



# Lichtkurven von Kleinplaneten und deren Auswertung

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# Lichtkurve eines Asteroiden

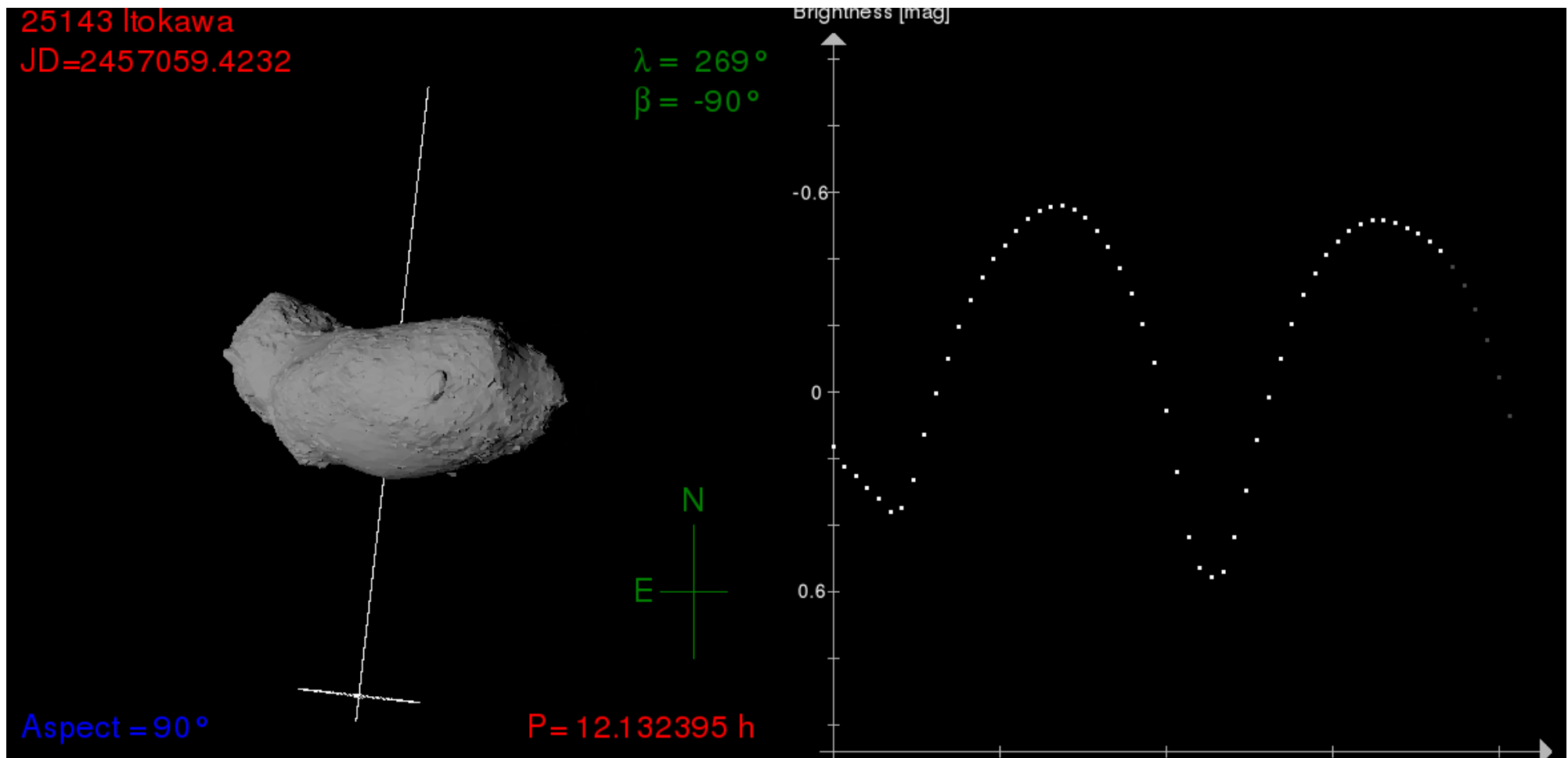


Bild: gaiagosa.eu



# Bestimmung dynamischer und physikalischer Parameter

- Dynamische Parameter: Bahnelemente, Dynamik, Evolution, Familien usw.
- Physikalische Parameter: Größe, Masse, Dichte, Form, Rotationsparameter (Dauer, Achse), Evolution, usw.
- (Geo-)Chemische bzw. Physikalisch-chemische Parameter.



# Aufgaben und Fragestellungen

## Generell: Mehr Daten !

**=> Statistik, Theorien & Modelle, Data Mining usw.**

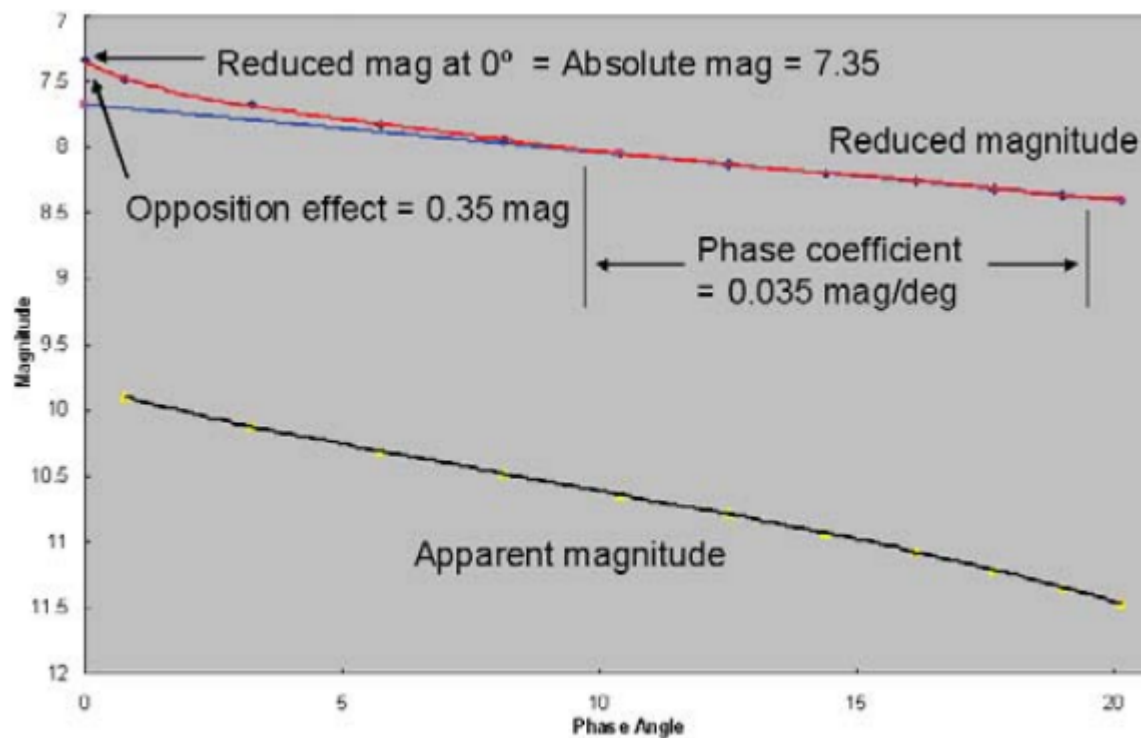
- ~700.000 Asteroiden (ca. 500.000 nummeriert).
- ~15000 Lichtkurven-Parameter (P oder zumindest Amplitude).
- ~1000 Asteroiden mit 3D-Modell, Polorientierung.
- ~150 Doppel-/Mehrfach-Systeme.
- H,G-Parameter (=> absolute Helligkeiten, Gaia!).
  - Interessant für Sternbedeckungen und Durchmesser-schätzungen.
- Phasenkurve (Oppositionseffekt), usw.

# Mehr Daten !

## Oppositions-Effekt, (H,G)-Bestimmung, Albedo (Durchmesser)

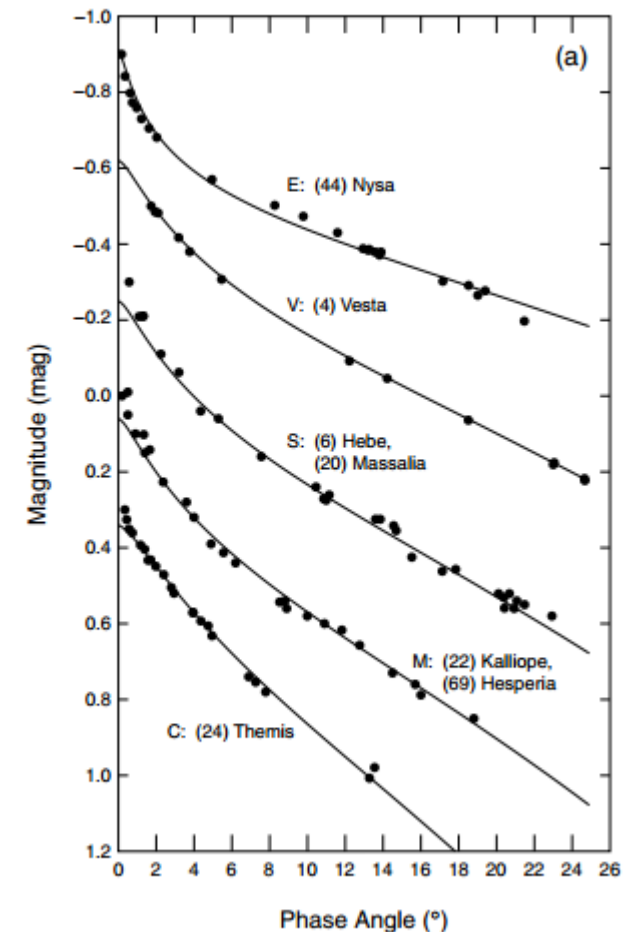
Neue Arbeiten zum H,G-System: Oszkiewicz und Muinonen et al.

Reduzierte Helligkeit:  $H(\alpha) = V - 5 \log (r \Delta)$



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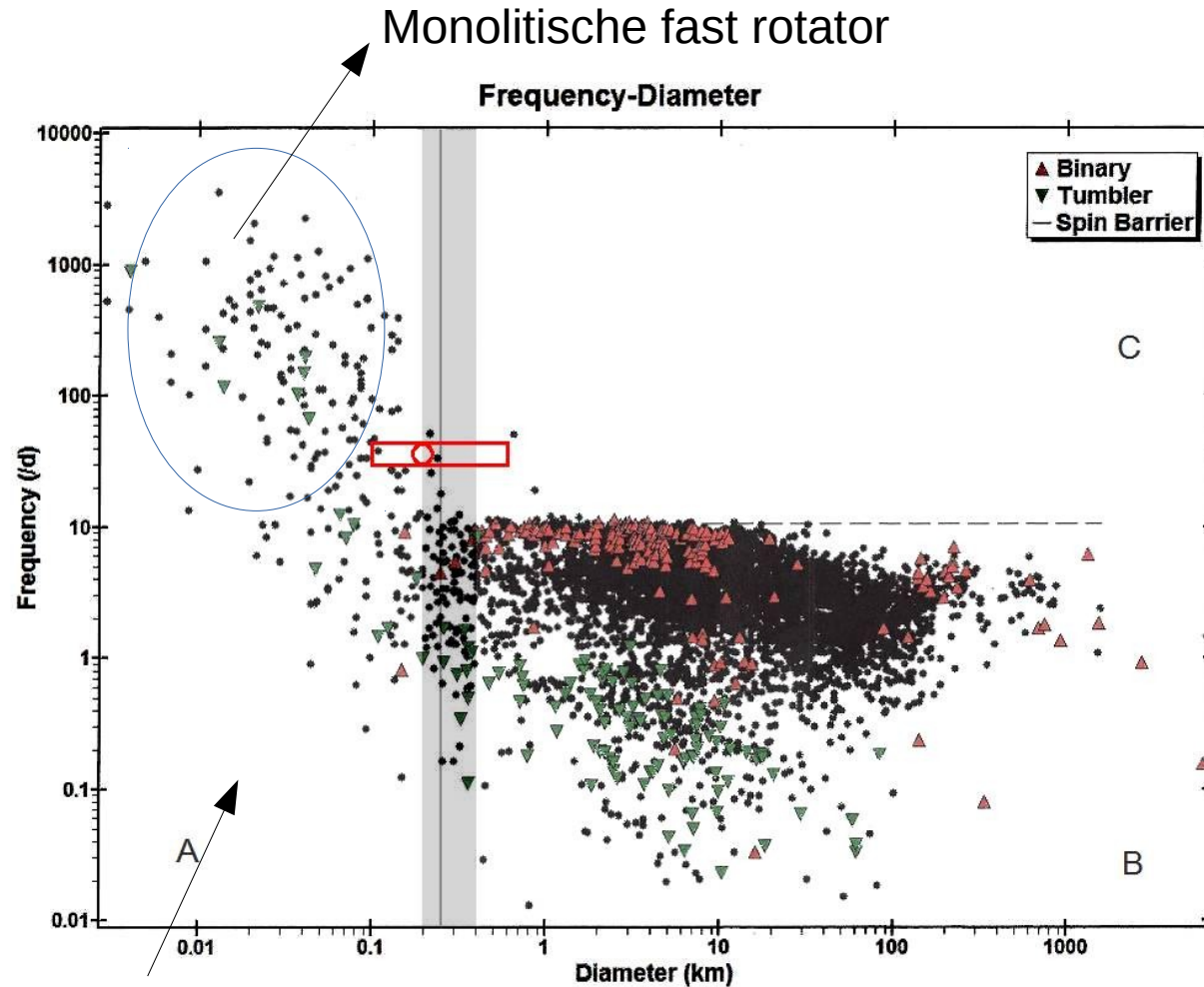
Asteroids III



Dymock (2007) *Figure 1. Effect of phase angle on magnitudes.*

# Mehr Daten !

## Rotationsperioden



Warum nicht populiert ?

Grafik: MPC

# YORP-Effekt

Allmähliche Veränderung des Rotationszustands kleiner Körper unter dem Einfluss der Sonnenstrahlung.

- Tritt bei *unregelmässig* geformten (kleinen) Körpern auf.
- Verändert Rotationsachse und Periode.
- Spin-up kann zu Doppel- / Mehrfach-Asteroiden führen
- Spin-down kann zu slow rotators und / oder tumblers (keine fixe Rotationsachse) führen.

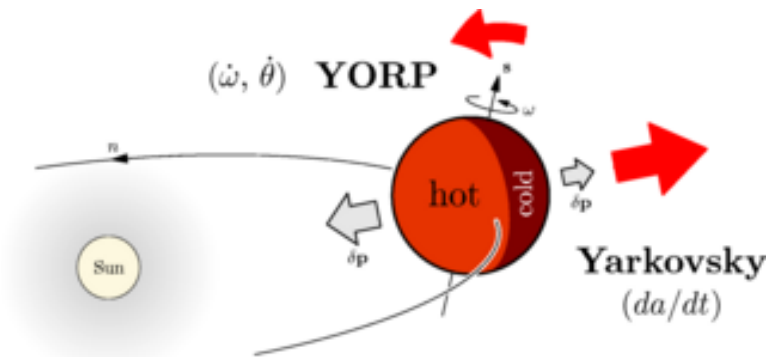
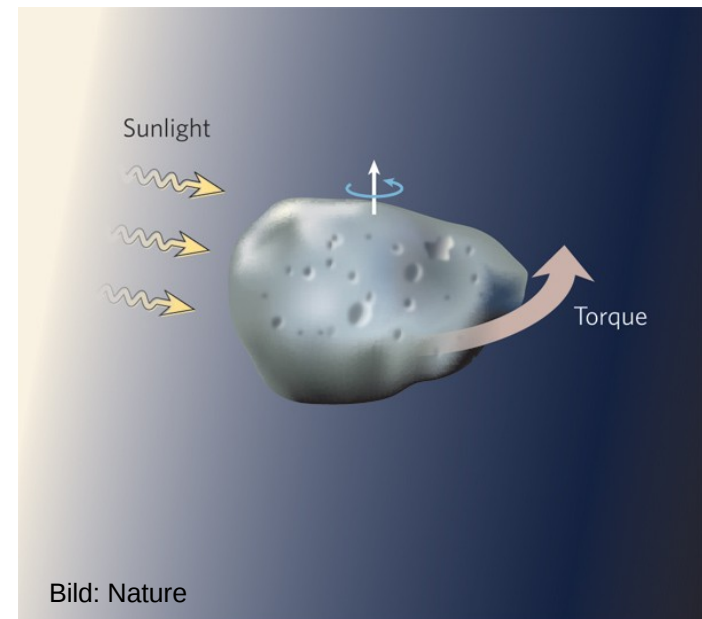


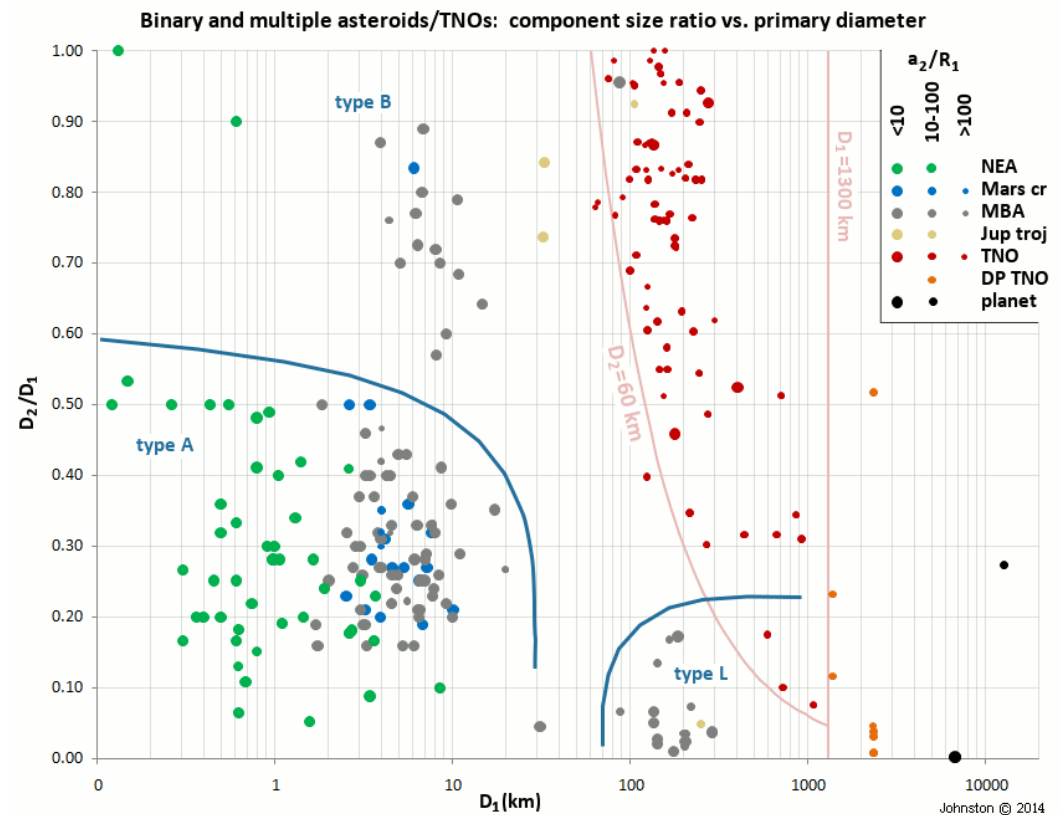
Bild: Miroslav Broz

# Mehr Daten!

## Asteroiden-Systeme: Doppel-Asteroiden, Monde etc.

Techniken um Asteroiden-Systeme zu entdecken

- Adaptive Optik
- Photometrie (Lichtkurven)
- Radar

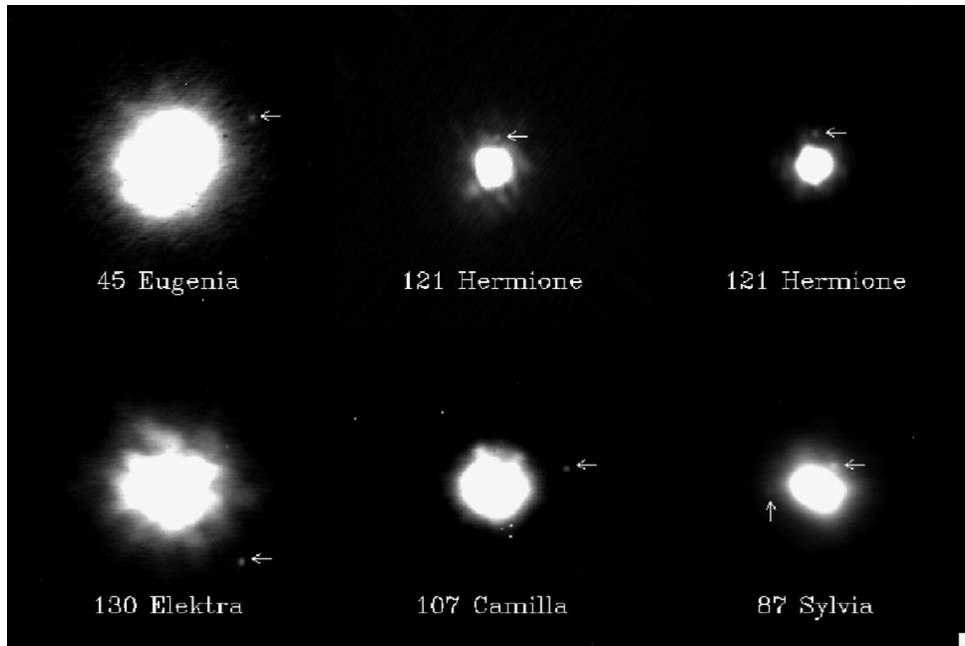


Grafik: johnstonsarchive.net

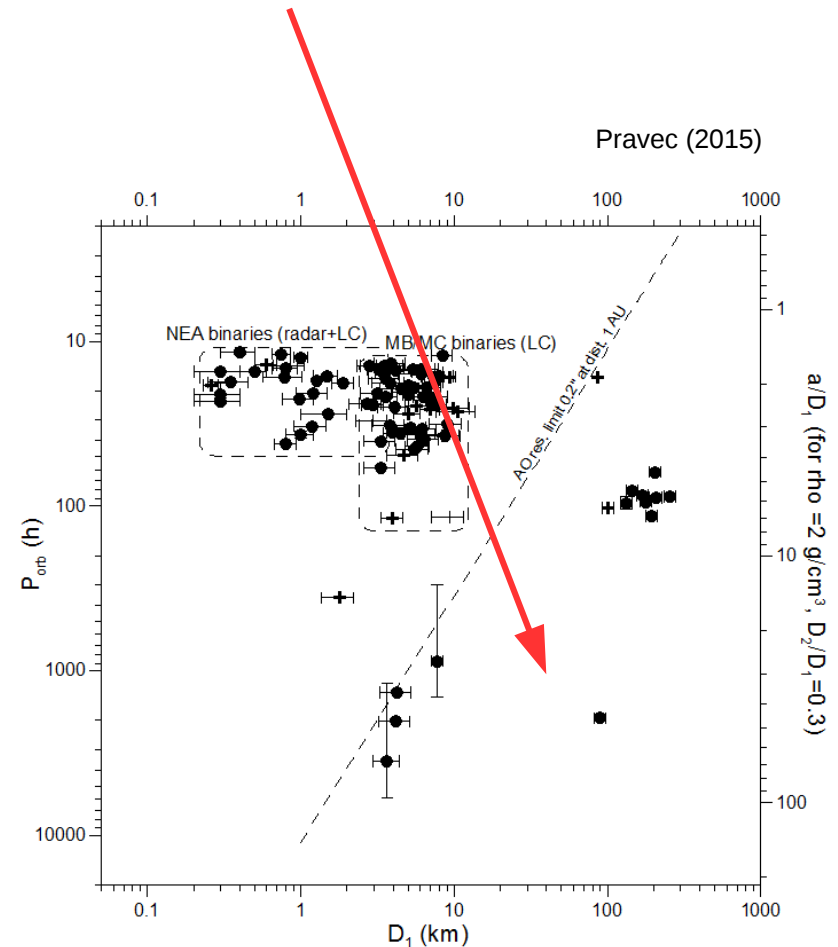


# Adaptive Optik

Typische Auflösung  $\sim 0.2$  arcs  $\Rightarrow$  Limitiert auf weite / große Systeme  
( $0.2$  arcs  $\sim 150$  km in 1 AE)



Marchis et al. (2007)



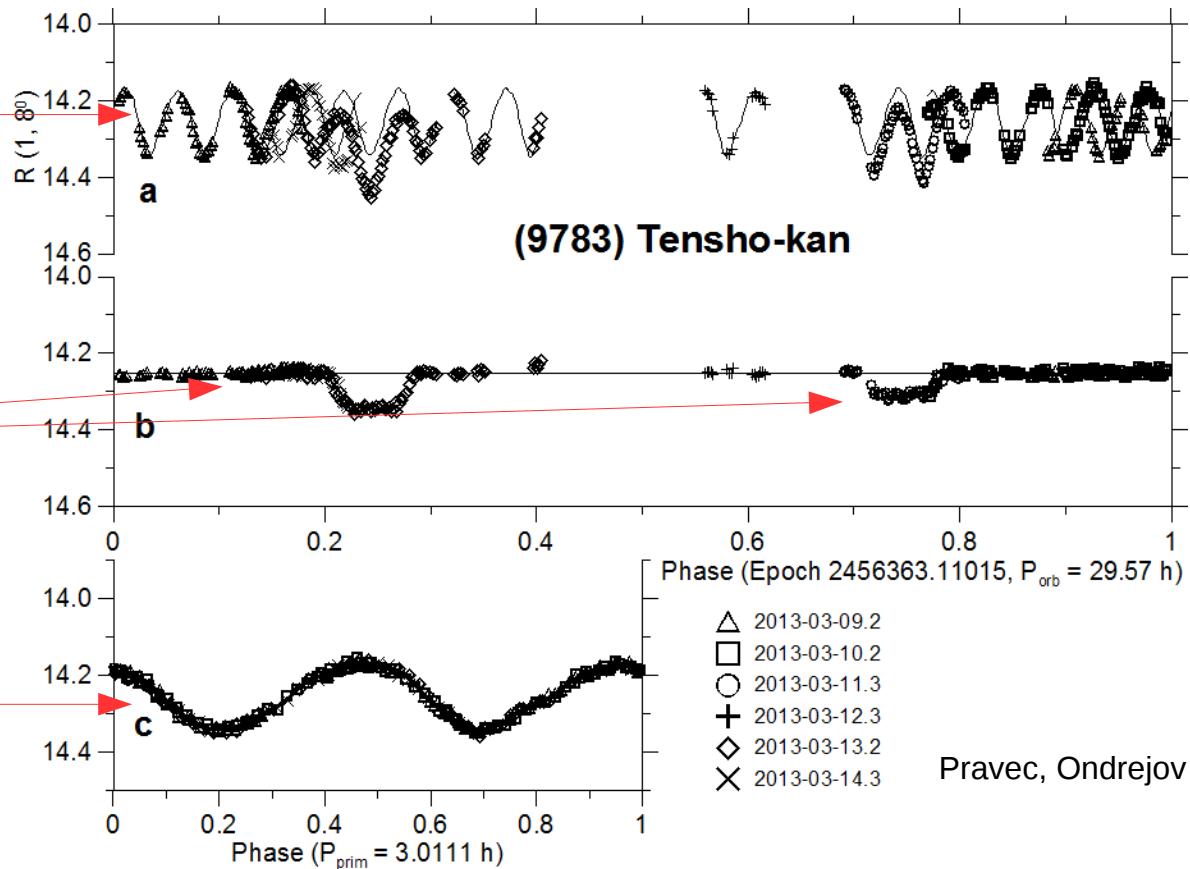
# Photometrische Beobachtung eines Doppel-Asteroiden

Gesamt-Lichtkurve

Entfaltung:

Finsternisse u. Bedeckungen

Lichtkurve des Hauptkörpers



# 3D-Modelle (Shape) und Rotationsachse aus LC-Inversion

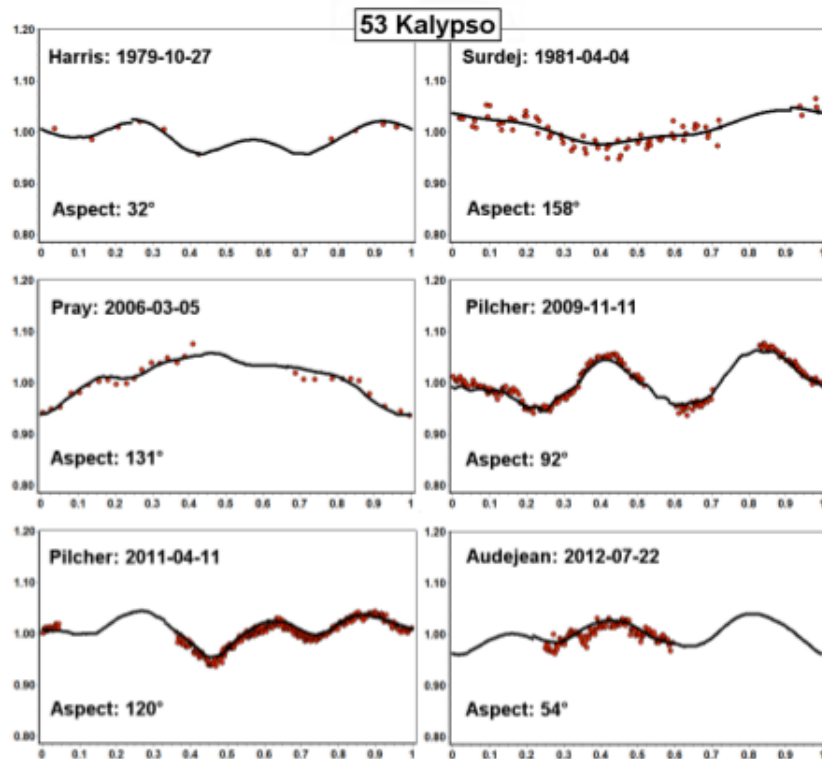


Figure 7. Model fit (black line) versus observed lightcurves (red points). Note the wide variety of lightcurve shapes.

Ref. Minor Planet Bulletin 43 (2016)

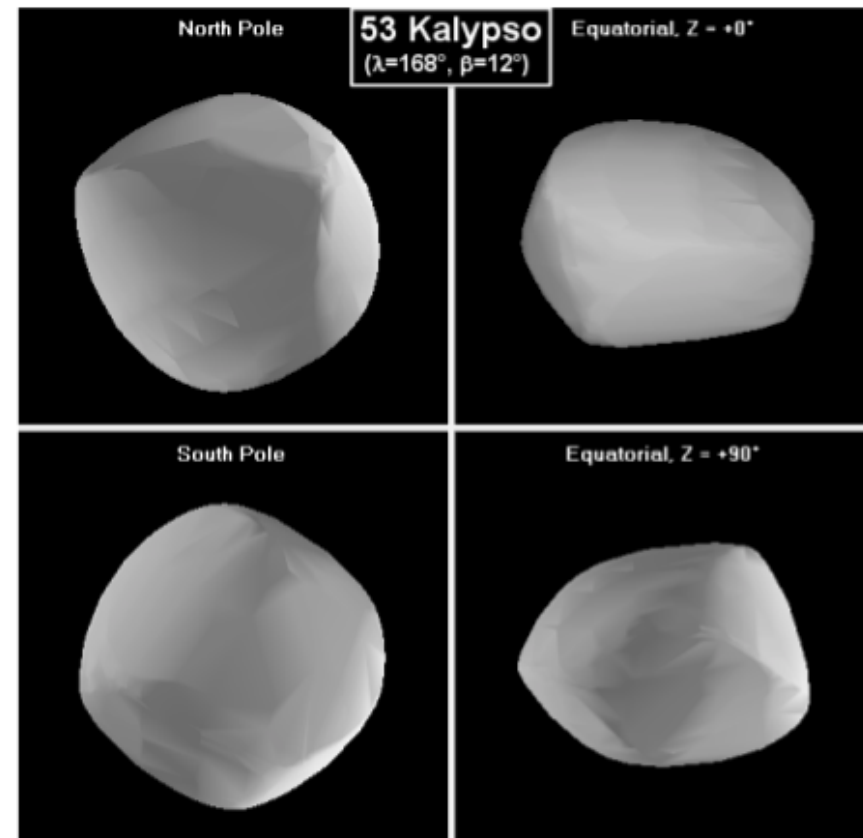
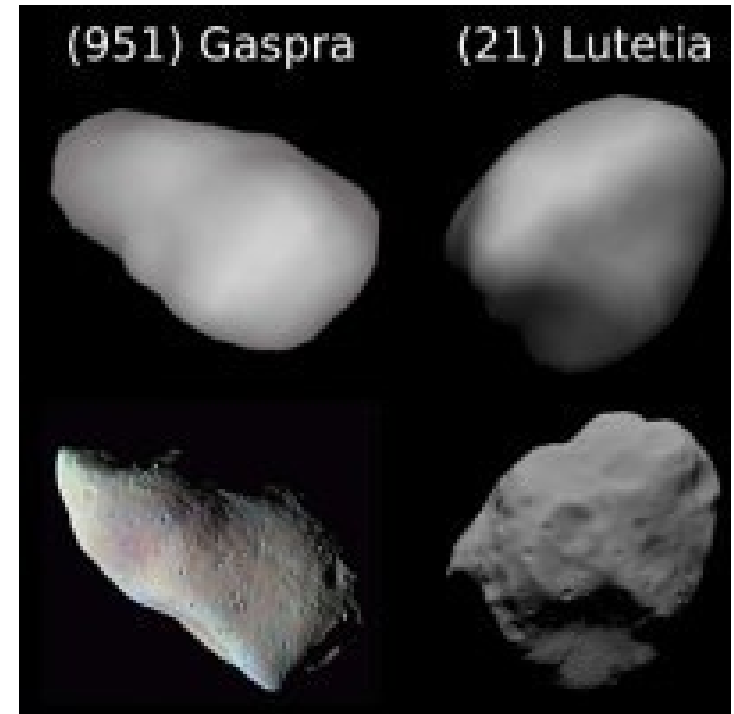
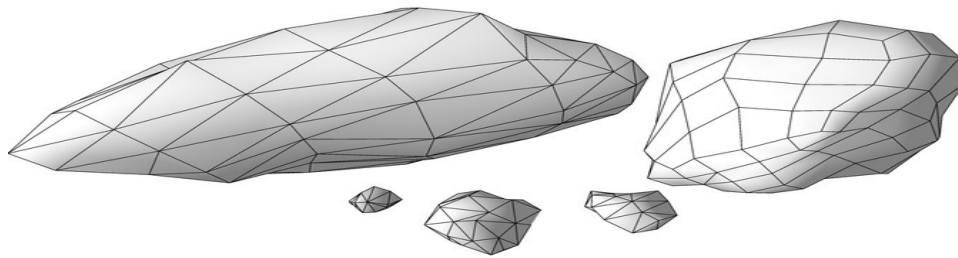


Figure 6. The shape model for 53 Kalypso ( $\lambda = 168^\circ$ ,  $\beta = 12^\circ$ ).

# Asteroiden 3D-Modelle (Polygon-Mesh)



# Polygon (Dreieck)-Mesh

## Face-Vertex Meshes

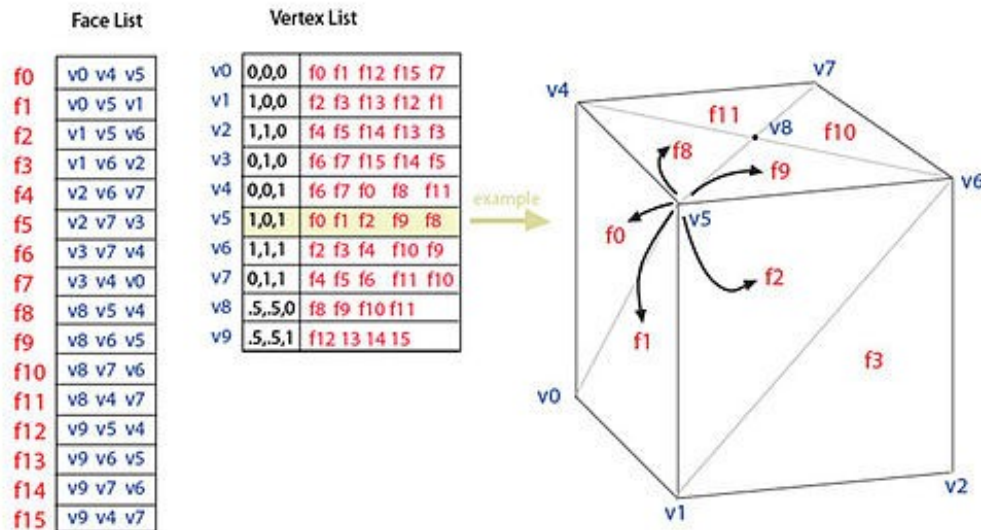
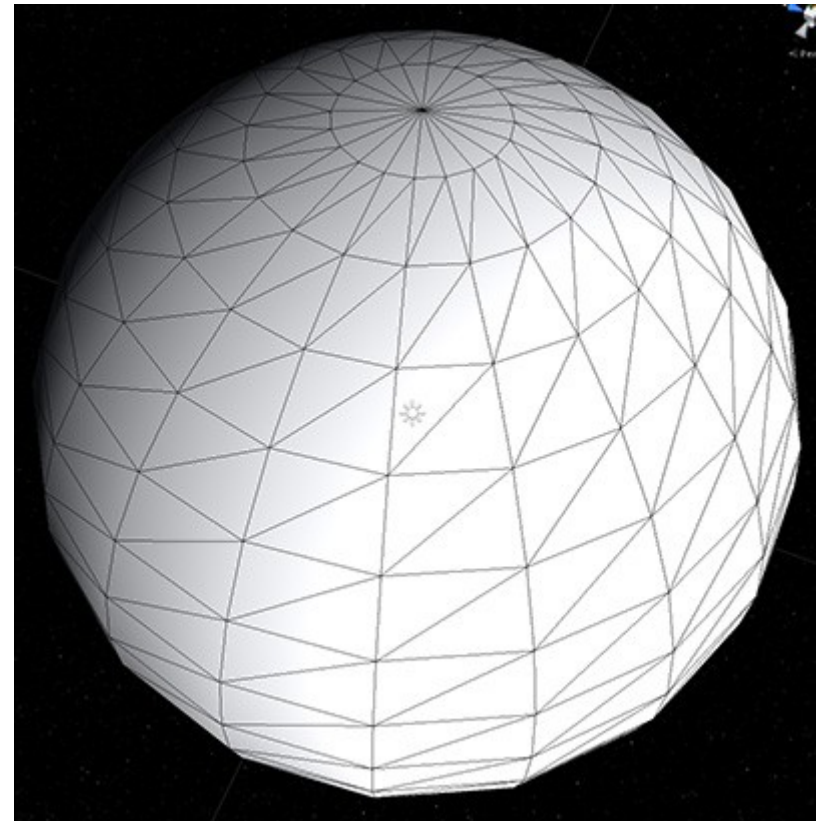


Bild: Wikipedia



Berechne Licht Ein- und Ausfall nach einem passenden Gesetz (Lommel-Seeliger) für jedes Facet und summiere über alle Facets (und das alles als Zeitreihe entsprechend der Rotation)

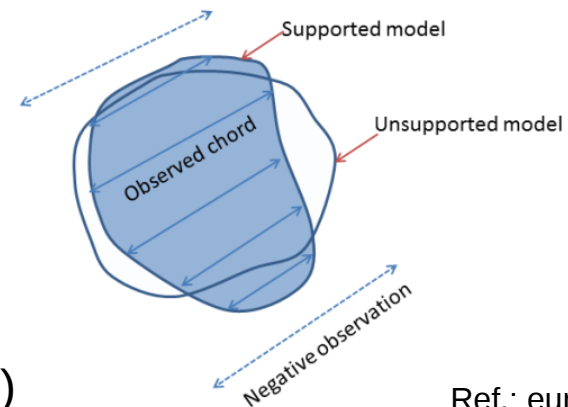
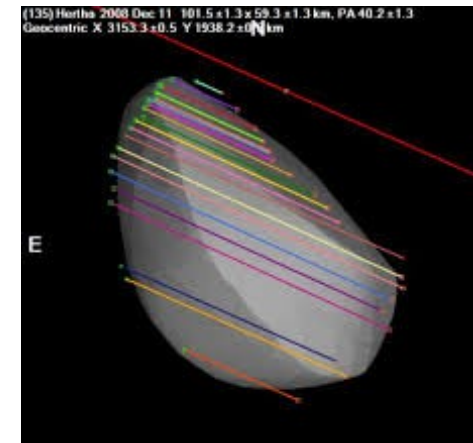
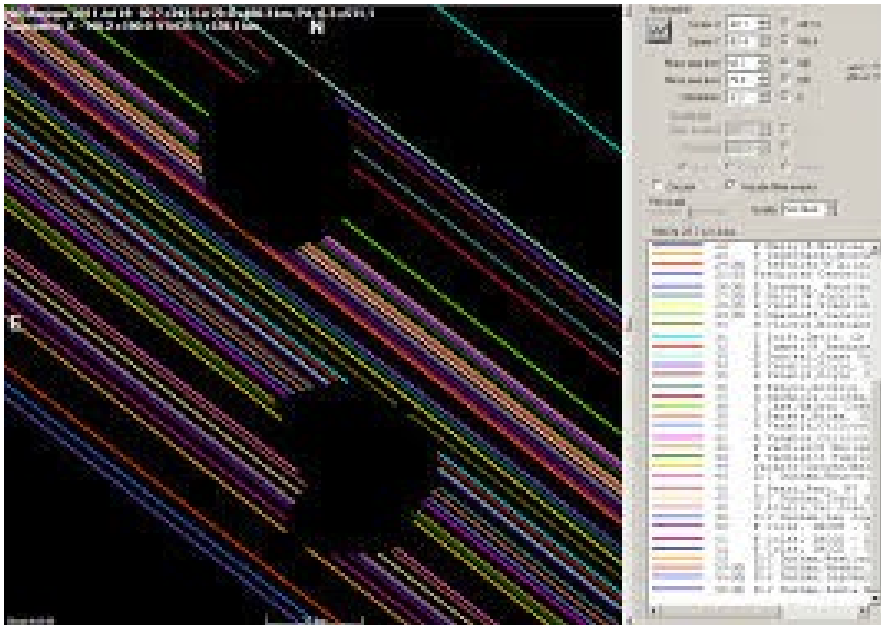
=> synthetische Lichtkurve, z.B. als Vorhersage für Beobachtungen, Sternbedeckungen etc.

# Demo 3D-Modell, LCgen

- Python-Skript zur Anzeige von 3D-Modellen (.obj)
  - Inzwischen existieren auch diverse Webseiten zur Visualisierung.
    - <http://space.frieger.com/asteroids/>
    - <http://isam.astro.amu.edu.pl>
    - etc.
- Python-Skript zur Generierung von (synthetischen) Lichtkurven aus 3D-Modellen (d.h. Umkehrung der LC-Inversion).

# Kombinierung von LC's und Sternbedeckungen

3D-Modelle aus Inversion: keine Größen.  
Bedeckung liefert dies hochauflösend !

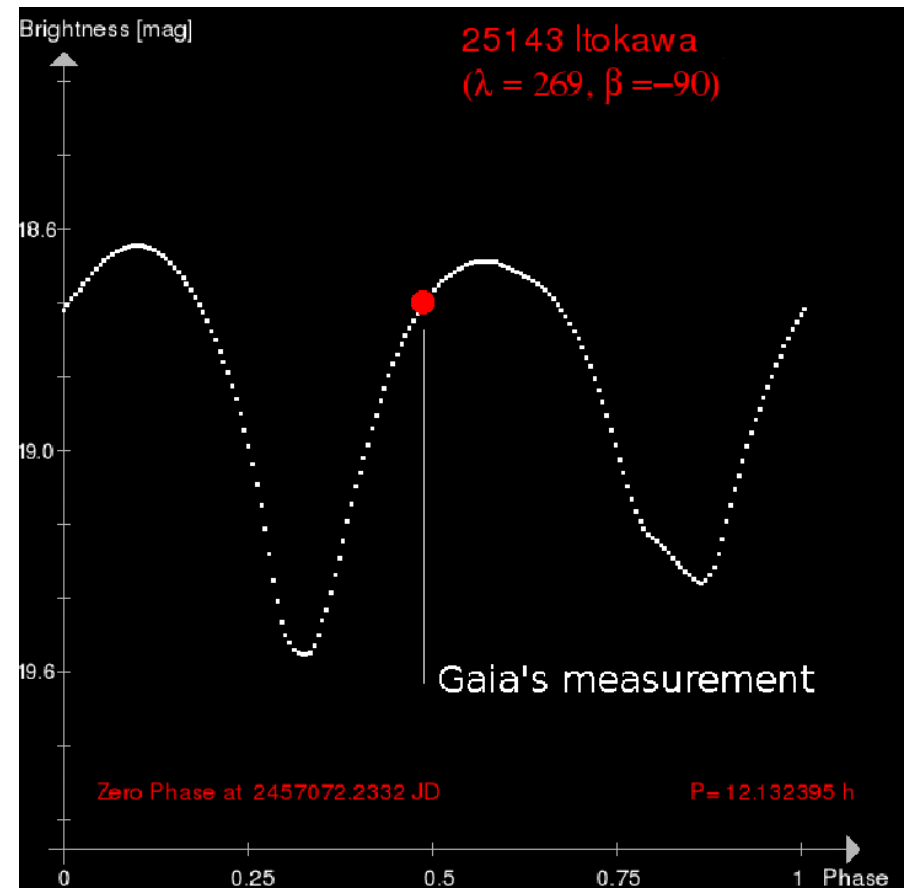
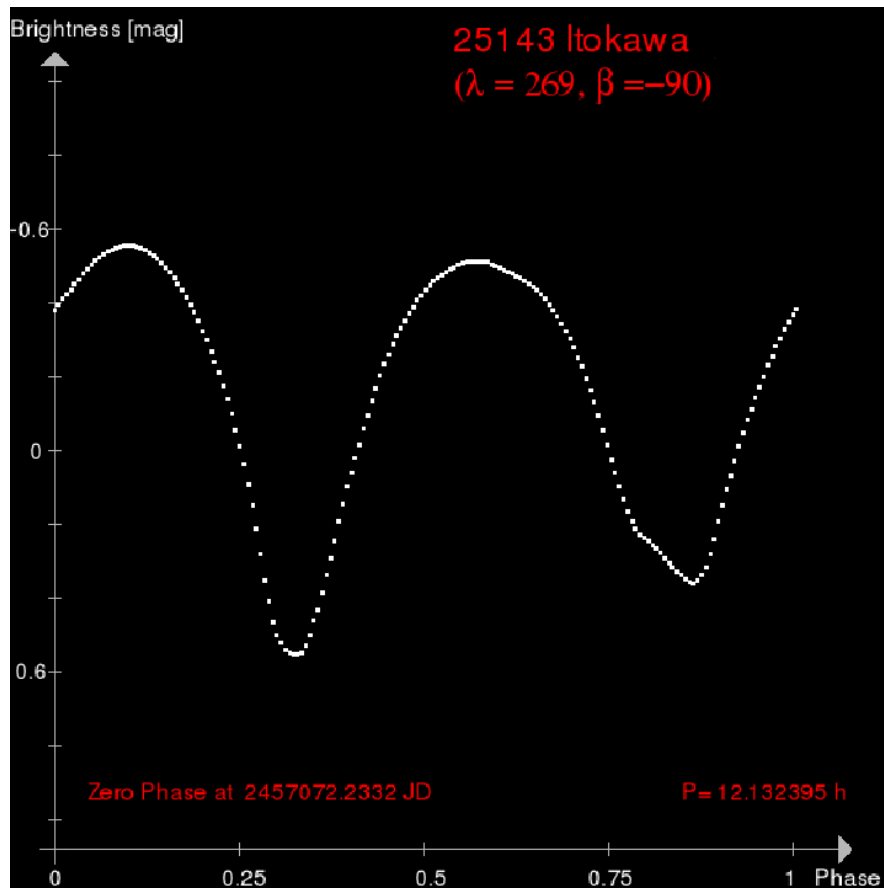


Außerdem können so Modelle (Mehrfachlösungen)  
Ausgeschlossen werden.

Ref.: euraster.net

# Gaia-GOSA (gaiagosa.eu)

Gaia-Groundbased Observational Service for Asteroids (Pro-Am Kollaboration)



=> (u.a.): neue H,G-Parameter (in einem [neuen] Gaia-System) => bessere Durchmesser etc.



# http://gaiagosa.eu

The screenshot shows the GOSA website interface. On the left is a dark sidebar with the GOSA logo and navigation links: Home, Gaia status, Guide, Observation planner, Observation processing, Forum, FAQ, and About (highlighted). The main content area has a top header with social media icons, a search bar, and a 'SIGN IN' button. Below this, it displays 'Active users: 78', 'Observations: 77', 'Forum posts: 150', and the current date/time: '2016-11-14 14:27:28 UTC'. The main content is divided into two columns. The left column is titled 'About' and contains a section 'About Gaia mission' with text about the Gaia mission and a list of statistics under 'Gaia Solar System science in numbers:'. The right column is titled 'About GOSA service' and contains text about the GOSA service and a link to the 'Observation planner'. Both columns feature video thumbnails. The left video is titled 'Inside Gaia's billion-pixel camera' and shows the Gaia spacecraft. The right video is titled 'A ground based observational service for asteroids' and shows a ground-based telescope.

**GOSA**

Anonymous

Home

Gaia status

Guide

Observation planner

Observation processing

Forum

FAQ

About

About

Active users: 78 | Observations: 77 | Forum posts: 150 | 2016-11-14 14:27:28 UTC

**About**

**About Gaia mission**

Gaia is an ambitious mission of the European Space Agency (ESA) to chart a three-dimensional map of our Galaxy, including our immediate neighbourhood, the Solar System, in the process revealing the composition, formation and evolution of the Galaxy.

Gaia will perform multi-epoch photometric observations of the Solar System's minor bodies. These observations will reveal their surface properties and composition by the amount of light that the minor bodies reflect at particular wavelengths.

A refined classification of the population of minor bodies will emerge from the giant data base, revealing the kinship between asteroids, NEOs, and meteoroids.

**Gaia Solar System science in numbers:**

- more than 300.000 asteroids observed over 5 years
- between 60 and 70 snapshots per asteroid on average
- 0.01 mag is the average photometric precision for each measurement
- at least 10.000 new three-dimensional models of asteroids

**Inside Gaia's billion-pixel camera**

**About GOSA service**

Gaia-Groundbased Observational Service for Asteroids (Gaia-GOSA) is an interactive tool which supports observers in planning photometric observations of asteroids. The asteroid prediction tool is based on the Gaia orbit and scanning law provided by the European Space Agency and the ephemerides of Solar System bodies provided by the Minor Planet Center. These inputs have been coupled by a software tool developed and run by the Gaia Data Processing and Analysis Consortium (DPAC).

Join the community today and start collaborating with a real space mission!

Check out the GOSA targets visible from your observing site using the [Observation planner](#).

**A ground based observational service for asteroids**

The link between the two data sets would then be very strong, as a single Gaia measurement provides a very precise absolute magnitude that can be used to calibrate the ground-based lightcurve.

# http://minorplanet.info

CALL

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Lightcurve Database

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Right-click on a link and select "Save Target As" from the popup menu to download the file directly to your hard drive. Otherwise, your browser will most likely try to open the file and it will not be automatically saved.

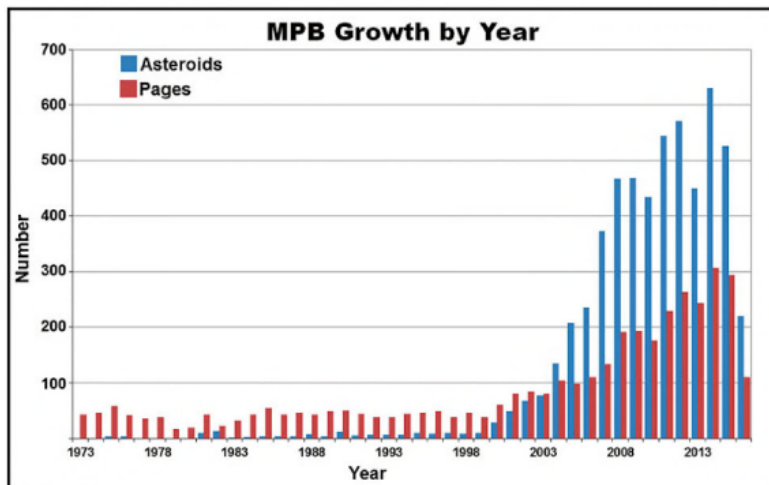
### Acknowledgments

Back issues from 1994-2003 were provided by Dan Coley. Thanks to MPB Editor, Prof. Richard Binzel, and Frederick Pilcher, Coordinator of ALPO's Minor Planets Section, for giving permission to make the files available.

### Corrigendum

The links at the bottom of the page are corrigendum (corrections) to papers in the MPB

<b>1994</b>	<b>2002</b>	<b>2010</b>
<a href="#">Jan-Mar, 21-1</a>	<a href="#">Jan-Mar, 29-1</a>	<a href="#">Jan-Mar, 37-1</a>
<a href="#">Apr-Jun, 21-2</a>	<a href="#">Apr-Jun, 29-2</a>	<a href="#">Apr-Jun, 37-2</a>





# Auswertung von Asteroiden-Photometrie

- CCD-Photometrie (bewegter Objekte des SS)
- (H,G)- Parameter, Phasenrelation
- Lichtkurven-Analyse (Zeitreihen-Analyse)
  - Standard: Periodenbestimmung, Amplitude
  - Fortgeschritten: 3D-Modelle, Spin, etc.
- Kombination der Techniken LC-Inversion, Sternbedeckungen, AO.
- Data-Mining (für Schreibtisch-Astronomen)!



# CCD-Photometrie

Problem: Bewegte Objekte !

- Standardprogramm in der Kleinplaneten-Photometrie: MPO Canopus von Brian Warner. CCD-Auswertung, Periodenbestimmung bis hin zur LC-Inversion (3D-Modell) mit Zusatzprogramm LCInvert. Aber nicht zwingend!
- Standard in der Kleinplaneten-Astrometrie: Astrometrica von Herbert Raab.
  - Begrenzte Anzahl von Bildern automatisch auswertbar.
  - Auch Photometrie, aber leider nicht batch-fähig.
- Andere Programme aus der Astronomie.
  - AIP, Audela, CCDsoft, Iris, MaximDL, Mira, MIDAS, IRAF usw.
- Neu: Gaia-GOSA : Upload der CCD-Bilder => fertige LC.



# CCD-Photometrie

## DIY-Varianten:

- Sextractor (Perl). Einige Projekte benutzen das Paket in ihrer “Prozess-Pipeline”.
- Python: PyFITS, PyEphem, pysex usw.

Vorteil: Anpassung an eigene Wünsche und Gegebenheiten, Automatisierung etc.

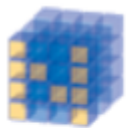


# Einfache Lichtkurven-Analyse

- Grundsätzlich Tools aus der Veränderlichen-Beobachtung nutzbar: z.B. Peranso.
- (Mathematisches) Standardverfahren: Fourier-Analyse. In der KP-Szene als FALC (Fortran Code) von A.Harris (1989) bekannt. Canopus (und auch Peranso) haben diesen Algorithmus implementiert.
- FALC-ähnliche Verfahren sind ausreichend und manchmal besser als PDM etc. aus der Veränderlichenbeobachtung.
- Anpassung (Least Squares Fit) an Fourier-Reihen ist in mathematisch-wissenschaftlicher Software (Matlab, IDL usw.) programmierbar.
- Oder in einer anderen (allgemeinen) Programmiersprache (C++, Java, Fortran, Python, Julia, usw.).

# Einfache Lichtkurven-Analyse mit Python

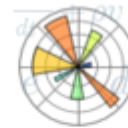
Python + NumPy + SciPy + Matplotlib = Unimog der (modernen) wissenschaftlichen Skripting-Welt



NumPy  
Base N-dimensional array  
package



SciPy library  
Fundamental library for scientific  
computing



Matplotlib  
Comprehensive 2D Plotting



IPython  
Enhanced Interactive Console



Sympy  
Symbolic mathematics



pandas  
Data structures & analysis

Mein Weg:

Einfache Skripte zur Periodensuche und zum Fitten (an Fourier-Reihe) sowie zu Plotten der Phasen-Lichtkurve:

- 1) Periode scannen (Range ausprobieren) und nach kleinsten RMS suchen.
- 2) Beobachtungen an diese Periode fitten (exaktes  $P + \text{Err}$ ), Phasenplot ausgeben.

Demo...