N. Kaloper, UC Davis

Planck Data and Ultralight Axions

with C. Csaki and J. Terning, to appear

OVERVIEW

- Ultralight axions and cosmology
- SNe
- CMB according to Planck
- Summary…

Dark energy

- You could just say it is c.c. and yell at those who disagree... or
- There is (still!) degeneracy in the data. SNe are the most sensitive to dark energy, limiting eq of state w in the range, roughly

$$-2.7 \le w_{eff} \le -0.7$$

- SNe like w < -1 (Planck best fit - -1.11 (only 1 sigma?) - but disagreement in measurement of H is ~ 5 sigma; still a moving target...)
- Popular `models' are phantoms - ghosts. But that is nonsense.
- A simpler explanation: dimmer SNe?
- A boringly opaque universe? Not enough - if there is too much dust it would equilibrate and glow in the IR
- Axions: photons transition into them in background B field - not in equilibrium if there's less background axions

- Comments from Adam Riess, meant for public dissemination:
- As you know, there is some tension between direct measurements of H0 and CMB+model inferences of H0.
- Either: a) the local measurement of H0 is in error b) the CMB observations are in error c) the model is in error
- If the model is in error, the easiest way of describing this is to say the Universe is now expanding faster than we thought. You could do this with strengthening dark energy (w~-1.1) which would be a big deal if true, not to mention the ramifications about a comic (sic! n.k.) rip, etc. Of course its much easier to imagine that its a) or b) since in observational cosmology we make errors all the time.
- But we should be open to c), as this is exactly how we are trying to learn about dark energy.

W. Hu & Y-S. Song, astro-ph/0508002

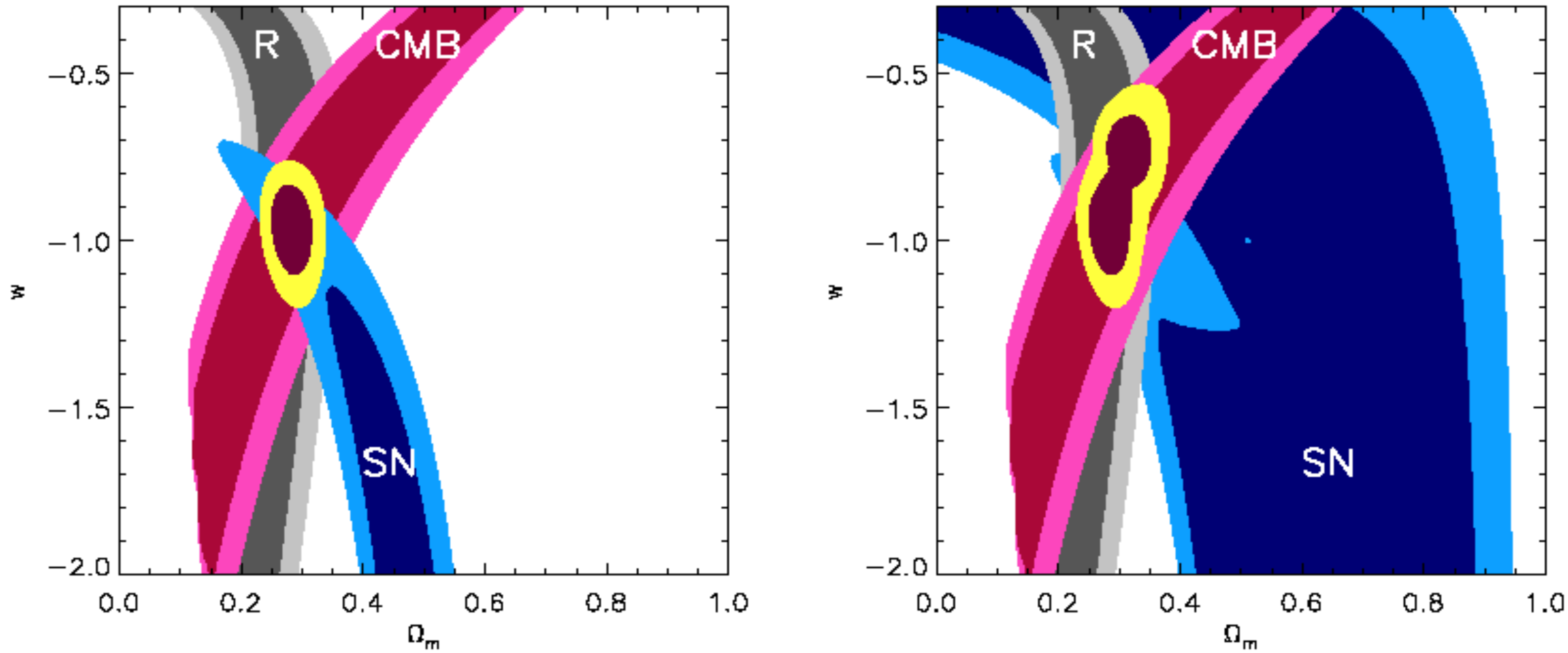


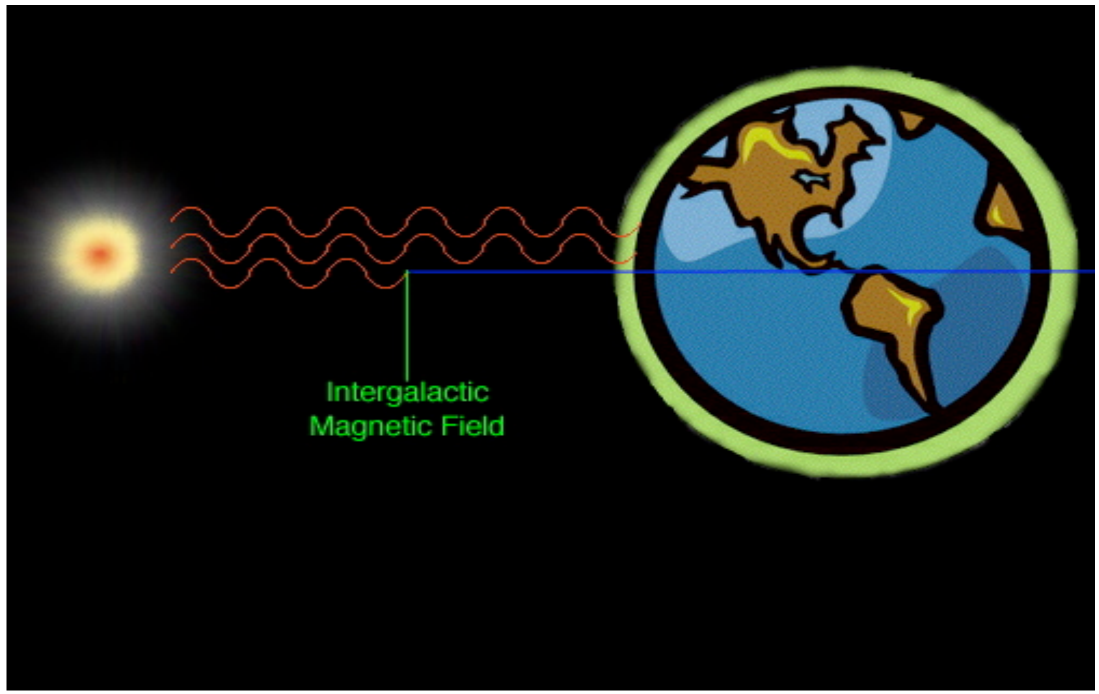
FIG. 2: $\Omega_m - w$ constraints at the 68% and 95% CL. Cosmologies without p-p dimming are shown in the left panel and those with dimming in the right. Separate contours denote supernovae constraints (SN), baryon oscillations (R), and CMB acoustic peak constraints (CMB) as labeled. The ellipses at the intersection denote the combination of all constraints.

PHOTON-AXION CONVERSION IN A MAGNETIZED UNIVERSE

Typical distance between us and SNe: ~ 10^3 MPc

Magnetic field with coherence length: ~ MPc

There's about ~ $O(10^3)$ cosmic magnetic (Weiss) domains between us and a supernova at $z \geq 0.5$



For this to work axions MUST be ultralight. Whence ultralight axions: THE AXIVERSE!

LUMINOSITY

Luminosity:

$$\mathcal{L} = \frac{\text{Luminosity}}{\text{distance}^2} \, P_{\gamma\to\gamma}$$

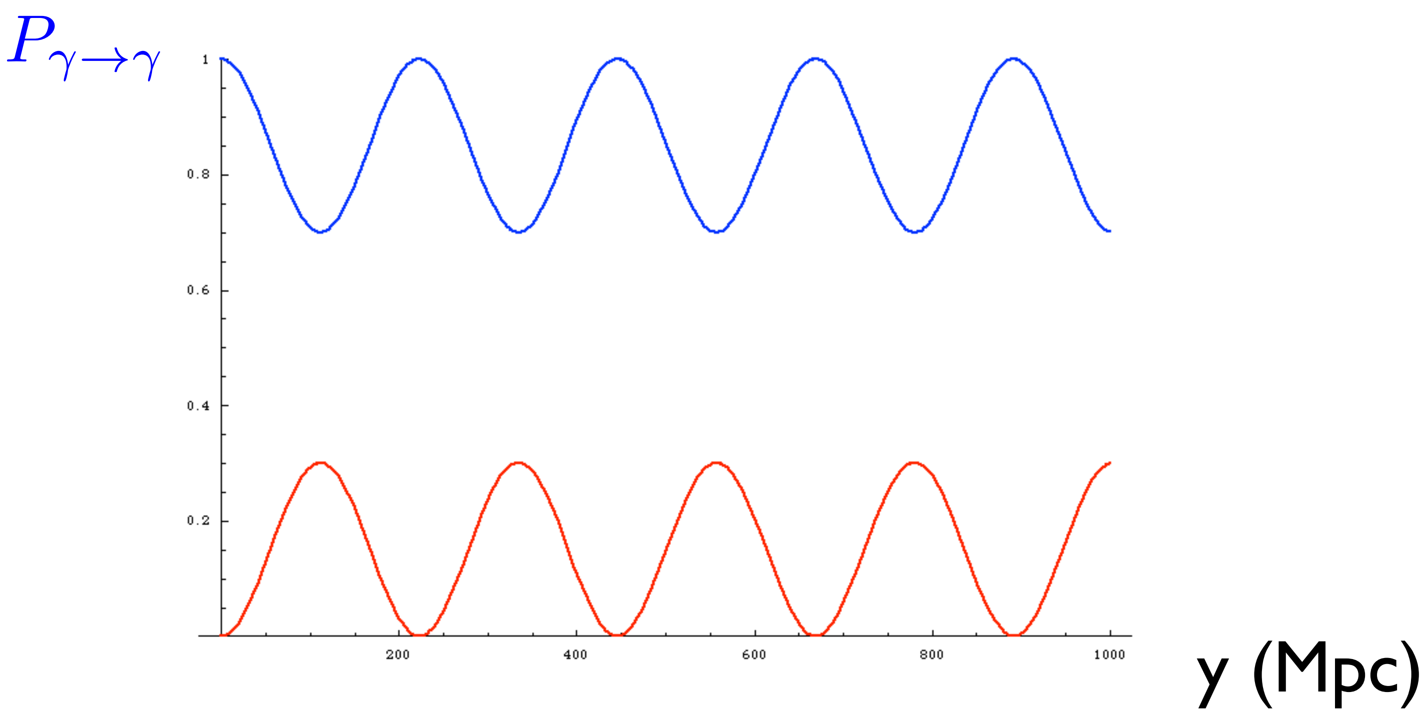
SNe may appear farther away since we may reinterpret additional dimming as distance:

$$d_{eff} = d \,/\, P^{1/2}(\text{ photon survival })$$

Coherent oscillations

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

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



- In random B fields with coherence length < distance travelled, and with negligible initial axion flux, one can treat the problem using intensities; solving ODEs,

$$I_\gamma(y) = (2 + e^{-y/L})\, I_\gamma(0)/3$$

$$I_a(y) = (1 - e^{-y/L})\, I_\gamma(0)/3$$

- Survival probability: $P = I_\gamma(y) / I_\gamma(0)$
- p«1, so only one in ~10000 photons converts; BUT there is about few 1000 domains along a line of sight.
- Because the initial axion flux is tiny, about 1/3 of photons will turn into axions after a long trip.

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

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

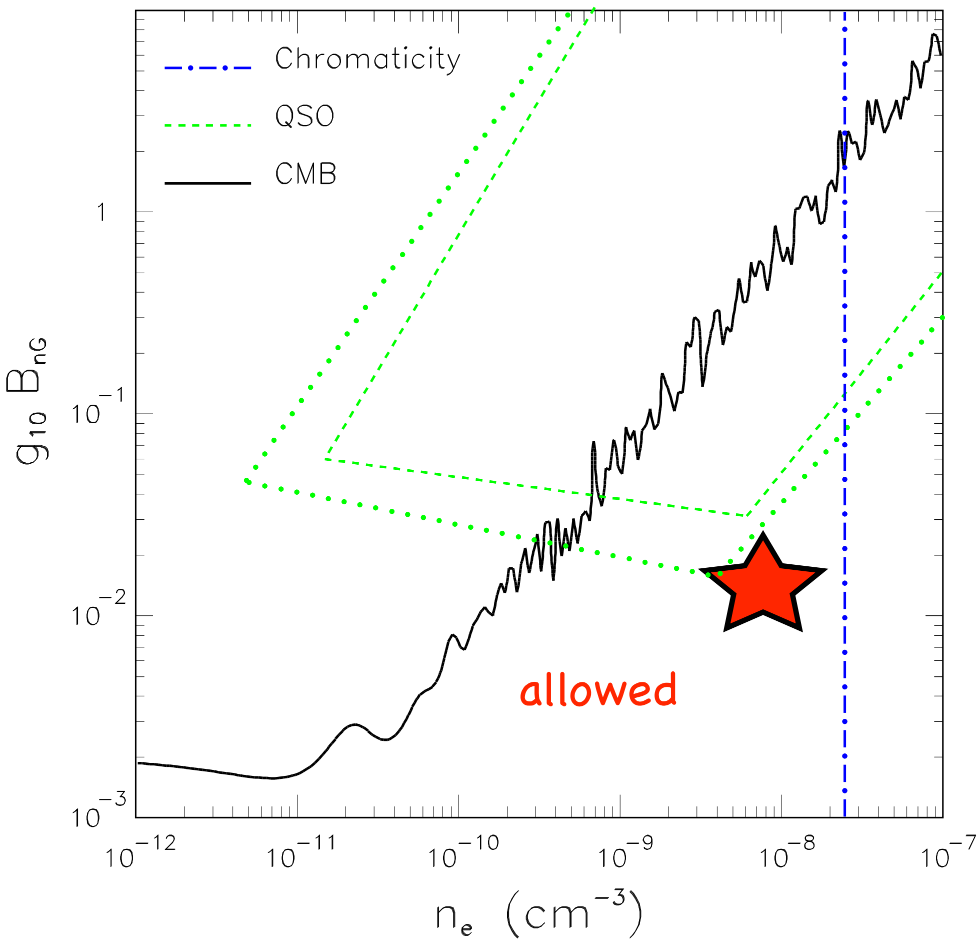
$$L \approx \frac{8}{3}\frac{M^2}{DB^2}$$

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

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

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

Constraints

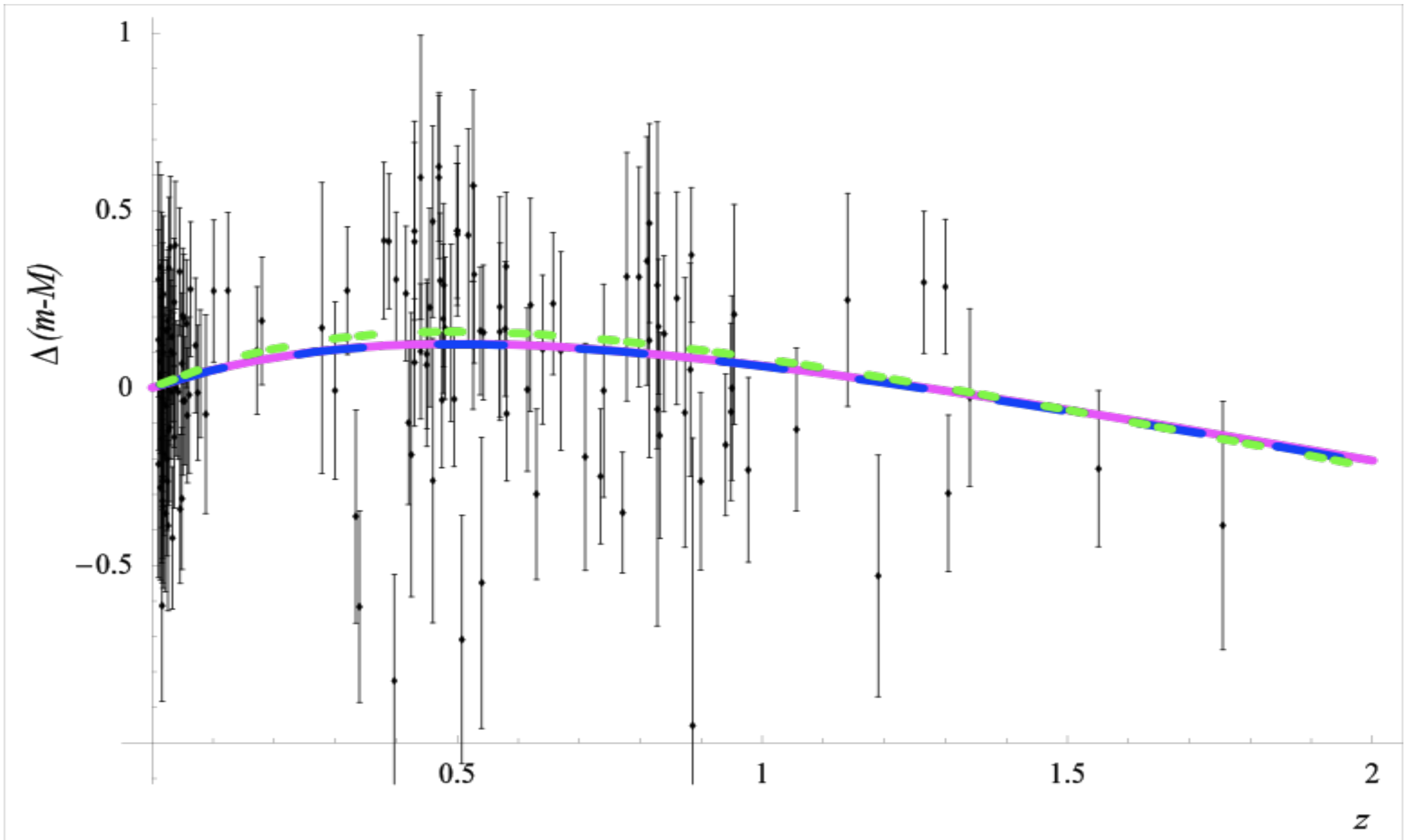


Mortsell, Goobar astro-ph/0303081

Mirizzi, Raffelt, Serpico astro-ph/0506078

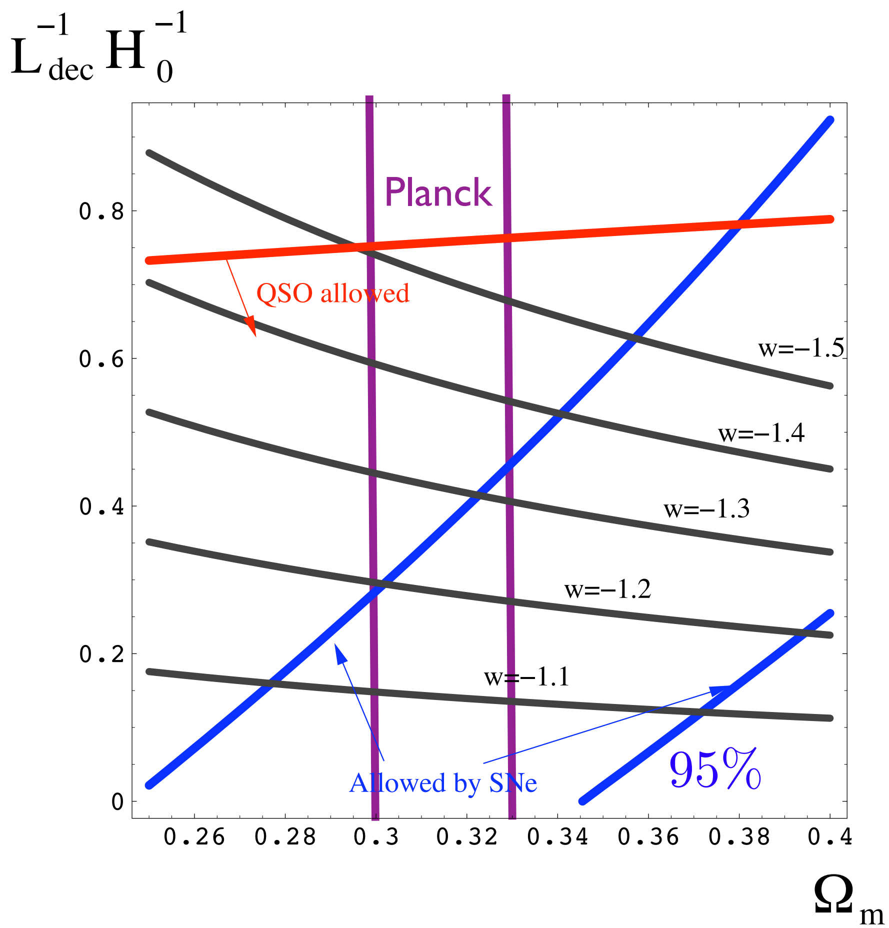
FITTING SNe

Green: Ω_{DE} = 0.65, w = -1.25;
Blue: Concordance model, ΛCDM;
Purple: Ω_Λ=0.65+ axions, mimicking w<-1.



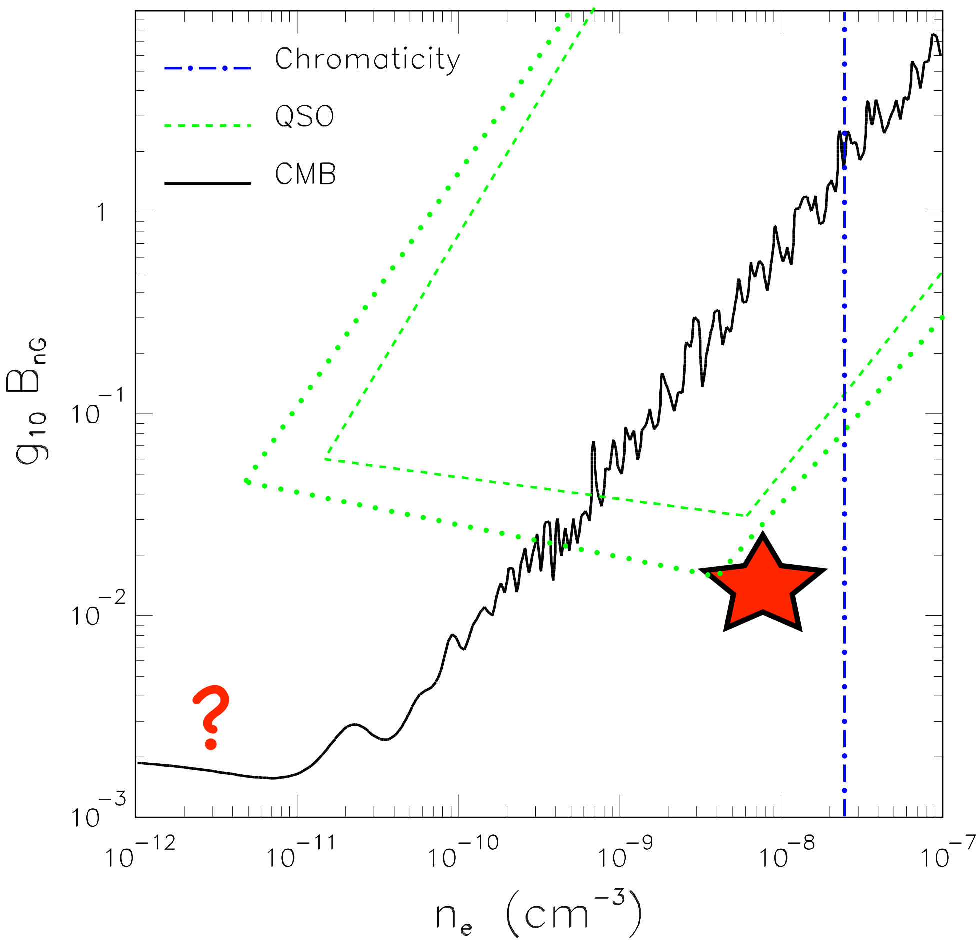
data: “gold sample” of 157 SNe, Riess et al.

Impersonating w<-1



Csaki, NK, Terning astro-ph/0409596

What of CMB?



Mortsell, Goobar astro-ph/0303081

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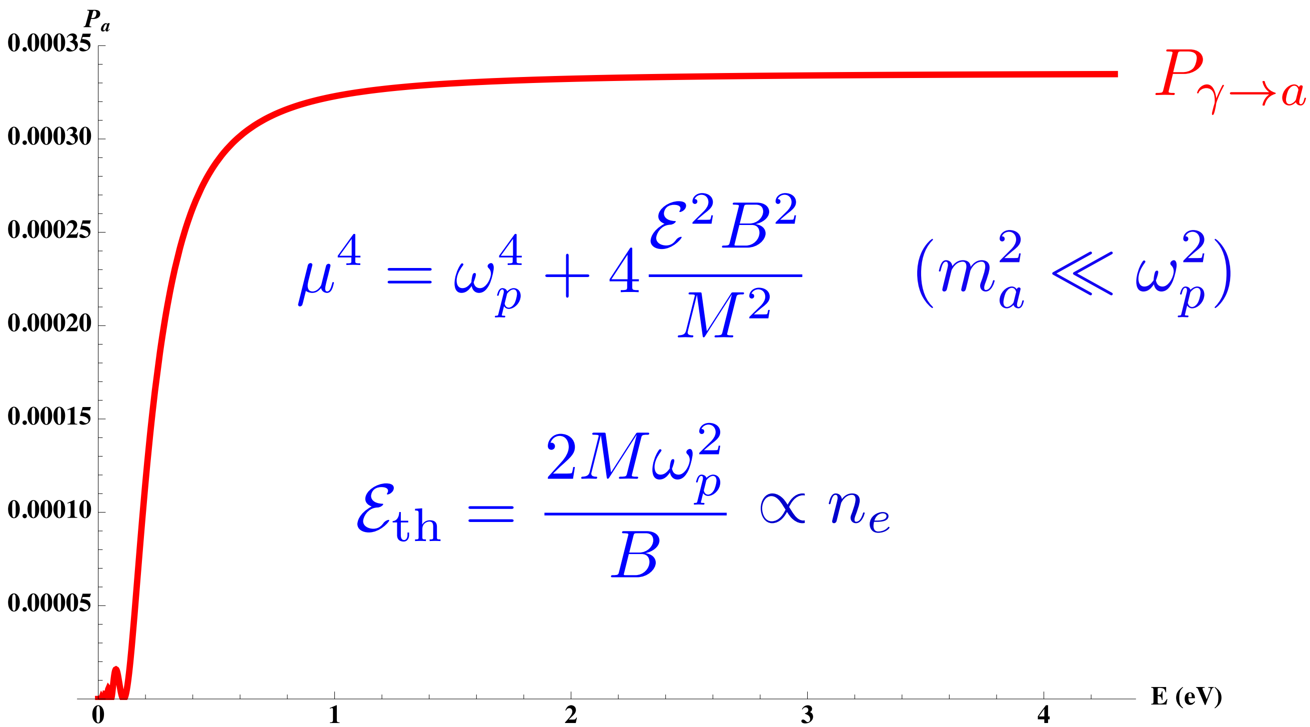
CMB?

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

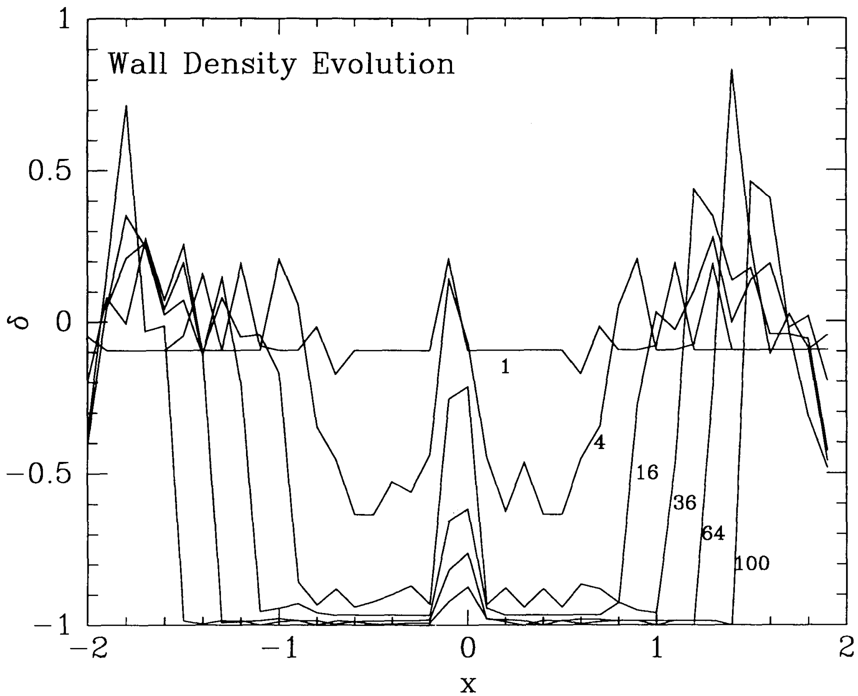


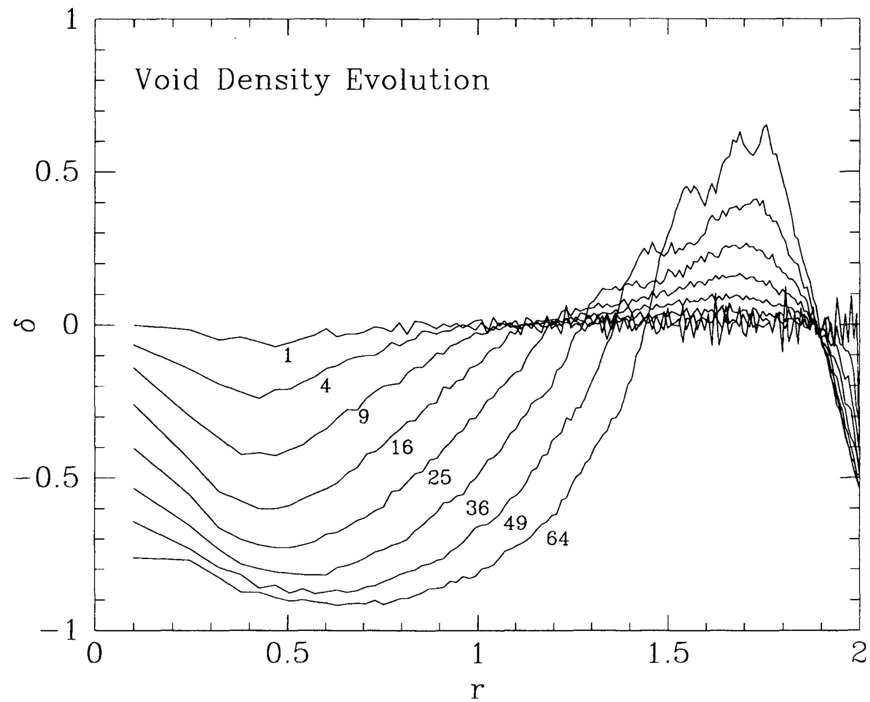
$$\mu^4 = \omega_p^4 + 4\frac{\mathcal{E}^2 B^2}{M^2} \qquad (m_a^2 \ll \omega_p^2)$$

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

Csaki, NK, Terning hep-ph/0111311, hep-ph/0112212

Where? In VOIDS!

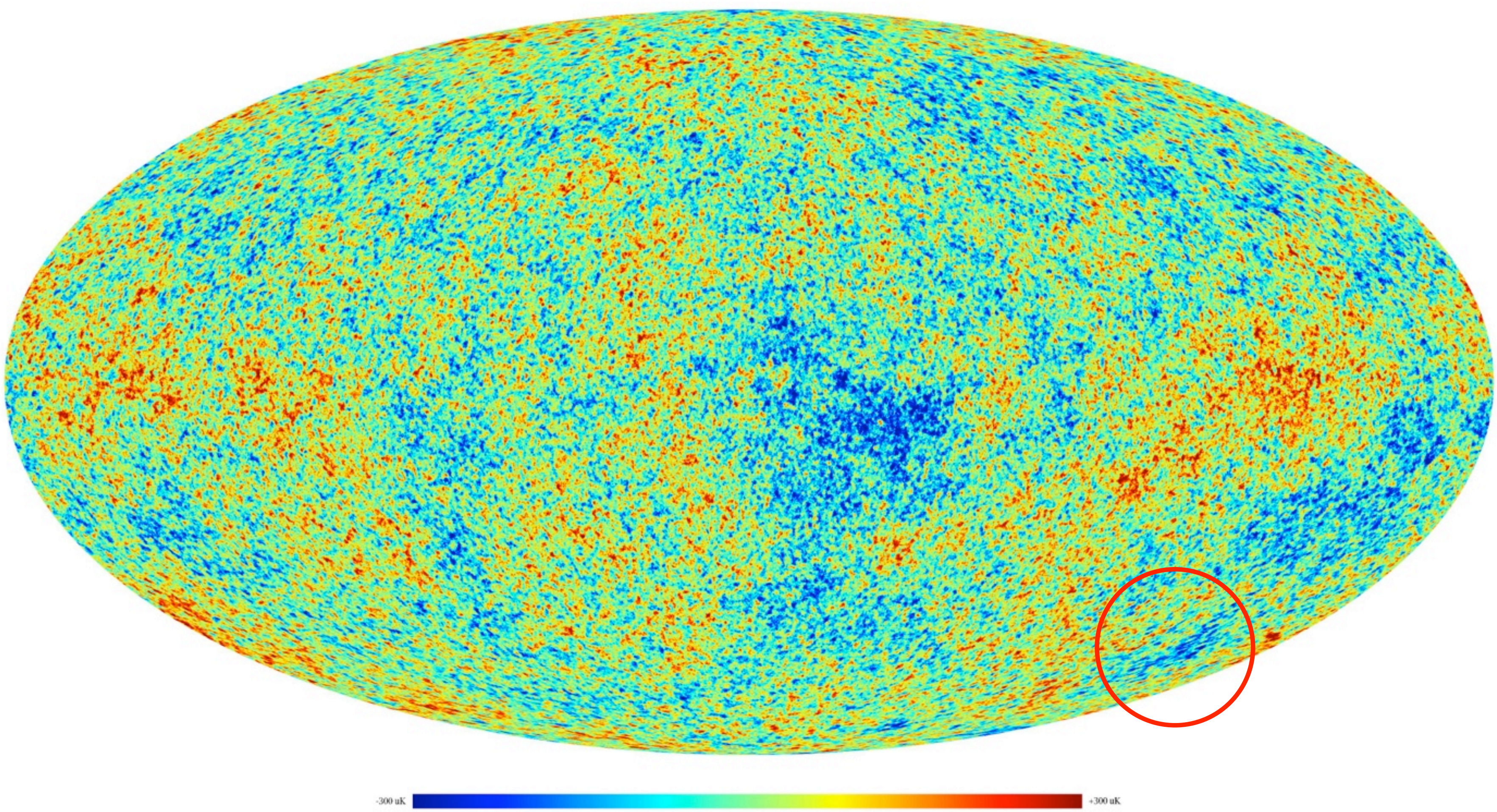




$$\mathcal{E}_{th} = \frac{2M\omega_p^2}{B} \propto n_e$$

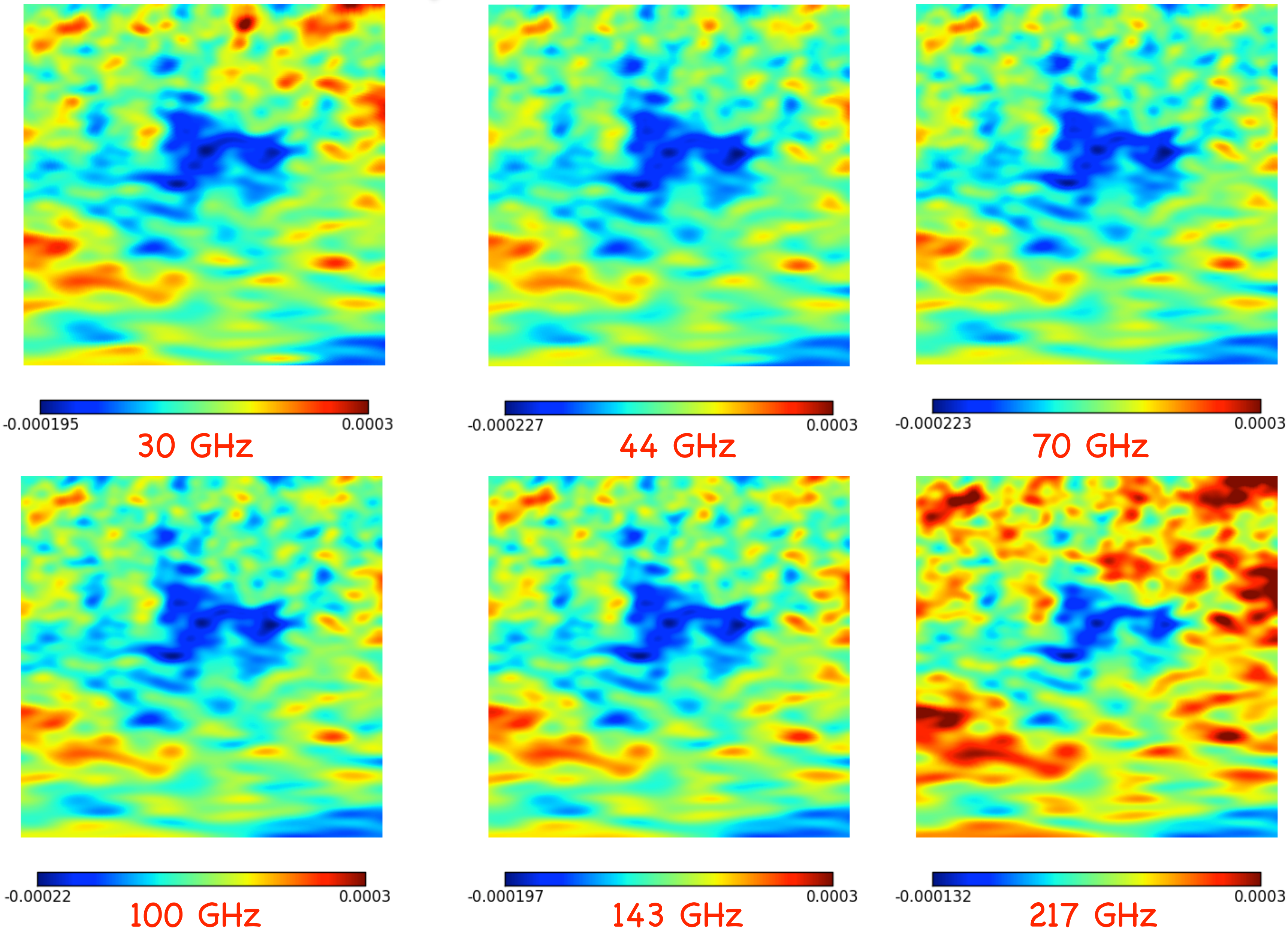
Dubinski et. al. Ap.J. 410 (1993) 458

E.g. the CMB Cold Spot



http://en.wikipedia.org/wiki/CMB_cold_spot

The Cold Spot

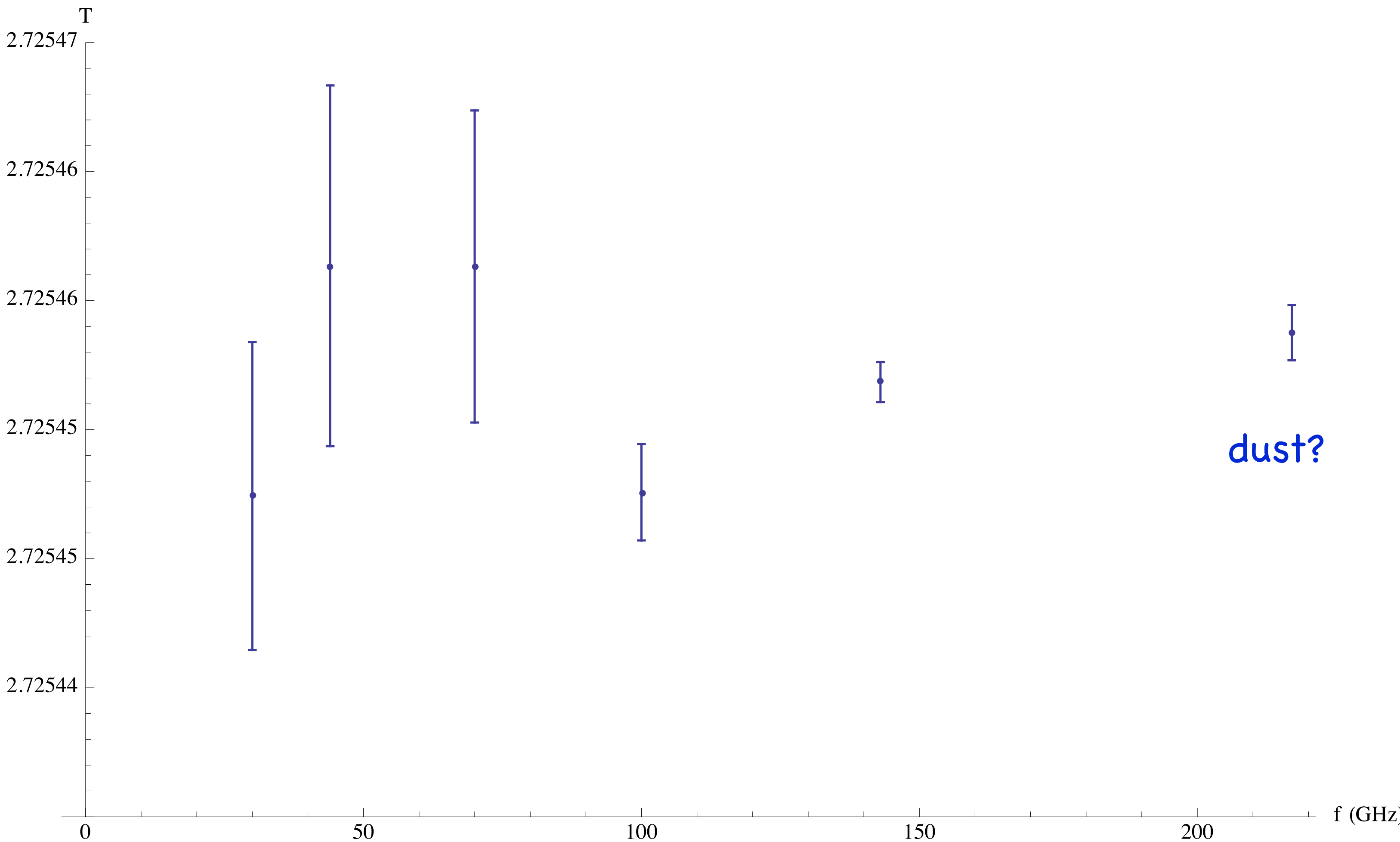


- People suggested ISW effect in at void along the line of sight can explain cold spot (Silk et al, Rudnick et al)

$$\frac{\Delta T}{T} = -2 \int dt \frac{dV_N}{dt}$$

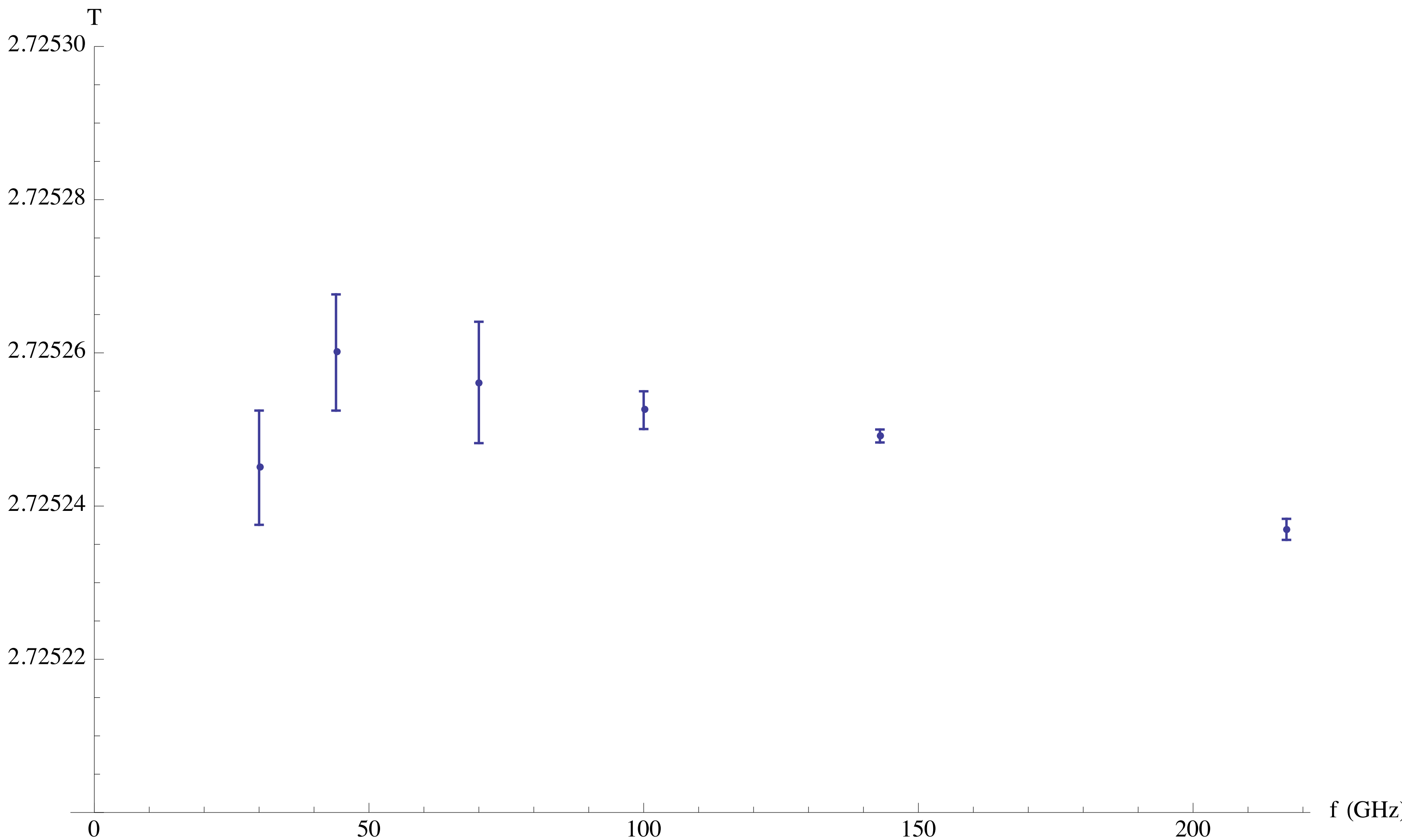
- This needs VERY large voids, > 150 MPc accross
- Reexamination of the LSS data showed no evidence for so large a void (Huterer & Smith)
- Resolution to ~ 50 MPc. Smaller voids OK (Szapudi et al).
- Those not large for ISW to generate enough cooling
- BUT: this is what axions CAN do! Mixing effect could be strong enough!

Temperature of (not so) random spot



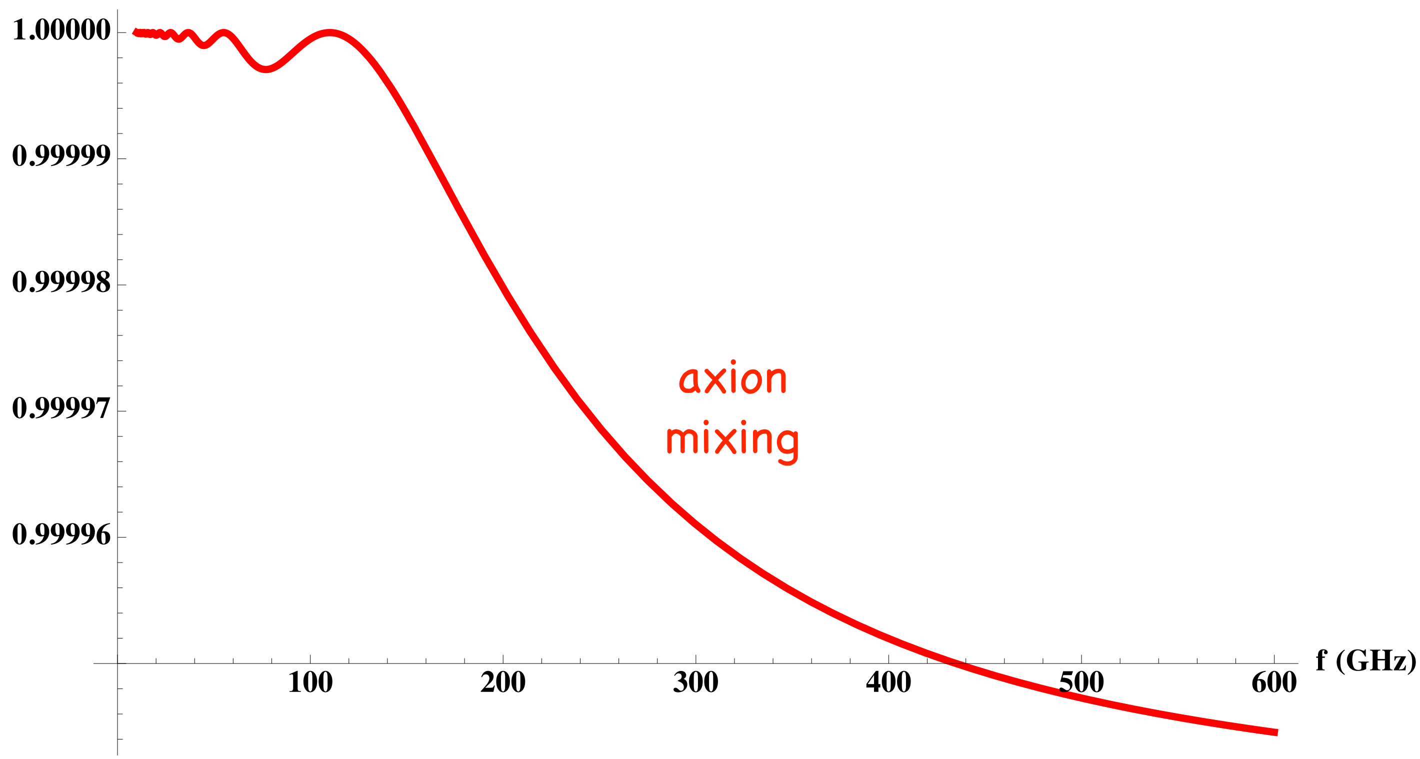
$$b = 56.4^\circ, \ell = -150.3^\circ$$

Temperature of the CMB Cold Spot



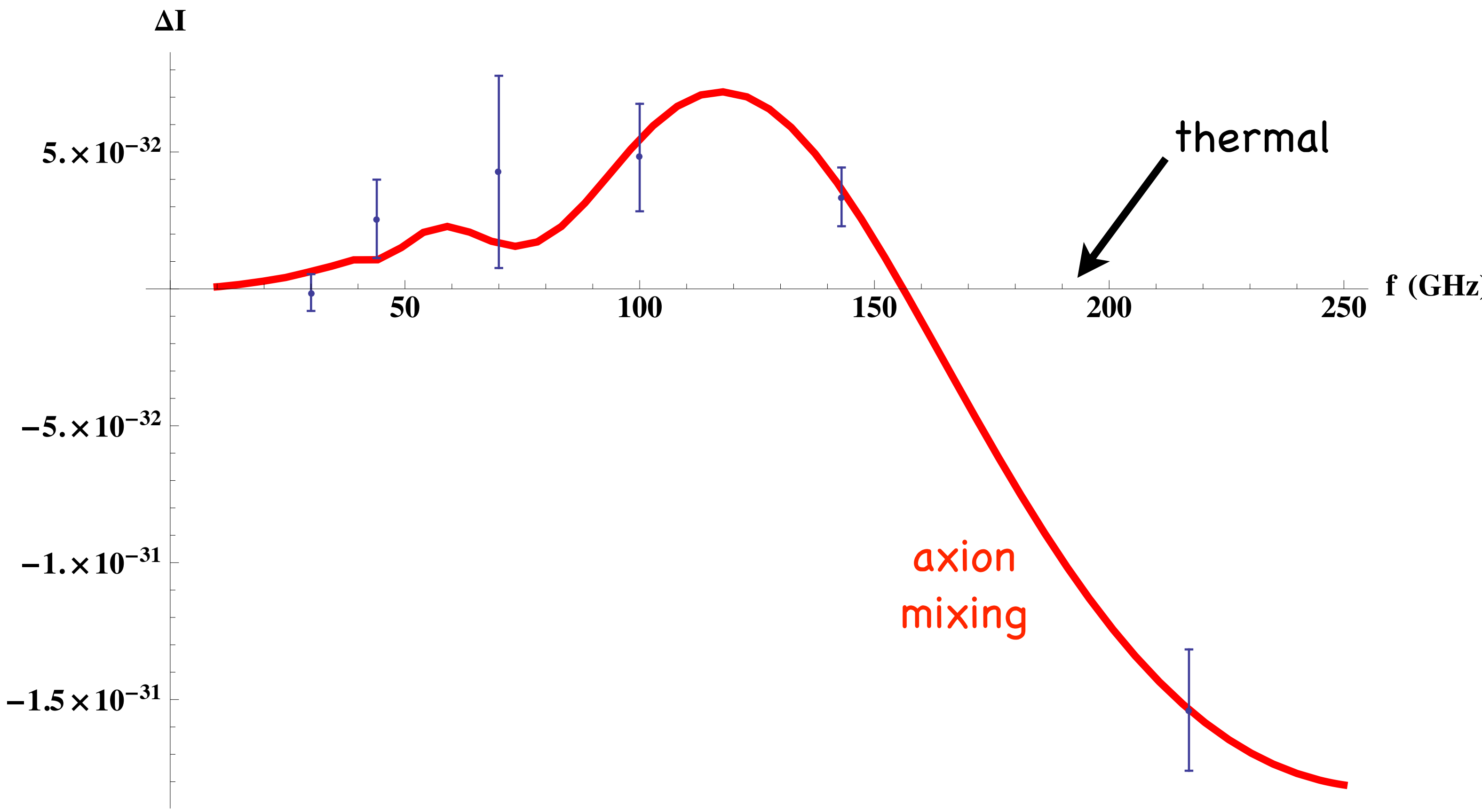
$$b = -56.4^\circ, \ell = -150.3^\circ$$

Residual intensity (after loss into axions)



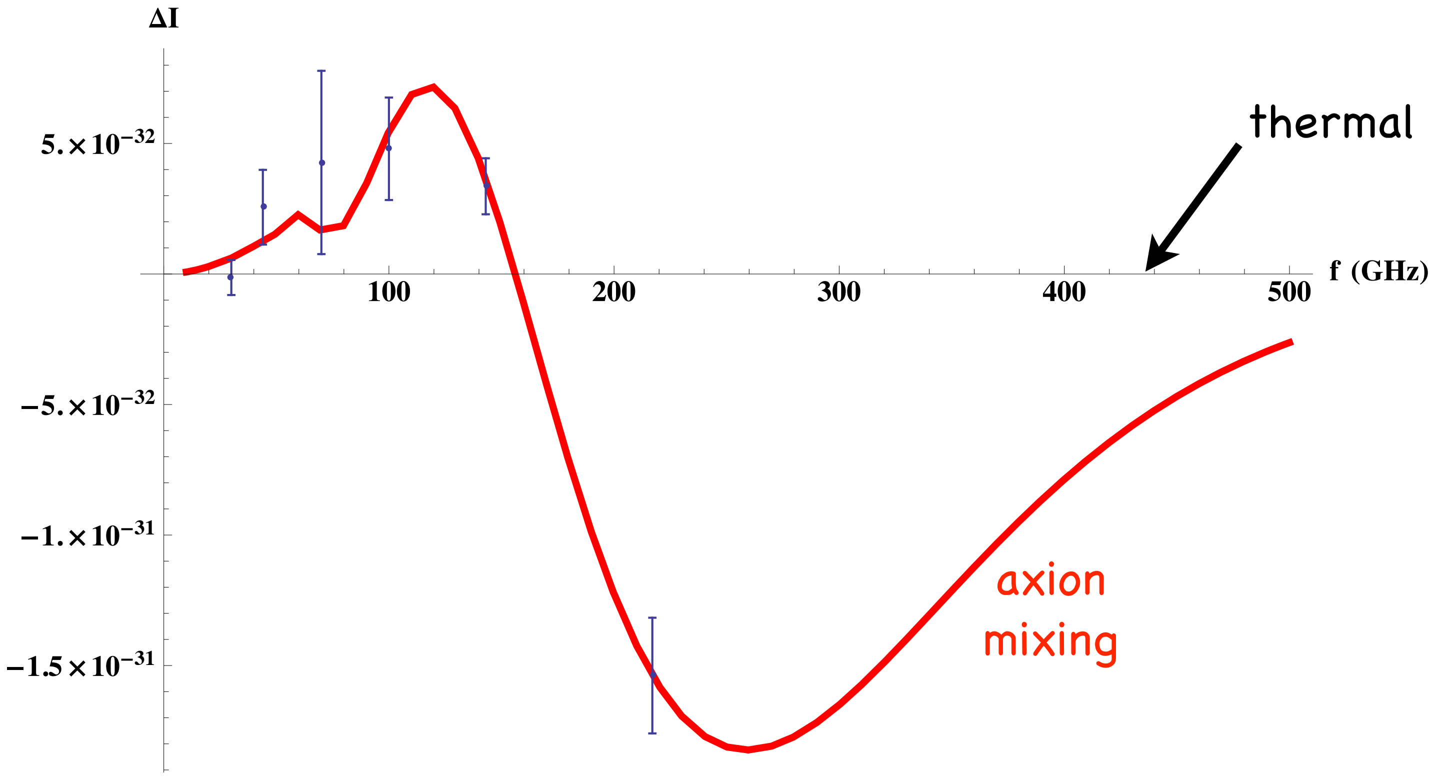
$\omega_p = 3.9 \cdot 10^{-17}\,\mathrm{eV}$ $B = 8.6 \cdot 10^{-11}\,\mathrm{G}$

All together now...



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

More to test... (in the future?)



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

Red flags (and emptor's caveats)

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

systematic survey should be done of known voids

better understanding of voids needed (longevity and evolution of underdensity)

Summary

- axions could resolve the tension between Planck and SNe by extra dimming; $w < -1$ would be an intriguing bit of weirdness, that could provide a keyhole peep into eg the axiverse.
- photon-axion mixing could also affect the CMB - not only polarization features but also the already observed temperature maps (anomalous?...). A prediction: there should be VERY EMPTY voids that could be discovered by Large Structure surveys.
- careful data cleaning is needed tho to be able to say anything precise - but while the dust effects must be removed one must take care to NOT remove any possible axion signals

Need the right cleaning tool...