THE CAUSE OF THE CORONAL TEMPERATURE INVERSION OF THE SOLAR ATMOSPHERE AND THE IMPLICATIONS FOR THE SOLAR WIND

J. D. Scudder

NASA Goddard Space Flight Center, Code 692, Greenbelt, MD 20771, U.S.A.

ABSTRACT

The energy contained in suprathermal tails at the base of the transition region is shown to be transformed into the rarefied, but hotter, transition region and low corona *WITHOUT* any further addition of energy to the gas above the base of the transition region. Quantitative agreement with the scale length of the transition region and the temperature of the coronal base at $1.03R_o$ are demonstrated, regardless of the magnetic topology. Possible critical point location and asymptotic wind speed are shown to be controlled by the suprathermal tail strength parameter used to model possible suprathermal velocity distribution functions at the base of the transition region. This process shows promise for producing temperature profiles that peak near, but outside of, the fluid critical point without *ad hoc* energy deposition. The ¬nal temperature inversion above the solar photosphere is argued to be a generic feature around all with non-thermal distributions at the heights where the atmosphere last becomes mostly ionized.

INTRODUCTION

The solar wind was theoretically suggested as the consequence of the known million degree temperature of the coronal base at $1.03R_o$ /1/. At the hydrodynamic level the known high temperature at $1.03R_o$ and density profile determine a strong outward gas pressure gradient which overcomes the attraction of gravity, yielding an organized outward average acceleration to supersonic flow. Such flows have come to be known as "thermally" driven, as contrasted with "radiation/wave" accelerated, winds. A crucial factor in the theory is the determinant of the coronal temperature of the gas; if it is too high the wind does not go supersonic; if it is too small the asymptotic wind speed is uninteresting. The cause of the observed, inverted multi-million degree corona above the 5500° photosphere and, hence, the supply of thermal energy for the solar wind has remained a mystery. The possible MHD wave source(s) for direct acceleration within the transition region of the incipient solar wind also remains ill-defined.

After the experimental verification of the existence of the supersonic solar wind, theoretical efforts focussed on finding magnetized fluid wind solutions supported by thermal conduction that predicted the observed bulk speed and radial variation of species temperature as a function of source regions on the sun. The coronal base temperature of the inner boundary of the solutions at $1.03R_o$ remained a given, constrained by the observations, but not explained. These models have only been partially successful /2-4/. The principal success is the recovery of a wind with 300-400km/s speed at 1AU. The predictions of the radial temperature profiles for electrons and ions and the strong correlation of the later with wind speed were not well described. The observations prompted considerable efforts to construct wave driven ¬ries that deposit energy above the critical point. Wave scenarios for providing heating/momentum ¬ion to the coronal plasma above $1.03R_o$ remain in vogue /5/, although there are serious questions wnether such waves 1) can be adequately transmitted into the low transition region after the strong attenuation/reflection that takes place below this distance /6/; 2) can deposit their energy or momentum at the necessary locations in the corona; 3) can be consistent with the observed, but low, levels witnessed at the orbit of Helios /7,8/; or 4) play any role in determining the coronal temperature inversion a the low TR.

The conflict between solar wind observations and theory is especially severe in the high speed wind over coronal holes. Most theorists, except Olbert /9/, have discounted the sufficiency of the internal energy density at the base of the transition region for such high speed winds in favor of some form of radiation pressure to produce the high speed wind. Alfven wave models are superficially attractive since they can provide a "direct" acceleration without building a thermal pressure gradient in the presence of the high thermal conductivity of the plasma as occurs with magnetosonic waves. The *ad hoc* nature of the wave amplitudes assumed is rarely discussed; neither is their possible origin. Occasionally, support for the appropriate wave amplitudes is sought in the excess Doppler widths of transition region lines. The wave driven wind modelers presuppose the temperature of the corona is given at $1.03R_o$ and then rely on the accuracy of polytrope closure, or the Spitzer conduction law (or its "saturated version") for its contributions to the extension of the solar wind. Since the Spitzer-Braginskii-Fourier heat loss down the transition region is a sink to the build up of the coronal temperature, significant depositions of energy above $1.03R_o$ are required by the wave treatments /10/ that explain a non-monotonic profile above $1.03R_o$.

While the low energy density content of the solar wind may be viewed as a possible perturbation to that of the transition region (TR), the TR determines which particles comprise *all* the transmitted mass, momentum, and energy included in the low corona. However, unlike fluid flow in a pipe, not *all* the particles that comprise the initial number density, mass flux, and energy flux at the base of the TR are transmitted across the TR into the low corona: the TR is a high pass, speed dependent strainer, or filter /11,18/ for particles enroute to the low corona. The boundary conditions suitable for a separate model of the corona must reflect and not stifle the kinetic signatures impressed by the energy dependent filter of the TR /11/. Of particular interest is the appropriate size of the higher order kinetic mor of the velocity distribution function at the usual inner boundary of the compartmentalized doma solar wind solutions above $1.03R_o$. Puzzling are the suggestions /12,13/ that the solar wind temperature profile above a recurrent coronal hole is consistent with being non-monotonic above $1.03R_o$. At the very least such possibilities together with the Fourier heat description appear to require a strong deposition of energy somewhere at the outermost extremity of the transition region; at their worst two distinct heat sources are required: one to form the corona above the transition region and another to produce the distended temperature maximum at 2-$6R_o$. Recent work /13/ questions the data and uniqueness of the Munro and Jackson conclusion about an energy source *above* $1.03R_o$, without addressing of the heat deposition required *near* $1.03R_o$.

It is the identity of this seemingly inescapable, localized energy source, disjoint from the mechanical power implied by the hydrogen convection zone (HCZ) and its attenuation /6/, that has eluded description for the 50 years since the temperature inversion of the corona was established. This paper suggests a promising, new way to retrieve the inversion above the low TR to multi-million degree coronal values, regardless of the magnetic topology; the same process explains the temperature profile rising outwards above $1.03R_o$.

The internal energy equation contains an effective heat source when $\nabla \cdot \underline{Q} > 0$. Spitzer's heat flux relation ($\underline{Q} = -\varkappa(T)\underline{\nabla}T$) is *not* model independent; it is not a valid synthesis of the kinetic physics if the microscopic distributions are not perturbatively close to local Maxwellians /14/. Spitzer's Fourier-like form for the heat flux closure suggests that a temperature profile requires a heat source at local maxima and other locations of strong negative curvature in the temperature profile as near $1.03R_o$. It has long been known that Fourier's heat law may be derived from a Taylor series perturbation expansion of the solution of the Boltzmann equation of transport for *neutral* gases, where the small parameter is the mean free path over the scale height and the lowest order distribution function is a spatially un Maxwellian. This scheme can work because the mean free path is nearly synonymous with the path of particles of any given energy, whether thermal or extremely suprathermal. When the velocity ıdent and unbounded free path in a *fully ionized plasma*, such as the low TR, is considered, it ɔw widely agreed /9,15-17/ that the Fourier-Spitzer-Braginskii estimate of the heat flux is not on solid theoretical grounds immediately at and above $1.03R_o$ and even lower in the TR /11, 16/. Even the possibility that the heat law can be formulated as a local functional relationship between moment variables or their gradients in the same place has been in question for the solar wind at least since 1979 /19/. Coulomb collisions by themselves are not sufficiently frequent, at a sufficiently broad spectrum of random speeds to make the Knudsen number small enough in an inhomogeneous, fully ionized plasma to suppress non-local effects /15,18/. Because of the strong inverse energy dependence of the free path, it is extremely difficult at finite density to have sufficient collisions to preempt non-local effects from "booming" through the locally scattered part of the velocity distribution function, f(v). These non-local effects preclude a consistent local description /19/, which in turn, is the foundation of the usual, truncated fluid theory of a plasma that leads to ($\underline{Q} = -\varkappa(T)\underline{\nabla}T$. The theoretical difficulties of the TR temperature profile, the solar wind energy supply at $1.03R_o$, and solar wind temperature profiles above $1.03R_o$ are argued in this and related previous work /11,18/ to be connected to our inability to accurately estimate the size or describe the process of the transport of internal energy from one locale to another in such violently inhomogeneous media, where the index of inhomogeneity is so strongly energy dependent and where Chapman-Enskog local gradient expansions are inappropriate.

THE MODEL OF VELOCITY FILTRATION

This paper examines a global transport process, called "velocity filtration", that cannot always be treated by the traditional fluid description /18/; it provides a novel, quantitative, alternate explanation for the temperature inversion of the corona relative to the base of the transition region, but does not involve energy deposition above the base of the transition region. The theoretical mechanism of energy rearrangement *is* a viable way to explain the temperature inversion of *either* "open" or "closed" field structures that ɿse the transition region /11/. While providing a detailed TR temperature profile, and suggesting the ingredients of a one fluid temperature profile that has its maximum above $1.03R_o$ and beyond the critical point, it also determines temperatures at critical points that are compatible with those isothermal temperatures Parker presupposed were appropriate in his earlier models. In suggesting what controls the temperature of the solar corona at the critical point, conclusions concerning the types of (supra)thermally driven winds that can be realized and the scaling of temperature inversions around other stars are suggested and compared with the data.

There is wide agreement that whatever remnants of the HCZ power that can get up into the chromosphere are either reflected or damped out by the time they reach the low transition region /6/. This attenuation presents severe difficulties for schemes that would transport or amplify waves from the HCZ to be damped in some other locale above the transition region /20/ in magnetic structures that permit the expanding solar wind to develop. Such waves are thought to somehow provide the increase of the temperature /12/, or the requisite momentum/heat addition outside the critical point thought to be essential for the fluid description of the high speed solar wind /21/.

There is no a priori reason /11,18/ that the fully ionized plasma that accepts the dissipating HCZ wave energy in the low transition region should do so in a self-similar (quasi-Gaussian) way, preserving a Maxwellian velocity distribution function with a single adjustable shape parameter, its variance or temperature. Much more likely, since the H-theorem does not apply in this locale /11/, is that there will be a (random) speed dependent response to the deposition of energy from the wave remnants: the more frequently scattered low energy particles will absorb and share energy in a more self- similar way; the suprathermal particles are relatively ineffective at sharing their acquired energy, yielding a more coherent response to the transfer of energy from the decaying waves of the HCZ /22-23/. This speed dependent ɿnse to energy deposition is exacerbated by the rapid decrease of the density (scattering centers) in ɩtward radial direction at the virtual "edge" of the star, with the higher energy particles sensing their collisional exobase at smaller radii than the lower energy particles.

The implications are now summarized of presupposing a non-thermal electron and/or ion distrib at the base of the low transition region where the plasma is fully ionized. At the outset it shou. mentioned that the fluid equation truncated at the energy equation cannot address the consequences of this suggestion /18/. The theoretical approach for the kinetic results summarized here has established /11,18/ that nonthermal distributions, self-similar in an attractive potential *at low energy* to a Maxwellian, approximately zero the collision operator at low energies even when collisions of the rms speed particle in the plasma are frequent. For such a restricted class of boundary functions, the collisional solution of interest reduces in first approximation to that of a collisionless Boltzmann form, even though collisions are not being ignored. It is for a similar reason that Maxwell's exponential, isothermal atmosphere can be interchangeably derived from the Vlasov or Boltzmann equations: the Gaussian boundary function is self- similar in the equivalent potential, remaining everywhere a solution of the collision operator by its special shape regardless of the thermal collision frequency /11/.

In an attractive potential, as at the base of an ionized stellar atmosphere, an equivalent potential well is formed (even with suprathermal f(v)'s) with a depth approximately 1/2 the gravitational one /11/. Conservation of energy prevents, or "filters", certain particles from the boundary distribution function from moving too far in the radial direction. All particles in the boundary function can be divided into positive and negative total energy particles based on their initial kinetic energy in the boundary velocity distribution. A counterintuitive consequence for a non-thermal boundary distribution function, illustrated in the left frame of Figure 1, is that conservation

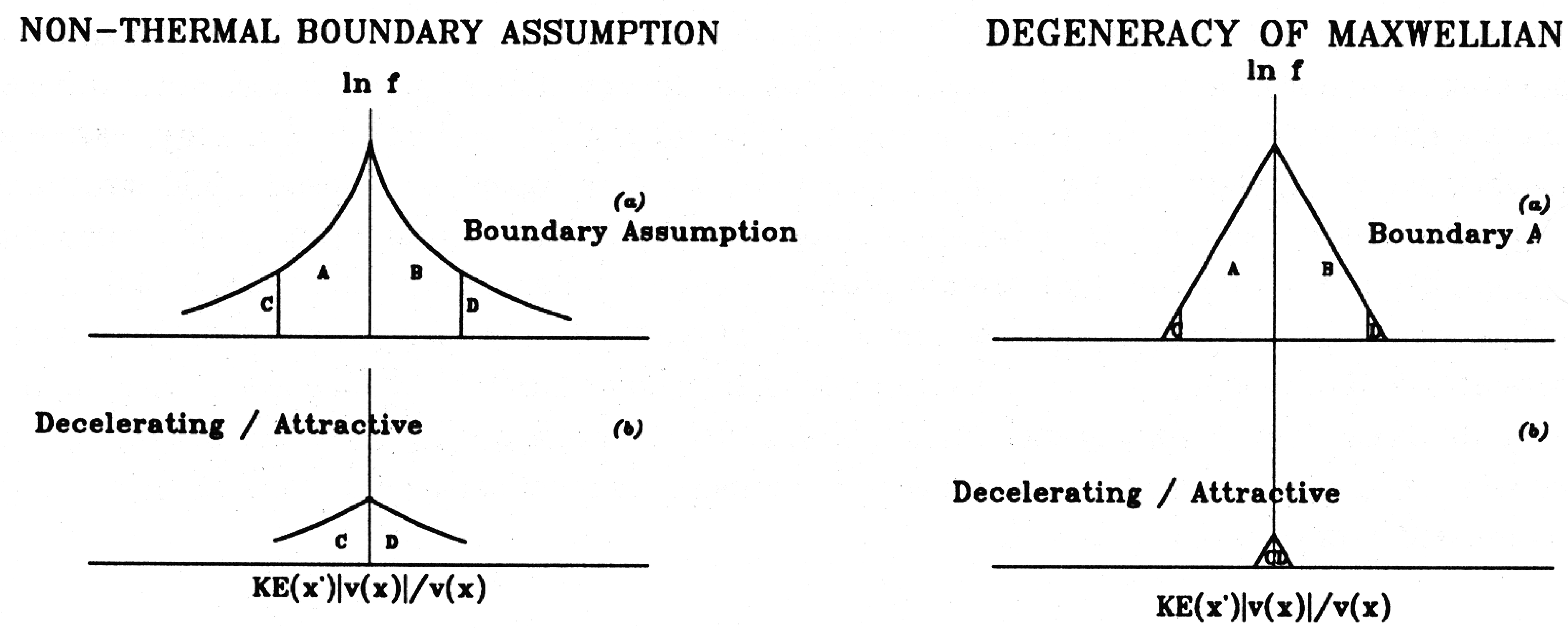

Fig. 1 Signatures of Velocity Filtration (left) for a non-thermal distribution and (right) for a exact Maxwell-Boltzmann distribution. Notice that the Maxwellian image under Velocity Filtration is similar to the boundary distribution and hence is at the *same* temperature; for any suprathermally over populated distribution /18/ Velocity Filtration *increases* the mean energy per particle, its kinetic temperature!

of energy causes the rms spread of the distribution of observable kinetic energies to increase as the over all density is decreased; this results from the exclusion of the low energy particles that cannot get out of the well - a process called "velocity filtration" /11,18/. The rms spread of a distribution controls the kinetic generalization, "T" = P/(nk), of thermodynamic temperature. Conversely, a Maxwellian distribution (the kinetic foundation for the fluid approximation and the premise of Spitzer's heat law) shows no evolution of rms temperature "T" under the same circumstances above (as illustrated in the right frame of Figure 1), even though its density is decreased for a similar reason. The anti-correlation of temperature "T" and density caused by an attractive potential with a non-thermal boundary velocity distribution function is a *generic* property of any non-thermal distribution /11/ under "velocity filtration". While velocity filtration follows directly from conservation of energy, its predictions cannot genera' retrieved from the truncated moment equation /18/; the existence of suprathermal tails are reflect moment signatures in the deviation of the fourth and higher even moments from their Gaussian based es, assumed unimportant in the usual truncation of the fluid moment hierarchy expansion /11,18/. itionally, no polytrope with a customary polytrope index $\gamma>1$ can replicate this effect!

Spatial solutions of the Vlasov equation have been found /11/ for a family of non-thermal velocity distribution functions of ions and electrons at the base of the solar transition region. The modeled non-thermal distribution is the generalized Lorentzian distribution, called the kappa, κ, distribution introduced by Olbert /24/. Mathematically defined by the relation

$$f_\kappa \propto \left(1+\frac{v^2}{\kappa w_c^2}\right)^{-(\kappa+1)}, \tag{1}$$

f_κ resembles a Gaussian at low speeds, and evolves smoothly into an inverse power law with increasing random speed, v, as controlled by κ. Velocity filtration alone operating on a wide range of non-thermal boundary distribution functions produces coronal temperatures in excess of several million degrees without *ad hoc* heating /11/.

An example of the radial profile of "T" that can be produced considering the effects of velocity filtration on a non-thermal distribution is illustrated in the left frame of Figure 2. Starting from a base low transition region temperature T$\simeq$ 5500°K, velocity filtration precipitously increases "T(r)", easily achieving values near 4–6x10^{6}°K by $3R_o$. As indicated below in eqtn (4), when there is a mass flux on an "open" field lines, about half of the available temperature is actually diverted into flow energy by the distance $R/R_o \simeq \kappa$, yielding estimates of 2–3x10^6 as the temperatures near the possible critical point. The dashed curve corresponds to the electron temperature profile and the solid curve to that of the ion; the different curves result from the slight differences in the velocity distribution function of ions and electrons ($\kappa_+ \neq \kappa_-$) assumed at the base of the transition region. This temperature "inversion" has been shown to occur if *either* electrons *and/or* ions are non-thermal at the innermost boundary of the solution in the ransition region /11/. A significant temperature inversion (greater than a million degrees) can be ined with κ between 2 and 8, which corresponds to a rather broad range of boundary distribution functions ranging from very strong tails (2) to very modest ones (8) /11/. The crucial ingredient is that κ not be large compared to this range. The logarithmic scale height of the temperature can easily be as short as 375-450km /11/, again comparable to that inferred from spectral observations /25/.

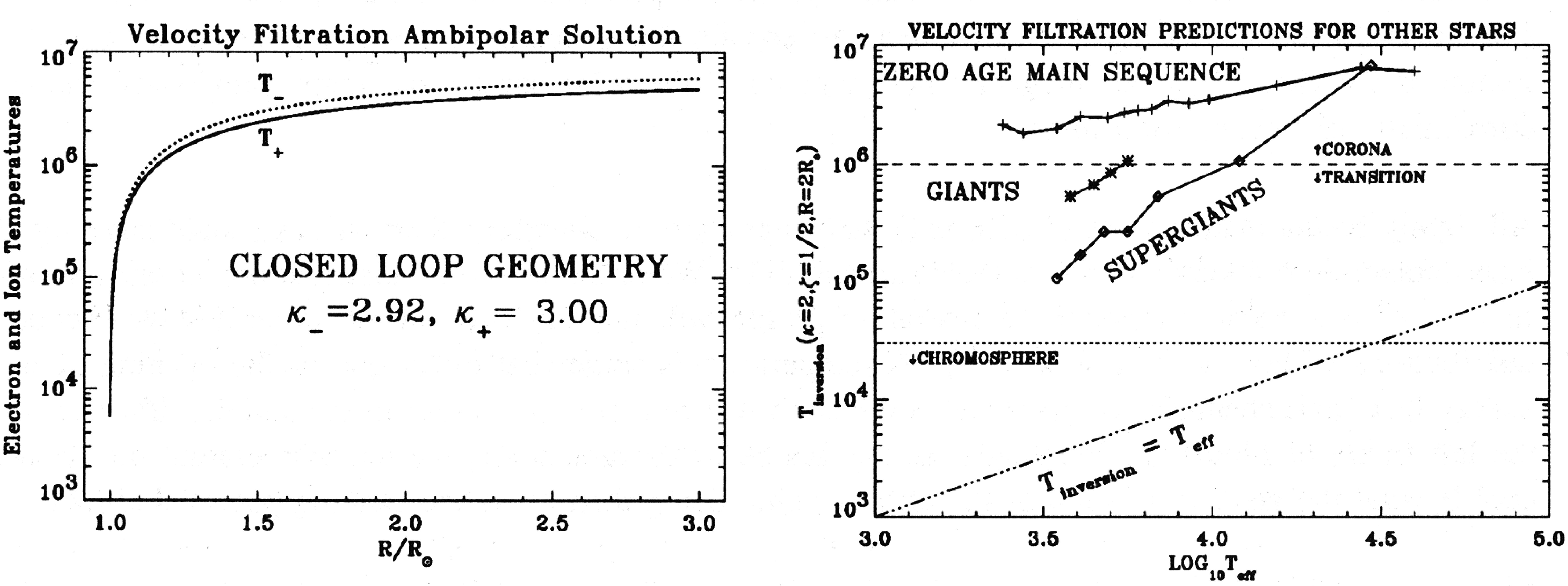

Fig. 2 (Left):Closed magnetic field configuration temperature profile according to Velocity Filtration solution; (Right): Estimates of stellar inversion temperatures at $2R_*$, assuming that non-thermal distributions like at the sun occur at the base of these atmospheres when they become fully ionized.

hysical and intrinsically kinetic reason for this sharp increase in "T" derives from the smallness of ean kinetic energy kT(R_*) in the TR (0.5eV) in relation to the depth of the equivalent gravitational plus electrical potential, $|\Delta\Psi(R_*)| \simeq$980eV. Before the particles move very far (379km, initially) up the potential hill they must store $kT(R_*)$ worth of kinetic energy as potential energy. It should be empha that unlike fluid model heating, where *all* the particles of the velocity space dilute any local enhancement of the energy density, velocity filtration excludes *part* of the velocity space preferentially, removing in an attractive potential more density than pressure. This kinetic effect fractionally depletes the density of a non-thermal distribution to a larger degree than the pressure, so that the *average* energy of those that defeat the filtration is higher than those that do not (cf Fig 1, left frame). The random speed, $v'(R_*)$, in the transition region boundary distribution that has zero speed at solar radius $r = R_*+h$ is given by the approximate relation $v'(R_*,h)/V_{th}(R_*) \simeq 30.7(h/R_*) = 5.3$ at the traditional base of the solar corona ($h = .03R_*$), where $V_{th}(R_*)$ is the thermal speed of the gas at the TR base. Only particles of the boundary distribution function, $f(v,R_*)$, above $v'(R_*) = 5.3V_{th}(R_*)$ can make up the distribution at the traditional coronal base at $1.03R_o$. In words, "... the typical particle at $1.03R_o$ is clearly the atypical, extremely suprathermal particle of the transition region only 2000 km below..." In turn, this implies that significant and rapid "filtration" has returned all the lower kinetic energy particles below $v'(R_*)$ at some intermediate altitude giving the transport physics a *global* character alien to the *local* premise that is the underpinning of the fluid closure.

Analytic forms for the effects of velocity filtration have been derived for a restricted, but representative, subset of analytic, nonthermal boundary distributions given by the kappa function /11,18/. In the isomagnetic flux tube limit, when $\kappa_+ = \kappa_-$, and when there is no mass flux, an especially simple summary of the effect is /18/

$$T(\Delta B = 0, r \to \infty) = T_*\left(1 + \frac{R_*}{(2\kappa - 3)L_D}\right), \tag{2}$$

where $T(R_*)$ is the temperature of the inner boundary condition at the base of the transition region, R_* is the solar radius at the base of the transition region, L_D is the density scale height, and 1/ measure of the non-thermal content of the boundary distribution function at the base of the trans region. The Maxwellian boundary condition corresponds to $\kappa \to \infty$. Mathematically, the temperature inversion owes its existence to the finite size of κ or, more generally, the existence of *any* suprathermal tail (figure 1) /18/; in the Maxwellian limit, velocity filtration reverts back to the well known isothermal exponential atmosphere /26,27/ and, consistently, the temperature inversion disappears in (2). Scudder /11/ develops the arguments that this effect can explain the temperature inversion across the transition region of the closed or open magnetic field regions of the solar corona and many previously reported correlations of heating signatures.

All tightly bound atmospheres ($R_*/L_D >> 1$) with suprathermal boundary distributions should have significant temperature inversions above their surfaces /11/. When the boundary distributions possess a mass flux, as over a coronal hole, the temperature profile will initially rise almost as rapidly as boundary distributions without a mass flux; the peak temperature is somewhat lower due to the opening of new energy flux "exit channels" of mass and conduction flux that are *not* present in the solution illustrated in the left frame of Figure 2. Eventually, as the gas becomes supersonic, the ion temperature profile will cool beyond the general location of the critical point, being then in an accelerating potential /18,28/.

The considerations of this paper that lead to the temperature inversion are not peculiar to the sun: 1) the speed dependence of the coulomb collision frequency; 2) the a strong gravitational potential in relation to the thermal energy of the gas at the stellar "surface" ($\Phi_G/kT_* \ggg 1$); and, 3) the ubiquity of non-thermal distribution functions in inhomogeneous, fully ionized plasmas. The form of equation (2) emphasizes that this effect should be commonplace in all stars with "bound" atmospheres. The ratio R_*/L_D is set by the ratio of surface strength of gravity and temperature which is set by the theory of stellar structure. The right frame of figure 2 illustrates the suggested inversion temperature around a subset of whose gravity and surface temperature are readily available /29/; all stars have been assigned $\kappa =$ their bases. All zero age main sequence stars (ZAMS) are calculated to possess super million degree ion envelopes about their surface, regardless of their surface temperature. Thus, all ZAMS stars are energetically capable of thermal X-ray emission, as observed. Giants and Supergiants with smaller R_*/L_D (less tightly bound atmospheres) cannot achieve such a high inversion temperature. By increasing κ /11/ to give inversion temperatures that do not contradict observations of emissions from a given group of stars, an estimate of the $\frac{U_\infty}{V_{esc}(R_*)} \simeq \left(\frac{2(\kappa-1)}{2\kappa^2-3\kappa} ln20\right)^{1/2}$ /11/ can be made, to illustrate that the Giants and Supergiants have winds that are generally smaller in the dimensionless sense than those on the main sequence. This too, is in accord with the stellar observations /25/.

Within any *possible* critical point the spatially dependent form of the "T" profile of (3) can be written as

$$T(r, U=0) = T_* \left(1 + \frac{2(\Psi(r) - \Psi(r_*))}{(2\kappa-3)kT_*}\right). \tag{3}$$

If the suprathermal tail strength of the ions and electrons is the same, then with rigor $\Psi=\Phi_G/2$, where Φ_G is the gravitational potential for a proton, and κ is the common suprathermal tail index of electrons and ions. While the flow is still subsonic (3) suggests that the temperature of the plasma and the gravitational potential are strongly coupled at each spatial location, viz

$$v_{th}^2(r) = v_{th}^2(R_*) + \frac{(V_{esc}^2(R_*) - V_{esc}^2(r))}{\alpha(r)(2\kappa-3)}, \tag{4}$$

where α(r) = 1 for field lines with no mass flux, but will, in the presence of a mass flux, increases from 1 towards 2 at the critical point r_*. The function α(r) accounts for the diversion of thermal energy into flow energy that will occur when mass flux is allowed at the coronal base. If a critical point is possible in the fluid equations at r_*, with (4) as the equation of state (and $\alpha(r \simeq r_*)$ is slowly varying), it then must [illegible] /11/ at $r_*/R_* \simeq \kappa$. According to velocity filtration, the temperature at the critical point would be

$$T_{VF}(r_*) \simeq 5500 + 1.1x10^7 \frac{(\kappa-1)}{(2\kappa^2-3\kappa)} {}^oK, \tag{5}$$

which ranges between 3.6x10^6 and 1.4x10^6°K for κ between 2.4 and 4.5, respectively. If Parker's critical point occurred at the radial locations required by velocity filtration above, the *isothermal* temperature required to allow a critical point at that location would be

$$T_{Parker}(r_*) = \frac{MV_{esc}^2(r_*)}{8k_B} = 5.25x10^6 \frac{R_*}{r_*} {}^oK, \tag{6}$$

which ranges between 2.2-1.6x10^6°K for critical point locations $r_*(\kappa)$ suggested above for κ between 2.4 and 4.5, respectively. Velocity filtration provides a temperature at the critical point, T(r_*), similar to that isothermal value above 1.03R_o presupposed by Parker. However, *unlike* Parker's isothermal temperature profile, the velocity filtration approach yields 1) a TR like profile below 1.03R_o *and* 2) a temperature profile that is still rising above the critical point $r_* \simeq \kappa R_*$ with an approximate, but positive, power law exponent $\beta = (\kappa-1)^{-1}$, consistent with the temperature profile of Munro and Jackson /12/, but *without* their inferred deposition of heat! Parker's original work /1/ exploited conservation laws to show that the conditions for the critical point permitted temperature gradients of either sign at the critical point so long as the power law exponent is between -1 and 2 at the critical point. Imposing this condition yields the requirement that κ >1.5. Actually $\kappa > 2$ is required /11/ for a finite flux energy supply to the corona, so that r_* > 2 R*. Thus Parker's critical point existence arguments translate into a *lower* bound on the possible value of the critical radius, r_*.

U[illegible] velocity filtration a transonic critical point may be realized 1) if the boundary distribution function's [illegible]rmal characteristics are suitable; 2) provided a mass flux exists at the inner boundary condition; an[illegible] 3) in the circumstances that the magnetic topology allows particle access above , $r_* = \kappa R_*$. If the magnetic tubes of force reenter the lower TR before extending beyond 2R*, no critical point can occur for any physically allowed value of κ at the inner boundary. To achieve supersonic flow the bou condition must possess a mass flux so that the transonic condition can be realized. Mass flux fro boundary distribution characterized by κ_*, on a magnetic arcade with its apex *inside* of $\kappa_* R_*$ might be a candidate for the (time dependent) spicules, which return most of their upwelling mass flux back to lower altitudes on the returning flux of the arcade. Conversely, the steady supersonic wind should come from boundary f_{κ_*}'s with a mass flux on magnetic tubes of force with loci r(s) that extend *beyond* r(s) = $\kappa_* R_*$.

Thus Parker's parametric freedom of the "coronal" temperature at the critical point is removed; with velocity filtration the temperature $T(r_*)$ at the critical point is calculated from the equilibrium kinetic solution as a reflection of the kinetic boundary conditions at the base of the TR (H $\simeq$ 2090km). Parker showed that the asymptotic wind speed is determined primarily by the temperature near the critical point. In particular, the wind speed would scale like the square root of the temperature at the critical point. The asymptotic wind speed can be estimated /11/ with these kinds of effects to suggest that faster winds would accompany smaller κ's. This situation has already been anticipated, at least for the electrons /30/. Assuming a $20R_o$ isothermal region, and noting that $V_{esc}(R_*)$ $\simeq$616km/s the following speeds {1066, 841, 542, 458, 346, 215} km/s correspond to κ's of size {2., 2.45, 4.5, 6, 10, 25} respectively. Such a range is consistent with the extremes observed in the solar wind.

SUMMARY

The most striking consequences of postulating a non-thermal electron and/or ion velocity distribution at the mid-transition region of H$\simeq$ 2100km is the recovery of a thin scale (L$\simeq$ 400km) transition region, a temperature profile anti-correlated with the density and a multi-million degree plasma at $1.03R_o$ starting from transition region temperatures ($\simeq$5500°K) *WITHOUT* distended heat addition to the system above the inner boundary where the non-thermal distribution is postulated. Excess Doppler widths of transition region lines have elsewhere /11/ been suggested to reflect unsurmised non-thermal r speed probability distribution functions (κ_+ = 2.48), rather than unresolved *coherent* motions, a explanation of the augmented Doppler lines widths reported in the TR. These inferred non-thermal ion distributions can, in turn, explain the inverted coronal temperature profile above either closed or open magnetic topologies. Velocity filtration causes the sound speed and gravitational escape speed at the critical point to be functionally set by the strength of the suprathermal portion of the boundary velocity distribution /11/. Estimates of critical point locations /11/ are encouragingly low 2.4-6RR_o. "Open" topology heating is still significant under velocity filtration as the plasma is accelerated; however, outside the critical point the ion temperature will cool. In the simplest closed loop regimes where there is no net flow, this is not possible and the temperature achieved is largest at the highest point of the loop consistent with observations /31/. When the inner boundary distribution is postulated to be a pure Maxwellian, the critical point recedes to large distance and the asymptotic wind speed becomes small; from the inferred suprathermal strengths required for the alternate interpretation of the the "turbulent" Doppler ion line widths in the TR /11/, the critical point is between 2.4 and $4.R_o$, consistent with our current picture of the solar wind expansion. More non-thermal distributions would yield lower critical points, although a minimum critical point radius r_* of approximately 2R* is suggested. By this same approach all stars should have distended coronal-like envelopes with temperatures limited only by the strength of the suprathermal distribution function where the atmosphere becomes fully ionized. In particular ZAMS stars are capable of X-ray emitting inversion shells, if their κ's near the base are similar to that of the solar case.

The process of "velocity filtration", is not new, but underlies the well known isothermal exponential atmosphere /26,27/. The new macroscopic effects result from considerations of velocity space transport possible when suprathermal distributions are NOT precluded in the kinetic specification of the boundary conditions on the plasma. Velocity filtration represents a very promising approach to the longstanding problem of the origin/maintenance of the corona and of the observed solar wind expansion; it op attractive new possibility that the coronal temperature inversion is *imprinted* on the velocity distri function in the form of a *suprathermal tail* in, or adjoining to, the same locale where the HCZ power is gly dispersed. Thus, the coronal heating problem comes full circle, with a mechanism for transporting quantity made by the attenuation of HCZ waves, stored in the microstate's suprathermal tail, and concentrated by the velocity filtration process to raise the mean energy of the particles that survive, thus determining a temperaure increase. This should be contrasted with the early scenario which has only recently been contradicted /6/: a subset of the HCZ waves deposit their energy sufficiently high in the thin overlying atmosphere to raise its mean energy to form the corona. Further ramifications of this idea including correlation of heating with orientation and strength of the magnetic field, scaling of excess "turbulent" Doppler widths with formation temperature, and a possible factor in solar wind minor ions having a temperature proportional to their masses are discussed at length in references /11,18/.

REFERENCES

1. Parker, E.N., Astrophys. J., 128, 664(1958a).
2. Chamberlain, J.W., Astrophys. J., 131, 47(1960); Whang, Y.C. and Chang, C.C., J. Geophys. Res., 70, 4175(1965); Jockers, K. Solar Physics, 3, 603(1968); Hartle, R.E. and Sturrock, P.E., Astrophys. J., 151, 1155(1968); Durney, B. Astrophys. J., 166, 669(1971); Roberts, P.H. and Soward, A.M., Proc. Roy. Soc., A328, 185(1972); Hartle, R.E. and Barnes, A., J. Geophys. Res., 75, 6915(1970); Olbert, S., Solar Wind 5, M. Neugebauer, ed., (Washington: NASA Conf. Pub. 2280), 149(1983).
3. Neugebauer, M. and Snyder, C.W. J. Geophs. Res.,71, 4469(1966); Burlaga, L.F. and Ogilvie, K.W., Astrophys. J.,, 159, 659(1970); Belcher, J.W. and Davis, L., Jr., J. Geophys. Res., 76, 3534(1971); Ogilvie, K.W. and Scudder, J.D.,J. Geophys. Res., 183, A8,3776(1978); E. C. Sittler, Jr. and J. D. Scudder, J. Geophys. Res., 85, 5131(1980); Rosenbauer, H., AGU Boulder, Co.(1976); Hundhausen, A.J., Coronal Expansion and the Solar Wind, (1972) Springer-Verlag, (Heidelberg); Schwenn, R. and Marsch, E., Physics of the Inner Heliosphere, 2. Particles Waves and Turbulence, (1991) Springer-Verlag, (Heidelberg).
4. Withbroe, G., Kohl, J.L., Weiser, H., Noci, G., and Munro, R.H., Astrophys. J., 297, 324 (1985).
5. Belcher, J.W. and Davis, L., Jr., J. Geophys. Res. 76, 3534(1971), and Fla, T., Habbal, S., Holzer, T.E., and Leer, E., Astrophys. J., 280, 382(1984).
6. Narain, U. and Ulmschneider, P., Space Sciences Review, 54, 377(1990); Ulmschneider, P., Rosner, R., and Priest, E. 1991, Mechanisms of Chromospheric and Coronal Heating, Springer-Verlag (Heidelberg).
7. Parker, E.N., Adv. Space Res., 10, (9) 17(1990).
8. Roberts, D.A., J. Geophys. Res., 94, 6899(1989).
9. Olbert, S., Solar Wind 5, M. Neugebauer, ed., (Washington: NASA Conf. Pub. 2280), 149(1983).
10. Withbroe, G., Kohl, J.L., Weiser, H., Noci, G., and Munro, R.H., Astrophys. J., 297, 324 (1985).
11. Scudder, J.D., Astrophys. J., in press(1992b).
12. Munro, R.H. and Jackson, B.V., Astrophys. J., 213 874(1977).
13. Lallement, R., Holzer, T.E., and Munro, R.H.,J. Geophys.Res.,91, 751(1986).
14. deGroot, S.R. and Mazur, P. , Non-Equilibrium Thermodynamics, (New York: Dover) 183(1984).
15. Scudder, J. D. and Olbert, S. J. Geophys.Res., 84, 2755(1979a); Scudder, J.D. and Olbert, S., 1983, in Solar Wind 5, M. Neugebauer, ed., (Washington: NASA Conf. Pub. 2280), 163.
16. Shoub, E.C., Astrophys. J.., 226, 339(1983); Ljepojevic, N.N. and MacNeice, P., Solar Physics, 117, 123(1988); and Ljepojevic, N.N. and MacNeice, P., Pys. Rev. A, 40, 981(1989).
17. Gray, D.R. and Kilkenny, J.D., Plasma Phys., 22, 81(1980).
18. Scudder, J.D., Astrophys. J. in press(1992a).
19. Scudder, J.D. and Olbert, S. J. Geophys. Res., 84, 2755(1979a) cf eqtn 11ff.

20. Parker, E.N., Adv. Space Res., 10, (9)17(1990).

21. Leer, E. and Holzer, T.E., J. Geophys. Res., 85, 4681(1980).

22. Parker, E.N., Astrophys. J.,128, 677(1958b).

23. Dreicer, H., Phys. Rev., 115, 238(1959).

24. Olbert, S., Egidi, A., Moreno, G., and Pai, L.G. Trans AGU, 48 177(1968); Olbert, S., 1969, Physics of the Magnetospheres, ed. R.C. Carovillano, J. F. McClay,and H.R. Radoski, (Dordrecht: Reidel), 641.

25. Cassinelli, J. P. and MacGregor, K.B., Physics of the Sun, III, P. A. Sturrock, ed., (Dordrecht: D. Reidel), 47(1986).

26. Maxwell, J.C., Nature, 8, 537(1873).

27. Boltzmann, L., Wien. Ber., 72, 427(1875).

28. Jockers, K., Astron. and Astrophys., 6, 219(1970).

29. Bowers, R. and Deeming, T., Astrophysics I, Stars, (Boston: Jones and Bartlett)(1984).

30. Fairfield, D.H. and J.D. Scudder, J. Geophys. Res., 90, 4055(1985).

31. Zirin, H. ,Astrophysics of the Sun,(Cambridge UK: Cambridge University Press)(1988).