

# Guide to Asteroid Discovery Using the Sierra Stars Observatory Network

BY RICH WILLIAMS

## Introduction

I discovered my first asteroid in 1997 at my observatory in Buckley, Washington with the 16-inch prototype of what was to become Optical Mechanics' line of robotic telescopes. I found it on my first attempt and I was ecstatic. I could hardly wait to do my follow up imaging the next night to submit the required data to the Minor Planet Center (MPC) and get my designation for my newly discovered asteroid! The telescope was equipped with an Apogee AP7, which was a state of the art CCD camera with very high quantum efficiency. The CCD chip had a matrix of 512 x 512 24-micron pixels giving a field of view of only about 7 x 7 arc minutes. Back then amateur astronomers were starting to use modest sized telescopes (some as small as 6 to 8 inches in diameter) and CCD cameras to image and discover asteroids.

Because of the newly perceived threat of near earth asteroids (NEOs) impacting earth and causing a global catastrophe, large dedicated NEO survey telescopes were built to find and monitor these potentially dangerous objects. The first to come on line was the *Lincoln Near-Earth Asteroid Research* (LINEAR) project comprised of two one-meter and one half-meter telescopes. Although the mandate of the project was to find NEOs it quickly discovered tens of thousands of main-belt asteroids in the process. Today there are several large observatories around the world performing dedicated NEO searches and the total number of discovered asteroids now numbers in the hundreds of thousands.

In the late 1990s and early 2000s amateurs using small telescopes could still discover asteroids as bright as 16<sup>th</sup> to 18<sup>th</sup> magnitude. However, as more of the large NEO survey telescopes came on line the opportunities for the discovery of these brighter asteroids greatly diminished. It's still possible to discover asteroids with small telescopes capable of detecting only brighter objects, but the odds are not very good. The best bet with small telescopes today is to search areas outside of where the surveys are looking, however, the chance of discovery in these areas is far less.

To "compete" with the NEO survey programs today and discover new asteroids your best chance is to use telescopes and CCD cameras that enable you to image and obtain astrometry data on asteroids as dim as 20<sup>th</sup> magnitude or fainter. Doing so enables you to detect asteroids even in the same fields covered by the large surveys. SSON offers observatories with the capability to do such projects and its users are quite successful discovering new asteroids. This guide will help you to be successful as well!

## Getting Started with Your Asteroid Discovery Project Using SSON

Anyone can discover asteroids using SSON, but before you start, you must understand the requirements for submitting your observations to the Minor Planet Center (MPC) to get recognition for your observations and credit for your discoveries. The MPC has a strict protocol and format for the submission of your asteroid data. If you do not adhere to these rules, your observations will not be accepted.

Your main resource for reading about the MPC and its requirement is the following link:

[www.cfa.harvard.edu/iau/mpc.html](http://www.cfa.harvard.edu/iau/mpc.html)

Before you start your asteroid discovery project using SSON you should carefully read all the information on the MPC link for the “Guide to Minor Body Astrometry”:

[www.cfa.harvard.edu/iau/info/Astrometry.html](http://www.cfa.harvard.edu/iau/info/Astrometry.html)

Please do your homework and follow their guidelines exactly. Again observations submitted to the MPC with improper formats will not be accepted and will only waste the valuable time of professionals who are very busy and doing a very valuable service.

All observations submitted to the MPC must include the observatory code for the SSON telescope you used for your observations. Each observatory has a unique code with all the relevant local parameters used to determine the orbital elements for your observations (latitude, longitude, altitude, local time, and so on).

After analyzing the quality of your data and determining whether your object is a new asteroid or one already known, the MPC sends an automated email response to the contact email address for each observatory code with the designation information for each submitted observation. SSON users can check for designation announcements for their observations on the SSON website and at the SSON Google Newsgroup.

Known asteroids already in the MPC database have designations preceded with a left parenthesis “(”, for example, (K05G49T). Designations for unknown objects (ones that do not match the location for any known object) have designations without a preceding parenthesis (for example, K09C00Y). If your object has such a designation, then it is unknown and very likely a new discovery. It’s very exciting to get a new designation for an unknown asteroid, which might ultimately lead to the object being numbered and give you the opportunity to name it in the future!

The current observatory code for SSON sites are:

- Sierra Stars Observatory: **G68**
- Rigel Telescope: **857**

Designation announcements from the MPC are promptly sent directly to SSON users and/or posted at a location on the SSON web site that each user is notified of.

## **Strategy for Discovering Asteroids Using SSON**

To be successful in your search for discovering new asteroids you need to focus on two basic concerns for your project:

- Where (and when) to search
- Image as faint as possible in relatively short exposures

### **Where to Search for Asteroids**

OK you've reviewed the requirements and procedures for submitting your observations to the MPC and you are ready to start. Where do you point the telescopes to discover new asteroids? The overwhelming majority of asteroids are "main belt" asteroids found within 20 degrees on either side of the ecliptic between the orbits of Mars and Jupiter. That makes sense as the asteroids originally formed in the same plane as the major planets did more than 4.5 billion years ago. Therefore, you are most likely to find new (and previously discovered) asteroids in this region of the sky.

The likelihood of detecting an asteroid depends on its size, its proximity to Earth (asteroids are brightest near opposition), and to a lesser degree its albedo. An asteroid at opposition that was 19<sup>th</sup> magnitude during the time of its discovery might quickly fade beyond detection a few months afterwards and not become bright enough to detect again with the same equipment for almost two years when it again approaches opposition.

The large telescopes of the NEO survey projects search intensively in the area between 30 degrees on either side of the ecliptic for NEOs and consequentially detect the majority of new main belt asteroids today. NEOs can have orbits quite inclined to the ecliptic because they likely were "kicked" into an orbit that approaches Earth from collisions inside the main belt or from gravitational "slinging" from one of the major planets (Jupiter in particular). Even so they almost always pass through the ecliptic at some point in their orbit in relation to Earth.

One strategy for discovering new asteroids is to search areas far from the ecliptic where most people are not looking. The chances of discovery are low, but on the other hand objects you do find are likely to be somewhat unusual objects or even the rare NEO. You might even accidentally discover a comet, which can appear in any area of the sky, but this is a long shot at best. Keep in mind that your best chance for discovering an asteroid is to search regions where the majority of asteroids orbit -- near the ecliptic.

## **Search Where and When the Major Surveys Are Not Searching for Greater Success**

Your biggest competitors for discovering new asteroids are the dedicated big surveys such as LINER, LONEOS, SPACEWATCH, and so on. Fortunately these organizations have packed schedules and publish where and when they plan to search for NEOs on the Minor Planet Center web site. You can check where they plan to search at the following link: [scully.cfa.harvard.edu/~cgi/SkyCoverage.html](http://scully.cfa.harvard.edu/~cgi/SkyCoverage.html).

You can still discover asteroids in the same areas these surveys are searching (and SSON users frequently do), but you can increase your chances by looking where the surveys are not searching. There are still plenty of areas to check that are not being searched on any given night.

Finally, you can use the position and phase of the moon to your advantage. The big surveys tend to optimize their observing runs during times when moonlight does not interfere with their observations. By observing areas of the sky between the first and last quarter of the moon around the full moon, you'll have less competition and an increased chance of discovering an asteroid. During these times though you've got to plan your observations to not be too close to the moon where the sky background overwhelms the data.

## **Find Areas of the Sky That Don't Have Known Asteroids**

Your images might contain one or many known asteroids listed in the extensive MPC database, but still hold one or more unknown asteroids. One potentially effective strategy for discovering new asteroids is to look in a small area (a little larger than the field of view of the telescope you plan to use) where the MPC lists no known asteroids. The MPC has a great online tool called the Minor Planet Checker (MPChecker) that lists all known asteroids within a specified radius in arc minutes for a given RA, DEC, date, and time. You can access this tool at the following link:

[scully.cfa.harvard.edu/~cgi/CheckMP](http://scully.cfa.harvard.edu/~cgi/CheckMP)

I use planetarium software that can download the latest MPC database of asteroids (they update the database daily). I set the software to display all asteroids near the ecliptic where I want to search, and look for "holes" that have no asteroids listed in the MPC database. I write down the coordinates for the center of RA and DEC for the field and schedule a job on SSON with those coordinates. Any asteroids I find in the resulting data are likely to be new discoveries.

## **Practical Techniques for Asteroid Discovery Using SSON**

Now that you have an understanding of the strategy for discovering asteroids using SSON, you need to put that strategy to work. As I stated earlier, to discover new asteroids today you'll likely need to acquire astrometry data of objects as dim as 20<sup>th</sup> magnitude or fainter. The key to gaining these measurements is obtaining data with a high signal to noise ratio (SNR).

SNR is a term for the power ratio between a signal (meaningful information) and the background noise. In our case, the signal is the photons collected from the object (asteroid) and the sky background is the noise. For our purposes it's only really important to be aware what the SNR number means for your astrometry work.

For photometry work astronomers strive for a SNR of 100 or greater to obtain photometric measurements with precisions of a hundredth a magnitude or greater. For your asteroid astrometry work you only need to obtain a SNR adequate enough to give you a precise measurement of the centroid of the detected asteroid to get an accurate position. This type of work is much more forgiving than typical photometry requirements and you can measure accurate positions on objects with a SNR as low as 5. However, a higher SNR for your measurements will ensure more accurate results.

## **Obtaining Appropriate SNR data on SSON Telescopes for Asteroid Discovery**

So how long of an exposure do you need to schedule for asteroid discovery runs on SSON? The short answer is "It depends". It depends on the sky background (no moon is best), the seeing, and the size of the aperture of the telescope used. All SSON telescopes use high quantum efficiency CCD cameras and high-quality calibration frames to obtain an excellent SNR.

As an example let's use the 24-inch SSO telescope in California as a baseline to determine a good exposure time to schedule for asteroid discovery work. Experienced and successful users of the SSO telescope typically schedule somewhere between four to 15 or more 90-second to 120-second images of a selected field (RA and DEC) taken over a time span from 15 to 60 minutes. Most of their newly discovered asteroids are 19.5 magnitude and fainter. All of these observations are made without a filter to achieve the highest possible SNR. Astrometry work typically does not require the use of filters.

The SSON 14.5-inch Rigel Telescope is a scaled down version of the SSO telescope made by the same manufacturer and using the exact same CCD camera. Because of its smaller aperture, you need to schedule longer exposures (or stack more exposures together) to achieve a SNR equivalent to the larger SSO telescope. Total exposure times about 2.5 times longer than those taken on the SSO telescope achieve approximately the same SNR. The cost in credits per hour for the Rigel Telescope is half of the SSO telescope so the cost vs. SNR is close. It's good to keep in mind that you can use Rigel as a backup to SSO as well. If the weather at the SSO site is bad and you need follow-up data for your required second night of observations for your new discovery, the Rigel telescope can save the day. Alternately you can use SSO as a backup for your Rigel observations.

## **Affect of Seeing and Sky Background on SNR**

Telescope aperture and high quantum efficiency cameras are not the only factors affecting the SNR for a given observing run. The full width half maximum (FWHM) seeing and the sky background (light pollution) also determine the SNR you can achieve on any given night.

Better seeing increases the SNR of your data. Seeing that is 4 arc-seconds at the zenith (poor seeing for any SSON site) results in a much worse SRN than seeing that is 2 arc seconds. Poor seeing “smears” the data providing degraded results.

Sky background (brightness of the sky) is the main contributor of the N (noise) in SNR. A bright sky caused by light pollution or moonlight has a great affect on the overall SNR of your data. SSON observatories are located at dark sky sites with little light pollution. The sky background measured at the SSO site on nights without moonlight and average transparency is typically 21.6+ magnitude (measured per arc second). The Rigel observatory site has a comparable nominal sky background.

Moonlight is light pollution that affects the sky background more or less evenly for all observatory sites. Even at the most pristine sites a full moon has a profound effect on the sky background increasing the sky background to about 18<sup>th</sup> magnitude or worse. This is one of the reasons why many of the big surveys curtail observations around the time of the full moon. Although the SRN is greatly reduced, there is still an opportunity - without major competition - to hunt for new asteroids during these times.

To get a better idea about how SNR varies for different apertures and conditions try using the SRN calculator link on the SSON web site ([www.tass-survey.org/richmond/signal.shtml](http://www.tass-survey.org/richmond/signal.shtml)). You can enter different parameters to do lots of “what if” situations.

## Getting Down to Business

Now that you are armed with the background information you need to get started, what’s the best procedure for discovering new asteroids and submitting your data using SSON? Start with the following procedure:

1. Log into your SSON account and click on “Schedule Jobs” on the main menu and then click on the “Schedule a Job” selection to bring up the “Observation Request Form”.
2. Enter Title and Observer information in the first presented fields. In the Title field you should enter a name that will remind you of the potential discovery field naming convention you choose for your discovery field. An example might be something such as: RichAstDiscField\_01RJW002 or whatever is meaningful to you.
3. Click on the Object or Position dropdown selection and enter an object name in the Observation Request Form. Again enter a name that signifies a nomenclature that makes sense for your project and observing run and is easy and obvious for you to understand.
4. Enter the Right Ascension and Declination of the coordinates you want to observe in the appropriate fields.

5. Click on the “Telescope, Filter(s) and Exposure Time(s) – SUBMIT JOB” dropdown selection and select which telescope you want to use for imaging.
6. Enter the duration of the exposure times for each filter you want to run for each sequence. For asteroid discovery and follow-up astrometry projects, you will almost always choose the clear (or no filter) to achieve the best SNR for your images.
7. Enter the number of times you want to repeat the exposures and the interval (delay) between each exposure in the appropriate fields.
8. After you are finished, click on the “Submit Schedule” at the bottom of the form to submit your jobs to the SSON Master Scheduling Program.

## **Processing Your Asteroid Data**

After you download your FITS files of your asteroid data from your SSON FTP directory, follow this general procedure to process your data:

1. Use an image processing program to blink or create a movie loop of the images in the order they were taken to look for asteroids moving relative to the stars in the images.
2. If you find any moving objects, use the Minor Planet Center MPCChecker program to check for any known asteroids in the field of view of your images. If you find an unknown object in your images, there is a good chance that you discovered a new asteroid.
3. Take precise astrometric measurements of the right ascension and declination coordinates of the unknown object(s) in the images and get the precise time the exposures were taken.
4. Save the measurements (and your image data!). The MPC requires a minimum of two measurement data for each object in an observing run and also requires additional measurement data of the same object on a different night (ideally on back to back nights).
5. Calculate where the object(s) will be the next night (or the soonest possible night) and schedule an SSON telescope to image at the projected coordinates where you expect the object to be. Then repeat the previous steps for your new images. The MPC has a great online tool, New Object Ephemeris Generator, which you can use to predict the coordinates of the object for your next observing run. The link to the tool is:  
[www.cfa.harvard.edu/iau/MPEph/NewObjEphems.html](http://www.cfa.harvard.edu/iau/MPEph/NewObjEphems.html)
6. Email your astrometry measurements from two (or more) nights to the MPC making sure that that you follow the required format exactly. You must submit a minimum of two measurements for each object for each night. If you cannot get a second night of data (maybe

the weather was bad at all SSON sites for a couple of days) and your object is “lost” then send in your single set of observations anyway.

7. You receive a confirmation (or rejection) of your astrometry data from the MPC and a new designation for your object if the MPC determines it is an “unknown”.

## **Searching for Unknown Asteroids in Your Data**

The easiest way to detect asteroids in your SSON FITS images is to use one of the available astronomy software programs that enable you to “blink” the images. Blinking is a process that quickly switches between images. Stars and other stationary objects in the images stay in the same position in the images while asteroids will change position and appear to move a little from one frame (image) to the next.

Blinking several images in the sequence they were taken produces a “movie” in which moving asteroids are usually easy to spot right away. Most of the commercial astronomical image processing software packages can arrange and align images to create movie loops of your FITS files. There are also free software programs available online that can do this as well.

## **Stretch Your Images to Find the Faintest Objects**

Use the “stretching” function of your image processing software to detect the faintest objects in your images. Some of the asteroids in your images may only have a SNR of 10 or less. Also inverting the images (switching black for white) can also help you better detect and measure asteroids in your data. SSON users frequently find and measure asteroids fainter than 20<sup>th</sup> magnitude. However, you’ll have to carefully adjust your settings to see and measure these faint objects.

## **Use MPChecker to Find Known Asteroids in Your Images**

You’ll often find one or more moving objects in the movie loops you create from your data. Many or all of these objects may be known asteroids listed in the MPC database. Use the Minor Planets Center’s MPChecker program ([scully.cfa.harvard.edu/~cgi/CheckMP](http://scully.cfa.harvard.edu/~cgi/CheckMP)) to check the coordinates of all moving objects in your data. Enter the RA and DEC coordinates for the approximate center of the images you want to check with MPChecker making sure you also enter the exact date and time of your exposures (you can find this information in the FITS headers of your images). After you enter the RA, DEC, date and time information in the appropriate fields of the MPChecker form, click on the “Produce List” button. The program produces a list of known asteroids located within the specified search radius. The default radius in the MPChecker form is 15 arc-minutes, which should work well for most SSON telescopes. You can change the radius if you need to.

If you find any object(s) that does not match any of the known asteroids listed by MPChecker, it is likely to be a new discovery. Also, check to see if any of the known objects need new measurements (MPChecker tells you whether or not new measurements are needed for each object listed). If new

observations are needed for a known object you find in your images, you should include measurements of them with the data you send to the MPC. Your measurements will help determine a better orbit for these objects and might lead to the asteroid being numbered. If the MPC links your data with other “one night stand” data, it’s possible your new discovery could be numbered and subsequently named by you fairly quickly. Otherwise it could take up to several years for the MPC to collect enough data to determine an orbit to a high enough precision to number it. Remember someday someone may send in data that will enable one of your asteroids to be numbered and maybe give you the chance to name it.

## Using Software to Automate Asteroid Detection

You can buy astronomy imaging software with built in tools for greatly automating the detection of asteroids in your data and some even have the capability to create MPC reports in the required format. These software packages can make the asteroid detection process much faster and less prone to errors. Keep in mind though that none of these software programs are guaranteed to pick up 100 percent of asteroids in your data. It’s still a good idea to always check your data visually. Here is a list of some of the available software for doing asteroid astrometry:

- Astrometrica
- Astro Art
- MaxIM DL
- CCDSoft
- MPO Canopus

## Submitting Your Astrometry Data to the MPC

After you measure and record astrometry data of each object with two or more nights of observations, you can send in your measurement data to the MPC. The MPC only accepts data that are submitted in the *exact required format*. (To review the required go to the following link:

[www.cfa.harvard.edu/iau/info/OpticalObs.html](http://www.cfa.harvard.edu/iau/info/OpticalObs.html)). Please check your data you submit carefully before you send them to make sure they are accurate. Read the MPC Guide to Minor Planet Astrometry ([www.cfa.harvard.edu/iau/info/Astrometry.html](http://www.cfa.harvard.edu/iau/info/Astrometry.html)) thoroughly before you submit your first data.

One of the most common mistakes new people make when starting out is to submit incorrect times (and/or dates!) of their observations. The MPC requires that you use the **mid-point time of the exposures** you use for your measurement data. Using the beginning or ending times of a two minute exposure instead of the mid-point of the exposure means that your data will be off by 60 seconds. Considering that your times must be accurate to one second or less, this is a huge error! The automated software of the SSO and Rigel Telescopes marks the time at **the end of when the exposures were taken**, *NOT in the middle of the exposures*, in the FITS headers. *Be sure that you account for this when you submit your data to the MPC.*

## Example of an SSON Submission to the MPC

Below is an example of a properly formatted submission to the MPC. The example is for observations using the SSO telescope in California, which has the Observatory Code G68. Refer to the MPC web site to for any questions you have about the specifics of the MPC format.

```
COD G68
OBS F. Tozzi
MEA F. Tozzi
TEL 0.61-m f/10 Cassegrain + CCD
ACK MPCReport file updated 2008.11.24 23.05.24
AC2 ftozzi@racine.ra.it
NET USNO-B1.0
    fabx007 C2008 11 24.27251 03 08 54.98 +38 54 40.3      18.6 R      G68
    fabx007 C2008 11 24.28293 03 08 54.23 +38 54 39.4      19.0 R      G68
    fabx007 C2008 11 24.29335 03 08 53.46 +38 54 39.2      19.2 R      G68
    fabx007 C2008 11 24.30376 03 08 52.64 +38 54 39.2      18.6 R      G68
```

## Conclusion

Doing your own asteroid discovery project using SSON is rewarding, educational, and fun. It also provides valuable data to the astronomy community. Anyone can do this work using SSON.

This paper is meant to help get you get started with your asteroid discovery project. There is much more to learn about asteroids, astrometry, and so on. There are many good books on these subjects and of course the Web has a huge amount of information for you to search. Also the Minor Planet Center website has many powerful tools to help you with your discovery work as you become more knowledgeable and proficient.