Study of Main-Belt and Near-Earth Asteroids with TRAPPIST and larger telescopes

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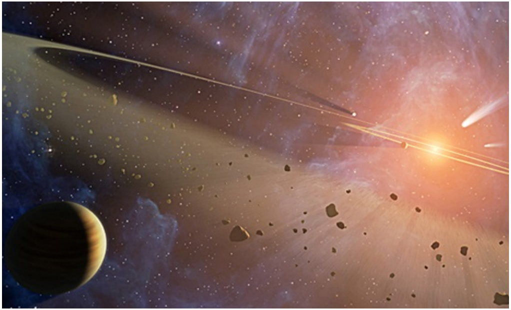


Artist view of the early Solar System (NASA)

Why to study asteroids ?

→ Pristine material

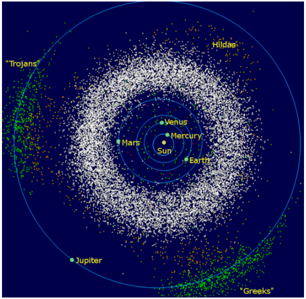
→ Building blocks of the planets

→ Dynamical evolution of the Solar System

→ Impact history

→ Threat to Earth

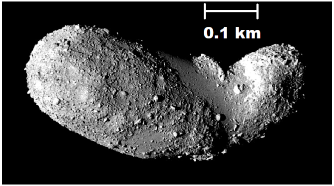
Main-Belt Asteroids (MBAs)



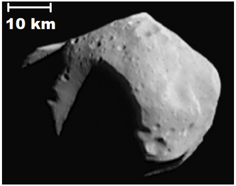
Asteroids in the Solar System

- More than 700 000 asteroids known in the Main-Belt
- About 200 larger than 100 km
- Various shapes, sizes and compositions

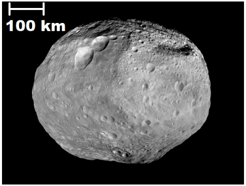
  $\rightarrow$ but lack of observations !



(25143) Itokawa (JAXA)

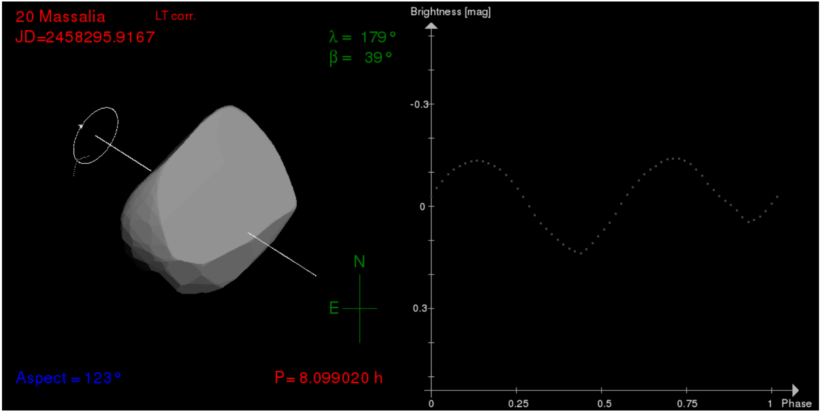


(253) Mathilde (NASA)



(4) Vesta (NASA)

Optical asteroid lightcurves: master thesis



Shape model of (20) Massalia (ISAM)

Data acquisition/reduction TRAPPIST telescopes

- **TRAPPIST-South**: ESO La Silla Observatory (Chile)
- **TRAPPIST-North**: Oukaïmeden Observatory (Morocco)

→ Twin robotic telescopes

→ D = 0.6 m

→ Good observing sites

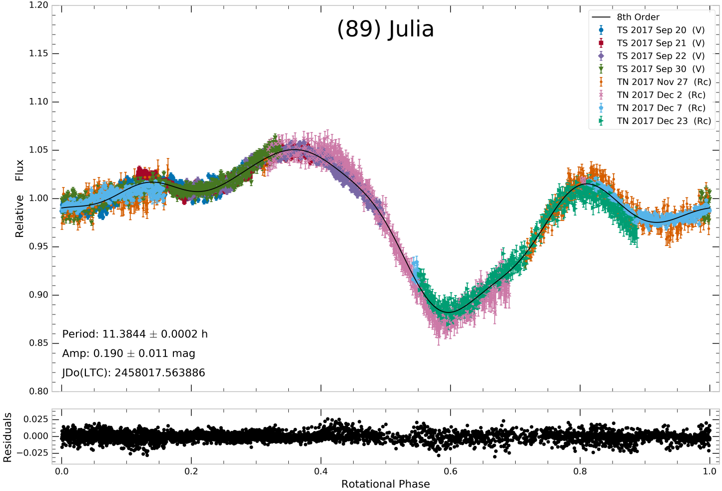
→ A lot of observation time

→ Large sky coverage

→ Long observing runs using both telescopes

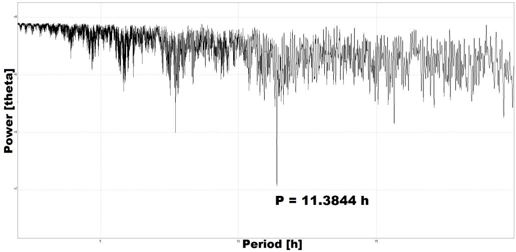
- https://www.trappist.uliege.be/

TRAPPIST rotational lightcurves

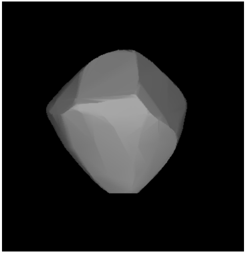


Phased lightcurve of (89) Julia (master thesis)

What can we learn from asteroid lightcurves?



Period spectrum of (89) Julia with the FALC method

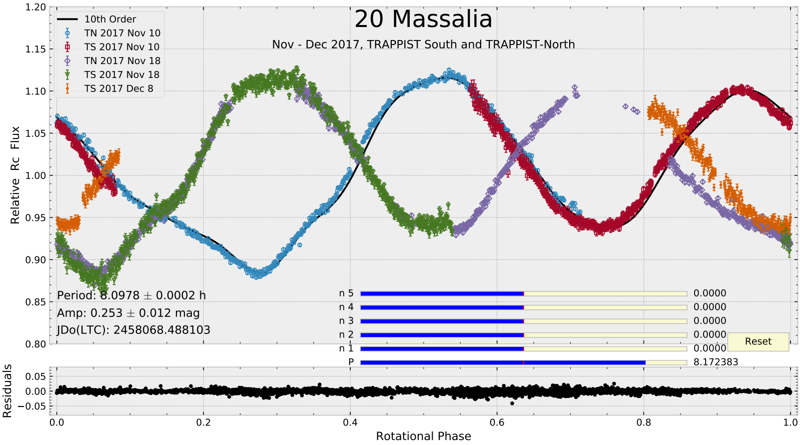


Shape model of (89) Julia

- Determination of the rotation period (Fourier analysis)
- Rotation state (excited or relaxed rotation)
- Spin axis coordinates (lightcurves inversion)
- Global convex shape model (lightcurves inversion)

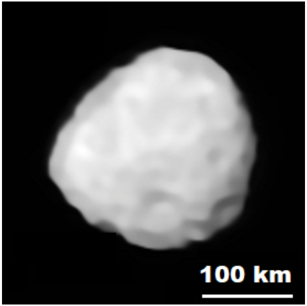
Build the phased lightcurve

An example with (20) Massalia



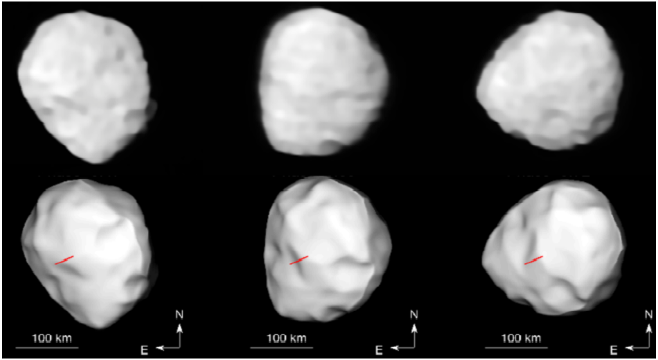
Probing the interior of primordial Main-Belt asteroids
ESO Large Programme (PI: Vernazza P.)

- AO observations of the 40 largest (D $\geq$ 100km) MBAs with the new SPHERE instrument at the ESO VLT
- TRAPPIST + VLT AO $\rightarrow$ shape modelling $\rightarrow$ precise volume $\rightarrow$ bulk density



AO image of (7) Iris
Resolution of $\sim$ 2.3 km/pixel !

Detailed models from multi data sources modelling



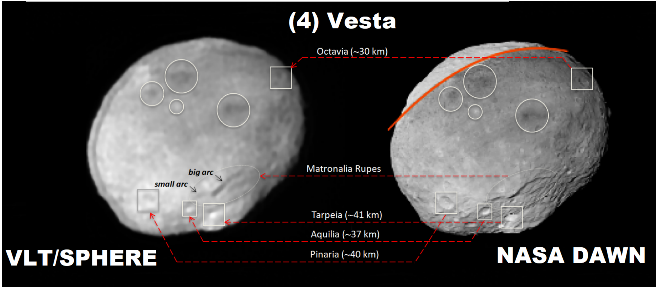
Comparison of the VLT AO observations (top) and the shape model (bottom) of (7) Iris at different rotation phases (**Hanus J.,...Ferrais M. et al., A&A**)

- Snapshots are taken at different viewing geometries with the AO instrument VLT/SPHERE
- Rotation lightcurves are needed to have a full coverage

What can we learn from detailed 3D shapes?

- 3D shape → volume → density (uncertainty < 10%)
  → constraints on the bulk compositions
  → constraints on the interior of asteroids (macroporosity)
- Origin of compositional classes (S, C, M)
- Crater size-frequency distribution (density of the outer shell)
- Origin of asteroid collisional families

→ Open new doors into ground-based asteroid exploration



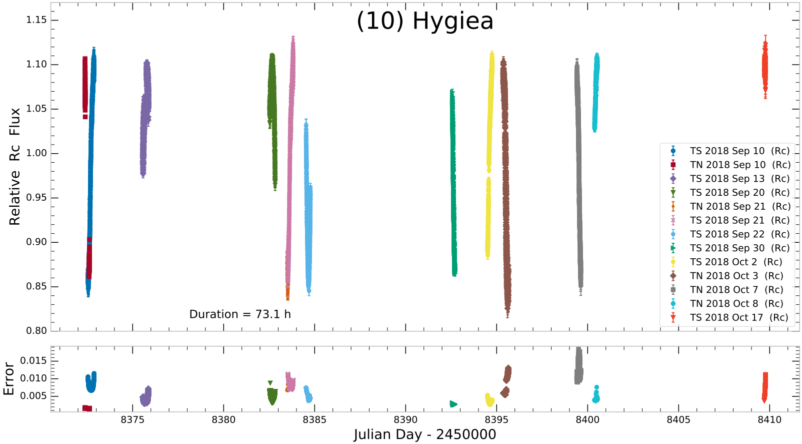
Ground (SPHERE) versus in-situ (Dawn) observations **(Fetick et al., A&A, 2019)**

ESO Large Programme: target list

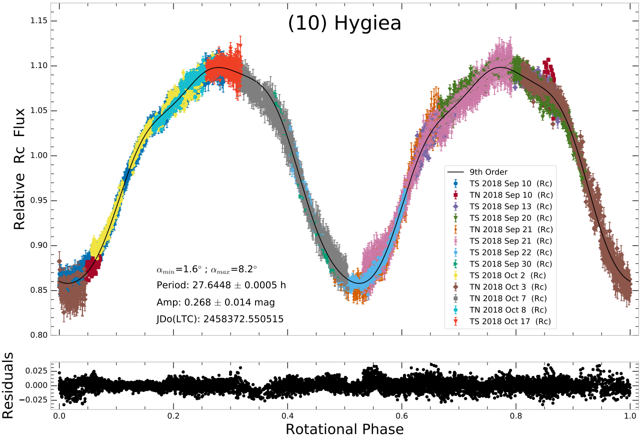
Targets (MBAs)	Type	Date	Mag
(2) Pallas	B	01/04/19	7.5
(3) Juno	S	01/11/18	7.3
(4) Vesta	V	01/11/19	6.5
(6) Hebe	S	01/01/19	8.1
(7) Iris	S	01/04/19	9.1
(8) Flora	S	01/05/19	9.5
(9) Metis	S	01/12/19	8.5
(10) Hygiea	C	01/12/19	10.2
(11) Parthenope	Sk	01/06/19	9.3
(12) Victoria	S	01/11/18	10.1
(13) Egeria	Ch	01/09/19	10.5
(15) Eunomia	S	01/09/18	8.1
(16) Psyche	M/P	01/08/19	9.2
(18) Melpomene	S	01/07/19	9.1
(19) Fortuna	Ch	01/05/19	10.6
(20) Massalia*	S	01/01/18	8.3
(22) Kalliope*	M	01/03/18	10.7
(24) Themis*	B	01/10/17	11.5
(29) Amphitrite	S	01/10/19	8.5
(31) Euphrosyne*	C	01/01/18	10.1
(40) Harmonia	S	01/12/18	9.3

Targets (MBAs)	Type	Date	Mag
(41) Daphne*	Ch	01/08/18	10.8
(45) Eugenia*	C	01/04/18	10.6
(48) Doris	Ch	01/02/19	10.8
(51) Nemausa	S	01/08/19	10.3
(52) Europa	C	01/11/19	10.6
(87) Sylvia	P	01/12/18	11.5
(88) Thisbe	B	01/08/18	9.5
(89) Julia*	S	01/09/17	8.6
(128) Nemesis	C	01/12/18	10.5
(145) Adeona*	Ch	01/01/18	10.7
(187) Lamberta*	Ch	01/04/18	10.1
(216) Kleopatra	M	01/01/19	10.4
(324) Bamberga	C	01/01/19	10.1
(354) Eleonora	S	01/12/18	10.1
(451) Patientia	C	01/03/19	11.1
(476) Hedwig*	P	01/11/18	12.1
(511) Davida	B	01/01/20	9.5
(532) Herculina	S	01/03/19	8.6
(596) Scheila*	P/D	01/06/17	11.6
(704) Interamnia	B	01/01/19	10.1

Intense observation of (10) Hygiea

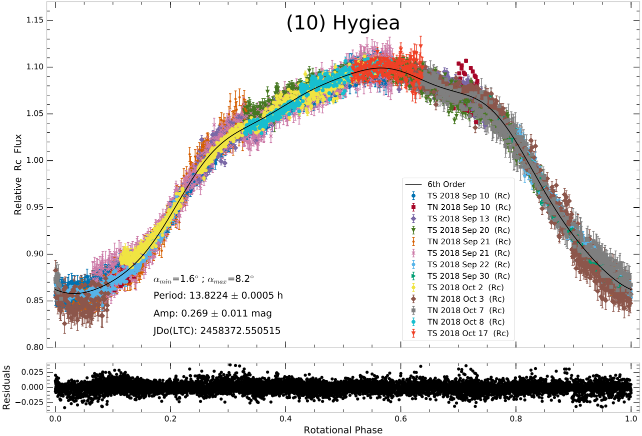


Result: revision of the rotation period



Phased lightcurve using the rotation period of 27.6 h

Result: revision of the rotation period



Using a rotation period of 13.8 h, half of the previous one (**Vernazza et al. Submitted to Nature Astronomy**)

Near-Earth Asteroids (NEAs)

NEA approaching the Earth

NEA (3122) Florence

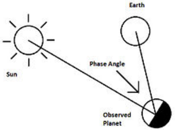
2014 JO25 in radar

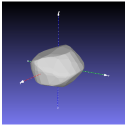
- NEAs are much smaller asteroids
- $\sim$ 19 000 known NEAs (fast growing number)
- Threat to the Earth
- Population steadily resupplied from Main-Belt
- Source of the various types of meteorites
- Seen at widely different viewing geometries

Impact crater on Earth (Meteor Crater)

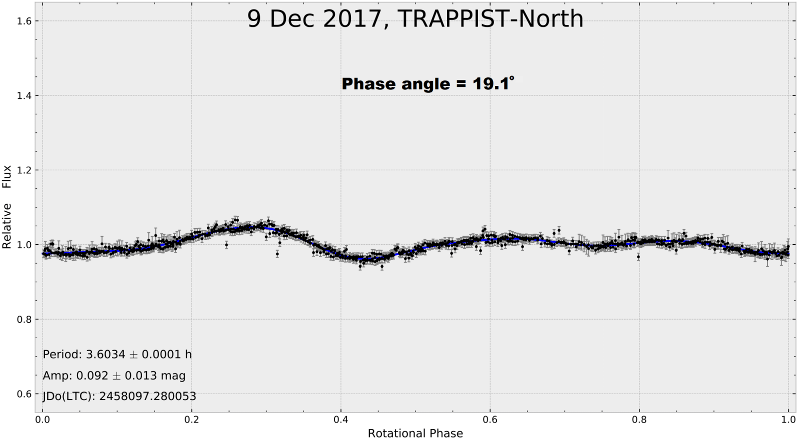
Lightcurve variation with the phase angle

The example of (3200) Phaethon



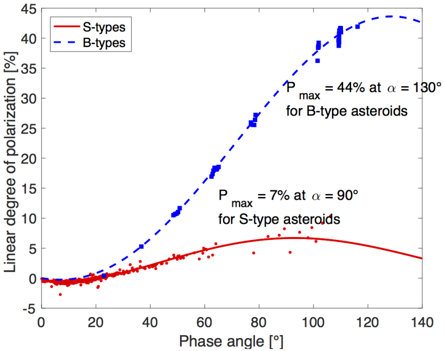


(Ferrais et al., in prep)



Phase-polarization curves of NEAs

- Linear degree of polarization: $P_r = \frac{I_\perp - I_\parallel}{I_\perp + I_\parallel}$
- Diagnostic of surface properties including the geometric albedo, refractive index and the size of regolith particles
- Rotational polarimetric curves $\rightarrow$ albedo maps $\rightarrow$ comparison with shape models



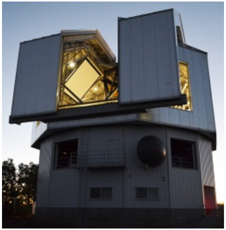
Typical phase-polarization curves for NEAs of S and B type (M. Devogèle, 2018)

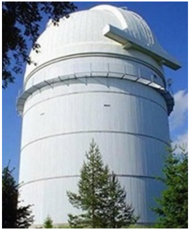
Target list of NEAs

Collaboration with M. Devogèle (Lowell, USA)

Target (NEAs)	Type	Date	Mag
(433) Eros	S	Jan-Mar 19	12.1
(1627) Ivar	S	Oct-Dec 18	12.2
(1916) Boreas	S	Sep-Nov 18	16.6
(2061) Anza	?	Sep-Nov 18	15.6
(3552) Don Quixote	?	Sep-Nov 18	16.3
(6456) Golombek	D	Oct-Dec 18	15.2
(13553) Masaakikoyama	?	Oct-Dec 18	14.5
(16690) 1998 QS52	Sq	Sep-Nov 18	15.2
(18109) 2000 NG11	?	Oct-Dec 18	15.6
(418929) 2009 DM1	?	Oct-Dec 18	15.1
(443923) 2002 RU25	?	Oct-Dec 18	15.4
2000 LC16	Xk	Oct-Dec 18	14.7
2001 CP44	?	Oct-Dec 18	13.1
2001 TE42	?	Sep-Nov 18	15.8
2002 RU25	?	Sep-Nov 18	15.3
2005 UD	B	Oct-Dec 18	15.7
2008 WM64	?	Jan-Mar 19	15.3
2009 DM1	?	Oct-Dec 18	15.7
2011UA	?	Oct-Dec 18	15.1
2012 MS4	?	Jan-Mar 19	16.3
2015 FP118	?	Oct-Dec 18	14.6

NEAs for which polarimetric observation time have already been allocated



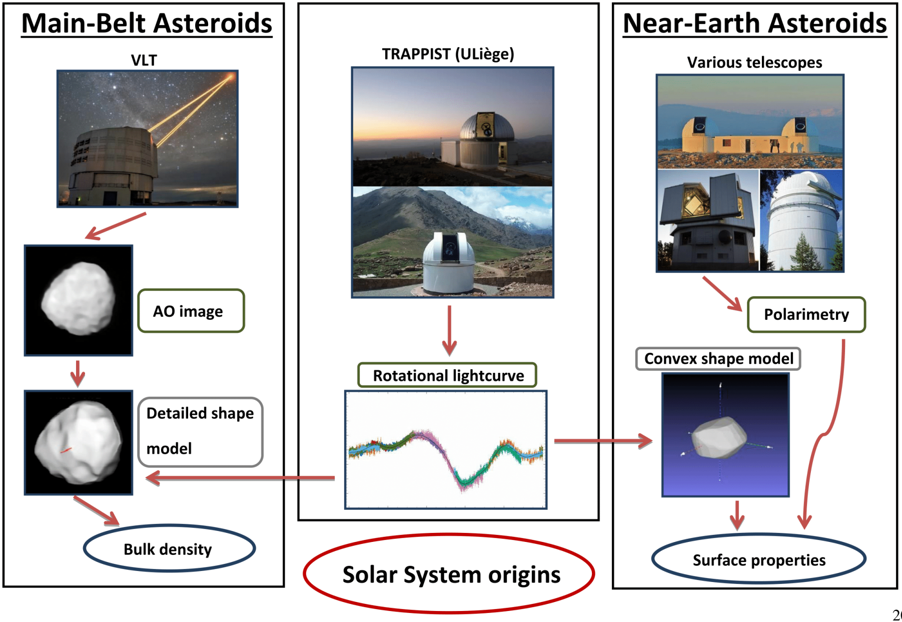


Top: C2PU observatory
Bottom left: DCT at Lowell observatory
Bottom right: RCC-2m at Rozhen

First publications

- **Vernazza P.,...Ferrais M. et al., A&A 618 (2018).**
  The impact crater at the origin of the Julia family detected with VLT/SPHERE?
- **Viikinkoski M.,...Ferrais M. et al., A&A letter 619 (2018).**
  (16) Psyche: A mesosiderite-like asteroid?
- **Carry B.,...Ferrais M. et al., A&A. 623 (2019).**
  The homogeneous internal structure of CM-like asteroid (41) Daphne.
- **Hanus J.,...Ferrais M. et al., A&A 624 (2019).**
  Evidence of an ancient large impact on (7) Iris.
- **Ferrais M., Jehin E., Manfroid J., Moulane Y., Pozuelos F., Minor Planet Bulletin, accepted.**
  TRAPPIST lightcurves of Main-Belt asteroids (31) Euphrosyne, (41) Daphne and (89) Julia.
- **Ferrais M., Jehin E., et al., in preparation for A&A.**
  TRAPPIST observations of NEA (3200) Phaethon during its 2017 flyby

Summary


Main-Belt Asteroids
VLT
AO image
Detailed shape model
Bulk density
TRAPPIST (ULiège)
Rotational lightcurve
Near-Earth Asteroids
Various telescopes
Polarimetry
Convex shape model
Surface properties
Solar System origins