JOINT DISCUSSIONS

https://doi.org/10.1017/S1539299600004998 Published online by Cambridge University Press

JOINT DISCUSSION NO. 1

SOLAR LUMINOSITY VARIATIONS

(Commissions 10, 27 and 35)

Organizing Committee:

J.A. Eddy (Chairman), P.V. Foukal,
D.O. Gough, G.A. Newkirk and G.W. Lockwood

https://doi.org/10.1017/S1539299600004998 Published online by Cambridge University Press

CONTENTS

JOINT DISCUSSION NO. 1

SOLAR LUMINOSITY VARIATIONS

https://doi.org/10.1017/S1539299600004998 Published online by Cambridge University Press

A SUMMARY OF THE JOINT DISCUSSION AT PATRAS ON SOLAR LUMINOSITY VARIATIONS

Summarized by J. Eddy and P. Foukal, of the Organizing Committee

The most interesting result in solar luminosity studies in the past decade has been the detection of significant variations in the total irradiance by precision radiometers on the NIMBUS-7 and SMM spacecraft. A substantial fraction of the observed variation can be attributed to sunspot blocking. Thermal storage models indicate that the blocked flux can be stored in a slight increase of the thermal and potential energy of the convective zone. The thermal storage time is likely to far exceed one solar activity cycle, implying an 11-year modulation of the solar constant at a level of about 0.1%. Direct observations of the 11-year or longer variations are more difficult but there is some evidence for secular trends below about 0.4% amplitude over the 14-year period of modern sampling. Ongoing stellar photometric programs suggest that luminosity changes exceeding 1% may have been detected in young, chromospherically active stars.

H. S. Hudson (University of California, San Diego) reviewed observations of short-term solar irradiance variations from spacecraft, commenting principally on the precision measurements of the solar constant (S) made by the Active Cavity Radiometer (ACRIM) on the Solar Maximum Mission (SMM) spacecraft (Willson et al., 1981). The ACRIM commenced observations in near-earth orbit in February of 1980, with a demonstrated sensitivity of 1.5 x 10^{-5} per 96 minute orbit, a stability against drift of better than 10^{-6} per month, and a time resolution of 1.5 seconds. The instrument operated for nine months in this optimum mode; it is still operational although since November 1980 failure of the spacecraft solar pointing has degraded the data. A longer time base of measurements of S has been compiled on a continuous basis since autumn 1978 with the Nimbus-7 radiometer (Hickey et al., 1980); these data, though of slightly poorer resolution, confirm in general the principal findings of the SMM ACRIM.

The SMM and Nimbus radiometers have established the presence of temporal dips of 0.1 to 0.3% in the measured solar constant that are the clear result of the blockage of radiation by large sunspots and

Richard M. West (ed.), Highlights of Astronomy, Vol. 6, 79–94.

https://doi.org/10.1017/S1539299600004998 Published online by Cambridge University Press

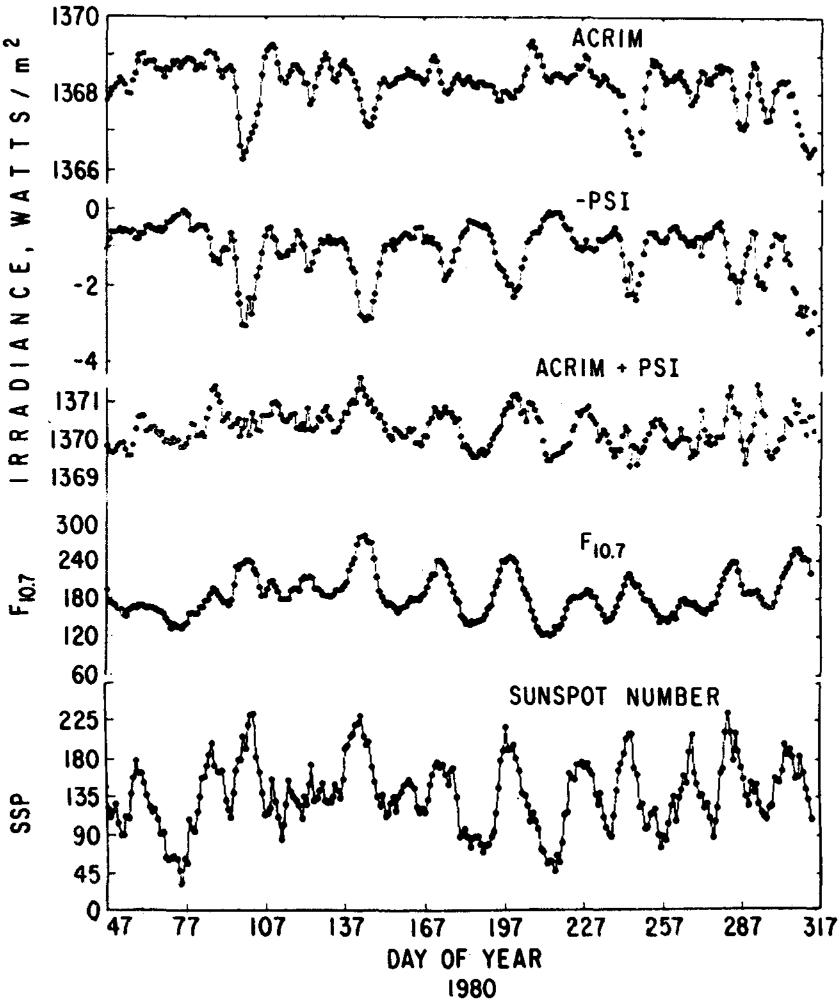

Figure 1: Daily means of solar irradiance from ACRIM (top line); solar irradiance variation (-PSI) calculated assuming sunspot blocking proportional to projected area and photometric contrast (second line); and difference (ACRIM + PSI) on the third line. The bottom lines show respectively the 10.7 cm flux and Zurich spot number. The ACRIM data have a clear tendency toward dips, which correspond (according to the PSI prediction) to the passage of large sunspot groups across the central meridian.

sunspot groups (Figure 1). These features are successfully replicated by models that invoke canonical values of umbral and penumbral contrast and the simple change of projected sunspot area due to solar rotation (Willson et al., 1981; Foukal et al., 1977). Observed sunspot areas explain only about half of the significant excursions in the ACRIM record; there is at least qualitative evidence that photospheric faculae make a positive contribution (Hudson and Willson, 1981). There is no analysis yet of the effect on S of the solar active network. Nor is there any obvious association with solar flare occurrence.

It is possible to confuse a re-direction of solar irradiance (such as is known to be caused by faculae) with intrinsic luminosity variations. But analysis of the ACRIM data does not indicate a "detailed balance" in total solar irradiance between sunspot blocking and any potential source (e.g., sunspot bright rings) of increased emission that might tend to cancel the spot effect, when integrated globally (Hudson et al., 1982). Thus, the precision measurements of S from spacecraft enable us to study the storage of energy over time scales at least as long as the lifetimes of surface active regions--i.e., for months or more. The precision measurements of S also show that p-mode, global oscillations of the sun can be detected as a high-frequency 5-minute modulation of S.

Almost certain to benefit from these new data are studies of the nature of convection in stars, studies of stellar interior structure and evolution, and the practical issue of the effect of solar variations on the Earth's atmosphere.

P. Foukal (Atmospheric and Environmental Research, Inc., Cambridge) reviewed the physical interpretation of the solar irradiance variations. The principal characteristics that constrain a mechanism for the spot-induced variations in S are; i) their amplitude $\Delta S/S \sim 0.2\%$, ii) their shape (which approximates the time profile of projected area of spots on the disc), iii) their duration $\tau_S \geq 10$ days, iv) the total flux deficit $\sim 10^{36}$ ergs in a given dip, and v) the relative phase between the observed changes in spot area and in S.

Changes in S do not necessarily imply variations in solar luminosity $L_{\odot}$. But a mechanism that would exactly compensate the observed dips is hard to identify. For instance, the flux deficit $\Delta S/S \sim 0.2\%$ is roughly 20 times larger than the total solar uv flux at $\lambda \lesssim 0.18\mu$, below which the absorptance of the radiometer black is not well characterized. As another example, the sunspot flux deficit roughly approximates the global energy loss rate from the chromosphere, corona and solar wind. But here it is difficult to envision how a decrease in the local thermal radiation from a spot could be rapidly translated into a corresponding increase in the global non-thermal losses from the sun.

Magnetic faculae are often associated with spot groups, and they are known to radiate more intensely than the mean photosphere, at large angles from the local normal. But their average lifetimes are much longer than those of spots, and their time coincidence with spots is also far from perfect. Thus we infer that while some energy transfer between spots and faculae cannot be ruled out, the dips in S require storage of roughly 10^{36} ergs over at least several months.

The storage mechanism is unlikely to be found in the work done in intensification of the spot magnetic field itself. Even under the most favorable circumstances, such storage of 10^{36} ergs in magnetic energy $B^2/8\pi$ for $B \sim 4 \times 10^3$ g would require a spot depth exceeding the solar radius.

A more promising mechanism is storage in a small increase of thermal and potential energy of the convection zone outside the spot. We may imagine that radiation from the photosphere is initially in equilibrium with the total (constant) heat flux Φ from the solar interior into the convection zone. At $t = 0$ a small fraction of the photospheric radiating area is blocked by a spot. A new equilibrium will be achieved after some time τ, when the photosphere has heated up (and expanded) slightly, so that the total radiative flux in the presence of the spot is again in balance with Φ. Over the time scale τ, the solar luminosity will be depressed below its initial value. For $t \ll \tau$ this factor can be shown to be proportional to the bolometric contrast and projected area of the blocking sunspots.

Such thermal storage of the blocked heat can be investigated quantitatively by adopting a model describing time-dependent heat flow in the convection zone. Several independent analyses based on the diffusion approximation, and using mixing length estimates of the eddy heat conductivity K, indicate that the storage time is very long, of order at least 10^3 years (Foukal, 1981; Foukal et al., 1982; Spruit, 1981, 1982a,b). This time approximates the radiative relaxation time scale of the convection zone. It far exceeds the diffusion time scale for heat throughout the convection zone of depth D, which is of order 1 year.

This result is insensitive to reasonable uncertainties in spot depth, geometry or internal dynamics. It depends mainly on the sharp inward increase of K predicted by all mixing length models of the solar convection zone. The analysis also assumes the conventional view that spot darkness is mainly a result of blocking of convective heat flux (Biermann, 1941). It would have to be re-examined if conversion of convective heat flux to non-thermal energy such as Alfven waves (Parker, 1974) were found to play a substantial role in spot thermodynamics.

The variations induced specifically by spots afford the best opportunity to confront theoretical mechanisms of changes in $L_\odot$ with a clear observational result. However, changes in sunspot area are unlikely to be the only mechanism for variation in $L_\odot$. Others that have been suggested include i) variations in the potential energy of the convection zone by changes in the pressure contributed by submerged magnetic flux tubes near the photosphere (Dearborn and Blake, 1982), ii) changing magnetic pressure influences on the superadiabatic gradient in the deep convection zone (Spiegel and Weiss, 1980), iii) stochastic rearrangements of potential, thermal and kinetic energy in non-axisymmetric large-scale convection (Gilman, 1978) and iv) changes in the area of faculae (Foukal and Vernazza, 1979; Hudson and Willson, 1981; Oster et al., 1982). The latter may influence S and $L_\odot$ in several different ways; through their chromospheric uv emission, through their anisotropic radiation field, and also (since they appear to be slender sunspots) through their thermal blocking as discussed above.

Several main conclusions emerge so far from efforts to physically understand the observed variations in S. The first is that the missing flux of 10^{36} ergs in a typical sunspot associated dip of S can easily be stored over time scales far exceeding the observed $\tau_S \sim 10$ d, in small increases of the thermal and potential energy of the convection zone. This provides some justification for believing that observed changes in S are likely to represent changes in $L_\odot$.

The models of thermal storage also indicate that the drop in $L_\odot$ and in S caused by spots near solar activity maximum will only be very slowly released over a time scale far exceeding the solar cycle. This implies that the 11-year variation of sunspot area should produce a modulation of S that can be calculated to the precision that we know the history of sunspot areas and their bolometric contrast. The amplitude of this modulation is discussed in the review by J. Eddy below.

Analysis of the luminosity variation induced by spots may also yield some useful insights into the depth of spots and the heat diffusivity of solar convection. This can be obtained through analysis of the phase difference between changes in S and in the true (not projected) area of spots at the photosphere. This phase difference depends (in the context of the thermal blocking model) on the spot depth and the rates of rise of magnetic fields and heat near the photosphere.

J. A. Eddy (High Altitude Observatory, Boulder) described a 108-year historical reconstruction of short-term solar constant variations and the climatic implications of these changes. The HAO atlas (Hoyt and Eddy, 1982) reconstructs daily values of the solar constant for the period 1874-1981 based on observed values of sunspot and facular areas, chiefly from the Royal Greenwich Observatory. The model used (see e.g., Hudson and Willson, 1981; Foukal, 1981) employs average contrast values for umbrae, penumbrae, and faculae and a standard limb-darkening formula. It is chosen for an optimum fit to the 1980 template period of best SMM/ACRIM observations. The best fit is obtained when storage times of at least six months are assumed and when the dominant modulation is taken to be the negative blocking by sunspots (see Figure 2).

The successful fit of the model to the ACRIM data lends confidence to the 108-year historical extrapolation. However, the reconstruction accounts only for the known, short-term effects of solar activity; the presence of other possible trends in S could introduce effects of equal or greater importance. The greatest effect of sunspot blocking was reached in 1957, with depletions of slightly more than 0.3% lasting several weeks. The averaged solar constant in that year, by the model,

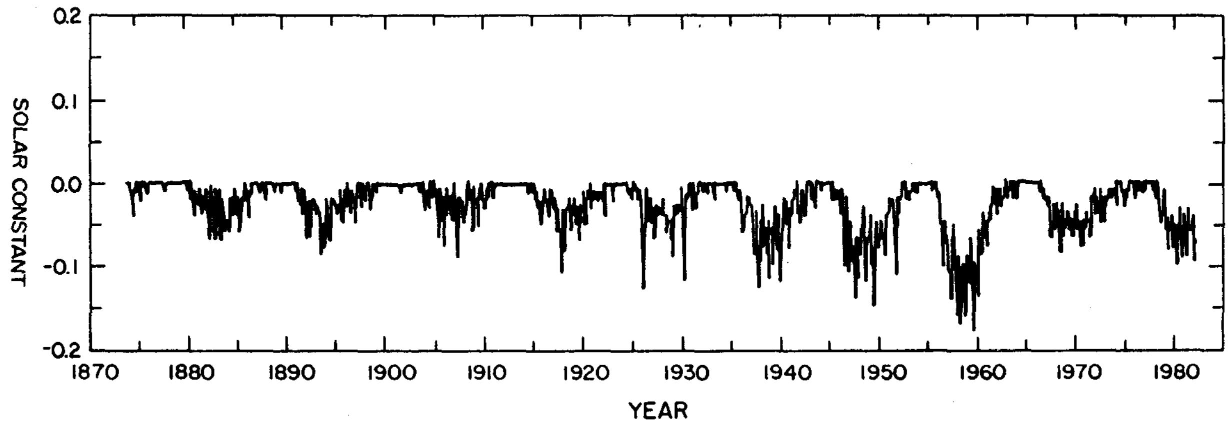

Figure 2: Plot of the calculated monthly mean variations in solar luminosity in percent deviation from a quiet sun for 1874 to 1981 for a time constant of storage (thermal relaxation) of 10 years for blocked solar energy.

https://doi.org/10.1017/S1539299600004998 Published online by Cambridge University Press

was depressed 0.12% below the level of an unspotted sun.

A consequence of the 11-year activity cycle on the reconstruction of S is a modulation of the same period, with S depressed about 0.1% in years of maximum solar activity. This in turn should produce, in simple climate models, an 11-year modulation in surface temperature, with temperatures depressed in continental regions by about 0.1° to 0.2° C in years of maximum activity. However, in other, maritime areas the effect will be damped by the 5-10 year thermal inertia of the oceans. It may be significant that precisely this effect has been found in 80 years of North American surface temperature data by Currie (1981). If this is a victory for so-called sunweather relationships, however, it is an academic one, because of the small amplitude of the effect (Eddy, Gilliland, and Hoyt, 1982).

C. Fröhlich (World Radiation Centre, Davos) reviewed measurements of the solar constant made from above the atmosphere in the 15-year period since 1967. For quantitative comparisons it was necessary in several cases to correct for differences in the standard calibrations used, for estimated residual atmospheric transmission, and for unspecified instrumental effects. Included in Fröhlich's review were balloon measurements by Kondratyev and Nikolsky (1970, 1979), X-15 rocket aircraft measurements by Drummond et al. (1967), balloon measurements by Murcray et al. (1969); Kosters and Murcray (1979); Mariner 6 and 7 spacecraft measurements by Plamondon (1970); balloon measurements by Brusa (1982); rocket measurements by Willson (1981); Nimbus 6 and 7 spacecraft data by Hickey et al. (1981) and SMM spacecraft data by Willson (1981).

When the solar constant determinations in the period 1967-1980 are corrected and put on a common scale, Fröhlich finds that measurements made in the earlier epoch (1967-1971) cluster about a lower mean value than those in the later (1976-1980) interval. A least squares fit to all the 1967-1980 data (14 measurements) shows an apparent increase in the solar constant of 0.024% per year. This result would seem to support the previously-published report by Kosters and Murcray (1979) of an increase in S of 0.38% between 1968 and 1978, based on balloon measurements in those years.

In contrast, when Fröhlich summarizes the more precise and more continuous spacecraft data in the 1975-1981 period from Nimbus 6, Nimbus 7 and SMM (Figure 3) there is a clear indication of a slight decrease in S. The Nimbus 7 data between late 1978 and 1981 are best fit as decreasing at the rate of 0.02% per year, the same magnitude but opposite in sign to the apparent increase in the earlier 14 years of collected data. The SMM ACRIM data suggest a steeper downward slope of 0.06% per year over an 18-month period.

The apparent increase between 1967-1980, if real, is clearly unrelated to the 11-year cycle of surface activity. The decrease after 1978 which seems more reliably determined, could be an accumulated

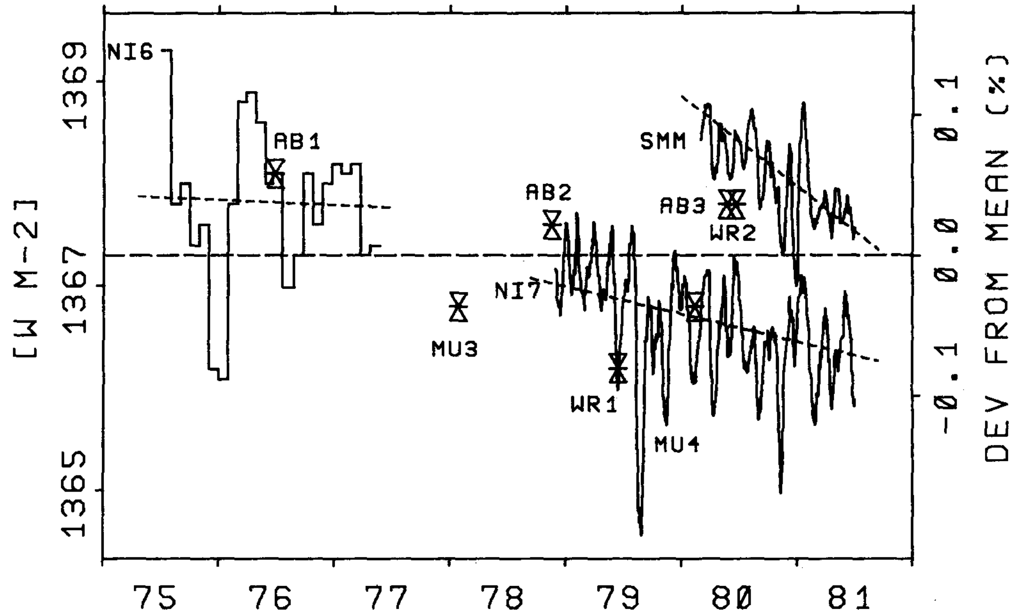

Figure 3: Summary of Solar Constant Determination from 1975 to 1981. For AB see; Willson (1981), MU; Kosters et al. (1981), WR; Brusa (1982). The data labeled NI6, NI7 and SMM are from the following satellite experiments: NIMBUS 6 and 7 Earth Radiation Budget (Hickey et al., 1982) and Solar Maximum Mission ACRIM experiment (Willson, 1981). The NIMBUS data are scaled to coincide with the rocket results AB1 and AB2 during the corresponding day. NI6 data are plotted as 30 day means, NI7 data as 20 day running means. SMM data are given as published by Willson (1981). The indicated slopes are the results of least square fits.

manifestation of sunspot blocking and hence related to the solar activity cycle. While sunspot numbers rose to a maximum in late 1979, leveled off and subsequently fell, the projected sunspot area continued to increase during the same time span. Continued precision measurements of S from space in the coming years should clarify the reality and perhaps the cause of these apparent secular trends in S.

The theory of evolutionary changes in solar luminosity was reviewed by J. Christensen-Dalsgaard (High Altitude Observatory, Boulder). Evolutionary models of the sun predict that at the time the sun settled down on the main sequence the solar luminosity was about 30 percent smaller than at present. This is probably one of the most robust predictions of stellar evolution theory. Provided the sun derives most of its luminosity from the transmutation of hydrogen into helium, there is a gradual increase in the mean molecular weight in the interior.

Because of the weight of the overlying material this forces the core to contract, and as a result the central pressure, density and temperature increase. This has two closely related effects: the increase in density causes an increase in the amount of energy generated by nuclear reactions, and the increase in temperature and density increase the conductivity, and hence the outward flow of energy. To preserve thermal equilibrium the increase in the rate of energy generation and the increase in the energy flow must be in balance, and this determines the detailed reaction of the core to the change in composition. The net effect, however, is clearly to increase the total amount of energy generated, and hence the luminosity of the sun.

Thus the increase in the luminosity is directly linked to the increase in the mean molecular weight in the core of the sun, and is largely independent of the details of the solar model calculation. This is confirmed by the results of a variety of non-standard solar model calculations (see e.g., Newman and Rood, 1977 for a review). Large-scale mixing brings hydrogen-rich material to the core and so slows down the increase in the molecular weight; but even with complete mixing the initial luminosity would still have been about 20 percent smaller than the present value.

If the laws of physics are changed the predicted variation in the solar luminosity may also change. Considerable attention has been given to the proposal, first made by Dirac, that the gravitational "constant" G is inversely proportional to time; Dirac later proposed that in addition the mass of the sun, $M_{\odot}$, might increase as the square of time. Not surprisingly these assumptions lead to significant changes in the predicted variations in the solar luminosity and the solar constant (e.g., Maeder, 1977). However, there seems to be little definite observational evidence for either hypothesis. Furthermore, Canuto and Hsieh (1980) argued that within the framework of Einstein's theory of general relativity any variation in G must be accompanied by a variation in $M_{\odot}$ such that $GM_{\odot}$ remains constant; in this case neither the solar luminosity nor the solar constant are affected.

The lower luminosity of the early sun might be expected to have resulted in a lower temperature on Earth; in particular highly simplified climate models, based on present conditions, have predicted that a reduction in solar luminosity of only a few percent would cause a climatic instability, leading to a completely ice-covered Earth. Furthermore, because of the large reflectivity of the Earth under these circumstances, a substantial luminosity increase would be needed to reverse the complete glaciation. On the other hand, geological evidence shows that the temperature of Earth has never departed drastically from the present value. However, it must be stressed that climatic modeling is subject to very considerable uncertainties. Thus an increase in the CO_2 abundance over the present value would have caused an enhanced greenhouse effect that might have counteracted the lower luminosity (e.g., Owen, Cess and Ramanathan, 1979). In addition, changes in the distribution between land and sea, and in the location of the continents, could have very significant climatic effects. Thus there is no obvious conflict between the predicted change in solar luminosity and the apparent constancy of the terrestrial temperature; however, it suggests that the temperature is controlled by a feedback mechanism, the precise nature of which has yet to be determined.

The characteristic thermal time scale for the entire sun is about 10^7 years. When averaged over times considerably longer than this, the sun must be in thermal equilibrium, so that the rate of energy generation balances the luminosity. However, departures from thermal equilibrium on time scales of 10^7 years or shorter are in principle possible. It was suggested by Dilke and Gough (1972) that departures might be caused intermittently by sudden mixing of the solar core triggered by the onset of instability towards non-radial gravity modes. Such mixing would cause a temporary decrease in the solar luminosity and in the flux of solar neutrinos. Dilke and Gough suggested that this might explain the discrepancy between the observed flux of neutrinos from the sun and the flux predicted from models in thermal equilibrium; they also linked the decrease in solar luminosity to the latest series of ice ages. An alternative explanation of the ice ages, also linked to intermittent variations in the solar luminosity, was proposed by Hoyle and Lyttleton (1939), who suggested that accretion might increase the luminosity of the sun when it passes through dense interstellar clouds associated with the spiral arms of the Galaxy. Neither hypothesis has yet been carefully analyzed. Furthermore, there has apparently been no attempt at reasonably detailed modeling of the climatic response to such luminosity variations.

These seems at present to be little prospect for testing the theoretical predictions of variations in the solar luminosity from geological investigation of the past climate of the earth, or indeed of any other planet. However, indirect evidence may be provided by studying the solar interior using the frequencies of solar oscillations. Thus ongoing calculations of Ulrich and Rhodes indicate that the observed frequency differences between the radial and the quadrupole modes of solar 5 min oscillations may be incompatible with the mixing proposed by Dilke and Gough. Although some problems remain in the calculation of oscillation frequencies and in their application as probes of the solar interior, there is little doubt that this kind of investigation will provide a sensitive test of our calculations of solar evolution, and hence of the predicted change in the solar luminosity.

W. Livingston (Kitt Peak National Observatory, Tucson) reviewed indirect methods of diagnosing solar irradiance changes. Given the Stefan-Boltzmann relation $L = 4\pi\sigma R^2T^4$, between the solar luminosity L, the effective temperature T and radius R, a number of workers are attempting to investigate variation of L for the sun by seeking to measure a temporal variation in R or T (see discussion of Sofia, 1981). The experiments are generally insensitive to telluric absorption errors, to first order, and benefit from the sun's brightness and from modern photometric technology. But the techniques developed for these studies are new and continue to require close examination to guard against subtle errors of instrumental and atmospheric nature.

At Kitt Peak a double-pass spectrometer is regularly used to measure the intensities of selected Fraunhofer lines in the solar flux spectrum. The aim is the detection of variability of the spectroscopic temperature. The strength of CI 5380.3 Å was noted to have declined by 2.3% 1976-1980 (Livingston and Holweger, 1982). However, if only recent CI 5380 data are examined, for the period 1979-82, and if the earlier results are excluded, a constant line strength is apparent. Clearly, a few more years of data are required to determine whether there is any 11-year cycle modulation.

This same equipment is being used to study the solar cycle behavior of Ca II H and K (White and Livingston, 1981). A peak variability of 40% in the central intensity of K_3 occurred in late 1979 near sunspot maximum. The possibility that the ground-based K-index can serve as a surrogate to space measures of Lα and the EUV is being investigated by Skumanich et al., 1982 and Lean et al., 1982. Similar Ca II K programs are also underway elsewhere (e.g., Oranje, 1982; Stimets and Londono, 1982; Keil, 1981).

Variations in limb-darkening observed in monochromatic continuum pass bands can be inverted to estimate variations in the emergent photospheric flux and in radial temperature gradient. A recent study of measurements made during 3 runs at KPNO in 1980 (Rosen et al., 1982) suggests day-to-day variations whose sign agrees with simultaneous changes in solar irradiance measured by the ACRIM and Nimbus-7 radiometers. But scattered light and detector hysterisis require further study in this continuing program. Correlations between limb-darkening changes and solar constant radiometry were also reported in a contributed paper by Bruning, Labonte and Howard, based on analysis of the extended data base of λ5250 intensity observations at Mt. Wilson. In a second contributed paper, T. Caudell et al. showed evidence for day-to-day changes in limb-darkening measured very close to the solar limb during solar diameter observations at SCLERA.

Solar radius measurements are pursued by many methods. A dedicated solar diameter telescope has been in operation in Boulder since August, 1981 (Brown, 1981). A day-to-day variance of $0\overset{''}{.}4$ is reported. Approximately the same variance is found at Kitt Peak by Duvall and Jones (1981) who feel that drift of the KPNO vacuum telescope is their dominant unknown. In other words, insufficiently understood systematic error, not seeing, sets the limit. The same is found by LaBonte and Howard (1981) who have analyzed 5 years of magnetograph data to find R is constant to within $\pm 0\overset{''}{.}1$. Occasional instantaneous measurements of the sun's diameter are also made at times of total eclipses, with an accuracy approaching $0\overset{''}{.}1$ arc (Sofia et al., 1981; Fiala et al., 1981).

The problem in all of these techniques is in how to relate any apparent diameter change to an unequivocal change in luminosity. How accurately must $\Delta R/R$ be known to deduce a change of $\Delta L/L = 0.1\%$? If thermal equilibrium is assumed, then by one analysis, $\Delta R \sim 0\overset{''}{.}5$ but with a time constant of 10^5 years. If changes in the granulation layer are involved the time constant is but a few days, but $\Delta R \sim 3'' \times 10^{-3}$ (Dearborn and Blake, 1982). A rotating mirror in space, repeatedly "flashing" a solar image to ground timing stations has been proposed to detect milli-arcsec changes in the solar diameter (Beckers, 1980).

A promising new diagnostic is spectrum line asymmetry which in the solar flux spectrum is a measure of granular convection (Dravins et al., 1981). Most theories of short-term luminosity variability call on a change of convective efficiency to modulate outward heat transport. Line bisector curvature is a direct, observable, diagnostic of this outer convection zone. Livingston (1982) finds that over the past 2 years the sun's convective signature has diminished about 10%. Is this a true trend or is it yet another example of inadequate time base in the data?

A contributed paper by S. Sofia (NASA Goddard Space Flight Center) described a proposed spaceborne Solar Disk Sextant (SDS) designed to overcome the problems of measuring the solar diameter from the ground. The instrument, now under study at NASA/GSFC, is an orbiting diffraction-limited telescope with a resolution of $0\overset{''}{.}1$ arc. The proposed SDS would employ an optical wedge with the dual purpose of decreasing the sensitivity of the results to instrumental changes and of providing a technique to measure image scale changes that may result from instrumental variations.

J. H. Parkinson (Mullard Space Science Laboratory, University College, London) described new measurements of the solar diameter made at the 1981 Siberian total solar eclipse, which when combined with his earlier interpretation of the historical data (Parkinson et al., 1980) suggest a possible secular trend over 250 years of $+0\overset{''}{.}046$ $\pm 0\overset{''}{.}172$ arc per century in the diameter. But Parkinson also concludes that a periodicity of about 80 years (the so-called Gleissberg cycle) may also exist in the historical diameter data, as described by Gilliland (1981).

G. W. Lockwood (Lowell Observatory, Flagstaff) reviewed observational evidence for luminosity variations of days to years in solar-type stars, based on work done at the Lowell, Mt. Wilson-Palomar and Cloudcroft (New Mexico) observatories.

Photoelectric b, v, observations of 16 F-, G-, and K-type main-sequence field stars was made from 1955 through 1966 at the Lowell Observatory by Jerzykiewicz and Serkowski (1966). Typically, 5 to 10 observations were obtained per year and reduced to an internally defined "system of ten year standards." For three stars, the rms fluctuations of the annual mean magnitudes were less than 0.004 mag (0.4%), and only one star (the double system ξ Boo) had an rms fluctuation greater than 0.008 mag (0.8%). Peak-to-peak amplitudes were in the range 0.01 to 0.02 mag except for ξ Boo (0.03 mag).

Four of these stars were included among the young, chromospherically active stars monitored for long-term H- and K-emission variations by Wilson (1978). There is tantalizing but inconclusive evidence that the 12-year period of H-K flux variability of ξ Boo B, observed by Wilson from 1966 through 1978, is in phase with the b, v light curve observed one cycle earlier at Lowell. If the 0.03 mag variations of the ξ Boo system are solely due to the fainter (B) companion, then the intrinsic luminosity variations of the star amount to ∿0.1 mag.

An analysis of variance of the nightly b, v Lowell magnitudes reveals significant (95% confidence) annual variations but these cannot be separated at this time from possible instrumental effects.

During the winter of 1981-1982, Radick and his colleagues at the Cloudcroft Observatory monitored the b and y magnitudes of about 100 solar-type F8V-K2V stars in three fields. About ten observations of each field were made over a period of several months. A fairly conservative statistic was derived for the detection of variability, which takes into account the magnitude-dependent internal precision attained for stars over a wide range of apparent brightness. In the "Malmquist field" near the North Galactic Pole, consisting of 41 solar-age main-sequence stars, only one star was found to be possibly variable. Five (possibly 10) out of 42 young solar-type stars in the Pleiades were found to be variable. Five (possibly 9) out of 42 intermediate-age solar-type stars in the Hyades were found to be variable.

At Lowell, 36 F-, G-, and K Hyades stars were observed differentially in groups of three in b and y on 5 to 10 nights per group during winter 1982. Fifteen stars were identified as definitely or probably variable at the 0.01-0.03 mag level.

All but one of the stars found to be variable at Cloudcroft or Lowell were of type G. No F stars were variable. Both data sets are too sparse to confirm possible rotational variations in the 5-30 day period range, but the presence of a rotational signal in the H-K flux analyzed by Vaughan leads to the suggestion that the b, y variations that are seen are likely to originate from longitudinal structure in the surface brightness of these stars.

In summary, long-term variability of solar-age main-sequence stars, over time intervals comparable to a solar cycle, appear to be absent at the 0.01-0.02 mag level, but may be present at lower levels. Short-term variations of young, chromospherically active stars are limited to stars of spectral type G and are absent in F stars. The observed 0.01-0.03 mag variations are likely associated with rotation. No short-term variations are found in older, solar-age G stars.

L. N. Mavridis and G. Asteriadis of the Department of Geodetic Astronomy, Univeristy of Thessaloniki, Thessaloniki, Greece and F. M. Mahmoud of the Helwan Institute of Astronomy and Geophysics, Cairo, Egypt presented a contributed paper on Long-Term Changes of the Flare-

Activity and the Quiet-State Luminosity of the Flare Stars EV Lac and BY Dra. A long-term program of photoelectric observations of flare stars of the solar neighborhood was initiated by the Department of Geodetic Astronomy, University of Thessaloniki in 1971. The program endeavored to monitor both flare activity and possible luminosity variations observed in one or more colors in part to determine whether flare activity is related to luminosity changes.

A total of 9 flare stars of the solar neighborhood were observed during the years 1971-81 (UV Cet, YZ CMi, AD Leo, DT Vir, BD+16° 2708, BD+55° 1823, BY Dra, DO Cep, and EV Lac) (Mavridis et al., 1982).

For the Joint Discussion Prof. Mavridis presented a brief discussion of the long-term changes of the flare activity and the quiet-state luminosity of two of the above stars, i.e., EV Lac and BY Dra.

J. Xanthakis, B. Petropoulos and H. Mavromichalaki (Research Center for Astronomy and Applied Mathematics, Academy of Athens) presented a brief contributed paper on coronal intensity and solar wind streamers for solar cycle No. 20. With Y. Lyritizis and T. Zachariadis, Prof. Petropoulos also gave a brief report on auroral activity and the magnetic intensity of the earth for the last 7000 years.

Biermann, L.: 1941, Vierteljahrsch Astr. Gesselsch 76, p. 194.

Beckers, J.: 1981, private communication.

Brown, T.: 1981, Bull. Amer. Astron. Soc. 13, p. 878.

Canuto, V., and Hsieh, H.: 1980, Astrophys. Journ. 237, p. 613.

Currie, R.: 1981, J. Atmos. Sci. 38, p. 808.

Dearborn, D., and Blake, J.: 1982, Astrophys. Journ. 257, p. 896.

Dilke, F., and Gough, D.: 1972, Nature 240, p. 262.

Dravins, D., Lindegren, L., and Nordlund, A.: 1981, Astron. Astrophys. 96, p. 345.

Duvall, T., and Jones, H.: 1981, in "Solar Instrumentation: What's Next," Sacramento Peak Observatory Publication, R. Dunn, ed.

Eddy, J., Gilliland, R., and Hoyt, D.: 1982, Nature, in press.

Fiala, A., Herald, D., and Dunham, D.: 1981, Amer. Astron. Soc. 13, p. 552.

Foukal, P.: 1981, in The Physics of Sunspots, Sacramento Peak Observatory Publication, L. Cram and J. Thomas, eds., p. 391.

Foukal, P., Mack, P., and Vernazza, J.: 1977, Astrophys. Journ. 215, p. 952.

Foukal, P., and Vernazza, J.: 1979, Astrophys. Journ. 234, p. 707.

Foukal, P., Fowler, L., and Livshits, M.: 1982, Astrophys. Journ., in press.

Gilliland, R.: 1981, Astrophys. Journ. 248, p. 1144.

Gilman, P.: 1978, Geophys. Astrophys. Fluid Dynamics 11, p. 157.

Hickey, J., Griffin, F., Jacobowitz, H., Stowe, L., Pellegrino, P., and Maschhoff, R.: 1980, EOS 61, p. 355.

Hoyle, F., and Lyttleton, R.: 1939, Proc. Camb. Phil. Soc. 35, p. 405.

Hoyt, D., and Eddy, J.: 1982, NCAR Technical Note TN-194 + STR.

Hudson, H., and Willson, R.: 1981, in The Physics of Sunspots, Sacramento Peak Observatory Publication, L. Cram and J. Thomas, eds., p. 434.

Hudson, H., Silva, S., Woodard, M., and Willson, R.: 1982, Solar Phys. 76, p. 211.

Jerzykiewicz, M., and Serkowski, K.: 1966, Lowell Obs. Bull. 6, p. 295.

Keil, S.: 1981, private communication.

LaBonte, B., and Howard, R.: 1981, Science 214, p. 907.

Lean, J., White, O., Livingston, W., Heath, D., Donnelly, R., and Skumanich, A.: 1982, in preparation.

Livingston, W.C.: 1982, Nature 297, p. 208.

Livingston, W. and Holweger, H.: 1982, Astrophys. Journ. 252, p. 375.

Maeder, A.: 1977, Astron. Astrophys. 56, p. 359.

Mavridis, L., Asteriadis, G., and Mahmoud, F.: 1982, in Compendium in Astronomy (ed. by E. Mariolopoulas, P. Theocaris and L. Mavridis), D. Reidel, Holland, p. 253.

Newman, M., and Rood, R.: 1977, Science 198, p. 1035.

North, G., Cahalan, R., and Coakley, J.: 1981, Revs. Geophys. Space Phys. 19, p. 91.

Oranje, B.: 1982, Astron. Astrophys., in press.

Oster, L., Schatten, K., and Sofia, S.: 1982, Astrophys. Journ. 256, p. 768.

Owen, T., Cess, R., and Ramanathan, V.: 1979, Nature 277, p. 640.

Parker, E.: 1974, Solar Phys. 36, p. 249.

Parkinson, J., Morrison, L., and Stephenson, F.: 1980, Nature 288, p. 548.

Rosen, W., Foukal, P., Kurucz, R., and Pierce, A.: 1982, Astrophys. Journ. Letters 253, p. 89.

Skumanich, A., Lean, J.L., White, R.R., and Livingston, W.C.: 1982, in preparation.

Sofia, S.: 1981, in Variations of the Solar Constant, S. Sofia ed., NASA Conf. Publ. 2191, p. 73-79.

Sofia, S., Dunham, D., and Fiala, A.: 1980, in Proc. Conf. on the Ancient Sun," R. Pepin et al., eds., Pergamon Press, NY, pp. 147-157.

Spiegel, E., and Weiss, N.: 1980, Nature 287, p. 616.

Spruit, H.: 1981, in The Physics of Sunspots, Sacramento Peak Observatory Publication, L. Cram and J. Thomas, eds., p. 480.

Spruit, H.: 1982a, Astron. Astrophys. 108, p. 348.

Spruit, H.: 1982b, Astron. Astrophys. 108, p. 356.

Stimets, R., and Londono, C.: 1982, Solar Phys. 76, p. 167.

White, O.R., and Livingston, W.C.: 1981, Astrophys. Journ. 249, pp. 498-816.

Willson, R., Gulkis, S., Johnson, J., Hudson, H., and Chapman, G.: 1980, Science 211, p. 700.

Wilson, O.: 1978, Astrophys. Journ. 226, p. 379.