Origin of Dark Matter

Manuel Drees

Bonn University

Contents

Contents

Contents

Contents

Contents

Contents

1 Introduction

Several observations indicate existence of non-luminous Dark Matter (DM) (more exactly: missing force)

1 Introduction

Several observations indicate existence of non-luminous Dark Matter (DM) (more exactly: missing force)

- Galactic rotation curves imply $\Omega_{\rm DM} h^2 \geq 0.05$.

Ω: Mass density in units of critical density; $\Omega = 1$ means flat Universe.

h: Scaled Hubble constant. Observation: $h = 0.72 \pm 0.07$ (?)

1 Introduction

Several observations indicate existence of non-luminous Dark Matter (DM) (more exactly: missing force)

- Galactic rotation curves imply $\Omega_{\rm DM} h^2 \geq 0.05$.

Ω: Mass density in units of critical density; $\Omega = 1$ means flat Universe.
h: Scaled Hubble constant. Observation: $h = 0.72 \pm 0.07$ (?)

- Models of structure formation, X ray temperature of clusters of galaxies, ...

1 Introduction

Several observations indicate existence of non-luminous Dark Matter (DM) (more exactly: missing force)

- Galactic rotation curves imply $\Omega_{\rm DM} h^2 \geq 0.05$.

Ω: Mass density in units of critical density; $\Omega = 1$ means flat Universe.
h: Scaled Hubble constant. Observation: $h = 0.72 \pm 0.07$ (?)

- Models of structure formation, X ray temperature of clusters of galaxies, ...

- Cosmic Microwave Background anisotropies (WMAP) imply $\Omega_{\rm DM} h^2 = 0.105^{+0.007}_{-0.013}$ **Spergel et al., astro–ph/0603449**

Need for non–baryonic DM

Total baryon density is determined by:

- Big Bang Nucleosynthesis

Need for non–baryonic DM

Total baryon density is determined by:

- Big Bang Nucleosynthesis
- Analyses of CMB data

Need for non–baryonic DM

Total baryon density is determined by:

- Big Bang Nucleosynthesis
- Analyses of CMB data

Consistent result: $\Omega_{\rm bar} h^2 \simeq 0.02$

Need for non–baryonic DM

Total baryon density is determined by:

- Big Bang Nucleosynthesis
- Analyses of CMB data

Consistent result: $\Omega_{\rm bar} h^2 \simeq 0.02$

$\Longrightarrow$ Need non–baryonic DM!

Need for exotic particles

Only possible non–baryonic particle DM in SM: light neutrinos!

Need for exotic particles

Only possible non–baryonic particle DM in SM: light neutrinos!

Make hot DM: do not describe structure formation correctly

$\Longrightarrow \Omega_\nu h^2 \lesssim 0.01$

Need for exotic particles

Only possible non–baryonic particle DM in SM: light neutrinos!

Make hot DM: do not describe structure formation correctly

$\Longrightarrow \Omega_\nu h^2 \lesssim 0.01$

$\Longrightarrow$ Need exotic particles as DM!

Need for exotic particles

Only possible non–baryonic particle DM in SM: light neutrinos!

Make hot DM: do not describe structure formation correctly

$\Longrightarrow \Omega_\nu h^2 \lesssim 0.01$

$\Longrightarrow$ Need exotic particles as DM!

Possible loophole: primordial black holes; not easy to make in sufficient quantity sufficiently early.

A remark on the “WMAP range”

- It does not only come from WMAP data!

A remark on the “WMAP range”

- It does not only come from WMAP data!
- It depends on many assumptions (e.g., nearly scale independent primordial power spectrum)

A remark on the “WMAP range”

- It does not only come from WMAP data!
- It depends on many assumptions (e.g., nearly scale independent primordial power spectrum)
- Need for DM is much more general than this!

A remark on the "WMAP range"

- It does not only come from WMAP data!
- It depends on many assumptions (e.g., nearly scale independent primordial power spectrum)
- Need for DM is much more general than this!
  E.g. Wiltshire (et al.), gr-qc/0702082, arXiv:0709.0732 [gr-qc], arXiv:0709.2535 [astro-ph], explains accelerated expansion in inhomogeneous universe: finds $\Omega_{\rm DM} = 3.1^{+1.8}_{-1.1}\Omega_{\rm baryon}$.

A remark on the "WMAP range"

- It does not only come from WMAP data!
- It depends on many assumptions (e.g., nearly scale independent primordial power spectrum)
- Need for DM is much more general than this!
  E.g. Wiltshire (et al.), gr-qc/0702082, arXiv:0709.0732 [gr-qc], arXiv:0709.2535 [astro-ph], explains accelerated expansion in inhomogeneous universe: finds $\Omega_{\rm DM} = 3.1^{+1.8}_{-1.1}\Omega_{\rm baryon}$.
  E.g. Ferreras, Sakellariadou, Yusaf, arXiv:0709.3189 [astro-ph]: Strong lensing implies that even MOND needs galactic DM!

What we need

Since $h^2 \simeq 0.5$: Need $\sim 20\%$ of critical density in

- Matter (with negligible pressure, $w \simeq 0$)

What we need

Since $h^2 \simeq 0.5$: Need $\sim 20\%$ of critical density in

- Matter (with negligible pressure, $w \simeq 0$)
- which still survives today (lifetime $\tau \gg 10^{10}$ yrs)

What we need

Since $h^2 \simeq 0.5$: Need $\sim 20\%$ of critical density in

- Matter (with negligible pressure, $w \simeq 0$)
- which still survives today (lifetime $\tau \gg 10^{10}$ yrs)
- and has (strongly) suppressed coupling to elm radiation

Network activities: Making DM

Let χ be a generic DM particle, n_χ its number density (unit: GeV^3). Assume $\chi = \bar{\chi}$, i.e. $\chi\chi \leftrightarrow$SM particles is possible, but single production of χ is forbidden by some symmetry.

Network activities: Making DM

Let χ be a generic DM particle, n_χ its number density (unit: GeV^3). Assume $\chi = \bar{\chi}$, i.e. $\chi\chi \leftrightarrow$SM particles is possible, but single production of χ is forbidden by some symmetry.

Evolution of n_χ determined by Boltzmann equation; in standard cosmology:

$$\frac{dn_\chi}{dt} + 3Hn_\chi = -\langle\sigma_{\rm ann} v\rangle \left(n_\chi^2 - n_{\chi,\,\rm eq}^2\right)$$

$H = \dot{R}/R$: Hubble parameter
$\langle \ldots \rangle$: Thermal averaging
$\sigma_{\rm ann} = \sigma(\chi\chi \to \text{SM particles})$
v : relative velocity between χ's in their cms
$n_{\chi,\,\rm eq}$: χ density in full equilibrium

In Supercritical String Cosmology

ref.: Lahanas, Mavromatos, Nanopoulos, hep-ph/0612152, Phys. Lett. **B649**, 83 (2007)

- New positive contributions to H: Increase Ω_χ

In Supercritical String Cosmology

ref.: Lahanas, Mavromatos, Nanopoulos, hep-ph/0612152, Phys. Lett. **B649**, 83 (2007)

- New positive contributions to H: Increase Ω_χ
- In Boltzmann eq.: $3H \to 3H - \dot{\phi}$ (ϕ : dilaton field): Reduces Ω_χ

In Supercritical String Cosmology

ref.: Lahanas, Mavromatos, Nanopoulos, hep-ph/0612152, Phys. Lett. **B649**, 83 (2007)

- New positive contributions to H: Increase Ω_χ
- In Boltzmann eq.: $3H \to 3H - \dot{\phi}$ (ϕ : dilaton field): Reduces Ω_χ
- 2nd effect wins; Ω_χ *reduced* by $\sim$ factor 10; widens acceptable SUSY parameter space (see below).

Model independent approach

ref: MD, Iminniyaz, Kakizaki, arXiv:0704.1590 [hep-ph]

- Parameterize deviation from standard cosmology:

$$H(T) = H_{\rm standard}(T)/A(T)$$

Model independent approach

ref: MD, Iminniyaz, Kakizaki, arXiv:0704.1590 [hep-ph]

- Parameterize deviation from standard cosmology:

$$H(T) = H_{\rm standard}(T)/A(T)$$

- Taylor expand A in $z = m_\chi/T$ around $z = z_F \simeq 0.05$, up to 2nd order

Model independent approach

ref: MD, Iminniyaz, Kakizaki, arXiv:0704.1590 [hep-ph]

- Parameterize deviation from standard cosmology:

$$H(T) = H_{\rm standard}(T)/A(T)$$

- Taylor expand A in $z = m_\chi/T$ around $z = z_F \simeq 0.05$, up to 2nd order
- BBN: Need $A(0) = 1 \pm 0.2$

Model independent approach

ref: MD, Iminniyaz, Kakizaki, arXiv:0704.1590 [hep-ph]

- Parameterize deviation from standard cosmology:

$$H(T) = H_{\rm standard}(T)/A(T)$$

- Taylor expand A in $z = m_\chi/T$ around $z = z_F \simeq 0.05$, up to 2nd order
- BBN: Need $A(0) = 1 \pm 0.2$
- Fix annihilation cross section to get right Ω_χ in standard cosmology

Model independent approach

ref: MD, Iminniyaz, Kakizaki, arXiv:0704.1590 [hep-ph]

- Parameterize deviation from standard cosmology:

$$H(T) = H_{\rm standard}(T)/A(T)$$

- Taylor expand A in $z = m_\chi/T$ around $z = z_F \simeq 0.05$, up to 2nd order
- BBN: Need $A(0) = 1 \pm 0.2$
- Fix annihilation cross section to get right Ω_χ in standard cosmology
- $0.3 \lesssim A(z_F) \lesssim 5$ still allowed (2σ)

Model independent approach

ref: MD, Iminniyaz, Kakizaki, arXiv:0704.1590 [hep-ph]

- Parameterize deviation from standard cosmology:

$$H(T) = H_{\rm standard}(T)/A(T)$$

- Taylor expand A in $z = m_\chi/T$ around $z = z_F \simeq 0.05$, up to 2nd order
- BBN: Need $A(0) = 1 \pm 0.2$
- Fix annihilation cross section to get right Ω_χ in standard cosmology
- $0.3 \lesssim A(z_F) \lesssim 5$ still allowed (2σ)
- Even if $A''(z_F) = 0$: $0.5 \lesssim A(z_F) \lesssim 1.8$ allowed

DM and BBN

ref: Jittoh, Kohri et al., arXiv:0704.2914 [hep-ph]

- Assume DM is lightest neutralino, $\chi = \tilde{\chi}_1^0$

DM and BBN

ref: Jittoh, Kohri et al., arXiv:0704.2914 [hep-ph]

- Assume DM is lightest neutralino, $\chi = \tilde{\chi}_1^0$
- Assume $\tilde{\tau}_1$ only very slightly heavier than $\tilde{\chi}_1^0$: $\tilde{\tau}_1$ still around at time of BBN:

DM and BBN

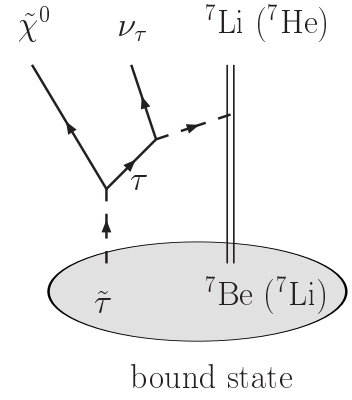
ref: Jittoh, Kohri et al., arXiv:0704.2914 [hep-ph]

- Assume DM is lightest neutralino, $\chi = \tilde{\chi}_1^0$
- Assume $\tilde{\tau}_1$ only very slightly heavier than $\tilde{\chi}_1^0$: $\tilde{\tau}_1$ still around at time of BBN:
  - Formation of $(\tilde{\tau}_1^7\mathrm{Be})$ bound states can lead to over-production of ^{6}Li through catalyzed fusion (Pospelov; . . .)

DM and BBN

ref: Jittoh, Kohri et al., arXiv:0704.2914 [hep-ph]

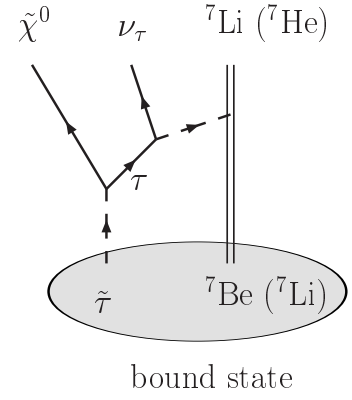
- Assume DM is lightest neutralino, $\chi = \tilde{\chi}_1^0$
- Assume $\tilde{\tau}_1$ only very slightly heavier than $\tilde{\chi}_1^0$: $\tilde{\tau}_1$ still around at time of BBN:
  - Formation of $(\tilde{\tau}_1^7\mathrm{Be})$ bound states can lead to over-production of ^{6}Li through catalyzed fusion (Pospelov; . . .)
  - Formation of $(\tilde{\tau}_1^7\mathrm{Li})$ bound states can lead to ^{7}Li depletion through interaction of π^- from $\tilde{\tau}_1$ decay



DM and BBN

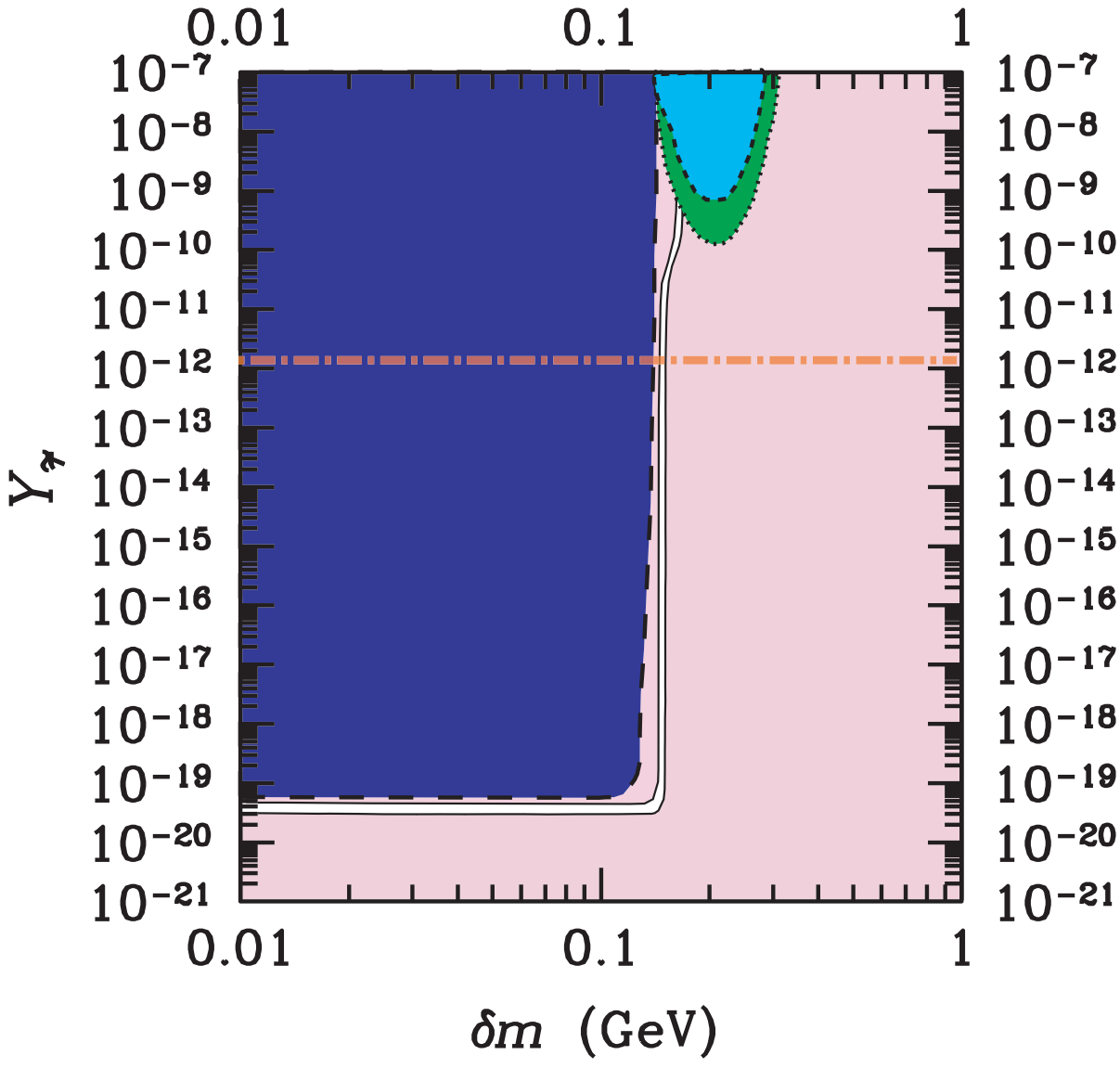
ref: Jittoh, Kohri et al., arXiv:0704.2914 [hep-ph]

- Assume DM is lightest neutralino, $\chi = \tilde{\chi}_1^0$
- Assume $\tilde{\tau}_1$ only very slightly heavier than $\tilde{\chi}_1^0$: $\tilde{\tau}_1$ still around at time of BBN:
  - Formation of $(\tilde{\tau}_1^7\mathrm{Be})$ bound states can lead to over-production of ^{6}Li through catalyzed fusion (Pospelov; . . .)
  - Formation of $(\tilde{\tau}_1^7\mathrm{Li})$ bound states can lead to ^{7}Li depletion through interaction of π^- from $\tilde{\tau}_1$ decay



- Can solve both Lithium problems in narrow range of parameter space.

DM and BBN (cont.'d)



Blue: Too much ^{6}Li

Pink: Excluded by ^{7}Li

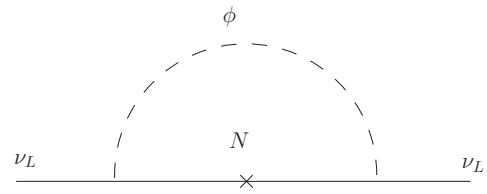
Light blue: Excluded by D

Green: Excluded by ^{4}He

DM and Neutrino Masses

ref: Boehm et al., hep-ph/0612228

Basic idea: Loop diagram with MeV–ish scalar DM particle creates eV–ish neutrino mass.

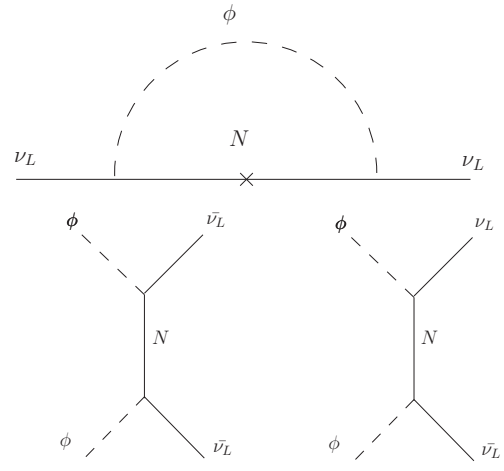


DM and Neutrino Masses

ref: Boehm et al., hep-ph/0612228

Basic idea: Loop diagram with MeV–ish scalar DM particle creates eV–ish neutrino mass.

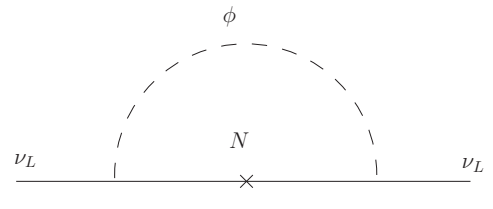
Cut version of same diagram determines ϕ relic density



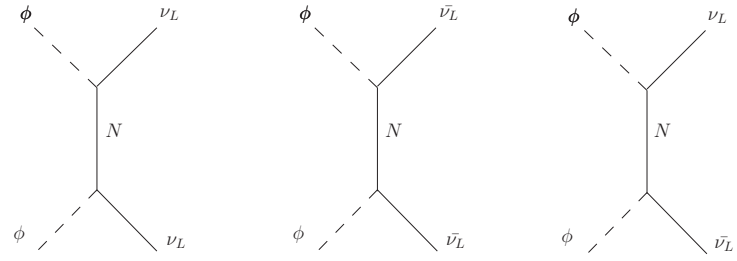
DM and Neutrino Masses

ref: Boehm et al., hep-ph/0612228

Basic idea: Loop diagram with MeV–ish scalar DM particle creates eV–ish neutrino mass.



Cut version of same diagram determines ϕ relic density



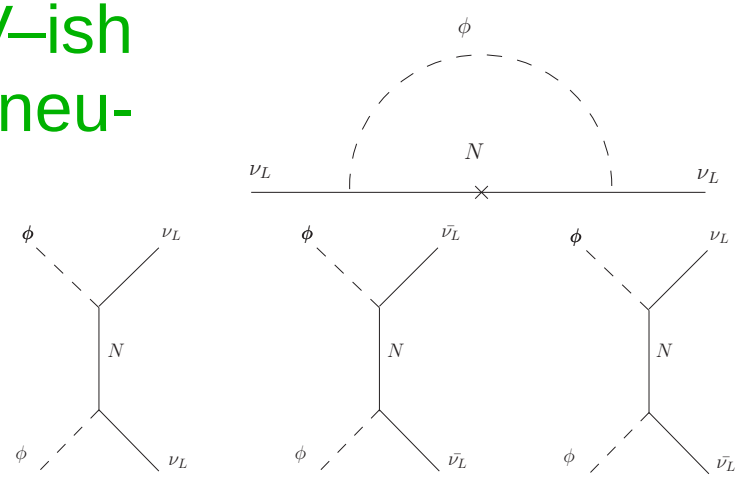
Problems:

- Effective interaction violates $SU(2) \times U(1)_Y$ gauge invariance

DM and Neutrino Masses

ref: Boehm et al., hep-ph/0612228

Basic idea: Loop diagram with MeV–ish scalar DM particle creates eV–ish neutrino mass.



Cut version of same diagram determines ϕ relic density

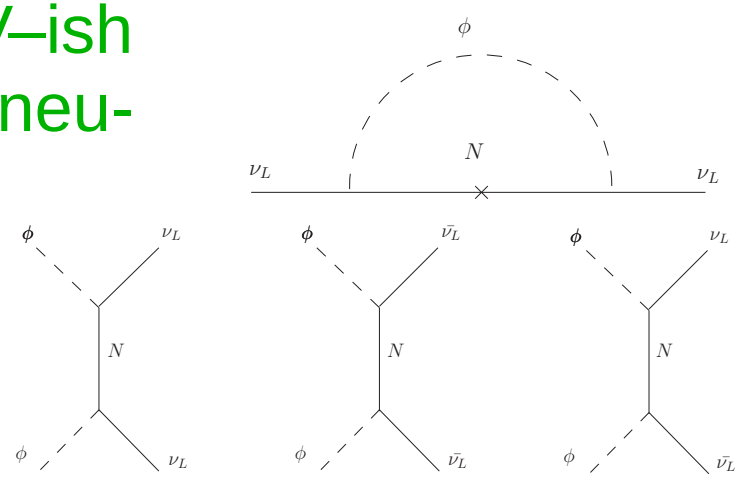
Problems:

- Effective interaction violates $SU(2) \times U(1)_Y$ gauge invariance
- Have sufficiently many parameters to adjust m_ν, Ω_ϕ independently

DM and Neutrino Masses

ref: Boehm et al., hep-ph/0612228

Basic idea: Loop diagram with MeV–ish scalar DM particle creates eV–ish neutrino mass.



Cut version of same diagram determines ϕ relic density

Problems:

- Effective interaction violates $SU(2) \times U(1)_Y$ gauge invariance
- Have sufficiently many parameters to adjust m_ν, Ω_ϕ independently
- No mechanism for $\phi\phi \to e^+e^-$, explaining 511 keV excess

DM and MSSM Inflation

ref: Allahverdi, Dutta, Mazumdar, hep–ph/0702112

- Can have inflation along MSSM flat direction, if certain relation between soft breaking masses holds to good approximation

DM and MSSM Inflation

ref: Allahverdi, Dutta, Mazumdar, hep–ph/0702112

- Can have inflation along MSSM flat direction, if certain relation between soft breaking masses holds to good approximation
- Get acceptable density perturbations for flat directions lifted by $d = 6$ operators

DM and MSSM Inflation

ref: Allahverdi, Dutta, Mazumdar, hep–ph/0702112

- Can have inflation along MSSM flat direction, if certain relation between soft breaking masses holds to good approximation
- Get acceptable density perturbations for flat directions lifted by $d = 6$ operators
- Preferred inflation mass near 100 GeV, $H_I \sim 0.01$ to 1 GeV

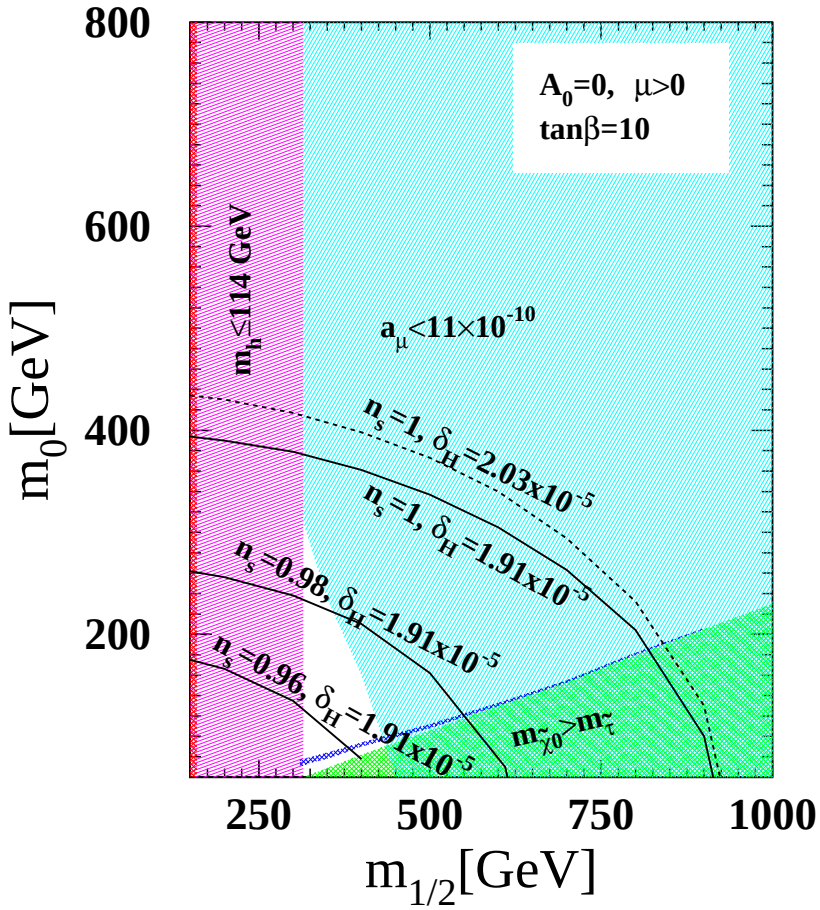
DM and MSSM Inflation

ref: Allahverdi, Dutta, Mazumdar, hep–ph/0702112

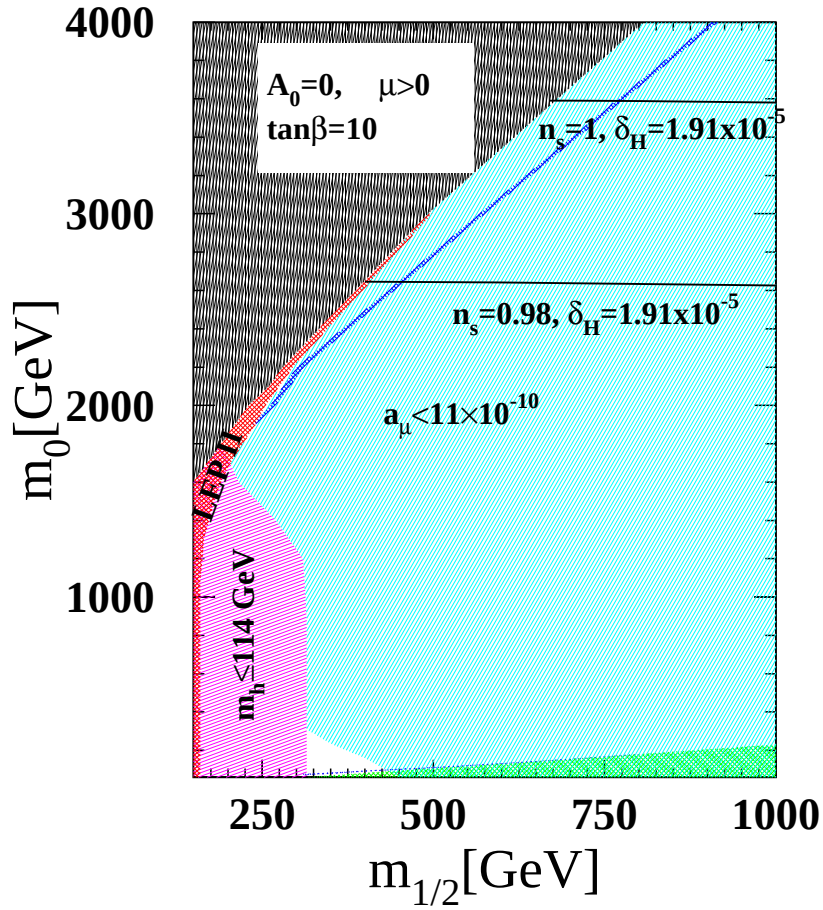
- Can have inflation along MSSM flat direction, if certain relation between soft breaking masses holds to good approximation
- Get acceptable density perturbations for flat directions lifted by $d = 6$ operators
- Preferred inflation mass near 100 GeV, $H_I \sim 0.01$ to 1 GeV
- Even in mSUGRA: Can be combined with thermal $\tilde{\chi}_1^0$ DM!

DM and MSSM Inflation (cont'd)

$\lambda = 1$



$\lambda = 0.1$



Learning from Direct WIMP Detection

ref: MD, Shan, astro-ph/0703651

- Direct detection rate $\propto \int_0^\infty \frac{f_1(v)}{v} dv$

Learning from Direct WIMP Detection

ref: MD, Shan, astro-ph/0703651

- Direct detection rate $\propto \int_0^\infty \frac{f_1(v)}{v} dv$
- Can be inverted to directly determine WIMP velocity distribution $f_1(v)$!

Learning from Direct WIMP Detection

ref: MD, Shan, astro-ph/0703651

- Direct detection rate $\propto \int_0^\infty \frac{f_1(v)}{v} dv$
- Can be inverted to directly determine WIMP velocity distribution $f_1(v)$!
- For one target: Need to know m_χ, but do not need to know cross section, ρ_χ

Learning from Direct WIMP Detection

ref: MD, Shan, astro-ph/0703651

- Direct detection rate $\propto \int_0^\infty \frac{f_1(v)}{v} dv$
- Can be inverted to directly determine WIMP velocity distribution $f_1(v)$!
- For one target: Need to know m_χ, but do not need to know cross section, ρ_χ
- Need hundreds of events to get meaningful result for $f_1(v)$

Learning from Direct WIMP Detection

ref: MD, Shan, astro-ph/0703651

- Direct detection rate $\propto \int_0^\infty \frac{f_1(v)}{v} dv$
- Can be inverted to directly determine WIMP velocity distribution $f_1(v)$!
- For one target: Need to know m_χ, but do not need to know cross section, ρ_χ
- Need hundreds of events to get meaningful result for $f_1(v)$
- Can get non–trivial info on moments of f_1 from few dozen events

Learning from Direct WIMP Detection

ref: MD, Shan, astro-ph/0703651

- Direct detection rate $\propto \int_0^\infty \frac{f_1(v)}{v} dv$
- Can be inverted to directly determine WIMP velocity distribution $f_1(v)$!
- For one target: Need to know m_χ, but do not need to know cross section, ρ_χ
- Need hundreds of events to get meaningful result for $f_1(v)$
- Can get non–trivial info on moments of f_1 from few dozen events
- With ≥ 2 targets: Allows model–independent determination of m_χ!

Other Theoretical Developments

- Lightest neutralino remains in good shape as thermal WIMP in various simple SUSY models (mSUGRA and slight generalizations). ref: Ellis et al., hep-ph/0607002, arXiv:0704.3446 [hep-ph], arXiv:0706.0652 [hep-ph]; Baer et al., hep-ph/0610154, hep-ph/0611387, hep-ph/0703024, arXiv:0707.0618 [hep-ph], arXiv:0708.4003 [hep-ph]

Other Theoretical Developments

- Lightest neutralino remains in good shape as thermal WIMP in various simple SUSY models (mSUGRA and slight generalizations). ref: Ellis et al., hep-ph/0607002, arXiv:0704.3446 [hep-ph], arXiv:0706.0652 [hep-ph]; Baer et al., hep-ph/0610154, hep-ph/0611387, hep-ph/0703024, arXiv:0707.0618 [hep-ph], arXiv:0708.4003 [hep-ph]
- Many other reasonably well motivated candidates continue to exist (WIMPs in Little Higgs models: branons; axions; . . .)

Other Theoretical Developments

- Lightest neutralino remains in good shape as thermal WIMP in various simple SUSY models (mSUGRA and slight generalizations). ref: Ellis et al., hep-ph/0607002, arXiv:0704.3446 [hep-ph], arXiv:0706.0652 [hep-ph]; Baer et al., hep-ph/0610154, hep-ph/0611387, hep-ph/0703024, arXiv:0707.0618 [hep-ph], arXiv:0708.4003 [hep-ph]
- Many other reasonably well motivated candidates continue to exist (WIMPs in Little Higgs models: branons; axions; . . .)
- Nevertheless, people keep inventing new WIMP models with little or no theoretical motivation

Other Theoretical Developments

- Lightest neutralino remains in good shape as thermal WIMP in various simple SUSY models (mSUGRA and slight generalizations). ref: Ellis et al., hep-ph/0607002, arXiv:0704.3446 [hep-ph], arXiv:0706.0652 [hep-ph]; Baer et al., hep-ph/0610154, hep-ph/0611387, hep-ph/0703024, arXiv:0707.0618 [hep-ph], arXiv:0708.4003 [hep-ph]
- Many other reasonably well motivated candidates continue to exist (WIMPs in Little Higgs models: branons; axions; . . .)
- Nevertheless, people keep inventing new WIMP models with little or no theoretical motivation
- Scenarios with gravitino DM and long–lived $\tilde{\tau}_1$ are now quite strongly constrained by BBN (Li overproduction): bad news for testability of this scenario

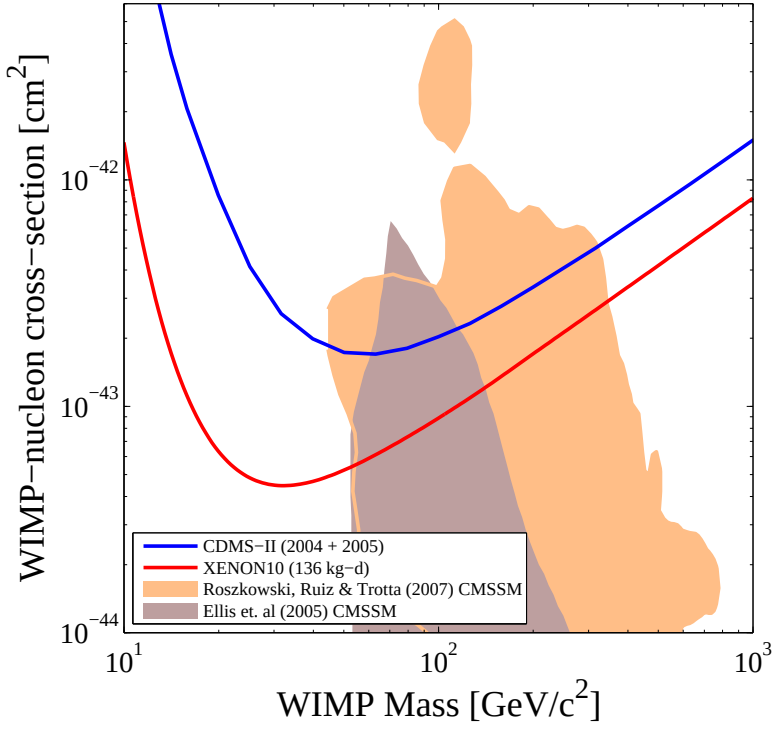
Direct DM Searches

- DAMA stands by their claim of having observed a signal for annual modulation (6.3σ, but χ^2 fit gives prob. for constant rate $\simeq 7 \cdot 10^{-4}$). Everybody else only gives bounds.

Direct DM Searches

- DAMA stands by their claim of having observed a signal for annual modulation (6.3σ, but χ^2 fit gives prob. for constant rate $\simeq 7 \cdot 10^{-4}$). Everybody else only gives bounds.

- Best bound on spin–independent interactions now from Xenon10 experiment ref: arXiv:0706.0039 [astro-ph]



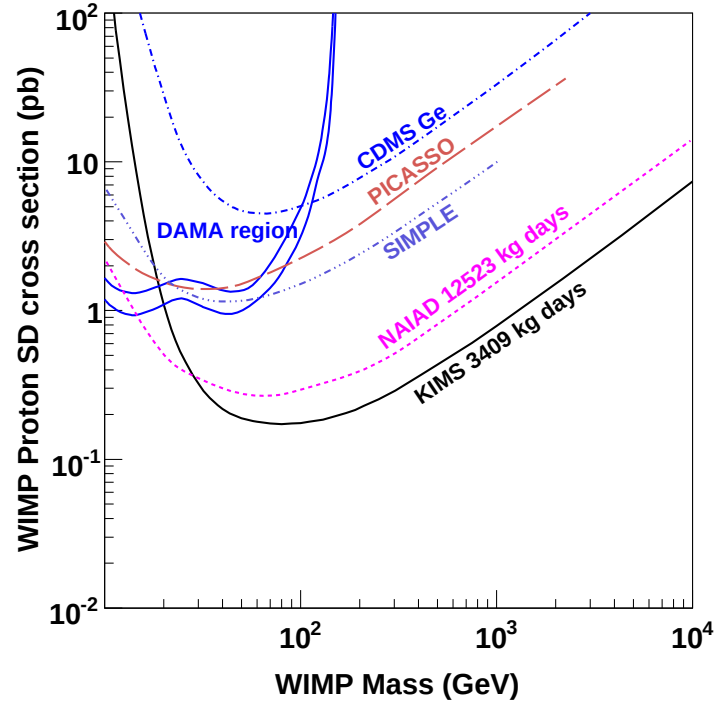
Direct DM Searches (cont'd)

- CDMS continues to give best limit for spin–dependent interaction with neutron (from 2005)

Direct DM Searches (cont'd)

- CDMS continues to give best limit for spin–dependent interaction with neutron (from 2005)

- KIMS experiment improved limit on spin–dependent interaction with proton. ref: arXiv:0704.0423 [astro-ph]



Indirect DM Detection: Photons

Signals are everywhere!

- “WMAP haze”: Excess of microwave photons from central region of our galaxy: Could be due to generic WIMP (synchrotron radiation) ref: Hooper et al., arXiv:0709.3114 [astro-ph]

Indirect DM Detection: Photons

Signals are everywhere!

- "WMAP haze": Excess of microwave photons from central region of our galaxy: Could be due to generic WIMP (synchrotron radiation) ref: Hooper et al., arXiv:0709.3114 [astro-ph]
- Excess of 511 keV photons from central region of our galaxy: Needs $m_e < m_\chi \lesssim 10$ MeV (e^+e^- annihilation at rest) ref: Boehm et al., Phys. Rev. Lett. **92**, 101301 (2004), astro–ph/0309686.

Indirect DM Detection: Photons

Signals are everywhere!

- "WMAP haze": Excess of microwave photons from central region of our galaxy: Could be due to generic WIMP (synchrotron radiation) ref: Hooper et al., arXiv:0709.3114 [astro-ph]
- Excess of 511 keV photons from central region of our galaxy: Needs $m_e < m_\chi \lesssim 10$ MeV (e^+e^- annihilation at rest) ref: Boehm et al., Phys. Rev. Lett. **92**, 101301 (2004), astro–ph/0309686.
- Excess of extragalactic MeV–ish photons: Could be due to decaying DM with $\delta m_\chi \sim 1$ MeV. ref: Cembranos, Feng, Strigari, arXiv:0704.1658 [astro-ph]

Indirect DM Detection: Photons (cont'd)

Signals are everywhere!

- Excess of GeV–ish photons everywhere: Could be due to (SUSY) WIMP with $m_\chi \sim 50$ GeV. ref: de Boer et al., Phys. Rev. Lett. **95**, 209001 (2005), astro–ph/0602325

Indirect DM Detection: Photons (cont'd)

Signals are everywhere!

- Excess of GeV–ish photons everywhere: Could be due to (SUSY) WIMP with $m_\chi \sim 50$ GeV. ref: de Boer et al., Phys. Rev. Lett. **95**, 209001 (2005), astro–ph/0602325
- TeV–ish photons from (near) galactic center: definietely *not* from DM. ref: H.E.S.S. collab., Phys. Rev. Lett. **97**, 221102 (2006), Erratum-ibid. **97**, 249901 (2006), astro-ph/0610509

Indirect DM Detection: Photons (cont'd)

Signals are everywhere!

- Excess of GeV–ish photons everywhere: Could be due to (SUSY) WIMP with $m_\chi \sim 50$ GeV. ref: de Boer et al., Phys. Rev. Lett. **95**, 209001 (2005), astro–ph/0602325
- TeV–ish photons from (near) galactic center: definietely *not* from DM. ref: H.E.S.S. collab., Phys. Rev. Lett. **97**, 221102 (2006), Erratum-ibid. **97**, 249901 (2006), astro-ph/0610509
- Lesson: Need to understand other sources of photons much better!

Sterile Neutrinos

- If $m_{\nu_s} \sim 5$ keV: Could make warm/cool DM: alleviate "DM crises"

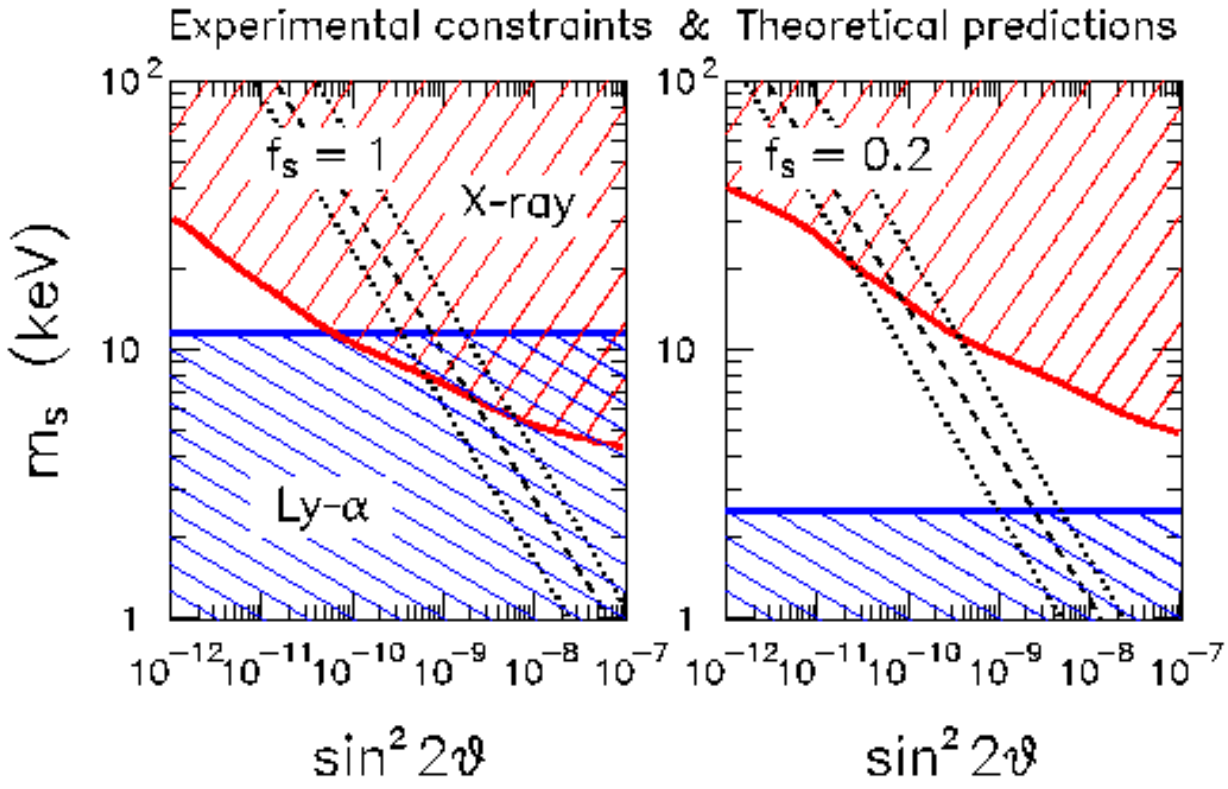
Sterile Neutrinos

- If $m_{\nu_s} \sim 5$ keV: Could make warm/cool DM: alleviate "DM crises"
- Are unstable, if they mix with ordinary neutrinos: $\nu_s \to \nu_i \gamma$: look for $X-$ray photons!

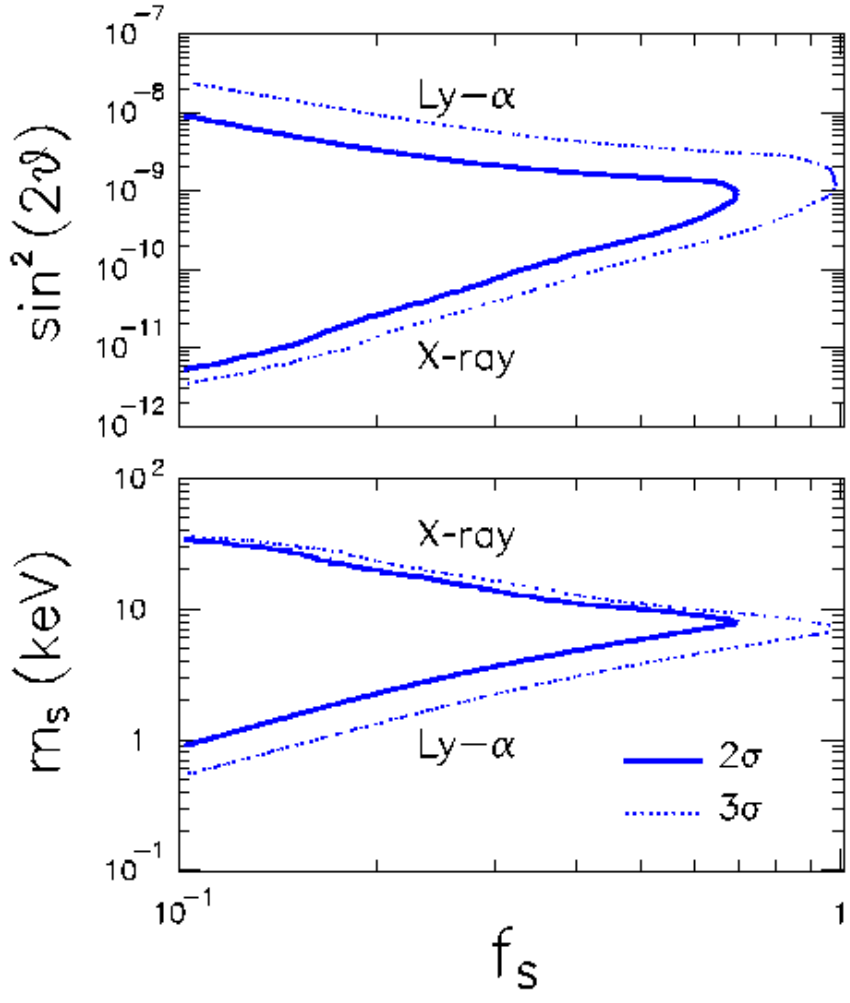
Sterile Neutrinos

- If $m_{\nu_s} \sim 5$ keV: Could make warm/cool DM: alleviate "DM crises"
- Are unstable, if they mix with ordinary neutrinos: $\nu_s \rightarrow \nu_i \gamma$: look for $X-$ray photons!
- No signals found: Simplest models excluded, if ν_s is to make all DM. ref: Palazzo, Cumberbatch, Slosar, Silk, arXiv:0707.1495 [astro–ph].

Sterile Neutrinos (cont'd)



Sterile Neutrinos (cont'd)



Summary and Conclusions

- We’re still pretty sure that non–baryonic Dark Matter exists

Summary and Conclusions

- We’re still pretty sure that non–baryonic Dark Matter exists
- We still don’t know what it’s made of

Summary and Conclusions

- We're still pretty sure that non–baryonic Dark Matter exists
- We still don't know what it's made of
- Experiment may give clues soon: LHC, GLAST, PAMELA, . . .