Further on-going laboratory measurements will be discussed. Supports from CNES and NASA are acknowledged.

[1] Kofman et al. Science 349, 6247 aab0639, 2015.
[2] Ciarletti et al. A&A (Rosetta issue), in press, 2015.
[3] E. Heggy et al. Icarus 221, 925, 2012.
[4] Brouet et al. A&A (Rosetta issue), in press, 2015.

**Author(s): A. Levasseur-Regourd4**, Wlodek Kofman1, Alain Herique1, Valérie Ciarletti5, Essam Heggy3, Jérémie Lasue2
**Institution(s):** *1. IPAG-CNRS, 2. IRAP-OMP, CNRS-UPS, 3. University of Southern California, 4. UPMC (Sorbonne Univ.), 5. UVSQ (UPSay)*

### 413.11 – 3D reconstruction of the final PHILAE landing site: Abydos

The Abydos region is the region of the final landing site of the PHILAE lander. The landing site has been potentially identified on images of this region acquired by the OSIRIS imaging system aboard the orbiter before (Oct 22, 2014) and after (Dec 6-13, 2014) the landing of PHILAE (Lamy et al., in prep.). Assuming that this identification is correct, we reconstructed the topography of Abydos in 3D using a method called ``multiresolution photoclinometry by deformation'' (MPCD, Capanna et al., The Visual Computer, 29(6-8): 825-835, 2013). The method works in two steps: (a) a DTM of this region is extracted from the global MPCD shape model, (b) the resulting triangular mesh is progressively deformed at increasing spatial resolution in order to match a set of 14 images of Abydos at pixel resolutions between 1 and 8 m. The method used to perform the image matching is the L-BFGS-b non-linear optimization (Morales et al., ACM Trans. Math. Softw., 38(1): 1-4, 2011).
In spite of the very unfavourable illumination conditions, we achieve a vertical accuracy of about 3 m, while the horizontal sampling is 0.5 m. The accuracy is limited by high incidence angles on the images (about 60 deg on average) combined with a complex topography including numerous cliffs and a few overhangs. We also check the compatibility of the local DTM with the images obtained by the CIVA-P instrument aboard PHILAE. If the Lamy et al. identification is correct, our DTM shows that PHILAE landed in a cavity at the bottom of a small cliff of 8 m height.

**Author(s): Claire Capanna2**, Laurent Jorda2, Philippe Lamy2, Gilles Gesquière3, Cédric Delmas1, Joëlle Durand1, Philippe Gaudon1, Eric Jurado1
**Institution(s):** *1. CNES, 2. Laboratoire d'Astrophysique de Marseille, 3. LIRIS*

### 413.12 – Report on the ground-based observation campaign of 67P/Churyumov-Gerasimenko

Rosetta gets closer to the nucleus than any previous mission, and returns wonderfully detailed measurements from the heart of the comet, but at the cost of not seeing the large scale coma and tails. The ground-based campaign fills in the missing part of the picture, studying the comet at about 1000 km resolution, and following how the overall activity of the comet varies. These data provide context information for Rosetta, so changes in the inner coma seen by the spacecraft can be correlated with the phenomena observable in comets. This will not only help to complete our understanding of the activity of 67P, but also to allow us to compare it with other comets that are only observed from the ground.
The ground-based campaign includes observations with nearly all major facilities world-wide. In 2014 the majority of data came from the ESO VLT, as the comet was still relatively faint and in Southern skies, but as it returns to visibility from Earth in 2015 it is considerably brighter, approaching its perihelion in August, and at Northern declinations. I will present results from the 2014 campaign, including visible wavelength photometry and spectroscopy, and the latest results from 2015 observations.

**Author(s): Emmanuel Jehin1**
**Institution(s):** *1. Université de Liège*

### 413.13 – Hubble Space Telescope Imaging Polarimetry of Comet 67P/Churyumov-Gerasimenko Obtained During the Rosetta Mission

We present pre- and post-perihelion, high-spatial resolution (0.05 arcsec/pixel) 0.6 micron imaging polarimetry of Comet 67P/Churyumov-Gerasimenko taken with the Advanced Camera for Surveys aboard the Hubble Space Telescope (HST). The pre-perihelion observations were obtained at two epochs chosen to bracket the times when the closest orbits of Rosetta were flown (down to 10 km for extended periods: 2014-Aug-19: $r_h$ = 3.52 au, Δ = 2.76 au, $\alpha \approx 12.0°$) and the Philae landing took place (2014-Nov-17: $r_h$ = 2.96 au, Δ = 3.43 au, $\alpha \approx 15.7°$). Our preliminary analyses of both pre-perihelion epochs shows that the polarization position angle lies in the scattering plane, thus is negative, with a degree of polarization p% ≈ -2%. The two post-perihelion epochs were matched to the first time after perihelion that the comet was observable with HST (2015-Oct-10: $r_h$ = 1.43 au, Δ = 1.80 au, $\alpha \approx 33.5°$), and when the comet was again viewed at small phase angle (2016-Feb-19: $r_h$ = 2.40 au, Δ = 1.49 au, $\alpha \approx 12.0°$). We discuss our polarimetry results in context with in situ measurements of dust particles obtained with the Rosetta spacecraft.

**Author(s): Dean C. Hines8**, Anny-Chantal Levasseur-Regourd 12, Edith Hadamcik13, Vadym Kaydash3, Matthew M. Knight 4, Ludmilla Kolokolova11, Jian-Yang Li6, Carey M. Lisse1, Karri Muinonen10, Max Mutchler8, Yuriy Shkuratov3, Colin Snodgrass5, Michael L. Sitko9, Matt G. G. T. Taylor2, Gorden Videen7, Padmavati A. Yanamandra-Fisher7, Evgenij Zubko3
**Institution(s):** *1. Applied Physics Laboratory, 2. ESA ESTEC, 3. Kharkov National University, 4. Lowell Observatory, 5. MPI for Solar System Research, 6. Planetary Science Institute, 7. Space Science Institute, 8. Space Telescope Science Institute, 9. University of Helsinki, 10. University of Helsinki, 11. University of Maryland, 12. UPMC (Sorbonne Univ.), 13. UPMC/ LATMOS*

### 413.14 – Water production rates of recent comets (2015) by SOHO/SWAN and the SOHO/SWAN survey

The all-sky hydrogen Lyman-alpha camera, SWAN (Solar Wind Anisotropies), on the SOlar and Heliospheric Observatory (SOHO) satellite makes observations of the hydrogen coma of comets. Most water molecules produced by comets are ultimately photodissociated into two H atoms and one O atom producing a huge atomic hydrogen coma that is routinely observed in the daily full-sky SWAN images in comets of sufficient brightness. Water production rates are calculated using our time-resolved model (Mäkinen & Combi, 2005, Icarus 177, 217), typically yielding about 1 observation every 2 days on the average for each comet. Here we describe the progress in analysis of observations of comets observed in 2015 and those selected from the archive for analysis. These include comets C/2013 US10 (Catalina), C/2014 Q1 (PanSTARRS), and possibly 67P/Churyumov-Gerasimenko. A status update on the entire SOHO/SWAN archive of water production rates in comets will also be given. SOHO is an international cooperative mission between ESA and NASA. Support from grants NNX11AH50G from the NASA Planetary Astronomy Program and NNX13AQ66G from the NASA Planetary Mission Data Analysis Program are gratefully acknowledged, as is support from CNRS, CNES, and the Finnish Meteorological Institute (FMI).

**Author(s): Michael R. Combi4**, J. T. T. Mäkinen2, Jean-Loup Bertaux3, Eric Quémerais3, Stéphane Ferron1
**Institution(s):** *1. ACRI-st, 2. Finnish Meteorologoical Institute, 3. LATMOS/IPSI, Université de Versailles Saint-Quentin, 4. Univ. of Michigan*

### 413.15 – The primordial nucleus of Comet 67P/Churyumov-Gerasimenko

Observations of Comet 67P/Churyumov-Gerasimenko by Rosetta show that the nucleus is bi-lobed, extensively layered, has a low bulk density, a high dust-to-ice mass ratio (implying high porosity), and weak strength except for a thin sintered surface layer. The comet is rich in supervolatiles (CO, $CO_2$, $N_2$), may contain amorphous water ice, and displays little to no signs of aqueous alteration. Lack of phyllosilicates in Stardust samples from Comet 81P/Wild 2 provides further support that comet nuclei did not

contain liquid water.
These properties differ from those expected for 50-200 km diameter bodies in the primordial disk. We find that thermal processing due to Al-26, combined with collisional compaction, creates a population of medium-sized bodies that are comparably dense, compacted, strong, heavily depleted in supervolatiles, containing little to no amorphous water ice, and that have experienced extensive aqueous alteration. Irregular satellites Phoebe and Himalia are potential representatives of this population. Collisional rubble piles inherit these properties from their parents. We therefore conclude that observed comet nuclei are primordial rubble piles, and not collisional rubble piles.
We propose a concurrent comet and TNO formation scenario that is consistent with these observations. We argue that TNOs form due to streaming instabilities at sizes of about 50-400 km and that about 350 of these grow slowly in a low-mass primordial disk to the size of Triton, causing little viscous stirring during growth. We propose a dynamically cold primordial disk, that prevents medium-sized TNOs from breaking into collisional rubble piles, and allows for the survival of primordial rubble-pile comets. We argue that comets form by hierarchical agglomeration out of material that remains after TNO formation. This slow growth is necessary to avoid thermal processing by Al-26, and to allow comet nuclei to incorporate 3 Myr old material from the inner Solar System, found in Stardust samples. Growth in the Solar Nebula creates porous single-lobe nuclei, while continued growth in a mildly viscously stirred primordial disk creates denser outer layers, and allow bi-lobe nucleus formation through mergers.

**Author(s): Bjorn Davidsson[26]**, Holger Sierks[14], Carsten Guettler[14], Francesco Marzari[23], Maurizio Pajola[3], Hans Rickman[17], Michael A'Hearn[21], Anne-Therese Auger[1], Mohamed El-Maarry[18], Sonia Fornasier[13], Pedro Gutierrez[10], Horst Uwe Keller[9], Matteo Massironi[3], Colin Snodgrass[19], Jean-Baptiste Vincent[14], Cesare Barbieri[24], Philippe Lamy[11], Rafael Rodrigo[2], Detlef Koschny[20], Antonella Barucci[13], Jean-Loup Bertaux[12], Ivano Bertini[3], Gabriele Cremonese[8], Vania Da Deppo[4], Stefano Debei[25], Mariolino De Cecco[5], Clement Feller[13], Marco Fulle[7], Olivier Groussin[1], Stubbe Hviid[6], Sebastian Hoefner[14], Wing-Huen Ip[15], Laurent Jorda[11], Joerg Knollenberg[6], Gabor Kovacs[14], Joerg-Rainer Kramm[14], Ekkehard Kuehrt[6], Michael Kueppers[16], Fiorangela La Forgia[24], Luisa Lara[10], Monica Lazzarin[24], Jose Lopez Moreno[10], Richard Moissl-Fraund[16], Stefano Mottola[6], Giampiero Naletto[22], Nilda Oklay[14], Nicolas Thomas[18], Cecilia Tubiana[14]
**Institution(s):** *1. Aix Marseille Universite, CNRS, LAM (Laboratoire d'Astrophysique de Marseille), 2. Centro de Astrobiologia, CSIC-INTA, 3. Centro di Ateneo di Studi ed Attivita Spaziali "Giuseppe Colombo" (CISAS), University of Padova, 4. CNR-IFN UOS Padova LUXOR, 5. Department of Industrial Engineering – University of Padova, 6. Deutsches Zentrum fuer Luft- und Raumfahrt (DLR), 7. INAF - Osservatorio Astronomico, 8. INAF, Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio, 9. Institut fuer Geophysik und extraterrestrische Physik (IGEP), Technische Universitaet Braunschweig, 10. Instituto de Astrofisica de Andalucia (CSIC), 11. Laboratoire d'Astrophysique de Marseille, 12. LATMOS, CNRS/UVSQ/IPSL, 13. LESIA-Observatoire de Paris, CNRS, Universite Pierre et Marie Curie, Universite Paris Diderot, 14. Max-Planck-Institut fuer Sonnensystemforschung, 15. National Central University, Graduate Institute of Astronomy, 16. Operations Department, European Space Astronomy Centre/ESA, 17. PAN Space Research Center, 18. Physikalisches Institut der Universitaet Bern, 19. Planetary and Space Sciences, Department of Physical Sciences, The Open University, 20. Scientific Support Office, European Space Research and Technology Centre/ESA, 21. University of Maryland, Department of Astronomy, 22. University of Padova, Department of Information Engineering, 23. University of Padova, Department of Physics and Astronomy, 24. University of Padova, Department of Physics and Astronomy, Vicolo dell'Osservatorio, 25. University of Trento, 26. University of Uppsala, Dept. of Physics and Astronomy*

### 413.16 – Comet 67P observations with LOTUS: a new near-UV spectrograph for the Liverpool Telescope

The European Space Agency's Rosetta spacecraft has been orbiting comet 67P/Churyumov-Gerasimenko (hereinafter "67P") since August 2014, providing in-situ measurements of the dust, gas and plasma content of the coma within ~100km of the nucleus. Supporting the mission is a world-wide coordinated campaign of simultaneous ground-based observations of 67P (www.rosetta-campaign.net), providing wider context of the outer coma and tail invisible to Rosetta. We can now compare these observations, augmented by "ground truth" from Rosetta, with those of other comets past and future that are only observed from Earth.
The robotic Liverpool Telescope (LT) is part of this campaign due to its unique ability to flexibly and autonomously schedule regular observations over entire semesters. Its optical imagery has recently been supplemented by near-UV spectroscopy to observe the UV molecular bands below 4000Å that are of considerable interest to cometary science. The LT's existing spectrographs FRODOSpec and SPRAT cut off at 4000Å, so the Liverpool Telescope Optical-to-UV Spectrograph - LOTUS - was fast-track designed, built and deployed on-sky in just five months. LOTUS contains no moving parts; acquisition is made with the LT's IO:O imaging camera, and different width slits for calibration and science are selected by fine-tuning the telescope's pointing on an innovative "step" design in its single slit.
We present here details of the LOTUS spectrograph, and some preliminary results of our ongoing observations of comet 67P.

**Author(s): Jon Marchant[1]**, Helen Jermak[1], Iain Steele[1], Colin Snodgrass[3], Alan Fitzsimmons[2], Geraint Jones[4]
**Institution(s):** *1. Liverpool John Moores University, 2. Queen's University Belfast, 3. The Open University, 4. University College London*

## 414 – Active Asteroids

### 414.02 – The Reactivation of Main-Belt Comet 324P/La Sagra (P/2010 R2)

We present observations using the Baade Magellan and Canada-France-Hawaii telescopes showing that main-belt comet 324P/La Sagra, formerly known as P/2010 R2, has become active again for the first time since originally observed to be active in 2010-2011. The object appears point-source-like in March and April 2015 as it approached perihelion (true anomaly of ν~300 deg), but was ~1 mag brighter than expected if inactive, suggesting the presence of unresolved dust emission. Activity was confirmed by observations of a cometary dust tail in May and June 2015. We find an apparent net dust production rate of <0.1 kg/s during these observations. 324P is now the fourth main-belt comet confirmed to be recurrently active, a strong indication that its activity is driven by sublimation. It now has the largest confirmed active range of all likely main-belt comets, and also the most distant confirmed inbound activation point at R~2.8 AU. Further observations during the current active period will allow direct comparisons of activity strength with 324P's 2010 activity.

**Author(s): Henry H. Hsieh[2]**, Scott Sheppard[1]
**Institution(s):** *1. Carnegie Institution for Science, 2. Planetary Science Institute*

### 414.03 – Evidence for an Impact Event on (493) Griseldis

An extended feature associated with the main-belt asteroid (493) Griseldis has been detected in three R-band exposures of 330 to 350 sec duration spanning 5 hours taken on 2015 Mar 17 UT with the HyperSuprimeCam instrument on the 8-m Subaru telescope. Additional observations of Griseldis were taken with the 6.5-m Magellan telescope on 2015 Mar 21 UT, and the extended feature was still detected, though weaker. No extended feature was detected in one unfiltered 600 sec exposure taken with the 2.2-m University of Hawaii telescope on 2015 Mar 24 UT, or in Magellan images taken on 2015 Apr 18 and May 21 UT. Griseldis is a 46 km diameter P-type asteroid with semimajor axis of 3.12 AU, eccentricity of 0.17, inclination of 15 deg, and Tisserand parameter of 3.187 relative to Jupiter. The heliocentric distance on 2015 Mar