Astrophysical Letters, 1969, Vol. 3, pp. 111–114



# INTENSITIES OF RADIO RECOMBINATION LINES

R. M. HJELLMING AND M. H. ANDREWS
*National Radio Astronomy Observatory, Green Bank, West Virginia, U.S.A.*
AND
T. J. SEJNOWSKI†
*Case Western Reserve University, Cleveland, Ohio, U.S.A.*

Strengths of α- and β-radio recombination lines are predicted for $40 \leqslant n \leqslant 225$ for H II regions with $T_e = 5\,000$, 7 500, and 10 000 °K, $N_e = 10^2$, $10^3$, $10^4$ cm$^{-3}$, and emission measures from $10^4$ to $10^{7.5}$ pc cm$^{-6}$.

The strengths of radio recombination lines emitted by H II regions are, for nebulae with large emission measures, very dependent upon the calculation of the non-LTE populations of the appropriate energy levels of hydrogen (see Goldberg 1966, 1968). The purpose of the present note is to utilize recent calculations of these level populations by Sejnowski and Hjellming (1969) to predict the strengths of the α-lines ($\Delta n = 1$) and the β-lines ($\Delta n = 2$) for values of the principal quantum number, $n$, from 40 to 225. This involves lines ranging between millimeter wavelengths and the wavelengths at which most H II regions are opaque.

The calculations of line strengths will involve the assumption that the nebulae are homogeneous, using the standard formulas as discussed by Goldberg (1966, 1968) and Hjellming *et al.* (1969). The resulting values for the ratio of line to continuum brightness temperature, $T_L/T_C$, are plotted in Figures 1 and 2 as functions of $n$ for values of the emission measure, $E$, from $10^4$ to $10^{7.5}$ pc cm$^{-6}$; sets of such plots are shown for electron temperatures of $T_e = 5\,000$, 7 500, and 10 000 °K and electron concentrations of $N_e = 10^2$, $10^3$, and $10^4$ cm$^{-3}$. The line broadening is assumed to be Doppler in origin and all calculations are based upon a ratio of Doppler width to line frequency of $6 \times 10^{-5}$. Also shown in Figures 1 and 2 are dashed curves representing the LTE solutions.

The results plotted in Figures 1 and 2 show in detail the dependence of non-LTE line enhancement upon $n$, $T_e$, and $N_e$. In particular, for small values of $n$, for which the nebulae are optically thin to the lines, the results reflect the fact that the solution reduces to $T_L/T_C = b_n(T_L/T_C)_{LTE}$, where $b_n$ is the ratio of the non-LTE population to the LTE population of the level $n$; while for higher $n$, the non-LTE line strengths are enhanced relative to the LTE solution to an extent which is very dependent upon $E$ when it is large. The line enhancement clearly decreases with increasing $T_e$ and/or increasing $N_e$, with the latter being particularly critical. As shown by Hjellming *et al.* (1969), it is essential to realize that the parameter $N_e$, when used in the context of a homogeneous nebula approximation, is an average along the line of sight in the sense $\langle N_e \rangle_E = \int N_e^3\, ds / \int N_e^2\, ds$; $\langle N_e \rangle_E$ is significantly greater than the rms electron concentration, $\langle N_e \rangle_{rms}$, for highly clumped H II regions. According to Hjellming *et al.* (1969), such a high degree of clumping is necessary for H II regions with large emission measure ($E \gtrsim 10^6$) in order to avoid predicting line enhancement greatly in excess of what is observed. For example, in the Orion nebula $\langle N_e \rangle_E / \langle N_e \rangle_{rms}$ is of the order of 6, so that $\langle N_e \rangle_E \sim 10^4$.

Given a knowledge of $E$ and $T_L/T_C$ for a variety of lines in observed nebulae, the results of Figures 1 and 2 can be used, not only to determine $T_e$ for the cases with low emission measure, but also, in the cases where line enhancement is appreciable, to derive information on both $T_e$ and $\langle N_e \rangle_E$.

Finally, if one uses the usual equation to calculate $T_C$, the curves in Figures 1 and 2 can be used to predict the probable observability of a wide range of radio recombination lines under a variety of conditions.

The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under contract with the National Science Foundation.

† Present address: Department of Physics, Princeton University, Princeton, New Jersey.

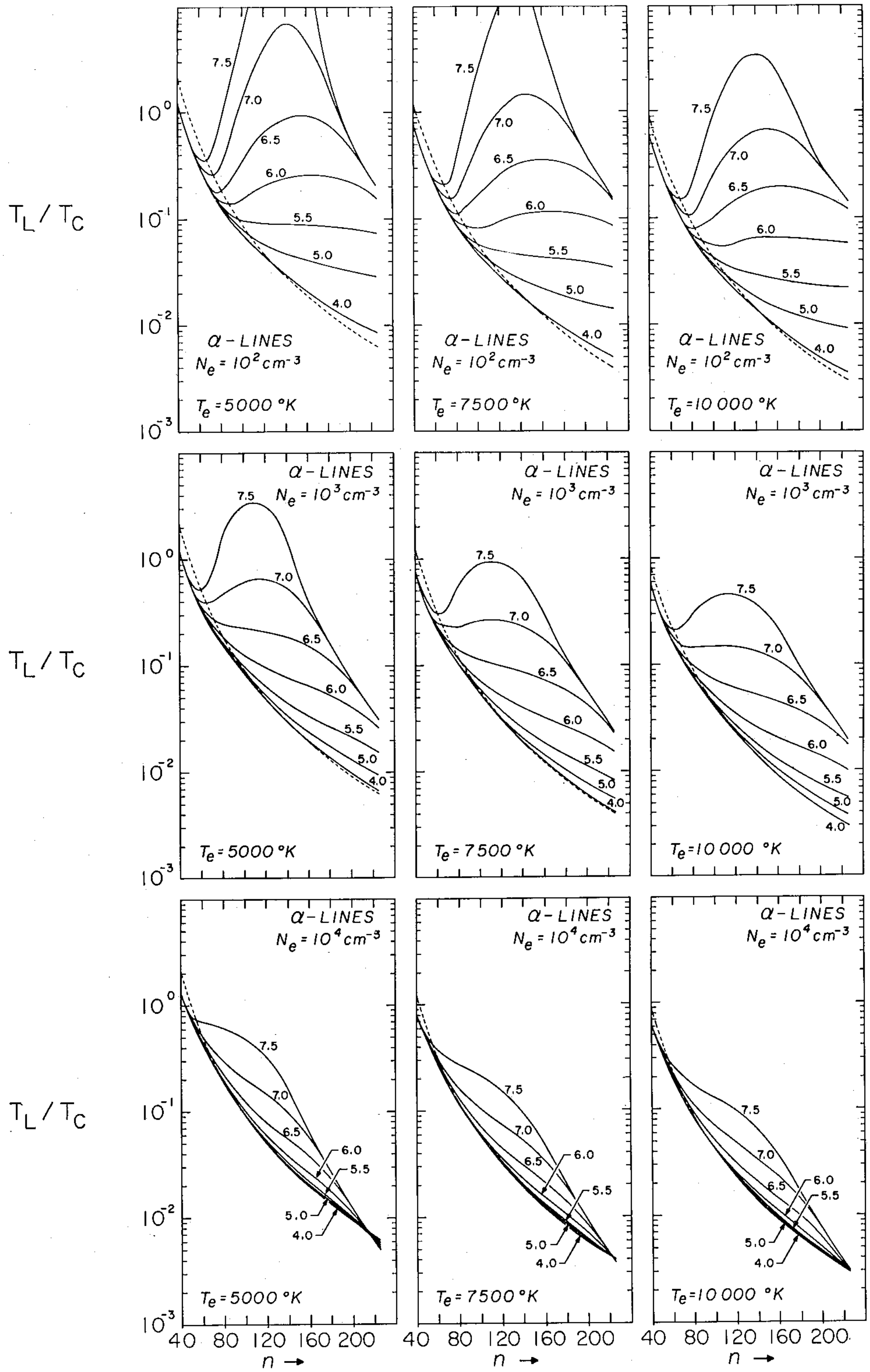


FIG. 1. Plots of $T_L/T_C$ for α-lines as functions of $n$ are shown for $E=10^4$, $10^5$, $10^{5.5}$, $10^6$, $10^{6.5}$, $10^7$, and $10^{7.5}$ pc cm$^{-6}$, $T_e=5\,000$, 7 500, 10 000°K, and $N_e=10^2$, $10^3$, and $10^4$ cm$^{-3}$. The dashed curves indicate the LTE solutions.

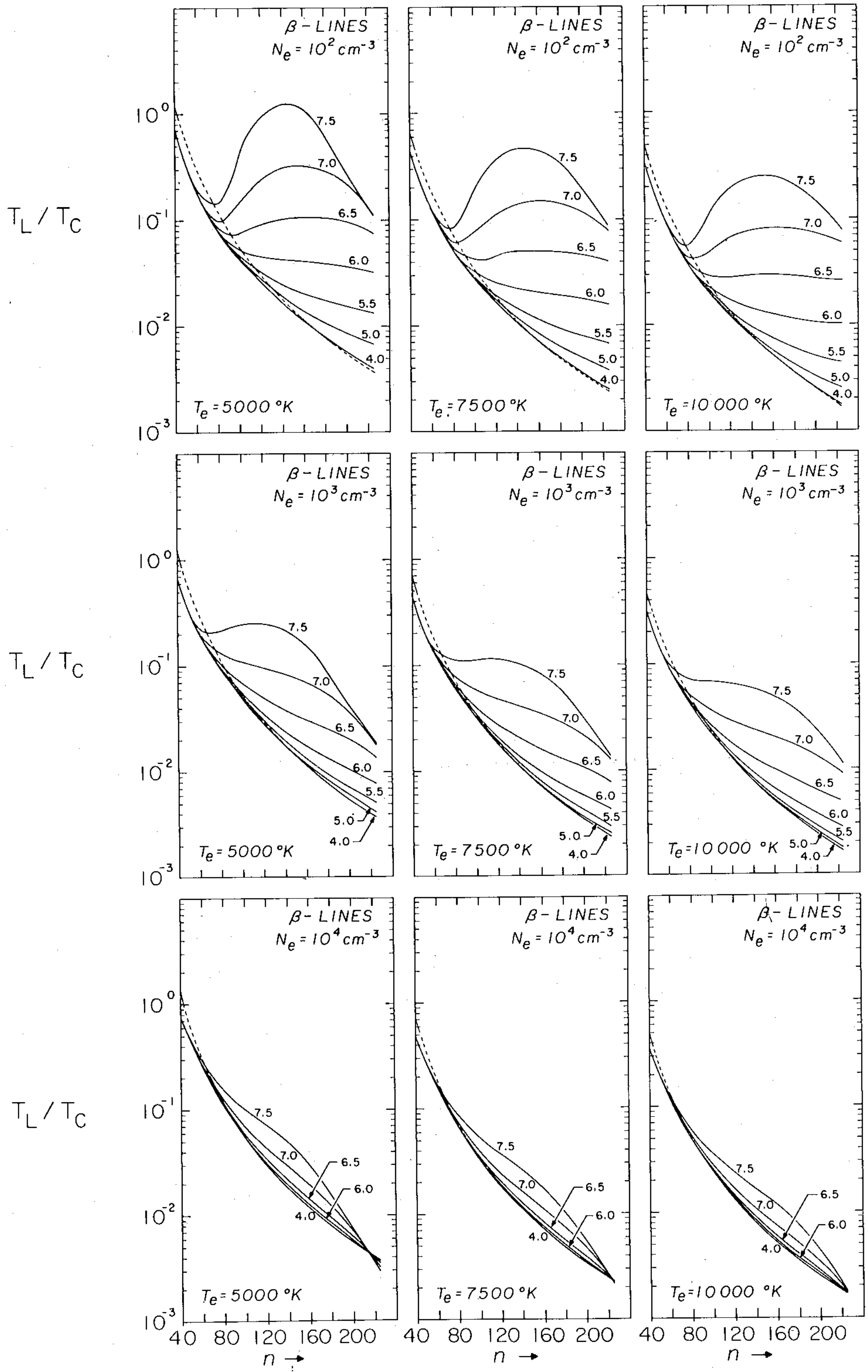


FIG. 2. Plots of $T_L/T_C$ for β-lines as functions of $n$ are shown for $E=10^4$, $10^5$, $10^{5.5}$, $10^6$, $10^{6.5}$, $10^7$, and $10^{7.5}$ pc cm$^{-6}$, $T_e = 5\,000$, 7 500, and 10 000 °K and $N_e = 10^2$, $10^3$, and $10^4$ cm$^{-3}$. The dashed curves indicate the LTE solutions.

REFERENCES

Goldberg, L., 1966, *Astrophys. J.*, **144**, 1225.
——, 1968, *Interstellar Ionized Hydrogen*, ed. Y. Terzian (New York: Benjamin Press).
Hjellming, R. M., Andrews, M. H., and Sejnowski, T. J., 1969, *Astrophys. J.* (to appear in August 1969 issue).
Sejnowski, T. J., and Hjellming, R. M., 1969, *Astrophys. J.* (to appear in June 1969 issue).

Received 24 February 1969