STELLAR KINEMATICS OF THE GALAXY NGC 1270

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ABSTRACT

Black holes (BHs) are believed to reside at the center of all massive galaxies. Past research has shown surprising correlations between BH masses and large-scale galaxy properties. To try to further our understanding of these correlations we examined the galaxy NGC 1270 using spectra obtained from the 10m Keck I telescope in Hawaii assisted by adaptive optics (AO) with the near-infrared, integral field unit (IFU) OSIRIS. We processed the raw frames using the OSIRIS data reduction pipeline to produce calibrated spectra at hundreds of different points within the galaxy. Then, using a Python routine that we wrote, a Penalized Pixel-Fitting (pPXF) method was applied to the spectra to determine the line-of-sight velocity distribution of the stars, characterized by the velocity, velocity dispersion, and higher-order moments that measure the distribution's deviation from a Gaussian shape. Analyzing this kinematic information will allow us to constrain the mass of the supermassive black hole at the center of NGC 1270.

INTRODUCTION

Research over the past two decades has shown correlations between BH mass and large-scale galaxy properties, such as galaxy bulge luminosity (e.g., Kormendy & Richstone 1995) and stellar velocity dispersion (e.g., Ferrarese & Merritt 2000, Gebhardt et al. 2000). These correlations surprise us as a BH's gravitational influence only significantly affects a small region at the center of its galaxy, so it should not impact larger-scale properties. This suggests that BHs and their host galaxies co-evolve and that BHs are essential components of galaxies, but we do not fully understand what role BHs play in galaxy evolution.

NGC 1270 is a local, massive, compact, early-type galaxy. Studies of three similar galaxies found some of the largest BHs known, and the objects deviated significantly from the BH mass-bulge luminosity relation (e.g. van den Bosch et al. 2012, Walsh et al. 2016). NGC 1270 potentially hosts a very massive BH as well. Using previous measurements of NGC 1270's large-scale velocity dispersion (327 km/s; Yildirim et al. 2017) and the current black hole mass - velocity dispersion relation (Saglia et al. 2016), a 2.6x10^9 $M_\odot$ BH may live at the center of NGC 1270. Here we determine the stellar kinematics at different spatial locations within the galaxy, which will be fit in the future with dynamical models to produce a BH mass.

DATA

Data for this research was collected with the 10m Keck I telescope in Hawaii. A series of 600 second exposures, totaling 4 hours, was taken in the near-infrared (K-band) with the help of AO and the IFU OSIRIS (Larkin et al. 2006). AO provides significantly improved angular resolution for ground based telescopes, allowing the Keck I telescope to achieve an angular resolution of approximately 0.1”. The higher angular resolution is critical for resolving the region where the gravitational potential of the BH dominates over the rest of the galaxy. In addition, the IFU allows us to obtain spectra at specific spatial locations within NGC 1270 instead of acquiring a single spectrum for the galaxy. This allows us to measure the stellar kinematics over a two-dimensional spatial field.

DATA REDUCTION

Each 600 s galaxy frame was reduced using the OSIRIS data reduction pipeline to produce a galaxy cube. The reduction process involves subtracting sky frames, eliminating glitches and cosmic rays, extracting spectra back to specific lenslets, calibrating the wavelength, correcting for atmospheric effects, assembling a data cube with two spatial dimensions and one spectral dimension, and applying a telluric correction using a reduced 1D spectrum of an A0 V star. Spatial offsets between galaxy data cubes were determined by collapsing each data cube and cross-correlating the resulting images. Then the data cubes were mosaiced together accounting for the offsets, creating a science ready galaxy cube.

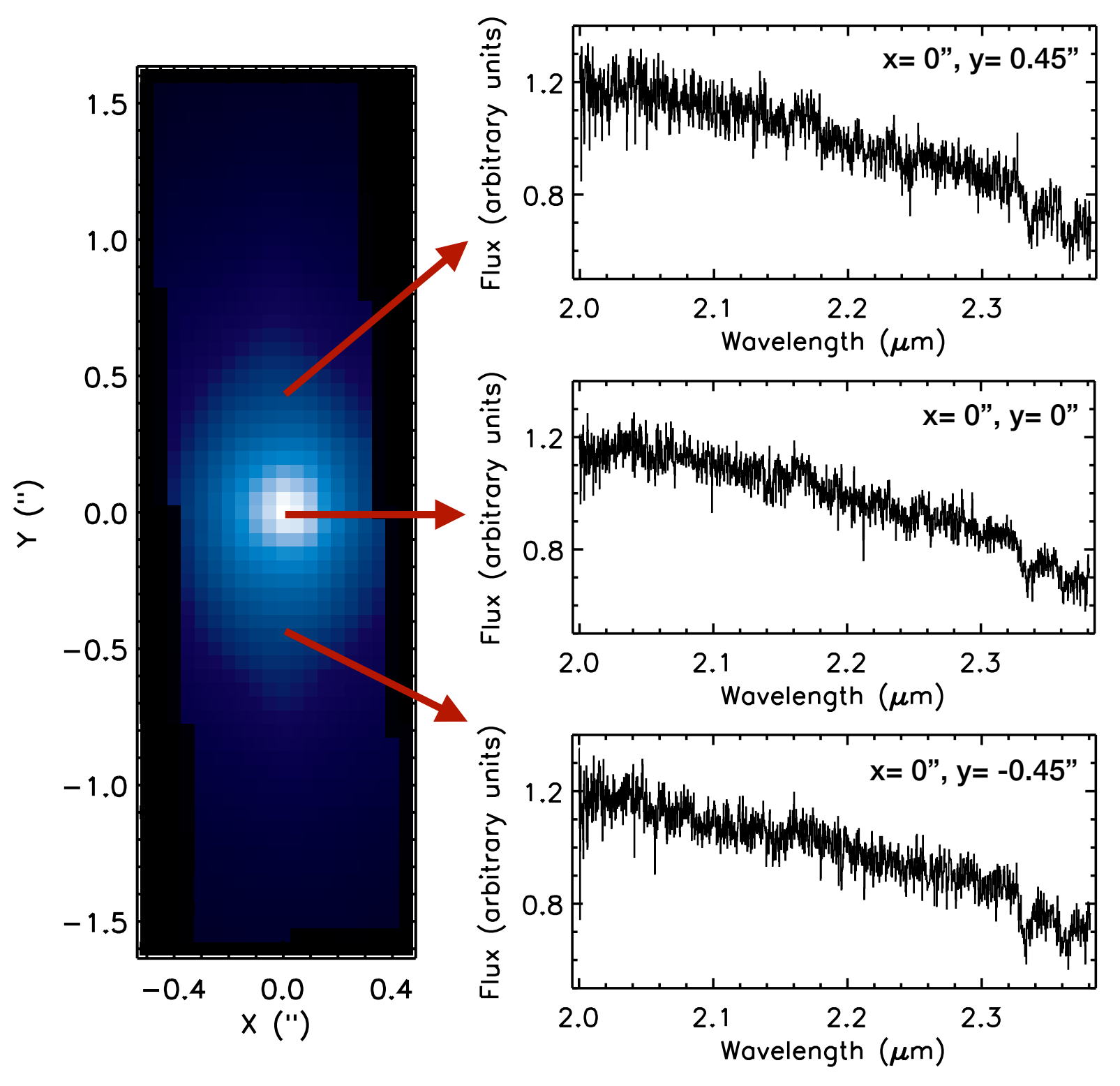

Figure 1. (Left) The NGC 1270 science ready galaxy cube and (right) spectra at different spatial locations extracted from single 0.05”x0.05” lenslets.

BINNING AND PPXF

In order to calculate galaxy kinematics, we had to bin our data to achieve a signal to noise (S/N) ratio of at least 40. We used a two-dimensional Voronoi binning Python routine (Capellari & Copin 2003) to bin our spectra in 54 spatial bins.

After binning our data, the spectrum from each bin was run through pPXF (Cappellari & Emsellem 2004, Cappellari 2017), which compares the given galaxy spectrum to template stars convolved with a line-of-sight velocity distribution (LOSVD). The LOSVD is described by the center [the velocity (V)], the width [the velocity dispersion (σ)], and higher-order moments [h_3 (skewness) and h_4 (kurtosis)] that characterize deviations from a Gaussian. We used a template star library composed of eight K and M giant stars, which emit most of the near-infrared light produced in early-type galaxies like NGC 1270. These stars were also observed on the Keck I telescope with OSIRIS.

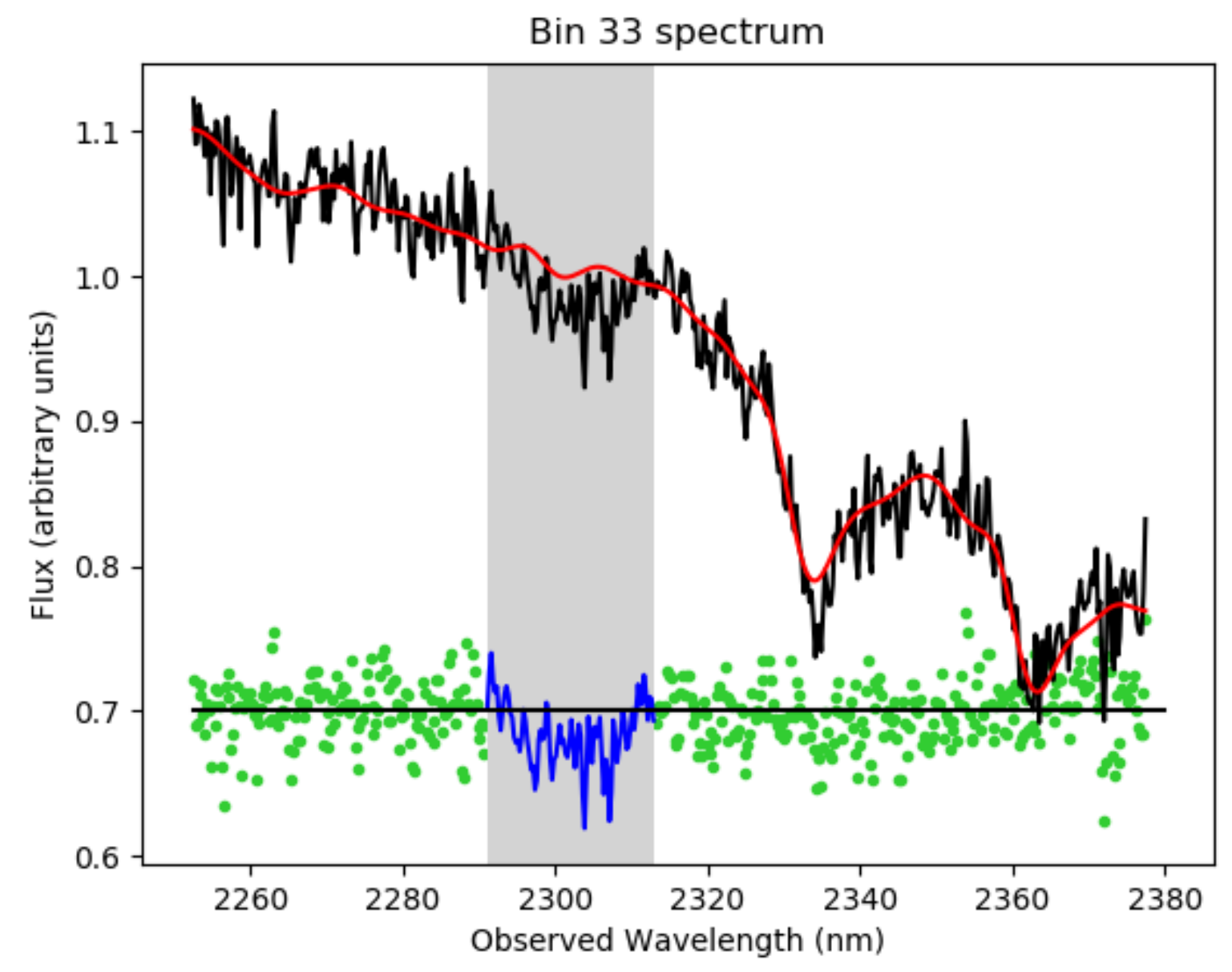

Figure 2. Spectrum (black line) for a bin near the center of NGC 1270. The pPXF best fit is plotted in red and the (adjusted, flat black line) residuals are plotted in green and blue. The gray shaded region displays the Ca I absorption line, which is ignored during the pPXF fit.

MONTE CARLO SIMULATION

We used a Monte Carlo simulation to determine errors on the galaxy kinematics. For each bin we used a Gaussian random number generator to create a realization of the observed galaxy spectrum. Random noise was added to the initial best-fit pPXF model spectrum and the level of noise was set equal to the standard deviation of the initial pPXF model residuals. Then we ran the mock galaxy spectrum through pPXF to produce kinematic information. This process was repeated 300 times for each bin, which allowed us to find the standard deviation of the resulting distribution for V, σ, h_3, and h_4.

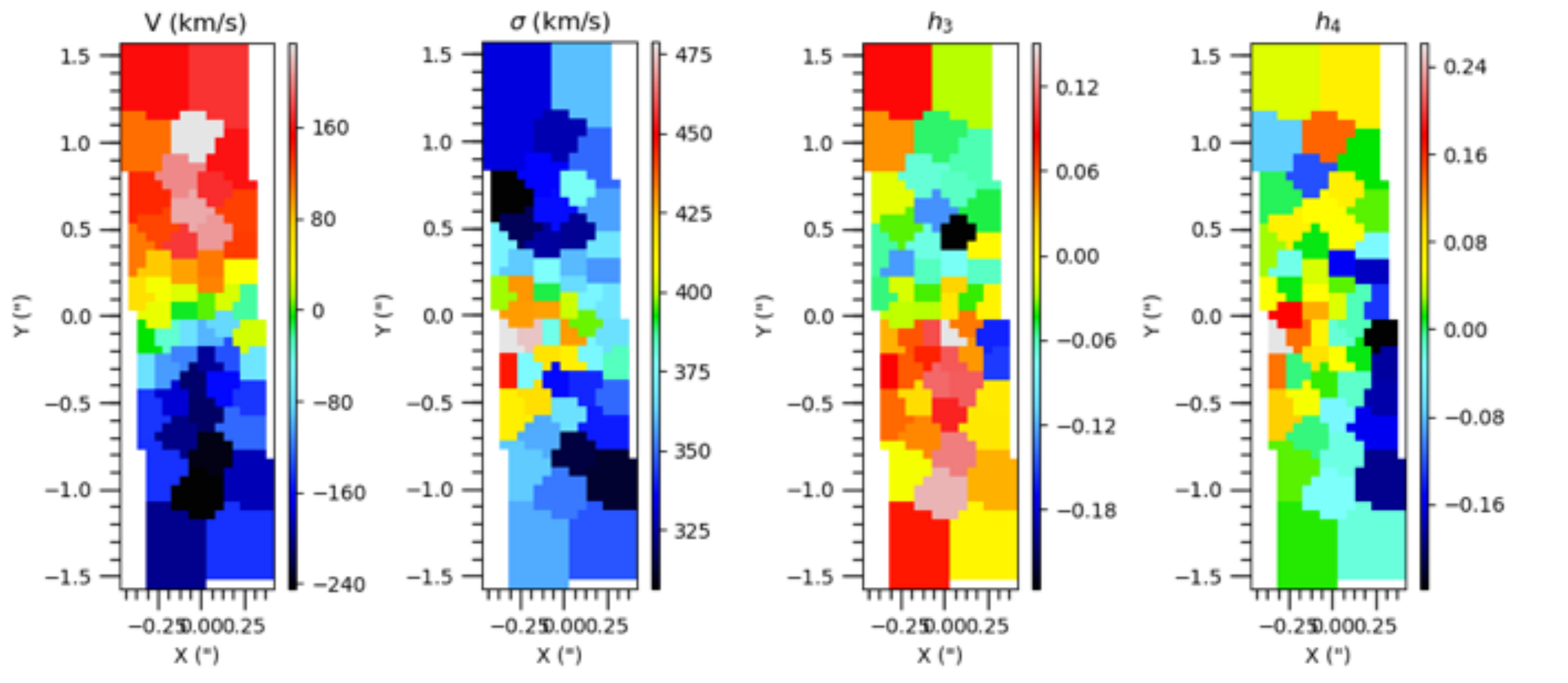

Figure 3, (a), (b), (c), (d). Maps of parameters produced by pPXF: (far left) velocity, (middle left) velocity dispersion, (middle right) skewness, (far right) kurtosis. Errors are roughly ±19 km/s in V, ±22 km/s in σ, ±0.04 in h_3, and ±0.05 in h_4.

RESULTS

We found that NGC 1270 is rotating, as can be seen in Figure 3 (a). The north end of the galaxy is rotating away from us and the south end is rotating towards us with velocities of -250 km/s to 230 km/s. Figure 3 (b) shows us that σ tends to increase at the galaxy center, reaching values of about 450 km/s. These results suggest that there is a BH at the center of NGC 1270. In addition, the h_3 map is anti-correlated with the V map, which is common for rotating, axisymmetric systems (e.g. Fisher 1997). Then we modified our pPXF fit by expanding the wavelength range to 2.138-2.380 μm, used additive and multiplicative polynomials from 0 to 2 (and in some cases, no additive polynomial), and assumed a Gaussian shape for the LOSVD. For nearly all spatial bins, similar kinematics were found.

FUTURE WORK

Going forward, we can examine the impact on the measured stellar kinematics by using a different template library with a larger number of stars. Then we can construct models of stellar orbits within the galaxy and find the model that best fits our stellar kinematics to determine the mass of the BH at the center of NGC 1270.

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