

Catalina Sky Survey Operations and Processing

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1. Introduction

This document provides an overview of the operations, including software, of the Catalina Sky Survey (CSS). CSS is a ground based telescopic survey project that seeks to discover Near-Earth Objects (NEOs) that potentially could impact Earth. In its current form, CSS has been in operation since 2003 and is currently funded under a NASA NEOO grant (“The Catalina Sky Survey for Near-Earth Objects”) which includes the requirement to make the CSS archives available to the public. To meet this requirement, CSS will deliver the data resulting from survey operations to the Planetary Data Systems Small Bodies Node (SBN) by means of an accredited configuration-controlled pipeline. The discussion below should aid users and implementers in understanding these data.

2. The Catalina Sky Survey Archive Pipeline

The Catalina Sky Survey operates several telescopes dedicated to the discovery and astrometric follow-up of NEOs. The CSS pipeline makes no distinction between survey and targeted observations, even from the same telescope. A NEO survey has many hardware and software subsystems and some are outside the purview of this document.

Processing begins with the reduction of raw camera images. Imaging data suitable for moving object detection is subject to the usual data reduction steps of photometric and astrometric calibration. CSS has generally operated its cameras unfiltered and the photometric steps are straightforward. Currently the Gaia DR2 catalog is used to provide both photometric and astrometric references. Other catalogs have been used in the past and this will undoubtedly change again in the future.

The most notable fact about CSS data is that each survey field is reimaged multiple times, typically interleaved with other fields over a period of a half hour or so. Survey data has four images per field; targeted follow-up may utilize *track & stack* mode where each of these four images is further split into several very short exposures to freeze the target’s motion. The components for each of the four stacks are then shifted and coadded to maximize the signal before moving object detection is performed.

The CSS pipeline implements two kinds of source detection. Most CSS detections result from a comparison between source catalogs for the four images. Others are generated from an image subtraction step. The detection lists from catalog comparison and image subtraction are

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combined for each image, and then the lists of many thousands of possible detections are searched for constant rate linear motion. The resulting candidate moving objects are scored by the likelihood of being real as well as their motion resembling that of near-earth objects.

These activities are under configuration management and create diverse controlled data products. The prioritized lists of candidates are matched against the known catalog of solar system objects and unknown objects are presented to the observer for visual validation using blinked images. The human validation process itself is outside configuration control, but the final step of report generation is a controlled step. Historically this has used the MPC 80-column format, but Catalina has transitioned to the IAU Astrometric Data Exchange Standard (ADES).

Label generation is the final controlled step and occurs the following day. Previous steps occur on computers at the telescopes while labels are created on a server at the CSS offices at the Lunar and Planetary Laboratory (LPL) on the University of Arizona campus. A data transfer process replicates the mountaintop data to LPL with a semaphore file being written as the final step after checksum verification. A Linux Cron process later copies the data into its permanent location on CSS storage. Finally, a script is executed to create the PDS4 labels for the diverse data products. The labels are written to a separate directory with their own checksums.

CSS maintains multiple copies of the data, automatically replicating data from LPL to the University of Arizona campus University Information Technology Services (UITS) data center. Transport of CSS data and the corresponding PDS4 labels to PSI will occur from UITS.

3. Controlled Pipeline Software

Controlled software begins with the pipeline reduction of raw images from the CCD or CMOS cameras. Software associated with controlling the survey planning, exposure queuing, telescope, camera, etc., is generally outside the scope of this document. CSS uses Subversion (SVN) for source code management of all modules described below. CSS software is being published via the NASA github and is mostly written in TCL and C. Figures 4, 5, and 6 in the appendix show the overall flow of the processing and the resulting archival SBN data products (and temporary working files surrounded by dashed lines). Circled numbers on the figures correspond to the general processing sub-sections below, and rectangular boxes represent specific software modules in the CSS pipeline.

The various software modules described in the rest of this section often have input parameters that differ from telescope to telescope, or between different generations of instrumentation, or differing modes of operation. These parameters are copied into each telescope-night's archive directory for all telescopes and instrumentation, not just the particular telescope being used. This is to support multiple telescopes in a single batch, for instance in support of archival modes such as precoveries. The master parameters are contained in the file *controlconfig.json*, which sets basic observatory operations details like:

```
site.MPCcode = G96
machines.name.acquisition = Tyche
directory.calibrations = /home/observer/calibrations
```

```
fits.observatory = Mt. Lemmon
```

as well as instrumental modes like:

```
G96_5280_2.platescale = 1.520  
G96_5280_2.rotate_angle = 180  
G96_5280_2.camera_bin = 2
```

and logistical or pipeline choices such as:

```
G96_5280_2.astrometry_minstars = 200  
G96_5280_2.submission_observatory = Catalina Sky Survey  
G96_5280_2.sextractor_detect_thresh = 1.16
```

There are many more parameters, of course. In general, key metadata is also later written into the resulting processed image header keywords.

3.1 Image Calibration

In the CSS context, image calibration means our version of normal CCD flat-fielding, de-biasing, trimming off overscan, masking vignetted pixels, etc. For cameras with multiple mosaiced detectors such as 90Prime at Steward Observatory’s Bok telescope (V00) on Kitt Peak the calibration step also includes compositing FITS Multiple Extension Format (MEF) files into FITS Single Image Format (SIF) files as with other cameras used by CSS. For V00 the raw *.fits and partially processed *.calb files are MEF files, one FITS extension per detector, while the fully calibrated *.arch files are SIF files covering the entire focal plane.

More generally calibration means whatever image processing is required prior to later steps, e.g., updating the raw header keywords from the camera software with information from the telescope control system, timekeeping infrastructure, etc. (Routine configuration changes include generating library flat fields, updating CCD parameters such as binning, retuning TCS and camera parameters, OS updates, and other familiar activities of ground-based telescope operations.) These steps are packaged into a single module with associated parameter and library routines that can overall be referred to as “**CALIBRATE**”. All CSS imaging data products will be delivered in FITS tile-compressed format as generated by the third-party **FPACK** command.

Digging a bit deeper into the steps that the CSS processing pipeline uses for bias subtraction and flat-fielding, and focusing on the G96 and 703 cameras: each raw image contains overscan pixels for each of the 16 readout segments. The active CCD area vs overscan is described in geometry files that do not change so they are not included in the nightly archive. **CALIBRATE** calculates the median pixel value for each of the readout segments which are reflected in keywords BIASCH00 through BIASCH15.

The channel offsets are then subtracted and a per pixel flat field correction is applied to the image area to create a calibrated image. The raw input images are .fits files, the flat-fielded files are .calb files. Calibration images (*mflat*.fits*) are automatically chosen for each image as

reflected in the FLATFILE keyword. The choice of flat files is automatically done based upon which one gives the lowest sky background noise and the fewest artifacts or fringe effects.

After per-pixel flat fielding is done, there are still image issues relating to sky effects like a tilted sky background, brighter on one side, or brighter sky around bright stars or varying backgrounds near galaxies and nebulas. These issues are corrected with the program **FLATSKY** which calculates a sky background image derived from a median convolution filter with a tuned radius generally between 15 to 25 pixels. The background image is used to flatten out the sky so **SEXTRACTOR** produces fewer sky background artifacts when pulling out low SNR detection points. **SEXTRACTOR** has a built-in ability to do this, but CSS finds it inferior to the **FLATSKY**.

3.2 Source Extraction

CSS relies on the community software package Source Extractor² to detect and measure the point sources contained in each of the many hundreds of images taken at each of its telescopes each clear night. **SEXTRACTOR** responds to many command line and parameter file settings and CSS will occasionally modify these for diverse reasons. **SEXTRACTOR** is initially executed on a per-image basis, and later interacts with **SCAMP**, described in the next section. The original **SEXTRACTOR** output is in FITS binary table format and later copies are in ASCII text format. Both formats are archived in SBN, and may contain different columns. A helper module called **SEXB2SEXT** creates the text files. Most of the larger CSS text data products will be delivered in **GZIP** compressed format.

3.3 Astrometric Calibration

CSS relies on the **SCAMP**³ package (using **SEXTRACTOR** output) to generate astrometric solutions which ultimately become asteroid observations submitted to the Minor Planet Center. **SCAMP** responds to many command line and parameter file settings and CSS occasionally changes these. **SCAMP** provides a calibration against an astrometric catalog, currently Gaia-DR2. When superior astrometric catalogs become available, CSS will adopt them. As shown in Figure 4(A), **SCAMP** may be executed more than once to update the calibrated image with a world coordinate system as well as generating log file and metadata output that are archived.

SEXTRACTOR outputs and **SCAMP** inputs FITS⁴ binary tables in the Leiden Data Analysis Center (LDAC)⁵ format. The LDAC catalog format consists of a primary FITS header followed by two binary tables. The first table contains image header keyword metadata and the second table contains the several columns and many records of point source detection data. Basic structure:

```
Header listing for HDU #1:
SIMPLE  =                               T / This is a FITS file
BITPIX  =                               8 /
NAXIS   =                               0 /
EXTEND  =                               T / This file may contain FITS extensions
END
```

² <https://www.astromatic.net/software/sextractor>

³ <https://www.astromatic.net/2010/04/20/scamp-1-7-0-release>

⁴ https://fits.gsfc.nasa.gov/fits_standard.html

⁵ https://marvinweb.astro.uni-bonn.de/data_products/THELIWWW/LDAC/LDAC_concepts.html

```

Header listing for HDU #2:
XTENSION= 'BINTABLE'           / THIS IS A BINARY TABLE (FROM THE LDAOOLS)
EXTNAME = 'LDAC_IMHEAD'       / TABLE NAME
TTYPE1  = 'Field Header Card'
TFORM1  = '16400A '
TDIM1   = '(80, 205)'
END

Header listing for HDU #3:
XTENSION= 'BINTABLE'           / THIS IS A BINARY TABLE (FROM THE LDAOOLS)
BITPIX  = 8 /
NAXIS   = 2 /
NAXIS1  = 116 / BYTES PER ROW
NAXIS2  = 70476 / NUMBER OF ROWS
PCOUNT  = 0 / RANDOM PARAMETER COUNT
GCOUNT  = 1 / GROUP COUNT
TFIELDS = 25 / FIELDS PER ROW
EXTNAME = 'LDAC_OBJECTS'     / TABLE NAME
. . .

```

If the input image(s) have been updated to include a world coordinate system (typically by **SCAMP**), the table will provide columns in celestial coordinates in addition to pixel coordinates.

3.4 Photometric Calibration

The initial photometric calibration for CSS observations is also performed by **SCAMP** (that's what the 'P' stands for), but the zero point is adjusted according to the photometric catalog (also Gaia DR2). In normal survey operations, CSS photometry is unfiltered, but our telescopes have the option of using filters. CSS occasionally tunes photometric settings and when new photometric catalogs become available, CSS will evaluate them. The final photometric calibration is performed by a module called **VPHOT**, and helper modules **SKY2XY**, **STARMATCH**, and **SCAMPFIELD** are used.

Digging deeper, the multistage operation starts with the **SEXTRACTOR** output parameter **MAG_ISOCOR**. This magnitude is relative to the assumed zero point in the **MAGZEROP** keyword. After an astrometric solution is provided by **SCAMP**, the program **STARMATCH** creates likely matches between stars from the Gaia catalog (DR2 currently) and **SEXTRACTOR** points. These matches are written to the .strm files.

Next **VPHOT** is run to determine the median offset between the catalog and **SEXTRACTOR** magnitude values. This offset is saved as the **VPHOTOFF** keyword and is used to correct all **SEXTRACTOR** magnitudes and to generate the **MAGZP** keyword which is the final calibrated zero point. All magnitudes are reported to the MPC in the Gaia G band. No additional PSF or color corrections are attempted.

3.5 Image Subtraction

Different solar system surveys use different detection techniques, generally falling under catalog-based and image-subtraction algorithms. CSS uses both and merges the candidate moving object detections from both as below. CSS image subtraction is performed on a per-field basis and does not use master templates for this purpose. As with other modules described here, tuning occasionally occurs. Image subtraction is implemented by the **IPMTD** module that accepts background-subtracted images on input. These are created by the **FLATSKY** module and are

archived in SBN along with the lists of candidate moving target detections from this branch of the pipeline.

3.6 Moving Object Detection

Nominally, each survey field is a sequence of four images. Stellar point sources and other stationary detections are removed, leaving hundreds or thousands moving objects. A moving object detection involves recognizing constant rate near-linear motions when comparing the lists of candidate detections from each image and is greatly dependent on the rate of tangential motion. A certain tolerance is allowed for centroiding uncertainties as well as possible non-linear motions for objects near Earth. Catalog-based moving object candidates are generated and combined with image-subtraction candidates via the [MTDLINK](#) module. In addition, the moving object detection algorithm incorporates instrumental effects and results from asteroid population simulations. Point source and thus moving object detections can be impacted by imaging artifacts of many types, with a few examples in figures 1 and 2, panels A-F. Artifacts can cause both false

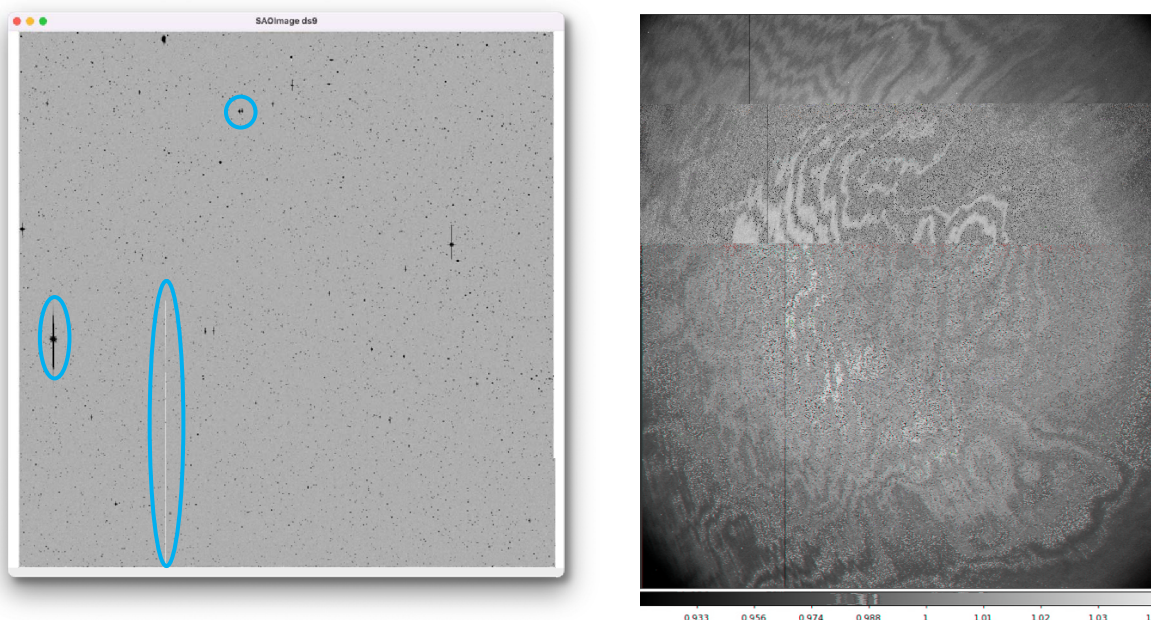


Figure 1 – Examples of imaging artifacts. Panel A is a typical reduced image from the CSS 0.7-m Schmidt telescope (MPC code 703) on Mt. Bigelow, 4.4 degrees on a side. CSS CCDs are generally quite clean of permanent bad columns, but these appear as do artifacts generated by saturated point sources as shown by the elongate blue ovals. These can be both negative and positive features. Sometimes two such artifacts are located close together, as in the blue circle, challenging the pipeline software. Panel B shows the low-level fringing structure in a flat field from the CSS 1.0-m follow-up telescope on Mount Lemmon (MPC code I52). Vignetting can be seen in the corners, as well as a bad column one-quarter of the way across the detector.

Catalina’s algorithms are tuned to minimize the impacts of the most frequently occurring image artifacts. Observers are sensitive especially to false detections of NEOs, since each of these are presented in near real time for validation.

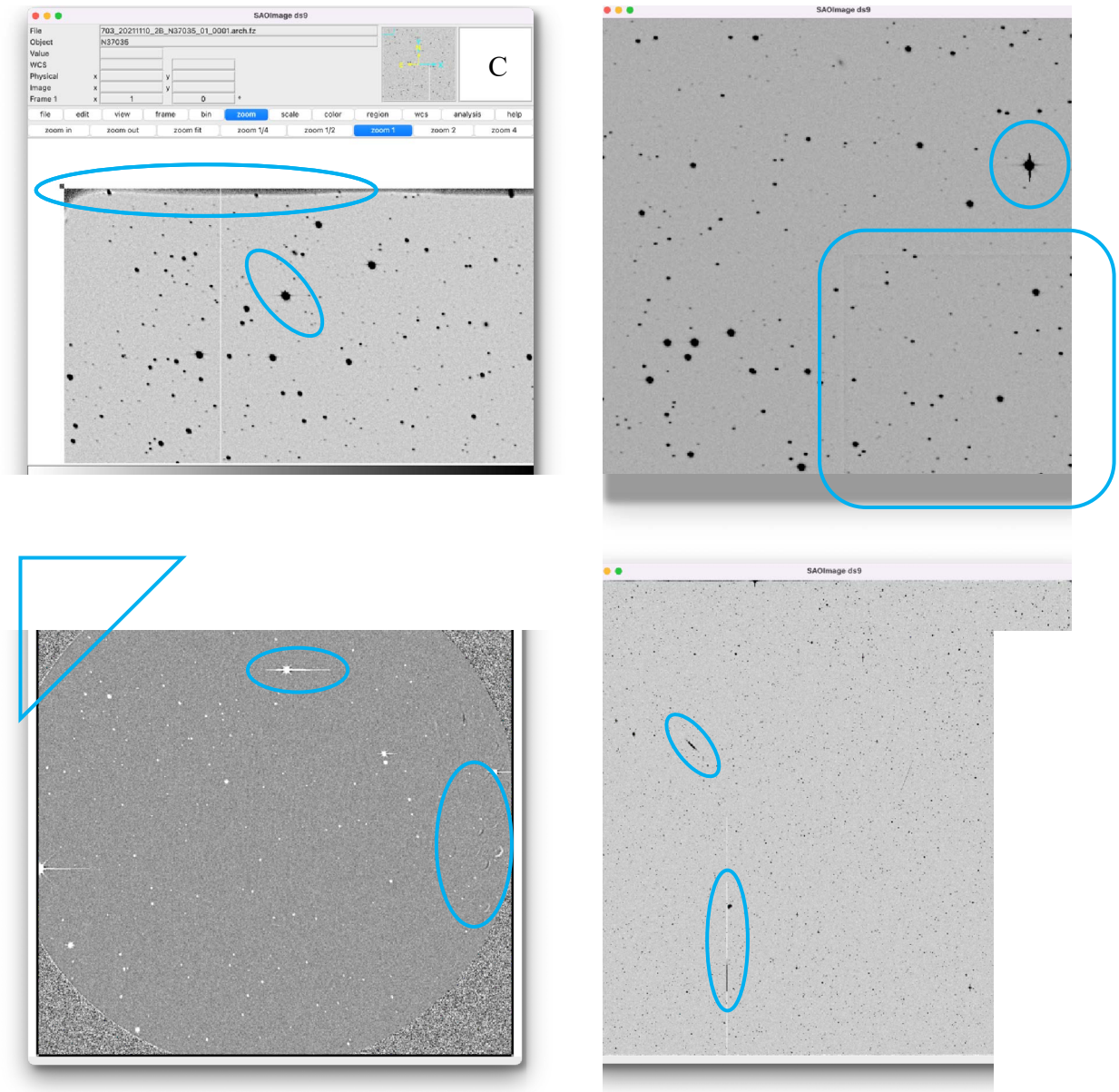


Figure 2 – Examples of imaging artifacts. Panel C is a small region of the corner of one image from Catalina's 10K camera at the Schmidt telescope (703) showing bad pixels near the edge of the CCD, as well as an elongated PSF near the corner of this very wide field detector (19 square degrees). Panel D shows print-through in this zoomed view in the blue box from a rectangular subsection of the large monolithic CCD. The blue oval shows a bright star with both 45° diffraction spikes and a vertical charge artifact. Panel E is an image from the camera of the 1.0-m follow-up telescope (I52) in cassegrain mode before its prime-focus conversion. Larger vignettted corners were filled with random noise to minimize false detections along the sharp circular edge. Saturation artifacts can occur in different orientations from different cameras. Flat-fielding artifacts from print-through of median-coadded flat fields are in the oval to the right. Panel F is a full-field image from the new I52 prime-focus configuration. Vignetting is much reduced and mostly flat-fields out. The blue oval at the bottom shows that single artifacts can swing between extreme pixel values. The galaxy in the smaller blue oval emphasizes that background stars and galaxies are in effect artifacts for the purpose of moving object detection.

3.7 Identifying Known Objects, Scoring Unknown Candidates

The lists of detections are compared against a list of known objects in the field, including the predicted magnitude of each object from its ephemeris, via the **MAKEEPHM** and **IDENTIFY** modules.

CSS imaging is very wide field, 5 square degrees for G96 and 19 square degrees for 703 (a Schmidt telescope). Each exposure, especially near the ecliptic, may have hundreds of detectable moving objects and many thousands of point sources. These are scored according to the likely reality of a moving object, as well as by its likelihood of being a Near Earth Object via the **DIGEST2** module from the Minor Planet Center. Annotated candidates are turned into the final list of candidate detections using **MTDF2DETS**. The most likely NEO candidates are presented to the observer for validation.

3.8 Human Validation and MPC Report Generation

At various steps in the community NEO workflow, humans monitor automated processes. Catalina implements near real time validation of all NEO candidate astrometry before submission to the Minor Planet Center. Thousands of times during a typical night at the telescope, the CSS observer will blink candidate detections and make a keystroke determination as to whether the candidate corresponds to a real object. This is implemented via the **VALIDATION** module. The **MKMPCREPORT** module generates the final reports for submission of asteroid astrometry to the Minor Planet Center. At the time of this writing this meets the “80-column” MPC 1992 format, but CSS and the larger community are transitioning to the IAU Astrometry Data Exchange Standard (ADES), developed since 2015. CSS will continue to generate the 1992 format after the transition.

3.9 Automated Confirmation of Follow-up Identifications

Sometimes community follow-up of catalog objects or of targets from the NEO Confirmation Page wrongly associates a tracklet (sequence of two-or-more moving object observations) with a known object, or a single observation may be spurious due to imaging artifacts or low signal-to-noise centroiding. To minimize such occurrences, and as a final check on Catalina follow-up observations, an orbital fit using the community **FIND_ORB**⁶ software of the new tracklet with all known observations is performed once the target is identified. Up to one detection exceeding a 3-sigma fit threshold will be removed if the rest are deemed good. If more than one detection point exceeds 3-sigma the entire auto-identification will be removed. This makes it less likely for a false detection to be fast-tracked (submitted near-autonomously) and reduces the number of poor fitting points that get fast-track submitted since objects with multiple poor fitting points will not get fast-tracked. The observer can manually override such automated decisions, but in that case is more likely to handcraft the resulting tracklet. The results of these automated fits are captured in the .focheck files.

⁶ https://www.projectpluto.com/find_orb.htm

4. Catalina Sky Survey Operations

The CSS pipeline software described in section 3 is very general purpose and has been applied to six telescopes used by Catalina Sky Survey⁷ over the years:

- Mount Bigelow 0.7-m Schmidt telescope, MPC code 703
- Mount Lemmon 1.5-m telescope, MPC code G96
- Siding Spring 0.5-m Uppsala Schmidt, MPC code E12
- Mount Lemmon 1.0-m telescope, MPC code I52 (*follow-up*)
- Mount Bigelow 1.54-m Kuiper telescope, MPC code V06 (*follow-up*)
- Kitt Peak 2.3-m Bok telescope, MPC code V00 (*in collaboration with Spacewatch and U. Minn.*)

Astrometric measurements of asteroids, comets, and other small solar system bodies benefit from coordinated observations between survey and follow-up telescopes. For Catalina Sky Survey observing strategies fall into the following general classes of use cases. The telescopes, instruments, and software support all these activities.

4.1 Near-Earth Object discovery and confirmation

A Near-Earth Object (NEO) discovery starts with the detection of moving celestial sources. These can be objects such as main belt asteroids, Jupiter Trojans, Trans-Neptunian Objects, artificial satellites, or they can be NEOs. Distinguishing between objects requires accumulating multiple observations that can be used to solve for the Keplerian orbit. Short-arc solutions are uncertain and multiple follow-up observations are needed to reduce uncertainty and to refine orbits.

Catalina survey telescopes have fields-of-view between 1 square degree to 19 square degrees. Survey patterns are a trade-off between exposure depth and speed of covering sky. Thirty second exposures are typical for CSS. The current survey pattern with the 10Kx10K CCD at Catalina's 1.5-m telescope on Mount Lemmon (MPC code G96) can cover the entire visible sky from Arizona about 1.5 times per month. A similar 10K camera on the Mount Bigelow 0.7-m Schmidt telescope covers the visible sky every three or four days to a brighter limiting magnitude.

Each night CSS will submit between a few and a few dozen NEO candidates to the NEO Confirmation Page⁸ (NEOCP) of the Minor Planet Center. Professional and amateur observers around the world will select objects for astrometric follow-up from the NEOCP, ideally leading to confirmation as NEOs. CSS also operates follow-up telescopes to perform this critical chore. Follow-up observing is also distinguished by techniques such as tracking at non-sidereal rates to match the motions of the asteroids, and/or a *track-and-stack* observing mode that acquires multiple exposures to coadd at the object's rate of motion to freeze each object's motion.

⁷ The CSS pipeline has also been applied to data from several external telescopes, but these data sets will not be included in the CSS PDS holdings.

⁸ https://minorplanetcenter.net/iau/NEO/toconfirm_tabular.html

Follow-up observations are reported to the Minor Planet Center for posting to the NEOCP. When a sufficient arc is accumulated for an acceptable orbit a Minor Planet Electronic Circular (MPEC) is published⁹ to convey the orbit and a designation for the newly discovered object.

4.2 NEO Arc Extensions

Observations of NEOs continue after discovery and indefinitely through future apparitions when Earth and asteroid are again well-placed for observations. Even large asteroids become invisible from a particular telescope when too near the Sun in the sky, or when their declinations are outside of those reachable from the observing site. NEOs have eccentric orbits and when the asteroids are far from the sun they may be too faint for any telescope on Earth or in space.¹⁰

Catalina Sky Survey's follow-up telescopes also take observations for the purpose of refining NEO orbits, with priority given to potentially hazardous objects.

4.3 NEO Precoveries

Just because an asteroid has yet to be discovered does not mean that NEO surveys have not imaged it, and archival searches for pre-discovery detections (so-called *precoveries*) can often extend an orbital arc backwards significantly. There are many reasons why the detection may not have been made when the data were originally acquired, such as interference from stars along the line-of-sight, imaging artifacts, or simply poor sky conditions that made a new discovery impossible. In later months or years the knowledge that an asteroid should have appeared in a particular field, at a certain magnitude, and moving at a known rate can be enough to confirm a detection. Multiple users can productively search for precoveries and CSS hopes that opening its data holdings to the public via the Planetary Data System will support many more precoveries in the future. A single precovery can significantly improve an orbit, increasing the efficiency of the entire NEO community.

4.4 Incidental Main Belt Asteroid astrometry

While observing foreground NEOs, surveys also acquire vast numbers of observations of background Main Belt Asteroids (MBAs) and other classes of objects. The orbits of many of these objects are known with high accuracy and precision. Large objects in circular orbits will be recovered many times over the years, and matching detections against the growing catalog of known objects permits reporting astrometry in an automated fashion. Several thousand automated MBA detections are made and reported each night by CSS.

4.5 Asteroid and comet photometry and time series

The discovery of asteroids and the improvement of their orbits is a requirement for their scientific study. Each astrometric observation provides a rough photometric measurement, but CSS telescopes can also be used to acquire more precise photometry. This can require many times the investment in exposure time compared to the short exposure, low signal-to-noise

⁹ <https://minorplanetcenter.net/mpec/RecentMPECs.html>

¹⁰ See Lowell Observatory's asteroid observability tool: <https://asteroid.lowell.edu/astobs/>

observations required for an efficient survey. Asteroids rotate and time series observations can characterize this. Such characterization observations amount to only a small fraction of CSS data-taking at present, but this is likely to increase in the future. Archival data sets can similarly be mined for detections of active asteroids and comets to extend photometric measurements far into the past.

Comets are routinely detected by the CSS moving object pipeline, though there is little special handling of cometary detections. Centroids are automatically assigned by **SEXTRACTOR**, and photometry is calibrated in the same manner as asteroids. Thus, for active, asymmetric objects, astrometry reported to MPC can be affected by a tailward bias.

Comets are excluded from the auto-identification step that associates moving object candidates with known asteroids. This is due to a combination of the way comet elements are published by MPC and limitations in the ephemeris software used by CSS for predicting the positions of known asteroids. As a result, all detected comets are presented to the observer for visual validation. Identification of known comets is generally done by the nighttime observer, with a query of **MPCHECKER** and/or the JPL Small Body Identification Tool. As with other unusual moving objects such as NEO candidates, observers may choose to report a detected comet's tracklet to MPC in a unique report during the night. Some comets are explicitly reported to MPC as such, and others are submitted without comment. However, given Catalina's primary task of NEO discovery and follow-up, known comets are generally not paid special attention by the nighttime observer.

The policy of CSS and the IAU allows for comets to be named for their discoverers, provided the observer acquired the data, identified cometary activity, and reported the new discovery through the proper channels. Otherwise, comets that are discovered in the course of the asteroid survey but are not noted to be cometary by the observer, may receive names for the CSS site at which they were discovered, like "Catalina", "Lemmon", or "Siding Spring".

4.6 Crowd-sourced validation

A hallmark of Catalina Sky Survey operations is real time validation. Our observers are presented with roughly 5,000 targets each night for rapid decisions on whether each object is real or not. An algorithm, *digest2*¹¹, provides an estimate of whether a particular short tracklet represents a NEO or rather some other class of object. Our observers are the ultimate limiting resource for CSS.

This approach scales well for same-night observations since a single observer can support one or two telescopes and adding telescopes generally means adding more observers. It does not scale for archival reprocessing which may deliver many additional detections than originally found because: 1) a newer version of the CSS pipeline with higher sensitivity is used which is likely to find many more moving object candidates, and 2) the catalog of known object will have grown which has the side effect of allowing us to dig deeper into the noise for unknown objects such as NEOs.

¹¹ <https://arxiv.org/abs/1904.09188>

Crowd-sourcing is one way to bring more resources to this task and CSS is currently operating a Trans-Neptunian Objects citizen science project on the Zooniverse.¹² This TNO project also serves as a prototype for a later deep NEO survey project which may rely on CSS holdings in the PDS.

4.7 Community follow-up with NEOfixer

This document has discussed not only how CSS operations work now, but also has touched on various ways Catalina may evolve in the future, often taking advantage of PDS facilities being built today. A general trend in astronomy and planetary science is ever more close cooperation between institutions and individuals. A number of trends for CSS and the NEO community involves the advent of transient broker technology to coordinate observing, archives, and processing to increase efficiency and data mining. CSS is commissioning its NEOfixer broker to better ensure that all NEO candidates receive timely follow-up and that the highest priority arc extensions are attended to, see figure 3.

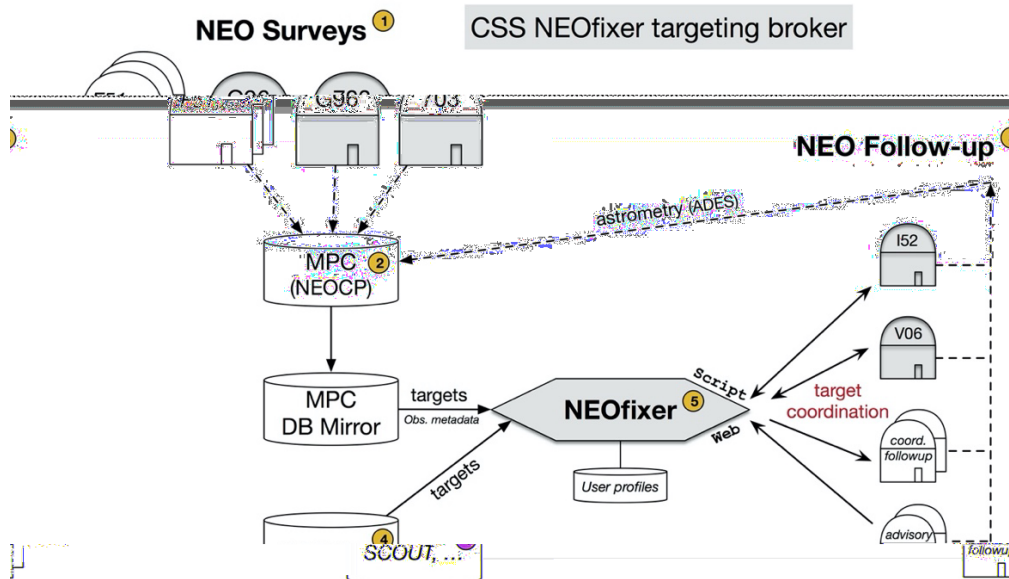


Figure 3 – NEO discovery and follow-up using NEOfixer. 1) NEO surveys submit NEO candidates to 2) the MPC. 3) NEO follow-up telescopes respond directly or indirectly, and 4) input from Scout and other sites (potentially PDS) also flows into the 5) NEOfixer broker which scores targets and provides priorities.

¹² <https://www.zooniverse.org/projects/fulsdavid/catalina-outer-solar-system-survey>

5. Appendix

Catalina Sky Survey data flow diagram v1.3

(A)

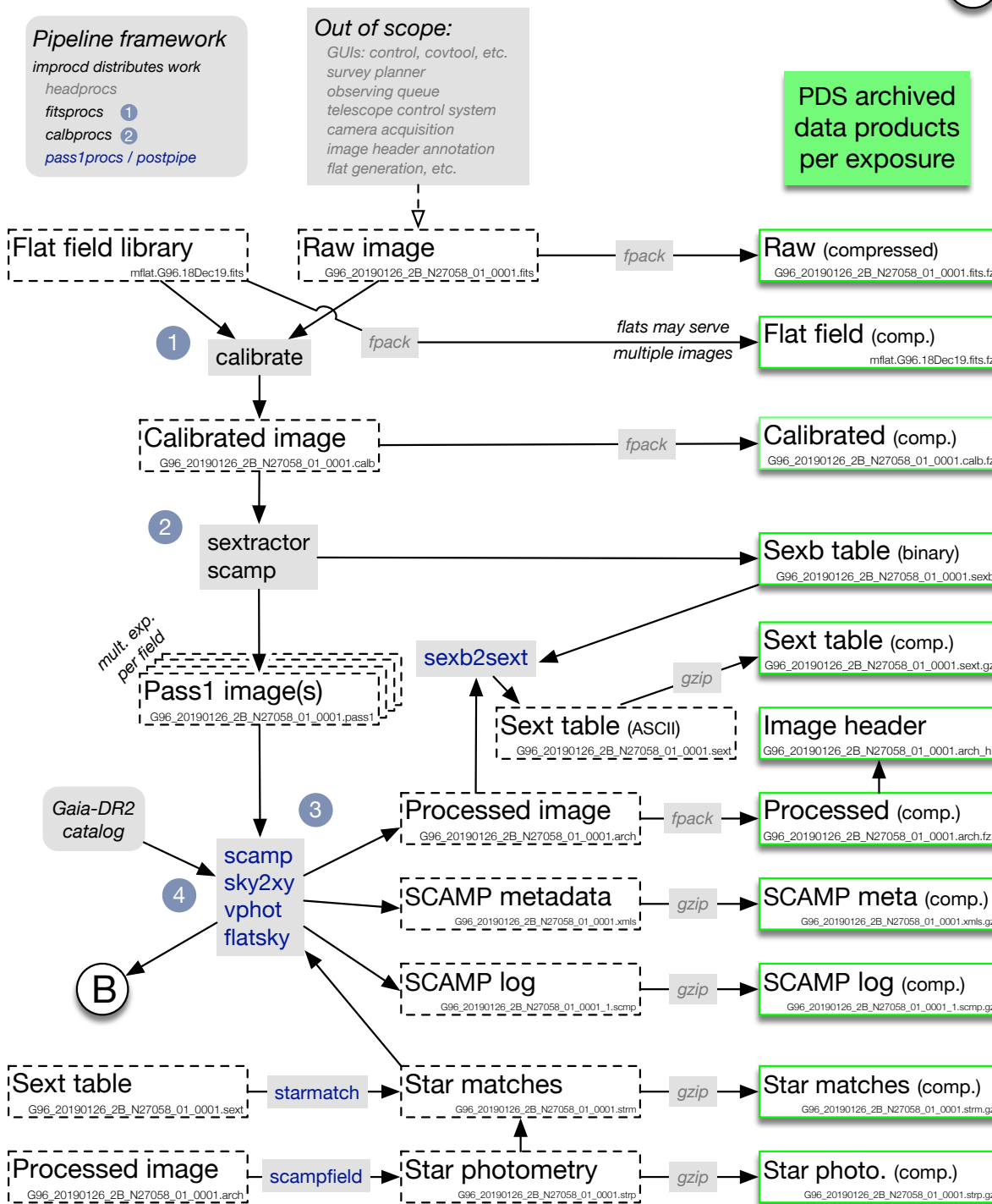


Figure 4 – CSS data flow with resulting SBN archival data products highlighted, generally in the column on the right. The CSS pipeline framework is outlined, with numbered references to module descriptions in section 3. Data product types on this page are archived one each per exposure of each telescope’s camera. (A flat field may be used for multiple raw images.)

Catalina Sky Survey data flow diagram v1.3

(B)

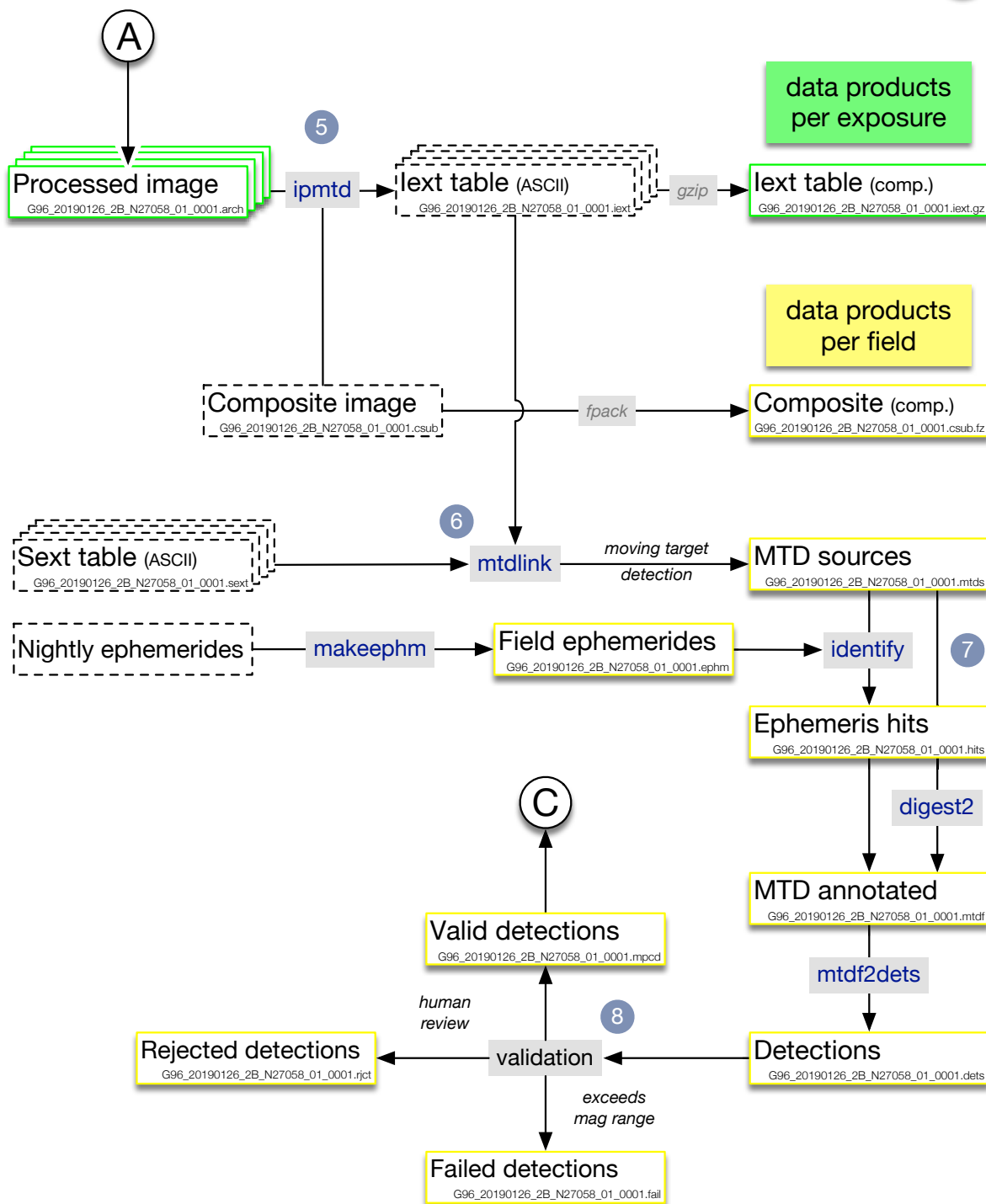


Figure 5 – CSS data flow continued. As indicated, data product types on this page are generally archived one each per multi-exposure field. Each field is reimaged four times in survey mode (three are sufficient for a moving object solution), and perhaps more times for targeted follow-up. Depending on the pipeline processing for a specific raw image, subsequent steps may be omitted due to various causes such as weather.

Catalina Sky Survey data flow diagram v1.3

(C)

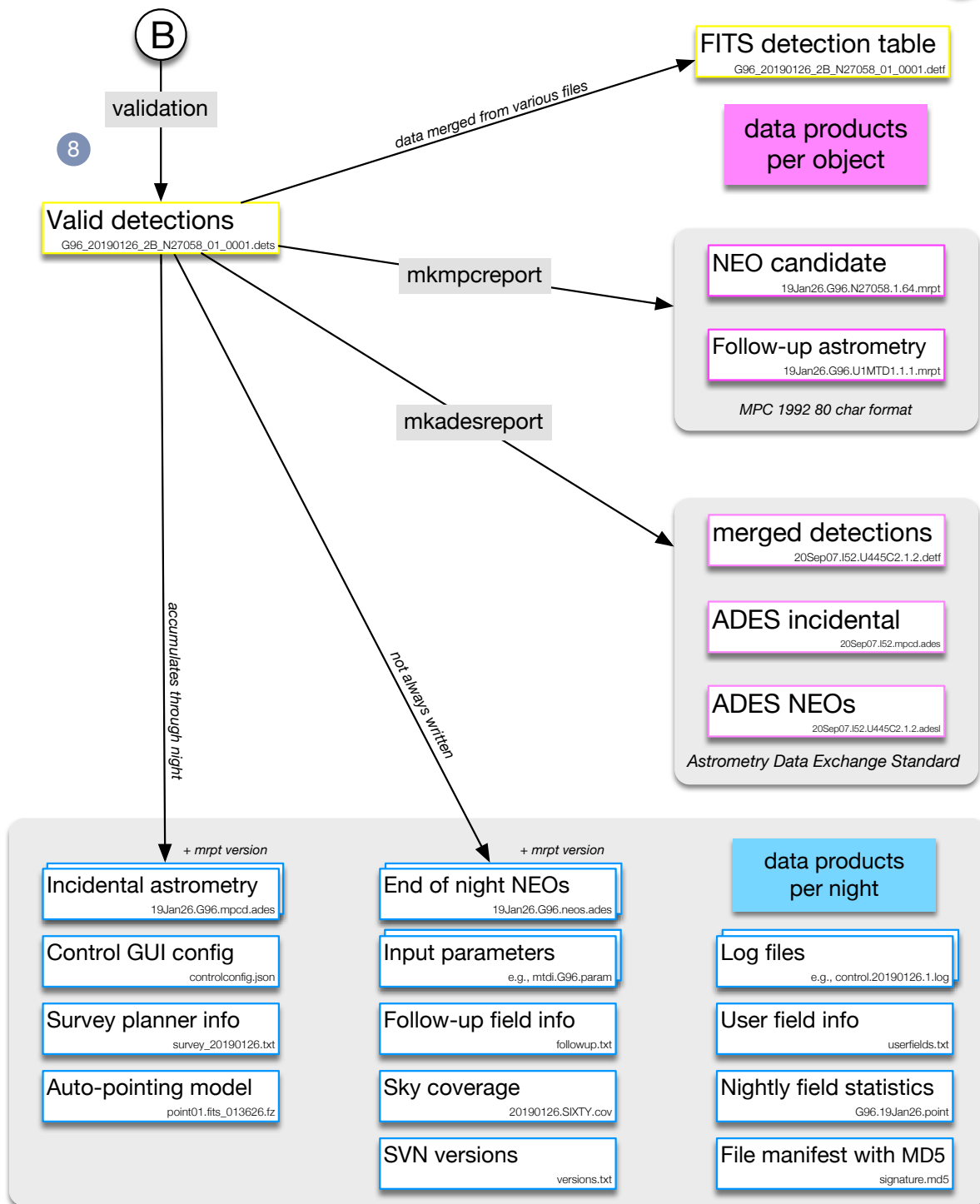


Figure 6 – CSS data flow continued. Data product types on this page may be archived one per candidate discovery or one or a few times per observing session (a night at one telescope).