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COMPARISON OF STELLAR OSCILLATIONS AND ACTIVITY DATA TO INFER INTERNAL ROTATION

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ABSTRACT Recently it has beeen suggested that the latitude distribution of the main surface features of solar activity is intimately related to the angular velocity profile inside the Sun through the working of a MHD dynamo in the boundary layer between the convective and the radiative zones (Belvedere et al. 1991).

Although the present observational capabilities are not very encouraging, here we want to point out, in the framework of the analogy to the Sun (solar-stellar connection), that space observations of surface distribution and latitudinal migration of active regions on stellar surfaces, which could be carried out in this decade with more sophisticated techniques, may conversely allow us to infer the rotation profile, and consequently the angular momentum distribution, in stellar interiors. This methodology may in principle be considered alternate or complementary to the classical one based on observation of acoustic oscillations.

PROLOGUE: WHAT WE HAVE LEARNED FROM THE SUN

Assuming the internal rotation profile inferred by the most recent helioseismological data (Harvey 1988; Morrow 1988; Brown et al. 1989; Dziembowski et al. 1989; Libbrecht 1989), Belvedere et al. (1991) carried out a non linear $\alpha - \omega$ dynamo model in the boundary layer betweeen the convective and radiative zones (about 0.65 $R_\odot$ to 0.70 $R_\odot$), reproducing the essential features of the solar activity cycle: the equatorward migration of sunspots and most faculae, which belong to the equatorial activity belt (latitude $\lambda < 35°$) and the poleward migration of polar faculae, filaments and large scale magnetic flux, which are characteristic of the polar activity belt ($\lambda > 40° - 50°$). This means that the two latitudinal belts of solar activity, which are distinguished by opposite latitudinal migration of tracers, would appear as a natural and direct consequence of the internal rotation profile, via the working of dynamo in the boundary layer. Specifically, it is a consequence of the rigid rotation rate $\omega_\circ = 2.7 \times 10^{-6}$ rad/s below the convection zone ($r = 0.65 R_\odot$) being precisely the value at the surface at the critical latitude $\lambda_\circ = 35°$, that defines the boundary between the two latitudinal belts. Since no radial variation of the surface rotation (a function of latitude) has been evidenced in the convection zone, we should have in the boundary layer $\partial\omega/\partial r > 0$ for $\lambda < \lambda_\circ$ and $\partial\omega/\partial r < 0$ for $\lambda > \lambda_\circ$. Accordingly, the $\alpha - \omega$ dynamo criterion (Parker 1955; Yoshimura 1975a), based on the sign of the product $\Gamma = \alpha\partial\omega/\partial r$ (with α negative in the boundary layer (Yoshimura 1975b; Glatzmaier 1985a,b)

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in the northern emisphere), allows equatorward propagation of dynamo waves for $\lambda < \lambda_o$ and poleward propagation for $\lambda > \lambda_o$.

Indeed, this picture has received a substantial support by the non linear $\alpha - \omega$ dynamo calculations performed by Belvedere et al.(1991) in a thin spherical shell ($d = 0.05 R_{\odot}$) representing the boundary layer, with full latitude-time resolution. In fact, they have shown the existence of periodic (dynamo wave-like) stable solutions with both equatorward and poleward migrating branches, for dynamo numbers $|D| = \alpha\omega_o d^3/\eta^2$, where η is the turbulent viscosity, of the order of the unity. This is a basic result: the simulation shows that horizontally propagating dynamo waves can exist even in a very thin layer.

SURFACE ACTIVITY - A PROBE OF INTERNAL STELLAR ROTATION

Although many uncertainties do still exist even in the case of the Sun, nevertheless we are tempted to suggest that, conversely, observation of latitudinal distribution and migration of active regions on late main sequence (G,K,M) slowly rotating stars, by photometric and spectro scopic methods, may in principle allow us to infer the internal rotation profile and angular momentum distribution in a conceptually simple and direct way, offering a tool to future investigation of their dependence on stellar parameters such as spectral type, average rate of rotation and age.

What a theorist needs from observers

For this purpose we need accurate measurements of: (i) angular velocity at the equator or at some fixed latitude; (ii) latitudinal differential rotation profile at the surface, over a suitable latitude interval; (iii) latitude drift of activity tracers over a suitable time span. All necessary data may in principle be given by photometric and spectroscopic observations (Baliunas & Vaughan 1985; Hartmann & Noyes 1987; Rodonò 1987).

This way it should be possible to determine the surface latitude (if any) at which the direction of migration changes its sign and the corresponding value of the surface angular velocity, that are the essential data in order to deduce the internal rotation profile. The angular momentum profile would consequently be computed taking into account the density profile given by theory of stellar structure. Of course, all this is based on the analogy to the Sun - that seems to be fairly supported in the context of the solar-stellar connection (Belvedere 1985; Noyes 1985; Belvedere 1990) - namely on the fact that late spectral type main sequence stars have outer convection zones, whose extent is theoretically known, and suitable boundary layers. Similar patterns of convection are also plausible, at least for slow rotators. Unfortunately, the present available photometric and spectroscopic data of surface distribution of stellar active regions (Rodonò 1986; Vogt et al. 1987; Vogt & Hatzes 1991) only refer to binary, fast rotating, hyperactive stars of RS CVn and BY Dra type - whereas analogy to the Sun requires single, slowly rotating, mild activity main sequence stars - and show a definite tendency of active regions to be concentrated at high latitudes. Moreover, the sensitivity and resolution power of present observational capabilities are far from making it possible to perform high precision measurements, like those we suggest here, not only for solar type single stars with relatively

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weak activity, but even for strong activity RS CVn and BY Dra type stars.

PERSPECTIVES

However, future improvement of observational techniques based on the analysis of both light curves and line profiles (to this regard we mention the Zeeman-Doppler Imaging Method (Semel 1989; Donati et al. 1989) that is an extension of the Doppler Imaging Method (Vogt et al. 1987) and allows surface magnetic cartography), as well as observation from space with large instruments, may make it possible in next future. We refer in particular to the 170 cm diameter Spectrum Ultraviolet telescope orbital station, SUV, a collaborative project proposed by USSR and Italy to perform, besides other things, observations of stellar chromospheres (Rodonò et al. 1991). As matter of fact, one of the reasons to organize the Catania "Space Projects" meeting, came out from the theorist's curiosity to explore the future observational capabilities in connection to some theoretical requirements.

Further, comparison between surface activity data and acoustic oscillations data for a suitable sample of stars, may offer the opportunity to test the validity of our internal rotation probing method, whose basic principles are outlined here, and eventually the reliability of the boundary layer dynamo. This may be performed within the present decade in the framework of a single space observation project, Probing Rotation and Interior of Stars: Microvariability and Activity , PRISMA , which is under consideration of ESA (Lemaire et al. 1991).

If reliable on both theoretical and observational sides, this methodology might allow us to get information on the dependence of internal rotation and angular momentum distribution on mass, average rotational rate and age. Of course, application to other stars of results of dynamo theory obtained for the Sun is certainly not to be considered definitive, but only tentative. We are well aware that there are several uncertainties even in the solar case. Anyway, the present attempt may provide a way which future observations may confirm or refute.

REFERENCES

Baliunas S.L., Vaughan A.H.: 1985, *Ann. Rev. Astron. Astrophys.* **23**, 379

Belvedere G.: 1985, *Solar Phys.* **100**, 363

Belvedere G.: 1990, in: Berthomieu G., Cribier M. (eds.) *Proc. IAU Coll.* **121**, Inside the Sun, Kluwer, Dordrecht, p. 371

Belvedere G., Proctor M.R.E., Lanzafame, G.: 1991, *Nature* **350**, 481

Brown T.M., Christensen-Dalsgaard J., Dziembowski W., Goode P.R., Gough D.O., Morrow C.A.: 1989, *Astrophys. J.* **343**, 526

Donati J.F., Semel M., Praderie F.: 1989, *Astron. Astrophys.* **225**, 467

Dziembowski W.A., Goode P.R., Libbrecht, K.G.: 1989, *Astrophys. J.* **337**, L53

Glatzmaier G.A.: 1985a, *Geophys. Astrophys. Fluid Dyn.* **31**, 137

Glatzmaier G.A.: 1985b, *Astrophys. J.* **291**, 300

https://doi.org/10.1017/S0252921100018649 Published online by Cambridge University Press

Hartmann L.W., Noyes R.W.: 1987, *Ann. Rev. Astron. Astrophys.* **25**, 271

Harvey J.W.: 1988, in Rolfe E.J. (ed.), Seismology of the Sun and Sun-like Stars, *ESA SP-286*, p. 55

Lemaire P., Appourchaux T., Catala C., Catalano S., Frandsen S., Jones A., Weiss W.: 1991, in Catalano S. & Stauffer J. (eds.), *Proc. Nato ARW*, Angular Momentum Evolution of Young Stars, Kluwer, Dordrecht, p.397

Libbrecht K.G.: 1989, *Astrophys. J.* **336**, 1092

Morrow C.A.: 1988, in Rolfe E.J. (ed.), Seismology of the Sun and Sun-like Stars, *ESA SP-286*, p. 91

Noyes R.W.: 1985, *Solar Phys.* **100**, 385

Parker E.N.: 1955, *Astrophys. J.* **122**, 293

Rodonò M.: 1987, in Schroter E.H. & Schussler M. (eds.) Solar and Stellar Physics, Lecture Notes in Physics **292**, 39

Rodonò M. et al.: 1986, *Astron. Astrophys.* **165**, 135

Rodonò M., Tanzi E.G., Boyarchuk A.A., Steshenko N.V.: 1991, in Catalano S., Stauffer J. (eds.), *Proc. Nato ARW*, Angular Momentum Evolution of Young Stars, Kluwer, Dordrecht, p. 405

Semel M., 1989: *Astron. Astrophys.* **225**, 456

Vogt S.S., Hatzes A.P.: 1991, in Tuominen I., Moss D., Rudiger G. (eds), *Proc. IAU Coll.* **130**, The Sun and Cool Stars: Activity, Magnetism, Dynamos, Lecture Notes in Physics **380**, 297

Vogt S.S., Penrod G.D., Hatzes A.P.: 1987, *Astrophys. J.* **321**, 496

Yoshimura H.: 1975a *Astrophys. J.* **201**, 740

Yoshimura H.: 1975b *Astrophys. J.* **29**, 467

https://doi.org/10.1017/S0252921100018649 Published online by Cambridge University Press