Abstract.

We analyze a composite broad-band optical/UV/X-ray spectrum of the Seyfert 1 galaxy NGC 5548. The spectrum consists of an average of simultaneous optical/IUE/Ginga observations accompanied by ROSAT and GRO/OSSE data from non-simultaneous observations. We show that the broad-band continuum is inconsistent with simple disk models extending to the soft X-rays. Instead, the soft-excess is well described by optically thick, low temperature, thermal Comptonization which may dominate the entire big blue bump. This might explain the observed tight UV/soft X-ray variability correlation and absence of a Lyman edge in this object. However, the plasma parameters inferred by the spectrum need stratification in optical depth and/or temperature to prevent physical inconsistency. The optical/UV/soft X-ray component contributes about half of the total source flux. The spectral variations of the soft-excess are consistent with that of the UV and argue that the components are closely related. The overall pattern of spectral variability suggests variations of the source geometry, and shows the optical/UV/soft X-ray component to be harder when brighter, while the hard X-ray component is softer when brighter.

INTRODUCTION

NGC 5548 is one of the brightest Seyfert 1 galaxies with optical/UV/X-ray continuum consisting of three characteristic components: the big blue bump, the soft-excess, and the hard X-ray thermal Comptonization continuum with the reflection hump. These components are known to be highly variable, but there have been no observing campaigns covering all of them simultaneously. The only simultaneous IUE/Ginga campaign (Clavel et al. 1992; Nandra et al. 1993) showed a tight correlation between the UV bump and hard X-ray
component, thus supporting UV/X-ray reprocessing models. Recently, Marshall et al. (1997) have found a correlation between the UV and the soft X-ray component which suggests that the soft-excess also participates in the reprocessing. We analyze a composite broad-band optical/UV/X\(\gamma\) spectrum in order to develop a continuum model and apply it to re-analyze the variability correlations in a simultaneous sub-set of available \textit{IUE/Ginga} observations.

**FIGURE 1.** The intrinsic (i.e., after the effect of Galactic absorption at the soft excess and optical/UV reddening have been removed) broad-band composite optical/UV/X\(\gamma\) spectrum of NGC 5548. The top panel shows the data and fitted model. The spectrum consists of an average over the simultaneous sub-set of optical/\textit{IUE/Ginga} data supplemented with non-simultaneous average \textit{ROSAT} and \textit{GRO/OSSE} observations. The non simultaneous data were fitted with free normalizations and renormalized on the figure. The bottom panel shows a deconvolution of the spectrum into continuum components. The dot-short-dashed and the short-dashed curves show the disk and the soft-excess component respectively. The long-dash and the dotted (in top panel) curves show the thermal Comptonization coronal spectrum and the reflection component respectively. The solid curve gives the resulting model. The dot-long-dash curve shows the disk component fitted to the optical/\textit{IUE} data alone. The energy scale is in the source frame.
BROAD-BAND SPECTRUM AND VARIABILITY

The optical/IUE and Ginga data come from the simultaneous sub set of the Jan. 1989–July 1990 campaign reported by Clavel et al. (1992) and Nandra et al. (1991) respectively. The ROSAT data is an average spectrum over a monitoring campaign of Dec. 1992–Jan. 1993 (Done et al. 1995). The GRO/OSSE data were compiled by McNaron-Brown et al. (1997, in preparation) from Phase 1 and 3 observations. We use the Ginga data from both the top-layer and mid-layer of the LAC detector. The mid-layer gives more effective area in the 10–20 keV range which is crucial for determining the Compton reflection component. That layer had previously been ignored due to problems with background subtraction.

Broad-band Continuum

We find the average spectra from non-simultaneous observations to be consistent within statistical discrepancies with that from the simultaneous campaign. However, the results have to be treated carefully since the averaging of the highly variable spectrum produces very wide confidence limits. The soft-excess component contributes significantly up to an energy $\sim 2$ keV (Fig. 1a) which is marginally observed in the Ginga data. As was shown by Fiore, Matt, and Nicastro (1997), this component can not be simply explained by atomic processes. The GRO/OSSE spectra are consistent with a constant high energy cut-off at about 100 keV, and no variations of the spectral shape. This gives Comptonizing plasma parameters of $kT_{HC} \sim 50$ keV and $\tau \sim 2$, consistent with those typical of Seyfert 1s (Zdziarski et al. 1997). Our re-analysis of the ROSAT campaign shows that the average data well constrain the soft-excess spectral index, $\Gamma = 2.1^{+0.3}_{-0.2}$, but do not constrain the energy cut-off. This, however, is well established at $E_{SE} = 0.6 \pm 0.1$ keV from Ginga observations. The average IUE data well constrain both the reddening of the spectrum $E(B-V) = 0.03 \pm 0.01$, and the maximum disk temperature $kT_d = 3.2 \pm 0.2$ eV. This argues against the high temperature disk (in agreement with Laor et al. 1997).

It is energetically possible for the entire blue bump (the dot-long-dash curve in Fig. 1b) to arise from reprocessing of the hard continuum assuming the X/$\gamma$ source forms a patchy corona above the surface of the disk. However, the nature of the soft excess remains unclear in such a model and it is hard to explain the tight correlation in simultaneous IUE–EUV observations (Marshall et al. 1997). On the other hand, extrapolation of the ROSAT soft X-ray power-law points exactly to the UV component, suggesting a Comptonization origin. Then the blue bump turns out to be dominated by Comptonization (the short-dash, and the dot-short-dash in Fig. 1b), and contains about half the total flux. However, Comptonizing the disk component by a hypotheti-
cal cold plasma requires an extreme optical depth (τ\sim 30), which needs to be explained by stratification of temperature and optical depth (Nandra et al. 1995).

**FIGURE 2.** Correlation between the total flux emitted in the X/γ hard continuum with (a) photon spectral index, and (b) amount of reflection (Ω/2π). When the source is brighter, it shows a softer spectral index and larger solid angle of cold matter intercepting the hard continuum.

**FIGURE 3.** Correlation of (a) the total flux emitted in the soft-excess, and (b) the cut-off energy of the soft-excess component with the total flux emitted in the X/γ hard continuum. The total flux emitted in the soft excess is positively correlated with that from the hard continuum, while the cut-off energy of the soft excess remains constant. The soft excess is modeled by a cut-off power-law with the spectral index frozen at Γ=2.2 (cf. Walter & Fink 1993). The plotted F_{SE} flux is the soft excess flux multiplied by a model dependent constant, A.
Variability Correlations

The hard X-ray continuum shows significant correlation between the total flux changes and the spectral index and amount of reflection (Fig. 2a, b). Such a pattern of spectral variability suggests changes in the source geometry which produce more reflection when the source is brighter and softer. The total X/γ flux is correlated with the total optical/UV flux (cf. Nandra et al. 1993), but the energy balance is dependent on the spectral model assumed. The soft excess component required by the Ginga data seems to vary in a correlated fashion with the total flux emitted by the X/γ continuum (Fig. 3a). The cut-off energy of the soft-excess is consistent with being constant over the hard continuum changes (Fig. 3b). The above results suggest that the soft-excess component is related to reprocessing. Marshall et al.’s (1997) results suggest much higher variability amplitude in the EUV than in the UV. Hence one should expect variability in the soft-excess spectral index, which is consistent with the overall ‘harder when brighter’ variability pattern in the optical/UV, but opposite to the ‘softer when brighter’ pattern in the hard X/γ continuum.

CONCLUSIONS

We have shown that the soft-excess component in NGC 5548 may contribute to the energy reprocessing and its variability behavior is consistent with that of the big blue bump. The soft-excess is consistent with optically thick Comptonization, probably in a complex, stratified plasma. If the soft-excess is actually related to optically thick Comptonization, the entire big blue bump and the soft-excess may be dominated by the same component. This would explain both the tight IUE–EUV correlation (Marshall et al. 1997), and the absence of a Lyman edge in the UV spectrum (Kriss et al. 1997).

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