Asteroseismology of the Pulsating sdB star and Suspected SNe Ia Progenitor KPD 1930+2752: A Whole Earth Telescope Campaign

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Abstract

We propose to observe KPD 1930+2752, a pulsating subdwarf B star with a particularly rich period spectrum that is also a short period (~ 2h17m) close binary system (as revealed by the presence of an ellipsoidal variation in the lightcurve). The companion is almost certainly a white dwarf as there are no indications of eclipse or reflection effect. Radial velocity measurements indicate that the total mass of the system exceeds the Chandrasekhar limit, making KPD 1930+2752 the first known (non-X-ray source) candidate for a Type Ia supernova progenitor. The pair should merge within an astrophysically interesting timescale (~ 200 Myr) due to gravitational wave radiation. Additionally, the tidal distortions are indicative of the strong tidal force incurred on the pulsating star by its companion. This will allow us to investigate the effects such strong tidal forces have on pulsations. Due to its outstanding astrophysical interest, this object is the primary target of the WET network Xcov 23 campaign (which includes the present proposal). The goal is to fully resolve the complex pulsation pattern of the pulsating sdB star, as well as the details of the ellipsoidal modulation. The asteroseismological analysis of the pulsation data, along with a detailed analysis of the folded, high S/N ratio ellipsoidal variation will lead to strong physical constraints on this particularly interesting and, so far, unique stellar object.

Justification

KPD 1930+2752 is, by all accounts, a rather extraordinary object. Multiperiodic luminosity variations in the lightcurve of this apparently unassuming V=13.8 hot B subdwarf (sdB) star have been reported by Billeres et al. (2000). Figure 1 shows a portion of the lightcurve which revealed the presence of at least 44 short-period modes (significantly more than is usually seen in the pulsating sdB -- or EC14026 -- stars) with periods and amplitudes respectively in the ranges 145--332 s and 0.06--0.45\% of the mean brightness of the star (Fig. 2). However, the light curve is dominated (~ 1.39% of the mean brightness) by a nearly sinusoidal modulation with a much longer period of ~ 4108.9s. The latter variation has no equivalent among the other known EC14026 stars and is interpreted as the ellipsoidal deformation (see Fig. 3) of the sdB star in a close, but detached binary system containing a faint, unseen companion (most likely a white dwarf). The analysis of Maxted et al. 2000 confirmed that KPD 1930+2752 is, indeed, a binary system by measuring, from the H-alpha and He I-6678A spectral lines, radial velocity variations with the same period (~ 2h17m) as the orbital period derived from the ellipsoidal deformation (ie., twice the observed modulation period). In addition, they found from the kinematics (the projected orbital velocity is K=349.3 +/- 2.7 km/s) that the unseen companion is almost certainly a white dwarf (as suspected by Billeres et al. 2000) and that the total mass of the binary system (at least 1.47 +/- 0.01 M_sun *exceeds* the Chandrasekhar limit (just under 1.4 M_sun for a C/O core white dwarf). Since the binary system should merge within only ~200 Myr due to gravitational wave radiation, KPD 1930+2752 becomes the first good candidate of a Type Ia supernova (SNe Ia) progenitor that can be associated with the double-degenerate SNe Ia model. Type Ia supernovae are of utmost importance as they can be seen out to enormous distances and are used to derive cosmological parameters (e.g., the cosmological constant; Perlmutter et al. 1999). However, the physical origin of these detonations is still unclear, which leads to uncertainties on the calibration of SNe Ia light curves. Consequently, as the first detected SNe Ia progenitor in which the visible component is a pulsating sdB star with a particularly rich pulsation period spectrum, KPD 1930+2752 becomes an object of outstanding astrophysical interest. Pulsation computations show (see Fig. 4) that the shorter periods are consistent with a theoretical, low radial order, low degree p-mode period spectrum which is rotationally split with a period of 8217.8 s, the value expected for a star tidally locked to its companion as would be the case for a close binary system. This assumption seems confirmed by a recent measurement of vsin i=90.2 +/- 4.2 km/s from high spectral resolution VLT data (Heber 2002). In addition, when tidal forces dominate the Coriolis (or centrifugal) force, as is the case in KPD 1930+2752, it has been suggested that the pulsation axis may align with the companion (in a way similar to roAp stars where the pulsation axis is aligned with the magnetic axis). If true, the pulsation axis should precess with the orbit and each pulsation period should create multiple peaks in the Fourier domain. These secondary peaks, along with phase cues, provide signatures of a tipped pulsation axis and, in principle, can also be used to uniquely identify the pulsation modes (Reed et al. 2002; see http://sdbv.smsu.edu/mreed/IAU185/).

In order to fully exploit the extraordinary circumstances that KPD 1930+2752 is *both* an ellipsoidal variable *and* a rich p-mode pulsator, this star has been chosen as the primary target of the Whole Earth Telescope (WET; Nather et al. 1990) Xcov 23 campaign. Its complex temporal spectrum requires continuous coverage (to eliminate daily aliases) and a long time baseline (2 weeks in the present case) to 1) fully and unambiguously resolve the pulsations, 2) search for a tidally induced tipped pulsation axis using the method outlined in Reed et al. (2002), and 3) build a folded ellipsoidal lightcurve with a significantly improved S/N ratio. After many years of efforts, we have developed the capability to model successfully the nonadiabatic pulsation properties of EC14026 stars (see Charpinet et al. 2001, for a review). The rich, fully resolved pulsation period spectrum, along with constraints on mode identification brought by an eventual tipped pulsation axis, will allow us to perform a very detailed asteroseismological analysis of the pulsating sdB component, similar to the recent success obtained for the sdB pulsators PG 0014+067 (Brassard et al. 2001) and PG 1047+003 (Charpinet et al. 2002).

In parallel, the quantitative analysis of the high S/N ratio folded ellipsoidal modulation will provide crucial constraints on the KPD 1930+2752 system that are *completely independant* of the sdB pulsation analysis. Put together, these studies promise to be extremely valuable for inferring the global structural parameters of the sdB star as well as those of the complete sdB+WD system. Since KPD 1930+2752 is the first known object that might lead to a SNe Ia detonation within a relatively short astrophysical timescale, the informations obtained on this object should have wide ranging scientific implications.

References

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Heber, U. et al. 2002, 13th European Workshop on White Dwarfs (Napoli)
Maxted, P.F.L., Marsh, T.R., & North, R.C. 2000, MNRAS, 317, L41
Nather, R.E. et al. 1990, ApJ, 361, 209
Perlmutter, S. et al. 1999, ApJ, 517, 565
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Figures

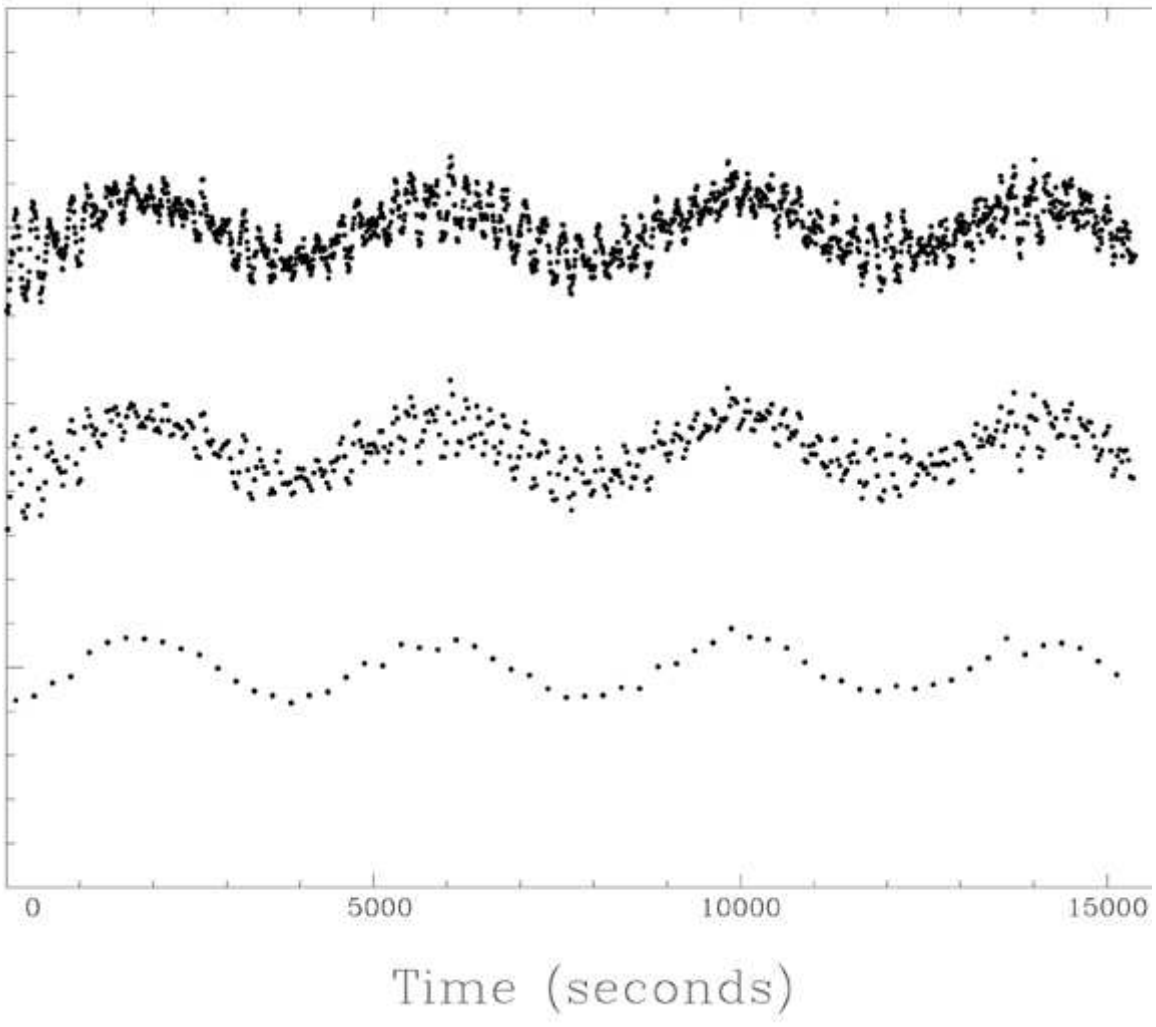


Figure 1: Light curve of KPD 1930+2752, expressed in residual amplitude relative to the mean brightness of the star. *Upper curve* (shifted upward by 0.10 units): complete light curve obtained with a sampling time of 10 s. The *middle curve* and *lower curve* (the latter being shifted downward by 0.10 units) are the binned light curve obtained with a sampling time of respectively 30 s and 250 s. These show the nearly sinusoidal, long period variation after partially eliminating the

pulsation signal.

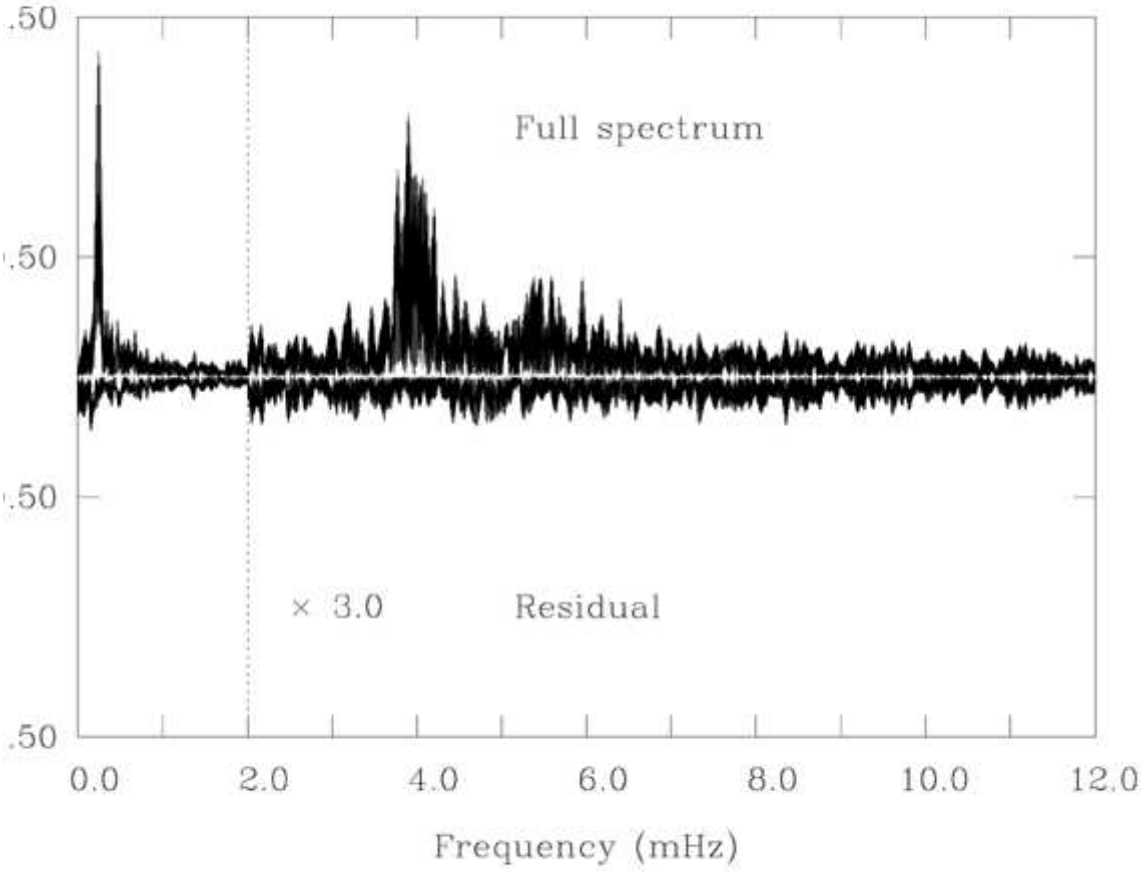
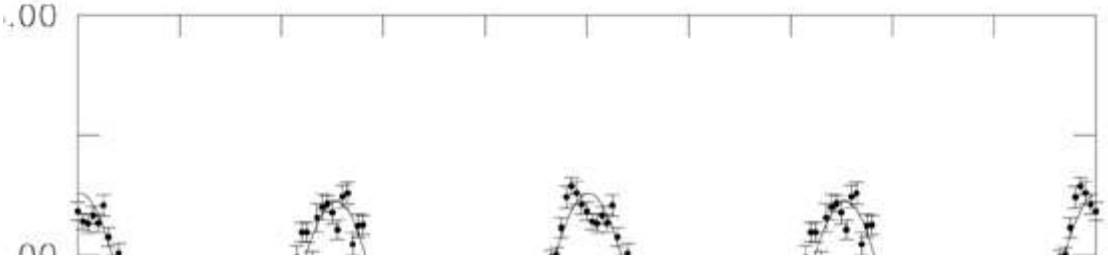


Figure 2: *Upper half*: Fourier amplitude spectrum of the complete light curve of KPD 1930+2752. The vertical scale has been multiplied by a factor of 3 for frequencies larger than 2 mHz in order to visualize better the numerous higher frequency components (due to pulsations) that have substantially smaller amplitudes. The dominant peak at low frequency corresponds to the ellipsoidal variation (see text). *Lower half*: Fourier amplitude spectrum (plotted upside down) of the residual light curve after substraction of the identified periods.}



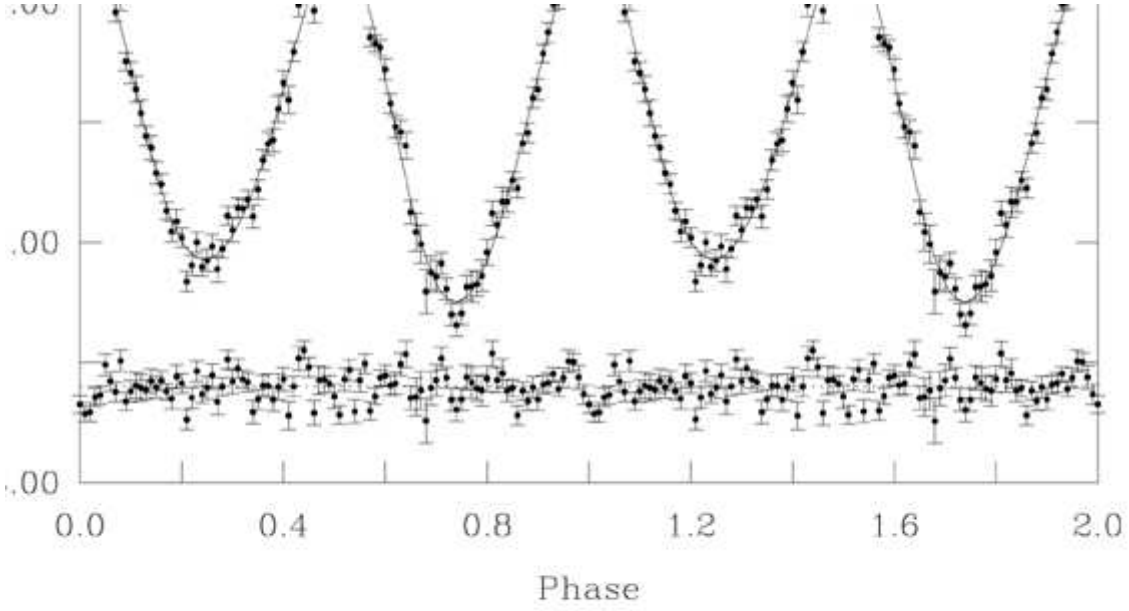


Figure 3: Light curve of KPD 1930+2752 prewithened of the short-period variations and folded on the period of 8217.76 s (using 100 frequency bins). As usual, the curve is plotted twice for better visualization. This curve shows the ellipsoidal modulation of the mean brightness of the sdB star. The lowest curve is the residual after substraction of a fitted model of the ellipsoidal modulation (shown as the plain line).

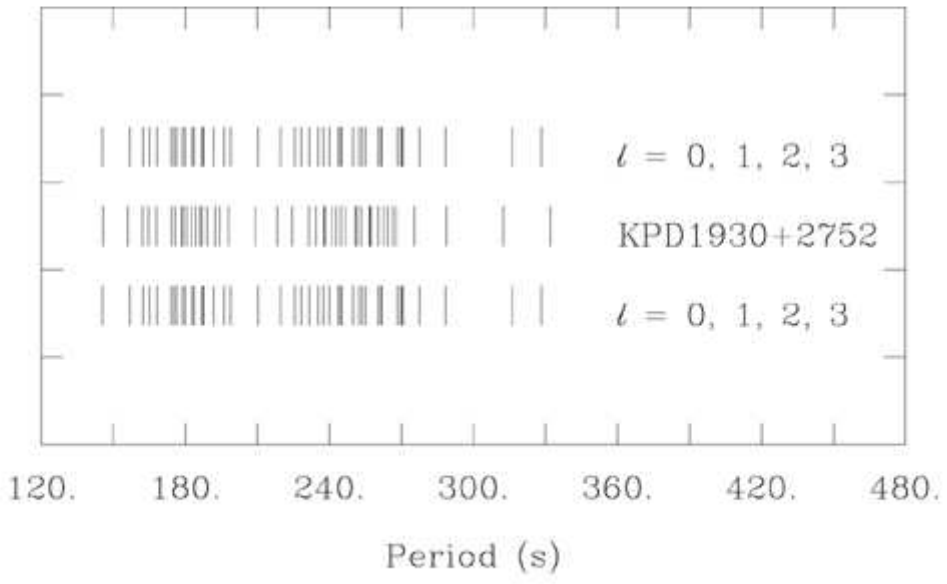


Figure 4: Comparison of the observed period spectrum of KPD 1930+2752 with a theoretical period spectrum that has been rotationally split through the effect of first-order uniform rotation on a representative stellar model rotating with a period of 8218 s. Note that no attempt has been made to perform a detailed fit because of the difficulty to extract the exact periods from our single site data.}

Download the KPD 1930+2752 justification

Download the KPD 1930 proposal in Gzipped PostScript format.
Download Figure 1 for the KPD 1930 proposal in Gzipped PostScript format.
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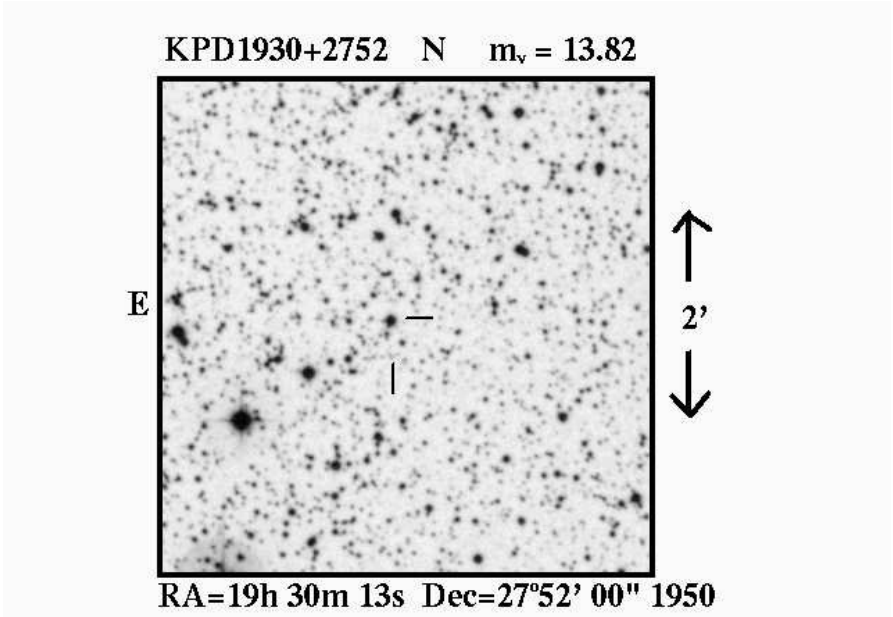
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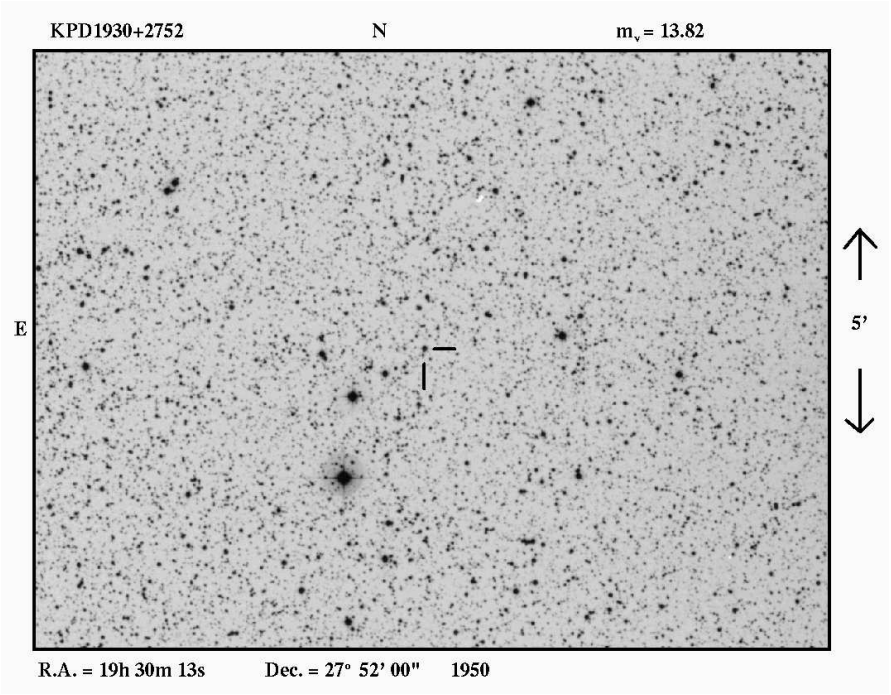
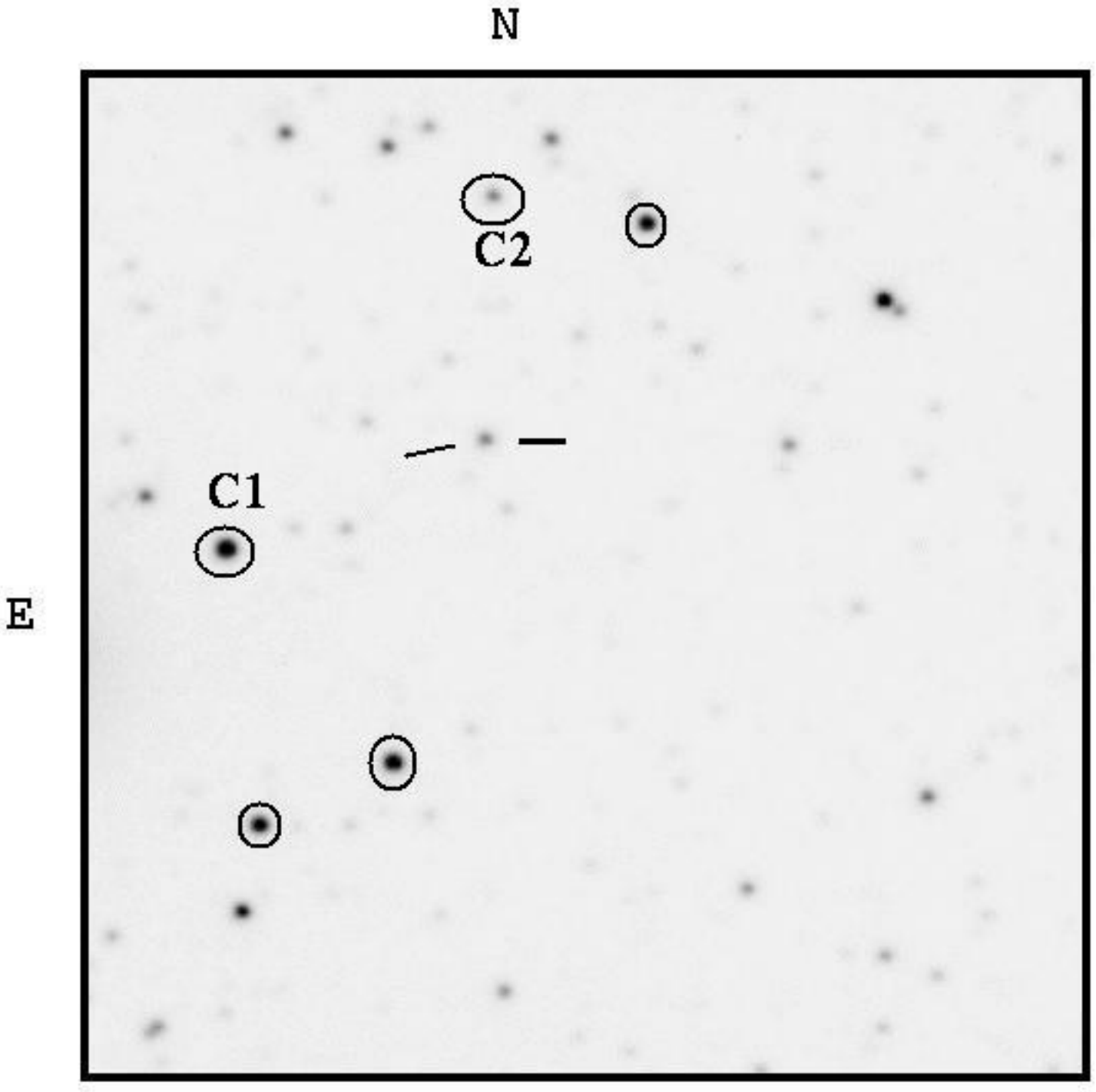
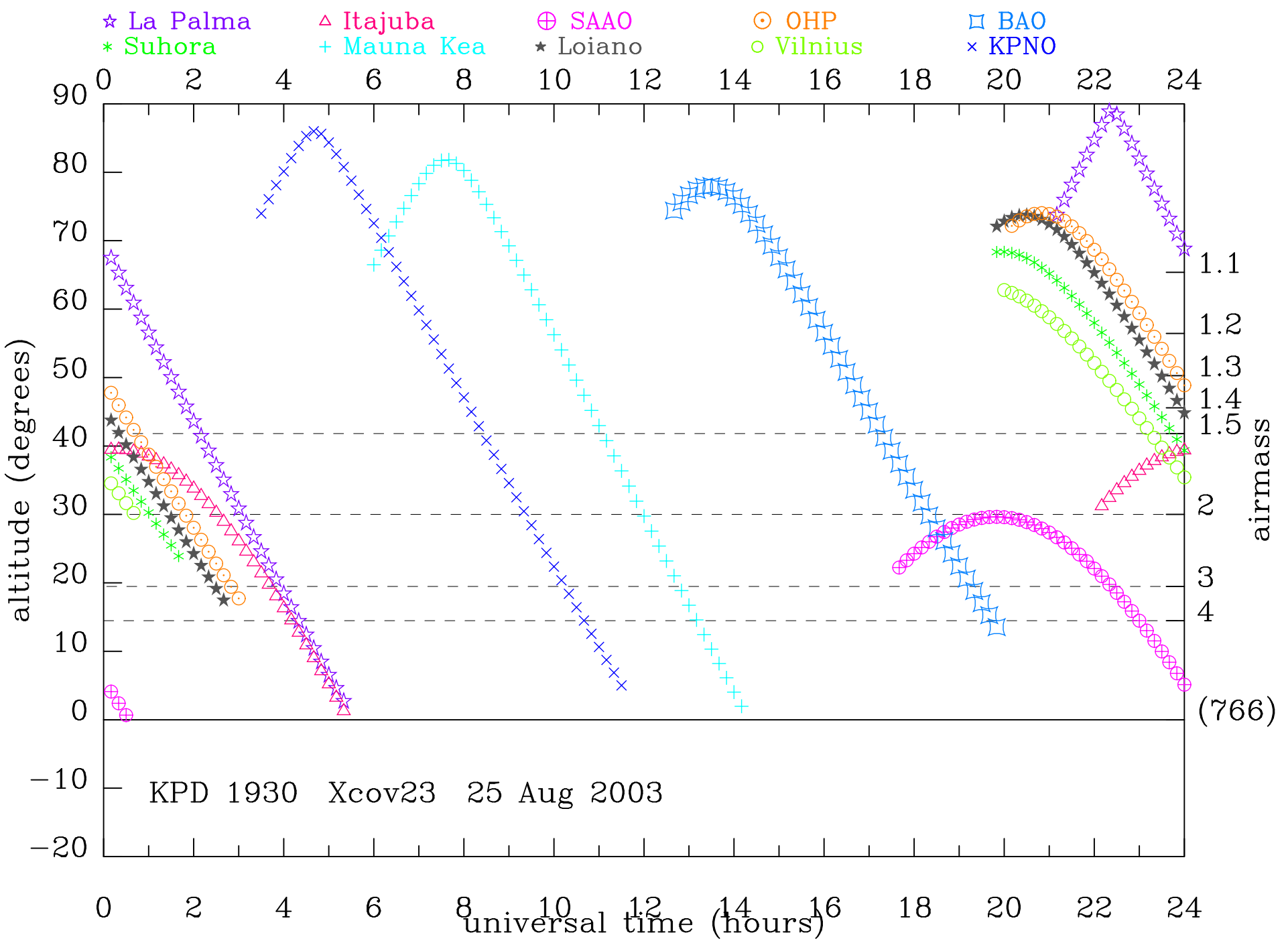
E
2'
RA=19h 30m 13s Dec=27°52' 00" 1950


KPD1930+2752
N
m_v = 13.82
E
5'
R.A. = 19h 30m 13s
Dec. = 27° 52' 00"
1950

CCD Image ~4' per side



KPD1930 10 sec exposure Fick 24"


La Palma
Itajuba
SAAO
OHP
BAO
Suhora
Mauna Kea
Loiano
Vilnius
KPNO
altitude (degrees)
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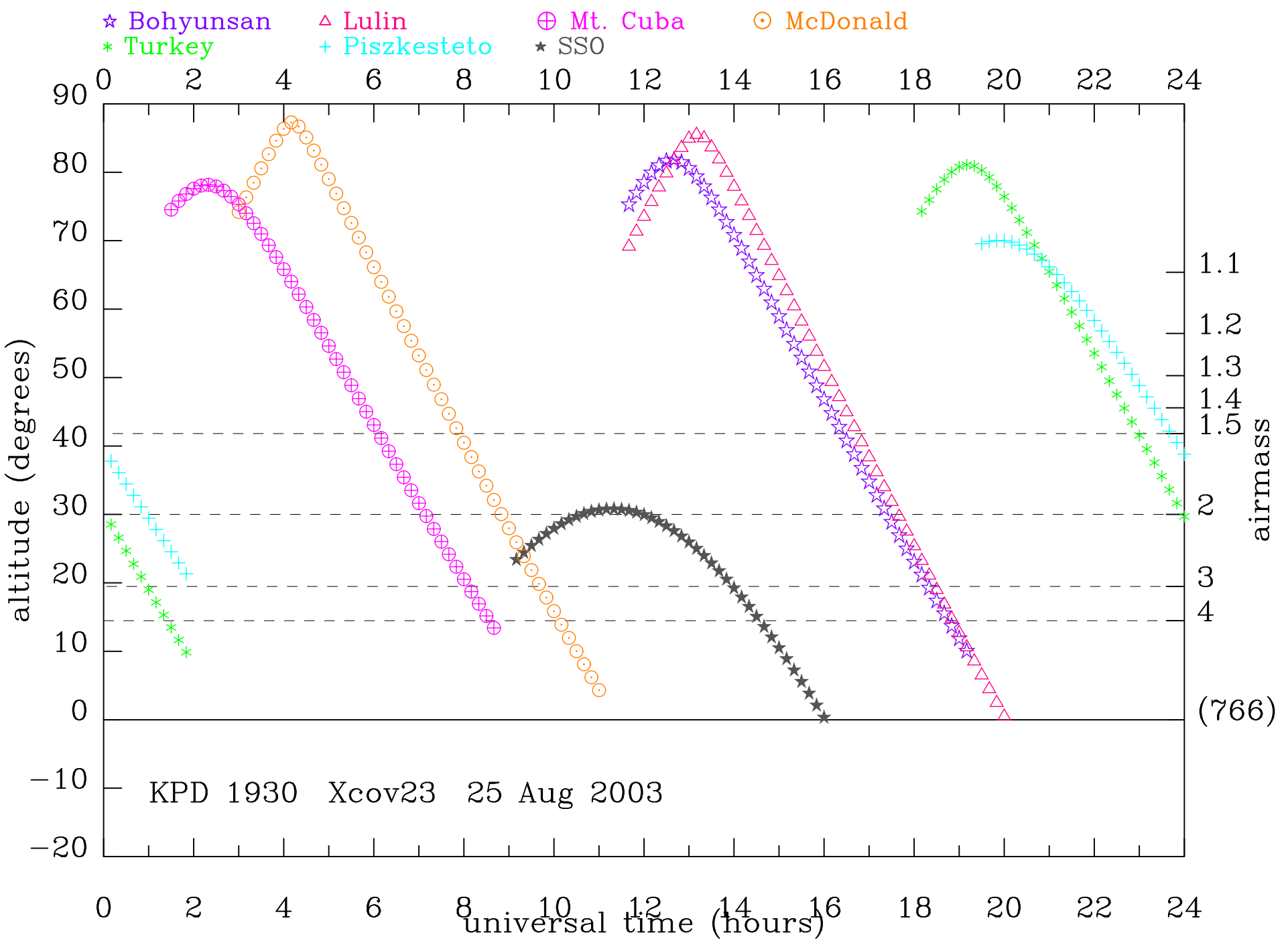
universal time (hours)
KPD 1930 Xcov23 25 Aug 2003
(766)


Bohyunsan
Lulin
Mt. Cuba
McDonald
Turkey
Piszkesteto
SSO
altitude (degrees)
airmass
universal time (hours)
KPD 1930 Xcov23 25 Aug 2003
(766)

Wet Run Info for KPD1930

RA: 19 46 54.0 **dec**: 27 58 35 Epoch 2000.00

2003 Aug 15 to 2003 Sep 11

computed using Wetcalc

August 11, 2003

KPD1930: 2003 Aug 15, Moon 87% full								
Site	Universal Time					Airmass		
	f.v.[1]	l.v.[1]	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory								
Turkish Natl. Obs.								
Moletai, Lithuania								
South Africa								
Suhora, Poland								
Piszkesteto, Hungary								
Bologna Uni. Obs., Italy								
Obs. of Haute-Provence								
Nordic Optical Telescope								
Itajuba, Brazil								
Mount Cuba, Maryland	1 40	8 34	3 13	1 40	8 34	1.08	2.42	1.02
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii								

KPD1930: 2003 Aug 16, Moon 80% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory								
Turkish Natl. Obs.								
Moletai, Lithuania								
South Africa								
Suhora, Poland								
Piszkesteto, Hungary								
Bologna Uni. Obs., Italy								
Obs. of Haute-Provence								
Nordic Optical Telescope								
Itajuba, Brazil								
Mount Cuba, Maryland	1 39	8 35	3 09	1 39	8 35	1.08	2.51	1.02
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii								

[1] *f.v.* and *l.v.* denote the time when the object is "first visible" and "last visible", respectively. This takes into account both the rise and set times as well as the evening and morning twilight times.

KPD1930: 2003 Aug 17, Moon 71% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory								
Turkish Natl. Obs.								
Moletai, Lithuania								
South Africa								
Suhora, Poland								
Piszkesteto, Hungary								
Bologna Uni. Obs., Italy								
Obs. of Haute-Provence								
Nordic Optical Telescope								
Itajuba, Brazil								
Mount Cuba, Maryland	1 37	8 37	3 05	1 37	8 37	1.08	2.62	1.02
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii								

KPD1930: 2003 Aug 18, Moon 62% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory								
Turkish Natl. Obs.	18 22	1 44	19 59	18 22	1 44	1.08	3.09	1.01
Moletai, Lithuania								
South Africa								
Suhora, Poland								
Piszkesteto, Hungary	19 52	1 37	20 40	19 52	1 37	1.08	1.97	1.06
Bologna Uni. Obs., Italy								
Obs. of Haute-Provence								
Nordic Optical Telescope								
Itajuba, Brazil								
Mount Cuba, Maryland	1 35	8 38	3 01	1 35	8 38	1.07	2.73	1.02
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii	6 05	14 08	8 20	6 05	14 47	1.18	5.00	1.01

KPD1930: 2003 Aug 19, Moon 53% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory								
Turkish Natl. Obs.	18 20	1 45	19 55	18 20	1 45	1.08	3.24	1.01
Moletai, Lithuania								
South Africa								
Suhora, Poland								
Piszkesteto, Hungary	19 49	1 40	20 36	19 49	1 40	1.08	2.04	1.06
Bologna Uni. Obs., Italy								
Obs. of Haute-Provence								
Nordic Optical Telescope	21 12	5 14	23 07	21 12	5 20	1.11	5.00	1.00
Itajuba, Brazil								
Mount Cuba, Maryland	1 33	8 39	2 57	1 33	8 39	1.07	2.85	1.02
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii	6 04	14 04	8 16	6 04	14 47	1.17	5.00	1.01

KPD1930: 2003 Aug 20, Moon 44% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea	11 42	19 13	13 17	11 42	19 13	1.08	3.50	1.01
Lulin Obs., Taiwan								
Beijing Observatory								
Turkish Natl. Obs.	18 18	1 46	19 51	18 18	1 46	1.07	3.42	1.01
Moletai, Lithuania	20 24	0 19	20 10	20 24	0 19	1.13	1.62	1.13
South Africa								
Suhora, Poland	19 56	1 31	20 32	19 56	1 31	1.08	1.98	1.08
Piszkesteto, Hungary	19 46	1 42	20 32	19 46	1 42	1.08	2.10	1.06
Bologna Uni. Obs., Italy								
Obs. of Haute-Provence								
Nordic Optical Telescope	21 10	5 10	23 04	21 10	5 21	1.10	5.00	1.00
Itajuba, Brazil	22 04	5 02	0 54	22 04	8 07	2.37	5.00	1.57
Mount Cuba, Maryland	1 31	8 41	2 53	1 31	8 41	1.07	2.98	1.02
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii	6 03	14 00	8 12	6 03	14 47	1.16	5.00	1.01

KPD1930: 2003 Aug 21, Moon 34% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea	11 41	19 14	13 13	11 41	19 14	1.07	3.70	1.01
Lulin Obs., Taiwan	11 44	19 41	13 46	11 44	20 16	1.13	5.00	1.00
Beijing Observatory								
Turkish Natl. Obs.	18 17	1 47	19 47	18 17	1 47	1.07	3.61	1.01
Moletai, Lithuania	20 20	0 23	20 06	20 20	0 23	1.13	1.66	1.13
South Africa								
Suhora, Poland	19 53	1 33	20 28	19 53	1 33	1.08	2.04	1.08
Piszkesteto, Hungary	19 44	1 44	20 28	19 44	1 44	1.08	2.17	1.06
Bologna Uni. Obs., Italy								
Obs. of Haute-Provence								
Nordic Optical Telescope	21 09	5 06	23 00	21 09	5 21	1.10	5.00	1.00
Itajuba, Brazil	22 04	4 58	0 50	22 04	8 06	2.32	5.00	1.57
Mount Cuba, Maryland	1 30	8 42	2 50	1 30	8 42	1.07	3.13	1.02
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii	6 02	13 56	8 08	6 02	14 48	1.15	5.00	1.01

KPD1930: 2003 Aug 22, Moon 26% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea	11 39	19 16	13 09	11 39	19 16	1.07	3.93	1.01
Lulin Obs., Taiwan	11 43	19 37	13 42	11 43	20 17	1.12	5.00	1.00
Beijing Observatory								
Turkish Natl. Obs.	18 15	1 48	19 43	18 15	1 48	1.07	3.83	1.01
Moletai, Lithuania	20 15	0 27	20 02	20 15	0 27	1.13	1.70	1.13
South Africa								
Suhora, Poland	19 50	1 36	20 24	19 50	1 36	1.08	2.11	1.08
Piszkesteto, Hungary	19 41	1 46	20 25	19 41	1 46	1.08	2.25	1.06
Bologna Uni. Obs., Italy								
Obs. of Haute-Provence	20 19	3 02	21 21	20 19	3 02	1.07	2.66	1.04
Nordic Optical Telescope	21 08	5 02	22 56	21 08	5 22	1.09	5.00	1.00
Itajuba, Brazil	22 04	4 54	0 46	22 04	8 06	2.27	5.00	1.57
Mount Cuba, Maryland	1 28	8 43	2 46	1 28	8 43	1.06	3.29	1.02
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii	6 01	13 52	8 04	6 01	14 48	1.15	5.00	1.01

KPD1930: 2003 Aug 23, Moon 17% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea	11 37	19 17	13 05	11 37	19 17	1.07	4.18	1.01
Lulin Obs., Taiwan	11 42	19 33	13 38	11 42	20 17	1.12	5.00	1.00
Beijing Observatory								
Turkish Natl. Obs.	18 13	1 50	19 39	18 13	1 50	1.06	4.07	1.01
Moletai, Lithuania	20 11	0 31	19 58	20 11	0 31	1.13	1.75	1.13
South Africa								
Suhora, Poland	19 47	1 38	20 20	19 47	1 38	1.08	2.18	1.08
Piszkesteto, Hungary	19 39	1 48	20 21	19 39	1 48	1.08	2.33	1.06
Bologna Uni. Obs., Italy								
Obs. of Haute-Provence	20 16	3 04	21 17	20 16	3 04	1.06	2.77	1.04
Nordic Optical Telescope	21 07	4 58	22 52	21 07	5 23	1.09	5.00	1.00
Itajuba, Brazil	22 05	4 50	0 42	22 05	8 05	2.22	5.00	1.57
Mount Cuba, Maryland	1 26	8 45	2 42	1 26	8 45	1.06	3.47	1.02
McDonald Observatory								
Kitt Peak	3 28	11 19	5 05	3 28	11 30	1.07	5.00	1.00
Mauna Kea, Hawaii	6 00	13 48	8 00	6 00	14 49	1.14	5.00	1.01

KPD1930: 2003 Aug 24, Moon 11% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia	9 04	15 17	11 41	9 04	19 08	2.95	5.00	1.96
Bohyunsan Obs., Korea	11 36	19 18	13 02	11 36	19 18	1.06	4.48	1.01
Lulin Obs., Taiwan	11 41	19 29	13 34	11 41	20 18	1.11	5.00	1.00
Beijing Observatory								
Turkish Natl. Obs.	18 12	1 51	19 35	18 12	1 51	1.06	4.35	1.01
Moletai, Lithuania	20 06	0 35	19 54	20 06	0 35	1.13	1.80	1.13
South Africa								
Suhora, Poland	19 45	1 40	20 16	19 45	1 40	1.08	2.25	1.08
Piszkesteto, Hungary	19 36	1 50	20 17	19 36	1 50	1.07	2.41	1.06
Bologna Uni. Obs., Italy								
Obs. of Haute-Provence	20 14	3 05	21 13	20 14	3 05	1.06	2.90	1.04
Nordic Optical Telescope	21 05	4 54	22 48	21 05	5 23	1.08	5.00	1.00
Itajuba, Brazil	22 05	4 46	0 38	22 05	8 04	2.17	5.00	1.57
Mount Cuba, Maryland	1 24	8 46	2 38	1 24	8 46	1.06	3.67	1.02
McDonald Observatory	2 53	10 42	4 31	2 53	11 04	1.07	5.00	1.00
Kitt Peak	3 26	11 15	5 01	3 26	11 31	1.07	5.00	1.00
Mauna Kea, Hawaii	5 59	13 44	7 56	5 59	14 49	1.13	5.00	1.01

KPD1930: 2003 Aug 25, Moon 5% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia	9 04	15 13	11 37	9 04	19 07	2.87	5.00	1.96
Bohyunsan Obs., Korea	11 34	19 19	12 58	11 34	19 19	1.06	4.81	1.01
Lulin Obs., Taiwan	11 40	19 25	13 30	11 40	20 18	1.11	5.00	1.00
Beijing Observatory								
Turkish Natl. Obs.	18 10	1 52	19 31	18 10	1 52	1.06	4.66	1.01
Moletai, Lithuania	20 02	0 38	19 50	20 02	0 38	1.13	1.85	1.13
South Africa								
Suhora, Poland	19 42	1 43	20 12	19 42	1 43	1.08	2.33	1.08
Piszkesteto, Hungary	19 33	1 52	20 13	19 33	1 52	1.07	2.51	1.06
Bologna Uni. Obs., Italy								
Obs. of Haute-Provence	20 12	3 07	21 09	20 12	3 07	1.06	3.03	1.04
Nordic Optical Telescope								
Itajuba, Brazil	22 05	4 42	0 34	22 05	8 03	2.13	5.00	1.57
Mount Cuba, Maryland	1 22	8 47	2 34	1 22	8 47	1.06	3.89	1.02
McDonald Observatory	2 52	10 38	4 27	2 52	11 05	1.07	5.00	1.00
Kitt Peak	3 25	11 11	4 57	3 25	11 32	1.07	5.00	1.00
Mauna Kea, Hawaii	5 58	13 40	7 52	5 58	14 49	1.12	5.00	1.01

KPD1930: 2003 Aug 26, Moon 1% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia	9 05	15 09	11 34	9 05	19 06	2.80	5.00	1.96
Bohyunsan Obs., Korea	11 32	19 17	12 54	11 32	19 20	1.06	5.00	1.01
Lulin Obs., Taiwan	11 38	19 21	13 26	11 38	20 19	1.10	5.00	1.00
Beijing Observatory	12 34	19 59	13 44	12 34	19 59	1.06	3.95	1.02
Turkish Natl. Obs.	18 08	1 53	19 27	18 08	1 53	1.06	5.00	1.01
Moletai, Lithuania	19 58	0 42	19 46	19 58	0 42	1.13	1.91	1.13
South Africa	17 38	23 36	20 05	17 38	3 39	2.90	5.00	2.02
Suhora, Poland	19 39	1 45	20 08	19 39	1 45	1.08	2.42	1.08
Piszkesteto, Hungary	19 31	1 54	20 09	19 31	1 54	1.07	2.61	1.06
Bologna Uni. Obs., Italy								
Obs. of Haute-Provence	20 10	3 09	21 05	20 10	3 09	1.06	3.18	1.04
Nordic Optical Telescope								
Itajuba, Brazil	22 05	4 38	0 30	22 05	8 02	2.09	5.00	1.57
Mount Cuba, Maryland	1 20	8 49	2 30	1 20	8 49	1.06	4.13	1.02
McDonald Observatory	2 51	10 34	4 23	2 51	11 05	1.07	5.00	1.00
Kitt Peak	3 24	11 07	4 53	3 24	11 33	1.06	5.00	1.00
Mauna Kea, Hawaii	5 58	13 36	7 48	5 58	14 50	1.12	5.00	1.01

KPD1930: 2003 Aug 27, Moon 0% full

Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia	9 05	15 05	11 30	9 05	19 05	2.73	5.00	1.96
Bohyunsan Obs., Korea	11 31	19 13	12 50	11 31	19 21	1.06	5.00	1.01
Lulin Obs., Taiwan	11 37	19 17	13 22	11 37	20 19	1.09	5.00	1.00
Beijing Observatory	12 32	20 01	13 40	12 32	20 01	1.05	4.21	1.02
Turkish Natl. Obs.	18 07	1 49	19 23	18 07	1 54	1.05	5.00	1.01
Moletai, Lithuania	19 54	0 45	19 42	19 54	0 45	1.13	1.97	1.13
South Africa	17 38	23 32	20 01	17 38	3 38	2.83	5.00	2.02
Suhora, Poland	19 36	1 47	20 04	19 36	1 47	1.08	2.51	1.08
Piszkesteto, Hungary	19 28	1 56	20 05	19 28	1 56	1.07	2.72	1.06
Bologna Uni. Obs., Italy	19 46	2 46	20 39	19 46	2 46	1.06	3.28	1.04
Obs. of Haute-Provence	20 08	3 10	21 01	20 08	3 10	1.06	3.35	1.04
Nordic Optical Telescope								
Itajuba, Brazil	22 06	4 34	0 26	22 06	8 02	2.05	5.00	1.57
Mount Cuba, Maryland	1 18	8 50	2 26	1 18	8 50	1.05	4.42	1.02
McDonald Observatory	2 49	10 30	4 19	2 49	11 06	1.06	5.00	1.00
Kitt Peak	3 22	11 03	4 49	3 22	11 34	1.06	5.00	1.00
Mauna Kea, Hawaii	5 57	13 32	7 44	5 57	14 50	1.11	5.00	1.01

KPD1930: 2003 Aug 28, Moon 1% full

Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia	9 06	15 01	11 26	9 06	19 04	2.67	5.00	1.96
Bohyunsan Obs., Korea	11 29	19 10	12 46	11 29	19 22	1.05	5.00	1.01
Lulin Obs., Taiwan	11 36	19 13	13 18	11 36	20 20	1.09	5.00	1.00
Beijing Observatory	12 30	20 02	13 36	12 30	20 02	1.05	4.50	1.02
Turkish Natl. Obs.	18 05	1 45	19 19	18 05	1 55	1.05	5.00	1.01
Moletai, Lithuania	19 50	0 49	19 38	19 50	0 49	1.13	2.03	1.13
South Africa	17 39	23 28	19 57	17 39	3 37	2.76	5.00	2.02
Suhora, Poland	19 33	1 49	20 00	19 33	1 49	1.08	2.61	1.08
Piszkesteto, Hungary	19 26	1 58	20 01	19 26	1 58	1.07	2.83	1.06
Bologna Uni. Obs., Italy	19 44	2 48	20 35	19 44	2 48	1.06	3.46	1.04
Obs. of Haute-Provence	20 06	3 12	20 58	20 06	3 12	1.06	3.53	1.04
Nordic Optical Telescope								
Itajuba, Brazil	22 06	4 30	0 22	22 06	8 01	2.02	5.00	1.57
Mount Cuba, Maryland	1 17	8 51	2 22	1 17	8 51	1.05	4.74	1.02
McDonald Observatory	2 48	10 26	4 15	2 48	11 07	1.06	5.00	1.00
Kitt Peak	3 21	10 59	4 46	3 21	11 35	1.06	5.00	1.00
Mauna Kea, Hawaii	5 56	13 28	7 41	5 56	14 50	1.11	5.00	1.01

KPD1930: 2003 Aug 29, Moon 4% full

Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia	9 06	14 57	11 22	9 06	19 03	2.61	5.00	1.96
Bohyunsan Obs., Korea	11 28	19 06	12 42	11 28	19 23	1.05	5.00	1.01
Lulin Obs., Taiwan								
Beijing Observatory	12 28	20 03	13 32	12 28	20 03	1.05	4.84	1.02
Turkish Natl. Obs.	18 03	1 41	19 15	18 03	1 56	1.05	5.00	1.01
Moletai, Lithuania	19 46	0 52	19 34	19 46	0 52	1.13	2.10	1.13
South Africa	17 40	23 24	19 53	17 40	3 35	2.70	5.00	2.02
Suhora, Poland	19 31	1 51	19 56	19 31	1 51	1.08	2.72	1.08
Piszkesteto, Hungary	19 23	2 00	19 57	19 23	2 00	1.07	2.96	1.06
Bologna Uni. Obs., Italy	19 42	2 50	20 31	19 42	2 50	1.06	3.65	1.04
Obs. of Haute-Provence	20 03	3 13	20 54	20 03	3 13	1.06	3.73	1.04
Nordic Optical Telescope								
Itajuba, Brazil	22 06	4 27	0 18	22 06	8 00	1.99	5.00	1.57
Mount Cuba, Maryland	1 15	8 51	2 18	1 15	8 52	1.05	5.00	1.02
McDonald Observatory	2 46	10 22	4 11	2 46	11 08	1.06	5.00	1.00
Kitt Peak	3 19	10 55	4 42	3 19	11 36	1.05	5.00	1.00
Mauna Kea, Hawaii	5 55	13 24	7 37	5 55	14 51	1.10	5.00	1.01

KPD1930: 2003 Aug 30, Moon 10% full

Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia	9 07	14 53	11 18	9 07	19 02	2.56	5.00	1.96
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory	12 26	20 02	13 28	12 26	20 05	1.05	5.00	1.02
Turkish Natl. Obs.	18 02	1 37	19 11	18 02	1 57	1.05	5.00	1.01
Moletai, Lithuania	19 42	0 55	19 31	19 42	0 55	1.13	2.17	1.13
South Africa	17 40	23 20	19 49	17 40	3 34	2.64	5.00	2.02
Suhora, Poland	19 28	1 54	19 52	19 28	1 54	1.08	2.84	1.08
Piszkesteto, Hungary	19 20	2 02	19 53	19 20	2 02	1.07	3.10	1.06
Bologna Uni. Obs., Italy	19 40	2 51	20 27	19 40	2 51	1.06	3.87	1.04
Obs. of Haute-Provence	20 01	3 15	20 50	20 01	3 15	1.06	3.95	1.04
Nordic Optical Telescope								
Itajuba, Brazil	22 06	4 23	0 14	22 06	7 59	1.95	5.00	1.57
Mount Cuba, Maryland	1 13	8 47	2 14	1 13	8 54	1.05	5.00	1.02
McDonald Observatory	2 45	10 18	4 07	2 45	11 08	1.05	5.00	1.00
Kitt Peak	3 18	10 51	4 38	3 18	11 36	1.05	5.00	1.00
Mauna Kea, Hawaii	5 54	13 20	7 33	5 54	14 51	1.09	5.00	1.01

KPD1930: 2003 Aug 31, Moon 18% full

Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia	9 07	14 49	11 14	9 07	19 00	2.51	5.00	1.96
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory	12 25	19 58	13 24	12 25	20 06	1.05	5.00	1.02
Turkish Natl. Obs.	18 00	1 33	19 08	18 00	1 58	1.04	5.00	1.01
Moletai, Lithuania	19 38	0 59	19 27	19 38	0 59	1.13	2.25	1.13
South Africa	17 41	23 16	19 46	17 41	3 33	2.59	5.00	2.02
Suhora, Poland	19 25	1 56	19 48	19 25	1 56	1.08	2.97	1.08
Piszkesteto, Hungary	19 18	2 04	19 49	19 18	2 04	1.07	3.26	1.06
Bologna Uni. Obs., Italy	19 38	2 53	20 23	19 38	2 53	1.06	4.11	1.04
Obs. of Haute-Provence	19 59	3 16	20 46	19 59	3 16	1.05	4.21	1.04
Nordic Optical Telescope								
Itajuba, Brazil	22 07	4 19	0 10	22 07	7 58	1.92	5.00	1.57
Mount Cuba, Maryland	1 11	8 43	2 10	1 11	8 55	1.05	5.00	1.02
McDonald Observatory	2 44	10 14	4 03	2 44	11 09	1.05	5.00	1.00
Kitt Peak	3 16	10 48	4 34	3 16	11 37	1.05	5.00	1.00
Mauna Kea, Hawaii	5 53	13 16	7 29	5 53	14 52	1.09	5.00	1.01

KPD1930: 2003 Sep 1, Moon 27% full

Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory	12 23	19 54	13 20	12 23	20 07	1.05	5.00	1.02
Turkish Natl. Obs.								
Moletai, Lithuania	19 35	1 02	19 23	19 35	1 02	1.13	2.33	1.13
South Africa	17 41	23 12	19 42	17 41	3 32	2.54	5.00	2.02
Suhora, Poland	19 22	1 58	19 45	19 22	1 58	1.08	3.11	1.08
Piszkesteto, Hungary	19 15	2 06	19 45	19 15	2 06	1.07	3.42	1.06
Bologna Uni. Obs., Italy	19 36	2 54	20 19	19 36	2 54	1.05	4.38	1.04
Obs. of Haute-Provence								
Nordic Optical Telescope								
Itajuba, Brazil								
Mount Cuba, Maryland								
McDonald Observatory								
Kitt Peak	3 15	10 44	4 30	3 15	11 38	1.04	5.00	1.00
Mauna Kea, Hawaii								

KPD1930: 2003 Sep 2, Moon 38% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory								
Turkish Natl. Obs.								
Moletai, Lithuania	19 31	1 05	19 19	19 31	1 05	1.13	2.41	1.13
South Africa								
Suhora, Poland								
Piszkesteto, Hungary	19 13	2 08	19 41	19 13	2 08	1.07	3.61	1.06
Bologna Uni. Obs., Italy	19 33	2 56	20 15	19 33	2 56	1.05	4.68	1.04
Obs. of Haute-Provence								
Nordic Optical Telescope								
Itajuba, Brazil								
Mount Cuba, Maryland								
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii								

KPD1930: 2003 Sep 3, Moon 49% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory								
Turkish Natl. Obs.								
Moletai, Lithuania	19 27	1 08	19 15	19 27	1 08	1.13	2.51	1.13
South Africa								
Suhora, Poland								
Piszkesteto, Hungary	19 10	2 10	19 37	19 10	2 10	1.07	3.82	1.06
Bologna Uni. Obs., Italy	19 31	2 57	20 12	19 31	2 57	1.05	5.00	1.04
Obs. of Haute-Provence								
Nordic Optical Telescope								
Itajuba, Brazil								
Mount Cuba, Maryland								
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii								

KPD1930: 2003 Sep 4, Moon 61% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory								
Turkish Natl. Obs.								
Moletai, Lithuania								
South Africa								
Suhora, Poland								
Piszkesteto, Hungary	19 08	2 12	19 33	19 08	2 12	1.07	4.04	1.06
Bologna Uni. Obs., Italy	19 29	2 53	20 08	19 29	2 59	1.05	5.00	1.04
Obs. of Haute-Provence								
Nordic Optical Telescope								
Itajuba, Brazil								
Mount Cuba, Maryland								
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii								

KPD1930: 2003 Sep 5, Moon 71% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory								
Turkish Natl. Obs.								
Moletai, Lithuania								
South Africa								
Suhora, Poland								
Piszkesteto, Hungary	19 05	2 14	19 29	19 05	2 14	1.07	4.30	1.06
Bologna Uni. Obs., Italy	19 27	2 49	20 04	19 27	3 00	1.05	5.00	1.04
Obs. of Haute-Provence								
Nordic Optical Telescope								
Itajuba, Brazil								
Mount Cuba, Maryland								
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii								

KPD1930: 2003 Sep 6, Moon 81% full

Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory								
Turkish Natl. Obs.								
Moletai, Lithuania								
South Africa								
Suhora, Poland								
Piszkesteto, Hungary	19 03	2 15	19 26	19 03	2 15	1.07	4.59	1.06
Bologna Uni. Obs., Italy	19 25	2 45	20 00	19 25	3 02	1.05	5.00	1.04
Obs. of Haute-Provence								
Nordic Optical Telescope								
Itajuba, Brazil								
Mount Cuba, Maryland								
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii								

KPD1930: 2003 Sep 7, Moon 89% full

Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory								
Turkish Natl. Obs.								
Moletai, Lithuania								
South Africa								
Suhora, Poland								
Piszkesteto, Hungary	19 00	2 17	19 22	19 00	2 17	1.07	4.92	1.06
Bologna Uni. Obs., Italy	19 22	2 41	19 56	19 22	3 03	1.05	5.00	1.04
Obs. of Haute-Provence								
Nordic Optical Telescope								
Itajuba, Brazil								
Mount Cuba, Maryland								
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii								

KPD1930: 2003 Sep 8, Moon 94% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory								
Turkish Natl. Obs.								
Moletai, Lithuania								
South Africa								
Suhora, Poland								
Piszkesteto, Hungary	18 58	2 15	19 18	18 58	2 19	1.07	5.00	1.06
Bologna Uni. Obs., Italy	19 20	2 37	19 52	19 20	3 05	1.05	5.00	1.04
Obs. of Haute-Provence								
Nordic Optical Telescope								
Itajuba, Brazil								
Mount Cuba, Maryland								
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii								

KPD1930: 2003 Sep 9, Moon 98% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory								
Turkish Natl. Obs.								
Moletai, Lithuania								
South Africa								
Suhora, Poland								
Piszkesteto, Hungary	18 55	2 11	19 14	18 55	2 21	1.07	5.00	1.06
Bologna Uni. Obs., Italy								
Obs. of Haute-Provence								
Nordic Optical Telescope								
Itajuba, Brazil								
Mount Cuba, Maryland								
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii								

KPD1930: 2003 Sep 10, Moon 99% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory								
Turkish Natl. Obs.								
Moletai, Lithuania								
South Africa								
Suhora, Poland								
Piszkesteto, Hungary	18 53	2 07	19 10	18 53	2 22	1.07	5.00	1.06
Bologna Uni. Obs., Italy								
Obs. of Haute-Provence								
Nordic Optical Telescope								
Itajuba, Brazil								
Mount Cuba, Maryland								
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii								

KPD1930: 2003 Sep 11, Moon 99% full								
Site	Universal Time					Airmass		
	f.v.	l.v.	meridian	eve. tw	morn. tw	rise	set	meridian
Siding Spring, Australia								
Bohyunsan Obs., Korea								
Lulin Obs., Taiwan								
Beijing Observatory								
Turkish Natl. Obs.								
Moletai, Lithuania								
South Africa								
Suhora, Poland								
Piszkesteto, Hungary	18 50	2 03	19 06	18 50	2 24	1.07	5.00	1.06
Bologna Uni. Obs., Italy								
Obs. of Haute-Provence								
Nordic Optical Telescope								
Itajuba, Brazil								
Mount Cuba, Maryland								
McDonald Observatory								
Kitt Peak								
Mauna Kea, Hawaii								