Examining a High Redshift Rotation Curve and Dark Matter Profile

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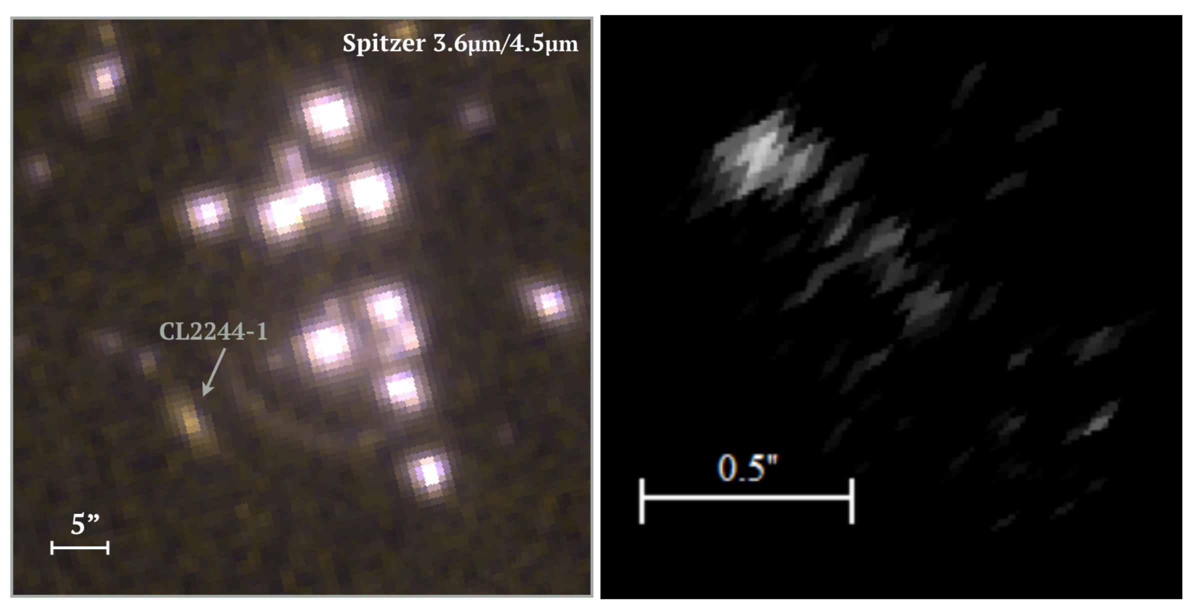
ABSTRACT

Examination of galactic rotation curves in the local universe has yielded evidence of both cusp and core type dark matter profiles. We present one of the first studies of a spatially resolved galactic rotation curve for a distant gravitationally-lensed galaxy, CL2244-1. This massive, dusty star-forming galaxy has a spectroscopic redshift of 1.77, existing when the universe was a mere 3.6 billion years old. Using VLT/X-SHOOTER spectroscopy, we perform a 2D spectral analysis of the Hα emission to obtain a total rotation curve. Follow up photometric observations with the Keck/MOSFIRE Ks-band were then obtained to estimate stellar mass through stellar population synthesis modeling. The resulting dark matter contribution was fit with Burkert (core) and NFW (cusp) profiles, with the Burkert profile being the better fit. Though this cored profile does not support the cold dark matter cosmological model on its own, we cannot rule out baryonic effects, like outflows, which may have shifted the dark matter distribution to a core without violating CDM. Alternatively, this result could be explained by self-interacting dark matter, whose interactions were strong enough to shift the density of the profile.



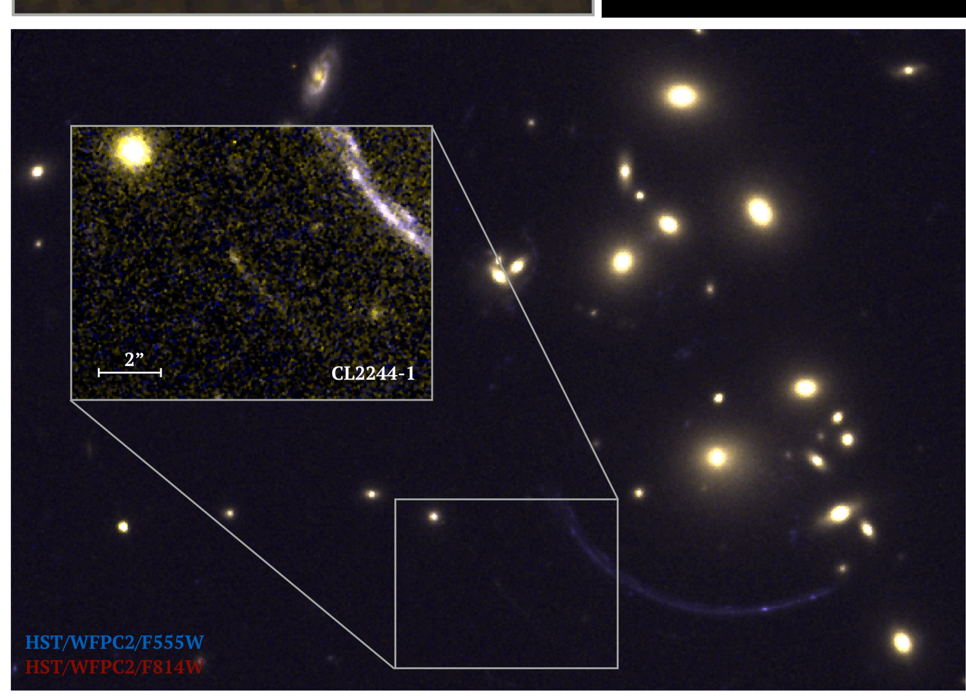


Figure 1. Spitzer IRAC 3.6μm (blue) and 4.5μm (red) and HST/WFPC2 F555W (blue) and F814W (red) color images of CL2244-1 (top left and bottom, resp). The zoom panel shows our target. HST F814W source plane reconstruction (top right). 1"=7.8 kpc at z=1.77.

BACKGROUND & DATA

Dark matter and its physical properties has proven to be difficult for astronomers to determine observationally. Analysis of rotation curves from galaxies in the local universe have shown that the distribution of dark matter in galaxies falls into one of two categories: cuspy or cored profiles. Cuspy profiles have dark matter densities that diverge as you approach the galactic center, while cores have a more constant density towards the center. Theoretically, cusps could point to our current understanding of dark matter as Cold Dark Matter (CDM), while cores could indicate Self Interacting Dark Matter (SIDM). One theoretical interpretation for the existence of both of these types of dark matter is that galaxies begin with cusps but are then dispersed into cores by dark matter interactions [1]. A more likely explanation is that baryonic effects, like outflows, can shift the density of dark matter at small radii, resulting in cores [2]. Measurements of rotation curves at different redshifts outside the local universe would provide more evidence of this hypothesis, however measuring rotation curves requires high resolution to determine the velocity sufficiently as a function of radius . In our case, we observed a gravitationally lensed galaxy (CL2244-1) at redshift 1.77 in order to obtain the necessary resolution.

CL2244-1 observations are listed below:

- VLT/X-SHOOTER spectroscopy
- Hubble Space Telescope (HST) F555W and F814W archival images
- Spitzer Space Telescope Channel 1 and 2 archival images
- Son of ISAAC (SofI) J- and K-band images
- Keck/MOSFIRE K_s-band images

METHODS & RESULTS

- Measured spectroscopic redshift of 1.77 from Hα and [NII] (Fig. 3, left).
- Extracted 1D spectra from 2D spectrum (Fig. 3, right) to obtain observed plane total rotation curve.
- Obtained errors on total rotation curve by a Monte Carlo bootstrapping.
- Using lensing model (Fig. 1, top right), transformed rotation curve into source plane (Fig. 2, black data points).
- Obtained Keck/MOSFIRE K_s-band image of CL2244-1 and combined with stellar population synthesis (FSPS) models to obtain radial stellar mass dependence.
- Derived observed and source plane stellar rotation curve contributions (Fig. 2, red line).
- Subtracted stellar contribution from total to obtain dark matter contribution (Fig. 2, blue data points).
- Fit Burkert (core) and NFW (cusp) dark matter profiles to the dark matter rotation curve contribution (Fig. 4).
- Obtained χ^2 values of 1.70 for the Burkert profile and 4.91 for the NFW profile.

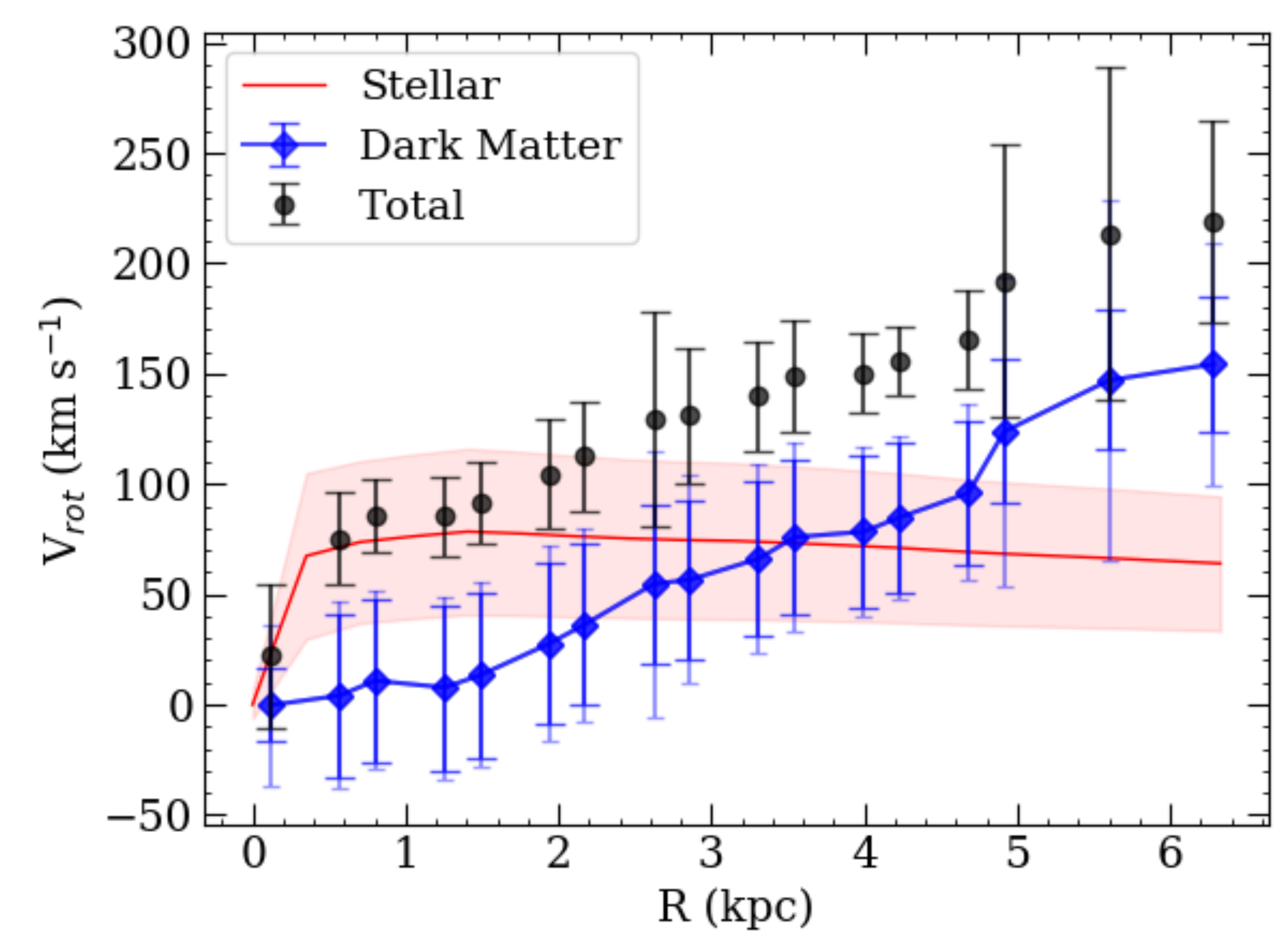


Figure 2. Source plane rotation curve of CL2244-1. The total rotation curve from Hα emission is shown in black, while the stellar rotation curve estimate and remaining dark matter component are in red and blue, respectively.

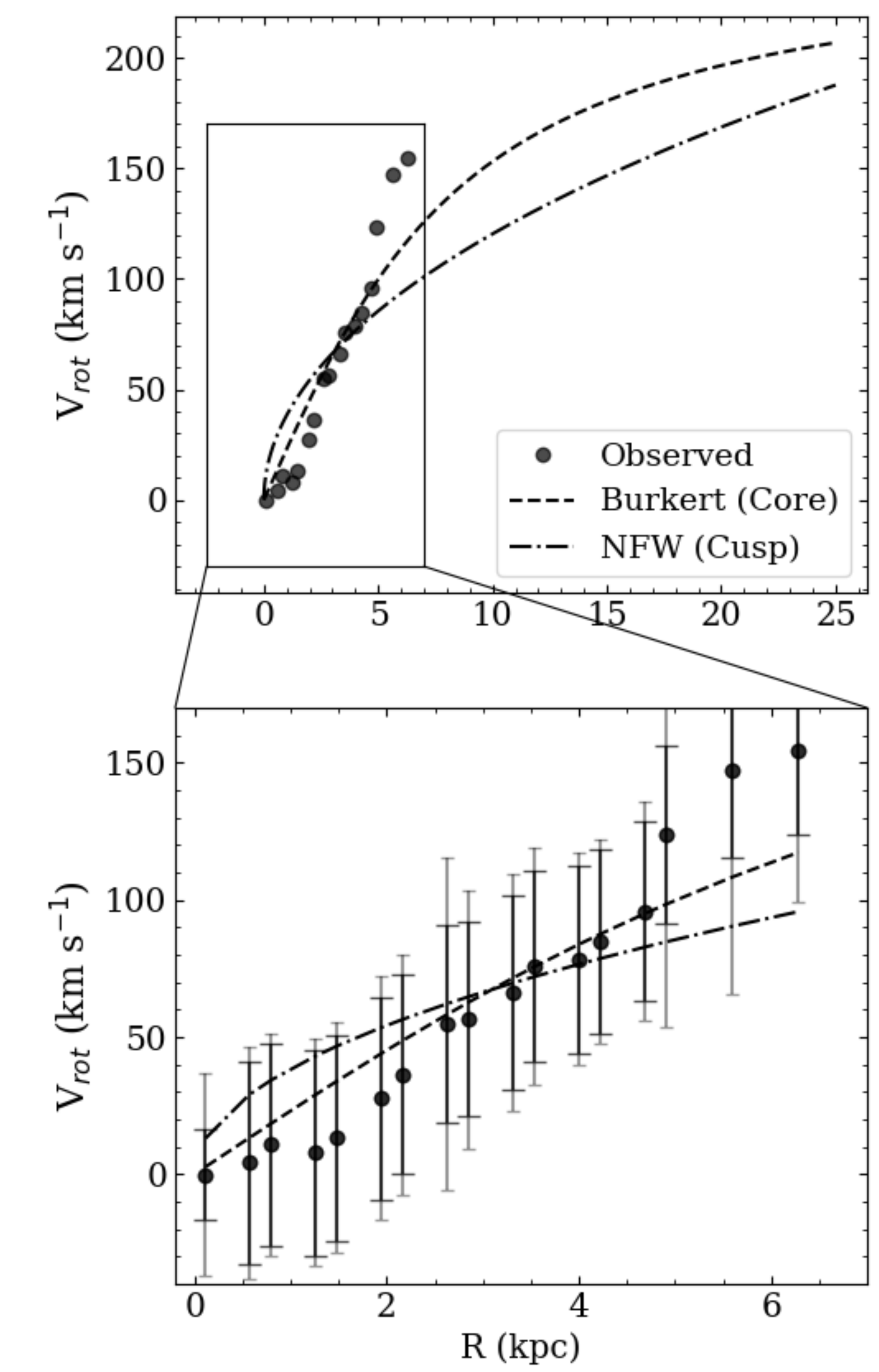


Figure 4. Burkert (core) and NFW (cusp) dark matter profile fits to observed dark matter rotation curve component, shown with dashed and dashed-dotted lines, respectively. The top panel shows the shape of the best fit profiles out to 25 kpc, while the bottom panel shows the fits on the scale of the observed data.

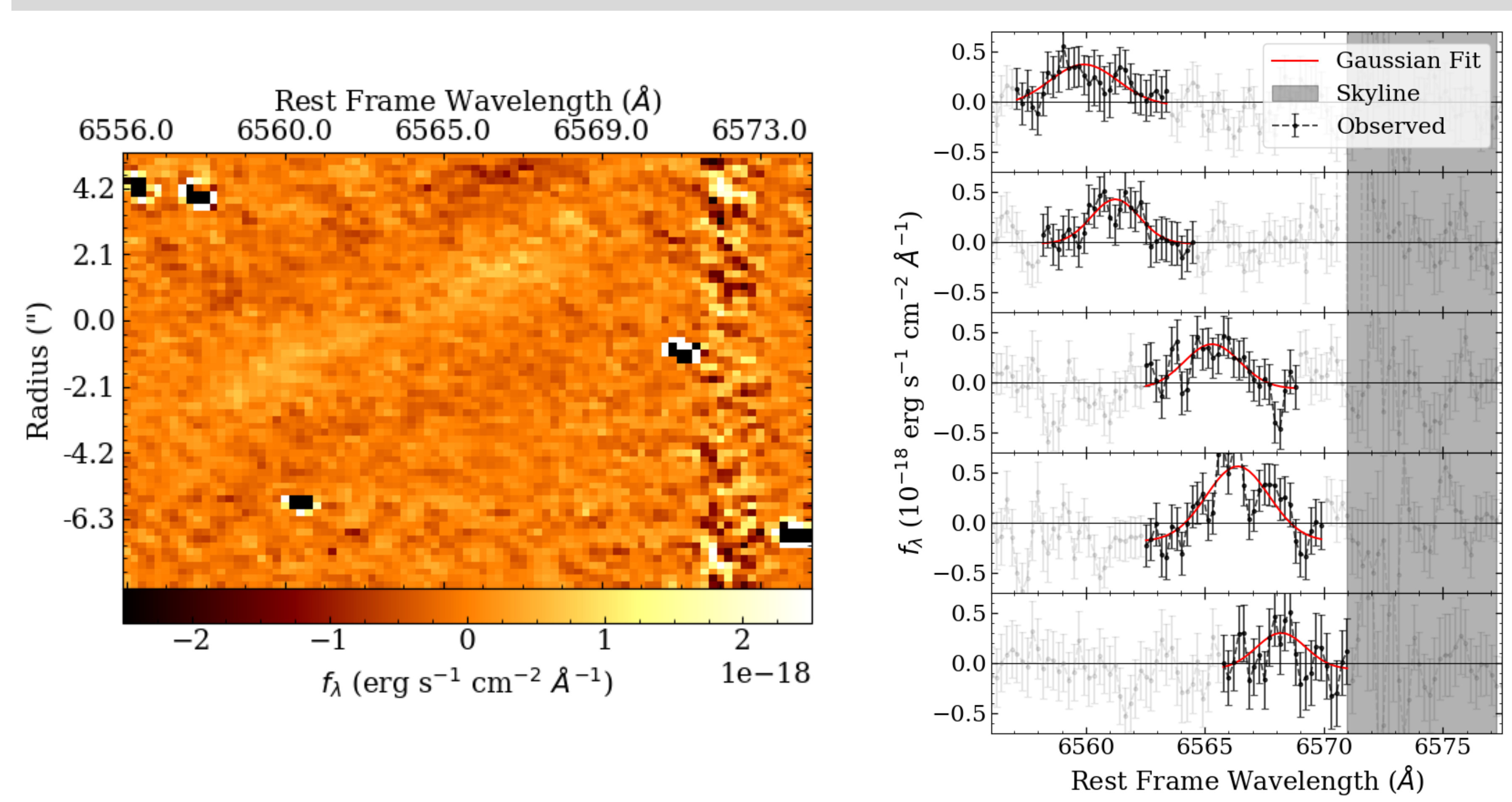


Figure 3. 2D spectrum of CL2244-1 showing the Hα emission (left) and example 1D spectra fits extracted from the 2D spectrum (right). The black data points indicate the observed flux, while the red line is the best fit gaussian to Hα for that 1D spectrum. The greyed region is a night skyline, visible in the 2D spectrum. The top, middle, and bottom panels were taken at -1.575", -0.315", and 1.785", respectively, with 0" being the galactic center.

CONCLUSIONS

- CL2244-1 is best fit by a Burkert (core) dark matter profile
- Similar to most galaxies in the local universe
- Opposes expected results from CDM simulations
- Possible conclusions:
  - CDM is flawed and dark matter self-interactions (SIDM) have prevented diverging densities in galactic centers
  - CDM is still correct and baryonic effects, like gas inflows/outflows, have shifted the density of dark matter to a cored profile

While the former is possible, it implies significant changes to the current cosmology. On the other hand, baryonic effects are much more reasonable and recent CDM+Hydrodynamics simulations have been able to recreate cored density profiles [2].

ACKNOWLEDGEMENTS & REFERENCES

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[2] Governato, F., Zolotov, A., Pontzen, A., et al. 2012, MNRAS, 422, 1231