Rocket Measurements of the Direct Solar Lyman-alpha Radiation Penetrating in the Atmosphere

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The resonance transition ^2P-^2S of the atomic hydrogen (Lyman-alpha emission) is the strongest and most conspicuous feature in the solar EUV spectrum. The Lyman-alpha radiation transfer depends on the resonance scattering from the hydrogen atoms in the atmosphere and on the O_2 absorption. Since the Lyman-alpha extinction in the atmosphere is a measure for the column density of the oxygen molecules, the atmospheric temperature profile can be calculated thereof. Rocket measurements of the direct Lyman-alpha radiation vertical profile in the summer mesosphere and thermosphere (up to 120 km), at high latitudes will be carried out in June 2006. The Lyman-alpha flux will be registered by a detector of solar Lyman-alpha radiation, manufactured in the Stara Zagora Department of the Solar-Terrestrial Influences Laboratory (STIL BAS). Its basic part is an ionization camera, filled in with NO. The scientific data analysis will include raw data reduction, radiative transfer simulations, temperature retrieval as well as co-analysis with other parameters, measured near the polar summer mesopause. This project is a scientific cooperation between STIL-BAS, Stara Zagora Department and the Atmospheric Physics Group at the Department of Meteorology (MISU), Stockholm University, Sweden. The joint project is part from the rocket experiment HotPay I, in the ALOMAR eARI Project, EU's 6th Framework Programme, Andoya Rocket Range, Andenes, Norway.

Introduction

The HotPay project is a part of the ALOMAR (Arctic Lidar Observatory for Middle Atmosphere Research) eARI Project of Andoya Rocket Range (ARR), Andenes, Norway, through EU's 6th Framework Programme.

In this rocket experiment newly developed, small, standardized payloads will be used, called "Hotel Payloads" – HotPay. Two rocket launches are envisaged: HotPay I and II. Data from all ground-based instruments in ALOMAR and ARR will be available for the scientific research.

HotPay I is a summer launch, planned for June 2006. Studies of the middle atmosphere in the 60 – 120 km altitude range will be carried out.

HotPay II will be launched in winter, January 2007. The rocket will reach 250 km altitude. Studies of the ionosphere and the aurora will be provided.

A number of projects have been approved for the two rocket launches.

Project of direct solar L_α measurements - ASLAF

The project ASLAF (Absolute Solar Lyman-Alpha Flux) is a joint project, based on the scientific cooperation between the Stara Zagora Department, Solar-Terrestrial Influences Laboratory, Bulgarian Academy of Sciences (STIL BAS) and the Atmospheric Physics Group at the Department of Meteorology (MISU), Stockholm University, Sweden.

The basic purpose of ASLAF is the measurement of the direct solar Lyman-alpha (L_α) radiation. The resonance transition ^2P-^2S of the atomic hydrogen (Lyman-alpha emission) is the strongest and most conspicuous feature in the solar EUV spectrum. It is one of the main characteristics of the solar radiation together with F10.7 MHz and, therefore it is the object of regular satellite and rocket measurements [1 - 5].

Due to the favourable circumstance, that the Lyman-alpha wavelength coincides with a minimum of the O_2 absorption spectrum, the direct Lyman-alpha radiation penetrates well in the mesosphere (Fig.1).

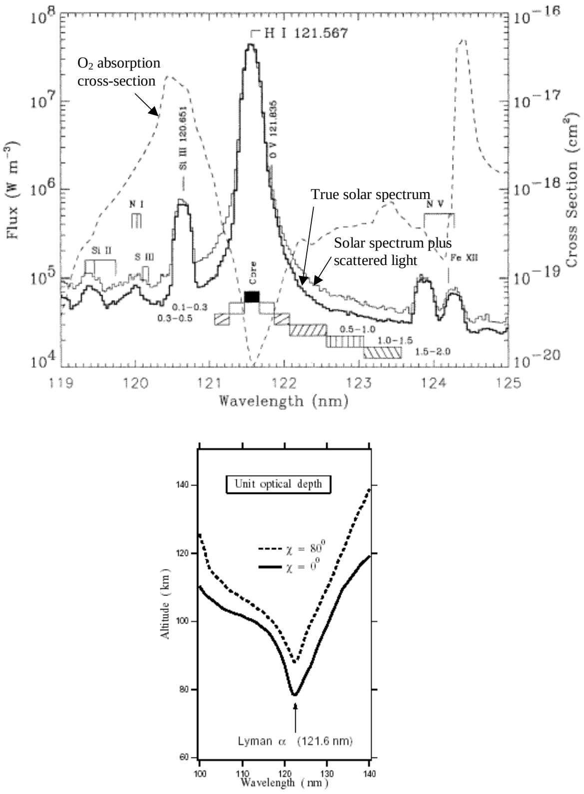

Fig.1. Solar and molecular O_2 cross-section spectra near L_α given from Woods et al. [4] (up), and the dependence of the altitude where the optical depth τ=1 for solar zenith angles 0° and 80° on the wavelength after Kockarts [6] (down).

Due to the high intensity of the L_α emission and its comparatively easy penetration in the earth atmosphere, it is the main source of energy, deposited in the mesosphere. Therefore, the knowledge of the L_α radiation and its variation is important for many investigations of the middle and upper atmosphere [5, 7]. The L_α study leads to a better understanding of the chemistry in the region mesosphere – low thermosphere, to including new chemical processes and transport mechanisms in the models. L_α influences the atmospheric structure and especially the D-region, allowing to determine the H content in the atmosphere [6, 8].

More *in situ* measurements of the L_α profile are necessary to understand all occurring processes in detail. For example, the origin and the structure of the noctilucent clouds (NLC), typical for the summer mesosphere at high latitudes are not fully clarified yet. It is possible that they are precursors of long-term changes in the upper atmosphere [9]. The vertical structure of NLC, the dynamics, concentration and dimensions of the ice particles inside them are investigated by Gumbel and Witt [10]. The generation, the evolution and the eventual sublimation of NLC, taking into account the influence of the solar L_α radiation, are modelled and their influence on the chemistry of O_2, O_3 and H is studied by Murray and Plane [11]. The influence of the mesospheric ionization level, connected with the changes of the solar L_α radiation and the precipitating particles is being studied and its further clarification antecedes, as well the study of the CO_2 changes influence on the mesopause region temperature and on the appearance of polar mesospheric solar echo (PMSE) and NLC [6, 12, 13]. The L_α change through the solar cycle together with the increase of methane in the atmosphere leads to long-term changes in the water vapour content in the mesosphere [14].

The process of L_α attenuation in the earth atmosphere is modelled for different seasons and geographical latitudes, taking into account different processes: the O_2 absorption and its temperature and wavelength dependence, the multi-resonance scattering from atomic hydrogen and the related Doppler effect [15].

Rocket sounding is the basic way to study the mesosphere and the low thermosphere. The aerodynamic effects in rocket flights are modelled and investigated in order to avoid errors in rocket *in situ* measurements, due to perturbations, as a result of the gas flux around the rocket [16].

Using rocket observations of the attenuation of the solar L_α radiation, registered by ionization chambers, the pressure, density and temperature in the mesosphere can be derived by traditional methods [17 - 20].

Basic goals of ASLAF

The interaction of the Lyman-alpha radiation with the atmospheric constituents produces the NO molecules ionization, thus generating the ionospheric D-layer, and the water vapour photolysis, being one of the main H_2O loss processes. The Lyman-alpha radiation transfer depends on the resonance scattering from the hydrogen atoms in the atmosphere and on the O_2 absorption. Since the Lyman-alpha extinction in the atmosphere is a measure for the column density of the oxygen molecules, the atmospheric temperature profile can be calculated thereof.

The importance of the L_α penetration in the thermosphere and mesosphere as a main source of energy input and its connection with the O_2 concentration and the temperature as well with all processes in these regions is known long ago. At the same time, lots of ambiguities in our concepts for the chemical and physical processes in the mesosphere, low thermosphere and, in particular near the mesopause, have been found out. Such not fully clarified questions are, for example, the influence of L_α on the trace gases, the role of CO_2 and CH_4 on the temperature distribution, the origin and structure of NLC and the properties of their constitutive ice particles [6, 9, 11, 14, 21 - 23]. That is why the L_α measurements and the study of the middle atmosphere processes are important features to be carried out.

With regard to this, the basic goals set out in the ASLAF Project, are the following:

- Design and manufacturing of a modern L_α detector;
- Participation in the rocket experiment HotPay I and registration of the direct L_α radiation;
- Retrieval of the real O_2 concentration and temperature profiles;
- Analysis of the obtained results jointly with data from other projects, taking part in the rocket experiment, as well with data from simultaneous ground-based and satellite measurements.

Method of observation

The direct solar radiation flux will be recorded from 50 to 110-120 km by means of a EUV solar Lyman-alpha detector. After a preliminary agreement, the measuring device will be manufactured in the Stara Zagora Department of STIL. The basic element of the L_α detector is an ionization chamber. The principle structure of such ionization chambers for the UV region is described, for example, by Stober et al. [24], Carver & Mitchel [25], Masuoka & Takanori [26], Thrane et al. [17]. In our experiment, an ionization chamber of the Artech Corporation will be used. It is filled with NO and is furnished with LiF window. Its sensitivity to radiation is between 105 nm and 135 nm, and the quantum efficiency is 40% ÷ 60% for voltages 25V ÷ 150V. The working voltage is usually chosen to be negative, about – 45V applied to the central electrode-collector. The role of the other electrode is executed by the chamber walls. The maximum photoelectric current output is estimated about 10 nA, when the window is fully illuminated, its effective surface being proportional to the cosine of the angle to the Sun. As the minimum measured

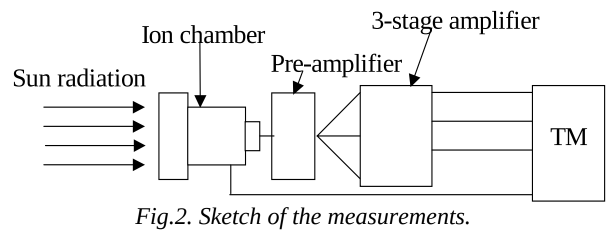

Fig.2. Sketch of the measurements.

current at 55 km altitude in the Thrane experiment [17] is about 50 pA, the measuring range of the L_α detector should be foreseen to cover 10^{-11}A ÷ 10^{-8}A.

The current from the ionization chamber passes through an associated low-noise pre-amplifier and then is fed to a three-stage amplifier with amplification 1x, 10x, 100 xs. The detected analogue signal is standardized to a TTL output from the amplifiers and is fed to three digital words/frame of the TM system together with an analogue sub-commutated signal to monitor the sensor conditions (voltage and temperature).

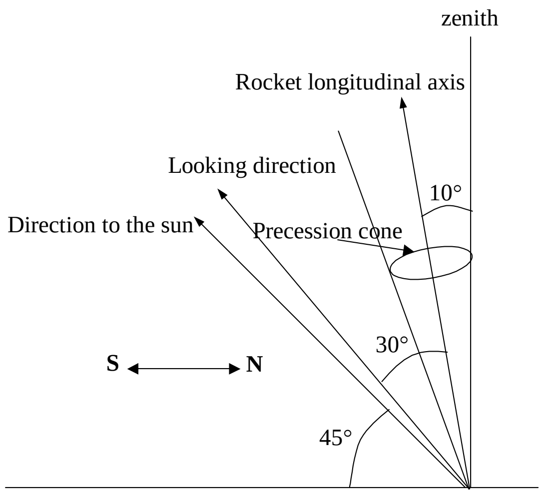

Fig.3. Possible mutual positions of the principal directions in the Lyman-alpha experiment in a plane, perpendicular to the azimuthal one. The appropriate looking direction of the solar Lyman-alpha detector is matched.

The possible mutual positions of the principal directions in the Lα experiment are shown in Fig.3, based on preliminary data. The launch zenith angle will be 10° and the rocket will precess around its axis describing a cone with opening angle 10°. The position of the Lyman-alpha detector in payload is chosen with consideration of the experiment conditions. It will be tilted towards the rocket longitudinal axis to an angle of about 50° in order to catch the Sun in its field of view when it will point to the South during the rocket rotation. The appropriate looking direction of the detector is marked in Fig.3, and a sketch of its position in payload is presented in Fig.4.

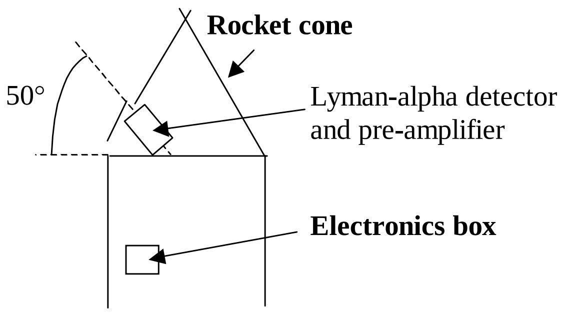

Fig.4. Position of the measuring instrument in payload.

The launch parameters and conditions as well as the input parameters for the electronics, depending on the ion chamber work parameters will be specified. The electronics and mechanics design will be worked out and co-ordinated with those of the other instruments onboard and the whole payload design. All details being specified, the Lyman-alpha detector will be manufactured.

REFERENCES

[1] J.Chamberlain, "*Theory of planetary atmospheres*", Academic Press, 1978.

[2] M. Ya. Marov, A.Kolesnichenko, "Introduction to the planetary aeronomy", Moscow, Nauka, 1987 (in Russian).

[3] R.C.Willson, "Solar irradiance variability during solar cycles 21 and 22", In: NASA, Goddard Space Flight Center, *Climate Impact of Solar Variability*, 1990, p. 279 (SEE N91-12456 03-92).

[4] Th.N.Woods, G.J.Rottman, O.R.White, J.Fontenla, E.H. Avrett, "The solar Lyα line profile", *Ap. J.*, Vol. 442, 1995, pp. 898-906.

[5] Th.N.Woods, W.K. Tobiska, G.J.Rottman, J.R.Worden, "Improved solar Lyman alpha irradiance modelling from 1947 through 1999 based on UARS observations", *JGR*, Vol. 105, I.A12, 2000, pp. 27195-27216.

[6] G.Kockarts, "Aeronomy, a 20th century emergent science: the role of solar Lyman series", *Ann.Geophys.*, Vol. 20, 2002, pp. 585-598.

[7] Th.N.Woods, G.J.Rottman, "Solar Lyman alpha irradiance measurements during two solar cycles", *JGR*, Vol.102, 1997, I.D7, pp. 8769-8780.

[8] J.Bishop, "Thermospheric atomic hydrogen densities and fluxes from dayside Lyman α measurements", *JASTP*, v.63, 2001, pp. 331-340.

[9] G.E.Thomas, J.Olivero, "Noctilucent Clouds as Possible Indicators of Global Change in the Mesosphere", *Adv. Space Res.*, Vol. 28, 2001, pp. 937-946.

[10] J.Gumbel, J.Witt, "*In situ* measurements of the vertical structure of a noctilucent cloud", *Geophys. Res. Lett.*, Vol. 25, I.4, 1998, pp. 493-496

[11] B.J.Murray, J.M.C.Plane, "Modelling the impact of noctilucent cloud formation on atomic oxygen and other minor constituents of the summer mesosphere", *Atmos. Chem. Phys. Discuss*., Vol. 4, 2004, pp. 7181-7216.

[12] D.Pancheva D., R.Schminder, J.Lastovicka, "27-day Fluctuations in the ionospheric D-Region", *J.Atmos.Terr.Phys*., (ISSN 0021-9169), Vol. 53, 1991, pp. 1145-1150.

[13] J.Bremer, P.Hoffmann, R.Latteck, W.Singer, "Seasonal and long-term variations of PMSE from VHF radar observations at Andenes, Norway", *JGR (Atmospheres*), Vol. 108, I.D8, 2003, pp. PMR 5-1, citeID 8438, DOI.

[14] S.Chandra, C.H.Jackman, E.L.Fleming, J.M.Russell, "The seasonal and long term changes in mesospheric water vapour", *Geophys.Res.Letters*, Vol. 24, I.6, 1997, pp. 639-642 .

[15] Th.Reddmann, R.Uhl, "The solar hydrogen Lyman-alpha photon density within the mesosphere", *EGS XXVII General Assembly, Nice, 21-26 April 2002*, Abstract #2186.

[16] J.Gumbel, "Aerodynamic influences on atmospheric in situ measurements from sounding rockets", *JGR*, Vol. 106, 2001, pp. 10553-10563.

[17] E.V.Thrane, I. Nyberg, B. Narheim, "Measurements of the extinction of solar hydrogen Lyman-α in the mesosphere", *Internal Report E-230, Norwegian Defense Research Establishment (FFI)*, Norway, 1974.

[18] E.V.Thrane, A.Johannessen, "A measurement of the extinction of solar hydrogen Lyman-α radiation in the summer arctic mesosphere", *J. Atm. Terr. Phys.*, Vol. 37, 1975, pp. 656-661.

[19] E.V.Thrane, O.Hagen, F.Ugletveit, "Rocket measurements of mesospheric density, pressure and temperature", *Internal Report E-269, Norwegian Defense Research Establishment (FFI)*, Norway, 1977.

[20] Vardavas, I.M., J. H. Carver, "Comments on the Newton-Raphson method for obtaining temperature profiles from radiative-convective models", *Planet. Space Sci.*, Vol. 32, 1984, pp. 803-807.

[21] R.G.Roble, R.E. Dickinson, "How will changes in carbon dioxide and methane modify the mean structure of the mesosphere and termosphere?", *Geophys. Res. Lett*., Vol. 16, 1989, pp. 1441-1444.

[22] G.E.Thomas, J.J.Olivero, M.DeLand, E.P. Shettle, "A response to the article by U. von Zahn", "Are Noctilucent Clouds Truly a "Miner's Canary" of Global Change?", *EOS Transactions*, American Geophysical Union, Vol. 84(36), 2003, pp. 352-353.

[23] U.Von Zahn, "Are noctilucent clouds truly a "Miner's Canary" of global change?", *EOS Transactions*, American Geophysical Union, Vol. 84(28), 2003, pp. 261-268.

[24] A.K.Stober, R.Scolnik, J.P.Hennes, "A vacuum ultraviolet photoionization detector", *Appl. Opt*., Vol. 2, 1963, pp. 735-739.

[25] J.H.Carver, P. Mitchel, "Ionisation chambers for the vacuum ultra-violet", *J. Sci. Instrum.*, Vol. 41, 1964, pp. 555-557.

[26] T.Masuoka, O. Takanori, "Lyman-alpha detector with MgF2 window", *Rev. Sci. Instrum.*, Vol. 45, 1974, pp. 1012-1014.