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TIME SCALES FOR Ca II EMISSION DECAY, ROTATIONAL BRAKING, AND LITHIUM DEPLETION

A. SKUMANICH
High Altitude Observatory, National Center for Atmospheric Research,* Boulder, Colorado
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ABSTRACT

A comparison of the Ca^+ emission luminosity—after correction for spectral-type effects—for the Pleiades, Ursa Major, and Hyades stars and the Sun indicate an emission decay which varies as the inverse square root of the age. Further, the rotational decay curve is found to satisfy the same law. It is further suggested that lithium depletion follows the same law but only as far as the Hyades age, after which the depletion proceeds exponentially. Since Ca^+ emission is linearly proportional to magnetic field strength at the surface, one can predict that the surface fields are proportional to angular velocity and decay as the inverse square root. The above results are predicated on the standard Hyades age (0.4 billion years).

In an effort to put the relation between stellar age and the intensity of emission reversal of the Ca^+ K- and H-lines (Wilson 1963; Wilson and Skumanich 1964) on a quantitative basis the author has reduced photoelectric observations of the cores of the K- and H-lines in the field stars (Wilson 1968), the Hyades (Wilson 1970), and the Sun (Wilson 1971) to a common spectral type (specifically, to $B - V = 0.60$). As Wilson (1970) has shown, K and H emission varies, for a given age group, with spectral type, so any meaningful age relation must be discussed after temperature differences are removed. The details of this procedure will be given elsewhere; our intent here is to compare the resulting (Ca^+ emission, age)-relation with that for rotational braking and lithium depletion.

In Figure 1 the temperature-corrected Ca^+ emission luminosity is plotted (after subtraction of the "zero" point flux as given by the lower envelope of Wilson's flux data) for the Sun and for the Hyades and Ursa Major stars. The latter are to be found among Wilson's field-star data. The Hyades emission luminosity is taken as unity at all spectral types. Also plotted are the Ca^+ emission data for the Pleiades as estimated from Kraft and Greenstein's (1969) equivalent-width measures of the late-type stars in the Pleiades and Hyades. The indicated errors are based on the spread in data. The figure indicates an inverse square-root law for the decay of Ca^+ emission.

Also plotted in Figure 1 are average equatorial velocities for the G stars in the Pleiades and Hyades and for the Sun (Kraft 1967; cf. Conti 1968 for further references of the data used). It is evident that the rotational data are in a constant ***proportion***, within experimental errors, with the Ca^+ emission data; i.e., the rotational decay also follows a square-root relation. The same can be said for the lithium-abundance data (for a review of this data, see van den Heuvel and Conti 1971) except that here the Sun has an overdepletion. It would appear that the lithium depletion follows the rotational and Ca^+ emission decay through times of the order of the Hyades age and then proceeds exponentially with a *e*-folding time of 1.1×10^9 years. Alternately, the lithium abundance in the Sun may be underestimated by a factor of 10.

According to Frazier's data (Frazier 1970), Ca^+ emission intensity, in a 1.1 Å band centered on the K-line, varies linearly with surface magnetic field strength. Thus it is appropriate to identify the stellar Ca^+ emission luminosity with the (average) surface magnetic field. Figure 1 then implies that the average surface (dynamo) field is ***pro-***

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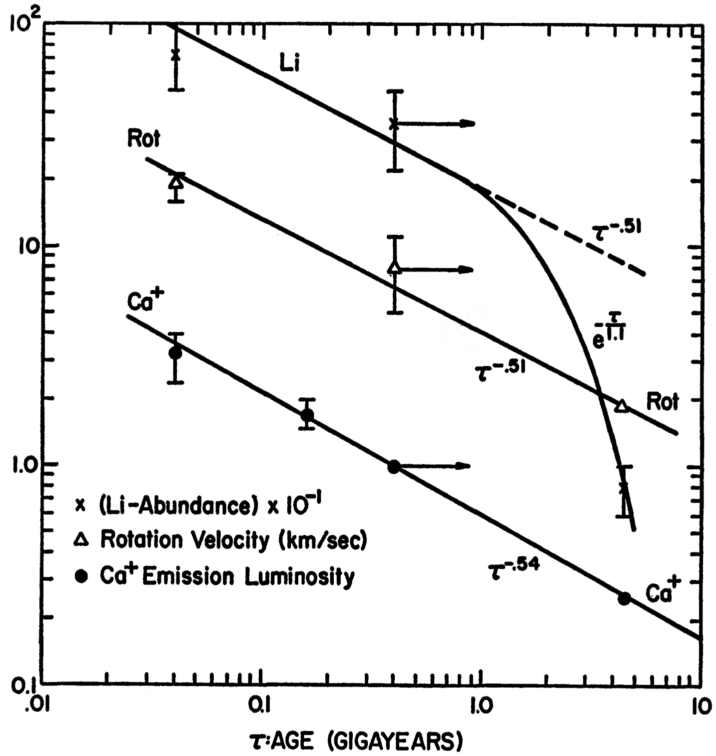

FIG. 1.—Ca^+ emission, rotation, and lithium abundance versus stellar age

portional to the rotational velocity and decays as the inverse square root of the time as the star "cooks" on the main sequence. This remarkable result has been shown to be theoretically consistent by Durney (1972) on the basis of a simple model for the stellar wind.

The above results are predicted on the basis of the "standard" age for the Hyades, viz., 0.4×10^9 years. If the revision by van den Heuvel (1969) proves to be correct, the derived square-root law will have to be revised. The *proportionality* between magnetic fields, rotation, and lithium abundance (except for the solar Li abundance) would be unchanged. The shift in the Hyades point due to the suggested age revision is indicated in Figure 1 by the arrows. As van den Heuvel and Conti (1971) show, one can fit the three points (using the revised age) with an exponential with an *e*-folding decay time of 1.1×10^9 years; however, the rotation curve was better fitted by *two* exponentials. The suggestion here, particularly when one tries to fit the Ca^+ data (the Ursa Major point is important here), is that a power law is even better. The use of the revised Hyades age leads to an inverse cube-root law up to the Hyades. The subsequent decay would be more rapid for all three quantities. Whether this is allowable theoretically remains to be seen.

Measures of the rotation and lithium abundance in the G stars in the Ursa Major group would help to resolve the question of the nature of the decay law.

I am indebted to Olin C. Wilson for his continual stimulation and kind sharing of his unique observational data on stellar chromospheres. Special thanks are due Robert P. Kraft for calling my attention to his Pleiades and Hyades data and for helping in the preliminary estimate of the Pleiades/Hyades ratio. My thanks also go to Peter S. Conti for calling my attention to his and other work on the lithium data.

REFERENCES

Conti, P. S. 1968, *Ap. J.*, **152**, 657.
Durney, B. 1972, *Proceedings of the 1971 Asilomar Conference on the Solar Wind* (ed. C. P. Sonnet)
Frazier, E. N. 1970, *Solar Phys.*, **14**, 89.
Heuvel, E. P. J., van den. 1969, *Pub. A.S.P.*, **81**, 815.
Heuvel, E. P. J., van den, and Conti, P. S. 1971, *Science*, **171**, 895.
Wilson, O. C. 1963, *Ap. J.*, **138**, 832.
———. 1968, *ibid.*, **153**, 221.
———. 1970, *ibid.*, **160**, 225.
———. 1971 (private communication).
Wilson, O. C., and Skumanich, A. 1964, *Ap. J.*, **140**, 1401.