Thermodynamics of a magnetized neutral vector bosons gas

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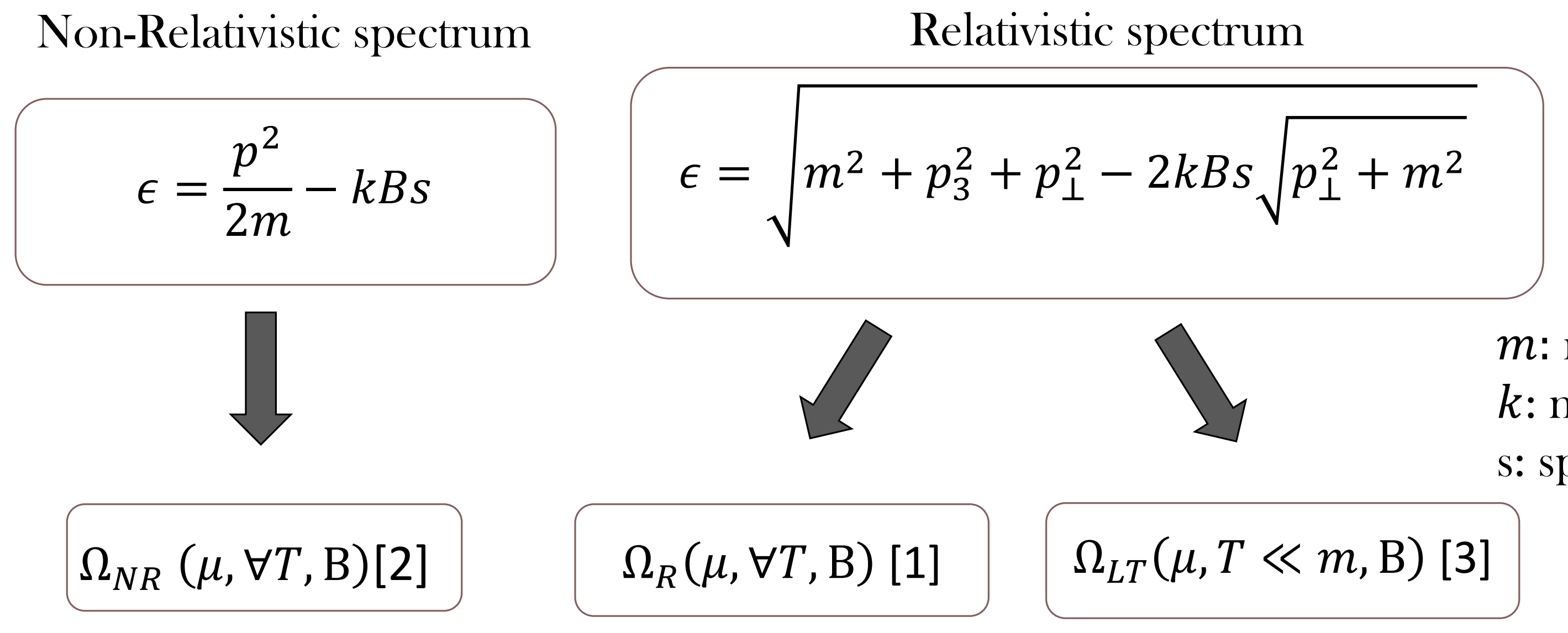
Abstract

This poster is dedicated to study the thermodynamic properties of a magnetized neutral vector boson gas at any temperature, with the aim to provide equations of state that allow more general and precise descriptions of astrophysical phenomena. The all-temperature analytical expressions for the thermodynamic magnitudes, as well as their non-relativistic limits, are obtained in [1]. With these expressions, and considering the system under astrophysical conditions (particle densities, temperatures and magnetic fields in the order of the estimated for Neutron Stars), we investigate the Bose-Einstein condensation and the magnetic properties of the gas, making a special emphasis on the influence of antiparticles and magnetic field. In all cases, the results are compared with their analogues in the low temperature (LT) and the non-relativistic limits (NR). This allows us to establish the ranges of validity of these approximations and to achieve a better understanding of their effects on the studied system.

Keywords: Bose-Einstein condensate, relativistic vector boson gas, magnetic field, antiparticles.

Neutral vector boson gas (NVBG)



Non-Relativistic spectrum

$$\epsilon = \frac{p^2}{2m} - kBs$$

$\Omega_{NR}\ (\mu, \forall T, \mathrm{B})$[2]

Relativistic spectrum

$$\epsilon = \sqrt{m^2 + p_3^2 + p_\perp^2 - 2kBs\sqrt{p_\perp^2 + m^2}}$$

$\Omega_R(\mu, \forall T, \mathrm{B})$ [1]

$\Omega_{LT}(\mu, T \ll m, \mathrm{B})$ [3]

$\vec{B} = (0,0,B)$
$s = -1,0,1$

m: mass
k: magnetic moment
s: spin

$b = B/B_c$
$Bc = m/2k$
$m = 2\mathrm{m_n}$
$k = 2\mathrm{k_n}$

Antiparticle contribution

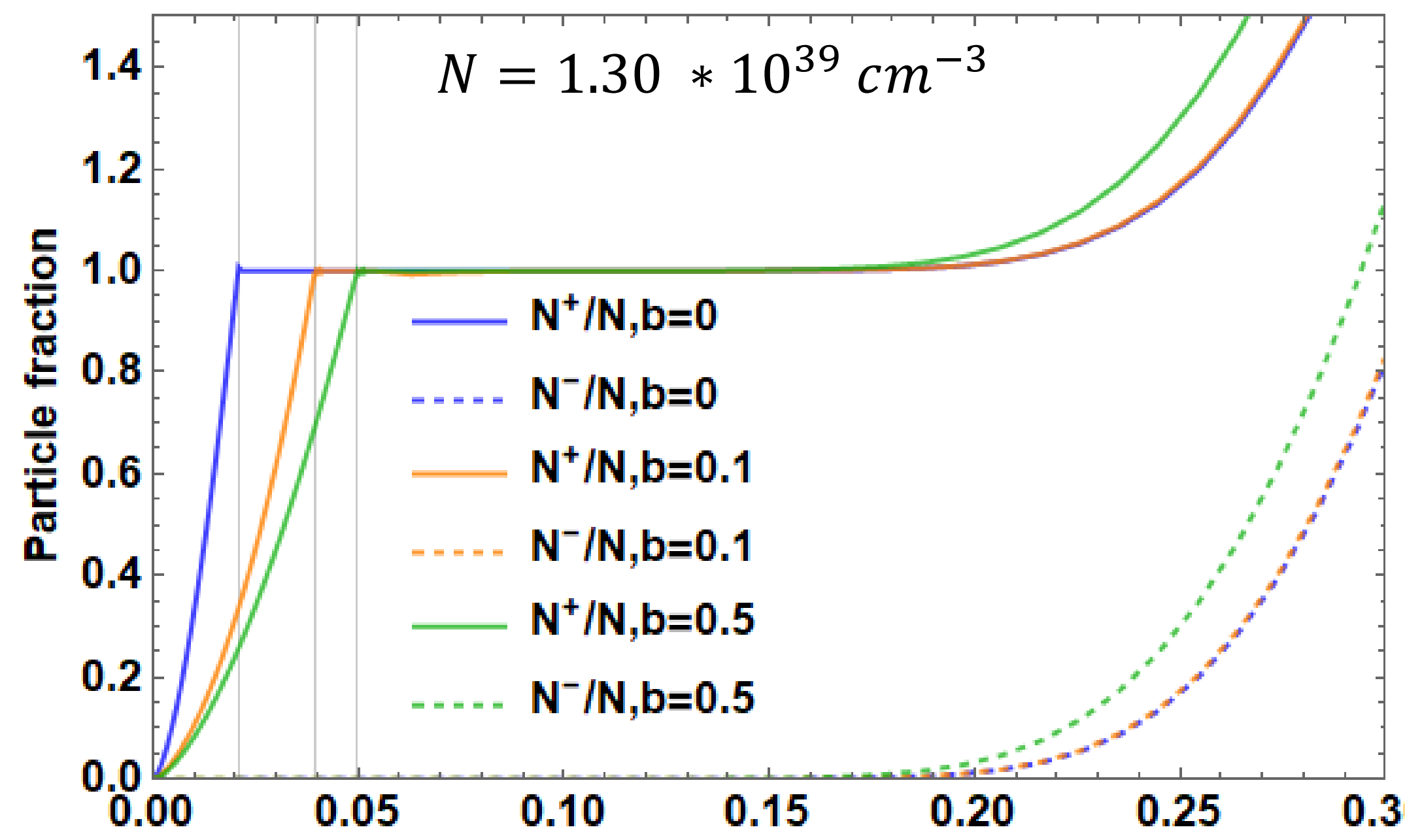


Figure 1. Particles and antiparticles fraction as a function of temperature for various values of magnetic field. The solid lines correspond to the particles fraction and the discontinuous lines to that of antiparticles. The horizontal lines indicate the critical temperature $T_c\ (b)$.

- ❑ The density of antiparticles begins to be appreciable for temperatures such that $\mathrm{T} \geq\ 0.2\ m$.
- ❑ The presence of the magnetic field favors the appearance of antiparticles. However, for this effect to be appreciable $B \rightarrow B_c$.

Bose-Einstein condensation phase-diagram

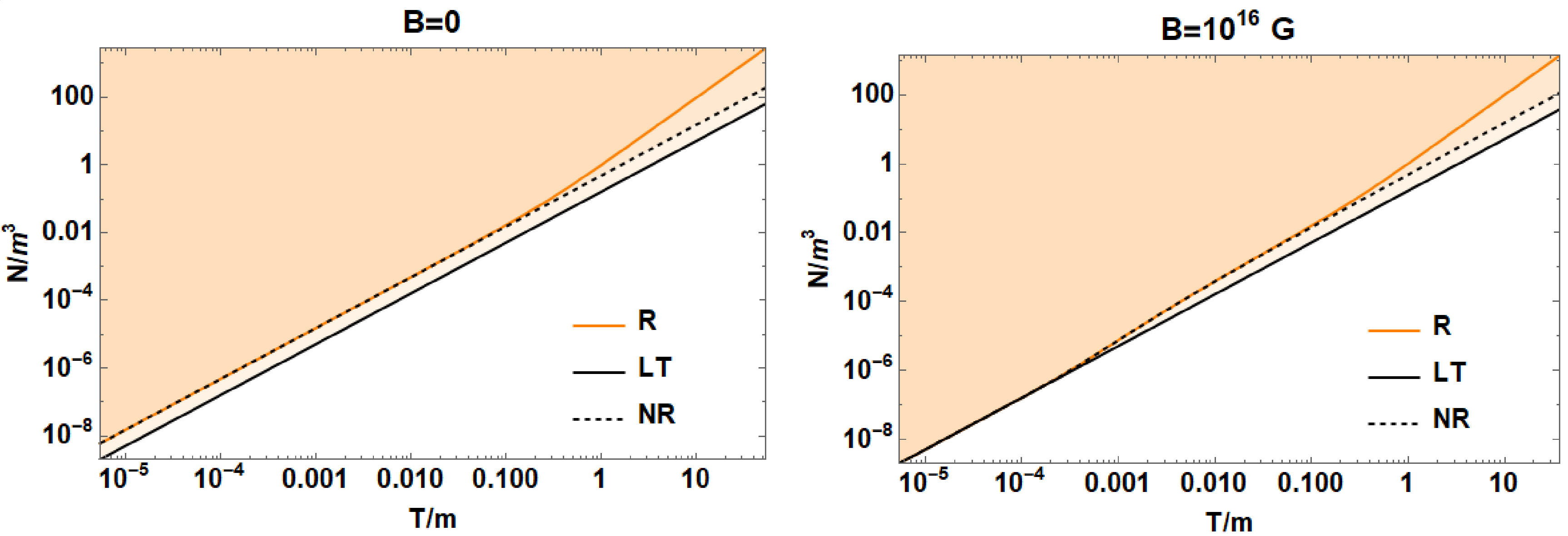
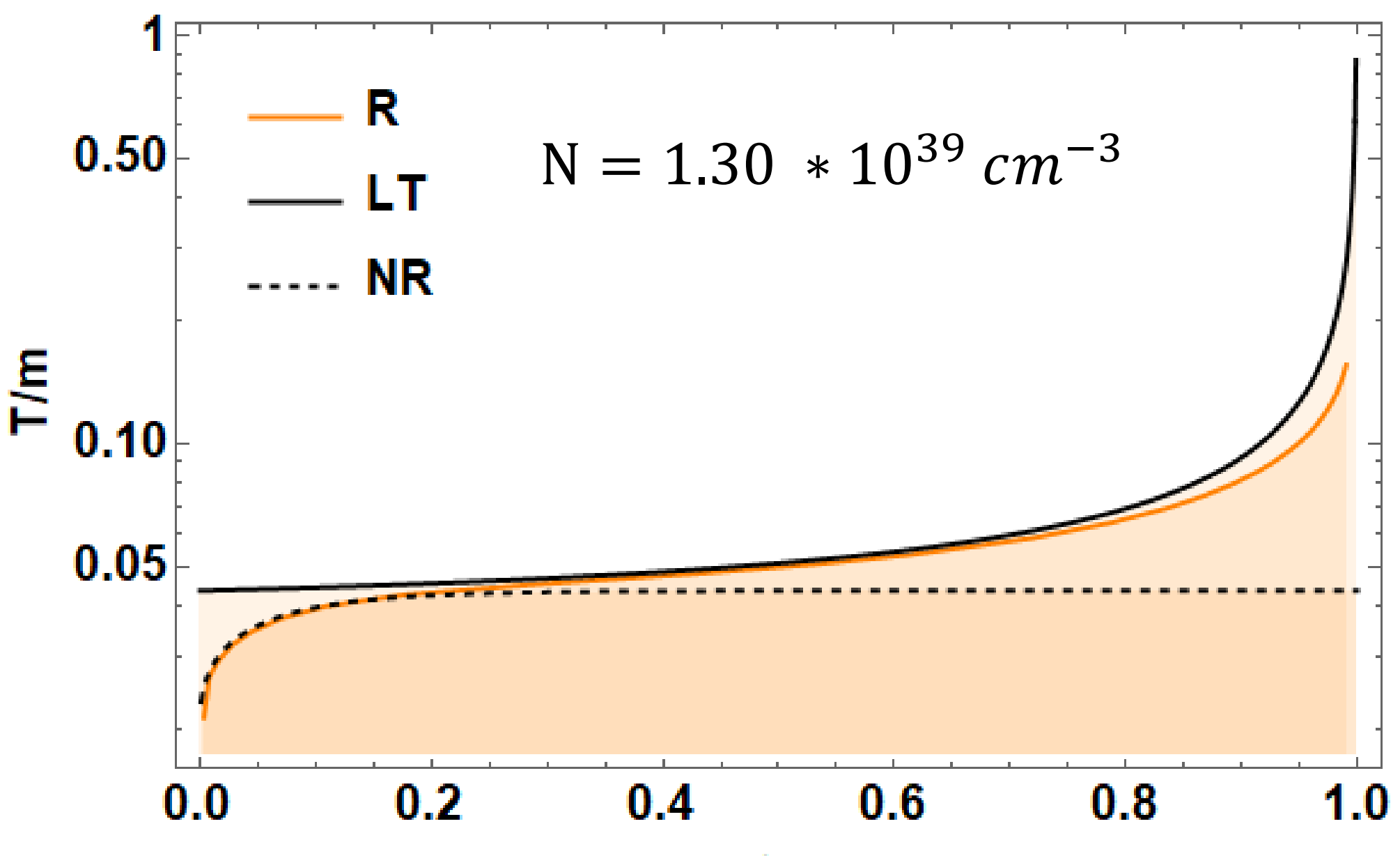


Figure 2. Phase diagram of the condensate in the N-T plane. The shaded region corresponds to the phase of the condensed state. The lines indicate the critical curves $N_c\ (T, b)$ for different descriptions of the gas of neutral vector bosons.

- At $B\ =\ 0$, there is a very noticeable difference between the low temperature limit and the other two cases.
- At $B = 10^{16}\ G$, around $T \sim 10^{-3}m$ the LT limit starts to be different from the other cases, indicating that this limit is not correct above those temperatures.
- At $B\ =\ 0$ and $B\ =\ 10^{16}\ G$ the R and NR curves separate around $T \sim m$ indicating the presence of antiparticles at those temperatures.



- The NR limit when $b\ \rightarrow\ 1$ gives wrong results.
- The BT limit when $b\ \rightarrow\ 0$ gives wrong results.
- The expressions for all temperatures correctly describe both the weak field and the strong field region.

Figure 3. Phase diagram of the condensate in the T-B plane. The shaded region corresponds to the phase of the condensed state. The lines correspond to the critical curves $T\_c\ (b)$ for different descriptions of the gas of neutral vector bosons.

Magnetic Properties

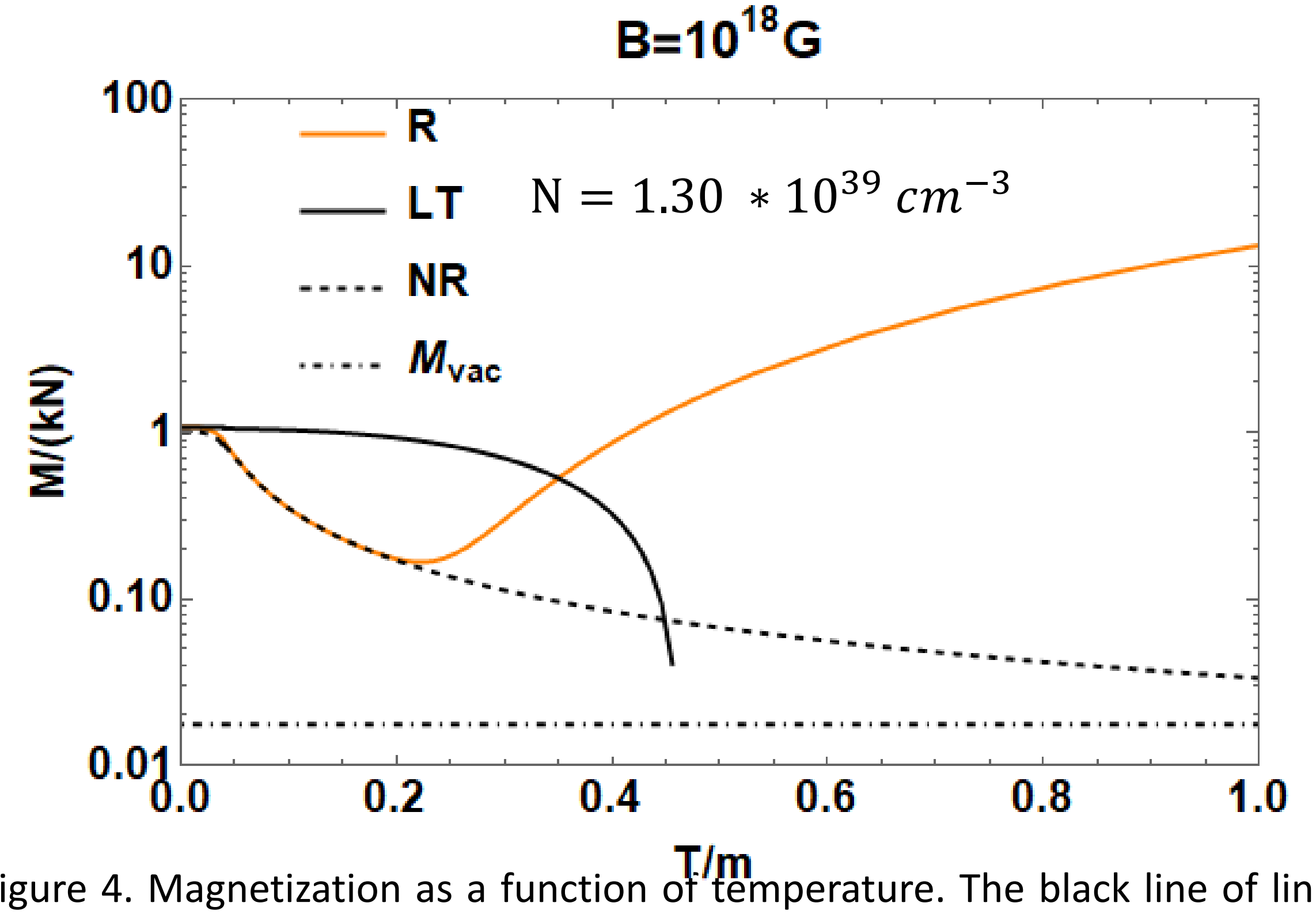


Figure 4. Magnetization as a function of temperature. The black line of lines and dots corresponds to the contribution of the vacuum. The orange, black and black dashed lines are the magnetization in the different gas descriptions of neutral vector bosons.

- ❑ The vacuum magnetization is negligible, and the curves corresponding to the magnetization of the R gas and the NR and LT limits coincide for $T \rightarrow 0$.
- ❑ As the temperature increases, the magnetization at the NR limit decreases and goes to zero when T tends to infinity.
- ❑ The magnetization of the R gas shows the same behavior as the NR limit up to $\mathrm{T} \sim 0.2$. This change in monotony is associated with antiparticles.
- ❑ In the LT limit, the magnetization also decreases when T increases, but its behavior is quite different from the other two cases. Even the magnetization in this limit becomes negative around $\mathrm{T} \sim 0.5\ m$ (the point where the curve ends).
- ❑ However, this negative magnetization does not imply that the gas has a diamagnetic behavior at these temperatures, but is a consequence of doing the limit $T \ll m$, and therefore, is not a physically correct result.

Conclusions

- ❖ We have studied the properties of a magnetized neutral vector boson gas at any temperature.
- ❖ We study antiparticle contribution as well as Bose-Einstein condensation and magnetic properties.
- ❖ For temperatures in the order of particle masses and higher antiparticle fraction is not negligible as well as their influence on the thermodynamic properties. This is clearly evidenced when we study the BEC phase diagram in which the behavior of the critical curves at high temperatures differs between the relativistic and the non relativistic cases, precisely due to antiparticle presence and in the graph of magnetization in which, we see that the effect of the antiparticles is to increase the magnetization in several orders.
- ❖ The limitations found in both approximations with respect to the relativistic calculation at all temperatures, demonstrate its importance, and reaffirm the necessity and relevance of the work carried out.

References

1. L.C Suárez-González,G. Q. Angulo, A. P. Martínez, and H. P. Rojas, “BEC and antiparticles in a magnetized neutral vector boson gas at any temperature”. Astronomical Notes Volume 340, Issue 9-10, 2019.
2. L.C Suárez-González,G. Q. Angulo, A. P. Martínez, and H. P. Rojas, “A non-relativistic magnetized vector boson gas at any temperature”, Journal of Physics: Conference Series Vol. 1239, p. 012004, May 2019.
3. G. Q. Angulo, A. P. Martínez, and H. P. Rojas, “Thermodynamic properties of a neutral vector boson gas in a constant magnetic field,” Physical Review C, vol. 96, no. 4, p. 045810, 2017