博士学位论文摘要选登

# 星系成团与并合研究

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宇宙结构的形成和星系演化是当今天体物理学的重大课题. 本论文的工作主要包括两部分：星系团的证认和研究；大质量早型星系的并合及引力波辐射.

本文第 1 部分讨论了从 SDSS DR6 测光数据中证认星系团并研究它们的性质. 前人从光学数据中得到的星系团绝大部分红移小于 0.3, 而且它们的富度估计不够准确. 利用星系测光红移, 我们在红移 $0.05 < z < 0.6$ 范围内证认出 39 716 个星系团. 这是目前最大的星系团样本, 比前人从 SDSS 数据中得到的样本都要深. 利用 SDSS 光谱红移数据, 我们发现星系团测光红移的误差小于 0.022, 用测光红移选出的星系团成员星系的污染率和完备性分别约为 20% 和 90%. Monte Carlo 模拟显示：我们的方法能够探测到红移 $z \leq 0.42$ 范围约 90% 的富星系团 (质量 $M_{200} > 2 \times 10^{14}\ M_{\odot}$), 星系团的探测错误率约为 5%. 我们还确定星系团的富度、总光度和总星系数, 发现它们与星系团 X 射线光度、温度紧密相关. 星系团质量也与富度和总光度紧密相关, 拟合的幂律关系为 $M_{200} \propto R^{1.90\pm0.04}$ 和 $M_{200} \propto L_r^{1.64\pm0.03}$. 我们将星系团样本与 ROSAT X 射线未证认源进行交叉证认, 发现了 790 个新的 X 射线星系团候选体.

在仔细检查每个星系团的图像时, 我们发现 13 例新的星系团强引力透镜系统候选体. 其中有 4 例几乎无需光谱证实就可以肯定是引力透镜系统, 有 5 例很可能的和 4 例可能的引力透镜系统.

论文的第 2 部分讨论了亮早型星系的并合率与超大质量黑洞并合引起的引力波辐射. 目前, 近邻宇宙中大质量星系的并合率还不清楚. 利用 SDSS DR6 数据, 我们从 87 889 个亮早型星系 (绝对星等 $M_r < -21.5$) 样本中选出一个大的星系对完备样本, 包括 1 209 个投影距离 $7\ \mathrm{kpc} < r_{\mathrm{p}} < 50\ \mathrm{kpc}$、红移 $z < 0.12$ 范围的星系对. 利用新的图像处理方法, 我们证认出 249 个有明显相互作用特征的并合星系对, 并由此得到近邻宇宙中亮早型星系并合比例为 0.8%, 并合率为 $R_{\mathrm{g}} \approx (1.0\pm0.4)\times10^{-5}\ \ \mathrm{Mpc}^{-3}\cdot\mathrm{Gyr}^{-1}$. 我们还估计出并合星系中超大质量黑洞的质量, 得到了并合星系中超大质量黑洞对的 chirp 质量, 发现它在 $5\times10^8 \sim 5\times10^9\ M_{\odot}$ 范围内大致满足幂律分布. 依据观测的并合率, 我们估计了 $10^{-9} \sim 10^{-7}$ Hz 频率范围的宇宙引力波背景辐射 $h_c(f) \approx 10^{-15}(f/\mathrm{yr}^{-1})^{-2/3}$, 与完全基于理论模型的结果一致. 另一方面, 我们提出了用脉冲星时探测背景引力波和单个引力波源对超大质量黑洞并合率进行限制的方法, 进而限制星系并合率演化.

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# Galaxy Clustering and Merging

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Cosmic structure formation and galaxy evolution are important subjects in astrophysics. The thesis consists of two parts: (1) identification of galaxy clusters and studies of their properties; (2) identification of the mergers of luminous early-type galaxies and gravitational waves (GWs).

Most of the galaxy clusters in the previous catalogs have redshifts $z \leq 0.3$ with richnesses not well determined. Using the photometric redshifts of galaxies from the Sixth Data Release of Sloan Digital Sky Survey (SDSS DR6), we identify 39716 clusters in the redshift range of $0.05 < z < 0.6$. This is the largest cluster catalog to date and goes to a deeper region than any previous catalogs from the SDSS. Using the SDSS spectroscopic redshifts, we find that the cluster redshifts are estimated accurately with an uncertainty of less than 0.022, the contamination rate and the completeness of member galaxies are found to be $\sim$20% and $\sim$90%, respectively. Monte Carlo simulations show that the cluster detection rate is larger than 90% for the massive ($M_{200} > 2 \times 10^{14}\ M_{\odot}$) clusters with $z \leq 0.42$. The false detection rate is $\sim$5%. We obtain the richness, the summed luminosity and the gross galaxy number. They are tightly correlated with the X-ray luminosity and the temperature of clusters. The cluster mass is also found to be tightly related to the richness and summed luminosity in the form of $M_{200} \propto R^{1.90\pm0.04}$ and $M_{200} \propto L_r^{1.64\pm0.03}$, respectively. In addition, 790 new candidates of X-ray clusters are found by cross-identification of our clusters with the unidentified source list of the ROSAT X-ray survey.

By visual inspections of the detected clusters, we recognize 13 gravitational lensing candidates. Among all the candidates, four can be sure strong lensing systems even without further spectroscopic identification, five are more probable and four are possible lenses.

In the second part, we discuss the merger rates of luminous early-type galaxies and GWs from the mergers of supermassive black holes (SMBHs). The merger rates of massive galaxies in the local universe are still not clear so far. We select a large sample (1209) of close pairs of galaxies with projected separations 7 kpc $< r_{\rm p} <$ 50 kpc and $z < 0.12$ from 87889 luminous early-type galaxies ($M_r < -21.5$) from the SDSS DR6. Using our newly developed technique for searching for interaction features, 249 mergers have been identified. We find that the merger fraction of luminous early-type galaxies is 0.8%, and the merger rate in the local universe is, $R_{\rm g} \approx (1.0 \pm 0.4) \times 10^{-5}$ Mpc$^{-3} \cdot$ Gyr$^{-1}$. We also estimate the masses of SMBHs in the merging galaxies. We find that the chirp masses of the SMBH binaries in the range of $5 \times 10^8 \sim 5 \times 10^9\ M_{\odot}$ follow approximately a power-law distribution. According to the SMBH population in the mergers, we investigate the stochastic GW background in the frequency range of $10^{-9} \sim 10^{-7}$ Hz. We obtain the spectrum of the GW background of $h_c(f) \approx 10^{-15}(f/{\rm yr}^{-1})^{-2/3}$, which is consistent with those calculated from galaxy formation models. In addition, we discuss the constraint of SMBH merger rate from detection of stochastic GW and individual GW using pulsar timing data, which then places the further constraints on the evolution of galaxy merging rates.