论文题目：太阳风高速流中重离子的研究

作者简介：李醒，男，1966 年生，1993 年师从中国科学技术大学胡友秋教授，于 1998 年获博士学位。

摘要

在过去，太阳风中的重离子因为其丰度较小，在太阳风的数值模型中常被处理为试探粒子。本文以太阳风高速流中全电离的氦核和只有两个外层电子的氧离子为例，研究重离子对背景高速流的影响。我们利用三成分太阳风模型，通过改变对重离子的能量注入和冕底重离子的丰度但是保持背景太阳风电子和质子的能量注入参数不变来研究重离子对背景太阳风的影响。我们的工作证实早先的工作：氦离子确实对太阳风质子流有着极大的影响。我们发现氦离子对太阳风没有影响的最小冕底丰度为 5 x 10-4，而氧离子这个最小丰度为 5 x 10-5。这两个值比它们光球层的丰度都小得多。随着冕底丰度的增加，背景太阳风的速度和质子通量对加在重离子上的能量变得非常敏感。当不给重离子加热时，重离子丰度的增加会引起背景风在 1AU 处质子流速的增加、质量通量的减少和温度的增加，但是当重离子的加热增加时，这些参数对重离子丰度的依赖关系会发生一个向相反方向的变化，即 1AU 处流速和质子温度的减小和质子通量的增加。这个研究表明：对于目前已知水平的光球层重离子丰度，重离子的流动性质不能孤立于电子－质子等离子体而单独研究。重离子对背景电子－质子等离子体的影响主要是通过在冕底附近它们之间的相互碰撞决定的。因此，要想研究重离子得到特别加热的物理机制，必须自洽地考虑这些机制引起的对电子－质子等离子体的影响。

我们研究了高速流中重离子的流速和温度问题，利用太阳风多成分模型，考虑了阿尔芬波对各离子的作用力进行必要的修正。我们假设重离子（包括质子，α 粒子）的能量来源于阿尔芬波，并且阿尔芬波是可以通过某种方式耗散的，这些耗散的能量用来加热质子和重离子。我们发现阿尔芬波在某种方式耗散时可以把重离子加速到比质子快近一个阿尔芬速，当重离子的速度达到阿尔芬波的相速度时，重离子的速度就不再增加，而是开始减速了，它们减速快慢取决于阿尔芬波的耗散机制，当采用 Hu et al (1997) 所近似描述的阿尔芬湍流加热率时，α 粒子和重离子在行星际空间始终保持比质子快一个局地阿尔芬速。与此同时，重离子的温度也近似保持与它们的质量成正比。我们的模型首次成功地定量地再现了行星际空间中的观测事实：即在阿尔芬波的作用下，重离子是在主要由质子携带的阿尔芬波上做冲浪运动。我们预言重离子在行星际空间在远离太阳的运动中是减速的，使重离子减速的力来源于波粒相互作用项，这一预言还有待于观测的进一步检验。

最近太阳和日球天文台卫星（SOHO）上的紫外光谱仪（UVCS）测量到冕洞中氧离子谱线 1032 和 1037.6 Å 轮廓及强度比表明 OVI 1037.6 Å 线存在 Doppler 变暗，以及来自色球层 CII 1037.0182 Å 线的泵激，观测也表明了 O5+离子有很强的温度各向异性。我们证明，温度的各向异性，特别是垂直于磁场方向的超高动力学温度是如何影响 Doppler 变暗和泵激行为的；我们认为，UVCS 观测到的氧离子两谱线强度比随日心距离的变化，可以用氧离子谱线 1037.6 Å 受到了色球层碳线 CII 1036.3367 Å 和 1037.0182 Å 的泵激来解释，UVCS 诊断离子速度的技术可以延伸到比原来更高的速度，CII 1036.3367 Å 的泵激表明氧离子的速度在 370 km/s 左右，

这一结果表明少数离子在内日冕中已经超过了质子的速度，亦即从几个太阳半径开始，重离子速度在高速流中就已超过质子的速度。这一结果对太阳风加速和加热机制的研究有重要意义，不论太阳风的加速和加热机制是什么，该机制必须能够在 3 个太阳半径把重离子加速到 370 km/s 左右，并且要超过质子的速度。

ABSTRACT

We present the results of a parameter study of the influence of heavy ions on the background solar wind, choosing doubly ionized helium, or alpha particles, and O+6, as examples. Using a three-fluid solar wind model, we keep the input parameters to the electrons and protons unchanged, and investigate the effects of changing the input energry flux to the heavy ions and their coronal abundance, i.e. their abundance at 1 Rs, on the background electron-proton solar wind. Our results confirm earlier studies that alpha particles can have a dramatic effect on the thermodynamic and flow properties of the protons in the solar wind. The maximum coronal abundance for which the changes in the energy input to heavy ions have no effect on the protons is 5 x 10-4 for the alphas, and 5 x 10-5 for the oxygen ions, which are well below the observed photospheric values. For larger coronal abundances, the sensitivity of the flow speed and proton mass flux to the energy input to the heavy ions increases sharply with increasing abundance. When the heavy ions are not heated, the increase in the coronal abundance leads to an increase in flow speed, a decrease in proton mass flux, and an increase in proton temperature at 1 AU. However, as the heat input to the heavy ions increases, the dependenve of these parameters on the abundance goes through a transition and starts to follow the oppisite pattern, namely a decrease in flow speed and proton temperature at 1 AU, and an increase in proton mass flux. This study shows that, for currently known photospheric elemental abundances, the flow properties of heavy ions cannot be inverstigated independently of those of the bulk proton-electron solar wind when the energy transfer between them becomes significant. The effect of heavy ions on the electron-proton bulk solar wind is determined primarily by the collisions occuring very close to the coronal base. Hence, including physical processes responsible for the preferential heating of heavy ions to temperatures exceeding those of protons in the inner corona, cannot be done without considering the subsequent influece on the protons and electrons in a self-consistent manner.

Self-consistent, one-dimensional, multi-fluid wave-driven solar wind models are presented. The energy from wave damping or turbulence dissipation is assumed to be apportioned to diffent ions. The Alfven waves have remarkable effect on the minor ions in the solar wind: minor ions can almost exactly surf on the Alfven waves in the high speed solar wind. Alfven waves tend to decrease the velocity diffrence among different species. When the minor ion speed surpasses the proton speed because of the preferential heating and reaches the local Alfven wave phase speed, minor ions will suffer a drag force from Alfven waves which makes them flow slower. The two observational facts, that heavy ions flow faster than protons, and that they are hotter than protons, are linked by a common explanation. The tempetures of heavy ions at 1AU are reasonable compared to observations. The well-known mass proportion temperatures of heavy ions are found in our models.

Recent observations of the spectral line profiles and intendity ratio of the OVI 1032 ? and 1037.6 ? doublet by the Ultraviolet Coronagraph Spectrometer (UVCS) on the Solar and Heliospheric Observatory (SOHO), made in coronal holes below 3.5Rs, provided evidence for Doppler dimming of the OVI 1037.6 ? line and pumping by chromospheric CII 1037.0182 ? line. Evidence for a significant kinetic temperature anisotropy of O5+ ions was also derived from these observations. We show how the component of the kinect temperature in the direction perpendicular to the magnetic field, for both isotropic and anisotropic temperature distributions, affects both the amount of Doppler dimming and pumping. Taking this component into account, we further show that the obserbed intensity ratio of the OVI doublet less than one can be accounted for only if pumping by CII 1036.3367 ? in addition to CII 1037.0182 ? is in effect. The inclusion of the CII 1036.3367 ? pumping implies that the speed of the O5+ ions reaches 370 km/s around 3Rs and that these ions are much faster than protons at that heliocentric distance.