Dark matter annual modulation and ANAIS-112 results testing the DAMA/LIBRA positive signal

María Martínez, ARAID & U. Zaragoza
Freiburg, December 18, 2019
• Intro: Dark matter annual modulation
• Historical review
  • DAMA/LIBRA positive signal
• Current NaI(Tl) experiments
• ANAIS-112
  - Experimental set-up
  - Detector performance
  - Results on annual modulation
  - ANAIS-112 sensitivity
• Summary
Intro: DARK MATTER
ANNUAL MODULATION
Evidence of Dark Matter

Zwicky (1933)

bullet cluster (1E0657-558)

DM dominates all the structures of the Universe!

Structure formation

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DM candidates

What we know:

• lifetime $> >$ age of Universe

• No (or very very small) interaction with light

• Non baryonic

• Cold (or Warm) (Moving non-relativistically when galaxies started to form)

• Beyond the Standard Model
DM candidates

What we know:

• lifetime $>>$ age of Universe
• No (or very very small) interaction with light
• Non baryonic
• Cold (or Warm) (Moving non-relativistically when galaxies started to form)
• Beyond the Standard Model
WIMPs

Weakly interacting Massive Particles (WIMPs) very well motivated

• For the observed DM density, $\sigma$ corresponds to the one expected for a new weak-interacting particle
• WIMPs predicted in many extensions of the Standard Model such as SUSY

Abundance of a termal relic

$\sim \frac{0.1 \text{ pb}}{\langle\sigma_A v/c\rangle}$

...but not only thermal WIMPs...

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Structure of the Universe

![Millennium Run](image)

500 Mpc/h
Milky Way dark matter halo

Earth

\[ V \sim 200 \text{ km/s} \]

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Density \( \sim 0.4 \text{ GeV/cm}^3 \)

Dark Matter Halo

\[ \phi_{WIMP, earth} \sim 10^8 - 10^{10} \text{ s}^{-1} \text{ m}^{-2} \]
WIMP direct detection

WIMPs scatter elastically off nuclei

Expected rate @ Earth:

\[
\frac{dR}{dE_R} = \frac{\rho_0 M_{Det} \sigma_{WN}}{2 m_W m_{WN}^2} \int_{v_{min}}^{v_{max}} \frac{f(v)}{v} dv^3
\]

TARGET DEPENDENT!

$f(v)$

Naïve approximation: SHM

Isothermal sphere

$\nu_0 = 220 \text{ km/s}$

$\nu_{esc} \sim 530 \text{ km/s}$

$M_W = 100 \text{ GeV}$

$\sigma_{SI} = 1 \times 10^{-46} \text{ cm}^2$

TARGET DEPENDENT!
Annual modulation

Due to the Earth revolution around the Sun, the relative speed Earth-halo present a cosine-like behavior with 1 year periodicity and small amplitude ($\sim 7\%$)

$v_{\text{orbital}} = 30 \text{ km/s}$

$\alpha = 60^\circ$

$v = 220 \text{ km/s}$
Annual modulation

\[ \frac{dR}{dE}(E, t) \approx S_0(E) + S_m(E) \cos \omega(t - t_0) \]

Where

\[ S_m(E) = \frac{1}{2} \left( \frac{dR}{dE}(E, t_0) - \frac{dR}{dE}(E, t_0 + 182) \right) \]

- Cosine behaviour
- 1 year period
- Maximum around June 2\textsuperscript{nd}
- Weak effect (1-10\%)
- Only noticeable at low energy
- Phase reversal at low E

Hard to mimic by background!
Annual modulation

*Caveat:* the modulation (phase and amplitude) depends on the halo model, in particular of the presence of substructure.

Freese, Lisanti, Savage, Rev. Mod. Phys 85 (2013)
DAMA: an observatory for rare processes @LNGS

DAMA/LXe

DAMA/R&D

low bckg DAMA/Ge for sampling meas.

DAMA/NaI

DAMA/LIBRA

http://people.roma2.infn.it/dama
DAMA/NaI & DAMA/LIBRA (phase 1)


- 10 × 9.7 kg NaI(Tl)
  (3x3 matrix)
- 7 annual cycles
- Exposure: 0.29 ton × y

The data support the presence of a modulation (1 y period, phase on May 20th) at **6.3σ CL**

DAMA/NaI & DAMA/LIBRA (phase 1)


- 10 × 9.7 kg NaI(Tl)
  (3x3 matrix)
- 7 anual cycles
- Expusure : 0.29 ton × y

The data support the presence of a modulation (1 y period, phase on May 20th) at **6.3σ CL**

DAMA / LIBRA (2003-2010)

- 25 × 9.7 kg NaI(Tl)
  (5x5 matrix)
- 7 anual cycles
- Expusure : 1.17 ton × y

The data support the presence of a modulation (1 y period, phase on May 20th) at **9.2σ CL**
DAMA/NaI & DAMA/LIBRA (phase 1)

- 10 × 9.7 kg NaI(Tl)
  (3x3 matrix)
- 7 anual cycles
- Exposure : 0.29 ton × y

DAMA / LIBRA (2003-2010)
- 25 × 9.7 kg NaI(Tl)
  (5x5 matrix)
- 7 anual cycles
- Exposure : 1.17 ton × y

The signal satisfies all requirements for DM and can be interpreted as a std WIMP in the SHM


Solid line: $\cos(\omega(t - t_0))$, with period 1 year and phase on June 2$^{nd}$

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2011-2013 exciting times

Hint of annual modulation in one experiment
CoGeNT (2011-2014)

One PPC HPGe @ SOUDAN

330 g Ge, 3.4 years
No $\beta/\gamma$ discrimination
(Sm 4-7 times larger than predicted in SHM)

ArXiv:1401.3295

M. Martinez, F. ARAID & U. Zaragoza
2011-2013 exciting times

Hint of annual modulation in one experiment

CoGeNT (2011-2014)

One PPC HPGe @ SOUDAN

330 g Ge, 3.4 years
No $\beta/\gamma$ discrimination
(Sm 4-7 times larger than predicted in SHM)

Excess of events in WIMP region in two experiments:

CRESST (2011)

One module (300 g CaWO$_4$)

SuperCDMS-Si (2013)

ArXiv:1401.3295

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2011-2013 exciting times

CoGeNT modulation too large, but can be in agreement with DAMA/LIBRA for some non-SHM haloes
2011-2013 exciting times

CoGeNT modulation too large, but can be in agreement with DAMA/LIBRA for some non-SHM haloes

But since 2013 ...

- CRESST-II (2014-2015) with an upgraded detector did not confirm the excess
- CoGeNT’s signal significance decreased with time (3.4y by 2014) to below 2σ. Different interpretations among the collaboration.
- CDMS-II-Si signal very small. No more data
Interpreting DAMA/LIBRA ph1 as WIMPs

DAMA clearly sees an annual modulation at 12.9σ

But the signal is in strong tension with the most sensitive experiments, even assuming more general halo/interaction models!
Other annual modulation searches


“Search for Electronic Recoil Event Rate Modulation with 4 Years of XENON100 Data”
PRL118, 101101 (2017)


“Search for annual modulation in low-energy CDMS-II data”, 1203.1309

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The data of DAMA/LIBRA phase1+phase2 favor the presence of a modulation with proper features at 11.9σ CL (2.17 ton × yr)

all PMTs replaced with new ones of higher Q.E.

2 more points

- 6 annual cycles
- Exposure: 1.13 ton × yr
Interpretation of the 1 keV point

1804.01231, Baum, Freese, Kelso “Dark Matter implications of DAMA/LIBRA-phase2 results”

“the observed annual modulation signal is no longer well fitted by canonical (isospin conserving) spin-independent WIMP nucleon couplings”
Interpretation of the 1 keV point

1907.06405, Bernabei et al. “Improved model-dependent corollary analyses after the first six annual cycles of DAMA/LIBRA-phase2”

“at present level of uncertainties the DAMA data, if interpreted in terms of DM particle inducing nuclear recoils through SI interaction, can account either for low and large DM particle mass and for a wide range of the ratio \( f_n/f_p \), even including the “standard” case \( f_n/f_p = 1 \).”

1804.01231, Baum, Freese, Kelso “Dark Matter implications of DAMA/LIBRA-phase2 results”

“the observed annual modulation signal is no longer well fitted by canonical (isospin conserving) spin-independent WIMP nucleon couplings”

“the purely SD scenarios are in good agreement with the DAMA results and can explain the dierent capability of detection among targets with dierent unpaired nucleon.”

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Interpreting DAMA/LIBRA ph1 as WIMPs

DAMA clearly sees an annual modulation at $12.9\sigma$

TO AVOID ANY MODEL DEPENDENCE, WE NEED A PROOF/DISPROOF WITH THE SAME TARGET

Dark matter or systematics?
Nuclear recoil quenching factor

An ER produces much more light than a NR of the same energy!

The spectra are calibrated with $X/\gamma$ sources, so it is given in keVee(*). In order to be interpreted as NR, $Q$ has to be measured to correct the energy scale:

$$Q = \frac{signal_{NR}/keV}{signal_{ER}/keV}$$

(* )keVee: electron-equivalent keV

First NaI quenching factor measurements (Spooner’94): $Q_{Na} = 0.3$ $Q_{I} = 0.09$

WHAT I WOULD MEASURE:

Mod Amplitude WIMP 50 GeV

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Recent measurements give lower values. Na quenching decreases when decreasing the energy.
Recent measurements give lower values. Na quenching decreases when decreasing the energy.


Is there a (large) dependence of the quenching factor with the crystal?
- Impurities
- TI level
- Crystal quality
- ...

Cosine+Anais combined measurements @ TUNL (Duke Univ.)
different NaI(Tl) crystals in the same setup
Results soon!
CURRENT NaI(Tl) experiments
Nal experiments around the World

ANAIS-112 (LSC)

SABRE NORTH (LNGS)

COSINE-100 (Y2L)

PICO-LON (Kamioka)

SABRE SOUTH (Stawell)

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NaI experiments around the World

IN DATA-TAKING Since Aug 2017
112 kg NaI(Tl)

IN DATA-TAKING Since Sep 2016
~60 kg NaI(Tl)

ANAIS-112 (LSC)
SABRE NORTH (LNGS)
COSINE-100 (Y2L)
PIKO-LON (Kamioka)
SABRE SOUTH (Stawell)

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Why took so long?

Sensitivity $\propto \sqrt{\frac{MT\epsilon}{B}}$

Large mass
Stable conditions over years
High efficiency at very low energy

Very low radioactive background!!

- The main contribution to the background comes from the crystal itself
- Long effort of ANAIS team looking for ultra pure NaI(Tl), R&D with Alpha Spectra → crystals now used by ANAIS-112 and COSINE-100
- However, up to the date, the quality of the DAMA crystals has not been reached by any group

<table>
<thead>
<tr>
<th></th>
<th>K (ppb)</th>
<th>$^{210}$Pb (mBq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAMA (Saint Gobain)</td>
<td>13</td>
<td>0.01-0.03</td>
</tr>
<tr>
<td>ANAIS/COSINE (Alpha Spectra)</td>
<td>18-44</td>
<td>0.7-3</td>
</tr>
</tbody>
</table>

$^{40}$K, $^{210}$Pb, $^3$H

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COSINE-100

• Data-taking started in Sep 2016, Y2L (South Korea)

• 8 ultra low-background NaI(Tl) crystals with 106 kg in total (but only \(\sim 60\) kg usable for DM search)

• Inside lead shielding and Liquid Scintillator tank to reject coincident events (\(^{40}\)K!)

• Muon veto & neutron monitoring

NEXT STEP: COSINE-200 (2020?)

Goal: Run 200 kg NaI(Tl) in the same set-up, with improved background (lower than DAMA/LIBRA)

Status: Power purification, crystal growing and handling facilities established, buy a factor 2 or more improvement in bkg is needed.

From G. Adhikari @ TAUP2019
COSINE-100 results

SET1 (59.5 days)

Background + WIMP signal is fit to data:

→ Model dependent exclusion of DAMA/LIBRA-phase1 (*)
  - Spin Independent interaction
  - Maxwellian velocity distribution

(*) But not excluded in effective models (COSINE coll. & S. Scopel, JCAP 1906 (2019) 06, 048)

SET2 (1.7 y, 97.7 kg·year exposure)


At 68.3% C.L., result is consistent with both a null hypothesis and DAMA/LIBRA's best fit value.

From Y. J. Ko @ TAUP2019

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SABRE

From S. Copello @ TAUP2019

- Ultra-clean NaI(Tl) (Princeton)
- Two sites (LNGS/ Stawell)

Proof of Principle: one NaI crystal in LS vessel

First crystal (3.5 kg) arrived @ LNGS on August 2019

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<tr>
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<th>K (ppb)</th>
<th>$^{210}$Pb (mBq/kg)</th>
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<tr>
<td>SABRE</td>
<td>4</td>
<td>0.4</td>
</tr>
<tr>
<td>DAMA</td>
<td>13</td>
<td>0.01-0.03</td>
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LS Vessel ready at LNGS

From S. Copello @ TAUP2019
GOAL: Development of highly radiopure NaI(Tl) scintillator

Status of NaI(Tl) purification (~April 2019)

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<tr>
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<tbody>
<tr>
<td>Size</td>
<td>3”ΦX3”</td>
<td>4”ΦX3#</td>
<td>3”ΦX3”</td>
<td>5”ΦX4”(*)</td>
<td>5”ΦX5”</td>
</tr>
<tr>
<td>⁴⁰K (ppb)</td>
<td>2630</td>
<td>120</td>
<td>&lt;20</td>
<td>&lt;20</td>
<td>&lt;20</td>
</tr>
<tr>
<td>²³²Th (ppt)</td>
<td>0.4±0.5</td>
<td>3.7±0.5</td>
<td>1.7±0.2</td>
<td>--</td>
<td>&lt;4</td>
</tr>
<tr>
<td>²³⁸U (ppt)</td>
<td>4.7±0.3</td>
<td>5.9±0.3</td>
<td>9.7±0.8</td>
<td>4.4±0.2</td>
<td>&lt;10</td>
</tr>
<tr>
<td>²¹⁰Pb (μBq/kg)</td>
<td>30±7</td>
<td>2300</td>
<td>1076</td>
<td>~560</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Method</td>
<td>Resin for Pb</td>
<td>I26+cation resin</td>
<td>double recrystallization</td>
<td>Pb resin + double recrystallization</td>
<td></td>
</tr>
</tbody>
</table>

DAMA

10-33

From K. Fushimi @ TAUP2019
First NaI detector with particle discrimination
(Two channel approach: HEAT and LIGHT)

With a moderate exposure of few O(100) kg-days, can confirm or rule-out a nuclear recoil origin of the DAMA/LIBRA dark matter claim


Present threshold: 8.26 keV_{NR}
(Goal: 1 keV_{NR})
ANAIS-112 experiment
Annual Modulation with NaI Scintillators

GOAL:
Confirmation of DAMA-LIBRA modulation signal - same target and technique / different experimental approach / different environmental conditions affecting systematics

WHERE:
At Canfranc Underground Laboratory, @ SPAIN (under 2450 m.w.e.)

THE DETECTOR:
3x3 matrix of 12.5 kg NaI(Tl) cylindrical modules = 112.5 kg of active mass

taking data since August 2017
- 9 NaI(Tl) cylindrical crystals (12.5 kg each) in 3x3 matrix
- Ultrapure NaI powder (Alpha Spectra Inc)
- Each coupled to two Hamamatsu R12669SEL2 PMT (QE ~40%)
Detectors equipped with a Mylar window!
Radon-free system for low energy calibration:
• $^{109}\text{Cd}$ sources on flexible wires (radon-free)
• Energies: 11.9, 22.6 and 88.0 keV
• Simultaneous calibration of the nine modules
• Performed every two weeks
In ANAIS we flag every muon that cross the shielding and set a (configurable) dead-time after every passage (DAMA/LIBRA has no muon veto).

The underground muon flux is annual-modulated!

DAMA reply:
- Modulation phase inconsistency
- Muons interacting directly in the detectors do not fulfill the DM requisites
- Not enough muon-induced fast neutrons to account for the signal

But still some open questions:
- (delayed) effect of muons in PMTs?
- Slow phosphorescence in NaI?

ANAIS can test these hypotheses

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ANAIS-112: Data acquisition system

- Individual PMT signals **digitized** and fully processed (14 bits, 2 GS/s)
- Trigger at phe level for each PMT signal
- AND coincidence in 200 ns window
- Redundant energy conversion by QDC
- Trigger in OR mode among modules
- Electronics at air-conditioned-room to decouple from temperature fluctuations
- Muon detection system: tag every muon event to offline processing
ANAIS-112: Slow control

• Monitoring **environmental parameters** since the start of DM run
  
  – Monitoring:
    - Rn content, humidity, pressure, different temperatures, N\(_2\) flux, PMT HV, muon rate, …
    - Data saved every few minutes and alarm messages implemented
  
  – Stability checks:
    - gain, trigger rate, …
DETECTOR PERFORMANCE

Detector Response: duty cycle & stability

- Excellent duty cycle

  1st year

  2nd year

- Good total rate and gain stability

Evolution of $^{109}$Cd lines from calibrations along the whole data-taking (~ 2 year)
Detector response: threshold

- Effectively triggering below 1 keV<sub>ee</sub>

bulk $^{22}$Na and $^{40}$K events identified by coincidences with high energy gammas
Detector response: threshold

- Effectively triggering below 1 keV_{ee}

- Energy threshold limited by PMT noise filtering protocols efficiency

  - Multiparametric cuts to properly select events with pulse shapes from NaI(Tl) scintillation (efficiency computed on $^{109}$Cd calibration and $^{22}$Na and $^{40}$K coincidence populations)
Background & efficiency

10% unblinded data

DAMA/LIBRA
Universe 4, 116 (2018), 1805.10486


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At very low energy (<20 keV), most significant contributions come from the crystal itself

- $^{40}$K and $^{22}$Na ($T_{1/2} = 2.6$ y) peaks
- $^{210}$Pb (bulk+surface) ($T_{1/2} = 22.3$ y)
- $^3$H ($T_{1/2} = 12.3$ y)

Very good agreement with data except between 1-2 keV

Prediction of the time evolution of rates from the model: cosmogenic isotopes ($^3$H, $^{22}$Na, …) and $^{210}$Pb:

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RESULTS ON ANNUAL MODULATION
Analysis strategy

**Background decay rate in the RoI consistent with our background model (in green)**

\[
R(t) = R_0 + R_1 \exp(-t/\tau) + S_m \cos(\omega(t + \phi))
\]

**ANALYSIS STRATEGY**

- Focus on model independent analysis searching from modulation
- In order to better compare with DAMA/LIBRA results, we use the **same** energy regions ([1-6] keV, [2-6] keV) and fit parameters

**Fixed parameters:**

\(\tau\) (background model)  
\(\omega\) (freq. corresponding to a period of 1 year)  
\(\phi\) (maximum in June, 2\textsuperscript{nd})

1.5 years data
1st Annual modulation results

Least squared fit to:  \( R(t) = R_0 + R_1 \exp(-t/\tau) + S_m \cos(\omega(t + \phi)) \)

Fixed parameters:
\( \tau \) (background model)
\( \omega \) (freq. corresponding to a period of 1 year)
\( \phi \) (maximum in June, 2\(^{nd}\))

\( S_m \) fixed to 0 in the null hypothesis and left unconstrained for the modulation hypothesis

\[ R_t = R_0 + R_1 \exp(-t/\tau) + S_m \cos(\omega(t + \phi)) \]

\[ S_m \text{ fixed to 0 in the null hypothesis and left unconstrained for the modulation hypothesis} \]

\[ \text{DAMA/LIBRA result with 1–free parameter is shown for comparison} \]

\[ \text{arXiv:1903.03973} \]

\[ \text{Phys. Rev. Lett., 123, 031301 (2019)} \]
1st Annual modulation results

\[ [2-6] \text{ keV} \rightarrow S_m = -0.0044 \pm 0.0058 \text{ c/keV/kg/d} \quad (S_m^{DAMA} = 0.0102 \text{ cpd/kg/keV}) \]

\[ [1-6] \text{ keV} \rightarrow S_m = -0.0015 \pm 0.0063 \text{ c/keV/kg/d} \quad (S_m^{DAMA} = 0.0105 \text{ cpd/kg/keV}) \]

- Null hypothesis is well supported by the $\chi^2$ test (p-values=0.18, 0.67)
- Best fits for the modulation hypothesis have p-values slightly lower than for the null hypothesis
- Best fits are compatible with no modulation and incompatible at 2.5$\sigma$ (2-6 keV) and 1.9$\sigma$ (1-6 keV) with DAMA/LIBRA results.
  Sensitivity (1.5 y) 1.8$\sigma$

**arXiv:1903.03973**

2 years results

M. L. Sarsa @ TAUP2019

PRELIMINARY

NEW!

mod hyp: $S_m = (-0.0029 \pm 0.0050)$ (cpd/kg/keV)
$\rightarrow \chi^2/NDF = 67.0 / 71$ [pval=0.61]
null hyp $\rightarrow \chi^2/NDF = 67.4 / 72$ [pval=0.63]

DAMA mod hyp: $S_m = 0.0102$ (cpd/kg/keV) $\rightarrow \chi^2/NDF = 74.5 / 75$ [pval=0.49]

mod hyp: $S_m = (-0.0036 \pm 0.0054)$ (cpd/kg/keV)
$\rightarrow \chi^2/NDF = 88.0 / 71$ [pval=0.08]
null hyp $\rightarrow \chi^2/NDF = 88.5 / 72$ [pval=0.09]

DAMA mod hyp: $S_m = 0.0105$ (cpd/kg/keV) $\rightarrow \chi^2/NDF = 95.5 / 75$ [pval=0.06]

Days after August 3, 2017

213.6 kg x yr

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2 years results

M. L. Sarsa @ TAUP2019

[2-6] keV → \( S_m = -0.0029 \pm 0.0050 \text{ c/keV/kg/d} \) \( (S_m^{DAMA} = 0.0102 \text{ cpd/kg/keV}) \)

[1-6] keV → \( S_m = -0.0036 \pm 0.0054 \text{ c/keV/kg/d} \) \( (S_m^{DAMA} = 0.0105 \text{ cpd/kg/keV}) \)

• Null hypothesis is well supported by the \( \chi^2 \) test (p-values=0.09, 0.63)
• Best fits for the mod. hypothesis p-values slightly lower than for the null hypothesis
• Best fits are compatible with no modulation and incompatible at 2.6σ with DAMA/LIBRA results. Present sensitivity 2σ

1.5 years (PRL 123 (2019) 031301)

2 years (TAUP 2019)
The absence of modulation is well supported also when we consider 1 keV bins in the RoI.
\[ R(t) = R_0 + R_1 \exp(-t/\tau) + S_m \cos(\omega(t + \phi)) \]

**Fixed parameters:**
- \( \tau \) (background model)
- \( \omega \) (freq. corresponding to a period of 1 year)

**Free parameters:**
- \( R_0, R_1, S_m, \phi \)
ANAIS-112
SENSITIVITY
Calculating the sensitivity

Least squared fit to: \( R(t) = R_0 + R_1 \exp(-t/\tau) + S_m \cos(\omega(t + \phi)) \)

Three free parameters \( (R_0, R_1, S_m) \)

The experimental sensitivity is given by the standard deviation of the modulation amplitude \( \sigma(S_m) \), that can be calculated analytically from:

- Updated background
- Efficiency estimate and its error
- Live time distribution

Expected sensitivity

We quote our sensitivity to DAMA/LIBRA result as the ratio $S_{m}^{DAMA}/\sigma(S_m)$.
Expected sensitivity

We quote our sensitivity to DAMA/LIBRA result as the ratio $S_m^{DAMA}/\sigma(S_m)$

- 1.5 and 2 y data confirm our sensitivity projection to DAMA/LIBRA result
- Present sensitivity: 2$\sigma$
- 3$\sigma$ at reach in 2.5 years from now
Model dependent (SI interaction)

Likelihood 90% - 90%

- Standard halo model
- Spin-independent interaction
- \( \rho_0 = 0.3 \text{ GeV/cm}^3 \)

- \( v_0 = 220 \text{ km/s} \)
- \( v_{esc} = 650 \text{ km/s} \)
- \( Q_{Na} = 0.30, Q_I = 0.09 \)

DAMA regions from:

C. Savage et al., JCAP04 (2009) 010
Summary

- Annual modulation is a distinctive signature of Dark Matter
- One positive signal (DAMA/LIBRA) for more than 20 years, in strong tension with other experiments
- Currently, many efforts trying to confirm / rule out DAMA/LIBRA signal with the same target. COSINE-100 and ANAIS-112 in data-taking
- ANAIS results compatible with absence of modulation and incompatible with DAMA/LIBRA at $2\sigma$ after 2 years of data-taking. $3\sigma$ sensitivity at reach in about 2.5 years from now.
Summary

• Annual modulation is a distinctive signature of Dark Matter

• One positive signal (DAMA/LIBRA) for more than 20 years, in strong tension with other experiments

• Currently, many efforts trying to confirm / rule out DAMA/LIBRA signal with the same target. COSINE-100 and ANAIS-112 in data-taking

• ANAIS results compatible with absence of modulation and incompatible with DAMA/LIBRA at $2\sigma$ after 2 years of data-taking. $3\sigma$ sensitivity at reach in about 2.5 years from now.

DANKE!!