Imperial College London

AXION GLOBAL FITS IN GAMBIT

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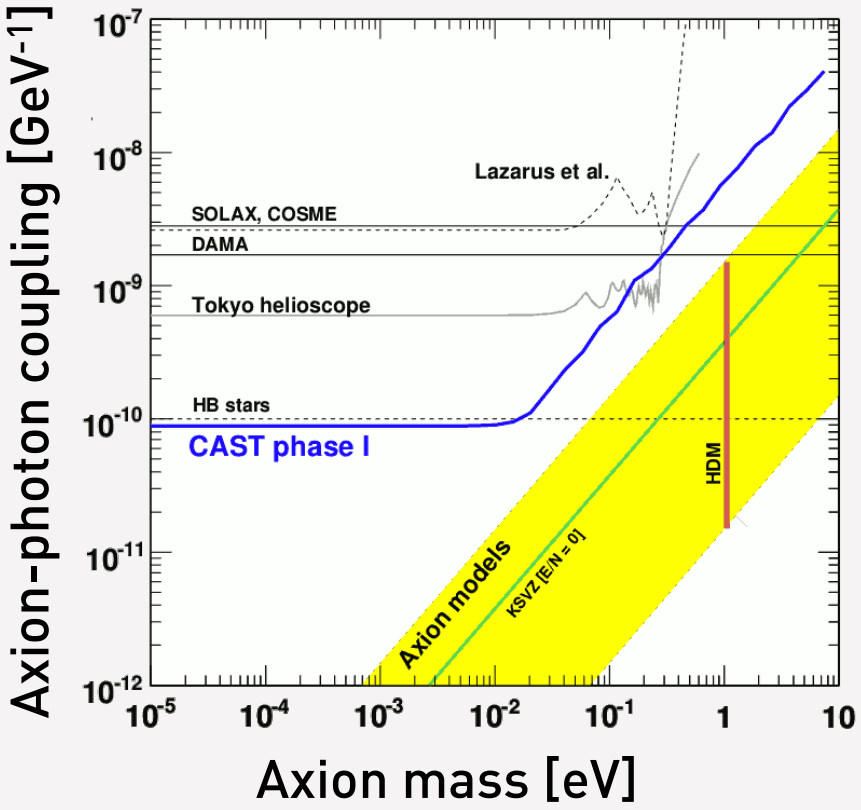
13th AxionWIMP Conference

Θεσσαλονίκη

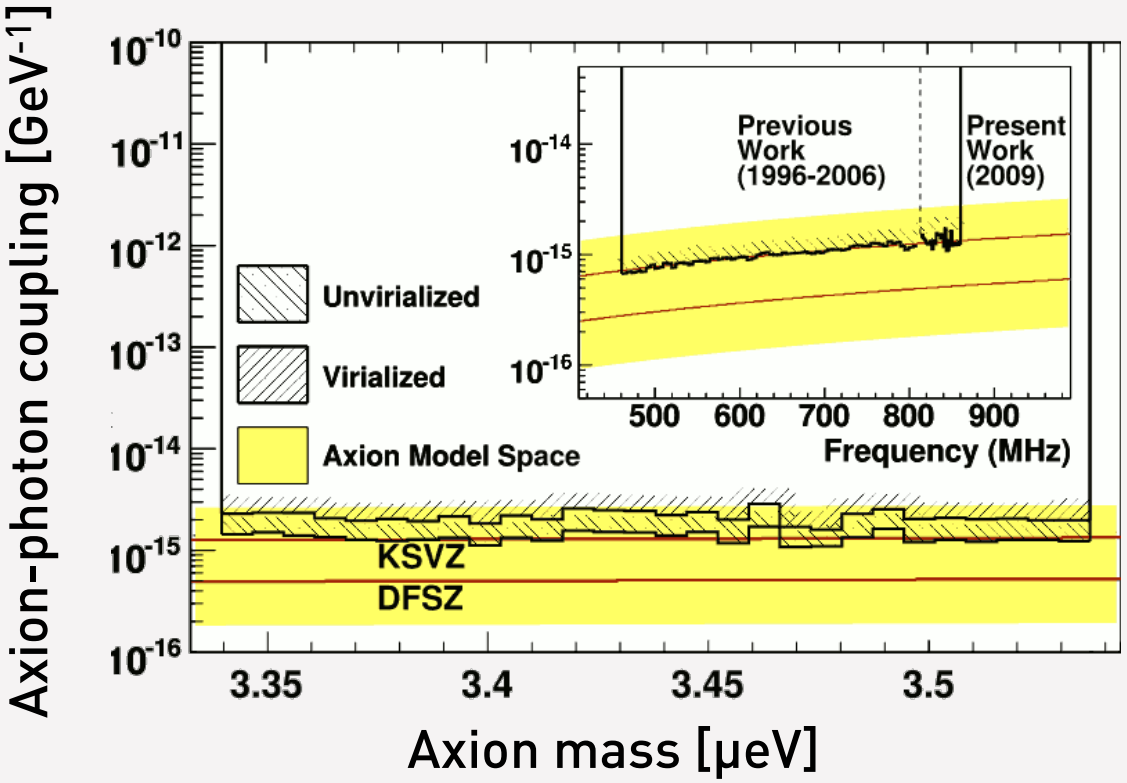
AXIONS – A BSM FAMILY?!

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

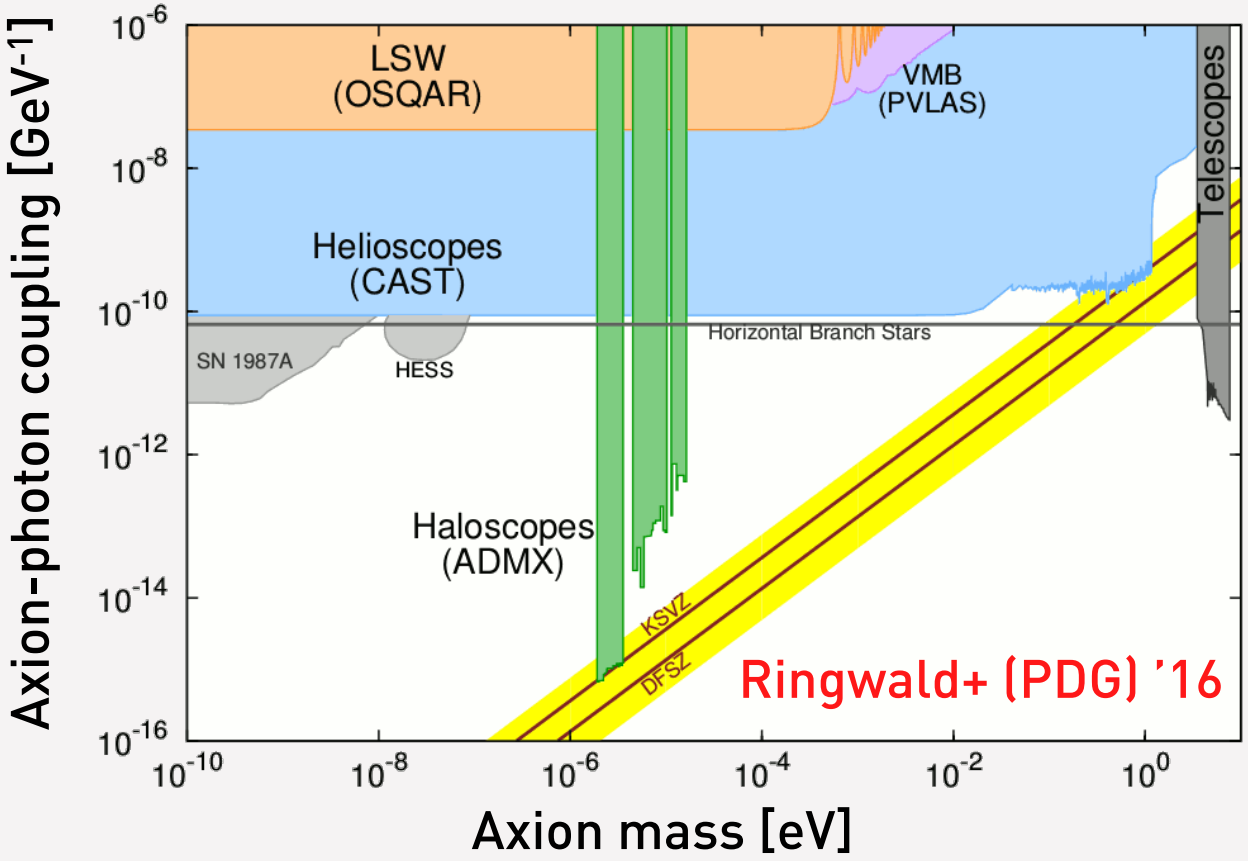
MOTIVATION



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

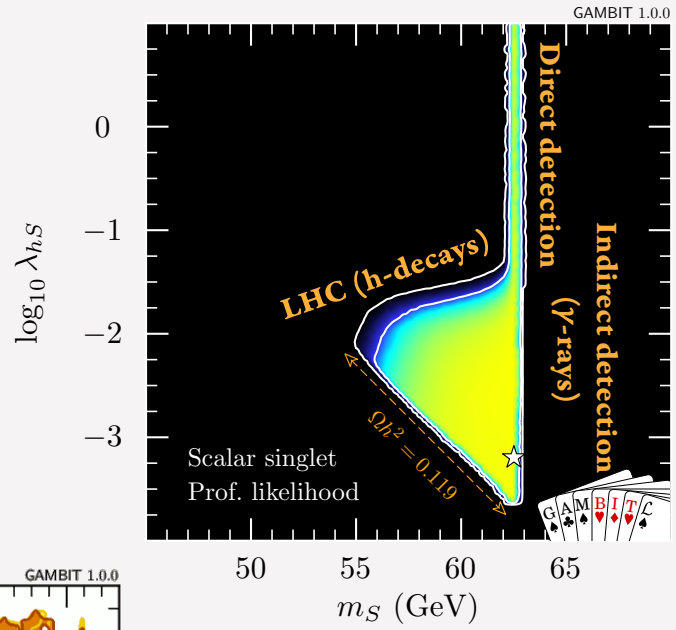
ATLAS, LHCb, Belle-II, Fermi-LAT, CTA, Hess, IceCube, XENON/DARWIN

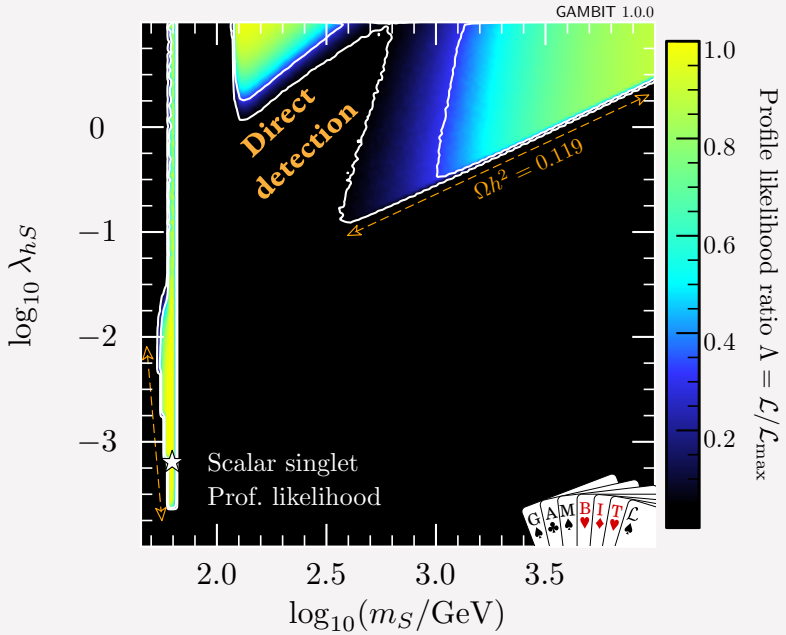
P. Athron, C. Balázs, F. Bernlochner, T. Bringmann, A. Buckley, M. Chrząszcz, J. Conrad, J. M. Cornell, J. Edsjö, B. Farmer, A. Fowlie, T. Gonzalo, J. Harz, S. Hoof, P. Jackson, F. Kahlhoefer, A. Kvellestad, N. Mahmoudi, G. Martinez, J. McKay, A. Raklev, C. Rogan, R. Ruiz de Austri Bazan, P. Scott, N. Serra, R. Trotta, C. Weniger, M. White, S. Wild

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

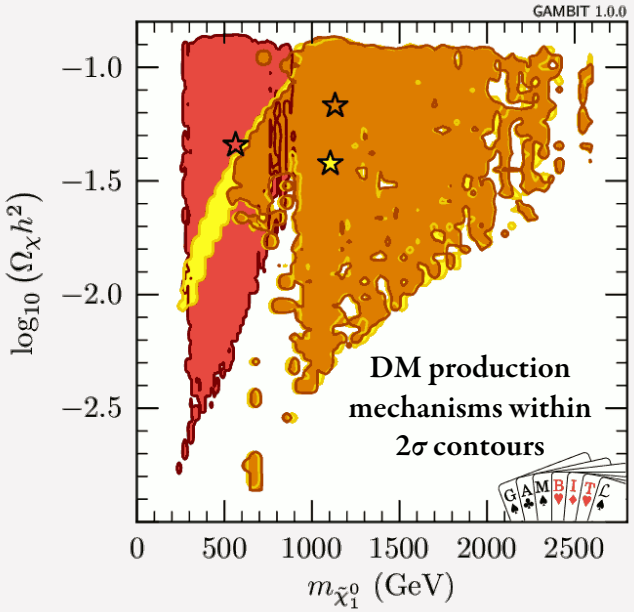
GAMBIT RESULTS

Scalar singlet DM

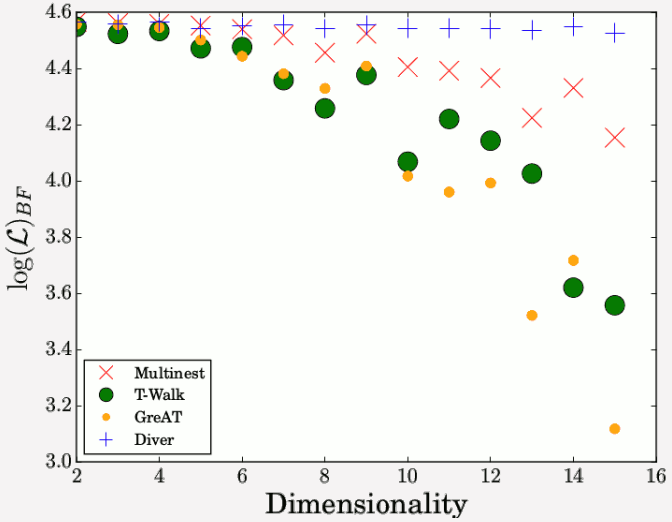




GUT scale CMSSM



Sampling performance



QCD AXION MODEL (7 PARAMETERS)

- Axion-photon and axion-electron interaction

$$\mathcal{L}_A = \ \ldots \ - \frac{g_{A\gamma\gamma}}{4} A F_{\mu\nu} \widetilde{F}^{\mu\nu} - \frac{g_{Aee}}{2m_e} \bar{e}\gamma^\mu \gamma_5 e \partial_\mu A$$

- Temperature-dependent mass

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

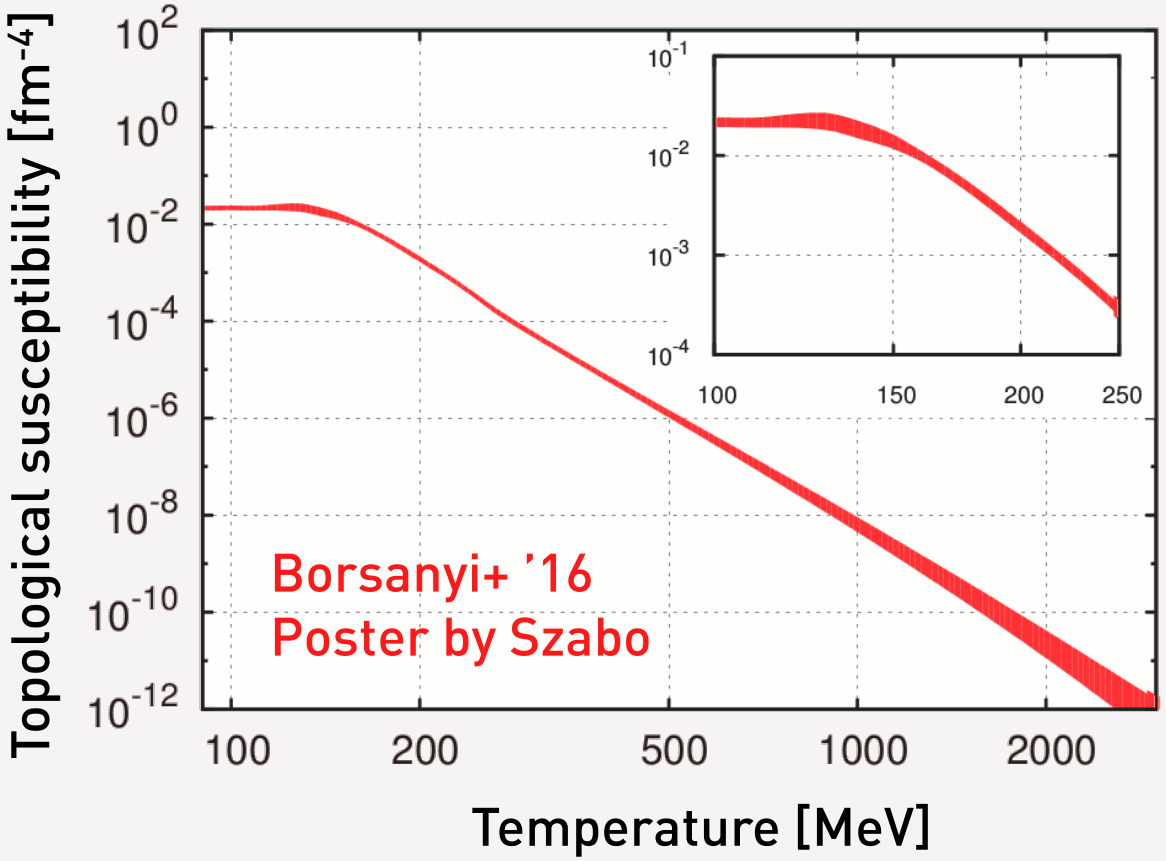
- Realignment using canonical potential with $\theta(0) = \theta_{\text{i}}$

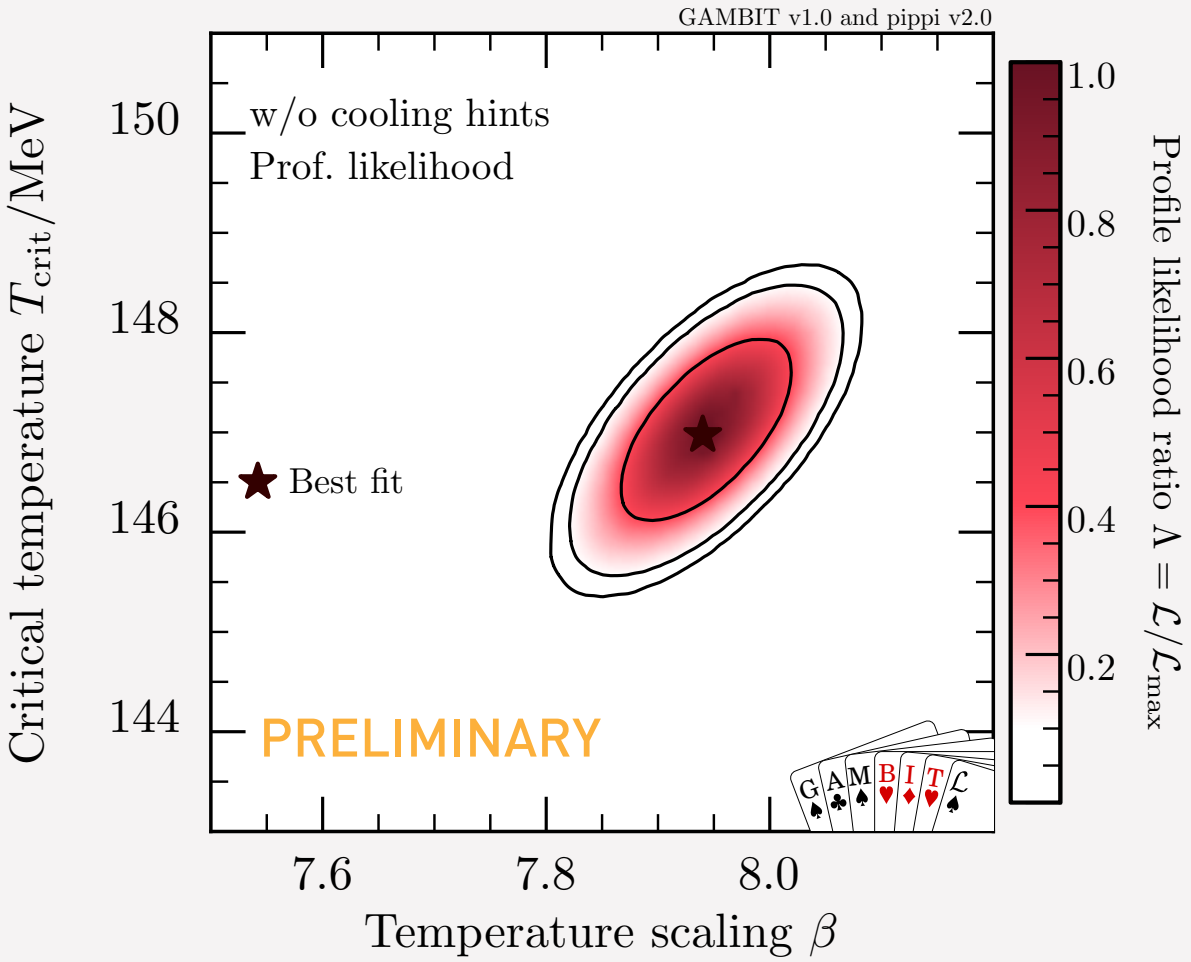
$$V(\theta) = f_A^2 \, m_A^2(T) \, (1 - \cos(\theta))$$

AVAILABLE LIKELIHOODS

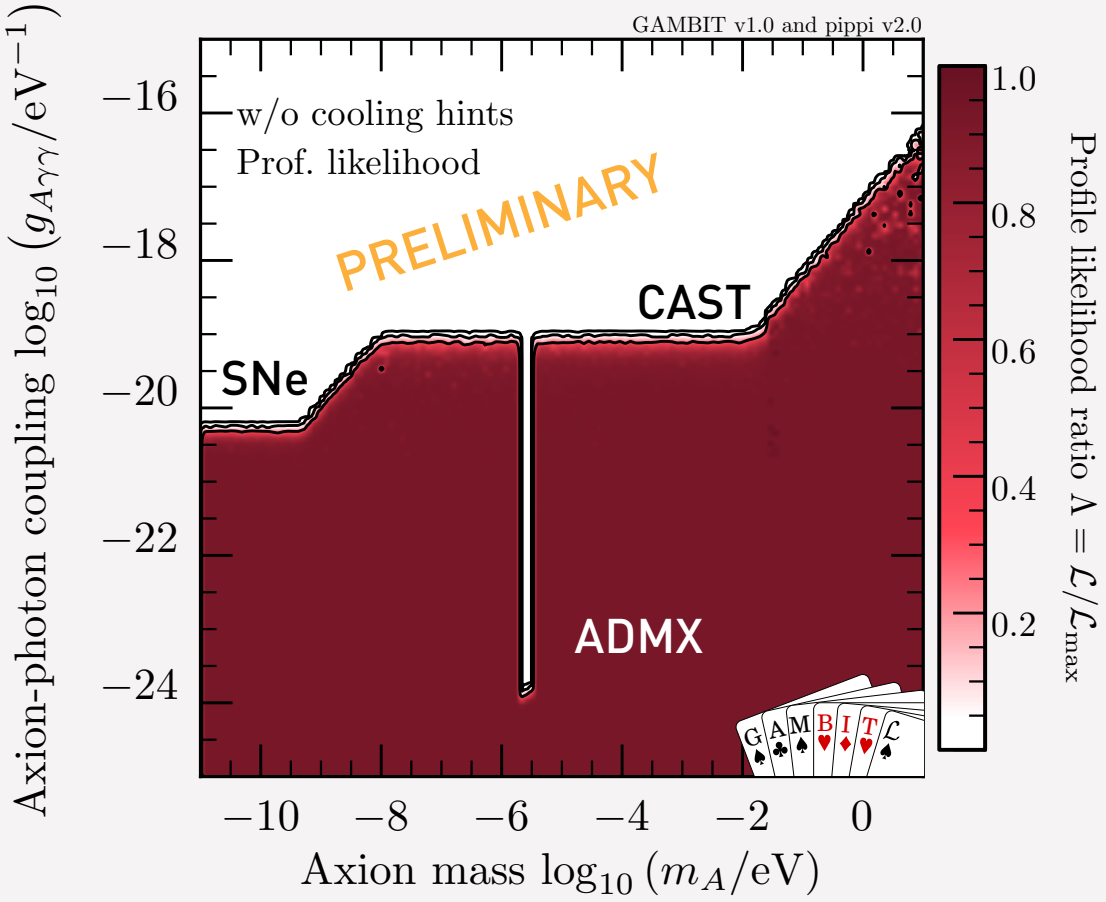
- **Experiments**
  - ALPS[Ehret+ '09; Talk by Mueller] (full likelihood)
  - CAST[Andriamonje+ '07, Barth+ '13; Talks by Karuza & Irastorza] (full likelihood for vacuum results)
  - *ADMX*[Hagmann+ '99; Talks by Lentz, Carosi & Stern] (approximated likelihood)
- **Cosmology**
  - DM density today[Planck '16] vs axion realignment density
- **Astrophysics**
  - Supernovae[Payez+ '15] (axion-photon conversion in the Milky Way's B-field)
  - White Dwarfs[Battich+ '16; Córsico+ '12, '12, '16] (cooling hints)
  - R-parameter[Giannotti+ '16; Talk by Straniero]
- QCD axion parameters[di Cortana+ '15, Borsanyi+ '16; Poster by Szabo]

QCD AXION MASS



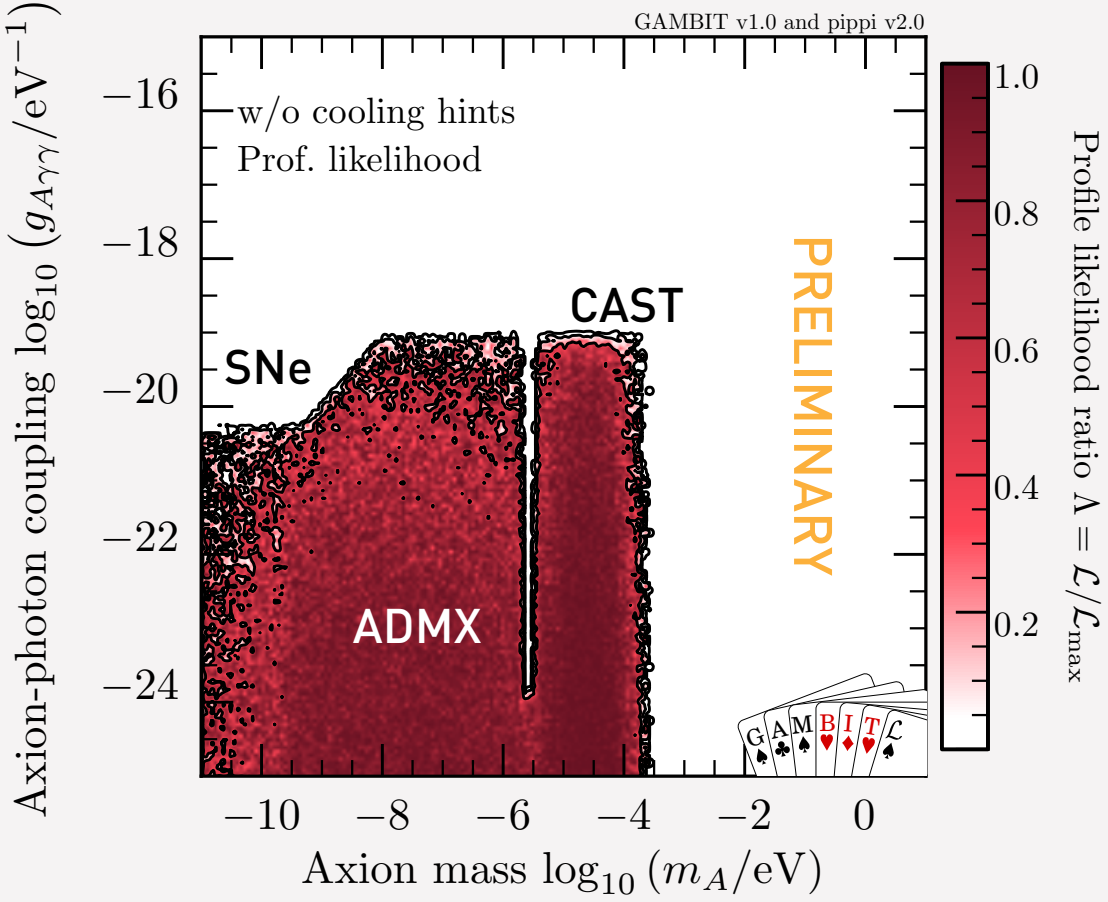


AXION-PHOTON COUPLING VS MASS



QCD axion

$\Omega_{\text{axion,local}} = \Omega_{\text{DM,local}}$



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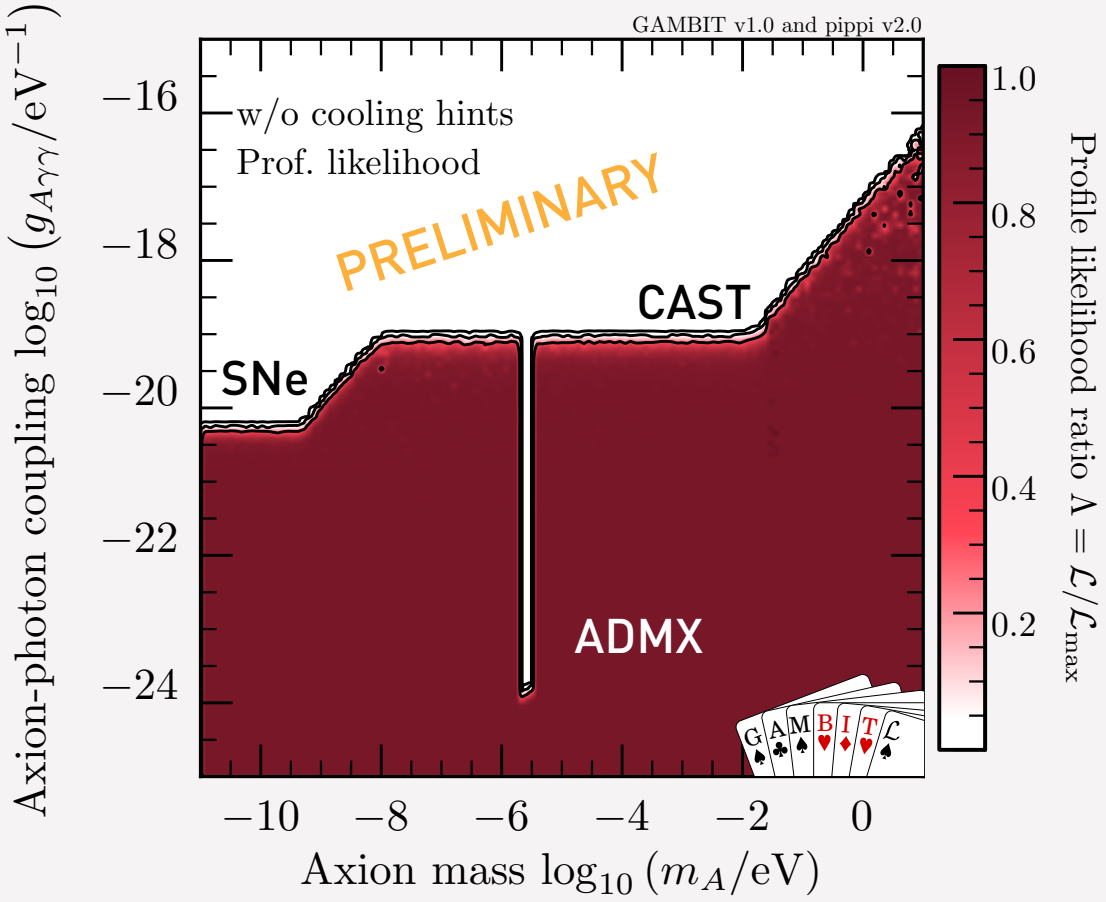

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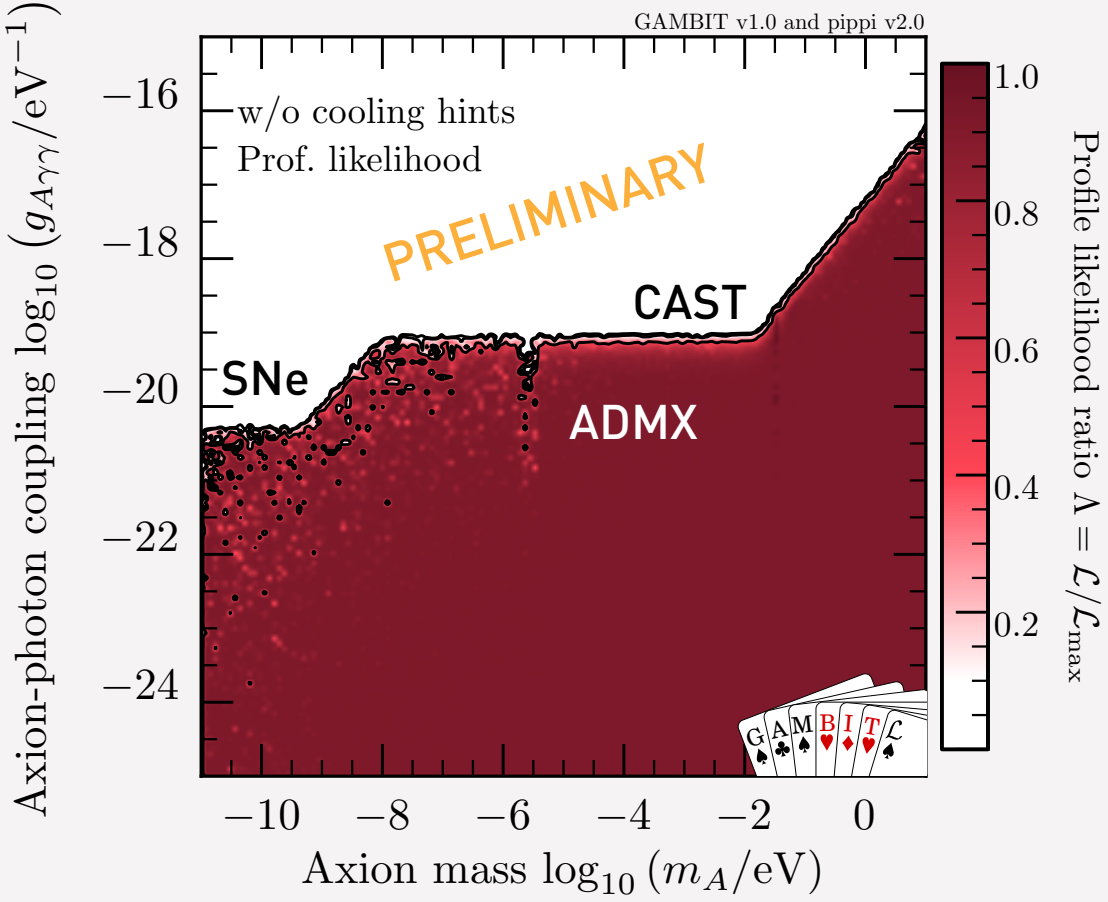
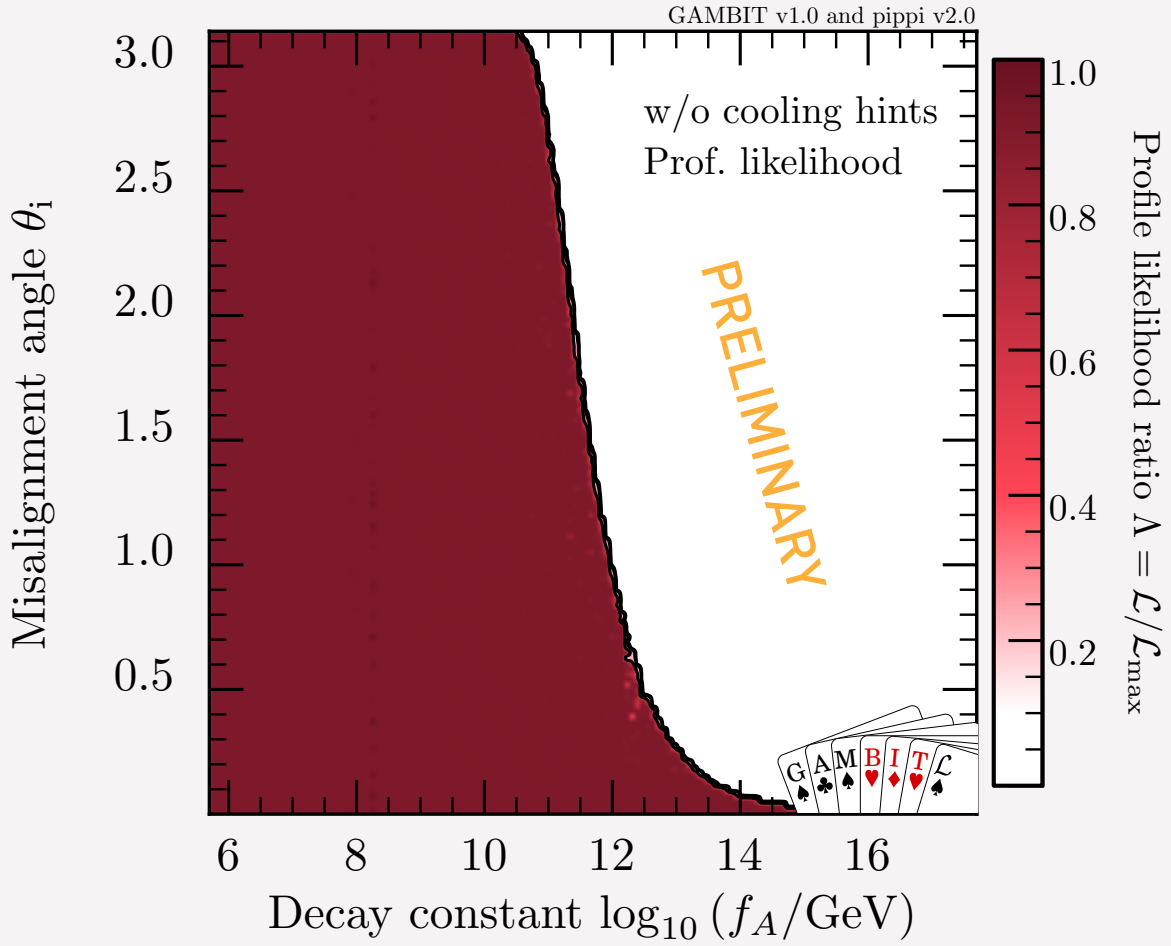


QCD axion

$\Omega_{\text{axion}} \leqslant \Omega_{\text{DM}}$ allowed

AXION DM DENSITY



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

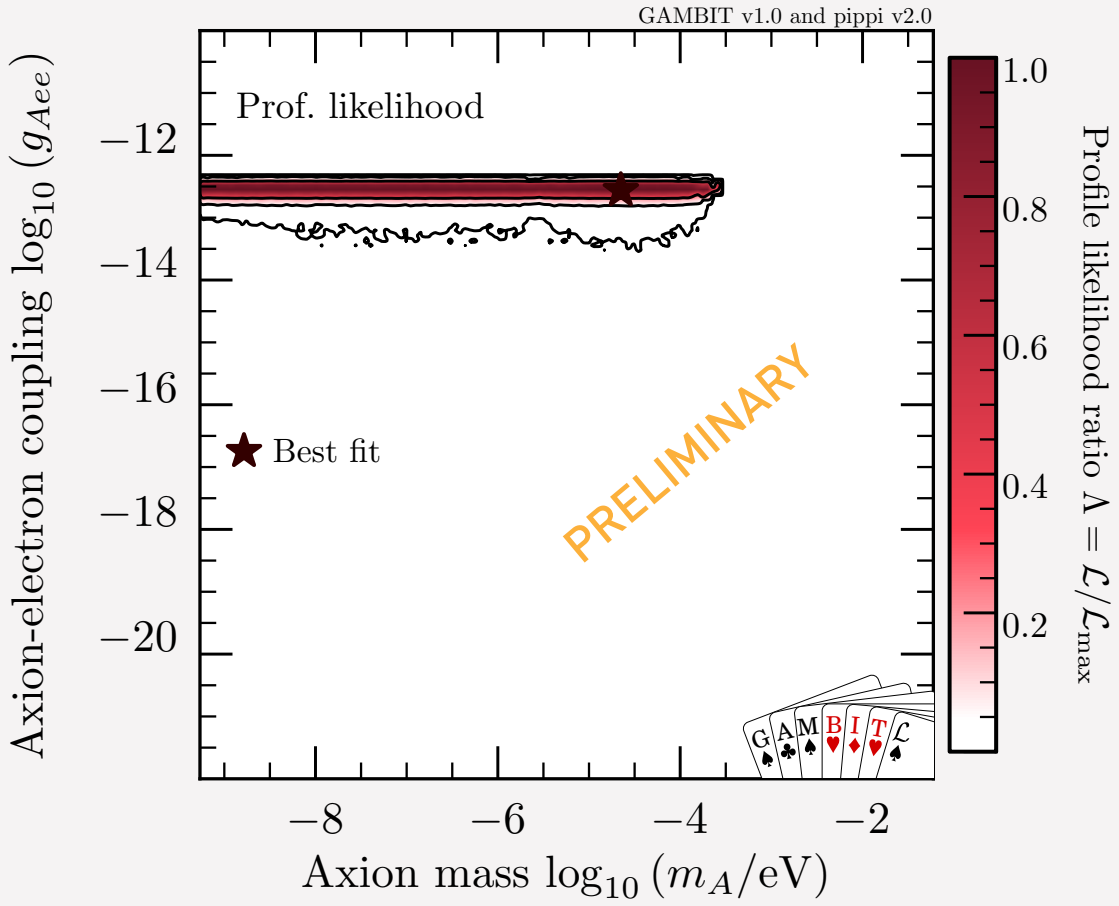
COOLING HINTS

- **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. Isern+ '92, ...

COOL(ING) HINTS

Object	Type	1σ CI or limit (10^{-13})
G117-B15A	DAV	$g_{Aee} \in [4.1, 5.5]$
L19-2	DAV	$g_{Aee} < 7.0$
PG 1351+489	DBV	$g_{Aee} < 5.5$
R548	DAV	$g_{Aee} \in [3.2, 6.0]$
R-parameter		$g_{Aee} \in [1.3, 2.9]$ for $g_{A\gamma\gamma} \equiv 0$

Battich+ '16; Córsico+ '12, '12, '16; Giannotti+ '16; Talk by Straniero



QCD axion
($\Omega_{axion} = \Omega_{DM}$)

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).