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Final Project – Proper Motion Measurement of the Comet 88P/Howell

Ludvig Doeser[1]

[1] *Department of Astronomy, The University of Texas at Austin, Austin, TX 78712, USA*

ABSTRACT

Every once in a while, one of the 3620 known comets passes closely by our planet. Most of their orbits are known, but unpredictable perturbations require us to constantly keep track and update our orbit models. The proper motion of the comet 88P/Howell was here measured on May 8, using the SDSS g-filter of the 30" telescope at McDonald's Observatory, to be 32.41 ± 5.16 arcseconds per hour, corresponding to 6.53 ± 1.04 km/s. This speed is lower than the *expected* of around $45''$/hr, which could be explained by the short observation period, resulting in a higher error, and/or by the comet moving more in the radial direction than predicted. The brightness was also measured to a lower value (16.2) than presented by the community ($12 - 15.7$), which most likely is a result of high cloud cover during the observation. Coming together and stacking all known measurements of comets are important so that we can predict and prevent a potential collision, and, in addition, learn more about our solar system. The result presented here is one vital piece in a larger puzzle that enables us to understand the motion of comets.

1. INTRODUCTION

Icy planetesimal space objects called Comets have been considered fascinating for long. Despite their beautiful appearance, they do pose a treat as they could collide with Earth. We, therefore, need to keep track of them and update current models of their orbits with observational data in case unpredictable perturbations have influenced them.

The comet 88P/Howell was discovered in 1981 by Ellen Howell and has a period of 5.48 years. On May 8 it will have a distance to us around 1 AU [Liv20b], which is basically as close it gets to us. As the comet starts to heat up as it approaches the sun, dust tails might become visible. This comet is believed to originate from the frozen depths of our Solar System and is believed to carry interstellar dust from the time when the Sun and the other planets were collapsed and formed under gravity. In 2006 NASA's Stardust program collected samples from another similar comet, and their analysis suggested that comets may be more complex than we thought [Div19]. As argued by [Owe08] comets might even have brought water and life to Earth. Without keeping track of comets like 88P/Howell we won't be able to find out the truth; we need to go visit them again, and people have been suggesting such trips for the 2020s.

What we can do right now is to observe comets like 88P/Howell to learn more about their orbits, by measuring their movement in the sky, and about their composition from spectroscopy. To enable future missions the most vital component is to keep track of is its orbit. It needs to be known to high precision, and this has been the main focus of this paper.

From [Liv20a] one can calculate the predicted velocity to $45''$/hr on May 8 and its magnitude is estimated and observed by JPL and COBS respectively to be around 13.4 [Liv20b], but with measurements ranging from 12 up to 15.7.

Problem Formulation—Measure the location, proper motion, and brightness of the comet 88P/Howell and compare to existing predictions/measurements.

2. OBSERVATIONS

Observation of the comet 88P/Howell was carried out on May 9 with the Sloan Digital Sky Survey (SDSS) mounted on the 0.8m telescope of the McDonalds Observatory. The g-filter was chosen due to it being the bluest filter with high sensitivity. As dust is most visible in blue a bluer filter was chosen as this could make it easier to track the comet in the case of tails being visible.

To satisfy the desired signal-to-noise ratio and concentration of comet luminosity to a few pixels of the CCD, five 2-3 min exposures were planned to be taken and stacked together. Due to the comet's proper motion of $45''$/hr and the pixel scale of the telescope being $1.35''$

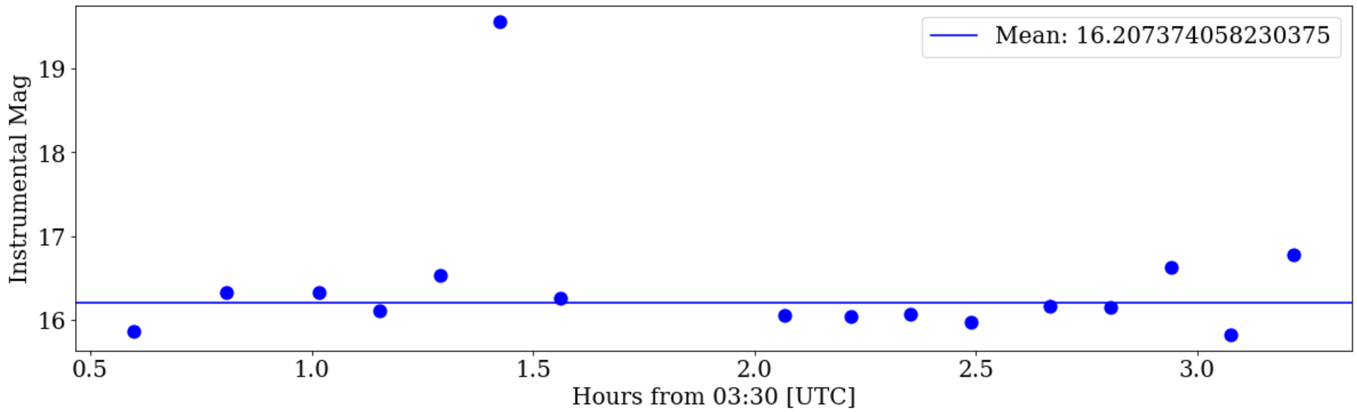

Figure 1. Magnitude for comet 88P/Howell measured from the 16 exposures on May 8. Apart from the outliner – frame 6 – which is a result of high cloud cover, the magnitude for the comet seems to be around 16.

the exposure time would ensure that the comet would only occupy around 2 pixels. In total, 5 such stacked frames were supposed to be taken.

During the night of observing it became evident that it wasn't easy to see the comet. Due to 10-40% cloud cover the observing plan had to be altered. Even after taking a 5 min test exposure, it could barely be seen, so 2-3 min exposures would not have worked. Even though the plane was to stack these shorter exposure images together, that itself would be pretty hard to do since (1) the comet could barely be seen, and (2) it wasn't clear exactly in what direction it was moving. It was also realized that the 3 min readout would make the stacking of light from the comet less effective. Therefore, 5 min exposures were taken all the time, which would result in a higher ratio of data gathering vs readout time.

15 images, each of 5min exposure, was taken in the g-band during a 3h period. In addition, one frame was taken in the r-band for robustness.

The focus was pretty good already from the beginning. About 40% into the observation, however, it had to be optimized for good seeing and this caused a slight hole in the data set. It improved the seeing, however, which was necessary due to the high cloud cover.

3. RESULT

To begin with, the fits-files were given WCS-headers using nova.astrometry.net. Then all images were calibrated and reprojected onto the first full-sized (2080x2048) image. To obtain a median value of zero in the images, the background – taken as the median – was subtracted.

3.1. *Magnitude*

After sorting, zeropoints were calcualted for each image using the PANSTARRS (ps) catalogue as a reference. Only the subregion were $12 < \text{ps\_mag} < 18$ and $22 \leq \text{ps\_mag-mag} \leq 31$ was used as to to only use the most reliable, bright, sources.

To do the photometry on each image DAOStarFinder's `DaoFind` was used with the parameters fwhm=4.0 and threshold=4std, where fwhm is the full-width-half-maximum and std is the standard deviation of the image's pixel values.

The magnitude of the comet was then obtained by using `DAOStarFinder` on a 150x250 subarray of the original images and extracting the $5-6$ brightest sources in the field of view. This always caught the comet and 4 bright adjacent stars. It became evident when zooming in that the FWHMs of around 10 pixels would be better in order to find the sources, and still with peaks approximately 4-sigma above the background. To measure the flux, the *aperture_sum* (f_{sum}) values were extracted from the table generated by the `aperture_photometry`-function for each image.

The fluxes were then calculated by

$$\begin{aligned} f_\nu &= f_{sum} 10^{-0.4 \cdot 48.6 - 0.4 \cdot zp} \\ m_{ab} &= (-2.5) \cdot log_{10}(f_\nu) - 48.6 \end{aligned} \tag{1}$$

The magnitude could be determined to around 16, as seen in Fig. 1.

3.2. *Proper motion*

Using the same subarray of the background-subtracted images as in Section 3.1 the right ascension (RA) and declination (Dec) for the 5-6 brightest sources could be extracted.

The error for the measurement was taken as the radius of the aperture used to find the sources converted to units of RA and Dec. The result is shown in Fig. 2 and Fig. 3, where Dec vs RA and Dec/RA vs time are shown respectively. In Fig. 4 a comparison with an expected coordinate for the comet is shown.

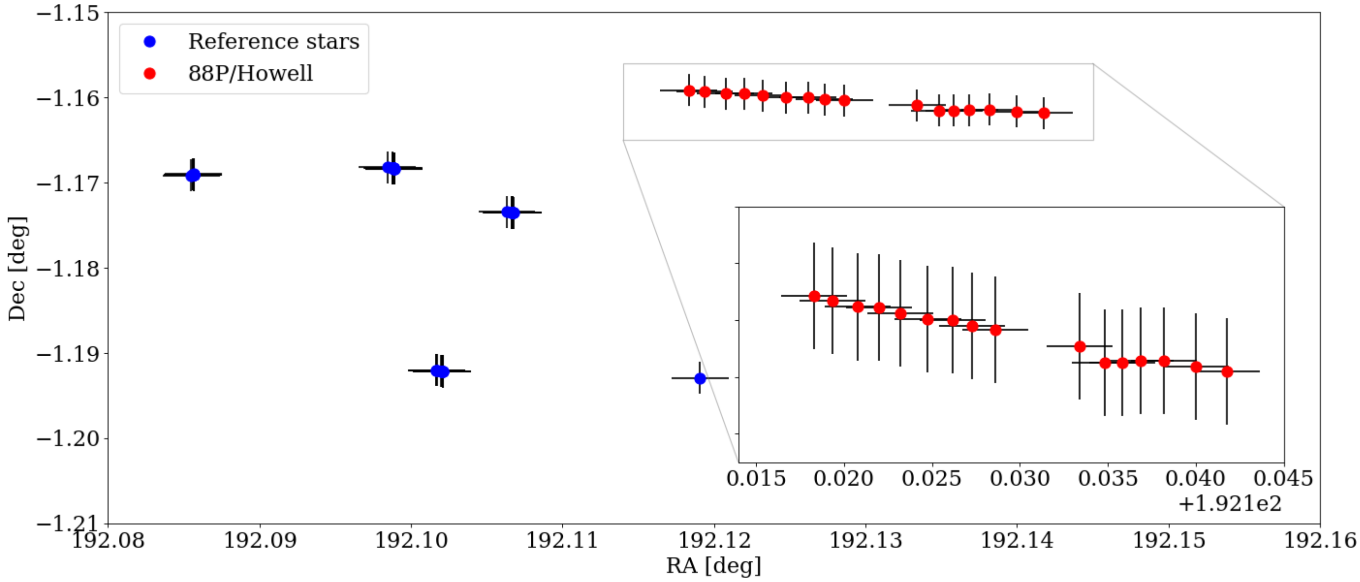

Figure 2. The movement of the comet 88P/Howell is clearly visible.

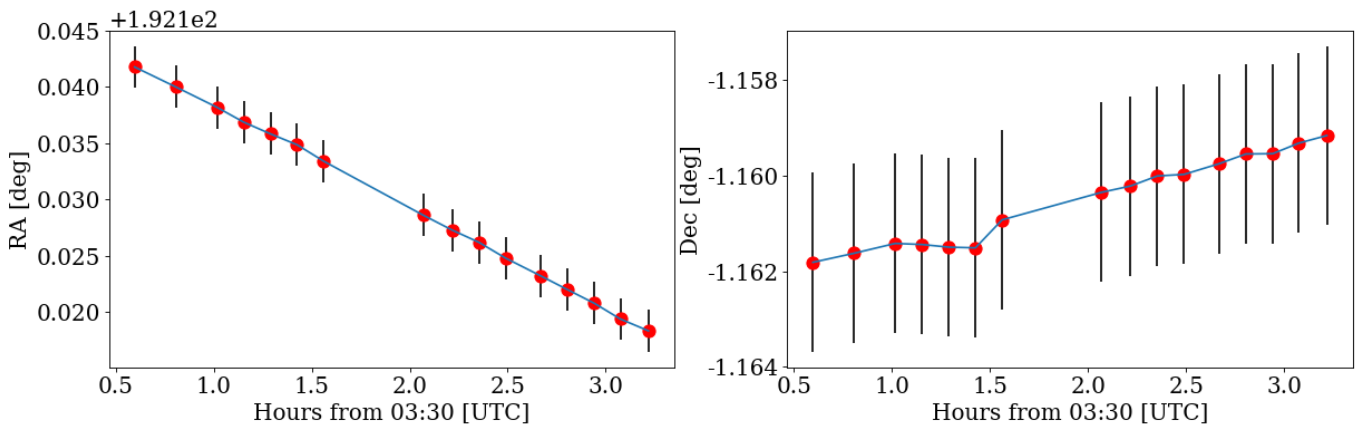

Figure 3. RA (left) is clearly changing with time, but Dec (right) doesn't seem to vary much.

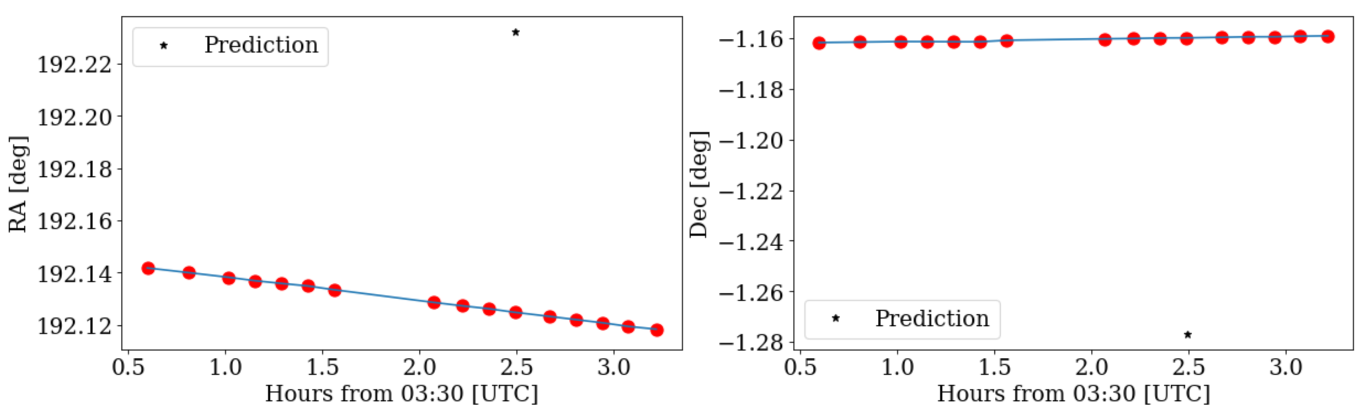

Figure 4. The prediction of where the comet was supposed to be is displayed. The difference is around 0.1 degree in RA and 0.12 degrees in Dec.

In the Appendix, the first and last images taken are displayed. In these ones can see the movement of the comet.

The velocity of the comet was determined by dividing the separation between two adjacent measurements with

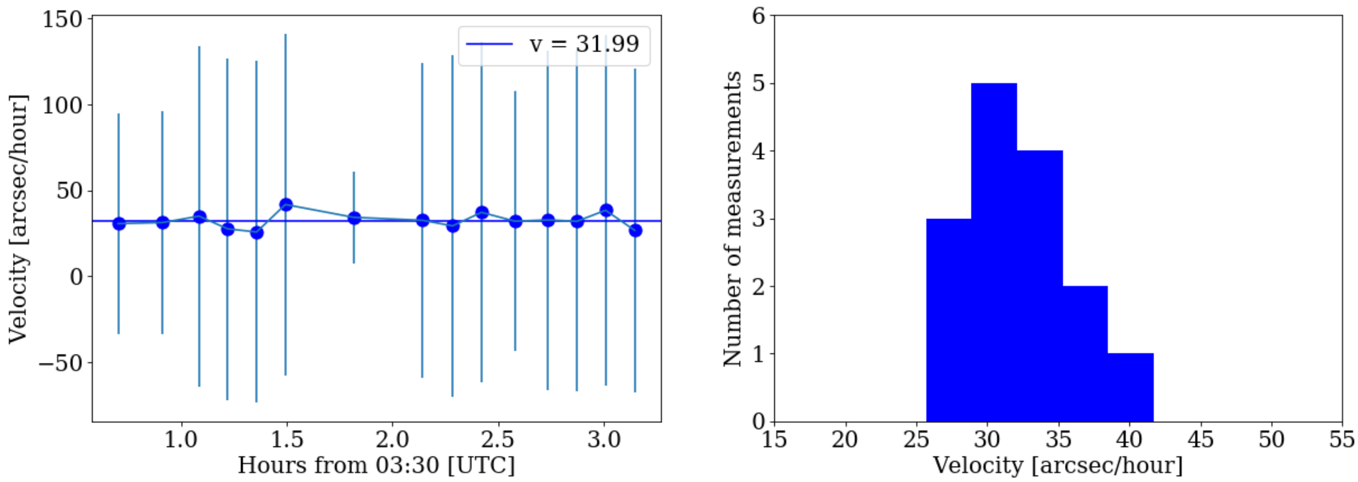

Figure 5. The velocity of the comet. Due to the relatively low proper motion the comet didn't move much during the time in between observations, leading to huge errorbars.

the time in between them. This resulted in huge errors when propagating the error as seen in Fig. 5, but with a mean of 31.99. Therefore, an average velocity was calculated instead, using the first and final images. This would result in a much lower error.

$$v_{88P/Howell} = 32.41 \pm 5.16''/hr. \tag{2}$$

4. DISCUSSION

The decision to change the observation plan to observe in 5 min exposures enabled the measurements of this paper. Due to the lower proper motion of the comet than expected, it only moved 1.97 pixels on average during a 5-min exposure, which was what we wanted in the first place.

Regarding the magnitude of the comet, it doesn't tell us too much. The deviation from the expected value is not clear and shouldn't be too influenced by the cloud cover as photometric calibration was done using zero-points. Nonetheless, some light was shielded by clouds and this would influence the comet more than the stars, which are much brighter and wouldn't be influenced as much. Therefore, the result provided here might very well be in agreement with the most recent published data [COB20], which ranges from $12.4 - 15.7$.

Furthermore, the slightly lower value in proper motion can't be explained by the cloud cover as the center of the comet was clearly visible in all but one frame. It could, however, be a result of the comet moving more in the radial direction than expected, which would produce a lower proper motion. Alternatively, one could explain it by the fact that the calculations made here were based on a 3 hour baseline, while the expected value was determined using 24 hour separations.

Now, using the known distance to 88P/Howell, presumably calculated through the Topocentric parallax method, the proper motion can be determined.

We cannot determine its full speed though since we don't have its motion in the radial direction, which would require photometric measurements. But we can obtain the transverse speed using 1 AU as the distance from Earth.

We know that

$$\tan\theta = \frac{d}{D} \implies d = D\tan\theta \approx D\theta, \tag{3}$$

where θ is how much the comet moved, i.e., the angular separation, d is the distance to the comet (assumed to be constant for the sake of this measurement) and D is the distance it traversed. Due to extremely small angles we could get rid off tan.

Conversion from arcsec to rad give a factor of 206265, so that we have

$$\theta(rad) = \frac{\theta('')}{206265}. \tag{4}$$

Then

$$d = D\theta(rad) = D\frac{\theta('')}{206265} = \frac{\theta('')}{206265}AU, \tag{5}$$

since $d = 1AU$. Finally, we have

$$v_\perp = \frac{d}{t} = \frac{\theta('')}{206265}\frac{AU}{t} = 6.53 \pm 1.04\frac{\text{km}}{\text{s}}, \tag{6}$$

which is a reasonable speed for a comet in elliptical orbit around the sun considering that the escape velocity is 42.1 km/s.

5. CONCLUSIONS

The comet 88P/Howell is currently moving towards Earth and was on May 8 only around 1AU away from us. Using the 30″ telescope at McDonald's Observatory the proper motion and brightness of the comet were determined.

These measurements will contribute to keeping track of the comet's orbit. It is important to be aware of what's happening in our surroundings so that we can avoid potential collisions. It is also vital to keep track of where the comets are going so that we can go grab samples from them in the future.

The brightness was determined to mag 16.2 and the proper motion to $32.41 \pm 5.16''$/hour, corresponding to 6.53 ± 1.04 km/s. This is not exactly in agreement with recently published data, but the discrepancy is not too large and could be a result of bad weather during the observation.

APPENDIX

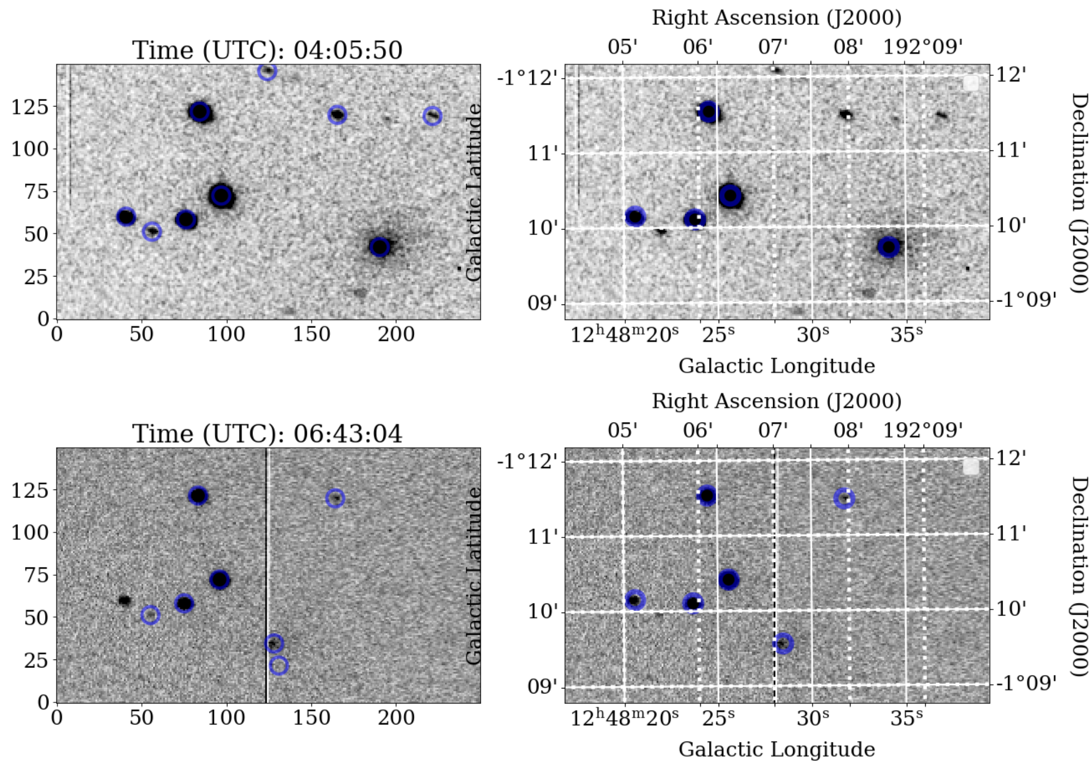

Figure 6. First and last image taken during the observation.

References

[Owe08] Tobias Owen. "The contributions of comets to planets, atmospheres, and life: Insights from Cassini-Huygens, Galileo, Giotto, and inner planet missions". In: *Space Science Reviews* 138.1-4 (July 2008), pp. 301–316. ISSN: 00386308. DOI: 10.1007/s11214-008-9306-7.

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[COB20] COBS. *Comet Observer DataBase – Recent Comet Brightness Estimates*. 2020. URL: https://cobs.si/recent (visited on 05/16/2020).

[Liv20a] The Sky Live. *The Sky Live – Info*. 2020. URL: https://theskylive.com/88p-info (visited on 04/17/2020).

[Liv20b] The Sky Live. *The Sky Live – Online Planetarium*. 2020. URL: https://theskylive.com/planetarium?localdata=30.58821%5C%7C-103.89463%5C%7CFort+Davis+TX+(US)%5C%7CAmerica%5C%2FChicago&obj=88p&aobj%5C%5B%5C%5D=88p&aobj%5C%5B%5C%5D=sun&aobj%5C%5B%5C%5D=moon&aobj%5C%5B%5C%5D=mercury&aobj%5C%5B%5C%5D=venus&aobj%5C%5B%5C%5D=mars&aobj%5C%5B%5C%5D=jupiter&aobj%5C%5B%5C%5D=saturn&aobj%5C%5B%5C%5D=uranus&aobj%5C%5B%5C%5D=neptune&aobj%5C%5B%5C%5D=pluto&h=06&m=00&date=2020-05-07#ra%7C13.03730310413315%7Cdec%7C5.4489416922608696%7Cfov%7C80 (visited on 04/17/2020).

Observation Date:		5/9/2020	2:09:00	UTC					
Observers:	Ludvig								

Type	FileName	ExpTime (s)	StartTime (UTC)	EndTime (UTC)	Number of exposures	Filter	Target	Comment
Object	img004	300	3:00	3:06:00	1	g	88P/Howell	only used rows 700-1300
Object	img005	300	3:10:00	3:20	1	g		full CCD: are we in the correct field?
Object	img006-10	300	3:24	4:04	5	g		300s+readout is probably too long.. the comet will move too much. start of img008:changed tracking
Object	img11	300	4:26	4:34	1	g		Think I've located the comet, it's moving! Now with better focus! Still going with 5 min. Not sure if it's needed. Should go down to 3 min and also reduce the rows to 700-1300; that will be enough
Object	img12-14	300	4:35	4:59	3	g		
Object	img15-17	300	5:02	4:25	3	g		
Object	img18	240	5:27	5:34	1	r		want to have two images in r-band; might be better? shorter exposure should be ok. Maybe should have taken 2 min? Now I went with 4. Decided to just take one image. It turned out pretty bad.
Object	img19	125	5:37	5:42	1	g		
Object								
Object								
Object								

2:23	opening dome					
2:30	filter is at u					
2:32	test-image --> "Warning FXF: cannot delete multiple fits extension file"					
2:40	opened ds9 & outside my folder...					
2:49	error on line 77... File write error					
3:20	got help from Dr Kraus to gzip a lot of files. Drive might have been full.					
3:24	filter is at g					
3:35	I killed xgterm and now I can't open it again, so I can't focus haha					
3:46	test image of spica... img002	img003 also test				
3:55	hunting for 12:49:51, -1:17:41					
3:59	taking first image of 88P/Howell					
4:18	tracking 12:49:02, -1:16:50					
4:22	tracking 12:49:04, -1:16:42					
4:23	mores(5)					
4:39	tracking 12:49:06,-1:16:15					
5:03	tracking 12:49:01,-1:16:24					
5:04	focus-sequence					
5:11	plus 900 in focus	focus1				
5:18	plus 900 in focus	focus2				
5:14	might be too hard to know in which direction it's going so it might be better to take 5min exposures after all. also slightly cloudy, rn around 40% according to the McDonald-weather tab. http://www.cleardarksky.com/c/McDonaldObTXkey.html	would be hard to stack them without knowing the direction.	If no clear comet I woudn't now how to reproject; would have been hard			
	didn't change anything. went down from 7 to 2 after these +1800	focus3				
5:26	ran next exposure					
5:27	oh man the moon is bright....					
5:31	tracking 12:49:05,-1:16:49					
5:34	mores(3)					
5:40	distance calc img11:	892,1173 -- 951,1139		from nearest bright star to potential come		68.1
5:43	distance calc img12:	841,1155 -- 895,1121				63.81
5:49	track 12:49:08,-1:16:48					
5:51	distance calc img13:	834,1158 -- 886,1122				63.24
6:00	track 12:49:05					
6:02	mores(3)					
6:17	track 12:49:13,-1:16:45					
6:26	filter is at r - want to test to take images here					
6:29	thought: not sure if I thought about the readout time when I suggest to stack 2-3 min images? Would move much more than just 2-3 min then, more like 5-7 min due to read out.					
6:34	track 12:49:52,-1:16:43					
6:35	filter is at g					
6:37	last image					
6:42	initializing shutdown					
6:49	closing dome					

Figure 7. Observing Log from May9