THE THERMODYNAMIC REQUIREMENTS ON ATMOSPHERIC MODELS IMPOSED BY OBSERVED STELLAR NONTHERMAL MASS-FLUXES AND BY THOSE OBSERVED NONTHERMAL FEATURES ENHANCED IN Xe STARS

Richard N. Thomas
Institut d'Astrophysique, Paris and Department of Astro-Geophysics, University of Colorado, Boulder, CO 80309

INTRODUCTION

If I understand correctly, this session of the Symposium on Mass-Loss and Evolution of O Stars aims at clarifying the merits and demerits of four "theories" for the observed, nonthermal mass-loss from these stars. Hearn has summarized what he considers to be the essential characteristics of each of the four, especially relative to a set of questions which, he considers, put the observational requirements on the "theories" in focus. Representatives of each of the "radiation-pressure initiated, radiative-equilibrium controlled", "hot corona", and "warm corona" alternatives have elaborated on Hearn's summary, to stress what they consider essential. So, now, I would do the same for what we caricature as the "imperfect wind-tunnel" model --- not theory, which I assert does not yet exist --- both for nonthermal mass-flux, and for other observed nonthermal phenomena,[1] in stellar atmospheres generally, not just in O stars particularly. I assert, that in studying nonthermal mass-flux from O stars, if you limit your attention only to nonthermal mass-flux, and only to O stars, you handicap, a priori, your chance to understand what is required for the general model of a stellar atmosphere, in order to produce this variety of nonthermal phenomena[2] observed, alike in all varieties of stars.

I think the merit of my assertion is well-illustrated by: (1) contrasting it to another assertion, at the 1972 Goddard conference on stellar chromospheres, by speculative-theoreticians, without considering observations, that no star hotter than Fo could have a chromosphere; so that any possible winds from these stars could have no relation to chromospheres; (2) by the modeling of hot-star mass-loss as radiation-pressure produced, cold winds, from RE-controlled, spherically-symmetric, time-independent thermal atmospheres, again by speculative-theory, without considering observations; (3) by observations of super-ionization (relative to RE, thermal models) in a number of these hot stars, culminating in OVI observed in Tau Scorp; (4) by historical and current observations of both rapid (2-15 min) and longer term (days to months) variations in the emission-line spectra of hot, cool, and intermediate

P. S. Conti and C. W. H. de Loore (eds.), Mass Loss and Evolution of O-Type Stars, 215–226.

stars alike (eg Andrillat and Fehrenbach, 1978; Doazan, 1976; Herbig, 1960; Hutchings, 1968; Kolotilov and Zaitseva, 1975; Rosendhal, 1973). I do not see how a homogeneous, radiation-pressure and radiative-equilibrium controlled, hot atmosphere can produce the OB star variations; nor how a cool star, plus *only* an extended atmosphere or shell, can produce these cool-star observed variations. So, our approach focuses on *empirical*-theoretical *modeling* of that *combined* entity of atmosphere+ subatmosphere which can produce the *observed* data --- thermal and non-thermal, and, hopefully, lead to inference of those nonthermal energy storage modes required to produce these observations. Such nonthermal modes are, a priori, unknown, as witness their ignoration in these *speculative*-theoretical models. So, only observations, not further speculation, can remove "unknown", and substitute "empirical-theoretical" kinds and amplitudes of nonthermal modes.

I aim especially for clarity, re the characteristics of our model, in the minds of you who are basically observers, and you who are concerned with the state of the subatmosphere. I stress such aim, because I believe the importance of the mass-loss problem, *together* with that of the interpretation of other, observed, correlated, nonthermal phenomena,[2] lie in what *these data* tell us --- how they guide us --- in establishing, *empirically*, the general thermodynamic structure of the star, and the particular values of the amplitudes of nonthermal storage modes, within the star, of matter and energy. I think it is quite evident that, a priori, or speculatively-theoretically, we do not know either this general thermodynamic structure, nor the kinds and amplitudes of any nonthermal, subatmospheric and atmospheric, storage modes. So, the general problems we face --- of which the mass-loss is but one aspect, but apparently strongly linked to the other nonthermal aspects[2] --- can only be resolved and solved by collaboration between observer, subatmospheric gas-dynamicist, and *empirical*-theoretician.

In the above, I question "theory", and stress *observed* and *nonthermal*, because, *before* such nonthermal mass-loss was observed/inferred, there existed *no* theory, atmospheric or interior, which predicted/required a nonthermal mass-flux. One can say precisely the same, re those other "nonthermal" phenomena that are enhanced in "abnormal" --- which we call Xe --- stars[3]: emission lines, abnormally-broad spectral lines, superionization and excitation, "symbiotic" properties --- and of course direct evidence for mass-flux in the form of line-*displacements*. At those epochs, and even considerably later, when such mass-loss was first observed-inferred, *all* physically-consistent stellar atmospheric models were thermal, imposed radiative-equilibrium (RE), and gave negligible thermal mass-loss. In effect, the star was modeled as a *closed* (energy fluxes only) thermodynamic system: indeed, as a *limited* closed system --- only radiative energy fluxes, whose appearance varied *only* in evolutionary time-intervals: *Observationally*: "normal" stars and stellar atmospheres were classified into (assumed-*)* homogeneous-population boxes, each characterized by only two observed quantities (luminosity-spectral appearance) *assumed* to give (total energy flux, surface-temperature).

Theoretically: only thermal models, as a priori, speculative-theoretical, constructions. No observations were applied, before axiomatizing the theory to establish the basic thermodynamic characteristics of the star, according to the following alternative possibilities:

1. Is the star an isolated (no fluxes), closed (only energy fluxes), or open (both mass and energy fluxes) thermodynamic system?
2. Are the energy and matter storage modes thermal only (only randon microscopic velocities), or also nonthermal (macroscopic mass-motions, systematic and possibly quasi-random; macroscopic magnetic fields)?
3. What is the degree of nonEquilibrium permitted: Equilibrium, Linear NonEquilibrium (all angle-averaged microscopic distribution functions having TE forms; all fluxes given by gradients of some thermodynamic potentials, which are expressed in terms of Equilibrium thermodynamic state parameters), or Nonlinear nonEquilibrium (no restrictions on distribution functions or fluxes)?

All attempts at modeling the "abnormal" stars were observationally-inspired, but wholly ad hoc in construction, seeking to preserve the "essential" axioms of "normal atmospheric theory", while adjoining certain features capable of superficially explaining the "abnormal" (what I call here nonthermal) observations. I would stress that an essential characteristic of the "imperfect wind-tunnel" model is that it regards "normal" and "abnormal" atmospheres as being built on the same nonthermal model, differing only in amplitudes of the subatmospheric storage modes. The observed differences between "normal and "abnormal" stars are not predicted by any existing theory: our empirical model uses the observations to infer differences in fluxes of mechanical energy and mass, between "normal (X)" and "abnormal (Xe)" stars lying in the same "classical" population-box (spectral class). Then, we try to develope diagnostic methods capable of giving at least a range of possible storage modes corresponding to these nonthermal fluxes.

The modern era of stellar "winds" began with Biermann's demonstration that the observed behavior of comet tails required a particle, not just radiative, solar flux: a "wind". The wind was modeled following Parker's demonstration that stars having coronas could not have atmospheres that are both static and smoothly merging into the interstellar medium; hence the corona must be nonstatic, and a wind must be an integral part of its structure. The existence of the (nonthermal) corona was linked to the existence of a particular kind of nonthermal energy storage in the solar subatmosphere (convection), but there still exists no theory for a convective storage mode, which both predicts the amplitude of the convection and links it to the amplitudes of nonthermal kinetic energy flux (popularly assumed to produce the chromosphere-corona) and of mass-flux. Indeed, current observations of the solar atmospheric velocity fields, and of the (space, time, amplitude) properties of the solar wind, have put into question whether a convective storage mode suffices to explain --- hence ultimately to predict --- the solar chromosphere, corona, and wind. So there does not yet exist a nonempirical theory for even the solar wind. The extension across the HR diagram of speculative-theories for possible subatmospheric nonthermal modes --- from solar-type to the very hot stars considered in this Colloquium --- has lagged; even having been opposed as unnecessary and unrealistic; even in the light of the existence of the above "abnormal" hot stars (WR,Of,Oe,Be) and the resemblance of certain of their spectral features to the solar chromosphere-corona; until observations, not theory, have shown the presence of chromospheres in even these hot stars. No speculative-theory has predicted them; empirical-theories are trying to model them.

In brief, the range of possibilities for speculative-theoretical modeling of stellar atmospheres --- even of subatmospheres and interiors --- is so great that the usual procedure of choosing the "simplest" speculative alternative is inefficient, unproductive --- and even psychologically inhibiting, when one holds to some "speculative" universal characteristic such as only thermal storage modes, and radiative-equilibrium, or closed system, or linear nonEquilibrium, because they are "easire" to compute, instead of asking, observationally, what the "real star" demands.

II. IMPERFECT WIND-TUNNEL MODEL:

A. Broad Approach:

For the reasons given in the Introduction, the basis of our model is naively simple: it is not a "theory" of why "hot" --- or any other type --- stars must have mass-fluxes. Rather, it is an algorithm --- a diagnostic approcah to deriving an empirical-theoretical model from as complete a set as possible of observations --- embedded in the framework of a self-consistent, a priori unrestricted, nonEquilibrium thermodynamic characteristics listed above: type of thermodynamic system; kind of storage modes; degree of nonEquilibrium. Then, for each star --- once it has been so characterized --- we attempt to obtain, empirically/observationally, the fluxes of mechanical energy and matter --- together with their scales --- to supplement the conventional empirical parameters of radiative flux and gravity. Then, we ask what such fluxes require in the way of storage modes to produce them.

Let me make clear the meaning of "imperfect" in the title of the model. As shown some time ago (Clauser, Germain, 1965) the gas-flow from a spherically symmetric stellar atmosphere can be considered to have an analogy with a wind-tunnel, or converging-diverging nozzle connecting some storage-pot of gas to its environment. A "perfect" nozzle is one where the flow passes smoothly from subsonic to supersonic flow, without aerodynamic heating or shocks either before or after the "throat" of the nozzle. Such a nozzle must be carefully designed, in terms of the "storage-reservoir" conditions, and the "environmental" conditions (in the star, the subatmosphere and the interstellar medium, respectively). All nozzles are not perfect, expecially if they are given a priori, as is the star. One must observe the flow, if he doesn't design the nozzle, to diagnose whether it is perfect or imperfect. Gas-dynamic history is full of examples where a priori, untested, speculation led to disaster:

wind-tunnels which either lost most of their energy in pre-nozzle shocks and heating, or never became supersonic; irrigation flumes pounded apart by the equivalent of shock-waves in the equibalent of too-rapidly converging nozzles for "smooth" flow to occur --- in astronomy, "chromospheres" in Tau Scor, when an "imposed perfect-nozzle" was observed to be imperfect, and to heat, mechanically, by the equivalent of a pre-nozzle shock = chromosphere. In analogy, note that the nonLTE "theory" was really only an algorithm, for diagnosing observations, whose maxim was "be sure you have LTE, by computing reaction rates in detail, before you assume it: allow the possibility of nonLTE". Similarly, here, the "imperfect" model is simply an algorithm, again for diagnosing data: ask, observationally, whether the particular star is an "imperfect" or "perfect" wind-tunnel, before imposing its "perfection": allow the possibility of imperfection. Then ask what other characteristics the star must have, to reach such an observed state.

In brief, that is our approach. First, establish "global" thermodynamic characteristics, empirically. Next, establish particular characteristics of the storage modes for the particular star observed: thermal or nonthermal, as the star tells us, not as we tell the star.

B. Specific Approach:

1. Global Thermodynamic Characteristics:

a. Type of thermodynamic system:

We see the star: so it cannot be an isolated system. Historically, stars have been modeled as closed systems: only radiative (energy)fluxes. Hack's (1969) summary of stars with observed/inferred mass-fluxes shows that at least some stars --- whose types range across the HR diagram --- must be open systems. While exact generalizations can never be established, the fact that such mass-fluxes exist so generally, even in the Sun, suggests that we must permit any given star to show that it does not have a mass-flux, before we "forbid" it to have one. So, we model stars as open thermodynamic systems, observationally; keeping open the possibility that somewhere, sometime, we may be able to establish that some star has no mass-flux, hence is closed.

b. Kind of subatmospheric and atmospheric storage modes:

Using any of a variety of existing thermal models for stellar atmospheres, we readily show that the predicted mass-fluxes by thermal evaporation are many orders of magnitude lower than the observed mass-fluxes, even admitting several orders of magnitude uncertainty in these latter. Also, most of the inferred mass-fluxes come from shifts, not just broadening, of spectral lines; indicating systematic, hence nonthermal, massflows. Moreover, larger-amplitude mass-fluxes are linked with the presence of emission lines; and, as mentioned, emission-line presence and absence is variable in times too short to be explained simply by extended atmospheres, so must be associated with mechanical heating. Thus we conclude that the stars having mass-fluxes have non-

thermal storage modes. Material is pushed out of the star from below. *IF* it could be shown that (thermal) radiation-pressure alone suffices to *initiate* mass-fluxes, the preceding conclusion *might* be disputed. Material would be *pulled out* of the star from above. However, the only stars for which such radiation-pressure *initiation* has been suggested are the hottest early stars: and, these "pulling-out" theories depend upon *imposing* the perfect wind-tunnel condition: smooth transition, from subthermal to superthermal flow, sans shocks, mechanical heating, chromospheres. However, even for these hot stars, the cited "associated nonthermal phenomena" are observed, so we reject these theories, and interest in them as representing a possibility to preserve thermal models in the atmosphere.

Sometimes, in discussing "coronal" origins of stellar winds, there is implicit implication that such models are thermal; that the winds have their *origin* in a "hot" (or warm, no matter) corona. This thermal implication is illusory; one must consider the origin of the corona itself. Even if the major part of the mechanical heating, which produces the corona, comes from a mechanical energy flux that does not transport mass --- such as a system of acoustic waves --- both this mechanical energy flux, *and* the mass-flux corresponding to the "coronal" wind, have nonzero values in some subatmospheric or atmospheric regions, where there is a nonthermal energy storage mode (convection, rotation, pulsation, magnetic field, whatever). The *boundary* conditions on these nonthermal storage modes, and the conditions that help fix their amplitudes in their nonlinear description, must include these values of nonthermal kinetic energy *and* mass fluxes. In the wind-tunnel analogy, the star --- or its subatmospheric regions --- is a *nonstatic reservior*, driven by whatever drives the (convection, rotation, pulsation, etc). So, we cannot regard a corona as the "origin" of a wind. Rather, the corona, the wind, chromospheric phenomena, emission lines, superionization and excitation, symbiotic phenomena, etc, are all *associated* phenomena, whose *origin* lies in the *existence* (*for whatever reason*) of subatmospheric and atmospheric nonthermal storage modes.

From this viewpoint, there is really very little evidence in *any* spectral class across the HR diagram for stars with *only* thermal storage modes, thus susceptible to thermal modeling. All main sequence stars cooler than A are *thought* to have *at least* subatmospheric convection zones, which produce acoustic fluxes; existing data confirm this thinking. Giants and supergiants in this region are characterized by variability and pulsational instability. Giant and supergiant stars of A and hotter are, observationally, also characterized by variability. The "last refuge" for thermal modeling was thought, for some years, to be the O-B main-sequence stars, where, *speculatively*, there were no subatmospheric motions that coupled to the atmosphere: *if* one neglected Be, Oe and Of, etc "abnormal" (because they exhibit nonthermal character) stars. Some of us have long-argued that the so-called hydrogen deficiency, but rather a chromosphere-corona. Now, OVI observed in Tau Scor removes the thermal possibility for O-B stars, and re-emphasizes the WR question.

So, we think the evidence is clear that most, if not all, stars have nonthermal storage modes in their atmosphere and subatmosphere. The question is what they are, where they are located, and what is their effect on atmospheric structure. For this, we must consider each star individually, because there is not a priori reason why such modes should be specified wholly by radiative flux and gravity, as many authors seem to assume. To begin with some kind of categoric simplification, we have simply chosen the (X,Xe) categorization. We conjecture --- on the basis of the observations --- that all nonthermal phenomena are stronger in Xe stars than in their X counterparts. An example is the T Tauri stars relative to the Sun, because it is thought these are all 1 solar mass stars. I cite this, because we are on the way to having the best data for a detailed (X,Xe) comparison. We hope that we will soon have the same kinds of results on O-B stars, from observational programs in progress, some typical results of which are being reported here by MMe Andrillat. Preliminary statistical studies of low-amplitude, short-periods B-star variability have been given by Bijaoui and Doazan, Hutchings, Walker, and by others. We hope that with these new TV scanner techniques, larger-amplitude variations will be found in Be stars.

c. Degree of nonEquilibrium:

I do not believe that, in 1978, I need to re-hash all the early nonLTE work --- observational and theoretical --- which led us to conclude that the nonlinear nonEquilibrium approach was the only acceptable one (Thomas and Athay, 1961; Thomas, 1965; Jefferies, 1968). The approach is routine, by now (Mihalas, 1970). The only point which I would emphasize is that we have not yet established where, in the atmosphere, significant deviations from a Maxwellian thermal velocity distribution must be introduced. It is not clear that these conditions are the same in static and moving gases. The same can, of course, be said for distinctions between radiation and collisional control in moving atmospheres. But these kinds of problems can be approached parametrically; it is only in defining the actual conditions in a stellar atmosphere, to which these parametric results can be applied, that problems arise. And these conditions can only be delineated by nonthermal studies of actual atmospheres.

2. Particular Applications to Particular Stars:

We are interested in the observable difference between thermal and nonthermal models: not only in terms of a wind, or a height variation of the systematic velocity associated with the wind, but in the change in atmospheric structure coming from the presence of these nonthermal modes, and the resultant change in the radiation by which we diagnose the atmosphere. I will not summarize here any algebraic details; these can all be found in our preceding work (Thomas, 1973; Cannon and Thomas, 1975, 1977). Here, let me simply show, schematically, how this empirical approach to modeling based on a general nonEquilibrium thermodynamic framework, proceeds.

a. The framework:

The three general descriptive equations for the matter, the energy associated with it, and its coupling to the radiation field, assuming spherical symmetry, can be writen, schematically:

matter: $$\Psi\,(U,\ \rho) = 0 \qquad (1)$$

thermal energy: $$F_1(U,\Sigma) + F_2(J_\nu, S_\nu, n_a, a_\nu, T_e) = 0 \qquad (2)$$

nonthermal energy: $$G_1(U,\Sigma) + G_2(p, \rho, T_e, F_\nu, g) = 0 \qquad (3)$$

I divide the equations in this way, so that $F_2 = 0$ and $G_2 = 0$ represent the usual thermal-model solutions, corresponding, respectively, to radiative-equilibrium and hydrostatic-equilibrium. Equation (1) does not exist, in the thermal model: being simply $0 = 0$. The symbol Σ simply signifies that the nonthermal terms, F_1 and G_1, depend upon the thermal parameters as well as upon the systematic velocity U.

Now, so long as U is less than 20 or 30% of the 1-dimensional thermal velocity, q, these thermal equations, ignoring the effect of U and its derivatives, suffice, under stellar atmospheric conditions (thermal viscosity and heat-conduction small) to give an adequate representation of ρ (t or τ) and T_e(r or τ). We note, in the low atmosphere and subatmosphere, before sphericity effects become of interest, and emphasizing this assumption of spherical symmetry, that (1) becomes:

$$U\rho = U_o\rho_o = F_M \qquad (1a)$$

where F_M is the mass-flux (per unit area) and subscript o denotes values at some arbitrary point. So, if one wants to ask what systematic velocities he can admit in the stellar atmosphere, without affecting his thermal model, all he needs do is to choose some U at some level and use the thermal model density distribution to compute U(r or τ), to determine where $U \sim q$ and the model fails. Clearly, any choice of U_o, which gives an observable velocity effect anywhere in the atmosphere, will reach q somewhere before leaving the atmosphere and entering the ISM, noting: (i) ρ for the ISM corresponds to some 1 particle/cm^3, while for photospheres, ρ corresponds to 10^{17} - 10^{11} particles/cm^3; (ii) classically T_e and q reach asymptotic values near T_{eff}. Thus, the only consistent thermal models set U_o = zero. Any model, no matter how it is produced --- speculatively or empirically --- where $U_o \neq 0$, produces $U \sim q$ somewhere, perturbs the equations (1) - (3) there, and heats, mechanically, the atmosphere, from this systematic velocity gradient alone. There may also be mechanical heating from nonsystematic velocities, such as acoustic waves, which affect (1) - (3) essentially through terms equivalent to viscosity, but macroscopic rather than thermal. All these terms do, is to produce a mechanical heating lower in the atmosphere than does the mass-flux term alone. q then rise above its "thermal-atmosphere" value; the distribution of ρ (r or τ) changes; but we can still use (1a) to determine U(r or τ), if (2) and (3), modified by these "viscosity" terms, do not depend upon U.

b. The Modeling Process:

So we have three choices of procedure to produce these nonthermal models:

(1) We solve completely the model of a subatmosphere nonthermal storage --- pulsation, rotation, convection, whatever --- leaving free the two parameters of mass-flux and mechanical energy flux. Whether the amplitudes of the subatmospheric modes depend sensitively upon these two fluxes remains to be seen: no solutions yet exist. This alternative is the most satisfactory one; as yet, no single solution to any such problem exists.

(2) We take the observed mass fluxes, and thermal-model density distributions, to ask where, in the photosphere, the value of U associated with this F_M from (1a) first reaches q, in that thermal model. We did this, some years ago, using available data (Thomas, 1973). No star, for which data existed, showed U to reach q more exterior than

$$R(q)/R(\text{photosphere base}) < 1.10 \qquad (4)$$

This "outer" limit was for an Mo supergiant. For OB stars, the value of the limit was more nearly 1.01. Prediction: chromospheres would exist and start no higher than this value. The OVI observations of Tau Sco were hardly a surprise, unless you believed Tau Sco had zero mass-flux. Then, given this upper limit on the beginning height of the chromosphere [upper, because it ignores heating due to mechanical energy fluxes that do not transport mass], one surveys the list of 'abnormal' features, which we have classed as nonthermal [see footnote 1], to ask whether a chromosphere-corona beginning at that depth would remove their 'abnormality'. An example is the cited OVI observations in Tau Scorp, plus the other ions incompatible with radiative equilibrium models. The problem on which we have thus far focused is that of an explanation of emission lines in terms of chromospheres beginning not higher than these limits, as opposed to emission lines arising in extended atmospheres under RE: we consider the problem to be the same in the cool [T Taur] and hot [Be, Of] stars. Our preliminary results on hydrogen Balmer-α fluxes, and central regions of their profiles, in the cool stars, are encouraging. We note that it is considerably easier to introduce a time-variation in emission line profile coming from a low-lying chromosphere than from an extended-atmosphere 'photosphere'. [3] We adopt a procedure intermediate to [1] and [2]. Thermal, closed-system, models take T_{eff} [or F_{rad}] and g as parameters; we assert that nonthermal, open-system models need, in addition to these two parameters, two others: mass-flux, and nonthermal kinetic energy flux. The values of all these four are specified at the base of the atmosphere; and the atmospheric model is specified at the base of the atmosphere; and the atmospheric model is specified by outward integration. We note that the radiation-pressure models discussed above contend that T_{eff} and g suffice, still, to discuss these mass-fluxes, which are computed, from values of these two thermal parameters and by imposing the equivalent of the ''perfect wind-tunnel'' condition at the ''throat''. We further note that the ''coronal'' models discussed above contend that, in addition to these two thermal parameters, it suffices to add a value of the nonthermal kinetic energy flux at the base of the atmosphere, and impose the equivalent of the ''perfect wind-tunnel'' condition at the ''throat''. The mass-flux is then predicted. So, the range of models discussed in this Colloquim essentially comes down to how many parameters, and what kind of conditions at the ''throat'', the authors consider are needed. I repeat: our ''imperfect wind-tunnel'' model is just that: conditions at the ''throat'' are not imposed, but investigated: essentially, the ''throat'' marks the end of the ''trans-sonic'' flow region, within which the chromosphere-corona have been steadily heated. Work is in progress, on this model, to compare the two cases: T Tauri [cool stars] and Be [hot stars] for which we have the best data.

[1] emission lines, superionization and excitation, BaC and IR excesses, abnormally-broad spectral lines, "symbiotic" properties in the visual spectrum; plus all those "symbiotic" features in the "rocket-UV", exemplified in the Sun.

[2] see footnote 1.

[3] eg. WR, Of, Oe, Be, Ae and Ap, T Taur, dMe, etc.

DISCUSSION FOLLOWING THOMAS

Hearn: I do find it a little surprising, Dick, that you mention diagnostics as being crucial. The three preceding speakers have made just such an effort to discuss the observations, whereas you have not mentioned them. I'm inclined to give you naught out of ten for answering the questions proposed to the panel.

Thomas: Tony, you must be careful. We were the first to predict the solar temperature distribution from the data. In the Cannon-Thomas theory we gave a velocity law; we predicted chromospheres in hot stars, and none of you people believed it was worth anything, so don't tell us we haven't predicted anything. You can take a vote if you want to, but I couldn't care less... . We were discussing hot winds linked to chromospheres, and both to emission lines when the rest of you were talking about cold winds and no chromospheres. Your public opinion polls leave me cold.

Heap: How do you account for the observations which show that two totally different kinds of O stars -- the young, massive ones, and the old, planetary nuclei -- having totally different interior conditions still have similar stellar winds?

Thomas: I'll comment if you tell me why two stars each of solar mass can show different spectral lines; one shows absorption and one shows emission lines.

Heap: I am not really looking for another question as an answer. You say it's very important to consider the interior conditions.

Thomas: The subatmosphere.

Heap: Could you clarify what you mean by the subatmosphere?

Thomas: Let's compare the Sun and T Tauri. In my eyes, to have a variation of the Hα profile from absorption to emission, there must be a hemisphere variation of the Balmer continuum. On the Sun I only observe variations in features the size of 1000 km or so, giving variability in the H and K lines. These Ca II lines depend only on quasi-local conditions. In the Sun, one thought for years that the convective zone was the whole answer to everything. On the basis of a statistically steady convection it was very hard to understand how you get the patchiness over the solar surface. Results of Deubner and calculations of others lead to a belief in non-radial pulsations, as also being important in the subatmosphere. With this, I can get all kinds of variation. In T Tauri it looks as though you have the entire hemisphere behaving in this manner. Now how do I have such different behavior from the Sun? In the same way in some other stars, how do I get similar behavior? That's what we are trying to understand from the observations. We must wait until we get a good aerodynamic theory to predict what are the motions of the subatmosphere. Look, honey, I have a choice, I have either convection and/or maybe I have non-radial pulsation. _A priori_, I don't know. The theory doesn't exist, but I can use comparative observations between normal and peculiar stars even if the theory is not very good to try to distinguish. I'd like enough new observations that can distinguish between sizes of mass flux and functions of the type of non-thermal kinetic energy flux (radiative flux is already present). Hopefully I can then use these observations to infer what kind of kinetic energy (macroscopic kinetic energy) is present in the subatmosphere. Are you with us? Geophysicists, by looking at the types of wave propagation in the earth's surface, decide density distribution with height.

Morton: Are you trying to say that for your model we should stop doing theory and obtain more data? If so, what observations do you suggest?

Thomas: I don't consider any of what has been discussed by this panel to be _theory_. We need good enough resolution observations, to be able to concentrate on the diagnostics. For example, if I have Hα emission, does it come from a hot or cold extended atmosphere or does it come from a low lying chromosphere? The superficial response has been that it's extended but this doesn't fit observed high dispersion profiles. One can quickly do a reasonably theory, with radiative transfer calculations, and for a deep lying chromosphere and corresponding velocity field, and get a reasonable fit. Another quick answer would be to get your friends to observe whether such profiles vary in time. If it varies in a few minutes, it's hard to believe the atmosphere is extended. So that justifies our going a little bit more sophisticated into the radiative transfer with the velocity field and energy dissipation, and calculations for a model of the upper photosphere of T Tauri. So please don't stop doing theory, but do empirical theory. Take some observations as a guide.