AXION GLOBAL FITS
IN GAMBIT

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13th AxionWIMP Conference
Θεσσαλονίκη
AXIONS – A BSM FAMILY?! 

- QCD axions solve the Strong CP problem 
- Axions as DM candidates 
- Axions in String Theory 
- Relaxion 
- Ultralight axions 
- ...
MOTIVATION

CAST (hep-ex/0702006)

ADMX (0910.5914)
Simple over-plotting is common practice and fine for ~ 2 parameters if caveats and additional assumptions are kept in mind (e.g. axions = DM, fixed QCD parameters, fixed Solar model, etc.).
BUT... WHAT IF WE WANT...

- more parameters?
- a statistically rigorous analysis for
  - model comparison?
  - varying QCD-related parameters? Or astrophysical models?
- to add new experimental results?
- to determine axion properties (from cooling hints)?
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GLOBAL FITS!
GAMBIT: THE GLOBAL AND MODULAR BSM INFERENCE TOOL

gambit.hepforge.org

- Fast definition of new datasets and theoretical models
- Plug and play for scanning, physics and likelihoods
- Many statistical/scanning options (Bayesian and frequentist)
- Extensive model database and observable/data libraries
- Fast LHC likelihood calculator
- Massively parallel
- Fully open-source

29 members, 9 experiments, 5 major theory codes

ATLAS, LHCb, Belle-II, Fermi-LAT, CTA, Hess, IceCube, XENON/DARWIN


Public code release + 9 papers (1 “core”, 3 physics studies, 5 modules)
GAMBIT RESULTS

Scalar singlet DM

GUT scale CMSSM

Sampling performance

Direct detection (\gamma-ray)
QCD AXION MODEL (7 PARAMETERS)

• Axion-photon and axion-electron interaction

\[ \mathcal{L}_A = \ldots - \frac{g_{A\gamma\gamma}}{4} A F_{\mu\nu} \tilde{F}^{\mu\nu} - \frac{g_{A ee}}{2m_e} \bar{e} \gamma^\mu \gamma^5 e \partial_\mu A \]

• Temperature-dependent mass

\[ m_A(T) = \frac{\Lambda^2}{f_A} \begin{cases} 1 & \text{if } T \leq T_{\text{crit}} \\ \left( \frac{T_{\text{crit}}}{T} \right)^{\beta/2} & \text{otherwise} \end{cases} \]

• Realignment using canonical potential with \( \theta(0) = \theta_i \)

\[ V(\theta) = f_A^2 m_A^2(T) (1 - \cos(\theta)) \]
AVAILABLE LIKELIHOODS

• Experiments
  - ALPS\textsuperscript{Ehret+ '09; Talk by Mueller} (full likelihood)
  - CAST\textsuperscript{Andriamonje+ '07, Barth+ '13; Talks by Karuza & Irastorza} (full likelihood for vacuum results)
  - ADMX\textsuperscript{Hagmann+ '99; Talks by Lentz, Carosi & Stern} (approximated likelihood)

• Cosmology
  - DM density today\textsuperscript{Planck '16 vs axion realignment density}

• Astrophysics
  - Supernovae\textsuperscript{Payez+ '15} (axion-photon conversion in the Milky Way’s B-field)
  - White Dwarfs\textsuperscript{Battich+ '16; Côrso+ '12, '12, '16} (cooling hints)
  - R-parameter\textsuperscript{Giannotti+ '16; Talk by Straniero}

• QCD axion parameters\textsuperscript{di Cortana+ '15, Borsanyi+ '16; Poster by Szabo}
QCD AXION MASS

Topological susceptibility $\chi$ vs. Temperature $T$ [MeV]

- Borsanyi+ '16
- Poster by Szabo

Critical temperature $T_{\text{crit}}$ [MeV] vs. Temperature scaling $\beta$

- Best fit
- Profile likelihood ratio $\Lambda = L/L_{\text{max}}$

PRELIMINARY

GAMBIT v1.0 and pippi v2.0

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**Axion-photon coupling vs mass**

**QCD axion**

\[ \Omega_{\text{axion},\text{local}} = \Omega_{\text{DM},\text{local}} \]

**Profile likelihood ratio**

\[ \Lambda = \frac{L}{L_{\text{max}}} \]

**Axion mass log**

\[ \log_{10}(m_A/\text{eV}) \]

**Axion-photon coupling log**

\[ \log_{10}(g_{A\gamma\gamma}/\text{eV}) \]

- w/o cooling hints
- Prof. likelihood

\[ \Omega_{\text{axion}} = \Omega_{\text{DM}} \]

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AXION-PHOTON COUPLING VS MASS

QCD axion
Ω_{axion,local} = Ω_{DM,local}

QCD axion
Ω_{axion} \leq Ω_{DM} \text{ allowed}
AXION DM DENSITY

QCD axion \( \Omega_{\text{axion}} \leq \Omega_{\text{DM}} \) allowed

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COOLING HINTS

• **White Dwarfs (WDs):** Electron-degenerate (i.e. supported by Fermi pressure) and dense star remnants.

• Initially very hot but radiate away energy and cool down monotonously.

• There are variable, pulsating WDs. The cooling rate can be related to the pulsation period decrease.

• There seem to be a need for additional channels when comparing observations to expectations. \cite{Isern+92}
COOL(ING) HINTS

<table>
<thead>
<tr>
<th>Object</th>
<th>Type</th>
<th>1σ CI or limit (10^{-13})</th>
</tr>
</thead>
<tbody>
<tr>
<td>G117-B15A</td>
<td>DAV</td>
<td>$g_{Aee} \in [4.1, 5.5]$</td>
</tr>
<tr>
<td>L19-2</td>
<td>DAV</td>
<td>$g_{Aee} &lt; 7.0$</td>
</tr>
<tr>
<td>PG 1351+489</td>
<td>DBV</td>
<td>$g_{Aee} &lt; 5.5$</td>
</tr>
<tr>
<td>R548</td>
<td>DAV</td>
<td>$g_{Aee} \in [3.2, 6.0]$</td>
</tr>
</tbody>
</table>

$R$-parameter: $g_{Aee} \in [1.3, 2.9]$ for $g_{AYY} \equiv 0$

Battich+ ‘16; Córsico+ ‘12, ’12, ’16; Giannotti+ ’16; Talk by Straniero
OUTLOOK

• Global fits (in GAMBIT) offer a consistent, rigorous and flexible framework for axion studies.
• Axion module will be fully integrated into the software & publicly available.
• Any type of likelihood function & nuisance parameters can be added
• Upcoming: First axion global fits for QCD, DFSZ, KSVZ & ALP (frequentist + Bayesian methods for exclusion limits, model comparison, ...).
• Afterwards: Cosmology modules, axions + other BSM physics (e.g. SMASH).