

Creating updated, scientifically-calibrated mosaics for the RC3 Catalogue

1. Introduction

The Third Reference Catalog of Bright Galaxies (RC3) (de Vaucouleurs et al. [7]) contains a complete listing of 23,022 galaxies with D_{25} apparent major isophotal diameter greater than 1 arcminute and with a total B-band magnitude greater than 15.5 (UNITS??). There has been existing literature on this subject using data from the Sloan Digital Sky Survey (SDSS). Hogg and Blanton made g,r,i colored images by using data from the SDSS DR6.¹ The FIGI catalog (Baillard et al. [2]), dedicated to studying morphology of galaxies, also obtained a subset of 4458 RC3 FITS and color images by discarding artifacted or missing data via visual inspection and using SDSS DR4 data. We perform the mosaicing procedures on the whole RC3 catalog using an automated positional update algorithm on the most recent SDSS DR10 imaging data. In addition, we designed a mosaicing pipeline that creates scientifically-calibrated mosaics, color-band images, as well as a set of updated positions, which can be easily adapted for existing surveys such as Two Micron All Sky Survey (2MASS), The Palomar Digital Sky Survey (DPOSS), or future imaging data release from Dark Energy Survey (DES) and Large Synoptic Survey Telescope (LSST) for larger sky coverage and multiband images.

2. Automation Program

2.1. Positional Inaccuracy in RC3 Catalog

The principle motivation behind the automation algorithm is to resolve the problem of centering galaxies and finding RC3 galaxy in a given field of view. Initially, using the standard mosaicking steps in Montage, we obtained many images whose galaxy are off center or can not be found due to the inherent inaccuracy of the positions in the catalog. The B2000 coordinates are denoted with two different levels of accuracy: HH MM SS.s, DD MM SS for the positions that has been updated (with accuracy of about 5-8 arcsec) and HH MM.m, DD MM for galaxies whose positional accuracy remain 1-2 arcminutes in the original catalog. In the latest version of the catalog (de Vaucouleurs et al. [6]), there remains 5492 RC3 galaxies that fall in the latter group.

2.2. Algorithm

The RC3 object contains its PGC number, updated and catalog ra,dec,radius for each galaxy in the RC3 catalog. We have decided to record The Catalogue of Principal Galaxies (PGC) number to identify the RC3 galaxy of interest for cases of source confusion, since every RC3 galaxy has a unique PGC number. The method `source_info` updates the position of individual RC3 objects by first creating a single band mosaic with a field of view of 6 times the radius of the galaxy, then SExtractor detects all sources in the mosaic and select only the ones with a radius greater than 5.94 arcseconds. If the mosaicking field is chosen correctly, then SExtractor's skylevel estimation is fairly accurate. Nevertheless, this size cut is large enough such that it eliminates most of the stellar point sources and mistaken background noise but retains the subset of RC2 galaxies inside the RC3 Catalog that are smaller than 1 arcminute as described in de Vaucouleurs et al. [5]. If there are multiple galaxies in the field of view that satisfy this criteria, then it is passed into the source confusion algorithm to verify which one is the galaxy of interest. Then we record the single source of interest and generate mosaic FITS file for all bands and a color image. If no sources are detected, then we mosaic the single band FITS using a larger field of view. This is done recursively, keeping track of the number of iterations in each recursive steps. The process is terminated at the 5th recursive step.

2.3. Source Confusion

(Something about galaxies living close to each other==cluster, gravity and stuff) The source confusion algorithm works on the assumption that the only galaxies that are large enough to cause source confusion also lie in the RC3 catalog, since the catalog is reasonably complete for galaxies having apparent diameters larger than 1 arcmin at the D_{25} isophotal level. First, the program retrieves a list of n number of RC3 galaxies that may lie in the field of view of the generated mosaic. The `otherRC3` method in the `Server` class queries this information using the Vizier Catalog. If this information is provided by a survey's query service (such as the RC3 Table in SDSS's SkyServer), it can be overridden. The goal is to match the results returned by the survey with the list of n largest sources detected by SExtractor.

We need to cross-correlate the coordinate by matching together the relative differences between the sources, due to the unreliability of absolute coordinates inherent to the

¹<http://cosmo.nyu.edu/hogg/rc3/>

catalog as discussed in section 2.1. We assume that the positional inaccuracy is due to instrumentation and measurement error but retains the galaxies' relative locations. First, we compute all the possible distances between any two RC3 galaxies that lies in our field. Then compare this with the set of differences generated by the SExtractor-generated list. We select n number of galaxies that has the closest values in both list, thereby matching together the galaxies from the catalog with the detected sources. Finally, we mosaic using that galaxy's coordinates as center. Our premises proves to be valid, as the algorithm executed with a success rate of 99.97% in the SDSS run, and correctly resolved up to 8 RC3 sources in one example.

3. Pipeline

We incorporate our automated mosaic-making framework to a general pipeline

we designed a mosaicking pipeline that creates scientifically-calibrated mosaics, color-band images, as well as a set of updated positions, which can be easily adapted for existing surveys such as Two Micron All Sky Survey (2MASS), The Palomar Digital Sky Survey (DPOSS), or future imaging data release from Dark E. We designed a mosaicking pipeline that can

3.1. Class Hierarchy

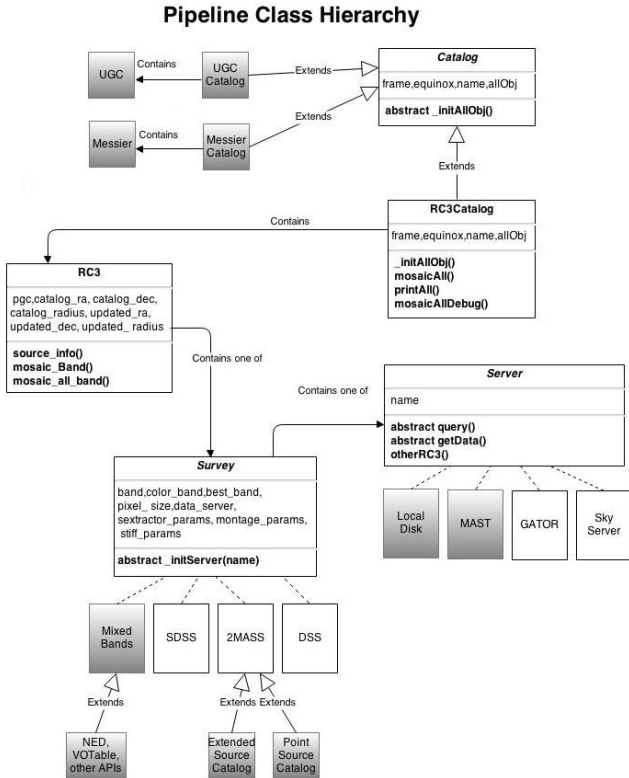


Figure 1: Greyed out boxes are possible extensions of this pipeline

The motivation behind building a class hierarchy is to establish a mosaicking pipeline for any given catalog and survey data. We identify the essential components required for mosaicking program to work. The relationship between these essential steps are reflected in our design of the abstract **Survey**, **Catalog**, and **Server** classes.

Server. Data acquisition is composed of two main tasks: querying imaging data and retrieving data from server. Most surveys have an API that enables data access by SQL or customized query. Figure out how to convert positional values (ra,dec) to record-keeping parameters dependent on the survey's telescope. (tiles, frames...etc) For example, SDSS image frames are uniquely identified by a particular combination of run,camcol,field. Usually this step can be done using the SQL search. Our choice of using a server instead of a data object enables code reusability across various surveys that uses common server tools, such as IPAC's GATOR query service (Alexov et al. [1]) or Astroquery.

Catalog. The **Catalog** class contains a list of objects that lies inside the catalog. Although the use of the Catalog container class seem unnecessary, it enables a clear separation between basic mosaicking functionality for individual galaxies. This can be used to study some particular object, executed on all objects in a **Catalog**, or simply used for debugging purposes. This abstraction barrier ensures minimal changes to the code in both classes when an investigator decides to input data from a new survey in the future.

3.2. Technical Details

Due to the recent surge in popularity of Python in astronomy, we wrote the program in Python 2.7.6 so that the program's dependencies are more widely supported for extending its usage on future datasets. Most of the mosaic steps are done using IPAC's Montage [8] mosaic engine along with the AstroPy Montage wrapper² and the final colored image is created using Astromatic's STIFF v.2.4 [3]. Our choice of the two program makes use of the best features from both programs. Montage creates scientifically-calibrated images by retaining the astrometry and photometry of input sources during image reprojection step. STIFF provides the flexibility of adjusting many variables for the final colored image, as well as automatically estimating upper and lower cuts on the dynamic range using statistics derived from a pixel histogram. The source extraction is done using SExtractor v.2.19.5 (Bertin and Arnouts [4]). The resulting database was created using the Python sqlite3 module and the web search interface was written with PHP.

²<http://www.astropy.org/montage-wrapper/>

3.3. Known Errors

Even though a series of exception handling and error prevention mechanisms were put in place,

- mProjectExec is the montage Mosaic procedure that creates the reprojected image from the raw FITS files. Sometimes reprojected images are not created even when Montages' debug statement clearly shows that the reprojection was successful and table and header files are corrupted. This results in an error in later mosaicing steps. We have implemented error prevention mechanism to ensure that mosaic procedures terminates correctly in such cases and wrote the problematic galaxy into failed_projection, which can be examined later.
- Montage's background rectification module is not used in creating the FITS mosaics. Attempts were made in implementing these procedure, however it is sometimes stuck in the step where the background model is applied to the projected images and produces huge difference images files (50GB) for reason that we have not figured out yet. This should not affect the astrometric quality of the data product. The only visible difference is observed in the color images for 2MASS, so will likely affect the photometric quality of the resulting 2MASS mosaics.(?)
- (We should probably fix this?) There was more galaxies affected by the source confusion issue since we are only taking one photographic plate to crop, it doesn't actually pass through the mosaicing algorithm. Subsequently, it was never passed through the source confusion algorithm.

3.4. Performance

We accelerate the mosaicing process by performing the recursive algorithm on only a single band FITS file designated as `best_band`, then mosaicing all bands only once per object. For SDSS, we use the image obtained by the r band filter since transmission curve in Stoughton et al. [11] shows that r band has the highest quantum efficiency.

Most of the computation time is spent on downloading the raw FITS files from the survey's specific server. Therefore, even though Montage's modular design enables its performance to scale with number of processor (Jacob et al. [8]), the process would not be significantly sped up by the use of Message Passing Interface (MPI). Therefore, the speed depends more on the bandwidth (downloading rate) rather than the number of cores in the machine. This average runtime would also depend on the sky coverage of the particular survey, the speed of query ...etc.

This process can be significantly sped up if the investigator already has imaging data stored locally on a disk or have access to running the mosaic program alongside the survey's datacenter. We have designed our class hierarchy such that this can be written as a subclass of `Server` with

user-defined details of where the images are stored. The Montage mBgExec takes a long time.

3.5. Result from SDSS / DPOSS run

There are a total of 12512 RC3 galaxies within the SDSS footprint. The mosaicing was successful for 90.22% of the galaxies. 2446 RC3 galaxies is mosaiced using updated positions that were more than 1 arcminute off the values recorded in the RC3 catalog. On jbigdog specs machine, the program processes on average about 80 RC3 objects per hour using SDSS data. The finished data product occupies GB of disk space.

For the DPOSS Run, on average 0.31galaxies per minute. (#More on this later..)

4. Conclusion

wide-area imaging survey

answer fundamental questions regarding large-scale structure and the cosmological history of the universe. generate mosaics on both per-image and per-catalog basis other wavelengths Can talk about here how LSST and future telescope can mask theses so that image not saturated We provide data product for SDSS and DPOSS. The FITS images can be used along with existing tools for scientific analysis on imaging data, such as Astrometry.net(Lang et al. [9]), SExtractor, APLpy(Robitaille and Bressert [10]). We have provided documentation on GitHub³ that guides investigators through the steps to adapting the pipeline for future imaging data. This can also be extended for other astronomical catalog such as the Messier Catalog or New General Catalog (NGC), as well as catalogs with user-defined selection limit.

Can be incorporated in the photo pipeline in future survey to make pretty rc3 images. with larger focal plane more photon such as the LSST saturation especially with the DSS data, full coverage of the sky map out where bright objects are.

The scientifically calibrated FITS images can be used as for individual studies. It can be used for improved astrometry (as we did) in updating the catalog. Can also do photometry to determine galaxy property

Another possible usage is to combine the calibrated mosaics into multiband color images with mosaics from single/double band surveys such as POSS-I and GALEX.

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³<https://github.com/ProfessorBrunner/rc3-sdss>

made use of Astropy, a community-developed core Python package for Astronomy (Astropy Collaboration, 2013).

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