Determining Quasar Galaxy Morphologies Using GALFIT

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ABSTRACT

Little is known about the morphologies of quasars. Quasars are the brightest of the active galaxies, in which a supermassive black hole is accreting material, creating an accretion disk that outshines the host galaxy. We model images obtained from the Hubble Space Telescope of 22 nearby quasars and the galaxies in their immediate neighborhood using the GALFIT software to determine how well they are fit by typical galaxy profiles. GALFIT is an image analysis algorithm which fits parametric functions to create light profiles from two-dimensional images. We fit the quasars using two main components - a Point Spread Function (PSF), which represents a point source object (the light of the accretion disk), and a Sérsic profile, which models galaxy structures, such as a disk or a bulge. We will present details on the models, including the types of components used in each fit as well as the residual maps after subtracting the model from the data.

BACKGROUND

Quasars are a rare example of an active galaxy - those with supermassive black holes accreting material - except that quasars have accretion disks that spin so fast the particles within the disk generate a tremendous amount of radiation, which illuminates the center nuclei so brightly it dominates the host galaxy's light. Little is known about quasar morphology or what causes quasars to exist in the first place and what is causing the black hole to accrete material so rapidly is a question that remains unanswered. There is no consensus what galaxies do quasars live in and what triggers the accretion of matter onto their central black hole. Once thought to be hosted by boring elliptical galaxies (e.g. Dunlop et al. 2003), deep imaging observations with HST revealed signatures of past galaxy collisions (e.g., Canalizo et al. 2007, Bennert et al. 2008). Understanding what the host galaxy looks like will shed light onto the cause of the existence of these objects. We model images obtained from the Hubble Space Telescope of 22 nearby quasar galaxies and their immediate galaxy neighbors using an image analysis algorithm called GALFIT. This algorithm fits parametric functions to create galaxy light profiles from two-dimensional images, determining the best-fit model via chi-squared minimization. We subtract our best-fit model from the data to create residual light maps which provide visual and quantitative details on the goodness of the fit.

OBJECT SAMPLE

The objects of interest are 22 local LoBAL quasars selected from the Sloan Digital Sky Survey Third Data Release (SDSS DR3). Details of the sample selection can be found in Lazarova et al. (2012). As most astronomical objects are categorized by their spectra, LoBAL QSO's are characterized by a blue-shifted broad absorption line of Mg II 2800Å. All the objects are within a cosmological redshift value of 0.50 < z < 0.60 as objects closer than z = 0.48 do not have the Mg II line in the SDSS spectral range. These redshift values correspond to distances 5.00-5.80 billion light years away from us. The images used in this report were obtained with the Hubble Space Telescope Wide Field Camera 3 with the broad band F125W filter by PI: Canalizo, (HST proposal ID 11557).

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METHODS

GALFIT is a program which takes parameterized functions to model light distributions from data. This program allows us to create different galaxy styles and features as we would in nature. Here, we outline the process of creating galaxy models using this image analysis algorithm to investigate properties of quasar galaxy morphologies. GALFIT runs through a UNIX terminal by executing parameter files that we create containing code that the algorithm knows how to read like control parameters and information on how to fit the different objects.

1. GALAXY PROFILE MODELS

We first manipulate functions/profiles which fit to the light from the telescope data. The functions used in this model were the Sérsic and PSF profiles.

A. The *Sérsic function* describes how the intensity of a galaxy changes with distance from the center and has the mathematical form of:

$$I(r) = I_0 exp[-k_n((\frac{r}{r_e})^{\frac{1}{n}} - 1)]$$

where the Sérsic index n determines how concentrated the light will be. Higher n values correspond to denser inner profiles with highly extended wings while lower n values have shallow inner profiles with steep truncations (see figure 1). The free parameters for the Sérsic profile are the object coordinates, magnitude, half-light radius, Sérsic index n, axis rotation, and the position angle which were. As shown in figure 2 below, the model for SDSS J085215+492040 features different types of galaxies all created with varying Sérsic function inputs. The arms of the spiral were created by adding a hyperbolic tangent log coordinate rotation. This specific rotation allows for the creation of bar spirals and creates a 3D model which we allows us to incline the model.

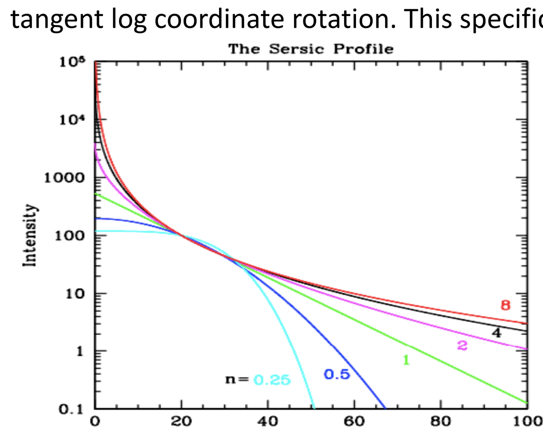

Figure 1. Graph showing how varying n values, "concentration parameter", correspond to longer truncations or denser centers. (Peng, 2002, AJ, 124, 266)

B. The *Point Spread function* (PSF) represents a point source object, such as a star. Since quasars are so bright and very far away, the light seen from Earth represents that of a point source. We observed a star to model the PSF response of the telescope and used that image to subtract the quasar light to reveal the underlying galaxy.

2. CREATING MASKS

Any light we want GALFIT to ignore while fitting must be specified by creating regions in SAO Image DS9. DS9 is an astronomical data visualization and imaging program that allows us to view FITS files, which are files with layers of data. Using 2 scripts created by Chien Peng, the creator of GALFIT (Peng et al. (2002), AJ, 124) to turn regions into a list of pixel coordinates for the program to ignore. We create outlined regions in DS9 as shown in figure 3 and use the first script to turn these regions into numerical vertices for a shape; the second script outputs the (X,Y) coordinate of each pixel in that region. A single list is compiled of all the pixels for every mask and is fed into GALFIT's control parameters to extrapolate over those as not to effect the galaxy fits.

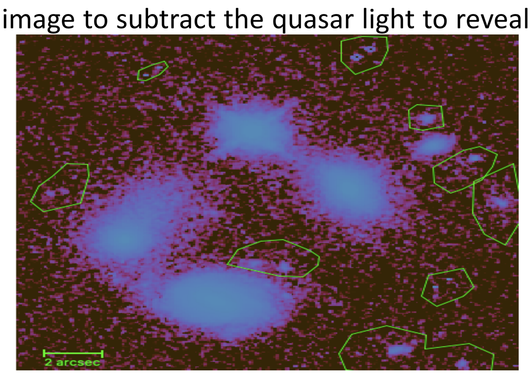

Figure 3. Image of HST data with the masked regions to be ignored represented by the green outlines. These shapes were translated into vertices which were then turned into a list of X,Y coordinates of each pixel within the shapes.

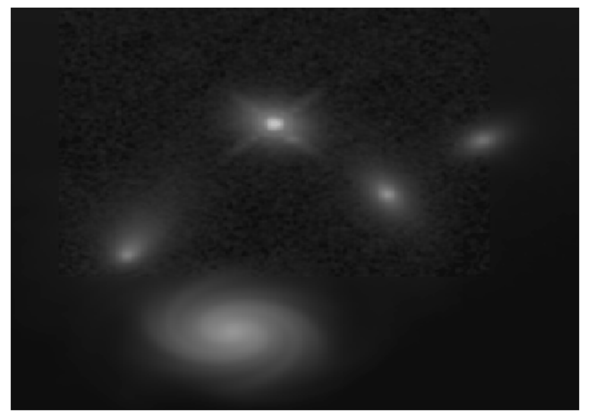

Figure 2. Initial model created for the object SDSS J085215+492040 using the Sérsic and PSF function to create these 5 galaxies.

3. MODEL OPTIMIZATION

GALFIT performs a minimization of the fit which determines the goodness of the fit and suggests how to adjust parameters for the next iteration. It uses a "Levenberg-Marquardt algorithm to find the optimum solution to a fit" (Peng et al. (2002), 2). The goodness of the fit is based off the normalized $\chi^2$and the closer this value is to 1, the better the model represents the data. Each iteration of an optimization provides its own model and residual map to gauge how well of a fit the run was.

4. RESIDUALS

Residual maps we created by subtracting the optimized model from the imaging data – this reveals visually how well the model fits the data. If the model for that object is a good fit, the galaxy will seem to have disappeared in the residual, leaving only background noise (see figure 4).

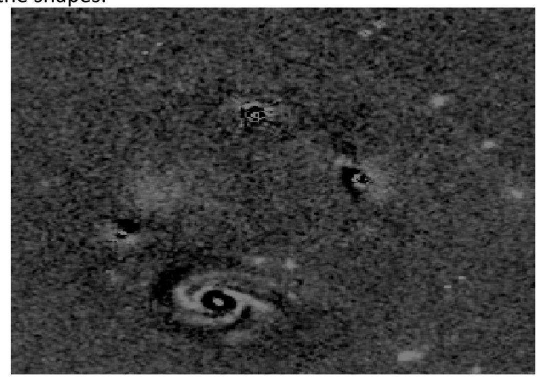

Figure 4. Residual map for one of the optimizations. Notice the top object, the QSO, is almost completely removed when fitted merging with a smaller companion as seen in Figure 3. The light from the spiral arms was not a good fit thus leaving light behind.

RESULTS

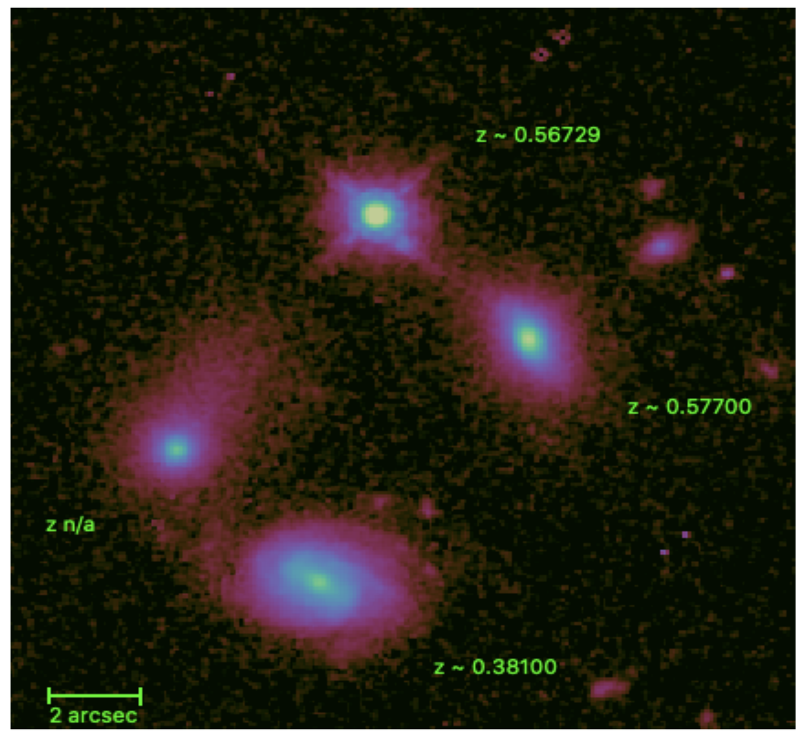

Figure 5. Imaged is the data from Hubble Space Telescope of SDSS J085215+492040. The z values correspond to their cosmological redshifts.

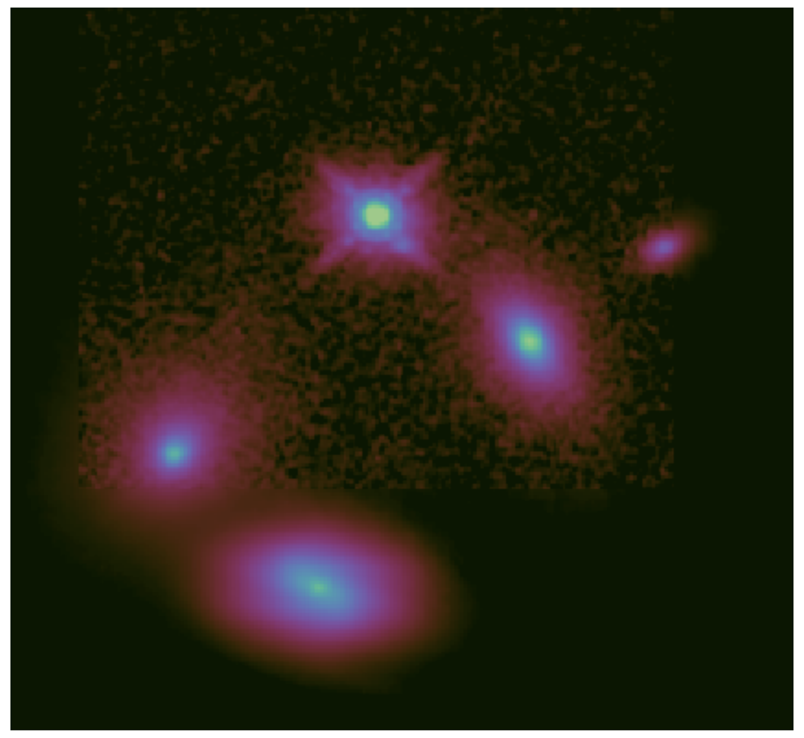

Figure 6. This is the final optimized model created for object SDSS J085215+492040.

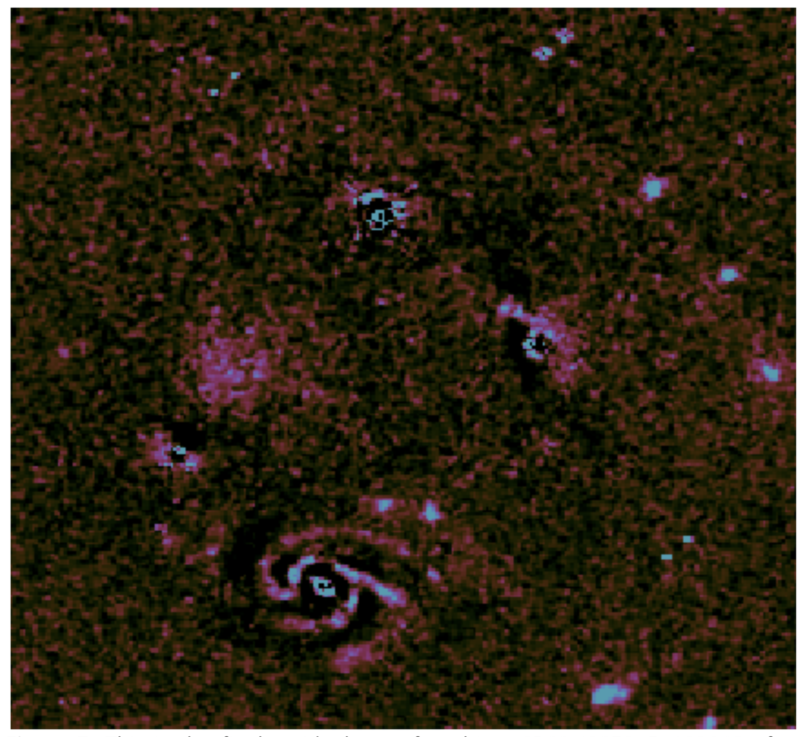

Figure 7. This is the final residual map for object SDSS J085215+492040 after subtracting the model in figure 6 from the original data in figure 5.

Shown above is the original data from HST (figure 5), the optimized model (figure 6), and the residual light map (figure 7) for the object SDSS J085215+492040. Our final Chi^2 value was 2.000 (compared to a 1.000 perfect Chi^2). The spiral arms were attempted but through the process of optimizing, GALFIT was better at modeling the light without defined arms like seen in the middle model as opposed to one with distinct arms like seen in Figure 2. The galaxy on the right of the quartet was best fit with a Sérsic function as normal but additionally with the PSF, which is normally only useful for fitting stars or quasars. This leads us to believe further that this galaxy is interacting with the quasar of attention and could also be a quasar itself.

The residual map provides the following information:

1. The quasar is best fit when there's a second companion to its 4 o'clock position.
2. The galaxy on the right does not well when using a normal elliptical galaxy profile. This gives more reason to believe it is merging with the quasar and its companion.
3. The galaxy on the left cannot be modeled using normal components, nor is it fit well when using perturbations to symmetrical properties (elongating the light). The object appears to have an extended low-surface brightness tidal tail extending towards the quasar - which leads us to suspect this object might be interacting with the quasar host galaxy. This also provides a visual reference that it is possibly merging with the quasar, its companion, and the rightmost galaxy.

CONCLUSIONS

While this is still a work in progress, I will outline some of the interesting findings from the detailed modeling of object SDSS J085215+492040:

1. The quasar (top of the quartet) is best fit by disk/elliptical profile.

2. The fit is improved with the addition of a smaller companion galaxy to its 4 o'clock position 5.748 kpc away. This indicates to us that the quasar seems to be merging with this companion.

3. After finding the cosmological redshift within the *Sloan Digital Sky Survey Data Release 16*, for each of the companion galaxies in, it was revealed that the larger spiral at the bottom of the quartet is not in contact with the rest of the system.

4. The object on the right of the quartet has a redshift value within the range as the quasar galaxy. The quasar's redshift is $z = 0.567 \pm 0.00036$ [0.566-0.567] while the rightmost galaxy's photometric estimated redshift is $z = 0.577 \pm 0.041$ [0.535-0.618]. These objects have redshifts that overlap the others as well as physically look like they're merging so we are confident in saying the right galaxy is also merging with the quasar and its smaller companion.

5. Although no redshift value can be found for the galaxy on the left, its elongated shape suggests to us this galaxy is also merging with the quasar system. This type of elongation is not found naturally in nature on an undisturbed galaxy – the "pulling" of light towards the quasar shows an interaction occurring.

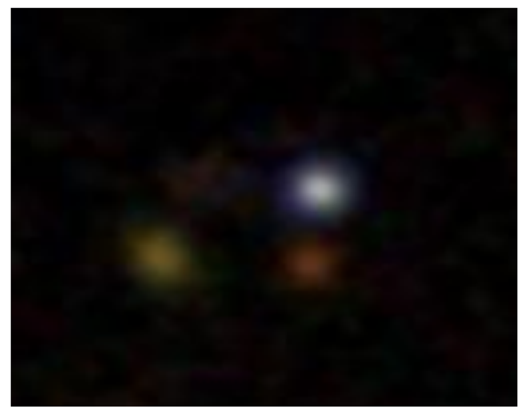

Figure 8. Screenshot of the quartet taken from the SDSS DR16 Navigate Tool viewer. The quasar looks like a star on the top (white dot) while the spiral galaxy is the yellow feature diagonal of that.

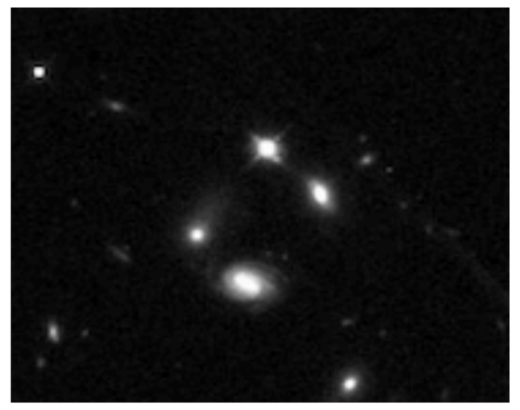

Figure 9. Different view of the quartet taken from *Mikulski Archive for Space Telescopes*.

SUMMARY

GALFIT is a powerful tool to model the galaxies we see. We were able to create models of object SDSS J085215+492040 and have unveiled residuals showing the inner structures of these galaxies. This is still a work in progress but has revealed many interesting findings including a possible triple merger with a quasar. This study is subject to be completed by this May.

REFERENCES

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5. Lazarova et al. (2012), *The Nature Of LoBAL QSOS: 1. SEDS and Mid-Infrared Spectral Properties.*
6. Peng et al., 2010, ApJ, 1139, 2097

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