0. Abstract

The X-Ray Telescope (XRT) is one of the instrument packages on-board the Hinode satellite observatory. This instrument can image the full solar disk, or a smaller area, in each of nine broadband X-ray passbands, with a resolution of about one arc-second and a grazing incidence telescope. With the inclusion of a coronal spectral model (as a function of temperature), thermal diagnostic analysis can be performed across a temperature range of log T = 5.5 to 8.0. Using the method of Singular Value Decomposition (SVD), we present an analysis to characterize the temperature discrimination capabilities of the XRT passbands when used as a set of observation vectors in a thermal diagnostic. We consider how the temperature diagnostic capability is uneven across the useful temperature range. This information could be used in designing thermal studies to increase the robustness of the temperature solutions, and in interpreting XRT data with physical models.

1. Introduction

The temperature response functions of the XRT passbands are broad and overlapping (Fig.1). These functions combine the broadband X-ray passbands, with a resolution of about one arc-second, using a modified grazing-incidence telescope. The temperature response functions of the XRT passbands are broad and overlapping (Fig.1). These functions combine the broadband X-ray passbands, with a resolution of about one arc-second, using a modified grazing-incidence telescope. The X-Ray Telescope (XRT) is one of the instrument packages on-board the Hinode satellite observatory. This instrument can image the full solar disk, or a smaller area, in each of nine broadband X-ray passbands, with a resolution of about one arc-second and a grazing incidence telescope. With the inclusion of a coronal spectral model (as a function of temperature), thermal diagnostic analysis can be performed across a temperature range of log T = 5.5 to 8.0. Using the method of Singular Value Decomposition (SVD), we present an analysis to characterize the temperature discrimination capabilities of the XRT passbands when used as a set of observation vectors in a thermal diagnostic. We consider how the temperature diagnostic capability is uneven across the useful temperature range. This information could be used in designing thermal studies to increase the robustness of the temperature solutions, and in interpreting XRT data with physical models.

2. Method

The XRT temperature response functions can be thought of as a linear mapping Rj between an "observation" vector of dimensionality Nv, where Nv is the number of T bins spanning the solution range (Fig.2). For this analysis, we chose Nv = 26. (It is not uncommon to choose bins of width 1/8 log T, and this nicely covers our range of log T = 5.5 to 8.0. We desire detail in our results, and we do not need to actually solve the under-constrained inversion problem in this analysis.)

The temperature response functions in x-ray channels are effectively treated as if their respective values of effective area with a model of solar coronal spectral model (as a thinning and thickest filters (i.e., saturation or zero counts). We consider how the temperature diagnostic capability is uneven across the useful temperature range. This information could be used in designing thermal studies to increase the robustness of the temperature solutions, and in interpreting XRT data with physical models.

3. Results & Discussion

Characterizing the Temperature Discrimination Capability of the X-Ray Telescope (XRT / Hinode)

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Figure 2. Response functions as a linear mapping between an "observation" vector space and a "DEM" vector space.

Figure 3. Four examples of the 26 "isothermal" DEMs. "Isothermal" DEMs were used as a set of observation vectors for the 26-dimensional "DEM space". Furthermore, 3 examples of DEM pairs are labeled (A, B, C) and can be found in Figure 4.

Figure 4. An example of the graphical plots with which we present our results. Shown is a color-coded symmetric matrix of DEMs for all pairs of isothermal DEMs, where j,k run from log T = 5.5 to 8.0 in 26 bins. The 3 coordinate points labeled (A, B, C) correspond to the 3 DEM pairs shown in Figure 3. The meaning of the color codes is given in Table 1 (below), and they indicate the confidence level at which XRT can distinguish that pair of temperatures.

Table 1. The Question: What is the difference between these plots?

- Temperature discrimination generally improves with increasing number of channels. We analyzed Δj,k for the baseline set of 9 single-filter channels, and for sets of 6, 4, and 2 filters.
- In practice, it is difficult to find isothermal plasmas in the corona along a line of sight. Even techniques of background subtraction are tricky to get right. Therefore we also analyzed Δj,k with extra background emission measure distributed across the temperature bins, to confuse the signals. The level of background emission measure we applied is expressed as a multiplicative of the emission measure contained in the "isothermal" DEMs.

- For small measurements, we estimate a minimum uncertainty of 5 DN.
- For large measurements, uncertainty is dominated by counting statistics.
- Note that smaller data sets are uncommon to choose bins of width 1/8 log T, and this nicely covers our range of log T = 5.5 to 8.0. We desire detail in our results, and we do not need to actually solve the under-constrained inversion problem in this analysis.)

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Details to be considered:
- XRT’s digitized measurements have a dynamic range of ~ 2000x.
- XRT’s exposure control has a dynamic range of ~ 1000x.
- The coolest temperatures, a DEM might not be observable in both the thinnest and thickest filters (i.e., saturation or zero counts).
- For large measurements, uncertainty is dominated by counting statistics.
- For small measurements, we estimate a minimum uncertainty of 5 DN.

(These are also the coordinate axis labels in Figure 4.)

A set of XRT observations can be used to solve the inversion of Eq.1 and thus derive the DEM, giving temperature and emission measure information about the observed solar plasma. However, the ability of XRT to "resolve" similar temperature profiles is subject to some complications:
- The inversion is ill-posed.
- The formal errors must be propagated.
- The DEM is often solved for more free parameters (i.e., temperature bins) than there are channels, making the problem underdetermined.

Therefore, the ability to perform T diagnostics is sensitive to the ability to distinguish between similar observations. In this paper, we investigate XRT’s temperature discrimination capability by looking at the separation of observation vectors as a function of the plasma T observed.

Figure 1. XRT temperature responses in x-ray passbands. Channel names correspond to selection of the diagnostic filters.

Figure 3. Four examples of the 26 "isothermal" DEMs. "Isothermal" DEMs were used as a set of observation vectors for the 26-dimensional "DEM space". Furthermore, 3 examples of DEM pairs are labeled (A, B, C) and can be found in Figure 4.

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