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NASA CASE NO. MFS-28013-2

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Serial No. 07/545,220
Date Filed June 28, 1990

MSFC

(NASA-Case-MFS-28013-2) VARIABLE MAGNIFICATION GLANCING INCIDENCE X RAY TELESCOPE Patent Application (NASA) 22 p

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PATENT APPLICATION ABSTRACT

VARIABLE MAGNIFICATION GLANCING INCIDENCE X-RAY TELESCOPE

The instant invention is directed to variable magnification glancing incidence x-ray telescopes capable of broadband high resolution imaging of solar and stellar x-ray sources having improved spatial and spectral resolution. The telescope may be used in the space shuttle or a space station for obtaining such images.

The telescope 10 comprises two or more ellipsoidal mirrors 16, 38 (or 38a) positioned behind the primary focus F1 of a primary Wolter I optical system 20, 22. Each mirror has a concave surface coated with a multilayer synthetic microstructure coating 33 to reflect a desired wavelength. The mirrors are segments of respective ellipsoids 18, 40 having a common first focus coincident with the primary focus. An x-ray sensitive photographic film detector 26 is positioned at the second focus F2 of each of the ellipsoids in one embodiment so that the mirrors may reflect the image at the first focus to the detector. In another embodiment the mirrors are inclined at different angles and separate detectors are located at the respective second focus F2. The mirrors are arranged one behind the other so that the magnification and field of view differ, and a solenoid activated arm 36 may

withdraw the first mirror 16 from the radiation beam to select the second mirror 38, 38a for impingement of the beam to obtain a lower magnification and greater field of view. The mirror 38a may also have a solenoid activated arm 62 to withdraw it from the incoming beam.

The novelty of the invention appears to lie in the arrangement of two mirrors one behind the other having a common first focus and having the capability of selecting one of the mirrors for reflecting the radiation beam to a detector at the respective second focus.

Inventor: Richard Hoover

Employed by: NASA - MSFC

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VARIABLE MAGNIFICATION 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.

REFERENCE TO RELATED APPARATUS

This application is a continuation-in-part of copending application serial No. 765,979 filed August 15, 1985, (now allowed).

BACKGROUND OF THE INVENTION

This invention relates to x-ray telescopes and more particularly to variable magnification glancing incidence x-ray telescopes capable of broadband high resolution imaging of solar and stellar x-ray sources having improved spatial and spectral resolution.

For applications of obtaining high spatial resolution observations with high sensitivity detectors, such as CCD's or Multi-Anode MicroChannel Arrays (MAMA'S), variable magnifications are highly desirable. However, this capability does not at present exist. Very high resolution telescopes, such as the optical system currently under development for the advanced X-Ray Astrophysics Facility (AXAF) have a fixed focal length and fixed field of view as dictated by the fundamental parameters of the primary mirror. These telescopes have been designed with the greatest emphasis placed upon the harder rather than the softer components of the x-ray spectrum.

The ability to produce images of sources at x-ray energies up to 10 keV is of profound significance to the solution of many of the most important problems of astrophysics and solar physics. An instrument for producing high spatial resolution images of the sun and of astrophysical sources at numerous well defined spectral wavebands is disclosed in applicant's copending application (serial No. 756,979) filed on August 15, 1985, entitled Multispectral Glancing Incidence X-Ray Telescope. In that application a telescope system was disclosed which made high resolution and magnification imaging of solar and stellar x-ray and extreme ultraviolet radiation possible. The telescope system there disclosed images over a broad band of hard x-ray and extreme ultraviolet radiation, in the range of 30 angstroms and below using Wolter type optics without increasing the physical size of the telescope. This was accomplished by combining ellipsoidal layered synthetic microstructure (LSM) mirrors operating at inclined orientations in combination with a glancing incidence Wolter I system with off-axis x-ray detector means with the LSM optics positioned behind the primary focus of the Wolter I primary mirror system, the LSM mirrors being concave in shape. The apparatus therein disclosed thus made it possible to obtain high spatial and spectral resolution images of point sources or of extended sources of x-ray emission at wavelengths shorter, i.e., higher energies, than could be imaged with the spectral slicing x-ray telescope disclosed in applicant's earlier U.S. Patent No. 4,562,583 dated December 31, 1985, which operated at normal incidence with all optical elements positioned on the optical axis.

Layered synthetic microstructure (LSM) coatings have during the past few years come to be more commonly called "multilayer coatings" or simply "multilayers", and hence the more modern terminology will be used in the present application.

In the prior art, Wolter x-ray telescopes have been used with single or nested mirrors to focus x-rays from astronomically distant point or extended sources. these telescopes use x-ray mirrors which operate at a glancing or grazing angle of incidence. The mirrors may be used uncoated or may be coated with a high-Z material such as gold, platinum or iridium. The solar x-ray telescopes which were flow on SKYLAB operated at grazing angles of 54 arc minutes and could effectively reflect only x-rays of energies lower than the 0.5 keV (wavelengths > 6 angstroms). These Wolter Type I mirrors use internally reflecting, coaxial and confocal paraboloidal and hyperboloidal mirrors. Astrophysical telescopes, such as HEAO, XMM and AXAF, have been designed to operate at glancing angles in the range of 20 to 50 arc minutes, making it possible for them to focus and image x-rays with energies up to 8 to 10 keV (wavelengths >1.2 angstroms). Images with these systems are typically recorded on high resolution photographic film or other solid-state or gas filled detectors such as CCD's Position Sensitive Proportional Counters, Multi-Anode Micro-Channel Arrays (MAMAS). Techniques for coupling Wolter telescopes to solid state detectors by means of convex hyperboloid mirrors were described in the aforesaid Patent No. 4,562,583. However, this device is not capable of operating over the entire wavelength range which can be covered by glancing incidence x-ray telescopes due to the difficulty of fabricating Layered Synthetic Microstructure (LSM) coatings capable of operating at wavelengths significantly less than 30 angstroms when cofigured at normal incidence.

The primary disadvantages of using the telescope directly with a solid state detector is that the full resolution capabilities of the primary x-ray mirror can not be utilized due to limitations that exist in the ability to fabricate solid state detectors with pixel sizes significantly smaller than 10 microns. In the applicant's copending application serial No. 756,979 entitled Multispectral Glancing Incidence X-Ray Telescope, a system was disclosed having the capability of obtaining high resolution images in different spectral bands over the entire wavelength range that the glancing incidence primary optic was capable of reflecting (~~1~~ 2 Å-100 Å). Also disclosed was a high resolution x-ray telescope capable of yielding images with variable magnification at wavelengths selected over the entire range of coverage which may be handled by means of conventional Wolter x-ray telescopes (i.e., in the order of 2Å-100Å). That species of the system was divided out of the aforesaid patent application and form the subject matter of the instant application.

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SUMMARY OF THE INVENTION

Accordingly, it is a primary object of the present invention to provide a high resolution x-ray telescope capable of yielding images with variable magnification at wavelengths selected over the entire range of coverage which may be handled by conventional Wolter x-ray telescopes.

It is another object of the present invention to provide a high sensitivity glancing incidence x-ray telescope capable of producing high spatial resolution images, with variable magnification and variable field of view, of solar and stellar x-ray/extreme ultraviolet radiation sources with good spectral resolution in a single narrow waveband at selected wavelengths in the entire range of coverage of the glancing incidence primary optic (2Å-100Å).

It is a further object of the present invention to provide a high sensitivity variable magnification and field of view glancing incidence x-ray telescope capable of producing high spatial resolution images of solar and stellar x-ray/extreme ultraviolet radiation sources with good spectral resolution onto a plurality of x-ray detectors in narrow x-ray/extreme ultraviolet wavebands selected within the entire wavelength range of coverage of the glancing incidence primary optic (2Å-100Å).

Accordingly, the present invention provides an optical system utilizing off-axis ellipsoid mirrors operating at angles of incidence of less than 60 degrees, polished to a high degree of smoothness and coated with a selected multilayer coating. The ellipsoidal multilayer optic system is placed behind the prime focus of a glancing incidence mirror and utilizes concave optics. Primary Wolter type mirrors focus the incoming x-rays to the prime focus of the glancing incidence optics which is coincident with the first focus of the ellipsoidal multilayer mirrors, and at least one high sensitivity, high resolution detector is placed at the other focus of the ellipsoidal multilayer optic. In the preferred embodiment, a plurality of multilayer ellipsoidal mirrors are employed to reflect x-rays of identically the same wavelength but to produce images of different magnifications and fields of view onto a single x-ray detector. In alternate embodiments a plurality of different x-ray detectors with the same or with different performance characteristics are utilized which can be matched to the optical properties of the imaging system as the magnification and field of view are varied.

The significance of this invention can be appreciated by considering that when the telescope is used at low magnification to image extended astrophysical sources, e.g., Supernova Remnants, clusters of galaxies, etc. or to produce full disk images of the Solar Corona, a low magnification and wide field of view (1 degree or more) are required. When detectors with fixed pixel sizes such as CCD's or MAMA's, are used, the spatial resolution will suffer at these low magnifications. Thus after an interesting region of the supernova remnant or the sun has been observed in the low resolution wide field mode, introduction of a different ellipsoidal mirror into the beam will allow the same region to be investigated at much higher magnification and spatial resolution. The very high sensitivity, low magnification mode is very useful for pointing the telescope precisely at faint galaxies or stars, wherein they could then be studied in detail by the lower sensitivity and yet higher magnification and enhanced spatial resolution component of the instrument.

The coating constitutes a synthetic Bragg crystal, and is comprised of a large number (50-1000) of alternating layers of high-Z diffractor material separated by low-Z spacer material. X-rays which strike the coating are reflected by Bragg Diffraction in accordance with the Bragg relation: $n(\lambda)=2D\sin(\theta)$, where n is the diffraction order, λ is the wavelength of radiation for which the peak reflectivity occurs, D is the multilayer parameter which is the sum of the thickness of one diffractor layer plus one spacer layer in the multilayer stack, and θ is the angle at which the incident x-ray strikes the mirror surface. It may be pointed out that glancing angles such as are usually required for Wolter systems are not required for multilayer mirrors designed to cover the wavelengths of x-radiation which can be reflected by conventional x-ray telescopes, however, such small angles might be chosen for some particular applications.

BRIEF DESCRIPTION OF THE DRAWINGS

The particular features and advantages of the invention as well as other objects will become apparent from the following description taken in connection with the accompanying drawings, in which:

Fig. 1 is a perspective view illustrating an orbiting space shuttle vehicle with the bay open to point an x-ray telescope constructed in accordance with the present invention;

Fig. 2 is a schematic view of the optics of a variable magnification glancing incidence x-ray telescope constructed in accordance with the present invention, the telescope utilizing a single detector;

Figs. 3 and 3a are schematic illustrations of concave ellipsoidal multilayer optical elements utilized in the present invention;

Fig. 4 is a perspective view, partially broken away, of a variable magnification glancing incidence x-ray telescope constructed in accordance with the present invention; and

Fig. 5 is a schematic illustration of the focal plane of a variable magnification glancing incidence x-ray telescope utilizing multiple detectors.

DESCRIPTION OF THE PREFERRED EMBODIMENT

This invention relates to a high resolution, glancing incidence x-ray telescope of variable magnification. The telescope is capable of producing high spatial resolution images in selected narrow wavebands. The field of view of the telescope and the magnification (and hence resolution) of the resultant image may be varied by selection of the multilayer ellipsoidal mirror, such selection also allowing the precise wavelength band of interest, over the entire spectral range for which the primary glancing incidence mirror is sensitive to be selected, typically 2 to 100 angstroms. The telescope has particular applications to missions in space. Fig. 1 illustrates the telescope, designated generally at 10, as pointed from the payload bay 12 of an orbiting Space Shuttle Vehicle V, the telescope 10 being mounted on the pointing platform 14, which is used to precisely point the telescope at the sun or at the selected astrophysical source and to maintain it stable and free from vibration for the duration of the exposure. The telescope may be used in an orbiting observatory as utilized in the High Energy Orbiting Observatory launched by the United States National Aeronautics and Space Administration (NASA) or on a major Astrophysical Facility such as AXAF, which is currently under development by NASA. As hereinafter described, the variable magnification glancing incidence x-ray telescope 10 uses concave ellipsoidal multilayer mirrors to achieve spectral discrimination, and to permit the image magnification and field of view to be varied.

Referring now to Fig. 2, the optical system is configured such that the first focus F1 of a concave ellipsoidal mirror 16 forming a segment of an ellipsoid 18 lies at the prime focus of a conventional single Wolter I or Wolter/Schwarzschild glancing incidence x-ray telescope system typically comprising a glancing incidence paraboloidal mirror 20 followed by a glancing incidence coaxial and confocal hyperboloidal mirror 22. Alternatively, the mirrors 20 and 22 may have surface configurations based upon the Wolter II design (internal hyperboloid followed by an externally reflecting hyperboloid), the Narai design (hyperboloid - hyperboloid), or other aspheric-aspheric design configuration of the optical system, without departing from the present invention. The first focus F1 and the center of the ellipsoidal mirror 16 lie on the optical axis 24 of the glancing incidence Wolter telescope optics. The ellipsoid 18 has a second focus F2 and a high resolution x-ray detector 26 is located at the second focus F2 off the optical axis, the detector being a Charge Coupled Device (CCD), a Ranicon, a Multi-Wire Position Sensitive Proportional Camera, a Multi-Annode Microchannel

Array, (MAMA) or a camera carrying x-ray sensitive photographic film. X-rays strike the mirrors 20, 22 at less than their critical angle and are effectively reflected to produce an image in the focal plane F1 of the mirror system, the incident beam of x-ray radiation 28 being reflected by the Wolter telescope mirrors 20 and 22 to become a convergent beam 30. After passing through principal focus F1, the x-ray beam diverges as illustrated at 32 until it strikes the concave ellipsoidal mirror 16, located behind the primary focus F1. The mirror 16, which is coated on its concave surface with an X-ray reflecting multilayer coating 33, is inclined relative to the optical axis 24, preferably 60 degrees or less, so that x-rays of shorter wavelengths can be reflected than are possible with normal incidence multilayer optics, the x-rays being reflected as a converging beam 34 toward the second focus F2 of the ellipsoid 18. Thus, the x-rays are reflected to the location of the detector 26 producing a high magnification, relatively low field of view image of the source on detector 26.

As hereinafter described the mirror 16 may be withdrawn from the x-ray beam by selection means such as a solenoid activated lever arm 36, which is not illustrated in Fig. 2 for purposes of clarity of presentation but is illustrated in Figs. 4 and 5, to permit the diverging beam 32 to continue aft until it is intercepted by another concave ellipsoidal mirror 38 forming a segment of an ellipsoid of revolution 40 larger than the ellipsoid 18, but sharing the common foci F1 and F2, the mirror 38 like the mirror 16 also being behind the primary focus F1. This mirror is also coated on its concave surface with an x-ray reflecting multilayer coating 41, and is also inclined relative to the optical axis 24. This will produce a lower magnification and relatively larger field of view image of the source on the detector 26, since the magnification is given by the equation M=d2/d1, where d1 is the distance from the first focus F1 to the concave ellipsoidal mirror and d2 is the distance from the concave ellipsoidal mirror to the second focus F2.

Referring to Fig. 3a, the ellipsoidal mirror 16 is provided with a multilayer coating 33 deposited on the concave surface 16a of the mirror. Fig. 3 shows the ellipsoid of revolution 18 which determines the surface contour of ellipsoidal mirror 16 employed in the instant invention. The ellipsoidal mirror 16 includes long sides 16b and corresponding ends 16d. Prior to the application of the multilayer coating 33, the concave surface 16a must be polished to a high degree of smoothness, in the order of 3-10 angstroms RMS, for imaging in soft x-ray/XUV range and to a precision of 0.5-3 angstroms RMS for producing high quality images in the x-ray to hard x-ray regime. ~~The~~ For multilayers designed to operate with a 2D spacing of 100Å or more surface finishes of 3-10Å RMS can be used, as can be achieved by conventional float or bowl feed polishing techniques. However, even at these wavelengths, the performance of the final mirror can be improved by starting with the best possible mirror substrate. Consequently, the superior results of ultrasmooth surfaces which can be achieved by the recently developed Ion Polishing and Advanced Flow Polishing methods are to be preferred. These techniques can produce ultra-smooth mirror surfaces (0.5Å-3 RMS). The mirror substrates should be of a stable material capable of receiving such an ultra-smooth surface finish and which can be contoured to the proper figure. Ideal substrates include Zerodur, Cervit, Fused Silica, ULE Fused Silica and some more exotic materials, such as sapphire and glassy carbon.

6/6/90

Low expansion coefficient is highly desirable for optics which will receive a significant thermal loading. For solar telescopes, the use of a heat rejecting pre-filter is desirable, and will permit materials such as Hemlite grade sapphire or glassy carbon to be used. These materials can yield the ultimate (0.2-0.7Å RMS) in ultra-smooth surfaces, but they have a somewhat higher thermal coefficient of expansion than materials such as Cervit or Zerodur.

The ellipsoid of revolution shown in Fig. 3a has the important optical property that radiation which emanates from one focus F1 of the ellipsoid is re-focused to the second focus F2 of the ellipsoid. For some embodiments, it may also be desirable to use a mirror surface which comprises a segment of a toroid of revolution, and this remains within the spirit and scope of the present invention. Mirror element 16 however, is preferably a concave, inclined ellipsoidal element. As aforesaid, the ellipsoidal element is configured such that one of its foci coincides with the principal focus F1 of the Wolter mirror system and the high resolution x-ray detector 26. The multilayer coating deposited upon the concave surface 18a of the mirror consists of multiple precise alternating layers of a high-Z diffractor material separated by low-Z spacer material layers. D is the thickness of the diffractor layer. The 2D spacing and the materials selected for the x-ray multilayer coating 19 are chosen so as to reflect the desired band of x-ray emission. Since these mirrors reflect radiation by Bragg diffraction, the precise wavelength at which the peak reflectivity occurs is determined by the 2D spacing of the multilayer coating and the angle of incidence at which the radiation strikes the mirror. The optical properties of the diffractor and spacer components at the wavelength of interest must be taken into consideration in order to select the optimal composition. Tungsten/Carbon, Rhodium/Carbon, Molydenum/Silicon and other material combinations have been proven to have superb properties of long term stability. Excellent reflectivities (approaching theoretical limits) have been achieved in practice with these materials. Reflectivities at normal incidence in the soft x-rays/XUV regime as high as 65% have been documented. At smaller angles of incidence, reflectivities of hard x-rays with reflection efficiencies in excess of 70% have also been measured. RJH 6/6/95

Referring now to Fig. 4, a telescope 10 according to the present invention is illustrated having a mount tube 42 affixed to a mounting plate structure 44 for mounting the telescope to the pointing platform of the vehicle V as illustrated in Fig. 1. The mirrors 20 and 22 are housed within a mirror mount cell 46 which maintains them in alignment and has a mounting flange 48 for mounting the mirrors to the telescope mount tube 42. In the preferred embodiment, the mirror mount cell 46 and the mount tube 42 may comprise filament wound fiber epoxy material, although other material such as Beryllium, Aluminum, or Invar may be suitable if requirements related to outgassing properties, thermoexpansion coefficient or weight should dictate their selection and if economy permits. An optical reference cube 50 may be used for aligning the optical axis of the telescope 10 to other instruments (not illustrated) which may be flown on the same spacecraft to collect simultaneous data at other wavelengths. Heat rejection plates 52 mounted at the forward end of the telescope may be used for solar studies to eject unwanted solar heat so as to protect the telescope from excessive heating which could cause de-focus effects. A front aperture stop 54 is utilized to prevent radiation from traveling directly through the center of the Wolter optics and reaching the concave ellipsoidal mirrors without first being reflected by the Wolter optics.

The incident radiation beam 28 enters the telescope through an entrance annulus 56 which is covered with a visible light rejection pre-filter 58, the pre-filter typically being 2000 Å of aluminum on a nickel mesh support structure 60. After the incident radiation beam 28 is reflected by the primary mirror system 20 and 22, the reflected convergent beam 30 converges toward the principal focus F1 and then diverges as a diverging beam 32 behind the principal focus F1 to strike the multilayer coated surface 33 of the inclined ellipsoidal mirror 16, the first focus F1 of the mirror 16 coinciding with the principal focus F1 of the primary Wolter I x-ray mirror. The narrow bandpass of the reflected radiation beam 34 then is brought to focus on the detector 26 which is disposed at the second focus F2 of the ellipsoidal mirror 16. Preferably the ellipsoidal mirror 16 is a high magnification mirror and may be withdrawn from the beam by means of the solenoid activated lever arm 36 so as to allow the beam to continue aft so as to be reflected by a preferably low magnification ellipsoidal mirror 38a having a multilayer coated surface 41 and which may be configured and inclined to operate at the same angle of incidence as the mirror 16 as illustrated. The mirror 38a is from the same ellipsoidal family with different semi-major semi-minor axes, such that the foci F1 and F2 are common and coincide, the first focus F1 of the ellipsoid being at the principal focus of the grazing incidence optics, and the second focus F2 of the ellipsoid being at the detector plane 26. Moreover, the mirrors may be arranged such that each may be selectively inserted in or withdrawn from the incident radiation beam by utilizing a solenoid activated lever arm 62 in conjunction with the mirror 38a similar to and in addition to the arm 36 associated with the mirror 16. Although only two concave ellipsoidal mirrors are illustrated, it should be clear that to permit minor control of the telescope magnification and field of view a plurality of mirrors in addition to the mirrors 16 and 38a may be utilized, in which case both mirrors 16, 38a may be withdrawn from the beam by the respective solenoid activated lever arm 36, 62 and permit one of other mirrors to receive the beam with remaining mirrors also being withdrawn from the beam by similar withdrawal means.

In the embodiment depicted in Fig. 4, the detector 26 is a photographic film carried on a spool 64 and pressed flat in the focal plane F2 by a platen 66. The film is advanced by a motor drive 68 in accordance with electronic signals received by drive electronics (not illustrated). The film and drive assembly may be mounted within a camera housing 70 equipped with a handle 72 to permit an astronaut to remove and replace the film camera during an EVA. The camera housing 70 is mounted to the telescope housing 42 by means of a flange 74 and an adapter plate 76. Although a film camera is herein illustrated, other detectors such as CCD's, MAMA's, etc. may be readily utilized in accordance with the present invention.

The multilayer coatings 33 and 41 can be deposited so as to be perfectly uniform if a broader spectral response is desired. If it is desired that the spectral response be as narrow as possible, multilayer coatings 33 and 41 will be deposited upon the ellipsoidal mirrors while the substrates are inclined at the appropriate angle with respect to the sputtering source, rather than lying flat as is the usual case for coating optics by the magnetron sputtering process. This will result in a multilayer coating which has a diffractor and spacer layer thickness which varies as a function of position on the mirror substrate. This type of wedge multilayer coating is called a "laterally graded multilayer coating", and the layers are thin wedges rather than plain parallel layers. With precisely the correct lateral grading of the mirror 2D parameter (for the particular angle at which the ellipsoidal mirror will be operating) the effect of x-ray chromatic aberration can be removed. This effect is produced because the beam 32 diverges after passing through the principal focus F1 of the Wolter optics. Hence rays reflected from the top of the Wolter mirrors strike the ellipsoidal mirror coating 33 at slightly different angles than the angle at which the rays reflected from the bottom of the Wolter mirror strike the ellipsoidal mirror. Rays from the right and left sides strike at exactly the same angles. Properly coated graded multilayer mirrors can correct the x-ray chromatic aberration effects and ensure that the reflected radiation is confined to a narrow x-ray bandpass.

The magnification M of the ellipsoidal mirror as aforesaid is given by the relation: M=d2/d1, so that when the first ellipsoidal mirror which is nearest to the principal focus of the grazing incidence primary optic is used to intercept the beam, the highest magnification and smallest field of view is recorded at detector 26. When a second ellipsoidal mirror, which is farther away from the principal focus F1 is used to intercept the beam, lower magnification and wider field of view images are obtained. Since the ellipsoidal mirrors are operating at the same angle of incidence, if they are constructed of multilayers of the same 2D spacing, the same bandpass will be reflected and all that results from a change from one mirror to another is to accomplish a change in the magnification and hence field of view for the fixed detector 26. Alternatively as aforesaid, if a plurality of ellipsoidal mirrors are utilized, they could be introduced to permit widely varying magnification and field of view so as to produce a "zoom" x-ray telescope with much finer adjustments in magnification than can be achieved with only two ellipsoidal mirrors as shown herein.

The construction illustrated in Fig. 4 utilizes a single detector 26, but as illustrated in Fig. 5, which depicts the focal plane for an alternate embodiment in which two retractable concave ellipsoidal mirrors 16 and 38b are respectively coated with an x-ray reflecting multilayer coating 33 and 41, two independent detectors 26a and 26b are proposed, the mirrors being segments of ellipsoids of revolution 18 and 40 which are inclined at different angles with respect to the optical axis 24 to have common foci F1 but different foci F2.

The ellipsoidal mirrors 16 and 38b represent different magnifications because of their relative placements with respect to the two foci F1 and F2. By coating these mirrors with the same multilayer coatings which have identical diffractor and spacer layers of the same 2D parameter, different wavelengths as well as different magnifications will be reflected to the two detectors 26a and 26b. However, alternatively, the mirrors may be coated with different multilayers with 2D spacings tailored such that the same wavelengths are reflected even though mirrors 16 and 38b are operating at different angles with respect to the incident radiation beam. The use of different detectors 26a and 26b provides a valuable system redundancy, such that the entire experiment is not lost should one detector fail.

Thus, it is seen that by the utilization of a plurality of inclined ellipsoidal mutlilayer mirrors operating at different magnifications and wavelengths, it is possible to produce a glancing incidence x-ray telescope with variable magnification. The use of concave ellipsoidal elements operating at an inclined angle make it possible to magnify and image selected narrow spectral segments of the incident radiation beam over the entire wavelength range which the glancing incidence primary is capable of operating. Variable magnification glancing incidence x-ray telescopes can be configured to operate with a single detector or with a plurality of detectors to provide system redundancy.

Accordingly, the present invention provides an improved telescope system for high resolution and magnification imaging of solar and stellar x-ray and extreme ultraviolet radiation, the telescope system imaging over a broadband of hard x-ray and extreme ultraviolet radiation in the range of 30 angstroms and below using Wolter type optics without increasing the physical size of the telescope. The utilization of a plurality of concave ellipsoidal mirrors having multilayer coatings using off-axis ellipsoids behind the primary focus of the glancing incidence mirror system and operating at non-normal angles of incidence permits the high resolution and variations in magnification and field of view to be realized.

Numerous alterations of the structure herein disclosed will suggest themselves to those skilled in the art. However, it is to be understood that the present disclosure relates to the preferred embodiment of the invention which is for purposes of illustration only and not to be construed as a limitation of the invention. All such modifications which do not depart from the spirit of the invention are intended to be included within the scope of the appended claims.

VARIABLE MAGNIFICATION GLANCING INCIDENCE X-RAY TELESCOPE

is disclosed, which

ABSTRACT OF THE DISCLOSURE

A multispectral glancing incidence x-ray telescope capable of broadband, high resolution imaging of solar and stellar x-ray and extreme ultraviolet radiation sources includes a primary optical system which focuses the incoming radiation to a primary focus. Two or more ellipsoidal mirrors are positioned behind the primary focus at an inclination to the optical axis, each mirror having a concave surface coated with a multilayer synthetic microstructure coating to reflect a desired wavelength. The ellipsoidal mirrors are segments of respective ellipsoids having a common first focus coincident with the primary focus. A detector such as an x-ray sensitive photographic film is positioned at the second focus of each of the ellipsoids so that each of the ellipsoidal mirrors may reflect the image at the first focus to the detector. In one embodiment the mirrors are inclined at different angles and has its respective second focus at a different location, separate detectors being located at the respective second focus. The mirrors are arranged so that the magnification and field of view differ, and a solenoid activated arm may withdraw at least one mirror from the beam to select the mirror upon which the beam is to impinge so that selected magnifications and fields of view may be detected.

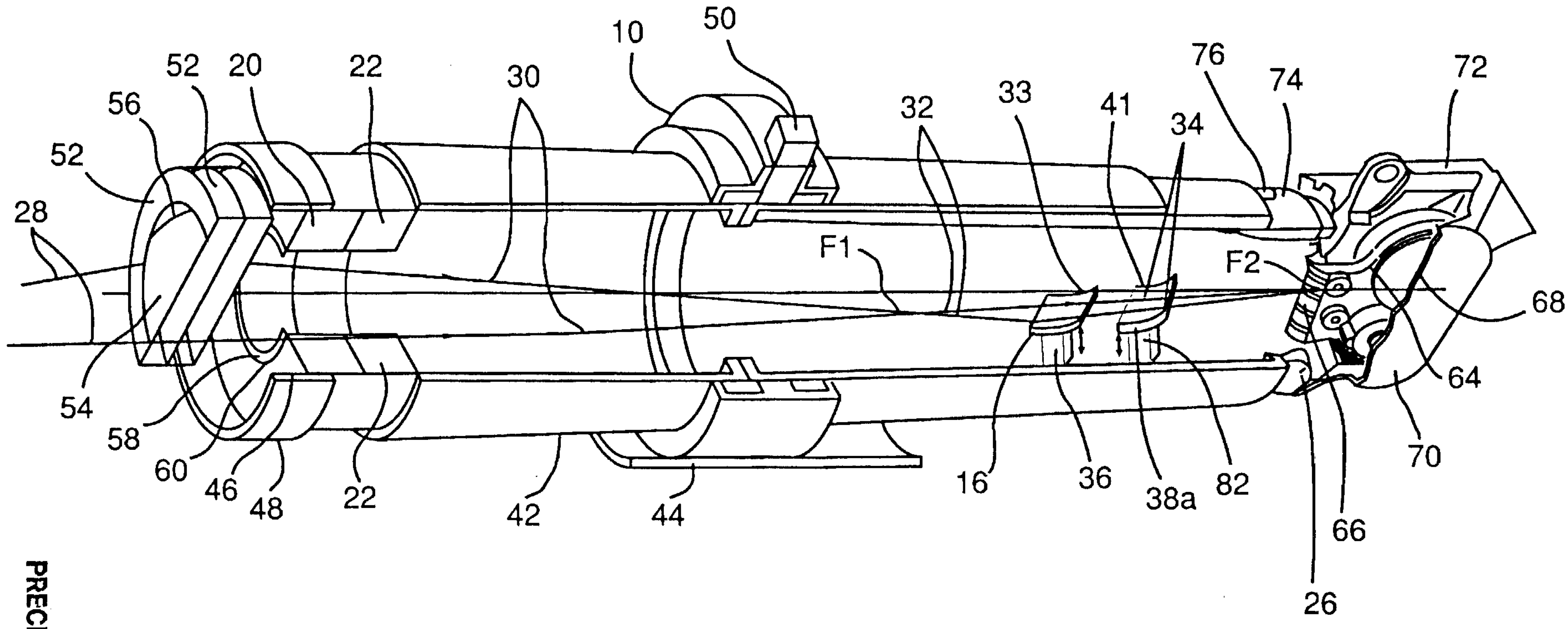

FIG. 4

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