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STELLAR ACTIVITY: CONSTRAINTS EXPECTED FROM SPACE EXPERIMENTS

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ABSTRACT

Dynamo theory needs to be guided and tested by observations. However, solar observations alone cannot provide sufficient tests of the dynamo models, and constraints obtained from stellar observations are still few, indirect, and poorly related to the properties of dynamos.

This review discusses which parameters must be observed on stars other than the Sun to usefully guide the theoretical efforts and test the resulting models. We show that most of these observables, which characterize the stellar activity phenomena, are accessible only from space, and that space-based experiments are one of the best tools to trigger progress in the field of solar and stellar activity in the next few decades.

INTRODUCTION

One of the major problems of stellar physics concerns the generation of magnetic fields in the interior of the sun and stars by dynamo action, and the effects of such magnetic fields in stellar atmospheres, known by the name of stellar activity.

The most widely accepted idea is that the sun and solar-type stars produce their magnetic fields by an $\alpha\omega$-type dynamo, for which the large scale magnetic field is maintained by the composition of two types of motions of the conducting plasma: turbulent motions, commonly assumed to be due to convection or overshooting, and differential rotation (Cowling 1980).

Two complementary theoretical approaches have been used to attack this problem:

- *the mean-field theory:* the collective action of small-scale motions is represented by a mean current parallel to the large scale magnetic field, the so-called α-effect (e.g. Steenbeck et al. 1966; Moffat 1978; Krause and Rädler 1980). Although the mean-field theory has been successful in reproducing some aspects of the solar cycle, like e.g. the solar cycle period and the butterfly diagram (Steenbeck and Krause 1969), it is only a linear theory, and does not take into account the feedback of the magnetic field B on the plasma motions through the Lorentz force, that limits the growth of B. Thus, the mean-field theory has two major limitations: first, it is not capable of predicting the intensity of the resulting magnetic field; second, we cannot be sure that the modes excited in the linear regime are still the dominant ones in the nonlinear situation. In other words, even the spatial large scale structure of the magnetic field derived from a linear analysis may be difficult to compare with the real situation in the sun and stars. However, several possibilities exist to take into account the nonlinear effects in a parameterized way (e.g. α–quenching). If the resulting parameterization can be guided and tested by appropriate observational constraints, there is hope that some meaningful models may be produced in the future.

- *the nonlinear numerical simulations:* these simulations aim at solving the full set of nonlinear MHD equations in 2D or 3D (Gilman and Miller 1981; Gilman 1983; Glatzmaier 1984; Brandenburg 1990). The problems encountered by the mean–field theory disappear, but a serious limitation remains: due to the limited (although quite large) capacity and power of modern computers, the spatial resolution reachable by these simulations is rather low, and consequently the small scales that play a decisive role in the stellar dynamo process are not resolved. However, we can hope that due to the rapid improvements in computer technology, we are not so far from being able to produce meaningful numerical experiments that can be used for understanding stellar dynamo.

The improvements in the theory that will certainly be achieved in the coming years will be of little impact if they are not accompanied by a solid observational basis, that is needed both as a guide and as a source of constraints for the models. Typically, one needs to determine *scaling laws* describing the dependence of the dynamo process upon several basic characteristic parameters of the stars, chosen to probe various regimes of the magneto–hydrodynamics in the stellar interiors.

Unfortunately, the observational constraints that can be placed on dynamo theories are still very poor. The only star for which we have a significant knowledge concerning the surface magnetic field is the Sun. The large scale spatial structure of the solar magnetic field, and in particular the latitude of appearance of sunspots, as well as the characteristics of the solar cycle, have been often used as constraints for the dynamo models. However, the Sun alone, in spite of the luxury of details that it can offer to us on all spatial scales, represents only one point in parameter space, and will never provide us with the scaling laws that are needed to guide and constrain the dynamo models.

In this paper, we shall extend the review of Mangeney and Praderie (1983), by discussing what kind of observables are needed for providing these constraints, and how these observables can be obtained. We show that most of the needed observables can be obtained only by space–based instruments, and that a mission like PRISMA (Lemaire et al. 1991), which will observe a large sample of stars in visible photometry, in UV and XUV spectro–photometry, continuously for large intervals of time, will certainly bring decisive elements for our understanding of solar and stellar dynamos.

WHAT OBSERVABLES DO WE NEED?

The observables

In order to guide and test the dynamo theories, we need to find out if there is a relation between the output of dynamo, i.e. the characteristics of the emergent magnetic field (magnetic flux, horizontal structure of the magnetic field, cyclic behavior) on one hand, and what we think are the ingredients of the dynamo, i.e. convection and rotation, on the other hand. If such a relation exists, we must derive it as accurately as possible. In other words, we need to determine scaling laws between these two classes of observables, that must be verified by the theoretical models.

1. The output of the dynamo

First of all, scaling laws concerning the *magnetic flux* are of utmost necessity for guiding the modelling efforts. The magnetic flux indeed provides a measurement of the efficiency of the dynamo process, and its dependence upon the basic stellar parameters would yield tests of the dynamo models.

The output of all types of dynamo theories also include some prediction about the large scale magnetic field structure at the stellar surface. A success of the mean–field theory, for instance, has been to reproduce the latitude of emergence of sunspots during the solar cycle (Steenbeck and Krause 1969). Therefore, the observation of the *latitudinal distribution of active regions* in other stars, and more precisely any trend that could be observed between this distribution and the basic stellar parameters would provide a guide and a decisive test for dynamo theories.

The *north/south asymmetry* in the number of sunspots is a well–known property of solar activity, that depends on the degree of nonlinearity of the dynamo, and that can be compared to the predictions of the models (Vizoso and Ballester 1990). A useful guide would be available if we could have this type of information for a large number of stars spanning the HR diagram.

Nonlinear dynamo theories can also predict the degree of non–axisymmetry of the resulting magnetic field. The existence of *active longitudes* on the Sun is already a useful constraint, but here again, we need a systematic exploration of the stellar parameter space to derive the trends of the departures from axisymmetry with the basic characteristics of the stars (rotation, mass, differential rotation, etc...).

Finally, the *period of the activity cycle* can also be predicted by dynamo theories, as well as the evolution of the magnetic field structure and intensity along the cycle. Very useful scaling laws involving these two parameters could be obtained if they could be estimated for a large number of stars.

2. The ingredients of the dynamo

In addition to the magnetic field structure and its intensity, another class of observables are needed for allowing us to guide and test the theoretical developments: we need to determine accurately enough the basic stellar parameters that presumably control the dynamo process. The first one of these observables is *rotation*. Differential rotation indeed generates a toroidal magnetic field from a poloidal one, by stretching the magnetic field lines. Rotation and differential rotation also enter the α–effect because of their infuence on the mean helicity of the small scale motions. It is usually assumed that differential rotation $\delta\Omega/\ell$ (where ℓ is a characteristic length for the variation of rotation rate) increases with Ω (that is ℓ does not increase much with Ω). In that case, we can look for scaling laws involving Ω only. However, it would be valuable to introduce the *differential rotation* in the analysis, *both in depth and in latitude*, whenever possible. Differential rotation indeed is directly involved in the $\alpha\omega$ dynamo, and therefore could be used in the derivation of scaling laws, were we able to observe it in a large number of stars.

In recent years, the evidence that the site of solar dynamo is at the bottom of the convection zone has accumulated (e.g. Stenflo 1990). It is not clear whether the convective motions themselves are responsible for the α–effect at that location, or whether the turbulence induced by overshooting or simply by the rotational shear plays the most important role. In all cases, the depth at which the dynamo action occurs, i.e. the depth of the convection zone, has a great importance in the process. This is why introducing estimates of the *depth of the convection zone* in the scaling laws can be very fruitful as a guide for stellar dynamo models.

The traditional description of convection by the mixing length theory may not be sufficient to properly take into account the small scale motions acting to produce the poloidal magnetic field through the α–effect. Therefore, it is also very important to improve the *modelling of convective velocity fields.* Such a progress in the theory of convection also needs accompanying observational tests.

Finally, since most of the observables that are needed depend on stellar *mass and age*, it is also necessary to determine these two quantities with the highest accuracy.

The scaling laws

1. Which magnetic tracers must we choose?

Since the direct measurement of the magnetic flux is possible only in some very few particular cases (very slow rotators for the Robinson method, see e.g. Saar 1990; bright fast rotators with large scale magnetic field for the Zeeman–Doppler technique, see e.g. Donati and Semel 1990), we have to rely on well–chosen magnetic tracers. The first question is thus: which tracers are best suited for a measure of the magnetic flux? Table I presents the most commonly used magnetic activity tracers, and summarizes the various problems encountered when using them.

The presence of an important photospheric contribution for visible lines makes them inconvenient to use for determining the chromospheric flux. This well–known problem disappears at shorter wavelengths.

For optically thick lines, it is not straightforward to translate the measured flux into an emission measure, which is a useful quantity for building empirical models of the atmosphere (Judge 1990). Even though this problem may be overcome by a careful treatment of the line transfer, it is always preferable to use optically thin lines. From Table I, it can be seen that all the relevant optically thin lines are in the UV and XUV ranges.

TABLE I the magnetic tracers

layer	lines	photospheric contribution	optical thickness	basal flux	stars
chrom.	Hα	yes	thick	strong?	very active cool stars
chrom.	Ca II H & K	yes	thick	strong	F to M stars
chrom.	Mg II h & k	no	thick	strong	F to M stars
chrom.	Si II 1810 A	no	thin	weak	F to M stars
chrom.	C II 1335 A	no	thin	weak	F to M stars
t.r. + chrom.	Lyα	no	thick	??	A7 to M stars
t.r.	C IV 1550 A	no	thin	weak	F to M stars
t.r.	He II 1640 A	no	thick	??	F to M stars
t.r.	N V 1240 A	no	thin	??	F to M stars
corona	XUV lines	no	thin	weak	all spectral types

Schrijver (1987) suggested the wide existence for cool stars of a non–magnetic energy flux (e.g. an acoustic flux), superimposed on the magnetic heating, witnessed by the presence of a lower limit for the flux in the magnetic activity tracers of a large sample of cool stars. This basal flux, if present, must be subtracted if one wants to study the scaling laws concerning magnetic activity. Since the determination of this basal flux is a complicated matter, lines with weak basal fluxes will be considered as more convenient magnetic tracers. Rutten et al. (1991) have studied the basal fluxes as a function of $B-V$ color for the usual magnetic tracers listed in Table I. Their work demonstrates that UV lines (except Mg II h & k) have very low basal fluxes, and therefore must be chosen rather than visible lines.

Lines formed at coronal temperatures (in the XUV range) have a major advantage: stars all over the HR diagram (and not only cool stars) show signs of coronae (Vaiana et al. 1981), and their X–luminosity seems to follow the same type of dependence on an effective Rossby number as the cool stars (Mangeney and Praderie 1984). If we can have access to the XUV range, stars of all spectral types can be included in the analysis, and the dependence of this type of activity upon the basic stellar parameters can be studied over a very wide range of stellar properties.

In conclusion, it is clear that the access to the UV and XUV ranges provided by space experiments brings enormous advantages, and allows us to choose the best magnetic tracers.

2. How does the magnetic flux scale with stellar parameters?

A significant test of the dynamo theories would come from the answer to the question: is dynamo efficiency related to the dynamo number N_D, which is the square of the ratio between the magnetic diffusion time and the magnetic field amplification time, $N_D = (\tau_{diff}/\tau_A)^2$?

Under several assumptions on the length scales involved in the α–effect, it can be shown that N_D scales as Ro^{-2}, where Ro is the Rossby number, measuring the ratio of the inertial forces to the Coriolis forces. The initial question has thus been translated by several authors into the following one: are magnetic tracers related to Ro, and if yes, how?

Many attempts have been made to answer this question, by looking for correlations between the emission flux in some magnetic activity tracers (see Table I) and either the rotation period, or a Rossby number, calculated differently from one author to another, or even simply the age (Noyes et al. 1984; Hartmann et al. 1984; Mangeney and Praderie 1984; Simon et al. 1985; Marilli et al. 1986; Basri 1987; Rutten and Schrijver 1987). The goal of this review is not to give a detailed account of all these (sometimes discrepant) results. A fair summary of these analysis would be that they are not entirely conclusive, in that sense that they do not demonstrate clearly which parameter, if any, controls the magnetic tracer fluxes.

There are three observational requirements to fulfill in order to improve the results of this type of analysis. First, the star sample must be as large and unbiased as possible, and must cover the HRD as completely as possible. This requirement implies in particular the access to the XUV range, because it is the only wavelength domain where hot stars are "active", as mentioned above. Second, we need to choose the best magnetic tracers available, which are in the UV and XUV, as discussed in the previous section. Finally, the calibration of these tracers in terms of magnetic flux (which relies only on solar measurements) must be improved, which implies the simultaneous observation of the tracers and of the magnetic flux in a sub–sample of these stars at different masses. This effort has been initiated (e.g. Marcy 1984; Saar and Schrijver 1987), but definitely needs to be continued. Thus methods for direct measurements of the magnetic flux must be strongly developed, even if they are limited to a small number of targets.

3. How does the structure of the magnetic field scale with stellar parameters?

Both the mean–field theory, and the nonlinear dynamo theories predict that the horizontal structure of the magnetic field depends on the properties of the dynamo, and in particular on the dynamo number. Therefore, we must try to correlate our estimates of the magnetic horizontal scale with N_D. This point is very important, and basically untouched so far. This is certainly where further efforts should concentrate in the near future.

What we need to study are the relationships between the various characteristics of the horizontal large scale structure of the magnetic field and the basic stellar parameters, including mass, age, rotation period, Rossby number, etc... The horizontal large scale structure of the magnetic field can be characterized by the existence of preferential latitudes for the emergence of the toroidal magnetic field that will give an estimate of the horizontal scale of the dynamo wave, or by north/south asymmetries and active longitudes that will describe some aspects of the nonlinearity of the dynamo.

We note that the calibration of magnetic tracers is no longer a problem here, since we are not interested in the magnetic flux itself, but simply in its spatial distribution.

HOW CAN WE OBTAIN THE NEEDED OBSERVABLES?

Activity cycles

The measurement of cycle periods requires systematic observations of the same stars over very long periods of time (≥ 10 years), much longer than the typical life–time of a space mission (a couple of years). These observations must rather rely on ground–based techniques, e.g. long–term monitoring of the Ca II H & K flux, than on space–based observations. A database of cool stars with measured cycle periods already exists (Wilson 1978; Vaughan et al. 1981), and a good selection of targets for a space mission like PRISMA should include objects from this database.

Magnetic flux at stellar surface

1. Magnetic tracers

The magnetic flux in the stellar atmosphere can be derived from the emission flux of convenient magnetic tracers. We have shown that these best tracers are in the UV and XUV domains, and therefore can be obtained only from space. These are the Mg II, C II, Si II, C IV, N V, He II, Lyα lines in the UV, and the coronal lines in the XUV. The instruments on board the PRISMA mission will provide accurate measurements of fluxes in these UV and XUV lines. As mentioned above, for a good calibration of these tracers in terms of magnetic flux, some of the studied stars will have to be observed simultaneously from the ground with the Robinson or the Zeeman–Doppler techniques, depending on their rotation rate. The lines mentioned above probe different temperature regimes, and thus different layers of the stellar atmosphere. Therefore, the simultaneous measurements of these line fluxes with PRISMA will provide a tool for studying the height dependence of the magnetic energy deposition, from the base of the chromosphere up to the corona. For those stars with a simultaneous direct measurement of the photospheric magnetic flux by the Robinson or Zeeman–Doppler techniques, the situation will be ideal, since we will have a simultaneous measure of a) the magnetic flux at the stellar photosphere and b) the radiative losses in various layers above the photosphere.

2. Mean value of the activity level

For a meaningful analysis of the dependence of the tracers of magnetic energy flux upon any kind of stellar parameter, it is of course necessary to determine first a mean value of the activity level. It can be rather dangerous to restrain on observations obtained at a particular rotational phase, since we may face a very active longitude at that moment, or on the contrary a very quiet region, not representative of the real activity level of the star.

Figure I illustrates this point by showing the amplitude of rotational modulation for some typical stars, superimposed on the original plot R'_{HK} versus Ro

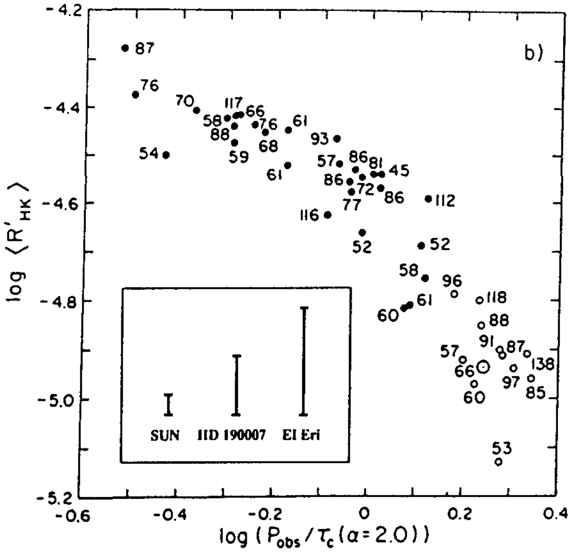

FIGURE I Amplitude of the rotational modulation for three types of stars (insert): the Sun near activity maximum, HD 190007 = active K dwarf, EI Eri = RS CVn system. The rotational modulation amplitudes are superimposed on the original plot showing the dependence of the Ca II H & K flux upon the Rossby parameter (adapted from Noyes et al. 1984)

by Noyes et al. (1984). This example shows that, without a careful averaging of the emission flux variations during the rotation (this averaging procedure was actually done in Noyes et al.'s paper), an artificial scattering of the data will appear and eventually hide possible scaling laws.

Thus, we conclude that an important requirement for the observations is a good rotational phase coverage, which implies *a monitoring of the stars on a time scale comparable to or greater than their rotation period.* Such a requirement does not necessarily imply the use of a space–based instrument, since ground–based multi–site campaigns will lead to similar results. However, the probability of success of such campaigns is rather low, and a space mission is by far the most efficient solution for obtaining a continuous coverage. The design of PRISMA makes it a perfect tool for the kind of observations described here.

Distribution of active regions, surface rotation, surface differential rotation

In the absence of spatial resolution at the stellar surface, the missing spatial information can be obtained by Doppler Imaging techniques. These methods rely on the stellar rotation that continuously modifies the aspect of the visible stellar disk, as well as the projected velocity of any given area at the stellar surface. A precise description of these methods is beyond the scope of this paper, but an excellent review on the subject can be found in Donati (these proceedings). The important point here is that they require a *good phase coverage of the stellar rotation.* Besides, since the magnetic structures can in principle grow and evolve on time scales shorter than the rotation period (this is indeed the case for the Sun), it is important that the data are obtained in a *monitoring as continuous as possible* to distinguish between rotation–induced variations and intrinsic variations of the lines.

Doppler Imaging techniques have been successfully applied for obtaining photospheric images (Vogt 1988; Piskunov et al. 1990; Strassmeier et al. 1991, Donati et al. 1992, Jankov and Foing 1992). These photospheric images have been obtained for extremely active stars only, for which the photospheric magnetic field appears to be on very large scales. On the other hand, in order to derive scaling laws concerning the horizontal structure of the magnetic field, we need to observe a sample of stars including moderately active stars in addition to very active stars. If we assume that the structure of the magnetic field in single moderately active stars looks like that of the Sun, then we expect that the magnetic field will be structured on small spatial scales at the photosphere (spots), whereas the scales at the level of the chromosphere, the transition region and the corona will be much larger. Figure II illustrates this point by showing two simultaneous images of the Sun, one at the photosphere (K1) and the other at the chromosphere (K3). Clearly, the small scale photospheric structures would be impossible to detect by Doppler Imaging, which provides only a coarse resolution of the stellar surface, while the large scale structures of the chromospheric image would be easily mapped by this technique, if the Sun was a faster rotator. The situation is even better in the transition region, where the active regions appear on larger scales. Therefore, the study of the magnetic field structure in single, moderately active stars will be possible only through chromospheric or transition region imaging. Since most of the convenient lines are in the UV, it is necessary to use a UV space mission providing a sufficient spectral resolution, and having the capability to monitor continuously its targets for long intervals of time, like PRISMA.

Chromospheric or transition region imaging has been limited so far to very simple analysis: recognizing and tracking emission components in line profiles (Gondoin 1986), or multi–Gaussian fitting (Neff et al. 1989). However, provided the S/N and resolving power are sufficiently high, more sophisticated Doppler Imaging methods, similar to those used for photospheric Doppler Imaging, can be applied to chromospheric and transition region data. Time–resolved, high spectral resolution, moderate– to high–S/N ratio data strings of chromospheric and transition region lines could be translated into ab–initio images of these layers. Simulations of such image reconstructions are under way, and preliminary results suggest that spectra with $R \approx 30000$ and S/N ratios of the order of 30–50 can yield useful chromospheric images of moderately active stars rotating with a period of 3–10 days (Donati and Catala, in preparation).

In particular, a very useful information that can be derived from such images is the presence or absence of preferential latitudes for the activity, easier to obtain for the active regions at chromospheric and transition region levels than for photospheric spots. This information is directly related to the large scale structure of the toroidal magnetic field (as are the latitudes of appearance of sunspots), and can provide strong constraints on the dynamo models, as discussed earlier.

The detection of north/south asymmetries may be more problematic: when a star is seen from a direction in its equatorial plane, Doppler Imaging cannot solve the north/south ambiguity; when it is seen from a direction near one pole,

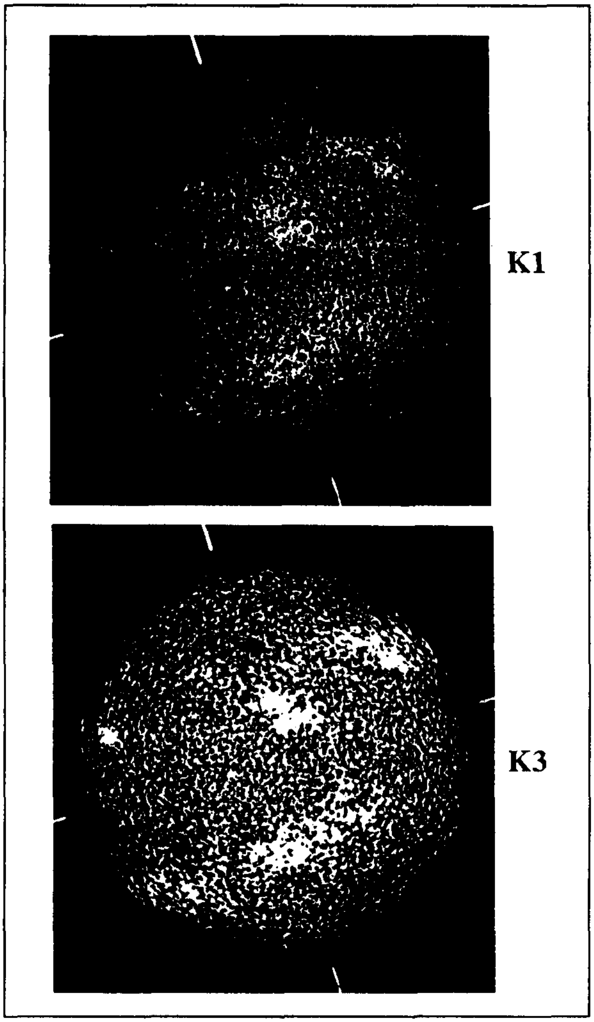

FIGURE II Quasi-simultaneous images of the Sun at photospheric (K1) and chromospheric (K3) levels, obtained with the Meudon Observatory spectroheliograph. Note the difference in the spatial scales of the magnetic structures between the photosphere and the chromosphere.

the other hemisphere is invisible. However, in some favorable cases, e.g. if the viewing angle is intermediate, and if the active regions are restricted to low latitudes (which is the case for the Sun), then the presence of a strong north/south asymmetry in the distribution of active regions can be detectable. Such observations could be used in replacement of the asymmetry of the number of starspots to constrain the nonlinearity of the dynamo.

Doppler images can also reveal the presence of active longitudes, if they are very prominent. In fact, the departures from axisymmetry are more easily detectable than latitudinal distribution of active regions. It is well–known indeed that the uncertainties in the Doppler image reconstruction are always more important in latitude than in longitude.

A by–product of the monitoring of UV and XUV lines is a confirmation of the surface rotation period, that can be obtained from the ground in principle (by Ca II H & K or photometric modulation). If the departures from axisymmetry are strong enough, the UV and XUV lines show a rotational modulation, and the rotation period can be obtained simply by a Fourier analysis of line–flux time series. Also, since starspots modulate the light curve with the rotation period, high precision photometric monitoring from space can also yield a precise measurement of the rotation period, if the star can be monitored for several rotation cycles. Thus, rotation periods can be measured for stars for which the rotational modulation amplitude is too low to be observed from the ground.

Finally, if chromospheric Doppler images corresponding to several successive rotation cycles can be obtained, surface differential rotation can be measured. Such a method has already been successfully applied to photospheric images of the RS CVn system UX Ari (Vogt and Hatzes 1990). The surface differential rotation can be useful in two different ways as a test of dynamo theories. First, we can assume that the surface latitudinal differential rotation prevades throughout the convection zone, as in the Sun, and therefore constrain its value at the base of the convection zone, presumably the site of the dynamo. Second, the mechanism by which the latitudinal differential rotation is maintained probably implies some feedback of the dynamo–generated magnetic field, and is not understood. Obtaining a significant number of measurements of this phenomenon for different types of stars spanning the HR diagram would provide a very useful guide to understand this problem.

Mass and age

These two basic parameters must be determined with a high accuracy, in order to analyze the evolution of active phenomena in time for different masses. The traditional methods for deriving them rely on stellar evolution models. For single main sequence stars, the mass is determined from the location in the HR diagram. The estimate of the age poses a more serious problem. Reliable estimates of stellar ages can be obtained only for members of open clusters. For field stars before and after the main sequence, theoretical evolutionary tracks can be used, but are not necessarily reliable enough to provide meaningful ages. On the main sequence, the situation is even worse, and age estimates for field stars must rely on measurements of surface Lithium abundances and basically untested theory of turbulent transport in radiative interiors.

As widely discussed in these proceedings, a major breakthrough is to be expected from space-based asteroseismological techniques. In particular, the measurements of low-degree p-modes frequencies and separations will provide very accurate estimates of mass and age of all types of stars, by examining their location in the asteroseismological HR diagram. The resulting gain in accuracy and reliability of mass and age determinations will have a tremendous impact on the analysis of stellar activity.

Modelling of convection

We have already insisted on the major role played by convective velocity fields. The description by the mixing length theory seriously limits the progress of $\alpha\omega$ dynamo theories. Asteroseismological observations will probably allow us to improve our modelling of convection well beyond the mixing length theory, and thus to introduce better descriptions of the convective velocity fieds into the dynamo theories.

Internal differential rotation

The rotational splittings of low-degree p-modes, which in principle can be measured for stars that rotate fast enough, can provide us with a crude estimate of the internal differential rotation. The rotational splittings of a given mode can indeed be written as

$$2\pi\Delta\nu_{n\ell m} = -m\int_0^R \Omega(r)K_{n\ell}(r)r^2dr$$

where $K_{n\ell}(r)$ is the rotational kernel, a function of the mode amplitudes depending only on n and ℓ. Thus, the quantity $2\pi\Delta\nu_{n\ell m}/m$ corresponds to the average of the internal rotation rate $\Omega(r)$, weighted with the normalized function $r^2K_{n\ell}(r)$. Although this function tends to favor the regions near the stellar surface, the contribution of the central regions to the rotational splittings can be significant if the rotation rate near the center is several times higher than the surface rotation rate. In these cases, the comparison between the surface rotation rate $\Omega_{\rm surf}$ and the rotational splittings can tell us how different from $\Omega_{\rm surf}$ the internal rotation rate can be, unfortunately without giving us more details about $\Omega(r)$. Although rather crude, this procedure can allow a comparison of the amount of differential rotation in different types of stars (e.g. young versus old stars; convective versus radiative stars, etc...).

Depth of the convection zone

The frequencies of low-degree p-modes can also yield an estimate of the depth of the convection zone. This estimate can perhaps be obtained directly through inversion techniques, but this requires extremely accurate measurements of the frequencies which may or may not be possible.

On the other hand, asteroseismology will necessarily lead to decisive improvements in stellar structure modelling, and the depth of the convection zone will thus be determined rather reliably through modelling in all cases.

SUMMARY AND CONCLUSION

In this review, we have shown that dynamo theories need meaningful observational guides and tests, in particular scaling laws followed by the characteristics of the magnetic field, which include the magnetic flux and the horizontal large scale structure of the magnetic field.

The major requirements for obtaining these scaling laws are *the use of UV and XUV spectroscopy and spectrophotometry, the continuous monitoring of targets over one or several rotation periods*, and the possibility to obtain *asteroseismological measurements.* This demonstrates the need for space–based instruments, dedicated to this type of observations. A mission like PRISMA, whose goal is precisely to provide a continuous monitoring of a large sample of stars, in high precision visible photometry, and in UV spectroscopy and spectrophotometry, is extremely well suited for these purposes, and is therefore expected to bring a major breakthrough in our study of stellar magnetic activity.

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