On the annual modulations in direct-detection experiments and the DAMA results

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McMaster University

Perimeter Institute

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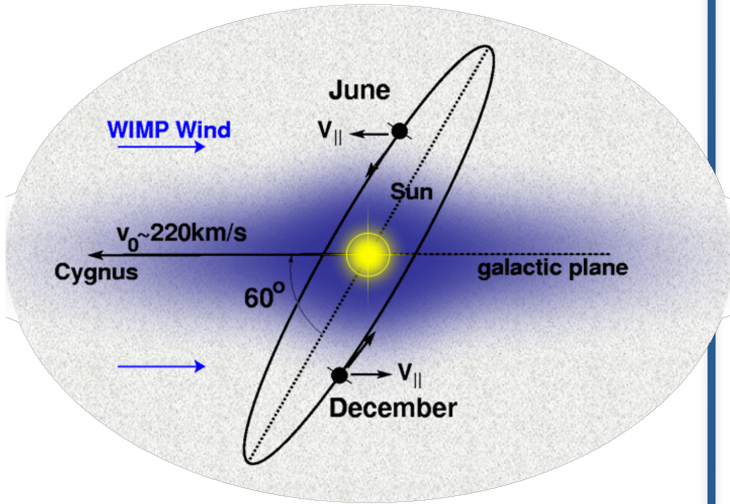
Aspen - *Closing in on Dark Matter* 29 January, 2013

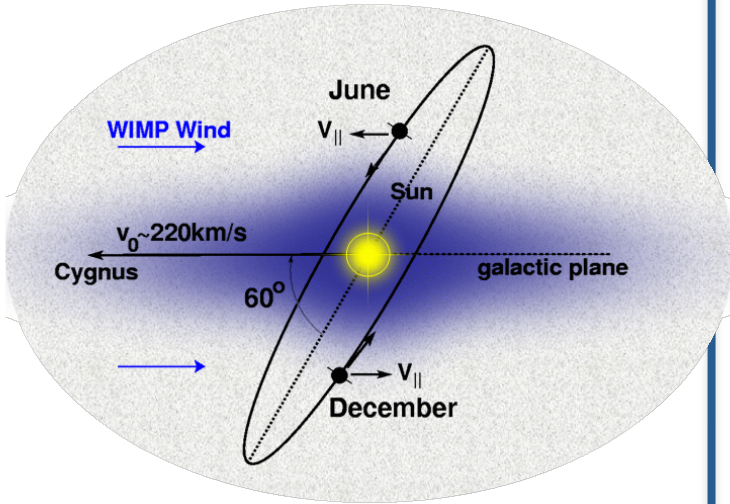
What can we measure?



What can we measure?

We measure the differential recoil rate,

$$\frac{dR}{dE_R} = N_{\rm T}\frac{\rho_{\rm DM}}{M_{\rm DM}}\int_{v_{\rm min}}^{v_{\rm max}} d^3v\, v f(v)\frac{d\sigma}{dE_R}$$



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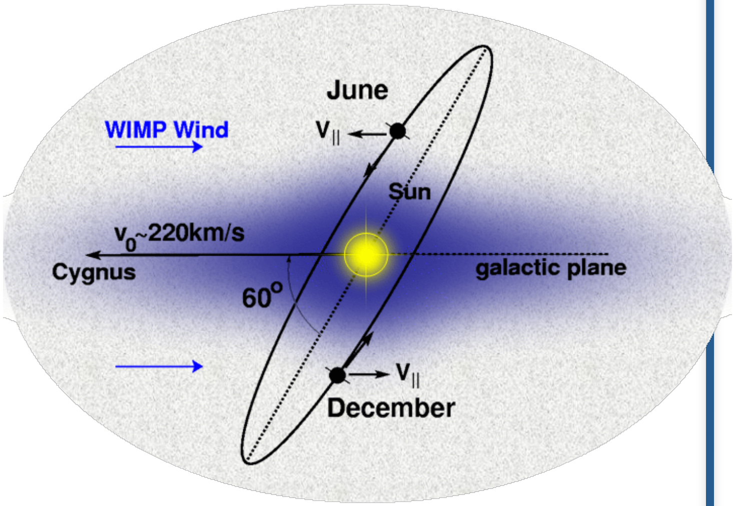

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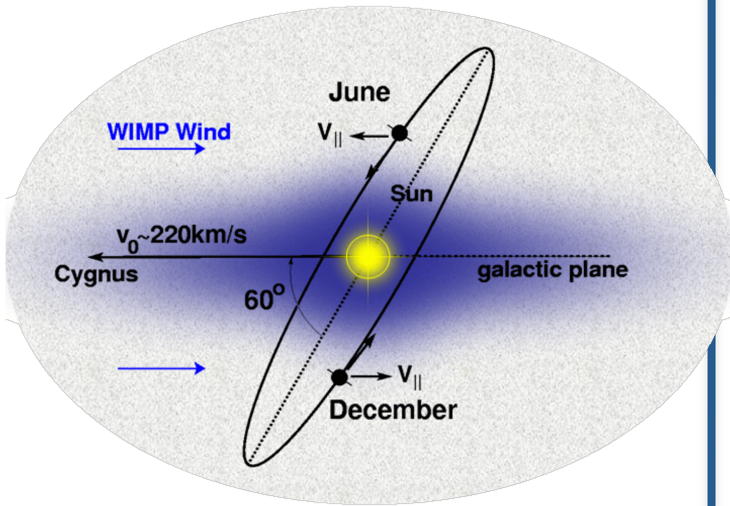

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This leads to the well known annual modulations (Drukier, Freese, Spergel, 1986) and more (Chang, Pradler, IY, 2011):

$$\frac{dR}{dE_R} \propto \int_{v_{min}}^{\infty} \frac{f(v)}{v} dv$$
$$\approx \sum_{n=0,1,\ldots} \tilde{c}_n(v_{min}) \left[\epsilon_v \cos\omega(t - t_0)\right]^n$$
$$= \sum_{n=0,1,\ldots} c_n(v_{min}) \cos\left[n\omega(t - t_0)\right]$$

expanding in powers of

$$\epsilon_v = V_{\oplus}/2v_{\odot} \approx 0.06$$

Testing the Null Hypothesis

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Use the Lomb-Scargle periodogram to test for dominant frequencies,

$$\mathrm{LS}(\omega) = \frac{1}{\sum_i \cos^2(\omega\tilde{t}_i)}\left[\sum_i d_i \cos(\omega\tilde{t}_i)\right]^2 + \frac{1}{\sum_i \sin^2(\omega\tilde{t}_i)}\left[\sum_i d_i \sin(\omega\tilde{t}_i)\right]^2.$$

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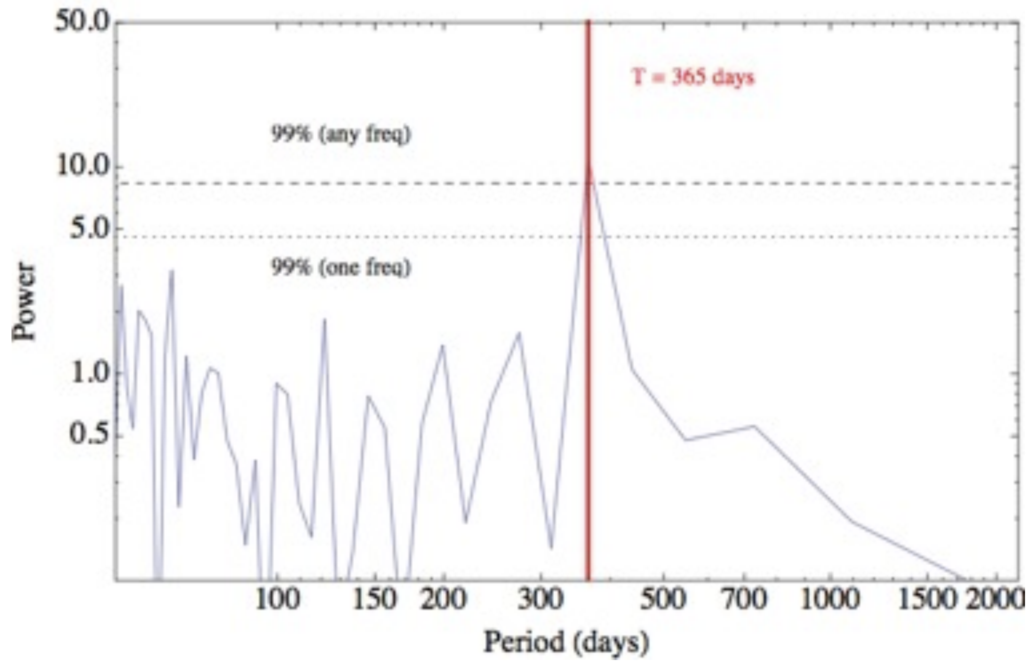
DAMA/LIBRA



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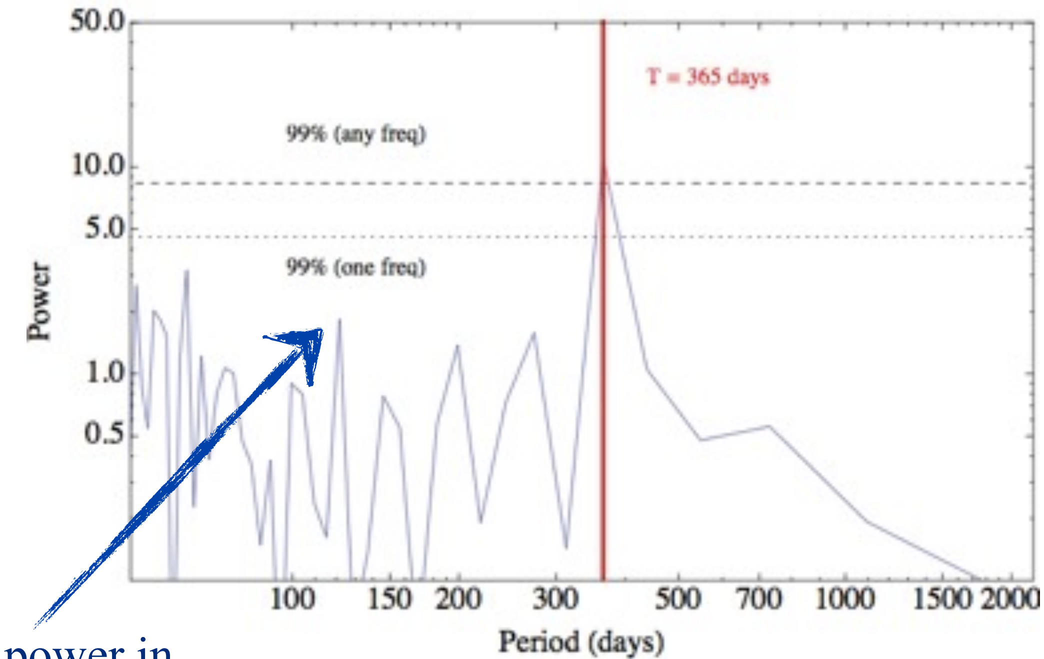

There also seems to be power in 1/3 year
(saw-tooth signal?)

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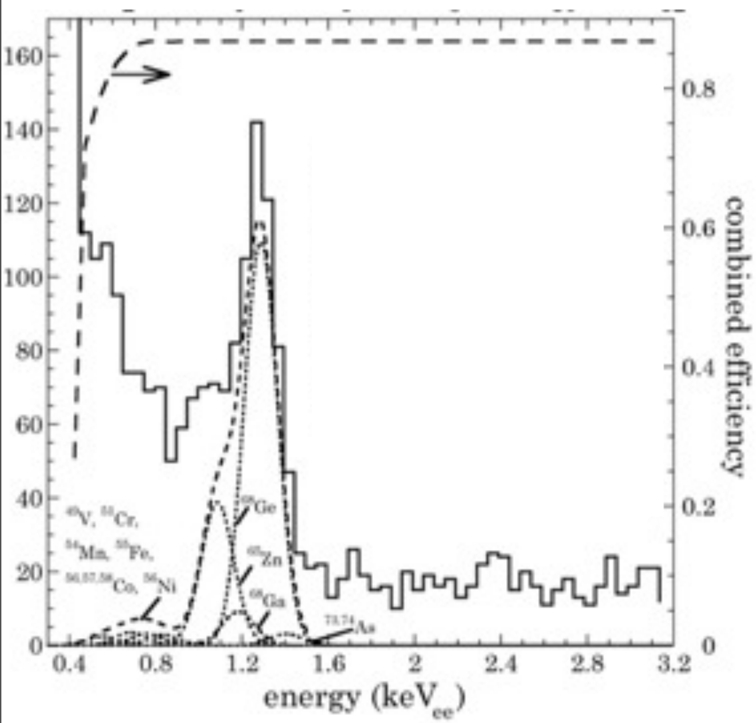
CoGeNT



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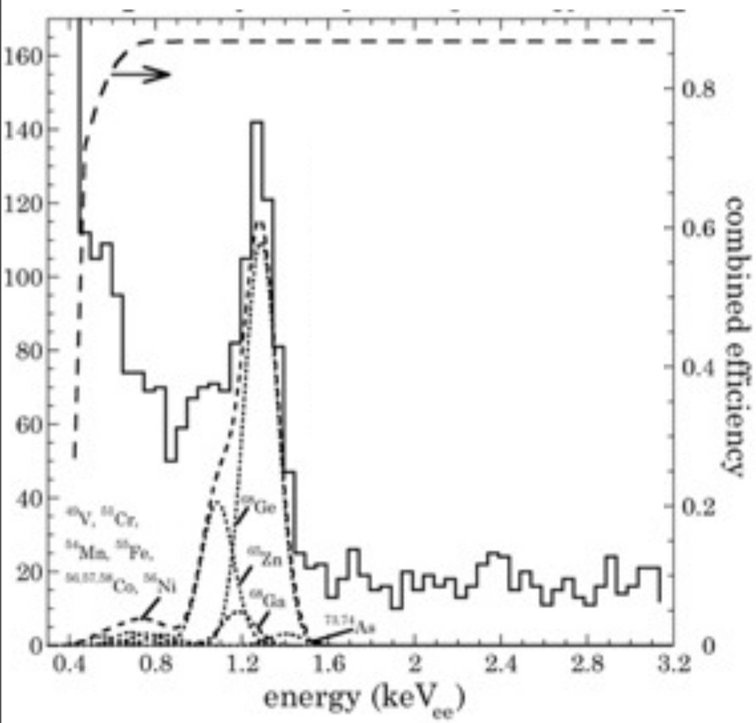

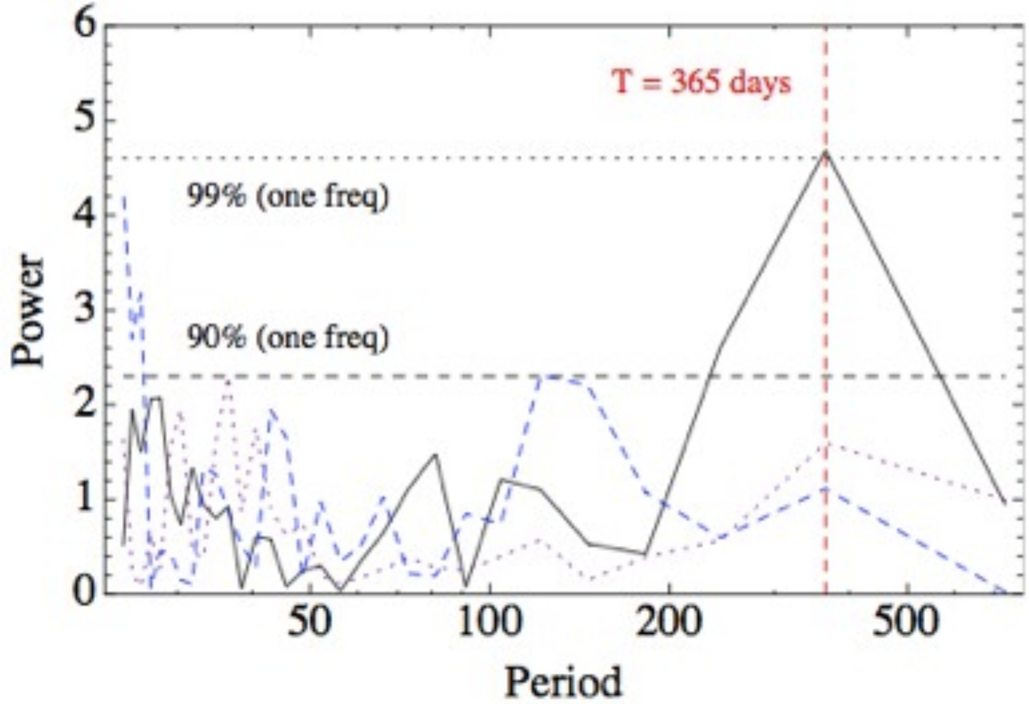

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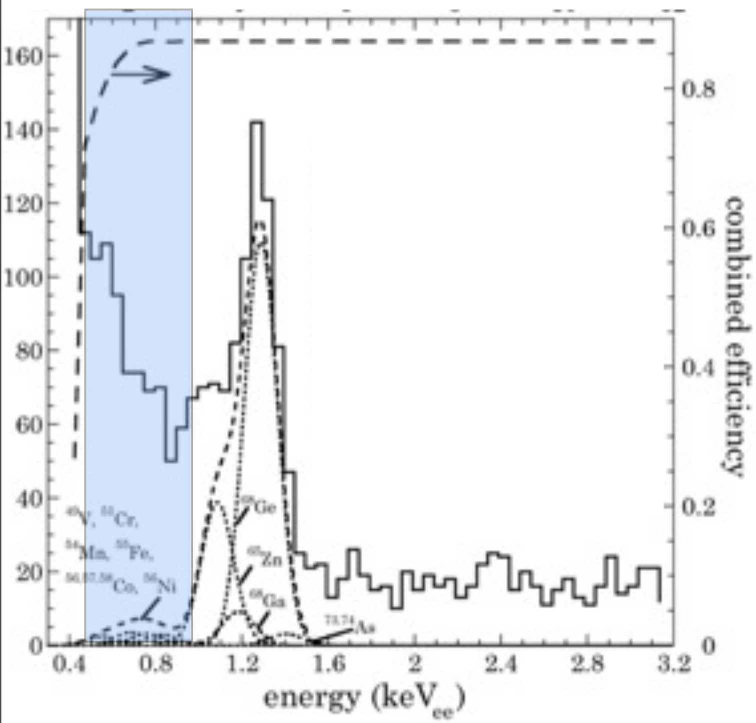

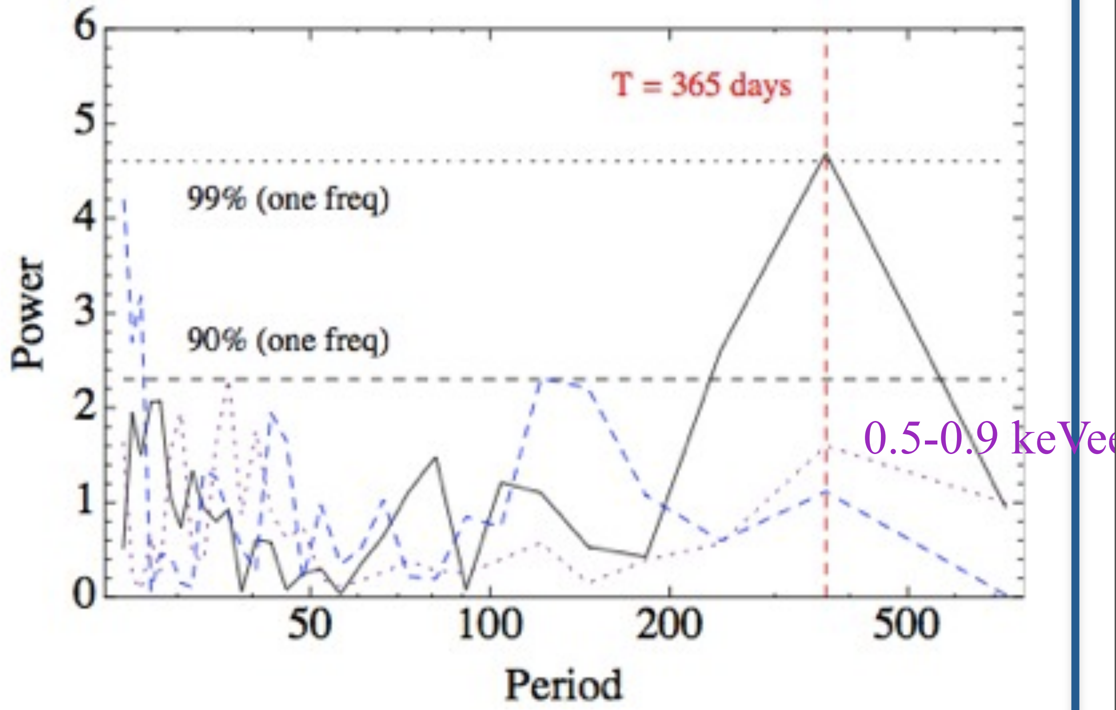

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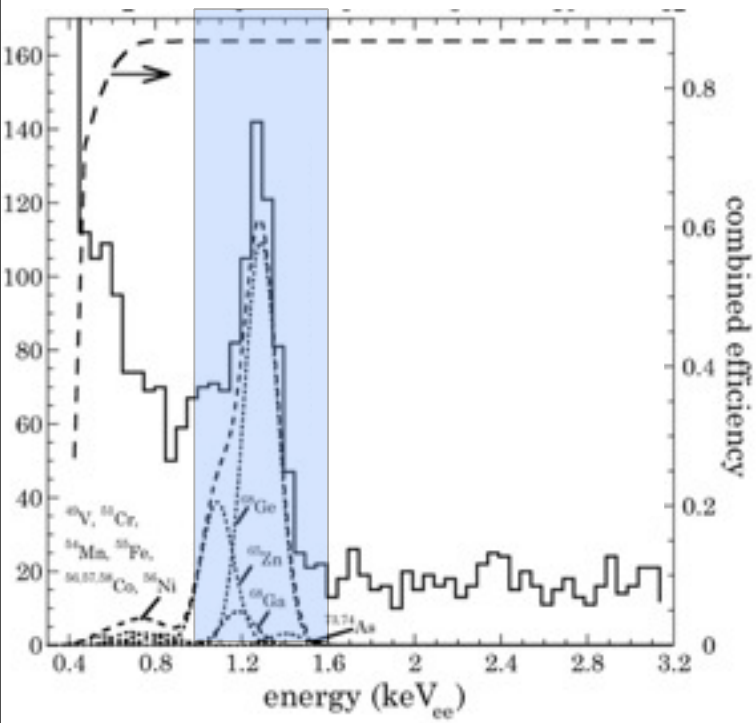

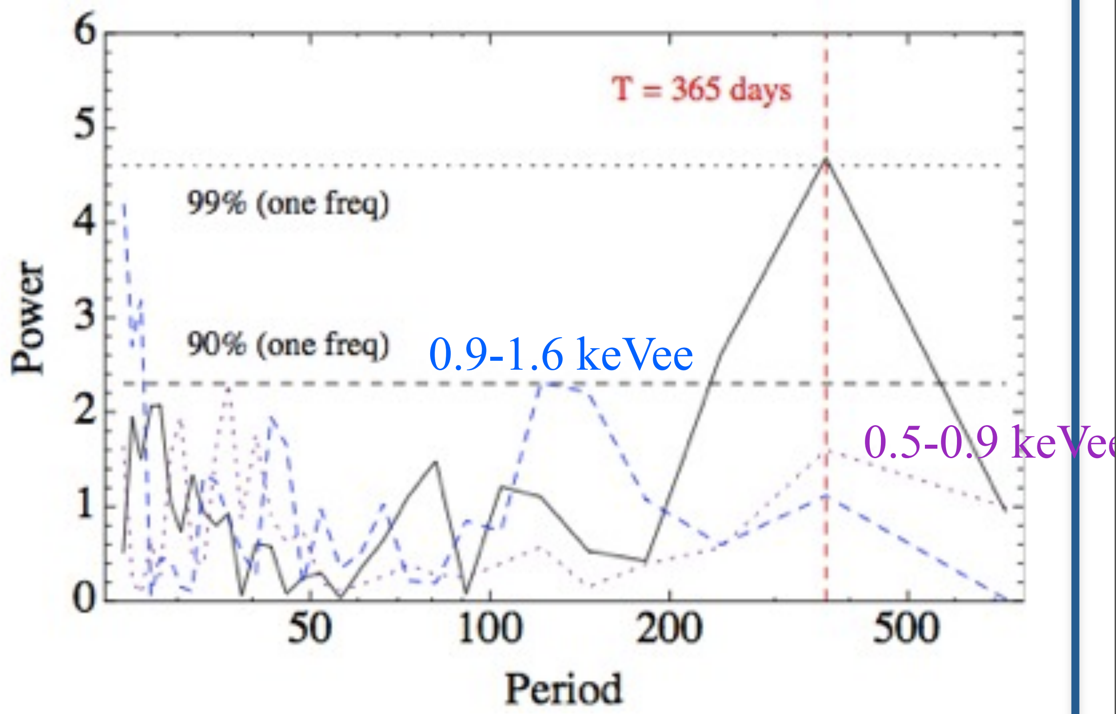

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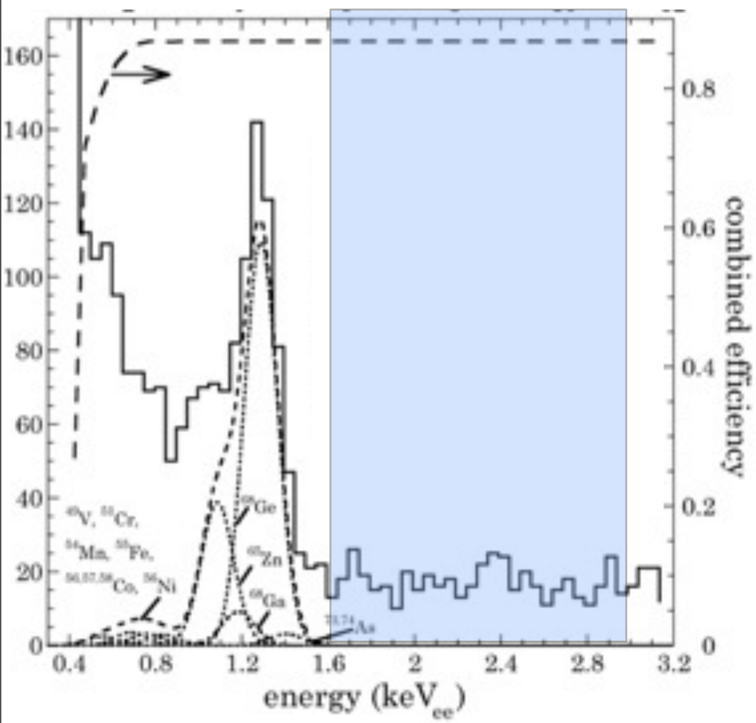

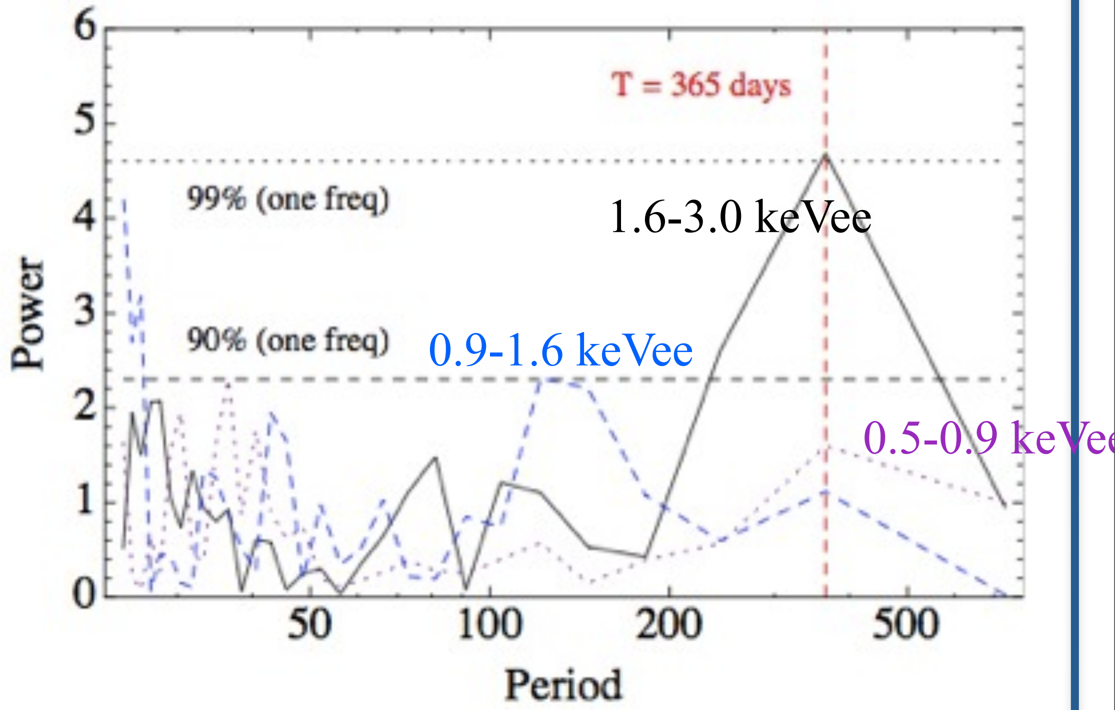

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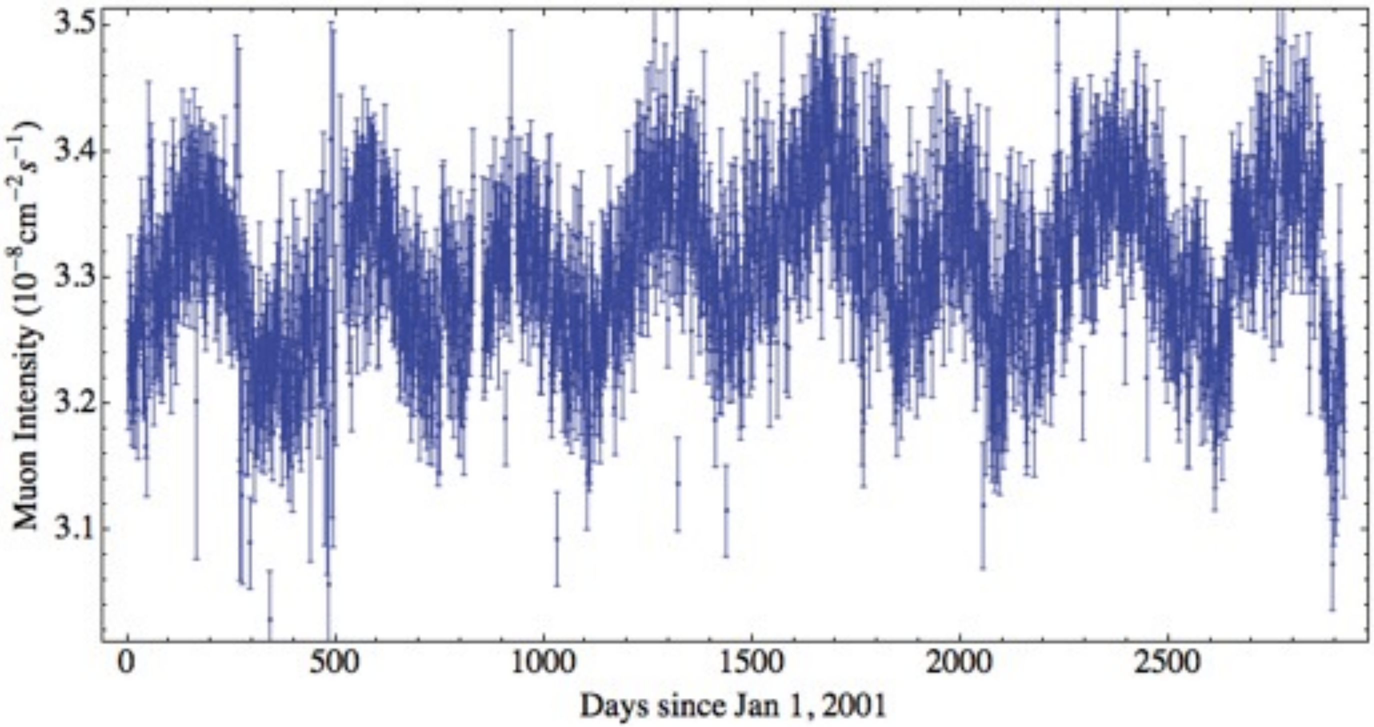

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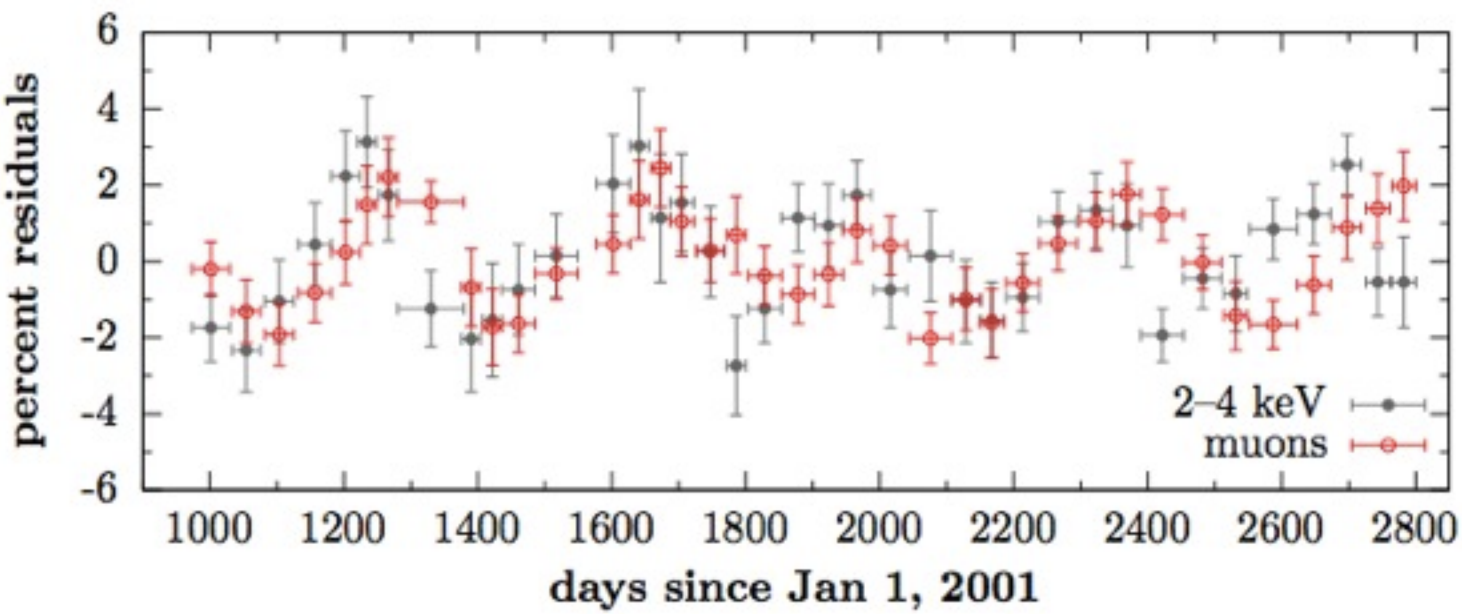
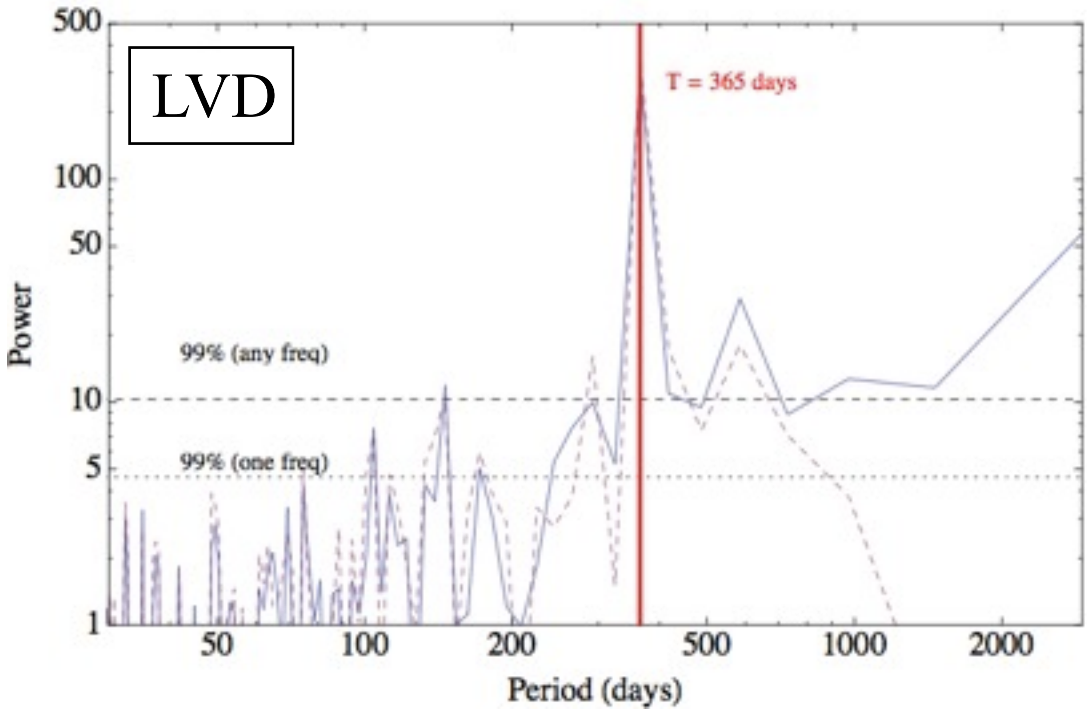


This has been discussed by several independent authors (Ralston 2010, Nygren 2011, Blum 2011).

Power Spectrum

Compare the LS power spectrum of the two datasets



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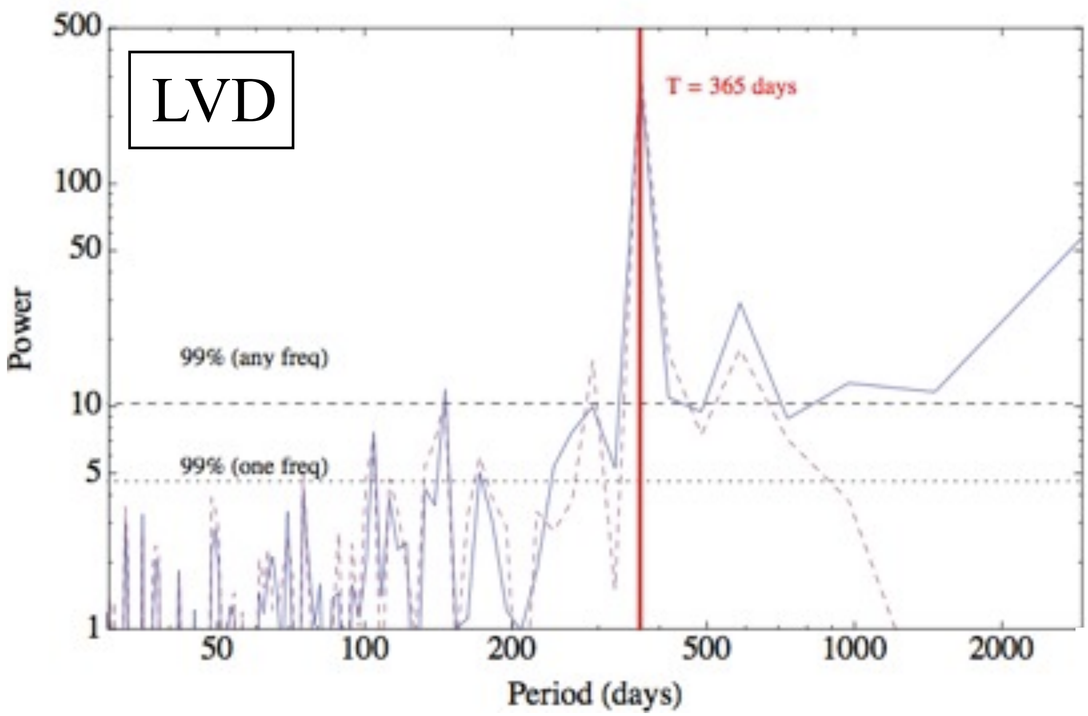

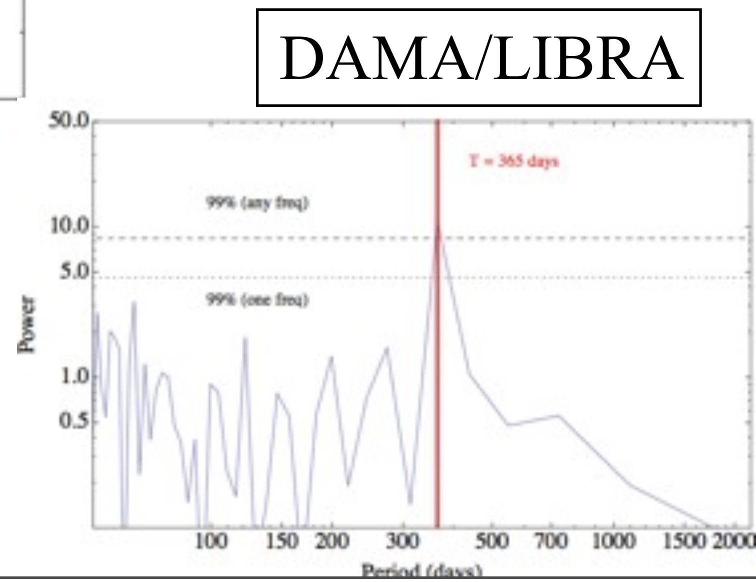

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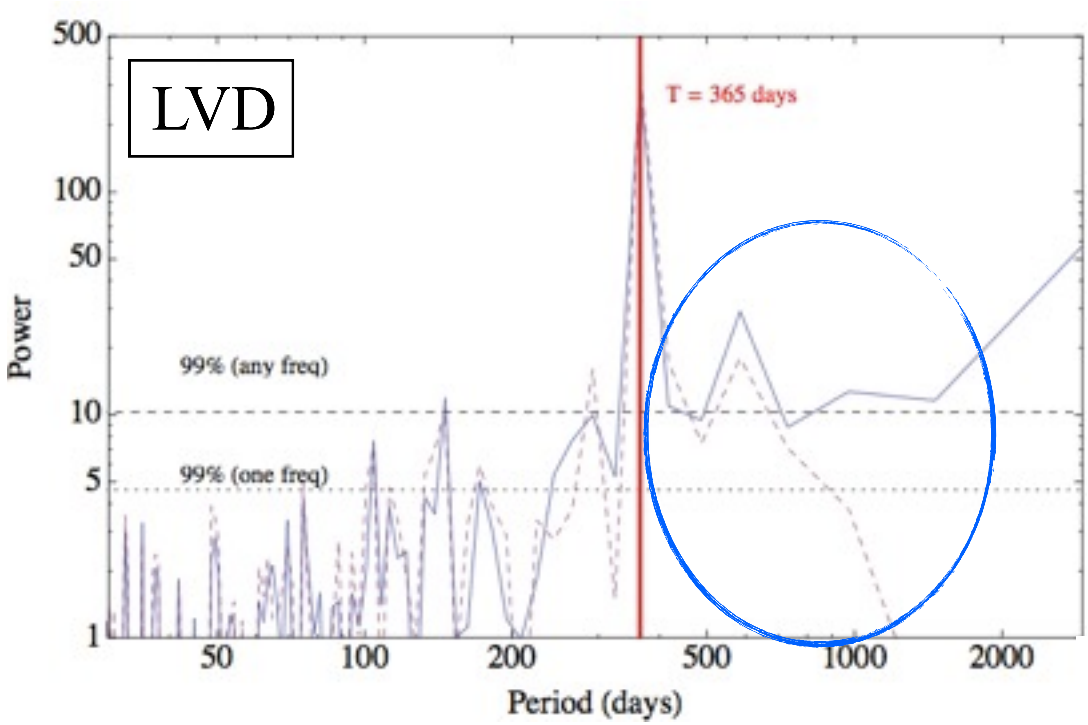

Clearly lacking power at high periods.

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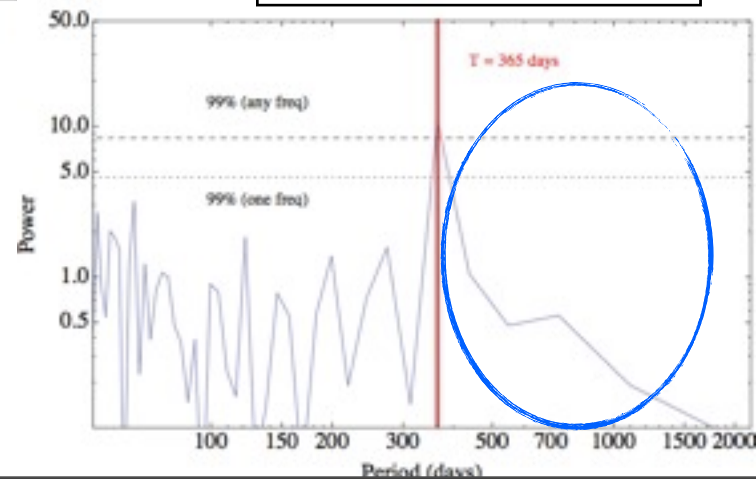

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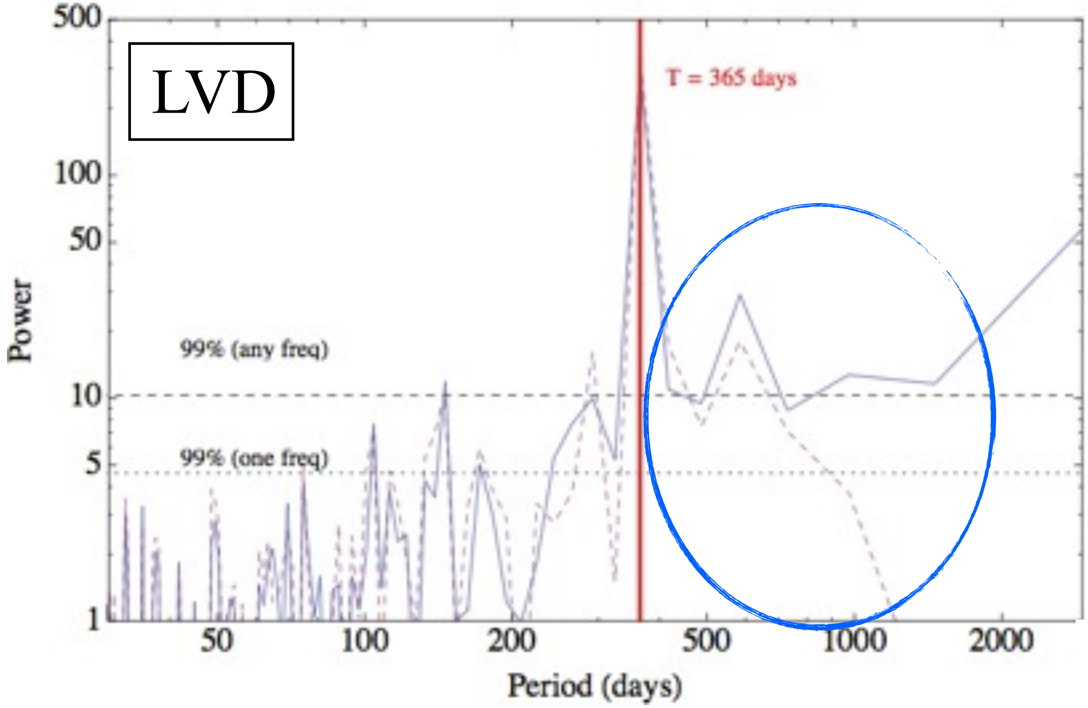

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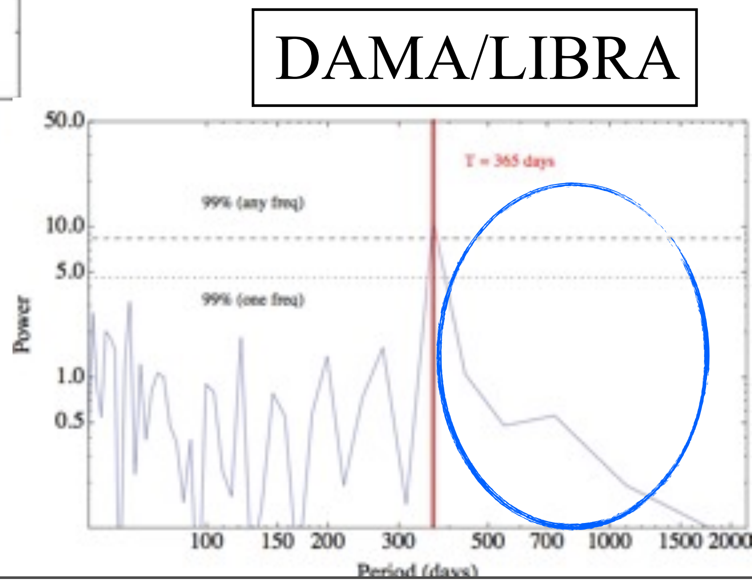
But maybe this is just an artifact of the way DAMA process their data?



Phaseogram

We can compare the two datasets in phase-period space using a generalization of the Lomb-Scargle periodogram

Chang, Pradler, IY, 1111.4222

$$P(\{\omega, t_0\}||d) \propto \frac{\sigma^{1-N}}{\sqrt{p}} \left[1 + \mathrm{Erf}\left(\frac{h}{\sqrt{2\sigma^2 p}}\right)\right] \times \exp\left(\frac{h^2}{2\sigma^2 p}\right),$$

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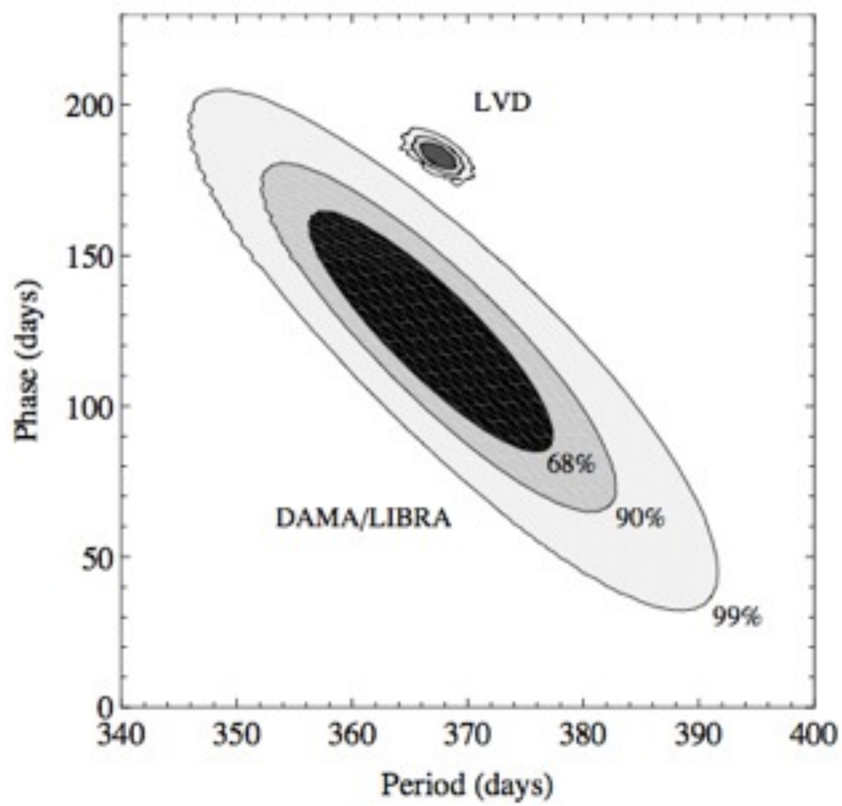

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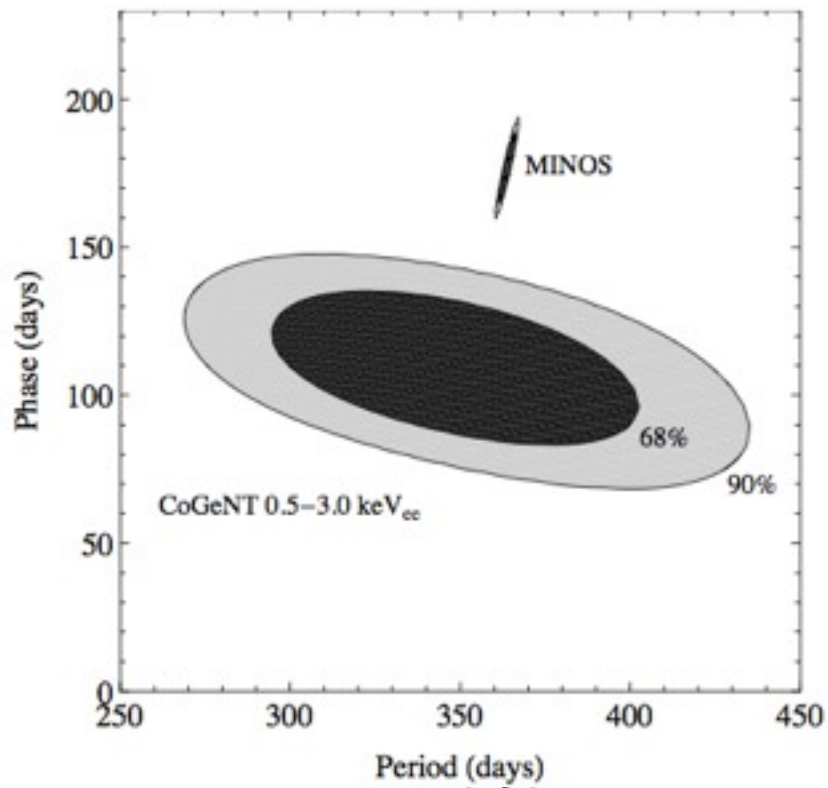

See also recent MINOS analysis 1212.1776

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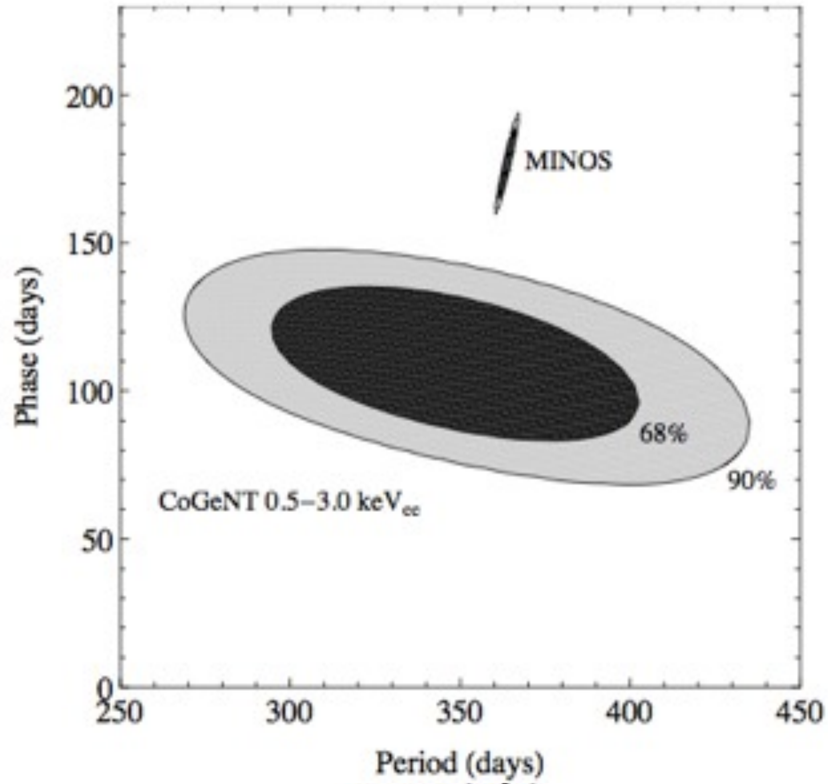

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Correlation Analysis

Without assuming any model, we can compute Pearson's coefficient of correlation between the two datasets.

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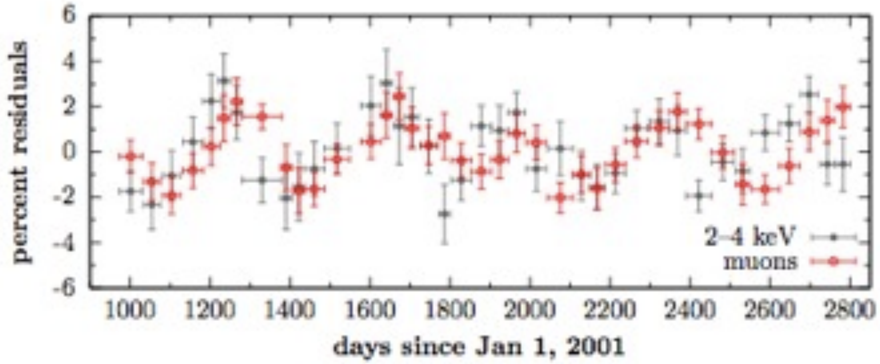

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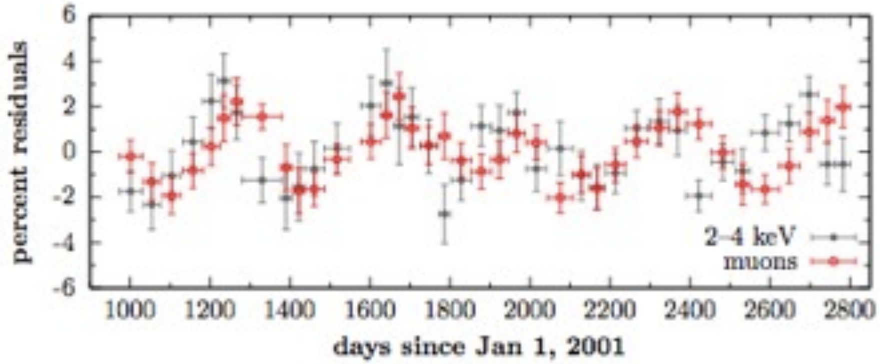

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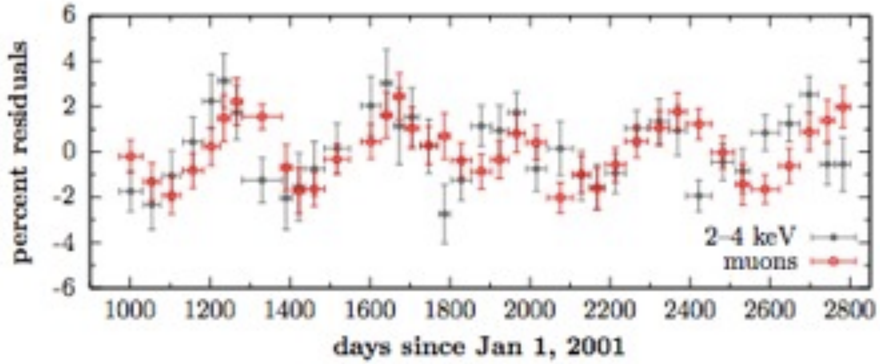

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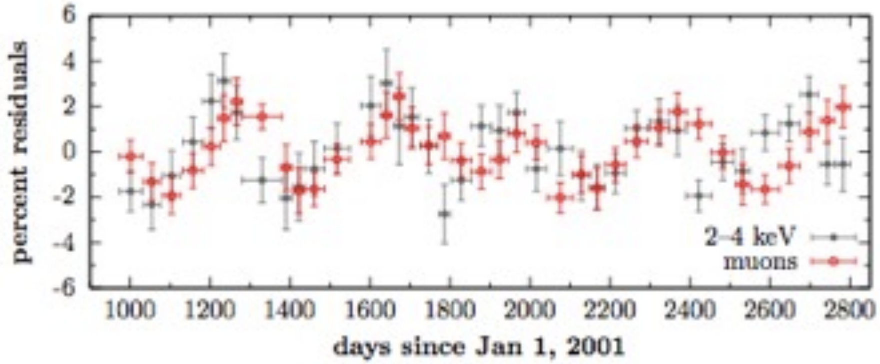

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$$s_i = \frac{y N_{\mu,i}}{M \Delta E \epsilon_i \Delta t_i}$$

where $N_{\mu,i}$ is Poisson distributed with mean

$$\langle N_{\mu,i} \rangle = A_{\text{eff}} I_{\mu,i} \epsilon_i \Delta t_i$$

Fisher Z Transform

This model implies a high degree of correlation. Too high.

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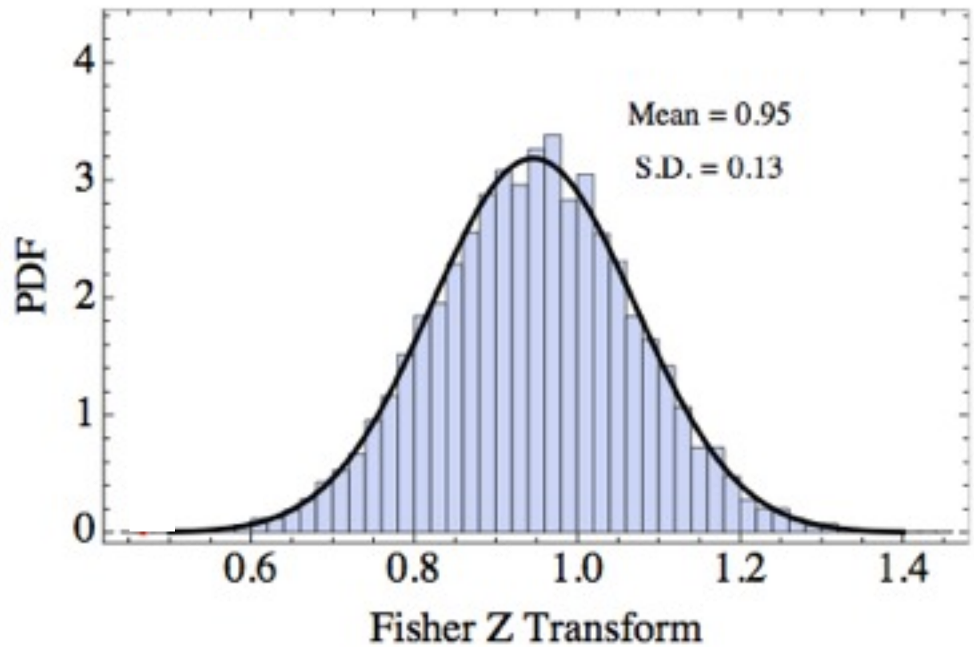

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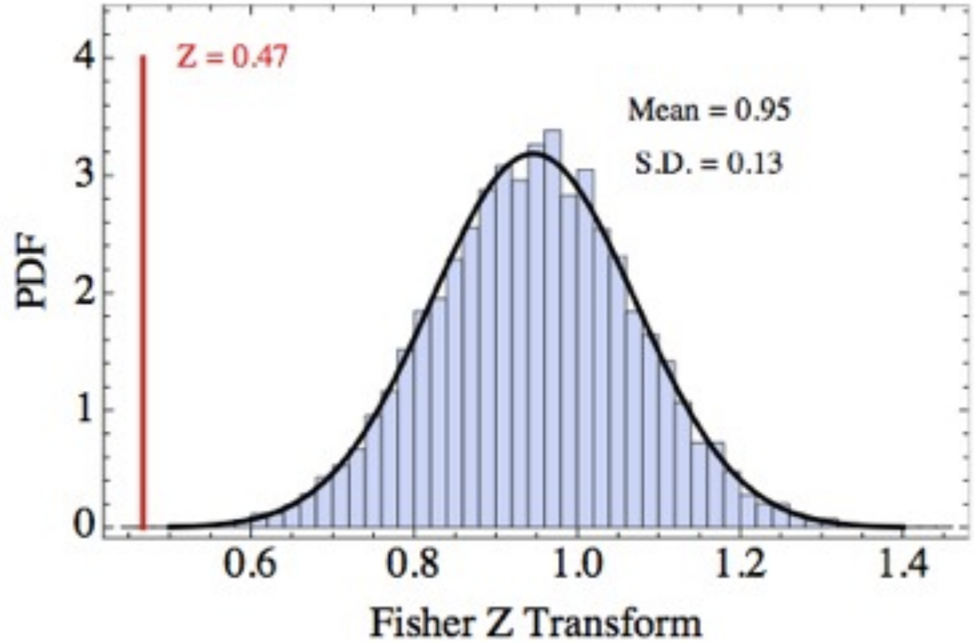

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4. Phaseogram seems robust even under biased binning.

Unmodulated part of the signal

Models

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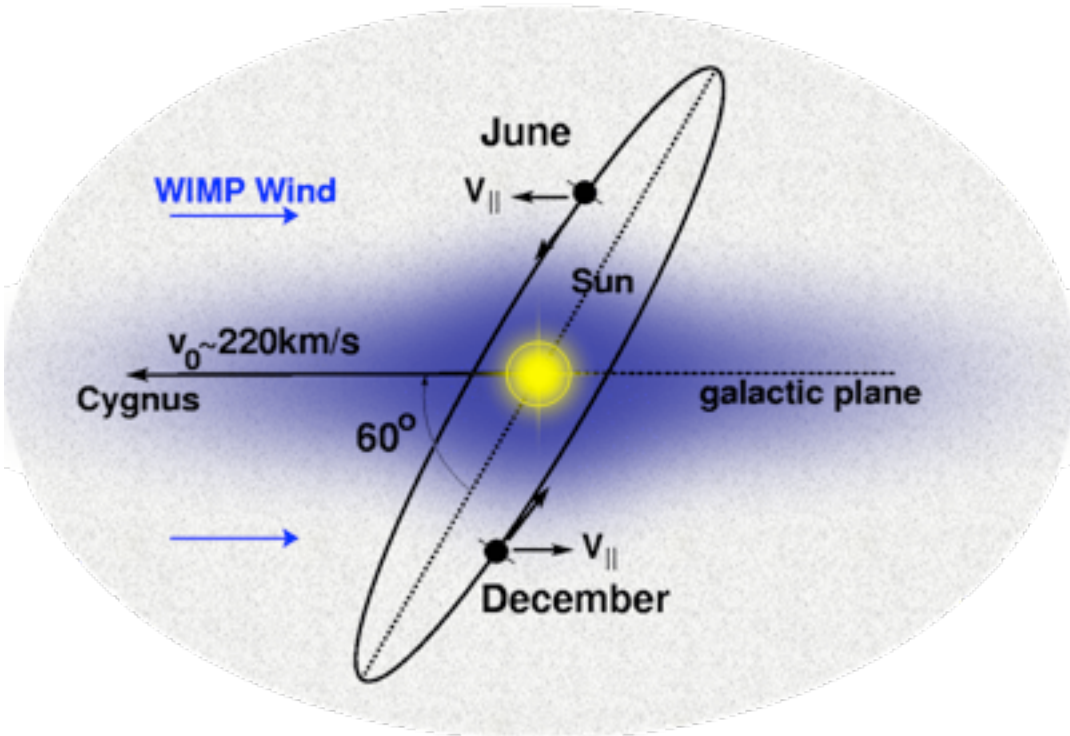
1) MiDM (Tucker-Smith and Weiner 2001, Chang, Weiner, IY, 2010)
2) LDM (Feldstein, Graham, & Rajendran 2010)
3) Light DM (Bottino, Donato, Fornengo, and Scopel, 2008, and others)
4) Channeling (Bozorgnia, Gelmini, and Gondolo 2010 and others)
5) RDM (Bai, Fox, 2009)
6) Leptonic DM (Bernabei 2008 and Kopp, Niro, Schwetz & Zupan 2009)
7) Neutrinos with new baryonic currents (Pospelov 2012)
8) Isospin violating (Chang, Liu, Pierce, Weiner, IY, 2010 and Feng, Kumar, Marfatia & Sanford and others)
9) . . .

Modulation Fraction

The modulation fraction expected in most models is no more than 10%. Is that compatible with the total number of events seen?



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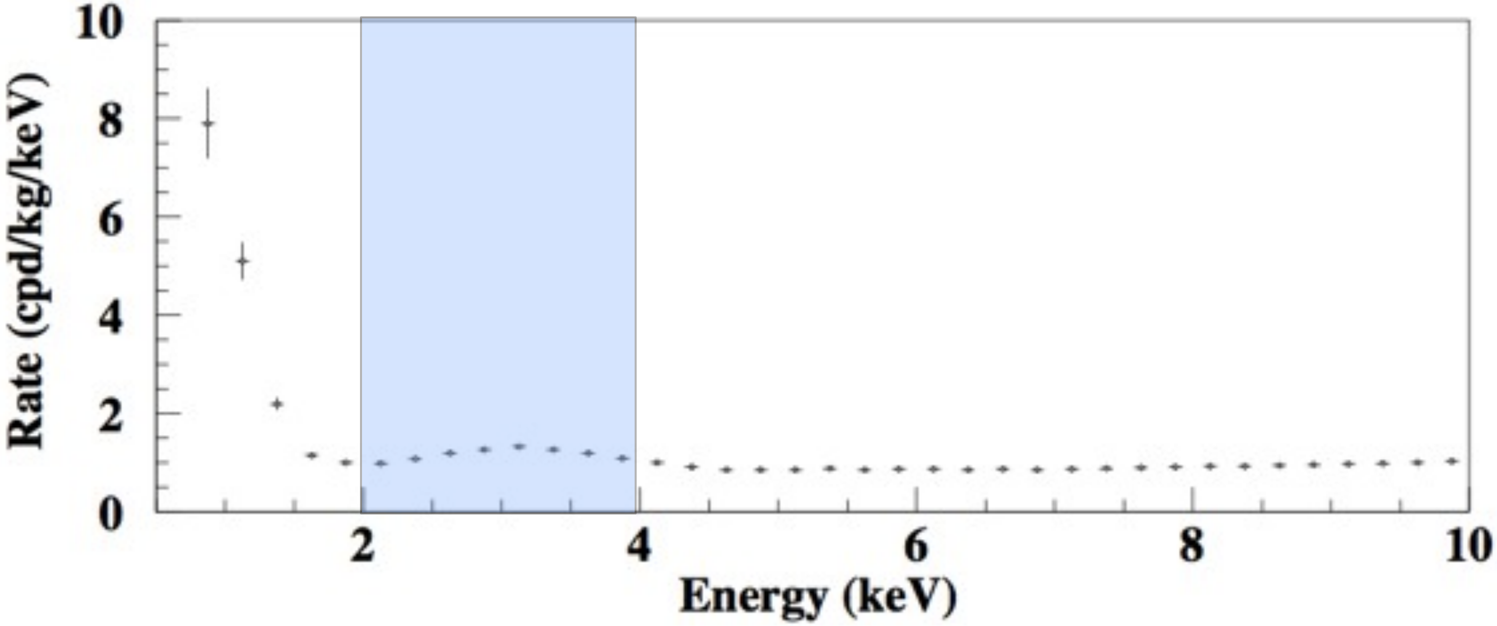

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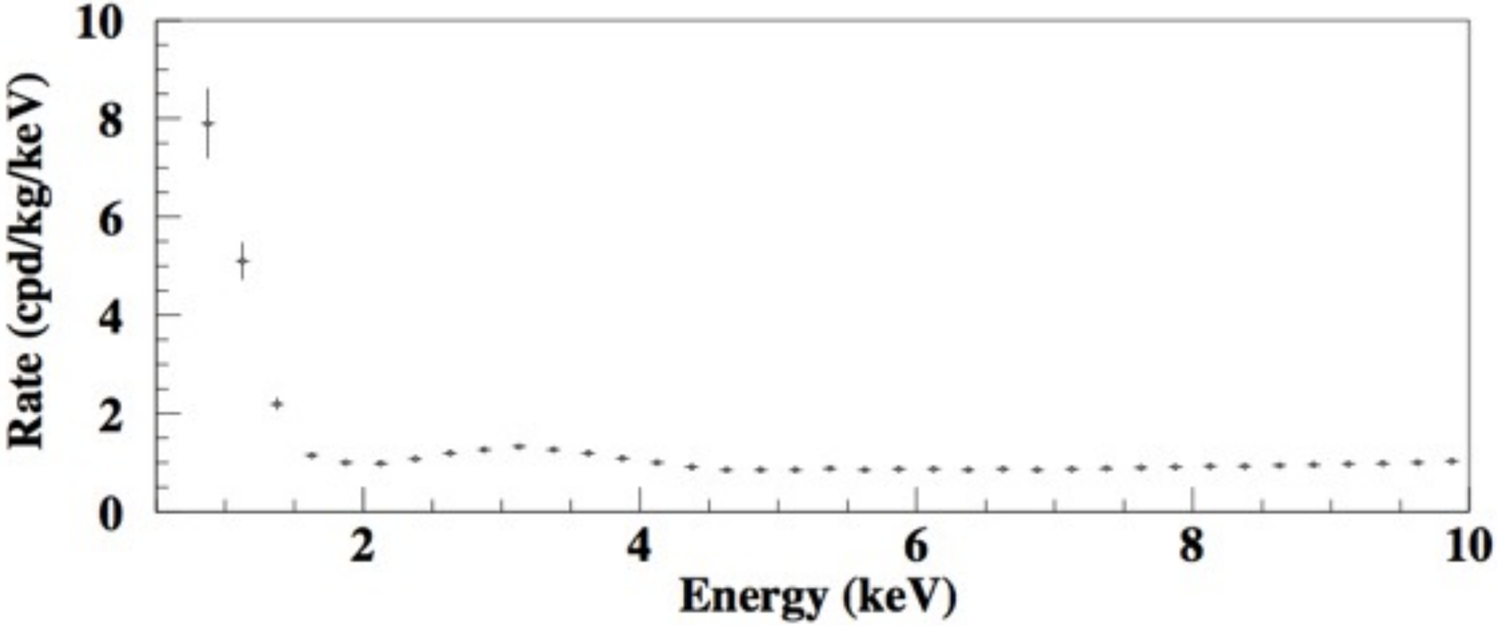

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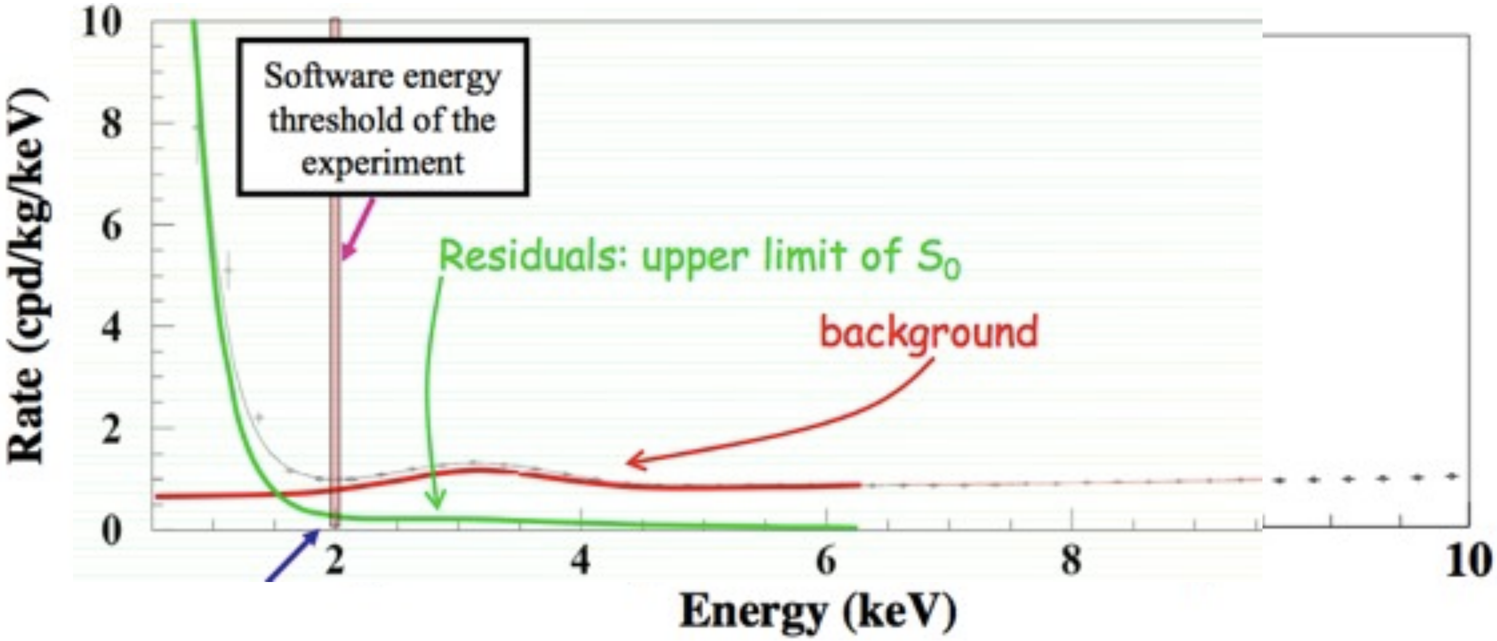

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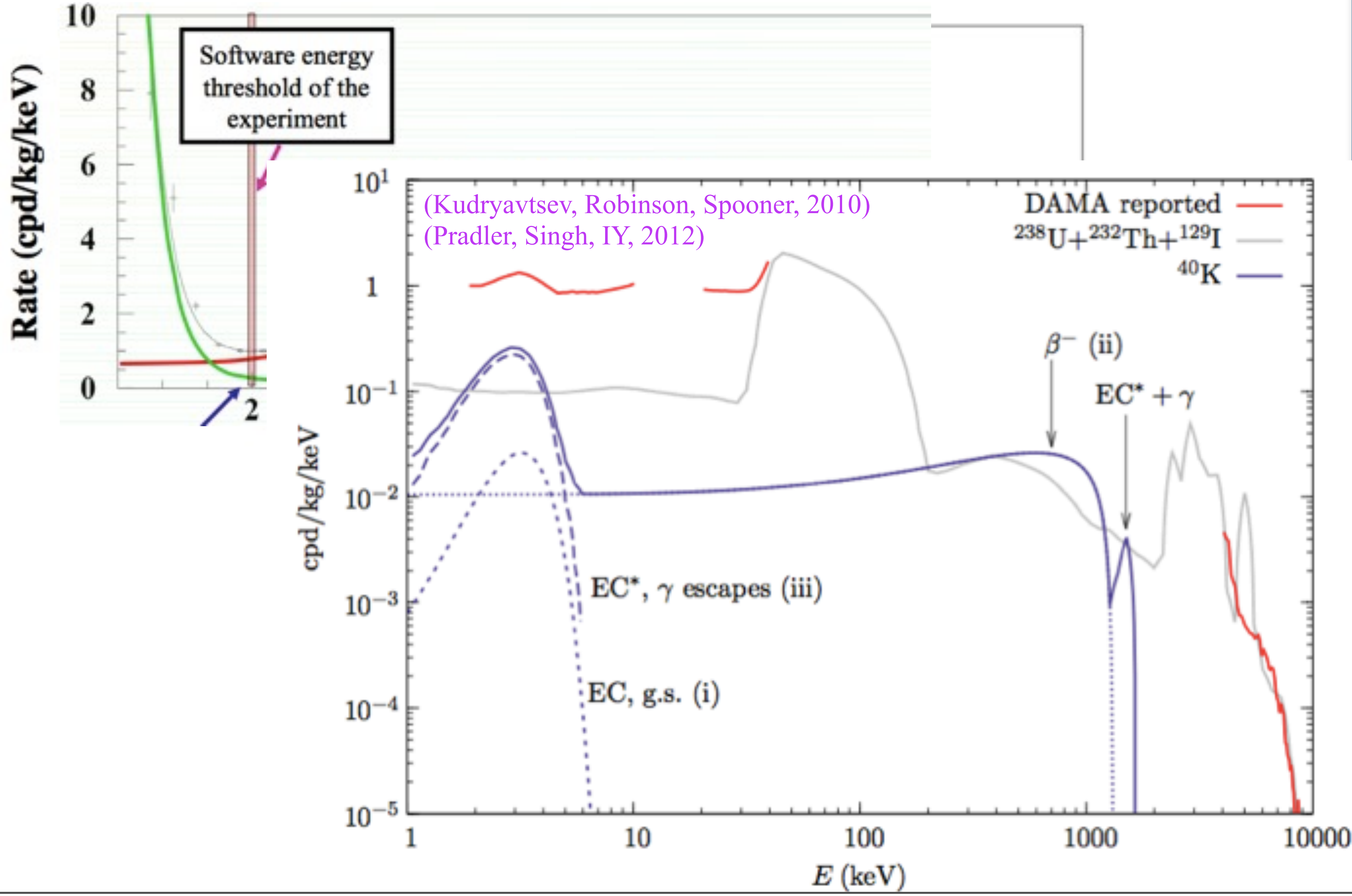
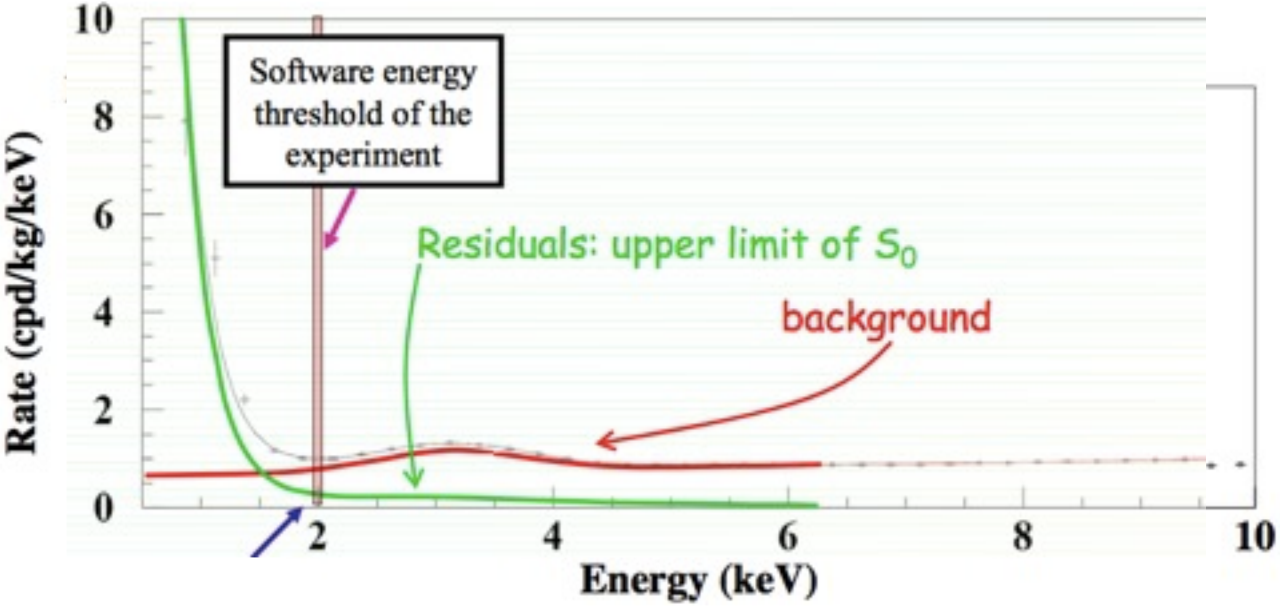


A Simple(r) Fit to the Background



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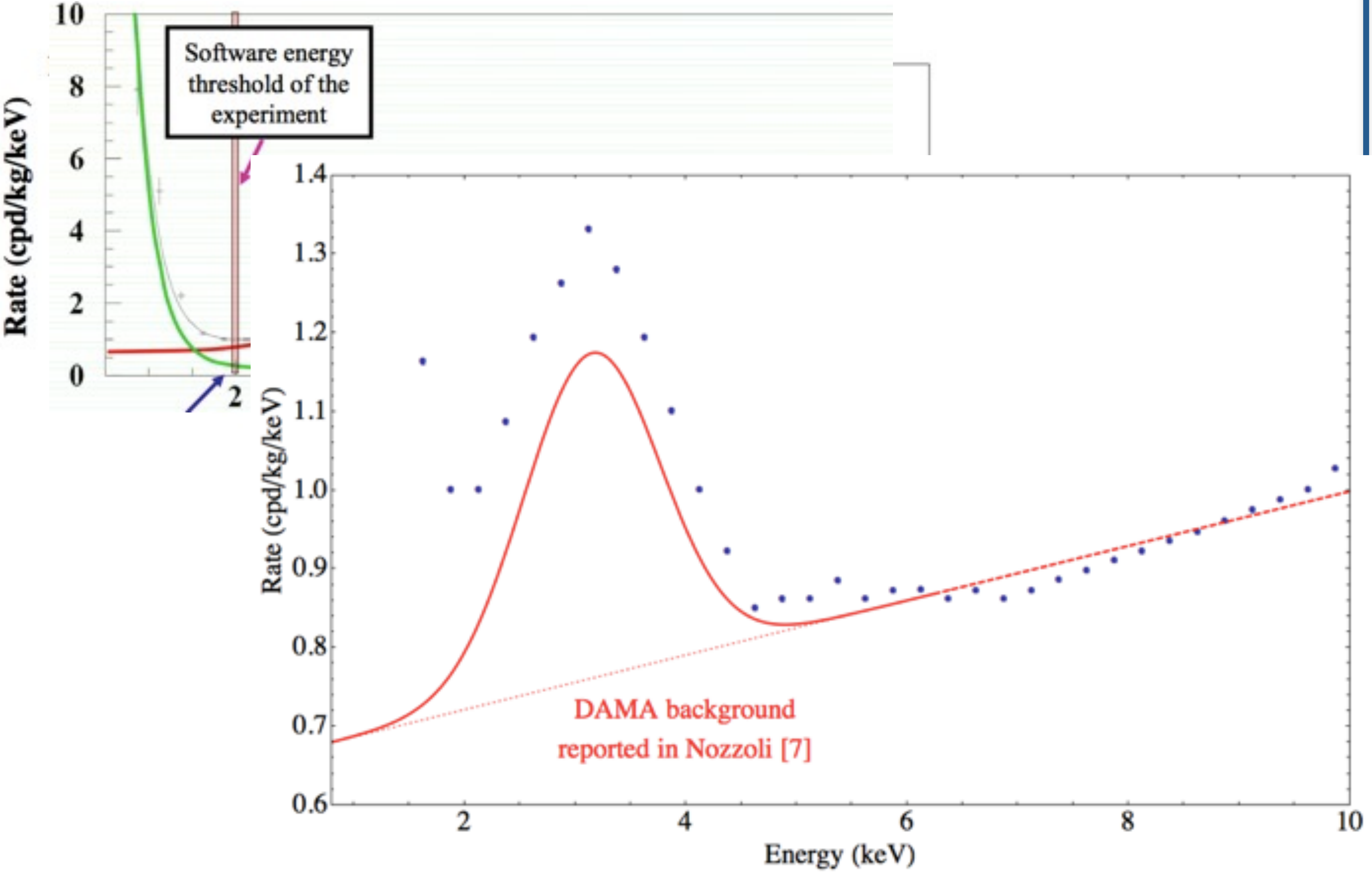

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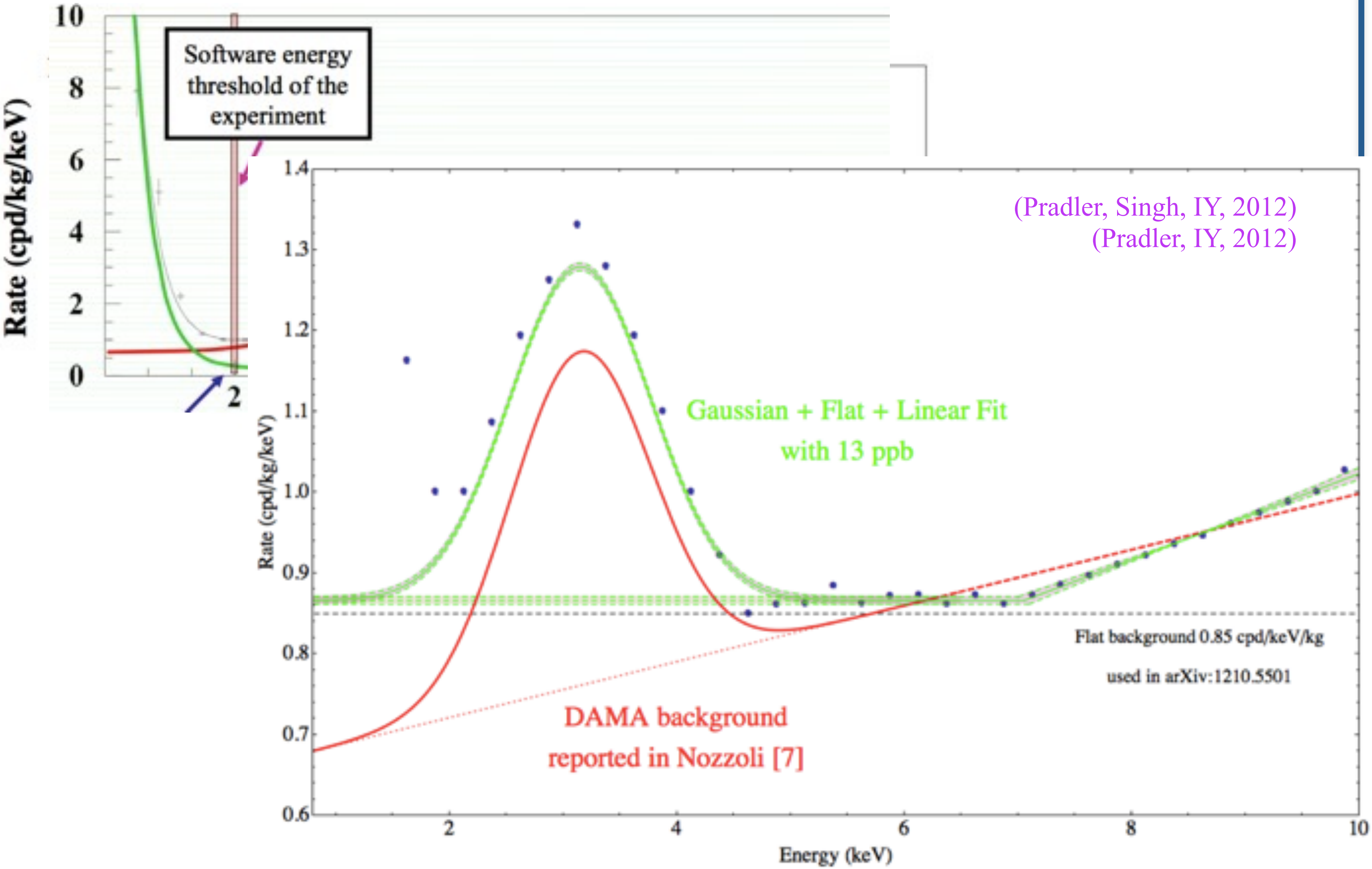

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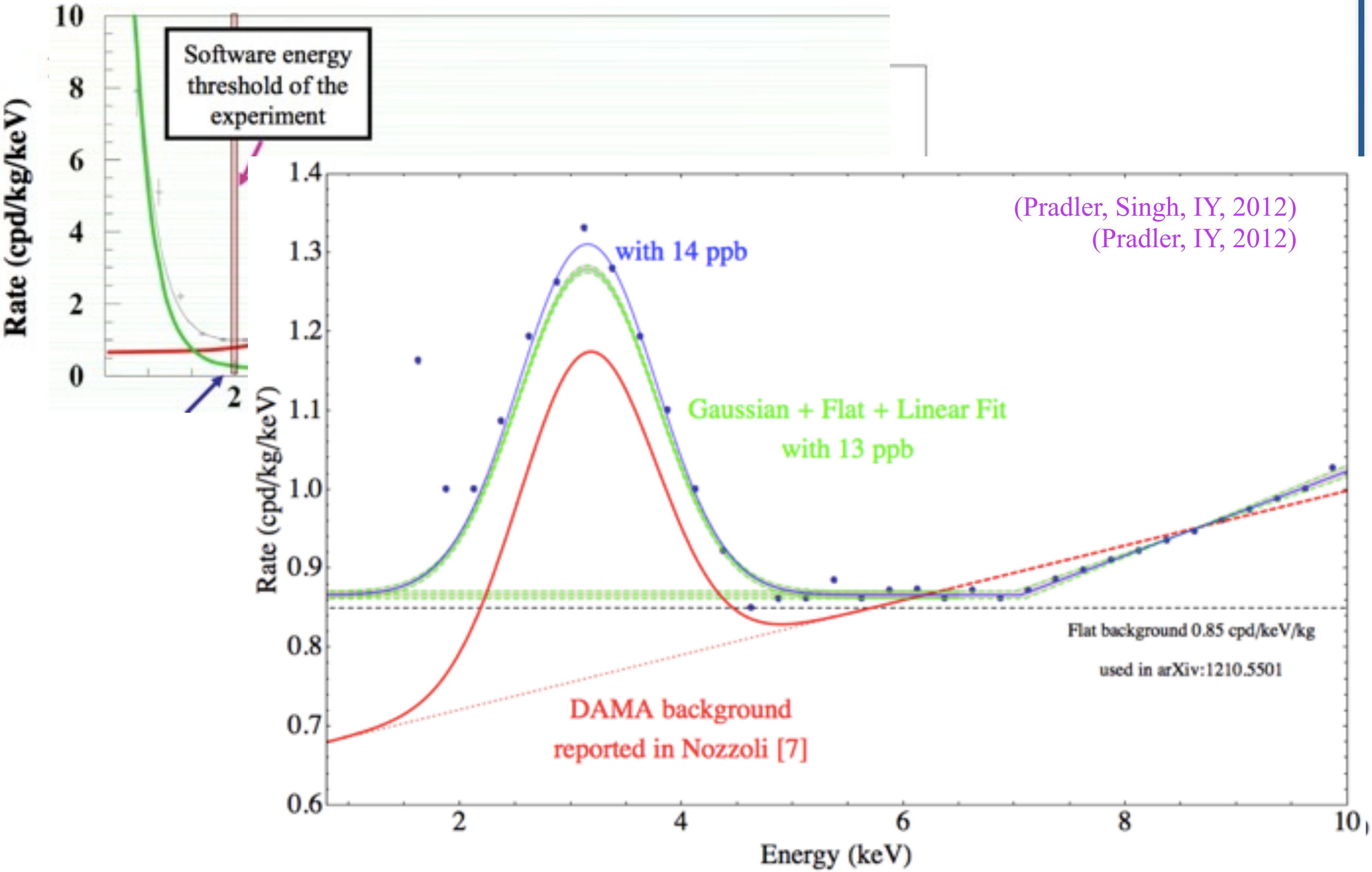
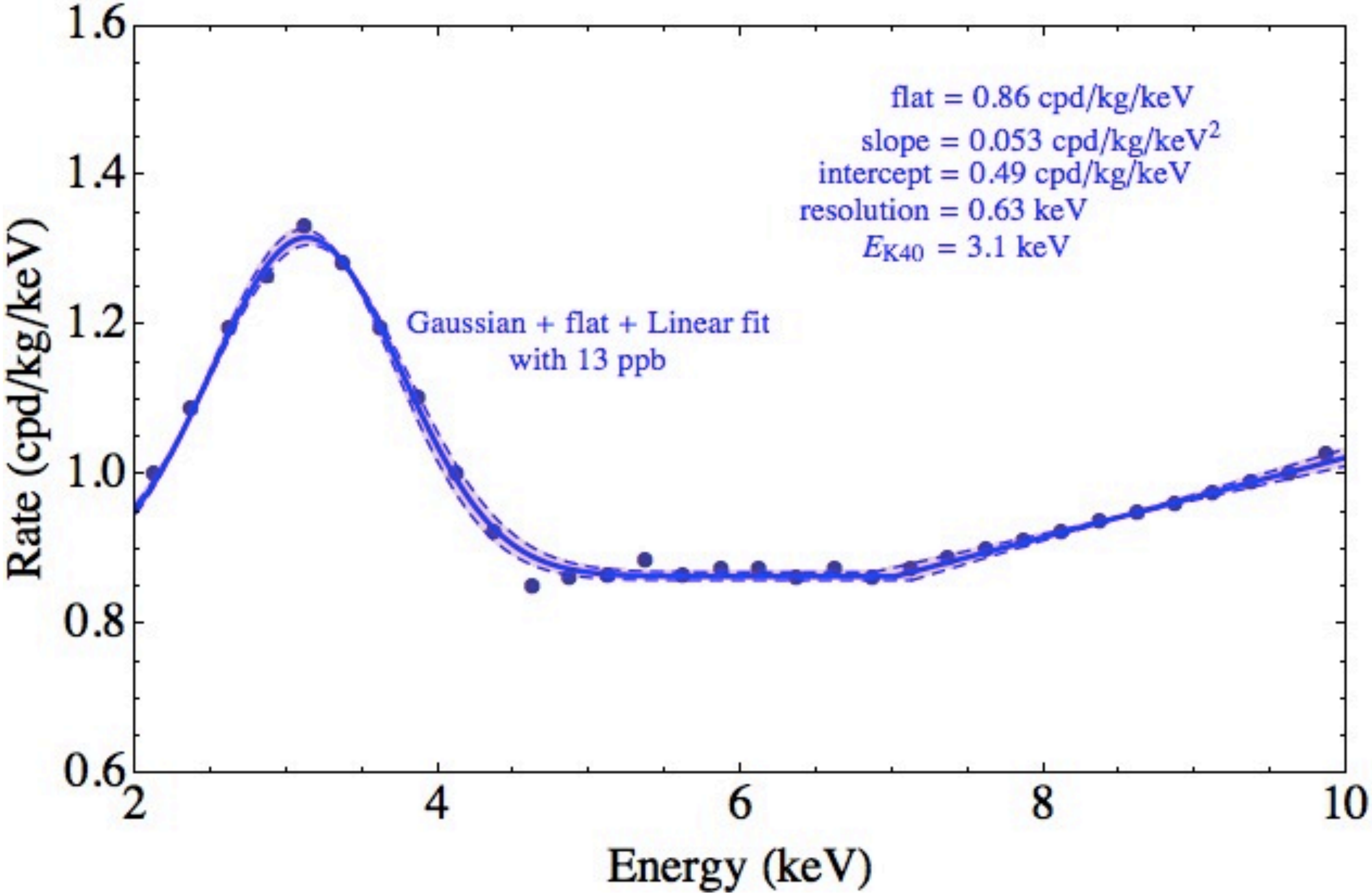


Full Fit - it only gets worse. . .



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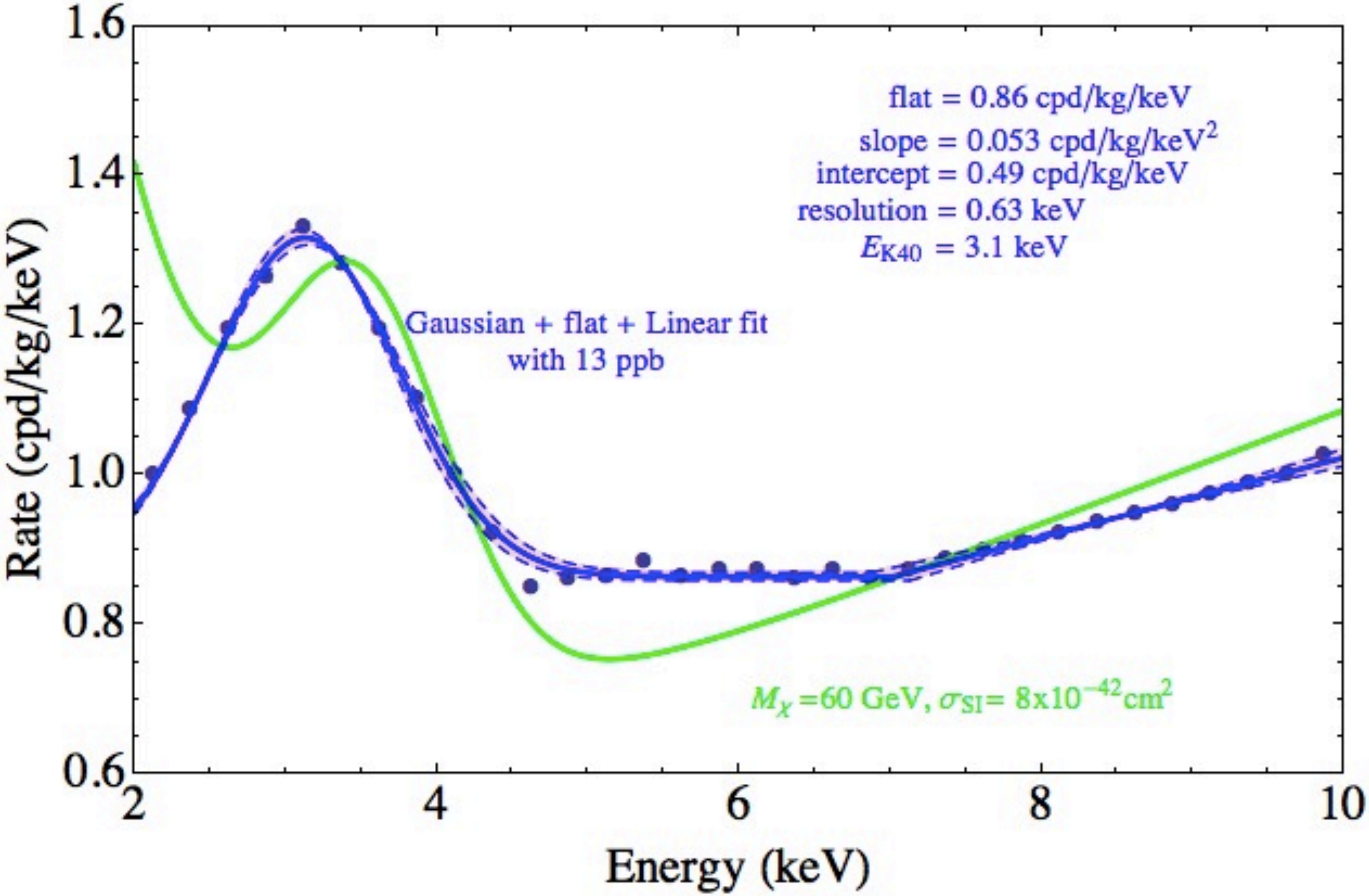

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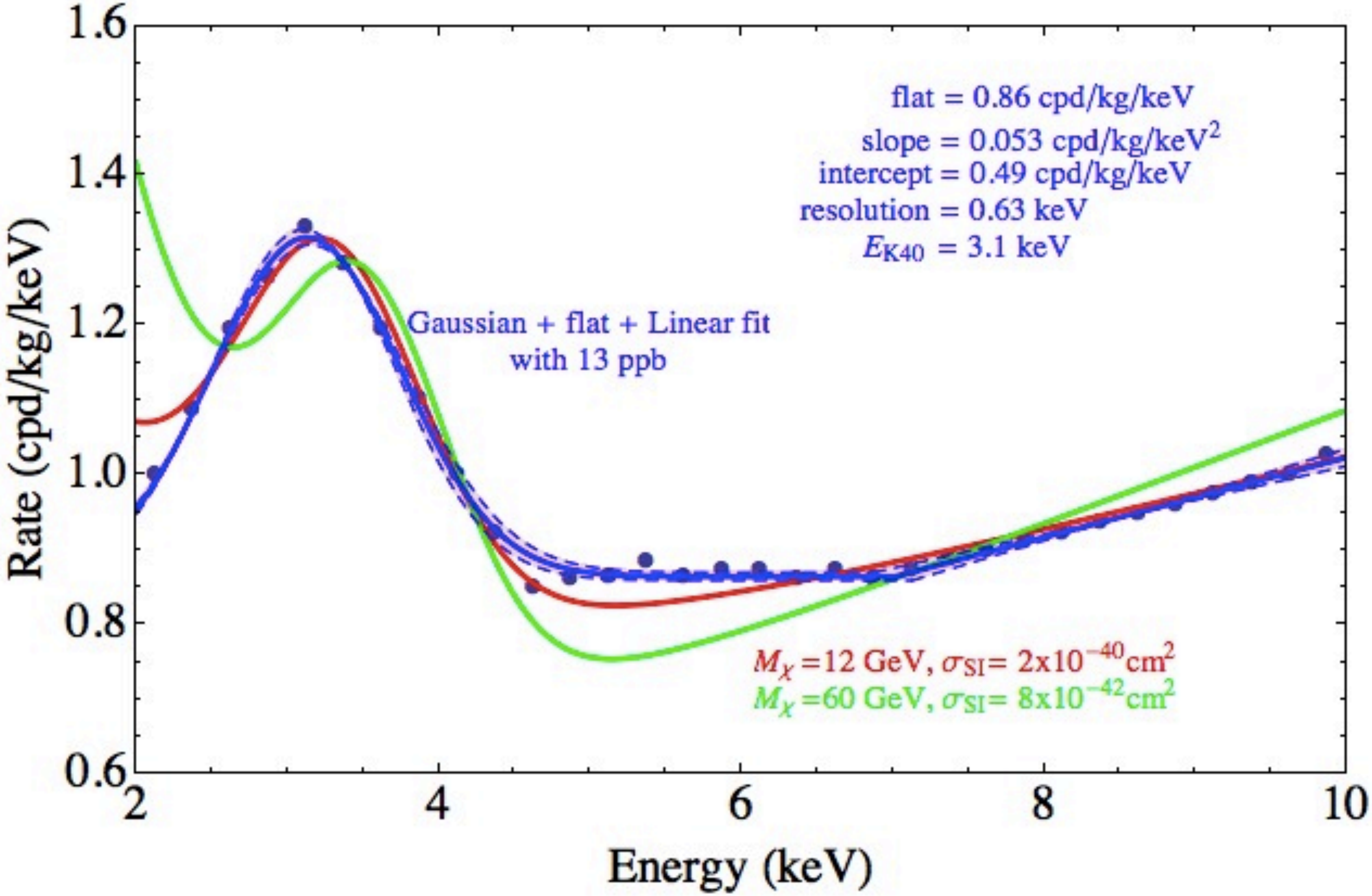
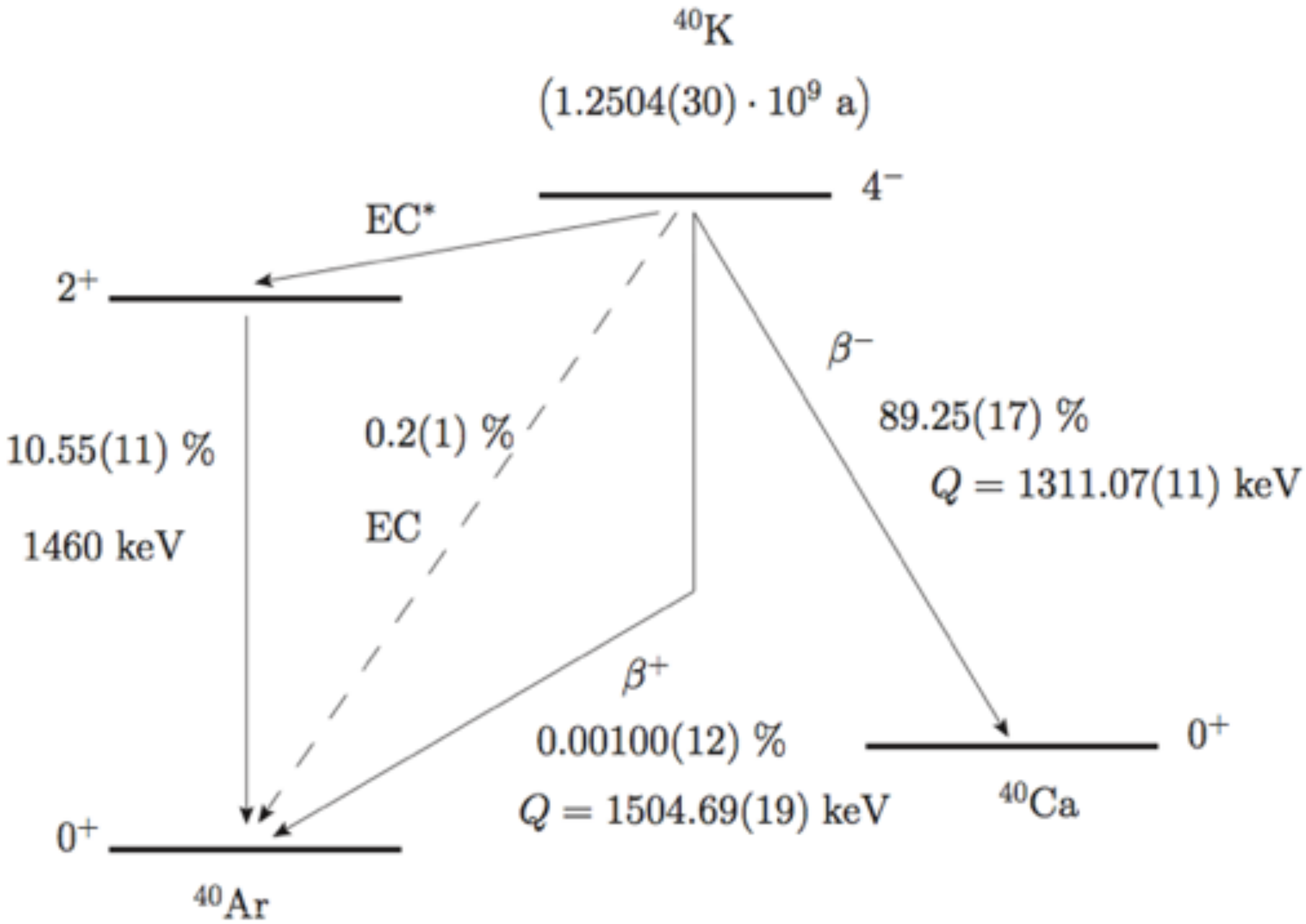


Unmeasured Nuclear Decay

One piece of nuclear physics that emerged out of it is the identification of an hitherto unmeasured special nuclear transition in potassium.



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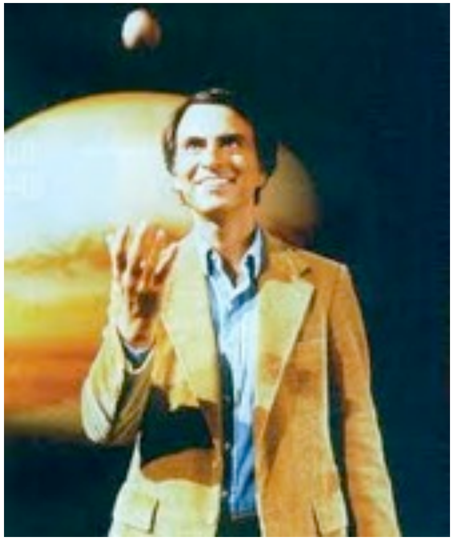
3) But, something is modulating in DAMA, what is it? Maybe DM, but higher modulation fraction, maybe something more exotic? Maybe something more mundane . . .

4) Our aim is not to claim that we now understand the background. This might be complicated and messy. But considering the gravity of the claims (DM), it seems only appropriate to devote more attention to this issue.

Extraordinary Claims

"Extraordinary claims require extraordinary evidence." - Carl Sagan



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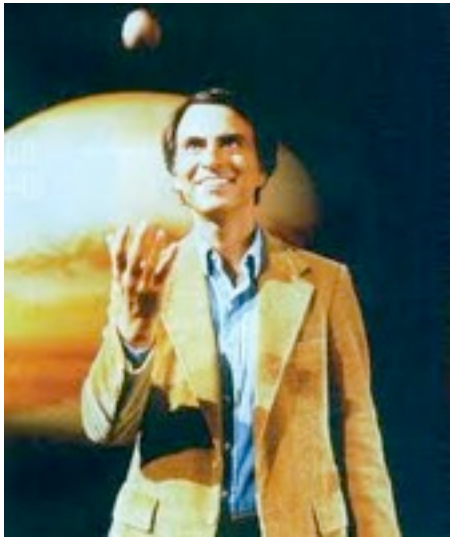

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Here is some information that I think can shed more light on many of these things, and that the community should demand from DAMA:

1. Release the day-to-day *unbinned unsubtracted* count rate.

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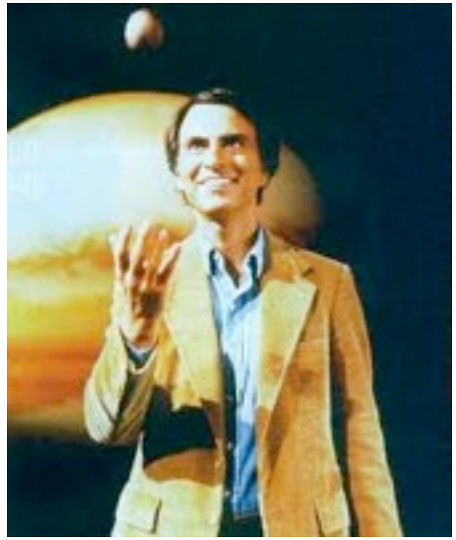

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Really, an experiment claiming something so extraordinary should release all its data. . .