In summary, even in this moderate-sized river (discharge, about 44.6 km^3/year) (*12, 16*), physical mixing is very effective in diluting the Hg content a short distance downstream from each source so that the Hg content of the bottom sediment returns to normal by the time the sediments reach the lower river (Fig. 2); in comparison, effective downstream dilution in polluted European rivers is not achieved until the estuaries are reached (*17*). Overbank and channel deposits close to lode Hg sources are important depositional sinks that remove Hg from dispersing bed load sediment. Unlike nonmineralized or polluted river systems elsewhere (*1, 11*), tidal flats and carbonaceous delta swamps are not such important Hg sinks on a per unit weight basis as river levees and banks in the Kuskokwim drainage system.

Cinnabar-rich sediment disperses the greatest distance in the finest size fraction (< 0.062 mm); it extends farther downstream in tributaries than in the main river where relatively more sediment and water from nonmineralized terrane are available for dilution. Mining activity appears to artificially increase the dispersal distance of cinnabar-rich sediment because Hg is found greater distances downstream from mining sites than from similar-sized Hg deposits that are eroding naturally (Fig. 1).

On the basis of the average Hg content measured in our study and discharge estimates (*12, 16*) at the river mouth, we calculate that a total of 16,700 kg of Hg per year enters the marine environment from the Kuskokwim River. Of this total Hg content, 80 percent (13,400 kg) is transported by the water, 19 percent (3,130 kg) within suspended sediments, and 1 percent (160 kg) within bed load sediment.

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8. Water samples were collected in acid-washed polyethylene bottles, forced through 0.1-mm cellulose acetate membrane filters with N_2, and preserved by freezing as soon as possible on the day collected; an aliquot of $KMnO_4$ was added to the frozen sample just prior to thawing to prevent any possible loss of Hg by vaporization during thawing and to recover any Hg loss to the sample container which may have occurred during filtration and freezing; the same procedure was used for filters containing suspended sediment [P. Avotins and E. A. Jenne, *J. Environ. Qual.* **4**, 515 (1975)]; digestion was carried out at 80°C after transfer to Pyrex bottles and the addition of $K_2S_2O_8$. In the analysis of Hg we used cold vapor atomic absorption, with a $KMnO_4$-H_2SO_4 trap to eliminate both positive and negative interferences [S. H. Omang, *Anal. Chim. Acta* **53**, 415 (1971)].
9. Samples of bottom sediment were analyzed with an atomic absorption mercury vapor detector [W. W. Vaughn and J. H. McCarthy, *U.S. Geol. Surv. Prof. Pap. 501-D* (1964), p. 123], 30-element semiquantitative emission spectroscopy [D. J. Grimes and A. P. Marinizino, *U.S. Geol. Surv. Circ. 591* (1968)], and colorimetric analyses for Sb plus As [F. N. Ward *et al.*, *U.S. Geol. Surv. Bull. 1152* (1963)]. Samples of suspended sediment and bottom sediment with a Hg content of greater than 10 mg/kg were analyzed by flameless atomic absorption. Bed sediments were hand-ground to minimize the effects of a scarcity of Hg particles in the samples without significant frictional heat being introduced. Sediment was removed from the membranes with an ultrasonic probe in the presence of $KMnO_4$ to prevent volatilization. Sediments were solubilized in Teflon-lined bombs and then digested and analyzed (*8*). All analyses are in the U.S. Geological Survey RASS computer file (Bering Sea II). Data sets have been compiled from different regions, sediment types, and depositional environments; STATPAC functions [A. T. Miesch, *U.S. Geol. Surv. Prof. Pap. 574-B* (1967)] have been used on the data to calculate geometric means and geometric deviations, in the correlation analyses, and in developing graphical representations of the frequency distributions.
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15. Fine-grained suspended sediment, delta deposits, and tidal flats of this fluvial system are dominated by silts in this as well as other arctic to subarctic drainages (*13*). The clay content rarely exceeds 25 percent.
16. Calculations are based on Lisitsyn's (*12*) estimates of yearly water, suspended sediment, and bottom sediment discharge, which appear to be verified by data from the U.S. Geological Survey in *U.S. Geol. Surv. Water Supply Pap. 1959* (1970), *1966* (1970), *1996* (1971), and *2016* (1972).
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18. We gratefully acknowledge the assistance of J. W. Ball and J. M. Burchard in the analyses of water and suspended sediment, K. W. Leong in the analysis of bulk sediment, and the staff of the U.S. Geological Survey Field Services Branch in the analyses of pan concentrate samples. The Alaska Fish and Game Department assisted with field support, and D. R. Kerr compiled data for the figures and table.

21 September 1976; revised 20 September 1977

Anomalous Solar Rotation in the Early 17th Century

Abstract. *The character of solar rotation has been examined for two periods in the early 17th century for which detailed sunspot drawings are available: A.D. 1625 through 1626 and 1642 through 1644. The first period occurred 20 years before the start of the Maunder sunspot minimum, 1645 through 1715; the second occurred just at its commencement. Solar rotation in the earlier period was much like that of today. In the later period, the equatorial velocity of the sun was faster by 3 to 5 percent and the differential rotation was enhanced by a factor of 3. The equatorial acceleration with declining solar activity is in the same sense as that found in recent Doppler data. It seems likely that the change in rotation of the solar surface between 1625 and 1645 was associated with the onset of the Maunder Minimum.*

For more than a century it has been known that the solar photosphere rotates differentially with latitude, the equator completing a turn around the sun appreciably faster than the poles. Differential rotation, both in latitude and radius, is now generally believed to be a principal cause of the cyclic behavior of solar activity, through its coupling with the sun's magnetic fields in a solar dynamo (*1*).

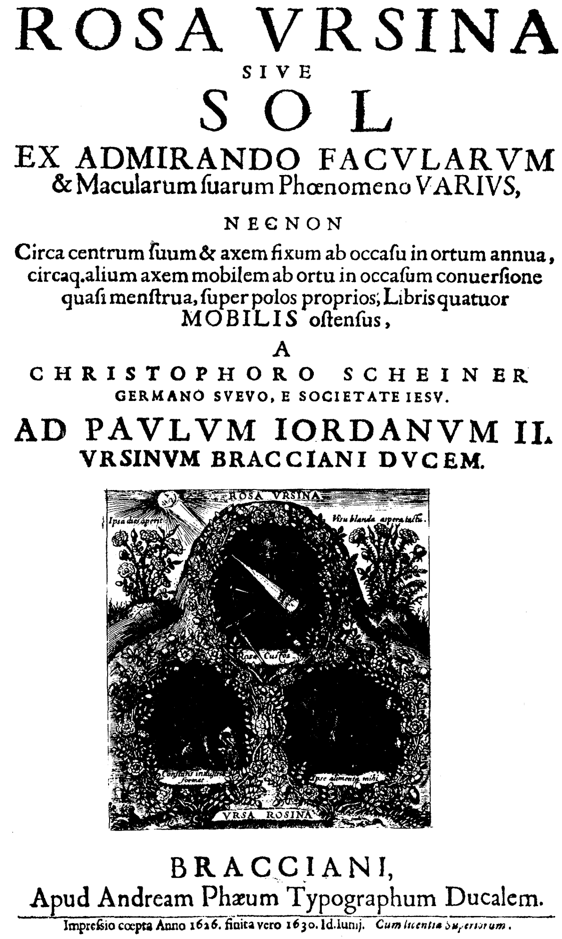
Until recently the character of solar differential rotation has been assumed to be constant. The present pattern was identified empirically by Carrington in 1863, from observations of sunspots as tracers over a 7-year period (*2*). Examination of subsequent sunspot data (*3, 4*) has produced no evidence for any systematic variation with solar activity, from minimum to maximum in the 11-year cycle, or from cycle to cycle. Differences of several percent were noted in the disk-averaged rotation rates derived before the time of Carrington (*5*), but these were attributed to the effect of sunspot "proper motions," or to less than adequate samples or technique rather than to any real, long-term changes in the character of the solar rotation itself.

A more immediate and potentially more precise picture of the differential rotation can be obtained from the Doppler shift of Fraunhofer lines at the limbs of the sun. With this method one measures directly the velocity of the photospheric gas rather than the possibly independent movements of the magnetic fields defined in sunspots; moreover, this method makes it possible to study solar rotation at higher latitudes where sunspots are seldom or never seen. Using the Doppler method, Howard has recently shown evidence for significant changes in the character of photospheric rotation in the current sunspot cycle (*6*), including a possible acceleration of the solar rotation at all latitudes as solar activity declines. These new results should be compared with earlier sunspot data for evidence of long-term or activity-related changes in the rotation of the sun.

We presented evidence earlier (*7*) that in the longer term the differential rotation may indeed vary. From an analysis of drawings of the sun made by Johannes Hevelius (*8*), we found that in the years 1642 through 1644—at the onset of a prolonged period, the Maunder Minimum, characterized by a dearth of sunspots—the pattern of surface rotation differed significantly from the modern norm. At that time equatorial regions completed a synodic rotation in about 25.9 days, or 1 day faster than the modern rate; differential rotation was present and, as now, was symmetric about the solar equator but was enhanced by about a factor of 3. We concluded that this change was probably associated, as cause or effect, with the Maunder Minimum anomaly of about 1645 through 1715 (*9*).

The implied change in surface rotation places new restrictions on models of the solar dynamo, and indirectly raises questions about the more basic issues of the stability and constancy of the solar convection zone and atmosphere. Thus it seems important to examine other available data from the same era as further checks on the reality of the rotational anomaly, and through probes of adjacent time periods to obtain a better definition of its onset and duration. Particularly important is the question of whether sunspot drawings made before the time of the Maunder Minimum show a normal or an abnormal rotational profile.

The best known and most extensive compilation of sunspot drawings before


ROSA VRSINA
SIVE
SOL
EX ADMIRANDO FACVLARVM
& Macularum ſuarum Phœnomeno VARIVS,
NECNON
Circa centrum ſuum & axem fixum ab occaſu in ortum annua, circaq. alium axem mobilem ab ortu in occaſum conuerſione quaſi menſtrua, ſuper polos proprios; Libris quatuor MOBILIS oſtenſus,
A
CHRISTOPHORO SCHEINER
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BRACCIANI,
Apud Andream Phæum Typographum Ducalem.
Impreſsio cœpta Anno 1626. finita vero 1630. Id. Iunij. Cum licentia Superiorum.

Fig. 1. Title page of the *Rosa Ursina*, printed in 1626 through 1630. The original size was 25 by 36 cm. The bear and rose in the title and plate were based on the name and emblem of the Duke of Orsini, who sponsored the work. [By permission of the Houghton Library, Harvard University]

Table 1. Solar rotation, 1625 through 1626 and 1642 through 1644. The synodic rotation rate $\bar{R}$ (in degrees per day) and the standard deviations σ and $\sigma/\sqrt{N}$ are from a sample N of sunspot measurements from Scheiner's *Rosa Ursina* and Hevelius's *Selenographia*.

Latitude	Individual spots				Sunspot groups			
	$\bar{R}$	σ	$\sigma/\sqrt{N}$	N	$\bar{R}$	σ	$\sigma/\sqrt{N}$	N
Longitude limit, 40°; Scheiner (1625 through 1626)								
30° to 25°	13.17	0.57	0.40	2	13.17			1
25° to 20°	13.00	1.03	.16	39	13.09	0.74	0.22	11
20° to 15°	13.28	1.02	.09	115	13.26	.79	.12	41
15° to 10°	13.25	0.85	.08	124	13.37	.58	.10	32
10° to 5°	13.24	.85	.09	100	13.29	.52	.09	34
5° to 0°	13.32	.80	.11	49	13.37	.39	.11	12
Longitude limit, 40°; Hevelius (1642 through 1644)								
20° to 15°	13.28	1.31	.24	29	13.25	.16	.09	3
15° to 10°	13.78	1.01	.19	68	13.79	.50	.15	12
10° to 5°	13.83	1.10	.09	150	13.76	.72	.12	36
5° to 0°	13.85	.84	.12	51	13.84	.27	.10	8
Longitude limit, 60°; Scheiner (1625 through 1626)								
30° to 25°	13.45	.55	.23	6	13.48	.45	.32	2
25° to 20°	13.16	.89	.13	55	13.35	.46	.13	13
20° to 15°	13.30	.98	.08	162	13.34	.67	.10	43
15° to 10°	13.32	.90	.07	164	13.35	.57	.10	35
10° to 5°	13.34	.90	.07	162	13.44	.59	.09	42
5° to 0°	13.46	.74	.09	71	13.48	.31	.09	13
Longitude limit, 60°; Hevelius (1642 through 1644)								
20° to 15°	13.25	1.26	.22	32	13.32	.12	.07	3
15° to 10°	13.84	1.00	.11	82	13.84	.44	.11	16
10° to 5°	13.93	1.35	.10	181	13.73	.84	.14	37
5° to 0°	13.83	.93	.11	69	13.68	.27	.09	10
Ward (1905 through 1954) (4)								
30° to 25°					12.95			
25° to 20°					13.15			
20° to 15°					13.30			
15° to 10°					13.40			
10° to 5°					13.48			
5° to 0°					13.53			

1640 is Scheiner's *Rosa Ursina* (*10*) published in 1630 (Fig. 1). This large and beautiful work deals exclusively with telescopic observation of the solar surface: sunspots, faculae, and the instruments and methods for observing them. The book has 784 pages and required 4 years to be printed. Included are thousands of individual observations on hundreds of engravings; among them are 66 full-page illustrations that show the whole disk of the sun, 22 cm in diameter, with exquisite sunspot details. In these large-scale data is an almost daily record of the sun from 1 January 1625 through 5 June 1626—about 20 years before the onset of the Maunder Minimum and 15 years after the introduction of the telescope. During this time solar activity seems to have been gradually falling: estimated sunspot numbers, according to Eddy's reconstruction (*9*), were 41 for 1625, 40 for 1626, and 22 for 1627 (Fig. 2). These numbers might correspond, for instance, to the declining phase in 1973, 1974, and 1975 of the solar cycle just ended.

Like Hevelius later, Scheiner recorded the passage of single spots or sunspot groups across the face of the sun on a single disk drawing, to demonstrate the solar rotation. Thus each full-disk drawing presents the appearance of the sun on about 13 consecutive days. This printing technique minimizes errors of registration between consecutive spot positions and is an invaluable assist in the data reduction reported here. Like Hevelius, Scheiner provided the precise time of day (in hours and fractions) at which each drawing was made. He also included as redundant information the elevation angle of the sun above the horizon, which we have used as a consistency check on the time of day through knowledge of the date and latitude of observation.

Scheiner's sunspot drawings were made, as today, by projecting the white-light image of the sun on a card, using a refractor with a focal length of about 2 m and an enlarging lens (Fig. 3). We suspect that these data, now 350 years old, are as accurate a representation of sunspot positions as one finds in modern drawings or photographs of the sun and are limited only by clock errors or possible distortion in the engraving and printing process. Certainly they show spatial detail equivalent to that achieved with a modern instrument of similar focal length. An example page is shown in Fig. 4.

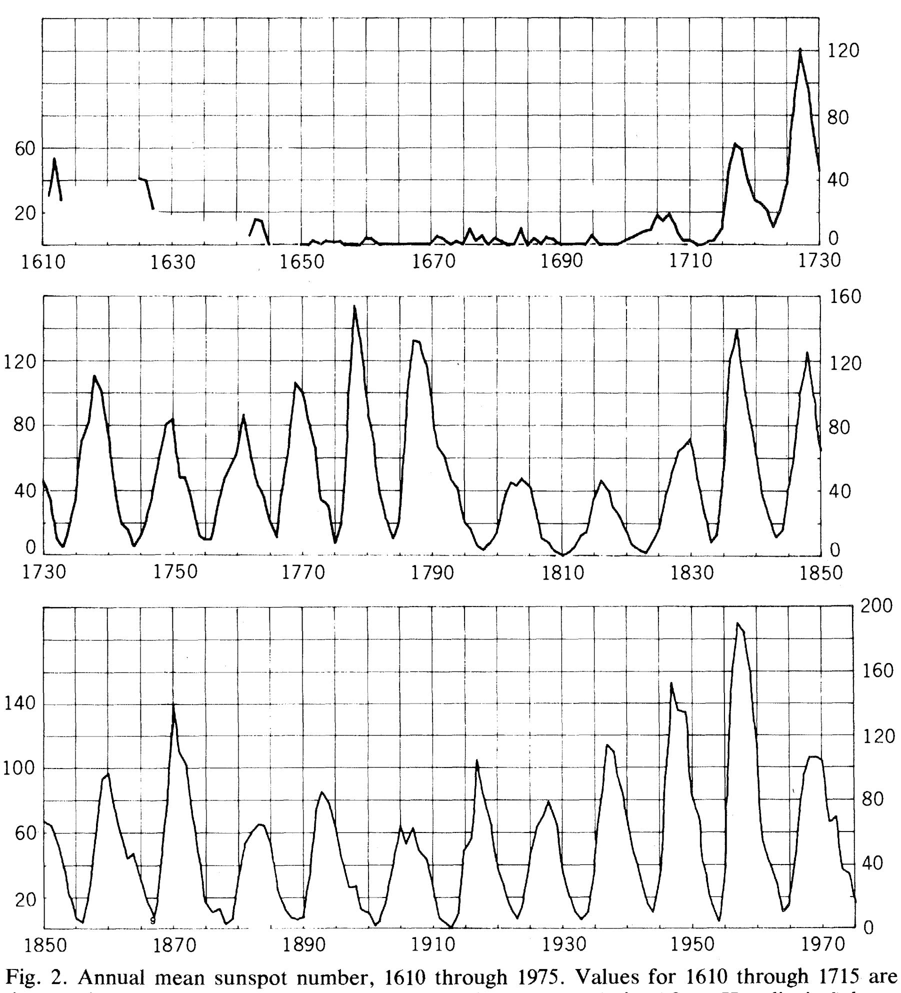

Fig. 2. Annual mean sunspot number, 1610 through 1975. Values for 1610 through 1715 are those estimated by Eddy (*9*). Data for 1642 through 1644 were derived from Hevelius's *Selenographia* (*8*); those for 1625 through 1627 are from the *Rosa Ursina* (*10*).

We have analyzed each of the 49 usable plates in the *Rosa Ursina* in the manner described in our earlier paper (*7*), to obtain measures of the rotation of the solar surface, using sunspot positions as tracers. In all, the positions of 768 recorded sunspots were utilized, covering the latitude range from 30°N to 23°S. The estimated positional accuracy for each spot is about ± 0.5° in heliographic latitude and longitude. We have used these spot positions and the differences in time between them to deduce surface rotation rates as a function of solar latitude for the period from 1625 through 1626.

Results are summarized below and are shown in Table 1 and Fig. 5.

1) Solar differential rotation between latitude limits of 20°N and 20°S was much less pronounced in 1625 through 1626 than in the apparently anomalous period 1642 through 1644; during the earlier period differential rotation was roughly the same as or slightly less than that during the modern era of "normal" solar activity.

2) The equatorial rate of solar rotation in 1625 through 1626 was less by about 0.6° per day than for 1642 through 1644, a difference of between 4 and 5 percent.

3) The latitude profile of solar rotation in 1625 through 1626 was more like that of the modern norm than that of the anomalous period from 1642 through 1644.

4) The distinctions described in items 1 through 3 persist when the data of 1625 through 1626 are broken into two consecutive, approximately equal subperiods. [This test was also applied to verify the findings for 1642 through 1644 (*7*).]

5) Sufficient observations are included in the two sets of 17th-century data to establish that four or five standard errors separate the derived rotation profiles for low-latitude regions in the data of 1625 through 1626 and 1642 through 1644. From this we conclude that the differences are statistically significant.

As with the etchings of Hevelius, Scheiner's drawings of the sun for 1625 through 1626 appear to have been executed and reproduced with considerable precision. Even so, it is possible that in either or both cases, optical distortions in the early telescopes could have introduced subtle systematic effects that the early astronomers could have overlooked and which would appear in our analysis as anomalies in the solar rotation. It is not hard to imagine the intrusion of such errors, particularly with the auxiliary, enlarging lens used then, as now, in projecting images of the sun large enough for tracing. If the outer zones of the solar image were to be magnified slightly more or slightly less than the center of the disk, the derived rotation rates would be proportionately distorted, no matter how careful the subsequent drafting. Indeed, Beckers (*11*) has recently shown that pincushion distortion in solar images from a modern refractor can lead to longitude errors of several degrees in apparent sunspot positions and to significant errors in derived solar rotation rates.

We have carried out several tests of both sets of 17th-century data to check on this possibility of error. In one we separated data by solar longitude intervals, to determine whether rotation rates derived for longitude zones nearer the limb of the sun differed systematically from rates derived from central zones. In this test we found no significant effects; differences found were at the level of 0.01° per day.

In another test, suggested by Beckers, we compared solar rotation rates determined from passage of spots across the central meridian, that is, for complete rotations of the sun, with those obtained from daily sunspot displacements. In this way, full rotation data might be expected to be free of distortion effects. Here, however, we are plagued by the Maunder Minimum anomaly: spots during the early 17th century, and particularly as the protracted sunspot absence developed, were few and noticeably short-lived. Only a small number were observed to persist for a full solar rotation in either of the 17th-century data sets, and so our sample is probably too small to permit application of the test. Moreover, to these few cases a large preliminary correction must first be applied: recurrent, long-lived spots are known to rotate almost 0.2° per day more slowly than the average of all spots, as shown in a comparison of the solar rotation data of Newton and Nunn (*3*), determined from recurrent spots, with that of Ward (*4*), for all spots.

In the period from 1625 through 1626, rotation rates derived from the five spots that persisted for a full rotation of the sun are not different from rates determined in the same data set from daily sunspot motions. In the data from 1642 through 1644, four recurrent spots were identified. All gave lower rotation rates than for daily displacements. For two of these the rate difference was about that anticipated, as described above, between recurrent and long-lived spots. For the other two the difference was about twice as large. These samples, we believe, are far too limited to signify more than a warning. Indeed, if an anomaly were found in two sunspots in modern data, it would surely be ignored.

We conclude that Scheiner's data from the *Rosa Ursina* establish a solar rotation behavior for 1625 through 1626 much like the modern norm, adding credence to the hypothesis that photospheric rotation developed an anomalous pattern at the subsequent onset of the Maunder sunspot minimum. In the 20 years between 1625 and 1645 the equatorial regions of the solar surface seem to have accelerated, to complete a rotation about 1 day faster than usual.

The sense of the acceleration, with higher equatorial rotation associated with lower sunspot activity, is the same as that reported by Howard in modern Doppler data (*6*), although about double the amplitude that he found between modern cycle maximum (1967 through 1970) and cycle minimum (1974 through

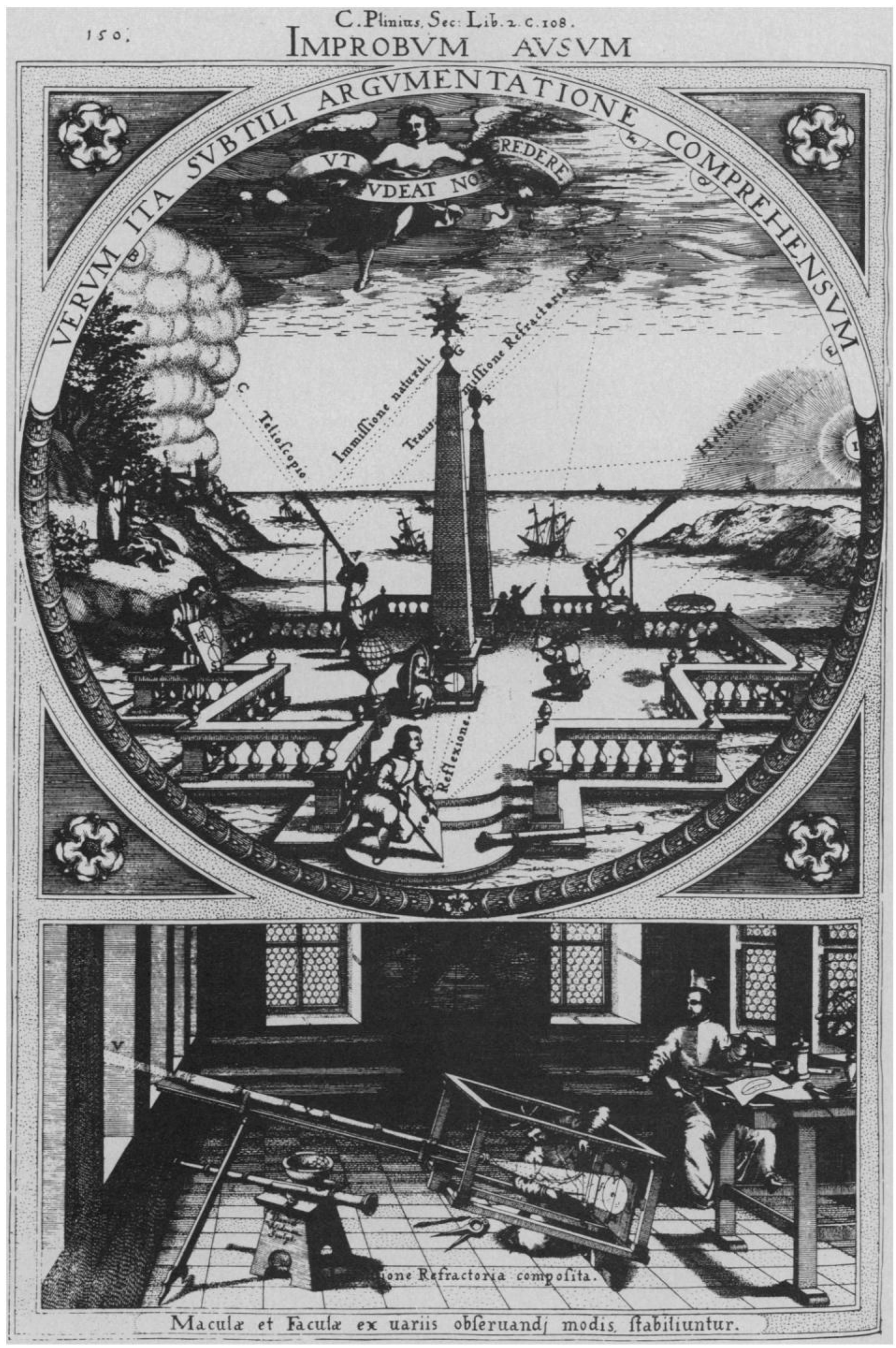

Fig. 3. An illustration from the *Rosa Ursina* demonstrating various methods for observing the sun in the 17th century. The lower inset portrays the more conventional manner in which drawings that became full-page plates were probably made; we may presume that the author, then about 50 and in appropriate clerical garb, is shown in this picture, probably at the right. [By permission of the Houghton Library, Harvard University]

1976). The correspondence may be misleading, for in one case we measure the velocity of sunspot magnetic fields and in the other photospheric gas. It is not known whether there was an increase in sunspot rotation rates from maximum to minimum in the cycle for which Howard made his measurements, but this possibility is being investigated. Also, the temporal regimes may be different: the apparent change in the 17th century may be of long term, possibly related to the gross depression of the envelope of solar activity; in the modern case the rotational change may reflect the phase of the 11-year sunspot cycle. Finally, the shape of the rotational profile derived for 1642 through 1644 differs from that found by Howard for the present cycle minimum, although the absence of sunspots above about 20°N and below about 20°S in the early data may hide crucial details of the distinction.

Further comparison of the 17th-century anomaly with modern evidence of cycle-related change requires that we identify the phases of the presumed 11-year cycle in which the early data were taken (Fig. 2). Unfortunately, there are not sufficient data to determine this unambiguously (*9*) or indeed to answer the more fundamental question of whether the 11-year cycle existed at all before about A.D. 1700 (*12*). In the rotational results reported here, for 1625 through 1626, we may have the suggestion of an affirmative answer: since differential rotation in Scheiner's observations was similar to that of modern times, we may assume that the action of the solar dynamo was like the modern norm and hence that there were 11-year sunspot cycles in existence at the time.

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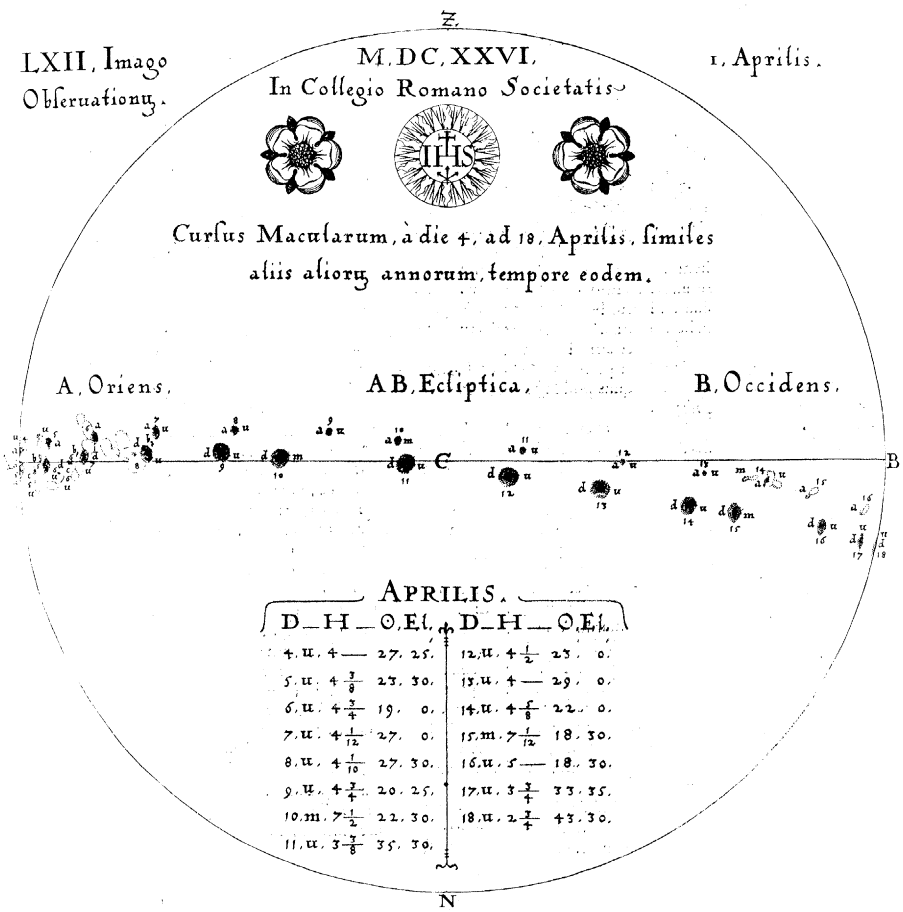

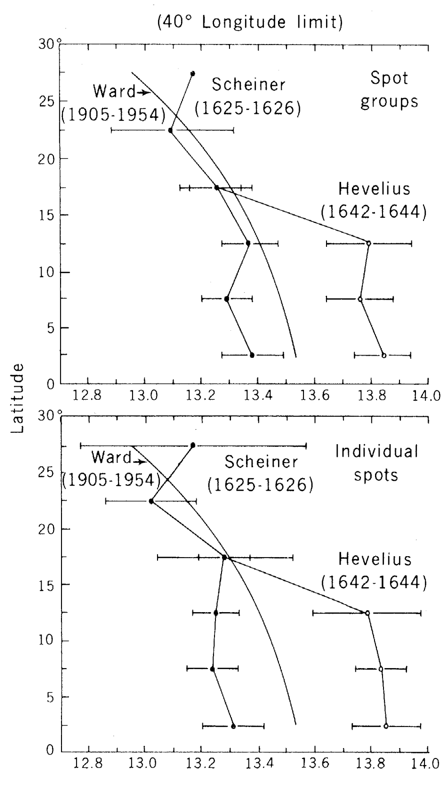

Fig. 4 (top). One of the 66 full-page plates of the sun from the *Rosa Ursina*, showing the daily locations of spots and faculae from 4 April to 18 April 1626. Original diameter, 22 cm. Flower medallions on either side of the Christian emblem at the top are the ursine or bearlike rose. [By permission of the Houghton Library, Harvard University] Fig. 5 (bottom left). Solar synodic rotation rates, in degrees per day, for the three periods 1625 through 1626 (solid circles) (*10*), 1642 through 1644 (open circles) (*8*), and 1905 through 1954 (smoth curve) (*4*), all from Table 1. Data shown are for spots within 40° of the central meridian. For each set, Northern Hemisphere and Southern Hemisphere data have been combined. Error bars on the 17th-century data depict the estimated standard deviation of the mean rotation rate determined for each belt of latitude. The data of Hevelius (open circles) extend only to the latitude belts 15° to 20° north and south of the equator.

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9. J. A. Eddy, *Science* **192**, 1189 (1976).
10. C. Scheiner, *Rosa Ursina sive Sol ex Admirando Facularum et Macularum . . .* (Bracciano, 1630). Christopher Scheiner (1575–1650), a Jesuit astronomer and mathematician, is best known as one of the codiscoverers of sunspots through the telescope—a distinction he shared with Galileo, Johan Goldsmid (Fabricius), and Thomas Harriot. His long enmity toward Galileo over the precedence of the discovery is a story often told. The truth seems of little import, however, since sunspots had been seen with the naked eye for nearly 2000 years before the advent of the telescope. Scheiner, to his credit, did the more thorough job of following up on the discovery,

as witnessed in the monumental *Rosa Ursina*. He chose the name *Ursine Rose* to honor the book's patron, Paolo Gordano, Duke of Orsini, whose family insigne featured a bear (from which the name Orsini derived) and a wild rose, which, as an elegant medallion, is generously sprinkled through the illustrations in the book. The subtitle ("Or the sun dotted by the surprising phenomenon of its faculae and spots, by the German Swabian Christopher Scheiner, of the Society of Jesus") (Fig. 1) explicitly describes the content of the volume and reveals Scheiner's particular interest in the photospheric faculae. The book includes scattered sunspot observations that were made during the full 18 years of the author's interest in the solar surface. In it he determined the rotation period of the sun as between 26 and 27 days (an average over latitude) and found the inclination angle of the solar axis to be between 6° and 8°—as compared to the accepted, modern value of 7°15′. He also noted that higher-latitude spots rotated more slowly.

11. J. M. Beckers, *Astrophys. J.*, in press.
12. J. A. Eddy, in *The Solar Output and Its Variation*, O. R. White, Ed. (Univ. of Colorado Press, Boulder, 1977).
13. Original copies of the *Rosa Ursina* used in this study are in the Houghton Library of Harvard University and in the George E. Hale collection at the Hale Observatories, Pasadena, Calif. We are indebted to O. Gingerich for assistance in securing photographic copies of the Scheiner data, and to J. Beckers, R. Noyes, and O. R. White for helpful comments. the work of J.A.E. was supported by National Aeronautics and Space Administration contract NAS5-3950, the Environmental Research Laboratories of the National Oceanic and Atmospheric Administration, and the Langley-Abbott program of the Smithsonian Astrophysical Observatory. The National Center for Atmospheric Research is sponsored by the National Science Foundation.

4 March 1977

Sedimentary Polycyclic Aromatic Hydrocarbons: The Historical Record

Abstract. *Polycyclic aromatic hydrocarbons in three sections of a dated sediment core from Buzzards Bay, Massachusetts, have been analyzed by gas chromatographic mass spectrometry. This historical information suggests that sedimentary polycyclic aromatic hydrocarbons, at least at this location, result primarily from the anthropogenic combustion of fossil fuels.*

The presence of complex mixtures of polycyclic aromatic hydrocarbons (PAH) and their alkyl homologs in soils and sediments from the New England region has been well established (*1–3*). In all cases, the qualitative distributions of the unsubstituted PAH and the relative abundances of the alkyl homologs within a given PAH series have been very similar (*4*). Before the geochemical significance of these findings can be determined, however, a detailed understanding of the sources of PAH in these recent sediments must be developed.

At present, there is a consensus that these PAH mixtures are not produced biologically (*3, 5*) but rather that they result from the deposition of combustion-generated airborne particulate matter (*3, 4, 6*). There is, however, no consensus on whether these particulates are natural (*2, 3*) or anthropogenic (*4, 6*). This is an important question. If the source were natural (forest fires, for example), man would have been exposed, for much of his history, to a burden of carcinogenic PAH to which he may well have developed a certain tolerance. On the other hand, if the source were man's activities, this tolerance probably would not exist since the level of environmental PAH would have been continuously increasing.

Semiquantitative measurements of the alkyl homolog distributions tend to suggest that sedimentary PAH could not result from anthropogenic airborne particulates (*3*). These data, however, are not conclusive because mechanisms which could modify the homolog distribution after the particulates have been deposited have not yet been taken into account (*4, 6*).

Other experimental information pertaining to the source of these PAH has been the recent finding of complex mixtures of azaarenes in sediments from Buzzards Bay (*7*). These investigators assume that azaarenes are produced by the incomplete combustion of plant material, and thus by inference that the PAH in these sediments are also produced by the combustion of plant material such as in a forest fire.

Still another experimental approach is to search for a historical record of PAH in the environment. Man's inputs of DDT (*8*), lead (*9*), and trace metals (*10*) have been recorded in the recent sedimentary record. Obviously, man's patterns of utilization of fossil fuels have also changed considerably over time, and, if the anthropogenic combustion sources of PAH are substantially larger than natural sources, this change should be reflected in the sedimentary record. We report here the analysis of PAH in three sections of a dated sediment core in an attempt to establish a historical record of PAH production and deposition.

The core sample was obtained from Buzzards Bay, Massachusetts (station P, 41°29.0′N, 70°52.5′W, 17-m depth), from an area where measurements of ^{210}Pb (*11*), ^{137}Cs, ^{239}Pu, and ^{240}Pu (*12*) provide a means of estimating the sedimentation rate. [An earlier study (*13*) of alkanes, cycloalkanes, and phenanthrenes in another sediment core from this location showed a trend of decreasing concentrations between the upper 2 cm and 54 to 58 cm, which pointed toward fossil fuel combustion as the principal source of hydrocarbons in these surface sediments.] The core was collected in August 1975 with a sphincter corer 21 cm in diameter and 1 m long (*14*). Three sections of the core were used for this study: the top 4 cm (1970), 20 to 24 cm (1900), and 38 to 42 cm (1850). There was no sulfide present in the top 8 cm. An oxic, bioturbation zone of about 4 cm was indicated by the ^{210}Pb depth

Table 1. Concentrations of PAH (dry weight basis) and distributions of alkyl homologs in three sections of a sediment core taken from Buzzards Bay. The estimated errors in the PAH concentrations are ± 20 percent. The relative abundances of PAH are expressed as a percentage of the total unsubstituted PAH (values in parentheses). The bioturbation zone is 4 cm (*11*); thus the error in the dates is ± 15 years.

Year of deposition	Depth (cm)	PAH concentration (ppb) and relative abundance						Homolog distribution	
		Phenanthrene	Fluoranthene	Pyrene	$C_{18}H_{12}$*	$C_{20}H_{12}$†	Total‡	Slope§	Standard deviation‖
1970	0–4	53 (7)	130 (16)	120 (15)	160 (20)	340 (43)	800	−1500	± 500
1900	20–24	42 (5)	130 (15)	120 (14)	200 (23)	380 (44)	870	−1400	± 600
1850	38–42	8 (13)	11 (17)	7 (11)	12 (19)	26 (41)	64	−1800	± 300

*Compounds of the formula $C_{18}H_{12}$, including chrysene, benzanthracenes, and triphenylene. †Compounds of the formula $C_{20}H_{12}$, including benzofluoranthenes and benzopyrenes. ‡Total unsubstituted PAH concentration, dry weight basis. §Slope of a least-squares line fitted to the average abundance (composited over the $C_{16}H_{10}$, $C_{18}H_{12}$, and $C_{20}H_{12}$ species) of the various alkyl homologs (normalized to 10^4 for the unsubstituted species) versus the number of alkyl carbon atoms. For details on this type of data presentation, see (*1–4*). ‖Standard deviation of the slope of the homolog distribution.