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LETTERS

Two suggested configurations for the Chinese space telescope

Ding-Qiang Su[1,2,3] and Xiang-Qun Cui[3]

[1] Department of Astronomy, Nanjing University, Nanjing 210093, China; *dqsu@nju.edu.cn*
[2] Key Laboratory of Modern Astronomy and Astrophysics (Nanjing University), Ministry of Education, Nanjing 210093, China
[3] National Astronomical Observatories/Nanjing Institute of Astronomical Optics and Technology (NIAOT), Chinese Academy of Sciences, Nanjing 210042, China

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Abstract China will establish a 2-meter space-based astronomical telescope. Its main science goals are performing a sky survey for research about dark matter and dark energy, and high resolution observations. Some experts suggest that this space telescope should be installed inside the Chinese space station. In accord with this suggestion we put forward our first configuration, i.e., to adopt a coudé system for this telescope. This coudé system comes from the Chinese 2.16 m telescope's coudé system, which includes a relay mirror so that excellent image quality can be obtained. In our second configuration, we suggest that the whole space telescope fly freely as an independent satellite outside the space station. When it needs servicing, for example, changing instruments, refilling refrigerant or propellant, etc., this space telescope can fly near or even dock with the core space station. Although some space stations have had accompanying satellites, the one we propose is a space telescope that will be much larger than other accompanying satellites in terms of weight and volume. On the basis of the second configuration, we also put forward the following idea: the space station can be composed of several large independent modules if necessary.

Key words: instruments — space telescope — space station — survey — high angular resolution

1 INTRODUCTION

China will build a space station. Yidong Gu et al. suggested the installation of a space astronomical telescope inside of the space station (inside meaning it is part of the science module, but outside of the pressurized living area) (Su 2012). According to them, this telescope can not only perform astronomical work but will also be a highlight of the space station. We support their suggestion. However, we think that such a telescope can also be outside of the space station. In March 2010, Dingbo Kuang suggested that this space telescope be a satellite and that it be connected to the space station by one or more strings, and several days later, Ding-Qiang Su suggested that the space telescope, as a satellite, be connected to the space station by a bar and Cardan joints (it could also be a yoke mounting). In this paper we take a further step and propose the idea of the whole space telescope flying freely with the space station. The following are two configurations for the Chinese space telescope to be installed inside and outside of the space station respectively.

The main science goals of the Chinese space telescope are performing a sky survey by means of weak lensing and baryon acoustic oscillation for research about dark matter and dark energy (Laureijs et al. 2010; Zhan 2011), and high resolution imaging observation like HST. This telescope has an aperture that is 2 meters in diameter. We will take the size of a CCD pixel to be 9 μm and the diameter of the Airy disk at $\lambda550$ nm to be equal to two pixels, i.e., 18 μm, thus the focal length should be 28 m, i.e., an f-ratio of 14. Our aim is that for the optical design, 80% geometry energy (by ray tracing) will be included in the Airy disk at $\lambda550$ nm in a 1.5° diameter field of view (FOV) and at $\lambda350$ nm in a 0.5° diameter FOV.

2 THE FIRST CONFIGURATION - THE SPACE TELESCOPE INSIDE THE SPACE STATION

With respect to the sky, the direction of the space telescope remains unchanged. However, the space station orbits around the earth, so the space telescope needs to rotate relative to the space station for tracking a given celestial area. In addition, the space telescope needs to slew when a different celestial area is observed. The size of modules that are part of the space station is limited, and there are several big instruments needed for the telescope. Considering that it is difficult for the telescope and all its instruments to move as a whole, we propose to adopt a coudé system for this space telescope. This design has the advantage that all instruments are fixed in the module, and only the telescope needs to rotate.

In a traditional telescope, the coudé system only has two aspherical mirrors, which are the primary and secondary mirrors, hence the image quality of the space telescope required above could not be obtained. In a traditional telescope there are two secondary mirrors for a Cassegrain system and a coudé system respectively. When these two systems are changed the secondary mirrors should also be changed. In the early 1960s, when designing the Chinese 2.16 m telescope, Ding-Qiang Su proposed to use the same secondary mirror for both Cassegrain (R-C) and coudé systems, and on the basis of this idea Su put forward a series of new coudé systems. Su introduced these options at the 2.16 m telescope conference held in November 1966 in Shanghai. In June 1972, Su put forward a coudé system which included a relay mirror. It was soon decided that such a coudé system would be adopted for the Chinese 2.16 m telescope. Since the shapes of the primary and secondary mirrors have been determined by the Cassegrain (R-C) system, only an ellipsoidal shape can be chosen for the relay mirror to eliminate the spherical aberration in this coudé system. At the end of 1973, Su found that when the Cassegrain (R-C) system is replaced by the coudé system, if the secondary mirror is moved 10.692 mm and an oblate relay mirror with $e^2 = -0.2585$ is used, such a coudé system could simultaneously eliminate both spherical aberration and coma. At that time in China, all the above work was only permitted to be reported and discussed inside the project group due to confidentiality requirements. In October 1977, on the occasion of a visit to China by a U.S. astronomical delegation which included ten distinguished astronomers, the above work received special permission to be introduced to these American astronomers. Such a coudé system, in particular the coudé and Cassegrain (R-C) systems sharing the same secondary mirror, was highly praised by them (see Reception Briefing No.3, Foreign Affairs Bureau of Chinese Academy of Sciences, 1977 October 4 and Goldberg's paper, 1978). In 1979, during their visit to China, A. B. Meinel and M. P. Meinel also applauded such a coudé system. They named this relay mirror the SYZ relay mirror (S, Y and Z are the initials of the three designers of the 2.16 m telescope optical system), and extended the SYZ relay mirror to the Nasmyth system. They adopted the SYZ relay mirror in some telescope configurations which they were considering (Meinel & Meinel 1980; Meinel et al. 1980; Meinel & Meinel 1981). Later, the ESO VLT (which included four 8.2 m telescopes) also used the same one secondary mirror for both the Cassegrain (R-C) and coudé systems, and used relay mirrors to form the coudé system (Enard 1988; ESO "The VLT White Book" 1998). A detailed description of the Chinese 2.16 m telescope optical system is available (Su et al. 1990).

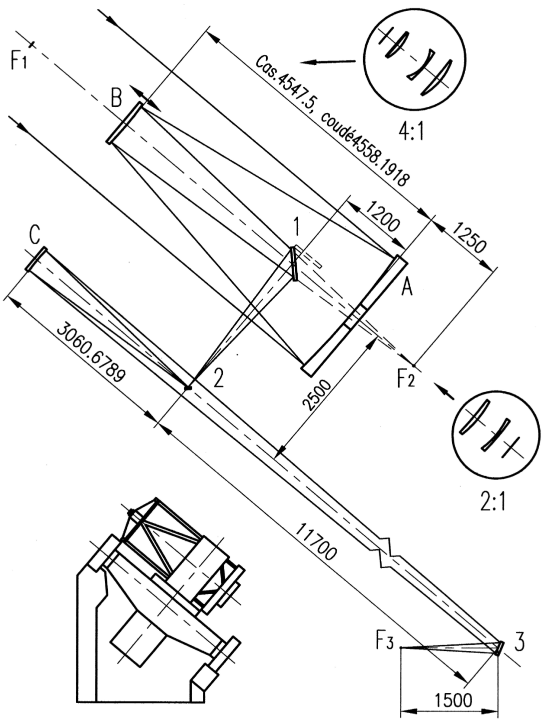

Fig. 1 The main optical system for the 2.16-m telescope. A, Primary mirror; B, secondary mirror; C, coudé relay mirror; 1-3, plane mirrors; F1, prime focus; F2, Cassegrain focus; F3, coudé focus. All lengths are in mm. Shown in the lower left corner is the structure of the 2.16-m telescope. (Fig. 1 is from reference Su et al. 1990).

There are three aspherical mirrors - primary, secondary and relay mirrors - in the Chinese 2.16 m telescope's coudé system (Fig. 1). In this space telescope, only one focus is used. As is well known among experts in the field of optics, spherical aberration, coma and astigmatism can be eliminated simultaneously if there are three aspherical surfaces with unrestrained shapes in an optical system. In an allowable range, through the choice of the curvature radii of mirror surfaces, a plane image surface may be obtained. In March 2010, we suggested that the 2.16 m telescope's coudé system be adopted for the Chinese space telescope.

Figure 2 shows this simple configuration of the space telescope. Since the available space for the space station module is limited, a primary mirror with an f-ratio of 1.2 is chosen; even so, the image quality required above can still be obtained in a plane image. The diameter ratio between the obstructed area and the beam of light is 0.37. Part A is the rotating part of the telescope. A fork mounting is used for this telescope. There are two axes in it. Axis I and axis II correspond respectively to the polar axis and the declination axis in a ground-based equatorial telescope. Axis I points to the pole of the space station's orbit. This telescope will rotate around axes I and II to track a celestial object and to point to a new celestial object. Part B accommodates instruments. Astronauts can enter it to service or change instruments and to inspect the image quality of the telescope. Since a space station is not as stable as earth's ground, it is very important and difficult to overcome the vibration and sway of the space station. Mirror 5, which is very near the exit pupil, is used as a tip-tilt mirror for accurate tracking. M8 can be rotated so that the final image can be reflected onto

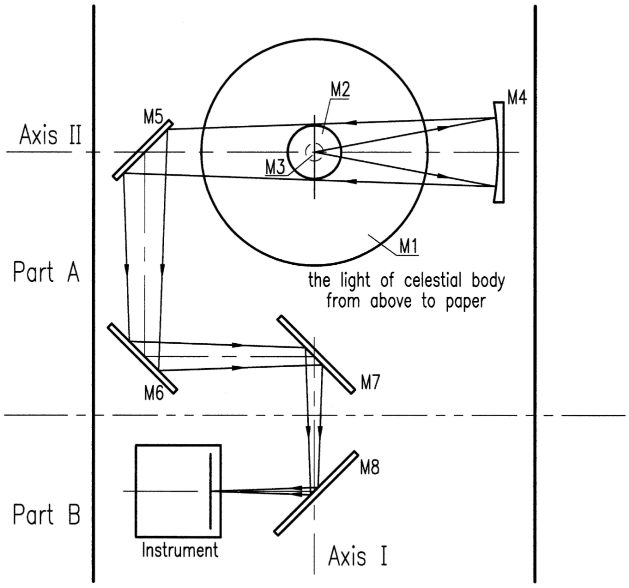

Fig. 2 The first configuration - space telescope inside the space station.

the different instruments. In such a telescope, the final image rotates during observations due to the field rotation. There is a mechanism which can correct the field rotation of the large CCD array (and other instruments if necessary).

3 THE SECOND CONFIGURATION - THE SPACE TELESCOPE OUTSIDE AND FREELY FLYING NEAR THE SPACE STATION

On 2013 October 5, Ding-Qiang Su and Xiangqun Cui sent an e-mail to Dingbo Kuang and Huixin Gong (copied to Yidong Gu, Hu Zhan and Guoping Li). In this e-mail, Su and Cui proposed the second configuration for this space telescope as follows: it is an independent free satellite (module) which flies near the core space station (i.e., the core module), with no string, bar or other device connecting it to the core space station. Due to the weight and volume of the space telescope, it needs to be launched independently from the ground. It flies with the core space station but keeps a distance from it, for example, 5 km to 15 km, a distance which is easy to be maintained by small rockets. When this space telescope needs servicing, fine adjustment, changing of instruments, refilling refrigerant or propellant, etc., it can move near or dock with the core space station. Such a space telescope can surely be considered as a part of the space station, or it may be said to form a space station together with the core space station. The direction of the space telescope will be unchanged with respect to the sky and only needs to rotate for small corrections and when a different celestial area is observed.

Figure 3(a) and (b) shows two arrangements for the second configuration. M6 can be rotated so that the final image can be reflected onto different instruments. In such a configuration, the vibration and sway of the space station have no influence whatsoever on the space telescope. For certain special goals there exist some space vehicles (small satellites), which are launched from the ground or from a space station; they come and go to other space vehicles or fly near space stations, such as the XSS-11 (Zimpfer et al. 2005) and the Companion Microsatellite in the Chinese SZ-7 Flight Mission (Chen et al. 2009). The configuration of the space telescope we propose here is similar to

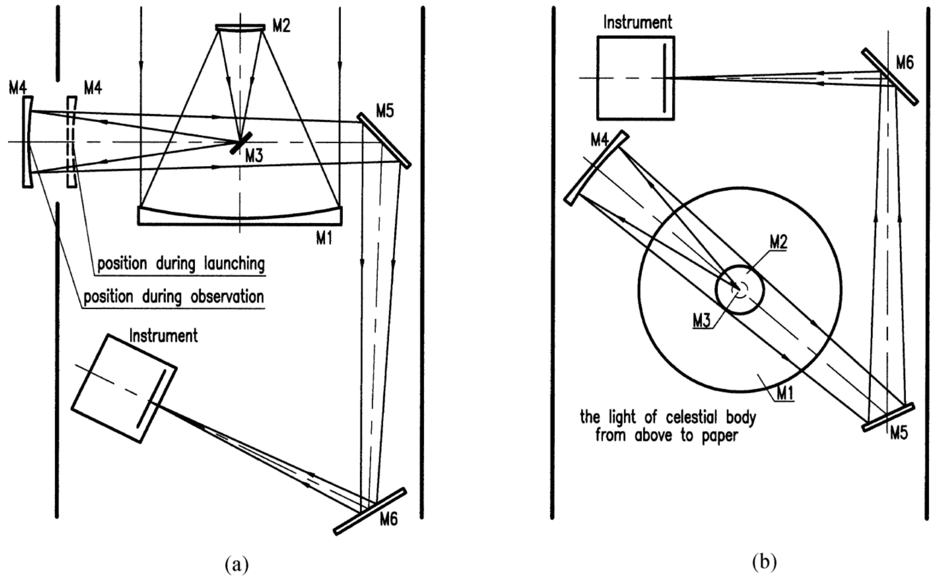

Fig. 3 Two arrangements for the second configuration – space telescope outside and freely flying near the space station.

theirs, but ours is a space telescope and it is much greater than those other accompanying satellites in terms of weight and volume. The optical system of the first configuration can still be used for this space telescope, but generally, this optical system is not arranged as a coudé system and the number of plane mirrors can be reduced. In this configuration, an f-ratio of 1.5 for the primary mirror is chosen. Thus better image quality is obtained, i.e., 80% geometry energy is included in the Airy disk at λ450 nm in a 1.5° FOV and at λ250 nm in a 0.5° FOV. The ratio of diameters between the obstructed area and the beam of light is still 0.37. The asphericity of the primary mirror is 1/2 of the corresponding asphericity when the f-ratio is 1.2. Such an optical system and its instruments can be arranged more properly (Fig. 3). Usually a space station is an integrated spacecraft which is assembled by several modules launched on several different occasions. However, on the basis of the second configuration, we contend that a space station could also be composed of several separate modules. In this case, there is a core module and the others are satellite modules, just like earth and moon, or Jupiter and its satellites. A space station can even be composed of several large modules which are similar in weight or volume, just like a binary star or multiple star. The gravitation among these modules is small, their orbits can be almost the same, and changes in their relative position can be corrected by small rockets. If necessary, one module (or several) could move to another orbit and come back in several months or even longer.

4 DISCUSSION AND EXPLANATION

(1) Many experts and us have researched and designed both above configurations and instruments. The results show that the two configurations we suggested have excellent image quality for a large FOV, and compact structure. Optical performance is better than the technical requirements.
(2) Since the f-ratio is relatively fast in our two suggested configurations, the requirement of collimation is quite high, active optics could be considered to be used.

(3) We think that the CCD could be segmented into a curving surface, and that even Xiangqun Cui believes each CCD chip could be made into a curving surface so that a more curved surface can be obtained. If a curving focal surface is applied, the sizes of an optical system can become more reasonable and better image quality can be obtained.
(4) In the second configuration, when it adopts the optical system of the first configuration but it is not arranged as a coudé system, such an optical system is similar to what some people call a Korsch system (Korsch 1972), which is a system we just heard about recently, but our optical system comes entirely from the Chinese 2.16 m telescope. We proposed such a coudé system in June 1972, in the same year that Korsch's paper was published. Furthermore, as is well known among experts in the field of optics, spherical aberration, coma and astigmatism can be eliminated simultaneously if there are three aspherical surfaces with unrestrained shapes in an optical system. Therefore, we do not call our optical system described above a Korsch system.
(5) Ding-Qiang Su is invited by Nanjing Institute of Astronomical Optics and Technology, Chinese Academy of Sciences as their specialist to participate in this space telescope project.

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