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Rotation Curve Measurement of Dark Matter Content of a z ~ 0.5 Galaxy

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### **Abstract**

Measurements of galaxy rotation curves provide direct measurements of the distribution of baryonic and dark matter in galaxies. Here, we present spectroscopic confirmation and one such rotation curve for a z = 0.5325 galaxy observed with Keck I/MOSFIRE as a filler target for the Web Epoch of Reionization Survey. The rotation curve was derived from H $\alpha$  6563 Å emission out to a galactocentric radius of approximately 24 kpc. The target's rotation curve is well fit by an arctangent curve, that when combined with broadbanned photometric constraints on the galaxy's stellar mass, predicts a dark matter fraction consistent with results from the literature for  $z \sim 0.5$ . We constrain the estimate for this galaxy's dark matter fraction to be 93%, out to a galactocentric radius of 30 kpc.

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those galaxies (Sofue & Rubin 2001). When measured in tandem with photometric observations, we

fractional mass of dark matter (Carignan & Freeman 1985). Here we examine the resolved spectrum

of a serendipitously observed  $z \sim 0.5$  galaxy. In Section 2 of this note we detail the observations for

the target, and in Section 3 we outline the analysis of the rotation curve, present our measurements

of dynamical mass and the dark matter fraction for the target, and discuss our results and

can determine the total dynamical mass as a function of galactocentric radius and estimate the

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1. Introduction Galaxy rotation curves provide valuable insight into the evolution of the baryonic and dark matter components of our universe, as they enable direct measurement of the distribution of matter within

## conclusions.

2. Observational Information COS J100047+022256 was chosen initially as a filler target for the Web Epoch of Reionization Lya Survey (WERLS, a Keck Key Strategic Mission Support Program supported by NASA, Casey et al. 2023, in preparation, Cooper et al. 2023, in preparation), and is located at 10<sup>h</sup>00<sup>m</sup>47½05 +02<sup>d</sup>22<sup>m</sup>56½ 0 (J2000). WERLS targets the COSMOS field with the goal of obtaining spectroscopic redshift measurements for photometrically-selected galaxies. Our target's observations were taken at the W. M. Keck Observatory with the MultiObject Spectrometer for Infra-Red Exploration (MOSFIRE; McLean et al. 2012) on 2022 February 14 and 2022 March 14 with 0"7 seeing. We reduced the raw data using the public MOSFIRE data reduction pipeline (mospy  $\frac{11}{2}$ ). The mospy pipeline provides a sky-subtracted, flat-fielded, and rectified 2D slit spectrum per slit object. The reduced spectra are wavelength-calibrated using telluric sky emission lines built specifically for the instrument. COS J100047+022256 is in the COSMOS2020 catalog with ID: 106340 (Weaver et al. 2022). We measured the redshift to be z = 0.5325 by identifying H $\alpha$  6563 Å, [NII] 6583 Å, and [NII] 6548 Å in the one-dimensional spectrum; we derive the spectroscopic redshift solution by fitting a Gaussian to the H $\alpha$  emission line. This measured redshift agrees well with the LePhare-Farmer photometric redshift estimate of  $z = 0.5318 \pm 0.008$  from COSMOS2020. Further analysis of the target's twodimensional spectrum revealed kinematically resolved spectral features, most notably Hlpha 6563 Å and [NII] 6583 Å.

### The rotation curve was extracted from the two-dimensional H $\alpha$ spectrum, shown in Figure 1(a). To

3. Rotation Curve Analysis

perform this extraction, we first identified the region which contains the entirety of the spectral feature, in both wavelength-space and spatial extent. After identifying the object's spatial extent, the units of that axis were converted to kiloparsecs using the MOSFIRE pixel scale. After converting the spatial axis from pixels to arcseconds and kiloparsecs in proper units based on angualr diameter distance at z = 0.5, we then plotted the measured velocities against spatial offset. We determined the maximum extent of the H $\alpha$  emission to lie at a galactocentric radius of approximately 24 kpc. To measure a rotation curve we extract a 1D spectrum along each spatial pixel (whose scale = 0"18=~ 2.69 kpc); we precisely measure a centroid wavelength for the emission line in each spatial row to then calculate a velocity relative to the systemic. The data were then fit to the following arctangent function (Courteau 1997; Weiner et al. 2006):

(Erb et al. <u>2006</u>): in units of solar masses, where  $V_m$  is the value of the fit function at  $r_m = 24$  kpc. We utilized the best

fit values of  $r_k = 19.2 \pm 4.3$  kpc,  $r_0 = -6.4$  kpc and  $V_a = 151.4 \pm 22$  km s<sup>-1</sup> to produce the rotation curve

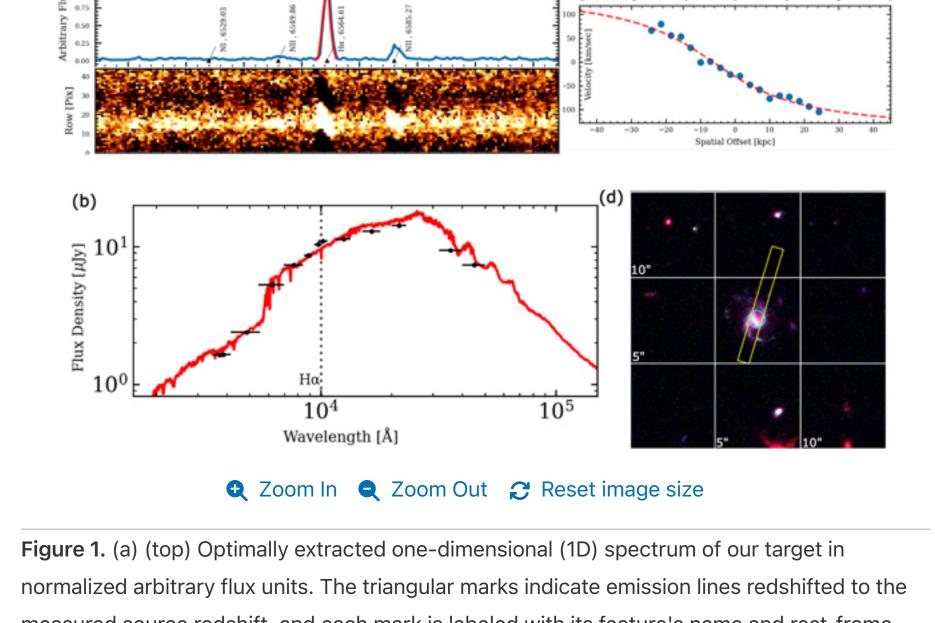
Solving for the knee radius  $r_k$ , the correction for the galaxy's center position  $r_0$ , and the asymptotic

velocity  $V_a$ , we extrapolated the dynamical mass of the target according to the following equation

shown in Figure 1(c), as well as to produce an estimate for the dynamical mass of the target out to a galactocentric radius of 30 kpc (i.e.,  $r_m - r_0$ ). The dynamical mass estimate is  $(6.7 \pm 3.1) \times 10^{10} M_{\odot}$ . Using this dynamical mass estimates and the stellar mass estimate derived from the Farmerextracted photometry from the COSMOS catalog  $M_{\cdot} = (4.7 \pm 0.4) \times 10^9 M_{\odot}$ , we can then determine an estimate for the dark matter fraction for this target according to the following equation: The estimate for  $f_{DM}$  is  $0.93 \pm 0.03$  (out to a galactocentric radius of 30 kpc). The radius for

measurement was chosen specifically to be both larger than  $r_k$  and to be in the flatter section of the

arctangent curve, placing our radius of measurement well within the dark matter halo of this galaxy. This dark matter fraction is largely consistent with what is expected both for  $z \sim 0.5$  galaxies as well as galaxies in the local universe (Rubin et al. 1980). However, we note that this dark matter fraction does not directly account for the gas content of this galaxy or underestimation of the stellar mass (e.g., Maraston et al. 2010), each of which would cause an overestimation of the DM fraction. For example, if the galaxy has a gas mass equal in magnitude to its stellar mass, the dark matter fraction would be reduced to  $f_{\rm DM} \sim 0.86$ . Conversely, resolved imaging of the galaxy suggests it is face-on, which could lead to an underestimation of  $f_{DM}$ . This underestimation could be accounted for by implementing an inclination correction. A more reliable estimate of dark matter content requires both gas observations and ideally Integral Field Unit spectroscopy. (c) (a)



measured source redshift, and each mark is labeled with its feature's name and rest-frame wavelength (in Angstroms). (bottom) Signal-to-noise two-dimensional (2D) spectrum of our target. (b) LePhare Spectral Energy Distribution (SED) fit to Farmer-extracted photometry for COSMOS ID 106340 from the COSMOS catalog. The vertical dashed line marks where H $\alpha$  was observed. (c) Rotation curve extracted from the 2D-spectrum, with the spatial offset converted to kiloparsecs. The red curve is an arctangent fit function with  $r_k = 19.2 \pm 4.3$  kpc. (d) RGB image of COSMOS ID 106340 generated from three HST images taken in the F606W, F814W, and F125W bands. The MOSFIRE slit is shown in yellow, and the cyan circle outlines the region on the slit in which the target lies. The dimensions of this cutout are 15" by 15". Download figure: Standard image High-resolution image

fortunate to have the opportunity to conduct observations from this mountain. **Footnotes** 

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the summit of Maunakea has always had within the indigenous Hawaiian community. We are most

The authors wish to recognize and acknowledge the very significant cultural role and reverence that

# 11 <a href="https://keck-datareductionpipelines.github.io/MosfireDRP/">https://keck-datareductionpipelines.github.io/MosfireDRP/</a>

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