



Using the Hubble Space Telescope to Search for Groups of Galaxies in the Distant Universe

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Abstract

Galactic evolution is an exciting topic in the field of extragalactic astronomy. Recent studies indicate that the epoch at redshift $z \sim 2$ is a pivotal period for determining how massive galaxies in our current epoch, $z=0$, formed their stars and why some stop forming stars. Galaxy clusters contain hundreds of massive galaxies but are increasingly rare in the distant universe. However, they are incredibly useful to the study of galactic evolution as they provide a large sample of similarly aged galaxies. Two new galaxy cluster candidates at redshifts $z \sim 1.6 - 2.1$, IRC0222A and IRC0222B, were recently imaged by the Hubble Space Telescope. We determine if the galaxies in these distant clusters are similar to massive galaxies in the nearby universe by analyzing the light from the candidate galaxies for this cluster. We find that the candidate cluster galaxies are red and faint, thus they are very likely to be at high redshift and can evolve into the massive galaxies in the current epoch.

Introduction

When most people picture a galaxy, a huge, beautiful, spiral structure made of millions of stars is the first thing they visualize. But not all galaxies have this iconic spiral shape and the galaxies that do have probably not always looked like this. To determine how galaxies form and evolve into the massive objects we see near the Milky Way, astronomers study the properties of distant galaxies. As the universe is also expanding, the further-away galaxies are moving away from us at higher rates than closer objects. This causes the ancient light we receive from them to be shifted in the red direction. This 'redshift,' often denoted by the letter z , is then used to determine how far away the galaxies are from us, and therefore how long ago the light we see from them was sent. Recent studies have shown that the epoch that has a corresponding $z \sim 2$, or approximately 10.4 Gyrs ago, is a crucial time period for understanding why and when some galaxies stop forming stars, resulting in a split of galaxies type at $z \sim 0$.

Cluster Candidates

In this project we investigated two recently discovered galaxy clusters, IRC0222A and IRC0222B. Color images of the two candidates can be seen in figure one. The candidates were identified by the Spitzer Space Telescope Infrared Camera and then imaged by the Hubble Space Telescope Wide Field Camera 3, producing the images that were used for this study.

Figure 2: IRC0222B color images taken with the Wide Field Camera 3 on the Hubble space Telescope. Galaxies in the $z \sim 2$ clusters are circled in red and labeled with their respective redshifts. Objects used for curve of growth analysis are shown in green circles.

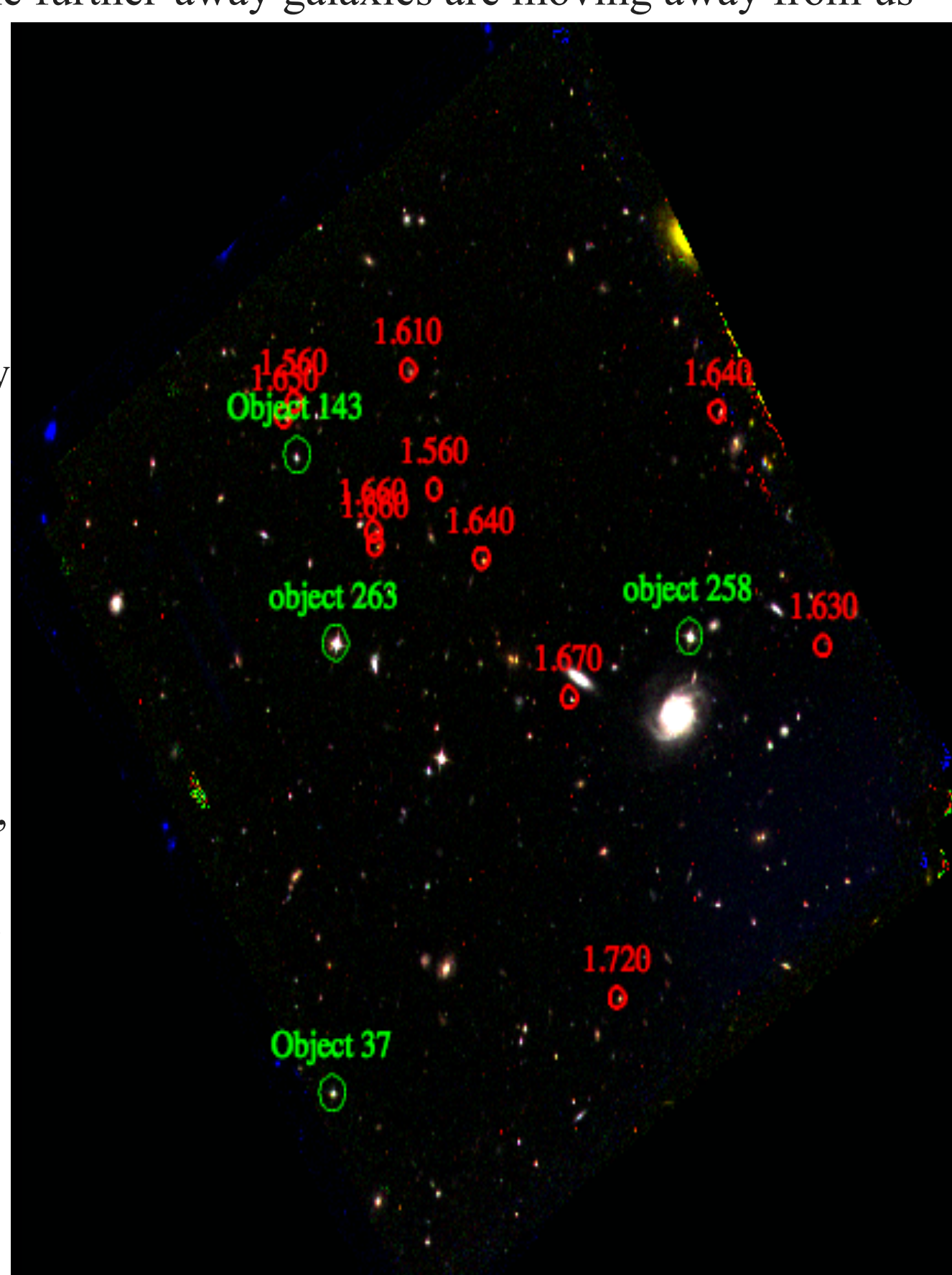
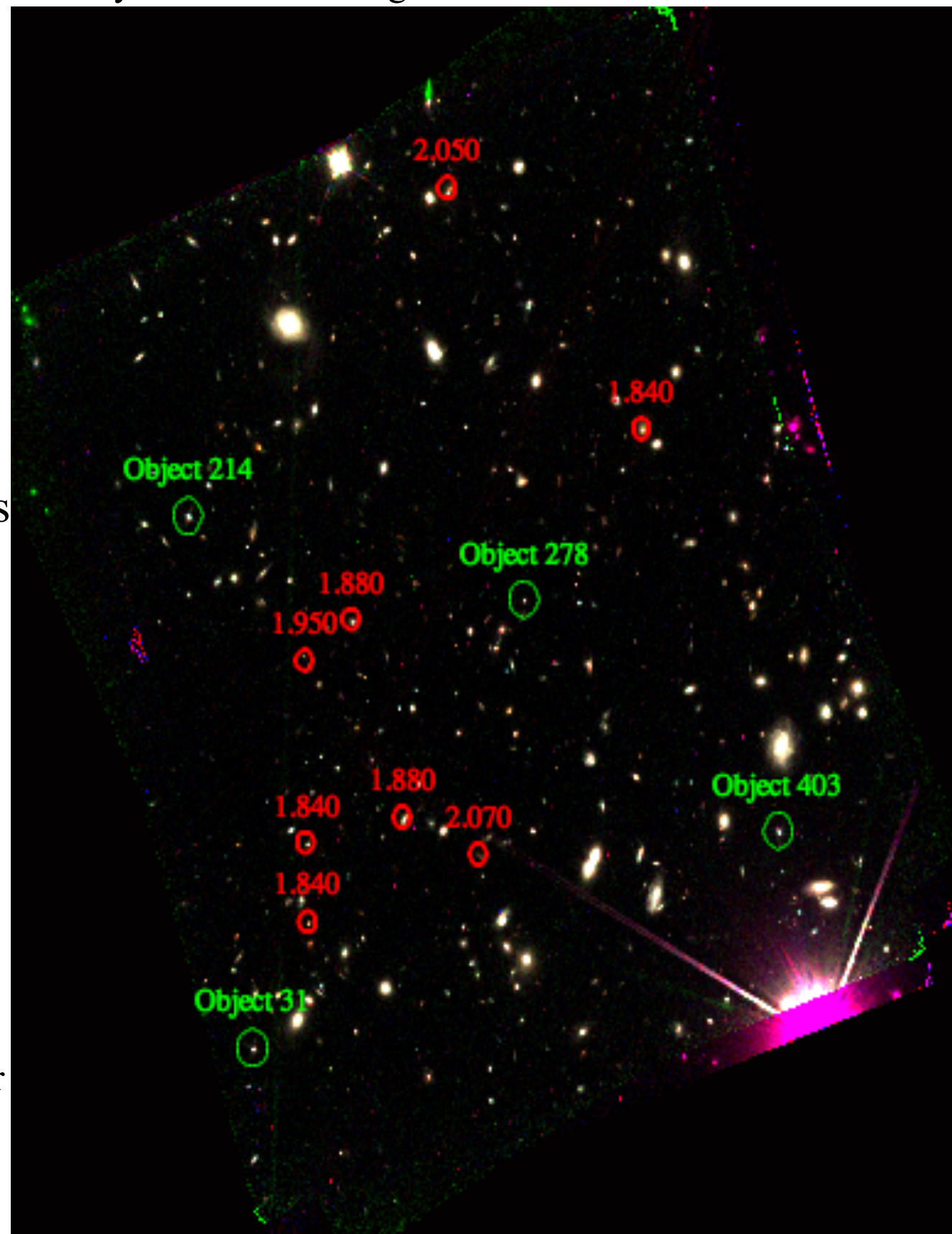


Figure 1: IRC0222B color images taken with the Wide Field Camera 3 on the Hubble space Telescope. Galaxies in the $z \sim 2$ clusters are circled in red and labeled with their respective redshifts. Objects used for curve of growth analysis are shown in green circles



Magnitude Measurements with Source Extractor

In this study we measured the brightness of the objects in the two fields with a program called Source Extractor. This program finds objects in the image in two major steps, separating the background from the objects and separating the objects from each other. After finding the objects, Source Extractor writes a catalog that includes user-specified parameters. Source Extractor also has the ability to make certain types of check images, which can be used to be certain that Source Extractor is finding all of the objects in each image. Two of these check images can be found in Figure 3.

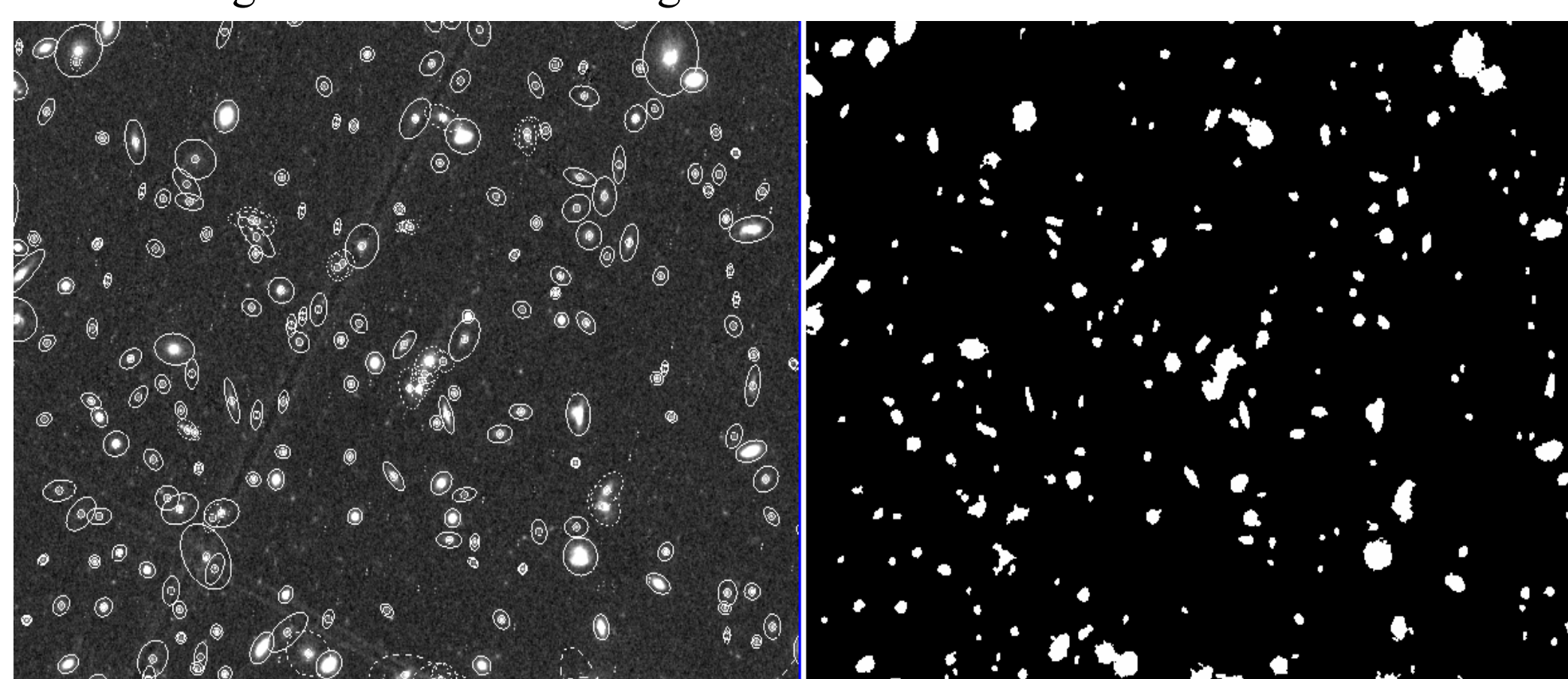


Figure 3: An apertures (left) and segmentation (right) map made by Source Extractor. The apertures map shows the area Source Extractor is measuring flux from while the segmentation map sets the value of each object equal to the number Source Extractor assigned it.

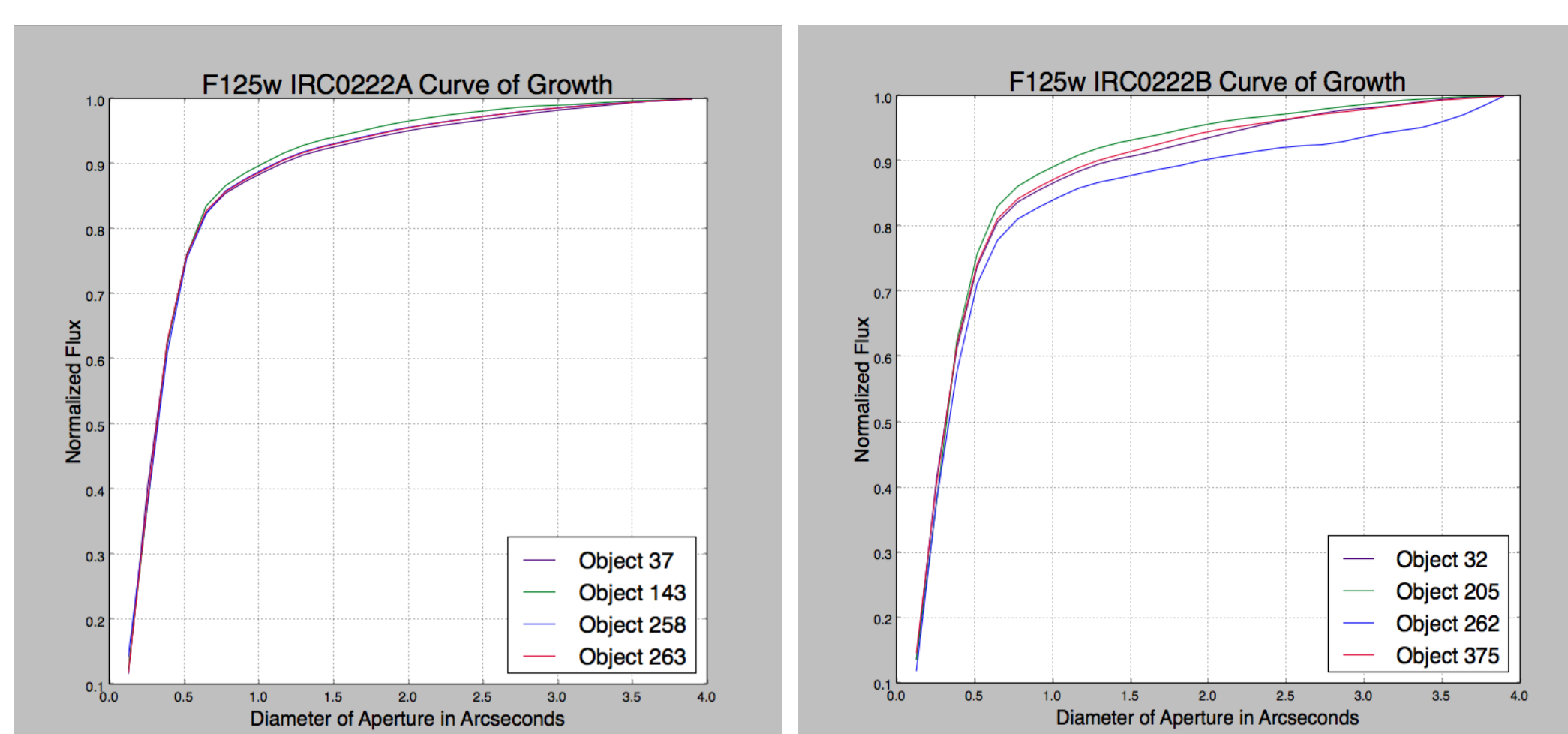


Figure 4: Curve of Growth for IRC0222A (left) and IRC0222B (right). This data shows what percentage of the flux of each object was measured when Source Extractor was run with different aperture sizes to inform us how we should correct for any light Source Extractor did not measure without picking up light from other objects or sources of noise.

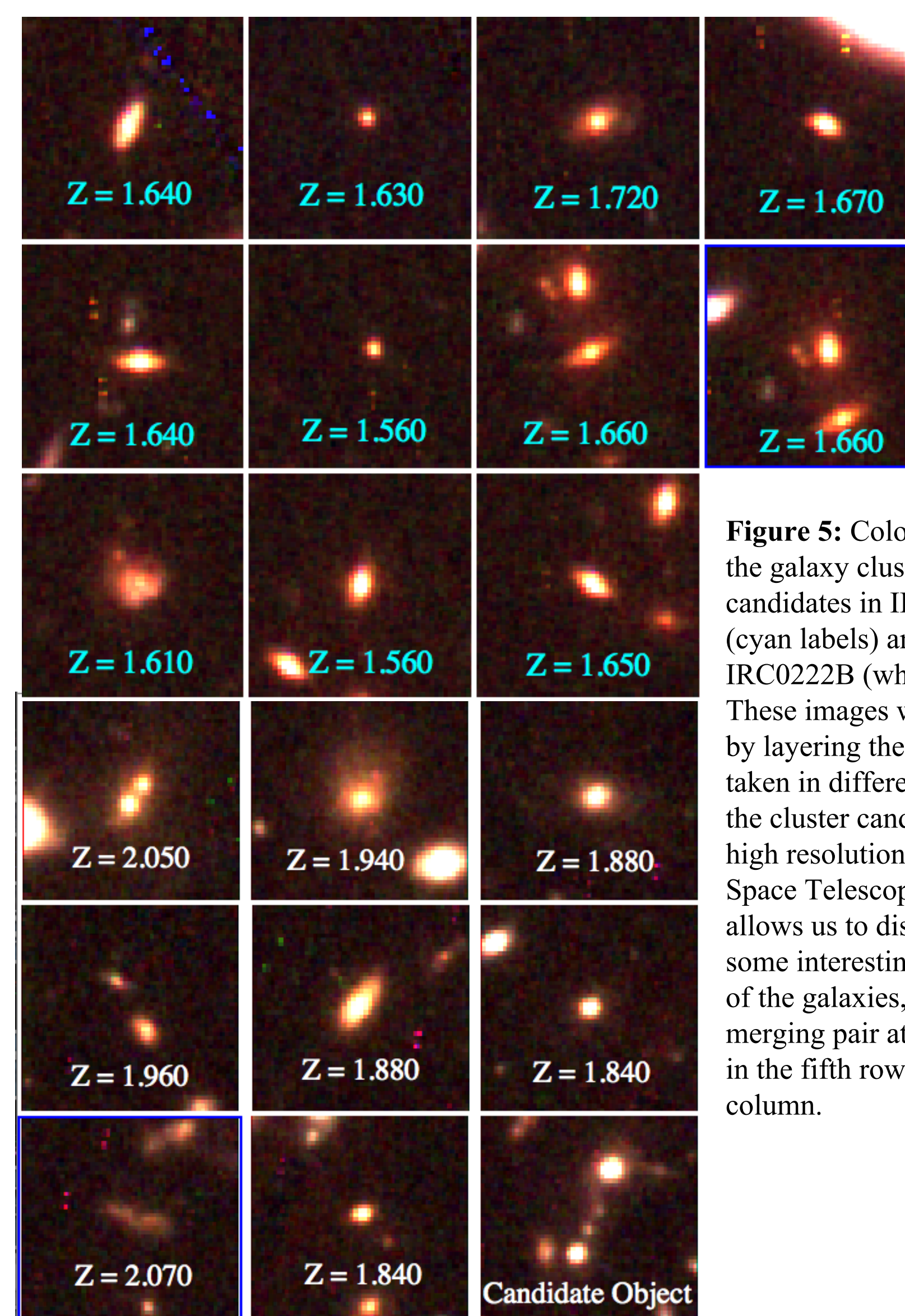


Figure 5: Color images of the galaxy cluster candidates in IRC0222A (cyan labels) and IRC0222B (white labels). These images were created by layering the images taken in different filters of the cluster candidates. The high resolution the Hubble Space Telescope provides allows us to distinguish some interesting properties of the galaxies, such as the merging pair at $z = 2.050$ in the fifth row of the first column.

Color and Brightness Measurements

In order to measure the brightness of the objects in these two images, we used the magnitudes determined by Source Extractor. In the magnitude system, large numbers represent dim objects, whereas low numbers mean the object is very bright. As seen in Figure 6 all the cluster candidates have a magnitude of at least nineteen, meaning that they are less bright and therefore farther away from us than the other objects. As the F160w filter measured the longest wavelengths of light, it was used as an indicator of how red the objects are. The difference in magnitude measurements between the F160w and F125w filter were used to determine the color of the objects.

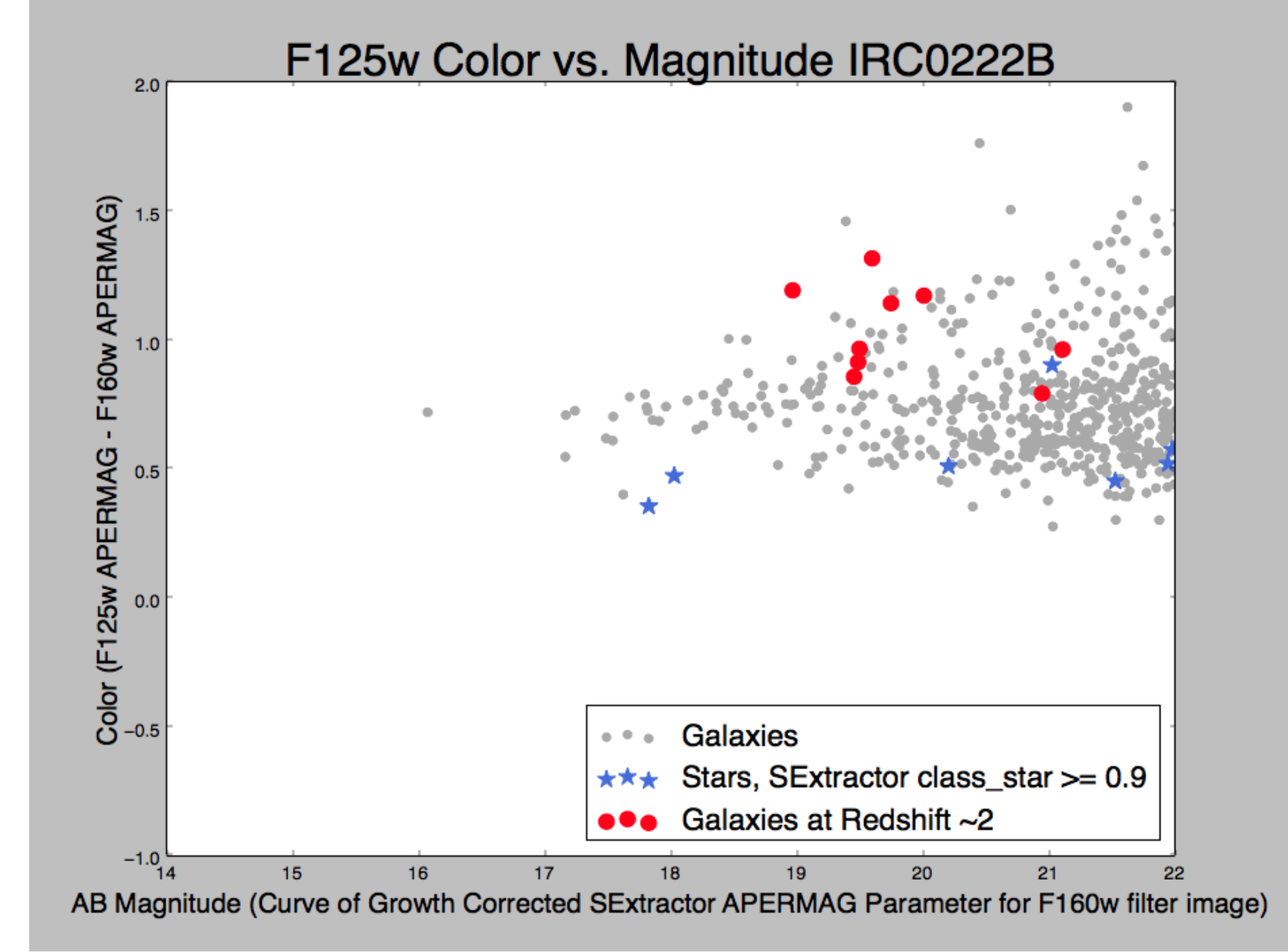
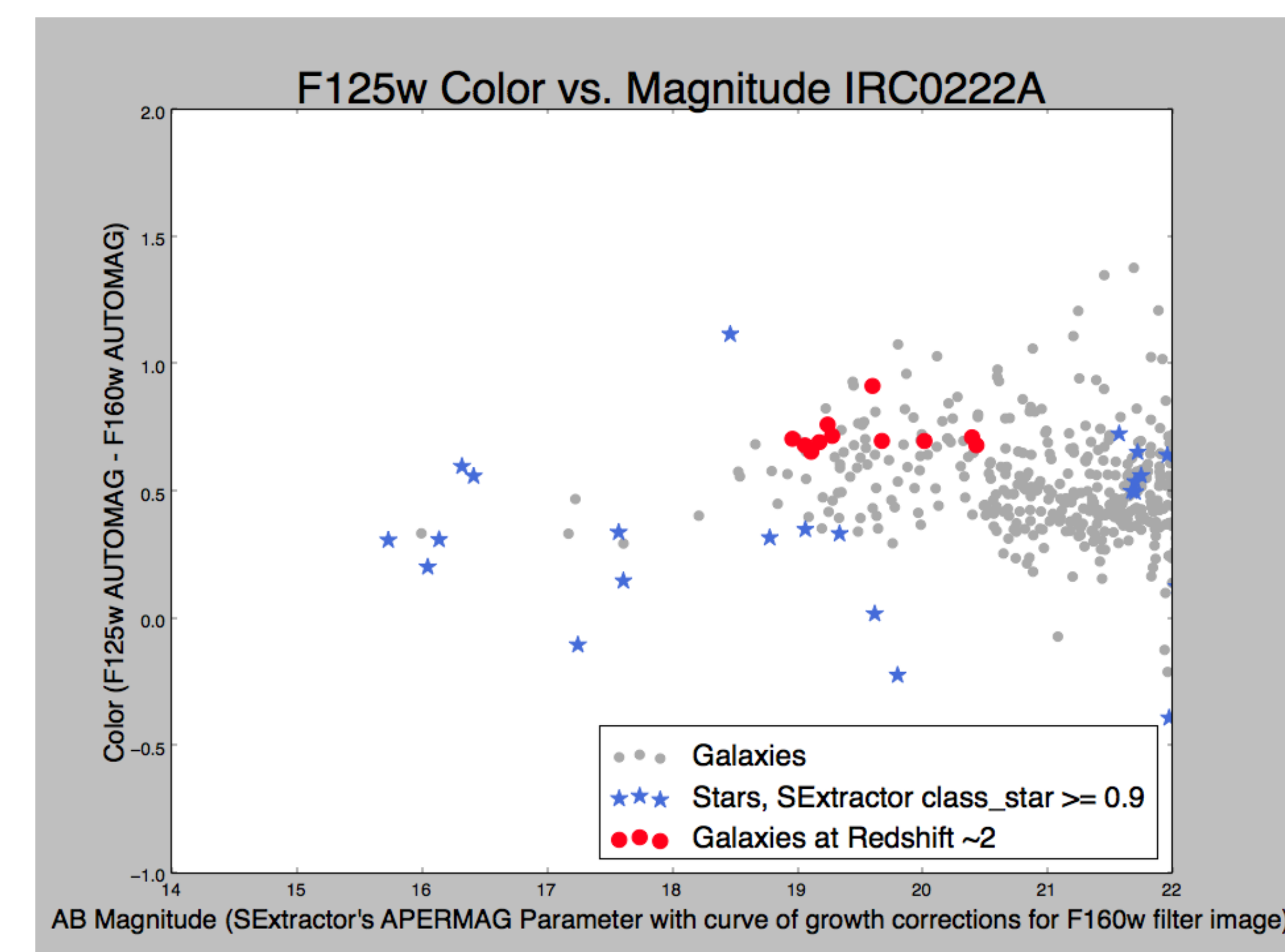


Figure 6: Color vs. magnitude plots for IRC0222A (upper) and IRC0222B (lower). The red circles are the high redshift objects identified in figures 1 and 4, the blue stars are objects SEExtractor marked as stars, and the small gray dots are the other galaxies. This plots show that the high redshift objects have similar properties and are more red and less bright than many other objects in the images, indicating that they are objects in the $z \sim 2$ clusters.

Conclusions

In our investigation of IRC0222A and IRC0222B we found that the cluster candidate galaxies selected are indeed more red and faint than many of the other objects in the images taken by the Hubble Space Telescope Wide Field Camera. This means that it is very likely that these objects are a cluster of galaxies at around $z \sim 2$ that could develop into the type of galaxies we see at $z \sim 0$. As we have determined this, these two clusters will be used for further investigation of galactic evolution.

Resources

- Skelton, R. et. al. March 14, 2014, "3D-HST WFC3-Selected Photometric Catalogs in the Five Canelds/3D-HST Fields: Photometry, Photometric Redshifts and Stellar Masses", Astrophysical Journal Supplements, in press.
- Bertin, E. 1996, "SEExtractor v. 2.13 User's Manual" (Institut d'Astrophysique & Observatoire de Paris)
- Rajan, A. et al. 2010, "WFC3 Data Handbook", Version 2.1, (Baltimore: STScI)

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