Kepler: A Search for Terrestrial Planets

SOC 9.3 DR25 Pipeline Parameter Configuration Reports

KSOC- 21227

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Reference Documents

The Kepler Science Data Processing Pipeline Source Code Road Map, KSOC-21226

Kepler Data Processing Handbook, KSCI-19081-002

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Table of Contents

1. Introduction

This document describes the manner in which the pipeline and algorithm parameters for the Kepler Science Operations Center (SOC) science data processing pipeline were managed. This document is intended for scientists and software developers who wish to better understand the software design for the final Kepler codebase (SOC 9.3) and the effect of the software parameters on the Data Release (DR) 25 archival products.[1]

2. Overview of Pipelines and Pipeline Reports

The Kepler Long Cadence (LC), Short Cadence (SC), and Full Field Image (FFI) data were processed in the SOC Pipeline to generate products for the archives. The data consisted of 18 quarters, nominally ~93 days long, named Q0 through Q17. Q0 was only 10 days long and was collected during commissioning. Q1 was only 34 days long because it was started late in the observation season, due to launch and commissioning. Q17 is also a short (~2 weeks long) as the second reaction wheel failed early in this quarter. See the Kepler Data Processing Handbook (KSCI 19081-002), the Kepler Data Characteristics Handbook (KSCI 19040-006), and the Kepler Archive Manual (KDMC 10008-006) for further details on the SOC Pipeline and Archive products[2].

The SOC Pipeline is a combination of multiple pipelines, where each pipeline is one or more software modules, of the Kepler SOC Software. Splitting or combining modules was done for convenience. For example, creating a pipeline to run all three Kepler short cadence months for a quarter in serial in the "PA+PDC x 3" pipeline; or combining the Light Curve (also called Flux) and Target Pixel File (TPF) exporter modules into a “Flux + TPF Exporter” pipeline which then exports the two data types in serial. When launching a pipeline with more than one software module, overrides can be set to run only some portion of that pipeline.

Each pipeline can be configured for a specific activity. When the pipeline is launched, that configuration becomes a specific pipeline instance. For each pipeline instance that ran, a pipeline instance report has been generated. The following sections will provide details on the pipelines that ran to produce the archive products and pipeline instance report. The archive products are created by either running an exporter pipeline, or command line tools.

The data processing and export activities are partitioned by the following categories.

1. **Long Cadence Data Processing Pipelines:** The Q0 through Q17 Long Cadence (LC) data was processed through each of the pipelines below to generate the products for the Kepler archive at the Mikulski Archive for Space Telescopes (MAST). See also Figure 1: Long Cadence Processing Activity.
    a. **"dynablack" Pipeline:** Processes a single quarter through Dynablack. The following quarters were not processed through Dynablack due to lack of input data required (FFIs): Quarter 0, Quarter 1, and Quarter 17.
    b. **"CAL MQ (parallel)" Pipeline:** Processes one or more quarters through the Calibration (CAL). Using the NASA Ames Supercomputer (NAS) resource, we can process multiple quarters in parallel.
    c. **"PA MQ (parallel)" Pipeline:** Processes one or more quarters through Photometric Assessment (PA). Using the NAS resource, we are able to process multiple quarters in parallel. This pipeline contains two software modules of PA,

[1] The DR 25 data available on the Mikulski Archive for Space Telescopes (MAST) at https://archive.stsci.edu/kepler/.
[2] Available at http://archive.stsci.edu/kepler/documents.html

set up to run in serial. The modules are then configured to process the Kepler data at the Q13-Q14 failure of the Reaction Wheel on the spacecraft. This pipeline was used twice in processing the Kepler Long Cadence (LC) data: first, called PA1, to calculate motion polynomials in order to update optimal apertures, and second, called PA2, to perform photometry using the updated apertures. The PA2 run also used new functionality to update apertures within PA itself.

d. **"PDC MQ (parallel)" Pipeline:** Processes one or more quarters through Presearch Data Conditioning (PDC). Using the NAS resources, we can process multiple quarters in parallel.
e. **"TPS-lite x 4" Pipeline:** Process four quarters through Transiting Planet Search (TPS), in serial. TPS-lite is the mode of TPS where only the CDPP calculation is performed. TPS does not perform any other planet search functions in lite mode. This pipeline consists of four software modules of TPS. We typically processed the quarters sequentially, i.e. Q0-Q3 then Q4-Q7. However, the pipeline could have been configured for up to any four quarters, which was done to address software issues, hardware maintenance, and so on.
f. **"PPA x 4" Pipeline:** Process four quarters through Photometer Performance Assessment (PPA), in serial. PPA is the set of the following modules: PAD, PMD, and PAG. This pipeline consists of four groupings of PAD+PMD+PAG software modules. We typically processed the quarters sequentially, i.e. Q0-Q3 then Q4-Q7. However, the pipeline could have been configured for up to any four quarters, which was done to address software issues, hardware maintenance, and so on.
g. **"TAD Supplemental" Pipeline:** Process one full quarter of Target List Sets, also referred to as Target Tables. This pipeline was used to update the optimal apertures using the motion polynomials calculated from the flight data; i.e. calculated in PA1. This pipeline consisted of the following modules: merge+coa+tadVal+ merge+coa+tadVal+ merge+coa+tadVal+ merge+coa+tadVal. The merge software module merged multiple target lists (such as Planetary, Guest Observers, Eclipsing Binary, etc.) into a single target list set. The Create Optimal Aperture (COA) software module selected the optimal aperture for each target in the Target List Set. The tadVal software module then performed checks to ensure the tables met mission requirements. Each set of merge+coa+tadVal can be configured for each Target Table associated with a single quarter: LC, SC-Month 1, SC-Month 2, and SC-Month 3.
h. **"merge x6" and "tadVal x6" Pipelines:** Process six quarters of Target List Sets in serial through the merge or tadVal module. These pipelines consisted of six merge or tadVal modules, respectively, run in serial. These pipelines were used to manage the Target List Sets updated by PA2 with the aperture updates performed within PA itself.

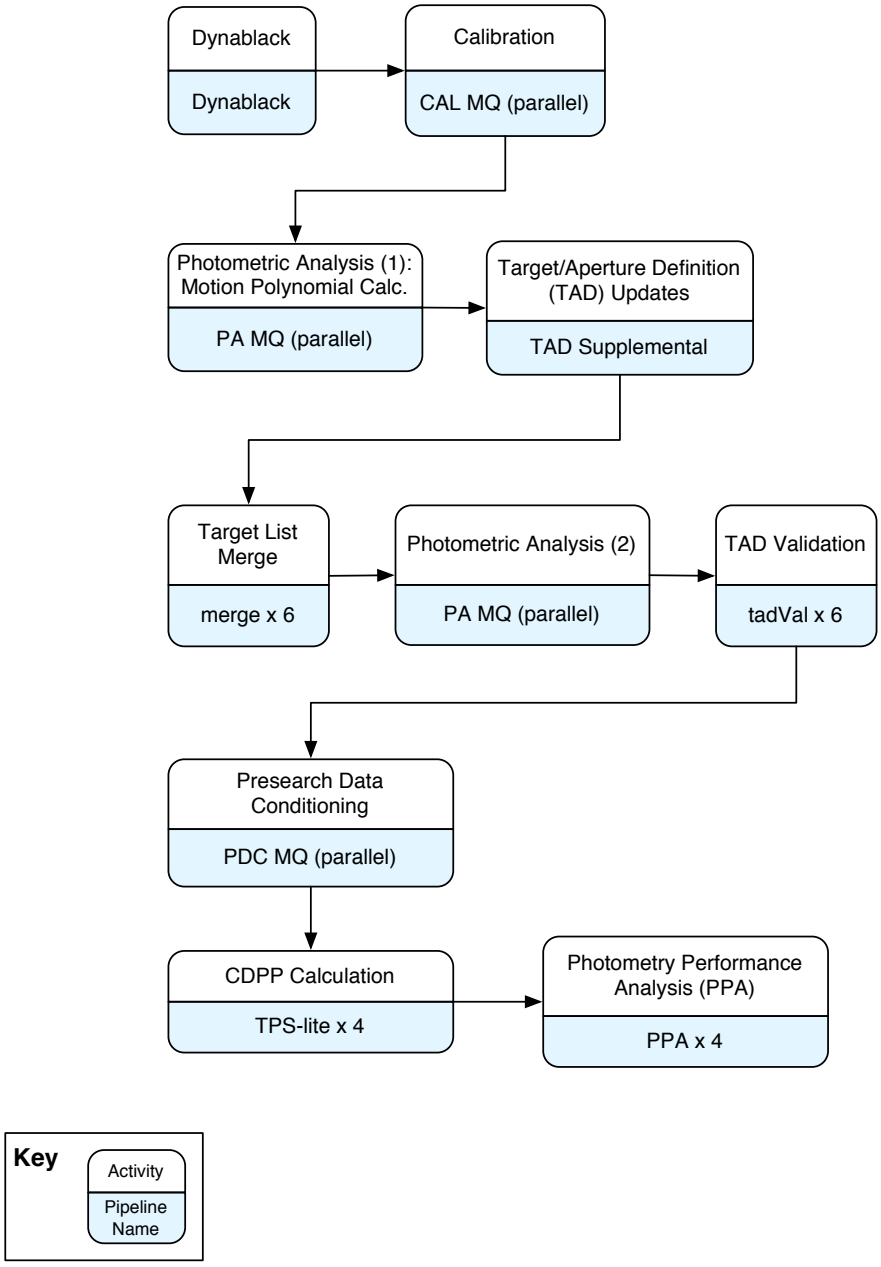

Figure 1: Long Cadence Processing Activity

2. **Planet Search Processing and Export Pipelines:** The Q1 to Q17 Long Cadence (LC) data were processed through the pipelines below to generate and export the products for the Exoplanet Archive at the NASA Exoplanet Science Institute (NExScI). See also Figure 2: Planet Search Processing and Export Activity.
    a. **"Planet Search" Pipeline:** Process the Long Cadence data through the Transiting Planet Search (TPS) and Data Validation (DV) modules.

b. **"DV Reports Exporter" Pipeline:** Export the DV reports (one per target) and DV Threshold Crossing Event (TCE) Summary reports (one per planet candidate), which processed through DV.
c. **"DV Time Series Exporter" Pipeline:** Export various DV time series data for each target that was processed in DV.
d. **"DV Results Exporter" command line tool:** Export the DV results (TCE table, etc.) for each target that was processed in DV.

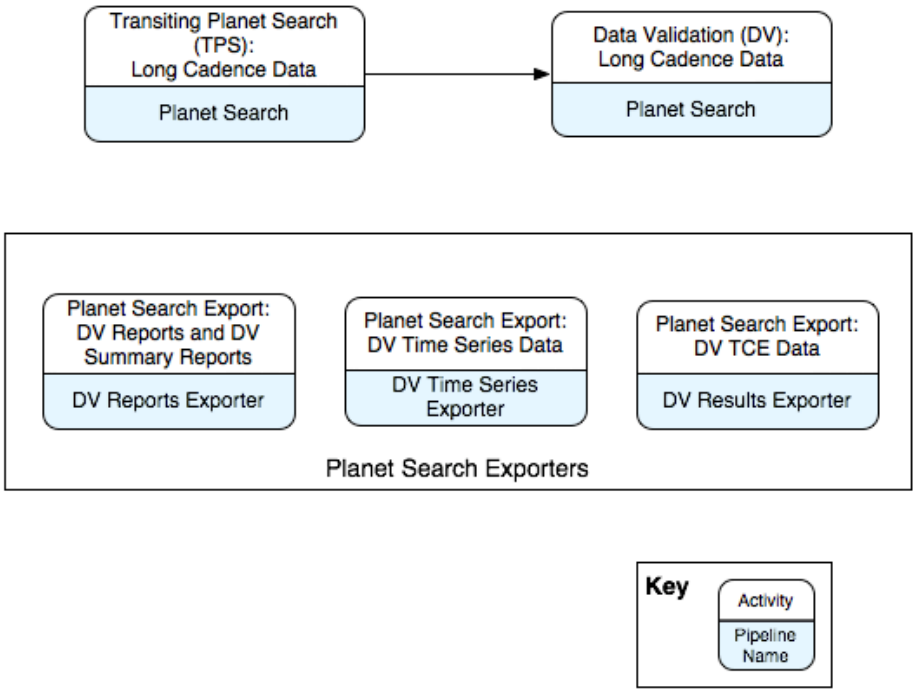

Figure 2: Planet Search Processing and Export Activity

3. **Short Cadence Data Processing Pipelines:** The Q0 through Q17 Short Cadence (SC) data was processed through each of the pipelines below to generate the products for the Kepler archive at MAST. Se also Figure 3: Short Cadence Processing Activity.
    a. **"CAL MQ (parallel)" Pipeline:** Processes one or more quarters through the CAL module. Using the NASA Ames Supercomputer resource, we can process multiple quarters in parallel.
    b. **"PA+PDC x 3" Pipeline:** Process three Short Cadence months in serial through PA and PDC. This pipeline contains the modules: pa+pdc+ pa+pdc+ pa+pdc.
    c. **"TAD Supplemental" Pipeline:** Process one full quarter of Target List Sets, also called Target Tables. This pipeline was used to update the optimal apertures using the motion polynomials calculated from the flight data; i.e. calculated in PA1. This pipeline consisted of the following modules: merge+coa+tadVal+ merge+coa+tadVal+ merge+coa+tadVal+ merge+coa+tadVal. Each set of merge+coa+tadVal can be configured for each Target Table associated with a single quarter: LC, SC-Month 1, SC-Month 2, and SC-Month 3.

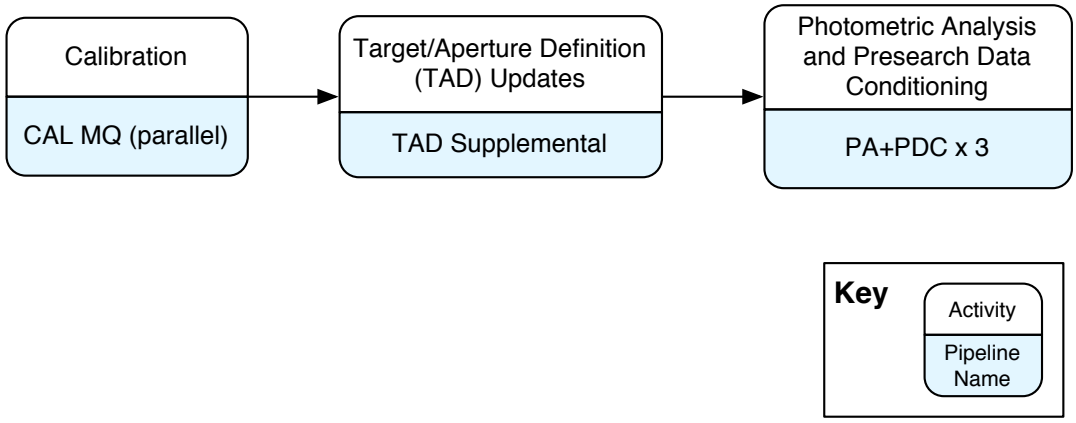

Figure 3: Short Cadence Processing Activity

4. **Long Cadence and Short Cadence Export Pipelines:** The Quarter 0 through Quarter 17 LC and SC data was processed through the pipelines below to write the archive products. See also Figure 4: Long / Short Cadence Export Activity.
    a. **"ABCC Exporter" Pipeline:** This pipeline consists of five modules: arpExporter, backgroundPixelExporter, collateralPixelExporter, and cbvFragmentGenerator, and cbvAssembler. It was used to export the Artifact Removal Pixel (ARP) data, Background Pixel data, LC Collateral Pixel data, and the Cotrending Basis Vector (CBV) data.
    b. **"Collateral Pixel Exporter" Pipeline:** This pipeline contains a single module: the collateralPixelExporter. It was used to export either LC or SC Collateral data.
    c. **"Collateral Pixel Exporter x 4" Pipeline:** This pipeline contains four modules of the collateralPixelExporter module, in serial. It was used to export either LC or SC Collateral data, for up to 4 Target Tables: LC, SC-Month 1, SC-Month 2, and/or SC-Month 3.
    d. **"Flux Exporter" Pipeline:** This pipeline was used to export the LC or SC Light Curve (Flux) data. It contains a single module.
    e. **"Flux Exporter x 4" Pipeline:** This pipeline was used to export up to four Target Tables' worth of the LC or SC Light Curve (Flux) data, in serial. It contains four fluxExporter modules.
    f. **"Flux+TPF Exporter" Pipeline:** This pipeline exports the Light Curve and Target Pixel data, in serial. It contains two modules: fluxExporter and targetPixelExporter.
    g. **"targetPixelExporter" Pipeline:** This pipeline was used to export the LC or SC Target Pixel data. It contains a single module.
    h. **"Target Pixel Exporter x 4" Pipeline:** This pipeline was used to export up to 4 Target Table's worth of the LC or SC Target Pixel data, in serial. It contains four targetPixelExporter modules.

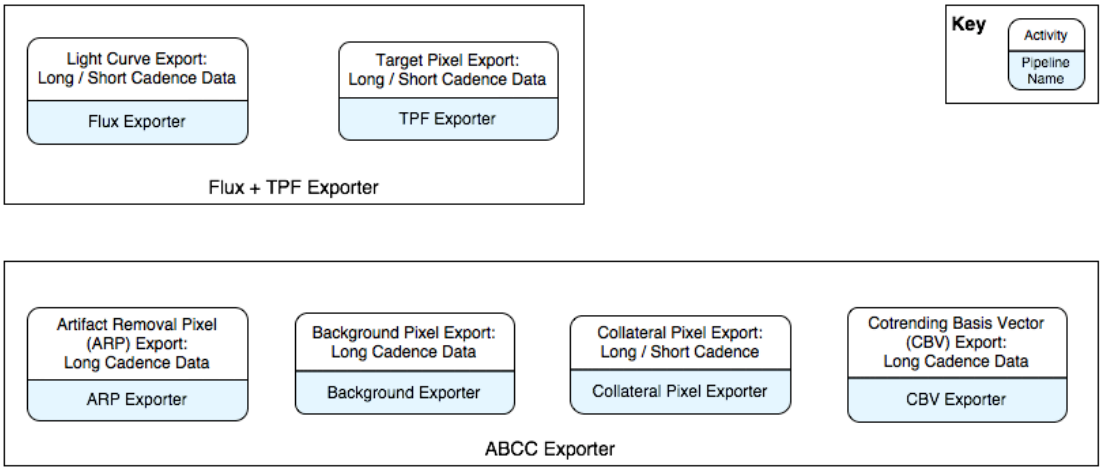

Figure 4: Long / Short Cadence Export Activity

5. **Full Field Image Data Processing and Export Pipelines:** The Q2 through Q16 Full Field Image (FFI) data were processed through each of the pipelines below to generate and export the products for the Kepler archive at MAST. See also Figure 5: FFI Processing and Export Activity.
    a. **"FFI: CAL+PA" Pipeline:** Process a single FFI through the FFI-specific calibration and photometry modules: calFfi and paFfi.
    b. **"FFI Exporter x4" Pipeline:** This pipeline was used to export up to four FFIs. It contains eight modules – four sets of: ffiFragmentGenerator+ffiAssembler.

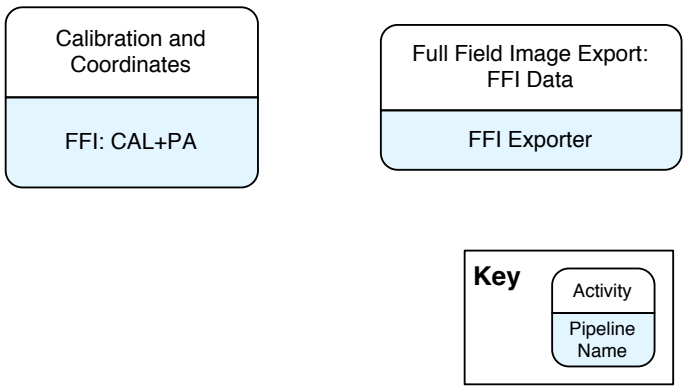

Figure 5: FFI Processing and Export Activity

3. Pipeline Instance Reports Structure:

Each Pipeline Instance will have a Pipeline Instance Report. This report is a record of the SOC Software version, the parameters, the focal plane models, and the modules that ran in the pipeline instance. Below is a description of the sections of the pipeline instance reports.

1. **Pipeline Instance Summary:** This section is a summary of the pipeline instance that includes the unique pipeline instance ID and name, the pipeline definition, and other information that applies to the run-time pipeline instance.
2. **Pipeline Parameter Sets:** This section lists the parameters used in the specific pipeline instance. Some Parameter Sets are assigned at the "pipeline level" because they are potentially used by more then one module in the pipeline. These Parameter Sets show up first in the report. Some Parameter Sets are assigned at the Module level and only used by that module - see Section (B)(3). The Parameter Sets assigned at the Module level are listed in the report under their respective module.
    a. **Parameter Set:** A structure containing one or more parameters. The Parameter Set has a defined type, such as calModuleParameters. There can be multiple instances of a parameter set. For example, the SOC environment has a "cal (LC)" and "cal (SC)" instance of the calModuleParameters Parameter Set.
    b. **Parameters:** Within a Parameter Set, there are one or more parameters. The parameters can be numeric, boolean, or strings; and can be single valued or arrays. See Section D for further discussion on the parameters.
3. **Modules:** This section lists each module that ran in the pipeline instance and the Parameter Sets assigned to each module. A module, and its Parameter Sets, will be included whether the module completed or failed.
    a. **Module Definition:** The definition of each module included in the pipeline instance will be included in the report with details such as the class name and memory allocation. The definition will also include the number of tasks (units of work) that ran and the SOC software version used.
    b. **Parameters Sets:** Parameter Sets assigned to each module will be listed under each module definition.
4. **Data Model Registry:** This section lists the models in place at the time the pipeline instance was run. Included in this section are:
    a. **Focal Plane Characteristic Models:** Bad Pixel Map, Gain, Geometry, Large Flat Field, Linearity, Pointing, PRF, Read noise, Roll-time, Saturation, Small Flat Field, 2-D Black, and Undershoot
    b. **Data Anomaly Flags:** Flags set manually to modify how various pipeline modules use cadences the flags are applied to
    c. **Data Observing Log:** Metadata about the quarters, such as start and end cadence numbers and target table IDs.
    d. **Supplementary Tables:** Eclipsing Binary (EB) Transit Parameters, External TCE table (used by DV if the appropriate flag is enabled), Transit Parameters, Transit Names (Kepler Object of Interest Names)
    e. **Kepler Input Catalog (KIC) updates:** KIC Extension to include the United Kingdom Infra-Red Telescope (UKIRT) catalog, and KIC overrides
    f. **Miscellaneous:** Ephemerides files, Leap Seconds file, Spacecraft Clock

4. Pipeline Instance Reports for the Kepler SOC 9.3 processing activity:

1. The Pipeline Instance report naming conventions are as follows:

   For a pipeline instance which ran a single quarter:

   Q<X>_<DATA_TYPE>_<CSCI>_<EXTRA_INFO>_pid_<PID>_pipeline_report.txt

   For a pipeline instance that ran multiple quarters in serial or parallel:

   Q<X>-to-Q<Y>_<DATA_TYPE>_<CSCI>_<EXTRA_INFO>_pid_<PID>_pipeline_report.txt

   Q<X>-Q<Y>-Q<Z>_<DATA_TYPE>_<CSCI>_<EXTRA_INFO>_pid_<PID>_pipeline_report.txt

   Where:

   - Q<X> is the quarter number, such as Q00, Q01 ... Q17
   - Q<X>-to-Q<Y> is the quarter range, such as Q00-to-Q04 (such as to run the first 5 quarters through LC CAL in parallel), or Q01-to-Q17 (such as to run Multi-Quarter TPS)
   - Q<X>-Q<Y>-Q<Z> is the quarters included, if not a sequential range, such as Q02-Q05-Q12
   - <DATA_TYPE> is the data type processed, one of: LC, SC, or FFI
   - <CSCI> is the pipeline module, one of: DYNABLACK, CAL, PA, PA1, PA2, PDC, TPS-lite, PPA, TPS, DV, sTAD, Merge, TadVal
   - <EXTRA_INFO> is additional information for the pipeline instance, if needed, such as “Module_3”, "TadVal_for_PA_COA" or "MPE_true"
   - pid_<PID> is the unique Pipeline Instance ID (PID)

2. Pipeline Instance Report content: A pipeline may have been configured for multiple quarters or for multiple modules and then fail for some quarter or module. The pipeline instance report will report the parameters for both the completed and failed quarters and/or modules. The failed quarter or module would have then been processed in a later pipeline instance.
3. One report was generated for each pipeline instance, regardless of the number of quarters included in the pipeline instance. There will not be one pipeline instance report per quarter, which would result in duplicate reports.
4. The pipeline instance reports will be named only for the quarters and/or modules that completed. When the quarter or module was re-run successfully, a new pipeline instance report was generated.

5. Differences between pipeline instance reports for the same CSCI

1. **Default values**: The majority of the pipeline parameters have been extensively reviewed, tested, and approved by the Data Analysis Working Group (DAWG). These parameters will be common between reports for the same activity covering different quarters. For example, calibration parameters for detecting cosmic rays will not have changed from one quarter to the next.
2. **Data-set specific parameters**: Some parameters are unique to the data set being processed. These parameters will be updated for each quarter or data type. For example, some parameters define the unit of work, such as the start and end cadence. Other parameters are changed based on the quarter which is being processed, such as the reaction wheel ancillary engineering parameter set which will change starting in Q14 due to the loss of the reaction wheel in Q14. Some parameters have been refined to process either the LC or SC data, or only apply to one or the other data type processing activity.
3. **Activity specific parameters**: Some parameters are updated based on the activity at hand. This group of parameters include those that modify the unit of work to balance the load across the data processing servers, those that determine how we use the NASA Ames Supercomputer (NAS) resource, and those that enable or disable functions within a module. For example the paCoaEnabled parameter is set to false for the LC PA1 iteration, true for the LC PA2 iteration, and false for the SC PA processing.
4. **Data-set and Activity specific parameters:** Some parameters fall into both categories of Data-set and Activity specific. These include parameter used for modifying the unit of work, which may be different between LC and SC processing. Other parameters that fall into this category are for turning on or off features in the code. For example, the paCoaEnabled parameter set is activity specific: false for LC PA1 but true for LC PA2, and data-set specific: true for LC PA2 but false for SC PA.

Parameter Set Name	Parameter Name	Data-Set Specific	Activity Specific	Used By Pipeline Software Module*
cadenceRange	startCadence	Yes	Yes	*A.2*
cadenceRange	endCadence	Yes	Yes	*A.2*
cadenceRange	minimumBinSize	Yes	Yes	*A.2*
cadenceRange	numberOfBins	Yes	Yes	*A.2*
cadenceRange	binByTargetTable		Yes	*A.2*
cadenceRange	excludeCadences		Yes	*A.1*
calFfi	fileTimeStamp	Yes		*C.1, E7*
completedDvPipelineSelection	pipelineInstanceId	Yes	Yes	*E.6*
dvExporter	dvPipelineInstanceId	Yes	Yes	*E.6*
dvExporter	tpsPipelineInstanceId	Yes	Yes	*E.6*
dvReports	dvReportSummariesDirectory		Yes	*E.5*
dvReports	dvReportsDirectory		Yes	*E.5*
dynablack	rawFfiFileTimestamps	Yes		*D.1*

Parameter Set Name	Parameter Name	Data-Set Specific	Activity Specific	Used By Pipeline Software Module*
exporter	startCadence	Yes		*E.1*
exporter	endCadence	Yes		*E.1*
exporter	fileTimeStamp	Yes		*E.2*
exporter	quarter	Yes		*E.1*
exporter	nfsExportDirectory	Yes	Yes	*E.1*
exporter	dataReleaseNumber	Yes	Yes	*E.1*
ffiAssembler	dataReleaseNumber	Yes	Yes	*E.7*
ffiAssembler	nfsExportDirectory		Yes	*E.7*
fluxExporter2	tpsPipelineInstanceId	Yes		*E.8*
moduleOutputLists	channelsPerTask	Yes	Yes	*A.1*
moduleOutputLists	channelForStoringNonChannelSpecificData	Yes	Yes	*A.1*
moduleOutputLists	channelExcludeArray	Yes	Yes	*A.1, E.3*
moduleOutputLists	channelIncludeArray	Yes	Yes	*A.1, E.3*
pa	onlyProcessPpaTargetsEnabled	Yes	Yes	*C.4*
pa	paCoaEnabled	Yes	Yes	*C.4*
paCosmicRay	k2 parameters (added between LC PA1 and PA2 – not relevant to Kepler processing)	Yes		*C.3*
paFfi	backgroundTableId	Yes		*C.2*
paFfi	targetTableId	Yes		*C.2*
reactionWheelAncillaryEngineering	intrinsicUncertainties	Yes		*C.3*
reactionWheelAncillaryEngineering	mnemonics	Yes		*C.3*
reactionWheelAncillaryEngineering	modelOrders	Yes		*C.3*
reactionWheelAncillaryEngineering	quantizationLevels	Yes		*C.3*
remoteExecution	gigsPerCore	Yes	Yes	*A.3*
remoteExecution	numElementsPerTaskFile	Yes		*A.3*
remoteExecution	reRunnable	Yes	Yes	*A.3*
remoteExecution	remoteNodeArchitectures	Yes		*A.3*
remoteExecution	remoteStateFilePath		Yes	*A.3*
remoteExecution	remoteTaskFilePath		Yes	*A.3*
remoteExecution	remoteUser		Yes	*A.3*
remoteExecution	requestedWallTime	Yes	Yes	*A.3*
remoteExecution	tasksPerCore	Yes	Yes	*A.3*

Parameter Set Name	Parameter Name	Data-Set Specific	Activity Specific	Used By Pipeline Software Module*
skyGroupIdLists	skyGroupIdExcludeArray	Yes		*B.1, E.4*
skyGroupIdLists	skyGroupIdIncludeArray	Yes		*B.1, E.4*
tadLc, tadSc*, tadPa	quarters	Yes	Yes	*F.1*
tadLc, tadSc*, tadPa	supplementalFor	Yes	Yes	*F.1*
tadLc, tadSc*, tadPa	targetListSetName	Yes	Yes	*F.1*
tadSc*, tadPa	associatedLcTargetListSetName	Yes	Yes	*F.1*
targetList	targetListNames	Yes	Yes	*B.1*
targetList	excludeTargetListNames		Yes	*B.1*
targetPixelExporter	tpsPipelineInstanceId	Yes		*E.9*
targetTable	TargetTableId	Yes		*E.2*
targetTable	ChunkSize	Yes	Yes	*E.2*
taskFileCopy	(various)	Yes	Yes	*A.2*
tps	tpsLiteEnabled		Yes	*B.1*

* The "Used by Pipeline Software Module" key is as follows:

- A.1: CAL, PA, PDC, PMD, Dynablack, FFI-CAL, FFI-PA, COA
- A.2: CAL, PA, PDC, PPA, Dynablack, TPS, DV
- A.3: CAL, PA, PDC, TPS, DV
- B.1: TPS, DV
- C.1: FFI-CAL, FFI-PA, FFI Export
- C.2: FFI-PA
- C.3: FFI-PA, PA
- C.4: FFI-PA, PA, DV
- D.1: Dynablack
- E.1: ARP Export, Background Export, Collateral Export, CBV Export, Flux Export, TPF Export, DV Time Series Export
- E.2: ARP Export, Background Export, Collateral Export, CBV Export, Flux Export, TPF Export
- E.3: ARP Export, Background Export, Collateral Export, CBV Export, FFI Export
- E.4: DV Reports Export, DV Time Series Export, Flux Export, TPF Export
- E.5: DV Reports Export
- E.6: DV Time Series Export

- E.7: FFI Export
- E.8: Flux Export
- E.9: TPF Export
- F.1: merge, tadVal, COA, PA

6. References

Jenkins, J.M., (ed.) 2017, ”Kepler Data Processing Handbook (KSCI-19081-002)”, http://archive.stsci.edu/kepler/documents.html.

Thompson, S. E. , D. Fraquelli, J. van Cleve and D. Caldwell, 2016, “Kepler Archive Manual (KDMC- 10008-006)", http://archive.stsci.edu/kepler/documents.html.

Van Cleve, J. E., Christiansen, J. L., Jenkins, J. M., et al., 2016, "Kepler Data Characteristics Handbook (KSCI-19040-005)", http://archive.stsci.edu/kepler/documents.html.

7. Acronym List

ABCC	ARP, Background, Collateral and CBV
ARP	Artifact Removal Pixel
CAL	Calibration
CBV	Cotrending Basis Vector
CDPP	Combined Differential Photometric Precision
COA	Create Optimal Aperture
CSCI	Computer Software Configuration Items
DAWG	Data Analysis Working Group
DV	Data Validation
EB	Eclipsing Binary
FC	Focal Plane Characteristics
FFI	Full Field Image
KIC	Kepler Input Catalog
KOI	Kepler Object of Interest
LC	Long Cadence
MAST	Mikulski Archive for Space Telescopes
MPE	Motion Polynomials Enabled
MQ	Mulit-Quarter
NAS	NASA Ames Supercomputer
NASA	National Aeronautics and Space Administration
NExScI	NASA Exoplanet Science Institute
PA	Photometric Assessment
PAD	PPA Attitude Determination
PAG	PMD Aggregator
PDC	Presearch Data Conditioning
PID	Pipeline Instance ID
PMD	PPA Metrics Determination
PPA	Photometer Performance Assessment
PRF	Pixel Response Function
Q	Quarter
SC	Short Cadence
SOC	Science Operations Center
sTAD	Supplemental Target and Aperture Definition

TAD	Target and Aperture Definition
TCE	Threshold Crossing Event
TPF	Target Pixel File
TPS	Transiting Planet Search
UKIRT	United Kingdom Infra-Red Telescope