Detection of binary asteroids from sparse photometry

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Outline

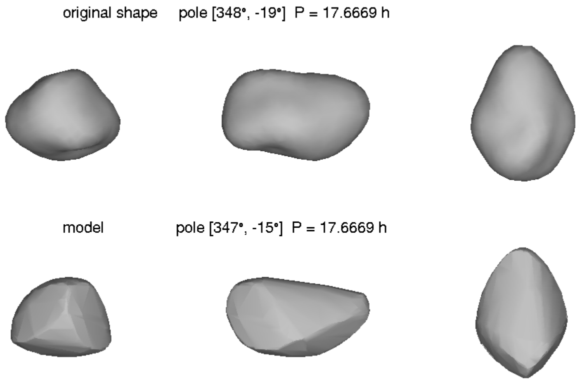
Sparse photometry

- contrary to standard dense lightcurves, sparse data consist of individual calibrated points – one or a few points per night
- tens to hundreds points from more apparitions
- all-sky surveys like Pan-STARRS, Gaia, LSST
- 100 points with $< 5\%$ error covering ~ 5 years is sufficient for deriving a unique model
- sparse data from astrometry – noisy but sometimes useful

Simulations

So far, our results are based mainly on simulated data:
Pan-STARRS cadences + artificial shapes + noise → inversion

shape reconstruction based on a simulated Pan-STARRS cadence
10 years of observation, 3% noise



Real data – combined datasets

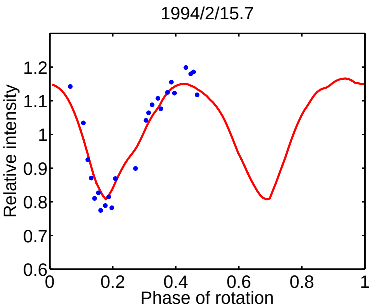
sparse photometry

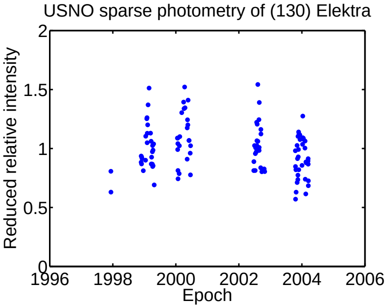
- accurate ($< 5\%$) sparse data are not yet available
- photometry obtained during astrometric observations is usually very noisy and spoiled by systematic errors
- US Naval Observatory, Flagstaff – data for ~ 2000 asteroids, estimated accuracy 0.08–0.1 mag, typically 50–200 points from five years.

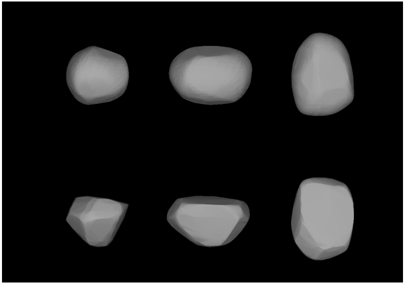
standard lightcurves

- Uppsala Asteroid Photometric Catalogue
- archives of individual observers

Combined datasets – (130) Elektra





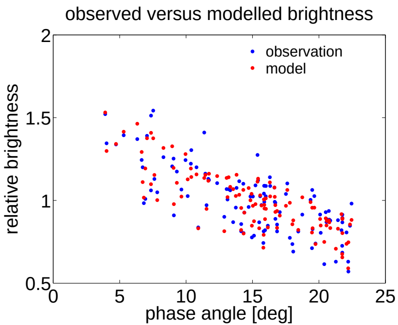


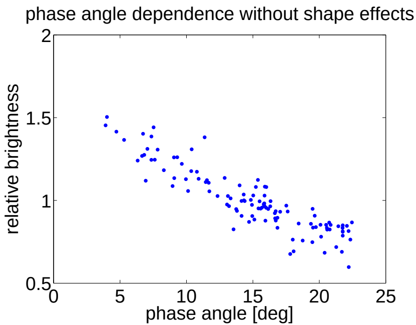
← full model based on 49 standard lightcurves from 9 apparitions

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

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

Phase angle dependence – (130) Elektra





rms = 0.08 mag

Asynchronous binaries (NEAs)

There are two periods in the data – rotation of the primary and orbital period of the secondary.

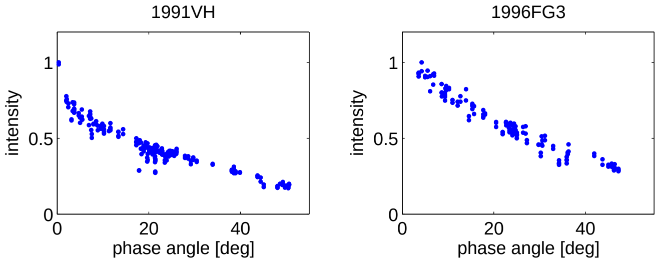
Any single-body model cannot fit the data well – high O-C residuals.

Can we somehow recognise it is a binary asteroid?

If the secondary/primary size ratio is large enough and the geometry is suitable, mutual events are visible in the phase angle plot as decrease of brightness.

Asynchronous binary NEAs – simulation

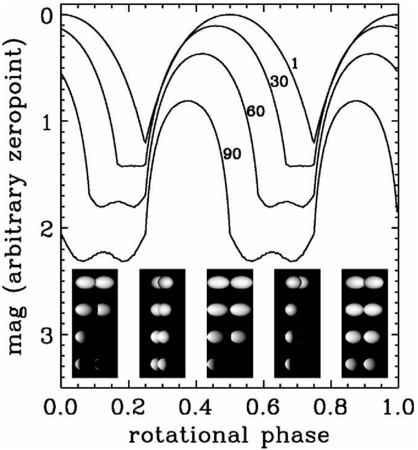
simulated Pan-STARRS observations of binary NEAs
10 years, noise 3%



$d_1/d_2 = 0.38$ $d_1/d_2 = 0.31$

Our results are based on synthetic data, everything will depend on real errors, outliers, etc.

Fully synchronous NEAs at high phase angles

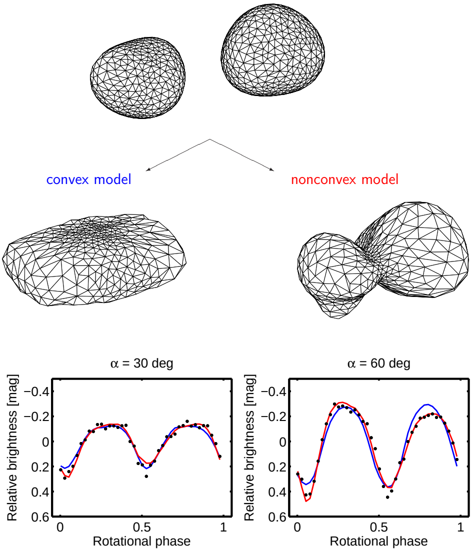


Lacerda (2008), ApJ 672,L57

Synchronous binaries are detectable by high amplitudes at high phase angles. No modelling, just 'looking' at data, then follow-up observations.

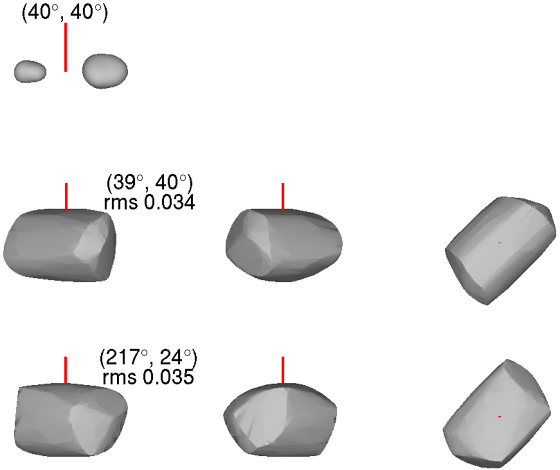
Amplitude-phase relationship: amplitudes increase for higher phase angles. Also the probability of measuring large amplitudes from sparse sampling increases with phase angle.

Convex models of synchronous binaries



From a lightcurve-inversion point of view, a fully synchronous binary behaves like a single (nonconvex) body – its lightcurves can be fitted by a convex model. The only indication that the original object is binary is the strange rectangular shape or pole-on silhouette of the model.

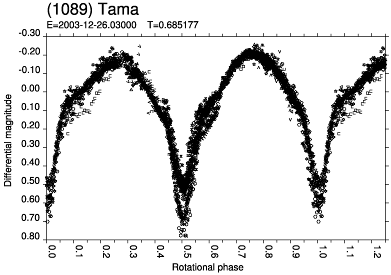
Synchronous binaries – synthetic Pan-STARRS sparse data

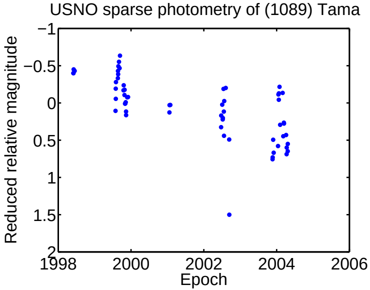


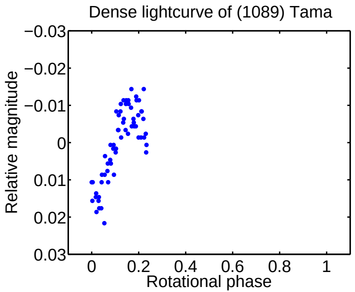
original noise 3%, two solutions with $\lambda \pm 180^\circ$

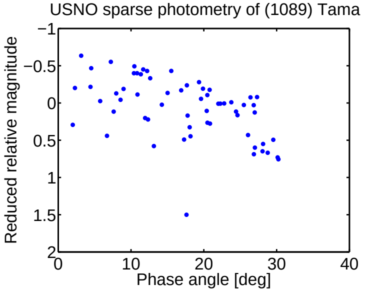
(1089) Tama – real data

Behrend et al. (2006)



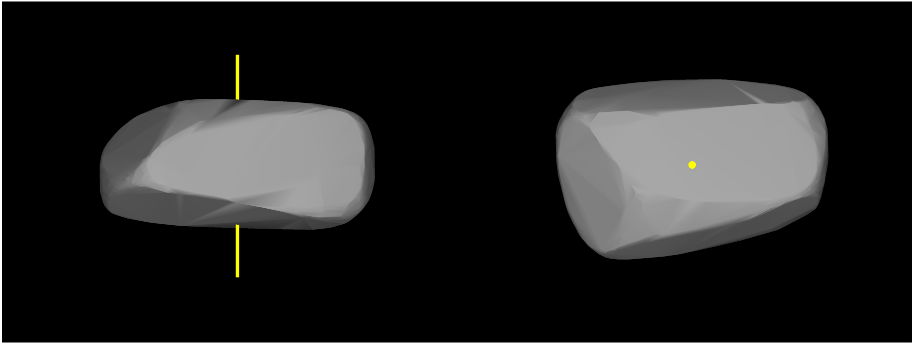






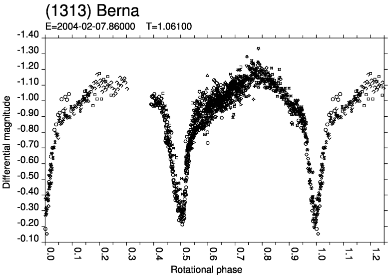
(1089) Tama – shape model

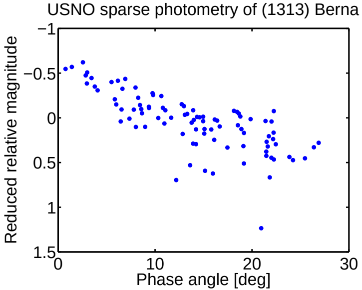
one of possible convex shape models
period P and pole ecliptic latitude β are well determined, pole longitude λ is not well constrained

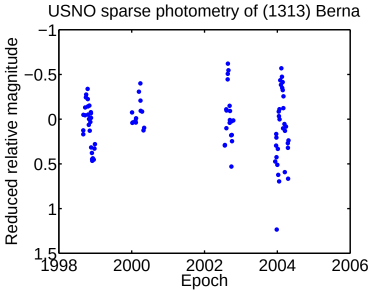


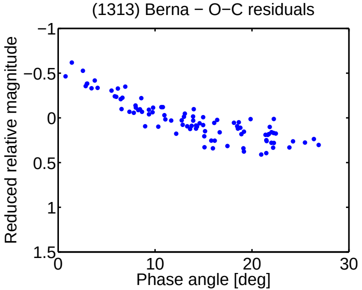
(1313) Berna – real data

Behrend et al. (2006)



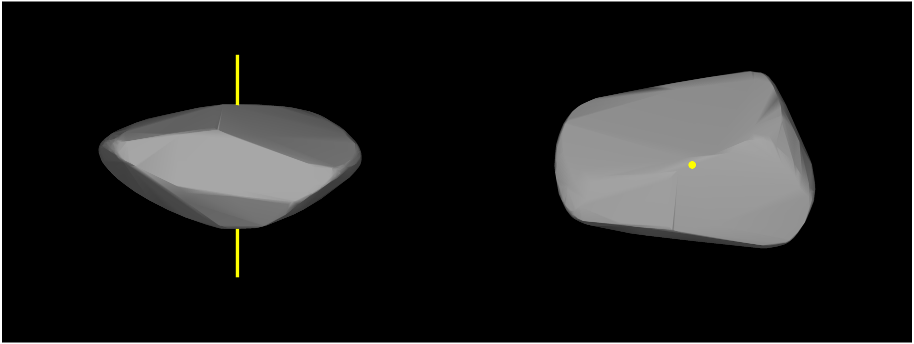






(1313) Berna – shape model

convex shape model



Summary

Asynchronous

- Data cannot be fitted with a single-body model.
- Mutual events might be visible in brightness vs. phase angle plot – only if the geometry is suitable and photometric errors are small

Fully synchronous

- A convex model that fits the data well can be derived.
- Rectangular pole-on silhouette is strong indication that the object is binary (or bifurcated).

Follow-up observations are necessary!