1

BH Mass and Accretion Disk Structure in Mrk 110

W. Kollatschny
University of Göttingen, Germany

Abstract
We have taken optical spectra of the variable narrow-line Seyfert 1 galaxy Mrk 110 over a period of six months. The observations were carried out with the 9.2m HET telescope at McDonald Observatory. We determined delays of the HeII, HeI and Balmer line light curves with respect to continuum variations. These measurements verify a stratification of the individual emission line regions at distances from 3 to 33 light days. We derived a central black hole mass of $2 \times 10^7 M_\odot$ from the distances of the line emitting regions and the widths of the rms line profiles. We studied in detail the 2D-line profile variability pattern of the broad emission lines. Only an AGN model predicting the formation of the broad emission lines in the wind of an accretion disk matches the observations. We derived a central black hole mass of $2 \times 10^7 M_\odot$ independently from the velocity-delay maps of the strongest emission lines.

1.1 Introduction

The central Broad Line Region (BLR) can not be spatially resolved in AGN. But with indirect methods we can get information about BLR structures by monitoring the variable central ionizing continuum source as well as variable broad emission lines. The delayed response of emission lines to variations of the ionizing continuum gives us information on the distance of the line emitting regions from the central ionizing source. Different delays of different emission lines contain information on structures in the BLR. Central black hole masses can be derived from the broad emission line widths under the assumption that the gas dynamics is dominated by the central massive object. More detailed information on BLR geometry and kinematics in AGN can be obtained by studying line profile variations.

1.2 Observations

We are monitoring variable Seyfert galaxies using the 9.2m HET telescope at McDonald Observatory. 26 spectra of Mrk 110 have been taken between 1999 Nov. 13 and 2000 May 14. All observations were made under identical conditions with exactly the same instrumentation. The S/N ratio was better than 100 in all our spectra. Some typical spectra are plotted in Fig.1 showing the continuum and e.g. HeII line profile variations. We determined relative line fluxes of the Balmer

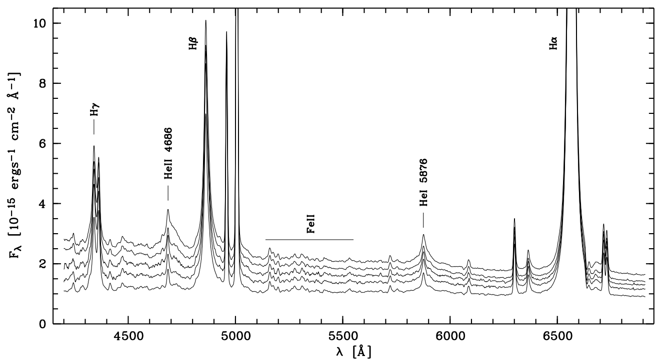

Fig. 1.1. Some HET spectra of Mrk 110 taken between Dec. 1999 and April 2000.

and Helium lines with an accuracy of better than 1%. Continuum and emission line light curves of our variability campaign were generated subsequently.

1.3 Results and Discussion

1.3.1 BLR Stratification and Black Hole Mass

We cross-correlated the light curves of the broad emission lines with the continuum light curve. The cross-correlation lag gives the characteristic distance in light days for the emission of the individual lines. Furthermore, we measured the line widths of the rms profiles. In Fig. 2 we plot the lags of the strongest emission lines as a function of their rms line width. There is a strong correlation between

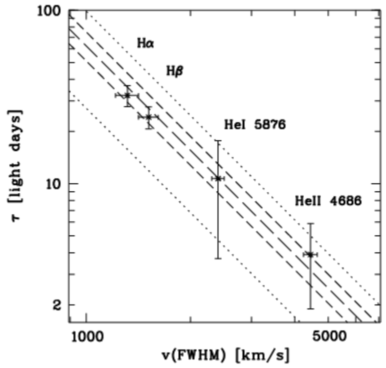

Fig. 1.2. Results of the HET variability campaign of Mrk 110: time lag of Balmer and Helium lines as a function of FWHM of the rms profiles. Dotted and dashed lines indicate virial masses of 0.8, 1.5, $1.8, 2.2, 2.9 \times 10^7 M_\odot$ (from bottom to top) (Kollatschny, 2003).

these two parameters and a clear stratification in the BLR of Mrk 110. Furthermore, we computed the relation between rms line width and distance of the line emitting region (Kollatschny, 2003) for different central black hole masses. The dotted and dashed lines in Fig. 2 indicate calculated virial masses for the central black hole between 0.8 and $2.9 \times 10^7 M_\odot$. We derive a central black hole mass of $2. \times 10^7 M_\odot$ in Mrk 110.

1.3.2 BLR Accretion Disk Structure and Kinematics

More detailed information on the BLR geometry and kinematics can be obtained by investigating line profile variations. Welsh & Horne (1991), Perez et al. (1992), and others calculated velocity-delay maps of line profiles for different motions and geometries of the BLR (inflow or outflow motions, random circular orbits, Keplerian disk orbits). We sliced the observed line profiles of Mrk 110 into velocity bins of $\Delta v = 400$ km/s width for comparing our line profile variations with the theoretical models. Afterwards we created light curves of the various Hβ emission

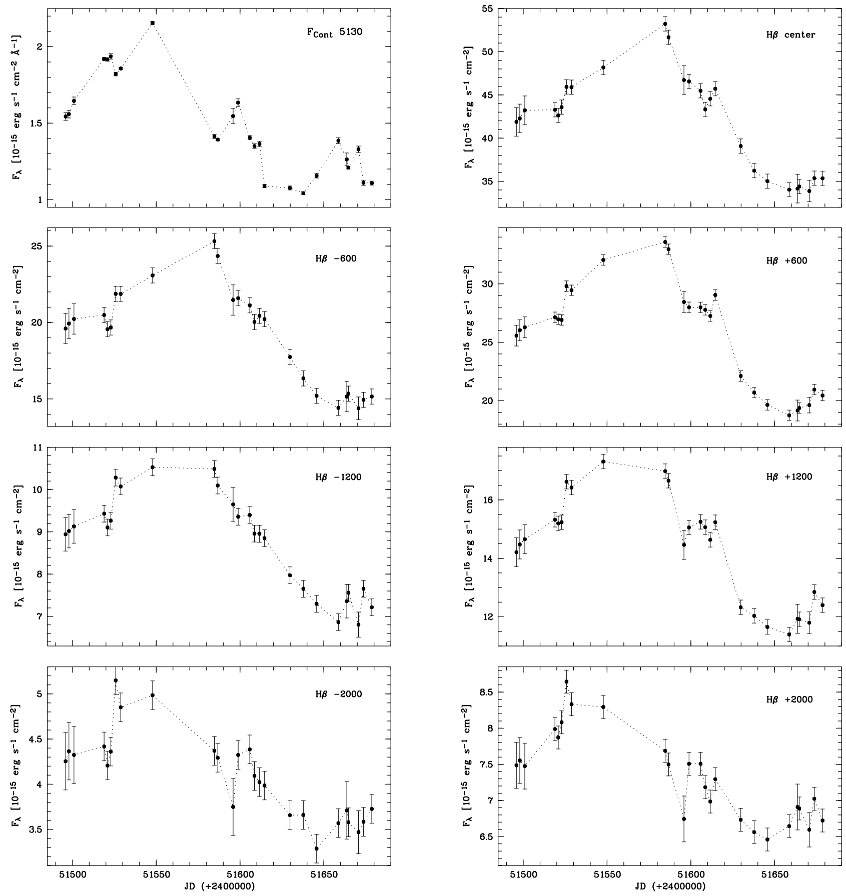

Fig. 1.3. Light curves of the continuum, of the Hβ line center as well as of different blue and red Hβ line wing segments ($v = \mp$ 600, 1200, 2000 km/s, $\Delta v = 400$ km/s) derived from our HET variability campaign of Mrk 110.

line segments (Fig. 3). The light curves are remarkably different. The outer line wings respond much faster to continuum variations than the inner line segments. In a next step we computed cross-correlation functions (CCF) of all line segment light curves with the continuum light curve. Finally, we created velocity delay maps of all

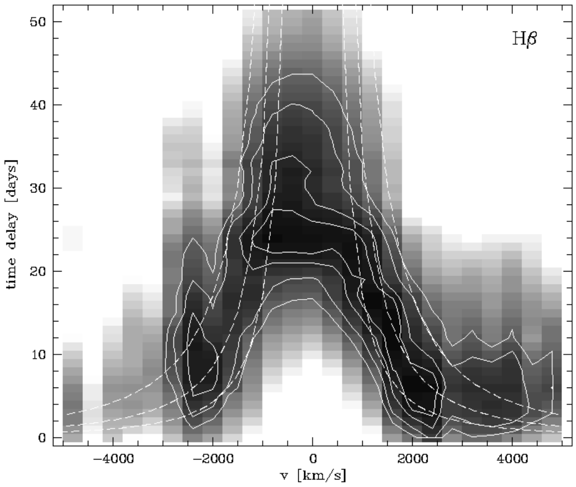

Fig. 1.4. The 2-D CCF(τ,v) shows the correlation of the Hβ line profile with continuum variations as a function of velocity and time delay (grey scale). Contours of the correlation coefficient are overplotted at levels of .85, .88, .91, .925 (solid lines). The dashed curves show computed escape velocities for central masses of 0.5, 1.0, 2.0 $\times$ $10^7 M_\odot$ (from bottom to top) (Kollatschny & Bischoff, 2002).

broad emission lines from the CCFs. The velocity delay map of Hβ is given in Fig. 4 (Kollatschny & Bischoff 2002). The 2-D CCFs are mathematically very similar to 2-D response functions. By comparing our velocity delay maps with model calculations we can rule out that inflow or outflow motions are dominant in the BLR of Mrk 110. But, Keplerian disk BLR models match our observed velocity-delay pattern. A disk like configuration of the central broad line region in AGNs has been proposed by e.g. Chiang & Murray (1996) or Bottorff et al. (1997).

A slightly faster and stronger response of the red emission line wing compared to the blue wing (as seen in Fig. 4) is predicted in disk-wind models (Königl & Kartje 1994, Blandford & Begelman 1999). The disk outflow models are distinguished from spherical wind models that their velocity decreases with radius rather than the other way around. Fig. 5 shows the accretion disk wind model of Mrk 110 schematically which we derived from our 2-D variability data.

1.3.3 Central Black Hole Mass in Mrk 110

The dashed curves overplotted in Fig. 4 show computed escape velocities for different central masses. We derive a central black hole mass of 2. $\times$ $10^7 M_\odot$ in Mrk 110 (Kollatschny et al. 2001, 2002). On the other hand, Ferrarese et al. (2001) determined a central mass of 3. $\times$ $10^6 M_\odot$ from the velocity dispersion in the CaII triplet lines of the host galaxy. But our velocity-delay maps of all emission lines confirm a value of the central mass of 2. $\times$ $10^7 M_\odot$ we derived previously from the

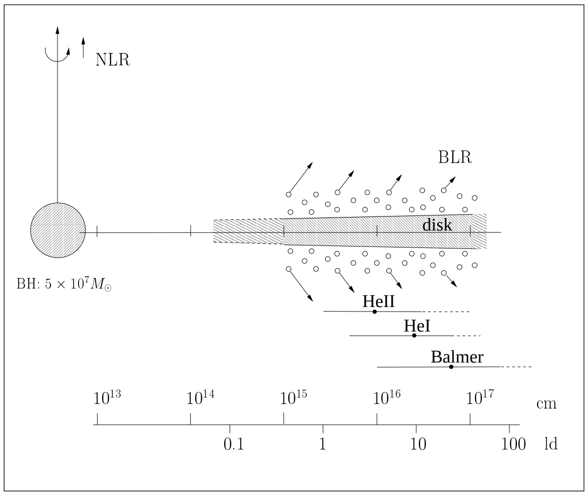

Fig. 1.5. Schematic BLR model of Mrk 110 (Kollatschny, 2003).

integrated line intensity variations. Furthermore, one has to keep in mind that our calculated mass value is a lower limit because of the unknown inclination angle of the accretion disk.

1.4 Conclusions

We monitored the variable emission line profiles in Mrk 110. An accretion disk scenario for the origin of the broad emission lines matches our velocity delay maps best. Furthermore, we derived with two different methods a central black hole mass of $2 \times 10^7 M_\odot$ in Mrk 110.

1.5 Acknowledgments

This work has been supported by the Deutsche Forschungsgemeinschaft, DFG grant Ko 857/24.

References

Blandford, R.D., & Begelman, M.C. 1999, MNRAS, 303, L1
Bottorff, M., et al. 1997, ApJ, 479, 200
Chiang, J., & Murray, N. 1996, ApJ, 466, 704
Ferrarese, L., et al. 2001, ApJ, 555, L79
Königl, A., & Kartje, J. F. 1994, ApJ, 434, 446
Kollatschny, W., et al. 2001, A&A, 379, 125
Kollatschny, W., & Bischoff, K. 2002, A&A, 336, L19
Kollatschny, W., et al. 2003, in prep.
Perez , E., et al. 1992, MNRAS, 256, 102
Welsh, W., & Horne, K. 1991, ApJ, 379, 586