Using Find Orb

Applies to the Find Orb release 8 Aug 2014

This document is a collection of notes describing some uses of Find Orb and the data it produces. It is assumed that you have Find Orb installed and configured as described in the Find Orb Reference Guide and you have a reasonable understanding of what the program does.

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CONTENTS

1 OBSERVATIONS

The first thing you will need is observations. They are available from several sources.

1.1 MPC Observations Database

Go to the Minor Planet Centre (MPC) website and select Observers/Observations Database. Enter the name, number or designation of your object in the box and select *Show*. A page will appear containing details of the object's orbit(s) and a table of observations. There is a link at the top of the table to download the observations. This will produce a page that can be saved as a text file.

You must search the Observations DB using the object's most recent designation or number. If you search using a Temporary Designation when the object has a number you will only get the observations published prior to numbering.

The situation may be more complicated for numbered comets especially if they have had multiple designations (e.g. due to re-discovery). You may need to assemble the complete set of observations from multiple designations and weed out duplicates.

Open the text file of observations using WordPad then save it again without changes. This will change the end-of-line characters from the UNIX "0A" to the Windows "0D0A" so that the file can in future be edited using Notepad.

1.2 NEOCP Observations

Go to the MPC NEOCP webpage and select the object of interest. Select *Get ephemerides* and a page will appear with a table of ephemerides. At the top there is a link to the observations. Unlike the observations from the database, this page is not set up to save as a text file and you will have to override the file name and type (e.g. UB12d45a.txt) to force it to save as text. You should also open the file in WordPad, strip away all the HTML header/trailer code and save.

1.3 AstDyS/NEODyS Databases

Go to the AstDyS or NEODyS website. Select *Search* from the top menu. Enter a name, designation or number and press enter. Select the appropriate match. Observational Info (left menu) provides a page of observation statistics. At the bottom of the page is a link to *ASCII file* that can be saved as a .rwo file. It may not be as up-to-date as the MPC file.

The .rwo file can be read by Find Orb but observations produced by Astrometrica cannot be added to it because it is in a different format. The advantage of the .rwo files is that they have positional uncertainties already calculated by AstDys/NEODyS and Find Orb will use these.

AstDys has asteroids (but not all); NEODyS has only NEOs but also carries risk-related information.

2 UNCERTAINTIES

There are three types of uncertainty associated with any observation:

- Positional uncertainty: depends on how accurately was the position measured.
- Time uncertainty: depends on how accurately the time stamp was set in the image.
- Magnitude uncertainty: depends on how accurately the magnitude was measured.

2.1 Positional Uncertainties

The "residual" of an observation is the difference between the measured position of the target and its theoretical position calculated from the orbital elements displayed by Find Orb.

The size of the residuals will vary greatly depending on the equipment being used, the weather and "seeing" at the observatory, the skills of the observer and the accuracy of the orbital elements. It is important to realise that a residual is not simply an "error"; it arises from limits in the accuracy of the observation combined with limits in the accuracy of the elements.

It is assumed that, for any given series of observations, the distribution of measurements is random. The spread of residual values follows the Normal bell-shaped curve defined by the value of its "Standard Deviation" (SD). In the example below it is assumed that the actual position of the object is at 0SD (the peak) and the spread of observations will be in proportion to the height of the curve.

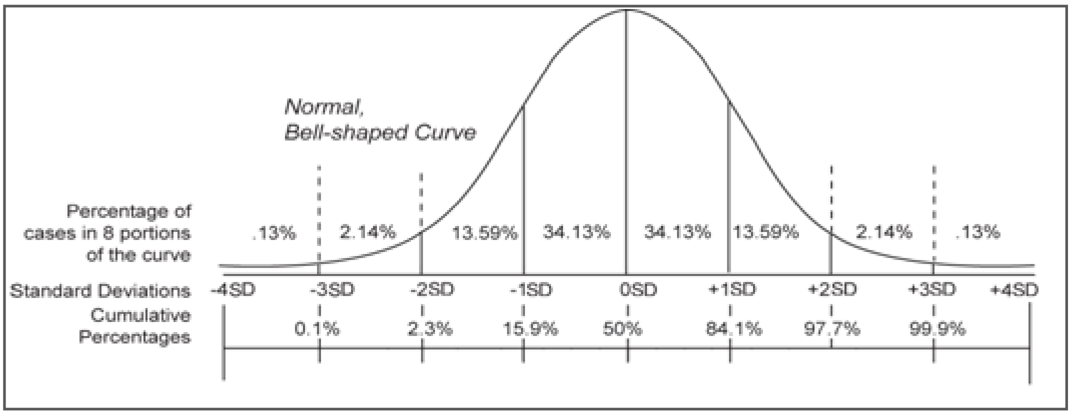


Figure 1 The Normal Curve

The standard deviation of a set of observations is calculated by averaging the squares of each individual residual and taking the square root of the result. For this reason it is often called the RMS (root mean square) value. In mathematics the standard deviation is represented by sigma (σ) and so standard deviations are also often called "sigmas".

As can be seen from the Normal Curve shown above, the majority of the observations fall in the central region (95% inside 2 sigmas) and we may elect to exclude (toggle off) "outlier" observations that fall towards the edge of the population. The Find Orb Filter will "toggle off" observations that fall outside a specified number of sigmas. I normally use 1.5 sigmas for asteroids and 2 sigmas for comets. These observations take no further part in the orbit calculations. This is intended to exclude "blunders" such as measuring the wrong object, not having the observatory clock correctly set, or measuring a really bad image.

Find Orb shows you the residuals for every observation and you can see that some observatories sometimes have much smaller residuals than others – leading to the conclusion that some observatories sometimes produce more accurate observations than others (surprise!). More accurate orbital elements may be produced when differences of performance between observatories are taken into account.

In Find Orb, it is possible to specify the sigma of observations from a specified observatory for a specified time period. For example you can say "in 2008 observatory G68 had residuals with sigma 0.7" while in 2013 their sigma was only 0.43".

When Find Orb is calculating the optimum value of orbital elements it knows that it can give more or less weight to an observation depending on the performance (sigma) of that observatory at the time of the observation.

The sigmas for each observatory, for each time period, can be set up in the file *sigma.txt* in the Find Orb folder. There is a version of *sigma.txt* included in the Find Orb download and this contains some specific sigmas for well-known sites as well as some interesting comments (go ready it!).

The MPC periodically publishes residuals performance data for all observatory codes and this data can be used to create a detailed *sigma.txt* file. The file is available here and will be updated periodically.

2.2 Time Uncertainties

Time uncertainties are particularly important for fast movers. If an object is moving at 0.5"/min then an error in the time stamp of 5 seconds will cause an error in position of 0.04" - lost in the noise. If it is moving at 50"/min the same timing error shows as 4.2" - enough for the observation to be rejected.

Observatory performance does vary considerably and time-sigmas can be set up as for positional uncertainty. Unfortunately there are no statistics, so the sigma.txt file has very little information.

2.3 Magnitude sigmas

The sigma.txt file can also be used to set up observatory performance sigmas for magnitudes, but there is currently only default data in it.

3 ORBITAL SOLUTIONS

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.

3.1 Basic Procedure

The basic procedure is:

1. Open a file of observations.
2. Set *All perturbers* on.
3. Use *Full step* several times until the orbit changes very little.
4. Use *Filter obs* several times until the "No changes" message is received.

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

3.2 Options and Alternatives

3.2.1 Perturbers

Find Orb will usually switch on those perturbers it considers relevant. Regardless of Find Orb's selection it is strongly advised to activate *All perturbers* before using *Full step* or *Filter obs*. The exception to this rule is when you have a recent discovery with very few observations in which case accept Find Orb's choice. If the object is close to earth (R1, R2 small) then ensure that at least Earth & Moon are set as perturbers.

Switching on asteroid perturbers is a matter of performance. In most cases it will make no difference – occasionally it will. A system set up with 300 asteroids will run slowly. Switch on asteroids only if it is essential to get the very best elements and the object has passed through the Main Belt or is a Main Belt Asteroid.

3.2.2 Too many observations

Objects with a long history will have too many observations for Find Orb to process in its initial attempt. In this case it will toggle "off" all observations except for those for a particular period. The initial solution will use observations only from that period and may leave many of the other observations with large residuals. The challenge is to encourage changes to the solution that will allow most of the observations to be toggled "on" and have small residuals.

The strategy is:

- Always set *All perturbers* on. Objects with long histories will have suffered a lot of perturbation.
- Select a group of "off" observations adjacent to the period containing the "on" observations. Force them "on" using the *Toggle obs* button. Then use *Full step* a few times. Repeat this until most of the observations have low residuals. You should now be able use *Filter obs*.
- 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. Do not worry if a lot of very ancient observations are "off" but your solution should have very few observations "off" in the last couple of decades.

3.2.3 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.

If Find Orb initially comes up with an impossible orbit you can try using the Vaislala or Herget method.

Remember, with very few observations, you are not going to get an accurate orbit. Anything that looks like a reasonable fit may suffice to provide ephemeris or residuals.

If the option *Alternative element format* is selected in Settings, the elements will include error sigmas for example "e=0.4865924 ± 2.1e-7". If the error sigmas are all small it means Find Orb has probably found a good orbit. If they are high then beware the orbit may not be good.

3.2.4 Filter Settings

Settings/Filter/Max residual between 1.5 and 2.0 sigma seems to give reasonable results with orbits and residuals similar to those obtained by the MPC and JPL Horizons.

If there are plenty of observations then you can afford to be fussy and use only the best with a low-sigma filter. If there are few observations then you do not want to reject too many and a high-sigma filter should 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 or inconsistent observations.

Comets are partially difficult to measure accurately and a high-sigma filter is normally used.

3.2.5 Non Grav and Solar Radiation

Non grav (for comets) and SRP (for asteroids) are parameters that describe how their effects cause deviation from a Newtonian path. It is only possible for Find_Orb to determine these parameters if the object has a long history of observations. Using these parameters is unlikely to make a meaningful difference for most objects.

In the case of an Oort Cloud comet the value of its Non-grav parameter can change significantly as it approaches the inner Solar System and passes through perihelion. To get a good orbit fit you may need to select observations from a limited period and run full step with Non-grav turned on.

3.2.6 Geocentric Orbits

This controls whether Find Orb can generate a geocentric orbit (or orbit centred on another planet).

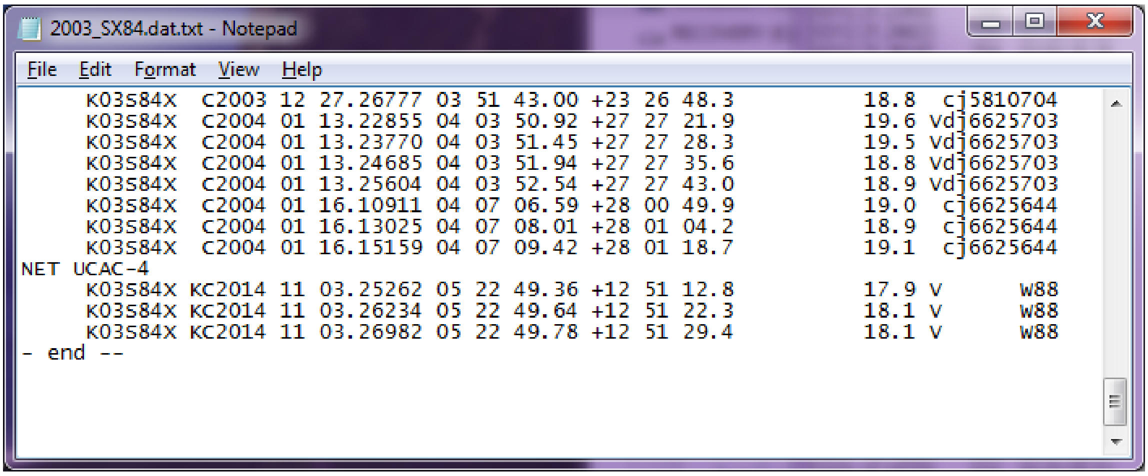
If *Settings/Heliocentric orbits only* is not selected and the object is close to Earth at the epoch then Find Orb may propose a Geocentric orbit. An object on a close approach will have a hyperbolic orbit (e>1) relative to Earth. If it has Perigee < radius of Earth + collision height an impact will be indicated.

4 USING THE ORBIT

4.1 Residuals

You can check the quality of observations using “residuals”. A residual is the angular difference between a position observed and a position predicted by orbital elements.

Open the file of observations for editing. Copy and paste your new observations to the end of the file. You can include any of the MPC Report headers as these will be ignored by Find Orb. Be careful to retain the proper format – don’t allow any extra spaces to creep in beyond the observation text and ensure the last line has an end-of-line by including the final “---end---”.


2003_SX84.dat.txt - Notepad

File Edit Format View Help

```
     K03S84X  C2003 12 27.26777 03 51 43.00 +23 26 48.3          18.8  cj5810704
     K03S84X  C2004 01 13.22855 04 03 50.92 +27 27 21.9          19.6 Vdj6625703
     K03S84X  C2004 01 13.23770 04 03 51.45 +27 27 28.3          19.5 Vdj6625703
     K03S84X  C2004 01 13.24685 04 03 51.94 +27 27 35.6          18.8 Vdj6625703
     K03S84X  C2004 01 13.25604 04 03 52.54 +27 27 43.0          18.9 Vdj6625703
     K03S84X  C2004 01 16.10911 04 07 06.59 +28 00 49.9          19.0  cj6625644
     K03S84X  C2004 01 16.13025 04 07 08.01 +28 01 04.2          18.9  cj6625644
     K03S84X  C2004 01 16.15159 04 07 09.42 +28 01 18.7          19.1  cj6625644
NET UCAC-4
     K03S84X KC2014 11 03.25262 05 22 49.36 +12 51 12.8          17.9 V      W88
     K03S84X KC2014 11 03.26234 05 22 49.64 +12 51 22.3          18.1 V      W88
     K03S84X KC2014 11 03.26982 05 22 49.78 +12 51 29.4          18.1 V      W88
- end --
```

Figure 2 Example observation file.

Save the modified observation file and open it with Find Orb. Establish the best possible orbit solution as described in Section 2.

You can produce two sets of residuals:

1. Make sure your observations are toggled "on" and press Full Step a few times. These are the residuals you get with your observations included.
2. Toggle your observations "off" and press Full Step a few times. These are the residuals you get when your observations are not included in the calculation.

You can save the residuals using *Save residuals*.

If there is a big difference between the residuals produced by (1) and (2) it means that your observations will have a significant impact in changing the elements (hopefully improving them).

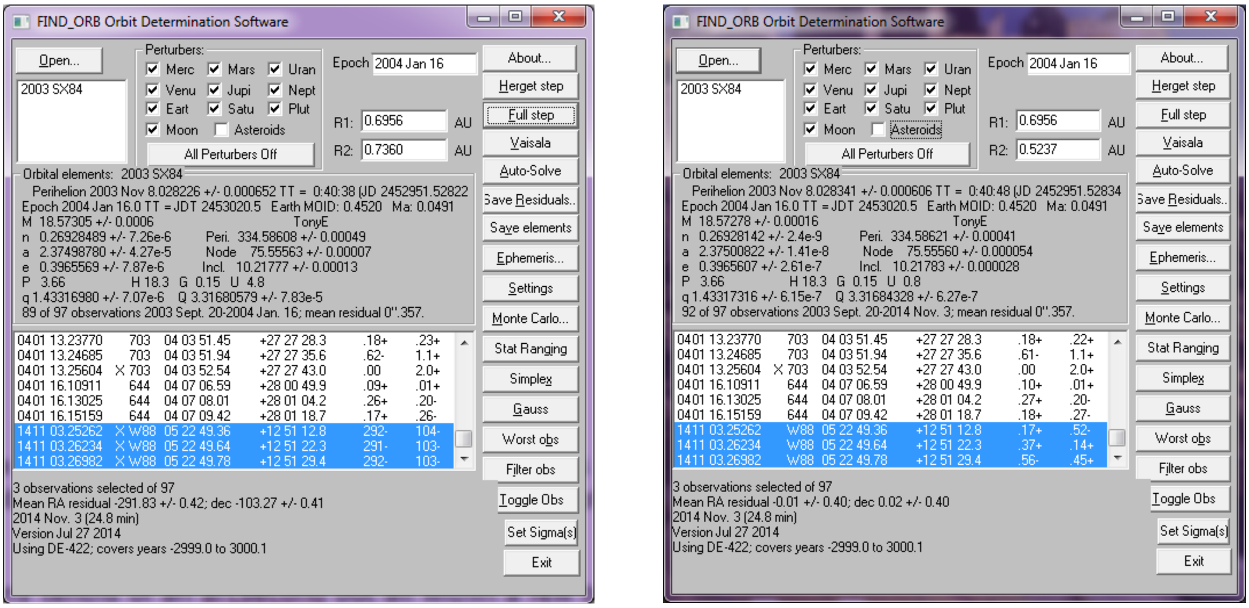


Figure 3 Residuals for 2003 SX84 with new observations from W88 toggled off or on.

Good quality observations will show consistency. Regardless of their magnitude, the residuals from (1) should be very similar. The residuals from (2) should be consistently low.

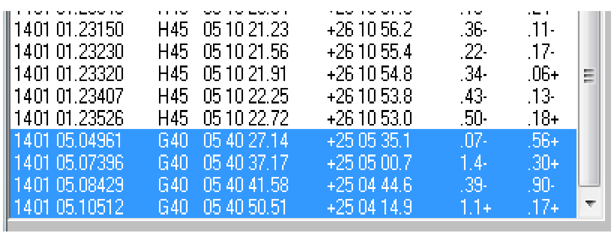


Figure 4 Inconsistent residuals.

If your residuals are high or mixed high/low and inconsistent then that may indicate problems with the image or the measurement approach. These observations should not be submitted to the MPC.

4.2 Ephemeris

Normally we will obtain ephemerides from the MPC or JPL Horizons. Sometimes it is useful to use Find Orb to generate the ephemerides.

- To include the effects of your own observations in the orbit.
- When the MPC has not yet published ephemeris but observations are available.

Obtain the observations and an orbital solution with minimal residuals as described in previous sections. Select *Ephemeris*. The mechanics of using the Ephemeris page are explained in the Reference Guide, but here are some comments about the fields and options based on experience.

Field	**Comment**
Start	Many formats are allowed for the start time see here. It is probably best to stick to some familiar formats such as: +0 (now) +3h (in three hours from now) 2014 01 10.8 2014 01 10 21:00
Stepsize	This is also quite flexible e.g. 1.0 (once per day – times shown as decimal) 0.1 (every 1/10th of a day – show times as decimal) 0.1: (every 1/10th of a day – show time as hh:mm:ss) 1h (every hour) 45m (every 45 minutes)
MPC Code	Should be set to your Observatory Code or insert your observing latitude and longitude. Set to 500 (Earth centre) when looking for a close approach.
Suppress output below mag	It is best to set this to 999 otherwise ephemerides may not be shown and you won't realise why.

The recommended selection Y or N for these options are based on my usage and preferences.

Option	**Select**	**Comment**
Show motion details	Y	To see whether the object is moving too fast for measurement. To get the speed and direction (PA) for Stack and Track in Astrometrica.
Separate motions	N	You don't often need to know separate RA and Dec motions.
Show Alt/Az	Y	To see when the object is high enough above the horizon and when it is near the meridian.
Radial Velocity	N	Only a matter of interest. You can easily tell if it is coming or going from how the delta (distance from observer) is changing with time.
Phase angle Phase angle bisector	N	Not normally of interest.

Heliocentric ecliptic Topocentric ecliptic	N	These types of coordinates are not normally useful when planning observations.
Round to nearest step	N	This forces the ephemeris times to an integer Stepsize fraction of a day regardless of the start time.
Human readable	Y	The alternative is definitely not readable (but can be useful a machine readable).
Ephem. Uncertainty	Y	This can warn that the object is in an uncertain orbit. The Sig /PA columns show the 1-sigma uncertainty in position and the direction of that uncertainty. Up to a few arcseconds is not a problem but if you see “5d” that means the object could be anywhere within 5 degrees!
Visibility Indicators	Y	The SM (Sun Moon) column can warn of visibility problems: C - civil twilight, Sun down to -6° N - nautical twilight, Sun down to -12° A - astronomical twilight, Sun down to -18° * - unobservable M -Moon is intrusive
Suppress unobservables	Y	Remove unobservable ephemerides.

4.3 Close Approaches

If the Earth MOID is small it may be of interest to look for a close approach. Proceed as for Ephemeris above, but select Close Approaches instead of Observables. Note that close approaches:

- Will only be shown for the requested period i.e. Start + #steps×Stepsize.
- May be in the past.
- Only appear if the object’s magnitude is brighter than “Suppress output below mag”.
- Can be requested for other planets by putting “Mer”, “Ven” etc. as the observatory code.

4.4 Uncertainty - Using Clones

The accuracy of orbital elements will depend on the quality and number of observations and there will always be some uncertainty. Indicators of uncertainty are shown in the MPC ephemeris (uncertainty and offset) and Find Orb ephemeris (Sig/PA). Uncertainty can be displayed by planetarium software, giving a graphical view of the range of possible positions of an object.

A set of “clone” objects is generated, each of which has a slightly different orbit generated statistically from the uncertainty of the original orbit. The “real” object is somewhere in the “cloud” of clones and the more densely the clones are packed together the more likely the real object will be in that region of the cloud.

There are two methods of generating clones in Find Orb; Monte Carlo and Statistical Ranging.

- To generate each clone, Monte Carlo applies “noise” to the observations (random adjustments based on the value in *Settings/Monte Carlo noise*) then re-calculates the

orbital elements from the modified observations. This method is generally considered the more statistically sound but may fail if there are too few observations.
- Statistical Ranging makes trial assumptions about the initial distance and radial velocity and looks for elements that bring the object to the final observation, saving them as a clone if they have reasonable residuals. This method has the advantage that it works with small numbers of observations but may fail when there are many.

Both methods are used in the same way. Press the *Monte Carlo* or *Stat. Ranging* button. The number of clones generated shows on the button. Press again when enough clones have been created; usually around 50 is enough. The clone orbits are saved in MPC 1-line format in the file *mpcorb.dat* in the Find Orb folder.

For the clones to show up correctly in planetarium software their epochs must be close to today. This can be achieved by entering today's date in *Epoch* and using *Full step* a few times before generating the clones. The overall procedure then becomes:

1. Obtain the observations.
2. Obtain a good orbital solution.
3. Set the *Epoch* to today (if necessary).
4. Generate clones with *Monte Carlo* or *Stat. Ranging.*
5. Transfer the clones from *mpcorb.dat* to your planetarium software and display.

The image on the left shows the spread of 50 clones of the NEOCP object N00087u at 2014-01-19.9 based on observations up to 2014-01-16.9.

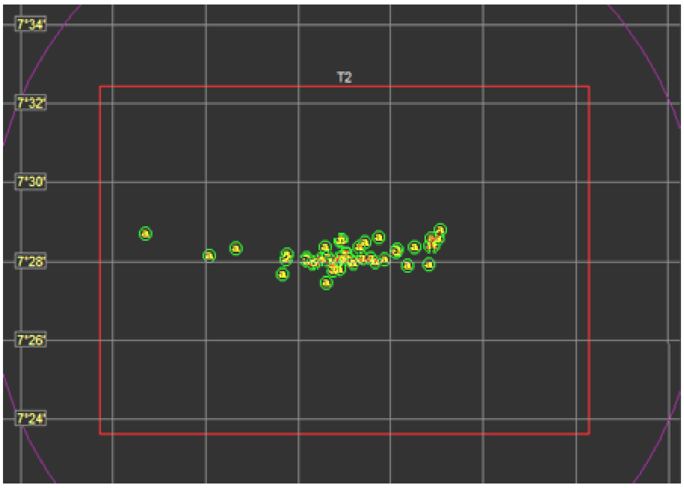


Figure 5 NEOCP N00087u clones 3 days into future.

4.5 Recovery – using clones

If the object you are seeking has not been seen for years then the method of using clones described above may not work because Find Orb cannot get good orbits for today's epoch from a handful of old observations.

We must create the clones with an epoch near the date of observations then simulate how each individual clone has moved in the interim period.

The program to do this is Integrat. It can be installed in the Find Orb directory and will use numerical integration to simulate the orbits of each clone in *mpcorb.dat* as it brings their epochs up to date. Appendix 1 explains how to install and run Integrat.

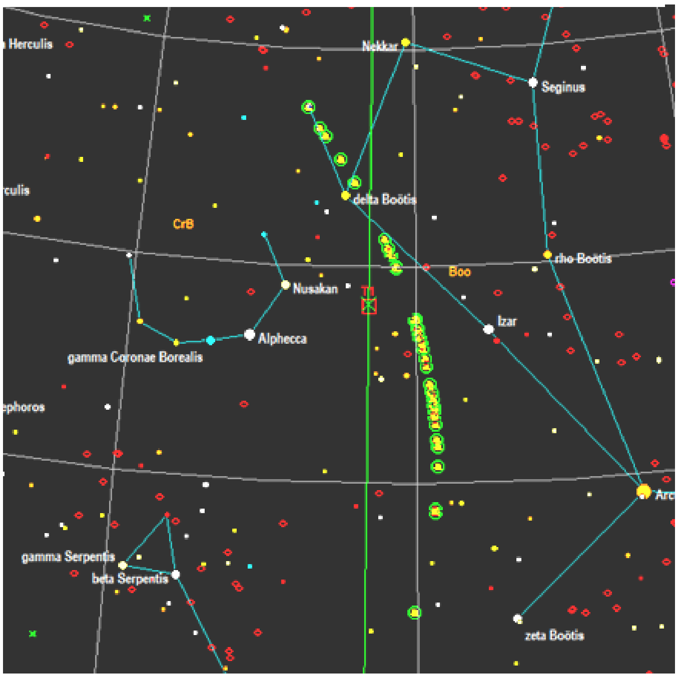


Figure 6 2007 EB26 clones as viewed in Jan 2014.

The procedure is:

1. Obtain the observations.
2. Obtain a good orbital solution.
3. Set the *Epoch* to around the last observation (or leave the Find Orb default).
4. Generate clones with *Monte Carlo.*
5. Run Integrat.
6. Transfer the clones from *newmpcorb.dat* to your planetarium software and display.

Don't be surprised if some of the objects listed as "recovery opportunities" are spread over tens of degrees of sky.

4.6 Virtual Impactors – using clones

There are two situations; the object will impact Earth at this close approach (i.e. in the next few days) or the object will miss Earth at this close approach but may impact at some future date.

If an object has an orbit with a MOID close to zero then see if Find Orb will generate a geocentric orbit (turn off *Heliocentric orbits only* in *Settings*). If it comes up with a geocentric orbit and Perigee is less than about 7000km then impacts may be possible. Generate clones using Monte Carlo or Statistical Ranging and, if any of the clones has an impact, the details will be recorded in *virtual.txt*.

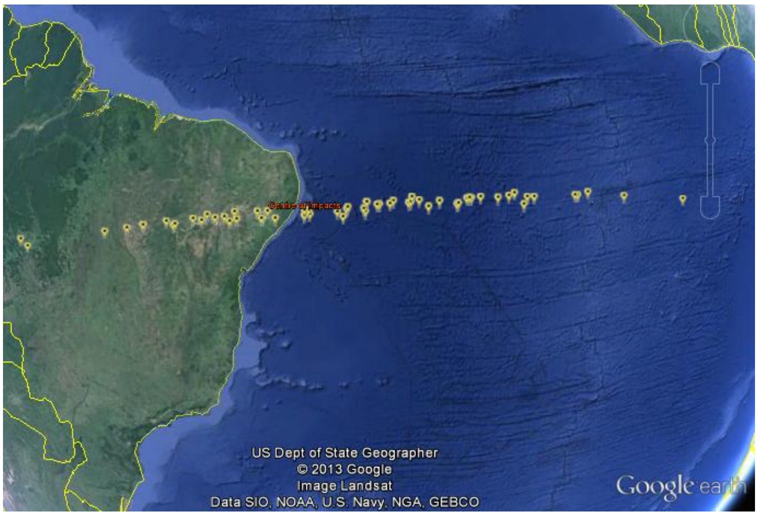


Figure 7 Impacts of 50 clones of 2014 AA

The impact data in *virtual.txt* can be use to generate a map showing the Range of possible impact locations.

(Notes on future impacts will be produced in the future! Meanwhile there is always the Sentry Table).

APPENDIX I INTEGRAT

The objective of Integrat is to perform numerical integration of orbits, simulating the movements of objects according to the laws of gravity and taking into account perturbations and close approaches. In this context it is used to simulate the movement of asteroid or comet clones from one epoch to another. Integrat is produced by the same author as Find Orb. It runs in the “DOS Box” but can be set up to run quite easily in Windows.

Create a folder called *integrat* that is a sub-folder of the one in which you have Find_Orb installed.

Go to the Integrat home page and download the program. The zip file will contain several files. These should be extracted into the *integrat* folder:

integrat.exe
lunar.dll
vsop.bin

The instructions on the website involve manually opening the DOS box and typing commands but it is easier to set up a .bat file:

Create a new text file in the Find Orb folder.

Copy and paste the following text into it:

```
echo
%CD%/integrat/integrat.exe MPCORB.dat newmpcorb.dat today
pause
```

Rename this file `runintegrat.bat`

When you double-click the .bat file it will read *mpcorb.dat*, evolve all the clones to today’s epoch and save them in the file *newmpcorb.dat*.

If you have the JPL DE files installed, Integrat will be faster and more accurate. To use them change the .bat file to add “-f” followed by the name of the DE file, e.g.:

```
echo
%CD%/integrat/integrat.exe MPCORB.dat newmpcorb.dat today -flnxm3000p3000.422
pause
```

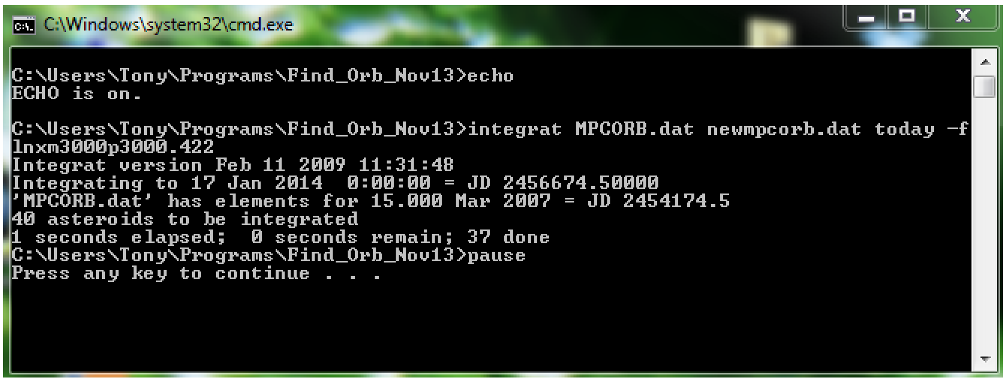


Figure 8 Integrat in the DOS box with 2007 EB26.