If Axions Make Up 20% of the Dark Matter and WIMPs Make Up 80% of the Dark Matter, How Would We Know?

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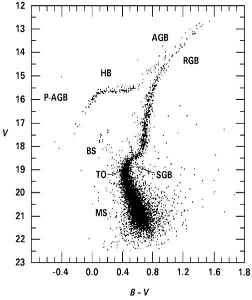
The Axion: Basics

- QCD has a CP violating term, the θ angle.
- To solve this problem, we promote that angle to a dynamical field.
- PQ axion: Goldstone of spontaneously broken PQ symmetry.
- The axion is a pseudoscalar field with couplings to gauge fields

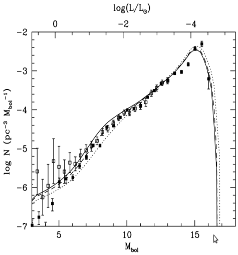
$$\mathcal{L}_a \supset \frac{g^2}{32\pi^2} \frac{a}{f_a} G^b_{\mu\nu} \tilde{G}^{b\mu\nu} \tag{1}$$

Globular Cluster M3, White Dwarf Cooling, SN 1987A

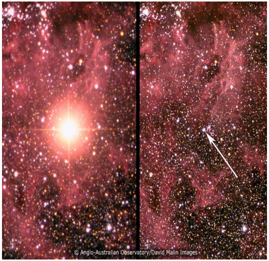


M3

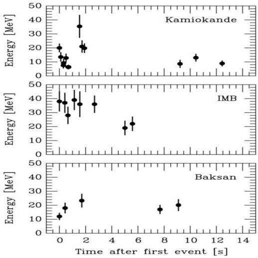
M3



White Dwarf Luminousity Function



SN1987A



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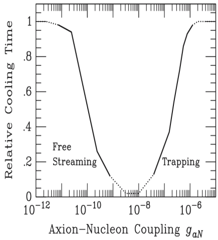
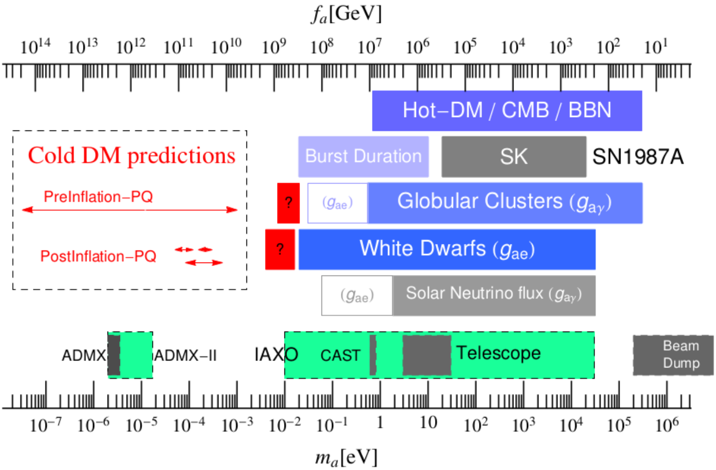


SN1987A

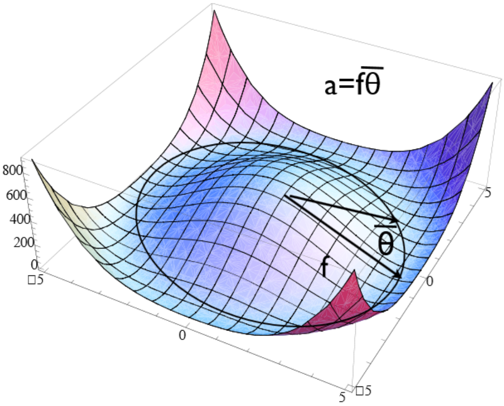
Axions Experimental Bounds

- Astrophysics: Globular Clusters (Sun), Cooling of White Dwarfs, Supernovae (SN 1987A)
- Direct detection: CAST, ADMX



Axion Cosmology

- There are two main transitions that determine the cosmological axion properties:
  1. The breaking of the PQ symmetry $\rightarrow$ the axion is the massless angular degree of freedom $a = \theta f_a$
  2. The QCD phase transition $\rightarrow$ the axion gets a mass from nonperturbative effects.

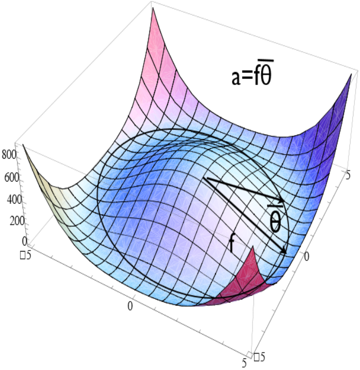


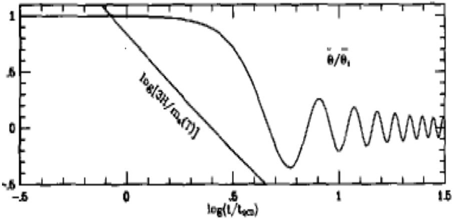
The PQ Phase Transition

- Once the PQ symmetry is broken, the evolution of the zero mode of the axion is given by

$$\ddot{\theta} + 3H\dot{\theta} + m_a^2(T)\theta = 0 \tag{2}$$

- Note that before the QCD transition, $m_a = 0$ so the solution is $\theta = constant$.
- The PQ phase transition can happen during or after inflation.





The QCD Phase Transition

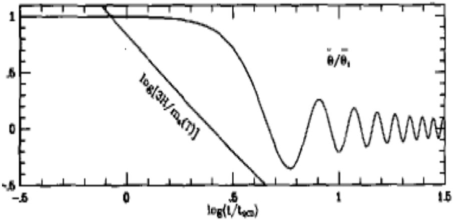
- After the QCD phase transition, the axion develops a potential.

$$V_{eff} \propto g^2 \frac{a}{f_a} < G^b_{\mu\nu} \tilde{G}^{b\mu\nu} > \quad (3)$$

where $< G^b_{\mu\nu} \tilde{G}^{b\mu\nu} >$ is a periodic gauge configuration in a.

- The axion minimizes the potential energy at a CP conserving point.
- From this potential the axion gets a mass (KSVZ model)

$$m_a = 6.3[eV] \frac{10^6 [GeV]}{f_a} \quad (4)$$



PQ Breaking After Or Before Inflation?

- If the PQ symmetry is broken during inflation, one particular random value of θ is seen across all our observable universe.
  - In this case, the main constrains come from isocurvature perturbations.
- If it is broken after inflation, there are no isocurvature perturbations, and the initial oscillation amplitude is $\theta \approx 1$

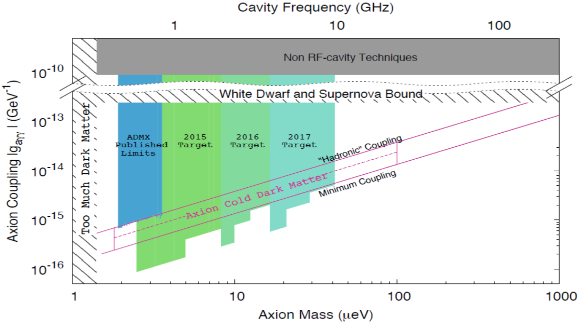
Relic Density

- The relic density is set by the vacuum misalignment mechanism in both cases.
- After the QCD phase transition the zero mode of the axion oscillates as $f_a \theta cos(m_a t)$.
- This sets the relic density *fraction* to be

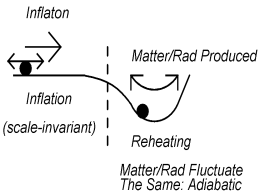
$$\Omega_a = 0.055 \left(\frac{f}{10^{11}[GeV]} \right)^{1.19} \theta^2 \tag{5}$$

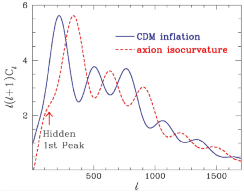
Axion relic density case 1, PQ broken after inflation

- If PQ is broken after inflation, recall that $\theta = 1$.
- If we assume $\theta = 1$, we obtain $f \approx 3 \cdot 10^{11} GeV$ ($m_a \approx 20\ \mu$eV) for 20% dark matter. (This is on the border of the ADMX exclusion.)



Isocurvature Perturbation Constraints





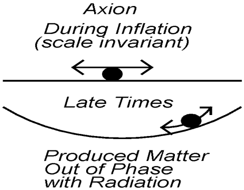
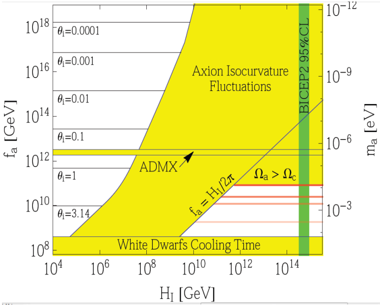
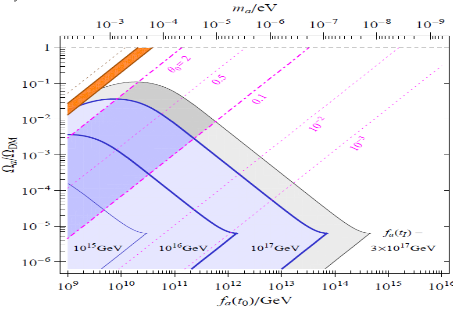


Figure Credit: Wayne Hu



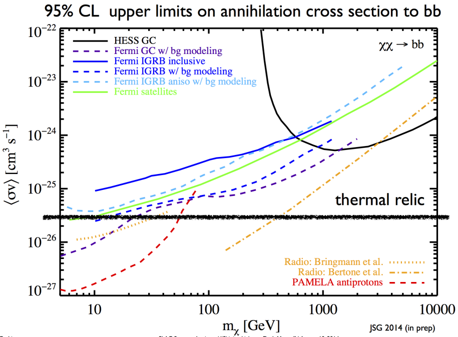
All DM Axions, f_a =const
Visinell and Gondolo (1403.4594)



Fraction DM Axions, $f_a = f_a(t)$
Choi, Jeong, and Seo (1404.3880)

The other 80%: the WIMPS

- To have a thermal WIMP relic density of order 80%, we need a WIMP annihilation xsec of order $< \sigma v > \approx 3 \cdot 10^{-26} [cm^3/s]$.
- The annihilation xsec is probed in indirect detection experiments.



J. Siegal-Gaskins

SLAC Summer Institute | "Shining Light on Dark Matter" | August 10, 2014

Conclusions

If Axions Make Up 20% of the Dark Matter and WIMPs Make Up 80% of the Dark Matter, How Would We Know?

- If PQ symmetry is broken DURING/BEFORE inflation, isocurvature constraints force $f_a(t)$ and $\Omega_a < \Omega_{DM}$. For the example shown of at most $\Omega_a/\Omega_{DM} \lesssim 10\%$, the theory is beyond the reach of the ADMX experiment.

- With PQ breaking AFTER inflation, the smoking gun signatures for 20% axionic dark matter and 80% WIMP DM would be a signal from ADMX around $f_a = 3 \cdot 10^{11} GeV$ plus a signal from WIMP indirect detection experiments at $< \sigma v > \approx 10^{-26} [cm^3/s]$.

Thank You!

DO YOU THINK IT'S A NEUTRALINO?!
I'D SAY IT'S AN AXION !
NO, A SNEUTRINO!
TO ME, IT LOOKS LIKE A BIT OF SPIT...
FIATTI