NASA CASE NO. MFS-28,013-1

PRINT FIGURE 6

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(NASA-Case-MFS-28013-1) MULTISPECTRAL GLANCING INCIDENCE X-RAY TELESCOPE Patent Application (NASA) 16 p HC A02/MF A01 CSCL 03A

N86-22459

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NASA Case No. MFS-28013-1

Multispectral Glancing Incidence X-Ray Telescope

Technical Abstract

This invention relates to a glancing incidence x-ray telescope system for broadband, high resolution imaging of solar and stellar x-ray and extreme ultraviolet radiation sources.

The telescope includes a primary optical system preferably of the Wolter I type having a primary mirror system (20, 22). The primary optical system further includes an optical axis (24) having a primary focus (F1) at which the incoming radiation is focused by the primary mirrors. A plurality of ellipsoidal mirrors (30a, 30b, 30c, and 30d) are carried at an inclination to the optical axis behind the primary focus (F1). A rotating carrier (32) is provided on which the ellipsoidal mirrors are carried so that a desired one of the ellipsoidal mirrors may be selectively positioned in front of the incoming radiation beam (26). In the preferred embodiment, each of the ellipsoidal mirrors has an identical concave surface carrying a layered synthetic microstructure coating tailored to reflect a desired wavelength of 1.58 or longer. Each of the identical ellipsoidal mirrors has a second focus (F2) at which a detector (16) is carried. Thus the different wavelength image is focused upon the detector irregardless of which mirror is positioned in front of the radiation beam. In this manner, a plurality of low wavelengths in a wavelength band generally less than 30 angstroms can be imaged with a high resolution.

Novelty of the invention is believed to reside in the use of off-axis ellipsoids operating at angles less than 45 degrees and in placement of layered synthetic microstructure elements so as to employ concave optics, along with use of a plurality of mirrors mounted on a carrier wheel. These features enable both the magnification and the particular spectral slice to be varied.

Inventor: Richard B. Hoover

Employer: NASA/MSFC

Patent Application S.N.: 765,979

Date Filed: August 15, 1985

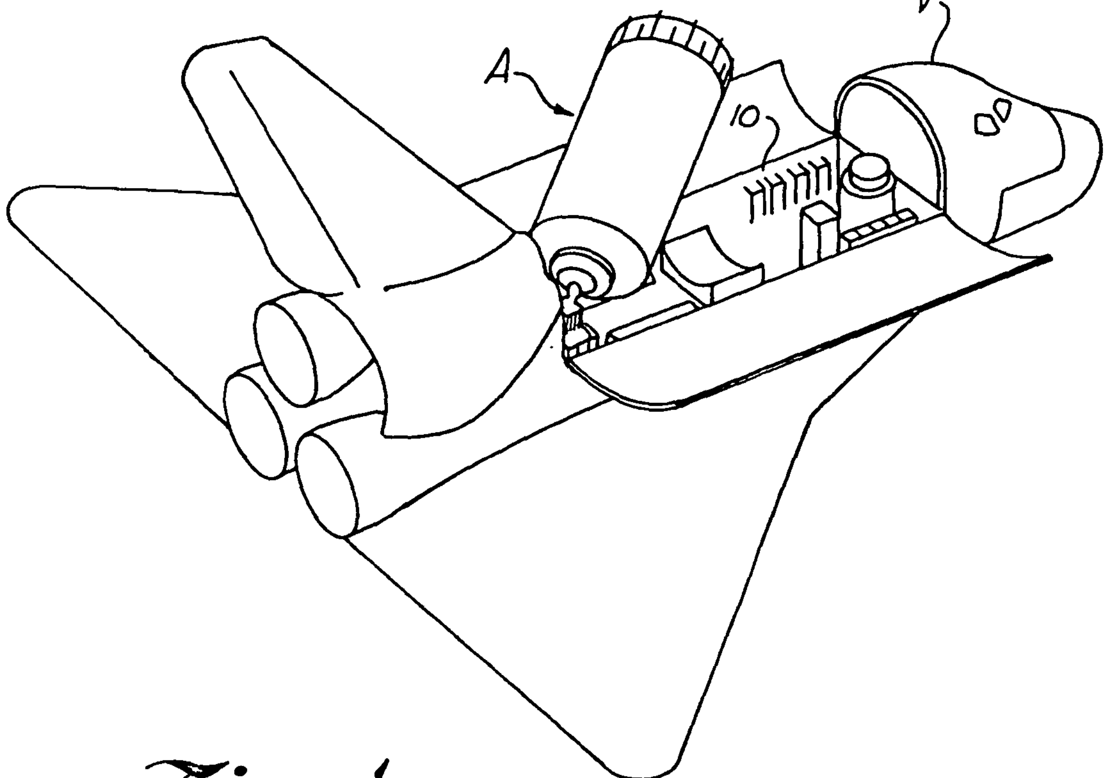

Fig. 1

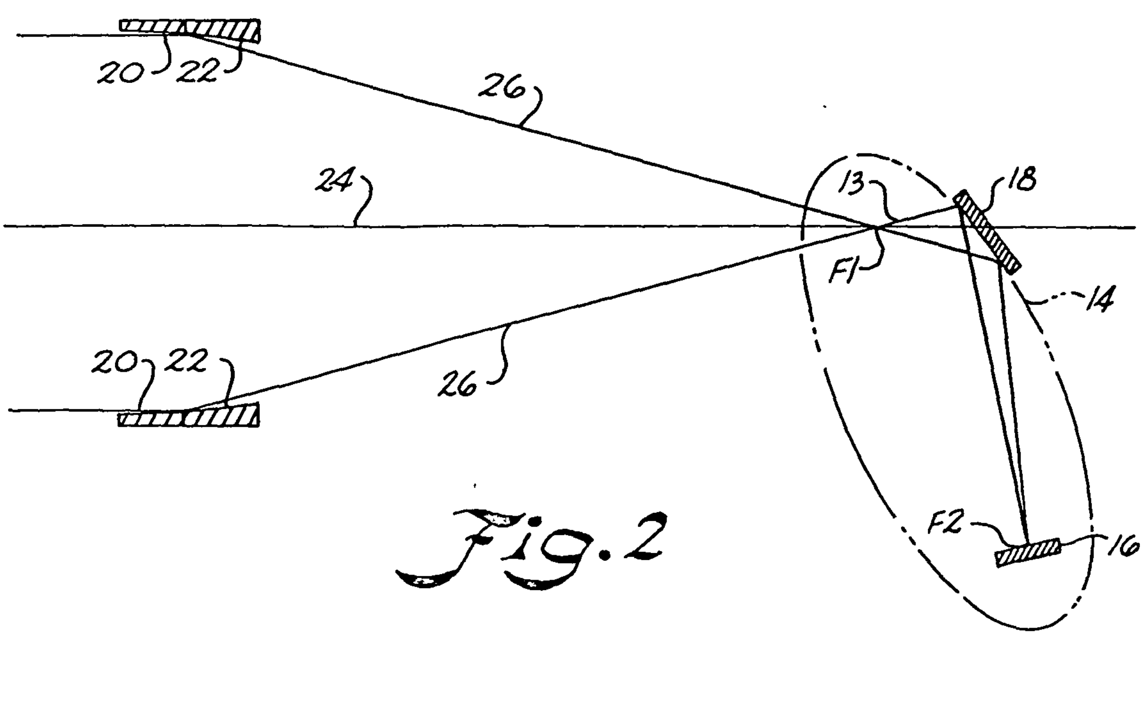

Fig. 2

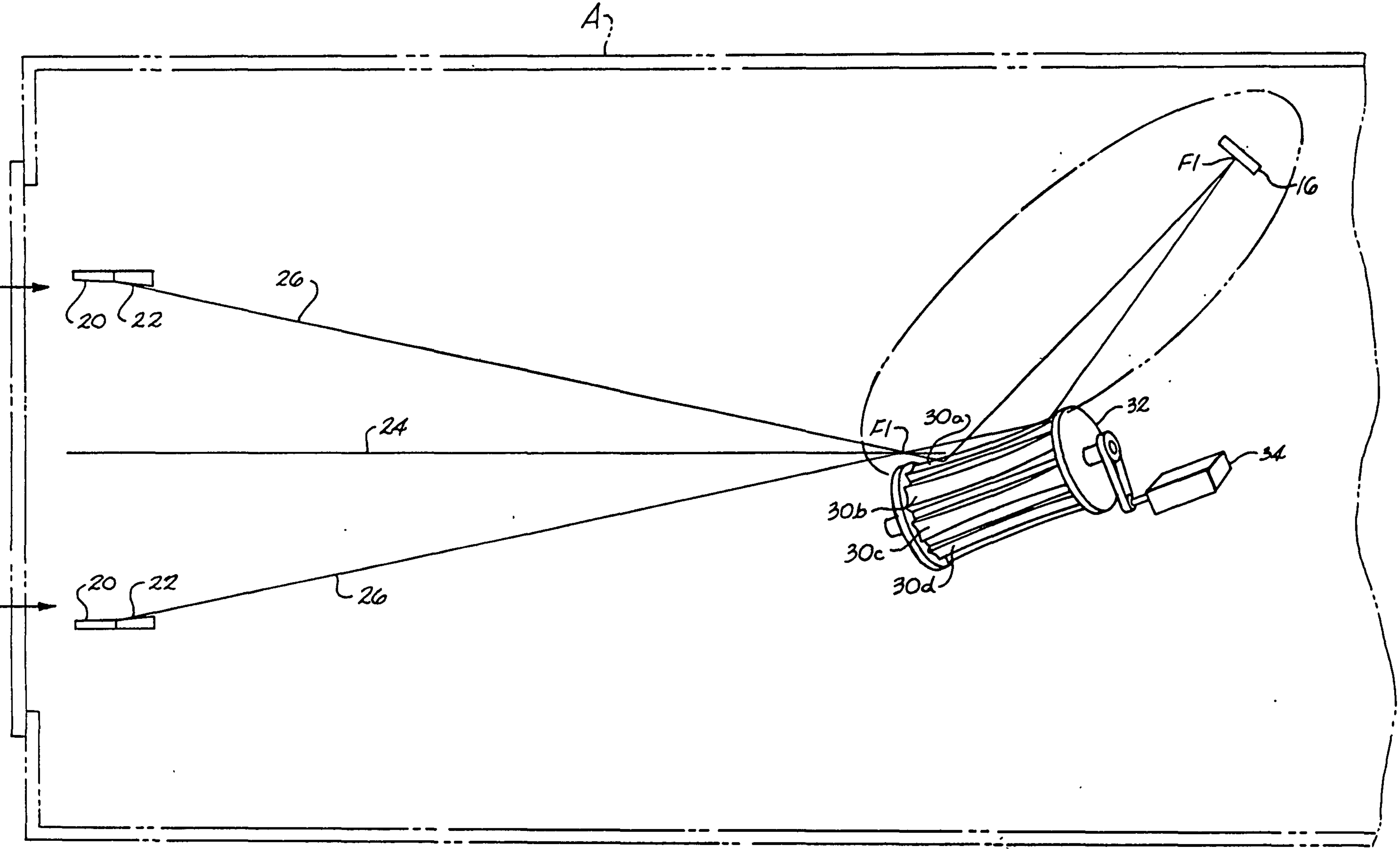

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Fig. 4

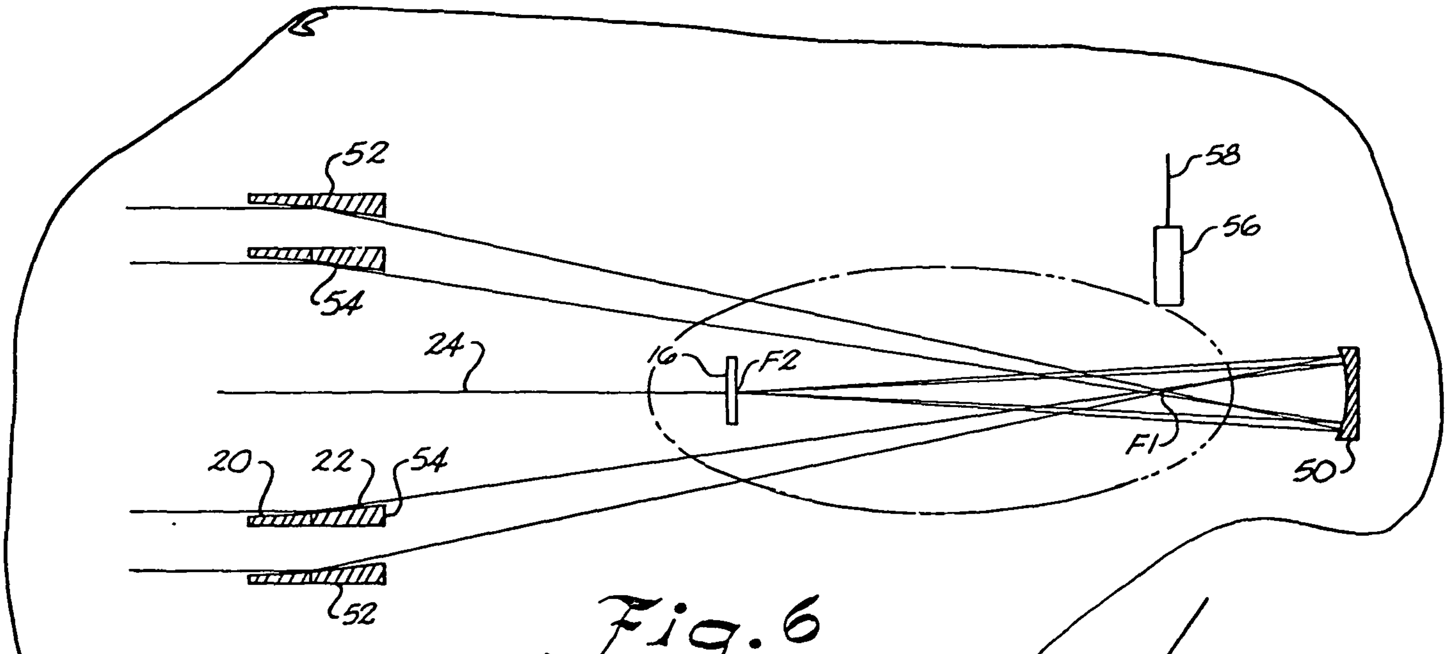

Fig. 6

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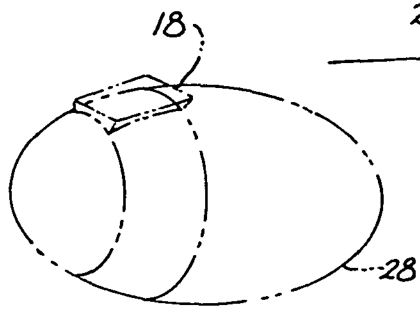

Fig. 3

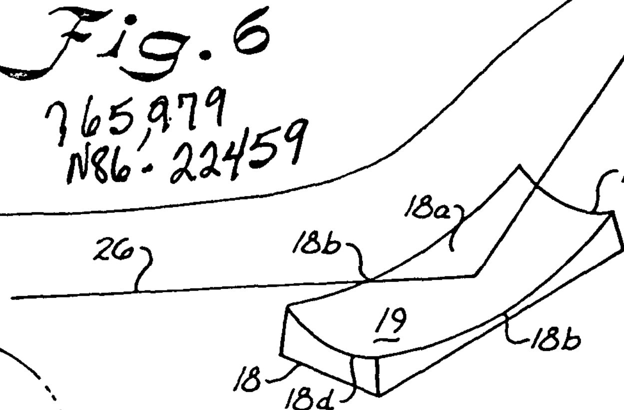

Fig. 3a

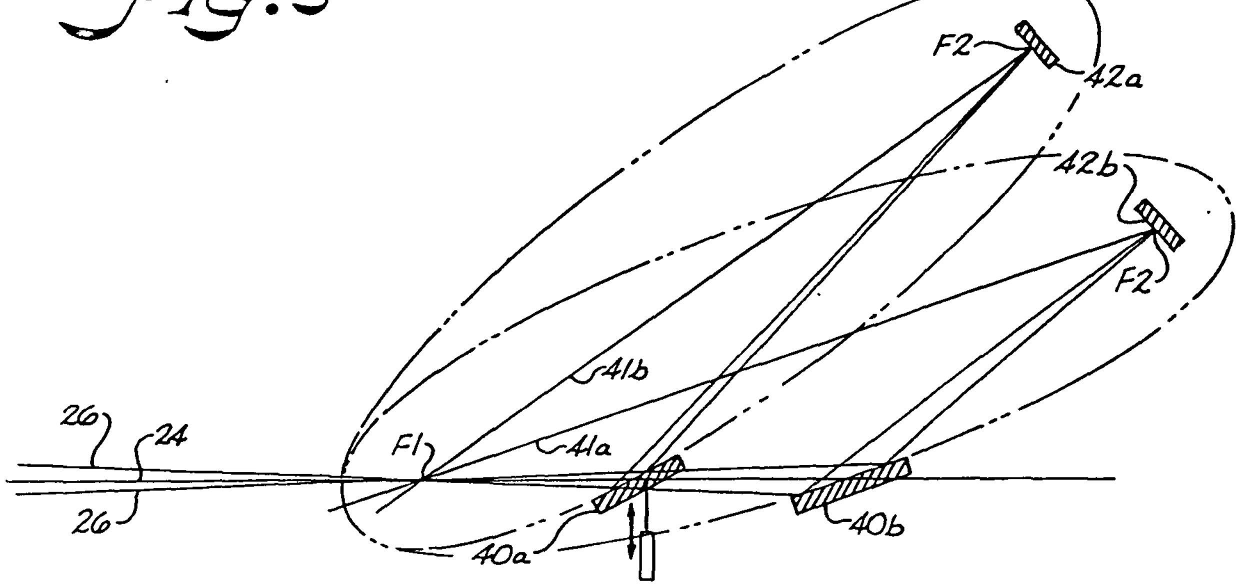

Fig. 5

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MULTISPECTRAL GLANCING INCIDENCE X-RAY TELESCOPE

Origin of the Invention

The invention described herein was made by an employee of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

Background of the Invention

The general purpose of this invention is to improve the spatial and spectral resolution performance characteristics of glancing incidence X-ray telescope systems capable of broadband, high-resolution imaging of solar and stellar X-ray and XUV (extreme ultraviolet radiation) sources. For certain applications, such as with very high resolution X-ray detectors coupled to extremely high spatial resolution primary mirror systems, very large magnifications may be of great value. Super high-resolution imaging with the most advanced X-ray telescope systems currently being planned for launch in the 1990's on NASA's space station program indicate the desire for coupling systems capable of providing very high magnifications to the initial image; possibly even as high as 10x to 40x.

Instruments such as the Advanced X-ray Astrophysical Facility (AXAF) are designed with the greatest emphasis upon the harder rather than the softer components of the X-ray spectrum. The requirements of high magnification, coupled with the short distance typically afforded by instrument envelope constraints, essentially rule out the possibility of the utilization of large magnification glancing incidence hyperboloid/ellipsoid X-ray microscope optics such as are currently being developed as a part of the NASA Extended Range X-ray Telescope Program.

Furthermore, systems such as have been disclosed in applicant's copending application Serial No.

571,613, filed on January 17, 1984, entitled SPECTRAL SLICING X-RAY TELESCOPE WITH VARIABLE MAGNIFICATION are not ideally suitable for this application, as normal incidence LSM (layered synthetic microstructure) optics cannot be utilized at wavelengths significantly below 30 angstroms or so.

In the prior art, the Wolter X-ray telescope system is typically used to focus the X-rays from a point source (or an extended source) at infinity to a high-resolution image on the sensitive surface of the detector situated at the prime focus of the Wolter system. For soft X-rays (wavelengths ranging from 2Å to 100A) the Wolter type I mirror system with coaxial and confocal, concave paraboloidal and hyperboloidal elements (both of which are internally reflecting) is typically used. Such telescopes were flown on the Skylab space station and have been used on the Einstein and Copernicus observatories in space.

High-resolution imagery has been achieved by use of high-resolution detectors, such as photographic emulsions directly in the prime focus of the Wolter X-ray telescope; or with a high-resolution solid state detector placed in the focal plane of a long focal length telescope. Photographic emulsions limit the spectral coverage of X-ray telescopes due to the absorption of soft X-ray and XUV radiation in the gelatin and, consequently, these detectors have relatively low effective quantum efficiencies. The solid state detectors limit the performance, from a spatial resolution point of view, due to the large size of the image elements.

Techniques for coupling Wolter telescopes to solid state detectors by means of convex hyperboloid mirror systems have been described in the above referenced copending application of applicants entitled SPECTRAL SLICING X-RAY TELESCOPE WITH VARIABLE MAGNIFICATION.

The primary disadvantages of utilizing the telescope directly with the detector is that the full resolution capabilities of the primary X-ray mirror system are not utilized.

Furthermore, these methods provide little or no spectral information. Thin metal foils have been mounted on a rotating filter wheel to obtain crude filtergrams of solar X-ray emissions. Due to the nature of these filters, the bandpass is of necessity very broad, which is a great detriment to detailed analysis and plasma diagnostics. Higher spectral resolution can be achieved by means of an objective grating placed immediately behind the Wolter telescope optics. However, for a multipurpose instrument, great care must be taken to ensure that the grating can always be removed from the optical path and that fail-safe mechanisms are employed. However, the concave ellipsoidal LSM optics that constitute the novel components of this disclosure can intercept all of the divergent beams from a complex nested system. These optics are easy to construct, even if it is desirable for the magnification to be in the range of 20x to 50x, which we believe will be desirable for certain high-resolution applications.

Accordingly, an important object of the present invention is to provide a glancing incidence X-ray telescope system capable of broadband, high-resolution imaging of solar and stellar X-ray and extreme ultraviolet radiation sources.

Another important object of the present invention is to provide an X-ray telescope system which can be utilized over a broad band of X-ray and extreme ultraviolet radiation sources in the range of thirty angstroms and below.

Summary of the Invention

The above objectives are accomplished according to the present invention by configuring an optical system utilizing off-axis ellipsoids, operating at angles of incident that are less than 45 degrees. It should be pointed out that glancing angles such as are usually used in Wolter systems are not required for the LSM optics; however, small angles may be chosen for particular applications. The ellipsoidal LSM optic is placed behind the primary focus of the primary mirror system and utilizes concave optics, rather than the convex mirrors such as have been described in the above referenced application for Letters Patent entitled SPECTRAL SLICING X-RAY TELESCOPE WITH VARIABLE MAGNIFICATION. The primary mirrors focus the X-rays to the first focus of the ellipsoidal LSM, and the high-resolution detector is situated at the other focus of this LSM optic. In the preferred embodiment, a plurality of ellipsoidal mirrors are mounted on a carrier wheel which is utilized to insert a desired LSM mirror into the diverging beam. This allows both the magnification as well as the particular spectral slice of the beam selected to be altered in accordance with the techniques and methods previously described. In other embodiments, for soft X-ray/XUV applications, the ellipsoids are configured to operate near normal incident, even though their surfaces still remain as concave ellipsoids. There also exist embodiments in which it is desirable to employ more than one LSM optic to render the beam in the most desirable configuration and these systems shall also be described.

Description of the Drawings

The construction designed to carry out the invention will hereinafter be described, together with other features thereof.

The invention will be more readily understood from a reading of the following specification and by reference to the accompanying drawings forming a part thereof, wherein an example of the invention is shown and wherein:

Figure 1 is a perspective view illustrating an orbiting space shuttle vehicle with the bay open to aim an X-ray telescope constructed in accordance with the present invention;

Figure 2 is a schematic view of a Wolter/Gregorian X-ray telescope constructed in accordance with the present invention;

Figures 3 and 3a are schematic illustrations of concave ellipsoidal LSM optical elements.

Figure 4 is a schematic illustration of a multispectral glancing incidence X-ray telescope constructed in accordance with the present invention;

Figure 5 is an alternate embodiment of a multispectral glancing incidence X-ray telescope constructed in accordance with the present invention; and

Figure 6 is another embodiment of a Wolter/Gregorian X-ray telescope constructed in accordance with the present invention.

Description of a Preferred Embodiment

The invention relates to a broadband, high-resolution, multispectral, glancing incidence X-ray telescope referred to as a Wolter/Gregorian X-ray telescope. The telescope is capable of broadband, high-resolution imaging of solar and stellar X-ray, and extreme ultraviolet radiation sources at wavelengths significantly below 30 angstroms. The telescope has particular applications to missions in space. Figure 1 illustrates the telescope, designated generally at A, as aimed from the payload bay 10 of an orbiting space shuttle vehicle V. The telescope may also be used in an orbiting observatory as utilized in the high-energy astronomy observatory launched by the United States National Aeronautics and Space Administration (NASA).

Referring now in more detail to the drawings, the multispectral telescope A is illustrated which utilizes concave ellipsoidal layered synthetic microstructure (LSM) mirrors to achieve image magnification and spectral discrimination. The optical system is designed such that the first focus F1 (Figure 2) of an ellipse 14 lies at the prime focus of a conventional glancing incidence Wolter I or Wolter/Schwarzschild X-ray telescope system 21. An X-ray detector 16 is located at the second focus F2 of the ellipsoid. Concave ellipsoidal mirror 18 is a segment of ellipsoid 14, with corresponding foci F1 and F2. A typical Wolter type I optical system includes a mirror 20 which is a paraboloidal element and a mirror 22 which is a coaxial and confocal hyperboloidal mirror element. X-rays strike these mirrors at less than their critical angle and are effectively reflected to produce an image in the focal plane of the mirror system which is also designated as F1.

Referring now to Figure 2, mirror element 18 is a concave, inclined, ellipsoidal element. The ellipsoidal element is configured such that one of its foci coincides with the prime focus F1 of the Wolter mirror system. A high-resolution X-ray detector such as a charge coupled device (CCD), a ranicon, a multi-annode microchannel array, or a camera carrying X-ray-sensitive photographic film is situated at the focus F2 constituting the detector 16. Since the X-rays strike the inclined LSM ellipsoidal mirror 18 at less than normal incident, it is possible to reflect X-rays with this mirror of shorter wavelengths than are possible with normal incident LSM systems. Inclinations of 45 degrees or less are preferred.

Referring now to Figure 3a, the ellipsoidal mirror 18 is provided with a layered synthetic microstructure coating 19 deposited on the concave surface 18a of the mirror. Figure 3 shows the ellipsoid of revolution 28 which determines the surface contour as ellipsoidal mirror 18 employed in the instant invention. The ellipsoidal mirror 18 includes long sides 18b and corresponding ends 18d.

The layered synthetic microstructure coating deposited on the mirror is constituted of many (100-1000) alternating layer pairs of different materials of precisely controlled thickness. For example, these may be alternating layers of tungsten and carbon, aluminum and gold, magnesium and gold, etc. The exact nature of the coatings and the thickness of the alternating layers determine the particular wavelength that is effectively reflected. The layers are used usually very thin, of the order of 7A to 40A. With the current technology, Good reflectives (i.e. 10% to 30%) can be achieved with synthetic microstructure mirrors reflecting a beam R at normal incident over the wavelength range from 30A to 400A or more. To some extent, the mirror coating can be tailored to select a desired spectral slice. Hence, in the preferred embodiment of the invention there would be a plurality of ellipsoidal mirrors, each of which is tailored to reflect a different wavelength.

As can best be seen in Figure 4, a preferred arrangement is provided in which a plurality of inclined concave ellipsoidal mirrors 30a, 30b, 30c, and 30d are mounted on a cylindrical carrier 32. The carrier 32 is oriented at a desired angle and positioned with respect to the optical axis 24 of the primary mirror system to present each mirror at a desired inclination to the axis and incoming radiation beam. Each of the mirrors 30a through 30d is of the same ellipsoidal sections and concave surface such that the primary image focused at F1 is always reimaged onto the image plane of detector 16 at focus F2. The exact LSM coating for each mirror element is changed from one surface to the next, hence each mirror 30a through 30d will reflect a different X-ray wavelength. A drive motor 34 is provided for rotating the cylinder 32 from a remote location. The drive motor may be a stepper motor, a Geneva mechanism, or other means of accurately positioning each mirror on the rotating cylinder onto the optical axis to allow a shift from one X-ray wavelength to another. While four mirrors are shown, it is to be understood that any number of mirrors may be employed.

Referring now to Figure 5, a method is illustrated in which the inclination axis of the ellipsoid mirror may be chosen to selectively change the angle of the radiation incident upon the mirror elements. LSM ellipsoid mirror elements 40a and 40b are illustrated having inclined axes 41a and 41b, respectively. In this embodiment, the mirrors focus the radiation from the same primary beam 26 to separate detectors 42a and 42b. In practice, mirror 40a may be removed from the primary beam whereby the beam strikes the mirror element 40b and is recorded on the detector 42b. Any suitable mechanism for retracting or removing the forward mirror from the beam may be utilized. The recorded image will be significantly lower in magnification than the image provided by mirror 40a. Furthermore, the mirror elements can have different LSM coatings so that they can also image a spectral slice of different X-ray wavelength. This arrangement has many advantages and protects against loss of an entire experiment by a detector failure since a plurality of detectors are utilized. It is also possible to utilize a single detector and to configure the ellipsoid so that both foci are coincident, even though different magnifications are provided. In this case, the shift from one mirror to the other would alter the image size and resolution for a single fixed detector.

Figure 6 represents an alternate embodiment which utilizes a normal incident concave ellipsoidal LSM optical element 50 to reflect the radiation back along the optical axis 24 after striking the element. The detector 16 is located at the second focus F2 of the ellipsoid on the optical axis 24. The radiation is initially reflected by a nested pair of Wolter Type 1 or Wolter/Schwarzschild X-ray mirrors 52 and 54, each comprizing a paraboloidal and hyperboloidal element 20 and 22 respectively. This design cannot be utilized with X-rays of wavelengths much shorter than 30 angstroms due to the normal incident of reflection. However, this embodiment may have advantages in certain ellipsoid configurations. Also, it offers the advantage of allowing the instrument to be considerably shorter and the X-rays are ~~instant~~ incident upon the LSM optics at uniform angles. In accordance with Bragg defraction, mirror 50 reflects only one given wavelength of X-rays. However, as described above, several concave ellipsoidal elements may be mounted on a carrier (not shown), or be inserted into the beam by means of remote control to observe different wavelengths and provide variation in magnification and, hence, resolution in field of view of the telescope. A means is illustrated for inserting a detector 56 into the primary beam at the prime focus F1 by means of a movable arm 58. This allows all of the wavelengths reflected by the Wolter optics to be imaged directly, without the spectral slicing and magnification introduced by the LSM optic. This aspect may be of particular value of complementing high spatial and spectral observations with high-sensitivity, broadband studies. This method can be particularly advantageous for sources that are inherently very faint.

Thus it can be seen that by utilization of inclined ellipsoidal elements, it is possible to operate LSM optics at shallower angles and thereby reflect X-rays down to the 1.5 angstrom region or lower. In certain other embodiments, it is possible to easily utilize redundant X-ray detectors to prevent against the loss or failure of an experiment due to detector failure. Normal incident concave elements can be utilized to achieve superior performance with nested Wolter mirror systems. Alternately, a detector may be placed into a beam prior to the LSM optic for high-sensitivity observations of faint sources over a broad spectral region than is realized with the LSM system.

Most important, however, is the use of concave ellipsoidal optics operating on the diverging beam, after it is passed through the prime focus, allowing harder X-rays to be magnified and imaged than can be achieved with normal incident LSM convex elements.

While a preferred embodiment of the invention has been described using specific terms, such description is for illustrative purposes only, and it is to be understood that changes and variations may be made without departing from the spirit or scope of the following claims.

Abstract of the Disclosure

A multispectural ~~Wolter/Gregorian~~ glancing incidence X-ray telescope is illustrated capable of broadband, high-resolution imaging of solar and stellar X-ray and extreme ultraviolet radiation sources which includes a primary optical system preferably of the Wolter I type having a primary mirror system (20, 22). The primary optical system further includes an optical axis (24) having a primary focus (F1) at which the incoming radiation is focused by the primary mirrors. A plurality of ellipsoidal mirrors (30a, 30b, 30c, and 30d) are carried at an inclination to the optical axis behind the primary focus (F1). A rotating carrier (32) is provided on which the ellipsoidal mirrors are carried so that a desired one of the ellipsoidal mirrors may be selectively positioned in front of the incoming radiation beam (26). In the preferred embodiment, each of the ellipsoidal mirrors has an identical concave surface carrying a layered synthetic microstructure coating tailored to reflect a desired wavelength of 1.5 Å or longer. ~~in the range below 30 angstroms.~~ Each of the identical ellipsoidal mirrors has a second focus (F2) at which a detector (16) is carried. Thus the different wavelength image is focused upon the detector irregardless of which mirror is positioned in front of the radiation beam. In this manner, a plurality of low wavelengths in a wavelength band generally less than 30 angstroms can be imaged with a high resolution.