SUMMARY

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Let me start by saying that we have heard some excellent review papers and I doubt very much that I can contribute much of importance in addition to what we have heard already.

I also wish to apologize to all those who have made important contributions during this meeting and who will not be mentioned in this 30-minute summary. If I wanted to mention everybody I would just have enough time to read the program.

I. Origin of Non Thermal Motions

The possible origins which we discussed the first day are summarized briefly in Table I. We did not come up with an explanation for the observed turbulence in B and O stars. G. Nelson confirmed that convection cannot be it, even though radiation pressure has some enhancing effects. K. Kodaira pointed out that circulation induced by rotation is unlikely to be the origin. However, S.R. Sreenevasan informed us that shear turbulence originating from inward increasing rotation might be a likely explanation.

For late type stars the general consensus seems to be that convection or at least the convection zone is the generator for all observed motions--except, of course, rotation.- J.P. Zahn pointed out the difficulties which the theoreticians encounter when trying to solve the highly nonlinear hydrodynamic equations in extended convection zones. So far it has not been possible to derive theoretically the expected velocity field. Therefore, I believe, the observers have to go to work and help the theoreticians. G. Nelson (1978) has pointed out ways how to do it: The maximum velocity in the convection zone is mainly determined by the turbulent exchange or the drag length while the overshoot or penetration into the stable zone is mainly determined by the horizontal scale. Therefore, I think such measurements as reported here by A. Nesis are very important. Progress in convection theory has been made by the inclusion of the pressure fluctuations which can be fairly large near the boundaries and lead to such interesting effects as antibuoyancy. The inclusion of the pressure fluctuations enables us to understand the observed scales of the granules (Nelson 1978) and the exploding granules as Nordlund has shown in his movie which was one of the highlights of this meeting, and we certainly would like to know more about the physics, numerical methods and boundary conditions that went into this numerical simulation of solar granulation.

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There was some suggestion that in the mixing length theory of convection the mixing length ℓ to be used should be two scale heights H instead of one in order to increase the thickness of the convection zone as seems to be required by P. Gilman's theory of differential rotation and apparently also by the observed oscillation modes of the sun. I would like to point out, however, that the possible increase in the extent of the convection zone is limited by the observed solar lithium abundance which I think does not permit the depth obtained for $\ell = 2H$.

I was quite surprised to hear a hydrodynamicist suggest to calibrate the elaborate hydrodynamic theory with the mixing length theory. I always thought it should go the other way.

Y. Osaki clearly pointed out the instabilities and the possible waves and oscillations in the upper layers of the sun and late type stars, most of which are actually observed in the sun as J. Becker showed. If observable in other stars they could be used to probe the deeper invisible atmospheric layers as is done for the sun. To the observers of special interest is the fact that the expected motions are an-isotropic, mainly vertical, while the convective motions are mainly horizontal in the stable surface layers, as we saw from A. Nordlund's velocity fields. Y. Osaki also pointed out that G and K stars are expected to be overstable to many nonradial p modes. If modern studies of turbulence confirm earlier observations indicating an increase in microturbulence from G to K main sequence stars (Chaffee et al. 1971), these instabilities could be the explanation. Convective motions are not expected to increase towards cooler stars.

Since for the sun, for which we have high spatial and time resolution, we can disentangle the observed velocity fields in the k-ω plane as J. Beckers demonstrated, we might hope that solar observations can in the future give us the velocity distributions for the different velocity fields. J. Beckers pointed out to me, however, that the observational integration over height would wipe out the information about the velocity amplitudes. Fortunately L.E. Cram told us later that there may still be some hope, though the relaxation times assumed to be negligible in his computations, will have to be checked.

II. Observations of Velocity Fields in the Sun and Stars

After having reviewed the complicated fields of motion in the sun we turned to the observed velocity fields in stars and the situation looks much simpler,at least from the observer's point of view, clearly only an effect of aspect as R. Glebocki pointed out nicely.

There was a divergence of opinions between theoreticians, who want to know the origin of the observed velocity fields,while the observers can reasonably only investigate what can be measured.

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At present there appear to be three ways to measure non-thermal motion fields. They are briefly summarized in Table 2.

(1) We can measure line shifts or asymmetries which occur if velocity fluctuations are correlated with intensity fluctuations or if asymmetries in the velocity field are present. We have seen theoretical line profiles for acoustic waves and for oscillations which beautifully demonstrated this. These asymmetries may help to separate such velocity fields from others where the velocity fluctuations are not coupled with intensity fluctuations. D. Dravins' studies may prove to be very important in this respect. The dependence on the excitation potential which gives information about the depth dependence of the generating velocity field may be another tool to separate different origins. Clearly theory and observation have to work in close collaboration to extract this information.

(2) We can measure the increase in the equivalent widths which will occur if velocity gradients over scales smaller than $\Delta\tau_\nu = 1$ are present. This leads to the concept of microturbulence. For different frequencies within the line the condition $\Delta\tau_\nu<1$ refers to different distances leading to some conceptual difficulties. A Gaussian velocity distribution is assumed for the microturbulence field which, if wrong, may lead to errors that have not yet been studied. The depth dependence of the microturbulence can be studied by the investigation of lines with different excitation potentials or of lines in spectral regions with large differences in the continuous κ. The Goldberg-Unno method (1958, 1959) using different depth points in line profiles of one multiplet suffers from the fact that the observations always integrate over the whole line forming region and one cannot decide whether the larger velocities are at the top or at the bottom of this layer.

(3) Line profiles can be measured. They reflect all velocity fields including rotation and therefore contain all the information but provide the largest difficulties in separating the different fields. After correcting for instrumental broadening, for thermal broadening and microturbulence, for rotation and for observational noise, the broadening that is left over is called macroturbulence, again assumed to have a Gaussian velocity distribution which, if wrong, can cause large errors in the separation of rotation and macroturbulence. Obtainable only after so many deconvolutions it will generally not be determined accurately. Since this turbulence does not increase the line strength it must refer to scales $\Delta\tau_\nu>1$. Large scale velocity changes occurring horizontally will be observed as macroturbulence.

The concepts of micro and macroturbulence have one property in common with the mixing length theory: for many years they have been criticized strongly but are still widely used for lack of knowing anything better. In the turbulence case the new concept of mesoturbulence is clearly a step forward since it does not rely on the assumption

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of either large or small scale velocity variations. It can be used for any scale of velocity variations. In the approach actually used in the numerical work shown to us by E. Sedlmayr it still uses one correlation length only which can have any size. However, the formalism presented to us by H.-R. Gail can well be used for fields with several correlation lengths. A correlation length of the order of $\Delta\tau_\nu=1$ will influence the equivalent width of the line, i.e. will manifest itself as microturbulence, but will also show up in additional line broadening, interpreted as macroturbulence. We have heard that the carefully determined values for microturbulence,--i.e. using the correct model, the correct oscillator strengths f and abundances Z as well as the correct damping constant γ--and macroturbulence can be used directly to determine the correlation length and the amplitude of the velocity field.

The concept of mesoturbulence clearly is not the ultimate solution, but, as G. Traving pointed out privately, is still a method suggested due to our ignorance. Ultimately we will have to determine the velocity distributions for the different velocity fields and see if and how the line profiles differ for different fields. The solar observations may provide some guidance. Theory will have to help. Hopefully different velocity fields will lead to measurably different line profiles or show different dependences on excitation energies and wavelengths, which may be used to distinguish different origins.

For the deconvolutions of the different contributions to the line profile the Fourier transformation, explored in this context especially by D. Gray, promises to be very helpful provided the profiles from the different velocity fields are measurably different in the frequency domaine. As D. Gray pointed out we cannot expect miracles from the Fourier transformation. Uncertain differences of line profiles in the frequency domaine will remain uncertain in the Fourier domaine even though the differences may appear amplified.

III. Measured Values of Micro-and Macroturbulence and their Origin

The modern carefully-determined micro-and macroturbulence velocities in F and G stars increase with increasing luminosity and with increasing effective temperature in accordance with the variations expected for the maximum convective velocities as T. Gehren pointed out. This confirms the suspicion that for the F and G stars micro-and macroturbulence have their origin in the convection zone. The measured macroturbulence values are generally larger than the microturbulence velocities but vary proportionately. In the concept of mesoturbulence as outlined by E. Sedlmayr this indicates a correlation length somewhat larger than $\Delta\tau_\nu=1$, again in qualitative agreement with mixing length theory expectations.

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Earlier measurements of microturbulence with wrong f values showed high microturbulence values also for late A stars. There are, however, several indications--see below-- that convection stops at F0. If microturbulence persists to higher temperatures we probably have to come back to the suggestion of Baschek and Reimers 1969 that for these stars microturbulence may be due to a superposition of many pulsation modes similar to the ones observed by L.B. Lucy for α Cyg.

IV. Effects of Velocity Fields on the Outer Layers of the Stars

R. Stein in his very clear review convinced us that none of the observed velocity fields and also magnetohydrodynamic waves could be responsible for the heating of the upper chromosphere and corona. Acoustic waves are dissipated in the lower chromosphere and can therefore well heat the lower chromosphere but they cannot penetrate to higher layers. Gravity waves travel mainly horizontally and for Alfvèn waves the energy distribution over large volumes in the corona seems to be a problem. Again the observers have to assist the theoreticians.

If acoustic waves are indeed responsible for the heating of the lower chromosphere then the energy input into these layers should be correlated with the acoustic energy generation in the convection zones. R. Stein pointed out that along the main sequence the acoustic energy generation in the convection zone increases roughly proportional to T_{eff}^{16}. Most of this energy is absorbed already in the photosphere but roughly 10% may heat the lower chromosphere. We should then expect chromospheres for all stars with convection zones. Indeed modern observations especially by the International Ultraviolet Explorer, IUE, reveals chromospheric emission line spectra for most late type stars as J. Linsky has reviewed here. Our own observations (Böhm-Vitense and Dettmann 1979) show that for luminous stars chromospheric emission stops at the Cepheid instability strip and on the main sequence for B-V = 0.3. This is also the color for which the average rotation for stars begins to decrease and is also the red edge of the gap in the two color diagram (Böhm-Vitense and Canterna 1974) which can also be attributed to the abrupt onset of convection. As G. Nelson (1978) has pointed out inhomogeneous photospheres of convective stars look more red than homogeneous ones.

Convective stars generally appear to have chromospheres--except perhaps old stars--. If acoustic heating is responsible for the energy input into the lower chromosphere then the energy loss of these layers should increase with increasing convective velocities, i.e. with increasing T_{eff} and luminosity. As J. Linsky pointed out, the energy loss in the lower chromosphere can be measured by the MgII h and k line emission. Ulmschneider claimed that a steep increase with T_{eff} is indeed observed while R. Stein expressed some doubt. Whether the MgII emission increases with increasing luminosity is still debated. In J. Linsky's graph most of the G and K supergiants appear to have

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a larger emission than most of the G and K giants. There are, however, a few supergiants which show very small MgII emission (for instance ȷ Aur and ξ Cyg). It will have to be checked whether interstellar absorption might have reduced their MgII intensity. Measuring uncertainties also appear to be very large for these stars, (see Weiler and Oegerle 1979). In the discussion of the luminosity dependence of the energy input varying amounts of absorption in the photosphere may also turn out to be important.

Additional information about the heating of the lower layers may be obtained from the Wilson Bappu effect. There are mainly two suggestions to explain the emission line width luminosity correlation. One group wants to relate the increasing width to the increasing "turbulent" velocities, the other group wants to explain it by an increasing optical depth effect. I always found it very important that the width luminosity effect holds independently of the emission line strength which obviously can be different for stars of the same luminosity. I wonder whether this can be understood if the width is determined by the optical thickness in the emission lines. This has not been discussed here.

Information about the transition layers can be obtained from the CIV emission lines. The situation is, however, somewhat unclear since, as J. Linsky pointed out, based on Mullan's study, the possibility exists that stellar winds may be an important energy sink for the transition region and may even eliminate it. In fact the possibility has been discussed here that for cool and luminous stars observable winds may reach down to the MgII and CaII emitting regions. For these stars the CIV lines become invisible. It is still debated whether they disappear abruptly or continuously. The early G supergiants observed by us (Böhm-Vitense and Dettmann 1979) show CIV emission.

Additional information may be obtained from the observations of old and metal poor stars. T. Gehren pointed out that, as expected from convection theory, they have the same observed microturbulence as young stars. The acoustic heating should therefore be the same. Wilson (1966) and Kraft (1967) found, however, that the CaII K_2 emission decreases with increasing age. From a few IUE observations obtained so far I also find a decrease in MgII emission. This line, however, is still observable in a few cases, but the far UV emission lines are completely invisible. Clearly more observations are needed before a final conclusion can be drawn. But based on those few observations we may perhaps speculate that some acoustic heating does occur in the layers which emit the CaII and MgII lines but that in young star the layers which emit the higher excitation lines are heated by another mechanism which decays with increasing age and is probably connected with rotation and magnetic fields.

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It was very interesting to me that Y. Cuny pointed out that the absorption of photospheric light, which may increase considerably with increasing turbulence, should not be neglected in the energy balance of chromospheric lines.

V. Major Open Questions

Let me conclude in summary by listing the major open questions discussed at this meeting:

1) Contributions of different velocity fields to the line broadening;
2) Origin of line broadening in A, B and O stars;
3) Origin of "chromospheres" in O and B stars;
4) The heating mechanism for the upper chromospheres, transition regions and coronae in convective stars;
5) The explanation of the Wilson Bappu Effect,
   a) is it due to an optical depth effect, or
   b) is it due to the velocity field?
6) Can coronae, transition layers and upper chromospheres in cool luminous stars be extinguished by stellar winds?

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TABLE 1

Origin of Non-Thermal Motions

	F Stars and Later			A Stars and Earlier	
SPEAKER:	Zahn	Osaki	Gilman, Durney	Nelson	Kodaira
	Convective Velocities due to buoyancy	*Waves*	*Differential Rotation*		
	Theory does not yet give v(x,y,z,t) because of highly non linear equations.	acoustic, gravity	for deep convection zones	not due to convection	probably not due to circulation
	(My question: Can observations provide v(x,y,z,t) to be put into theory?	*Pulsations* radial, non-radial oscillations	No influence of rotation on convection in early F stars	A Stars: pulsations? (Baschek & Reimers, Lucy)	
	Δp leads to anti= buoyancy. Numerical work explains observed solar Δt, ξt, exploding granules size of granules (Nordlund, Nelson 1978)	excitation mainly by κ mechanism seated in convection zone		O, B stars: shear turbulence from rotation? (Sreenivasan)	
		motions are anisotropic mainly vertical		Radiation driven instabilities? (Hearn & Nelson)	
		G K stars are overstable for many non-radial p modes			

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TABLE II

Observations of Velocity Fields in Stars

Asymmetric Line Shifts	*Microturbulence*	*Macroturbulence*	*Rotation*
if ΔV_r is coupled with ΔI	gives increase in A_λ	additional line broadening	additional line broadening
or if	implies $\frac{dV_r}{d\tau_\nu} \neq 0$	$\frac{dv_r}{d\theta}, \frac{dv_r}{d\phi} \neq 0$	$\frac{dv_r}{d\theta}, \frac{dv_r}{d\phi} \neq 0$
asymmetric velocity distribution	for $\Delta\tau_\nu < 1$	for $\Delta\tau_\nu > 1$	characteristic velocity distribution
or if	may occur for expansion: global or local contraction: global or local pulsations waves small scale turbulence	possibilities: pulsations waves expansion contraction differential rotation large scale turbulence	
asymmetric areas with opposite V_r			

Mesoturbulence (Traving) (joint heading under the Microturbulence and Macroturbulence columns)

$$\frac{dv_r}{dt} \neq 0$$

for any scale s
statistical description with correlation lengths (Gail)
s can be determined from ratio of apparent microturbulence to apparent macroturbulence (Sedlmayr)

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