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Are Narrow Line Seyfert 1 Galaxies Viewed Pole-on?

Travis C. Fischer[1]
Georgia State University
Physics and Astronomy, One Park Place South SE, Suite 700, Atlanta, GA 30363 USA
E-mail: fischer@chara.gsu.edu

D. M. Crenshaw
Georgia State University
Atlanta, GA USA
E-mail: crenshaw@chara.gsu.edu

S. B. Kraemer
The Catholic University of America
Washington, D.C. USA
E-mail: steven.b.kraemer@nasa.gov

H. R. Schmitt
Naval Research Laboratory
Washington, D.C. USA
E-mail: schmitt.henrique@gmail.com

Current attempts to dissect the inner workings of Narrow-Line Seyfert 1 galaxies (NLS1s) rely on the concept that narrow widths of their permitted lines are due to low central black hole masses resulting in high Eddington ratios. Could these narrow lines instead be due to a near pole-on orientation? We analyze spatially resoved spectra of the NLS1 NGC 4051 using the HST STIS G430M grating centered on the bright [O III] emission lines to model the narrow-line region (NLR) outflow and determine its inclination.

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1. Introduction

Active Galactic Nuclei (AGN) are axisymmetric systems, where their observed properties are strong functions of inclination with respect to our line of sight. For example, according to unified models, Seyfert 1 and Seyfert 2 galaxies are intrinsically the same, but the broad-line region (BLR) and central continuum source (accretion disk) are obscured in Seyfert 2 galaxies by a roughly toroidal distribution of dusty gas at a distance 1 pc, whereas the more extended narrow-line region (NLR) is visible in both types. Does the connection between Seyfert type and inclination extend to other types of AGN, such as Narrow-line Seyfert 1s (NLS1s)? NLS1s have permitted lines with widths from their “BLRs” that are ≤ 2000 km s^{-1} (FWHM), which are narrower than those of “normal” broad-line Seyfert 1s (BLS1s), but still broader than forbidden lines from the NLR (typically ~ 500 km s^{-1} FWHM).

A promising technique for determining the inclinations of nearby AGN is to map the kinematics of their narrow-line regions (NLRs), which are easily resolved with HST . Using long-slit spectra from the Space Telescope Imaging Spectrograph (STIS), we have shown that the NLR kinematics are dominated by radial outflow in the approximate shape of a bicone, as expected from collimation by a torus (Fischer et al. 2010;2011).

The current paradigm for NLS1s is that they have supermassive black holes (SMBHs) with relatively low masses compared to BLS1s and they are therefore radiating at close to their Eddington limits (Pounds et al. 1995). But are these properties due instead to a special viewing angle for NLS1s? Could NLS1s be more “pole-on” than normal broad-line Seyfert 1s (BLS1s), as suggested by their compact radio morphologies (Ulvestad et al. 1995)? If the BLR has a strong rotational component, as suggested by a number of studies (see Gaskell 2000), then the velocities and black-hole masses ($M_\bullet$) of NLS1s are underestimated, and if NLS1s are viewed pole-on, their Eddington ratios ($L/L_{Edd} \propto L/M_\bullet$) are overestimated. The other unusual properties of NLS1s might then also be explainable by a special viewing angle. In order to address these issues, we employ our kinematic model on the individual NLS1 NGC 4051 in order to determine its inclination.

2. Observations

We obtained archival Space Telescope Imaging Spectrograph (STIS) long-slit spectra of NGC 4051 from the Multimission Archive at the Space Telescope Science Institute (MAST). Two sets of spectra were taken on 2000 April 15 under Hubble Program ID 8253 (M. Whittle, PI) with a 52'' x 0.2'' slit using a medium-dispersion G430M grating (4950-5240Å), which includes [O III] λ5007. The spectral resolution was 0.56Å, with an angular resolution of 0.051'' per pixel in the cross dispersion direction. Both observations were taken at a position angle of 90° with cross dispersion offsets for slits 1 and 2 being -0.05'' and 0.2'' respectively. Figure 1 displays the position of each slit over a Barbosa et al. (2009) GMOS IFU image of the [S III] flux (which originates in the same gas that emits [O III]).

To determine the kinematics of the NLR, we incorporated the calibrated spectral images into a program that fits [O III] λ5007 emission-line components with Gaussians over an average continuum, taken from available line-free regions in the spectra (Das et al. 2005). [O III] emission lines near the nucleus contained a blue wing that was fit separately by subtracting the flux from the main component. Calculating the central peak location for each Gaussian allowed us to determine the central wavelength for the corresponding [O III] line, which in turn was used to calculate its Doppler shifted velocity. Subtracting the systemic velocity of the galaxy (cz = 718 km s^{-1}) from velocities calculated via [O III] line centroid shifts, we were able to determine the radial velocities along each slit in the rest frame of NGC 4051. Figures 2 and 3 show the rest frame radial velocities for the measure [O III] λ 5007 emission lines from both slit positions.

3. Model

To generate kinematic models, we assume the ionizing radiation responsible for the NLR is biconical in nature, as it is the simplest geometric shape produced by a central obscuring torus. As with our previous kinematic models (Das et al. 2005, 2006; Crenshaw et al. 2010B; Fischer et al. 2010, 2011), we also initially assume that the bicone is hollow, where the separate NLR emission components represent opposite sides of the bicone. We employed our kinematics program from Das et al. 2005, which allows us to recreate the observed radial velocities along a fixed slit position by altering various parameters of our model bicone outflow. Our models include seven alterable parameters (as seen in Fischer et al. 2010, 2011) with initial values taken from the NLR imaging in Figure 1 (deprojected height of bicone [z_{max}], outer half-opening angle [θ_{max}], and position angle) and the kinematics from Figures 2 and 3 (maximum velocity [v_{max}] and turnover radius [r_t]), leaving the inner half-opening angle (θ_{min}) and inclination of the bicone axis out of the plane of the sky to be alterable parameters free of restriction. We adopted our previous velocity law (Fischer et al. 2010), a linear increase starting with zero km s^{-1} at the nucleus and subsequent linear decrease at r_t ending at zero km s^{-1}, because it is the simplest law that matches the observations.

4. Results

Figure 4 shows the full kinematic model created by our final set of parameters. From this model, we recreate the 2-D kinematics along the position of each STIS slit, depicted as the shaded regions overlaid on the kinematics data in Figures 2 and 3. The modeled kinematics provide a fair qualitative fit to the data,
matching well to the inner accelerating blueshifted outflows. Using our final model parameters, we find that the axis of the bicone is inclined 12 degrees away from pole-on, with our line of sight running near the edge of the NLR, between the inner and outer opening angles of the outflow. As we assume the highly blueshifted radial velocities are due to a biconical outflow, there is a noticeable lack
of corresponding highly redshifted velocities near the nucleus. Combining the outer opening angle of the kinematic model with the inner disk geometry (Barbosa et al. 2009), as shown in Figure 5, we suggest that the lack of redshifted outflow could be due to disk obscuration.

While we do find that the inclination of NGC 4051 is near pole-on at 12°, we also find that the inclination between the outer opening angle and our line of sight to be near identical. Additionally, the effects of our line of sight being between the inner and outer opening angles of the outflow is unclear. Thus, it is difficult from this single target to confirm whether a pole-on or near pole-on geometry can be utilized as an explanation for the unique parameters found in NLS1s. Additional analysis has been done for two more NLS1s, Mrk 766 and Mrk 1040, that shows similar highly blueshifted velocities near their nuclei, suggesting that a near pole-on orientation may be common. Unfortunately, the emission for these targets is too compact to fit with an accurate outflow model. Further study on the asymmetrical distribution of outflow velocities on either side of nuclei for both NLS1s and BLS1s is required to test the pole-on hypothesis for NLS1s.

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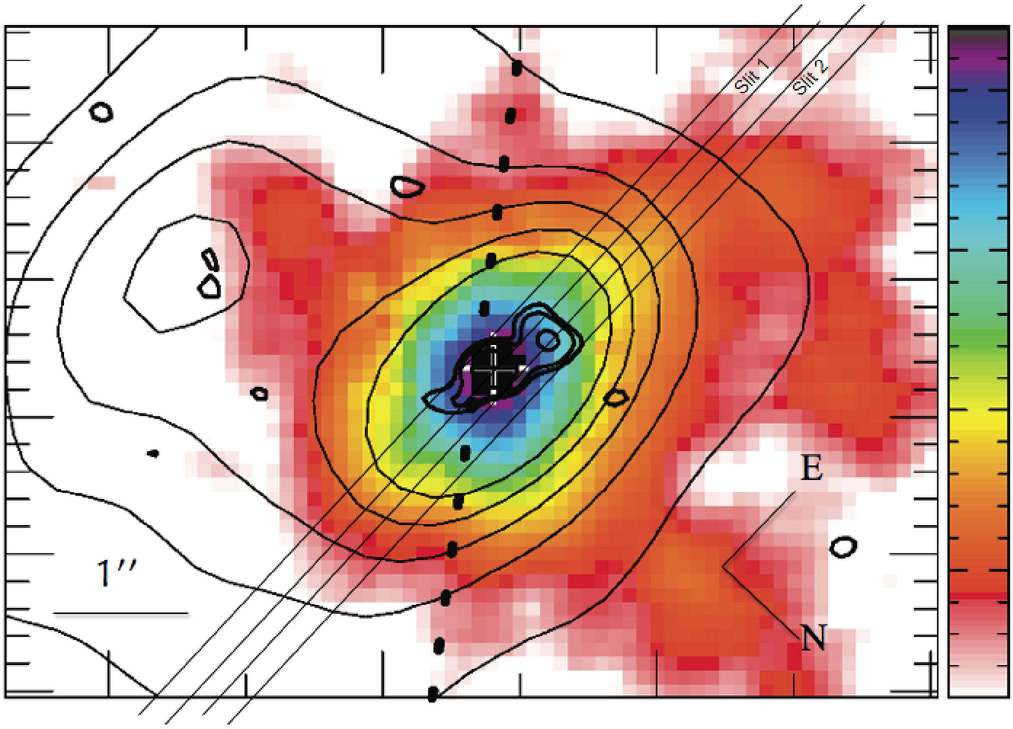

Figure 1: NGC 4051 GMOS IFU image showing integrated [SIII] flux (Barbossa et al. 2009). Black contours are radio 3.6 (compact contours) and 20 cm maps. Dashed line represents major axis of galaxy. Solid lines represent STIS slit positions.

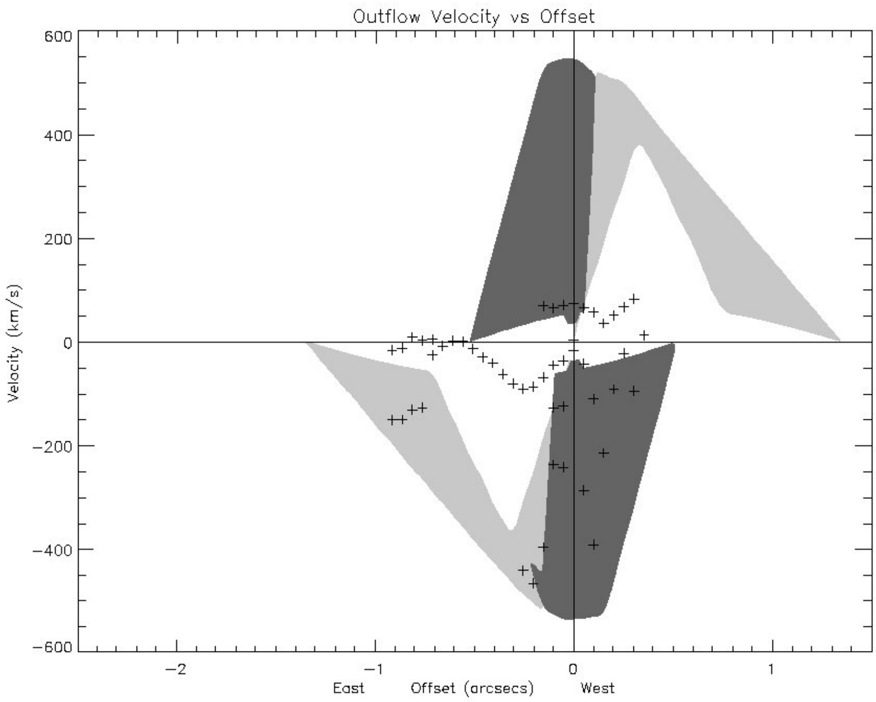

Figure 2: Radial velocities and corresponding kinematics model for STIS slit 1.

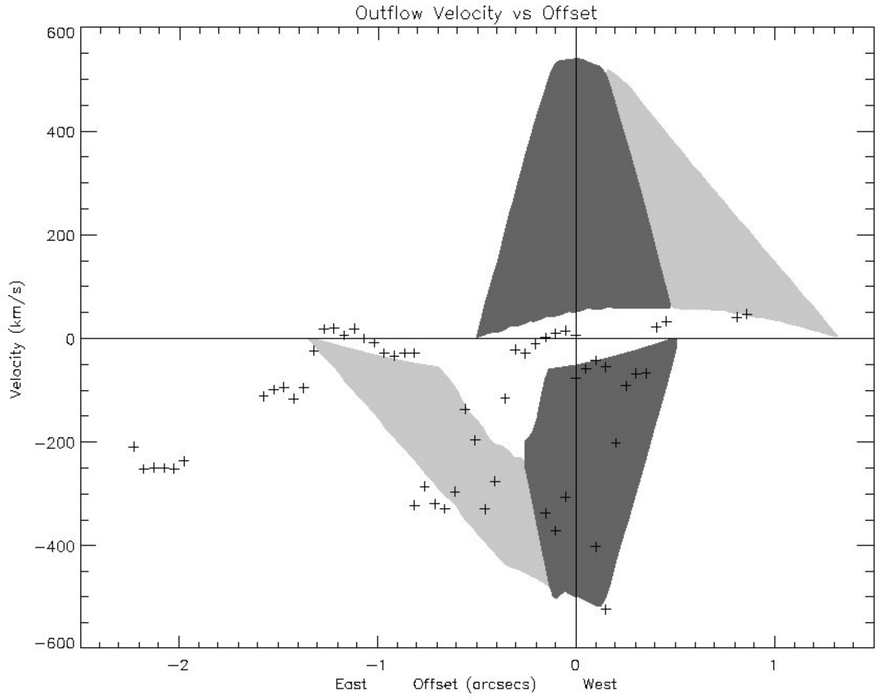

Figure 3: Radial velocities and corresponding kinematics model for STIS slit 2.

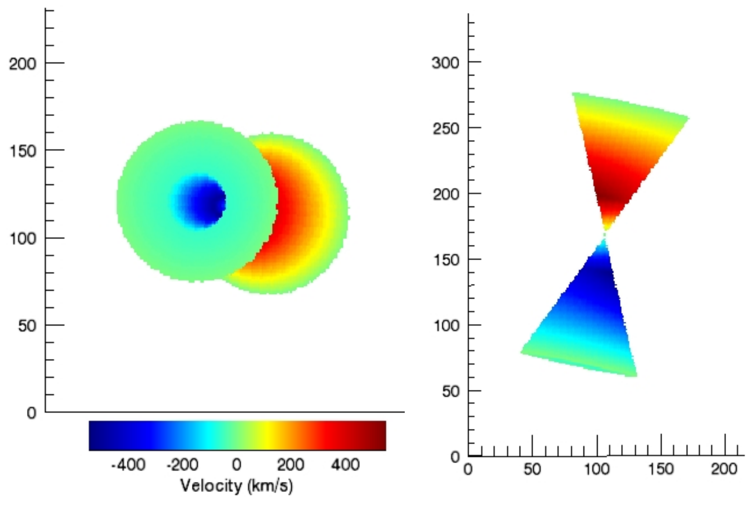

Figure 4: Kinematic models along our line of sight (left) and from above (right) of NGC 4051's NLR illustrating that our line of sight is in between the inner and outer opening angles of the outflow.

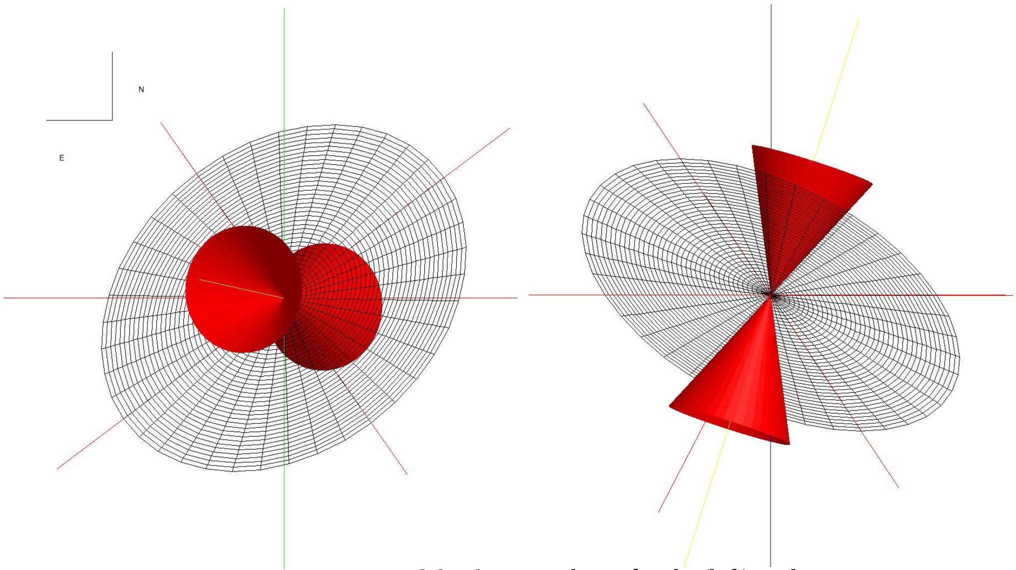

Figure 5: Kinematic models along our line of sight (left) and from above (right) of NGC 4051's NLR illustrating that our line of sight is in between the inner and outer opening angles of the outflow.