The Galaxy Population

Environmental dependence & Simulations

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University of Rochester

Environmental dependence



Kauffmann et al (2004) - Colors correspond to galaxy density: red being the highest, and cyan being the lowest.

Environmental dependence



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Central galaxies on small scales



M_B-5log(h)

Conroy et al. (2007)

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Satellite galaxies on small scales



Weinmann et al. (2006)

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Effects on large scales



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Effects on large scales



Moorman et al. (2015)

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Effects on large scales



Blanton & Berlind (2007)

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Let $u(\mathbf{x}|M)$ be the normalized function describing the average spatial distribution of galaxies within a halo of mass *M*.

If $GG^{2h}(\mathbf{r})$ describes the total number of galaxy pairs separated by \mathbf{r} within one halo, and $GG^{2h}(\mathbf{r})$ describes the total number of pairs separated by \mathbf{r} between two halos, then we can describe the statistical significance of galaxy clustering with the two-point correlation function:

$$\boldsymbol{\xi}_{gg}(\mathbf{r}) = \frac{\left[GG^{1h}(\mathbf{r}) + GG^{2h}(\mathbf{r})\right]dV_1dV_2}{RR(\mathbf{r})dV_1dV_2} - 1$$

where $RR(\mathbf{r})dV_1dV_2 = \bar{n}_g^2 dV_1 dV_2$ is the expected number of pairs if there was no clustering.

Assuming a structure formation model, ξ_{gg} depends on the halo occupation distribution, P(N|M), and $u(\mathbf{x}|M)$.

On scales much larger than the typical halo size, the halo correlation function, ξ_{hh} , is related to the matter correlation function, ξ , by a bias term:

 $\xi_{hh}(r|M_1, M_2) = b_h(M_1)b_h(M_2)\xi(r)$

Propagated through to the galaxy correlation function,

 $\xi_{gg}(r) \approx b_g^2 \xi(r)$

where b_g is the mean bias parameter of the galaxy population:

$$b_g = \int n(M) b_h(M) rac{\langle N | M \rangle}{ar{n}_g} \, dM$$

 $\langle N|M\rangle$ is the first moment of the halo occupation distribution, P(N|M).

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DESI Collaboration (2024)

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It is also possible to relate the halo occupation distribution to luminosity via the conditional luminosity function, $\Phi(L|M)$, so that the galaxy bias becomes

$$b_g(L_1, L_2) = \frac{1}{n_g(L_1, L_2)} \int_{L_1}^{L_2} dL \int_0^\infty \Phi(L|M) b_h(M) n(M) \, dM$$

where

$$n_g(L_1, L_2) = \int_{L_1}^{L_2} \phi(L) \, dL = \int_{L_1}^{L_2} dL \int_0^\infty \Phi(L|M) n(M) \, dM$$

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Galaxy and halo clustering at high-z

As a function of redshift, and assuming that the luminosity of a galaxy is determined entirely by its halo mass, the galaxy bias becomes

$$b_g(L,z) = \sqrt{rac{\xi_{gg}(r|L,z)}{\xi(r|z)}}$$

for sufficiently large *r*.

The bias factor we would measure today is related to the bias factor of its predecessors:

$$b' = 1 + D(z) [b_h(M, z) - 1]$$

where D(z) is the linear growth rate of structure.

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Semi-analytic models of galaxy formation

- 1. Specify cosmological model
- 2. Use N-body simulations to trace merger histories for series of DM halos of different (final) masses
- 3. Follow hot gas, cold gas, and stars within each halo
- 4. Use simple relationships to convert these baryonic components from one to the other.
- 5. Use a stellar population synthesis model to convert the metallicity and star formation history into luminosity and color
- 6. Adopt a prescription for the mergers.
- 7. Assume that satellite galaxies will merge with their central galaxies on the dynamical friction time scale.
- 8. Repeat for a large number of halos that represent the halo mass function at z = 0.

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Results from semi-analytic models of galaxy formation

Some sort of energy input is required to prevent a large fraction of the baryons from cooling and forming stars at high redshifts.

Even with this addition, semi-analytic models cannot reproduce the faint-end slope of the observed luminosity function.

A mechanism is required to suppress gas cooling in massive galaxies to prevent the number density of bright galaxies from being overpredicted and to prevent too many bright blue galaxies from forming.

Outstanding issues

- Rotational velocities are too large
- Too many red satellites
- Mismatch of the evolution of the galaxy mass function with redshift

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Hydrodynamical simulations

- 1. Specify cosmological model
- 2. Set the initial density field, either on a large grid or with a large particle number
- 3. Evolve the density field forward in time by numerically solving the gravitational and hydrodynamical equations.

While both the gas and dark matter can be followed simultaneously, computational power limits the simulation to either resolving large-scale structure or small-scale structure (internal galactic structure), but not both.

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Results of hydrodynamical simulations

Either supernova or AGN feedback is required to reduce the number density of galaxies at all masses, especially at the low and high ends.

Even with the addition of this feedback, massive galaxies are still too blue.

When the ISM is simulated as a multi-phase medium, where the SN feedback is injected primarily into the hot diffuse phase, the feedback is more effective in driving outflows and reducing the star formation.

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