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RAPID H-ALPHA VARIABILITY IN PHI PERSEI

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ABSTRACT

A search for rapid variability of Hα with a time resolution from 30 to 45 seconds is performed for φ Per. In total, 42 spectra in Hα were obtained during three nights. Our results show the presence of rapid irregular variability (time scale of a few minutes) of the equivalent width of the Hα line in φ Per.

Key words: φ Per–rapid Hα variability–emission-line profiles

I. Introduction

According to Slettebak (1979), Be stars may be defined as nonsupergiant early-type stars showing Balmer emission lines in their spectra, including also Oe and Be shell stars. Origin of emission lines is from an extended gaseous envelope surrounding the central star. The majority of the studied Be stars are rapid rotators and are irregularly variable both spectroscopically and in magnitude. Moreover, there are many Be stars which can completely lose their line-emitting envelopes for extended intervals of time, leaving a normal absorption-line B-type star, until some time later on a new envelope develops again (Hubert-Delplace and Hubert 1979; Slettebak 1979; Jaschek *et al.* 1980; Underhill and Doazan 1982; Kogure and Hirata 1982). Thus, studies of variability for a variable-unstable system may be of great importance for understanding the Be-star phenomenon.

The variability of Be stars with time scales of years, months, and days is well known (Underhill and Doazan 1982). However, regarding rapid variations on time scales of hours and minutes, there are different opinions by different authors. These variations have been reported for the lower Balmer lines. Many observations have been taken for rapid variations in the total emission strength (Bahng 1971, 1976; Slettebak and Snow 1978) and also for line-profile variations (Hutchings *et al.* 1971; Hutchings 1967, 1969, 1976; Doazan 1976; Fontaine, Lacombe, and Wesemael 1983; Chalabaev and Maillard 1983). To find out the rapid variability, a method of cross-correlation analysis was developed by Bijioui and Doazan (1979) which they applied to high-resolution (0.15 Å) observations of α Columbae. Their results show a slow, weak variation extending over several nights and also show rapid irregular variations. They have shown from statistical tests that these variations are real. On the basis of low-resolution observations (4 Å to 5 Å) Lacy (1977) has found that fewer than 5% of the Be stars undergo detectable variations, and the reality of these rapid variations has been questioned by him. A similar conclusion has been drawn by Slettebak and Reynolds (1978) on the basis of their low-resolution observations (5.5 Å). On the other hand, Slettebak and Snow (1978) have also indicated the presence of rapid variations in γ Cassiopeiae. Fontaine *et al.* (1983) and Chalabaev and Maillard (1983) obtained rapid high-resolution observations (0.2 Å) of Hα and Paschen lines for certain Be stars, but they did not detect any rapid variations of the line profiles. Thus, in the present situation no clear picture is available for rapid variability in the envelope of Be stars.

It is important to mention here that instrumental and atmospheric variations which can produce spurious results have to be analyzed very carefully to confirm the reality of the rapid variations. In this paper we present the results of rapid Hα equivalent-width (EW) variations of φ Persei, which is a binary Be star.

II. Observations

The Hα scans were obtained on three nights between October 1985 and November 1985, using the photoelectric spectrometer at the 102-cm Cassegrain reflector of Vainu Bappu Observatory, Kavalur, India. The automated spectrum scanner has been described by Bappu (1977).

Hα line profiles were always measured in the first order of the scanner grating (1800 lines mm^{-1} blazed at 5000 Å), using an exit slot the width of which corresponds to 3 Å in the spectrum. The diameter of the entrance diaphragm is 0.60 mm and the exit slot is 0.33-mm wide, which corresponds to 3 Å in the first-order spectrum. Forward scans were recorded in wavelength increments of 3 Å over a wavelength range of 180 Å to 200 Å centered on Hα. For present observations the detector was an EMI 9658 photomultiplier connected to a photon-counting system.

For program stars, integration times range between 30 to 45 seconds to obtain a minimum photoelectron number of about 25,000 counts per scan per Å per second at the peak of the emission line. On each night three standard stars HR 718, HR 2160, and HR 3454 were scanned to provide the nightly extinction values, the wavelength dependence of instrumental sensitivity, and atmospheric variations. The sky background plus dark counts were measured immediately preceding and following the star scans and subtracted from the results of the scans.

III. Results

A total of 42 and 37 Hα line-profile observations were obtained for ϕ Per and standard stars, respectively. Since the Hα line profile of ϕ Per has extended wings, it can affect the normalization procedure (Slettebak and Reynolds 1978; Fontaine *et al.* 1982). One must be careful in choosing the region of the continuum. We have normalized at 6523 Å which is believed to be necessary and sufficient. The normalization point may change from one spectrum to another due to the instrumental shift. The change of normalization point will introduce a serious error which is important for the variability studies. To avoid this error we have displayed each profile along with the standard source spectrum on the screen of a VT 240 graphic system and the instrumental shift for each profile was obtained. All data for Hα line profiles were reduced on a VAX 11/780 computer at Vainu Bappu Observatory, using the spectrophotometric reduction package developed by A. V. Raveendran, to yield the normalized flux. Correction has been applied to the measured values for the wavelength dependence of instrumental sensitivity. Spectra obtained in the Hα region for ϕ Per are plotted in Figure 1(a) and Figure 1(b). It is necessary to mention here that the normalized spectra are always expressed in terms of the relative flux, F_λ/F_c, and not in terms of the relative intensity, I_λ/I_c. The normalized spectra can be expressed in terms of I_λ/I_c when both line and continuum emissions have equal solid angles, which cancel during the normalization procedure. For the Hα line of Be stars this condition is not satisfied.

In Table I, a summary of observational conditions and measured values of the Hα line profile for ϕ Per are given. The first four columns of Table I list the date of observations, the mean UT of the exposure time, the number of scans, and the exposure time for a single spectrum, respectively. The fifth and sixth columns list the photoelectron counts of continuum emission at 6523 Å (averaged over $\pm$ 5 Å) and the variations of continuum counts. The measured EW of Hα [$W(\alpha)$] and F_{max}/F_c are given in the seventh and eighth columns, respectively. Variations of $W(\alpha)$ are listed in the ninth column.

Since we are interested in finding out the reality of rapid variations of $W(\alpha)$, we need to determine the total observational error (instrumental and atmospheric variations) in the $W(\alpha)$ measurements. In order to do this we have monitored three standard stars (HR 718, HR 2160, and HR 3454) in the Hα region and we find that HR 3454 shows more variations in $W(\alpha)$ than the other two stars. In total we have obtained 18 Hα profiles of HR 3454 and its mean value of $W(\alpha)$ is + 3.51 Å with a standard-deviation (σ) value of $\pm$ 0.16 Å (Fig. 2). From Figure 2 it is clearly seen that the observed variations in $W(\alpha)$ of HR 3454 from its mean value are $\pm$ 1.3 σ. So, the total observational error limit in $W(\alpha)$ measurements for ϕ Per may be fixed as $\pm$ 5 σ ($\pm$ 0.80 Å) which is believed to be sufficient. Thus, for ϕ Per, if the observed variations of $W(\alpha)$ are beyond the $\pm$ 5 σ limit, we shall consider those variations as true variations.

From Table I we find that there are many irregular variations of $W(\alpha)$ which are beyond the $\pm$ 5 σ limit and the time scale of these irregular variations are of the order of a few minutes (Fig. 3). These rapid irregular changes of $W(\alpha)$ in the envelope of ϕ Per may be considered as true variations.

IV. Discussion

Our observational results show that rapid irregular variations of $W(\alpha)$ on a time scale of a few minutes (see Table I and Fig. 3) are present in the envelope of ϕ Per. Variations of $W(\alpha)$ are mainly due to changes of the stellar flux. In general, stellar flux (F_λ) can be decomposed into a sum of the continuum flux (F_c) and the bound-bound flux (L_λ). Thus, the rapid irregular variability of the Hα emission line depends on the variations due to continuum flux and bound-bound emission flux.

A search of the rapid variations of the continuum flux seems to be particularly interesting. In order to find out the observational error in continuum-flux measurements, we have calculated the standard deviation (σ_1) of observed continuum counts for HR 3454, and the maximum and minimum variations of the counts with respect to their mean value are within $\pm$ 1.1 σ_1. So for ϕ Per, if the variations of the continuum counts are above and below $\pm$ 1.1 σ_1, respectively, we shall consider those variations as true variations.

Table I shows that the continuum-level variations are within the limit of observational error except for two cases on 1985 October 29 (UT = $15^h08^m59^s$ and UT = $15^h10^m33^s$). Even if we consider the observed continuum-level variations as true variations, we find that in most cases EW variations increase when continuum-level variations decrease and vice versa. Thus, the rapid irregular variations of $W(\alpha)$ are mainly due to the changes of bound-bound flux emission from the envelope of ϕ Per.

ϕ Per is a binary system made up of a B1 primary and a B3 secondary (both emission-line stars) which was suggested by Hendry (1976) on the basis of her radial-velocity data. But a UCLA series of spectrograms obtained by Peters (1976) showed no evidence of duplicity. Suzuki

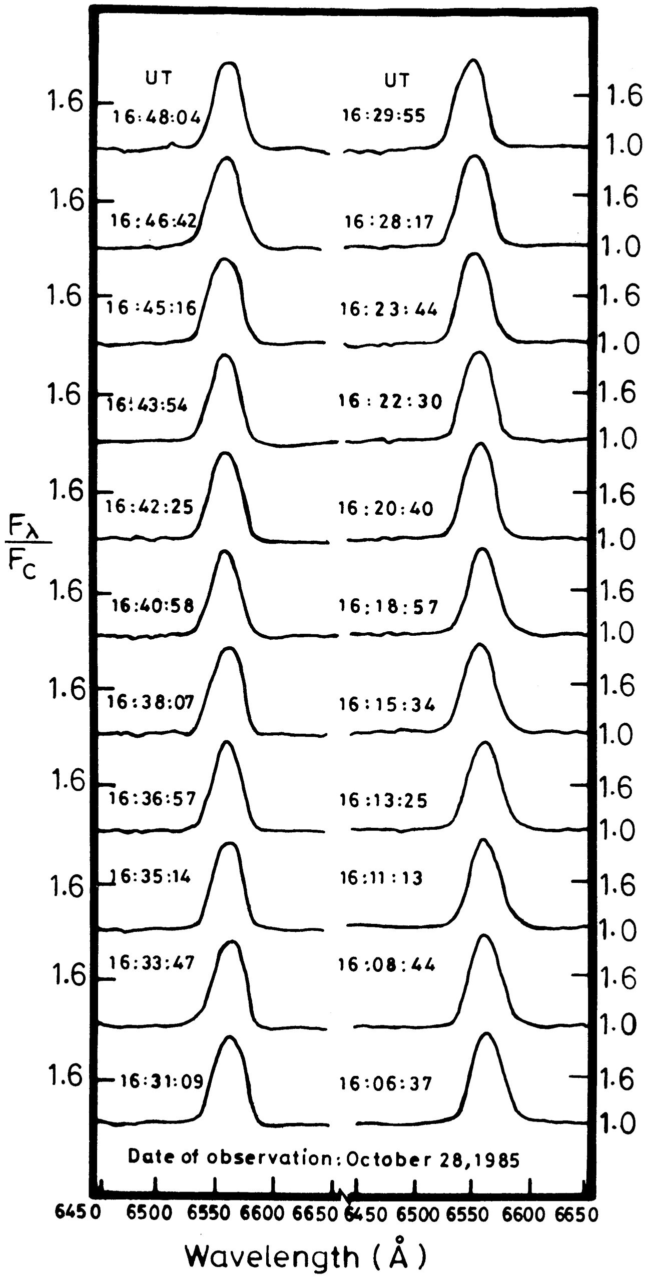

FIG. 1(a)–Spectra of ϕ Per in the Hα region.

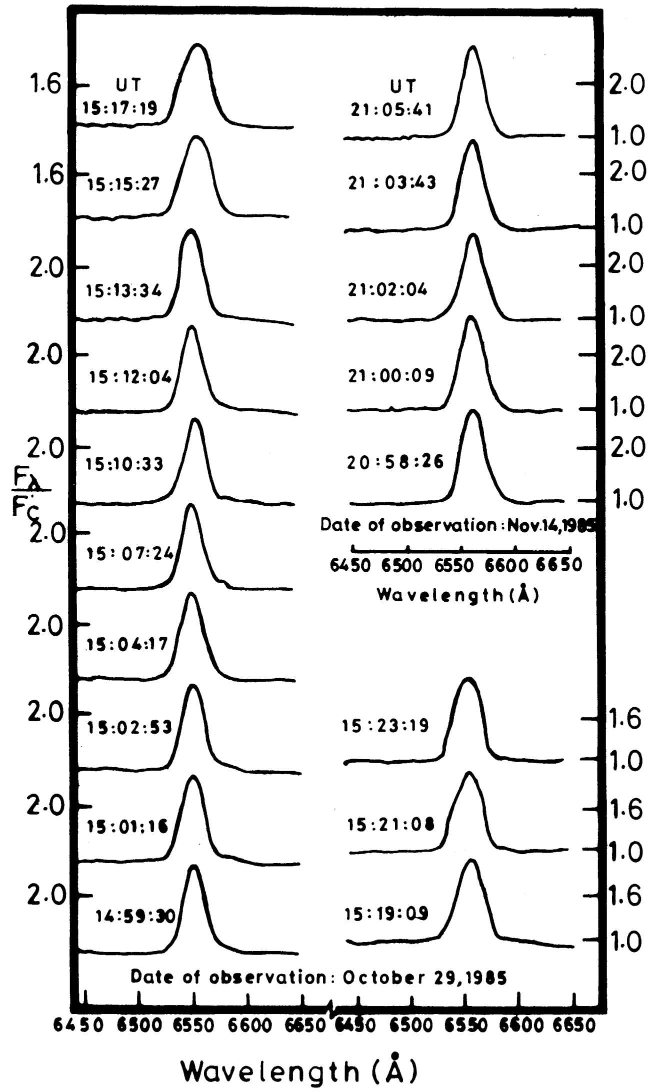

FIG. 1(b)–Spectra of ϕ Per in the Hα region.

(1976, 1980) applied his stable-orbits model to Hyneck's (1940, 1944) observed data of ϕ Per. From his results he obtained the masses of the primary and the secondary stars as 20 $\mathfrak{M}_\odot$ and 4 $\mathfrak{M}_\odot$, respectively, with a gas ring revolving around the primary star in the orbital plane of the system. Poeckert (1979, 1981), using his high-dispersion spectrograms of ϕ Per, detected He II (4686 Å) emission which arises from within the vicinity of the secondary. He finds masses of the primary and the secondary as 21 $\mathfrak{M}_\odot$ and 3.4 $\mathfrak{M}_\odot$, respectively, very similar to Suzuki's values. He suggested a model which consists of a Be primary enclosed by a nearly circular disk emitting Fe II and Balmer emission lines and a small secondary (W-R star) with a disk emitting He II emission. Pockert (1981) has also observed an increase in the strength of some shell lines around the conjunction with the secondary in front and an increase in their radial velocities in later phases which suggests a gas stream flowing from the secondary to the primary.

In general, periodic mass transfer or mass accretion onto the Be star from a companion in a binary system (Křiž and Harmanec 1975; Plavec 1970, 1976; Harmanec 1981) is also well known to the astronomical community. Also, mass outflow in the form of winds and/or discrete components was observed in ϕ Per from ultraviolet observations (Peters and Polidan 1981). These two processes, i.e., mass inflow (or gas-stream flow) from the secondary to the primary and mass outflow from the primary, may produce a material circulation in the envelope of ϕ Per which may produce rapid irregular variations of L_λ as well as $W(\alpha)$.

Table I

Observations of ϕ Per in the 6450 – 6645 Å spectral region

Date of observation (1985)	Mean UT of exposure	Number of scans	Exposure time (sec)	Photoelectron counts of continuum at 6523 Å (/sec/Å/scan)	Variations of continuum counts (in units of σ_1)	$W(\alpha)$ (Å)	Fmax / Fc	W $W(\alpha)$ variations w.r.t. its mean value (in units of σ)
Oct 28	16 06 37	10	30	10436	0.14	38.81	2.24	8.2
Oct 28	16 08 44	10	30	10731	0.73	38.74	2.25	7.7
Oct 28	16 11 13	10	30	10298	−0.13	38.32	2.23	5.1
Oct 28	16 13 25	10	30	10568	0.40	38.08	2.22	3.6
Oct 28	16 15 34	10	30	10176	−0.38	37.87	2.22	2.3
Oct 28	16 18 57	10	30	10427	0.12	36.85	2.23	− 4.1
Oct 28	16 20 40	10	30	10115	−0.50	40.70	2.35	19.9
Oct 28	16 22 30	10	30	10530	0.33	36.09	2.23	− 8.8
Oct 28	16 23 44	10	30	10214	−0.30	37.75	2.24	1.5
Oct 28	16 28 17	15	45	10350	−0.03	38.36	2.26	5.4
Oct 28	16 29 55	10	30	10277	−0.18	37.33	2.25	− 1.1
Oct 28	16 31 09	10	30	10394	−0.05	36.72	2.23	− 4.9
Oct 28	16 33 47	10	30	10550	0.37	35.99	2.22	− 9.4
Oct 28	16 35 14	10	30	10145	−0.44	35.87	2.22	−10.2
Oct 28	16 36 57	10	30	10305	−0.12	37.85	2.26	2.2
Oct 28	16 38 07	10	30	10289	−0.15	36.73	2.23	− 4.8
Oct 28	16 40 58	10	30	10387	−0.04	36.44	2.22	− 6.6
Oct 28	16 42 25	10	30	10358	−0.02	36.00	2.22	− 9.4
Oct 28	16 43 54	10	30	10353	−0.02	37.52	2.23	0.1
Oct 28	16 45 16	10	30	10197	−0.34	37.69	2.22	1.2
Oct 28	16 46 42	10	30	10501	0.18	38.81	2.26	8.2
Oct 28	16 48 04	10	30	10456	0.58	36.52	2.22	− 6.1
Oct 29	14 59 30	10	30	11182	0.49	40.80	2.61	10.5
Oct 29	15 01 16	10	30	11138	0.27	41.00	2.61	11.8
Oct 29	15 02 53	10	30	11028	0.20	40.67	2.59	9.7
Oct 29	15 04 17	10	30	10902	0.16	42.24	2.61	19.5
Oct 29	15 07 24	15	45	10807	−0.07	39.89	2.59	4.8
Oct 29	15 08 59	10	30	10288	−1.20	42.39	2.65	20.4
Oct 29	15 10 33	10	30	10318	−1.14	40.44	2.59	8.3
Oct 29	15 12 09	10	30	10540	−0.69	40.43	2.62	8.3
Oct 29	15 13 34	10	30	10591	−0.59	40.47	2.65	8.4
Oct 29	15 15 27	10	30	10879	−0.02	34.56	2.20	−28.4
Oct 29	15 17 19	10	30	11120	0.46	35.82	2.19	−20.6
Oct 29	15 19 09	10	30	10981	0.18	37.44	2.25	−10.5
Oct 29	15 21 08	10	30	11368	0.96	35.57	2.20	−22.2
Oct 29	15 23 19	10	30	11308	0.84	35.91	2.21	−20.0
Nov 14	20 55 59	15	45	12332	1.10	38.44	2.54	−18.7
Nov 14	20 58 26	15	45	12050	0.54	42.30	2.69	5.4
Nov 14	21 00 09	15	45	11639	−0.28	43.50	2.75	12.9
Nov 14	21 02 04	15	45	11567	−0.43	41.41	2.62	− 0.2
Nov 14	21 03 43	15	45	11726	−0.11	40.70	2.65	− 4.6
Nov 14	21 05 41	15	45	11372	−0.82	42.33	2.69	5.6

σ_1 -- standard deviation of continuum counts of HR 3454

σ -- standard deviation of $W(\alpha)$ of HR 3454

However, the observed data supply only a small fraction of the necessary information and any reasonable conclusion regarding the cause of rapid Hα variability in ϕ Per is not possible at present.

V. Conclusions

Our present study of rapid irregular variations of Hα emission-line profiles of ϕ Per allow the following conclusions to be drawn:

1. Rapid irregular variations of $W(\alpha)$ are present in the envelope of ϕ Per.
2. Continuum-level variations are within the limit of observational error so the reality of these variations is doubtful. In addition to this we have also found that in most cases EW increases when continuum level decreases and vice versa. That means rapid irregular variations of $W(\alpha)$ are not due to continuum-level variations.
3. Observed variations of $W(\alpha)$ may be mainly due to bound-bound flux variations which are probably due to the material circulation in the envelope of ϕ Per.

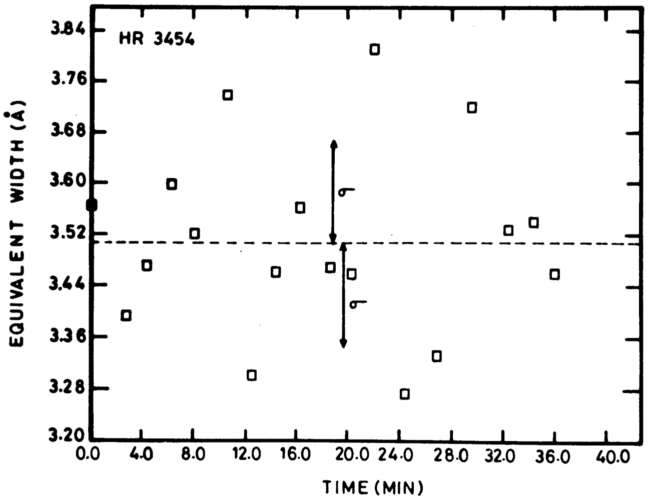

FIG. 2–Variations of $W(\alpha)$ of HR 3454 as a function of time. The time axis represents the elapsed time in minutes from the first observation of HR 3454 (UT of first observation is 21:59).

The valuable suggestions of the referee, Dr. T. P. Snow, helped improve the final presentation of the data and are gratefully acknowledged.

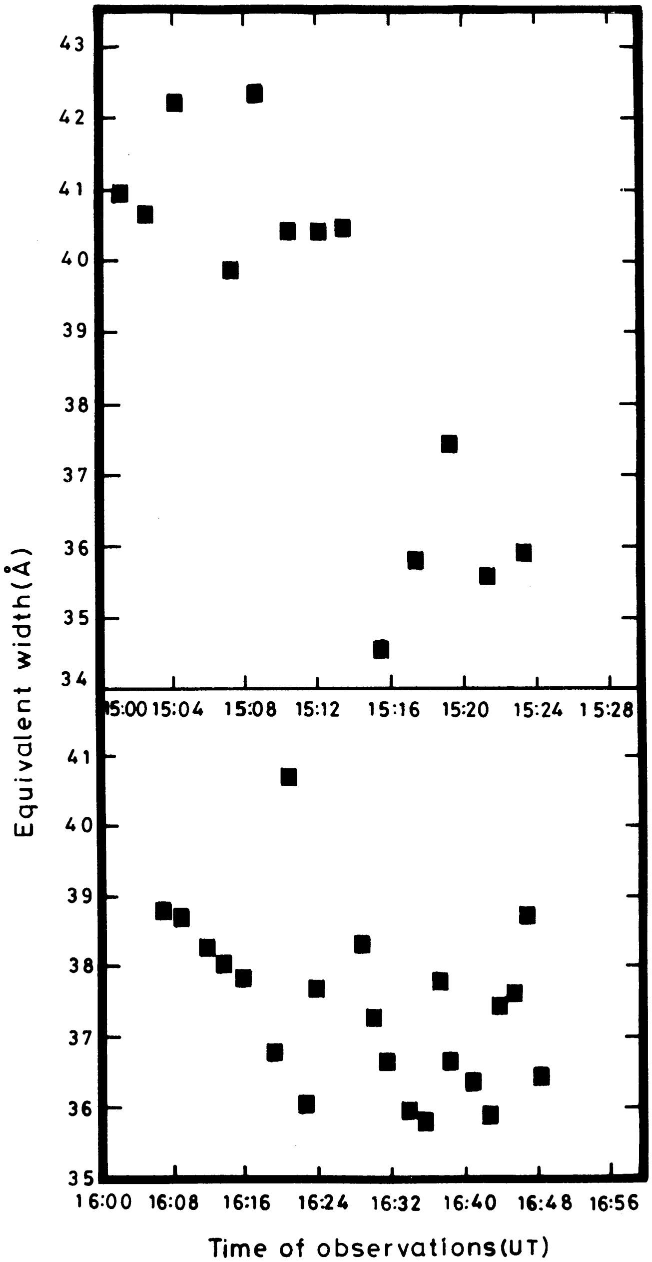

FIG. 3–Variations of $W(\alpha)$ of ϕ Per as a function of time in UT.

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