Lou, Y.Q., and Rosner R.: 1986, Ap. J. **309**, 874
McClymont, A.N. and Graig, I.J.D.: 1987, Ap. J. **312**, 402
Rabin, D. and Moore, R.: 1984, Ap. J. **285**, 359
Steinolfson, R.S., Priest, E.R., Poedts, S., Nocera, L., and Goosens, M.: 1986, Ap. J. **304**, 526
Tsubaki, T., Saito, Y., and Suematsu, Y.: 1986, Publ. Astron. Soc. Japan **38**, 251
Ulmschneider, P., Muchmore, D., and Kalkofen, W.: 1987, Astr. Ap. **177**, 292
Ulmschneider, P. and Muchmore, D.: 1986, "Small Magnetic Flux Concentration in the Solar Photosphere", W. Deinzer, M. Knölker and H.H. Voigt (eds.), Abhandl. Akad. Wissensch., Vandenhoeck and Ruprecht, Göttingen
Van Ballegooijen, A.A.: 1985, Ap. J. **298**, 421
Withbroe, G.L., Kohl, J.L. and Weiser, H.: 1985, Ap. J. **297**, 324

VI. THE SUN AS A STAR

(L.E. Cram)

Studies of the global (spatially unresolved) output from the sun are important for two main reasons: (1) the global solar output directed towards the earth plays a central role in solar-terrestrial relations, and (2) global solar observations form a link between (neccessarily) global observations of stars and the more refined spatially resolved observations which are available for the sun. This report covers both aspects (insofar as they concern the sun), using the time-scales of various phenomena as a basic distinguishing characteristic. Note that certain studies of spatially unresolved solar output have not been discussed, since they are actually directed toward the investigation of phenomena of strictly limited spatial extent [e.g. radiospectrograph observations (e.g. Wiehl et al. 1985) and studies of X-ray bursts (e.g. Thomas et al. 1985)]. Collections of relevant papers may be found in De Jager and Svestka (1985) and Labonte et al. (1984), while a review of germane stellar work is available in Baliunas and Vaughan (1985) and solar-terrestrial work in Donnelly and Heath (1985). A comprehensive summary of the subject by Hudson will appear soon in Review of Geophysics and Planetary Physics.

(a) Long-term variations (> several months)

The first 5 years (1980 to 1985) of observations of total solar irradiance by the Active Cavity Radiometer Irradiance Monitor (ACRIM) aboard the NASA Solar Maximum Mission (SMM) satellite have shown a clearly defined decline of -0.019% per year (Willson 1984; Willson et al. 1986). The trend detected by ACRIM is consistent with observations made by the NOAA Nimbus-7/ERB experiment and by sounding rockets, although there is some inconsistency in the actual values of the slopes derived from the various experiments. The observed decline could represent a dependence of the solar luminosity on the solar magnetic cycle. Pap (1986a) noted that the amplitude of variations (on time scales of days to weeks) in the irradiance is smaller at sunspot minimum than at maximum, and she also claims that the dominant period of irradiance modulation increased from 23.5 days at sunspot maximum to 28 days at minimum.

In addition to work on long-term variations in total irradiance, there have been several reports on long-term variations in narrower spectral regions. Livingston and Wallace (1987) reported that several photospheric lines exhibit long-term variations after instrumental effects are removed. In particular, a small change in the central depth of CI λ 538 nm is reminiscent of the ACRIM result described above. Cavallini et al. (1986) have shown that long-term changes occur in the asymmetry and width of photospheric lines observed at disk centre, while Snodgrass (1984) has re-examined the long-term trends in a number of absorption line properties measured as part of the Mt. Wilson magnetogram program. Deming et al. (1987) have reported what seem to be significant long-term shifts in

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the wavelengths of disk-averaged photospheric lines (presumably reflecting changes in the line bisector shape).

Observations of the variations in the Ca II lines over cycles 20 and 21 have been presented by Keil and Worden (1984), Sivaraman et al. (1987) and White et al. (1987). At sunspot maximum, the K-line intensity reached a maximum level about 20% above the background at sunsport minimum. To account for the total K-line emission and its waveform, Skumanich et al. (1984) found it necessary to include three separate components (active network, plage and quiet sun) in the analysis.

There have been a number of studies of intriguing long-term variations in other solar properties. Sonett and Trebisky (1986) have reported that a measure of the 11-to-22-year asymmetry of the sunspot cycle has been changing systematically over a period of ~ 2.5 Gyr (BP) with an exponential time constant of ~ 2 Gyr. Raychaudhuri (1986) has exhibited statistically significant correlations between variations in the solar neutrino flux, galactic cosmic ray flux and smoothed sunspot number which are claimed to strongly indicate that the solar activity cycle is due to the pulsating character of solar nuclear energy generation. Reiger et al. (1984) have suggested that there is a 154 d periodicity in the occurrence of hard solar flares. The suggestion has been confirmed by Bogart and Bai (1985), who conjecture that the period emerges from beating between incommensurable periods, either on rotational time scales or g-mode time scales. Delache et al. (1985) have published a power spectrum of variations of the solar diameter measured with a visual astrolabe which displays several peaks, the most prominent of which appears to be closely related to a 320 d periodicity in the Zurich sunspot number time series.

(b) Short-term variations (irregular)

The ACRIM observations described above represent the long-term trends of a time series of irradiance data which also exhibit significant fluctuations on shorter time scales. It has been clear for some time that an important contributor to these fluctuations are due in part to sunspots which "block" the solar output to produce the irradiance deficit. This picture has been confirmed in further recent work by Hudson (1984) and Pap (1985, 1986a,b,c). However, Pap has refined this result by noting that the marked decrements in irradiance coincide with the appearance of "active" - i.e. young - spot groups, while older spot groups are less effective. She argues that the fast-developing, complex active regions may be better able to inhibit convective energy transport than are the simpler fields of older active regions.

The energy flux initially blocked by sunspots can eventually emerge in at least two quite different ways: (1) by slow diffusion over time-scales of the order of decades or millenia, or (2) over a period of a few weeks or months in association with the appearance of faculae or plages. A final choice between these alternatives cannot be made at this time. However, studies of the behaviour of specific spots and facular regions suggest that facular regions radiate over their lifetime a flux which has between 70% and 110% of the time-integrated missing flux in sunspots (Chapman et al. 1986). This implies that faculae are an important component of the global energy budget of an active region and, furthermore, that the flux blocked by spots may be "stored" for only a few weeks. Many studies of this important phenomenon have concentrated on the behaviour of individual active regions (Chapman 1984, 1987; Chapman et al. 1984, 1986; Chiang and Foukal 1985; Schatten et al. 1985; Foukal and Duvall 1985; Lawrence et al. 1985; Chapman and Meyer 1986; Chapman and Boyden 1986; Foukal and Lean 1986).

The fact that active regions change the disk-integrated solar spectrum, combined with the non-uniform disposition of active regions in longitude, implies that rotational modulation of disk-integrated spectral features could be detect-

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able. Keil and Worden (1984), Drescher et al. (1984), Singh and Prabhu (1985), and Singh and Livingston (1987) have confirmed that rotational modulation of the Ca II flux can indeed be detected, although the intrinsic evolution of the Ca II structures on time scales of a few days often significantly alters the derived rotation rate. The relationship between rotationally modulated Ca II fluxes and other chromospheric and coronal emission has been studied by Fisher et al. (1984), who found a correlation between Ca II flux and total coronal mass over a 60 d interval. The temporal characteristics of the solar UV flux and and He I λ 1083 nm have been investigated by Donnelly et al. (1985). The possibility that photospheric lines exhibit rotational modulation of their bisector shape has been raised by Bruning and Labonte (1985). A number of workers have undertaken observational studies of spectral lines formed in solar active regions with a view towards predicting the influence of such active regions on the disk-integrated line in the spectrum of the sun or other stars (Labonte 1986a,b; Sivaraman et al. 1987).

(c) Short-term Variations (regular)

It has been known for about a decade that global "5-minute" oscillations can be detected in integrated sunlight. The modes have been identified as low degree modes ($l < 3$) of high radial order ($n \sim 20$-30), and impressive progress has been made towards a theoretical interpretation of their observed frequencies (Fossat 1985; Osaki and Shibahashi 1986). A result of considerable interest was the announcement by Woodard and Noyes (1985) that the frequencies of the global modes appeared to decrease significantly between 1980 and 1984 (in parallel with the declining phase of the solar cycle). Pallé et al. (1986) could not confirm the decrease, but Fossat et al. (1987) did find a significant decrease in frequency between observations made in 1980 and in 1985.

The possibility that sluggish global oscillations with periods exceeding 1 month could also be present in the sun has been discussed by Wolff and Blizard (1986) and Wolff and Hickey (1987). Physically, the modes arise from Coriolis forces, and they have been variously termed r-modes, Rossby wave or inertial oscillations. Although the modes have been predicted to be damped under solar conditions, Wolff and Hickey claim that more than half of the variance of the solar irradiance in the period range 13-85 days could be due to r-modes.

(d) Temporally Invariant Global Observations

All of the work described above is related to variations in the integrated solar spectrum due mainly to activity and oscillations. There have been suprisingly few studies which seek to explore the "solar-stellar connection" independently of such variations. Published studies in this area include reviews of the formation of Fe II lines in the solar spectrum by Rutten (1987) and Rutten and Kostyk (1987), and studies on rotation, temperature and turbulence effects on photospheric lines by staff at Kiev Observatory (Sheminova 1984; Gadun and Kostyk 1985).

References

Baliunas, S.L. and Vaughan, A.H.: 1985, Ann. Rev. Astron. Astrophys. **23**, 379
Bogart, R.S. and Bai, T.: 1985, Astrophys. J. **299**, L51
Bruning, D.H. and LaBonte, B.J.: 1985, Solar Phys. **97**, 1
Cavallini, F., Ceppatelli, G. and Righini, A.: 1986, Astron. Astrophys. **158**, 275
Chapman, G.A.: 1984, Nature **308**, 252
Chapman, G.A.: 1987, J. Geophys. Res. **92**, 809
Chapman, G.A. and Boyden, J.E.: 1986, Astrophys. J. **302**, L71
Chapman, G.A. and Meyer, A.D.: 1986, Solar Phys. **103**, 21
Chapman, G.A., Herzog, A.D., Lawrence, J.K. and Shelton, J.C.: 1984, Astrophys. J.

282, L99
Chapman, G.A., Herzog, A.D. and Lawrence, J.K.: 1986, Nature **319**, 654
Chiang, W.-H. and Foukal, P.: 1985, Solar Phys. **97**, 9
de Jager, C. and Svestka, Z.: 1986 (eds.) Solar Phys. **100**
Delache, Ph., Laclare, F. and Sadsaoud, H.: 1985, Nature **317**, 416
Deming, D., Espanak, F., Jennings, D.E., Brault, J.W. and Wagner, J.: 1987, Astrophys. J. **316**, 771
Donnelly, R.F. and Heath, D.F.: 1985, Adv. Space Res. **5**, 145
Donnelly, R.F., Harvey, J.W., Heath, D.F. and Repoff, T.P.: 1985, J. Geophys. Res. **90**, 6267
Drescher, Th., Woehl, H. and Kueveler, G.: 1985, ESA SP-220, 29
Fisher, R., McCabe, M., Mickey, D., Seagraves, P. and Sime, D.G.: 1984, Astrophys. J. **280**, 873
Fossat, E.: 1985, ESA SP-235, 209
Fossat, E., Gelly, B., Grec, G. and Pomerantz, M.: 1987, Astron. Astrophys. **177**, L47
Foukal, P. and Duvall, T.: 1985, Astrophys. J. **296**, 739
Foukal, P. and Lean, J.: 1986, Astrophys. J. **302**, 826
Gadun, A.S. and Kostyk, R.I.: 1985, Kinematika Fiz. Nebesn. Tel. **1**, 24
Hudson, H.S.: 1984, Adv. Space Res. **4**, 113
Keil, S.L. and Worden, S.P.: 1984, Astrophys. J. **276**, 766
Labonte, B.J., Chapman, G.A., Hudson, H.S. and Willson, R.: 1984 (eds.) NASA CP-2310
Labonte, B.J.: 1986a,b, Astrophys. J. Suppl. **62**, 229, 241
Lawrence, J.K., Chapman, G.A., Herzog, A.D. and Shelton, J.C.: 1985, Astrophys. J. **292**, 297
Livingston, W. and Wallace, L.: 1987, Astrophys. J. **314**, 808
Osaki, Y. and Shibahashi, H.: 1986, Astrophys. Space Sci. **118**, 195
Pallé, P.L., Pérez, J.C., Regulo, C., Roca-Cortes, C., Isaak, G.R., McLeod, C.P. and Van der Raay, H.B.: 1986, Astron. Astrophys. **170**, 114
Pap, J.: 9185, Solar Phys. **97**, 21
Pap, J.: 1986a, Astrophys. Space Sci. **127**, 55
Pap, J.: 1986b, Adv. Space Res. **6**, 65
Pap, J.: 1986c, Bull. Astron. Inst. Czechosl. **37**, 202
Raychaudhuri, P.: 1986, Solar Phys. **104**, 415
Rieger, E., Share, G.H., Forrest, D.J., Kambach, G., Reppin, C. and Chupp, E.L.: 1984, Nature **312**, 623
Rutten, R.J.: 1987, in "Physics of Formation of Fe II Lines", IAU Coll. No. 94 (Reidel: Dordrecht)
Rutten, R.J. and Kostyk, R.I.: 1987, in "Physics of Formation of Fe II Lines", IAU Coll. No. 94 (Reidel: Dordrecht)
Schatten, K.H., Miller, N., Sofia, S., Endal, A.S., Chapman, G. and Hickey, J.: 1985, Astrophys. J. **294**, 689
Sheminova, V.A.: 1984, Soln. Dannye **7**, 70
Singh, J. and Livingston, W.C.: 1987
Singh and Prabhu, T.P.: 1985, Solar Phys. **97**, 203
Sivaraman, K.R., Singh, J., Bagare, S.P. and Gupta, S.S.: 1987, Astrophys. J. **313**, 456
Skumanich, A, Lean, J.L., White, O.R. and Livingston, W.C.: 1984, Astrophys. J. **282**, 776
Snodgrass, H.B.: 1984, Solar Phys. **94**, 13
Sonnett, C.P. and Trebisky, T.J.: 1986, Nature **322**, 615
Thomas, R.J., Starr, R. and Crannell, C.J.: 1985, Solar Phys. **95**, 323
Willson, R.C.: 1984, Space Sci. Rev. **38**, 222
Wilson, R.C., Hudson, H.S., Frohlich, C. and Brusa, R.W.: 1986, Science **234**, 1114
White, O.R., Livingston, W.C. and Wallace, L.: 1987, J. Geophys. Res. **92**, 823
Wiehl, H.J., Benz, A.O. and Aschwanden, M.J.: 1985, Solar Phys. **95**, 167
Wolff, C.L. and Blizard, J.B.: 1986, Solar Phys. **105**, 1
Wolff, C.L. and Hickey, J.R.: 1987, Science **235**, 1631

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Woodard, M. and Noyes, R.: 1985, Nature **318**, 449

VII. INSTRUMENTATION FOR THE STUDY OF SOLAR RADIATION AND STRUCTURE

(J. Harvey)

This report complements the report on solar instrumentation presented by Commission 10 in that subjects treated there are not repeated here. Both reports taken together should give a fair, though necessarily incomplete, idea of solar instrumentation activity during the period June 1984 through June 1987.

A. Absolute Spectral Radiometry

Broad-band radiometers on the Solar Maximum Mission and Nimbus-7 satellites continue to operate and have revealed interesting changes in solar irradiance. Radiometers have been flown on Spacelabs 1 and 2 with good results (Crommelynck et al., 1986; Labs et al., 1987; Van Hoosier et al., 1986). The difficult region between 5 and 57 nm has been investigated by Carlson et al. (1984). A long term program, using modern equipment and techniques, to measure solar irradiance from the ground has started (Palmer et al. 1983).

B. Spectro- and Differential Photometry

One of the most active research areas during the past three years has been precision differential photometry, often directed toward limb observations. Most of these instruments involve rapid scanning of the image with detector arrays to reduce atmospheric noise. Seykora (1985) uses low amplitude, high frequency chopping to detect tiny intensity variations. Rösch and Yerle (1984), Hirayama et al. (1985a), Dicke et al. (1986) and Herzog et al. (1986) scan parallel to the solar limb to measure facular contrast and image geometry. Limb-to-limb scanning is employed by Chapman et al. (1986). A unique instrument to measure solar diameter fluctuations, the solar disk sextant, has recently been ground tested by Sofia and his colleagues.

Ultraviolet spectrometers and results have been described by Samain and Lemaire (1985), Hirayama et al. (1985b), Parkinson and Gabriel (1986) and Epstein et al. (1987). A 1024-element, linear array detector has been added to the spectrograph at Purple Mountain Observatory (Wang et al., 1987). At the Crimean Astrophysical Observatory, an ingenious spectrometer using a Michelson interferometer and lazer stabilization, has been used for precise Doppler shift measurements (Didkovsky et al. 1986).

C. Polarimetry

Careful design has allowed Henson and Kemp (1984) to achieve broadband circular polarization measurements to one part per million. New Stokes polarimeters are under construction by the High Altitude Observatory and the Applied Physics Laboratory of Johns Hopkins University for installation at the National Solar Observatory. The high sensitivity video magnetograph of the Big Bear Solar Observatory is described by Wang et al. (1985) and the video Solar Magnetic Field Telescope of the Beijng Observatory has been described in great detail (Beijng, 1986). Video techniques are also used in a spectromagnetograph being built at the National Solar Observatory (Jones, 1987). Markov (1985) present the characteristics of the 1024-element magnetograph operated by SibIZMIR.

D. High Angular Resolution

The flight of Spacelab 2 in the summer of 1985 at last provided extended periods of solar observations with sub-arc-second resolution and no atmospheric