Measuring the galaxy bias with Weak Lensing and Galaxy Clustering

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The broad picture

Dark energy

- Explains the recent acceleration of Universe expansion
- Slows down the formation of cosmological structures
The growth of structures

N-body Simulations from Millenium

100 Mpc

Growth of Power Spectrum

$P(k)$ vs $k$ [

$z=0$

$z=1.5$

$z=4.5$

$k$ [1/Mpc]

10^{-6} 10^{-4} 10^{-2} 10^{0} 10^{2} 10^{4}$

$10^{-8} 10^{-6} 10^{-4} 10^{-2} 10^{0} 10^{2} 10^{4}$

The Euclid Mission 2020

Euclid will explore the following key fundamental questions:

1. Is dark energy merely a cosmological constant, as first discussed by Einstein, or
2. Is it a new kind of field that evolves dynamically with the expansion of the universe?
3. Is it a manifestation of a break-down of General Relativity and deviations from the law of gravity?
4. What are the nature and properties of dark matter?

Euclid is based on 2 main observational techniques:

- Gravitational Lensing
- Galaxy Clustering

Merson et al. 2013
Galaxy and Matter clustering

Density contrast of matter... and galaxies

\[ \delta(x) = \frac{\rho_m(x) - \bar{\rho}_m}{\bar{\rho}_m} \]

\[ \delta_g(x) = \frac{\rho_g(x) - \bar{\rho}_g}{\bar{\rho}_g} \]

Galaxy bias is the ratio \( b^2 = \frac{\langle \delta_g^2 \rangle}{\langle \delta^2 \rangle} \) or in Fourier \( b^2(k, z) = \frac{P_g(k, z)}{P_m(k, z)} \).
Why do we care about bias?

⇒ Bias increases the S/N of BAO peaks

$$\text{SN}_{\text{BAO}} \propto n_g P_g \propto n_g b^2 P_m$$

⇒ Bias decreases the S/N of RSD ($\beta = f/b$)

$$\frac{\delta \beta}{\beta} \approx 4.9 \times 10^2 \, b^{0.7} \, V^{-0.5} \exp \left( \frac{1.7 \times 10^{-4}}{b^2 n} \right)$$

Galaxy bias conditions the type of measurement to do cosmology

Anderson et al. 2012

Bianchi et al. 2012

de la Torre et al. 2012
Typical Galaxy Bias behavior

From COSMOS measurements
⇒ Bias increases with redshift
⇒ Bias increases with luminosity
⇒ At high-z, sBzK are less biased than pBzK at small scales (McCracken+2010)
⇒ Bias is larger for active galaxies at large scales (Tinker+2012)

From SDSS measurements
⇒ Bias increases with luminosity (Zehavi+11)
⇒ Bias increases with stellar mass (Li+06)
⇒ Bias increases with halo mass (Johnston+07)
⇒ Bias increases at small scales (Cresswell+09)

From SUBARU DEEP SURVEY
⇒ Bias is large at high redshift (@z=4) (Ouchi+04)
Galaxy bias with WL and GC
(Schneider 1998, Van Waerbeke+98, Hoekstra+ 2002)

=> Aperture statistics is half way between theory and observations

- It is the integral of the projected lensing power spectrum $P_κ(l)$ filtered by a Besel function
- It is the integral of the 2-pt correlation function filtered by a compensated function

=> Galaxy bias comes naturally as a ratio of aperture statistics

\[ b(\theta) = f_1(\theta, Ω_m, Ω_Λ) \times \sqrt{\frac{\langle N^2(θ) \rangle}{\langle M_{ap}^2(θ) \rangle}}, \]

Figure: Lensing of background galaxies (yellow) by foreground structures (white galaxies + dark matter halos)
HST-COSMOS (2 deg$^2$)

The astrophysical dependence

- Bias increases with redshift
- Bias increases with stellar mass
- Agreement with theory for halos btw $10^{10}$ and $10^{12}$ $h^{-1} M_{\odot}$
- Agreement with other measurements
  - zCOSMOS (Kovac+09)
  - VVDS (Marinoni+05)

![Graph showing redshift vs. linear bias with data points and curves for different mass ranges.](image)
=> Goal: Measure the bias of the most luminous galaxies in redshift bins

- SDSS-CFHT-Stripe 82 field of 150 deg$^2$
- SDSS color-color selection of galaxies (~100,000 gal. per sample)
- Lensing catalog available from CFHT-Megacam observations
Are the most luminous highly biased?

Comparat et al. 2013

BOSS-CMASS
\(w_0 = 0.87 \pm 0.24, b \approx 2\)

Anderson et al. 2012

Figure: Galaxy bias of our CC selected galaxy samples. In Blue: Comparison to theoretical power spectrum
Red: Comparison to WL power spectrum measurements
1. Galaxy bias conditions the type of measurement to do cosmology
   - BAO requires highly biased galaxies
   - RSD requires weakly biased galaxies

2. Typically Galaxy bias increases for high-z, luminous and quiescent galaxies (from COSMOS, SDSS, etc.)

3. Combination of WL and GC can measure galaxy bias
   - In COSMOS (2 deg$^2$), we measured galaxy bias in the following bins
     - In scales $0.2 < R < 15$ h$^{-1}$ Mpc
     - In Redshift $0.2 < z < 1$
     - In Stellar mass $10^9 < M_* < 10^{11}$ h$^{-2}$ M$_\odot$
   - In CFHT-Stripe 82 (150deg$^2$), we found for luminous galaxies at $z \sim 1$
     - Bias is roughly equal $b = 2 \rightarrow$ our color-color selection is good for BAO
Expected constraints from Euclid