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Department of Astronomy

Final Report

BASIC SOLAR RESEARCH: THE SOLAR CHROMOSPHERE AND HIGH ENERGY RADIATION

For the Period: July 1, 1956 - September 30, 1970

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FINAL REPORT

BASIC SOLAR RESEARCH: THE SOLAR CHROMOSPHERE AND HIGH ENERGY RADIATION

INTRODUCTION

The Office of Naval Research and The University of Michigan have supported a program in basic solar research since 1948. The contract now expiring, Nonr-1224(19), began on July 1, 1956 with Dr. Leo Goldberg as Principal Investigator. Its stated purpose was basic research on the physics of the solar atmosphere and on the effects of solar radiation on the earth. In 1962, Dr. Orren C. Mohler became the Principal Investigator and served in this capacity until April 1970 when the responsibility was transferred to Dr. Helen D. Prince.

Throughout the more than fourteen years in which Nonr-1224(19) was in effect, the programs supported wholly or in part by funds from the contract adhered closely to the original purpose. The research was based primarily on the measurement, analysis, and interpretation of solar spectra and monochromatic photographs of the solar chromosphere obtained at the McMath-Hulbert Observatory.

All research conducted under the contract already has been reported to ONR. It has been described briefly in a series of reports and proposals prepared at appropriate time intervals throughout the duration of the contract. More importantly, it has been described in detail in research articles published in the professional journals. A review of the solar programs at The University of Michigan carried out with the support of Nonr-1224(19) since 1956, shows that this continuing aid has played a significant role in the initiation and development of four general aspects of solar research:

1. Maps and analyses of high dispersion, high resolution solar spectra obtained with the McGregor Vacuum Spectrograph of the McMath-Hulbert Observatory.
2. Studies of solar activity with special emphasis on λ -sweep spectroheliograms.
3. Research and development leading to improvements in solar instrumentation.
4. Investigations in solar-terrestrial relationships.

The body of this report will be organized around the above four topics. Additional reference to the results of the research will be made through a listing of the articles in which the studies have been published in professional journals.

RESEARCH SUPPORTED IN PART BY Nonr-1224(19)

1. Maps and Analyses of high dispersion, high resolution, solar spectra obtained with the McGregor vacuum spectrograph

Contract Nonr-1224(19) was initiated in 1956, the first year after the McGregor Vacuum Spectrograph became operational. Funds from the contract were used in subsequent years to provide improvements for the instrument, and research assistants and associates to observe with the spectrograph and to aid in the research program. The contract also assisted in covering the costs of publication of the results of research in scientific journals.

The McGregor Vacuum Spectrograph can perhaps be regarded as the first of the large, modern, solar spectrographs. An excellent grating yields a resolving power of the order of 600,000 and a level of scattered light of only $\sim 3\%$. From its introduction, the spectrograph could be used either photoelectrically or photographically. In the early 1960's three complete atlases of the solar spectrum, covering the wavelength range 7000 to 3900 Å, were obtained with the spectrograph. Each atlas referred to a different location on the solar disk, viz. at positions where $\mu = 1.0, 0.5,$ and 0.3 respectively. The three records are published together as "The Michigan Atlas of the Solar Spectrum." This atlas is available on microfilm (University Microfilms, Ann Arbor, Michigan).

In recent years, the spectrograph has been improved through the introduction of a double pass system that reduces instrumentally induced changes in the true intensities of the spectrum lines. More importantly, the double pass system provides a means by which the intensity of extraneous light in the system can be measured, and in turn subtracted from the observed intensities to give true intensities. The acquisition of a small computer or data processing unit has made it possible to record the output of the spectrograph in digital form suitable for computer analysis. With the aid of this auxiliary equipment, a new recording of the high dispersion solar spectrum has been undertaken. This record, known as The Michigan Digital Atlas of the Solar Spectrum is approximately one-third completed, as of September 30, 1970.

Throughout the life of the contract, observations from the McGregor Vacuum Spectrograph have provided the observational

material for a large number of research projects including definitive studies of the abundances of the chemical elements in the solar atmosphere, determinations of factors affecting line-formation, and analyses of turbulence and Doppler shifts in Fraunhofer lines. Studies relating to the sunspot spectrum, solar magnetic fields, and H α flare emission also have stemmed from observations with the McGregor Spectrograph. The results of these research projects, supported in part by funds from Nonr-1224(19), have been published in the articles listed below.

"Solar Spectroscopy with a Vacuum Spectrograph," Ap.J. 123, 1-8, 1956, Robert R. McMath.

"Preliminary Results with a Vacuum Solar Spectrograph," Ap.J. 124, 1-12, 1956, Robert R. McMath, Orren C. Mohler, A. Keith Pierce, and Leo Goldberg.

"Width of the Infrared Helium Line in the Solar Spectrum," Ap.J. 124, 13-19, 1956, Orren C. Mohler and Leo Goldberg.

"A Connexion between the Granulation and the Structure of the Low Chromosphere," Nature 179, 369, 1957, Orren C. Mohler, Leo Goldberg, and J. D. Brown.

"Turbulent Velocities inferred from the H & K Emission Lines in Stellar Spectra," Ap.J. 126, 318, 1957, Leo Goldberg.

"On the Empirical Determination of Line-absorption Coefficients," Ap.J., 127, 308, 1958, Leo Goldberg.

"The Profile of H α during the Limb Flare of February 10, 1956," Ap.J., 127, 302, 1958, Leo Goldberg, Orren C. Mohler, and E. A. Müller.

"Solar Spectroscopy," Science, 128, 505, 1958, Orren C. Mohler.

"The Double Reversal in the Cores of the Fraunhofer H & K Lines," Ap.J. 129, 119, 1959, Leo Goldberg, Orren C. Mohler and E. A. Müller.

"The Center-Limb Variation of the Intensities of Selected Solar Lines," Ap.J., 129, 93, 1959, Walter E. Mitchell, Jr.

"Turbulent Motion in the Solar Atmosphere: I. Doppler Widths of Photospheric Lines," Ap.J., 129, 375, 1959, W. Unno.

"Turbulent Motion in the Solar Atmosphere: II. Turbulent Velocities in the Lower Chromosphere," Ap.J. 129, 388, 1959, W. Unno.

"The Distribution of Electron Pressure in the Solar Photosphere," Ap.J., 129, 369, 1959, Walter E. Mitchell.

- "The Photosphere of the Sun," Handbuch Der Astrophysik, 52, 1-79, 1959 (edited by S. Flugge, Berlin, Springer-Verlag), Leo Goldberg and A. Keith Pierce.
- "Solar Experiments," Astron. Journal, 65, 274, 1960, Leo Goldberg.
- "Measurements of the K-line in Spectra of Sunspots," Astron. Journal, 65, 55, 1960, Orren C. Mohler.
- "The Measurement of the Local Doppler Shift of Fraunhofer Lines," Ap.J., 132, 184, 1960, Leo Goldberg, Orren C. Mohler, Wasaburo Unno and Jacqueline Brown.
- "The Abundances of the Elements in the Solar Atmosphere," Ap.J. Supp. No. 45, 1960, Leo Goldberg, E. A. Müller, and L. A. Aller.
- "Fraunhofer Lines and Heights in the Sun's Atmosphere," Sky & Telescope, 20, 124, 1960, Orren C. Mohler.
- "Solar Spectroscopy," Encyclopedia of Spectroscopy, p. 684-693, 1960, Orren C. Mohler.
- "The H α Line in the Flare of November 12, 1960," Ap.J., 136, 534, 1962, Richard G. Teske.
- "Small-scale Structure of Solar Fraunhofer Lines," Ap.J., 138, 271, 1963, Richard G. Teske.
- "An Observation of the Longitudinal Magnetic Field in a Sunspot Group," Ap.J., 139, 1336, 1964, Richard G. Teske, Helen W. Dodson and E. Ruth Hedeman.
- "Effects of Deviations from Local Thermo-dynamic Equilibrium on Solar Abundances," Ap.J. Supp., 9, 1-64, 1964, Edith A. Müller and S. Paul Mutschlecner.
- "A Study of the Violet System of Cyanogen in the Solar Atmosphere," Ap.J., 139, 1344, 1964, Charles R. Cowley.
- "On the Determination of Rotational Temperatures from Solar Lines of Cyanogen," Ap.J., 139, 1351, 1964, Charles R. Cowley.
- "The Magnetic Field in an Actively Flaring Sunspot Group," Astron. Journal, 70, 695, 1965, Richard G. Teske.
- "Ca I Lines in Auto-ionization in the Solar Spectrum," Ap.J., 141, 1126, 1965, Orren C. Mohler and W. E. Mitchell, Jr.
- "The Distinction between Micro- and Macroturbulence in the Solar Photosphere using Line Profiles," Ap.J., 148, 857, 1967, Guenther H. E. Elste.

- "Profiles of the Ca II H & K Reversals near Solar Minimum,"
 Publ. Astron. Soc. of the Pacific, 79, 110, 1967,
 Richard G. Teske.
- "The Abundance of Lead in the Sun," Proc. Nat. Acad. Sci., U.S.A.,
59, 1, 1968, O. C. Mohler, J. Ross, and L. H. Aller.
- "Comments on the Bilderberg Continuum Atmosphere," Solar Physics,
3, 106, 1968, Guenther Elste.
- "Selective Excitation in the Flare of 1958 August 7," Ap.J. 158,
 803, 1969, Charles Cowley and J. M. Marlborough.
- "Electric Current in a Sunspot," Solar Physics, 12, 104, 1970,
 R. Jayanthan.
- "Observations of the Infrared Triplet of Singly Ionized Calcium,"
 Solar Physics, 11, 374, 1970, J. L. Linsky, R. G. Teske,
 and C. W. Wilkinson.
- "The Ionization of Atoms in the Umbra by the Radiation Field of
 the Penumbra," Bull. Amer. Astron. Soc., 2, 193, 1970,
 Guenther H. E. Elste.

2. Studies of solar activity with special emphasis on λ -sweep
 spectroheliograms

Until the decade of the 1960's records of solar activity usually were obtained with radiation from the centers of appropriate Fraunhofer lines, in most cases the hydrogen line, H α , or the K-line of ionized calcium. Such spectroheliograms provided information about changes in intensity and motion across the line-of-sight for gases without a significant velocity in the line-of-sight.

In order to record more complete information on solar features with spectrum lines widened or displaced by Doppler shifts or by other causes, the McMath-Hulbert Observatory, in the early 1950's, began an experimental program of securing spectroheliograms in the wings as well as in the centers of the H α and K-lines of the solar spectrum. Observing techniques were developed by which a series of spectroheliograms were recorded in rapid succession with systematic changes in λ from 3 Å or more on the violet, to 3 Å or more on the red side of the center of the respective lines. It is of interest that observing techniques related to this program now have been adopted at a number of observatories.

Support from Nonr-1224(19) made possible detailed inspection of the early λ -sweep records obtained at the McMath-Hulbert

Observatory and led to the recognition on the solar disk of the solar features associated with the spectroscopic phenomenon known as Ellerman's "Solar Hydrogen Bombs," and the realization that the great systems of loop-type prominences constitute one aspect of certain great flares. In subsequent years, these spectroheliographic records have contributed to a series of analyses of the great center of activity of July 1959, and to the study of mass motions in solar flares for the 9th Nobel Symposium which was devoted to this topic. Certain of the observations of major H α flares in regions with small or no spots also stemmed from this program.

The publications listed below present the results of research on solar activity based on spectroheliographic data obtained at the McMath-Hulbert Observatory and sponsored, in part, by contract Nonr-1224(19).

- "Solar Features associated with Ellerman's 'Solar Hydrogen Bombs'," Proc. Nat. Acad. Sci., 46, 165, 1960, Robert R. McMath, Orren C. Mohler and Helen W. Dodson.
- "A Study of a Solar Active Region using Combined Optical and Radio Techniques," Ann. d'Ap., 23, 75, 1960, W. Christiansen, D. S. Mathewson, J. L. Pawsey, S. F. Smerd, A. Boischof, J. F. Denisse, P. Simon, T. Kakinuma, Helen Dodson Prince and John Firor.
- "Observations of Loop-type Prominences in Projection against the Disk at the Time of Certain Solar Flares," Proc. NAS, 47, 901, 1961, Helen W. Dodson.
- "Moving Material accompanying the Flare of 1959 July 16^d21^h14^m UT." AAS-NASA Symposium on the Physics of Solar Flares, NASA-SP50 October, 1963, p. 15, Helen W. Dodson and E. Ruth Hedeman.
- "Related Flares," Ap.J., 145, 224, 1966, Helen W. Dodson and E. Ruth Hedeman.
- "Direct Comparison of High Resolution Spectra with Concurrent Spectroheliograms," Report of Capri Conference on The Fine Structure of the Solar Atmosphere, June 1966, (published by Fraunhofer Institut, Freiburg, Germany), Orren C. Mohler and Helen W. Dodson.
- "East Limb Passage of An Active Solar Region, July 7-10, 1959," Ap.J., 150, 1087, 1967, Susan M. P. McKenna.
- "An Identification of Three Different Varieties of Solar Flare," Ap.J., 153, 367, 1968, Susan M. P. McKenna.
- "The Proton Flare of August 28, 1966," Solar Physics, 4, 229, 1968, Helen W. Dodson and E. Ruth Hedeman.

"Increasing Optical Evidence for Mass Motions in Solar Flares, 1937-1967," Report of 9th Nobel Symposium, 1968, pp. 37-52, Helen W. Dodson and E. Ruth Hedeman.

"The Behavior of the Active Region prior to the Proton Flare, July 7, 1966, based on λ -Sweep Records," Annals of IQSY, (M.I.T. Press, Cambridge, Mass.), 3, 1969, pp. 154-162, Helen W. Dodson.

"The Occurrence of High Energy Releases during Flares in Localized Areas of an Active Center and Time-associated Changes in Spot Umbrae," Ap.J. 159, 51, 1970, Susan McKenna-Lawlor.

"Major H α Flares in Centers of Activity with Very Small or No Spots," Solar Physics, 13, 401, 1970, Helen W. Dodson & E. Ruth Hedeman.

3. Research and development leading to improvement in solar instrumentation

Contract Nonr-1224(19) was granted in the year following the initiation of observations with the McGregor high dispersion, high resolution, vacuum spectrograph. Subsequent years saw almost continuous effort to improve still further the excellence of this fine telescope and spectrograph. New types of optical paths were developed and new instruments for analysis were designed and constructed.

With the aid of funds from Nonr-1224(19) the observatory pioneered in the introduction of mirrors of the new materials with "zero" coefficient of expansion. The success of the Cervit mirrors at the observatory's telescopes apparently was influential in the rapid and widespread adoption of this new type of material for astronomical mirrors.

Research under this contract also has led to the successful use of autopositive film in the photography of sunspots. Additionally, new types of film transport permit the rapid recording of spectra of changing solar features. In the most recent years, funds from Nonr-1224(19) have permitted the digitization of the output of the McGregor Spectrograph. The records of high resolution spectra are now obtained in forms ready for computer use and analysis.

The work in instrumental development at the McMath-Hulbert Observatory during the years of support from Nonr-1224(19) is reflected in part in the publications listed below.

"Performance of an Eight-Inch Babcock Grating in a Large Vacuum Spectrograph," JOSA, 47, 6-14, 1957, A. Keith Pierce.

"A High-Resolution Isophotometer," Ap.J. 125, 285, 1957, Orren C. Mohler and A. Keith Pierce.

- "Astronomical Telescopes," Encyclopedia of Sci. & Techn., p. 449, 1960, Robert R. McMath.
- "Telescope Driving Mechanisms," Stars & Stellar Systems 1, 62-79, 1960, (ed. by Kuiper & Middlehurst), Orren C. Mohler and Robert R. McMath.
- "Solar Instruments," Handbuch der Physik/Encyclopedia of Physics, 54, Astrophysics 5: Miscellaneous (Springer-Verlag, Berlin, 1962), Orren C. Mohler, Robert R. McMath.
- "Astronomical Telescopes," McGraw-Hill Enc. of Sci. & Techn. - Year Book 1962, p. 497, Orren C. Mohler.
- "A Double-Pass Pfund Spectrograph for Solar Research," Applied Optics, 3, 467, 1964, Orren C. Mohler and W. E. Mitchell, Jr.
- "The Herschel Effect and Solar Photography," Solar Physics, 12, 163, 1970, R. Jayanthan.

4. Studies directed towards a better understanding of solar-terrestrial relationships

Early studies of the radio frequency radiation at the times of solar flares made it clear that consideration of this aspect of the total flare event should lead to improved understanding in the complex field of the relationships between solar activity and geophysical phenomena. This work led to a number of publications directed towards a better recognition of the relationships between optical aspects of solar activity and phenomena observed at radio frequencies. A special investigation was made of flares associated with geomagnetic crochets. Finally, numerous studies were made of the flares that were associated with the great proton events and Polar Cap Absorptions.

In 1962, at the request of the Inter-Union Commission on Solar-Terrestrial Relationships, a study of a somewhat different type was undertaken. It appears as the article, "Problems of Differentiation of Flares with Respect to Geophysical Effects" and reviews the geophysical effects of flares during the years of maximum in solar cycle 19.

The following publications present the results of research on the effects of solar radiation on the earth, supported in part by Nonr-1224(19).

- "Resume of Visually and Photographically Observed Solar Activity at Time of 200-Mc/s Noise Storms near 1954 Solar Minimum," Ap.J. 125, 827, 1957, Helen W. Dodson and E. Ruth Hedeman.

- "Relation between Optical Solar Features and Solar Radio Emission,"
I.A.U. Symposium 4, Radio Astronomy, 327-333, 1957,
Helen W. Dodson.
- "Studies at the McMath-Hulbert Observatory of Radio Frequency
Radiation at the Time of Solar Flares," Proc. of the IRE,
46, No. 1, 149-159, 1958, Helen W. Dodson.
- "Geomagnetic Disturbances associated with Solar Flares with Major
Premaximum Bursts at Radio Frequencies \leq 200 Mc/s,"
J. Geophys. Res. 63, 77, 1958, Helen W. Dodson & E. Ruth Hedeman.
- "Crochet-Associated Flares," Ap.J. 128, 636, 1958, Helen W. Dodson
and E. Ruth Hedeman.
- "Flares of July 16, 1959," AJ, 65, 51, 1960, Helen W. Dodson and
E. Ruth Hedeman.
- "Photographic Observations of Certain Flares associated with Polar
Cap Absorption," Arkiv für Geofysic, 3, 469, 1961, Helen W.
Dodson and E. Ruth Hedeman.
- "Selected High-resolution Strip Scans of the 10.7-cm Sun," Ap.J. 135,
531, 1962, Arthur E. Covington, Gladys A. Harvey and Helen W.
Dodson.
- "Problems of Differentiation of Flares with respect to Geophysical
Effects," 10th Report on Solar-Terrestrial Relations of the
Inter-Union Commission on Solar and Terrestrial Relationships.
Pl. & Space Sci. 12, 393, 1964, Helen W. Dodson and E. Ruth
Hedeman.
- "An Unexpected Effect in Solar Cosmic Ray Data related to 29.5 Days,"
J. Geophys. Res. 69, 3965, 1964, Helen W. Dodson and E. Ruth
Hedeman.
- "The Proton Flare of 1965 February 5," Studies on Energetic Solar
Particle Events, 2, 4, 1966 (edited by Obayashi, Kyoto),
Helen W. Dodson.
- "Comparison of Solar Activity in Optical and Radio Wavelengths,"
The Obs., 86, 207, 1966, Susan M. P. McKenna.
- "Later Development of the Center of Activity of the Proton Flare,
July 7, 1966," Ann. of IQSY, 3, 1969, p. 215 (M.I.T. Press,
Cambridge, Mass.) Helen W. Dodson and E. Ruth Hedeman.
- "The Solar Particle Event of 1966 July 16-19 and its Possible
Association with a Flare on the Invisible Solar Hemisphere,"
Solar Physics, 6, 294, 1969, Helen W. Dodson, E. Ruth Hedeman,
S. W. Kahler and R. P. Lin.

"Description and Evaluation of the Major H α Flare, May 23, 1967,"
Publ. of World Data Center A, Rep. UAG-5, "Data on Solar
Event of May 23, 1967 and its Geophysical Effects" Feb. 1969,
Helen W. Dodson and E. Ruth Hedeman.

"Solar Circumstances at the Time of the Cosmic Ray Increase on
January 28, 1967," Solar Physics, 9, 278, 1969, Helen W.
Dodson and E. Ruth Hedeman.

"Comments on Solar Circumstances at the Time of the Great Radio
Frequency Burst, 1968 October 29, 1516 U.T." Upper Atmosphere
Geophysics (ESSA) Report No. 8, pp. 154-157, 1970,
Helen W. Dodson and E. Ruth Hedeman.

"Time Variations in Solar Activity," In press, Reidel Publishing
Company, for Leningrad Symposium of Inter-Union Commission
on Solar-Terrestrial Physics, Helen W. Dodson and E. Ruth
Hedeman.

CONCLUSION

It is with deep regret that the solar astronomers of
The University of Michigan face the termination of the long stand-
ing assistance of ONR in the pursuit of solar studies as represented
by Nonr-1224(19). It is with even deeper gratitude, however,
that they acknowledge the significance of ONR's sustained support
through this contract, to the progress of solar research. It is
hoped that this sense of appreciation by the solar astronomers
at The University of Michigan can be extended to all in ONR who
have been associated with Nonr-1224(19), and especially to Miss
Jean Streeter who for many years supervised the contract.

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13. ABSTRACT

Contract Nonr-1224(19), Project NR 046-799, terminated September 30, 1970 after fourteen years of support at The University of Michigan of a program directed towards basic research on the physics of the solar atmosphere and the effects of solar radiation on the earth. This continuing aid by ONR has played a significant role in the initiation and development of four general aspects of solar research: (1) Maps and analyses of high dispersion, high resolution solar spectra obtained with the McGregor Vacuum Spectrograph of the McMath-Hulbert Observatory; (2) Studies of solar activity with special emphasis on λ -sweep spectroheliograms; (3) Research and development leading to improvements in solar instrumentation; (4) Investigations in solar-terrestrial relationships.

All research conducted under the contract already has been reported through a series of reports and proposals prepared at appropriate times, and more especially through research articles published in professional journals. Funds from this contract provided partial support for research that led to the publication of 75 articles related to the purpose of the contract. These articles are referred to in the body of the report.

14. KEY WORDS	LINK A		LINK B		LINK C	
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