Non-thermal dark matter and dark radiation from strings

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Based on:

1) Non-thermal dark matter: Allahverdi, MC, Dutta, Sinha, Phys.Rev. D88 (2013) 9, 095015
2) SUSY-breaking from strings: Aparicio, MC, Krippendorf, Maharana, Muia,Quevedo, JHEP 1411 (2014) 071
3) Non-thermal CMSSM: Aparicio, MC,Dutta, Krippendorf,Maharana, Muia,Quevedo, arXiv:1502.05672
4) Axionic dark radiation: MC, Conlon, Quevedo, Phys.Rev. D87 (2013) 4, 043520
5) Dark matter-dark radiation: Allahverdi, MC, Dutta, Sinha, JCAP 1410 (2014) 002
6) Axions and the 3.5 keV line: MC, Conlon, Marsh, Rummel, Phys.Rev. D90 (2014) 023540

Contents

- String moduli dynamics in early Universe

- Post-inflationary string cosmology:

  i) Non-thermal dark matter in CMSSM
  ii) Axionic dark radiation
  iii) Cosmic axion background
  iv) Soft X-ray excess and 3.5 keV line in galaxy clusters

Focus on phenomenology more than maths

⟶ Indirect predictions from generic features of string compactifications!

String Moduli

- Perturbative string theory lives in 10D and needs supersymmetry for consistency
- Compactified extra dimensions: $X_{10D} = M_{4D} \times Y_{6D}$ with $\mathrm{Vol}(Y_{6D}) = \mathcal{V} M_s^{-6}$
- 4D EFT below $E << M_{KK} \approx \mathrm{Vol}(Y_{6D})^{-1/6} = M_s \mathcal{V}^{1/6}$ is N=1 SUSY if Y_{6D} is Calabi-Yau
- Y_{6D} can de deformed in size and shape remaining CY

i) Maths: deformations parameterised by moduli

ii) 4D Physics: moduli are new scalar particles with only gravitational couplings to matter

- Moduli ϕ massless at classical level → flat potential $V(\phi)=0$ → $<0|\phi|0>$ unfixed!

- Two big problems:

i) Unobserved long-range forces for $m < 1$ meV
ii) Unpredictability of low-energy theory since:

1) String coupling $g_s = g_s(\phi)$
2) Gauge couplings $g_{YM} = g_{YM}(\phi)$
3) Yukawa couplings $Y_{ijk} = Y_{ijk}(\phi)$
4) Low-energy gauge group depends on ϕ

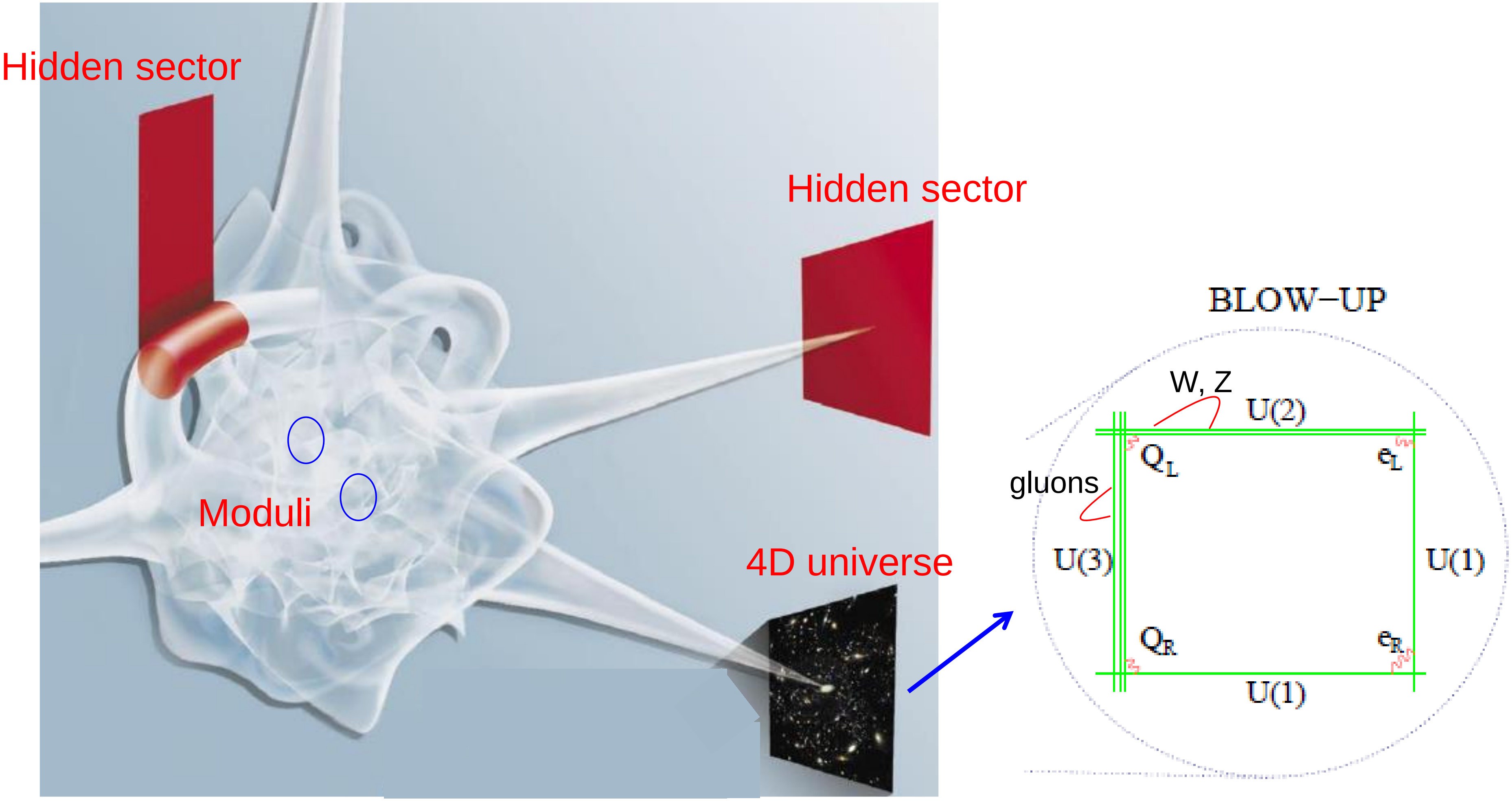
→ need to develop $V(\phi)\neq 0$ via quantum corrections → fix $<0|\phi|0>$

→ moduli get a mass $m > 1$ meV due to moduli stabilisation

Standard Model

- Ordinary particles are open strings living on branes
- Branes provide non-Abelian gauge symmetries and chiral matter
- Standard Model (or MSSM/GUT theories) localised on branes

  ⟶ model-building is a local issue while moduli stabilisation is a global issue



Cosmological Moduli Problem

- Moduli potential $V = \frac{1}{2} m^2 \phi^2 \quad \text{with} \quad m \approx m_{3/2} \approx M_{soft} \approx O(1)\,\text{TeV}$
- Extra contribution during inflation

$$V = \frac{1}{2} m^2 \phi^2 + c H_{\inf}^2 (\phi - \phi_0)^2 \approx c H_{\inf}^2 (\phi - \phi_0)^2 \quad \text{for} \quad m << H_{\inf}$$

→ ϕ displaced from $\phi = 0$ during inflation

- ϕ behaves as harmonic oscillator with friction $\ddot{\phi} + 3H\dot{\phi} + m^2\phi = 0$
- End of inflation: friction wins → ϕ frozen at $\phi = \phi_0$
- Reheating → thermal bath with temperature T and $H \approx T^2 / M_P$
- Universe expands and cools down → H decreases
- ϕ starts oscillating when H ≈ m → ϕ stores energy $\rho_\phi \approx m^2 \phi_0^2 \approx H^2 M_p^2 \approx T^4 \approx \rho_{\rm rad}$
- ϕ redshifts as $\rho_\phi \propto T^3$ while thermal bath redshifts $\rho_{\rm rad} \propto T^4$

→ ϕ dominates energy density of the Universe → dilutes everything when it decays!

- ϕ decays when $H \approx \Gamma \approx m^3 / M_P^2$ → Reheating temperature $T_{\rm rh} \approx \sqrt{\Gamma M_P} \approx m\sqrt{m / M_P}$
- Need $T_{rh} > T_{BBN} \approx$ 3 MeV → m > 50 TeV

Non-standard cosmology from strings

Focus on $m_\phi > 50$ TeV $\Rightarrow$ ϕ decay dilutes any previous relic [Moroi,Randall]:

- Axionic DM diluted if $T_{\rm rh} < \Lambda_{\rm QCD} \simeq 200$ MeV [Fox,Pierce,Thomas]
  $\Rightarrow$ if $T_{\rm rh} \gtrsim T_{\rm BBN}$ can have $f_a \sim 10^{14}$ GeV without tuning
- Standard thermal LSP DM diluted if $T_{\rm rh} < T_{\rm f} \simeq m_{\rm DM}/20 \sim \mathcal{O}(10)$ GeV
- Baryon asymmetry diluted if produced before ϕ decay
  $\Rightarrow$ good for Affleck-Dine baryogenesis which can be too efficient [Kane,Shao,Watson,Yu]

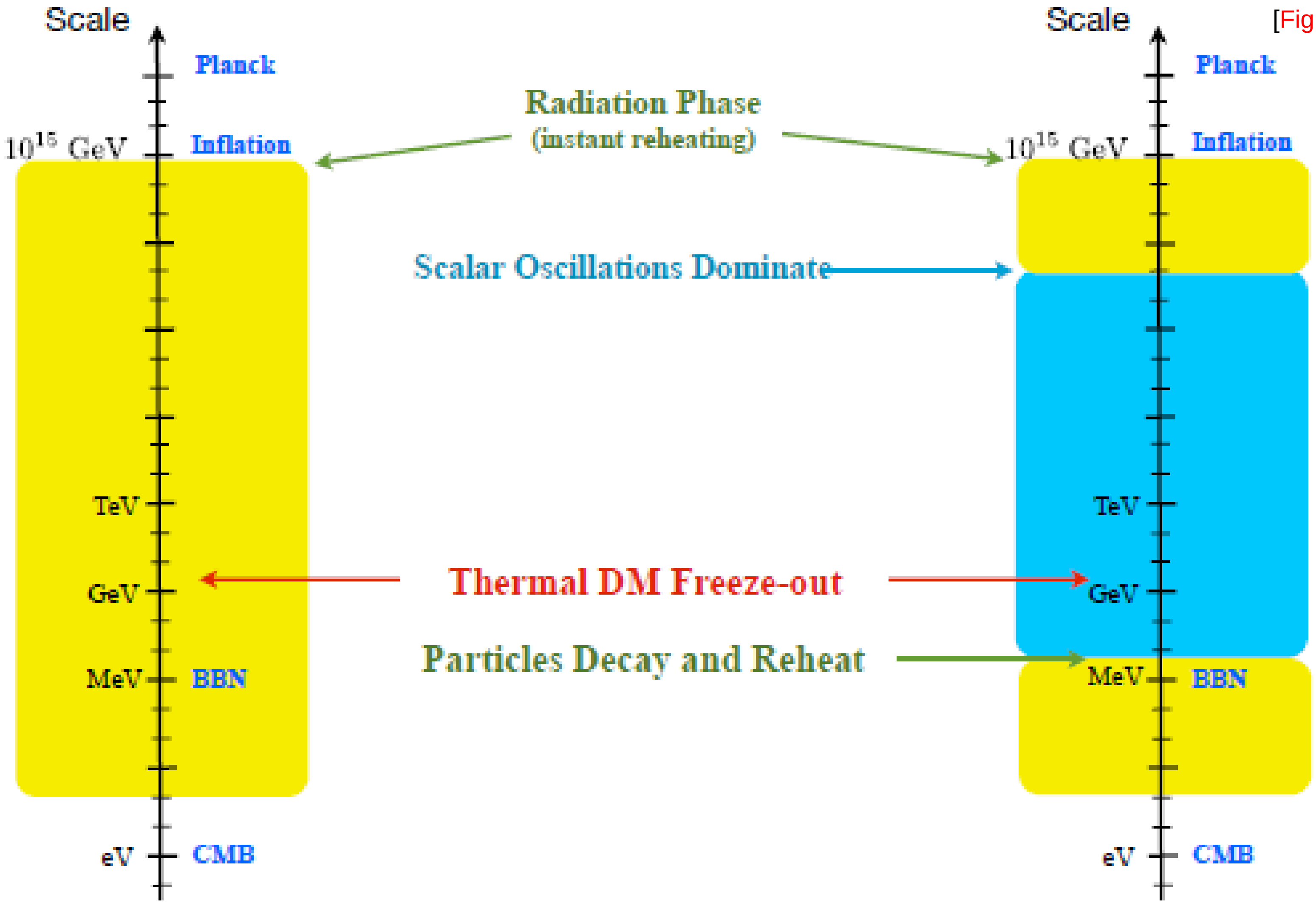
Decay products:

- Non-thermal LSP DM from ϕ decay [Acharya et al][Allahverdi,MC,Dutta,Sinha]
  - Annihilation scenario for high $T_{\rm rh}$ (close to $T_{\rm f}$)
    1. abundant initial production of DM
    2. subsequent efficient annihilation $\Rightarrow$ Wino/Higgsino-like DM
  - Branching scenario for low $T_{\rm rh}$ (close to $T_{\rm BBN}$)
    1. smaller initial production of DM
    2. subsequent inefficient annihilation $\Rightarrow$ Bino-like DM
- Baryon asymmetry from ϕ decay $\Rightarrow$ Co-genesis of DM and baryogenesis due to new $O({\rm TeV})$ coulored particles with B- and CP-violating couplings [Allahverdi,Dutta,Sinha]

Thermal vs Non-thermal cosmology

Thermal History

Alternative History



Radiation Phase
(instant reheating)

Scalar Oscillations Dominate

Thermal DM Freeze-out

Particles Decay and Reheat

[Fig. from S. Watson]

Non-thermal dark matter from strings

Q: What is generic value of T_{rh} from strings?

Generically in string compactifications :

i) SUSY breaking generates m_ϕ

ii) Moduli mediate SUSY breaking to MSSM via gravitational interactions ⟶ $M_{soft} = k\, m_\phi$

iii) Since $m_\phi > 50$ TeV, can get TeV-scale SUSY only for $k \ll 1$

iv) $k = O(10^{-2})$ from loop suppression or $k = O(10^{-3} – 10^{-4})$ from sequestering

v) For $M_{soft} = O(1)$ TeV, reheating temperature is

$$T_{\mathrm{rh}} \approx m\sqrt{m/M_P} \approx k^{-3/2} M_{\mathrm{soft}}\sqrt{M_{\mathrm{soft}}/M_P} \approx k^{-3/2} O(10^{-2})\,\mathrm{MeV}$$

$$\text{for } 10^{-4} \le k \le 10^{-2} \longrightarrow 10\,\mathrm{MeV} \le T_{\mathrm{rh}} \le 10\,\mathrm{GeV}$$

Below freeze-out temperature for LSP masses between O(100) GeV and O(1) TeV!

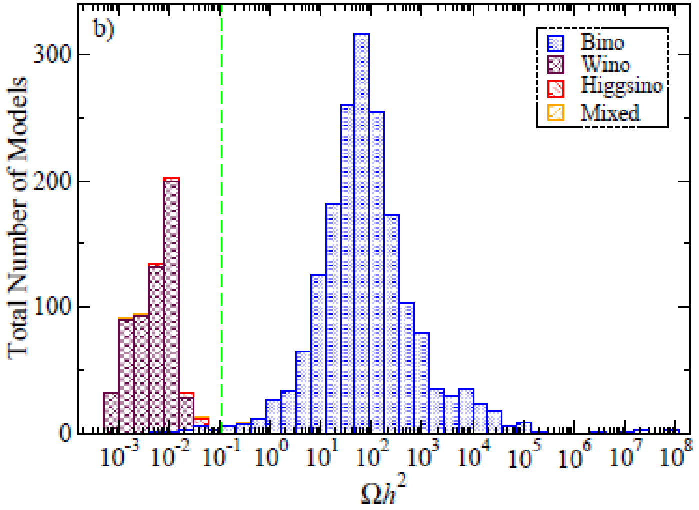
$$10\,\mathrm{GeV} \le T_{\mathrm{f}} \approx m_{\mathrm{DM}}/20 \le 100\,\mathrm{GeV}$$

⟶ Non-thermal dark matter from strings!

Non-thermal dark matter production

- ϕ decay dilutes thermal DM

→ larger parameter space



[Baer et al]

- Non-thermal DM from ϕ decay:

$$\frac{n_{\mathrm{DM}}}{s} = \left(\frac{n_{\mathrm{DM}}}{s}\right)_{\mathrm{obs}} \frac{\langle\sigma_{\mathrm{ann}}v\rangle_{\mathrm{f}}^{\mathrm{th}}}{\langle\sigma_{\mathrm{ann}}v\rangle_{\mathrm{f}}} \left(\frac{T_{\mathrm{f}}}{T_{\mathrm{rh}}}\right)$$

where $\left(\frac{n_{\mathrm{DM}}}{s}\right)_{\mathrm{obs}} \approx 5\cdot 10^{-10}\left(\frac{1\,\mathrm{GeV}}{m_{\mathrm{DM}}}\right)$ and $\langle\sigma_{\mathrm{ann}}v\rangle_{\mathrm{f}}^{\mathrm{th}} \approx 3\cdot 10^{-26} cm^3 s^{-1}$

i) Need $\langle\sigma_{\mathrm{ann}}v\rangle_{\mathrm{f}} = \langle\sigma_{\mathrm{ann}}v\rangle_{\mathrm{f}}^{\mathrm{th}} (T_{\mathrm{f}} / T_{\mathrm{rh}})$

ii) Since $T_{\mathrm{rh}} < T_{\mathrm{f}}$ → $\langle\sigma_{\mathrm{ann}}v\rangle_{\mathrm{f}} > \langle\sigma_{\mathrm{ann}}v\rangle_{\mathrm{f}}^{\mathrm{th}}$

→ Wino/Higgsino-like LSP DM

iii) Bino-like LSP: $\langle\sigma_{\mathrm{ann}}v\rangle_{\mathrm{f}} < \langle\sigma_{\mathrm{ann}}v\rangle_{\mathrm{f}}^{\mathrm{th}}$ → DM overproduction

Non-thermal CMSSM

- CMSSM with non-thermal LSP dark matter [See Aparicio’s talk]
- Impose: [Aparicio, MC, Dutta, Krippendorf, Maharana, Muia, Quevedo]

i) radiative EW symmetry breaking + Higgs mass around 125 GeV

ii) no dark matter overproduction

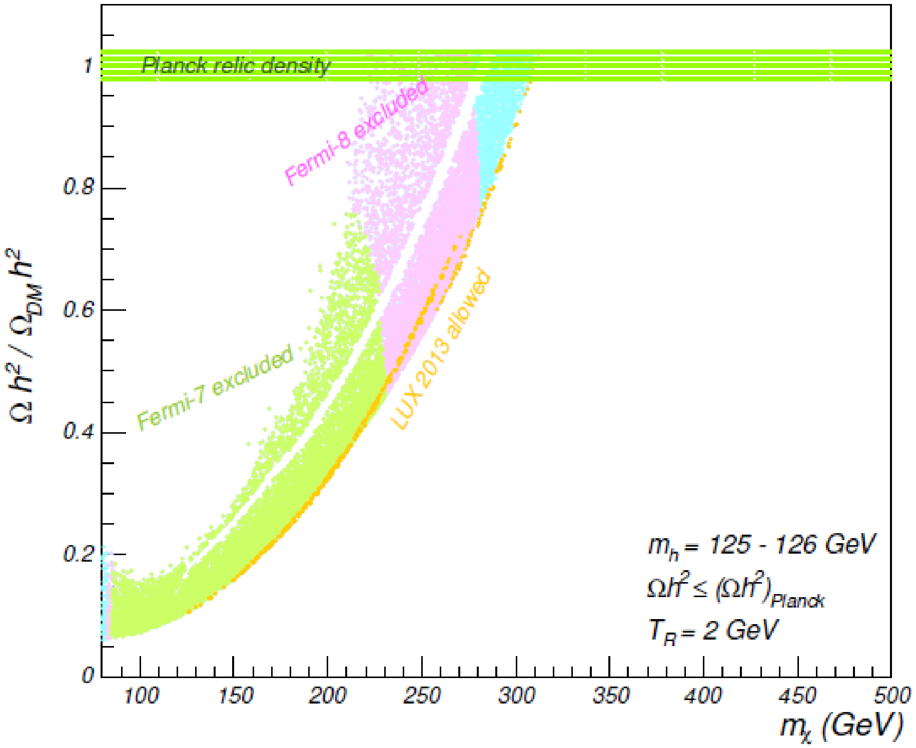
iii) bounds from colliders (LHC), CMB (Planck), direct (LUX) and indirect (Fermi) DM searches

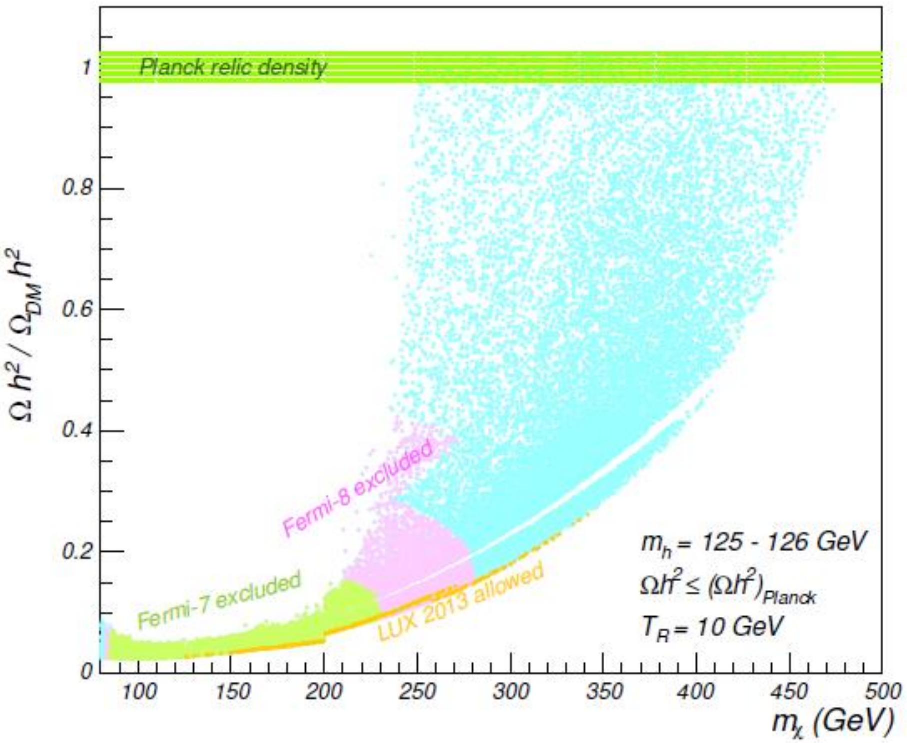
  a) observed DM content saturated for $T_R = 2$ GeV and 300 GeV Higgsino-like LSP

  b) Natural SUSY spectrum: $m_{\tilde{g}} \simeq 2 \div 3\, TeV$, $m_{\tilde{t}} \simeq 4 \div 5\, TeV$, almost degenerate $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^+$

  c) LHC signature: neutralino production via VBF [Dutta, Gurrola, Kamon, John, Sinha, Sheldon]

  d) realised in string models with sequestered SUSY breaking





Sequestered string models

Type IIB LVS models: moduli masses and couplings can be computed explicitly
⇒ can study cosmological history of the universe [MC, Conlon, Quevedo]

- Lightest modulus mass:

$$m_\phi \simeq m_{3/2}\sqrt{\epsilon} \ll m_{3/2} \qquad \text{where} \qquad \epsilon \equiv \frac{m_{3/2}}{M_P} \simeq \frac{W_0}{\mathcal{V}} \simeq e^{-\frac{2\pi}{N g_s}} \ll 1$$

  1. NO gravitino problem
  2. CMP if $m_{3/2} \simeq \mathcal{O}(M_{\rm soft}) \simeq \mathcal{O}(1)$ TeV ⇒ $m_\phi \simeq \mathcal{O}(1)$ MeV

- Way-out: focus on sequestered models [Blumenhagen et al]:[Aparicio,MC,Krippendorf,Maharana,Muia,Quevedo]
  1. Visible sector in the singular regime (fractional D3-branes at singularities)

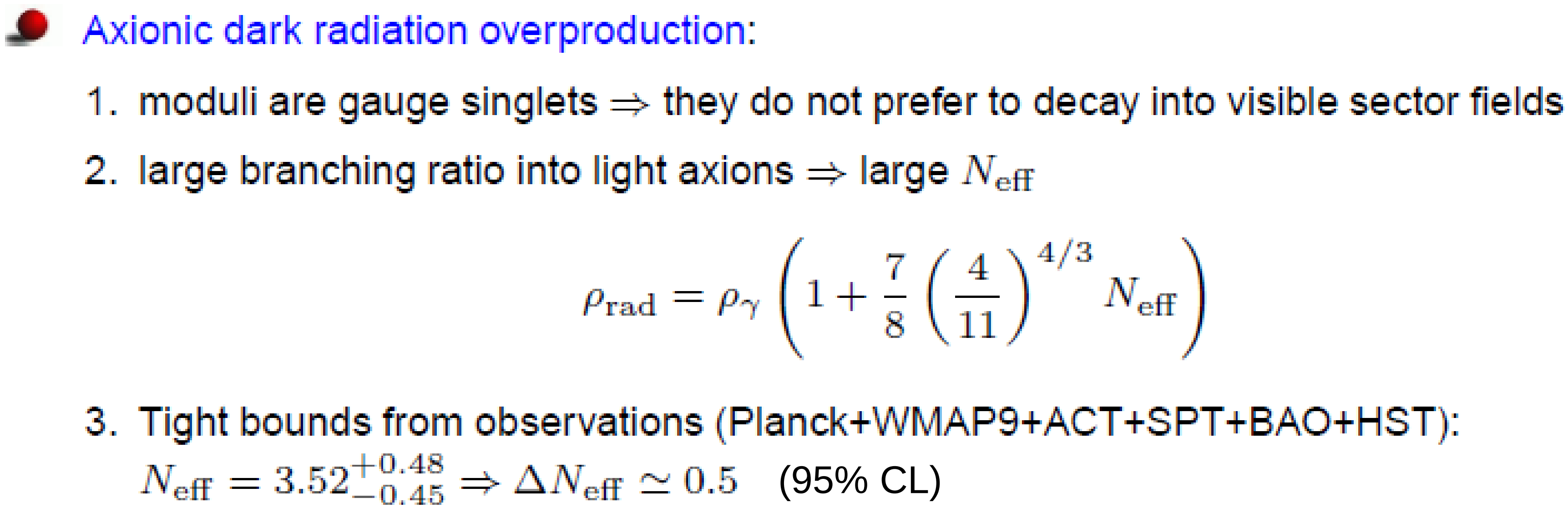
$$M_{\rm soft} \simeq m_{3/2}\epsilon \ll m_\phi \simeq m_{3/2}\sqrt{\epsilon} \ll m_{3/2}$$

  2. NO CMP for $\epsilon \simeq 10^{-7}$
     $\Rightarrow M_{\rm soft} \simeq \mathcal{O}(1)\,{\rm TeV} \ll m_\phi \simeq \mathcal{O}(5 \cdot 10^6)\,{\rm GeV} \ll m_{3/2} \simeq \mathcal{O}(10^{11})\,{\rm GeV}$
  3. High string scale: $M_s \simeq \mathcal{O}(10^{16})$ GeV
     ⇒ good for GUTs and inflation

[MC,Burgess,Quevedo]

A challenge for moduli decays

GENERIC feature of string compactifications: presence of light axionic degrees of freedom UNAVOIDABLE in most string models [Allahverdi, MC, Dutta,Sinha]



- Axionic dark radiation overproduction:
  1. moduli are gauge singlets ⇒ they do not prefer to decay into visible sector fields
  2. large branching ratio into light axions ⇒ large $N_{\rm eff}$

$$\rho_{\rm rad} = \rho_\gamma \left(1 + \frac{7}{8}\left(\frac{4}{11}\right)^{4/3} N_{\rm eff}\right)$$

  3. Tight bounds from observations (Planck+WMAP9+ACT+SPT+BAO+HST):

$N_{\rm eff} = 3.52^{+0.48}_{-0.45} \Rightarrow \Delta N_{\rm eff} \simeq 0.5$ (95% CL)

GENERIC PREDICTION of string compactifications: axionic dark radiation production from ϕ decay is UNAVOIDABLE in most string models!

Planck 2015: $N_{\rm eff} = 3.13 \pm 0.32$ (68% CL)
reduced evidence for dark radiation BUT……

Dark radiation and Planck 2015 data

- Positive correlation between N_{eff} and H_0
- Planck indirect value of H_0 :

$H_0 = 67.3 \pm 1.0$ km s^{-1} Mpc^{-1} (68% CL)

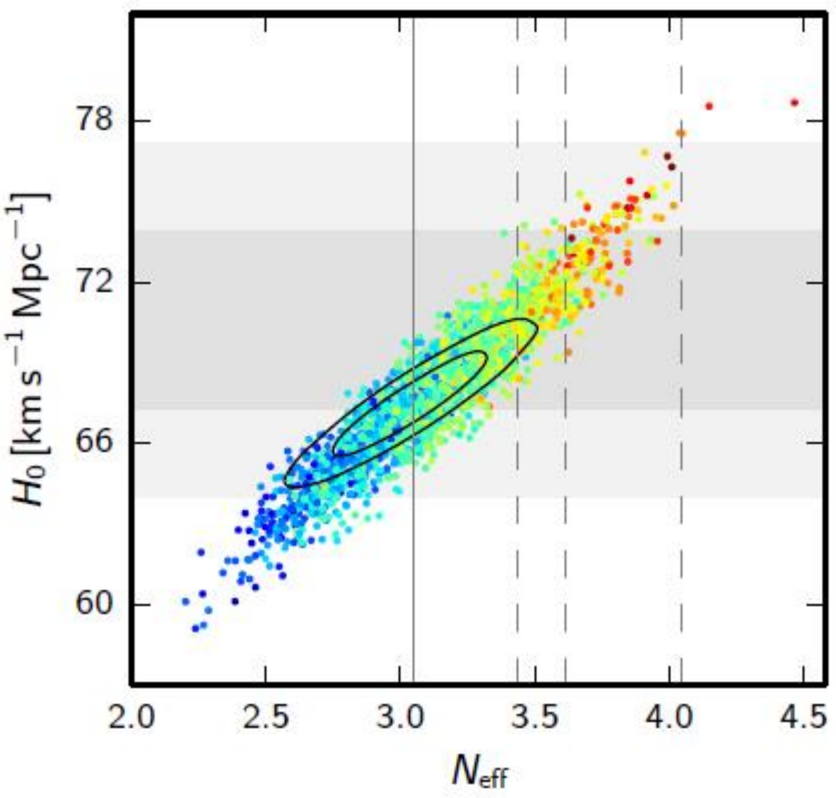
- HST direct value of H_0 :

$H_0 = 73.8 \pm 2.4$ km s^{-1} Mpc^{-1} (68% CL)

2.4 σ tension ➡ need new physics: $\Delta N_{eff} > 0$

BUT HST data reanalysed by Planck:

$H_0 = 70.6 \pm 3.3$ km s^{-1} Mpc^{-1} (68% CL)



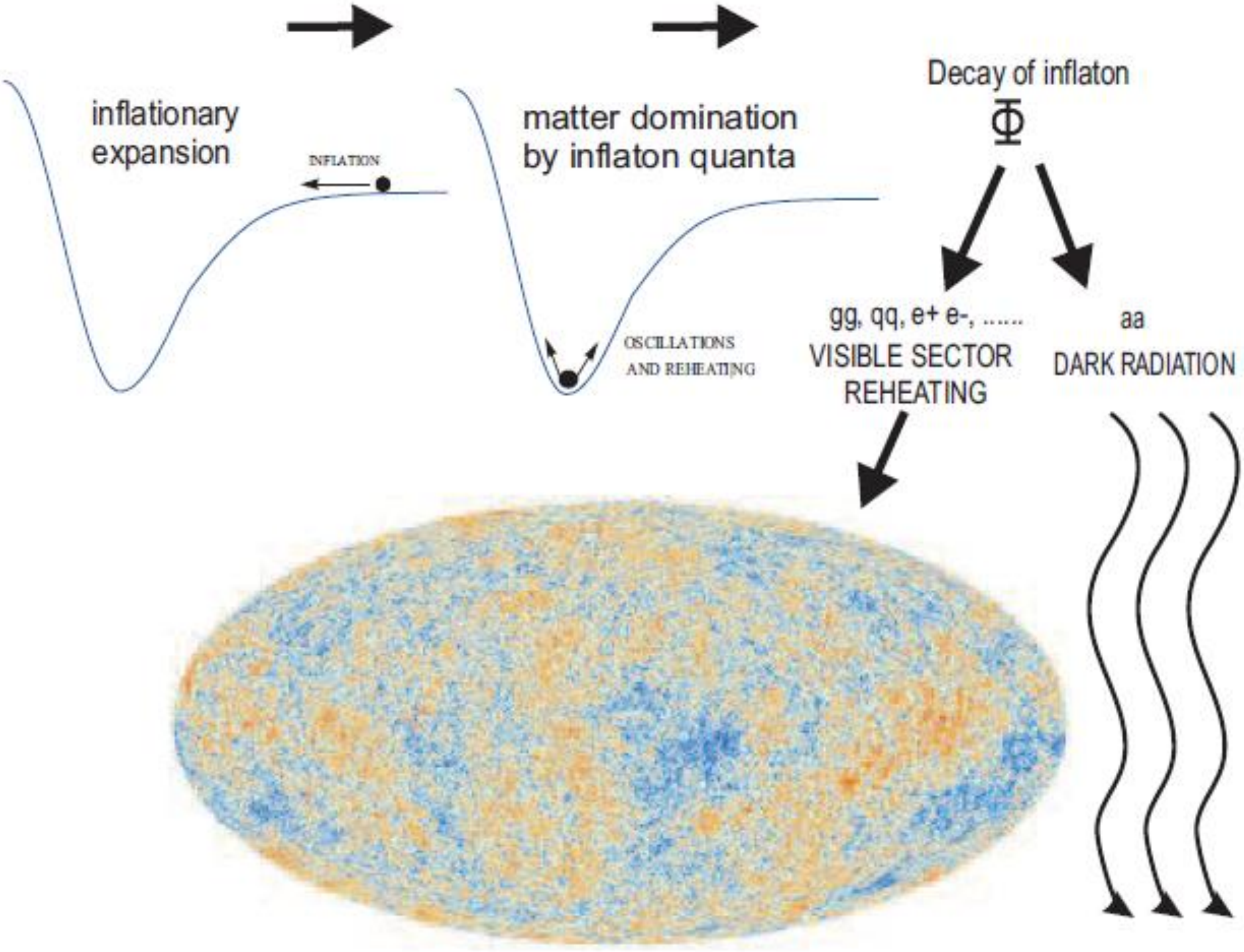
only 1σ away from Planck value ➡ no need new physics: $\Delta N_{eff} \to 0$

BUT $\Delta N_{eff} > 0$ still allowed by Planck! (HST value of H_0 still controversial)

E.g.: for $\Delta N_{eff} = 0.39$ Planck data give (68% CL):
$H_0 = 70.6 \pm 1.0$ km s^{-1} Mpc^{-1} ➡ better agreement with HST!
$n_s \simeq 0.983 \pm 0.006$ ➡ larger central value!

➡ Need reliable direct measurements of H_0 !

Dark radiation production

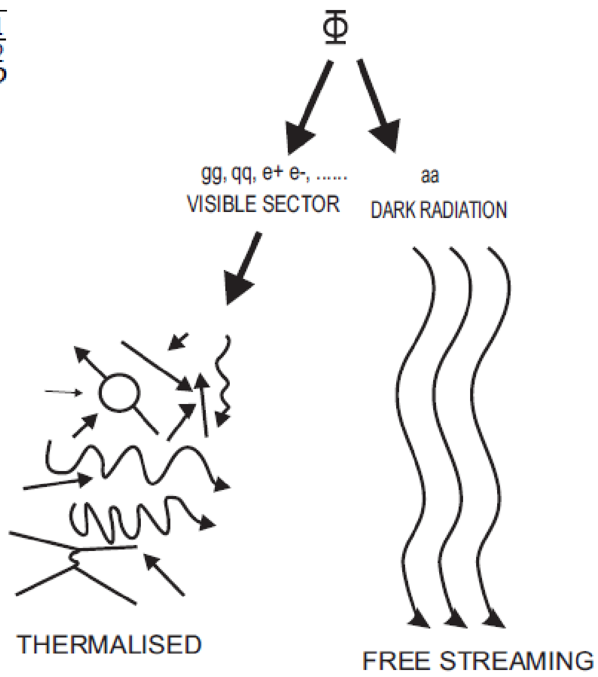


Free streaming

Cosmological evolution of dark radiation

$\Phi \to gg, \ldots$: Decays thermalise $T_\gamma \sim T_{reheat} \sim \frac{m_\Phi^{3/2}}{M_P^{\frac{1}{2}}}$

$\Phi \to aa$: Axions never thermalise $E_a = \frac{m_\Phi}{2}$



Thermal bath cools into the CMB while axions never thermalise and freestream to the present day:

Ratio of axion energy to photon temperature is

$$\frac{E_a}{T_\gamma} \sim \left(\frac{M_P}{m_\Phi}\right)^{\frac{1}{2}} \sim 10^6 \left(\frac{10^6\,\mathrm{GeV}}{m_\Phi}\right)^{\frac{1}{2}}$$

Retained through cosmic history!

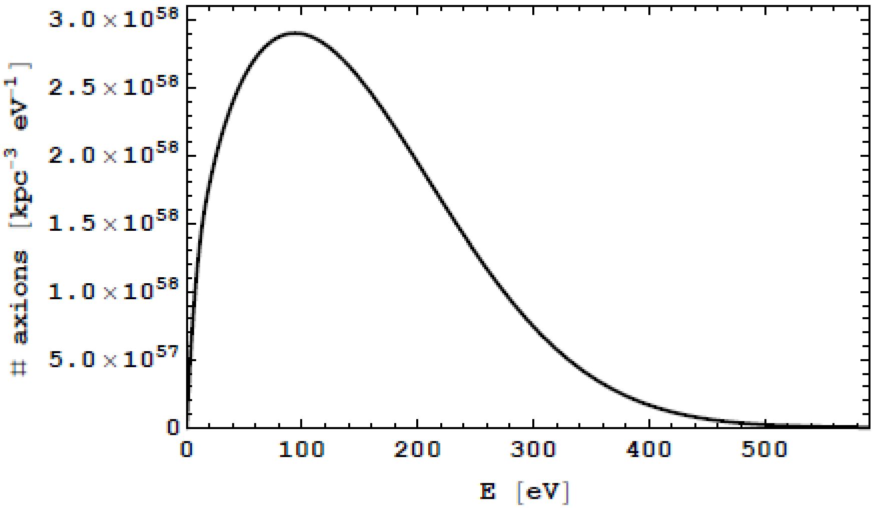
No absolute prediction, but a lightest modulus mass $m \sim 10^6\,\mathrm{GeV}$ arises in many string models - often correlated with SUSY approaches to the weak hierarchy problem.

- KKLT hep-th/0503216 Choi et al
- Sequestered LVS 0906.3297 Blumenhagen et al + 1409. 1931 Aparicio, MC, Krippendorf, Maharana, Muia, Quevedo
- 'G2 MSSM' 0804.0863 Acharya et al

Cosmic Axion Background

PREDICTION: Cosmic Axion Background

$$E_a \sim 200\text{eV} \left(\frac{10^6 \text{ GeV}}{m_\Phi} \right)^{\frac{1}{2}}$$



The expectation that there is a dark analogue of the CMB at $E \gg T_{CMB}$ comes from very simple and general properties of moduli.

It is not tied to precise models of moduli stabilisation or choice of string theory etc.

It just requires the existence of massive particles only interacting gravitationally.

For $10^5\text{GeV} \lesssim m_\Phi \lesssim 10^8\text{GeV}$ CAB lies today in EUV/soft X-ray wavebands.

Axion-photon conversion

- Axion-photon conversion in coherent magnetic fields

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

M ≥10^{11} GeV from supernovae cooling

- Axion-photon conversion probability in plasma with frequency ω_{pl}

i) for $m_a < \omega_{pl}$

$$P_{a\to\gamma} \approx \frac{1}{4} \left(\frac{B\,L}{M} \right)^2$$

ii) for $m_a >> \omega_{pl}$

$$P'_{a\to\gamma} \approx P_{a\to\gamma} \left(\frac{\omega_{\mathrm{pl}}}{m_a} \right)^4 << P_{a\to\gamma}$$

negligible

- Need large B and L to have large conversion probability ➡ galaxy clusters

i) typical size $R_{cluster}$ ~ 1 Mpc

ii) ICM plasma frequency ω_{pl} ~ 10^{-12} eV

➡ axions with $m_a >> 10^{-12}$ eV (QCD axion) give negligible conversion

iii) B ~ 1 ÷ 10 μG

iv) L ~ 1 ÷ 10 kpc

CAB evidence in the sky

- Soft X-ray excess in galaxy clusters above thermal emission from ICM observed since 1996 by several missions (EUVE, ROSAT, XMM-Newton, Suzaku and Chandra)
- Statistical significance around 100σ!
- No good astrophysical explanation
- Typical excess luminosity

$$\mathcal{L}_{\mathrm{excess}} \approx 10^{43}\ \mathrm{erg\ s^{-1}}$$

- CAB energy density

$$\rho_{\mathrm{CAB}} = 1.6 \times 10^{60}\ \mathrm{erg\ Mpc^{-3}} \left(\frac{\Delta N_{\mathrm{eff}}}{0.57} \right)$$

- Soft X-ray luminosity from axion-photon conversion

$$\mathcal{L}_{a\to\gamma} = \rho_{\mathrm{CAB}} P^{\mathrm{cluster}}_{a\to\gamma} = 3.16 \times 10^{43}\ \mathrm{erg\ s^{-1}} \left(\frac{\Delta N_{\mathrm{eff}}}{0.5} \right) \left(\frac{B}{\sqrt{2}\,\mu\mathrm{G}} \frac{10^{12}\,\mathrm{GeV}}{M} \right)^2 \left(\frac{L}{1\,\mathrm{kpc}} \right)$$

- Match data for

$$\Delta N_{\mathrm{eff}} \approx 0.5 \qquad m_a < 10^{-12}\,\mathrm{eV} \qquad M \approx 10^{12}\ \mathrm{GeV}$$

[Conlon, Marsh]

3.5 keV line

- Detection of a 3.5 keV line from:

i) Stacked galaxy clusters (XMM-Newton) and Perseus (Chandra) [Bulbul et al. 1402.2301]

ii) Perseus and Andromeda (XMM-Newton) [Boyarsky et al. 1402.4119]

iii) Perseus (Suzaku) [Urban et al. 1411.0050]

- Non-detection of a 3.5 keV line from:

i) Dwarf spheroidal galaxies (XMM-Newton) [Malyshev et al. 1408.3531]

ii) Stacked galaxies (XMM-Newton and Chandra) [Anderson et al. 1408.4115]

- Simplest explanation: DM with m_{DM} ~ 7 keV (sterile neutrinos, axions, axinos,…..) decaying into photons [Higaki, Jeong, Takahashi] [Jaeckel,Redondo, Ringwald]

- Astrophysical explanation: new atomic transition line from ICM plasma

- Forthcoming Astro-H mission has sufficient spectral resolution to resolve the line!

Problems with DM decay

- Problems with simplest explanation DM $\longrightarrow \gamma$:

i) Inconsistent inferred signal strength

Line traces only DM quantity in each cluster ➡ clear prediction

$$F^{i}_{\mathrm{DM}\to\gamma} \propto \Gamma_{\mathrm{DM}\to\gamma}\,\rho^{i}_{\mathrm{DM}} \quad \Rightarrow \quad \frac{F^{i}_{\mathrm{DM}\to\gamma}}{F^{j}_{\mathrm{DM}\to\gamma}} \propto \frac{\rho^{i}_{\mathrm{DM}}}{\rho^{j}_{\mathrm{DM}}} \quad \text{fixed}$$

BUT signal strength from Perseus larger than for other stacked galaxy clusters (XMM-Newton and Chandra) and Coma, Virgo and Ophiuchus (Suzaku)

ii) Inconsistent morphology of the signal

Non-zero signal from everywhere in DM halo

BUT stronger signal from central cool core of Perseus (XMM-Newton, Chandra and Suzaku) and Ophiucus + Centaurus (XMM-Newton)

iii) Non-observation in dwarf spheroidal galaxies

Dwarf galaxies are dominated by DM ➡ they should give cleanest DM decay line

BUT the line has not been observed + non-observation in stacked galaxies

Alternative explanation: DM $\rightarrow$ ALP $\rightarrow \gamma$

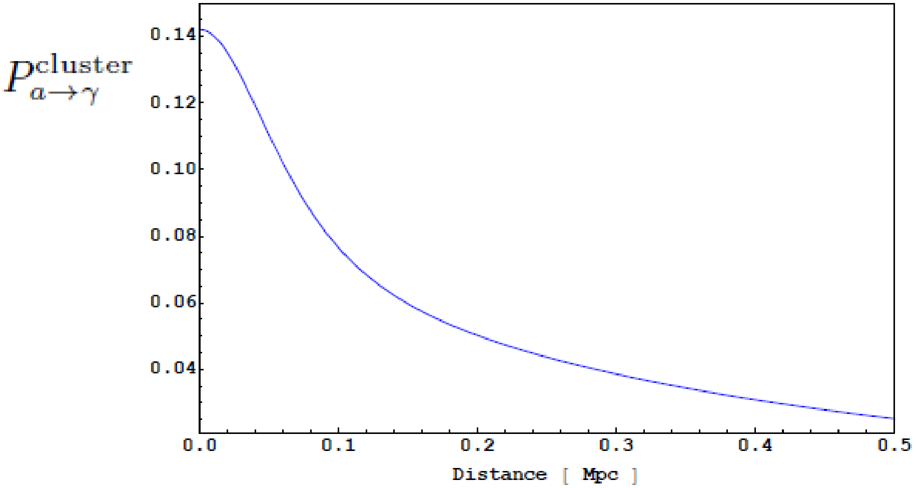
- Monochromatic 3.5 keV axion line from DM decay with $m_{DM} \sim 7$ keV

a) $\frac{\Phi}{\Lambda}\partial_\mu a \partial^\mu a \rightarrow \Gamma_\Phi = \frac{1}{32\pi}\frac{m_\Phi^3}{\Lambda^2}$ b) $\frac{\partial_\mu a}{\Lambda}\bar{\psi}\gamma^\mu\gamma^5\chi \rightarrow \Gamma_{\psi\to\chi a} = \frac{1}{16\pi}\frac{(m_\psi^2 - m_\chi^2)^3}{m_\psi^3\Lambda^2}$

- Axion-photon conversion in cluster magnetic field [MC, Conlon, Marsh, Rummel 1403.2370]

$$F^i_{\mathrm{DM}\to\gamma} \propto \Gamma_{\mathrm{DM}\to a} P^i_{a\to\gamma}\rho^i_{\mathrm{DM}} \quad \Rightarrow \quad \frac{F^i_{\mathrm{DM}\to\gamma}}{F^j_{\mathrm{DM}\to\gamma}} \propto \frac{\rho^i_{\mathrm{DM}} P^i_{a\to\gamma}}{\rho^j_{\mathrm{DM}} P^j_{a\to\gamma}} \propto \left(\frac{B^i}{B^j}\right)^2$$

- Morphology of the signal: B-field peakes at centre



$$B(r) = B_0\sqrt{\frac{n_e(r)}{n_e(0)}}$$

- Match data for same values which give soft X-ray excess: $m_a < 10^{-12}\,\mathrm{eV} \quad M \approx 10^{12}\,\mathrm{GeV}$

DM → ALP → γ: advantages and predictions

- B-dependent line strength can explain:

i) Inferred signal strength in Perseus:
Photon flux depends on both DM density and B-field

ii) Stronger signal from cool core:
B-field peaks in central cool core in galaxy clusters

iii) Non-observation in dwarf galaxies:
Dwarf galaxies have L and B-field smaller than galaxy clusters
Predicted in MC, Conlon, Marsh, Rummel 1403.2370 ⟹ confirmed in Malyshev et al. 1408.3531

iv) Non-observation in galaxies:
Galaxies have L and B-field smaller than galaxy clusters
Predicted in MC, Conlon, Marsh, Rummel 1403.2370 ⟹ confirmed in Anderson et al. 1408.4115

v) Observation in Andromeda:
it is almost edge on to us
⟹ axions have significant passage through its disk and enhance conversion probability

Conclusions

- Connection between string theory and 4D physics → string compactifications
- Extra dimensions → Moduli ϕ: new scalars with gravitational couplings
- Moduli stabilisation: give mass to moduli and break SUSY
- Cosmological moduli problem: $m_\phi > 50$ TeV
- Reheating driven by lightest modulus decay
- Non-standard cosmology: dilution of thermal DM
- Non-thermal dark matter: CMSSM with a 300 GeV Higgsino LSP saturating DM for $T_R = 2$ GeV
- Generic production of axionic dark radiation
- Cosmic axion background with $E_a \sim 200$ eV
- CAB detectable via axion-photon conversion in B
- Explain soft X-ray excess in galaxy clusters
- Explain 3.5 keV line from galaxy clusters improving simplest decaying DM interpretation