Observation of the lunar ionosphere by the dual-spacecraft radio occultation technique in SELENE

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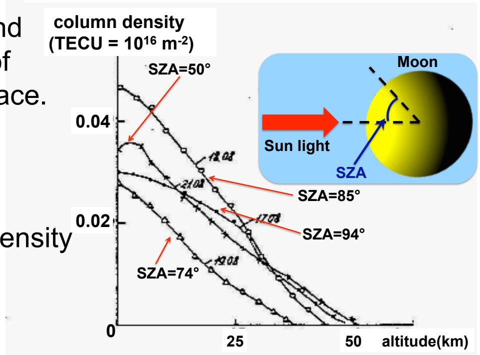
◯ Lunar ionosphere: Does it exist ?

Positive results

- Refraction of the radio waves was observed during occultations of radio stars by the moon in 1960s.
- Altitude-dependent phase shift was observed in the radio occultation experiments in Russian Luna missions in 1970s.

} The electron density around the moon is on the order of 100 cm^{-3} on the sunlit surface.

The observation results in Luna Mission



[A.S.Vyshlov et al.(1976)]

Opposing arguments

- Solar wind removes plasmas quickly.
- The lunar atomosphere is as thin as < 10^6 cm^{-3}.
- Some occultation observations using radio stars deny the existence of the lunar ionosphere.

} Theories predict the electron density will be on the order of 1 cm^{-3}.

◯ Possible sources of electrons near the lunar surface

Ⅰ. Photoelectrons emitted from suspended lunar dust

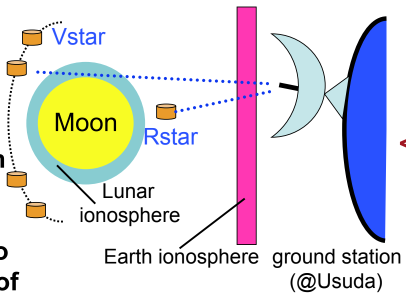
It is considered that there are a lot of small charged dust particles elevated above the lunar surface. Photoelectrons emitted from these dust particles may explain the observed electron density.

Ⅱ. Ionization of the water molecule emitted from the lunar surface

It was recently discovered that water molecules exist in a thin layer of the lunar surface. A portion of such water will be released from the surface and photodissociated to yield H or OH , which will be photoionized to increase the electron density.

◯ Observation method

Each of the sub-satellites, Vstar and Rstar, transmits two radio waves with different frequencies. A linear combination of the measured phase variations at these frequencies can distinguish the plasma contribution from the influence of the fluctuation of the onboard oscillator. The use of two satellites enables the separation of the lunar ionosphere and the terrestrial ionosphere.



$$\Delta\phi_1(t) = \frac{\alpha}{cf_1} N_e(t) + \beta f_1$$
$$\Delta\phi_2(t) = \frac{\alpha}{cf_2} N_e(t) + \beta f_2$$

$$\delta\phi(t) = \Delta\phi_1(t) - \frac{f_1}{f_2}\Delta\phi_2(t) = \frac{\alpha}{c} f_1\left(\frac{1}{f_1^2} - \frac{1}{f_2^2}\right)\bullet N_e(t)$$

$(\alpha = e^2/8\pi^2\varepsilon_0 m_e \approx 40.3 \ \ m^3 s^{-2})$

<dual spacecraft method>

While Vstar is occulted by the moon, Rstar monitors the earth ionosphere.

[merit]

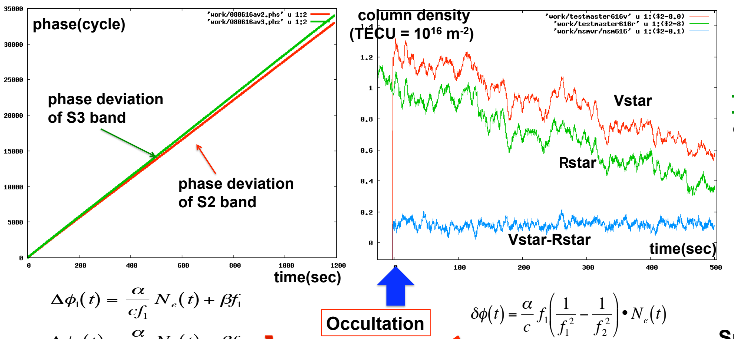
The contribution from the interplanetary electron densities and the earth ionosphere can be removed from the measured total electron density.

[drawback]

The mesurement noise in the obtained electron density becomes large because of the nearby frequencies used in this method(S_2 band:2218 MHz and S_3 band:2287 MHz). The number of observation opportunities is limited as compared to single-spacecraft method.

◯ Analysis method

Ⅰ. differential phase → the column density for the time



$$\Delta\phi_1(t) = \frac{\alpha}{cf_1} N_e(t) + \beta f_1$$
$$\Delta\phi_2(t) = \frac{\alpha}{cf_2} N_e(t) + \beta f_2$$

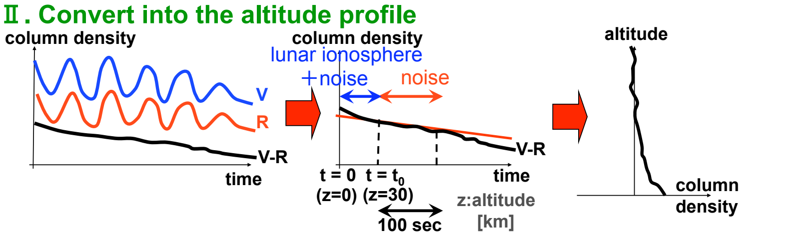
$$\delta\phi(t) = \Delta\phi_1(t) - \frac{f_1}{f_2}\Delta\phi_2(t)$$

$$\delta\phi(t) = \frac{\alpha}{c} f_1\left(\frac{1}{f_1^2} - \frac{1}{f_2^2}\right)\bullet N_e(t)$$

The phase deviation from the basic phase of S_2 band and S_3 band are calculated.

The differential phase is calculated for both Vstar and Rstar, and then it is converted into the column electron density.

Ⅱ. Convert into the altitude profile

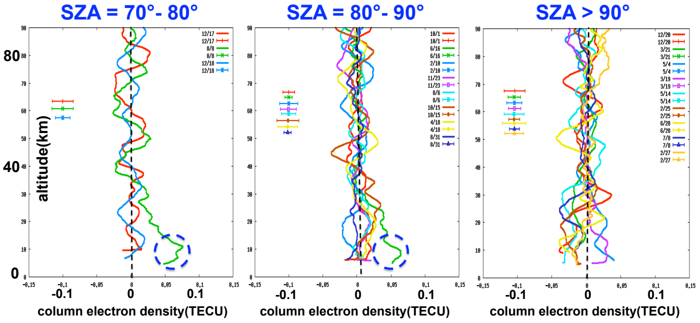


Subtract the column electron density obtained by Rstar from one obtained by Vstar.

Assuming that the lunar ionosphere exists below 30 km altitude, the overall trend of the noise component is obtained by fitting a linear function to the 100 sec interval above this altitude.

The trend component is subtracted from the original data and the resulting lunar ionosphere component is converted to an altitude profile.

◯ Result



◯ Summary

- Although some theories might be able to explain the existence of the lunar ionosphere, there are many uncertain factors .
- We tried to measure the lunar ionosphere by the dual spacecraft method, which had never been carried out before.
- The result shows that the lunar ionosphere is not generated steadily (this is different from the conclusion of the Luna Misson) even on the sunlit side for SZA > 70°.
- However, two exceptions were found, where the electron density seems to increase near the lunar surface. Sporadic ionized layers might be generated under some conditions.