Planck Data and Ultralight Axions

John Terning
work in progress
with Csaba Csaki and Nemanja Kaloper

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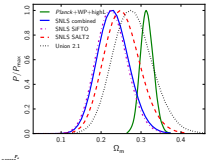
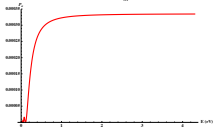
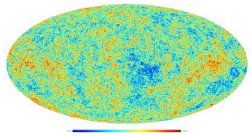
Planck vs Supernovae dimming



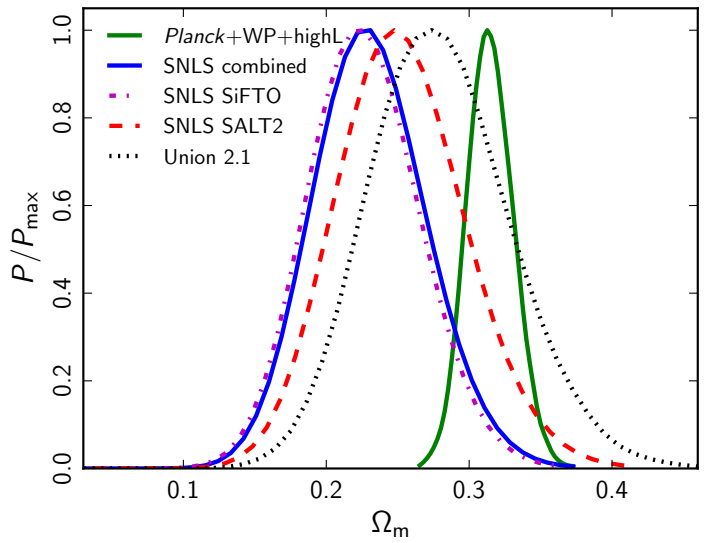
Limits on axions

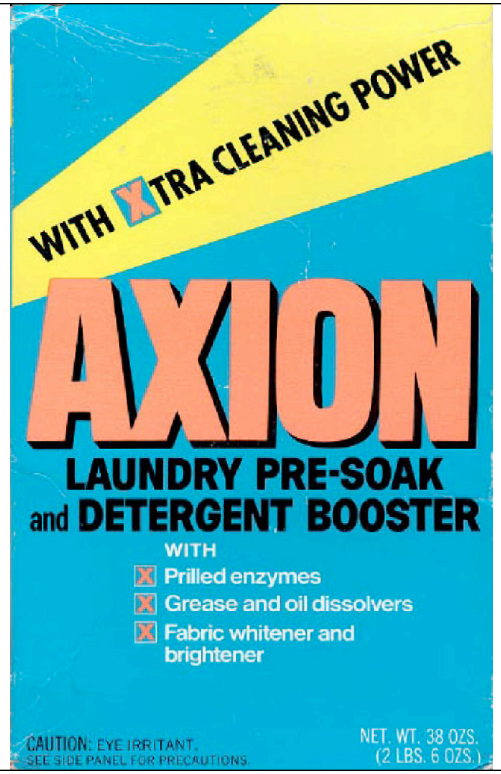


Axion contamination of CMB



Planck vs SNe: the Tension





$$\mathcal{L} = \frac{a}{M} F^{\mu\nu} \tilde{F}_{\mu\nu}$$

Photon-Axion Mixing

$$\left\{\frac{d^2}{dy^2}+\mathcal{E}^2-\begin{pmatrix}\omega_p^2 & i\mathcal{E}\frac{B}{M}\\ -i\mathcal{E}\frac{B}{M} & m_a^2\end{pmatrix}\right\}\begin{pmatrix}|\gamma\rangle\\ |a\rangle\end{pmatrix}=0$$

$$\omega_p^2=\frac{4\pi\alpha n_e}{m_e}$$

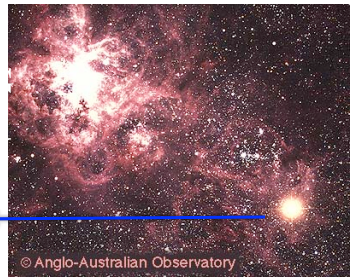
$z<1$

$$n_e\leq 6\cdot 10^{-9}\mathrm{cm}^{-3}$$

$$\omega_p\leq 3\cdot 10^{-15}\mathrm{eV}$$

SN1987a

$M\geq 10^{11}\mathrm{GeV}$

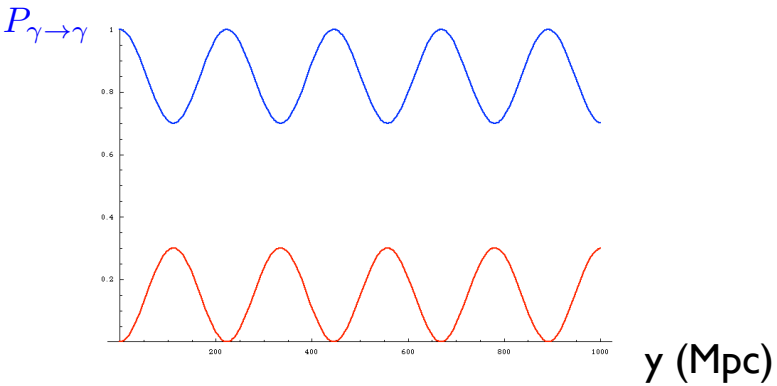


G. Raffelt hep-ph/9903472

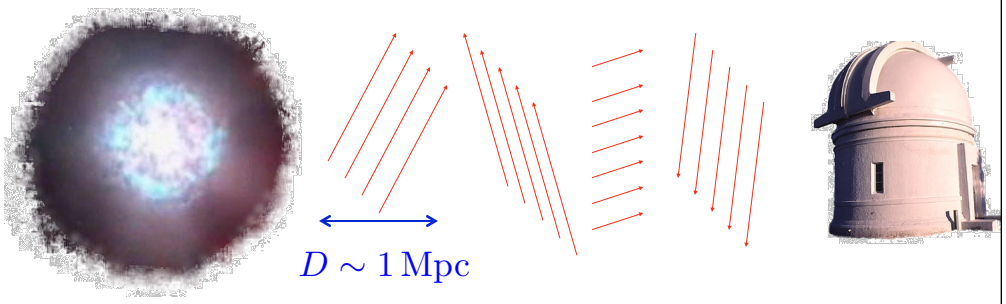
Photon-Axion Oscillations

$$\mu^4 = (\omega_p^2 - m_a^2)^2 + 4\frac{\mathcal{E}^2 B^2}{M^2}$$

$$P_{\gamma\to\gamma} = 1 - 4\frac{\mathcal{E}^2 B^2}{\mu^4 M^2}\sin^2\left(\frac{y\mu^2}{4\mathcal{E}}\right)$$



Photon-Axion Dimming



$$P_{\gamma\to\gamma} = \frac{2}{3} + \frac{1}{3}e^{-y/L} \qquad L \approx \frac{8}{3}\frac{M^2}{DB^2}$$

Csaki, Kaloper, JT hep-ph/0111311, hep-ph/0112212

The Axion "Miracle"

$$|\vec{B}| \sim \text{few} \cdot 10^{-9}\text{Gauss}$$

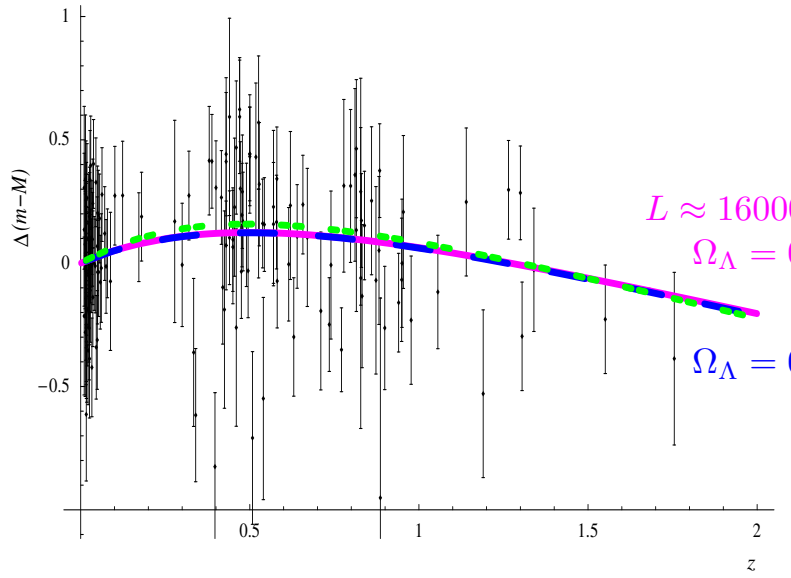
$$L \approx \frac{8}{3}\frac{M^2}{DB^2}$$

$$\approx \frac{8}{3}\frac{(10^{11}\,\text{GeV})^2}{1\,\text{Mpc}\,(10^{-9}\,\text{Gauss})^2}\left(\frac{6.4\times 10^{-39}\,\text{Mpc}}{\text{GeV}^{-1}}\right)^2\left(\frac{5.1\times 10^{19}\text{Gauss}}{\text{GeV}^2}\right)^2$$

$$\approx 2850\,\text{Mpc}$$

$$\approx \frac{1}{2}H_0^{-1}$$

Supernovae Dimming

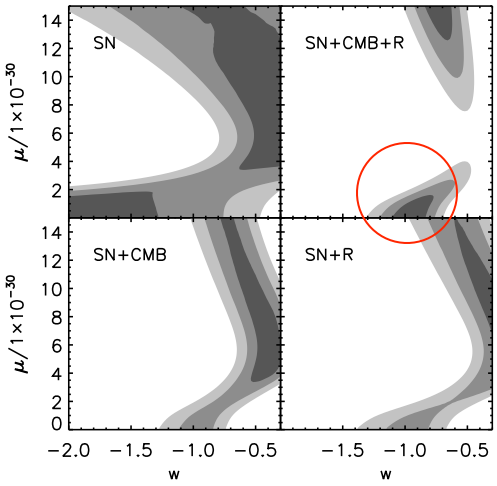


$L \approx 16000\,\mathrm{Mpc}$
$\Omega_\Lambda = 0.65$

$\Omega_\Lambda = 0.7$

Baryon Oscillations

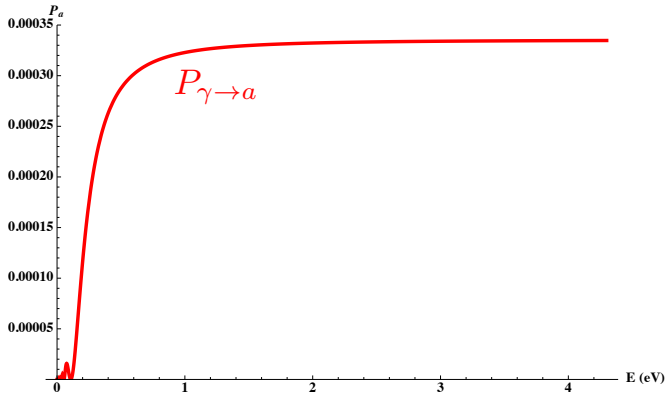
$\frac{B}{M}$



Song, Hu astro-ph/0508002

Energy Dependence

$$P_{\gamma\to a} = 4\frac{\mathcal{E}^2 B^2}{\mu^4 M^2}\sin^2\left(\frac{y\mu^2}{4\mathcal{E}}\right)$$



Csaki, Kaloper, JT hep-ph/0111311, hep-ph/0112212

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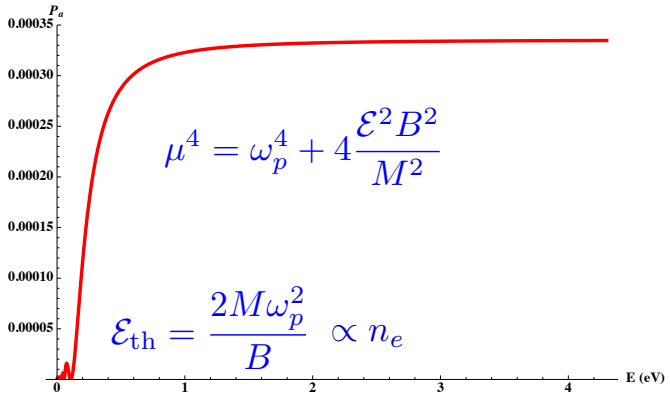
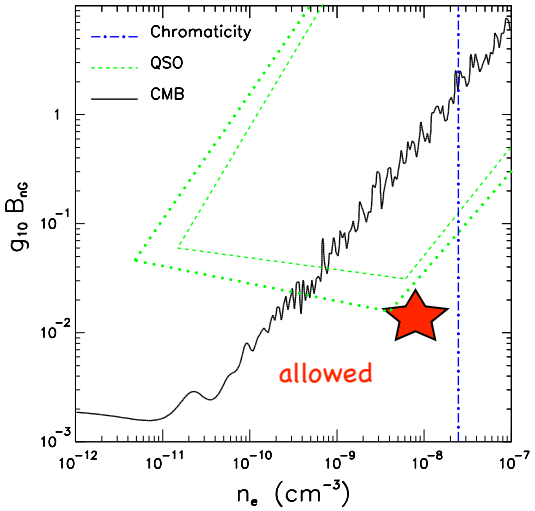


$$\mu^4 = \omega_p^4 + 4\frac{\mathcal{E}^2 B^2}{M^2}$$

$$\mathcal{E}_{\rm th} = \frac{2M\omega_p^2}{B} \propto n_e$$

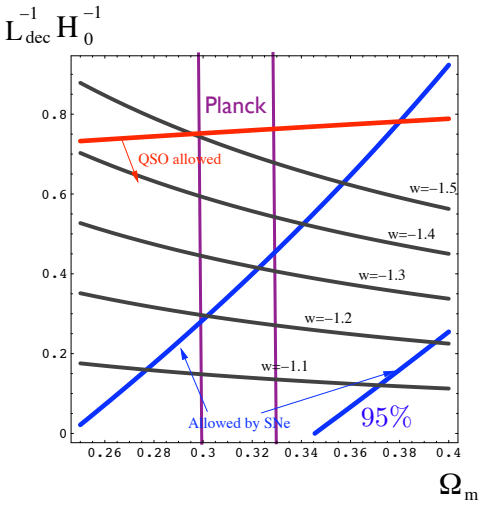
Csaki, Kaloper, JT hep-ph/0111311, hep-ph/0112212

Constraints



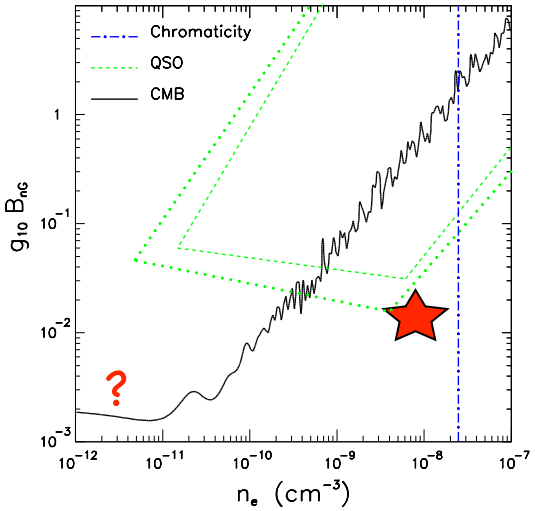
Mortsell, Goobar astro-ph/0303081
Mirizzi, Raffelt, Serpico astro-ph/0506078

Phaking a Phantom with Axions



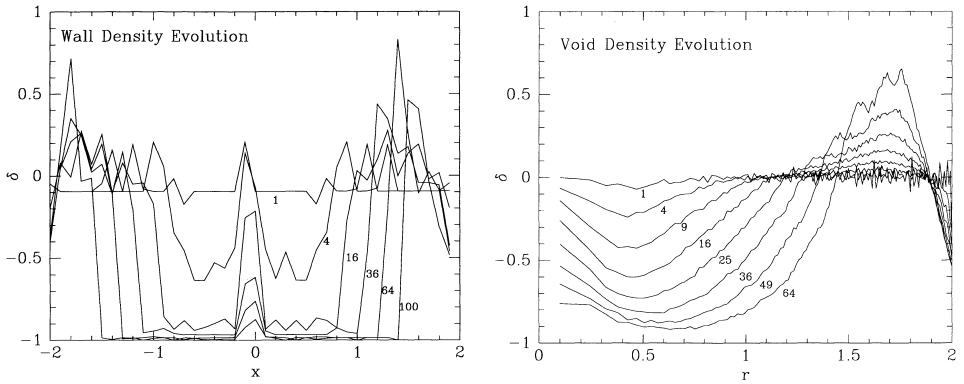
Csaki, Kaloper, JT astro-ph/0409596

Can Axions affect CMB?



Mortsell, Goobar astro-ph/0303081
Mirizzi, Raffelt, Serpico astro-ph/0506078

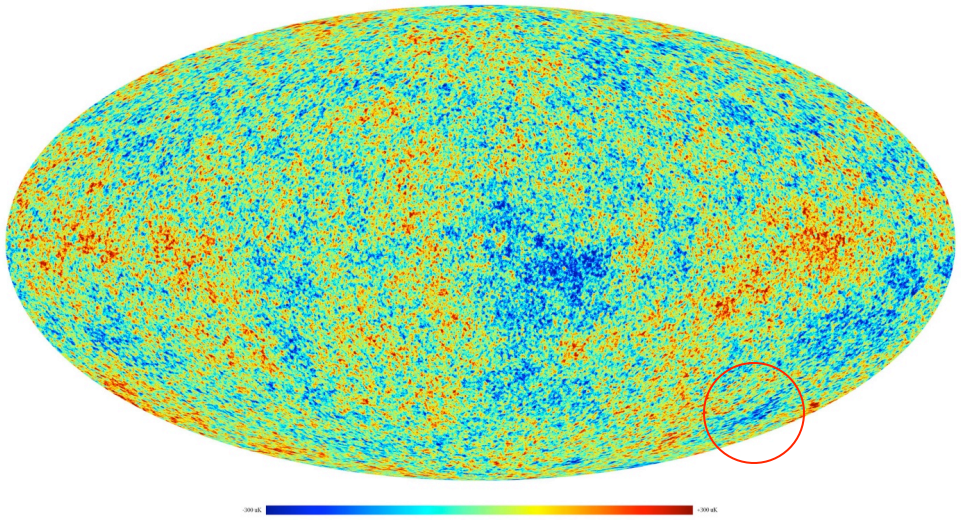
Voids are called that for a reason



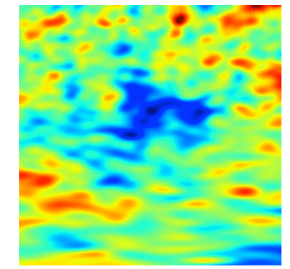
$$\mathcal{E}_{th} = \frac{2M\omega_p^2}{B} \propto n_e$$

Dubinski et. al. Ap.J. 410 (1993) 458

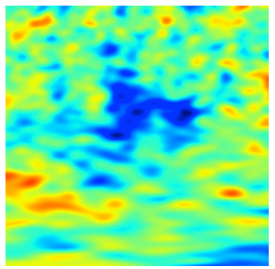
Interesting Spots on the Sky



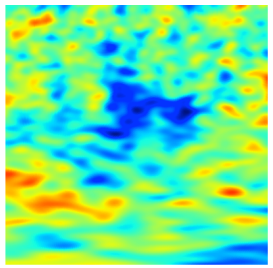
The Cold Spot



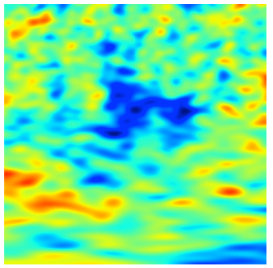
30 GHz



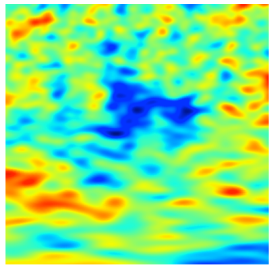
44 GHz



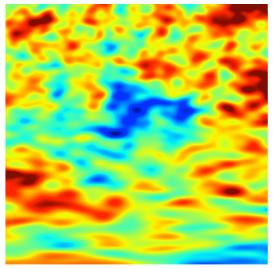
70 GHz



100 GHz

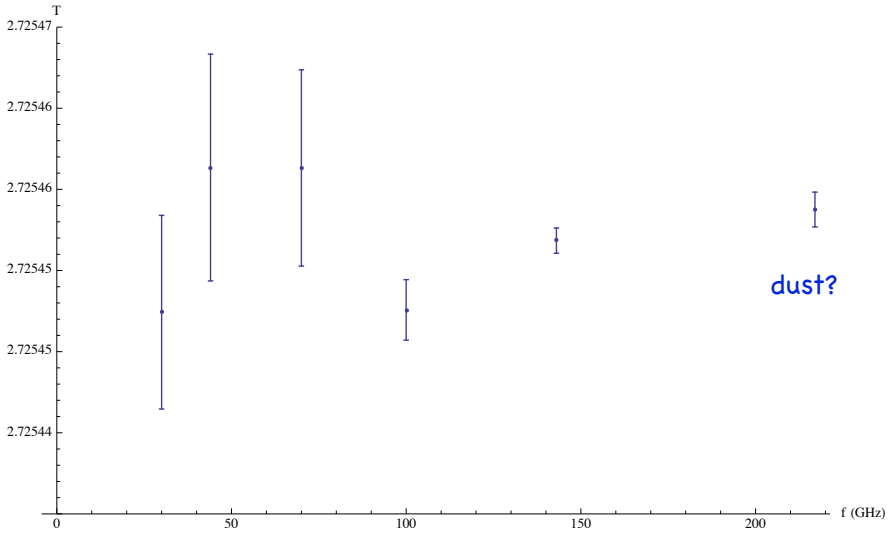


143 GHz



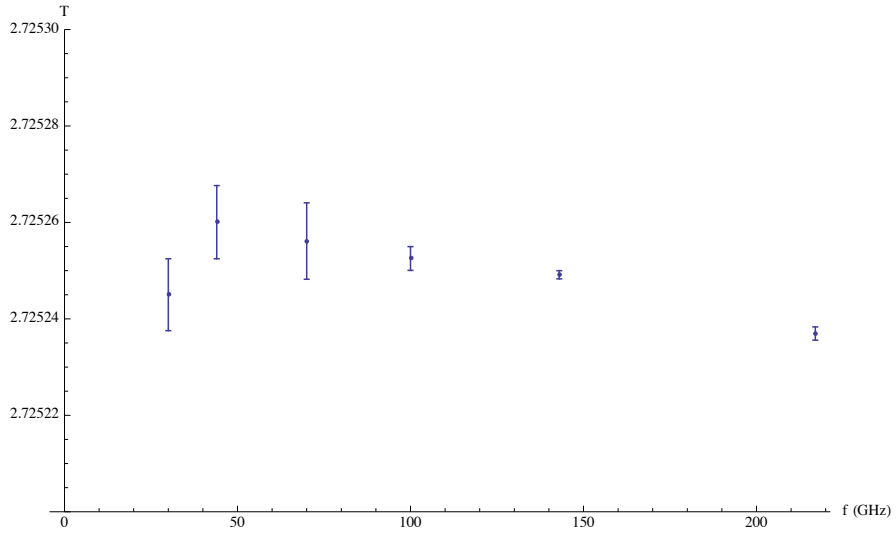
217 GHz

Temperature of a Random Spot



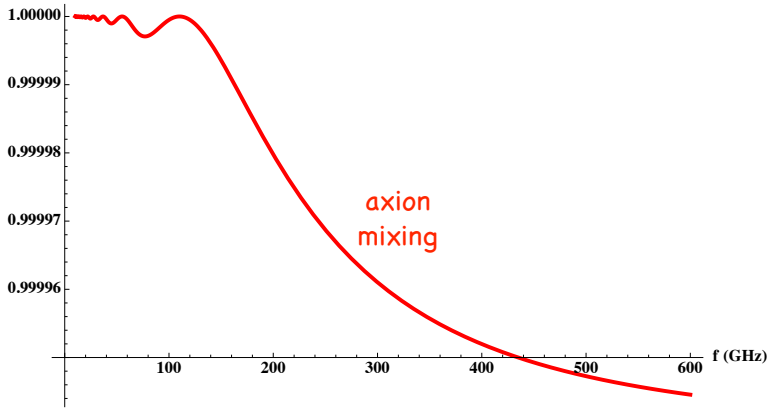
$b = 56.4°, \ell = -150.3°$

Temperature of The Cold Spot



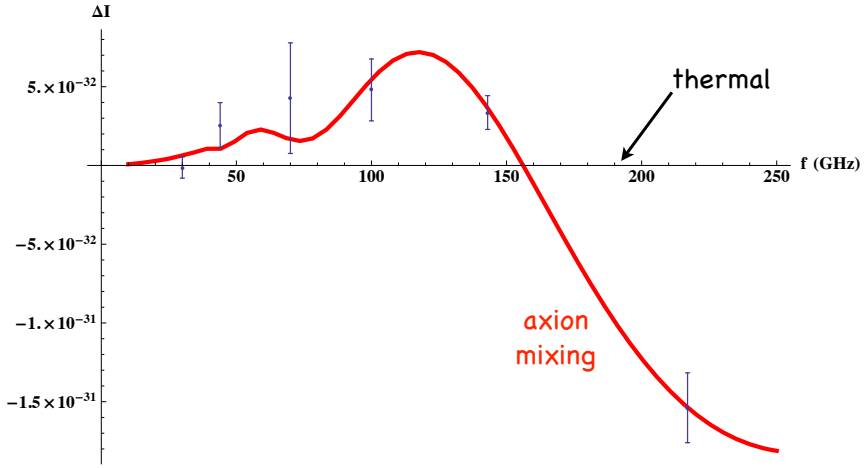
$b = -56.4^\circ, \ell = -150.3^\circ$

Residual Intensity



$\omega_p = 3.9 \cdot 10^{-17}\,\mathrm{eV}$ $\qquad$ $B = 8.6 \cdot 10^{-11}\,\mathrm{G}$

Residual Intensity



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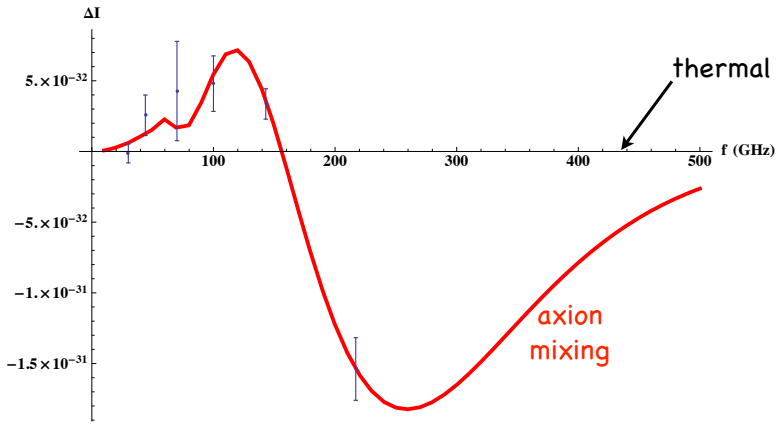
Residual Intensity



$\omega_p = 3.9 \cdot 10^{-17}\,\mathrm{eV}$ $\quad B = 8.6 \cdot 10^{-11}\,\mathrm{G}$

Searches

cleaning of maps should be done without removing a potential axion signal

systematic survey should be done of known voids

Conclusions

axions could resolve the tension between
Planck and Supernovae dimming

photon-axion mixing can affect the CMB spectrum
requires more careful cleaning of higher frequencies