Title: A CoGeNT Modulation Analysis

Date: Sep 23, 2011 11:20 AM

URL: http://pirsa.org/11090084

Abstract: We analyze the recently released CoGeNT data with a focus on their time-dependent properties. Using various statistical techniques, we confirm the presence of modulation in the data, and find a significant component at high (Eee \gtap 1.5 keVee) energies. We find that standard elastic WIMPs in a Maxwellian halo do not provide a good description of the modulation. We consider the possibility of non-standard halos, using halo independent techniques, and find a good agreement with the DAMA modulation for QNa

A CoGeNT modulation analysis

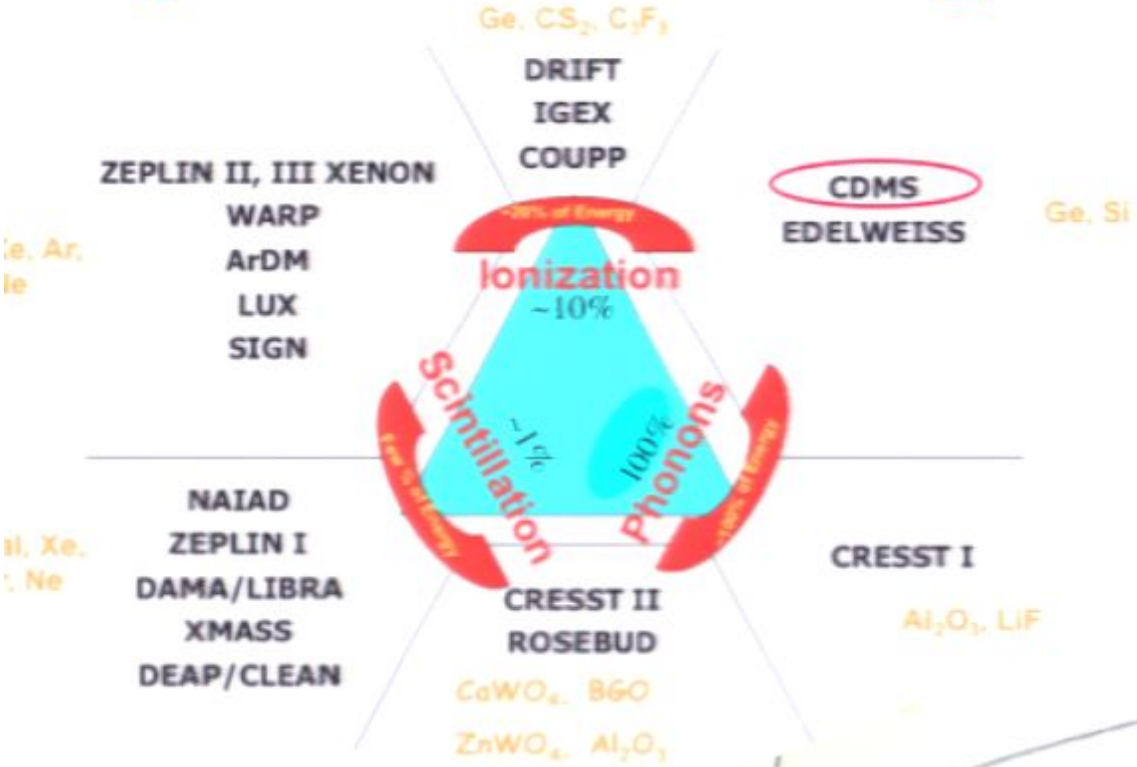
Patrick Fox

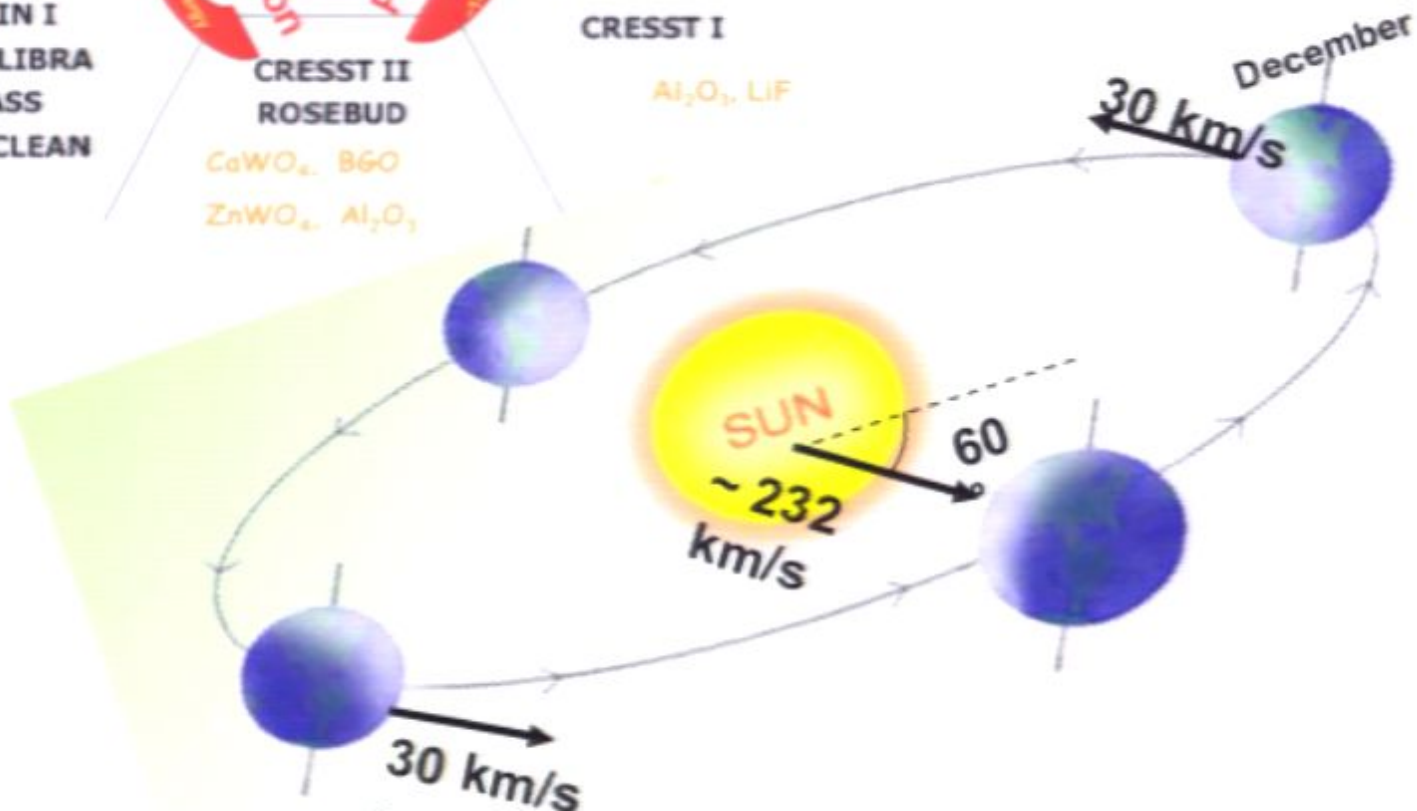
Fermilab

with Joachim Kopp, Mariangela Lisanti
and Neal Weiner
(arXiv:1107.0717)

or related works see:
Collar, Hall, Hooper and McKinsey (1007.1005)
Hooper and Kelso (1106.1066)
Zupan and Schwetz (1106.6241)
Farina, Pappadopulo, Strumia and Volansky (1107.0715)

Ways to find a DM signal



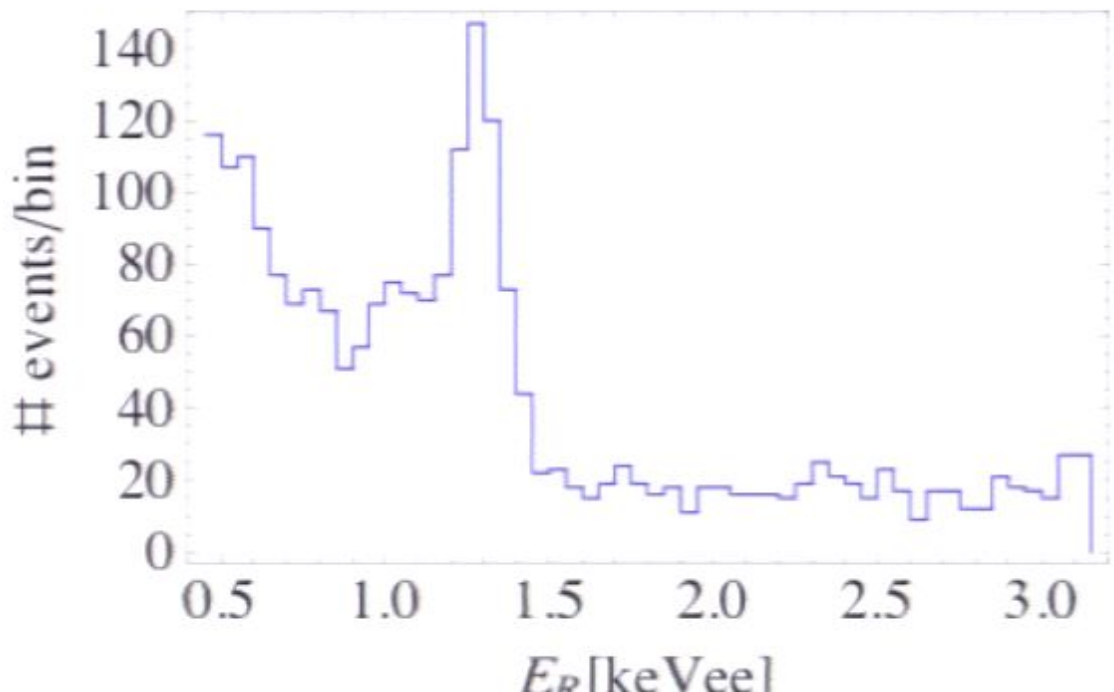


CoGeNT

·330 g Ge detector, very low threshold
)ata taking [Dec. 4, 2009-Soudan fire]
pans 458 days, 442 live days

Collaboration kindly provided time-stamped data

t [days]	E [keVee]
0.419763	0.576587
0.587532	0.362542
0.677681	1.11571
0.840586	1.35503
0.961931	0.414923
1.016340	2.22568
1.028094	1.82074
1.029199	2.67502
1.358892	0.872435
1.834660	0.329431
1.892096	0.366899
1.919907	1.30808
2.395985	1.05583
2.408826	1.04175
2.492828	0.6463
2.500264	0.443454
2.503603	1.04213
2.612438	0.563312
2.674741	1.28464
.	.



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[illegible]	0.563312
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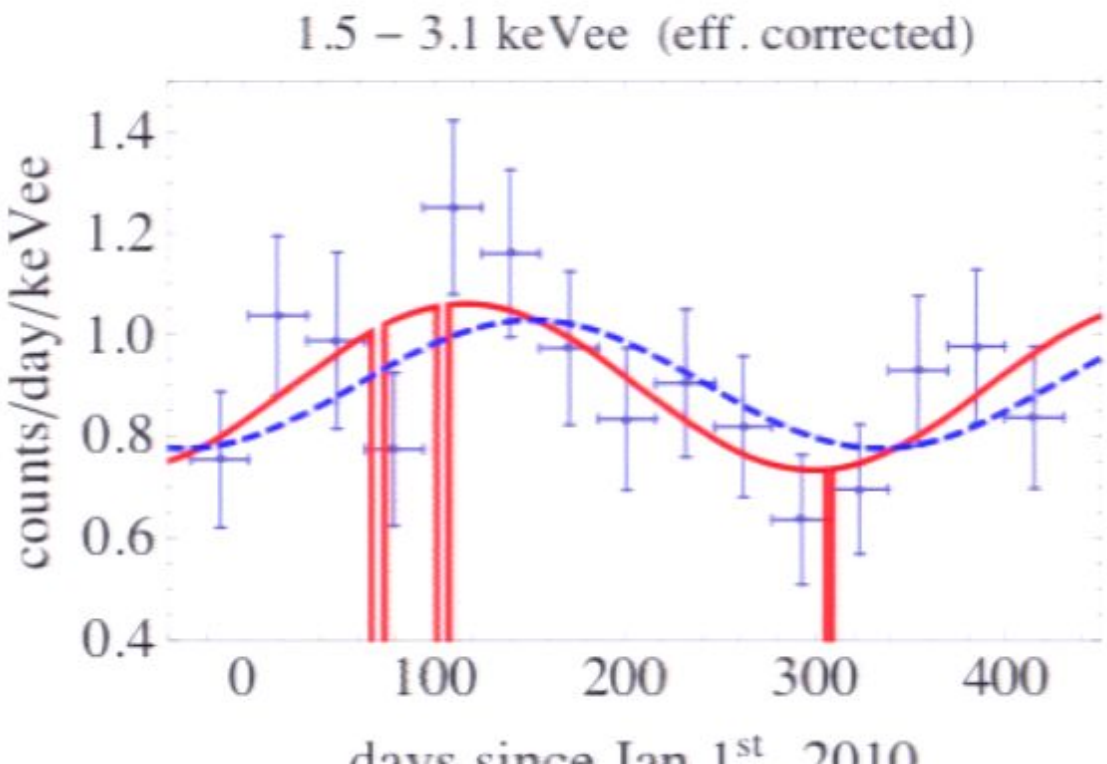
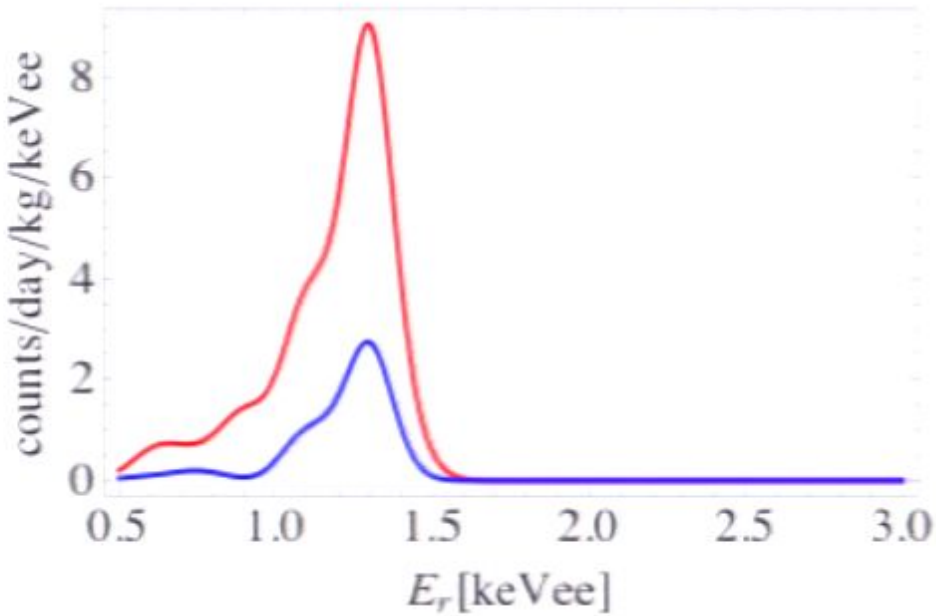
⋮	⋮



Statistical techniques

After taking into account cosmogenic backgrounds



Fit what remains to $R(t) = A_0(1 + A_1 \cos(\omega(t - t_0))$

A_0 contains DM piece and constant background

SHM predicts $t_0 = 152$ days

Statistical techniques

Binned in energy and time (least squares)
Binned in energy unbinned in time (max likelihood)
Completely unbinned (max likelihood)

$$(t) = \left[0.33\,\mathrm{kg} \times \Delta\mathrm{E}\,\bar{f}_{\mathrm{eff}}(\mathrm{E})\Big(A_0(1 + A_1\cos(\omega(t - t_0))\Big) + \int_{\mathrm{E_{low}}}^{\mathrm{E_{high}}} f_{\mathrm{cosmo}}(E,t) f_{\mathrm{eff}}(\mathrm{E})\right] f_{\mathrm{gaps}}(t)$$

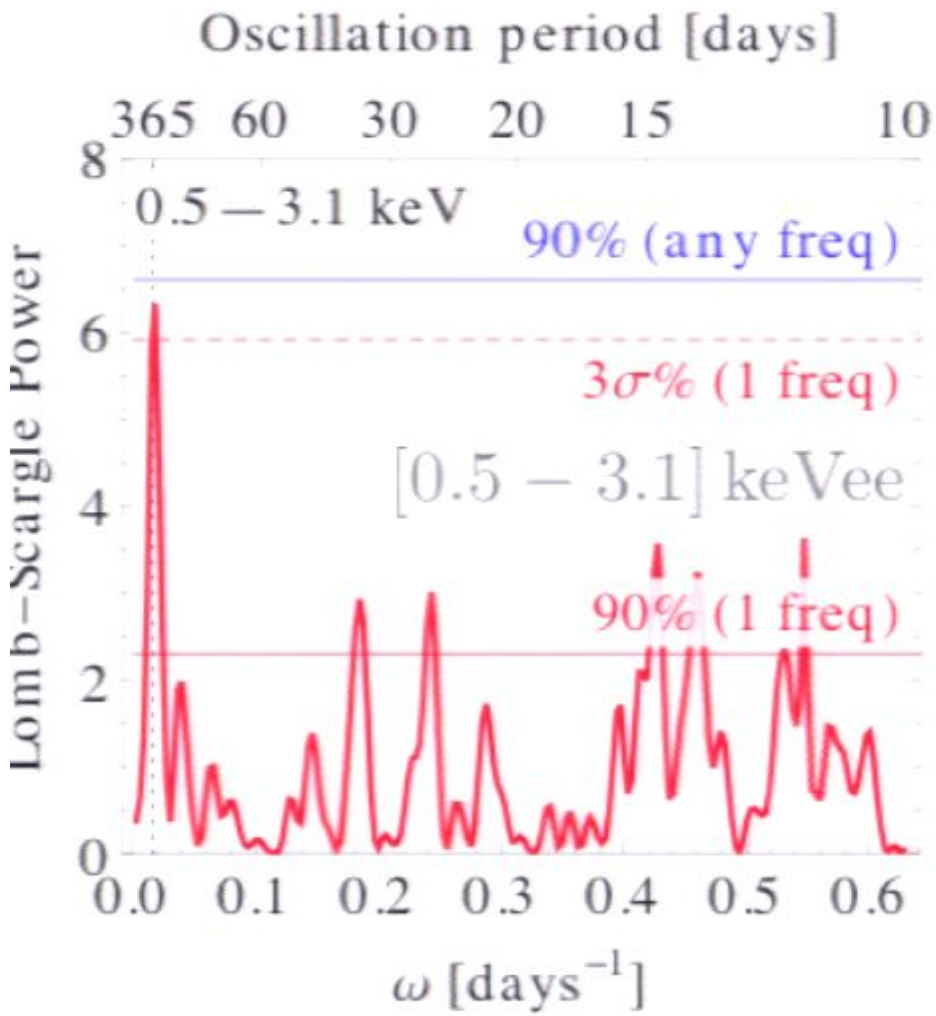
$$2\log L(A_0, A_1, \omega, t_0) = 2\sum_i \phi(t_i) - 2\int_{t_{\mathrm{start}}}^{t_{\mathrm{end}}} dt\,\phi(t)$$

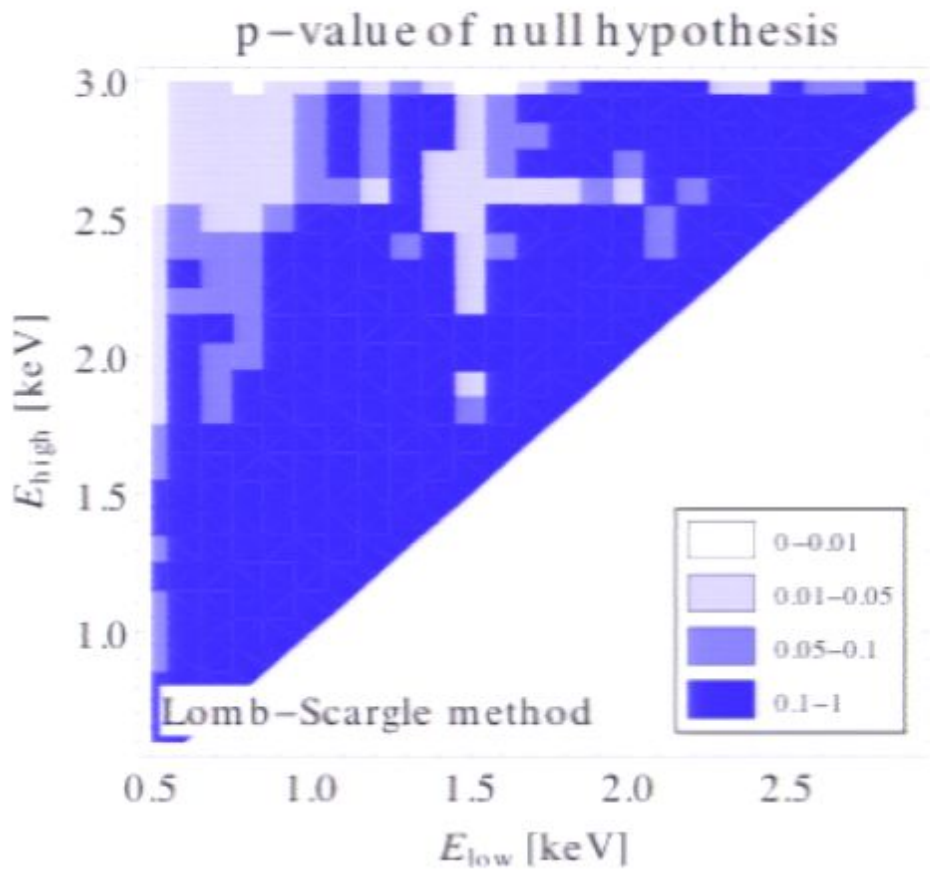
Weighted Lomb-Scargle periodogram

$$P(f) = \frac{1}{2\sigma^2}\left(\frac{\left[\sum_{i=1}^{N} W_i\,(y(t_i) - \bar{y})\,\cos\omega(t_i - \tau)\right]^2}{\sum_{i=1}^{N} W_i\,\cos^2\omega(t_i - \tau)} + \frac{\left[\sum_{i=1}^{N} W_i\,(y(t_i) - \bar{y})\,\sin\omega(t_i - \tau)\right]^2}{\sum_{i=1}^{N} W_i\,\sin^2\omega(t_i - \tau)}\right)$$

What's in the data?

Modulation frequency (Lomb-Scargle)





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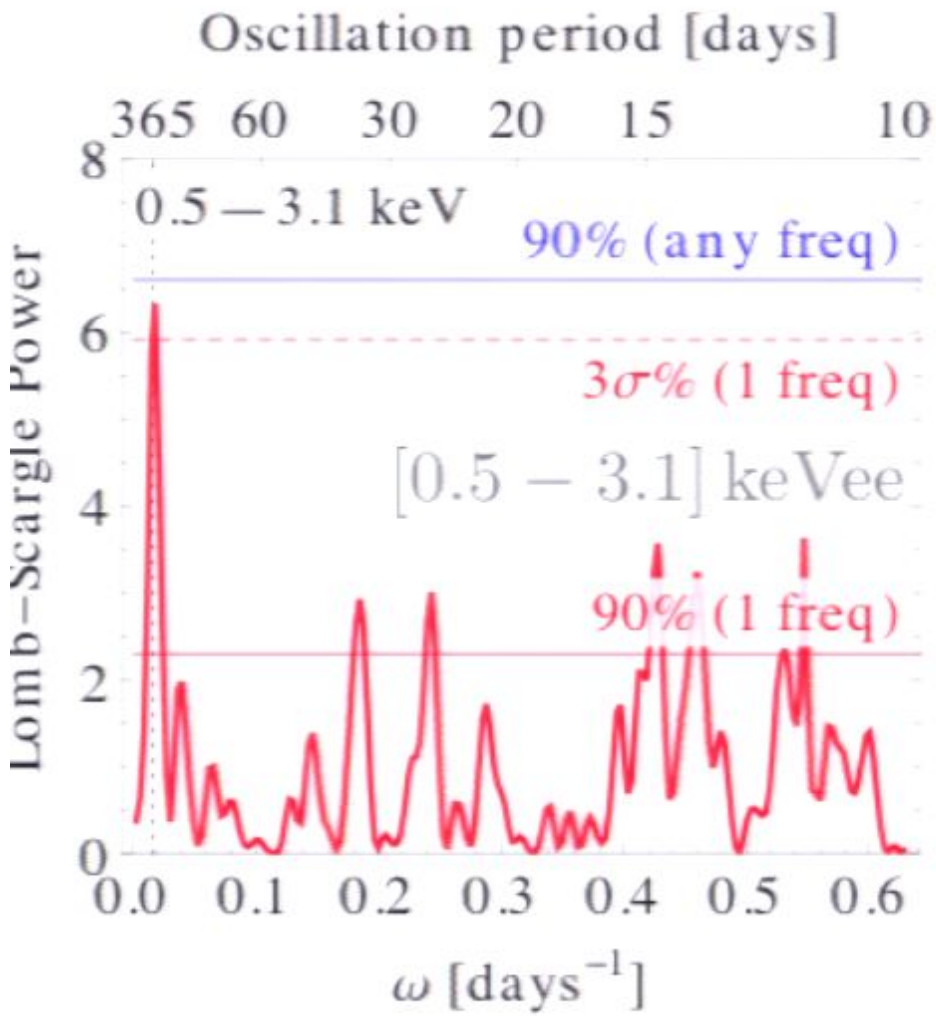
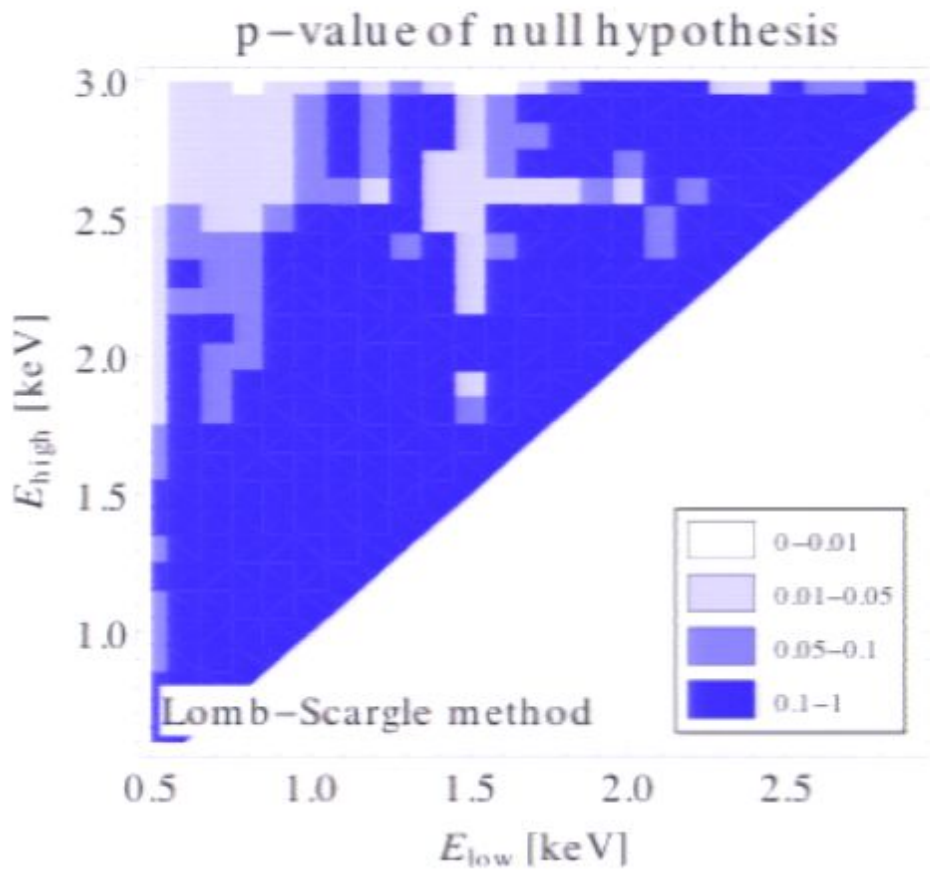
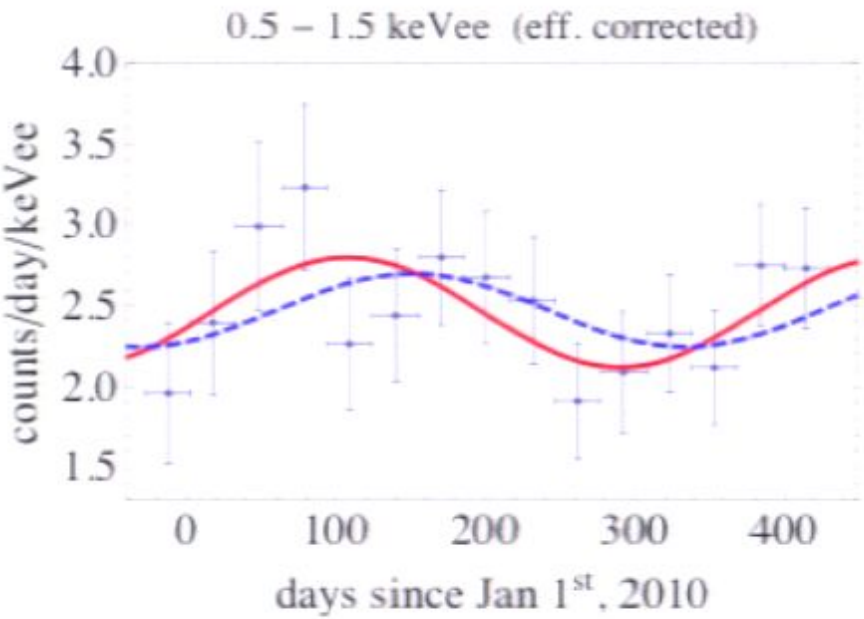
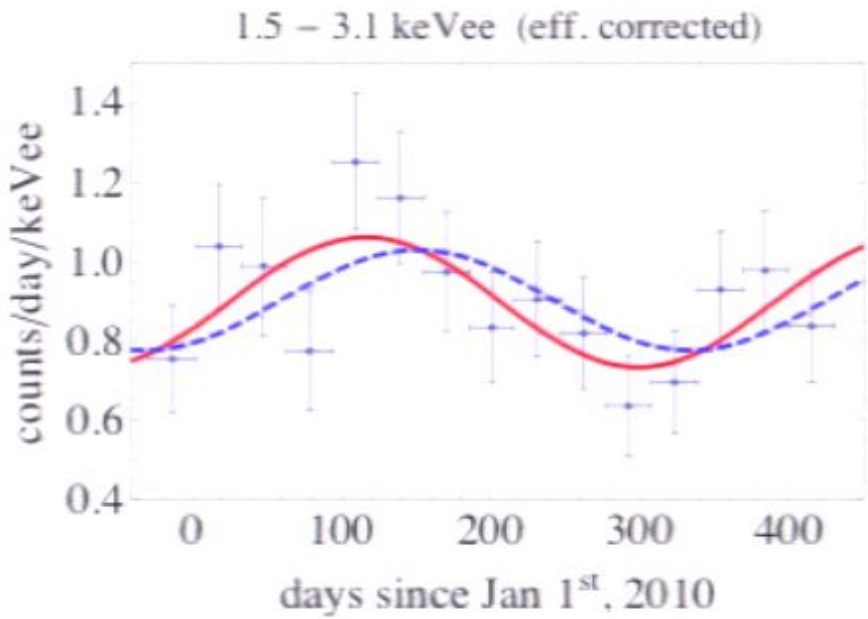




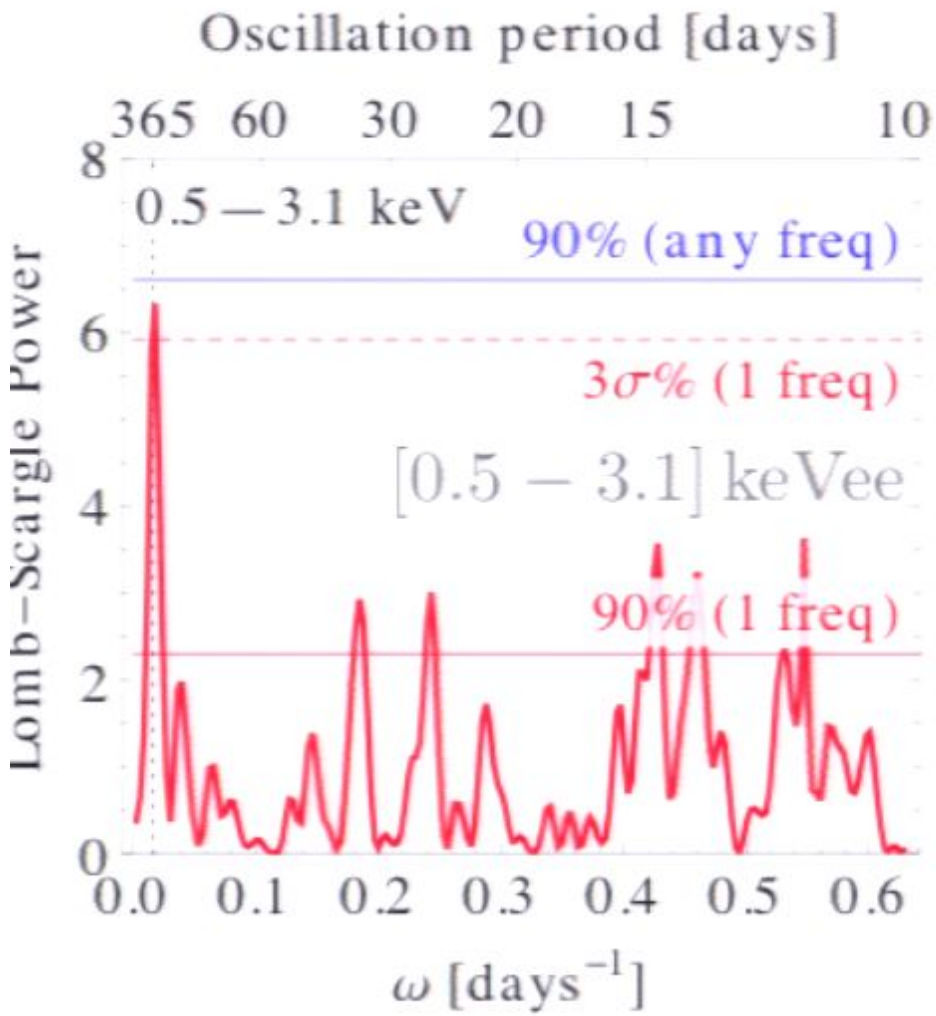
Modulation amplitude (Binned)

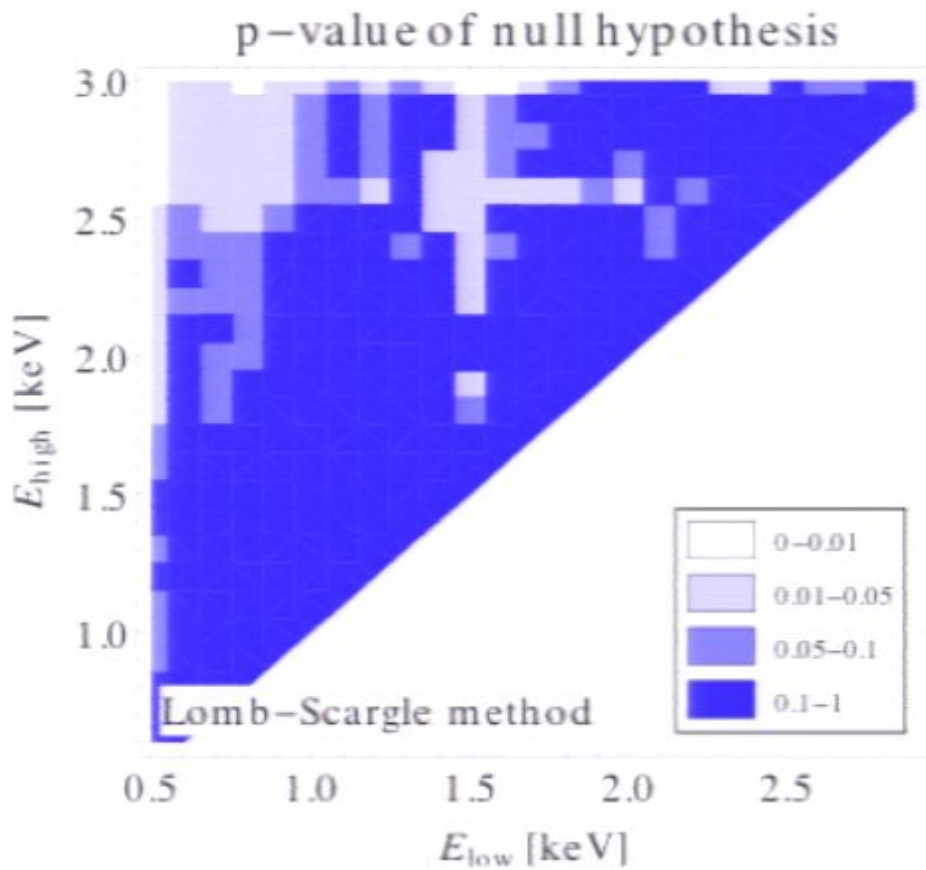




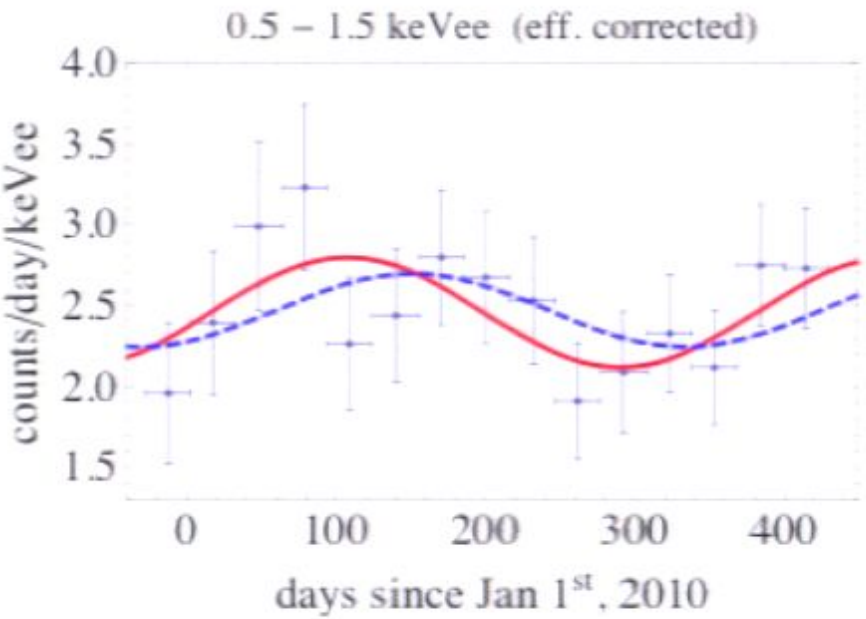
Free phase	$A_0 = 7.4$ events/day/kg/keVee $A_1 = 0.14$ $t_0 = 107$ days $\Delta\chi^2 = 4.7$	$A_0 = 2.7$ events/day/kg/keVee $A_1 = 0.18$ $t_0 = 116$ days $\Delta\chi^2 = 8.2$
MB phase $t_0 = 152$ days	$A_0 = 7.5$ events/day/kg/keVee $A_1 = 0.09$ $\Delta\chi^2 = 2.3$	$A_0 = 2.7$ events/day/kg/keVee $A_1 = 0.14$ $\Delta\chi^2 = 5.2$

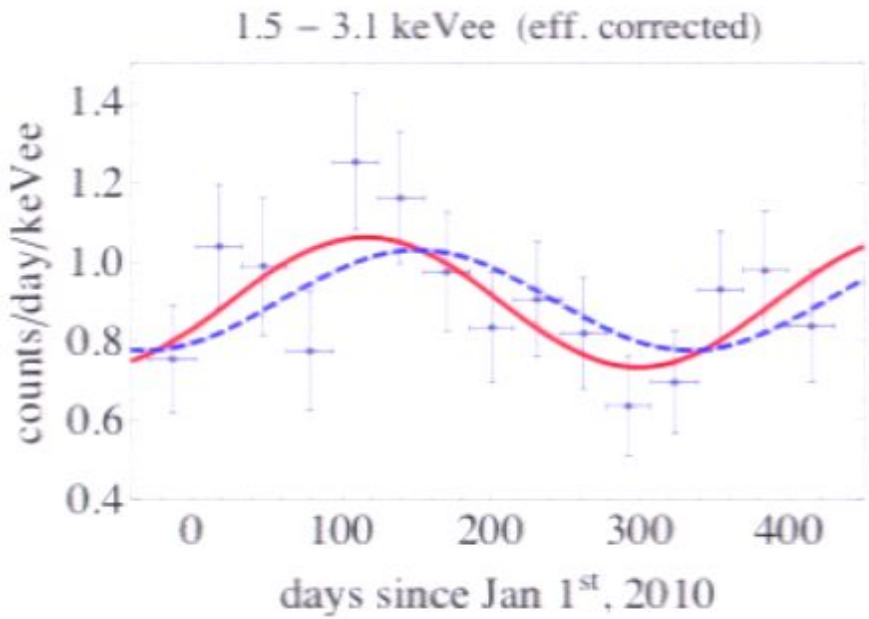
Modulation frequency (Lomb-Scargle)





Modulation amplitude (Binned)





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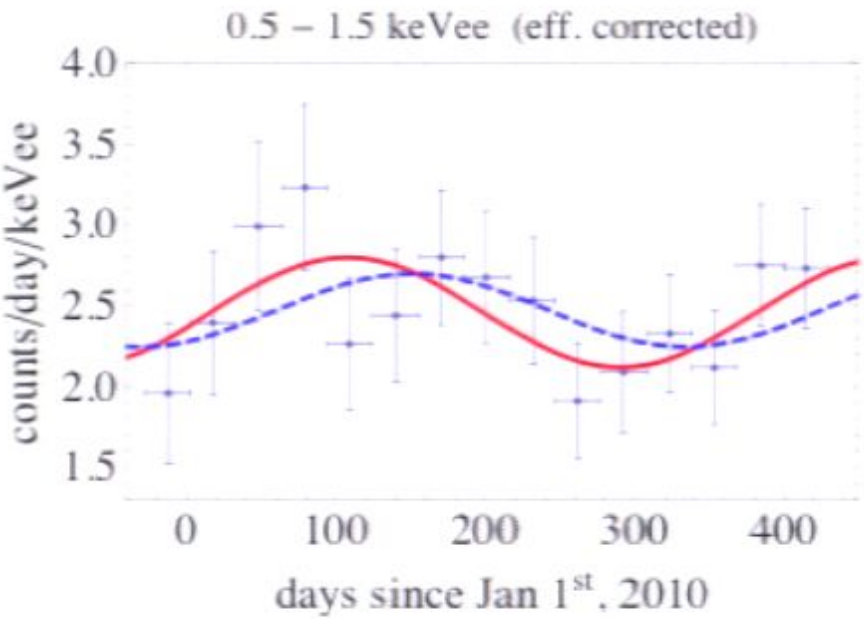

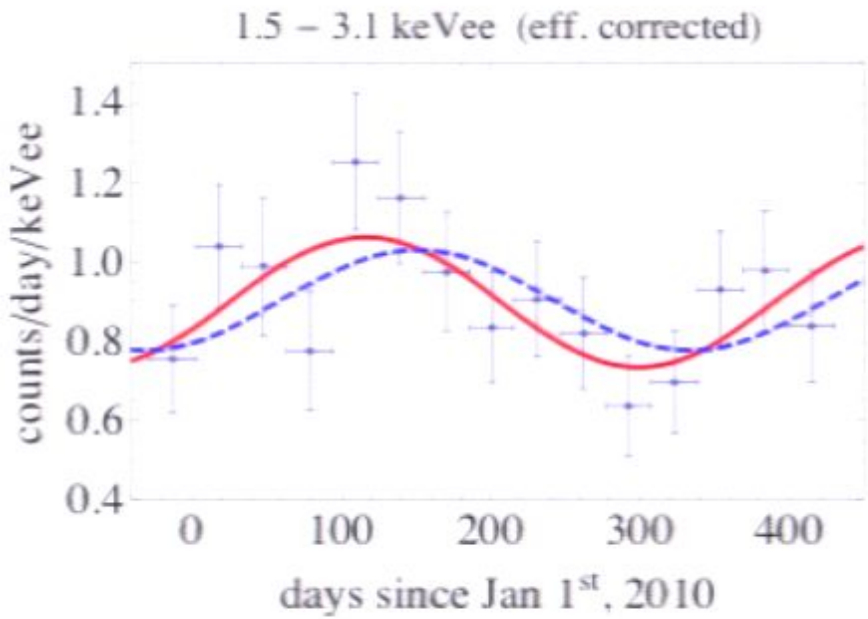

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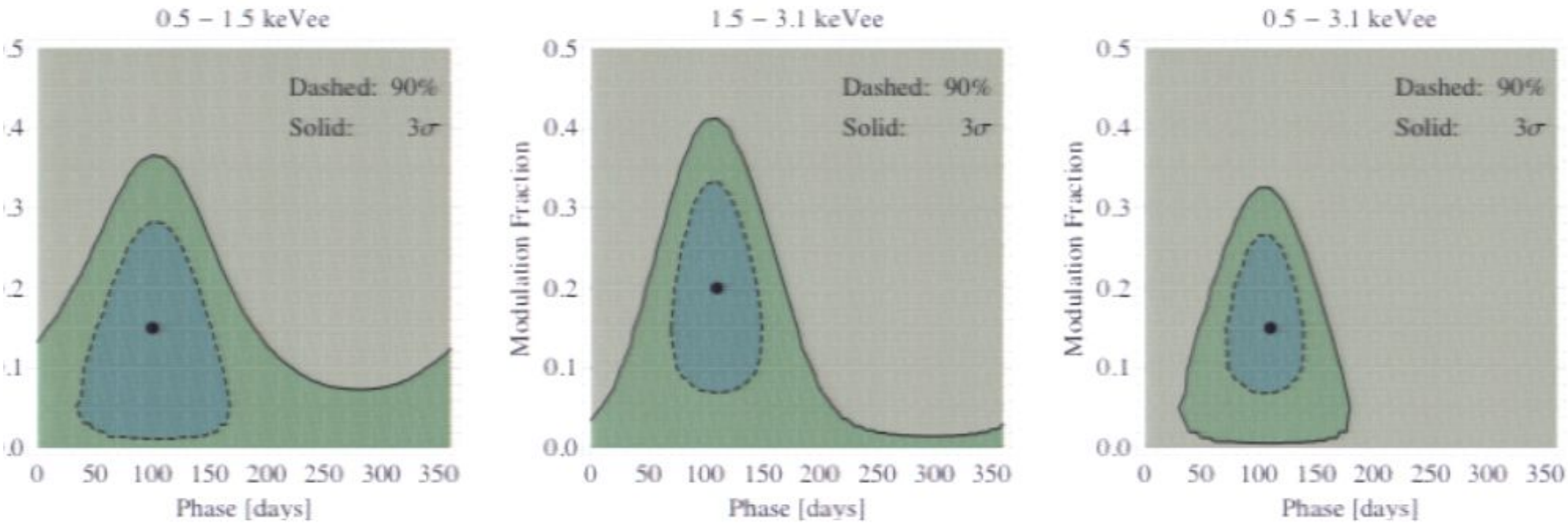
Phase and amplitude (Maximum likelihood)



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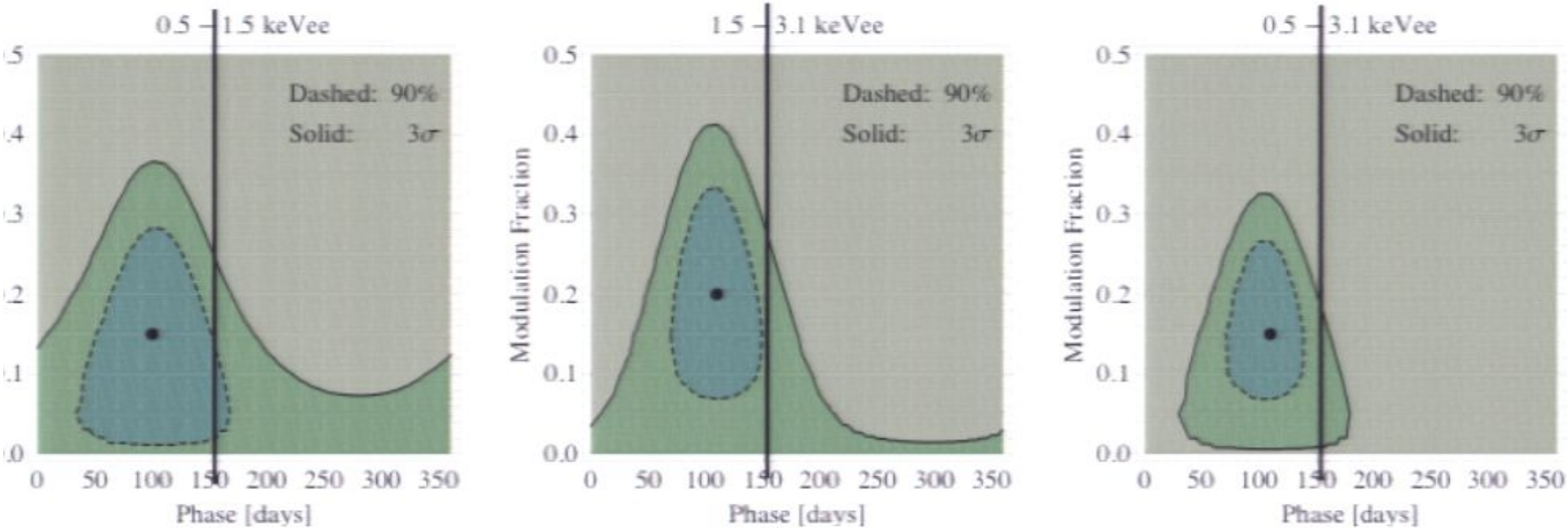
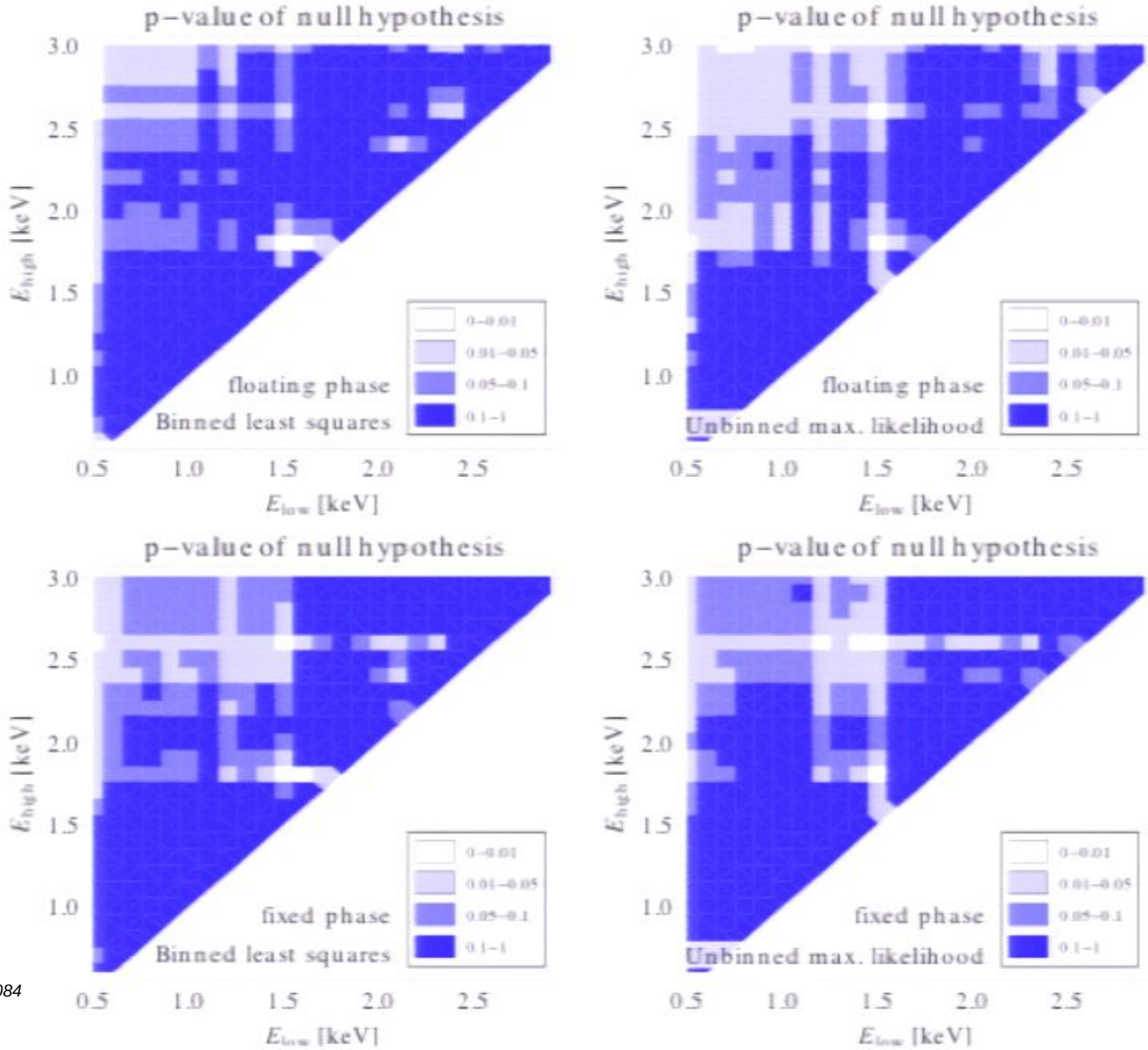
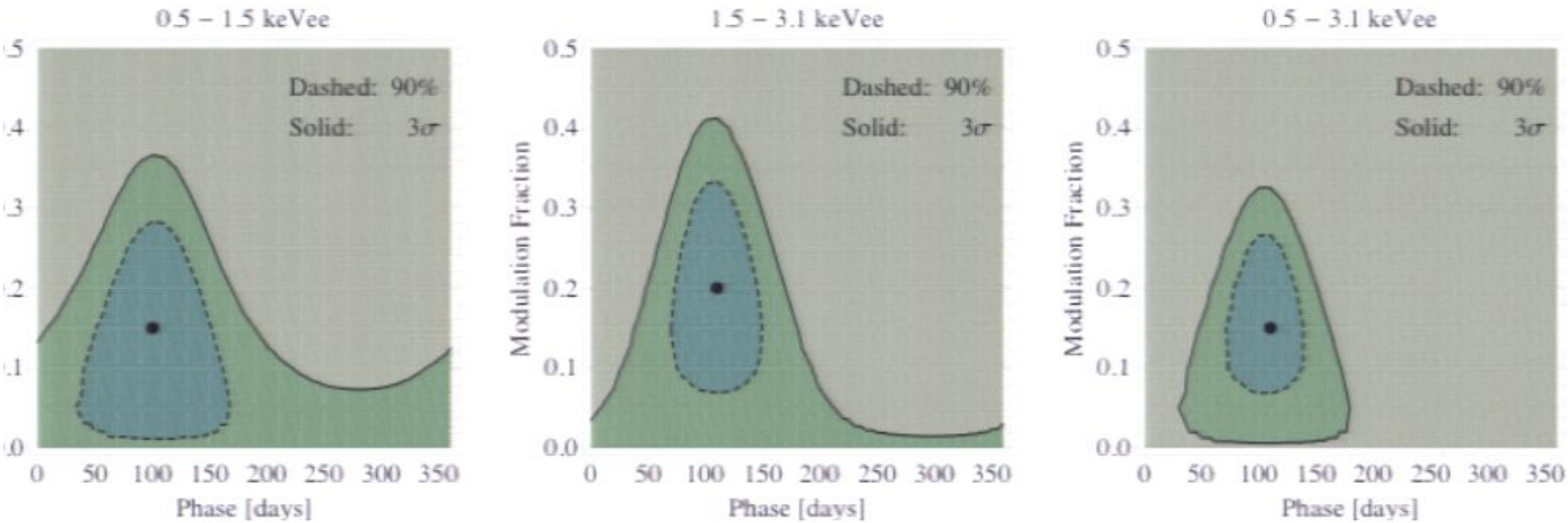


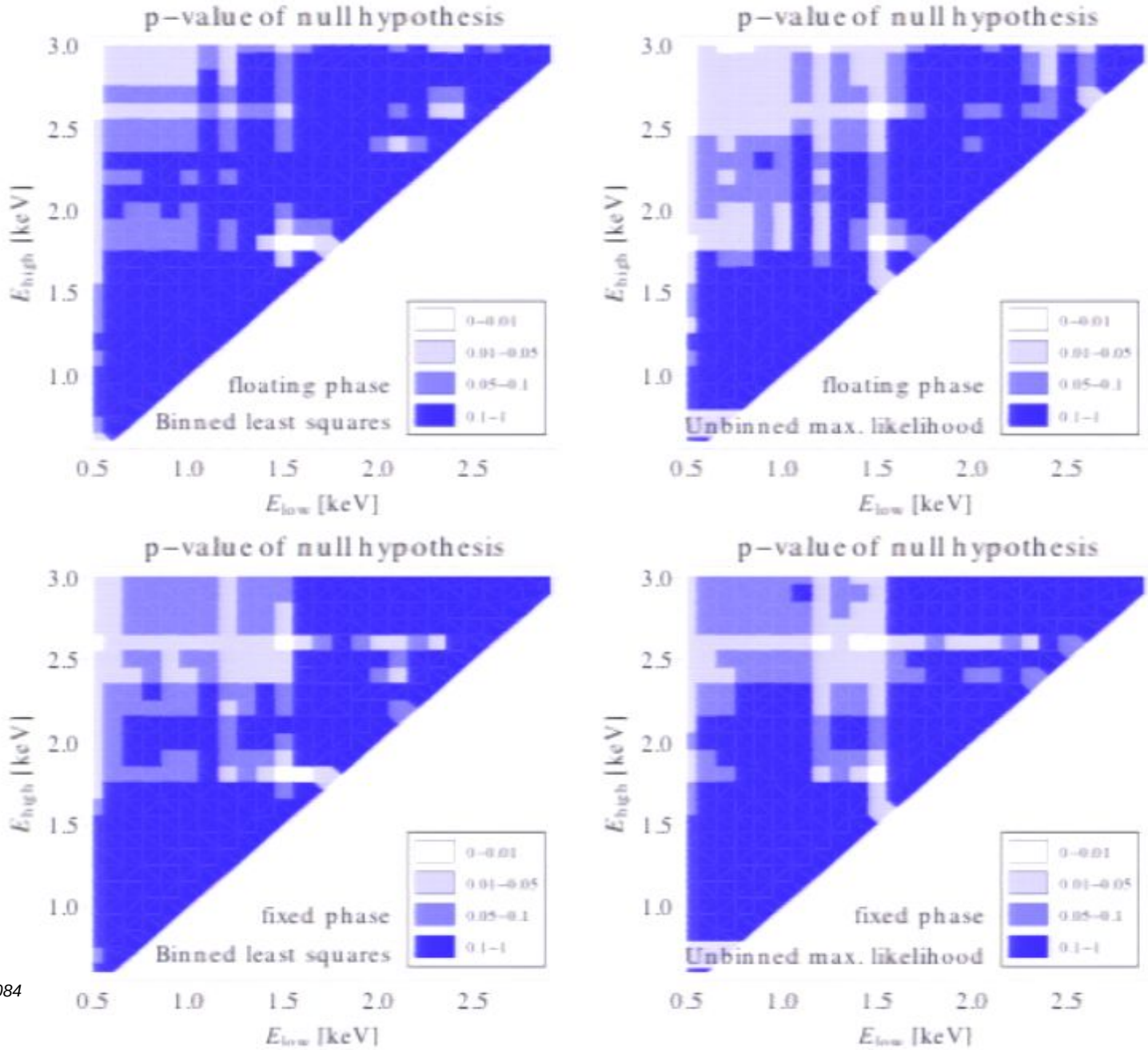
P-values


p−value of null hypothesis
floating phase
Binned least squares
p−value of null hypothesis
floating phase
Unbinned max. likelihood
p−value of null hypothesis
fixed phase
Binned least squares
p−value of null hypothesis
fixed phase
Unbinned max. likelihood
0–0.01
0.01–0.05
0.05–0.1
0.1–1
E_{high} [keV]
E_{low} [keV]
1.0
1.5
2.0
2.5
3.0
0.5

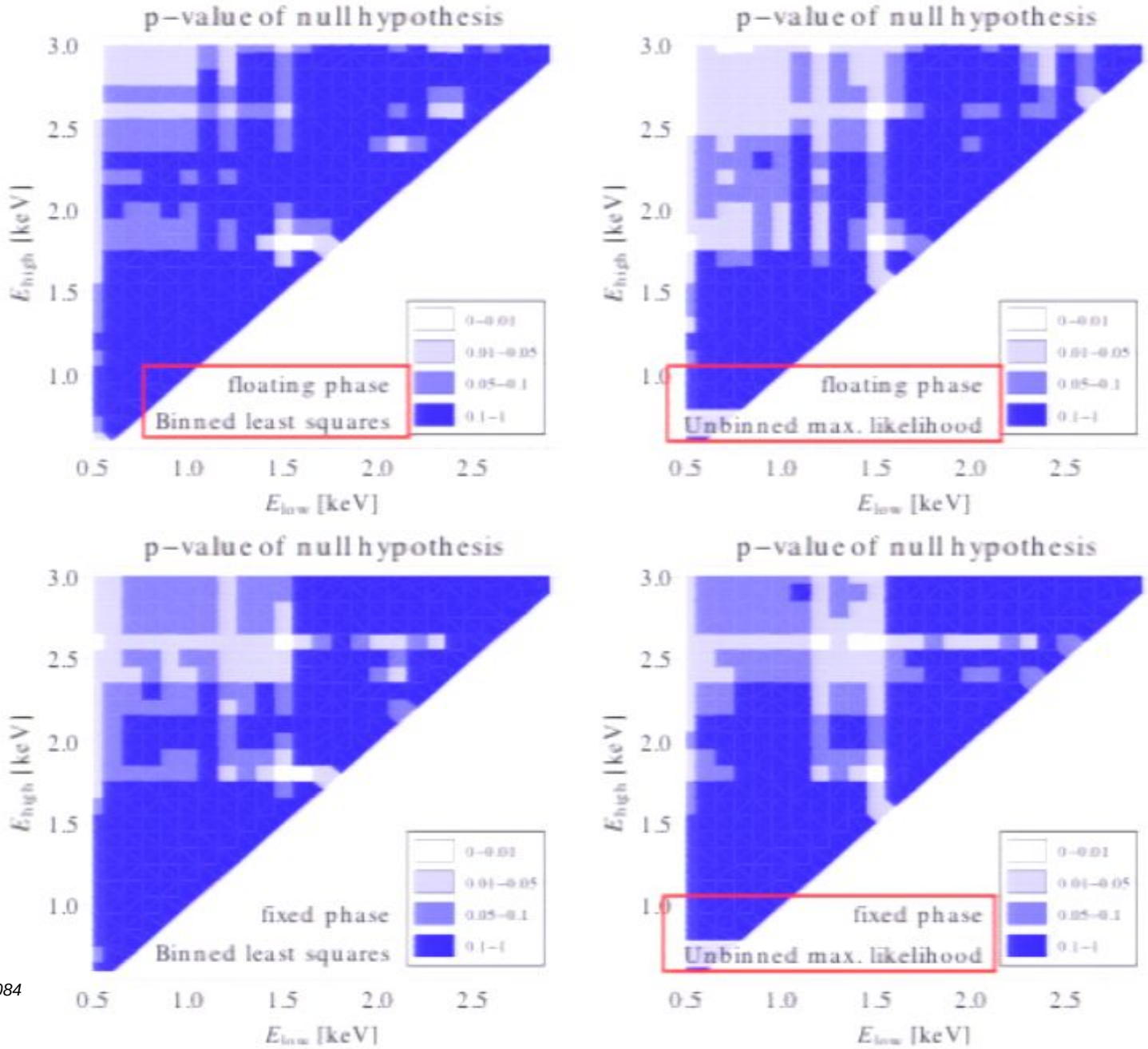
Phase and amplitude (Maximum likelihood)



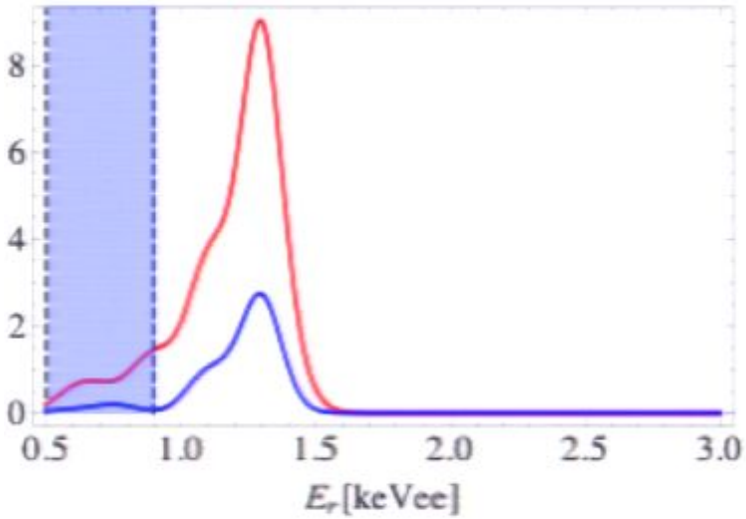
P-values


p−value of null hypothesis
floating phase
Binned least squares
p−value of null hypothesis
floating phase
Unbinned max. likelihood
p−value of null hypothesis
fixed phase
Binned least squares
p−value of null hypothesis
fixed phase
Unbinned max. likelihood
0–0.01
0.01–0.05
0.05–0.1
0.1–1
E_{high} [keV]
E_{low} [keV]
1.0
1.5
2.0
2.5
3.0
0.5

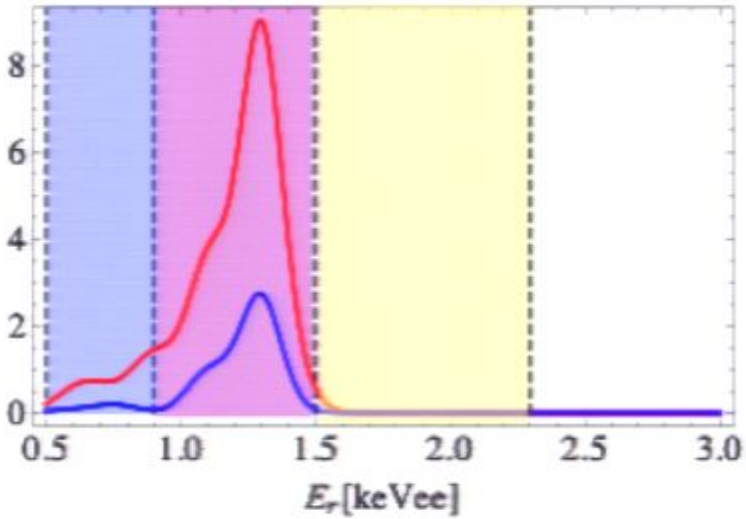
P-values


p−value of null hypothesis
floating phase
Binned least squares
p−value of null hypothesis
floating phase
Unbinned max. likelihood
p−value of null hypothesis
fixed phase
Binned least squares
p−value of null hypothesis
fixed phase
Unbinned max. likelihood
E_{high} [keV]
E_{low} [keV]
0.5
1.0
1.5
2.0
2.5
3.0
0–0.01
0.01–0.05
0.05–0.1
0.1–1

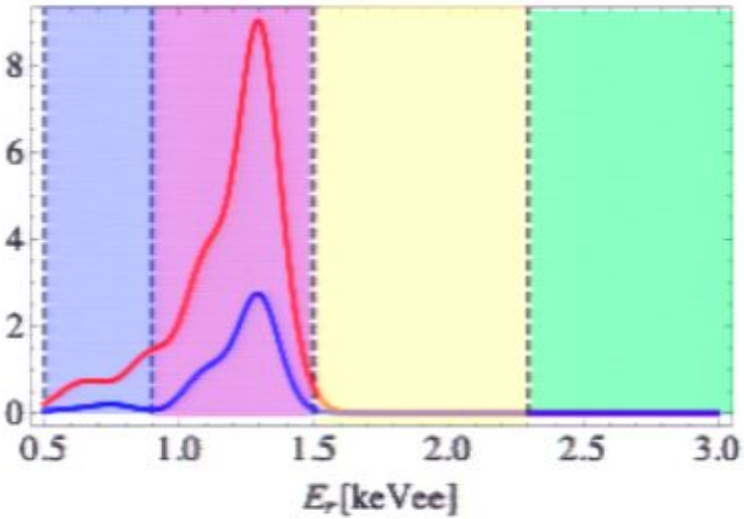
Spectra



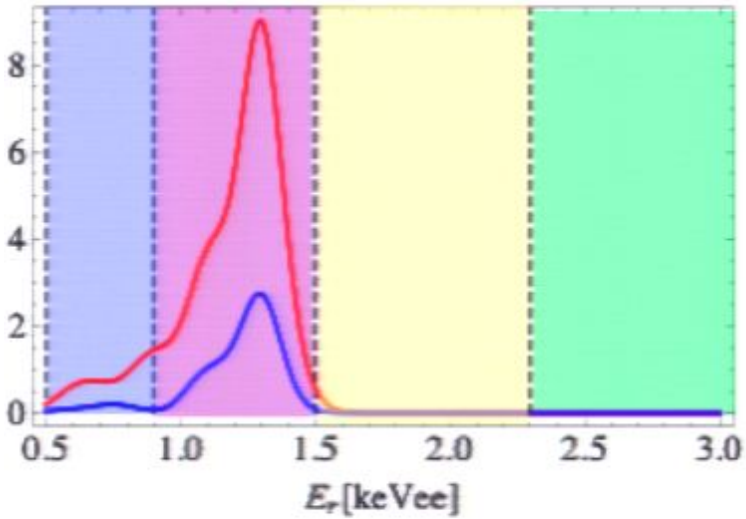
Spectra

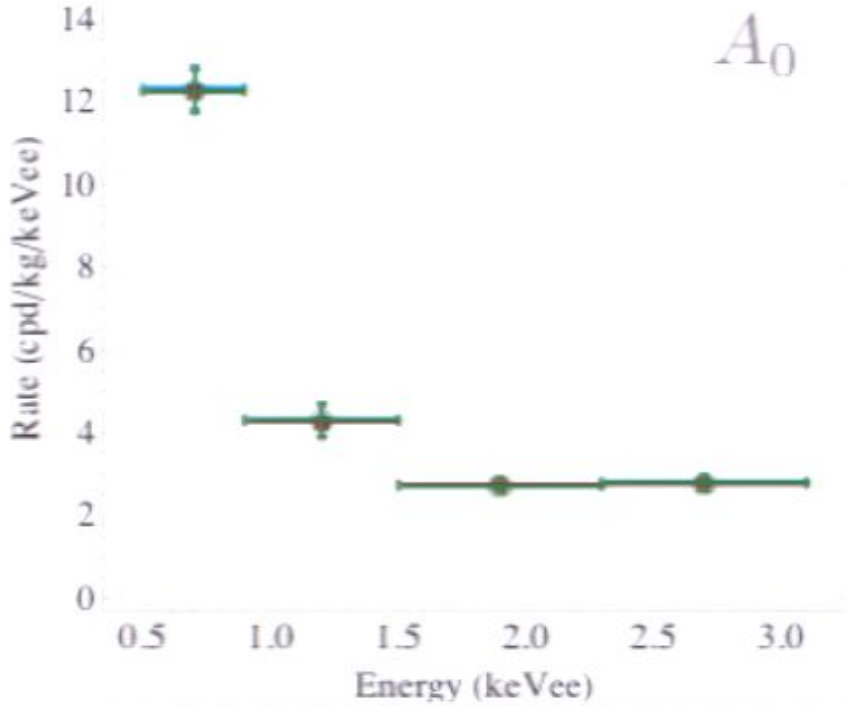


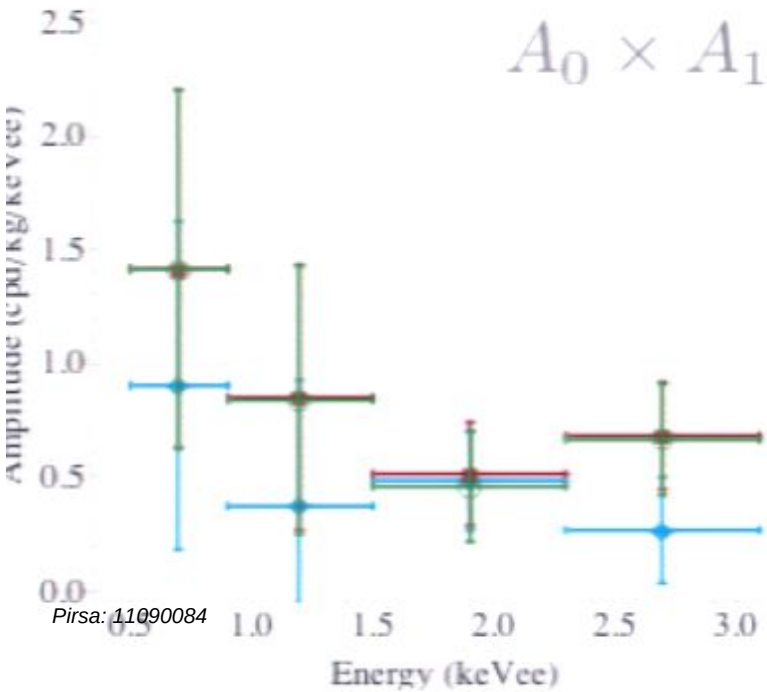
Spectra

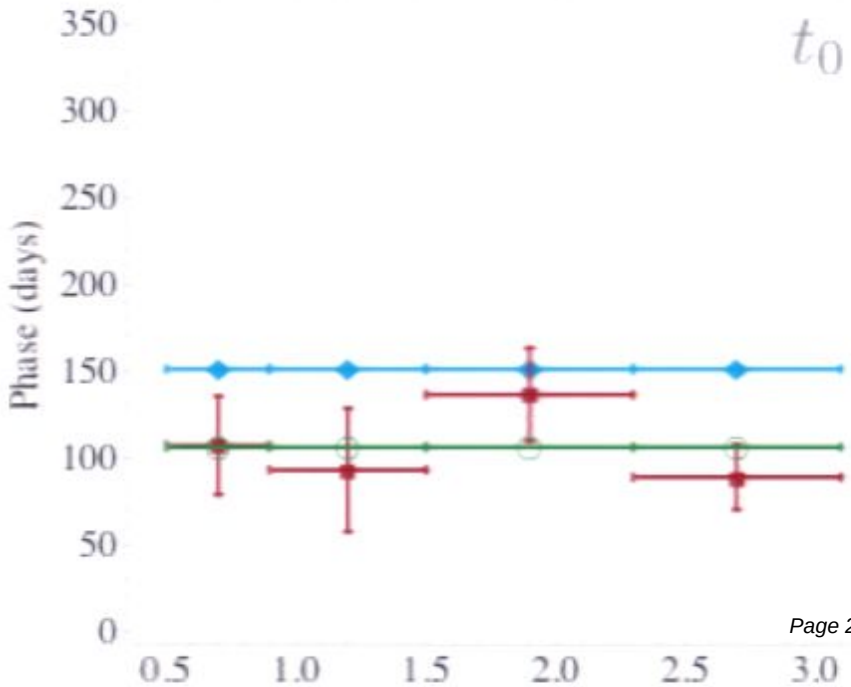


Spectra


8
6
4
2
0
0.5
1.0
1.5
2.0
2.5
3.0
E_r[keVee]


A_0
Rate (cpd/kg/keVee)
Energy (keVee)

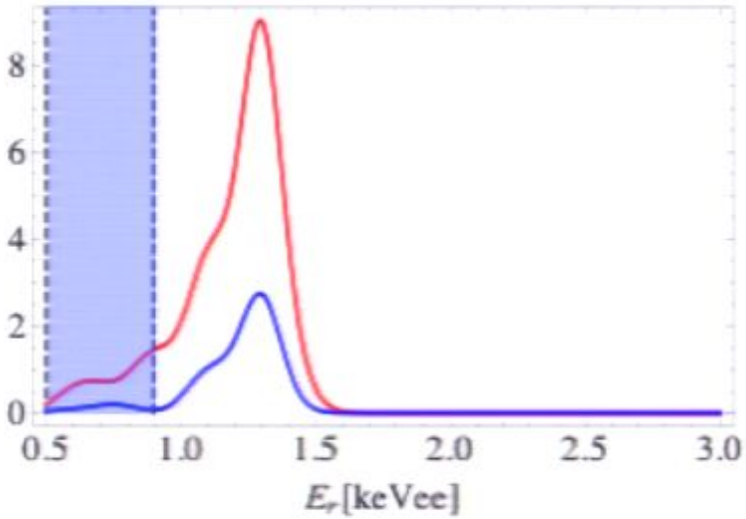

$A_0 \times A_1$
Energy (keVee)


t_0
Phase (days)

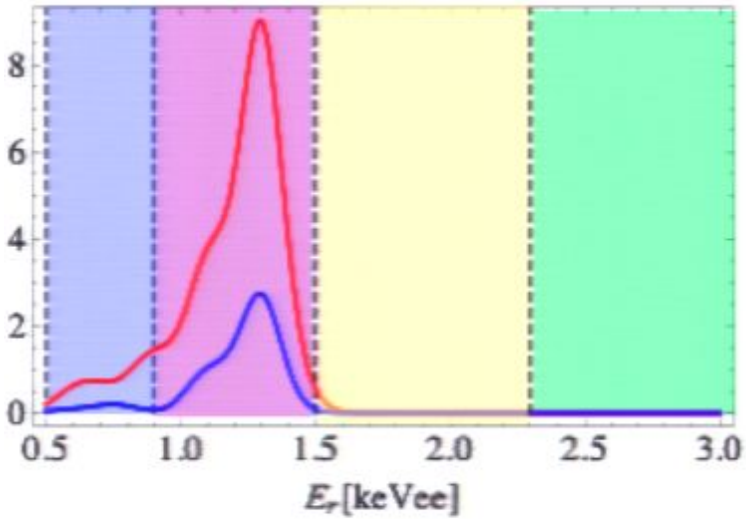
Data Summary

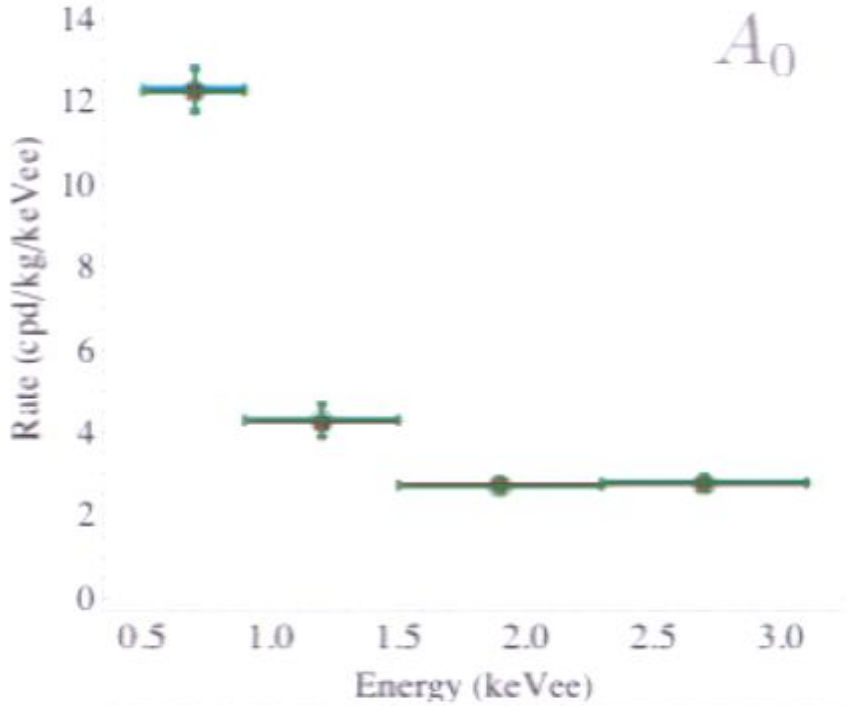
There is modulation in the data 2-3 sigma
Most significant at high recoil energy, ~20% modulation
Best fit phase ~106 days
Does not appear to be consistent with vanilla WIMP (MB alo etc)

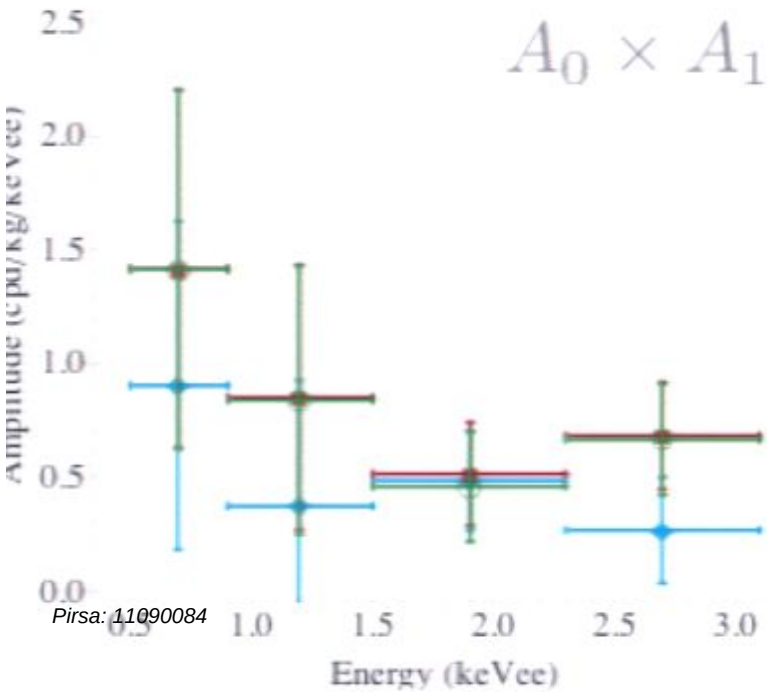
Spectra

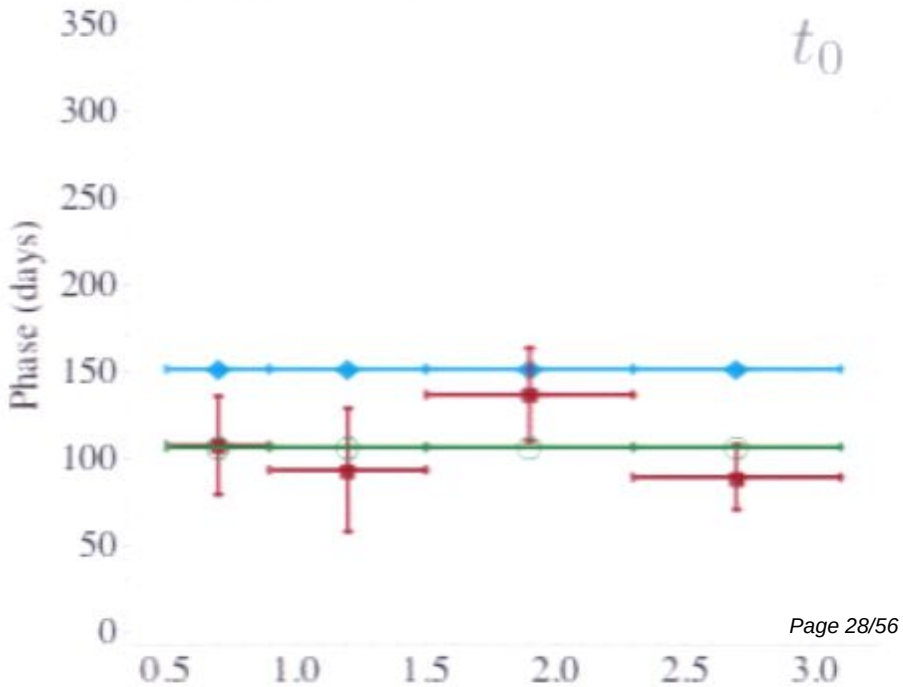


Spectra


0
2
4
6
8
0.5
1.0
1.5
2.0
2.5
3.0
E_r[keVee]


A_0
Rate (cpd/kg/keVee)
0
2
4
6
8
10
12
14
0.5
1.0
1.5
2.0
2.5
3.0
Energy (keVee)


$A_0 \times A_1$
0.0
0.5
1.0
1.5
2.0
2.5
1.0
1.5
2.0
2.5
3.0
Energy (keVee)


t_0
Phase (days)
0
50
100
150
200
250
300
350
0.5
1.0
1.5
2.0
2.5
3.0

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What about Maxwell Boltzmann?

DM fits

$$f(v) \propto \left(e^{-v^2/v_0^2} - e^{-v_{esc}^2/v_0^2}\right)\Theta(v_{esc} - v)$$

$$v_{\rm esc} = 550\,{\rm km/s} \qquad v_0 = 220\,{\rm km/s}$$

Scenario	Spect+Mod		Spect only		Mod only ($c_i \geq 0$)	Mod only	iDM Mod only
d.o.f.	72	[n/a]	47	[n/a]	68	68	67
$\sigma/10^{-41}$ cm^2	13.8	[8.9]	10.1	[8.2]	6.0	8.6	64
m_χ/ GeV	7.2	[8.1]	7.7	[8.2]	10.0	12.0	16.3
δ/ keV							24
c_i/(cpd/kg/keVee)	2.5	[2.5]	2.5	[2.6]	$\begin{pmatrix}1.5\\0\\1.5\\2.3\\2.3\end{pmatrix}$	$\begin{pmatrix}-5.9\\-4.6\\-1.0\\1.1\\1.7\end{pmatrix}$	$\begin{pmatrix}8.7\\0.4\\0.4\\1.2\\1.5\end{pmatrix}$
χ^2	57.3	[n/a]	50.8	[n/a]	53.7	51.4	51.3

DM fits

$$f(v) \propto \left(e^{-v^2/v_0^2} - e^{-v_{esc}^2/v_0^2}\right)\Theta(v_{esc} - v)$$

$$v_{\rm esc} = 550\,{\rm km/s} \qquad v_0 = 220\,{\rm km/s}$$

Null: $\chi^2 = 58.2$ for 70 degrees of freedom

Scenario	Spect+Mod		Spect only		Mod only ($c_i \geq 0$)	Mod only	iDM Mod only
d.o.f.	72	[n/a]	47	[n/a]	68	68	67
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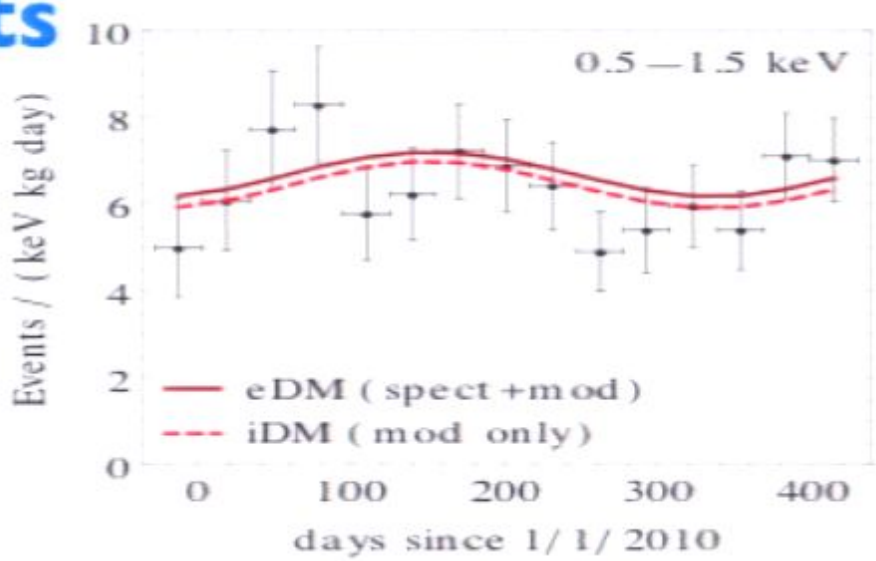
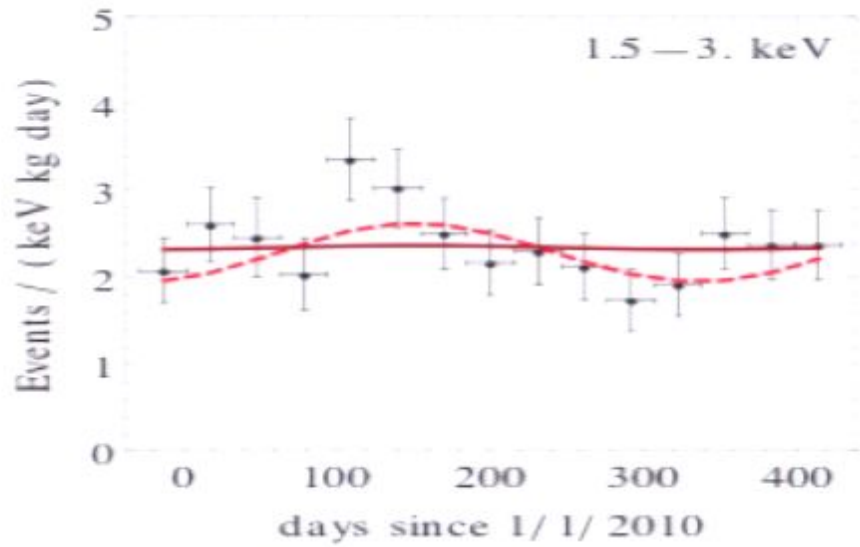
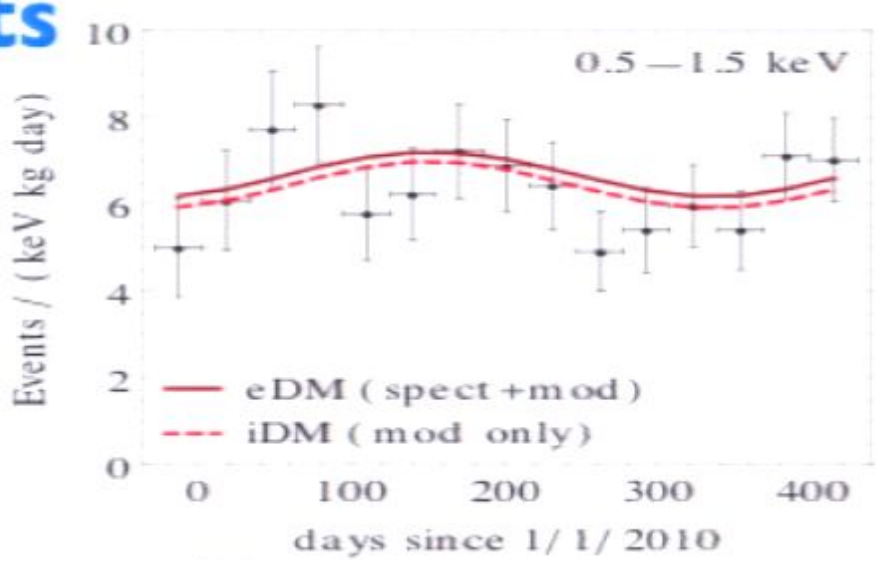
χ^2	57.3	[n/a]	50.8	[n/a]	53.7	51.4	51.3

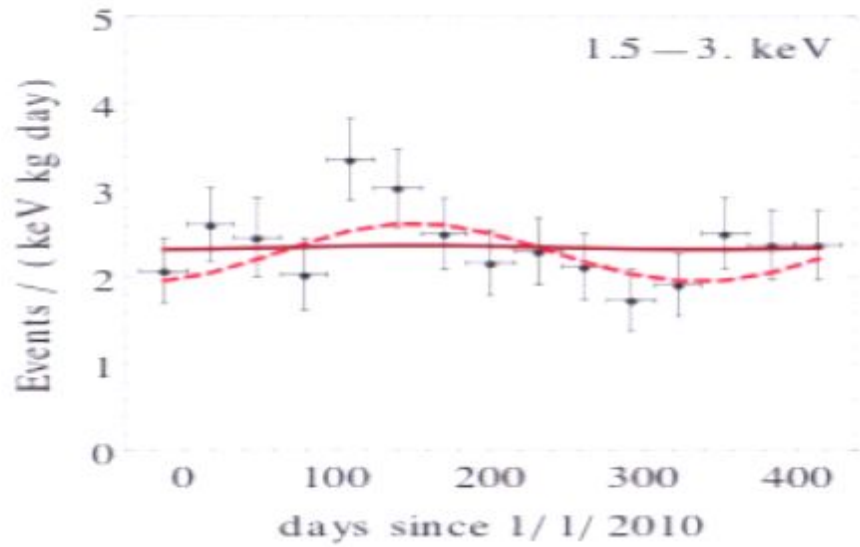
DM fits

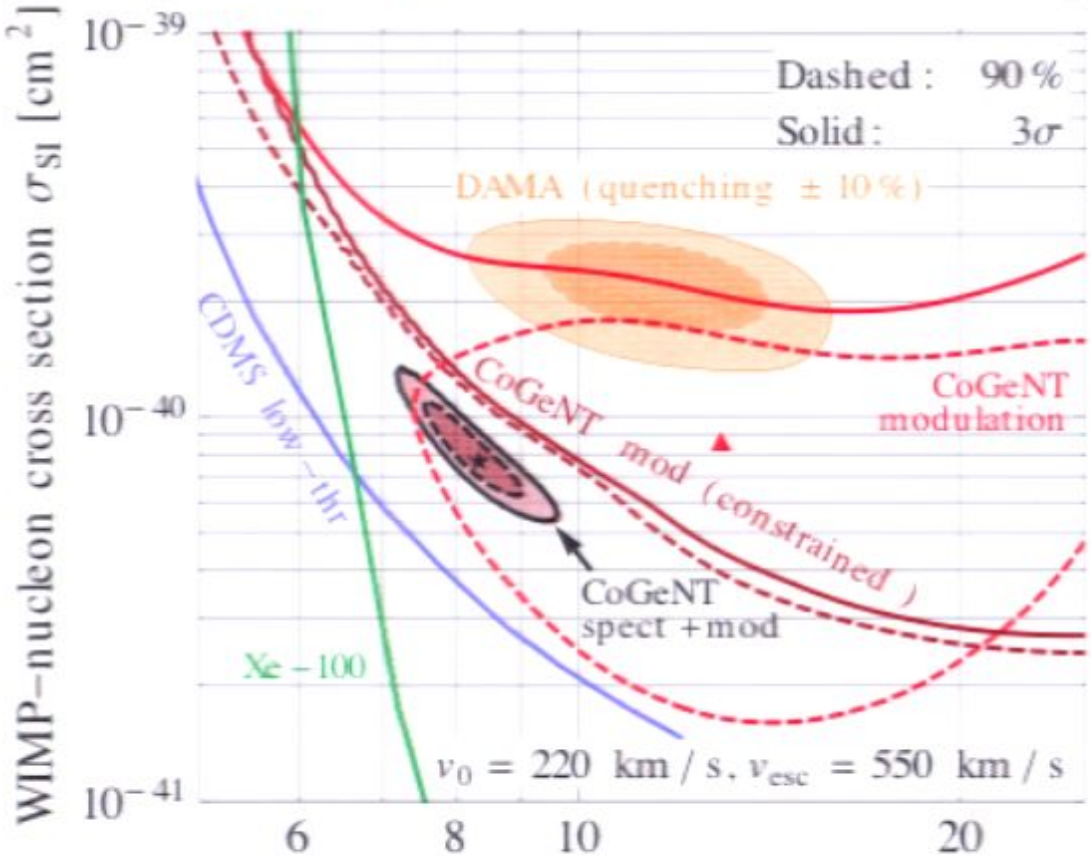

0.5 — 1.5 keV
Events / (keV kg day)
eDM (spect + mod)
iDM (mod only)
days since 1/ 1/ 2010


1.5 — 3. keV
Events / (keV kg day)
days since 1/ 1/ 2010

DM fits

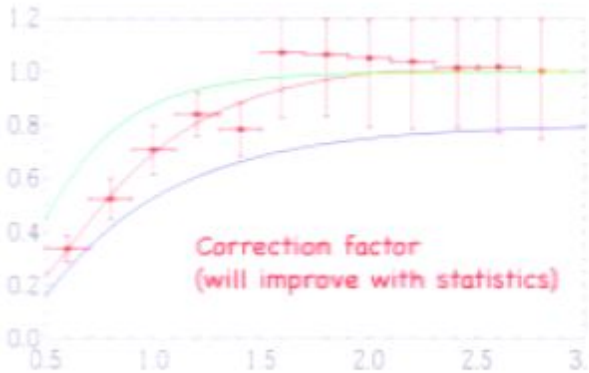

0.5 — 1.5 keV
Events / (keV kg day)
eDM (spect + mod)
iDM (mod only)
days since 1/ 1/ 2010

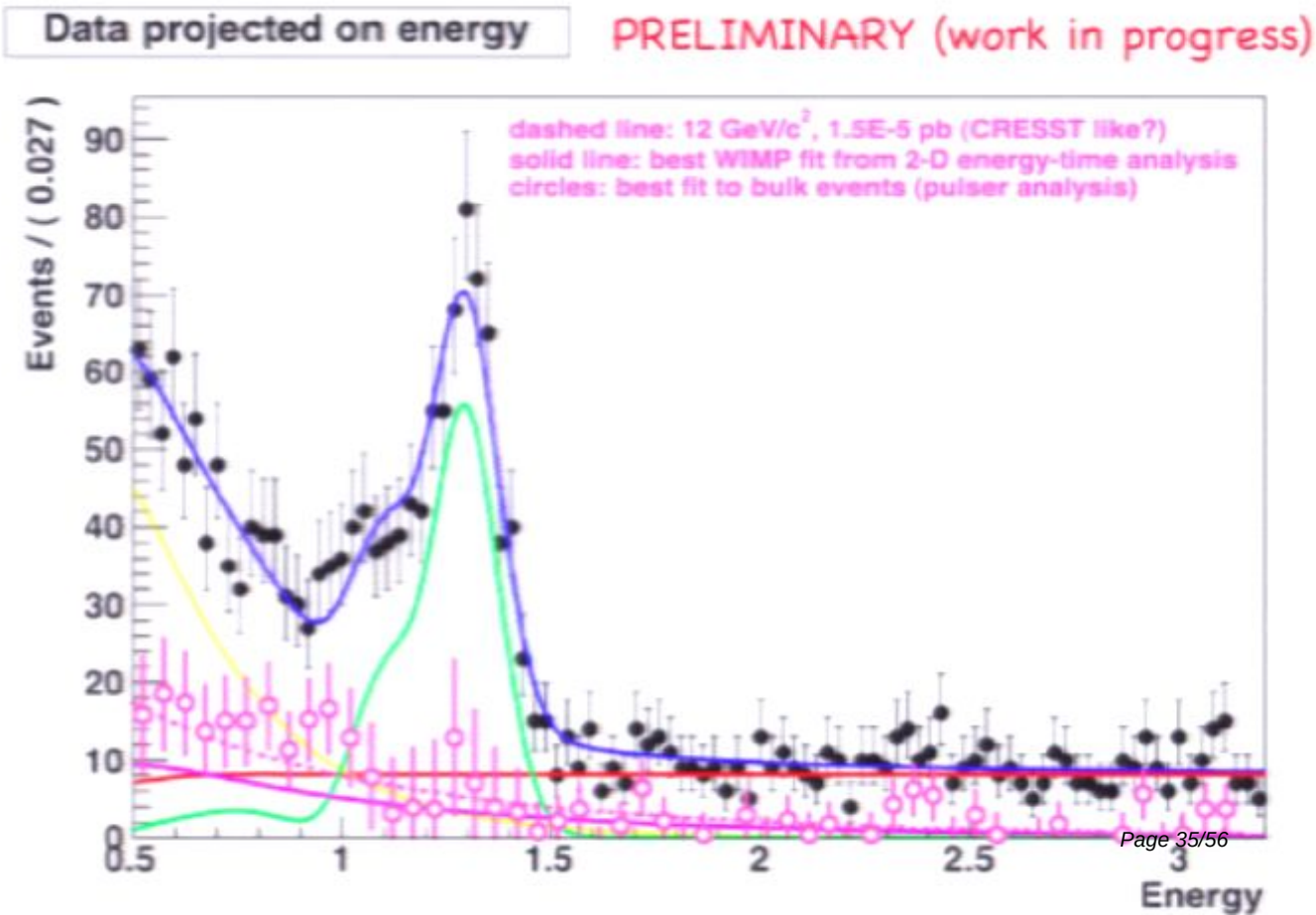

1.5 — 3. keV
Events / (keV kg day)
days since 1/ 1/ 2010


WIMP–nucleon cross section σ_{SI} [cm^2]
Dashed : 90 %
Solid : 3σ
DAMA (quenching ± 10 %)
CDMS low–thr
CoGeNT mod (constrained)
CoGeNT modulation
CoGeNT spect + mod
Xe – 100
v_0 = 220 km / s, v_{esc} = 550 km / s

CoGeNT updates

Makes "tension" with MB even larger





What about other halo models?

CoGeNT updates

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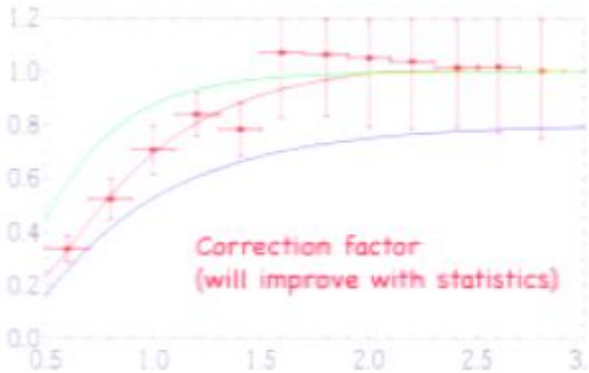
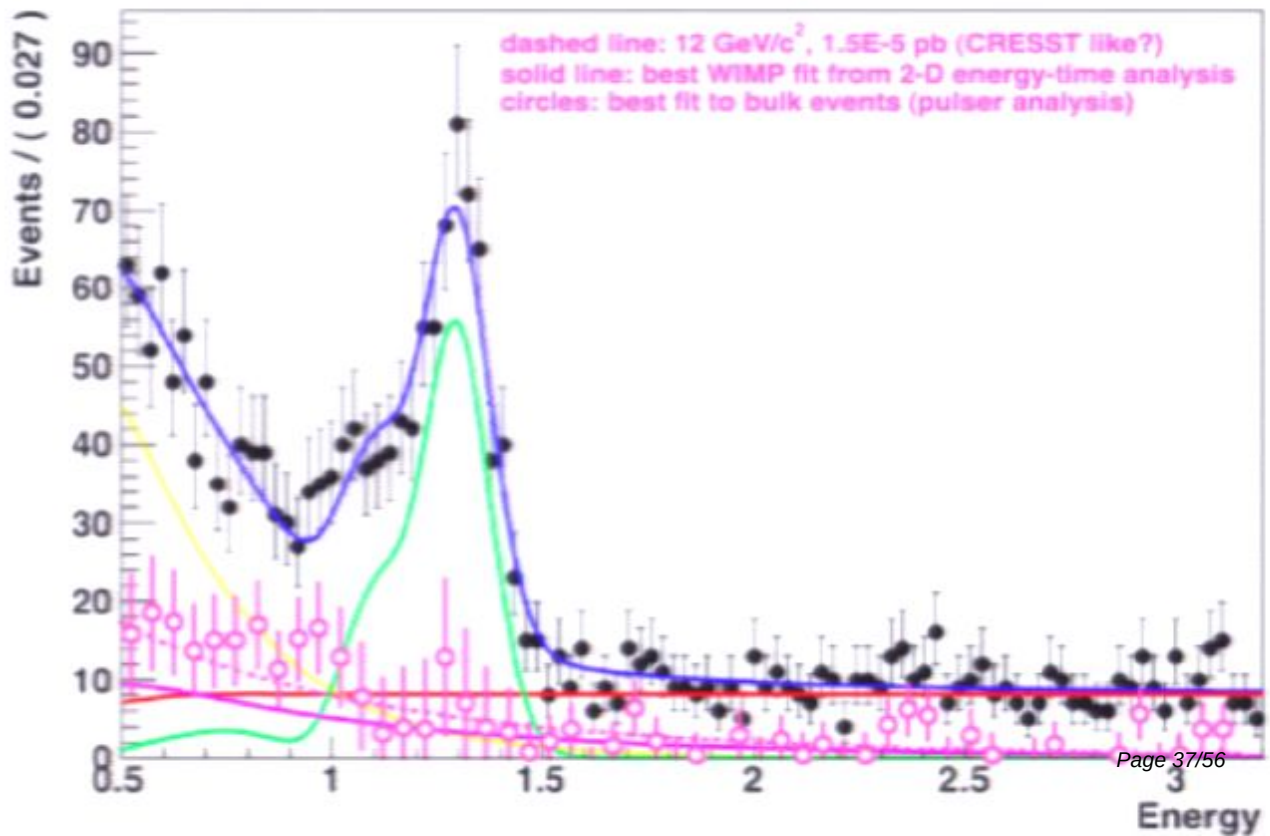


Data projected on energy

PRELIMINARY (work in progress)



What about other halo models?

Halo model independence

$$\frac{dR}{dE_R} = \frac{N_T M_T \rho}{2 m_\chi \mu^2} \underbrace{\int_{v_{min}}^{v_{max}} d^3\vec{v} \frac{f(\vec{v}, \vec{v_E})}{v}}_{g(v)} \sigma(E_R)$$

$$\frac{dR}{dE_R} = \frac{N_T M_T}{2\mu^2} \frac{\rho\sigma}{m_\chi} g(v)$$

Target specific

Target independent

$$_{min} = \sqrt{\frac{M_T E_R}{2\mu^2}}$$

Recoil energy uniquely determines **minimum** DM velocity

Halo model independence

$N_T = \kappa N_A m_p / M_T$

Solve for g(v)

$$g(v_{min}) = \frac{2 m_\chi \mu^2}{N_A \kappa\, m_p\, \rho\, \sigma(E_R)} \frac{dR_1}{dE_1}$$

$$\frac{dR_1}{dE_1} \Longleftrightarrow g(v_{min}) \Longleftrightarrow \frac{dR_2}{dE_2}$$

The master formula (SI):

$C_T^{(i)} = \kappa^{(i)} \left(f_p Z^{(i)} + f_n \left(A^{(i)} - Z^{(i)} \right) \right)^2$

$$\frac{dR_2}{dE_R}(E_2) = \frac{C_T^{(2)}}{C_T^{(1)}} \frac{F_2^2(E_2)}{F_1^2\left(\frac{\mu_1^2 M_T^{(2)}}{\mu_2^2 M_T^{(1)}} E_2\right)} \frac{dR_1}{dE_R}\left(\frac{\mu_1^2 M_T^{(2)}}{\mu_2^2 M_T^{(1)}} E_2\right)$$

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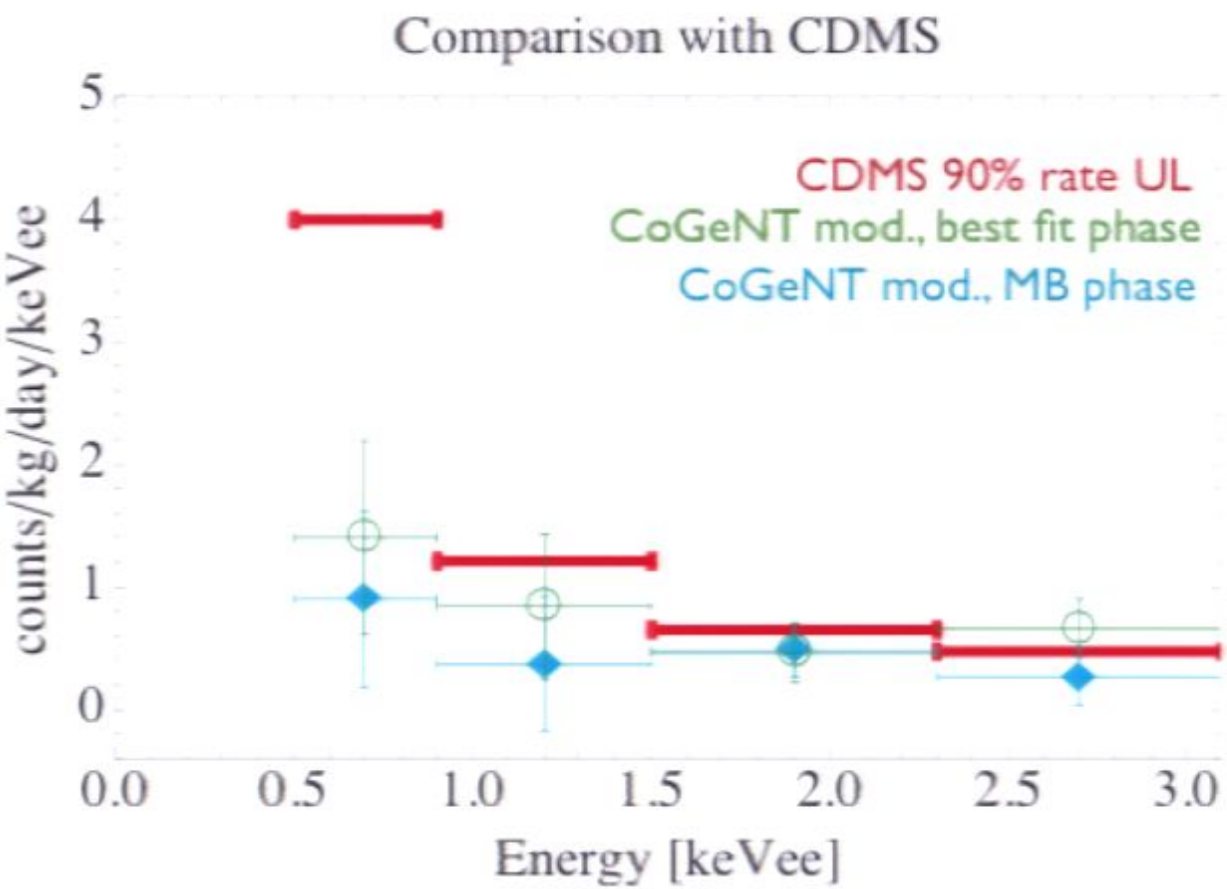
CDMS (Ge) and CoGeNT

(easy one since both Ge)



Modulation should be large in CDMS

CDMS modulation analysis??

CRESST (O) and CoGeNT

CoGeNT CRESST (O)

$[0.5, 1.5] \rightarrow [5.8 - 15.6]$

$[1.5, 3.1] \rightarrow [15.6, 29.8]$

$(m_\chi = 7\,\mathrm{GeV})$

Expect ~11 modulation events, they see ~30

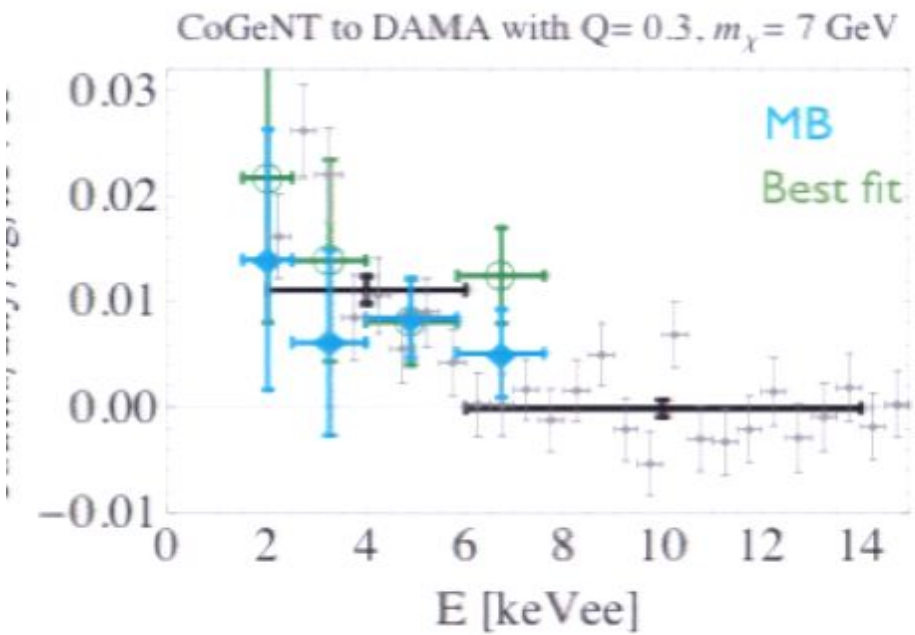
Xenon100 and CoGeNT

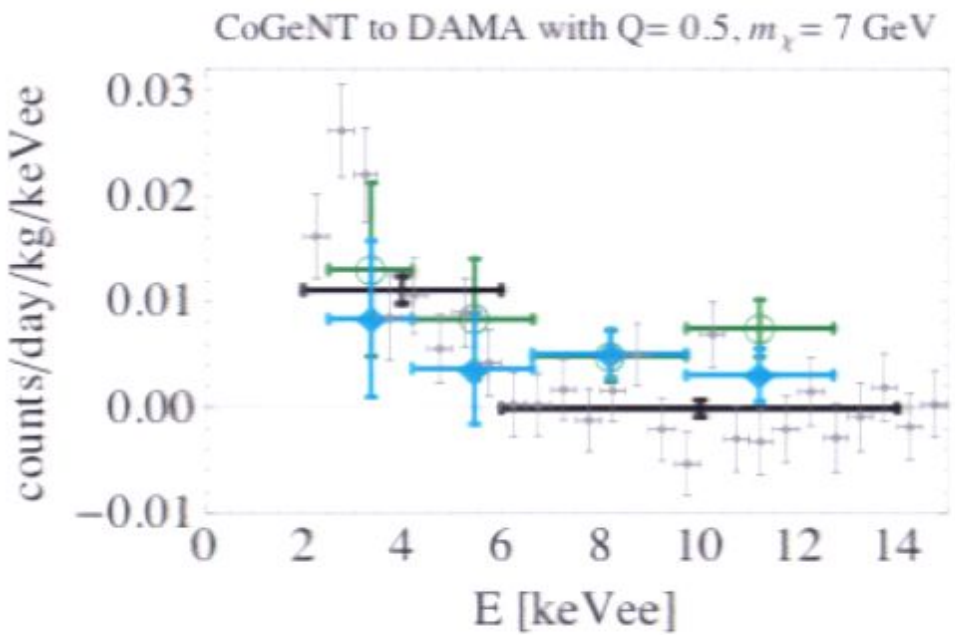
All about Leff: $1.5\,\mathrm{keVee} \rightarrow 3.7\,\mathrm{keVnr}$

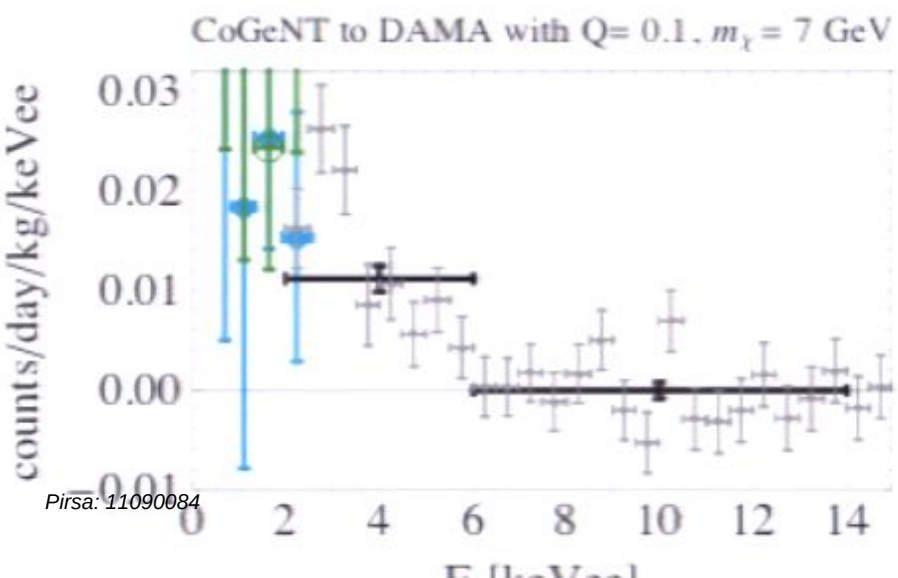
$$L_{eff} = 0.07 \Rightarrow (\sim 15, \sim 30)$$

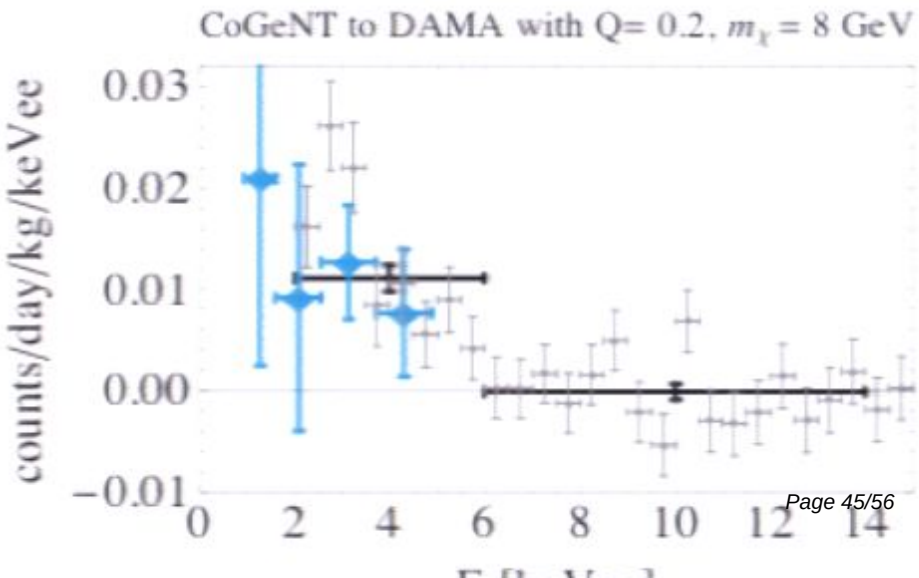
Need $L_{eff} \lesssim 0.04$ to get event rate down

DAMA and CoGeNT









Conclusions-CoGeNT

If CoGeNT modulation is from DM it is not a MB halo
Should compare to other results in halo-independent way

Conclusions-global

Conclusions-CoGeNT

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Conclusions-global

?

Conclusions-CoGeNT

If CoGeNT modulation is from DM it is not a MB halo
Should compare to other results in halo-independent way

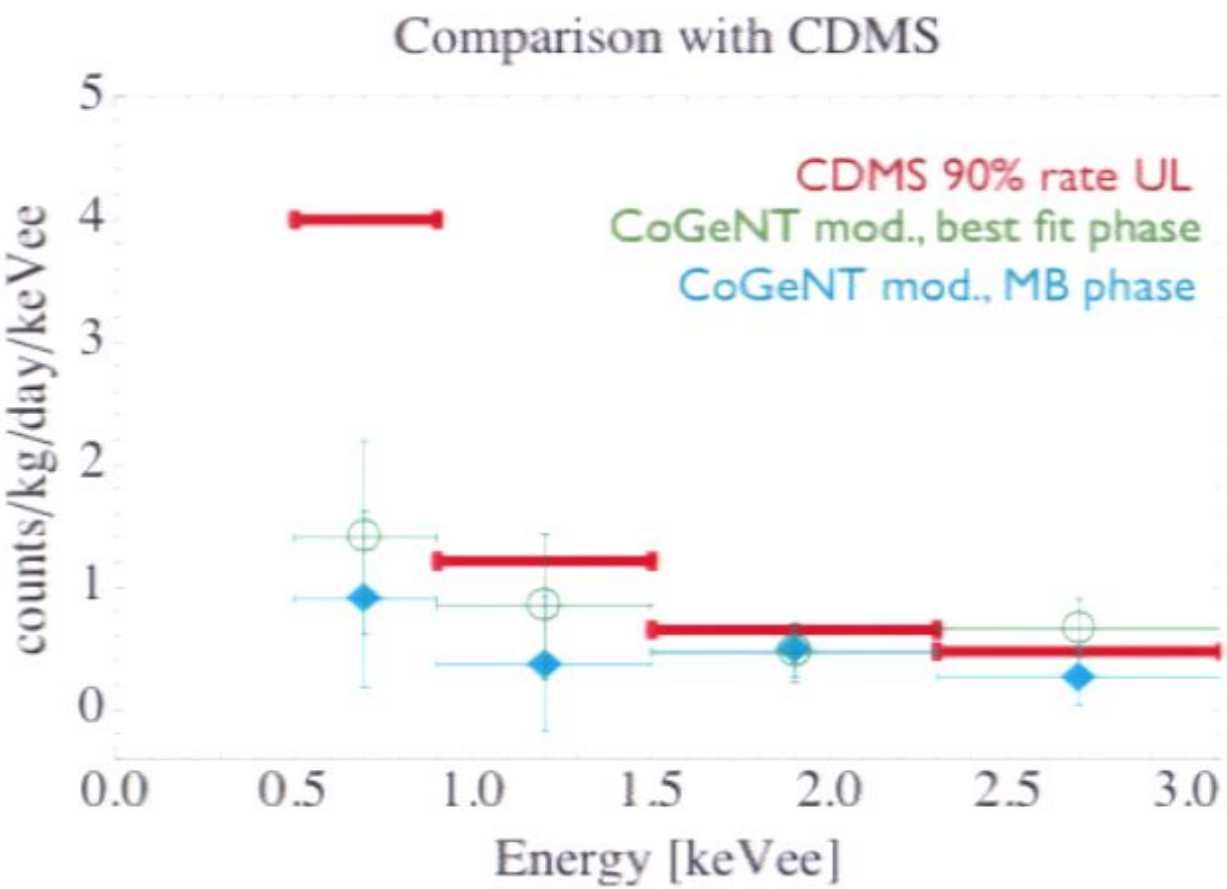
Conclusions-global

?

...but at least DM is not moving faster than c!

CDMS (Ge) and CoGeNT

(easy one since both Ge)



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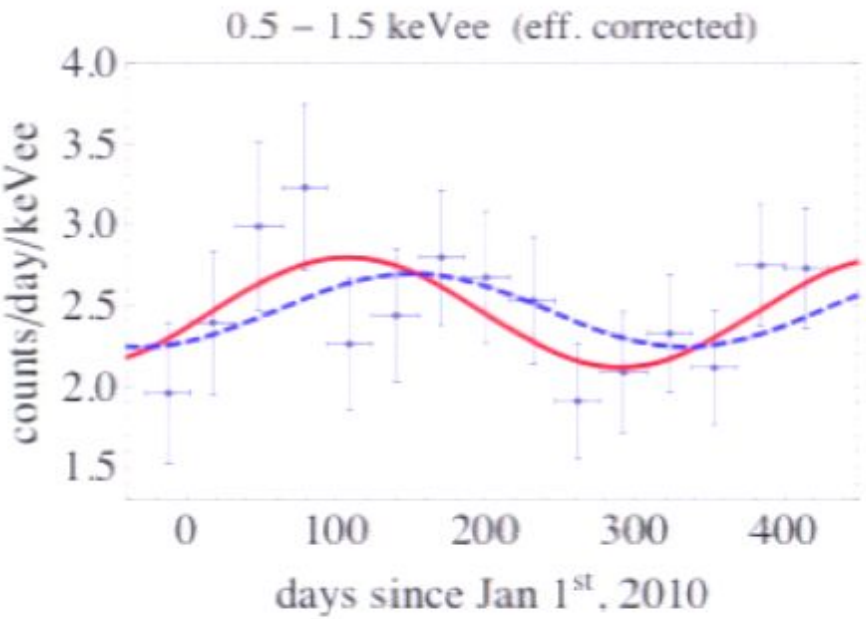
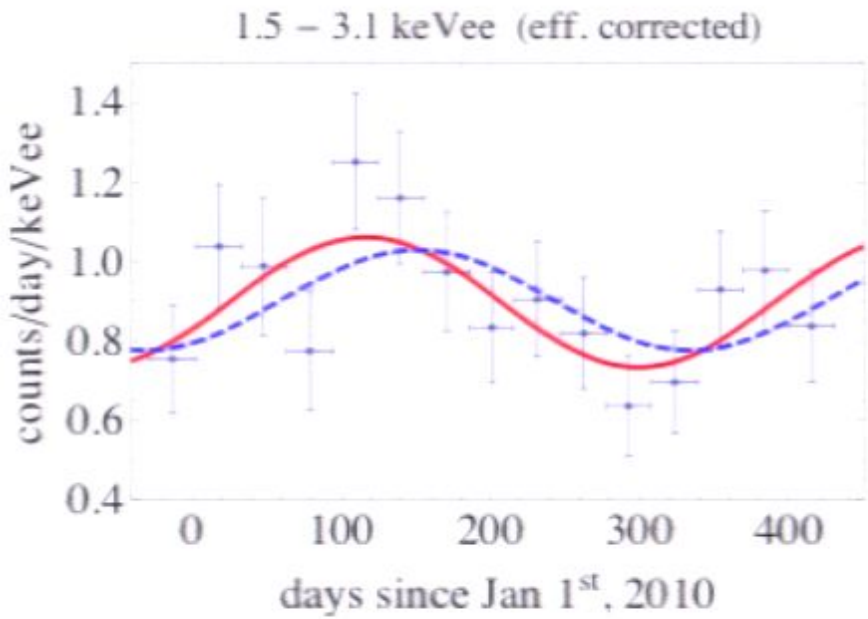
Modulation amplitude (Binned)





Free phase	$A_0 = 7.4$ events/day/kg/keVee $A_1 = 0.14$ $t_0 = 107$ days $\Delta\chi^2 = 4.7$	$A_0 = 2.7$ events/day/kg/keVee $A_1 = 0.18$ $t_0 = 116$ days $\Delta\chi^2 = 8.2$
MB phase $t_0 = 152$ days	$A_0 = 7.5$ events/day/kg/keVee $A_1 = 0.09$ $\Delta\chi^2 = 2.3$	$A_0 = 2.7$ events/day/kg/keVee $A_1 = 0.14$ $\Delta\chi^2 = 5.2$

No Signal

VGA-1

No Signal

VGA-1

No Signal

VGA-1

No Signal

VGA-1