36. THEORY OF STELLAR ATMOSPHERES
(THEORIE DES ATMOSPHERES STELLAIRES)

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This report is the assembled and edited contributions of several members of the organizing committee, and as such ranges widely in style and content. It is not our intent to give here a complete review or full coverage of research falling within the domain of our commission. Instead, it is a sample of some of the more important issues studied during the last three years.

1. ROTATION AND DYNAMO ACTIVITY

Magnetic activity is becoming more and more a part of our discipline. Several conferences have recently been held on these topics. Among them are the sixth meeting on cool stars (Wallerstein 1990), the meeting *Angular Momentum and Mass Loss for Hot Stars* (Willson and Stalio 1990), IAU Colloquium 130 entitled *The Sun and Cool Stars: Activity, Magnetism, Dynamos* (Tuominen 1991), and *Angular Momentum Evolution of Young Stars* (Catalano and Stauffer 1991).

Catalano, S., and Stauffer, J. (eds.) 1991, Angular Momentum Evolution of Young Stars, (Kluwer: Dordrecht).
Tuominen, I. (ed.) 1991, The Sun and Cool Stars: Activity, Magnetism, Dynamos, (Kluwer: Dordrecht).
Wallerstein, G. (ed.) 1990, Cool Stars, Stellar Systems, and the Sun, (Astron. Soc. Pacific: San Francisco).
Willson, L.A., and Stalio, R. (eds.) 1990, Angular Momentum and Mass Loss for Hot Stars, (Kluwer: Dordrecht).

2. RADIATIVELY DRIVEN WINDS

Owocki et al. (1988) have made time dependent hydrodynamic calculations of the non-linear evolution of instabilities in radiatively driven winds. The strongest shocks are reverse shocks which decelerate high speed rarified gas as it impacts slower gas that has been compressed into dense shells. Features of the solutions may explain the formation of narrow absorption components in the UV line profiles and the X ray emission. Poe et al. (1990) studied stationary solutions for radiatively driven winds in which the Sobolev approximation is not used. Unlike the Parker solar wind solution and the Castor-Abbott-Klein solution, these solutions of Poe et al. do not have a uniquely defined saddle critical point, but they have a nodal topology in which a large number of solutions converge as they approach the sonic point. This implied degeneracy in the solution leads to intrinsic variability in the solutions.

Owocki, S.P., Castor, J.I., and Rybicki, G.B. 1988, Ap.J. 335, 914.
Poe, C.H., Owacki, S.P., and Castor, J.I. 1990, Ap.J. 358, 199.

D. McNally (ed.), Reports on Astronomy, Vol. XXIA, 439–445.

3. ASYMPTOTIC-GIANT-BRANCH STARS

Bowen (1988) has made extended calculations of mass loss from Miras driven by radial pulsations and dust. If the dust forms about two stellar radii from the star, this model can explain the observed mass loss rates. Wood (1990) argues from the observed temperature of the dust that the dust forms further out and that the mass loss would be then orders of magnitudes less than the observed mass loss. Pijpers and Hearn (1989) have proposed that the mass loss is driven by sound waves, but Wood doubts that the mechanism can work against the supersonic radial pulsations.

The evolutionary relationship between the Miras and OH-IR stars is still being discussed. Are the OH-IR stars with their very long pulsation periods just the evolutionary extension of Miras? Although the two groups of stars appear to represent a continuous distribution of pulsation periods, the mass loss and wind velocity measurements form two distinct groups (Sivagnanam et al. 1989, Schild 1989)

Bowen, G.H. 1988, Ap.J. 329, 299.
Pijpers, F.P., and Hearn, A.G. 1989, Astron. Ap. 209, 335.
Sivagnanam, P., Le Squeren, A.M., Foy, F., and Tran Minh, F. 1989, Astron. Ap. 211, 341.
Schild, H. 1989, Mon. Not. Roy. Astron. Soc. 240, 63.
Wood, R.P. 1990, `Colloquium on Confrontation between pulsation and evolution`, (Astron. Soc. Pacific: San Francisco), C. Cacciari, ed., in press.

4. Be STARS

Do Be stars show non-radial pulsations? Balona (1990) finds a highly significant correlation between the projected rotational velocity and the photometric period measured for 36 Be stars. He concludes that the cause of the photometric variation is not non-radial pulsations but rotational modulation caused by active regions. But high resolution spectroscopic observations have built up an extensive picture of non-radial pulsations in Be stars (Baade 1987). Are these two observational approaches contradictory or is there just an observational selection effect?

The IRAS observations of Be stars have been extended to 2 cm radio observations by Taylor et al. (1990). The results demonstrate that at least some circumstellar discs extend out to several hundred or a thousand stellar radii. The radio observations do not fit an extrapolation of the IRAS measurements. It is not clear what the explanation for this difference is (Waters et al. 1989).

The mechanism driving the mass loss forming the circumstellar disc is still not clear. Friend (1989) has constructed Castor-Abbott-Klein wind models with rotating magnetic fields for Be stars. This gives a dense slow equatorial flow and a fast tenuous polar wind. These models produce an equatorial wind that is perhaps an order of magnitude too fast. In addition they give no explanation for the extreme variability of Be stars.

Balona, L.A. 1990, Mon. Not. Roy. Astron. Soc. 245, 92.
Baade, R. 1987, IAU Coll. 92, 361.
Friend, D. 1990, in `Angular Momentum and Mass Loss for Hot Stars`, (Kluwer: Dordrecht), L.A. Willson and Stalio, R., eds., p. 199.
Taylor, A.R., Waters, L.B.F.M., Bjorkman, K.S., and Dougherty, S.M. 1990, Astron. Ap. 231, 453.
Waters, L.B.F.M., Boland, W., Taylor, A.R., van de Stadt, H., and Lamers, H.J.G.L.M. 1989, Astron. Ap. 213, L19.

5. STELLAR CORONAE AND TRANSITION REGIONS

Much of the progress in studies of stellar coronae and transition regions over the past few years has come from re-analysis and consolidation of the wealth of data gathered by the IUE, Einstein, and Exosat satellites. For example, Schrijver and coworkers established the existence of tight correlations between stellar x-ray and EUV fluxes, and other parameters such as the photospheric magnetic flux. The phenomenology of coronae in pre-main-sequence stars has been discussed by Feigelson and Kriss (1989), while Pallavicini (1988) has reviewed observations of flares in stellar coronae.

Feigelson, E.D., and Kriss, G.A. 1989, Ap.J. 338, 262.
Pallavicini, R. 1988, in `Activity in Cool Stars Envelopes`, (Kluwer: Dordrecht), O. Haynes et al., eds., p. 249.

6. THE CORONAL DIVIDING LINE

The explanation of this division in the Hertzsprung-Russell diagram remains uncertain. Reimers et al. (1990) observed an extended corona round the G9 II star HR 6902. Its corona has a temperature of 87000 K and a mass loss of 2 E -11 solar masses per year. These observations seem to confirm that the physical conditions in the outer layers of cool stars change across the dividing line, and that the open extended corona is contrary to the earlier explanation that the dividing line lies in the instability of coronal loops in stars of low surface gravity. An explanation based on the rotation of stars has been suggested (Gray 1990).

Reimers, D. Baade, R., and Schrö der, K.-P. 1990, Astron. Ap. 227, 133.
Gray, D.F. 1990, in `Cool Stars, Stellar Systems, and the Sun`, Sixth Cambridge Workshop, (Astron. Soc. Pacific: San Francisco), G. Wallerstein, ed., p. 155.

7. STELLAR CHROMOSPHERES

Recent results of UV and x-ray observations of stars from many different regions of the H-R diagram (e.g., Kondo et al. 1989, Maggio et al. 1990), combined with increasingly sophisticated modelling techniques (Judge 1990), have improved our understanding of the physical processes behind chromospheric phenomena. Recent reviews can be found in Ulmschneider (1990), and Van Balegooijen (1990).

Judge, P.G. 1990, Ap.J. 348, 279.
Kondo, Y., Boggess, A., and Maran, S. 1989, Ann. Rev. Astron. Ap. 27, 397.
Maggio, A., Viana, G.S., Haische, B.M., Stern, R.A., Bookbinder, J., and Harnden, F.R., Jr. 1990, Ap.J. 348, 253.
Van Ballegooijen, A.A. 1990, in `Cool Stars, Stellar Systems, and the Sun`, (Astron. Soc. Pacific: San Francisco), G. Wallerstein, ed., p. 15.
Ulmschneider, P. 1990, in `Cool Stars, Stellar Systems, and the Sun`, (Astron. Soc. Pacific: San Francisco), G. Wallerstein, ed., p. 3.

8. STELLAR PHOTOSPHERES

It is becoming increasingly clear that structure in the photospheric layers is common, perhaps universal. Granulation occurs for all stars on the cool side of the granulation boundary (Gray 1988, Gray and Nagel 1989). Several numerical investigations of stellar granulation have been completed (Dravins 1990, Dravins & Nordlund 1990a, 1990b). Evidence for strong velocities in photospheres of stars on the hot side of the granulation boundary is also found (Gray 1989). The proceedings of *Solar and Stellar Granulation* (Rutten and Severino 1989) has many useful articles.

Other types of inhomogeneous structure are exemplified in starspots (Wallerstein 1990, Gray

1988, and the colloquium on *Surface Inhomogeneities on Late-type Stars* held in Armagh July 1990) and starpatches (Toner & Gray 1988). Numerous studies of rotational modulation, usually based on chromospheric indicators, also attest to atmospheric structure. Other information such as the CO behavior require heterogeneous thermal structure (Ayres 1990).

Ayres, T.R. 1990, in `Cool Stars, Stellar Systems, and the Sun`, (Astron. Soc. Pacific: San Francisco), p. 106.
Gray, D.F. 1988, `Lectures on Spectral-Line Analysis: F, G, and K Stars`, (The Publisher: Arva, Ontario, Canada N0M 2A0).
Gray, D.F. 1989, Publ. Astron. Soc. Pacific 101, 832.
Gray, D.F., and Nagel, T. 1988, ApJ. 341, 421.
Dravins, D. 1990, Astron. Ap. 228, 218.
Dravins, D., and Nordlund, Å 1990a, Astron. Ap. 228, 184.
Dravins, D., and Nordlund, Å 1990b, Astron. Ap. 228, 203.
Rutten, R., and Severino, G. (eds.) 1989, `Solar and Stellar Granulation`, (Kluwer: Dordrecht).
Toner, C.G., and Gray, D.F. 1988, ApJ. 334, 1008. Wallerstein, G. (ed.) 1990, `Cool Stars, Stellar Systems, and the Sun`, (Astron. Soc. Pacific: San Francisco).
Wallerstein, G. (ed.) 1990, `Cool Stars, Stellar Systems, and the Sun`, (Astron. Soc. Pacific: San Francisco).

9. SEISMOLOGY

Stellar seismology has undergone rapid development in the last three years and is emerging as a powerful tool for studies of stellar structure and stellar evolution. Most observations of non-radial oscillations have concentrated on rapidly rotating Ap stars, reviewed by Kurtz (1990, 1988), and white dwarfs, reviewed by Winget (1988). On solar-type stars, probable detections of oscillations have been made on Arcturus (Belmont et al. 1990, Irwin et al. 1989, Smith et al. 1987) and Proycon (Brown et al. 1990), with unsuccessful attempts on α Cen A (Brown & Gilliland 1990) and β Hyi (Frandsen 1987).

Belmont, J.A., Jones, A.R., Palle, P.L., and Roca Cortes, T. 1990, ApJ. 358, 595.
Brown, T.M., and Gilliland, R.L. 1990, ApJ. 350, 839.
Brown, T.M., Gilliland, R.L., Noyes, R.W., and Ramsey, L.W. 1990, ApJ. in prep.
Frandsen, S. 1987, Astron. Ap. 181, 289.
Irwin, A.W., Campbell, B., Moreby, C.L. Walker, G.A.H., and Young, S. 1989, Publ. Astron. Soc. Pacific 101, 147.
Kurtz, D.W. 1990, Ann. Rev. Astron. Ap. 28, in press.
Kurtz, D.W. 1988, in `Multimode Stellar Pulsations`, (Konkoly Observatory-Kultura: Budapest), G. Kovacs, L. Szabados, and B. Szeidl, eds., p. 107.
Smith, P.H., McMillan, R.S., and Merline, W.J. 1987, ApJ. 317, p. L79.
Winget, D.E. 1988, in `Advances in Helio- and Asteroseismology`, (Kluwer: Dordrecht), J. Christensen-Daalsgard and S. Frandsen, eds., p. 305.

10. VERY COOL STARS

Generally speaking, progress with observations of very cool stars has been rather rapid and theoretical interpretations still seem to lag behind despite extensive efforts of modeling.

One of the fundamental problems in stellar atmospheres is how accurately the stellar abundances can be determined, and this problem is still poorly understood in very cool stars. Recent progress on chemical analyses of cool stars has been reviewed critically by Gustafsson (1989), who emphasized that further methodological studies should be needed. One prerequisite for accurate abundance analyses is to improving model atmospheres, and some attempts have been made (e.g., Alexander et al. 1989, Bessell et al. 1989, Jorgensen 1989). Actual analyses of high resolution spectra of cool giant stars also progressed, and complicated evolution in AGB phase can now be traced by detailed chemical analyses (e.g., Smith and Lambert 1990). High resolution spectroscopy also revealed that the differential shifts and asymmetries of spectral lines tend to be large in cool giant stars, and this fact points to the inadequacy of the usual model of depth-independent, isotropic Gaussian microturbulence (Tsuji 1990).

The IRAS survey opened a new era in the study of AGB stars (e.g., Van der Veen and Habing 1988). One enigma is the presence of the peculiar carbon stars that show the emissions of silicate. Several hypotheses to explain these objects have been proposed: binaries consisting of O-rich and C-rich stars (Benson and Little-Marenin 1987), rapid evolution from O-rich star to C-rich star leaving a remnant of O-rich ejecta (Willems and De Jong 1988, Cahn and Kwok 1988), chemical effect in the envelope with O/C ratio near unity (Skinner et al. 1990), C-star accompanied by an accretion disk that may supply silicate (Lloyd Evans 1990; Lambert et al. 1990). A more complete understanding of the physics and chemistry of circumstellar envelopes is needed to answer such a problem. Some recent progress has been made on such subjects as dust formations (e.g., Gail and Sedlmayr 1988), modelling of circumstellar envelopes (e.g., Keady et al. 1988, Hashimoto et al. 1990), dynamical modelling of the envelopes of Mira variables (e.g., Bowen 1988), and mass loss mechanisms (e.g., Morris 1987, Bedjin 1988).

The possible existence of brown dwarfs is still of major interest. Several candidates that are young and thus relatively bright have been proposed. Unfortunately, it is difficult to distinguish between the young brown dwarfs and cool main sequence stars using spectroscopic or photometric observations, since the theory of the atmospheres of cool dwarf stars is not sophisticated enough to distinguish between them (e.g., Lunine et al. 1989). Future observations may make it possible to identify faint dwarfs below the main sequence, and then the question can be answered unambiguously. Despite the efforts in the past decades, the observed radii (or effective temperatures) of red dwarfs are not satisfactorily understood (Burrows et al. 1989).

Alexander, D.R., Augason, G.C., Johnson, H.R. 1989, Ap.J. 345, 1014.
Bedijn, P.J. 1988, Astron. Ap. 205, 105.
Benson, P., Little-Marenin, R. 1987, Ap.J. Lett. 316, L37.
Bessell, M.S., Brett, J.M., Scholz, M., Wood, P.R. 1989, Astron. Ap. 213, 225.
Bowen, G.H. 1988, Ap.J. 329, 299.
Burrows, A., Hubbard, W.B., Lunine, J.I. 1989, Ap.J. 345, 939.
Cahn, S.J., Kwok, S. 1988, Ap.J. 334, 362.
Gail, H.P., Sedlmayr, E. 1988, Astron. Ap. 206, 153.
Gustafsson, B. 1989, Ann. Rev. Astron. Ap. 27, 701.
Hashimoto, O., Nakada, Y., Onaka, T., Tanabe, T., Kamijo, F. 1990 Astron. Ap. 227, 465.
Jorgensen, U.G. 1989, Ap.J. 344, 901.
Keady, J.J., Hall, D.N.B., Ridgway, S.T. 1988, Ap.J. 326, 832.
Lambert, D.L., Hinkle, K.H., Smith, V.V. 1990, Astron. J. 99, 1612.
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Lunine, J.I., Hubbard, W.B., Burrows, A., Wang, Y.P., Garlow, K. 1989, Ap.J. 338, 314.
Morris, M. 1989, Publ. Astron. Soc. Pacific 99, 1115.
Skinner, C.J., Griffin, I., Whitmore, B. 1990, Mon. Not. Roy. Astron. Soc. 243, 78.
Smith, V.V., Lambert, D.L. 1990, Ap.J. Suppl. 72, 387.
Tsuji, T. 1990, Astron. Ap. submitted.
Van der Veen, W.E.C.J., and Habing, H.J. 1988, Astron. Ap. 194, 125.
Willems, F.J., and De Jong, T. 1988, Astron. Ap. 196, 173.

11. NUMERICAL RADIATIVE TRANSFER

The development of operator perturbation methods has continued, with the emphasis on further simplification of the approximate operator. Recent summaries of the background can be found in Kalkofen (1984, 1987). For multilevel line transfer problems with a small number of lines in plane stratified atmospheres, the method with Scharmer's operator is the preferred vehicle. For this, the well-known program of Carlsson (Scharmer & Carlsson 1985) is widely used. Problems in several dimensions are mainly solved with an approximate operator given by diagonal operators; different operators differ in the construction of the diagonal elements. Two papers elucidate the approach, Klein et al. (1989) and Steiner (1990). New features contained in the two papers are: efficient acceleration methods, and nearest-neighbor coupling in the construction of flux-conserving atmospheres.

Klein et al. (1989) propose a method for solving multidimensional line transfer problems for a time-dependent medium in statistical equilibrium with a diagonal transfer operator and the equivalent-two-level-atom formulation. They write the transfer equation in terms of moment equations, where a variable Eddington tensor (the ratio of the K-integral to the mean intensity) takes the place of the Eddington factor. The method is described as an accelerated double-splitting iteration technique; it is, in essence, operator perturbation with a diagonal operator (cf. Hamann 1987; Werner 1987). The procedure amounts to the decomposition of the large system of equations, whose order is given by the product of the number of frequency grid points in the line considered and the number of spatial points in the one-dimensional or multidimensional grid, into two systems of equations, one with order equal to the number of frequency points, the other with order equal to the number of spatial points.

Acceleration advances an estimate on the basis of the solutions of preceding iterations. Among the acceleration methods Klein et al. investigate are the methods due to Ng (1974), (see Olson, Auer, & Buchler 1986) and Orthomin (Vinsome 1976); the latter is usually the faster; unlike Ng's, it is applied at every step in the iteration. The demonstration solution is for a line in a one-dimensional medium with partial frequency redistribution; the time-dependence is only in the transfer equation, which is differenced completely implicitly; the equations of statistical equilibrium are in the quasistatic approximation.

Steiner (1990) investigates temperature correction in the construction of model atmospheres. For this problem the requirements for accuracy of the operator are higher than for a line transfer problem. When the optical thickness is very large, the equations with a purely diagonal operator may fail to converge for a flux-conserving atmosphere although they still would be expected to converge, albeit slowly, in a line transfer problem. It is then essential that the approximate operator approach the unit operator plus the second-derivative operator; the latter is important for flux conservation. This is achieved with a nearest-neighbor formulation.

As a particular case Steiner investigates convergence with approximate Λ operators for a grey LTE atmosphere in two dimensions and for a non-gray model of the solar atmosphere with line blanketing, using the opacity distribution functions of Kurucz (1979) representing more than 10^6 lines. The purely local (i.e., diagonal) operator converges extremely slowly when the optical thickness of the medium exceeds $\tau \approx 100$. On the other hand, with an approximate Λ operator containing the second-derivative operator, convergence at large depth is excellent. But a much larger system of equations must be solved since the approximate operator that accounts for nearest-neighbor coupling is expressed by a band matrix with nine nonzero diagonals, corresponding to quadratic interpolation on a nine point stencil.

Steiner achieves the required accuracy of the operator with the so-called short characteristic equations of Kunasz and Olson (1988). In addition he employs the acceleration method due to Ng (1974). In the construction of a line-blanketed, multidimensional model atmosphere in radiative and hydrostatic equilibrium he solves the equations by partial linearization of the Planck function with respect to temperature, lagging the Λ operator.

Peraiah et al. (1987) computed line profiles in an extended and expanding spherically symmetric dusty shell. Radiation transfer has been studied in rapidly moving fluids (Peraiah 1987), and with Compton scattering (Peraiah 1990, Peraiah & Varghese 1990). Using an expanding corona model, computed profiles of the solar lines Fe XIV λ5303 and Fe X λ6374 are found to agree with the observations (Peraiah & Varghese 1989).

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Steiner, O. 1990, Astron. Ap. 231, 278.

Vinsome, P.K.W. 1976, in: Proceedings of the Fourth Symposium on Reservoir Simulation, Society of Petroleum Engineers, p. 149.

Werner, K. 1987, in Numerical Radiative Transfer, (Cambridge: Cambridge), p. 67.