Description of the EPOCh Stellar Transit Observations and Photometry

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EPOCh Stellar Transit Observations

The EPOCh stellar transit observations utilized a broad optical band, extending from 350 to 1000 nanometers (clear filter number 6), of the HRIV CCD. Each resulting image data file represents a single 50-second exposure, using a subarray mode. The units of the archived raw images are raw data counts while units of the archived calibrated images are Watts per square meter per steradian per micron. (Both raw and calibrated data files are archived at Multi-mission Archive at STScI (MAST) and the NASA Planetary Data System (PDS).) In most instances, the subarray size is 128x128 pixels. But sometimes during transit and/or secondary eclipse, a 256x256 subarray size was used. The larger subarray size ensured that pointing jitter did not cause the star to fall beyond the edges of the subarray. The stellar images are defocused (a permanent on-orbit property of the telescope) to about 10 pixels (4 arcsec) FWHM. The calibrated HRIV CCD images have been bias-subtracted with removal of electronic crosstalk and transfer smear and nominally flat-fielded, using flat-field calibration exposures of an integrating sphere made on the ground before launch; these radiance images are archived at the PDS (http://pds.nasa.gov) under data set with an ID of DIF-X-HRIV-3-EPOXI-EXOPLANETS-V1.0. Raw images are archived at the PDS with a data set ID of DIF-X-HRIV-2-EPOXI-EXOPLANETS-V1.0.

However, the CCD detector has changed in space, and the ground flat-field calibration is not adequate for precision stellar photometry. The EPOCh team used an independent bootstrap procedure, fitting aperture photometry to a 2-D spline to define corrections to the flat-field calibration (that is, the archived radiance images). Table 1 lists the steps that the team applied to the calibration and photometry of each EPOCh stellar target. The resulting photometry data are archived at the PDS under data set with an ID of DIF-X-HRIV-5-EPOXI-EXOPLANETS-PHOT-V1.0.

Calibration Step	*Reference*	*Comment*
bias and dark current subtraction	Klassen et al. 2008	pipeline at Cornell
preliminary flat-fielding	Klassen et al. 2008	pipeline at Cornell
corrections for central rows and columns, subarray size, and quadrant-dependent bias	Ballard et al. 2010 Christiansen et al. 2010	
construct PSF using drizzle	Barry et al. 2010	each target star used to make its own PSF
secondary flat-fielding using stimulator lamp data	Christiansen et al. 2010	
fit PSF to each stellar image	Ballard et al. 2010	determines stellar X,Y position
aperture photometry, 10-pixel radius	Ballard et al. 2010	circular aperture centered on star
correct aperture photometry using 2-D spline surface	Ballard et al. 2010	spline surface based on random subset of points
lower right quadrant correction	Ballard et al. 2011	only needed for contingent TrES-2 and HAT-P-4 data
point-by-point correction	Christiansen et al. 2010	for points within a 3-hour window centered on transit

Table 1. Listing of the steps applied to the calibration and photometry of each EPOCh stellar target.

Error levels for EPOCh stellar photometry are given in the following tables (2-7), one table for each transiting planet system. The EPOCh CCD detector has a spatially non-uniform response. Coupled with spacecraft pointing jitter, this leads to noise levels that are a function of the time scale, i.e. the number of points that are averaged. The ideal photon-limited case would produce standard deviations for binned data that decrease as the inverse square root of the total number of binned points (equivalently, as the square root of the total time interval). The tables give the number of averaged points (NP), the time interval (Ntime, in minutes) and the standard deviation for that time interval in units of the stellar flux. Each point that is binned represents 50-seconds of exposure time, plus a few seconds of overhead. Overhead is included in the Ntime values.

HAT-P-4		
NP	***Ntime (minutes)***	***Standard Deviation***
1	0.843667	0.0011568513
2	1.68733	0.00090268208
4	3.37467	0.00073773344
8	6.74933	0.00055135903
16	13.4987	0.00042166669
32	26.9973	0.00034057043
64	53.9947	0.00026740742
128	107.989	0.00019248507
256	215.979	0.00012183909
512	431.957	5.9978127e-05

Table 2. Photometry error levels for HAT-P-4.

HAT-P-7		
NP	***Ntime (minutes)***	***Standard Deviation***
1	0.843667	0.00075210299
2	1.68733	0.00064274314
4	3.37467	0.00054440071
8	6.74933	0.00050449965
16	13.4987	0.00043062094
32	26.9973	0.00036409640
64	53.9947	0.00029516709
128	107.989	0.00020787818
256	215.979	0.00017629711
512	431.957	0.00014063646

Table 3. Photometry error levels for HAT-P-7.

GJ 436		
NP	***Ntime (minutes)***	***Standard Deviation***
1	0.843667	0.00050875102
2	1.68733	0.00043097194
4	3.37467	0.00036651007
8	6.74933	0.00032530082
16	13.4987	0.00022578942
32	26.9973	0.00018538466
64	53.9947	0.00012555730
128	107.989	0.00011223905
256	215.979	8.4118445e-05
512	431.957	3.1448330e-05

Table 4. Photometry error levels for GJ 436.

TrES-2		
NP	***Ntime (minutes)***	***Standard Deviation***
1	0.843667	0.0015681651
2	1.68733	0.0012356165
4	3.37467	0.00093257416
8	6.74933	0.00070808700
16	13.4987	0.00055674871
32	26.9973	0.00044851966
64	53.9947	0.00034450906
128	107.989	0.00031302523
256	215.979	0.00027201473

Table 5. Photometry error levels for TrES-2.

TrES-3		
NP	***Ntime (minutes)***	***Standard Deviation***
1	0.843667	0.0025323839
2	1.68733	0.0019495520
4	3.37467	0.0014570355
8	6.74933	0.0010532849
16	13.4987	0.00079664454
32	26.9973	0.00062819093
64	53.9947	0.00048610280
128	107.989	0.00041822722
256	215.979	0.00027489904
512	431.957	0.00019008991

Table 6. Photometry error levels for TrES-3.

WASP-3		
NP	***Ntime (minutes)***	***Standard Deviation***
1	0.843667	0.00083660282
2	1.68733	0.00073821470
4	3.37467	0.00064862869
8	6.74933	0.00054654607
16	13.4987	0.00045596197
32	26.9973	0.00037014380
64	53.9947	0.00030564962
128	107.989	0.00020876195
256	215.979	0.00016026215
512	431.957	0.00010886080

Table 7. Photometry error levels for WASP-3.

Finally it is important to note that the spacecraft clock is affected by a systematic drift relative to ground clocks, due to the changing thermal environment of the spacecraft. The EPOCh team has calibrated the spacecraft clock versus ground clocks, and the corrected times were computed by the EPOCh team for each transiting system (giving Julian Date, and Barycentric Julian Date, corresponding to each file name). However, the computation was eventually implemented in the mission's automated data pipeline, and the EPOCh team verified the resulting values were consistent with theirs. Thus the Barycentric Julian Date (when light from the target reaches the solar system barycenter) is provided by the KPKSSBJT keyword in the FITS headers of raw and calibrated data files archived at MAST and PDS.

References

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