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Evaluation of Lijiang Gaomeigu site for astrophysical observation

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Abstract. The work on the site testing at the Gaomeigu village Lijiang county in the northwest of Yunnan province, was started in 1994 after the completion of the investigation on optical astronomical observatory site survey over Yunnan Province. From six years of systematic study of astro-climate conditions, the average seeing is found to be about 0.9 arcsec from 32636 DIMM observations of 426 nights. The number of useful nights is more than 200. The sky brightness and the extinction coefficients are acceptable and the climate conditions are suitable for an astrophysical observational station. A 2.4m and some 1-m class telescopes will be installed here in the coming years.

1. Gaomeigu, Lijiang

At the beginning of 1990s, Chinese Academy of Sciences decided to conduct a site survey to find potential optical/infrared observational sites and make preparation for developing more powerful equipments in China. After the collection of daily cloud cover data of 192 ground meteorological stations (Zhang et al., 1996) in China from 1978 to 1990, the probability of finding cloud free skies is calculated at 02h, 08h, 14h and 20h (Beijing time). It is shown that the general environment of astro-climate conditions in China is not the best in the world. However, it is possible to find some relatively better sites from a few promising areas due to local topographical conditions (Huang et al., 1994). Generally speaking, the cloud cover decreases gradually in the direction from southeast to northwest. But, from Southwest Sichuan to Northwest Yunnan there is a relatively less cloudy south-north zone with better seeing quality than that in the north. This region is a prime candidate site for a southern observatory. The cloud cover in Yunnan is also calculated by using the polar-orbit satellite data, and the above mentioned cloud free zone, with several counties of Yunnan, including Lijiang, is confirmed. After the site investigation across the zone, five mountains are selected as the candidates for the second phase survey. From August 1993 to March 1994, the site testing team made 10 rounds of sampling observations in these places. According to the pattern of the Danjon stellar diffraction ring, it is shown that the seeing at Gaomeigu of Lijiang is the best among the five. Gaomeigu is located at the Taian township of Lijiang County (Fig. 1), Yunnan

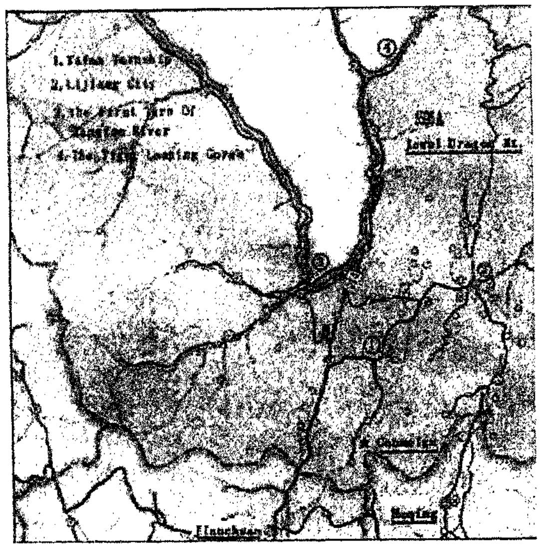

Figure 1. The Location of Gaomeigu.

province, with an elevation of 3200 meters, 26°42′ N and 100°02′E roughly. The relative height difference between Gaomeigu and Lijiang is 800 m to the east, and that between Gaomeigu and Jianchuan County is 1100 m to the southwest. The Gaomeigu area is a small plateau terrace with a smooth terrain, about 11 km long from north to south and 1 or 2 km wide from east to west. The site is about 300 km away from Kunming and 200 km from Panzhihua of Sichuan Province. Lijiang is accessible from Kunming by air, and it is about forty minutes driving time from Lijiang to the site. The site area is about 20 hectares including about ten peaks. A 150 KVA power transformer was installed. A water well 350 meters deep with 80 cubic meters water flow per day was finished. A new highway of 12 km from main highway to the site is under construction.

2. Cloud coverage

The cloud coverage was observed every hour round the clock by the observers trained at weather stations. The observed results for two years (i.e. from July 2, 1994, to July 1, 1996) are listed in Table 1. The definitions (A), as given in Zhang et al. (1999), are as follows : A photometric hour means that the total cloud cover=0, and a useful hour stands for the total cloud cover ≤ 3. A photometric night has a succession of 6 photometric hours. A half photometric night has a succession of 3-6 photometric hours, and a spectroscopic night has more than two successive useful hours or one photometric hour and another useful hour. In Table 1, I stands for photometric nights, II for half photometric nights, III for spectroscopic nights, IV for useful nights, V for photometric hours, VI for useful hours and VII for meteorological clear days. The variation of the number of useful nights month by month from July 1995 to June 1996 is shown in Fig. 2. Wind speed ≤ 15 m/s and relative humidity < 90% are considered as the conditions for the photometric hour and the useful hour (definition B). The results for one year are :

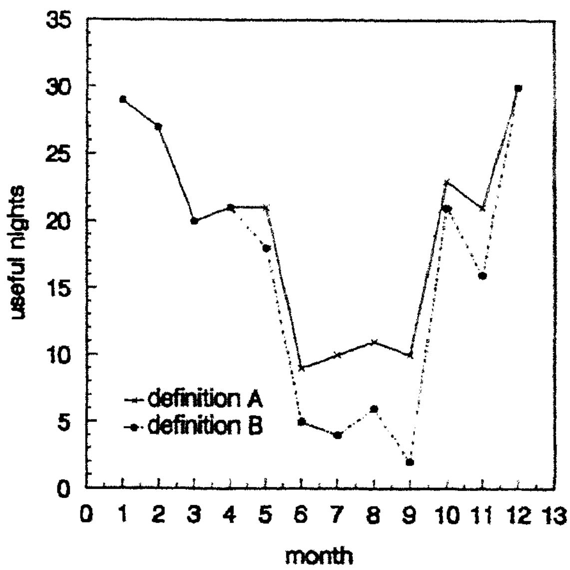

Figure 2. The monthly variation of the number of useful nights.

Items	I	II	III	IV	V	VI
One year	83	45	71	199	1061	1463

The difference of useful time of definition B with A is significant from June to October, since during the rainy season the relative humidity is frequently over 90%. It is shown from the last column of Table 1 that the number of meteorological clear days is 80.5 per year during

Table 1. Average of astronomical useful time (def. A) (July 2, 1994 to July 1, 1996).

Month	I	II	III	IV	V	VI	VII
Jul.	0.5	1	8.5	10	12	42.5	0
Aug.	0	4.5	8	12.5	26.5	69.5	0.5
Sep.	1.5	1	10	12.5	26	63	0.5
Oct.	11	3	9	23	139.5	195	8.5
Nov.	11.5	6.5	7	25	142.5	197.5	8.5
Dec.	23.5	3.5	3	30	281	329.5	22.5
Jan.	20.5	4	3.5	28	246	303.5	18.5
Feb.	12.5	2.5	10.5	25.5	167	238.5	10.5
Mar.	7	3.5	11.5	22	85.5	162	8
Apr.	5.5	1.5	12.5	20.5	74	148.5	2.5
May	4	6	10.5	20.5	65.5	118	0.5
June	0	2	6	8	10.5	41	0
Aver.	97.5	39	100	237.5	1276	1908.5	80.5

1994 to 1996, which is lower than the number of clear days, 84.8 per year, average from 1959 to 1994. If the astronomical useful time is proportional to the number of meteorological clear days, the number of useful days for a long-term averaging should be around 250 (iden.A) or 210 days (iden.B).

3. Water vapor

By using the IRA-935 infrared water vapor metre made by Beijing Normal University, we observed the Sun for 251 days and the moon for 54 nights. The precipitable water vapor was then calculated from the residual intensity of the 935 nm water absorption band relative to the continuum and normalized to the zenith. The average of the water vapor is listed as below.

Season	day time	night
Rainy (May to Oct.)	15.6 mm	13.0 mm
Dry (Nov. to Apr.)	5.1 mm	4.3 mm

The variation of water vapor from Aug 24, 1995 to Aug 23, 1996 is shown in Fig. 3. It is clearly shown that Gaomeigu is not a perfect place for infrared astronomy. At the most some work in the near infrared in the dry season can be done.

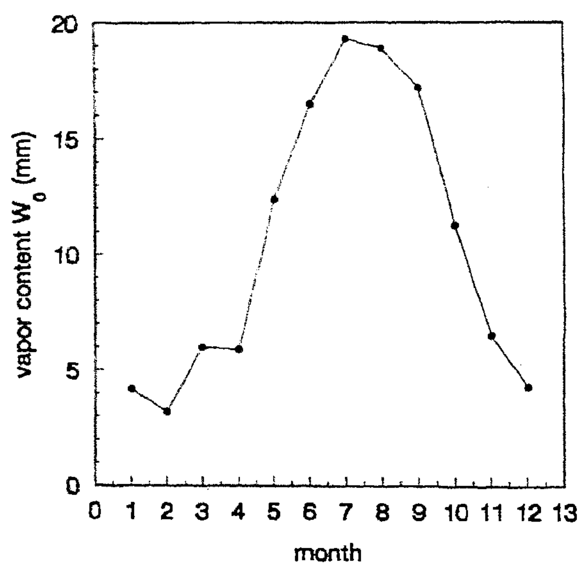

Figure 3. Water vapor integral content.

4. Other meteorological factors

An automatic weather tower was set up on Gaomeigu to measure weather data over two years (1995-1997). The monthly variation of air temperature is shown in Fig. 4. The annual average temperature is 6.8°C. The highest is 22.3°C while the lowest is –7.3°C for the two years. It is suitable for observations and not too harsh for the observer's life. The relative humidity is higher than the expected as shown in Fig. 5. It is possible that water may condense on the mirror surface, when the enclosure is opened during the rainy season. The wind speed is not

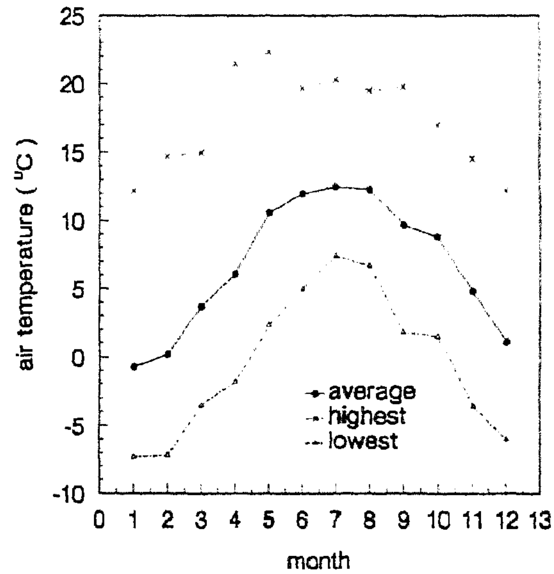

Figure 4. Monthly vairation of air temperature.

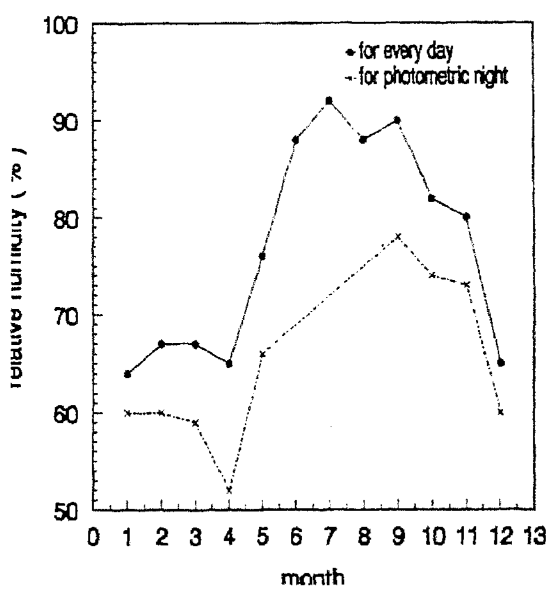

Figure 5. Monthly variation of average relative humidity from May, 1995 to April, 1997.

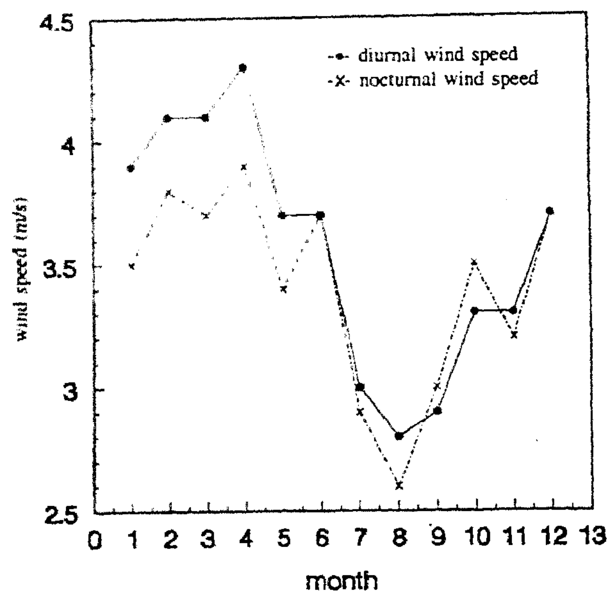

Figure 6. Monthly variation of average wind speed.

so high. Monthly variation of average wind speed (diurnal and nocturnal) is drawn in Fig. 6. The highest speed is around 15 m/s from the observed data. The wind direction is mostly from south, southeast or southwest (76.5%).

5. Seeing

Following the idea of Fried (1975), Saragin & Ruddier (1990), a three-sub-aperture differential image motion monitor (DIMM) made by our group was used and attached to a 35 cm reflector with focus ratio 15 (Tan et al., 1995). From March, 1995 to the end of 1997, 20 ms exposure time was used and 8 ms exposure time has been used since 1998. We designed an experimental device to do sampling simultaneously at 20 ms and 8 ms exposure time. Through a beam splitter 30% of starlight are reflected to the 20 ms exposure CCD and 70% is transmitted to the 8 ms CCD. The two sets of data (200 groups for each) show a linear relation $r_{020ms} = 1.1399 \times r_{08ms} - 0.0418$, with a correlation coefficient of 0.862 (Qian Tong-ling et al., 2001). All results were normalized to that of the 8 ms exposure time. The variation of seeing with time during night is shown as Fig. 7. It is clearly shown that the seeing improves after the twilight in the evening and becomes stable from the middle of the night to the morning. The variation from month to month is tabulated as below :

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Seeing(″)	0.76	0.77	0.87	0.85	0.80	0.88	0.83	0.82	0.77	0.77	0.90	0.82

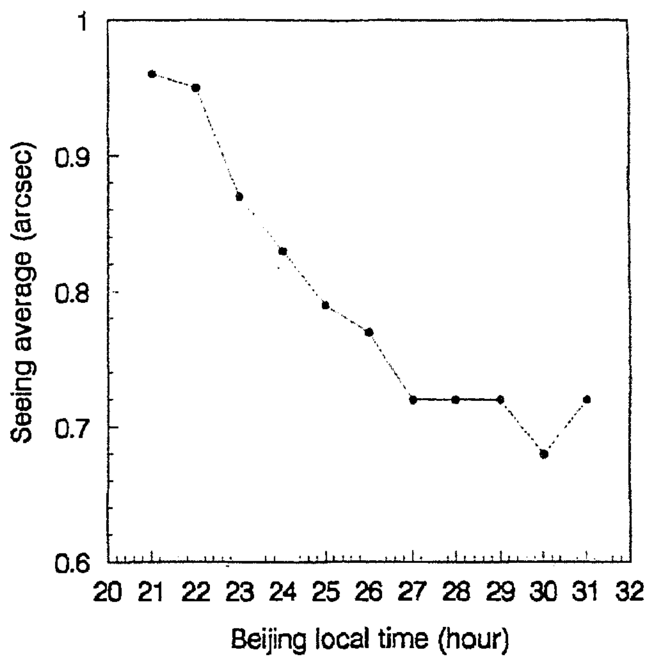

Figure 7. Seeing variation with time during night.

Table 2 is the summary of the results on observed seeings.

Table 2. Monthly average seeing at Gaomeigu.

Month	Obs. Nights	Data sets	Monthly average (")
1995			
Mar.	15	557	0.99
Apr.	8	382	0.97
May	14	762	0.86
Jun.	6	55	0.92
Jul.	8	196	0.80
Aug.	2	60	0.84
Sep.	11	387	0.71
Oct.	24	1659	0.80
Nov.	16	1128	0.80
Dec.	29	3008	0.86

Table 2. continued.

Month	Obs. Nights	Data sets	Monthly average (″)
1996			
Jan.	21	1730	0.76
Feb.	8	1340	0.77
Mar.	4	309	0.75
Apr.	19	2011	0.72
May	21	1027	0.75
Jun.	9	1182	0.78
Jul.	1	7	0.86
Aug.	12	247	0.80
Sep.	5	58	0.83
Oct.	12	1162	0.74
Nov.	12	677	0.93
Dec.	2	176	0.83
1997			
Apr.	6	340	0.86
May	7	390	0.80
Jun.	1	65	0.95
Oct.	4	353	0.79
Nov.	10	1149	0.98
Dec.	10	1062	0.80
1998			
Oct.	3	193	0.88
Nov.	14	1484	0.90
Dec.	15	1306	0.91
1999			
Jan.	4	466	0.92
Feb.	16	1305	0.97
Mar.	6	634	1.01
Apr.	6	585	1.05
May	5	188	1.01
Jun.	6	68	1.00
Jul.	1	39	0.93
Aug.	1	14	0.80
Oct.	2	66	0.96
Nov.	19	1704	1.03
Dec.	18	1214	0.86
2000			
Sep.	3	104	1.05
Oct.	4	552	1.05
Nov.	3	667	1.01
Dec.	6	555	0.92

Two sites, namely hill 3 and hill 6, 1 km apart, were chosen to measure the seeing simultaneously by comparison. The two DIMM equipments and telescopes have the same technical parameters. Based on the statistical results of 4756 sets of observed data from 6 Feb 1999 to 31 Dec 1999, we have found the average seeing variation with time almost the same. They are shown in Fig. 8.

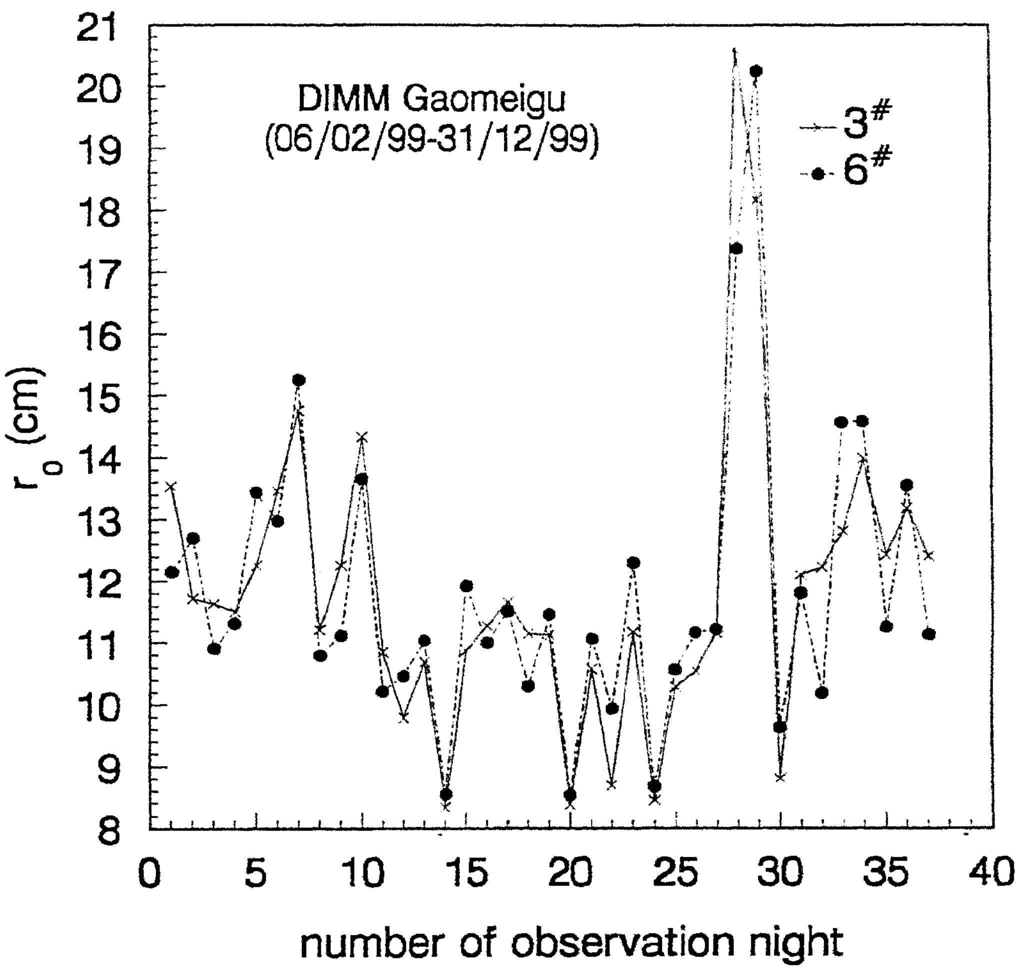

Figure 8. Variation curves of the night average seeing at No. 3 and No. 6 hill.

The seeing values obtained for the longitudinal and transverse components are compared in Fig 9. In which 381 sets of data from 6 nights (Dec 19, 2000 to June 14, 2001) were employed, all with 4 ms exposure time. 8 ms exposure time were used for other 1822 sets data from 12 nights (Oct 9, 2000 to July 15, 2001). We have drawn a line of unit slope and zero intercept. The data points are almost symmetric around the line. This means that r_{0L} are nearly identical. The relationship of r_{0L} and r_{0T} for different exposure times does not show any obvious differences.

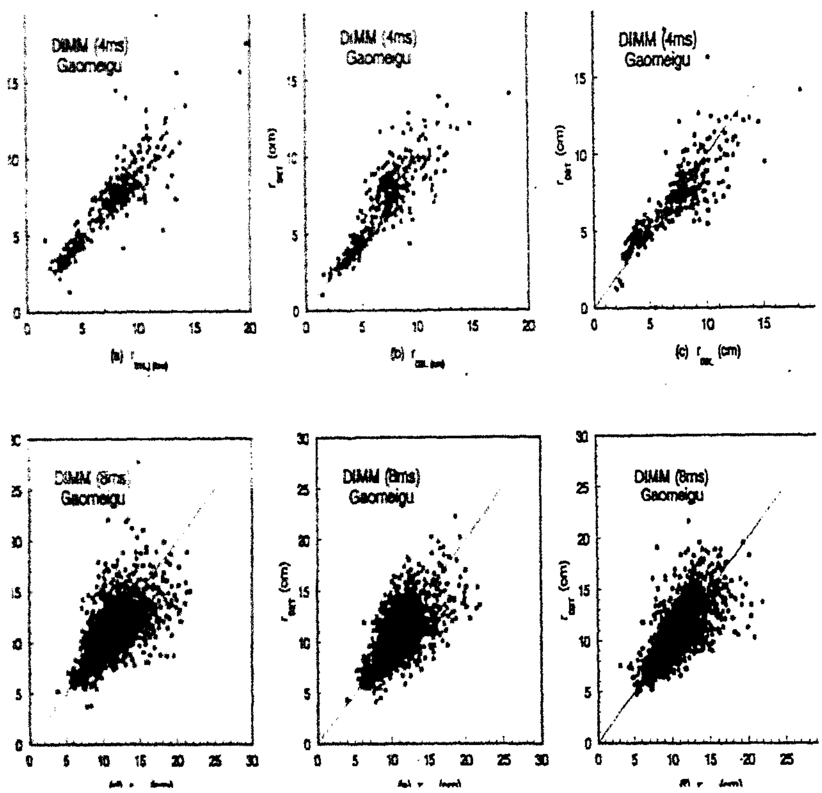

Figure 9. A comparison of longitudinal and transverse seeing for 4ms and 8ms exposure time.

6. Error estimation of seeing measurements

The uncertainty in the determination of centroid of an image due to detector noise introduces an error in the seeing measurements.

$$\Delta FWHM \ / \ FWHM = 3\Delta\delta_n^2/5\delta_*^2 \tag{1}$$

δ_n and δ_* are standard deviation for noise and star image respectively. The estimation of the instrumental noise was carried out in our lab. The intensity levels of the images were kept similar to stellar magnitude 1^m–3^m. The uncertainty, measured in the separation of the images of 0.015 pixel, is equivalent to 0''.0065.

The statistical errors of the seeing measurements were calculated using the formalism (Frieden, 1983).

$$\Delta\delta_n^2 / \delta_n^2 = \sqrt{2/(N-1)} \tag{2}$$

N is the number of samples and equals 512.

$$\Delta FWHM / FWHM = 0.6\,\Delta\delta_n^2 / \delta_n^2 = 0.6\sqrt{2/511} = 3.75\% \tag{3}$$

The different wavelengths used in seeing measurements also introduce an error.

$$\Delta r_0 / r_0 = 1.2\Delta\lambda / \lambda \tag{4}$$

V filter was used in our seeing measurement, similar to ESO (Sarazin and Roddier, 1990). This error, therefore, should be small.

Additionally, the size of sub-aperture and their separation, the exposure time, the criteria used to calculate the image center of the star, could introduce errors. Considering all of these errors, we suppose that the relative error should be less than 10%.

7. Sky brightness

A photometer with the photomultiplier 1P21 was used to measure the sky brightness (Tan Huisong et al., 1999). The diaphragm was 87 arc seconds in diameter. Two colors, B and V, were employed. The results obtained for 14 nights (1996 to 1998) and normalized to standard system are as follows :

Sky brightness	average	best	worst
V mag./sq.sec.	21.54	21.77	21.10
B mag/sq.sec.	22.34	22.79	21.92

A low luminosity photometer was also used to measure the overall brightness of about one hundred square degrees in the sky. The results of sky brightness are similar to that obtained by using the photometer. We measured specifically the effects of artificial lights from three towns nearby (Lijiang, 31 km away, twenty thousand residents, Jianchuan, 30 km and ten thousands, Heqing, 18 km and five thousand) for three nights. There are no obvious effects which are brighter than 0.05 man. However the Zodiacal light may increase the brightnes by 0.5 mag per square arcsecond while the scattering light of Milky way is around 0.1 mag.

8. Coefficients of extinction

A photometer with B and V band filters attached to a 35 cm reflector was used to study the coefficients of extinction at Gaomeigu. The differential photometry was employed to observe a star pair consisting of an early type standard star and a late type standard star. The normalization coefficients were obtained by observing six standard stars. The results from 14 night's observations are summarized as follows :

Band	Average	best	worst
V	0.135	0.103	0.163
B	0.298	0.227	0.376

9. Comparison with Devasthal site

Devasthal, a new site of India (Pant et al., 1999; Sagar et al., 2000) and Gaomeigu, a new station of China, 2000 km apart, are proximity sites in Himalaya range. It is worth comparing various astronomical conditions of the two sites. The various items and the observed results are listed in Table 3. We make some comments on this table. The definition of photometric night and spectroscopic night has had some differences (Zhang et al., 1999; Sagar et al. 2000). The cloud coverage and the water vapor at Devasthal are obviously less than that at Gaomeigu. The seeing at Gaomeigu is better than that at Devasthal. Many parameters and conditions are similar. Even the name Devasthal in Hindi language means the place of God and the name Gaomeigu in Naxi language means that the place is higher than the heaven.

Table 3. Comparison of Gaomeigu and Devasthal sites.

Site	Gaomeigu	Devasthal
Longitude	100°02′E	79°41′E
Latitude	26°42′N	29°23′N
Altitude	3200 m	2540 m
Temperature Variation	−7°.3C–22°.3C	−4°.5C–21°.5C
Temp. Variation during night	4°.2C	≤ 2°C (73%)
Relative humidity	62%	generally below 60%
Wind speed	3.5m/s	77% below 3m/s
Wind direction	SW	NW
Spectroscopic nights	199	208
Photometric nights	128	175
Seeing (Ave.)	$0''.9$	$1''.2 \pm 0''.3$
Water vapor	13.0 mm (May - Oct.)	21% 1-2 mm
	4.3 mm (Nov. - April)	43% 2-3 mm, 36% > 3 mm
Extinction	Ave. 0.30 in B, 0.14 in V	Lowest 0.40 in U, 0.22 in B,
	(Lowest 0.23 in B, 0.10 in V)	0.12 in V
Sky brightness	$22^m.34$ / *arcsec*^{2} in B,	$22^m.2$ / arsec^2 in B
	$21^m.54$ / *arcsec*^{2} in V,	$21^m.1$ / arsec^2 in V
First telescope	2.4 m reflector	3 m class reflector

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