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MENZEL AND ECLIPSES

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1. *Introduction*

Eclipses played an important role in Donald Menzel's life, and thanks to him they do in mine.[1] In 1959, when I was a freshman, Harvard was trying to invigorate undergraduate education and started a project to bring senior faculty together with these first-year students. Underscoring the "Educator" portion of the title of this Centennial Symposium, Donald Menzel was one of the professors offering freshman seminars that first year. There were a dozen of us in the seminar,[2] and a substantial fraction went on to be professional astronomers.

A total eclipse of the Sun began over Massachusetts on 2 October of that year (Figure 1) and Dr Menzel arranged for an airplane to fly his freshman-seminar students and Observatory staff members above the expected clouds. I remember well this early morning flight, and obviously was inspired by the phenomenon that proved to be the first of the thirty-two solar eclipses I have seen. But it was the science and the spectacle that enthralled at the time; for all I knew all eclipses occurred over Boston. I only recently learned that we freshmen were not add-ons to the staff but, rather, it was vice versa. Menzel wrote:[3]

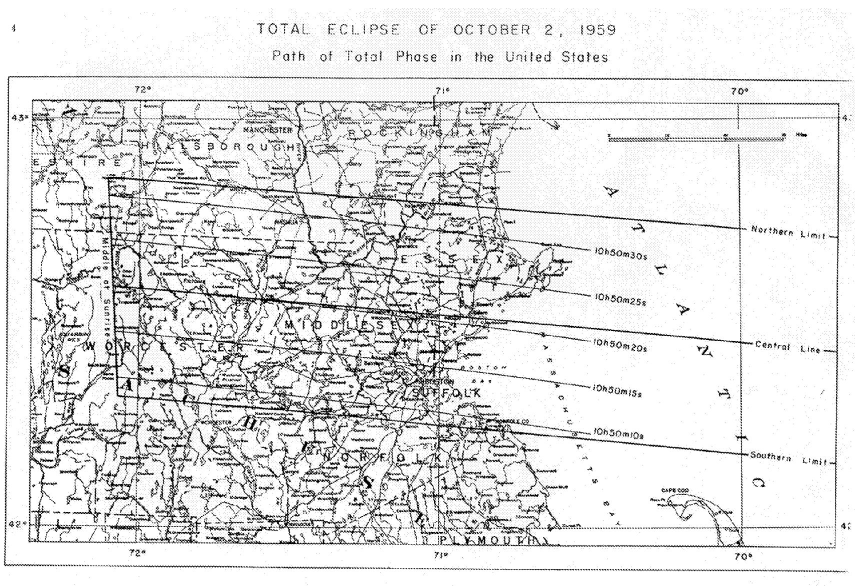

FIG. 1. The beginning of the path of the total solar eclipse of 1959 (U.S. Naval Observatory Circular).

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> We had a most auspicious beginning. Shortly after the start of the term, a total eclipse of the sun was scheduled to occur in the Boston area. The time was early in the morning, and at that season of the year, clouds were almost inevitable. I conferred with one of the high officials of Northeast Airlines, who generously placed a plane [a DC-6] at our disposal. As passengers, in addition to my Seminar Students, I included a few graduate students, faculty members, and McGeorge Bundy, Dean of Faculty. We had a marvelous view of the event and obtained some excellent photographs.

Menzel taught us about the Sun, of course, and I remember the Wednesday afternoons in the Building A classroom with the lights off, the temperature rising, and coronagraph movies showing. How lucky I was not only to have become interested in the solar atmosphere but also to have my dozing off during every movie interpreted in the most favourable way by D.H.M.: that I was bored and needed independent work. Dr Menzel set me up with Hector Ingrao to work on experimental matters, which led to my first published paper and to my career.

By the time I came on the scene, Menzel was just about my current age. He had published in a wide variety of fields. In addition to the many scientific papers, he had published several books, including books for kids and books for the general public. These books included the Peterson *Field guide to the stars and planets*, with which I am proud to be associated.[4]

In what follows, I have the benefit of a long autobiographical account written by Menzel in 1974. He reported, for example, that just before his senior year as a student at Denver University,

> On June 8, 1918, as a Boy Scout, I had witnessed my first total solar eclipse. There was also a Nova, a 'new star' in the constellation of Aquila, the brightest so far in the century and second in brightness only to Sirius. But I saw it and began to take an interest in astronomy and the constellations.[5]

2. *Observing Solar Eclipses*

Menzel received his Master's degree in 1921,

> and I accepted the offer of an assistantship at Princeton University.... During the summers of 1922 and 1923, I accepted a research position with the renowned Harlow Shapley of Harvard Observatory....[6] I also decided that I would like to see the total solar eclipse of September 1923 from Catalina Island, California.... At Catalina Island I found hopes high for the eclipse, since the 30 days prior to the event had been completely clear. But eclipse day found the sun covered with clouds and we had to be content with a few scant views of the crescent of the partial phases. Even so, I did not consider the eclipse a total loss, since I had the opportunity of meeting a number of well-known astronomers, especially those from the Yerkes Observatory, whose expedition I had been permitted to join.

TABLE 1. Donald Menzel's eclipses.

15 total eclipses	
8 June 1918	Evergreen, Colorado
10 September 1923*	Catalina Island, California
28 April 1930	Camptonville, California
31 August 1932	Freyburg, Maine
19 June 1936	Southwestern Siberia (Ak Bulak)
9 July 1945*	Canada
30 June 1954	Minneapolis-St. Paul
2 October 1959	Atlantic coast of Massachusetts
15 February 1961	Northern Italy
20 July 1963*	Orono, Maine
20 May 1966	Athens/Sunion road, Greece
12 November 1966	Arequipa, Peru
7 March 1970	Miahuatlán, south of Oaxaca, Mexico
10 July 1972	Prince Edward Island, Canada
30 June 1973	western Mauritania
* cloudy	(Florence Menzel was at ten of them)
annular eclipse	
24 December 1973	Pacific Coast of Costa Rica
our mutual experiment in absentia	
22 September 1968	Siberia

Eventually, Menzel was to go on to the sites of a total of fifteen total solar eclipses (Table 1), whose paths covered the world (Figure 2). His interest returned to solar eclipses while a post-doctoral astronomer at the Lick Observatory.

> In 1926, William Wallace Campbell was the Director of Lick Observatory. But he was also President of the University of California.... Dr. and Mrs. Campbell would sometimes visit the mountain for as long as a week or two. We became

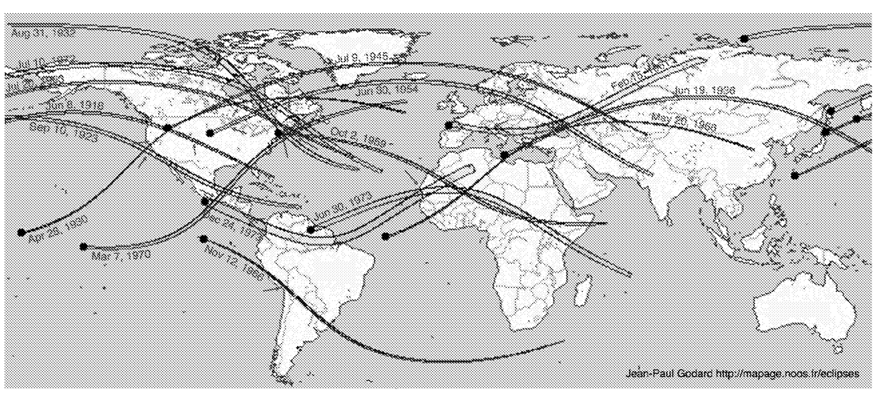

FIG. 2. The paths of eclipses that Menzel observed (courtesy of Jean-Paul Godard).

very good friends. We had a great deal in common, including a basic interest in that up-coming branch of astronomy: Astrophysics. No other member of the Lick organisation had more than a passing interest in Astrophysics and I felt very much alone, with no one to talk to, until Dr. Campbell visited the mountain.

Menzel did not enjoy his work on stellar spectra.

First of all, it was not my program and I had nothing to show for it, apart from my job except mention in a long list of contributing observers when the catalogue of radial velocities was finally published a number of years later.... Dr. Aitken assigned me one further task, which indeed I found extremely enjoyable. In fact, he had chosen me over a number of other possible contenders, since Professor Russell had spoken highly of my abilities to analyse spectra.

Dr. Campbell had been to many total solar eclipses: 1898 in India, 1900 in Georgia, 1905 in Spain and 1908 in Flint Island of the South Pacific. He had been to other total eclipses as well, but on the ones just mentioned he had secured spectra of the sun's chromosphere, the pinkish-hued atmosphere of the sun that gives, when the moon covers the bright, shining surface, a spectrum of bright lines.... Dr. Campbell had indeed secured a number of remarkable spectra, including some by his own unique method: the moving plate.... This assignment I found most exciting and, within less than a week, had made two fairly important discoveries... [Figure 3]. The moving plates clearly depicted the change from dark-line to bright-line spectrum at the moment of totality. I found, first of all, that the change from dark to bright was quite sudden for lines coming from "neutral" metals, whereas it was gradual for lines coming from "ionized" metals.... My second discovery was the occurrence of some peculiar lines that remained bright for a long time during the eclipse, often showing no indication of an associated dark line. This was puzzling indeed and I carefully measured the wavelengths of a couple of dozen of the most outstanding examples. Consulting a list of wavelengths, I was surprised to see that most of them came from a group of metals often referred to as "rare earths....

Years later, Charlotte Moore Sitterly confirmed the identifications of the 100 or so "c-lines" Menzel had found.

Menzel did not find Lick hospitable scientifically. As he wrote,

Dr. Aitken, learning of my interest in *theoretical* astrophysics, periodically scolded me for wasting my time. "After all," he would say, "this is an *Observatory*! Your responsibility is to make the observations and record them. Leave the theory to the poor, underprivileged British astronomers, such as Milne and Eddington, who don't have an observatory...." From time to time he asked me to report in detail on the tables I had produced of the lines of the flash spectrum and their identification. He thought this was fine. These were the observations. Publish them and get it over with.

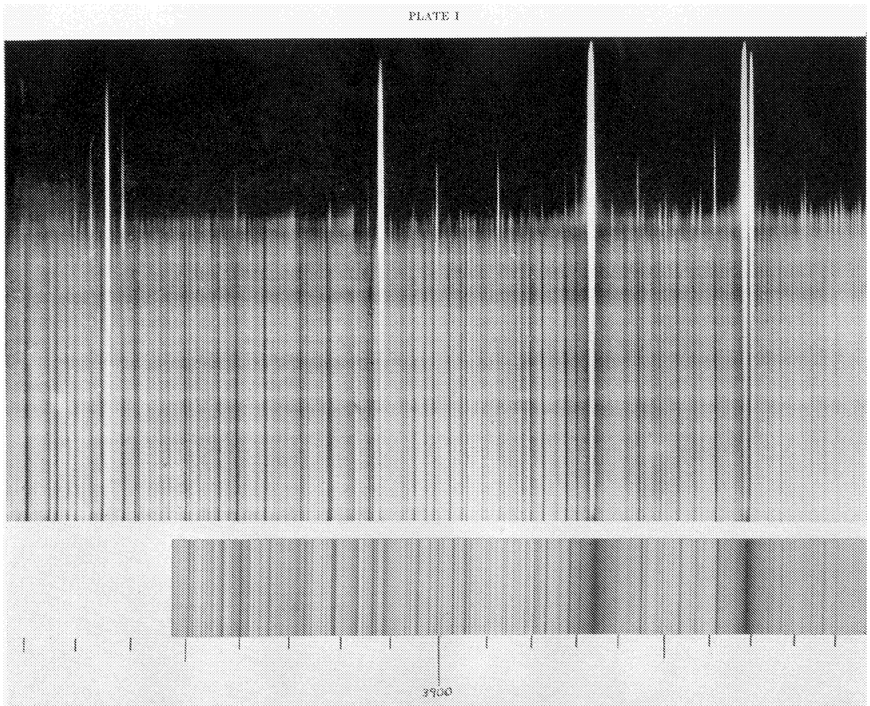

FIG. 3. A plate showing the evolution of the solar spectrum from absorption to the emission flash spectrum using the moving-film technique, from Menzel's 1931 magnum opus, in *Publications of the Lick Observatory*, xvii (1931).

> My work on the flash spectrum piqued my desire to obtain such a record for myself. The projected solar eclipse of April 28, 1930, over California gave us the opportunity. The eclipse was unusual, in that totality was predicted to last for a single second. This meant that we could not expect to get a flash spectrum on both sides of the sun. Indeed, I developed an adaptation of Dr. Campbell's moving-plate method for the purpose. Dr. Moore and I operated the instrument and obtained excellent spectra. One of the most startling features, which Doc found hard to believe, was the great intensity of the green and red coronal lines, which we photographed with an effective exposure of only one second.... From this single fact, we predicted that, under special circumstances, it should be possible to observe the spectrum of the sun's corona outside of eclipses.[7]

This prediction came true with Lyot's coronagraph, similarly to the way that Janssen's observations of a bright chromospheric line at the 1868 eclipse had led to his successfully observing the chromosphere outside of eclipse. Menzel wrote:

> On my return, I tried unsuccessfully to photograph the coronal spectrum with a

> 36-inch refractor. But I found that the amount of sunlight scattered by the numerous fine scratches on the objective completely obliterated the corona. A few years later, the French astronomer B. Lyot developed and invented the coronagraph and succeeded in photographing the coronal spectrum outside of eclipse.
>
> Between eclipses and other observing chores, I continued my theoretical analysis of the flash spectrum and obtained some results that, to me, were extremely exciting, though many of the old-timers simply refused to believe them.

In particular, on the basis of the high intensity of helium and ionized helium lines, he concluded that the chromospheric temperature was higher than that of the photosphere.

Menzel published minor articles on several aspects of the flash spectrum and eclipses in the intervening years, while he was preparing his major paper.[8]

> When, in the fall of 1930, after four years of concentrated work, I submitted my manuscript on the flash spectrum and the solar chromosphere to Dr. Aitken, he had — as I had expected — a fit. The publication was, I had to admit, a veritable tome about the size of a volume of the *Encyclopedia Britannica*. And I had stubbornly followed my own inclination, developing one of the first significant papers in the new Astrophysics.

Eventually, Menzel was allowed to publish his work.[9] Menzel found large deviations from thermodynamic equilibrium in the emission lines of hydrogen and helium. He derived the curve of growth for emission lines. He identified hundreds of spectral lines and multiplets (Figure 4). Cecilia Payne's initial results from analysing Harvard spectra,[10] that hydrogen dominated solar abundances, needed observational backing. Menzel's result that the mean molecular weight in the solar chromosphere was 2 persuaded Henry Norris Russell, and therefore others, that the light elements hydrogen and helium dominate the Sun and, eventually, the universe.

Leo Goldberg, in Menzel's obituary in *Sky & telescope*, summarized:[11]

> Among the chief results from this pioneering investigations were 1, a derivation of the abundances of the elements in the chromosphere; 2, a demonstration that the excited levels of hydrogen are overpopulated relative to a Boltzmann distribution; and 3, evidence that the neutral and ionized helium lines in the upper chromosphere and prominences are being formed in regions hotter than 20,000° Kelvin. The anomalously great intensities of the hydrogen and helium lines gave the first indication that the solar chromosphere was not simply a low-temperature extension of the photosphere.

As Menzel wrote,[12] "I became addicted to solar eclipses at an early age. Seventeen to be exact".

> My next opportunity to observe a solar eclipse came on August 31, 1932. We selected a site at Freyburg, Maine, for our expedition. Again, Dr. Moore and

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TABLE 1—(*Continued*)

Wave-lengths I. A. Sun	Flash	Intensities Sun	I	II	Spot	Heights Kms. × 10⁻³ I	II	III	Rev.	Class	Element Sun	Element Flash	Multiplet	Remarks
3912.983	.63	2		1N	1		2.5				Ni	Ni Pr⁺? *	Ni $a\,^3D_3-z\,^3D^o_4$	King
13.472	.49	5d?	20	25	3	20.8	24		15.9	b P10	Ti⁺	**Ti⁺** Fe	Ti⁺ $a\,^2G_{9/2}-z\,^2G^o_{9/2}$	Fe $a\,^3P_2-w\,^3D^o_3$
13.639		4			3						Fe			
14.183	.12	0		0	−1		2.5				Ce⁺?	Ce⁺?		
14.289	.30	3		1N	3		3				Fe	Ti V⁺? Fe	Ti $a\,^3F_3-y\,^3D^o_2$	V⁺ $a\,^3G_5-z\,^3F^o_4$
14.340		2									Ti			
14.514	.49	1	3Nd	3N	0	9.1	8.5			c? *	Ni ?	Ni ?		Estimated from Plate II
14.956	.30	0N		0			2.5				?	Dy⁺? *		King. Dy⁺ probably too faint
15.220	.30	1		1	0		2.5				Fe	**Fe**		
15.614	.62	3		1	2		3				?	Dy⁺? *		King. Dy⁺ probably too faint
15.812		5d?			3						– Cr?			
15.941	.92	1	3	3	0	7.5	8			cb *	Zr⁺	Cr? **La⁺ Zr⁺**	Cr $b\,^3D_3-z\,^3P^o_2$	La⁺ $a\,^3D_1-z\,^3P^o_1$ Double, c to red
16.060		0Nd?									La⁺			
16.407	.41	3	2	2	2	7.5	8			c	– V⁺	**V⁺** Gd⁺⁺	V⁺ $a\,^3P_1-y\,^3D^o_2$	King
16.723	.74	5	6	1	4	7.1	3.5				Fe	**Fe**		
17.186	.19	5	1	2	6	7.1	5			d	Fe	**Fe**	$a\,^3F_2-y\,^3D^o_2$	
17.655	.66	−2	1	0		5.5	2.5			c	?	Ce⁺?		
17.859	.89	0Nd?		0	−1		2.5				?	?		
18.258	.30	0		0			2.5				– Ce⁺	Ce⁺⁺		King
18.326	.38	4	3	2Nd?	3	8.0	7.5		1.3	d	**Fe** Mn	**Fe** Mn	Fe $a\,^3P_2-x\,^3D^o_3$	
18.420		4			3						Fe			
18.653	.64	5	1	1	4	8.0	3.5				Fe	**Fe**	$b\,^3G_5-28^o_5$	
18.897	.88	0		0	−1		2.5				?	**Pr⁺⁺**		King
19.071	.06	3		0	2		2.5				Fe	**Fe**	$b\,^3G_4-32^o_4$	
19.170	.18	3	3	3	3	7.9	6		0.9	d	Cr	**Cr**	$a\,^3D_1-z\,^3D^o_2$	
19.819	.82	0	0	1	0	5.2	2.5			c	Ti Ce⁺	**Ce⁺⁺**		King
20.271	.27	10	8	8	7	13.3	21.5		1.3	dw*P2	Fe	**Fe**	$a\,^3D_2-z\,^3D^o_1$	c to red
20.846	.81	2		0	1		2.5				Fe	**Fe**	$z\,^3D^o_2-3_2$	$z\,^3D^o_2-4_3$
20.968	.06	0	2N	1N		6.9	5			cd	Nd⁺	**Cr Nd⁺⁺**	Cr $a\,^3D_2-z\,^3D^o_3$	King
21.051		3			2						Cr			
21.558	.55	4	2	1N	2	6.9	3.5			c	La⁺ –	**La⁺**	$a\,^3D_2-y\,^3D^o_2$	
21.718	.70	4	1		2	6.9?				c	– Ce⁺	**Ce⁺⁺**		King
22.086	.14	1		0N	0		2.5				Fe Mn?	Fe Mn?	Fe $z\,^5D^o_4-e\,^5D_4$	Fe $z\,^7D^o_5-e\,^5D_4$
22.423	.38	1N	1	1	1	5.9	3.5			c?	V	V **Sa⁺** *	V $a\,^4D_{7/2}-x\,^4D^o_{5/2}$	King
22.925	.90	12d?	10	10	8	14.2	23		1.1	dw*	Fe	**Fe**	$a\,^3D_2-z\,^3D^o_2$	c to red?
23.504	.48	0		0	−1		2.5				Sc⁺	Sc⁺	$a\,^3D_3-z\,^3D^o_3$	
23.535	.56	4	1	0	4	6.6	3			cdw	Ti	**Ti Ce⁺⁺** V	Ti $a\,^3F_2-y\,^3D^o_3$	King
23.654		0			0						Ce⁺ – V			
25.016	.05	−1N	0		−1N	3.9	3				?	?		
3925.211	.25	4		1	4		3			c	Fe – V	V⁺ Fe	V $a\,^4F-{}^4F$	Fe $z\,^5D^o_3-3_2$

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Multiplet	I. Q.	E. P.	λ Lab.	Int. Lab. and T. C.	Intensity Sun	Element Sun	Spot	Intensity Flash	Element Flash	Theor.	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Height I	Height III	Height Rev.	Class	Remarks
																					H
$2^2P^o-4^2D$		10.15	4861.33	(9)	30	Hβ	9	100	**H**								25.6*			b	
$2^2P^o-5^2D$		"	4340.46	(8)	20N	Hγ	3	85	**H**				*8600*	*4720*	*1900*	*577*	26.7*			bP75	
$2^2P^o-6^2D$		"	4101.74	(7)	40N	Hδ	3	75	**H**				*4000*	*2300*	*1345*	*339*	27.6*			bP70	limit of plate
$2^2P^o-7^2D$		"	3970.08	(6)	5N	Hε		60	**H**				*2900*	*1260*	*657*	*107*	27.8*			bwP50	
$2^2P^o-8^2D$		"	3889.05	(5)	0	Hζ		75	**H He**								27.7*			bP75	
$2^2P^o-9^2D$		"	3835.39	(4)	abs.	Hη		55	**H**								27.0*			P50	
$2^2P^o-10^2D$		"	3797.90	(3)	0	Hθ		50	**H**											bP50	
$2^2P^o-11^2D$		"	3770.63	(2)	1	Hι		50	**H**											bP45	
$2^2P^o-12^2D$		"	3750.15	(1)	abs.	Hκ		45	**H**								60			bP40	
$2^2P^o-13^2D$		"	3734.371		abs.	Hλ		40	**H**								50			bP35	
$2^2P^o-14^2D$		"	3721.941		abs.	Hμ		35	**Ti⁺ H**								50			bP30	
$2^2P^o-15^2D$		"	3711.973		abs.	Hν		30	**H**								50			bP25	
$2^2P^o-16^2D$		"	3703.855		abs.	Hξ		25	**H**								45			bP20	
$2^2P^o-17^2D$		"	3697.154		abs.	Hο		20	**H**								45			bP18	
$2^2P^o-18^2D$		"	3691.557		abs.	Hπ		15	**H**								40			bP15	
$2^2P^o-19^2D$		"	3686.834		abs.	Hρ		10	**H**								30			bP12	
$2^2P^o-20^2D$		"	3682.810		abs.	Hσ		8	**H**								30			bP10	
$2^2P^o-21^2D$		"	3679.355		abs.	Hτ		8	**H**								30			bP9	
$2^2P^o-22^2D$		"	3676.365		abs.	Hυ		6	Fe Cr **H**								23			bdP8	
$2^2P^o-23^2D$		"	3673.761		abs.	Hφ		5	**H**								30			bP7	
$2^2P^o-24^2D$		"	3671.478		abs.	Hχ		5	**H**								23			bP6	
$2^2P^o-25^2D$		"	3669.466		abs.	Hψ		5d?	V⁺? **H**								23			bP5	
$2^2P^o-26^2D$		"	3667.684		abs.	Hω		4	**H**								17			bP4	
$2^2P^o-27^2D$		"	3666.097		abs.			4	**H**								17			b	
$2^2P^o-28^2D$		"	3664.679		abs.			4	**Y⁺ H**								17			b	
$2^2P^o-29^2D$		"	3663.405		abs.			1	**H**								8.5				
$2^2P^o-30^2D$		"	3662.258		abs.			7	**Ti⁺** H								23			bP3	
$2^2P^o-31^2D$		"	3661.221		abs.			−1	H								3				
$2^2P^o-32^2D$		"	3660.280		abs.			1	**Fe** H								6				
$2^2P^o-33^2D$		"	3659.423		abs.			1s	**Fe** H?								2				
$2^2P^o-34^2D$		"	3658.641		abs.			0	H?								6				
$2^2P^o-35^2D$		"	3657.926		abs.			1	**Ti** H?								7.5				
$2^2P^o-36^2D$		"	3657.269		abs.			1	Fe H?								6				
$2^2P^o-37^2D$		"	3656.666		abs.			0	H?								3				

FIG. 4. Parts of the tables of spectral lines (Table 1) and of multiplets (Table 3) from Menzel's 1931 tome.

> I concentrated on the flash spectrum. We decided to employ an entirely new technique, which has been more or less standard ever since. We called it the 'jumping-film....' It gave precise measures for a considerable interval during the pre- and post-totality phases, exactly timed, which enabled us to determine the density gradients in the sun's atmosphere.

The following day was his first on the Harvard Faculty. Later, he reported that he had

> learned a great deal from the study of my flash spectra. 1932, as it so happened, was the minimum of the sunspot cycle. Hence, the green coronal line was extremely weak. Alternatively, the red coronal line was strong. From this fact alone, I deduced that the atom responsible for the green line required higher excitation than that for the red line. And, to support my conclusion, I noted further that the flash spectrum underlying the area of the corona that showed one rather intense green region also had strong lines of helium and ionized helium. Since helium is an atom that requires very high excitation, I felt that the association between the green coronal line and the strength of the helium spectrum was no means a coincidence. Moreover, quantitative studies showed that the helium lines throughout the flash spectrum were much fainter in 1932 than they had been back in 1905, when Dr. Campbell obtained his excellent spectrum. Thus I inferred, there must be a close association between the intensity of helium lines and the activity of sunspots.

Menzel's development of the jumping-film spectrograph allowed him to get better detail in the spectra.[13] Menzel worked with Gawie Cillié, who was on a postdoctoral year at Harvard, on the intensities of the Balmer series, which Menzel had measured up to H_{31} at the 1932 eclipse. They analysed the hydrogen spectrum and the cause of its excitation. A major result was the derivation of the electron density in the lower chromosphere from measurements of the Balmer continuum.[14] Cillié died in 2000, and his obituary in *Astronomy & geophysics* cites this important paper.[15]

3. *The Discovery of Deuterium*

Of course, Menzel was doing other things than eclipses, and his next idea was an important one. In a paper for *Physical review* with R. T. Birge submitted on 27 May 1931, on the basis of the system of atomic weights, he computed the atomic weights expected for several elements and compared the results with mass-spectrograph measurements by Aston. Birge and Menzel found agreement for carbon, nitrogen, and helium.[16] But then, "Of the elements that permit an accurate comparison of the chemical and mass-spectrograph results, there remains only hydrogen". Aston's value was discrepant from the chemical value slightly, but

> outside the limits of error. It could be removed by postulating the existence of an isotope of hydrogen of mass 2, with a relative abundance of $H^1/H^2 = 4500$.

> It should be possible, although difficult, to detect such an isotope by means of band spectra.

The next year, also in *Physical review*, Harold Urey, F. G. Brickwedde, and G. M. Murphy reported that "Birge and Menzel have shown that the discrepancy between the chemical atomic weight of hydrogen and Aston's value by the mass spectrograph could be accounted for by the assumption of a hydrogen isotope of mass 2 present to the extent of 1 part in 4500 parts of hydrogen of mass 1".[17] They went on to evaporate "large quantities of liquid hydrogen and collecting the gas which evaporated from the last fraction of the last cubic centimeter". They increased the exposure time of their spectrograms enough to reach a ratio of 4500:1, and found faint spectral lines of what we now call deuterium. Indeed, "they were so weak that it was difficult to be sure that they were not ghosts of the strongly overexposed atomic lines". In their sample that had been evaporated near the triple point instead of at the boiling point, the lines were stronger, and they finally confirmed that "The relative abundance in ordinary hydrogen, judging from relative minimum exposure time, is about 1: 4000, or less, in agreement with Birge and Menzel's estimate". (Brickwedde, fifty years later, reported[18] that Aston later revised his result, invalidating the Birge and Menzel calculation, but that historically the calculation remains, as Urey reported in an addendum to his published Nobel lecture, "of importance in the discovery of deuterium. Without it, it is probable we would not have made a search for it and the discovery of deuterium might have been delayed for some time".) Indeed, there is more deuterium in the universe than any isotope other than those of helium.[19]

4. *Physical Processes in Gaseous Nebulae*

The 1930s also set Menzel off on a major set of scientific studies, which began with a famous paper by Menzel and Pekeris in 1935 about absorption coefficients and hydrogen line intensities.[20] This paper was followed by one by Menzel alone setting out a substantial research plan that was eventually to comprise eighteen research papers over the next eight years on the subject of physical processes in gaseous nebulae (Table 2).[21] Unlike the Sun, these nebulae are transparent, so solutions are more readily obtained. James Baker was one of his major collaborators; he was coauthor on eight of the papers. Lawrence Aller joined the team in 1938, becoming coauthor or author of thirteen of the papers. Only Malcolm Hebb and the senior physicist George Shortley for two papers each, and Leo Goldberg for one paper, supplemented the basic team of Menzel, Baker, and Aller. Menzel must have liked sequential work, since he went on in the early 1950s to coauthor a set of three papers on radiative transfer with Hari Sen.[22]

5. *Eclipse Expeditions*

To return to the post-1932 eclipse era, Menzel's next opportunity to test his ideas about the intensities of the coronal lines was at the 19 June 1936 eclipse, whose

TABLE 2. "Physical processes in gaseous nebulae" (a series of papers in the *Astrophysical journal*).

Menzel: I. Physical processes in gaseous nebulae: I. Absorption and emission of radiation, 1937
Menzel, Baker: II. Theory of the Balmer decrement, 1937
Baker, Menzel: III. The Balmer decrement, 1938
Menzel, Aller, Baker: IV. The mechanistic and equilibrium treatment of nebular statistics, 1938
Baker, Menzel, Aller: V. Electron temperatures, 1938
Aller, Baker, Menzel: VI. The equations of radiative transfer, 1939
Baker, Aller, Menzel: VII. The transfer of radiation in the Lyman continuum, 1939
Aller, Baker, Menzel: VIII. The ultraviolet radiation field and electron temperature of an optically thick nebula, 1939
Shortley, Menzel: IX. On the excitation of fractional multiplets by electron capture, 1940
Hebb, Menzel: X. Collisional excitation of nebulium, 1940
Shortley, Aller, Baker, Menzel: XI. Strengths of forbidden lines in p^2, p^3 and p^4 as a function of coupling, 1941
Menzel, Aller: XII. The electron densities of some bright planetary nebulae, 1941
Menzel, Aller, Hebb: XIII. The electron temperatures of some typical planetary nebulae, 1941
Aller: XIV. Spectrophotometry of some typical planetary nebulae, 1941
Goldberg: XV. The statistical equilibrium of neutral hydrogen, 1941
Menzel, Aller: XVI. The abundance of O III, 1941
Menzel, Aller: XVII. Fluorescence in high-excitation planetaries, 1941
Aller, Menzel: XVIII. The chemical composition of the planetary nebulae, 1945

path went from Greece into Siberia. As he wrote, "Dr. Shapley did not object to my expedition, provided that I not call on him for any financial support from observatory funds". He thus teamed up with M.I.T., especially to make use of its shop. They borrowed optical equipment from Lick and Yerkes, and received donations from over forty businesses. His expedition[23] included thirty-eight members, more than half the foreign visitors who observed that eclipse. He benefited from the assistance of Boris Gerasimovich, Director of the Pulkova Observatory in Leningrad. Only much later did his friendship and association with Gerasimovich cause him trouble, when he was investigated by anti-Communist zealots in the 1950s.

In 1936, Menzel's team joined Gerasimovich's expedition in Ak Bulak, a tiny village in southwestern Siberia, now in Kazakhstan, for two minutes of totality. His three months in Russia, transporting and setting up 14 tons of equipment, makes any of today's expeditions pale in comparison.[24] In Siberia, they travelled three days by private railway car, and then operated their experiments from that car and two baggage cars, which were placed on a siding. Less than three days before the eclipse, some of the local people dropped the largest spectrograph. Menzel reports that he "worked continuously, without sleep, for a full 56 hours".

> ... the morning of eclipse day dawned clear. But heavy clouds shortly began to form, and presently the sky was completely overcast. We did obtain occasional, fleeting glimpses of the sun at 'first contact,' ... but the situation was so unfavorable that ... I commented that I would sell out for about two kopeks.... But the cooling that occurred with the progress of the eclipse caused the clouds to drop into lower, warmer layers of air, where they began to dissipate. As totality

> approached, the sky became completely clear. We carried out our program without a single hitch.

Though scientifically the expedition was a big success, Gerasimovich himself was sent to a work camp in Siberia, in spite of Menzel's and Shapley's invitation for him to come to Harvard, and it was in Siberia that he died.

Scientifically, the 1936 eclipse substantiated Menzel's prediction that the coronal green line would be much stronger at that maximum phase of the sunspot cycle than it had been at the previous eclipse.[25] Remember that in the 1930s, the cause of the coronal green line and the coronal red line were still said to be from "coronium", though the periodic table had been filled in long since and only "helium" remained as an element discovered at an eclipse. Menzel's work was one of several lines of evidence at the time that the corona was indeed hot. Grotrian had reported that electrons moving rapidly in a hot corona could broaden the photospheric absorption lines so much that they became all but invisible. He reported that he might even have detected a broad dip in the spectrum from the strong ultraviolet lines, though Menzel and I showed in *PASP* in the 1960s that his supposed detection was below the film accuracy.[26] The topic remains a current one, rejuvenated by theoretical work by Lawrence Cram in Australia in the 1970s and by observational work by several groups, including my own, at recent eclipses.[27]

CCD two-dimensional detectors now allow observations to be made at the 1 percent photometric accuracy needed to provide temperatures to a few hundred thousand kelvins. Ichimoto's group from Japan and my own group made spectral and polarization observations at the 1994 eclipse.[28] Davila and Reginald and my own group made observations at the 1999 eclipse to provide coronal temperature maps with this method, useful to compare with maps from SOHO based on permitted spectral lines observed in the ultraviolet rather than the forbidden lines that were the subject of Menzel's studies.

In any case, with the work of Bengt Edlén in the early 1940s, identifying the coronal green line as coming from thirteen-times ionized iron and the coronal red line as coming from ten-times ionized iron, the problem of "coronium" was solved. The corona is millions of degrees, as we see every day with X-ray observations from Yohkoh and with far ultraviolet observations from SOHO's Extreme-ultraviolet Imaging Telescope and from TRACE, both observing at the wavelengths of highly-ionized spectral lines that come only from atoms at temperatures at millions of kelvins.[29]

Menzel's war service was interesting and complicated, and prevented him from pursuing eclipse work. He writes,[30] "Hence it was not until 1945, near the end of the war, that I was able to organize another expedition. I was still an officer in the U.S. Navy, on active duty, but our studies of the effects of solar activity on radio propagation had convinced the high command of the value of such basic research". Collaborating with the director of the Dominion Observatory and with the Canadian spectroscopist Gerhard Herzberg, they involved amateur astronomers in the expedition, a forerunner of Menzel's work with amateurs of Educational Expeditions

TABLE 3. Books by Donald H. Menzel.

Menzel, *Stars and planets: Exploring the universe*, 1931, 1935, 1938
Menzel, *Mathematical physics*, 1947, 1953, 1961
David Todd and Menzel: *The story of the starry universe*, 1948
Menzel, *Flying saucers*, 1953
Menzel, *Our Sun*, 1949; 2nd edn 1959
Menzel, *Fundamental formulas of physics*, 1960
Menzel, B. Z. Jones, L. G. Boyd, *Writing a technical paper*, 1961
Menzel, *Selected papers on physical properties in ionized plasmas*, 1962
Menzel, P. L. Bhatnagar, H. K. Sen, *Stellar interiors*, 1963
Martha Martin and Menzel, *The friendly stars*, 1964
B. W. Shore and Menzel, *Principles of atomic spectra*, 1968
Menzel, F. L. Whipple, G. de Vaucouleurs, *Survey of the universe*, 1970
Menzel: *A field guide to the stars and planets*, 1964
  Menzel and J. M. Pasachoff: 2nd edn, 1983
  Pasachoff and Menzel: 3rd edn, 1992
  (Pasachoff, 4th edn, 2000)
Menzel, C.-S. Yu, *Astronomy*, 1971
Menzel, E. H. Taves, *The UFO enigma: The definitive explanation of the UFO phenomenon*, 1977

International (EEI), now Earthwatch, at the 1972 eclipse, years later. Unfortunately, heavy clouds obscured the eclipse for them.

In 1954, faced with bad weather forecasts for an early morning eclipse, Menzel decided to observe the eclipse from the air near Minneapolis. He was disappointed in the photographs, though, because of the plane's motion, and more disappointed when it turned out to have been clear on the ground.

By 1959, he had revised his popular book, from the Harvard Series on Astronomy, *Our Sun*, whose first edition had been ten years earlier. The book was the basis for an award-winning television show, "Our Mr. Sun" (1956), which is still readily available on videotape, and to the influence of which there are many testimonies posted on the World Wide Web. In his many books (Table 3) Menzel discussed not only the Sun but also the rest of astronomy and, famously, English grammar and writing style.

The 1959 eclipse, my first with him, we have already discussed. In 1961, he took some people, including students, to northern Italy. They saw the eclipse in perfect weather over the Mediterranean.[31] On 20 July 1963, he went to Maine for the eclipse, and was clouded out. In 1966, he saw two eclipses. The first was from midway between Athens and Cape Sunion, in Greece. It was an annular eclipse so close to total that one could take spectra of not only the chromosphere but also the corona.[32] In November 1966, he saw the total eclipse from an Indian village near Arequipa, Peru.[33] He worked there with his old friend Fernando de Romaña, a Peruvian amateur astronomer.

In 1968, I was to join him on an eclipse expedition to the Soviet Union. He had a formal invitation to visit. But in the aftermath of the Soviet invasion of Prague, exchanges were cancelled and so was our expedition. We sent some apparatus to a Russian colleague, who produced polarization measurements for us.[34]

1970 was the year when I worked with him as the Menzel Research Fellow in the

Harvard College Observatory, my first postdoctoral year and the first time since my freshman year I had official relations with him. Although I had remained at Harvard for my graduate work, my Ph.D. had been with Bob Noyes and Gene Avrett (on the fine structure of the solar chromosphere as observed from Sac Peak and Kitt Peak). Menzel had graciously drawn the frontispiece for my thesis (Figure 5). As Menzel reports, "In February of 1970, from a small Indian village in southern Mexico, I viewed what was my most spectacular eclipse. Never had I seen such a perfectly clear sky. A deep blue right up to the edge of the sun".[35] Menzel and I had built a spectrograph for the occasion to take wide-field coronal spectra, with a Schmidt-camera design by Jim Baker (Figure 6). It was quite an education to watch and assist Menzel and Baker set up the spectrograph for testing in the Building A classroom at the Observatory. I learned about shims, about tightening screws by hand, and about a host of other tricks of the trade that one doesn't learn from reading books. We had the support of a grant from the Committee for Research and Exploration of the National Geographic Society, and on our return were able to publish a popular story about the expedition in *National Geographic magazine*, a separate activity of the Society from the research committee.[36] Our observations were made in exceptionally clear conditions,[37] perhaps the best that obtained until the African eclipse of 2001.

Our observations were so successful that on returning to Cambridge, Mass. from Mexico, Menzel and I decided to look ahead immediately to the 1973 eclipse, at 7 minutes and 4 seconds at its peak the second longest in the saros series (second only to the preceding eclipse in the sequence, in 1955) and almost as long as theoretically possible. We put a large *National Geographic* map of Africa up on Dr Menzel's office door, and I plotted the points from the eclipse predictions. I looked at the zone in which the eclipse exceeded 7 minutes and searched for the nearest city: Timbuktu.

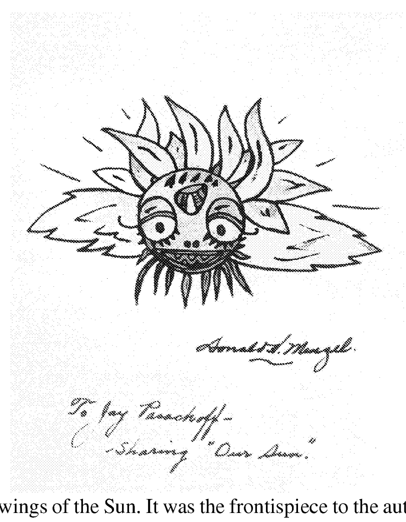

FIG. 5. One of Menzel's drawings of the Sun. It was the frontispiece to the author's Harvard Ph.D. thesis, 1969, and was subsequently coloured.

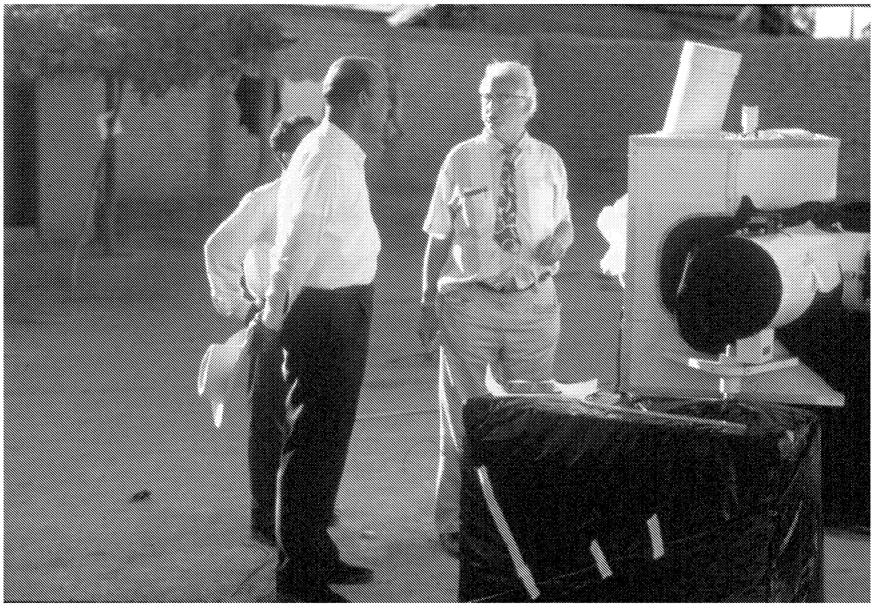

FIG. 6. Donald Menzel with M. K. Vainu Bappu at the 1970 eclipse in Miahuatlán. A former student of Menzel's, Bappu was leading the Indian eclipse expedition to Mexico. To the right is part of the Harvard-Smithsonian spectrograph. Photograph by Jay Pasachoff.

I hadn't even known Timbuktu existed. Sure enough, Menzel and I were within weeks on a plane to the Sahara desert reconnoitring. We went to Agadez in Niger and Timbuktu in Mali. Though the trip was one of the most fascinating of my life, we decided that the Sahara desert two hours north of Timbuktu was not a desirable place to bring tons of equipment, a decision endorsed by a dust storm in the Sahara for much of the next couple of years.

First we did a joint expedition to Prince Edward Island, Canada, for the 10 July 1972 eclipse. We involved a young machinist and amateur astronomer, Dennis di Cicco, now a distinguished editor at *Sky & telescope*. We took our big Baker-designed coronal spectrograph. Unfortunately, the weather on the ground was partly hazy. Though one could see the eclipse through the clouds, it impeded the observations.

Finally, Menzel and I coordinated our activities for the 30 June 1973 eclipse, but we went to different places. Menzel took a group and a set of scientific experiments to Mauritania, with the assistance of EEI. They were to have over 6 minutes of totality there, but a high chance of obscuration by dust. I went with the official NSF US team of astronomers to northern Kenya for more than 5 minutes of totality, a somewhat higher chance of clouds, but a better chance of dust-free skies. In the event, a dust storm came up in Mauritania, dropping transparency to 10 percent. They did image the corona and its polarization. We had clear weather in Kenya, where our principal experiment was observing the ratio of the infrared spectral lines of twelve-times-ionized iron, using a new kind of electronic detector, a silicon vidicon.

That series ended Menzel's total eclipses. The Menzels had a retirement home in Costa Rica, and the annular eclipse of 24 December 1973, was visible there. Joined by a group of amateurs, Menzel observed the eclipse. Dennis di Cicco's well known series of views on a single frame showing the progression of the annular eclipse, which graced the cover of *Sky & telescope*[38] and many a wall, was taken there.

6. *The Value of Eclipse Observations*

I will let Menzel have the last word on eclipses, since he expresses sentiments with which I heartily agree.[39]

> Although space research and coronagraphs have lessened the need for eclipse observations, there are nevertheless still problems and puzzles concerning the physical conditions of the sun's outer atmosphere, especially of the corona, which can best be resolved only at such events. Hence, I predict that for some decades to come, astronomers will continue to observe eclipses. But even when no more scientific gain is to be expected, people the world over will continue to enjoy the experience of such an observation, and its beauty.... Science itself has contributed enormously to human knowledge, by making it possible for mankind to observe and enjoy a spectacle which, centuries earlier, nearly everyone regarded with superstitious fear.[40]

Acknowledgments

Menzel's eclipse work was sponsored in his later years by the Committee for Research and Exploration of the National Geographic Society, and I am grateful for their sponsorship of my own eclipse research as well since our joint expedition in 1970. My recent expeditions have also been supported by grants from the Atmospheric Sciences Division of the National Science Foundation, most recently through ATM-0000575.

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2. Menzel's Freshman Seminar, Fall 1959: *Four who became astronomers:* Ken Janes, Professor and former Chair, Boston University; John Leibacher, former Director, National Solar Observatory; Don Goldsmith, former professor, astronomy author; Jay Pasachoff, Professor and Observatory Director, Williams College and, during 1969–70, Donald H. Menzel Research Fellow in the Harvard College Observatory, a position funded in honour of D.H.M. for a five-year term by his friend Edwin Land of the Polaroid Corporation. *Other members:* Nan (Evans) Krien, daughter

of Jack Evans, director of the Sacramento Peak Observatory; John Fryer, now of Washington, DC; Richard Goodman, now professor of mathematics, University of Miami; Tony Rossmann, now a lawyer, San Francisco; Margaret (Horton) Weiler, now of Bradford, NH; K. Paul Smith, Aloha, OR; Aquila Chase, now of Santa Barbara, CA; Jeff Hill, Washington, DC, lawyer, Office of Management and Budget.

3. Quotations throughout will be taken from Menzel's unpublished *Autobiography* (1974), a 681-page double-spaced typescript. I thank Florence Menzel, Elizabeth Menzel Davis, and Suzy Menzel Lindeman Snyder for permission to read and to quote from this autobiography. Copies have been deposited at the Niels Bohr Library, American Institute of Physics, College Park, Maryland, and the Harvard University Archives.
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G. Baker, Julian W. Feiss, Fred L. Whipple, John W. Evans, Ernest H. Taves, and Leo Goldberg. Goldberg writes: "He continued to be fiercely loyal to his former students long after they had departed from Cambridge. I never saw the letters of recommendation he wrote for me, but Harlow Shapley once told me he had read one that even made him squirm a bit."

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Defense Research Board and carried out auroral research. Osterbrock concludes, from the writing style, that Petrie may have made the measurements in the summer of 1942 and written the paper. Menzel was busy with war-related projects at the time. No doubt, other scientists also published results based on the joint Harvard-MIT expedition that Menzel had headed.

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38. D. di Cicco, *Sky & telescope*, xlvii/3 (March 1974), cover, 145, 147. The annular eclipse of 24 December 1973 was photographed from Playa Flamingo, Costa Rica.
39. Jay M. Pasachoff, "Solar-eclipse science: Still going strong", *Sky & telescope*, ci (2001), February issue, 40–47.
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