ASTRONOMY
TEXAS A&M UNIVERSITY

Measuring Stellar Kinematics in the S0 Galaxy NGC 4203

Zuzana Calbo[1], Jonelle Walsh[2]

[1]Hofstra University Department of Physics and Astronomy, [2]Texas A&M University Department of Physics and Astronomy

Abstract

At the center of every massive galaxy lies a black hole. The masses of black holes have been found to depend on the large-scale properties of the galaxy, which suggests that black holes and galaxies evolve together over time. However, there are very few objects at the low-mass end of the black hole-host galaxy relations. Here we present measurements of the stellar kinematics of NGC 4203, an S0 galaxy possibly harboring a $< 5 \times 10^7$ M_{sun} black hole. Data used in this study were taken with the integral-field spectrograph OSIRIS, assisted by adaptive optics, on the Keck II telescope in the near infrared. We fit the observed galaxy spectra with template stars to extract the velocity, velocity dispersion, and higher-order moments within ~100 pc of the galaxy nucleus. We find that the galaxy is rotating and there appears to be a drop in the stellar velocity dispersion at the center of the galaxy. The stellar kinematics on these small spatial scales are an excellent tracer of the inner galaxy potential and are essential for a robust determination of the NGC 4203 black hole mass.

Introduction

Through numerous studies, it has been found that the masses of central black holes are closely correlated with the large-scale properties of galaxies, such as the bulge luminosity and the bulge stellar velocity dispersion. Although the black hole gravitationally influences only the innermost regions of galaxies, the black hole mass is dependent on the overall properties of the galaxy. This suggests that black holes and their host galaxies evolve together, with the growth of one somehow affecting the growth of the other.

Figure 1. SDSS image of NGC 4203

NGC 4203 is a nearby S0 galaxy. Based on the bulge stellar velocity dispersion of 110 km/s (Sarzi et al. 2002), the mass of the black hole is expected to be around 2.3×10^7 M_{sun} (Kormendy & Ho 2013; Figure 2). Other studies have estimated a black hole mass upper limit ranging from 3.6×10^7 M_{sun} to 1.3×10^8 M_{sun} (Sarzi et al. 2002, Beifiori et al. 2009) by modeling the rotation of a nuclear gas disk. Therefore, NGC 4203 could lie at the sparsely populated low end of the black hole-host galaxy relations, and help provide insight into how black holes and galaxies grow together.

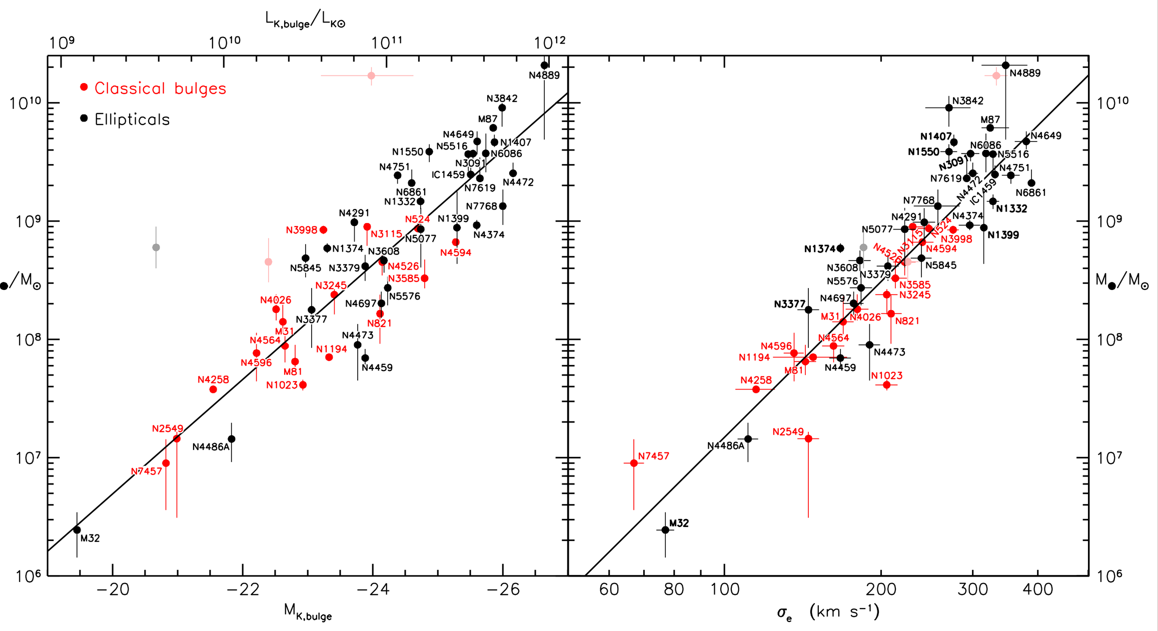

Figure 2. The left graph shows the black hole mass - bulge luminosity relationship, and the right panel shows the correlation between the black hole mass and bulge stellar velocity dispersion. It is evident from the plots that the black hole mass and the large-scale galaxy properties are tightly correlated, and that there exist very few measurements at the low end of these relations..

Our work focuses on measuring the stellar kinematics within the central ~100 pc of NGC 4203. The stellar kinematics will later be modeled to infer the mass of the black hole. NGC 4203 affords us the unique opportunity to compare this stellar-dynamical black hole mass measurement to a gas-dynamical determination. It is important to compare the results from the two methods because they each suffer from different systematic errors.

Observations

Data were taken on May 5-6, 2010 using the integral-field spectrograph OSIRIS on the Keck II telescope with the aid of adaptive optics. We used the K broadband filter to cover 1.865 - 2.381 µm, and spent a total of 3.6 hours observing the galaxy. Velocity template stars were observed with OSIRIS in the same setup as well. These high angular resolution observations allow us to map out the stellar kinematics in NGC 4203 on scales comparable to the black hole's gravitational sphere of influence.

Method

From the OSIRIS observations of NGC 4203, we measured the line-of-sight velocity distribution (LOSVD) of the stars in 53 spatial bins using the penalized pixel fitting method (pPXF; Cappellari et al. 2004). First, we constructed an optimal template from our OSIRIS observations of K and M giant stars. This stellar template was then shifted and broadened to match the observed galaxy spectra in each of the spatial bins, providing measurements of the velocity (V) and velocity dispersion (σ). The comparison between the optimal stellar template and each of the observed galaxy spectra also gave us measurements of the LOSVD's asymmetric (h_3) and symmetric (h_4) deviations from a Gaussian.

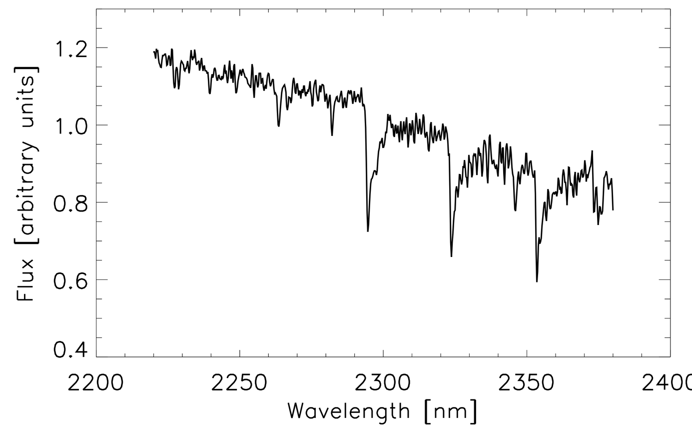

Figure 3. Plot of the rest-frame spectrum of a K2 III star. This star dominated the optimal template that was used to measure the NGC 4203 stellar kinematics. The most prominent absorption features are the CO bandheads.

Errors on the stellar kinematics were calculated using a Monte Carlo simulation. During each realization, we took the best-fit model spectrum and added random Gaussian noise to simulate an observed spectrum, then re-fit pPXF. We used pPXF to fit over a wavelength range of 2.22-2.38 µm, which covers prominent absorption features like the CO bandheads.

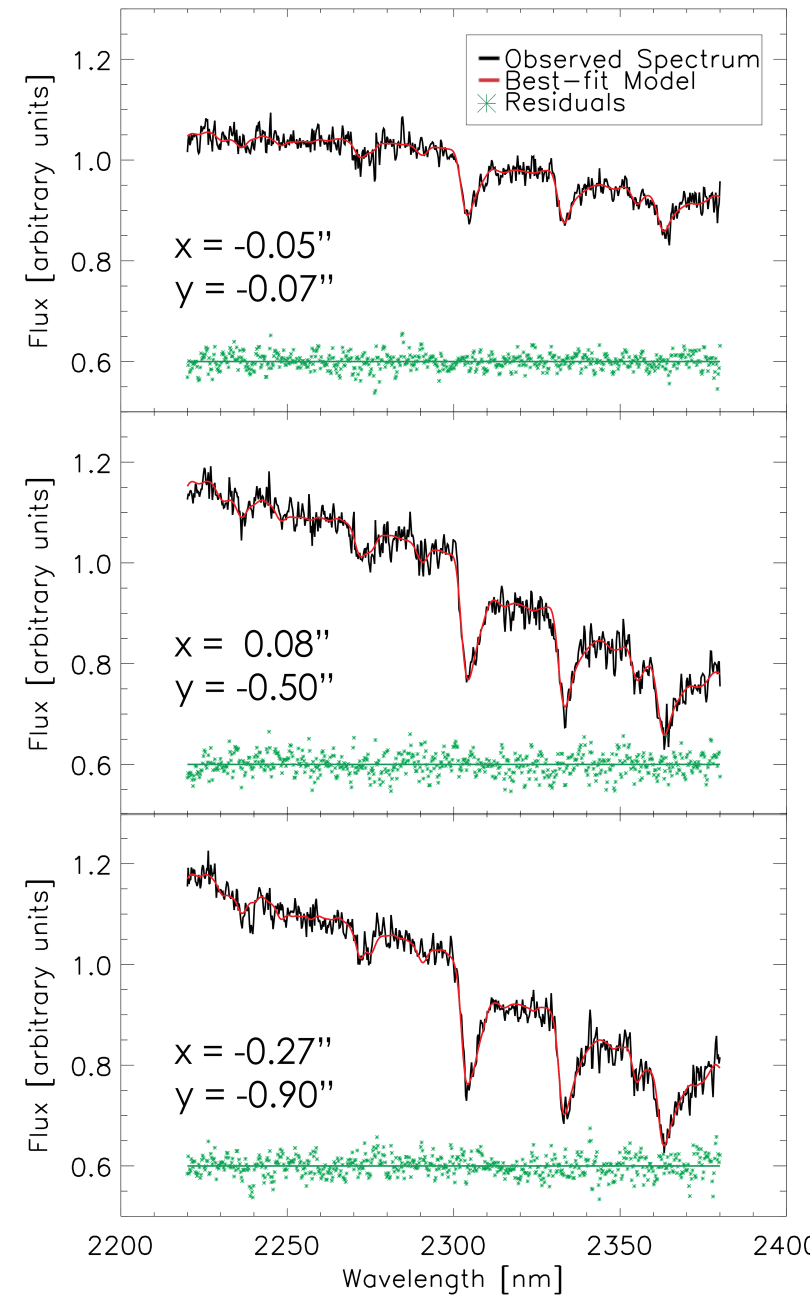

Figure 4. Example fits of the NGC 4203 spectra at three different spatial locations. The black line represents the observed galaxy spectrum, the red line is the best-fit model from pPXF, and the green points are the residuals that have been shifted up by an arbitrary constant.

Results

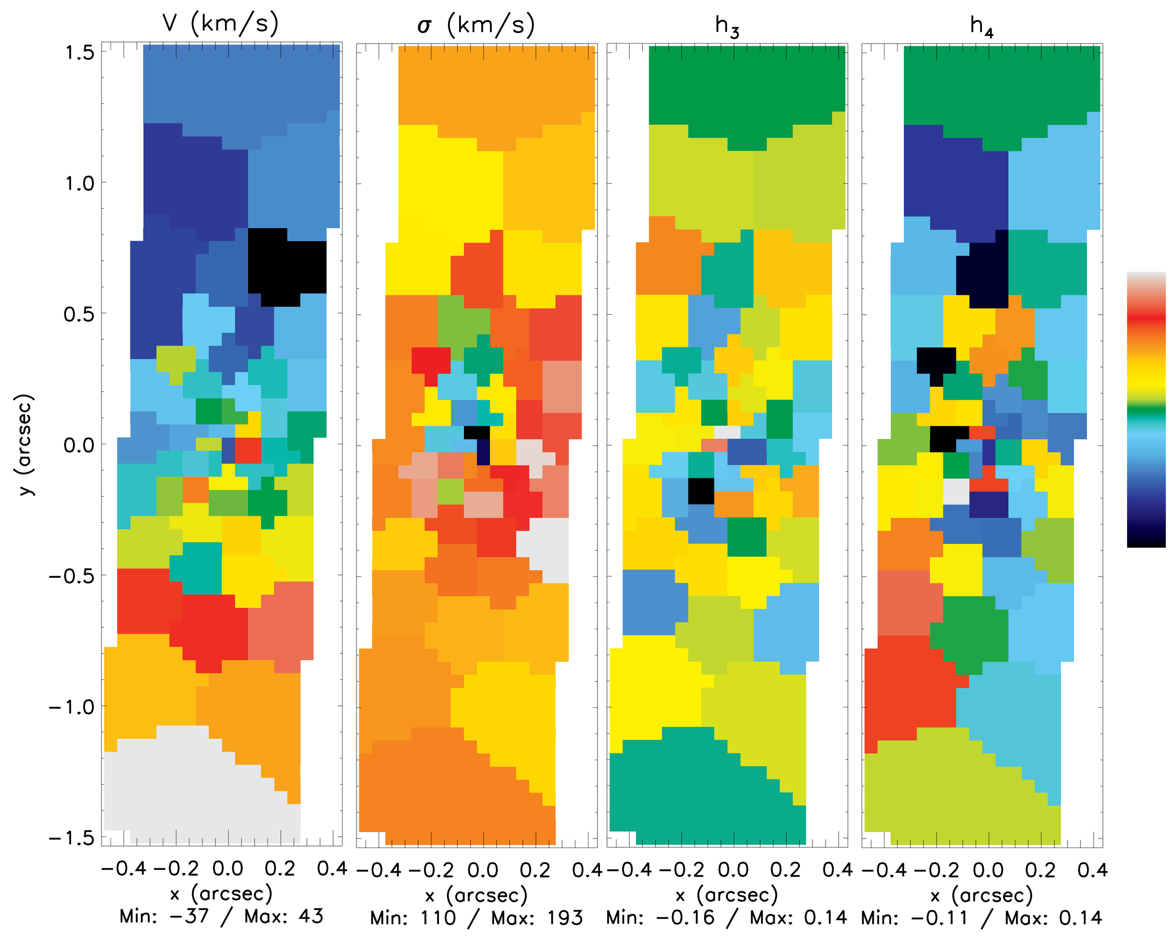

Figure 5. Maps of the stellar kinematics (V, σ, h_3, and h_4) for each spatial bin. The velocity map shows that the galaxy is rotating, as one side of the galaxy is blue-shifted and the other side is red-shifted. The velocity dispersion map shows smaller values at the nucleus compared to the outer spatial bins. There are no clear trends in the maps of h_3 and h_4. Typical errors on the kinematics are 8.12 km/s, 10.23 km/s, 0.037, and 0.045 for V, σ, h_3, and h_4, respectively. For NGC 4203, 1" corresponds to 73 pc.

The stellar kinematics as a function of spatial location are presented in Figure 5. We find that the galaxy is rotating, with velocities of -37 km/s to the north and 43 km/s to the south, and that the velocity dispersion decreases from ~170 km/s at a radius of 1" to 110 km/s at the center.

NGC 4203 has an active galactic nucleus (AGN), which makes measuring reliable stellar kinematics at the center more difficult. We therefore constructed a new set of spatial bins in which the central spectra showing clear AGN contamination were excluded. Figure 6 shows that even when removing the innermost spectra, there appears to be a drop in the stellar velocity dispersion near the nucleus. We also examined the robustness of the stellar kinematics by changing how the measurements were made with pPXF. We varied the wavelength range we fit over, changed how the continuum shape was modeled, found a new optimal stellar template in each spatial bin, and used three other template libraries. These various tests produced consistent results as those plotted in Figure 5.

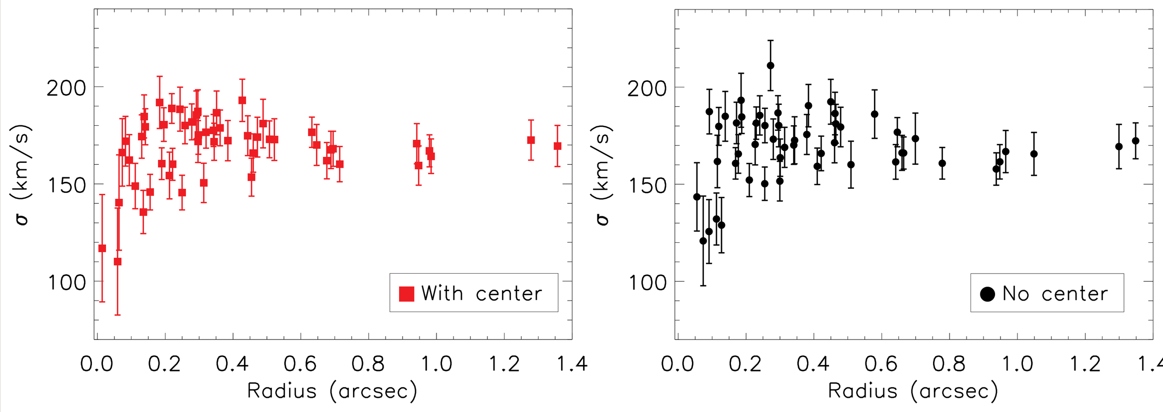

Figure 6. Plots of the velocity dispersion as a function of projected distance from the nucleus. We construct spatial bins using all the OSIRIS data (left) and excluding the central spectra with clear AGN contamination (right). In both cases, the velocity dispersion appears to fall at small radii.

Conclusion

Measuring stellar kinematics on small spatial scales is a crucial step in determining the mass of the black hole at the center of NGC 4203. In this study, we have established a robust set of kinematics from integral-field unit observations assisted by adaptive optics. The next step of the project involves measuring kinematics from seeing-limited, large-scale spectroscopy. All of the kinematics, along with information from imaging observations, will be fit with orbit-based dynamical models, leading to a secure black hole mass measurement for this important galaxy.

References

Kormendy & Ho, 2013, ARAA, 51, 511; Sarzi et al. 2002, ApJ, 567, 237; Beifiori et al. 2009, 692, 856; Walsh et al. 2012, ApJ, 753, 1, ; Capellari et al. 2004, AA, 116, 138.

Texas A&M University Department of Physics and Astronomy is an institutional member of:

Munnerlyn Astronomical Instrumentation Lab
Texas A&M University

GMT

HETDEX Illuminating the Darkness
Hobby-Eberly Telescope Dark Energy Experiment

LSST
Large Synoptic Survey Telescope

DARK ENERGY SURVEY

Acknowledgments

This work was supported by NSF grant AST-1263034, "REU Site: Astronomical Research and Instrumentation at Texas A&M University." Data were obtained at Keck Observatory, operated as a partnership among Caltech, UC and NASA. The Observatory was made possible by the financial support of the W. M. Keck Foundation. We acknowledge the significant cultural role that Mauna Kea has had within the indigenous Hawaiian community. We are most fortunate to be able to conduct observations from this mountain.