CROSSLINK OCCULTATION MEASUREMENTS AT MARS

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Introduction: Radio waves propagating through a refractive medium like a planetary atmosphere or ionosphere experience phase shifts which can be used to study the refraction properties of the medium along the signal ray path. Converting these refractivity profiles into vertical electron density profiles and profiles of neutral number density, temperature and pressure can give important information about structure and dynamic processes of the ionosphere and lower/middle atmosphere of planetary bodies.

The experiments are mostly conducted in a special operational mode, the so-called Earth occultation mode. Since the first experiment of this kind, which was performed during the flyby of the Mariner 4 spacecraft at Mars [1], radio occultation experiments became an essential component of almost all flyby and orbital missions in the solar system (e.g.[2,3,4,5,6,7]).

In an Earth occultation geometry a radio signal transmitted by a spacecraft propagates through the planetary ionosphere and atmosphere before and after the spacecraft is occulted by the planetary disc as seen from the Earth. The signals are received and recorded at an Earth ground station. The planet-spacecraft-Earth geometry does not allow all times to perform these measurements but restricts the opportunities to occultation seasons, dependent on the planetary constellations and the spacecraft orbit.

An occultation geometry, however, does not necessarily involve an Earth ground station. The ground station can also be realized by a second satellite orbiting the planet, leading to so-called crosslink occultations. Numerous Earth orbiting satellites., i.e. spacecraft in a low Earth orbit (e.g. CHAMP, COSMIC, GPS-MET) can be used in combination with satellites of the Global Positioning System (GPS) to study the Earth environment (e.g. [8]). Whenever the GPS satellite sets or rises as seen from the low Earth orbiting satellite a radio occultation experiment can be performed. This results in hundreds of occultation opportunities per day.

Mars Express MaRS radio occultations: The Mars Express radio science experiment (MaRS) has been performing radio occultation measurements since the beginning of the mission in 2004 (e.g. [8], [9], 10]). More than 800 profiles have been obtained so far. MaRS was the first radio science experiment which could analyse the convective daytime boundary layer in detail [11], and the first radio occultation experiment which reported on sporadic ionospheric layers on Mars [12]. These radio occultation experiments are performed in a coherent two way-mode where the radio link is stabilized on ground by a hydrogen maser and transmitted to the spacecraft. The spacecraft receives an X-band uplink signal, converts it to two coherent downlinks at X- and S-band frequencies and transmits them to Earth. The two-way approach limits the measurement to the entry (ingress) part of the occultation event but has the advantage of a higher sensitivity to the atmospheric parameters compared to one-way experiments. The Earth-Mars configuration restricts the Earth occultations to regions on Mars with intermediate values of solar zenith angle. Earth occultation experiments are also restricted by the availability of ground stations to transmit and record the radio signal.

Crosslink occultations at Mars: The first crosslink occultation experiments on other planets were performed at Mars between the Mars Odyssey spacecraft and the Mars Reconnaissance Orbiter (MRO) ([13,14]). The ultra high frequency (UHF) proximity link signal,which is normally required to provide relay telecommunication and navigation services to Mars landers and rovers,was transmitted by the Mars Odyssey spacecraft and received by MRO. All currently active Mars missions, except for India's Mars Orbiter Mission (MOM) are equipped with an ultra high frequency (UHF) proximity link.The fundamental observable is the carrier phase on the proximity link. Crosslinks depend on the orbital configurations of both

spacecraft and the capabilities of the proximity link. The accuracy of these measurements depend on the transmitted power, the receiver sensitivity, the transmit and receive antenna gains and the precise knowledge of the spacecraft orbital parameters [13].
Apart from the X- and S-band radio system, Mars Express is equipped with the UHF transponder MELACOM (401 - 437 MHz) and 2 patch antennas. The MELACOM system, designed for communications at closer distances (hundreds to thousands km),was originally designed to communicate with the Beagle-2 lander.
Generally, MELACOM can communicate with any landed station on the Mars surface and other orbiters which support the CCSDS (Consultive Committee for Space Data Systems) Proximity-1 protocol. MELACOM is able to record UHF received signals in open loop mode, convert the received signal to baseband, and sample it at high frequency [15]. It has been successfully used to test the link with the NASA Mars Exploration Rovers Spirit and Opportunity, to perform Doppler measurements with Opportunity, and to record the entry, descent and landing of Phoenix in 2008 [15].

Conclusions:
Crosslink occultations at Mars are a powerful tool for retrieving highly accurate ionospheric and atmospheric profiles at Mars. Compared to Earth occultations, the cross link occultations have significant advantages: they are not limited to Earth occultation seasons, not restricted by the availability of groundstations and can retrieve observations at much smaller and larger solar zenith angles.

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