

黑洞天体活动的基本面研究

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活动星系核(中心黑洞质量 $M_{\text{BH}} \sim 10^6 - 10^{10} M_{\odot}$)和黑洞X射线双星($M_{\text{BH}} \sim 10 M_{\odot}$)普遍被认为具有相似的中心引擎: 黑洞、吸积盘和喷流. 类似的中心引擎、质量相却差如此之大(6-9个数量级)的两类黑洞系统是否具有相似的物理仍不清楚. 本文围绕不同尺度黑洞天体的物理性质和观测特性展开, 主要研究了不同尺度黑洞天体活动的基本面关系以及黑洞X射线双星的能谱演化.

本文首先研究了黑洞X射线双星不同射电-X射线关系及其可能的物理本质. 近年来, 射电-X射线的“例外”分支被发现, 它的拟合斜率比正常分支更陡, 表明可能具有与正常分支不同的吸积模式. 该工作首先利用同时或准同时性的射电-X射线观测, 研究了4个黑洞X射线双星光子指数随流量的演化. 发现在3-9 keV的流量 $F_{3-9\text{keV}}$ 在低于和高于临界流量 $F_{\text{X,crit}}$ 处, 射电-X射线相关性也发生了明显的变化: 当 $F_{3-9\text{keV}} \geq F_{\text{X,crit}}$ 时, 射电-X射线流量的拟合斜率 b 较陡($\sim 1.1 - 1.4$), 处于例外分支; 当 $F_{3-9\text{keV}} \leq F_{\text{X,crit}}$ 时, 处于正常分支或转换分支. 该工作通过分析硬X射线谱指数的演化, 验证了射电-X射线相关性的正常分支和例外分支的X射线辐射分别来自于辐射低效和辐射高效的吸积模式, 表明 Γ - $F_{3-9\text{keV}}$ 正、反相关性的变化是吸积模式转换的结果, 其中 Γ 为X射线谱指数.

其次, 研究了高辐射效率黑洞天体的基本面关系 $\lg L_{\text{R}} = \xi_{\text{X}} \lg L_{\text{X}} + \xi_{\text{M}} \lg M_{\text{BH}} + c$, 其中 L_{R} 和 L_{X} 分别为射电光度和X射线光度, M_{BH} 是黑洞质量, ξ_{X} 和 ξ_{M} 是拟合系数, c 为拟合常数. 该工作首先构建了1个辐射高效黑洞天体的样本, 包括高光度射电宁静活动星系核和例外源(热光度 L_{bol} 和爱丁顿光度 L_{Edd} 满足 $L_{\text{bol}} \geq 1\% L_{\text{Edd}}$). 样本的 Γ - $F_{3-9\text{keV}}$ 都是正相关的, 且它们的5 GHz射电光度 $L_{5\text{GHz}}$ 与爱丁顿的比值 $L_{5\text{GHz}}/L_{\text{Edd}}$ 和2-10 keV X射线光度 $L_{2-10\text{keV}}$ 与爱丁顿光度的比值 $L_{2-10\text{keV}}/L_{\text{Edd}}$ 具有相似的相关性: $L_{5\text{GHz}}/L_{\text{Edd}} \propto (L_{2-10\text{keV}}/L_{\text{Edd}})^c$, $c \sim 1.50$. 既然这两类源具有相似的性质, 本文分析并给出了它们的基本面关系: $\xi_{\text{X}} = 1.59^{+0.28}_{-0.22}$, $\xi_{\text{M}} = -0.22^{+0.19}_{-0.20}$, $c = -28.97^{+0.45}_{-0.45}$, 拟合弥散度为 $\sigma_{\text{R}} = 0.51 \text{ dex}$. 与辐射低效黑洞基本面关系相比, 该基本面关系适用于辐射高效的黑洞天体.

再次, 研究了宁静态黑洞天体物理性质. 宁静态时射电-X射线的相关性是否延续低/硬态时的演化一直存在着两种不同的观点. 我们首先构建了1个比较完备的样本, 包括黑洞X射线双星和低光度活动星系核, 其光度范围为 $L_{\text{X}} = (10^{-9} - 10^{-3}) L_{\text{Edd}}$. 然后, 分析了黑洞活动的基本面关系, 得到了与辐射低效黑洞基本面关系相似的结果($\xi_{\text{X}} \sim 0.60$, $\xi_{\text{M}} \sim 0.80$). 该结果表明宁静态黑洞的基本面关系仍然在低/硬态时的延长线上. 同时, 本文还利用黑洞质量小范围变化、X射线光度相差数个量级的活动星系核模拟了单个活动星系核从低/硬态向宁静态的射线-X射线相关性的演化并得到了相似的结果, 表明宁静态和低/硬态时的黑洞天体具有相似物理机制.

最后, 以GX 339-4为例初步研究了黑洞X射线双星的X射线能谱演化. 本文利用RXTE 2007-2008年的观测, 研究了GX 339-4整个爆发过程谱指数 Γ 随X射线流量 $F_{2-10\text{keV}}$ 的演化. 结果表明, 在光度上升和下降阶段 Γ - $F_{2-10\text{keV}}$ 相关性遵循两个不同的演化轨迹. 该工作仅仅分析了GX 339-4一个完整的爆发, 后续工作将对更多的黑洞X射线双星、更多的完整的爆发进行研究, 这对于进一步限定黑洞吸

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积盘的物理机制具有重要意义.

Research on the Fundamental Plane of Black Hole Activity

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It is generally believed that active galactic nuclei (AGNs) and black hole X-ray binaries (BHXRBS) have a similar central engine: black hole (BH), accretion disc, and jet. Whether the two kinds of sources with 6-10 orders magnitude differences in BH masses have a similar physical properties is still unknown. In this paper, we explore the physical properties in these BH sources, and especially investigate the possible universal correlations for these different-scale BH sources.

We firstly explore the possible physical reason that regulated the different radio-X-ray correlations as found in X-ray binaries (XRBS). We firstly explore the hard X-ray spectral evolution in four black-hole X-ray binaries with multiple quasi-simultaneous radio and X-ray observations, and find that the hard X-ray photon indices, Γ , are negatively and positively correlated with the X-ray fluxes respectively when the X-ray flux $F_{3-9\text{keV}}$ is below and above a critical value $F_{X,\text{crit}}$, which is consistent with predictions of the advection-dominated accretion flow and the Shakura & Sunyaev disc-corona (SSD-corona) model, respectively. Most importantly, the radio-X-ray correlations are also changed simultaneously at this critical X-ray flux. As we know, the anti- and positive correlations of hard X-ray photon index and Eddington ratio are most possibly triggered by different accretion processes. Therefore, this work gives the direct evidence that the different tracks of radio-X-ray correlation may be triggered by different accretion processes.

Since the former fundamental plane ($\lg L_R = \xi_X \lg L_X + \xi_M \lg M_{\text{BH}} + c$, where L_R and L_X are the radio and X-ray luminosity, respectively, M_{BH} is the BH mass, the fitting slopes $\xi_X \sim 0.60$, $\xi_M \sim 0.80$) is mainly applied to the radiatively inefficient BHs (e.g., low-luminosity AGNs and low/hard state of XRBS), we next explore this issue for the radiatively efficient BHs. We firstly construct a sample consisting of the bright radio-quiet AGNs and outliers of XRBS with $L_X \geq 1\%L_{\text{Edd}}$, where L_X is the X-ray luminosity, and L_{Edd} is the Eddington luminosity. We find these two populations follow a similar correlation between the hard X-ray photon indices and Eddington ratios. Basing on these similarities, we present a new fundamental plane ($\xi_X = 1.59^{+0.28}_{-0.22}$, $\xi_M = -0.22^{+0.19}_{-0.20}$, $c = -28.97^{+0.45}_{-0.45}$) with a scatter of $\sigma_R = 0.51$ dex, which is suitable for the radiatively efficient BHs.

In order to investigate whether the L_R - L_X correlation as defined in low/hard state of XRBS can extend to the quiescent state, or has a break when the X-ray luminosity L_X is less than a critical value $L_{X,\text{crit}}$, we construct a sample consisting of XRBS and low luminosity active galactic nuclei (LLAGNs) with a wide distribution of the Eddington ratios. We find that there is a similar fundamental plane ($\xi_X \sim 0.6$) for $L_X \geq L_{X,\text{crit}}$ and $L_X \leq L_{X,\text{crit}}$. We further simulate a single AGN with a narrow mass range evolving from the sub-Eddington to quiescent state, and find that the highly sub-Eddington sources still roughly stay on the extension of radio-X-ray correlation as defined by the sub-Eddington BHs. Therefore, our

results support that the properties of quiescent BHs are similar to those of low/hard state.

Finally, we study the spectral evolution of XRBs in a whole outburst period, and try to constrain the possible accretion physics based on the spectral evolution. Because part of the work is still ongoing, we only take the whole 2007–2008 outburst of GX 339-4 as an example. We find that there are two different spectral evolutions in the rising and the decay periods of the 2007–2008 outburst. We will further study the spectral evolution of more complete outburst of XRBs to constrain the physical mechanism of BH accretion mode.

栏目征稿启事

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