



**青年学者学术报告活动**

**喜鹊：银河系高精度数值模拟**

**邵实（计算宇宙学团组）**



# 报告内容



- 一、研究背景**
- 二、研究方案**
- 三、初步结果**



# 报告内容

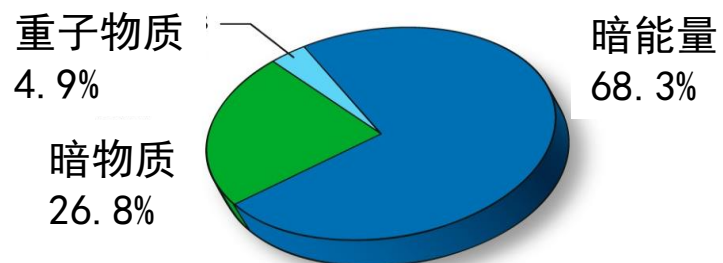


**一、研究背景**

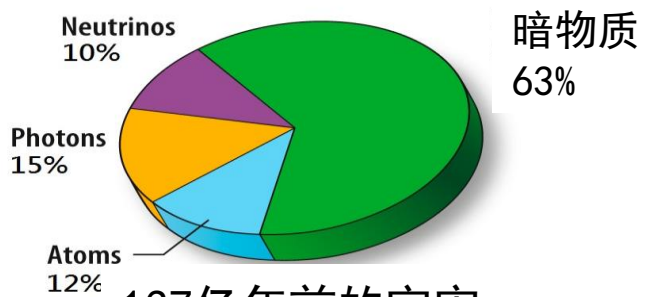
**二、研究方案**

**三、初步结果**

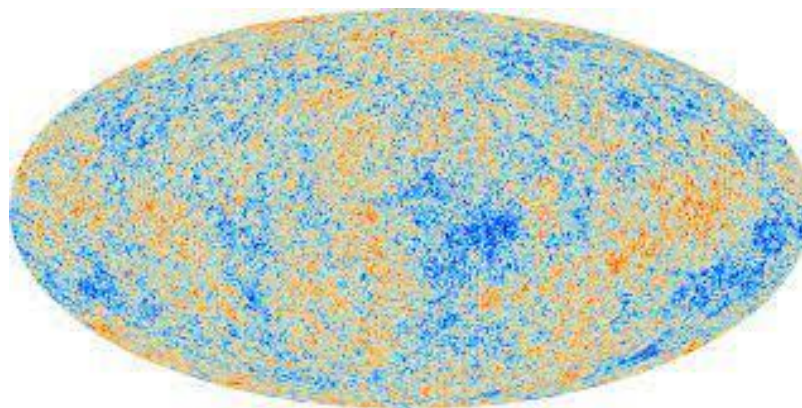
## 过去的四十年，标准宇宙学模型 ( $\Lambda$ CDM) 得到了极大的发展



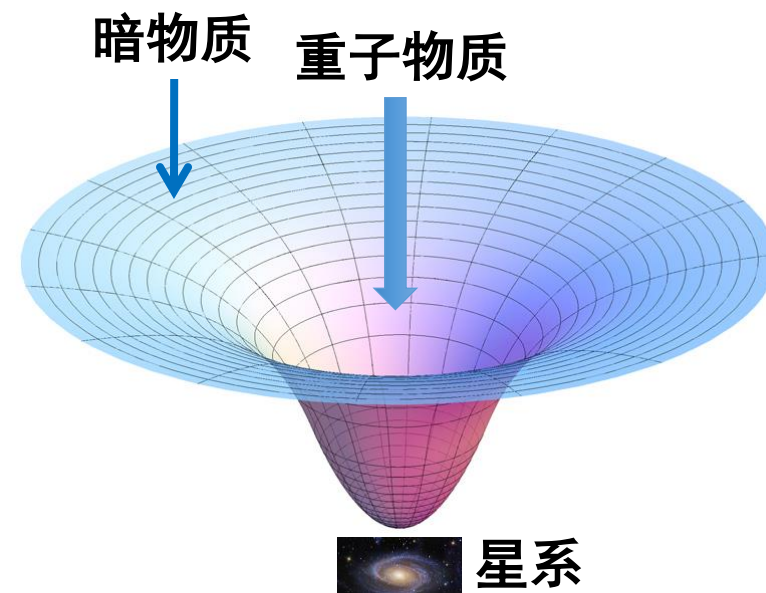
今天的宇宙



137亿年前的宇宙

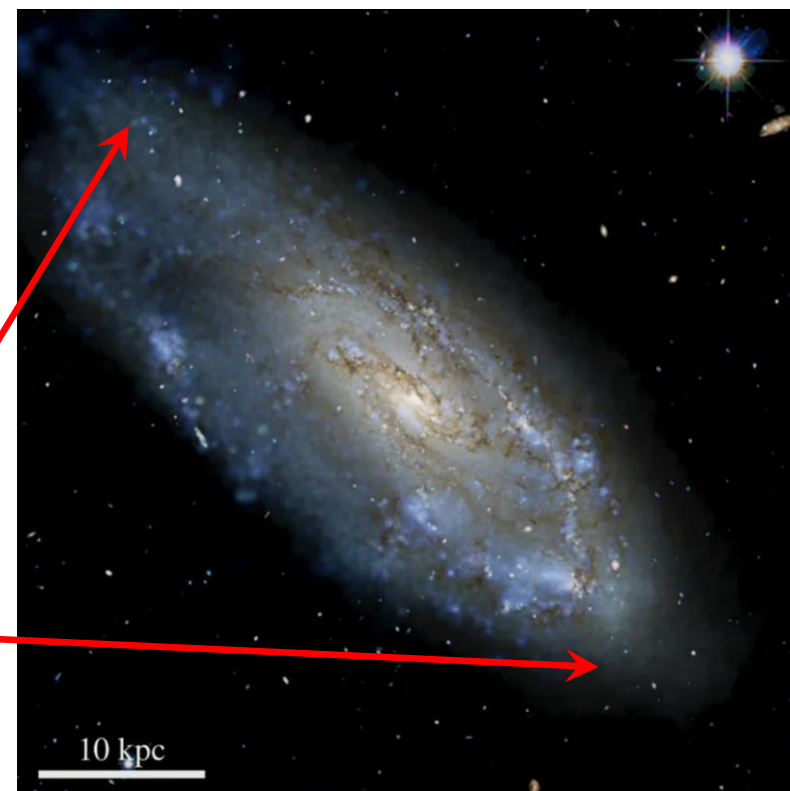
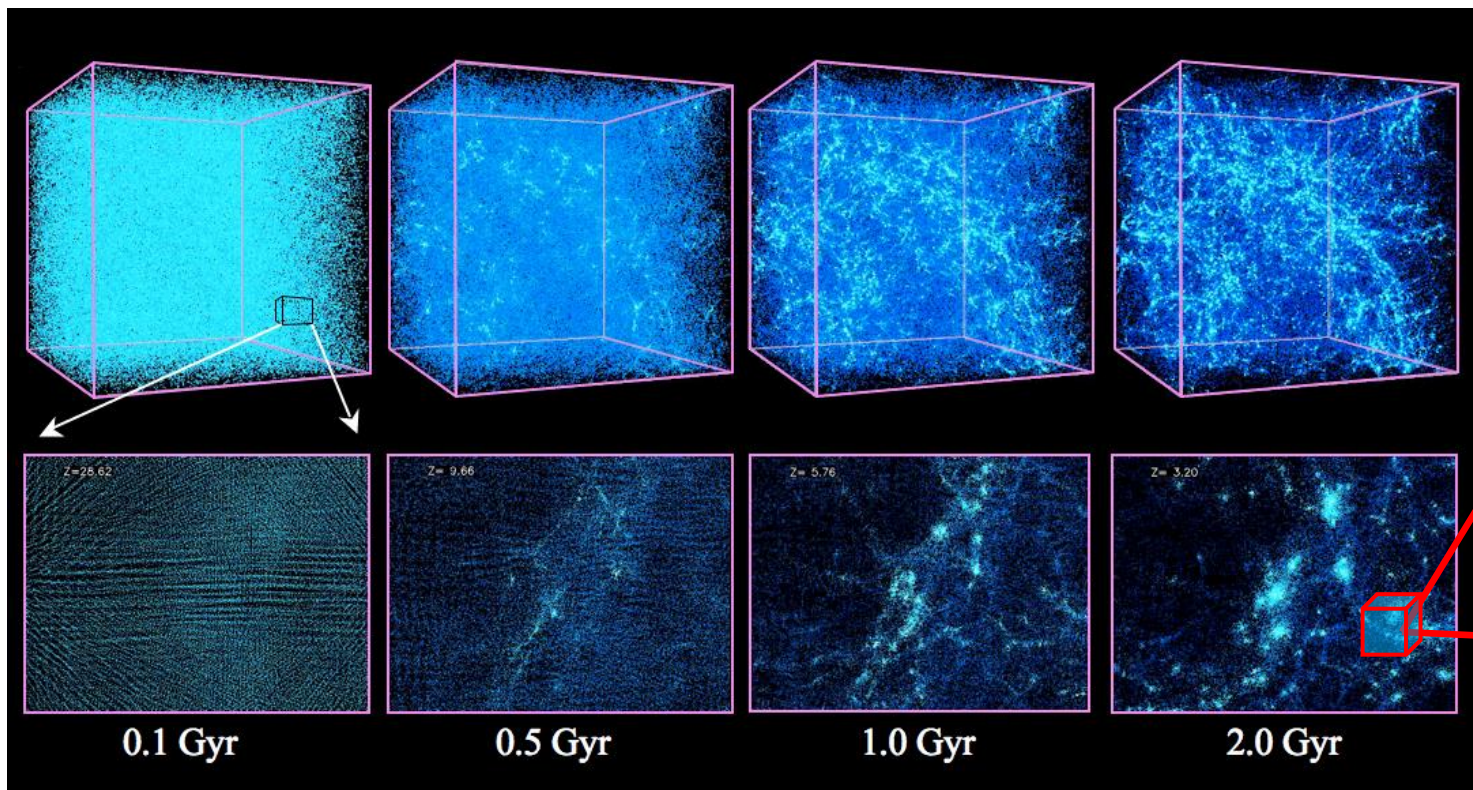


宇宙早期的密度涨落是结构形成的种子



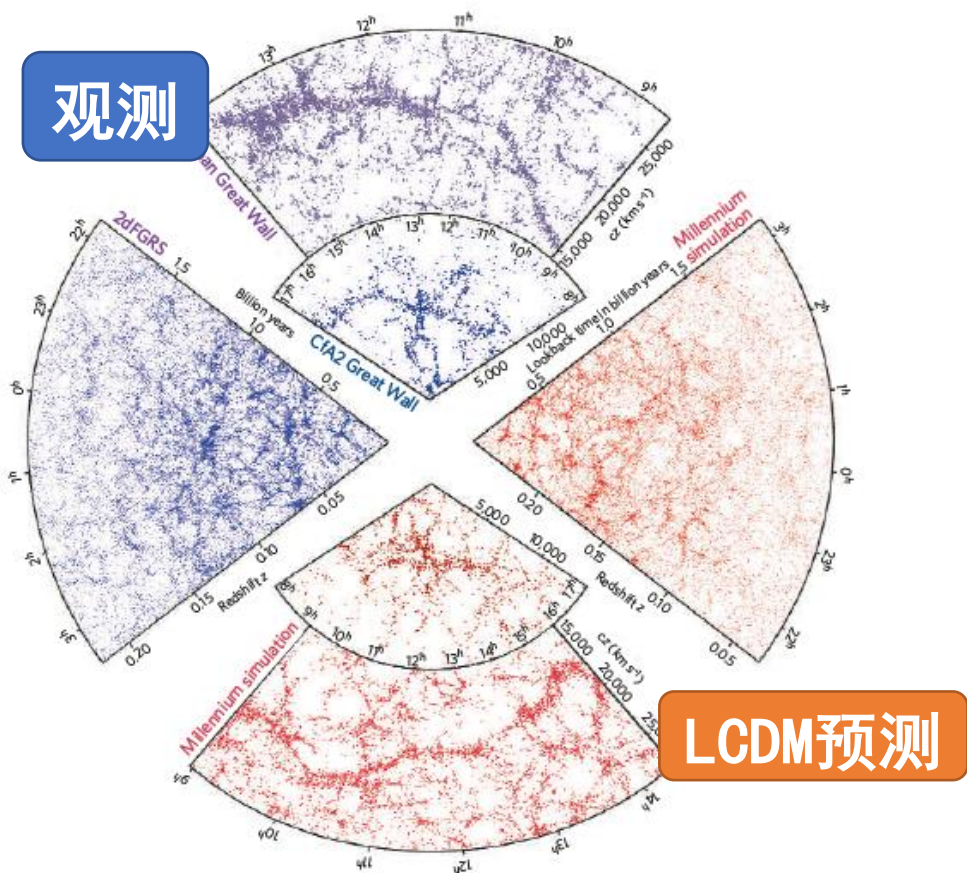
暗晕形成高度非线性化

星系形成涉及复杂重子物理过程

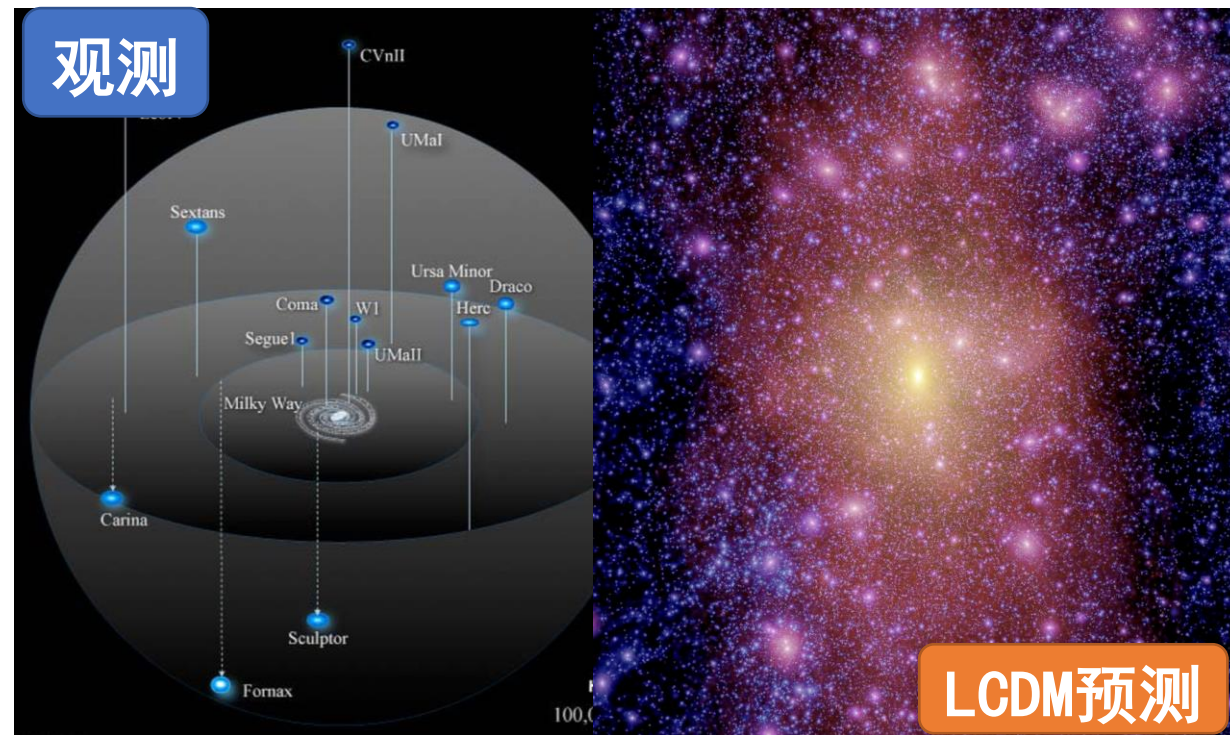


**宇宙学流体模拟是研究结构形成的最有效方法！**





宇宙大尺度结构一致



小尺度结构存在分歧



# 研究背景



## Small-Scale Challenges to the $\Lambda$ CDM Paradigm

Annual Review of Astronomy and Astrophysics

天体物理年度综述报告 (影响因子37)

<https://doi.org/10.1146/annurev-astro-091916-055313>

### 小尺度结构对标准模型的挑战

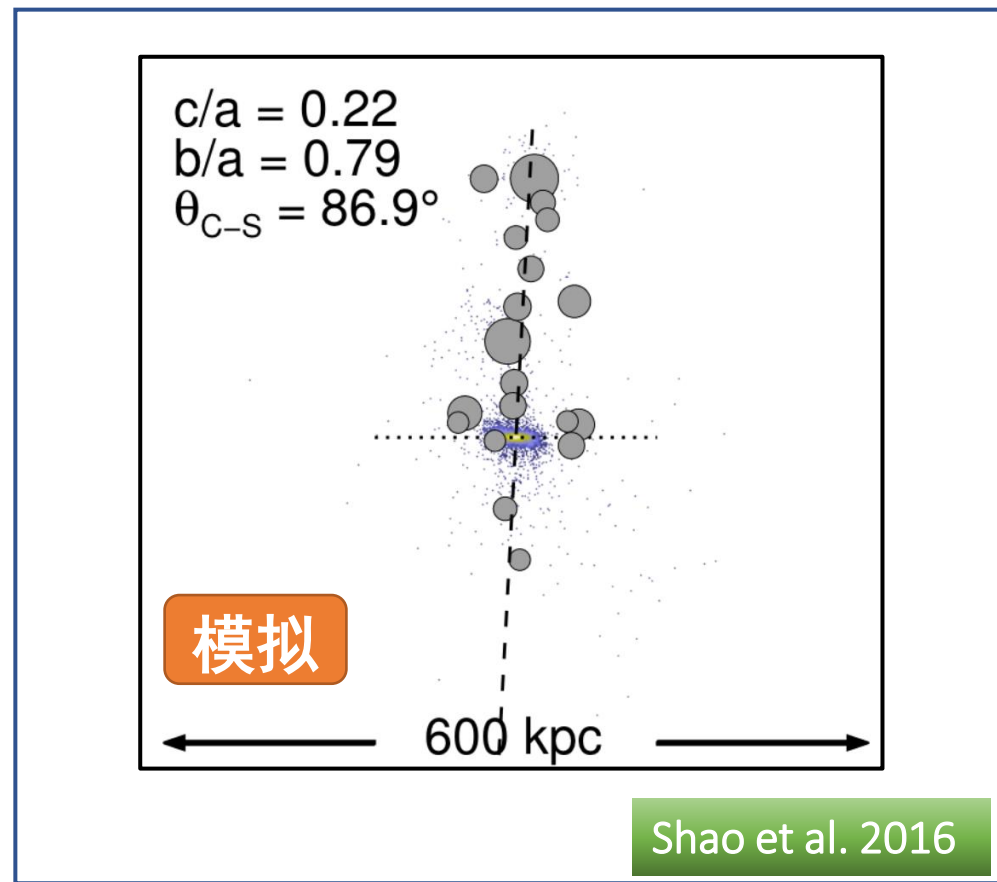
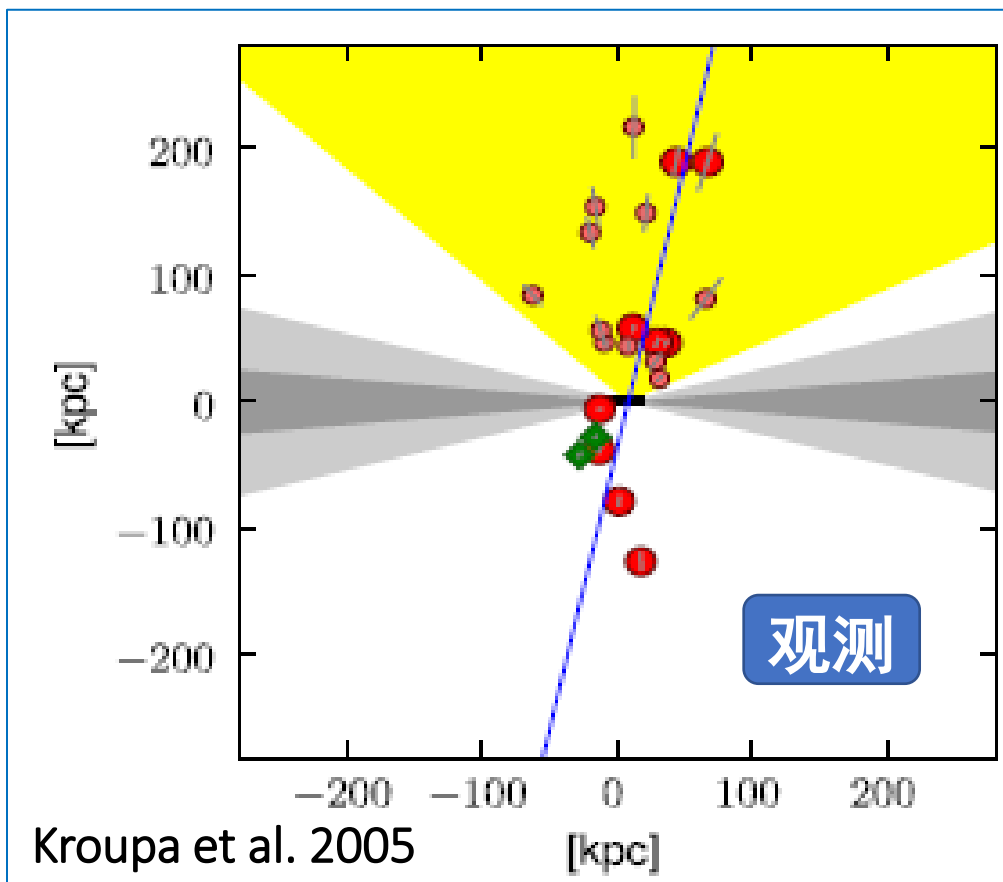
James S. Bullock<sup>1</sup> and Michael Boylan-Kolchin<sup>2</sup>

<sup>1</sup>Department of Physics and Astronomy, University of California

<sup>2</sup>Department of Astronomy, The University of Texas at Austin

- ❑ 卫星星系中心密度轮廓问题 core-cusp problem
- ❑ 卫星星系空间分布各向异性问题 plane of satellite
- ❑ 卫星星系丢失问题 missing satellite problem
- ❑ 大质量卫星星系缺失问题 too-big-to-fail problem

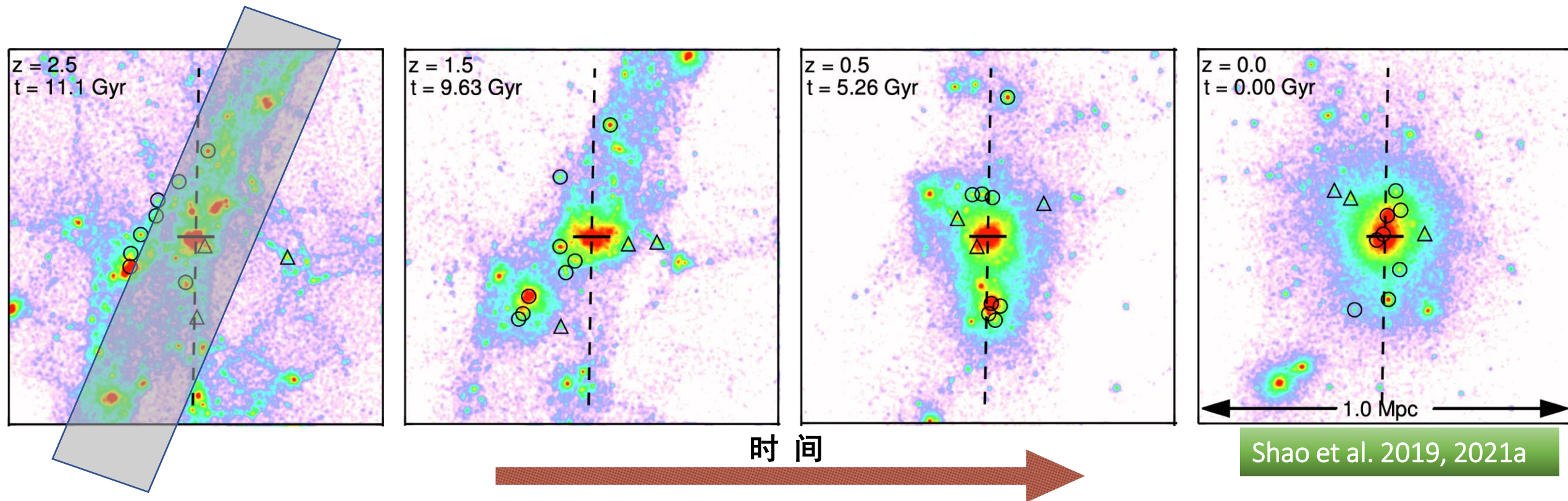
## 卫星星系的空间分布各向异性问题



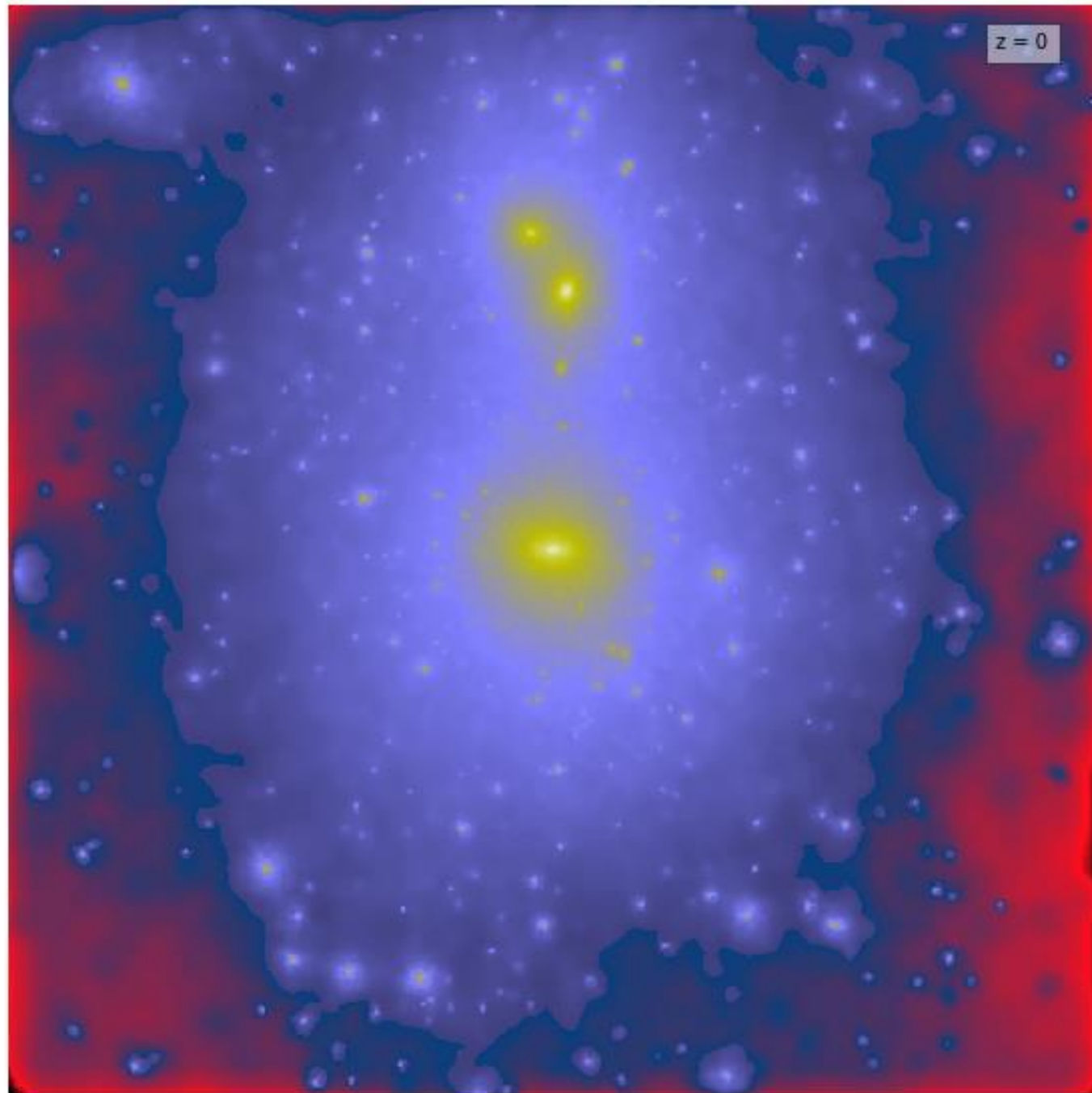
发现标准模型中卫星星系也存在非对称分布



## 卫星星系的空间分布各向异性问题



发现卫星星系分布各向异性是由宇宙片状塌缩造成的



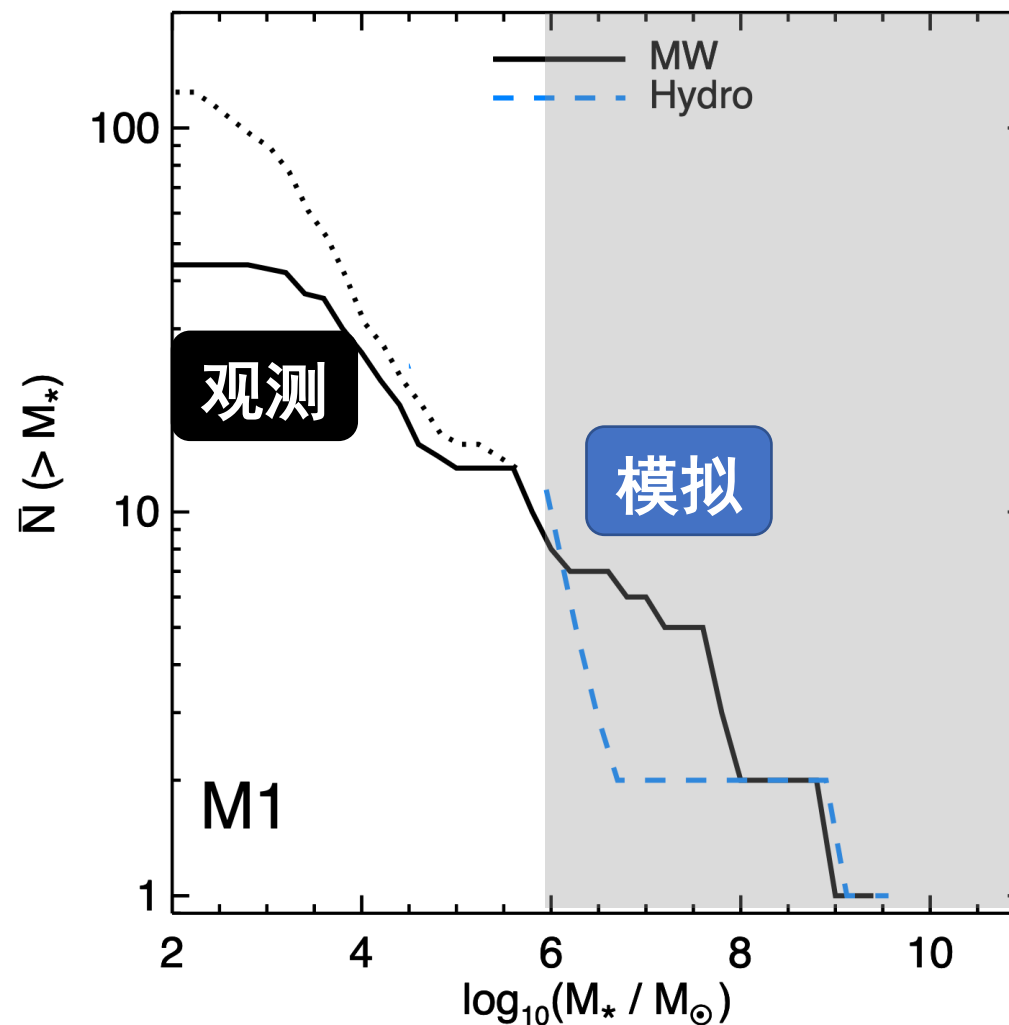
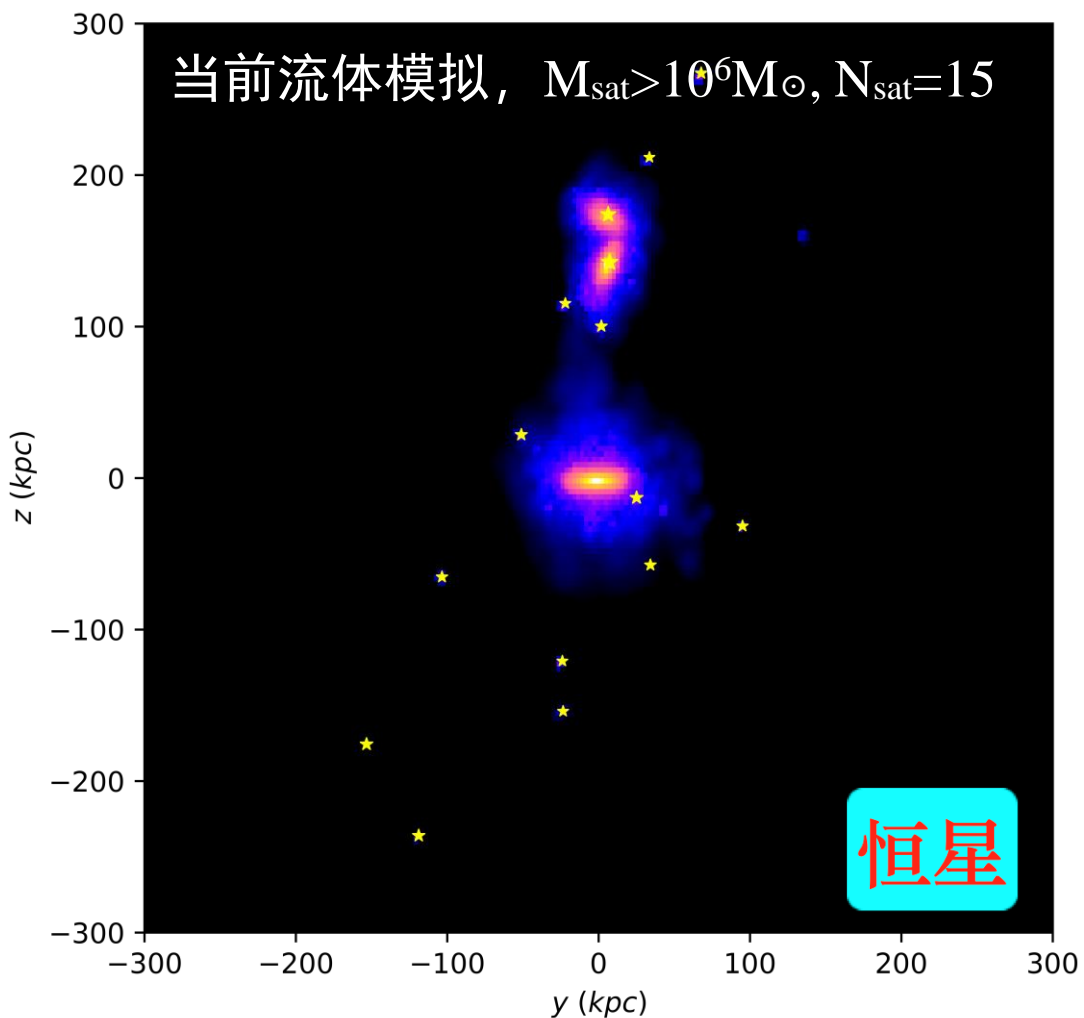
内晕扁平状  
外晕纺锤形



# 研究背景



中央星系和卫星星系有很强相互作用



模拟中的卫星星系样本不完备





# 报告内容

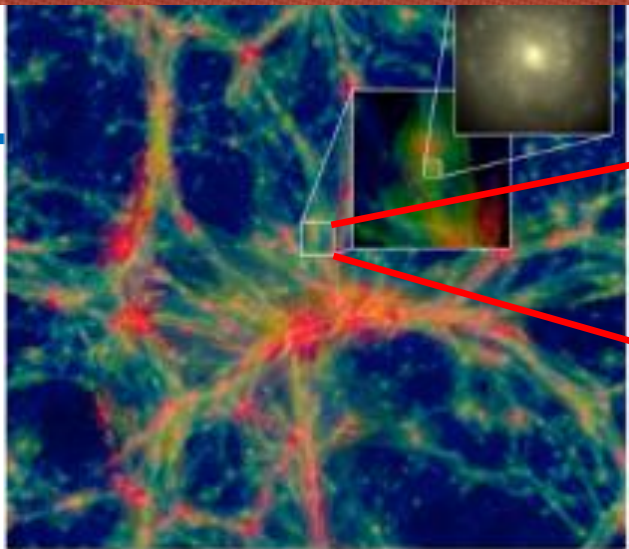


**一、研究背景**

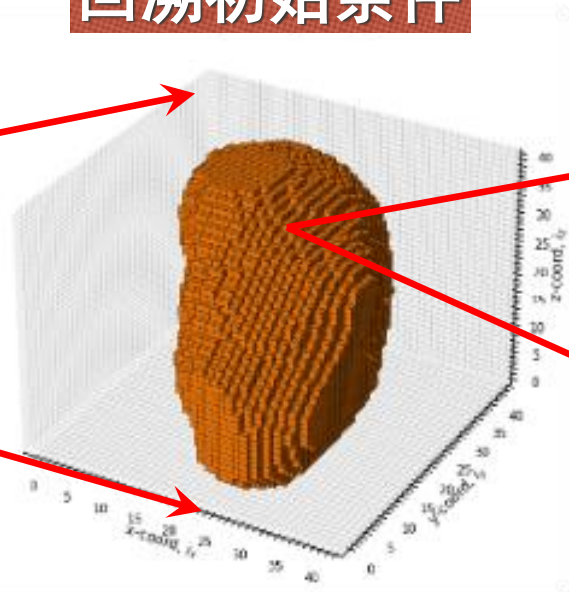
**二、研究方案**

**三、初步结果**

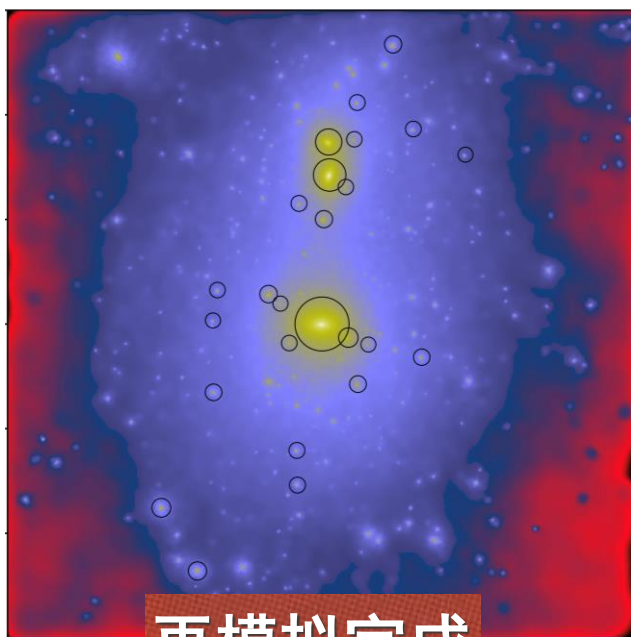
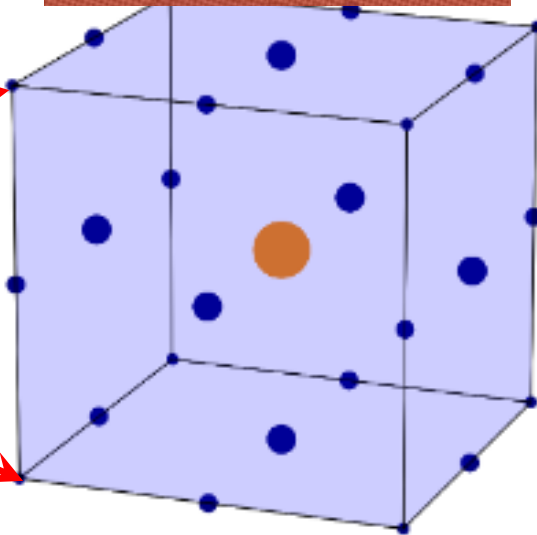
宇宙学模拟中挑选样本



回溯初始条件



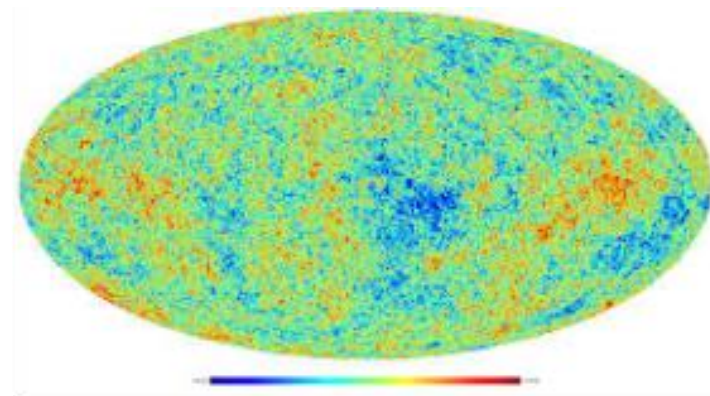
填充高精度粒子



再模拟完成

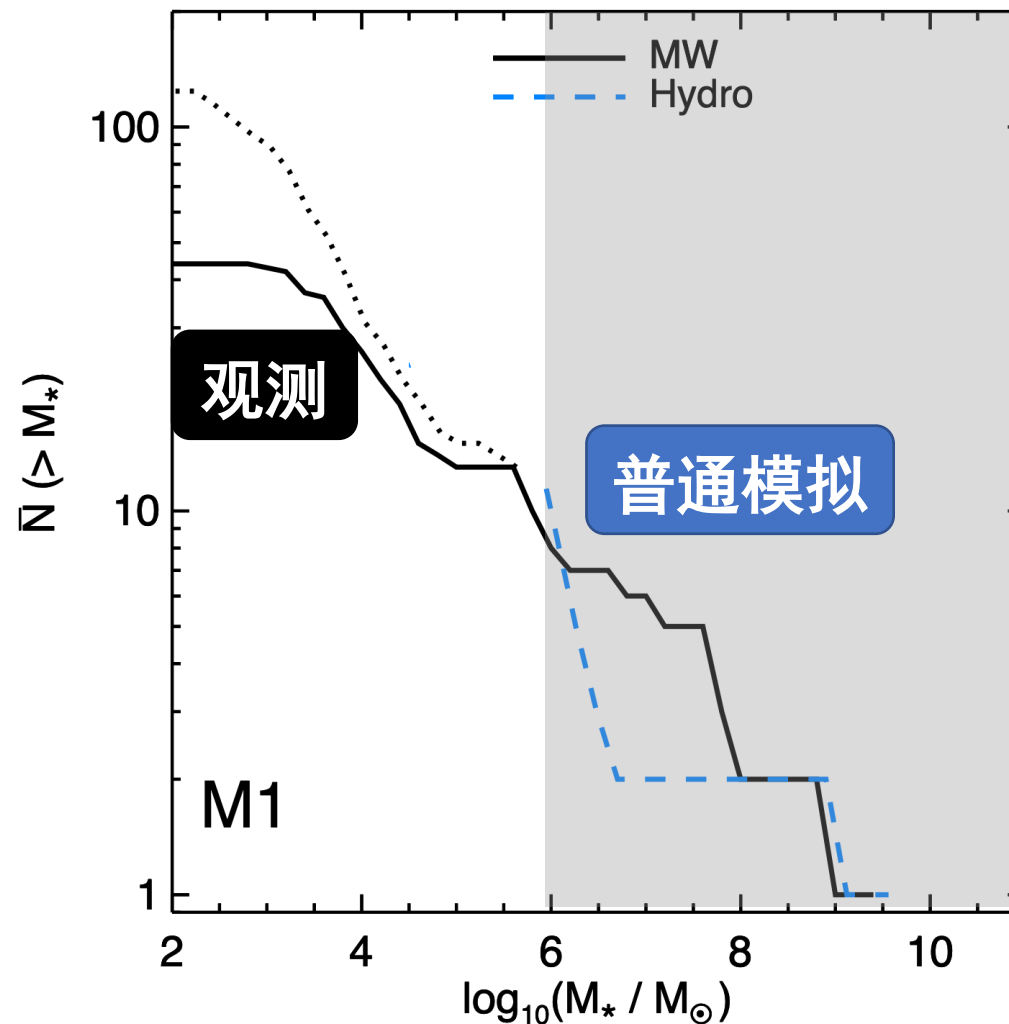
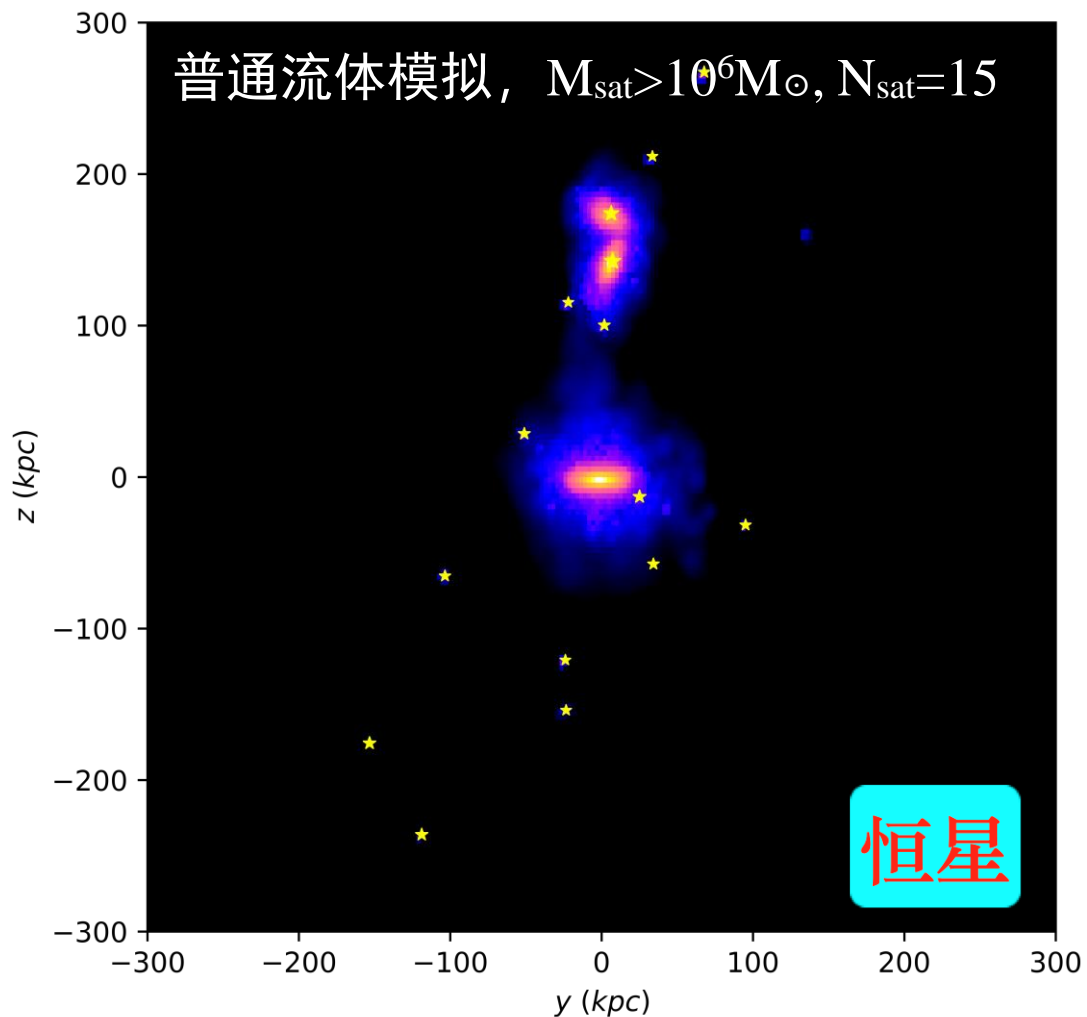


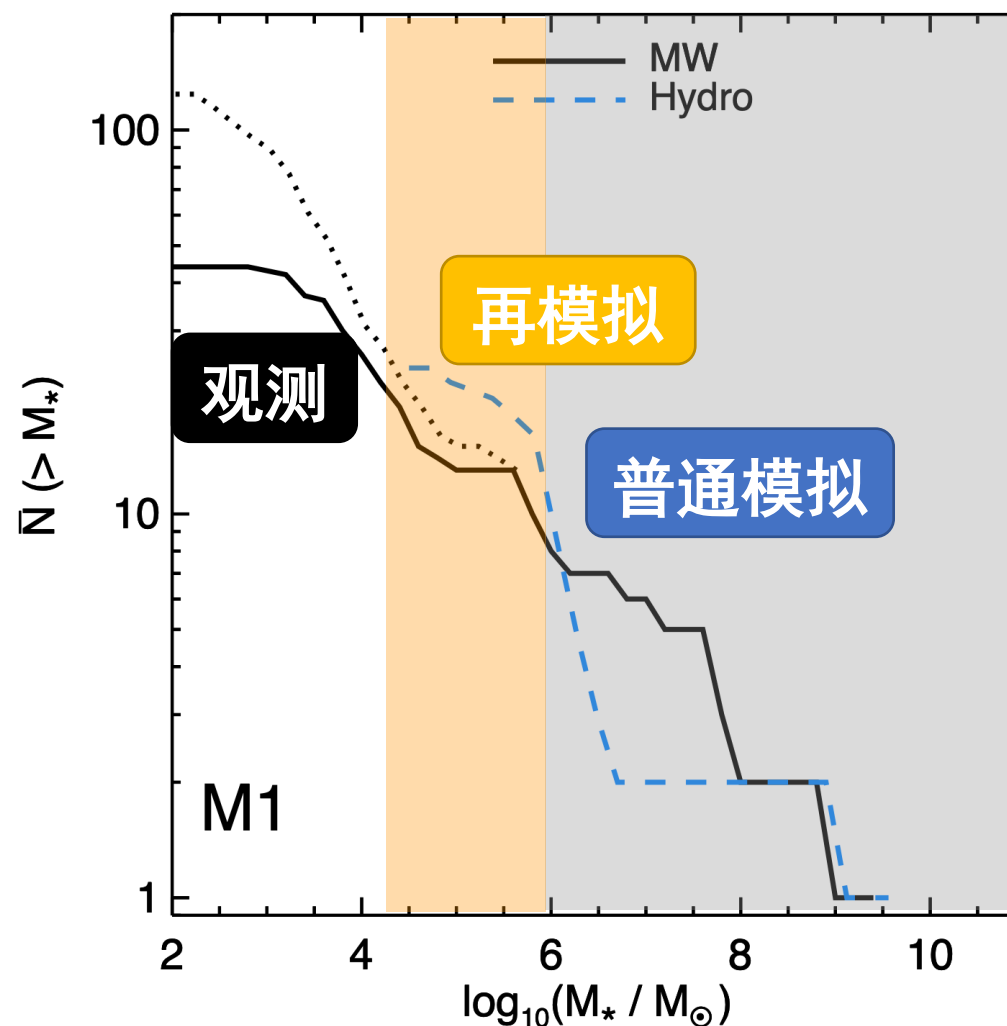
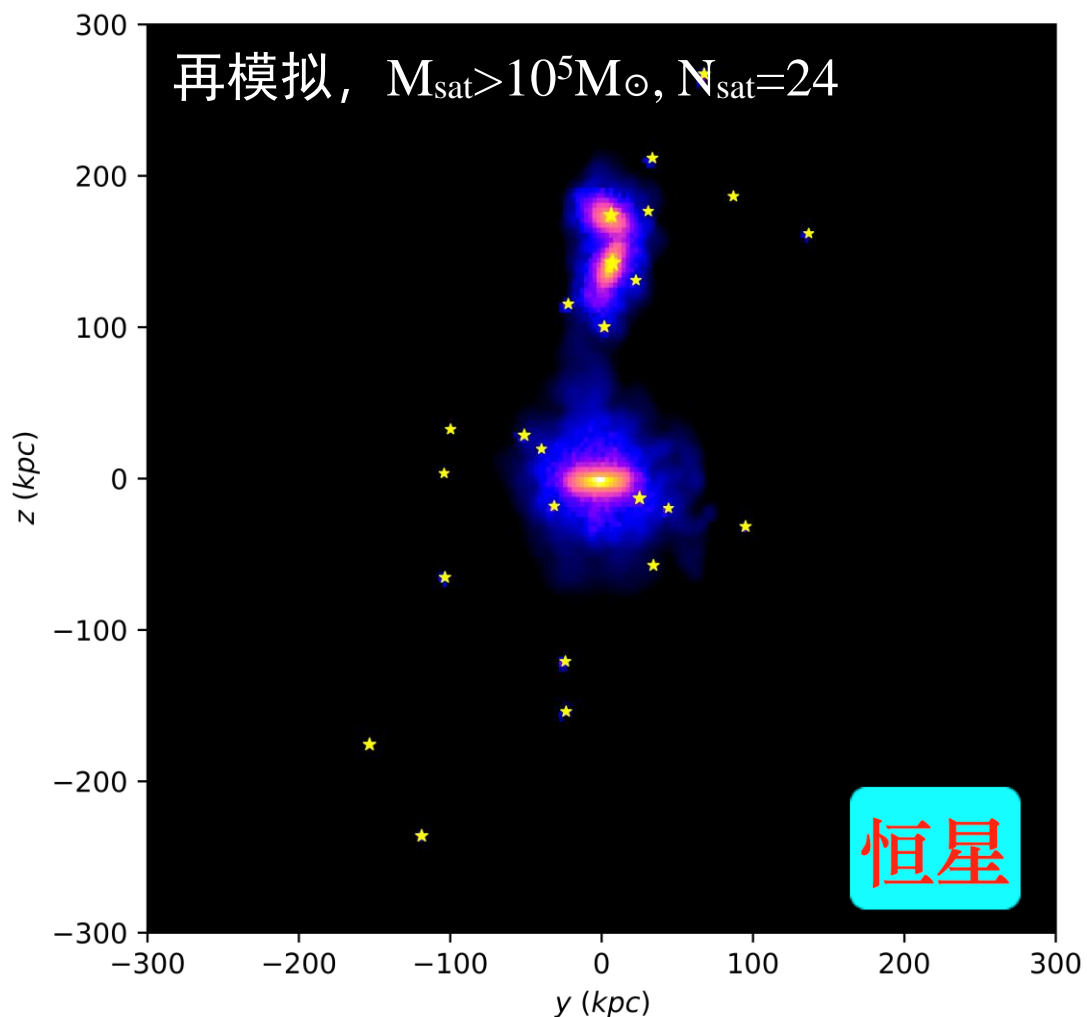
流体模拟运行



对粒子进行扰动

# 研究方案

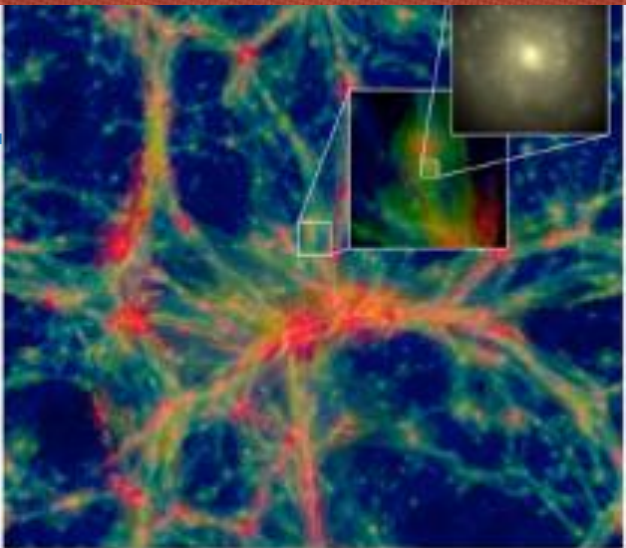




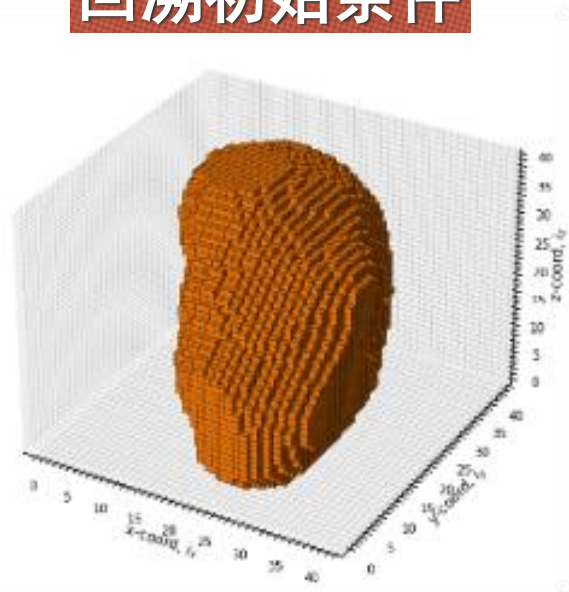
利用再模拟技术将分辨率提高一到两个量级



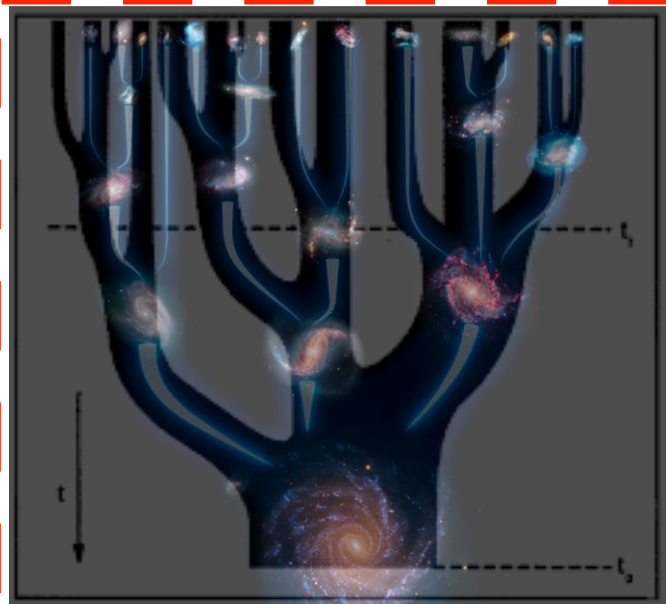
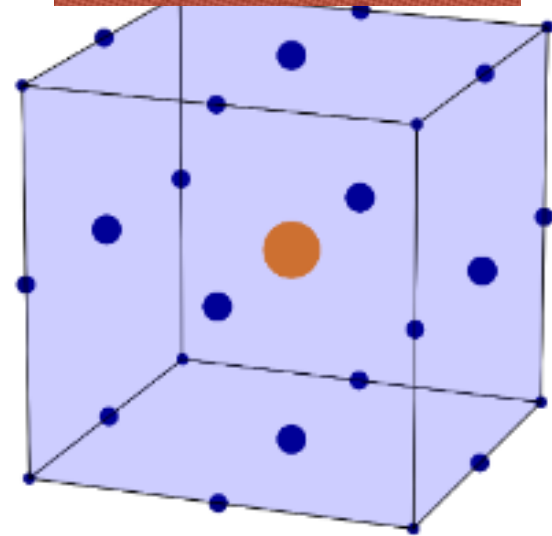
宇宙学模拟中挑选样本



回溯初始条件



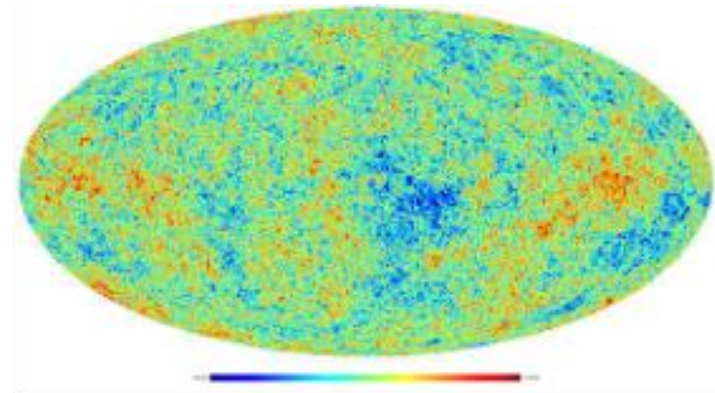
填充高精度粒子



半解析模型植入星系



流体模拟运行

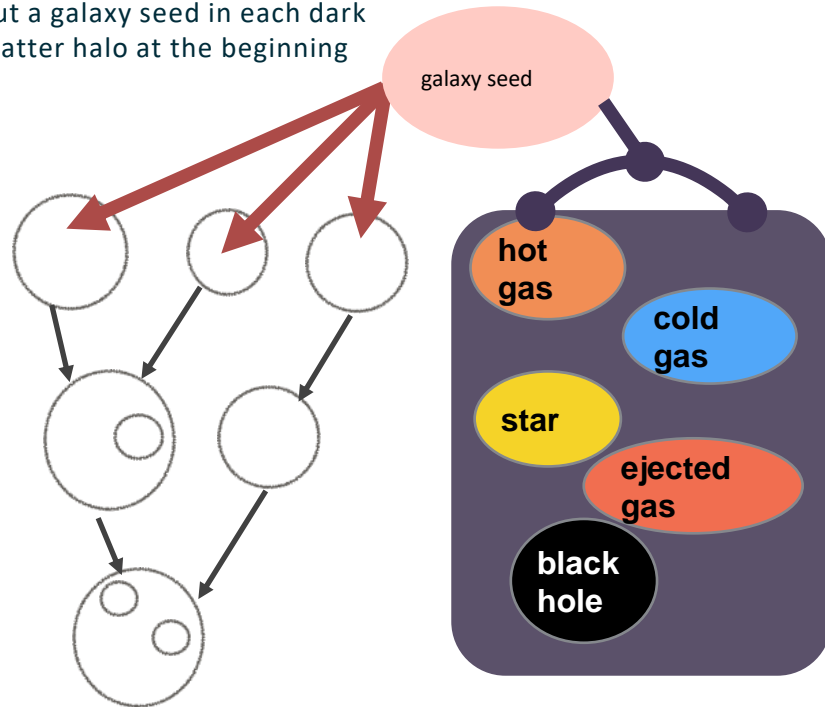


对粒子进行扰动

# 研究方案

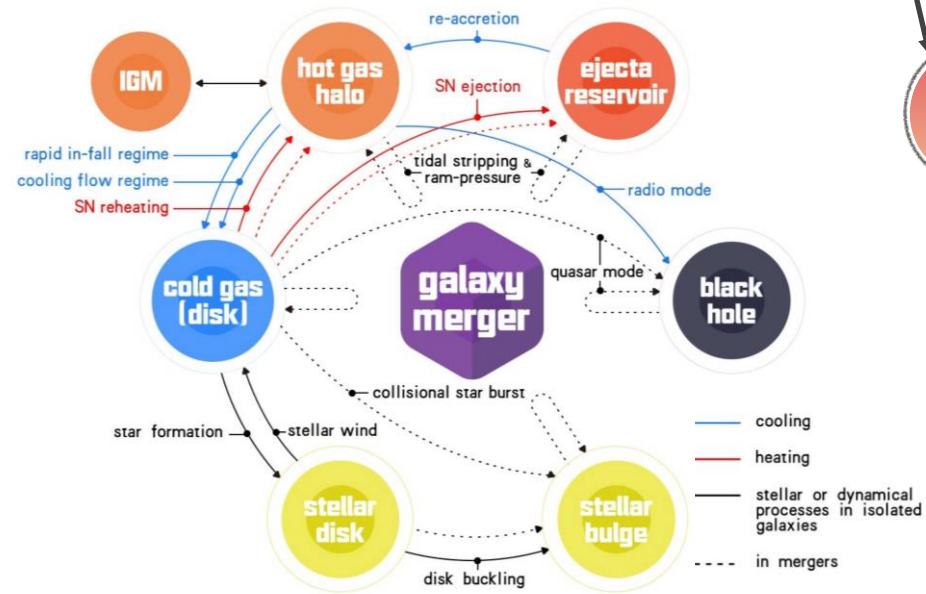
## SEMI-ANALYTIC GALAXY FORMATION MODEL

put a galaxy seed in each dark matter halo at the beginning

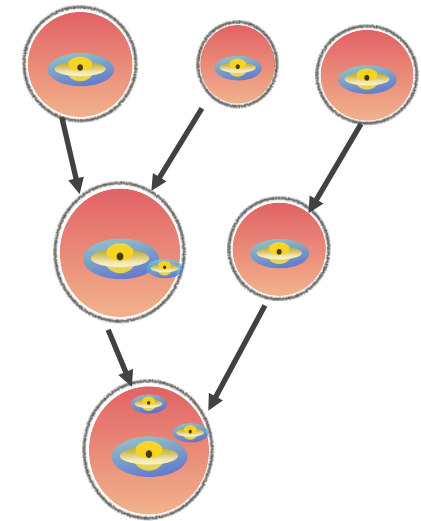


Each galaxy is divided into several discrete components

Evolve a galaxy by counting the mass increase/decrease of each component while calculating physically/empirically motivated equations in each time step.

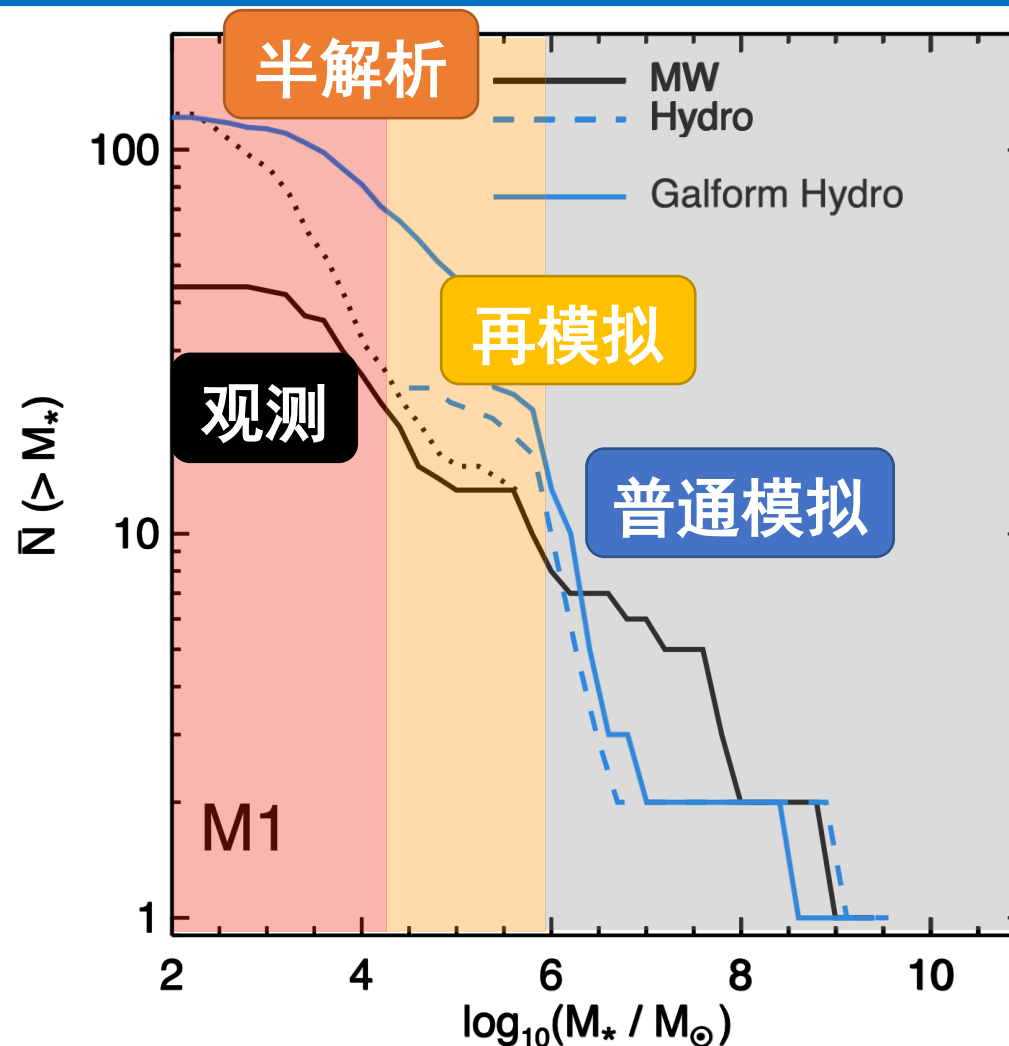
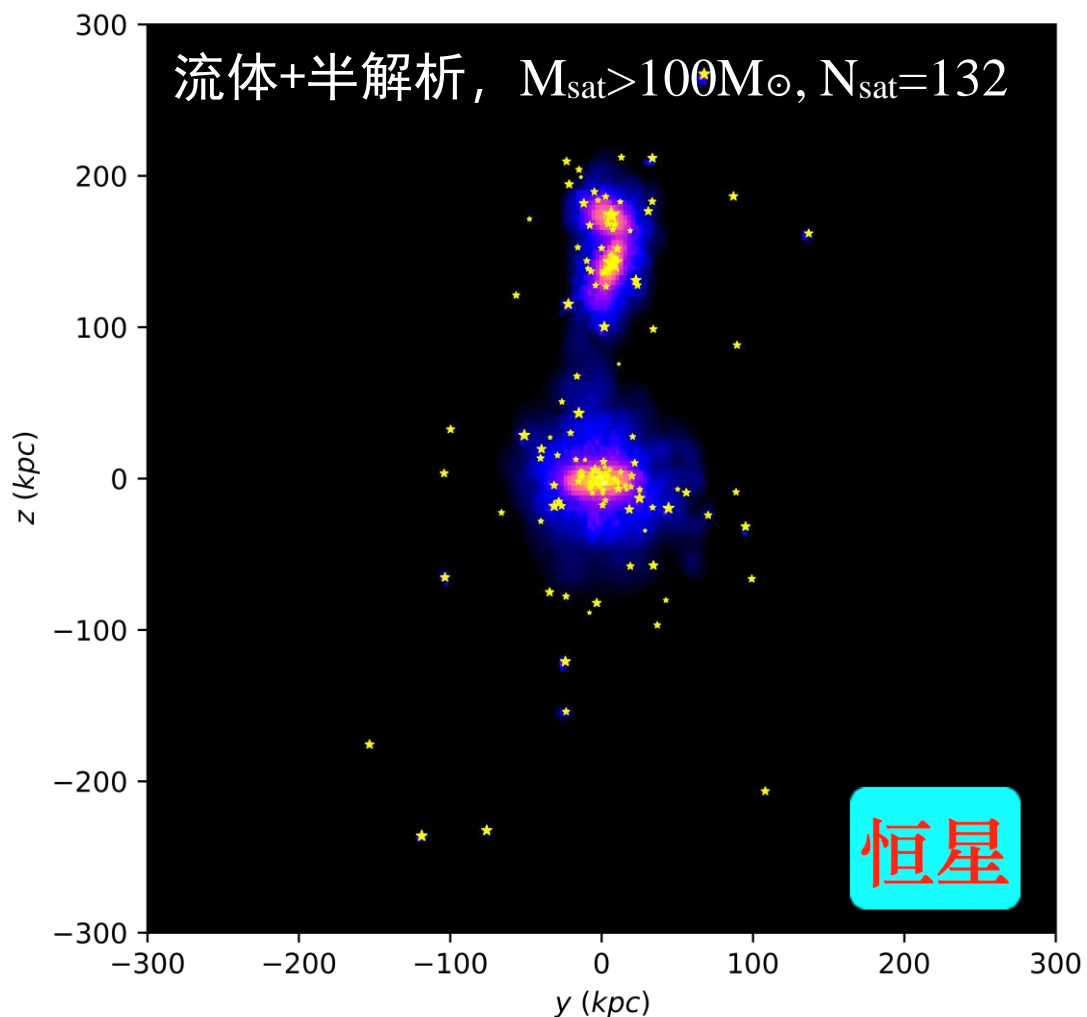


Jiang et al. 2019



knowing the properties of each galaxy at different times, merge galaxies when time is up, now you get the galaxy merger tree

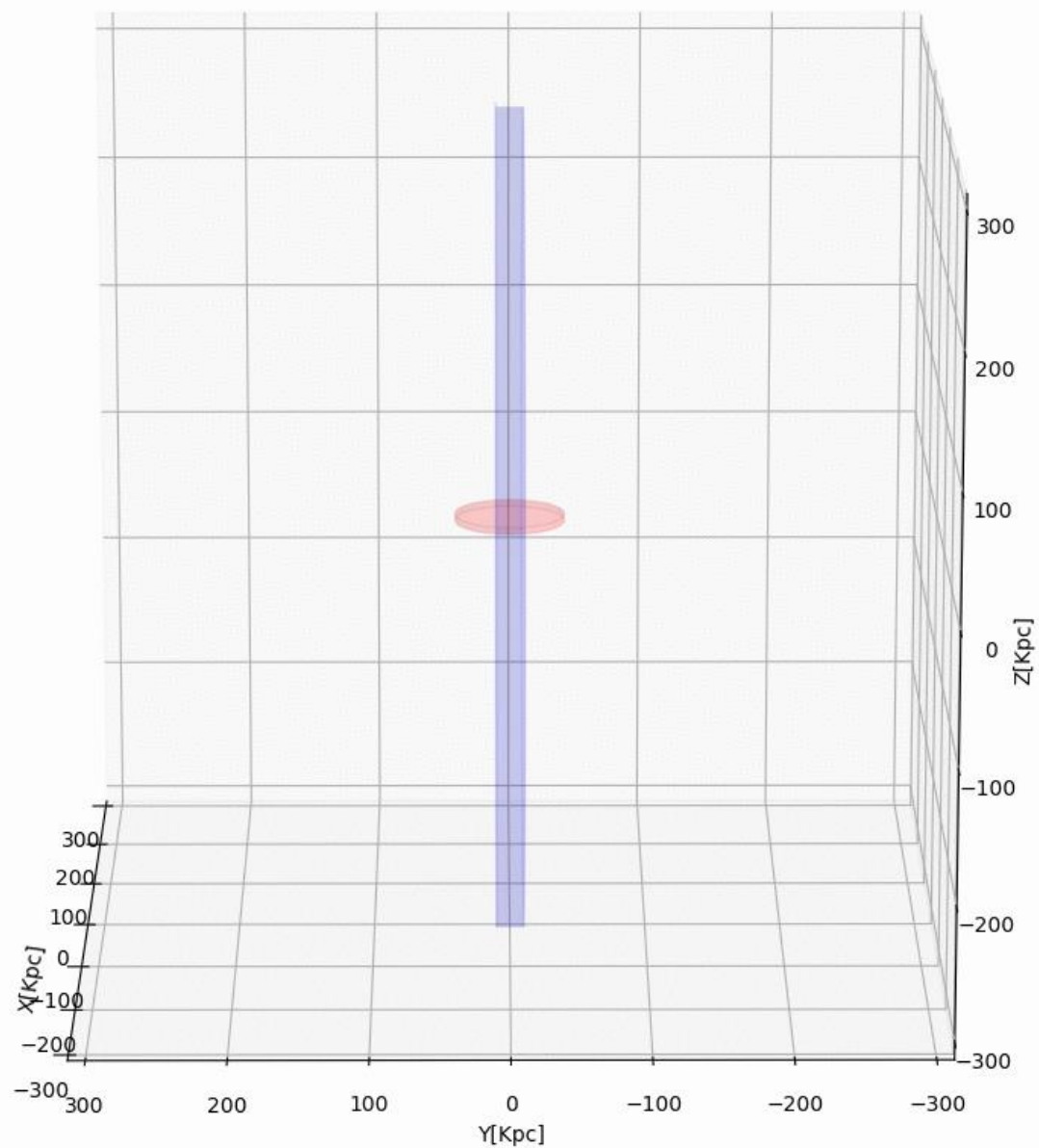
半解析模型可以弥补流体模拟分辨率不足的问题



利用星系半解析模型将分辨率提高三个量级

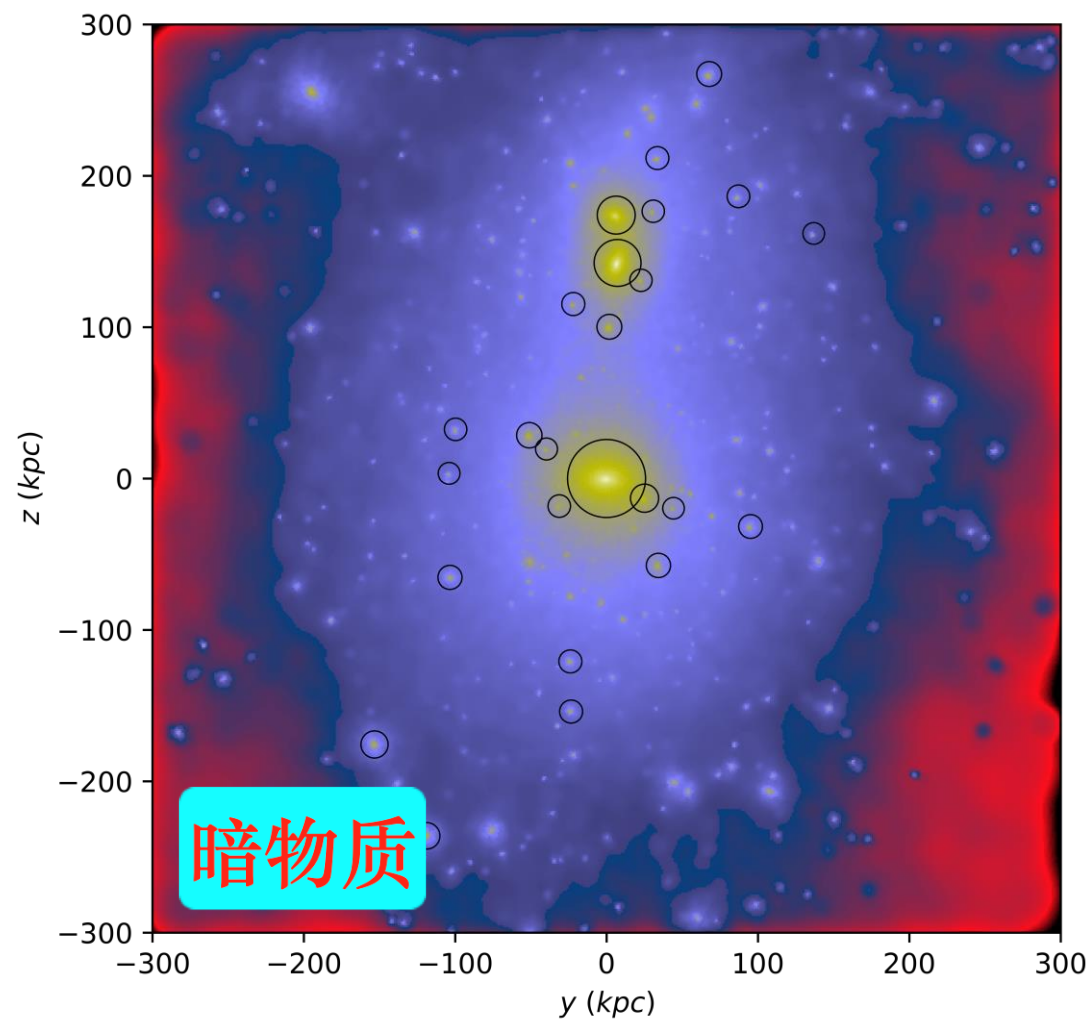
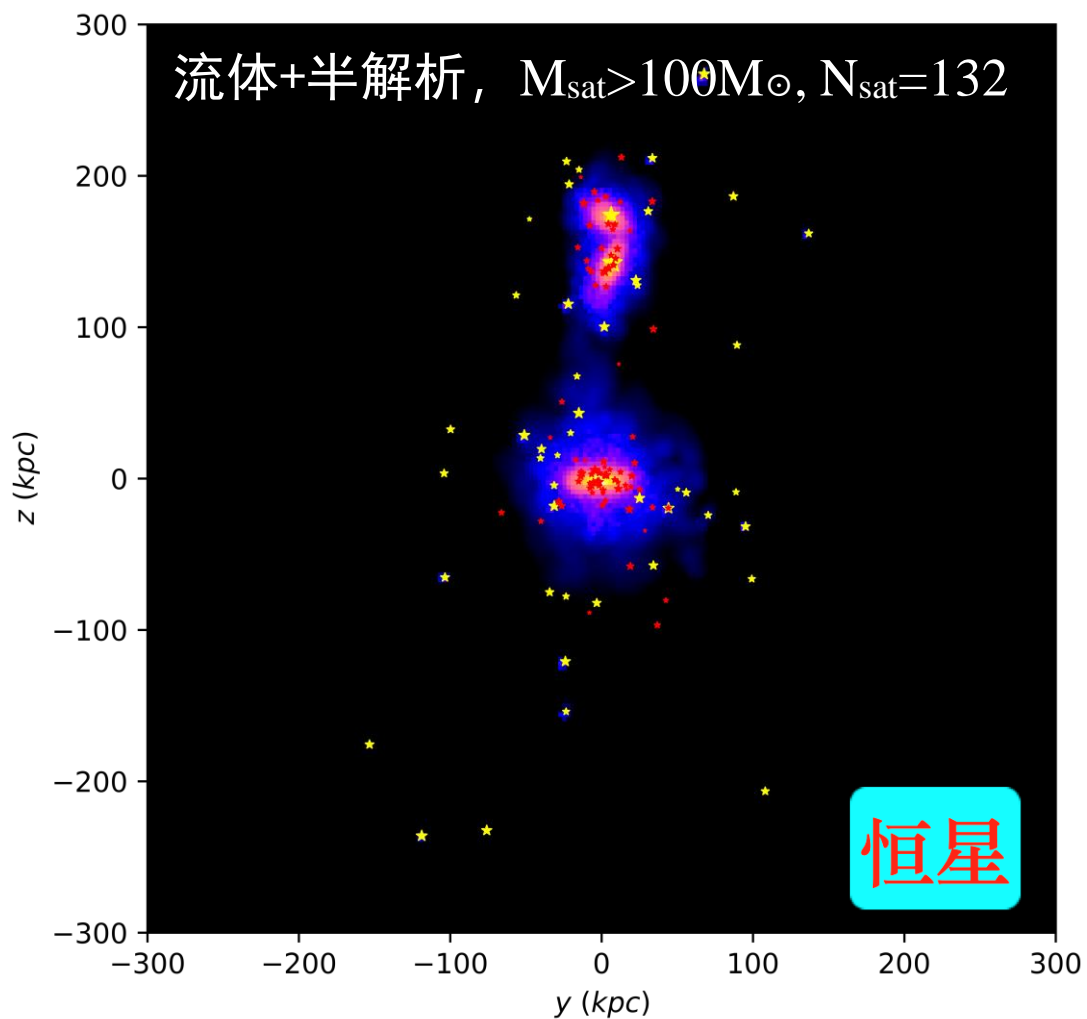
## Satellite Trajectory

t = 0.20 Gyr  
z = 18.82

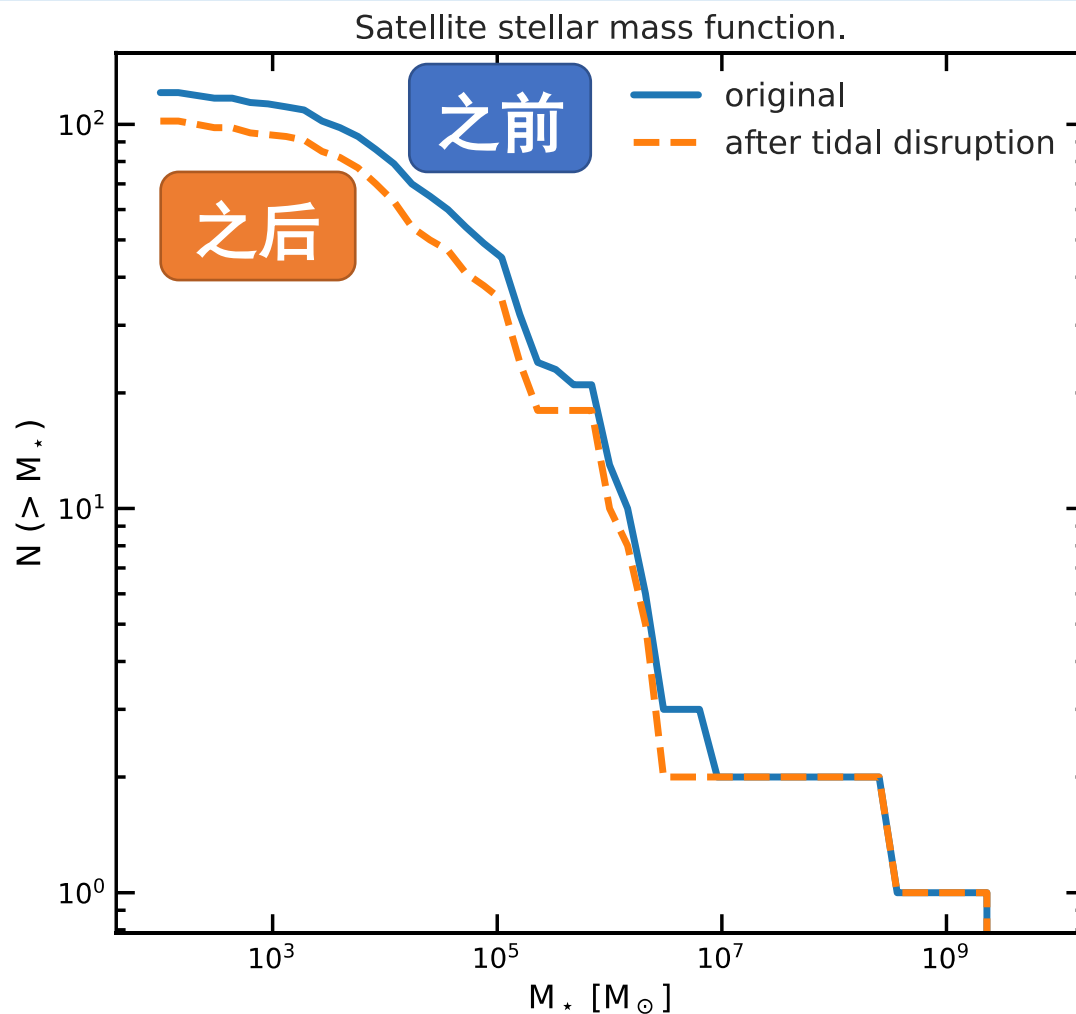
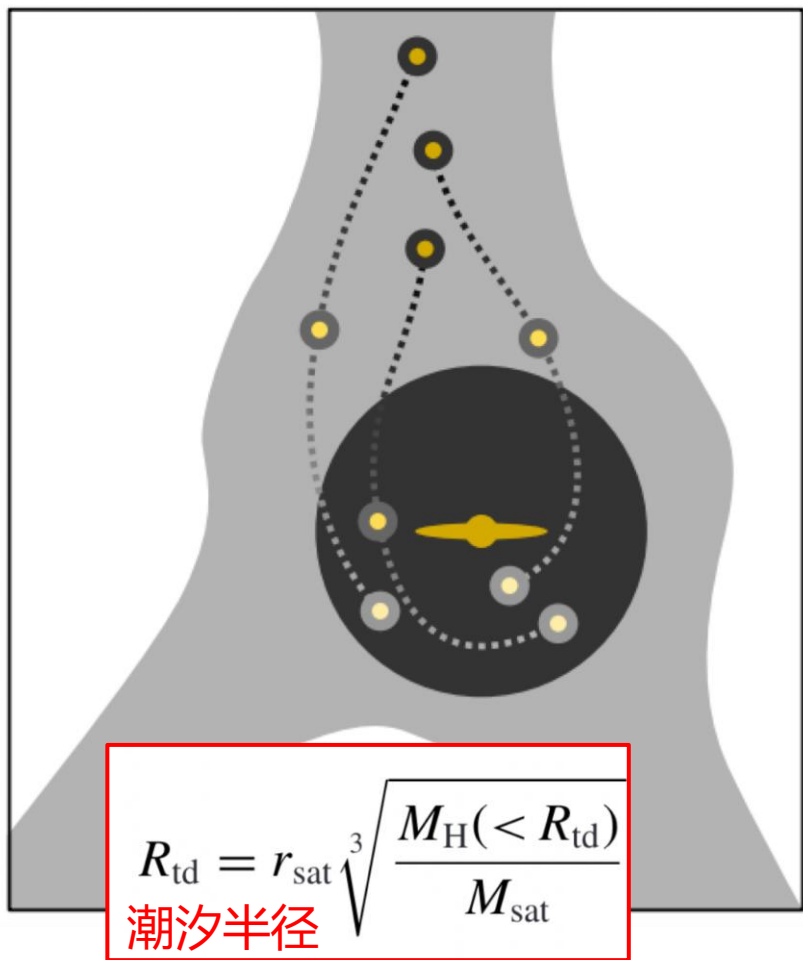


卫星星系主要分布于中央星系以及大质量卫星星系周围





孤立星系占全部卫星星系的60%



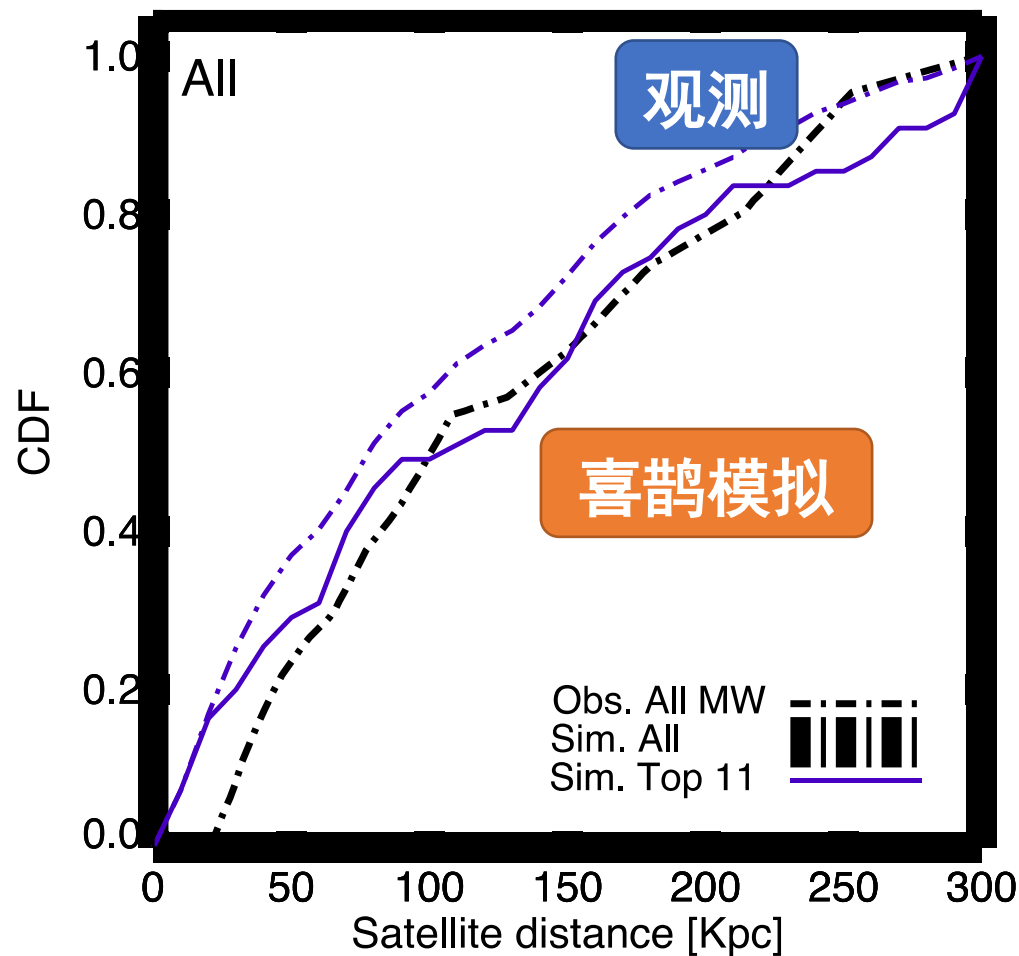
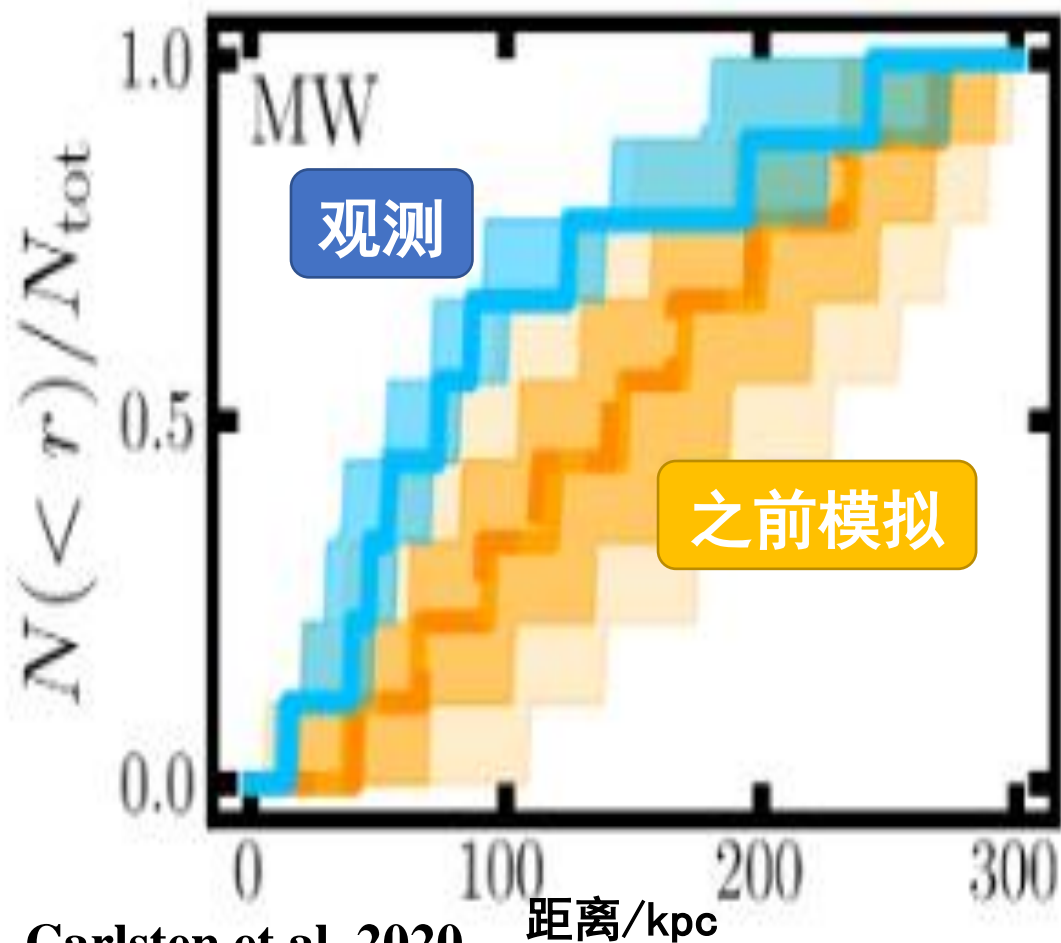
约25%的孤立星系最终会被潮汐瓦解



# 报告内容



- 一、研究背景
- 二、研究方案
- 三、初步结果



我们的结果与观测最为接近





# 初步结果



## □ 拟解决的关键科学问题

- 极暗卫星星系分布
- 银河系暗晕精细结构
- 卫星星系和银河系吸积历史的关系
- 数值模拟中的孤立星系现实中是否存在?
- 大麦云星系对银河系的重要作用



# 总结



- 喜鹊模拟样本符合**多种银河系观测特征**
- 结合使用**半解析+流体**方法，弥补了流体分辨率的不足
- 将分辨率提高**三个量级**，解析最小至**100M<sub>⊙</sub>**的完备卫星星系样本



# 报告结束

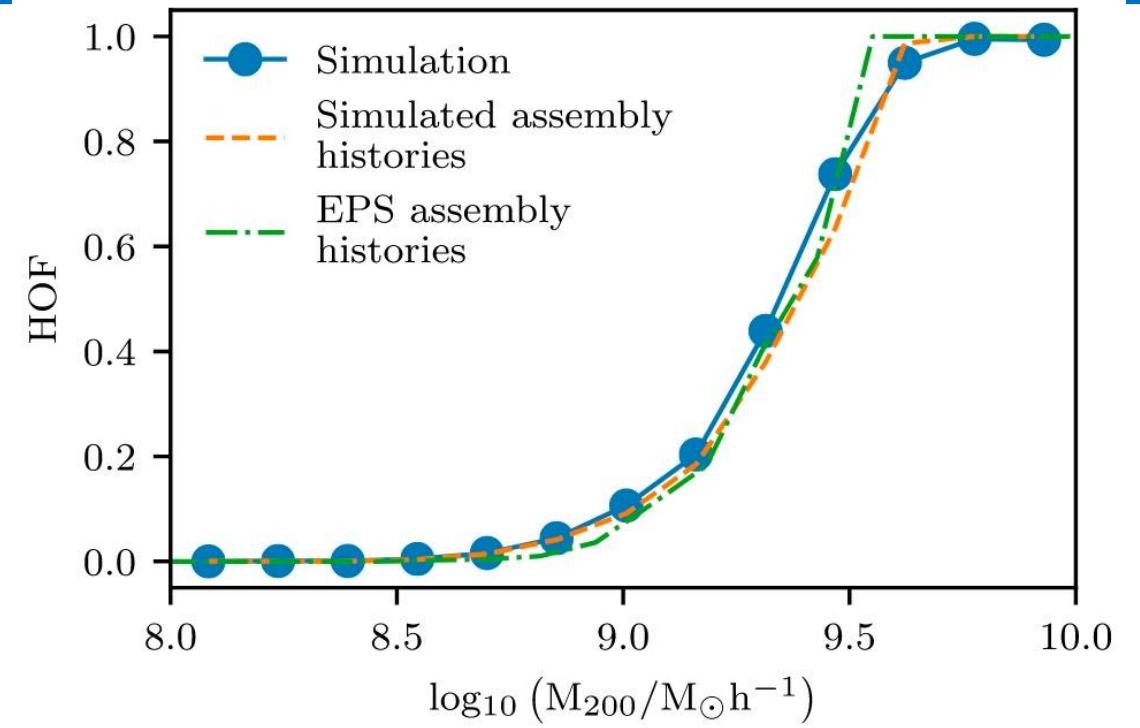
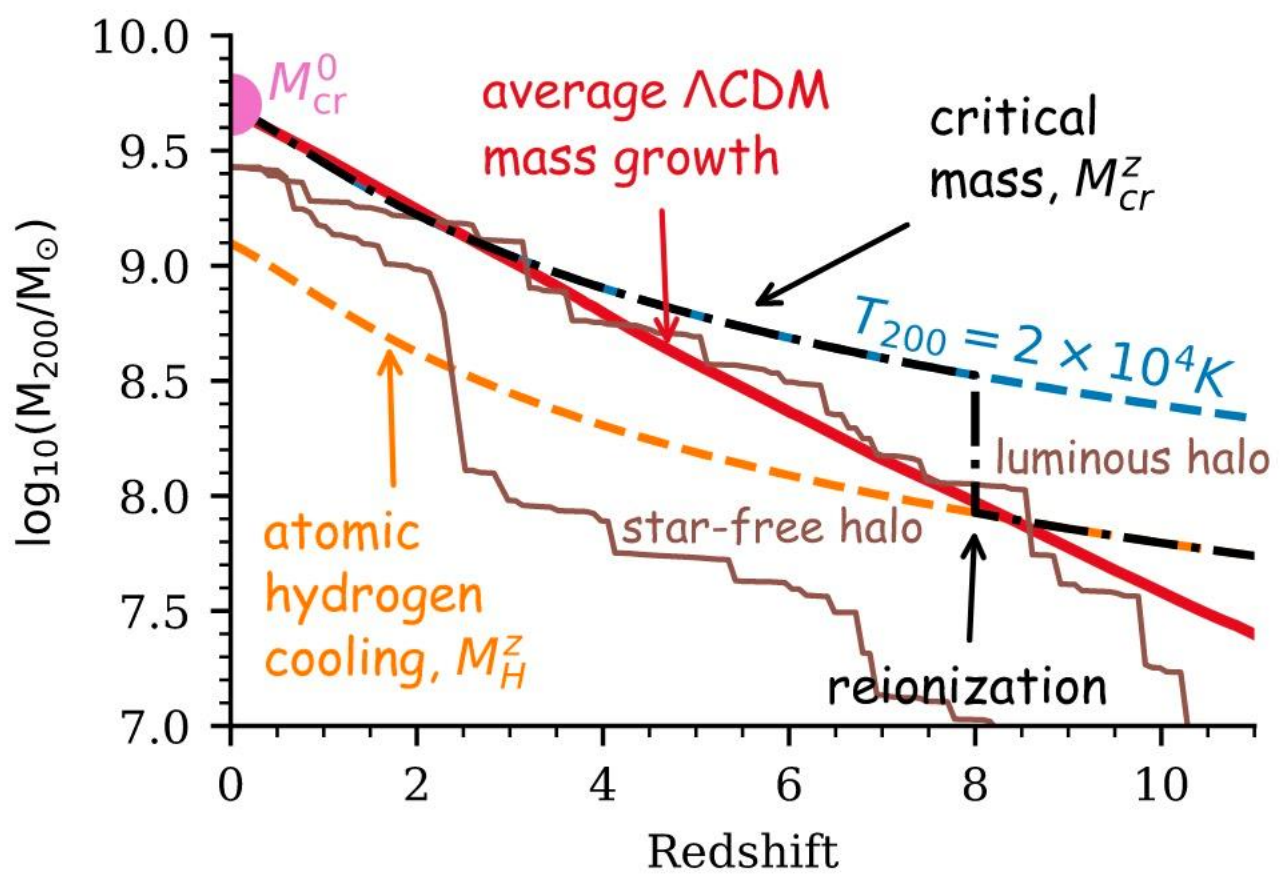


感谢各位评委老师

敬请批评指正

# 补充

Schematic picture of the impact of cosmic reionization on galaxy formation

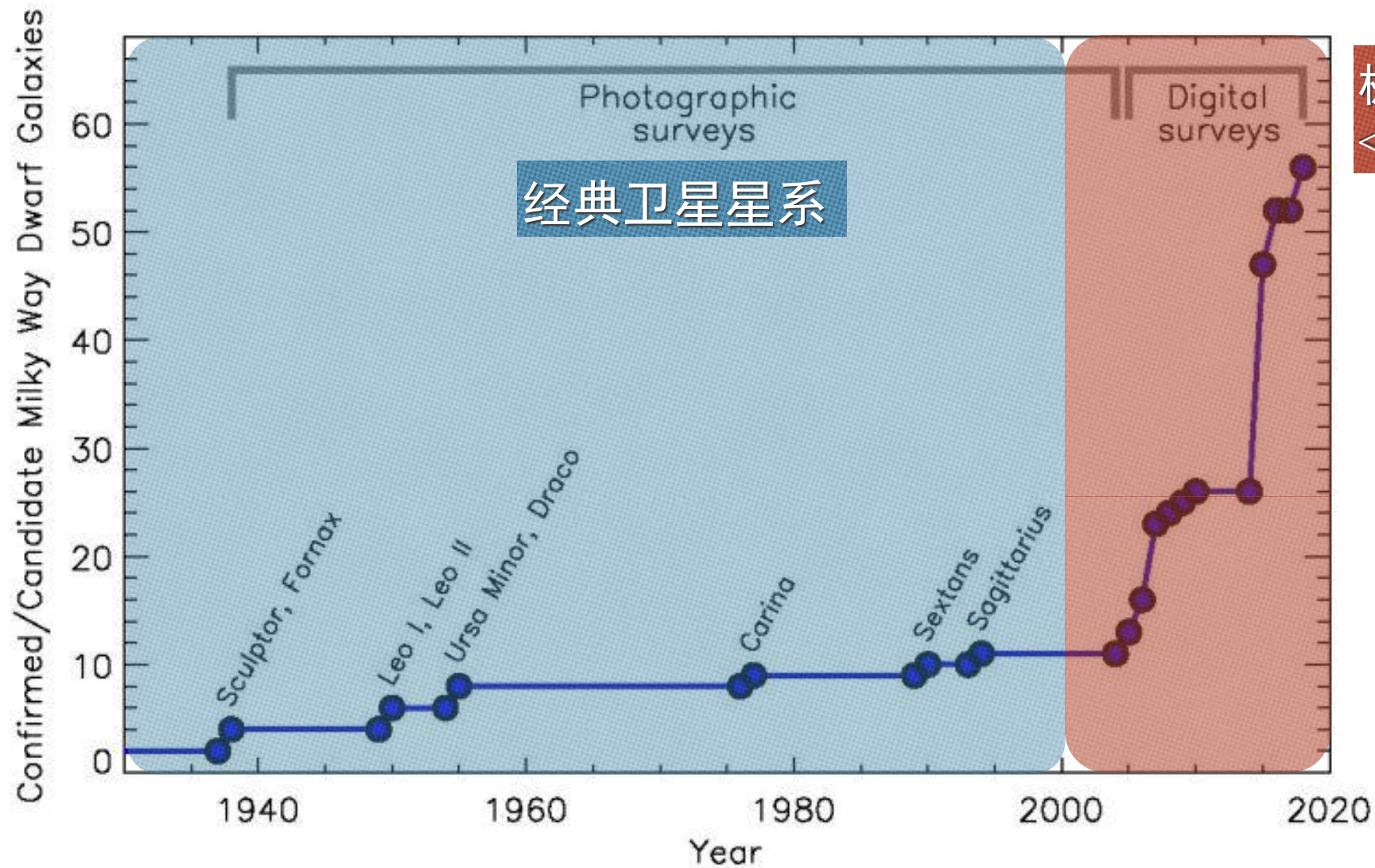


$$M_H^z \sim (4 \times 10^7 M_{\odot}) \left( \frac{1+z}{11} \right)^{-3/2}$$

Benitez-Llambay ++ 2020

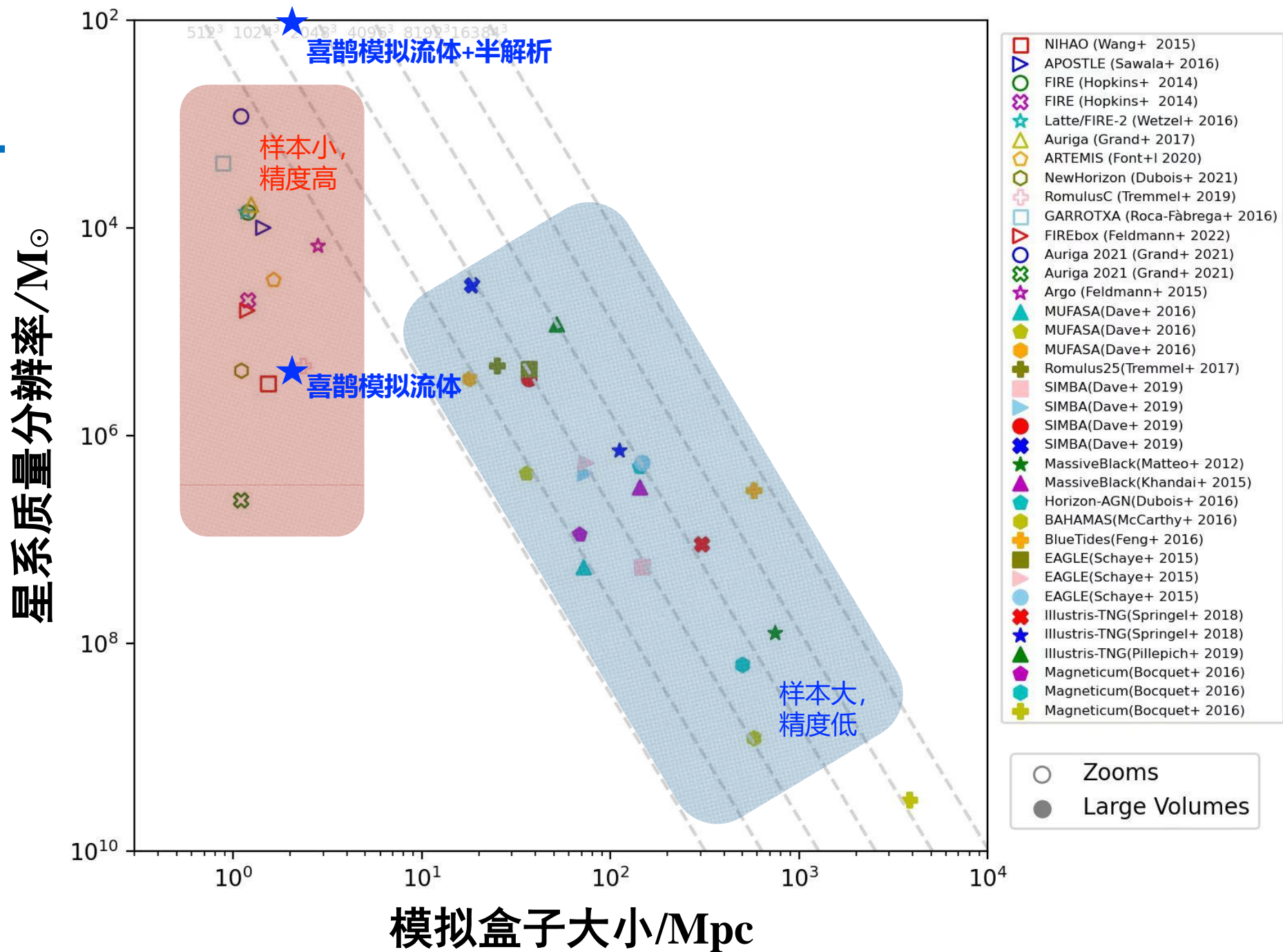


# 研究背景

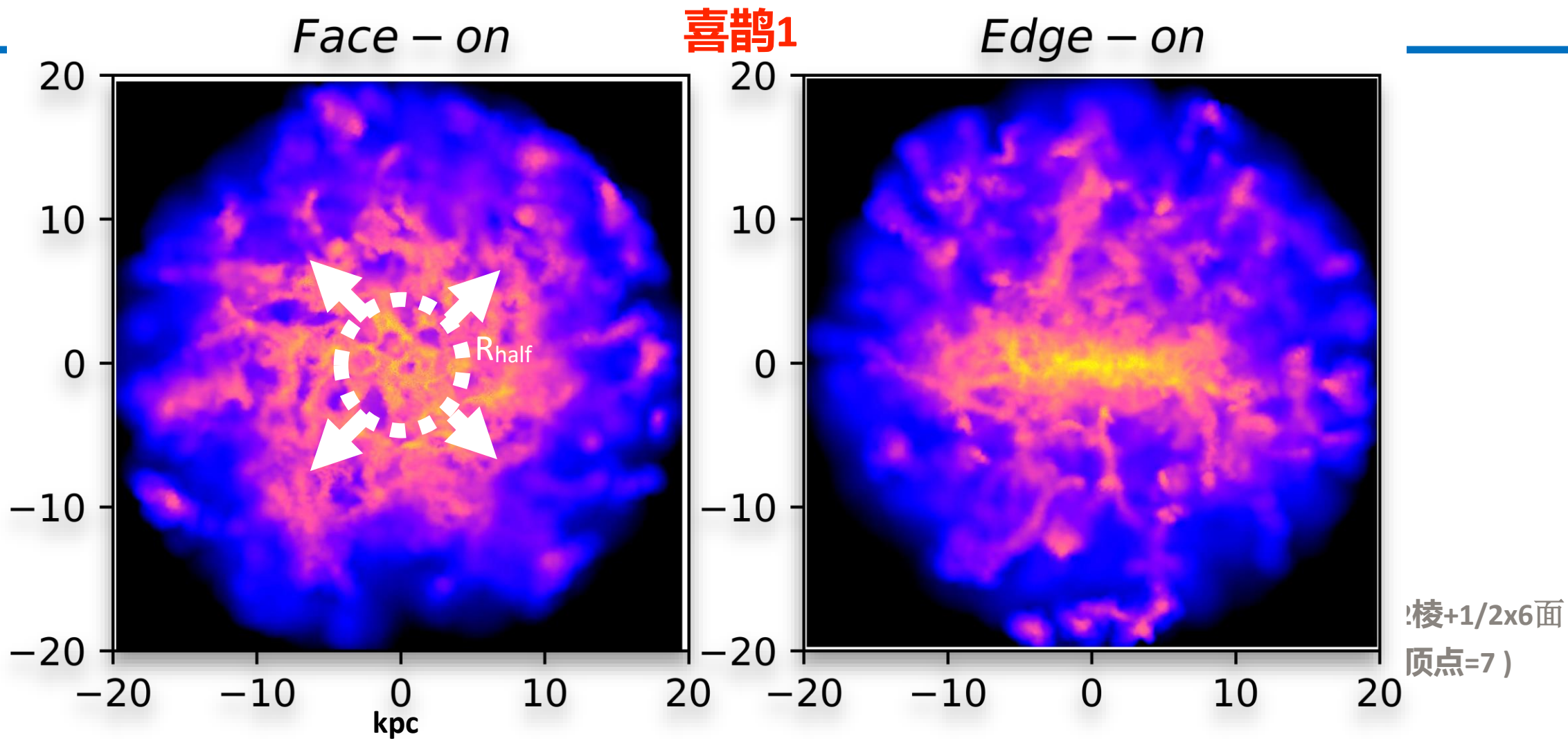


经典卫星星系

极暗卫星星系,  
 $<10^5 M_{\text{sun}}, M_V > -8$



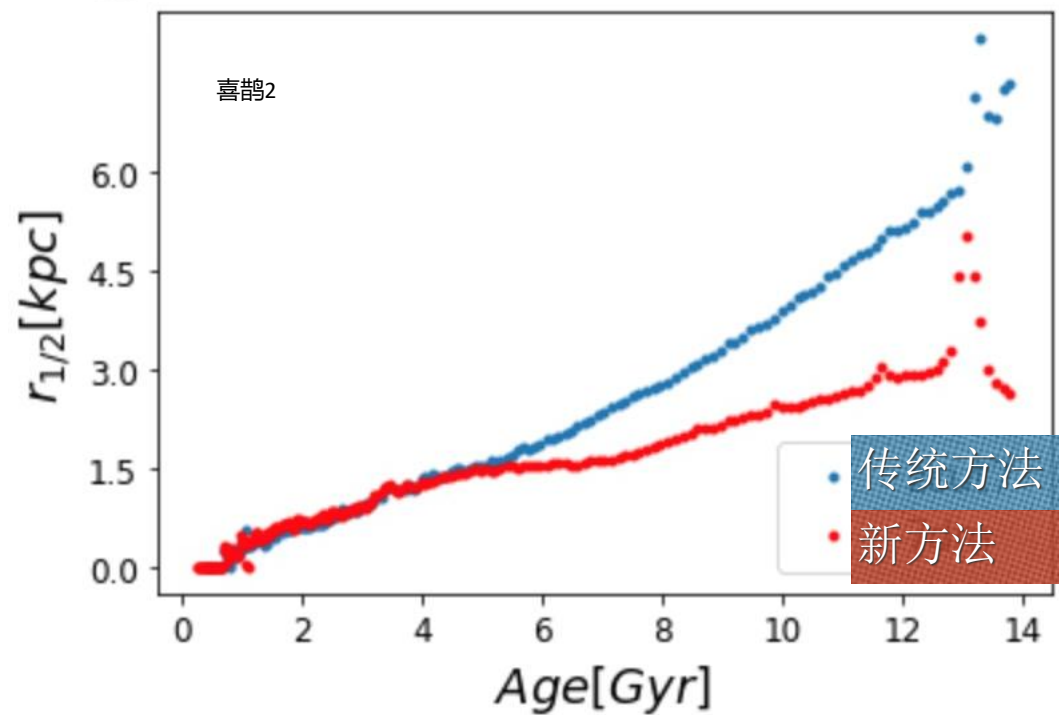




减弱暗物质粒子质量过大对星系中心的散射效应

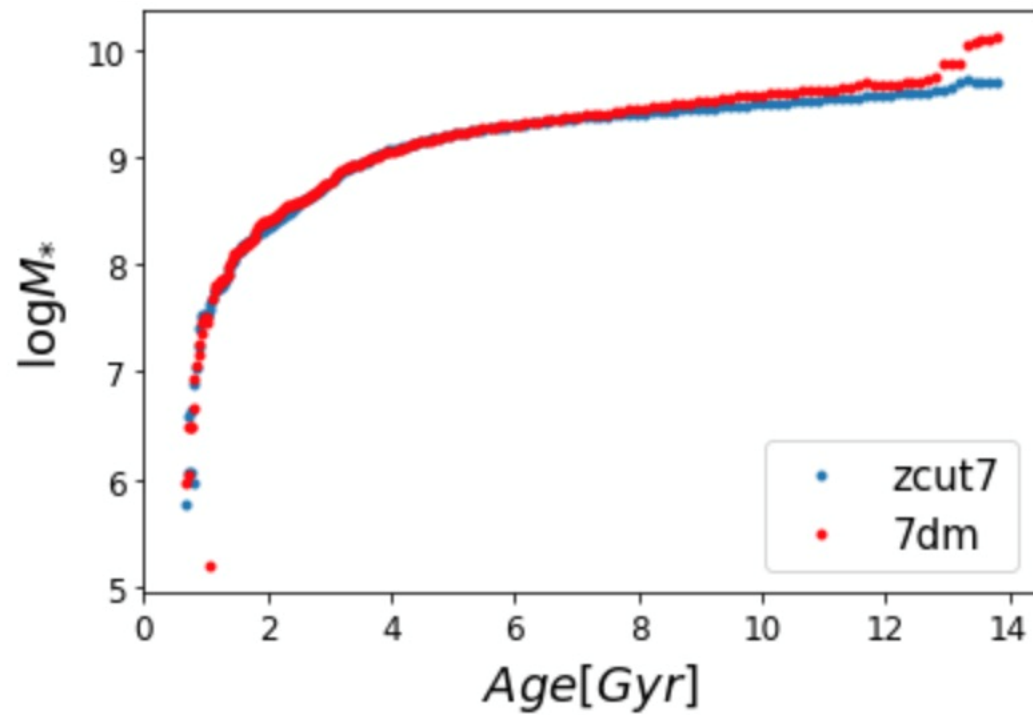
# 初步结果

星系的半质量半径



时间

星系质量



时间

Yang, Shao, Gao in preparation