A search for annual and diurnal rate modulations in the LUX experiment

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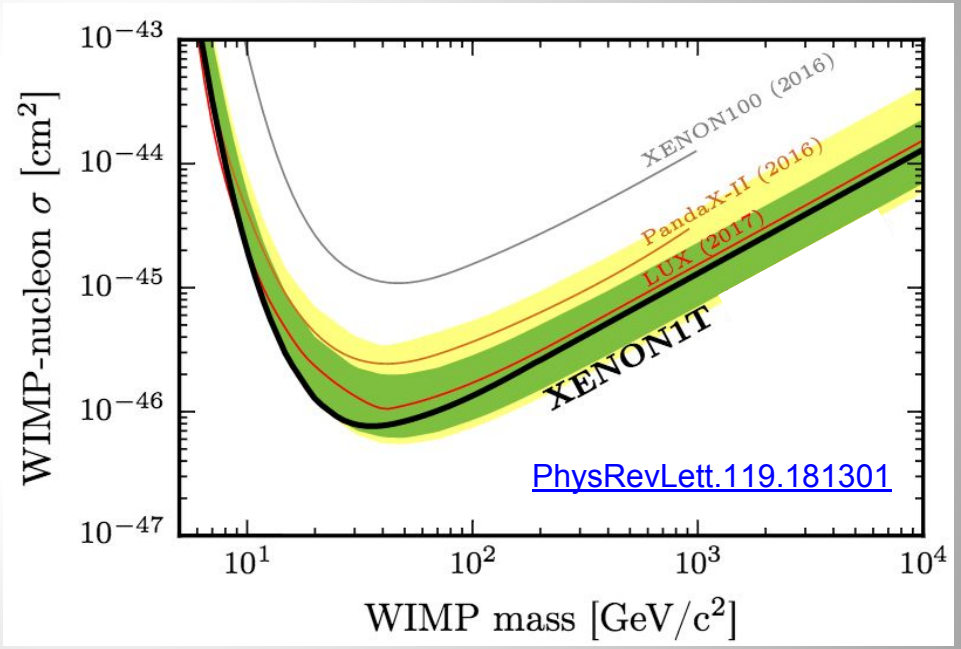
There is dark matter - but where?

The Surprise:

- Direct detection dark matter experiments have gained great sensitivity over the past decades
- No definitive dark matter signal has been observed.

The Question:

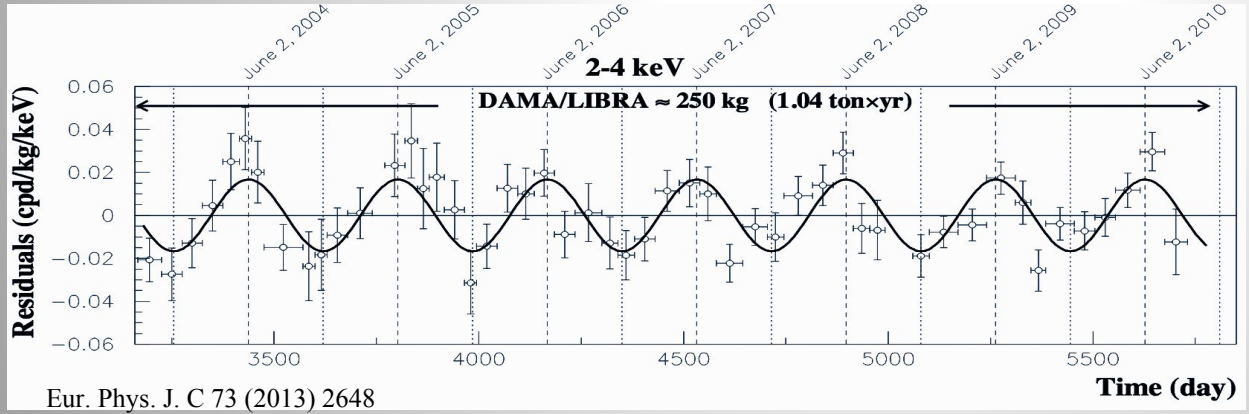
Where else can dark matter be hiding?



No definitive dark matter observations?

A longstanding dark matter claim by DAMA:

- An unexplained annual rate modulation (only present at low energies) in a large array of low background NaI(Tl) detectors
- Conflict with many other dark matter experiment if the modulation were to be explained by WIMP interactions



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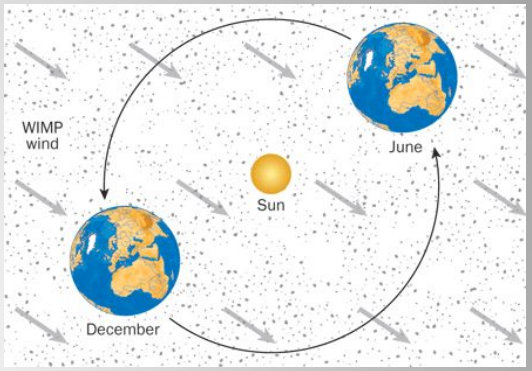


Dark matter interaction rate in an Earth-based experiment is expected to modulate due to the motion of the Earth around the sun. DM velocity distribution changes:

- Flux of DM particles
- Interaction cross section

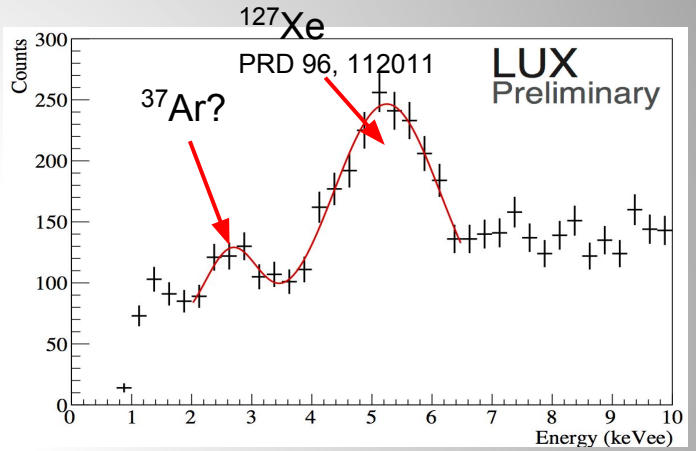
Modulation analysis with LUX

LUX is well positioned for a modulation search:

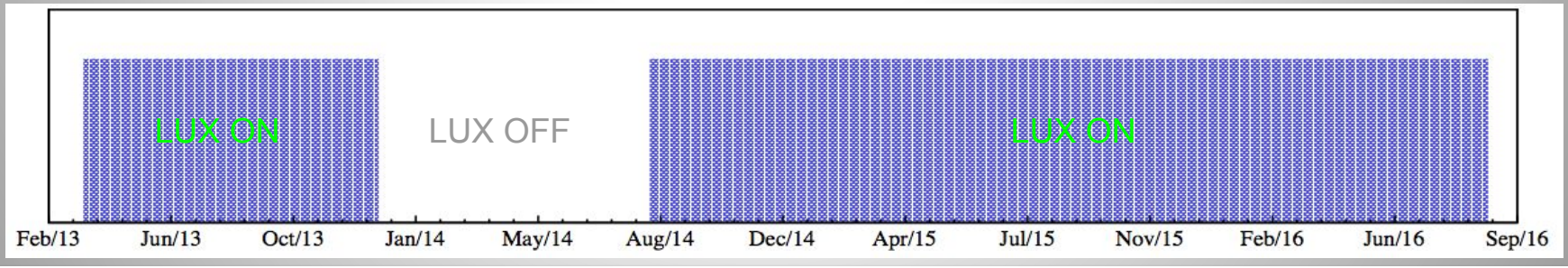
- Low background rate: ~3 cpd/keV$_{ee}$/ton
- ~2 calendar years of dark matter search

LUX observed a modest rate excess at 3 keV$_{ee}$

- Electron recoil events uniformly distributed
- May be explained as ^{37}Ar background
- No conclusion has been drawn due to low statistics



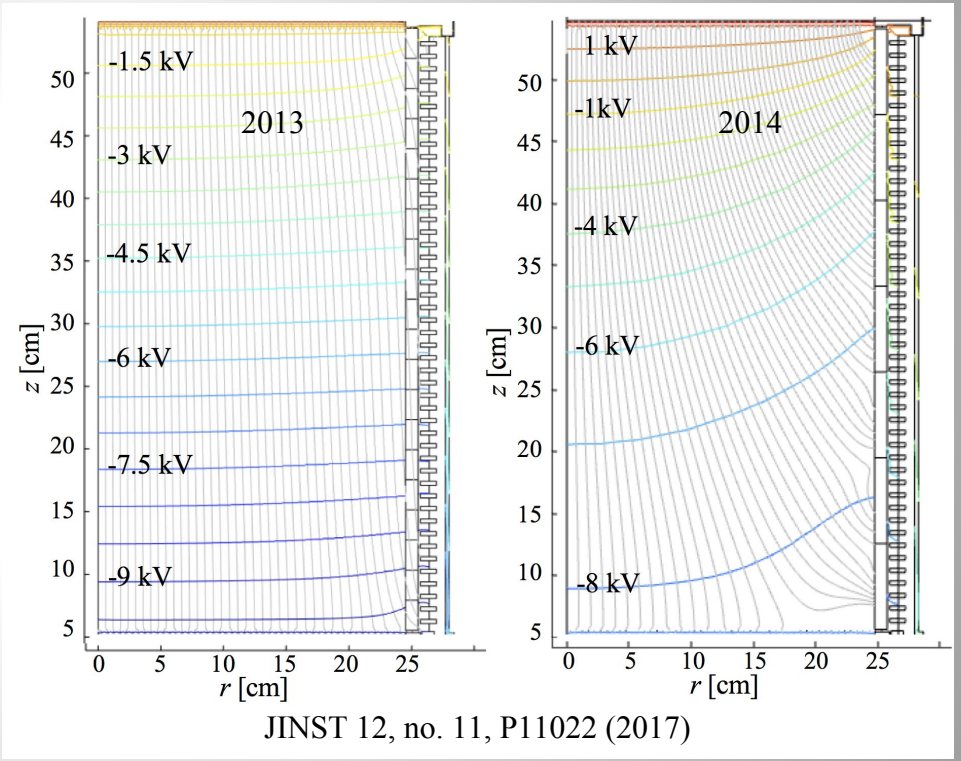
Low energy spectrum observed in LUX WS2013



Time dependence of electric field in LUX

Charge buildup on PTFE reflector surface occurred between WS2013 and WS2014-16 and throughout WS2014-16:

- Distortion of drift electric field
- Bias in position reconstruction
- Inhomogeneity of recombination efficiency
  - Energy reconstruction
  - ER/NR discrimination



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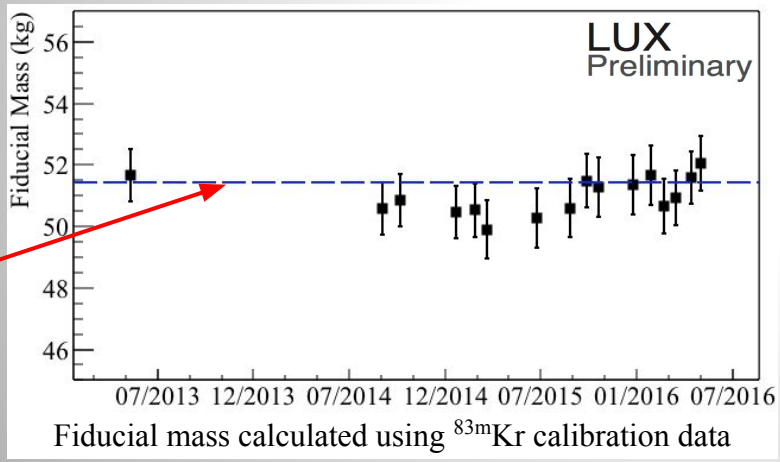
Fiducial volume cut

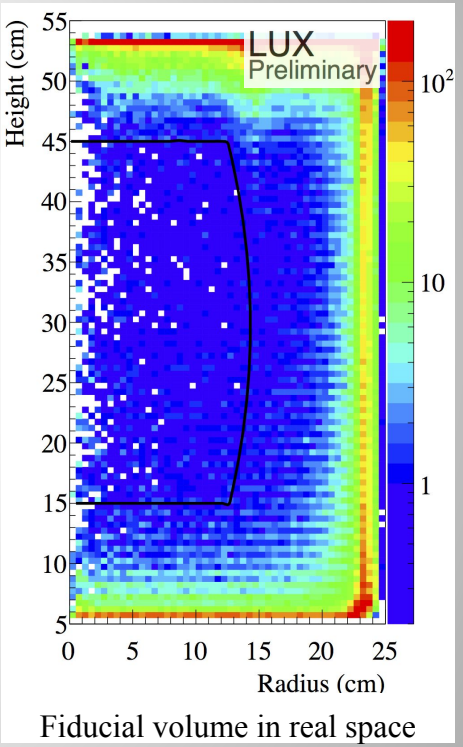
Using innermost volume (51.4 kg) of LUX for modulation analysis

- Fiducial volume defined in real space
- Region with lowest ER background rate
- ER rate doesn't have strong position dependence at fiducial edge
- Fiducial cut mapped to S2 positions using field map



Mass calculated using geometry

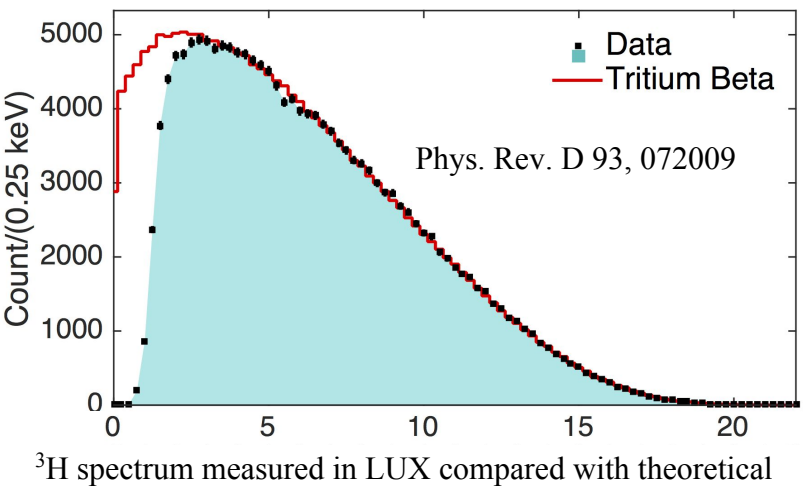
Fiducial mass calculated using ^{83m}Kr calibration data



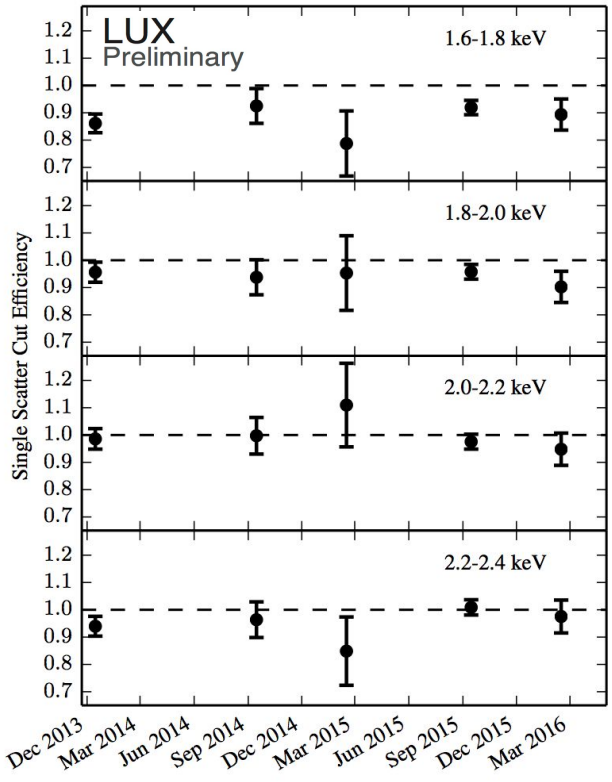
Fiducial volume in real space

Single scatter event selection

- Single scatter cut efficiency depends on S1 collection efficiency and threshold
- Use ^{3}H calibration to evaluate efficiency over time
- Selected 2 keV$_{ee}$ analysis threshold for ~100% efficiency



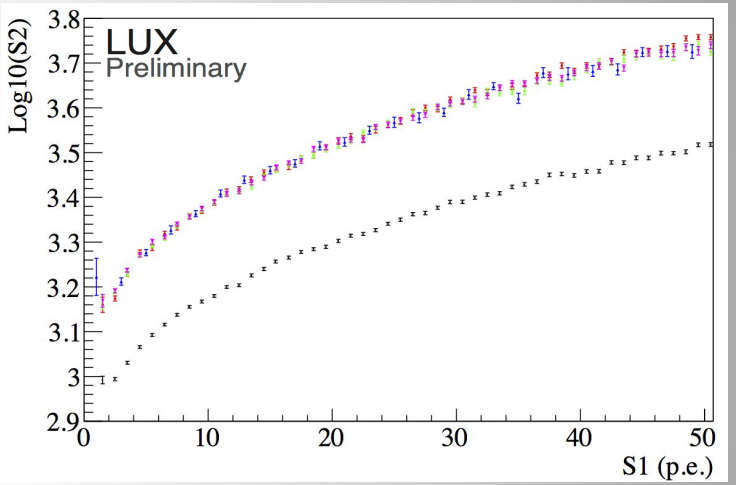
^{3}H spectrum measured in LUX compared with theoretical



Data quality cuts

Cuts to remove pathological background events:

- Reject electron background events within 20ms of a high energy trigger
- Reject events in which the S1+S2 pulse pair account for <50% of the total event area
- Reject events that fell >3σ away from the ER band mean (defined using ^{3}H and ^{14}C calibrations)



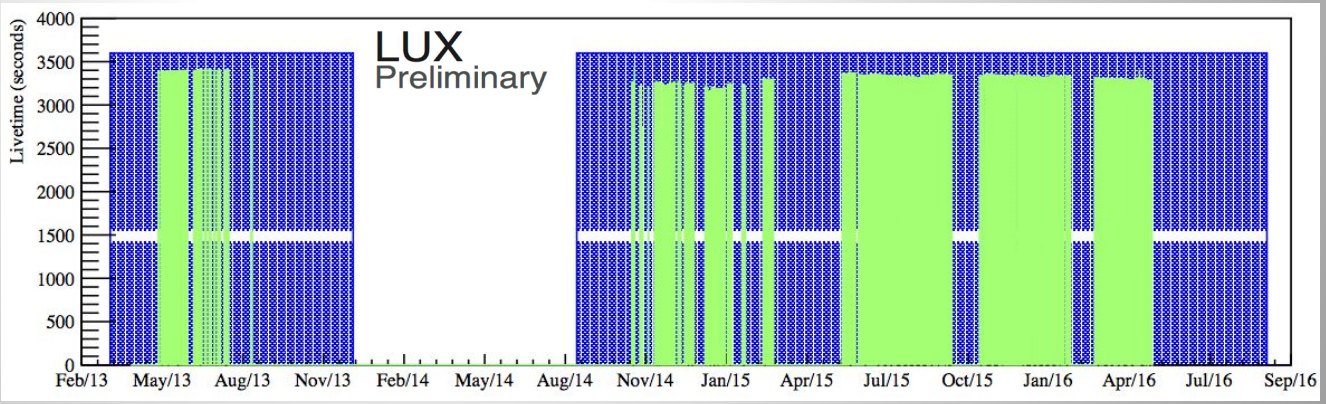
The mean of $\log_{10}$S2-S1 distribution for ER events in LUX, measured with ^{3}H in Dec 2013 (black), Sept 2014 (green), Feb 2015 (blue), Feb 2016 (magenta) and with ^{14}C events in July 2016 (red). Difference in WS2013 and WS2014-16 was due to different operating electric fields.

Live-time exclusions

Periods of data excluded from this analysis:

- Unstable slow control periods: temperature, pressure and liquid level
- Calibrations: ^{83m}Kr, ^{3}H, DD, AmBe, ^{252}Cf
- 1st month of WS data in 2013 (^{127}Xe, ^{37}Ar)
- Low liquid xenon purity periods
- Daylight saving time shifts, trigger holdoff (1ms), end-of-livetime (500 us)

271 live-days (green) after all exclusions; the approximate LUX operation time shown in blue

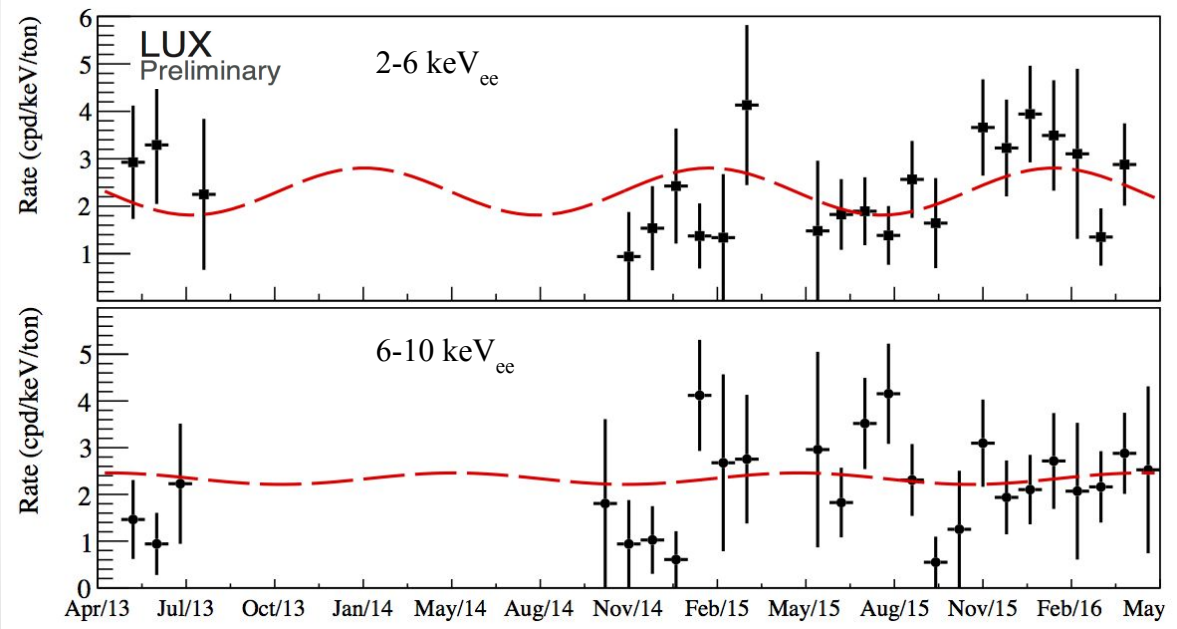


LUX event rate evolution

Event rate as a function of time in the signal region (2-6 keV_{ee}) and that in the control energy region (6-10 keV_{ee})

- ~135 events each group
- ~5 events each bin
- ~2 cpd/keV/tonne, 400 times lower than DAMA
- Best fits using unbinned extended maximum likelihood are shown in red

Control region event can be fully explained as background.

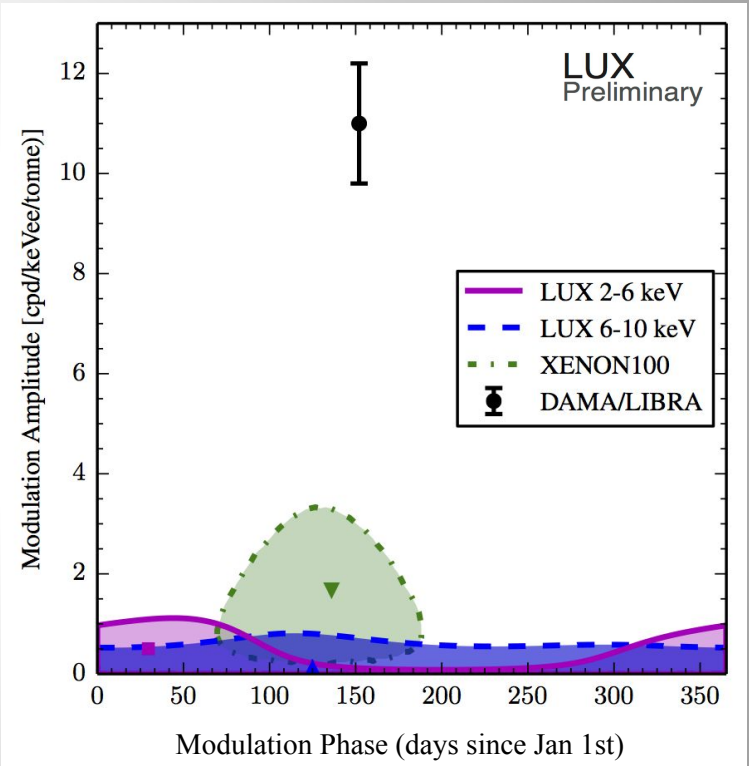


Annual modulation result

Best fit results for annual modulation searches:

Energy window	Modulation amplitude (cpd/keV/tonne)	Modulation Phase (days since Jan 1st)
2-6 keV_{ee}	0.50 +/- 0.27	30 +/- 35
	-0.33 +/- 0.27	**152 +/- 0**
6-10 keV_{ee}	0.12 +/- 0.32	124 +/- 113
	0.10 +/- 0.30	**152 +/- 0**

Significance contours were determined using toy Monte Carlo simulations (consistent with Wilks's Theorem).



Diurnal modulation result

- Diurnal NR dark matter modulations are predicted to be very small (<1%)
- Certain ER dark matter models predict diurnal modulation amplitude up to ~10%

Asymmetry factor for the diurnal modulation analysis:

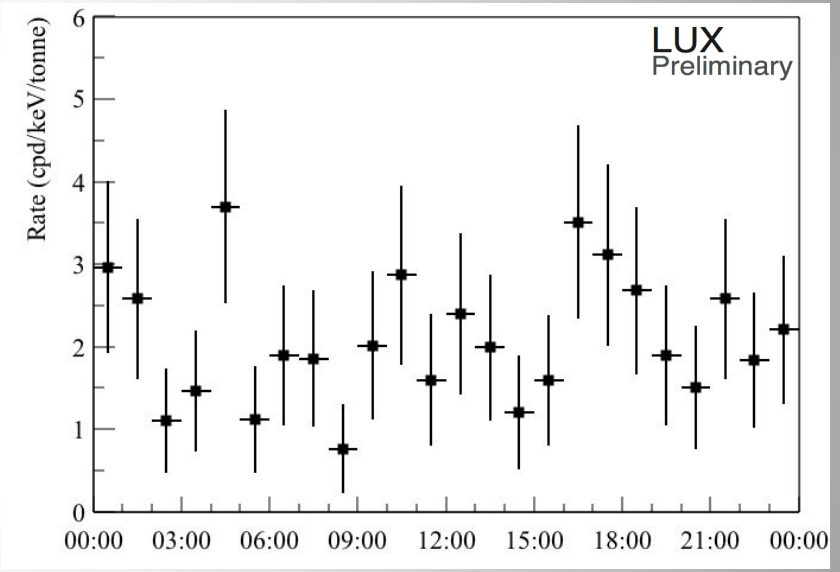
$$\mathcal{A}_t = \frac{R_t - \bar{R}_t}{R_t + \bar{R}_t}$$

Day/night rates: 2.06 / 2.14 cpd/keV/tonne

Asymmetry: -1.6% +/- 8.7% (stats only)

Morning/evening rate: 1.99/2.21 cpd/keV/tonne

Asymmetry: -5.4% +/- 8.7% (stats only)



ER event rate in LUX (2-6 keV_{ee}) as a function of time in the day (local MT w/ DST corrected for).

Conclusions

- We carried out annual and diurnal modulation searches with LUX ER events
- We demonstrated outstanding data stability through corrections and cuts
- No significant annual or diurnal modulation features are identified
- This work produces the most sensitive modulation searches to date

Thank you for your attention!