

# Remote Measurement of Geomagnetic Field on Thermosphere

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**Abstract:** The geomagnetic field on the thermosphere contains abundant information about solar activity, ion dynamics, global climate change, and Earth's interior. By now, most geomagnetic data is from satellite-born in-situ magnetic sensors. However, satellite-born in-situ schemes have some drawbacks, such as high expenses, measurement areas, etc. To address these drawbacks of satellite-born in-situ schemes, we put forward a remote sensing scheme based on Helium Lidar. Our scheme uses the metastable helium as tracing atoms, which is the dominant species of the thermosphere. In our scheme, we use a synchronous optical pumping method to detect the Larmor precession frequency of metastable helium in the thermosphere. The Larmor precession frequency is proportional to the strength of the geomagnetic field. We have simulated the signal with parameters from our current helium lidar in Hainan. Our simulation results show sensitivities of  $5.15 \text{ nT/Hz}^{1/2}$ ,  $7.14 \text{ nT/Hz}^{1/2}$ , and  $71.33 \text{ nT/Hz}^{1/2}$  for D0, D1, and D2 lines of metastable helium with laser intensity of  $10 \text{ W/m}^2$ . Sensitivity can further be optimized by optimizing our lidar parameters.

## 1. Introduction

The magnetic field is a crucial part of the study of the thermosphere. The magnetic field contains information about the interaction between the sun and the upper atmosphere of Earth. Meanwhile, the magnetic field is one key part of the monitoring of the space weather. Some critical environments like magnetic storms may influence the operation of low-orbit satellites and space stations. A high-precision map of the magnetic field on the thermosphere can also help reveal the inner structure of the earth[1].

Recently, helium lidar has extended the detection area of ground-based lidar to an altitude of 200-1000 km, the thermosphere[2]. Helium lidar measures the density of metastable helium by detecting the laser-induced fluorescence of metastable helium. By taking the approach of synchronizing optical pumping (SOP)[3], [4], [5], which emits an amplitude-modulated circular-polarizes laser into the thermosphere, helium lidar can be used to measure the magnetic field of the thermosphere remotely.

In our study, we demonstrate the possibility of remote measurements of magnetic fields in the thermosphere by simulating the fluorescent signal at different amplitude-modulated

frequencies. The parameters in the simulation are based on the designation of our helium lidar in Hainan, China. We also estimate the sensitivity of the three fine lines of metastable helium. In the end, we proposed a scheme of remote measurements of the magnetic field in the thermosphere.

## 2. Simulation

Figure 1 shows the fine energy structure of metastable helium with Zeman splitting in the magnetic field. The transition wavelengths are about 1083 nm. The evolution equation of the state of metastable helium can be written as

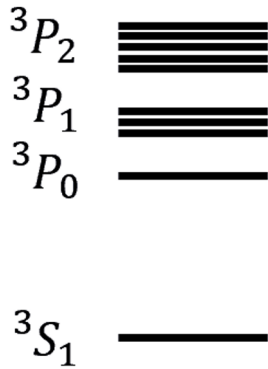
$$i\hbar \partial \rho / \partial t = [H, \rho] - i\hbar(\Gamma \rho + \rho \Gamma) + i\hbar \Lambda \quad (1)$$

Where  $\rho$  is the density matrix of the atom, and  $H = H_0 + V$ , is the Hamiltonian of the system.  $H_0$  is the Hamiltonian of the atom and  $V$ , the light-atom interaction Hamiltonian, equals

$$V = -\mu E \quad (2)$$

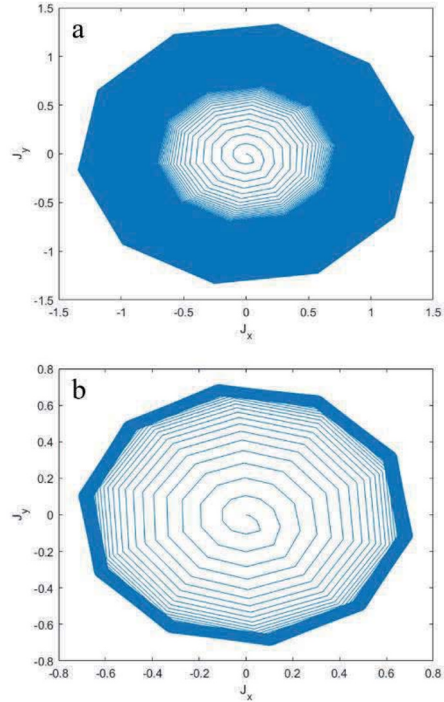
Where  $\mu$  stands for the polarization of the atom. Dissipation effects are also included in the Eqn. (1), where matrix  $\Gamma$  corresponds to excited atoms leaving and metastable atoms entering the laser beam. Taking rotation wave approximation, we solve Eqn. (1) numerically. In this simulation, the magnetic field strength is

50000 nT, and the corresponding Larmor precession frequency for metastable helium is 1.4 MHz. Figure 2 shows the evolution of the atom's angular momentum with time under two different amplitude-modulated frequencies. The amplitude-modulated frequency equals the Larmor frequency for Figure 2a while deviate 10 kHz for Figure 2b. It can be seen from Figure 2 that atoms can have larger angular momentum when modulation frequency equals Larmor frequency.



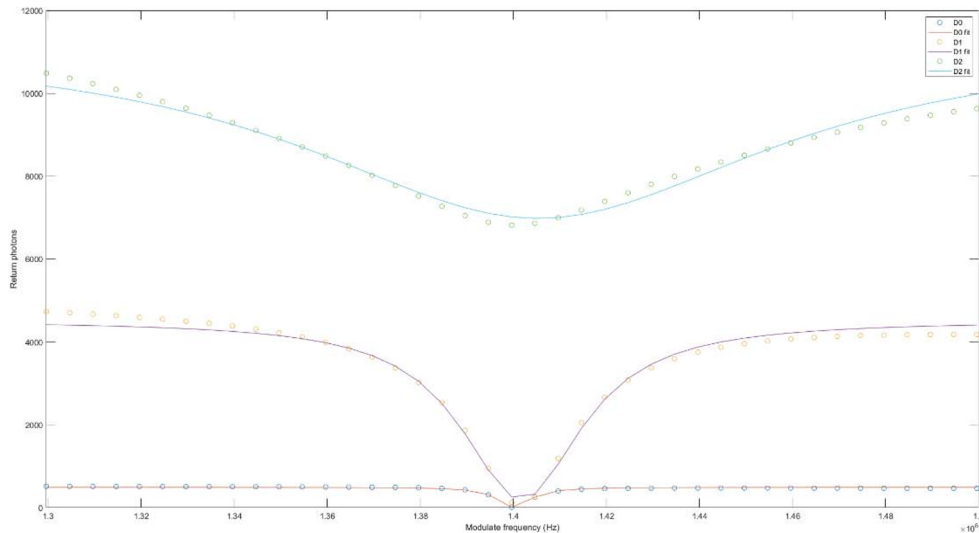
**Figure 1** Energy level metastable helium

The fluorescent signal counted by a single photon detector is simulated by the laser radar equation with parameters from our helium lidar in Hainan, China. The laser is a CW laser with a power of 10 W, and the beam size at 200 km



**Figure 2** Angular momentum evolution with time. a Modulation frequency equals the Larmor frequency. b Modulation frequency equals the Larmor frequency+10 kHz.

diameter of 1 m in an array receiving fluorescence. In the simulation, we set the density of metastable helium as  $1 \text{ cm}^{-3}$ , which is metastable helium's maximum density in the thermosphere. Figure 3 shows the fluorescent



**Figure 3** Fluorescence under different modulation frequencies of metastable helium.

height is 2 m. There are six telescopes with a

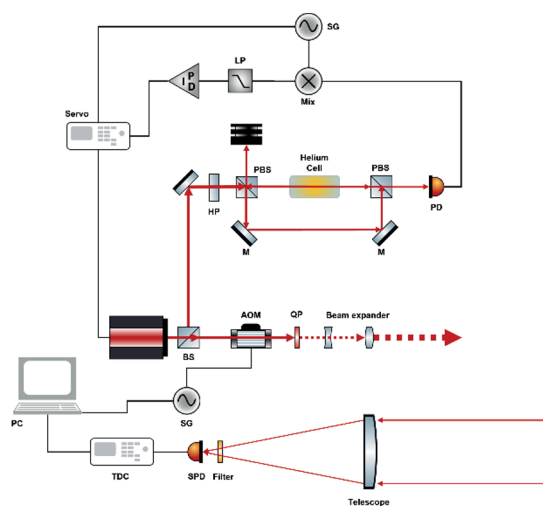
signal at different modulation frequencies for

D0, D1, and D2 lines of metastable helium. The three lines all reach minimum fluorescence when modulation frequency equals Lamor frequency. We also calculated the sensitivity of magnetic measurements at the max slope point of Lorenz fitting of each line. The sensitivities are 5.15 nT/Hz<sup>1/2</sup>, 7.14 nT/Hz<sup>1/2</sup> and 71.33 nT/Hz<sup>1/2</sup> for D0, D1 and D2 line separately.

The simulation results show that the D0 line has the highest sensitivity, however, the dark count of a single photon detector hasn't been included in our simulation. The sensitivity of the D0 line could be even lower if the dark count was considered. Thus D1 line could be a better choice because of its higher fluorescent strength.

### 3. Conclusions and Discussions

In this study, we simulated the possibility of remote measurement of the magnetic field in the thermosphere by using SOP.



**Figure 4** Experimental scheme for remote magnetic measurement of thermosphere.

In the next step, we plan to conduct a field experiment on our helium lidar. Figure 4 shows the experimental scheme. In this scheme, a small part of laser energy is used to lock the laser frequency on the saturated absorption line by modulation transferring technology. Most of the laser energy is amplitude-modulated by an AOM. A quarter-wave plate turns the laser's polarization into circular polarization. Then the laser beam is expanded and sent to the sky. The return fluorescence is collected by telescopes, and a filter is used to filter out background light. A single photon detector (SPD) and a time

digital converter (TDC) are used to register the photon events.

### 4. Acknowledgements

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