Stockholm University

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21 CM COSMOLOGY AND SPIN-DEPENDENT DARK MATTER

AXEL WIDMARK

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21 cm cosmology and spin temperature reduction via spin-dependent dark matter interactions

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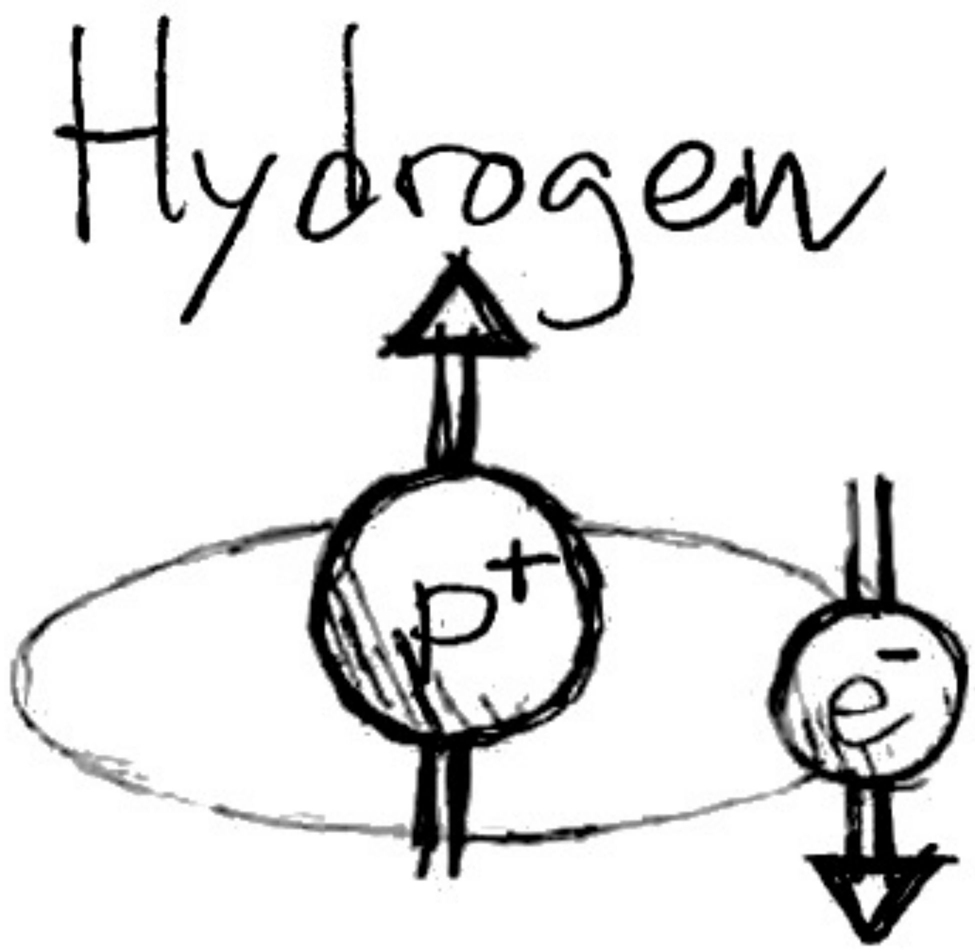
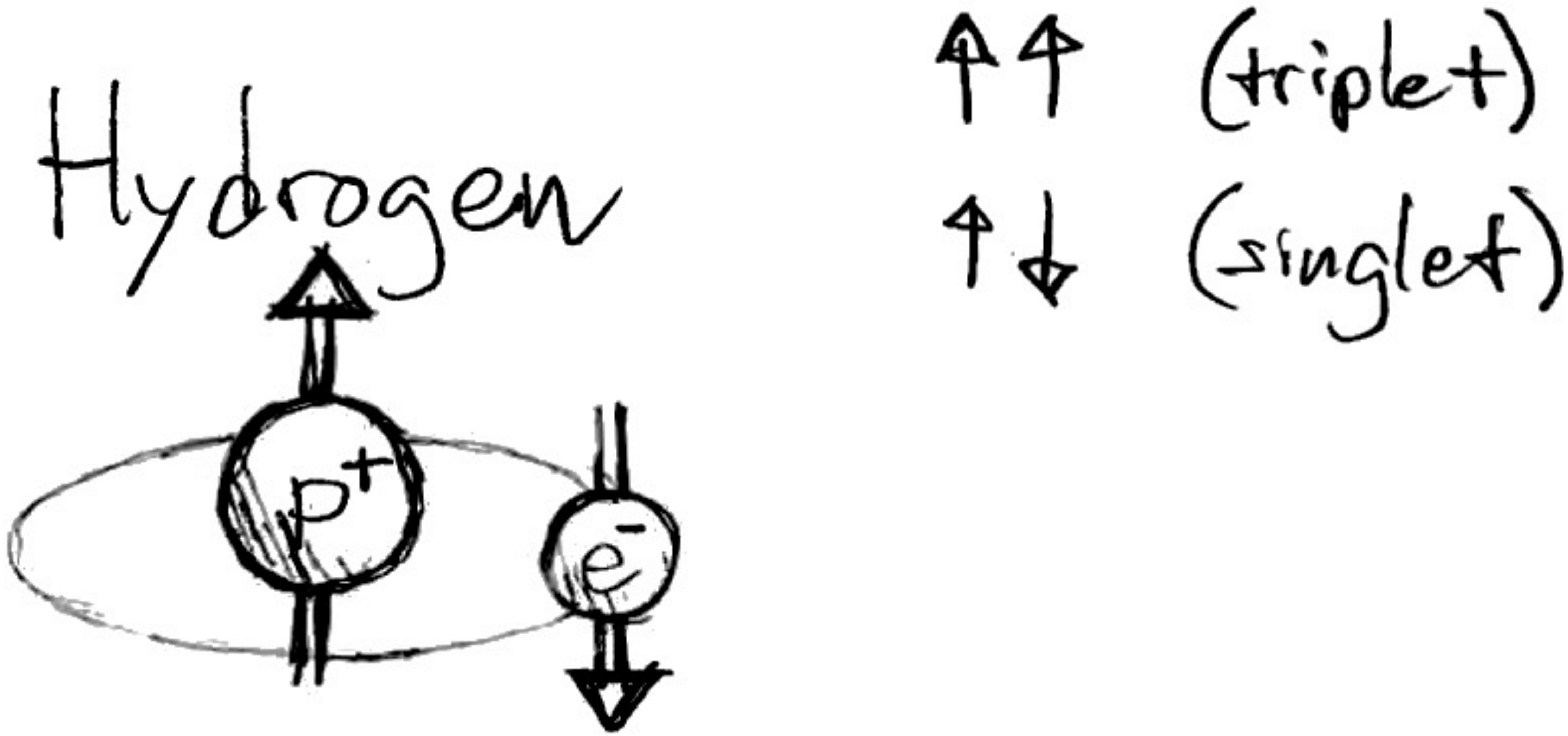
BACKGROUND

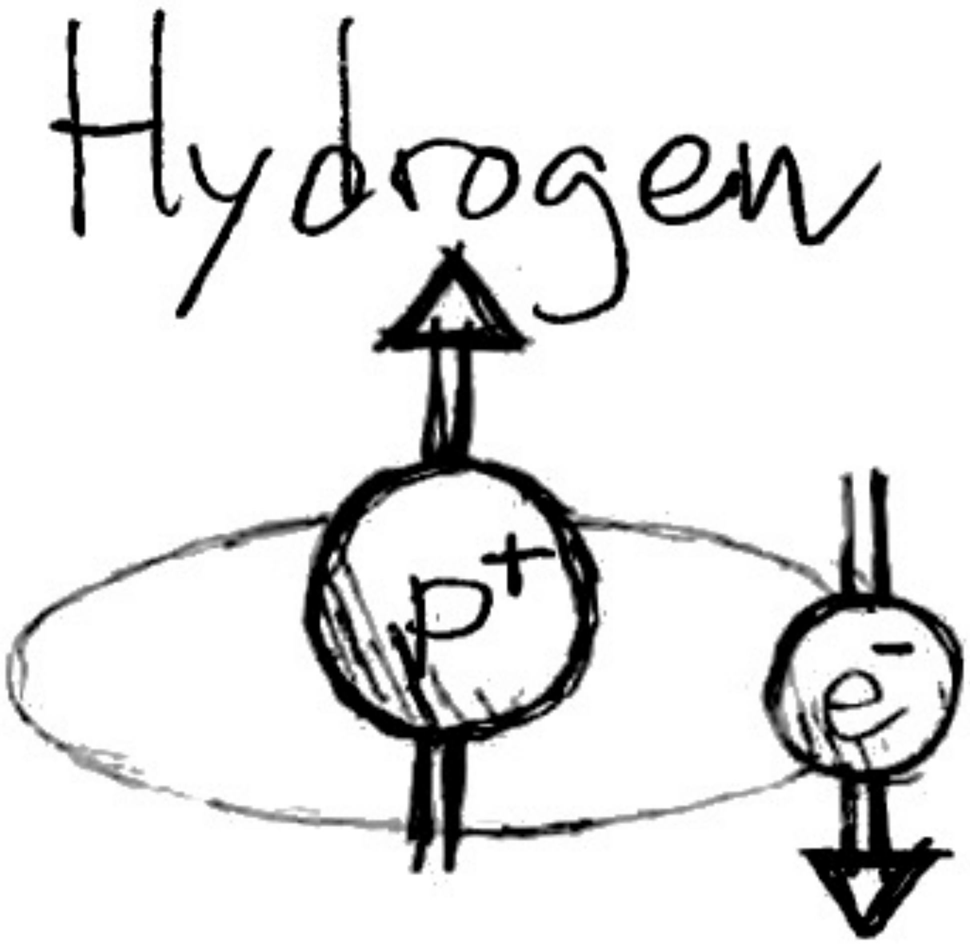
HYPERFINE STRUCTURE



HYPERFINE STRUCTURE



HYPERFINE STRUCTURE



↑↑ (triplet)

↑↓ (singlet)

$$E_* = 5.9\ \mu eV$$

$$T_* = 0.068\ K$$

$$\lambda_* = 21\ cm$$

SPIN TEMPERATURE

$$\frac{n_{\uparrow\uparrow}}{n_{\uparrow\downarrow}} = 3e^{-\frac{T_*}{T_s}}$$

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Spontaneous decay rate

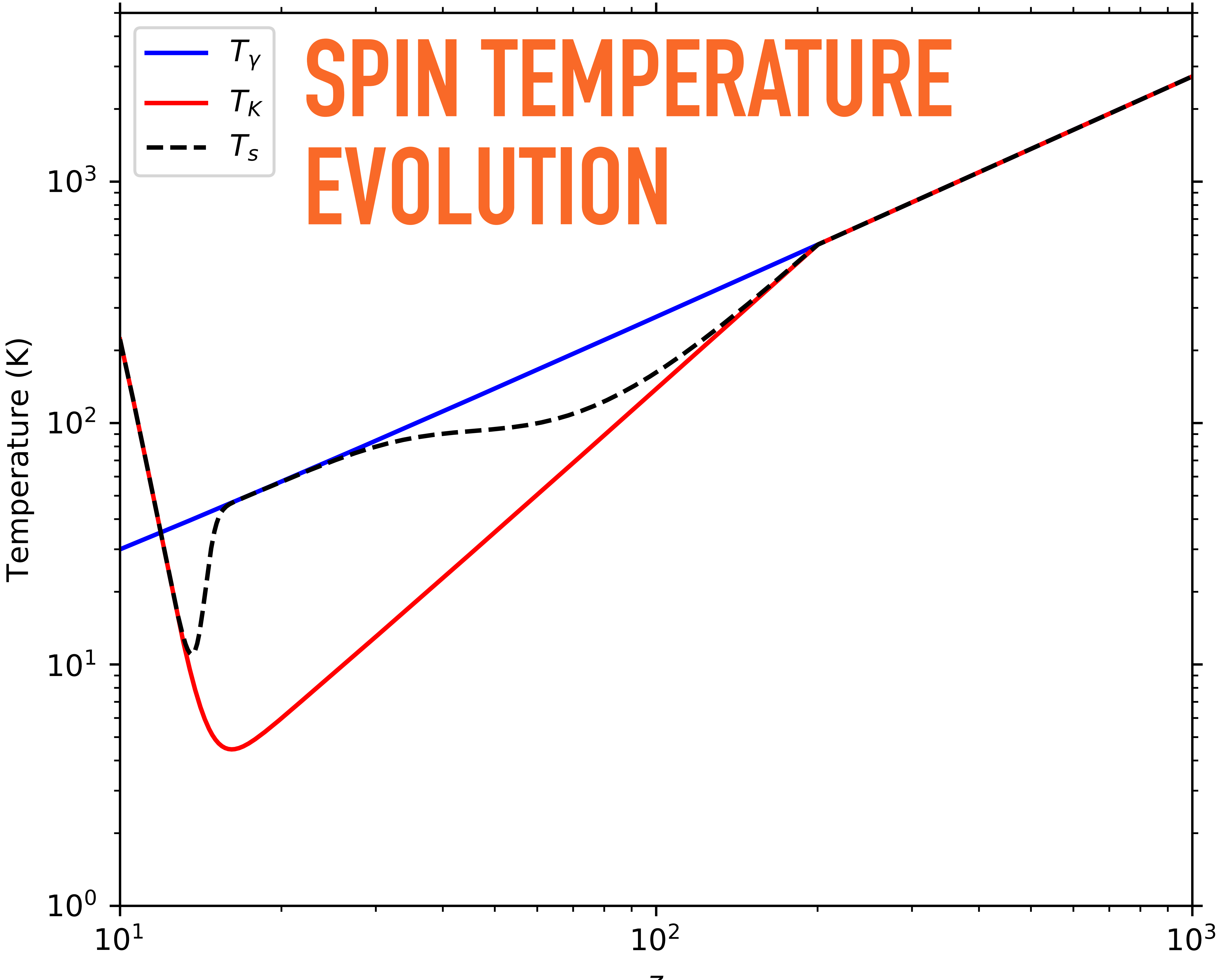
$$A_{-} = 2.85 \times 10^{-15}\ s^{-1}$$

SPIN TEMPERATURE

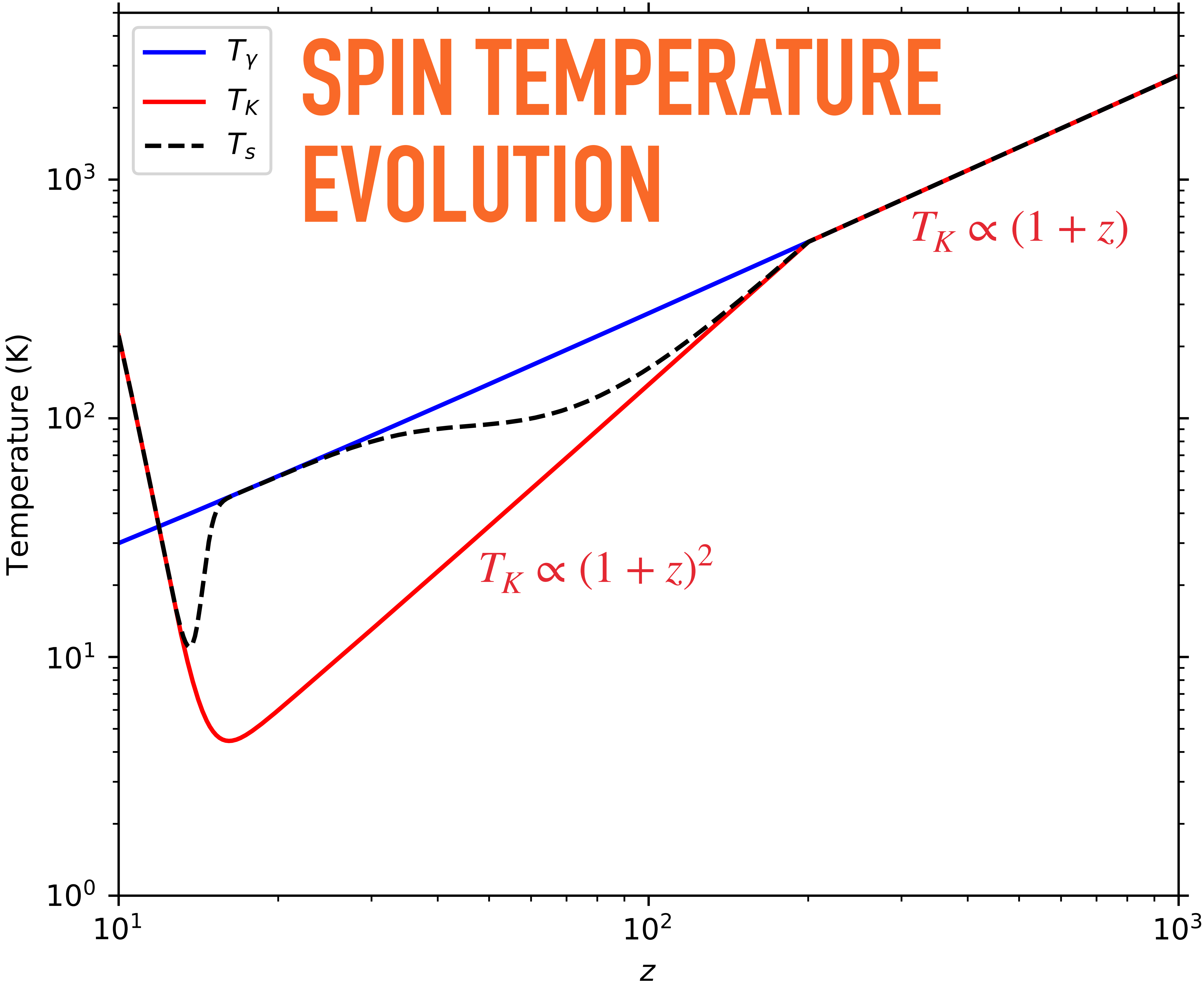
$$\frac{n_{\uparrow\uparrow}}{n_{\uparrow\downarrow}} = 3e^{-\frac{T_*}{T_S}} = \frac{P_+^{\gamma} + P_+^{\kappa} + P_+^{\alpha}}{P_-^{\gamma} + P_-^{\kappa} + P_-^{\alpha}}$$

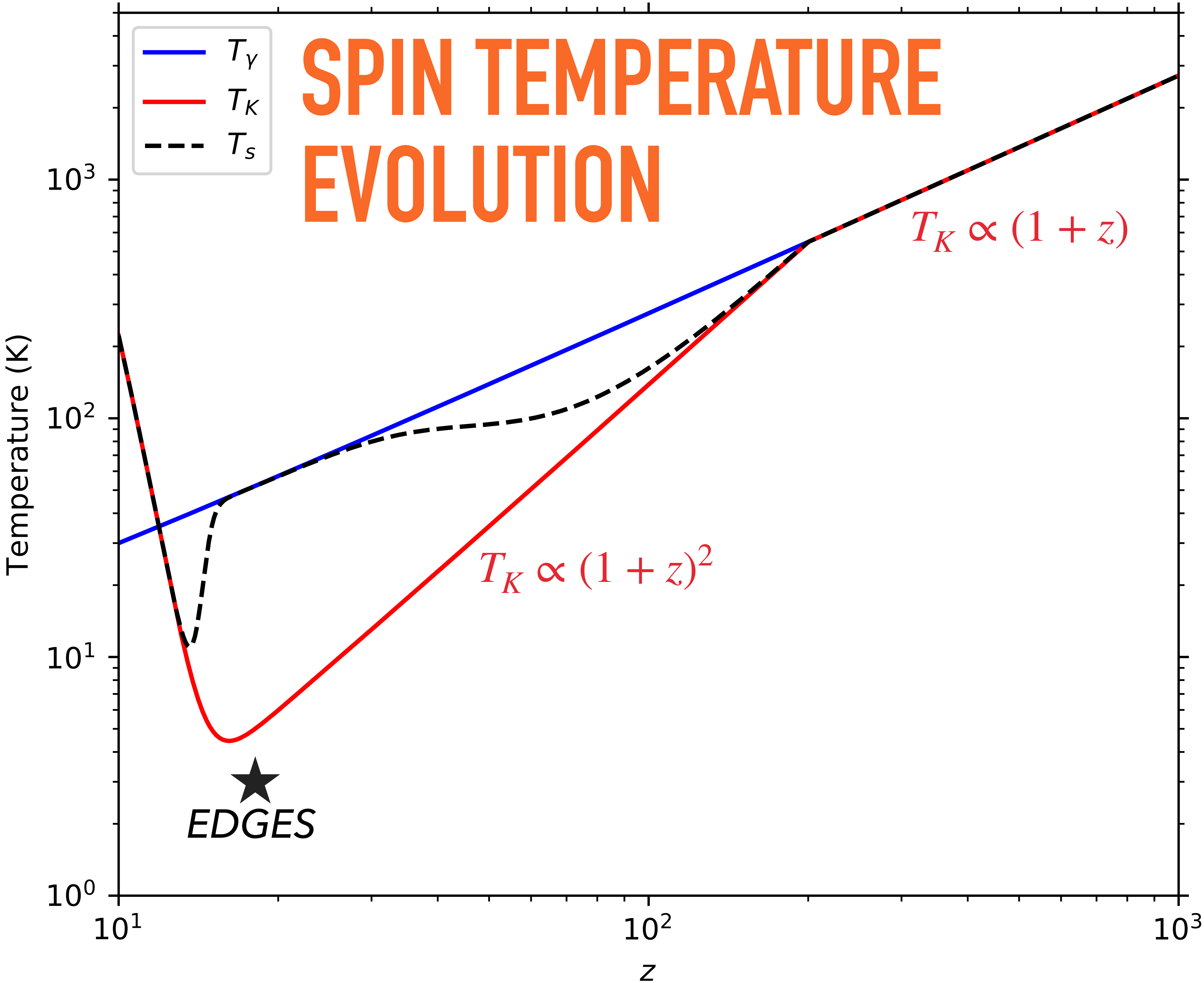
Spontaneous decay rate

$$A_- = 2.85 \times 10^{-15}\ s^{-1}$$


SPIN TEMPERATURE EVOLUTION
T_γ
T_K
T_s
Temperature (K)
z
10^0
10^1
10^2
10^3

SPIN TEMPERATURE EVOLUTION




SPIN TEMPERATURE EVOLUTION
T_γ
T_K
T_s
$T_K \propto (1+z)$
$T_K \propto (1+z)^2$
EDGES
Temperature (K)
10^0
10^1
10^2
10^3
z
10^1
10^2
10^3

INTRODUCING A DARK SECTOR

DARK SECTOR COOLING

- Can a cold dark matter component explain the *EDGES* signal?
  - Reduce the kinetic temperature of the hydrogen gas, ~2 % DM subcomponent of milli-charged dark matter (Berlin et al. 2018, Muñoz et al. 2018, Barkana et al. 2018)
- Alternate idea: affect the spin temperature directly, via spin dependent dark matter interactions

SPIN DEPENDENT DARK MATTER

- Light dark matter fermion: χ (~MeV)
- Very light pseudo-vector force mediator: V (~eV)
- Hydrogen and dark fermion masses are mismatched – ineffective momentum transfer
- Cross section is enhanced like v^{-4}, down to $v/c \simeq m_V/m_\chi$
- Further enhancement from collision inelasticity

DEEXCITATION (1)

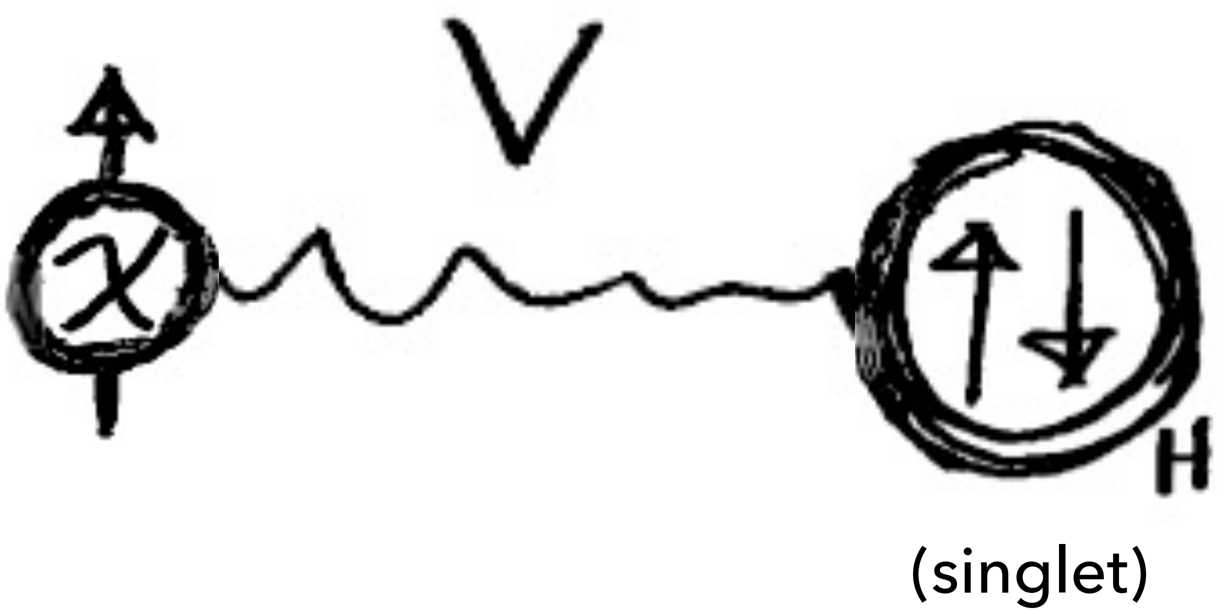
DM fermion

Hydrogen atom

(triplet)

DEEXCITATION (2)

DEEXCITATION (3)

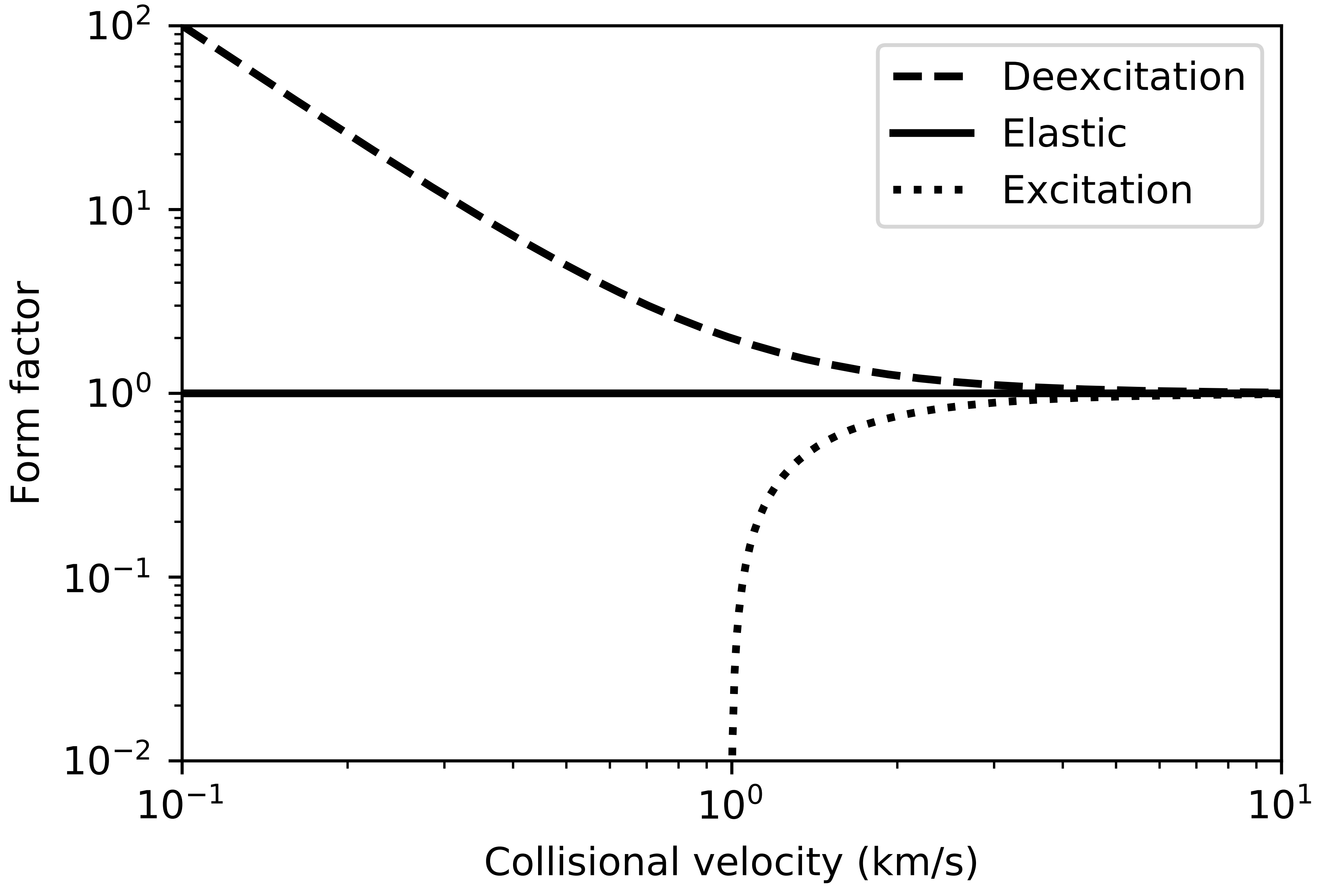


DEEXCITATION (4)

excess energy
is carried away
by DM fermion

(singlet)

INELASTIC FORM FACTOR



EFFECTIVE TEMPERATURE

- The hydrogen and DM gas temperatures are different ($T_K \neq T_\chi$), but the relative velocity between them can be parametrised by an effective temperature

$$\tilde{T}(m_H^{-1} + m_\chi^{-1}) = T_H m_H^{-1} + T_\chi m_\chi^{-1}$$

- In the ideal case, where $m_\chi \ll m_H$ and $T_\chi = 0$, we get

$$\tilde{T} = \frac{m_\chi}{m_H} T_H$$

DARK SECTOR LIMITS

COUPLING CONSTANTS

$$\mathscr{L} \supset g_\chi V_\mu \bar{\chi} \gamma^\mu \gamma^5 \chi + g_N V_\mu \bar{N} \gamma^\mu \gamma^5 N$$

DM-nucleon interaction: $$\sigma_{\chi N} = \frac{g_\chi^2 g_N^2 m_\chi^2}{4\pi[(m_\chi v/c)^2 + m_V^2]^2}$$

DM self-interaction: $$\sigma_{\chi\chi} = \frac{g_\chi^4 m_\chi^2}{8\pi[(m_\chi v/c)^2 + m_V^2]^2}$$

LIMITS FROM DM SELF-INTERACTION

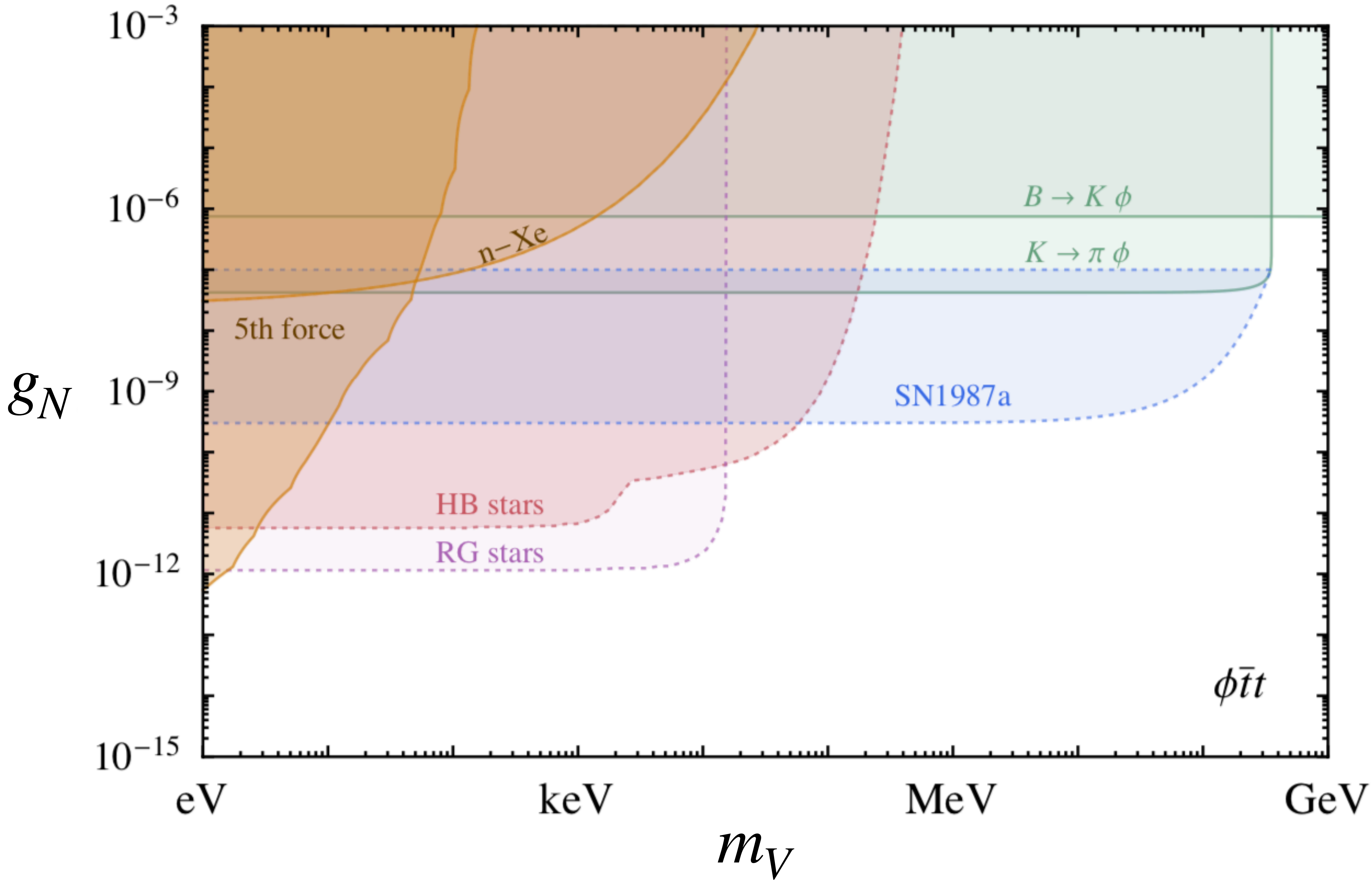
Bullet Cluster: $$g_\chi^4 \lesssim 1.8 \times 10^{-13} \left(\frac{m_\chi}{\text{MeV}}\right)^3$$

If we consider a DM subcomponent (<30 %), self-interaction can be arbitrarily strong

$$g_\chi \simeq 1$$

Fan et al., Phys. Dark Univ. 2 (2013) 139–156.

SCALAR MEDIATOR



Knapen et al., Phys. Rev. D 96, 115021 (2017)

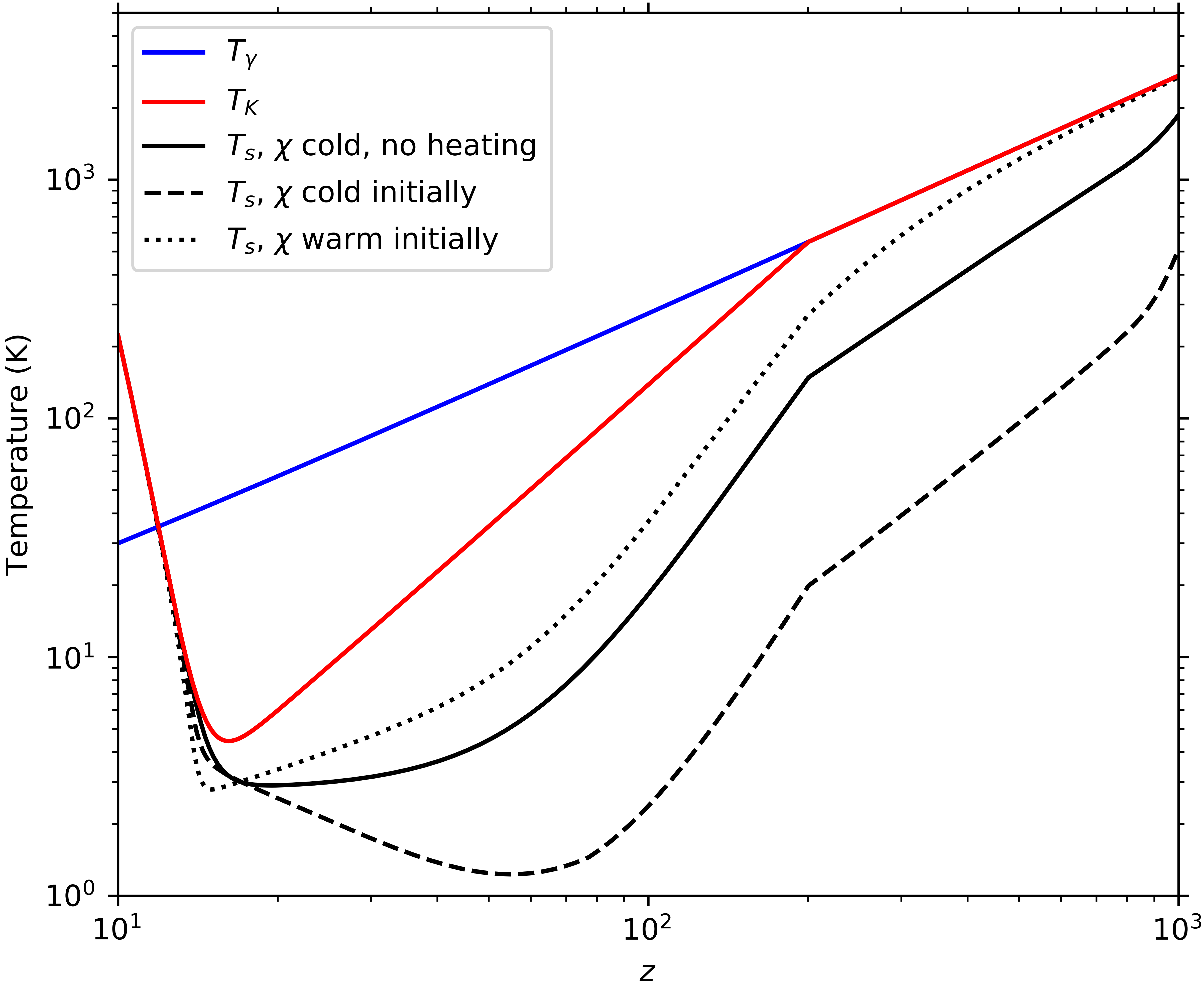
PSEUDO-VECTOR MEDIATOR

- Similar limits apply in the spin-dependent case, although there are some additional complications for pseudo-vector mediators
- Energy/m_V^2 enhanced coupling to the mediator's longitudinal mode in stellar cooling bounds, giving

$$g_N < 10^{-12} \times \frac{m_V}{10\ \mathrm{keV}}$$

- Such bounds are model dependent, a more complete particle model is highly constrained
- The dominant process of stellar cooling is the Compton process with He, which is suppressed for spin-dependent interactions

RESULTS



T_γ
T_K
T_s, χ cold, no heating
T_s, χ cold initially
T_s, χ warm initially
Temperature (K)
10^0
10^1
10^2
10^3
10^1
10^2
10^3
z

DOES IT WORK?

- Significant spin temperature cooling by this mechanism requires $g_N > 10^{-11}$
  - Excluded by a few orders of magnitude (stellar cooling bounds give $g_N < 10^{-12}$, or even stronger with longitudinal mode enhancement) – similar scenario for coupling to the electron
  - Maybe some limits can be relaxed (helium Compton process suppression, more complete dark sector)
- Perhaps the same mechanism can cool the spin gas in an alternative model, subject to a different set of constraints