Detecting Mass Loss in Main Belt Asteroids

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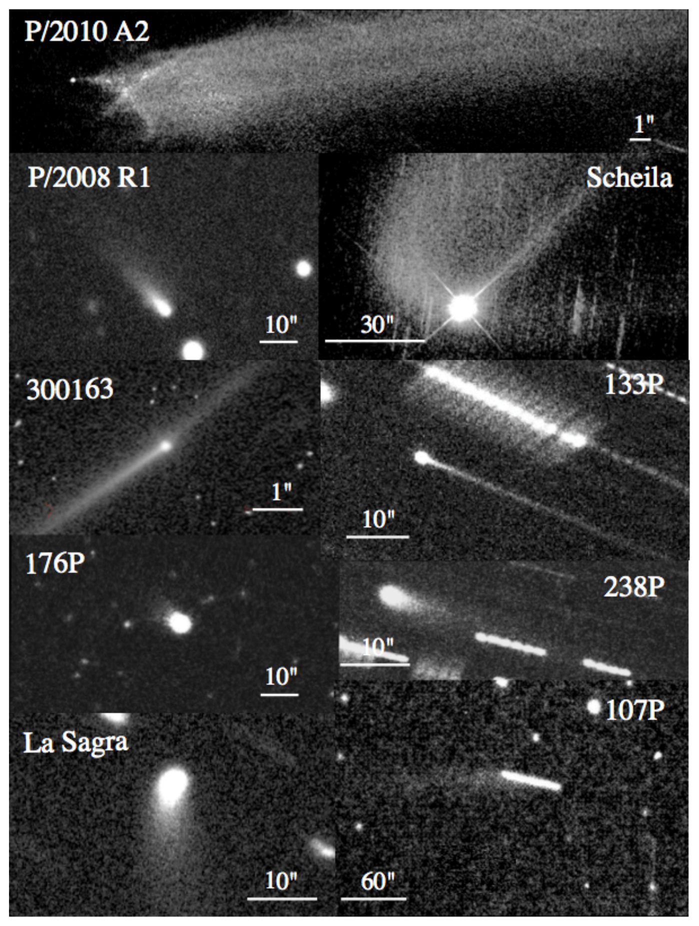
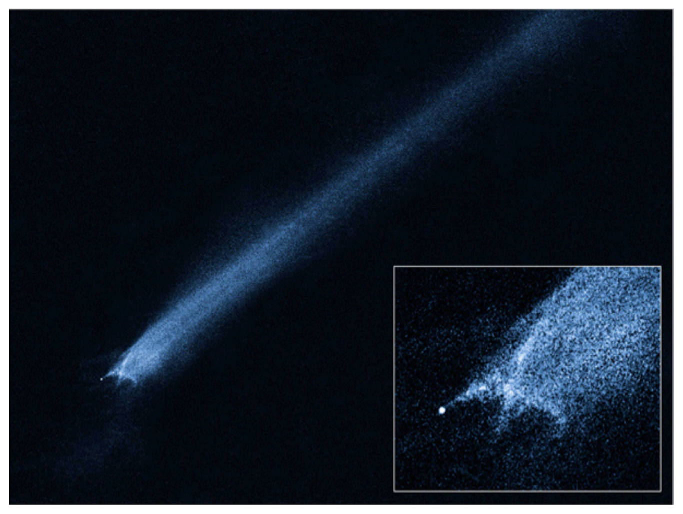
Introduction to Main Belt Asteroids

Main Belt Comets (MBCs) or active asteroids are asteroids which exhibit signs of dust/ice ejection and reside within the main asteroid belt between Mars and Jupiter. Until recently, it was thought that only comets were capable of producing these transient mass loss effects. This was an issue because scientists have thought that exo-planetary debris disks needed a source alongside cometary mass loss to produce the amount of dust that was being observed (Jewitt 2011). The dust in these debris disks cannot be simply from leftover planetary formation because eventually the radiation effects from the star would force it to dissipate. Mass loss from asteroids could be a nontrivial part of this source.



Jewit 2011

Above, several pictures of active asteroids. Examples of both comae and tails can be seen. This is what we want to see when looking through our non-sidereal stacks (figures 1 and 2) which are pictures of inactive asteroids.



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This project is part of a larger search for Near Earth Objects (NEOs) which is led by Dr. Lori Allen. The primary goals of her project are to identify any asteroids with high impact risk, which is dependent on the size and orbit of asteroids, as well as mapping the distributions of small NEOs. These NEOs are closer to Earth than the Main Belt Asteroids (MBAs) that were the focus of this project, which is important in classifying these moving objects as NEOs or MBAs. The closer the object to the Earth, the faster the angular speed across the sky. This means that NEOs will have a different rate of motion across the sky than MBAs, allowing us to differentiate the objects. Typical rates for asteroids in the main belt are 20 to 50 arcsec per hour.

Instruments and Observing Strategy

The data used on this project came from the Victor M. Blanco 4m mounted with the Dark Energy Camera (DECam), which is a collection of 62 2048x4096 pixel CCD cameras. The DECam has a 2.2 square degrees field of view. The routine used to observe was to take images to form 2x2 squares, with a one minute exposure each. This process was repeated until all four images in the square had been visited five times, resulting in five one minute exposures of the same part of the sky, with each of these exposures separated by roughly five minutes. The five minute wait allows any asteroids to have moved slightly relative to the sidereal rate and thus the asteroid can be detected by finding sources which show up in different places in the corresponding images.

The raw science images were put through a standard CCD data reduction pipeline. They were then put through a moving object pipeline by Dr. Frank Valdes. A median stacked image was made for each pointing on the sky and subtracted from each of the five individual images that were use to create it. This left a difference image, which due to the sidereal tracking of the telescope only leaves behind sources moving at a non sidereal rate. Small cut outs of 300x300 pixels are then made around these possible asteroids.

Analysis

After going through Dr. Valdes' reduction and extraction pipeline, the images corresponding to the same patch of sky were stacked together both in a sidereal (stacking the stars) and non-sidereal (stacking the asteroid) manner using Swarp. Source finding and photometry was then done by Sextractor. The software written to use these packages was written by Dr. Ralf Kotulla. One of the largest problems with looking for mass loss in asteroids is the assumption that a non-point source like object is characteristic of mass loss. This is not strictly true because during the one minute exposures, the asteroid moves slightly in the frame (the telescope is tracking on the stars). Due to this motion, there will always be some elongation in the asteroid's PSF along the direction of motion.

Two solutions can be used when faced with this situation: a) only look at the asteroids PSF in a direction perpendicular to its motion across the sky or b) consider the motion negligible and search for elongation in any/all directions. Solution a) may be able to detect asteroid comas or tails in that direction, but one loses the opportunity of finding a tail in any other direction. Solution b) will produce a large number of false positives since all the asteroids have some level of elongation, but allows the observer to be able to capture any present mass loss effects. Up till this point, all the work done this summer was using solution b).

Abstract

The Dark Energy Camera (DECam) on the 4m Blanco telescope at the Cerro Tololo Inter-American Observatory (CTIO) is being used for a survey of Near Earth Objects (NEOs). Here we attempt to identify mass loss in main belt asteroids (MBAs) from these data. A primary motivation is to understand the role that asteroids may play in supplying dust and gas for debris disks. This work focuses on finding methods to automatically pick out asteroids that have qualities indicating possible mass loss. Two methods were chosen: looking for flux above a certain threshold in the asteroid's radial profile, and comparing its PSF to that of a point source. After sifting through 490 asteroids, several have passed these tests and should be followed up with a more rigorous analysis.

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Stacking Images

In order to get the most accurate PSF for both the asteroids and the stars, the five images were stacked on each other. Both sidereal and non-sidereal stacks were created, which can be found in figures 1 and 2 respectively. This allowed an average PSF to be made for the asteroid, and by combining the PSFs from several stars an average point source PSF was modeled. It is important to use the stars' PSF rather than simply generating a perfect point source because the atmosphere, camera, and telescope can cause distortion. This distortion is accounted for by the fact that both the stars' and the asteroid's PSF have been affected in

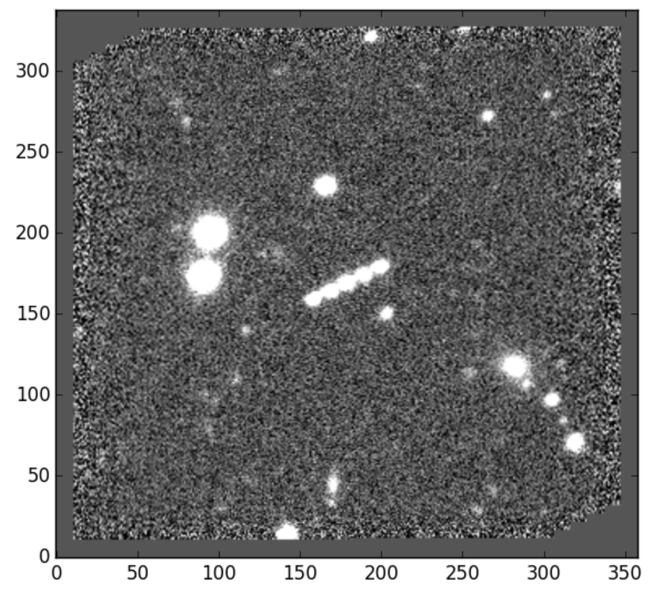

Figure 1

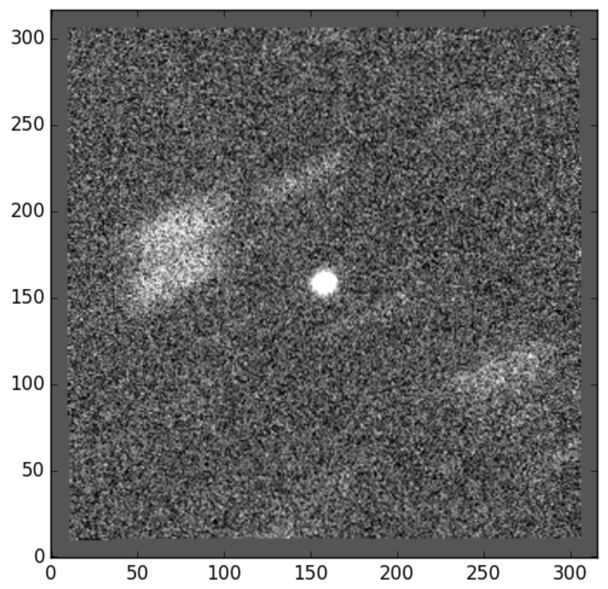

Figure 2

Several methods were attempted to choose the asteroid. First, we tried picking the brightest source from the non-sidereal stack, but sometimes bright stars or galaxies would bleed too much into the non-sidereal frames and be brighter than the asteroid. Next, the most central source was chosen, but due to some asteroids being near an edge of the DECam they were not centered in order to keep the 300x300 pixel frame size. Finally, using the source closest to coordinate estimates that Dr. Valdes had calculated earlier, we identified the asteroid roughly 100 per cent of the time.

PSF Subtractions

After correctly choosing the asteroid in every non-sidereal image and having a PSF for it and the stars (the point source model), some simple subtractions were done. Figure 3 shows the radial profiles for the asteroid (black dots) and point source model (red line), along with the residuals of their subtraction (blue Xs). Figure 4 was created for each asteroid to visually interpret the residuals from the subtractions. Two main things were being checked here: whether the residuals far away from the source (the noise) was Gaussian, and if they were centered about zero. if the mean values of the residuals were not around zero, it would hint toward errors in sky subtractions from each frame. The results from these showed that the models and asteroids varied from each other more than expected which was presumed to be due to sub-pixel shifts of the centers of the asteroid PSFs which were unaccounted for.

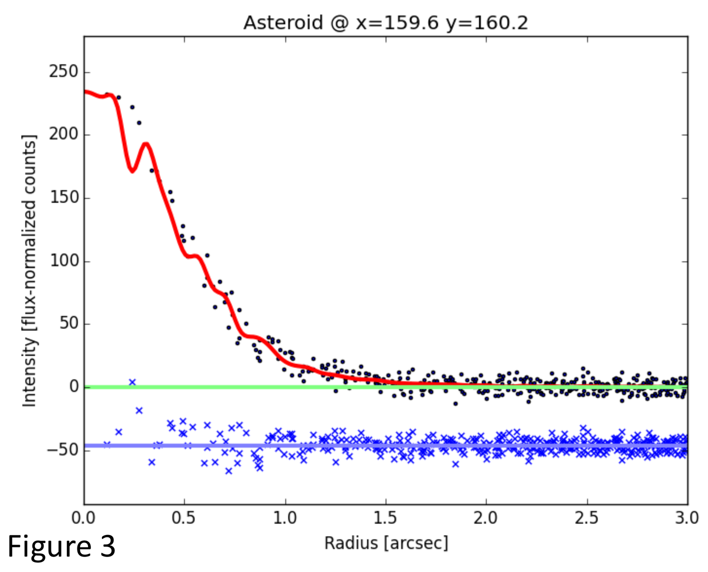

Figure 3

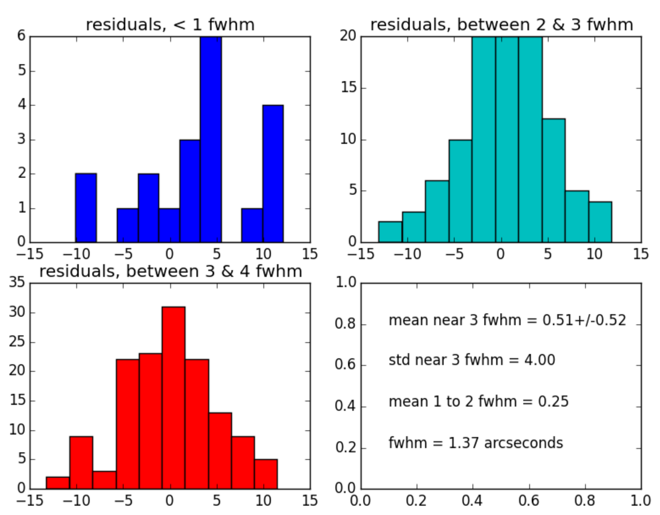

Figure 4

After correcting for this, figure 3 was made which clearly shows the PSFs and subtraction process. To identify an asteroid as a possible mass loss candidate, any asteroid that had a flux at one full width half max (FWHM) of more than 3x the standard deviation of the points in an area around four FWHM out was flagged. The reasoning behind this approach was that the points at four FWHM would be almost completely noise, and mass loss (if there was any) is expected to be evident around the one FWHM mark. Essentially, where mass loss is expected there should be an increase in flux, and the background noise (which is the level at which we can no longer see our signal) is used as a threshold. Every candidate selected by this program was then checked by eye to look for obvious extensions in the images and bumps in the subtraction from figure 3, which could hint at mass loss. None of the candidates seemed to have anything out of the ordinary going on, but some of them were slightly blurred in the direction of motion. Some tweaks were made to this approach, such as choosing different areas to look for mass loss and going further away from the center to calculate the sky standard deviations, but still no candidates had obvious mass loss. This method clearly needed more refining, but due to the limitation of time, an altogether different method was taken to identify candidates.

FWHM Comparisons

While the subtraction technique should work, thoughts were that subtracting induces too many unpredictable errors. A simpler, yet still viable way of comparing the shape of the asteroid and stars was to simply look at the FWHM of their respective radial profiles as calculated by SExtractor. In order to do this, the point source model and the asteroid must be normalized to the same maximum counts.

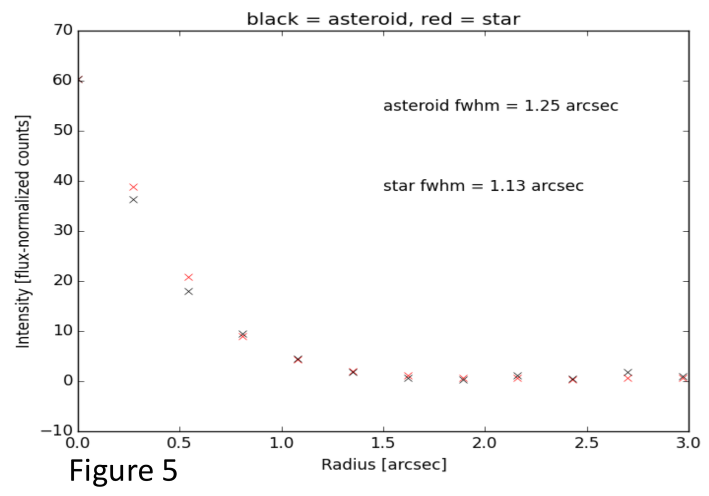

Figure 5

This was done by simply dividing the point source model by a scalar to set the maximum equal to the maximum of the asteroid. Brighter sources tend to have larger FWHMs, so normalizing the two ideally makes sure that any differences in FWHM come from only the shape of the object. In order to get these precise FWHMs, several radial profiling techniques were compared. The brightest star was looked at in every image and the radial profile was computed using Dr. Kotulla's program, a second program developed by Jessica R. Lu, and a variation of the second by Ian J. Crossfield. After looking at how compact the PSF was for several asteroids, it was decided upon to use Jessica R. Lu's program. Figure 5 shows the data used for comparing the FWHMs of the asteroids.

Large Scale Statistics

After running through every asteroid in the one pointing being used, figures 6 and 7 were made to try to understand how many asteroids had FWHMs large enough to be considered interesting. The idea was that most of the asteroids would be point sources, so there should be a large portion of the data that is clumped together. In figure 6, which shows the ratio of FWHMs for the asteroid and brightest source, this clump is in the center of the histogram near a value of unity. The same data is represented differently in figure 7, in which the clump is the vertical streak on the left of the plot. The points that deviate from this area are the points that are interesting. This is where important statistics like the number of asteroids that show low levels of mass loss relative to the total number of asteroids can be obtained. While there is no doubt that there are imperfections, this plan is a good start to producing real science results.

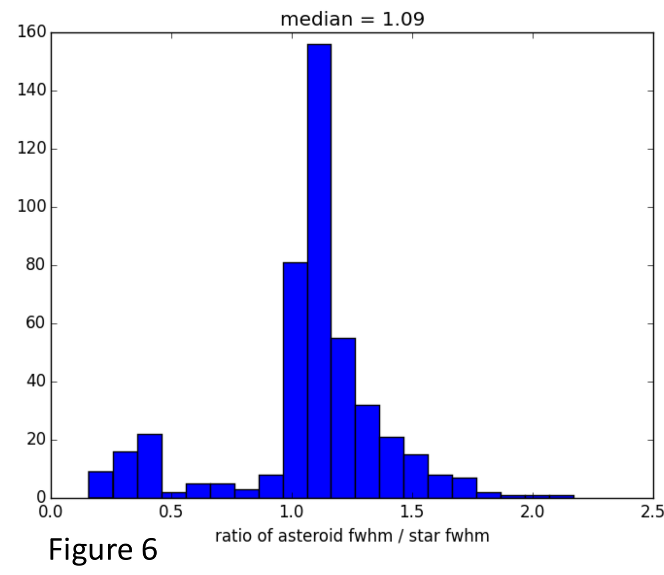

Figure 6

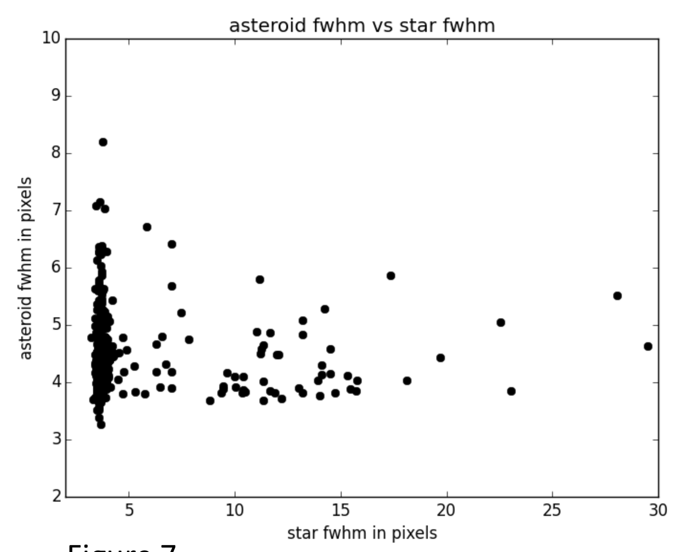

Figure 7

Conclusions

While the goal of identifying mass loss in asteroids is a fairly simple concept, one must occasionally remind themselves that there are quite a number of steps along the way to get there. Asteroids must be identified, stacked appropriately, and compared to the stars (which are the model of a point source) in the image. A large portion of the work was checking and making sure that the asteroid was not being overlooked, and if it was then figuring out why. The means of illustrating the dissimilarities between PSFs was approached in two ways: simple radial profile subtraction and FWHM comparisons. The final results from figures 6 and 7 show several possible candidates for mass loss, which should be scrutinized with several other tests to confirm or deny the suspicion.

Future Work

Due to the fact that all the information in this project was done with a single pointing, the next natural step is to apply the analysis to the entirety of the data set. In order to determine whether the asteroid's rate of motion across the sky was the reason for being marked as a mass loss candidate, a plot should be made comparing the angular speed to ellipticity of the source. If the mass loss candidates from figures 6 and 7 were found in this plot as having high angular speed, then they may have their status revoked. Also, another idea to see even lower levels of mass lass would be to stack all of the asteroids on top of each other. This would allow mass loss signals that were below the noise level to rise above, since stacking these would add to the signal quicker than to the noise. No information would be obtained about any one asteroid, but it would allow for more large scale statistics.