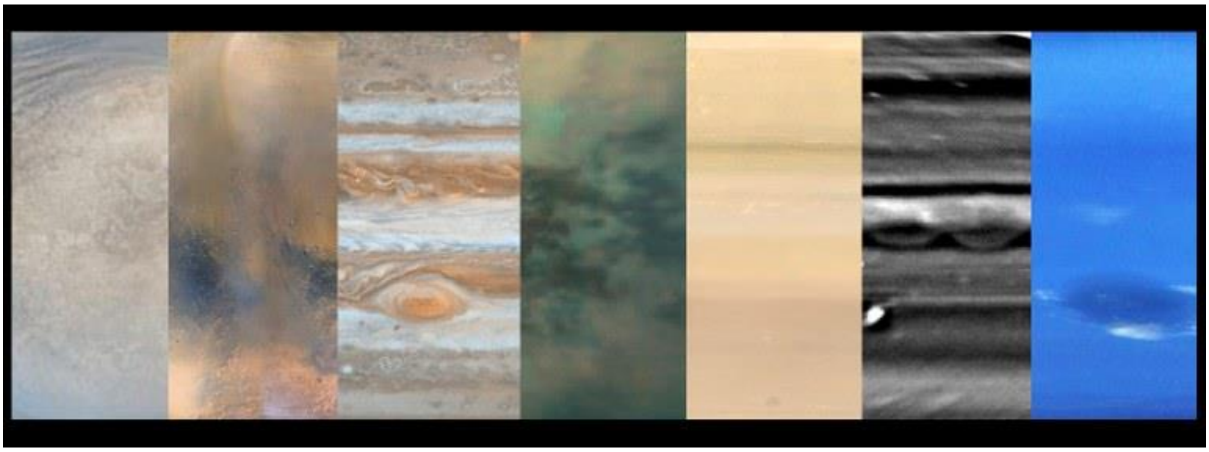
UK Solar System Planetary Atmospheres Meeting 2020

Royal Astronomical Society
February 14th 2020



Atmospheric science is a key component of the UK's planetary science portfolio, enabling global leadership roles in space instrumentation, multi-spectral data analysis (both space- and ground-based), and numerical simulation.

In recent decades, this has provided unique atmospheric science results from astronomical observatories and visiting spacecraft (e.g., Venus Express, Mars Express, ExoMars Trace Gas Orbiter, Galileo, Cassini, and Juno). A vibrant community of planetary atmospheres researchers exists in a number of UK institutions, bridging the gap between Earth observation science and exoplanetary astronomy.

This RAS Discussion Meeting will bring together the UK Planetary Atmospheres community to foster future collaborations, permit exchange of knowledge, and to provide timely updates on the cutting edge research in this field. We aim to propose this as an annual meeting to improve the organisation and visibility of this key research area in the UK, with report summaries made available to STFC and UKSA advisory structures via a website.

A UK community meeting is timely given: (i) upcoming atmospheric research opportunities from JWST and ELT in the 2020s; (ii) the ongoing development of the ESA/JUICE science strategy; (iii) capitalising on data being provided by missions including ExoMars/TGO and Juno; (iv) preparing for the ESA/Roscosmos ExoMars2020 Rover and landing platform, which features atmospheric instruments and represents a big UK investment; and (v) paving the way for future atmospheric science investigations on Venus and Ice Giant missions. Developing a UK atmospheric science strategy could also feed into ESA's 2035-2050 "Voyage" survey (the replacement for the Cosmic Vision), the US Planetary Decadal Survey (~2021), and future mission calls.

Agenda:

The structure of the RAS discussion meeting is as follows:

- 10:00 - 10:30 Arrival; Tea/Coffee in the Library; Poster Viewing Session
- 10:30 - 13:00 Session I: Outer Solar System

- 13:00 - 14:00 Lunch (Not Provided); Poster Viewing Session
- 14:00 - 15:30 Session II: Inner Solar System
- 15:30 - 16:00 Tea at the Geological Society
- 16:00 - 18:00 RAS Monthly A&G (Ordinary) Meeting

<u>Session I: Outer Solar System (Chair: Naomi Rowe-Gurney)</u>

10:30-10:35 Welcome to the UKSSPA Meeting
Leigh N. Fletcher (University of Leicester)

10:35-11:00 [Invited] In situ Exploration of Giant Planet Atmospheres
Olivier Mousis (Laboratory of Astrophysics of Marseille)

11:00-11:12 Cosmic ray ionization of Ice Giant atmospheres
Karen Aplin (University of Bristol)

11:12-11:24 The role of deep jets in bringing order to Jupiter’s polar regions
Stephen Thomson (University of Exeter)

11:24-11:36 Synergy between Juno and amateur observations of Jupiter: The Great Red Spot as an example
John Rogers (British Astronomical Association)

11:36-11:48 Temperature and aerosol variability during Jupiter's 2006-07 Equatorial Zone Disturbance
Arrate Antunano (University of Leicester)

11:48-12:00 Exploring clouds and composition of Ice Giants in the visible/near-IR
Patrick Irwin (University of Oxford)

12:00-12:12 Investigating the Ice Giants with James Webb Space Telescope during GTO
Naomi Rowe-Gurney (University of Leicester)

12:12-12:24 Characterization of the vertical distribution of C2N2 in Titan’s stratosphere
Melody Sylvestre (University of Bristol)

12:24-12:40 Poster Presentations (60s each, single slide)
Sub-Chair: Leigh Fletcher

12:40-13:00 [Invited] Exploring Planetary Atmospheres: A Retrospective
Fred W. Taylor (University of Oxford)

<u>Session II: Inner Solar System (Chair: Arrate Antunano)</u>

14:00-14:26 [Invited] Observing the atmosphere of Mars with the InSight lander
Aymeric Spiga (Laboratoire de Météorologie Dynamique)

14:26-14:38 The dynamics of Mars's annular polar vortices
William Seviour (University of Bristol)

14:38-14:50 Assimilation of Mars Satellite Observations with a Mars GCM
James Holmes (Open University)

14:50-15:02 On the Photochemistry of Methane and Ethane in the Martian Atmosphere: Towards Indirect Detection of Methane Emissions
Ben Taysum (University of Edinburgh)

15:02-15:14 Ares - An atmospheric retrieval system for the ExoMars Trace Gas Orbiter
George Cann (University College London)

15:14-15:26 The ACS investigation of the Martian atmosphere after 1.5 years in operation
Kevin Olsen (University of Oxford)

15:26-15:30 Closing Remarks

Poster Presentations:

1. Juan Alday (University of Oxford) - *Atmospheric science using PanCam, ISEM and FAST on the ExoMars 2020 Rover and Surface Platform*
2. Jason Sharkey (University of Bristol) - *Structure and dynamical evolution of Titan's northern polar vortex*
3. Narissa Patel (Open University) - *Distribution of Subsurface Carbon Dioxide Ice at Different Obliquities*
4. Paul Streeter (Open University) - *Martian Polar Vortex Dynamics and the 2018 Global Dust Storm*
5. Nicholas Heavens (Space Science Institute) - *A Multiannual Record of Gravity Wave Activity in Mars's Lower Atmosphere from On-Planet Observations by the Mars Climate Sounder*
6. Lori-Ann Foley (Open University) - *Climate change and the water cycle on Mars*
7. Amethyst Johnson (University of Manchester) - *Modelling aerosol charging in the lower atmosphere of Venus*
8. James Blake (University of Leicester) - *Saturn's Seasonal Atmosphere: Cassini CIRS contrasts to VLT and IRTF observations*
9. Jan Vatant D'Ollone (University of Leicester) - *Radiative modelling of the Ice Giant atmospheres – A first step toward Global Circulation Models*
10. Alexandru Valeanu (University of Oxford) - *From spacecraft data to rover measurements – Martian atmospheric modelling and observations*
11. Gregory Colyer (University of Oxford) - *Semi-grey radiative modelling of Jupiter's atmosphere and clouds*
12. Kevin Douglas (University of Leeds) - *Meteor Ablated Phosphorus as a Source of Bioavailable P to the Terrestrial Planets*

Abstracts (Alphabetical by surname):

Atmospheric science using PanCam, ISEM and FAST on the ExoMars 2020 Rover and Surface Platform

J. Alday, C. F. Wilson, P. G. J. Irwin, H. Sheng, D. Chowdhury

The ExoMars 2020 mission comprises two science elements: a rover and a surface platform. We have performed radiative transfer analyses for PanCam, ISEM (rover) and FAST (surface platform) instruments, focussing on their ability to characterize atmospheric dust, temperature, and water vapour.

PanCam is a panoramic camera mounted on the rover mast. Observations of the Sun using filters at 925 and 935 nm allow the characterisation of atmospheric water vapour.
ISEM is an infrared spectrometer mounted on the rover mast, below PanCam, covering a wavelength range between 1.15 and 3.3 µm. Observations of the Martian sky allow the characterisation of aerosols, and absorption by water vapour and carbon dioxide.

FAST is an infrared spectrometer located on the surface platform, covering a wavelength range between 3 and 17 µm. FAST's climatology mode allows the characterisation of the diurnal cycle of the aerosol and temperature fields in the near-surface environment. Observations of the Sun will be made in order to search for the presence of trace gases.

Temperature and aerosol variability during Jupiter's 2006-07 Equatorial Zone Disturbance

Arrate Antuñano et al.

Jupiter's Equatorial Zone (EZ) undergoes a quasi-periodic planetary-scale disturbance that completely alters its appearance both at visible wavelengths (sensing the ammonia cloud deck at ~700 mbar) and at 5 µm (sensing the 1-4 bar pressure level) with a periodicity of ~7 years. During these events, the EZ displays a significant brightening at 5 µm and darkening at visible wavelengths, suggesting that the EZ undergoes a quasi-periodic thinning/removing of the ammonia ice clouds, revealing the dynamic structure at higher pressures. The last infrared EZ disturbance occurred between April 2006 and October 2007, although a new EZ disturbance started to be observable in late 2018. Here, we use ground-based mid-infrared data captured by three different instruments between 2005 and 2008 to characterize the variability of tropospheric temperatures and aerosol opacity during the 2006-2007 disturbance. The data reveals a significant brightening at 8.6 µm, sensing tropospheric aerosol opacity and temperature near 0.5-0.7 bar, between 2005 and early 2007. This agrees with cloud clearance during these events. At the rest of the wavelengths, sensing tropospheric ammonia and temperatures between 150-600 mbar, the brightness temperature remains largely invariant between 2005 and 2008. We use radiative-transfer and retrieval codes known as NEMESIS to retrieve the tropospheric vertical temperature profile and aerosol opacity for different epochs between 2005 and 2008. The retrieved aerosol opacity shows a decrease of 45% and 65% in 2006 and 2007, respectively, compared to 2008, at 2-5° S. The retrieved temperatures at 150-600 mbar do not show any remarkable variability between 2005-2008. These results indicate that EZ disturbances are not simply the result of tropospheric warming.

Cosmic ray ionization of Ice Giant atmospheres

K. L. Aplin, T. A. Nordheim, J. A. Sinclair, J. M. Jasinski

Galactic cosmic rays (GCRs) represent a major ionization source in planetary atmospheres, particularly within deeper layers that are largely unaffected by solar UV and charged particle precipitation. When GCR particles undergo inelastic collisions with atmospheric nuclei they create large numbers of secondary interactions, resulting in extensive nuclear and electromagnetic particle cascades. In thick atmospheres, such as those of the giant planets, these cascades can develop much more extensively than what is the case at Mars and Earth. Furthermore, GCRs are strongly modulated by the heliosphere, and therefore GCR fluxes are significantly higher at the Ice Giants than in the inner Solar System. Intriguingly, observations of Uranus and Neptune show brightness variations that appear to be associated with GCR variability (Aplin et al. 2016;2017).

Using a full 3D Monte Carlo particle physics code, we have carried out the first detailed study of cosmic ray ionization within the atmospheres of Uranus and Neptune. We will show preliminary results of this study and discuss the possible importance of GCR ionization to atmospheric chemistry and atmospheric electricity. We will also discuss the effect of GCR shielding by the planetary magnetic fields of Uranus and Neptune.

Saturn's Seasonal Atmosphere: Cassini CIRS contrasts to VLT and IRTF observations

James Blake, Leigh Fletcher, Arrate Antuñano, Henrik Melin, Michael Roman, Mael Es-Sayeh, Padraig Donnelly, Naomi Rowe-Gurney, Oliver King, Thomas Greathouse, Glenn Orton

Observations from the Texas Echelon Cross Echelle Spectrograph (TEXES) on NASA's IRTF and the VISIR instrument on the VLT are used to characterize the Saturn's seasonal changes. Radiative transfer modelling (using NEMESIS [1]) provides the northern hemisphere temperature progression of the atmosphere over 10 years, both during and beyond the Cassini mission. Comparisons between imaging observations taken one Saturn year apart (1989-2018) show the extent of the interannual variability of Saturn's northern hemisphere climate for the first time. Infrared imagery from the VISIR instrument collected in September 2017 and September 2018 have provided a unique opportunity, as they were acquired approximately one Saturn year apart from the 1989 observations of Gezari et al, (1989) [2], which were the first ever 2D images of Saturn in the mid-IR. Examining the differences in brightness temperatures and composition will indicate the extent of any interannual variation for Saturn's northern hemisphere. This study will also provide unique insight into the timescale of the QPO which will be contrasted with a previously suggested biennial cycle [3]. The seasonal temperature progression also enables us to place this interannual variability in a wider context and provides further opportunity for insightful comparison with the comparatively shorter-term temperature variability.

[1] Irwin et al. 2008, JQSRT 109:1136-1150
[2] Gezari et al., 1989, Nature, 342, 777–780
[3] Fletcher et al., 2017, Nature Astronomy, 1, p765-770

Ares - An atmospheric retrieval system for the ExoMars Trace Gas Orbiter

George Cann, Ahmed Al-Rafaie, Ingo Waldmann, Dave Walton, Jan-Peter Muller.

Introduction: The Nadir and Occultation for MArs Discovery (NOMAD) instrument, onboard the European Space Agency's Exomars Trace Gas Orbiter (TGO) was designed to investigate methane (CH_4) on Mars.[1][2][3][4][5] However, the arrival and subsequent science mission has resulted in no CH_4 detected above an upper limit of 0.05 ppbv.[6] In contrast, NASA's Curiosity Sample Analysis at Mars Tunable Laser Spectrometer (SAM-TLS) recently measured a spike of 21 ppbv at Teal Ridge in Gale Crater.[7] Furthermore, the Planetary Fourier Spectrometer (PFS) onboard Mars Express detected 15.5 ± 2.5 ppbv of CH_4, above Gale Crater on 16th June 2013, one day after SAM-TLS detected a CH_4 spike of 5.78 ± 2.27 ppbv. [8] Since then PFS has not reported any detections of CH_4. [9] The discrepancy between NOMAD observations and the agreement between surface measurements by SAM-TLS and orbital measurements by PFS of CH_4, significantly constrains the mechanisms to corroborate the measurements.

Here we present a novel retrieval framework, *Ares,* designed for TGO NOMAD Solar Occultation (SO) channel solar occultation measurements, that could help unravel the mystery of CH_4 on Mars. Ares is the Mars branch of Tau-REx-3, the 3rd generation of Tau-REx. Tau-REx, (Tau Retrieval for Exoplanets)[10][11] is a fully Bayesian atmospheric retrieval framework that uses Multinest, Markov chain Monte Carlo (MCMC) and Nested Sampling methods to sample the entire likelihood space of possible solutions. This allows Tau-REx to produce marginalised and conditional posterior distributions of forward model parameters, subsequently showing correlations between these parameters.

Acknowledgements: We would like to thank UK Space Agency for their support of this studentship through the Aurora science programme. STFC no: 535385.

References:

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[4] Webster et al. (2015), Science, Vol. 347 (6220), pp. 415-417. [doi: 10.1126/science.1261713].
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[9] ESA's Mars orbiters did not see latest Curiosity methane burst, (2019), 13/11/19, url: http://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/ExoMars/ESA_s_Mars_orbiters_did_not_see_latest_Curiosity_methane_burst, ESA.
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[11] A. F. Al-Refaie et al. (2019), *Submitted to The Astrophysics Journal*. [doi: 1912.07759]

Semi-grey radiative modelling of Jupiter's atmosphere and clouds

Gregory Colyer

We consider semi-grey radiative schemes for the giant-planet atmospheres, suitable for use within idealized radiative-convective column model (RCM) and general circulation model (GCM) codes. Building on the Oxford Jupiter model (Young et al. 2019) and on the work of Robinson and Catling (2012), we consider optical depth parameterizations more generally.
Formal solutions for the temperature profile in radiative balance are obtained, and exact analytical solutions for useful classes of parameterization. These results are applicable to the upper atmosphere, where small-scale convection and large-scale circulation are absent or weak, but they are also informative for time-dependent models in which radiative balance is not directly imposed. We illustrate how such solutions may be joined together with matching conditions to make a simple model for radiatively active (reflective) clouds, which could be coupled to the dynamics in a GCM code.

Meteor Ablated Phosphorus as a Source of Bioavailable P to the Terrestrial Planets

Kevin M. Douglas, Thomas Mangan, David L. Bones, Juan Diego Carrillo Sanchez, Wuhu Feng, Mark A. Blitz, John M.C. Plane

Phosphorus, P, is a key biological element with major roles in replication, information transfer, and metabolism. Interplanetary dust contains ~0.8 % P by elemental abundance, and meteoric ablation in a planetary atmosphere is a significant source of atomic P. Orthophosphate (oxidation state +5) is the dominant form of inorganic P at the Earth's surface, however, due to their low water solubility and reactivity, such P(V) salts have a poor bio-availability. Less oxidised forms of P (oxidation state ≤ +3) are however far more bio-available. Previous studies have focused on the direct delivery of P to the surface in meteorites, to undergo processing through aqueous phase chemistry. In contrast, the atmospheric chemistry of P has so far been ignored.

The vaporized P atoms entering the upper atmospheres of the terrestrial planets will undergo chemical processing to form a variety of compounds in which P may exist in different oxidation states due to the presence of both oxidizing and reducing agents. Initial oxidation of P will proceed to produce PO_2. From PO_2, an exothermic route to phosphoric acid (H_3PO_4) exists *via* the formation of $HOPO_2$; however, the bio-available compound phosphonic acid (H_3PO_3) should also form *via* HPO_2.

Using a combination of both experiment and theory, both the delivery of P *via* the ablation of interplanetary dust particles, and the reaction kinetics of meteor ablated P, have been investigated. These results have been input into a global chemistry-climate model of the Earth's atmosphere, and the relative amounts of phosphoric and phosphonic acid produced from meteor ablated P assessed.

Climate change and the water cycle on Mars

Lori-Ann Foley, Stephen Lewis and Matthew Balme

The water cycle is a crucial element of the Martian climate past and present. Water, in all its forms, can have significant effects on the planet's geological features. Understanding the role of the water cycle involves understanding how the climate has changed due to variations in the planet's orbital parameters – obliquity, eccentricity and perihelion, which go through cycles lasting thousands to millions of years. The first phase of this research has been to run experiments with the UK version of the Laboratoire de Météorologie Dynamique (LMD) Mars Global Circulation Model, varying the obliquity over a range from 5° – 55° and placing ice sources at one or both of the poles or in the tropics. We will show what the results from these simulations tell us about the water cycle on a global scale at different times in the planet's history, focusing on where water vapour is generated, how it is transported around the planet and where it is deposited as surface ice. During the next phase of research, this data will be used to provide the boundary conditions needed by the LMD Mars Mesoscale Model to simulate the conditions in and around Lyot crater. This second phase will study the relationship between the water cycle and the crater's geological features since its formation. It will consider whether Lyot crater has a microclimate in which water is sometimes stable and whether modelled mesoscale meteorological conditions can be related to the observed distribution of landforms, both now and in the past.

A Multiannual Record of Gravity Wave Activity in Mars's Lower Atmosphere from On-Planet Observations by the Mars Climate Sounder

Nicholas G. Heavens, David M. Kass, Armin Kleinböhl, John T. Schofield, J. Michael Battalio, Alexey Pankine

Gravity waves in Mars's atmosphere strongly affect the general circulation as well as middle atmospheric cloud formation, but the climatology and sources of gravity waves in the lower atmosphere remain poorly understood. At Earth, the statistical variance in satellite observations of thermal emission above the instrumental noise floor has been used to enable measurement of gravity wave activity at a global scale. Here we analyze radiance in three channels within the 15 micron CO_2 band from off-nadir and nadir observations by the Mars Climate Sounder (MCS) on board Mars Reconnaissance Orbiter (MRO); a major expansion in the observational data available for validating models of Martian gravity wave activity. These observations are sensitive to gravity waves at 10-30 km altitude with 10-100 km horizontal wavelengths and vertical wavelengths greater than 5 km, which make them likely to affect middle and upper atmospheric dynamics. We find that the spatial distribution of gravity wave activity is consistent with the Tharsis Montes and any topography interacting with the winter westerly jets being the dominant gravity wave sources, but contributions from boundary layer convection and other convective processes cannot be excluded. Suppression of boundary layer convection during regional and global dust storms noticeably reduces gravity wave activity in areas where topographic gravity wave sources are weak. This work is funded by NASA's Mars Data Analysis, Solar System Workings, and Nexus for Exoplanet System Science Programs.

Assimilation of Mars Satellite Observations with a Mars GCM

James Holmes

Interpretation of retrievals from multiple satellites orbiting Mars is key to solving remaining mysteries about the martian surface and atmosphere, such as how much water has been lost from the atmosphere over time, the mechanisms that initiate global dust storm events and the interannual variability in climate.

Retrievals provide a local measurement of the atmosphere and are limited by spatio-temporal constraints. Combining a Mars Global Circulation Model (GCM) with retrievals in a self-consistent way provides an evolving local and global context for physical, dynamical and chemical processes occurring in the martian atmosphere. This approach provides a global perspective of the underlying atmospheric processes and is one of the primary goals of data assimilation, a technique that combines a Mars GCM with retrievals to provide the best estimate of the global atmospheric state.

Benefits of data assimilation over direct comparison between GCM and observed quantities include providing constrained estimates for parameters which are not directly observed, investigating interactions between chemical species such as water vapour and ozone and the ability to combine observational datasets (including of different observations such as water vapour, dust and temperature profiles) into one unified consistent dataset.

We are providing interpretation of the recent observations of the martian atmosphere by combining Mars satellite observations of temperature, dust and trace gases with a Mars GCM used at the Open University. Current status and recent work involving the assimilation of water vapour retrievals from the ongoing ExoMars Trace Gas Orbiter mission will be discussed.

Exploring clouds and composition of Ice Giants in the visible/near-IR.

P.G.J. Irwin, J. Dobinson, A. James, A. Braude, L.N. Fletcher, N.A. Teanby, D. Toledo, G.S. Orton, B. Bézard.

Uranus and Neptune, known as the 'Ice Giants', are amongst the most mysterious planets in our Solar System. Their extremely cold temperatures at the cloud tops means that their main bulk constituents, thought

to be rock and normally 'icy' materials such as H_2O and NH_3 are condensed well below their main visible cloud decks. In this presentation we will describe ground- and space-based observations of these planets that: A) show that gaseous H_2S is present above the main cloud decks of these planets at a pressure ~ 3 bar, indicating that that these clouds almost certainly contain H_2S ice and that the abundance of H_2S must exceed that of NH_3 at the condensation level of ammonium hydrosulphide (NH_4SH);
B) show that the abundance of CH_4 at the cloud tops changes greatly with latitude, with abundances of ~4% seen at equatorial latitudes, reducing to ~2% near the poles, consistent with previous HST/STIS determinations; and C) show that the polar 'cap' or 'hood' of Uranus (region of higher reflectivity seen pole-wards of 40 - 50° N) can at least be partly explained by the lowering of methane abundance at polar latitudes.

Modelling aerosol charging in the lower atmosphere of Venus

Amethyst Johnson and Karen Aplin

Atmospheric electrification (such as lightning), has been detected in multiple planets across the solar system, but remains largely controversial for Venus. With its thick ubiquitous cloud layer, it is almost impossible to remotely detect signs of electrification within the deep atmosphere. However, recently revisited Venera lander missions from the 1980s have provided insight into a potentially charged layer of aerosols near the surface of Venus, consistent with terrestrial thunderstorms and dust devils. This study aims to use this Venera lander data along with terrestrial analogies to construct a range of aerosol size and number concentration models for the lower boundary layer. The charges detected by the landers will be evaluated by applying ion-aerosol theory and surface ionisation rates to the models, in an attempt to explain the charges recorded on the Venera landers by the presence of a charged aerosol layer.

The ACS investigation of the Martian atmosphere after 1.5 years in operation

Kevin Olsen

The Atmospheric Chemistry Suite (ACS) on the ExoMars Trace Gas Orbiter consists of three spectrometers capable of investigating the composition and physical state of the atmosphere. The mid-infrared solar occultation channel (MIR) provides unprecedented spectral resolution, and vertical sensitivity. One of our main objectives is to solve the mystery of Mars methane, which may potentially have a biogenic origin. So far we report no methane detection. Another primary objective is to study the water cycle, on Mars. We have been able to measure the first vertical profiles of the D/H ratio on Mars, and observed supersaturation of water at high altitudes. Both results have implication for hydrogen loss to space and the past climate of Mars. Finally, the CO abundance is critical for maintain the photochemical stability of the Martian atmosphere, and we report the first measurements of the vertical distribution of CO, the impact of a global dust storm on CO abundance.

Distribution of Subsurface Carbon Dioxide Ice at Different Obliquities

N. Patel, S. R. Lewis, A. Hagermann and M. Balme

We present initial results from the UK version of the LMD Mars Global Circulation Model using a newly developed subsurface model showing the distribution of subsurface carbon dioxide (CO_2) at four different obliquities (15°, 25°, 35° and 45°). These results use an initial condition of subsurface CO_2 ice at latitudes >50° N/S and are an initial study that will inform future investigations because the amount and distribution of subsurface CO_2 ice in the present day is unknown. Studies of subsurface ice on Mars focused mostly on the distribution of water ice, because subsurface CO_2 ice is unstable outside of the polar regions. However, subsurface CO_2 ice is more likely to be stable at the higher pressures expected for Early Mars [e.g. 1].

Studies [e.g. 2, 3] have also shown that water ice becomes more widespread across the surface at high obliquities due to sublimation of the polar caps and the equatorward transport of water [e.g. 3, 4]. However, since it has been assumed that CO_2 ice can only occur within the polar regions, any changes in subsurface CO_2 ice distribution with obliquity are unknown. We have included CO_2 ice physics in the subsurface to account for potential subsurface CO_2 ice outside of the polar regions.

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Synergy between Juno and amateur observations of Jupiter: the Great Red Spot as an example

John Rogers, Clyde Foster, Shinji Mizumoto, Andy Casely, Marco Vedovato, Gerald Eichstädt, Candice J. Hansen, Glenn S. Orton, Tom W. Momary

Jupiter's atmosphere shows variations on a wide range of timescales, ranging from convective outbreaks that erupt over 1-2 days to circumglobal climatic cycles that repeat after several years or decades. Amateur ground-based imaging gives a nearly continuous record that provides valuable predictions and context for targetted spacecraft observations. This has particularly been the case during the NASA Juno mission, as we show using the Great Red Spot (GRS) as an example. First, amateur tracking of the GRS enabled us to successfully predict that Juno would pass directly over its centre at perijove-7, and also informed planning of later orbits for a second pass over the GRS, which occurred at perijove-21. These passes enabled the Juno team to probe the depth of the GRS using both the microwave radiometer and the gravity mapping. Second, from perijove-17 onwards, red 'flakes' detaching from the GRS were observed both by Juno's 'public outreach' camera (JunoCam) and by amateur imagers, and were monitored intensively during 2019. Frequent amateur images enabled us to document the timeline of all the flakes and to show that they resulted from incoming anticyclonic vortices that were disrupting the perimeter of the GRS more than in the past, before its shrinkage in recent years. JunoCam images, at several perijoves, gave higher-resolution views in visible colour and the 889-nm methane band. There is now close collaboration between amateur groups and the Juno team, which can continue for the rest of the Juno mission and for the JUICE mission.

Investigating the Ice Giants with James Webb Space Telescope during GTO

N. Rowe-Gurney, L. Fletcher, H. Hammel, S. Milam, H. Melin

The upcoming James Webb Space Telescope (Webb) will observe the Ice Giants for ~14 hours in the first 12 months of operation during the Guaranteed Time Observations (GTO) programme. Webb's increased sensitivity, spectral coverage, and spatial resolution will allow it to advance our understanding of the atmospheres of all four of the Solar-System's giant planets, Uranus and Neptune in particular (Norwood et al. 2016). The Ice Giants will be observable over the entire spectral range of the Webb's suite of instruments (0.6 – 28.5 μm). In particular, observations of thermal emission in spatially-resolved global spectroscopic maps will reveal atmospheric temperatures and composition in regions that have never before been explored, even by the visiting Voyager 2 spacecraft three decades ago.

During the GTO, the MIRI Medium Resolution Spectrograph (MRS) will sample Uranus and Neptune at three separate longitudes to span 360 degrees and generate global maps of both planets. The spectra will reveal the atmospheric circulation of the Ice Giant stratospheres in exquisite detail, and be able to directly compare circulation and chemistry on both worlds to better understand what makes the two planets different. The NIRSpec instrument will be used to map H3+ and other upper atmospheric emissions at Uranus near-simultaneously with the MRS, allowing us to understand the coupling between the upper, middle and lower atmospheric layers for the first time. It is hoped that these first Ice Giant observations from Webb could form part of a long-term campaign to monitor seasonal and non-seasonal variability on these worlds, as a necessary precursor to future missions to these tantalising destinations.

We outline the plans for the GTO and discuss the advancements that the Webb will give with respect to previous instruments, both ground and space-based.

The dynamics of Mars's annular polar vortices

William Seviour

In common with several other planetary bodies, Mars's atmosphere has strong circumpolar zonal winds during winter, known as polar vortices. A distinctive feature of the Martian polar vortices is that they consist of an annulus of high potential vorticity (PV) with opposing meridional gradients on the equatorward and poleward sides, and a local minimum at the geographic pole. This recent finding is surprising given that a strip of uniform vorticity is barotropically unstable, a result going back to Rayleigh.

Here I will present recent and ongoing work aiming to understand the creation, maintenance, and stability of Mars's annular polar vortices. This work makes use of observational reanalyses, an idealized shallow water model, and a comprehensive general circulation model.

It is shown that the annular structure is linked to both latent heating from CO_2 condensation over the winter pole, as well as forcing from Mars's global Hadley cell. The persistence of the annular structure depends on the fast radiative time scales of Mars's atmosphere. I will also discuss implications for the mixing and chemical composition of polar air.

Structure and dynamical evolution of Titan's northern polar vortex

J. Sharkey, N. A. Teanby, M. Sylvestre, C. A. Nixon, and P. G. J. Irwin

Titan is host to a unique and variable atmosphere. The obliquity of Titan's orbital plane results in varying levels of insolation throughout the Titan year (⇡ 30 Earth years) producing strong seasonal effects. In the winter hemisphere, a polar vortex is formed which sees cold stratospheric temperatures and increased abundances of trace gas species. The Cassini spacecraft recorded 127 flybys of Titan between 2004 and 2017, equivalent to about 1/2 a Titan year, corresponding to northern winter through northern summer. Using CIRS recorded infrared spectra, we use radiative transfer retrieval algorithm to obtain temperatures and compositions in the northern vortex (Irwin et al., 2008). Most CIRS studies have investigated either the zonally averaged variations in temperature and composition of the atmosphere from nadir data (Teanby et al., 2008; Vinatier et al., 2015) or composition and temperature profiles from limb data (Coustenis et al., 2016; Sylvestre et al., 2018). Here, using the retrieved vortex temperatures and compositions, we present the first investigation of the 2D structure of the vortex. We also investigate zonal wind speeds in the vortex and potential vorticity gradients to determine the vortex boundary and its size evolution. A comparison of Titan's vortex evolution with the vortices of other planets offers insights into the main processes which influence their behaviour.

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Observing the atmosphere of Mars with the InSight lander

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It has been a little more than one year since the InSight lander is operating at the surface of Mars. The meteorological instrumentation onboard Insight has unprecedented characteristics of sampling frequency, accuracy and continuity. I will review the discoveries and new vision of the Martian atmosphere that InSight allowed, in the context of Mars' current atmospheric exploration with observations and modeling.

Martian Polar Vortex Dynamics and the 2018 Global Dust Storm.

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Mars' winter atmosphere is characterized by a polar vortex of low temperatures around the winter pole, circumscribed by a strong westerly jet [e.g. 1]. These vortices are a key part of the atmospheric circulation and impact heavily on dust and volatile transport. Regional and global dust events have been shown to cause rapid vortex displacement [2,3] in the northern vortex, while the southern vortex appears more robust. This has implications for tracer transport through the zonal jets associated with the vortices, including the intra-vortex transport of dust itself [4]; a more coherent and low-latitude zonal jet should provide a more effective barrier against tracers entering the polar regions. Mars Global Dust Storms (GDS) are spectacular, planet-spanning events which dramatically increase atmospheric dust loading. The 2018 GDS was observed through its lifecycle by the Mars Climate Sounder (MCS) instrument aboard the Mars Reconnaissance Orbiter [5]; using data assimilation [6] to integrate MCS retrievals [7] with the LMD-UK Mars Global Circulation Model (MGCM) [8] therefore offers an opportunity to examine the effects of the GDS on the polar vortices. We present results on the effects of the 2018 GDS on both southern and northern polar dynamics, focusing on zonal wind speed and potential vorticity at a range of altitudes.

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Characterization of the vertical distribution of C2N2 in Titan's stratosphere

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Titan's atmosphere hosts a complex photochemistry initiated by the dissociation of N2 and CH4, mainly by solar UV and EUV photons. It produces a large variety of hydrocarbons and nitriles (CxHyNz). Data from the Cassini spacecraft (2004-2017) are a great opportunity to measure the abundances of these species at different seasons and latitudes, in order to better understand the atmospheric processes shaping their distributions. In this study, we present the first measurements of the meridional and seasonal variations of the C2N2 (cyanogen) profile. We analyse Cassini/CIRS (Flasar et al., 2004) limb and nadir far-infrared pectra to probe the abundance of C2N2, using its v5 band at 234 cm-1. We use the constrained non-linear inversion code NEMESIS (Irwin et al., 2008) to retrieve C2N2 profiles in the stratosphere, between 0.2 mbar and 15 mbar. We focus on 3 regions undergoing very different atmospheric conditions: the equatorial latitudes (30˚N – 30˚S) between 2006 and 2014, where insolation and temperature have weak seasonal variations; high southern latitudes in autumn, during the polar night, and where strong dynamical effects have been inferred from previous Cassini/CIRS measurements (e.g. Teanby et al. 2017); and high northern latitudes in late spring, where insolation is close to its maximum. These profiles are compared to photochemical models predictions (Vuitton et al., 2019; Dobrijevic et al., 2016), and profiles of other species with different photochemical lifetimes such as HC3N, C4H2 or H2O, thus providing constraints on the chemical and dynamical processes controlling the vertical distribution of C2N2.

On the Photochemistry of Methane and Ethane in the Martian Atmosphere: Towards Indirect Detection of Methane Emissions

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Detecting the presence of atmospheric methane (CH_4) on Mars is an ongoing scientific debate, with multiple observations reporting elevated CH_4 abundances that are difficult to reconcile with current photochemical models detailing Martian atmospheric chemistry. We have expanded the LMD-UK Mars General Circulation Model's 1-D photochemistry submodule to include a comprehensive description of organic chemistry that includes oxidation products of CH_4 and ethane (C_2H_6), a longer chain hydrocarbon that often accompanies abiotic releases of CH_4 on Earth. We report the atmospheric lifetime of CH_4 as a function of altitude along Mars' solar orbit, highlighting regions above the water vapour saturation point where abundances of $O(^1D)$ reduce the lifetime to 25 – 60 years, and a region between 50 – 70 km where loss rates reach a minimum resulting in lifetimes in excess of 1000 years. We use the 1-D model to study the photochemical products from the oxidation of CH_4 and C_2H_6, and how they vary with latitude and altitude. We find that formaldehyde (HCHO) and formic acid (HCOOH) are significant products from the oxidation of CH_4, both which absorb at IR wavelengths. We also identify an atmospheric source of CH_4 from the ultraviolet photolysis of acetaldehyde (CH_3CHO), a product from the oxidation of C_2H_6. We have recently developed the tangent linear model (TLM) and the adjoint for the 1-D photochemistry model, representing valuable mathematical tools that allow us to perform routinely sensitivity analyses that can be used to help reconcile model calculations with satellite observations.

The role of deep jets in bringing order to Jupiter's polar regions

Stephen Thomson

Within the solar-system, the polar regions of planets tend to contain single cyclones centred on or near the poles. These are known as polar vortices. On Jupiter, however, NASA's Juno probe has recently revealed a much more complex structure, with a single cyclone over each pole surrounded by a crystalline arrangement of other cyclones. This observation was rather unexpected, as previous dynamical models of Jupiter's polar regions found a sea of chaotically-moving vortices rather than the crystalline order that is observed. In this study we begin to look at what possible mechanisms might be bringing order to Jupiter's polar regions, with a specific focus on the jet streams below the weather layer, so-called `deep jets'. We first investigate the processes that connect the deep layer and the weather layer in a simple shallow-water model, showing that the competition between radiative damping and high-latitude jet-suppression plays a key role. We then go on to show that the presence of deep jets can bring significant order to the polar regions, even if polar jet streams are not subsequently formed in the weather layer. Implications of these results for polar-vortex crystal formation will be discussed, as well as possible mechanisms for how deep jets will influence vortex-crystal formation in the presence of moist convection.

From spacecraft data to rover measurements – Martian atmospheric modelling and observations

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Introduction: The circulation at Gale crater is studied from the comparison between model and in situ observations from the REMS instrument on-board the NASA's Curiosity rover. As the site has a highly interesting topography, we opted to embed the Laboratoire de Météorologie Dynamique (LMD) Mars Mesoscale Model (or MMM throughout this abstract) into the fields of the UK version of the LMD Mars GCM (or MGCM throughout the abstract) to reach 5 km grid-boxes in resolution. The novelty of this work is the first involvement of data assimilation within such a configuration of models. Essentially, data from the Mars Climate Sounder (MCS) instrument on-board the Mars Reconnaissance Orbiter spacecraft was assimilated in the MGCM to produce a T170L25 reanalysis. Subsequently, the reanalysis forced the MMM, and its output was compared with REMS measurements. The Singular Spectrum Analysis (SSA) decomposition was used for the comparison.

Motivation: The landing site of Curiosity, unlike the Viking landing sites, is not ideal at studying baroclinic waves due to its proximity to the equator, however it is excellent at analysing atmospheric tides [1]. The diurnal variability is altered by the rich and tight topography of Gale Crater, making REMS valuable for studying the effects of topography on the region-al atmospheric circulation, and for studying the smaller scale meteorological effects, such as orographic gravity waves, small scale convection, effects on the planetary boundary layer (PBL) and many others ([2][3][4] and more).

Methodology: The highly computationally expensive configuration forced us to only look at short periods of 5-10 sols at the start of each season. 7x7x25 points from the T170 MGCM reanalysis (less than a degree in resolution) were provided to the MMM as boundary conditions, which were downscaled to 80x80x60 grid-boxes, covering a 400(km)x400(km) region surrounding the crater. The results were extrapolated to REMS' position and both the time-series from the reanalysis and the rebinned observations were de-composed into their SSA eigenvectors and principal components. The boundary conditions were infused at a 2-hourly frequency to capture the diurnal variability of the environment.

Results: The reanalysis and REMS eigenvectors show an almost perfect agreement between the first two signals (diurnal and semidiurnal); an expected feature provided that a reanalysis is driving the mesoscale fields. The (noncorrelative) principal components show a larger amplitude for the REMS observations in comparison to the model predictions. Both the eigenvectors and principal components can be used to reconstruct the signals, essentially filtering out anything else.

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