H_3^+ IN COOL, VERY METAL POOR STARS.

G. J. Harris[1], A. E. Lynas-Gray[2], S. Miller[1], J. Tennyson[1], R. J. Barber[1].

[1]Department of Physics and Astronomy, University College London, Gower street, London. WC1E 6BT. UK.
[2]Department of Physics, University of Oxford, Keble Road, Oxford, OX1 3RH, UK.

Abstract

In a cool hydrogen-helium gas, the molecular ion H_3^+ is known to be an important electron donor and as such has a strong effect upon the continuous opacity of the gas. This extra opacity can affect both the structure and evolution of hydrogen-helium stars of less than half a solar mass (Harris et al. 2004, ApJ 600, 1025).

In stars of solar metallicity, H_3^+ is largely destroyed by the electrons liberated by the ionised metals. However as metallicity is reduced toward the hydrogen-helium limit, H_3^+ becomes increasingly abundant and hence important. Here we discuss the range of metallicities over which H_3^+ is the dominant positive ion. Furthermore we present some preliminary infrared synthetic spectra for cool very metal poor stars, and discuss the possibility of detecting rotation-vibration lines of H_3^+ in these stars.

Key words: Stars: very metal poor, synthetic spectra.

1. Introduction

After the nucleosynthetic phase of the big bang the universe is believed to have consisted almost entirely of hydrogen and helium, with trace quantities of Li and B. It therefore seems inescapable that the first stars (population III) formed from hydrogen and helium. During the course of their evolution these stars enriched the universe with the metals, the products of their nucleosynthesis. No population III stars have yet been identified, however recent surveys have yielded ever-more metal poor stars, such as HE0107-5240 ([Fe/H]=–5.3) (Christlieb et al. 2002). These very metal poor stars provide a window through which to study the early epochs of the Galaxy, and indeed Universe.

It is known (Lenzuni et al. 1991) that in the absence of metals the molecular ion H_3^+ acts as an electron donor and as such can significantly affect the opacity of a hydrogen helium gas. Harris et al. 2004 have shown that this increase in opacity can significantly effect the structure and evolution of population III stars of mass less than 0.4 M. However in a solar metallicity gas, the electrons released by the metals all but destroy H_3^+. In section 2 we show that as the metallicity of a gas is reduced toward the zero metallicity limit the electron abundance decreases, and in turn this gives rise to a greater abundance of H_3^+. Furthermore in section 3 we show that H_3^+ lines appear in our preliminary synthetic spectra of cool very metal poor stars. Finally we discuss the prospects for observing H_3^+ in a cool very metal poor star in section 4, and conclude in section 5.

2. H_3^+ the electron donor

As the dissociation reaction $H_3^+ \rightarrow H_2 + H^+$, is endothermic, in a cool moderately dense hydrogen-helium gas H_3^+ is the dominant positive ion. Figure 1 shows the number densities of various hydrogen-helium species at a density of 10^{-6} g cm^{-3}, as a function of temperature. Clearly at a density of 10^{-6} g cm^{-3} and below 3500 K, H_3^+ is the dominant positive ion and the source of all the free electrons. Thus H_3^+, through the abundance of e- and H-, strongly affects the continuous opacity of the gas.

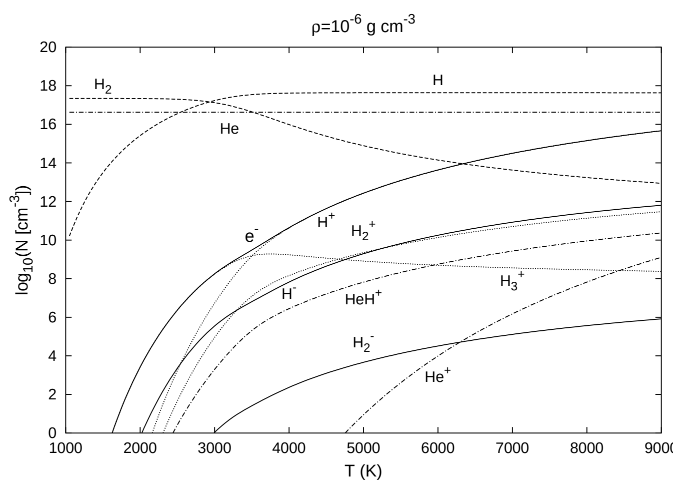

Figure 1. The number densities of various species in a hydrogen helium gas as a function of temperature. Electrons and H^- are solid lines, positive hydrogen ions are dotted lines, H and H_2 are dashed lines, and Helium and helium containing molecules are dot-dashed lines. Taken from Harris et al. 2004.

To investigate the importance of H_3^+ in very metal poor gases we have included the 10 most abundant metals in the sun at solar abundance ratios, in our equation of state.

Figure 2 shows the abundances of H_3^+, e^-, H+ and the electrons liberated from the metals as a function of metallicity. This figure indicates that H_3^+ can affect the continuous opacity of a gas with solar metal abundance ratios and a metallicity of less than $[Z/Z_\odot]$=–5 (10^{-5} solar).

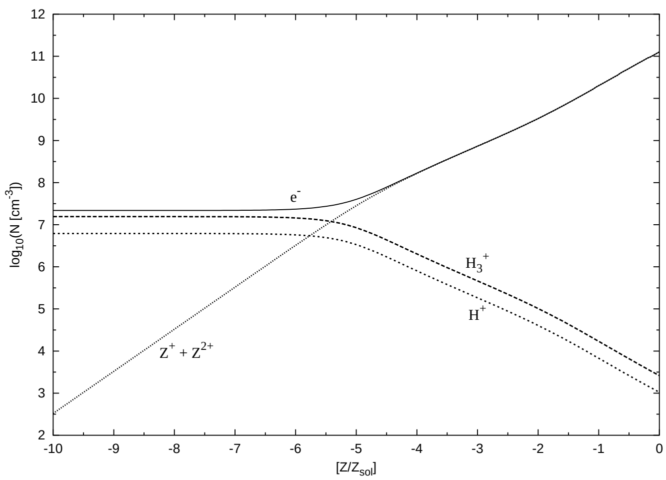

Figure 2. The number densities of e^-, H_3^+, H^+ and the electrons liberated from the metals (denoted $Z^+ + Z^{2+}$), as a function of metal abundance relative to solar. Calculated at a temperature of 3000 K, a density of 10^{-7} g cm^{-3} and using a solar metal mix.

3. Preliminary synthetic spectra

As reported in Harris et al. 2004, we have incorporated the Neale et al 1996 H_3^+ linelist into our opacity calculations. This linelist has previously been incorporated in brown dwarf model atmospheres by Allard et al. 2001. Full details of the other opacity data sources that we use can be found in Harris et al. 2004. Figure 3 shows the total and H_3^+ line opacity of a hydrogen helium gas at a temperature of 3500 K and density of 10^{-8} g cm^{-3}. Clearly H_3^+ lines contribute to the opacity and, as we see below, may well result in absorption lines within the spectra of cool very metal poor stars.

Further to the hydrogen-helium opacity reported in Harris et al. 2004 we have incorporated the molecular linelists for HCN/HNC Harris et al. 2002, H_2O Barber & Tennyson 2004, CO Goorvitch 1994, CN red Jørgensen & Larsson 1990, CH Jørgensen et al. 1996, OH Kurucz 1995, NH Kurucz 1995 and C2 Querci et al 1971; Querci et al 1974 into our calculations. The resulting opacity function for a solar metal mix with $[Z/Z_\odot] = -3.5$, a temperature of 3500 K and a density of 10^{-8} g cm^{-3}, has window between strong molecular absorption features at 2.1 μm. This corresponds to the K-band, the relatively weak H_3^+ lines contribute to the total gas opacity only in this region.

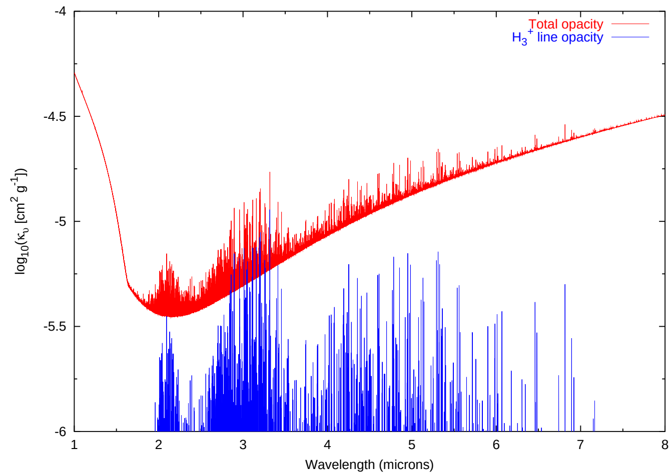

Figure 3. The total opacity of a hydrogen-helium gas at 3500 K and 10^{-8} g cm^{-3}, as a function of wavelength. H_3^+ lines are shown for comparison.

Figure 4 shows LTE plane parallel synthetic spectra based upon an ATLAS9 (Kurucz 1991) model atmosphere at T_{eff}=3750 K, log g =1.0, and $[Z/Z_\odot] = -3.5$, calculated with and without H_3^+ line opacity. Again the H_3^+ lines at 2.1 μm, appear between strong molecular absorption features. Figures 5 & 6 show the 2.1 μm region at T_{eff} =3750,4500 and log g = 1.0, 4.5 respectively, with and without H_3^+ line opacity. H_3^+ lines appear in both these figures.

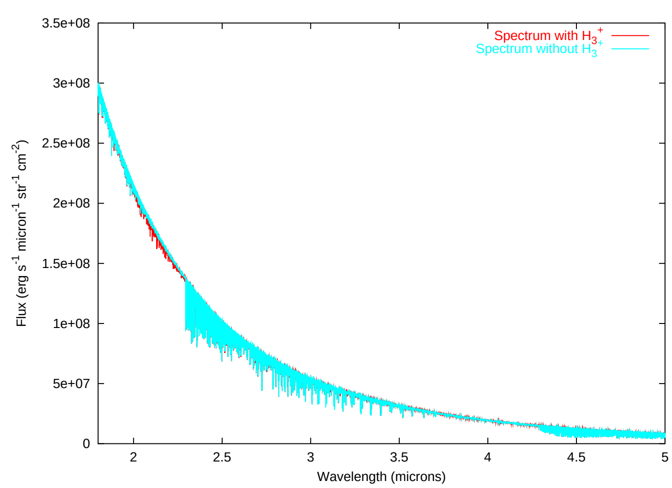

Figure 4. Synthetic spectra for an atmosphere of T_{eff} = 3750, log g=1.0 and a metallicity of $10^{-3.5}$ solar. Spectra are calculated with and without H_3^+

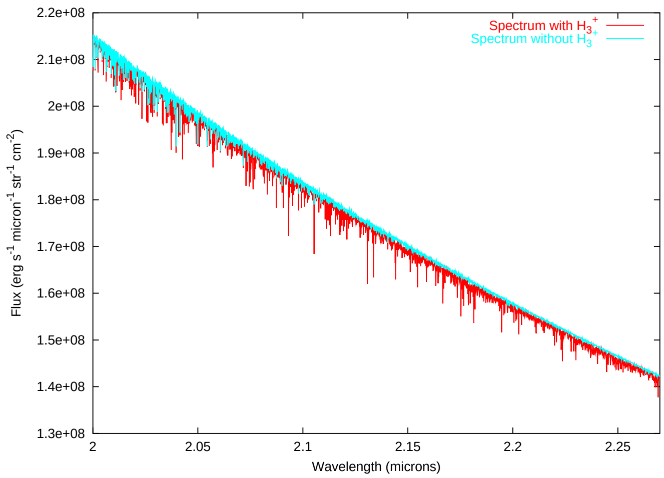

Figure 5. Synthetic spectra for an atmosphere of T_{eff} *= 3750, log g=1.0 and a metallicity of* $10^{-3.5}$ *solar. Spectra are calculated with and without* H_3^+*.*

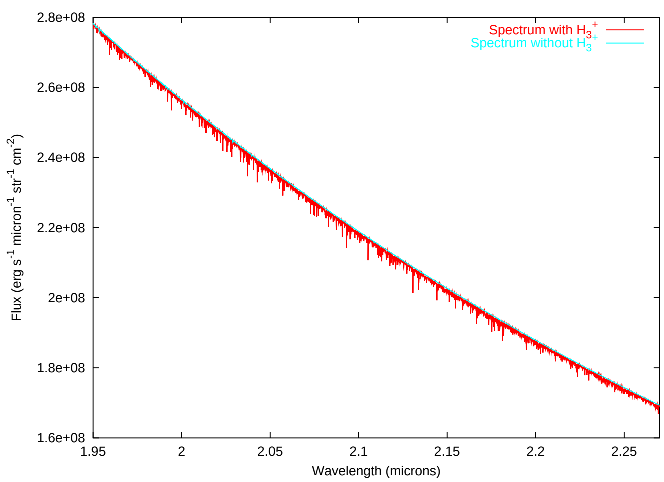

Figure 6. Synthetic spectra for an atmosphere of T_{eff} *= 4500, log g=4.5 and a metallicity of* $10^{-3.5}$ *solar. Spectra are calculated with and without* H_3^+*.*

4. Could H_3^+ be detectable?

The strongest H_3^+ lines in our preliminary synthetic spectra for $T_{eff} = 3750$ K and log g =1.0 show a 7% reduction in flux. Whereas for the $T_{eff} = 4500$ K and log g =4.5 the lines show a 3% reduction in flux. If surface gravity, metallicity and effective temperature are reduced the H_3^+ lines become stronger, if these parameters are increased the lines become weaker. It is certainly possible for modern high resolution, high signal to noise, spectroscopes to detect such lines in reasonably bright stars. However stars of metallicity $[Z/Z_\odot] < -3.5$ are rare, and so invariably dim, furthermore the low effective temperatures required for H_3^+ lines, imply yet dimmer stars. Stars such as CD $-38°245$ and CS 22172-002 at [Fe/H] = –3.98 and –3.61, (Norris et al 2001) meet the metallicity requirements, but with T_{eff}= 4850 and 4900 K, log g = 1.8 and 2.0, are too hot to show H_3^+ lines. We are currently searching the literature for candidates that meet the metallicity, temperature and surface gravity requirements.

5. Conclusion

It has been shown that for a solar metal mix that H_3^+ is a significant electron donor for metallicities of less than 10^{-5}. We have also shown that H_3^+ line opacity can contribute to the opacity of a gas of solar metal mix with a metallicity of $10^{-3.5}$ solar or less.

We have presented preliminary infrared synthetic spectra for very metal poor stars. These spectra indicate that H_3^+ lines will be observable for stars with a metallicity of $10^{-3.5}$ solar or less and effective temperature less than 3750 K and 4500 K for a giant and dwarf respectively.

Acknowledgements

GJH would like to thank the UK particle physics and astronomy research council (PPARC) for post-doctoral funding.

References

Allard, F., Hauschildt, P. H., Alexander, D. R., Tamanai, A.,Schweitzer, A., 2001, ApJ 556, 357
Barber, R. J., Tennyson, J., 2004, MNRAS (IN PREPARATION)
Christlieb, N., Bessell, M. S., Beers, T. C., et al. 2002, Nature 419, 904
Goorvitch, D., 1994, ApJS 95, 535
Harris, G. J., Polyansky, O. L., Tennyson, J., 2002, ApJ 578, 657
Harris, G. J., Lynas-Gray, A. E., Miller, S., Tennyson, J., 2004, ApJ 600, 1025
Jørgensen, U. G., Larsson, M., 1990, A&A 238, 424
Jørgensen, U. G., Larsson, M., Iwamae, A., Yu., B., 1996, A&A 315, 204
Kurucz, R. L., 1991, BAAS 23, 967
Kurucz, R. L., 1995, Astrophysical applications of powerful new databases, ASP conference Series, Vol. 78, S. J. Adelman & W. L. Weisse (eds.).
Lenzuni, P., Chernoff, F. P., and Salpeter, E. E. 1991, ApJS 76, 759
Neale, L., Miller, S., and Tennyson, J. 1996, ApJ 464, 516
Norris, J. E., Ryan, S. G., Beers, T. C., 2001, ApJ 561, 1034
Querci, F., Querci, M., Kunde, V. G., 1971, A&A 15, 256
Querci, F., Querci, M., Tsuji, T., 1974, A&A 31, 265