Solar System Science with the Madawaska Highlands Observatory Wide-Field Telescope

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Abstract

The proposed Wide-Field Telescope, a high efficiency wide-field imaging platform, is shown to be an extremely good instrument at detecting small solar system bodies such as asteroids, comets, Main-Belt asteroids, Near-Earth-Objects etc. The geographic position at 45 degrees north latitude is also excellent for detecting objects located over Earth's North Pole.

Introduction

The MHO is designed to provide a highly corrected monolithic 5 degrees^2 field-of-view with superb camera performance. Small Main-Belt solar system bodies, typically moving at 1 arcsec/minute, are difficult to detect even with larger instruments because of this rapid motion against the background stars. The key components in enabling the detection of fast moving bodies are:

1. A large ΩA
2. Widest possible FOV
3. Efficient camera system, i.e. fast download times
4. Low cycles times
5. Largest possible spectral bandwidth
6. Good balance between pixel size and seeing

The integration time is limited by the motion of the object across a pixel. The MHO has a pixel pitch of 1.52"/pixel (2x2 binning with 0.76"/pixel) and expected seeing of 1.25" this would imply maximum exposure time of 90s for an object moving at 1"/min. This case is only true if the seeing is equal or smaller than the pixel. If the seeing disc is larger than the pixel than the seeing disc would determine the maximum exposure time, for example the CHFT has mean seeing of 0.85"/pixel and a pixel pitch of 0.187"pixel yielding a maximum exposure of 40s.

Detecting rapidly moving Bodies

The MHO is an efficient tool at detecting the faint (small) rapidly moving solar system bodies. Its key performance characteristics are as follows (all tables and data provided are derived from these numbers):

1. Omega-Area → 6.0
2. Camera download time → 2s
3. FOV → 5 degrees^2

4. Spatial sampling → 0.76/1.52 arcsec/pixel, single/2x2 binning
5. Spectral bandwidth → 400nm
6. QE → 92%
7. Read noise → 12e-
8. Seeing → 1.25 arcsec (expected)
9. Sky Brightness → 21.80 mag/arcsec^2 (v) measured
10. Telescope move → 2s to move to the next field
11. Total cycle time → Exposure + 4 seconds, typically 94s
12. Guiding and acquisition → Not required because of the short exposures
13. Angle relative to zenith → 0 degrees
14. Altitude → 400m

The longest exposure time would be limited by the motion of the object across the pixel grid. The MHO has a raw spatial sampling of 0.76 arcsec/pixel and an expected seeing of 1.25 arcsec; a 2x2 binning (1.52″/pixel) taking about 90s to cross a pixel at 1″/min.

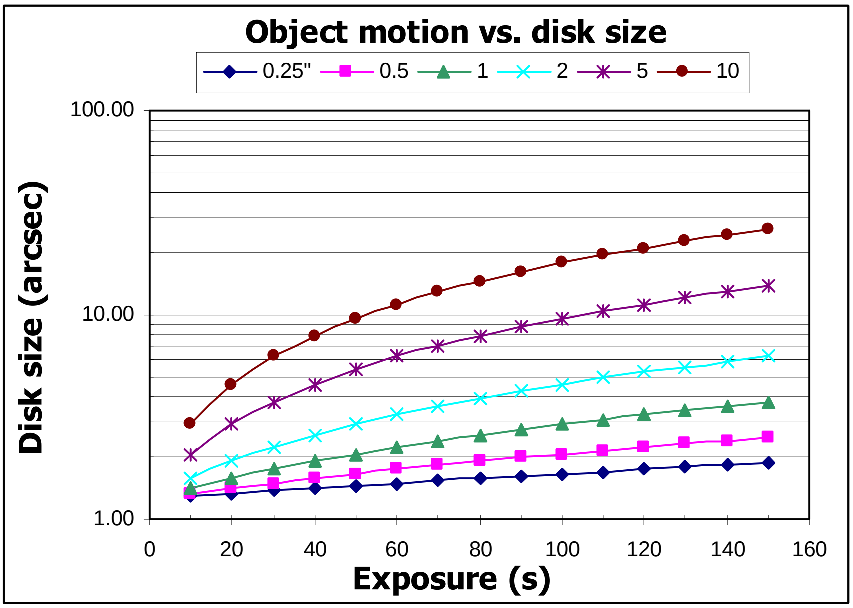


Figure 1 – MHO curves of object motion (arcsec) vs. disc size (arcsec) this is in effect the trailing caused by the motion of the object across the pixel grid, and severally limits the maximum integration time thus the smallest detectable object. The curves represent motions from 0.25″/min to 10″/min. The curves are calculated by taking the seeing disc (1.25″) and adding the motion of the object. For example for an object moving at 1″/min with an 90 second exposure the total apparent trail would be an 1.25″ disc stretched by 1.5″ yielding 2.75 arcsec

Three key factors determine the optimum exposure time: the seeing disk, the pixel size and the motion of the object. Typically for best s/n you would want the entire seeing disk (1.25″ expected for the MHO) to be smaller than the pixel pitch. Thus some spatial information is sacrificed in order to maximize the signalto-noise ratio. Another very important reason for keeping the pixel pitch bigger than the seeing is to 'track' the object as long as possible. In this case a large pixel size compared to the object disc has a higher probability of keeping the flux on the same pixel for a longer time before it drifts over to the next pixel. Fig. 2 shows the time it would take an object to cross a pixel. The measurement is calculated from the 50% entry (50% of the object is in the pixel) to the 50% exit point. The larger the pixels relative to the object image the longer the possible integration time.

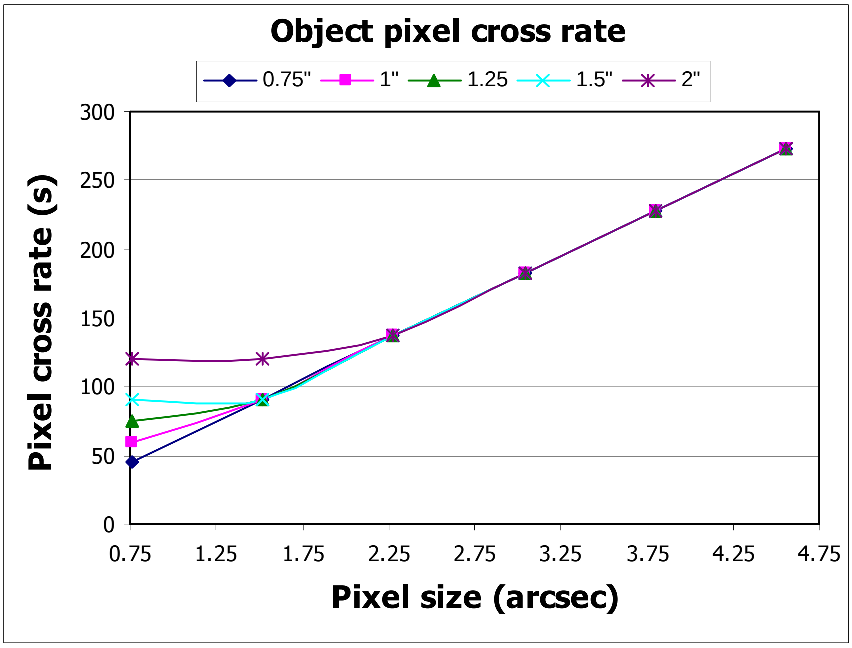


Figure 2 – MHO object cross rate for a motion of 1"/min for different seeing discs. Curves for seeing discs from 0.75" to 2" are shown.

For a given pixel size, and as the seeing disc gets larger, it covers more and more adjacent pixels and thus will in effect stay on any given pixel that much longer. As a consequence the larger disc seeing has a degraded s/n and thus reduced limiting magnitude. The MHO is expecting a seeing disc in the vicinity of 1.25", with 2x2 binning (1.52"/pixel) the cross rate is 90 seconds, which means in 90 seconds most of the flux will on any given pixel. Fig. 3 clearly shows that larger pixels (relative to the seeing disc) will be able to integrate longer and achieve a deeper limiting magnitude, at the cost of spatial sampling (i.e. confusion limited).

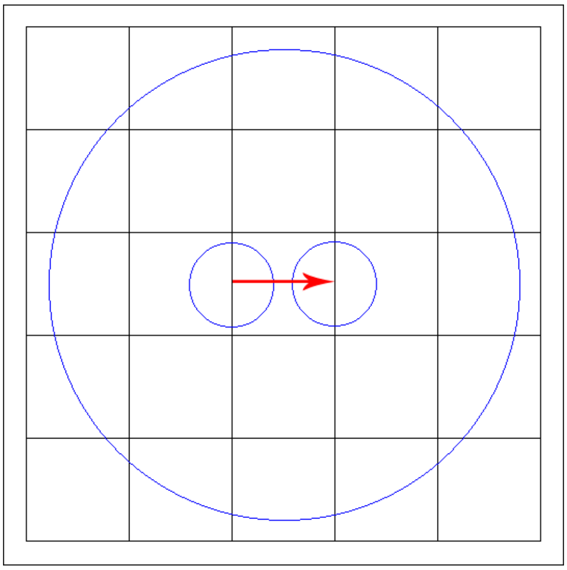


Figure 3 – An object takes about 90s to cross the 1.52″ pixel; this is in effect the longest possible integration time and thus limits how small an object could be detected. In this particular case the seeing disc is 64% by area (80% by linear diameter) the size of the pixel (1.25″ seeing and 1.52″/pixel). The large blue circle indicates the CFHT seeing (0.85″) to its pixel area (0.187″/pixel) for comparison. As the seeing disc becomes larger than the pixel, the cross rate actually takes longer because the entire seeing disc must cross the pixel. For example in the case of the CFHT with its 0.85″ seeing disc it takes about 40s to cross a pixel at 1″/min motion.

Positional Information

Most of the time the seeing disc will be on 4 pixels (1.52″/pixel) thus yielding a positional accuracy of 0.1 pixel or about 0.15 arcsec, Fig. 6 demonstrates the concept.

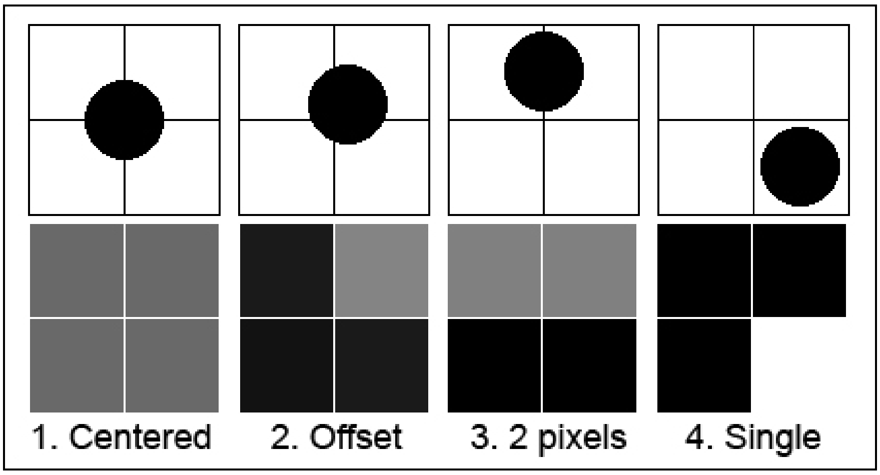


Figure 4 – The majority of the time the object would most likely be in the 'offset' situation where the flux is distributed in 4 pixels for a dim object. Bright objects (mag~17) will always occupy more than 4 pixels. A single pixel situation (#4) is expected only a very small percentage of the time. In a worst case situation the

positional accuracy can be determined to better than 0.5″ and in most cases to 0.15″ (1/10th of a pixel).

Limiting Magnitude

The limiting magnitude is determined by the length of time the flux remains on a single pixel, as shown in figure 5.

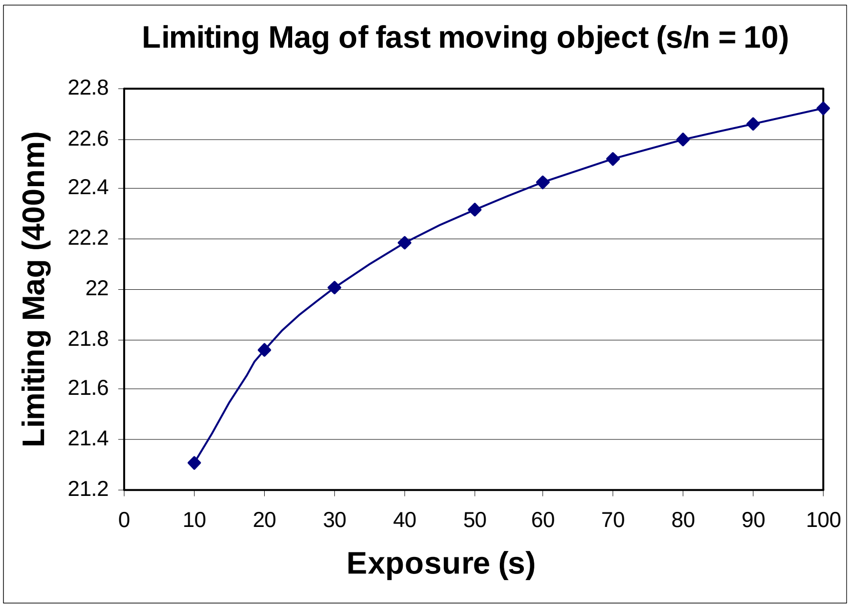


Figure 5 - The limiting magnitude with a mean seeing of 1.25″ and a pixel pitch of 1.52″/pixel (2x2 binning).

Sky Coverage

The Sky coverage depends on the total cycle time; exposure + (download + telescope move) in seconds and of course the FOV. The MHO sweet spot in terms of limiting magnitude and field coverage is with a 90s exposure, whereas the MHO could cover some 650 degrees^2 in 10 hours with 3 passes.

Exposure	Area	Size	Size	Limiting mag	Coverage	2-P Coverage	3-P Coverage	4-P Coverage	Notes
	arcsec²	x	y	magnitude	per hour	per 10 hrs	per 10 hrs	per 10 hrs	
Seconds		arcsec	arcsec	s/n =10	degrees²	degrees²	degrees²	degrees²	
10	1.77	1.42	1.25	21.31	1,268	6339	4226	3169	10% overlap
20	1.98	1.58	1.25	21.76	740	3698	2465	1849	
30	2.19	1.75	1.25	22.01	522	2610	1740	1305	
40	2.40	1.92	1.25	22.19	403	2017	1345	1008	
50	2.60	2.08	1.25	22.32	329	1643	1096	822	
60	2.81	2.25	1.25	22.43	277	1387	924	693	
70	3.02	2.42	1.25	22.52	240	1199	799	600	
80	3.23	2.58	1.25	22.6	211	1056	704	528	
90	3.44	2.75	1.25	22.66	189	944	629	472	
100	3.65	2.92	1.25	22.72	171	853	569	427	

Table 1 – Parameters used in graphs with 1 arcsec/minute motion. The cycle time includes 4s to move the telescope to the next position, 5 degrees away and settle. During the telescope move the camera is downloaded which takes about 2s. These short exposures do not require guiding thus improving the cycle time.

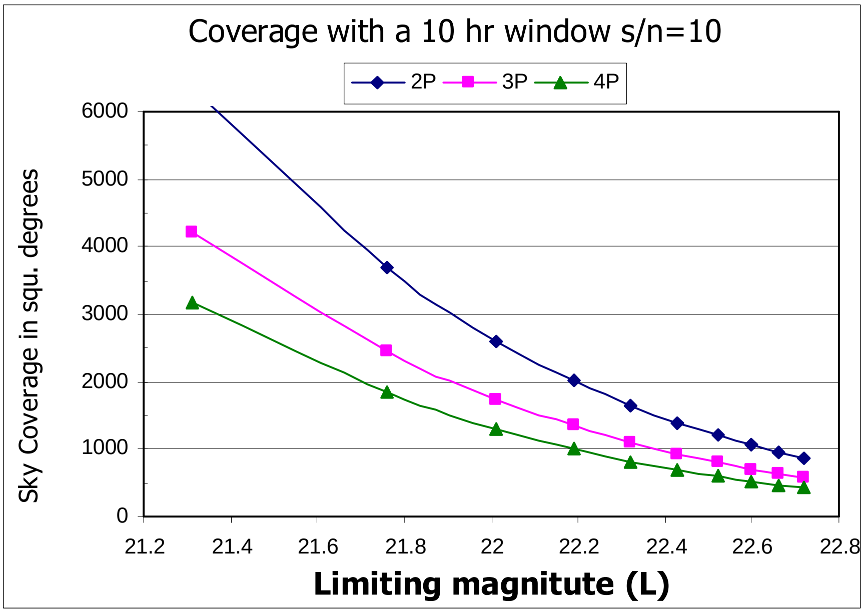
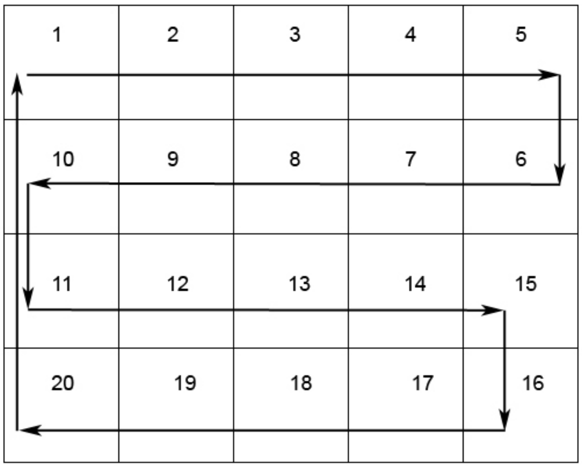


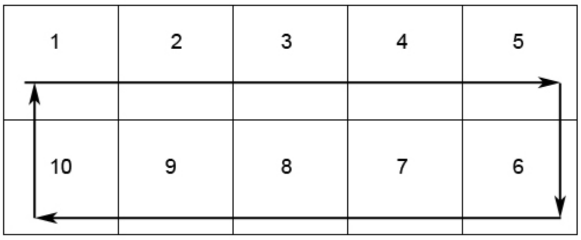
Figure 6 – Sky coverage vs. limiting magnitude with varying passes.

Search Pattern

With a 94 second cycle time, three passes separated by 16 and 32 minute interval as in Fig. 7 will yield about 625 degrees^2 per 10 hour period reaching magnitude 22.5 with a s/n of 10. This will produce block coverage of about 50 degree^2 and 100 degrees^2. The pattern is optimized for minimum telescope slew distance.



Search pattern with 32 min. interval encompassing 100 degrees^2



Search pattern with 16 min. interval encompassing 50 degrees^2

Figure 7 – MHO 5x2 and 5x4 search patterns. As suggested this will yield about 625 deg^2 in a 10 hour period with a 94s cycle times and reaching magnitude 22.5. The interval is 16 and 32 minutes between the passes.

Conclusion

Discovering rapidly moving objects is only one of the many capabilities of the MHO. Due to its ability to detect very faint objects over a very large coverage area the MHO can make valuable contributions to discovering NEO's and other fast moving objects.

Acknowledgement

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