STELLAR ACTIVITY CYCLES

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ABSTRACT. The main features of solar and stellar activity cycles are
summarized, followed by a discussion of some outstanding observational
problems for the future.

1.   SOLAR ACTIVITY CYCLES

1.1. What has been observed?

The classical indicators for the solar activity cycle are the sunspot
number and the magnetic field polarity, which vary with the well-known
periods of 11 and 22 years, respectively. However, also many other
parameters vary during the solar cycle, e.g.

        Corona: Solar wind velocity
                         Coronal density structure
                         X-ray bright points

        Chromosphere: Ultraviolet and radio fluxes
                         Emission and absorption lines
                         Flare frequency

        Photosphere: Magnetic field patterns
                         Granulation structure
                         Spectral irradiance?

        Deeper layers: Temperature gradient changes?
                         Torsional oscillations?
                         P-mode oscillation frequencies?

The observational difficulties often increase as one goes to deeper
layers in the Sun. Solar-cycle variations in the shape of the corona
seen at total eclipses can be watched with the unaided eye; chromospheric
activity changes can be followed with a modest telescope, but more
powerful spectroscopic or imaging instrumentation is required to reveal

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photospheric changes and a convincing detection of variations in the
solar interior may require great sophistication in the observations and
in their interpretation. At the same time, the more fundamental
mechanisms behind solar activity are likely to be found in the deeper
layers.

   Although all the parameters listed probably vary with an 11 or 22
year period, it is important to note that many of them are definitely
not in phase with one another or with the sunspot number indicator.

   As examples of indicators that seem to be completely out of phase,
we note in the photosphere the number density of facular bright points
(presumably associated with magnetic field concentrations), which have
a minimum at sunspot number maximum (Muller and Roudier, 1984). In the
chromosphere, the same seems to hold for the D_3 emission seen at total
eclipses (Gulyaev, 1975), and in the corona for the density of X-ray
bright points (Golub et al., 1979). Chromospheric Ca II H & K emission
and He I λ 1083 nm absorption indicators are phaseshifted by some year
relative to the sunspot number cycle. There exist further varying
parameters related to sunspots besides their number, e.g. the umbral
brightness. An overview of solar cycle properties is by Newkirk and
Frazier (1982).

   Perhaps one could compare the solar activity cycle to that of a
blossoming apple garden. This garden will have its general 12-month
activity cycle, but the activity maxima for the leaves, the flowers, and
the fruits will definitely be out of phase with respect to one another.
A challenge for an observer would be to understand the fundamental 12-
-month cycle from limited observations of the variation in the number of
leaves, of the brightness of flowers or the flavor of the fruits.

1.2. Outstanding Observational Problems

A number of fundamental observational problems can be identified, for
example:

1.2.1. Magnetic flux variation during the solar cycle? The amount of
magnetic flux emerging through the solar photosphere is an awkward
quantity to measure. The reason is that the spectral line polarization
signal being measured by solar magnetographs depends in a complex manner
upon the detailed surface distributions of magnetic flux densities, and
their correlations with temperature inhomogeneities. Further, the
apparent net flux in regions with intermingled polarities also very much
depends on telescope resolution and atmospheric seeing. It has even
been suggested that the solar cycle might be characterized as an
oscillation in magnetic wavenumber space, with little variation in the
average total amount of emerging flux (Golub et al., 1979).

1.2.2. Changes in the deeper layers and in the convection zone? Solar
seismology has now measured p-mode oscillation eigenfrequencies during
a sizable fraction of an 11-year cycle, and secular changes in these
oscillations are suggested (Woodard and Noyes, 1986). One could perhaps
suspect that some process in a magnetic dynamo would, during some phase
of the cycle, lead to an increased amount of magnetic fluxtubes in the

upper convection zone, and thus to an additional source of pressure
support for the solar mantle, which should affect the oscillation
frequencies being measured.

1.2.3. Activity in the ancient Sun and stability of the cycle period?
Past activity of the Sun can be studied through proxy indicators such as
the ^{14}C radiocarbon abundance in samples with known age. However,
following its production by cosmic rays in the upper atmosphere, ^{14}C is
stored in the atmosphere and in the oceans for some decade before being
absorbed by e.g. a tree, and thus the 11-year cycle is washed out in ^{14}C
data. In principle, there exist other radionuclides such as ^{10}Be (half-
-life $2 \cdot 10^6$ y) that might allow one to follow the year-by-year activity
variations back over millions of years (e.g. Pepin et al., 1980).
     Geological deposits of glacial sediments have been found that show
an 11-year variation in the deposit thickness, and this variation has
been suggested to be of solar origin, via a terrestrial climate response
(Williams, 1981). If this suggestion of a solar origin is correct, this
could be evidence for the stability of the 11-year period over $\approx 10^9$ years
(although the activity *level* may have varied considerably). To evaluate
the plausibility of such climate modifications, it would be of great
interest to measure the irradiance variations over at least the present
11- and 22-year cycles. Astronomical data have been searched for periods
other than these, but the limited timespan of historical observations
does not really lend support for the significance of other cycle periods.
     Some hint of the *future* Sun might be obtained through studies of
stars that are near solar-twins, only correspondingly older. Such an
ongoing study of an old G2 subgiant (Dravins et al., 1983) shows the
activity level lower than solar, and an indication of variations that
cannot exclude a cycle around 11 years.

2. STELLAR ACTIVITY CYCLES

2.1. What has been observed?

The current great interest for stellar activity cycles is to no small
part due to Olin Wilson´s extensive series of observations of Ca II K
chromospheric fluxes from cool main-sequence stars (Wilson, 1978; Wilson
et al., 1981). Evidence of cyclic activity now exists for several
classes of stars:

2.1.1. Ordinary stars: chromospheric activity cycles. A large number of
late-type main-sequence stars have now been monitored for some 20 years,
and a fair number of activity cycles have been identified, the shortest
of about 3 years. There seems to be no obvious correlation between the
cycle period and other primary stellar parameters. What is being measured
is the photometric flux in a narrow band around Ca II K line center,
normalized to the stellar continuum. For the Sun, such an activity index
mainly gives a measure of the active region plage area coverage and
brightness. Besides the identification of activity changes over several
years, the rotational modulation of the Ca II K emission can be seen in

several cases. This modulation must originate from stellar active
regions rotating into and out from the visible stellar disk. A very
intriguing suggestion of changes in this rotational period over some
years has been seen, possibly a measure of the stellar differential
rotation with latitude. In analogy with the solar case, the preferred
latitude of stellar activity might be drifting with phase in the activity
cycle. A well-written review of the results from these programs, carried
out mainly at the Mt.Wilson Observatory, is by Baliunas and Vaughan
(1985).

2.1.2. Spotted stars: irradiance cycles. Large and cool starspots are
known to exist on some evolved and active stars in some binary systems,
in particular those of the RS CVn and BY Dra types. From photographic
plate collections, it has been possible to follow the brightness of some
of these for almost a century, giving evidence to stellar irradiance
cycles with periods up to perhaps 60 years (Hartmann et al., 1981). In
eclipsing binaries of these types, a photometric 'wave' can sometimes
be seen when the starspots (marking stellar rotation) lead or lag the
geometrical stellar eclipse. Such behavior seems consistent with
differential rotation with latitude in spot cycles with deduced periods
in the range 4 - 10 years. A discussion of spotted stars is included in
the reviews by Paternò (1983) and Baliunas and Vaughan (1985).

     Also more ordinary high-activity stars possess irradiance variations
due to the apparent presence of dark spots that seem to correlate with
bright chromospheric emission lines, indicating that starspots and
stellar active regions are nearly cospatial (Blanco et al., 1979; Radick
et al., 1983).

2.1.3. Flare stars: flare frequency cycles? The strong variability of
many very late-type dwarfs, together with their photometric faintness,
makes the monitoring of chromospheric emission lines rather difficult in
searches for activity cycles. Pettersen et al. (1986) instead collected
a substantial amount of high-speed U-band photometry for the flare star
AD Leo (dM4e) spanning 14 years. Supposing that the data are complete
for all stronger flares, their frequency of occurence was studied as a
function of time, and some (marginal?) evidence for an 8-year cycle
found. Irrespective of the reality of the cycle in AD Leo, these types
of studies are very promising for the search of possible cyclic activity
in very late-type stars which might be convective throughout. For the
modeling of possible activity cycles in such stars, several of the
standard magnetic dynamo theories will not be applicable.

2.2. Outstanding Observational Problems

2.2.1. Magnetic cycles in ordinary stars? Although the term 'magnetic'
is sometimes loosely being used to describe stellar chromospheric activity,
it should be remembered that (with the exception of periodic phenomena in
Ap and other magnetic stars) no stellar magnetic cycles have yet been
identified. Since the magnetic field is believed to be a fundamental
parameter underlying most stellar activity, such observations would
obviously be of considerable interest. One possible way could be to

search for circular polarization reversals in stellar microwave radio
bursts, as has been tried by Gibson (1984). If, in analogy with the Sun,
the two polarity areas in stellar active regions are not symmetric, and
one of them has a more spread-out magnetic field, the result must be that
e.g. the gyroresonance opacity will make the radio source optically thick
at different atmospheric heights above the two different polarities.
Since the measured polarization depends on the ratio of effective emission
areas for each magnetic polarity, reversals in a magnetic cycle should
show up as circular polarization reversals in microwave emission. (This
is essentially the inverse of the problem discussed in Section 1.2.1. -
the discrepancy between a magnetic polarization signal and the true
stellar magnetic flux.)

2.2.2. Cyclic activity in ordinary evolved stars? Most studies so far
have been made for either main-sequence stars or for special evolved stars
in close binary systems. Among the original main-sequence stars in
Wilson's early survey, improved spectral data has now reclassified some
as giants, for which there thus are long time-sequences available. There
is an example of a G2 III star with an apparently cyclic behavior, not
much different from other dwarf stars (Baliunas and Vaughan, 1985). The
He I λ 1083 nm absorption line in Capella (G5 III + G0 III) may vary on a
timescale of $\simeq$ 10 years (Katsova and Shcherbakov, 1983), but in neither
case the evolutionary state of the star is very well understood. It would
obviously be of great interest for the understanding of the fundamental
activity mechanisms, if the cyclic activity of a typical star could be
followed along the stellar evolutionary path from the main sequence to
the giant stage. Possibly, the (unfortunately faint) stars in some
evolved galactic clusters could be suitable objects for such a study.

2.2.3. Starspot imaging throughout an activity cycle. One of the awaited
breakthroughs in stellar astrophysics during the next decades is the
direct imaging of stellar surfaces, enabled by the advent of very large
telescopes and long-baseline interferometers. Such imaging in either the
spectral continuum or in chromospheric emission lines should reveal the
size, shape and location of active regions on the stellar disk. The
monitoring of these with time should allow the study of their development
and decay and reveal the presence (if any) of differential rotation or of
latitude drifts of the activity zone. Awaiting such interferometers,
spectroscopic methods allow a certain reconstruction of starspot images
for at least spotted stars with moderately rapid rotation, as demonstrated
in the Doppler imaging by e.g. Vogt and Penrod (1983). Ultimately,
stellar surface imaging (and spatially resolved stellar spectroscopy) will
be required to gain a more realistic appraisal of stellar activity and
stellar surface structure. Quite possibly, our present understanding of
stellar surface features may be equally naive as was the understanding of
planetary system objects before the revelation of their surfaces by
spacecraft.

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