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博士学位论文摘要选登

冕洞内矢量磁场的分布和演化

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冕洞是太阳日冕中低温低密度的区域，是高速太阳风的源区. 目前，冕洞的很多性质还远未被人们所理解. 磁场研究是理解太阳上各种现象的重要手段. 因此，我们力图通过研究冕洞内的磁场特别是矢量磁场的分布和演化，回答冕洞研究中存在的问题.

综合利用 SOHO 、 Hinode 、 STEREO 、 SDO 等卫星数据，我们第 1 次对冕洞内矢量磁场的演化、冕洞磁场的非势性等方面进行了较详细的研究，取得了一系列的研究成果. (1) 冕洞不同层次太阳大气对冕洞小尺度磁场结构分布和演化的响应. 我们研究了冕洞内及冕洞边界上磁场的分布和演化，展示了冕洞大气对小尺度磁场结构分布和演化的响应；定量分析了磁通量密度与不同波段大气辐射之间的对应关系，发现磁场强度与 G 波段单色像亮点的对应关系强于与 Ca II H 单色像之间的对应. (2) 冕洞内的双极磁场演化及其对冕洞演化的影响. 利用卫星数据，我们研究了一个低纬冕洞内的双极磁场演化，第 1 次在冕洞区域观测到磁环系统浮现后又下沉到光球层之下的过程. 双极演化改变了冕洞内开放场的分布，影响了原有的磁场位形. 在双极演化的最后阶段，部分冕洞演变成了宁静区. 研究冕洞内双极磁场的演化可能是理解冕洞衰退和消失的一种有效手段. (3) 冕洞内矢量磁场的分布以及冕洞光球磁场的非势性情况. 利用 Hinode/SP 数据，我们研究了冕洞内的矢量磁场、电流密度和电流螺度密度，并将其与宁静区进行了对比. 我们发现：冕洞和宁静区电流螺度密度大的地方均对应于强的纵场和横场区域；冕洞内的横场、磁倾角、电流密度和电流螺度密度均高于宁静区；综合考虑冕洞和宁静区，平均电流密度和电流螺度密度分别为 0.008 $\mathrm{A\cdot m^{-2}}$ 和 0.005 $\mathrm{Gs^{2}\cdot m^{-1}}$; 当纵向磁场强于 100 Gs 时，冕洞和宁静区的平均电流密度约为 0.012 $\mathrm{A\cdot m^{-2}}$, 与耀斑多发的活动区的电流密度相当；冕洞和宁静区磁场都是非势的. (4) 冕洞边界上磁重联的观测. 利用 SDO 极紫外波段数据，我们研究了冕洞边界上的活动现象，在冕洞边界上发现了大量的日冕喷流. 日冕喷流被认为是由磁重联引起的，是磁重联发生的证据. 我们还利用 SDO 观测到的高质量磁场数据，研究了冕洞边界光球磁场的变化. 在日冕喷流发生时，喷流下方的光球层表现出了磁场的浮现对消. 通过对冕洞边界处太阳自转的定量测量，我们证明了磁重联维持冕洞的刚体自转. (5) 太阳北极冕洞内极羽的结构和演化. 我们利用日全食期间观测所得的高时空分辨率白光数据，研究了北极冕洞内极羽的结构和演化，并与低纬日冕的羽毛状结构进行了对比，定量给出了它们的长度、宽度、倾角等参数. 结果显示，越靠近冕洞中心的极羽越垂直；极羽寿命远长于日全食持续的时间尺度；极羽可能不存在短时标的振荡.

本论文所取得的成果有助于提高人们对冕洞性质的认识，有助于加深人们对冕洞演化和冕洞磁活动的理解. 作为高速太阳风的源区，冕洞是空间天气的一类驱动源. 因此，本文成果也可以为太阳风加速机制和空间天气过程的研究提供必要的物理基础和观测依据.

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Distribution and Evolution of Vector Magnetic Fields in Coronal Holes

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Coronal holes (CHs) are low density and low temperature regions in the solar corona, and they are the sources of fast solar wind. Nowadays, many properties of CHs are far from being understood. Magnetic fields are the key to understand the solar phenomena. Therefore, we try to answer the questions relative to CHs by studying the distribution and evolution of magnetic fields, especially the vector magnetic fields, in CHs.

With the observations from the SOHO, Hinode, STEREO, and SDO, we investigate some aspects of CHs in detail for the first time, such as the evolution of vector magnetic field and magnetic nonpotentiality in CHs, and obtain a series of results. (1) Response of the solar atmosphere to the magnetic field distribution and evolution in a CH. We study the magnetic fields in a CH and at the CH boundary, and present the corresponding atmospheric response of different overlying layers to the magnetic field distribution and evolution. We also quantitatively analyze the relationship between the magnetic flux density and atmospheric emissions at different wavelengths. (2) Evolution of dipoles in an equatorial CH and its effect on the decay of the CH. We investigate the evolution of dipolar magnetic fields in an equatorial CH region. In the CH, the submergence of initial loops after their emergence is observed for the first time. The area where the dipoles are located becomes a place of mixed polarities instead of the unipolar fields, resulting in the change of the overlying corona from a CH area to a quiet region. (3) Distribution of vector magnetic fields and magnetic nonpotentiality of CHs. We investigate the vector magnetic fields, current densities, and current helicities in two CHs, and compare them with two quiet regions. We find that: (i) in the areas where the large current helicities are concentrated, there are strong vertical and horizontal field elements; (ii) the mean current density in the magnetic flux concentrations with the vertical fields stronger than 100 Gs is as large as (0.012 ± 0.001) A$\cdot$m^{-2}, consistent with that in the flare productive active regions; (iii) the magnetic fields in both the CHs and the quiet regions are nonpotential. (4) SDO observations of magnetic reconnection at CH boundaries. At the CH boundaries, we find many coronal jets as the signatures of magnetic reconnection, below which the magnetic emergence and cancellation are observed. We study the shifts of CH boundaries, and prove that the magnetic reconnection at CH boundaries maintains the rigid rotation of CHs. (5) Structures and evolution of polar plumes in the north polar CH. With the total solar eclipse observations, we investigate the properties and evolution of the polar plumes. The results reveal that the plumes which are closer to the CH center are more vertical. It seems that the lifetimes of plumes are much longer than the timescale of eclipse, and there may be no short timescale oscillations.

The above results are helpful for us to understand the properties of CHs, and to get more insight into the evolution of CHs and the magnetic activities in CHs. As the source of fast solar wind, CHs are one kind of triggering regions of space weather. Therefore, our results can also provide an essential physical basis and observational evidence for studying the mechanism of solar wind acceleration and the course of space weather.