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博士学位论文摘要选登

太阳双带耀斑中的剪切磁场

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太阳耀斑、暗条爆发以及日冕物质抛射 (CME) 对我们生存的空间环境有着重大影响. 这些爆发所释放的能量储存在剪切的或扭曲的非势性磁场中. 本论文对与太阳爆发有关的剪切磁场位型及其在爆发中的重要作用进行了深入系统的研究. 这对理解和预言空间灾害性天气起着至关重要的作用. 本论文的研究方法包括多波段观测 (从个例的深入研究到大样本的统计分析) 和数值模拟.

本论文的主要研究成果为: (1) 对一个 X17 级的大耀斑中足点的剪切程度由强到弱的变化的详细研究显示, 这种剪切变化在脉冲相的中间停止. 该现象被解释为发生在耀斑早期的高度剪切核心场的剪切外壳场的分裂. (2) 我们发现足点剪切运动是双带耀斑的常见特征, 即我们所研究的 50 个有较好 TRACE 观测的双带耀斑中有 43 个显示该运动, 我们将这种耀斑称为类型 I 耀斑. 对 10 个有剪切角测量和相应的硬 X 射线观测的耀斑的详细研究表明, 大部分事件中剪切变化的停止比脉冲相的结束早 0∼2 min, 这可能暗示由脉冲相到缓变相的变化与磁剪切的变化有关. (3) 对 18 个伴随 CME 的双带耀斑, 我们发现磁通量和足点剪切角的变化与耀斑 /CME 事件的强度之间有很强的相关性, 然而后者与最初剪切角却没有相关性. 这指出耀斑 /CME 事件的强度取决于耀斑过程中释放的能量而不是爆发前储存在日冕中的总自由能. 我们还发现上述多个参数的组合与耀斑 /CME 事件强度的相关性比单个参数强许多. (4) Hinode/XRT 对发生在 2006 年 12 月的两个 X 级大耀斑的观测显示, 在耀斑中有部分剪切磁弧抛射出去而另一部分却留在日冕中, 这可以解释为什么耀斑后还可以观测到大部分暗条. 我们还发现耀斑后的核心场的剪切程度远比耀斑前弱, 这与耀斑中释放的能量是耀斑前储存在高度剪切磁场中的自由能的观点相一致. (5) 最后, 我们利用磁通量绳插入法对一个简单偶极活动区 (NOAA 10953) 进行了非线性无力场 (NLFFF) 模拟. 该活动区产生了多个小耀斑 (包括一个 C8.5 级耀斑) 和暗条活动. 我们找到了符合 C8.5 级耀斑前该活动区观测的 NLFFF 模型, 但耀斑后却没有找到. 与该活动区的观测符合最好的模型拥有强剪切但弱扭曲的磁通量绳. 我们还发现在 C8.5 耀斑之前, 此活动区接近一个爆发状态: 磁通量绳的轴向磁通量接近爆发的阈值.

Magnetic Shear in Two-ribbon Solar Flares

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Solar flares, filament eruptions and coronal mass ejections (CMEs) are energetic events that have great influences on the space weather that we live in. Storage of the energy

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released in these eruptions requires non-potential magnetic fields, i.e., sheared or twisted fields. In this thesis, we carry out a detailed and systematic study on the sheared magnetic field configuration as well as its important role in solar eruptions. This is an important part of our effort to understand and predict our space weather. This work primarily focuses on the analysis of multi-wavelength observations, while the nonlinear force-free field (NLFFF) modeling of one active region is also explored.

The main results of this study are: (1) For the X17 flare on Oct. 28th 2003, we find that the cessation of the strong-to-weak shear change of the footpoints occurs in the middle of the impulsive phase. The phenomenon is interpreted in terms of the splitting of the sheared envelope field of the greatly sheared core rope during the early phase of the flare. (2) This shear motion of the footpoints has been found to be common, i.e., 43 out of 50 of the well-observed (by TRACE) two-ribbon flares we studied show this shear motion, we call these flares type I flares. We also find that in 10 Type I flares having both measured shear angles and corresponding hard X-ray observations, the cessation of shear change is 0$\sim$2 min earlier than the end of the impulsive phase, which may suggest that the change from the impulsive to gradual phase is related to magnetic shear change. (3) For a sample of 18 Type I flares associated with CMEs, we find that the magnetic flux and the change of shear angle of the footpoints are significantly correlated with the intensity of flare/CME events, while the initial shear angle of the footpoints is not. This observations indicate that the intensity of flare/CME events may depend on the released magnetic free energy rather than the total free energy stored prior to the flare. We also find that a linear combination of the aforementioned parameters shows a much stronger correlation with the intensity of flare/CME events than each parameter itself. (4) Hinode/XRT observations of two X-class flares which occurred in December 2006 show that one part of the sheared core field erupted, while the other stayed behind during the flares. This may explain why a large part of the filament is still seen in TRACE after the flare. We also find that the post-flare core field is clearly less sheared than the pre-flare core field, which is consistent with the idea that the energy released during the flares is stored in the highly sheared fields prior to the flare. (5) Using the flux rope insertion method, we explore the NLFFF modeling of active region 10953, which produced several small flares and filament activations. We find good NLFFF models that fit the observations before a C8.5 flare, but not for the case after the flare. The flux rope contains strongly sheared but weakly twisted magnetic fields. Before the C8.5 flare, this active region is close to an eruptive state: the axial flux in the flux rope is close to the threshold value for eruption.