第60卷 第6期 天 文 学 报 Vol.60 No.6
2019年11月 ACTA ASTRONOMICA SINICA Nov., 2019

doi: 10.15940/j.cnki.0001-5245.2019.06.011 博士学位论文摘要选登

# 高红移恒星形成星系的研究

安芳霞[†]

(中国科学院紫金山天文台 南京 210033)

星系是组成宇宙的基石, 其形成与演化是天体物理研究的重要内容. 星系中的恒星形成活动是星系成长和演化的主要驱动力之一. 已有的星系巡天给出比较一致的宇宙恒星形成历史: 宇宙的恒星形成密度从高红移一直增加到红移$z\sim 2$，随后按指数率下降直到$z=0$. 系统地研究宇宙恒星形成峰值时期恒星形成星系的性质对我们理解并限制星系形成与演化的理论模型至关重要.

论文的第2章和第3章描述我们基于窄带观测技术研究高红移发射线星系的工作. 在第1个工作中我们应用“双窄带”巡天技术, 探测同一红移($z=2.24$)、同一观测场(Extended *Chandra* Deep Field South)的Ly$\alpha$和H$\alpha$发射体. 我们比较了Ly$\alpha$光度/光度密度和修正了尘埃消光的H$\alpha$光度/光度密度，并据此估算了红移$z=2.24$处单个星系和宇宙整体的Ly$\alpha$光子逃逸概率. 我们的研究发现: (1)高红移恒星形成星系中电离气体和恒星连续谱之间尘埃消光的差异随星系恒星形成率的增加而增大; (2) Ly$\alpha$光子逃逸概率与星系的尘埃消光反相关; (3)红移$z=2.24$处宇宙总体的Ly$\alpha$光子逃逸概率为(3.7±1.4)%; 我们的工作首次指出不同的尘埃消光改正方法对高红移恒星形成星系的研究具有显著影响. 在第2部分工作中, 我们应用窄带巡天探测到的发射线星系来寻找高红移宇宙空间的“原星系团”以及其周围的大尺度结构. 我们的初步结果为: (1)对比平均场, 我们选定的两个红移$z=2.24$的致密区域BOSS (Baryon Oscillation Spectroscopic Survey) 1244和BOSS1542中H$\alpha$发射线候选体的数密度$\delta_{\rm g}\geqslant 11$; (2) BOSS1542场中H$\alpha$发射体的分布展现出了明显的纤维状大尺度结构.

研究表明在宇宙恒星形成峰值时期, 极亮红外星系的恒星形成率占宇宙总量的一半. 我们在第4章和第5章描述了这类极端星系的物理性质. 我们首先利用高空间分辨率的干涉阵观测数据构建了训练样本，并发展了机器学习方法来证认单天线亚毫米波段探测源的多波段对应体. 我们的研究结果为: (1)我们机器学习方法的召回率为(77.2±4.7)%, 精确度为(82.0±4.9)%, 结合射电证认, 召回率可以提高至85%; (2)训练样本的自测试和一系列独立测试证实了我们方法的成功性; (3)我们的方法可以成功证认出那些亚毫米辐射比较弥散或者/以及比较暗弱的亚毫米星系的对应体, 即使它们的亚毫米辐射低于干涉阵观测的探测阈值. 这表明我们发展的方法有效解决了亚毫米研究中单天线亚毫米源的低空间分辨率对后续研究的限制. 我们的研究工作也是首次将机器学习的方法应用于亚毫米星系的研究, 提高了研究的效率. 我们将该机器学习方法应用于COSMOS (Cosmic Evolution Survey)场中最新的单天线亚毫米巡天(S2COSMOS)探测到的亚毫米源, 并成功证认出了约1200个单天线亚毫米源的光学/近红外/射电波段的对应体. 基于这个精确的亚毫米星系对应体样本, 我们研究了亚毫米星系的多波段性质. 我们证实了机器学习方法证认的亚毫米星系的对应体可以完备地反映亚毫米星系的物理性质, 比如它们趋向于在高红移宇宙空间, 星系中正在进行恒星形成率高达$10^2\ M_\odot\cdot{\rm yr}^{-1}$的大质量星暴活动. 同时我们将该方法应用于整个COSMOS场, 并从中选出了约9000个没有被单天线亚毫米观测探测到但是被机器学习方法归类为亚毫米星系对应体的近红外源. 基于这个统计上足够大的样本, 我们研究了亚毫米星系的成团性. 通过比较亚毫米星系和同一宇宙时期以及低红移宇宙空间中其他类型天

[†]2019-01-06获得博士学位, 导师: 紫金山天文台郑宪忠研究员; fangxiaan@pmo.ac.cn

体的成团性的强度, 我们可以研究亚毫米星系和其他类型天体的演化关联. 我们的这些研究工作促进了对高红移恒星形成星系物理性质的认识, 为理解星系尤其是大质量星系的形成与演化提供了更为精确的限制.

# A Study of High-redshift Star-forming Galaxies

AN Fang-xia
(*Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210033*)

Galaxies are fundamental building blocks of the Universe. Understanding their detailed formation and evolution is a major task in modern astronomy. Star formation is a key process that regulates galaxy formation and evolution. A consistent picture is emerging from modern galaxy surveys, whereby the star formation rate density peaks at $z \sim 2$, and exponentially declines to the present day. Systematic study of star-forming galaxies at the peak epoch holds the key to our understanding of galaxy formation and evolution.

Chapters 2 and 3 of this dissertation present our studies based on the narrow-band imaging techniques. In Chapter 2, we present the results from the dual narrow-band imaging surveys in the search of Ly$\alpha$ and H$\alpha$ emitters at the same redshift ($z = 2.24$) and in the same field (Extended *Chandra* Deep Field South). We estimate the mean Ly$\alpha$ escape fraction at $z = 2.24$ by comparing the observed ratio between the Ly$\alpha$ luminosity to total luminosity and to the extinction-corrected H$\alpha$ luminosity fraction. We find that: (1) the difference in the dust attenuation between ionized gas and stellar continuum increases with star formation rate; (2) there is an anti-correlation between Ly$\alpha$ escape fraction and dust attenuation; (3) the global Ly$\alpha$ escape fraction at $z = 2.24$ is (3.7±1.4)%; For the first time we point out that different extinction corrections significantly affect the studies of high-redshift star-forming galaxies. In the second project presented in this dissertation, we use the narrow-band-selected emission-line galaxies to identify the protoclusters, and map the cosmic structure around them in the early universe. Our preliminary results show that: (1) comparing to the random field, the galaxy overdensity in our two overdense fields BOSS (Baryon Oscillation Spectroscopic Survey) 1244 and BOSS1542 is $\delta_{\rm g} \geqslant 11$; (2) a large-scale filamentary structure is shown by the H$\alpha$ emitters in the BOSS1542.

The extremely luminous infrared galaxies contributed almost half of the cosmic star formation at the epoch of the peak star formation. In our third and forth projects, we study the physical properties of this extremal galaxy extreme population through the submillimeter observations. We develop a machine-learning method to identify the possible multi-wavelength counterparts of submillimeter detected source in panoramic, single-dish submillimeter surveys using a training set constructed from higher angular resolution interferometric submillimeter observations. The results show that: (1) the recovery rate and precision of the developed machine-learning method are (77.2±4.7)% and (82.0±4.9)%, respectively, and the recovery rate of Submillimeter Galaxies (SMGs) reaches to 85% if we combine the radio identifications; (2) the self-test of the training set and a set of independent tests confirm the robustness of our method; (3) our analysis based on the stacked images demonstrates that the method can recover faint and/or diffuse submillimeter galaxies even if they are below the detection threshold of interferometric observations. These results mean that we have efficiently reduced the uncertainties in the follow-up studies of submillimeter sources resulting from the coarse angular resolution of single-dish submillimeter surveys. Our project is the first application of machine-learning techniques in the studies of submillimeter galaxies. We apply this method to the recent single-dish submillimeter survey in the Cosmic Evolution Survey (COSMOS) field (S2COSMOS). About 1200 optical/near-infrared/radio counterparts of submillimeter galaxies have been identified. We study the multi-wavelength properties of submillimeter galaxies based on these precisely identified counterparts. We confirm that these identified counterparts to single-dish submillimeter sources represent the complete physical properties of submillimeter galaxies, i.e., they tend to lie at higher redshift and they are undergoing massive bursts of star formation at rates of $\geqslant 10^2\, M_\odot \cdot \mathrm{yr}^{-1}$. We also apply our method to the whole COSMOS field and identify ~9000 likely optical/near-infrared counterparts of submillimeter galaxies, which are below the detection limit of single-dish submillimeter observations. We can investigate the evolutionary connections between submillimeter galaxies and other populations at the same epoch or in the lower-redshift Universe by comparing their clustering strength, which reflect their underlying dark matter distributions. Our studies provide more accurate constraints on galaxies formation and evolution models, particularly for the massive ones.