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Galactic thermal evaporation and the implications for low-mass haloes.

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ABSTRACT

A gas of ions sitting in a galaxy, if we assume that it is collisionally ionised, will have some characteristic temperature relevant to that species depending on the ionisation potential of the species. At this characteristic temperature the velocity distribution of gas molecules will follow the Maxwell-Boltzmann distribution. For a given halo with some mass there will be some espace velocity. Some fraction of the gas, due to the distribution of velocities, will have a velocity which exceeds the escape velocity of the halo and will therefore escape. In the gas itself the mean-free-path of the particles will be short compared to the length-scales which the gas need to escape due to the assumption of collisional excitation, but at the interface between the gas and the IGM, som fraction of the gas will be able to escape. This should lead to a net escape of atoms from the halo and behave similar to evaporation. This additionally requires that the cooling timescale for the ion is longer than the characteristic timescale for escape.

This process is very similar to the process which describes evaporation from a water-surface, where some small fraction of the water-molecules at the interface between the water and air will have a finite chance of moving out of the water. Or somewhat equivalently the escape of the lighter elements from the atmospheres of planets.

Key words: keyword1 – keyword2 – keyword3

1 INTRODUCTION

Gas dynamics on galactic scales are controlled by the thermal pressure of the gas and the radiation pressure of the stars equilibrated to the compressional pressure of gravity. Radiative cooling, either though continuum emission or line-emission allows the gas to contract under gravity whereas feedback processes such as stellar winds, supernovae and AGNs causes the gas to expand.

Ionic species in varying degrees of ionization is observed in galaxies and assuming that they are collisionally exited, indicates that for each ionic species considered, different effective local temperatures regulate the thermal pressure of the gas. Since the effective temperature is a generalization of the average kinetic energy of the gas, this corresponds to a distribution of particle velocities given by the Maxwell-Boltzmann distribution. At any given time for a gas in thermal equilibrium, there will be particles with high velocity and particles with low velocity. Due to the assumption of thermal equilibrium, the gas particles will not travel far before another particle is encountered and the kinetic energy shared. At the edge of a cloud, however, there will be a chance for the gas to escape given that the mean-free-path of the particle is longer than the interface between the gas and the surrounding material. In the universe, gas is confined by it's own self-gravity, but for a given gravitational potential generated by the gas and the nascent dark-matter halo, there will be an escape velocity which will allow a gas particle to escape. This is very similar to thermal evaporation of water, as we know from Earth, where the velcity can overcome the " chemical potential " of the water and turn to vapor. Given enough time, all gas in galaxies should in principle escape, but the time-scale for this is extremely long, however for high-ionization gasses which have a high effective collisional equilibration temperature sitting in low-mass haloes, potentially some fraction of the gas will escape on at time-scale shorter than a few dynamical time-scales. In this letter we try to calculate the mass-loss rate for a given ionic species and assess the implication for low-mass haloes, especially explaining the missing CIV in very low-mass haloes found by Burchett et al.

TODO : Limitations: One issue would be if the high-ionization gas is embedded in a cooler gas making the mean-free-path short compared to the escape scale.

TODO : A discussion of hydrodynamical escape versus thermal escape.

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2 METHODS, OBSERVATIONS, SIMULATIONS ETC.

In this work, two approaches to the calculation of the mass-loss rate of gas due to thermal evaporation are attempted. The upper limit is provided by the classical Jeans escape (**?**) in which a high-velocity tail of the Maxwell-Boltzmann velocity distribrution is assumed to be populated at all times and the continuity equation is used to find the mass-loss rate. The lower limit on the escape-rate is provided by the 'lid'-approximation (**?**) in which the high-velocity end of the velocity distribution is assumed re-populated on some timescale after which a 'lid' is lifted and the high-velocity end is allowed to escape. Common for both methods are the exploitation of the Maxwell-Boltzmann distribution which is the probability for a single particle in a thermally equilibrated gas to have a certain velocity based on internal energy of the gas,

$$f(v) = \sqrt{\left(\frac{m}{2\pi kT}\right)^3} 4\pi v^2 e^{-\frac{mv^2}{2kT}}, \quad (1)$$

where v is the velocity, m is the particle mass, k is the Boltzmann constant and T is the gas temperature.

Another quantity of prime importance to this calculated is the escape velocity of a particle in a gravitational potential which is the velocity with which a particle has enough energy to escape to infinity from a isolated potential. The escape velocity is given by

$$v_{esc} = \sqrt{\frac{2GM(<r)}{r}}, \quad (2)$$

where r is the radius and $m(<r)$ is the mass contained with the radius, r. Assuming an NFW-profile (**?**) for the halo in which the gas is embedded, allows us to calculate the escape velocity as a function of radius for a halo of any given mass. *TODO* : Think more about what escape velocity to use - use the maximum over the entire profile or max of outer escape-layer

2.1 Jeans escape

The flux of escaping particles is found by integrating the Maxwell-Boltzmann distribution from the escape velocity and up in three dimensions and multiplying with the number density of particles

$$v_{esc} = \sqrt{\frac{2GM(<r)}{r}}, \quad (3)$$

Refer back to them as e.g. equation (**??**).

2.2 Figures and tables

Figures and tables should be placed at logical positions in the text. Don't worry about the exact layout, which will be handled by the publishers.

Figures are referred to as e.g. Fig. 1, and tables as e.g. Table 1.

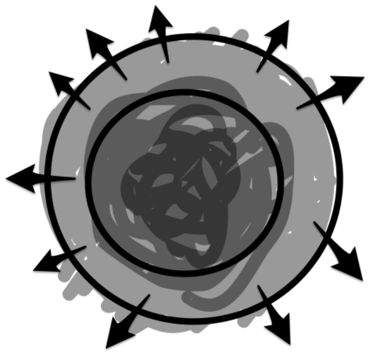

Figure 1. Schematic illustration of the thermal evaporation. *TODO* : Placeholder

Table 1. This is an example table. Captions appear above each table. Remember to define the quantities, symbols and units used.

A	B	C	D
1	2	3	4
2	4	6	8
3	5	7	9

3 CONCLUSIONS

The last numbered section should briefly summarise what has been done, and describe the final conclusions which the authors draw from their work.

ACKNOWLEDGEMENTS

The Acknowledgements section is not numbered. Here you can thank helpful colleagues, acknowledge funding agencies, telescopes and facilities used etc. Try to keep it short.

REFERENCES

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