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LONG AND SHORT TERM VARIABILITY IN THE SEYFERT GALAXY MRK 110

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RESUMEN

Revisamos brevemente los resultados de una campaña prolongada de variabili- dad en la galaxia Seyfert 1 Markarian 110. Además, presentamos nuevos resultados basados en datos adquiridos entre noviembre 1999 y abril 2000 con el Telescopio Hobby–Eberly (THE). Mrk 110 fue observada entre cada tres y diez días con el THE. La línea HeIIλ4686 sigue las variaciones del contínuo con un retraso de sólo 5 días, mientras que las líneas de Balmer se originan a distancias mayores a 23 días luz. Las variaciones de intensidad en la línea He II son extremadamente fuertes. Al interpretar el corrimiento al rojo de la componente ancha de la línea He II (relativa al de las componentes Balmer y angosta) como un corrimiento gravitacional, podemos estimar la masa del hoyo negro central. Este valor es 4 veces mayor que el estimado mediante la cinemática del gas.

ABSTRACT

We briefly review results of a long–term variability campaign on the Seyfert 1 galaxy Markarian 110. Furthermore, we present new results based on data taken between November 1999 and April 2000 with the Hobby–Eberly Telescope (HET). Mrk 110 was monitored every three to ten days with the HET. The He II λ4686 line follows the continuum variations with a delay of only 5 days while the Balmer lines originate at distances over 23 light days. The intensity variations in the He II line are extremely strong. Interpreting the higher redshift of the broad HeII line component (with respect to the Balmer and narrow line components) as gravitational redshift we can estimate the central black hole mass. This value is 4 times higher than the value estimated from gas kinematics.

Key Words: **GALAXIES: INDIVIDUAL — GALAXIES: SEYFERT — LINE: PROFILES**

1. INTRODUCTION

Many Seyfert 1 galaxies and quasars are variable in their continuum and broad emission lines. If it is possible to determine the time delays between the ionizing continuum light curve and the emission–line light curves, we can deduce the radial distances of the emission line regions with respect to the central source. This spectroscopic distance estimate is important because it is not possible to resolve the inner broad line region (BLR) where the emission lines originate by direct imaging methods. Furthermore, in addition to the size scale given by line *intensity* variations, line *profile* variations give us information on the velocity structure and kinematics in the BLR (e.g. Kollatschny & Dietrich 1997).

Using several different 2–4 m class telescopes, we took 24 optical spectra of the Seyfert galaxy Mrk 110 over the time interval of 1987 through 1995 (Bischoff & Kollatschny 1999). Markarian 110 is a nearby, bright, narrow lined Seyfert 1 galaxy. The continuum and the Balmer and He II emission lines varied by a factor of 2 to 8 within a time scale of ∼10 years (see Fig. 1).

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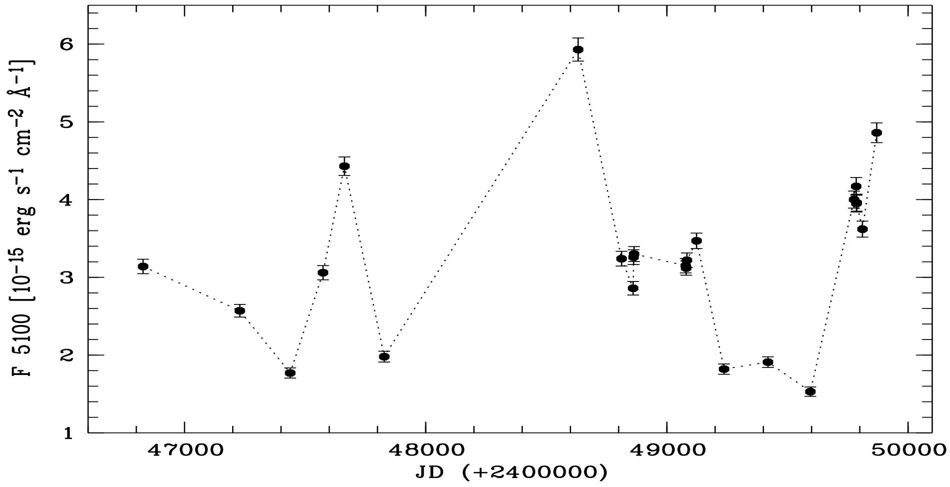

Fig. 1. Long term continuum light curve of Mkn 110 from 1987 through 1995. The points are connected by a dotted line to aid the eye.

A cross-correlation analysis of the continuum and emission line light curves indicated that the broad He II $\lambda4686$ line originates at distance of about 9 light days, the Hβ line at a distance of 30–40 light days and the He I $\lambda5876$ and Hα lines at distances of 60–80 days. We found strong indications that the profiles of the different emission lines differ and that the internal redshifts of the broad line centers (especially that of the He II $\lambda4686$ line) are different. Therefore, Mrk 110 was one of our prime targets to investigate line intensity and profile variability in detail. For this, we used the new Hobby–Eberly Telescope (HET), which has the ability to give us high S/N ratio and dense temporal sampling through its queue–scheduled operation.

2. THE HET VARIABILITY CAMPAIGN

We started our HET variability campaign of Mrk 110 on Nov.14, 1999. The low resolution spectrograph (LRS) at prime focus was used for all observations. Exposure times were typically 10 minutes, giving a S/N ratio of more than 100 in the continuum. The campaign ended in May 2000, yielding spectra at 26 epochs. In Fig. 2 four spectra of Mkn 110 taken at different epochs are shown. These spectra have been normalized to the same constant [O III] $\lambda5007$ intensity. In Fig. 3 the region near He II $\lambda4686$ and Hβ is shown, illustrating the significant rapid profile changes. The high quality of the spectra is demonstrated, for example, by the identical Fe II spectral features beyond 5300Å. Most of the weak, small scale spectral structures in Fig. 3 are due to the underlying host galaxy spectrum. In Fig. 4 the light curves of the continuum, He II $\lambda4686$, and Hβ lines are shown. These are preliminary light curves, covering the period from Nov.14, 1999 until Mar.26, 2000. We estimate that the errors will be smaller than 2 percent when we finish our data reduction.

The continuum and the He II $\lambda4686$ line intensity rose monotonically through December and reached their highest intensity at the beginning of January. In contrast, the Balmer line intensities increased from December through February, peaking some time before March; see Figs. 3 and 4. Although there is a substantial gap in the light curves, it is obvious by inspection that Hβ behaves differently than the continuum and He II line.

3. DISCUSSION

We correlated our new continuum light curve with the emission line light curves using a new interpolation cross–correlation function method (Welsh, Kollatschny & Robinson 2001). We calculated delays of $\sim$5 lightdays for He II $\lambda4686$ and $\sim$23 lightdays for Hβ.

The mass of the central object in Mrk 110 can be estimated from the width of the broad emission line profiles under the assumption that the central object is gravitationally dominating the gas dynamics (e.g. Koratkar

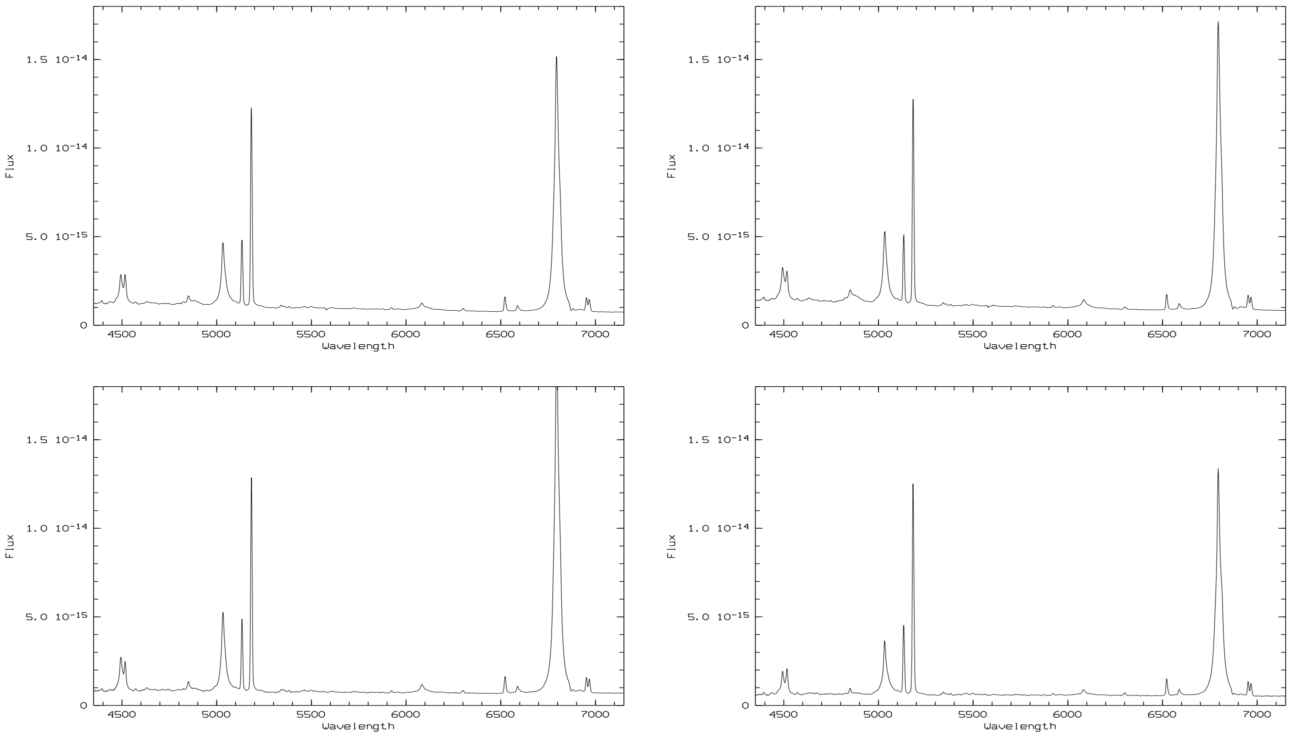

Fig. 2. Normalized HET spectra of Mkn 110 taken in Dec.1999, Jan.2000 (top row), Febr.2000 and Apr.2000 (bottom row).

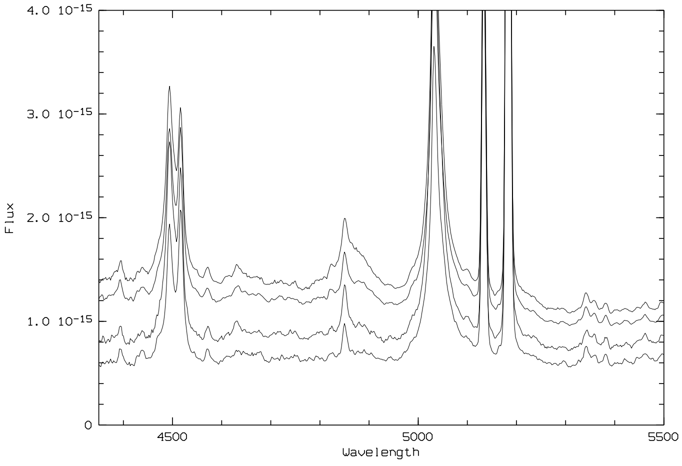

Fig. 3. Enlarged spectral region showing the continuum and He II $\lambda4686$ line profile variations. From top to bottom: Jan.2000, Dec.1999, Feb.2000, Apr.2000

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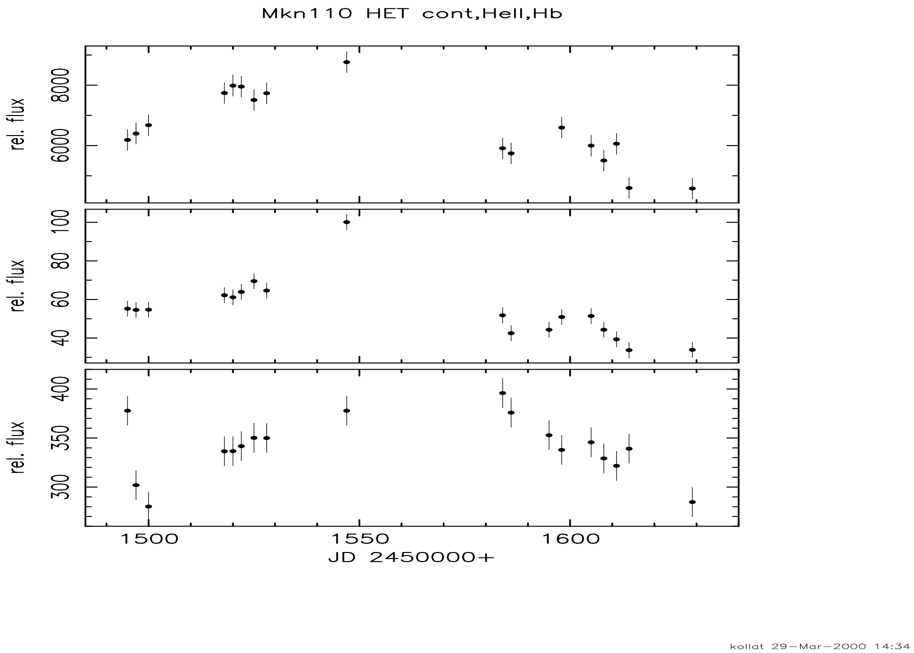

Fig. 4. Short term variations of Mrk 110 from Nov.14, 1999 until Mar.26, 2000: Preliminary light curves of the continuum and the integrated emission line fluxes of He II $\lambda4686$ and Hβ (from top to bottom)

& Gaskell 1991). In addition to the velocities, one needs the radial distance of the line emitting clouds to the ionizing source. From the different lines widths and time–delays we observed, we estimate a central mass of

$$M = 3.4^{+3}_{-3} \times 10^7 M_\odot .$$

If we interpret the observed redshift ($\Delta z = 0.0013$) of the broad He II line with respect to the other emission lines as a gravitational redshift, we can independently estimate the mass of the central object (e.g. Zheng & Sulentic 1990). We find a mass of $M = 1.2 \times 10^8 M_\odot$. Interestingly, this value is 4 times higher than the estimate from the gas kinematics plus reverberation lags. We are investigating the cause of such a systematic discrepency.

We have presented a preliminary look at our HET data on Mrk 110. We are currently continuing to reduce and analyse this data. Special emphasis will be given to the study of the line profiles and their variations, to be used to constrain the kinematics of gas in the broad line region.

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