

# Asteroid 2 Pallas Physical Properties from Near-Infrared High-Angular Resolution Imagery

**B. Carry**<sup>1,2</sup>

**M. Kaasalainen**<sup>3</sup>

**C. Dumas**<sup>1</sup>

**J. Berthier**<sup>4</sup>

**W. Merline**<sup>5</sup>

**A. Conrad**<sup>6</sup>

**T. Fusco**<sup>7</sup>

**D. Hestroffer**<sup>4</sup>

**M. Fulchignoni**<sup>2</sup>

**S. Erard**<sup>2</sup>



<sup>1</sup>European Southern Observatory

<sup>2</sup>LESIA, Observatoire de Paris

<sup>3</sup>University of Helsinki

<sup>4</sup>IMCCE, Observatoire de Paris

<sup>5</sup>Southwest Research Institute

<sup>6</sup>Keck Observatory

<sup>7</sup>ONERA

# Asteroid 2 Pallas



- ▷ Second Asteroid Discovered
  - H. Olbers, 1802
- ▷ Unusual among Big Asteroids
  - High Inclinaison
  - High Excentricity
- ▷ Almost **NOT** studied
  - Only Mass Measurement since 1996
  - Half Studies Joint with Ceres
  - “Unloved Little Brother”

# Asteroid 2 Pallas



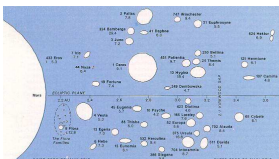
- ▷ Second Asteroid Discovered
  - H. Olbers, 1802
- ▷ Unusual among Big Asteroids
  - High Inclinaison
  - High Excentricity
- ▷ Almost **NOT** studied
  - Only Mass Measurement since 1996
  - Half Studies Joint with Ceres
  - “Unloved Little Brother”

## Asteroid 2 Pallas



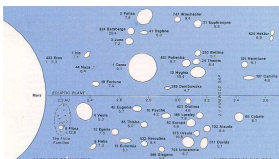
- ▶ Second Asteroid Discovered
  - H. Olbers, 1802
- ▶ Unusual among Big Asteroids
  - High Inclinaison
  - High Excentricity
- ▶ Almost **NOT** studied
  - Only Mass Measurement since 1996
  - Half Studies Joint with Ceres
  - “Unloved Little Brother”

# Asteroid 2 Pallas



- ▷ Second Asteroid Discovered
  - H. Olbers, 1802
  
- ▷ Unusual among Big Asteroids
  - High Inclinaison
  - High Excentricity
  
- ▷ Almost **NOT** studied
  - Only Mass Measurement since 1996
  - Half Studies Joint with Ceres
  - “Unloved Little Brother”

# Asteroid 2 Pallas



- ▶ Second Asteroid Discovered
  - H. Olbers, 1802
  
- ▶ Unusual among Big Asteroids
  - High Inclinaison
  - High Excentricity
  
- ▶ Almost **NOT** studied
  - Only Mass Measurement since 1996
  - Half Studies Joint with Ceres
  - “Unloved Little Brother”

2001, Goffin *et al.*, A&A, 365  
 1996, Mitchell *et al.*, Icarus, 124  
 1993, Saint-Pé *et al.*, Icarus, 105  
 1989, Drummond *et al.*, Icarus, 78



## Observations



- Keck II Observatory
  - 2003 opposition
  - $\phi \sim .44''$
  - 10 m mirror
  - 1/2 hour, 1 night
  
- NACO on Yepun/VLT
  - 2005 opposition
  - $\phi > .44''$
  - 8.2 m mirror
  - 4 hours, 5 nights



## Observations



- Keck II Observatory
  - 2003 opposition
  - $\phi \sim .44''$
  - 10 m mirror
  - 1/2 hour, 1 night

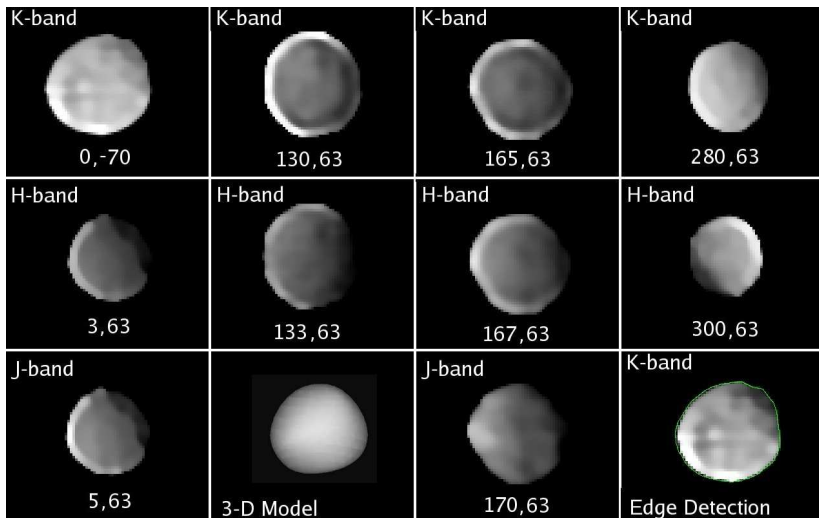


- NACO on Yepun/VLT
  - 2005 opposition
  - $\phi > .44''$
  - 8.2 m mirror
  - 4 hours, 5 nights

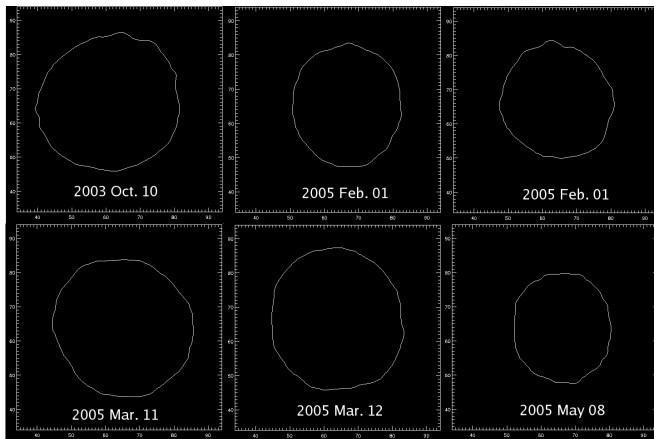




## Pallas at Near-Infrared Wavelengths



# Edges Detection



<http://thames.cs.rhul.ac.uk/~multires/>  
2007, Conrad *et al.*, Icarus, *in press*

# Lightcurve Inversion Model

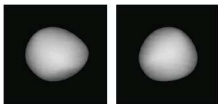
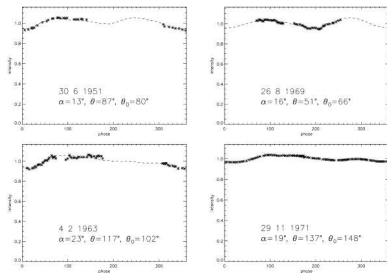


Fig. 1. Shape model of 2 Pallas, shown at equatorial viewing/illumination geometry, with rotational phases 90° apart.



- Many Lightcurves
- Many Solar Phases
  
- ▷ ONE Sidereal Period
- ▷ TWO Pole Solutions
- ▷ TWO Shape Models
- ▷ CONVEX Shape Models

2003, Āurech *et al.*, A&A, 404  
 2003, Kaasalainen *et al.*, Icarus, 159  
 2003, Kaasalainen *et al.*, Icarus, 153

# Lightcurve Inversion Model

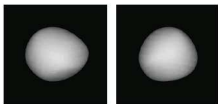
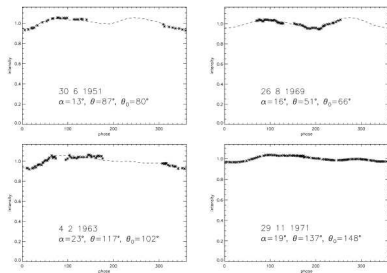


Fig. 1. Shape model of 2 Pallas, shown at equatorial viewing/illumination geometry, with rotational phases 90° apart.



- Many Lightcurves
- Many Solar Phases
  
- ▷ ONE Sidereal Period
- ▷ TWO Pole Solutions
- ▷ TWO Shape Models
- ▷ CONVEX Shape Models

2003, Āurech *et al.*, A&A, 404  
 2003, Kaasalainen *et al.*, Icarus, 159  
 2003, Kaasalainen *et al.*, Icarus, 153

# Lightcurve Inversion Model

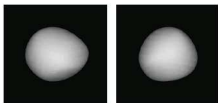
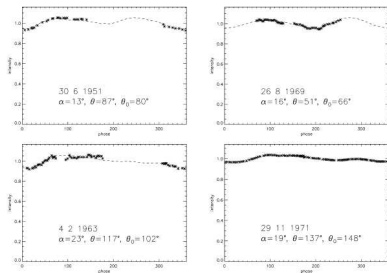


Fig. 1. Shape model of 2 Pallas, shown at equatorial viewing/illumination geometry, with rotational phases 90° apart.



- Many Lightcurves
- Many Solar Phases
  
- ▷ ONE Sidereal Period
- ▷ TWO Pole Solutions
- ▷ TWO Shape Models
- ▷ CONVEX Shape Models

2003, Āurech *et al.*, A&A, 404  
 2003, Kaasalainen *et al.*, Icarus, 159  
 2003, Kaasalainen *et al.*, Icarus, 153

# Lightcurve Inversion Model

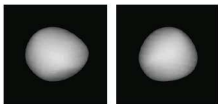
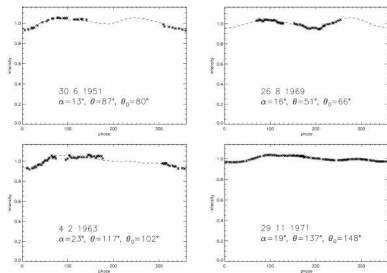


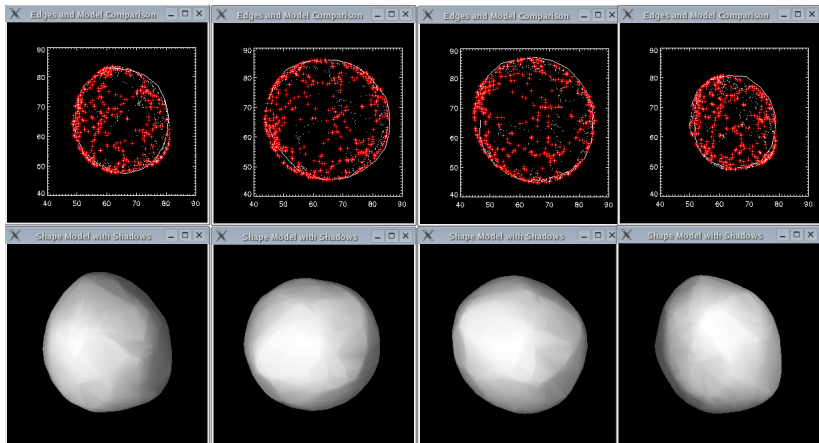
Fig. 1. Shape model of 2 Pallas, shown at equatorial viewing/illumination geometry, with rotational phases 90° apart.



- Many Lightcurves
- Many Solar Phases
  
- ▷ ONE Sidereal Period
- ▷ TWO Pole Solutions
- ▷ TWO Shape Models
- ▷ CONVEX Shape Models

2003, Āurech *et al.*, *A&A*, 404  
 2003, Kaasalainen *et al.*, *Icarus*, 159  
 2003, Kaasalainen *et al.*, *Icarus*, 153

## LC + AO Analysis



2003, Torppa *et al.*, Icarus, 164

# Results

## ▷ Unique Pole Solution

- Ecliptic J2000.0  $\lambda = 34^\circ$ ,  $\beta = -11^\circ$  ( $\pm 5^\circ$ )
- Future Observations Prediction via Ephemeris

## ▷ Precise Size Measurement

- $a \times b \times c = 277 \text{ km} \times 213 \text{ km} \times 208 \text{ km}$
- 1- $\sigma$  dispersion:  $10 \text{ km} \times 8 \text{ km} \times 8 \text{ km}$
- $\rho \sim 4500 \pm 500 \text{ kg.m}^{-3}$

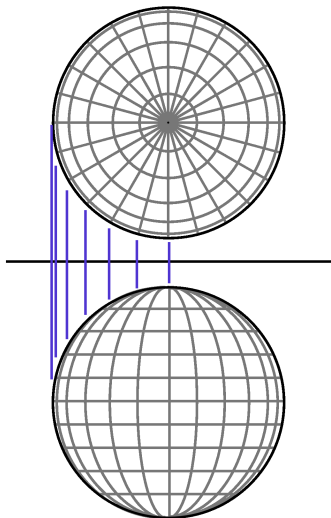
## ▷ More Complex Shape Model

- Render Better the Global Shape
- Allows Concavity
- Allows Surface Mapping

2007?, Carry *et al.*, *in prep.*  
2007, Kaasalainen *et al.*, DPS Meeting  
2006, Marchis *et al.*, Icarus, 185

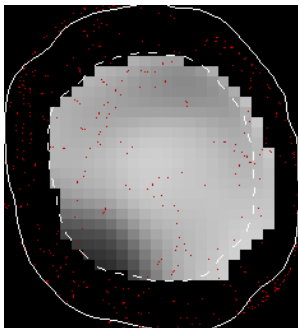


# Surface Mapping



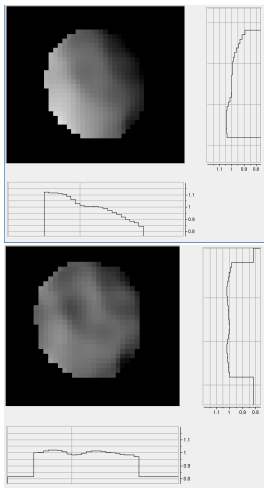
- 1 Geometry Election
- 2 Region of Interest Definition
- 3 Phase Angle Effect Removal
- 4 Coordinates Conversion

# Surface Mapping



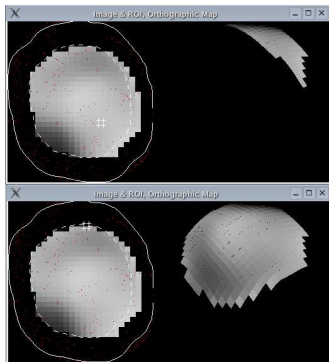
- 1 Geometry Election
- 2 Region of Interest Definition
- 3 Phase Angle Effect Removal
- 4 Coordinates Conversion

# Surface Mapping



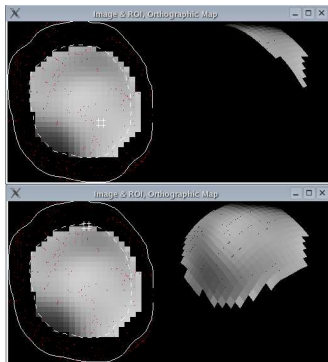
- 1 Geometry Election
- 2 Region of Interest Definition
- 3 Phase Angle Effect Removal
- 4 Coordinates Conversion

# Surface Mapping



- 1 Geometry Election
- 2 Region of Interest Definition
- 3 Phase Angle Effect Removal
- 4 Coordinates Conversion

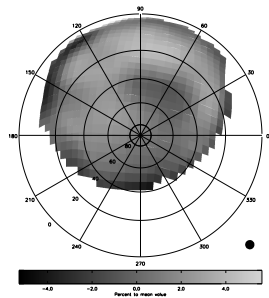
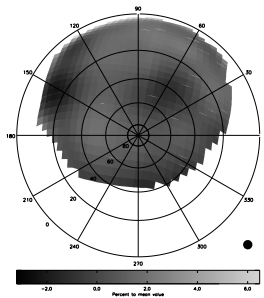
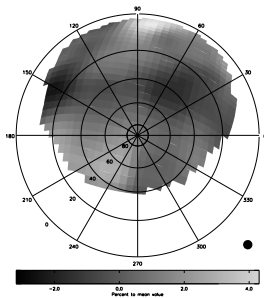
# Surface Mapping



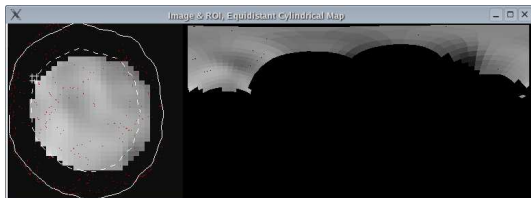
- 1 Geometry Election
- 2 Region of Interest Definition
- 3 Phase Angle Effect Removal
- 4 Coordinates Conversion

2007, Carry *et al.*, *A&A*, *submitted*  
2006, Li *et al.*, *Icarus*, 182

# Surface Mapping



1990, Greeley *et al.*  
**Planetary Mapping**  
 Cambridge University Press



# Summary

- ▶ Spin Vector Determination
  - Ephemeris Solution
  
- ▶ Size Measurement & Shape Modelisation
  - Quite far from  $285 \times 262 \times 241$ , [1989, Drummond *et al.*, Icarus, 78]
  - Density Measurement
  
- ▶ Surface Mapping
  - To be Analyzed...