# BROADENING OF THE INTERPLANETARY HELIUM CONE STRUCTURE DUE TO ELASTIC COLLISIONS OF LISM HELIUM ATOMS WITH SOLAR WIND IONS.

Hans J. Fahr, Hans U. Nass and Daniel Rucinski[+]
Institut für Astrophysik der Universität Bonn and
[+]Space Research Center of Polish Academy of Sciences, Warsaw

## ABSTRACT

Neutral interstellar particles penetrating into the heliosphere, besides being subject there to specific loss processes, suffer elastic collisions with KeV-solar wind ions. The momentum transfer to the neutrals connected with these collisions leads to a loss of angular momentum with respect to the sun and to a fractional compensation of the effective solar gravity. The dynamical particle trajectories hence are changed into non-Keplerians leading to density and temperature distributions differing from those calculated in the past. This is found from a solution of the Boltzmann equation that linearizes the effect of this additional force. It is shown here that the HeI-584A resonance glow of the heliospheric helium cone lead to substantially lower interstellar helium temperatures if re-interpreted on the basis of this revised theory. These temperatures now seem to be in accordance with the derived temperatures for interstellar hydrogen.

## INTRODUCTION

The problem of an LISM diagnostics based on interplanetary resonance glow interpretations is closely connected with the modelling of the penetration of neutral interstellar gases into the inner regions of the heliosphere, where they are resonantly excited by the solar radiation field. This modelling was done up to now taking into account only the effects of the net solar gravity and specific loss processes. There is, however, a definite need to consider also the effect of elastic collisions between interstellar neutrals and solar wind ion species, because, as shown by Fahr, Nass, Rucinski (1984), these substantially modify the LISM density structure in the heliosphere.

The virtue of elastic collisions to transfer specific amounts of energy to the neutrals, and thus to increase the mean velocity dispersion of their local velocity distribution function, had already been appreciated in a series of papers in the past (Fahr, 1974, Fahr and Lay, 1974, Wallis, 1975, Holzer, 1977, Fahr, 1978, Wu and Judge, 1978, Hassan and Wallis, 1983, Kunc et al., 1983). However, it was noticed only recently (Fahr, Nass, Rucinski, 1984) that due to these collisions also a linear momentum transfer to the neutrals takes place which results in a "drag-like" force of non-negligible magnitude operating into the direction of the relative velocity $\underline{v}_{rel}$ between a neutral and the solar wind bulk flow. The individual interaction is connected with the Coulomb field of the ion and the electric multipole field of the polarized atomic shell of the neutral.

In this context the "drag-like" force results from the averaging effect of many distant elastic collisions that one neutral undergoes simultaneously with a statistically relevant sample of solar wind ions passing over it per



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unit of time. Each individual collision, when considered as a separate event, would turn the relative velocity $\underline{v}_{rel}$ of the collision partners around their center-of-mass-velocity $\underline{V}$ by specific angles $\chi, \phi$ as illustrated in Figure 1. Due to the homogeneity of the solar wind flow over a Debye length $l_D$ ($10^3$ cm!) this results in a cancellation of velocity changes perpendicular to $\underline{v}_{rel}$, but leads to a systematic change of the neutral particle velocity, equivalent with the action of a force in the direction $\underline{v}_{rel}$.

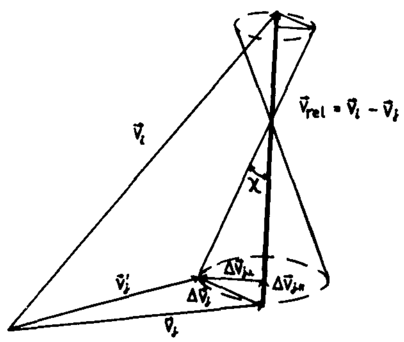


Fig. 1: Schematic illustration in velocity space of velocity changes $\Delta\vec{V}_j$ of the neutral species j elastically colliding with solar wind ion species of velocity $\vec{V}_i$.

This force can be calculated from the following formula (Fahr, Nass, Rucinski, 1984):

$$(1)\quad \underline{F}_v(\underline{r},\underline{v}) = n_i v_{rel}\, \mu_{ij}\, \underline{v}_{rel} \int_0^{l_D} (1-\cos\chi)\, 2\pi\, p_{el}(\chi)\, dp_{el}(\chi)$$

where $n_i$ is the density of the solar wind ion species, $\mu_{ij}$ is the reduced mass of the collision partners, and $p_{el}$ is the collisional impact parameter. The two components of the above force, the radial component, $\underline{F}_{v,r}$, and the latitudinal one, $\underline{F}_{v,\rho}$, yield the following ratio:

$$(2)\quad F_{v,\rho}/F_{v,r} = v_{rel,\rho}/v_{rel,r} \approx 10^{-1}$$

It turns out that for helium 30 percent of the gravity is compensated by $\underline{F}_{v,r}$, whereas for hydrogen even a full compensation of gravity can be established.

The joint influence of these two drag force components on the neutral atom velocity distribution function cannot be disentangled. Nevertheless, for clarifying purposes, their pinciple effects may be described separately:

1) The component $\underline{F}_{v,r}$ partly compensates solar gravity leading to particle trajectories that are less curved towards the sun. This would cause smaller helium cone densities, but no change of the half angle of the density cone, as is made evident in the Feldman-formula for this angle (Feldman et al., 1972).

2) The component $\underline{F}_{v,\rho}$ leads to an angular momentum loss of neutrals with



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respect to the sun. Hence neutrals would be forced to move along trajectories with a stronger inclination towards the sun. A continuous change from a hyperbolic into elliptic Keplerians is occuring, even enabling a capture of interstellar neutrals into bound orbits. In an isolated consideration of this latter effect on LISM helium, an increase of the helium cone densities is obtained, even overcompensating the density decrease due to the first effect. Furthermore a broadening of the density structure of the helium cone, i.e. an increase of the cone angle, is caused.

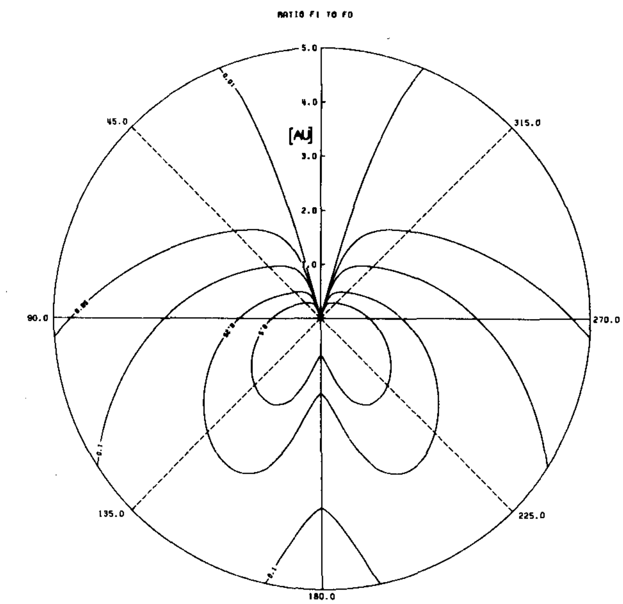
It is clear that only the combined influence of the two drag force components on the velocity distribution function is worthwhile to be treated. This kinetic theory for particles moving under gravity- and drag-forces has been developed by Fahr, Nass, Rucinski (1984) as solutions of an appropriate Boltzmann equation, where use had been made of the solution $f_o(\underline{r},\underline{v})$ known for the simpler problem of sole gravitational forces. The local neutral atom density then is represented by

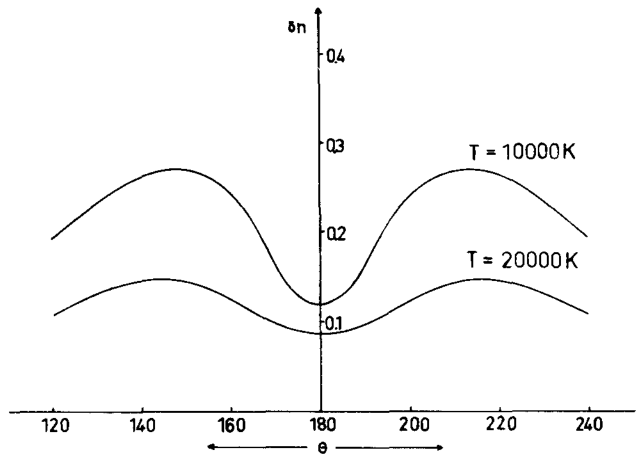
(3) $n(\underline{r}) = n_o(\underline{r})\ (1 + \delta n(\underline{r}))$

where $\delta n(\underline{r})$ is the relative change of the local density with respect to the density $n_o(\underline{r})$, obtained from $f_o(\underline{r},\underline{v})$ as the first velocity moment. The density $n_o(\underline{r})$ has to be considered as the conventional LISM model density in the heliosphere used in the up-to-now model fits for the observed interplanetary EUV resonance glow intensities. In the following we shall give results of an application of our theory to interstellar helium.

In Figure 2 we have given a contour plot of $\delta n(\underline{r})$ in a plane containing the sun and the interstellar wind vector $\underline{V}_{\infty}$. It can be seen that the relative helium density changes with respect to $n_o(\underline{r})$ are of inferior importance on the upwind side, whereas appreciable values are attained on the downwind side, especially pronounced at regions $\pm 40^o$ apart of the downwind axis, i.e. at regions flanking the conventional helium density cone. This is especially evident from Figure 3 where $\delta n(r=3AU)$ is shown for different interstellar helium temperatures.

Figure 4 now displays the total helium density n(r) obtained with formula (3) at a constant solar distance of r = 3AU versus the angle $\theta$ from the downwind axis. The lower curve in this figure gives, for comparison, conventional model densities $n_o(\underline{r})$ that would have been obtained for the same LISM helium temperature $^oT_{He}=10^4$K. As is evident in a comparison of these two curves the $n_o$-density structure yields lower helium densities at the downwind axis and a smaller cone angle. In order to fit the helium density profile, a 10 percent increase of the LISM helium density and an increase of the LISM helium temperatures by 4000 K had to be applied to the conventional theory. This effectively means that the realistic density structure described by the formula (3) would give rise to the deduction of substantially too high helium temperatures $T_{He}$ if interpreted with the help of the conventional model approaches. Since the effect raised here is of importance only for neutrals that reach the downwind side at relatively small solar distances $r < 3AU$, we believe that this leads to a mis-derivation of temperatures only for helium, but not for hydrogen. Therefore we conclude that the up-to-now outstanding problem of helium and hydrogen showing up in the heliosphere as gases of drastically different temperatures is brought to a satisfactory solution.




<u>Fig. 2:</u> Contour plot $\delta n(\underline{r})$=const showing curves of equal relative helium density enhancement in a circumsolar plane containing the interstellar wind vector $\underline{V}_\infty$. The solar distance r and the angle θ have been used as coordinates in this plane. The unperturbed interstellar helium temperature is taken to be $T_\infty = 1 \cdot 10^4$ K. (For solar data used, see: Fahr, Nass, Rucinski, 1984).-

<u>Fig. 3:</u> The relative helium density enhancement $\delta n(r = 3AU, \theta)$ for both $T_\infty = 1 \cdot 10^4$ K and $T_\infty = 2 \cdot 10^4$ K is shown versus the angle θ at a constant solar distance of 3 AU.



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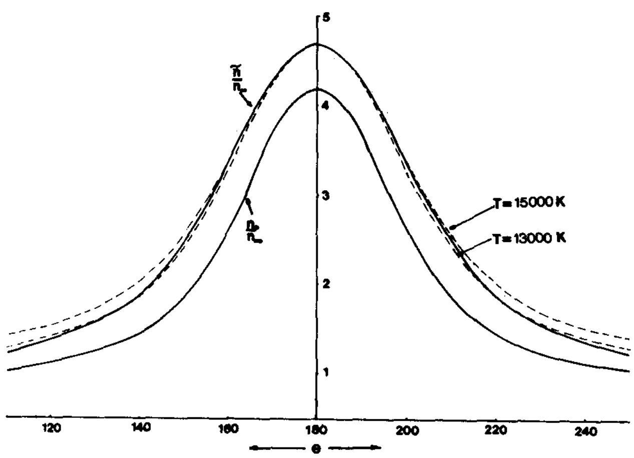


Fig. 4: The unperturbed densities $n_o(\underline{r})$ and perturbed densities $\tilde{n}(\underline{r})$ in the downwind cone region are shown versus the angle-$\theta$ at a constant solar distance of 3 AU. All densities are normalized with the helium density at large solar distances, $n_\infty$. For comparison, the dashed curves give solutions for unperturbed densities $n_o'$ which yield on the downwind axis a density that is identical to $\tilde{n}(r=3AU,\theta=\pi)$, but which belong to elevated interstellar helium temperatures $T_\infty'$. The solid lines are calculated for $T_\infty=1\cdot 10^4$K.




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