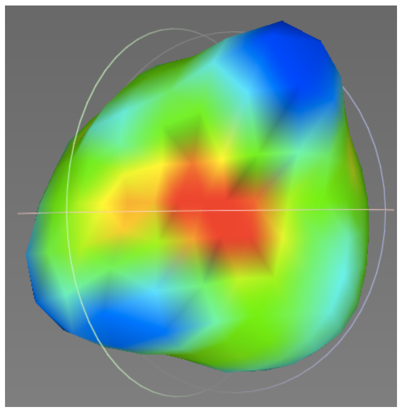
Portraits of Barbarians:
linking anomalous polarimetry to physical properties



COST European Cooperation in Science and Technology
Polarisation as a tool to study the Solar System and beyond
Action MP1104

INAF - Arcetri

Armagh Observatory

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2 : INAF/Osservatorio Astrofisico di Torino, Italy
3. Armagh Observatory, UK

Observatoire de la CÔTE d'AZUR

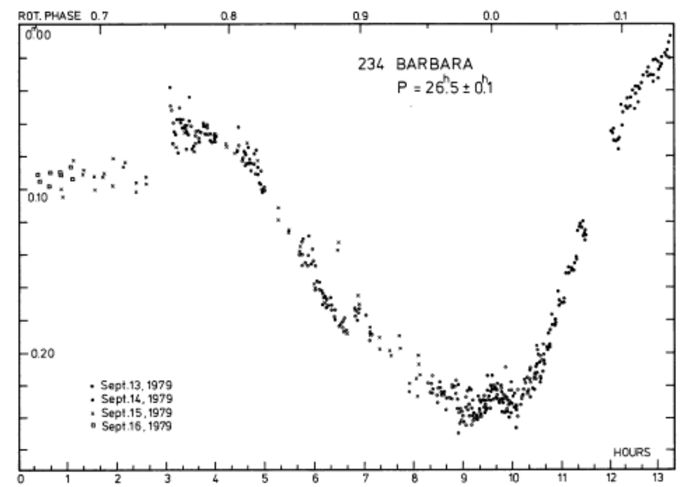
LAGRANGE

234 Barbara

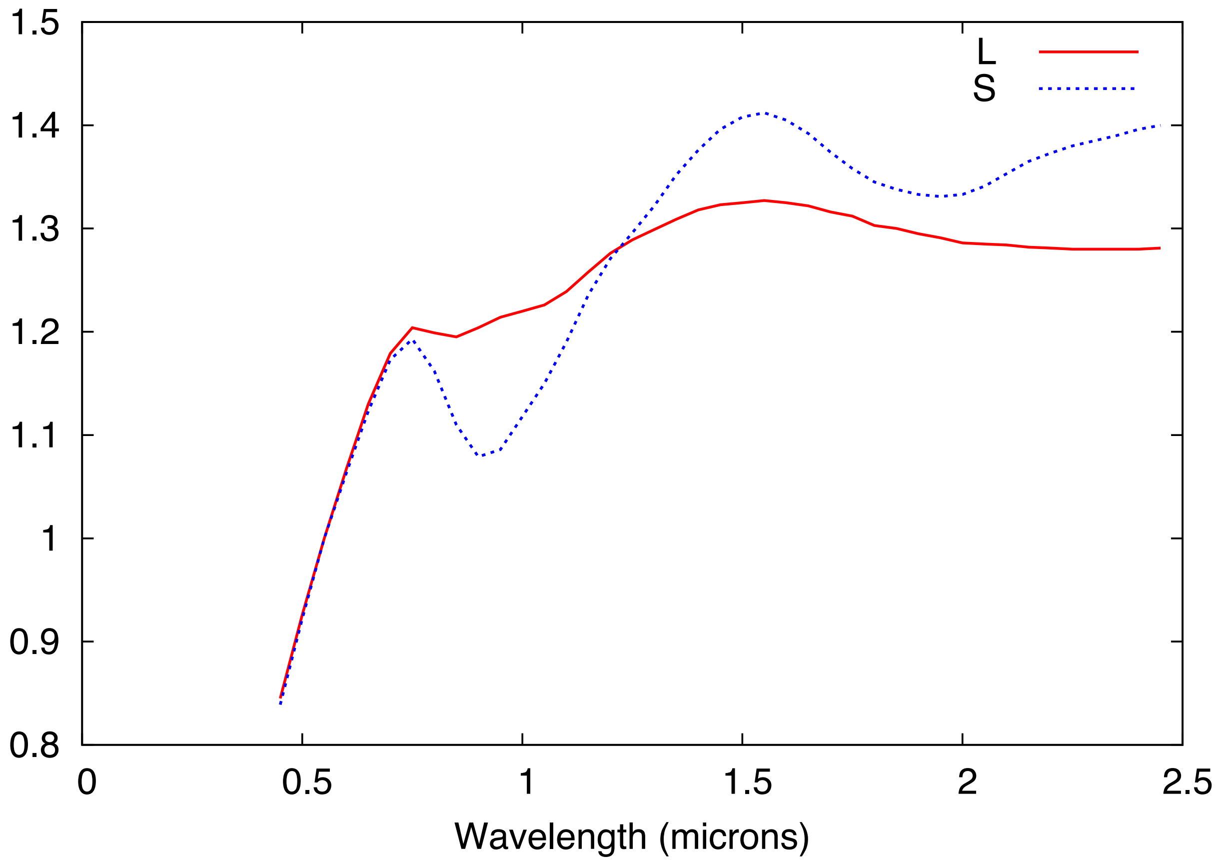
Discovered on August 12, 1883 by C.H.F. Peters in Clinton, NY

Magnitude H	9.02
Inclination	15.35305
Eccentricity	0.2437485
Semimajor Axis	2.3864727
Tholen class	S
SMASS II class	Ld

	WISE	*AKARI*	*IRAS*
Size km	53.8	47.8	43.7
Albedo	0.15	0.19	0.22



Shober et al. 1981



Bus and Binzel (2002):

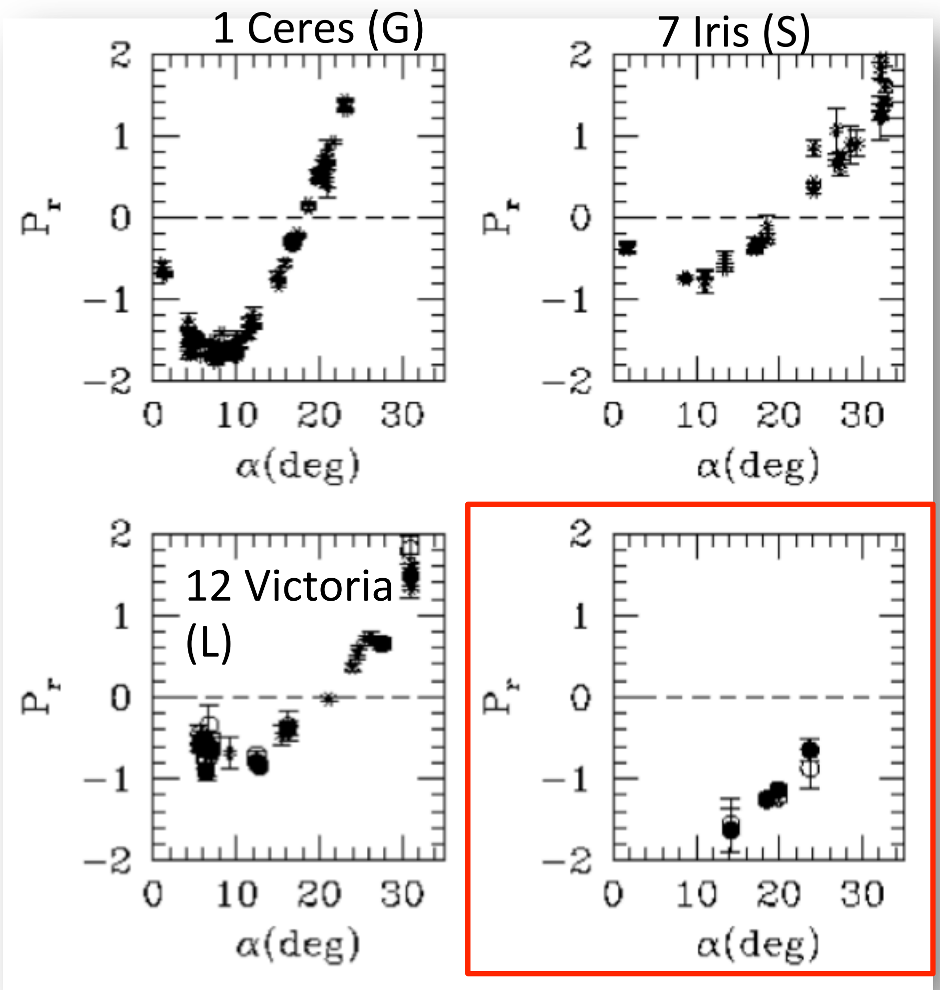
L-class: similar to S, but strongly reddish <750 nm and featureless >750 nm

Ld class: even redder

Cellino et al., 2006

"The strange polarization of 234 Barbara"

Icarus 180, 2, 565



New findings: Gil-Hutton et al. 2008

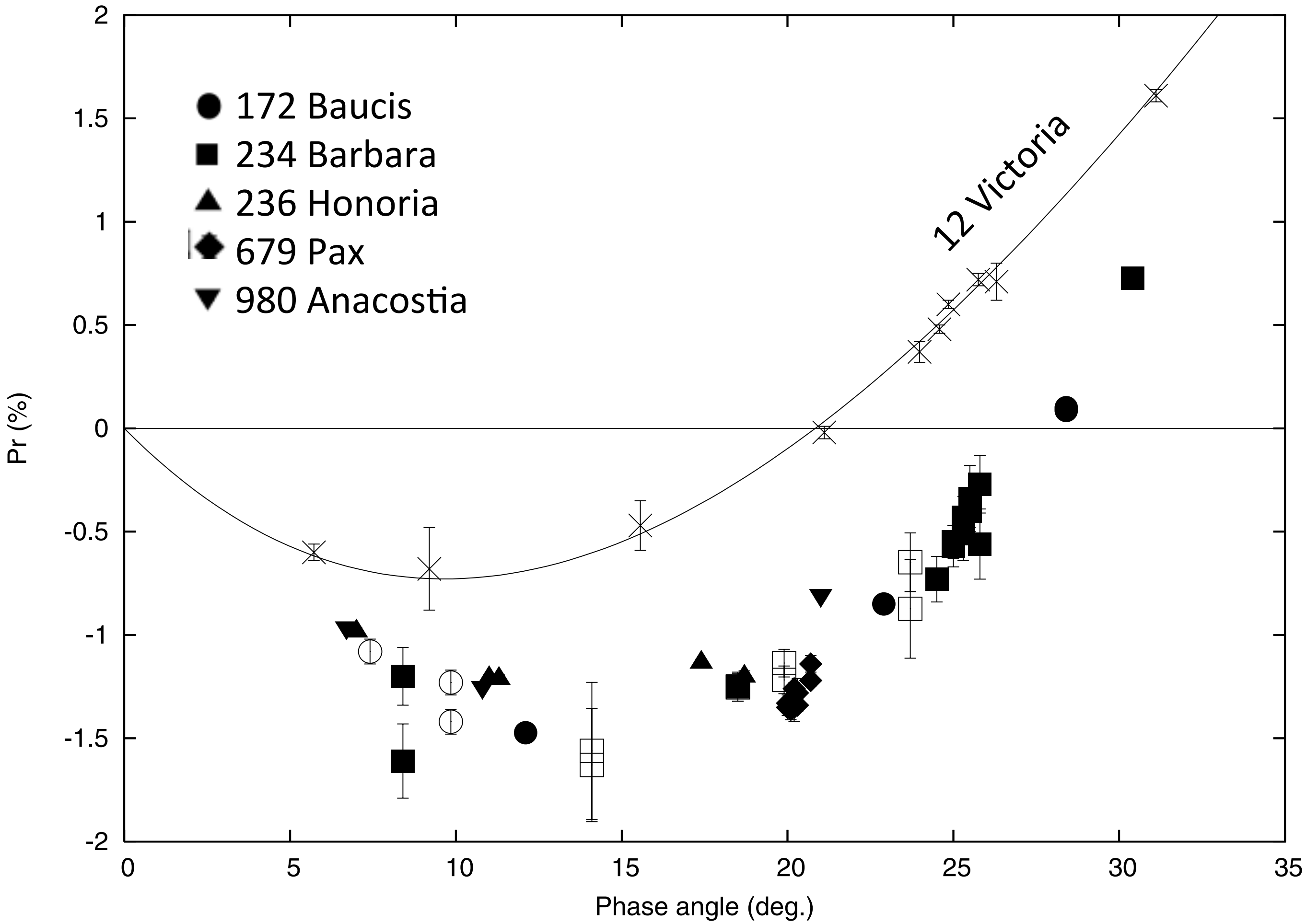


Fig. 1. Polarimetric observations of asteroids with Barbara-like polarimetric properties. Data for (172) Baucis are indicated by circles, for (234) Barbara by squares, for (236) Honoria by triangles, for (679) Pax by diamonds, and for (980) Anacostia by inverted triangles. Filled symbols indicate data taken during our present campaign. For a comparison, data for the L-class asteroid (12) Victoria are displayed by crosses, together with the corresponding fit of its phase-polarization curve.

Tentative explanations of the polarimetric anomaly:

- "a very speculative possibility": very large impact craters/concavities on the surface (Cellino et al. 2006)

- CO3/CV3 spinel-bearing meteorites have high negative polarization and inversion angles (Zellner 1977).

  Spinel = $MgAl_2O_4$ often associated to metals (Fe, Cr) → reddening of the spectrum

CO3/CV3 → relation to K- and L-class asteroids (Burbine et al 1992, 2001, Sunshine et al 2007)

The connection to CV meteorites

Sunshine et al., 2007

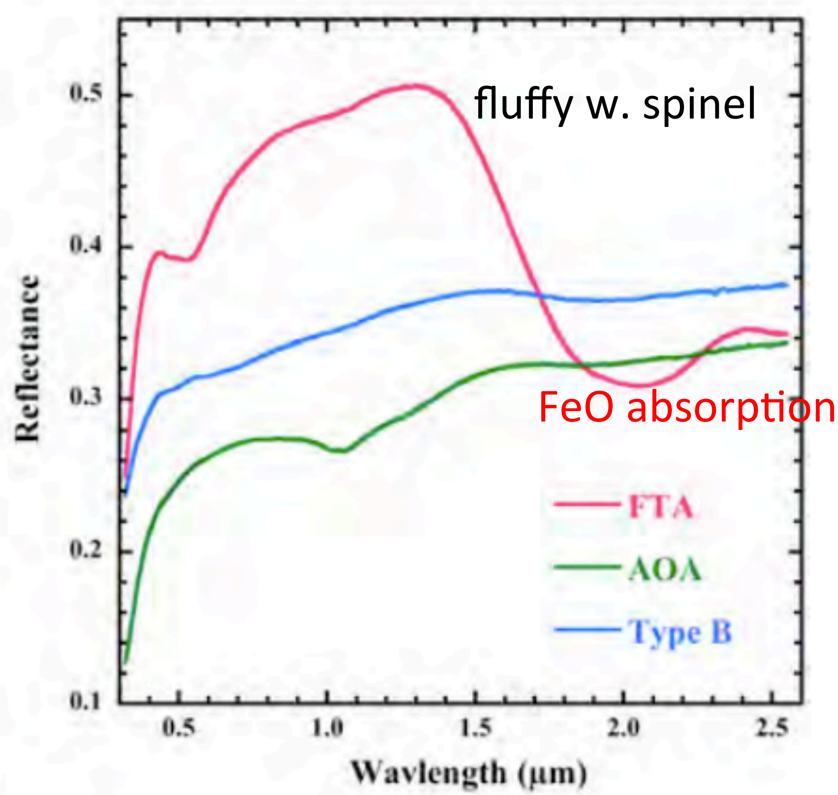


***Fig. 1**: Spectra of CAI's from Allende*

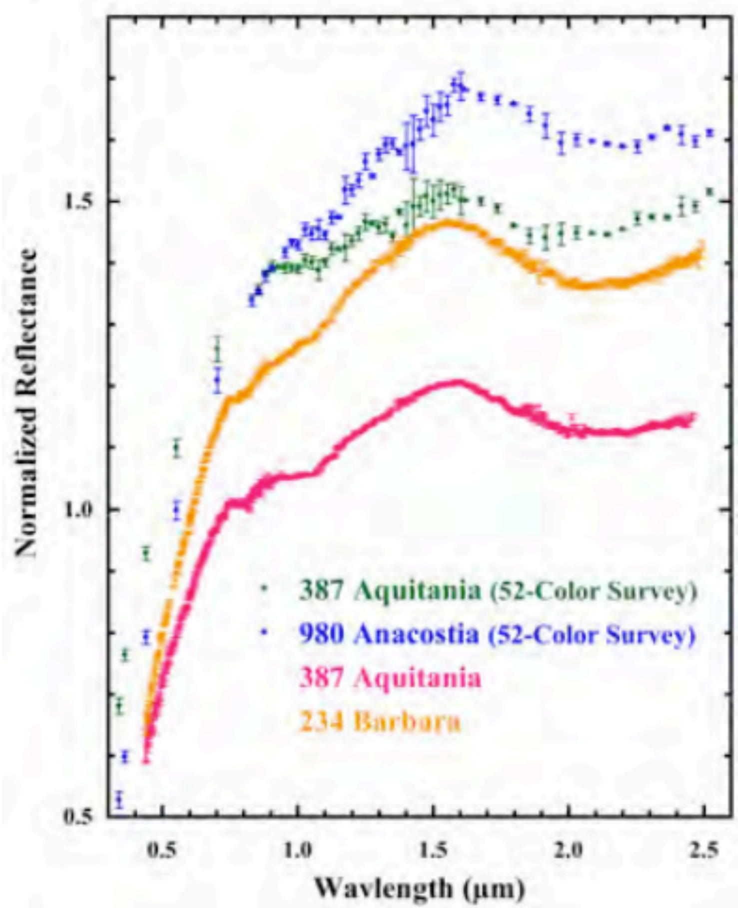
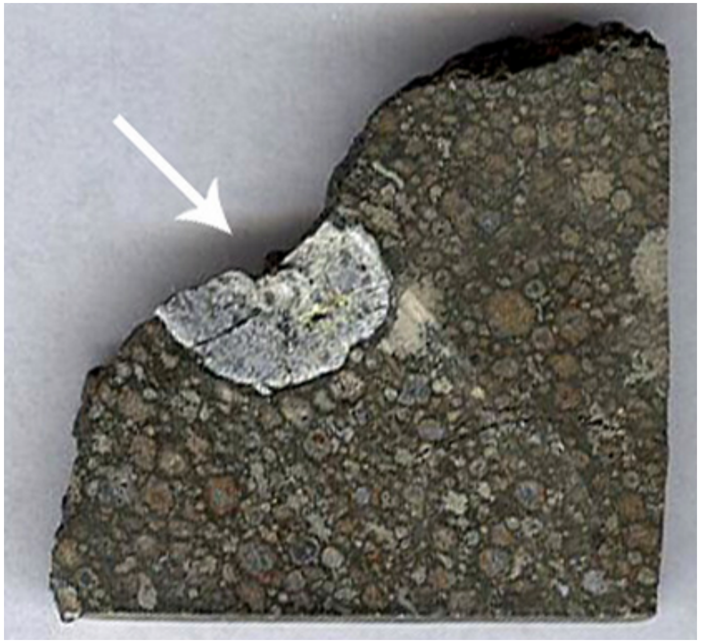


Fig. 2. *52-Color [5] and SpeX asteroid spectra, which are all dominated by spinel absorptions at 2 µm*

Northwest Africa group of CV3s

NWA 2086 (CV3)

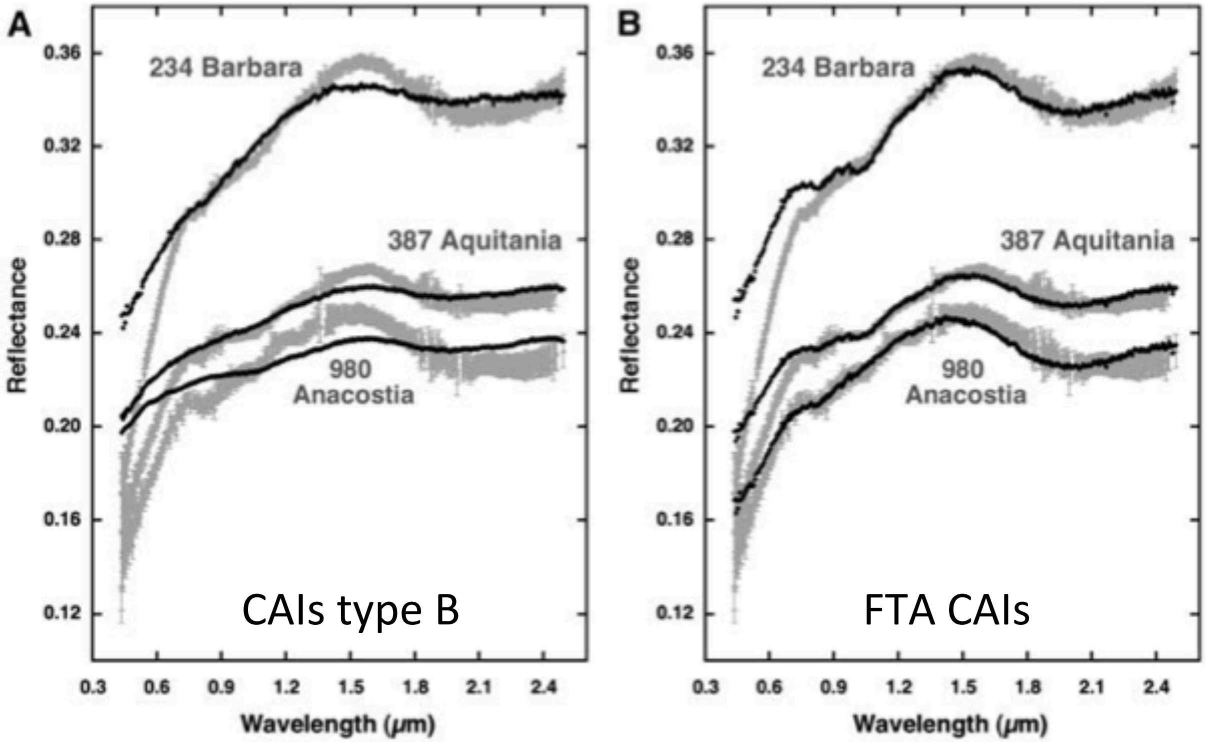


NWA 2364 (CV3)

Refractory inclusions up to **13%** in CV3.

Most ancient materials in the Solar System ever dated:
4.568 billion yrs

No meteorite samples of this kind?



Radiative transfer model by Sunshine et al 2008.
30% of fluffy-type (unaltered) CAIs are required…

(Note: visual portion poorly modeled)

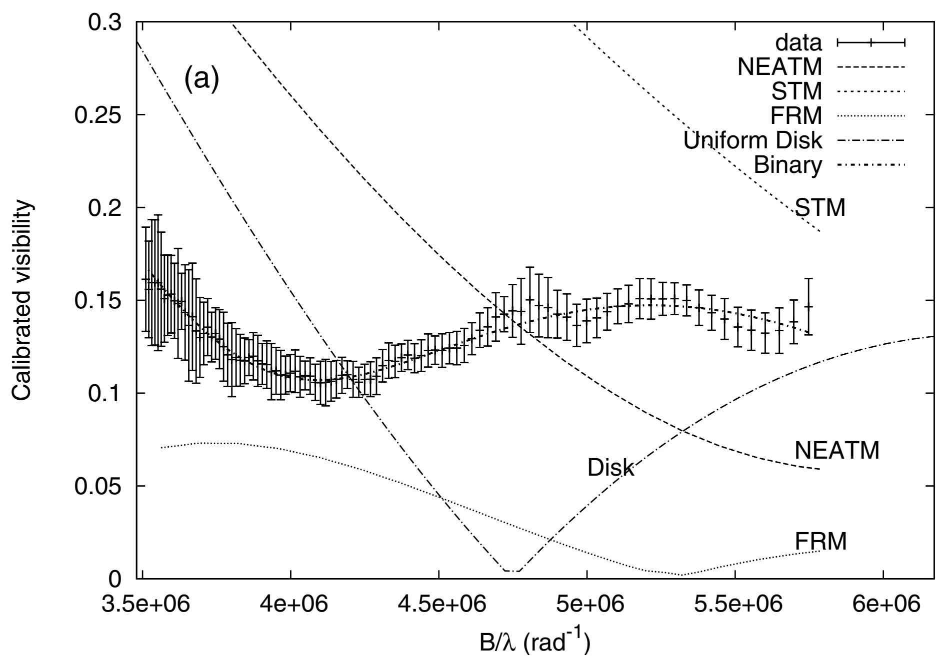
More on 234 Barbara

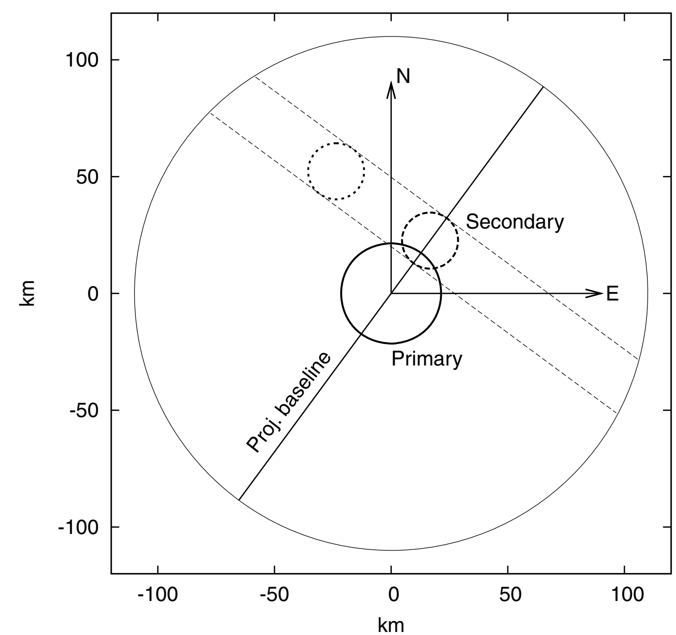
THE ASTROPHYSICAL JOURNAL, 694:1228–1236, 2009 April 1

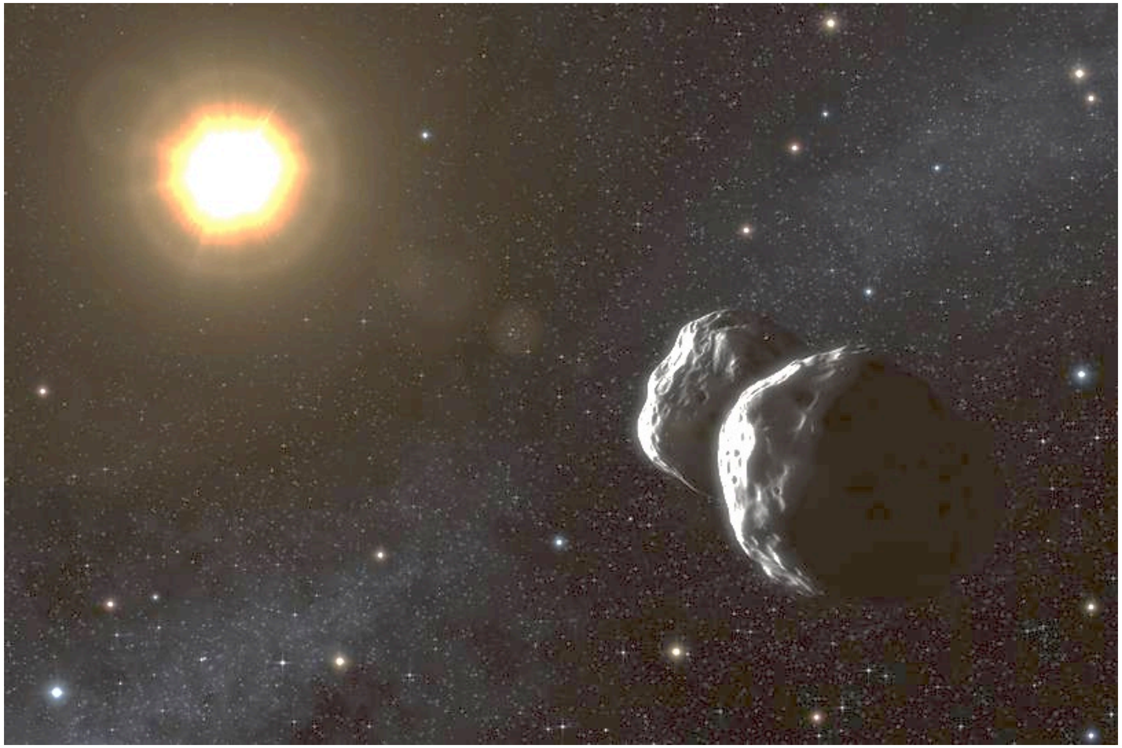
FIRST VLTI-MIDI DIRECT DETERMINATIONS OF ASTEROID SIZES*

M. DELBO[1,2], S. LIGORI[3], A. MATTER[4], A. CELLINO[5], AND J. BERTHIER[6]

MIDI@VLTI, 8-13 μm (in Nov. 2005)

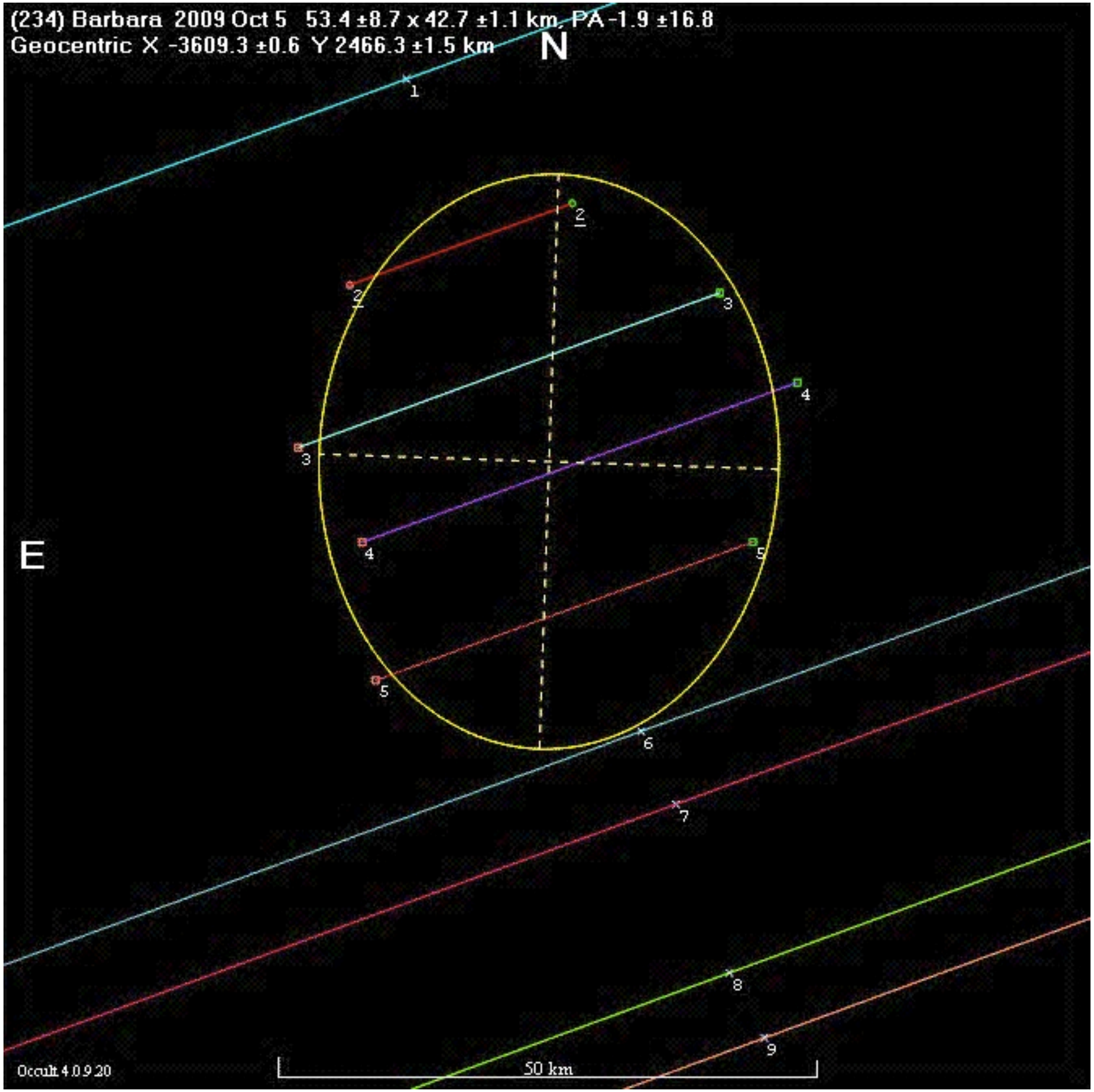


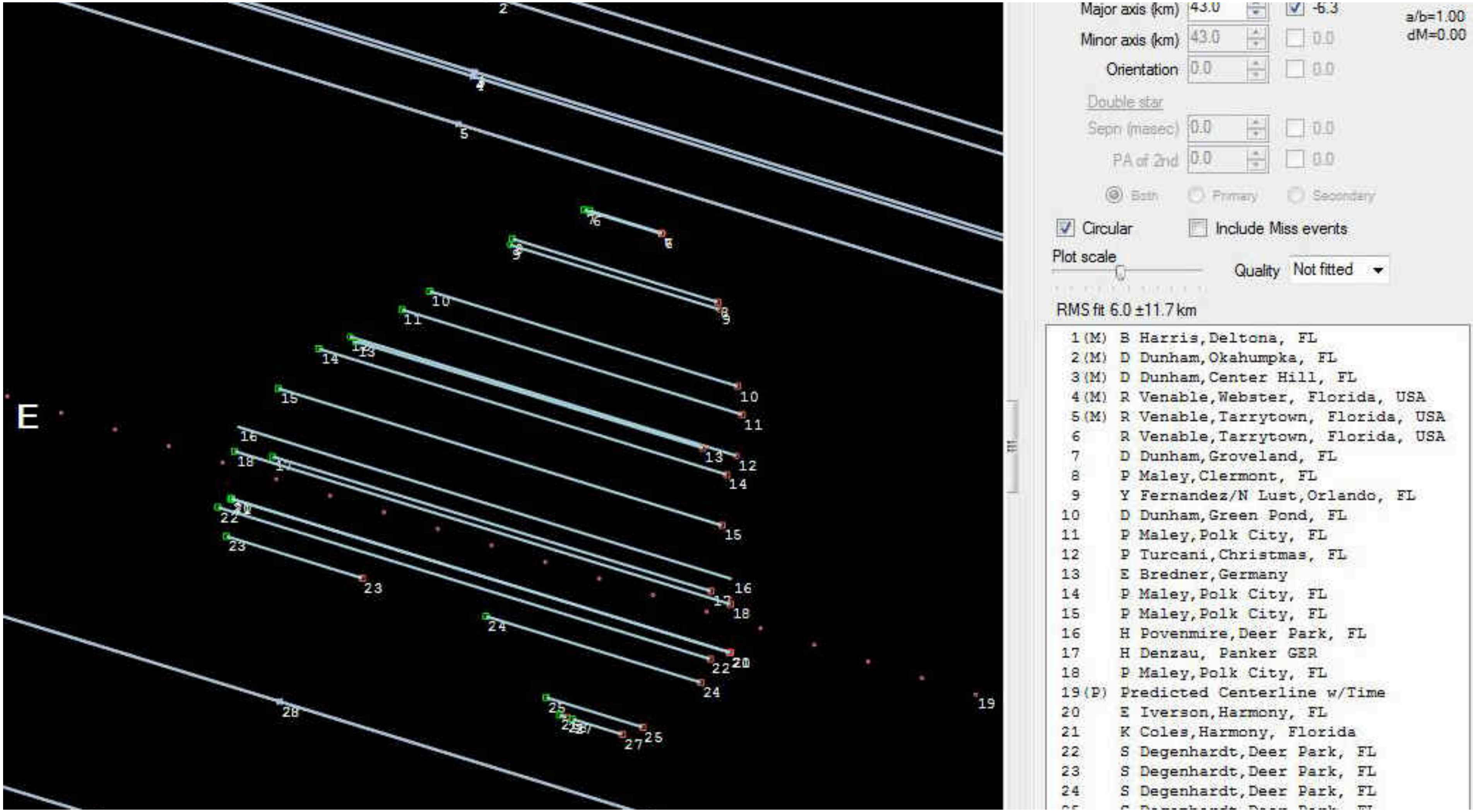




Predicted stellar occultation events :

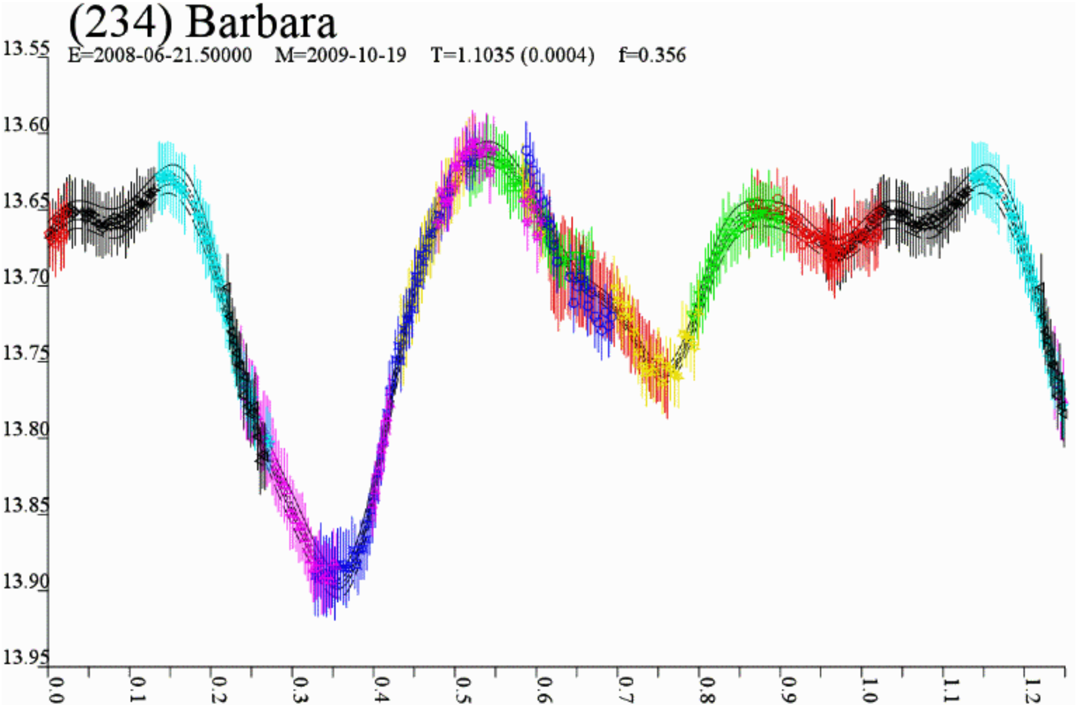
2009 October 5	Canary Islands	star V = 7.2
2009 November 21	Florida	star V = 6.5


(234) Barbara 2009 Oct 5 53.4 ±8.7 x 42.7 ±1.1 km, PA -1.9 ±16.8
Geocentric X -3609.3 ±0.6 Y 2466.3 ±1.5 km
N
E
1
2
2
3
3
4
4
5
5
6
7
8
9
Occult 4.0.9.20
50 km

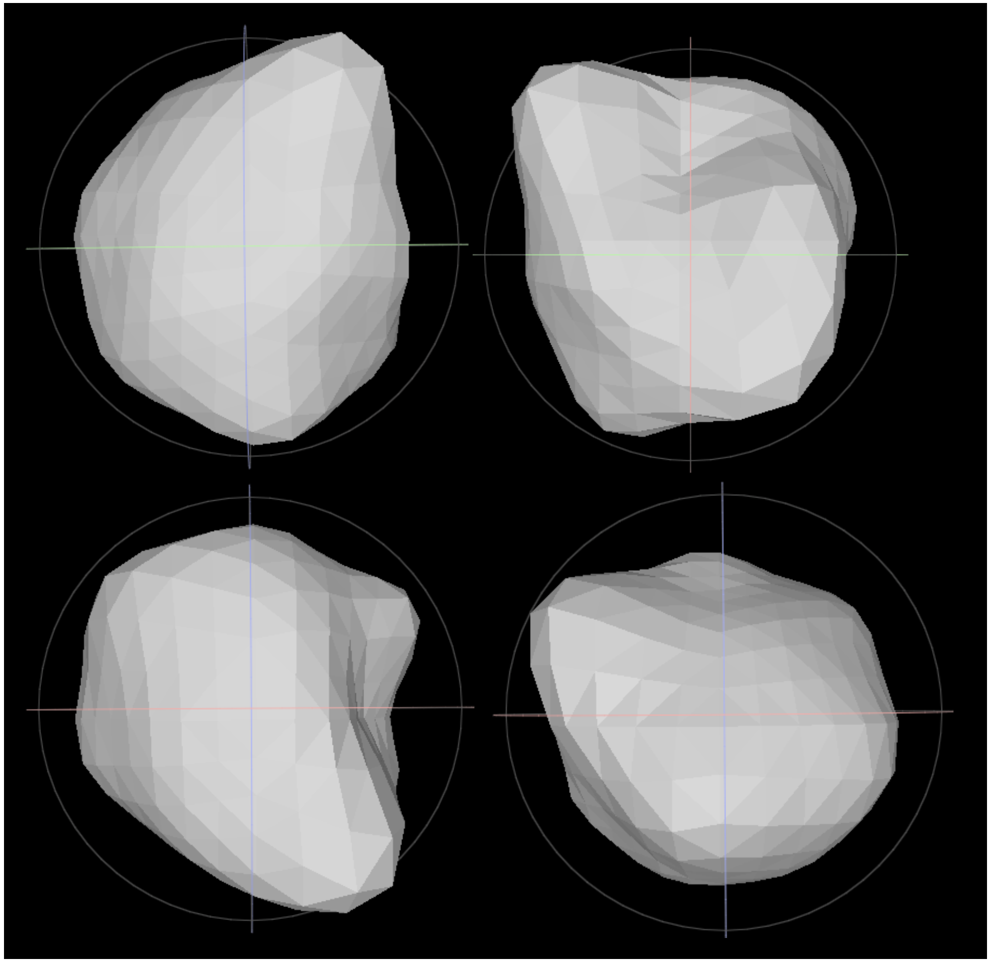

E
Major axis (km) 43.0 -6.3
Minor axis (km) 43.0 0.0
Orientation 0.0 0.0
a/b=1.00
dM=0.00
Double star
Sepn (masec) 0.0 0.0
PA of 2nd 0.0 0.0
Both Primary Secondary
Circular
Include Miss events
Plot scale
Quality Not fitted
RMS fit 6.0 ±11.7 km
1 (M) B Harris, Deltona, FL
2 (M) D Dunham, Okahumpka, FL
3 (M) D Dunham, Center Hill, FL
4 (M) R Venable, Webster, Florida, USA
5 (M) R Venable, Tarrytown, Florida, USA
6 R Venable, Tarrytown, Florida, USA
7 D Dunham, Groveland, FL
8 P Maley, Clermont, FL
9 Y Fernandez/N Lust, Orlando, FL
10 D Dunham, Green Pond, FL
11 P Maley, Polk City, FL
12 P Turcani, Christmas, FL
13 E Bredner, Germany
14 P Maley, Polk City, FL
15 P Maley, Polk City, FL
16 H Povenmire, Deer Park, FL
17 H Denzau, Panker GER
18 P Maley, Polk City, FL
19 (P) Predicted Centerline w/Time
20 E Iverson, Harmony, FL
21 K Coles, Harmony, Florida
22 S Degenhardt, Deer Park, FL
23 S Degenhardt, Deer Park, FL
24 S Degenhardt, Deer Park, FL

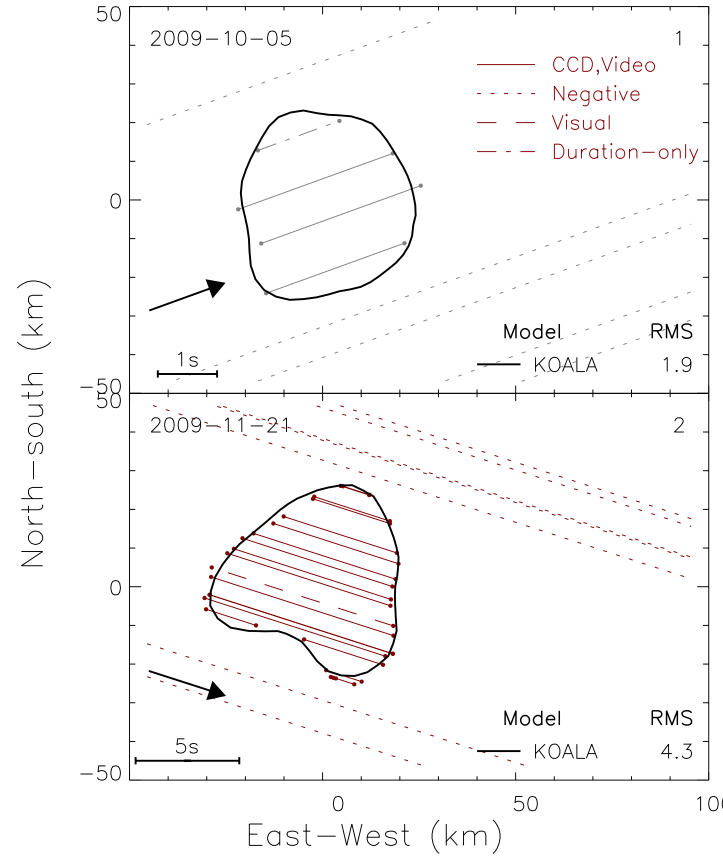
Photometry campaign

- From 2008 to 2011
- 19 teams

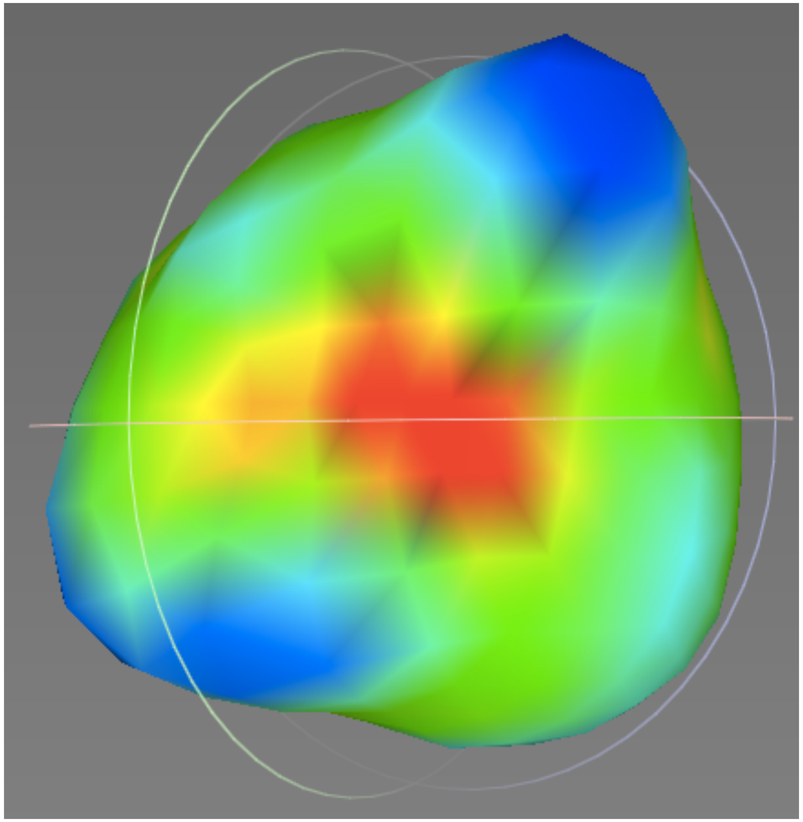


Shape determination by B. Carry (IMCCE, Paris)
Simultaneous inversion of light curves and occultation data (KOALA)





Curvature map



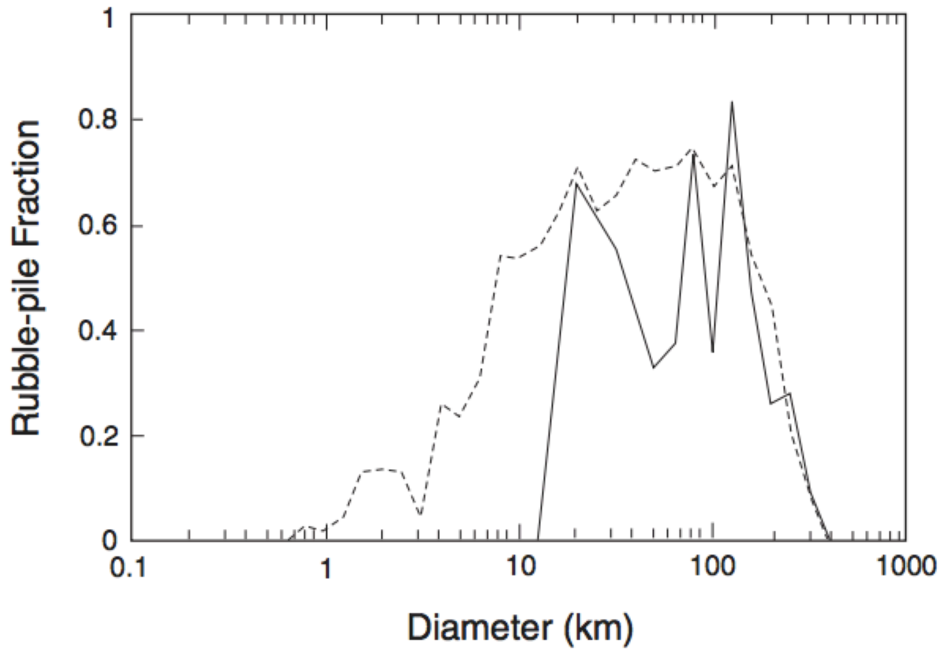
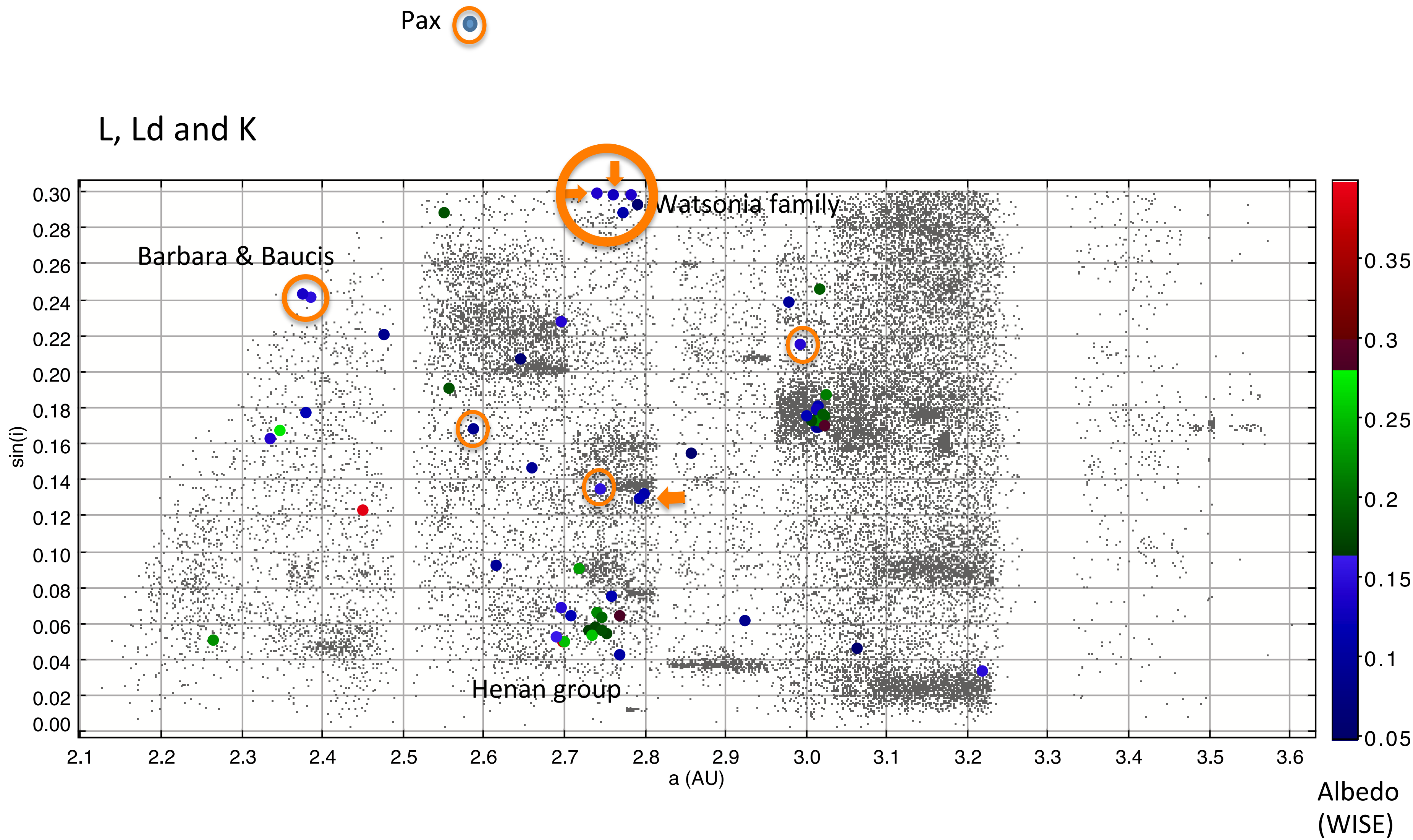


Fig. 6. Fraction of rubble piles in the asteroid belt as a function of size, according to different reaccumulation models (solid line: mass-velocity dependence with r = 1/6; dashed line: no mass-velocity relation, i.e., r = 0), and keeping $f_{KE} = 0.01$ (see text).

Davis et al. 2002 (Asteroids III)

Other barbarians, more mystery…

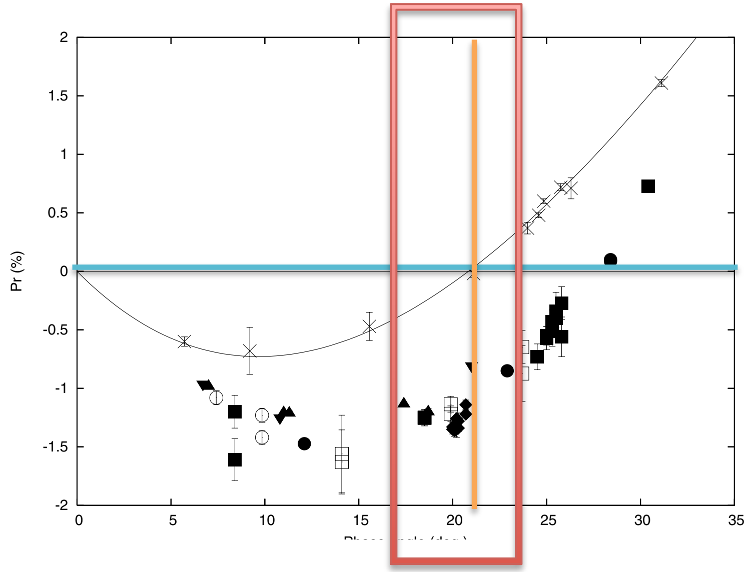
Where the Barbarians (could) hide?



729 Watsonia: chief of the 1st Barbarian family?

- Observations close to “ordinary” inv. angle < 20°
  - Negative polarization → barbarian

- Approach:
  - FORS2 @ VLT in polarimetric mode
  - between April and September 2013

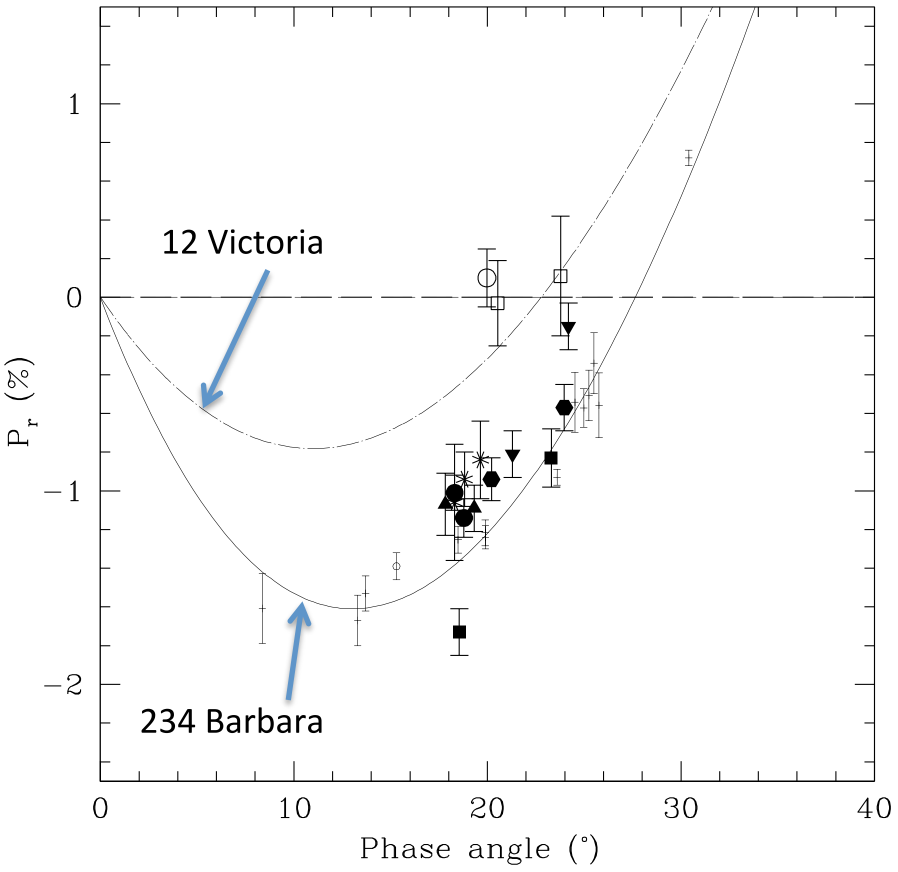


Polarimetry of Watsonia family members – results 1

7 new Barbarians
over 9 observed targets!

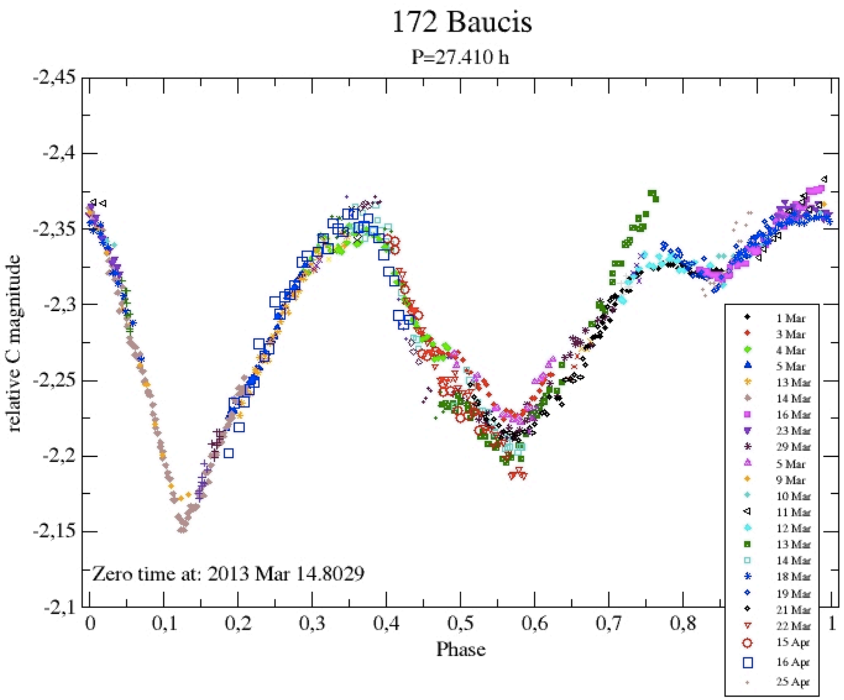
Date (yyyy mm dd)	Time (UT) (hh:mm)	Exp (sec)	Object	Phase angle (DEG)	P_Q (%)
	23:41	480	5492	18.79	-1.14 ± 0.10
	01:44	960		18.31	-1.01 ± 0.09
	09:40	2000	42365	23.30	-0.83 ± 0.15
2013 08 03	09:08	960		18.55	-1.73 ± 0.12
2013 07 12	23:50	960	56233	17.83	-1.07 ± 0.16
2013 08 05	01:03	2200		19.31	-1.09 ± 0.12
2013 07 30	00:38	2000	106059	18.30	-1.06 ± 0.30
2013 08 04	01:09	4000		18.82	-0.94 ± 0.14
2013 08 28	01:24	4800		19.64	-0.84 ± 0.20
2013 07 06	01:33	1400	106061	20.21	-0.94 ± 0.11
2013 08 09	02:46	4000		23.97	-0.57 ± 0.12
2013 07 06	02:05	960	144854	21.30	-0.81 ± 0.12
2013 08 05	02:06	4000		24.19	-0.15 ± 0.12
2013 07 07	02:40	3440	247356	19.97	0.10 ± 0.15
2013 08 13	06:28	4000	236408	18.31	-0.97 ± 0.15
2013 04 17	08:58	4800	320971	23.78	0.11 ± 0.31
2013 06 03	07:08	3440		20.53	-0.03 ± 0.22

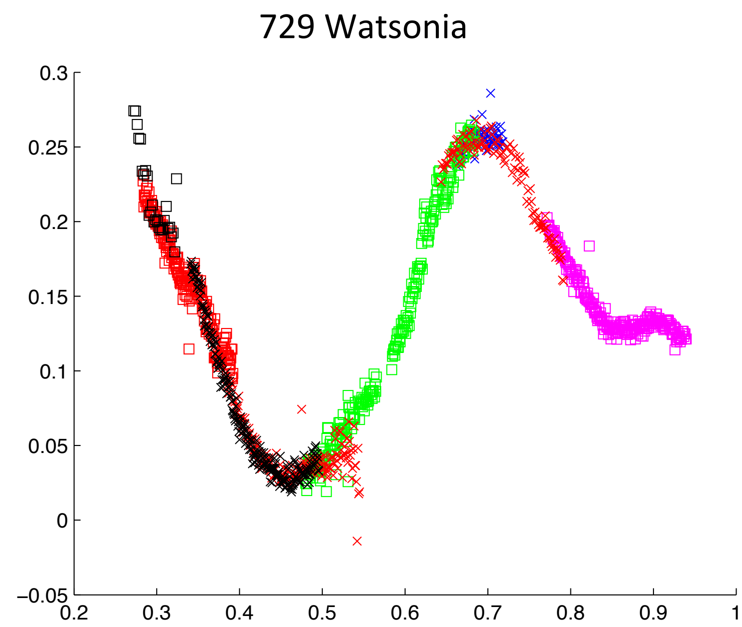
Polarimetry of Watsonia family members – results 2



Other anomalies?

Light curves - Rotation periods





New period = 25.19 h …!

Photometry by:

C2PU + M. Devogele, J. Surdej (OCA Nice + Liege)

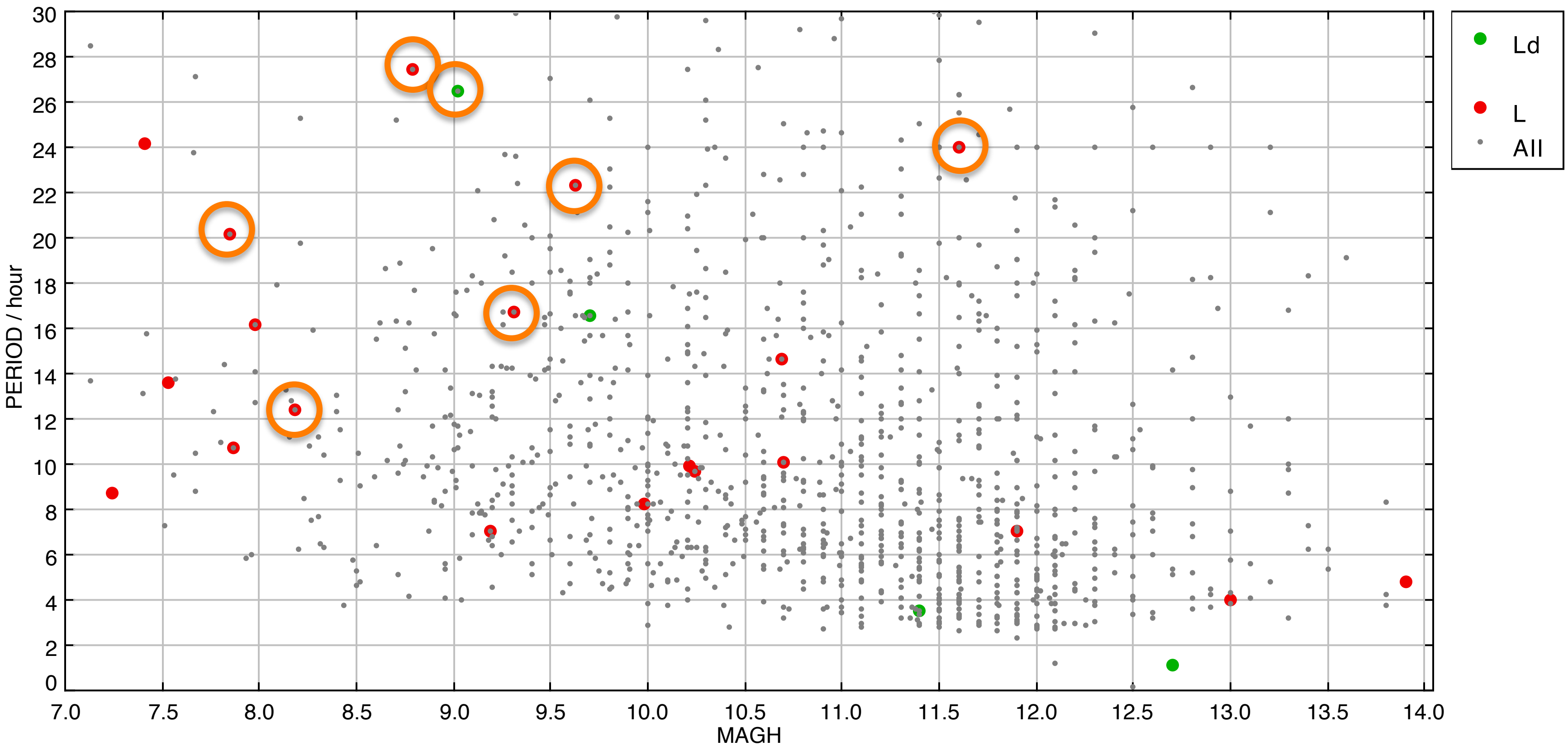
P. Hickson, Cerro Tololo, Chile

A. Marciniak, T. Michalowski, Poznan

F. Pilcher, NM, USA

M. Todd, Australia

Rotation periods – all "lazy" rotators?



Despinning aggregates by collisions

Icarus 202 (2009) 514–524

Mass dispersal and angular momentum transfer during collisions between rubble-pile asteroids. II. Effects of initial rotation and spin-down through disruptive collisions

Takaaki Takeda[a,*], Keiji Ohtsuki[b]

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[b] Laboratory for Atmospheric and Space Physics, University of Colorado, 392 UCB, Boulder, CO 80309-0392, USA

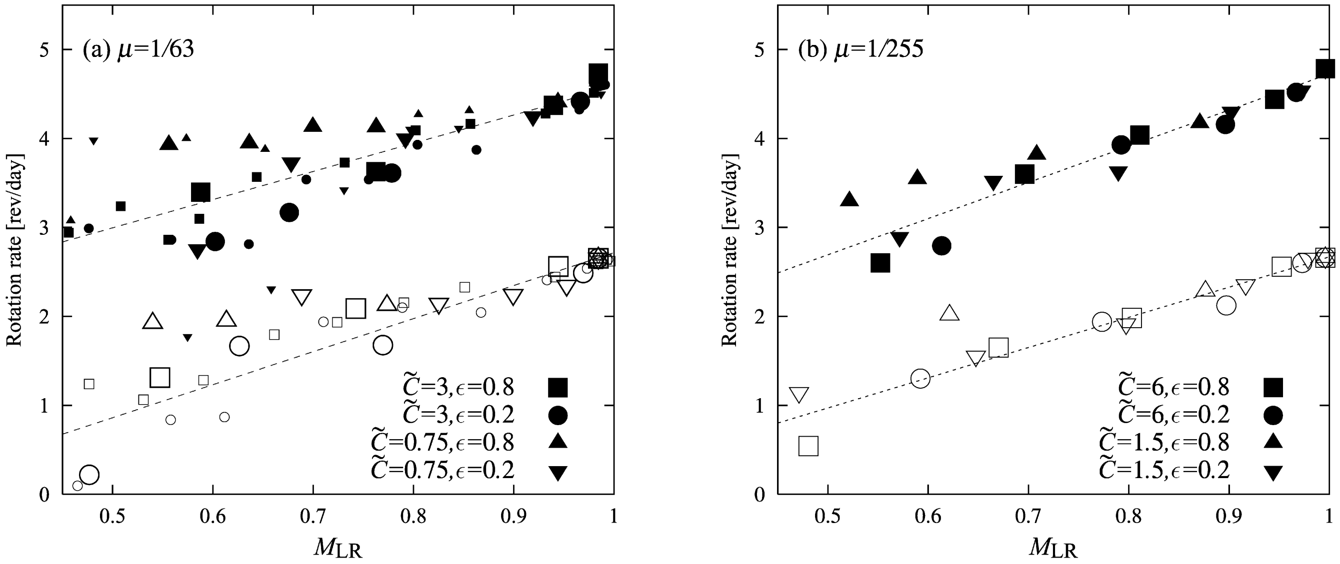

Fig. 4. Rotation rate of the largest remnant after head-on impacts, as a function of its mass fraction to the total mass. The trajectory of the impactor before collision lies in the $z = 0$ plane, and the impactor collides onto the target's equatorial plane. Panels (a) and (b) show results for $\mu = 1/63$ and $1/255$, respectively. Filled and open symbols represent results with different initial rotation rates of the target (4.6 and 2.6 rev/day, respectively). Small and large symbols represent results with different total numbers of particles used in simulation (4096 and 16384, respectively). Squares and circles represents hard targets ($\tilde{C} = 3$ or 6, $\epsilon = 0.8$ and 0.2, respectively), while upward and

The puzzle: putting the pieces together

- Over 20 among L, Ld types observed by polarimetry today:
  - 14 are certainly Barbarians + 1 uncertain
  - 4 are not + 1 uncertain

  (spectral type ambiguities possible with S and K types; 1 K-type Barbarian: Pax)

- 234 Barbara: a very irregular body
  - Large craters ~20 km in diameter? → rubble pile structure?

- Possible role of collisions
  - Excavation of concavities in 234 Barbara
  - Angular momentum reduction
    - L-Ld types: lazy rotators? To be confirmed by more data
  - Creation of families
    - Shared polarimetric properties inside the family of Watsonia (Cellino et al. 2013, MNRAS)

- CAI-extreme composition in L, Ld types?
  - The highest concentration of the oldest Solar System material
  - 30% CAI composition...? Not found on Earth
  - Not entirely satisfactory spectral fit in the visual range

Tentative conclusions / open questions

- The Watsonia family, an important evidence:
  - Barbarian “state" is “genetically” transmitted

  → It is not just a surface property

- The oldest Solar System objects that accreted?
  - Oldest material known, in high concentration
  - Fragmented and de-spinned over time?

- Compositions AND concavities both needed to explain spectra + polarization?

The End