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DIFFERENTIAL PHOTOMETRY – EXOPLANET TRANSIT

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ABSTRACT

The search for exoplanets in our universe is a huge endeavor, with some hoping to find other Earth-like planets that can host its own life, either as search for extra-terrestrial life or a new home for us. Similar to eclipsing binaries, we can understand the transit of these exoplanets through photometry and the light curves as the measured magnitude of light dips when it is blocked by the exoplanet. From data using AstroImageJ, we can calculate the size of the exoplanet we are observing.

1. INTRODUCTION AND PURPOSE

By analyzing the exoplanet's transit and making some astronomical calculations, we can ascertain the size of the exoplanet. In order to be as accurate as possible, we aim to use multiple comparison stars as necessary. In this report, the WASP10 star with a radius of $R_* = 0.78 R_\odot$.

Please note that due to the size of the tables, all tables will be listed at the end of the paper for the reader to reference.

2. DATA DESCRIPTION AND REDUCTION

Simply put, exoplanets are planets that are not found within our solar system. The "exoplanet system" is then just the solar system that the observed exoplanet belongs within; so to other exoplanets, our Solar System with Earth, the Sun, Jupiter, and all the other aspects would be an exoplanet system in its reference frame. With the planets in our solar system being relatively close, we can learn how big these planets are in many different ways, and one way that we have utilized is by sending our different probes - either that fly-by or actually land on the planet. For exoplanets, we don't have the luxury of sending out crafts to make these measurements. Instead, we can imagine it similar to a binary system and observe the exoplanet pass in front of a star facing the Earth edge-on. For WASP10, there are at least 3 stars that we can use this method to measure the exoplanet's size. As the exoplanet travels around the star, when it is in our view, the magnitude observed from the star 'dips'. The light curves produced by these transits can relate to the diameter of the planet, and possibly more given other information such as the radial velocity.

The reduction steps performed for these images included a bias level, dark current, and flat-field. Ultimately the goal is that the pictures we take should be as accurate to what's in space as possible. The sensors on cameras and the telescopes can collect issues over time that can effect the resulting image.

The first reduction step involves correcting for the bias using a 'bias frame'. The bias frame utilizes the exposure with the least length as possible with the shutter closed. The image can be used to recognize the specific signal-to-noise ratio within each pixel. These ratios should be consistent for each image taken, so with the bias frame taken, we can compare these ratios with each image to subtract out as much noise as possible.

Another issue with sensors is due to the heat produced when taking long exposure images. This is known as the 'dark current'. To calibrate for this, an exposure image is taken with almost the same conditions and criteria as the observed images, though without any light striking the CCD image. With this frame, there is an expected similar consistency of the dark current heating some pixels more than others that can be subtracted out to a neutral image. The temperature of the pixels has an incredibly significant effect of the pixels, so the importance of the dark current corrections cannot be underestimated.

Finally, we focus on the different raw sensitivity to light in each pixel with the Flat-Field Calibration. Occasionally, dust can find a way onto these sensors forming 'dust donuts' - muddying the image along with the innate sensitivity errors from each pixel. Similarly, the flat-field frame is created through an exposure taken with a uniform light source, exposing the base of the sensors image.

3. ANALYSIS

With the processed images, the data collection utilzing AstroImageJ is collected with information from the FITS files. The first step is to determine the magnitude through Equation 1 for each star during the transit of the exoplanet, where the 'mean flux' in the equation represents a value found in the FITS files' data. This is done for the variable star as well as each of the 3 stars used for comparisons.

$$m = -2.5 * \log('meanflux') \tag{1}$$

Note that the third comparison star is an extinction star, where we assume that the airmass is close to 0 for our purposes.

As we compare the change in magnitude during the exoplanet's transit, we record the time, magnitude of both the variable and comparison star, and the differential magnitude in each Table, all listed at the end of the report. The differential magnitude is critically important because there is no light curve produced without these values, calculated using Equation 2.

$$\Delta m = m_{var} - m_{comp} \tag{2}$$

The light curves for each comparison star are then produced by the Heliocentric Julian Date (HJD) v. Differential Magnitude. Within these light curves, we will calculate a 'depth' value that in essence represents the difference in magnitude as the exoplanet moves in front of the star. This depth value is geometrically related to the exoplanet's size through Equation 3.

$$R_{exo} = R_* \sqrt{depth} \tag{3}$$

3.1. *Comparison Star 1*

The light curve for the first comparison star, shown in Figure 1, has a 'depth' value of approximately 0.0775. The values used to create the light curve are shown in Table 1. By applying Equation 3, we find that the exoplanet's radius using this comparison star is approximately $0.217 R_\odot$.

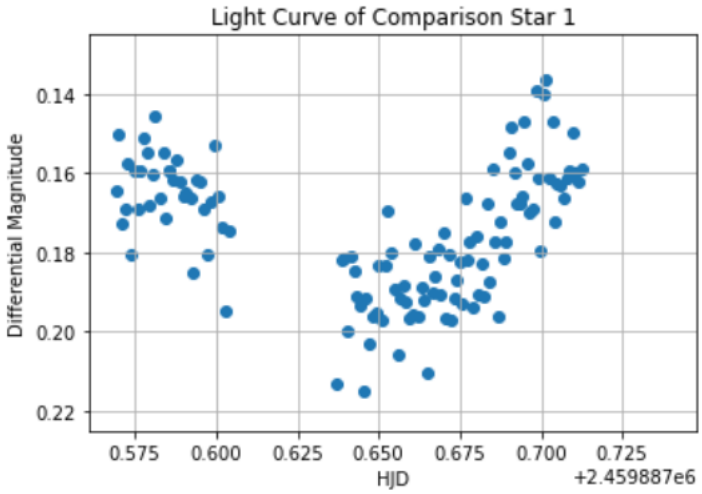

Figure 1. Comparison Star 1 Light Curve

3.2. *Comparison Star 2*

Using the light curve for the second comparison star, shown in Figure 2, the 'depth' value is approximately 0.075. Again, we find the approximate radius of the exoplanet using Equation 3 to be about $0.214R_{\odot}$.

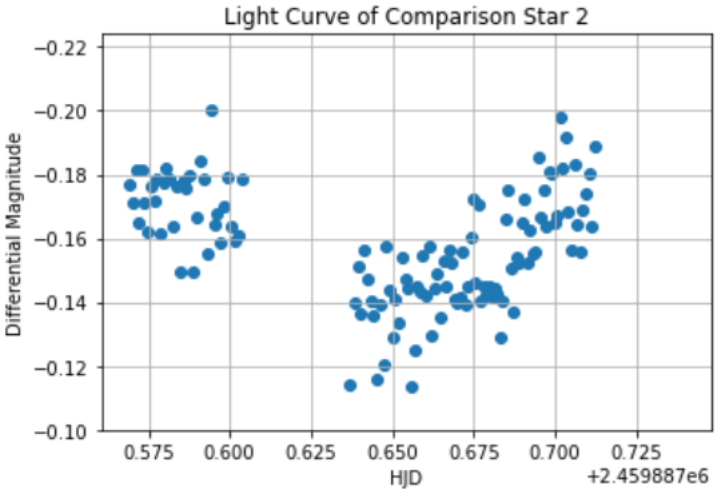

Figure 2. Comparison Star 2 Light Curve

3.3. *Comparison Star 3*

Here, I wanted to note that there may be some issue in my data that I cannot seem to find the source of. The calculations are applied uniformly, but it seems that the data separates and breaks the curve that it is almost completing. This result is shown best in Figure 3. Though it is possible that one source of error could be due to the assumption on airmass mentioned earlier, it isn't enough of a basis for why this occurs. Given that it follows the trend after the break, it is genuinely odd that this is the perceived effect. However, we can still move on to apply our analysis with the general curve that is being made, shown best in Figure 4.

We find the depth from Figure 4 to be about 0.077, and thus the exoplanet's radius to be about $0.216R_{\odot}$.

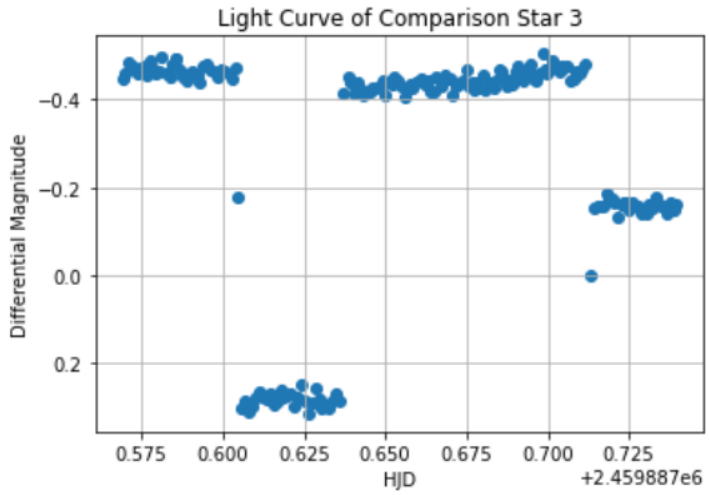

Figure 3. Zoomed Out Light Curve for Last Star

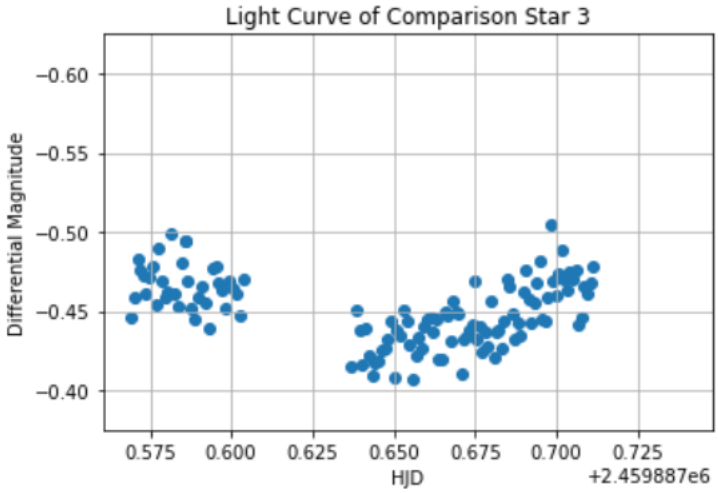

Figure 4. Light Curve for Comparison 3

4. CONCLUSIONS

Using these different comparison stars, we can find the average of the radius of the exoplanet to determine its most likely value.

$$\frac{R_{comp1} + R_{comp2} + R_{comp3}}{3} = \frac{(0.217 + 0,214 + 0.216)R_{\odot}}{3} = 0.216R_{\odot} \tag{4}$$

From these calculations, the exoplanet is found to have a radius of $0.216R_{\odot}$, and thus a diameter $D_{exo} = 2 * 0.216R_{\odot} = 0.431R_{\odot} = 300,078,600m$. The exoplanet is known to have a radius of $75,503,880m$. This is almost double the expected amount, with a 98.7% error.

[ht]

Table 1. Magnitudes – Comparison Star 1

JD	v_{var}	m_{comp}	Δm
2459887.569178241	−7.942	−8.107	0.165
2459887.57	−7.951	−8.101	0.150
2459887.571140047	−8.028	−8.200	0.173
2459887.572019676	−8.032	−8.202	0.169
2459887.572899306	−8.042	−8.200	0.158
2459887.573790509	−8.037	−8.217	0.180
2459887.574670139	−8.035	−8.194	0.159
2459887.57583912	−8.030	−8.199	0.169
2459887.57671875	−8.035	−8.194	0.159
2459887.577725695	−8.039	−8.190	0.151
2459887.578605324	−8.036	−8.191	0.155
2459887.579484954	−8.032	−8.200	0.168
2459887.580364584	−8.035	−8.195	0.160
2459887.581244213	−8.055	−8.201	0.146
2459887.582482639	−8.173	−8.339	0.166
2459887.583674768	−8.175	−8.330	0.155
2459887.584670139	−8.166	−8.337	0.171
2459887.585665509	−8.177	−8.337	0.159
2459887.585665509	−8.177	−8.337	0.159
2459887.58666088	−8.171	−8.333	0.162
2459887.587737268	−8.168	−8.325	0.157
2459887.588732639	−8.169	−8.331	0.162
2459887.589728009	−8.170	−8.336	0.166
2459887.59072338	−8.180	−8.345	0.165
2459887.591967592	−8.246	−8.412	0.166
2459887.593020833	−8.233	−8.418	0.185
2459887.594085648	−8.258	−8.420	0.161
2459887.595138889	−8.247	−8.410	0.162
2459887.596192129	−8.233	−8.402	0.169
2459887.597245371	−8.223	−8.403	0.181
2459887.598298611	−8.240	−8.408	0.167
2459887.599351852	−8.247	−8.400	0.153
2459887.600405092	−8.237	−8.403	0.166
2459887.601608796	−8.224	−8.398	0.173

Table 1 *continued on next page*

Table 1 *(continued)*

JD	v_{var}	m_{comp}	Δm
2459887.602662037	−8.222	−8.417	0.195
2459887.603715278	−8.241	−8.416	0.174
2459887.604768518	−8.241	−8.232	-0.009
2459887.605821759	−7.782	−8.238	0.456
2459887.607025463	−7.767	−8.230	0.463
2459887.608078704	−7.758	−8.224	0.465
2459887.609131944	−7.765	−8.241	0.477
2459887.610196759	−7.786	−8.225	0.439
2459887.611342593	−7.793	−8.215	0.422
2459887.612395833	−7.783	−8.201	0.419
2459887.613449074	−7.794	−8.212	0.418
2459887.614513889	−7.799	−8.217	0.418
2459887.61556713	−7.776	−8.224	0.448
2459887.616689815	−7.769	−8.219	0.450
2459887.617743055	−7.808	−8.227	0.418
2459887.618796296	−7.808	−8.211	0.403
2459887.619849537	−7.786	−8.208	0.422
2459887.620972222	−7.787	−8.199	0.412
2459887.622025463	−7.774	−8.213	0.439
2459887.623078704	−7.793	−8.213	0.420
2459887.624143519	−7.786	−8.199	0.413
2459887.625196759	−7.777	−8.208	0.432
2459887.62625	−7.771	−8.202	0.431
2459887.627303241	−7.780	−8.194	0.414
2459887.628425926	−7.787	−8.202	0.416
2459887.629479167	−7.780	−8.210	0.430
2459887.630532407	−7.771	−8.209	0.438
2459887.631585648	−7.765	−8.221	0.455
2459887.632638889	−7.764	−8.204	0.439
2459887.633784722	−7.782	−8.210	0.428
2459887.634837963	−7.790	−8.198	0.407
2459887.635891204	−7.784	−8.204	0.420
2459887.636944444	−8.196	−8.410	0.213
2459887.638408564	−8.154	−8.336	0.182
2459887.639403935	−8.155	−8.337	0.182
2459887.640399306	−8.141	−8.341	0.200
2459887.641527778	−8.081	−8.262	0.181
2459887.642465278	−8.083	−8.268	0.185

Table 1 *continued on next page*

Table 1 *(continued)*

JD	v_{var}	m_{comp}	Δm
2459887.643402778	−8.079	−8.270	0.191
2459887.644340278	−8.071	−8.264	0.194
2459887.645277778	−8.055	−8.270	0.215
2459887.646215278	−8.072	−8.264	0.192
2459887.647222222	−8.052	−8.255	0.203
2459887.648159722	−8.071	−8.267	0.196
2459887.649097222	−8.074	−8.269	0.195
2459887.650034722	−8.076	−8.259	0.183
2459887.651041667	−8.058	−8.255	0.197
2459887.651979167	−8.066	−8.249	0.183
2459887.652916667	−8.073	−8.242	0.170
2459887.654045139	−8.005	−8.185	0.180
2459887.654924769	−7.996	−8.185	0.189
2459887.655804398	−7.980	−8.186	0.206
2459887.656684028	−7.991	−8.183	0.192
2459887.657633102	−7.991	−8.180	0.188
2459887.658512732	−7.994	−8.186	0.192
2459887.659392362	−7.997	−8.193	0.197
2459887.660271991	−7.994	−8.189	0.196
2459887.661151621	−8.001	−8.178	0.178
2459887.662158565	−7.980	−8.176	0.196
2459887.663038195	−8.005	−8.194	0.189
2459887.663917824	−7.995	−8.187	0.192
2459887.664930556	−7.904	−8.114	0.210
2459887.665752315	−7.924	−8.105	0.181
2459887.666574074	−7.926	−8.116	0.190
2459887.667395833	−7.927	−8.114	0.186
2459887.668217593	−7.934	−8.113	0.179
2459887.669039352	−7.919	−8.110	0.191
2459887.669861111	−7.924	−8.100	0.175
2459887.67068287	−7.911	−8.108	0.197
2459887.67150463	−7.926	−8.106	0.181
2459887.672384259	−7.918	−8.115	0.197
2459887.673206019	−7.922	−8.114	0.192
2459887.674027778	−7.934	−8.121	0.187
2459887.674849537	−7.929	−8.111	0.182
2459887.675671297	−7.912	−8.104	0.193
2459887.676493056	−7.924	−8.090	0.166

Table 1 *continued on next page*

Table 1 *(continued)*

JD	v_{var}	m_{comp}	Δm
2459887.677314815	−7.909	−8.091	0.182
2459887.678136574	−7.915	−8.092	0.177
2459887.678958334	−7.903	−8.097	0.194
2459887.679918982	−7.923	−8.099	0.176
2459887.680740741	−7.910	−8.100	0.191
2459887.6815625	−7.916	−8.099	0.183
2459887.68238426	−7.918	−8.109	0.191
2459887.683206019	−7.921	−8.088	0.167
2459887.684027778	−7.920	−8.107	0.187
2459887.684930556	−7.926	−8.084	0.159
2459887.685752315	−7.928	−8.105	0.177
2459887.686574074	−7.909	−8.105	0.196
2459887.687395833	−7.914	−8.087	0.172
2459887.688217593	−7.916	−8.097	0.181
2459887.689039352	−7.917	−8.094	0.177
2459887.689965278	−7.922	−8.076	0.155
2459887.690787037	−7.940	−8.088	0.148
2459887.691608796	−7.932	−8.092	0.160
2459887.69244213	−7.934	−8.101	0.167
2459887.693263889	−7.931	−8.098	0.168
2459887.694085648	−7.929	−8.095	0.166
2459887.694907408	−7.944	−8.091	0.147
2459887.695729167	−7.922	−8.080	0.158
2459887.696550926	−7.917	−8.087	0.170
2459887.697372685	−7.927	−8.096	0.169
2459887.698310185	−7.943	−8.082	0.139
2459887.699131945	−7.928	−8.089	0.161
2459887.699953704	−7.921	−8.101	0.180
2459887.700775463	−7.941	−8.081	0.140
2459887.701597222	−7.950	−8.086	0.136
2459887.702418982	−7.928	−8.090	0.161
2459887.703333334	−7.926	−8.073	0.147
2459887.704155093	−7.916	−8.089	0.172
2459887.704976852	−7.927	−8.090	0.163
2459887.706047454	−8.008	−8.171	0.163
2459887.706938657	−7.994	−8.160	0.166
2459887.707818287	−7.983	−8.144	0.161
2459887.708697917	−7.996	−8.155	0.159

Table 1 *continued on next page*

Table 1 *(continued)*

JD	v_{var}	m_{comp}	Δm
2459887.709577546	−8.002	−8.152	0.150
2459887.710561343	−7.997	−8.157	0.160
2459887.711440973	−8.001	−8.163	0.162
2459887.712320602	−7.998	−8.157	0.159
2459887.713200232	−8.159	−7.820	-0.339
2459887.714079862	−8.146	−7.819	-0.327
2459887.715283565	−8.153	−7.811	-0.342
2459887.716163195	−8.161	−7.817	-0.344
2459887.717042824	−8.165	−7.816	-0.349
2459887.717922454	−8.155	−7.822	-0.332
2459887.718802084	−8.154	−7.830	-0.324
2459887.719681713	−8.137	−7.811	-0.326
2459887.720572917	−8.128	−7.815	-0.312
2459887.721545139	−8.153	−7.812	-0.341
2459887.722424769	−8.148	−7.815	-0.334
2459887.723304398	−8.151	−7.809	-0.343
2459887.724184028	−8.137	−7.818	-0.319
2459887.725063657	−8.141	−7.799	-0.342
2459887.725943287	−8.127	−7.802	-0.325
2459887.726903935	−8.139	−7.811	-0.329
2459887.727783565	−8.123	−7.796	-0.327
2459887.728663194	−8.136	−7.818	-0.318
2459887.729542824	−8.132	−7.789	-0.343
2459887.730422454	−8.120	−7.796	-0.324
2459887.731302083	−8.135	−7.792	-0.343
2459887.732181713	−8.131	−7.790	-0.341
2459887.733142362	−8.132	−7.780	-0.352
2459887.734021991	−8.120	−7.804	-0.315
2459887.734901621	−8.132	−7.805	-0.327
2459887.73578125	−8.110	−7.793	-0.317
2459887.73666088	−8.132	−7.800	-0.332
2459887.73754051	−8.119	−7.794	-0.325
2459887.738628472	−8.109	−7.790	-0.319
2459887.739508102	−8.117	−7.790	-0.327

[ht]

Table 2. Magnitudes – Comparison Star 2

JD	v_{var}	m_{comp}	Δm
2459887.569178241	−7.942	−7.766	−0.177
2459887.57	−7.951	−7.780	−0.171
2459887.571140047	−8.028	−7.846	−0.182
2459887.572019676	−8.032	−7.867	−0.165
2459887.572899306	−8.042	−7.861	−0.181
2459887.573790509	−8.037	−7.865	−0.171
2459887.574670139	−8.035	−7.873	−0.162
2459887.57583912	−8.030	−7.854	−0.176
2459887.57671875	−8.035	−7.863	−0.172
2459887.577725695	−8.039	−7.860	−0.178
2459887.578605324	−8.036	−7.874	−0.162
2459887.579484954	−8.032	−7.854	−0.178
2459887.580364584	−8.035	−7.852	−0.182
2459887.581244213	−8.055	−7.876	−0.179
2459887.582482639	−8.173	−8.009	−0.164
2459887.583674768	−8.175	−7.998	−0.177
2459887.584670139	−8.166	−8.016	−0.150
2459887.585665509	−8.177	−7.999	−0.178
2459887.585665509	−8.177	−7.999	−0.178
2459887.58666088	−8.171	−7.996	−0.175
2459887.587737268	−8.168	−7.988	−0.180
2459887.588732639	−8.169	−8.020	−0.149
2459887.589728009	−8.170	−8.004	−0.166
2459887.59072338	−8.180	−7.996	−0.184
2459887.591967592	−8.246	−8.067	−0.178
2459887.593020833	−8.233	−8.078	−0.155
2459887.594085648	−8.258	−8.058	−0.200
2459887.595138889	−8.247	−8.083	−0.164
2459887.596192129	−8.233	−8.065	−0.168
2459887.597245371	−8.223	−8.064	−0.159
2459887.598298611	−8.240	−8.070	−0.170
2459887.599351852	−8.247	−8.068	−0.179
2459887.600405092	−8.237	−8.073	−0.164
2459887.601608796	−8.224	−8.065	−0.159
2459887.602662037	−8.222	−8.061	−0.161
2459887.603715278	−8.241	−8.063	−0.178
2459887.604768518	−8.241	−8.408	0.166
2459887.605821759	−7.782	−8.400	0.618

Table 2 *continued on next page*

Table 2 *(continued)*

JD	v_{var}	m_{comp}	Δm
2459887.607025463	−7.767	−8.393	0.627
2459887.608078704	−7.758	−8.407	0.649
2459887.609131944	−7.765	−8.415	0.650
2459887.610196759	−7.786	−8.406	0.620
2459887.611342593	−7.793	−8.399	0.606
2459887.612395833	−7.783	−8.406	0.623
2459887.613449074	−7.794	−8.402	0.608
2459887.614513889	−7.799	−8.387	0.588
2459887.61556713	−7.776	−8.403	0.627
2459887.616689815	−7.769	−8.400	0.631
2459887.617743055	−7.808	−8.403	0.594
2459887.618796296	−7.808	−8.399	0.592
2459887.619849537	−7.786	−8.387	0.601
2459887.620972222	−7.787	−8.405	0.618
2459887.622025463	−7.774	−8.405	0.631
2459887.623078704	−7.793	−8.400	0.607
2459887.624143519	−7.786	−8.404	0.618
2459887.625196759	−7.777	−8.399	0.622
2459887.62625	−7.771	−8.391	0.620
2459887.627303241	−7.780	−8.403	0.623
2459887.628425926	−7.787	−8.386	0.599
2459887.629479167	−7.780	−8.395	0.616
2459887.630532407	−7.771	−8.411	0.640
2459887.631585648	−7.765	−8.395	0.630
2459887.632638889	−7.764	−8.404	0.640
2459887.633784722	−7.782	−8.396	0.614
2459887.634837963	−7.790	−8.398	0.608
2459887.635891204	−7.784	−8.405	0.621
2459887.636944444	−8.196	−8.082	−0.114
2459887.638408564	−8.154	−8.014	−0.140
2459887.639403935	−8.155	−8.004	−0.151
2459887.640399306	−8.141	−8.005	−0.136
2459887.641527778	−8.081	−7.925	−0.156
2459887.642465278	−8.083	−7.936	−0.147
2459887.643402778	−8.079	−7.939	−0.140
2459887.644340278	−8.071	−7.935	−0.136
2459887.645277778	−8.055	−7.939	−0.116
2459887.646215278	−8.072	−7.933	−0.139

Table 2 *continued on next page*

Table 2 *(continued)*

JD	v_{var}	m_{comp}	Δm
2459887.647222222	−8.052	−7.931	−0.121
2459887.648159722	−8.071	−7.914	−0.157
2459887.649097222	−8.074	−7.930	−0.144
2459887.650034722	−8.076	−7.947	−0.129
2459887.651041667	−8.058	−7.917	−0.141
2459887.651979167	−8.066	−7.932	−0.133
2459887.652916667	−8.073	−7.919	−0.154
2459887.654045139	−8.005	−7.858	−0.147
2459887.654924769	−7.996	−7.852	−0.144
2459887.655804398	−7.980	−7.866	−0.114
2459887.656684028	−7.991	−7.866	−0.125
2459887.657633102	−7.991	−7.847	−0.145
2459887.658512732	−7.994	−7.850	−0.143
2459887.659392362	−7.997	−7.842	−0.155
2459887.660271991	−7.994	−7.852	−0.142
2459887.661151621	−8.001	−7.843	−0.157
2459887.662158565	−7.980	−7.851	−0.129
2459887.663038195	−8.005	−7.861	−0.144
2459887.663917824	−7.995	−7.846	−0.149
2459887.664930556	−7.904	−7.769	−0.135
2459887.665752315	−7.924	−7.771	−0.153
2459887.666574074	−7.926	−7.781	−0.145
2459887.667395833	−7.927	−7.771	−0.156
2459887.668217593	−7.934	−7.782	−0.152
2459887.669039352	−7.919	−7.778	−0.141
2459887.669861111	−7.924	−7.785	−0.140
2459887.67068287	−7.911	−7.770	−0.141
2459887.67150463	−7.926	−7.770	−0.156
2459887.672384259	−7.918	−7.779	−0.139
2459887.673206019	−7.922	−7.777	−0.145
2459887.674027778	−7.934	−7.774	−0.160
2459887.674849537	−7.929	−7.756	−0.172
2459887.675671297	−7.912	−7.765	−0.146
2459887.676493056	−7.924	−7.753	−0.171
2459887.677314815	−7.909	−7.769	−0.141
2459887.678136574	−7.915	−7.770	−0.145
2459887.678958334	−7.903	−7.761	−0.142
2459887.679918982	−7.923	−7.778	−0.145

Table 2 *continued on next page*

Table 2 *(continued)*

JD	v_{var}	m_{comp}	Δm
2459887.680740741	−7.910	−7.768	−0.142
2459887.6815625	−7.916	−7.772	−0.144
2459887.68238426	−7.918	−7.776	−0.143
2459887.683206019	−7.921	−7.791	−0.129
2459887.684027778	−7.920	−7.780	−0.140
2459887.684930556	−7.926	−7.760	−0.166
2459887.685752315	−7.928	−7.752	−0.175
2459887.686574074	−7.909	−7.758	−0.150
2459887.687395833	−7.914	−7.777	−0.137
2459887.688217593	−7.916	−7.762	−0.154
2459887.689039352	−7.917	−7.765	−0.152
2459887.689965278	−7.922	−7.757	−0.165
2459887.690787037	−7.940	−7.767	−0.172
2459887.691608796	−7.932	−7.780	−0.152
2459887.69244213	−7.934	−7.772	−0.163
2459887.693263889	−7.931	−7.775	−0.155
2459887.694085648	−7.929	−7.773	−0.156
2459887.694907408	−7.944	−7.758	−0.185
2459887.695729167	−7.922	−7.756	−0.166
2459887.696550926	−7.917	−7.742	−0.175
2459887.697372685	−7.927	−7.764	−0.164
2459887.698310185	−7.943	−7.762	−0.181
2459887.699131945	−7.928	−7.748	−0.180
2459887.699953704	−7.921	−7.756	−0.165
2459887.700775463	−7.941	−7.774	−0.167
2459887.701597222	−7.950	−7.752	−0.198
2459887.702418982	−7.928	−7.746	−0.182
2459887.703333334	−7.926	−7.734	−0.192
2459887.704155093	−7.916	−7.748	−0.168
2459887.704976852	−7.927	−7.771	−0.156
2459887.706047454	−8.008	−7.825	−0.183
2459887.706938657	−7.994	−7.829	−0.164
2459887.707818287	−7.983	−7.827	−0.156
2459887.708697917	−7.996	−7.827	−0.169
2459887.709577546	−8.002	−7.828	−0.174
2459887.710561343	−7.997	−7.817	−0.180
2459887.711440973	−8.001	−7.837	−0.164
2459887.712320602	−7.998	−7.810	−0.189

Table 2 *continued on next page*

Table 2 *(continued)*

JD	v_{var}	m_{comp}	Δm
2459887.713200232	−8.159	−7.530	−0.629
2459887.714079862	−8.146	−7.508	−0.638
2459887.715283565	−8.153	−7.515	−0.638
2459887.716163195	−8.161	−7.521	−0.640
2459887.717042824	−8.165	−7.533	−0.631
2459887.717922454	−8.155	−7.528	−0.627
2459887.718802084	−8.154	−7.519	−0.636
2459887.719681713	−8.137	−7.554	−0.583
2459887.720572917	−8.128	−7.522	−0.605
2459887.721545139	−8.153	−7.519	−0.633
2459887.722424769	−8.148	−7.526	−0.622
2459887.723304398	−8.151	−7.512	−0.639
2459887.724184028	−8.137	−7.528	−0.609
2459887.725063657	−8.141	−7.492	−0.650
2459887.725943287	−8.127	−7.512	−0.615
2459887.726903935	−8.139	−7.515	−0.625
2459887.727783565	−8.123	−7.521	−0.602
2459887.728663194	−8.136	−7.517	−0.619
2459887.729542824	−8.132	−7.509	−0.623
2459887.730422454	−8.120	−7.528	−0.592
2459887.731302083	−8.135	−7.501	−0.634
2459887.732181713	−8.131	−7.512	−0.619
2459887.733142362	−8.132	−7.507	−0.624
2459887.734021991	−8.120	−7.505	−0.615
2459887.734901621	−8.132	−7.508	−0.624
2459887.73578125	−8.110	−7.501	−0.609
2459887.73666088	−8.132	−7.519	−0.613
2459887.73754051	−8.119	−7.522	−0.597
2459887.738628472	−8.109	−7.513	−0.597
2459887.739508102	−8.117	−7.512	−0.604

[h]

Table 3. Magnitudes – Comparison Star 3

JD	v_{var}	m_{comp}	Δm
2459887.569178241	−7.942	−7.496	−0.446

Table 3 *continued on next page*

Table 3 *(continued)*

JD	v_{var}	m_{comp}	Δm
2459887.57	−7.951	−7.492	−0.459
2459887.571140047	−8.028	−7.545	−0.483
2459887.572019676	−8.032	−7.557	−0.476
2459887.572899306	−8.042	−7.570	−0.472
2459887.573790509	−8.037	−7.576	−0.461
2459887.574670139	−8.035	−7.564	−0.471
2459887.57583912	−8.030	−7.552	−0.478
2459887.57671875	−8.035	−7.581	−0.454
2459887.577725695	−8.039	−7.549	−0.490
2459887.578605324	−8.036	−7.567	−0.469
2459887.579484954	−8.032	−7.573	−0.459
2459887.580364584	−8.035	−7.572	−0.462
2459887.581244213	−8.055	−7.556	−0.499
2459887.582482639	−8.173	−7.712	−0.461
2459887.583674768	−8.175	−7.722	−0.453
2459887.584670139	−8.166	−7.686	−0.480
2459887.585665509	−8.177	−7.683	−0.495
2459887.585665509	−8.177	−7.683	−0.495
2459887.58666088	−8.171	−7.703	−0.468
2459887.587737268	−8.168	−7.716	−0.451
2459887.588732639	−8.169	−7.725	−0.445
2459887.589728009	−8.170	−7.712	−0.458
2459887.59072338	−8.180	−7.715	−0.466
2459887.591967592	−8.246	−7.791	−0.455
2459887.593020833	−8.233	−7.794	−0.439
2459887.594085648	−8.258	−7.782	−0.477
2459887.595138889	−8.247	−7.769	−0.478
2459887.596192129	−8.233	−7.766	−0.468
2459887.597245371	−8.223	−7.759	−0.463
2459887.598298611	−8.240	−7.788	−0.452
2459887.599351852	−8.247	−7.778	−0.469
2459887.600405092	−8.237	−7.773	−0.464
2459887.601608796	−8.224	−7.763	−0.461
2459887.602662037	−8.222	−7.775	−0.447
2459887.603715278	−8.241	−7.771	−0.470
2459887.604768518	−8.241	−8.065	−0.176
2459887.605821759	−7.782	−8.082	0.301
2459887.607025463	−7.767	−8.055	0.288

Table 3 *continued on next page*

Table 3 *(continued)*

JD	v_{var}	m_{comp}	Δm
2459887.608078704	−7.758	−8.068	0.310
2459887.609131944	−7.765	−8.062	0.297
2459887.610196759	−7.786	−8.065	0.279
2459887.611342593	−7.793	−8.059	0.266
2459887.612395833	−7.783	−8.061	0.278
2459887.613449074	−7.794	−8.075	0.281
2459887.614513889	−7.799	−8.068	0.268
2459887.61556713	−7.776	−8.069	0.293
2459887.616689815	−7.769	−8.054	0.285
2459887.617743055	−7.808	−8.070	0.262
2459887.618796296	−7.808	−8.086	0.278
2459887.619849537	−7.786	−8.061	0.275
2459887.620972222	−7.787	−8.055	0.269
2459887.622025463	−7.774	−8.074	0.300
2459887.623078704	−7.793	−8.071	0.278
2459887.624143519	−7.786	−8.035	0.249
2459887.625196759	−7.777	−8.063	0.286
2459887.62625	−7.771	−8.086	0.315
2459887.627303241	−7.780	−8.070	0.290
2459887.628425926	−7.787	−8.045	0.259
2459887.629479167	−7.780	−8.060	0.281
2459887.630532407	−7.771	−8.072	0.301
2459887.631585648	−7.765	−8.060	0.294
2459887.632638889	−7.764	−8.068	0.304
2459887.633784722	−7.782	−8.069	0.287
2459887.634837963	−7.790	−8.060	0.269
2459887.635891204	−7.784	−8.070	0.286
2459887.636944444	−8.196	−7.781	−0.415
2459887.638408564	−8.154	−7.703	−0.450
2459887.639403935	−8.155	−7.717	−0.438
2459887.640399306	−8.141	−7.725	−0.416
2459887.641527778	−8.081	−7.643	−0.439
2459887.642465278	−8.083	−7.661	−0.422
2459887.643402778	−8.079	−7.670	−0.409
2459887.644340278	−8.071	−7.654	−0.417
2459887.645277778	−8.055	−7.637	−0.418
2459887.646215278	−8.072	−7.647	−0.425
2459887.647222222	−8.052	−7.625	−0.427

Table 3 *continued on next page*

Table 3 *(continued)*

JD	v_{var}	m_{comp}	Δm
2459887.648159722	−8.071	−7.640	−0.432
2459887.649097222	−8.074	−7.629	−0.444
2459887.650034722	−8.076	−7.667	−0.408
2459887.651041667	−8.058	−7.620	−0.438
2459887.651979167	−8.066	−7.631	−0.434
2459887.652916667	−8.073	−7.622	−0.450
2459887.654045139	−8.005	−7.561	−0.444
2459887.654924769	−7.996	−7.567	−0.429
2459887.655804398	−7.980	−7.573	−0.407
2459887.656684028	−7.991	−7.570	−0.422
2459887.657633102	−7.991	−7.558	−0.433
2459887.658512732	−7.994	−7.567	−0.426
2459887.659392362	−7.997	−7.557	−0.440
2459887.660271991	−7.994	−7.549	−0.445
2459887.661151621	−8.001	−7.554	−0.446
2459887.662158565	−7.980	−7.544	−0.436
2459887.663038195	−8.005	−7.561	−0.445
2459887.663917824	−7.995	−7.576	−0.420
2459887.664930556	−7.904	−7.484	−0.420
2459887.665752315	−7.924	−7.474	−0.450
2459887.666574074	−7.926	−7.479	−0.447
2459887.667395833	−7.927	−7.496	−0.431
2459887.668217593	−7.934	−7.477	−0.457
2459887.669039352	−7.919	−7.470	−0.449
2459887.669861111	−7.924	−7.477	−0.448
2459887.67068287	−7.911	−7.501	−0.410
2459887.67150463	−7.926	−7.494	−0.432
2459887.672384259	−7.918	−7.484	−0.434
2459887.673206019	−7.922	−7.485	−0.437
2459887.674027778	−7.934	−7.493	−0.441
2459887.674849537	−7.929	−7.460	−0.469
2459887.675671297	−7.912	−7.479	−0.432
2459887.676493056	−7.924	−7.483	−0.440
2459887.677314815	−7.909	−7.485	−0.424
2459887.678136574	−7.915	−7.477	−0.437
2459887.678958334	−7.903	−7.475	−0.428
2459887.679918982	−7.923	−7.466	−0.456
2459887.680740741	−7.910	−7.489	−0.421

Table 3 *continued on next page*

Table 3 *(continued)*

JD	v_{var}	m_{comp}	Δm
2459887.6815625	−7.916	−7.480	−0.437
2459887.68238426	−7.918	−7.481	−0.438
2459887.683206019	−7.921	−7.494	−0.427
2459887.684027778	−7.920	−7.476	−0.444
2459887.684930556	−7.926	−7.456	−0.470
2459887.685752315	−7.928	−7.462	−0.465
2459887.686574074	−7.909	−7.461	−0.448
2459887.687395833	−7.914	−7.482	−0.433
2459887.688217593	−7.916	−7.474	−0.442
2459887.689039352	−7.917	−7.483	−0.434
2459887.689965278	−7.922	−7.459	−0.463
2459887.690787037	−7.940	−7.464	−0.476
2459887.691608796	−7.932	−7.474	−0.457
2459887.69244213	−7.934	−7.491	−0.443
2459887.693263889	−7.931	−7.476	−0.455
2459887.694085648	−7.929	−7.461	−0.468
2459887.694907408	−7.944	−7.462	−0.481
2459887.695729167	−7.922	−7.477	−0.445
2459887.696550926	−7.917	−7.473	−0.444
2459887.697372685	−7.927	−7.469	−0.459
2459887.698310185	−7.943	−7.439	−0.504
2459887.699131945	−7.928	−7.459	−0.469
2459887.699953704	−7.921	−7.461	−0.460
2459887.700775463	−7.941	−7.467	−0.474
2459887.701597222	−7.950	−7.462	−0.488
2459887.702418982	−7.928	−7.458	−0.470
2459887.703333334	−7.926	−7.462	−0.464
2459887.704155093	−7.916	−7.442	−0.474
2459887.704976852	−7.927	−7.456	−0.471
2459887.706047454	−8.008	−7.532	−0.476
2459887.706938657	−7.994	−7.552	−0.441
2459887.707818287	−7.983	−7.536	−0.446
2459887.708697917	−7.996	−7.531	−0.466
2459887.709577546	−8.002	−7.541	−0.461
2459887.710561343	−7.997	−7.529	−0.468
2459887.711440973	−8.001	−7.522	−0.479
2459887.713200232	−7.998	−8.000	0.001
2459887.714079862	−8.159	−8.005	−0.154

Table 3 *continued on next page*

Table 3 *(continued)*

JD	v_{var}	m_{comp}	Δm
2459887.715283565	−8.146	−7.988	−0.158
2459887.716163195	−8.153	−7.997	−0.156
2459887.717042824	−8.161	−8.002	−0.159
2459887.717922454	−8.165	−7.980	−0.184
2459887.718802084	−8.155	−7.980	−0.174
2459887.719681713	−8.154	−7.981	−0.173
2459887.720572917	−8.137	−7.972	−0.165
2459887.721545139	−8.128	−7.994	−0.133
2459887.722424769	−8.153	−7.992	−0.160
2459887.723304398	−8.148	−7.983	−0.165
2459887.724184028	−8.151	−7.987	−0.164
2459887.725063657	−8.137	−7.989	−0.148
2459887.725943287	−8.141	−7.976	−0.165
2459887.726903935	−8.127	−7.969	−0.158
2459887.727783565	−8.139	−7.984	−0.156
2459887.728663194	−8.123	−7.984	−0.139
2459887.729542824	−8.136	−7.985	−0.151
2459887.730422454	−8.132	−7.990	−0.142
2459887.731302083	−8.120	−7.960	−0.159
2459887.732181713	−8.135	−7.981	−0.154
2459887.733142362	−8.131	−7.951	−0.179
2459887.734021991	−8.132	−7.967	−0.164
2459887.734901621	−8.120	−7.963	−0.157
2459887.73578125	−8.132	−7.972	−0.159
2459887.73666088	−8.110	−7.968	−0.142
2459887.73754051	−8.132	−7.966	−0.166
2459887.738628472	−8.119	−7.968	−0.151
2459887.739508102	−8.109	−7.950	−0.160

6. CITATIONS

SBIG Aluma CCD User's Manual Version 1.04 – March 29, 2020, Diffraction Limited