Rosetta VIRTIS/GIADA

Attività scientifica nella fase post-operativa della missione

Fabrizio Capaccioni for the
Rosetta-VIRTIS/GIADA Teams

Audizione INAF CSN3 28 May 2021

Angioletta Coradini
(Rovereto 1946 – Roma 2011)

Angioletta was pure energy, so lively and so positive in every one of her endless endeavours.

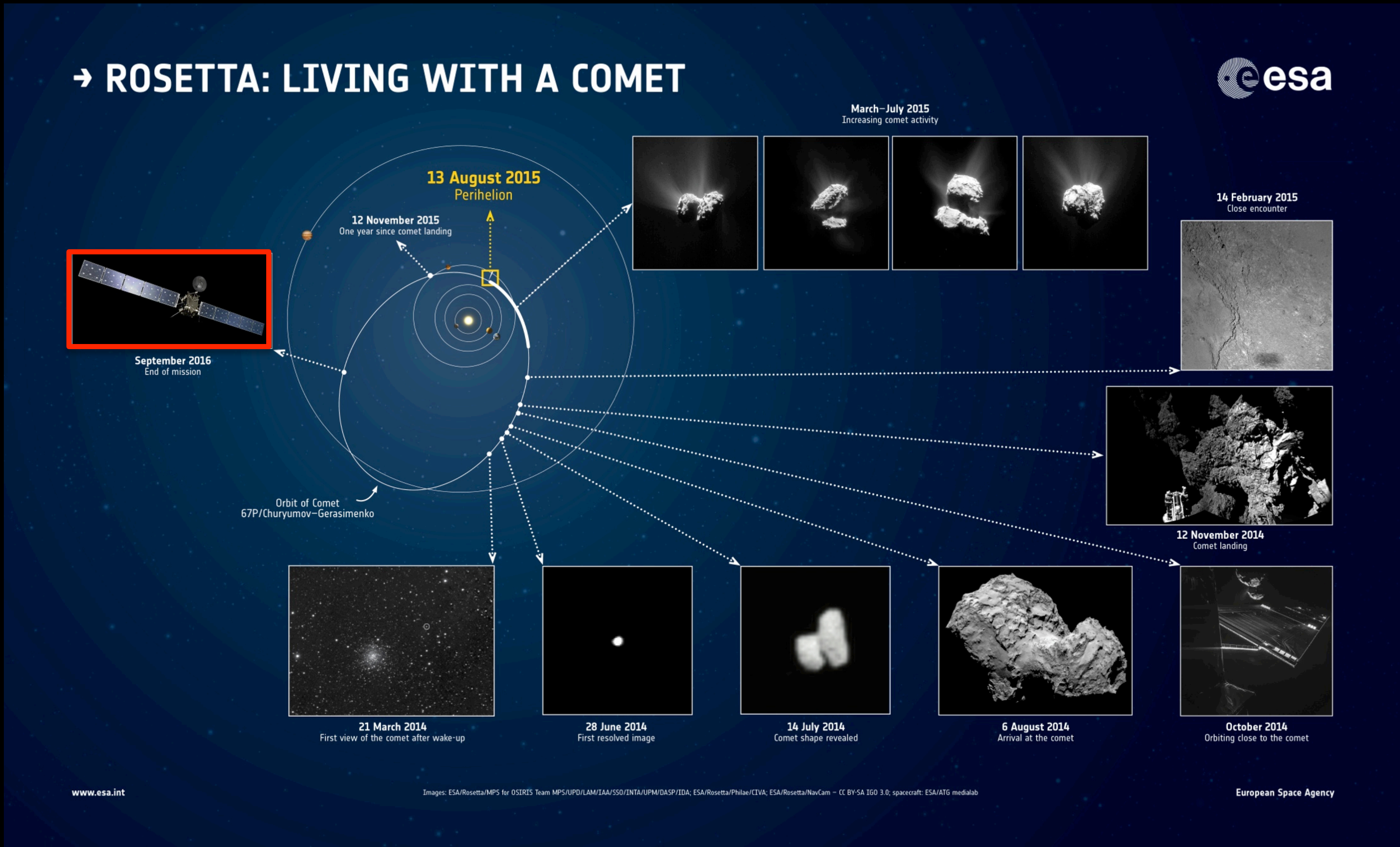
Angioletta was honest and generous, her vision always focused not on herself but to the support of science and of her young scientists.

Angioletta has been one of the few that played a major role in the revolution in Planetary Science in the last few decades.

Angioletta was a first day architect of the Rosetta mission.

You populated the entire solar system with unique means of deciphering the mysteries of evolution, you paved the path for future generations to share your passion, all with a tremendous generosity, sense of humor , and humanity. Thank you

Rosetta: 2.5 years with 67P/CG



30th September 2016 @13:19
Rosetta landed on the nucleus of 67P/CG

Scientific Objectives of the Rosetta Mission

How comets were formed?

- Comets are time capsules containing primitive material left over from the epoch from the early phases of evolution of the Solar System.

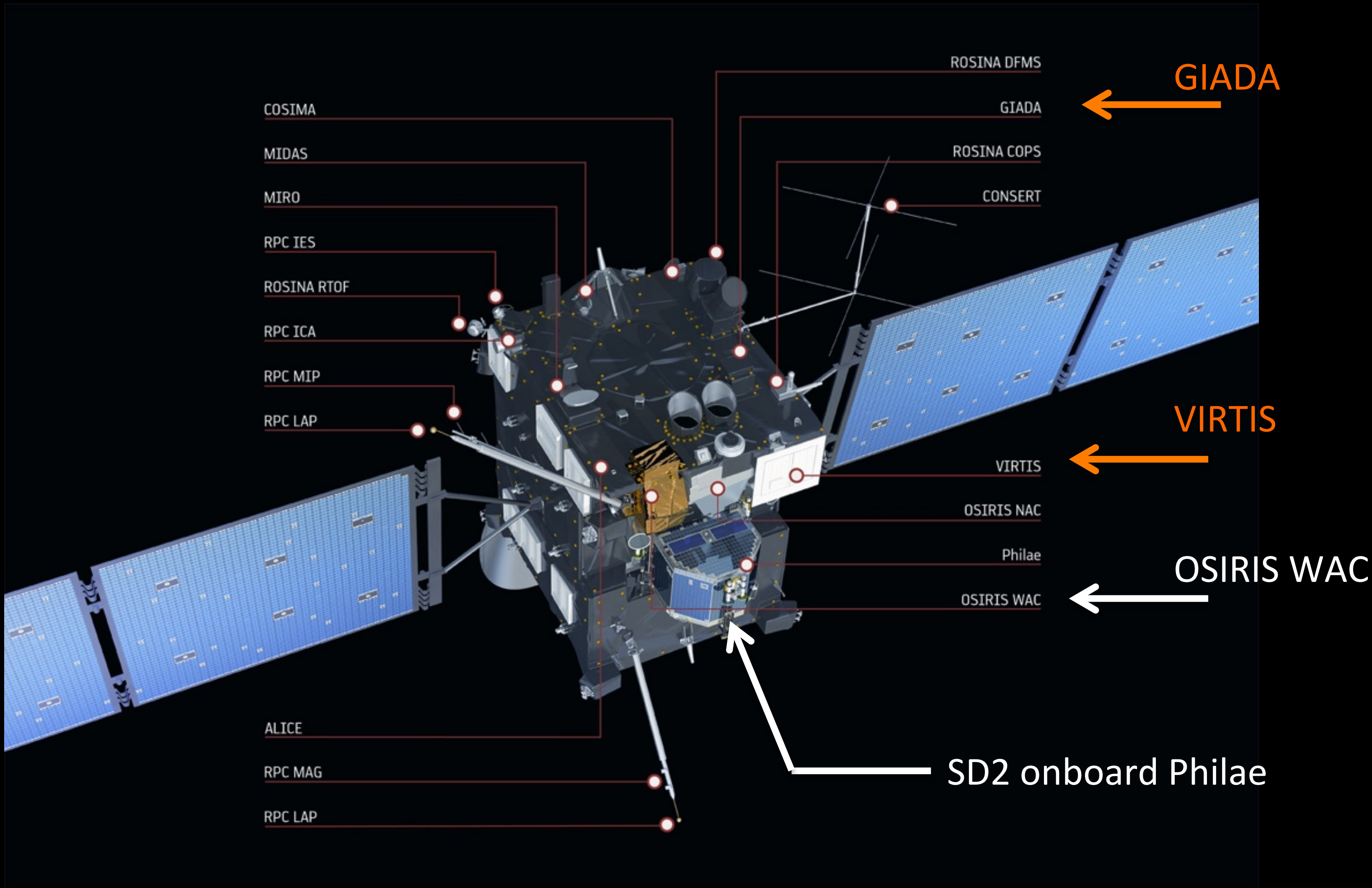
How do comets work?

- Basic idea: On approach to the sun, ice evaporates and carries dust with it. However:
  - ✓ Little amount of ice is found on surface
  - ✓ Activity limited to few areas
  - ✓ Localised outburst drive rejuvenation?

How do comets evolve?

- Comets show marked differences; what do we see is the result of evolution or of different formation conditions?

Full suite of in-situ and remote sensing instruments: **28 different experiments between Orbiter and Lander**

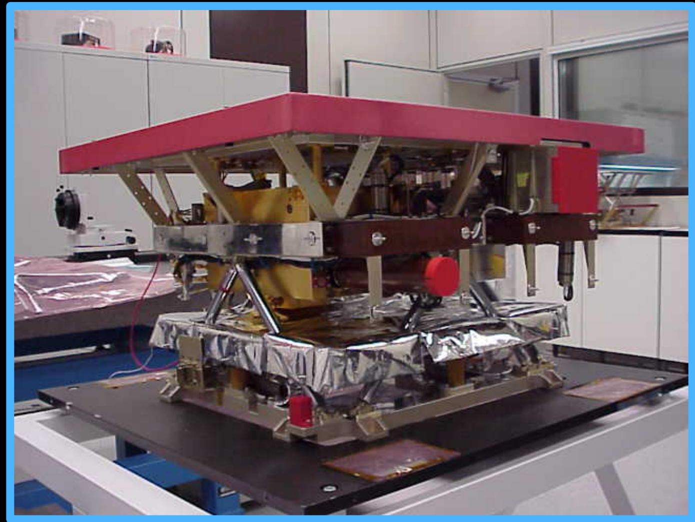


Variety of investigations key for the success of the mission

VIRTIS

Visible, InfraRed and Thermal Imaging Spectrometer

Principal Investigator: Angioletta Coradini IAPS- INAF from 2011 Fabrizio Capaccioni IAPS- INAF
Deputy PI: Gianrico Filacchione IAPS-INAF
National Team Leader: Stephane Erard LESIA-Observatoire de Paris
National Team Leader: Gabriele Arnold – Institut für Planetenforschung - DLR



VIRTIS combines an imaging spectrometer (VR-M) and a high resolution spectrometer (VR-H).

VIRTIS –M is a slit spectrometer; acquires hyperspectral images, using an internal scan mirror, with a max spatial resolution of 250µrad (2.5m@10km) in the spectral range 0.25-5 µm with CCD and MCT detectors.

VIRTIS –H is a high-resolution infrared spectrometer in the 2-5 µm range. It uses a prism and a grating to achieve a spectral resolution as high as 3000 on a MCT matrix detector identical to the VIRTIS-M IR FPA.

(Coradini et al, SSR 2007)

agenzia spaziale italiana
INAF
l'Observatoire de Paris LESIA
Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique
cnes De l'espace pour la Terre
DLR

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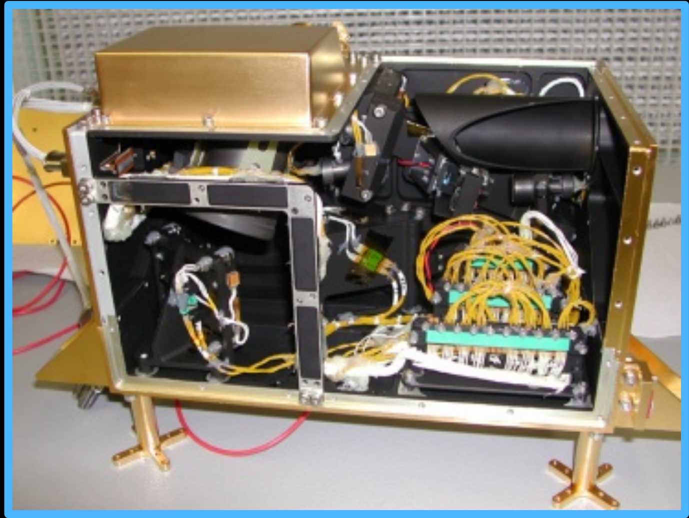

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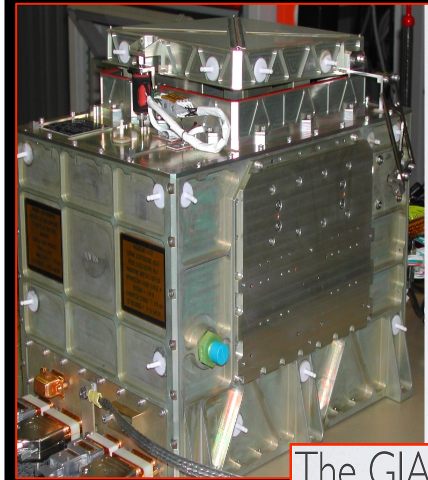
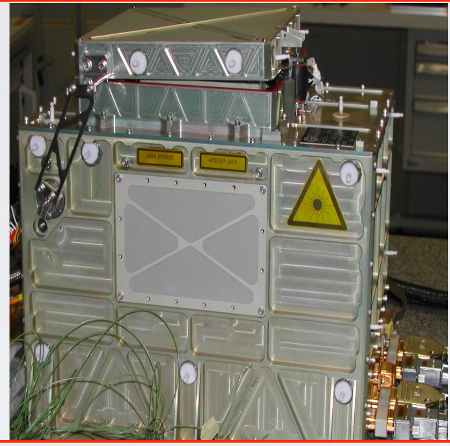
DLR

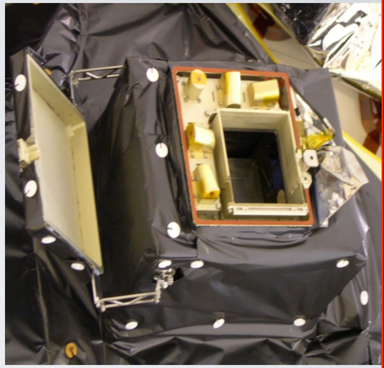
GIADA

Grain Impact And Dust Accumulator

PI: Alessandra Rotundi, Univ. Parthenope Napoli & INAF-IAPS
Deputy-PI: Vincenzo Della Corte, IAPS-INAF





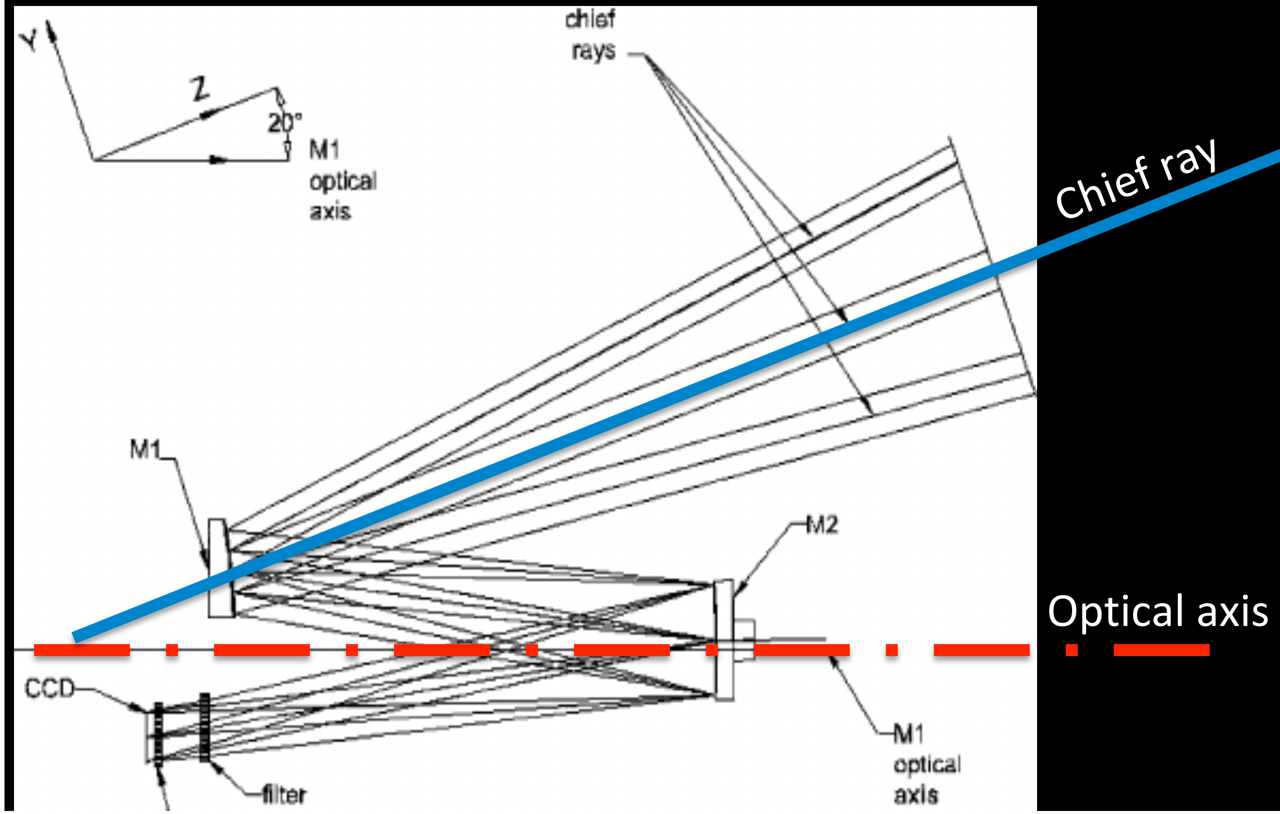


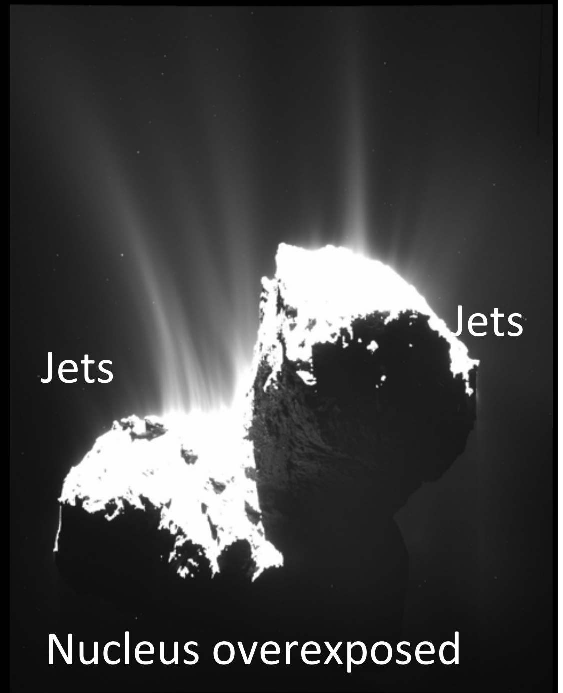
The GIADA instrument consists of three measurement subsystems:

- The GDS (Grain Detection System), an optical device measuring the optical cross-section for individual dust grains. It detects the transit of each single grain entering GIADA.
- The IS (Impact Sensor) an aluminum plate with connected 5 piezo-sensors measuring the momentum of impacting single dust grains
- The MBS (Micro Balance System) is constituted by 5 Quartz Micro Balances (QCM). The five QCMs point towards different space directions and measure the cumulative deposition in time of dust smaller than 10 μm.

The imaging system onboard Rosetta: OSIRIS - WAC

- The third italian instrument onboard Rosetta is the Wide Angle Camera (Led by C. Barbieri UniPd)
- Major INAF-OaPd contribution related to the optical design;
- The main target was to observe the dust and gas coma near the bright nucleus allowing a contrast 10^{-4}, it means:
  - Not obstructed (PSF without important “wings”)
  - No lenses (to avoid light diffusion in the glass)
  - Wide field (to monitor the jets)
- Competition with UK/F/D for the best design
- All-reflective solutions with chief ray off-axis





Team Organisation – Operative Phase

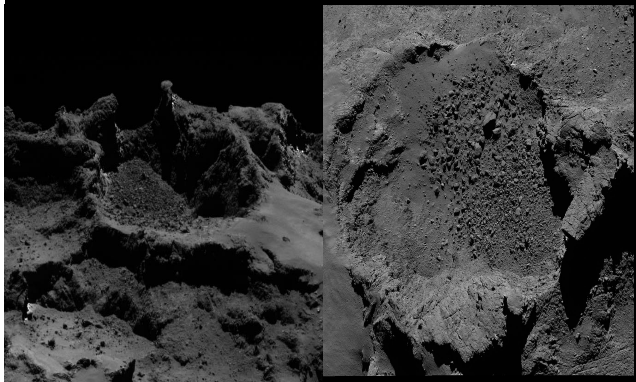
- VIRTIS International Team: 42 Co-Is, 25 Associated Scientists, 10 technical support.
- Collaborazioni: INAF-IAPS, INAF-OAC, INAF-OAAr, UniSalento, UniPerugia, LESIA Observatoire de Paris, IAPG-Grenoble, IAS-CNRS DLR-Berlin, Helmholtz-Zentrum Berlin, JPL, University of Michigan, LPL-University of Arizona, Bear Fight Institute, ESA, Polish Academy of Science, NCU Taiwan, Oxford University

- GIADA International Team: 32 Co-Is, 8 Associated Scientists.
- Collaborazioni: INAF-IAPS, INAF-OAC, INAF-OATS, Instituto de Astrofisica de Andalucia, Universidad de Granada , CNRS, Laboratoire d'Astronomie Spatiale, Observatoire de Haute Provence, University of Kent, Open University, MPI, JPL, University of New Mexico, University of Florida, ESTEC/SRE-SM

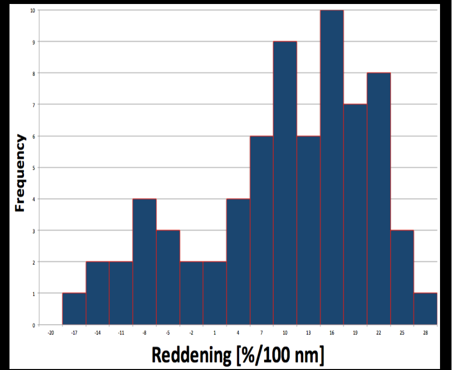
- The OSIRIS cameras were provided by a consortium of 9 institutes from 5 European countries and ESA under the leadership of the the Max-Planck-Institute for Solar System Research (MPS) Göttingen: LAM, Upd, IAA, University of Uppsala, ESTEC, UPM, INTA, IDA.
- OSIRIS Italian Team: 10 CoIs, 8 Associate Scientists, 10 Assistants, 2 Collaborators. About 1/3 INAF or Associates

- Interdisciplinary Scientists: Marco Fulle (INAF-OaTs)

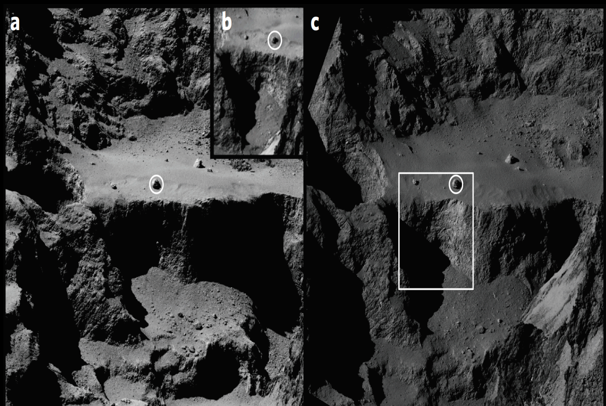
The imaging system onboard Rosetta: OSIRIS - WAC



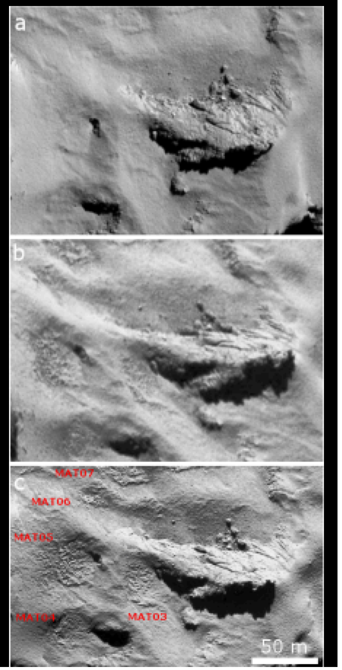
67P LANDSLIDES (Lucchetti et al., 2019)
Landslides on 67P reveal a clear rocky-type behaviour for cometary material that once collapsed assumes a rock avalanche mobilization associated to relatively high friction coefficients.



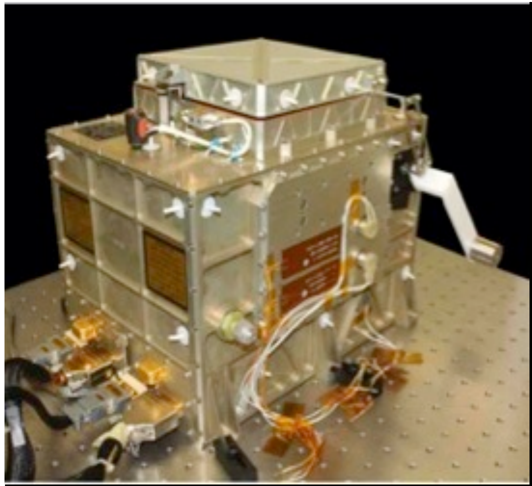
Monitoring of Single grains (Cremonese et al. 2015)
Observation of dust grains in the inner coma of 67P. Most of the grains have a color very similar to the nucleus, i.e. they have been released directly from the surface or sub-surface



Cliff Collapses (Pajola et al., 2017) → Outburst associated to a newly occurred cliff collapse on 67P, caused by extreme thermal gradients. The collapse revealed the cometary pristine water ice rich interior (6 times brighter than the overall surface).



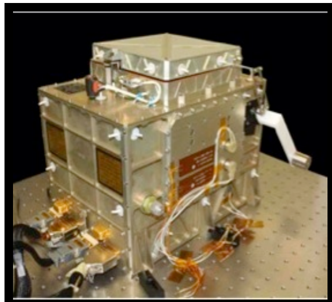
Surface Dust erosion & deposition (Cambianica et al. 2021)
Observations confirm the link between the erosion of the Southern hemisphere and the fallout in the northern regions.



GIADA

Main Scientific Objectives reached

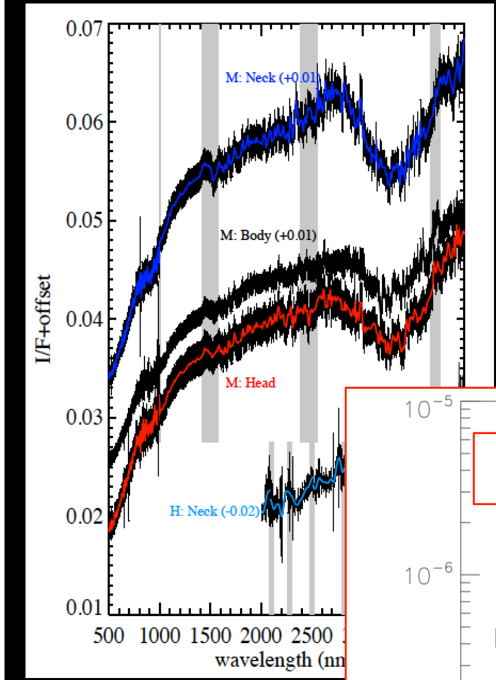
- Characterized the dust particles:
  - Physical properties: Number, Mass, Momentum, Morphology & Density;
  - Optical Properties;
  - Size & Velocity Distribution;
- Reconstructed the 3D+t dust environment of 67P;
- Studied the dust/gas coupling in the acceleration region.



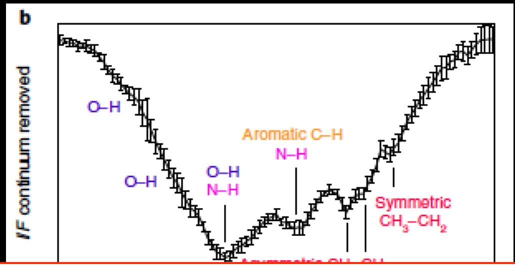
GIADA
Additional Scientific Results

- 67P Refractory to ice ratio (Rotundi et al Science, 2015; Fulle et al., MNRAS 2016 ; 2019);
- 67P Dust classification (a reference for Comet Interceptor dust Instrument calibration); (Guettler, Mannel, Rotundi et al. A&A; Della Corte et al., A&A 2015; MNRAS 2016)
- Cometary Activity Model consistent with Rosetta payload data (Fulle et al.A&A 2020; MNRAS 2021)
- Dust-gas coma model (Zakharov et al., Icarus 2018;2021a; 2021b)
- Contribution of the electrostatic effect on GIADA dust measurement (Della Corte et al. A&A 2019);
- 67P active areas identification by GIADA and VIRTIS data fusion (Longobardo et al. MNRAS 2019; 2020);
- Characterization of submicron to micron particles dust flux (Della Corte et al. A&A 2019);
- Non spherical dust dynamics (Ivanosky et al. MNRAS 2017; Icarus 2017; A&A 2015)
- 67P dust spatial distribution (Della Corte et al., MRAS 2016)

67P Nucleus Composition



Capacconi etal, Science



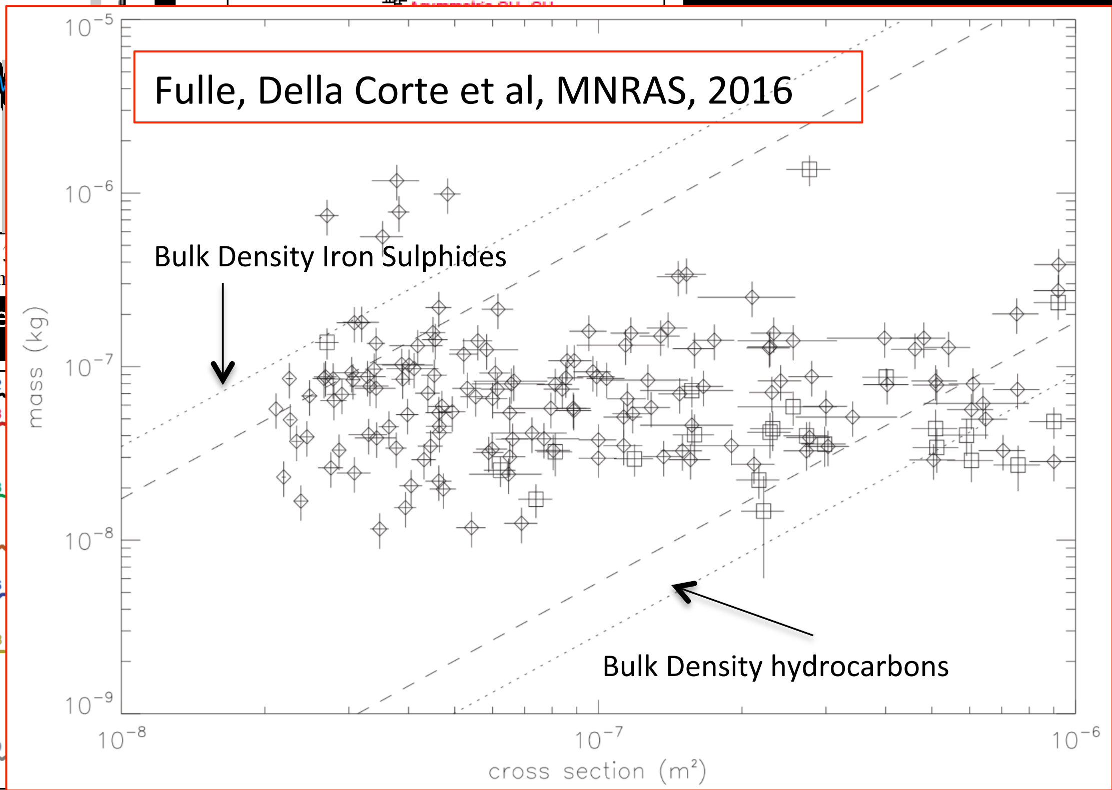
- CH_2/CH_3 features in 67P spectrum comparable to ISM features; evolutionary link between hydrocarbons in the diffuse ISM and comets.
- Continuum between comets and asteroids.

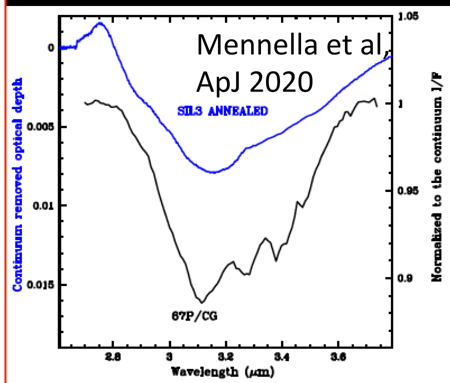
lanets with organic

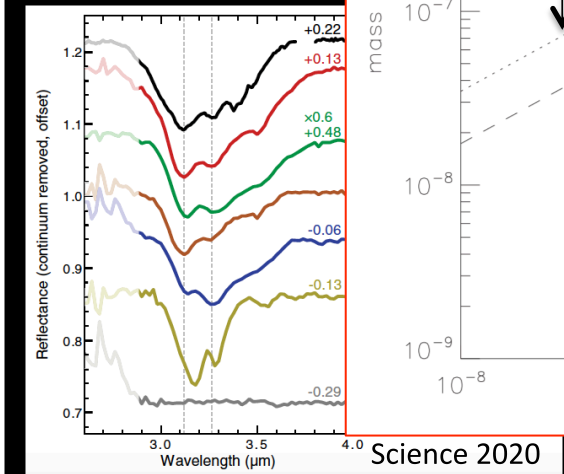
from the ISM

ailability of building

le the Solar System







Science 2020

ydrogen atoms with Mg-

silicates determines the

ation of hydroxyl groups.

Reinforcing the compositional link between asteroids, comets, and the parent interstellar cloud.

The resulting IR spectrum exhibits a broad feature around 3.2 μ m similar to that of comet 67P/ CG

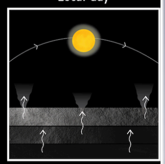
Comets: the most active bodies of the Solar System

Exposed water ice on the nucleus

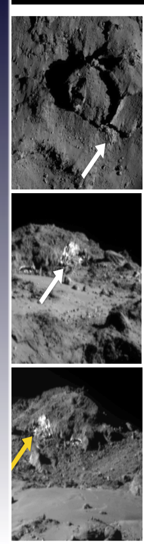
7P/CG

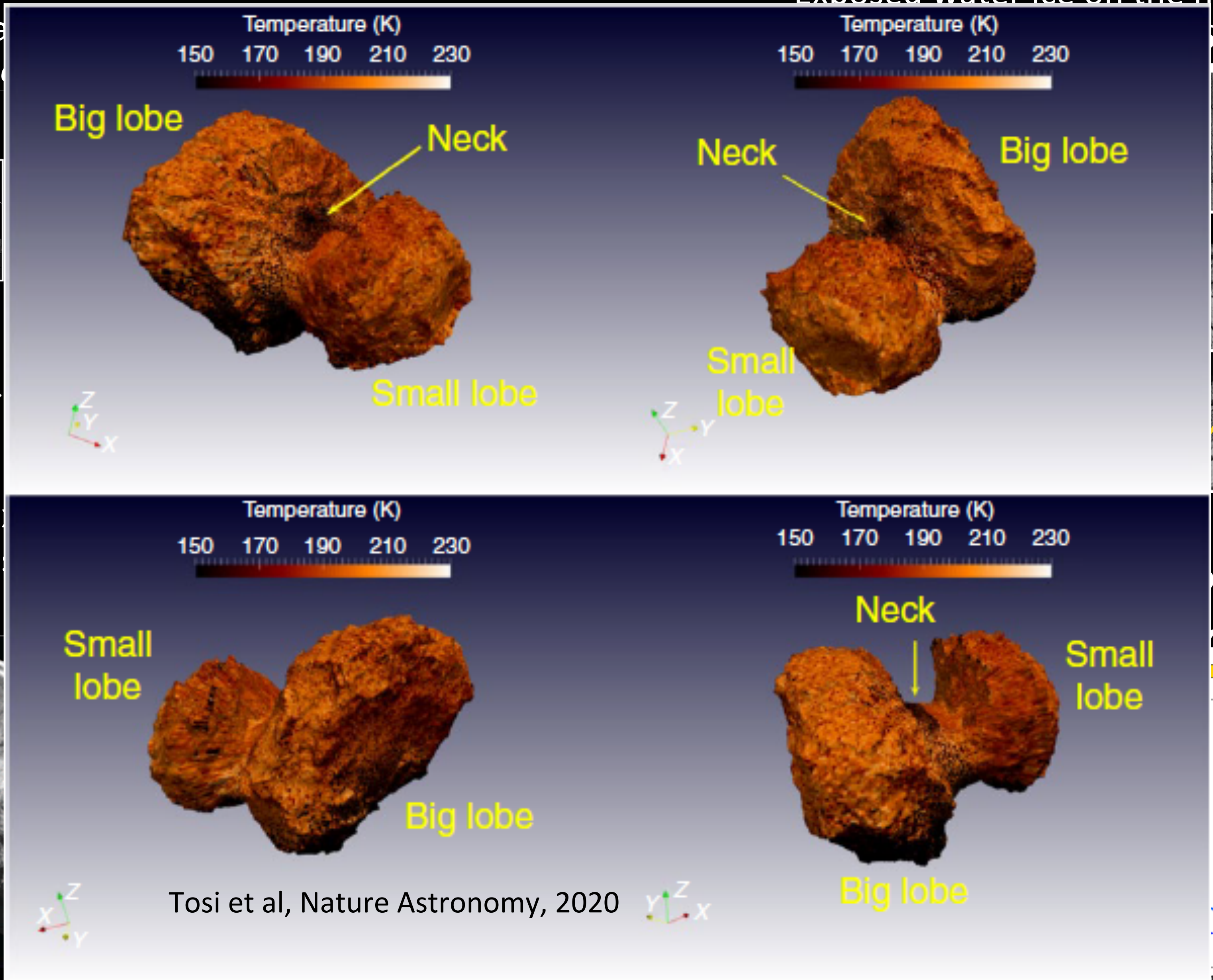
The diurna

De Sanctis



Heated by sunlight, water ice on and a few cm below the surface sublimates, turning into gas and escaping.





Tosi et al, Nature Astronomy, 2020

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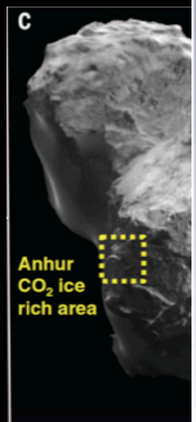
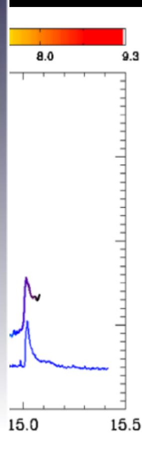
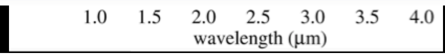
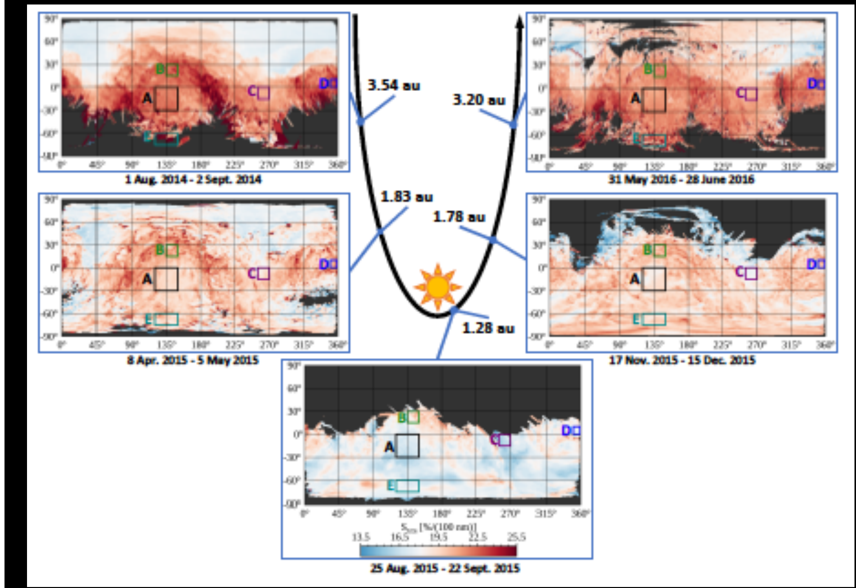


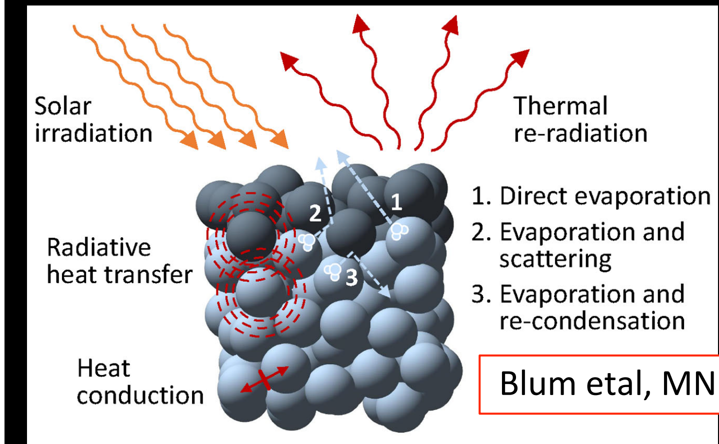


Filacchione et al, Science 2016

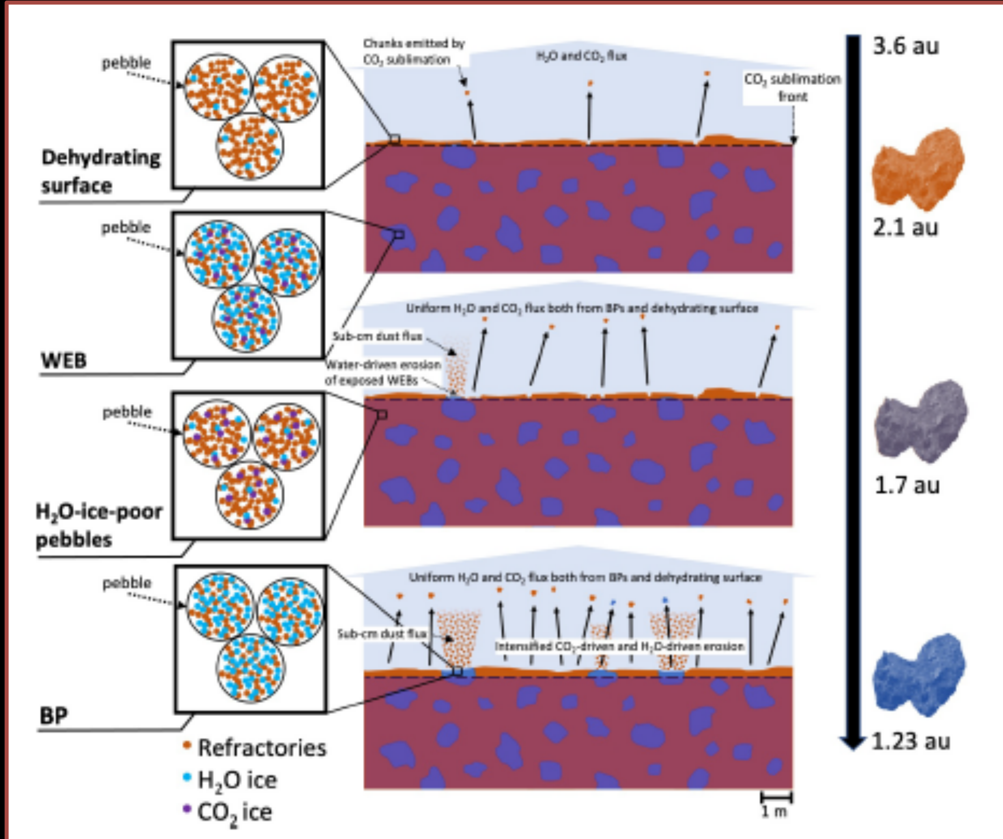


A New Nucleus Model





Blum etal, MNRAS 2016



Seasons of comets reconcile the macro and micro structures of nuclei

Mauro Ciarniello[1,*], Marco Fulle[2], Andrea Raponi[1], Gianrico Filacchione[1], Fabrizio Capaccioni[1], Alessandra Rotundi[3,1], Giovanna Rinaldi[1], Michelangelo Formisano[1], Gianfranco Magni[1], Federico Tosi[1], Maria Cristina De Sanctis[1], Maria Teresa Capria[1], Andrea Longobardo[1], Pierre Beck[4,5], Sonia Fornasier[5,6], David Kappel[7,8], Vito Mennella[9], Stefano Mottola[7], Batiste Rousseau[1], and Gabriele Arnold[7]

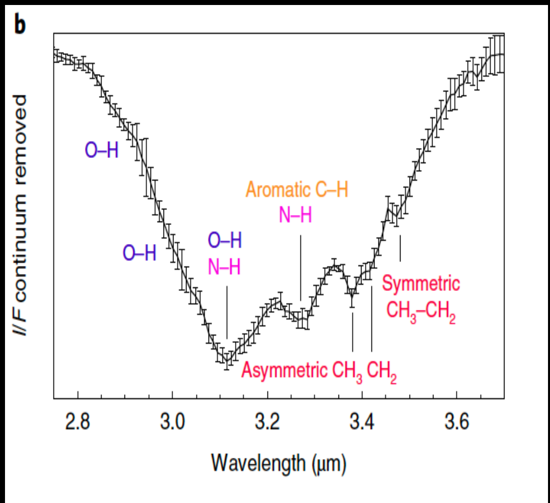
Submitted to Nature Astronomy

Scientific Production

- INAF + Associates took part in more than 220 refereed papers related to Rosetta (about 30% of the total)
- More than 100 led by INAF + Associates.
- 20 published in Science, Nature, Nature Astronomy.
- H-number = 47

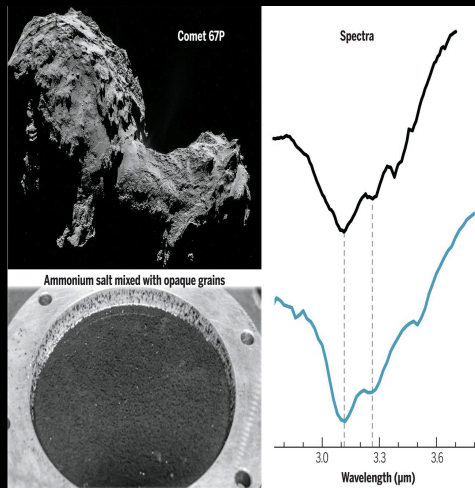
ISSI international team: "Comet 67P/CG surface composition as a playground for radiative transfer modeling and laboratory measurements (PI: M. Ciarniello - IAPS)"

- 67P/CG surface composition from laboratory measurements and radiative transfer models applied to VIRTIS-Rosetta spectrophotometric observations of the nucleus
- Test and improvement of radiative transfer model applied to atmosphereless bodies

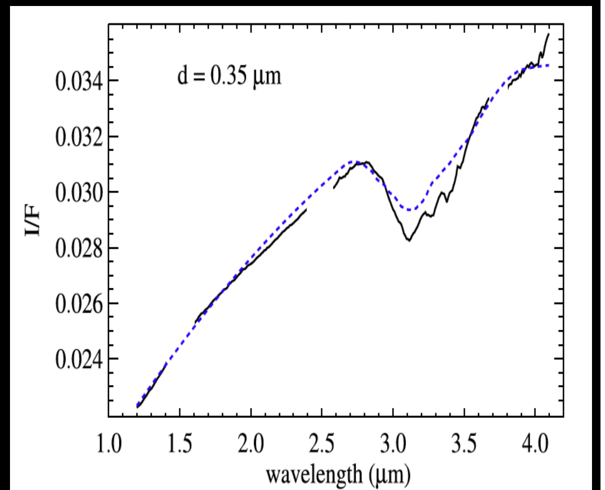


Aliphatic organics on 67P
(Raponi+,2020, Nature Astronomy)

Ammonium salts on 67P
(Poch+,2020, Science)



Hydroxylated Mg-rich Amorphous Silicates on 67P (Mennella+,2020, ApJ Letters)



<u>ISSI International Team</u>: Characterization of 67P/CG cometary activity (PI A. Longobardo - IAPS)

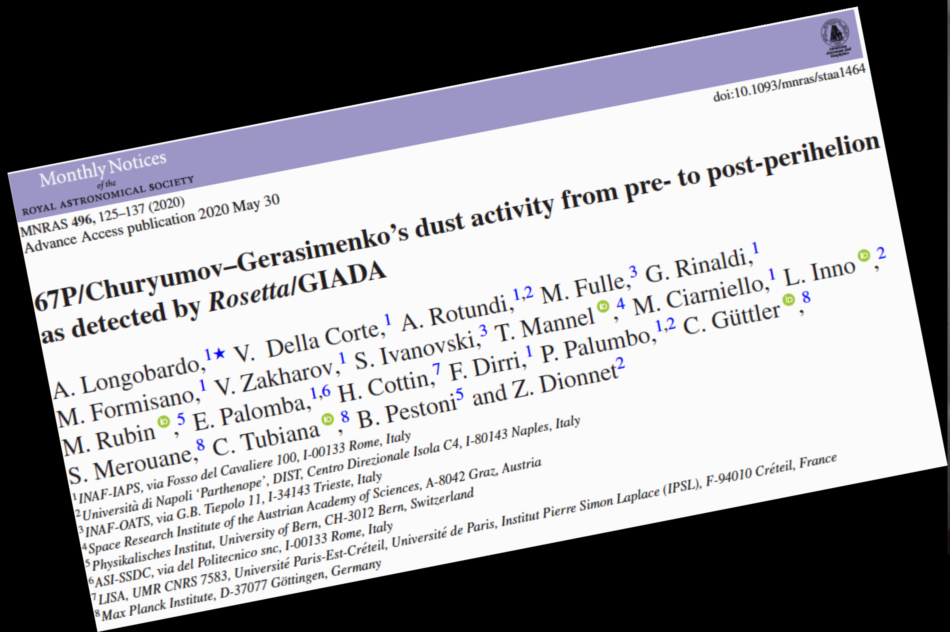
Goals:

- Retrieve the activity degree of 67P regions through dust motion
- Cometary activity Vs geometry/Dust properties/Nucleus Morphology and composition

Method: data fusion of six Rosetta instruments

Main results obtained so far:

- Traceback of the dust particles detected by GIADA (Longobardo et al., 2020)
- Fluffy particles more abundant in rough terrains, in line with their embedding within cm-sized pebbles (Longobardo et al., 2020)
- Ejection of mm-sized dust, even during the 106 outburst (Longobardo et al., 2021)


Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS 496, 125–137 (2020)
Advance Access publication 2020 May 30
doi:10.1093/mnras/staa1464

67P/Churyumov–Gerasimenko's dust activity from pre- to post-perihelion as detected by *Rosetta*/GIADA

A. Longobardo,[1★] V. Della Corte,[1] A. Rotundi,[1,2] M. Fulle,[3] G. Rinaldi,[1] M. Formisano,[1] V. Zakharov,[1] S. Ivanovski,[3] T. Mannel,[4] M. Ciarniello,[1] L. Inno,[2] M. Rubin,[5] E. Palomba,[1,6] H. Cottin,[7] F. Dirri,[1] P. Palumbo,[1,2] C. Güttler,[8] S. Merouane,[8] C. Tubiana,[8] B. Pestoni[5] and Z. Dionnet[2]

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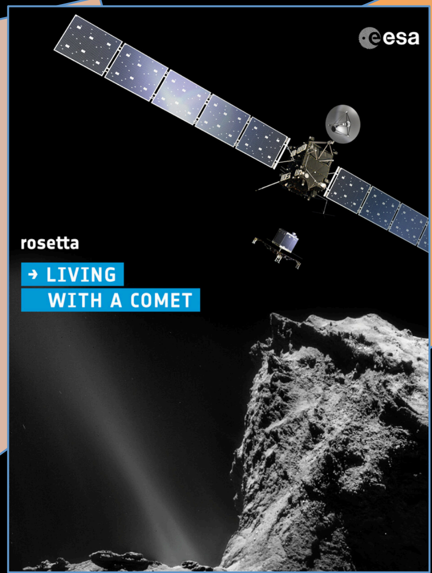
[3] INAF-OATS, via G.B. Tiepolo 11, I-34143 Trieste, Italy
[4] Space Research Institute of the Austrian Academy of Sciences, A-8042 Graz, Austria
[5] Physikalisches Institut, University of Bern, CH-3012 Bern, Switzerland
[6] ASI-SSDC, via del Politecnico snc, I-00133 Rome, Italy
[7] LISA, UMR CNRS 7583, Université Paris-Est-Créteil, Université de Paris, Institut Pierre Simon Laplace (IPSL), F-94010 Créteil, France
[8] Max Planck Institute, D-37077 Göttingen, Germany

Prospettive: The Rosetta Heritage

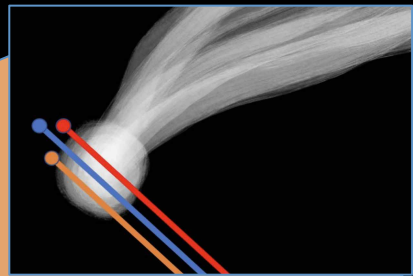
- New Missions

Europe Leadership in Cometary Exploration

Giotto 1986



Rosetta 2016



Comet Interceptor
F-Class 2028

INAF
Vincenzo della Corte
DISC PI

AMBITION
Comet Sample Return
Voyage 2050

INAF
G. Filacchione
Mission Deputy PI

Prospettive: The Rosetta Heritage

- New Missions

- New Science

Water Vapour Loss Rate

Fulle's model of erosion and dehydration coupled to the Ciarniello's New Nucleus Model can explain several cometary processes among which the seasonal evolution of the Water Vapour Loss Rate

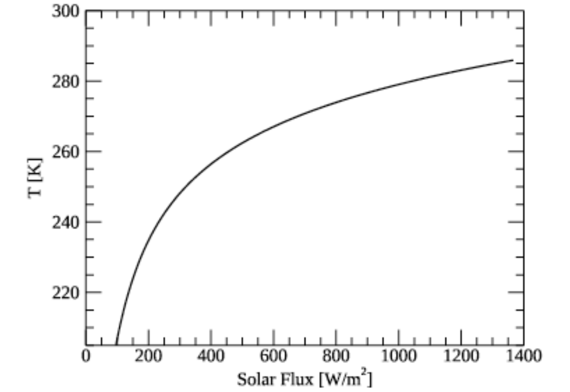


Figure 1. Average temperature of the sunlit pebbles as a function of the incident Solar flux at the nucleus surface as provided by [7]. Temperatures lower than 205 K make a comet water-inactive, so they are not shown here.

Ciarniello etal, 2021 in preparation

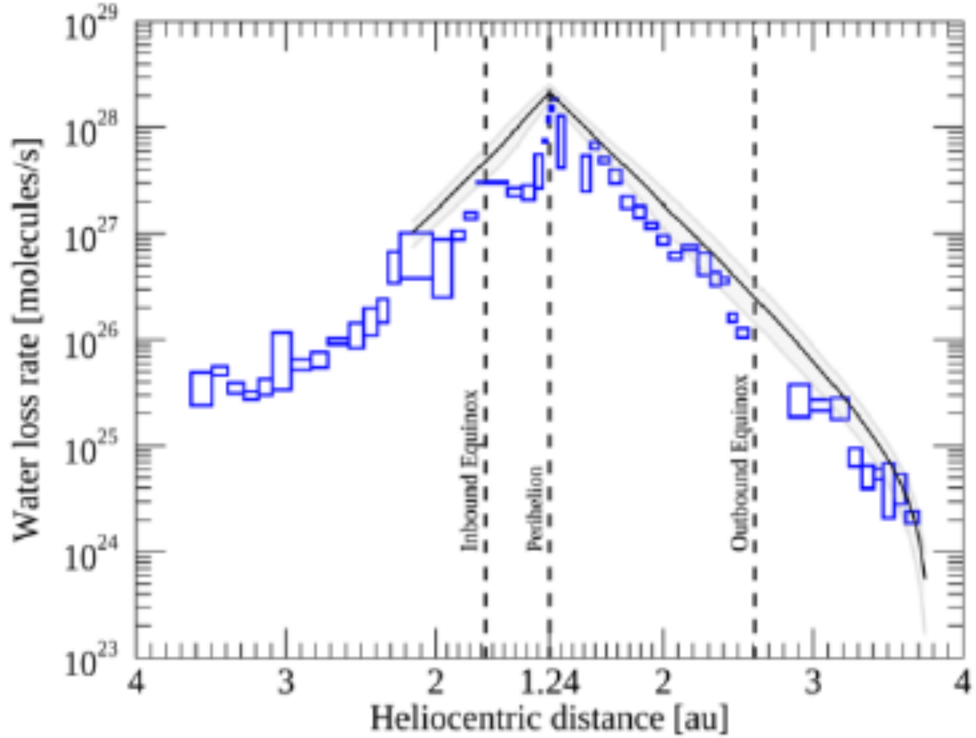


Figure 3. Computed water vapor loss rate (solid line) compared with the estimates by the DFMS/COPS observations (blue boxes). All the nucleus surface at T>205K is assumed to eject water. The gray band encompasses the maximum and minimum simulated water loss rate over one comet rotation, while the average value is represented by the black line. The blue boxes account for the uncertainties of the observed loss rate.

Protoplanetary disks and stars interaction in young Open Clusters

The early dynamical evolution of our protoplanetary disk likely occurred in an non isolated context (Pinto et al, 2019)

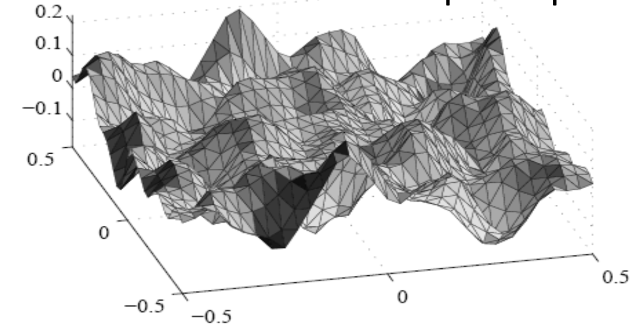
- By means of a 3D Lagrangian Smoothed Particles Hydrodynamics (SPH) scheme, we calculate the evolution of the gas by including also the thermal effects induced by both the propagation of the radiation through the optically thick disk and the effects of the radiation coming from the stars.
- The temperature profile of a disk, which is substantially dependent on the thermal scheme assumed, may determine the turbulent viscous evolution of the disk itself and its susceptibility to the strong macroscopical perturbations induced by fly-by events.

Modeling non-resolved rough planetary surfaces by means of a statistical multi-facets approach (A. Raponi)

Consistently with Hapke theory (Hapke, 2012) we model the surface with a distribution of non-spatially resolved facets, being the distribution of their slopes completely described by the roughness parameter $\overline{\theta}$ (mean slope).

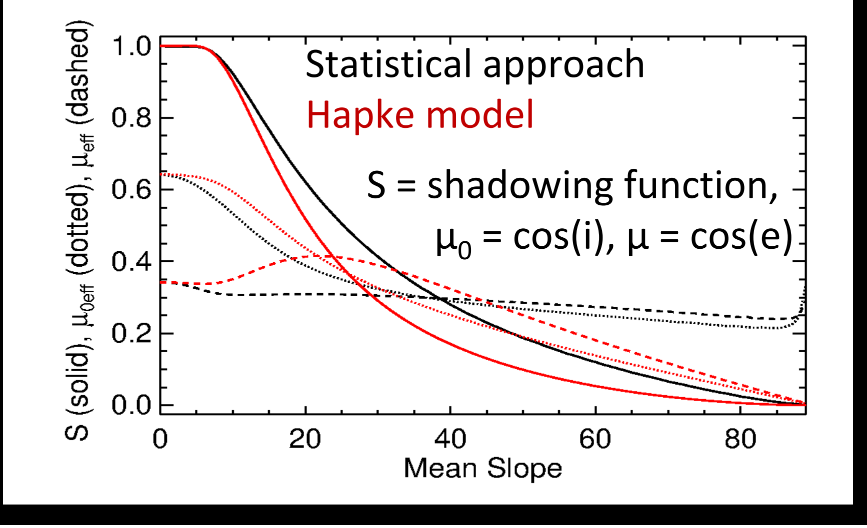
The parameters in input are the average incidence <*i*>, emission <*e*>, and phase <*g*> angles as inferred from shape model, illumination direction and spacecraft attitude,
e.g., i = 70°, e = 50°, g = 120° (plots below)

Simulated terrain in one spatial pixel

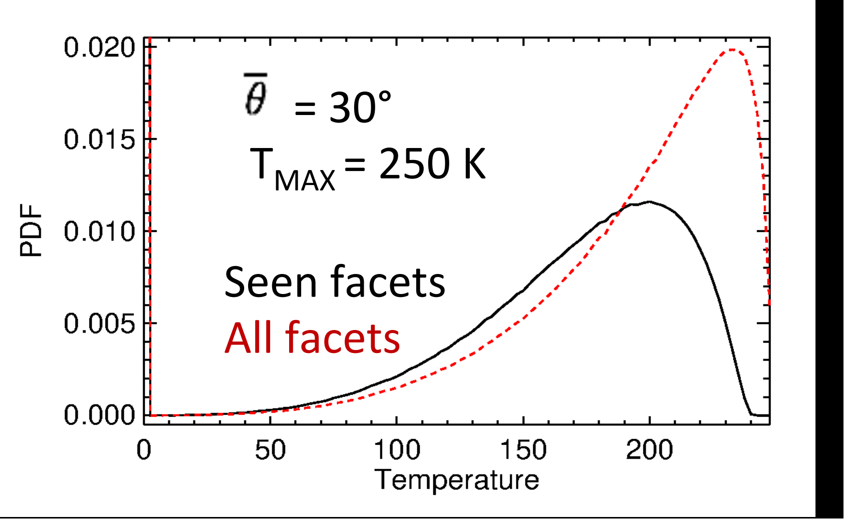


THE APPROACH CAN BE USED TO RETRIEVE:

PHOTOMETRIC QUANTITIES



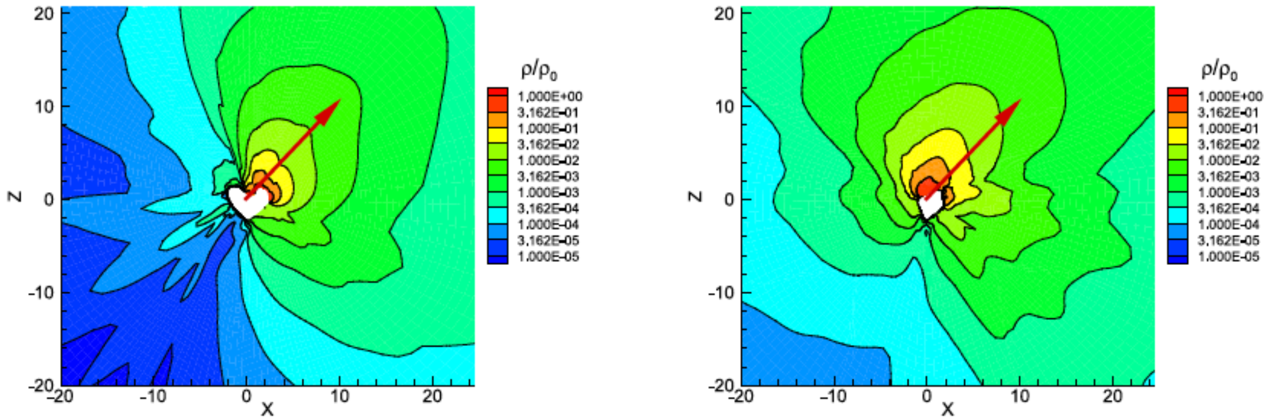
THERMOPHYSICAL PARAMETERS



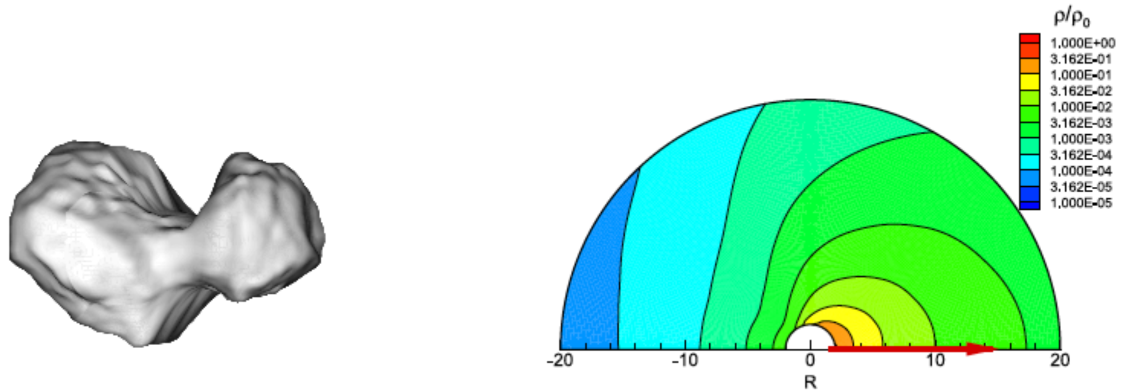
Development of a realistic, but simple & scalable dust-gas coma model

To ensure the safety of a spacecraft and efficiency of the instrument operations it is indispensable to have simple models for the assessments of the dynamics of a dusty-gas coma.

The main goal of the work is to develop a simplified model of gas environment which allows to estimate spatial distribution of gas parameters in the coma in the range of nucleus-centric distances from ten to thousand radius of the nucleus.



Zakharov et al, Icarus, 2021



This model has been selected as the reference model for the Comet Interceptor Mission.

Prospettive: The Rosetta Heritage

- New Missions
- New Science
- New Collaborations

Protoplanetary disks - Solar System

- **Outer Solar System Objects (OSSOs)** are believed to host th... ost pristine material in the Solar System**

JUICE
Moons and Jupiter Imaging Spectrometer

- Recently concluded (**Roset**... ...he **Saturn system**, and **Da**... ...still active missions (**New Horizon** at the ...nd **Kuiper Belt**) and **Juno (Jupiter and its moons)** ...**unprecedented opportunity to extensively observe** representative members of the **different classes of OSSOs**

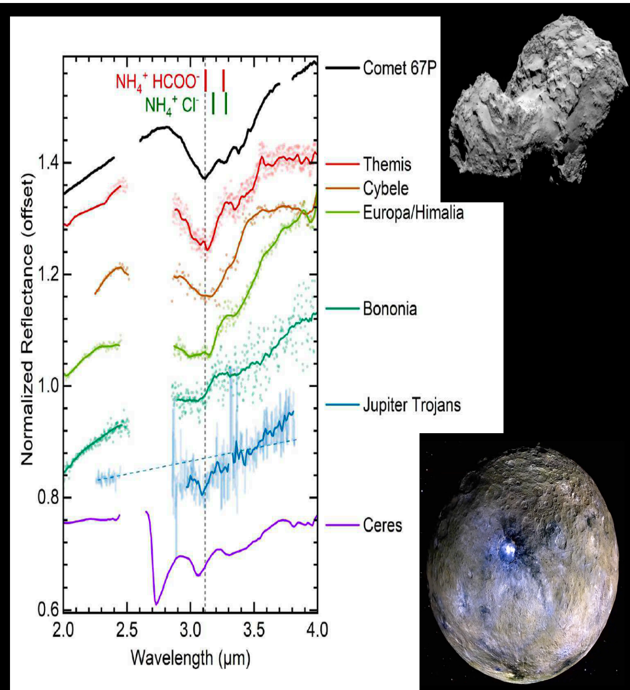
ASTROLAB
Cosmic Analogs and Extraterrestrial Materials

- The ... ...AF-IAPS in particular, provided a **leadi**... ...**xperiments onboard spacecrafts** (... ...ccioni), VIR-Dawn (PI: M.C. De Sanctis), JIRAM-Ju...

- Space- and ground-based reflectance spectroscopy investi... provides now a **statistically significant sampling of** ... **spectrophotometric properties of OSSOs** ... ...**ation of OSSOs compositional and phys**... ...**ective framework**.

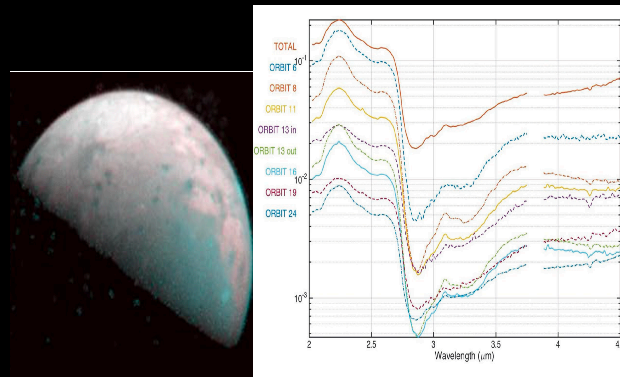
ASTROCHEMISTRY@INAF:
from protoplanetary disks to primitive planetary system bodies

- This all... ...he **compositional gradients in the outer So**... ...ly **compared with** the ones obtained in ana... ...e **protosolar nebula by** exploiting the unique database of **Al**...**A data probing the disk chemical composition** from the protostellar (10^4 yrs) to the protoplanetary (10^6 yrs) stages



67P and Ceres spectra compared to main belt asteroids and Jupiter trojans ...och+2020, Raponi+2020, De ...nctis+2015)

Ganimede as observed by Juno-Jiram (Mura et al., 2020)



Team Organisation

Stima dell'inviluppo complessivo di FTE INAF dall'inizio a fine attività	250.0
Stima delle FTE INAF a Tempo Indeterminato dall'inizio a fine attività	150.0
Stima dell'inviluppo complessivo di FTE (includendo tutti i partners dall'inizio a fine attività)	410.0

15. Team Summary

15. Personale INAF coinvolto

Numero di partecipanti INAF al progetto: 19

Struttura	Nfte	N0	TI 21	TI 22	TI 23	TD 21	TD 22	TD 23	Nex	Extra
IAPS ROMA	10	7	0.90	0.80	0.75	1.80	1.80	2.00	2	0.35
O.A. CAPODIMONTE	1	0	0.10	0.10	0.10	0	0	0	0	0.00
O.A. TRIESTE	1	0	0.10	0.10	0.10	0	0	0	0	0.00
Totali	12	7	**1.10**	**1.00**	**0.95**	**1.80**	**1.80**	**2.00**	2	**0.35**

16. Personale Associato INAF coinvolto

Numero di partecipanti Associati INAF: 3

#	Struttura	TI 2021	TI 2022	TI 2023	TD 2021	TD 2022	TD 2023	Extra
1	Universita di Napoli "Parthenope"	0.10	0.10	0.10	0.40	0.40	0.40	0.00
	Totali	**0.10**	**0.10**	**0.10**	**0.40**	**0.40**	**0.40**	**0.00**

Budget

Sorgente finanziamenti: ASI.

Dal 2012 al 2022 un inviluppo di circa 3.9Meuro

Questo budget includeva anche l'attività scientifica e di laboratorio della trivella SD2 a bordo del lander Philae; attività terminata essenzialmente con la fine della missione.

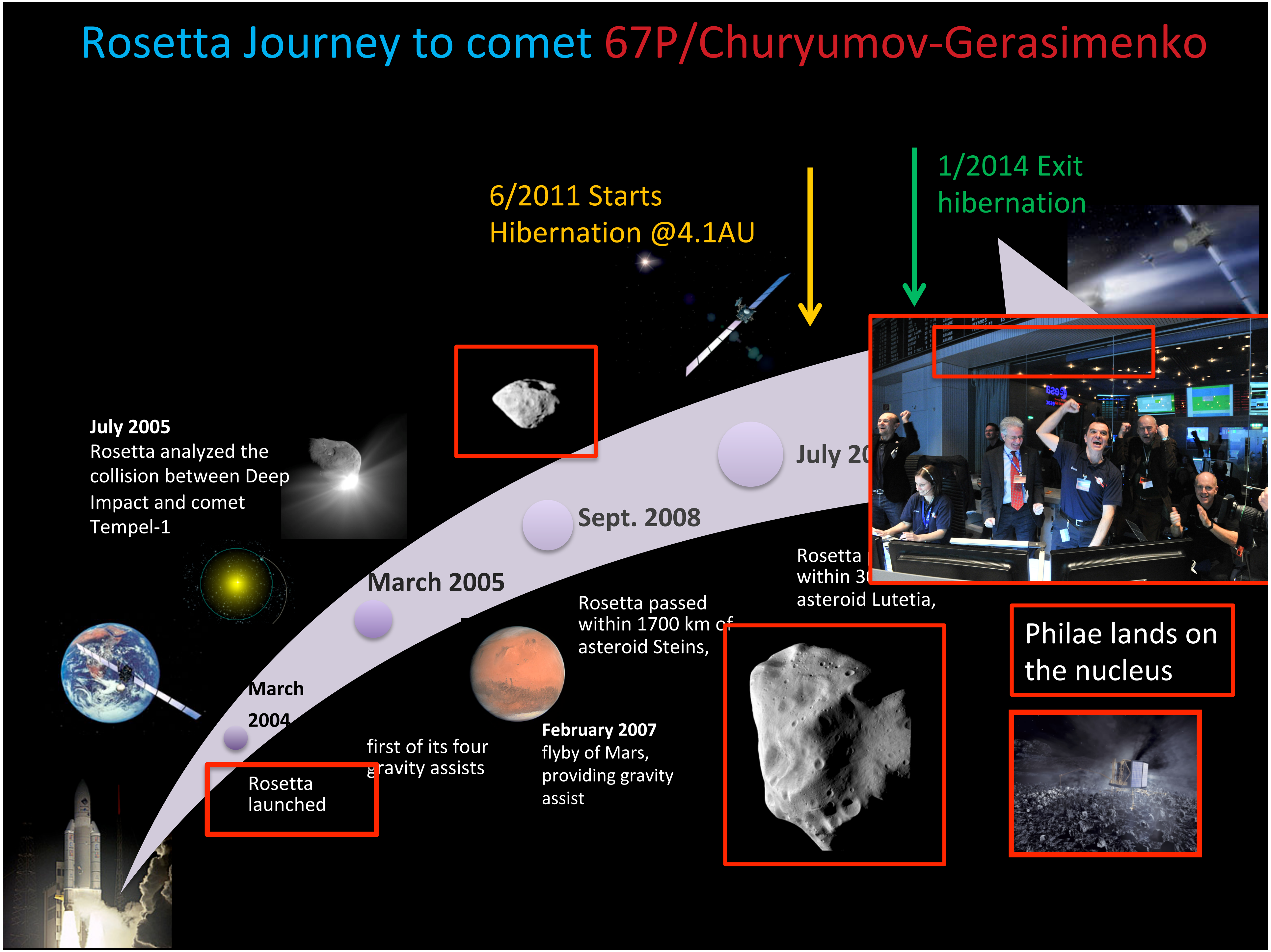
Inviluppo complessivo INAF fino a fine attività 1.465 Meuro

#	Provenienza	Certi 2021 (k€)	Certi 22 (k€)	Certi 23 (k€)	Presun. 2021 (k€)	Presun. 22 (k€)	Presun. 23 (k€)	Totale Certi (k€)	Totale Presunti (k€)
1	ASI	75	80	0	0	0	0	155	0

Criticità

- 2AdR+1 Borsa di Studio (INAF) + 1 TDA (UniParthenope)
- La terza, ed ultima, estensione dell'Accordo ASI-INAF che ha finanziato le attività della comunità scientifica legate a Rosetta terminerà il 31 Dicembre 2022 (estensione in corso di approvazione).
- Deve essere compito dell'INAF pianificare in maniera opportuna il finanziamento alla ricerca per mettere a disposizione della comunità forme certe e diversificate di supporto:
  - Mainstream
  - PRIN
  - Ricerca di Base (>> attraverso CSN?)
- Ulteriores soluzione è un approccio simile al Data Analysis Program della NASA che veda uno sforzo comune di ASI ed INAF.

BACK-UP



Rosetta Journey to comet 67P/Churyumov-Gerasimenko
6/2011 Starts Hibernation @4.1AU
1/2014 Exit hibernation
July 2005
Rosetta analyzed the collision between Deep Impact and comet Tempel-1
March 2005
Sept. 2008
July 20
March 2004
Rosetta launched
first of its four gravity assists
Rosetta passed within 1700 km of asteroid Steins,
February 2007
flyby of Mars, providing gravity assist
Rosetta
within 3
asteroid Lutetia,
Philae lands on the nucleus