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Ultrasoft Narrow-line Seyfert 1 Galaxies: An Extreme of Accretion onto Supermassive Black Holes

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Abstract. X-ray studies of ultrasoft narrow-line Seyfert 1 galaxies are revealing surprising new phenomena that are expanding our understanding of Seyfert activity, and they may well allow us to observe the effects of high mass accretion rates onto supermassive black holes. I briefly review the basic properties of these galaxies, their importance in a general context, and the prospects for studying them further in the future.

1. Introduction and Observed Properties

Ultrasoft narrow-line Seyfert 1 galaxies (hereafter NLS1) are a class of Seyferts showing extreme X-ray and optical properties. Their most notable property in the X-ray band is their extremely strong and hot soft X-ray excess components. These have a quasi-thermal spectral shape and can dominate the X-ray spectrum up to ≈ 1.5 keV. They are rapidly variable, and they are thought to be associated with the inner accretion disk. However, the effective temperature of the soft X-ray excess can range up to ≈ 1 million K, hotter than expected for simple thermal radiation from a standard accretion disk. Compton scattering and relativistic effects probably modify the shape of the soft X-ray excess.

Like "classical" hard X-ray selected Seyfert 1s, ultrasoft NLS1 show power-law continua from 2–10 keV. However, these power laws are often substantially steeper than for hard Seyfert 1s; power-law photon indices in the range $\Gamma = 2.1$–2.5 are commonly seen (hard Seyfert 1s typically have $\Gamma = 1.7$–2.0). Strong soft excesses and steep (2–10 keV) power laws make the broad-band X-ray continua of ultrasoft NLS1 reminiscent of those of "high state" Galactic black holes. Studies of broad-band X-ray continua also reveal that many ultrasoft NLS1 emit the bulk of their X-ray power below 1 keV. This has important implications for X-ray reprocessing scenarios; it appears unlikely that the soft X-ray excesses in these objects are made by the reprocessing of hard power-law photons.

Many ultrasoft NLS1 also show extremely rapid and large-amplitude X-ray variability, and the most dramatic examples of Seyfert X-ray variability have been found among these objects. It has been established that ultrasoft NLS1 show statistically enhanced X-ray variability compared to hard Seyfert 1s of matched luminosity (on timescales of ~ 0.1–1 days). The variability sometimes appears to be nonlinear or non-Gaussian, with relatively steady states being punctuated by large outbursts. This is important because it argues against the idea that the variability is produced by the simple linear superposition of a large number of independent flares. In a few cases, the variability has been so extreme that relativistic X-ray flux boosting appears to be implicated.

Finally, ultrasoft NLS1 have distinctive optical spectra with unusually narrow permitted lines (e.g., Hβ FWHM $\sim$ 500–2000 $\mathrm{km\,s^{-1}}$). They also often show strong optical Fe II emission and weak O III emission.

2. Importance in a General Context

X-ray missions such as *ROSAT* have established that ultrasoft NLS1 are a significant part of the Seyfert population. They comprise about 30% of soft X-ray selected Seyferts at low redshift, and > 150 new members of this class have been found over the past few years in *ROSAT* follow-up studies. About 1000–2000 are thought to have been detected in the *ROSAT* All-Sky Survey, and ultrasoft NLS1 are found over a wide range of luminosity up to quasar levels. Thus, to understand the Seyfert population as a whole, we must understand not only the "classical" hard X-ray selected Seyfert 1s but also the ultrasoft NLS1. As described above, studies of ultrasoft NLS1 directly show that there is more X-ray spectral diversity among Seyferts than was previously recognized.

Furthermore, the extreme spectral and variability properties of ultrasoft NLS1 appear to arise from an extreme value of a primary physical parameter, perhaps mass accretion rate relative to the Eddington rate ($\dot{M}/\dot{M}_{\rm Edd}$). If we can establish that ultrasoft NLS1 indeed have high $\dot{M}/\dot{M}_{\rm Edd}$, we will have gained a way to gauge the *primary driver* of these accretion powered sources. A high value of $\dot{M}/\dot{M}_{\rm Edd}$ would help to explain the high observed soft X-ray excess temperatures, and by analogy with "high state" Galactic black holes it might also explain the steep 2–10 keV power laws. Enhanced X-ray variability at a given luminosity could also arise from high $\dot{M}/\dot{M}_{\rm Edd}$ since the black hole mass and emission region size would be smaller. However, the analogy with "high state" Galactic black holes is not present for variability ("high state" Galactic black holes tend to vary less, not more), and it is not clear why a high $\dot{M}/\dot{M}_{\rm Edd}$ would lead to nonlinear, non-Gaussian variability and relativistic flux boosting. A high $\dot{M}/\dot{M}_{\rm Edd}$ can explain the narrow optical lines if the Broad Line Region clouds are virialized and the Broad Line Region size is mainly a function of luminosity. While it has not yet been firmly established that ultrasoft NLS1 indeed have high $\dot{M}/\dot{M}_{\rm Edd}$, there is suggestive evidence and it is clear that research along these lines is driving our understanding of Seyferts.

3. Future Prospects and Additional Information

The next generation of X-ray observatories should allow great advances in the study of ultrasoft NLS1. These observatories will provide the first high-resolution spectra of the energetically dominant soft X-ray excess, allowing detailed modeling of the primary radiation source. They will also perform high-quality studies of spectral features (e.g., broad iron Kα lines) as well as precision flux and spectral variability studies.