# Manipulating stored energy in NaI(Tl) and DAMA-LIBRA background modulation

## Natural nano-explosive detector?

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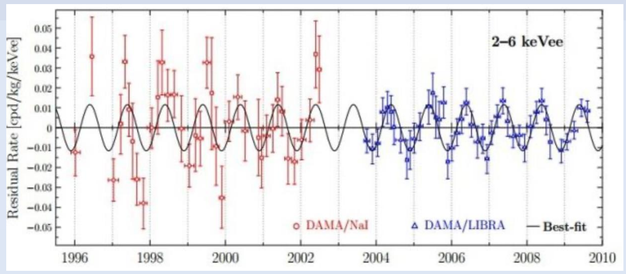
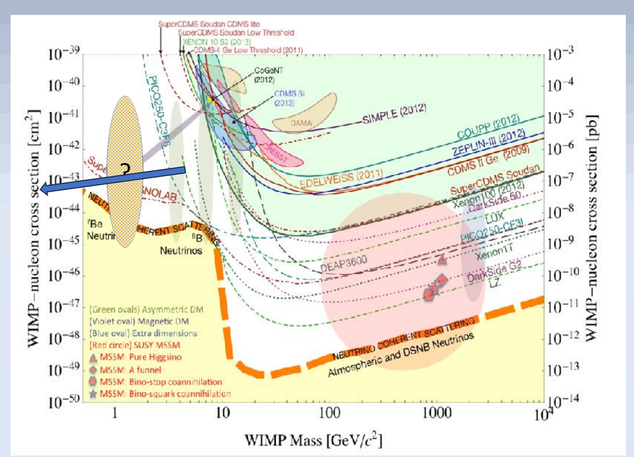
## DAMA/LIBRA controversy

- In the last few decades, the quest for dark matter has given a null result but for a few exceptions.
- To this date, the DAMA/LIBRA collaboration maintains the sole remaining claim, which has been in strong tension with other experiments




## Hypothesis: Naturally occurring nano-explosive detector

### Low-energy interactions cause detectable releases of stored energy in NaI(Tl)




- Energy effectively pumped in by muons (minimally ionizing particles) and UV
- Residual radioactivity mostly destroys long-storage states
- Nuclear recoils below 1 eV due to Solar neutrino or low-mass DM trigger energy releases
- Multiple photon events (D-L signal) and the random delayed photon flux exhibit yearly modulation- phases can be different (no checks yet on random delayed photons)

## Saint Gobain's observations

*With mild UV exposure, several pulses per second can be seen in the 6–10 keV region of a spectrum. If the crystal is stored in a dark area, this mild UV exposure will eventually disappear, although it may take from several hours to several days for the effects to stop.*

to explain the DAMA/LIBRA observation, the photons emitted need to:
- look like NaI pulses to pass DAMA/LIBRA cuts
- seasonal modulation phase for DAMA/LIBRA - needs modulation mechanism in addition to Muon flux
- mechanism to "kill" modulation by residual radioactivity in "less-pure" NaI(TL) samples

## Excessive low-energy background and delayed signals *are common* for dark matter particles and CEvNS detectors



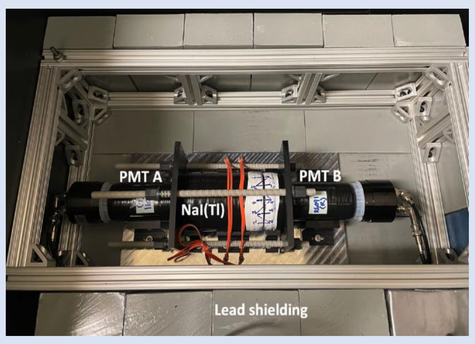

EXCESS workshops



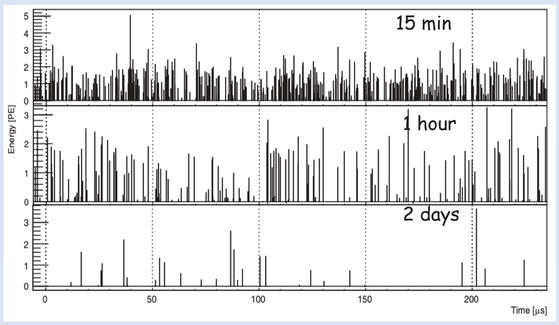

a: Xenon 10 experiment, b: Xenon 100,
c: Dark Side 50 experiment, 50 kg liquid Ar TPC;
d: DAMA-LIBRA experiment, NAI(Tl) scintillator, energy deposition of 1 keV results here in registration 5.5-7.5 photons (Nygren paper0

Common features: a sharp rise in the number of low-energy events
*Long, (history-dependent, glass-like) relaxation processes after cooling down; background depends on the crystal support, etc.*

## Delayed luminescence in NaI(Tl): 365 nm UV light and $^{60}$Co exposure; Setup and Waveforms




Event waveform (PMT A + PMT B):

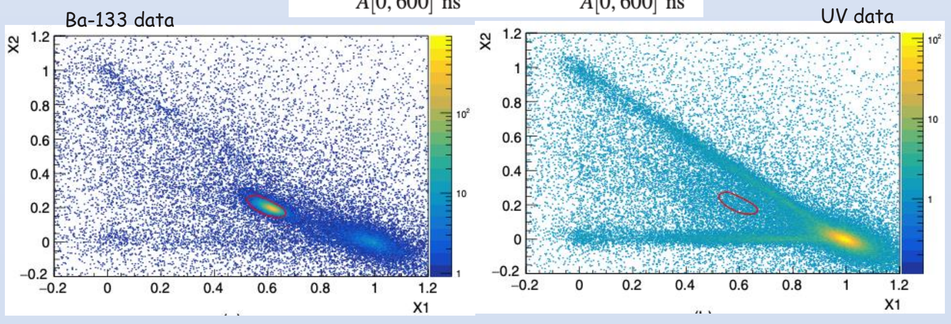



3" NaI crystal (Saint Gobain);; Hamamatsu R6091 PM; CAEN V975 amplifier (10x gain); 16-channel 250-MHz 14-bit Struck digitizer; Two data taking modes: coincidence trigger & periodic trigger $xx nm UV lamp (we choose longer penetration depth)

**photoelectrons following UV exposure are dominated by uncorrelated single-photoelectron pulses.**
(We do not know how Saint Gobain choose particle-like events).

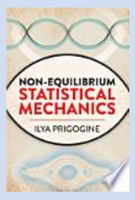
## DAMA-LIBRA style pulse-shape discrimination

$$X_1 = \frac{A[100, 600]\ \text{ns}}{A[0, 600]\ \text{ns}}, \qquad X_2 = \frac{A[0, 50]\ \text{ns}}{A[0, 600]\ \text{ns}}.$$

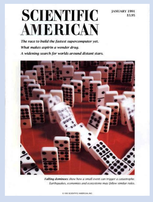



- **UV-induced background is capable of contaminating the region where genuine NaI(Tl) pulses are located**
- Note that this is simply an illustrative analysis, and the contamination level may vary from one experiment to another due to the variations in the crystal properties, data acquisition methods, and analysis cuts

## Systems with energy flow & Self-Organized Criticality




Ilya Prigogine (Noble Price 1977)
**Dissipative structures**, irreversibility, **complexity**, order out of chaos




- **Polynomial events spectrum (catastrophes possible)**
- **Noise power spectrum close to 1/f (pink noise}**
- **Absence of characteristic time or size of the avalanche**
- **Low energy particles can cause "large events"**
- **Large events suppression by helping "small relaxation"**

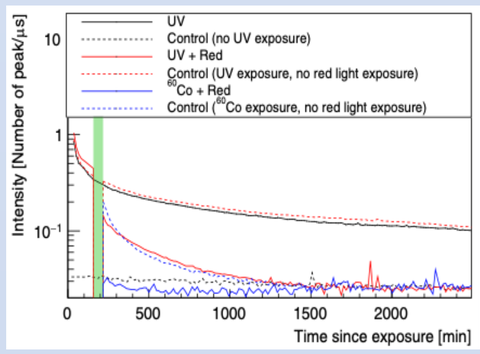
Per Back, Chao Tang and Kurt Wiesenfeld ( 1991 paper)
**Self-Organized Criticality**

## Thermally-stimulated luminescence, electron emission

Effects of stored energy release present in most materials, including NaI(Tl)
up to 15 % of energy deposited by radiation exposure can come out as TSLs

**modulation of Delayed Luminescence (phosphorescence) due to seasonal modulation of muon flux should be present in all detectors- but overwhelmed by other factors**

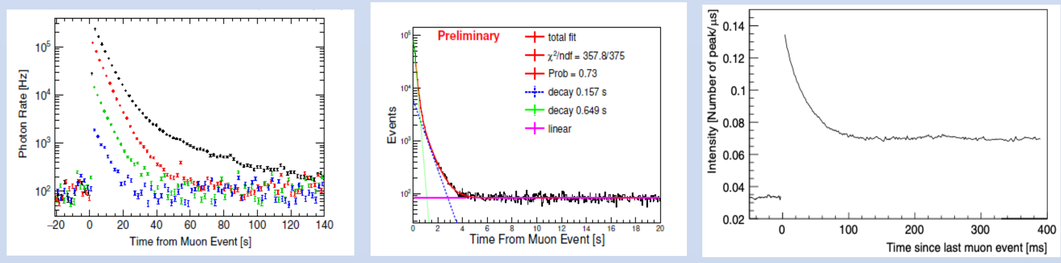
## Delayed emission rate and its suppression




- We tested irradiation of the NaI(Tl) crystal with red light after UV exposure to study how it may change the delayed photon emission (as exposure to red/IR light suppresses TSL) i
- A large drop in the light intensity is observed after the red-light exposure, and the residual light emission rate also decreases at a faster pace
- To the best of our knowledge, our result is the first demonstration of delayed luminescence reduction following UV and gamma radiation via red-light exposure in NaI(Tl) detector

## NaI(Tl) delayed luminescence after muons

### Strongly material and residual radioactivity dependent

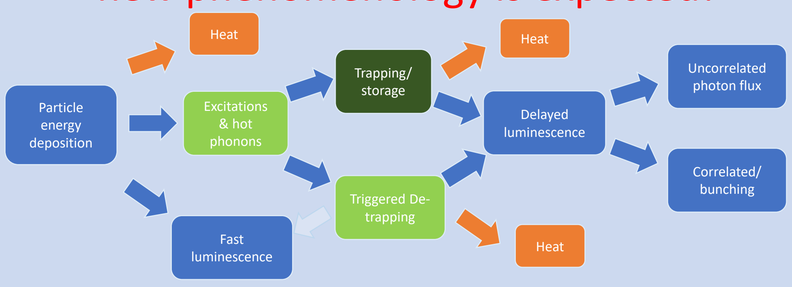



Ice cube (2016), CONUS (2016), Our data (averaged, many events)
We suspect that residual radioactivity effectively destroys long-living states produced by muons or UV light

How delayed luminescence after muons looks like in DAMA-LIBRA?
Delayed luminescence after UV for DAMA-LIBRA crystals underground?

## Realistic empirical model for delayed luminescence

### new phenomenology is expected!



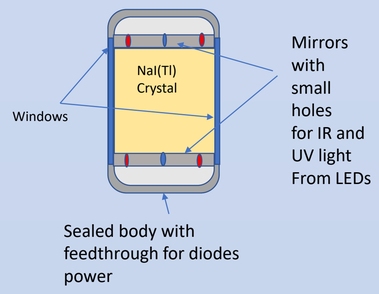

Environment (temperature, pressure, the electric and magnetic fields can modulate distribution from primary to heat, fast luminescence, and storage; from storage to heat and luminescence, and ratio between uncorrelated/correlated luminescence.
**nano-explosives**: Neutrinos/dark matter can cause de-trapping (without primary luminescence) and modulation.
**One needs to monitor uncorrelated luminescence as check for environmental modulation factors**
**Temperature is a strong known factor.** Changes in vibration level (traffic) can cause modulation, etc.

## Questions to experiments & important new effects

- Will exposure of NaI(Tl) to $^{60}$Co after irradiation with UV light kill long (two-days) delayed luminescence?

One can surround NaI(Tl) crystal with cylindrical mirror with small holes for radiation from IR and UV LEDs, and incapsulate the assembly. In such setup:

- Periodic exposure to UV light can make detector sensitive to reactor antineutrinos
- Periodic exposure to UV light can increase the DAMA-LIBRA modulation
- Periodic exposure to IR light will "kill" the Dama-Libra signal
- Important: crystals with low residual radioactivity are required!

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