The Stellar Kinematics of the Galaxy NGC 4203

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Abstract

At the center of every massive galaxy lies a supermassive black hole. Such black holes have masses that correlate with the large-scale properties of their host galaxies, suggesting that black holes and galaxies co-evolve. To better understand this process, more black hole mass measurements are needed over a wide range of galaxy types. Our research was focused on the S0 galaxy NGC 4203 (Figure 1), which is located at a distance of 15 Mpc. Spatially-resolved spectroscopy of this galaxy was obtained with the Keck I 10-meter telescope in Hawaii using the instrument LRIS in long-slit mode. The data were reduced in PyRAF, and steps included bias subtraction, flat fielding, cosmic-ray cleaning, geometric rectification, wavelength calibration, sky subtraction, and flux calibration. Then using the Penalized Pixel-Fitting (pPXF) method, we measured the line-of-sight velocity distribution of stars at different distances from the galaxy center. The distribution was characterized by the velocity, velocity dispersion, and higher-order moments that describe the distribution's deviations from a Gaussian. By analyzing these stellar kinematics, we can infer the mass of the supermassive black hole at the center of NGC 4203.

Background

Over the past two decades correlations between the masses of central black holes and the global properties of their host galaxies have been clearly established (Figure 2). The relations imply that supermassive black holes and galaxies grow and evolve together, but we need more robust black hole mass (M_{BH}) measurements to better understand how the relations come about. There are two main ways M_{BH} can be measured- by modeling the stellar or gas kinematics. The object we studied is an S0 galaxy suitable for both stellar and gas-dynamical modeling techniques. The galaxy can be used to compare the calculated M_{BH} from these from these two completely separate methods. Using these methods, different parameters can be measured to determine the M_{BH}.

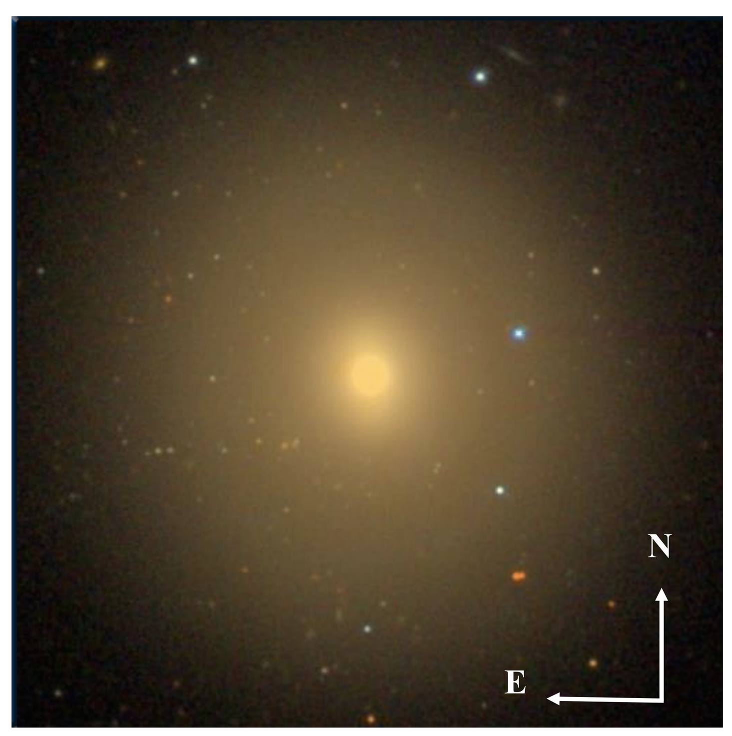

Figure 1. Sloan Digital Sky Survey image of NGC 4203. Each side of the image is 15 kpc.

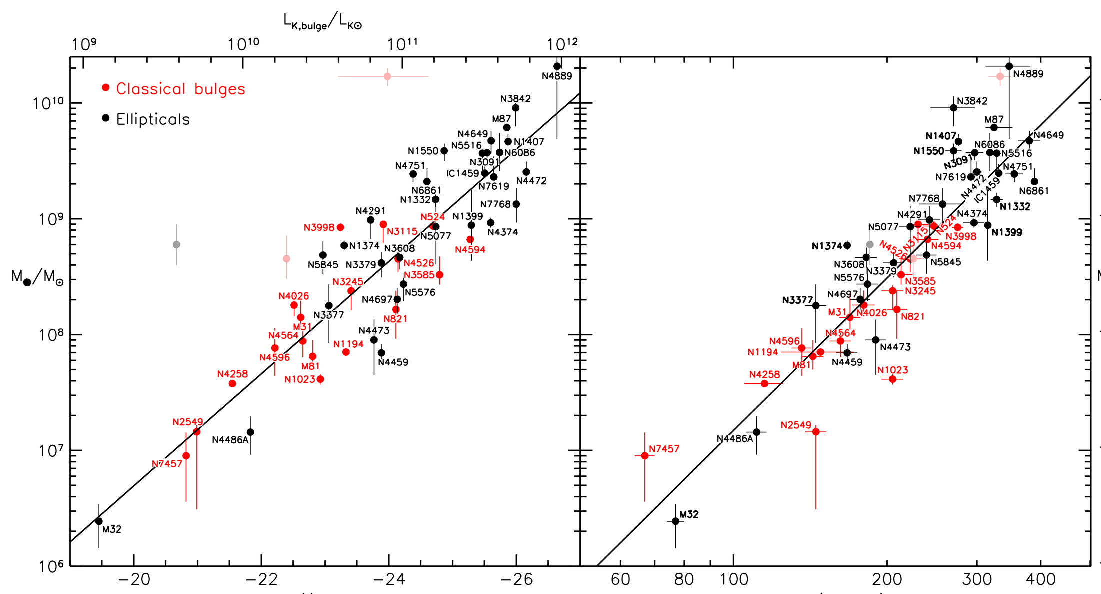

Figure 2. M_{BH}-bulge luminosity (left) and M_{BH}-effective stellar velocity dispersion (right) relations from Kormendy & Ho (2013).

Previous studies of this galaxy have found an upper-limit on the gas-dynamical M_{BH} of 5.2×10^7 $M_\odot$ (Sarzi et al. 2002) and 1.3×10^8 $M_\odot$ (Beifiori et al. 2009). Additional *Hubble Space Telescope* (*HST*) observations of the nuclear emission-line disk will be able to better constrain the gas-dynamical M_{BH} (*HST* program 11571).

Our project focused on the stellar kinematics of NGC 4203, specifically on how the parameters changed as a function of distance from the galaxy nucleus. The data we studied provides information on large spatial scales, extending to ~15" (~1 kpc), and will be combined with previous work that measured the stellar kinematics from adaptive optics observations of the innermost region of the galaxy. Both small- and large-scale stellar kinematics are essential for determining the M_{BH} and mass that can be attributed to the stars.

Observations

Data for this project was taken with the Keck I telescope using the Low Resolution Imaging Spectrograph (LRIS; Oke et al. 1995) on March 27, 2012. Three exposures of the galaxy were taken for 600 seconds each along the galaxy major axis at a position of 10° East of North. Nine G and K giant stars were also observed to use as velocity templates. The seeing was ~0.8" during the night.

Data Reduction and Measurements

These observations were reduced using functions in PyRAF. The two-dimensional (2D) spectral images were trimmed, bias subtracted, flattened, and geometrically rectified so that the wavelength and spatial axes would run parallel along rows and columns, respectively. During the rectification process, an arc lamp exposure was used to wavelength calibrate the 2D spectral images. The three spectral images were combined and cosmic-rays were rejected, followed by sky subtraction and flux calibration (Figure 3).

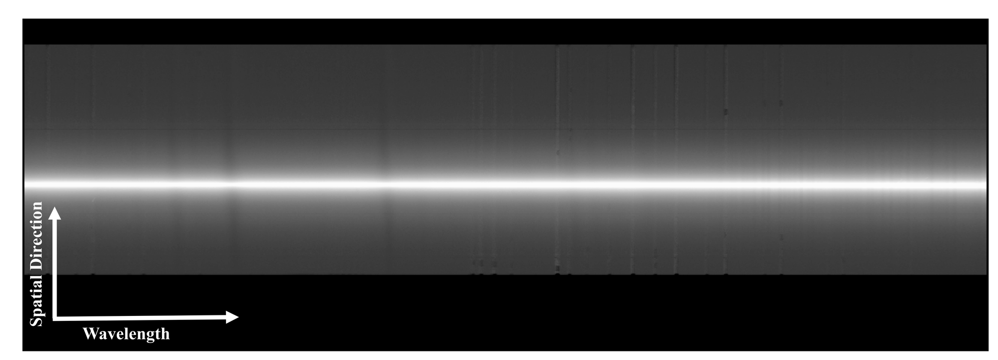

Figure 3. 2D flux and wavelength calibrated spectrum.

One-dimensional (1D) spectra were extracted on a row-by-row basis from the reduced 2D image of NGC 4203. At projected distances ~10" away from the galaxy center, we binned together multiple rows to reach the minimum signal-to-noise ratio (S/N) of 40 needed to reliably measure the stellar kinematics. We used the pPXF method (Cappellari & Emsellem 2004) to measure the line-of-sight velocity distribution of stars, given by the velocity, velocity dispersion, h_3 (skewness), and h_4 (kurtosis). The pPXF code takes in a 1D galaxy spectrum and velocity template star spectra and compares the two (Figure 4). For example, the velocity and velocity dispersion are measured by shifting and broadening the template spectra to match the observed galaxy spectrum. The absorption features being used in our research are the Calcium II triplet lines.

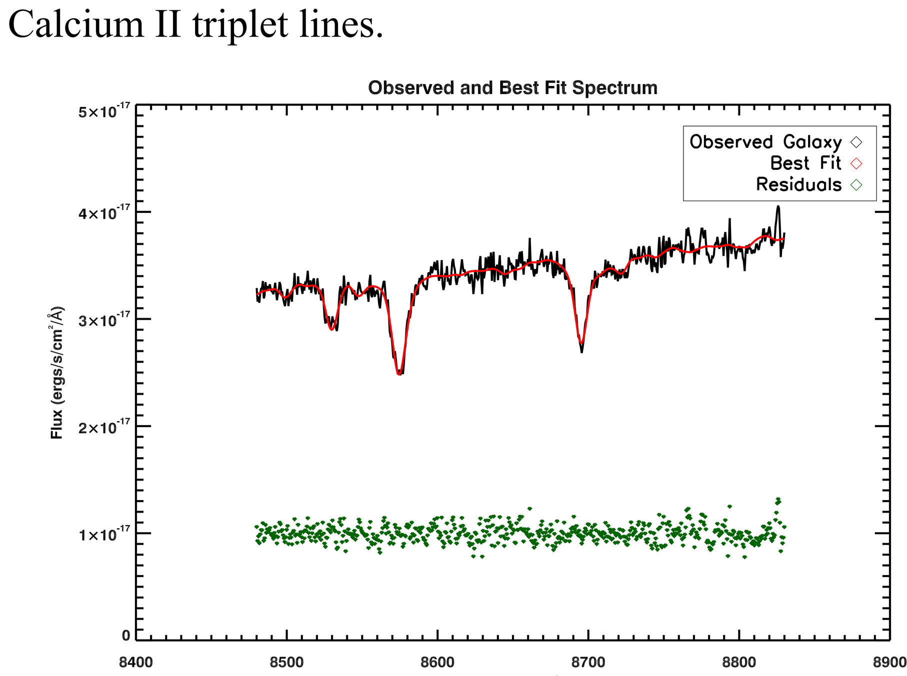

Figure 4. Example fits to a spectrum located 7.29" (530 pc) from the galaxy nucleus. The residuals are calculated as the best-fit spectrum subtracted from the observed galaxy spectrum. An arbitrary value of 1×10^{-17} ergs/s/cm²/Å was added to the residuals to make them visible on the graph.

The next step was to measure the error on the kinematic parameters. We took the best-fit model calculated by pPXF and added random Gaussian noise to it in a Monte Carlo simulation, for 200 iterations. pPXF was then run on each simulated spectrum, and the standard deviation of the distribution was taken to be the error. These values were then used in the resulting graphs depicting the parameters as functions of distance from the nucleus of the galaxy.

Results

We plotted the stellar kinematics measured with pPXF as a function of projected distance from the center of the galaxy (Figure 5).

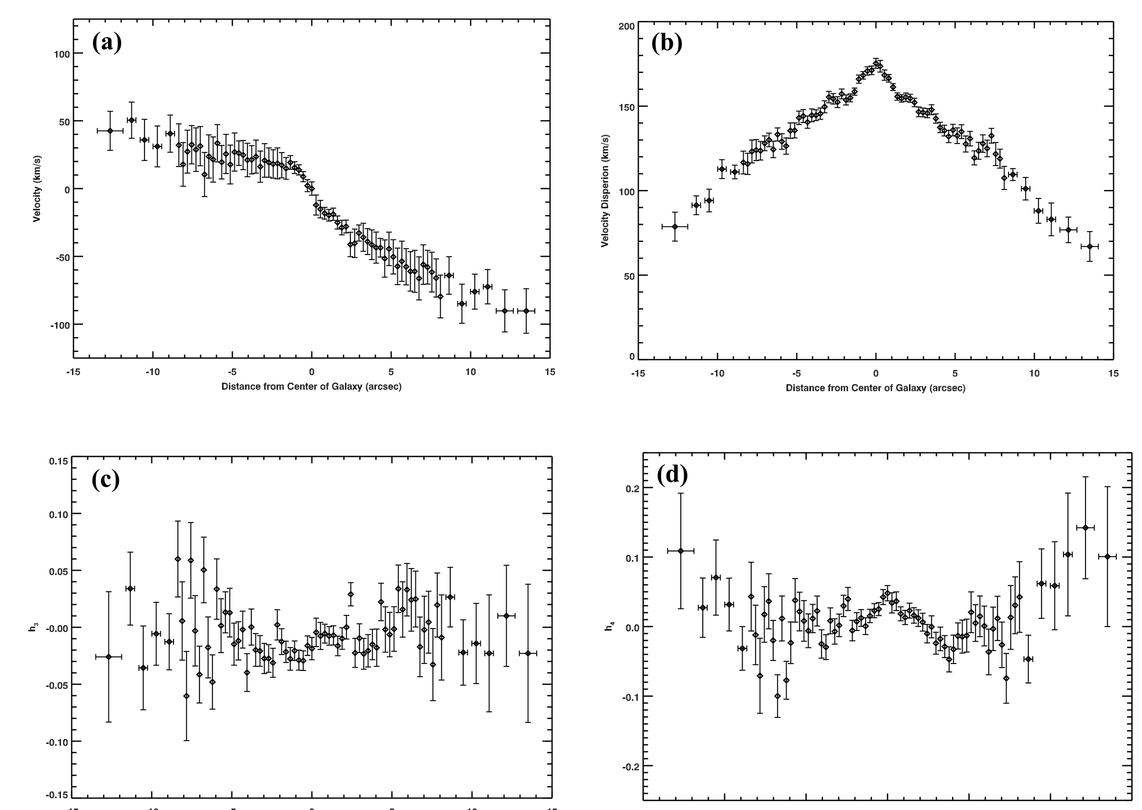

Figure 5. These graphs depict (a) velocity, (b) velocity dispersion, (c) h_3, and (d) h_4 as a function of distance from the center of the galaxy.

In the figure above, we see the results of this study. The stellar kinematics change as a function of distance from the galaxy nucleus. We find that the galaxy is rotating, with the north side of the galaxy (positive distances) being blueshifted and the south side of the galaxy being redshifted. There is a rise the velocity dispersion toward the nucleus, suggestive of a massive black hole. We also see a slight peak in h^4 at the center.

Conclusions

To conclude, we analyzed the stellar kinematics of the S0 galaxy NGC 4203 using observations from LRIS at the Keck I telescope. We reduced the data using PyRAF, and then ran spectra through the pPXF code. We determined the values and errors for different kinematic parameters (velocity, velocity dispersion, h_3, and h_4 as a function of spatial location. It is apparent that the kinematics change with distance from the nucleus. In the future, this analysis along with previous work will be used to put constraints on the supermassive black hole located at the center of NGC 4203.

References

Beifiori et al., 2009, ApJ, 692, 856; Cappellari & Emsellem, 2004, PASP, 116, 816; Kormendy & Ho, 2013, ARA&A, 51, 511; Oke et al., 1995, PASP, 107, 375; Sarzi et al., 2002, ApJ, 567, 237

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