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高红移亚毫米星系中星际介质的物理状态

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随着亚毫米波望远镜的发展, 利用这些新的探测设备, 人们在亚毫米波段发现了一类高红移且富含尘埃的星系, 将其称为亚毫米星系. 这类星系的发现革新了我们对星系的演化以及极端条件下的恒星形成过程的认知. 这些亚毫米星系是宇宙中最强的星暴星系, 其中的恒星形成过程产生的能量接近爱丁顿极限. 人们普遍认为这类星系正是近邻宇宙中那些大质量星系的前身天体. 但是，很难解释其在高红移为何具有较高的数密度. 它们其中非常少的一部分会被处于视线方向上的大质量星系通过引力透镜作用放大变亮. 尽管这类处于引力透镜系统中的亚毫米星系十分稀少, 但近来人们通过大视场河外巡天, 发现了上百个此类天体, 这为我们研究高红移亚毫米星系中的星际介质提供了一个令人振奋的新途径.

我们从*Herschel*-ATLAS巡天获得的源表中仔细地挑选出了一组受强引力透镜作用的亚毫米星系的样本. 我们利用IRAM (Institut de Radioastronomie Millimétrique)的干涉阵NOEMA (NOrthern Extended Millimeter Array)和30 m单天线望远镜, 从16个亚毫米星系中探测到了水分子(H_2O)谱线. 我们发现水分子谱线的光度和星系的红外光度之间存在一个紧密的近似线性的相关性. 我们利用水分子的远红外激泵激发模型, 从观测数据中求出了水分子气体和尘埃辐射的物理性质. 我们发现这些由水分子气体示踪的致密热分子气体很可能跟剧烈的恒星形成活动紧密关联. 除了水分子气体谱线之外, 我们还在样本中的3个星系中探测到了H_2O^+的若干条发射线. 我们发现从近邻的极亮红外星系到高红移的亚毫米星系, 它们的H_2O和H_2O^+发射线的光度之间呈现出紧密的线性关系. 通过分析这两者的谱线强度比, 我们推测这些星系中星际介质的氧化学过程很可能由其中剧烈的恒星形成活动所产生的宇宙射线主导.

除了水分子气体, 另外一个重要的分子气体探针为一氧化碳(CO)分子气体. 因此, 我们使用IRAM 30 m单天线毫米波射电望远镜对亚毫米星系样本中的多能级CO谱线进行了观测. 通过分析CO发射线的谱线轮廓, 我们发现引力透镜的非均匀放大效应会使观测到的谱线宽度被低估, 这个低估最大可以到2倍左右. 通过基于大速度梯度(LVG)的CO谱线辐射转移模型, 并利用结合了贝叶斯思想的马尔可夫链蒙特卡洛方法, 我们得到了多能级CO谱线所示踪的分子气体的物理性质, 包括: 分子气体的体密度、温度以及CO分子的柱密度. 通过对样本整体的统计分析, 我们发现星系整体的气体热压力与其恒星形成效率呈紧密的线性相关. 同时还研究了星系的分子气体与其整体恒星形成之间的关系, 比如通过比较这些星系的气尘比以及气体耗散时标, 发现样本星系具有的这些性质与其他亚毫米星系并无差异. 最后, 我们对比了样本星系的CO谱线和H_2O谱线的线宽, 发现这两者比较一致. 这意味着这两种分子气体辐射分布的空间区域较为类似.

为了更进一步了解高红移亚毫米星系中分子气体的性质、结构以及动力学的性质, 十分有必要利用高空间分辨率的观测对其进行研究. 因此, 我们利用目前最强大的(亚)毫米波干涉阵ALMA (Atacama Large Millimeter/sub-millimeter Array)和北半球最先进的毫米波干涉阵NOEMA对样本

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中最亮的两个星系进行了高空间分辨率的观测. 我们对CO谱线和H_2O谱线的高分辨率成图进行了对比, 发现星系冷尘埃的辐射区域要小于CO和H_2O的区域, 但是后两者的分布比较一致. 通过构架其动力学模型我们发现这两个星系的运动学图像可以很好地用一个旋转盘模型来解释. 据此, 我们求出了其动力学质量以及有效半径.

随着未来NOEMA的发展以及ALMA的不断运行升级, 我们将不断地扩大受强引力透镜作用的高红移亚毫米星系样本, 并在条件容许的情况下探测那些未经过引力透镜作用的星系. 通过观测这些星系中不同种类的分子气体探针, 我们将对这些星系中的星际介质的物理化学状态以及其与恒星形成的关系有更新的认识.

Physical Conditions of the Interstellar Medium in High-redshift Submillimetre Bright Galaxies

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The discovery of a population of high-redshift dust-obscured submillimeter galaxies (SMGs) from ground-based submillimetre (submm) cameras has revolutionised our understanding of galaxy evolution and star formation in extreme conditions. They are the strongest starbursts in the Universe approaching the Eddington limit, and are believed to be the progenitors of the most massive galaxies today. However, theoretical models of galaxy evolution have even been unable to explain the large number of detections of high-redshift SMGs. A very few among them are gravitationally lensed by a foreground galaxy. Recent wide-area extragalactic surveys have discovered hundreds of such strongly lensed SMGs, opening new exciting opportunities for observing the interstellar medium in these exceptional objects.

We have thus carefully selected a sample of strongly gravitational lensed SMGs based on the submm flux limit from the *Herschel*-ATLAS sample. Using the IRAM (Institut de Radioastronomie Millimétrique) telescopes, we have built a rich H_2O-line-detected sample of 16 SMGs. We found a close-to-linear tight correlation between the H_2O line and total infrared luminosity. This indicates the importance of far-IR pumping to the excitation of the H_2O lines. Using a far-IR pumping model, we have derived the physical properties of the H_2O gas and the dust. We showed that H_2O lines trace a warm dense gas that may be closely related to the active star formation. Along with the H_2O lines, several H_2O^+ lines have also been detected in three of our SMGs. We also find a tight correlation between the luminosity of the lines of H_2O and H_2O^+ from the local ULIRGs (UltraLuminous Infrared Galaxies) to the high-redshift SMGs. The flux ratio between H_2O^+ and H_2O suggests that cosmic rays from strong star forming activities are possibly driving the related oxygen chemistry.

Another important common molecular gas tracer is the CO line. We have observed multiple transitions of the CO lines in each of our SMGs with the IRAM 30 m telescope. By analysing the CO line profile, we discovered a significant differential lensing effect that might cause underestimation of the linewidth by a factor of ~ 2. Using the LVG (Large Velocity Gradient) modelling and fitting the multi-J CO fluxes via a Bayesian approach, we derived gas densities and temperature, and the CO column density per unit velocity gradient. We then found a correlation between the gas thermal pressure and the star formation efficiency. We have also studied the global properties of the molecular gas and its relationship with star formation. We have derived the gas to dust mass ratio and the gas depletion time of our sample galaxies, which show no difference compared with other SMGs. With the detections of atomic carbon lines in our SMGs, we extended the local linear correlation between the CO and CI line luminosity. Finally, we compared the linewidths of the CO and H_2O emission lines, which agree very well with each other. This suggests that the emitting regions of these two molecules are likely to be co-spatially located.

In order to understand the properties of molecular emission in high-redshift SMGs, and more generally, the structure and the dynamical properties of these galaxies, it is crucial to acquire high-resolution images. We thus observed two of our brightest sources with the ALMA (Atacama Large Millimeter/sub-millimeter Array) and NOEMA (NOrthern Extended Millimeter Array) interferometers using their high spatial resolution configuration. These images have allowed us to reconstruct the intrinsic morphology of the sources. We compared the CO, H_2O, and dust emission. The cold dust emission has a smaller size compared with the CO and H_2O gas, while the latter two are similar in size. By fitting the dynamical model to the CO data of the sources, we have shown that the sources can be modelled with a rotating disk, and the projected dynamical mass and the effective radius of those sources have been obtained.

With the future NOEMA and ALMA, we will be able to extend such kind of observations to a larger sample lensed SMGs and even to unlensed SMGs, to study various gas tracers, and to refresh our understanding of the physical conditions of the ISM and their relation to the star formation.