On the accuracy and uncertainty of asteroidal occultation predictions

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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, Error, Uncertainty, …

- 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.

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

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 grewing 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.
- Seperation 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.

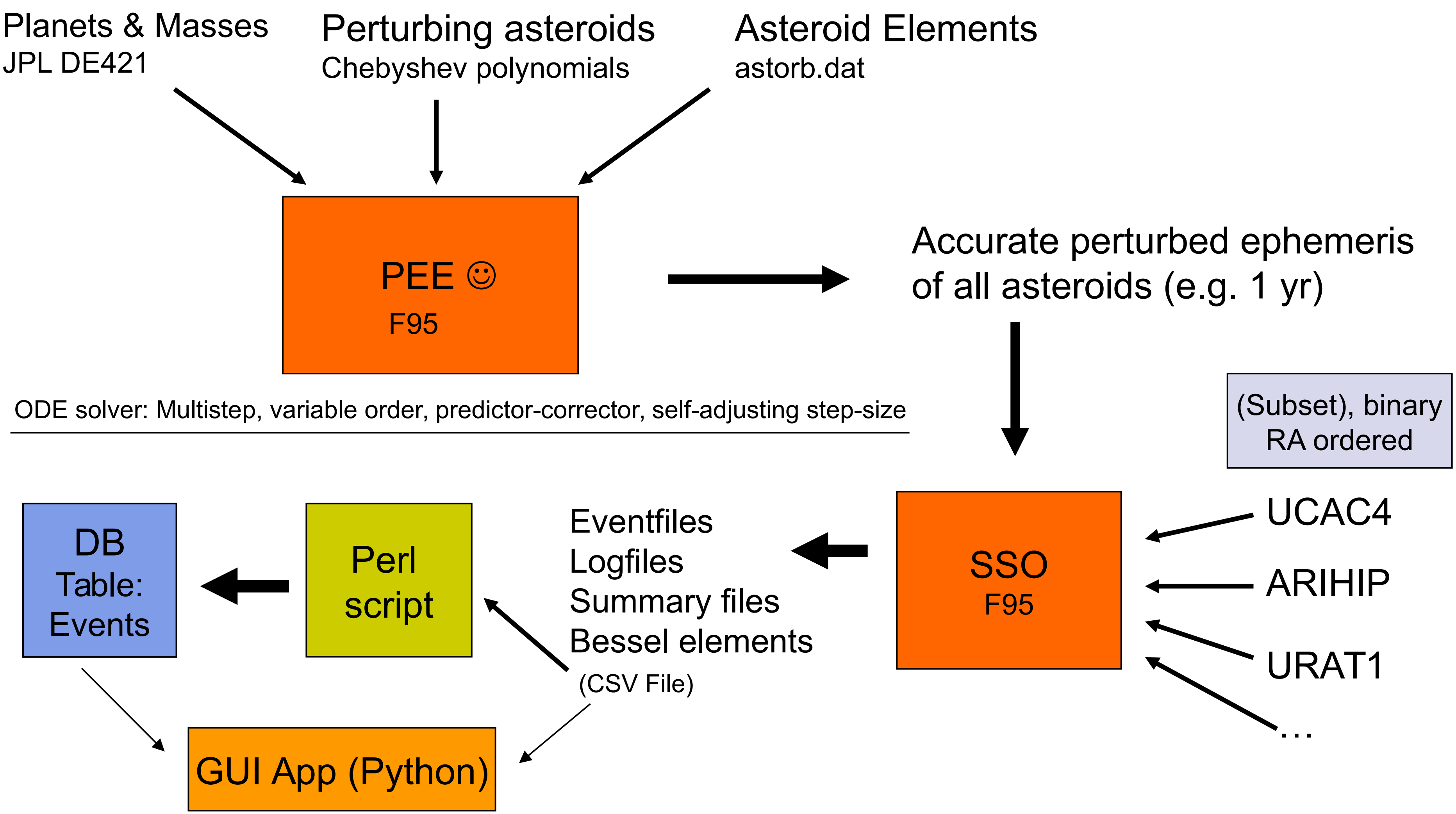
Transformation (projection) to the Earth surface (ground track plot)

- Apply for precession and nutation
- Transform from geocentric to geographic coordinates

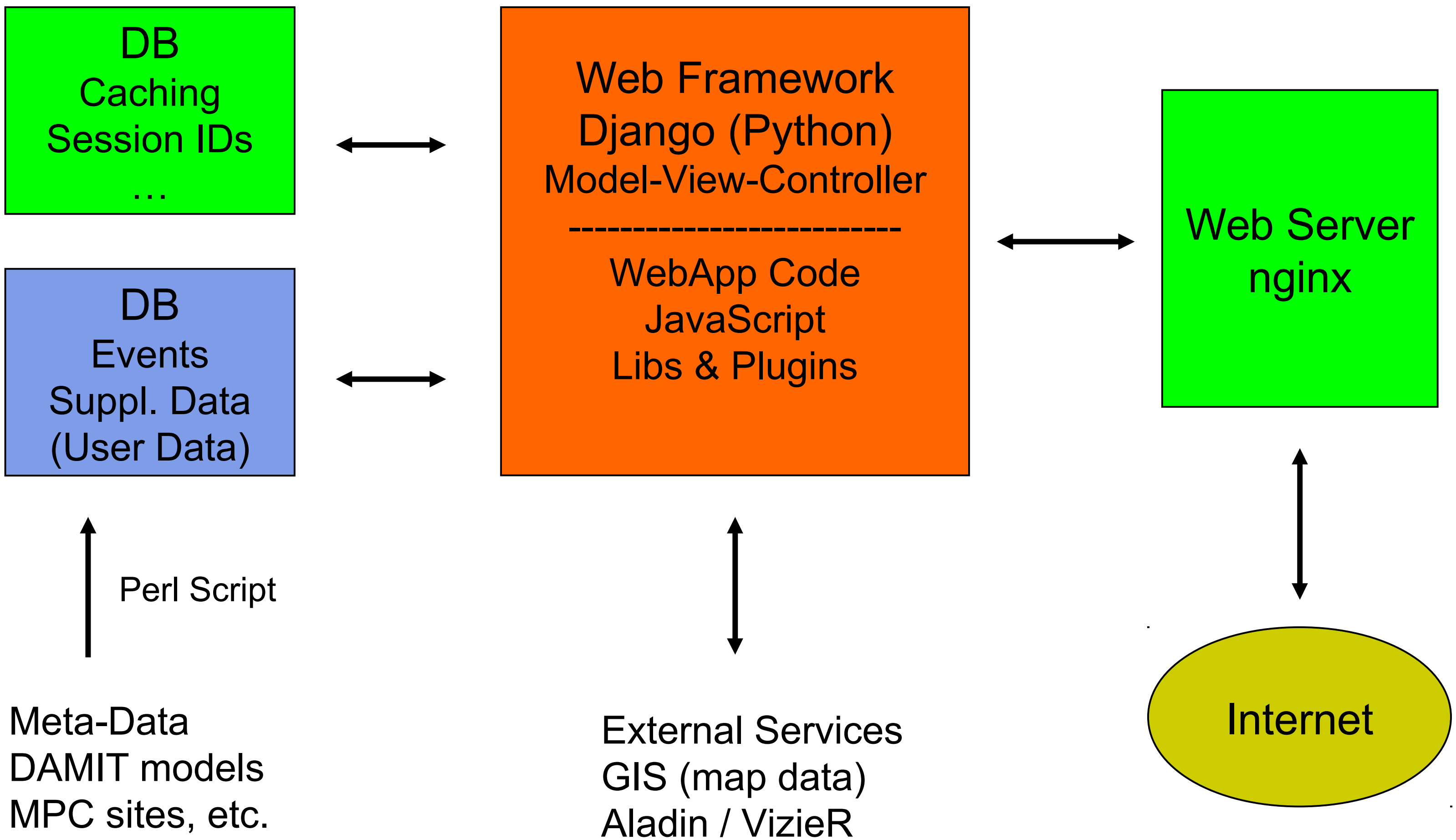
Producers of occultation predictions

- Win-App OCCULT by Dave Herald (AU).
  - Steve Preston (USA).
  - Other contributors and (local) coordinators, preparing and selecting events, web presentation etc.
- Edwin Goffin (BE / EAON). Non-public software. Access: PDF.
- Mike Kretlow (DE / IOTA-ES). Non-public software. Access: WebApp.
- Andrey Plekhanov (RUS), LinOccult. Access: Mail?

Workflow and tool chain (1)



Workflow (2) and WebApp



http://occult.kretlow.de/occpre
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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 ~10^3 better than current.
- Total prediction uncertainty on FP << 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 !

Conculsion

- 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).