Spectroscopic Observations of the Mass Donor Star in SS 433

Kaori Kubota[1], Yoshihiro Ueda[1], Sergei Fabrika[2], and Elena Barsukova[2]

[1] Department of Astronomy, Kyoto University, Kyoto 606-8502, Japan
[2] Special Astrophysical Observatory, Nizhnij Arkhyz, Karachaevo-Cherkesiya 369167, Russia
E-mail(KK): Kaori.k@kusastro.kyoto-u.ac.jp

Abstract

We present the results of optical spectroscopic observations of the mass donor star in SS 433 with Subaru and Gemini. Subaru/FOCAS observations were performed on 4 nights of 2007 October, covering the orbital phase of $\phi \approx 0$. We calculate cross correlation function of these spectra with that of the reference star HD 9233 in spectral regions that are selected to avoid "strong" absorption lines accompanied with contaminating emission components. The same analysis is applied to the archive data of Gemini/GMOS by Hillwig and Gies (2008). From the Subaru and Gemini CCF results, the amplitude of radial velocity curve of the donor star is determined to be 56.7±3.7 km s^{-1} with a systemic velocity of 61.3±2.5 km s^{-1}. Combining with the radial velocity of the compact object, we derive the mass of the donor star and compact object to be $M_{\rm O} = 12.2^{+2.3}_{-2.1}$ $M_\odot$ and $M_{\rm X} = 4.1^{+0.8}_{-0.7}$ $M_\odot$, respectively. However, these values should be taken as *upper limits* if we consider the heating effects (Kubota et al. 2009). We conclude that the compact star in SS 433 is most likely a low mass black hole, although the possibility of a massive neutron star cannot be firmly ruled out.

Key words: accretion, accretion disks — stars: individual (SS 433)

1. Introduction

The microquasar SS 433 is a target of great interest in modern astronomy as a unique Galactic source that shows steady relativistic ($v = 0.26c$) jets (for a review, see Margon 1984; Fabrika 2004). Although it has been studied for about 30 years since its discovery, the identification of the compact object has remained unsolved.

A simple way to identify the compact object in SS 433 is to determine its mass function by directly measuring the Doppler shifts of the mass donor star due to the orbital motion. Since most of the optical light from SS 433 is emitted from the compact object, it is relatively easy to measure the radial velocity of the compact object. The measurement of the radial velocity of the donor star is more complicated, however. In this paper, we present the most updated determination of the radial velocity of the donor star.

2. Subaru observations of SS 433

We observed SS 433 with the FOCAS instrument on the Subaru telescope on 2007 October 6, 7, 8, and 10. The jets of this source are known to exhibit precession with a period of 162.15 days. This epoch was chosen to catch the system in a special precession phase where the disk is the most open toward us ($\psi \approx 0$), to prevent the gas stream from the donor to the compact object from intersecting the line-of-sight, and in orbital phases around the eclipse of the compact object by the donor star ($\phi \approx 0$).

Since a large fraction of the optical emission of SS 433 originates from the compact object, absorption lines from the donor star become very weak, and hence careful analysis is required to study their features. For the analysis of cross-correlation function (CCF) with the spectrum of a reference star, we define three different regions that are free from prominent emission lines from the compact object; Region 1 (4490–4630 Å), Region 2 (4740–4840 Å), and Region 3 (4950–4990 Å). To make the absorption features clearly visible, we further divide the normalized spectra by a continuum function modeled by Legendre polynomials of ≈15 orders in each region. We call the resultant spectra "highly rectified spectra".

Figures 1 and 2 show the highly rectified spectra of SS 433 in Region 1 and Region 2–3, respectively, together with the normalized spectrum of the reference star HD 9233, observed with Subaru. HD 9233, spectral type of A4 Iab, is known to have a similar spectrum to the donor star of SS 433 (Hillwig et al. 2004). To make easy comparison, all the spectra have been shifted into the rest frame. As noticed from the figures, the spectra of HD 9233 and SS 433 contain the same absorption lines. These absorption features in the SS 433 spectra become deeper as the donor star hides the compact star, providing evidence that they are originated from the donor star.

3. Radial velocity of the donor star

Figure 3 shows the radial velocity curve of the donor star in SS 433 as determined from the CCF analysis of the Subaru spectra. We find that the amplitudes of the radial velocity is different between spectral regions used in the analysis (Region 2 > Region 3 > Region 1). The difference in the amplitude is related to the strength of the spectral features; the absorption lines in Region 1 are the deepest and have underlying emission components, while those in Region 2 are the weakest and mainly do not have emission components. We interpret that the strong absorption lines are more significantly affected by emission from the wind, gas stream, and/or heated surface of the donor star, making the amplitude of the radial velocity curve apparently smaller.

In this context, to select "weak" lines are important to trace the true motion of the donor star. Under this assumption, we can estimate the amplitude of the radial velocity by fitting them with a Keplerian solution. From all the Subaru and Gemini results obtained from the CCF analysis of Region 2, we obtain the semi-amplitude of the radial velocity of $K_{\rm O} = 56.7 \pm 3.7$ km s^{-1} and systemic velocity of $\gamma_{\rm O} = 61.3 \pm 2.5$ km s^{-1}.

4. An estimate for the mass of the compact star in SS 433

Combining $K_{\rm O}$ with the amplitude of the radial velocity of the compact object, which we adopt $K_{\rm X}$=168±10 km s^{-1} (the averaged value of Fabrika & Bachkova 1990, Fabrika et al. 1997, Gies et al. 2002, and our estimate from the He$_{\rm II}$ emission line), we derive the mass of the donor star and compact object to be $M_{\rm O} = 12.2^{+2.3}_{-2.1}$ M$_\odot$ and $M_{\rm X} = 4.1^{+0.8}_{-0.7}$ M$_\odot$, respectively. However, these values should be taken only as upper limits if we consider the heating effect (Kubota et al. 2009). We conclude that the compact star in SS 433 is most likely a low mass black hole, although the possibility of a massive neutron star cannot be firmly ruled out.

This work was partly supported by Grant-in-Aid for JSPS Fellows for young researchers (KK).

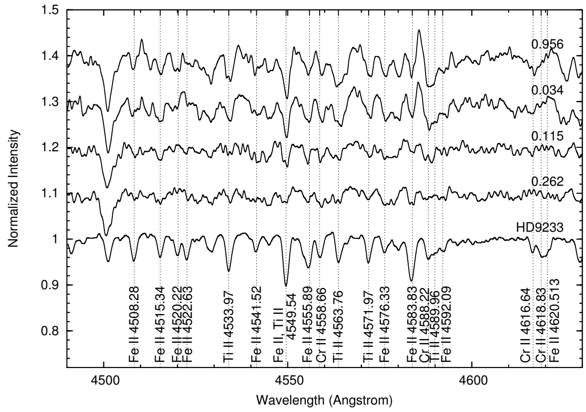

Fig. 1. Spectra of SS 433 (highly rectified) and HD 9233 (normalized) in Region 1 obtained with the Subaru FOCAS. The numbers on the right side indicate the corresponding orbital phases ϕ. The flux level of HD 9233 spectrum is reduced by a factor of 0.36 (Hillwig et al. 2004). The absorption feature near 4501.79 Å is an interstellar absorption (Hobbs et al. 2008).

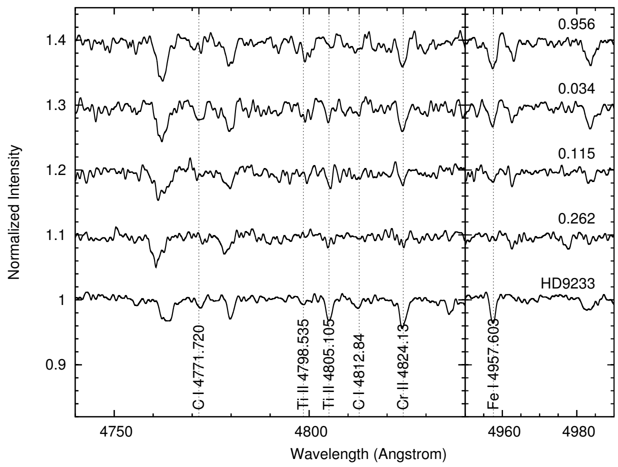

Fig. 2. Same as Figure 1 in Regions 2 and 3. The absorption features near 4762.61 Å, 4780.02 Å, and 4963.88 Å are interstellar absorptions.

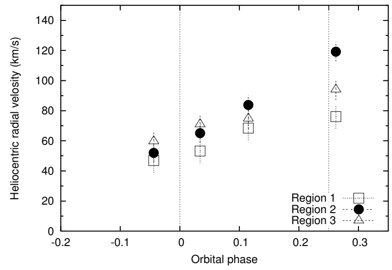

Fig. 3. Radial velocity curve of the donor star in SS 433 obtained by the CCF analysis of the Subaru data. The squares indicate the results from Region 1, filled circles Region 2, and triangles Region 3.

References

Fabrika S. 2004 Astrophys. and Space Phys. Rev., 12, 1
Fabrika S. & Bychkova L. V. 1990 A&A, 240, L5
Fabrika S. et al. 1997 Bull.Special Astrophys.Obs.,43,75
Gies D. R. et al. 2002 ApJ, 566, 1069
Goranskii V. P. et al. 1998 Astronomy Reports, 42, 209
Hillwig T. C. & Gies D. R. 2008 ApJ, 676, L37
Hillwig T. C. et al. 2004 ApJ, 615, 422
Hobbs L. M. et al. 2008 ApJ, 680, 1256
Kubota et al. 2009 ApJ submitted
Margon B. 1984 ARA&A, 22, 507
Margon B. & Anderson S. F. 1989 Apj, 347, 448