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耀变体的喷流物理研究

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活动星系核(AGN)是一类特殊的活动星系, 核心存在着猛烈的活动现象和剧烈的物理过程. 耀变体(blazar)是活动星系核的一个子类, 其具有相对论性喷流且喷流视角很小, 因此集束效应较强, 观测到的辐射基本都来自于喷流. 相对论性喷流物理还很不清楚, 如喷流的形成、喷流的准直和喷流的物质成分等. 耀变体多波段辐射为喷流主导, 为研究喷流物理提供了理想的实验室.

本论文第1章介绍了AGN和blazar研究的部分进展. 第2章进一步介绍了blazar常用的喷流模型. 第3章我们利用χ^2的方法和喷流模型, 同时考虑了不同的外软光子场(宽线区或尘埃环)的影响, 对一个具有同时性(或准同时性)多波段能谱数据的低同步峰(low-synchrotron-peaked, LSP)耀变体样本进行了拟合, 发现假定外软光子来源于尘埃环红外辐射比假定外软光子来源于宽线区辐射的能谱(Spectral Energy Distribution, SED)拟合的χ^2小, 表明这些LSP blazar的γ射线辐射区可能位于宽线区以外. 同时利用较好的软X射线数据, 限制了喷流中一个重要的物理参数(最小电子洛仑兹因子) $\gamma_{\rm min}$, 其值的范围为5–160 (中值为55), 该参数对估算喷流功率具有重要意义. 如果假设喷流内一个电子对应一个质子, 发现通过模型拟合估算的LSP耀变体喷流功率比Fanaroff-Riley type II (FR II)喷流功率高, 可能的解释为这些耀变体喷流存在正电子. 若喷流内存在正电子, 喷流功率将减小. 因此我们认为, 喷流成分为正负电子和质子的混合等离子体. 假设LSP耀变体的喷流功率与FR II喷流的功率相同, 我们发现这些耀变体为正负电子对主导的轻子喷流, 喷流正负电子对数密度为质子数密度的几倍, 但喷流功率仍由质子主导.

对于高同步峰(high-synchrotron-peaked, HSP) BL Lac天体PKS 1424+240, 前期用同步自康普顿(synchrotron self-Compton, SSC)模型拟合其多波段SED时发现拟合参数不合理(比如具有特别大的多普勒因子δ), 该工作中我们考虑了外软光子场, 用轻子喷流模型拟合了耀变体PKS 1424+240天体在不同态的多波段SED, 探讨了高同步峰耀变体PKS 1424+240天体的软光子起源问题, 发现SSC+外康普顿(external-Compton, EC)模型给出的δ值比较合理. 但是需要的外软光子能量密度值小于宽线区或尘埃环软光子能量密度的典型值, 这与最近一些BL Lac的研究结果一致, 这意味着耀变体的外软光子场随着耀变体光度的减小可能存在演化(平谱射电类星体(flat spectrum radio quasars, FSRQs)-BL Lac: 低能峰BL Lac (low energy peaked BL Lac, LBL)-中能峰BL Lac (intermediate energy peaked BL Lac, IBL)-高能峰BL Lac (high energy peaked BL Lac, HBL)).

在此基础上, 第5章进一步通过EC过程研究耀变体中外软光子场的演化问题. 我们用轻子喷流模型(SSC+EC)和χ^2的方法拟合不同光度耀变体样本的同时性(或准同时性)多波段SED, 模型计算中外软光子场能量密度$U_{\rm ext}$作为自由参数. 研究不同类型耀变体的外软光子场能量密度, 我们发现: (1)高光度LSP耀变体(FSRQs和LBLs)的外软光子场能量密度基本保持不变, 但拟合的宽线区外软光子能量密度比观测值小; 而红外外软光子能量密度与观测的结果基本一致. 这进一步支持LSP耀变体软光子场可能起源于尘埃环, 喷流辐射区位置在宽线区外; (2)对于部分IBL天体仍然需要考虑EC过程, 但光

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子场能量密度U_{ext}远小于宽线区(尘埃环)的外软光子能量密度的典型值且随光度的减小而逐渐减小, 这种演化与射电宁静(RQ) AGN中宽线区或尘埃环的演化是一致的. 最后, 我们对耀变体及喷流物理进行了小结和展望.

The Study on the Physical Properties of Blazar Jets

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Active galactic nuclei (AGNs) belong to a special class of active galaxies, and have violent active phenomena and intense physical processes in the nuclei. Blazar is a subclass of AGNs, and has a relativistic jet with a small jet viewing angle. Therefore, the boosting effect is very important, and almost all the observed radiation is dominated by the jet. The relativistic jet physics is not very clear yet, such as the jet formation, collimation, and matter content etc. The multi-waveband radiation of blazar is dominated by jet, which provides an ideal laboratory for studying the jet physics.

The first chapter of this thesis introduces the recent progress of AGNs and blazars. We further introduce the jet model that commonly used in blazars in the second chapter. In the third chapter, we fit simultaneously (or quasi-simultaneously) the multi-waveband spectral energy distributions (SEDs) for a sample of low-synchrotron-peaked (LSP) blazars with the jet model and χ^2 procedure, which takes into account different soft photon fields (broad line region or a molecular torus). We find that the SED fitting with an external soft photon from IR torus is systematically better than that from the broad line region (BLR) based on a χ^2 test, which suggests that the γ-ray emitting region most possibly stays outside the BLR. The minimum electron Lorentz factor, $\gamma_{\min}$, is constrained from the modeling of these LSP blazars with good soft X-ray data, and in a range from 5 to 160 (with a median value of 55), which plays a key role in jet power estimation. Assuming one-to-one ratio of proton and electron, we find that the jet power for LSP blazars is systematically higher than that of Fanaroff-Riley type II (FR II) radio galaxies. A possible reason for this is that there are some positrons in the jets of these blazars. If this is the case, the jet power will be reduced. Therefore, we propose a mixed composition of $e^{\pm} - p$ in the jets of these LSP blazars. If we assume that the jet power of LSP blazars is the same as that of FR IIs, we find that it is an electron-positron pair dominated leptonic jet in these blazars, and the number density of electron-positron pairs is several times higher than that of electron-proton pairs, but the jet power is still dominated by protons.

For the high-synchrotron-peaked (HSP) BL Lac PKS 1424+240, the SED fitting with the synchrotron self-Compton (SSC) model gave unreasonable fitting parameters (e.g., a very large Doppler factor δ). In this work, we take into account the possible external soft photon field, and then fit the multi-waveband SEDs of blazar PKS 1424+240 with one-zone leptonic jet models in both states. We find the SSC+external-Compton (EC) model can give a better fitting result if the EC process is included. However, the needed energy density of external soft photon field (U_{ext}) is much lower than the typical value. This result is consistent with the results of some other BL Lacs, where the BLR or torus is very weak or disappearing. It means that there is evolution of the energy density of external soft photon

field with decreasing of the luminosity of blazars (the flat spectrum radio quasars (FSRQs)-BL Lac: low energy peaked BL Lac (LBL)-intermediate energy peaked BL Lac (IBL)-high energy peaked BL Lac (HBL)).

And on this basis, in the chapter 5, we further explore the possible evolution of the external soft photon field of blazars based on the EC process. We employ the one-zone homogeneous leptonic jet model and χ^2 procedure to fit simultaneously or quasi-simultaneously multi-waveband SEDs for a sample of blazars with a wide distribution of luminosities. In our model, we set $U_{\rm ext}$ as a free parameter. Studying the energy density of the external photon field in different subclasses of blazars, we find: (1) the $U_{\rm ext}$ of the high luminosity blazar (FSRQs and LBLs) keeps roughly as a constant, which is, however, smaller than that constrained from BLR observations. Assuming IR as the source of soft photons, the $U_{\rm ext}$ is roughly consistent with the torus observational result. This further supports the result that the external soft photon field may originate from torus, and the γ-ray emitting region of these LSP blazars locates outside the BLR. (2) For some IBLs, the EC process may be still needed, but the photon energy density is less than the typical values of the photon energy density of BLR (or dust torus), where the $U_{\rm ext}$ decreases with decreasing of the luminosity. This evolution is consistent with the BLR or torus as directly constrained from the radio-quiet AGN. The final part summarizes the study on the subject, and makes some suggestions for further researches.