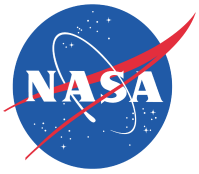

Kepler & K2 Ancillary Engineering Data for Science Data Analysis:

Pointing Telemetry, Reaction Wheel Speeds, and Temperatures

KSCI-19150-001

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Contents

1 Introduction

The Kepler mission was designed to survey a region of the Milky Way galaxy to detect and characterize transiting planets as small as Earth in or near the habitable zone. This was accomplished by observing changes in the brightness of stars in the same patch of sky for 4 years between May 2009 and May 2013 (Borucki et al., 2010; Koch et al., 2010). After the failure of two reaction wheels, the *Kepler* spacecraft could no longer maintain stable pointing at the original field. The spacecraft was subsequently repurposed to observe fields of view along the ecliptic plane. Each field of view was monitored for ∼80 days consecutively. Called the K2 mission (Howell et al., 2014), it conducted 20 different observing campaigns between May 2014 and September 2018.

During both missions, in addition to the scientific photometric data collected by the CCD detectors, a very large amount of ancillary engineering data (AED) was also collected. This included spacecraft pointing performance, reaction wheel speeds, requested and measured temperatures of spacecraft components, power systems voltages and currents, communication equipment switch states, and other various spacecraft status readings. Some of these measurements were known to correlate with focus changes and CCD behaviors. In order to enable investigations which may result in improved calibration of Kepler photometric data, files containing selected AED were made available with each delivery of Kepler and K2 data to the Mikulski Archive for Space Telescopes (MAST) at the Space Telescope Science Institute (STScI).

These "long-cadence-bundled" AED files are formatted as FITS files and contain parameter values for many AED measurements secured during single long-cadence observations obtained during the Kepler or K2 missions. There are 136,679 long-cadence-bundled AED files currently available at MAST. Appendix B.5 of the MAST Kepler Archive Manual (MKAM; Mullally, 2020) has a listing of the AED parameters recorded in long-cadence-bundled AED files.

In order to make this engineering data more usable, the Kepler/K2 Mission has created user-friendly files that, instead of putting the AED in one file per long cadence, bundle the data by parameter. Called "parameter-bundled" files, these contain all the data for parameters with the same sampling rate (i.e., are read out simultaneously) in one file for the entire Kepler or K2 mission time spans. In addition, parameter-bundled files only contain parameters that are likely to be useful for enhancing the calibration and interpretation of the scientific data (e.g., the spacecraft bus voltage parameter was included in the long-cadence-bundled files, but since it is extremely unlikely to affect the science data, it is not included in the parameter-bundled files). Conversely, the parameter-bundled files also include values for some telemetry and temperature parameters that were not delivered in the long-cadence-bundled files, but are likely to be useful for enhancing the calibration and interpretation of the scientific data; these will be referred to as "supplemental-parameter-bundled" files.

This document is meant to be read with the following companion Kepler and K2 mission documents, which are retrievable from MAST (http://dx.doi.org/10.17909/t9-2btd-va80):

- Kepler Instrument Handbook (KIH; Van Cleve & Caldwell, 2016)
- MAST Kepler Archive Manual (MKAM; Mullally, 2020)
- Kepler Data Characteristics Handbook (KDCH; Van Cleve et al., 2016a)
- Kepler Data Processing Handbook (KDPH; Jenkins et al., 2020)
- K2 Handbook (K2H; Mighell & Van Cleve, 2020)

Sections 2, 3, and 4 of this document describe the filename patterns, internal data structures, and the data retrieval instructions for the different types of ancillary engineering data files now available at MAST for the Kepler and K2 missions, where

- §2 describes the previously existing 136,679 long-cadence-bundled AED files,
- §3 describes the 16 new parameter-bundled AED files (8 for Kepler and 8 for K2), and
- §4 describes the 11 new supplemental-parameter-bundled AED files (4 for Kepler and 7 for K2).

Finally, Section 5 gives examples of how parameter-bundled AED files and supplemental-parameter-bundled AED files can be used to investigate the variation of ancillary engineering data parameter values during the Kepler and the K2 missions. Appendix A is a detailed description of the contents and format of the 27 new AED files. Appendix B presents a list of acronyms used in this document.

2 Long-Cadence-Bundled Kepler/K2 AED Files

The *Kepler* spacecraft flight system collected about 10,000 engineering telemetry data (measurement) items including temperatures, voltages, currents, motor and mechanism positions, reaction wheel speeds, attitude, thruster events, and software states (KIH §2.5.5). A subset of 198 data items were selected as ancillary engineering data early in the Kepler mission for the purpose of removing systematic errors from the photometric data and validating cadence data (see Appendix B.5 of the MKAM). Of the 198 data items, 116 were thought to be possibly the most useful given their physical location, update rate, signal-to-noise, and quantization (KIH §2.5.5).

Several telemetry items, such as the reaction wheel housing temperatures (KDCH §5.2), were not included in the long-cadence-bundled AED files even though they were later determined to have a correlation with the pixel time series (photometry). Also, while maps of the exact locations of the sensors are not available in the Kepler or K2 archives, approximate locations can often be inferred from the telemetry item descriptions, the flight system drawings in KIH §2.5, and/or descriptions given in this document.

2.1 Filename Structure

There is one long-cadence-bundled ancillary engineering data file per long-cadence (LC) data collection interval, and in some cases long-cadence-bundled ancillary engineering data exists for time intervals where no valid science data was collected (MKAM §2.3.10). Long-cadence-bundled Kepler/K2 AED files are named as follows: `kplr`[UTC]`_anc- eng.fits` where [UTC] is the UTC timestamp associated with the end of the corresponding Kepler/K2 long-cadence number in the format of `YYYYDDDHHMMSS` with `YYYY` being the 4-digit year number, `DDD` is the 3-digit day number (001 to 366), `HH` is the 2-digit 24-hour number (00 to 23), `MM` is the 2-digit minute number (00 to 59), and `SS` is the 2-digit second number (00 to 59).

2.2 Internal Data Structure

Long-cadence-bundled Kepler/K2 AED files conform to the FITS format standard (https://fits.gsfc.nasa.gov/fits_standard.html). Values for each recorded parameter are contained in an individual FITS binary table extension containing 2 columns: one for the readout time given as a Modified Julian Date (MJD) and the other for the parameter value. The sampling rates and readout times are not the same for all parameters. Furthermore, the parameter measurements are not necessarily provided in chronological order. Also, some ancillary engineering data was obtained during time intervals when no valid science data was collected.

2.3 Data Retrieval

The simplest way to obtain the long-cadence-bundled Kepler AED files is to retrieve the files from MAST at http://dx.doi.org/10.17909/t9-2w9p-7e82. The current MAST website has a subsection called `Ancillary Engineering Files (Long-Cadence Bundled)` which has links to bulk download scripts for the file type `ANC-ENG` that can be used to retrieve these files from MAST for the Kepler mission years of 2009, 2010, 2011, 2012, and 2013. There are 67,420 long-cadence-bundled Kepler AED files, each with a typical size of 3.9 M (megabytes).

The simplest way to obtain the long-cadence-bundled K2 AED files is to retrieve the files from MAST at http://dx.doi.org/10.17909/t9-pr3a-mf61 . The current MAST website has a subsection called `Ancillary Engineering Files (Long-Cadence Bundled)` which has links to bulk download scripts for the file type `ANC-ENG` that can be used to retrieve these files from MAST for the K2 mission years of 2014, 2015, 2016, 2017, and 2018. There are 69,259 long-cadence-bundled K2 AED files, each with a typical size of 3.9 M.

Some additional information about long-cadence-bundled Kepler/K2 AED files can be found at MAST via http://dx.doi.org/10.17909/t9-0339-6015.

3 Parameter-Bundled AED Files

Each new parameter-bundled ancillary engineering data file contains all the data for parameters with the same sampling rate (i.e., are read out simultaneously) in one file for the entire Kepler or K2 mission time spans. The new parameter-bundled ancillary engineering data files are in comma separated value (CSV) format. The included parameter measurements have the same values as those provided in the long-cadence bundled AED files, but are organized in a more convenient (user-friendly) form. The header contains information on the long-cadence-bundled files used to create each parameter-bundled file and defines each column. MAST has also created FITS versions of the delivered parameter-bundled AED CSV files — this document only specifically describes the format of the CSV files, but the FITS files contain the same data in the same row and column order. Users should contact the MAST Help Desk at STScI (archive@stsci.edu) with any questions about the FITS files.

Every data row in a parameter-bundled AED file gives selected parameter values from a single MJD measurement time; these data are taken from different FITS extensions of the same long-cadence-bundled AED file. Parameter-bundled AED files are big with millions of rows. The time coverage of parameter-bundled AED files spans most of the Kepler mission or the K2 mission. As with long-cadence-bundled AED files, sometimes parameter-bundled AED files have engineering data that exists for time intervals where no valid science data was collected. Note that the sampling rate for some parameters changed between Kepler and K2, and some changed during K2. The sampling rate changes were done to reduce the amount of data transmitted from the spacecraft due to decreasing bandwidth, which was a result of the spacecraft's increasing distance from Earth.

Of the 198 parameters given in the long-cadence-bundled AED files, only 35 parameters are recorded in the new parameter-bundled AED files. These were selected as the parameters most likely to enhance the calibration and interpretation of the science data. The 35 parameters cover three different categories: fine pointing (attitude) errors, reaction wheel speeds, and temperatures. A short summary of the 35 parameter-bundled AED parameters (highlighted in blue) is given below.

Note that the MKAM refers to parameters as mnemonics, since the parameter names themselves encode information about the purpose of the AED sensor and its location onboard the spacecraft. Examining `TH1SPIDT` for example, the letter `T` at the end indicates a temperature sensor, and the four characters `SPID` indicate the sensor is located on one of the four spider supports of the box containing the local detector electronics. The same use of mnemonic is thus sometimes employed in this document. Also, the naming convention in Appendix B.5 of the MAST Kepler Archive Manual for the reaction wheel speed parameters used a underscore character at the end of each reaction wheel speed parameter name — this document maintains the MKAM naming convention for all parameters in order to minimize confusion.

Fine Pointing (attitude) Errors (sampling period: ∼40 s) [units: radian] :

- `ADATTERRMX` : Fine Pointing Error: mean of rotation about the `X` axis
- `ADATTERRDX` : Fine Pointing Error: standard deviation of rotation about the `X` axis
- `ADATTERRMY` : Fine Pointing Error: mean of rotation about the `Y` axis
- `ADATTERRDY` : Fine Pointing Error: standard deviation of rotation about the `Y` axis
- `ADATTERRMZ` : Fine Pointing Error: mean of rotation about the `Z` axis
- `ADATTERRDZ` : Fine Pointing Error: standard deviation of rotation about the `Z` axis

NOTE: The X axis is the boresight of the *Kepler* photometer; +X points towards the center of the observation field. The Y axis is perpendicular to the solar balance ridge; +Y points towards, but not necessarily directly at, the Sun. The +Z axis completes the right-handed orthogonal triad. More information about the orientation of the *Kepler* spacecraft is given in §1.3 of the K2H.

Reaction wheel speeds (sampling period range: ∼120–240 s) [units: rpm] :

- `ADRW1SPD_` : Reaction Wheel #1 Speed
- `ADRW2SPD_` : Reaction Wheel #2 Speed
- `ADRW3SPD_` : Reaction Wheel #3 Speed
- `ADRW4SPD_` : Reaction Wheel #4 Speed

Temperatures (sampling period range: ∼4–120 s) [units: C] at various locations on the *Kepler* spacecraft (refer to Figures 2–4 of the KIH):

- *Spacecraft-Telescope Mount*: `TH1SCMNTT` , `TH2SCMNTT`
  These sensors are located on the Schmidt Corrector Mounting Ring.
- *Spider*: `TH1SPIDT` , `TH2SPIDT`
  These sensors are located about halfway along their respective spider support arms.
- *Telescope Structure*: `TH1TELET` , `TH2TELET`
  These sensors are located on the exterior of the upper telescope section.
- *Schmidt Corrector*: `PEDCRRT1` , `PEDCRRT2` , `PEDCRRT3` , `PEDCRRT4`
  The `PEDCRRT1` and `PEDCRRT2` sensors are on the edge of the Schmidt Corrector.
  The `PEDCRRT3` and `PEDCRRT4` sensors are located on the exterior of Schmidt Corrector Mounting Ring.
- *Primary Mirror*: `PEDPMAT1` , `PEDPMAT2` , `PEDPMAT3` , `PEDPMAT4`
  The `PEDPMAT1` and `PEDPMAT2` sensors are located on the edge of the primary mirror.
  The `PEDPMAT3` and `PEDPMAT4` sensors are on the bottom (non-reflective side) of the primary mirror.
- *Keltic Driver Boards*: `PEDDRV1T` , `PEDDRV2T` , `PEDDRV3T` , `PEDDRV4T` , `PEDDRV5T`
  The `PEDDRV N T` sensor is located on/near the Keltic `N` Driver Board.

- *Keltic Acquisition Boards*: `PEDACQ1T`, `PEDACQ2T`, `PEDACQ3T`, `PEDACQ4T`, `PEDACQ5T`
  The `PEDACQNT` sensor is located on/near the Keltic `N` Acquisition Board.
- *Telescope Spacecraft Mount #1*: `PEDTELMNTT1`
  The `PEDTELMNTT1` sensor is located on the Telescope-Schmidt Corrector Mount near the bottom of the photometer.

3.1 Filename Structure

The values of the 35 parameter-bundled AED parameters are distributed among the following parameter-bundled AED CSV files (highlighted in orange), 8 each for the Kepler and K2 missions:

- `XXXX_anc-eng_AttitudeErrors.csv`
- `XXXX_anc-eng_BoardTemperatures.csv`
- `XXXX_anc-eng_MountTemperature.csv`
- `XXXX_anc-eng_OpticsTemperatures1of2.csv`
- `XXXX_anc-eng_OpticsTemperatures2of2.csv`
- `XXXX_anc-eng_ReactionWheelSpeeds.csv`
- `XXXX_anc-eng_TelescopeTemperatures1of2.csv`
- `XXXX_anc-eng_TelescopeTemperatures2of2.csv`

where `XXXX` is `kplr` for the Kepler mission and `ktwo` for the K2 mission. See Appendix A for detailed information about the contents of the 16 parameter-bundled AED CSV files.

3.2 Internal Data Structure

All 16 of these parameter-bundled AED files are CSV files; they have a total of $N + 4$ columns where N is the number of parameters. Each file also has 10 header (comment) rows describing documentation reference and data format of that file. The first column is the MJD of the time of the measurement as taken from the long-cadence-bundled FITS file. The second column is the time of the measurement given as a computed UTC timestamp based on the MJD value. The third column is computed long-cadence number,

$$\text{LC\_CADENCENO} = \text{int}(48.9390076863(\text{MJD} - 56728.01285243) + 87434 + 0.0011)\,, \quad (1)$$

where MJD is the Modified Julian Date of the measurement and 0.0011 is a calibration constant of ∼2 seconds. The fourth column of all parameter-bundled AED files is the computed short-cadence number,

$$\text{SC\_CADENCENO} = \text{int}(1468.17023059(\text{MJD} - 56728.01285243) + 2611480 + 0.0333)\,, \quad (2)$$

where MJD is the Modified Julian Date of the measurement and 0.0333 is a calibration constant of ∼2 seconds. The remaining N columns are the N parameter measurement values at the time of the measurement (MJD: column #1). The computed long-cadence numbers and short-cadence numbers are provided to help the user in identifying matching flux values in Kepler/K2 light curve and target pixel files.

3.3 Data Retrieval

The 8 parameter-bundled AED files (highlighted in orange) for the Kepler mission,

- `kplr_anc-eng_AttitudeErrors.csv`
- `kplr_anc-eng_BoardTemperatures.csv`
- `kplr_anc-eng_MountTemperature.csv`
- `kplr_anc-eng_OpticsTemperatures1of2.csv`
- `kplr_anc-eng_OpticsTemperatures2of2.csv`
- `kplr_anc-eng_ReactionWheelSpeeds.csv`
- `kplr_anc-eng_TelescopeTemperatures1of2.csv`
- `kplr_anc-eng_TelescopeTemperatures2of2.csv`

can be retrieved from MAST at http://dx.doi.org/10.17909/t9-2w9p-7e82. The current MAST website has a subsection called `Ancillary Engineering Files (Parameter-Bundled)` which has a link to a bulk download script (`kepler_aed_parameter_bundled_csv.sh`) to retrieve the CSV files from MAST. A similar script (`kepler_aed_parameter_bundled_fits.sh`) can be used to retrieve the MAST-created FITS versions. The format of the Kepler parameter-bundled AED CSV files is described in Appendix A.

The 8 parameter-bundled AED files (highlighted in orange) for the K2 mission,

- `ktwo_anc-eng_AttitudeErrors.csv`
- `ktwo_anc-eng_BoardTemperatures.csv`
- `ktwo_anc-eng_MountTemperature.csv`
- `ktwo_anc-eng_OpticsTemperatures1of2.csv`
- `ktwo_anc-eng_OpticsTemperatures2of2.csv`
- `ktwo_anc-eng_ReactionWheelSpeeds.csv`
- `ktwo_anc-eng_TelescopeTemperatures1of2.csv`
- `ktwo_anc-eng_TelescopeTemperatures2of2.csv`

can be retrieved from MAST at http://dx.doi.org/10.17909/t9-pr3a-mf61. The current MAST website has a subsection called `Ancillary Engineering Files (Parameter-Bundled)` which has a link to a bulk download script (`k2_aed_parameter_bundled_csv.sh`) to retrieve the CSV files from MAST. A similar script (`k2_aed_parameter_bundled_fits.sh`) can be used to retrieve the MAST-created FITS versions. The format of these K2 parameter-bundled AED CSV files is described in Appendix A.

4 Supplemental-Parameter-Bundled AED Files

Over the course of the mission, analyses revealed that the the reaction wheel housing temperatures (`TH1RW3T` and `TH1RW4T`) and the spacecraft primary mirror assembly and launch vehicle adapter temperature sensors (`TH2PMAT` and `TH2LVAT`) were correlated with observed focus changes and thus photometric variations (see §5.2 of the KDCH and §6.4 of Kepler Data Release 8 (Machalek & Christiansen, 2010)). Similarly, even though measurements of the pointing error were taken every ∼4 seconds, only the ∼40 second mean values and the associated standard deviations were previously delivered in long-cadence-bundled AED files.

These seven previously undelivered ancillary engineering data parameters are now delivered in new supplemental-parameter-bundled ancillary engineering data files. These files have the same format as the parameter-bundled AED files described in §3. For transparency, note that the data source available to the mission for the supplemental data had time reported only in UTC — the MJD value and the long- and short-cadence numbers given in the new supplemental-parameter-bundled files have been computed from this UTC value.

Just as noted in §3, the sampling rate for some parameters changed between Kepler and K2, and some changed during K2. The sampling rate changes were done to reduce the amount of data transmitted from the spacecraft due to decreasing bandwidth, which was a result of the spacecraft's increasing distance from Earth. MAST has also created FITS versions of the delivered supplemental-parameter-bundled AED CSV files — this document only specifically describes the format of the CSV files, but the FITS files contain the same data in the same row and column order. Users should contact the MAST Help Desk at STScI (archive@stsci.edu) with any questions about the FITS files.

The time coverage of supplemental-parameter-bundled AED files spans most of the Kepler mission or the K2 mission. As with long-cadence-bundled AED files and parameter-bundled AED files, sometimes supplemental-parameter-bundled AED files have engineering data that exists for time intervals where no valid science data was collected. For example, engineering data was collected prior to the start of Kepler Quarter 0.

For transparency, Equation 2 gives positive short-cadence (SC) numbers only for MJD $\gtrsim$ 54949.283050926 [2009-04-28T06:47:35.600 (UTC)], which was ∼3.75 days before the start of Kepler Q0 — the middle of the first short-cadence observation of Kepler Quarter 0 was at MJD ∼54953.028 (KSCI-19042: Kepler Data Release Notes 2). Although some AED was collected prior to this date, in order to ensure all given cadence numbers are positive, as is typically assumed to be the case, AED from before MJD 54949.283050926 were not included in the supplemental-parameter-bundled AED files. (The earliest data available for long-cadence-bundled and parameter-bundled files is ∼54952.9, and thus all cadences numbers for those data are positive.)

A short summary of the 7 supplemental-parameter-bundled parameters (highlighted in blue) is given below:

Fine Pointing (attitude) Errors (sampling period: ∼4 s) [units: radian] :

- `ADATTERRX` : Fine Pointing Error: rotation about the X axis
- `ADATTERRY` : Fine Pointing Error: rotation about the `Y` axis
- `ADATTERRZ` : Fine Pointing Error: rotation about the `Z` axis

NOTE: These new ∼4-s fine pointing error values are only available for the K2 mission; similar ∼4-s data for the Kepler mission were not available at the time of this delivery, but as discussed in §3 the ∼40-s averages are provided.

Reaction wheel housing temperatures (sampling period range: ∼58–118 s) [units: C] :

- `TH1RW3T` : Reaction Wheel #3 Housing Temperature Sensor
  The `TH1RW3T` sensor is located on the housing of Reaction Wheel #3.
- `TH1RW4T` : Reaction Wheel #4 Housing Temperature Sensor
  The `TH1RW4T` sensor is located on the housing of Reaction Wheel #4.

Primary mirror assembly and launch vehicle adapter temperature sensors (sampling period range: ∼58–118 s) [units: C]

- `TH2PMAT` : Spacecraft Primary Mirror Assembly Temperature Sensor
  The `TH2PMAT` sensor is located on the primary mirror assembly underneath the mirror.
- `TH2LVAT` : Spacecraft Launch Vehicle Adapter Temperature Sensor
  The `TH2LVAT` sensor is located near the boundary between the spacecraft and the primary mirror.

4.1 Filename Structure

The values of the 7 supplemental-parameter-bundled AED parameters are distributed among the following 11 supplemental-parameter-bundled AED CSV files (highlighted in orange) — 4 files for the Kepler mission and 7 files for the K2 mission:

- `ktwo_anc-eng_ADATTERRX.csv`
- `ktwo_anc-eng_ADATTERRY.csv`
- `ktwo_anc-eng_ADATTERRZ.csv`
- `XXXX_anc-eng_TH1RW3T.csv`
- `XXXX_anc-eng_TH1RW4T.csv`
- `XXXX_anc-eng_TH2LVAT.csv`
- `XXXX_anc-eng_TH2PMAT.csv`

where `XXXX` is `kplr` for the Kepler mission and `ktwo` for the K2 mission. See Appendix A for detailed information about the contents of the 11 supplemental-parameter-bundled AED files.

4.2 Internal Data Structure

All 11 supplemental-parameter-bundled AED files are CSV files; they have a total of five columns. Each file has 10 header rows describing documentation reference and data format of the file. The second column is the UTC timestamp value, which was used to compute the MJD value given in column #1. The third column is the computed long-cadence number (Equation 1) and the fourth column is the computed short-cadence number (Equation 2). The fifth column gives the supplemental-parameter-bundled parameter AED value at the time of measurement (UTC: column #2).

4.3 Data Retrieval

Just like the parameter-bundled files, the 4 supplemental-parameter-bundled AED files for the Kepler mission,

- `kplr_anc-eng_TH1RW3T.csv`
- `kplr_anc-eng_TH1RW4T.csv`
- `kplr_anc-eng_TH2LVAT.csv`
- `kplr_anc-eng_TH2PMAT.csv`

can be retrieved from MAST at http://dx.doi.org/10.17909/t9-2w9p-7e82. The current MAST website has a subsection called `Ancillary Engineering Files (Parameter-Bundled)` which has a link to a bulk download script (`kepler_aed_parameter_bundled_csv.sh`) to retrieve the CSV files from MAST. A similar script (`kepler_aed_parameter_bundled_fits.sh`) can be used to retrieve the MAST-created FITS versions. The format of these Kepler supplemental-parameter-bundled AED CSV files is described in Appendix A.

Just like the parameter-bundled files, the 7 supplemental-parameter-bundled AED files for the K2 mission,

- `ktwo_anc-eng_ADATTERRX.csv`
- `ktwo_anc-eng_ADATTERRY.csv`
- `ktwo_anc-eng_ADATTERRZ.csv`
- `ktwo_anc-eng_TH1RW3T.csv`
- `ktwo_anc-eng_TH1RW4T.csv`
- `ktwo_anc-eng_TH2LVAT.csv`
- `ktwo_anc-eng_TH2PMAT.csv`

can be retrieved from MAST at http://dx.doi.org/10.17909/t9-pr3a-mf61. The current MAST website has a subsection called `Ancillary Engineering Files (Parameter-Bundled)` which has a link to a bulk download script (`k2_aed_parameter_bundled_csv.sh`) to retrieve the CSV files from MAST. A similar script (`k2_aed_parameter_bundled_fits.sh`) can be used to retrieve the MAST-created FITS versions. The format of these K2 supplemental-parameter-bundled AED CSV files is described in Appendix A.

5 AED Variation over the Kepler and K2 Missions

This section gives four examples of how parameter-bundled AED and supplemental-parameter-bundled AED files can be used to investigate the variation of ancillary engineering data values during the Kepler and the K2 missions.

5.1 Attitude (Fine Pointing) Errors

Kepler's stable pointing was achieved by using reaction wheels to counteract torques on the spacecraft due to solar radiation pressure. Every ∼3 days during the Kepler mission, and ∼2 days during the K2 mission, the wheel speeds were reset so they would remain within their operating limits. The resulting changes in angular momentum were counteracted by brief thruster firings. These important station-keeping events are referred to as "desats" or "resats" or "momentum dumps" in the Kepler and K2 documentation (e.g., KDCH §5.3).

The fine pointing errors for rotation about the `X`, `Y`, and `Z` and axes during the K2 mission are shown in Figure 1. The angular attitude errors are given in angular units of radians. The blue points show the ∼40 second mean values `ADATTERRMX`, `ADATTERRMY`, and `ADATTERRMZ` (see §3 and Appendix A). The orange points show the higher-resolution ∼4 second values `ADATTERRX`, `ADATTERRY`, and `ADATTERRZ` (see §4 and Appendix A).

Figure 2 shows a magnified view of the attitude errors during the K2 mission for the MJD range of 57160–57164 days (2015-05-18 to 2015-05-22). The angular attitude errors are now displayed in angular units of arcseconds [arcsec] instead of radians. Two momentum dumps (resats) are clearly seen at MJD ∼57160.6 and ∼57162.6 days in the high resolution ∼4 second error data (orange points). The ∼40 second average attitude errors (`ADATTERRMX`, `ADATTERRMY`, and `ADATTERRMZ`) do not show pointing errors caused by the momentum dumps because they effectively act as low-pass temporal filters.

During the K2 mission, the combination of the spacecraft roll motion (due to solar radiation-pressure torque) and occasional pointing corrections (by spacecraft thruster firings) would impress a sawtooth waveform with an amplitude of several percent on uncorrected simple aperture photometry light curves (Van Cleve et al., 2016b) for targets near the edge of the Field of View (FOV) of the spacecraft's photometer. The top graph of Figure 2 clearly shows the sawtooth pattern in the rotation about the `X` axis.

K2 targets near the edge of the FOV suffer the largest effect of the sawtooth pattern on their simple aperture photometry flux measurements. Figure 3 shows a magnified view of the attitude errors in units of pixels for a detector near the edge of the FOV. The angular errors were converted from radians to pixels using a pixel scale of 3.98 arcsec/px (KDPH §3.1.1) and a radius of 8° from the center of the FOV. Note that 8° was chosen as it is approximately half of the FOV's diameter of 16.1° (KIH §2.1).

Using solar radiation pressure and occasional thruster firings to maintain the pointing accuracy of the *Kepler* spacecraft with only two working reaction wheels was a pseudo-stable solution (Van Cleve et al., 2016b). Considerable effort was expended by the K2 team

to keep the fine pointing error of the *Kepler* spacecraft to within ±1 px during most of the K2 mission. Figure 4 shows that the fine pointing error of the rotation about the `X` axis was kept well within ±0.01 px during most of the Kepler mission.

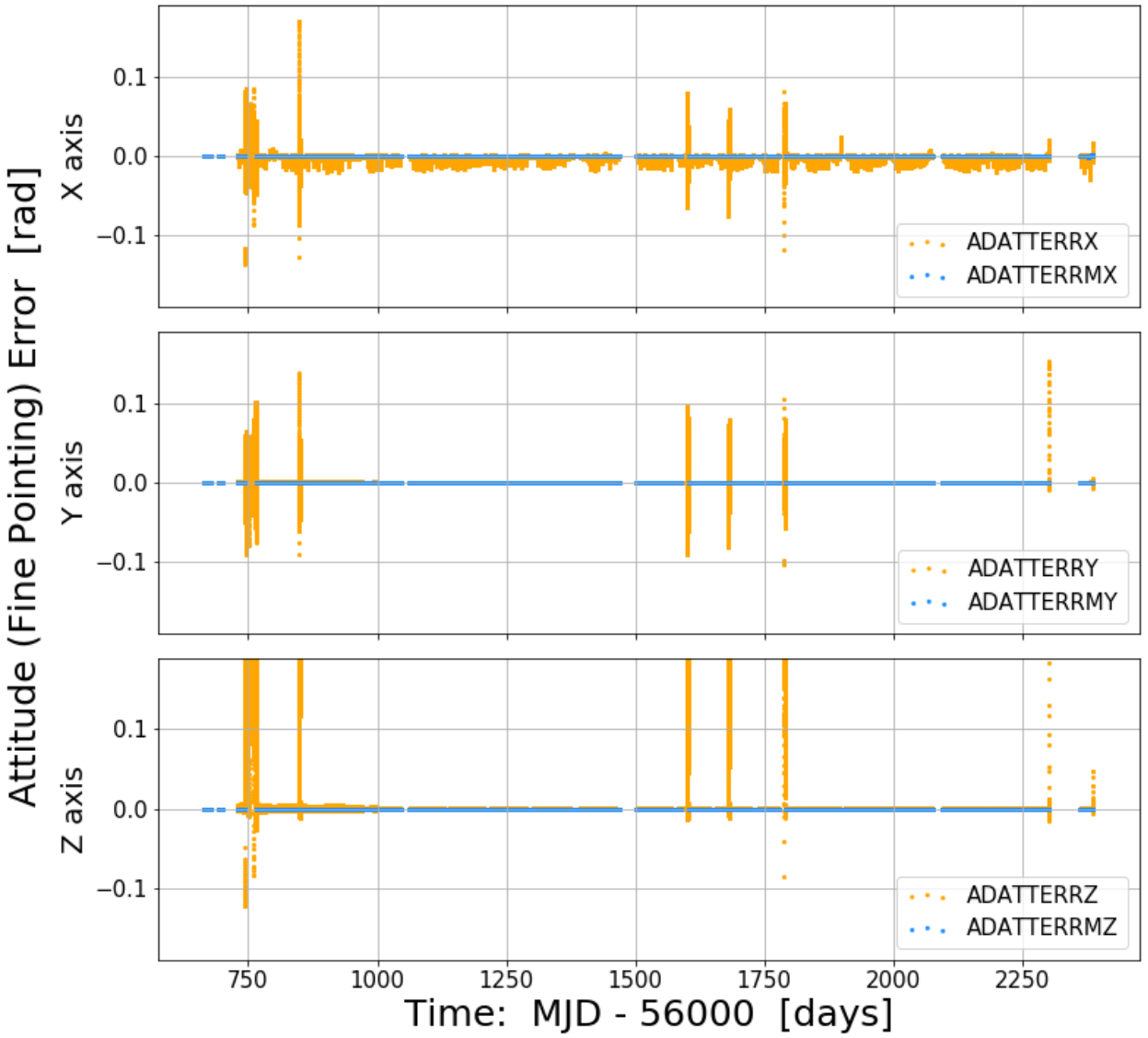

Figure 1: Attitude (fine pointing) errors during the K2 mission. The errors are given in angular units of radians. The orange points shows the now-available ∼4 second attitude error measurements, while the blue points show the previously available ∼40 second averages. Note that AED data is recorded even when no valid science data was collected (e.g., during station-keeping activities like momentum dumps).

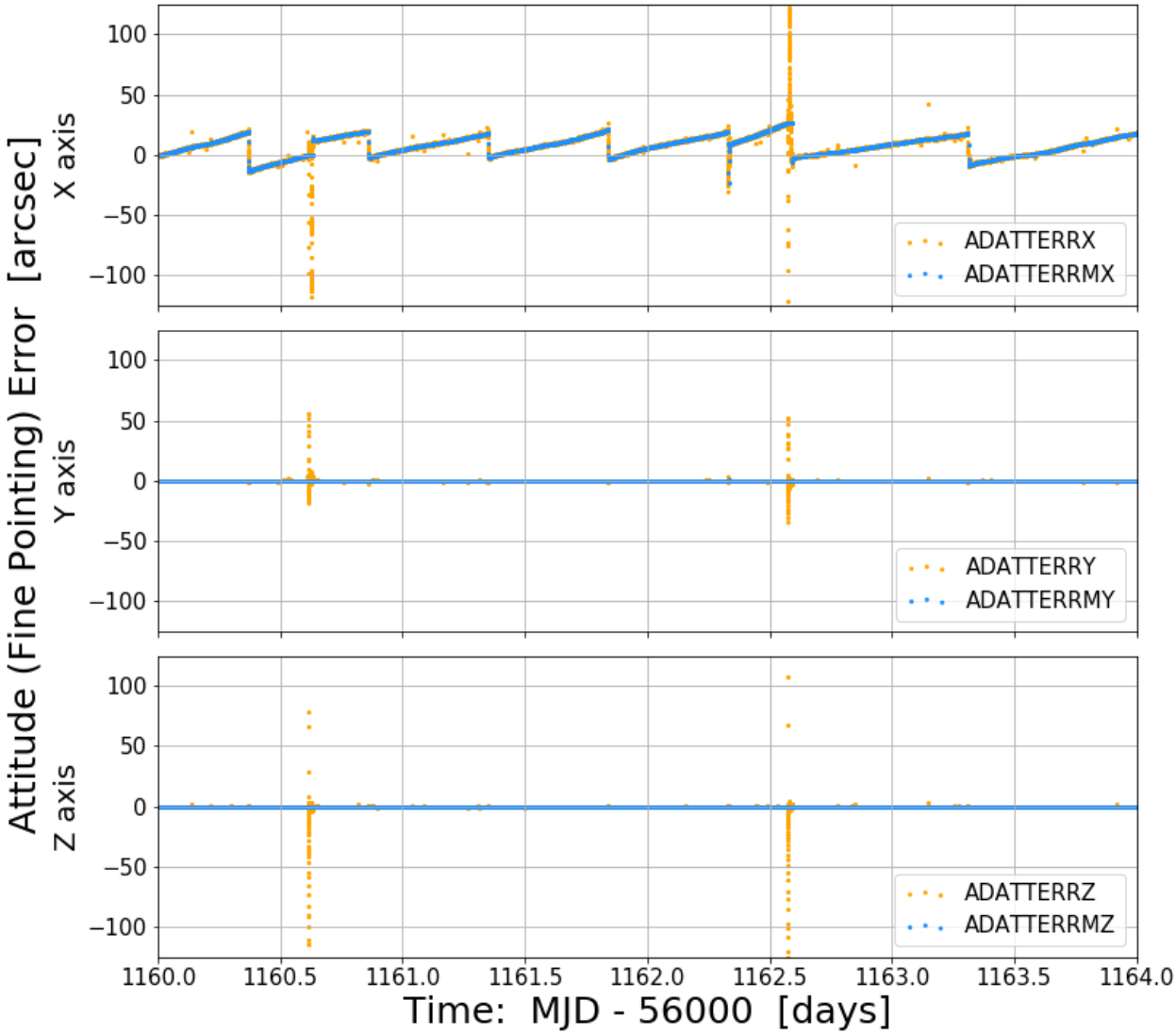

Figure 2: Magnified view of the attitude (fine pointing) errors during the K2 mission for the MJD range of 57160–57164 days (2015-05-18 to 2015-05-22). The errors are given as angular units of arcseconds. The orange points show the ∼4 second attitude error measurements, while the blue points show the ∼40 second averages. Two momentum dumps are clearly seen at MJD ∼57160.6 and ∼57162.6 days with the ∼4 data (orange points).

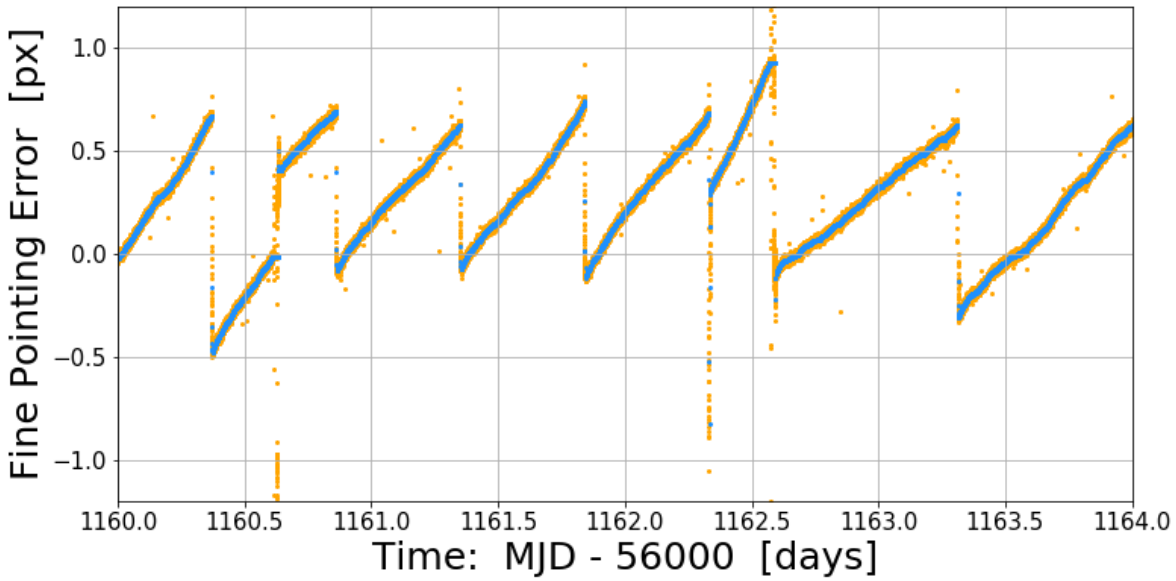

Figure 3: Magnified view of the roll error (rotation about the `X` axis) near the edge of the FOV during the K2 mission. The errors have units of pixels [px]; angular errors were converted from radians to pixels using a pixel scale of 3.98 arcsec/px and a radius of 8° from the center of the FOV. The orange points show the transformed ∼4-s fine pointing errors on the rotation about the `X` axis (`ADATTERRX`), while the blue points show the transformed ∼40s fine pointing errors on the rotation about the `X` axis (`ADATTERRMX`).

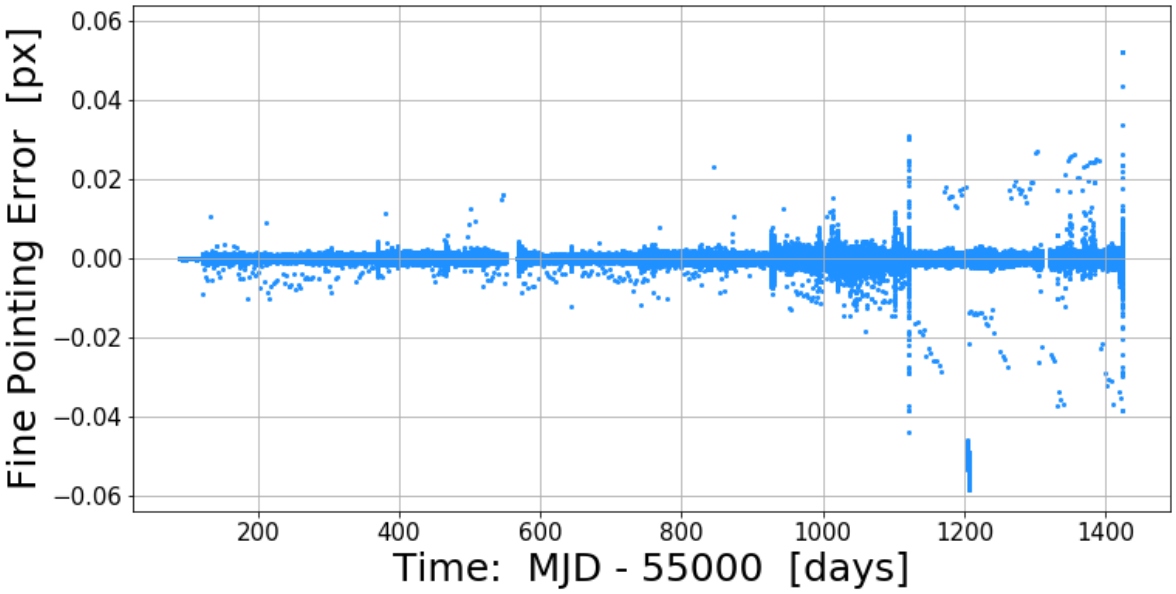

Figure 4: Magnified view of the roll error (rotation about the `X` axis) near the edge of the FOV during the Kepler mission. The errors have units of pixels; angular errors were converted from radians to pixels using a pixel scale of 3.98 arcsec/px and a radius of 8° from the center of the FOV. The blue points show the transformed ∼40s fine pointing errors on the rotation about the `X` axis (`ADATTERRMX`).

5.2 Reaction Wheel Speeds

The *Kepler* spacecraft was designed to maintain accurate pointing in three dimensions using 4 reaction wheels; the Kepler mission characteristic for pointing jitter was 3 milliacr-seconds (0.75 millipixels) per 15 minutes (1σ per axis) (Borucki et al., 2010; Koch et al., 2010). Precisely spinning (in two directions) up to ∼3000 revolutions per minute, the reaction wheels would maintain the orientation of the spacecraft through careful control of the speed of the reaction wheels.

The top graph of Figure 5 shows the speeds of Kepler's 4 reaction wheels during the Kepler mission. These parameters are available in the parameter-bundled AED file `kplr_anc-eng_ReactionWheel Speeds.csv`. On MJD 56123.476898958 (2012-07-15 11:26:44.070 UTC) reaction wheel #2 stopped working (`ADRW2SPD_` = 0 rpm). The failure of this reaction wheel is seen the top graph of Figure 5 where the data values of `ADRW2SPD_` (orange) flatline at MJD−55000 $\gtrsim$ 1123.48. A minimum of 3 reaction wheels were required for the *Kepler* spacecraft to achieve its original mission goals. Reaction wheel #4 (`ADRW4SPD_`) failed after MJD 56423.51101852 (2013-05-11 12:15:52 UTC). With only 2 reaction wheels working, the *Kepler* spacecraft was no longer able to operate as designed to to achieve the original Kepler mission goals, thus ending data collection for the mission.

Over the course of the next 10 months, the Kepler team developed and tested a new mission concept. Three-axis pointing control was achieved with only 2 reaction wheels by orienting the *Kepler* spacecraft such that the solar radiation pressure in the roll direction was minimized. Since this spacecraft control approach defined the relative orientation between the spacecraft and the sun, only limited regions of the sky (confined to be near the ecliptic plane) could be observed. The new mission, K2, began its first observing campaign (C0) on 2014-03-12 00:18:30 UTC.

The bottom graph of Figure 5 shows the speeds of Kepler's 4 reaction wheels during the K2 mission. These parameters are available in the parameter-bundled AED file `ktwo_anc-eng_ReactionWheel Speeds.csv`. The failed reaction wheels #2 (orange) and # 4 (magenta) are flatlined during the K2 mission. The remaining working reaction wheels were used at faster speeds in the K2 mission, up to ∼5000 rpm, to accommodate the K2 mission operations.

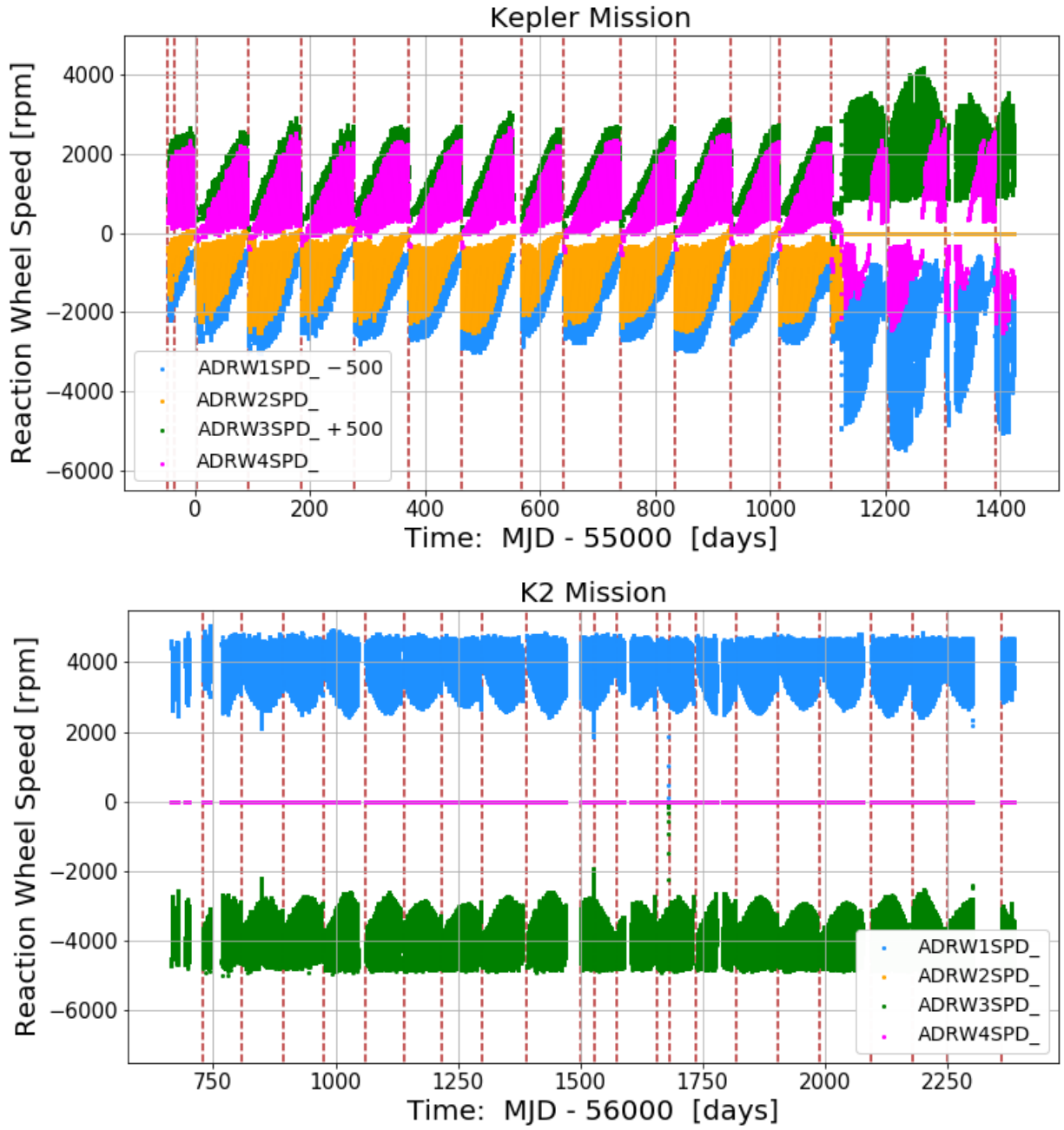

Figure 5: *Kepler* spacecraft reaction wheel speeds for Wheel #1 (`ADRW1SPD_` : blue), Wheel #2 (`ADRW2SPD_` : orange), Wheel #3 (`ADRW3SPD_` : green), and Wheel #4 (`ADRW4SPD_` : magenta) during the Kepler (top) and K2 (bottom) missions. The `ADRW1SPD_` and `ADRW3SPD_` values in the top plot (Kepler) have an offset of ±500 applied to them to enhance visibility. The vertical dashed lines in the top graph show the start times of Kepler Quarters Q0–Q17. The start times of K2 Campaigns C0–C8, C9a, C9b, C10a, C11a, C11b, and C12–C19 are shown as vertical dashed lines in the bottom graph.

5.3 Focus Variation and Spacecraft Temperatures

The focus of the *Kepler* photometer exhibited an annual cycle during the Kepler mission (KDCH §5.2). The spacecraft temperature sensors `TH2PMAT` and `TH2LVAT` showed a similar yearly cycle. Figure 6 compares these spacecraft temperatures with the focus-change induced variation in the Pixel Response Function (PRF). The photometric effect of the focus changes are also evident in the cotrending basis vectors (MKAM §2.3.4) used to produce the detrended `PDCSAP_FLUX` flux time series.

The Kepler spacecraft pointed at a single field nearly continuously during the entire Kepler mission, but pointed to a different field approximately every 80 days during K2. Correspondingly, the `TH2PMAT` and `TH2LVAT` temperatures exhibited an annual cycle during the Kepler mission, but exhibited a campaign-based cycle during the K2 mission (see Figure 7). The peak-to-peak `TH2PMAT` temperature range was the same during the Kepler and K2 missions (∼12° C). However, the peak-to-peak `TH2LVAT` temperature range was about 4 times larger during the K2 mission than during the Kepler mission (∼100° C vs. 25° C). The temperature curve during forward-facing K2 campaigns (9, 16, 17, and 19) is reversed compared to the more common backward-facing campaigns.

The Keltic 3 Driver Board (`PEDDRV3T`) and the Keltic 3 Acquisition Board (`PEDACQ3T`) temperature sensors show similar behavior and correlation with spacecraft focus. Figure 8 shows the value `PEDDRV3T` and `PEDACQ3T` over the course of the Kepler and K2 missions. Kepler exhibited a small (∼2° C) peak-to-peak temperature range in an annual cycle, while K2 exhibited a slightly larger (∼3–4° C) peak-to-peak range in a campaign-based cycle. Comparing `PEDDRV3T` to `PEDACQ3T`, the temperatures recorded by the two sensors for Kepler and K2 are morphologically similar except for a small (∼2.5° C) offset.

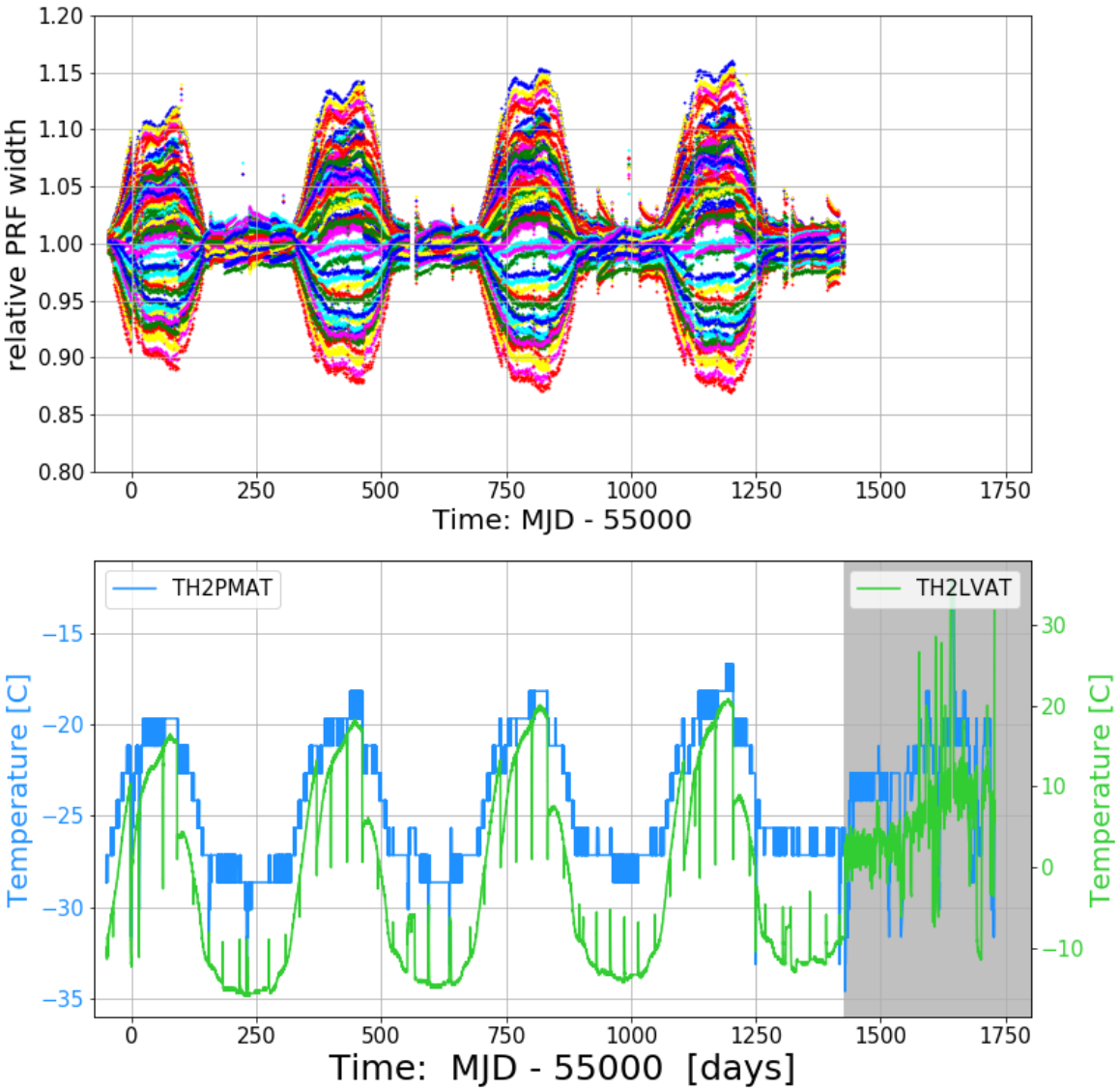

Figure 6: Correlation of variation of the PRF width (top graph; copied from Figure 10 of the KDCH) with the spacecraft primary mirror assembly (`TH2PMAT`; blue) and launch vehicle adapter (`TH2LVAT`; green) temperature sensors during the Kepler mission (bottom graph). The top graph shows the PRF width, relative to commissioning, for stars on each of the 84 Kepler photometer channels using a rotating set of 6 colors; the PRF data ends soon after the loss of reaction wheel #4 (MJD ~56424.6). The gray area on the right of the bottom graph shows thermal data for several months after the loss of reaction wheel #4, when the *Kepler* spacecraft was no longer pointed at the Kepler Field.)

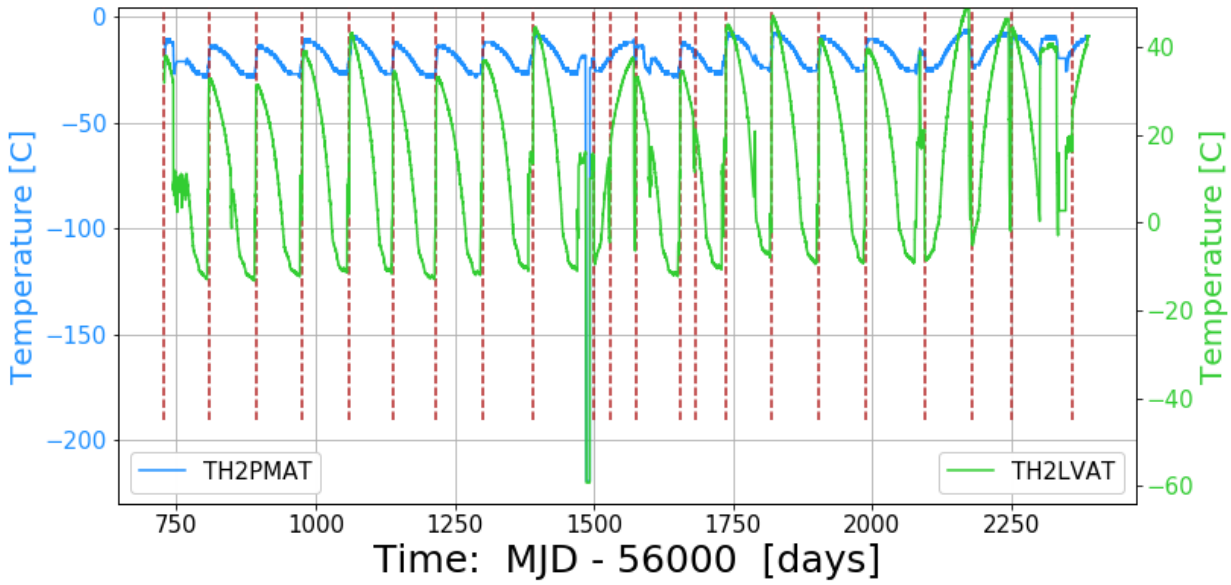

Figure 7: The value of the spacecraft primary mirror assembly and launch vehicle adapter temperature sensors `TH2PMAT` (blue) and `TH2LVAT` (green) during the K2 mission. The sharp dip seen occurred on MJD 57485.00354167 (2016-04-07 00:05:06 UTC) during an emergency mode event in K2 Campaign 9. The start times of K2 Campaigns C0–C8, C9a–b, C10a, C11a–b, C12–C19 are shown as vertical dashed lines in the bottom graph.

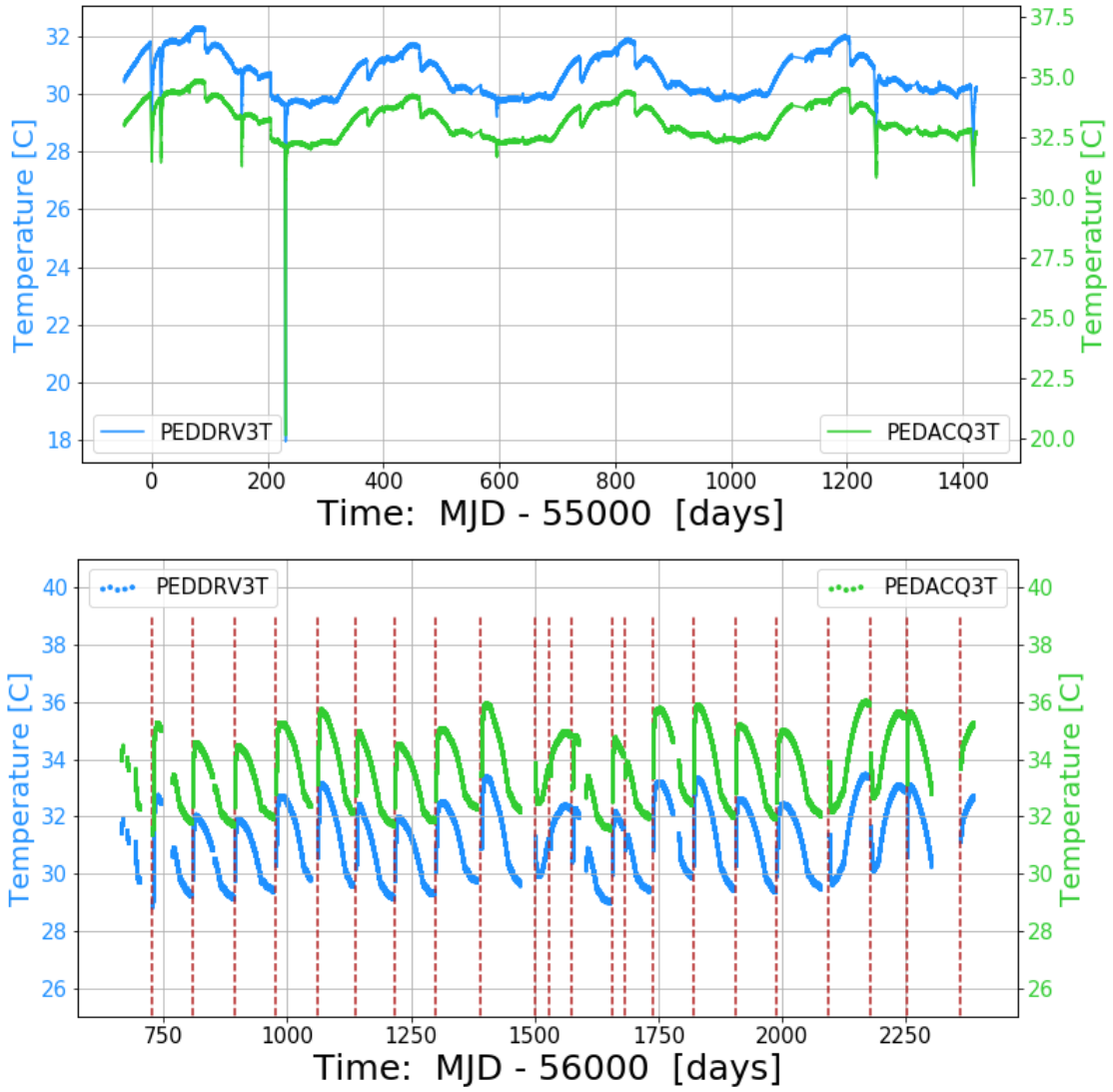

Figure 8: Keltic 3 Driver Board Temperature (`PEDDRV3T`: blue, left y-axis) and the Keltic 3 Acquisition Board Temperature (`PEDACQ3T`: green, right y-axis) during the Kepler (top) and K2 (bottom) missions. The large sharp dip seen in the top graph for both the `PEDDRV3T` and `PEDACQ3T` temperatures occurred during Kepler Quarter 4 at MJD ∼55231.21 (2010-02-04 05:02:24 UTC) due to the loss of Module 3. The vertical dashed lines in the bottom graph mark the start times of K2 Campaigns C0–C8, C9a, C9b, C10a, C11a, C11b, and C12–C19.

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A Detailed Format of AED CSV Files

This appendix details the data format of the 27 delivered AED CSV files. Table 1 contains the list of delivered AED CSV and a number (#) used only in this document for ease of reference. Table 2 contains a list of parameter names, a brief description, the measurement unit, and which AED CSV file(s) contain the parameter. Tables 3–29 give the filename, data format, comment and data row descriptions, sampling period, column descriptions, and first and last MJD values for each AED CSV file.

The following conventions are used in this appendix:

- Filenames are highlighted with orange (e.g., `kplr_anc-eng_AttitudeErrors.csv`).
- Kepler mission data filenames start with `kplr`; K2 mission filenames start with `ktwo`.
- The ancillary engineering data parameter values stored in the file are highlighted with blue (e.g., `ADATTERRMX`). See Appendix B.5 of the MAST Kepler Archive Manual (Mullally, 2020) for more information about the meaning of the parameters.
- The number of data rows in a file is highlighted with tan (e.g., 3000023 rows).
- The data sampling period is highlighted with yellow (e.g., 4.0000 to 4.0001 s).
- The precision of the measurement data is described using `C`-language `printf` format codes between ⟨ and ⟩ symbols (e.g., ⟨%16.9f⟩).

Table 1: AED CSV File Names and Numbers

File #	File Name
1	kplr_anc-eng_AttitudeErrors.csv
2	kplr_anc-eng_BoardTemperatures.csv
3	kplr_anc-eng_MountTemperature.csv
4	kplr_anc-eng_OpticsTemperatures1of2.csv
5	kplr_anc-eng_OpticsTemperatures2of2.csv
6	kplr_anc-eng_ReactionWheelSpeeds.csv
7	kplr_anc-eng_TelescopeTemperatures1of2.csv
8	kplr_anc-eng_TelescopeTemperatures2of2.csv
9	kplr_anc-eng_TH1RW3T.csv
10	kplr_anc-eng_TH1RW4T.csv
11	kplr_anc-eng_TH2LVAT.csv
12	kplr_anc-eng_TH2PMAT.csv
13	ktwo_anc-eng_ADATTERRX.csv
14	ktwo_anc-eng_ADATTERRY.csv
15	ktwo_anc-eng_ADATTERRZ.csv
16	ktwo_anc-eng_AttitudeErrors.csv
17	ktwo_anc-eng_BoardTemperatures.csv
18	ktwo_anc-eng_MountTemperature.csv
19	ktwo_anc-eng_OpticsTemperatures1of2.csv
20	ktwo_anc-eng_OpticsTemperatures2of2.csv
21	ktwo_anc-eng_ReactionWheelSpeeds.csv
22	ktwo_anc-eng_TelescopeTemperatures1of2.csv
23	ktwo_anc-eng_TelescopeTemperatures2of2.csv
24	ktwo_anc-eng_TH1RW3T.csv
25	ktwo_anc-eng_TH1RW4T.csv
26	ktwo_anc-eng_TH2LVAT.csv
27	ktwo_anc-eng_TH2PMAT.csv

Table 2: AED Parameter Names, Descriptions, Units, and File Number

Parameter	Description	Units	File #
ADATTERRX	Fine Pointing Error: rotation about the X axis	rad	13
ADATTERRY	Fine Pointing Error: rotation about the Y axis	rad	14
ADATTERRZ	Fine Pointing Error: rotation about the Z axis	rad	15
ADATTERRMX	Fine Pointing Error: mean of rotation about X axis	rad	1,16
ADATTERRMY	Fine Pointing Error: mean of rotation about Y axis	rad	1,16
ADATTERRMY	Fine Pointing Error: mean of rotation about Z axis	rad	1,16
ADATTERRDX	Fine Pointing Error: std. dev. of rotation about X axis	rad	1,16
ADATTERRDY	Fine Pointing Error: std. dev. of rotation about Y axis	rad	1,16
ADATTERRDY	Fine Pointing Error: std. dev. of rotation about Z axis	rad	1,16
ADRW1SPD_	Reaction Wheel # 1 Speed	rpm	6,21
ADRW2SPD_	Reaction Wheel # 2 Speed	rpm	6,21
ADRW3SPD_	Reaction Wheel # 3 Speed	rpm	6,21
ADRW4SPD_	Reaction Wheel # 4 Speed	rpm	6,21
TH1SCMNTT	Spacecraft-Telescope Mount Temperature	C	7,22
TH2SCMNTT	Spacecraft-Telescope Mount Temperature	C	7,22
TH1SPIDT	Spider Temperature	C	8,23
TH2SPIDT	Spider Temperature	C	8,23
TH1TELET	Telescope Structure Temperature	C	8,23
TH2TELET	Telescope Structure Temperature	C	8,23
TH1RW3T	Reaction Wheel #3 Housing Temperature Sensor	C	9,24
TH1RW4T	Reaction Wheel #4 Housing Temperature Sensor	C	10,25
TH2PMAT	Spacecraft Primary Mirror Assembly Temperature	C	12,27
TH2LVAT	Spacecraft Launch Vehicle Adapter Temperature	C	11,26
PEDCRRT1	Schmidt Corrector #1 Temperature	C	4,19
PEDCRRT2	Schmidt Corrector #2 Temperature	C	4,19
PEDCRRT3	Schmidt Corrector #3 Temperature	C	4,19
PEDCRRT4	Schmidt Corrector #4 Temperature	C	5,20
PEDPMAT1	Primary Mirror #1 Temperature	C	4,19
PEDPMAT2	Primary Mirror #2 Temperature	C	4,19
PEDPMAT3	Primary Mirror #3 Temperature	C	4,19
PEDPMAT4	Primary Mirror #4 Temperature	C	4,19
PEDDRV1T	Keltic 1 Driver Board Temperature	C	2,17
PEDDRV2T	Keltic 2 Driver Board Temperature	C	2,17
PEDDRV3T	Keltic 3 Driver Board Temperature	C	2,17
PEDDRV4T	Keltic 4 Driver Board Temperature	C	2,17
PEDDRV5T	Keltic 5 Driver Board Temperature	C	2,17
PEDACQ1T	Keltic 1 Acquisition Board Temperature	C	2,17
PEDACQ2T	Keltic 2 Acquisition Board Temperature	C	2,17
PEDACQ3T	Keltic 3 Acquisition Board Temperature	C	2,17
PEDACQ4T	Keltic 4 Acquisition Board Temperature	C	2,17
PEDACQ5T	Keltic 5 Acquisition Board Temperature	C	2,17
PEDTELMNTT1	Telescope Spacecraft Mount #1 Temperature	C	3,18

Table 3: Contents of AED CSV File #1

Filename	`kplr_anc-eng_AttitudeErrors.csv` (Kepler data) [size: 547 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	2955458 rows by 10 columns
Sampling period	39.9999 to 40.0001 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) (computed) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`ADATTERRMX` value at MJD (column 1) ⟨%21.13e⟩
Column 6	`ADATTERRDX` value at MJD (column 1) ⟨%21.13e⟩
Column 7	`ADATTERRMY` value at MJD (column 1) ⟨%21.13e⟩
Column 8	`ADATTERRDY` value at MJD (column 1) ⟨%21.13e⟩
Column 9	`ADATTERRMZ` value at MJD (column 1) ⟨%21.13e⟩
Column 10	`ADATTERRDZ` value at MJD (column 1) ⟨%21.13e⟩
MJD: first row	MJD 54952.905503935 = 2009-05-01 21:43:55.540 UTC
MJD: last row	MJD 56424.205961690 = 2013-05-12 04:56:35.090 UTC

Table 4: Contents of AED CSV File #2

Filename	`kplr_anc-eng_BoardTemperatures.csv` (Kepler data) [535 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	1989143 rows by 14 columns
Sampling period	59.7300 to 59.7701 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) (computed) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`PEDDRV1T` value at MJD (column 1) ⟨%16.12f⟩
Column 6	`PEDACQ1T` value at MJD (column 1) ⟨%16.12f⟩
Column 7	`PEDDRV2T` value at MJD (column 1) ⟨%16.12f⟩
Column 8	`PEDACQ2T` value at MJD (column 1) ⟨%16.12f⟩
Column 9	`PEDDRV3T` value at MJD (column 1) ⟨%16.12f⟩
Column 10	`PEDACQ3T` value at MJD (column 1) ⟨%16.12f⟩
Column 11	`PEDDRV4T` value at MJD (column 1) ⟨%16.12f⟩
Column 12	`PEDACQ4T` value at MJD (column 1) ⟨%16.12f⟩
Column 13	`PEDDRV5T` value at MJD (column 1) ⟨%16.12f⟩
Column 14	`PEDACQ5T` value at MJD (column 1) ⟨%16.12f⟩
MJD: first row	MJD 54952.905680671 = 2009-05-01 21:44:10.810 UTC
MJD: last row	MJD 56424.205826350 = 2013-05-12 04:56:23.397 UTC

Table 5: Contents of AED CSV File #3

Filename	`kplr_anc-eng_MountTemperature.csv` (Kepler data) [270 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	3360754 rows by 5 columns
Sampling period	4.0000 to 59.7700 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) (computed) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`PEDTELMNTT1` value at MJD (column 1) ⟨%18.13f⟩
MJD: first row	MJD 54952.905680671 = 2009-05-01 21:44:10.810 UTC
MJD: last row	MJD 56424.205823457 = 2013-05-12 04:56:23.147 UTC

Table 6: Contents of AED CSV File #4

Filename	`kplr_anc-eng_OpticsTemperatures1of2.csv` (Kepler data) [693 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	3360811 rows by 11 columns
Sampling period	4.0000 to 59.7700 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) (computed) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`PEDCRRT1` value at MJD (column 1) ⟨%18.12f⟩
Column 6	`PEDCRRT2` value at MJD (column 1) ⟨%18.12f⟩
Column 7	`PEDCRRT3` value at MJD (column 1) ⟨%18.12f⟩
Column 8	`PEDPMAT1` value at MJD (column 1) ⟨%18.12f⟩
Column 9	`PEDPMAT2` value at MJD (column 1) ⟨%18.12f⟩
Column 10	`PEDPMAT3` value at MJD (column 1) ⟨%18.12f⟩
Column 11	`PEDPMAT4` value at MJD (column 1) ⟨%18.12f⟩
MJD: first row	MJD 54952.905680671 = 2009-05-01 21:44:10.810 UTC
MJD: last row	MJD 56424.205823457 = 2013-05-12 04:56:23.147 UTC

Table 7: Contents of AED CSV File #5

Filename	`kplr_anc-eng_OpticsTemperatures2of2.csv` (Kepler data) [270 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	3360807 rows by 5 columns
Sampling period	4.0000 to 59.7700 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) (computed) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`PEDCRRT4` value at MJD (column 1) ⟨%18.12f⟩
MJD: first row	MJD 54952.905680671 = 2009-05-01 21:44:10.810 UTC
MJD: last row	MJD 56424.203748804 = 2013-05-12 04:53:23.897 UTC

Table 8: Contents of AED CSV File #6

Filename	`kplr_anc-eng_ReactionWheelSpeeds.csv` (Kepler data) [144 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	1003577 rows by 8 columns
Sampling period	119.8967 to 119.9033 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) (computed) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`ADRW1SPD_` value at MJD (column 1) ⟨%18.10f⟩
Column 6	`ADRW2SPD_` value at MJD (column 1) ⟨%1d⟩
Column 7	`ADRW3SPD_` value at MJD (column 1) ⟨%18.10f⟩
Column 8	`ADRW4SPD_` value at MJD (column 1) ⟨%1d⟩
MJD: first row	MJD 54952.906420602 = 2009-05-01 21:45:14.740 UTC
MJD: last row	MJD 56424.205796142 = 2013-05-12 04:56:20.787 UTC

Table 9: Contents of AED CSV File #7

Filename	`kplr_anc-eng_TelescopeTemperatures1of2.csv` (Kepler data) [211 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	2080771 rows by 7 columns
Sampling period	57.9900 to 58.0066 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) (computed) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`TH1SCMNTT` value at MJD (column 1) ⟨%18.13f⟩
Column 6	`TH2SCMNTT` value at MJD (column 1) ⟨%18.13f⟩
MJD: first row	MJD 54952.905437230 = 2009-05-01 21:43:49.777 UTC
MJD: last row	MJD 56424.205557022 = 2013-05-12 04:56:00.127 UTC

Table 10: Contents of AED CSV File #8

Filename	`kplr_anc-eng_TelescopeTemperatures2of2.csv` (Kepler data) [298 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	2080780 rows by 8 columns
Sampling period	57.9900 to 58.0066 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) (computed) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`TH1SPIDT` value at MJD (column 1) ⟨%19.11f⟩
Column 6	`TH2SPIDT` value at MJD (column 1) ⟨%19.12f⟩
Column 7	`TH1TELET` value at MJD (column 1) ⟨%19.12f⟩
Column 8	`TH2TELET` value at MJD (column 1) ⟨%19.11f⟩
MJD: first row	MJD 54952.905437230 = 2009-05-01 21:43:49.777 UTC
MJD: last row	MJD 56424.205557022 = 2013-05-12 04:56:00.127 UTC

Table 11: Contents of AED CSV File #9

Filename	`kplr_anc-eng_TH1RW3T.csv` (Kepler data) [178 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	2419515 rows by 5 columns
Sampling period	57.9919 to 58.0080 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) (computed) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`TH1RW3T` value at Time (column 2) ⟨%20.14f⟩
MJD: first row	MJD 54949.283050926 = 2009-04-28 06:47:35.600 UTC
MJD: last row	MJD 56728.012735417 = 2014-03-12 00:18:20.340 UTC

Table 12: Contents of AED CSV File #10

Filename	`kplr_anc-eng_TH1RW4T.csv` (Kepler data) [178 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	2419515 rows by 5 columns
Sampling period	57.9919 to 58.0080 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) (computed) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`TH1RW4T` value at Time (column 2) ⟨%20.14f⟩
MJD: first row	MJD 54949.283050926 = 2009-04-28 06:47:35.600 UTC
MJD: last row	MJD 56728.012735417 = 2014-03-12 00:18:20.340 UTC

Table 13: Contents of AED CSV File #11

Filename	`kplr_anc-eng_TH2LVAT.csv` (Kepler data) [180 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	2431183 rows by 5 columns
Sampling period	57.9919 to 58.0080 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) (computed) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`TH2LVAT` value at Time (column 2) ⟨%20.15f⟩
MJD: first row	MJD 54949.283050926 = 2009-04-28 06:47:35.600 UTC
MJD: last row	MJD 56728.012735417 = 2014-03-12 00:18:20.340 UTC

Table 14: Contents of AED CSV File #12

Filename	`kplr_anc-eng_TH2PMAT.csv` (Kepler data) [181 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	2432989 rows by 5 columns
Sampling period	57.9919 to 58.0080 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) (computed) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`TH2PMAT` value at Time (column 2) ⟨%20.15f⟩
MJD: first row	MJD 54949.283050926 = 2009-04-28 06:47:35.600 UTC
MJD: last row	MJD 56728.012735417 = 2014-03-12 00:18:20.340 UTC

Table 15: Contents of AED CSV File #13

Filename	`ktwo_anc-eng_ADATTERRX.csv` (K2 data) [2.5 G]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	31562017 rows by 5 columns
Sampling period	4.0000 to 4.0001 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) (computed) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`ADATTERRX` value at Time (column 2) ⟨%23.16e⟩
MJD: first row	MJD 56728.012923738 = 2014-03-12 00:18:36.611 UTC
MJD: last row	MJD 58387.037467188 = 2018-09-26 00:53:57.165 UTC

Table 16: Contents of AED CSV File #14

Filename	`ktwo_anc-eng_ADATTERRY.csv` (K2 data) [2.5 G]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	31562017 rows by 5 columns
Sampling period	4.0000 to 4.0001 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) (computed) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`ADATTERRY` value at Time (column 2) ⟨%23.16e⟩
MJD: first row	MJD 56728.012923738 = 2014-03-12 00:18:36.611 UTC
MJD: last row	MJD 58387.037467188 = 2018-09-26 00:53:57.165 UTC

Table 17: Contents of AED CSV File #15

Filename	`ktwo_anc-eng_ADATTERRZ.csv` (K2 data) [2.5 G]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	31562017 rows by 5 columns
Sampling period	4.0000 to 4.0001 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) (computed) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`ADATTERRZ` value at Time (column 2) ⟨%23.16e⟩
MJD: first row	MJD 56728.012923738 = 2014-03-12 00:18:36.611 UTC
MJD: last row	MJD 58387.037467188 = 2018-09-26 00:53:57.165 UTC

Table 18: Contents of AED CSV File #16

Filename	`ktwo_anc-eng_AttitudeErrors.csv` (K2 data) [size: 575 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	3056921 rows by 10 columns
Sampling period	39.9999 to 40.0000 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) (computed) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`ADATTERRMX` value at MJD (column 1) ⟨%21.13e⟩
Column 6	`ADATTERRDX` value at MJD (column 1) ⟨%21.13e⟩
Column 7	`ADATTERRMY` value at MJD (column 1) ⟨%21.13e⟩
Column 8	`ADATTERRDY` value at MJD (column 1) ⟨%21.13e⟩
Column 9	`ADATTERRMZ` value at MJD (column 1) ⟨%21.13e⟩
Column 10	`ADATTERRDZ` value at MJD (column 1) ⟨%21.13e⟩
MJD: first row	MJD 56664.688927585 = 2014-01-07 16:32:03.343 UTC
MJD: last row	MJD 58387.036857022 = 2018-09-26T00:53:04.447 UTC

Table 19: Contents of AED CSV File #17

Filename	`ktwo_anc-eng_BoardTemperatures.csv` (K2 data) [307 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	1125947 rows by 14 columns
Sampling period	59.7500 to 119.7833 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) (computed) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`PEDDRV1T` value at MJD (column 1) ⟨%16.12f⟩
Column 6	`PEDACQ1T` value at MJD (column 1) ⟨%16.12f⟩
Column 7	`PEDDRV2T` value at MJD (column 1) ⟨%16.12f⟩
Column 8	`PEDACQ2T` value at MJD (column 1) ⟨%16.12f⟩
Column 9	`PEDDRV3T` value at MJD (column 1) ⟨%16.12f⟩
Column 10	`PEDACQ3T` value at MJD (column 1) ⟨%16.12f⟩
Column 11	`PEDDRV4T` value at MJD (column 1) ⟨%16.12f⟩
Column 12	`PEDACQ4T` value at MJD (column 1) ⟨%16.12f⟩
Column 13	`PEDDRV5T` value at MJD (column 1) ⟨%16.12f⟩
Column 14	`PEDACQ5T` value at MJD (column 1) ⟨%16.12f⟩
MJD: first row	MJD 56664.689335803 = 2014-01-07 16:32:38.613 UTC
MJD: last row	MJD 58387.035941049 = 2018-09-26 00:51:45.307 UTC

Table 20: Contents of AED CSV File #18

Filename	`ktwo_anc-eng_MountTemperature.csv` (K2 data) [94 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	1126105 rows by 5 columns
Sampling period	59.7500 to 119.7833 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) (computed) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`PEDTELMNTT1` value at MJD (column 1) ⟨%18.13f⟩
MJD: first row	MJD 56664.689335803 = 2014-01-07 16:32:38.613 UTC
MJD: last row	MJD 58387.035941049 = 2018-09-26 00:51:45.307 UTC

Table 21: Contents of AED CSV File #19

Filename	`ktwo_anc-eng_OpticsTemperatures1of2.csv` (K2 data) [236 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	1126105 rows by 11 columns
Sampling period	59.7500 to 119.7833 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) (computed) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`PEDCRRT1` value at MJD (column 1) ⟨%18.12f⟩
Column 6	`PEDCRRT2` value at MJD (column 1) ⟨%18.12f⟩
Column 7	`PEDCRRT3` value at MJD (column 1) ⟨%18.12f⟩
Column 8	`PEDPMAT1` value at MJD (column 1) ⟨%18.12f⟩
Column 9	`PEDPMAT2` value at MJD (column 1) ⟨%18.12f⟩
Column 10	`PEDPMAT3` value at MJD (column 1) ⟨%18.12f⟩
Column 11	`PEDPMAT4` value at MJD (column 1) ⟨%18.12f⟩
MJD: first row	MJD 56664.689335803 = 2014-01-07 16:32:38.613 UTC
MJD: last row	MJD 58387.035941049 = 2018-09-26 00:51:45.307 UTC

Table 22: Contents of AED CSV File #20

Filename	`ktwo_anc-eng_OpticsTemperatures2of2.csv` (K2 data) [94 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	1126105 rows by 5 columns
Sampling period	59.7500 to 119.7833 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) (computed) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`PEDCRRT4` value at MJD (column 1) ⟨%18.12f⟩
MJD: first row	MJD 56664.689335803 = 2014-01-07 16:32:38.613 UTC
MJD: last row	MJD 58387.035941049 = 2018-09-26 00:51:45.307 UTC

Table 23: Contents of AED CSV File #21

Filename	`ktwo_anc-eng_ReactionWheelSpeeds.csv` (K2 data) [83 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	562998 rows by 8 columns
Sampling period	119.9000 to 239.9033 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) (computed) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`ADRW1SPD_` value at MJD (column 1) ⟨%18.10f⟩
Column 6	`ADRW2SPD_` value at MJD (column 1) ⟨%1d⟩ [did not work in K2]
Column 7	`ADRW3SPD_` value at MJD (column 1) ⟨%18.10f⟩
Column 8	`ADRW4SPD_` value at MJD (column 1) ⟨%1d⟩ [did not work in K2]
MJD: first row	MJD 56664.689193788 = 2014-01-07 16:32:26.343 UTC
MJD: last row	MJD 58387.034542207 = 2018-09-26 00:49:44.447 UTC

Table 24: Contents of AED CSV File #22

Filename	`ktwo_anc-eng_TelescopeTemperatures1of2.csv` (K2 data) [120 M]
Data format	comma-separated values (csv) file)
Comment rows	10 describing documentation references and format
Data rows	1147377 rows by 6 columns
Sampling period	58.0000 to 118.0000 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) (computed) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`TH1SCMNTT` value at MJD (column 1) ⟨%18.13f⟩
Column 6	`TH2SCMNTT` value at MJD (column 1) ⟨%18.13f⟩
MJD: first row	MJD 56664.688936111 = 2014-01-07 16:32:04.080 UTC
MJD: last row	MJD 58387.035877045 = 2018-09-26 00:51:39.777 UTC

Table 25: Contents of AED CSV File #23

Filename	`ktwo_anc-eng_TelescopeTemperatures2of2.csv` (K2 data) [168 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	1147374 rows by 8 columns
Sampling period	58.0000 to 118.0000 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) (computed) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`TH1SPIDT` value at MJD (column 1) ⟨%19.11f⟩
Column 6	`TH2SPIDT` value at MJD (column 1) ⟨%19.12f⟩
Column 7	`TH1TELET` value at MJD (column 1) ⟨%19.12f⟩
Column 8	`TH2TELET` value at MJD (column 1) ⟨%19.11f⟩
MJD: first row	MJD 56664.688936111 = 2014-01-07 16:32:04.080 UTC
MJD: last row	MJD 58387.035877045 = 2018-09-26 00:51:39.777 UTC

Table 26: Contents of AED CSV File #24

Filename	`ktwo_anc-eng_TH1RW3T.csv` (K2 data) [96 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	1284377 rows by 5 columns
Sampling period	58.0000 to 118.0000 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) (computed) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`TH1RW3T` value at Time (column 2) ⟨%20.14f⟩
MJD: first row	MJD 56728.013406817 = 2014-03-12 00:19:18.349 UTC
MJD: last row	MJD 58390.999219572 = 2018-09-29 23:58:52.571 UTC

Table 27: Contents of AED CSV File #25

Filename	`ktwo_anc-eng_TH1RW4T.csv` (K2 data) [96 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	1284377 rows by 5 columns
Sampling period	58.0000 to 118.0000 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) (computed) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`TH1RW4T` value at Time (column 2) ⟨%20.14f⟩
MJD: first row	MJD 56728.013406817 = 2014-03-12 00:19:18.349 UTC
MJD: last row	MJD 58390.999219572 = 2018-09-29 23:58:52.571 UTC

Table 28: Contents of AED CSV File #26

Filename	`ktwo_anc-eng_TH2LVAT.csv` (K2 data) [97 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	1284303 rows by 5 columns
Sampling period	58.0000 to 118.0000 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) (computed) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`TH2LVAT` value at Time (column 2) ⟨%20.15f⟩
MJD: first row	MJD 56728.013406817 = 2014-03-12 00:19:18.349 UTC
MJD: last row	MJD 58390.999219572 = 2018-09-29 23:58:52.571 UTC

Table 29: Contents of AED CSV File #27

Filename	`ktwo_anc-eng_TH2PMAT.csv` (K2 data) [98 M]
Data format	comma-separated values (csv) file
Comment rows	10 describing documentation references and format
Data rows	1284310 rows by 5 columns
Sampling period	58.0000 to 118.0000 s (10th to 90th percentile range)
Column 1	Modified Julian Date (MJD) (computed) ⟨%16.9f⟩
Column 2	Time (UTC timestamp) ⟨%23s⟩
Column 3	Long-Cadence number (computed) ⟨%6d⟩
Column 4	Short-Cadence number (computed) ⟨%7d⟩
Column 5	`TH2PMAT` value at Time (column 2) ⟨%20.15f⟩
MJD: first row	MJD 56728.013406817 = 2014-03-12 00:19:18.349 UTC
MJD: last row	MJD 58390.999219572 = 2018-09-29 23:58:52.571 UTC

B List of Acronyms

AED	Ancillary Engineering Data
CCD	Charge Coupled Device
CSV	comma-separated variable file (digital file format)
DOI	Digital Object Identifier
FITS	Flexible Image Transport System (digital file format)
FOV	Field of View
gzip	GNU zip compressed file (digital file format)
K2H	K2 Handbook (KSCI-19116-003)
KIH	Kepler Instrument Handbook (KSCI-19033-002)
KDCH	Kepler Data Characteristics Handbook (KSCI-19040-005)
KDPH	Kepler Data Processing Handbook (KSCI-190081-002)
LC	Long Cadence
MAST	Barbara A. Mikulski Archive for Space Telescopes
MJD	Modified Julian Date: MJD = Julian Date - 2,400,000.5 days
MKAM	Kepler MAST Archive Manual (Mullally, 2020)
PDCSAP	Pre-search Data Conditioning Simple Aperture Photometry
PRF	Point Response Function
SC	Short Cadence
STScI	Space Telescope Science Institute
UTC	Coordinated Universal Time