On the accuracy and uncertainty of asteroidal occultation predictions

Mike Kretlow – ESOP 34
2015, Hannover, Germany
Motivation

- What is accuracy what is uncertainty?
- Occultation predictions and uncertainty in the Pre-Hipparcos era.
- Occultation predictions and uncertainty in the Post-Hipparcos era.
- Future prospects (GAIA).
Accuracy refers to how closely the measured value of a quantity corresponds to its "true" value.

An uncertainty estimate should address error from all possible effects (both systematic and random) and, therefore, usually is the most appropriate means of expressing the accuracy of results.
Pre-Hipparcos era (and in general time before ~ mid 1990ies)

- Typical error of star positions ~0.5-1 arcs, sometimes even 1.5 arcs.

- (Photographic) astrometry based on this catalogs.
  - Not so much reference stars (=>averaging random errors) like today even in smaller CCD fields because of star density of modern catalogs.
  - Sometimes wide-field issues in plate solutions.

- Astrometrical data set of asteroids usually not so comprehensive like today (more observatories, more CCD observations).

- Typical orbit solution RMS of a good observed asteroid 0.5-1 arcs (do not confound this with the ephemeris error ellipse).

- Other (more or less negligible) influences: planetary dynamical model, reference system (issues), precision and nutation theory and time scales.
Pre-Hipparcos era

- In summary the total prediction uncertainty (star + ephemeris) on the fundamental plane was typically ~1-1.5 arcs for an MB asteroid.

<table>
<thead>
<tr>
<th>--</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
<th>2.5</th>
<th>3.0</th>
<th>3.5</th>
<th>4.0</th>
<th>5.0</th>
<th>10.0</th>
<th>20.0</th>
<th>30.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>36</td>
<td>54</td>
<td>72</td>
<td>90</td>
<td>108</td>
<td>126</td>
<td>145</td>
<td>181</td>
<td>362</td>
<td>725</td>
<td>1087</td>
</tr>
<tr>
<td>0.1</td>
<td>72</td>
<td>108</td>
<td>145</td>
<td>181</td>
<td>217</td>
<td>253</td>
<td>290</td>
<td>362</td>
<td>725</td>
<td>1450</td>
<td>2175</td>
</tr>
<tr>
<td>0.5</td>
<td>362</td>
<td>543</td>
<td>725</td>
<td>906</td>
<td>1087</td>
<td>1269</td>
<td>1450</td>
<td>1813</td>
<td>3626</td>
<td>7252</td>
<td>10878</td>
</tr>
<tr>
<td>1.0</td>
<td>725</td>
<td>1087</td>
<td>1450</td>
<td>1813</td>
<td>2175</td>
<td>2538</td>
<td>2901</td>
<td>3626</td>
<td>7252</td>
<td>14505</td>
<td>21757</td>
</tr>
<tr>
<td>1.5</td>
<td>1087</td>
<td>1631</td>
<td>2175</td>
<td>2719</td>
<td>3263</td>
<td>3807</td>
<td>4351</td>
<td>5439</td>
<td>10878</td>
<td>21757</td>
<td>32636</td>
</tr>
<tr>
<td>2.0</td>
<td>1450</td>
<td>2175</td>
<td>2901</td>
<td>3626</td>
<td>4351</td>
<td>5076</td>
<td>5802</td>
<td>7252</td>
<td>14505</td>
<td>29010</td>
<td>43515</td>
</tr>
<tr>
<td>5.0</td>
<td>3626</td>
<td>5439</td>
<td>7252</td>
<td>9065</td>
<td>10878</td>
<td>12691</td>
<td>14505</td>
<td>18131</td>
<td>36262</td>
<td>72525</td>
<td>108788</td>
</tr>
</tbody>
</table>
Post-Hipparcos era

- Hipparcos / Tyc-2 itself and secondary catalogs linked to the HCRF improved accuracy and homogenity of astrometric observations.

- Orbits improved over the years due to growing number of observations in the Hipparcos system.

- More and better CCD astrometry in past ~ 20yrs.

- But also better planetary ephemerides (JPL), planetary models (e.g. masses of perturbing asteroids), etc. Though not so big impact.
Post-Hipparcos era

- Typical uncertainty for star position at current:
  - URAT1 : < ~ 50 mas
  - UCAC4 : < ~100mas

- Typical ephemeris uncertainty for MB asteroid: anything from ~10…500 mas (dedicated updated orbit solutions typically < 50 mas)

- Typical uncertainty for MB asteroids < 200km
  - With updated orbit < 100km
From astrometry to occultation (a long way with a lot of uncertainties)

- In brief: astrometry – orbit improvement – calculate perturbed ephemeris – compare with star position for given time – calculate occultation on FP – transformation to Earth surface.
Astrometry of asteroids

- Very individual process: instrument, observing conditions, detector, star catalog, timing, reduction process.
- A lot of errors involved, random and systematic. Folding of errors. Etc.
- Separation of systematic errors practical impossible for orbit computers.
- Correction for systematic errors due to star catalog achievable if debiasing information for catalog is known.
Orbit improvement

- LSQ fit of orbital elements to the astrometric observations.
- Different methods and strategy of weighting and rejecting observations => influence on the resulting orbit and the mean error of the elements.
- Influence of the observation distribution and characteristics on the resulting orbit. Large number of observations reduced by same catalog can ´force´ orbit into this system.
Ephemeris calculation

- We need a precise perturbed ephemeris.
  - Planetary model (JPL DExxx, perturbing asteroids etc.)
  - Start integration from previous orbit improvement or from catalog elements (MPCORB, ASTORB).

- We want also a mean error of the ephemeris to get an prediction uncertainty based on the star position and ephemeris uncertainty.

- In case of an orbit improvement we can use the covariance matrix to calculate an ephemeris error (Propagation).

- In case of an orbital elements catalog as input (MPCORB) we cannot compute an ephemeris error. Astorb.dat gives some quantities which allows to compute a rough ephemeris error.
Search for an occultation

- Compute (astrometric) star position for given time considering proper motion.
- Compute m.e. for current position from m.e. for position and PM (or if not given for individual entry use some standard values).
- Search for occultation (e.g. conjunction in RA) and check whether shadow hits Earth.
Transformation (projection) to the Earth surface (ground track plot)

- Apply for precession and nutation
- Transform from geocentric to geographic coordinates
Producers of occultation predictions

- Win-App OCCULT by Dave Herald (AU).
  - Steve Preston (USA).
  - Other contributors and (local) coordinators, preparing and selecting events, web presentation etc.


- Andrey Plekhanov (RUS), LinOccult. Access: Mail?
Workflow and tool chain (1)

Planets & Masses
JPL DE421

Perturbing asteroids
Chebyshev polynomials

Asteroid Elements
astorb.dat

PEE ⧫
F95

Accurate perturbed ephemeris
of all asteroids (e.g. 1 yr)

UCAC4
ARIHIP
URAT1
...

(Eventfiles
Logfiles
Summary files
Bessel elements
(CSV File))

SSO
F95

(Subset), binary
RA ordered

ODE solver: Multistep, variable order, predictor-corrector, self-adjusting step-size

DB Table:
Events

Perl script

GUI App (Python)
Workflow (2) and WebApp

Web Framework
Django (Python)
Model-View-Controller
---------------
WebApp Code
JavaScript
Libs & Plugins

Web Server
nginx

External Services
GIS (map data)
Aladin / VizieR

Internet

Perl Script

Meta-Data
DAMIT models
MPC sites, etc.

DB
Caching
Session IDs...

DB
Events
Suppl. Data
(User Data)
Example

- http://occult.kretlow.de/occpre/
Future prospects

What can we expect from GAIA?

- Positions and PMs with ~20µas (at G ~ 15 mag) accuracy on a high-quality global reference frame. => immediately improvement of star position by factor ~10^3!
- GAIA high-quality astrometric observations (~0.2-1 mas) of all asteroids down to ~20 mag (and app.size < 200mas).
- But also sparse photometry (~0.005 mag accuracy) data for all this asteroids (about 50-100 times in 5 yrs) => Periods and 3D-models by inversion.
Gaia impact on asteroidal occultations

- Asteroid orbits from pure GAIA data set will be $10^2$-$10^3$ better than current.

- Star positions $\sim 10^3$ better than current.

- Total prediction uncertainty on FP $\ll 1$ mas (for asteroid orbits based on pure GAIA data)

- Prediction uncertainty will drop from $10^1$-$10^2$ km to sub-km for a MB asteroid!
Concussion

- GAIA will have a major impact on asteroid science in general (dynamics, physical properties).

- But also (our) occultation work will be influenced significantly in terms of observing strategy (due to the prediction accuracy).