X-ray/γ-ray spectra of Cygnus X-1 from *Ginga* and OSSE and their theoretical implications

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Abstract

We present the results of 4 simultaneous observations of Cygnus X-1 by *Ginga* and OSSE. The X-ray/γ-ray spectra can be described by an intrinsic continuum and a component due to Compton reflection including an iron Kα line. The intrinsic spectrum at X-ray energies is a power law with a photon spectral index of $\Gamma \approx 1.6$. However, the broad-band intrinsic spectrum cannot be described in terms of neither an exponentially cut-off power law, nor thermal Comptonization. Some distribution of plasma temperature and optical thickness is required. We have found a good approximation of the intrinsic continuum by a two-temperature model in which emission comes predominantly from the optically thin ($\tau \sim 0.4$) plasma of $kT_e \sim 150$ keV, with an addition from optically thick plasma of $kT_e \sim 50$ keV.

1. Observation

Cygnus X-1 was observed several times by *Ginga* and OSSE on July 6, 1991. Observation periods from both instruments overlap in time, providing us with four sets of simultaneous data of excellent quality. The *Ginga* spectrum can be approximated by an intrinsic power law of photon index $\Gamma \approx 1.6$, and a Compton reflection feature with the covering factor of the reflecting medium, $R \approx 0.34$. We assumed the disk inclination angle of 30°. This component includes the iron $K\alpha$ line of the mean equivalent width 75 ± 19 eV. OSSE data can be excellently described by a power-law function ($\Gamma \approx 1.3$) with exponential cutoff (e-folding energy, $E_f \approx 150$ keV). Thermal Comptonization model can approximate the OSSE data as well. The plasma temperature was found ~ 80 keV, and optical depth, τ, around 0.9.

2. Broad-band spectra

Though we found excellent models to *Ginga* and OSSE data alone, the broad-band spectrum of Cygnus X-1 in 2-1000 keV range is not consistent with any single-temperature plasma model. This might be due to some distribution of plasma temperature and optical thickness in the emitting region. We have approximated that distribution with a two-temperature plasma. The dominant component of this model is a simple, exponentially cut-off power law with Compton reflection and a Gaussian line at 6.4 keV. The photon spectral index, $\Gamma \approx 1.6$ is similar to that obtained from the *Ginga* data alone, and the e-folding energy, E_f is ~ 250 keV. Cut-off power law can be regarded as a good approximation of the emission from the hot, optically thin plasma. We have compared it to the Monte Carlo simulations and found the plasma temperature, $kT_e \sim 150$ keV and optical thickness, $\tau \sim 0.4$. However, this model requires an additional component, peaking around 200 keV, in order to obtain a good fit. This secondary element can

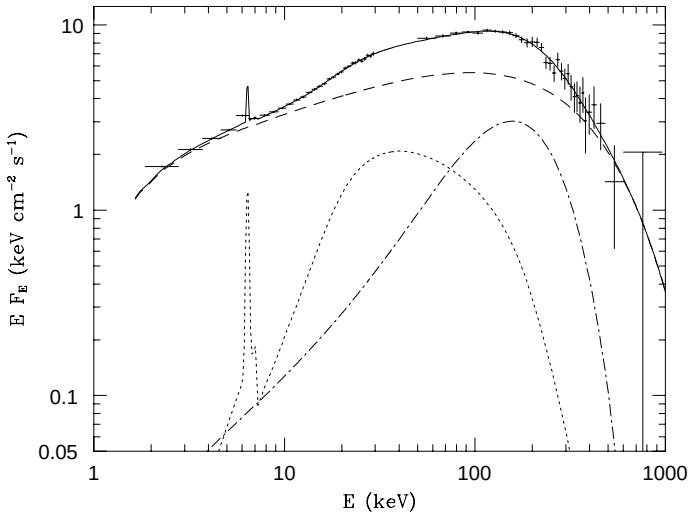

Fig. 1. The two-temperature model for the *Ginga*/OSSE data set number 1. The dashed curve represents the main, exponentially cut-off power-law component, the dotted curve—a disk reflection continuum, and the dash-dotted curve—the additional thermal Comptonization component. Solid curve shows the sum.

be represented by a thermal Comptonization from the optically thick plasma (Lightman and Zdziarski 1987). The plasma temperature found was ~ 50 keV, and the optical depth, $\tau' \sim 7$. Figure 1 shows the resulting fit with model components specified.

3. Conclusions

The observed spectra of Cygnus X-1 cannot be described neither by an exponentially cut-off power law nor by thermal Comptonization model (Titarchuk 1994). We suggest that some distribution of plasma temperatures and optical thickness exist in the emitting region. The two-temperature model fits data very well. In this model X-ray and γ-ray emission comes predominantly from the optically thin ($\tau \sim 0.4$) plasma with temperature ~ 150 keV, with some addition from the thick plasma ($\tau \sim 7$) with temperature ~ 50 keV. We have shown that Compton reflection feature, reported before as a "high enegy excess" (Done et al. 1992), constitutes a hump, peaking around 30 keV, and can be attributed to the reflection of the Comptonized emission from the accretion disc. The reflection continuum is accompanied by an Fe Kα fluorescence line. According to the most recent ASCA observations (Ebisawa et al. 1996) the line is very narrow ($1\sigma < 0.2$ keV). This can be explained assuming that reflected component comes from the outer part of the disk.

4. References

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