Constraining Axion-like Particles with HAWC observations of TeV Blazars

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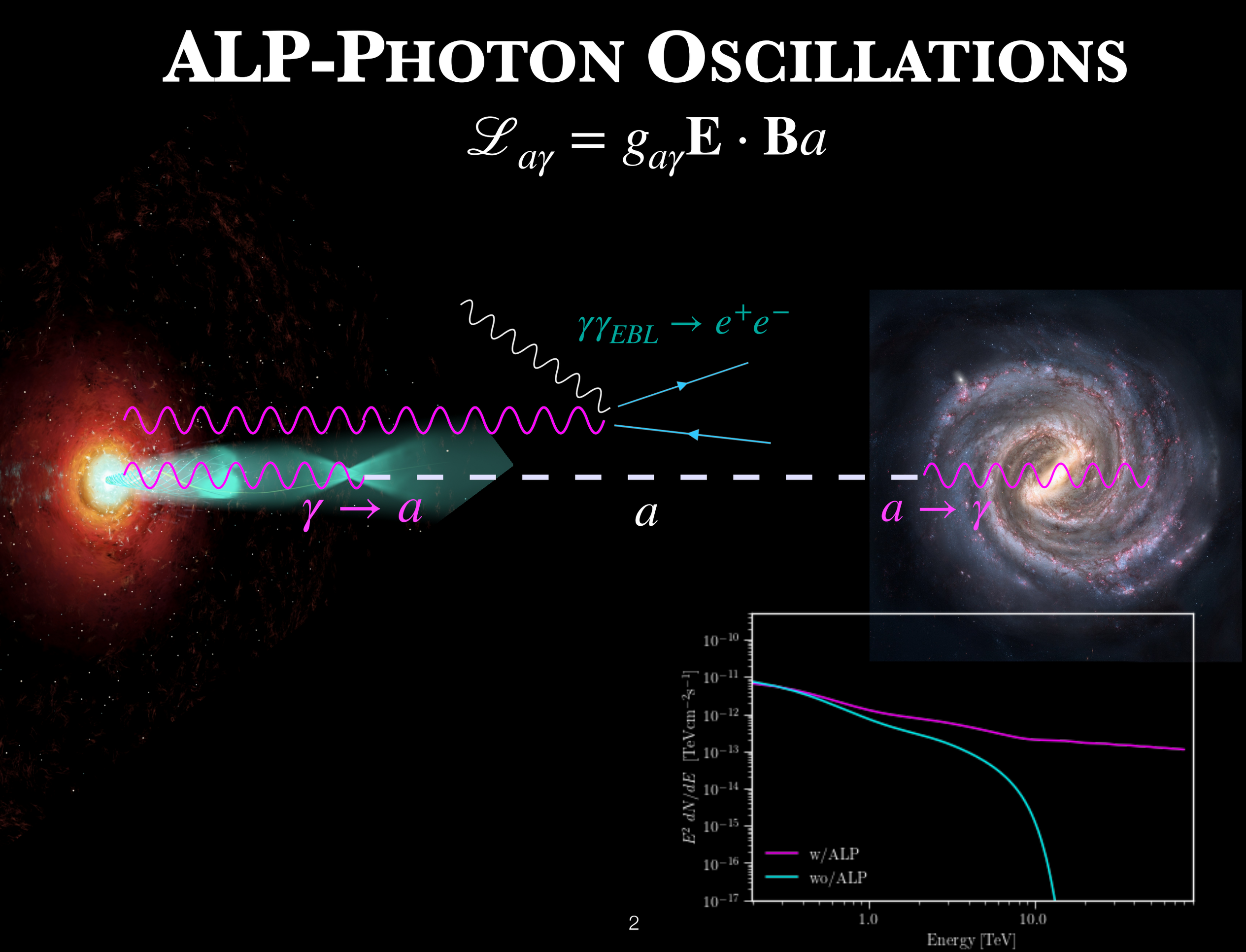
arXiv:2203.04332

ALP-Photon Oscillations

$$\mathscr{L}_{a\gamma} = g_{a\gamma}\mathbf{E}\cdot\mathbf{B}a$$



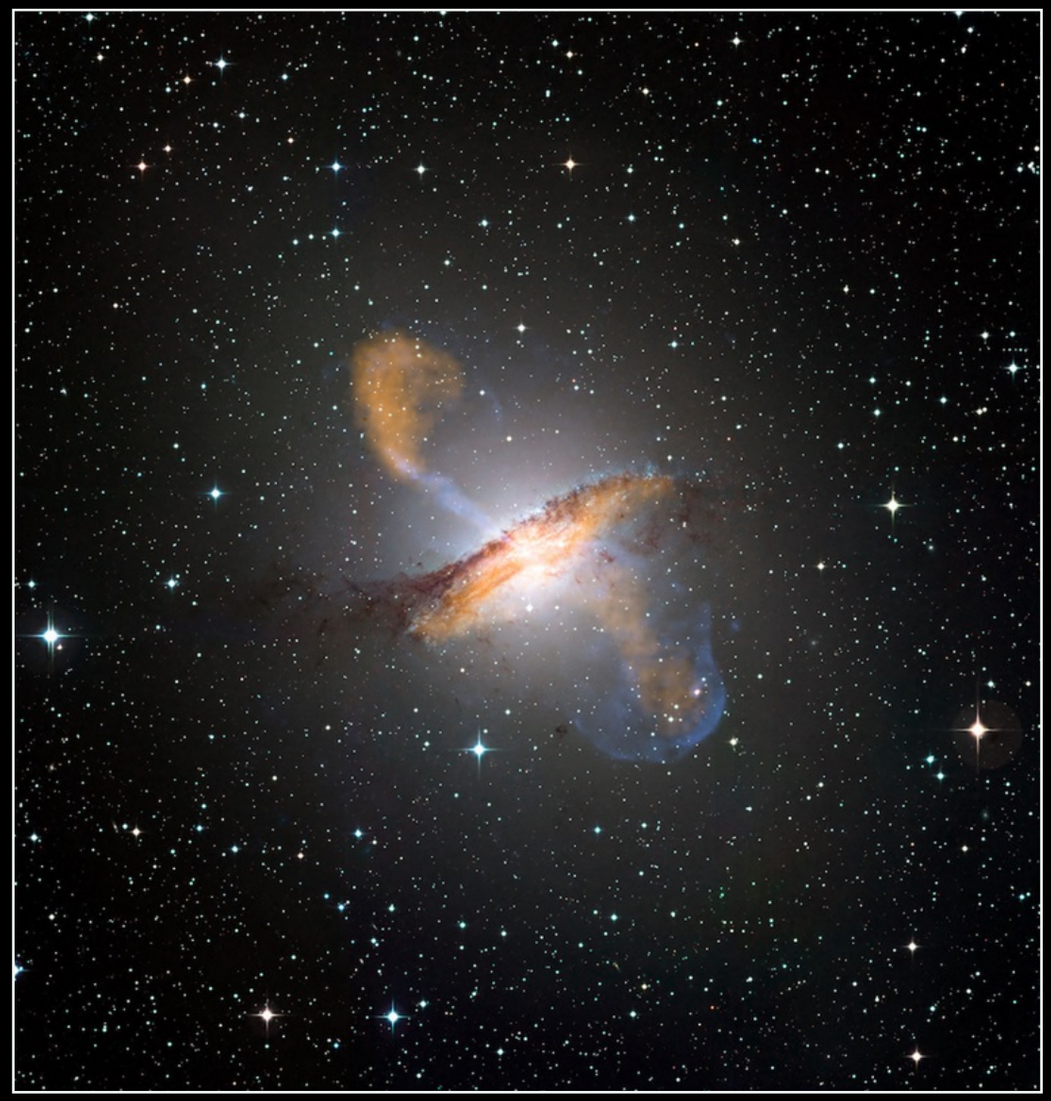
Blazars

Active Galactic Nuclei(AGN): Highly luminous galactic centers

AGN may have jets: Ionized matter and radiation are emitted as a beam along the axis of rotation

Blazars: Jet is directed towards the Earth

Ideal sources: Strong magnetic field in the jet, high γ-ray flux



Centaurus A ESO/WFI (visible); MPIfR/ESO/APEX/A.Weiss et al. (microwave); NASA/CXC/CfA/R.Kraft et al. (X-ray)

The HAWC Observatory

The High Altitude Water Cherenkov Observatory

Large field-of view: -10 - 50 dec

Large effective area: 10^5 m^2

Sensitive to VHE photons: 1-100 TeV

3HWC: Provide upper limits on the 7 TeV flux from a large part of the sky

J. Goodman, Nov. 2016

Blazar Selection

Search for Fermi blazars that have also been observed by other ACTs in an energy range 100MeV-1TeV.

Low variability

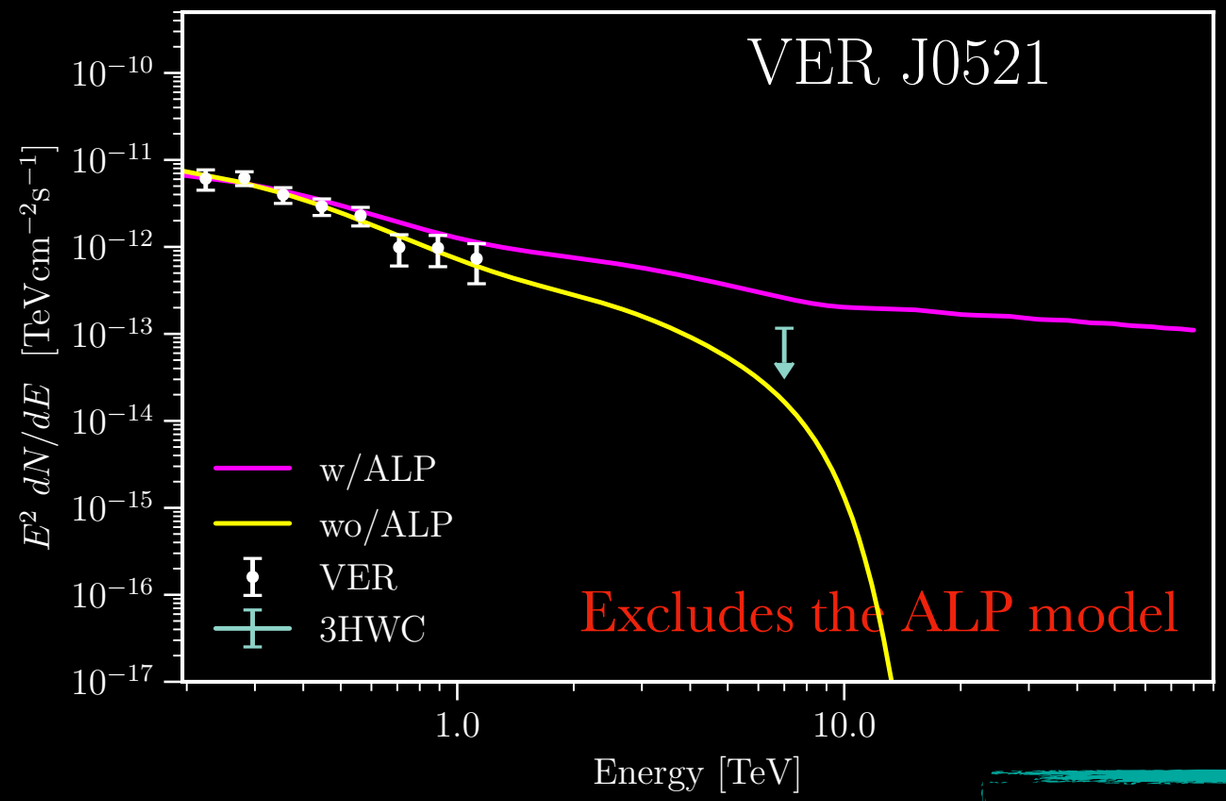
Optically thick regime

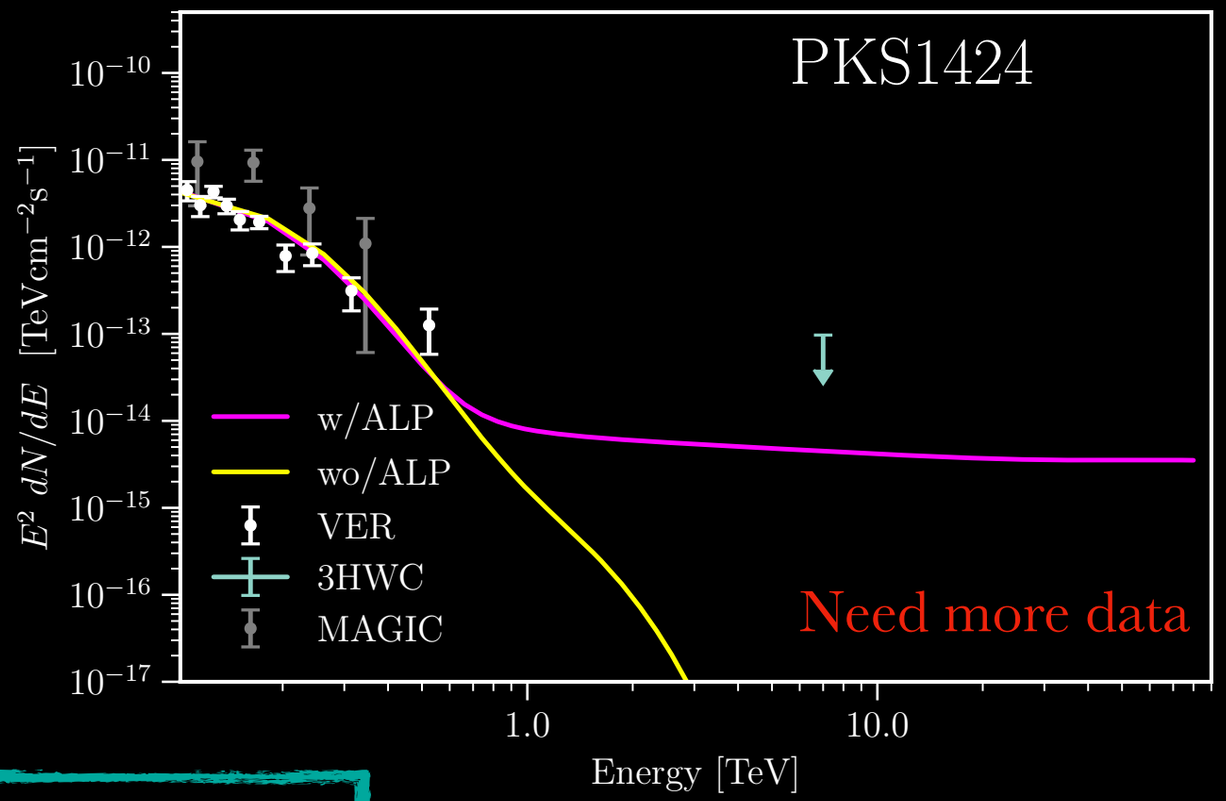
This gives us 7 sources: 1ES 0229+200, PKS 1424+240, PG 1553+113, VER J0521+211, 1ES 1218+304, 3C 66A and 1ES 1011+496

How do we use this to constrain ALP models?

HAWC provides an upper limit of the 7 TeV flux

Test statistic: $TS = 2\left(\mathscr{L}_{\mathrm{ALP}} - \mathscr{L}_{\mathrm{noALP}}\right)$ - in short, if the expected flux is larger than the HAWC upper limit, the ALP model is ruled out.

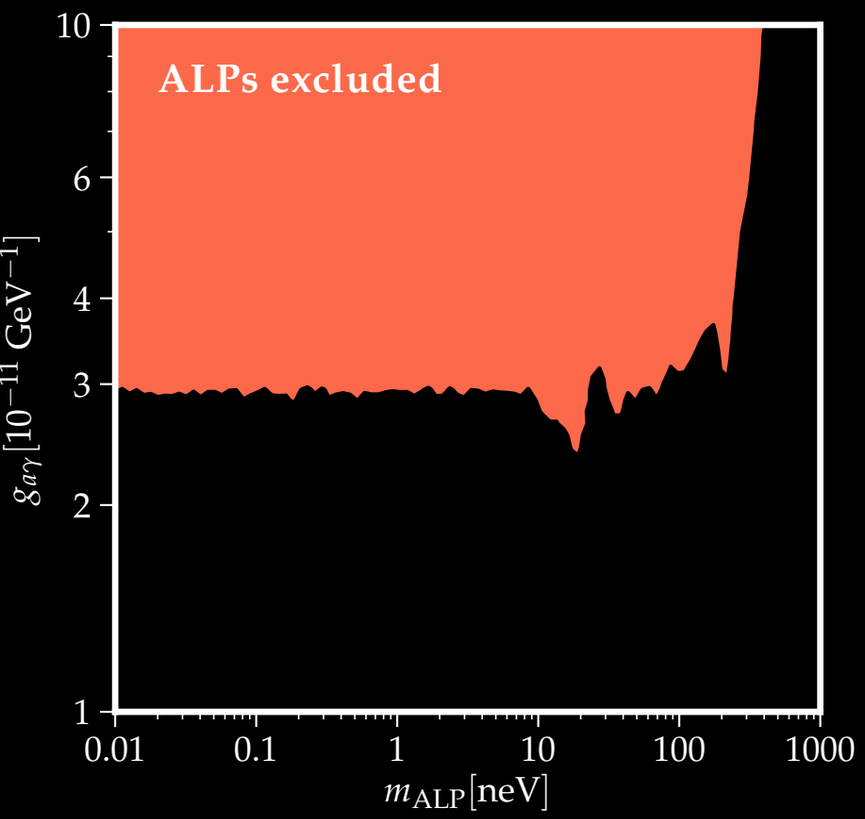




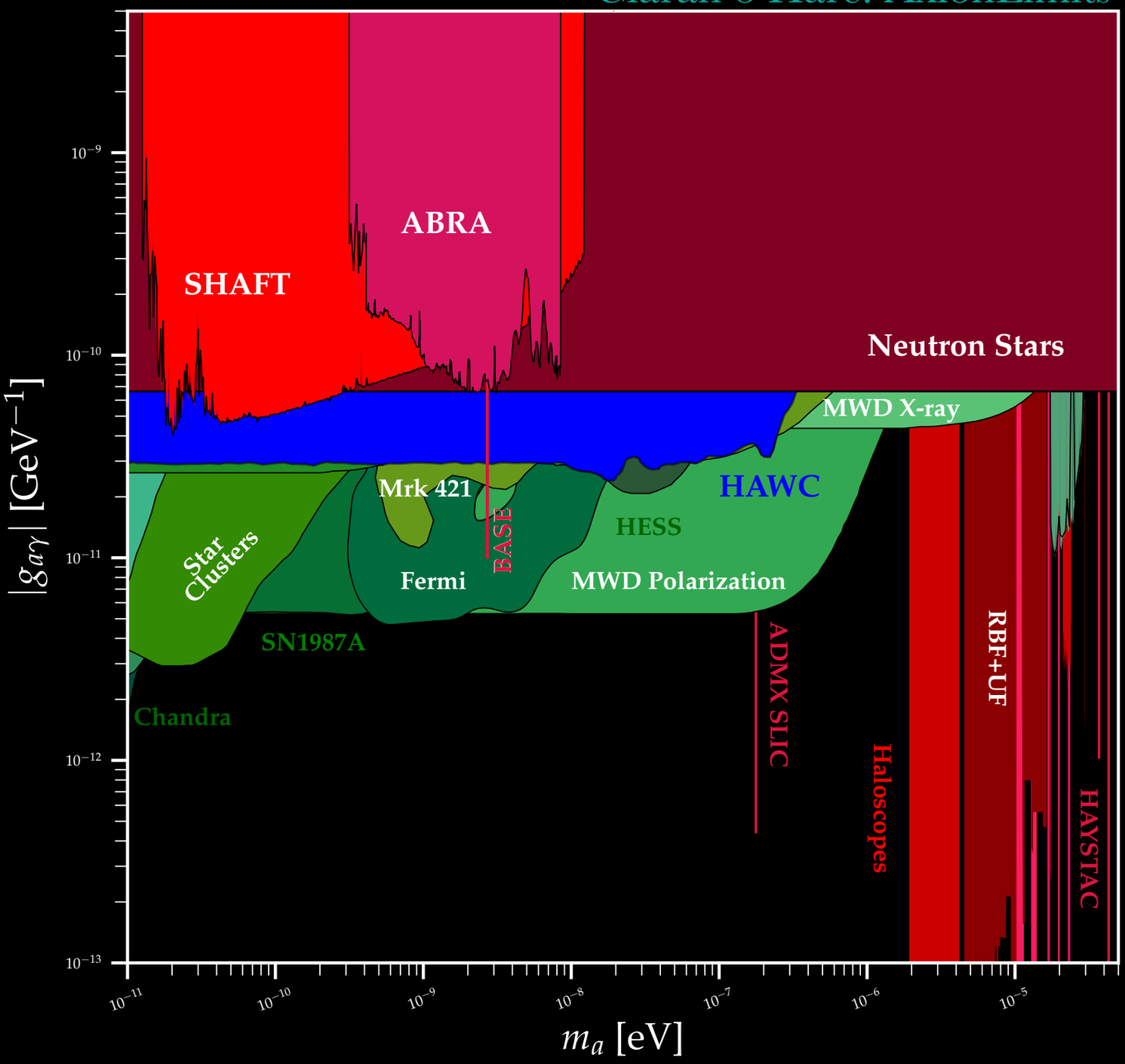
$m_{ALP} = 5 \times 10^{-9}\mathrm{eV}$

$g_{a\gamma} = 4 \times 10^{-11}\mathrm{GeV}^{-1}$

Stacked likelihood of 7 sources:
PKS 1424, PG1553, VER J0521,
1ES 1218+304, 1ES0229+200,
3C 66A and 1ES 1011



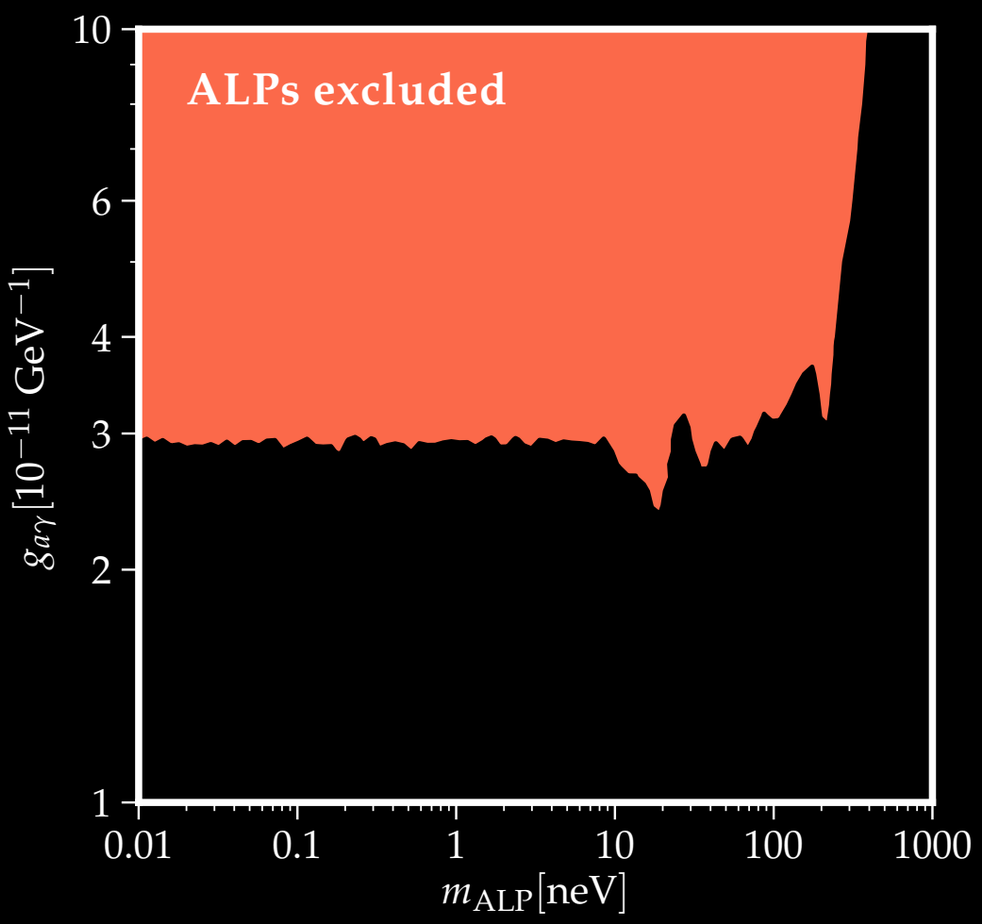
Ciaran o'Hare: AxionLimits



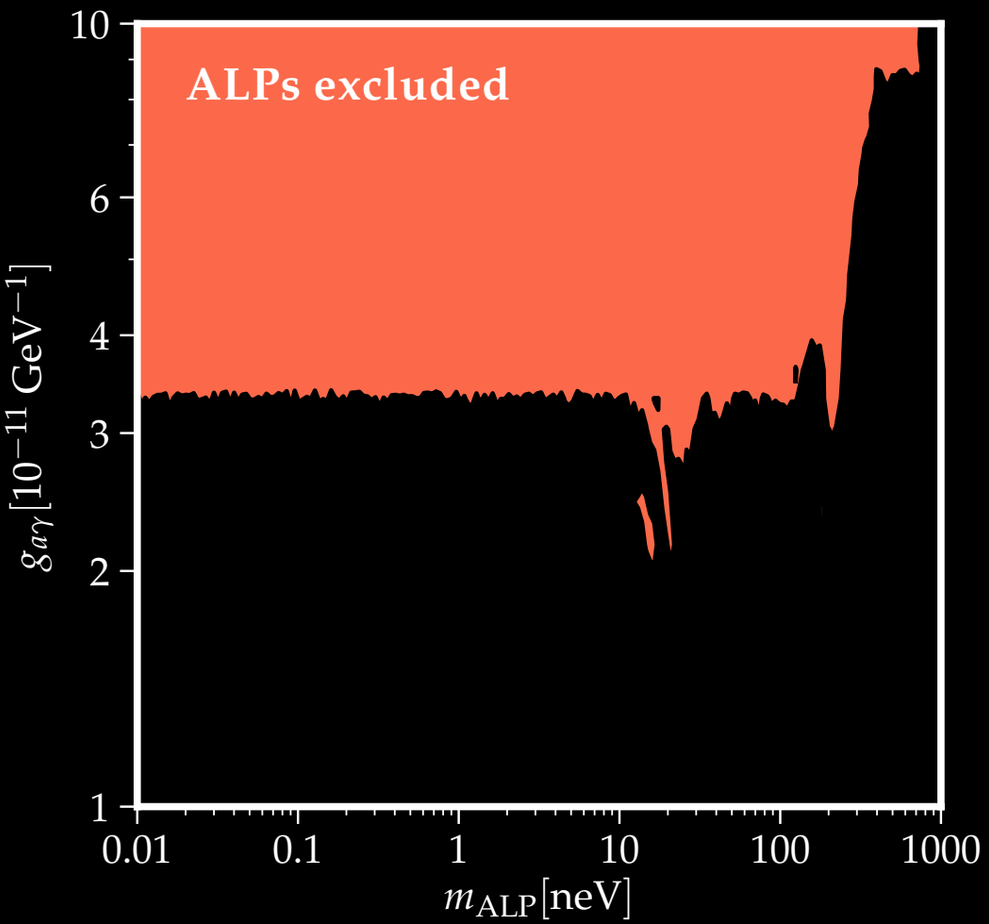
Backups

Alternative Jet MF models

Simple jet model



Davies et al. 2011.08123: Jet magnetic field model based on the Potter & Cotter model.



The Photon Survival Probability

$$P_{\gamma\gamma} = \mathrm{Tr}\left[\left(\rho_{11} + \rho_{22}\right)\mathcal{T}\,\rho(0)\mathcal{T}^{\dagger}\right]$$

The transfer matrix can be divided into N domains:

$$\mathcal{T}\left(z_N, z_1; \psi_N, \ldots, \psi_1\right) = \prod_{i=1}^{N} \mathcal{T}\left(z_{i+1}, z_i; \psi_i; E\right)$$

Jet magnetic field

Magnetic field strength ~ G
Highly dependent on the blazar
Short distances ~pc

$$B(r) = B_0 r_{VHE} r^{-1}$$

Intra-cluster MF

Magnetic field strength $\sim \mu G$
Long distances: ~100 kpc
Only for certain blazars

$$B^{\mathrm{ICM}}(r) = B_0^{\mathrm{ICM}} \left(\frac{n(r)}{n_0}\right)^{\eta}$$

Milky Way MF

Modified Jansson & Farrar model (arXiv:1204.3662)

Method

Follow the method derived in Meyer and Conrad's 2014 paper: 1410.1556

1. Extract the observed flux of a blazar source from atmospheric Cherenkov telescopes (ACT) such as VERITAS, MAGIC or H.E.S.S

2. Find the deabsorbed spectrum by taking into account absorption in the EBL and possible ALP effects - calculate $P_{\gamma\gamma}$

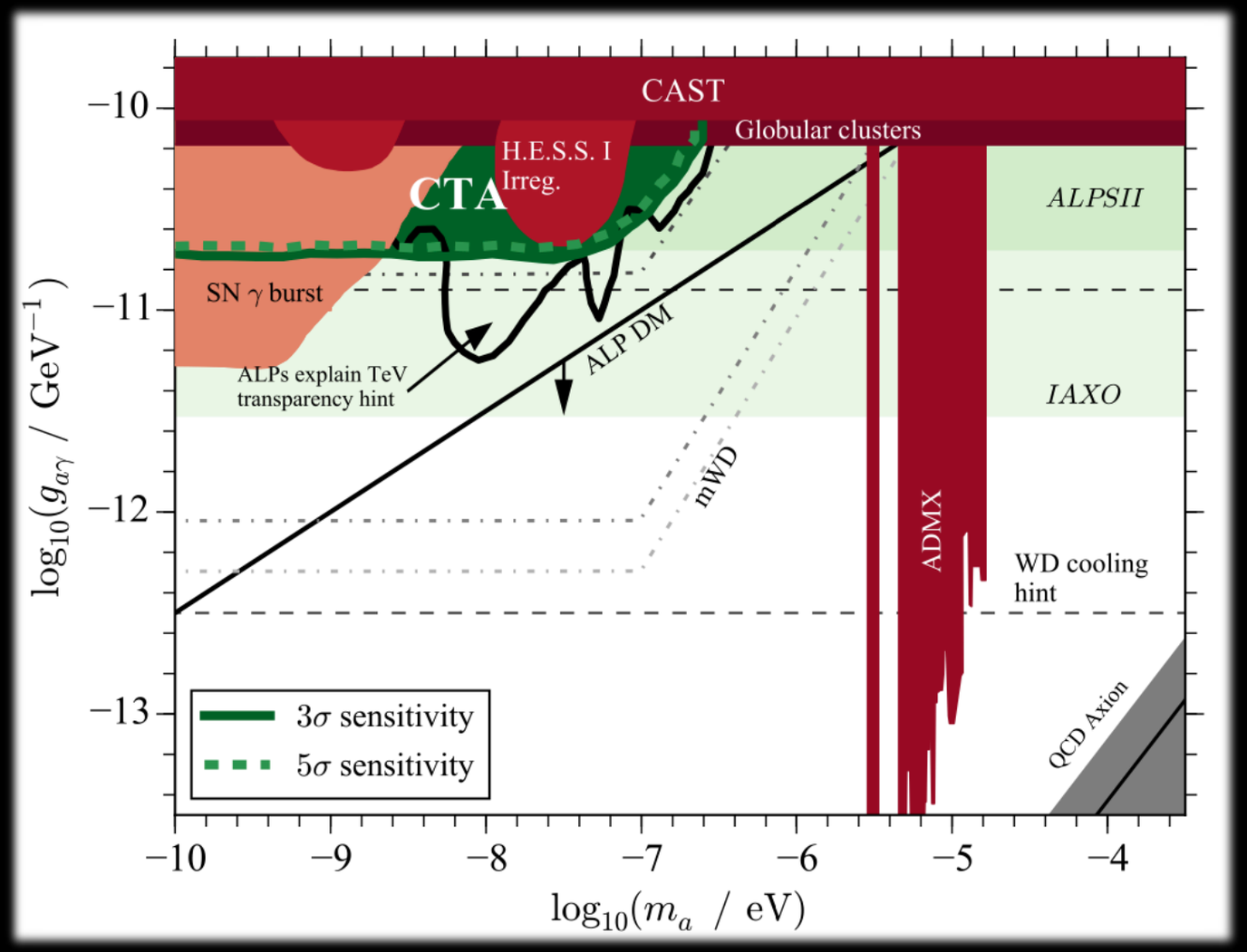
3. Calculate the expected spectrum with and without ALP effects at Earth, by multiplying the intrinsic blazar spectrum with $P_{\gamma\gamma}$

4. Do a goodness-of-fit analysis of the spectra both with and without ALPs to the 7 TeV flux from HAWC and observed spectrum from ACTs: TS = $2(\mathscr{L}_{ALP} - \mathscr{L}_{noALP})$

Meyer & Conrad (2014)

Projected sensitivity of the Cherenkov Telescope Array to detect ALPs

Sensitivity:
$g_{a\gamma} \gtrsim 2 \times 10^{-11}\text{GeV}^{-1}$ for ALP masses $m_a \lesssim 10^{-7}\text{eV}$



ArXiv: 1410.1556