Bounds on evolution histories of the early Universe from indirect dark matter searches

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22.07.10

R. C., N. Fornengo, M. Pato, L. Pieri and A. Masiero, Phys. Rev. D **81** (2010)
M. Schelke, R. C., N. Fornengo, A. Masiero and M. Pietroni, Phys. Rev. D **74** (2006)
R. C., N. Fornengo, A. Masiero, M. Pietroni and F. Rosati, Phys. Rev. D **70** (2004)

Overview

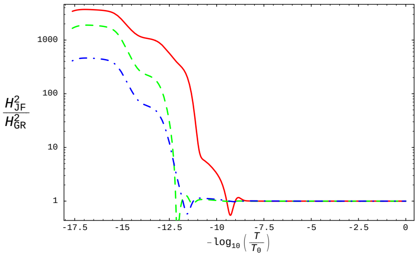
- Can the early Universe expand faster than in General Relativity?

- If yes, thermal dark matter has *larger annihilation cross section*:

$$\Omega_{DM} h^2 \propto \frac{H_f}{\langle \sigma_{\rm ann} v \rangle_f} \quad \Longrightarrow \text{"Cosmological boost factor"}$$

- In Scalar-Tensor theories it is possibile to realize $H/H_{\rm GR} >> 1$

. C., N. Fornengo, A. Masiero, M. Pietroni and F. Rosati, Phys. Rev. D **70** (2004)



$$H_{\rm GR}^2 = \frac{1}{3M_p^2}\rho_{\rm tot} \simeq 2.76\, g_* \frac{T^4}{M_p^2}$$

1. Change the number of relativistic d.o.f.'s, g_* ;

2. Consider a $\rho_{\rm tot}$ not dominated by relativistic d.o.f.'s;
   - Kination
     P. Salati, Phys. Lett. B **571** (2003) 121

3. Consider theories where the effective Planck mass is different from the constant M_p:
   - Scalar-Tensor theories
     R. C., N. Fornengo, A. Masiero, M. Pietroni and F. Rosati, Phys. Rev. D **70** (2004) 063519
   - Extradimensions
     L. Randall and R. Sundrum, Phys. Rev. Lett. **83** (1999) 4690
   - ...

-Can we set an upper bound for such cosmological boosts? Yes

- Main assumption: Thermal dark matter production

- Method: The Boltzmann equation

$$\dot{n} + 3Hn = -\langle \sigma_{\rm ann} v \rangle (n^2 - n_{eq}^2)$$

$$\Omega_{DM} h^2 \propto \frac{H_f}{\langle \sigma_{\rm ann} v \rangle_f}$$

$$\left.\begin{array}{l} \Omega_{DM} h^2 \Longrightarrow \text{from WMAP} \\ \langle \sigma_{\rm ann} v \rangle_f \Longrightarrow \text{bounds from indirect dark matter detection} \end{array}\right\} \Longrightarrow \text{Constraints on } H_f$$

Outline

1. The dark matter decoupling
2. Bounds on $\langle\sigma_{ann} v\rangle_f$ from indirect dark matter searches
3. Bounds on the Hubble expansion
4. Conclusions

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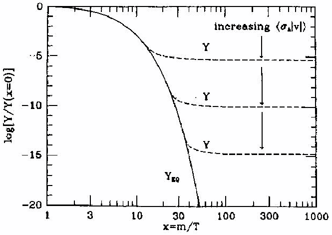
- The Boltzmann equation:

$$\dot{n} + 3Hn = -\langle \sigma_{\rm ann} v \rangle (n^2 - n_{eq}^2)$$

- Two rates:

1) Hubble rate H
2) Annihilation rate $\Gamma = n\langle \sigma_{\rm ann} v \rangle$

- When $H/\Gamma > 1 \Longrightarrow$ dark matter decoupling



- From the Boltzmann equation:

$$\Omega_{DM} h^2 \propto \frac{H_f}{\langle \sigma_{\rm ann} v \rangle_f}$$

- The ratio $H_f / \langle \sigma_{\rm ann} v \rangle_f$ is fixed by CMB observations

$\Longrightarrow$ A bound on $\langle \sigma_{\rm ann} v \rangle_f$ can constrain H_f

Charged particles:

-Antiprotons (PAMELA)
-Positron fraction (PAMELA)
-Electron+positron flux (FERMI,HESS)

γ-rays:

-Diffuse emission (Fermi,EGRET)
-From the galactic center (HESS)

Radio photons:

-Radio observations from the galactic center
R.D.Davies, D.Walsh, R.S.Booth, MNRAS 177, 319-333 (1976)

Optical depth of CMB photons (WMAP)

Bounds on $\langle \sigma_{\rm ann} v \rangle$ from indirect dark matter searches: assumptions

-s-wave annihiations

-Dark matter profile:

1) Via Lactea II simulation

2) Aquarius simulation

3) Cored profile with $\rho_{\rm local} \simeq 0.4\,{\rm GeV\,cm}^{-3}$

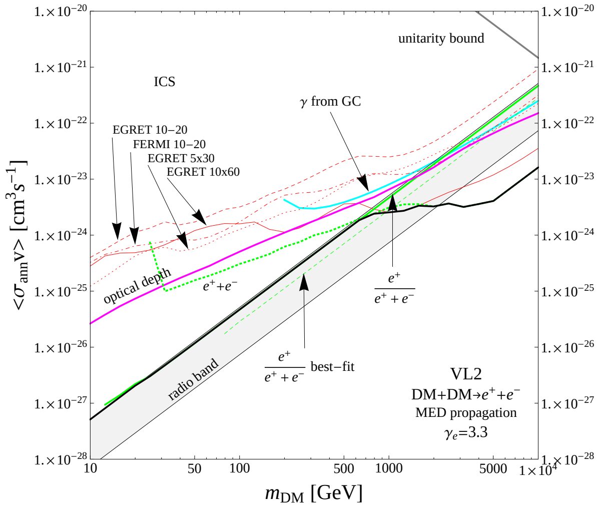
R. Catena and P. Ullio, arXiv:0907.0018 [astro-ph.CO]. To be published in JCAP

-Diffusion model:

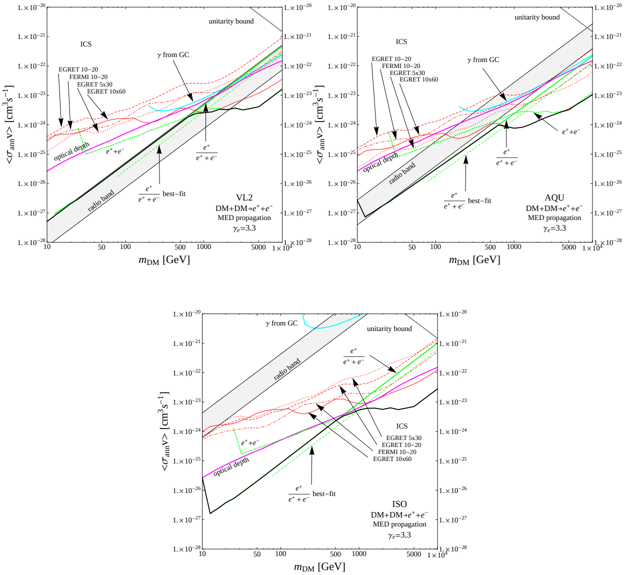
F. Donato, N. Fornengo, D. Maurin and P. Salati, Phys. Rev. D **69** (2004) 063501
J. Lavalle, Q. Yuan, D. Maurin and X. J. Bi, arXiv:0709.3634 [astro-ph]

-Annihilation channels:

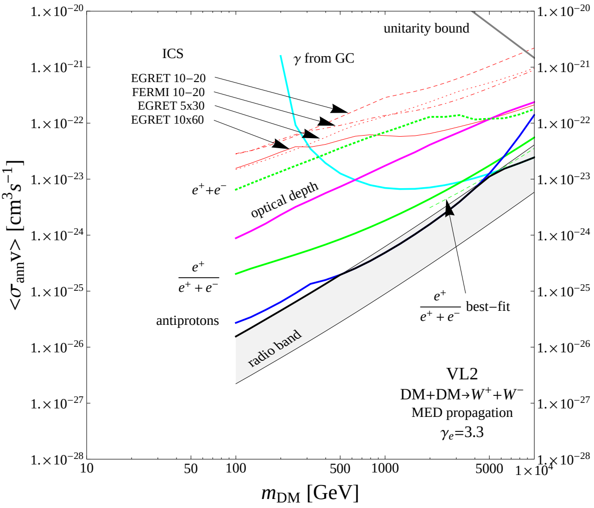
DM+DM $\rightarrow e^+ + e^-, \tau^+ + \tau^-, \mu^+ + \mu^-, W^+ + W^-, b + \bar{b}$

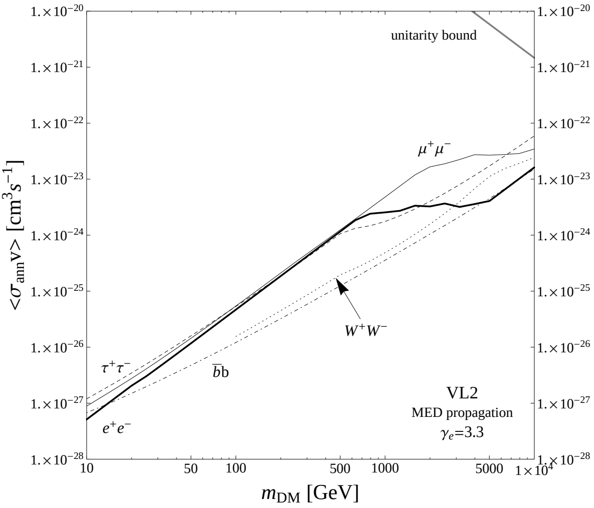

unitarity bound
ICS
γ from GC
EGRET 10−20
FERMI 10−20
EGRET 5x30
EGRET 10x60
optical depth
$e^+ + e^-$
$\frac{e^+}{e^+ + e^-}$
$\frac{e^+}{e^+ + e^-}$ best−fit
radio band
VL2
DM+DM→e^++e^-
MED propagation
γ_e=3.3
$<\sigma_{\rm ann}V>$ [cm^{3}s^{-1}]
$m_{\rm DM}$ [GeV]
1.×10^{-20}
1.×10^{-21}
1.×10^{-22}
1.×10^{-23}
1.×10^{-24}
1.×10^{-25}
1.×10^{-26}
1.×10^{-27}
1.×10^{-28}
10
50
100
500
1000
5000
1×10^4

Bounds on $\langle\sigma_{\rm ann} v\rangle$ from indirect dark matter searches: DM+DM $\rightarrow e^+ + e^-$



Bounds on $\langle \sigma_{\rm ann} v \rangle$ from indirect dark matter searches: DM+DM $\to W^+ + W^-$




unitarity bound
$\mu^+\mu^-$
W^+W^-
$\tau^+\tau^-$
$\bar{b}$b
e^+e^-
VL2
MED propagation
γ_e=3.3
$<\sigma_{\rm ann}$V> [cm^{3}s^{-1}]
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10
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100
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1000
5000
1×10^4

- A naive bound comes from:

$$\Omega_{DM} h^2 \propto \frac{H_f}{\langle \sigma_{\rm ann} v \rangle_f}$$

- The correct calculation (Boltzmann equation):

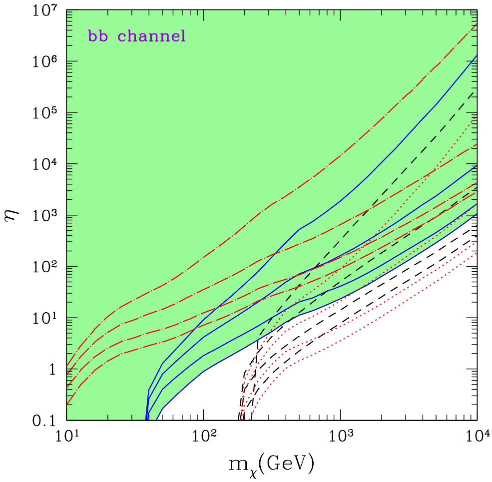
$$\dot{n} + 3Hn = -\langle \sigma_{\rm ann} v \rangle (n^2 - n_{eq}^2)$$

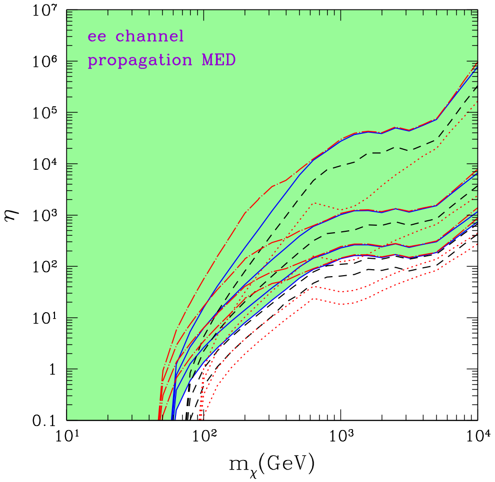
where H is a function of the temperature

- In the following:
- Parametric approach

$$\frac{H^2}{H_{\rm GR}^2} = 1 + \eta \left(\frac{T}{T_{\rm f}} \right)^{\nu} \tanh\left(\frac{T - T_{\rm re}}{T_{\rm re}} \right)$$

Bounds on H: Parametric approach




ee channel
propagation MED
η
10⁷
10⁶
10⁵
10⁴
10³
10²
10¹
1
0.1
10¹
10²
10³
10⁴
m_χ(GeV)

- If dark matter is a thermal relic, the Hubble expansion can be constrained at $T \gg T_{\rm BBN}$

- Indeed, present bounds on $\langle\sigma_{\rm ann} v\rangle_f$ can be translated in bounds on H_f

- These bounds depends on the assumed dark matter profiles and diffusion model

- However, for a 100 GeV WIMP, large departures from GR ($H/H_{\rm GR} > 100$) are unlikely