A-Team Tutorials
Level 2 with Astrometrica

Targets and Priorities

The objective at Level 2 is to identify targets that are of scientific interest.

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.

NEOFixer

The main source of NEO priority information is now NEOFixer. This site is used by professional observatories as well as amateurs. You will need to register and set up your profile to show targets for the Slooh telescopes.

Once you have an account, select your profile (Username) and add the telescopes E62, G40 and W88 using the Telescopes tab and entering the three Observatory codes. Eventually you will get a confirmation from NEOFixer.

On the Targets page you can view a list of objects visible from a specified observatory. On the Activity page you can view targets for any of your "authorised" telescopes.

There are lots of options to sort and filter the lists. Read the FAQ.

When you select an object, you can obtain various pieces of information about it and generate ephemeris.

MPC "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 objects. 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).

The lists are 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.

MPC NEO Observation Planning Aid

The MPC provides a NEA Observation Planning Aid. It is a bit complicated but you can try it.

International Asteroid Warning Network

This page lists objects that will pass within one lunar distance. It provides direct links to the MPC pages related to the object.

Goldstone Observation schedule

The Goldstone radar station targets are listed for the upcoming weeks and there maybe something of interest there.

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.

A-Team.space

A targets list can be found at the A-Team.space website. This is a simplified list based on data from NEOFixer. Use the filter and observatory buttons to list objects of interest. You can select them and generate ephemeris from the MPC.

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 current the orbit data is. Close-approach NEOs will not be shown correctly if the software is using old data.

Find_Orb

You can download the currently published observations from the MPC Explorer and use Find_Orb to generate the ephemeris. Use of Find_Orb is described in a separate tutorial.

Tycho Tracker

If you are using Tycho Tracker, it has a Session Planning module you can try.

Visibility

You will need to obtain coordinates and check several factors:

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 reasonable results down to V=17 or 18. It is probably

best to stay at least a magnitude brighter to practice missions and measurements.

If you use the Multi-luminance recipe for your missions you will be able to "stack" multiple images for each observation and achieve 1 or 2 magnitudes fainter. On poor visibility nights the limit is 1 – 2 magnitudes brighter than on good nights.

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 which of the Slooh observatories will give you the best view.

Motion

Fast objects will leave faint trails and will be difficult to measure: Ideally the object should not move more than 3 or 4 pixels during the exposure. Work out what is the maximum speed for the length of integration you are using. In practice up to 5 or 6 arcseconds/min is manageable with 50-second exposures, maybe a bit more with practice and good clear images. For bright objects you can use 20-second exposures and get good results for objects up to 20"/m provided they are bright enough to be measured accurately after such short exposures.

Moon

Consider its impact on visibility. Remember Slooh will not allow a reservation if it thinks the Moon is too close and too bright. T1 and A1 are 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.

Uncertainty

Most 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 are probably "lost", and the ephemeris is meaningless.

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.

Missions

Check what slots are available for the coming night. Check the weather forecast for Chile, Canary Isles and Australia.

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 about 10 minutes apart (or 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.

If you have a Slooh double-membership, schedule three pairs of consecutive missions.

Multi Luminance

Missions should be set up using the Multi-Luminance recipe. This will yield multiple images for each mission, and we can use "Stack and Track". That means multiple images are averaged to get a better Signal-to-Noise ratio.

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.

The following is specific to Astrometrica.

Identify and Measure

As in Level 1, download the FITS from each mission and store them in a folder. Each mission should have produced at least two images, hopefully more.

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 header.

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

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

- Stacking involves adding or averaging 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:

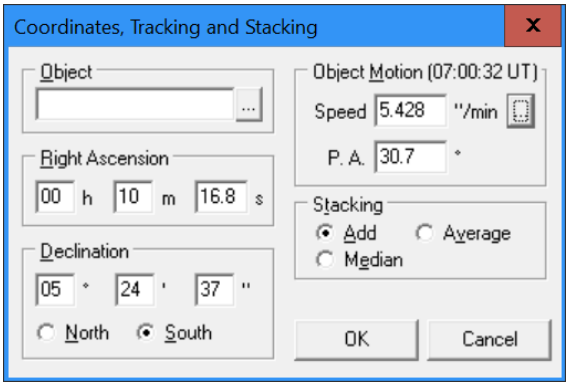
- Select the button […] next to Speed “/m.
- Enter the designation of your object in the search box.
- Press the magnifying glass,
- Select the correct object from the list displayed and press OK again.

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.



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.

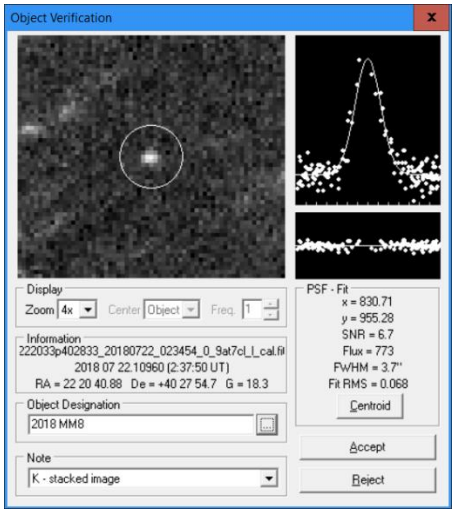
Press OK to stack. The process is like data reduction, and it is possible you may be asked to do manual alignment of reference stars.

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.

If the object is a recent discovery or 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

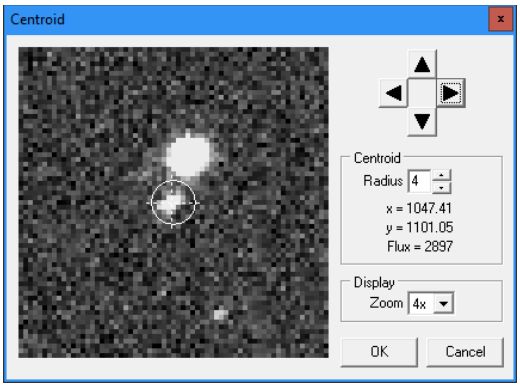
A star is a "point source" of light but its image gets spread out by a combination of factors including atmospheric movement (seeing), diffraction, telescope optics, errors in tracking etc. The overall effect is that a disk of brightness is produced in the image with the brightest point in the centre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

If you used Stack and Track, 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. (The NEO update takes a long time! There is an experimental fast updater here.).

Having objects nicely "in their boxes" is not actually necessary 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.

- 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).

Quality and Residuals

As with Level 1, check your residuals using the on-line Find_Orb service.

At this point you should also look at the Find_Orb application as described in the Find_Orb Tutorial. This is quite a complex application but if you want to get seriously into Near Earth Object tracking then you should learn to use it.

What are reasonable residuals?

I would recon that residuals under 0.5" are good enough.

For an object that has been recently observed by others, your residuals should be at least comparable to theirs. There is no point in submitting poor observations to the MPC if good observations are already in the database.

For an object that is in urgent need of observations, you can be more lenient.

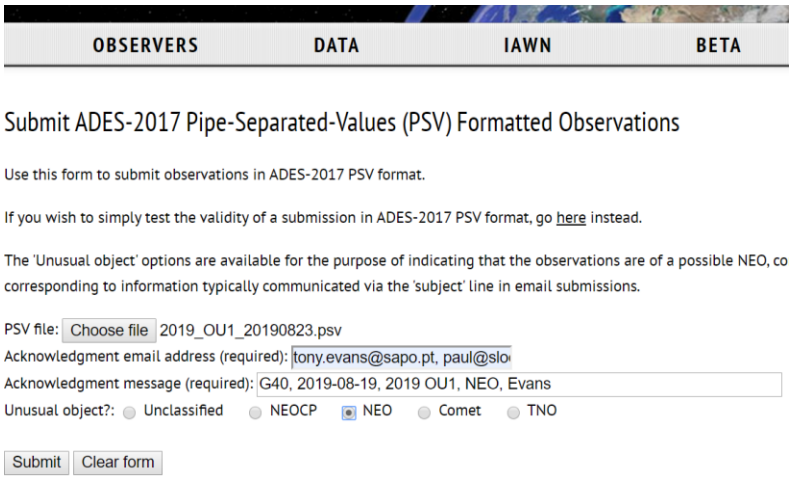
Reports and Publications

A-Team Report

As for Level 1, send a copy of the ADES report and your residuals to your tutor. If the report is of appropriate quality, your tutor will invite you to send it to the MPC as follows.

MPC Report

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



MPC ADES Submission Page

When authorised to submit a report:

- 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 or "unclassified" if none of the 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.

Keep a copy of the submission ID as it may be needed later to check the status of your report.

Acknowledgement

If everything goes OK, 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. Save this information. 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 each observatory. 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. Check "Where are my observations" to find out if your observations have been published. 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. (You can now retrieve ADES reports from the MPC but they are in JSON format and suitable only for computer processing).

NEOs and "Unusuals"

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

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.

Tony Evans, last update Aug 2025