附件 2

论文中英文摘要

作者姓名：薛向辉

论文题目：日冕物质抛射的对地有效性及近地空间环境的研究

作者简介：薛向辉，男，1979 年 12 月出生，2002 年 9 月师从于中国科学技术大学窦贤康教授硕博连读学习，于 2007 年 7 月获博士学位。

中 文 摘 要

作为灾害性空间天气的一种重要起源--日冕物质抛射(CME)，一直是空间物理学家关注和研究的热点；另一方面，作为空间天气的最直接表现的层次--近地空间环境，随着地基探测手段的不断建立和完善也成为日—地关系链研究中的一个重要方面。本文主要从空间天气这因果两端出发，对CME的对地有效性问题，以及近地空间环境的探测和动力学过程进行了初步的研究。

在CME的对地有效性方面，主要工作包括：

CME冰淇淋锥模型的建立。根据SOHO/LASCO和SOHO/EIT对CME的观测，我们发展了CME的三维冰淇淋锥模型。通过CME在天空平面投影在不同方位角上的时间-高度关系来确定CME投影速度，并且利用日面观测资料限定CME的源区位置，通过假定CME在LASCO观测范围内具有定常的速度和角宽度，可以利用模型拟合给出CME的动力学和几何学参数，即速度v、角宽度α和爆发点位置。

CME对地有效性-主要影响因素。一般认为爆发点靠近日面中心的向地晕状CME最具潜在地磁效应，我们通过分析2005年9月7-13日5次主要的CME事件的日面和行星际观测资料，发现爆发点在E67°的第2个CME和爆发点在E47°的第3个CME到达了地球位置，而爆发点在E77°、E39°和E10°的第1、4、5个CME则错过或者仅仅擦过地球。结合冰淇淋锥模型和CME行星际偏转模型，我们发现除爆发点位置外，CME的角宽度和CME在行星际介质中的偏转角度也是影响CME对地有效性的主要因素。较大的张角宽度，使得中间2个爆发点位置偏离日面中心的CME到达了地球位置；第1个CME虽然有很大的角宽度，但是显著的偏转效应却使得它偏离了地球，同时较小的角宽度和偏转效应也使爆发点非常接近日面中心的第5个CME偏离了地球。因此我们认为考察CME对地有效性时，要综合考虑CME的源区、角宽度和在行星际中的偏转。

CME对地有效性--特大地磁暴起因。利用ACE和Wind卫星的观测数据，认证了在太阳活动高年2000-2001年发生的特大地磁暴的CME源和行星际源，分析了何种CME和其相应的行星际结构具有最强的地磁效应，以及产生如此显著对地有效性的有效机制。我们发现在特大地磁暴的形成中，磁云扮演了一个很重要的角色，同时还认为与特大地磁暴事件相对应的强行星际磁场南向分量Bs的形成，除了2000年7月16日和2000年8月12日这两次事件，其余的都与磁场压缩机制有关：1）行星际CME（ICME）之间的压缩，如多重磁云，激波追赶磁云；2）ICME和背景太阳风介质之间的压缩，如激波压缩，复杂抛射高速流压缩，以及场覆盖。约有一半

的特大地磁暴与连续CME的活动相关，具有不同抛射速度的CME在行星际空间中传播时可能互相追赶、互相作用或者互相溶合，形成不同行星际结构，如多重磁云、激波穿越磁云、或者复杂抛射物等等。当高速的后随ICME本体或者其驱动的激波追赶上前面相对较慢速的ICME时，它会传递很高的动力学压力，使前导的ICME或者ICME的鞘区内磁场被压缩，特别是当前一个ICME或者其鞘区中的磁场是南向的时候，就可能因压缩造成ICME更显著的地磁效应，增加了CME对地的有效性。同时我们进一步验证了在引起地磁暴的行星际参数中，$\overline{-VB_z}$的贡献远大于其持续时间Δt，说明了压缩后的行星际南向磁场具有更加强烈的地磁效应。

在近地空间环境研究方面，主要工作包括：

激光雷达对近地空间环境的探测。中国科学技术大学于2005年底建成一部具有双波长发射三通道探测的激光雷达系统，可以实现对80-110km高度钠层密度、30-70km高度大气温度和密度、以及近地面至30km高度大气气溶胶消光系数的探测。我们展开了这部激光雷达的建设、调试和观测工作。阐述了该激光雷达的技术特征和对不同大气参数探测的反演算法，特别从荧光激光雷达系统结构和设计原理出发，提出了对接收系统中发射光束与接收视场的精确匹配进行调节的方法、基于系统本身的波长校正方法。同时利用激光雷达对合肥上空钠层长达1年的探测数据，分析了合肥地区钠层的主要形态特征、夜间变化和季节变化。夜间观测表明钠层中存在显著的波动扰动，并经常伴有突发钠层事件。合肥钠层柱密度最小的值$1.126\times10^{9}cm^{-2}$出现在6月份，最大值$6.014\times10^{9}cm^{-2}$出现在12月份。在冬季（特别是12月份）柱密度表现出显著的峰值，而在夏季月份柱密度则表现出相当宽广的极小值；质心高度没有明显的季节变化；RMS宽度则表现出准半年变化。

流星雷达对近地空间环境的探测和大气潮汐模式的研究。利用流星雷达观测，结合典型相关分析，对大气周日潮汐和半日潮汐的模式进行了初步研究。典型相关分析可以将某个特定的频带（如周日，半日）中存在的多种波动结构按照它们的相关性提取出来，利用该方法处理武汉流星雷达2002年一年的观测数据，我们获得了武汉上空大气周日潮汐和半日潮汐的典型相关模式。对于周日潮汐共获得6阶有效的潮汐典型相关模式，携带了90%以上的总变差，这些模式与大气不同的激励/调制源相对应，即周日潮汐的季节变化（最显著的模式）、准半年变化、太阳27日周期调制变化和行星波（10d，16d等）调制变化。通过分析各阶模式的垂直波长以及水平风场的偏振特性，发现在武汉的周日潮汐风中的主导模式是经典潮汐模S(1,1)，典型的偏振特性为圆偏振。对于半日潮汐共获得4阶有效的潮汐典型相关模式，携带了大约2/3的总变差。在半日潮汐模式中没有出现准半年周期变化，第1阶典型相关模式仍然是最显著的模式，它代表了半日潮汐的季节变化特征；高阶典型相关模式中也存在10d，16d，27d的调制周期，分别对应着10日或者16日行星波，以及太阳27日活动的调制。

关键词： 日冕物质抛射，行星际日冕物质抛射，磁云，地磁暴，激光雷达，中高层大气动力学，潮汐

Studies on Geoeffectiveness of Coronal Mass Ejections and Near-Earth Space Environment

Xue Xianghui

ABSTRACT

Coronal mass ejections (CMEs) are considered by many space scientists as the main source of space weather. Understanding the relationship between geoeffective CMEs and their interplanetary counterparts (ICMEs), and predicting whether a halo CME can encounter the Earth are the important topics in space weather research. On the other hand, the near-Earth space (20-200km) as the ending response for space weather, is highly relative with our everyday living and has become an key region in solar-terrestrial studies. In this thesis, we emphasize on the source and the end of space weather, the following two aspects are studied observationally and theoretically:

1. CMEs and their geoeffectiveness

Firstly, we set up a 3D geometric model for CMEs using an Ice-Cream Cone to analyze the geometrical and kinematical properties of CMEs. Assuming in early phase, CMEs propagate with near constant speed and angular width,some useful properties of CMEs, such as the radial speed (v),the angular width (α) and the location at the heliosphere, can be obtained. This model is improved by (1) using an ice-cream cone to show the near real configuration of a CME, (2) determining the radial speed via fitting the projected speeds calculated from the height-time relation in different azimuthal angles, (3) not only applying to halo CMEs, but also applying to non-halo CMEs.

Secondly, We analyze five major CMEs originating from NOAA active region (AR) 808 during the period of September 7 to 13, 2005, when the AR 808 rotated from the east limb to near solar meridian. Several factors that affect the probability of the CMEs' encounter with the Earth are demonstrated. The solar and interplanetary observations suggest that the 2nd and 3rd CMEs, originating from E67 and E47 respectively, encountered the Earth, while the 1st CME originating from E77 missed the Earth, and the last two CMEs, although originating from E39 and E10 respectively, probably only grazed the Earth. Based on our ice-cream cone model and CME deflection model, we find that the CME span angle and deflection are important for the probability of encountering Earth. The large span angles allowed the middle two CMEs hit the Earth, though their source locations were not close to the solar central meridian. The significant deflection made the first CME totally miss the Earth though it also had wide span angle. The deflection may also have made the last CME nearly miss the Earth though it originated close to the disk center. We suggest that, in order to effectively predict whether a CME will encounter the Earth, the factors of the CME source location, the span angle, and the interplanetary deflection should all be taken into account.

Thirdly, we try to illustrate what kind of CMEs and their interplanetary counterparts are the most geoeffective and the mechanism of causing such notable geoeffectiveness by analyzing the

solar and interplanetary causes of 8 great geomagnetic storms (*Dst*<-200nT) during the solar maximum (2000-2001). We find the magnetic clouds (MCs) play an important role in causing great geomagnetic storms, at the same time, the result also shows that the notable characteristic among the causal mechanism is compression of the southward magnetic fields. Six of eight great geomagnetic storms were associated with the compression, which can be classified into (1) the compression between ICMEs (2)the compression between ICMEs and interplanetary medium. It suggests that the compressed magnetic field would be more geoeffective. Half of all great storms were related to successive halo CMEs, most of which originated from the same active region. The interactions between successive halo CMEs usually can lead to greater geoeffectiveness by enhancing their southward field Bs interval either in the sheath region of the ejecta or within MCs. The types of them included: the compression between the fast speed transient flow and the slow speed background flow, the multiple MCs, besides shock compression. Further, the linear fit of the *Dst* versus $(\overline{-VB_z})^{\alpha}\Delta t^{\beta}$ gives the weights of $\overline{-VB_z}$ and Δt as $\alpha = 2.51$ and $\beta = 0.75$ respectively. This may suggest that the compression mechanism, with associated intense Bs rather than duration, is the main factor in causing a great geomagnetic storm.

2. Observations of the near-Earth space and studies of atmospheric tides

Firstly, we introduce a newly installed Mie-Rayleigh-Na fluorescence lidar system in USTC at Hefei. This lidar system employs dual-wavelength laser at 532nm and 589nm and has three transmitting and receiving channels for detecting sodium density at 80-110km, atmospheric density and temperature at 30-70km, and aerosol extinction coefficient below 30km. We illustrate the typical techniques of the lidar system in detail and summarize the lidar equations for back-scatter detecting lidars. In the past one year after the lidar was set up, we have carried on routine observations of sodium layer over Hefei, the characteristics of the shape, nocturnal variations and seasonal variations of sodium layer are given in this part. The results show that during the night, there are evident wave activities in sodium layer and sporadic sodium layers often occur. Sodium abundance reaches maximum value $6.014\times10^{9}\mathrm{cm}^{-2}$ during December approximately 5 times larger than the June minimum value $1.126\times10^{9}\mathrm{cm}^{-2}$. The abundance shows rather broader minimum values throughout the summer months, the centroid height has no evident seasonal variations, but the RMS width illustrates semi-annual variations.

Secondly, we use Canonical Correlation Analysis (CCA) method to investigate the mesosphere and low thermosphere (MLT) diurnal tidal winds during the year 2002 observed by a newly installed meteor radar at Wuhan (30.6^{o}N, 114.4^{o}E). In general, 6 effective diurnal tidal pairs of patterns are obtained, which represent over 90% total variances of the origin data set. These patterns are expected to correspond to the atmospheric oscillations of diurnal frequency band excited or modulated by different sources, namely, the seasonal variations and the modulations by semi-annual-like variations, solar 27-day rotation and the planetary wave oscillations. Among all of the patterns, the 1st pattern is the most notable which represents ~40% of total variances and the amplitudes of the 1st pattern show maximum values in spring and autumn as well as sudden phase-transit near equinox month, which is in line with the results obtained from traditional harmonic analysis. The vertical wavelengths (~30km) suggest the classic tidal mode S(1,1) is dominant, and the preceding phases (~5-6h) of the meridional components of the diurnal tidal wind

show right rotating circular polarization maybe the main characteristic in tidal wind. For the semi-diurnal tides, 4(3) effective semi-diurnal tidal pairs of patterns are obtained, representing ~2/3 total variances.They also correspond to the seasonal variations, the modulations by the planetary wave oscillations or the solar 27-day activity. However, no semi-annual variations is found in semi-annual canonical correlation patterns. The 1st pattern is still the most notable. Its amplitudes show maximum values in spring and autumn, and the vertical wavelengths are longer in summer and shorter in winter. The vertical wavelengths of the higher order patterns (~50km) suggest the classic semi-tidal mode S(2,4)/S(2,5) is dominant.

Key words: CME, ICME, Magnetic cloud, Geomagnetic storms, Lidar, Middle atmosphere dynamics, Tide