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Mixing and Diffusion in Stars: Theoretical Prediction and Observational Constraints

Chairpersons & Editors: D. VandenBerg & J.–P. Zahn

https://doi.org/10.1017/S1539299600013460 Published online by Cambridge University Press

Highlights of Astronomy, Vol. 12
International Astronomical Union, 2002
H. Rickman, ed.

Joint Discussion 5 – Mixing and Diffusion in Stars: Introduction and Brief Overview

Don A. VandenBerg

University of Victoria, Dept. of Physics & Astronomy, Box 3055, Victoria, B.C. V8W 3P6 Canada

Jean-Paul Zahn

Observatoire de Paris, 92195 Meudon, France

Our understanding of transport processes in stars is still in its infancy. First consider overshooting. There is now ample evidence from, e.g., the best-observed binary stars and fits of models to observed colour-magnitude (C-M) diagrams that some amount of mixing must occur beyond the classical boundary of the convective core set by the Schwarzschild criterion. Such mixing can be achieved by convective penetration; however, despite impressive progress on the theoretical front, a rigorous prediction of the extent of overshooting has not yet been achieved. As a result, most stellar evolutionary calculations have simply opted to extend convective core sizes by an amount (usually measured as a fraction of a pressure scale height) that produces reasonable consistency with observations. But how realistic are such models? To what extent does the overshooting depend on mass and/or evolutionary state? What is the role of rotation in determining the size of convective cores? How much does rotation-induced meridional circulation contribute to such mixing?

In the Sun, helioseismology reveals the presence of a sharp transition in the rotation rate which changes abruptly from differential (i.e. latitude-dependent) in the convection zone to almost uniform in the radiative interior. What is the structure of this tachocline, what is the efficiency of particle transport through it, and what role does it play in the Li depletion? Is this depletion correlated with the loss of angular momentum from solar-type stars? In that case one would expect tidally-locked binaries to be less depleted than single stars; but is this property confirmed by the observations? Why do current models of rotational mixing fail to predict the almost uniform rotation of the radiative interior of the Sun? Further, what link does this tachocline have to the magnetic field? Is it the seat of the solar dynamo?

Convective transport in the giant phase is at least as problematic. The evidence is compelling that giants are able to dredge matter up to their surface layers from the vicinity of their H-burning shells. Even in subsolar mass stars, there is apparently sufficient internal rotation to set up the circulation currents that are presumably responsible for the observed abundance "anomalies". However, what is particularly disconcerting is that there appears to be some nucleosynthesis of such elements as Al and Mg in bright, first-ascent red giants (in several metal-deficient globular clusters). This should not occur, even if matter is mixed into the H-burning shell, because such shells are too cool for significant processing to occur via the Ne–Na and Mg–Al cycles. There are also some indications that the mixing commences in some systems when stars are just beginning to ascend the red-giant branch. According to theory, circulation currents should be able to reach down to the vicinity of the H-burning shell only along the upper giant branch, when there is no longer a steep gradient of chemical composition above the shell. How are we to explain such observations? Similarly, the Li-rich giants appear to require a fine tuning of convective transport which is not yet understood.

The surface chemistry of stars is also apparently modified by turbulent, diffusive, and radiative acceleration processes. In the Sun, helioseismology has confirmed the importance of the gravitational settling of helium. In AmFm, Ap, and HgMn stars, most anomalies appear to be caused by radiation-driven diffusion. However the anomalies are rarely as large as the atomic diffusion processes alone would lead to, so that competing hydrodynamical processes must also (apparently) play a role in those objects. We are forced to the same conclusion regarding the halo dwarfs that comprise the so-called "Spite plateau". The latter have such exceedingly uniform Li abundances that it seems impossible to reconcile the observations with either diffusive or rotationally-mixed models. Moreover, isochrones that don't include diffusion are able to mimic observed C-M diagrams much better than those that do. What are the competing hydrodynamical process that are serving to reduce the effects of diffusion in Population II stars?

Given the considerable importance of these processes for the modelling of stars and stellar populations and for assessing the primordial abundance of Li, Be, and B, Commission 35 took the initiative of organising a one-day Joint Discussion on "Mixing and Diffusion in Stars" (with the support and participation of Commissions 26, 29, 36, 37, and 45). The first session dealt with the observations of chemical abundances in stars, and featured reviews by J. Landstreet (on Population I main-sequence stars), D. Lambert (on highly evolved field stars), R.P. Kraft (on globular cluster stars), J. Norris (on the special case of ω Centauri), F. Grundahl (on the photometric evidence for abundance anomalies), and S. Balachandran (on the constraints provided by Li, Be, and B abundances). The second session concentrated on the theoretical progress that has been made in understanding the observed chemistry of stars: oral contributions were given by G. Michaud (on main-sequence stars), S. Brun (on mixing in the solar tachocline), G. Meynet (on rotation and mixing in massive stars), and A.V. Sweigart (on horizontal-branch models as a test of mixing on the giant branch). The third (and last) session was concerned with more theoretical issues and included talks by V. Canuto (on the theoretical basis for convective overshooting), B. Freytag (on hydrodynamical simulations of mixing), and P. Charbonneau (on mixing in magnetized stellar radiative zones). Short summaries of all of the above contributions (except D.L.'s), along with invited papers by P. Denissenkov (on a mechanism for extra mixing in globular cluster red giants) and L. Mestel (on rotation and mixing in stars), as well as summarizing remarks by J.-P. Zahn, are provided in the pages which follow.

Important contributions to the discussion of both the theoretical and observational issues were made by several others in the form of poster papers. These included (in alphabetical order by first author):

- Abundances of 54 Chemical Elements in Przybylski's Star: HD 101065 — C.R. Cowley, T.A. Ryabchikova, F. Kupka, D. Bord, G. Mathys, & W.P. Bidelman.
- Abundance Anomalies in Globular Cluster Stars: Clues from the Main Sequence — G.S. Da Costa, J.E. Norris, R.D. Cannon, & B.F. Croke
- Some Very High Rotating Li-Rich K Giant Stars — N.A. Drake, R. de la Reza, & L. da Silva.
- Neon Abundances in Mercury-Manganese Stars: Radiative Accelerations and non-LTE Calculations — M.M. Dworetsky & J. Budaj.
- A New Model of Elemental Mixing in Stars and its Implications — Y. Fujimoto.
- Self-Consistent Model Atmospheres Including Diffusion — A. Hui-Bon-Hoa, F. LeBlanc, & P.H. Hauschildt.
- Stochastic Clump Model: A Clue to Understanding the Mixing in the Early-Type Star Atmospheres — A.F. Kholtygin.
- Mixing by Internal Waves Beneath the Convection Zone: Comparison with Analytical Models — M. Kiraga, K. Jahn, M. Różyczka, K. Stępień, & J.-P. Zahn.
- On the Chemical Abundances of Post-AGB Stars — M. Parthasarathy, T. Sivarani, & P. Garcia-Lario.
- Modeling Temporal Changes of Spectral Energy Distribution of Sakurai's Object (V 4334 Sgr) — Ya.V. Pavlenko & H.W. Duerbeck.
- An Observational Test of Tidally Induced Mixing in a Massive Binary System — K. Pavlovski & H. Hensberge.
- Lithium in Cool Magnetic CP Stars. II. Abundance Analysis of Two "Spotted" roAp Stars, HD 83368 and HD 60435 — N. Polosukhina, A. Shavrina, M. Hack, P. North, V. Tzymbal, V. Khalack, J. Zverko, & J. Zižňovský.
- Relation Between the Li Spots, Dipolar Magnetic Field, and Other Variable Phenomena in the roAp Star HD 83368 — N. Polosukhina.
- International Project: Lithium in Magnetic CP Stars — H. Hack, N. Polosukhina, V. Malanushenko, P. North, I. Ilyin, & J. Zverko.
- Observational Features Sensitive to Convective Core Overshooting in the CMDs of Star Clusters — R. Sagar.
- Analysis of Stratification of Cr with Depth in the Atmospheres of Normal and CP Stars — I.S. Savanov.
- Evolutionary Effects in Atmospheres of Red Horizontal Branch Stars — G. Tautvaišienė, B. Edvardsson, I. Tuominen, & I. Ilyin.
- New Constraint on Ap Star Diffusion Models from Stokes I, V, Q, and U Profiles — G.A. Wade, S. Bagnulo, & J.D. Landstreet.
- The Li I 6708Å Line in Spectra of the Magnetic CP Stars HD 60435, HD 134214, HD 137949, & HD 166473 — J.Zverko, J. Žižňovský, N. Polosukhina, & P. North.

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