*Cool Stars, Stellar Systems, and the Sun, Eighth Cambridge Workshop*
*ASP Conference Series, Vol. 64, 1994*
*Jean-Pierre Caillault (ed.)*

# THE EVOLUTION OF STELLAR DYNAMO VARIATIONS

S. H. SAAR
Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138

A. BRANDENBURG
High Altitude Observatory, NCAR P.O. Box 3000, Boulder, CO 80307

R.A. DONAHUE AND S. L. BALIUNAS[1]
Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138

ABSTRACT We qualitatively classify the form of the Mount Wilson Ca II time series, and find that these morphological groups show trends with stellar parameters, rotation, and age.

## INTRODUCTION AND MORPHOLOGICAL CLASSIFICATION

The chromospheric Ca II H and K emission lines are well-known magnetic field diagnostics in the sun and stars (e.g., Schrijver et al. 1989) and show clear variations in phase with the solar magnetic activity cycle. To study the properties of stellar activity cycles, the Mount Wilson HK project has followed the Ca II emission of ≈100 cool dwarfs for over 25 years. Early analysis (e.g., Vaughan 1980) indicated that stars with high Ca II emission fluxes were more likely to show irregular long-term behavior, while less active stars showed solar-like cycles, or no variations. Since Ca II flux is correlated with stellar rotation and age (e.g., Skumanich 1972), an evolution of dynamo morphology is implied. We explore this further in this paper.

We began by visually classifying the variation in $S$ (the total H+K flux in 0.1 nm passbands, normalized to the continuum) of 92 dwarfs (including the sun) monitored over the full 25 years of the Mount Wilson survey. We defined four major cycle morphology classes: stars with cyclic behavior, stars showing multiple cycles, those with irregular, non-periodic variations, and stars with a non-variable (or nearly so) level of activity (cf. Baliunas & Vaughan 1985). In some cases, stars showed a secondary trait - e.g., cyclic with a strong irregular component (these are plotted as thin-lined symbols in Fig. I). This qualitative classification was then compared with a quantitative cycle analysis (Wilson 1978; Baliunas et al., in prep.), and minor adjustments were made. We ultimately classified 30 of the 92 stars as cyclic, 5 as multicyclic, 35 as irregular, and 21 as constant (one remained unclassified). We ignore the long term trends seen in some stars, whose origin (instrumental vs. stellar) is uncertain.

---

[1] also: Center for Excellence in Information Systems, Tennessee State University

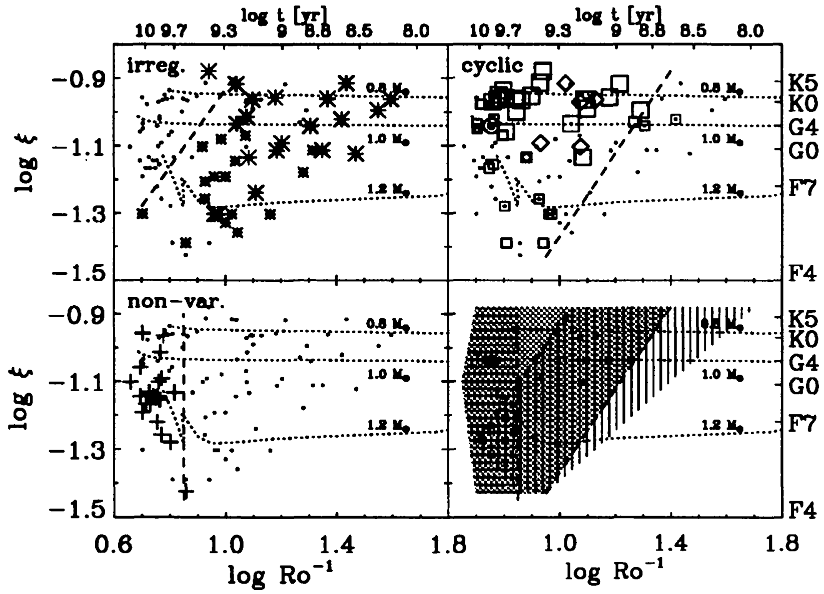

FIGURE I Dynamo morphology classes (irregular = $*$, cyclic = $\square$, multicyclic $=\diamond$, non-variable $=+$, sun$=\odot$) in a $\xi$ vs. $\mathrm{Ro}^{-1}$ diagram; approximate spectral types and ages (from Soderblom et al. 1991) are also labeled. Symbol size denotes the variation's fractional amplitude, and long dashes are class boundaries, while short dashed lines are evolutionary tracks. Summary is given in the lower right (irregular = vertical lines, non-variable = horizontal lines, cyclic = shaded, multicyc. = $\bullet$).

## ANALYSIS AND DISCUSSION

The groups show several distinct trends. There are fewer cyclic, and more irregular or non-variable stars as the convection zone (CZ) grows thinner. Stars with deeper CZs tend to have larger (fractional) variations, whether irregular or cyclic. Faster rotators at a given spectral type typically show irregular behavior. To relate the trends to dynamo theory, we follow Brandenburg et al. (1990; cf. their Fig. 3) and plot the stars in a $\xi$ - $\mathrm{Ro}^{-1}$ diagram (Fig. I). Here, $\xi$ is the mixing length normalized to the stellar radius, $\xi = \ell/R$, and $\mathrm{Ro}^{-1}$ is the inverse Rossby number, $\mathrm{Ro}^{-1} = 2\Omega\tau_c$, where $\tau_c$ is the convective turnover time (Noyes et al. 1984) and $\Omega$ is the angular velocity. The standard $\alpha\Omega$ dynamo number can be written $\mathrm{N}_{\alpha\Omega} \propto \xi^{-3}\mathrm{Ro}^{-2}$.

The location of the stars in a roughly triangular region is primarily a selection effect due to maximum stellar ages (left), minimum ages (right), and lack of M stars (top). *Internal* boundaries are significant, however. Non-variable stars lie in a narrow, vertical band at small $\mathrm{Ro}^{-1}$. Stars with irregular behavior are located in a broad diagonal strip on the right hand side, while cyclic stars lie between these two regimes, though there is a significant overlap between the groups (esp. between cyclic and non-variable), and stars with multiple periods lie in the overlap area between the irregular and cyclic regions. The approximate ages suggest a general trend of irregular → multicyclic/cyclic → cyclic/non-variable.

A more careful age calibration (Donahue 1993) confirms this impression. Figure II shows a clear progression of irregular ($\overline{\log t} = 9.03$) → cyclic ($\overline{\log t} =$

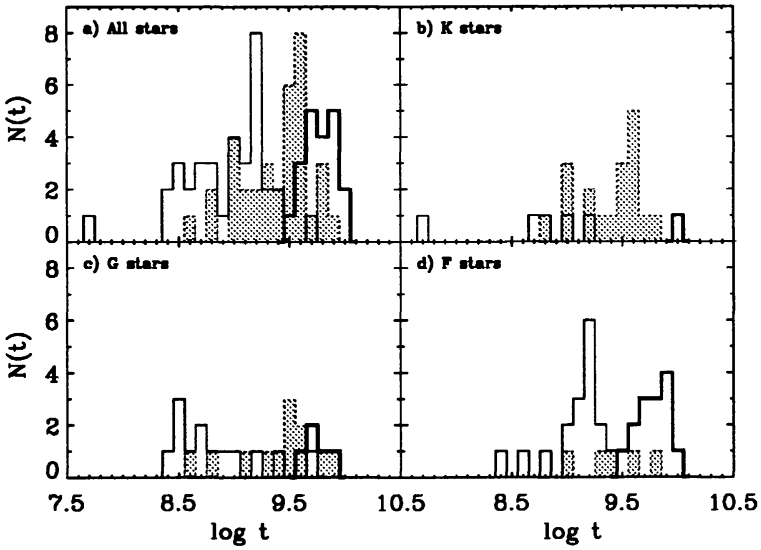

FIGURE II Histogram of ages by spectral class and morphology type (thin = irregular, shaded = cyclic/multicyclic, thick=non-variable).

9.46) → constant stars ($\overline{\log t} = 9.86$). Cyclic activity first appears at $\log t \approx 8.8$ in G and K stars, later ($\log t = 9.3$) in F stars. Multicyclics are somewhat younger than cyclics on average, with $\overline{\log t} = 9.22$. Cyclic variability dominates in the K stars (5 irregular, 18 cyclic, 1 constant), while in G (13:12:5) and F (18:4:14) stars there is a gradual shift to other behavior. With one exception, irregular variables have $\log t \leq 9.5$, while constant stars have $\log t \geq 9.6$. The low activity, non-variability, and age of the constant stars suggest many of them may be in the equivalent of Maunder minima (Baliunas & Jastrow 1990). If this is true, Maunder minima decline in frequency and/or duration as CZs deepen. There is a period around $\log t \approx 9.5$ when G and K stars can show cycles, but not Maunder minima. These clues to dynamo evolution should prove useful in constraining dynamo models.

We thank the Mount Wilson team for their tireless collection of Ca II photons! NCAR is sponsored by the NSF.

## REFERENCES

Baliunas, S.L., Jastrow, R. 1990, Nature, **348**, 520

Baliunas, S.L., Vaughan, A.H. 1985, ARA&A, **23**, 379

Brandenburg, A., et al. 1990, Solar Phys., **128**, 243

Donahue, R.A. 1993, PhD thesis, New Mexico State University

Noyes, R.W., et al. 1984, ApJ, **279**, 763

Schrijver, C.J., et al. 1989, ApJ, **337**, 964

Skumanich, A. 1972, ApJ, **171**, 565

Soderblom, D.R., et al. 1991, ApJ, **375**, 722

Vaughan, A.H. 1980, PASP, **92**, 392

Wilson, O.C. 1978, ApJ, **266**, 379