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Dynamics of gas in the NLR of NGC 4151 and interaction of the jet with gas

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We observed the [FeII]$\lambda 1.644\mu$m emission line in the inner arcsecond of NGC 4151 using the imaging field spectrograph OSIRIS at Keck observatory to determine the kinematics of gas in the narrow line region (NLR). Model predictions assuming acceleration and simple ejection of gas are compared to centroid velocities derived from multi-Gaussian fits to the emission line profile. Based on our data the kinematics of [FeII]$\lambda 1.644\mu$m suggests acceleration in the inner arcsecond around the nucleus which agrees well with [OIII]$\lambda 501$nm observations previously performed with the Hubble Space Telescope. We also see evidence that the jet, traced by 21 cm radio continuum observations, locally enhances emission of [FeII]$\lambda 1.644\mu$m. The correlation between outflowing gas and radio intensity is weak and we assume that the jet is not the dominant mechanism driving the excitation in the NLR.

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1. Introduction

NGC 4151 is a well studied Seyfert 1.5 galaxy at a distance of about 13.25 Mpc. Due to this proximity the NLR of NGC 4151 can be well resolved on scales of a very few parsecs with adaptive optics assisted near-infrared observations. Previous investigations of the NLR revealed acceleration of gas probing the [OIII]λ500 nm emission line using the Hubble Space Telescope [2] but also constant ejection of gas probing the [SIII]$\lambda0.9533$ μm emission line with the GEMINI near-infrared imaging field spectrograph [4]. Both species have ionization potentials above 30 eV and are assumed to emerge from regions exposed to the nuclear radiation field of the active nucleus. [FeII]$\lambda1.644\mu$m has a somewhat lower ionization potential and can therefore be shock-enhanced by the highly confined jet emerging from the nucleus traced by 21 cm radio continuum emission [3]. Because of the longer wavelengths involved derived quantities are less hampered by dust extinction and the angular resolutions achieved in our adaptive optics assisted observations are well suited to investigate the interaction of individual gas and dust clouds with the jet. In this article we investigate the dynamics of the NLR in NGC 4151 using the [FeII]$\lambda1.644\mu$m emission line observed with the imaging field spectrograph OSIRIS at Keck observatory.

2. Analysis

Usually the [FeII]$\lambda1.644\mu$m emission line profiles appears skewed or even double peaked. At these positions the emission line profile is fitted with a double Gaussian with the Gaussian dispersions tied to another. At other positions we fit a single Gaussian. The NLR is usually modeled as a hollow bicone (see [1] and [2]) that is inclined by 45° to the plane of the sky at a PA of 60°. The inner/outer opening angles are 15° and 33° respectively and emission is primarily seen to emerge from between the two bicones. [2] and [4] adopt this geometry but apply different distance velocity laws ([2] predict acceleration of gas in the NLR while [4] claim simple ejection of the gas thus moving with constant velocity, see the corresponding articles for more details). We adopt the geometry and above distance velocity laws to model the dynamics of the NLR in NGC 4151. Finally we compare our measured centroid velocities with the model predictions in terms of position velocity-diagrams presented in 1 and 2. Results from single-Gaussian fits to the emission line are plotted in figure 1. This emission primarily arises with systemic velocity and we assume that this emission component can be attributed to the galactic disk. However, for pseudslit positions around the nucleus (ΔY between -0.11 and +0.11) for positive slit positions we do see emission around -250 km/s but there is no evidence that these clouds are pushed by the jet since the 21 cm radio continuum intensity is not increased at these positions in the pseudoslits. Figure 2 shows the results from our double-Gaussian fits. The high-velocity component (top) does not correlate with the radio data suggesting that this high-velocity component primarily arises from an outflow. The velocity signature of this component and that from single-Gaussian fits already implies acceleration in the NLR. However, the low-velocity component partially correlates with the radio data, especially at Δ Y = -0.21 at negative slit positions, and at Δ Y = 0.21 at positive slit positions with the low-velocity component deviating from systemic. Here, we assume to see gas accelerated/enhanced by the jet. The main jet axis deviates significantly from the direction of the mayor axis of the bicone such that it seems unlikely that the jet is the dominant source for driving the dynamics of the NLR but locally

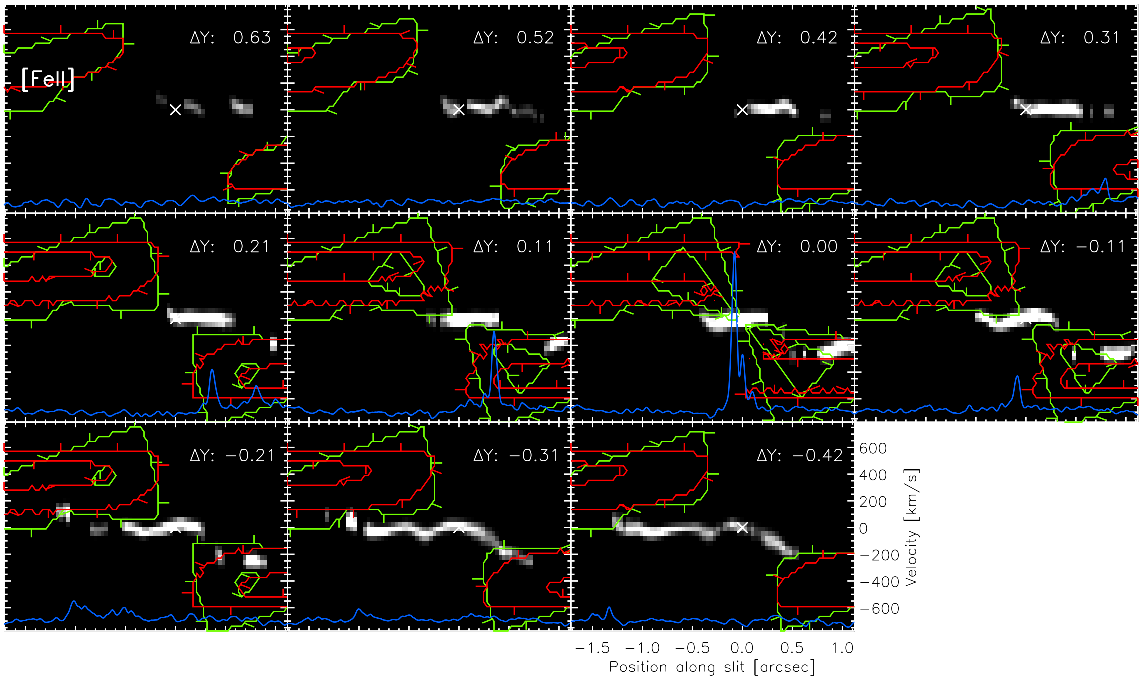

Figure 1: Position velocity diagrams of 0.105 arsecond wide pseudoslits aligned with the NLR at a PA of 60° extracted from the modeled datacube which contains emission from the single-Gaussian fits to the emission line. ΔY denotes the separation of the pseudoslits in arcseconds. For ΔY=0 the pseudoslit covers the nucleus. The green/red contours indicate the allowed regions according to the velocity laws by [2] and [4] where tick marks point into the direction of not allowed velocity ranges. The slightly staggered arrangement of the model calculations is not real but is rather due to calculations performed on a grid. The cross marks the center position of the pseudoslit and coincides with the position of the nucleus. 21 cm radio intensity along the pseudoslits are in blue.

enhances emission of [FeII]$\lambda 1.644\mu$m emission. Finally we compare the model predictions with our measurements. Taking only the high-velocity centroid velocities into account the acceleration model matches 80 % of all derived centroid velocities while the simple ejection model matches only about 60 %. From this we also conclude that the jet is not responsible for imprinting an acceleration signature to the kinematics observed and that the acceleration observed is dominated by, e.g., a wind.

References

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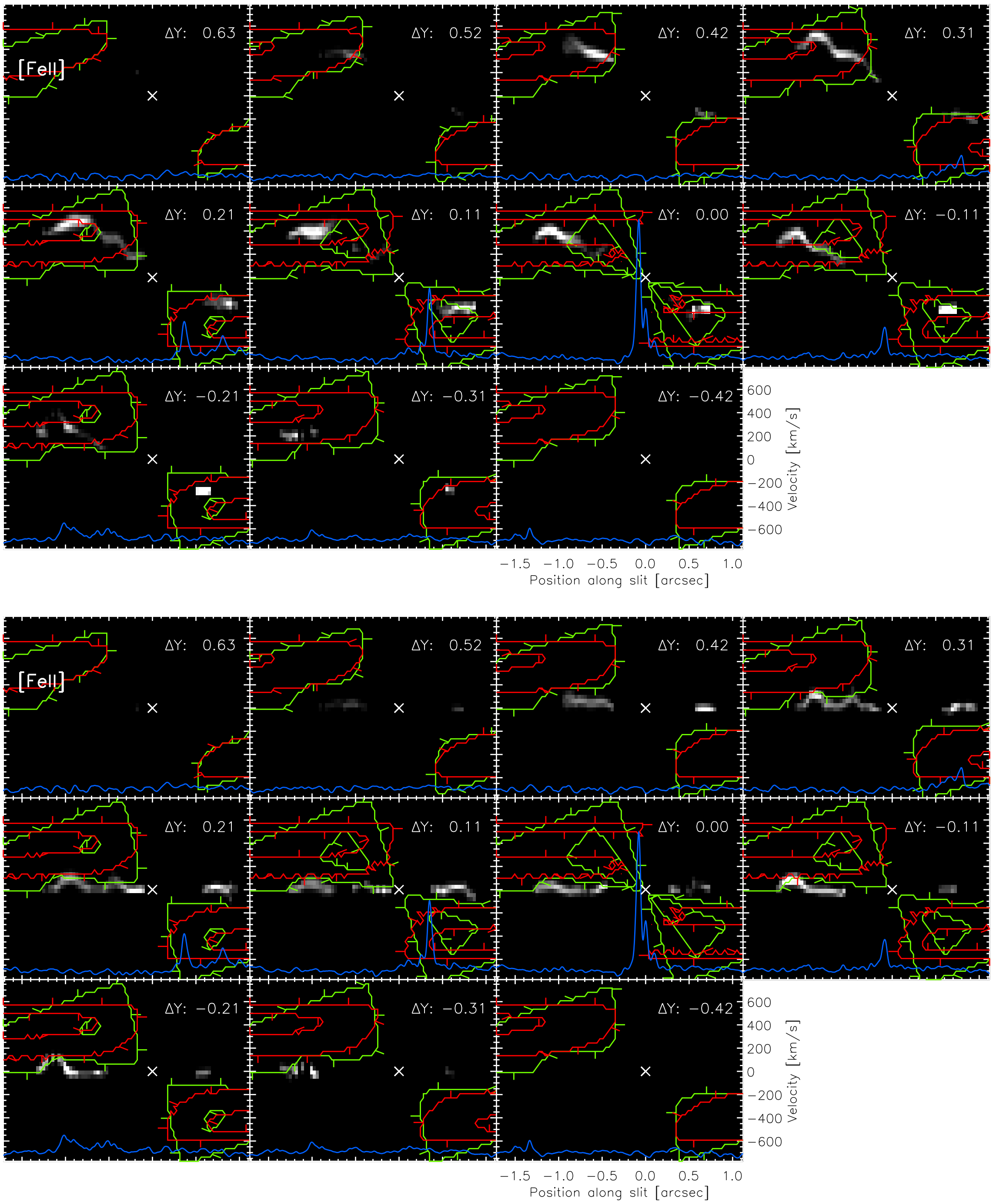

Figure 2: Same as figure 1 but for double-Gaussian fits to the emission line, high-velocity component (top) and low-velocity component (bottom).