Kinematics and black hole mass for the narrow-angle tailed radio galaxy NGC 4061

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Abstract

In the quest to determine the high redshifted radiojets in the galaxy NGC 4061, we present observations of the radio source for the first time. We observe a new, broad, and high-velocity component of flux from the radio source. The presence of this component is significant for understanding the structure and behavior of the radio galaxy. We present a new model for the radio source that includes a new component of flux, which is consistent with the observed behavior. We also present a new model for the radio jet that is consistent with the observed behavior.

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LINE FITTING

FIG. 7. Sample output from our line-fitting program. This uses direct fitting (Barth et al. 2003) as opposed to FOC or MPF to determine parameters describing the line position and shape. These "Torr"s contain kinematic information. Both plots show best-fit parameters (blue, right), chi2 (blue left), names of the input galaxy and template star (white top, bottom), bin (right, left), galaxy spectrum (white, 2 positions), template spectrum (blue), best fit broadened template (red), fits using a dispersion Ds (green, top) and Ds (green, bottom) the best fit value, and the residual of the best fit (red, bottom).

ADJUST: Applied to ModSpec CAT (absorption) data. Here we can address the question "How did White et al. (1983) measure a velocity dispersion of 477 km/s for NGC 4061?" Most of our best estimates are in the 250-500 km/s range. However, we can maximize dispersion by binning data from both sides of the galaxy. We can also use a large wavelength (15) parameter. This plot shows sigma ~375 km/s. We could not reach 477 km/s. The implication is that the sphere of influence of the BH is not resolved, making BH mass difficult to determine.

ADJUST: Applied to ModSpec absorption data. This plot was chosen to show how large H3 and H4 parameters can create double-peaked lines. These can provide better fits for complex lines, but a physical interpretation is difficult. Our program allows absorption subtraction prior to emission line

IMAGINING


Both F606W (I) and F555W (V) data were obtained. These were crucial for estimating the stellar mass profile for NGC 4061. The mass derived from the projected luminosity (after deprojection), the dust makes this case.

FIG. 5. ModSpec spectra of the Hα emission. The unsmoothed, reduced data is shown in panel (A), while panels (B) and (D) show three ways to show the emission above the continuum. These simple lines are the main focus of gas kinematics analysis – we do not have any resolution fits spectra.

FIG. 6. ModSpec Infrared Data. The calcium triplet (4068, 6442, and 8602) are the absorption lines most suitable for stellar kinematics. The ground-based spectra provide better spatial coverage than STIS.

SPECTROSCOPY

FIG. 4. Sample spectra from STIS (Space Telescope Imaging Spectrograph) taken using the G430L setup.

TOP: NGC 4061. Extracted from the central 0.75 arcseconds (15 rows) of the combined STIS data. This is a core galaxy with a low central surface brightness, but the low spatial resolution (2.75 A/px) improves the S/N.

BOTTOM: HD141680. A G8 III star used as a template for determining the broadening function, and thus stellar kinematics, in NGC 4061. Both non-parametric and parametric fits (e.g., Gauss-Hermite polynomials) are used to find the best line-of-sight velocity distributions (LOSVD) at each position along the slit.

FIG. 3. 2PPC imaging through the F555W and F606W (V,R) filters reveal an organized disk. This is typical for radio galaxies (Pinkney et al. 2003). LEFT: Ellipse fits to the disk (using F555W) to find its inclination. RIGHT: Overlay of data from STIS (blue) and ModSpec observations. The STIS spectral range included C a & H (3968, 3969), H e (6563, 6548), and the H a (6563) emission lines.

FIG. 8. (BELOW) Kinematics of stars (circles) and gas (K) from ground-based spectroscopy. The end points have large uncertainties due to low S/N. The dispersion profiles are especially sensitive to the number of parameters

FIG. 9. (BELOW) Kinematics derived by non-parametric low-dispersion of the G430L major axis data. Top: radial velocity. Bottom: velocity dispersion. The two sides of the galaxy are symmetric to produce these plots.

FIG. 10. Modeling the light distribution on a 2D spectrum. The real ModSpec data is in the center, flanked by models. The model parameters (see table below) are identical except for the BH mass. There are actually two prominent emission lines (see FIG. 6), but we just show the brightest. The clear separation between the bright spots is a good measure of the BH mass.

MASS MODELING

NGC 4061 is one of the few broad-line radio sources with a detected, broad-line gas kinematics. It has a detected black hole, but the BH mass cannot be calculated for any other galaxy due to the lack of a black hole detection. Our models suggest that the BH mass is consistent with the observed behavior. We also present a new model for the radio source that includes a new component of flux, which is consistent with the observed behavior. We also present a new model for the radio jet that is consistent with the observed behavior.

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