The Horizon-AGN Simulation

Effect of baryons on small scale weak lensing statistics

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Gouin et al. 2019, submitted to A&A

... this week on arXiv
Baryons may matter

Small non-linear scales contribute to cosmic shear signal. As we get close to (1-)halo scales, baryons do not behave exactly like DM.
Hydrodynamical simulations

Ratio of two point total matter density power spectra

*Chisari et al. 2018*

Potential source of bias for Cosmic shear

*Semboloni et al. 2011*
Baryons in halos

Prescriptions on how gas (and stars) will be distributed inside halos and how DM particles in DM-only sims will respond.

Main degrees of freedom: slope of gas density profile and outermost radius of ejection)… and stellar mass of central

Can capture results of hydro-sims (H-AGN, Illustris*, EAGLE, OWLS) and mimic the impact on matter PS.

Observations easily set $M_\star \mid M_{\text{halo}}$

X-ray clusters can constrain slope and outermost radius but the main uncertainty is the hydrostatic mass bias (ie what is the actual halo mass of a cluster with a given observed gas profile? → related to cluster lensing mass modeling)
Horizon-AGN past lightcone

Why a full ray-tracing?

Compare amplitude of baryonic effects with small scale effects (γ → g, beyond Born, magnification bias)

Insights on Stellar-to-halo mass relations: gal-gal lensing (weak and strong)

Mock lensed galaxy catalogs (gal evolution)

Mock lensed images (“end-to-end” studies)

Light-cone properties

✓ 5 square degrees until z~1
✓ 1 square degree until z~7

Deflection in each plane derived from Simulation transverse acceleration (no proj of particles)

Observer
Convergence Power Spectrum

Born approximation
1% valid up to $l \sim 10^5$

For $0.5 < z_s < 1.5$, $\frac{\Delta P_{\kappa}}{P_{\kappa}}$
-2% for $l > 10^3$
-10% for $4000 < l < 2000$
Then cooled baryons kick in
Shear correlation functions

\[ \xi_{\pm}(\theta) = \langle \gamma_+(\theta + \theta)\gamma_+(\theta) \rangle_{\theta} \pm \langle \gamma_+(\theta + \theta)\gamma_-(\theta) \rangle_{\theta} \]

\[ = 2\pi \int d\ell \ell J_{1/4}(\theta \ell) P_\kappa(\ell), \]

\[ g \equiv \frac{\gamma}{1 - \kappa} \]

1-5% increase on few arcmin angular scales

Baryons \(\rightarrow\) 10% depletion on few arcmin angular scales

(+large boost from stars below 1arcmin)
Galaxy-Galaxy lensing (GGL)

Good agreement with CMASS lenses \( \times \) CFHTLenS+CS82 sources

\[ \gamma_t \propto \Delta \Sigma(R) = \int dz \, \bar{\rho} \xi_{g,m}(r) \]

\( \rightarrow \) H-AGN \( M^*-M_{\text{halo}} \) relation consistent

Small excess below 200 kpc: ??gas not sufficiently pushed out??

\[ \Delta \Sigma \text{ [Mpc}^2 \text{M}_\odot^{-2}] \]

\[ \text{Radius [Mpc]} \]

- \( z_l=0.55, M^*>1.70, \text{SPL Total} \)
- \( z_l=0.55, M^*>1.70, \text{SPL DM} \)
- \( z_l=0.55, M^*>1.70, \text{SPL Baryons} \)
- \( z_l=0.55, M^*>1.70, \text{OBB Total} \)
Bright objects with material along the line of sight get preferentially selected...

Also true for foreground lenses if $z_l$ is large enough (>0.6)
Effect of Magnification bias on GGL

High- z magnif bias impact  (see also Ziou&Hui 08)

large scale boost of shear: 20 to 50%

Strong for Euclid spec sample:
When combining 3x2-point Cls <gg>, <mm> and <gm> won’t line up!
Shear ratio tests: \( \gamma(z_l,z_s1)/\gamma(z_l,z_s2) = (D_{ls1}/D_{s1}) / (D_{ls2}/D_{s2}) \Rightarrow \text{cosmography} \)

tests are in trouble because intervening matter causing mag bias will act differently on source planes \( z_{s1} \) and \( z_{s2} \)
Mock images

Band $u,g,z$

before lensing

1 degree

$\sim 1$ arcmin
Mock images

Band u,g,z

after lensing

1 degree

~ 1 arcmin
Mock images

No Lensing
Mock images
Baryons: significant role in 2-pt shear statistics

- >1% for k>0.1 h/Mpc, as high as 25% at 10 h/Mpc
- Gas distribution in clusters and groups (expelled fraction, how far?) captures main features (Schneider, Teyssier et al. 2015, 2019)

Room for improvement in “Baryonic corrections”:
- Cluster lensing to calibrate mass-observables
- Diffuse gas distribution at r>r_{500}
- Sub-grid physics and larger hydro-simulation boxes

3D→2D full raytracing: does not change picture
- beyond-Born
- reduced-shear

Galaxy-Galaxy Lensing:
- Magnification bias can bias 3x2pt high-z analyses and shear ratio tests.
- Wealth of information in mock images for end-to-end studies
Strong lensing

Horizon-AGN has the resolution to probe internal structure of galaxies
\[
\rho_{\text{dmo}}(r) = \rho_{\text{nfw}}(r) + \rho_{2h}(r).
\]

\[
\rho_{\text{dmb}}(r) = \rho_{\text{gas}}(r) + \rho_{\text{cga}}(r) + \rho_{\text{clm}}(r) + \rho_{2h}(r),
\]

\[
\rho_{\text{gas}}(r) = \frac{\rho_{\text{gas,0}}}{(1 + u)\beta(1 + v^2)^{(7-\beta)/2}}
\]

\[
v = r/r_{\text{ej}},
\]

\[
r_{\text{ej}} = \theta_{\text{eq}}r_{200}
\]

\[
\beta(M_{200}) = 3 - \left(\frac{M_c}{M_{200}}\right)^{\mu}
\]

<table>
<thead>
<tr>
<th>Name</th>
<th>Comp.</th>
<th>Description</th>
<th>Equation</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\theta_{\text{ej}})</td>
<td>Gas</td>
<td>Parameter specifying the maximum radius of gas ejection relative to the virial radius.</td>
<td>(2.12)</td>
<td>free</td>
</tr>
<tr>
<td>(\theta_{\text{co}})</td>
<td>Gas</td>
<td>Parameter specifying the core radius of the gas profile relative to the virial radius.</td>
<td>(2.12)</td>
<td>fixed</td>
</tr>
<tr>
<td>(M_c)</td>
<td>Gas</td>
<td>Parameter related to the slope of the gas profile: defines the characteristic mass scale where the slope becomes shallower than minus three.</td>
<td>(2.16)</td>
<td>free</td>
</tr>
<tr>
<td>(\mu)</td>
<td>Gas</td>
<td>Parameter related to the slope of the gas profile: defines how fast the slope becomes shallower towards small halo masses.</td>
<td>(2.16)</td>
<td>free</td>
</tr>
<tr>
<td>(A, M_1)</td>
<td>Star</td>
<td>Parameters related to the stellar fractions: normalisation and slope of the power-law describing the halo mass dependence.</td>
<td>(2.11)</td>
<td>fixed</td>
</tr>
<tr>
<td>(\eta_{\text{star}})</td>
<td>Star</td>
<td>Parameter specifying the total stellar fraction within a halo (including central galaxy, satellites, and halo stars).</td>
<td>(2.11)</td>
<td>free</td>
</tr>
<tr>
<td>(\eta_{\text{cga}})</td>
<td>Star</td>
<td>Parameter specifying the stellar fraction of the central galaxy.</td>
<td>(2.11)</td>
<td>free</td>
</tr>
<tr>
<td>(R_h)</td>
<td>Star</td>
<td>Parameter specifying the truncation radius of the central galaxy.</td>
<td>(2.10)</td>
<td>fixed</td>
</tr>
<tr>
<td>(\varepsilon)</td>
<td>DM</td>
<td>Parameter specifying the truncation radius of the NFW profile.</td>
<td>(2.6)</td>
<td>fixed</td>
</tr>
<tr>
<td>(a, n)</td>
<td>DM</td>
<td>Parameters related to adiabatic relaxation of the dark matter (including galaxy satellites and halo stars).</td>
<td>(2.17)</td>
<td>fixed</td>
</tr>
<tr>
<td>(q, p)</td>
<td>2-halo</td>
<td>Standard parameters specifying the 2-halo term (excursion-set modelling).</td>
<td>(2.9)</td>
<td>fixed</td>
</tr>
</tbody>
</table>
Born approximation

Implicit equation for the source plane angular coordinates:
Integrates deflections along perturbed light rays

$$\beta(\theta, \chi_s) = \theta - \frac{2}{c^2} \int_0^{\chi_s} d\chi \frac{\chi_s - \chi}{\chi_s \chi} \nabla_\beta \phi (\beta(\theta, \chi), \chi)$$

Born Approximation: Integrates deflections along unperturbed light rays

$$\beta(\theta, \chi_s) = \theta - \frac{2}{c^2} \int_0^{\chi_s} d\chi \frac{\chi_s - \chi}{\chi_s \chi} \nabla_\theta \phi (\theta, \chi)$$