ELSEVIER

Chinese Astronomy and Astrophysics 38 (2014) 454–471

CHINESE
ASTRONOMY
AND ASTROPHYSICS

A Preliminary Research on the Development of the Hard X-ray Imaging Telescope † ⋆

ZHENG Chun-xiao[1,2,3△] CAI Ming-sheng[1,2] HU Yi-ming[1,2]
HUANG Yong-yi[1,2] GONG Yi-zhong[1,2]

[1] *Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210008*

[2] *Key Laboratory of Dark Matter and Space Astronomy, Chinese Academy of Sciences, Nanjing 210008*

[3] *University of Chinese Academy of Sciences, Beijing 100049*

Abstract The hard X-ray imaging telescope based on the Fourier transform imaging technique is introduced. The double-layer parallel gratings are used to make the modulation and coding on the light emerging from a celestial X-ray source, the modulated light is acquired, to make the optoelectronic conversion by scintillation crystal detectors, and finally read out by the electronic system. The modulation collimator X-ray telescopes can be divided into two types: the spatial modulation and temporal modulation. The temporal modulation system requires the scanning motion of the detector system, but the spatial modulation system requires no motion. The technology of grating fabrication is investigated, and the basic structure design of the collimators is given. The principal components of the prototype hard X-ray imaging telescope of spatial modulation type are successfully developed, including the 8 CsI crystal detector modules (containing photomultipliers or PMTs), 8-channel shaping amplifiers (two of them are prepared for experiments), and the data acquisition system. And the preliminary test results of the electronic system are also given.

Key words: instrumentation: detectors—instrumentation: telescopes, miscellaneous —sun: X-rays, gamma rays—techniques: spectroscopic

† Supported by National Natural Science Foundation (10973046)
Received 2013–03–04; revised version 2013–05–23
⋆ A translation of *Acta Astron. Sin.* Vol. 55, No. 2, pp. 154–169, 2014
△ zhengchx@mail.las.ac.cn

doi:10.1016/j.chinastron.2014.10.012

1. PRINCIPLE OF GRATING COLLIMATOR MODULATION FOR HARD X-RAY IMAGING TELESCOPES

In 1965 Oda proposed the method of modulation by grating collimators, namely, to make the modulation and coding on the light emerging from a celestial X-ray source by using the double-layer parallel gratings, then the modulated light is acquired to make the optoelectronic conversion by crystal detectors, and finally read out by the electronic system[1]. The grating-type collimators used for the hard X-ray source imaging have obtained many results, for example, by the Japanese HINOTORI satellite, YONKOH/HXT satellite, and the American RHESSI satellite[2]. The imaging principle of grating collimators can be described as follows.

Fig.1 shows the cross-section of an ideal double-grating collimator, which consists of the upper and lower layer gratings with the distance L, and for convenience sake the widths of the gratings are assumed to be $d = d_1 = d_2$. Assuming a stable point source at infinity, upon the grating collimator is a bundle of parallel incident photons, on the plane perpendicular to the grating slits, the incident angle α is the included angle between the incident direction and the normal direction of the grating plane, as the incident angle varies, the photon beam passed through the upper grating will fall on the narrow strips or the slits of the lower grating, or fall simultaneously on the narrow strips and slits of the lower grating. In the ideal case, the minimum transmissivity of this grating system is zero, the maximum transmissivity is 50%. The transmissivity T is a trigonometric periodical function of the incident angle, by making its Fourier expansion we obtain:

$$T(\Phi) = \frac{1}{4}\left[1 + \frac{8}{\pi^2}\cos(\Phi) + \frac{8}{9\pi^2}\cos(3\Phi) + \frac{8}{25\pi^2}\cos(5\Phi) + \cdots\right], \tag{1}$$

in which the grating pitch $p = 2d$, and $\Phi = \frac{2\pi\alpha L}{p}$. Because of the $1/n^2$ attenuation of high-order harmonics, as well as the orthogonality of harmonics, deleting the high-order harmonics will not cause any errors, except for the reduced signal-noise ratio. And the DC component is equivalent to the averaged value, to neglect the DC component will neither cause any imaging errors[2]. Hence, Eq.(1) can be simplified as:

$$T(\Phi) = \cos\left(\frac{2\pi}{p}\alpha L\right). \tag{2}$$

The form of Eq.(2) is a cosine trigonometric function, so it is also called as the cosine grating collimator, in which αL represents the deflection of the incident light after passing through the upper and lower gratings.

Relative to the cosine grating collimator, exists also the sine grating collimator, with the similar structure, only the relative position between the upper and lower gratings is slightly changed, for the cosine grating collimator the slits and narrow strips of the upper and lower gratings are two-by-two faced, but for the sine grating collimator the relative positions of the slits and narrow strips of the upper and lower gratings are deviated by a distance of $p/4$, and therefore have a phase difference of $\pi/2$. The transmissivity of a sine grating collimator is expressed as