Splinter Meeting A

Observation and Modelling of Planetary Atmospheres

Contributed Talks: A 01 . . . 06

Chairpeople:

PAUL HARTOGH and
CLAUDIA-VERONIKA MEISTER, Katlenburg-Lindau

Related posters: P 01 and 02

Submillimetre Radiative Transfer and Retrieval Simulations of Molecular Species in the Atmosphere of Mars and the Giant Planets

A 01

PAUL HARTOGH and CHRISTOPHER JARCHOW

Max-Planck-Institut für Aeronomie, Max-Planck-Straße 2, 37191 Katlenburg-Lindau, Germany
hartogh@linmpi.mpg.de, jarchow@linmpi.mpg.de

In the near future two new instruments will help to improve our knowledge about the structure and composition of planetary atmospheres. The German REceiver for Astronomy at THz frequencies (GREAT, from 2004) on the Stratospheric Observatory For Infrared Astronomy (SOFIA) and the Heterodyne Instrument for the Far Infrared (HIFI, from 2007) on the Herschel Space Observatory will sound planetary atmospheres in ranges of the submillimetre-wave spectrum not accessible from ground. Since the sensitivity of these instruments is very high, a large number of new species may be detected during so-called deep line surveys. In case of good signal-to-noise ratios, altitude profiles of the detected molecules can be retrieved using the information of the pressure broadening and the optical thickness of the lines. Among others the vertical profiles of water vapor and its isotopes in the lower and middle atmosphere of Mars and the upper atmosphere of the giant planets is of great interest.

In this talk we will present simulations of molecular spectra as they may be detected by GREAT and HIFI, taking into account the absorption of the Earth middle and upper atmosphere (GREAT only), nadir and limb emissions and absorptions of the planets, the instrument specific parameters including telescope size, sensitivity of the heterodyne receivers, efficiency of the observations modes, calibration and finally the frequency resolution of the spectrometers. As an example the figure below shows the submillimetre spectrum of Jupiter as we believe HIFI will see it. We define detection of a line, if the line amplitude is larger than three times the measurement noise (RMS). This detection can provide information about the column density of the species. In case the lines are much stronger they may contain information about the vertical distribution of the molecule in the planetary atmosphere. We will present a number of inversion calculations of our radiative transfer model. These retrievals will show which altitude resolution of a vertical profile can be expected as a function of the signal-to-noise-ratio of the simulated lines.

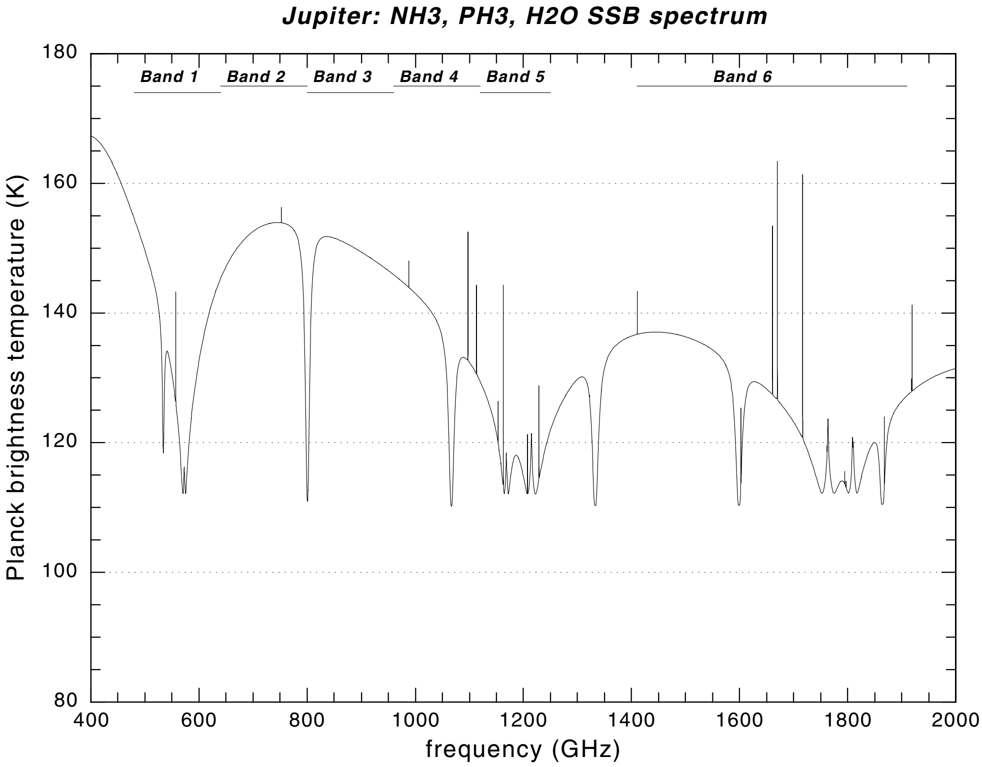

Fig. A 01. Simulated submillimetre spectrum of Jupiter. Indicated at the top are the spectral bands of the HIFI instrument.

On the Sub-grid Modelling of Turbulent Dust Formation in Substellar Atmospheres

A 02 CHRISTIANE HELLING[1,2], RUPERT KLEIN[2,3], PETER WOITKE[1], ULRICH NOWAK[2] and ERWIN SELDMAYR[1]

[1] Zentrum für Astronomie und Astrophysik, TU Berlin, Hardenbergstraße 36, 10623 Berlin, Germany
[2] Konrad-Zuse-Zentrum für Informationstechnik Berlin, Takustraße 7, 14195 Berlin, Germany
[3] Potsdam Institut für Klimafolgenforschung, Telegraphenberg A31, 14473 Potsdam, Germany
chris@astro.physik.tu-berlin.de

Substellar atmospheres are largely – though not completely – convective and considerably cool, where gas – solid/liquid phase transitions can be expected to occur out of a turbulent fluid. Turbulence exhibits a whole spectrum of scales of which only about 2 % are numerically and observationally resolvable. Therefore, a strong need exists to study the remaining 98 % of the multi-scale problem with the aim to build an appropriate sub-grid model which is required to solve the closure problem in macroscopic simulations (e. g. Large Eddy Simulations). We have studied the multi-scale problem of turbulent dust formation starting from the small-scale end where $l_{\rm ref} \ll H_{\rm p}$. Here, a feedback loop between wave induced dust formation and radiative cooling has been identified to cause a transition from an almost adiabatic to an isothermal behavior of the system (Helling et al. 2001).

Utilizing a pseudo-spectral method for driven turbulence in the mesoscopic regime, we have studied the response of the dust complex to a stochastical excitation by a spectrum of waves, typical for a warm layer in the substellar atmosphere: Due to the temporal superposition of expansion waves, nucleation events occur which lead to a strongly intermittent dust distribution. The challenge is now to extract the essential information about the dust complex which allows the construction of appropriate sub-grid closure terms. Therefore, the mean values of the resultant quantities are studied first.

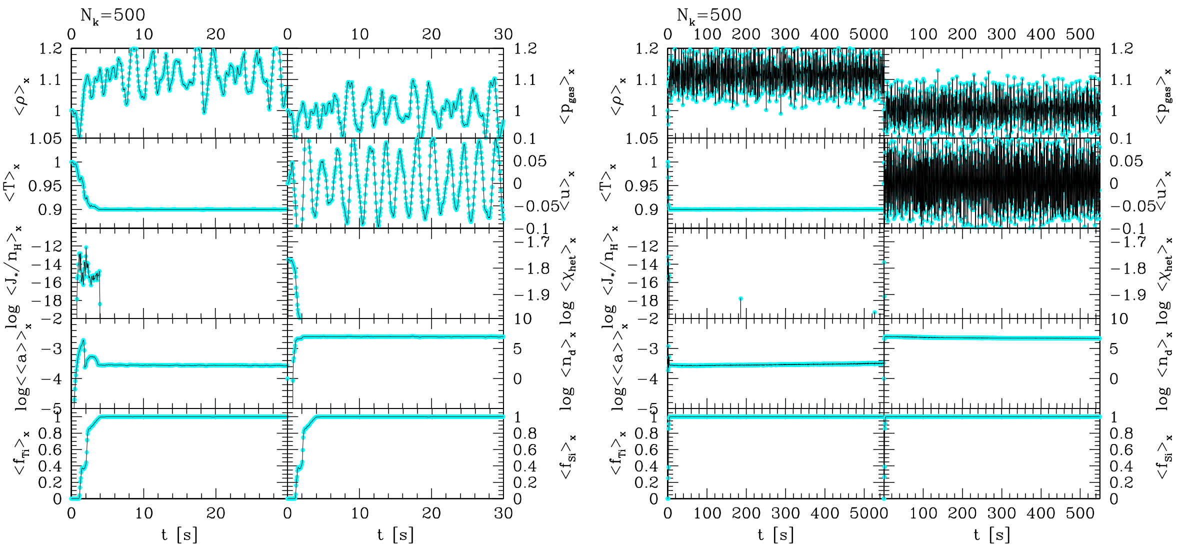

Fig. A 02. Time evolution of the space mean values for a medium excited with $N_k = 500$ wave modes.
Left: short term, *Right:* long term. ($T_{\rm ref} = 2100\,$K, $T_{\rm RE} = 1980\,$K, $\rho_{\rm ref} = 3.16\,10^{-4}\,$g cm^{-3}, $v_{\rm ref} = c_S/10$, $l_{\rm ref} = 10^5$cm, space resolution $N_x = 500$)

The Figure shows that the time means of the hydrodynamic variables still undergo considerable variations in the long run while the mean temperature reaches its constant radiative equilibrium level after a very short time. The l.h.s. of the Figure demonstrates that the whole dust complex is mostly determined during a short initial time interval wherein nucleation and growth take place. In the long term (r.h.s.) the characteristic mean dust quantities (mean particles size $\langle a \rangle$; number of dust particles n_d; degrees of condensation $f_{\rm Ti}$, $f_{\rm Si}$) achieve constancy. Therefore, it has to be tested if it might be appropriate to provide a sufficient turbulent closure term just for the nucleation rate and the grain growth velocity.

References:

Helling Ch., Oevermann M., Lüttke M.J.H., Klein R., Sedlmayr E 2003a, A&A 376, 194

Non-LTE Problem for Molecular Gas in Planetary Atmospheres

A 03 ALEXANDER A. KUTEPOV[1,2], ARTEM G. FEOFILOV[2], WILLIAM C. MAGUIRE[3] and OLEG A. GUSEV[4]

[1]Max Planck Institute for Extraterrestrial Physics, Postfach 1312, 85741 Garching, Germany
[2]Institute for Astronomy and Astrophysics, University of Munich, Scheinerstr. 1, 81679, München, Germany
[3]NASA/Goddard Space Flight Center Greenbelt, MD 20771, U.S.A.
[4]University of Wuppertal, Gauss Str. 20, 42097 Wuppertal, Germany
akutepov@lepvax.gsfc.nasa.gov

The treatment of infra-red molecular band radiation by non-LTE techniques is important for a variety of applications in modeling of planetary atmospheres: for diagnostics of planetary spectra, for estimation of radiative contribution to the energy budget, etc.
We formulate the multilevel non–LTE problem for neutral gas in planetary atmospheres [1] treating explicitly radiative transfer in the overlapping ro-vibrational bands of different molecular species and coupling of molecular and atomic energy levels by various collisionally induced energy transfer processes. Various limiting cases of non-LTE effects are discussed. Three techniques – lambda iteration, matrix and accelerated lambda iteration (ALI) – which are used to solve this problem are discussed and compared. In the case of the CO_2 non-LTE problem in the Martian atmosphere, it is demonstrated [2] that ALI is far superior to the other algorithms in minimizing computer time and storage and in converging much more rapidly. The applications are illustrated by modelling the TES/MGS spectra [3] and by analysis of the non–LTE radiative cooling/heating of the middle and upper Martian atmosphere.

References:
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[2] Gusev, O. A., and Kutepov, A. A., Non-LTE problem for molecular gas in planetary atmospheres, in book: Stellar Atmosphere Modeling, I. Hubeny, D. Mihalas, & K. Werner, eds., ASP Conference Series Vol. 288, 318 (2003)
[3] Maguire, W. C. et al., Observation of high altitude, CO_2 hot bands on Mars by the orbiting thermal emission Spectrometer, J. Geophys. Res. E107, 5063, 10.1029/2001JE001516 (2002)

Diurnal and Annual Variations of the Martian Atmosphere

A 04 CLAUDIA-VERONIKA MEISTER[1], PAUL HARTOGH[1] and UWE BERGER[2]

[1]Max-Planck-Institut für Aeronomie, Max-Planck-Straße 2, 37191 Katlenburg-Lindau, Germany
[2]Leibniz-Institut für Atmosphärenphysik, Schloß-Straße 6, 18225 Kühlungsborn, Germany
berger@iap-kborn.de, meister@linmpi.mpg.de, hartogh@linmpi.mpg.de

The diurnal and seasonal dependence of the Martian general circulation and climate is studied within a fully non-linear, global and three-dimensional hydrodynamic Eulerian gridpoint model which extends from the ground to the lower thermosphere. The atmosphere is a dust-free pure carbon dioxide one, the dynamics of which is driven by the input of solar energy and by gravity. Generally, the radiation transport is assumed to proceed within local thermodynamic equilibrium. Besides, also modifications are considered which are caused by the thermodynamic nonequilibrium above an altitude of 80 km. Diffusive effects like Rayleigh friction, vertical eddy diffusion, molecular heat conduction and dynamic viscosity are taken into account. The horizontal resolution used in the simulations equals 5^o (148 km) in latitude, 22.5^o (475 km) in longitude and about 1 km in altitude.
The numerical results obtained for the temperature profiles and the horizontal wind velocities compare reasonably well with the results of other general circulation models. The temperature profiles reflect the large-scale structure of the martian atmosphere obtained also experimentally. The maximum surface temperatures at summer in the northern and southern hemispheres differ by about 34 K. The zonal mean values of the zonal wind at solstice are up to three times larger than at equinox. In dependence on the season, the meridional wind pattern shows the existence of one or two Hadley cells. The Hadley circulation is strongest on the southern hemisphere in summer in daytime.

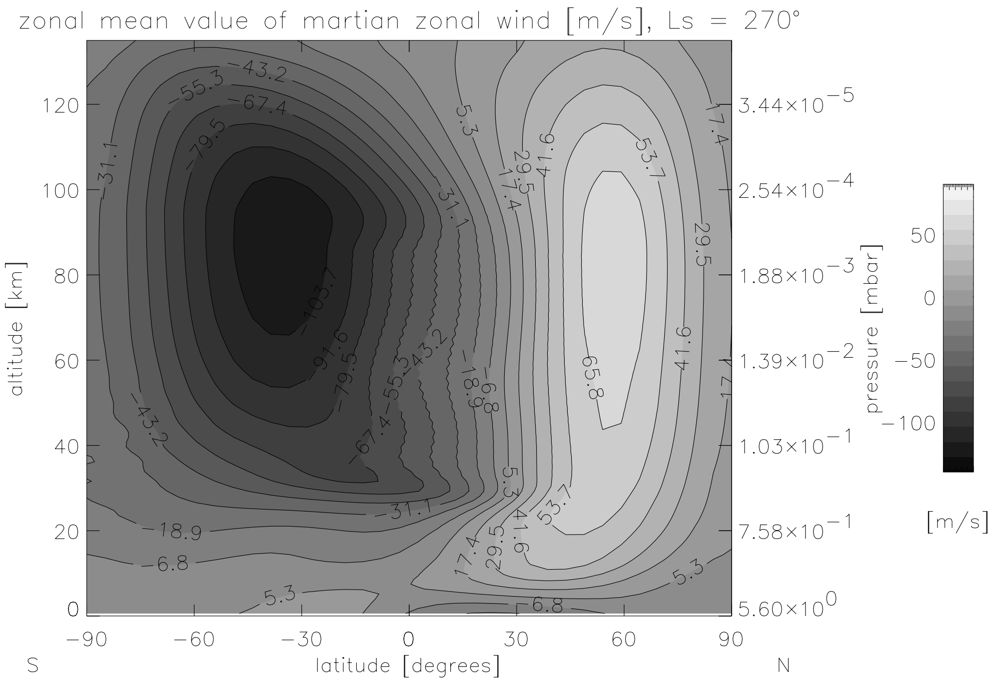

Fig. A 04. Zonal mean value of the zonal wind velocity of the martian atmosphere at nothern hemisphere winter solstice as function of latitude and altitude calculated by MART-ACC.

Schumann Resonances in the Atmosphere of Titan

A 05 Bruno B. Besser[1], Konrad Schwingenschuh[1], Herbert I.M. Lichtenegger[1], Gregorio J. Molina-Cuberos[2], Juan A. Morente[3] and Alexander P. Nickolaenko[4]

[1]Institut für Weltraumforschung, Österreichische Akademie der Wissenschaften, Schmiedlstraße 6, A-8042 Graz, Österreich

[2] Dept. Fisica, Grupo Electromagnetismo Aplicado, Universidad de Murcia, E-30100 Murcia, Espana

[3] Departamento de Fisica Applicada, Universidad de Granada, E-18071 Granada, Espana

[4] Usikov Institute for Radio-Physics and Electronics, National Academy of Sciences of the Ukraine, Kharkov, 61085, Ukraine

Bruno.Besser@oeaw.ac.at

The Saturnian system, and in particular the moon Titan, is the destination of the NASA/ESA mission Cassini/Huygens, launched in 1997. The Huygens probe will investigate Titan's atmosphere in-situ during its descent to the surface beginning of 2005. One of the instruments on-board is the Huygens Atmospheric Structure Instrument (HASI), with the capability also to measure low frequency electric fields and acoustic waves.

Resonances of electromagnetic waves in spherical cavities formed by shells are called SSchumann resonancesïn honor of Winfried Otto Schumann, a German professor of electrical engineering at the Technical University Munich, who investigated them in the beginning of the 1950s. We present results of both numerical and analytical Schumann resonance frequency calculations for spherical cavities. Due to mathematical problems encountered analytical solutions can be obtained for rather simple configurations only. Nevertheless, these solutions are useful as test cases for validating different numerical methods before applying it to the more realistic configurations and problems. A spherical body with a surrounding concentric shell represents an idealization of a planet-ionosphere cavity.

These simple configurations serve as a starting point for investigations of the natural cavity of Saturn's moon Titan. To take into account a more realistic scenario for Titan one has to allow for losses and finite conductivities of the surface and a height profile of the atmospheric conductivity. These calculations can hardly be done by analytical methods, only for rather simple cases.

We compare the resonances derived for a lossless cavity with results of numerical simulations using the Transmission Line Method (TLM). In addition we investigate the underlying eigenvalue problem with a commercial software product based on the finite element method. The simulations show that the Schumann resonance properties are very sensible to the atmospheric conductivity profiles and the properties of Titan's surface. The derived frequencies are up to about 40 percent lower than for a lossless spherical cavity.

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First X-ray Detection from Saturn with Chandra

A 06 JAN-UWE NESS[1], JÜRGEN H.M.M. SCHMITT[1], SCOTT J. WOLK[2], KONRAD DENNERL[3] and VADIM BURWITZ[3]

[1]Universität Hamburg, Hamburger Sternwarte, Gojenbergsweg 112, 21029 Hamburg
[2]Chandra X-ray Center, Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA
[3]Max-Planck-Institut für extraterrestrische Physik (MPE), Giessenbachstrasse, 85748 Garching, Germany
jness@hs.uni-hamburg.de

We obtained a 70 ks observation of Saturn with the ACIS-S detector aboard Chandra. A first detection of X-rays was reported by Ness & Schmitt 2000 (A&A, **355**, 394) measured with ROSAT, however, this detection was only marginal. In our 70 ks observation we collected 236 counts that can be attributed to Saturn. The spectrum is very faint, but a spectral feature at $\sim$ 600 eV can be identified, which must be attributed to oxygen K-shell emission. A smoothed image covering the full observation is presented in the figure. The observation covers two planetary rotations.

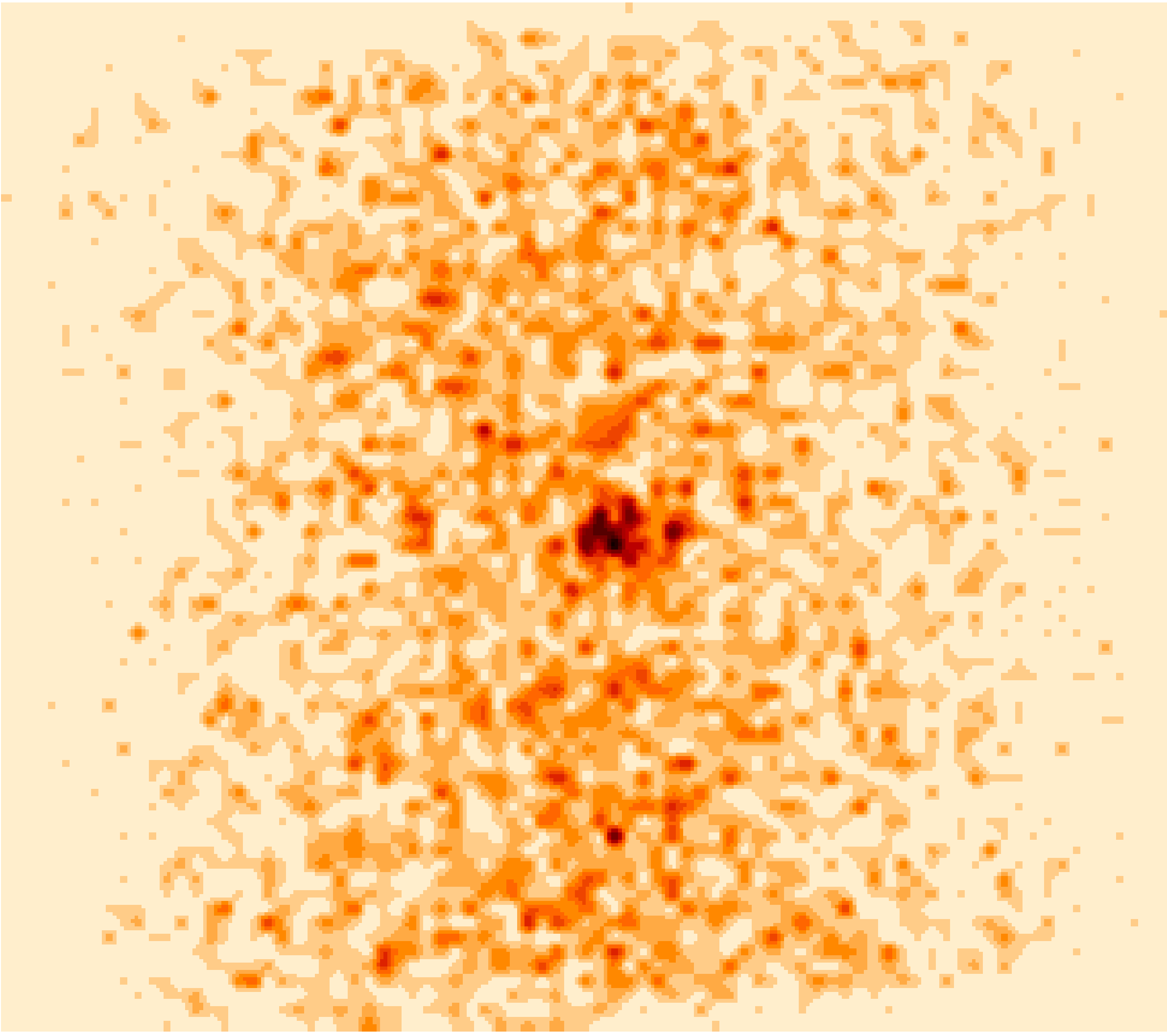

Fig. A 06. Smoothed image of ACIS-S exposure of Saturn (Exposure time 70 ks, image size is $150'' \times 150''$)