HIDDeν
Hunting Invisibles: Dark sectors, Dark matter and Neutrinos

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN IN PUBLICA COMMODA SEIT 1737

University of Goettingen, Institute for Theoretical Physics

FIMP@DIRECT DETECTION

Francesco Costa

C. Cosme, FC, O. Lebedev, arXiv: 2306.13061
FC, L. Covi, to appear soon

FREEZE-IN AND ITS PROBLEMS

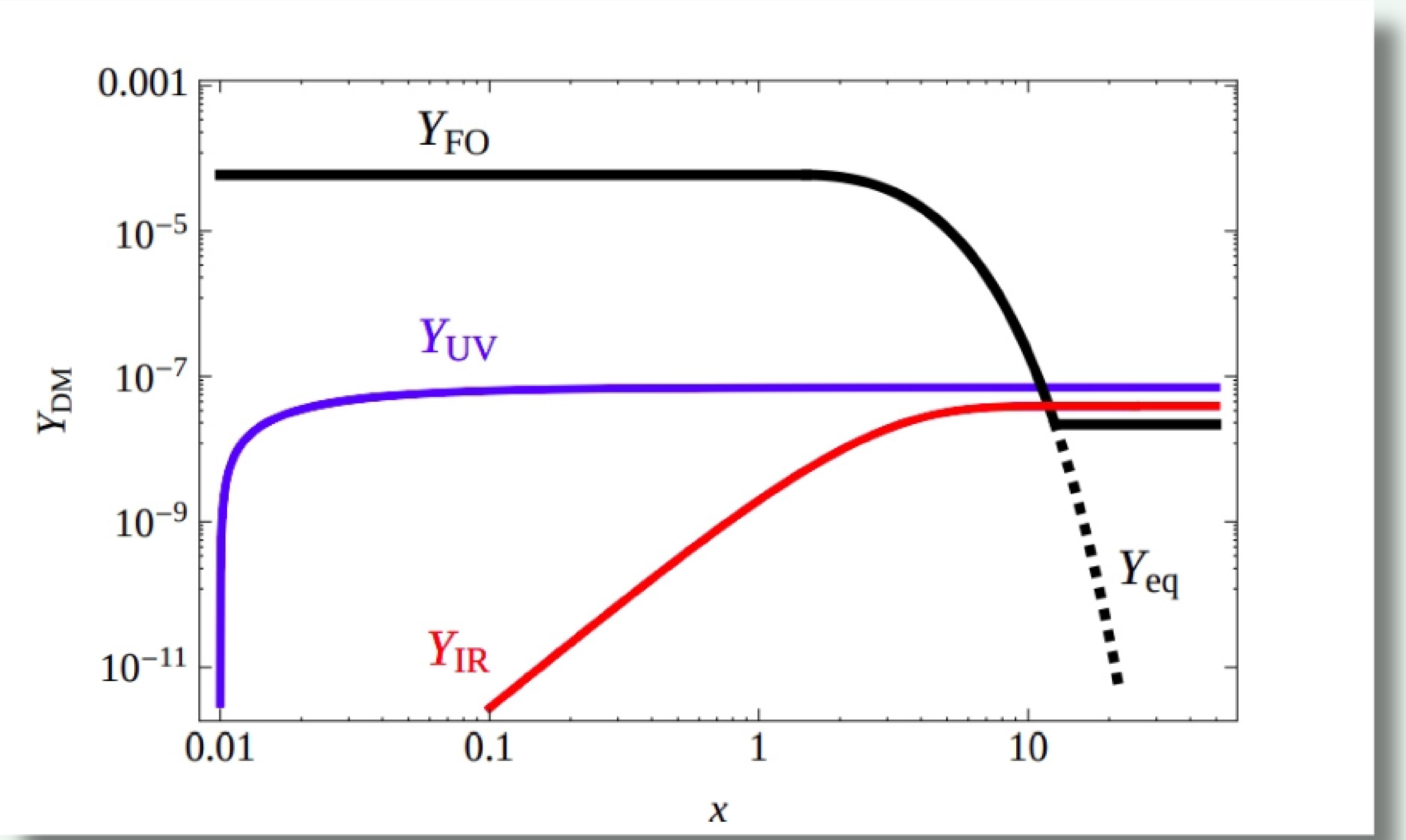
- Out-of-equilibrium
- Very low couplings
- Dependence on the initial conditions

IR freeze-in:

- Production peaks at the relevant mass

UV freeze-in:

- Production peaks at TR



J. McDonald, hep-ph/0106249
L. J. Hall, K. Jedamzik, J. March-Russell, S. M. West, 0911.1120
F. Elahi, C. Kolda, J. Unwin, 1410.6157

GRAVITATIONAL PRODUCTION

$$\ddot{X}_k + \left[\frac{9}{4}wH^2 + \frac{k^2}{a^2} + m_s^2\right] X_k = 0$$

Long wavelenght: $k/a \lesssim H$

→ The s "condensate" is ~ H or larger

Dilution

Inflaton quadratic potential

Example: $\frac{1}{2}m_\phi^2\phi^2$

Dilution factor $\Delta_{\mathrm{NR}} \equiv \left(\frac{H_{\mathrm{end}}}{H_{\mathrm{reh}}}\right)^{1/2} \simeq \frac{T_{\mathrm{inst}}}{T_R}$

A. A. Starobinsky, J. Yokoyama, astro-ph/9407016
L. H. Ford 2112.02444
P. J. E. Peebles, A. Vilenkin, astro-ph/9904396
O. Lebedev, 2210.02293

DURING INFLATION

O. Lebedev, 2210.02293
Y. Ema, R. Jinno, K. Mukaida, K. Nakayama, 1502.02475

$$\Delta_{\rm NR} \gtrsim 10^7 \lambda_s^{-3/4} \left(\frac{H_{\rm end}}{M_{\rm Pl}}\right)^{3/2} \left(\frac{m_s}{\rm GeV}\right)$$

INFLATON OSCILLATION

$$\Delta_{\rm NR} \gtrsim 10^6 \left(\frac{H_{\rm end}}{M_{\rm Pl}}\right)^{3/2} \left(\frac{m_s}{\rm GeV}\right)$$

QUANTUM GRAVITY

$$C\frac{\phi^4 s^2}{M_{\rm Pl}^2} \rightarrow \Delta_{\rm NR} \gtrsim 10^6 C^2 \frac{\phi_0^8}{H_{\rm end}^{5/2} M_{\rm Pl}^{11/2}} \frac{m_s}{\rm GeV}$$

GRAVITATIONAL PRODUCTION

FEEBLE COUPLINGS

BOLTZMANN SUPPRESSION

Scalar potential

$$V(s) = \frac{1}{2}\lambda_{hs} s^2 H^\dagger H + \frac{1}{2} m_s^2 s^2$$

Boltzmann equation

$$\dot{n} + 3Hn = \Gamma\left(h_i h_i \to ss\right) - \Gamma\left(ss \to h_i h_i\right)$$

Freeze-in rate

$$\Gamma\left(h_i h_i \to ss\right) = \langle \sigma\left(h_i h_i \to ss\right) v_r \rangle\, n_h^2 = \frac{2\pi^2 T}{(2\pi)^6} \int_{4m_s^2}^{\infty} d\, \mathrm{s}\sigma \left(\mathrm{s} - 4m_h^2\right) \sqrt{\mathrm{s}} K_1(\sqrt{\mathrm{s}}/T)$$

$$\Gamma(h_i h_i \to ss) \simeq \frac{\lambda_{hs}^2 T^3 m_s}{2^7 \pi^4}\, e^{-2m_s/T}$$

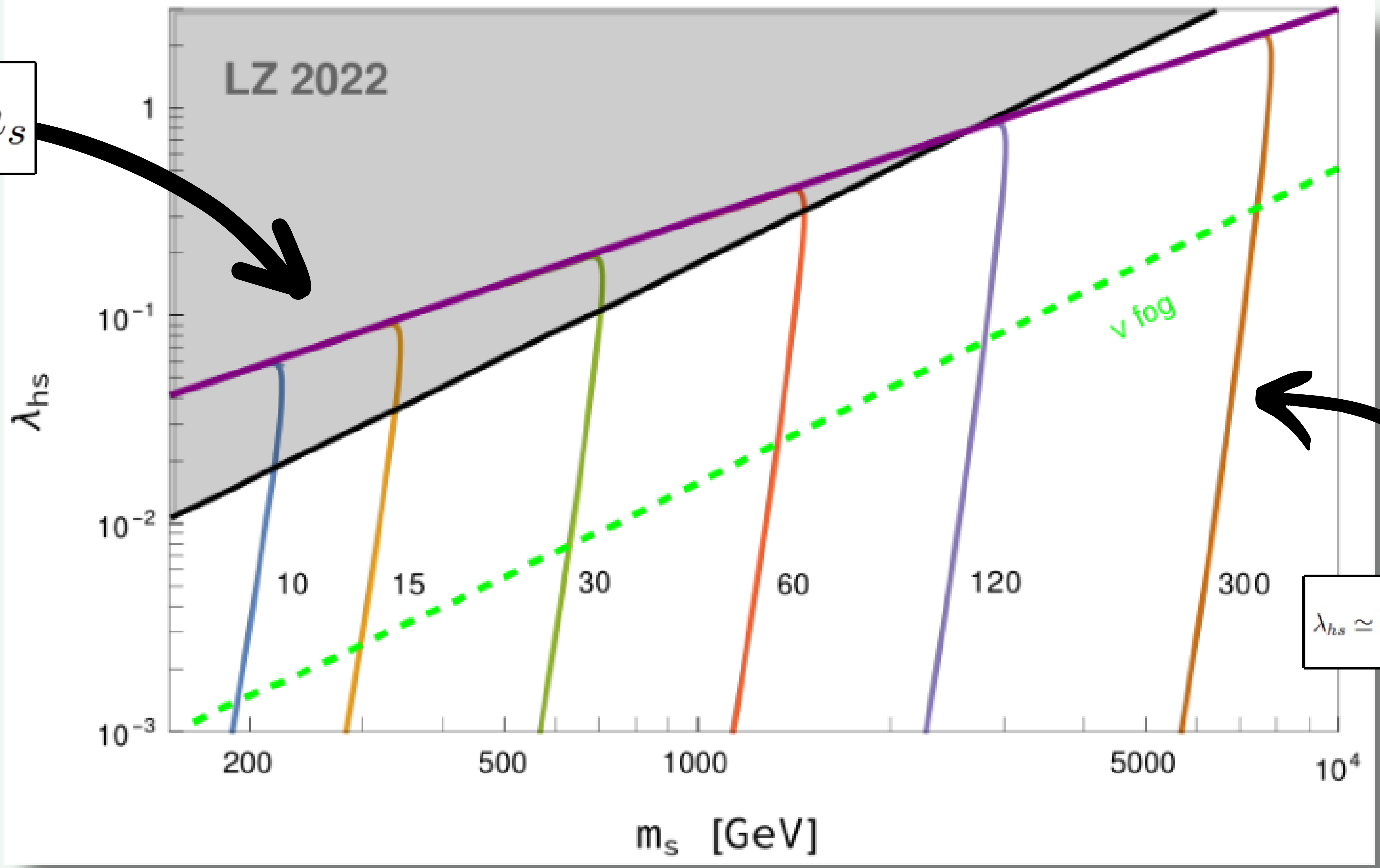
$$\lambda_{hs} \simeq 3 \times 10^{-11}\, e^{m_s/T_R} \sqrt{\frac{T_R}{m_s}}$$

C. Cosme, FC, O. Lebedev, arXiv: 2306.13061

C. Cosme, FC, O. Lebedev, arXiv: 2306.13061

DIRECT DETECTION

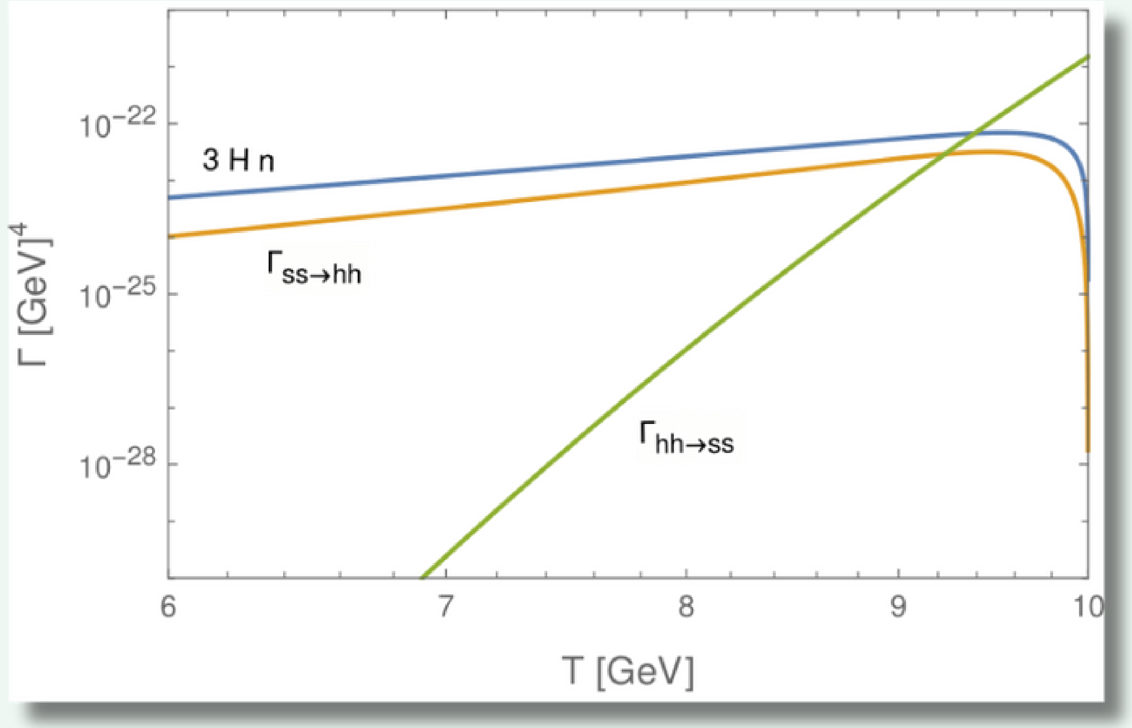
$$\lambda_{hs} \propto m_s$$



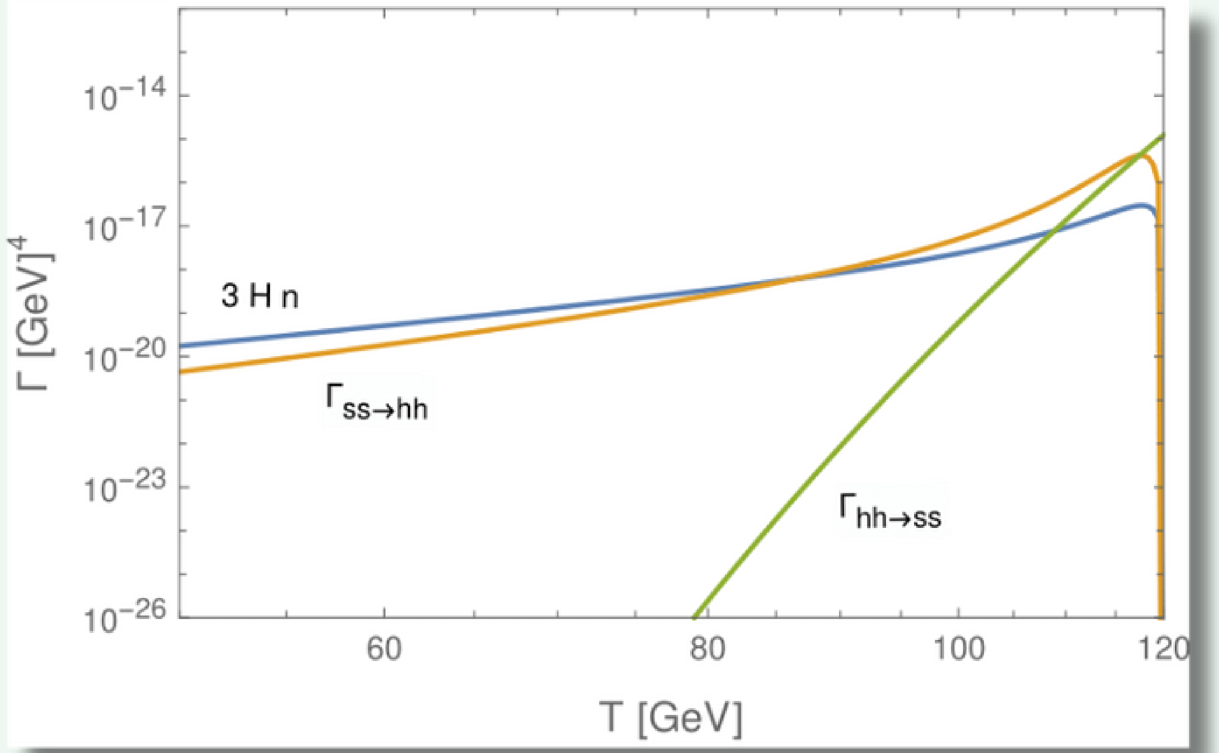
$$\lambda_{hs} \simeq 3 \times 10^{-11}\, e^{m_s/T_R} \sqrt{\frac{T_R}{m_s}}$$

THREE REGIMES

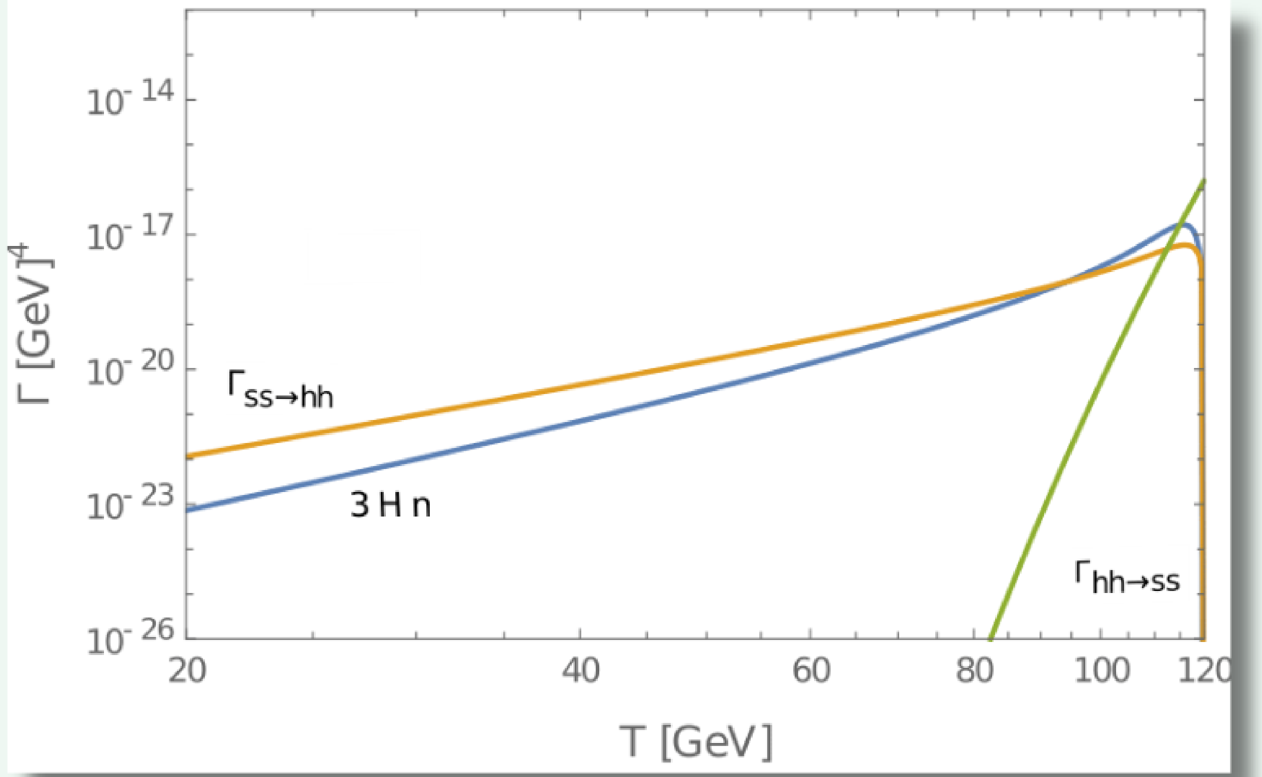
Boltzmann suppressed freeze-in



Annihilation becomes relevant



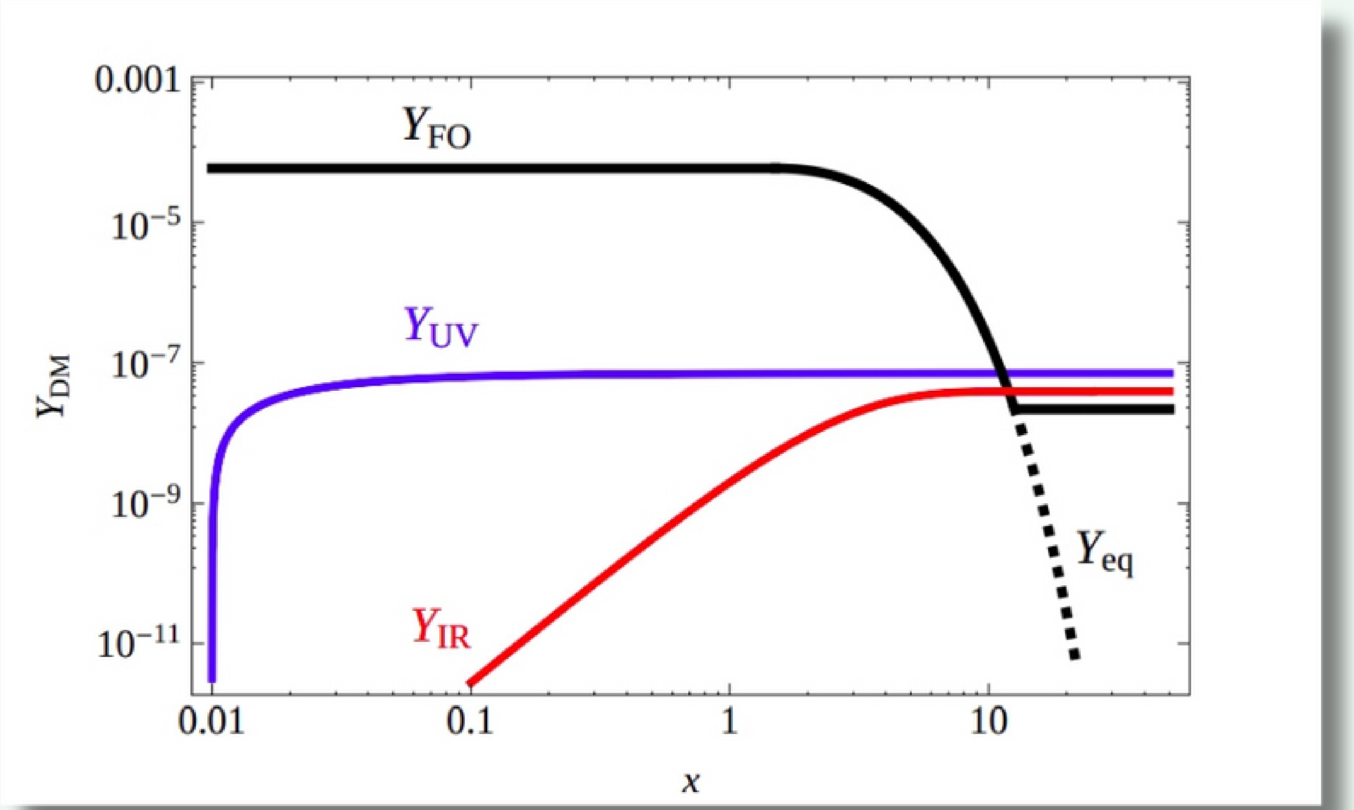
Dark Matter thermalises



C. Cosme, FC, O. Lebedev, arXiv: 2306.13061

William Rarita and Julian Schwinger, Phys. Rev. 60, 61

SPIN 3/2 DM: A NATURAL UV FIMP



Rarita Schwinger Lagrangian

$$\mathcal{L}_{RS} = -\frac{1}{2}\epsilon^{\mu\nu\rho\sigma}\bar{\Psi}_\mu\gamma_5\gamma_\nu\partial_\rho\Psi_\sigma - \frac{1}{4}m_\Psi\bar{\Psi}_\mu\left[\gamma^\mu,\gamma^\nu\right]\Psi_\nu$$

with the conditions

$$\gamma_\mu\psi^\mu = 0 \qquad \partial_\mu\psi^\mu = 0$$

Spin sum

$$\Pi(p)_{\mu\nu} = \sum_{spin} u(p)^s_\mu\bar{u}(p)^s_\nu = -\left(\not{p} + m_\Psi\right)\left(P_{\mu\nu} - \frac{1}{3}P_{\mu\rho}P_{\nu\sigma}\gamma^\rho\gamma^\sigma\right), \quad P_{\alpha\beta} \equiv g_{\alpha\beta} - \frac{p_\alpha p_\beta}{m_\Psi^2}$$

$$\mathcal{L} \supset \frac{\alpha_3}{\Lambda}\bar{\psi}_\mu \psi^\mu |H|^2$$

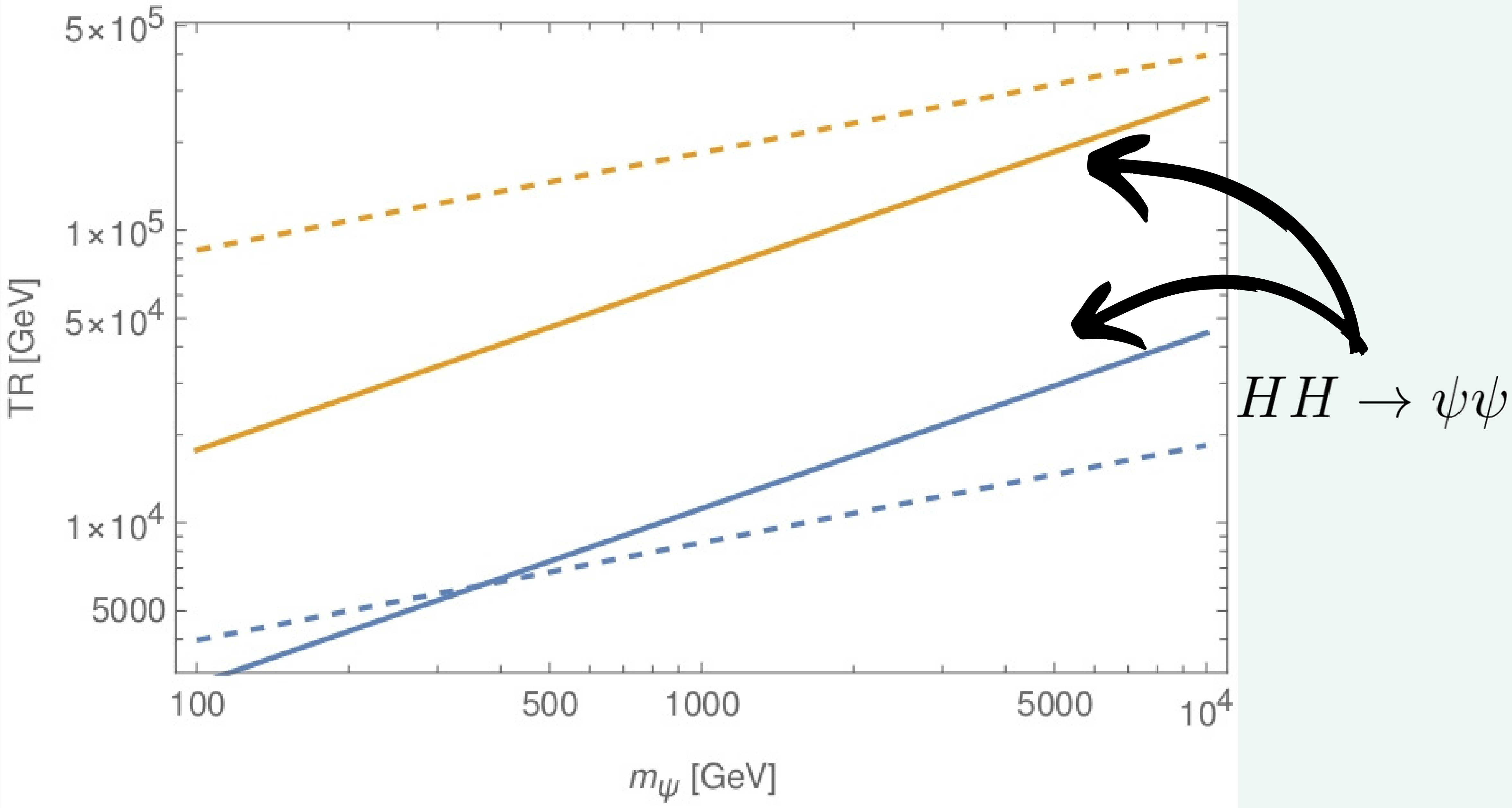
FC, L. Covi, to appear soon

RELIC DENSITY (HIGH TR)

$$|\mathcal{M}|^2 \propto \left(\frac{1}{\Lambda}\right)^2 \frac{s^3}{m_\psi^4}$$

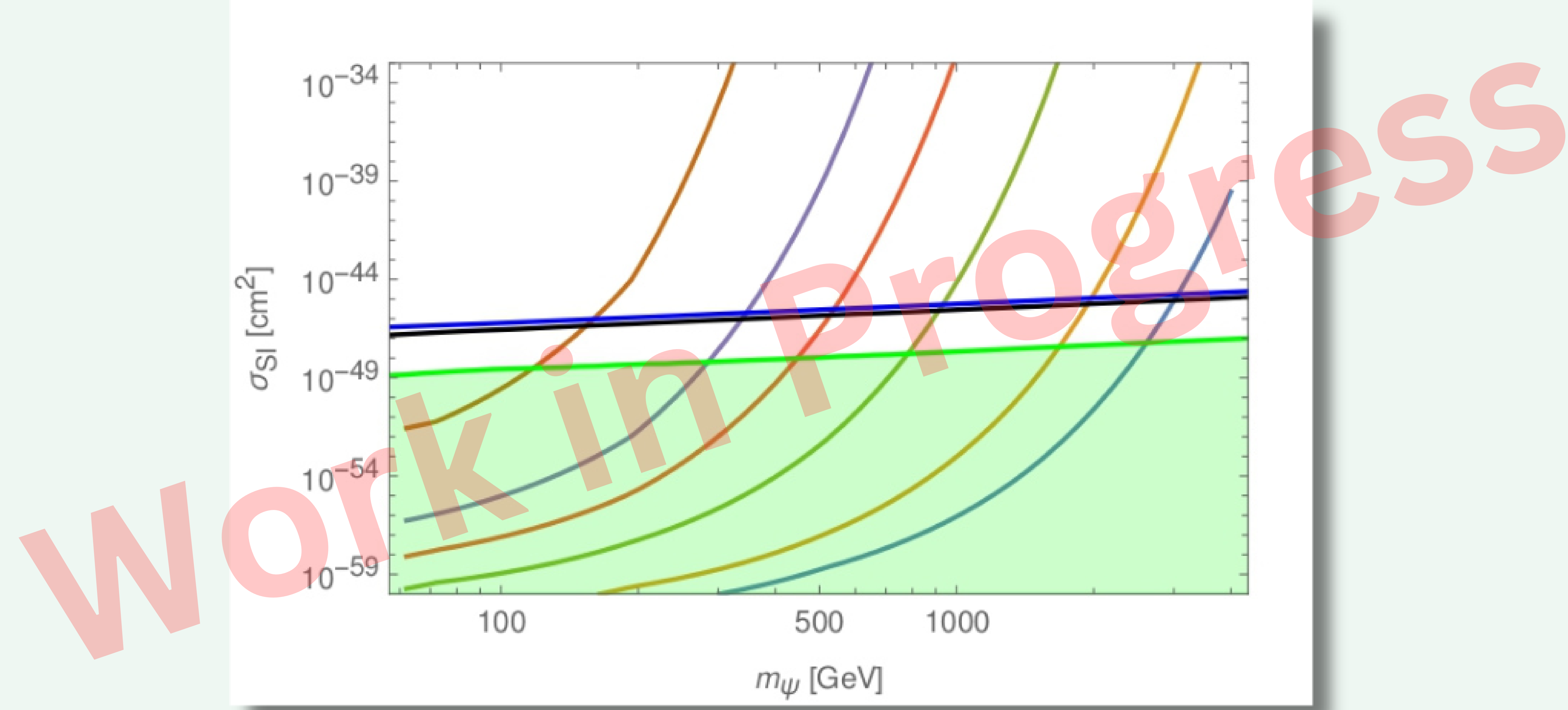
Boltzmann equation

$$m_\psi Y \propto \frac{T_R^5}{\Lambda^2}\frac{M_{pl}}{m_\psi^3}$$



FC, L. Covi, to appear soon

DIRECT DETECTION (LOW TR)



GRAVITATIONAL PRODUCTION

DIRECT DETECTION

THANK YOU

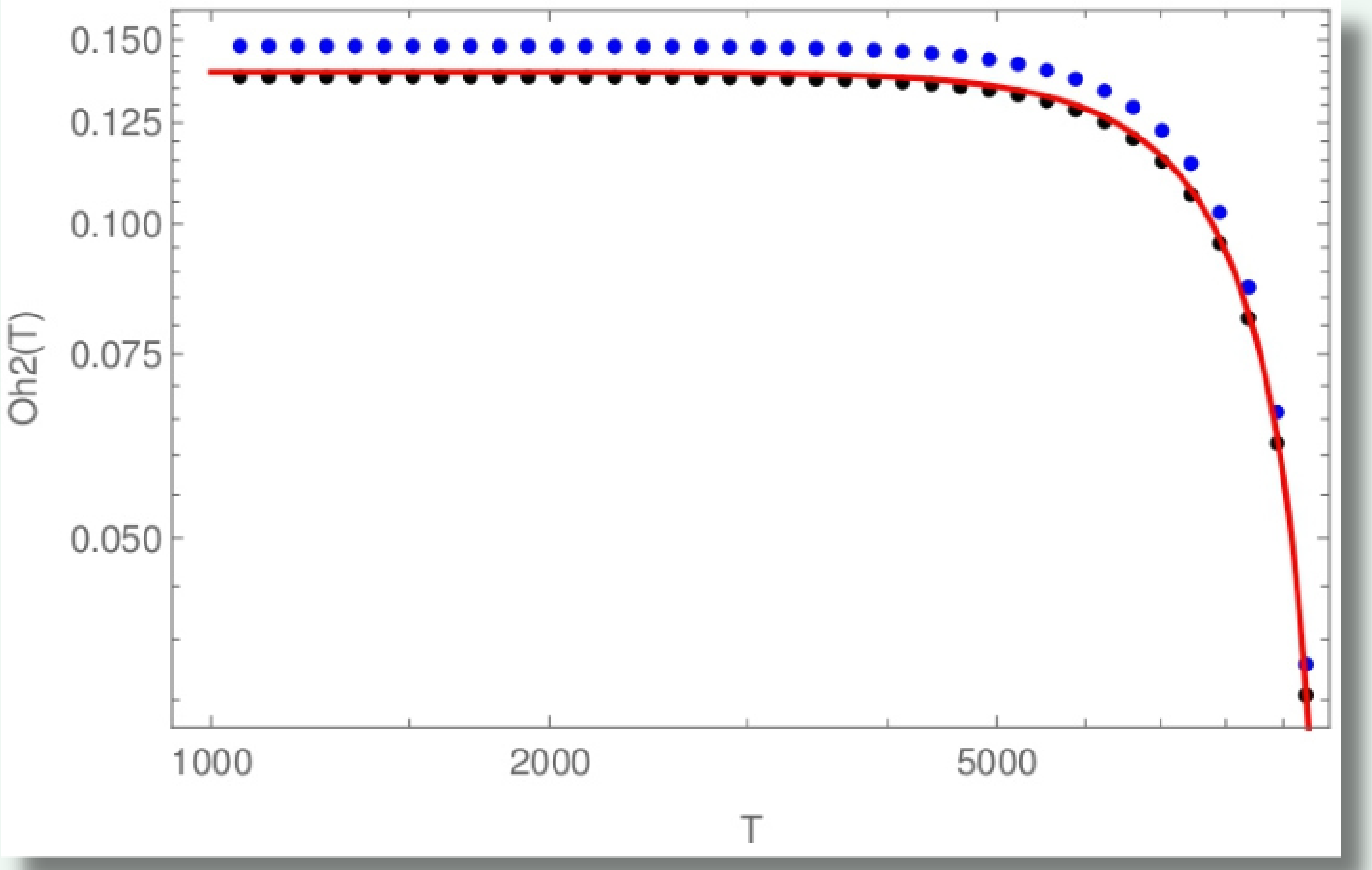
Presentation by Francesco Costa

University of Goettingen

This project has received funding/support from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 860881-HIDDeN

BACK-UP

Relativistic effect



Non-instantaneous reheating

$$m_\psi Y = 4 \times m_\psi Y_{inst}$$