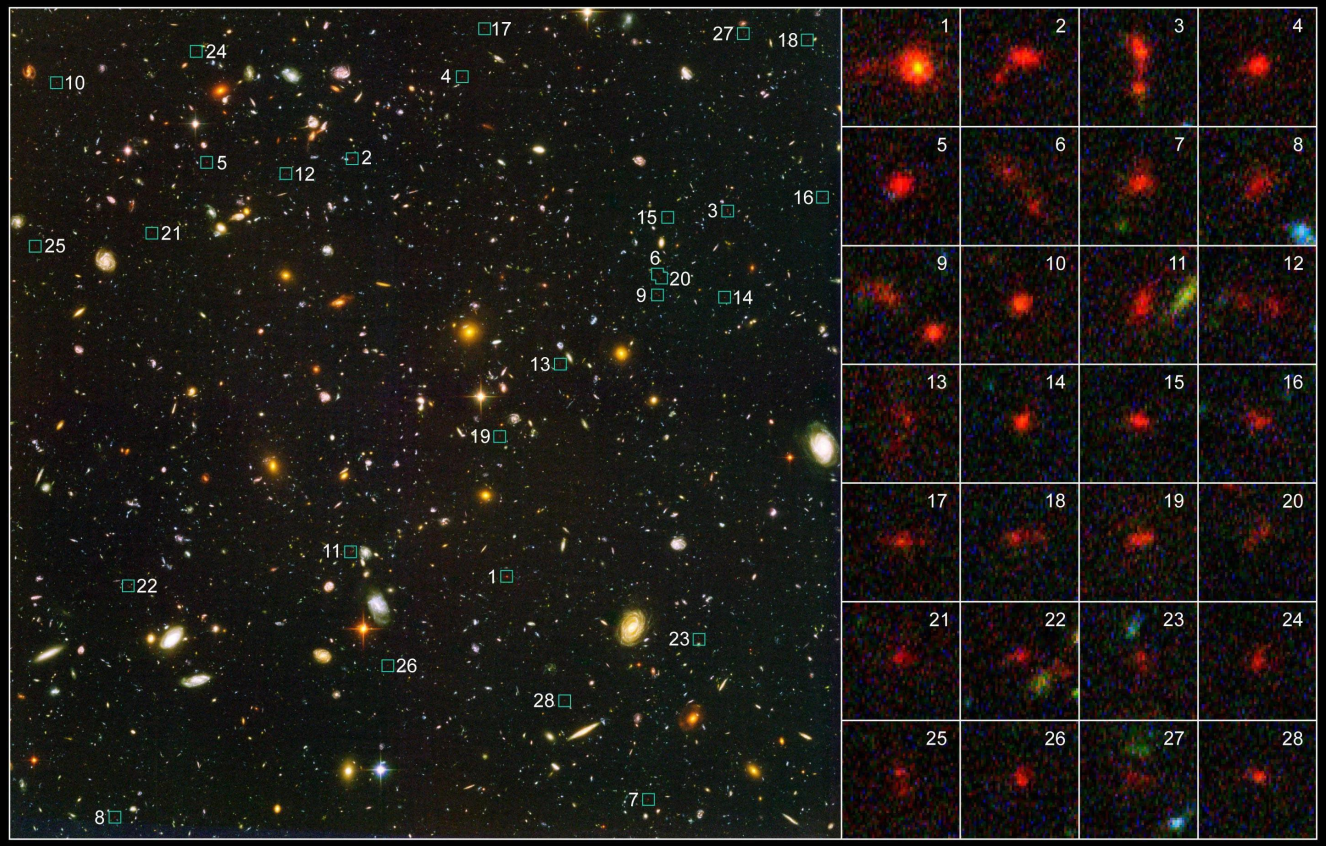
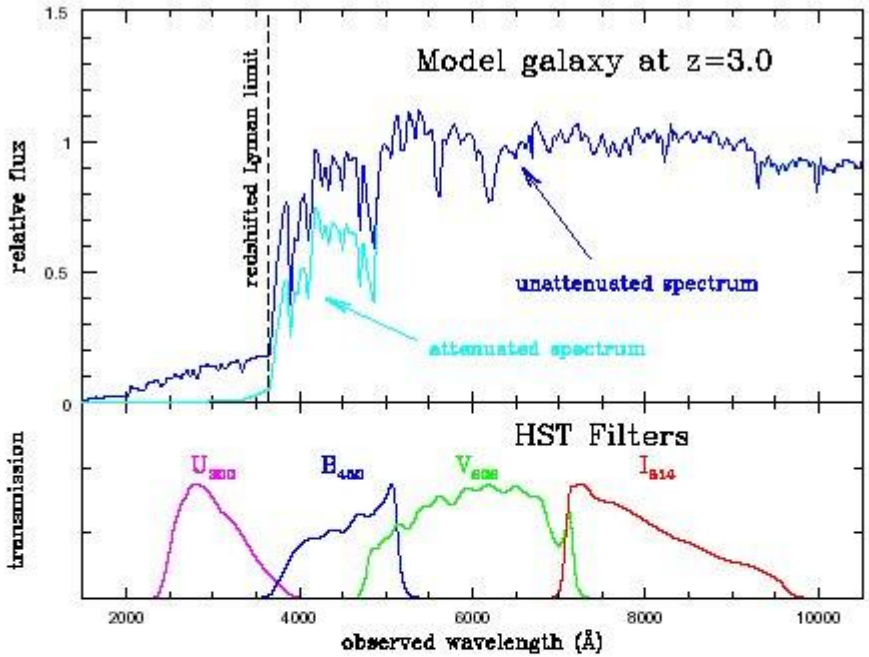
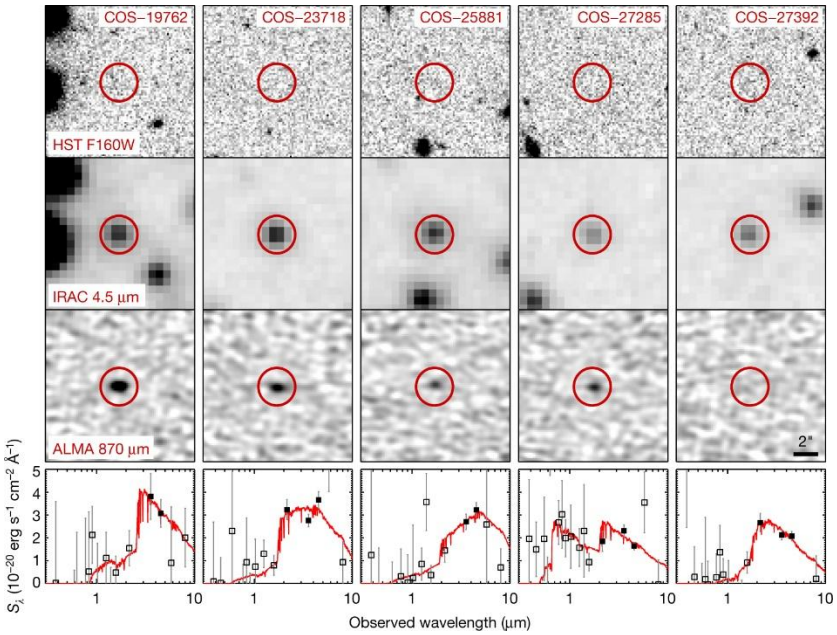
9.4 高红移星系

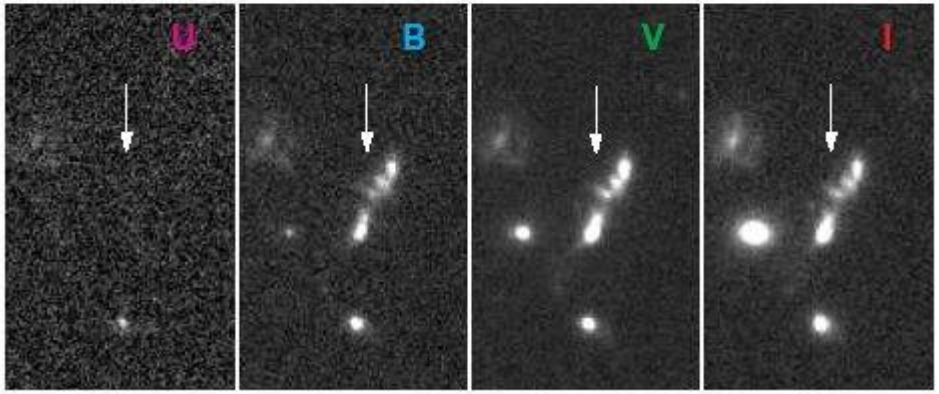

Distant Galaxies in the Hubble Ultra Deep Field
Hubble Space Telescope • Advanced Camera for Surveys
NASA, ESA, R. Bouwens and G. Illingworth (University of California, Santa Cruz)

高红移星系

- Lyman-break galaxies (LBGs)
  - 高红移的星暴星系
  - 可以通过紫外波段（静止波长）912Å的Lyman连续谱吸收快速证认（dropout）

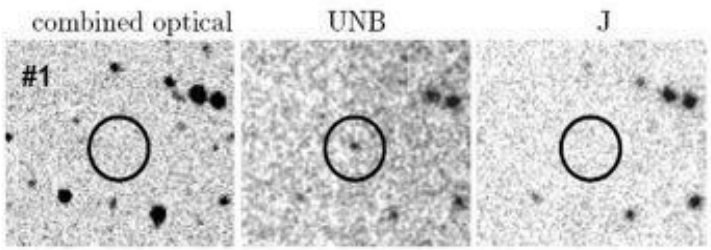


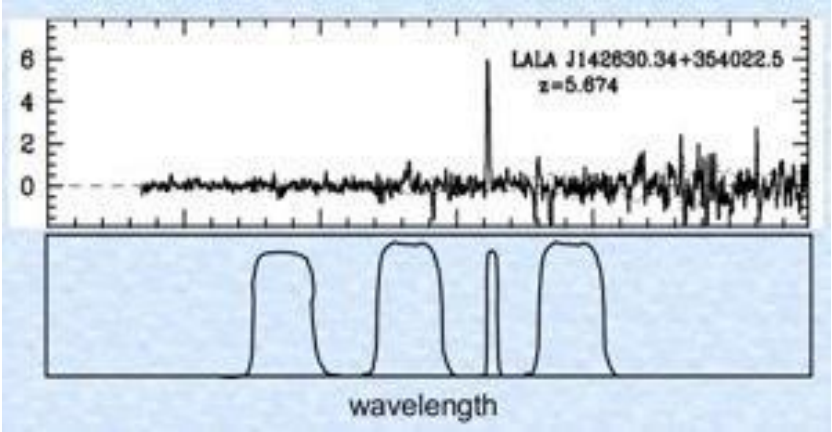


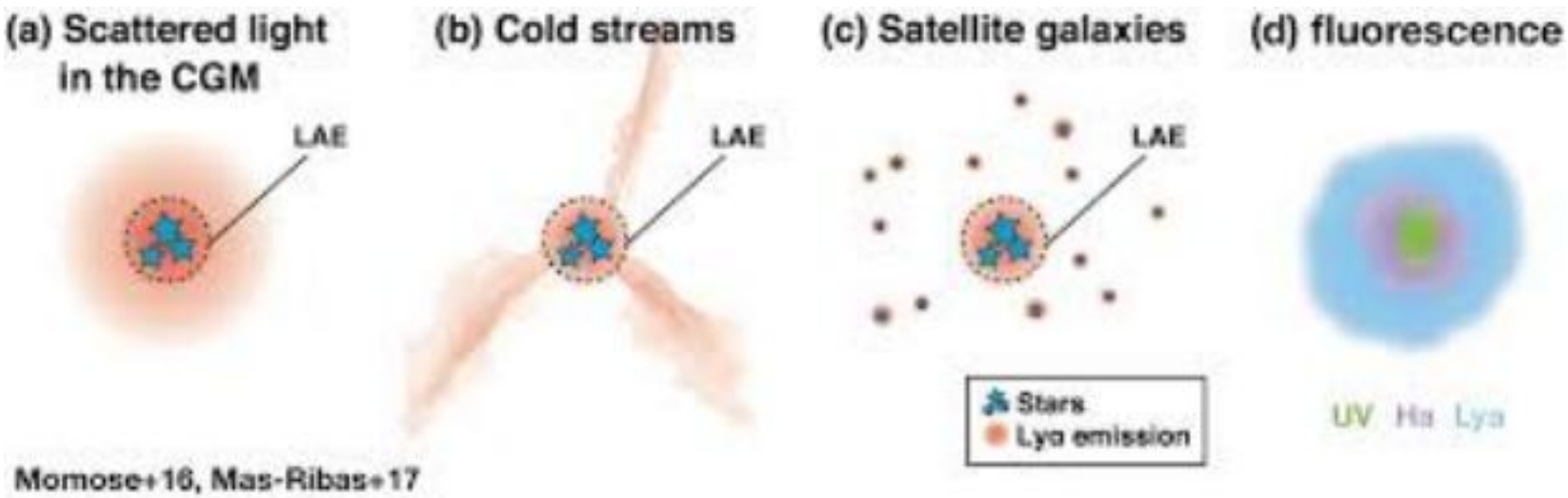


高红移星系

- Lyman alpha emitter (LAE)
  - 小质量高红移星暴星系
  - 可以通过窄带滤光片进行证认

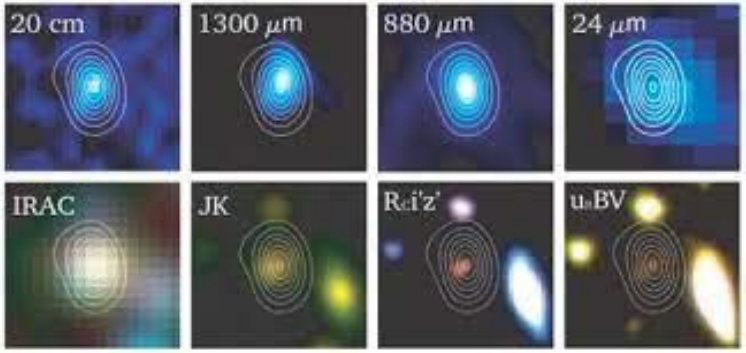


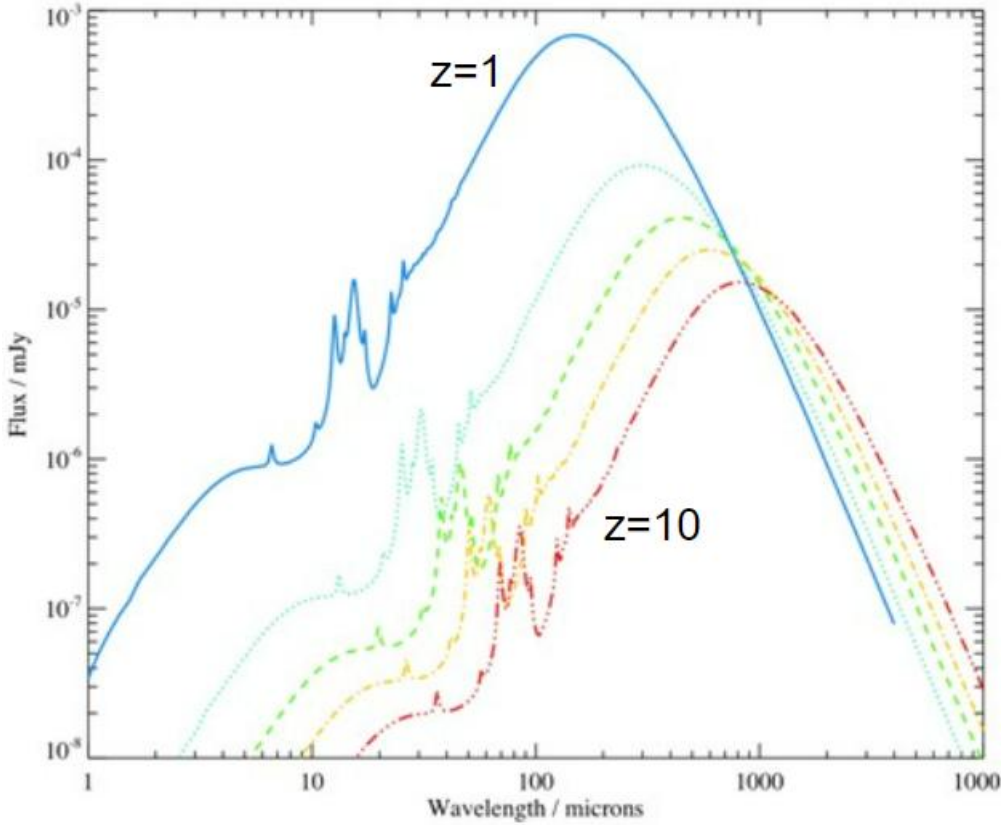




高红移星系

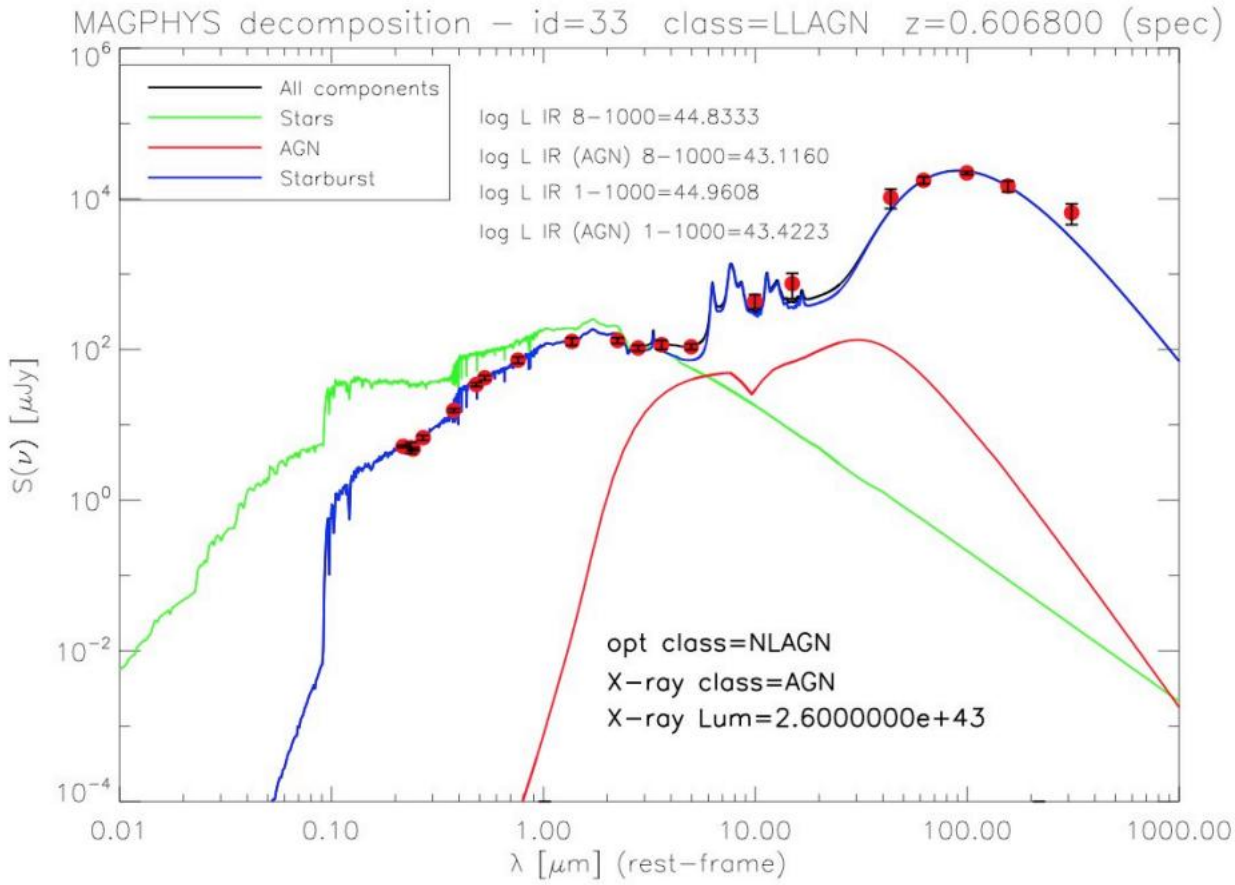
- 亚毫米波星系（sub-millimeter galaxy, SMG）
  - 在1mm处，z=10星系的流量与z=1星系相当
  - 在1mm附近，流量梯度越平红移越高





高红移星系

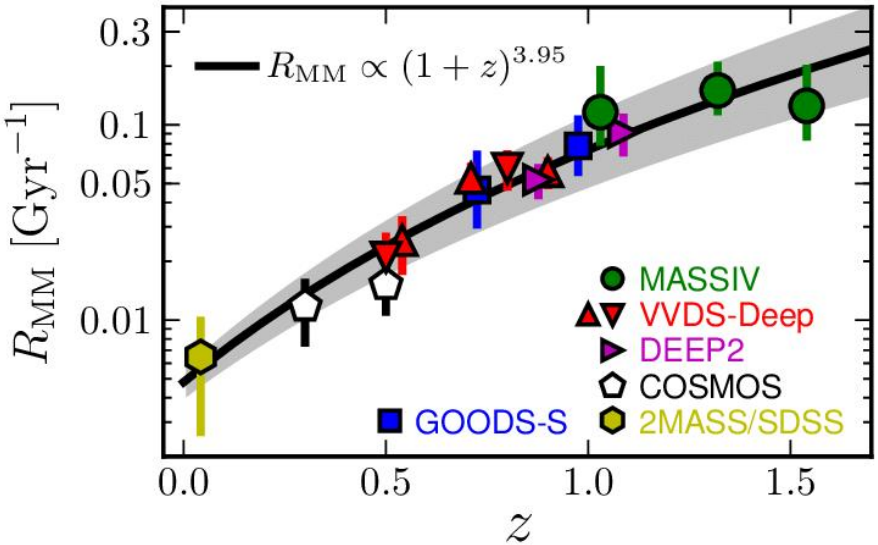
➢ **测光红移**

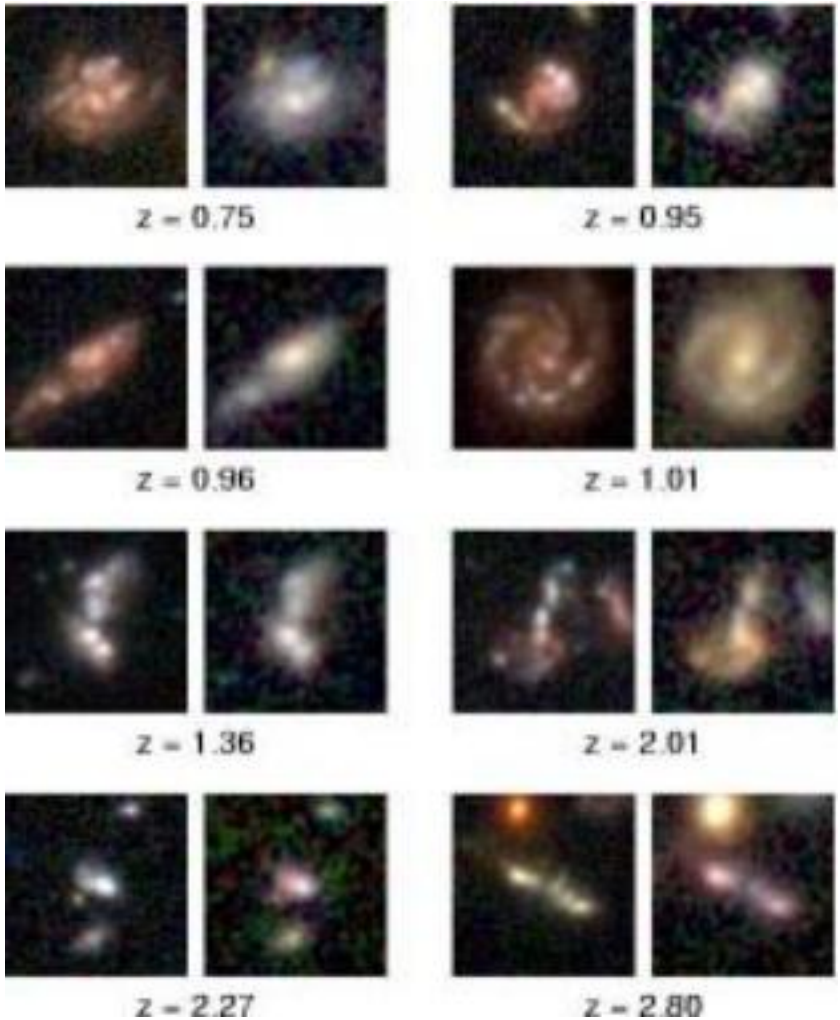

MAGPHYS decomposition – id=33 class=LLAGN z=0.606800 (spec)
All components
Stars
AGN
Starburst
log L IR 8–1000=44.8333
log L IR (AGN) 8–1000=43.1160
log L IR 1–1000=44.9608
log L IR (AGN) 1–1000=43.4223
opt class=NLAGN
X–ray class=AGN
X–ray Lum=2.6000000e+43
S(ν) [μJy]
λ [μm] (rest–frame)
0.01
0.10
1.00
10.00
100.00
1000.00

高红移星系形态

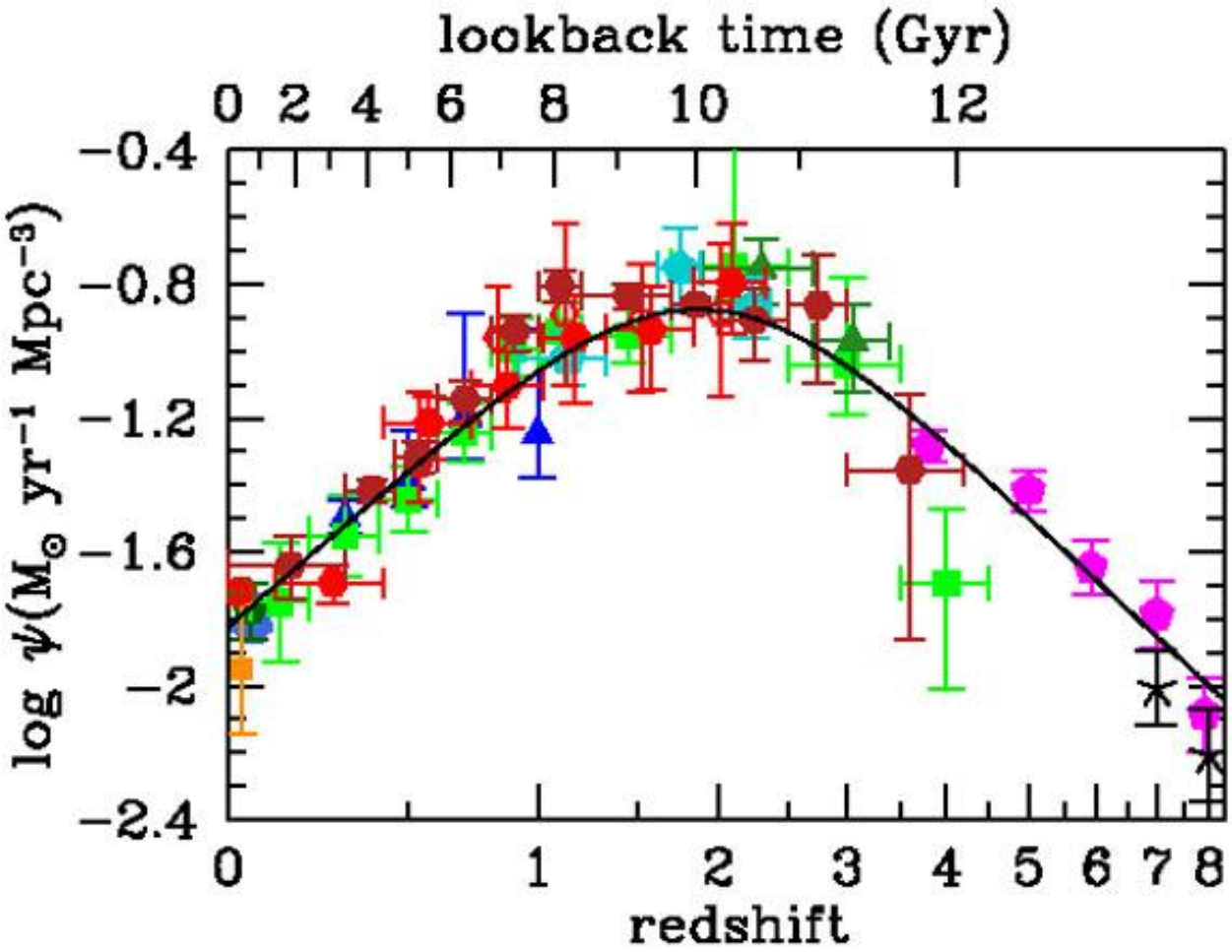
- 高红移星系的形态更加不规则

→ 更高的并合率

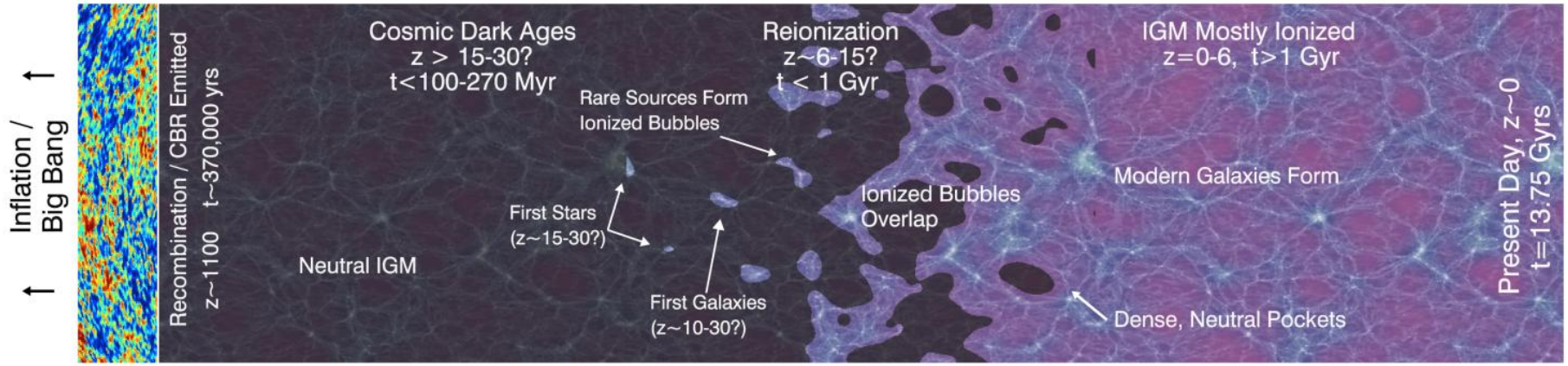


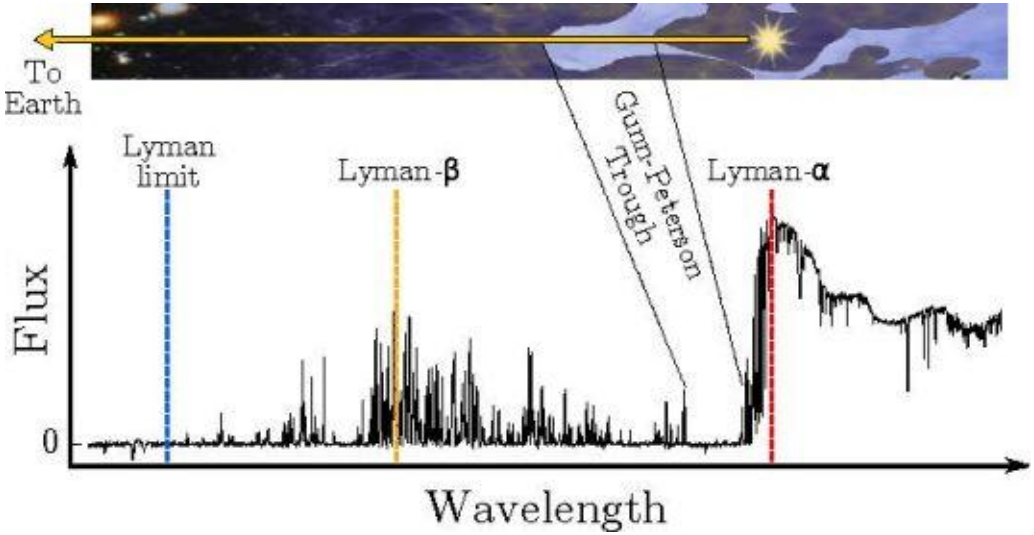


宇宙的恒星形成历史

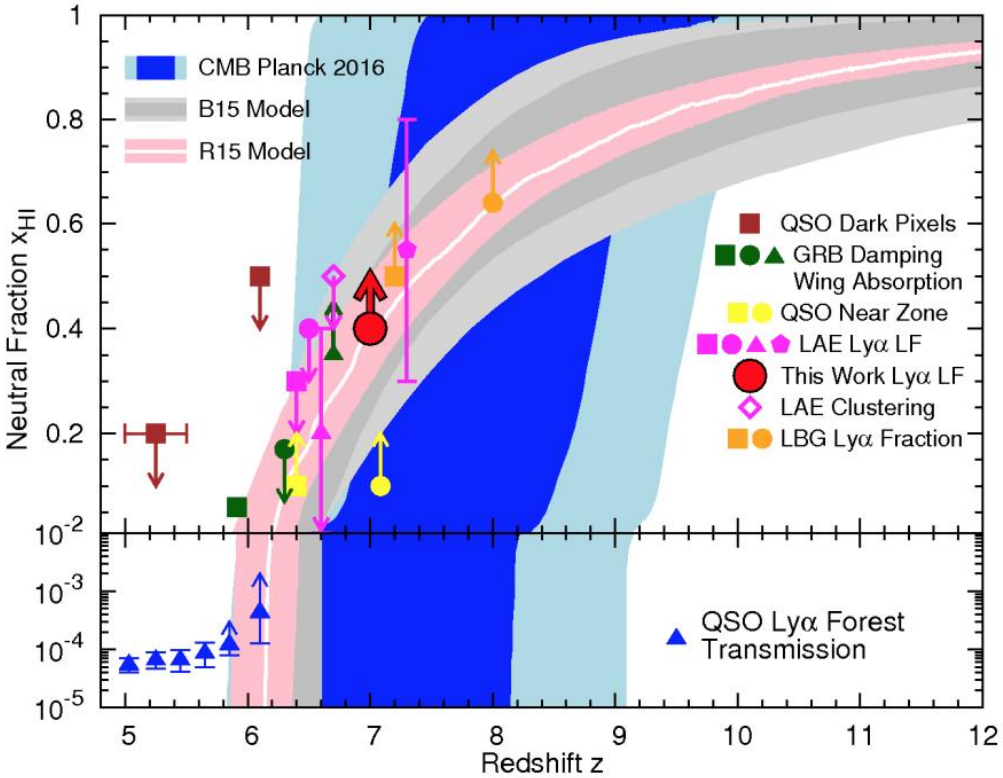

lookback time (Gyr)
0 2 4 6 8 10 12
−0.4
−0.8
−1.2
−1.6
−2
−2.4
log ψ(M⊙ yr⁻¹ Mpc⁻³)
0 1 2 3 4 5 6 7 8
redshift

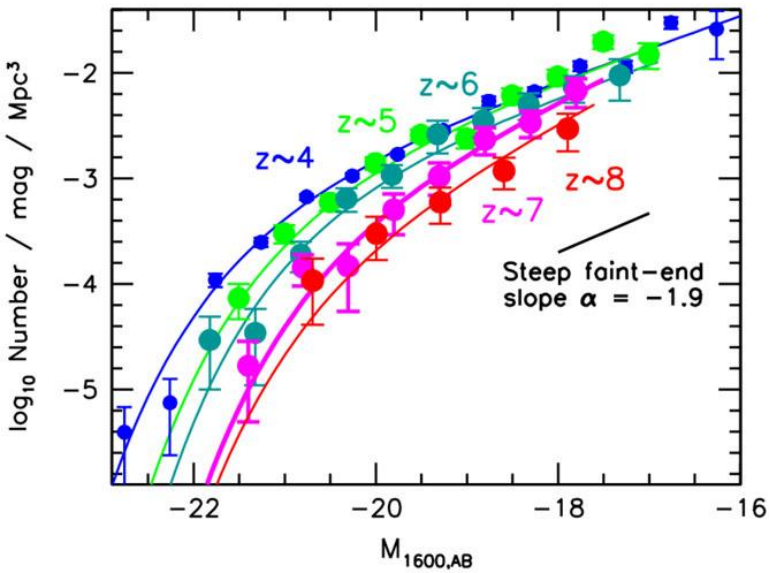
宇宙再电离


Inflation / Big Bang
Recombination / CBR Emitted
z~1100 t~370,000 yrs
Cosmic Dark Ages
z > 15-30?
t<100-270 Myr
Neutral IGM
Rare Sources Form
Ionized Bubbles
First Stars
(z~15-30?)
First Galaxies
(z~10-30?)
Reionization
z~6-15?
t < 1 Gyr
Ionized Bubbles
Overlap
IGM Mostly Ionized
z=0-6, t>1 Gyr
Modern Galaxies Form
Dense, Neutral Pockets
Present Day, z~0
t=13.75 Gyrs


To Earth
Lyman limit
Lyman-β
Gunn-Peterson Trough
Lyman-α
Flux
0
Wavelength

宇宙再电离

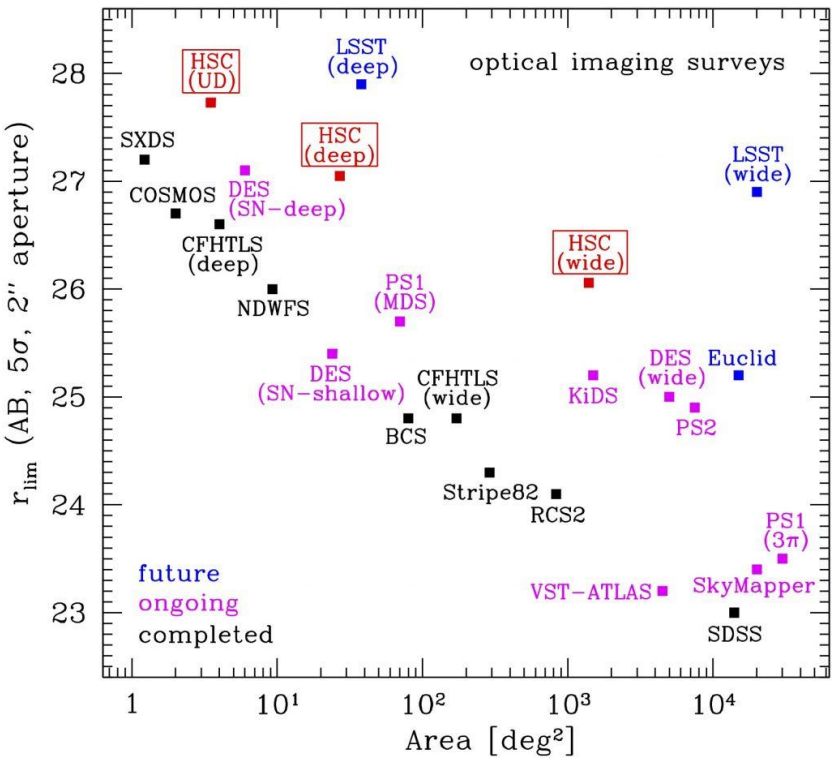

CMB Planck 2016
B15 Model
R15 Model
QSO Dark Pixels
GRB Damping Wing Absorption
QSO Near Zone
LAE Lyα LF
This Work Lyα LF
LAE Clustering
LBG Lyα Fraction
QSO Lyα Forest Transmission
Neutral Fraction x_{HI}
Redshift z

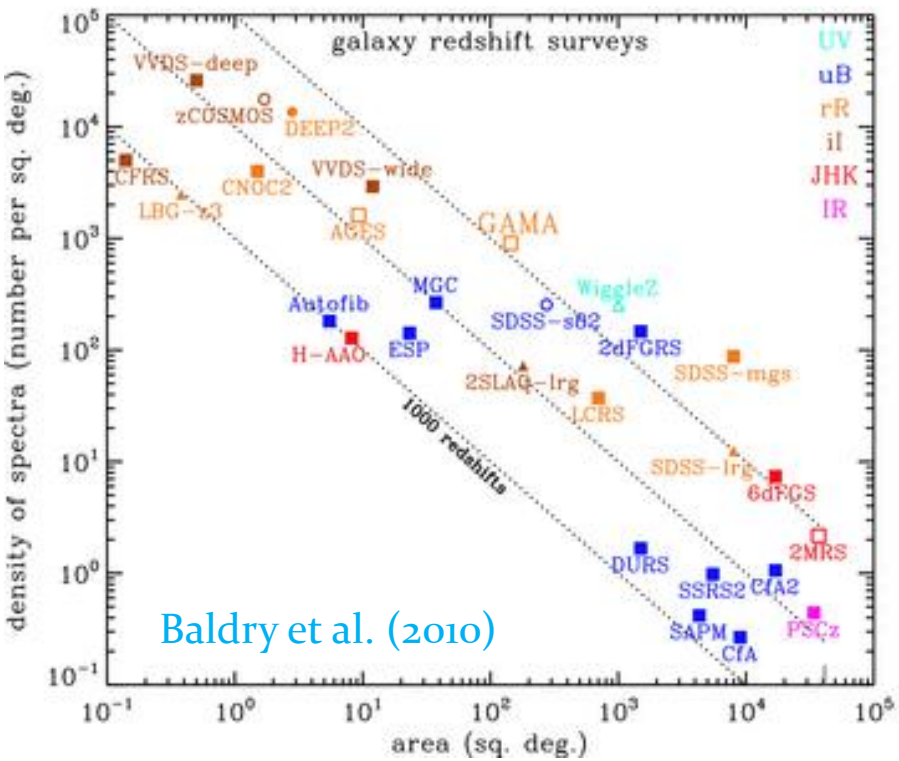

z~4
z~5
z~6
z~7
z~8
Steep faint-end slope α = −1.9
$\log_{10}$ Number / mag / Mpc³
$M_{1600,AB}$

星系的统计性质

星系巡天

- 大视场的星系巡天 → 星系统计规律 → 约束星系形成演化理论
  - 测光巡天：星系的形态、星等、颜色
  - 光谱巡天：星族、电离气体、运动学
  - 多波段巡天：X-ray, IR, radio



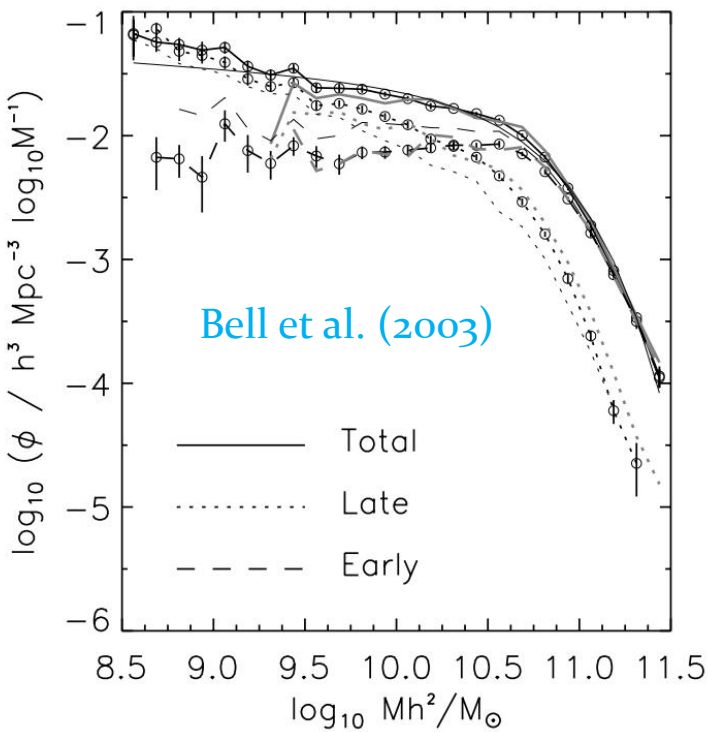


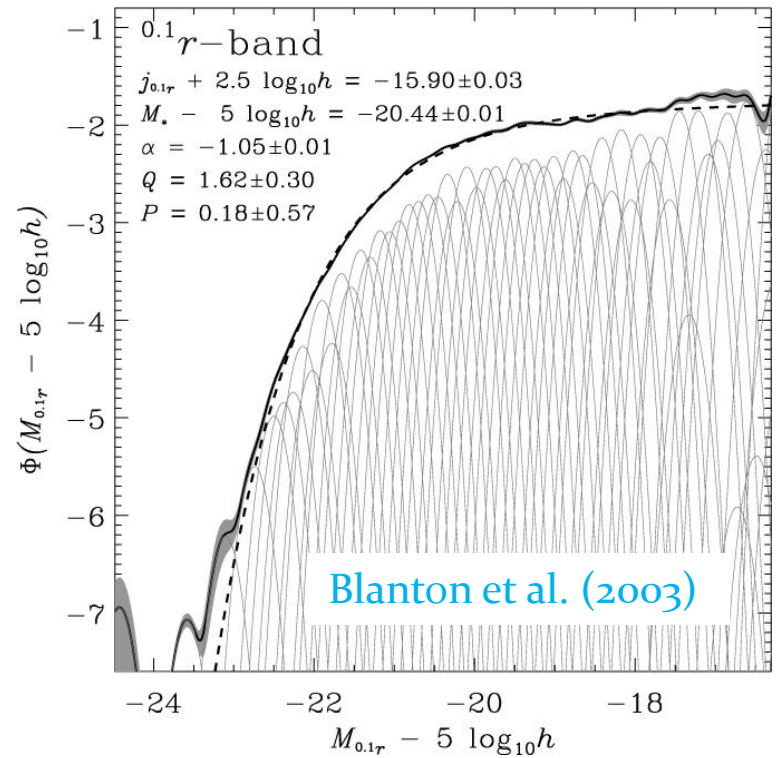
Baldry et al. (2010)

星系的光度和质量函数

- 光度函数：单位光度间隔范围内的星系数密度，**Φ(L)dL**
- 质量函数：单位（恒星）质量间隔范围内的星系数密度，**Φ(*M*)dM**
- 均可用Schechter函数描述，特征星等M*=-20.5，特征质量logM*~10.5

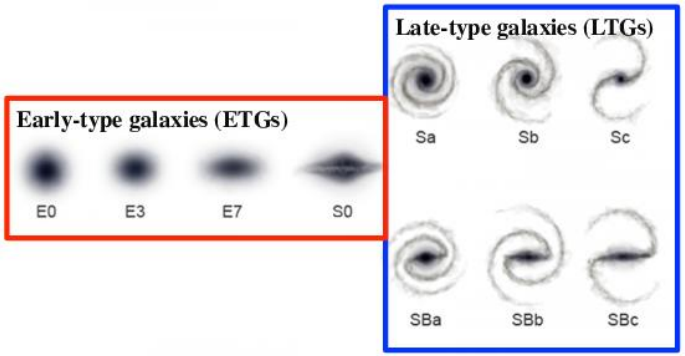
$$\Phi(L)\mathrm{d}L=\left(\frac{\Phi^*}{L^*}\right)\left(\frac{L}{L^*}\right)^{\alpha}\exp\left(-\frac{L}{L^*}\right)\mathrm{d}L,$$

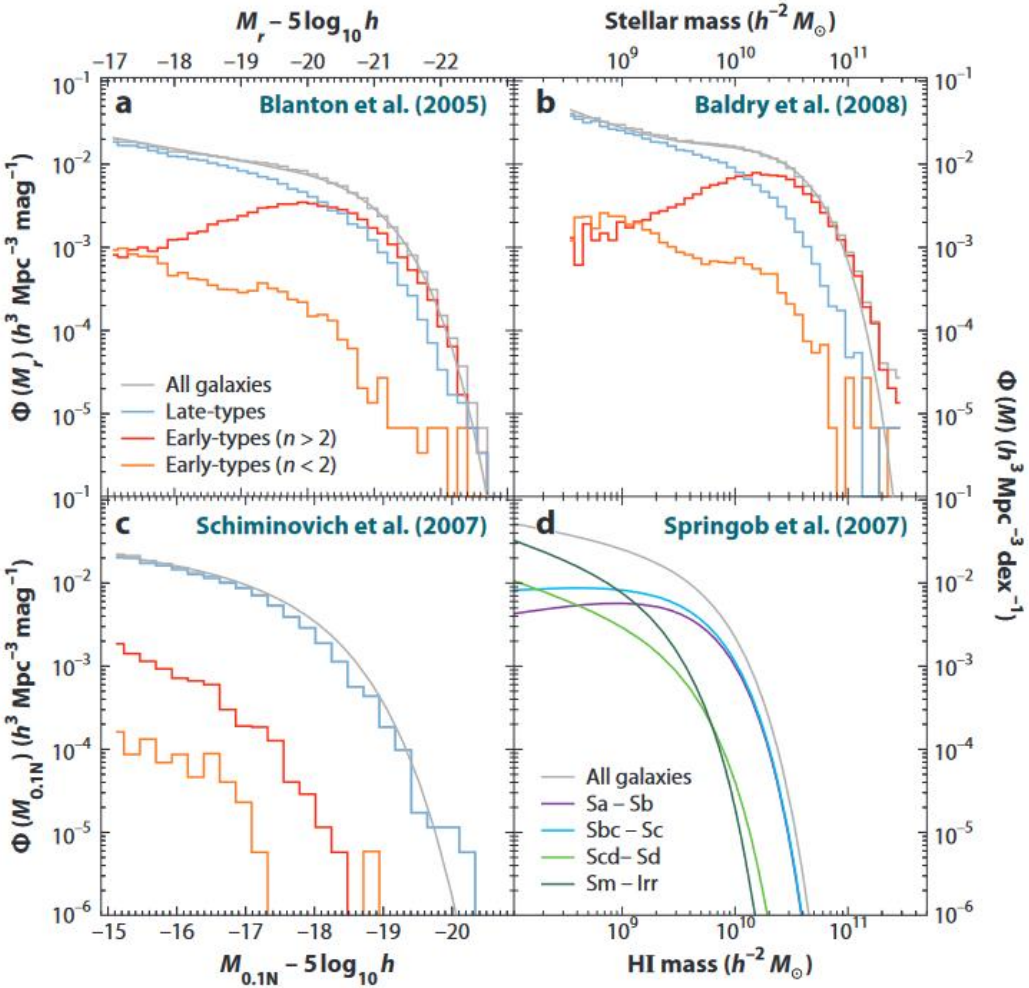




星系的形态

- 早型星系(n>2)
  - 椭圆星系、透镜星系
  - 高光度、高恒星质量、无HI气体
- 晚型星系(n<2)
  - 盘星系、不规则星系
  - 低光度、低恒星质量、富气体

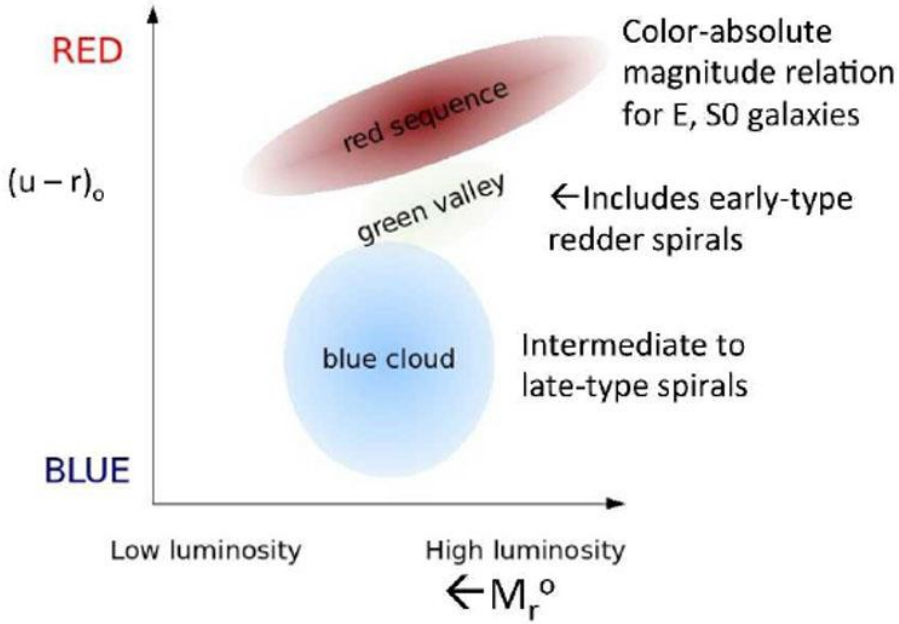


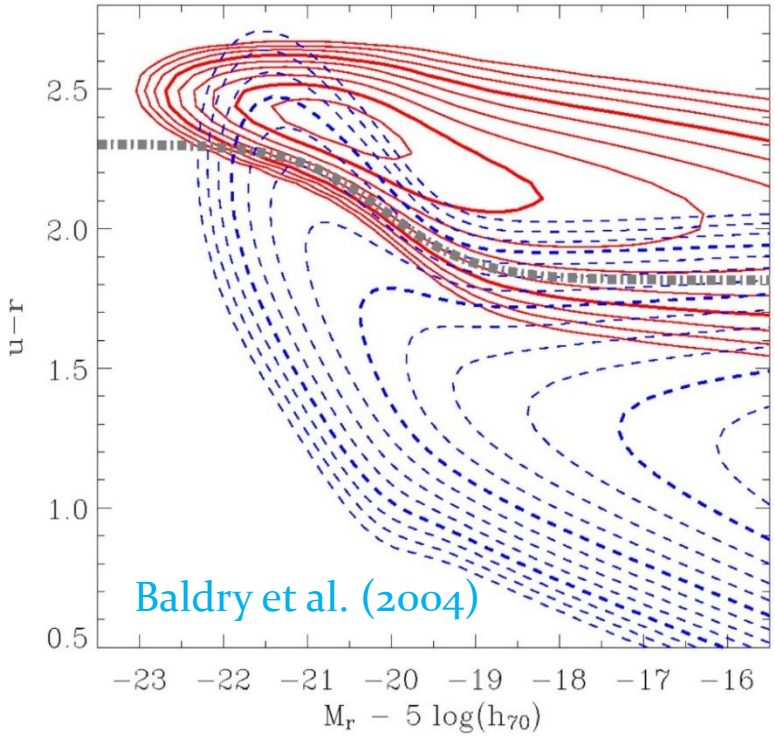


Blanton et al. (2009)

星系的颜色

- 星系的颜色呈现双模分布
  - Red sequence：大质量、早型星系、星族年老、恒星形成弱
  - Blue cloud：小质量、晚型星系、星族年轻、恒星形成强
  - Green valley：转变态?





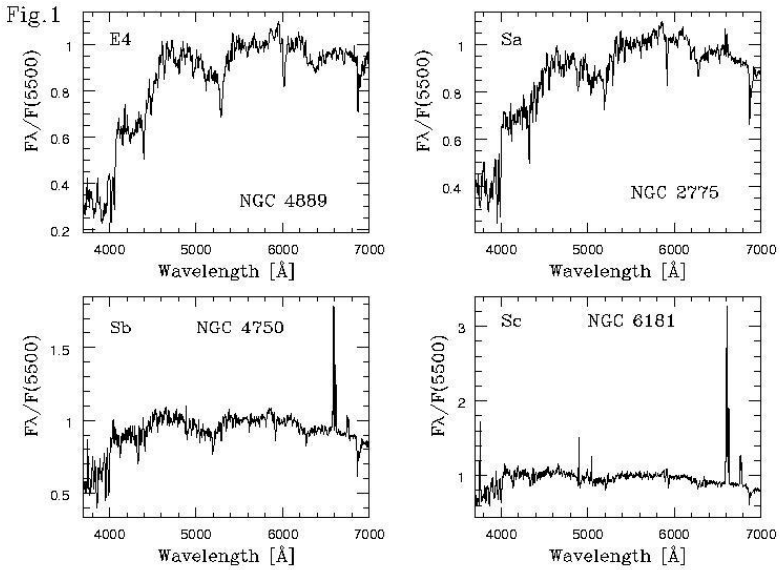
星系的恒星形成率

- **恒星形成率（star formation rate, SFR）**
  - **单位时间内新形成恒星的总质量，$M_\odot$/yr**
  - **定标方法：**
    - UV光度、红外光度、射电连续谱
    - 特征发射线(Hα、[OII])
    - 分子谱线(CO, PAH, HCN)

$$\mathrm{SFR}(M_\odot\,\mathrm{year}^{-1}) = 7.9\times10^{-42}L(\mathrm{H}\alpha)(\mathrm{ergs\,s}^{-1}) = 1.08\times10^{-53}Q(H^0)(\mathrm{s}^{-1}).$$

$$\mathrm{SFR}(M_\odot\,\mathrm{year}^{-1}) = (1.4\pm0.4)\times10^{-41}L[\mathrm{OII}](\mathrm{ergs\,s}^{-1}),$$

$$\mathrm{SFR}(M_\odot\,\mathrm{year}^{-1}) = 4.5\times10^{-44}L_{FIR}(\mathrm{ergs s}^{-1})(\mathrm{starbursts}),$$

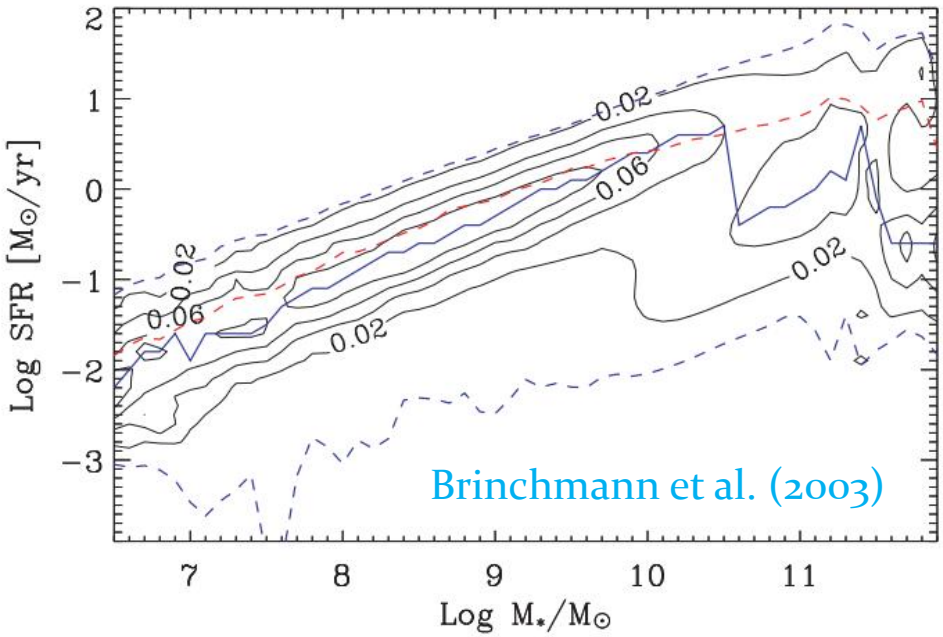


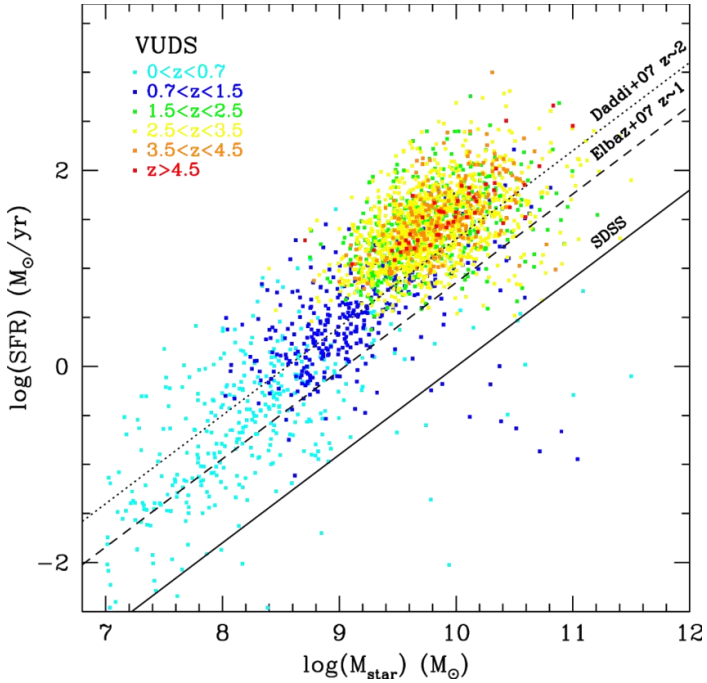
星系的恒星形成率

- 恒星形成主序（star formation main sequence, SFMS）
  - 星系的恒星质量与恒星形成率紧密相关

$$\log(\mathrm{SFR}/M_*) = -0.35(\log M_* - 10) - 9.83.$$

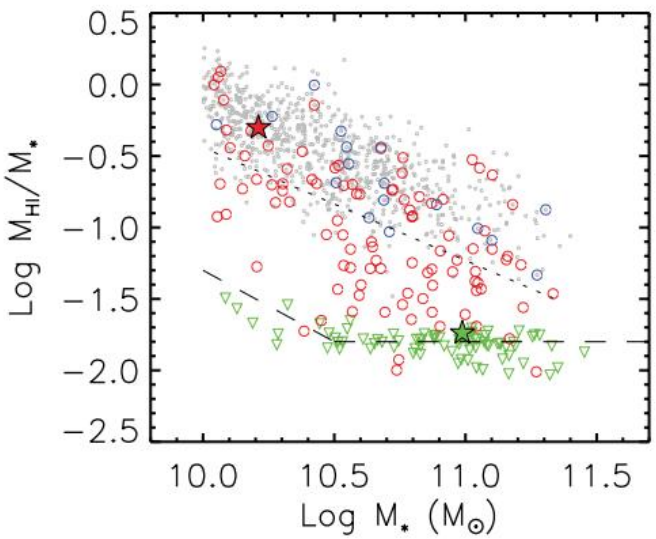
  - 恒星形成主序有明显的演化效应：高红移星系的SFR更高



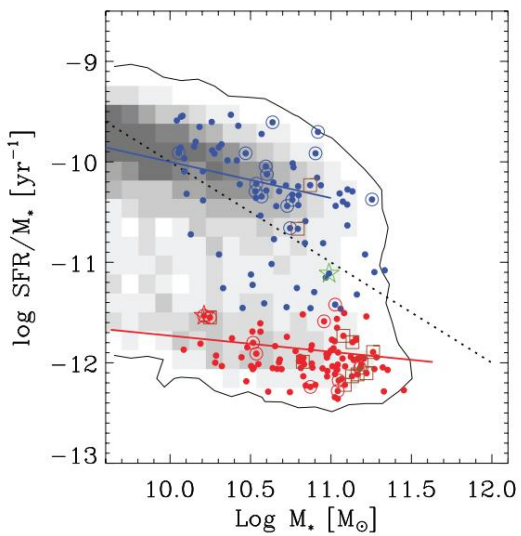


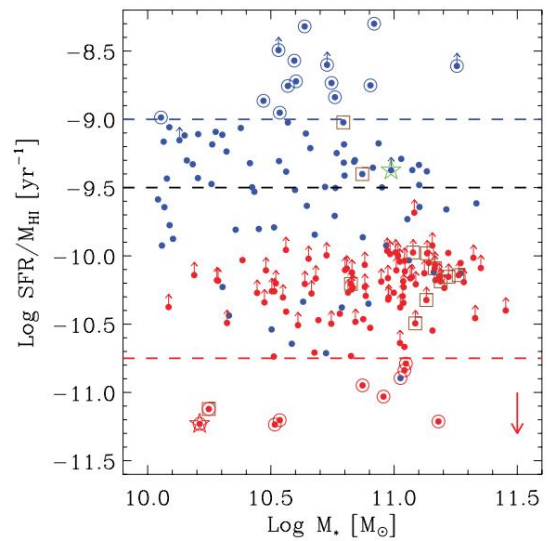
星系中的冷气体

- **星系的中性氢含量（$f_{HI} = M_{HI}/M_\star$）**
  - **大质量星系的HI含量更低，小质量星系的Hi含量较高**
- **星系的恒星形成效率（$SFE = SFR/M_{HI}$）**
  - **恒星形成星系的恒星形成效率更高**



Catinella et al. (2010)

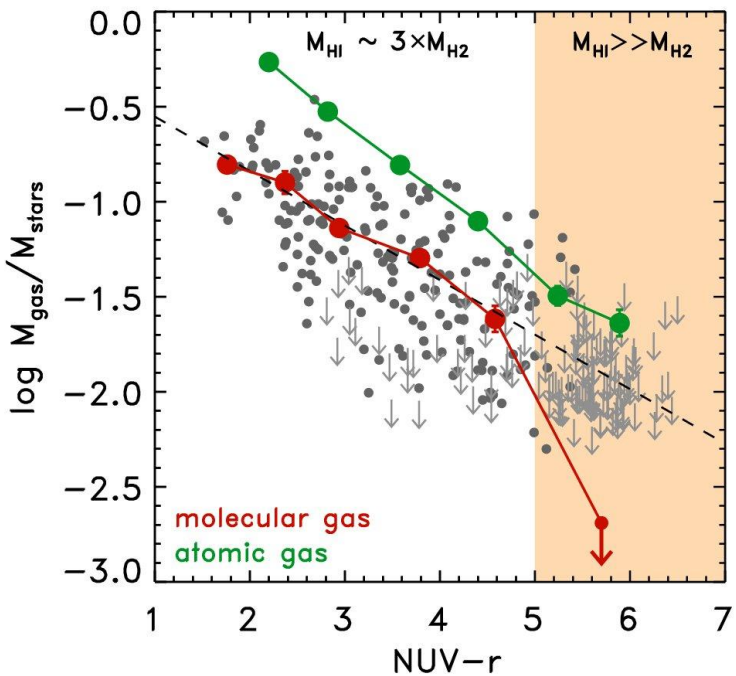


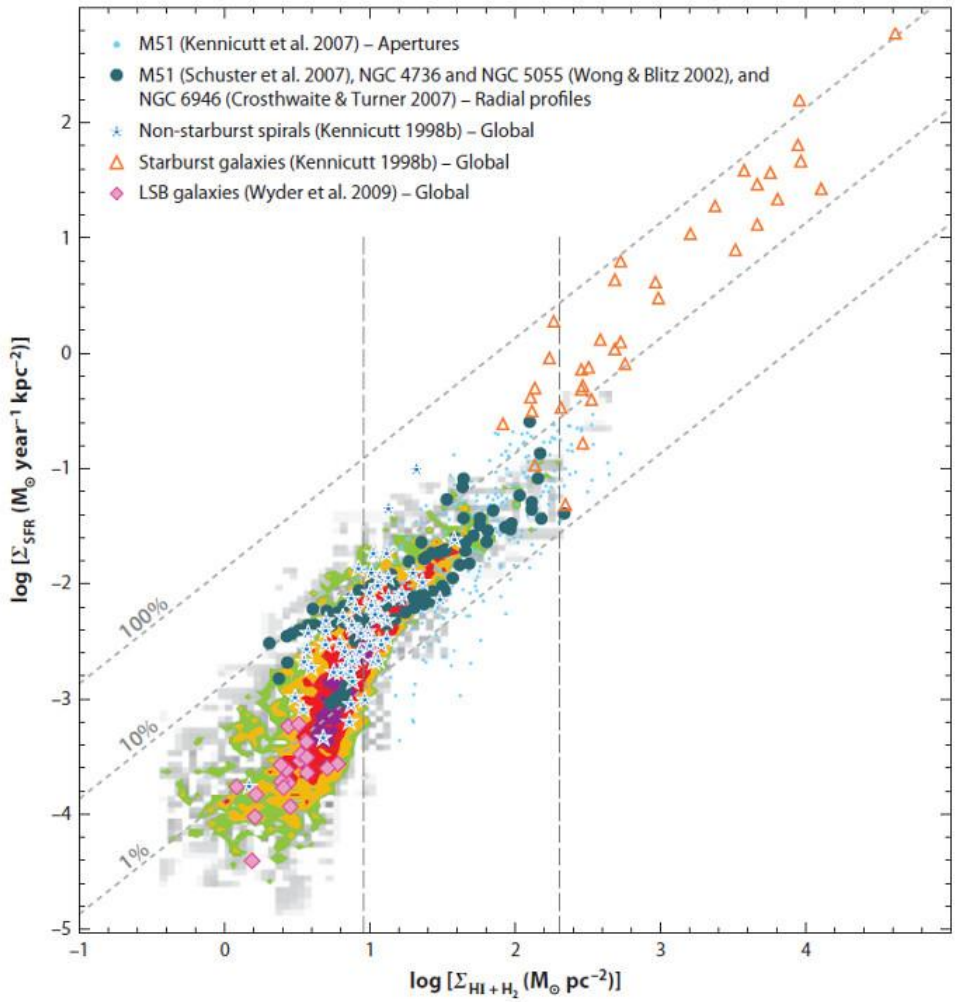


Schiminovich et al. (2010)

星系中的冷气体

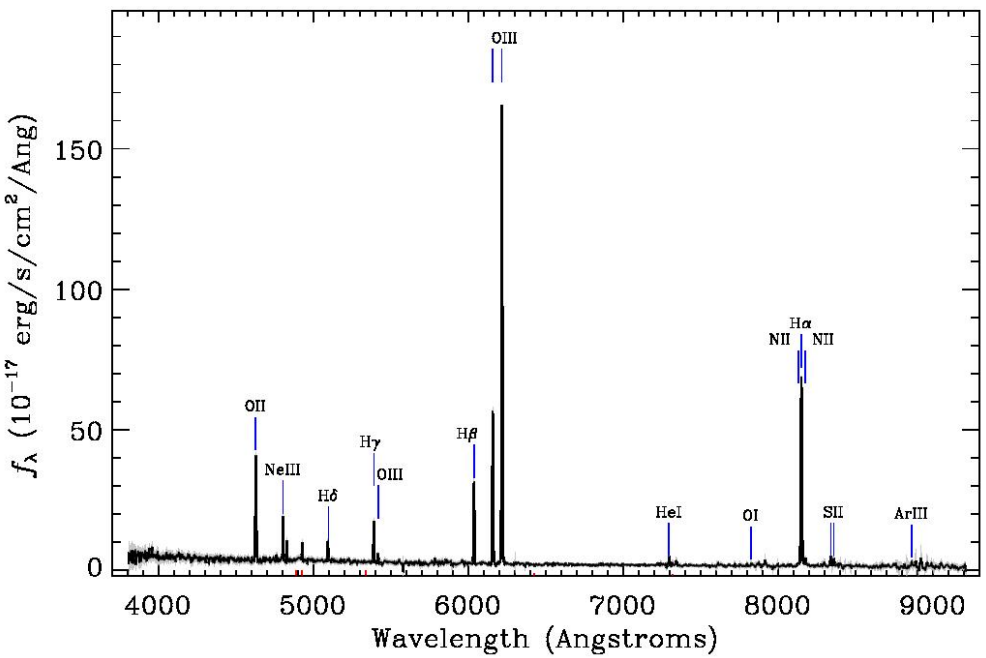
中性气体（HI）
→ 分子气体（H_2，CO）
→ 恒星

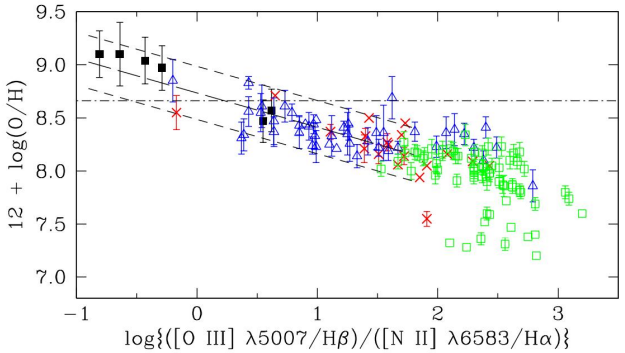


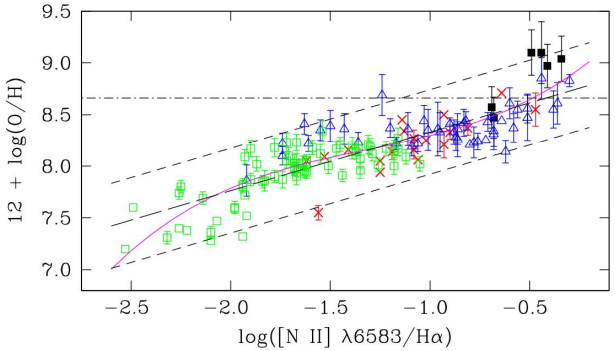


星系的化学丰度

- 恒星金属丰度：星系中恒星星族的化学丰度（恒星表面大气），[Z/H]
  - 可以通过星族合成方法计算
- 气相金属丰度：星系中星系介质的化学丰度，12+log(O/H)
  - 可以通过电离气体发射线的线强比进行计算

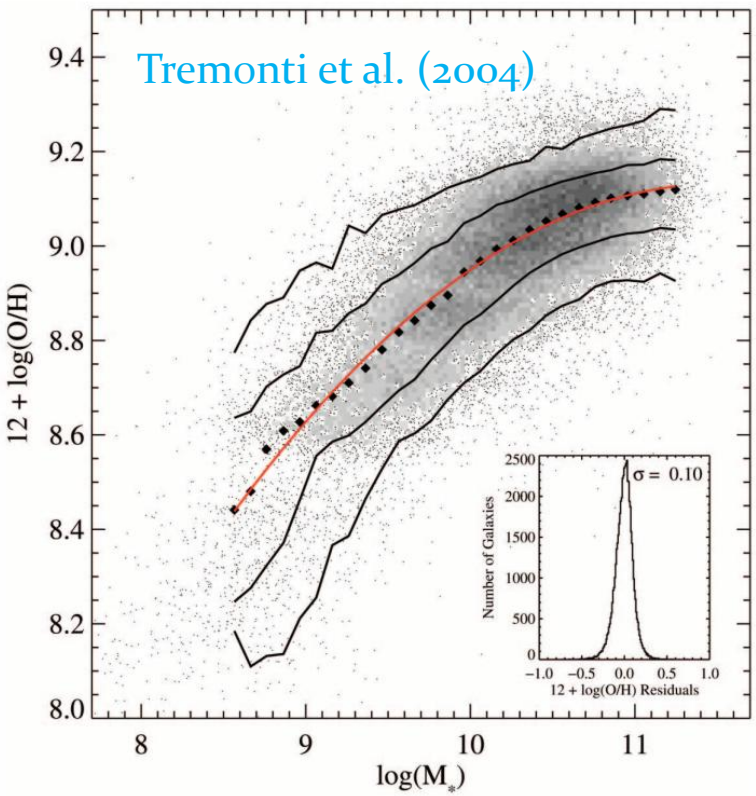


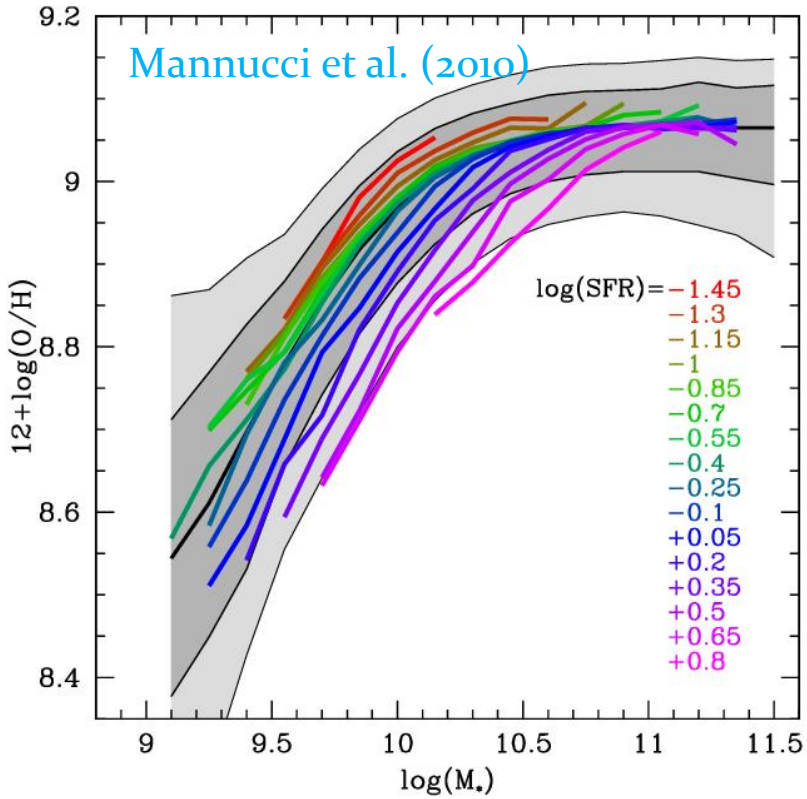




气相金属丰度的标度关系

- 质量-金属丰度关系（mass-metallicity relation, MZR）
  - 质量越大，气相金属丰度越高
- 气相金属丰度基本关系（fundamental metallicity relation, FMR）
  - 恒星形成率越高，气相金属丰度越低

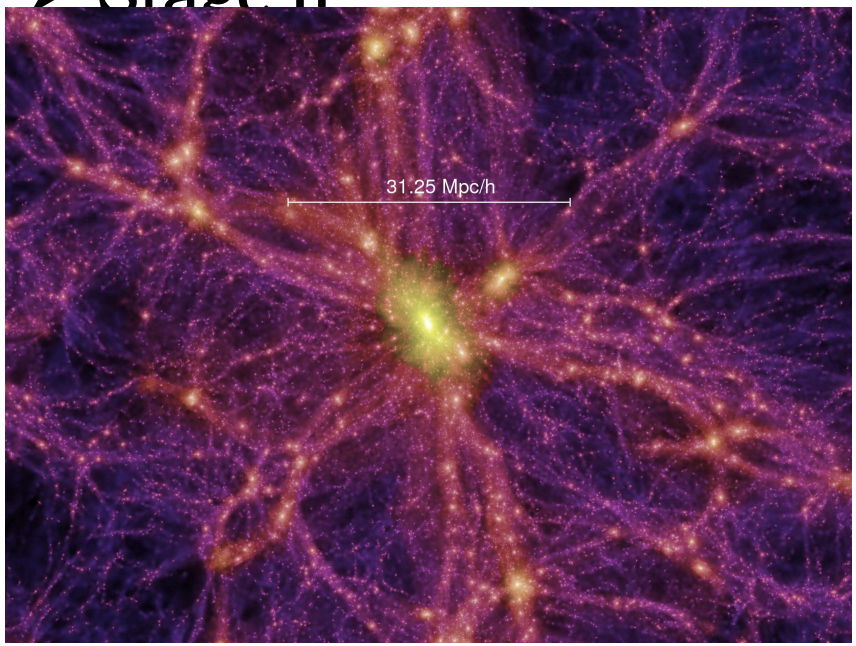




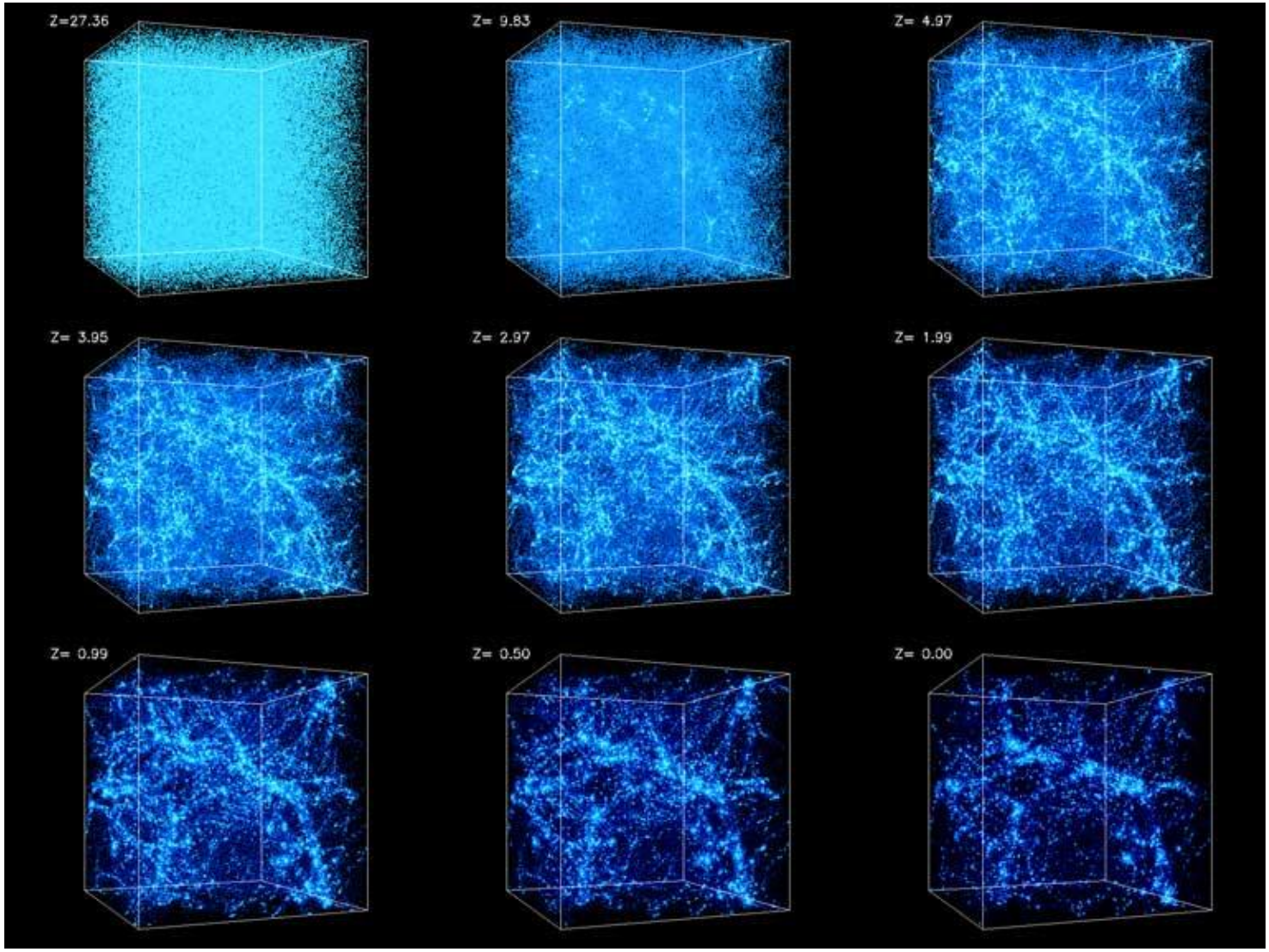
星系形成与演化理论

星系形成模型

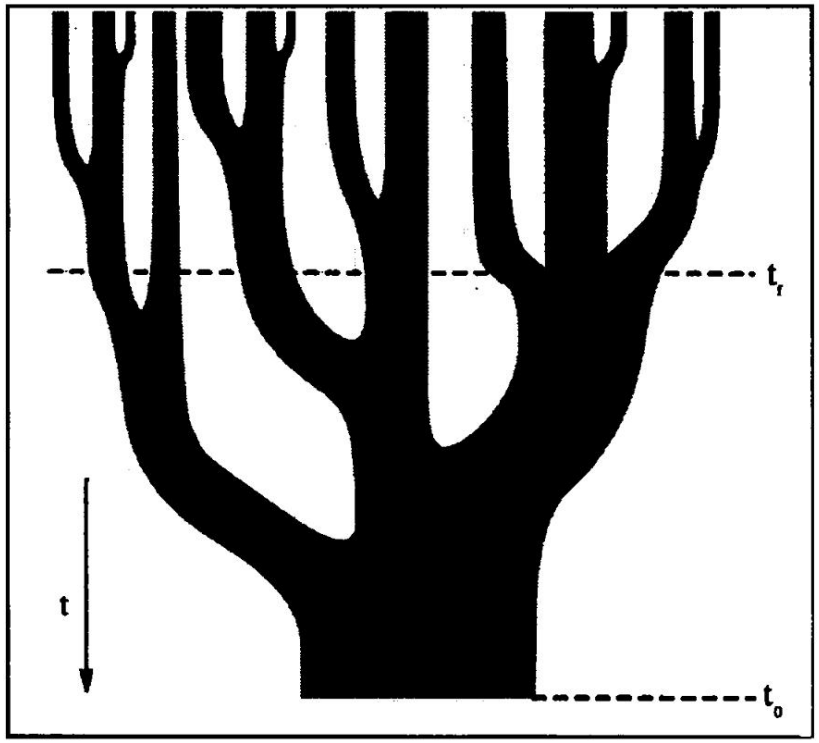
- Stage I
  - 大尺度结构的形成
  - 暗物质晕的形成
- Stage II

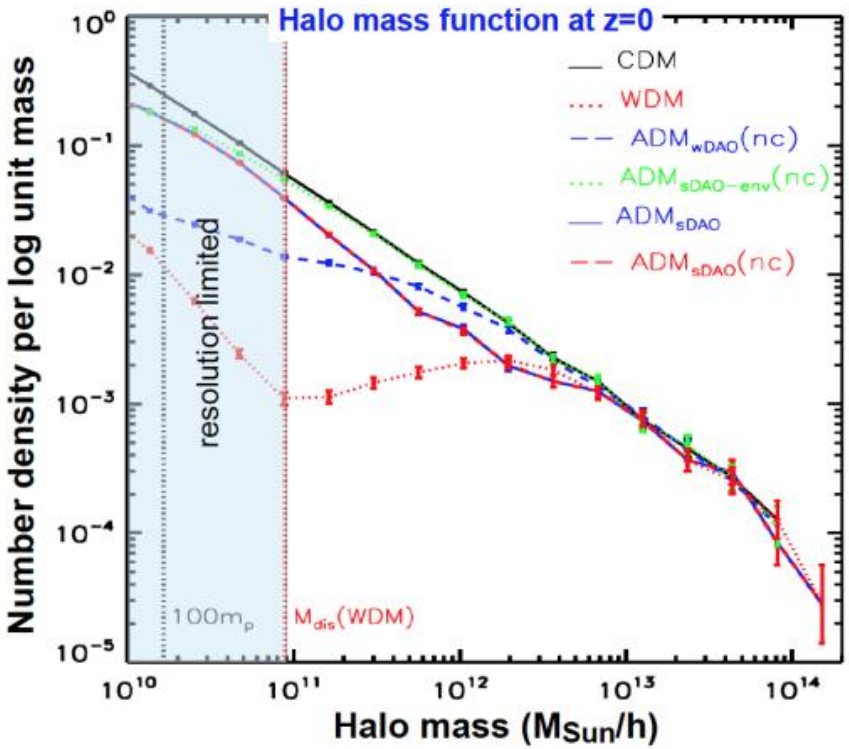


大尺度结构的形成



暗物质晕性质


t_f
t
t_0


Halo mass function at z=0
CDM
WDM
$ADM_{wDAO}(nc)$
$ADM_{sDAO-env}(nc)$
ADM_{sDAO}
$ADM_{sDAO}(nc)$
resolution limited
$100m_p$
$M_{dis}(WDM)$
Number density per log unit mass
Halo mass (M_{Sun}/h)
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}

暗物质晕性质

A UNIVERSAL DENSITY PROFILE FROM HIERARCHICAL CLUSTERING

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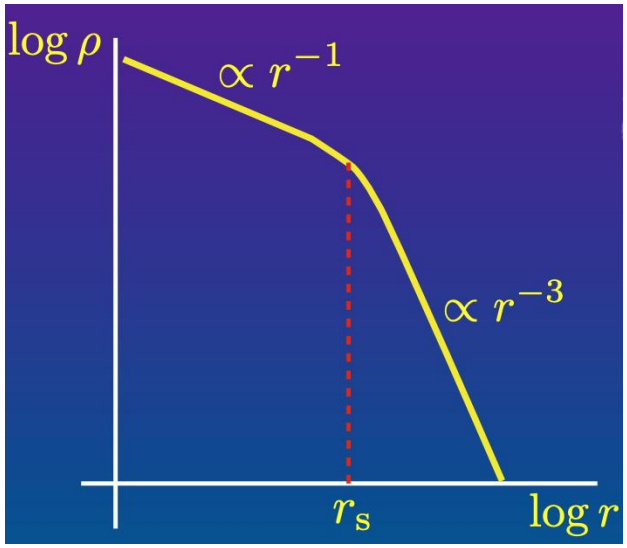
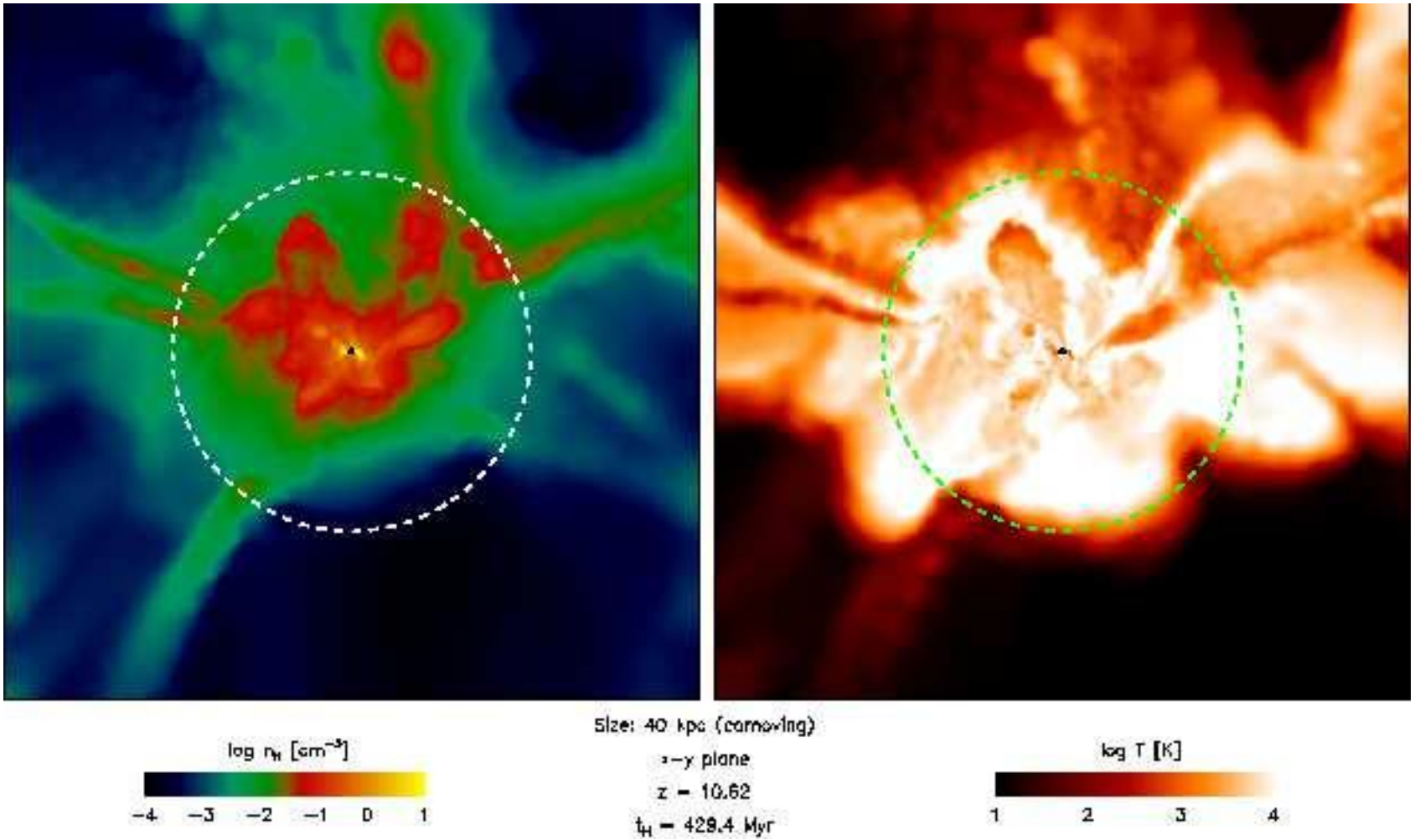
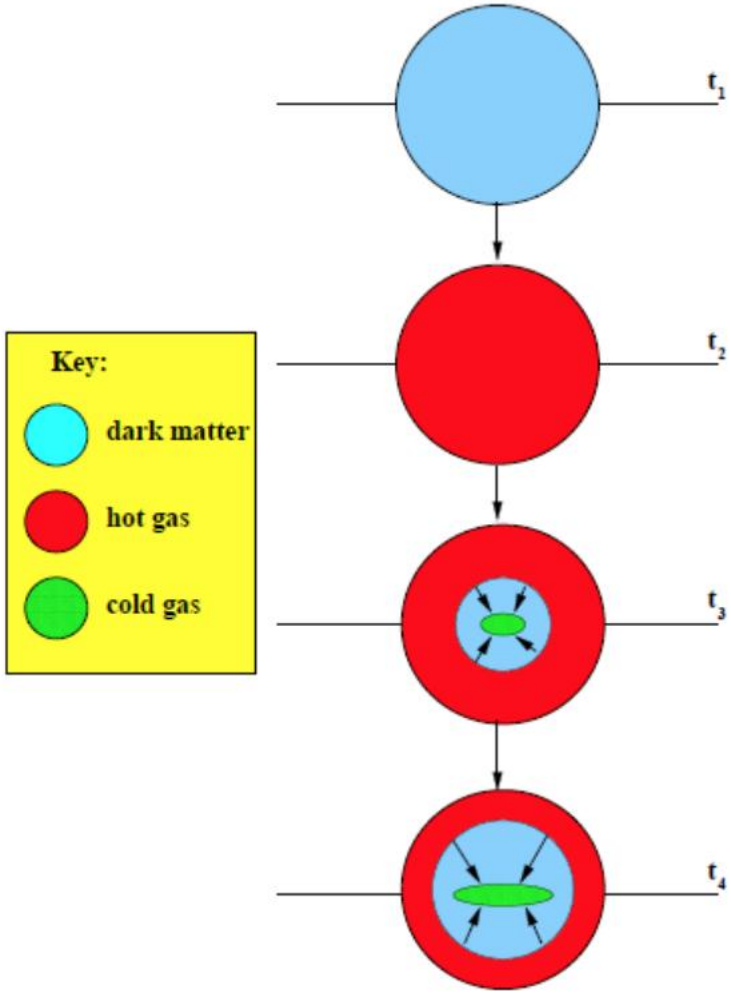
$$\rho(r) = \rho_{\rm crit} \frac{\delta_{\rm char}}{(r/r_{\rm s})\,(1 + r/r_{\rm s})^2}$$

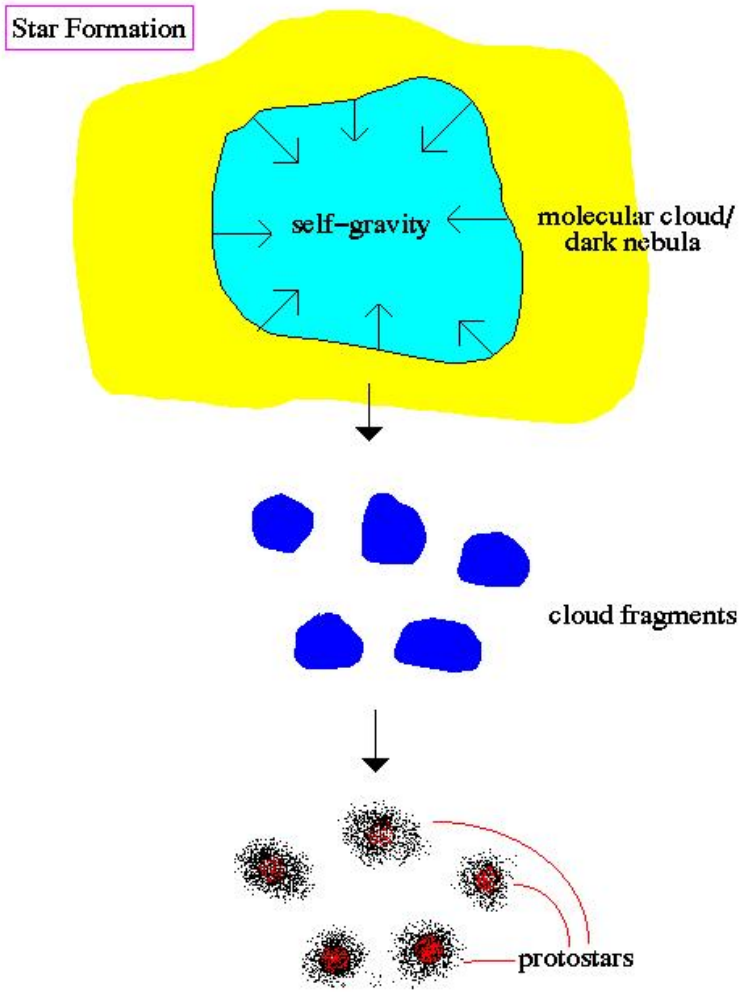


重子物质内流

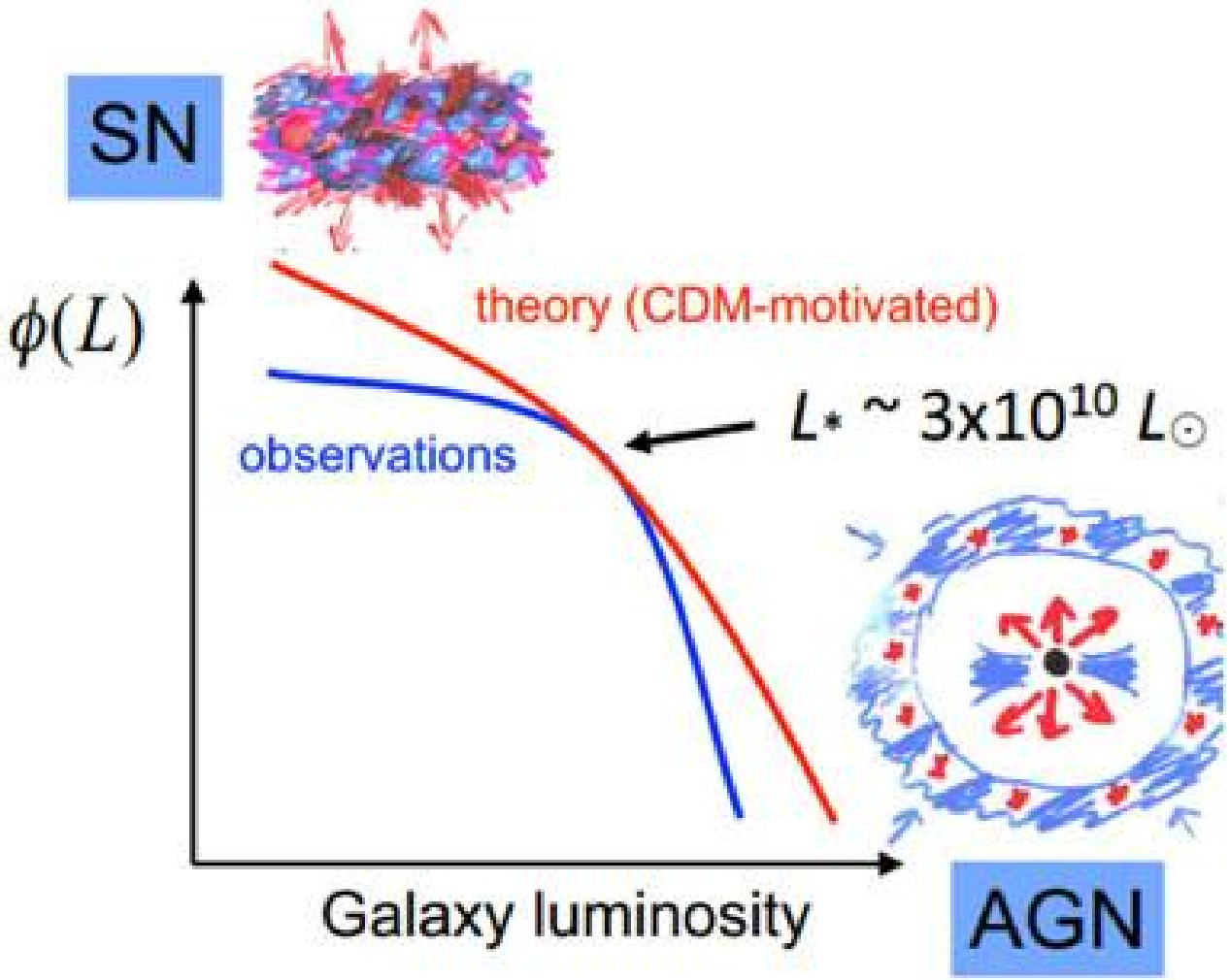

log n_H [cm^{-3}]
−4 −3 −2 −1 0 1
Size: 40 kpc (comoving)
x−y plane
z = 10.62
t_H = 429.4 Myr
log T [K]
1 2 3 4

热气体冷却和恒星形成

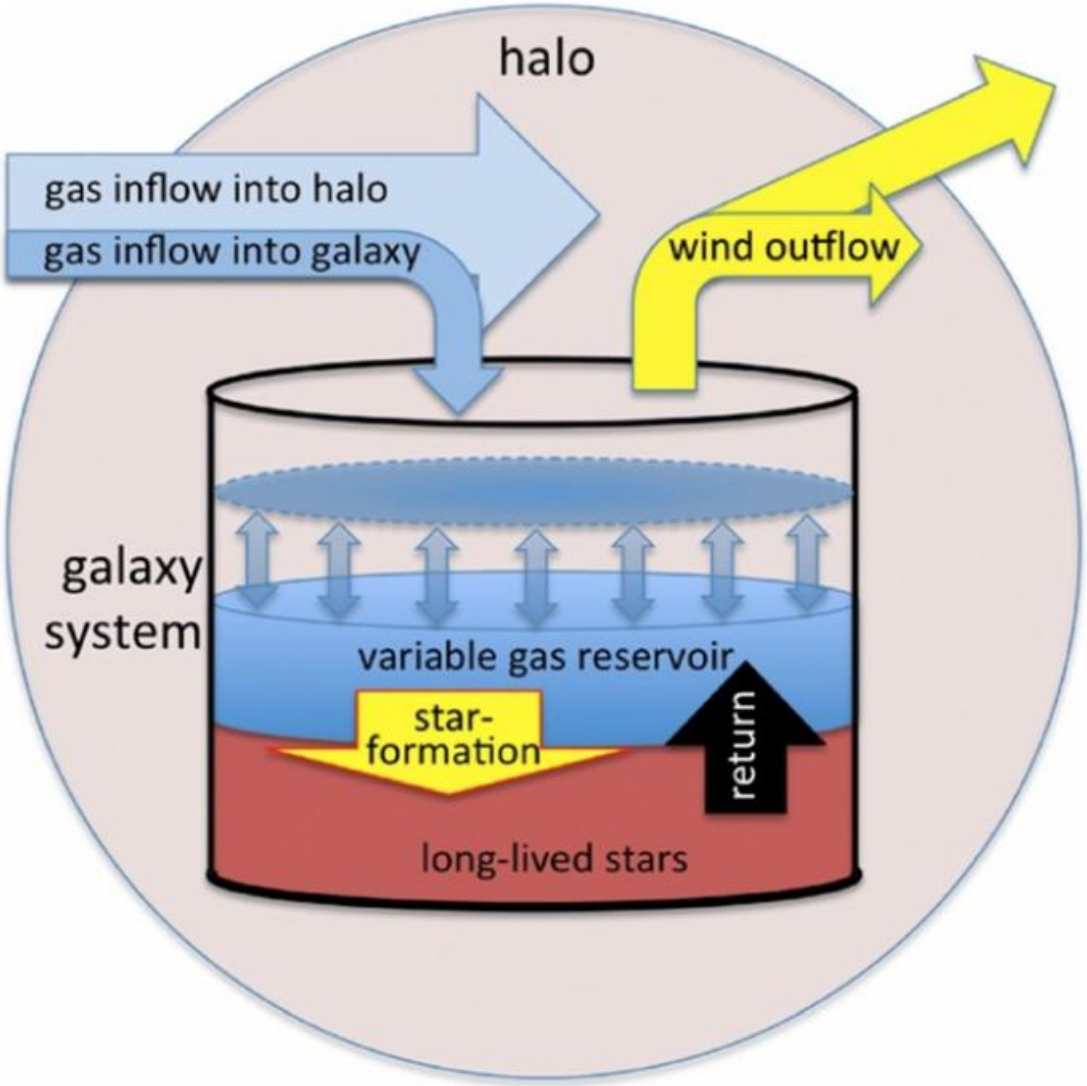

Key:
dark matter
hot gas
cold gas
t_1
t_2
t_3
t_4


Star Formation
self-gravity
molecular cloud/
dark nebula
cloud fragments
protostars

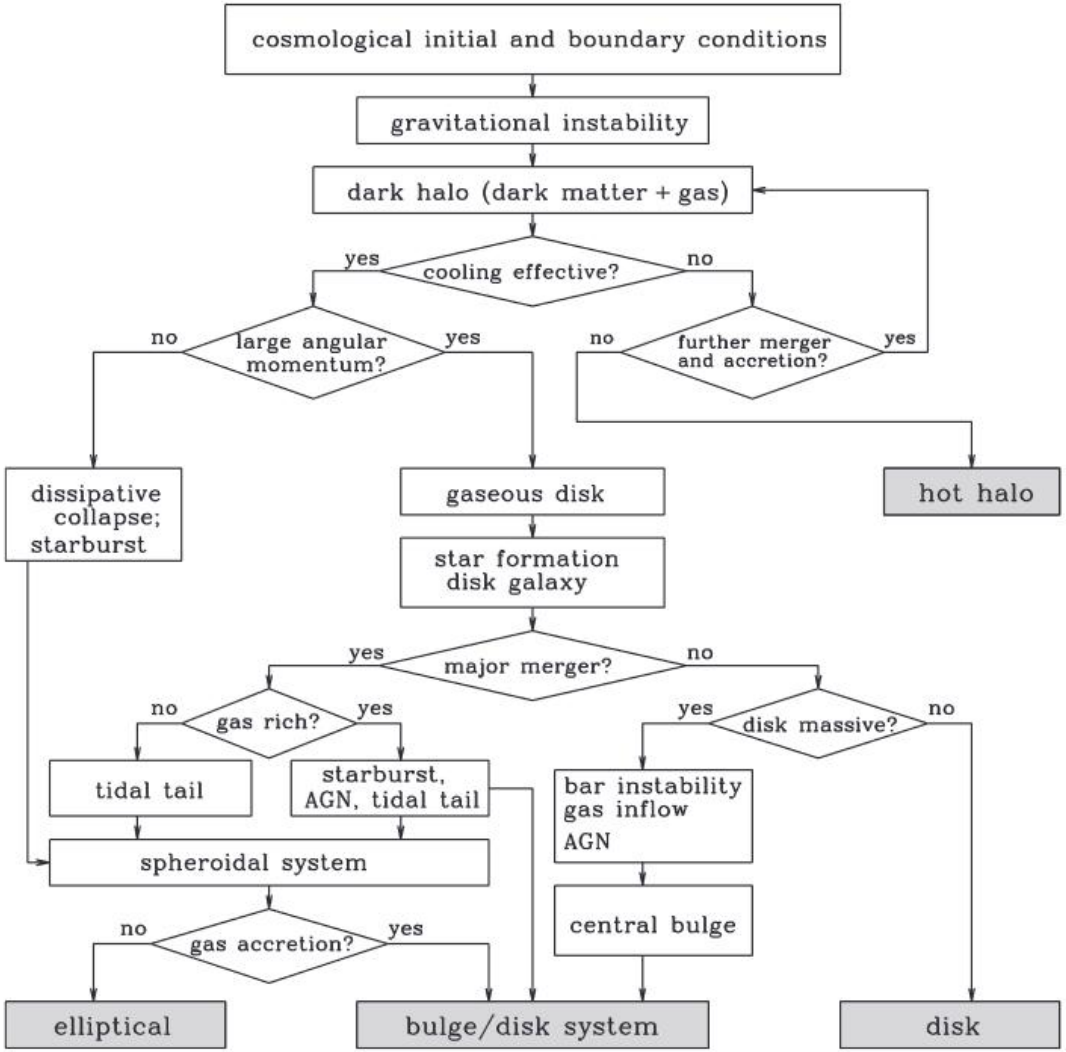
反馈机制


SN
$\phi(L)$
theory (CDM-motivated)
observations
$L_* \sim 3\times10^{10}\ L_\odot$
Galaxy luminosity
AGN

星系中的气体循环


halo
gas inflow into halo
gas inflow into galaxy
wind outflow
galaxy
system
variable gas reservoir
star-
formation
return
long-lived stars

理论框架


cosmological initial and boundary conditions
gravitational instability
dark halo (dark matter + gas)
cooling effective?
yes
no
large angular momentum?
no
yes
further merger and accretion?
no
yes
dissipative collapse; starburst
gaseous disk
hot halo
star formation disk galaxy
major merger?
yes
no
gas rich?
no
yes
disk massive?
yes
no
tidal tail
starburst, AGN, tidal tail
bar instability gas inflow AGN
spheroidal system
central bulge
gas accretion?
no
yes
elliptical
bulge/disk system
disk