The Hubble Space Telescope (HST) Advanced Camera for Surveys (ACS) Quicklook Project

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Abstract—What is an abstract, really?

1 Introduction

The Advanced Camera for Surveys (ACS) is a third-generation imaging instrument on board the Hubble Space Telescope (HST), installed in 2002 during Servicing Mission 3B. It is comprised of three detectors: (1) the Wide Field Camera (WFC), which is designed for wide-field imaging and spectroscopy in visible to near-infrared wavelengths, (2) the High Resolution Channel, which is designed for high resolution near-ultraviolet to near-infrared wavelength images and coronography, and (3) the Solar Blind Channel (SBC), desingned for far-ultraviolet imaging and spectroscopy. ACS expererienced an electronics failure in 2007 that affected the WFC and HRC detectors, until 2009 when astronauts succesfully restored the WFC detector during Servicing Mission 4; the HRC still remains unoperational.

Besides these few hiccups, the ACS instrument has been steadily acquiring astronomical images over its 15 on-orbit lifetime. Figure 1 shows an estimates of the number of observations over time for each of the three detectors. To date, there have been nearly 200,000 of observations total. Further information about the ACS instrument including its history, configuration, performance, and scientific capability can be found in the ACS Instrument Handbook (Avila et al., 2017).

ACS data, along with all other data from the other HST instruments past and present (e.g. The Wide Field Camera 3 (WFC3), The Cosmic Origins Spectrography (COS), etc.), are primarily stored and publicly-available in the Barbara A. Mikulski Archive for Space Telescopes (MAST)[1] (Barbara, 2017). Through MAST, users can request and retreive data for any publicly-available dataset via `ftp`, `sftp`, or DVD by mail[2]. The ACS data, like most all other astronomical

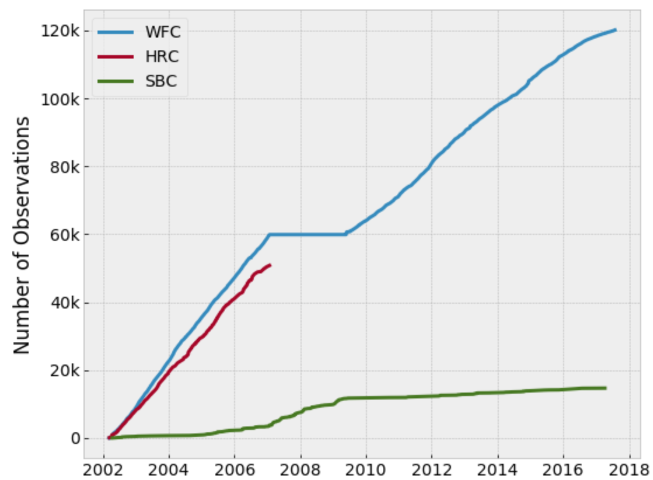

Fig. 1. The number of observations over time for each of the three detectors on ACS.

data, are stored in the Flexible Image Transport System (FITS) filetype (FITS, 2008). This filetype has several unique characteristics, as will be discussed in section N.

The ACS Quicklook Project is a `python`-based application for discovering, viewing, and querying all publicly-available ACS data. It consists of several subsystems: (1) A filesystem that stores ACS instrument data files and "Quicklook" JPEGs in an organized Network File System (NFS), (2) A `MySQL` database that stores image metadata of each observation, (3) A `python/Flask`-based web application for interacting with the filesystem and database, and (4) A `python` code library (named `acsql`) that contains code for connecting to the database, ingesting new data, logging production code execution, and building/maintaining the database and web application. Each of these subsystems are explained in further detail in the Methodology section of this paper.

This paper aims to outline and detail the ACS Quicklook project as part of the Towson University Computer Science Masters Program Graduate Project. The remaining subsections in this chapter discuss the motivation and use cases

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1. named after the U.S. Senator from Maryland who has been a pivitol political driving force behind the manned servicing missions, the Hubble Space Telescope, and the forthcoming James Webb Space Telescope

2. Not all HST data are publicly available; most HST data of scientific targets are considered proprietary for up to one calendar year, after which they are publicly released.

for this application, as well as details on the underlying data structure on top of which this project was built. Chapter 2 discusses related work to this project and how the ACS Quicklook project differs from existing similar applications. Chapter 3 details the implementations of each of the ACS Quicklook subsystems. Chapter 4 outlines the results of the project, namely the project deliverables. Lastly, chapters 5 and 6 conclude the paper with a discussion of possible extensions and modifications to the application.

It should be noted that the work that went into this project by the authors was accomplished on behalf of the Space Telescope Science Institute (STScI) located in Baltimore, Maryland. STScI is the home institution for instrument, data, and user support of HST, the forthcoming James Webb Space Telescope (JWST), and MAST. STScI is part of the Association of Universities for Research in Astronomy (AURA).

1.1 Motivation

The motivation for the ACS Quicklook system is driven by several shortcomings of the FITS file structure as well as the current capabilities of MAST from a specific user perspective (inteded users and their use cases are discussed in section 1.2). Some of these shortcomings are described below along with the intended way the ACS Quicklook application will address them.

Data retreival letency: Currently, users who wish to retreive data from the MAST archive must submit a retreival request via the MAST online interface. Once the retreival request is processed (usually automatically unless it is a request of a large number of datasets), the data are either transfered to the user directly via `sftp`, transfered to a "staging area" in which the user can log into and copy the data via `ftp` at their leisure, or sent by mail via DVD, depending on which option the user selects. In the case of any one of these options, the time between a download request and the the time in which the user has fully retreived the data is a non-significant amount of time. In the fastest scenario of the `sftp` option, a typical request can take minutes to hours to be completed. The ACS Quicklook system attempts to circumnavigate this retreival process by making the full data products instantly available via read-only access of the filesystem subystem, as well as a subset of the data products (and corresponding metadata) instantly available to view through the web application.

File I/O: Users who

Data redundancy: Something.

Data discovery: Something

1.2 Use Cases

The intended user of ACS Quicklook are ACS instrument scientists, analysts, or scientific users who wish to perform one or more of the following use cases:

1. View

1.3 Data Structure

The design of the ACS Quicklook application, especially the database, is heavily dependant on the underlying data structure of ACS FITS files. As such, it is important for the reader to understand this data structure and thus the next four sections are dedicated to giving an overview on the subject.

1.3.1 Filenames

Each ACS data file is named in a consistent fashion:

```
<rootname>_<filetype>.fits
```

where each <rootname> consists of nine unique alphanumeric characters, and <filetype> is one of several three-character filetype options (discussed in proceeding section N). For example, one ACS observation has the rootname `j6mf16lhq_raw.fits` (Principle Investigator Gary Bernstein, observation date `2016-09-22`). Each character in the 9-character `rootname` has meaning, and is discussed in section 5.2 of the Introduction to the HST Data Handbooks (Smith et al., 2011). The `.fits` extension at the end of the filename signifies that the file is of FITS format.

1.3.2 FITS file structure

Each ACS FITS file consists of several "Extensions", with each extension serving a purpose to describe a particular aspect of the observation. Each extension consists of two parts: (1) an extension "header", which contain key/value pairs describing image metadata (for example, `DATE-OBS = '2016-09-22'` indicates that the observation date was `2016-09-22`) (discussed in the next section), and (2) the extension data, which may be a binary table or, more commonly, a multi-dimensional array of detector pixel values.

The type of extension data can also vary. The most common extension data types are (1) 'science' (`SCI`), in which the extension data describe a scientific observation, (2) 'error' (`ERR`), in which the extension data describe the uncertainty in the pixel values of the `SCI` data, and (3) 'data quality' (`DQ`), in which the extension data describe the quality of the pixel values for the detector (for example, they may indicate that certain pixels were affected by cosmic rays durring the observation). Typically, for a given file, the 1st extension is the `SCI` extension, the 2nd extension is the `ERR` extension, and the 3rd extension is the `DQ` extension. Furthermore, the 0th extension typically has no extension data and only an extension header that contains metadata that is common to all extensions. This is referred to as the 'Primary Header'.

Tables 1-3 describe the different extensions of ACS FITS files for each of the three ACS detectors. Note that there are two sets of `SCI/ERR/DQ` extensions for WFC since WFC is comprised of two separate CCD chips.

Over the years, there have been several tools written in various programming languages to read in FITS files and automatically convert their extension data to multi-dimensional array data types and their extension headers to dictionary data types. For this project, the `astropy.fits python` library is used extensivly to read and interact with ACS FITS files (Robitaille et al., 2013).

TABLE 1
ACS/WFC FITS file extensions

Extension	Purpose	Image Dimensions (pixels)	Data Type
0	Primary header	–	String
1	SCI, Chip 2	(4096, 2048)	Float
2	ERR, Chip 2	(4096, 2048)	Float
3	DQ, Chip 2	(4096, 2048)	Integer
4	SCI, Chip 1	(4096, 2048)	Float
5	ERR, Chip 1	(4096, 2048)	Float
6	DQ, Chip 1	(4096, 2048)	Integer

TABLE 2
ACS/HRC and ACS/SBC FITS file extensions

Extension	Purpose	Image Dimensions (pixels)	Data Type
0	Primary header	–	String
1	SCI	(1024, 1024)	Float
2	ERR	(1024, 1024)	Float
3	DQ	(1024, 1024)	Integer

```
SIMPLE  =                    T / data conform to FITS standard
BITPIX  =                   16 / bits per data value
NAXIS   =                    0 / number of data axes
EXTEND  =                    T / File may contain standard extensions
NEXTEND =                    6 / Number of standard extensions
GROUPS  =                    F / image is in group format
DATE    = '2016-09-22'         / date this file was written (yyyy-mm-dd)
FILENAME= 'j6mf16lhq_raw.fits                     ' / name of file
FILETYPE= 'SCI      '          / type of data found in data file

TELESCOP= 'HST'                / telescope used to acquire data
INSTRUME= 'ACS   '             / identifier for instrument used to acquire data
EQUINOX =               2000.0 / equinox of celestial coord. system

              / DATA DESCRIPTION KEYWORDS

ROOTNAME= 'j6mf16lhq                         ' / rootname of the observation set
IMAGETYP= 'DARK              ' / type of exposure identifier
PRIMESI = 'ACS   '             / instrument designated as prime

              / TARGET INFORMATION

TARGNAME= 'DARK                          ' / proposer's target name
RA_TARG =   0.000000000000E+00 / right ascension of the target (deg) (J2000)
DEC_TARG=   0.000000000000E+00 / declination of the target (deg) (J2000)

              / PROPOSAL INFORMATION

PROPOSID=                 9433 / PEP proposal identifier
LINENUM = '16.055         '    / proposal logsheet line number
PR_INV_L= 'Bernstein                     ' / last name of principal investigator
PR_INV_F= 'Gary                ' / first name of principal investigator
PR_INV_M= '                    ' / middle name / initial of principal investigat

              / EXPOSURE INFORMATION

SUNANGLE=            93.563698 / angle between sun and V1 axis
MOONANGL=            33.222004 / angle between moon and V1 axis
SUN_ALT =            68.062172 / altitude of the sun above Earth's limb
FGSLOCK = 'FINE              ' / commanded FGS lock (FINE,COARSE,GYROS,UNKNOWN)
GYROMODE= '3'                  / number of gyros scheduled, T=3+OBAD
REFFRAME= 'GSC1    '           / guide star catalog version
MTFLAG  = ' '                  / moving target flag; T if it is a moving target

DATE-OBS= '2003-01-27'         / UT date of start of observation (yyyy-mm-dd)
TIME-OBS= '15:20:01'           / UT time of start of observation (hh:mm:ss)
EXPSTART=   5.266663890058E+04 / exposure start time (Modified Julian Date)
EXPEND  =   5.266665048715E+04 / exposure end time (Modified Julian Date)
EXPTIME =          1000.000000 / exposure duration (seconds)--calculated
```

Fig. 2. An example header.

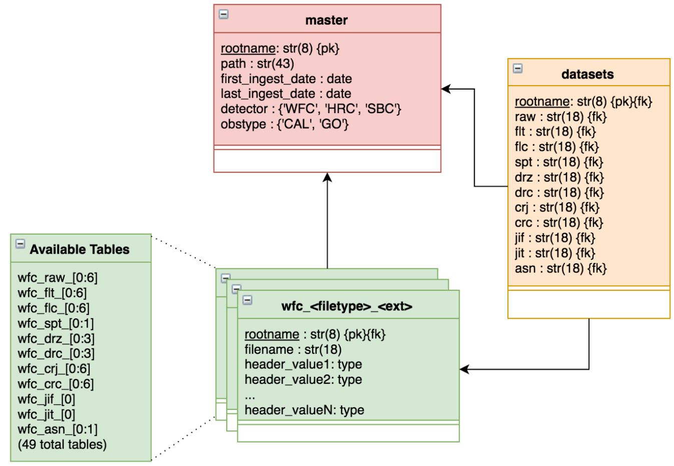

Fig. 3. The relational database schema for the `acsql` database.

1.3.3 *FITS file headers*

1.3.4 *FITS filetypes for ACS*

1.4 Key Metadata

2 Related Work

Topics to discuss:

1. The MAST archive 2. The MAST portal 3. The WFC3/Quicklook project 4. Other Astronomy Institutions 5. How ACS/Quicklook is different

3 Methodology

Topics to discuss:

1. Version control 2. Programming and Documentation Standards 3. Filesystem: The MAST public Cache 4. Filesystem: Archive of JPEGs and Thumbnails 5. Database: Relational Schema 6. Database: MySQL + SQLAlchemy 7. Database: ORMs 8. Data ingestion software 9. Website:

4 Results

Topics to discuss: 1. GitHub repository 2. ReadTheDocs documentation repository 3. Quantification of Database records 4. Quantification of Code repository 5. Website location

5 Conclusion

The conclusion goes here.

6 Discussion

Topics to discuss:

1. Possible simplification based on MAST archive 2. Possible extensions to other insturments

Appendix A
Proof of the First Zonklar Equation

Appendix one text goes here.

Appendix B

Appendix two text goes here.

Acknowledgments

The authors would like to thank...

References

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