A-Team Tutorials
2.1 Targets and Priorities

The objective at Level 2 is to identify targets that are of scientific interest while not being too difficult to image or measure.

In general, the desirability of observations comes from having an uncertain orbit, and no recent observations. Desirability is much increased if the object has a degree of “risk” associated – a recently discovered Virtual Impactor (VI) is an object for which a possible future Earth impact has not been ruled out and would therefore carry a high priority.

Different organisations assign priority in different ways and there are multiple sources of information that are sometimes confusing. Here are some lists that seek to focus attention on those objects that need observation.

ESA Priority List

The Near-Earth Objects Coordination Centre (NEOCC) of the European Space Agency (ESA) maintains various lists. Their home page is at NEOCC Home.

The menu on the left includes:

- Priority list. Observations required with priority *Urgent*, *Needed*, *Useful* and *Low-Priority*. This is based on the desire to ensure enough observations are made so that NEOs can be assessed for risk and recovered at the next opposition. Many of the objects may be too faint for us, but some useful candidates may be found.
- Risk list. Those objects that have a non-zero probability of Earth impact at some point in the future.
- Close Approaches list. Upcoming and recent objects passing within 10 lunar distances.

Many newly detected objects are “lost” before enough observations are made, so anything important enough to get onto the priority list is worth considering as a target.

Minor Planet Centre

The MPC, as custodian of Minor Planet Data, will welcome observations that will make a positive contribution to the accuracy of an object’s orbit or provide missing observations that allow the object to become "numbered". The MPC tends to regard any object with a current positional uncertainty greater than 2 arcseconds as being in need of observation regardless of whether it is a NEO or not. However, this rule does not seem to be applied with 100% consistency as some objects with small uncertainty are marked as "Useful" while others with larger uncertainty are not.

Ephemeris page

Whenever you look up the ephemeris of an object at the MPC, the page will comment on "Further observations?"

The current scheme of comments is not very informative, as it may say "Useful" for all sorts of objects regardless of any risk or urgency. Also, it may say "Not needed" for an object on the ESA Priority list.

No one seems to understand the way in which the MPC assigns priority and I suspect the logic is buried in the computer code somewhere and undocumented.

On the ephemeris page you will also see information about when the object was last observed. This refers to the date on which the most recent observations were published by the MPC. In the case of a main belt asteroid this can be days or weeks out of date relative to the last reported observation but for a NEO it is usually correct.

"Observable" Lists

There are several lists published by the MPC but most useful is the customisable list that allows the user to set limits (e.g., for magnitude) and to select different types of object. The page can be found at the Observable Object List Customizer:

http://www.minorplanetcenter.net/iau/lists/Customize.html

Some of the lists are quite long and, just because an object appears on a list, it does not necessarily mean the MPC urgently requires observations. There may well be observations "in the pipeline" that the MPC has not yet processed (and in practice I sometimes find objects in these lists that should not be there).

However, this can be useful place to start looking. Go to the list customizer.

- Set Dec. limits from -27 to +83 (for Teide) or +22 to -90 (for Chile) to exclude objects too near, or below the horizon.
- Set V magnitude range 0 to 18.5. (or a bit fainter if you plan to use stack & track or you are expecting particularly good seeing).
- Select all kinds of objects.

- Select “Dates of Last Observations of NEOs”.
- Press the Customize Page button.
- At magnitude 18.5 the list will probably not be very long.
- You can also try “Dates of Observation of Unusual Minor Planets” (usually plenty of these).

(Note that the “Recovery Opportunities” lists are no longer available.)

The lists are generally structured in three parts, and you should read the page headings carefully to understand what is included in each part. The displayed data varies from list to list but there are some key things to focus on:

- “Currently” shows low-resolution RA and Dec, V-magnitude, Elongation and Motion. Elongation refers to angular distance from the Sun. Check that the V-magnitude is within your capabilities and that Motion is less that about 5.0″ (arcseconds per minute). For faster objects, (up to around 20″ /m) you may be able to use the Multi-Luminance 20s recipe if the object is bright enough.
- “Last obs” tells you when it was last seen. If it has not been seen for a while, observations may be needed and there are various coded signals next to observation dates (read the introductions at the top of the list to find what they mean).
- Check the column “U” (uncertainty of the orbit). Objects of zero uncertainty may not be of much interest but objects of very high uncertainty should be avoided. An uncertainty of 9 means “this could be anywhere” so don’t waste missions looking for it! Objects with 1<u<6 may need observations and should be relatively easy to find.

There is another observation planning aid called the NEA Observation Planning Aid. This one is a bit complicated but by all means have a go with it.

Minor Planet Mailing List (MPML)

On groups.io there is the Minor Planet Mailing List that you can subscribe to. There is always lots of chatter about current targets. Most of it is from professionals and involves objects too faint or fast for us, but sometimes there is an interesting target.

(Incidentally, you can also find an Astrometrica group here as well).

Sormano Observatory

The Sormano Observatory also maintains a priority list of objects based on their current uncertainty and Minimum Orbit Intersection Distance (MOID).

A-Team.space

A targets list can be found at the A-Team.space website. This is a simplified list based on a combination of MPC and NEOCC data and may provide some useful ideas.

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Tony Evans

A-Team Tutorials
2.2 Visibility and Missions

At Level 2 you are trying to capture an object of scientific value. It may well be fainter than objects observed previously and requires more careful planning.

Ephemerides

There are several different ways of obtaining ephemerides (and the data needed to complete the checklist discussed below). You may wish to try them and decide on your favourite:

Minor Planet Centre Ephemeris Page

http://www.minorplanetcenter.net/iau/MPEph/MPEph.html

This is the one I recommended in Level 1 and remains my favourite. If you are OK with this one, don't bother about the others.

NEODyS (for NEOs) and AstDyS (Other asteroids)

These are sites maintained by ESA. They contain more information but are quite complex to use.

- NEODyS-2
- ASTDyS-2

Go to Objects, and search to find your target and you will see links to obtain all the information you might need.

JPL Horizons

HORIZONS Web-Interface (nasa.gov) is probably the most accurate for longer term predictions of highly perturbed objects but not always fully up to date on the latest discoveries.

Lowell Observatory ASTEPH

Lowell astorb DB. Beware this may not have the latest orbits for recent discoveries and close approach objects.

Planetarium Software.

Any one of the many PC and on-line packages may supply coordinates and other data. Make sure you understand how up to date the orbit data is. If it is not downloaded from the MPC on the day you use it, close approach NEOs will not be shown in the right place.

In Level 3 you will learn how to generate your own ephemeris directly from the available observations.

Visibility Check

You will need to obtain coordinates and check a number of factors.

- Check magnitude. It is very difficult to give an exact guide as to how faint you will be able to go. On a good night (good seeing, no Moon, no hazy clouds etc) you may get down to V=18 with C1 or V=19 at T1, T2 and C2 using single images. It is probably best to stay at least 0.5 magnitudes brighter than that to practice missions and measurements. Once you become familiar with Stack & Track in Astrometrica (see next section) you should be able to use the Multi-Luminance 50s recipe to get 1 or 2 magnitudes fainter. On poor visibility nights the limit is 1 – 2 magnitudes brighter than on good nights.
- Check Altitude. Go for objects that are well above 30 degrees from the horizon. Higher altitude will give access to fainter objects. (I would normally like my objects above 40 degrees). Check whether Teide or Chile will give you the best view.
- Check Azimuth. Remember the meridian black-out half-an-hour either side of the time the object crosses the meridian. You can judge this by looking at the Altitude figures in the ephemeris – it will be maximum at the time of meridian passage.
- Check Sky motion. Fast objects will leave faint trails and will be difficult to measure. Ideally the object should not move more than about 2-3 pixels during the exposure. Work out what is the maximum speed for the length of integration you are using. In practice up to 4 or 5 arcseconds/min is manageable and maybe a bit more with practice and good clear images. When using Stack & Track and the Multi-luminance 20-second exposures you can get good results for objects up to 20”/m provided they are bright enough to be measured accurately after such short exposures, (one or two magnitudes brighter than the normal limit). Objects faster than 20”/m should not be measured because the image timestamps are not precise enough.
- When checking motion, it’s a good idea to make a note of the motion and PA at the times of your missions, as you will need it later for Stack and Track.
- Check the status of the Moon. Consider its impact on visibility. Remember Slooh will not allow a reservation if it thinks the Moon is too close and too bright. T1HM is more sensitive to Moonlight coming in from the side than the other telescopes. I would normally like the Moon 60 degrees away if it is more than 50% full. The Moon is less of a problem when it is close to the

horizon than when it is high up. A bright Moon in the sky can easily reduce your limit by two magnitudes.

- Check the Uncertainty. Mostly the objects will have only a few arcseconds of uncertainty and that is of little concern. Objects that have not been observed for a long time may have much larger uncertainty and risk not being found in the FOV of the telescope. The MPC ephemeris usually tells you the uncertainty in arcseconds or provides an “uncertainty map”. Beware objects that have not been observed for a long time and have no uncertainty data – they may be “lost”.
- Consider Galactic Latitude. The Galactic equator is the plane of the disk of the Milky Way galaxy and therefore is the direction of the mass of Milky Way stars. Targets close to the Galactic Equator may get lost in the glare of stars or be too close to a star for accurate measurement. It is best to look above or below ~20 degrees of Galactic Latitude. One way to investigate this issue is to use planetarium software to plot the movement of your object against SDSS background images.

Missions

Check what slots are available for the coming night. Check the weather forecast for Chile and Teide. Objects with a significant southerly declination may only be visible from Chile, and northerly ones from Teide.

If you intend to make an MPC report, you should try for 3 good measurements spread out over sufficient time that the object has moved significantly. The missions should be 10-20 minutes apart (or even more for a very slow object). Clearly there will always be a compromise between the factors listed in the ephemeris and the availability of mission slots.

Multi Luminance

When hunting asteroids, we normally use Stack and Track in Astrometrica. That means we stack up multiple images to get a better Signal-to-Noise ratio. To do that we need to capture multiple images with each mission. This is done by selecting a Multi-Luminance recipe which gives multiple luminance images. Some telescopes offer the option of a 50s exposure which gives us the maximum light or a 20-second exposure that can be used for fast and bright objects.

Select the mission slots you want and put them on 1 hour hold. Then go back and set up the coordinates. That way nobody can jump in and take one of the slots you wanted.

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Tony Evans.

A-Team Tutorials
2.3 Identify and Measure

Data Reduction

Hopefully your missions all ran correctly. Download the FITS into a suitable folder and perform Data Reduction on them the same way as you did at Level 1. You may have lots of images from using the Multi-Luminance recipe so you may be able to do reduction on batches rather than one-by-one.

Make sure you have Settings/CCD/Auto-save FITS with WCS selected so that Astrometrica will save the data reduction information in the FITS file.

As you load each of the images for reduction you can have a quick visual check of their quality. It may be best to discard any that are of poor quality.

Stack and Track

If you have images from a Multi-Luminance recipe you can use Stack and Track.

- Stacking involves adding several images of the same area of sky together to make faint objects more visible.
- Tracking means that each image is shifted according to the movement of your target object before it is added to the stack. The image of your target is reinforced while images of stars get stretched out or “trailed”. The signal-to-noise ratio (SNR) of your target is improved so fainter objects stand out from the background noise.

To set up the stacking:

- Select Astrometry/Stack & Track,
- Select “Add”,
- Select all the FITS from one mission (or a pair of consecutive missions),
- Press OK,
- Check that the RA and Dec correctly identify the centre of the image. The pre-set values should be OK if you have previously completed data reduction on the images. Otherwise use the coordinates in the filename.

Tell Astrometrica how to track your target. There are a couple of ways to do this:

1) If your copy of MPCORB is up to date and your target is a normal asteroid (not a recent discovery or fast-moving Near-Earth Object) then you can obtain its motion by:

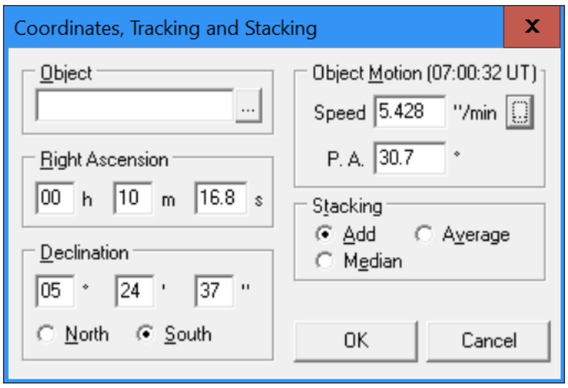
- Select the button […] next to Speed "/m.
- Enter the designation of your object in the search box.
- Press the magnifying glass,
- Select the correct object from the list displayed and press OK again.

The motion and position angle data should now be filled in.

2) If you are not sure that MPCORB is up to date or the object may have an uncertain orbit, obtain the Motion and P.A. figures from the MPC ephemeris page at the time of the mission.

Select Add, Average or Median.

- Add literally adds the pixel values together. This this is a good way to do noise reduction, but it has the disadvantage that the brighter objects may become saturated and all the hot pixels and other artefacts from all the images are added in.
- Average takes the average of the pixel values. This is good at reducing noise and avoids saturation. If there are several images in the stack, hot pixels and artefacts are also reduced.
- Median takes the median value of the pixels. It also reduces noise but not quite as well as Average. It sometimes helps to reduce the interference from stretched-out stars in a crowded field.



Stack & Track Dialog

Average is recommended as that tends to give the best results in most situations. Median can sometimes help if there are a lot of background stars.

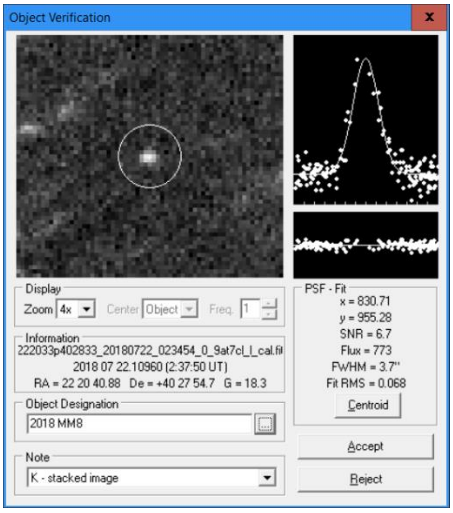
Press OK to stack. The process is like data reduction and it is possible you may be asked to do manual alignment of reference stars.

Stack each of the missions so you now have multiple stacked images open in Astrometrica.

Object Verification

Instead of having a set of individual images open in Astrometrica, you now have a set of stacked images. Use "Known Objects" and Object Verification tools as before to obtain measurements. However, you should take a closer look at some of the functions and displays available when doing Object Verification.

Note that, if the object is a recent discovery and your MPCORB has not been updated recently, the Known Object box may not appear. If the object is making a close approach, the Known Object box may be in the wrong place regardless of the currency of MPCORB.



Object Verification

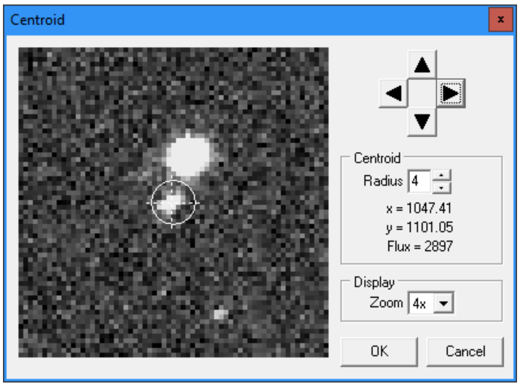
PSF and Centroid

A star is a "point source" of light but its image gets spread out by a combination of factors including atmospheric movement (seeing), diffraction, telescope optics, errors in tracking etc. The overall effect is that a disk of brightness is produced in the image with the brightest point in the centre and reducing brightness towards the edges.

- The shape of a graph showing how brightness varies from the centre outwards is called the "Point Spread Function" (PSF).

Astrometrica puts a circle, the size of the Aperture Radius in your settings, round a selected object. The circle is sometimes called a Synthetic Aperture. Astrometrica tries to fit a mathematical ideal PSF to the counts in the pixels inside the aperture. This allows it to find the centre of the object with sub-pixel accuracy. The object should lie inside the aperture so that the complete PSF curve just fits with a bit of the background noise showing either side and a nice smooth curve in the middle.

The size of objects in the image will vary depending on magnitude and “seeing”. The size of the aperture should already be set (in Settings) appropriately for the objects you are measuring but it can be adjusted during measurement using the Centroid button.



Adjusting Centroid

When you use the Centroid button, you can adjust the size of the aperture and move it around. Astrometrica will put crosshairs at the point of the centre of flux (using a calculation like centre of gravity rather than trying to fit a PSF) and will use this as the centre of the object. Sometimes it is possible to make a measurement of an asteroid close to a bright star using this facility, but you will probably get better residuals by having the Settings correctly defined rather than changing the aperture and using the centroid.

PSF Fit

Astrometrica compares the counts in the pixels to the ideal PSF curve and calculates residuals (differences between actual and calculated counts). These are shown in the small graph below the PSF graph. It should be “noisy” at the edges, low and flat in the middle. Deviation from that may indicate the PSF is not fitting well and therefore measurement may be suspect.

The “mean residual” is standard deviation of the residuals and is shown as “Fit RMS”. A figure below 0.1 is good.

The main reason for looking at the PSF information is to judge how well Astrometrica has been able to measure the exact position of the centre of the object and therefore how likely it is to get an accurate measurement.

Full Width Half Maximum (FWHM)

This refers to the width of the region of the PSF where the brightness of pixels falls off to half the maximum value.

The Aperture Radius should be set so that it is about 2 to 3 times the FWHM. Much smaller and there are too few pixels involved to fit the PSF curve to the pixel values; much larger and the aperture will become dominated by noise or may overlap nearby objects.

The FWHM should also be reasonable for what you might expect from the telescope and seeing. Somewhere around 2" – 4" might be expected on a good night. The FWHM of stars will vary from night to night depending on seeing.

The Aperture Radius values recommended for configuration files are for typical conditions, but you may change them for particularly good or bad seeing.

Signal to Noise Ratio (SNR)

The value (count) in each pixel ideally reflects the amount of light that fell on the corresponding pixel (photosite) of the camera. There is always a certain amount of random variation in the background luminosity of the sky and introduced by quantum variations in the electronic circuits. This variation is called "noise".

Noise is visible in the background of the image as displayed by Astrometrica and at the edges of the PSF graph.

For a good measurement, the variation of pixel value caused by the object must be significantly greater than the variation caused by noise. The Signal-to-Noise Ratio (SNR) is a measure of this relationship and the SNR is shown in the Object Verification dialog.

A SNR in the range 5 to 10 (or above) is normally needed for good measurements. Lower SNR values may yield usable results but do not be surprised if they have poor residuals.

Flux

Flux is the total number of counts from all the pixels inside the aperture. At this stage it is not of interest to us.

Object Designation

You should always click the […] button and select the target from the list (it should be at the top). If the object is a very recent discovery and your MPCORB has not been updated recently then you may need to enter the designation manually. It should be entered in its normal format (e.g., 2019 AA21) and not in the "packed" format previously used.

Notes

The "Note" drop-down allows you to make a note against an observation. In practice this code does not get published and will be overwritten by your Program Code by the MPC. (Program code is an identifier for an individual observer). However, it can be convenient to use these notes as reminders to yourself of any problems with the measurement. When looking at the residuals later, it can be useful to see why a particular measurement is poor.

With the ADES reporting format, the Note codes get passed to the MPC and I presume they must store them in the database. However, the published observations do not show them (yet).

If you use Stacking (see below), Astrometrica will automatically put a "K" in the notes field of the observation in addition to any notes code you manually select.

MPCORB

Astrometrica uses the file MPCORB.DAT from the Minor Planet Centre. It contains details of the orbits of over 1 million minor planets. It is used to calculate the position of the Known Object boxes, to find the nearest object in the Object Verification dialog and to find the motion of an object during Track & Stack.

MPCORB.DAT needs to be kept up to date otherwise you may find some objects are not "in their box" or recently discovered objects are completely missing. The current orbits of NEOs undergoing a close approach may not be reflected accurately in MPCORB and their known object boxes can be quite far from their actual position.

Internet/Download MPCOrb and Internet/Update MPCOrb/Near Earth Asteroids can be used to refresh the whole file or just the NEOs. (Sorry, yes, the NEO update takes a long time!).

Having objects nicely "in their boxes" is <u>not actually necessary</u> for measurement purposes but it can help you find faint objects, so it is your decision how often to refresh the file.

Incidentals

It can happen that objects other than your target have Known Object boxes in the same image. We refer to these as "incidentals". In most cases these objects will turn out to be Main Belt Asteroids with well-established orbits and of no particular interest. However, you can practice on these if you like. It is sometimes a good idea to measure and report at least a few incidentals as this can help the MPC to check the quality of your observations and measurements generally.

- However, you should never mix NEOs and Main Belt objects in the same ADES Report.

Don’t forget that, if you are using Stack & Track, you will need to repeat the stacking for each incidental using their individual motions and PAs. Luckily, Astrometrica will give you this information by clicking on them (in the Object Verification Dialog).

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Tony Evans

A-Team Tutorials
2.4 Residuals and Quality

Residuals

Residuals describe the difference between the positions you have measured versus the positions predicted from the object's orbit and the perturbation caused by the planets. The residuals are partly due to errors in measurement (seeing, image quality etc) and partly due to errors in the orbital elements.

Our main objective is to check that an orbit can be produced, including both our new observations and past observations. If an orbit can be produced with low residuals. That will mean that our observations are probably good.

Find Orb

In Level 1 we used the on-line version of Find_Orb to generate the residuals for our observations. That remains a convenient tool to check residuals for asteroids with well-defined orbits.

- You can do exactly the same with your NEO observations. However, the on-line application does not always produce a satisfactory result. It sometimes struggles to find the right orbit or does not incorporate your observations properly, leading to unexplained high residuals.

At those times you will need to give Find_Orb some help, such as telling it to include/exclude some planets as perturbers, include/exclude some observations, or filter the observations to use only those that "fit" best. You will need to use the desktop version of the program that gives far more flexibility and control.

In Feb 2021, a new version of Find_Orb was released. The older version was Windows based and, although not simple, was relatively easy to use. The new version is console based and looks like something out of the 1960's. Admittedly, the new version is better at solving difficult orbits, but it is rather messy to operate.

- So, the Tutorials remain based on the older version, and I will send a link to a packaged copy of a working system. All you will need to do is unzip it into a folder, download a couple of additional files and begin using it.

I am assuming that you have some basic understanding of Keplerian Orbits. If not, maybe it's time to do a bit of revision!

It is the basic function of Find_Orb to calculate the elements of a Keplerian Orbit of an object based on the available observations. Find_Orb will take into account perturbations from the planets (and up to 300 of the most massive asteroids) to calculate elements, residuals and ephemeris.

Installation

It is a good idea to visit the Find Orb website and read some of the material there to get an idea of what it is all about. Rather than downloading the program from the website, you will receive a link to a file containing the older Windows x64 version of Find_Orb.

Download the file and extract it into a folder (which I will refer to as the "Find_Orb" folder). It is useful to create a short-cut for find_o64.exe or pin it to your start menu.

The program will now run but there are a couple of extra files you should get before using it seriously.

Observatory codes

It is important that the observatory locations are correctly defined for all observations. The file *ObsCodes.html* contains the names and locations associated with observatory codes. The latest version of this file should be retrieved from the MPC and placed in the Find Orb folder, overwriting the existing file. Find Orb will remind you to do this again if it comes across an observatory code it does not recognise.

JPL DE Ephemerides

The Find Orb package comes with files that enable it to calculate the positions of the Moon and planets. These are adequate for casual use of the program but a set of JPL Development Ephemerides (DE) will improve performance and accuracy.

There are numerous versions and subsets of DE Ephemeris files, and you can read all about them here. The easy solution is to get this one that covers years 1600 to 2201:

- DE422 Ephemeris for 1600 – 2200 (53Mb).

If you really want to investigate the distant past or future, I have a copy of DE422 going from -3000 to +3000 which I could get to you somehow. (Half a Gig).

Make sure you do not have multiple DE files in your Find_Orb folder as the program may not select the right one.

Orbits and Residuals

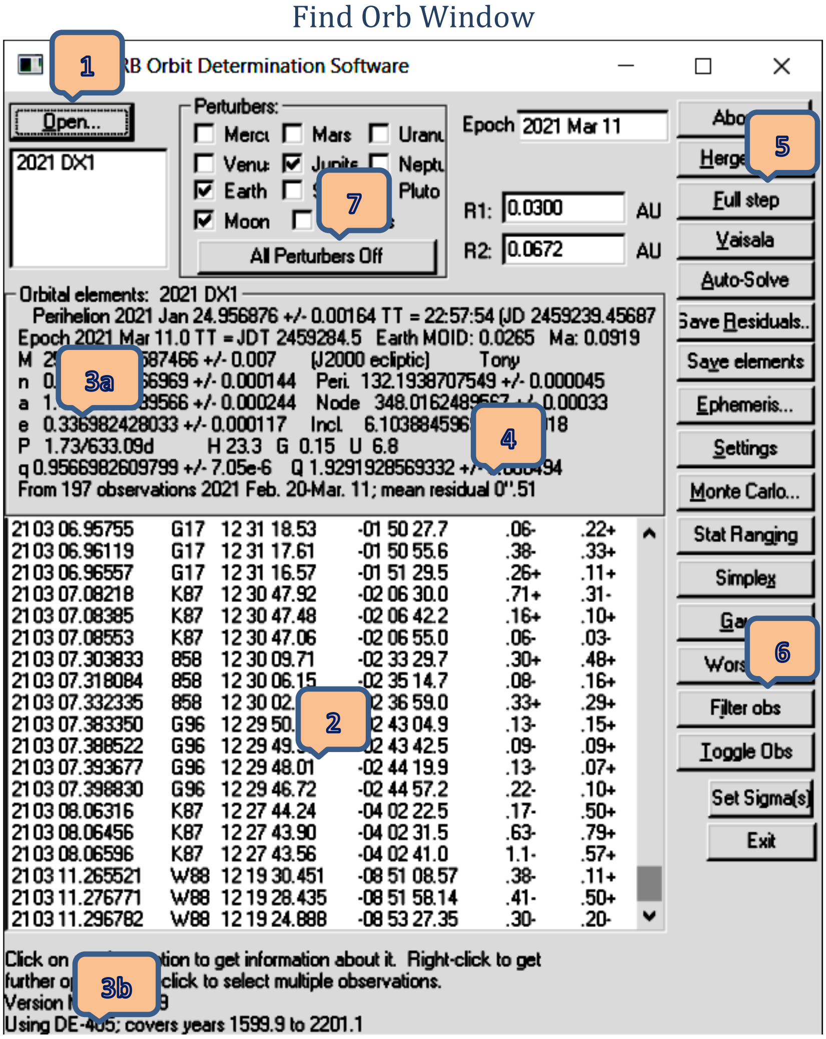
This section discusses how to obtain orbital elements from observations. The process is, to some extent, an art as much as a science and you will need to develop a "feel" for how Find Orb reacts in different situations.

Go to the MPC Observations database, enter the name, number or designation of your object and “show”. Under the heading “Observations” there is a link to “download”. Follow that link and save the resulting page. It will save with a name (objectname).txt.

Open the file of observations in any plain text editor and examine it. If the object has a long history, delete everything prior to the last two or three oppositions. Add your ADES report (complete contents of the Astrometrica ADES report) to the end of the file and save.

Start Find_Orb and Open the observation file.

Find Orb Window



Basic Procedure

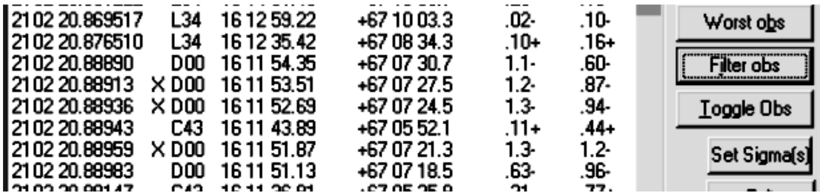
1. Open the file of observations. If there are observations for more than one object in the file, then you will need to select one of them from the little window under the Open button.
2. Check the observations list. The two numbers on the right are residuals in RA and Dec. You should see your observations in the list, but there may be opportunities to improve the residuals.
   Observations with an X next to the observatory code have been "toggled off" by Find Orb because their residuals are too high. You can toggle any observation on or off by double clicking on it or by selecting a range of observations and using the Toggle button.
3. Note the panel (3a) above the observation list that contains details of the orbit. Click in this area to toggle between two different sets of information. The panel (3b) below the list contains version information or details of any selected observation(s).
4. Note the "mean residual". This is the RMS value of residuals of all observations (except those toggled off). We are looking to get this number as small as possible.
5. The *Full step* button will try to improve the orbit using a least-squares approach. Use this and see if that improves the mean residual.
6. The *Filter obs* button will modify the on and off status of observations, turning off those with a statistically high residual and turning on those with a low residual, then it runs a Full Step to optimise for the changes. Use this repeatedly and see if that improves the mean residual.
7. Note the selections in the Perturbers panel. These are the objects that are considered as having a gravitational influence. Try selecting All Perturbers and then use the Full Step and Filter buttons to see if that makes an improvement.

Getting a good fit

For many objects, this basic procedure will provide good orbital elements that can be used to check your residuals or generate ephemeris. However, there are various situations where different actions should be taken, or options applied.

Toggle on/off

It will often happen that some objects are toggled "off" by Find_Orb during its initial processing or by your use of the Filter. You can toggle an observation on/off by double clicking it or by selecting it and using the Toggle Obs button. Your observations should not be "off". If they are, try switching them "on" and running Full Step and Filter a few times.



Objects with an X are toggled off.

Perturbers

Find_Orb will switch on those perturbers it considers relevant. Regardless of Find_Orb's selection, it is usually better to activate *All perturbers* before using *Full step* or *Filter obs*. The exception to this rule is when you have a recent discovery with a short arc of observations in which case accept Find Orb's choice.

- If the object is close to Earth, ensure that at least Earth & Moon are set as perturbers.
- For NEOs generally, Mars and Venus may be needed and if the observations span more than a week or so, Jupiter should be included.
- Switching on asteroid perturbers is a matter of performance. In most cases it will make no difference – very occasionally it will.

Too many observations

Objects with a long history will have too many observations for Find Orb to process in its initial attempt. Our normal strategy is to delete most of the old observations from the input file.

If you do want to fit a long history, the challenge is to encourage changes to the solution that will allow most of the observations to be toggled "on" and have small residuals.

- Always set *All perturbers* on. Objects with long histories may have suffered a lot of perturbation.
- Select a small group of "off" observations, adjacent to the period containing the "on" observations, and toggle them on. Then use *Full step* a few times. Repeat this until most of the observations have low residuals.
- When most of the observations have reasonable residuals use *Filter obs* repeatedly until the "No change" message

appears. That should ensure most of the observations are toggled "on" and the residuals are minimal.

Too few observations

Recent discoveries may have very few observations. If Find Orb initially comes up with a solution that looks reasonable, that may be as good as you will get. You can try *Full step*; if it works, fine, but it may have little effect or may result in rubbish. (Rubbish = eccentricity way above 1, orbital elements turn red)

There are various alternative orbit-solving methods like Vaisala, Herget, Gauss etc. These are described in the Find_orb website but you will not normally need them.

Settings

The downloaded program will come with some default settings, but if you want to “play” here are some suggestions.

Constraints

You can put in constraints for the solution like e<0.5 or a>2.0.

Element centre

This controls which body is used as the central mass for the orbital elements. It is normally set to Automatic, but you may want to override the automatic choice:

- If the object is close to Earth at the epoch, Find Orb may propose a Geocentric orbit, but you would normally want a heliocentric orbit for an asteroid.
- You may want to force a Geocentric orbit for an object when analysing for a potential impact or if it is an ARTSAT.

Physical Model

This is normally set to Standard, which is Newtonian gravity (with some corrections for relativity). Alternatives are:

- Include SRP (Solar Radiation Pressure) only of you are studying the long-term obit of something that may be affected. This can also be used for an ARTSAT that may be close to re-entry and will (partially) compensate for high-altitude drag.
- Comet non-grav handles comet out-gassing and we will discuss more in Level 3.

Filtering

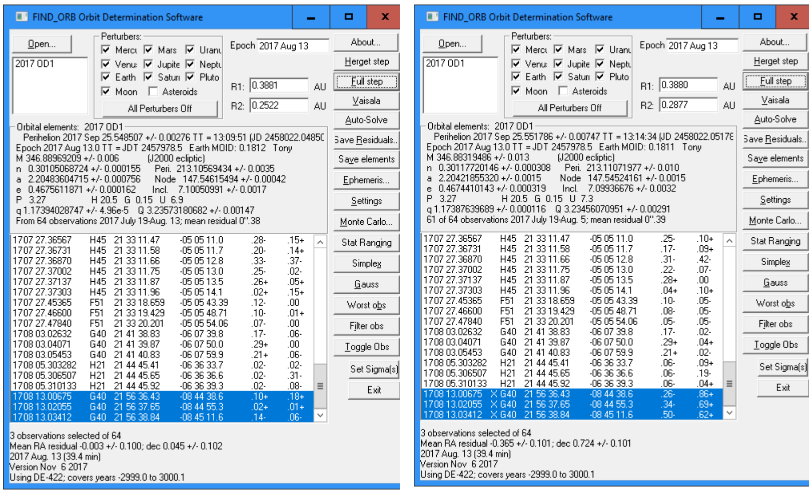
This is the residual size used when the Filter button is pressed. Max residual between 1.5 and 2.0 sigmas seems to give reasonable results with orbits and residuals like those obtained by the MPC and JPL Horizons.

- If there are plenty of observations, you can afford to be fussy and use only the best with a low-sigma filter. If there are few observations, you do not want to reject many and a higher sigma filter may be used. For very recent objects with only a handful of observations do not use the filter, although you may want to toggle "off" any obviously bad observations.

Over-observing

Some observatories submit huge numbers of observations, and this function helps stop them having a disproportional effect on the orbit.

Residuals



Residuals generated with my observations "on" and "off"

Solve the orbit as described above, making sure your new observations are toggled "on".

- Save Residuals to a file.
- Select your new observations and toggle them "off".
- Press Full Step a few times and Save Residuals to another file.
- Copy your residuals from the two files and present them as part of your report.

The purpose of this is:

- To ensure that an orbit can be produced with your observations included.
- To see how different the orbit is with and without your observations.

Quality

The orbit derived by Find_Orb is calculated to minimise the mean residual of all the observations presented to it. When this includes your new observations (toggled "on") we would expect the residuals to be small.

As a rough guide for an A-Team students:

- <0.25″ excellent.
- <0.50″ good.
- <0.75″ acceptable for a difficult object in need of observation.
- >0.75″ try again! (or maybe the images are simply not good enough).

Qualified A-Team members would hope to do better than this but will consider how difficult the object is to observe and the residuals being experienced by other observatories for the same object.

If your residuals are not looking good, it may be worth having another try at measuring.

Revised 7 Mar 2022

Tony Evans

A-Team Tutorials
2.5 Reports & Publications

Reports

A-Team Report

At this point you should have a set of observations sitting in the Astrometrica ADES Report file and two sets of Residuals (observations "on" and observations "off").

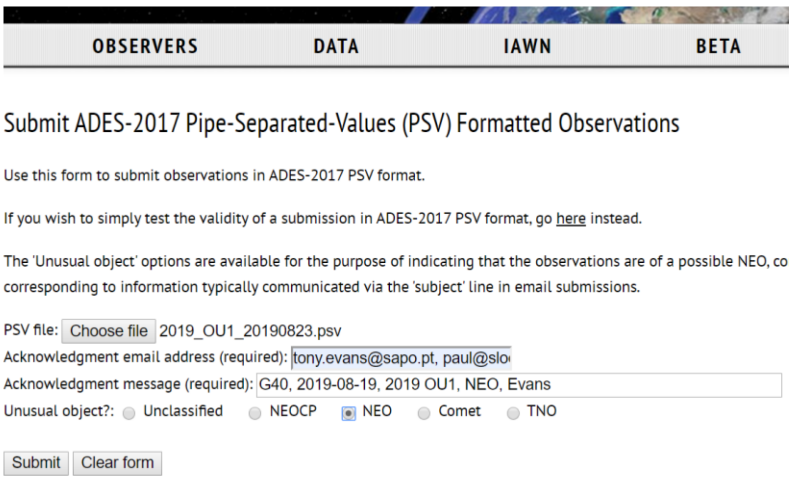
Make a report in the A-Team Club, or emailed to your tutor, that includes:

- A statement as to why the target was chosen.
- A description of any special considerations in setting up the missions.
- The measurements (ADES Report).
- The two sets of Residuals from Find Orb.
- Analysis saying whether you think the observations should be reported or not.

If the tutor agrees that the observations should be submitted, then proceed to generate a report file and submit it.

MPC Report file

MPC Reports are submitted in a .psv (pipe-separated-values) file and using an on-line page.



MPC ADES Submission Page

<u>When authorised to submit a report:</u>

- Create a blank text file with the name (objectname-date).psv.
- Copy and paste the entire contents of the Astrometrica ADES Report file into the .psv file and save it.
- Go to the MPC ADES Submission page.
- Click Choose file and select the psv file you just created.
- Set the acknowledgement email addresses to yourself and paul@slooh.com.
- Set the acknowledgement message to something like: (observatory-code), (todays date), (object designation), (object-type), (your name). The exact format is not critical, but this is the email message you and Paul will get to confirm receipt.
- Select which type of object this is or “unclassified” if none of other listed options are appropriate.
- Press “Submit”.

After a few seconds a green confirmation text should appear in the page looking like:

```
2019_AV2_20190110.psv received – submission ID is 2019-01-10T14:24:56.437_0000D3Rf
```

Note that the selection of the correct object type is important because that tells the MPC which “processing pipeline” to use. If you present NEO observations but do not correctly identify them, they will go into the wrong pipeline and will take a long time to process or may be lost.

Acknowledgement

If everything goes OK, then you should receive an email acknowledgement within a few minutes. The acknowledgement only indicates that the report has been received and recognised as having observations in it.

The acknowledgement will include the contents of your acknowledgement message and some identifiers for each individual observation. You can use these identifiers in the “Where are my observations” (WAMO) page.

Program Code

Each observer at each observatory has a “program code” for that observatory. It is recorded in the database to show who submitted what.

Your program code is assigned when you first submit observations from an observatory you have not submitted from before. It can take some time for the MPC to get round to assigning a new program code and during that period your observations will not be published. You will have to keep watching the MPC Observations Database to see your observations eventually appear. Your program code for that observatory appears in the observation record as a one-character code that replaces the normal Note code.

```
K19O01U KC2019 08 22.91383 20 39 02.03 -21 43 58.1          16.8 GVEQ043L06
K19O01U KC2019 08 22.91733 20 39 01.61 -21 44 19.2          16.7 GVEQ043L06
K19O01U KC2019 08 22.92083 20 39 01.16 -21 44 40.6          16.9 GVEQ043L06
K19O01U 3C2019 08 23.01427 20 38 52.86 -21 53 42.5          16.3 GVEQ057G40
K19O01U 3C2019 08 23.01742 20 38 52.38 -21 54 02.0          16.4 GVEQ057G40
K19O01U 3C2019 08 23.02740 20 38 50.86 -21 55 03.5          16.3 GVEQ057G40
```

My program code at G40 is "3"

Publications

You will receive no feedback from the MPC regarding its acceptance or use of your observations but "no news is good news".

You may get an email if there is a problem with your report.

Once you have a program code, observations of NEOs will begin to appear in publications and databases within 24 hours of submission while observations of less critical objects may take a week or two.

Observation format

Observations published by the MPC are still in the old obs80 (80 column punched card) format and they do not show all the details that were carried by the ADES report. (I assume the MPC will publish the full ADES data one day.)

NEOs and "Unusuals"

The easiest place to look for your observation is the observations database.

NEO observations will appear quickly and there will be an MPEC (Minor Planet Electronic Circular) number against it. Links to recent MPECs can be found here.

Your observation will probably be in a Daily Orbit Update MPEC. You can check the Daily Orbit Update MPEC each day until you see your observations.

The MPEC will show each observation record slightly changed from your original submission. The "Note" code in each observation will be replaced by your Program Code and a special catalog code will be inserted in the space between magnitude and observatory code.

After a few days or weeks, the MPEC number against your observations in the database will change to a MPS (Minor Planet Circular Supplement) number. This can be retrieved from the archive and represents the permanent publication of the observations. MPSs are published about once per week but can get a bit irregular when the MPC is busy.

Ordinary Asteroids

Observations of Main Belt asteroids may take a few days or weeks to appear. This is because they are batched up and processed periodically, usually when other work is quiet around the full Moon. There will be no MPEC number, but the observation will eventually appear with an MPS number that can be retrieved from the archive.

Minor Planet Electronic Circular (MPEC)

MPECs are published whenever there is any worthwhile news. This can be many times every day. Each time a new object is designated or a “lost” object is recovered, it gets its own MPEC. Other NEO observations are batched up into a Daily Update MPEC. Some MPECs contain huge batches of orbit updates as the MPC works its way through calculating new orbits for all the known objects.

Minor Planet Circulars (MPC)

MPCs are published about once per month and (among other things) they summarise which objects have been observed by who at which observatory. Your name and Program Code will appear together with a list of objects you have reported on.

NEODyS and AstDyS

These databases will reflect your observations soon after the MPC has published them. They include residuals and indicators as to whether your observations were accepted for use in calculating the latest orbit and calculating the latest estimate of absolute magnitude (H).

Level 2 completed!

Congratulations on getting this far! It is worth practising what you have learned on a few different objects using different telescopes then move on to Level 3.

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Tony Evans