Rosetta at Comet 67P/Churyumov-Gerasimenko: Get Ready for the Ride

NASA SBAG Report

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Jet Propulsion Laboratory
California Institute of Technology

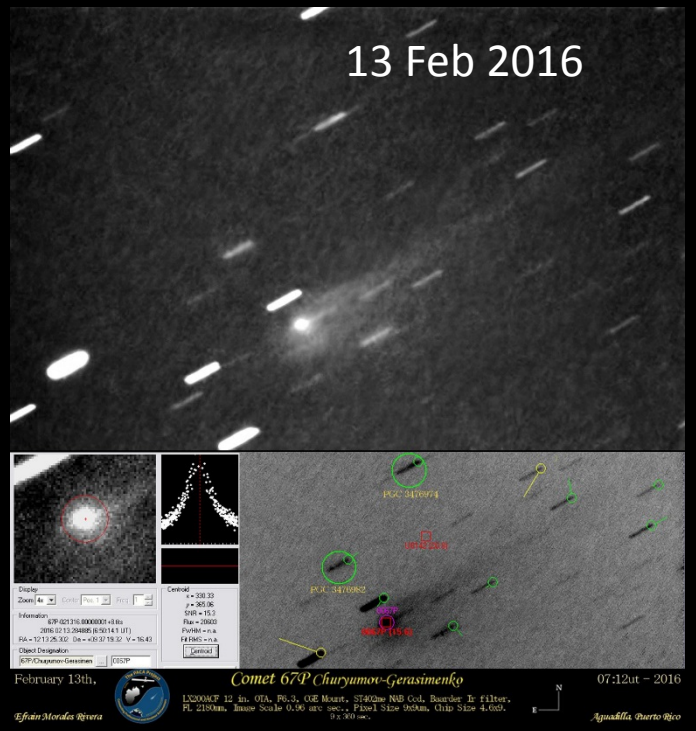
June 28, 2016

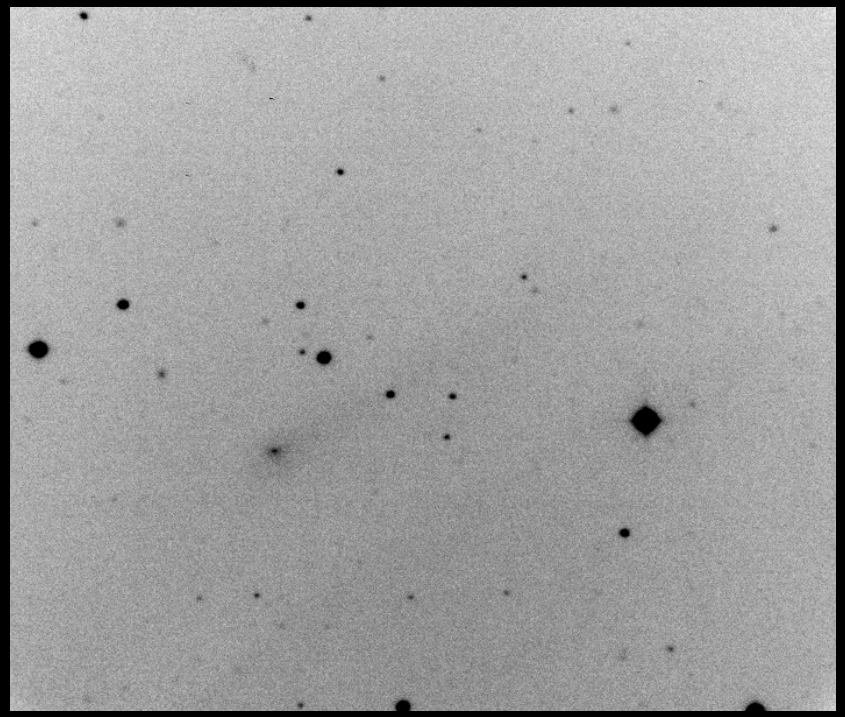
Rosetta is an ESA mission with contributions from its member states and NASA. Rosetta's Philae lander is provided by a consortium led by DLR, MPS, CNES and ASI.

The US Contribution to Rosetta

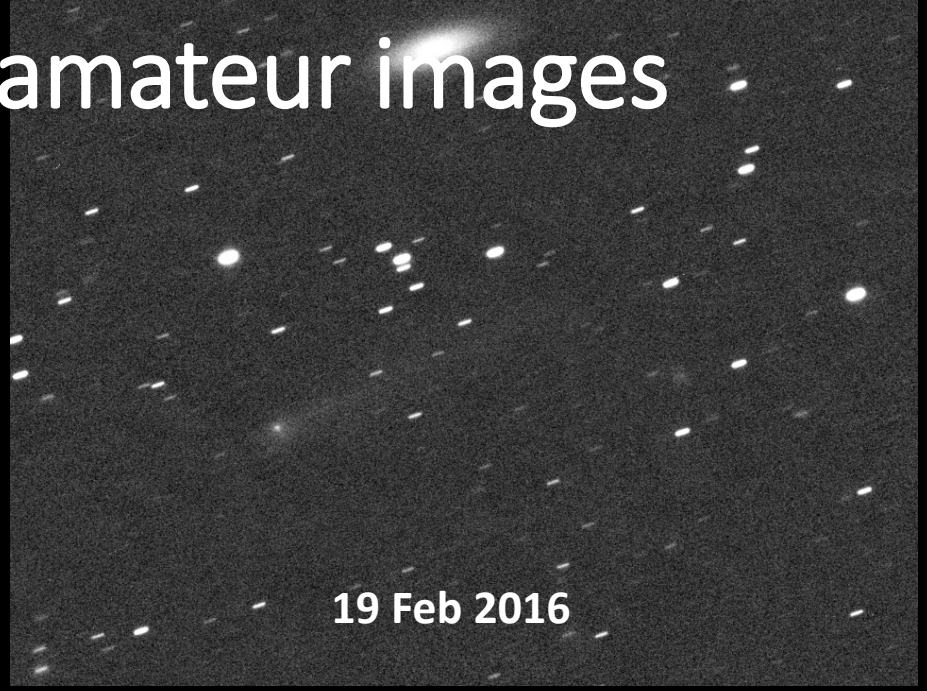
1. 3 ½ instruments
2. 3 PI's, PS, DPS, IDS
3. 46 Co-I's and researchers
4. DSN 70 m and 34 m support
5. ASPEN scheduling software for science observations
6. SPICE support
7. Comet modeling
8. Shadow navigation for flight dynamics verification
9. Outreach and media products
10. Leadership for ESA's Amateur Ground Observing Campaign

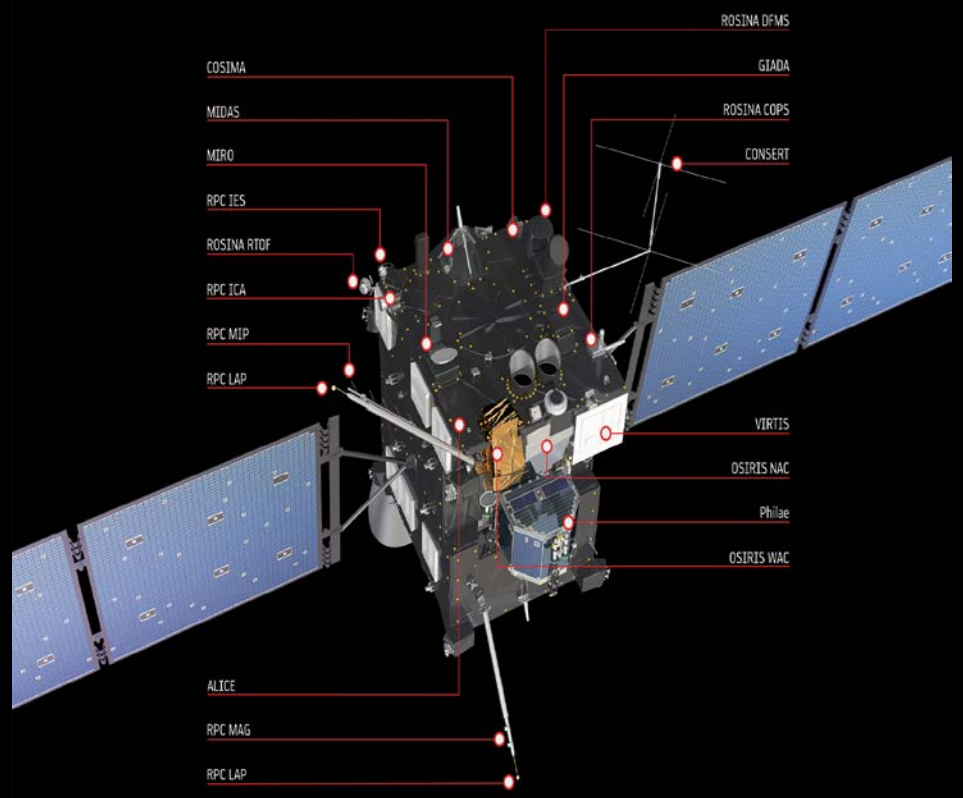
Pre-and post- 19 Feb 2016 outburst amateur images mages of 67P



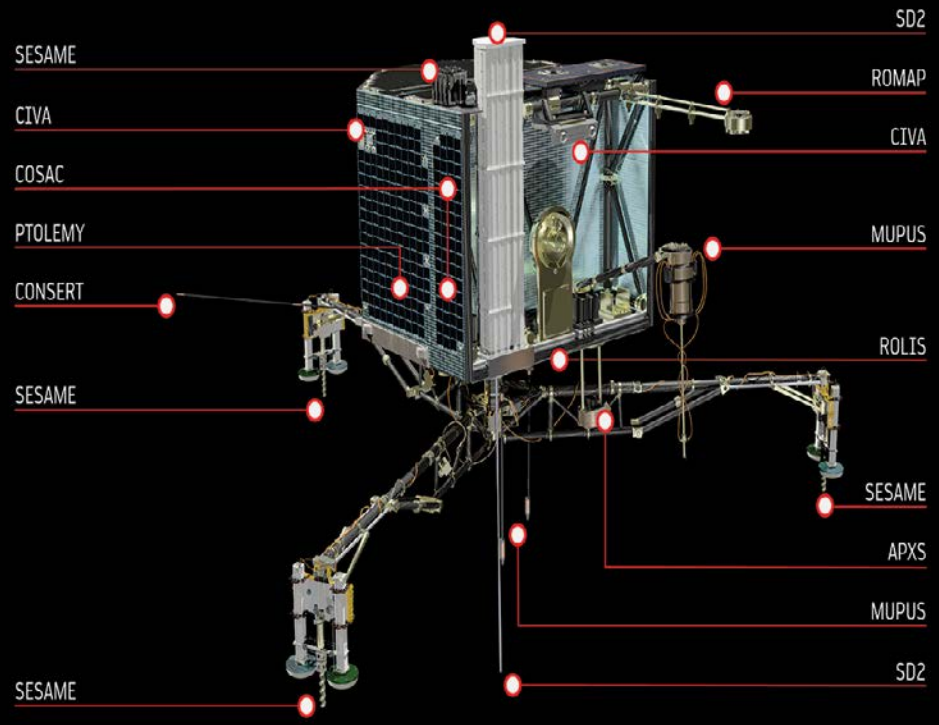


17 Feb 2016





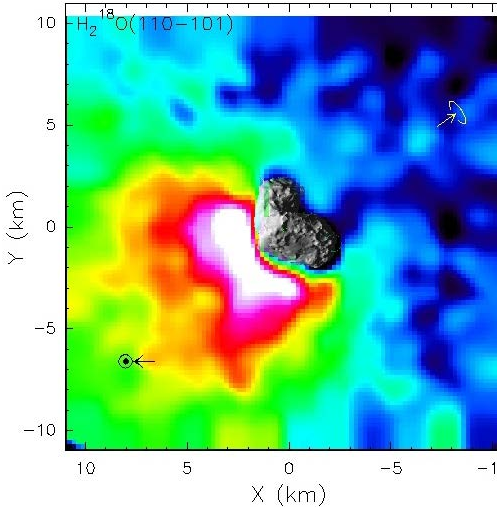
Instrument	Purpose	Country of Origin
Alice	Ultraviolet spectrometer	United States
CONSERT	Radar tomography	France
COSIMA	Dust composition	Germany
GIADA	Dust detector	Italy
MIDAS	Atomic Force Microscope	Austria
MIRO	Microwave spectrometer/radiometer	United States
OSIRIS	Narrow-angle and wide-angle cameras	Germany
ROSINA	Gas composition	Switzerland
RPC	Magnetometer, plasma detectors	Various, inc. US
RSI	Radio science investigation	Germany
VIRTIS	Infrared spectrometer	Italy



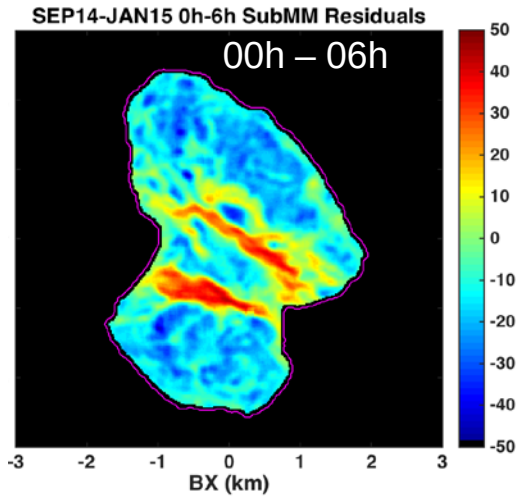
Instrument	Purpose	Country of Origin
APXS	Alpha/x-ray spectrometer	Germany
CIVA	Panoramic cameras and microscope	France
CONSERT	Radar tomography of nucleus	France
COSAC	Evolved gas analyzer: molecules	Germany
Ptolemy	Evolved gas analyzer: isotopes	United Kingdom
MUPUS	Surface and subsurface properties	Germany
ROLIS	Descent imaging	Germany
ROMAP	Magnetometer and plasma monitor	Germany/Hungary
SD2	Sample drill and distribution system	Italy
SESAME	Surface electric/acoustic properties	Germany/Finland

MIRO: Microwave Instrument on the Rosetta Orbiter

- MIRO is a millimeter/submillimeter radio telescope. It is a NASA instrument with contributions from France, Germany, and Taiwan.
- Continuum receivers at wavelengths of 0.5 and 1.6 mm probe the thermal and electrical properties of the nucleus subsurface (depths from ~1 mm to 10 cm), and the abundance of millimeter-sized dust grains in the coma.
- A high resolution spectrometer measures the abundance, velocity, and temperature of H_2O, $H_2{}^{17}O$, $H_2{}^{18}O$, CO, NH_3, and CH_3OH gas in the coma.
- Our overall science objective is to study the structure and evolution of the coma and nucleus as a coupled system.



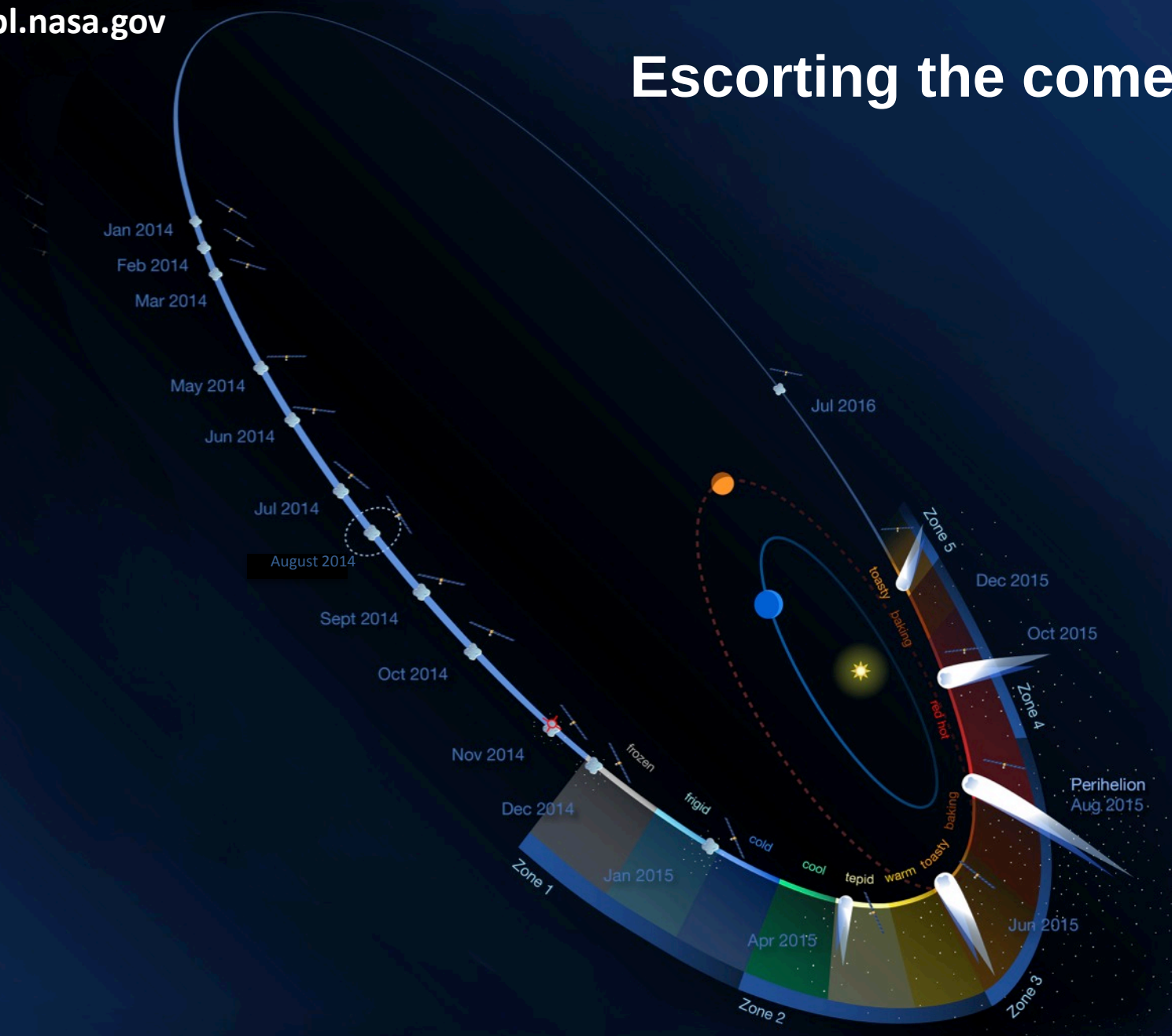
The distribution of $H_2{}^{18}O$ in the coma on 24 October 2015. White areas have high concentrations. The Sun is to the left. (Nicolas Biver, Obs. de Paris.)



Residual map (data minus model) of nucleus temperatures. Red areas indicate “self heating” where the non-spherical shape of the comet allows some regions to radiatively heat others. (F. Peter Schloerb, UMass.)

Rosetta.jpl.nasa.gov

Escorting the comet

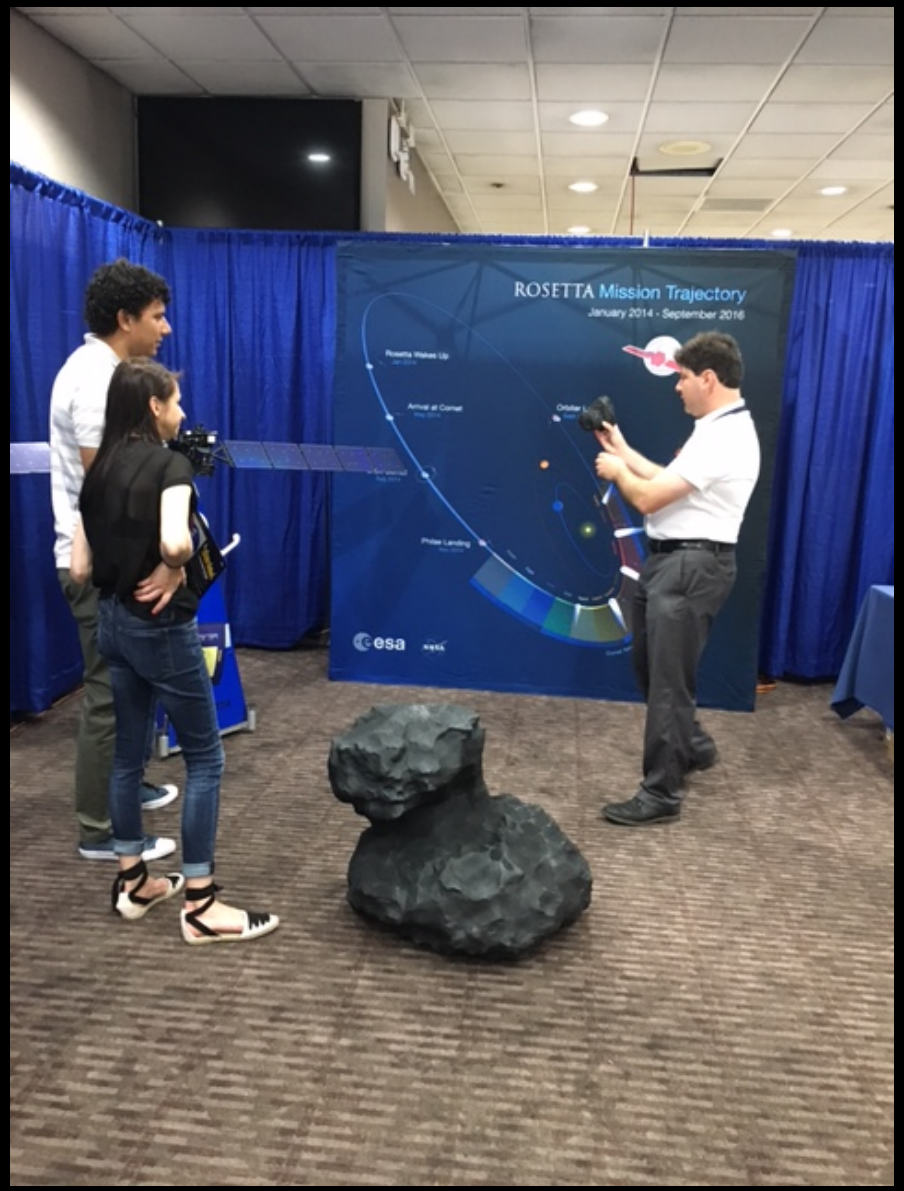


Credit: NASA/JPL Caltech

Outreach activities 2016

- Claudia Alexander was a tireless proponent of outreach, and we have tried to continue on that path
- An Educators' Workshop at JPL is planned for Sept. 24 with space for 60 teachers. The full day event will include lectures on small bodies and *Rosetta*, plus hands-on activities such as "kitchen comets".
- Strong presence at JPL's Open House June 4-5 (20,000 participants each day) with demos and *Rosetta* and comet models ("misting" comet)
- Partnership with Chinle (Arizona) school district for month-long science program in June; 20-30 students from Navajo Nation participate
- Public lecture (von Karman series) on August 11 and 12
- Sept. 30: Friends & Family program prior to "landing" leading into NASA TV live from Darmstadt and into ESA feed.
- Popular NASA Rosetta Blog written by co-Is_

JPL Open House June 4-5, 2016



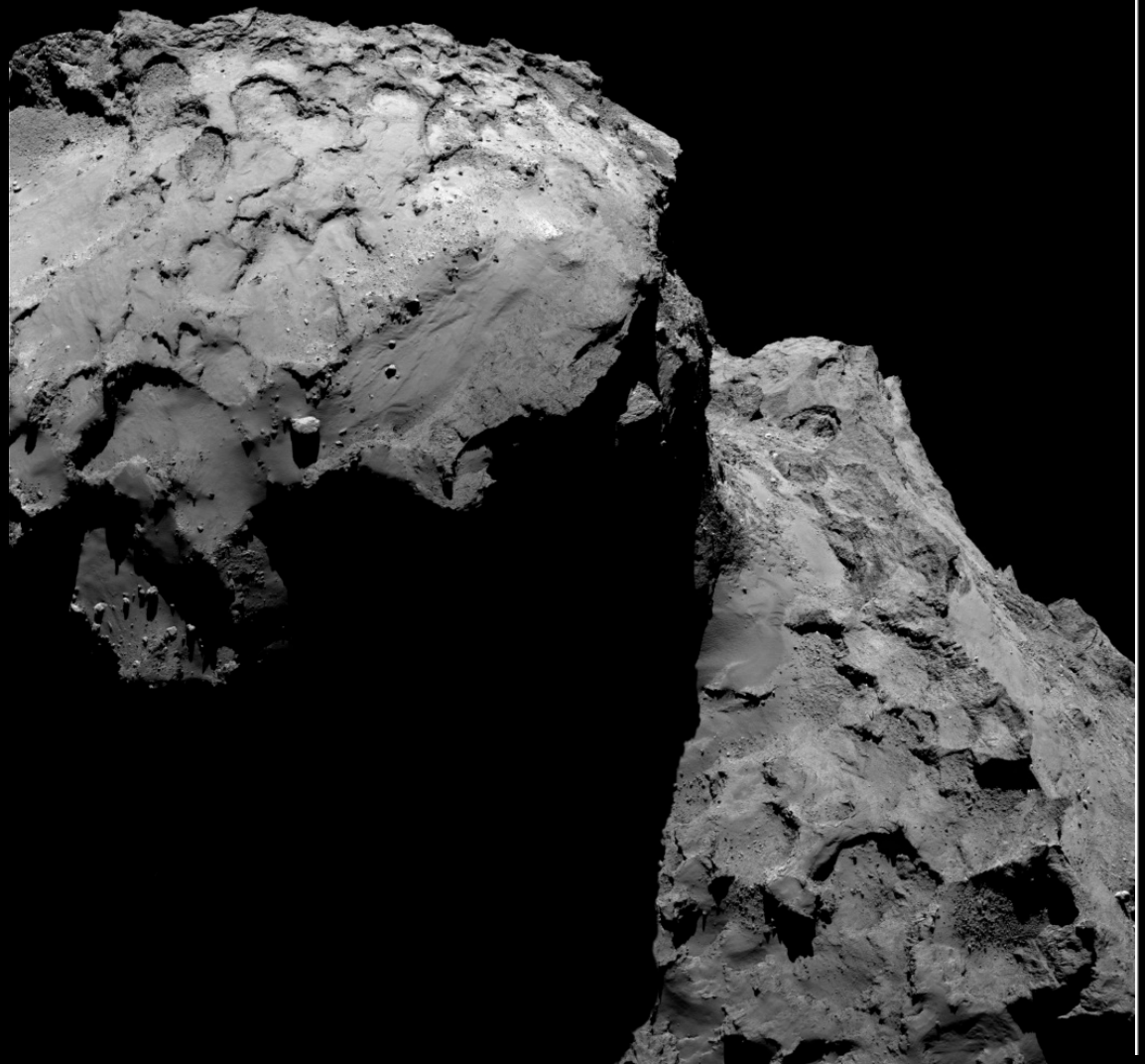
Mathieu Choukroun, NASA Deputy Project Scientist, demonstrates Rosetta activities with C-G model at JPL's Open House on June 4. Large model of comet in front.


Ekaterina Smirnova
Space Artist

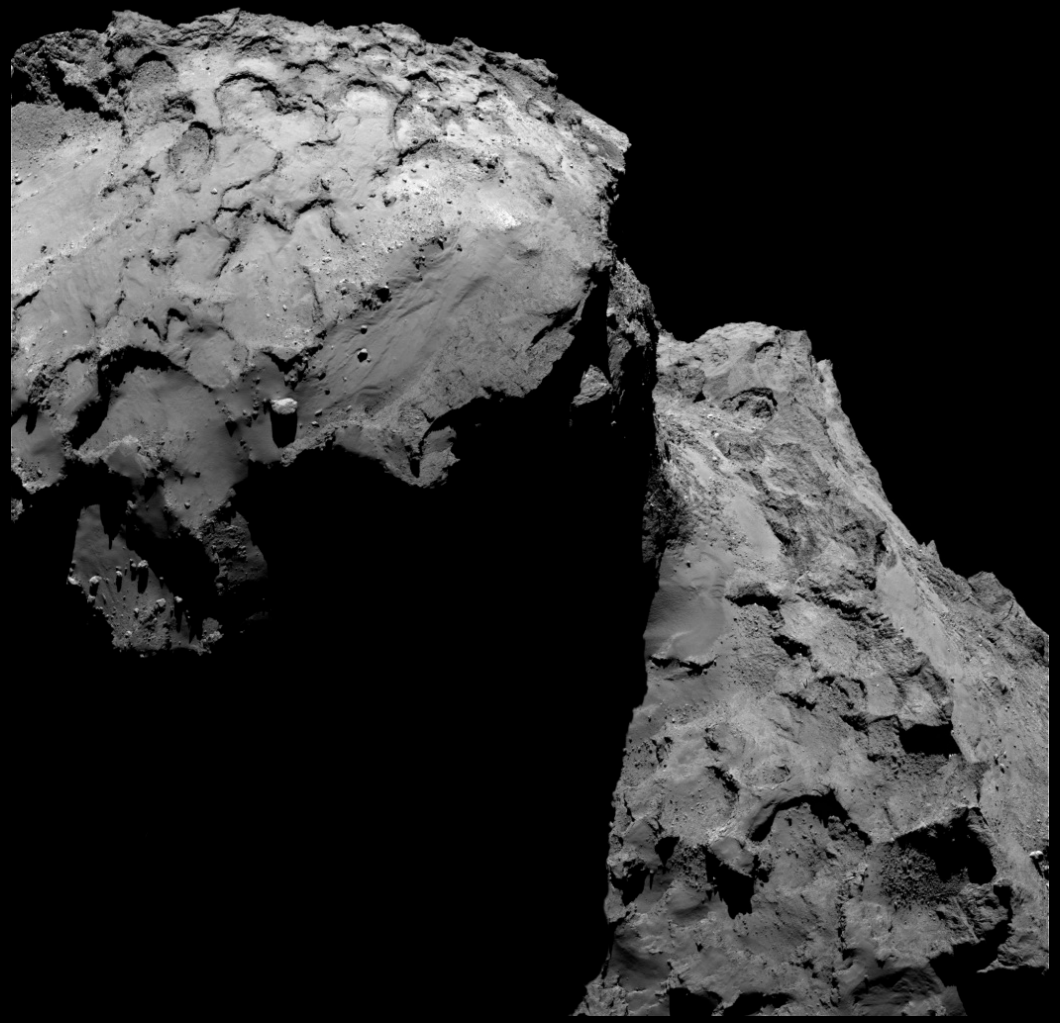
Dec 10, 2015 *OSIRIS* image: Comet formed from two planetestimals

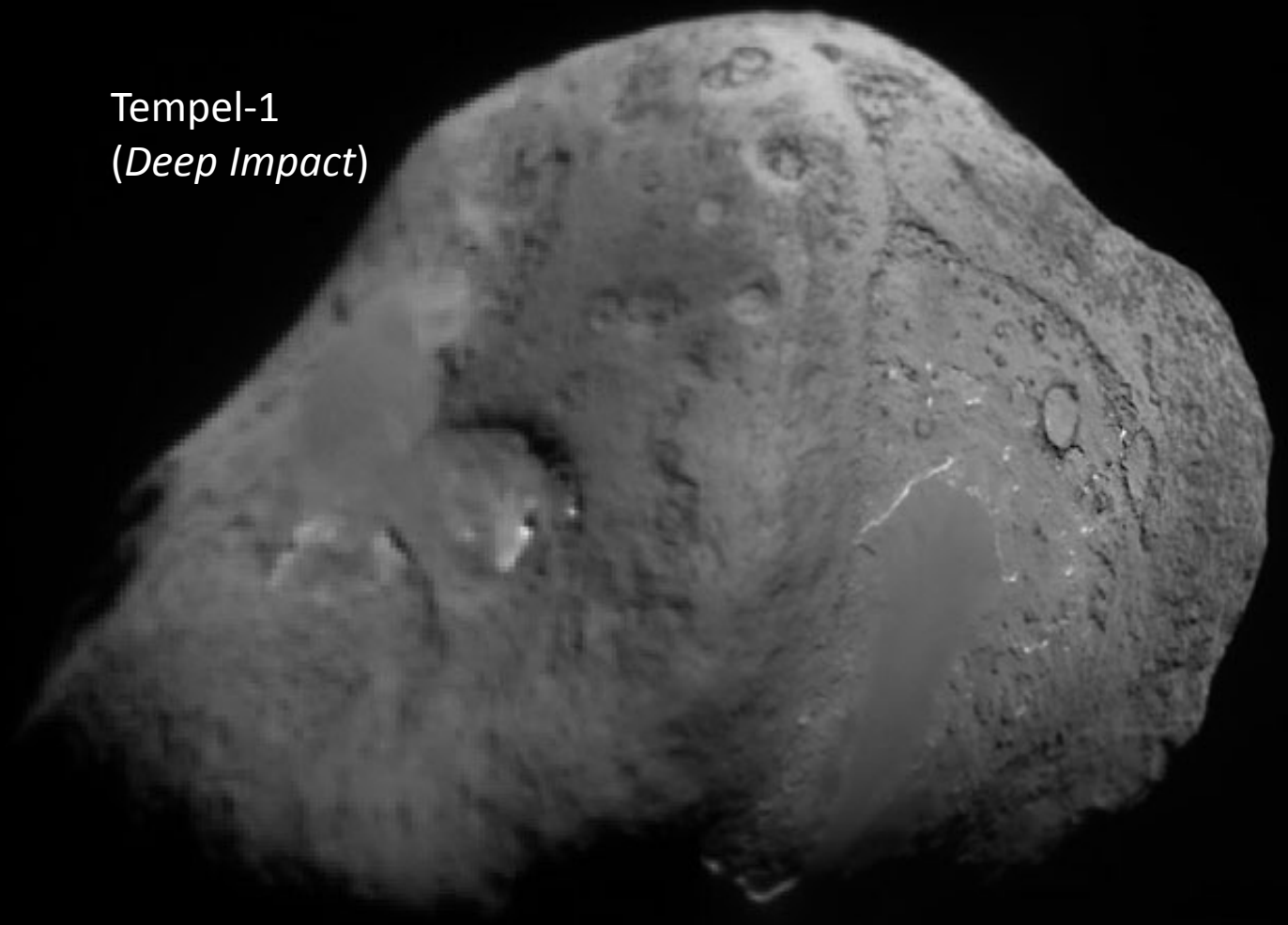
Different layering
Different physical properties

Dec 17, 2015: compare with Wild-2; cavities may be regions of previous outgassing

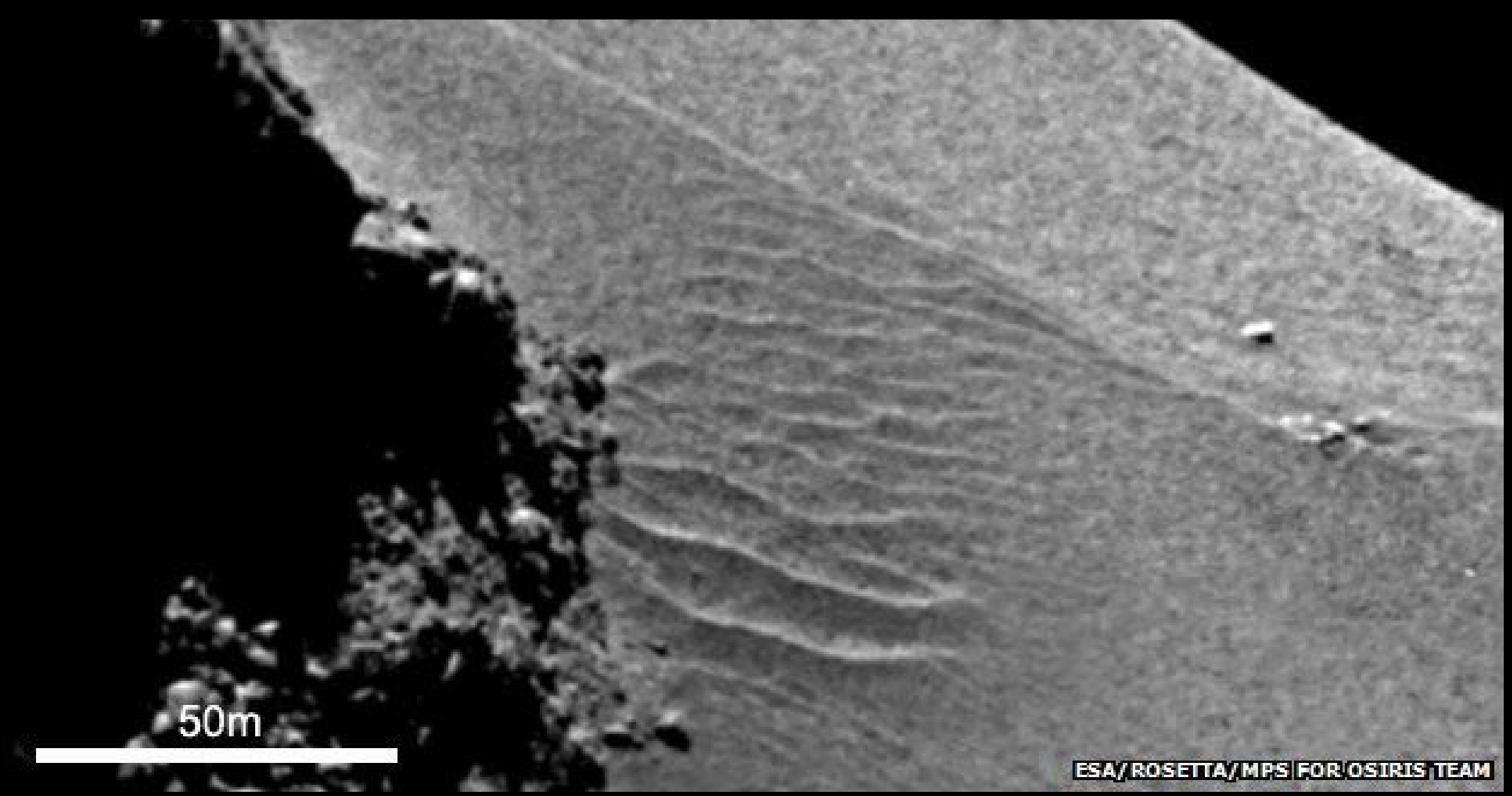


Dec 17, 2015 compare with Tempel 1 flow features

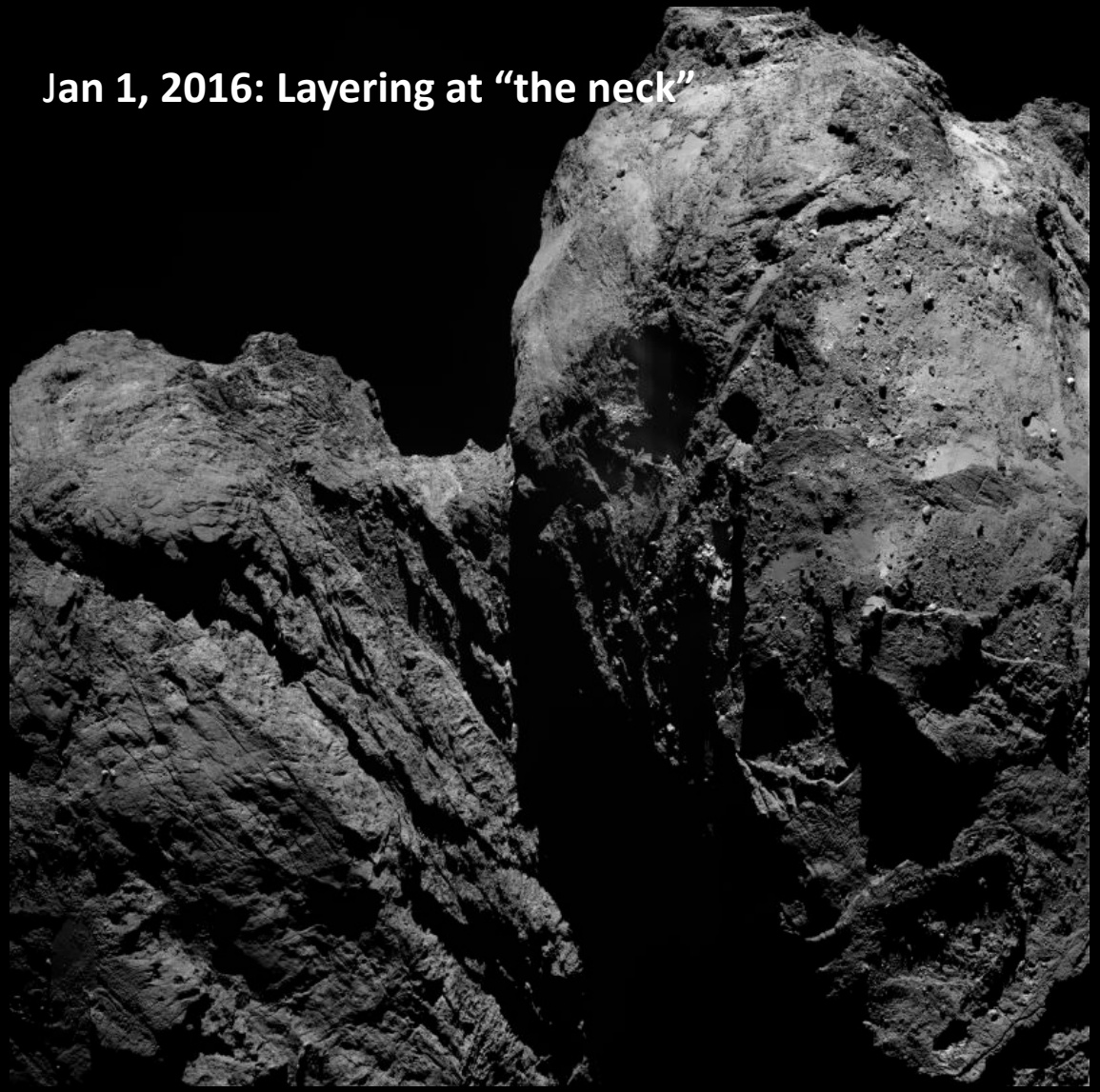




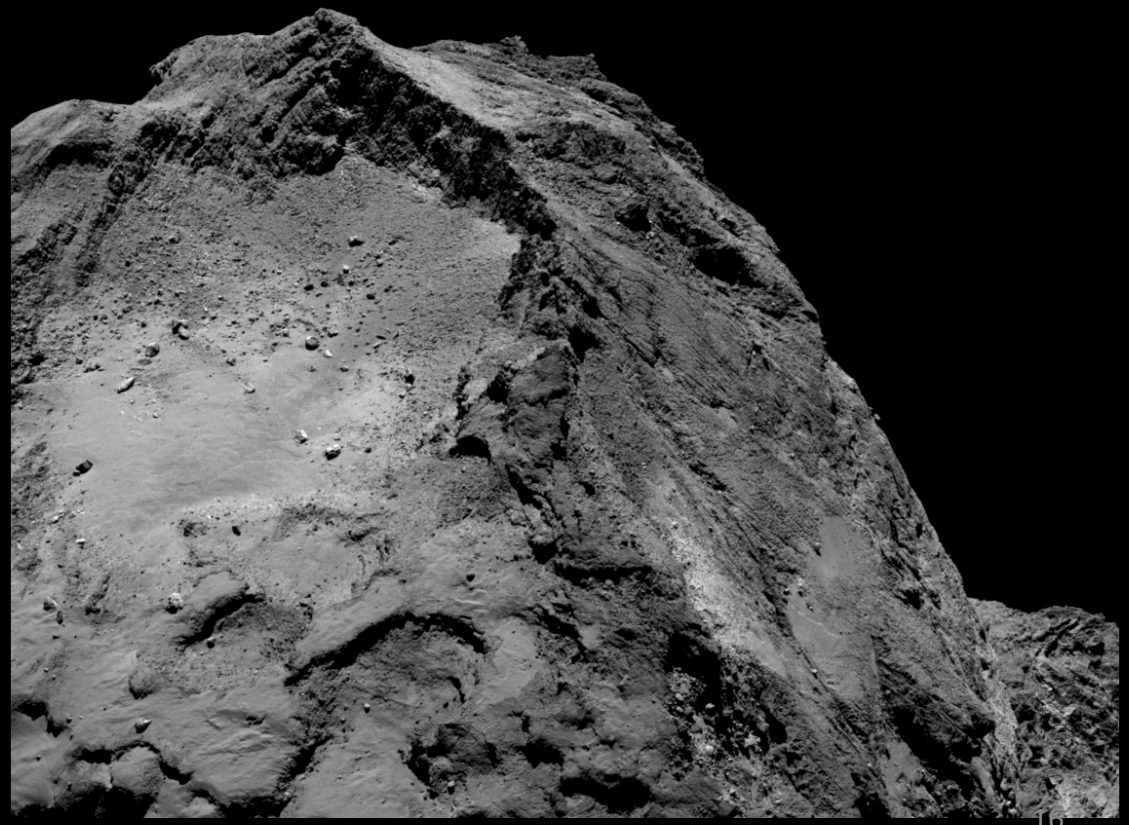
Tempel-1
(*Deep Impact*)


50m
ESA/ ROSETTA/ MPS FOR OSIRIS TEAM

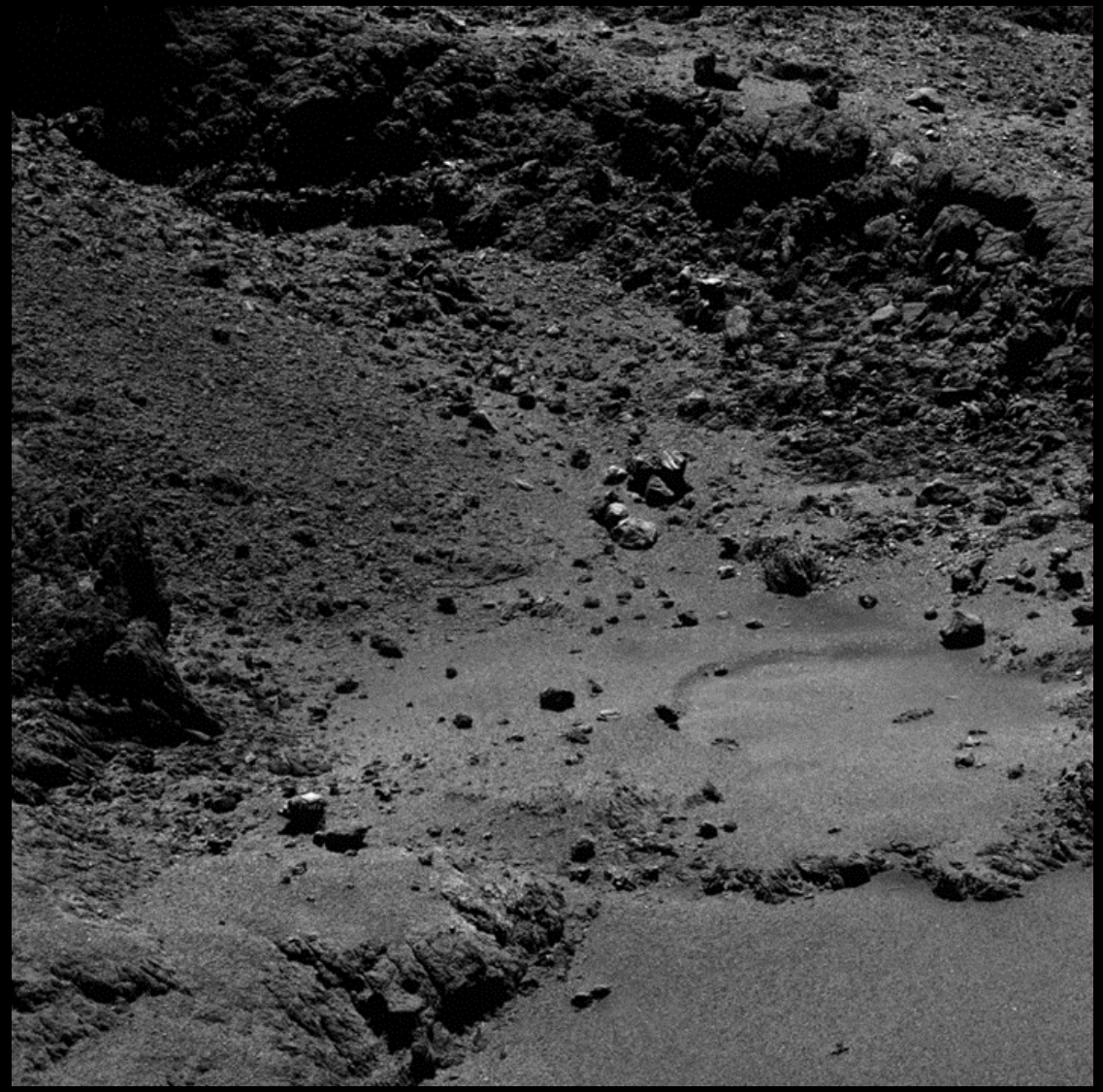
Layering and boulders



Feb 10 and 13: ponding, boulders, aeolian?



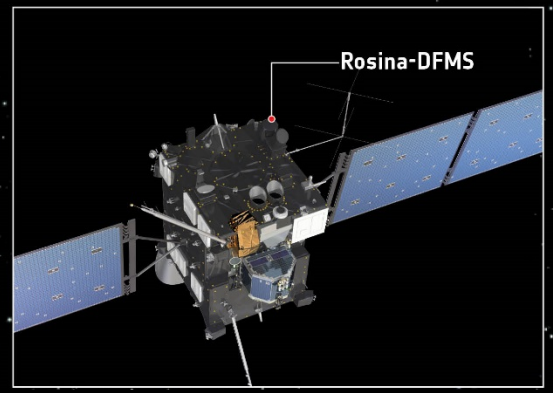
May 11 and June 6



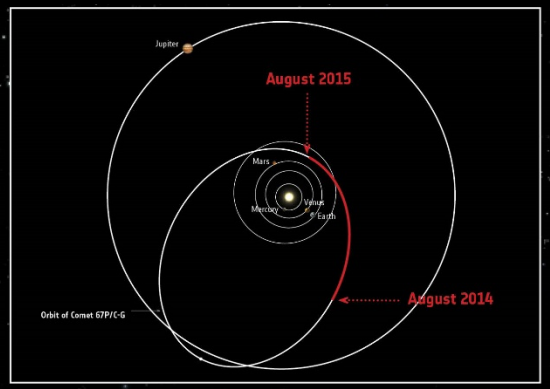
Zero phase (April 9): The comet was fully illuminated

Zero phase observations can be modeled to derive surface porosity

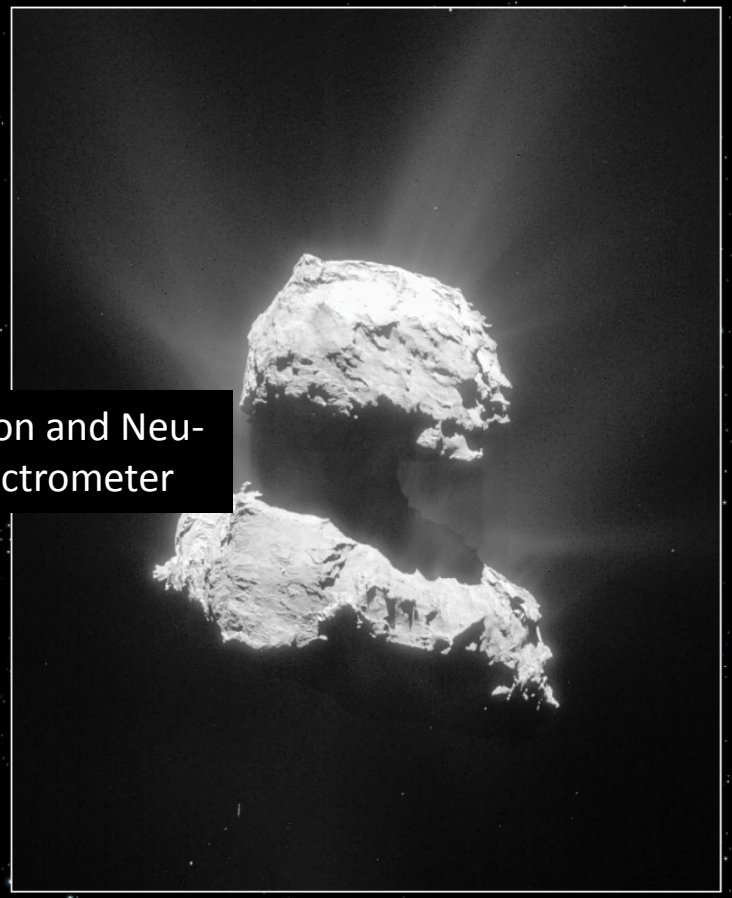
Rosetta's Comet Contains Ingredients for Life



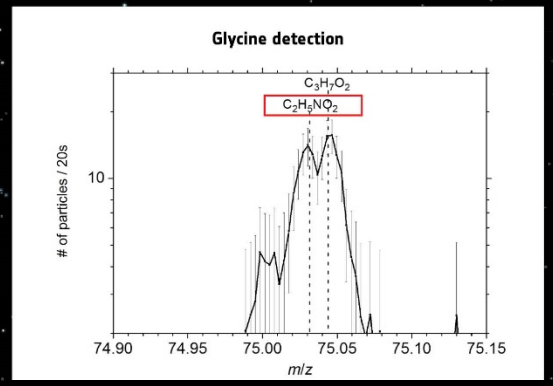
The Rosetta Orbiter Spectrometer for Ion and Neutral Analysis Double-Focusing Mass Spectrometer



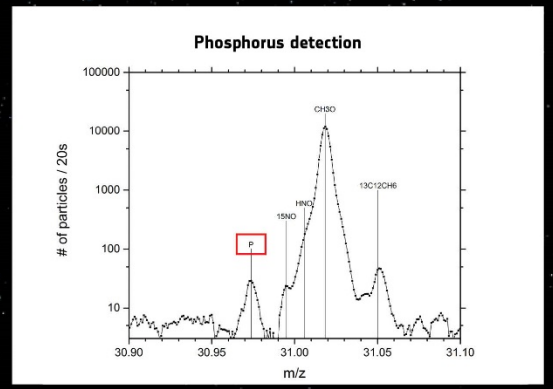
The data were collected between August 2014 and 2015



Rosetta was between 10 and 200 km from the comet when the data were obtained.



Spectrum indicating glycine, a simple amino acid commonly found in proteins.



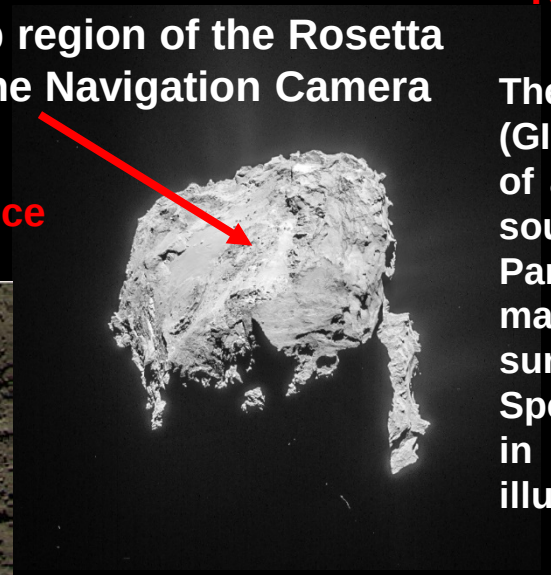
Spectrum indicating phosphorus and other gasses. Phosphorus is a key element for living organisms, Found in DNA and cell membranes. It also plays a key role in metabolic processes.

Water and Ice on Comet 67P/Churyumov-Gerasimenko

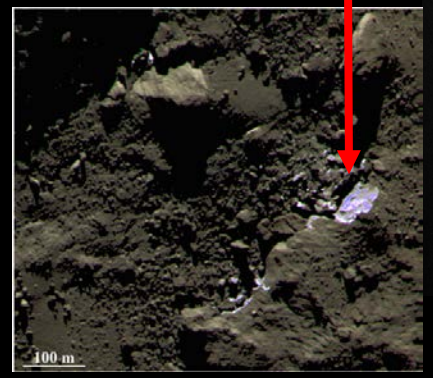
Like comets in general, 67P/ Churyumov-Gerasimenko is a abundant source of water. This water is released from the comet as it approaches the sun. The Microwave Instrument for the Rosetta Orbiter (MIRO) found that during its active period the comet produces sufficient water to fill an Olympic swimming pool every 100 days. The ultraviolet spectrometer ALICE found indirect evidence for water: electrons from water molecules that were ionized by sunlight. The water that is released forms the jets and coma that give comets their glorious appearance.

Regions where water ice was detected by VIRTIS

Illuminated Imhotep region of the Rosetta comet as seen by the Navigation Camera



A bright spot of fresh ice



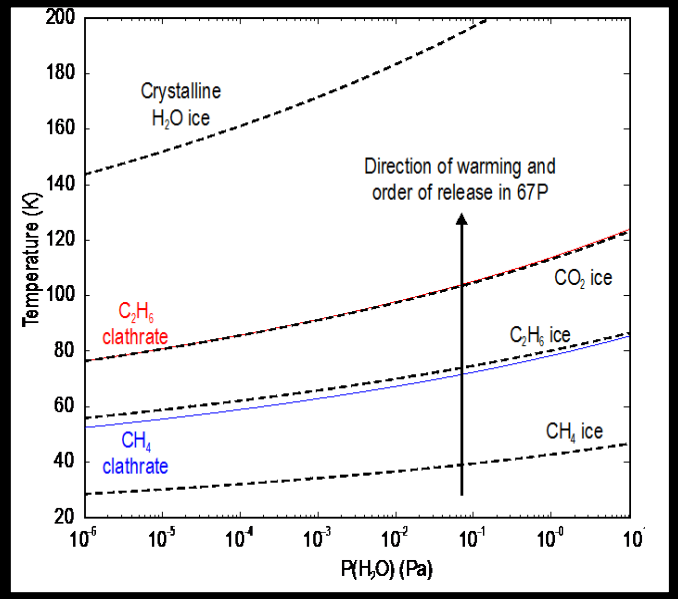
The Grain Impact Analyzer and Dust Accumulator (GIADA) revealed a surface of ice and dust in the ratio of about 1 to 4. But the presence of water ice, the source of the outgassed material, has been elusive. Part of the reason is that the dust is very dark and masks the presence of water ice on the comet's surface. Finally, the Visual Infrared Thermal Mapping Spectrometer (VIRTIS) obtained spectra of water ice in the Imhotep region of the comet as it was illuminated by solar radiation.

Filacchione et al., 2016; Image credits: ESA

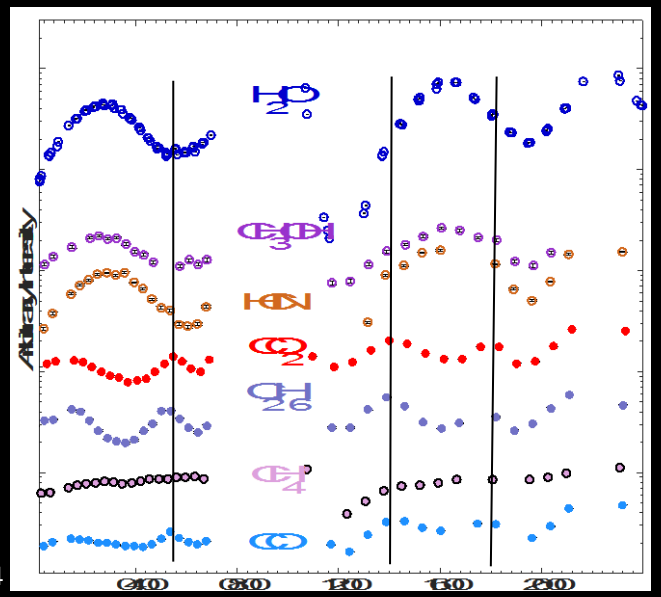
Evidence for Clathrates in Comet 67P

While the main cometary volatile is undoubtedly water ice, the form of this ice — amorphous or crystalline — has been long debated. The phase of the ice is important because it tells us about how and where in the solar nebula comets may have formed. Since volatiles other than water will be stored and released differently in amorphous and crystalline water ices, the order of gas release into the coma carries key information about the ice phase in the nucleus. Such features are well-distinguishable before the onset of water sublimation, which was the case over the southern hemisphere of 67P pre-equinox.

CH_4 and C_2H_6 clathrates are consistent with ROSINA/DFMS observations



Minor species followed H_2O or CO_2, except CH_4



The diurnal outgassing pattern observed by ROSINA/DFMS at this time was found to be consistent with gas release from a particular form of crystalline ice called clathrates. Gas release from amorphous ice that occurs simultaneously for all species cannot explain the observations, even when combined with recondensation and sublimation. If the presence of clathrates in the nucleus means that the building blocks of 67P were themselves made out of crystalline ices and clathrates instead of amorphous ice, then 67P likely formed closer to the Sun than previously considered for Jupiter Family Comets (Luspay-Kuti et al. 2016, *Sci. Adv.* 2, e1501781).

Rosetta Shadow Navigation for Landing on Churyumov-Gerasimenko: Background

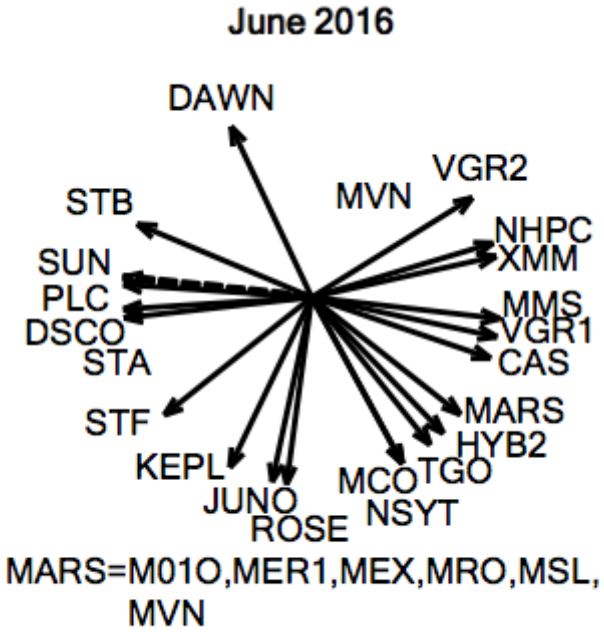
- JPL MDNAV provided independent navigation support to ESA for approach, proximity operations, and landing of Philae from January – November 2014
- Support ended after Philae landing
  - 2 papers from JPL navigation team written describing experience and results from navigation support
- Current plan is to land Rosetta spacecraft on comet at end of September 2016
- At a TIM in the Fall of 2015, ESOC Flight Dynamics requested JPL shadow navigation support, as was done for Philae landing

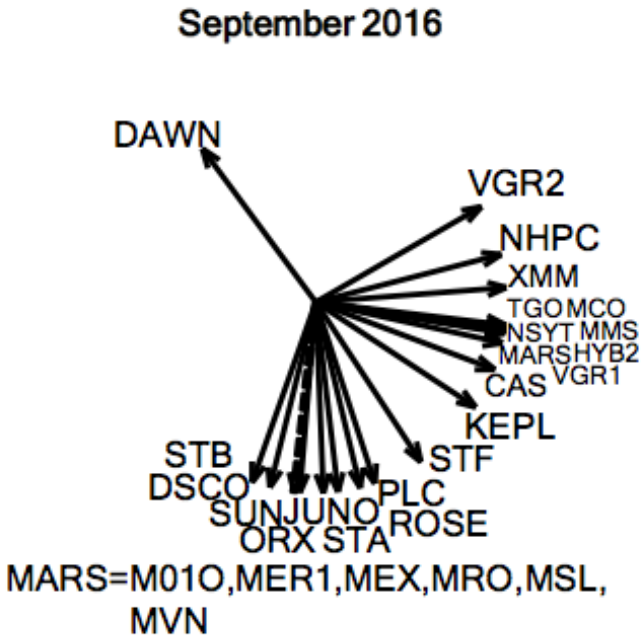
Shadow Navigation Plan

- As was done during the comet approach and proximity operations leading to the Philae landing, JPL will provide an independent orbit determination capability for the Rosetta soft landing
- JPL will start providing regular OD solutions in late July and continue through the landing event, using radiometric and optical tracking data provided by ESOC
- At weekly intervals (and more frequently in the days leading up to landing), ESOC and JPL will compare OD solutions, which include, in addition to the spacecraft trajectory reconstruction and predicted orbit, parameters which describe the physical environment, such as the C-G gravity field, rotational state, and outgassing accelerations
- JPL solutions are used solely for comparison against ESOC solutions; only ESOC solutions will be used to update the s/c onboard ephemeris, planning, and delivery to the Project, etc.
- JPL also does not provide any designs of future maneuvers, just reconstructions of past maneuvers as part of the OD solution

Rosetta DSN Scheduling

- **Rosetta's Competition for DSN time:**

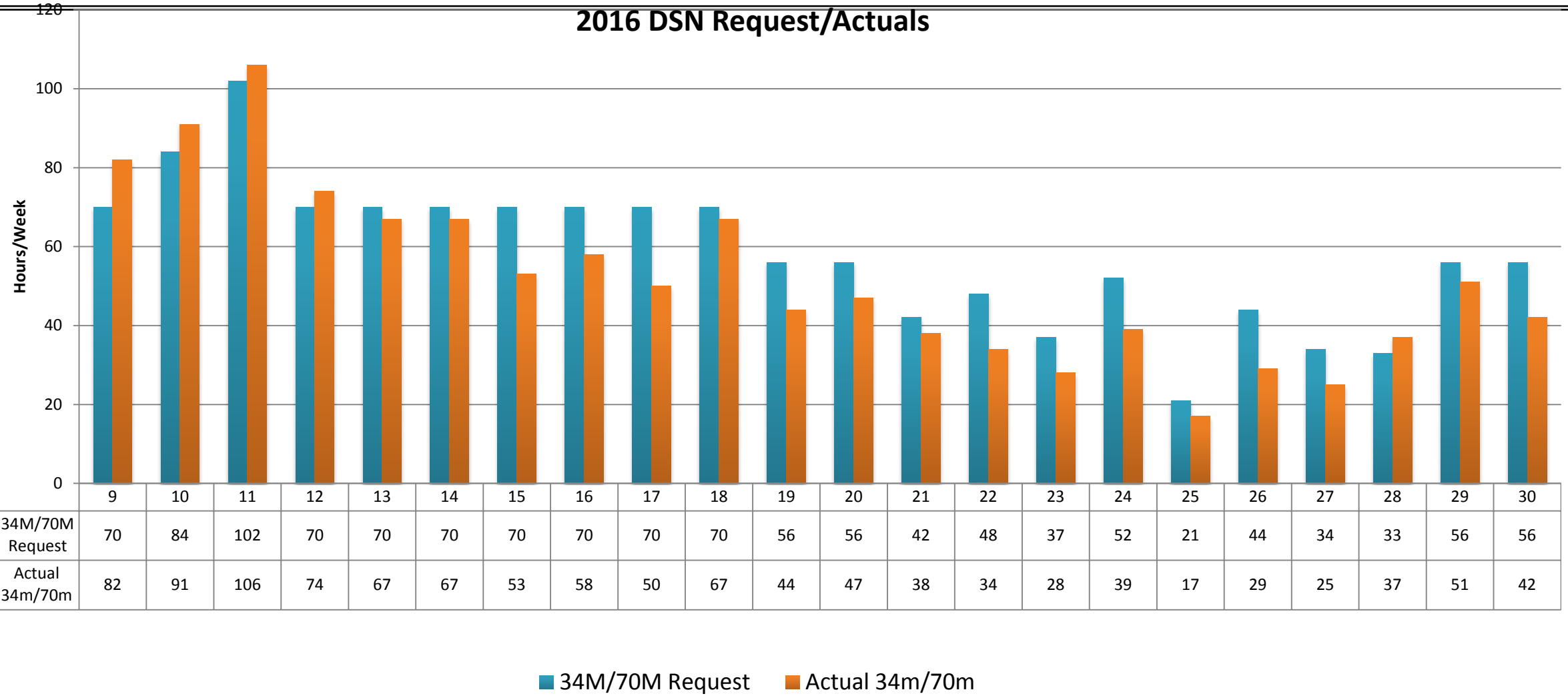




- **Negotiation Status:**
  - As of June 1 negotiations have been completed through September 4, 2016
  - Despite heavy contentions Rosetta is meeting 66-117% of requirement for February 29, 2016 –July 31, 2016

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Rosetta DSN Request vs. Actuals



	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
34M/70M Request	70	84	102	70	70	70	70	70	70	70	56	56	42	48	37	52	21	44	34	33	56	56
Actual 34m/70m	82	91	106	74	67	67	53	58	50	67	44	47	38	34	28	39	17	29	25	37	51	42

Week 25 is the current week. Coverage for weeks 25-30 is subject to change.

Data Analysis Program (DAP)

- The intent of the Rosetta Data Analysis Program is to provide the funding that will allow for continued analysis and interpretation of data, provide the opportunity for new collaborations and investigators, and support limited laboratory and field measurements (including astronomical data) to interpret space measurements correctly. Synergistic analyses are encouraged, including comparisons with data from other missions
- Proposed budget: FY 17 - $2.5M, FY-18 $3.5M, FY19 - $4.5M, FY20 - $5M
- FY17 Call for Proposal submitted to NASA Headquarters. Most recent comment from Hdqrtrs is “we intend to have one.”
- Can propose analysis of PDS data that is available at time of issue
- $100-200K/year/3 years award levels
- Collaborations with European PIs encouraged (no funding to international investigations)

Upcoming significant events

- The controlled crash on Sept 30. Data and images up until the end. First ever such event on a comet

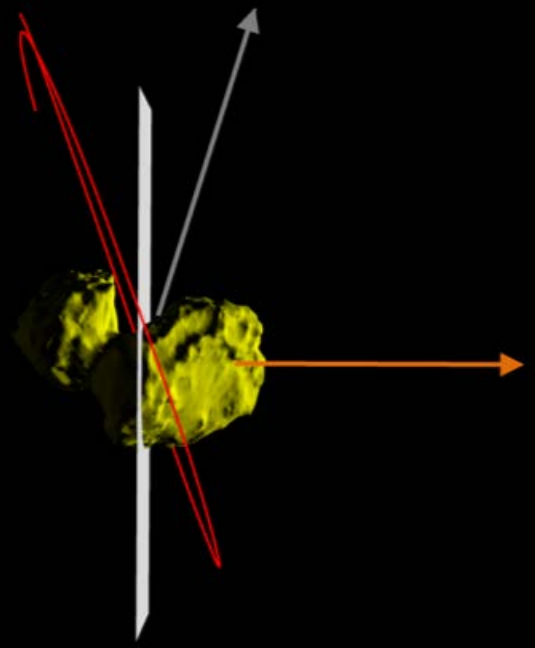
  -Press events in Europe (Darmstadt) with US Team there; NASA TV coverage

  - Friends and family event at JPL

- US co-I meeting at AGU
- US Scientific Working Team (SWT) meeting in the US in 2017 – first ever. Location is New York City; Date TBD

End of Mission

July

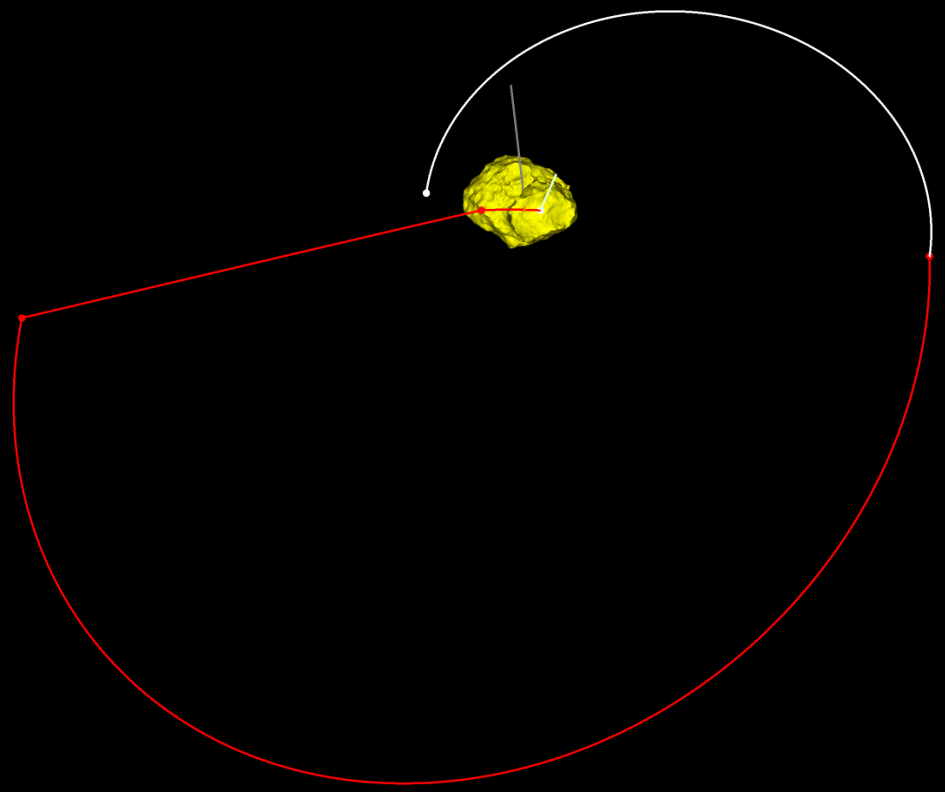


August -September

rosetta

European Space Agency

End of Mission



Timeline:

1. Last flyover (Sep 23rd) before controlled impact preparations
2. After flyover apocentre (Sep 25th), transition arc of ~4.5 days
3. From ~20 km, ~12h before impact , **collision manoeuvre** initiating the descent to the comet surface
4. First descending arc of ~9 h
5. From ~1.7 km altitude, **braking manoeuvre**
6. Second descending arc of ~2 h
7. Impact at a relative speed of ~50 cm/s

Concerns

1. DSN coverage during “landing”
2. Status of Rosetta Data Analysis Program

The US Rosetta Project would like to thank:

- ESA for the fabulous ride
- NASA HQ - Jim Green, Tony Carro and David Schurr for steadfast support over the years