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A new configuration for a 10-metre optical/infrared telescope † ⋆

CUI Xiang-qun[1] SU Ding-qiang[1] WANG Shou-guan[2]

[1]*Nanjing Astronomical Instruments Research Center, Chinese Academy of Sciences, Nanjing 210042*

[2]*Beijing Astronomical Observatory, Chinese Academy of Sciences, Beijing 100012*

Abstract A new configuration for a 10 m optical/infrared telescope for high-resolution work is proposed. While similar in some respects to the Hobby Eberly 9 m telescope (HET) and the Large Area Multi-Object Spectroscopic Telescope (LAMOST), its characteristics are: a spherical segmented primary made of 91 hexagonal sub-mirrors of size 1.2 m each, (with real-time co-focus, and, for infrared observation only, co-phase), a focal ratio of 1.7, giving a field of 6–8 arc min, a meridian-instrument type of mounting, covering 100° in declination, the primary being fixed during observation, the tracking being done by a 4-component corrector housed in a frame that moves along guides, themselves fixed to the ground. It is a low-cost (about 13–20 million US dollars), low risk configuration, and it can be expected to be also suitable for much larger telescopes of apertures several tens of metres.

Key words: astronomical optics—telescope—active optics

1. INTRODUCTION

In 1610, Galileo made the first refracting telescope in the world based on the invention of Hans Lippershey, and Newton invented the first reflecting telescope in 1660. Since then, experts in astronomical optics and astronomers have kept up the quest for astronomical telescopes of ever larger apertures, wider fields of view and better image quality. During the past and coming few years, some eleven 8–10 m optical/infrared telescopes on which

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new techniques of the 80s and 90s were adapted have been or will be successively put into operation. Even so, the experts and astronomers have not stopped thinking of configurations for large-aperture telescopes. The reason is that the development of astronomy and people's exploration of the secrets of the universe are endless and the possibility of development in astronomy is based on development in astronomical technology. At the coming of the new century, colleagues have proposed a series of ideas and suggestions for the development of Chinese astronomy in the early part of the 21st century. Here, keeping in view the capability of the country and the requirements for the development of Chinese astronomy, we will give our configuration study of a new 10 m (or larger) optical/infrared telescope.

2. POSSIBLE WAYS TO A LARGE TELESCOPE WITH APERTURE LARGER THAN TEN METRES

To build a large telescope with aperture larger than 10 metres, shall we take the conventional design of a small telescope then magnify according to the ratio of sizes, or take new technique and unconventional concept and design afresh ? This problem has been one of great concern for the experts of astronomical telescopes and astronomers since 20 years ago. At present, the conclusion of research and consensus is that new technique and unconventional design concept have to be taken; otherwise the cost of the telescope will be too high to be acceptable to the astronomical research community, and the implementation too difficult.

The Keck telescope is the first telescope in the world with a segmented primary mirror. It paved the way for manufacturing large telescopes with apertures greater than 10 metres. But it exhibits the manufacturing difficulty of off-axis aspherical surfaces, and it is difficult to further reduce the cost for making a larger telescope. Therefore, the experts began to consider configurations with spherical primary mirrors. In the past ten years, Wilson et al.[1] and Ardeberg[2] have separately proposed 16 m and 25 m optical telescopes with segmented spherical primary mirrors. In 1998, based on Wilson's configuration, ESO suggested a 100 m optical/infrared ground base telescope with a segmented spherical primary mirror[3]. Two American universities built the Hobby Eberly 9 m telescope (HET) at McDonald Observatory[4] (Observations will be started in 1999). It is an astrolabe-type telescope with a segmented spherical primary mirror and follows an unconventional design concept. Compared to the Keck telescope with same aperture size, its cost is less than one fifth.

In fact, as early as the end of the 70's and the beginning of the 80's, optimization study of optical systems with spherical primary mirrors was started in China. China is one of the earliest countries to consider using spherical primary mirrors. In 1981, Liang Ming completed the optical system design for a telescope with spherical primary mirror in his thesis for Master's degree. In the past ten years, a project for replacing the spherical primary mirror with a paraboloidal mirror and the project of a 12 m×4 m spectroscopic survey telescope CSST (the predecessor of LAMOST) were proposed in China[5,6]. For the latter, the unconventional design concept of HET was consulted, i.e., the primary mirror was fixed during observation, and the primary focal corrector undertook the task of tracking. LAMOST (Large Sky Area Multiobject Fiber Spectroscopic Telescope) which is being undertaken in China, is a transit type telescope with a segmented spherical primary mirror and an unconventionally designed reflecting Schmidt telescope. Besides low cost, its outstanding feature is the simultaneous achieving of a large aperture size and a large field of view. It will be the largest telescope in the world with a large field of view.

All the examples above may be taken as configurations for a 10 metre-plus telescope. They have two features in common: the technique of segmented mirror is adopted, i.e., small sub-mirrors are combined into a large spherical mirror;—the adoption of spherical mirror avoids the manufacturing difficulty of off-axis aspherical surfaces and reduces the cost. The other is that all of them follow unconventional designs to keep the telescope as simple and compact as possible, resulting in great reduction in cost for some small loss in sky coverage or in the function of the telescope. For the same cost, an unconventional design will give us a larger telescope than does a conventional one.

In our study of the configuration for a new telescope of our country with aperture size greater than 10 metres, we have considered the following three possible choices:

(a) Segmented aspherical primary mirror or segmented spherical primary mirror;

(b) Conventional design or unconventional design;

(c) A telescope with a high spatial resolution or one with a large field of view.

For a very considerable reduction in cost and for reducing the difficulties in manufacturing, we propose an unconventionally designed 10 m telescope with a segmented spherical primary mirror. In addition, because LAMOST, the large telescope with a large field of view is being undertaken, so we decide that this 10 m telescope should be used mainly for high-resolution astronomical observations.

3. A 10-METRE OPTICAL/INFRARED TELESCOPE FOR CHINA IN THE TWENTY-FIRST CENTURY

Figure 1 shows the configuration of the 10 m optical/infrared telescope that we studied and proposed. It is an unconventionally designed telescope with a spherical primary mirror and mainly used for high-resolution observations.

Similar to the HET, this telescope consists of a segmented spherical primary mirror and a primary focal corrector. During observation the spherical mirror is fixed, the tracking task is undertaken by the corrector, and the images of the celestial bodies are transferred to a receiver through optical fibers. It is also similar to the CSST and LAMOST, in that it will only observe celestial objects near the local meridian, and coverage of the observable area is realized by changing the altitude angle.

The 10 m spherical primary mirror of the telescope is segmented with 91 sub-mirrors. Each sub-mirror is a hexagon with diagonal length 1.2 m. The primary mirror is installed on a mounting with altitude axis only. It has a focal ratio of F/1.7; near its primary focus is a four-component reflecting corrector like the one in HET (Figure 2). The diameter of the corrector is 50 cm, the field of view will be 6 arc minutes, and the final image quality of the telescope is better than 0.6 arc second. If the diameter of the corrector is increased to 90 cm, then a field of view of 8 arc minutes will be achieved for the same image quality. During observation, the corrector will track in the east-west direction on its frame and undertake focusing at the same time. For switching to a different area of observation, the corrector, which is housed in a curved frame (shown straight in Figure 1 for simplicity), moves together with the frame along the guide tracks that are fixed to the ground to follow the movement of the primary mirror in elevation until the target position is reached. The correct relative position between the corrector and primary mirror is guaranteed by real-time monitoring of an autocollimator on the frame and by real-time control.

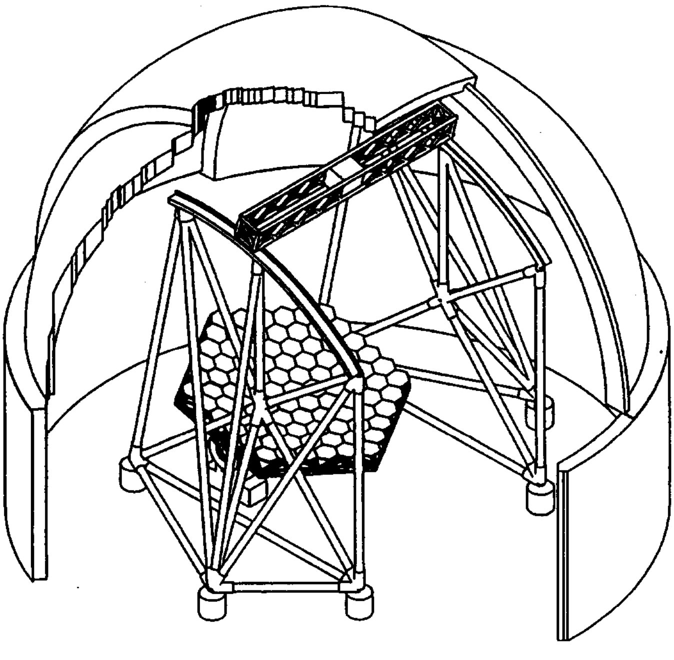

Fig. 1 A new 10 m optical/infrared telescope configuration

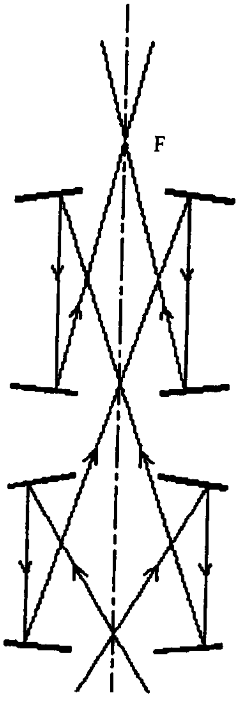

Fig. 2 Optical system of the corrector

The telescope has an observable declination range of 100 degrees. It can be used for high-resolution spectral and high-resolution imaging observations. Small and light focal surface instruments may be put directly at the primary focus. For big and heavy focal surface instruments, optical fibers will be used to transfer the images from the primary focus to a separate instrument platform. The use of optical fiber guiding may enable the telescope to be used in future optical interferometric work (although we still have some problems with infrared optical fiber at present).

For common observations, co-phasing of the sub-mirrors will not be required, but co-focusing is necessary. This is because for a 1.2 m sub-mirror the diffraction resolution in the visible range will be as high as 0.1 arc second, sufficient to meet the requirement of high-resolution imaging. Similar to the Keck telescope, co-phasing is necessary only for high-resolution imaging in the infrared. The spherical primary mirror of LAMOST is segmented with 37 hexagonal sub-mirrors of size 1.1 m. The co-focus experience of its sub-mirrors will be useful for this new 10 m telescope. For the co-phasing of the 91 sub-mirrors of this telescope in the infrared band, we shall refer to the experiences of the 36-sub-mirror Keck telescope.

The cost of this 10 m telescope will be approximately the same as the HET, about 13 million US dollars. If the co-phase is required, it will cost 20 million at most.

4. DISCUSSION

4.1 The Configuration of the 10 m Telescope has the following Advantages compared to HET

(1) For the HET, observation can be made only for celestial objects crossing some circle of altitude. To have a large coverage of observable celestial area, the zenith angle of the altitude circle must not be too small. For this 10 m telescope, observations are made when the celestial bodies pass through the meridian circle, and the zenith angle of the targets can be very small at the best position of observation.

(2) The sky coverage of HET is a zone of $\pm 35°$ ($70°$). The sky coverage for our configuration will be a zone of $\pm 45°$ ($90°$), or even $\pm 50°$ ($100°$). Some celestial objects that are invisible for HET will be observable with this 10 m telescope.

(3) For HET, the whole telescope has to move along the azimuth direction when changing the observing area. The telescope has a tube with the corrector placed on the tube. The 10 m telescope suggested in this paper, on the other hand, only rotates in the elevation angle when changing to a different observing area. There is no longer a need for the tube, and the guide track of the corrector frame is connected directly to the ground base. The corrector (which may incorporate a light receiving instrument for imaging or a spectrometer with low or medium dispersion) thus is in a better condition for stiffness, and it will be smoother in its tracking movement. It can also be made larger if a larger field of view is required.

(4) The optical system of the proposed new 10 m telescope has about the same parameters as has the HET, but the 10 m telescope has a slower focal ratio of F/1.7. Thus, if the 4-component corrector (one spherical and three aspherical reflectors) like that of HET is adopted, it will have a larger field of view (6 arc minutes) than that of HET (4 arc minutes). After further effort, a field of view as large as 8-9 arc minutes should be possible.

(5) HET is an astrolabe-type instrument. If a longer observation time (such as 1.5 hour) is required, the size of its whole primary mirror has to be enlarged. For the telescope proposed here, the size of primary mirror will be increased in the east-west direction only, and therefore the cost will be less. The astrodome of HET has to rotate together with the telescope when changing the observing area. For our configuration, only the shutter of the astrodome has to move up and down, the astrodome itself does not have to rotate. It can be made fixed unless there is some other special demand to satisfy.

4.2 The New 10-Metre Telescope has the following Advantages and Drawbacks compared to LAMOST

(1) LAMOST has two large reflecting mirrors, and they are both segmented. The new 10 m telescope has only one large segmented mirror; it will have a better diffraction mottle and will be more suitable for high-resolution observations, especially in the infrared band.

(2) It is more compact in structure compared to LAMOST.

(3) The configuration of LAMOST can be used to make a telescope with aperture of about 10 metres, but will be hard put to make one with aperture of several tens metres. This new configuration can be used to make a telescope with aperture of several tens metres.

(4) LAMOST has a large field of view, 4000 objects can be observed each time. This new 10 m telescope will have a rather small field of view, only one or a few objects can be observed at a time, but it is suitable for high-resolution work.

5. CONCLUSION

The configuration of 10 m large ground base optical/infrared telescope proposed in this paper has the advantages of large aperture size, high resolution, simplicity and stability in structure, low cost, and less technical risk. It is also appropriate for the capability of the country. This configuration provides not only a blueprint for a Chinese 10 m optical/infrared telescope in early 21st century, but also a reference for making a giant ground-based optical/infrared telescope with aperture of several tens metres in the future. We have suggested to Yunnan Observatory to build such a 4 m telescope at Gaomeigu site. According to the budget of LAMOST, we estimated that such a 4 m telescope itself will cost about 25 million Chinese Yuan.

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