with this scheme is that such powerful laser, also creates complicated coherent effects, causing high electric field and creating e^+ & e^- .**

Dark Matter search

We will now discuss two new detectors to search for low mass Dark Matter

- **Spherical TPC measuring single electrons and single photons could:**

- a light mass WIMP ($\sim 1 \text{ GeV}/c^2$) detection,
- a small hydrogen atom detection, or
- any other WIMP capable of interacting with shell-electrons.

Note: Spherical TPC was invented by I. Giomataris : Giomataris and J.D. Vergados, Nucl.Instr.Meth.A530:330, 2004, and Nucl.Phys.Proc.Suppl.150:208,2006 (**but he did not have a light detection**).

- **Light TPC measuring single photons:**

- a small hydrogen atom detection, or
- any other WIMP capable of interacting with shell-electrons.

Spherical TPC detector concept: Detection of small hydrogen

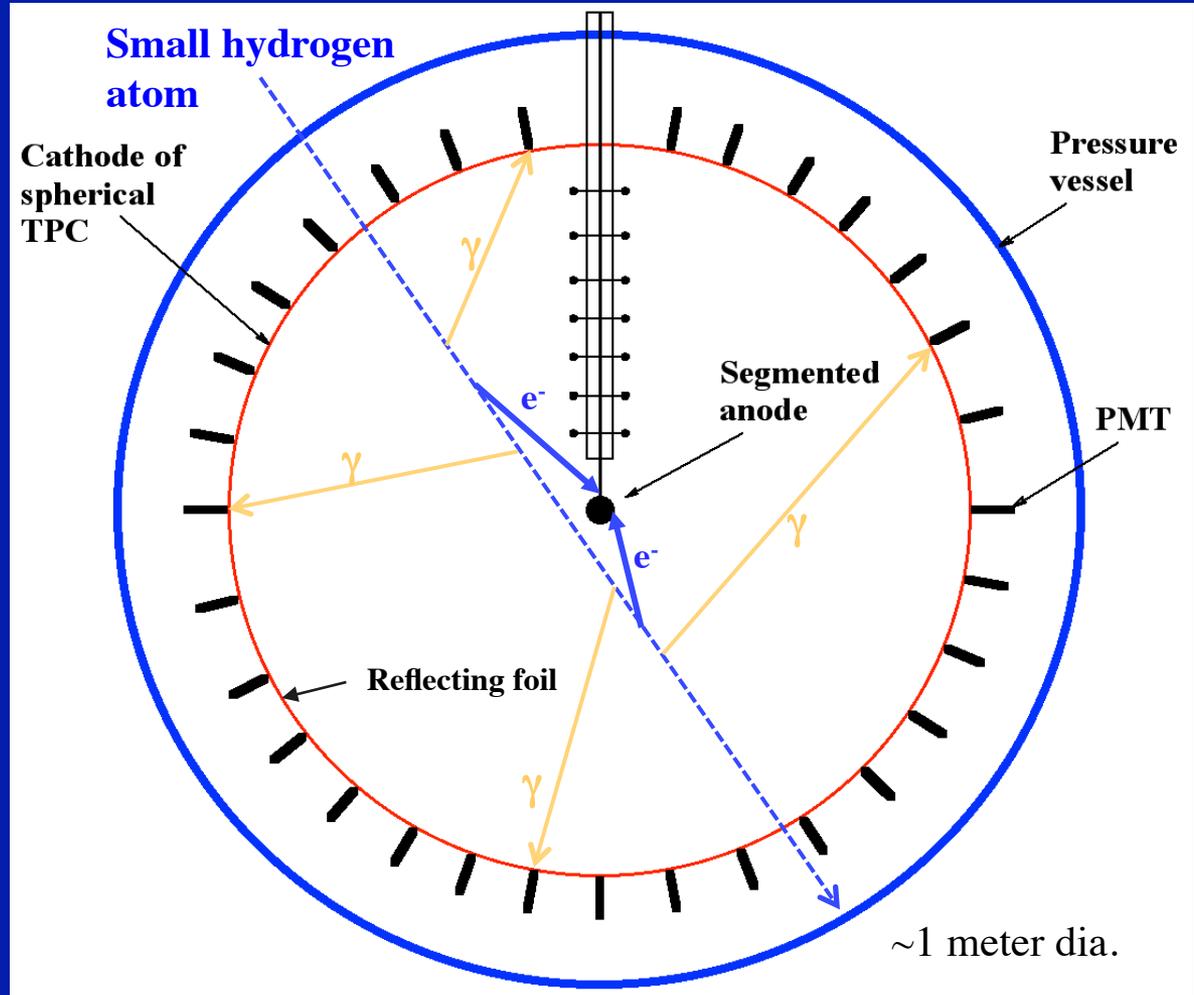
J. Va'vra, arXiv:1304.0833v3 [astro-ph.IM] 9 Jun 2013

Bialkali photocathode of DIRC PMTs will detect single photons of 2.5-4 eV energy

Single photon and single electron detection sensitivity.

For a particle with a velocity of ~ 230 km/sec, i.e., $\beta = v/c \sim 0.00077$, it takes $\sim 3-4 \mu\text{sec}$ to cross 1 meter.

One could, of course, use a square TPC as well. However, it would require more readout channels.



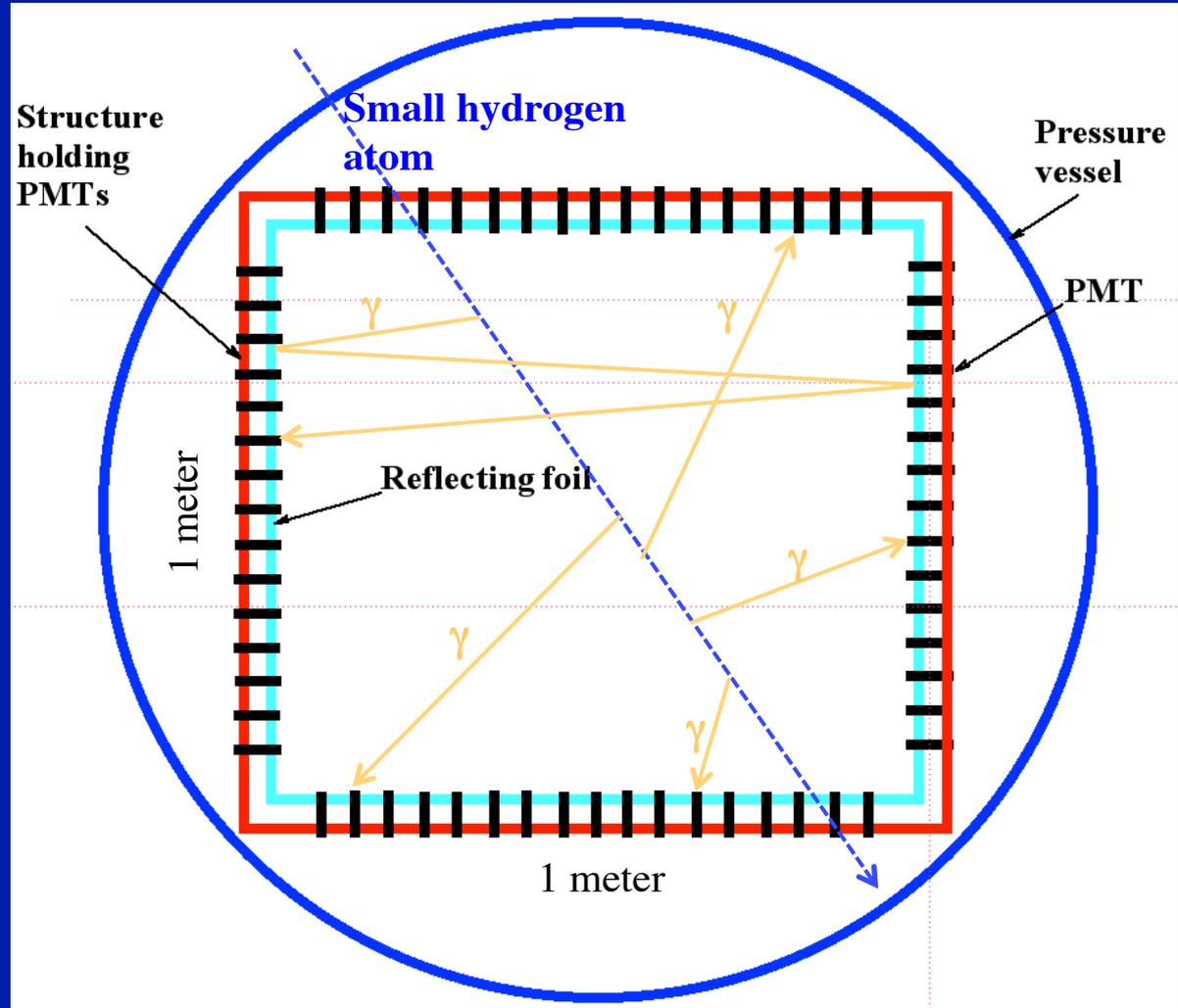
Light TPC (LTPC) detector concept: Detection of small hydrogen

Photon detectors would detect single photons of 2.5-4 eV energy

Single photon detection sensitivity.

For a particle with a velocity of ~ 230 km/sec, i.e., $\beta = v/c \sim 0.00077$, it takes $\sim 3-4 \mu\text{sec}$ to cross 1 meter.

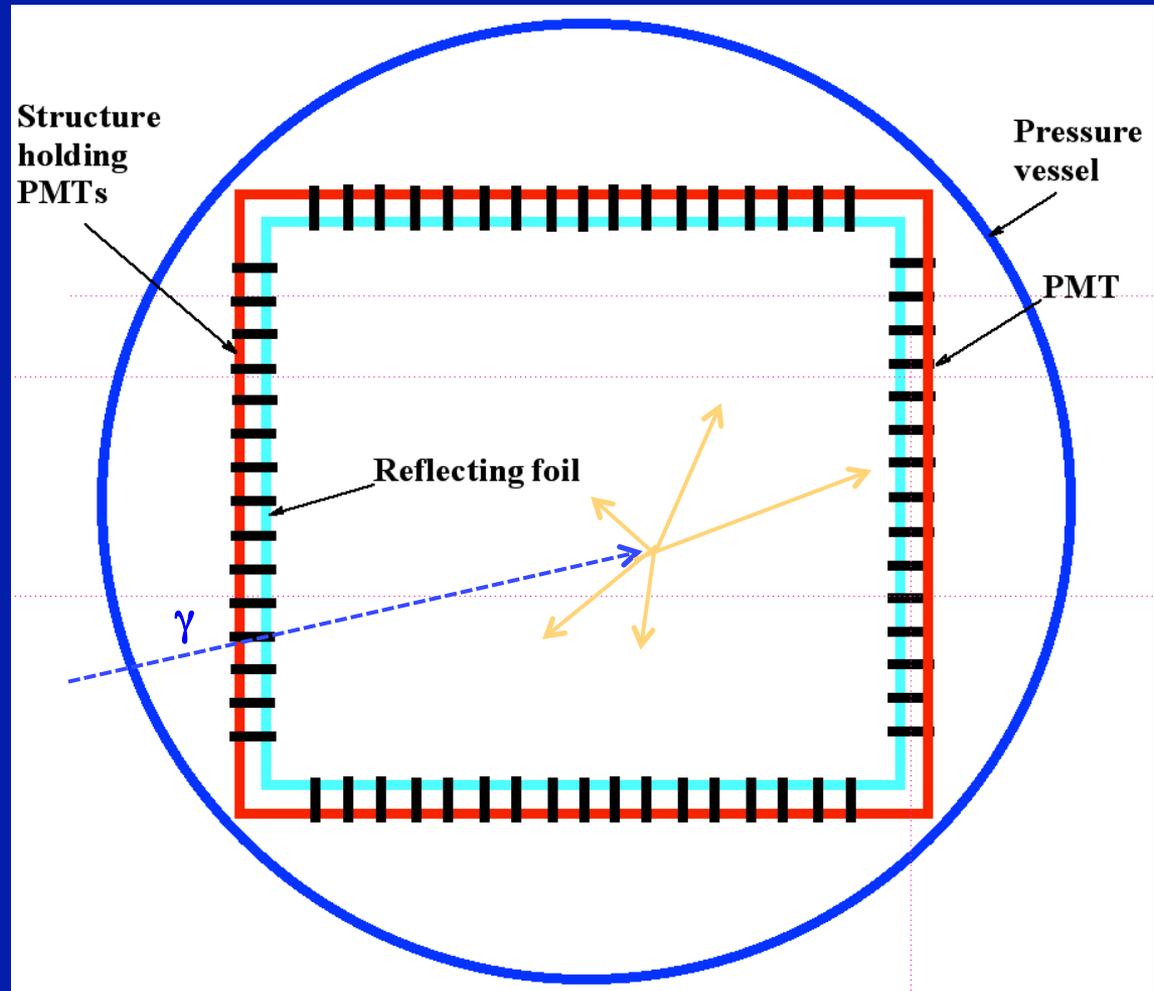
If one will use ~ 400 DIRC PMTs, their total photocathode area is only $\sim 3\%$ of the total sensitive surface. This will severely reduce the photon detection efficiency. Add a reflecting foil to increase the photon detection efficiency.



Light TPC (LTPC) detector concept: Detection of a gamma background

Photons from Gammas, produced either by a radioactivity in the detector or from surrounding rock, will produce photons, which will be prompt.

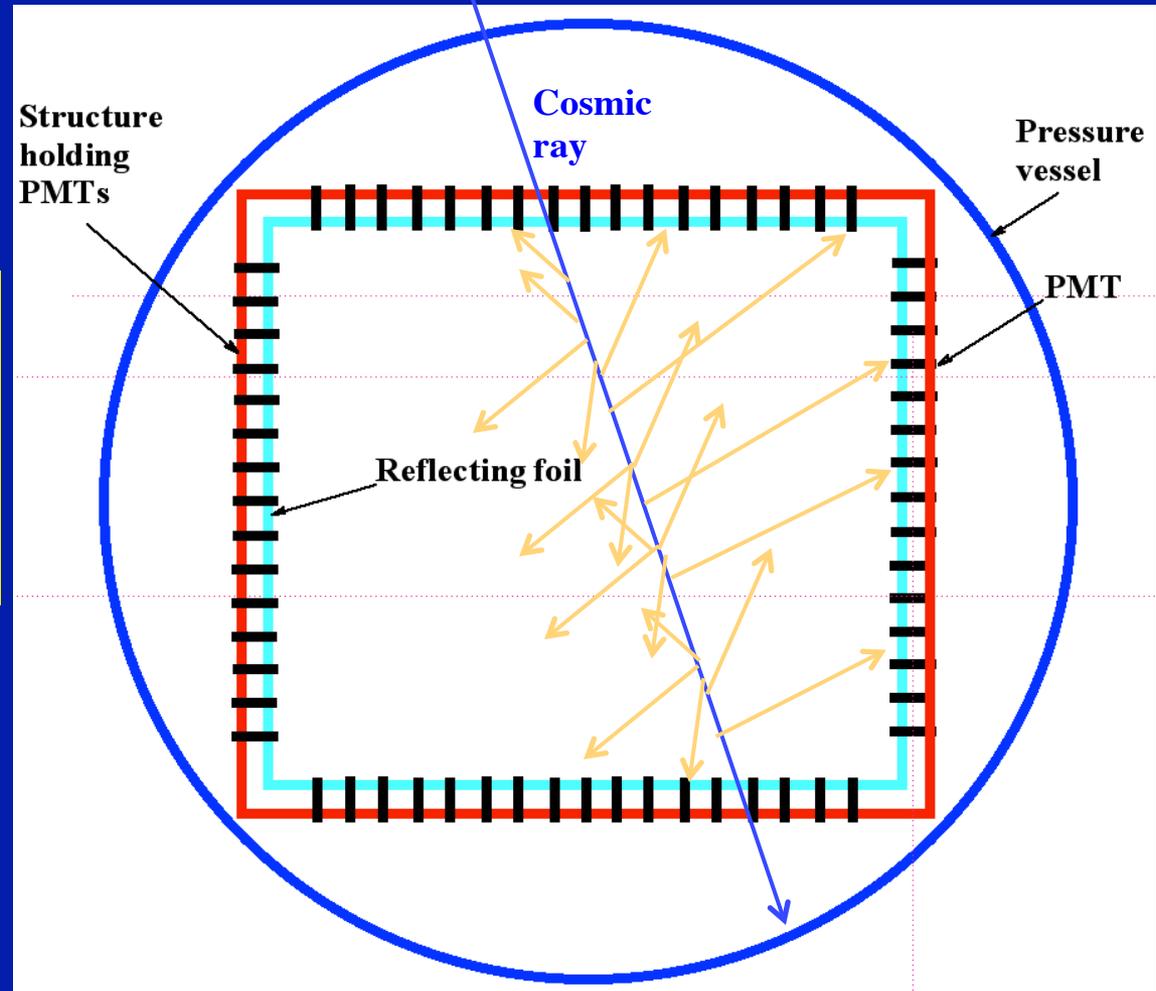
Therefore they can be recognized and eliminated easily.



Light TPC (LTPC) detector concept: Detection of cosmic ray background

Cosmic ray will produce many photons, which will be prompt. It can be easily recognized and eliminated. However, after-pulsing may create subsequent triggers.

To be less sensitive to cosmic ray showers we plan to place the detector to PEP-II tunnel, which is underground.



What is the radiator ?

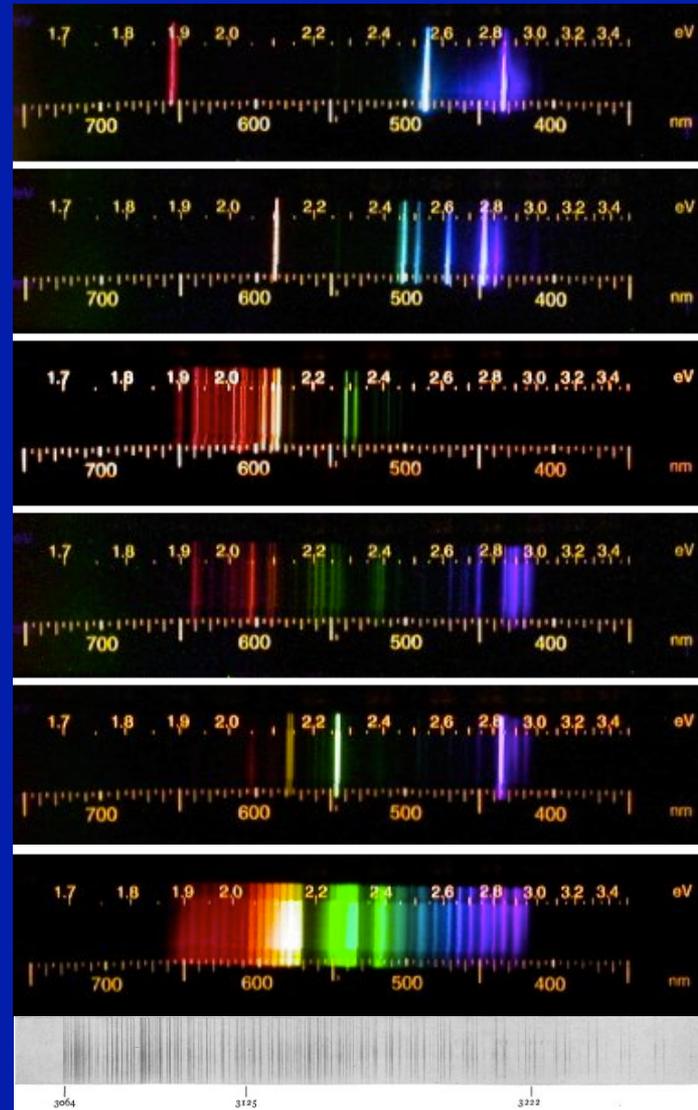
The aim is to maximize emission in the energy region matching the Bialkali photocathode.

One wants to have a simple and reliable operation.

The radiator must be transparent to improve a photon detection efficiency (the reflector has to be re-used several times).

Options for radiator choice:

- Boil-off N_2 gas at higher pressure.
- A simple purified water.
- I have also contacted Minfang Yeh about his “metal-loaded liquid scintillator” (WbLS).



Hydrogen

Helium

Neon

Argon

Mercury

Air (O_2 & N_2)

Water

Trigger and electronics

- Event signature:

- A real event will produce a sequence of single photons spread over 8 μ sec interval !!!
- Gammas will produce a shower of photons arriving within ~ 5 -10 ns.
- The cosmic rays will produce a large number of photons, which are prompt as well.

- Trigger & Analysis:

- Will trigger on a single photon \Rightarrow a trigger rate may easily approach ~ 1 MHz.
- For every trigger read all TDC's into a buffer.
- Write the buffer out if more >2 single photons within a ~ 8 μ sec window.
- This is an "event candidate" of interest; record these events.

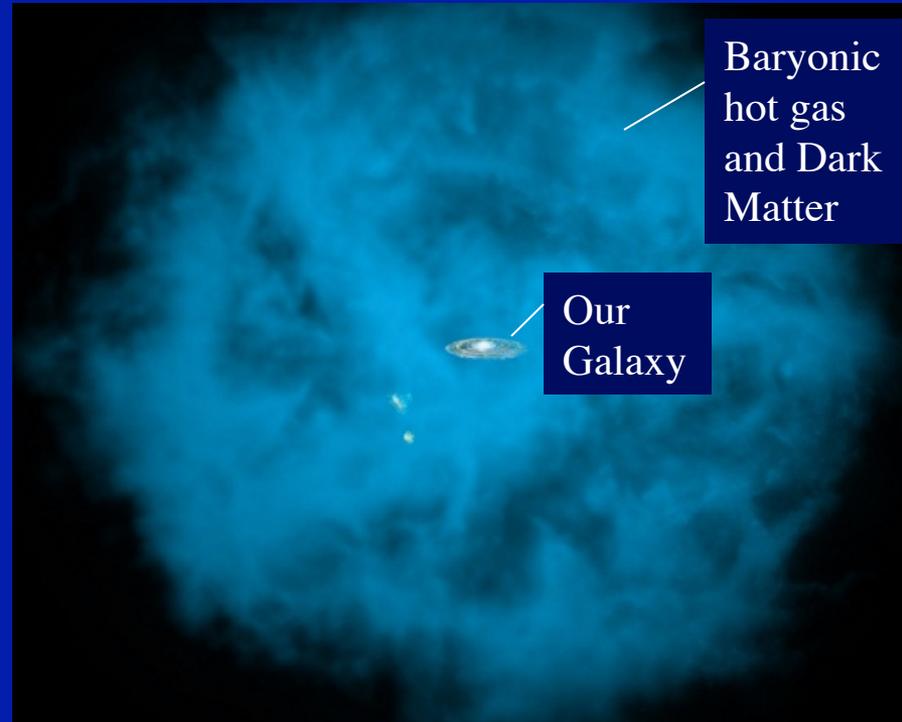
- Plot number of these "events" as a function of time to determine yearly modulation in (a) the total average event drift spread and (b) a slight dE/dx modulation ($\beta = v/c = 0.00077 \pm 0.0001$, or $v = 230$ km/sec ± 30 km/sec).

- One should select low noise PMTs to reduce a rate of random coincidences !!
- Suppress some time period after a cosmic ray event because of PMT after-pulses.
- The experiment may not have to be deep under ground.

Summary

- **If the Dark Matter mass is the small hydrogen, there is lots of it. It acts as a gas and, which is being absorbed by the Earth. It may do a nuclear capture.**
- **We have proposed our preferred detector to detect it, and several other possible detection schemes how to discover it directly.**
- **It is clearly important to estimate the dE/dx of the small hydrogen better to be able to design this experiment.**
- **It is also important to encourage the QED calculations by J. Vary's group.**

Chandra: Our Galaxy with its baryonic hot gas halo:
(I am assuming that the Dark Matter may have a similar shape)



They estimate this distribution from the X-ray attenuation.

Spherical TPC detector concept: Detection of light mass WIMP

J. Va'vra, arXiv:1304.0833v3 [astro-ph.IM] 9 Jun 2013

Bialkali photocathode of DIRC PMTs will detect single photons of 2.5-4 eV energy

Single photon and single electron detection sensitivity.

A light mass Dark matter collision with a light nuclei will produce a single photon and single electron.

The signal photon signal must precede the charge signal. This will be a signature for the event.

