Optical Observations of the ULX in NGC 6946

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Abstract

We present optical spectroscopic observations of the brightest ultraluminous X-ray source (ULX), ULX4, in NGC 6946 (associated with optical source MF16). Some 50 lines are identified, almost double the number of any previous study. The 3100-9360 Å spectrum, obtained via Keck long-slit spectroscopy, is dominated by emission lines, suggesting that we are observing a circum-source nebula or the accretion disk rather than the companion star. The emission lines include not only low-excitation lines, but high-ionization lines such as the emission-line pair [Ne V] 3346, 3426, and the emission lines [Ne III] 3869, N V 4604, He II 4686 and [Ar IV] 7171. The photoionizing luminosity of 5×10^{39} erg/s necessary to create the He II 4686 line rules out the beaming scenario. Thus, NGC 6946 ULX4 is truly ultraluminous; it can either be an intermediate-mass BH or a stellar-mass BH with super-Eddington flows.

Key words: accreting objects: primary and reprocessed emission — black hole physics — workshop: proceedings

1. Introduction

Ultraluminous X-ray sources (ULXs, Makishima et al. 2000) are non-nuclear point X-ray sources with X-ray luminosities intermediate between those of stellar mass black holes and supermassive black holes. If accretion onto these ULXs obeys the Eddington limit, they could be a new class of intermediate-mass black holes (100-1000 $M_\odot$).

NGC 6946 is a nearby (5.5 Mpc, Tully 1988), nearly face-on spiral galaxy, containing five ULXs, the brightest of which is ULX4. On 2005 May 11 UT, a spectrum of NGC 6946 ULX4 was obtained using the Low Resolution Imaging Spectrometer on the Keck 1 10-meter telescope on Mauna Kea, Hawaii, USA. The observation details are summarized in Table 1. Though there are several sources within the *Chandra* raw position error circle of 0.6″, the slit was positioned on the source singled out by the corrected position error circle of 0.4″. The spectral resolution was ~ 6 Å (as measured from the FWHM of sky emission lines).

Table 1. Observation Log for NGC 6946 ULX4

Parameter	Value
UT Date	2005 May 11
Exposure (s)	300
Airmass	1.34
Slit Position Angle (deg.)	205
Parallactic Angle (deg.)	201
Slitwidth (″)	1
Seeing (″)	0.6

2. Discussion

The spectrum of NGC 6946 ULX4 is presented in Figure 1. Of the ∼50 lines identified, we will concentrate on He II 4686 in this discussion.

2.1. He II 4686

This line is formed in or close to the accretion disk (assumed to be a multicolour disk blackbody; i.e., one of the components of the best-fit model in Roberts & Colbert 2003) around the black hole.

The He II 4686 line luminosity found here is 1.3×10^{37} erg/s. This is about two orders of magnitude greater than that observed from a similar nebula around the black hole candidate LMC X-1 (Pakull & Angebault 1986), and a factor of five higher than in the Holmberg II X-1 ULX (Kaaret, Ward, & Zezas 2004) suggesting that NGC 6946 ULX4 contains a much more powerful soft X-ray/far UV source.

He II 4686 is a recombination line, entailing that a He^+ ion in its ground state has become photoionized by a single Lyman continuum (E > 54.4 eV, $\lambda < 228$ Å) photon; the resulting He^{++} ion recombines with an electron resulting in the emission of a (n=4 → n=3) λ=4686 Å photon. The line thus acts as a photon counter of the original Lyman photons. Because two luminosities (He II 4686 and the total Lyman luminosities) are being compared, the distance factor "cancels out"; this line is a way of ruling out the beaming scenario for ULXs.

2.2. Cloudy Simulations

Cloudy is a photoionization code that calculates the recombination processes (first order effects) but also takes into account second order effects. Given the measured He II luminosity, calculations were performed with version 07.02 of Cloudy, last described by Ferland et al. (1998) in order to find the luminosity of the original Lyman continuum.

We used and obtained the following parameters:

- The hydrogen density was kept fixed at log (nH)(cm^{-3})=2.60 (BFS01).
- We used the solar (default) abundance set in Cloudy, with a metallicity of 0.75 we determined using the abundance diagnostics in Kewley & Dopita (2002) e.g., log([N II] 6583/[O II] 3726). Changing the metallicity by a factor of 10 only changes the flux by a factor of 0.25.
- We defined the geometry of the nebula to be spherical with an outer radius of 5 parsecs. This radius was chosen to match optical narrowband images.
- We also required that the radial profiles (flux as a function of distance from the center of the nebula) of the lines match the input radius, rather than getting absorbed in the outer part of the nebula. The filling factor that allowed for this was 0.17.
- We further refined the model by requiring the Cloudy run to reproduce the observed ratio of [Ne V] 3426/He II 4686, within errors. The neon to helium ratio was chosen because it is likely to be sensitive to photoionization (as opposed to [O III] 5007/Hβ 4861, which is more likely to have some shock-ionized component). This model is within error of the observed value of [Ne V] 3426/He II 4686=$1.3^{+0.3}_{-0.2}$.

To summarize, a number of simulations were run until a photoionizing luminosity and temperature was found that came closest to reproducing our observed He II luminosity. The model we obtained was a multi-colour disk blackbody continuum of log L(erg/s)=39.66±0.09 and log T(K)=5.70.

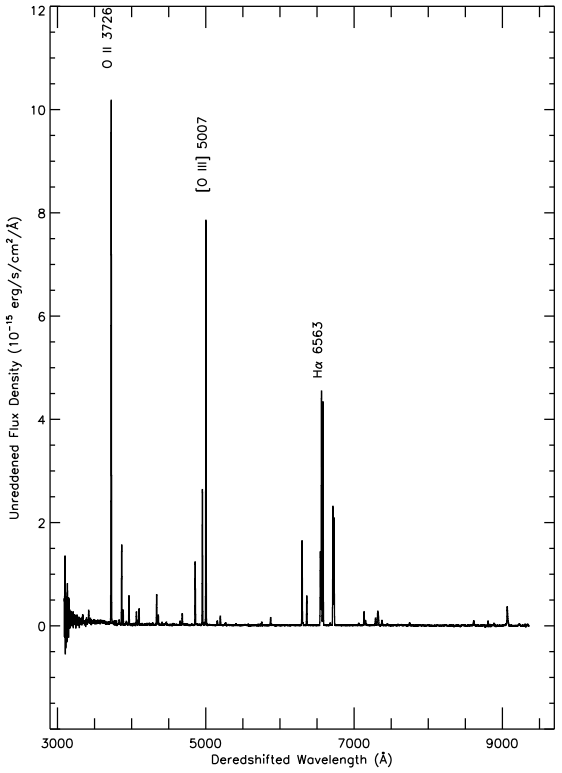

Fig. 1. Keck LRIS spectrum of NGC ULX4 as a function of deredshifted wavelength. Some emission lines are labelled. Note that there is very little continuum. Some 50 lines are identified, almost double the number of any previous study.

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