Astronomical Telescopes

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2009 Asian Science Camp
August 3
• **Galileo Galilei and International Year of Astronomy**

A telescope was invented in 1608 by a Dutch technician, although there are many other stories about the invention. In 1609, Galileo Galilei (1564-1642) made a small refractor telescope with a lens of 42mm diameter, its field of view being only 6 minutes of arc. He pointed it to the moon, Jupiter, the Sun, Milky Way and others. And he discovered many craters on the lunar surface, the four bright satellites of Jupiter, now called as Galilean satellites, sunspots on the solar surface and found that Milky Way consists of many stars.

The International Astronomical Union declares 2009 as International Year of Astronomy and the idea was endorsed by the United Nation and UNESCO. And many events associated with this project are going on.
Refractor and Reflector

- It was J. Kepler (1571-1638) who designed a refractor with much wider field of view by introducing a concave lens as the eyepiece. Then large refractors were made. The largest refractor in the world is 102cm telescope built in 1898 at Yerkes Observatory (USA).

- The weakness of the refractor is that its focus is shifted according to the wavelength of light, which is called color aberration. Several idea was introduced to eliminate the color aberration. However, it has not been completely eliminated.

As spectroscopic observations became important to study stars and galaxies, large telescopes built later became reflecting ones with main mirror. Two of the very famous reflecting telescopes made by the middle of the 20th century are 2.57m (1905) one at Mt Wilson and 5m (1948) at Palomar Observatory, both in USA.
• **Advantage of larger telescopes** is large collecting power of light as well as higher angular resolution, which is expressed by $\lambda /D$. In this expression $\lambda$ and D are, respectively, wavelength of light, or more generally of electromagnetic wave, and the diameter of the main mirror or the objective lens. Therefore, the image size by a telescope with 1m diameter and 1 $\mu$m wavelength light is theoretically 0.2 seconds of arc. However scintillation effect which is caused by non-uniform density distribution of the atmosphere is dominant, as large as 1 to 2 seconds. Therefore, Hubble space telescope with 2.5m diameter has much advantage.

• Also now larger telescopes are built at an astronomically good site. For example Subaru telescope with 8.2m diameter is at Mauna Kea, Hawaii, where the trade wind is blowing to reduce the scintillation (typically 0.6, seconds of arc), the sky is dark and the weather is very good.
Any star moves due to the rotation of the earth. To mount telescopes two systems are available. One of them is the equatorial mounting system, which has the polar axis directed to the north pole in the sky and the declination axis perpendicular to the polar axis. To follow stars it is necessary to rotate the telescope only around the polar axis. However, it is not so easy to hold heavy telescope by the polar axis which is not perpendicular to the ground.

Therefore, to mount any heavy telescope the alt-azimuth mounting is usually used. This system has an axis perpendicular to the ground and an horizontal axis. To follow stars the telescope should be rotated around the two axes. One disadvantage of this system is that the focal plane rotates as the axes rotate, therefore, it should be compensated.
Equatorial Mounting
102cm
Refractor
of Yerkes
Observatory
Yerkes Observatory
• Palomar 5m Telescope under full moon
5m Telescope Dome
• **Subaru telescope** To obtain any good image the mirror surface should be kept with the accuracy of \( \lambda /10 \), that is, 100nm accuracy for optical telescope. The main mirror of the Subaru telescope is as thick as 20cm, therefore, it is easily deformed as the elevation of the telescope changes. This deformation is compensated by 264 actuators after analyzing stellar images 100 times every second of time. And when the analysis is made 1000 times every second the stellar image becomes 0.06 arc seconds by compensating the scintillation (adaptive optics).

• The telescope has a primary focus (f=15m) with 80 million element CCD camera, 34x27 arc minute wide, a Cassegrain focus and two Nasmyth foci (platform) for heavy instruments like high resolution spectrographs. The field of view of Cassegrain and Nasmyth foci is 6 minutes of arc.
Subaru Telescope
• Main focus
• Nasmyth
• Cassegrain
Active optics system of the 8-m primary mirror
Mauna Kea Observatory
Andromeda Galaxy by Subaru
M31, M32, M110（アンドロメダ大銀河と伴銀河）

1997年9月10日，21時26分（JST）

焦点距離300mm望遠レンズ（タムロン300mmF2.8LD／絞り開放），冷却CCDカメラ（MUTOH CV-16）
露出時間：赤2分×4，緑4分×4，青2分×4，フィルタ：R-60，G-533，B-460，3色分解撮像カラール合成画像
画像範囲：2.58×1.70°，観測場所：長野県コロナ観測所
• **Radio telescope** The wavelength of radio, and even only of microwave, ranges between meter and sub-millimeter. Therefore, the angular resolution is weak for radio. As far as the surface accuracy is concerned, for 1m wavelength radio the necessary surface accuracy of the telescope is 10cm so that some type of antenna is enough to receive the radio. Still for millimeter radio the surface accuracy should be of the order of 0.1mm. Therefore, it is very difficult to keep any large telescope within this accuracy when the telescope is moved. Still for 45m radio telescope for millimeter wavelength at Nobeyama Radio Observatory, a device is introduced to keep the telescope in the shape of paraboloid of revolution even though the focal point is shifted according to the elevation of the telescope. This telescope has a good spectrometer and found many interstellar molecule as well as supermassive blackhole in the center of a remote galaxy.
Nobeyama Radio Observatory
• **Interferometer** To obtain high angular resolution for radio telescope interferometer system is introduced. By a classical interference method outputs of two telescopes are connected by wire to make interference pattern. As far as the angular resolution is concerned the length of the baseline connecting the two telescopes corresponds to $D$, the diameter of the telescope.

• As the computer system as well as clock synchronizing device have been much improved, a new method has been introduced. Namely, by the two telescopes observation to a common object is made simultaneously and the output data are together analyzed in a single computer. By this way VLBI (very long baseline interferometer) system has been realized.

• Now a satellite with 8m dish has been launched and VLBI with the telescope on the satellite and telescopes on the ground has been realized.
Interferometer
• **ALMA project**  The interferometer is operated not only between two telescopes but also among several telescopes. Now National Astronomical Observatory, Japan, US National Radio Observatory representing North American countries and European Southern Observatory are jointly constructing ALMA (Atacama Large Millimeter/Sub-millimeter Array) at Atacama plateau, 5000m high, in Chile.

• ALMA consists of 80 radio telescopes including 16 high precision telescopes of 12m aperture in the region ranging 14km area. The angular resolution expected is 0.01 seconds of arc.