Upper limit on the mean collapse rate parameter λ of CSL models

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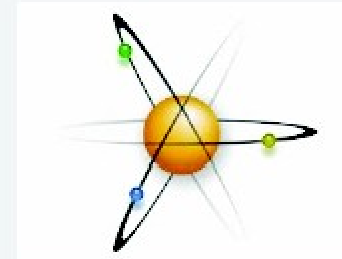
Which values for λ and r_c?

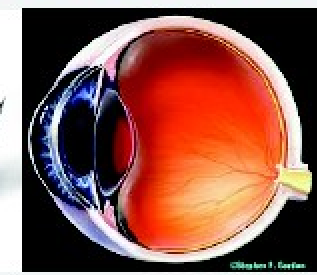
Microscopic world
(few particles)



$\lambda \sim 10^{-8\pm2}\mathrm{s}^{-1}$

QUANTUM – CLASSICAL TRANSITION
(Adler - 2007)

Mesoscopic world
Latent image formation
+
perception in the eye
(~ 10^4 - 10^5 particles)



S.L. Adler, JPA 40, 2935 (2007)

A. Bassi, D.A. Deckert & L. Ferialdi, EPL 92, 50006 (2010)

$\lambda \sim 10^{-17}\mathrm{s}^{-1}$

QUANTUM – CLASSICAL TRANSITION
(GRW - 1986)

Macroscopic world
(> 10^{13} particles)

G.C. Ghirardi, A. Rimini and T. Weber, PRD 34, 470 (1986)

$r_C = 1/\sqrt{\alpha} \sim 10^{-5}\mathrm{cm}$

Increasing size of the system

… upper limit on the reduction rate parameter from the spontaneous emission process ...

… spontaneous photon emission

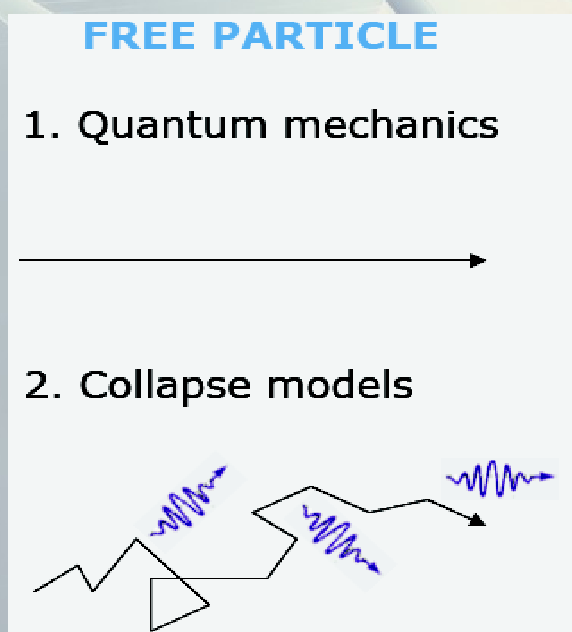
Besides collapsing the state vector to the position basis in non relativistic QM the interaction with the stochastic field increases the expectation value of particle's energy

↓

implies for a charged particle energy radiation (not present in standard QM) !!!

↓

The comparison between theoretical prediction and experimental results provide constraints on the parameters of the CSL model



$$\frac{d\Gamma_k}{dk} = \frac{e^2\lambda}{4\pi^2 r_c^2 m^2 k}$$

Q. Fu, Phys. Rev. A 56, 1806 (1997)

S.L. Adler, A. Bassi & S. Donadi, ArXiv 1011.3941

Expected X-ray rate from Ge low activity experiments

Q. Fu, Phys. Rev. A 56, 1806 (1997) → only upper limit on λ based on comparison with the radiation appearing in an isolated slab of Ge (raw data not background subtracted)

H. S. Miley, et al., Phys. Rev. Lett. 65, 3092 (1990)

Energy (keV)	Expt. upper bound (counts/keV/kg/day)	Theory (counts/keV/kg/day)
11	0.049	0.071
101	0.031	0.0073
201	0.030	0.0037
301	0.024	0.0028
401	0.017	0.0019
501	0.014	0.0015

TABLE I. Experimental upper bounds and theoretical predictions of the spontaneous radiation by free electrons in Ge for a range of photon energy values.

Comparison with the lower energy bin, due to the *non-relativistic constraint* of the CSL model

$$\left.\frac{d\Gamma_k}{dk}\right|_{th} = (2.74 \cdot 10^{-31}) \cdot 4 \cdot (8.29 \cdot 10^{24}) \cdot (8.6 \cdot 10^{4}) \cdot \frac{1}{k} < \left.\frac{d\Gamma_k}{dk}\right|_{ex}$$

$$\frac{e^2\lambda}{4\pi^2 r_c^2 m^2}$$

4 valence electrons are considered
BE ~ 10 eV « energy of emitted γ ~ 11 keV
***quasi-free* electrons**

(Atoms / Kg) in Ge

1 day

Result → λ < 0.55 x 10^{-16} s^{-1} the GRW theory predicts 45% more radiation than the observed upper bound.

Result possibly biased by the punctual evaluation of the rate at one single energy bin.

Expected X-ray rate from Ge low activity experiments

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H. S. Miley, et al., Phys. Rev. Lett. 65, 3092 (1990)

Result → $\lambda < 0.55 \times 10^{-16}\ s^{-1}$

According to S. L. Adler and F. M. Ramazanoglu, J. Phys. A40; 13395 (2007)
such value is to be divided by a factor 4π

↓

No mass-proportional **$\lambda < 4.38 \times 10^{-18}\ s^{-1}$**

for a mass proportional coupling …

$$\lambda \to \lambda \left(\frac{m_e}{m_N}\right)^2$$

mass-proportional **$\lambda < 1.54 \times 10^{-11}\ s^{-1}$**

Expected X-ray rate from Ge low activity experiments

S. L. Adler & F. M. Ramazanoglu (2007):

No mass-proportional $\lambda < 4.38 \times 10^{-18}\ s^{-1}$

mass-proportional $\lambda < 1.54 \times 10^{-11}\ s^{-1}$

More .. the preliminary TWIN data set resulted to under-estimate the rate for energies < 200 keV

(factor about 50 at 10 keV)

A new analysis (J. Mullin and P. Pearle, Phys. Rev. A 90, 052119 (2014)) employing improved data (B. Collett, P. Pearle, F. Avignone and S. Nussinov, Found. Phys.25, 1399 (1995)) gives:

No mass-proportional $\lambda < 2 \times 10^{-16}\ s^{-1}$

mass-proportional $\lambda < 8 \times 10^{-10}\ s^{-1}$

Upper limits on λ from different approaches

Laboratory experiments	Distance (decades) from the enhanced CSL value	Cosmological data	Distance (decades) from the enhanced CSL value
Fullerene diffraction experiments	11-12 (2-3)	Dissociation of cosmic hydrogen	18 (9)
Decay of supercurrents (SQUIDs)	15 (6)	Heating of Intergalactic medium (IGM)	9 (0)
Spontaneous X-ray emission from Ge	8 (-1)	Heating of protons in the universe	13 (4)
Proton decay	19 (10)	Heating of Interstellar dust grains	116 (7)

Updated from S.L. Adler and A. Bassi, *Science* 325, 275 (2009)

IGEX data analysis: using published data of the IGEX experiment

The IGEX experiment is a low-activity Ge based experiment dedicated to the ββ0ν decay research. (C. E. Aalseth et al., IGEX collaboration Phys. Rev. C 59, 2108 (1999))

In (A. Morales et al., IGEX collaboration Phys. Lett. B 532, 8-14 (2002)) the published data acquired for an exposure of 80 *kg day* in the energy range:
$\Delta E = (4 - 49)\ keV \ll m_e = 512\ keV$ → compatible with the non-relativistic assumption.

Low-energy data from the IGEX RG-II detector (Mt = 80 kg day)

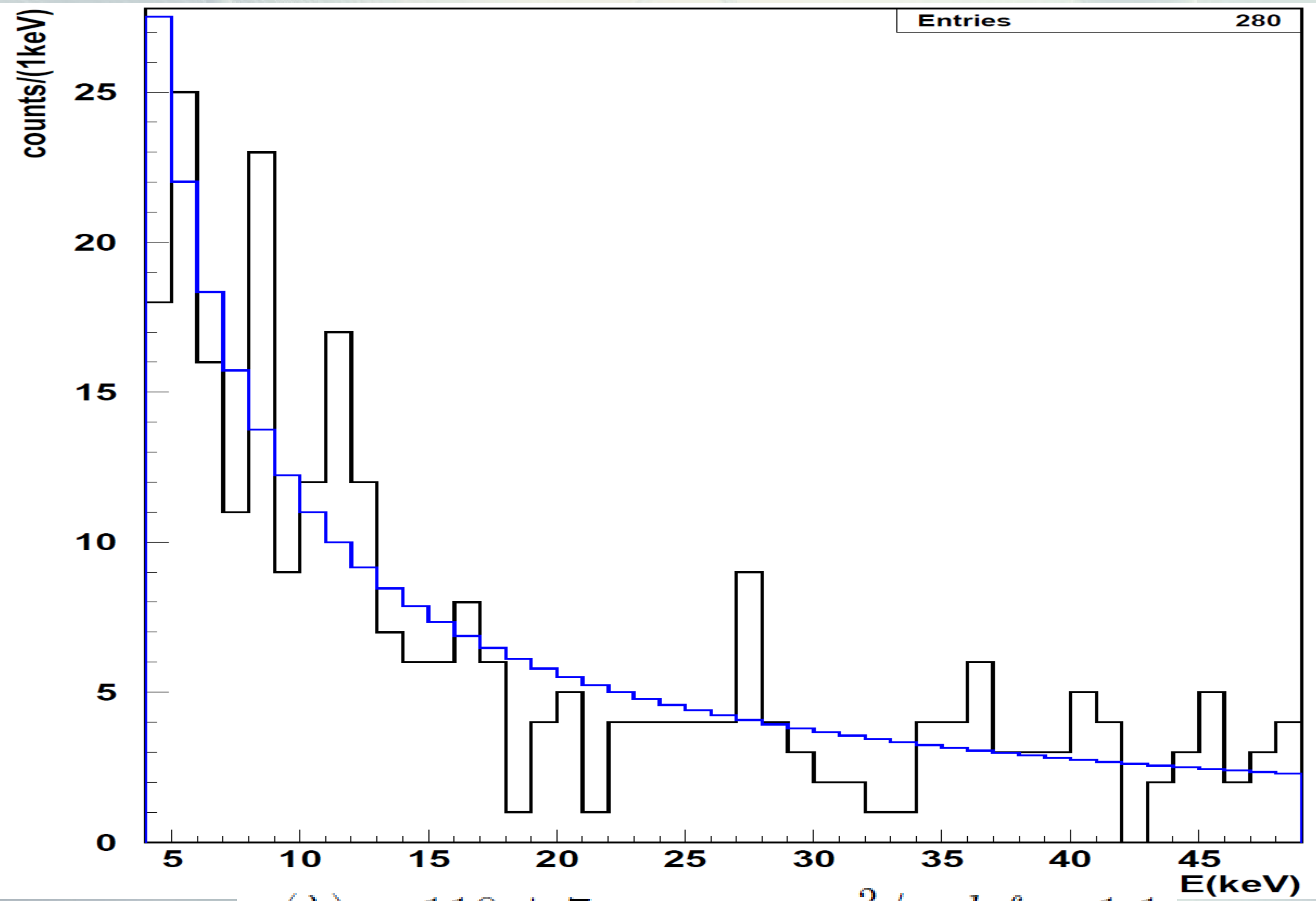
E (keV)	Counts	E (keV)	Counts	E (keV)	Counts
4.5	18	19.5	4	34.5	4
5.5	25	20.5	5	35.5	4
6.5	16	21.5	1	36.5	6
7.5	11	22.5	4	37.5	3
8.5	23	23.5	4	38.5	3
9.5	9	24.5	4	39.5	3
10.5	12	25.5	4	40.5	5
11.5	17	26.5	4	41.5	4
12.5	12	27.5	9	42.5	0
13.5	7	28.5	4	43.5	2
14.5	6	29.5	3	44.5	3
15.5	6	30.5	2	45.5	5
16.5	8	31.5	2	46.5	2
17.5	6	32.5	1	47.5	3
18.5	1	33.5	1	48.5	4

IGEX data analysis: results and discussion

The X-ray spectrum was fitted assuming the predicted energy dependence:

$$\frac{d\Gamma_k}{dk} = \frac{\alpha(\lambda)}{k}$$

With $\alpha(\lambda)$ free parameter, bin contents are treated with Poisson statistics.



Fit result: $\alpha(\lambda) = 110 \pm 7 \quad , \quad \chi^2/n.d.f = 1.1$

Analysis results and discussion

The performed fit enables to set an upper limit on the reduction rate parameter:

$$\frac{d\Gamma}{dE} = \frac{\lambda \hbar e^2}{4\pi^2 \epsilon_0 c^3 m_e^2 r_c^2 E} = K\,\frac{\lambda}{E} < \frac{110}{E}$$

1 O.M. improovement

1) **assuming $r_c = 10^{-7}\,m$ → $\lambda < 1.4 \pm 0.1 \times 10^{-17}\ s^{-1}$**

2) **if a mass-proportional model is assumed (noise having a gravitational origin?)**

$$\lambda \to \lambda \left(\frac{m_e}{m_N}\right)^2$$

then → $\lambda < 4.7 \pm 0.3 \times 10^{-11}\ s^{-1}$ *Acta. Phys. Polon. B46 (2015) 147*

3) **taking the 22 outer electrons (down to the 3s orbit BE_{3s} = 180.1 eV) in the calculation:**

2 O.M. improovement

No mass-proportional	mass-proportional
$\lambda < 2.5 \pm 0.2 \times 10^{-18}\ s^{-1}$	$\lambda < 8.5 \pm 0.5 \times 10^{-12}\ s^{-1}$

ArXiv:1502.05961
Accepted in JAP

Upper limits on λ from different approaches

Limits from the spontaneous emission rate:

$\lambda < 2.5 \pm 0.2 \times 10^{-18}\ s^{-1}$	$\lambda < 8.5 \pm 0.5 \times 10^{-12}\ s^{-1}$
No mass-proportional	Mass-proportional

No mass-proportional EXCLUDED if white noise is assumed

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K^-
Thanks