



60
years

THE SOLAR SYSTEM

FEET ON THE GROUND

EYES ON THE SKY



B. CARRY

Université Côte d'Azur
Observatoire de la Côte d'Azur
CNRS
Laboratoire Lagrange

Discovering and monitoring

- Solar system on photographic plates

ESO COMET

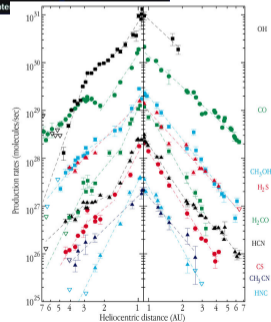
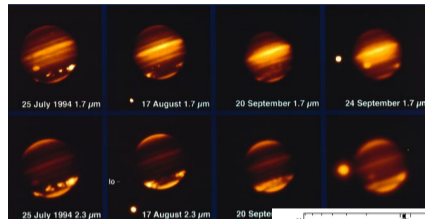
Photo of the latest comet discovered by astronomers working at the La Silla observatory in Chile of the European Southern Observatory, taken by the 3.6 m telescope. The Comet was first detected by Hans-Emil Schuster on a plate exposed in the 1-m Schmidt telescope that is used by ESO for mapping the southern celestial sphere. Computations made at the Smithsonian Observatory in Cambridge, Mass. show that the comet, whose magnitude was around 16.5 at the time the photograph was taken, moves in an elliptical orbit round the sun with a period of 7 1/2 years.



Europhysics News, 1977

Discovering and monitoring

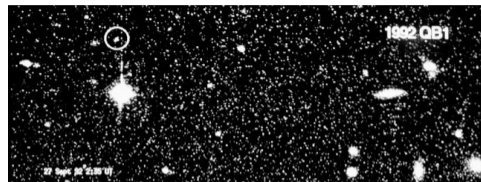
- Solar system on photographic plates
- Study of comets
 - Halley
 - Shoemaker-Levy 9 on Jupiter
 - Hale-Bopp



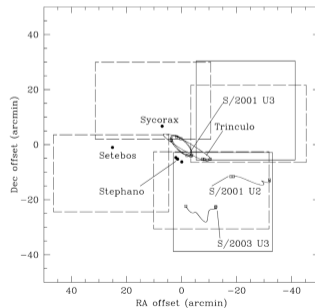
Drossart+1995, Biver+1998

Discovering and monitoring

- **Solar system on photographic plates**
- **Study of comets**
 - Halley
 - Shoemaker-Levy 9 on Jupiter
 - Hale-Bopp
- **Astrometry**
 - Kuiper belt
 - Irregular satellites
 - Mutual phenomena



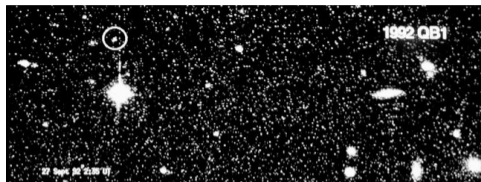
A. Smette, C. Vanderriest, O. Hainaut - 1992



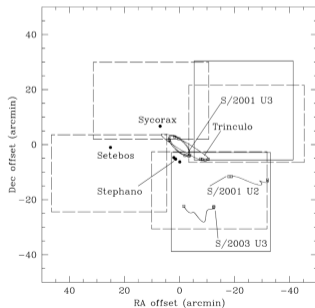
Veillet1982, Dourneau+1986, Arlot+1989, Kavelaars+2004

Discovering and monitoring

- **Solar system on photographic plates**
- **Study of comets**
 - Halley
 - Shoemaker-Levy 9 on Jupiter
 - Hale-Bopp
- **Astrometry**
 - Kuiper belt
 - Irregular satellites
 - Mutual phenomena
- **Days of celestial mechanics**



A. Smette, C. Vanderriest, O. Hainaut - 1992



Veillet1982, Dourneau+1986, Arlot+1989, Kavelaars+2004

Discovering and monitoring

- **Solar system on photographic plates**
- **Study of comets**
 - Halley
 - Shoemaker-Levy 9 on Jupiter
 - Hale-Bopp
- **Astrometry**
 - Kuiper belt
 - Irregular satellites
 - Mutual phenomena
- **Days of celestial mechanics**

PAF Ephemeris Generator Misade - VO Solar system portal
2015, IMCCE/OSPM/CNRS

To fill in the form, enter your values in each input element with the correct syntax. By putting the cursor on the label of each field you will access its description. The request is submitted by clicking the button 'Request ephemerides' at the bottom of the form. The results are shown below the form, and can be downloaded by clicking on the dedicated button. If an error occurs, a message will be displayed below the form instead of the results.

Target	<input type="text" value="Enter target name(s) (e.g. p:Mars, a:Ceres)"/>
Cutoff parameters	<input type="text" value="<airmass ≤ 2.6>, <sun elevation ≤ 0°>"/>
Start epoch (Year-Month-Day h:m:s)	<input type="text" value="2022-10-28T00:00:00.0"/>
Stop epoch (Year-Month-Day h:m:s)	<input type="text" value="2022-11-04T00:00:00.0"/>
Step size	<input type="text" value="1"/> <input type="text" value="hour"/>
Observer location	<input type="text" value="Cerro Paranal [309]"/>

eso.org - Moving Target Procedures

Discovering and monitoring

- **Solar system on photographic plates**

- **Study of comets**

- Halley
- Shoemaker-Levy 9 on Jupiter
- Hale-Bopp

- **Astrometry**

- Kuiper belt
- Irregular satellites
- Mutual phenomena

- **Days of celestial mechanics**

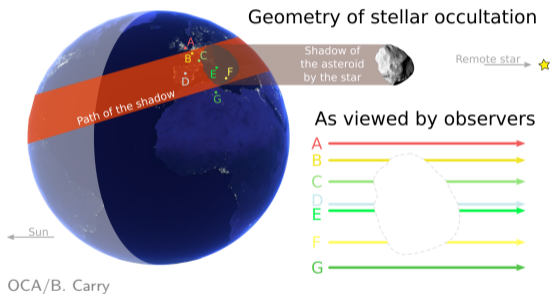
- ▶ **What's next?**

The screenshot shows a web form with a light green background. It contains several input fields and dropdown menus. At the top left, there is a checkbox labeled 'Target Name' which is checked. To its right is an empty text input field. Further right is a dropdown menu labeled 'Resolved by SIMBAD' with a downward arrow. Below these, there are two columns of input fields. The left column has a label 'RA' above an empty text input field. Below that is a label 'Search Box' above a text input field containing '00 10 00'. Below that is a label 'Output' with a checked checkbox, followed by a dropdown menu showing 'Sexagesimal (h, deg)'. The right column has a label 'DEC' above an empty text input field. Below that is a label 'Input' above a dropdown menu showing 'RA(h) DEC(deg)'. To the right of the 'DEC' input field is the text 'J2000'. At the bottom left, there is a label 'List of Targets' followed by a 'Browse...' button and the text 'No file selected.'

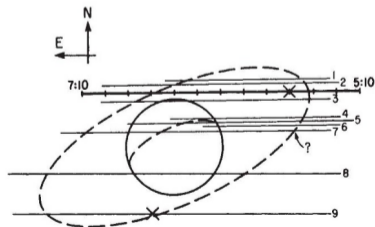
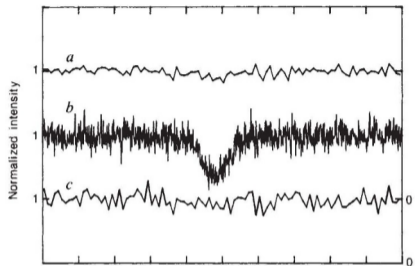
archive.eso.org

Stellar occultations

- Stellar occultations



Stellar occultations



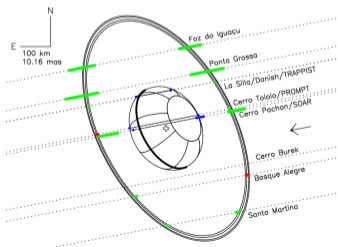
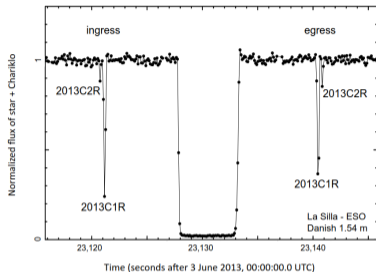
Hubbard+1986

- **Stellar occultations**
- **Discovery of Neptune's rings**

- Partial rings in **arcs!**

Sicardy+1986, French+1992

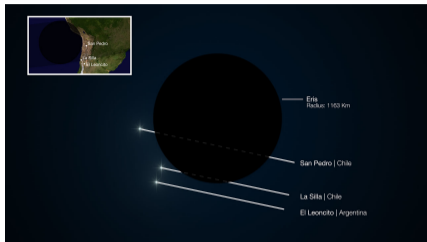
Stellar occultations



Braga-Ribas+2014

- **Stellar occultations**
- **Discovery of Neptune's rings**
 - Partial rings in **arcs!**
Sicardy+1986, French+1992
- **More rings!**
 - Centaur Chariklo! $D = 250$ km
 - KBO Haumea! $D = 1250$ km
Ortiz+2017, Sicardy+2022

Stellar occultations



ESO/L. Calçada

- **Stellar occultations**
- **Discovery of Neptune's rings**

- Partial rings in **arcs!**

Sicardy+1986, French+1992

- **More rings!**

- Centaur Chariklo! $D = 250$ km

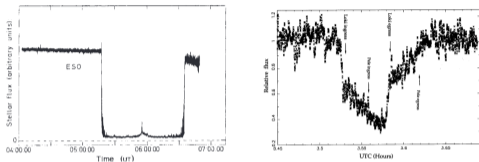
- KBO Haumea! $D = 1250$ km

Ortiz+2017, Sicardy+2022

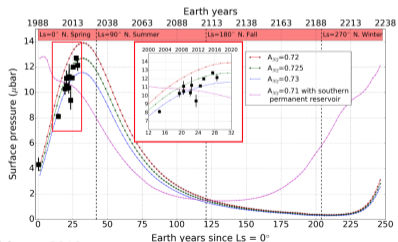
- **Sizes of KBOs**

Sicardy+2006, Ortiz+2012, Braga-Ribas+2013, Benedetti-Rossi+2019

Stellar occultations



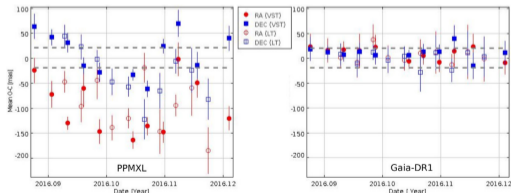
Lellouch+1986, Descamps+1992



Meza+2019

- **Stellar occultations**
- **Discovery of Neptune's rings**
 - Partial rings in **arcs!**
Sicardy+1986, French+1992
- **More rings!**
 - Centaur Chariklo! $D = 250$ km
 - KBO Haumea! $D = 1250$ km
Ortiz+2017, Sicardy+2022
- **Sizes of KBOs**
Sicardy+2006, Ortiz+2012, Braga-Ribas+2013, Benedetti-Rossi+2019
- **Exploring atmospheres**
 - Conditions
 - Activity

Stellar occultations



Spoto+2017

- **Stellar occultations**

- **Discovery of Neptune's rings**

- Partial rings in **arcs!**

Sicardy+1986, French+1992

- **More rings!**

- Centaur Chariklo! $D = 250$ km

- KBO Haumea! $D = 1250$ km

Ortiz+2017, Sicardy+2022

- **Sizes of KBOs**

Sicardy+2006, Ortiz+2012, Braga-Ribas+2013, Benedetti-Rossi+2019

- **Exploring atmospheres**

- Conditions

- Activity

► **What's next?**

Planets, rings & satellites

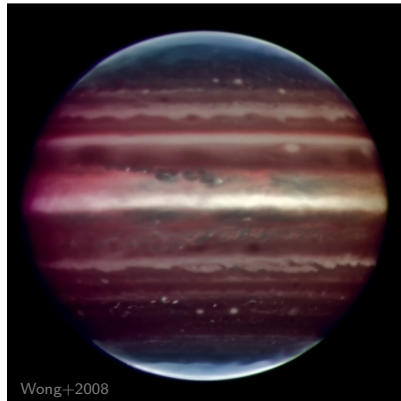
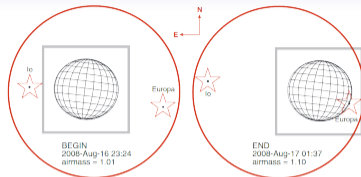
- **Moving to 8m & adaptive optics**



ESO/P. Weilbacher (AIP)

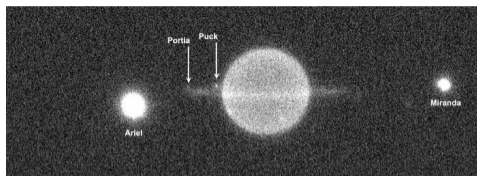
Planets, rings & satellites

- Moving to 8m & adaptive optics

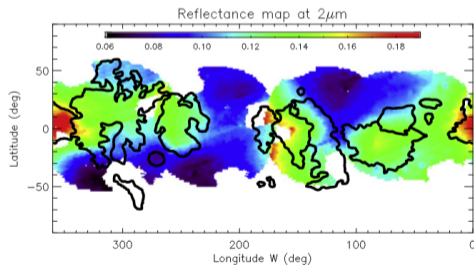


Planets, rings & satellites

- Moving to 8m & adaptive optics
- Planetary environment
 - Dust properties & dynamics
 - Satellite dynamics & surfaces
 - Atmospheres of satellites



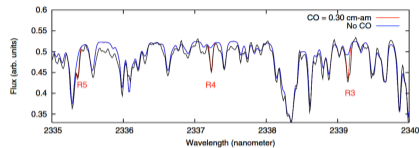
Arlot+2008, Gomes-Júnior+2015



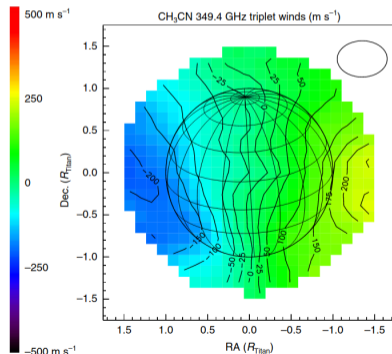
Lellouch+2004, Ligier+2016, Merlin+2018

Planets, rings & satellites

- Moving to 8m & adaptive optics
- Planetary environment
 - Dust properties & dynamics
 - Satellite dynamics & surfaces
 - Atmospheres of satellites



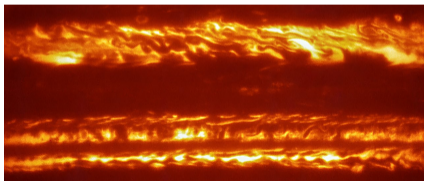
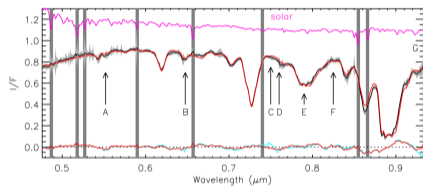
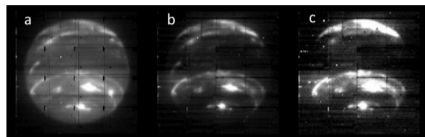
Combes+1981, Lellouch+2010



Lellouch+2019

Planets, rings & satellites

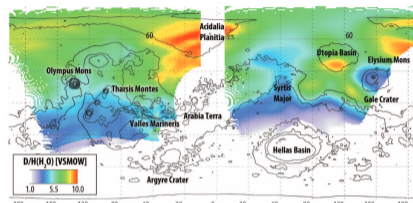
- **Moving to 8m & adaptive optics**
- **Planetary environment**
 - Dust properties & dynamics
 - Satellite dynamics & surfaces
 - Atmospheres of satellites
- **Atmospheres**
 - Composition
 - Winds, circulation, storms



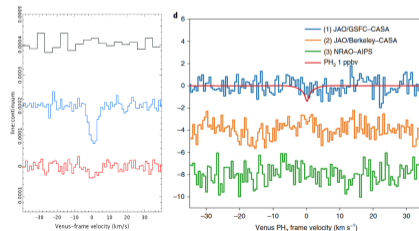
Encrenaz+2004, Orton+2007, Irwin+2017, Fletcher+2017

Planets, rings & satellites

- **Moving to 8m & adaptive optics**
- **Planetary environment**
 - Dust properties & dynamics
 - Satellite dynamics & surfaces
 - Atmospheres of satellites
- **Atmospheres**
 - Composition
 - Winds, circulation, storms
- **Terrestrial planets**
 - Ancient water on Mars
 - Phosphine (life?) on Venus



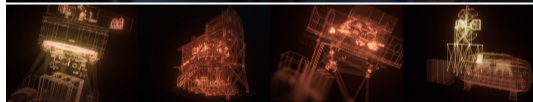
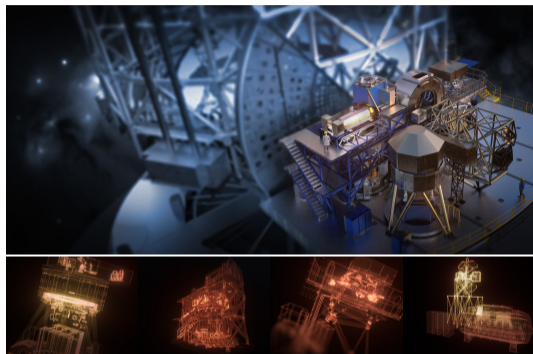
Doressoundiram+2010, Erard+2011 – Villanueva+2015



Greaves+2021, Encrenaz+2020, Akins+2021, Villanueva+2021

Planets, rings & satellites

- **Moving to 8m & adaptive optics**
- **Planetary environment**
 - Dust properties & dynamics
 - Satellite dynamics & surfaces
 - Atmospheres of satellites
- **Atmospheres**
 - Composition
 - Winds, circulation, storms
- **Terrestrial planets**
 - Ancient water on Mars
 - Phosphine (life?) on Venus
- ▶ **What's next?**



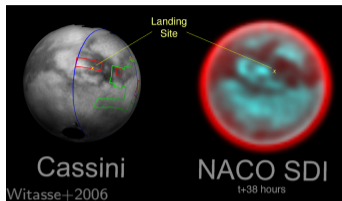
Synergy with upcoming missions:

ESA JUICE

NASA Europa Clipper

NASA Uranus/Neptune mission

Support to space missions



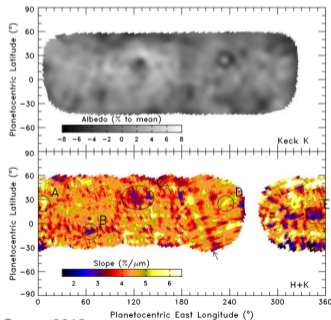
• To planetary bodies

ESA Huygens → Titan

NASA Dawn → Ceres & Vesta

NASA New Horizons → Pluto

Vernazza+2005, Witasse+2006, Benedetti-Rossi+2014




Carry+2012

Support to space missions

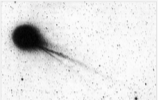
ABOUT IMAGES VIDEOS **NEWS** ESOSHOP TELESCOPES & INST

Press Releases > 1985-1990 > 1985

 European Southern Observatory

Press Releases 1985

Subscribe to receive news from ESO in your language!



[eso8501 – Science Release](#)

Comet Halley Develops a Tail

17 December 1985: Comet Halley was photographed with the ESO 1 metre Schmidt telescope at La Silla on 1985 December 9. The exposure was 10 min on a blue-sensitive emulsion. The telescope was guided on the moving comet. The stars in the field are therefore seen as short trails.

[READ MORE](#)

Showing 1 to 1 of 1

West+1986, Schulz+2003, Jehin+2006, Vincent+2013

• To planetary bodies

ESA Huygens → Titan

NASA Dawn → Ceres & Vesta

NASA New Horizons → Pluto

Vernazza+2005, Witasse+2006, Benedetti-Rossi+2014

• To comets

ESA Giotto → 1P/Halley

NASA Deep Impact → 9P/Tempel 1

ESA Rosetta → 67P/Churyumov–Gerasimenko

Schulz+1998, Meech+2005, Snodgrass+2010

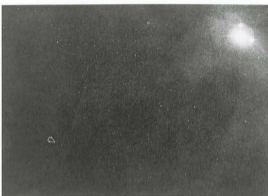
Support to space missions

A Visit to Gaspra

This is a ground-based photo of the first minor planet ever to be visited by a spacecraft. On October 29, 1991, the NASA spacecraft Galileo flew past minor planet No. 951 Gaspra on its way to Jupiter where it will arrive in December 1995. The distance to Gaspra from the Earth was 410 million km at the time of the fly-by. Although Galileo's high-gain antenna has not yet been unfolded and could therefore not be used, JPL engineers succeeded in getting a 300-line image via the low-gain antenna; the others will be sent when Galileo is again near the Earth. The first image showed the irregular form of Gaspra and several craters on its surface with a resolution of about 130 metres. The diameter was measured as 16 kilometres.

Gaspra was discovered on July 30, 1916 at the Simeis Observatory in the mountains of Crimea, the Russia. The discoverer was the well-known Russian astronomer Grigori Nikolajevich Neujmin (born 1886 in Tbilisi, Georgia; died 1946 in Leningrad), who later became Director of that observatory (1925–1931 and 1936–1941) and Director of the Pulkovo Observatory near St. Petersburg (1944–1948). During three decades he discovered 72 minor planets and 6 comets.

Neujmin's dedication for (951) Gaspra reads as follows: "Named after the re-



sort on the southern coast of Crimea, in which the famous Russian writer Lev Nikolajevich Tolstoj (1828–1910) spent many years of his life." The village of Gaspra is located about 10 km southwest of Yalta.

The present photo was obtained with the 1-metre ESO Schmidt telescope at La Silla on April 9, 1991 and served to measure an accurate position of Gaspra, in support of the navigation of Galileo. The exposure lasted 10 minutes and Gaspra is indicated with an arrow.

On this date, its distance from the Earth was 262 million km and the magnitude was about 15.

The background of the photo is a region in the southern constellation Ophiuchus (the Serpent-holder) which is characterized by relatively few stars, but many bright and dark nebulae. The brightest of the three stars in the top right corner is the 5th-magnitude Rho Ophiuchi, a hot and young double star. It is surrounded by nebulosity that reflects the light from the stars.

• To planetary bodies

ESA Huygens → Titan

NASA Dawn → Ceres & Vesta

NASA New Horizons → Pluto

Vernazza+2005, Witasse+2006, Benedetti-Rossi+2014

• To comets

ESA Giotto → 1P/Halley

NASA Deep Impact → 9P/Tempel 1

ESA Rosetta → 67P/Churyumov–Gerasimenko

Schulz+1998, Meech+2005, Snodgrass+2010

• To asteroids

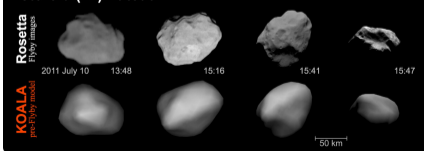
NASA Galileo → Gaspra

JAXA Hayabusa 1 & 2 → Itokawa & Ryugu

ESA Rosetta → Šteins & Lutetia

Sekiguchi+2003, Fornasier+2004, Müller+2017

Asteroid (21) Lutetia



Carry+2010

Support to space missions



Upcoming missions:

- ESA Hera
- ESA Comet Interceptor
- NASA Lucy
- NASA OSIRIS-APEX

• To planetary bodies

- ESA Huygens → Titan
- NASA Dawn → Ceres & Vesta
- NASA New Horizons → Pluto

Vernazza+2005, Witasse+2006, Benedetti-Rossi+2014

• To comets

- ESA Giotto → 1P/Halley
- NASA Deep Impact → 9P/Tempel 1
- ESA Rosetta → 67P/Churyumov–Gerasimenko

Schulz+1998, Meech+2005, Snodgrass+2010

• To asteroids

- NASA Galileo → Gaspra
- JAXA Hayabusa 1 & 2 → Itokawa & Ryugu
- ESA Rosetta → Šteins & Lutetia

Sekiguchi+2003, Fornasier+2004, Müller+2017

► What's now? What's next?

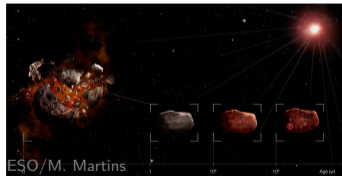
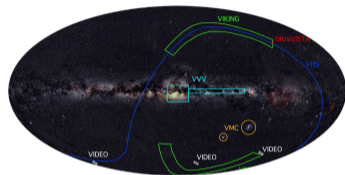
Characterization of small bodies

- **Asteroids**

- Population studies
- Focused analyses

S³OS²: the visible spectroscopic survey of 820 asteroids

D. Lazzaro^{*,†}, C.A. Angeli^{*}, J.M. Carvano^{*}, T. Mothé-Diniz^{*}, R. Duffard^{*}, M. Florczak[†]



Vernazza+2009, Fornasier+2014, Popescu+2016, Perna+2018

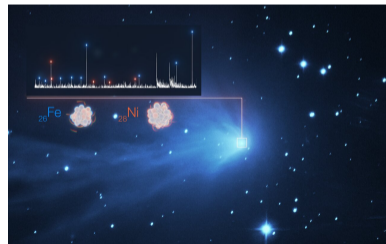
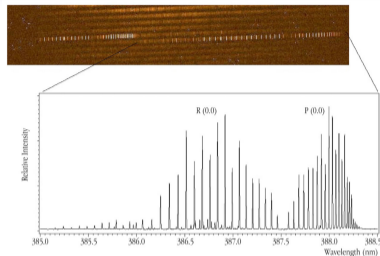
Characterization of small bodies

- **Asteroids**

- Population studies
- Focused analyses

- **Comets**

- Dust-gas production rate
- Composition



Biver+2000, Arpigny+2003, Jehin+2006,
Rousselot+2011, Opatom+2016, Manfroid+2021

Characterization of small bodies

• Asteroids

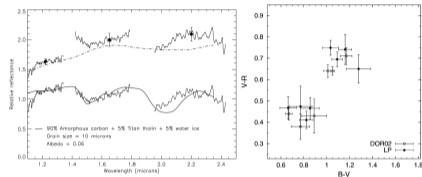
- Population studies
- Focused analyses

• Comets

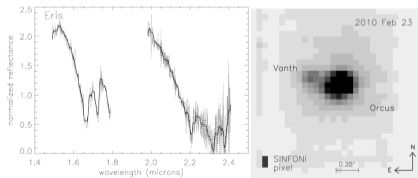
- Dust-gas production rate
- Composition

• Kuiper belt objects

- Composition of ices
- Distribution of colors



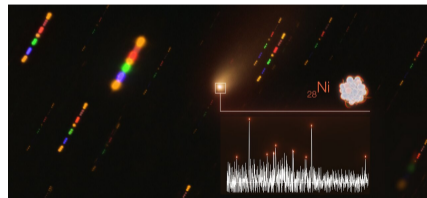
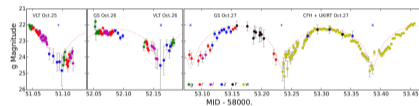
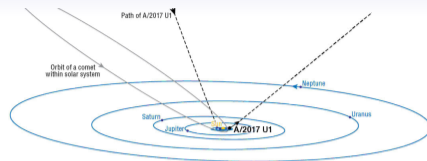
Barucci+2002, Peixinho+2004, Delsanti+2006, Brunetto+2006



Guilbert+2009, Fornasier+2009, Carry+2011, Barucci+2011

Characterization of small bodies

- **Asteroids**
 - Population studies
 - Focused analyses
- **Comets**
 - Dust-gas production rate
 - Composition
- **Kuiper belt objects**
 - Composition of ices
 - Distribution of colors
- **Interstellar objects**
 - Trajectory & shape
 - Composition



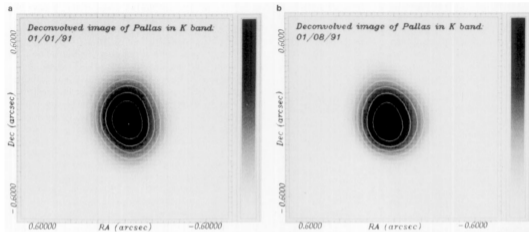
Meech+2017, Bailer-Jones+2020, Guzik & Drahus 2021

Characterization of small bodies

- **Asteroids**
 - Population studies
 - Focused analyses
- **Comets**
 - Dust-gas production rate
 - Composition
- **Kuiper belt objects**
 - Composition of ices
 - Distribution of colors
- **Interstellar objects**
 - Trajectory & shape
 - Composition
- ▶ **What's next?**

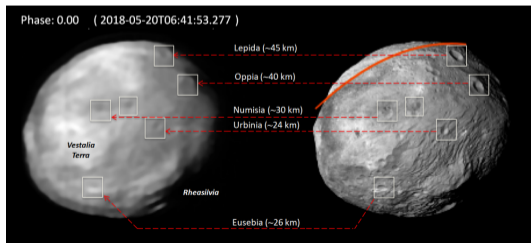


Small bodies - High resolution



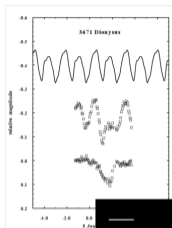
Saint-Pé+1993

- Moving to adaptive optics

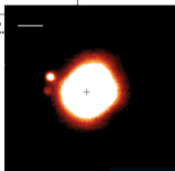


Fétick+2019

Small bodies - High resolution

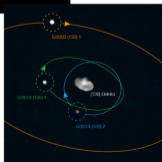


1997
Dionysus



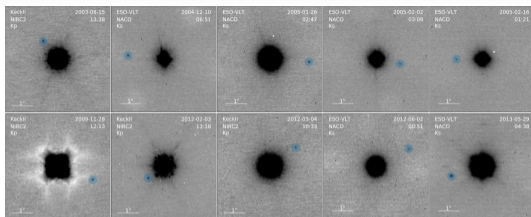
2005
Sylvia

2022
Elektra

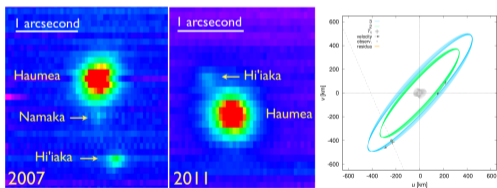


- **Moving to adaptive optics**
- **Multiple systems**
 - Discoveries!
 - Characterization

Small bodies - High resolution

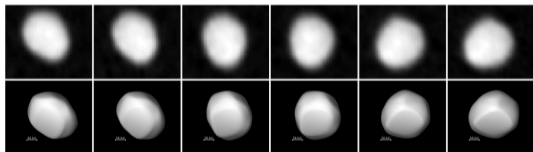
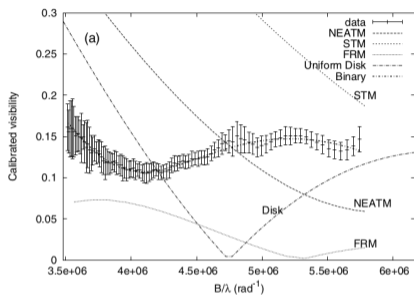


- Moving to adaptive optics
- Multiple systems
 - Discoveries!
 - Characterization



Dumas+2011, Marchis+2011, Gourgout+2016
 Berthier+2014, Carry+2020, Brož+2022, Vachier+2022

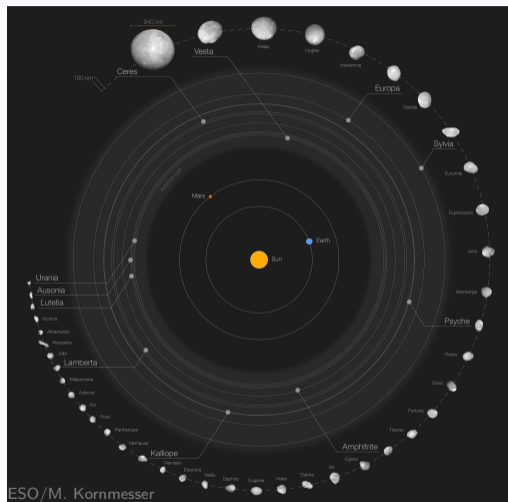
Small bodies - High resolution



Delbo+2009, Matter+2011, Carry+2015, Viikinkoski+2015

- **Moving to adaptive optics**
- **Multiple systems**
 - Discoveries!
 - Characterization
- **Pushing angular resolution**
 - VLTI / MIDI
 - ALMA

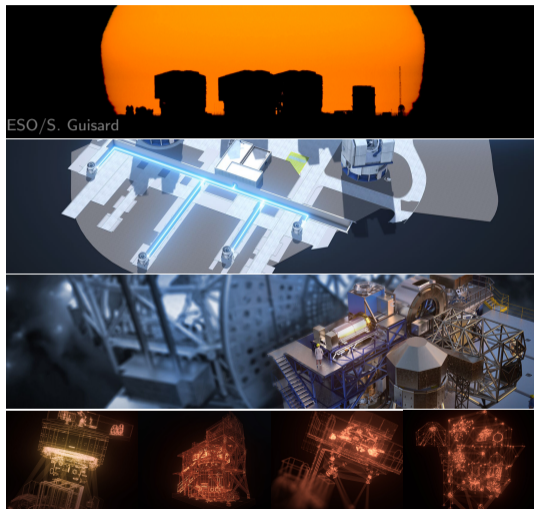
Small bodies - High resolution



Vernazza+2021, Carry+2019, Marsset+2020, Hanuš+2020
 Borž+2020, Ferrais+2022, Marchis+2021, Yang+2020

- **Moving to adaptive optics**
- **Multiple systems**
 - Discoveries!
 - Characterization
- **Pushing angular resolution**
 - VLT / MIDI
 - ALMA
- **Physical properties**
 - Topography
 - Internal structure

Small bodies - High resolution



- **Moving to adaptive optics**
- **Multiple systems**
 - Discoveries!
 - Characterization
- **Pushing angular resolution**
 - VLTI / MIDI
 - ALMA
- **Physical properties**
 - Topography
 - Internal structure
- ▶ **What's next?**

ESO turns 60 and the Solar System

- **Early solar system studies with ESO**
 - Astrometry and photometry
 - Focus on comets and atmospheres
- **The jewel of the mountaintop**
 - Outer Solar System became accessible
 - Disk-resolved (spectro-)imaging
 - High-resolution spectroscopy
- **Exciting developments for a bright future**
 - New generation of instruments at the VLT
 - ELT sensitivity and angular resolution

