Asteroid models from sparse photometry

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Outline

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   - Period search
   - Hipparcos data example
2. Questions
   - How many data do you need? Number of points, spread over how many years?
   - How much data do you expect (Pan-STARRS, Gaia, LSST, VO)?
   - Photometric precision you need to do any work
   - Sensibility to phase angle, sub-Earth point latitude
   - Advantage of adding one single dense LC
   - Advantage of adding one single occultation or image
   - DAMIT
3. Current and future work

Two types of photometric data

standard lightcurves

- one lightcurve per night, 10–100 points
- we need tens of lightcurves from three or more apparitions to derive a model
- it takes time to collect enough lightcurves
- $\sim$ 3800 asteroids have at least one LC – period determination
- $\sim$ 100 asteroids with enough lightcurves to make a full model

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sparse photometry

- data sparse in time with respect to the rotation period
- one or a few points per night
- tens to hundreds points from more apparitions
- all-sky surveys like Pan-STARRS, Gaia (Hipparcos), LSST
- sparse data from astrometry – noisy but sometimes useful

Dense vs. sparse photometry

when modelling, the both data types can be treated the same way, no principal difference

dense

- relative photometry is sufficient
- by Fourier analysis we derive synodic rotation period that is close to the sidereal one
- finding the global minimum in the parameter space is fast, we know where to search

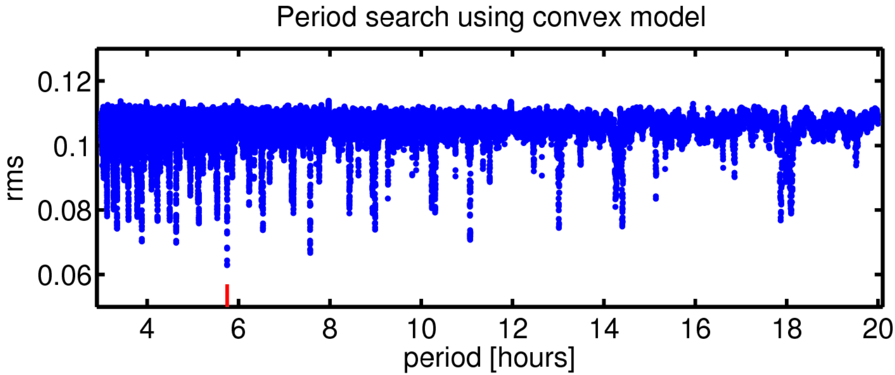
sparse

- data must be calibrated to connect observations spread over years
- Fourier analysis does not work ($P <<$ typical interval between data points)
- finding the global minimum in the parameter space takes much longer time – (many) hours

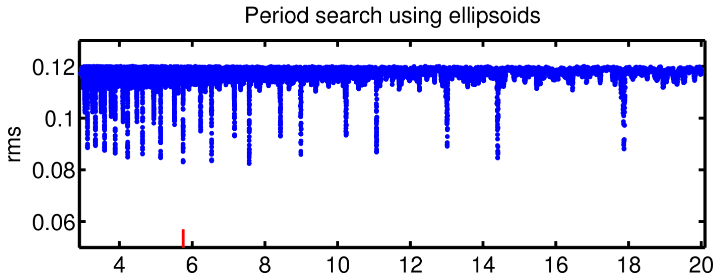
Period search – example

The main problem is to determine the correct rotation period.

(174) Phaedra, sparse data from US Naval Observatory, 173 points, $\sim$ 50 000 trial periods in 3–20 hr, the correct period $P = 5.75$ hr gives the lovest rms residual



Period search using ellipsoids – much faster



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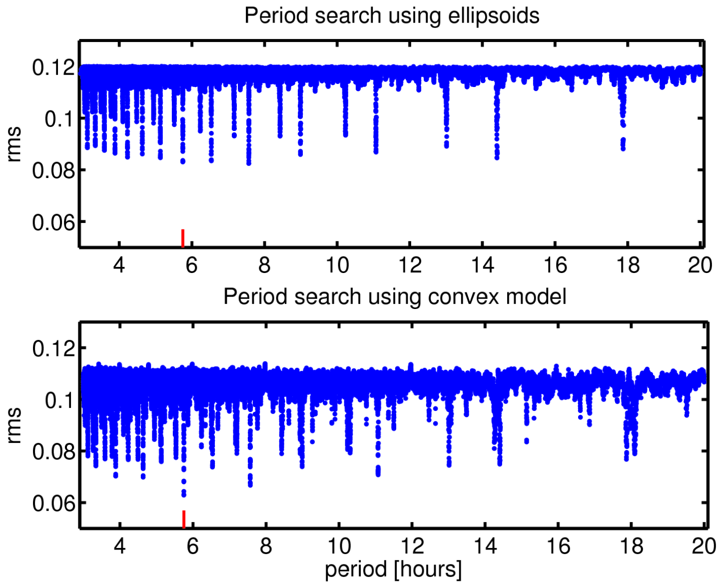
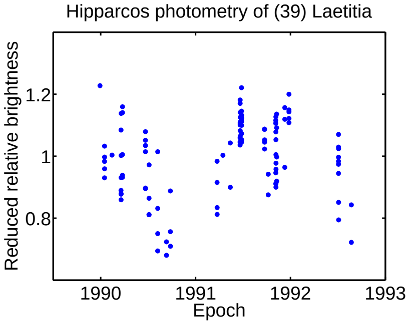
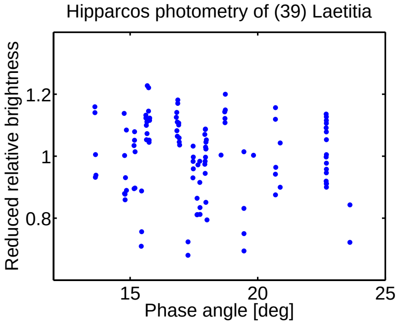


Real data from Hipparcos – (39) Laetitia

112 brightness measurements within ~ 3 years

Hipparcos best case – all other asteroids have less data

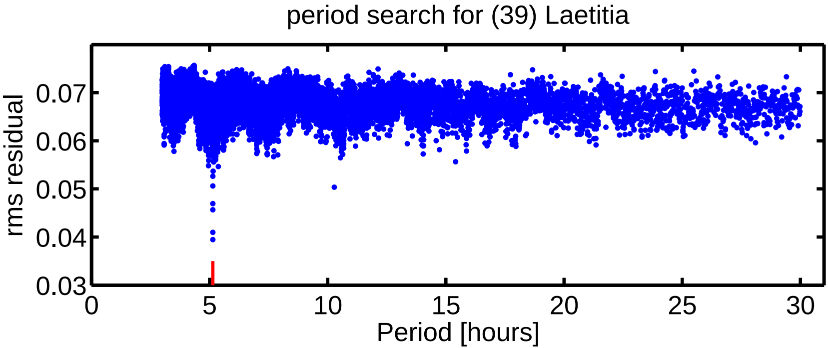




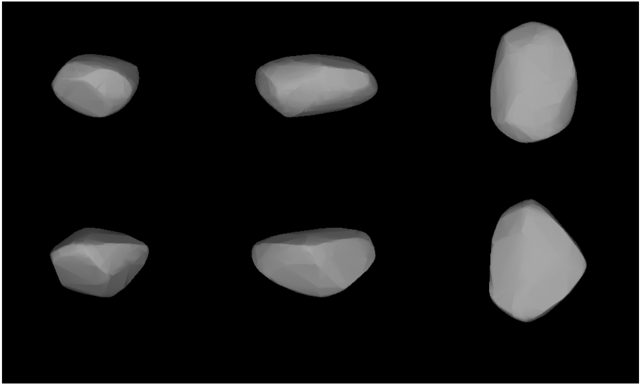
Hipparcos data – (39) Laetitia – period search

the rotation period is not 'visible' in the sparse data – a wide interval of possible periods (3–30 hr) must be densely searched for the best value

one deep global minimum in this case



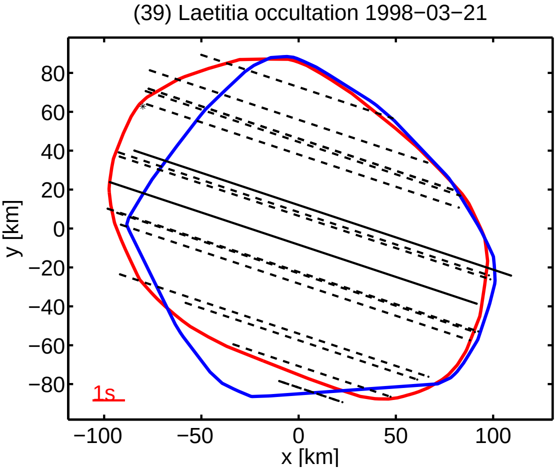
Hipparcos data – (39) Laetitia – shape model



full model (top) based 56 lightcurves from 19 apparitions
$P = 5.138238\,\text{hr}$, pole $(323^\circ, 32^\circ)$
Hipparcos model (bottom) $P = 5.1382\,\text{hr}$, pole $(325^\circ, 34^\circ)$

Hipparcos data – (39) Laetitia – occultation

both models can be scaled using the occultation data

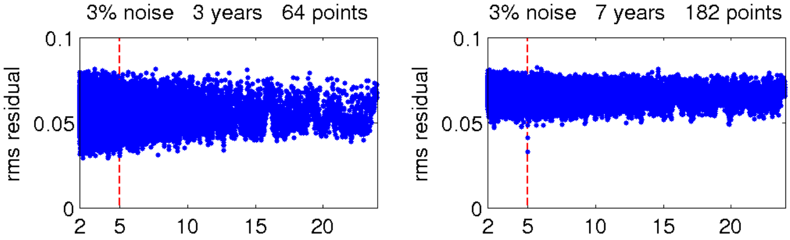


— full model — Hipparcos model - - - visual — photoelectric

Q: How many data do you need? Spread over how many years?

A: We need hundreds of points spread over several years.

Pan-STARRS simulations



real data from USNO, accuracy $\sim 0.1\,\text{mag}$: 200 points is usually not enough

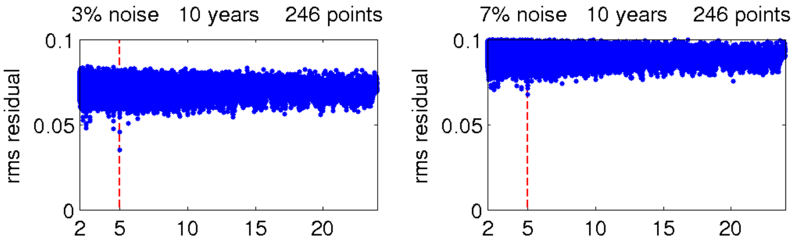
Q: How much data do you expect?

- Pan-STARRS is delayed, real scientific data from 'demo month' in March.
  Currently working PS1 is only $1/4$ of the whole Pan-STARRS.
  Each field observed twice each night separated by $\sim 15\,\mathrm{min}$.
  Most asteroids observed 6 times over three nights in single lunation, observable 2–3 lunations.
  Typically $150 - 300$ points in 10 years.
  For $\sim 10^5$ asteroids!
- Gaia should launch in 2012.
  5-year mission, ≤ 100 points.
  High photometric accuracy.
- LSST – similar to Pan-STARRS, larger telescope, fainter objects.

Q: Photometric precision you need to do any work?

There is no exact limit. The answer depends mainly on the amplitude and the number of points. Random errors need to be significantly lower than the amplitude. Systematic errors can spoil everything.

Pan-STARRS simulations



Even noisy data ($\sim 0.1\,\mathrm{mag}$) are useful!

Q: Sensibility to phase angle, sub-Earth point latitude?

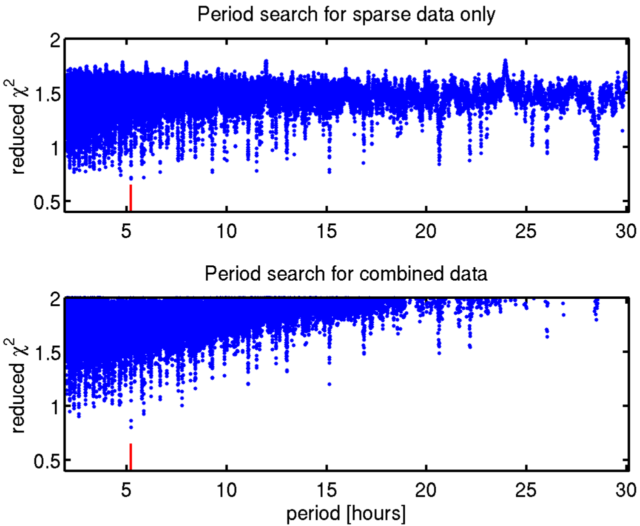
- is in other words sensitivity to viewing/illumination geometry
- the geometry has to change significantly (no models for TNOs)
- which means we need several oppositions for a MBA $\rightarrow \sim 5$ years at least
- NEAs can be modelled faster because geometry changes quickly
- 100 points with $< 5\%$ error covering ~ 5 years is sufficient for deriving a unique model

Q: Advantage of adding one single dense LC?

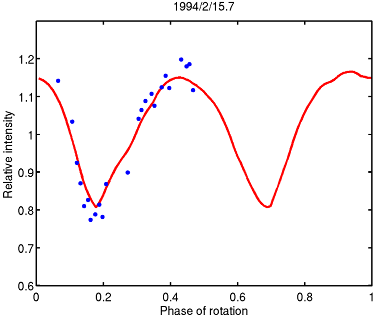
- even one dense LC is crucial because it tells us much about the period
- we can significantly shrink the interval of periods to be searched
- we do not need the lightcurve as data, just the information about the period is enough
- sparse + dense → combined

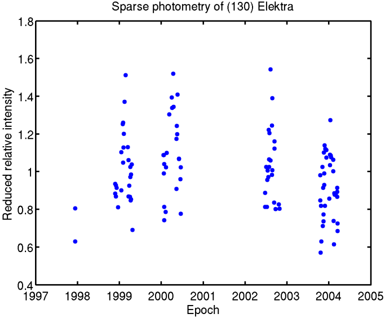
Combined datasets – period search example (130) Elektra

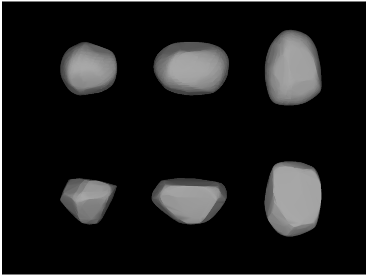
For noisy data (from USNO, for example), there are more solutions. Even one standard lightcurve helps a lot.



Combined datasets – (130) Electra







← full model based on 49 standard lightcurves from 9 apparitions

periods are the same
pole difference $\sim 7^\circ$ of arc

← model based on 1 lightcurve and sparse data (113 points)

Q: Advantage of adding one single occultation or image?

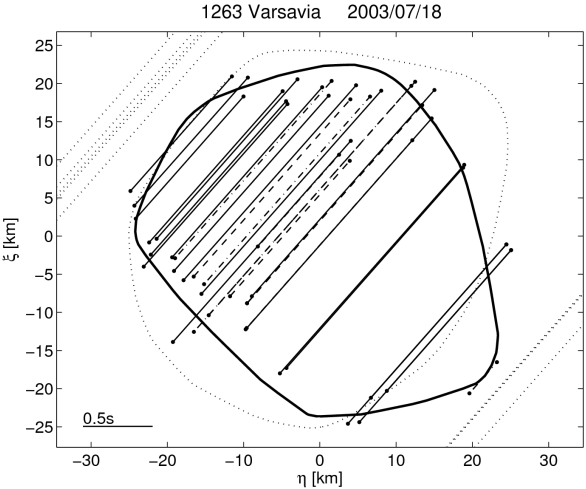
i.e., is it worth or do we need a complete rotation coverage to make any use of this?

A: Not so important because running the general LC+AO+Occ inversion on a wide range of periods would be difficult. When searching for the period, we use convex models (fast, robust). The 3D shape is not known during the optimization. Reconstructed afterwards for the best model(s).

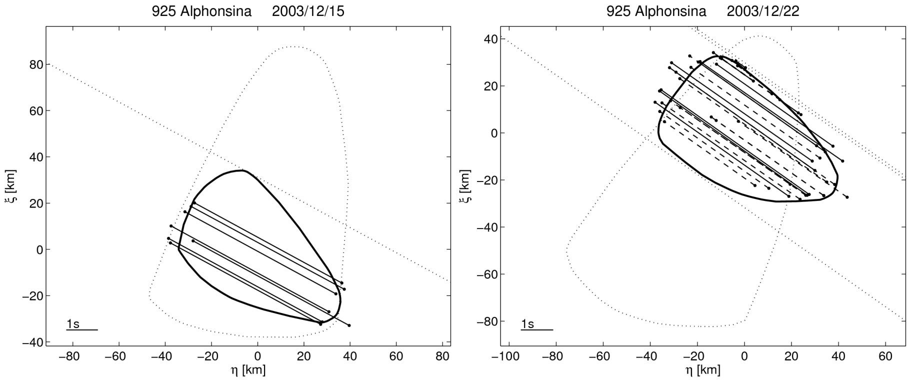
Occultations are important for scaling the model and for possible rejection one of the two mirror pole solutions.

Adding one single occultation – example (1263) Varsavia

6 dense LCs + 143 sparse data points from USNO → unique period, two pole solutions, one of them is significantly better

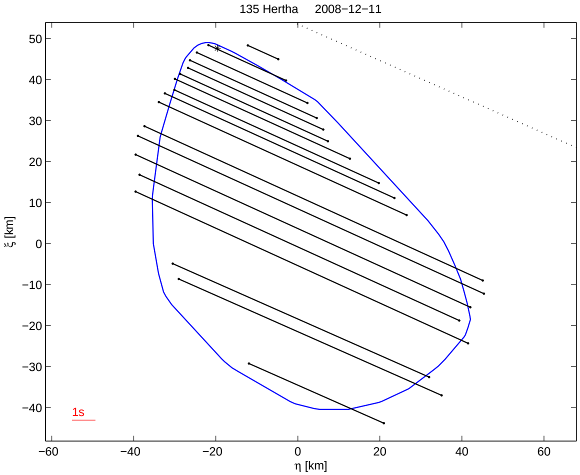


Occultations – example (925) Alphonsina



Occultations – example (135) Hertha

clear discrepancy between the convex model and the nonconvex occultation profile $\longrightarrow$ needs proper LC + Occ modelling



DAMIT

- Database of Asteroid Models from Inversion Techniques
- `http://astro.troja.mff.cuni.cz/projects/asteroids3D`
- MySQL database, PHP scripts, Web interface
- Aim: provide access to up-to-date models of asteroids derived (mainly) from lightcurves and other supplementary data (AO, Occ, thermal IR)
- contains 112 asteroids (179 models)
- users can download results (shape, spin) and original data (LCs)
- we continuously update the content (new models, update of old models) and also the interface (layout, tools for the administrator, etc.)

Current and future work, plans, ideas...

- While waiting for Pan-STARRS data, we do 'data mining' of astrometric databases – extracting photometry.
- There is information about rotation states of asteroids in currently available sparse 'astrometric' photometry.
- US Naval Observatory, Flagstaff – data for ~ 2000 asteroids, estimated accuracy 0.08–0.1 mag, typically 50–300 points from six years.
- ~ 100 new models
- Combining noisy sparse photometry with a few standard lightcurves can lead to a unique and correct solution of the inverse problem, i.e., to a shape/spin model of an asteroid.
- Asking individual observers for data of selected asteroids is possible for individual targets.
- If we had the lightcurve data for all > 3000 measured asteroids we could derive other hundreds(?) of models.
- The main problem is access to data.