博士学位论文摘要选登

暗晕次结构的演化

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在主流的冷暗物质 (cold dark matter, CDM) 模型中，暗物质由于引力不稳定性塌缩成位力化的结构，形成所谓的暗物质晕 (dark matter halo), 然后重子气体由于辐射消耗能量而落入这些暗晕的中心，最终形成星系．暗晕一般是通过等级成团的方式形成，即小质量暗晕先塌缩形成，进而通过并合形成更大尺度的暗晕．并合后的小质量暗晕不会立即消失，而形成暗晕 (主暗晕， host halo) 的次结构 (dark matter halo substructure 或 subhalo). 在次结构中形成的星系是在主暗晕中形成的中心星系的伴星系 (satellite galaxy, 亦称卫星星系). 伴星系因为质量小、光度低而成为观测中的矮星系.

次结构进入主暗晕后，由于动力磨擦的作用将最终与主暗晕中心并合，并合所需要的时间称为动力磨擦时标 $T_{\rm df}$. 我们构建了一个次结构进入主暗晕后的动力学演化模型，模型中考虑的重要物理过程有动力磨擦、潮汐质量剥离、潮汐加热和潮汐瓦解等．我们发现 $T_{\rm df}$ 的幅度主要取决于潮汐剥离的效率，效率越高， $T_{\rm df}$ 越长，这同时也解释了前人得到的 $T_{\rm df}$ 在幅度上的差异．我们还发现在研究 $T_{\rm df}$ 对轨道形状的依赖性时，样本中不同次结构与主暗晕质量比所占的比例是一个关键性的问题．在次结构的晚期演化问题上，通过比较模型和数值模拟预言的次结构角动量演化，我们发现潮汐质量剥离只在早期的演化中比较有效，而在后期的演化中潮汐效应可以忽略．另外，动力磨擦中的一个重要参量是库仑对数，其取值目前还没有比较好的表述．通过比较模型和数值模拟预言的 $T_{\rm df}$, 我们拟合了库仑对数并给出一个拟合式.

结合次结构的动力学演化模型和 EPS (Extended Press-Schechter) 理论预言的暗晕形成历史 (即暗晕并合树), 我们考察了每个被吸积的次结构在主暗晕中的演化历程．该模型能预言给定形成历史的暗晕内次结构的分布，包括空间分布和质量分布等，其结果可以和数值模拟或观测进行比较．将模型应用到银河系大小暗晕的形成历史中，我们发现潮汐剥离的效率是影响次结构质量函数 (subhalo mass function, SHMF) 的主要原因，效率越高， SHMF 的幅度越低，而不同的库仑对数取值和潮汐瓦解定义对 SHMF 没有影响．模型预言的次结构径向分布比数值模拟的结果致密，但与银河系中的伴星系分布却是一致的．次结构径向分布与次结构在吸积时刻和今天的质量基本无关，但不同时刻被吸积的次结构的分布却有明显区别，这个结论与前人数值模拟或半解析模型的结果是一致的.

将上述模型应用到不同大小暗晕的形成历史中，我们发现主暗晕质量对 SHMF 的幅度有较大的影响，但对次结构径向分布的影响较弱．不同质量的主暗晕中，潮汐场的强度对 SHMF 的幅度均有同样很强的影响．模型预言在不同质量主暗晕中，不同质量的次结构的暗晕占据分布 (halo occupation distribution) 均满足泊松分布.

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Modelling the Evolution of Dark Matter Subhaloes

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In the popular cold dark matter (CDM) model, the structure is formed during the collapse of dark matter due to gravitational instability, and the virial structure is seen as dark matter halo. The baryonic gases condense in the radiative cooling, fall into the halo, and finally form a galaxy. The halo formation is processed in a hierarchical manner that small haloes form first, and they subsequently merge to form bigger haloes. After the merger, the small haloes survive as self-bound entities and become the substructures (subhaloes) of the bigger halo (host halo). The galaxy in the subhalo is the satellite galaxy of the central galaxy formed in the host halo. The satellite galaxies usually have low masses and luminosities, and are observed as dwarf galaxies.

When the subhalo falls into the host halo, it will merge with the host halo center due to dynamical friction. The time interval needed for the merger is called the dynamical friction timescale $T_{\rm df}$. The dynamical evolution model for subhalo includes some important physical processes such as the dynamical friction, tidal mass stripping, tidal heating and tidal disruption. We find that the $T_{\rm df}$ depends strongly on the efficiency of tidal stripping. The $T_{\rm df}$ increases with the increasing tidal stripping efficiency, and this is the main reason for the discrepancies among the previous results. We also find that the dependence of $T_{\rm df}$ on orbital circularity is determined by the merging samples, in which the distribution of mass ratio between the subhalo and host halo is crucial. With respect to the late stage of subhalo evolution, we find that the tidal mass stripping is only efficient in the early stage, but this effect can be ignored in the late evolution. The Coulomb logarithm in the dynamical friction has not been well stated. By comparing the predicted $T_{\rm df}$ with simulation, we give a fitting formula of Coulomb logarithm.

Combining the dynamical model with the halo formation histories (merger trees) predicted by the Extended Press-Schechter (EPS) formalism, we have followed the evolution of the accreted subhaloes in the host haloes. The predicted subhalo population, including the spatial distribution and subhalo mass function (SHMF), can be compared with the results of the simulation or observation. In the application to a Milky-Way sized halo, we find that the SHMF is mainly determined by the tidal stripping efficiency with the trend that a higher efficiency of tidal stripping leads to a lower amplitude of SHMF. The SHMF is insensitive to the Coulomb logarithm and definition of tidal disruption. The predicted radial distribution of subhaloes is more concentrated than that of simulation, but is consistent with the distribution of the satellite galaxies in Milky Way galaxy. The radial distribution of subhaloes depends weakly on the masses of subhaloes at both present day and the accretion time, but strongly depends on the accretion time.

Applying the model to the formation histories of the host haloes with different masses, we find that the masses of host haloes influence strongly on SHMF, but weakly on the radial distribution of subhaloes. In different host haloes, the tidal field has the same effect on SHMF. The predicted halo occupation distribution of subhaloes follows the Poisson distribution well, and this distribution is independent of the masses of host haloes and subhaloes.