The Illustris simulation: a new look at galaxy – black hole co-evolution

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Cosmological simulations of galaxy and structure formation

Hierarchical growth of dark matter halos

Boylan-Kolchin et al. (2009)

Large scale distribution of galaxies

Springel et al. 2006

Large scale environments of galaxies: inflows and outflows

Illustris project

Galaxy morphologies

Shen et al. 2013
Cosmological simulations of galaxy and structure formation

One of the main issues:
Gas overcooling in massive galaxies

Croton et al. 2006

Sijacki et al. 2007
Cosmological simulations of galaxy and structure formation

In modern hydro sims gas overcooling even worse!
Cosmological simulations of galaxy and structure formation

Observational evidence for the feedback from supermassive black holes: high z QSOs

$z = 6.4$

Figure 1. IRAM PdBI continuum-subtracted spectrum of the [CII]158\,$\mu$m line, redshifted to 256.172 GHz, in the host galaxy of the quasar J1148+5152 extracted from an aperture with a diameter of 4$''$, top, and 6$''$, bottom. The spectrum has been resampled to a bin size of 85 km s$^{-1}$. The red lines show a double Gaussian fit (FWHM=345 km s$^{-1}$ and FWHM=2030 km s$^{-1}$) to the line profile, while the blue line shows the sum of the two Gaussian components.

Maiolino et al. 2012

Costa, Sijacki, Trenti, Haehnelt 2012
Cosmological simulations of galaxy and structure formation

Observational evidence for the feedback from supermassive black holes: low z Universe

M87, Forman et al.

Kormendy & Ho 2013

see also McConnell & Ma, 2013

Perseus cluster, Fabian et al.
The Illustris project

DM DENSITY with overlaid GAS VELOCITY

Box size = 106.5Mpc
Min cell size = 48pc
3 x 1820^3
dark matter particles
gas cells
passive tracers -> 18 billion
8192 cores, 19 MCPUh

Physics:

primordial & metal line cooling
+ self-shielding
stellar evolution
stellar feedback
gas recycling
chemical enrichment
black hole growth
black hole feedback:
quasar, radiative and radio bubbles
(see Springel et al. 2005
Sijacki et al. 2007,
Vogelsberger et al. 2013)
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COSMIC STAR FORMATION RATE DENSITY

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STELLAR VS. HALO MASS

\[ \frac{M_\star}{M_{200,\text{crit}}/\Omega_m} \%
\]

\( M_\star^{\text{Tot}} \)
\( M_\star^{r_\star} \)

The Illustris project

GALAXY MORPHOLOGIES

- ellipticals
- disk galaxies
- irregular

see also e.g. EAGLE, HORIZON AGN, MASSIVE BLACK and MAGNETICUM projects

Genel et al., MNRAS, 2014
Vogelsberger et al., MNRAS, 2014
BHs in Illustris

SFR DENSITY & BH ACCRETION RATE DENSITY

BH MASS DENSITY

DUTY CYCLE DUE TO THE RADIO MODE

Sijacki et al., MNRAS, 2015

Volonteri et al. 2013

Ueda et al. 2014
BH MASS – BULGE MASS RELATION

Kormendy & Ho, 2013: best fit
| circles: ellipticals; stars: spirals with bulges; squares: pseudo bulges

Sijacki et al., MNRAS, 2015
Some of the problems in Illustris...

TOO LOW GAS FRACTIONS IN MASSIVE GALAXIES

Ewald Puchwein's talk: effect on the matter power spectrum

Genel et al., 2014
Some of the problems in Illustris...

TOO LOW GAS FRACTIONS IN MASSIVE GALAXIES: ZOOMS OF ELLIPTICALS

Shen, Sijacki et al, in prep.
Some of the problems in Illustris...

Shen, Sijacki et al, in prep.
Fast cold gas in hot AGN outflow

PR “A galactic hailstorm in the early Universe”

IRAM Plateau de Bure Interferometer
[C II] 158 um emission line
SDSS J1148+5251 QSO z = 6.4189
very extended (30kpc projected) cold gas with large velocities up to ~1400km/s
Fast cold gas in hot AGN outflow


Resolving flows around BHs

super-Lagrangian refinement

Resolving flows around high $z$ QSOs

Curtis & Sijacki, in prep.
Resolving flows around high z QSOs

Carniani et al. 2013
ALMA data of a QSO/SMG
At $z = 4.7$

$z = 4.89$
$m_{BH} = 27027.66 \times 10^5 M_{\odot}$

Curtis & Sijacki, in prep.
Conclusions

→ Calibrating galaxy formation physics in simulations requires careful study of numerics and unbiased comparison with large observational datasets

→ Black hole – host galaxy scaling relation in very good agreement with observations:

1. steepening at the massive end
2. no strong correlation for low mass, blue star-forming galaxies

→ Future: detailed properties of outflows and galaxy kinematics