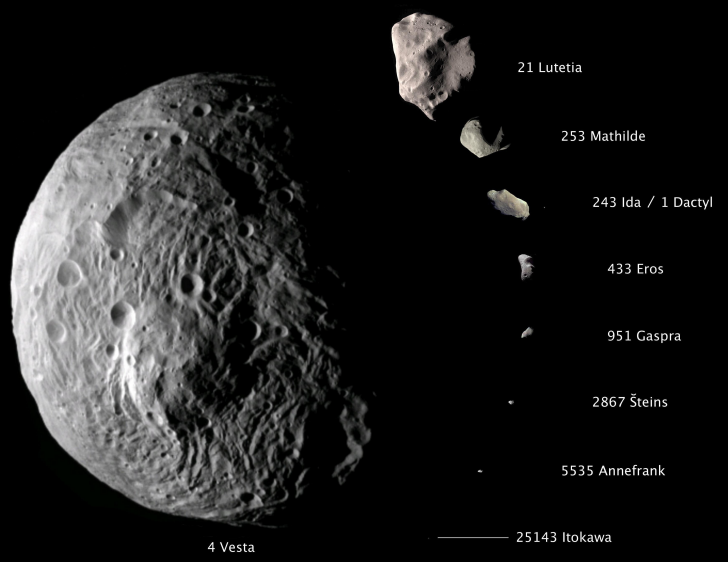
Solar system science in the E-ELT era



B. Carry[1,2]

[1]IMCCE, Observatoire de Paris
[2]Lagrange, Observatoire de la Côte d'Azur

1. Contamination by Small Bodies

2. Composition of Small Bodies

3. Physical properties of Small Bodies

4. Summary

Contamination by asteroids

A vermin

Anonymous

- E-ELT detection capability
  - Schroeder (1987)
  - Exposure: 300 s
  - V≈26 → SNR 5
  - V≈29 → SNR 20
- Foreground asteroids?
  - V≈26 → 100 000
  - V≈29 → **millions**
- Contamination risks
  - Undetected → Confusion noise
  - Detected → False candidate
  - Identified → Ok (if not blended)

Contamination by asteroids

A vermin

Anonymous

- E-ELT detection capability
  - Schroeder (1987)
  - Exposure: 300 s
  - V≈26 → SNR 5
  - V≈29 → SNR 20
- Foreground asteroids?
  - V=21 → 700,000
  - V=29 → **millions**
- Contamination risks
  - Undetected → Confusion noise
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  - Identified → Ok (if not blended)

Contamination by asteroids

A vermin

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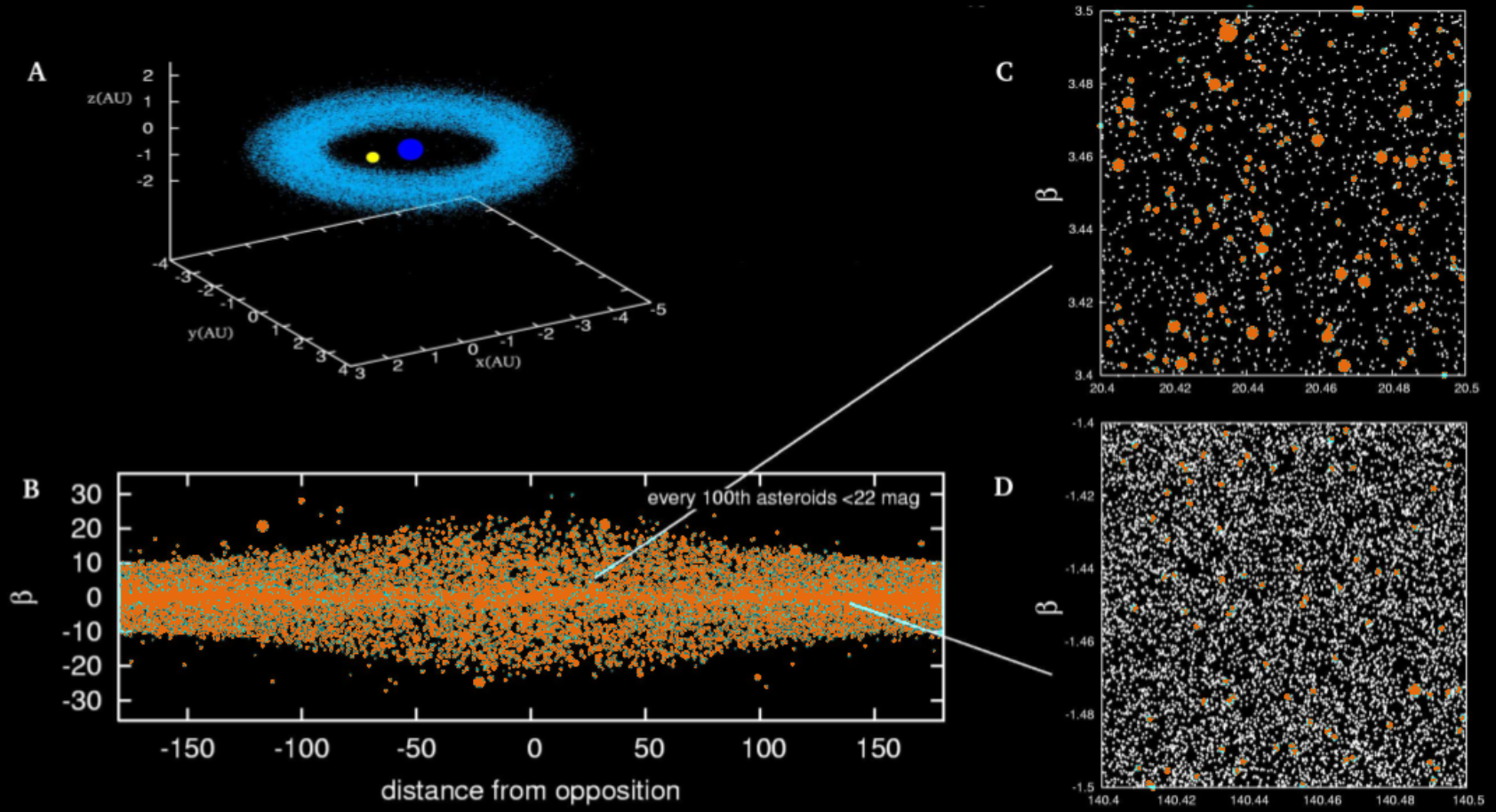
The Vermins Strike Back!

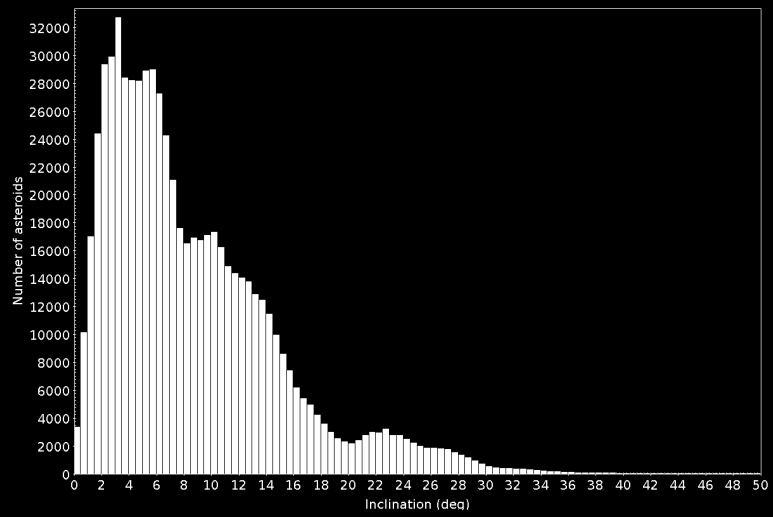


Szabo & Simon 2009

The Vermins Strike Back!

Back-of-the-envelope computation:

- Moving object at V=30
  - 1% error on V=25 target
  - MBA: 5 mas/s
  - KBO: 0.5–1 mas/s
- From SAM (Tedesco et al. 2005)
  - V = f(α, β)
  - **Number per sq. degree?**
  - (α, β) = (0°,3°) → 20,000
  - (α, β) = (40°,1°) → 10,000
  - (α, β) = (0°,10°) → 10,000
  - (α, β) = (0°,20°) → 2,000



The Vermins Strike Back!

Instr.	FOV	β=0°		β=10°		β=20°	
	(″)	(%)	(#)	(%)	(#)	(%)	(#)
CODEX	1x1	0.1	648	–	1300	–	6500
HARMONI	10x5	7	13	4	26	0.8	130
METIS	17x17	45	2	22	5	4	22
MICADO	11x11	19	5	9	11	2	54
MICADO	53x53	433	1	210	1	43	2

1. Contamination by Small Bodies

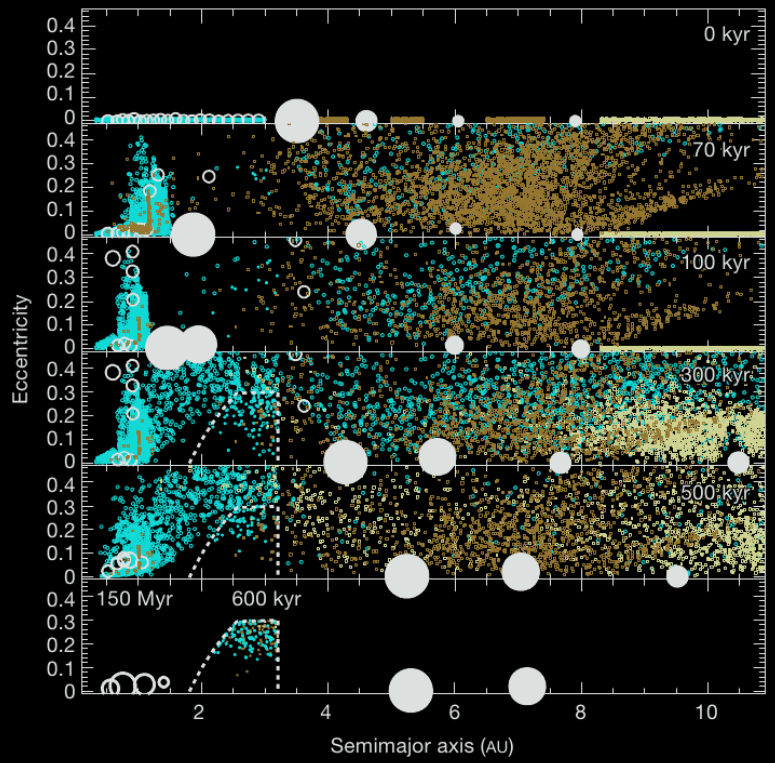
2. Composition of Small Bodies
   - Composition of Asteroids
   - Composition of Kuiper-Belt objects
   - Composition of Comets

3. Physical properties of Small Bodies

4. Summary

Composition of asteroids

- Remnants of planet formation
  - Orbit
  - Composition
- Asteroid composition
  - Broad absorption band
  - Classification from spectra
- Multi-filter classification
  - SDSS: R=5, 2 wavebands
  - Gaia: R=20, 14 bands
  - LSST: R=5, 6 bands

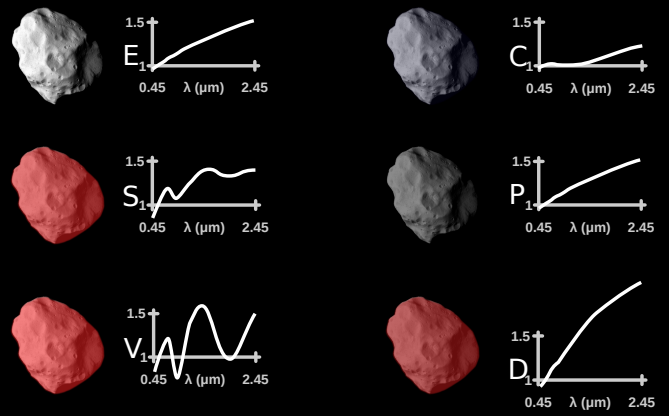


Walsh et al. 2011

Composition of asteroids

- Remnants of planet formation
  - Orbit
  - Composition
- Asteroid composition
  - Broad absorption band
  - Classification from spectra
- Multi-filter classification
  - SDSS: R=5 @ 900,000
  - Gaia: R=20 @ 150,000
  - LSST: R=5 @ 1,000,000

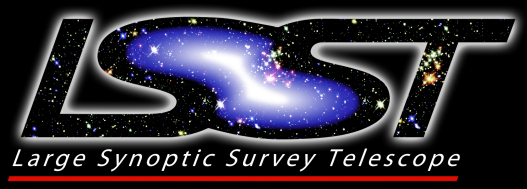
DeMeo-Carry Classification



DeMeo & Carry, 2013, 2014

Composition of asteroids

- Remnants of planet formation
  - Orbit
  - Composition
- Asteroid composition
  - Broad absorption band
  - Classification from spectra
- Multi-filter classification
  - **SDSS:** R=5 & 400,000
  - **Gaia:** R=35 & 150,000
  - **LSST:** R=5 & 1,000,000



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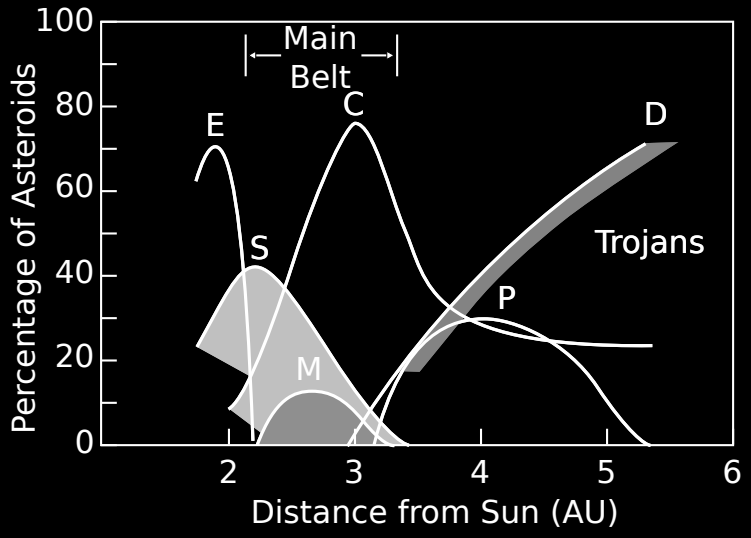
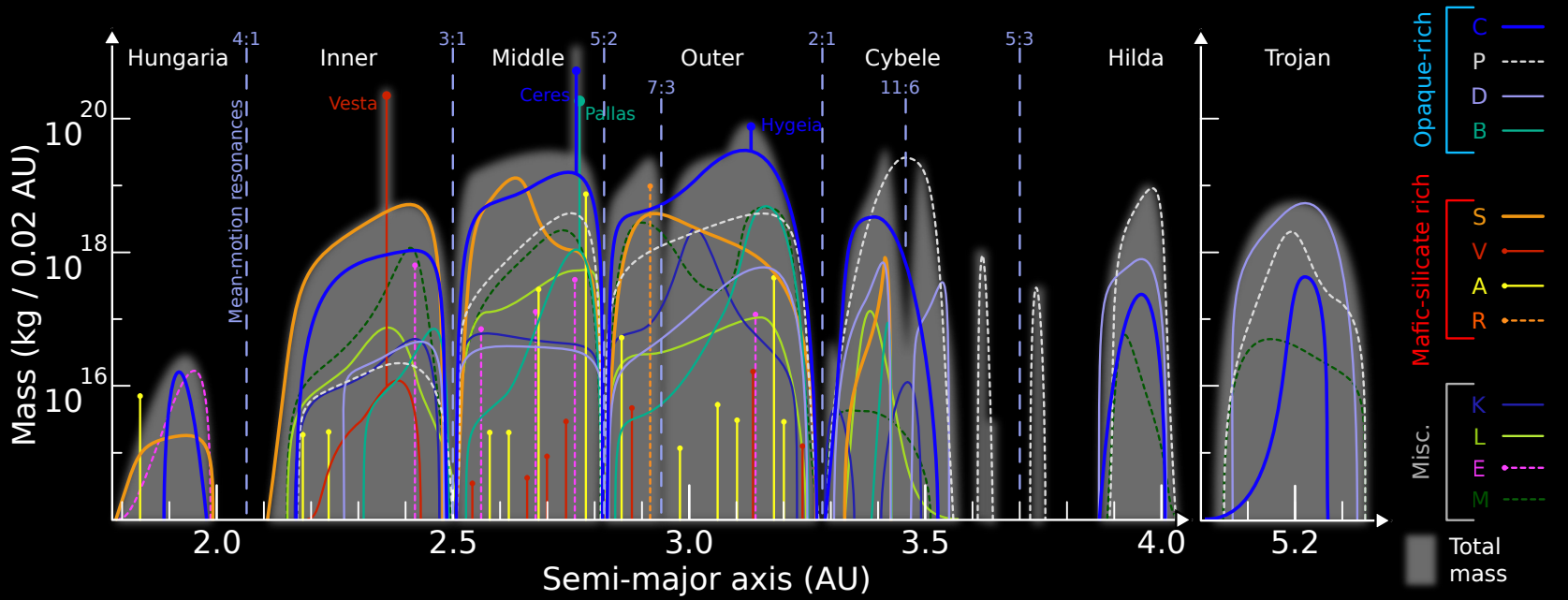


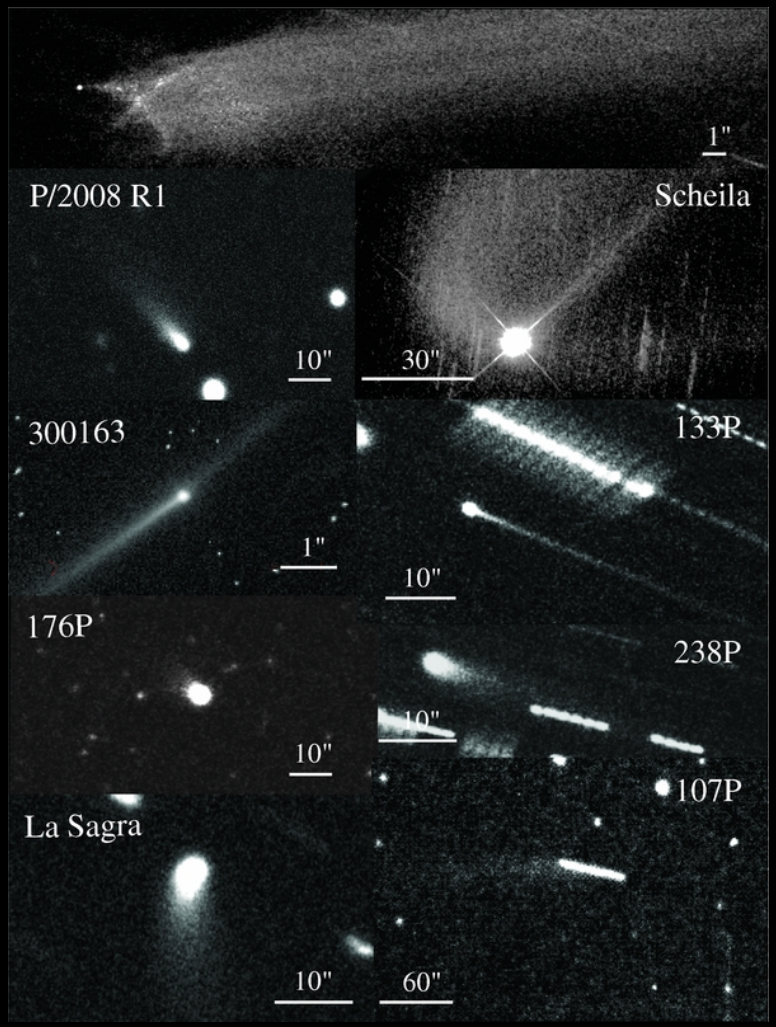
Gradie & Tedesco 1982

Composition of asteroids



DeMeo & Carry, 2014

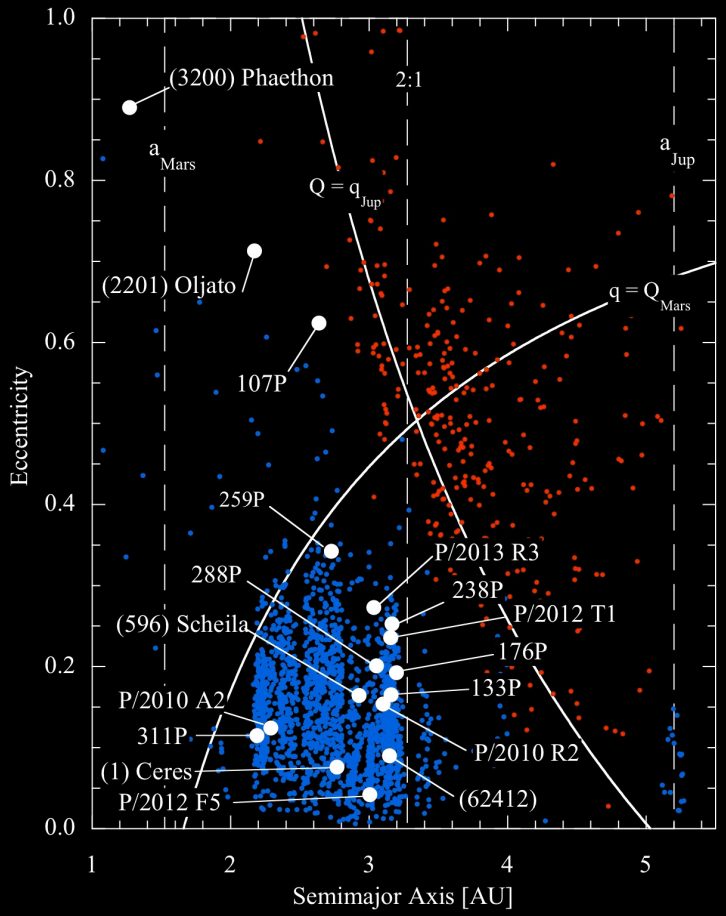
E-ELT and Asteroids



Jewitt 2012

- Active asteroids
  - Discovered in 2006
  - Comet morphology
  - Asteroid orbit
  - Water in asteroids?
  - Periodic phenomena, or not
  - Mechanisms?
- Near-Earth asteroids
  - Targets for HARMONI
  - Targets for METIS

E-ELT and Asteroids



Jewitt et al. 2015

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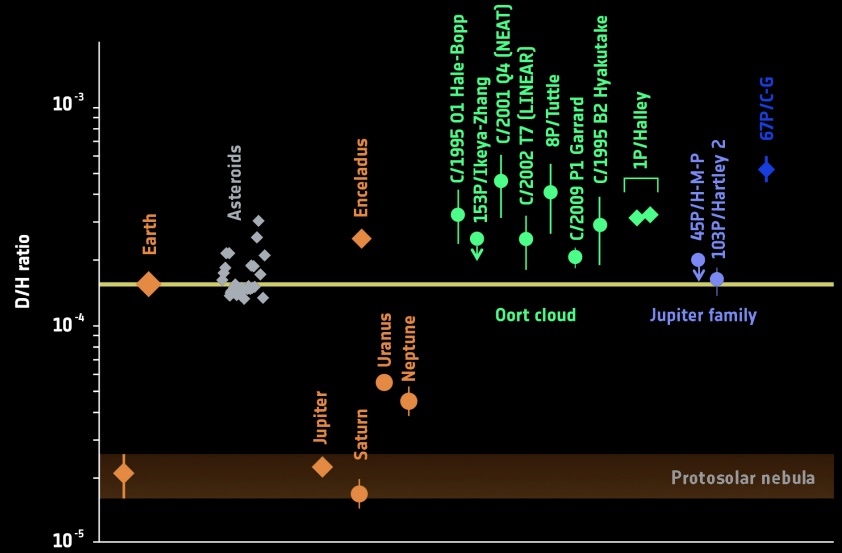

Adapted from Bockelee-Morvan et al. 2014

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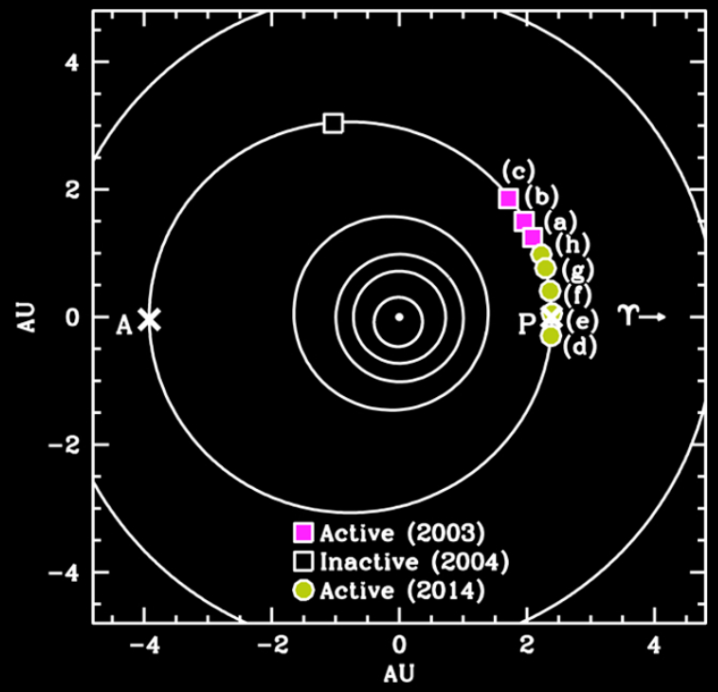
E-ELT and Asteroids

313P/Gibbs



Adapted Hsieh et al. 2014, 2015

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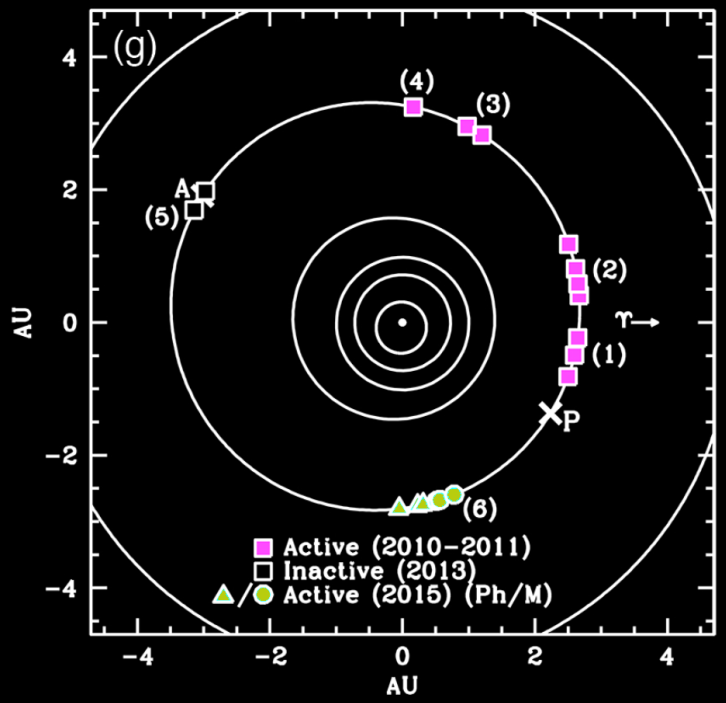
E-ELT and Asteroids

324P/La Sagra



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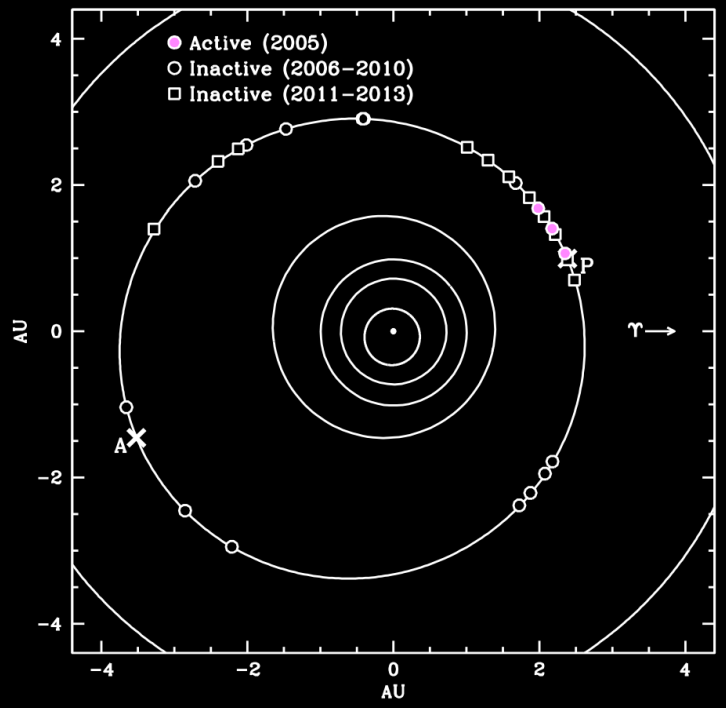
E-ELT and Asteroids

176P/LINEAR



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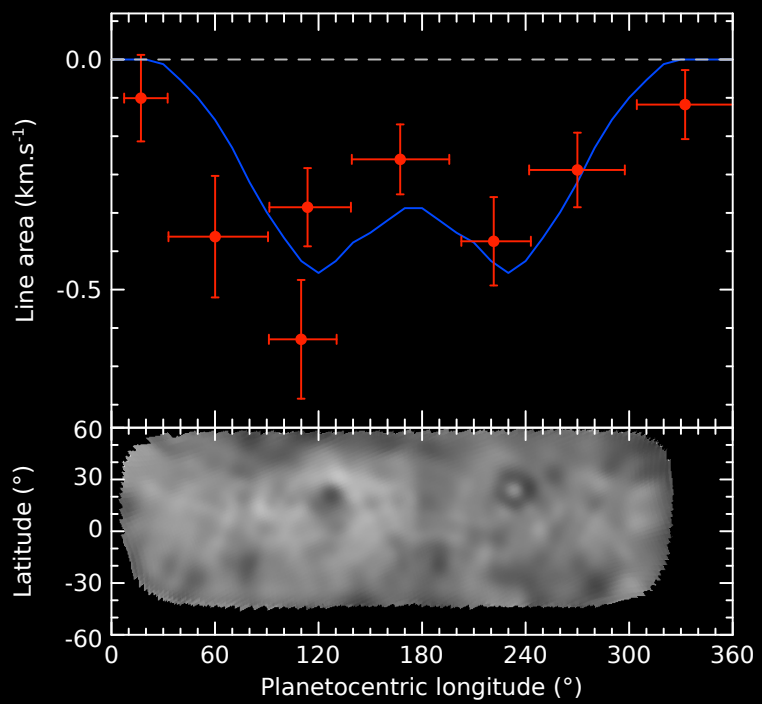
E-ELT and Asteroids

Water ice sublimation



Küppers et al. 2014

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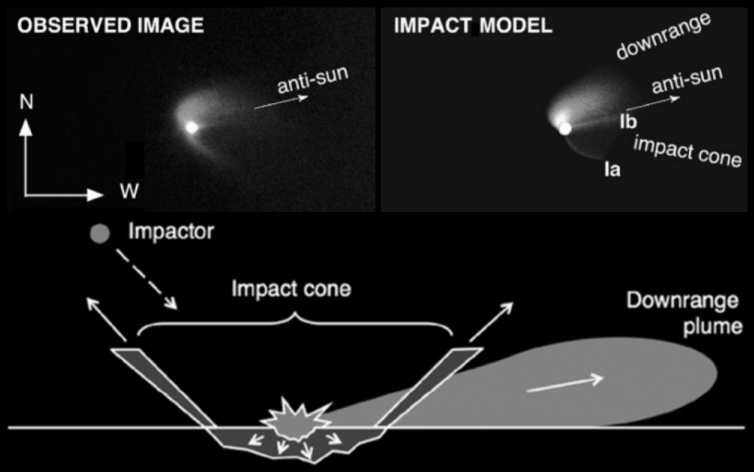
See the review by Jewitt, Hsieh & Agarwal 2015

E-ELT and Asteroids

Impact ejecta



Ishiguro et al. 2011

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See the review by Jewitt, Hsieh & Agarwal 2015

E-ELT and Asteroids

YORP spin-up & fission

Walsh et al. 2008

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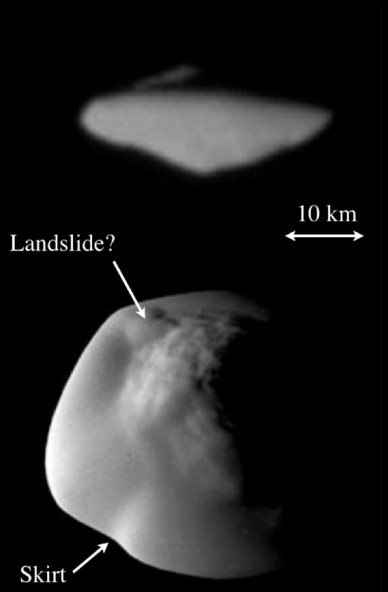
See the review by Jewitt, Hsieh & Agarwal 2015

E-ELT and Asteroids

YORP spin-up & fission



JPL/Cassini/ISS

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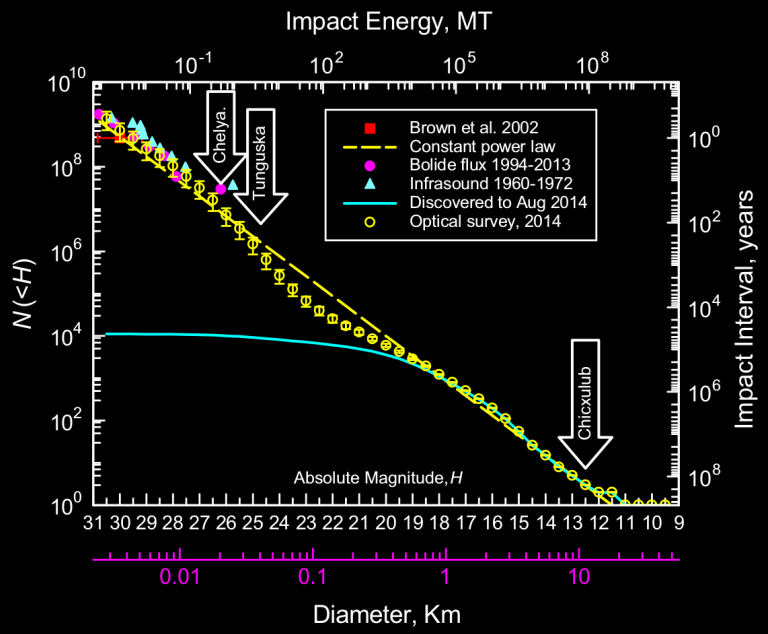
E-ELT and Asteroids



Harris & D'Abramo 2015

- Active asteroids
- Near-Earth asteroids
  - Tail of size-frequency distribution
  - Potential Earth impactors
  - Laboratory of surface processes
- Targets for HARMONI
- Targets for METIS

E-ELT and Asteroids

- Tunguska in 1908

- Carancas in 2008

- Chelyabinsk in 2013

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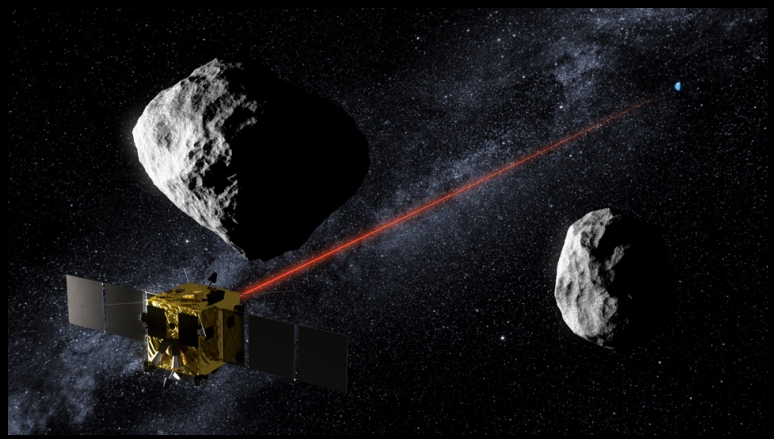

Credit: ESA/AIDA

E-ELT and Asteroids

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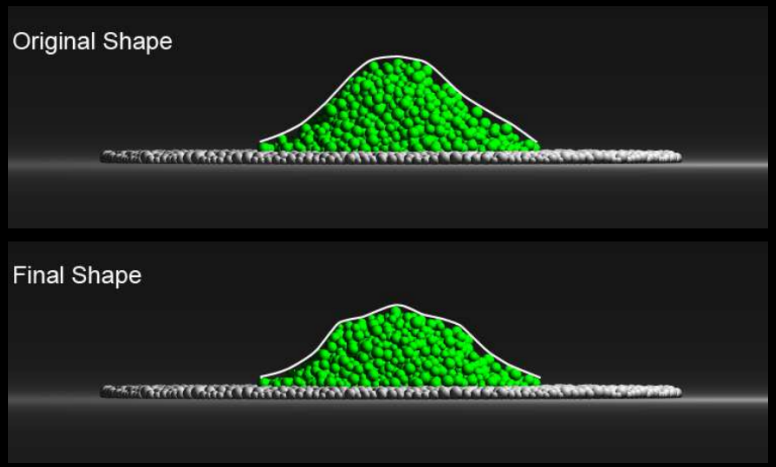
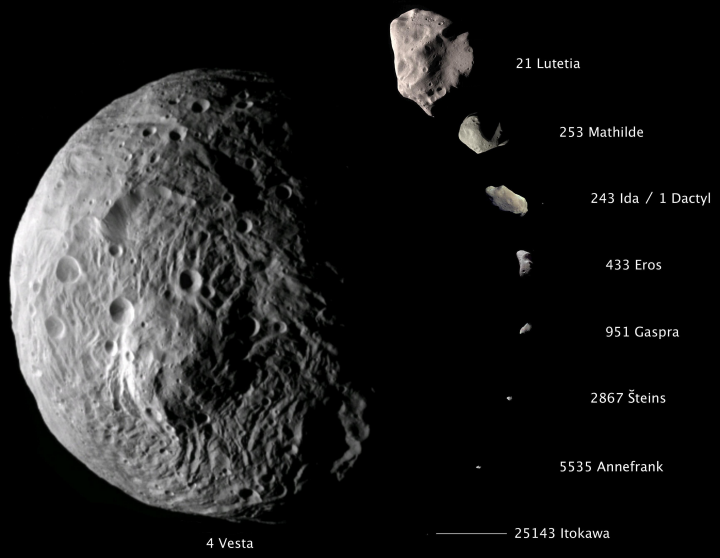
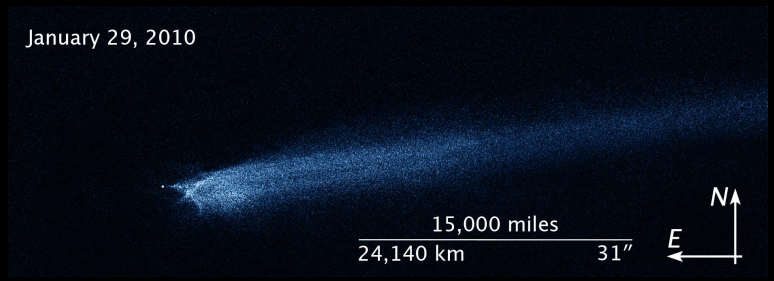


Yu et al. 2014

E-ELT and Asteroids

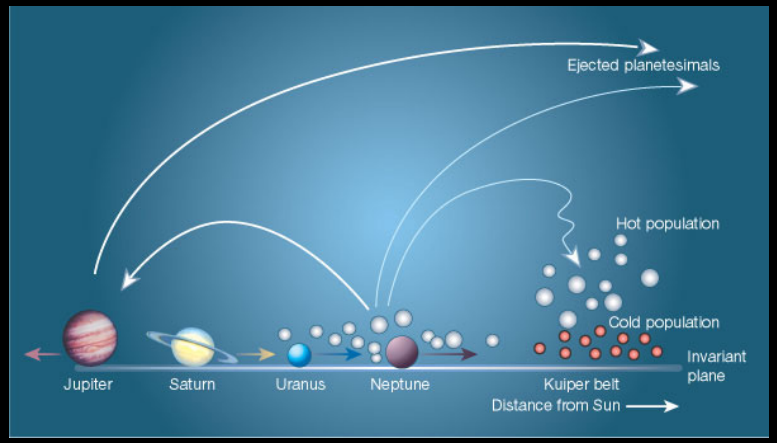




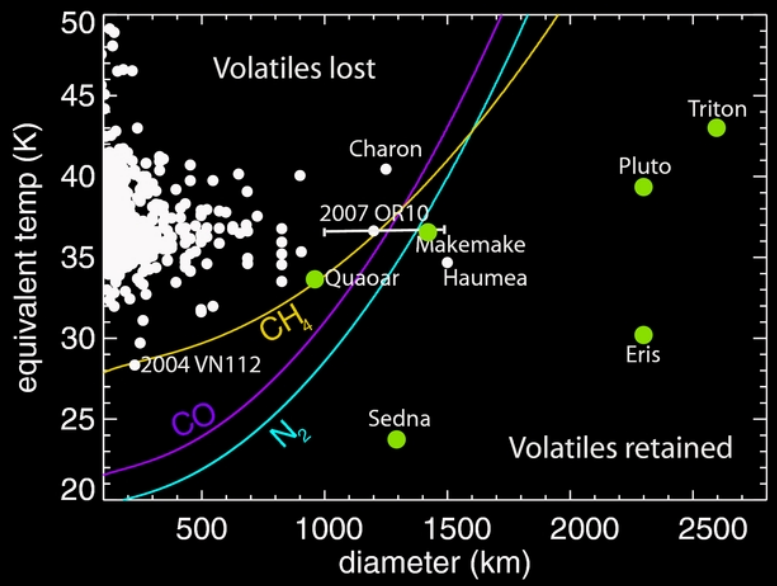
- Active asteroids
- Near-Earth asteroids
- Targets for HARMONI
  - V $\in$ [18, 26+]
  - Windows of days/weeks
  - Spectra in 0.4-2.5 μm
  - Low resolution (R$\approx$500)
  - HARMONI $>$ JWST/NIRSPEC
- Targets for METIS
  - Isotope abundances
  - Spectra in 3-5 μm
  - High resolution (R$\approx$100,000)

E-ELT and EKBO

- Remnants of planet formation
  - Orbit & Composition
  - Now: 2,000 & D≥50 km
  - LSST → 40,000
- KBO composition
  - Narrow absorption band
  - Ices beam spreader
  - Surface heterogeneity
  - Atmospheres!
  - Breakthrough AO @ Keck/VLT
- HARMONI/MICADO
- METIS/HIRES



Morbidelli/Tsiganis/Gomez et al. 2005



Brown et al. 2012

E-ELT and EKBO

- Remnants of planet formation
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- HARMONI/MICADO
  - Spectra in 0.4-2.5 μm
  - Medium resolution (R$\approx$5000)
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  - Spectra in 3-15 μm
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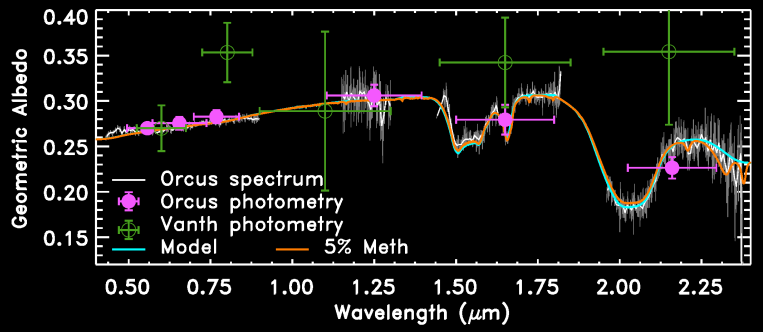
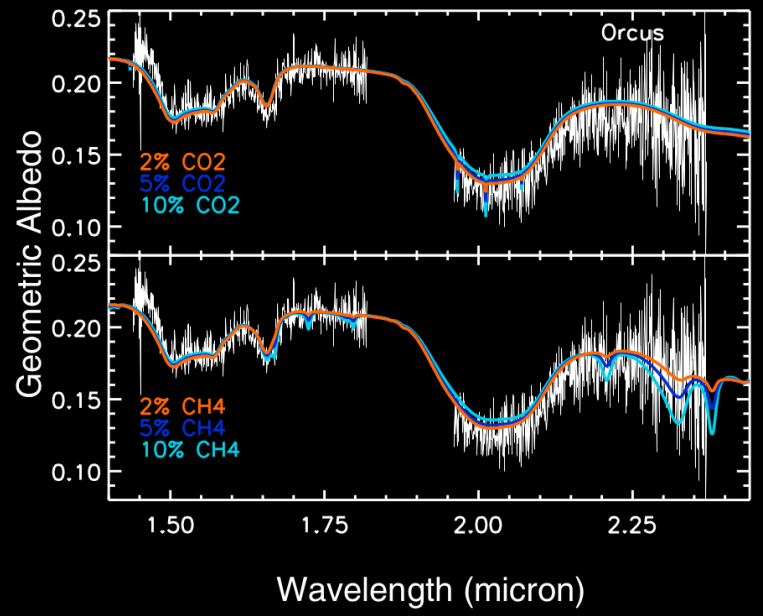


Carry et al., 2011



DeMeo et al., 2010

E-ELT and EKBO

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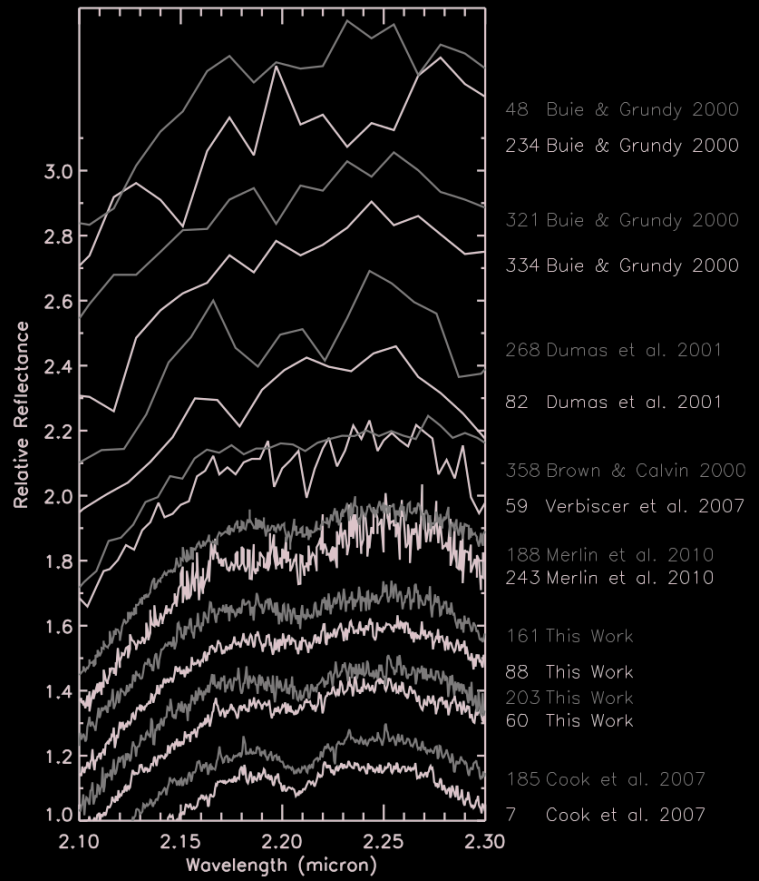

DeMeo et al., 2015

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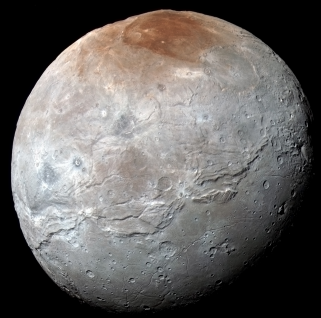

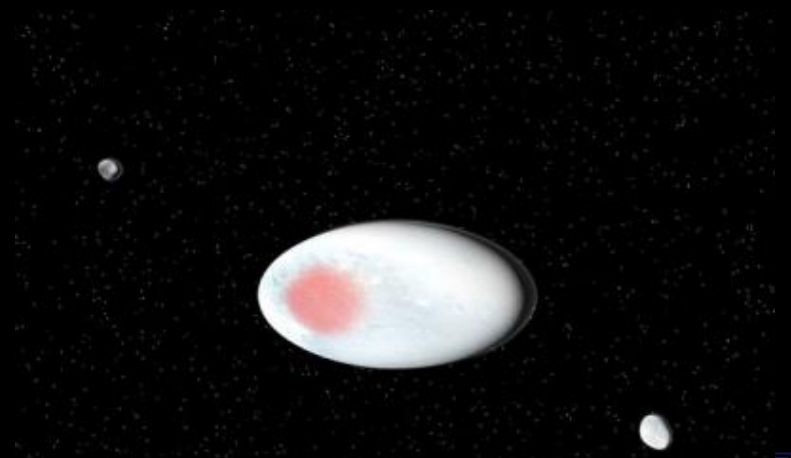

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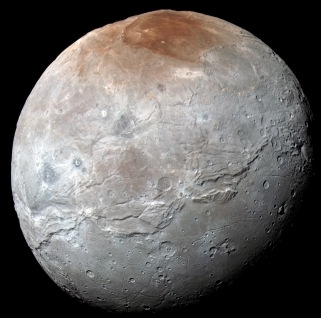
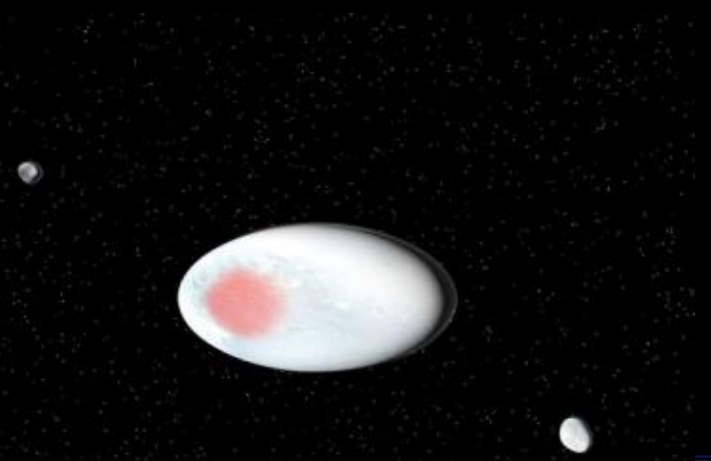
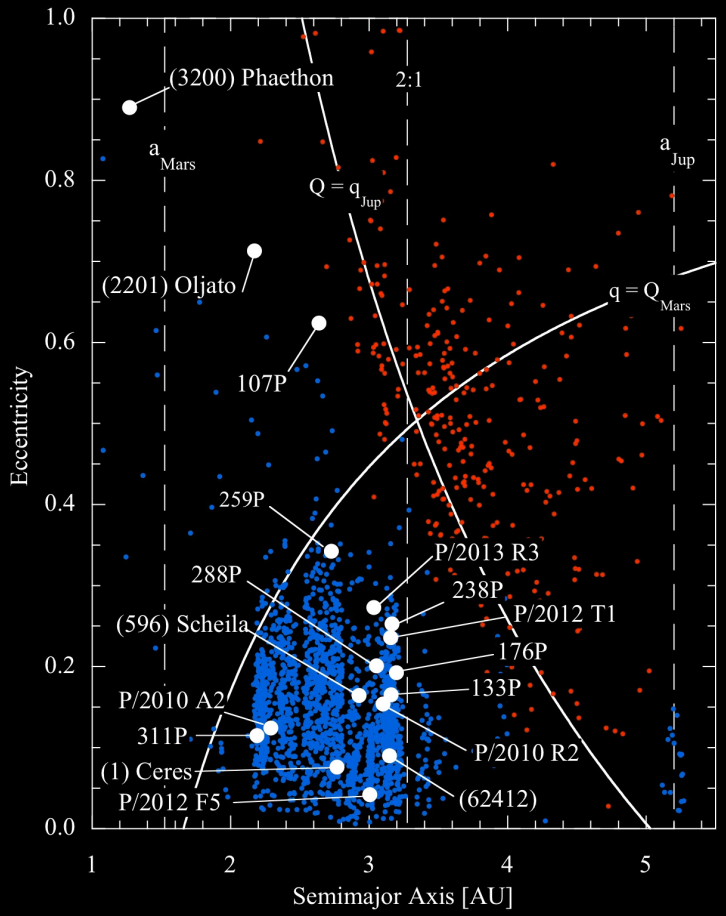




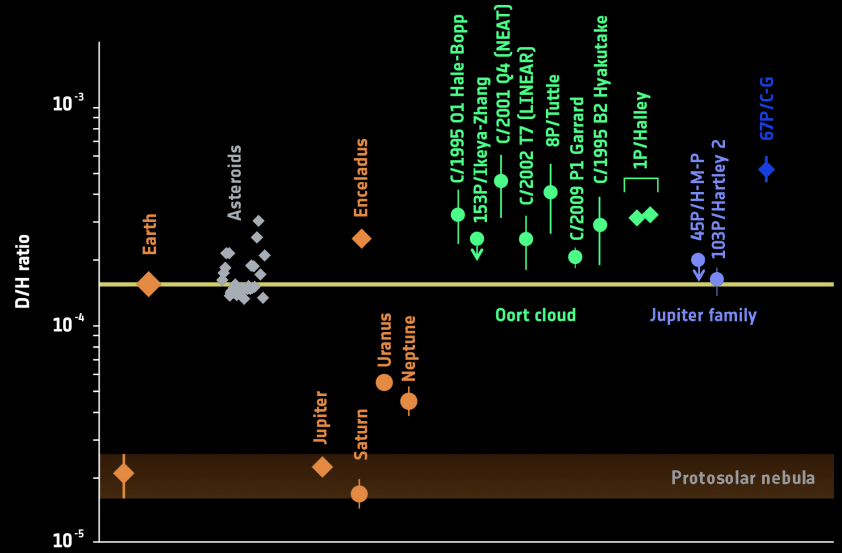
E-ELT and Comets



Jewitt et al. 2015

- Remnants of planet formation
  - Sample for outer-disk
  - Now: 2,000
  - LSST → 10,000
- Origin of Earth water?
  - HIRES/METIS
  - Ices and organics?
  - D/H, O, N, Ni, Fe
- Nucleus properties?
  - MICADO
  - Spin/Size/Shape?
  - Link with activity? Orbit?

E-ELT and Comets



Adapted from Bockelee-Morvan et al. 2014

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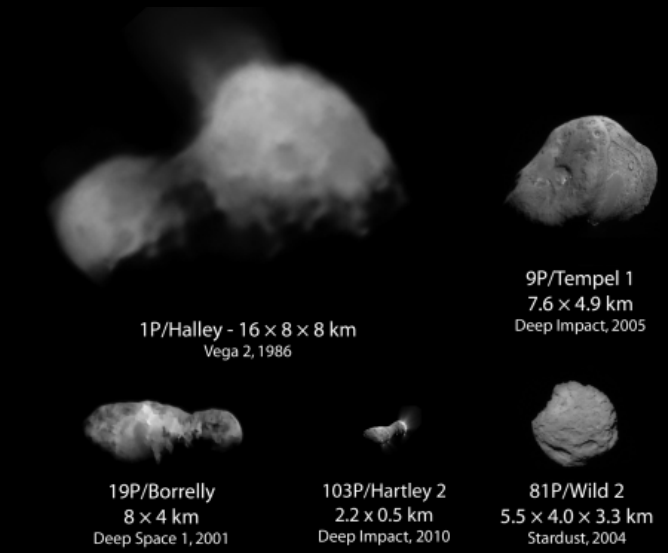

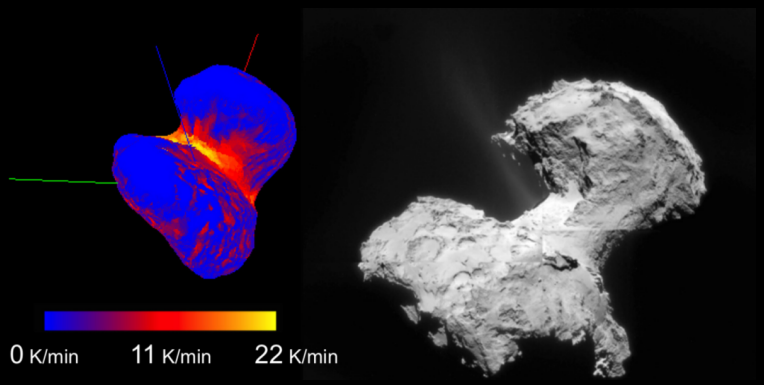

Ali-Lagoa et al. 2015

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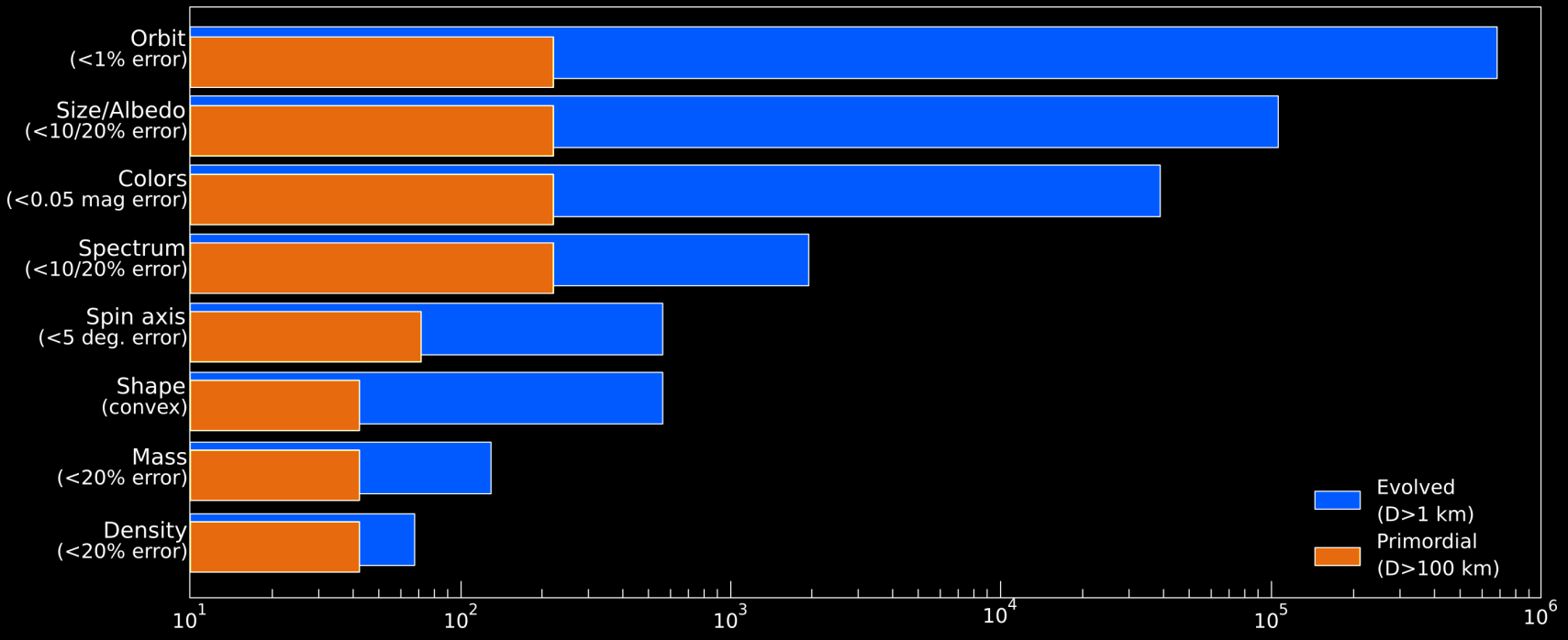
1. Contamination by Small Bodies
2. Composition of Small Bodies
3. Physical properties of Small Bodies
   - What do we know?
   - What do we want to know?
   - Density of SSOs
4. Summary

Current census

- Asteroids



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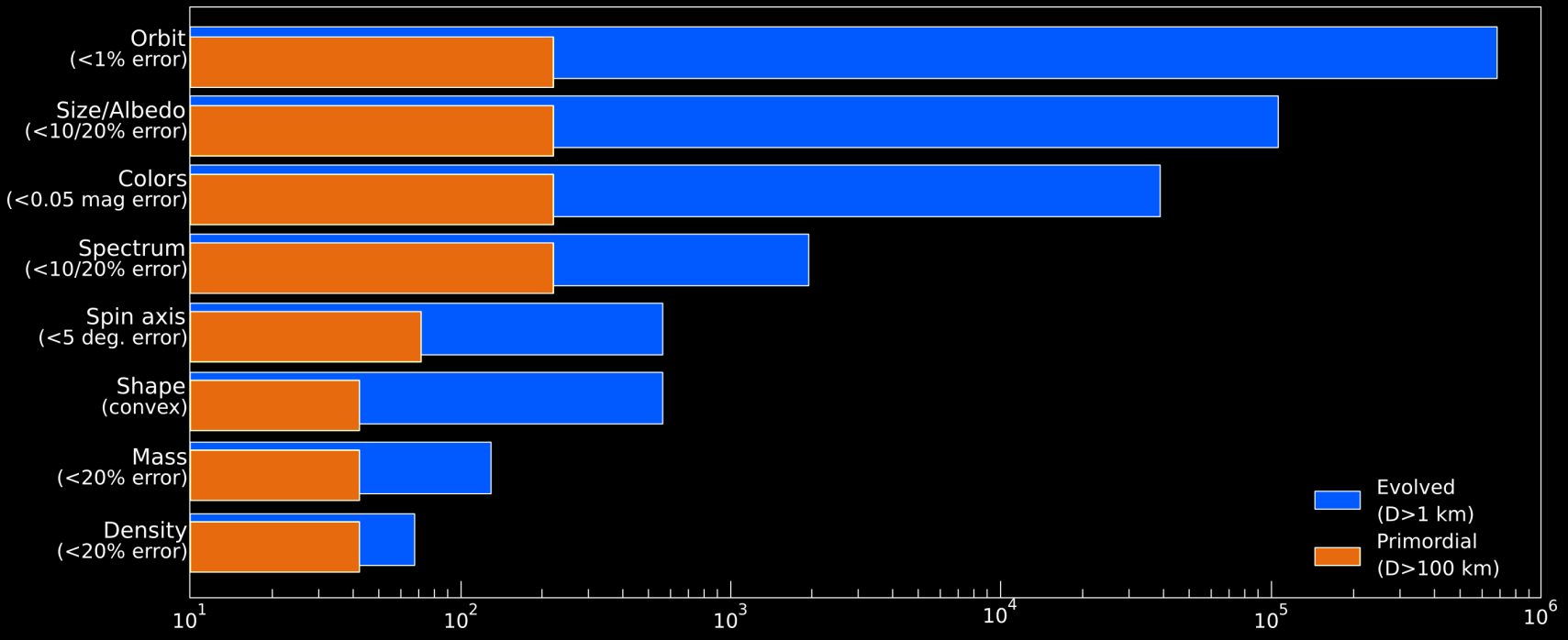
- Asteroids



- TNOs & Comets

  2000 objects $\rightarrow$ A handful known!

Some open questions

A. What is the distribution of spin-axis?

B. What is the shape of SSOs?
   - What is the distribution of craters?
   - For comets, is activity linked with topography?

C. What is the internal structure of SSOs?
   - Is there a relation between density and surface composition?
   - Is there a relation between structure and population?

D. What is the multiplicity rate among SSO populations?
   - How does it relate to their formation?
   - How does it relate to their composition?

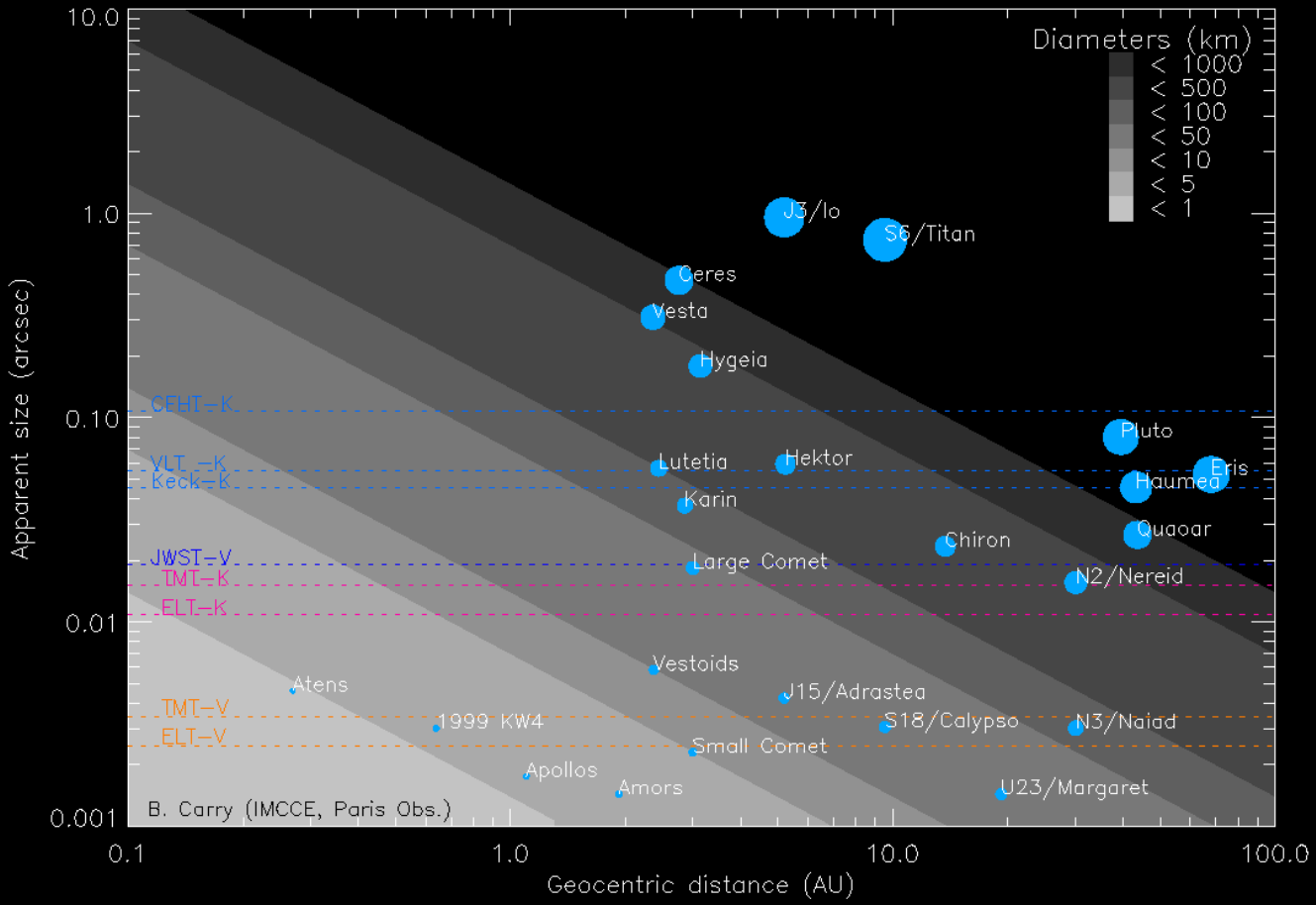
Some open questions

A. What is the distribution of spin-axis?

B. What is the shape of SSOs?
   - What is the distribution of craters?
   -

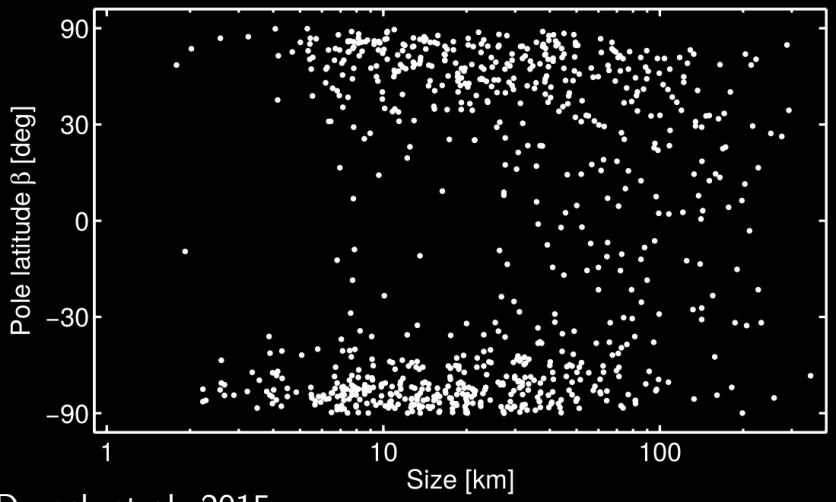
C. Wh
   -
   -

D. Wh
   -
   -



Opening the door...

- Spin-axis



Durech et al. 2015

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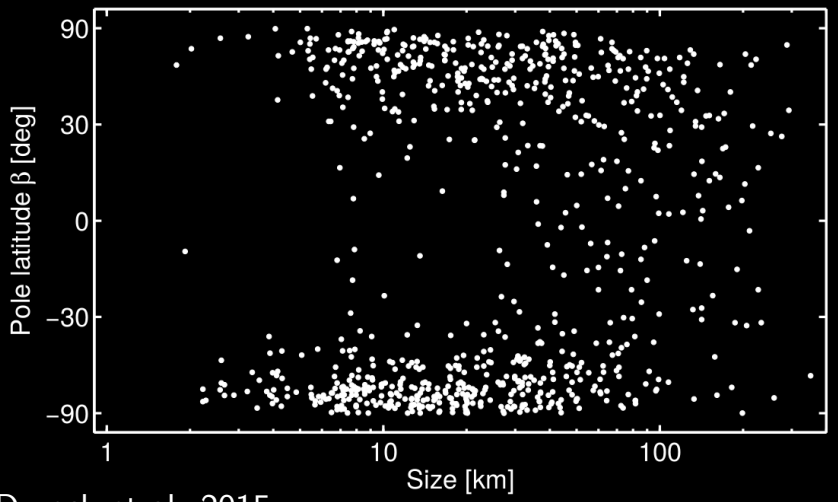
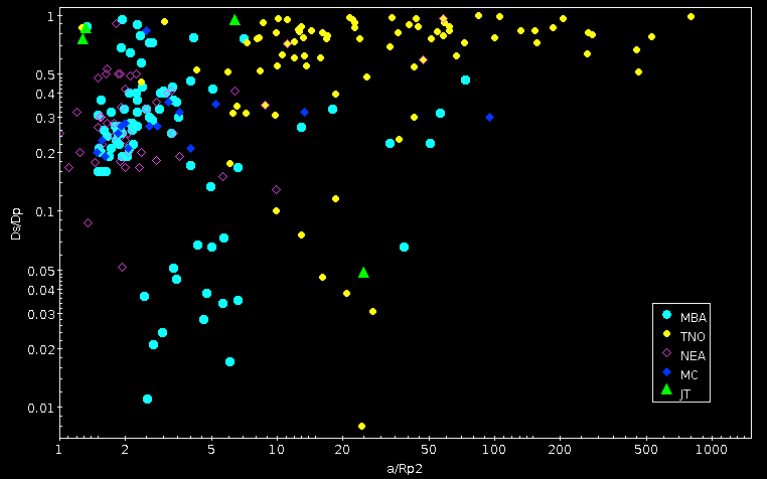


Durech et al. 2015

- Multiplicity



From Johnston 2015

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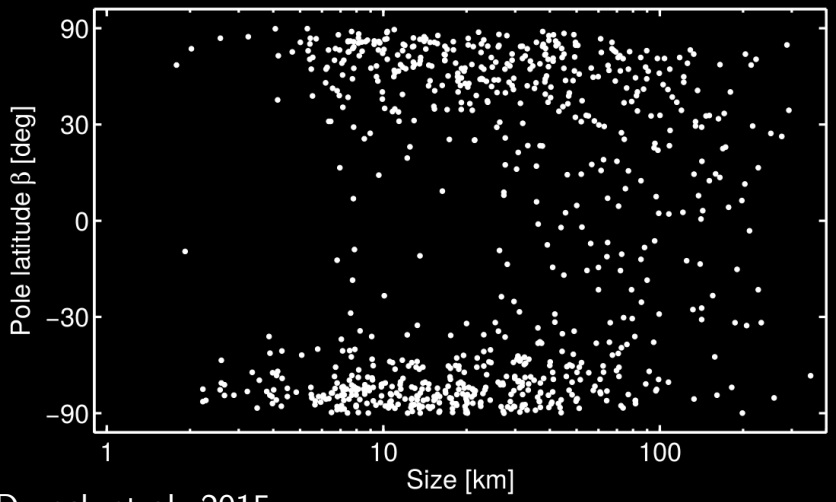
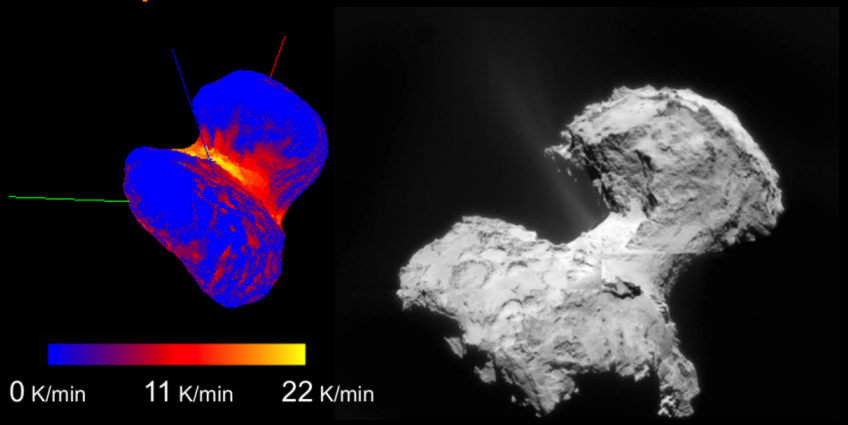


Durech et al. 2015

- Shape



Ali-Lagoa et al. 2015

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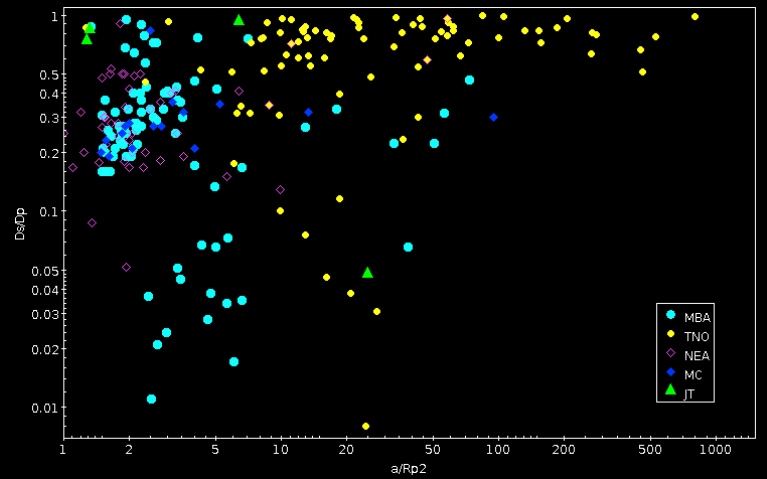

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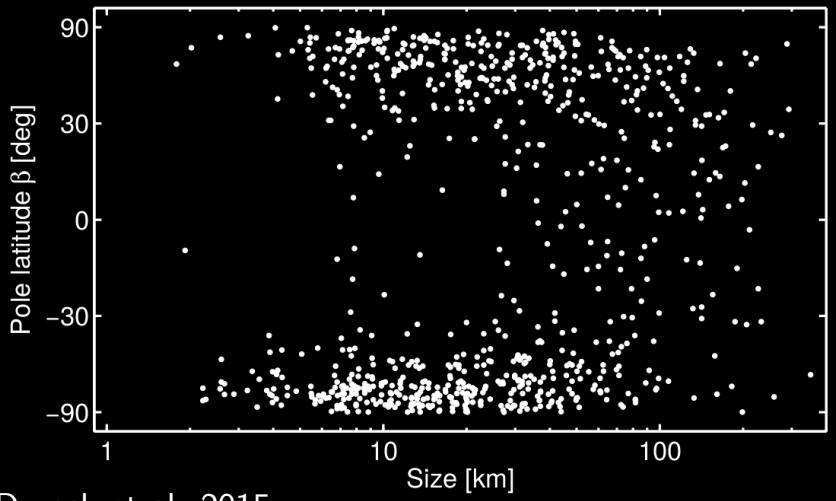
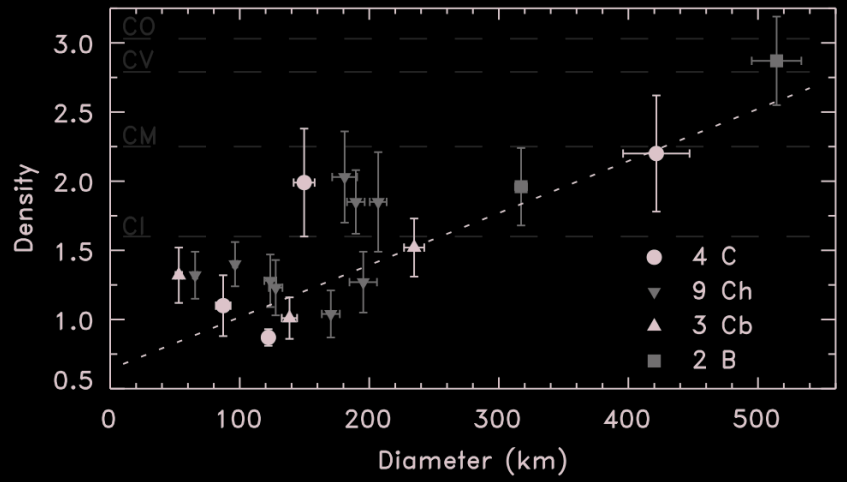


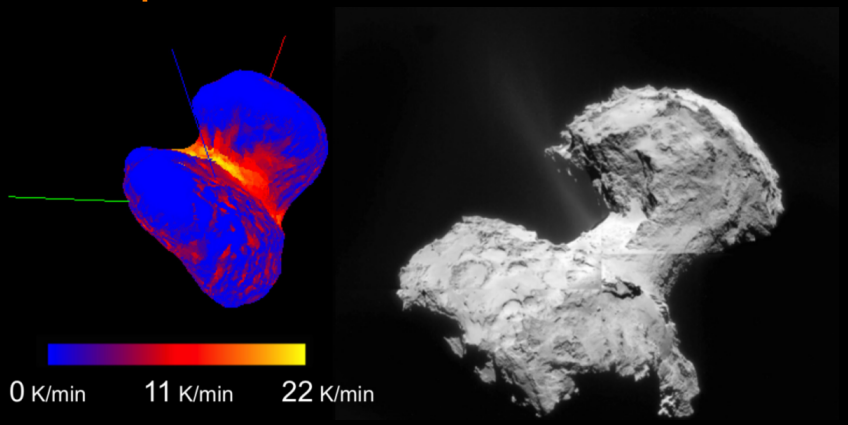
Durech et al. 2015

- Internal structure



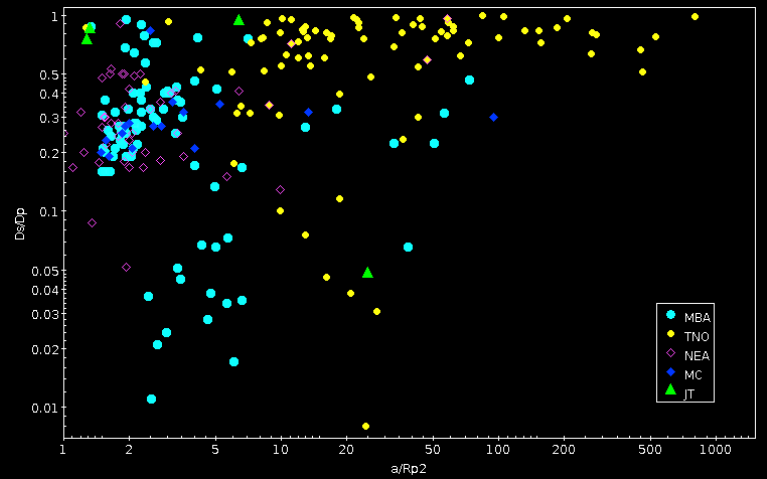
Carry 2012

- Shape



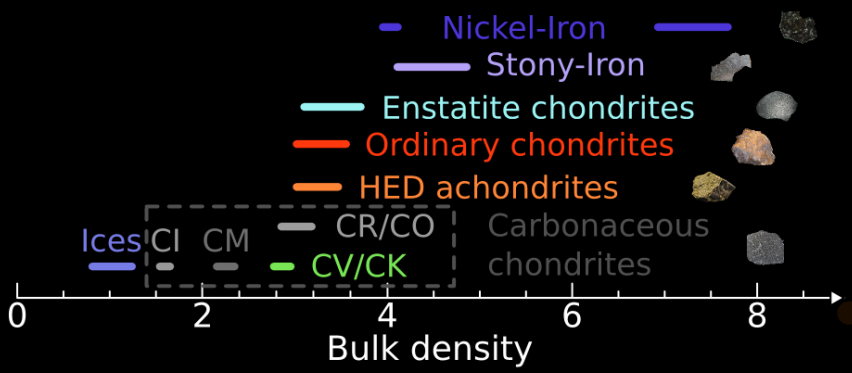
Ali-Lagoa et al. 2015

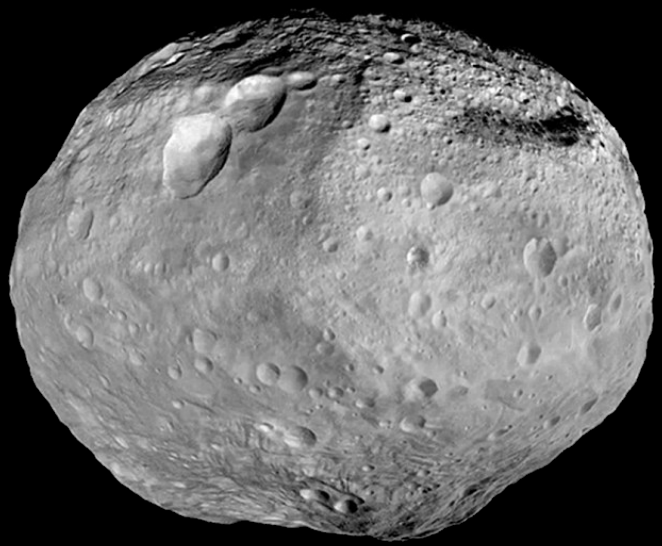
- Multiplicity



From Johnston 2015

Density of SSOs



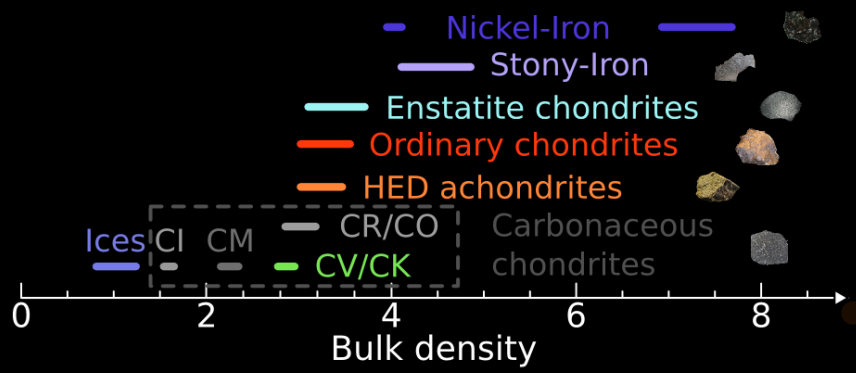


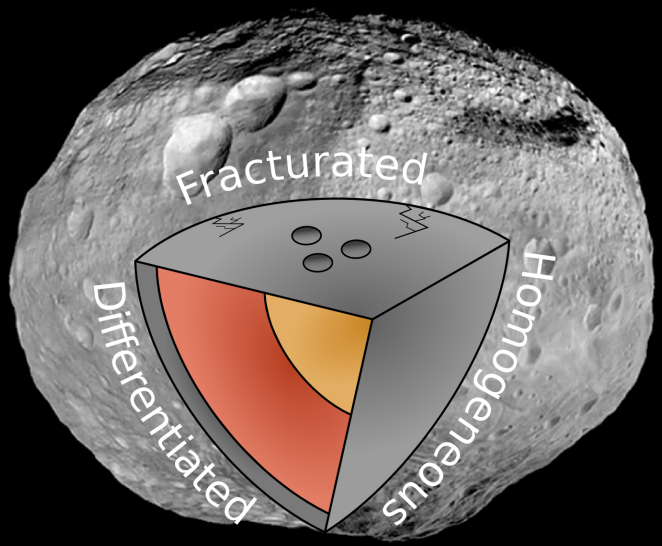
- Density $\Leftrightarrow$ composition
  - Ices: $\rho \approx 1$ g.cm^{-3}
  - Rock: $\rho \approx 2$–3 g.cm^{-3}
  - Metal: $\rho \approx 7$ g.cm^{-3}
  - Earth: $\rho = 5.5$ g.cm^{-3}
- Density = Mass / Volume
  - Satellite $\rightarrow$ mass
  - 3-D Shape $\rightarrow$ volume
- History of binary imaging

1990s: No AO $\rightarrow$ No satellites
2000s: AO $\rightarrow$ One satellites
2010s: XAO $\rightarrow$ **Two** satellites

- Big expectations for E-ELT

Density of SSOs





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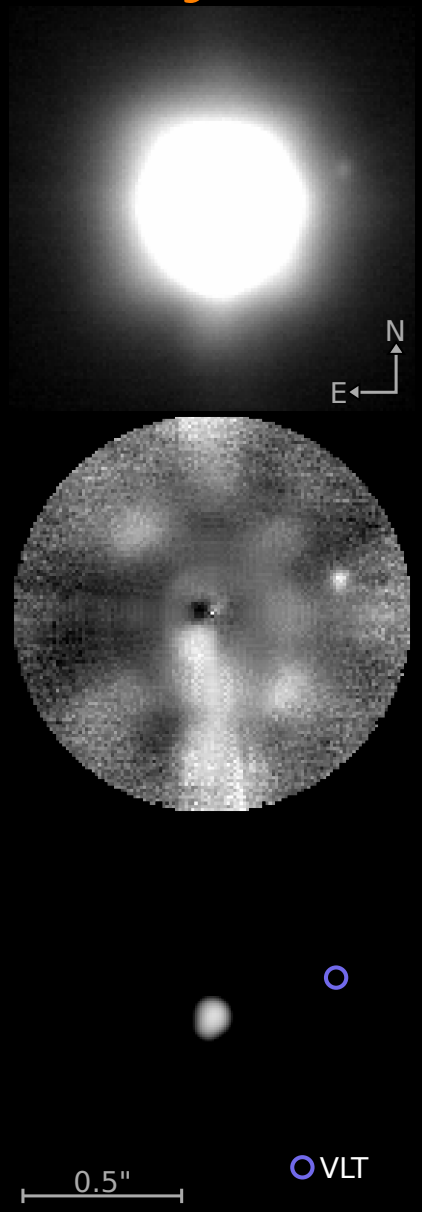

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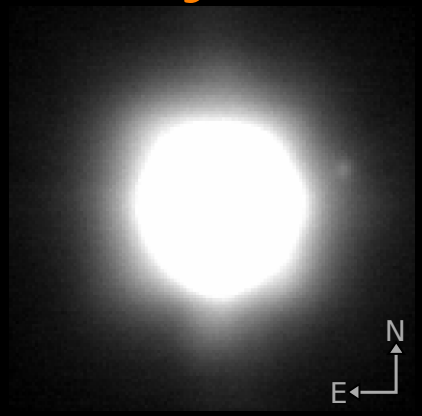

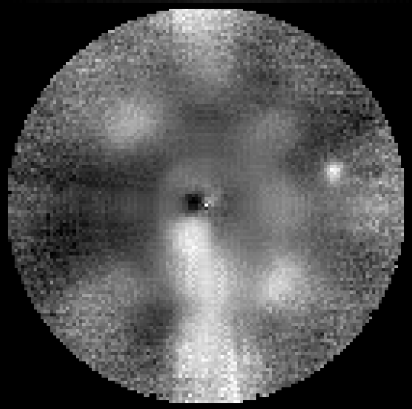

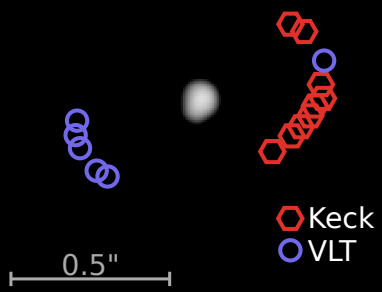

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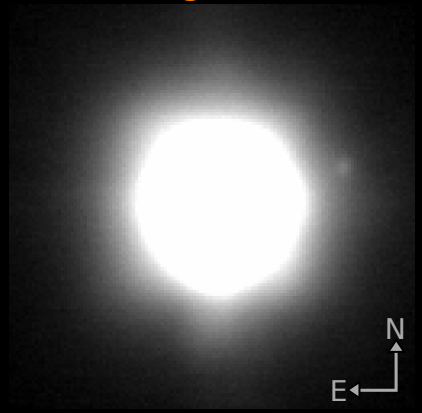

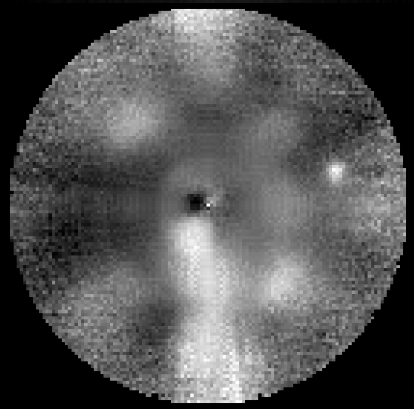

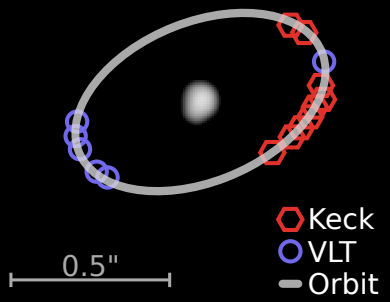

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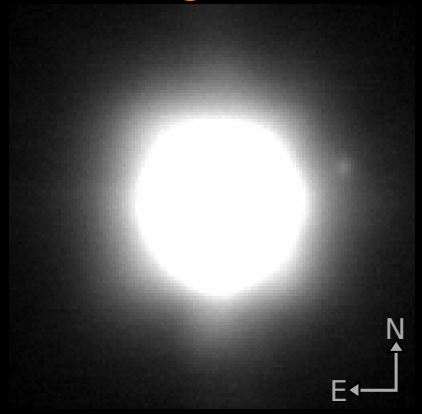

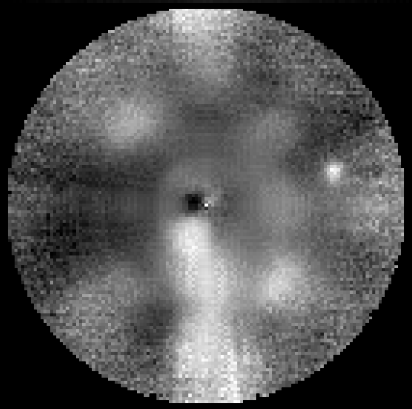

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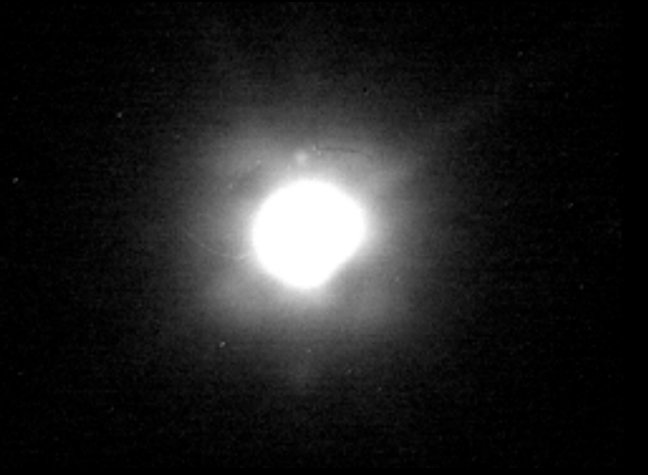
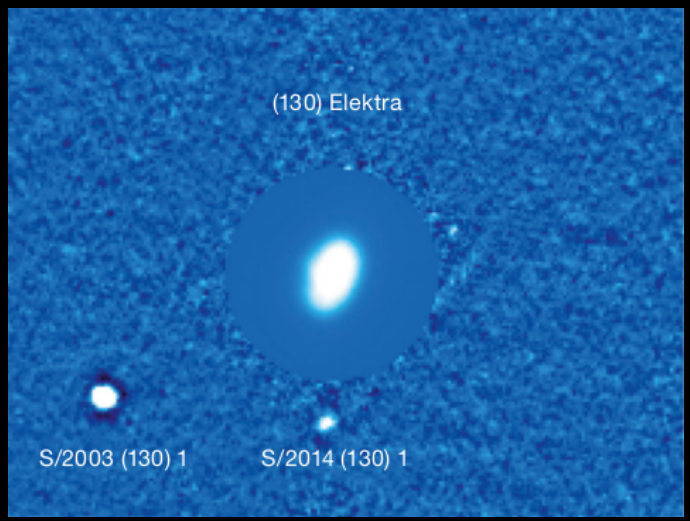


Marchis et al. 2008



Yang et al. 2014

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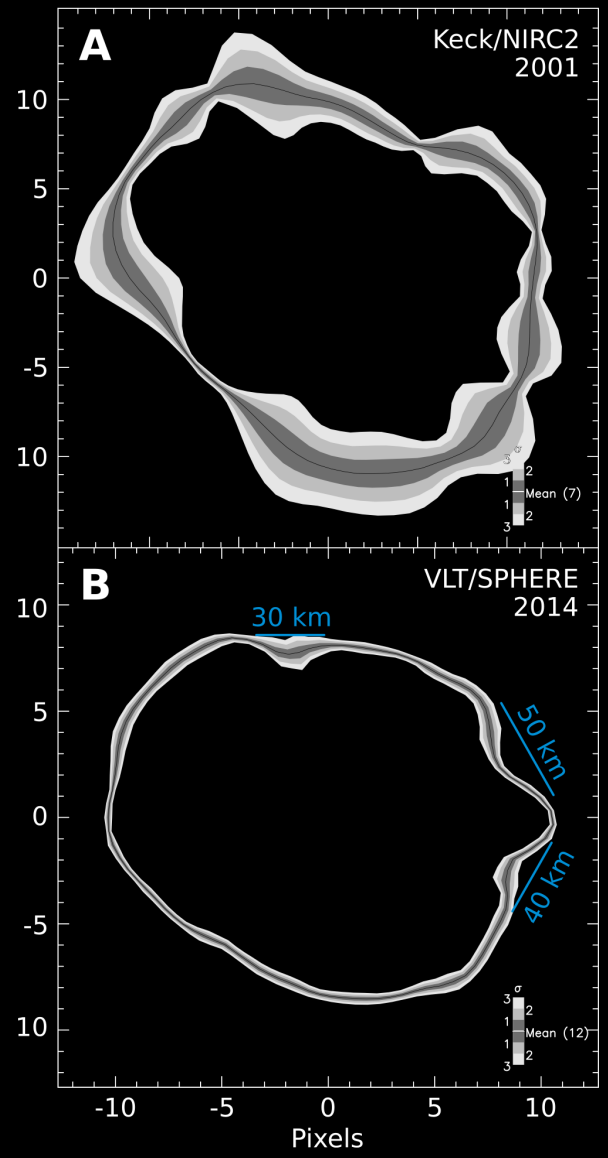

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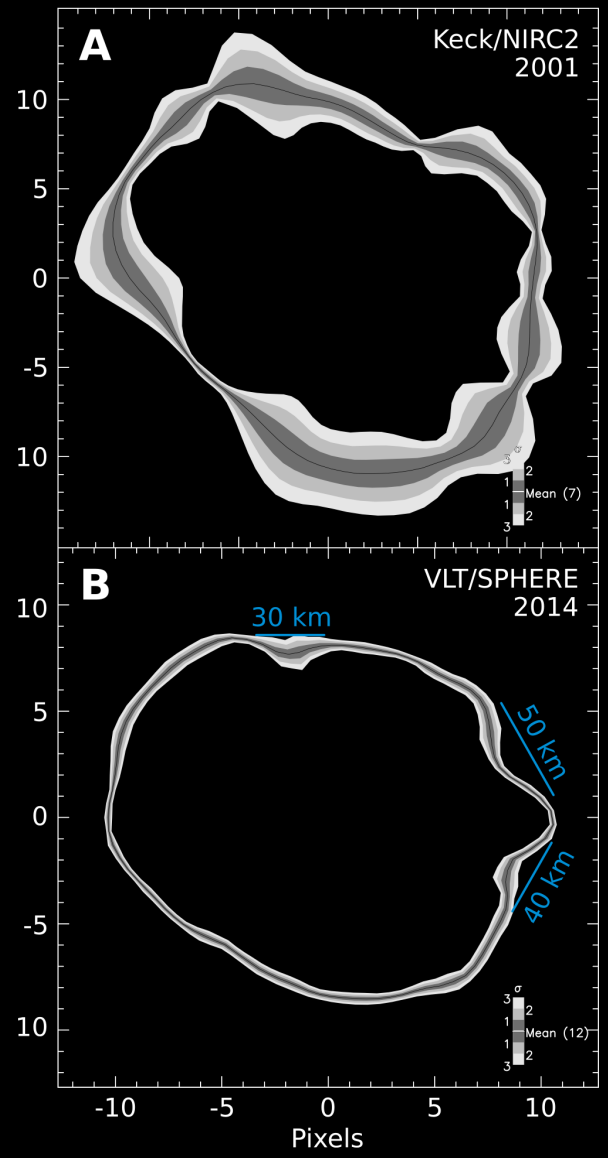

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Summary

- E-ELT for Solar System means observing
  - Fainter: Smaller, Farther, or Less abundant
  - Smaller: Smaller or Farther
  - Finer: Minor species
- E-ELT will provide a breakthrough for
  - Giant planet atmospheres
  - Comet nuclei
  - Surfaces of TNOs
  - Ring dynamics and composition
  - Multiplicity of small bodies
- E-ELT will push further our knowledge of the
  - Physical properties of asteroids
  - Composition of comets
  - Dynamics of giant planet systems