

Overview:

This Cume is based on the paper “Stellar Velocity Dispersion of a Massive Quenching Galaxy at $z = 4.01$ ” by Tanaka et al. 2019.

The exam contains 11 questions, worth 66 total points. The anticipated passing grade is 75%.

Additional Instructions:

- Please start each question on a new page and write legibly.
- Aim to answer questions completely but **concisely**, generally in a few statements.
- Be careful with your time management. Do not spend too much time on any one question. I recommend that you try to get through all the questions within ~ 90 minutes, and then use the remaining ~ 30 minutes to go back and complete any parts you skipped.
- Calculators may be used for calculations, but you may not use any other outside resources (i.e., no stored equations, notes, books, internet access, etc.).
- If at any point you aren’t able to remember or calculate a specific value, just introduce a variable or state your assumption and proceed with the rest of the question.
- At the end of the exam, put your responses in question order, scan or photograph them, and email them back to me directly (mkpresco@nmsu.edu). I will check your submitted document for clarity and completion and reply to acknowledge your submission.

MOTIVATION

1. (6 points) In the Introduction, the authors assert that massive galaxies underwent an intense starburst in the early universe and passively evolved after that. Given what you know about the spectroscopic properties of massive galaxies, give evidence to support their claims that (a) the stars formed early, and (b) in a short burst.
2. (6 points) In a few sentences, describe (a) the scientific analysis performed in this paper and (b) at least one important result, including how this result fits into the larger picture addressed by the paper.

GALAXY MAIN SEQUENCE

3. (6 points) Based on the information in Section 2.1, sketch the Main Sequence of Star-forming Galaxies, and then show where the target galaxy is in relation to it. Be sure to label the axes, include one approximate numerical value on each axis, and show how you determined where to place the target galaxy.
4. (4 points) If a galaxy were located substantially **above** the Main Sequence of Star-forming Galaxies, what would that suggest about the galaxy?

EMISSION LINES

5. (10 points) The Balmer Formula has the form $\frac{1}{\lambda} = R_H(\frac{1}{n^2} - \frac{1}{m^2})$, and relates the wavelength of a transition to the energy levels of the Hydrogen atom that produce it, with a coefficient R_H , the Rydberg constant for Hydrogen. Use the Balmer Formula and **the labeled features in Figure 1** to (a) estimate the restframe wavelength of $H\gamma$ and (b) show that $R_H = 1.09 \times 10^7 \text{ m}^{-1}$.
6. (4 points) In Section 2.2, the authors use the fact that there are no optical emission lines and no infrared emission detected from the target galaxy to argue that the galaxy is quiescent. Explain why it is important to have **both** constraints to rule out star formation.

SPECTRAL MODELING

7. (6 points) In Section 3, the authors decided to exclude models with subsolar metallicity. Given what you know about galaxy metallicities, sketch and explain a well-known plot that would help justify this decision. Numerical values aren't necessary, but be sure to label what is plotted on each axis.
8. (4 points) The authors mention in Section 5 that they assume a Chabrier initial mass function (IMF). Sketch and describe what the IMF is and how the Chabrier IMF differs qualitatively from the Salpeter IMF.

FUNDAMENTAL PLANE

9. (4 points) The “Mass Fundamental Plane” shown in Figure 5 (right panel; dotted line). Using the information in the figure, write the “Mass Fundamental Plane” relationship down as an equation of the form $x \propto y^a z^b$.
10. (10 points) Starting with the idea of Virial equilibrium, derive the rough scaling that is expected for the **classical** Fundamental Plane, a relationship between the key observable quantities for elliptical galaxies (i.e., σ_0 , the central velocity dispersion; r_{eff} , the effective radius; and I_{eff} , the surface brightness at the effective radius).

KINEMATICS

11. (6 points) In Section 6, the authors discuss the challenges of measuring the amount of rotation in the galaxy with the current data. Describe a complementary observation that would enable measurement of the amount of rotation in a $z \approx 4$ galaxy similar to the target galaxy, and be sure to explain how the observation would work and the key advantage over the current data.