McLeanゼミ

Sec.3.3.3-End of Sec.3

2024.5.17

3.3.3 Survey Telescopes

- Each survey telescope is optimized for its task, always highly automated and has a moderate aperture(up to ~3.5m).
- The Sloan Digital Sky Survey (SDSS) is one of the most well-known survey telescopes. Its 2.5m telescope (right in the figure) is located on Apache Peak, New Mexico.

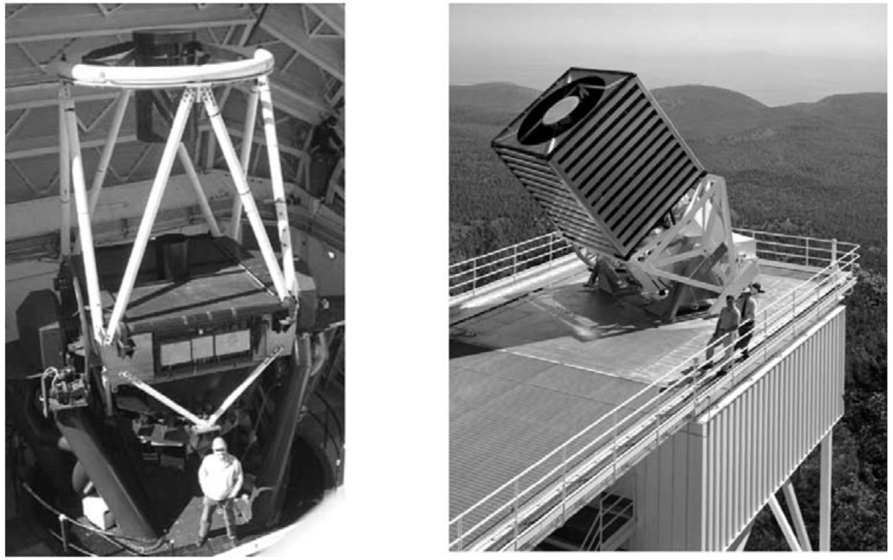


Figure 3.9. Left: the 2 m robotic Liverpool Telescope (alt-az) with founder Mike Bode in front. Right: the 2.5 m Sloan Digital Sky Survey Telescope (SDSS).

- The tasks of SDSS are
  1. to make a map of half of the northern sky in five bands (u, g, r, i, z)
  2. to select ~one million galaxies and ~100000 quasars for spectroscopy

3.3.3 Survey Telescopes

Other examples of survey telescopes so far are listed below.

- MACHO, EROS and OGLE Telescopes: 1m class telescopes to search for gravitational lensing effects.
- DENIS and 2MASS: 1m class telescopes for a near-infrared all-sky survey.

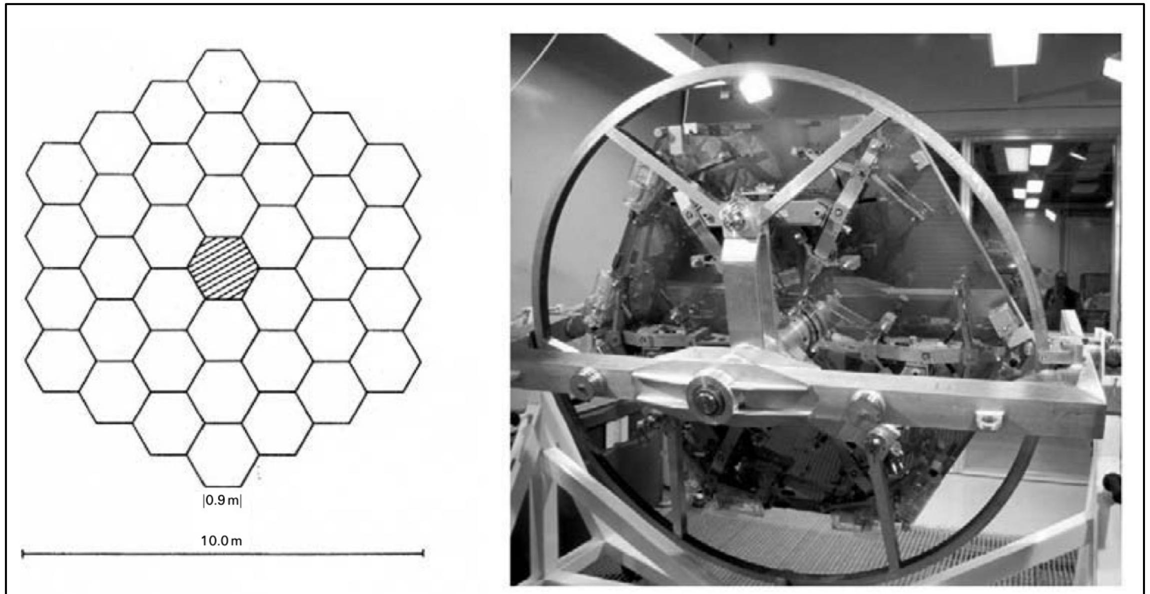
The projects of survey telescopes for the future are as follows.

- VISTA: 4m class survey telescope for the next-generation near-infrared survey.
- Pan-STARRS: a group of four 1.8 m telescopes being built by the University of Hawaii and intended for rapid surveys.

3.4 VERY LARGE TELESCOPE DESIGN
3.4.1 Segmented primaries

- Among the new-generation large telescopes was the pair of 10m telescopes at the W.M. Keck Observatory (WMKO).
- Each primary mirror is composed of 36 hexagonal ”segments.”
- The mirror segment can be moved by the actuators at a rate of twice per second to maintain the global shape of the hyperboloid to within 50nm.

→This system is called active control system(ACS).



3.4.1 Segmented primaries

- In 1977, by the fact that the impact of mirror bending due to gravity was proportional to D^4 (D=diameter), Jerry Nelson, who was at the Lawrence Berkeley Labs, thought that <u>gathering smaller segment mirrors into one mirror</u> was preferred for a new telescope.
- However, the surface accuracy is so small that a system actively correcting deformation of the surface figure was needed. (ACS)
- For a vision of a 10m telescope, Jerry worked on all the technical issues, especially the active control system.
- Technical issue was solved, but another hurdle was funding.

3.4.1 Segmented primaries

- In 1984, the Hoffman Foundation granted 50 million dollars to University of California (UC), but this was not enough. After that, by the W. M. Keck Foundation, who wanted to fund the entire project, funding issue was solved.
- In 1991, the first Keck telescope was shown to be able to produce astronomical images with a segmented mirror, which motivated the Keck Foundation to begin the second telescope.
- WMKO's segmented mirror approach worked very well, and this fact led astronomers to apply this technology to even larger telescopes.
- Segmented mirror telescopes: the Hobby-Eberly Telescope (11m,96segments), the South African Large Telescope (10m,91), the Gran Telescopio Canarias (10m,12~36)

3.4.2 Thin-meniscus mirrors

- In 1988 the European Southern Observatory (ESO) announced its intention to build an array of four independent 8m telescopes on Cerro Paranal in Chile.(This leads to VLT)
- Each telescope has a large monolithic glass meniscus primary mirror. (f/1.8)
- This mirror is so thin for its size that it needs to be actively supported to correct distortions of its figure caused by gravitational stress, thermal effects and so on.
- Forces supplied by the mirror support need to be updated a few times per second under computer control.

3.4.2 Thin-meniscus mirrors

- VLT Unit Telescope No.1 has an 8.2m diameter thin-meniscus mirror of 17.5cm thick.
- The Japanese National Large Telescope (Subaru) also has an 8.2m thin-meniscus mirror of 20cm thick and has a computer control system which compensates mainly for gravity.
- The Gemini Telescopes Project is also using thin-meniscus mirrors for its twin 8-meter telescopes. The alignment and figure is updated every few minutes to correct for gravity and thermal deformation.

3.4.3 Spin-cast honeycombs

- The primary mirror has a curved parabolic surface.
- The deeper this curved surface, the shorter the mirror’s focal length.

→The shorter focal length means the smaller the overall length and total weight of the telescope!

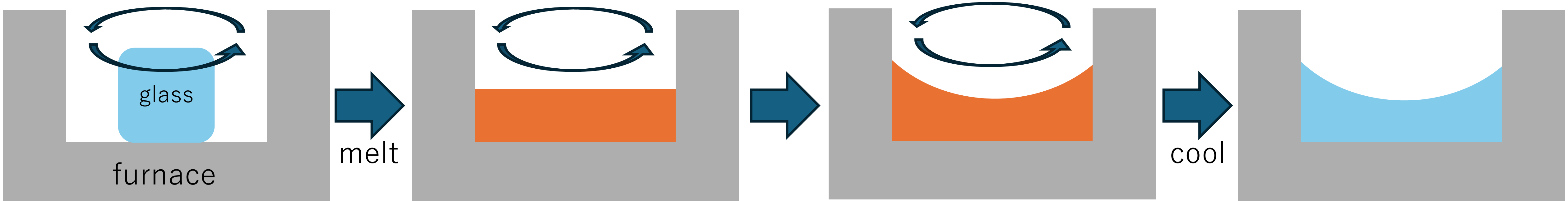
- Therefore, making a telescope with shorter focal length is preferable. For this, the deep curved mirror is necessary.

→ To make deep curved mirror, the huge amount of glass must be ground and polished away from the original flat mirror.

3.4.3 Spin-cast honeycombs

- Roger Angel (University of Arizona and the Steward Observatory) came up with an idea to make a deep parabolic mirror: melt the glass in the rotating furnace, then cool it.
- The furnace's rotation produces the centrifugal force. This force makes the liquid glass into a deep curved form in the shape of a parabola.
- Then, keeping its shape, it gradually gets cool while spinning.

→This method is named "**spin-casting**".

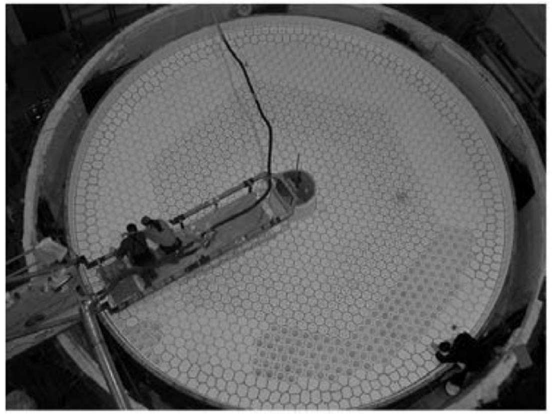


3.4.3 Spin-cast honeycombs

- The mirror can be made very stiff and yet lightweight by using a “**honeycomb**” construction on the back surface.

→To do this, a mold is made with a hexagonal block of ceramic fiber attached to the base of the furnace.

- The spin-cast honeycomb mirror is used in several telescopes. e.g. The Large Binocular Telescope(LBT) has a pair of 8.4m spin-cast honeycomb primary mirrors.



3.4.4 Prospects for Extremely Large Telescopes

- Keck telescopes were successfully completed in the mid-1990s.

→Astronomers at Caltech and UC thought of constructing larger telescopes.

- In 2000, an idea of California Extremely Large Telescope(CELT), a 30m telescope, was discussed.

→The cost of building and operating CELT was too high!

- California universities cooperated with the U.S. and Canadian national observatories, and formed a public-private partnership.

→This partnership was later renamed the Thirty Meter Telescope (TMT) project.

3.4.4 Prospects for Extremely Large Telescopes

Not only TMT, but also other Extremely Large telescopes (ELTs) have been planned.

- The Giant Magellan Telescope (GMT)

…a project to build a multiple mirror telescope with an effective aperture of 20 m

- Over-Whelmingly Large telescope (OWL)

…a project by the European Southern Observatory for a telescope with a diameter of 100 m! (then scaled back to a 42m aperture)

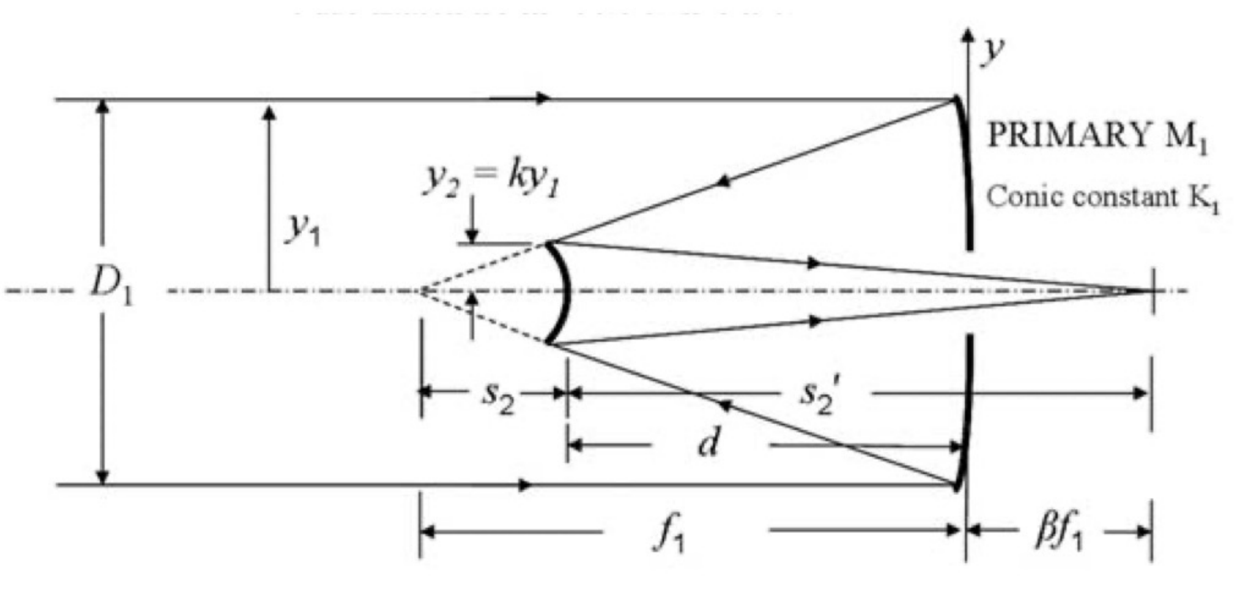
3.5 Case study: Design of a two-mirror telescope

- For a two-mirror system, the thick-lens power formula can be applied.

$$P = 1/f = 1/f_1 + 1/f_2 - [(d/n)/(f_2 f_1)] \text{ or } f = (f_1 f_2)/[f_1 + f_2 - |d|]$$

- The net focal length f is determined by the focal lengths of the two mirrors and their separation d.
- Some useful parameters are defined as follows:

$k = y_2/y_1$	where y_1 and y_2 are the heights of the rays at the edge of the primary and secondary, respectively;
$\rho = R_2/R_1$	where R_1 and R_2 are the vertex radii of the curvature of the primary and secondary mirror, respectively;
$m = -s_2'/s_2$	transverse magnification of secondary;
$f_1\beta = D_1\eta$	back focal distance: β and η are the back focal distance in units of the primary focal length f_1 and primary diameter D_1, respectively;
$F_1 = f_1/D_1$	primary focal ratio;
$F = f/D_1$	the system focal ratio, where f is the net focal length.



3.5 Case study: Design of a two-mirror telescope

- If the secondary mirror is moved, then both m and k changes, and so does the position of the focal surface.

$$ds'_2 - ds_2 = -(m^2 + 1)\, ds_2.$$

→A slight movement of the secondary leads to a large change in the location of the final focal plane.

- Because d of the conic surfaces was selected to make the on-axis spherical aberration zero, and because the change of d will reintroduce spherical aberration, motion of the secondary is limited.

3.5 Case study: Design of a two-mirror telescope

- At least five design parameters are required.

1. y_1 (the size of the entrance pupil)

… determines the light-gathering power and resolution.

2. F (the system focal ratio)

… determine magnification $m=F/F_1$, effective focal length $f=m\,f_1$

3. $f_1\beta$ (the back focal distance)

…determines the working distance for mounting instruments.

4. F_1 (the focal ratio of the primary mirror)

… determines the alignment tolerance and the size of dome.

5. 2θ (the field of view)

... the angular blur for astigmatism (AAS) and distortion (ADI)

3.5 Case study: Design of a two-mirror telescope

$$\mathrm{AAS} = (\theta^2/2F)[(m(2m+1)+\beta)/(2m(1+\beta))]$$

$$\mathrm{ADI} = \theta^3[(m-\beta)/(4m^2(1+\beta)^2)]\{m(m^2-2)+(3m^2-2)\}$$

$$\kappa R_1 = 2[(m+1)/m^2(1+\beta)]\{m^2-\beta(m-1)\}$$

- From this equation, for example, it can be shown that AAS for the Aplanatic Gregorian (AG) < AAS for the classical Cassegrain < AAS for the Ritchey-Chretien version of the Cassegrain (RC).
- If aberrations only matter, the AG would be best because it has the smallest astigmatism and distortion, and the least curvature.

3.5 Case study: Design of a two-mirror telescope

- But the impact of obstruction of light by the secondary is larger in the Gregorian than in the RC.
- Also, the Gregorian costs a lot because the primary diameter and the physical length of the Gregorian is substantially greater.
- These factors notwithstanding, two excellent 6.5 m Aplanatic Gregorian telescopes exist in the form of the twin Magellan telescopes at Las Campanas, Chile.

3.6 Summary

- Many technological advances in constructing and controlling telescopes, such as segmented, meniscus, honeycomb, and active control of the mirror shape, have led to a new generation of very large telescopes (8 m~10 m).
- Benefiting from these advances, a large number of semi-automated survey telescopes have also been developed.
- Basic optical relationships for mirrors and lenses have been presented, and we have shown how to carry out a first-order design for a two-mirror telescope.