Ground and space observatories:
a joint venture to planetary science

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Goal of the workshop

Exploration of the Solar system and subsequent discoveries are made with planetary missions and ground-based observatories. These two means are complementary from each other, and even sometimes strategically linked as in the case of the Deep Impact mission. Dedicated ground-based observation campaigns in support of planetary missions, as for Cassini-Huygens and Venus Express, have been successfully organized.

During this workshop, we expect to further explore the synergies between these two ways of exploring space, and to foster collaboration between both communities by sharing scientific and technical knowledge, needs, requirements, and techniques. Capabilities of major ground and space based observatories will be discussed. We will take advantage of the workshop location to showcase the current and future capabilities of ALMA for planetary science, and encourage planetary scientists to use this facility.

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Scientific programme

Day 1, Monday 2 March 2015	
08:00 - 09:00	Registration, posters set up
09:00 - 10:30	Welcome + keynote (Eric Villard)
09:00 - 09:10	Welcome by organizers Eric Villard, Olivier Witasse
09:10 - 09:20	Welcome by ALMA Pierre Cox, ALMA Director
09:20 - 09:30	Welcome by ESO Claudio Melo, ESO Director of Science in Chile
09:30 - 10:30	The Revolution in Space and Ground-based Astronomy for Planetary Science (keynote) Michael Mumma
10:30 - 11:00	Coffee break
11:00 - 12:30	Science session 1: Giant planet atmospheres (Bryan Butler)
11:00 - 11:30	Dynamics, Composition and Chemistry of the Giant Planets (invited) Leigh Fletcher
11:30 - 11:45	Longitude-resolved VLA Radio Maps of Jupiter Imke de Pater
11:45 - 12:00	The deep cloud structure of Jovian planets derived from 5-micron spectra Gordon Bjoraker
12:00 - 12:15	Long-term Observations of Jovian Mid-Infrared Aurora, Hydrocarbon Abundances and Temperature: Ground-based and Space based Comparison Theodor Kostiuk
12:15 - 12:30	Highlight of posters
12:30 - 14:00	Lunch (on site) + poster session
14:00 - 15:30	Facility session 1 (Martin Cordiner)
14:00 - 14:20	ALMA capabilities for Planetary Sciences Eric Villard
14:20 - 14:50	The Submillimeter Observatories on Mauna Kea: SMA, JCMT, & CSO (invited talk) Mark Gurwell
14:50 - 15:10	Planetary science with balloons (invited talk) Eliot Young
15:10 - 15:30	Terrestrial planets: Mars Express, Venus Express, Exomars TGO Olivier Witasse
15:30 - 16:00	Coffee break
16:00 - 18:00	Panel discussion

Day 2, Tuesday 3 March 2015	
09:00 - 10:30	Science session 2: Atmospheres of terrestrial planets and moons (Olivier Witasse)
09:00 - 09:30	Jointly Exploring Terrestrial planets using Space and Ground-based observatories: JWST, ExoMars, ELT, TMT, ALMA (invited talk) Geronimo Villanueva
09:30 - 09:45	Space-based (VEx/VIRTIS) and ground-based (CFHT/ESPaDOnS) simultaneous observations of Venus' cloud tops wind circulation regimes. Consistency, complementarity and cross-validation of the Doppler Pedro Machado
09:45 - 10:00	Gravity waves modelization in the upper atmosphere of Venus Alessandra Migliorini
10:00 - 10:15	Comparison of the thermal structure of Venus' mesosphere retrieved by submillimeter ground-based observations with ALMA and by stellar occultations with SPICAV/Venus Express Arianna Piccialli
10:15 - 10:30	Synergistic Planetary Science with the JCMT and ALMA: Applications to Venus Brad Sandor
10:30 - 11:00	Coffee break
11:00 - 12:30	Science session 3: Atmospheres of terrestrial planets and moons (Theodor Kostiuk)
11:00 - 11:30	Upper Atmospheric Studies of Terrestrial Planets (invited talk) Tom Slanger
11:30 - 11:45	Diurnal Variation of Isotope Ratios in Mars Atmospheric Carbon Dioxide Timothy Livengood
11:45 - 12:00	Probing Titan's atmospheric chemistry and dynamics: Cassini/ALMA synergy Martin Cordiner
12:00 - 12:15	Constraining the volcanic contribution to Io's atmosphere with ALMA maps Arielle Moullet
12:15 - 12:30	Investigating variability in Io's volcanic activity and surface frosts Katherine de Kleer
12:30 - 14:00	Lunch (on site) + poster session
14:00 - 15:40	Facility session 2 (Imke de Pater)
14:00 - 14:30	The Very Large Array, Very Long Baseline Array, and Green Bank Telescope Bryan Butler

14:30 - 14:50	Between ground and space: Stratospheric Observatory for Infrared Astronomy (invited talk) Bill Reach
14:50 - 15:20	Ground-Based Support of Past and Future Missions: Galileo, Cassini and Juno (invited talk) Glenn Orton
15:20 - 15:40	The Deep Space Network: A Science Instrument Linking Ground and Space Joseph Lazio
15:40 - 16:10	Coffee break
16:10 - 18:00	Panel discussion

Day 3, Wednesday 4 March 2015	
09:00 - 10:30	Science session 4: Asteroids, TNOs, comets (Arielle Moullet)
09:00 - 09:30	Surface Composition of Asteroids (invited talk) Cristina Thomas
09:30 - 09:45	Radar observations of asteroids and mission support Lance Benner
09:45 - 10:00	Low and High Albedo Jovian Trojans and Hildas: A similar or different origin? Michael Marsset
10:00 - 10:15	Rings in Chariklo, Chiron, and where else? Rene Duffard
10:15 - 10:30	Particle size in Chariklo's wider ring Margaret Pan
10:30 - 11:00	Coffee break
11:00 - 12:15	Science session 5: Asteroids, TNOs, comets (Rita Schulz)
11:00 - 11:30	Trans-Neptunian Objects : recent Advances, Synergy from ground and space-based observations, and Perspectives (invited talk) Miriam Rengel
11:30 - 11:45	Synergy of occultation and thermal infrared measurements of trans-neptunian objects Csaba Kiss
11:45 - 12:00	Stellar occultations by Trans-neptunian objects Jose L. Ortiz
12:00 - 12:15	Volatile Abundances in Comets using IR Spectroscopy: Current Status and Future Observational Prospects Michael DiSanti
12:15 - 13:45	Lunch (on site) + poster session
13:45 - 15:05	Facility session 3 (Katherine de Kleer)
13:45- 14:15	VLT, Gemini, Keck Christophe Dumas
14:15 - 14:45	The NASA Infrared Telescope Facility: Current and Future Plans (invited talk) Alan Tokunaga

14:45 - 15:05	The Rosetta Mission – How to Explore Solar System Formation (invited talk) Rita Schulz
15:05 - 24:00	Social event
	Coordination between space agencies and national observatories Kelly Fast, Rita Schulz

Day 4, Thursday 5 March 2015	
10:00 - 10:45	Science session 6: Exoplanets (Claudio Melo)
10:00 - 10:15	The solar system planets as templates for exoplanet characterization Enric Palle
10:15 - 10:30	Exocomets: a new chapter for planetary science in the ALMA era Luca Matrà
10:30 - 10:45	About the possibility to study different stages of planet formation with ground and space observations Olga Zakhozhay
10:45 - 11:15	Coffee break
11:15 - 11:45	Science session 7: Ground support (Joseph Lazio)
11:15 - 11:30	EPN2020-RI - NA1 Innovation through Science Networking": Supporting synergies between ground-based observations and space missions" Manuel Scherf
11:30 - 11:45	The role of high angular resolution in support of spacecraft missions Albert Conrad
11:45 - 13:30	Lunch (on site) + poster session
13:30 - 15:00	Facility session 4 (Stefanie Milam)
13:30 - 14:00	Solar System science at millimetre wavelengths with IRAM 30m and PdBI/NOEMA instruments (invited talk) Jeremie Boissier
14:00 - 14:30	Hubble and James Webb Space Telescopes: Tools for Solar System Exploration (invited talk) John Stansberry
14:30 - 15:00	New Horizons mission Will Grundy
15:00 - 15:15	Coffee break
15:15 - 16:45	Panel discussion
16:45 - 17:15	Workshop summary Michael Mumma
17:15 - 17:30	Conclusion Eric Villard and Olivier Witasse

Abstracts for the science talks

Radar observations of asteroids and mission support

Lance Benner *(Jet Propulsion Laboratory, California Institute of Technology, USA)*

Radar is an extremely powerful astronomical technique for characterizing near-Earth objects and for refining their orbits. The Goldstone and Arecibo radars can image near-Earth asteroids (NEAs) with resolutions as fine as four meters, which greatly exceeds the finest resolution available from any ground- or space-based optical telescope. Radar images reveal an object's size, shape, spin state, and features on its surface such as craters, valleys, and even large boulders. Among NEAs larger than 200 m in diameter, radar imaging has revealed that ~16% are double and triple systems, that ~15% are contact binaries, and that oblate shapes with pronounced equatorial ridges are relatively common. Two-thirds of binary and both ternary systems have been discovered by radar. Radar can determine the masses of binary NEAs and, in some cases, solitary NEAs through detection of the Yarkovsky effect. Multiple opportunities for high-resolution radar imaging occur annually that yield images that are exceeded in resolution only by spacecraft rendezvous or flyby missions.

Radar echoes from NEAs have revealed stony and metallic objects, featureless spheroids, shapes that are elongated and irregular, monolithic objects, unconsolidated rubble piles, rotation periods ranging from a few minutes to several weeks, objects whose rotation is accelerating, non-principal axis rotators, and surfaces that are extraordinarily rough.

Radar is invaluable for refining orbits of potentially hazardous NEAs. Range-Doppler measurements provide astrometry with resolutions as fine as 4 m in range and ~1 mm/s in velocity, with fractional precisions that are orders of magnitude finer than with optical measurements. Radar astrometry can add centuries to the interval over which we can predict close Earth approaches and dramatically refines collision probability estimates based on optical astrometry alone.

A sequence of radar images can be inverted to estimate an asteroid's 3D shape and spin state, which constrains its formation and evolution and which opens up a number of important geophysical investigations into its dynamical environment that can be very useful for spacecraft planning and navigation. Radar observations have supported numerous asteroid and comet spacecraft missions such as NEAR-Shoemaker, Hayabusa, EPOXI, Dawn, OSIRIS-REx, Rosetta, Chang'e 2, and NEA Scout, and contributed to mission proposals such as Asteroid Retrieval Mission, Aim-Dart, BASiX, Marco Polo-R, Don Quijote, Deep Interior, Galahad, MAX, and Amor. Radar observations have supported missions by orbital improvement; estimation of 3D shapes and spin states; estimation of masses and bulk densities; constraining surface roughness, and estimation of spin states.

The deep cloud structure of Jovian planets derived from 5-micron spectra

Gordon Bjoraker *(NASA/GSFC, USA),* Imke de Pater, Michael H. Wong, Mate Adamkovics, Nancy Chanover, and Tilak Hewagama

The 5-micron window of Jupiter and Saturn provides a wealth of information about the gas composition and cloud structure of the troposphere of these giant planets. Chemical models of their cloud structure predict three distinct layers: an NH3 ice cloud (near 0.5 bars on Jupiter, 1 bar on Saturn), an NH4SH cloud formed from a reaction of NH3 and H2S (2 bars Jupiter, 4 bars Saturn), and a massive water ice cloud (5 bars Jupiter, 10 bars Saturn)[10]. Jupiter and Saturn both exhibit remarkable spatial structure at 5 microns due to the variable opacity of these three cloud layers. Thermal emission at 5 microns originates near the 10-bar level where tau=1 due to pressure-induced H2[2,3]. In a relatively cloud-free Hot Spot, such as where the Galileo Probe entered in 1995, the radiance is an order of magnitude higher than in adjacent cloudy regions. Images at 5 microns reveal information on the morphology of deep cloud features,[6,7], but in order to obtain the pressure level of the clouds, it is necessary to obtain spectra at high spectral and spatial resolution. Some of the same techniques may be applied to probe the deep atmosphere of exoplanets once spectra at 5 microns become available.

Water clouds on Jupiter are very difficult to study. Water ice has been detected in isolated regions where active convection lofted the ice well above its condensation level[9], but water clouds are generally hidden by overlying NH3 and NH4SH clouds. However, spectroscopy at 5 microns can probe levels below Jupiter's upper clouds, unless these clouds are completely opaque. Spectrally resolved line shapes at high spatial resolution allow us to identify the altitude of water clouds on Jupiter and NH4SH clouds on Saturn even when overlying NH3 clouds are present. Absorption lines at 5 microns are pressure-broadened due to collisions with 2 to 10 bars of H2; therefore, they are fully resolved at a resolving power of 20,000 available using ground-based telescopes. Measurements of the pressure of the water clouds when combined with the detection of Doppler-shifted gaseous H2O lines will permit us to characterize the local meteorology in diverse regions on Jupiter.

Hot Spots are characterized by strong pressure-broadened absorption lines at 5 microns. Low-flux regions on both Jupiter and Saturn have weaker, narrower absorption spectra with the line formation region limited to the column above an opaque cloud layer. Jupiter's zones and most regions of Saturn have a substantial component of reflected sunlight. We can quantify this by measuring Fraunhofer lines in the spectra of the giant planets and comparing them with the Sun. If, for example, a Fraunhofer line on Jupiter is half as strong as in the Sun, then this can be explained by equal amounts of reflected sunlight and thermal emission from the deep atmosphere.

In the past two years we have acquired spectra of Jupiter's Great Red Spot, North Equatorial Belt Hot Spots, and the Equatorial Zone. We have also observed the latitudinal variation of cloud structure by aligning the slit North/South on Jupiter. We used both the NIRSPEC spectrometer on Keck and the CSHELL spectrometer on the Infrared Telescope Facility (IRTF) in Hawaii. We observed absorption lines of CH3D and gaseous H2O. Deuterated methane does not condense on Jupiter and the D/H ratio is not expected to vary spatially at the 2 to 6-bar level on Jupiter. Any variation in spectral line shape is therefore entirely due to cloud structure rather than changes in the abundance of methane. We detected gaseous H2O in each of these diverse regions on Jupiter thanks to a large Doppler shift and low humidity above Mauna Kea. We will present preliminary results for the cloud structure and relative humidity in selected regions on Jupiter.

Similarly, we have acquired spectra of Saturn[4,5] showing significant differences in the deep cloud structure between the Equatorial Zone and other regions on the planet. For Saturn it is necessary to use NH3 and PH3 absorption lines to probe the deep cloud structure because the CH3D spectral region is dominated by reflected sunlight rather than thermal emission. Our most recent observations include a region at 40 degrees North that was remarkably cloud-free following the Great Storm of 2010-11.

Our observations of water clouds on Jupiter will be complementary to data to be acquired by the Juno mission en route to Jupiter, which will measure O/H via microwave radiometry[8] as well as column abundances of H2O using JIRAM[1]. These ground-based data will add great value to the interpretation of the JIRAM results by providing a model for the spatial variation of the deep cloud structure on Jupiter. Our gaseous H2O lines sound the same pressure levels as several of the shortest wavelength channels of the Microwave Radiometer on Juno, thus providing complementary information.

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The role of high angular resolution in support of spacecraft missions

Albert Conrad *(LBTO, USA)*, Jarron Leisenring, Katherine de Kleer, Andy Skemer, Philip Hinz, Michael Skrutskie, Christian Veillet, Imke de Pater, Mario Bertero, Patrizia Boccacci, Denis Defrère, Karl-Heinz Hofmann, Andrea la Camera, Dieter Schertl, John Spencer, Gerd Weigelt, Charles E. Woodward

High angular resolution stands as a key technology for synergistic programs that combine ground-based observations with those carried out from spacecraft. We present first ever resolved images of an Io eruption site taken from the ground, images of Io's Loki Patera taken with Fizeau imaging at the 22.8 meter LBT, as a case study for synergy with spacecraft missions -- past, present and future -- Voyager, Hisaki, and IVO. We also present future plans to observe cloud systems on Neptune and ice features on Ceres at high resolution with LBT in the context of current and future space missions.

Probing Titan's atmospheric chemistry and dynamics: Cassini/ALMA synergy

Martin Cordiner *(NASA Goddard, USA)*, C. A. Nixon, M. Y. Palmer, S. B. Charnley, J. Serigano, M. J. Mumma, S. N. Milam, G. Villanueva (NASA Goddard Space Flight Center), P. G. J. Irwin (University of Oxford), N. Teanby (Bristol University), Z. Kisiel (Polish Academy of Sciences), Y.-J. Kuan, Y.-L. Chuang, Kuo-Song Wang (National Taiwan Normal University), D. C. Lis (Observatoire de Paris), A. Remijan (NRAO)

The Atacama Large Millimeter/Submillimeter Array (ALMA) is a unique tool for mapping the distributions and dynamics of molecules in planetary atmospheres. For the first time, snapshot imagery of molecules in Titan's entire Earth-facing hemisphere is possible, and polar species such as HNC and C2H5CN -- not directly observed by Cassini but with strong radio transitions -- are now detectable. We present spectrally and spatially-resolved maps of emission from HNC, HC3N, CH3CN, CH3CCH and C2H5CN on Titan, obtained using ALMA in 2012-2013. Our C2H5CN observations constitute the first definitive measurement of this molecule on Titan, with over 30 resolved rotational emission lines detected. The molecular maps (with angular resolution of about 0.5'') show anisotropic spatial distributions for all observed species, with resolved emission peaks in Titan's northern and southern hemispheres. The HC3N maps indicate enhanced concentrations of this molecule over the poles, consistent with previous Cassini observations. The observed spectral line shapes indicate that HNC and C2H5CN reside predominantly in the mesosphere and above (at altitudes greater than about 400 km), whereas HC3N is abundant at a broader range of altitudes (about 70-500 km). From spatial variations in the HC3N line profile, the locations of the HC3N peaks are shown to be variable as a function of altitude. The integrated emission peaks for HNC and the upper-atmosphere HC3N component (at altitudes above about 300 km) are found to be asymmetric with respect to Titan's polar axis, indicating that the mesosphere may be more longitudinally-variable than previously thought. Between now and the end of the Cassini mission in 2017, combined ALMA and Cassini observations will provide new insights into these phenomena and will facilitate detailed examinations of seasonal variability in Titan's atmospheric temperatures, abundances and wind patterns.

Synergy of occultation and thermal infrared measurements of transneptunian objects

Csaba Kiss *(Konkoly Observatory, Hungary)*, Thomas Mueller, René Duffard, Emmanuel Lellouch

In this contribution we present a new method that uses thermal emission and occultation data together to constrain the main physical properties of transneptunian objects. With this technique the size, shape, thermal properties and axis orientation of these bodies can be determined with a much higher accuracy than with occultations and thermal emission modeling alone. A case study is presented for the dwarf planet Eris, using the latest thermal infrared measurements obtained with the Herschel Space Observatory.

Investigating variability in Io's volcanic activity and surface frosts

Katherine de Kleer *(University of California, Berkeley, USA)*, Imke de Pater, UC Berkeley

Volcanic activity on Jupiter's moon Io exhibits a range of energy scales and thermal signatures, and can be accompanied by the release of volcanic gasses and large plumes. We have been monitoring Io in the near-infrared with adaptive optics imaging at the Keck and Gemini N telescopes for the past year and a half in order to characterize this variability. Such observations allow us to derive a timeline of thermal emission from specific volcanically-active sites, as well as the spatial distribution of Io's sulphur dioxide surface frost from year to year.

We will discuss the potential for using near-infrared adaptive optics observations such as these to help interpret observations of Io's atmosphere at radio wavelengths. Io's atmosphere is believed to be supported by a combination of surface frost sublimation and direct volcanic outgassing, but the relative contribution of each component is still uncertain. We can gain unique insight into this question through analyzing atmospheric observations in conjunction with observations of Io's surface frost distribution and simultaneous thermal activity. The high sensitivity and spatial resolution of ALMA make such investigations possible for the first time from the Earth.

Longitude-resolved VLA Radio Maps of Jupiter

Imke de Pater *(University of California, Berkeley, USA)*

Visible light and 5-micron infrared images of Jupiter reveal the familiar zone-belt structure, where the brown belts appear as warm regions at 5 μm. As clouds are a major source of opacity at this wavelength, the high 5 μm temperatures are indicative of no or relatively thin cloud decks so that deeper warmer layers are probed. In the mid-eighties microwave images at 1 – 6 cm showed a similar zone-belt structure, where deeper warmer layers were probed in the belts, due to a lower NH3 abundance in the belts than in the zones. Conventional radio interferometric images are integrated over many hours to meet the required sensitivity and to use Earth rotation synthesis to achieve good sampling of the Fourier plane. Consequently, any potential structure in longitude is smeared out in such maps. In 2004, we published an innovative technique to synthesize together many hours of radio data to produce a longitude-resolved map [1]. This map showed the hot spots on Jupiter very clearly, and we showed that the NH3 gas abundance must be depleted significantly down to several bars in these hot spots.

This past year we embarked on a program to map Jupiter at multiple wavelengths with the much-improved (order of magnitude in sensitivity) VLA. In this talk we will present our progress on this program, including showing our first longitude-resolved maps of Jupiter at the X (3.6 cm) and Ku (2 cm) bands. We will compare these maps with maps produced by the amateur community at optical wavelengths, with similar resolution. We will also present radiative transfer calculations of a select number of features, and summarize the advantages and challenges we face in interpreting these data.

[1] Sault, R.J., C. Engel, and I. de Pater, 2004. Longitude-resolved Imaging of Jupiter at λ=2 cm. Icarus, 168, 336-343.

Volatile Abundances in Comets using IR Spectroscopy: Current Status and Future Observational Prospects

Michael DiSanti *(NASA-Goddard Space Flight Center, USA)*, Boncho P. Bonev, Geronimo L. Villanueva, Lucas Paganini, Erika L. Gibb, Michael J. Mumma

More than any other Solar System material, the ices in comets retain vital information related to their formation, thus their composition should reflect natal conditions plus potential processing in the proto-solar nebular environment (Mumma and Charnley 2011 ARAA 49). Modern near-infrared ($\lambda \sim 1 - 5$ μm) spectroscopy allows measurement of a suite of molecules having vibrational bands falling within this wavelength range. Comparing abundances of the chemically related oxidized carbon molecules CO, H2CO, and CH3OH provides one measure of the efficiency of H-atom addition reactions on pre-cometary grains, and also a more complete picture of their inventory with other volatile abundances (most notably H2O, C2H2, CH4, C2H6, HCN, and NH3). Comparing among the approximately 30 comets measured to date has permitted building an emergent taxonomy based on volatile composition.

There are currently available two long-slit spectrographs, both on Maunakea, HI – CSHELL at the NASA-Infrared Telescope Facility (IRTF) and NIRSPEC at Keck 2 – that feature the high spectral resolving power (typically $\lambda/\Delta\lambda$ = 2 – 3 x 10^4) required for isolating individual molecular emission lines. CSHELL is the legacy instrument of this type (Tokunaga et al. 1990 Proc SPIE 1235). Its limited spectral grasp (coverage per echelle setting) requires judiciously targeting molecular emissions that can be co-measured with H2O or OH prompt emission (OH*) – a direct proxy for the production and spatial distribution of water vapor in comets (Bonev et al. 2006 ApJ 653:774). Unlike CSHELL, which operates in a single echelle order, NIRSPEC is cross-dispersed (McLean et al. 2000 Proc SPIE 4008), with successive echelle orders displaced spatially on its detector array. A single NIRSPEC setting affords simultaneous measures of trace volatiles and H2O, but three settings are needed to span inter-order gaps and provide complete wavelength coverage.

A significant further advance will be provided by a new facility IR spectrograph (iSHELL) at the IRTF, replacing CSHELL in late 2015 or early 2016 (Rayner et al. 2012 Proc SPIE 8446). It will incorporate the latest array detector and silicon immersion grating technologies, will deliver $\lambda/\Delta\lambda$ up to 70,000, and will have continuous wavelength coverage through most of the L-band (wavelengths short-ward of about 4 μm). For example, a single iSHELL setting that spans 3.32 - 3.62 μm will provide simultaneous and full spectral coverage of H2CO (in two vibrational bands) and CH3OH (in three bands), co-measured with multiple emissions from OH*, C2H6, and CH4. Between 4.58 and 4.93 μm, iSHELL will co-measure the isotopes 12CO and 13CO, together with carbonyl sulfide (OCS) and H2O. Most significantly, unlike CSHELL this instrument will feature an IR slit-viewing camera and, coupled with the unique ability (among IR platforms) to conduct daytime observations at the IRTF, this will greatly extend our studies of comets, particularly those with limited solar elongation angle at which time they are typically most productive.

Despite these advances, CO2 remains unobservable from the ground because of atmospheric opacity. This form of volatile oxidized carbon has in recent years assumed a previously unappreciated but highly important role, particularly owing to the paradigm-shifting survey by the AKARI spacecraft, which identified a newly established class of CO2-rich comets. We expect JWST to play a crucial role in measuring CO2 in comets, through its fundamental vibrational band centered at 4.26 μm. Additionally, JWST will measure fundamental transitions of H2O, and so will greatly extend sensitivity to comets with lower gas productivities and larger heliocentric distances, compared to ground-based observations (these are restricted to weaker, non-resonant bands of H2O owing to atmospheric opacity). Our current taxonomy, and prospects for future ground-based and space-based observations will be discussed.

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Rings in Chariklo, Chiron, and where else?

Rene Duffard *(Instituto de Astrofisica de Andalucia - CSIC, Spain),* Pinilla-Alonso, N.; Alvarez-Candal, A.; Sicardy, B.; Braga-Ribas, F.; Santos-Sanz, P.; Morales, N.; Fernandez-Valenzuela, E.

The intriguing behavior of the absolute magnitude of Chariklo and Chiron was solved this year. The discovery of a ring system around Chariklo using the stellar occultation technique allowed us to look at the Centaurs photometry from a different point of view. The computation of the brightness from a ring system whose tilt angle changes with respect to the observer can explain the long term variations in the absolute photometry of Chariklo and Chiron. Besides, the depth of water ice band features in the spectra of Chariklo and Chiron is correlated with the tilt of the ring systems, revealing that the rings contain water ice, like in the saturnian rings. The formation mechanisms for these rings is not well known yet, but ring systems might be ubiquitous in centaurs and small TNOs, and maybe in other bodies. We are implementing a search campaign using ground-based and space-based telescopes to discover more examples.

Dynamics, Composition and Chemistry of the Giant Planets

Leigh Fletcher *(University of Oxford, United Kingdom)*

The gas and ice giants of our solar system are the closest representatives of a broad class of astrophysical objects, spanning from the coldest H2-rich giants to the hottest exo-Jupiters and Brown Dwarfs. Infrared remote sensing from a variety of ground-based and space-based observatories, using both reflected light and thermal emission, allows us to characterise the environmental conditions prevailing on these gaseous worlds and to study their climates as a function of their bulk composition, thermal evolution and the importance of solar energy deposition. Thermal-infrared imaging and spectroscopy allows determinations of the 3D temperature and cloud structure, as well as the spatial distributions of key volatiles (e.g., NH3 humidity), disequilibrium species (PH3, para-H2) and photochemical products (e.g., stratospheric hydrocarbons). These can be used as (i) tracers of giant planet circulation, from the characteristic belt/zone structure to large-scale seasonal inter-hemispheric overturning; (ii) indicators of the dominant thermochemical and photochemical reactions; and (iii) signatures of the bulk composition of the giant planets imprinted at the time of planetary formation. In this talk I will summarise key recent results that have required the combination of multiple ground- and space-based facilities (notably the Cassini spacecraft at Saturn), focussing on time-variable storm activity and upheavals to the banded structures of the four giant planets. These spectacular eruptions provide insights into the sources of energy hidden deep below the visible clouds, and reveal how energy is transported from the convective weather layer into the stable upper atmosphere.

Long-term Observations of Jovian Mid-Infrared Aurora, Hydrocarbon Abundances and Temperature: Ground-based and Space based Comparison

Theodor Kostiuk *(NASA Goddard Space Flight Center, USA),* Tilak Hewagama (UMD/GSFC), Timothy Livengood (UMD/GSFC), Kelly Fast (NASA HQ), Gordon Bjoraker (NASA/GSFC), Ronald Carlson (Catholic U. A.), Donald Jennings (NASA/GSFC), Frank Schmoelling (DLR), G. Sonnabend (U. Cologne/RPG)

Previously acquired spectral data in the thermal infrared wavelength region acquired from ground-based observatories as well as by Voyager IRIS and Cassini CIRS during Jupiter flybys will be investigated using current improved methods and capabilities. The thermal (mid-) infrared aurora from Jupiter's polar regions, hydrocarbon abundances and thermal structure retrieved form the ground and space based investigations will be compared and used to illustrate the different capabilities and complementarity of the measurement platforms. We report on the reexamination and re-analysis of hydrocarbon emission spectra from Jupiter obtained using ground based ultra-high spectral resolution infrared heterodyne spectroscopy (IRHS) and Fourier transform spectroscopy (FTS) from Cassini CIRS during its flyby of Jupiter in 2000-2001 and Voyager IRIS data obtained during flybys in 1979. Measurements with IRHS were made over 30 years, primarily of ethane near 12 micrometer wavelength. They provide fully resolved individual spectral lines whose shape provides unique information on variability of temperature and abundance. CIRS and IRIS data at lower spectral resolution provide extended spatial distributions and cover a broad spectral region including abundances and auroral response of ethane as well as several other hydrocarbons in the 8 - 13 micrometer wavelength region (methane, ethylene, and acetylene). These spectra are radiometrically calibrated and can serve as a sensitive thermometer of the Jovian atmosphere. Recently improved analysis techniques show detailed spatial enhancements of the primary hydrocarbons in northern latitudes. Temporal changes of the ethane line emission over three solar cycles and comparison of retrievals from ethane data taken contemporaneously during the Cassini flyby by both techniques will be compared and results discussed.

Results will be useful for the Juno mission in 2016, since it does not have instrumentation in this spectral region and this work provides complementary information and diagnostic for studying Jupiter in a spectral region and altitude range not directly probed by Juno.

Diurnal Variation of Isotope Ratios in Mars Atmospheric Carbon Dioxide

Timothy Livengood *(CRESST/UMD/GSFC, USA)*, Theodor Kostiuk, NASA/GSFC; John Kolasinski, NASA/GSFC; Tilak Hewagama, UMD/GSFC; Wade G. Henning, CRESST/UMD/GSFC; Manuela Sornig, Rhenish Institute for Environmental Research; Tobias Stangier, University of Cologne; Pia Krause, University of Cologne; Guido Sonnabend, Radiometer Physics GmbH; Hiromu Nakagawa, Tohoku University; Paul R. Mahaffy, NASA/GSFC

The atmosphere of Mars has been shown by ground based high-resolution infrared spectroscopy and in situ measurements with the Phoenix lander and Mars Science Laboratory Curiosity rover to be enriched in C and O heavy isotopes, consistent with preferential loss of light isotopes in eroding Mars' primordial atmosphere. The relative abundance of heavy isotopes, combined with contemporary measurements of loss rates to be obtained with MAVEN, will enable estimating the primordial atmospheric inventory on Mars. IR spectroscopy of Mars collected in May 2012 as well as in March and May of 2014 from the NASA IRTF has resolved transitions of all three singly-substituted minor isotopologues of carbon dioxide in addition to the normal isotope, enabling remote measurements of all the carbon and oxygen isotope ratios as a function of latitude, longitude, and time of day. Earlier measurements obtained in October 2007 demonstrated that the relative abundance of O-18 increased linearly with increasing surface temperature over a relatively warm early-afternoon temperature range, but did not extend far enough to inspect the effect of late-afternoon cooling. These results imply that isotopically enriched gas is sequestered overnight when surface temperature is minimum and desorbs through the course of the day as temperature increases. Current spectroscopic constants indicate that the peak isotopic enrichment could be significantly greater than what has been measured in situ, apparently due to sampling the atmosphere at different time of day and surface temperature. The observing runs in 2012 and 2014 measured O-18 enrichment at several local times in both morning and afternoon sectors as well as at the subsolar, equatorial, and anti-subsolar latitudes. The two runs in 2014 have additionally observed O-17 and C-13 transitions in the morning sector, from local dawn to noon. These observations include a limited sampling of measurements over Gale Crater, which can be compared with contemporary in situ measurements by the Curiosity rover to investigate the degree of agreement between in situ and remote methods and potentially to calibrate the spectroscopic constants required to accurately evaluate isotope ratios all over Mars.

Space-based (VEx/VIRTIS) and ground-based (CFHT/ESPaDOnS) simultaneous observations of Venus' cloud tops wind circulation regimes. Consistency, complementarity and cross-validation of the Doppler velocimetry and cloud tracking techniques

Pedro Machado *(Institute of Astrophysics and Space Sciences, Portugal)*

We present results based on inter comparison of ground-based Doppler velocimetry of cloud-top winds and cloud tracking measurements from the Venus Express spacecraft. We will discuss the consistency and the complementarity between space-based and ground-based observations in our project. Our analysis technique allows an unambiguous characterization of the zonal wind latitudinal, local time profile and its temporal variability (Machado et al., 2014). We present the first detection from the ground of a poleward meridional wind flow on the morning dayside hemisphere. Doppler wind velocimetry obtained with the 3.60 m Canada-France-Hawaii telescope

(CFHT) and the Visible Spectrograph ESPaDOnS. We compared our measurements with simultaneous observations using the VIRTIS instrument from the VEx orbiter.

Low and High Albedo Jovian Trojans and Hildas: A similar or different origin?

M. Marsset *(ESO, Chile)*, P. Vernazza, F. Gourgeot, C. Dumas, M. Birlan, P. Lamy, R. P. Binzel

Jupiter Trojans and Hilda asteroids are small primitive bodies located near or beyond the snow line, around respectively the L4 and L5 Lagrange points of Jupiter at ~5.2 AU from the sun (Trojans) and in the 2:3 mean-motion resonance with Jupiter near 3.9 AU (Hildas). Our current understanding of the early dynamical evolution of the Solar System tells us that they probably originated from the primordial transneptunian region from which they were captured in their current location (Nice model; [1, 2]). In addition, this region not only comprised planetesimals formed beyond the snow line (D-, T- and X-type asteroids) but also a minor population of rocky interlopers (e.g., A-, S-, V-type asteroids) that migrated outward during the very early evolutionary phases of the Solar System 5 to 7 My after its formation (Grand Tack model; [3]). The recent discovery by WISE [4, 5] and Spitzer [6] of high albedo (p_V ~ 0.15) asteroids within jovian Trojans and Hildas opened the possibility of an observational evidence for the presence of a small fraction (~2 %) of such interlopers among these two low albedo (p_V ~ 0.07) populations. We report the very first spectroscopic characterization of a sample of high albedo Trojans and Hildas obtained with X-SHOOTER and SpeX in the visible and/or near-infrared ranges. This study allows us to investigate the origin of these high albedo objects and to provide an estimate of the contamination rate of jovian Trojans and Hilda asteroids by objects that do not belong to the C/T/D-type complex (e.g., A-, S-, V-type asteroids), thus constraining migration models [1, 2, 3, 7, 8]. The results of this study will be presented in details.

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Exocomets: a new chapter for planetary science in the ALMA era

Luca Matrà *(ESO / Institute of Astronomy, University of Cambridge, Chile)*, William Dent (ALMA, Santiago), Mark Wyatt (Institute of Astronomy, University of Cambridge)

Analogously to our Solar System, cometary bodies are an integral part of exoplanetary systems, where they are part of debris disks with solid masses that can be several orders of magnitude higher than in our own Kuiper belt. This causes a much higher level of collisions and consequent release of a substantial amount of volatile species. The relative youth of these systems also contributes, since we expect 1) an enhanced volatile/rock ratio in comets and 2) planetary dynamics acting to stir the comet population and cause enhanced collisions / Late Heavy Bombardment events. However, host stars need not be Sun-like and the lifetime of the released volatiles and circumstellar environments can vary considerably. So far, it has been prohibitive to detect this so-called secondary generation gas, with the few detections favoured by either the geometry or the extreme youth of planetary systems. The increased sensitivity of ALMA, however, will allow us not only to detect, but also characterise the volatile component of exocomets, through analysis of sub-mm lines, e.g. from CO, C, HCN. I will present early results from ALMA observations and modelling of cometary gas in the Beta Pictoris system, and review results and current efforts for other detected systems. Finally, I will consider future prospects and discuss the need for synergy between the Solar System comet and the debris disk communities in the ALMA era.

Gravity waves modelization in the upper atmosphere of Venus

Alessandra Migliorini *(IAPS-INAF, Italy)*

Oxygen nightglow emissions are well-known features to track the atmospheric circulation in the terrestrial planets. In this work, the observations in the IR spectral range of the O2(a1Δ) emissions at 1.27 μm with VIRTIS on board Venus Express are used to study the gravity waves properties in the upper mesosphere of Venus. We analyzed the profiles acquired at limb during the mission period from 2006-07-05 to 2008-08-15. Among the observed profiles, some show double peaked structures that can be attributed to gravity waves action.

Similarly to the Earth's and Mars cases, the model developed by Swenson and Gardner (1998) is applied to investigate how the O2 nightglow emissions are modified by the gravity waves propagations. Gravity waves properties, like vertical wavelength and wave amplitude are discussed. On average, the double peaked profiles are compatible with the effect of gravity waves with vertical wavelength ranging between 7 and 16 km, and a wave amplitude of the order to 3-14 %. The intrinsic horizontal phase velocity is estimated to vary in the range 32 m/s and 85 m/s. Further details are described in Altieri et al. (2014).

The positive detections are located in the mid to high latitudes region; however we cannot exclude a different explanation for the double peaks features observed in the O2 nightglow.

Constraining the volcanic contribution to Io's atmosphere with ALMA maps

Arielle Moullet *(NRAO, USA)*, E. Lellouch, M. Gurwell, R. Moreno, J. Black, B. Butler

Io's atmosphere is mostly likely fed by volcanic plume outgassing and SO2 frost sublimation. However the relative contributions of those different sources are still poorly understood. To better constrain them it is necessary to establish with good precision the spatial distribution of the atmosphere.

We used the Atacama Large Millimeter Array (ALMA) to map simultaneously the distribution of SO2, SO and KCl. The observations obtained, while achieving only a modest improvement in angular resolution (down to 0.45" in the longitudinal direction), are of much better quality than previous (sub)millimeter maps thanks to the high sensitivity of ALMA. The maps clearly demonstrate that each atmospheric component displays a strikingly different spatial distribution. SO2, the main component, appears to be relatively spread out in a latitudinally-bound equatorial band, which is consistent both with previous HST observations and the hypothesis of a mainly sublimation-sustained bulk atmosphere on the day-side. On the other hand, KCl, for which we are presenting the first significant detection, is limited to small areas. This suggests it is only present in active volcanic plumes and quickly condenses once outside the plumes. Finally the SO distribution roughly traces the spread out distribution of SO2, but its offset emission maximum is indicative of an additional distinct source.

The Revolution in Space and Ground-based Astronomy for Planetary Science

Michael Mumma *(NASA Goddard Space Flight Center, USA)*

The interplay of space- and ground-based observations is crucial to the success of planetary science. Earth-based observatories have played and will continue to play a central role, by establishing the scientific context for space missions, expanding their discoveries during the operational phase, and later extending their legacy to bodies and processes not covered during their lifetimes.

A new Era has opened with ALMA now operational, the SKA and ELT approved, LSST, GMT and TMT under development, and still other ground-based telescopes in the pre-proposal stage. In the space arena, GAIA has begun its science mission, MAVEN is now exploring Mars, and ExoMars 2016 (Trace Gas Orbiter) is 10 months from launch (with ExoMars 2018 & NASA's Mars 2020 to follow). James Webb Space Telescope is under construction, Millimetron is approved, ATLAS is under consideration, and other space observatories are in the dream stage.

Ground-based interests are marshaling forces to meet these challenges. Mounting campaigns of a focused nature with combinations of observatories is now a common theme. At this Conference we will explore specifics for exploiting the emergent observational capabilities to challenge the frontiers of planetary science in the coming decade. I will provide an overview of the frontiers today, and will attempt to provide a glimpse of them 10 years from now.

Stellar occultations by Trans-neptunian objects

Jose L. Ortiz *(Inst. Astrofisica Andalucia CSIC, Spain)*, B. Sicardy, F. Braga-Ribas, the Granada team, the Paris team and Rio team

The best way to derive physical properties of solar system bodies is to send spacecraft to observe them. Probably the second best means to learn about important physical properties of solar system objects is through stellar occultations. Trans-Neptunian Objects (TNOs) are very important solar system bodies that deserve being studied through this technique. Since October 2009, around twenty occultations by Trans-Neptunian Objects other than Pluto have been detected, thanks to the efforts of several teams. Due to the complications of accurately predicting and observing these events, most of the successes have been achieved by an international collaboration of three main teams that coordinate different important aspects, but there have also been other successes in the field. Thanks to the future GAIA stellar astrometry and thanks to specific efforts from the ground to determine accurate orbits for TNOs we will soon be able to observe stellar occultations by an increasingly large number of TNOs. Here we will present some results from stellar occultations by TNOs and some of our plans for the future in this regard.

The solar system planets as templates for exoplanet characterization

Enric Palle *(Instituto de Astrofisica de Canarias, Spain)*

Over the past decades a large diversity in planetary systems, accompanied by a large diversity of planetary natures, have been discovered. Nevertheless, despite probable surprises, our knowledge of the solar system planets will be our guidance in the interpretation of the physical properties of extrasolar planet atmospheres. Thus, the solar system offers a unique playground to determine the best observables for such planet characterization. In the past few years, our group has performed observations aimed at retrieving the reflection and transmission spectrum of some of the solar systems planets. These observations include the transmission spectrum of Earth (via a lunar eclipse), the transmission spectrum of Venus (via the transit of Venus in 2012 observed from SOFI) and the transmission spectrum of Jupiter (via a Ganymedes eclipse). Together they have revealed a wealth of new information, such as the detectability of dimer bands (usable as tracers of atmospheric pressure) in earth-like planets, or the signatures of aerosols, hazes and metallic layers in giant planets. Here I am planning to offer a review of the observational setup of these observations, and what they have revealed about Earth, Venus and Jupiter.

Particle size in Chariklo's wider ring

Margaret Pan *(University of Toronto, Canada)*, Yanqin Wu

Recent observations of Centaur 10199 Chariklo indicate that it is an oblate spheroid with oblateness ~0.2 and that its wider ring has an eccentricity of order 0.1 (Braga-Ribas et al. 2014, Sicardy et al. 2014). In such a narrow ring, this eccentricity requires apse alignment among the ring particles, ie that the entire ring precess at a single rate. Assuming that Chariklo's oblateness, ring self-gravity, and particle collisions conspire to maintain the apse alignment, we estimate the ring’s total mass and the maximum ring particle size as well as the ring's eccentricity profile.

Comparison of the thermal structure of Venus' mesosphere retrieved by submillimeter ground-based observations with ALMA and by stellar occultations with SPICAV/Venus Express

Arianna Piccialli *(LESIA-Observatoire de Paris, France)*, R. Moreno, T. Encrenaz, F. Montmessin, T. Fouchet, E. Lellouch, A. Moullet, T. Widemann, J.-L. Bertaux

Venus upper atmosphere (70 – 150 km altitude) is one of the most intriguing regions on the planet. It corresponds to a transition region characterized by a complex dynamics and circulation: strong retrograde zonal winds dominate the lower mesosphere while a solar-to-antisolar circulation driven by a day-to-night temperature gradient can be observed in the upper mesosphere/lower thermosphere [1]. Density and temperature profiles of Venus upper atmosphere have been measured from both ground-based [2,3,4] and spacecraft missions [5,6]. The thermal structure of Venus upper mesosphere/lower thermosphere shows a significant variability both on day-to-day as well as longer timescales. More recently, a layer of warm air has been detected at altitudes of 90 – 120 km on the nightside both by SPICAV/SOIR [7,8] and by ground-based [3] observations.

Ground-based observing campaigns of Venus were organized in support of space exploration observations since the early stage of Venus Express operations in 2006 [2,3,4]. Earth-based observations provide complementary information to spacecraft data by allowing a complete view of the planetary disk at a given time and a long-term coverage, which is of particular interest in view of the approaching end of Venus Express operations.

The Atacama Large Millimeter Array (ALMA) offers a unique opportunity of probing Venus' upper mesosphere (60 – 120 km) and of monitoring minor species, winds and the thermal structure. A first set of observations was obtained in November 2011 during the first ALMA Early Science observation cycle [9,10]. These observations targeted SO2, SO, HDO and CO transitions around 345 GHz during four sequences of 30 minutes each. The Venus' disk was about 11" with an illumination factor of 90%, thus most of the observations were acquired on the dayside.

The SPICAV (Spectroscopy for the investigation of the characteristics of the atmosphere of Venus) instrument has been operating on board of the European spacecraft Venus Express since 2006 [11]. In the stellar occultation mode the ultraviolet channel (118 – 320 nm) offers the possibility to probe the nightside of Venus upper atmosphere. It provides CO2 local density and temperature vertical profiles of Venus upper atmosphere (90 – 140 km) with a vertical resolution ranging from 500 meters to ~ 7 km. Recently, the entire SPICAV database, collected during seven years of operations, was analyzed [12]. The thermal structure of Venus mesosphere and thermosphere measured by SPICAV shows a large temporal and spatial variability.

Here, we report on the first ALMA retrievals of CO thermal vertical profiles obtained over the entire disk of Venus on November 14, 15, 26, and 27, 2011. We analyze both latitudinal and temporal variations and compare the results to SPICAV/VEx vertical temperature profiles.

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Trans-Neptunian Objects : recent Advances, Synergy from ground and space-based observations, and Perspectives

Miriam Rengel *(Max-Planck-Institut fuer Sonnensystemforschung, Germany)*

More than 1400 small bodies inhabit the region beyond Neptune. These remote and cold objects are called trans-Neptunian (TNOs) and represent the primitive remnants of the disk from which the planets formed. The physical properties of these TNOs are largely unexplored and the thermal properties are difficult to measure. I will review recent advances in this field, focusing on studies combining ground and space-based observations and sophisticated models to interpret the data, which have been reporting physical and thermal properties of a growing sample of TNOs and Centaurs.

These findings are of significance because they provide unique and important constraints on the almost unprocessed material coming from the frontiers of the Solar System, and on the formation and evolution of the Solar System itself.

Synergistic Planetary Science with the JCMT and ALMA: Applications to Venus

Brad Sandor *(Space Science Institute, USA)*, R. Todd Clancy (Space Science Institute)

Understanding of phenomena that are strongly variable in both space and time requires an investigational strategy in which both spatial resolution and temporal sampling of the observations are optimized to provide information at the both the spatial and temporal scales most appropriate to the scales at which the respective spatial, temporal variations occur. ALMA offers unprecedented capability for spatial resolution of planetary atmospheres at submm wavelengths, but with less flexibility to optimize temporal sampling. Some aspects of its temporal sampling constraints are fundamental (eg. impossibility of matching timescale of array configuration changes to the range of timescale variations exhibited by planetary atmospheres). Others will be relaxed in ALMA's ongoing development, but optimization for time sampling neither is nor should be among ALMA's highest priorities. The JCMT operates at many of the same frequencies as ALMA, and like most single-dish instruments, it has inherent flexibility capability for time sampling. JCMT observations of the Venus atmosphere have revealed geophysical variations on timescales ranging from hours to a decade. As one example (among many), JCMT data show abundances of SO and SO2 vary between Venus dayside and nightside, over the observational timescale of the 19 month Venus phase cycle, but also are strongly variable by a factor of two at fixed local time over a 1 week period, with both timescale variations defined in terms of JCMT's measurement of a spatial average of the entire Venus sub-Earth disk. Only JCMT can provide the necessary number of measurements on daily, weekly, monthly, yearly intervals to separate the multiple timescales of each process driving temporal variation. However, only ALMA can provide the spatial resolution needed to characterize diurnal variation at local time resolution better than day vs night, and only ALMA can adequately investigate possible latitude variation of SOx. Only by using both ALMA and the JCMT can sulfur chemistry of the Venus mesosphere be fully investigated. While this talk will focus on applications to Venus, the importance of synergistic use of ALMA and the JCMT is not confined to Venus sulfur chemistry, is not confined to Venus, and is not confined to specifically leveraging the complementary capabilities for spatial vs temporal resolution. Broader applications will be discussed.

EPN2020-RI - NA1 "Innovation through Science Networking": Supporting synergies between ground-based observations and space missions

Manuel Scherf *(Space Research Institute, Austria)*, A.-M. Harri, K. Szego, N. Krupp, G. Kargl, N. Mason, S. Miller

The potential future EU-Horizon 2020 research infrastructure EPN2020-RI builds on the foundations of the highly successful FP6 and FP7 Europlanet programmes and is intended to kick off in summer 2015. In FP7 the Europlanet Networking Activity 1 (NA1) already promoted synergies between ground- and space-based observations, mainly via the funding of workshops with the focus on the organisation of dedicated ground-based observation campaigns in support of space missions. Examples of past workshop-highlights, which were supported and organised within Europlanet-NA1 are the Workshop on "Planning of Rosetta Ground-Support" which culminated in a major observational campaign (see http://www.rosetta-campaign.net/), as well as the workshop series on ground-based observations in support of Venus Express.

Within the hopefully upcoming EPN2020-RI the Work Package Networking Activity 1 "Innovation through Science Networking" will continue its support and enhance its work to strengthen the planetary sciences community. A highly important task of NA1 will again be the funding and organization of dedicated workshops for the coordination of ground-based observation campaigns to explore synergies to space missions like Rosetta, Venus Express, or upcoming missions like Juice or Bepi-Colombo.

This presentation will give a short overview on EPN2020-RI as a whole and in particular on NA1 "Innovation through Science Networking" with the focus on its specific task towards the support and organization of combined ground- and space-based observation campaigns.

Upper Atmospheric Studies of Terrestrial Planets

Tom Slanger *(SRI International, USA)*

All planets produce atmospheric emissions, by various processes. In the terrestrial atmosphere we see nightglow, dayglow, and aurora. Dayglow is ubiquitous through its solar high energy source, and its nature is coupled to the gross atmospheric composition. Thus, Mars and Venus will have similar dayglows, distinct from the terrestrial version. Planets with magnetic fields show aurora, which tend to be similar to their dayglows. Nightglows of the three terrestrial-like planets are generally a consequence of the same process - oxygen atom recombination - although the products may differ.

Nightglow studies of the Earth and Venus have advanced in recent years with the aid of broadband high-resolution instruments, specifically cross-dispersed echelle spectrographs. These are standard on most large telescopes, and we have taken advantage of the fact that sky spectra are routinely generated by astronomers at these facilities. These are spectra of the blank sky, for subtraction from stellar spectra, and result in superb representations of the nightglow. An atlas is available of 2800 spectral lines seen with the UVES spectrograph at the VLT [Cosby et al., 2006].

With the same class of instruments, i.e. HIRES at Keck I and ARCES at APO, we have targeted the nightside of Venus, confirming the O2 Herzberg II emission reported many years ago [Krasnopolsky et al., 1976], and sporadically finding the oxygen green line emission (557.7 nm), apparently related to CME episodes from the sun [Gray et al., 2014].

In the terrestrial atmosphere, a new high-resolution spectrograph (CESAR) sited in Alaska is revealing new details of auroral emissions. Considering that emissions from the three planets are probably representative of many rocky extra-solar planets, information gathered from the airglows of our local planetary atmospheres will one day lead to the characterization of the composition of distant atmospheres.

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Krasnopolsky, V.A., A.A. Krysko, V.N. Rogachev,and V.A. Parshev, Cosmic Res. 14, 687, 1976.
Work partially supported by NSF (ATM-0723232) and NASA (NNG04GF46G).

Surface Composition of Asteroids

Cristina Thomas *(ORAU/NASA GSFC, USA)*

Knowing the composition of asteroid surfaces enables us to investigate the geologic evolution of individual bodies and the dynamical evolution of the Solar System. Their mineralogies can be investigated remotely by utilizing diagnostic spectral features. The combination of ground and space based telescopes have enabled observations from ultraviolet to thermal infrared wavelengths. This talk will discuss the current state of knowledge regarding the variety of known asteroid compositions and how complementary ground and space-based observations can be used to expand our knowledge of asteroid surfaces and the Solar System as a whole.

Jointly Exploring Terrestrial planets using Space and Ground-based observatories: JWST, ExoMars, ELT, TMT, ALMA

Geronimo Villanueva *(NASA - Goddard Space Flight Center / CUA, USA)*

Orbiting and landed missions to Mars have revolutionized our understanding of the history and evolution of the terrestrial planets in our Solar System, yet little is known about the abundance of trace species and the photochemical / dynamical processes acting on their atmospheres. Recent observations reveal rapid changes of the atmosphere (e.g., Mumma et al. 2009; Smith 2004) and on the surface of Mars (e.g., Malin et al. 2006) that are particularly challenging to detect with current orbiting assets due to restricted spectral resolution and the limited cadence and repeatability of the sampled regions. Isotopic ratios, normally assumed to be invariant and to contain unique evolutionary information, have been found to vary greatly (by an order of magnitude) across Mars and at short time scales (Villanueva et al. 2008).

Within the next decade, unique space and ground-based assets will become available opening unprecedented windows to explore the atmospheres of Mars and Venus. The rich instrumental suite of the James Webb Space Telescope (JWST) will permit sampling Mars from a unique perspective at the second Sun-Earth Lagrange point (L2), while the ExoMars 2016 TGO will sample trace species with unprecedented sensitivities. High-resolution spectroscopy with ground-based observatories (ALMA, ELT, ALMA) will permit the search for complex molecules at record sensitivities and to measure wind velocities with extraordinary spatial resolution and accuracy.

In this talk, I will present the current frontiers in the exploration of terrestrial planets and how the synergies between future space and ground astronomical assets will transform our understanding of the composition, stability and evolution of the atmospheres of Mars and Venus.

About the possibility to study different stages of planet formation with ground and space observations

Olga Zakhozhay *(Main Astronomical Observatory, National Academy of Sciences of Ukraine, Ukraine)*

Based on the modern theory of the planet formation, planetary systems are formed in the protoplanetary disks that could surround young stellar and substellar objects. In the first hundred thousand years, such disks could contain hot and massive fragments. After a few million years, planetary and substellar companions may be detected in protoplanetary disks, and later in debris disks. Disk sizes, masses and structures are determined by the initial core characteristics and can be derived from the central object's physical parameters, assuming a given evolutionary stage. We investigate the possibility to identify the different stages of planet formation with ground and space based observations. We will present the synthetic spectral energy distributions, SEDs (as they would be measured with VLT, SPITZER and HERSCHEL telescopes) and images (as they would be observed with ALMA) of the protostellar disks with active fragmentation and of the protoplanetary and debris disks with embedded planets. The results of our modelling show that at the protostellar stage, planetary formation has the most evident signatures, because the intensity of the hot and massive fragment is comparable to the intensity of the emission that comes from the star, although it is challenging to find a proper observational target because such fragments could survive only for a few tens of thousands of years. The results of our modelling also indicate that it is very difficult to identify a single planet (or even a brown dwarf) in the debris disk with SED profile analysis.

Abstracts for the facility talks

Solar System science at millimetre wavelengths with IRAM 30m and PdBI/NOEMA instruments

Jérémie Boissier *(IRAM, France)*

IRAM is a collaboration between France, Germany and Spain that operate two instruments observing at millimetre wavelengths: the 30m single dish telescope near Granada (Spain) and the NOEMA interferometre on the Plateau de Bure (France). I will present the institute, the instruments in their present state as well as the upgrades that will occur in the near future. The presentation will also contain an overview of the major results that were obtained thanks to observations of Solar System bodies with the IRAM instruments and how such observations can be combined with other ground- or space-based observations in all wavelength domains.

The Very Large Array, Very Long Baseline Array, and Green Bank Telescope

Bryan Butler *(National Radio Astronomy Observatory, USA)*

I will discuss the ability of the National Radio Astronomy Observatory (NRAO) telescopes to observe solar system objects and the possible synergies with spacecraft observations. The telescopes include the Very Large Array (VLA), Very Long Baseline Array (VLBA), and Green Bank Telescope (GBT). All three of these telescopes can perform observations of planetary bodies which can be used to determine properties of solid surfaces, atmospheres, rings, and magnetospheres of these bodies. Observations of thermal emission, reflected emission (radar), and spacecraft signals can all be done with these telescopes. Such long wavelengths are unique in their ability to probe deep into subsurfaces and atmospheres. I will discuss the current state of these instruments, future prospects, and possibilities for improvements.

Facility session (VLT, Gemini, Keck)

Christophe Dumas *(ESO, Chile)*

I will provide an overview of the instrumentation available for studying our solar system at the current 8-10m class ground-based optical facilities.

New Horizons mission

Will Grundy *(Lowell Observatory, USA)*

This talk will describe capabilities and plans for NASA's New Horizons science investigation of the Pluto system and of the Kuiper belt beyond and will explore how this mission fits into the broader context of observational studies of the outer solar system.

The Submillimeter Observatories on Mauna Kea: SMA, JCMT, & CSO

Mark Gurwell *(Harvard-Smithsonian Center for Astrophysics, USA)*

In this talk I will highlight past contributions to solar system astronomy from the three submillimeter facilities located on Mauna Kea, Hawaii. The varied science includes studies of the comae and nuclei of comets, detection of the broad PH3 lines from the tropospheres of Jupiter and Saturn, measurement of molecules and winds in the atmospheres of Venus and Mars, and interferometric imaging of the atmospheres and surfaces of Mars, Titan, and the Pluto-Charon system. I will also discuss current and coming upgrades and their application to solar system observations.

The Deep Space Network: A Science Instrument Linking Ground and Space

Joseph Lazio *(Jet Propulsion Laboratory, California Institute of Technology, USA)*

The Deep Space Network is well known for its role in commanding and communicating with planetary spacecraft that are producing a steady stream of new discoveries. The Deep Space Network antennas, in collaboration with European Space Agency Deep Space Antennas, also are used to perform precision astrometry of spacecraft, which is a critical element of navigating them to their destinations.

However, the antennas within the Deep Space Network are science instruments in their own right, complementing and extending the observations conducted with spacecraft. Using radio science techniques that link a spacecraft and ground antenna, the atmospheres and interiors of solar system objects ranging from asteroids to planets can be probed. Using radar transmissions, surface and sub-surface characteristics of asteroids, moons, and planets can be probed and orbits determined to high precision.

I summarize these science uses for the antennas of the Deep Space Network, highlighting recent discoveries, and sketch the path toward future capabilities and discoveries.

Ground-Based Support of Past and Future Missions: Galileo, Cassini and Juno

Glenn Orton *(Jet Propulsion Laboratory, California Institute of Technology, USA)*

For missions to Jupiter and Saturn, Earth-based observations have provided important support beginning as early as the Pioneer and Voyager missions. The Galileo mission at Jupiter (1995-2003) serves as a quintessential example of how critical support Earth-based observations can be. Because none of the remote-sensing instruments could operate when the Galileo probe descended into the atmosphere, it was left to ground-based experiments to characterize the conditions of the entry site. Despite the difficulty of Jupiter being only 9 degrees from the sun, these results determined that the probe entered one of the most anomalously dry and cloudless regions of the atmosphere, shedding light on why the abundance of water vapor may be been so much lower than expected from the solar O/H ratio. Galileo's limited bandwidth also required ground-based rather than spacecraft observations to predict the location of features of interest to atmospheric scientists. Ground-based observations also provided a global or regional context for observations that were confined to narrow regions, again as a result of the limited downlink capability. The Cassini mission at Saturn (2004-2017) has no similar bandwidth issues, but nevertheless benefits from supporting ground-based observations. For example, a long time series of observations of temperatures provide an extended context for constraining seasonal dependences in global-climate models, and they determined that low-latitude waves detected in profile from limb-sensing measurements constituted a long-term periodic wave structure that might be a 14.7-year semi-annual oscillation. The scientists and engineers associated with the Juno mission at Jupiter (2016-2017) are actively recruiting Earth-based supporting observations. The spin-stabilized spacecraft will only observe narrow swaths of longitude at its low-latitude perijove epochs, and the orbits will track Jupiter's terminator – rendering half of the planet inaccessible to observations of reflected sunlight. The mission instrument complement is quite spare regarding remote sensing: there is no scientific-grade CCD imaging and no mid- or far-infrared camera or spectrometer. Thus it will be up to Earth-based experiments to supply the spectral context to determine upper-tropospheric and stratospheric temperatures, upper-tropospheric trace constituents, and auroral-related heating and chemistry, mid-level cloud properties. In addition, it will be up to Earth-based measurements to supply the badly needed spatial context and provide more continuous monitoring of both meteorological and auroral phenomena from a variety of experiments.

Between ground and space: Stratospheric Observatory for Infrared Astronomy

William Reach *(USRA, USA)*

The Stratospheric Observatory for Infrared Astronomy (SOFIA) flies above 99% of the water in the Earth's atmosphere, enabling observations at infrared wavelengths. It is also a mobile platform, allowing occultation observations from optimal locations. This presentation covers the scientific capabilities and logistical and data analysis challenges for planetary science.

The Rosetta Mission – How to Explore Solar System Formation

Rita Schulz *(ESA/SSO/ESTEC, Netherlands)*

In summer 2014 ESA's Rosetta spacecraft has rendezvoused with Jupiter-family comet 67P/Churyumov-Gerasimenko, went in orbit around the nucleus and is escorting it along its way toward perihelion. On 12 November 2014 the Philae lander performed the first ever landing on a comet nucleus and provided in-situ measurements of its physical and compositional properties. With the 12 scientific instruments on board the Orbiter, Rosetta is investigating the comet nucleus and the coma, and their evolution as a function of increasing solar flux input. An overview of the Rosetta mission will be given with special emphasis on the capabilities of its scientific payload.

Hubble and James Webb Space Telescopes: Tools for Solar System Exploration

John Stansberry *(Space Telescope Science Institute, USA)*

The Hubble Space Telescope has made many significant, highly diverse contributions to our understanding of the Solar System. HST observations have been key for understanding the atmospheres of the giant planets, for exploring binary systems in the Kuiper Belt, characterizing plumes from Io and Europa, recording the effects of the Shoemaker-Levy 9 impacts on Jupiter, resolving surface features on large asteroids, studying Martian seasons, and mapping the surface of Pluto, among other things. In addition to its scientific impact, HST observations of our Solar System have resulted in 180 press releases so far, generating significant public support for astronomy and planetary exploration in particular. Near the end of this decade the James Webb Space Telescope will become operational, offering spatial resolution comparable to that of HST (but in the near-IR), and with imaging and spectroscopic capabilities from visible wavelengths out to 28 microns. JWST will be capable of tracking the vast majority of Solar System targets. Although its instruments are too sensitive to observe the planets in all modes, it will make significant contributions to our understanding of them. Its real power may be for characterizing the composition of primitive bodies throughout the outer Solar system. Because it can access wavelengths where fundamental molecular absorption occur, and which are inaccessible from the ground and by HST, JWST is likely to reveal a menagerie of compositions for primitive bodies. Such data will be important in their own right, and even more powerful when combined with observations from spacecraft (Juno, New Horizons, OSIRIS-REx, and future missions) or from complementary observatories such as ALMA.

The NASA Infrared Telescope Facility: Current and Future Plans

Alan Tokunaga *(University of Hawaii, USA)*

The NASA Infrared Telescope Facility (IRTF) is located at the summit of Mauna Kea and provides observations to support NASA missions as well as planetary astronomy research. 50% of the time is allocated to solar system observations and the rest to astronomy in all fields. We schedule the IRTF in a flexible manner to allow multiple short programs during the night. Remote observing from any location in the world is supported. Some examples of current observing programs will be discussed. Our primary science instrument is a low to moderate-resolution 1-5 micrometer spectrograph (SpeX; R=250-2,000) with a slit-viewing camera that serves as an infrared imager. There is also a high-speed CCD camera attached to SpeX that allows for simultaneous imaging at visible wavelengths. We also have a high-resolution 1-5 micrometer spectrograph (CSHELL; R=40,000). We are building a cross-dispersed high-resolution 1-5 micrometer spectrograph (iSHELL; R=70,000) that we plan to commission in early 2016 to replace CSHELL. We plan to bring online a mid-infrared 8-25 micrometer camera after the commissioning for iSHELL is completed. In the longer term, we will seek funding to build an adaptive optics imager that will operate at 0.75-2.5 micrometer. Some mid-infrared visitor instruments are available to the community. For further information see: http://irtfweb.ifa.hawaii.edu/

Planetary science with the Atacama Large Millimeter/submillimeter Array

Eric Villard *(JAO/ALMA, Chile)*

ALMA has started observing science projects in October 2011, and is now in its third cycle of science observing. The next cycle of observing will start in October 2015, with a call for proposals out end of March 2015. Although it is still being expanded, ALMA has already reached a level that makes it a wonderful tool to do planetary science, as proven by the number of discoveries made recently.

I will present the current science capabilities of the observatory, as well as the ones that will be offered for the next cycle, and I will show some examples of investigations that can be done in the domain of planetary science.

Terrestrial planets: Mars Express, Venus Express, Exomars TGO

Olivier Witasse *(European Space Agency, The Netherlands)*

In the recent years, ground-based observation campaigns have been successfully coordinated with planetary missions: Cassini-Huygens, Venus Express, and Deep Impact are remarkable examples. This presentation will summarise the added value of such combination of observations. Concerning Huygens, coordinated ground-based observations of Titan were performed around or during the Huygens atmospheric probe mission at Titan on 14 January 2005, connecting the momentary in situ observations by the probe with the synoptic coverage provided by continuing ground-based programs (Witasse et al., 2006). These observations consisted of three different categories: (1) radio telescope tracking of the Huygens signal, (2) observations of the atmosphere and surface of Titan, and (3) attempts to observe radiation emitted during the Huygens Probe entry into Titan's atmosphere. Both radio and optical, were of fundamental importance for the interpretation of results from the Huygens mission. Regarding Venus Express, a dedicated ground-observation campaign was organised in 2007 (Lellouch and Witasse, 2008), and it boosted Venus science, in particular in the area of the composition and dynamics of Venus' atmosphere. Joint observations have also been organised (or are under preparation) with Mars Express. The case of methane investigations- a topic widely debated in the scientific community- and the monitoring of dust storms will be outlined. The needs for the ExoMars Trace Gas Orbiter will be discussed. For the long-term, the case of the JUICE mission will also be mentioned.

Planetary science with balloons

Eliot Young *(Southwest Research Institute, USA)*

NASA's Balloon Program Office regularly flies large balloon payloads to altitudes of 35 - 38 km, above 99.3% - 99.6% of the Earth's atmosphere. A planetary science balloon mission at those altitudes would realize several of the advantages of a space-based telescope, including spectral access to UV through IR wavelengths longer than 300 nm, turbulence-free seeing, stable photometry and excellent sensitivity to faint sources. While NASA's longest-duration missions to date have flown during daylight over Antarctica, proposers are now encouraged to take advantage of new, large super-pressure balloons that can span 100 day/night cycles at mid-latitudes. In addition, several recent flights have demonstrated pointing systems that stabilized their telescopes at the few arcsecond level. Last September, the BOPPS flight used a fine steering mirror to achieve pointing stability at the 66 mas level. BOPPS also observed flux from comet Jacques (C/2014 E2) at 4.3 μm, a CO_2 band that is opaque to ground-based observers and SOFIA. Future IR observations will require cooled telescope optics: recent work indicates that passive measures, such as sunshades, Earth-shades and thermal blankets, can cool OTAs to temperatures below 180 K. At those temperatures, the thermal self-emission from the telescope optics becomes less important than the stratospheric background flux from 1 - 5 microns.

Abstracts for the posters

Titan unveiled through a 35-year synergy of ground and space observations

Carrie Anderson *(NASA GSFC, USA)*, R.E. Samuelson, G.L. Bjoraker, and E.F. Young

Over the past 35 years a suite of instruments onboard deep space planetary spacecraft, and space- and ground-based observatories have produced a detailed collective story regarding the captivating world of Titan, Saturn's largest moon. Examples of these three classes of observatories are listed below.

1. Deep space planetary missions. One example is Cassini/Huygens. Based on recorded data from Voyager 1, it was realized early on that near-IR wavelengths were needed in order to sound down to Titan's lower atmosphere and the surface. We now know from Cassini that there are dunes, riverbeds, lakes at the poles, and rounded pebble-like rocks on the surface.

2. Space-based observatories. One example is ISO, which was responsible for the discovery of water vapor in Titan's stratosphere. This detection supported the idea that water ice enters Titan's atmosphere through meteoritic debris.

3. Ground-based observatories. Two examples are IRAM and Keck. The former is responsible for discovering acetonitrile in Titan's atmosphere and the latter is responsible for tracking tropospheric methane clouds in the near-IR with AO.

The above mentioned are just a few examples of the instrument suites that have been brought to bear on the understanding of the complex world of Titan. This presentation will focus on the collective knowledge gained about Titan from Pioneer 11, Voyager 1, Cassini, HST, ISO, Herschel, Keck, IRTF, and IRAM. Following the end of the Cassini Mission in September 2017, the next big advances in our understanding of Titan will come from ALMA and JWST. We will discuss the prospects for identifying new molecules in Titan's atmosphere utilizing ALMA. We will exploit ALMA's high spectral resolution to retrieve the vertical distribution of the numerous gases in Titan's atmosphere. This will allow us to continue the study of seasonal variations on Titan post Cassini.

Studying Mars' Atmosphere with ALMA (JAO student project)

Rodrigo Carvajal *(Universidad de Chile, Chile)*

The ALMA telescope allows millimeter and sub-millimeter observations for studies of Mars' atmosphere providing meteorological data via molecule spectra.

We use the CASA reduction package to construct the calibrated data cubes, and ARTS put constraints on spatially resolved temperature profiles and dynamical processes. The results are being contrasted with information from the Mars Climate Database (MCD).

Measurement of the distribution and excitation of cometary volatiles using ALMA

Martin Cordiner *(NASA Goddard, USA)*, Anthony Remijan, Jeremie Boissier, Stefanie Milam, Michael Mumma, Steven Charnley, Lucas Paganini, Geronimo Villanueva, Dominique Bockelee-Morvan, Nicolas Biver, Yi-Jehng Kuan, Dariusz Lis, Jacques Crovisier, Iain Coulson, Dante Minniti

Comets are believed to have accreted at around the time the planets formed (c. 4.5 Gyr ago), and many have remained in a frozen, relatively quiescent state since then. Studies of cometary compositions using Earth and space-based instruments thus provide unique information regarding the physical and chemical conditions of the early Solar System. Use of gas-phase coma observations as a probe of cometary ice requires a complete understanding of the gas-release mechanisms. However, previous observations have been unable to ascertain the precise origins of fundamental coma species such as H2CO, HCN and HNC, and details regarding the possible formation of these species in the coma are not well understood. In this work, we report results from the first cometary observations using the Atacama Large Millimeter Array (ALMA), and present measurements of spatially and spectrally-resolved distributions of HCN, HNC, H2CO, CH3OH and dust within the comae of three comets: C/2012 F6 (Lemmon), C/2012 S1 (ISON) and C/2012 K1 (PanSTARRS). Our observations reveal an unprecedented level of detail in the distribution and excitation of these fundamental cometary molecules, and highlight the importance of high signal-to-noise, sub-arcsecond imaging for the derivation of cometary compositions. The powerful spectral imaging capabilities of ALMA and next-generation ground-based telescopes such as the E-ELT will provide a crucial framework for the interpretation of results from current and future space-based comet observing missions.

Meterwave observations of Saturn to constrain its water content

Régis Courtin *(LESIA - CNRS/Observatoire de Paris, France)*

We present radio observations of Saturn at metric wavelengths obtained with the Giant Meterwave Radio Telescope in India, the eVLA interferometer in the USA, and the LOFAR interferometer in Europe. These measurements aim at contraining the ammonia and water abundances in the deep atmosphere of Saturn below the ice clouds at a few kilobar pressure levels. Radiative transfer models of the planet's thermal emission at these wavelengths, fitted to these measurements, allow us to then derive a range of possible values for the bulk NH3 and H2O abundances.

Planetary Radio Interferometry and Doppler Experiment (PRIDE) for Planetary Science

Dmitry Duev *(Joint Institute for VLBI in Europe, The Netherlands)*, T.M. Bocanegra Bahamon, G. Cimo, L.I. Gurvits, G. Molera Calves, S.V. Pogrebenko

The Planetary Radio Interferometry and Doppler Experiment (PRIDE) led by the Joint Institute for VLBI in Europe (JIVE, Dwingeloo, The Netherlands) is designed as a multi-purpose, multi-disciplinary enhancement of space missions science return. The essence of PRIDE lies in its ability to provide ultra-precise estimates of spacecraft state vectors based on phase-referenced Very Long Baseline Interferometry (VLBI) tracking and radial Doppler measurements. The observations are carried out by an array of ground-based radio telescopes. These measurements can be used for a variety of scientific applications, both fundamental and applied, including planetary science, ultra-precise celestial mechanics of planetary systems, gravimetry, spacecraft orbit determination, and fundamental physics.

In this presentation, we describe the principles of measurements, processing, and analysis of PRIDE data and present demonstration results of the latest observing campaigns conducted with several operational science missions.

Herschel Space observatory and ground based observations of transneptunian Objects and Centaurs

Rene Duffard *(Instituto de Astrofisica de Andalucia – CSIC, Spain)*, Ortiz, J.L.; Mueller, T.; Santos-Sanz, P. and the TNO's are Cool team

"TNOs are cool" was a Herschel Space observatory key Project granted with more than 370 hours whose main goal was determining sizes and albedos of a large sample of more than 100 trans-neptunian objects (TNOs). The interpretation of the Herschel thermal measurements requires accurate knowledge of absolute magnitudes and other parameters for the TNOs. That information has to be determined using ground based observatories. Also, for the initial planning and target selection, high accuracy astrometry for many of the targets was obtained to guarantee the correct pointing of Herschel to within the required specifications. Here we describe the combined efforts from Herschel and from the ground that have led to a considerable success. We will also describe the improvements we plan to do in the future to gain an even better knowledge of the physical properties of the TNOs.

ALMA position determination of Pluto for New Horizons Mission

Edward Fomalont *(JAO/NRAO, Chile/USA)*

Multi-Band Mid-Infrared Observation of Saturn's Rings

Hideaki Fujiwara *(Subaru Telescope, NAOJ, USA/Japan)*, Takuya Yamashita, and Takuya Fujiyoshi

In this presentation, we present multi-band mid-infrared (MIR) images of Saturn's rings in 2008 obtained with COMICS mounted on Subaru Telescope. From the images, we measured surface brightness of several positions in the rings, and composed spectral energy distributions (SEDs). We found that the composed MIR SEDs are fitted fairly well with a single-temperature blackbody without dust features. We also present the radial

profiles of the surface brightness, color, and optical depth in the MIR, and temperature of Saturn's rings, and discuss their characteristics.

PICARD ground-based and space observatories: a joint venture to study the Sun

Mustapha Meftah *(CNRS – LATMOS, France)*

The PICARD project involves not only a space mission but also a ground-based observatory at Calern (France) dedicated to the study of the Sun. Thus, measurements are taken in orbit by the PICARD mission satellite in order to avoid the impact of atmospheric effects. Nevertheless, it is important to understand and interpret the ground-based measurements, which actually constitute the longest series of currently available measurements. This is why an important ground-based measurement programme ("PICARD SOL") is associated with the space operation before, during, and after the PICARD space mission.

Space observations are a priori most favourable, however, space entails also technical challenges, a harsh environment, and a finite mission lifetime. The PICARD spacecraft, launched on June 15, 2010 was retired in April 2014. On ground, the instruments are less affected by in-space degradation and maintenance is easily provided, so, if the atmosphere is properly monitored and taken into account, they still represent an opportunity to generate the needed long-term time-series. That is why ground measurements have been carried out since May 2011, and will be pursued after the space program.

In this talk, we will describe both sets of instruments, and then will present our current results. We will highlight the importance of ground-based and space measurements. Indeed, our measurements show the benefit of simultaneous measurements obtained from ground and space observatories. As a result, these two means are complementary from each other and represent a feedback for planetary science.

Hydroxyl infrared emission modeling from space observations of the Earth

Alessandra Migliorini *(IAPS-INAF, Italy)*

During the Rosetta mission flyby with the Earth in November 2009, hydroxyl nightglow emissions were observed with the Visible and Infrared Thermal Imaging Spectrometer (VIRTIS) on board the Rosetta mission. Data are analyzed to investigate the relative population of the $\nu=1$ to 9 OH vibrational levels. These observations are unique because the instrument could simultaneously acquire an image at each wavelength in the range 1-5.1 μm. This allows one to simultaneously study the emissions of the OH ($\Delta\nu=1,2$) sequences, while observing the same region of the planet. In addition, observations from space allow overcoming the difficulties associated with corrections for atmospheric absorption.

We obtained a mean spectrum of the night side of the Earth covering the altitude range 85-95 km. Following correction for background, we compared the observations with a synthetic spectra model, based on the PGOPHER code. This allowed us to infer the relative population from levels from 1 to 9. In particular, the relative population of level 1 has been determined for the first time.

Our results are in general satisfactory agreement with previous observations and models developed for mid-latitudes conditions. They favor models where sudden death deactivation by atomic oxygen is a major process controlling the vibrational population.

Solar System Observations with the James Webb Space Telescope

Stefanie Milam *(NASA Goddard Space Flight Center, USA),* J. Norwood, H. Hammel, J. Stansberry, J. Lunine, N. Chanover, D. Hines, G. Sonneborn, M. Tiscareno, M. Brown, and P. Ferruit

The James Webb Space Telescope's unprecedented sensitivity and angular resolution will make it NASA's premier space-based facility for infrared astronomy. This 6.5-meter telescope, which is optimized for observations in the near and mid infrared, will be equipped with four state-of-the-art instruments which include imaging, spectroscopy, and coronagraphy. These instruments, along with the telescope's moving target capabilities, will enable the infrared study of solar system objects with unprecedented detail. A new white paper (Norwood et al., 2014) provides a general overview of JWST observatory and instrument capabilities for Solar System science, as well as updates and expands upon an earlier study by Lunine et al. (2010). A number of hypothetical solar system observations are discussed as a means of demonstrating potential planetary science observing scenarios; the list of applications is far from comprehensive. We will present a few case studies of compelling new science JWST will be able to conduct.

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Titan Science With the James Webb Space Telescope

Conor Nixon *(NASA GSFC, USA)*

In January 2014 the Solar System Working Group (SSWG) for the James Webb Space Telescope (JWST) chartered ten science focus groups (SFGs) to examine the potential science applications of the observatory for various solar system targets (Mars, comets, asteroids, etc), with memberships drawn from the international scientific community. Each group was tasked to produce a white paper by end of the year that would include: (a) descriptions of specific scientific questions that could be addressed using JWST data; (b) summary of observation scenarios and data products needed to address those questions; (c) assessment of JWST instrument and observatory performance in light of the above. This presentation will show the findings of the Titan SFG, who identified five key science themes: (1) Titan surface; (2) clouds; (3) composition of the lower atmosphere; (4) composition of the middle atmosphere; (5) hazes. Our investigation encompassed such issues as: Titan observability; spatial resolution available and required for various science investigations; spectral resolution, signal-to-noise ratio and saturation times for various observing modes of NIRSpec, NIRCam and MIRI. We will present the strengths and weaknesses of JWST for the various proposed observations, including outcomes such as the need for sub-arraying and high spectral resolution to avoid saturation. We conclude by discussing the role and place of the JWST amongst the suite of current and forthcoming major observatories that can study Titan, including Cassini, ALMA, SOFIA and next-generation optical telescopes.

Ground- and Space-based observations of the Kuiper Belt

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Study of the Kuiper Belt requires observations from both large ground-based and space-based facilities. The faintness of the population requires access to major observatories. Study of the many binary systems found in this population requires high angular resolution. The great variety of the Kuiper Belt, both in dynamical structure and physical properties, drives the need to study statistically significant numbers of objects. Because the primitive objects in the Kuiper Belt are a link to early solar system history and because the Belt is the nearest example of a debris disk, intensive study is likely to be of high scientific priority for the foreseeable future.

The post-Rosetta era: New perspectives on nucleus composition and the role of radio and IR ground-based observations

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Do ground-based observations of cometary comae describe the nucleus composition? Rosetta is allowing a unique opportunity to test this hypothesis. The space-based mission is unveiling incredible results, and its upcoming observations throughout perihelion promise to be the most detailed study yet of a comet. The significance of these studies is not trivial, and the results stemming from the expected worldwide observational campaign will trigger great involvement, including professional astrophysicists, amateur astronomers and the public.

To enhance the outcome from past, present and future space-based missions, ground-based observations are a critical supporting strategy to put spacecraft results in context. It is through such synergy that we can establish the true means for quantitative detections on the study of comets, thanks to improved observational strategies, data analysis techniques and instrument performance.

High-resolution spectroscopy at radio and infrared wavelengths provides measurements of the global properties of release and composition that can give context for Rosetta's local measurements, allowing us to compare direct measurements of the nucleus to those inferred from ground-based observations of the coma. Indeed, extrapolation of the local measurements from the Rosetta spacecraft and ground-based observations can reveal essential coma information, including gas temperatures, production rates, and outgassing patterns as observed from the ground. Moreover, Rosetta's lander Philae will measure the composition of the nucleus and that close to the surface. In this presentation, I will discuss unique aspects of cometary studies that can be solely achieved by ground-based radio and IR observations of the cometary comae, as well as benchmarks and challenges that we might need to address as a result of the Rosetta findings.

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Results of the HssO Key Programme with the Herschel Space Observatory

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The HssO (Herschel solar system Observations) programme (Hartogh et al., 2009) aims at determining the distribution, the evolution and the origin of water in Mars, the Outer Planets, Titan, and comets, using the three Herschel instruments HIFI, PACS and SPIRE. It addresses the broad topic of water and its isotopologues in planetary and cometary atmospheres.

- The nature of cometary activity) and the thermodynamics of cometary comae was investigated by studying dust/gas properties (Bockelée-Morvan et al. 2010), composition (Biver et al, 2012, Bockelée-Morvan et al. 2014) and water production and excitation (Hartogh et al. 2010a, de Val-Borro et al., 2010, 2012,2014, Lis et al. 2013) in a sample of comets including one main-belt comet.
- The D/H ratio, the key parameter for constraining the origin and evolution of solar system materials, was determined for the first time in a Jupiter family comet to be the same as the terrestrial value (Hartogh et al, 2011a). D/H observed in an Oort cloud comet turned out to be not compatible with former observations (Bockelée et al, 2012). New measurements of D/H in Giant Planets, similarly to comets constraining the composition of proto-planetary ices, were obtained (Lellouch et al, 2010, Feuchtgruber et al, 2013).
- Isotopic ratios, diagnostics of the evolution of Mars' atmosphere, were accurately measured in H2O and CO. The role of water vapour in the atmospheric chemistry of Mars is studied based on monitoring vertical profiles of H2O and HDO. Seasonal changes in H2O2 were observed and upper limits of HCl determined. Furthermore the first submillimetre determination of molecular oxygen in the martian atmosphere was performed (Hartogh et al, 2010 b/c) and a SPIRE full range spectrum obtained (Swinyard et al, 2010).
- A cometary origin of Jupiter's stratospheric water was determined based on measuring its spatial distribution (Cavalié et al, 2013).
- The Enceladus water torus was directly detected/characterized for the first time and is probably the main source of water in Saturn's and Titan's upper atmospheres. (Hartogh et al. 2011b, Moreno et al. 2012).
- The composition of Titan's atmosphere has been measured with high accuracy with SPIRE (Courtin et al, 2011), PACS (Rengel et al. 2014) and HIFI and includes the first detection of hydrogen isocyanide (HNC) (Moreno et al. 2011).

The Submillimetre Wave Instrument on JUICE

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The Submillimetre Wave Instrument (SWI) is part of the JUICE (Jupiter ICy moon Explorer) payload. SWI's primary scientific objectives are the investigation of the middle atmosphere of Jupiter and the atmospheres and exospheres of the Galilean satellites. SWI will contribute to the understanding of the circulation regime in the atmosphere of Jupiter as a function of latitude and altitude, how the various atmospheric regions are dynamically coupled, and how the energy originating in Jupiter's interior vertically propagates to the upper layers to be radiated in space. In this sense SWI complements the Juno mission. Furthermore SWI will determine important isotopic radios, monitor and trace known gases and search for new molecules. SWI will – for the first time – investigate the density, structure and distribution of the water atmospheres of Ganymede, Callisto and Europa from ground up to a few hundred km, determine its isotopic composition and general circulation. Io's volcanic atmosphere will be studied through lines of SO2, SO, NaCl, and perhaps other species.. The secondary scientific objectives concerns the determination of thermophysical properties of the Galilean satellite surfaces by radiometric observations.

In the proposed configuration SWI will operate in two submm wave bands around 600 GHz and 1200 GHz. Basline however at the present time are two 600 GHz receivers. Both receivers will be tunable within a bandwidth of approximately 20 % around the centre frequency. The antenna has a diameter of 30 cm and will be movable in two dimensions. Two high resolution Chirp Transform Spectrometers with 1 GHz bandwidth and two 4 GHz wide low resolution autocorrelator spectrometer are used for determining the spectral line shapes and for line surveys. The observations geometry includes limb and nadir sounding. The total mass of the instrument is aimed at below 12 kg and the power consumption below 50 W.

System architecture for a 65-95 GHz, mm-wave instrument for space based solar event monitoring observation

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This presentation is progress work for the Ph.D research study and it deals with comparing different system architectures for a compact, low cost mm-wave sun observation instrument. Single conversion and double conversion superheterodyne receivers are evaluated with regards to performances of commercially available components. State-of-the-art (SOTA) component parameters that were used are alternatives where commercially off-the-shelf (COTS) components are not available. thus based on SOTA parameters, components will be designed using IBM process. The

system covers a frequency range of 65 to 95 GHz and it investigates new integration techniques on planar substrates.

COSIMA - Cometary Dust Analysis in the Inner Coma of Comet 67P/Churyumov-Gerasimenko

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The COmetary Secondary Ion Mass Analyser (COSIMA) is one of the scientific instruments on the ROSETTA spacecraft orbiting the nucleus of Jupiter-family comet 67P/Churyumov-Gerasimenko. COSIMA is collecting cometary grains from the near-nucleus region and the inner coma of the comet onto special target plates, which are subsequently imaged and compositionally investigated. For the latter a secondary ion mass spectrometer with an indium ion source is used. The obtained high resolution mass spectra contain ions of complex mixtures of mineral compounds and organic molecules as well as molecular fragments representing the elements and molecules on the surface of these grains. We will report results of our in-situ analysis of cometary grains as captured, imaged and compositionally investigated by COSIMA. A special emphasis will be put on how the results of telescopic observations of comets can support the interpretation of the in-situ investigations.

Isotopic Ratios from CO in Titan's Atmosphere Using ALMA

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The advent of the Atacama Large Millimeter/Sub-millimeter Array (ALMA) has provided a new and powerful facility for probing the atmospheres of solar system targets at long wavelengths (84-720 GHz) where the rotational lines of small, polar molecules are prominent. In the complex atmosphere of Titan, photochemical processes dissociate and ionize molecular nitrogen and methane in the upper atmosphere, creating a unique richness of trace hydrocarbons. Utilization of ground-based sub-millimeter observations of Titan has already proven to be a powerful tool to complement results from spacecraft observations in order to further understand the behavior of molecules such as HCN, HC3N, and CH3CN. Recent ALMA studies have presented spectrally and spatially-resolved maps of HNC and HC3N emission as well as the first spectroscopic detection of ethyl cyanide (C2H5CN) in Titan's atmosphere. In this study, we employ data obtained from the ALMA Science Archive to search for CO emission lines and determine the vertical mixing ratio and isotopic ratios for carbon and oxygen. We will compare our results to previous measurements for Titan and other values in the solar system. General implications for the history of Titan from measurements of CO will be discussed.

Far-Infrared Interferometric Telescope Experiment : FITE

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We have developed a balloon-borne far-infrared interferometer, FITE (Far-Infrared Interferometric Telescope Experiment). FITE is the two-beam Fizeau type interferometer with the baseline of 8 m. The aperture diameter is 40 cm for each beam. The optical system of FITE consists of the interferometer optics, which includes four plane mirrors and two off-axis parabolic mirrors, and the cold sensor optics in a Liquid helium cooled cryostat. The purpose is to achieve 1 arcsecond spatial resolution at the wavelength of 100 Œºm by using the baseline of 20 m. This resolution will enable us to measure thermal structures of proto-planetary disks. In 2008, the first launch of FITE was planned in Brazil. Though FITE was assembled and checked out for its performance, the launch was postponed to 2010 due to unsuitable weather condition. In 2010, the launch was postponed again because of a trouble of the ring-laser gyroscope. For the next launch opportunity, we made a CFRP gondra. In addition, we have developed a new two-dimensional, stressed Ge:Ga array with high sensitivity, an optical adjustment system, a quasi-parallel mechanism as an alignment mechanism of the off-axis parabolic mirrors. In particular, the quasi-parallel mechanism has newly developed and has strong structures which mean the hardly broken mechanism. We are planning to make its first flight as soon as possible in Australia.

Photometric Properties of Kuiper Belt Objects: Towards the Characterization of the Next Targets for the New Horizons Spacecraft

Anne Verbiscer *(University of Virginia, USA),* Alan Stern, John Spencer, Simon Porter, Susan Benecchi, and the New Horizons KBO Search Team

Following the July 2015 encounter with Pluto and its five moons, the New Horizons spacecraft will continue its journey through the Kuiper Belt and, pending approval from NASA for an extended mission, make a close flyby of a Cold-Classical KBO. After an extensive search using ground-based telescopes turned up empty in the effort to find a KBO within reach of New Horizons, the search team enlisted the Hubble Space Telescope and found two candidate targets. I will review the photometric properties of Cold-Classical KBOs and place the candidate targets in context with the rest of this population of Solar System objects soon to be explored by the New Horizons spacecraft.