Multi-Spectral Solar Telescope Array V: temperature diagnostic response to the optically thin solar plasma

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Abstract. We have developed compact soft x-ray, extreme ultraviolet (EUV), and far-ultraviolet (FUV) multilayer coated telescopes for the study of the solar chromosphere, corona, and corona/solar wind interface. Because these systems operate at short wavelengths (~40 Å < λ < 1550 Å), the modest apertures of 40 to 127 mm allow observations at very high angular resolution (0.1 to 0.7 arcsec). In addition to permitting traditional normal incidence optical configurations (such as Cassegrain, Ritchey-Chrétien, and Herschelian configurations) to be used at soft x-ray/EUV wavelengths, multilayer coatings also allow a narrow wavelength band (λ/Δλ ~ 15 — 100) to be selected for imaging. The resulting telescopes provide a very powerful and flexible diagnostic instrument for the study of both the fine-scale structure of the chromosphere/corona interface and the large-scale structure of the corona and corona/solar wind interface. In previous papers, we have described a new solar rocket payload, the Multi-Spectral Solar Telescope Array (MSSTA), which is composed of 17 of these compact telescopes. In the present paper, we report on the ability of the MSSTA payload to obtain temperature diagnostic information about the optically thin solar plasma. We also discuss applications of this information to studies of coronal structure.

Subject terms: x-ray/EUV optics; multilayer optics; solar corona; solar plasma diagnostics.


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1. INTRODUCTION

The Multi-Spectral Solar Telescope Array (MSSTA) is a comprehensive rocket-borne solar observatory that is capable of obtaining narrow band images of chromospheric and coronal structures in the soft x-ray, extreme ultraviolet (EUV), and far-ultraviolet (FUV), with very high (0.1 to 0.7 arcsec) angular resolution. Spectral resolution is achieved by use of an array of compact multilayer coated normal incidence telescopes that are able to achieve a resolving power of λ/Δλ ~ 15 — 100. The MSSTA payload includes two Cassegrain, seven Ritchey-Chrétien, and eight Herschelian telescopes, which form images in narrow wavelength bands in the soft x-ray, EUV, and FUV. We have previously described the optical design of the Ritchey-Chrétien, Cassegrain, and Herschelian telescopes, as well as the arrangement of the MSSTA telescopes within the 22-in. (56-cm)-diameter rocket shroud. In the present paper, we discuss the effectiveness of the MSSTA instrument as a temperature-sensitive diagnostic of the solar coronal plasma.

2. SOLAR EMISSION

The solar soft x-ray (5 to 100 Å) and EUV (100 to 1000 Å) spectrum arises largely from the upper chromosphere and lower corona, where the scale (typically 70 to 7000 km, or ~0.1 to 10 arcsec as viewed from Earth) and density (~10^5 to 10^10 cm^-3) of the structures (coronal loops, spicules, polar plumes, streamers) that dominate the atmosphere are such that they are transparent to most of their own emissions (i.e., optically thin). FUV (1000 to 2000 Å) lines, such as the Lyman α line of H I at 1216 Å, and a few EUV lines, such as He I at 504 Å and He II at 304 Å, can have large optical depths in the chromosphere.

Because each of these lines is emitted by a single species of ion, and different ionization states dominate the plasma at different temperatures, each line is excited in a distinct temperature range. The optics of each MSSTA telescope are designed to be sensitive to a small number of lines that are excited at nearly the same temperature, enabling each telescope to selectively detect plasma in a particular temperature range. Table 1 shows the major emission lines in each of the MSSTA telescope bands, with the temperature of peak emission for each line.

Let I(λ,T(x,y,z),ν(x,y,z))dν be the power per unit wavelength radiated from the volume element dV at the location x,y,z.
TABLE 1. Characteristics of the MSSTA optical systems.

<table>
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<tr>
<th>Telescope</th>
<th>Wave-</th>
<th>Mirror</th>
<th>Filter (+) (Thickness in μm)</th>
<th>Band-</th>
<th>Solar</th>
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<tbody>
<tr>
<td></td>
<td>length (Å)</td>
<td>Coating</td>
<td></td>
<td>pass (Å)</td>
<td>Focal</td>
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<td>Richey Chrétiens XII A</td>
<td>1216</td>
<td>H I</td>
<td>AlMgF4:Oss</td>
<td>MgF2:Al</td>
<td>65</td>
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<tr>
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<td>1548</td>
<td>C IV</td>
<td>AlMgF4:Oss</td>
<td>MgF2:Al</td>
<td>100</td>
</tr>
<tr>
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<td>He II</td>
<td>Mo-MgSi</td>
<td>Al (28)/C (0125)</td>
<td>18</td>
</tr>
<tr>
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<td>O VI</td>
<td>Mo/S</td>
<td>Be(60)</td>
<td>8</td>
</tr>
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<td>6</td>
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<td>Mo/S</td>
<td>Al (28)/B(10)</td>
<td>15</td>
</tr>
<tr>
<td>Richey Chrétiens XII G</td>
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<td>Fe XVI</td>
<td>Mo-MgSi</td>
<td>Al (18)/C (008)/Te (14)</td>
<td>23</td>
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<tr>
<td>Cassegrain VII-a</td>
<td>173</td>
<td>Fe IX X</td>
<td>Mo/S</td>
<td>Al (28)/C (04)</td>
<td>7</td>
</tr>
<tr>
<td>Cassegrain VII-b</td>
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<td>Fe XI V</td>
<td>Mo/S</td>
<td>Al (28)/B(10)/Water (01)</td>
<td>14</td>
</tr>
<tr>
<td>Herschelien IV-a</td>
<td>143.3</td>
<td>Ne V</td>
<td>Mo/S</td>
<td>Be(3)/Mo (28)</td>
<td>7</td>
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<tr>
<td>Herschelien IV-b</td>
<td>68.1</td>
<td>Ne VIII</td>
<td>Rh/C</td>
<td>Rh(68)/C (0275)/Phy(0.344)/Mo (28)</td>
<td>4</td>
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<tr>
<td>Herschelien IV-c</td>
<td>69.7</td>
<td>Si VIII</td>
<td>Rh/C</td>
<td>Rh(68)/C (0389)/Phy (256)</td>
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<tr>
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<td>54.7</td>
<td>Fe XVI</td>
<td>Rh/C</td>
<td>Rh(68)/C (0389)/Phy (256)</td>
<td>1.2</td>
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<tr>
<td>Herschelien IV-g</td>
<td>93.9</td>
<td>Fe XXIII</td>
<td>Rh/C</td>
<td>Rh(68)/C (0275)/Phy(0.344)/Mo (28)</td>
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<td>Herschelien IV-h</td>
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<td>Fe XX</td>
<td>Mo/S</td>
<td>Be(3)/Mo (28)</td>
<td>5</td>
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Notes:
1. Phth is Phthalocyanine
2. Bandpasses for 173 Å include L-edge of aluminum filter. Number in parentheses are for a single mirror
3. These high temperature lines are only expected to contain appreciable flux during or shortly after flares
4. The higher fluxes at 1215.6 Å and 304 Å will allow higher resolution (and hence lower sensitivity) film to be used in these systems.
5. The resolution at 1215.6 Å is diffraction limited, while the resolution at 304 Å is limited by the optics figure. A higher resolution film may be used in some of the other Richey-Chrétiens systems, allowing a resolution greater than 0.33" to be achieved.

within the optically thin solar plasma. If one assumes that elemental abundances are the same everywhere in the Sun, I is approximately proportional to the square of the electron density. It is therefore convenient to define the quantity

\[ I_n[\lambda, T(x,y,z)] = \frac{n_e T(x,y,z)}{n_e^2} n(x,y,z) \]  

(1)

where \( n_e \) is the electron density, and I is the solar emissivity at a given wavelength and location. We shall henceforth refer to I as the "emissivity"; it is (approximately) constant across changes in electron density. The intensity at the film plane of a solar telescope, caused by a solar feature at angular location \((x,y)\), is then given by (neglecting the finite resolution of the telescope)

\[ \Phi(x',y') = \frac{\pi}{4 f_{tel}^2} V(x,y) \int_{-\infty}^{\infty} ds \left[ n_e^2(x,y,z) \sum_{k} I_n[\lambda, T(x,y,z)] \right] \epsilon_{tel}(\lambda) \]  

(3)

where \( \lambda \) is the wavelength of the \( k \)th emission line, \( I_{nk} \) is the solar emissivity in the \( k \)th emission line, and \( V(x,y) \) is the vignetting function of the telescope. Further, the integral over \( s \) can be rewritten in terms of the temperature distribution along the line of sight, as follows:

\[ \Phi(x',y') = \frac{\pi}{4 f_{tel}^2} V(x,y) \int_{-\infty}^{\infty} dt \, n_e^2(T_e, x, y) \]  

(4)

where \( n_e^2(T_e) \), the emission measure, is characteristic of the solar structure under study. The "kernel" of the integral \( K(T_e) \), which is the convolution of the telescope efficiency and the solar emissivity, is given by a \( \Lambda \) sum indexed by element \( Z \), ionization stage \( z \), and transition from excited state \( i \) to lower state \( j \):

\[ K(T_e) = \sum_{k} I_{nk} \epsilon_{tel}(\lambda_k) = \sum_{zij} A_{zij} \alpha_{zij}(T_e) \alpha_{zij}(T_e) \epsilon_{tel}(\lambda) \]  

(5)

where \( A_{zij} \) is the abundance of element \( Z \), \( \alpha_{zij} \) is the fractional population of ionization stage \( z \), and \( \alpha_{zij} \) is the excitation function for transition \((i\to j)\) (including all population processes for the upper level \( i \) and branching ratios to the lower level \( j \)). These relations only hold for optically thin lines; thus, this derivation is not valid for the 1216-Å telescope, which is sensitive to the optically thick Lyman \( \alpha \) line. However, it is approximately valid for the remainder of the telescopes onboard MSSTA.
We have obtained theoretical calculations of the functions $A_{2g_2}(T_e)\alpha_{2g_2}(T_e)$ from Mewes et al. for lines with $1 < \lambda < 300$ Å and from Landini and Fossi for lines with $300 < \lambda < 2000$ Å. If one uses this data, and the throughput information for a MSSTA telescope, it is possible to evaluate the sum in Eq. (5) to find the response (incident power density at the film plane) of each telescope to a unit mass of solar plasma, as a function of temperature of the plasma. Conversely, it is possible to design the telescope throughput function $\varepsilon_{tel}(\lambda)$ to achieve maximal temperature resolution for the telescope. Ideally, each telescope would respond strongly to solar plasma in a narrow temperature range, and very weakly to plasma outside that range.

3. DESCRIPTION OF MSSTA OPTICAL SYSTEMS

The telescope throughput $\varepsilon_{tel}(\lambda)$ provides a means of discriminating between different spectral lines, and, thus, between structures at different temperatures in the solar atmosphere. If the throughput of a telescope includes only a small number of lines, temperature selectivity of that telescope will be high; if many lines are admitted, temperature selectivity will be low, and little temperature information will be contained in the image. There are two optical elements in each telescope that provide wavelength selectivity: the multilayer mirrors, which provide a narrow bandpass near the desired wavelength and a thin-film filter, which eliminates offband contamination from specular and high-order reflectivity in the multilayers, and may contribute to the sharpness of the primary bandpass. The overall throughput efficiency of the telescope is the product of the efficiencies of its elements, so that, for a dual-reflection telescope with a filter in place, we can write:

$$\varepsilon_{tel}(\lambda) = \varepsilon_p(\lambda)\varepsilon_f(\lambda)\varepsilon_r(\lambda),$$

where $\varepsilon_p$ is the reflectivity of the primary mirror, $\varepsilon_f$ is the reflectivity of the secondary mirror, and $\varepsilon_r$ is the transmission of the filter.

The multilayer coatings on the optical surfaces provide sharp bandpass throughput curves near the desired wavelength but admit significant amounts of contaminating radiation at wavelengths far from the primary bandpass. At wavelengths shortward of the primary bandpass, there are second- and higher-order bandpasses at integer harmonics of the desired wavelength, possibly admitting additional multiples of shorter wavelength lines. At wavelengths much longer than the primary bandpass, specular reflectivity of the coatings dominates the throughput curve; this admits contamination by all sufficiently long-wavelength solar emissions, including visible light (see Fig. 1). In the MSSTA telescopes, thin-film metal filters are used to block out this undesired radiation. The throughput function for each telescope, as defined in Eq. (6), is the product of the reflectivities of all mirrors and filters in the telescope. For the 173-Å telescopes, an additional improvement of spectral selectivity is gained by the use of aluminum in the filter: the aluminum L absorption edge at 171 Å effectively cuts the primary bandpass in half, improving the selectivity of the primary throughput peak.

Another method of improving the spectral selectivity of a multilayer telescope is to use the multilayer in second order. The ideal full-width at half-maximum of the second-order bandpass is half that of the first-order bandpass, because there are twice as many nodes in the standing wave pattern in second order. Thus, a 304-Å multilayer mirror with a $\lambda/\Delta\lambda$ of 20 can be used in second order as a 152-Å element, with a $\lambda/\Delta\lambda$ of roughly 40. There are two main drawbacks to using the second-order peak for the main bandpass: the lower peak reflectivity of the second-order bandpass; and the potential, in double-reflection telescopes, for band mismatch of the two mirrors caused by the narrower bandpass. These problems could be avoided by using a single-reflection (Herschelian) configuration, or by using a hybrid design in which one mirror is operated in second order, while the other is used in first order.

The bandpasses of the telescopes in the MSSTA were chosen so that the cluster would "see" a variety of spectral lines. Figure 2 shows the predicted reflectivity curves versus wavelength of the MSSTA multilayer telescopes. The curves for the Cassegrain and XUV Ritchey-Chrétien telescopes are based on multilayer reflectivities measured at the Stanford Synchrotron Radiation Laboratory in the spring of 1990, and theoretical filter throughputs. The curves for the Herschelian and FUV Ritchey-Chrétien telescopes are based on theoretical multilayer reflectivities and filter throughput.

4. TEMPERATURE RESPONSE

The utility of an image as a plasma temperature diagnostic is described by the kernel function (Eq. 5). As discussed earlier, we have sufficient information to evaluate the sum in Eq. (5) for each telescope, giving the kernel $K$ from Eq. (4), i.e., the telescope response versus plasma temperature. Figure 3 shows the temperature response kernels for the single- and double-reflection telescopes on the MSSTA.
As can be seen in Fig. 3, many of the actual temperature responses contain significant contributions from other temperatures than the desired one, because of the inclusion of multiple lines. Figure 4 illustrates how multiple lines can affect the response of a telescope: the 93.9-Å Herschelian telescope was designed to respond to the Fe XVIII line at 93.93 Å, which has peak emission at $5 \times 10^6$ K. However, two other classes of lines are also included in the bandpass: several Fe lines (primarily an Fe X line at 94.0 Å) which peak at $10^7$ K; and some Ne and Mg lines on opposite sides of the bandpass, which contribute to a peak at $5 \times 10^5$ K. This results in the trimodal response curve seen at bottom of Fig. 4.

The inclusion of many lines in a telescope’s bandpass does not necessarily result in poor temperature selectivity for the telescope. For example, consider the MSSTA 193 Å Ritchey-Chrétien telescope, for which the major spectral lines are shown in Fig. 5. There are at least 20 lines that contribute 2% or more of the overall response; however, since most of the lines peak at or near the same temperature, the response curve is still sharp, as seen at bottom of Fig. 5.

Temperature resolution can be considerably improved by reducing contamination during the design phase of a telescope. In general, adjusting the multilayer characteristics of a telescope affects the onband contamination, while modifying the filter characteristics changes the offband characteristics. For example, the 54.7-Å Herschelian telescope, as originally designed, had the temperature response shown in Fig. 6. The chosen line for the telescope was the Fe XVI line at 54.7 Å, which peaks at $3.0 \times 10^5$ K. However, there are several other lines in the bandpass, notably an Si IX line at 55.4 Å, which is stronger than the 54.7-Å line, and dominates the temperature response kernel of the telescope. Changing the width of the multilayer bandpass strongly affects the relative strength of the contaminant line in the temperature response kernel. The multilayer reflectivity $\epsilon_{\text{ref}}(\lambda)$ of the 54.7-Å telescope was fitted by two half-gaussians joined together at the center of the bandpass; then the full width half maximum $\Delta \lambda$ of the overall modeled bandpass was varied from 0.5 Å to 1.5 Å, and the resulting temperature response kernel was calculated for several values of $\Delta \lambda$. Figure 7 shows how small variations in the width of the bandpass can strongly affect the selectivity of the response kernel.

Even with telescopes that have significant contamination in the temperature response kernel, it is possible to generate images with high-temperature selectivity. After the flight, images from several telescopes can be combined through linear combination, to improve the composite temperature response kernel of the final image. For example, both the 193-Å and the 173-Å Ritchey-Chrétien telescopes on the MSSTA flight show some contamination from nearby oxygen lines. Each telescope has a temperature response kernel that peaks near $10^6$ K, with a subsidiary peak near $3 \times 10^5$ K. The 150-Å Ritchey-Chrétien has a similarly dual-peaked response kernel. By taking a linear combination of these three kernels, it is possible to produce a composite kernel that is much more sharply peaked at $10^6$ K than any of the original kernels; similarly, a different linear combination produces a relatively sharp peak at $3 \times 10^5$ K (see Fig. 8). Pointwise linear combination of images from separate telescopes in the same flight of the MSSTA can be used in this way to produce composite images with greater temperature resolution than an image from any single MSSTA telescope.

Clearly, alignment is crucial to this technique of combining separate solar images. Unless the solar images used in the final combination process are aligned to within less than the effective angular resolutions of the telescopes, the composite temperature response kernel will be poorly defined. For this technique to be successful, good knowledge of the separate telescopes’ orientations, resolutions, and plate scales are required.
5. CORONAL LOOPS

As an illustration of the MSSTA's utility as a plasma diagnostic tool, the response of the MSSTA to a variety of coronal features has been calculated. Figure 9 shows the theoretical temperature and density profiles of two coronal loops, calculated with the model of Vesecky et al. This example illustrates the ability of the MSSTA to distinguish between features of similar size, shape, and density, but with different temperatures and different coronal heating intensities. Both loops are symmetric arcs, extending $2.5 \times 10^9$ cm from footpoint to summit, with radius of curvature $3 \times 10^9$ cm and peak density $10^{10}$ cm$^{-3}$. Loop no. 1 is heated uniformly at $1.5 \times 10^{-3}$ erg s$^{-1}$ cm$^{-3}$ and loop no. 2 at $3.7 \times 10^{-3}$ erg s$^{-1}$ cm$^{-3}$, resulting in peak temperatures of $2.3 \times 10^8$ K and $3.0 \times 10^8$ K, respectively.

By fitting theoretically calculated telescope responses to data from digitized images, it will be possible to determine the actual temperature and density profiles of coronal loops, and to discern the magnitude of the coronal heating. Figure 10 shows the responses of the 193-Å and 304-Å Ritchey-Chrétien telescopes to the two theoretical coronal loops. Because these telescopes will resolve a few tenths of an arc second (0.1 arcsec $= 7.3 \times 10^6$ cm at 1 AU), all of the salient features of the response curves would be easily observed, providing a good temperature diagnostic. Temperature resolution may be further enhanced by the techniques outlined in the previous section.

It has been speculated that coronal loops are heated by many small impulsive events rather than by a steady energy input. If so, then images of loops may show a highly irregular and asymmetric brightness, depending on how the exposure time compares with the time scale of the impulsive heating mechanism. Because thermal conduction is so efficient, it is unlikely that the spatial dependence of coronal heating will significantly affect the shapes of the temperature and density curves given in the Fig. 9 example, unless the heating is highly localized, as in...
the impulsive heating model. Because the MSSTA telescope exposure time will be relatively short (on the order of a few seconds to a minute), the MSSTA should be able to distinguish between these two models of coronal loop heating.

6. CONCLUSIONS
The analysis of the response of the Ritchey-Chrétien, Cassgrain, and Herschelian telescopes to the solar spectrum indicates that we should meet our objective of obtaining high spatial resolution images that are dominated by emission from the coronal plasma in a narrow temperature range (by isolating XUV bandpasses corresponding to a single emission line or line multiplet) for most of our bandpasses. For those bandpasses that have a significant contribution from the plasma at more than one temperature, we have developed analytical techniques that can extract the single temperature response. The utility of this high-temperature resolution has been theoretically demonstrated with an example of coronal loop analysis.

7. ACKNOWLEDGMENTS
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Contributions to the Telescope Response Kernel of the MSSTA 54.7 Å Herschelian, vs. Plasma Temperature and Wavelength, with List of Significant Spectral Lines

<table>
<thead>
<tr>
<th>Ion</th>
<th>Wave length (Å)</th>
<th>Rel. Max.</th>
<th>log T</th>
<th>m peak</th>
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<td>55.36</td>
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<td>30.2</td>
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Temperature Response Kernel of the MSSTA 54.7 Å Herschelian (orig. design)

Fig. 6. Original telescope response kernel for the MSSTA 54.7-Å telescope. Note the double-humped shape of the curve, caused by on-band contamination of the desired Fe XVI peak (at roughly 3 million K) by Si IX. Note that the contaminant line actually dominates over the desired Fe XVI line.

Theoretical primary bandpass of the MSSTA 54.7 Å Herschelian telescope, for several values of Δλ

Theoretical Temp. Response Kernel of the MSSTA 54.7 Å Herschelian, for several values of the bandpass width Δλ

Fig. 7 Theoretical bandpasses and temperature response kernels for several values of the bandpass width Δλ in the 54.7-Å Herschelian. Note the dramatic differences in temperature selectivity that result from relatively small differences in the width of the bandpass.
Fig. 8. Linear combination of temperature response kernels for three Ritchey-Chrétien telescopes to produce two different composite response kernels. Each of the composite response kernels is more sharply peaked than any of the three original kernels, each of which is bimodal with a peak near $10^{5.0} \text{ K}$ and a peak near $10^{6.5} \text{ K}$. By selecting linear combinations of the kernels so that one peak was reduced and the other enhanced, more sharply peaked composite kernels were produced. The separate response kernels for the 150-Å, 173-Å, and 193-Å telescopes were multiplied by $-0.1$, $-0.7$, and $3.5$, respectively, and added and renormalized to produce the curve at the top. The curve at the bottom was produced similarly, but with coefficients of $10.0$, $1.6$, and $-5.0$, respectively.

8. REFERENCES


Troy W. Barbee, Jr.: Biography and photograph appear with the paper "Multi-Spectral Solar Telescope Array II: soft x-ray/EUV reflectivity of the multilayer mirrors" in this issue.

Richard B. Hoover: Biography and photograph appear with the guest editorial in this issue.

Biographies and photographs for other authors not available.
Multi-Spectral Solar Telescope Array IV: the soft x-ray and extreme ultraviolet filters

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Abstract. The multilayer mirrors used in the normal-incidence optical systems of the Multi-Spectral Solar Telescope Array (MSSTA) are efficient reflectors for soft x-ray/extreme ultraviolet (EUV) radiation at wavelengths that satisfy the Bragg condition, thus allowing a narrow band of the soft x-ray/EUV spectrum to be isolated. However, these same mirrors are also excellent reflectors in the visible, ultraviolet, and far-ultraviolet (FUV) part of the spectrum, where normal incidence reflectivities can exceed 50%. Furthermore, the sun emits far more radiation in the ultraviolet and visible part of the spectrum than it does in the soft x-ray/EUV. For this reason, thin foil filters are employed to eliminate the unwanted longer wavelength solar emission. With the proper choice of filter materials, the filters can also be used to eliminate EUV radiation at longer wavelengths, where the increasing specular reflectivity of multilayer mirrors and the high intensity of solar emissions can cause "contamination" of the image in the narrow band defined by the Bragg condition. In addition, filters can eliminate higher order multilayer reflections. Finally, filter absorption edges can sometimes be utilized to reduce the width of the primary bandpass. The MSSTA instrument uses various combinations of thin foil filters composed of aluminum, carbon, tellurium, potassium bromide, beryllium, molybdenum, rhodium, and phthalocyanin to achieve the desired radiation rejection characteristics. We discuss issues concerning the design, manufacture, and predicted performance of MSSTA filters.

Subject terms: x-ray/EUV optics; x-ray filters; x-ray windows; thin metal foils.


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1. INTRODUCTION

The wavelength-selective property of multilayer mirrors constitutes a powerful tool for astronomical observations of extreme ultraviolet (EUV) and soft x-ray sources. However, most astronomical soft x-ray/EUV sources are also luminous at other wavelengths [particularly in the far ultraviolet (FUV), ultraviolet (UV), and visible], where multilayer optics are unable to eliminate unwanted radiation. If the detector being used is sensitive at these wavelengths, then this radiation must be attenuated before it reaches the focal plane. In most cases, attenuation can be done by adding broadband filters to the optical path. In addition, with careful choice of filter materials, the same broadband filter can be used to reduce or to eliminate certain types of unwanted soft x-ray/EUV radiation (such as higher order multilayer reflections or contamination from longer wavelength EUV radiation that is specularly reflected by the multilayer optics). Due to the high absorption coefficients of most materials in the soft x-ray/EUV, these filters must be made extremely thin, typically less than 1 μm thick. Thin foils such as these, in the size range required (>100 mm²), necessitate special precautions in their manufacture, mounting, and use.¹ ²

The function of thin foil filters for use with soft x-ray/EUV multilayer optics can be loosely divided into four categories:

1. Eliminate visible, UV, and FUV radiation.
2. Reduce the contribution from specular reflection at wavelengths longward of the telescope bandpass.
3. Eliminate higher-order reflections from multilayer mirrors.
4. Make the primary bandpass narrower with the help of absorption edges.

To illustrate these functions, we look first at a representative astronomical soft x-ray/EUV source spectrum (the sun) and the characteristics of a typical multilayer mirror. Figures 1(a) through 1(c) show typical solar spectra as measured by Malinovsky and