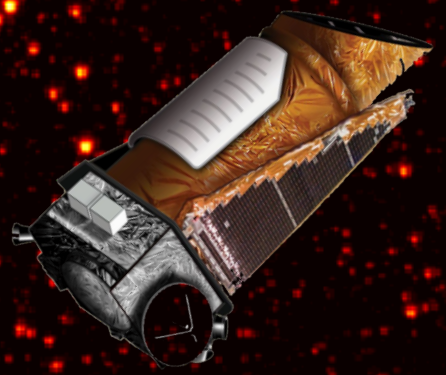
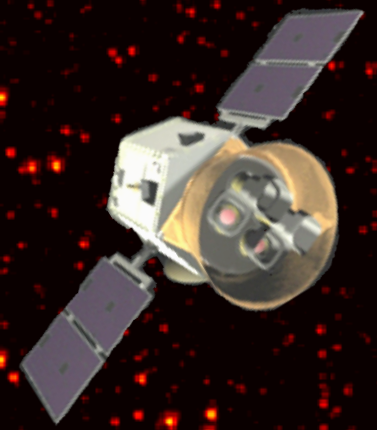
TESS Science Processing Operations Center Pipeline and Data Products

Jon M. Jenkins
NASA Ames Research Center

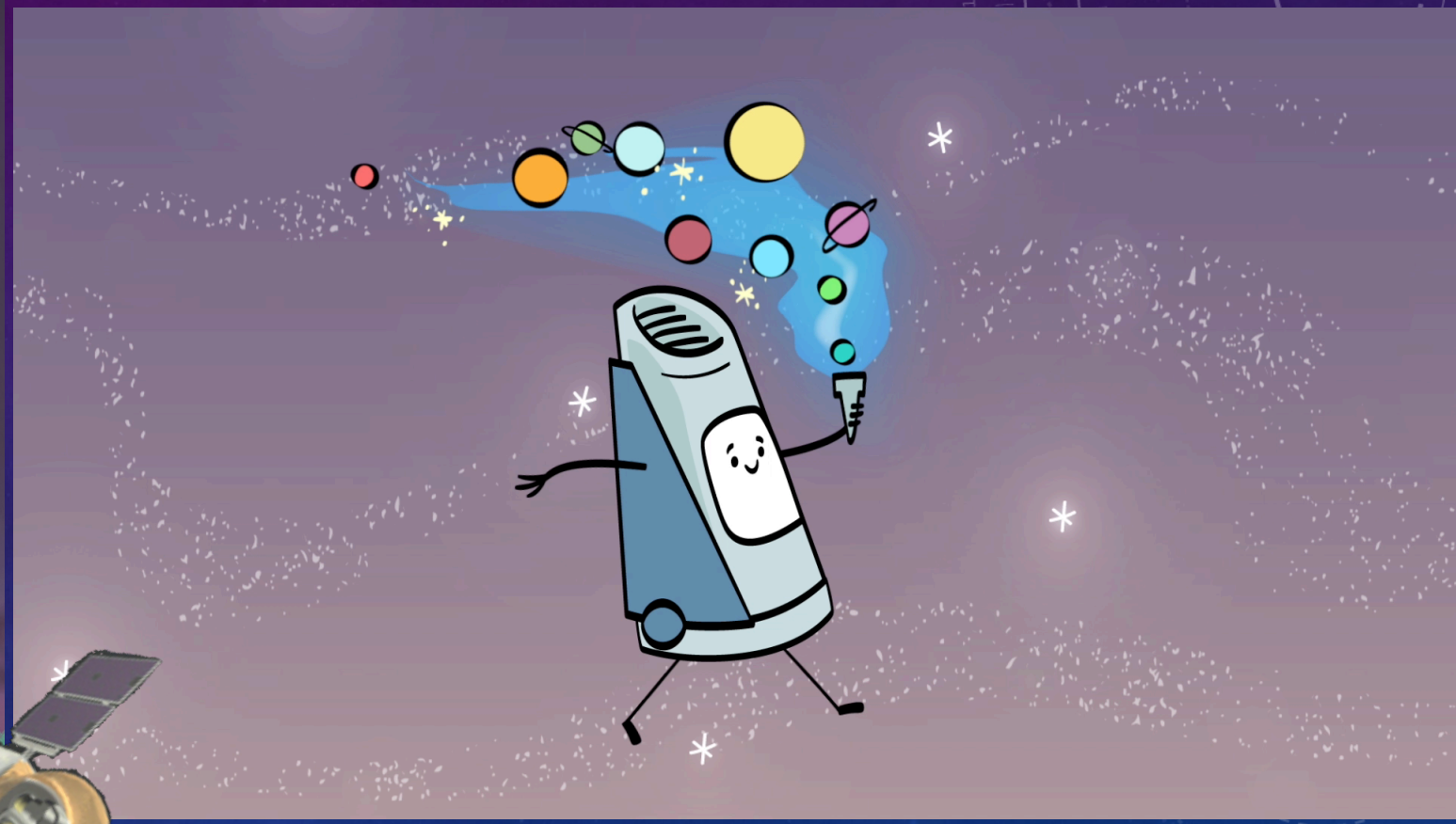




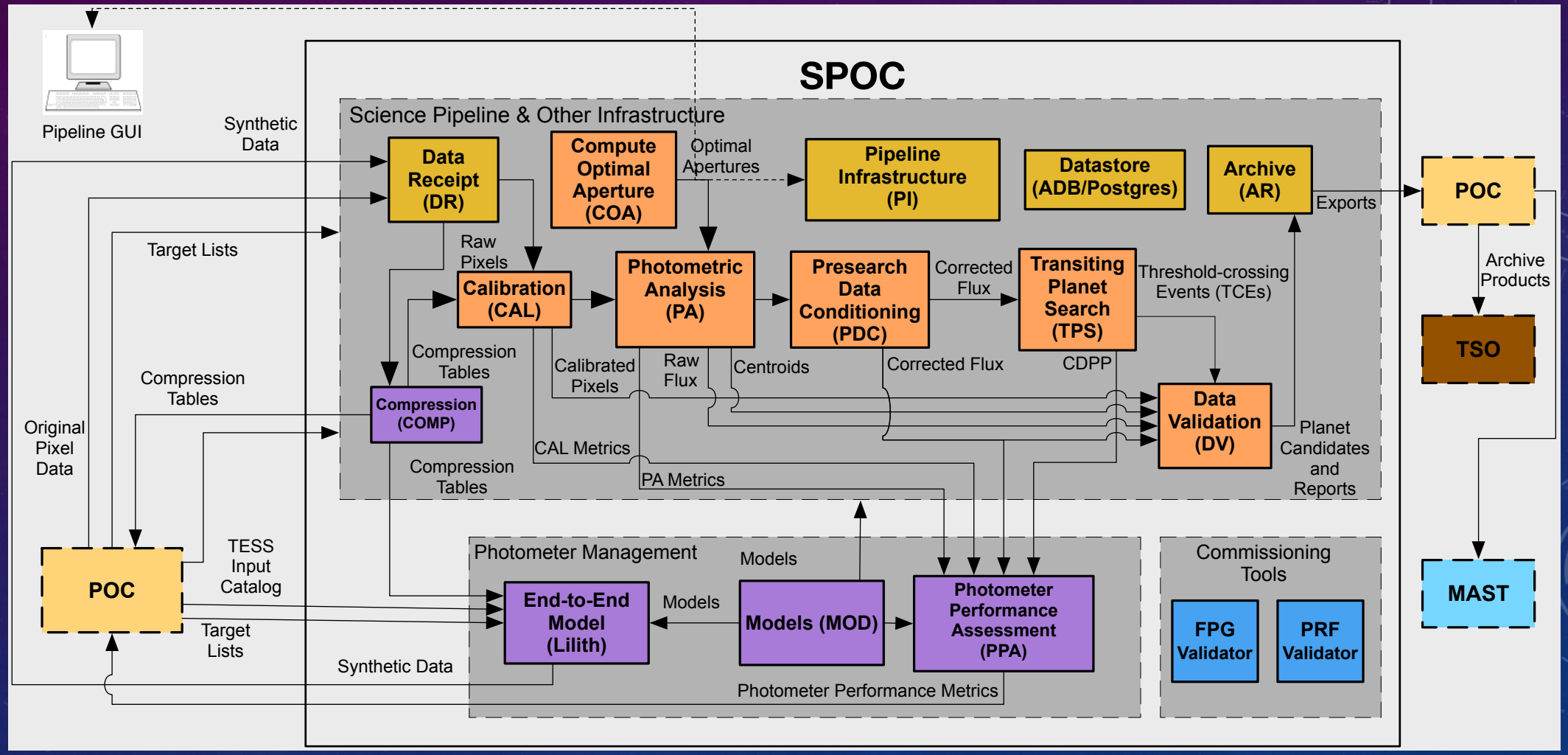
Wednesday July 31 2019

TSC-I
Cambridge, MA

Kepler Passes the Torch to TESS

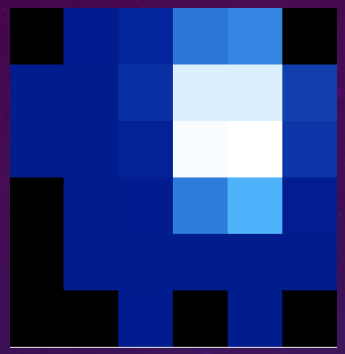


Science Processing Operations Center Architecture



Science pipeline and data products are modeled after the *Kepler Mission* science pipeline and products

The TESS Science Pipeline: From Pixels To Planets



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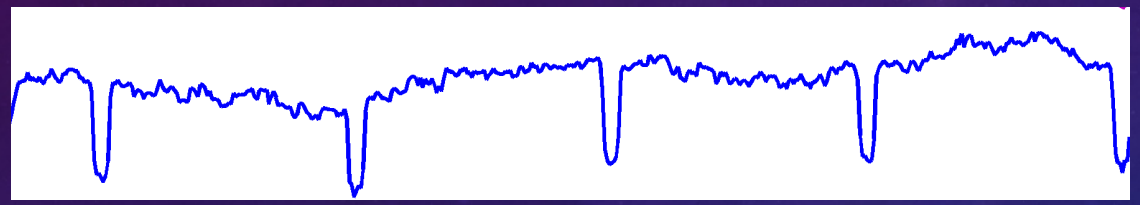

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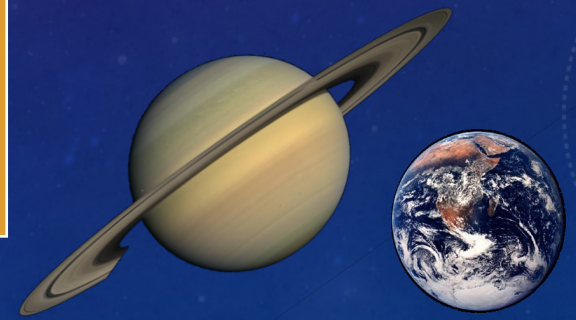

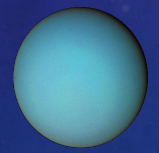

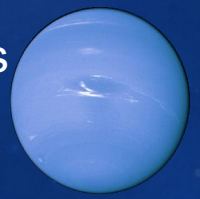

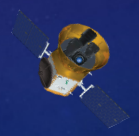

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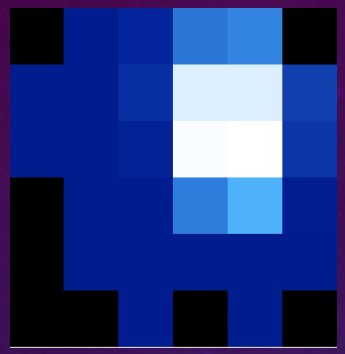

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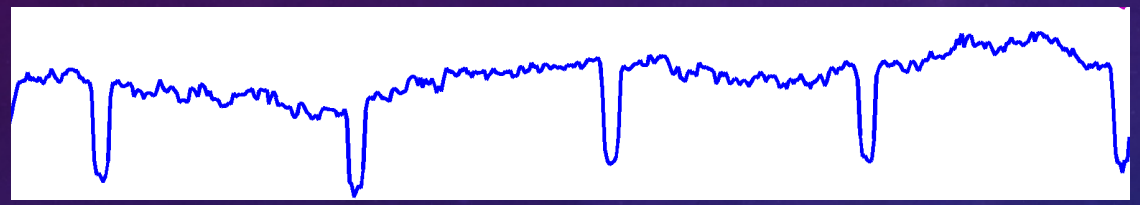

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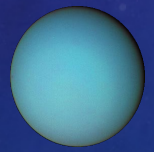

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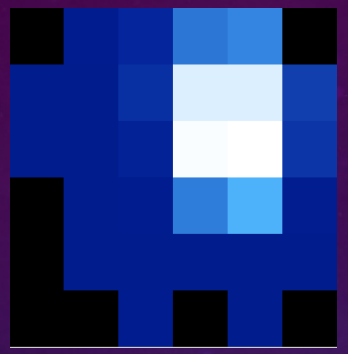

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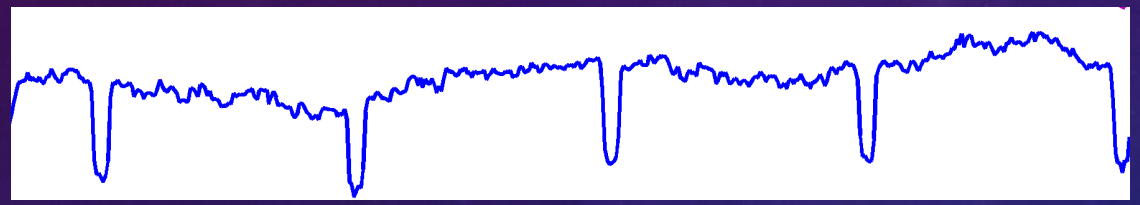

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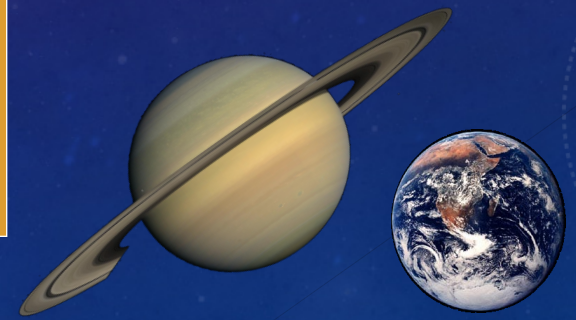

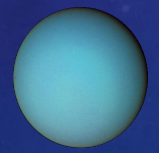

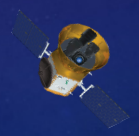

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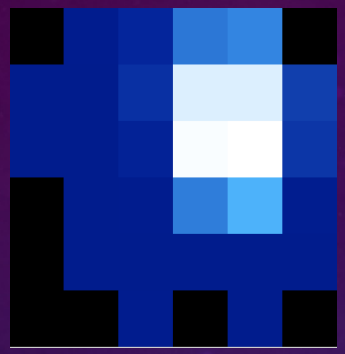

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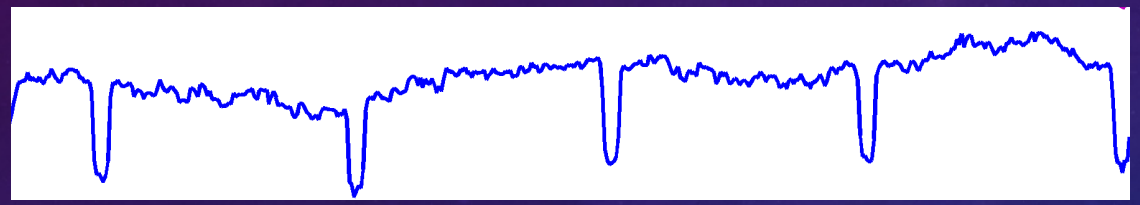

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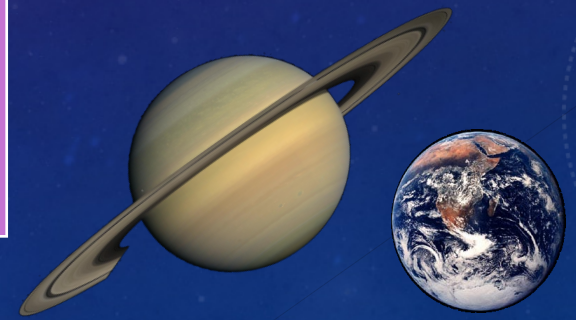

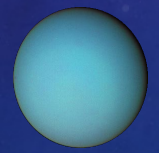

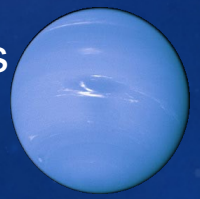

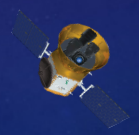

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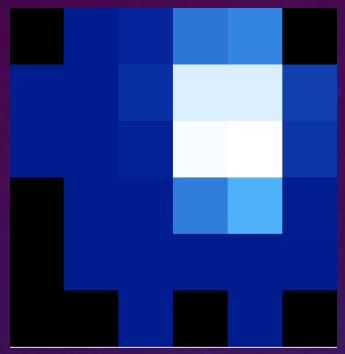

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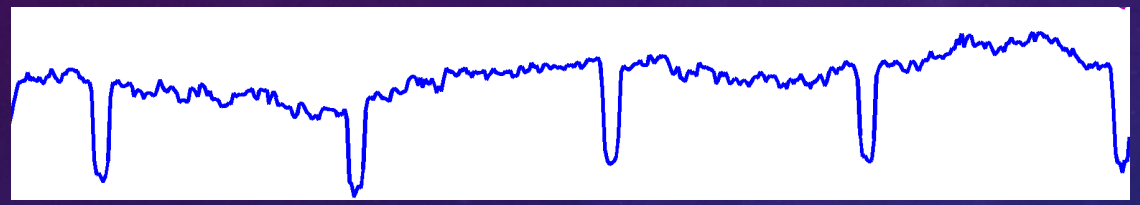

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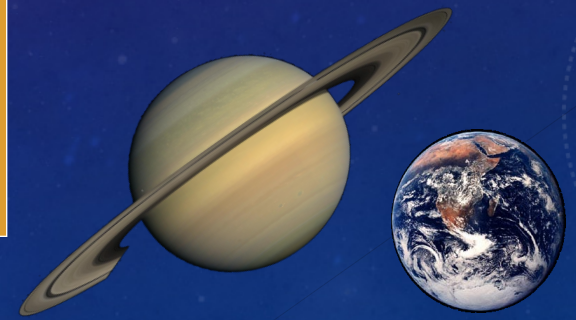

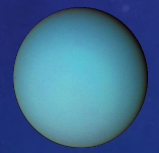

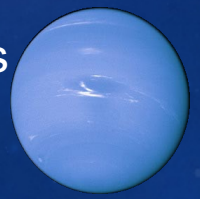

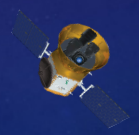

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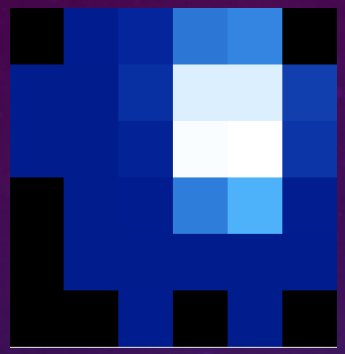

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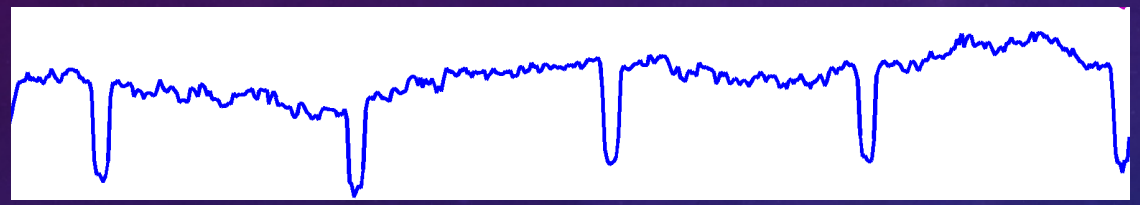

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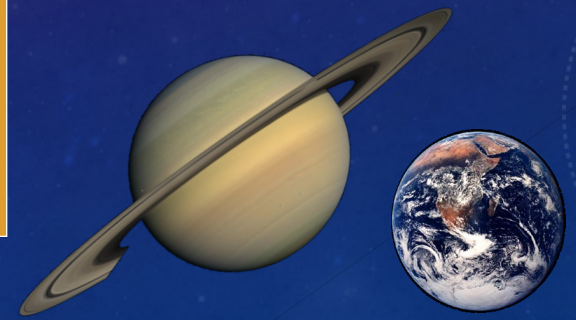
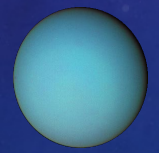
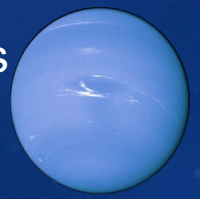
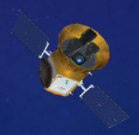








Data Products

Data Type	Naming Convention	File Type
Uncalibrated full frame image	tess*yyyyydddhhmmss*-s*sctr*-*cam*-*ccd*-*scid*-*cr*_ffir.fits.gz	FITS+GZIP
Calibrated full frame image	tess*yyyyydddhhmmss*-s*sctr*-*cam*-*ccd*-*scid*-*cr*_ffic.fits.gz	FITS+GZIP
Target pixels	tess*yyyyydddhhmmss*-s*sctr*-*tid*-*scid*-*cr*_tp.fits.gz	FITS+GZIP
Light curves	tess*yyyyydddhhmmss*-s*sctr*-*tid*-*scid*-*cr*_lc.fits.gz	FITS+GZIP
Collateral target pixel files	tess*yyyyydddhhmmss*-s*sctr*-*type*-*cam*-*ccd*-*output*-*scid*-*cr*_col.fits.gz	FITS+GZIP
Cotrending basis vectors	tess*yyyyydddhhmmss*-s*sctr*-*cam*-*ccd*-*scid*-*cr*_cbv.fits	FITS
Full data validation report	tess*yyyyydddhhmmss*-s*startsctr*-*endsctr*-*tid*-*pin*_dvr.pdf	PDF
TCE summary report	tess*yyyyydddhhmmss*-s*startsctr*-*endsctr*-*tid*-*pn*-*pin*_dvs.pdf	PDF
Data validation results	tess*yyyyydddhhmmss*-s*startsctr*-*endsctr*-*tid*-*pin*_dvr.xml.gz	XML
DV Results XML Schema Definition	tess*yyyyydddhhmmss*_dvr.xsd	XML Schema
Data validation time series	tess*yyyyydddhhmmss*-s*startsctr*-*endsctr*-*tid*-*pin* dvt.fits.gz	FITS+GZIP

ssctr, sstartsctr, sendsctr := sector, start/end sector
cam, ccd := Camera #, CCD #
scid := spacecraft configuration
cr := cosmic ray mitigation performed? 'x': no, 's': spacecraft, 's': SPOC pipeline, 'b': both
output := CCD output # 'A', 'B', 'C' or 'D'
pin := monotonically increasing index for each SPOC pipeline run
pn := planet number for each target star system
tid := TESS input catalog number
type := type of collateral data included: "lvcol", "tvcol", "smrow", or "vrow".

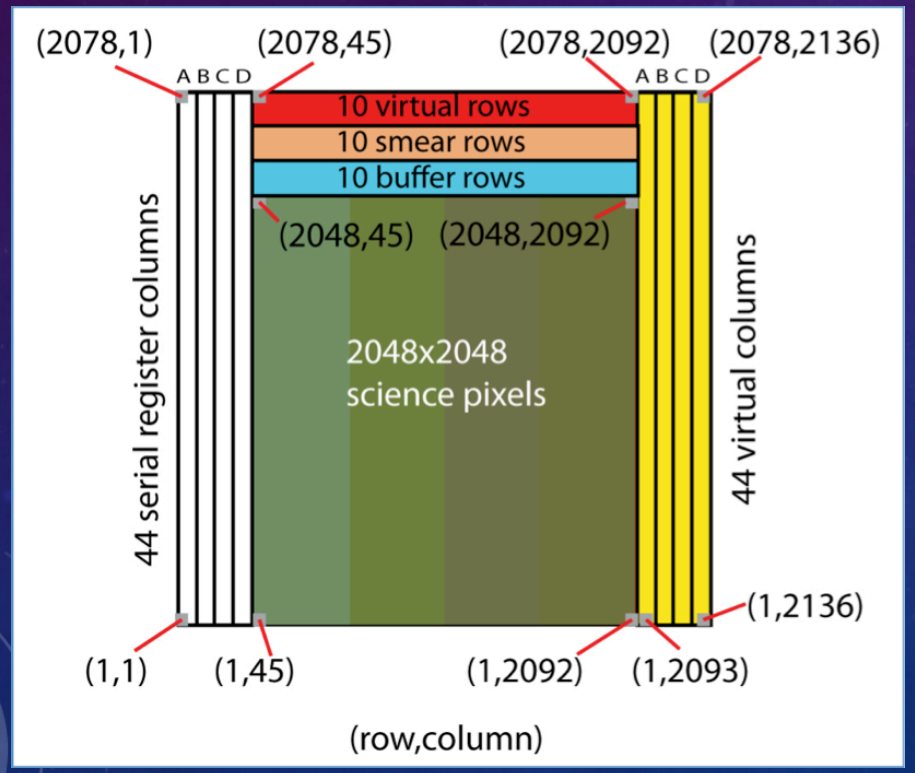
Date Stamp in **UTC**	
yyyy	4 digit year
ddd	3 digit day of year [001,366]
hh	2 digit hour [00,23]
mm	2 digit minute [00,59]
ss	2 digit second [00,60]

See the Science Data Products Description Document
https://heasarc.gsfc.nasa.gov/docs/tess/documentation.html

Full Frame Images (FFIs)

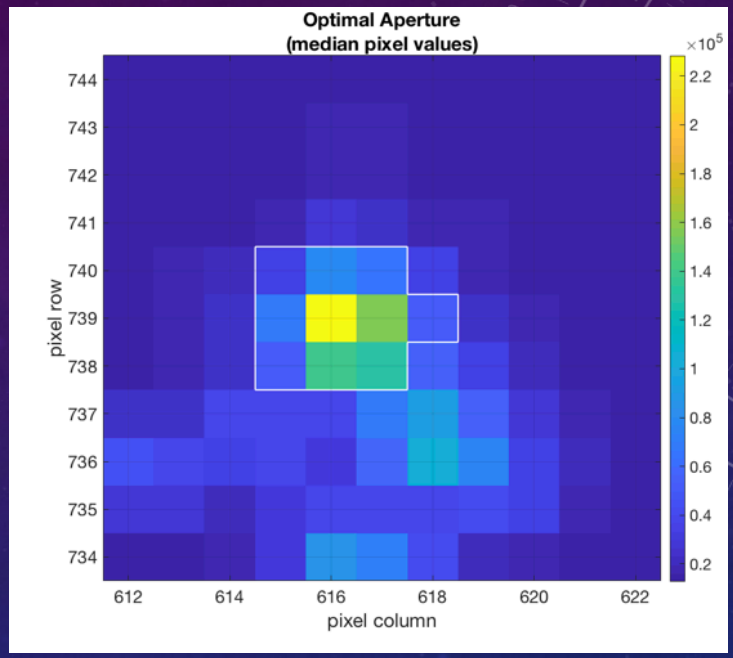
Uncalibrated and Calibrated 30-minute FFIs supplied

- Calibrated includes uncertainties
- No background correction, but all the pixel calibrations
- Collateral pixels included in the FFIs
- One file for calibrated/uncertainties and one file for raw
- Includes WCS
- Flags: Coarse/Fine Point, Stray Light, Momentum Dump

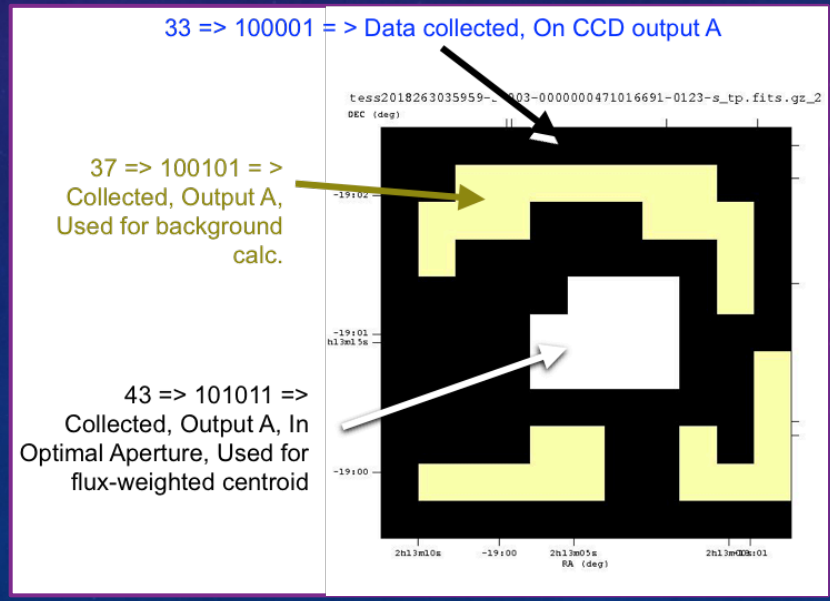


Target Pixel Files and Collateral Data

- Contains calibrated, background-subtracted pixel data time series for each 2-minute target
- One file per sector, per target
- Number of pixels collected per target (typically 11x11) and the aperture HDU is always a bounding box around the collected pixels
- Collateral Pixels:
  - Leading virtual Column (lvcol): Measures bias voltage
  - Trailing virtual Column (tvcol): Measures bias
  - Smear row (smrow): Measures shutterless smear and dark current
  - Virtual row (vrow): Measures shutterless smear charge and dark current during readout



Bit	Value	Description
1	1	Pixel was collected by the spacecraft.
2	2	Pixel was in optimal aperture.
3	4	Pixel was used in background calculation.
4	8	Pixel was used to calculate the flux weighted centroid.
5	16	Pixel was used to calculate the PRF centroid.
6	32	Pixel is on CCD output A
7	64	Pixel is on CCD output B
8	128	Pixel is on CCD output C
9	256	Pixel is on CCD output D



Cotrending Basis Vectors (CBVs)

CBVs represent the systematic trends present in the data per CCD.

- Singular vectors from an SVD analysis

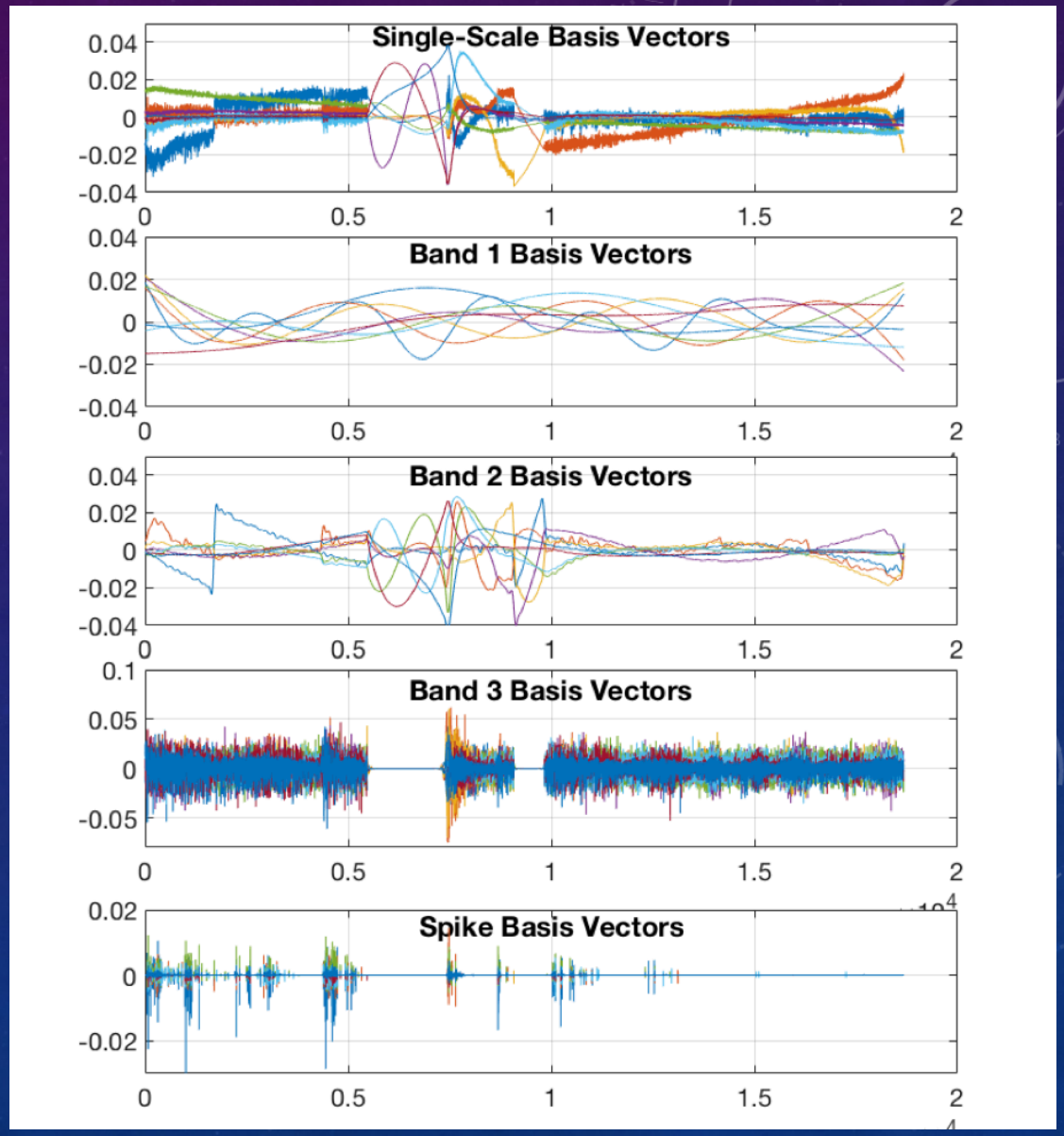
Several types of CBVs available:

- Single-Scale
- Multi-Scale
- Spike

Every effort made so that the CBVs only contain systematic signals (“Entropy Cleaning”) and Bayesian Priors used to regularize the fits in PDC

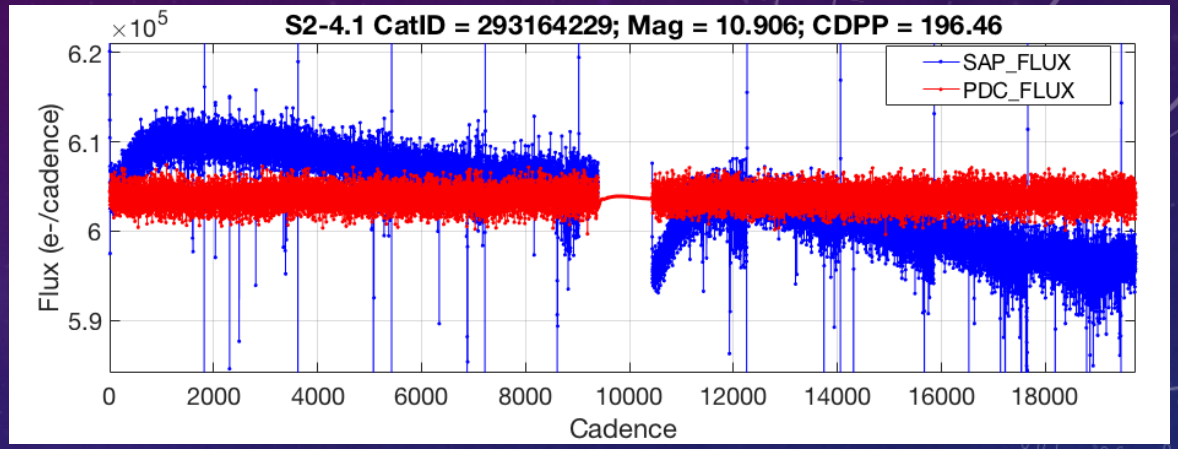
- But overfitting *can* still occur.
- You can perform your own fit to CBVs if PDC did not perform well on your target.

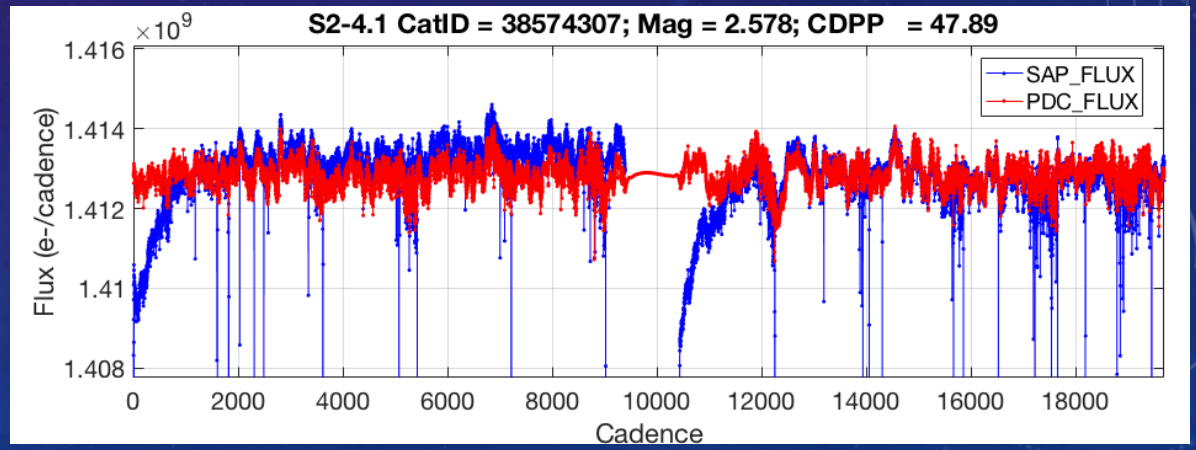
Coming soon for FFIs!



Light Curves

- SAP_FLUX: Simple Aperture Photometry, background subtracted
- PDC_FLUX: Pre-search Data Conditioning: removal of instrumental systematics
  - Goodness metrics
  - CDPP
  - other quality metrics
- PSF_CENTR#: PSF-fitted centroids (only for PPA targets)
  - Better, but not for every target
- MOM_CENTR#: Flux-weighted (moment-derived) centroid motion
  - Available for (almost) every target





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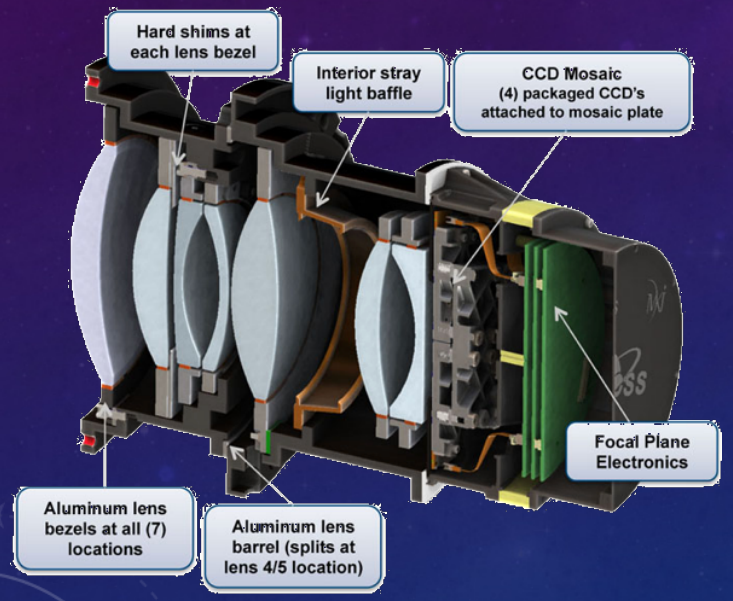
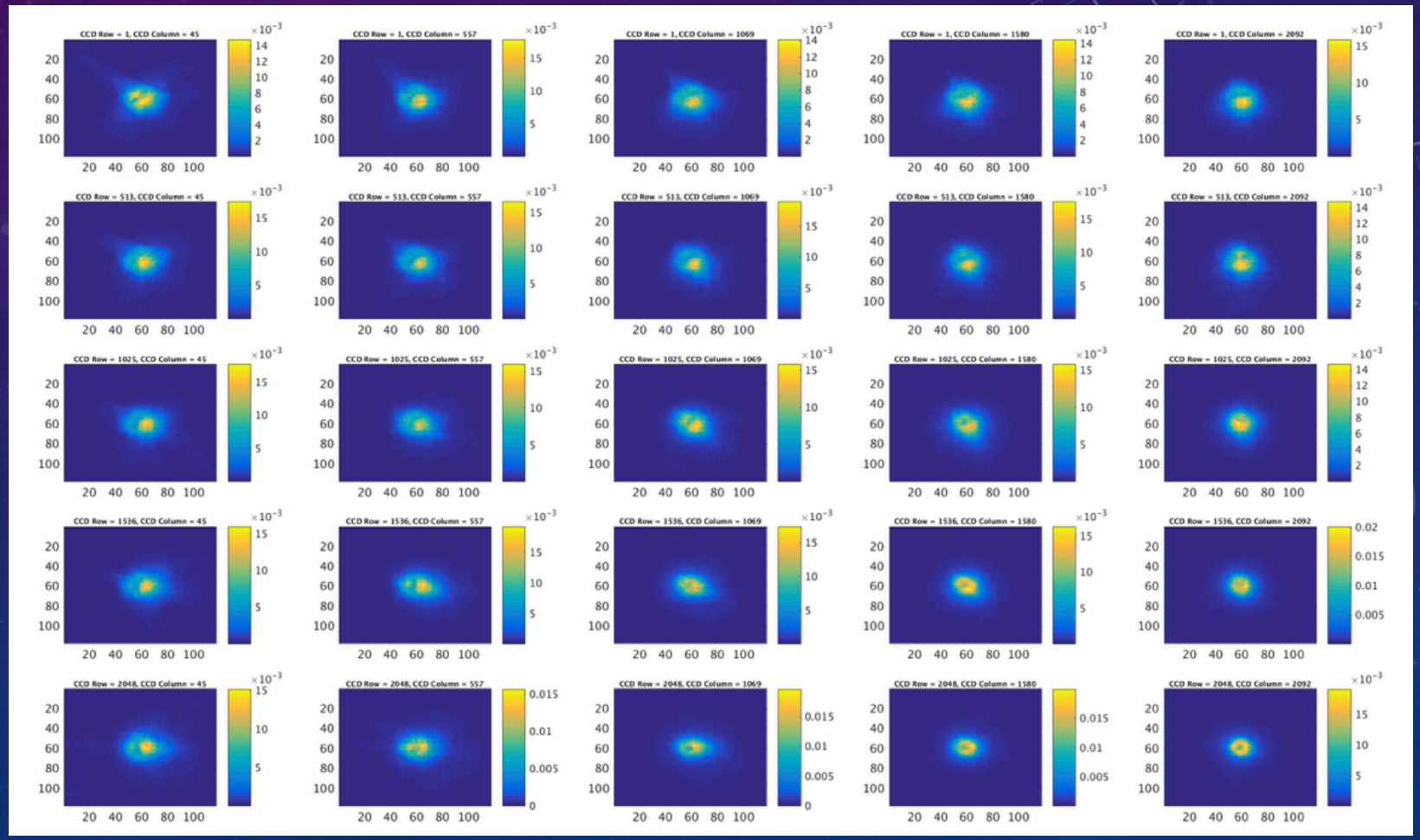
Pixel Response Function (PRF) Models

- Discrete PRF models for all 16 CCDs generated during commissioning.
- Updated in November 25 models per CCD
- Can be interpolated to any focal plane location





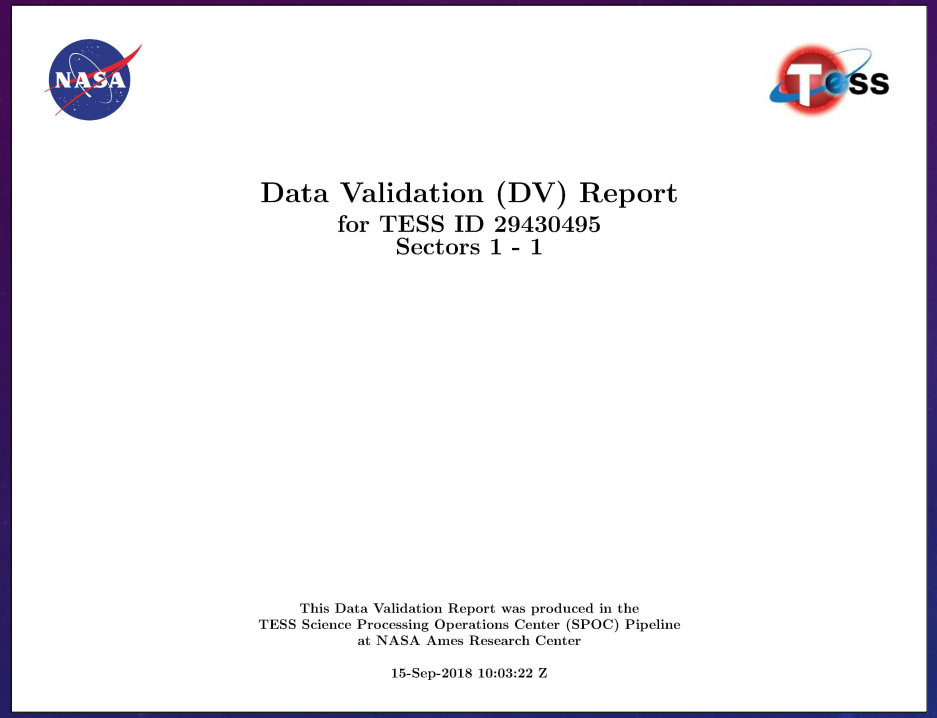
Data Quality Flags

Bit	Value	FFI	Description
1	1	Y	Attitude Tweak
2	2	N	Safe Mode
3	4	Y	Spacecraft is in Coarse Point
4	8	Y	Spacecraft is in Earth Point
5	16	Y	Argabrightening event
6	32	Y	Reaction Wheel desaturation Event
7	64	N	Cosmic Ray in Optimal Aperture pixel
8	128	Y	Manual Exclude. The cadence was excluded because of an anomaly.
9	256	N	Discontinuity corrected between this cadence and the following one.
10	512	N	Impulsive outlier removed before cotrending.
11	1024	Y	Cosmic ray detected on collateral pixel row or column.
12	2048	Y	Straylight from Earth or Moon in camera FOV.

Data Quality Flags are bit-encoded – each bit represents a separate event/issue

Data Validation Products: DV Reports

DV Full Reports

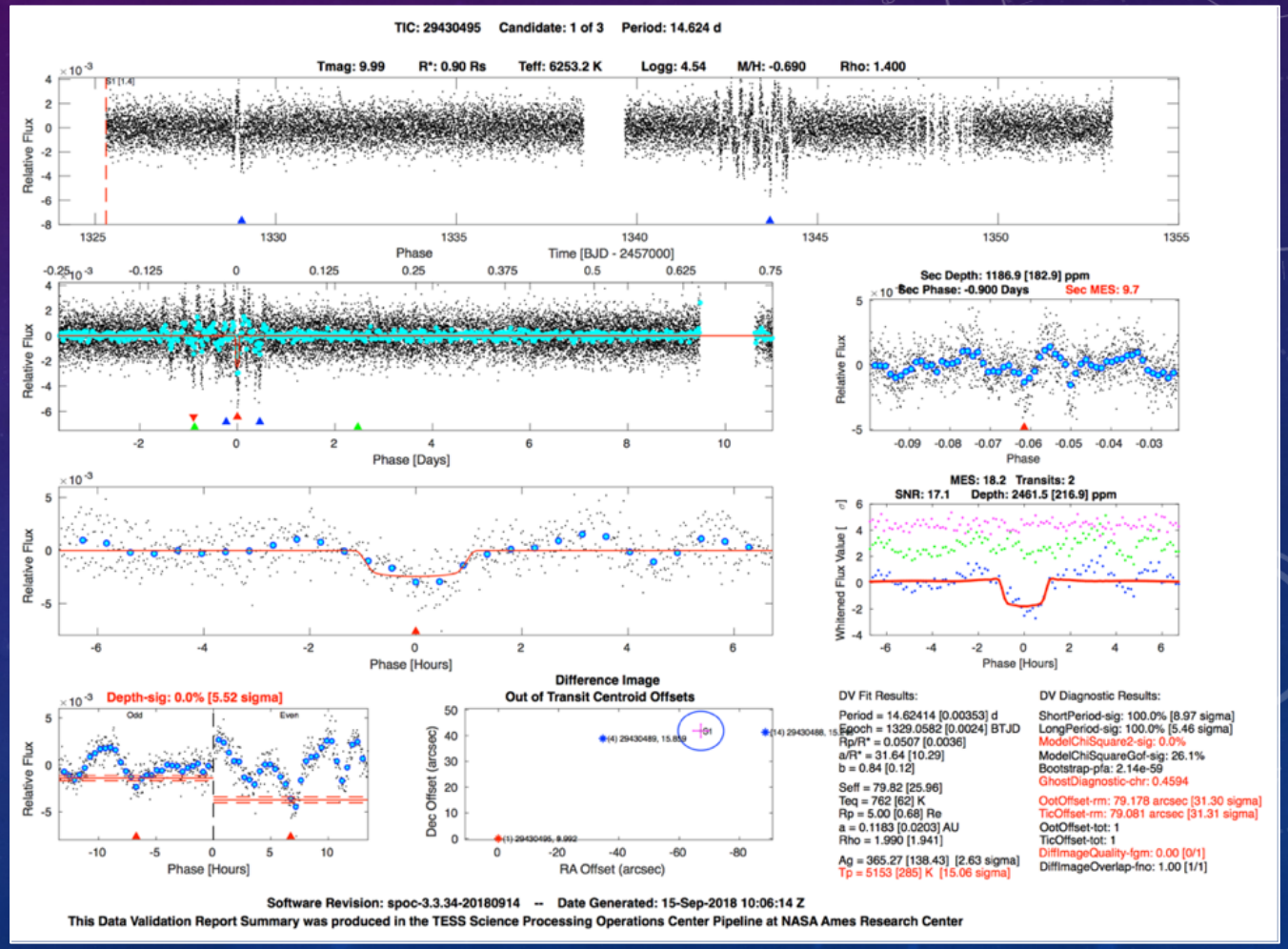


Data Validation (DV) Report
for TESS ID 29430495
Sectors 1 - 1

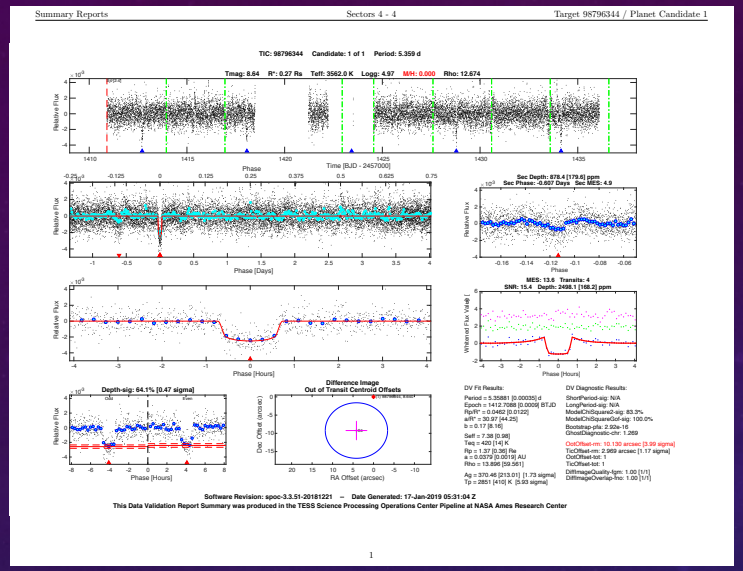
This Data Validation Report was produced in the
TESS Science Processing Operations Center (SPOC) Pipeline
at NASA Ames Research Center

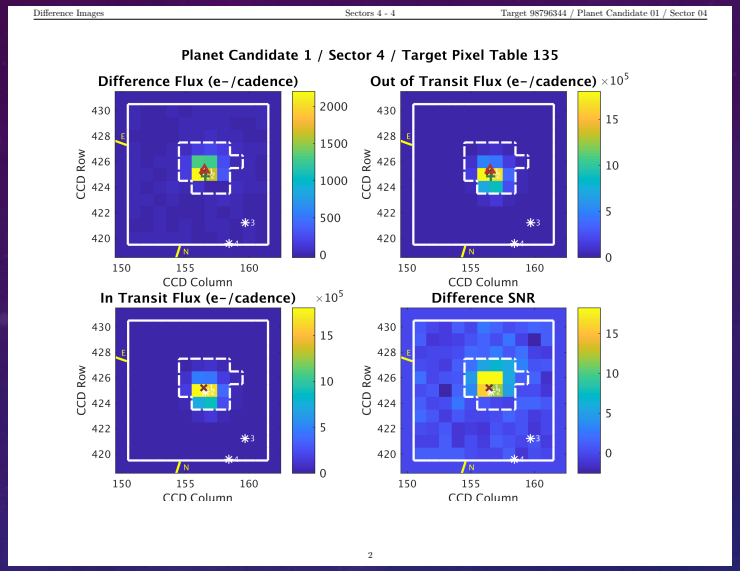
15-Sep-2018 10:03:22 Z

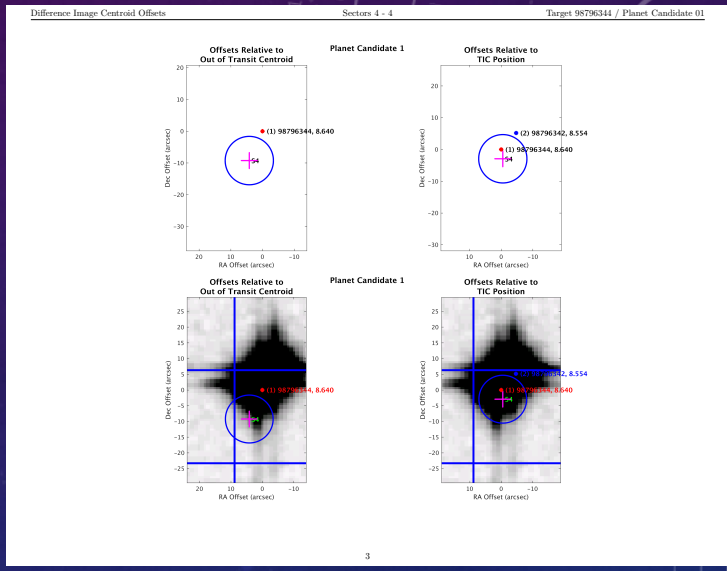
DV Summary

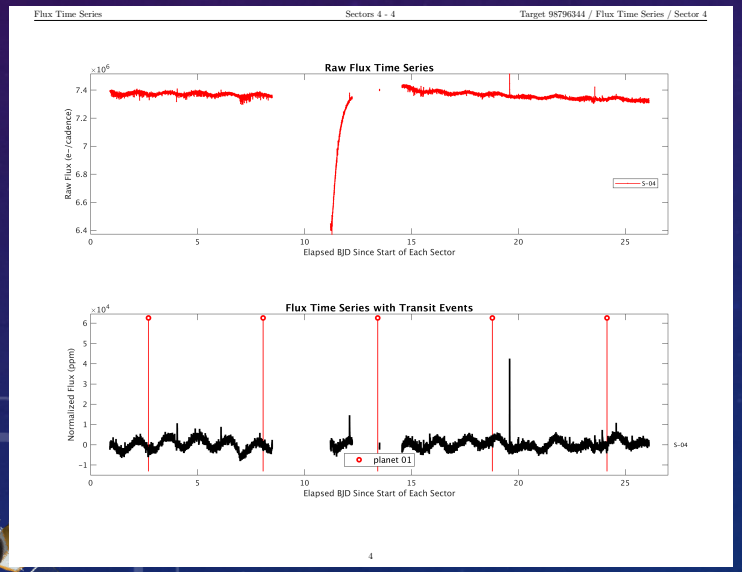


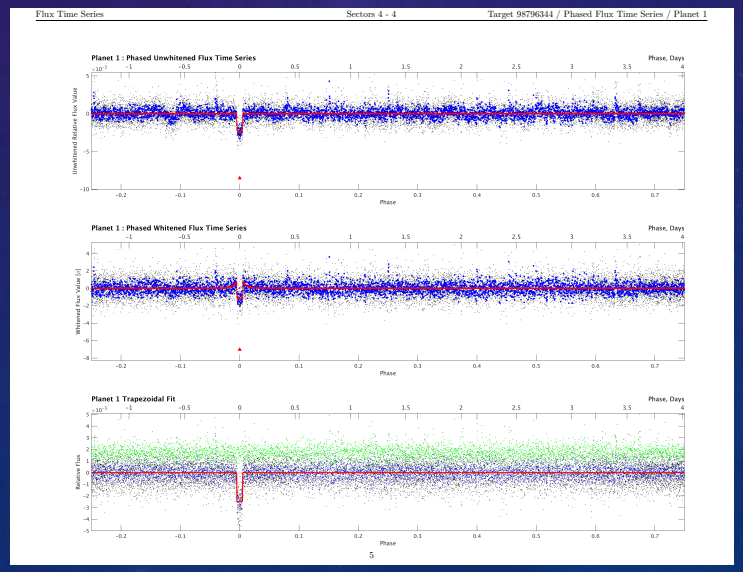
Data Validation Products: DV Mini Reports

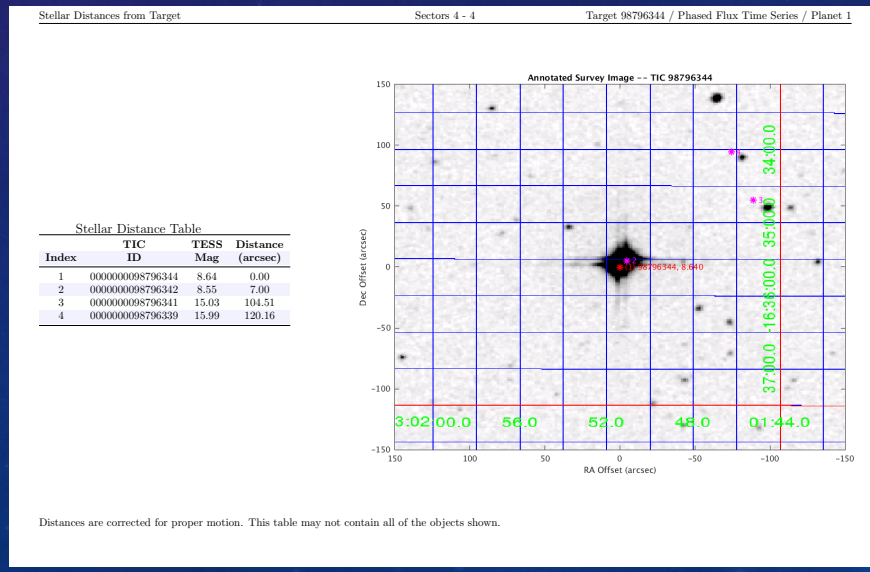




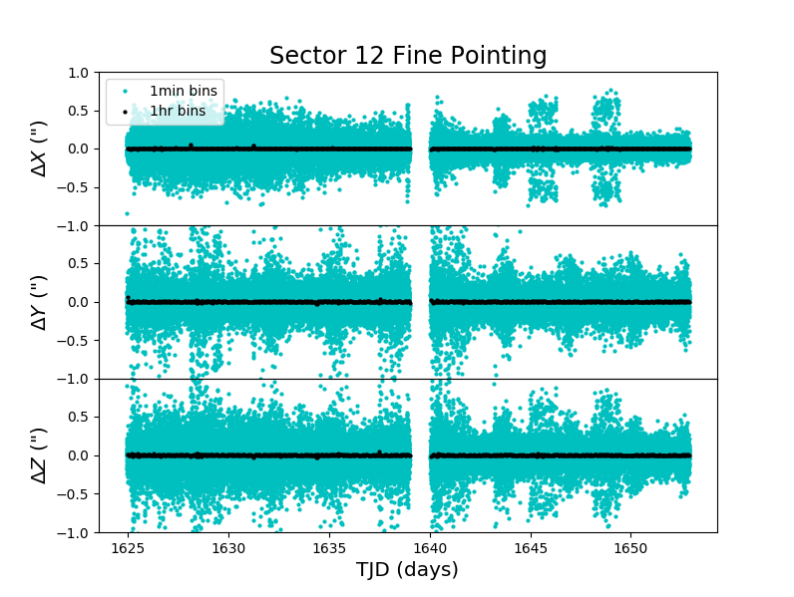


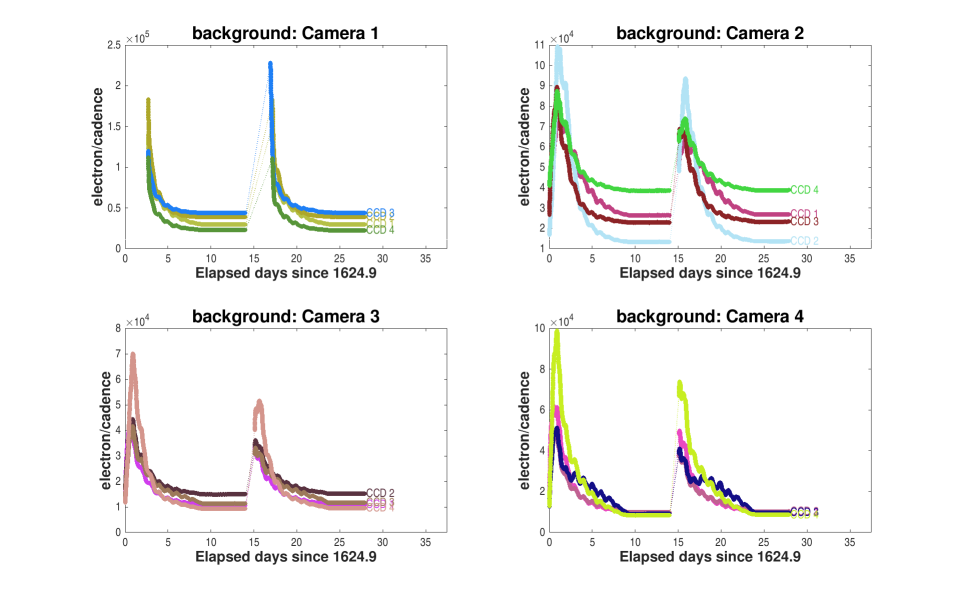






Data Release Notes: Pointing Quality, Background, Scattered Light

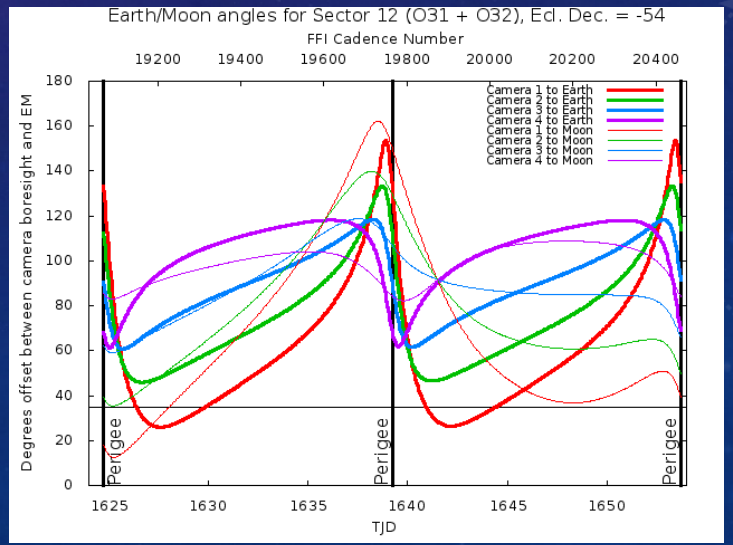




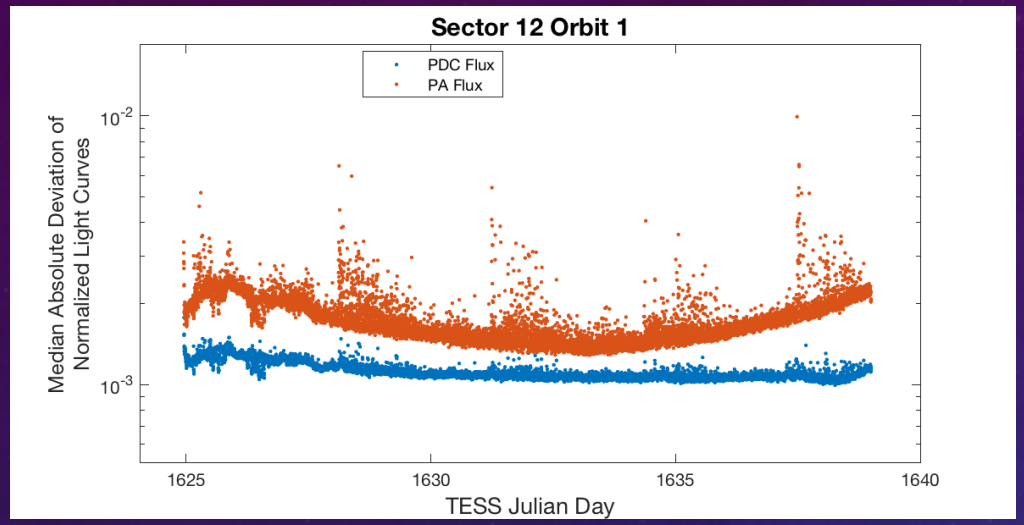
Cadences affected by fireflies/fireworks noted.
Cadences excluded due to scattered light also noted:

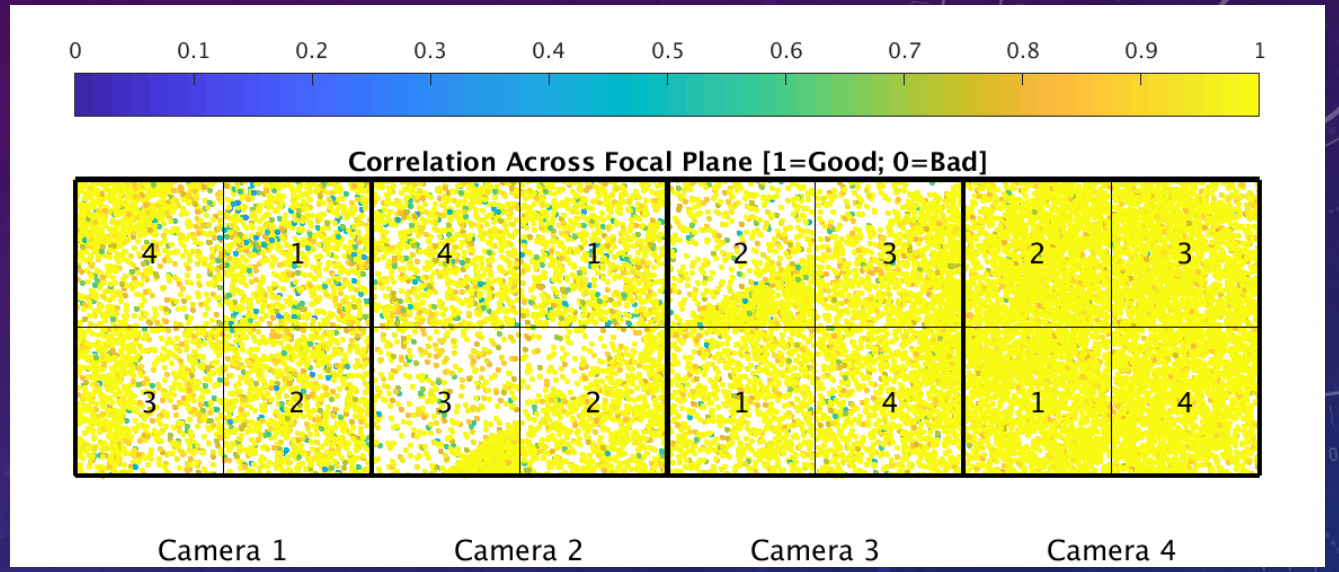
Table 2: Cadence ranges for data excludes due to scattered light

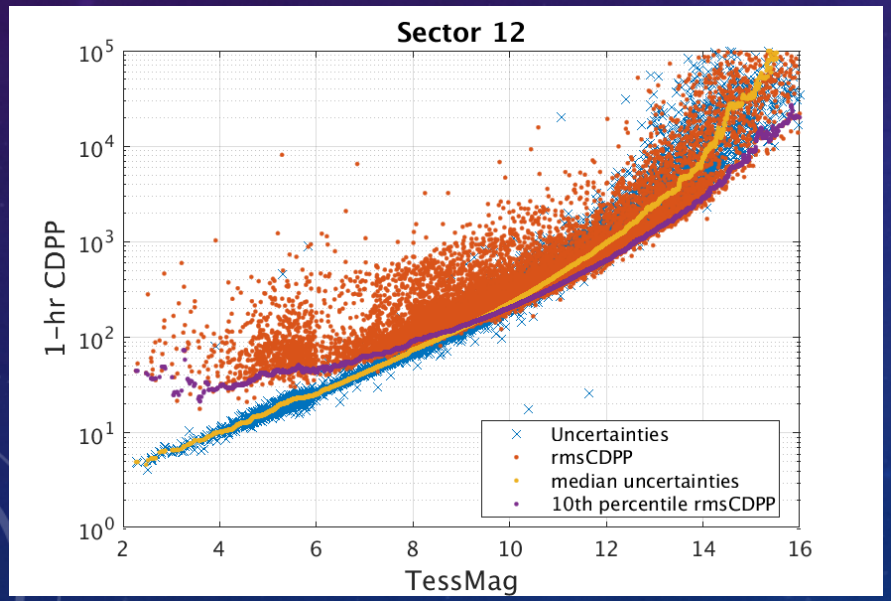
Cam	CCD	Orbit 31	Orbit 32
1	1	286196–288125	297056–298530
1	2	286196–288125	297056–298542
1	3	286196–288125	297056–298375
1	4	286196–288125	297056–298543

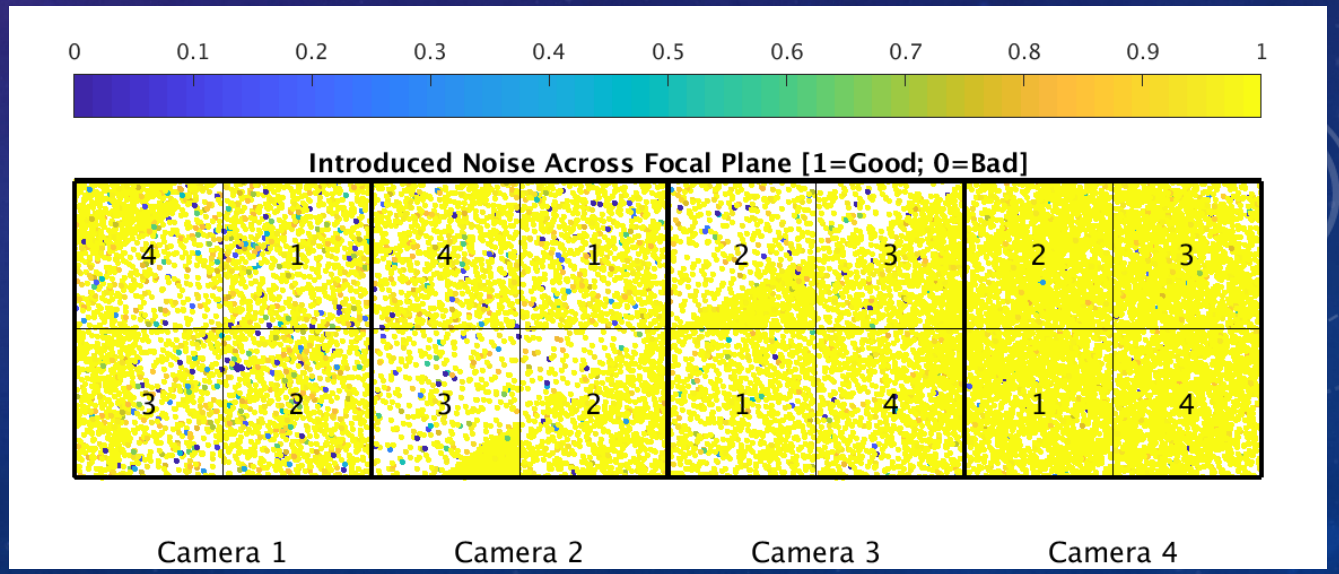


Data Release Notes: Quality of Flux Time Series

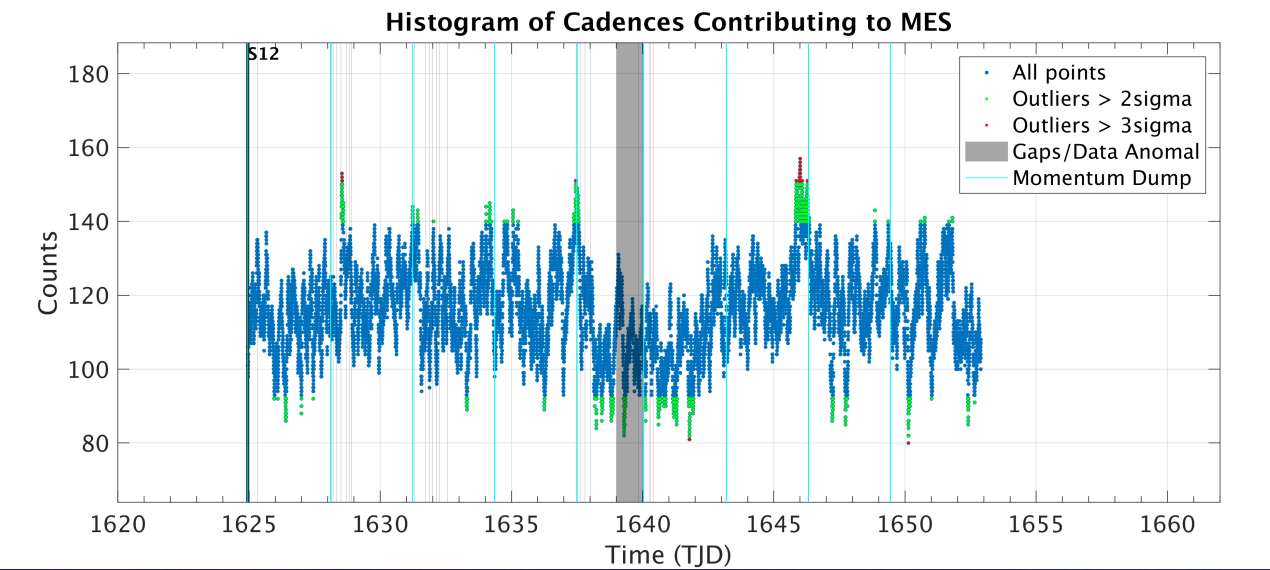








Data Release Notes: Transit Search Summary Information



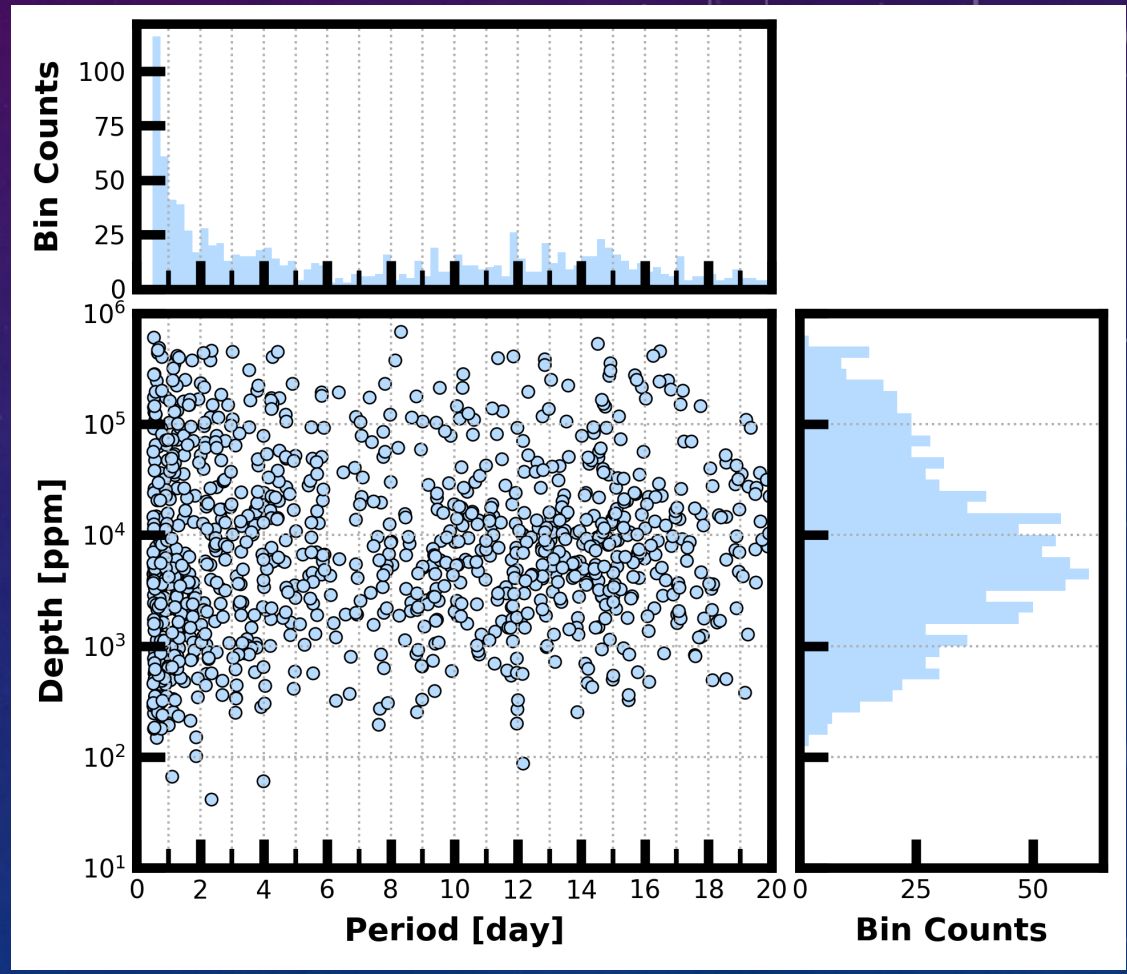


Table 4: Sector 12 TCE Numbers

Number of TCEs	Number of Targets	Total TCEs
1	683	683
2	296	592
3	45	135
4	9	36
5	0	0
6	2	12
–	1035	1458

Summary

- TESS Science Pipeline is modeled after the *Kepler* pipeline
- TESS Data products are closely modeled after *Kepler's*
- FFIs, Target Pixel files, Light Curve files, Transit search products are available at MAST
- Calibration models also available at MAST (PRFs, etc.)
- Documentation available at MAST:
  - Science Data Products Description Document
  - Kepler Data Processing Handbook
  - Data Release Notes
  - TESS Instrument Handbook

We want to hear from you!

Thanks to the SPOC, the POC and the DAWG

SPOC Team Members (Past and Present*)

- Dwight Sanderfer, Misty Davies (Software Development Manager)
- Masoud Mansouri-Samani, Eric Omelian (Systems Engineer), Terry Trombly (Scheduler)
- Eric Ting, Jennifer Campbell (Lead Operations Engineer)
- Dean Chacon, David Lung (SQA)
- Joe Twicken, Jeff Smith, Rob Morris, Jie Li (Data Scientist)
- Peter Tenenbaum, Mark Rose, Sean McCauliff, Todd Klaus (Lead Software Engineer)
- Doug Caldwell (Support Scientist), Chris Henze (NAS Pleiades)
- Bill Wohler, Forrest Girouard, Roberto Carlino, Khai Nyunt, Chris Hull, Christine Xiolan (Software Engineer)

Data Analysis Working Group Members at MIT:

- Michael Fausnaugh, Chris Burke, Avi Shporer (Pipeline Scientist)
- Roland Vanderspek, Ed Morgan, Joel Villasenor, John Doty (Instrument Scientist/Engineer)

Payload Operations Center:

- Jim Francis (Manager/Software Engineer), Scott Dynes (Manager)
- Ed Morgan (Scientist/Engineer), Michael Vezie, Kari Hayworth, Ana Glidden (Software Developer)

Remembering David Lung and Forrest Girouard who passed away during TESS development