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Implementation of the earth-based planetary radio occultation inversion technique in Shanghai Astronomical Observatory

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Comparing to the other atmosphere detection techniques, a radio science experiment only involves the telecommunication subsystems onboard the spacecraft and ground stations, and does not use any special space borne scientific instruments. By examining the changes in the frequency, phase, amplitude and polarization of a radio signal propagating from a spacecraft to a ground station, investigators can study the atmospheric and ionospheric structure of planets and their satellites, planetary gravitational fields, shapes, masses, planetary rings, ephemerides of planets, solar corona, magnetic fields, cometary comae, and such aspects of the theory of general relativity like gravitational waves and gravitational redshift[1].

The history of radio occultation studies goes back to the early 1960s. The first radio occultation experiment was implemented in 1965 when Mariner IV flew by Mars. Scientists used occultation data to determine the features of the Martian atmosphere, and proved that the Martian atmosphere is predominantly CO_2 and that the surface pressure is less than one percent that of Earth, or an order of magnitude less than what had been previously believed[2].

In 2007-2008, Shanghai Astronomical Observatory (SHAO) successfully conducted the radio tracking experiment of the Chang'E-1 (CE-1) satellite. This experience is valuable for the upcoming joint Russian-Chinese Yinghuo-1(YH-1) & Phobos-Grunt(FGSC) Mars exploration project, in which the earth-based planetary radio occultation experiment will be carried out. The newly developed SHAO Earth-based Planetary Occultation observation Processing System (SPOPS) is especially designed for this project. The main objective of SPOPS is to retrieve the temperature, pressure, molecular number density profiles of Martian atmosphere and electron density profiles of the ionosphere from the earth-based planetary occultation observations. This system includes five parts: control module, observation arrangement module, observation pre-processing module, ionosphere and neutral atmosphere inversion modules. Utilizing the open-loop and closed-loop Doppler residual data of the Mars Express (MEX) radio occultation experiment provided by the ESA Planetary Science Archive (PSA) and the NASA Planetary Data System (PDS), the temperature, pressure, number density profiles of the Martian atmosphere and electron density profiles of the ionosphere are successfully retrieved by the Abel inversion method. The results are validated by the released level 04 radio science products of the ESA MaRS group.

As the MEX Doppler residual data has already been calibrated for effects such as: relative position and motion of the ground station and spacecraft, tuning of the transmitter, and a model-based correction for one- or two-way propagation through the Earth's neutral atmosphere. We have only to do a zero-reference correction for the Doppler data by subtracting any Doppler bias that may remain after the gross effects of the trajectory, and Earth's atmosphere. This Doppler bias is determined by taking the mean of the Doppler residuals obtained prior to the start of the profile.

The neutral atmosphere and ionosphere inversion profiles of MEXMRS_0046 on DOY 139, 2004 by SPOPS and the level 04 product of MaRS are compared. The lowest sample of MEXMRS_0046 is located at (267.350˚E, 52.523˚N), with local true solar time 17.025h, solar zenith angle 69.965˚, and solar longitude 32.339˚E. This is an observation in the spring afternoon of the northern mid-latitude.

In the neutral atmosphere inversion by SPOPS, we assume the Martian atmosphere is composed of 27% N_2, 95.3% CO_2 and 16% Ar[3]. Three upper boundary temperatures, 130K, 165Kand 200K are considered at the altitude of 40 km. The inversion results of the S-band and X-band Doppler residuals by SPOPS are consistent. Compared with the X-band inversion result, higher noise is observed in S-band, especially in the temperature profiles between 20 $\sim$ 40km, which may come from the small structures in the atmosphere, Doppler quantification error, and the specific data processing method. Although three kinds of atmospheric boundary conditions are adopted, the retrieved pressure and temperature profiles converge to the same extent below 10 km above the Martian surface. For the selected observation MEXMRS_0046, the pressure on the Martian surface is about 627Pa, the temperature is about 227K, and the molecular number density is about $0.2\times10^{24}/m^3$.

The retrieved ionosphere profiles by SPOPS generally agree well with the result given by MaRS, with the same order of density magnitude and a similar profile shape. Both profiles reflect the basic features of the main peak (M2) and secondary peak (M1) of the Martian ionosphere. Because of the possible difference in height calculation and baseline correction methods used, deviations exist in the M2 peak density and peak height of the two profiles. Our derived M2 peak height is 130.53 km, and the peak electron density is 10.313×10^{10}el/m^3, while the results of MaRS are 137.933 km (potential height) and 10.891×10^{10}el/m^3 respectively.

In order to determine whether or not the two-way closed-loop and three-way open-loop experiments can yield consistent results, we also compare the inversion results of the IFMS A (X-band), IFMS B (X-band) and IFMS RS (S-band) closed-loop observation (MEXMRS_0669) on DOY 355, 2005. The inverted neutral atmosphere profiles of IFMS A (X-band), IFMS B (X-band), and IFMS RS (S-band) are basically consistent. Since the sample rate of IFMS B and IFMS RS is ten times that of IFMS A, and IFMS RS is in the RS post-processing mode, the temperature profile of IFMS A is smoother compared to the other two profiles. The noise in IFMS B and RS profiles may come from the small structures of the atmosphere, and may also come from some uncertain errors which need further study. It was shown that the accuracies of the open-loop and closed-loop inversion results are comparable.

The completion of SPOPS can be directly applied to the occultation observation process in China's upcoming YH-1 Mars Exploration Project.

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