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Effect of non-spherical atmospheric charged particles and atmospheric visibility on performance of satellite-ground quantum link and parameters simulation

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Abstract

In order to study the relationship between the non-spherical atmospheric charged particles and satellite-ground quantum links attenuation. The relationship among the particle concentration, equivalent radius, charge density of the charged particle, the attenuation coefficient and entanglement of the satellite-ground quantum link can be established first according to the extinction cross section and spectral distribution function of the non-spherical atmospheric charged particles. The quantitative relationship between atmospheric visibility and communication fidelity of satellite-ground quantum link were analyzed then. Simulation results show that the ellipsoid, Chebyshev atmospheric charged particle influences on attenuation of the satellite-ground quantum link increase progressively. When the equivalent particle radius is 0.2 μm and the particle concentration is 50 μg/m^3, the attenuation coefficient and entanglement of the satellite-ground quantum link is 9.21 dB/km, 11.46 dB/km and 0.453, 0.421 respectively; When the atmospheric visibility reduces from 8 km to 2 km, the communication fidelity of satellite-ground quantum link decreases from 0.52 to 0.08. It is shown that the non-spherical atmospheric charged particles and atmospheric visibility influence greatly on the performance of the satellite-ground quantum link communication system. Therefore, it is necessary to adjust the parameters of the quantum-satellite communication system according to the visibility values of the atmosphere and the shapes of the charged particles in the atmosphere to improve reliability of the satellite-ground quantum link.

Keywords satellite-ground quantum link, non-spherical atmospheric charged particles, atmospheric visibility, degree of quantum entanglement

1 Introduction

Quantum satellite communication has the advantages of wide coverage and so on. It is an important part of constructing global quantum communication network. It has become a hot research topic in this field. At 1:40 on August 16(th), 2016, the successful launching of ‘Mozi’ scientific experimental satellite, marks Chinese quantum satellite communications and space science research has taken an important step.

In 2012, Pan Jianwei and his team completed the ‘free space entanglement photon distribution’ experiment [1], the first successful realization of hundreds of miles of free space quantum teleportation and entanglement distribution [2] for the launch of the world’s first ‘quantum communication satellite’ laid the technical foundation. Yearly, the team has successfully realized the lower limit measurement of quantum entanglement associated collapse velocity without localized vulnerability [3], which laid the necessary theoretical basis for large-scale theoretical basis test of quantum science experiment satellite. In 2009, Guo

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et al. built a multi-level 'quantum government network' in Wuhu city of Anhui province [4] through the network can be completed between any two points of unconditional security and confidential communications.

The shape of the charged particles is very irregular. Under normal circumstances, the particles are regarded as spheres. The scattering properties are calculated by Mie scattering theory [5]. In fact, the atmospheric charged particles are not strictly spherical. The application of Mie scattering theory to the non-spherical atmospheric charged particles will cause a large error. The calculation of non-spherical aerosol scattering properties, generally uses T matrix method [6], discrete dipole approximation (DDA) [7], finite-volume time-domain (FVTD) [8] and other methods, which T matrix method is recognized as a more effective method. In this paper, the T matrix method is used to calculate the scattering properties of two kinds of non-spherical charged particles, named ellipsoid and Chebyshev.

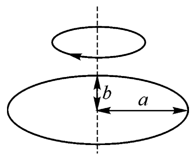
When the quantum satellite communicates with the ground station, atmospheric charged particles have the effect of scattering and absorption on the photon quantum signal. As the concentration of the charged particles increases, the extinction effect becomes more and more obvious. Accordingly, it affects the high fidelity transmission of the signal, and then influences the communication performance of the satellite-ground quantum link communication system seriously. The atmospheric visibility directly affects the physical properties of the atmospheric charged particles, and then influences the extinction effect and signal transmission. Thus, it is of great significance to study the effect of non-spherical charged particles and atmospheric visibility on the performance of satellite-ground quantum link communication. In 2008, Pei Changxing team of Xidian University studied the propagation characteristics of stratospheric quantum communication system [9]. Their results demonstrated that the ground air path propagation effect has an important impact on the quantum key distribution. The Ref. [10], studied the effect of PM2.5 air pollution on the free space quantum communication performance, and laid a theoretical foundation for the improvement of free space quantum communication quality under PM2.5 air pollution. The Ref. [11], studied the effect of ice water mixed cloud on the performance of quantum satellite communication, which provides a reference for the performance of the hybrid cloud environment. The Ref. [12], studied the influence of mesoscale dust storms on satellite communications and laid the foundation for the study of quantum satellite communication under dust conditions. Based on the T matrix theory, the Ref. [13], studied the effects of non-spherical aerosol particles and atmospheric relative humidity on the performance of free space quantum communication.

Nevertheless, previous studies did not take into account the impact of particle charge on the performance of quantum channel communications, is to study the influence of Mie scattering on light quantum for spherical particles, either studied the influence of Mie scattering on light quantum for spherical particles, or to studied the influence of T matrix on the photon for non-spherical particles.

In this paper, we studied two kinds of non-spherical atmospheric charged particles, named ellipsoid and Chebyshev. We investigated the relationship between the attenuation and the entanglement of the particles with different charge density and different particle concentration, analyzed the quantitative relation between the atmospheric visibility and the communication fidelity of satellite-ground quantum link. We aimed to provide a reference for the orderly operation of the satellite-ground quantum link communication system in different non-spherical atmospheric charged particles and different atmospheric visibility backgrounds.

2 Non-spherical atmospheric charged particle model

We Consider a uniform, isotropic, non-magnetic and non-spherical particles [14] in the atmosphere or air environment. There is a certain atmospheric electric field, set the electric field in the vertical direction, showed E_e. Because of the collision between particles, the surface charge density can be represented as σ_1. Taking ellipsoid and Chebyshev as two kinds of common non-spherical atmospheric charged particles, two kinds of particles and incident light quantum signal and particle orientation (elliptical particles as an example) as shown in Fig. 1:



(a) Ellipsoidal aerosol particles