Variability of the UV/Soft X-ray Continuum in NGC 5548

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Abstract. We present a broad band spectral model of the intrinsic continuum in the Seyfert 1 galaxy NGC 5548, based on analysis of available archival data from optical, *IUE*, *ROSAT*, *Ginga*, *ASCA*, and *GRO*/OSSE observations. We use the model as a framework to interpret correlated variability in the different observing bands. Variability in this source suggests a dominant role of the UV/soft X-ray component in the formation of the overall spectral phenomenology, and a complex, multiphase accretion flow near the black hole.

1. The Overall Spectral Energy Distribution

Fig. 1 shows an average continuum spectral energy distribution of NGC 5548 compiled from simultaneous, archival optical, *IUE*, and *Ginga* data, along with non-simultaneous *ROSAT* and *GRO*/OSSE data. After accounting for the iron Kα line and Compton reflection hump, we have decomposed the spectrum into three basic continuum components: *a cool* (< 5 eV) *multitemperature accretion disk* contributing to the optical/UV, *a hot* (~ 50 keV) *Comptonizing corona* producing the hard X-ray power law, and *a warm* (~ 0.3 keV) *optically thick Comptonizing medium* producing UV, EUV, and soft X-ray emission. The last component is reminiscent of models of the soft X-ray excess which invoke thermal Comptonization in the inner regions of the accretion disk (e.g. Czerny & Elvis 1987; Maraschi & Molendi 1990). Variability in the three spectral components suggests to us, however, that the geometry may be more complex: a multiphase inner region of the accretion flow, which might arise from instabilities.

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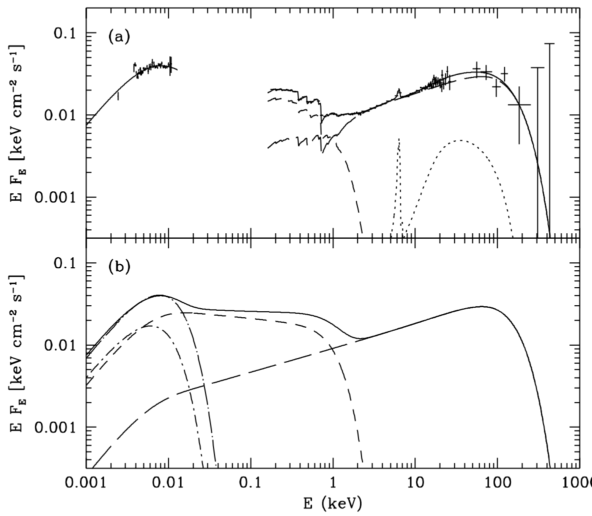

Figure 1. The intrinsic broad band average spectrum of NGC 5548 (Magdziarz et al. 1998). Panel (a) shows the data and fitted model, and panel (b) shows the decomposition into the main spectral components. The dot-short-dashed, short-dashed, long-dashed, and dotted curves show the disk, soft excess, thermal Comptonization X/γ continuum, and reflection components, respectively. The dot-long-dash curve shows the disk component fitted to the optical/*IUE* data separately.

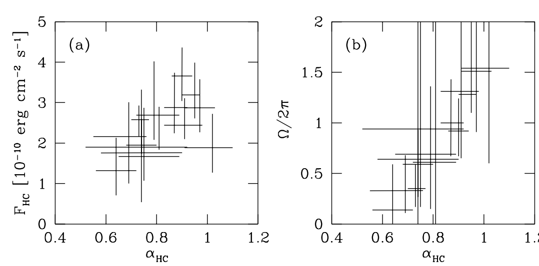

Figure 2. Correlation between the energy spectral index of the hard X/γ continuum and (a) its total flux emitted, and (b) the amount of reflection, i.e. the solid angle of cold matter seen by the X/γ source. When the source is brighter, it shows a softer hard X-ray spectral index and larger solid angle of cold matter intercepting the hard continuum (Magdziarz et al. 1998).

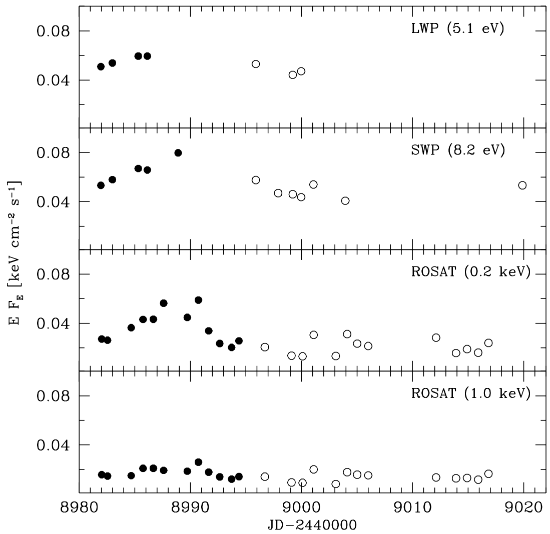

Figure 3. *IUE* and *ROSAT* light curves during the Dec. 1992 - Jan. 1993 monitoring campaign (Done et al. 1995). The quiescent period is marked by open circles, while the filled circles represent the active period when the *ROSAT* spectrum was significantly brighter and softer.

2. Correlations Between Spectral Components

We used the broadband spectral model to characterize the variability observed in this source from simultaneous optical, *IUE*, and *Ginga* data (Magdziarz et al. 1998). The three components tend to be correlated in flux, in the sense that if one brightens, so do the other two.

When the hard X-ray spectrum brightens, it gets softer (Fig. 2a) and the fractional flux in the Compton reflection hump increases (Fig. 2b). This can be interpreted as an increase in the solid angle of the reflector as seen from the X-ray source. Similar trends have been seen in Galactic X-ray transients (e.g. Nova Muscae: Życki, Done, & Smith 1998). When the optical/UV spectrum gets brighter, it gets harder. This is consistent with an interpretation of this component as being due to a somewhat cool accretion disk whose spectrum is turning over in this region (e.g. Krolik et al. 1991; Molendi, Maraschi, & Stella 1992), implying that the disk emission cannot contribute significantly to the soft X-ray region.

We have also recently reanalyzed the simultaneous *IUE*/*ROSAT* data from the Dec. 1992 – Jan. 1993 monitoring campaign (Done et al. 1995) to better characterize the variability of the EUV/soft X-ray excess. The source exhibited a bright "flare" during the early part of this campaign, which we refer to henceforth as the active period (Fig. 3). We refer to the faint state of the source in the later part of the campaign as the quiescent period. The character of the X-ray variability seems to be the same both in the quiescent period and in the active

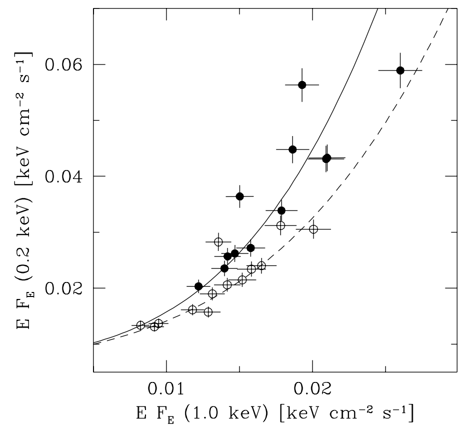

Figure 4. Correlation between the *ROSAT* hard (0.4-2.5 keV) and soft (0.1-0.4 keV) energy bands. The filled and open circles are the same as in Fig. 3. The dashed and solid lines show fits to the correlation assuming a linear relation between the spectral index and the total flux in the hard X-ray component (cf. Fig. 2a). Larger variations of the spectral index with respect to changes in the flux occur during the active period, suggesting a stronger radiative coupling between the seed photons and the Comptonizing hot plasma.

period, when the X-ray source is softer. However, the active period appears to require a stronger coupling between the flux and the spectral index (Fig. 4). This is also reflected in the UV, where the temperature-flux correlation appears to be absent in the faint, quiescent period (Fig. 5).

The UV flux is linearly correlated with the soft excess (Fig. 6) which suggests that a dominant part of the variability comes from the same component (cf. Fig. 1). The correlation shows that the soft excess is significantly more variable than the UV component (cf. Marshall et al. 1997) which contains some constant, or significantly less variable emission. The *ROSAT*/*IUE* simultaneous spectra in the epochs MIN and MAX marked in Fig. 6 suggest that in the bright epochs the UV spectrum may have a significant contribution from the low energy tail of the soft excess component while in the faint epochs the UV is dominated by the cold disk component. Assuming a simple thick Comptonization model for the soft excess (Fig. 1), the spectral variations in the soft excess may be explained by effective changes in optical depth by a factor ~ 1.5.

3. The Source Picture

The overall spectral behavior suggests that the variability mechanism is related to changes in the geometry of the continuum emitting regions, and an excess in the amount of reflection ($\Omega/2\pi > 1$; Fig. 2b) *requires deviations from a simple*

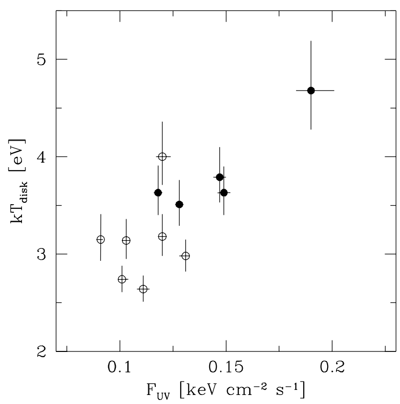

Figure 5. Correlation between the total UV flux emitted by the disk and its temperature. The fits assume that the total flux observed by *IUE* comes from the disk component. The filled and open circles are the same as in Fig. 3. The correlation appears to be defined entirely by the active period (filled circles).

plane disk picture. Variations in the hard spectral index can then be explained by increased cooling of the hot plasma due to an increased number of seed photons. One possibility is that variations in the source geometry are caused by a breakup of the inner regions of the cool disk into a much hotter, more rarefied flow. Thermal/viscous instabilities could lead to an inhomogeneous disk consisting of cool clouds surrounded by an intercloud medium (Krolik 1998). Fragmentation modes could lead to a separation of the photon and the matter field on scales comparable to the disk height (Gammie 1998).

Reprocessing by clouds in a complex fragmented medium could conceivably give rise to the energetically important soft excess (Kuncic, Celotti, & Rees 1997). This reprocessing in the fragmented part of the disk might then explain the dramatic UV/soft X-ray variability. Since the low energy tail of the emission from the fragmented matter may contribute a comparable flux to the UV continuum as the less variable cold disk, the dynamical evolution in the disk may lead in some epochs to radiative decoupling between the components and significant time delays (as observed, e.g., in NGC 7469; Nandra et al. 1998). Such a complex, Comptonized UV component might also explain why there is no Lyman edge feature observed in NGC 5548 (Kriss et al. 1997).

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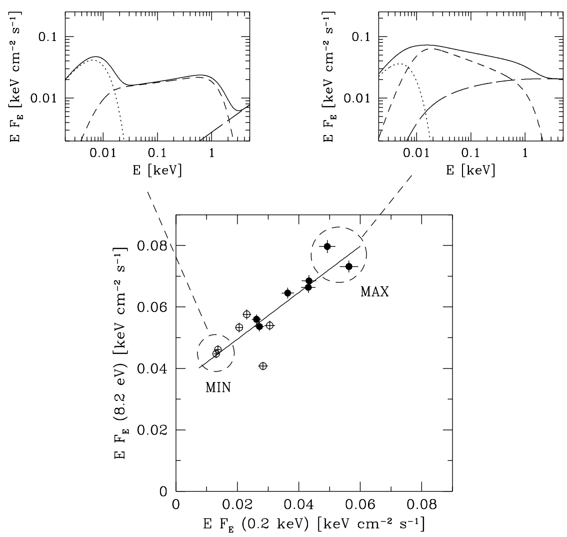

Figure 6. Correlation between the fluxes emitted in the *ROSAT* soft (0.1-0.4 keV) and *IUE*/SWP (6.3-10.7 eV) energy bands. The filled and open circles are the same as in Fig. 3.

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