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Inferring the Existence of Dark Matter from the Rotation Curve of an Edge-on Galaxy

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1. OBSERVATIONS

The edge-on galaxy UGC 11876 was observed under spectroscopic conditions on UT 2019 September 26 with the KAST Double Spectrograph on the 3-m Shane Telescope at Lick Observatory. The KAST has two spectrographs—one optimized for observations at blue wavelengths and one for red. The KAST was configured with its red detector so Hα could be used to measure Doppler velocities. Observational parameters are summarized in Table 1.

Three spectra of UGC 11876 were taken with the red detector's slow ($\sim$ 20 s) readout mode using the d57 dichroic, which splits the incident flux between the red and blue arms of the spectrograph at around 5700 Å. Observations used the 1200/5000 grating, which has a resolution of 0.65 Å pix^{-1} and 1720 Å of coverage. The slit width was 1".5 and the exposure time for each observation was 360 seconds. Seeing on UT 2019 September 26 was favorable, at about 1".

2. DATA REDUCTION AND ANALYSIS

Science images were median combined, dark and bias subtracted, and flat-fielded. The wavelength solution was calculated by fitting a third-order polynomial to nine spectral features from the red detector's 1200/5000 Ne Ar lamp. The spectral features used for fitting span from about 6140 Å to about 7245 Å. The RMS error in our wavelength solution with respect to the true wavelengths of the nine lamp features is 0.23 Å. We expect that this level of error is negligible for our purposes, since the dominant source of error should come from fitting for the centroids of the Doppler-shifted Hα lines. However, a detailed quantification of the error in the centroid fitting process has yet to be completed.

Velocities were measured by fitting Gaussians to Hα at 129 pixels spanning the apparent spatial extent of UGC 11876. The start and end pixels were defined to be where the Hα SNR reached $\sim$1. The Gaussians were inspected by eye to cull for poor fits, leaving us with 124 measurements. Using each fit, we calculated the Doppler velocity between the mean wavelength of the Gaussian and H$\alpha_{\rm obs}$ = 6651.77 Å, where H$\alpha_{\rm obs}$ is the average of each of the 124 Gaussian means.

To convert from pixels to galactic radius, we first calculated the distance to UGC 11876 by estimating the galaxy's redshift from H$\alpha_{\rm obs}$, and using H_0 = 69.8 km s^{-1} Mpc^{-1} (Freedman et al. 2019). We find z = 0.0135, which matches the value for UGC 11876 found by Matthews & van Driel (2000). The galactic radius, r, of the ith pixel is then

$$r_i = \tan\left(\frac{2\pi}{360\times 3600}\times S\times|\mu - p_i|\right)\times d, \qquad (1)$$

where S = 0.43 arcseconds pix^{-1} is the red detector's plate scale, μ is the average pixel number of the 124 used, p_i is the ith pixel, and d is the distance to UGC 11876.

3. RESULTS

The rotation curve for UGC 11876 is shown in Figure 1. The curve begins to flatten out at larger radii rather than decay, suggesting the presence of a dark matter halo that surrounds the galaxy.

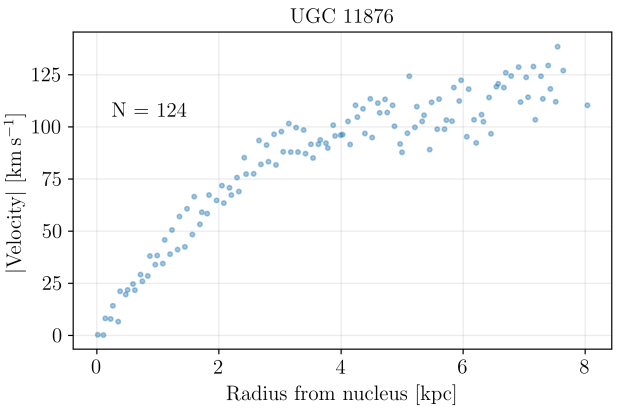

Figure 1. The rotation curve of the edge-on galaxy UGC 11876.

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Table 1. Summary of the KAST Spectrograph observations on UT 2019 September 26.

Target	Airmass	Grating	Grating Tilt	Center Wavelength (Å)	Exposure Time (s)	Slit Width (")	Position Angle (°)	Decker	Dichroic
UGC 11876	1.35	1200/5000	24900	6535.7	360	1.5	140	Open	d57
UGC 11876	1.33	1200/5000	24900	6535.7	360	1.5	140	Open	d57
UGC 11876	1.31	1200/5000	24900	6535.7	360	1.5	140	Open	d57

REFERENCES

Freedman, W. L., Madore, B. F., Hatt, D., et al. 2019, ApJ, 882, 34

Matthews, L. D., & van Driel, W. 2000, A&AS, 143, 421

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