SPECTRAL PROPERTIES OF LIGHTNING RETURN STROKE

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ABSTRACT: Using a slit-less spectrograph the spectra in the range of 390-660 nm for first return strokes of CG lightning flashes have been obtained both in Qinghai plateau, northwestern China and in coastal area of Guangdong, southern China respectively. The heights of two observation sites differ by 2500 meters. Applying the atomic structure theory to the research work on lightning spectra, parameters such as wavelengths, oscillator strengths and excited energies have been calculated for the transitions related to lightning spectra. Compared the calculated results with experimental spectra, it shows that the geographic situation and absolute altitude of observation site have a remarkable influence on the feature of lightning spectra.

INTRODUCTION

Lightning channels are full of plasma, their characteristic parameters close correlated to the physical process in the initiation and development of lightning discharge. Therefore, as an important ways of diagnosing the channel plasma, the lightning spectroscopy has been a subject attracting great interests of researchers since the last century. A lot of works have been done [Barasch, 1970; Orville et al., 1968; 1980; 1984; Wallace, 1964; and Weidan et al., 1989] in this filed, and many physical parameters on lightning channel, such as temperature, density and pressure were reported. Since lightning process related to many factors like latitude, geographical condition etc., so works on regional variety of spectra property have an especial importance for the study of lightning physics, and farther quantitative information about it are necessary for the understanding of the physical conditions surrounding the lightning channel.

COMPUTATIONAL METHOD

To calculate the level energies and transition probabilities, atomic structure codes GRASP92 [Parpia et al., 1996] and REOS99 [Fritzsche et al., 2000] have been used, which is an implementation of the Multi-configuration Dirac-Fock (MCDF) method and included the most important effects of relativity, correlation, and relaxation. In MCDF model, an atomic state wave function (ASF) with total angular momentum J and parity P is written as a linear combination of the configuration state wave function (CSF) of the same symmetry

\[ \left| \alpha(JM) \right| = \sum_{r=1}^{n_c} C_r(\alpha) \left| \Gamma_r(PJ, M) \right| \]  

(1)

where \( n_c \) is the number of the CSF reflecting the extent to which electron correlations are taken into account, and \( C_r(\alpha) \) configuration mixing coefficient corresponding to each single CSF \( \left| \Gamma_r(PJ, M) \right| \). Further relativistic corrections to the electron-electron interactions are added by diagonalizing the Dirac-Coulomb-Breit Hamiltonian matrix. The dominant quantum electrodynamic (QED) contributions, i.e. self-energy and vacuum polarization effect, have also been included in the computations of the total energy as a perturbation.

EXPERIMENT AND DATA ANALYSIS

Lightning spectra were taken by a SONY digital camera, with a 3CCD digital imaging system and focuses of f=4.3-51.6 mm. A transmission grating of 600/mm is put in front of the object lens. The observed Spectra have a dispersion of approximately 1.3 nm/pels in the first order. The prominent lines are identified by comparison with previously published spectra of lightning and the spectra of high-pressure mercury lamp. During the May to August of 2002, the experiment were performed both in coastal area of Guangdong, southern China and in Qinghai plateau, northwestern China, the observation sites being located at E113°09'73", N22°58'77", with the height of 35 m, and E101°34'57", N37°03'47", with the height of 2534 m above sea level respectively. During the experiment, about 70 spectra from 390-660 nm for first return stroke of CG lightning have been captured, figure 1-2 being four of them. In order to analyze spectral properties clearly, fine structure of spectral transitions have been calculated, and compared with experimental results. The calculated wavelengths, oscillator strengths (gf) and excited energies of upper levels are listed in Table 1. The representative transitions in Table 1 denote those that with maximal oscillator strengths in the corresponding multiplet lines. It can be seen from data analyzing, that in visible range, transitions between lower excited states in NII ion are main composition of lightning spectra. For instance, lines with wavelengths of 500.5 and 568.0 nm can be recorded in nearly all of the lightning spectra obtained in two regions. From calculation results, they are mostly transitions from 2s\(^2\) 2p\(^3\)p and 2s\(^2\) 2p\(^2\) 3d configuration of NII ion, corresponding upper excited energy being around 22 eV, called essential lines. Parameters on physical conditions surrounding the lightning discharge provided by Orville...
et al. [1968] were mainly derived from these lines. Besides essential lines, the spectra structures and characteristic for different strokes are varied. There are also distinct properties for the spectra observed in the two regions. Figure 1 are spectra obtained in the coastal area, where channels of return strokes are relatively long, the intense transitions of NII and OII ions being dominant member of the spectra. For instance, transitions from $2s^2 2p 4f$ and $2s 2p^2 3d$ configuration of NII ion, with wavelengths of 404.1, 417.6, 423.7, 444.7, and 517.9 nm are obvious in most lightning strokes, their upper excited energies being around 28 ev. For very intense stroke, transitions from OII ion are enhanced, lines such as 436.9, 425.3, 419.0 and 407.5 nm, their upper excited energy being around 30 ev, could be recorded. Figure 2 are spectra taken in the plateau region, where the lightning discharges are relatively weak, transitions between low-lying states of NII, NI and OI ions being principal component of spectral emissions. Lines from neutral atom, like 600.8, 533.0, 543.6, 604.6 and 619.4 nm, with upper excited energies of nearly 13 ev are intensified. These obvious differences may be due to the diversity of temperature and electron density, which closely related to current of lightning channel in two regions.

CONCLUSION

The study in this work shows, that the transitions from excited states of $n=3$ in NII ion are main composition of lightning spectra. Geographic situation and absolute altitude of observation site have a remarkable influence on the feature of lightning spectra. In coastland, transitions from OII ion and excited states of $n=4$ in NII ions enhanced. On the other hand, spectra in plateau area are comparatively weak, and transitions from neutral NI and OI atoms are intensified. It can be deduced from spectra properties, that the temperatures and pressures of stroke channel in two regions should have a notable difference.

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Figure 1 Spectra obtained in the Guangdong coastland. Besides essential lines, intense transitions of NII and OII ions are dominant member of the spectra.

Figure 2 Spectra taken in the Qinghai plateau region. Besides essential lines, transitions between low-lying states of NII, NI and OI ions are principal component of spectral emissions.

Table 1 Observed spectra compared with calculated wavelength (in nm), oscillator strengths ($gf$) and upper excited energy levels (in ev).
<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Representative transitions</th>
<th>$g'f$</th>
<th>Upper excited energies</th>
</tr>
</thead>
<tbody>
<tr>
<td>399.5</td>
<td>2p($^2P$°) 3p $^1D_2$ - 2p($^2P$°) 3s $^3P^o_1$</td>
<td>1.61092</td>
<td>21.599</td>
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<tr>
<td>463.0</td>
<td>2p($^2P$°) 3p $^1P_2$ - 2p($^2P$°) 3s $^3P_2$</td>
<td>1.91082</td>
<td>21.160</td>
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<td>480.3</td>
<td>2p($^2P$°) 3d $^3D_3$ - 2p($^2P$°) 3s $^3P_1$</td>
<td>0.81433</td>
<td>23.246</td>
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<tr>
<td>500.5</td>
<td>2p($^2P$°) 3p $^3P_2$ - 2p($^2P$°) 3s $^3P_1$</td>
<td>3.87350</td>
<td>23.142</td>
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<tr>
<td>558.0</td>
<td>2p($^2P$°) 3p $^3P_1$ - 2p($^2P$°) 3s $^3P_1$</td>
<td>1.68368</td>
<td>20.665</td>
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<tr>
<td>594.2</td>
<td>2p($^2P$°) 3d $^3D_3$ - 2p($^2P$°) 3s $^3P_1$</td>
<td>2.08281</td>
<td>23.246</td>
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<tr>
<td>648.2</td>
<td>2p($^2P$°) 3p $^3P_2$ - 2p($^2P$°) 3s $^3P_1$</td>
<td>0.57156</td>
<td>20.409</td>
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<tr>
<td>656.3</td>
<td>2p($^2P$°) 4d $^3D_{7/2}$ - 2p($^2P$°) 3p $^3D_{5/2}$</td>
<td>0.21045</td>
<td>13.668</td>
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**Essential lines**

**Lines in coastal lightning and plateau intense lightning**

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Representative transitions</th>
<th>$g'f$</th>
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<tr>
<td>404.1</td>
<td>2p($^2P$°) 4f $^3G_4$ - 2p($^2P$°) 3d $^3F_4$</td>
<td>1.26148</td>
<td>26.209</td>
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<td>417.6</td>
<td>2p($^2P$°) 4f $^3D_3$ - 2p($^2P$°) 3d $^3D_2$</td>
<td>1.38659</td>
<td>26.212</td>
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<td>423.7</td>
<td>2p($^2P$°) 4f $^1F_4$ - 2p($^2P$°) 3d $^3D_2$</td>
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<td>26.168</td>
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<td>616.8</td>
<td>2p($^2P$°) 4p $^3D_1$ - 2p($^2P$°) 3d $^3F_4$</td>
<td>1.05893</td>
<td>25.151</td>
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<tr>
<td>517.9</td>
<td>2p($^2P$°) 4p $^3D_3$ - 2p($^2P$°) 3d $^3D_2$</td>
<td>4.72651</td>
<td>30.139</td>
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<td>517.931</td>
<td>2s$^2$2p($^4P$) 3d $^3F_4$ - 2s$^2$2p($^4P$) 3p $^3D_4$</td>
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<td>30.373</td>
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<td>520.650</td>
<td>2p($^2P$°) 3d $^3D_{3/2}$ - 2p($^2P$°) 3p $^3P_1$</td>
<td>0.54019</td>
<td>28.942</td>
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<td>444.7</td>
<td>2p($^2P$°) 3d $^3D_{3/2}$ - 2p($^2P$°) 3p $^3P_1$</td>
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<td>444.818</td>
<td>2p($^2P$°) 3d $^3D_{3/2}$ - 2p($^2P$°) 3p $^3P_1$</td>
<td>1.20913</td>
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**Typical lines in coastal intense lightning**

<table>
<thead>
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<th>Wavelength</th>
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<th>$g'f$</th>
<th>Upper excited energies</th>
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</thead>
<tbody>
<tr>
<td>436.9</td>
<td>2p($^2P$°) 3d $^3D_{3/2}$ - 2p($^2P$°) 3p $^3D_{3/2}$</td>
<td>0.40876</td>
<td>29.062</td>
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<td>425.3</td>
<td>2p($^2P$°) 3d $^3D_{3/2}$ - 2p($^2P$°) 3p $^3D_{3/2}$</td>
<td>8.10192</td>
<td>34.233</td>
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<tr>
<td>419.0</td>
<td>2p($^2P$°) 3d $^3D_{3/2}$ - 2p($^2P$°) 3p $^3D_{3/2}$</td>
<td>5.21095</td>
<td>31.319</td>
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<tr>
<td>407.5</td>
<td>2p($^2P$°) 3d $^3D_{3/2}$ - 2p($^2P$°) 3p $^3D_{3/2}$</td>
<td>4.92864</td>
<td>28.706</td>
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</tbody>
</table>

**Typical lines in plateau lightning**

<table>
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<th>Wavelength</th>
<th>Representative transitions</th>
<th>$g'f$</th>
<th>Upper excited energies</th>
</tr>
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<tbody>
<tr>
<td>600.8</td>
<td>2p($^2P$°) 4d $^3P_{3/2}$ - 2p($^2P$°) 3p $^3S_{1/2}$</td>
<td>0.07682</td>
<td>13.665</td>
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<tr>
<td>533.0</td>
<td>2s$^2$2p($^4P$) 4p $^3D_{3/2}$ - 2s$^2$2p($^4P$) 3p $^3P_{3/2}$</td>
<td>0.00701</td>
<td>13.250</td>
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<td>532.856</td>
<td>2p($^2P$°) 4p $^3D_{3/2}$ - 2p($^2P$°) 3p $^3P_{3/2}$</td>
<td>0.03978</td>
<td>13.021</td>
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<td>543.6</td>
<td>2p($^2P$°) 4s $^3S_{1/2}$ - 2p($^2P$°) 3p $^3P_{3/2}$</td>
<td>0.02913</td>
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<td>619.4</td>
<td>2p($^2P$°) 5d $^3D_{3/2}$ - 2p($^2P$°) 3p $^3D_{3/2}$</td>
<td>0.00281</td>
<td>14.001</td>
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**REFERENCES**


