

# How to measure seeing

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## Abstract

The work deals with measuring of seeing. The unrest of air is a big problem for astronomers, therefore, it is important to know how much the unrest influences the observing quality on the Earth. The own measuring was carried out on two different stations by two different methods: detecting the changes in angular distance between the stars and measuring of FWHM. The first method did not bring the conclusive results which would evaluate seeing. The second method showed more demonstrable results. Values of seeing were higher and showed worse observing conditions.

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# 1 What does seeing mean?

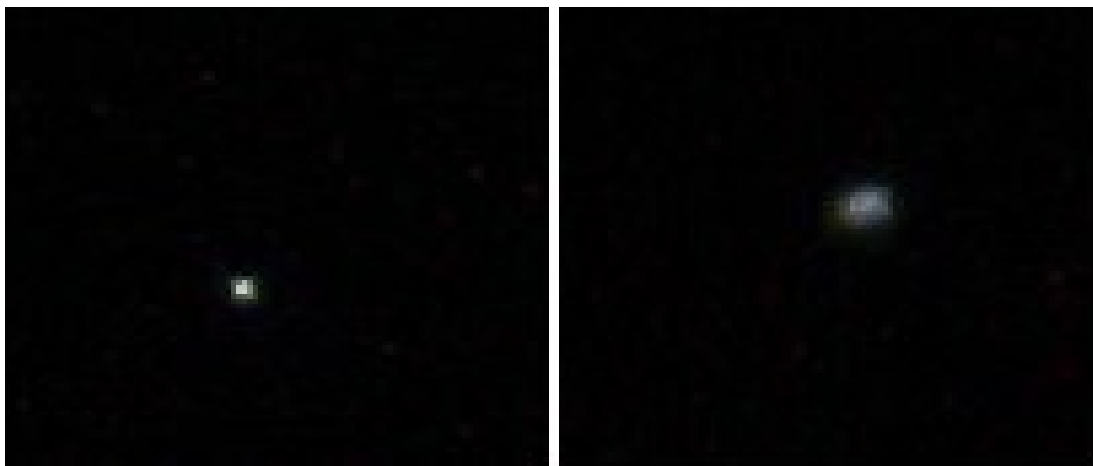
## 1.1 Astronomical observing

Astronomy is scientific field which deals with all objects beyond Earth's atmosphere. We can divide astronomical observing into daily and night observing. The daily observing is limited by the brightness of the Sun. The Sun is the most sought after object for the daily observing. It is necessary to use a special solar filter to protect our sight. In day we can also observe other objects in addition to the Sun, but only the brightest (the Moon, Jupiter, Venus, Sirius). At night the situation is better.

There are many types of objects for observing – stars, planets and their moons, DSO (star clusters, nebulas, galaxies).

During the observing we can see that the image formed in the telescope is not sharp and it can slightly move or shake. It is caused by the atmosphere of Earth especially by thermal turbulence. The air is not calm. This unrest of the air is called astronomical seeing. It has fundamental influence on the quality of the image.

Seeing is mainly associated with observing stars and planets and with photographing. There are two kinds of seeing – fast and slow. The slow seeing exists mostly in lower altitudes of the atmosphere. It makes the image moving and oscillating, although the image stays still and relatively sharp. The slow seeing doesn't influence visual observing but it has substantial impacts in astrophotography. On the other hand the fast seeing has more destructive effects. It is formed in higher altitudes in the atmosphere. The image is completely blurred and we can see only a blurry blot. The kinds of the astronomical seeing can exist independently or they can occur in combination.



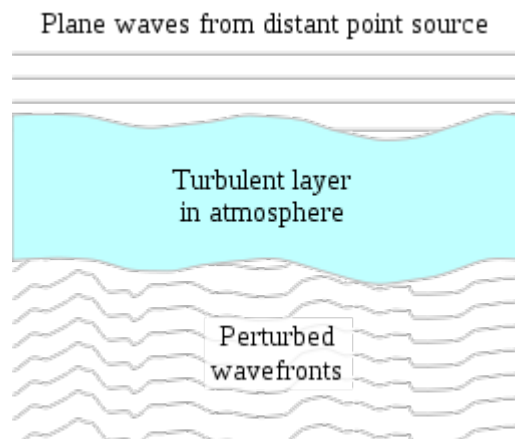
Picture 1 – The star Alcor, on the left with relative good seeing conditions, on the right with bad seeing conditions

## 1.2 The emergence of seeing

Seeing is the effect of the atmosphere of Earth. The atmosphere contains gaseous, liquid and solid particles. It consists of several layers and many air cells. The cells differ in their size – from tens of centimetres to units of metres. They also differ in refractive index  $n$ . It is a dimensionless physical quantity which shows how much slower is the light in given environment than in the air. The refractive index for air is:

$$n_a = 1,0026$$

The differences between refractive index of the cells are almost minuscule – only tenths. But these differences are relevant for motionlessness of image. We can liken the Earth's atmosphere to some system of lenses. The light which comes from space objects refracts and changes its direction.



Picture 2 – The transmission of the light through the Earth's atmosphere

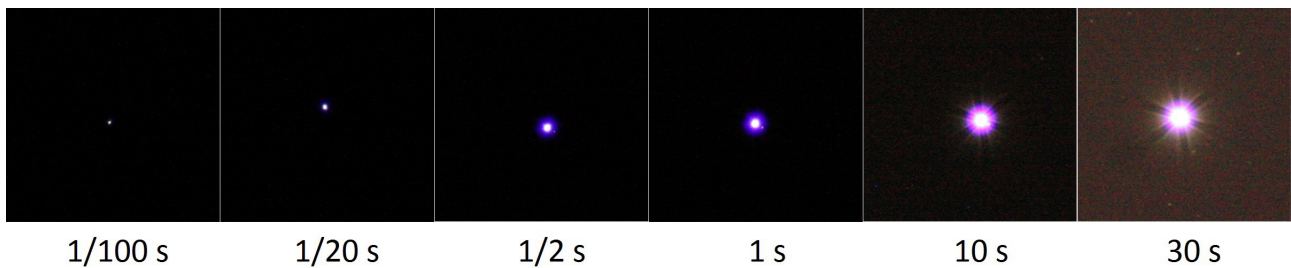
Another thing which contributes to the creation of seeing is the weather. Fine mist and fine haze improve seeing. The air is calmer and the observing conditions are therefore better. Conversely at lower temperatures and stabilized pressure above seeing is worse.

## 2 Eliminations of seeing

### 2.1 Lucky imaging

Lucky imaging is an elimination method which is used for partial removal of seeing effects in astrophotography. Its principle is based on sensing of the large number of photos with very short exposure time (fractions of seconds). The photos that are influenced by the effects of the atmosphere too much are deleted. The rest of the photos are folded to one resultant photo.

The exposure time can affect the final quality of the photo, I tried to find out how much. Below are photos of the star Polaris in the star constellation Ursa Minor with six distinct exposure times. The difference between the shortest and the longest exposure time was enormous.



Picture 3 – The photos of the star Polaris with different exposure times

### 2.2 Adaptive optics

The adaptive optics system serves to correction of the failures caused by seeing. It has been known since the 50s of the 20<sup>th</sup> century, but its realization was possible only with modern powerful computers. The operating principle of the system is not too complicated.

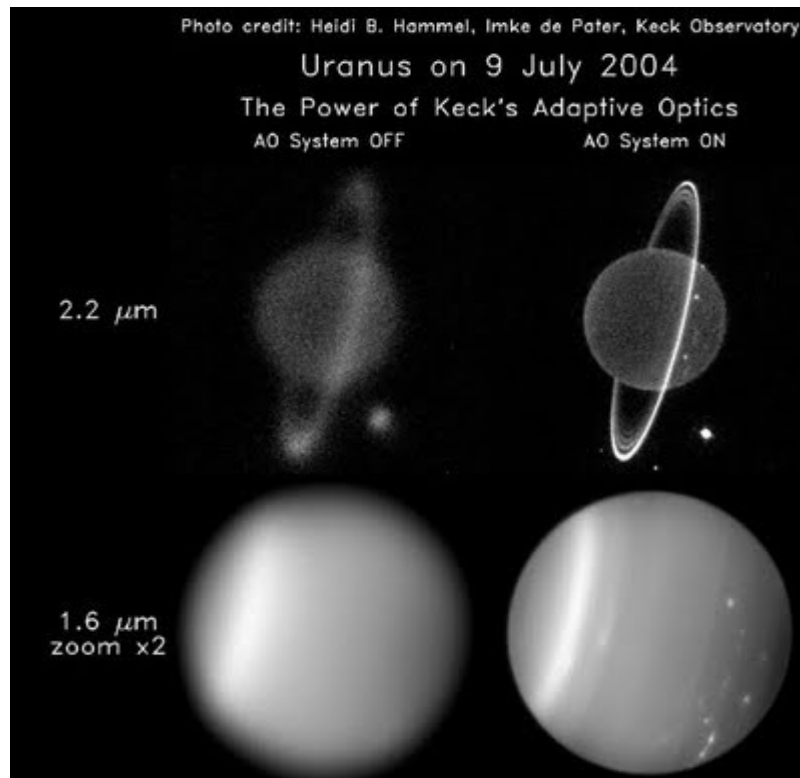
The wavefronts coming from the space objects deform during passage through the atmosphere. Fried parameter shows the length where the wavefronts are not deformed. seeing is better with bigger Fried parameter. The time of coherence is another important quantity. It describes how fast seeing is another important quantity. It describes how fast seeing is changed by air conditions. The deformed wavefront goes to a sensor. There are many types of sensors but the most common is a Shack-Hartman wavefront sensor. The sensor measures the deformation of wavefronts. The computers process the information about deformation, calculate action interventions and send these data to actuators – action elements. Then the actuators deform secondary mirrors. The computers have to work in real time because the time of calculating and deforming has to be shorter or the same as the time of coherence. In the end a beam of light is forwarded to a scientific apparatus.

If the sensor can indicate correct and useful values, a sufficiently bright source of the light is needed. For this purpose the guide stars are used. Natural guide stars (NGS) have to be near the observing object and have to be bright enough (12 – 15 mag). Laser guide stars are used more often because number of NGS is very small.



Picture 4 – The Very Large Telescope with the system of adaptive optics at work

The system of adaptive optics is still new and developing. It can almost completely eliminate seeing influence. However, the system is very expensive.



Picture 5 – Photos of Uranus with and without the system of adaptive optics

### 2.3 Other eliminations

Buildings heat the surrounding air at night and this results in the local air turbulence. It is better to place an observing post further from these buildings. The altitude can also play an important role. Generally in the large altitude air conditions are better. But the noticeable differences in air quality will take effect at very big height differences (thousands of metres).

The height of the observing object is important too. The best conditions are always in the zenith, where the astronomers see the objects through the smallest mass of air.

There is only one way how to completely eliminate seeing effects –placing a telescope behind the border of the atmosphere. In 1990 Hubble Space Telescope was launched into Earth orbital. It is used mainly for photographing deep sky objects. The telescope is a reflector. The mirror has diameter 2,4 meters and focal length 57.6 metres. The telescope still works and it is going to work until 2018.

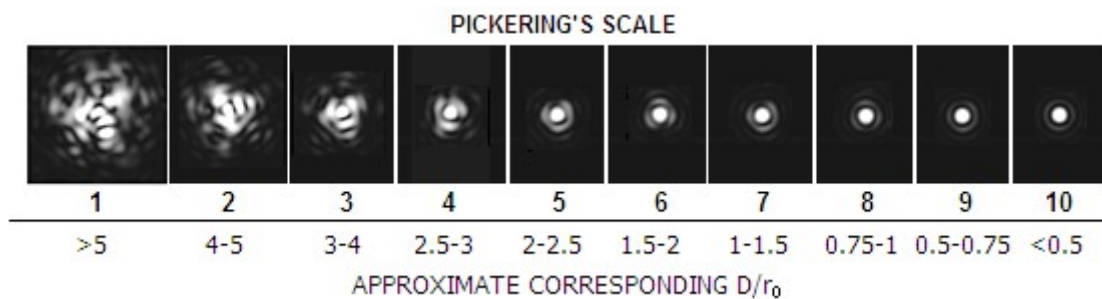


### 3 Measuring of seeing

#### 3.1 Existing methods

##### 3.1.1 Seeing scales

Amateur astronomers evaluate seeing conditions using some seeing scales. There are several types of scales. The Pickering scale is divided to degrees from 1 to 10. Number 1 shows a very poor seeing and number 10 shows an excellent seeing conditions (the image is calm and sharp).



Picture 6 – The Pickering scale

Another scale is the Antoniadi scale which describes five points of seeing quality.

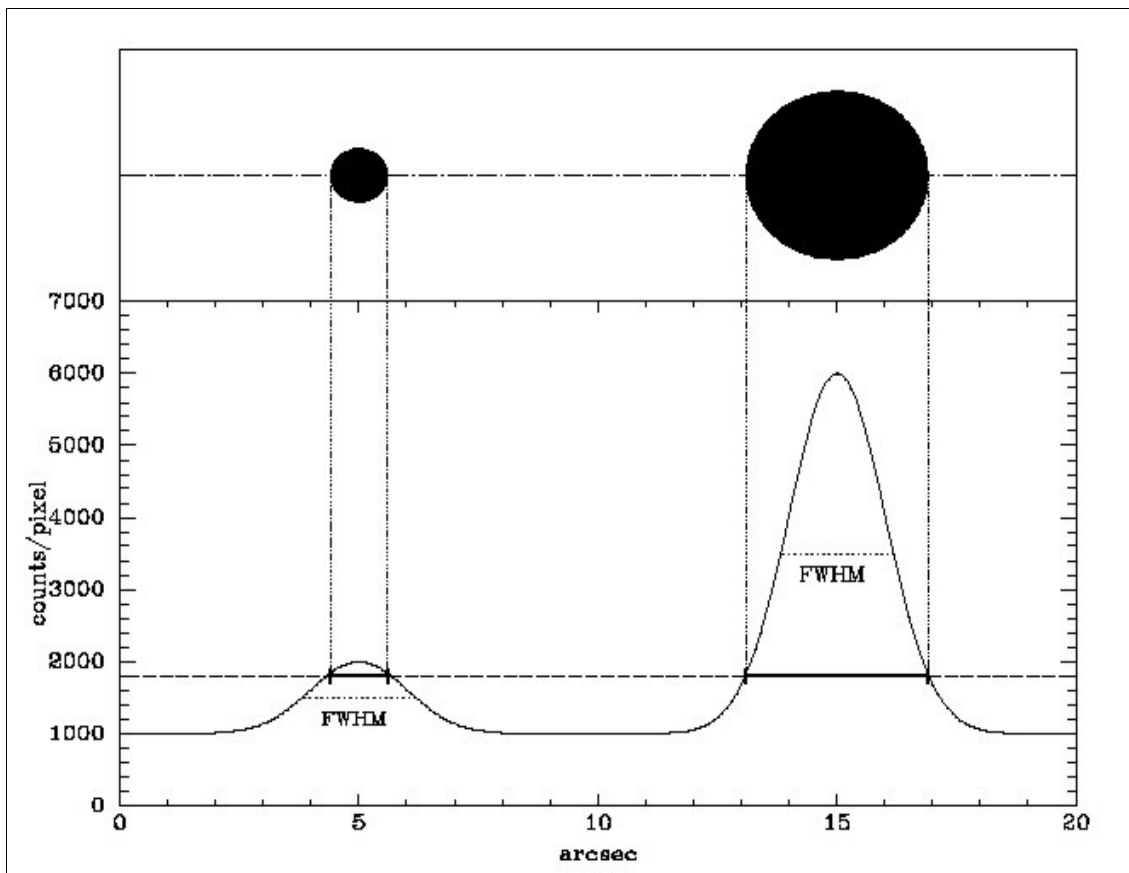
Point	Seeing conditions
I	Perfect seeing, the perfect image without shaking
II	Good seeing, slight shaking of the objects
III	Moderate seeing the image is still not absolutely sharp
IV	Poor seeing, undulation of the image
V	Very poor seeing, the flashing image

Table 1 – The Antoniadi scale

Measuring of seeing with scales is only amateurish. There are not determined the exact interfaces between the points. It depends on the each astronomer and his experiences how he choose the point in the scale. Every astronomer can choose another point in the scale. The measuring is therefore relatively imprecise and subjective.

### 3.1.2 Angular size

The measuring of angular sizes of the almost pointy stars is more professional than measuring by seeing scales. FWHM (Full width half maximum) serves in astrophotography to measure seeing in arcseconds. seeing conditions are mainly measured in arcseconds, even the scales are sometimes approximated to the arcseconds. The maximum is divided into a half. The width in the half of maximum shows the value of seeing as the diagram below show. It is determined that a bigger value of FWHM means worse conditions for observing. The common values of seeing in the Czech republic are 2 – 5 arcsec.



Picture 7 – The method of measuring FWHM

## 3.2 Own measuring

### 3.2.1 Used equipment

We used a telescope Sky-Watcher refractor 90/910. We mounted a camera Canon EOS 450D to the telescope and with this technique we took series of photos. Every photo was then processed in the program DeepSkyStacker (DSS).

Measuring was carried out at two stations – balcony on the fourth floor and the observatory in Prostějov (the second floor). The exposure time was 1/20 second on each photo. The photos were not edited.



Picture 8 – The telescope Sky-Watcher 90/910 on the station 1

### 3.2.2 Changes in angular distance

The first method that we used was based on the knowledge of angular distance between two stars. In this method we concentrated predominantly on the measuring of the slow seeing causing a light move of the image. We chose for this measuring the stars Mizar and Alcor in the starstar constellation Ursa Major. The angular distance between these stars is 708 arcsec (11,8 arcmin). We took 11 series of photos at the station 1 and 14 series of photos at the station 2. We inserted each photo to the program DSS. The program DSS marked the coordinates of the centers of the stars. With these coordinates we counted the distance between Mizar  $X [x_1; x_2]$  and Alcor  $Y [y_1; y_2]$  in pixels:

$$|XY| = \sqrt{((y_1 - x_1)^2 + (y_2 - x_2)^2)}$$

This procedure was used for all the photos. After processing all the series we gained an overall average distance in pixels. The overall average distance has the value 596,61 px. It corresponds with 708 arcsec, we counted that:

$$1 \text{ px} = 1,18 \text{ arcsec}$$

It is necessary to convert the values in pixels to the values in arcseconds.

The next step was a comparison between the overall average distance and the distance in every series. The difference between these values indicate the value of seeing.



Picture 9 – A photography with the stars Mizar (above, two stars) and Alcor (down)

The following tables show the dates and the times of acquisition of the photos and the values of seeing.

Station 1					
Date	Beginning	Ending	Distance (px)	Change in the distance (px)	The value of the seeing (arcsec)
4/10 2013*	19:35	20:05	594,03	2,64	3,12
19/10 2013*	19:25	19:50	596,90	0,23	0,27
31/10 2013	21:00	21:10	596,96	0,29	0,34
3/2 2014	20:15	20:30	596,05	0,62	0,73
14/2 2014	22:00	22:20	597,65	0,98	1,16
17/2 2014	22:10	22:25	597,05	0,38	0,45
20/2 2014	21:20	21:40	597,17	0,50	0,59
28/3 2014	20:05	20:20	596,98	0,31	0,37
28/3 2014	21:25	21:35	597,24	0,57	0,67
29/3 2014	20:15	20:25	597,12	0,45	0,53
30/3 2014*	19:45	20:00	597,46	0,79	0,93
Average			596,54	0,51	(0,60 ± 0,35)

Table 2 – The average values of the angular distance between the stars Mizar and Alcor on the station 2, \* means the summer time

Station 2					
Date	Beginning	Ending	Distance (px)	Change in the distance (px)	The value of the seeing (arcsec)
4/10 2013*	20:25	20:40	598,18	1,64	1,94
19/10 2013*	21:00	21:50	596,52	0,02	0,02
31/5 2014*	23:40	23:55	597,00	0,46	0,54
26/6 2014*	23:10	23:30	595,68	0,86	1,01
17/7 2014*	23:20	23:35	596,25	0,29	0,34
18/7 2014*	22:15	22:30	596,93	0,39	0,46
21/8 2014*	21:55	22:20	596,84	0,30	0,35
22/8 2014*	21:50	22:00	596,26	0,28	0,33
5/9 2014*	21:15	21:25	596,29	0,25	0,30
5/9 2014*	22:20	22:35	596,10	0,44	0,52
6/9 2014*	21:55	22:10	595,85	0,69	0,81
Average			596,54	0,51	(0,60 ± 0,35)

Table 3 – The average values of the angular distance between the stars Mizar and Alcor on the station 2, \* means the summer time

### 3.2.3 FWHM

The measuring of FWHM was focused more on the measuring of the fast seeing which causes blurring of the image. We chose the same objects and the same photos as in the method of measuring the changes in angular distance. At every station we took 10 series of photos. The program DSS can directly determine the values of FWHM – the values of seeing. This Method was not as challenging as the first method because there was no need to convert the values in the pixels to the values in the arcseconds.

Station 1			
Date	Beginning	Ending	Seeing (arcsec)
4/10 2013*	19:35	20:05	(5,94 ± 0,62)
19/10 2013*	19:25	19:50	(6,82 ± 0,60)
14/2 2014	22:00	22:20	(5,06 ± 0,62)
28/3 2014	20:05	20:20	(4,14 ± 0,32)
28/3 2014	21:25	21:35	(5,48 ± 0,59)
29/3 2014	20:15	20:25	(4,61 ± 0,47)
30/3 2014*	19:45	20:00	(5,92 ± 0,71)
4/4 2014*	21:45	21:55	(4,11 ± 0,38)
16/8 2014*	23:00	23:20	(6,52 ± 0,59)
20/8 2014*	00:05	00:20	(5,16 ± 0,36)
Average			(5,38 ± 0,53)

Table 4 – The values of FWHM on the station 1, \* means the summer time

Station 2			
Date	Beginning	Ending	Seeing (arcsec)
19/10 2013*	19:25	19:50	(6,91 ± 0,49)
31/5 2014*	23:40	23:55	(5,01 ± 0,35)
26/6 2014*	23:10	23:30	(5,63 ± 0,44)
17/7 2014*	23:20	23:35	(4,45 ± 0,40)
18/7 2014*	22:15	22:30	(4,58 ± 0,31)
21/8 2014*	21:55	22:20	(4,76 ± 0,46)
22/8 2014*	21:50	22:00	(4,10 ± 0,24)
5/9 2014*	21:15	21:25	(3,95 ± 0,32)
5/9 2014*	22:20	22:35	(3,78 ± 0,21)
6/9 2014*	21:55	22:10	(4,47 ± 0,33)
Average			(4,76 ± 0,36)

Table 5 – The values of FWHM on the station 2,\* means the summer time

### 3.2.4 Summary of the results

In the tables 6 and 7 are summarized the average values of seeing measured by both methods.

Changes in angular distance	
Station 1	(0,85 ± 0,45) arcsec
Station 2	(0,60 ± 0,35) arcsec
Average	(0,73 ± 0,40) arcsec

Table 6 – The average values of seeing measured by the method of measuring of the changes in angular distance

FWHM	
Station 1	(5,38 ± 0,53) arcsec
Station 2	(4,76 ± 0,36) arcsec
Average	(5,07 ± 0,45) arcsec

Table 7 – The average values of seeing measured by the method of measuring of FWHM

During the measuring I recorded the current climatic conditions (temperature, humidity, wind speed and atmospheric pressure) and the height of the object (Mizar) above the horizon (in degrees). From recorded conditions, I created statistics and calculate the correlation coefficient  $r$ . The following table summarizes the results of this statistic.

Condition	Station 1	Station 2	Average
Height of the object	-0,63	-0,05	-0,34
Temperature	-0,31	-0,68	-0,50
Wind speed	0,57	0,42	0,50
Humidity	0,58	0,11	0,34
Atmospheric pressure	0,18	0,80	0,49

Table 8 – The values of the correlation coefficient

The statistics shows that seeing depends indirectly on the temperature and the height of the object. On the other hand seeing depends directly on the wind speed, atmospheric pressure and humidity.

The data obtained by the first method do not match the values that seeing would take. Average values are less than 1 arcsec but seeing usually takes values 2 – 5 arcsec. A short exposure time could cause that we measured the better conditions than they were in reality. The angular distance between the stars Mizar and Alcor is relatively short (708 arcsec). On a such small area in atmosphere air can behave homogeneously. The blurring in all the area can be the same and distance between the stars can be almost changeless.

The results obtained by measuring FWHM seem to be more correct and closer to reality than results of the first method. However the average value of seeing 5,07 arcsec shows bad air conditions.

## 4 Conclusion

I tried to objectively measure astronomical seeing in the locality of the town Prostějov. This task we fulfilled. The first method showed the not very realistic results. The average value of seeing was in this method 0,73 arcsec, less than the values that seeing should acquire. The results measured by the second method (the average value 5,07 arcsec) were more correct and realistic and show bad conditions for observing. For measuring FWHM were demonstrated the dependencies on some climate conditions and height of the observed object.

I used two methods but there exist more methods for measuring seeing. It is necessary to study the theoretical aspects in more details and make another practical experiments of this kind.



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### Pictures

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