Universidad de los Andes
Colombia

UNIVERSIDAD DE ANTIOQUIA
1803
Facultad de Ciencias Exactas y Naturales

Dark Matter production in non-standard cosmologies

Valentina Franco Velásquez

Advisors: Óscar Zapata and Nicolás Bernal

VII Uniandes Particle Physics School. *Bogotá, 2022*

Outline

1. Generalities
   - Standard cosmologies
   - Non-standard cosmologies
2. Research project
3. References

Standard Cosmology

'The simplest model that provides a reasonably good account of several properties of the universe.'

*The current standard cosmology corresponds to the ΛCDM model.

ΛCDM model

It is successful explaining:

- The existence and structure of the **CMB**.
- **The large-scale structure** in the distribution of galaxies.
- The observed **abundances** of H (^{2}H), He y Li.
- **The accelerating expansion** of the universe.

*General relativity is the correct theory of gravity on cosmological scales.

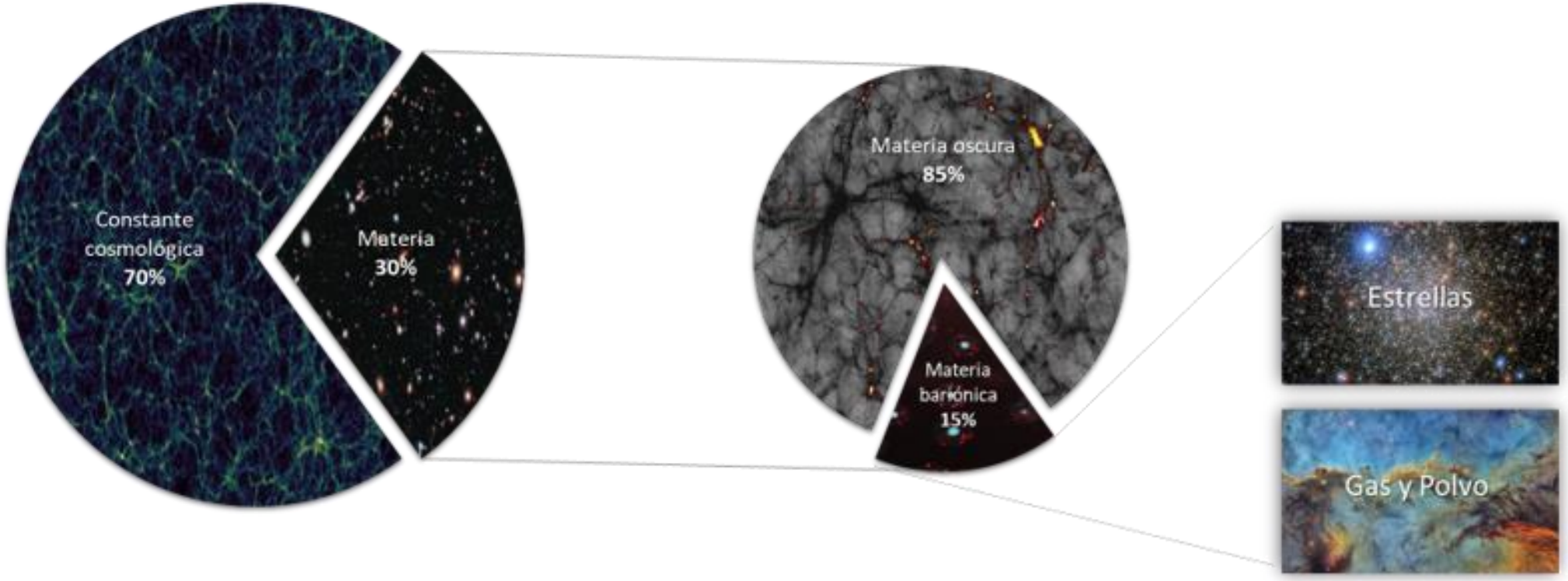
ΛCDM model

A universe made of…

Λ : *Cosmological constant*

CDM : *Cold Dark Matter*

Matter : *Barions*



ΛCDM model

$\longrightarrow \rho_{rad}, w = 1/3$

$\longrightarrow \rho_m, w = 0$

$\longrightarrow \rho_\Lambda, w = -1$

$$p = w\rho$$

$$\rho \propto a^{-3(1+w)}$$

'During its evolution, the universe goes through several stages characterized by definite processes and the dominance of a component over the rest.'

ΛCDM model

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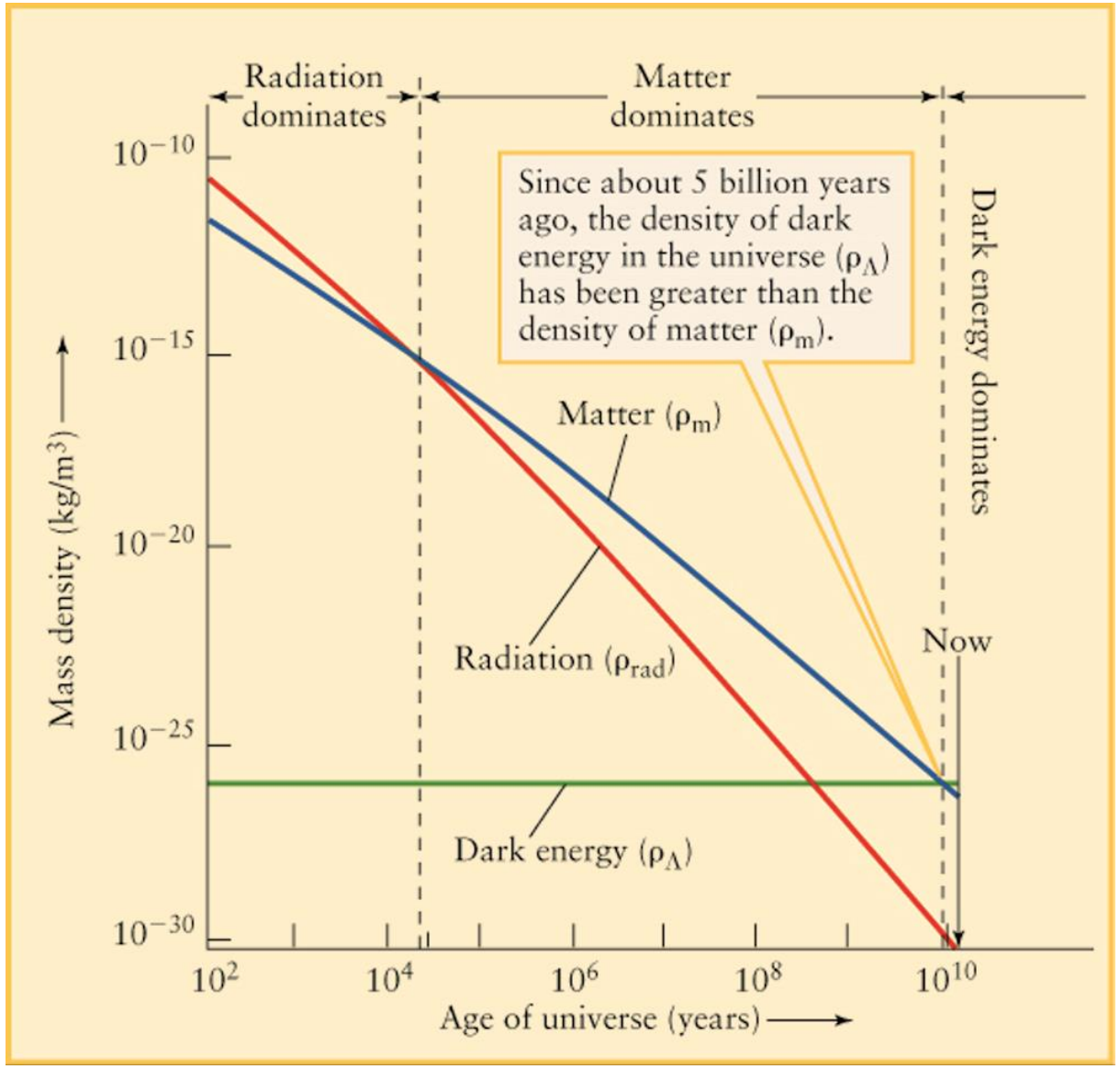
'During its evolution, the universe goes through several stages characterized by definite processes and the dominance of a component over the rest.'



ΛCDM model

POSSESS SOME PROBLEMS…

*The **horizon** problem*
*The **flatness** problem*
*The **monopole** problem*

**They are solved if it is considered inflation*

AND SOME ANOMALIES…

Baryonic asymmetry
*The nature of **Dark Energy***
*The nature of **Dark Matter***
And so on…

Physics beyond ΛCDM

P. Peebles, Anomalies in physical cosmology, Annals of Physics 447, 169159 (2022).

Non-Standard Cosmology

'Any physical cosmological model of the universe that is proposed as an alternative to the current standard model of cosmology'

*In this research project, we are interested in models in which some **stage** in the history of the early universe is **modified**.

Non-Standard Cosmology

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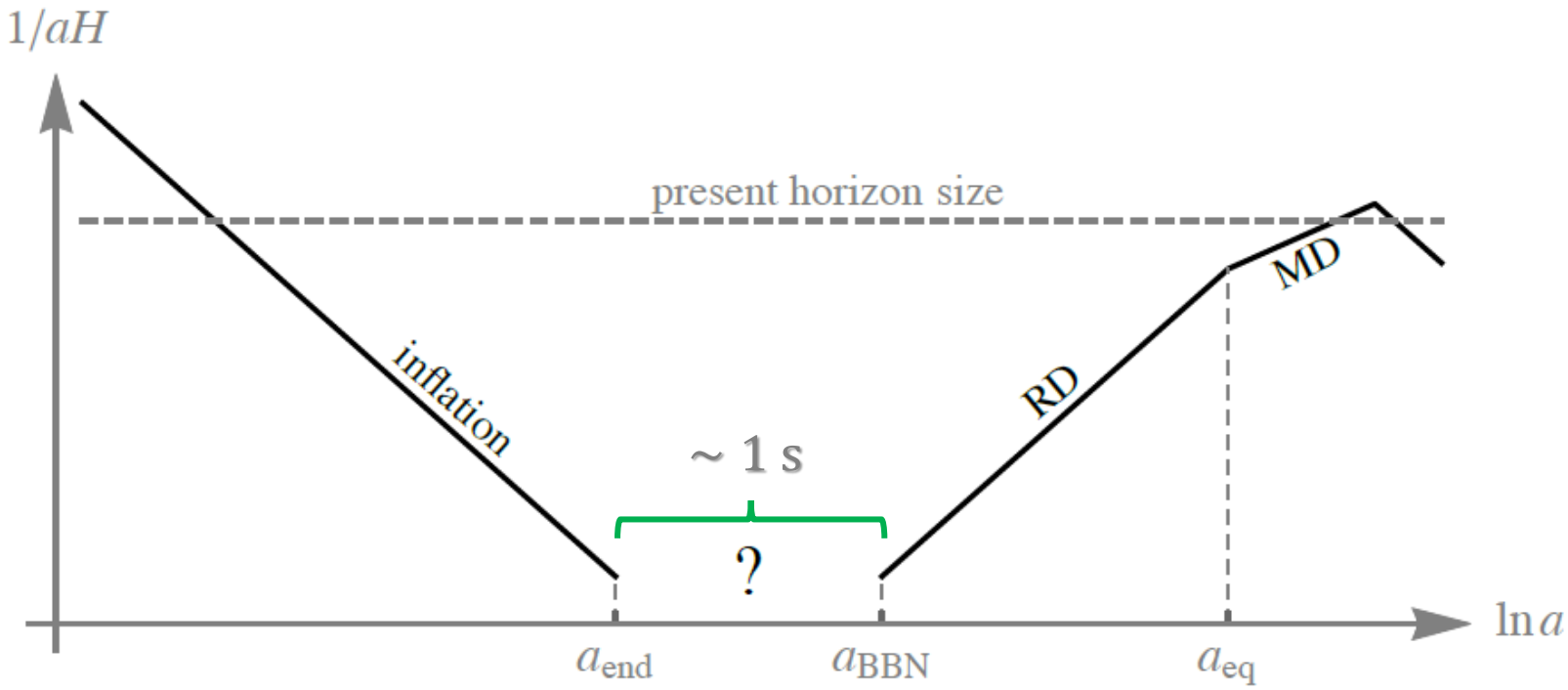
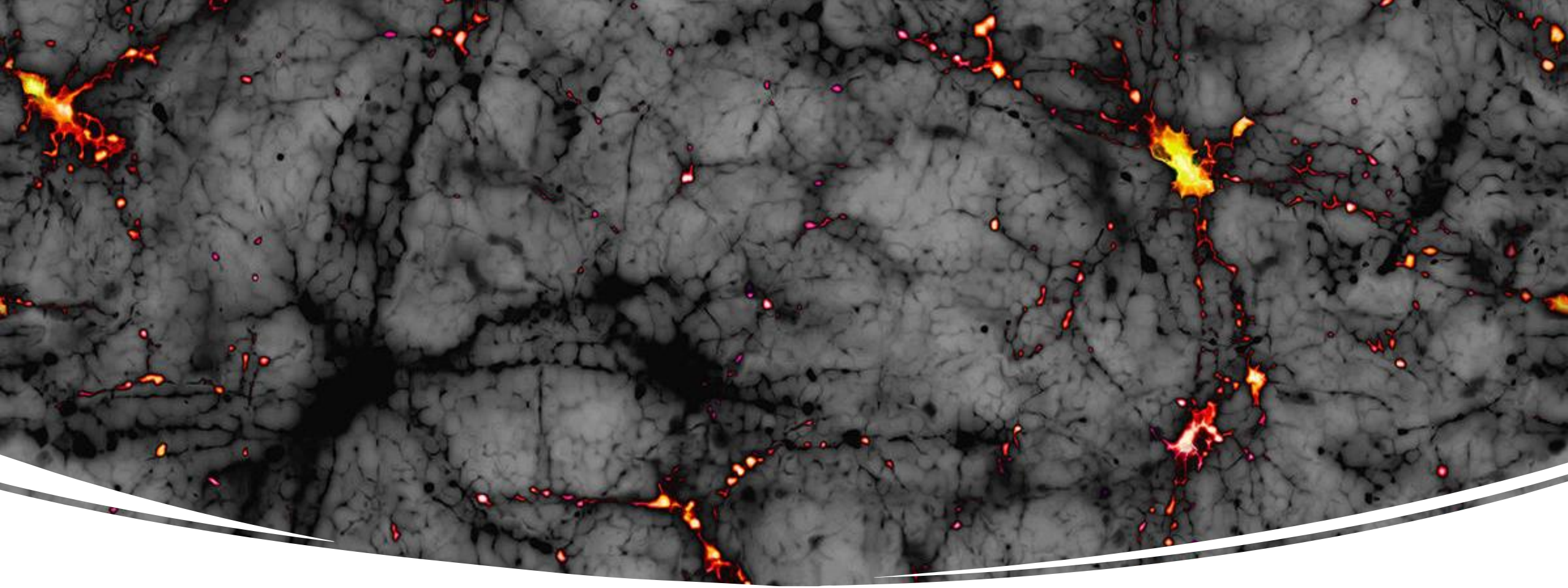


We have a gap in our understanding of the early universe!

R. Allahverdi et al., The first three seconds: a review of possible expansion histories of the early universe, The Open Journal of Astrophysics 4, 10.21105/astro.2006.16182 (2021).



Cold Dark Matter

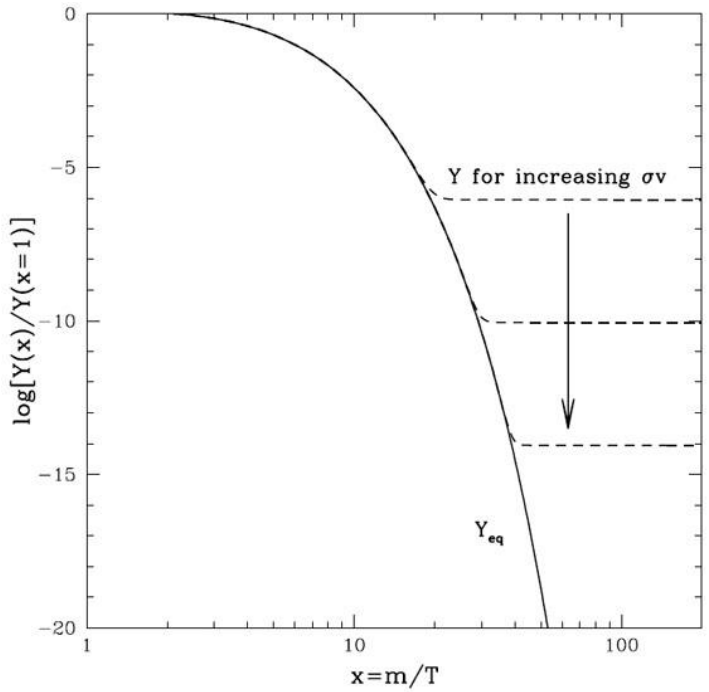
Non-baryonic

Cold: *Non- relativistic.*

Dark: *Interacts very weakly with ordinary matter and electromagnetic radiation.*

Cold dark matter candidates

- *Interacts via **gravity and** any **other force** which is as weak as or weaker than the weak nuclear force.*
- ***Thermally produced** in the early Universe.*



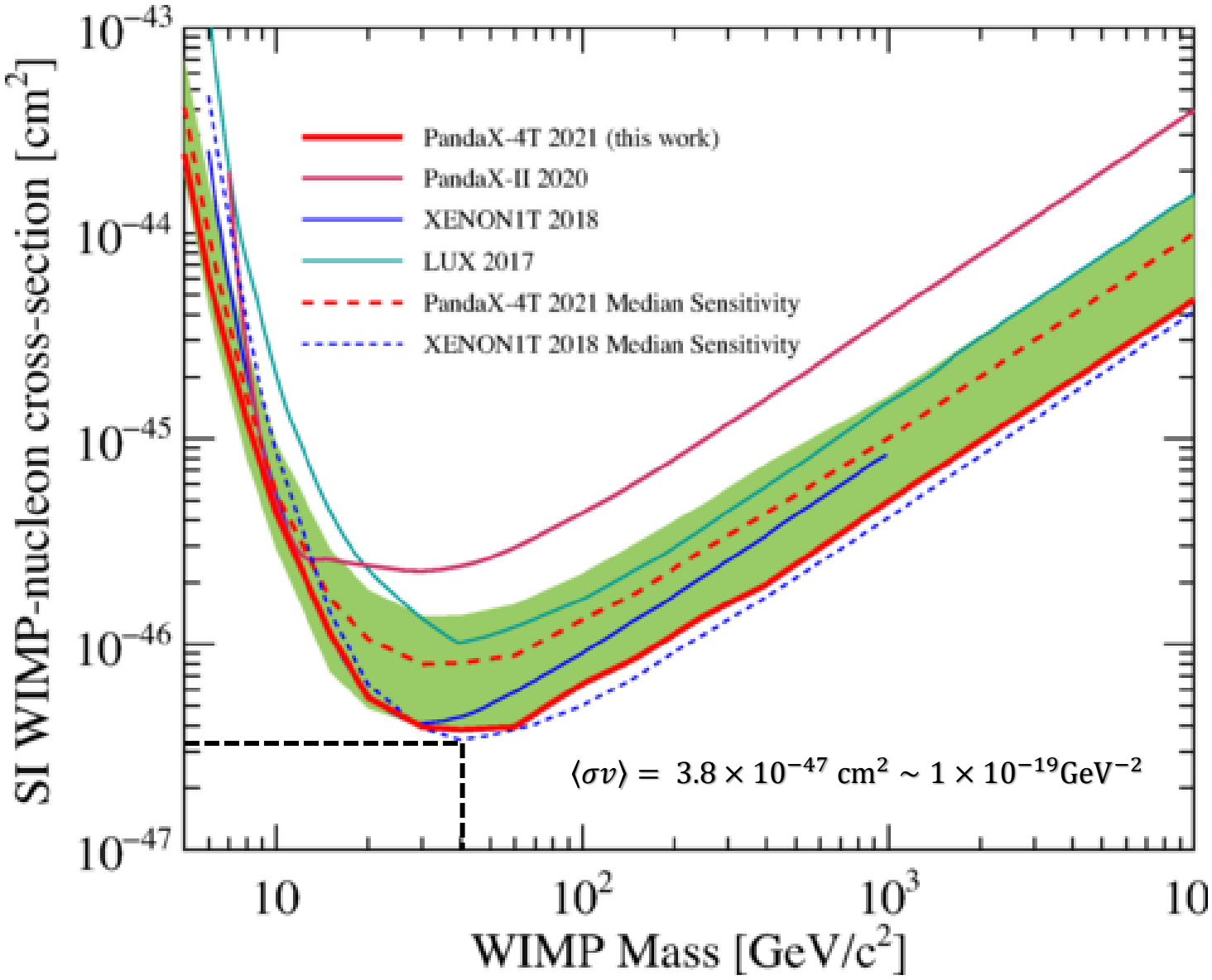
$m \sim 100\ GeV$

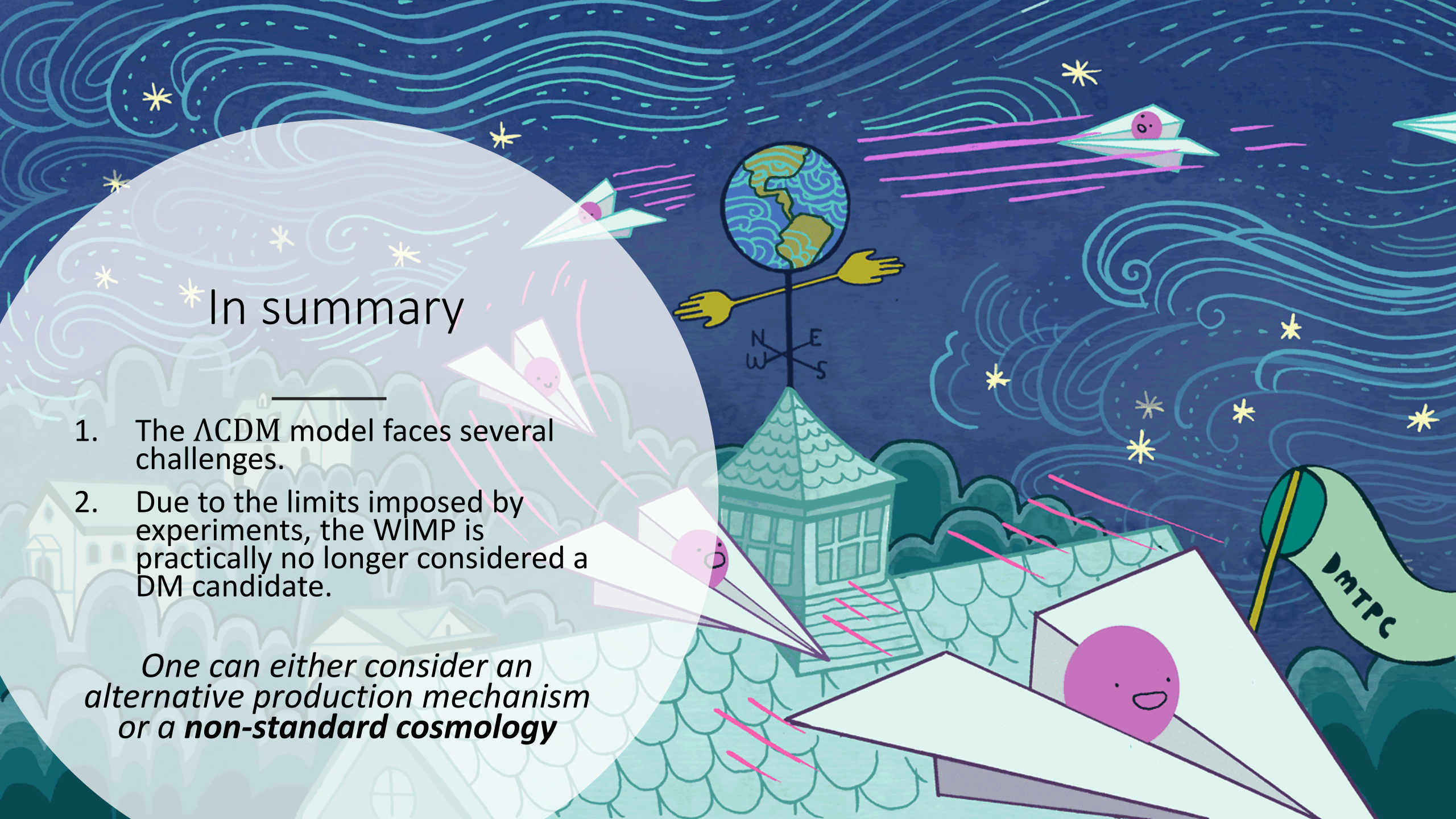
$\langle \sigma v \rangle \sim 10^{-9}\ GeV$

Detection of WIMPs

1. Direct detection
2. Indirect detection
3. Production in colliders

So restrictive upper limits for WIMPs cross-sections!





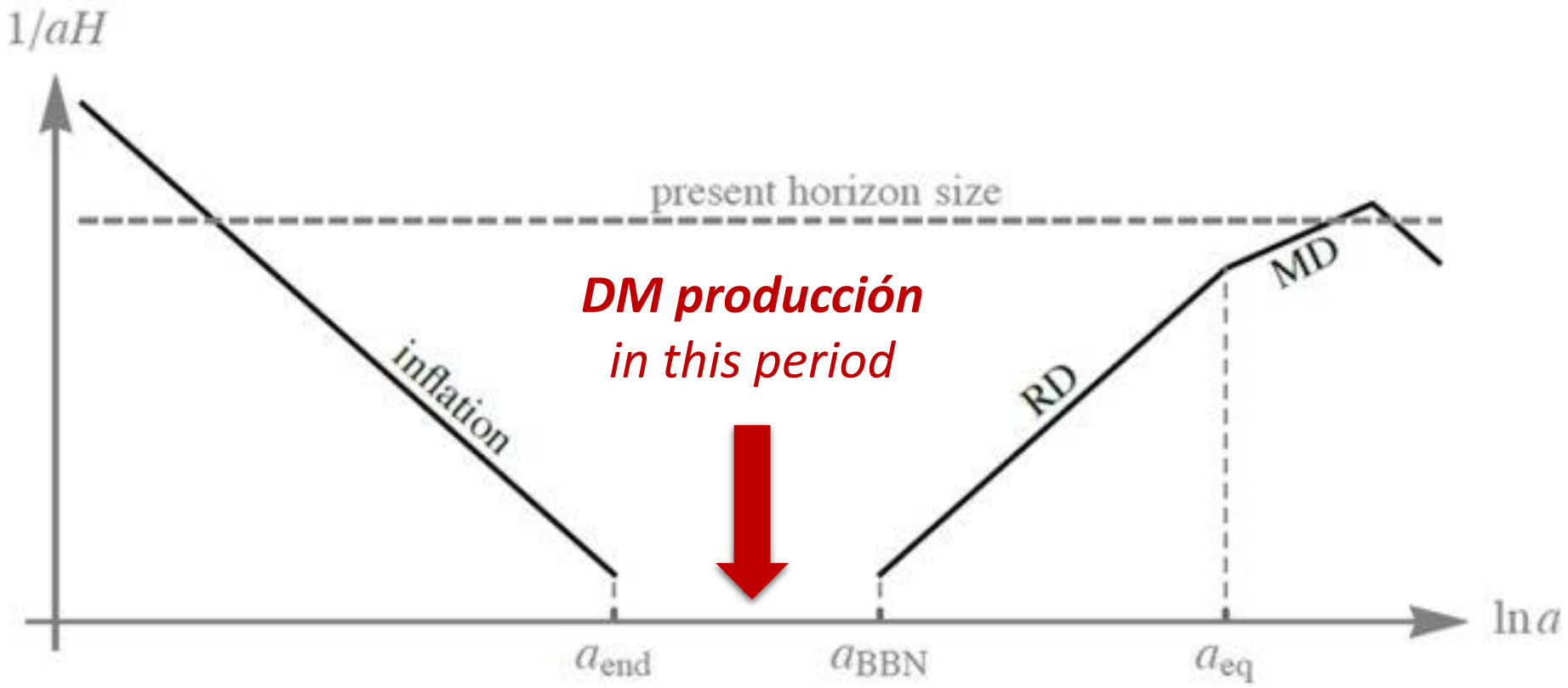
In summary

1. The ΛCDM model faces several challenges.
2. Due to the limits imposed by experiments, the WIMP is practically no longer considered a DM candidate.

One can either consider an alternative production mechanism or a ***non-standard cosmology***

Research project

To study the simplest WIMP-like DM model in the frame of a non-standard cosmology.



Research project

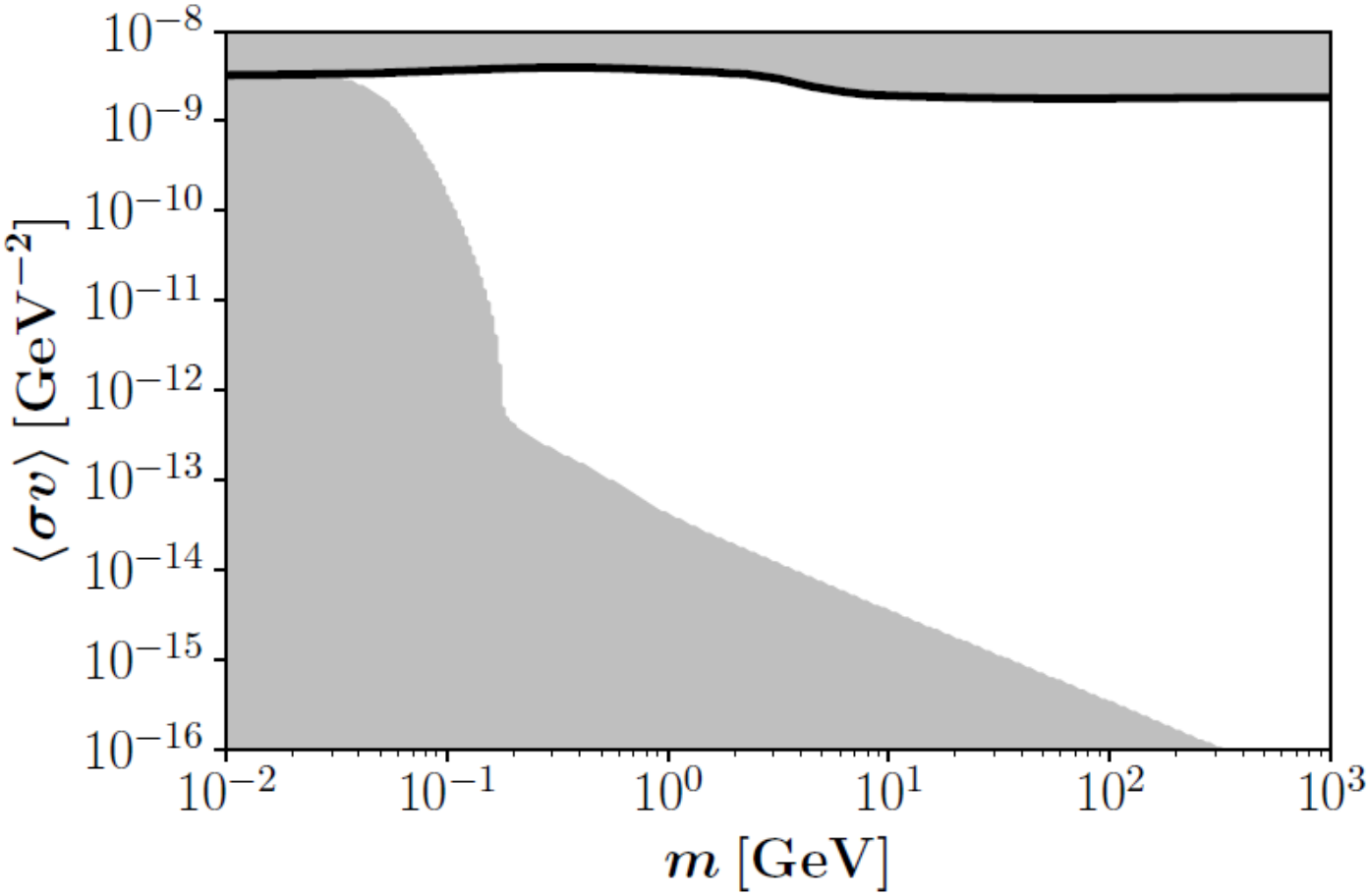


Figure 1. *Parameter space (in white) that could reproduce the observed DM abundance via the WIMP mechanism with non-standard cosmologies.*

P. Arias, et al., Reconstructing non-standard cosmologies with dark matter, Journal of Cosmology and Astroparticle Physics 2019 (10), 047-047.

Standard to Non-Standard Cosmology

Decoupled *system of* ***Boltzmann*** *differential equations.*

$$\frac{d\rho_\phi}{dt} + 3(1+w)H\rho_\phi = 0$$

$$\frac{ds}{dt} + 3Hs = 0$$

Coupled *system of* ***Boltzmann*** *differential equations.*

$$\frac{d\rho_\phi}{dt} + 3(1+w)H\rho_\phi = -\boldsymbol{\Gamma_\phi}\rho_\phi$$

$$\frac{ds}{dt} + 3Hs = c(T)\boldsymbol{\Gamma_\phi}\rho_\phi$$

$$\frac{dn}{dt} + 3Hn = -\langle\sigma v\rangle(n^2 - n_{eq}^2)$$

$$\frac{dn}{dt} + 3Hn = -\langle\sigma v\rangle(n^2 - n_{eq}^2)$$

Thermal production of Dark Matter

Research project

$$w = 0$$

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Reconstructing non-standard cosmologies with dark matter

Paola Arias,[a] Nicolás Bernal,[b] Alan Herrera[b,c] and Carlos Maldonado[a]

[a]Departmento de Física, Universidad de Santiago de Chile, Casilla 307, Santiago, Chile
[b]Centro de Investigaciones, Universidad Antonio Nariño, Carrera 3 Este # 47A-15, Bogotá, Colombia
[c]Department of Physics and Astronomy, University of Rochester, Rochester, NY 14627, U.S.A.

E-mail: paola.arias.r@usach.cl, nicolas.bernal@uan.edu.co, aherrer9@ur.rochester.edu, carlos.maldonados@usach.cl

Received June 17, 2019
Revised September 5, 2019
Accepted October 3, 2019
Published October 18, 2019

$$\Gamma_\phi = cte$$

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Increasing temperature toward the completion of reheating

Raymond T. Co,[a] Eric Gonzalez[a] and Keisuke Harigaya[b]

[a]Leinweber Center for Theoretical Physics, Department of Physics, University of Michigan, Ann Arbor, MI 48109, U.S.A.
[b]School of Natural Sciences, Institute for Advanced Study, Princeton, NJ 08540, U.S.A.

E-mail: rtco@umich.edu, ericgz@umich.edu, keisukeharigaya@ias.edu

Received July 21, 2020
Accepted October 5, 2020
Published November 19, 2020

$$\Gamma_\phi = \Gamma_\phi(t)$$

Research project

Temperature

$$\Gamma_\phi(a,T) = cH_{end}\left(\frac{a}{a_{end}}\right)^k\left(\frac{T}{T_{end}}\right)^q ;\quad H_{end} = \frac{\pi T_{end}^2}{3M_{pl}}\sqrt{\frac{g_*(T_{end})}{10}};\quad \kappa = \frac{\rho_\phi}{\rho_R}\Big|_{T=m}$$

Scale Factor

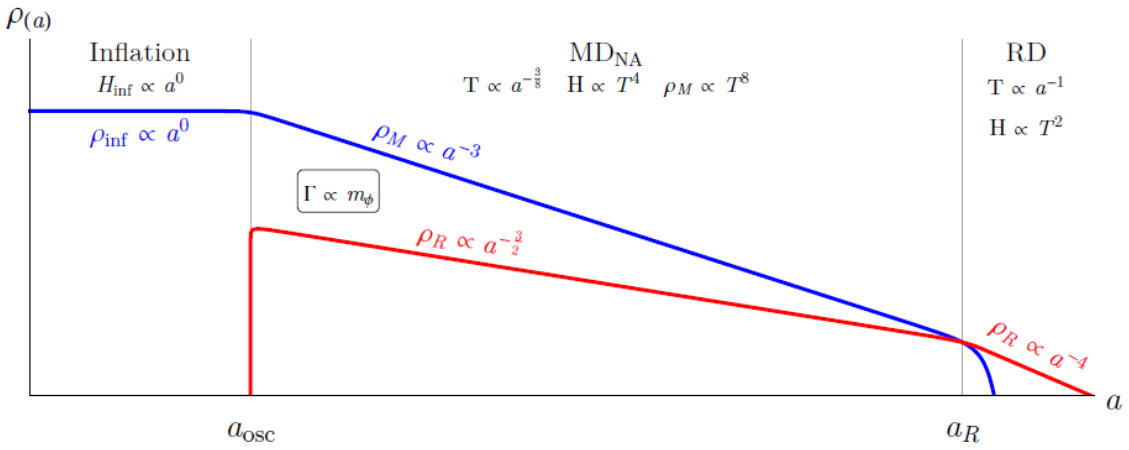
There are five free parameters:

$$\kappa,\ T_{end},\ k,\ q,\ w$$

Research project

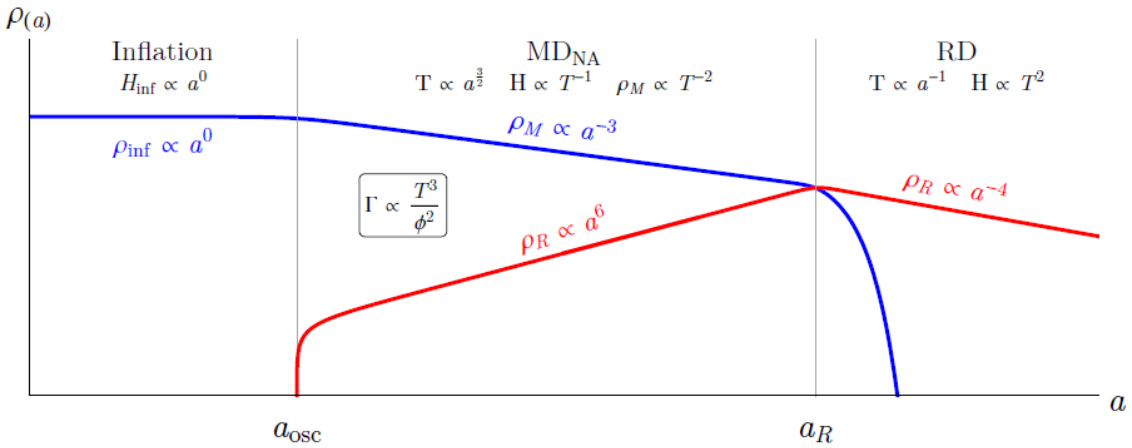
$$\Gamma_\phi(a,T) = cH_{end}\left(\frac{a}{a_{end}}\right)^k\left(\frac{T}{T_{end}}\right)^q$$

*Depending on **k** and **n**, the thermal history of the universe is modified.*



k=q=0

case with $\Gamma_\phi = cte$

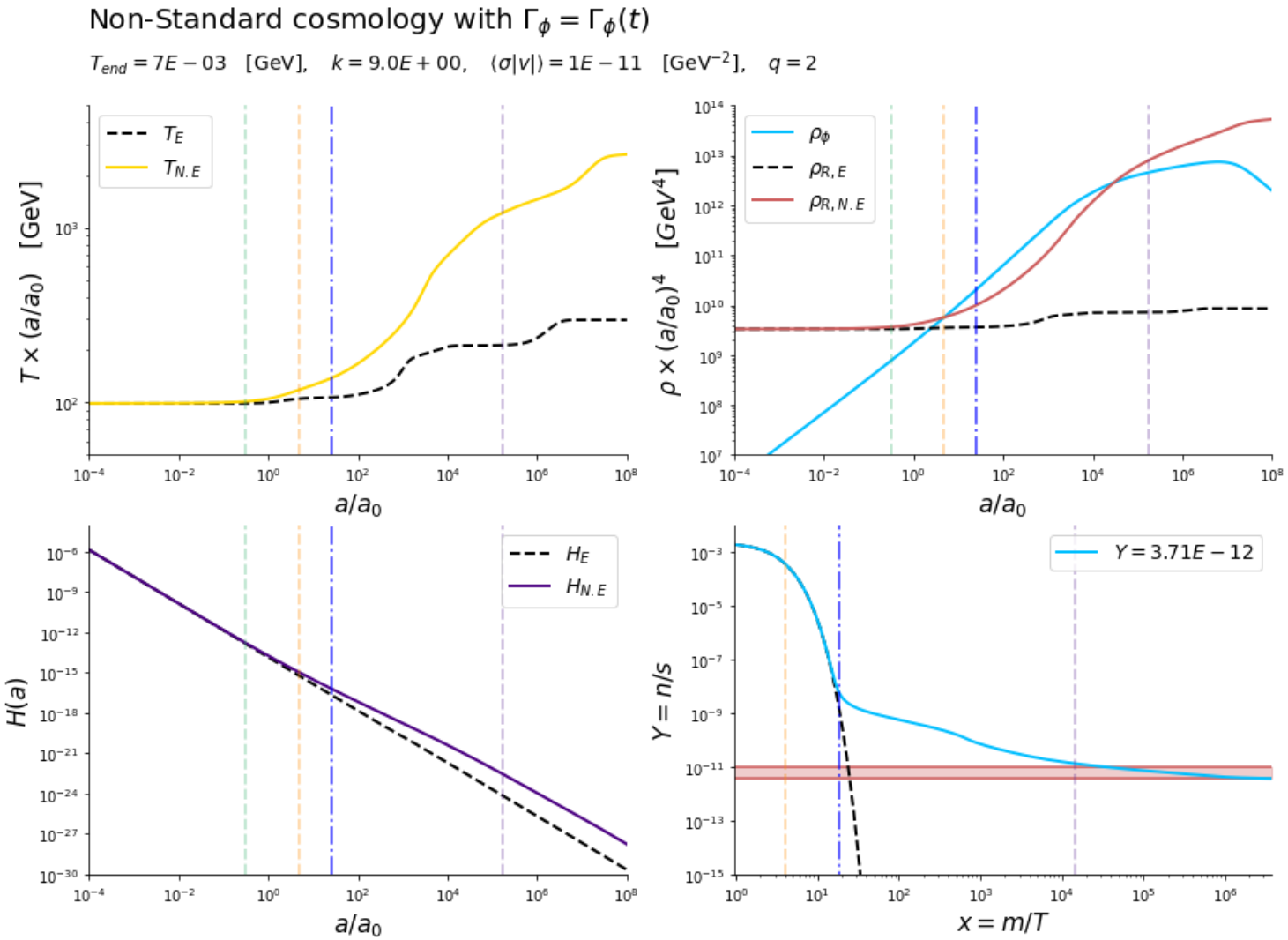


k=q=3

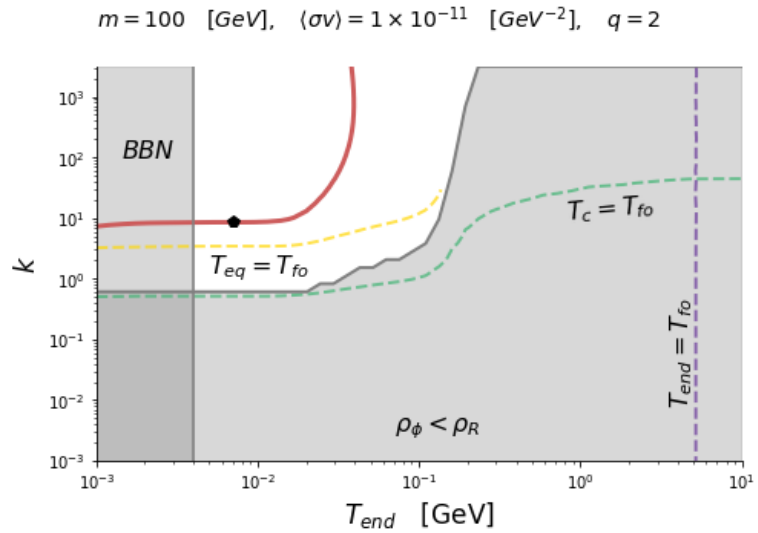
R. T. Co, et al., Increasing temperature toward the completion of reheating, Journal of Cosmology and Astroparticle Physics 2020 (11), 038–038.

Research project

$$\Gamma_\phi(a,T) = cH_{end}\left(\frac{a}{a_{end}}\right)^k\left(\frac{T}{T_{end}}\right)^q$$



k = 0; q = 2



THANK YOU!

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