Astrophysical Searches for Oscillations in the Axiverse

James Maxwell

Collaborators: Francesca Chadha-Day and Jessica Turner

- String compactifcation generates a large number (up to 200) pseudoscalar states
- ALPs could explain dark matter
- The mass states are generally misaligned with the interaction states
- Oscillations akin to those involving neutrinos

Interaction basis

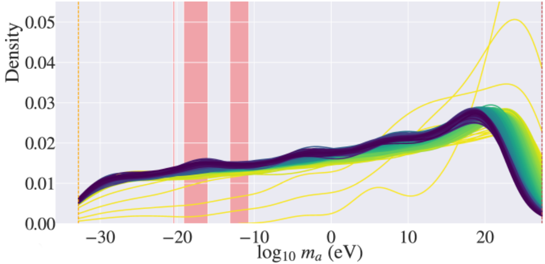
$$\mathcal{L} = \sum_{ij} \left(\frac{1}{2} \partial_\mu \phi_i \partial^\mu \phi_i - \frac{1}{2} m_i m_j \phi_i \phi_j \right) + \frac{1}{4} g_{a\gamma} \phi_\gamma F_{\mu\nu} \tilde{F}^{\mu\nu}$$

Mass Basis

$$\mathcal{L} = \sum_{i} \left(\frac{1}{2} \partial_\mu \phi_i^{'} \partial^\mu \phi_i^{'} - \frac{1}{2} m_i^2 \phi^{'2} + \frac{1}{4} g_{i\gamma} \phi_i^{'} F_{\mu\nu} \tilde{F}^{\mu\nu} \right)$$

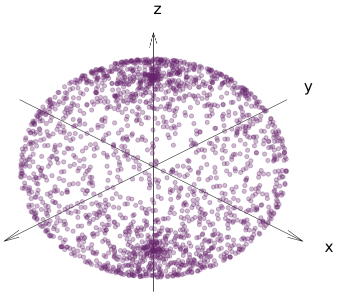
Motivation

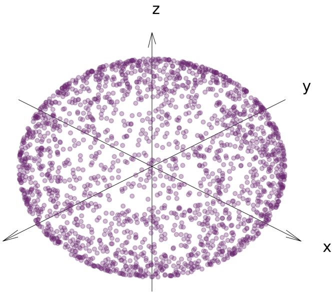
- String theory predicts logarithmically distributed masses
- Couplings are hard to extract from ST so use Anarchy hypothesis



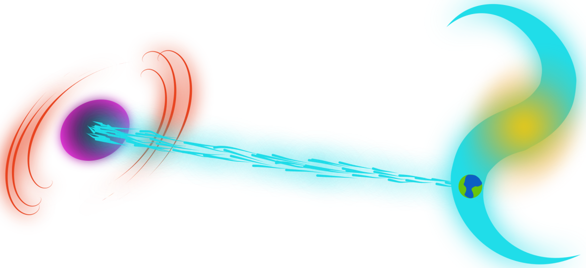
Source: *arXiv:2011.08693v2*

- SM couplings determined by rotating from interaction basis to mass basis
- Use Haar measure to sample distributions in SO(n) to find most probable mixing angles
- In d=3, $ds = \sin^2\theta\, d\theta\, d\phi$





- Universe is too transparent to Blazar photons
- Photons could be converting to axions and *sneaking* through
- Intergalactic B-field has domain like structure with B∼nG
- Simulations can be used to compare the effect of many axions on photon survival



Axion Photon Coupling

- Working in the mass basis all axions couple to the photon
- Coupling are found by rotating using the SO(n) matrices found using the Haar measure

In the mass basis for an individual axion:

$$\mathcal{L} = \frac{1}{2}\partial_\mu \phi \partial^\mu \phi - \frac{1}{2} m_a^2 \phi^2 - \frac{1}{2} F_{\mu\nu} \tilde{F}^{\mu\nu} + \frac{1}{4M} a F_{\mu\nu} \tilde{F}^{\mu\nu}$$

Vary w.r.t. ALP field:

$$(\Box + m_a^2)\phi = \frac{1}{M} \boldsymbol{E} \cdot \boldsymbol{B}$$

Let $\boldsymbol{E} = \omega \left(A_{\parallel}, \quad A_{\perp}, \quad 0 \right) e^{i\omega t}$ and assume photon B field negligible:

$$\left[\omega + \begin{pmatrix} \Delta_\gamma & 0 & 0 \\ 0 & \Delta_\gamma & \Delta_{\gamma a} \\ 0 & \Delta_{\gamma a} & \Delta_a \end{pmatrix} - i\partial_z \right] \begin{pmatrix} |A_\perp\rangle \\ |A_\parallel\rangle \\ |a\rangle \end{pmatrix} = 0,$$

where $\Delta_{\gamma a} = \frac{B_{0,n}}{2M}$, $\Delta_a = \frac{-m_a^2}{2\omega}$ and $\Delta_\gamma = \frac{-\omega_p^2}{2\omega}$

- Low numbers of axion states increase photon survival
- Increasing further causes the photon energy to scatter into hidden axion states