Cosmology and the String Axiverse

David Marsh

Supervisor: Pedro Ferreira

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Oxford Physics™

Outline

- Motivation: strings and cosmology
- Setup: cosmological pertubations
- Results: power spectra
- Outlook

Motivation 1: The String Axiverse

Arvanitaki et al: arXiv:0905.4720v2 [hep-th]

"String theory suggests the simultaneous presence of many ultralight axions, possibly populating each decade of mass down to the Hubble scale 10^{-33}eV"

PGBs from an SSB:

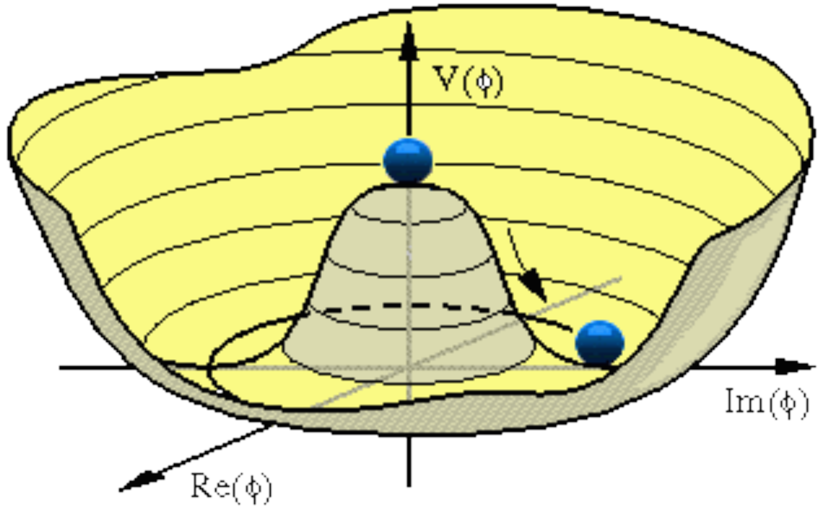
$$f_a \sim \frac{M_{pl}}{S}$$

$$f_a \sim 10^{16}\mathbf{GeV}$$

Varies little from axion to axion, c.f. the mass.

After SSB: instantons tilt the Mexican hat →

vacuum realignment production



http://www.hep.ph.ic.ac.uk/cms/physics/higgs.html

Effective 4d Lagrangian:

$$\mathcal{L} = \frac{f_a^2}{2}(\partial\theta)^2 - \Lambda^4 U(\theta)$$

Motivation 2: Cold and Fuzzy Dark Matter

Hu et al arXiv:astro-ph/0003365v2

- Ordinary CDM has too much "small scale power".

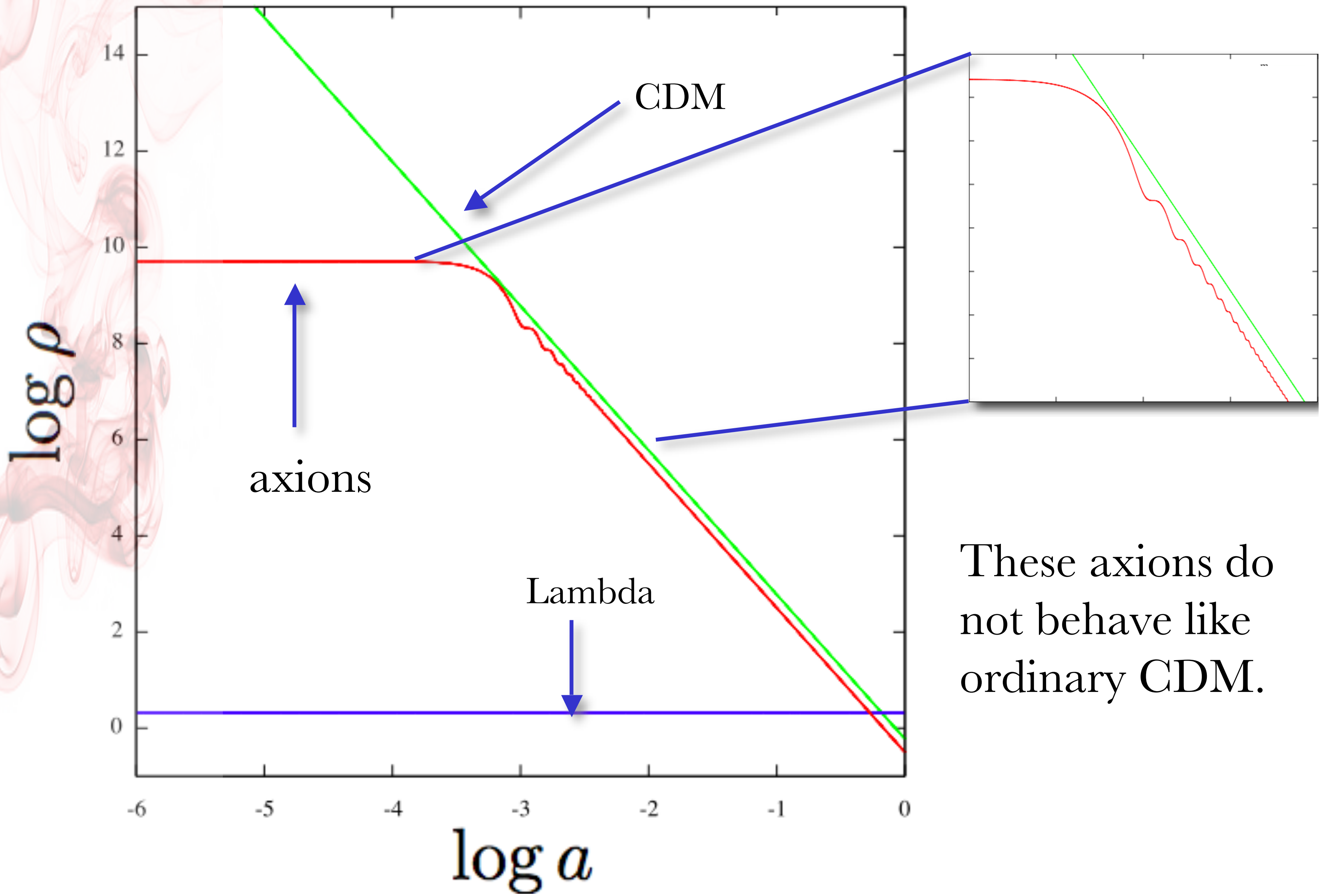
- Very light particles have large Compton wavelength manifest on astrophysical scales:

$$10^0 H_0 \lesssim m \lesssim 10^{10} H_0$$

- High occupation numbers (BEC) allow us to treat the axions as a classical field:

$$\begin{aligned} c_s^2 &= \frac{k^2}{4m^2a^2}; \quad k < 2ma \\ c_s^2 &= 1; \quad k > 2ma \end{aligned}$$

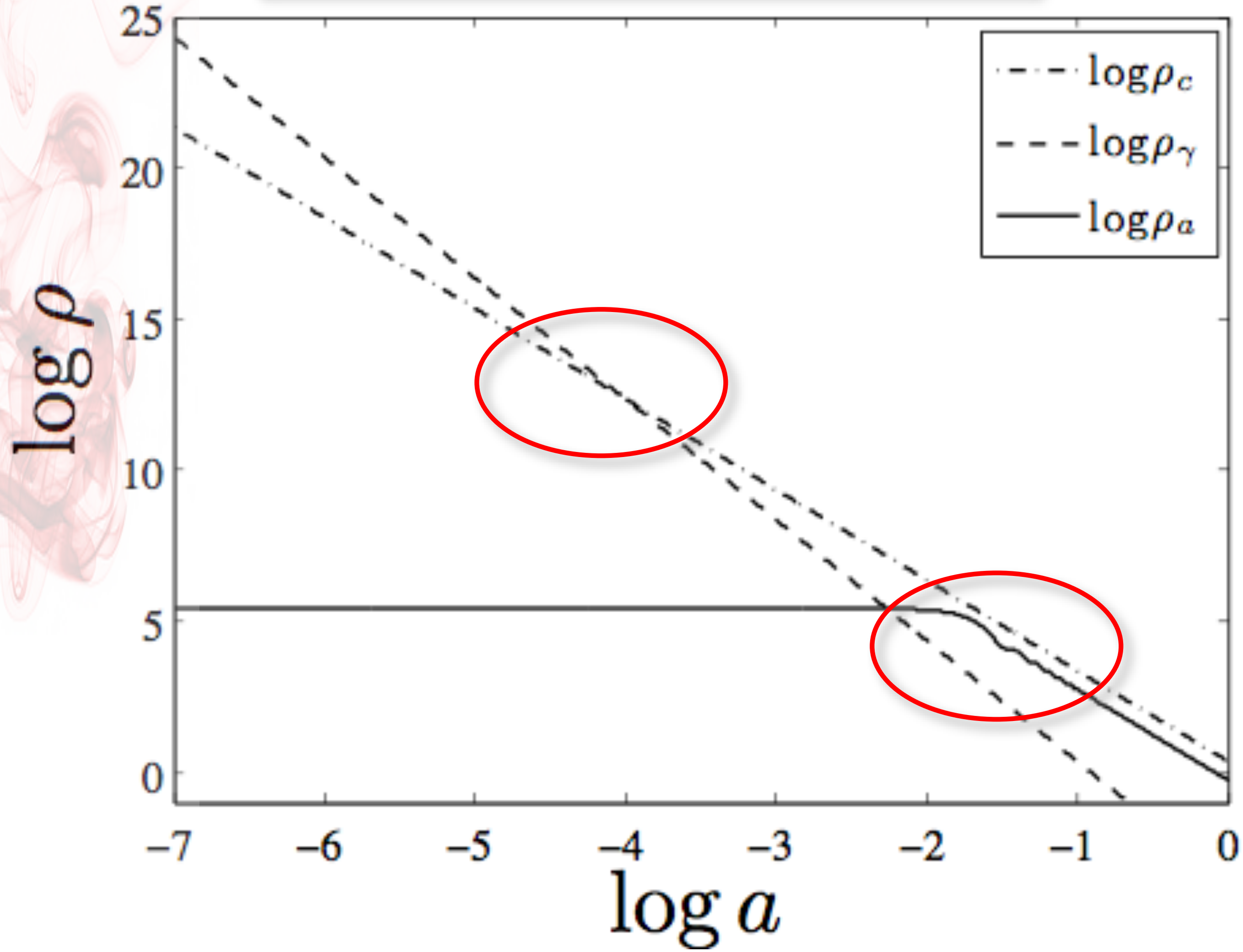
Background evolution: generalities



These axions do not behave like ordinary CDM.

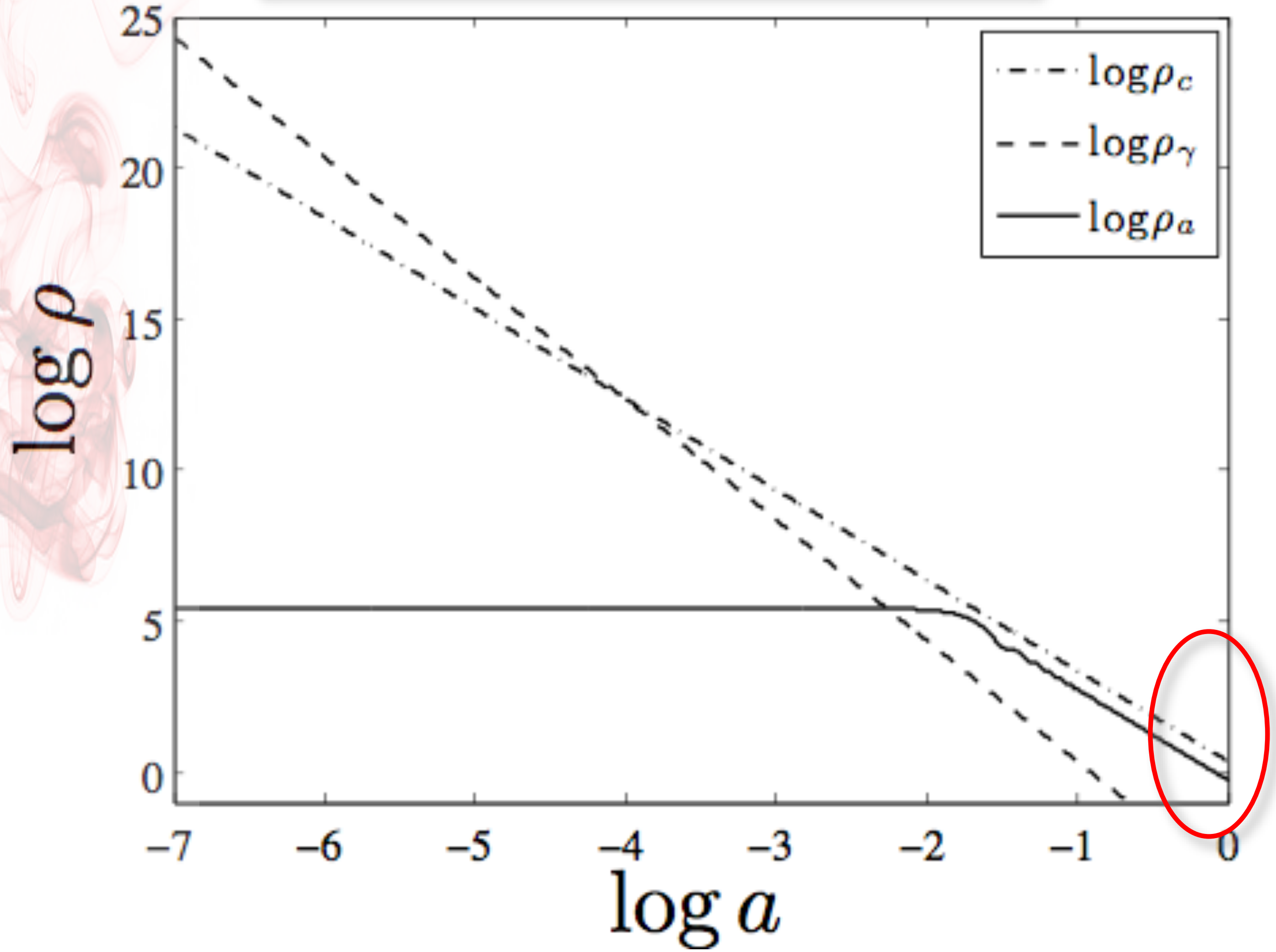
Background evolution: specifics I

$$10^{-31}\text{eV} \lesssim m \lesssim 10^{-27}\text{eV}$$



Background evolution: specifics II

$$\rho_a(t_0) \sim \rho_c(t_0)$$



Cosmological Perturbation Theory

Ma & Bertschinger arXiv:astro-ph/9506072v1

Flat Ω=1 universe, perturbed FRW metric, synchronous gauge:

$$ds^2 = a^2(\tau)(d\tau^2 + (\delta_{ij} + h_{ij})dx^i dx^j)$$

Perturb the fluid of axions, photons and dark matter; unperturbed Λ:

$$T^0{}_0 = -(\bar{\rho} + \delta\rho)$$

$$T^0{}_i = (\bar{\rho} + \bar{P})v_i$$

$$T^i{}_j = (\bar{P} + \delta P)\delta^i{}_j$$

Suppression of Power

$$P(k) = \delta^2$$

$$\delta = \frac{\delta\rho_m}{\bar{\rho}_m}$$

Modes inside the horizon have:

$$k \gtrsim Ha$$

Modes become non-relativistic when:

$$k \lesssim ma$$

Suppress structure formation in modes that cross the horizon whilst still being relativistic. This is just like free streaming neutrinos (Bond et al, 1980).

$$\delta \propto a \quad k \lesssim k_m \qquad\qquad k_m \sim m^{1/3}$$

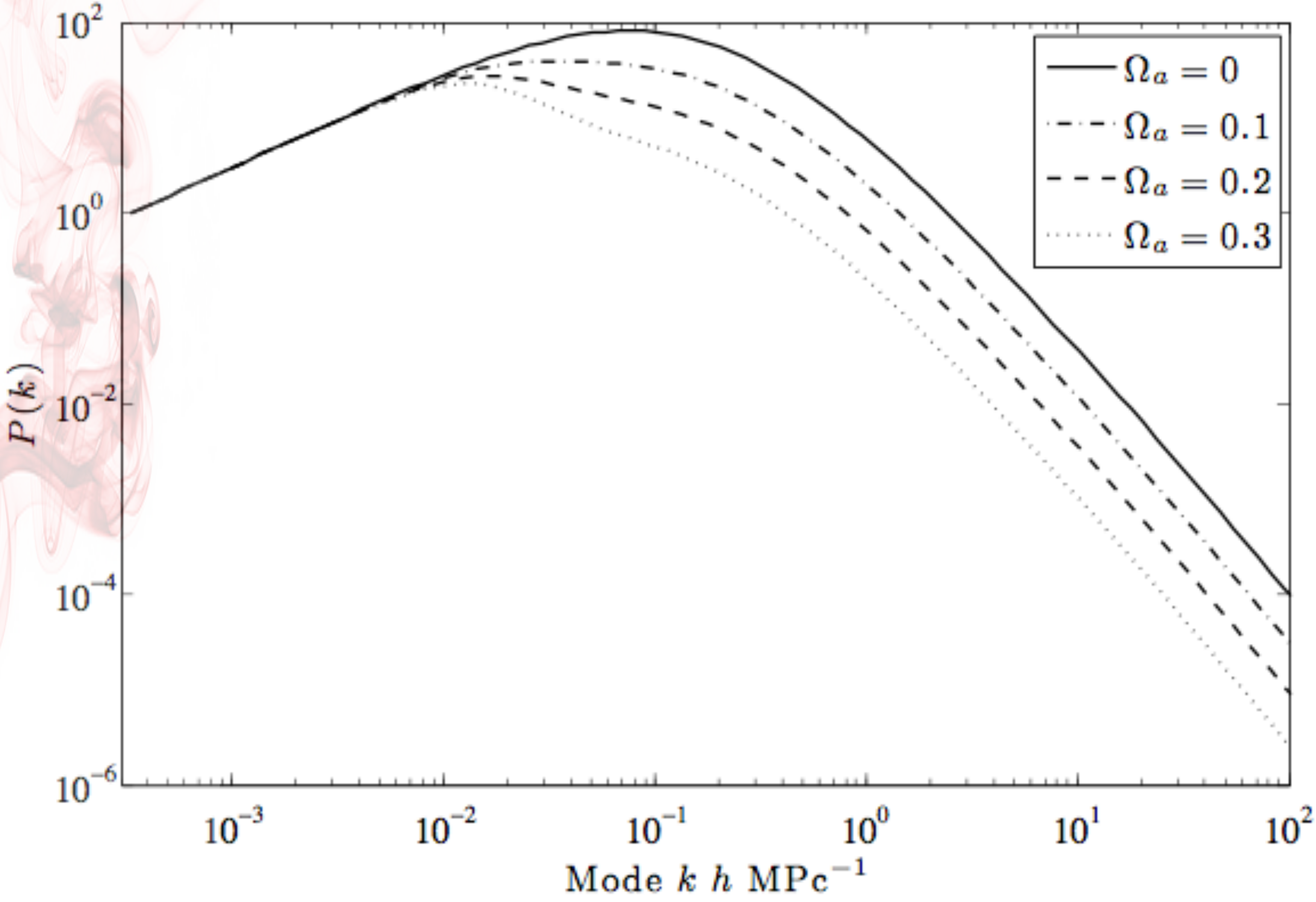
$$\delta \propto a^q \quad k \gtrsim k_m \quad q = 1/4(-1 + \sqrt{25 - 24f})$$

Power Spectra

Amendola and Babrbieri: arXiv:hep-ph/0509257v1

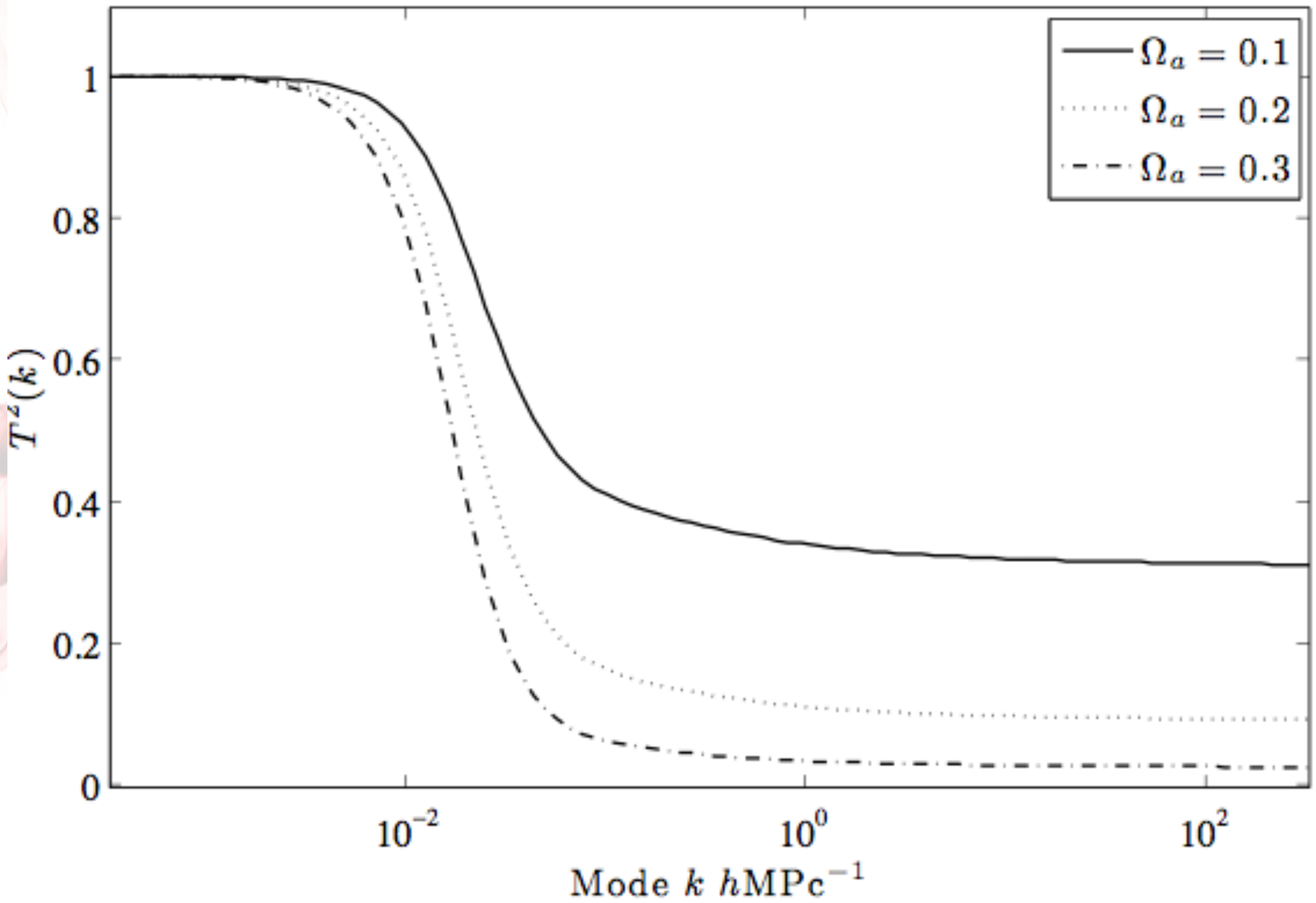
Arvanitaki et al: arXiv:hep-th/0905.4720v2

DM and P. G. Ferreira: arXiv:hep-ph/1009????



Power Spectra

$$T^2(k) = \frac{P(k)_{\mathrm{ALPs\ +CDM}}}{P(k)_{\mathrm{CDM}}}$$

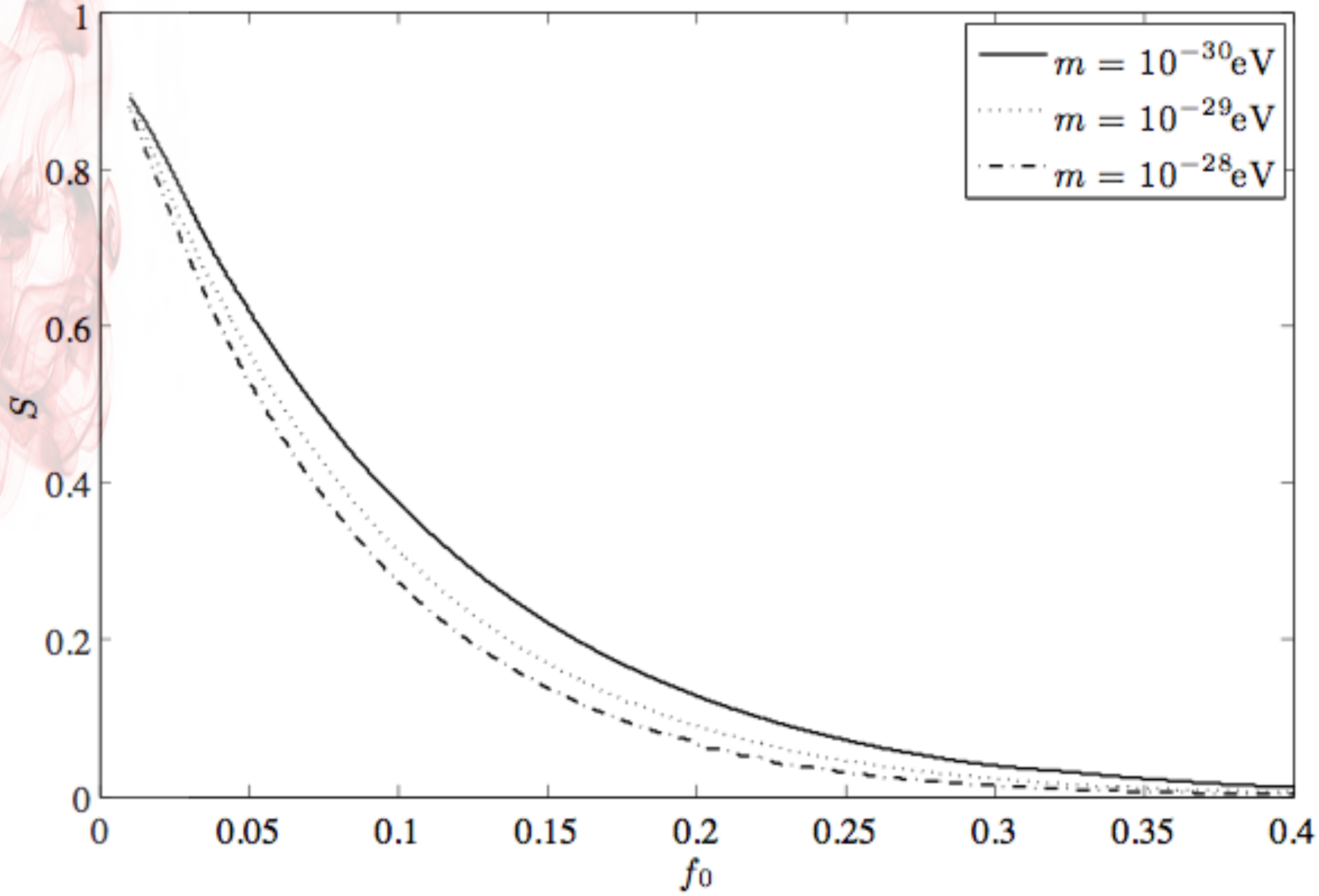


Fits and Results

$$S(z) = \left(\frac{(1+z)^{1+\beta_1}}{(1+z_{osc})^{1+\beta_2}} \right)^{2(1-q)}$$

$\beta_1 = 0$

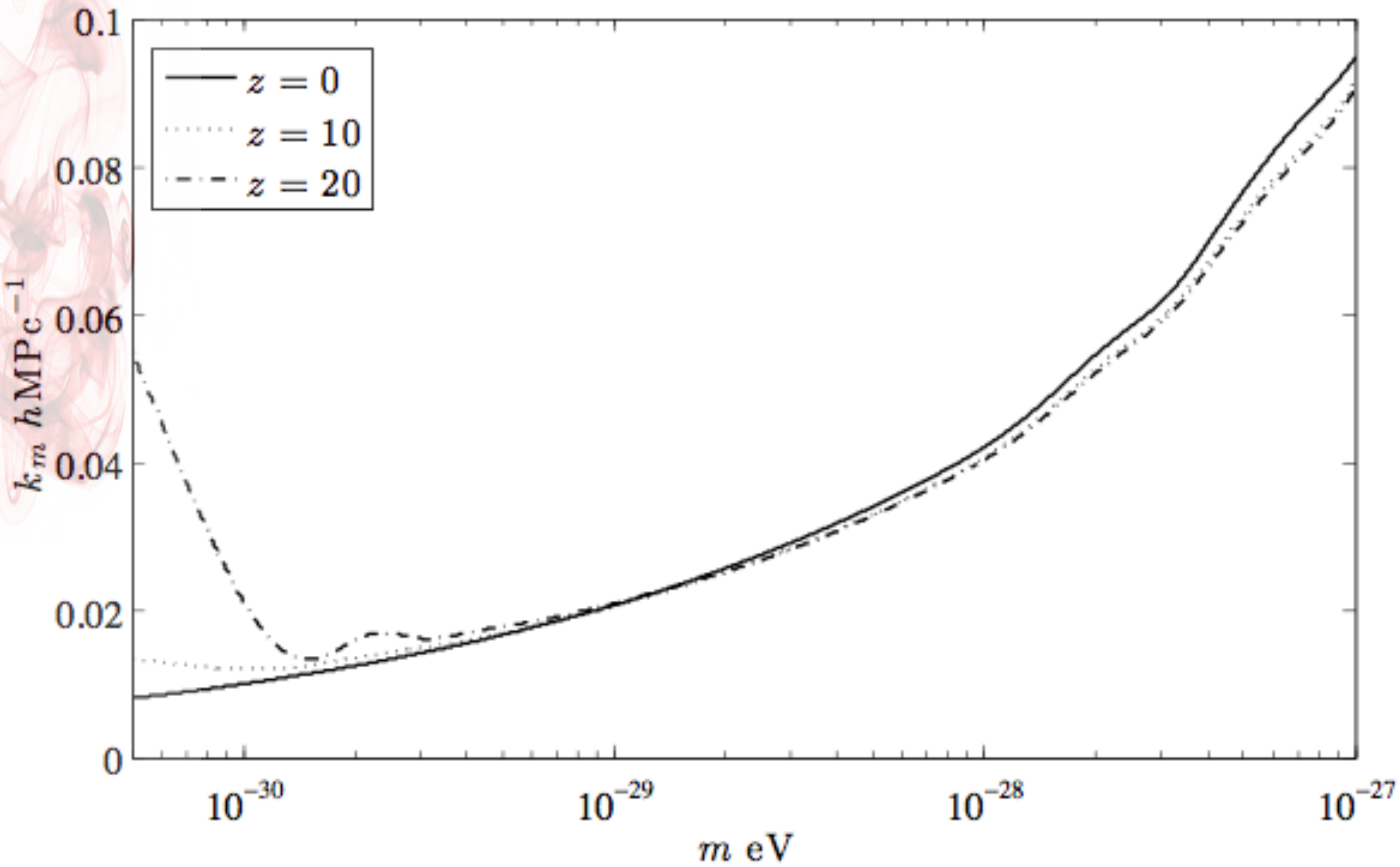
$\beta_2 = 0.6$



Fits and Results

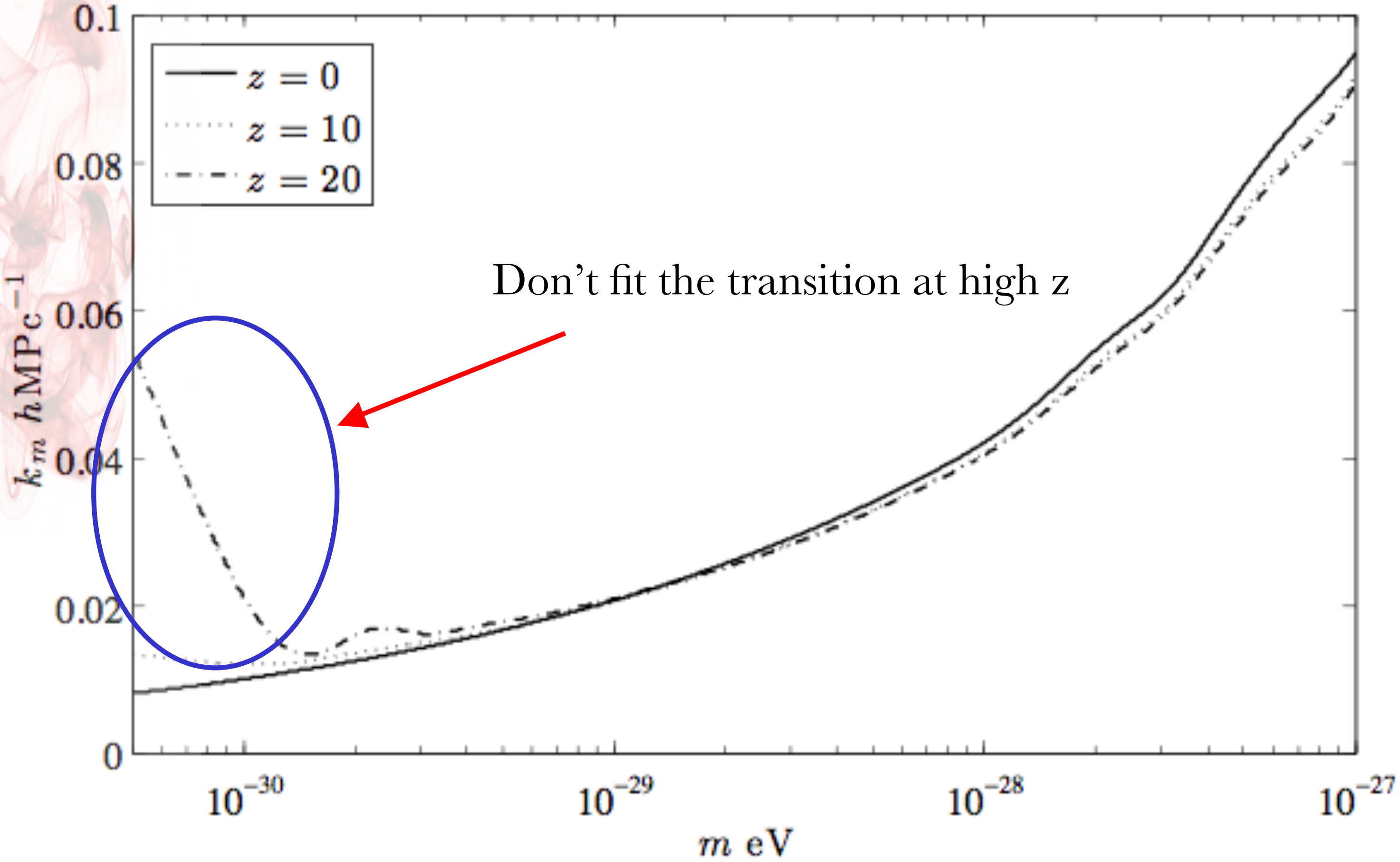
$$k_m = A\left(\frac{f_0}{\tilde{f}_0}\right)^{\alpha_1}(1+z)^{\alpha_2} m^{1/3}$$

$$\alpha_1 = -0.5$$
$$\alpha_2 = 0$$



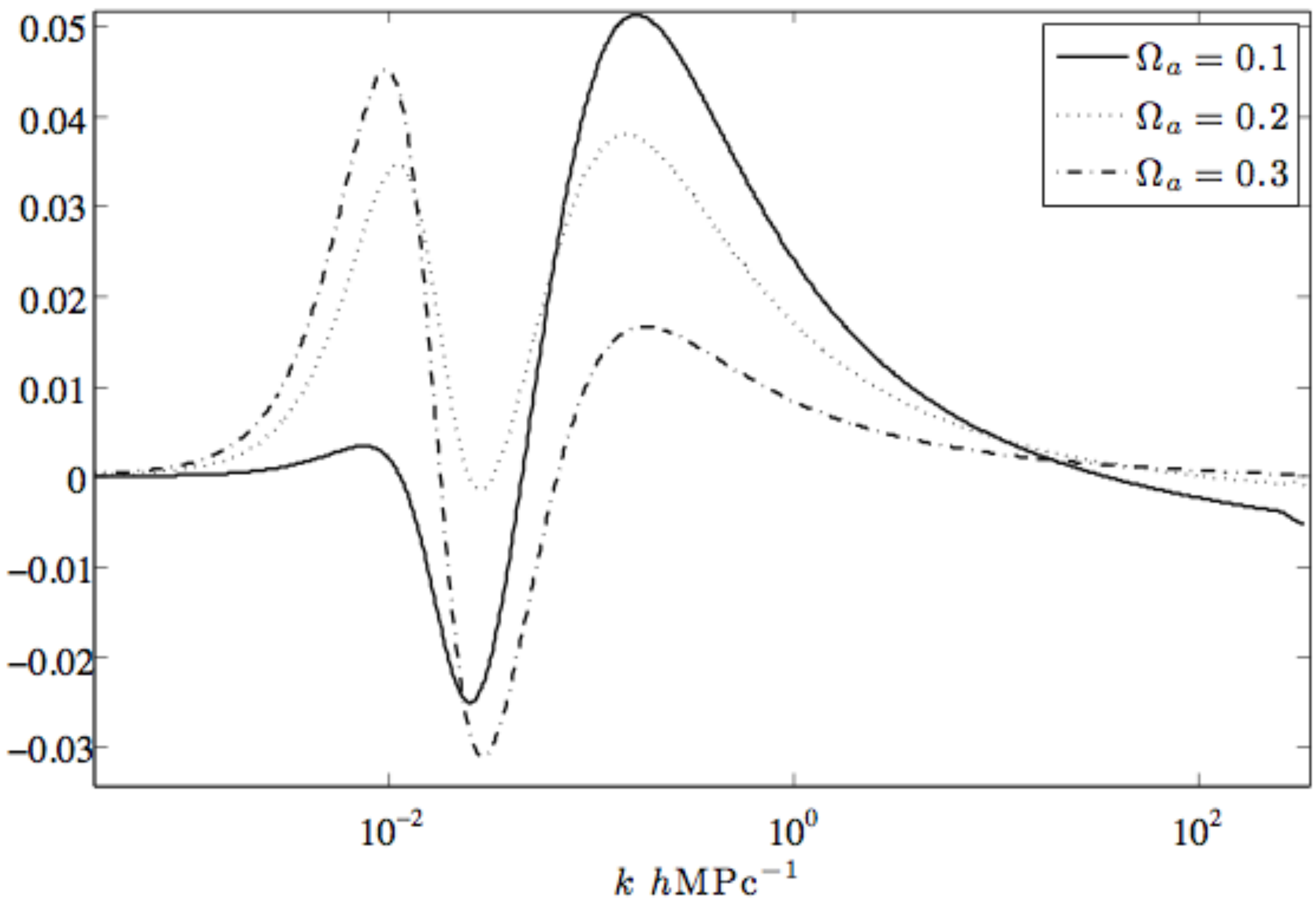
Fits and Results

$$k_m = A\left(\frac{f_0}{\tilde{f}_0}\right)^{\alpha_1}(1+z)^{\alpha_2} m^{1/3} \qquad \alpha_1 = -0.5 \quad \alpha_2 = 0$$



Fits and Results

$$T^2(k) = \frac{1 + S(k/k_m)^\gamma}{1 + (k/k_m)^\gamma} \qquad \gamma = 2$$

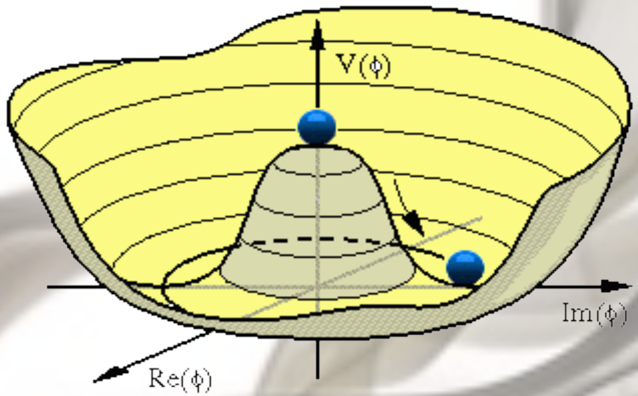


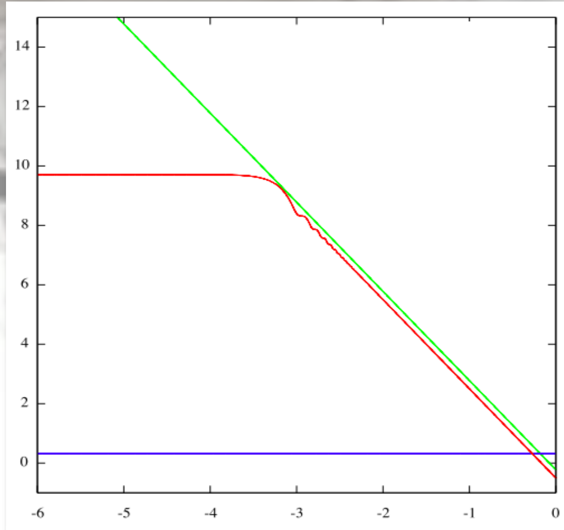
Outlook

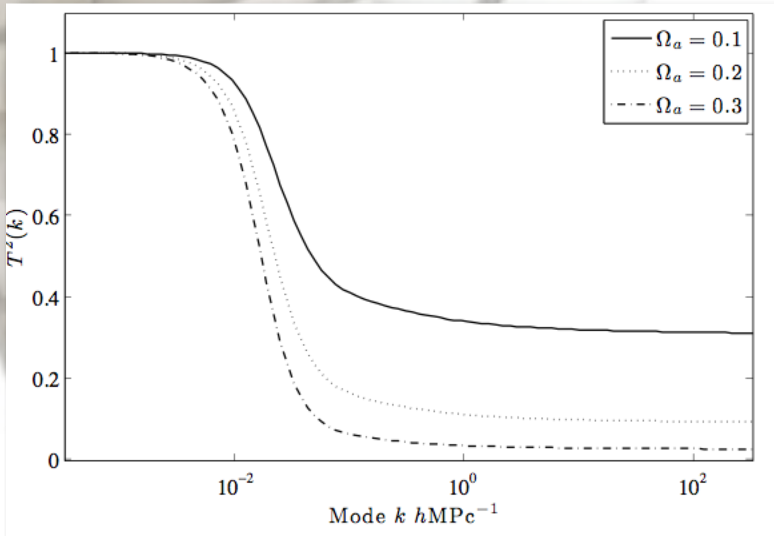
We would like to use Cosmology to constrain the parameters in this model, i.e. axion mass and fraction in axions.

- Redshift space distortions
- ISW
- Weak lensing
- …

Summary


V(ϕ)
Im(ϕ)
Re(ϕ)


14
12
10
8
6
4
2
0
-6
-5
-4
-3
-2
-1
0


$\Omega_a = 0.1$
$\Omega_a = 0.2$
$\Omega_a = 0.3$
$T^2(k)$
1
0.8
0.6
0.4
0.2
0
10^{-2}
10^{0}
10^{2}
Mode k hMPc^{-1}