Are Deep JWST Surveys of the First Light Epoch limited by Instrumental, Natural, or "Gravitational" Object Confusion?

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In Wyithe et al. (2011, Nature, 469), we show that gravitational lensing will lead to a correlation between the sky positions of high redshift candidates and foreground galaxies at z≃1–2, and present evidence for this correlation among a sample tentatively identified at z≃10.6. By extrapolating the evolution of the galaxy LF-slope and amplitude to z≳8, we suggest that gravitational lensing may dominate the observed properties of galaxies at z≳10 discovered by JWST. The observed surface density of galaxies at z≳12–15 will likely be boosted by an order of magnitude, and most z≳12–15 galaxies may be part of a multiply-imaged system, located ≲1″ away from a brighter foreground galaxy at z≃1–2.

This means that deep JWST surveys of the First Light epoch at z≳10 may be limited by "gravitational" confusion, where a good part of the First Light "forest" may be gravitationally amplified by the foreground galaxy "trees". Gravitational lensing bias will therefore need to be carefully considered for First Light studies with JWST. The exquisite resolution and sensitivity of JWST will be essential to properly address this issue at z≳8–10.

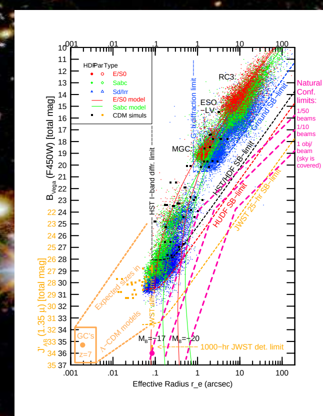
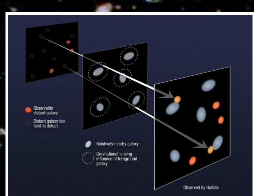


Fig. 1. B- or J_{AB} -mag vs half-light radius r_e for the galaxy population from the RC3 to the HUDF limit. Blue, black or red slanted lines (with slope=+5) indicate the survey surface brightness (SB)-sensitivity limits, and where these turn horizontal is the point source sensitivity limit. Pink lines indicate the natural confusion limit, where galaxy overlap becomes significant because of their own sizes. For deep JWST surveys with ≳0.08" FWHM resolution, the natural confusion limit may become as important for the definition of faint object samples as the survey SB-limit (Windhorst et al. 2008). This may already be visible in the deepest HUDF images for AB≳25 mag. This does, however, not mean that the deepest JWST samples will be fundamentally limited by natural confusion. Instead, from hierarchical simulations (orange points), faint objects with AB≳28 mag seen by JWST are likely mostly unresolved at ≳0.08" FWHM. For such objects, instrumental confusion doesn't set in until AB≳33.5 mag, which JWST will not likely reach (unless it exposes ≳1000 hrs). Does this mean that the confusion limit is irrelevant for JWST?



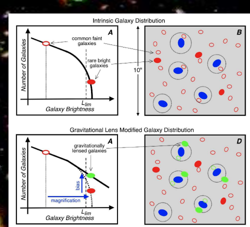


Fig. 2a. [Left]: Schematic representation showing how magnification bias leads to an association between foreground galaxies and high redshift candidates. Fig. 2b. [Right]: Panel A: The Schechter LF of high redshift galaxies. Panel B: High redshift galaxies (red) and foreground galaxies (blue). Open symbols indicate undetected galaxies ($m_{AB} \gtrsim m_{\rm lim}$). Closed symbols are detected galaxies ($m_{AB} \lesssim m_{\rm lim}$). Black dotted areas are regions of sky where background sources will be multiply imaged by the foreground galaxy (blue) halo. Panel D: The lensed faint galaxies are multiply-imaged, producing a detected image with $m_{AB} \lesssim m_{\rm lim}$ (green), and an undetected faint image with $m_{AB} \gtrsim m_{\rm lim}$ (dashed green). (Galaxies near the lines of sight to foreground galaxies that are not multiply imaged are deflected to larger separations, resulting in a lowering of observed source density, *i.e.*, "depletion"). Panel C: The resulting effect of gravitational lensing bias on z≳8-10 galaxy samples. The observed LF can get modified from a Schechter function to a double power-law, with the brighter objects gravitationally lensed into the sample (see Wyithe et al. , 2011).

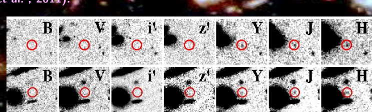


Fig. 3. Six examples of gravitationally lensed z≃8–10 candidates behind foregound galaxies at z≃1–2 (Yan et al. 2010) in the HUDF in BViz (ACS) YJH (WFC3). The background image of this poster also shows all available 506 orbits of the HUDF in the BVizYJH filters (properly color balanced), where Y-drops or z≳8 candidates are marked as green circles, and J-drops or z≳10 candidates as red circles.

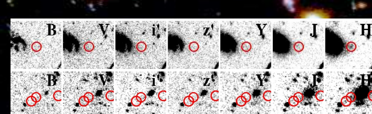
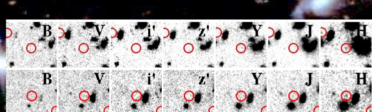


Fig. 3 (cont). Until spectroscopic confirmation is available, these Y-band and J-band dropouts are only considered z≳8 and z≳10 candidates, resp. JWST will be essential to get spectra for such objects, especially for those z≳8–10 candidates that are gravitationally lensed into the sample by z≃1–2 foreground galaxies. (All Figures and Captions were placed to maximize the visibility of z≳8–10 canidates.)



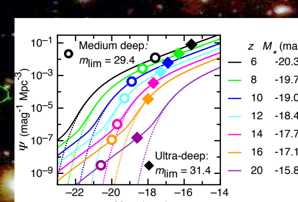


Fig. 4. Gravitational lensing bias of the bright-end of the galaxy LF to be observed with JWST. Thin curves present the intrinsic LF (Ψ), and solid curves the observed LF following modification from gravitational lensing. Uniform magnification was assumed outside regions of sky that are multiply-imaged, such that flux is conserved over the whole sky. The LF parameters α, Φ^*, and M^* were extrapolated to z≳8, using Bouwens et al. (2010b) for z≲8. Solid and open points show luminosities and densities of the faintest galaxies to be observed with JWST, assuming limiting magnitudes for both an ultra-deep survey ($m_{\rm AB} \lesssim 31.4$ mag), and a medium-deep JWST survey ($m_{\rm AB} \lesssim 29.4$ mag), respectively. The probability for gravitational lensing will become of order unity in the steep exponential parts of the LF at sufficiently high redshifts (Wyithe et al. 2011). This figure clearly shows that gravitational lensing bias will likely be important for JWST. We now need the exquisite resolution and sensitivity of JWST more than ever to properly disentangle First Light objects at z≳8–10 from lensing foreground galaxies at z≃1–2, especially for z≳12, where the majority of such objects may be lensed into the JWST samples.

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CONCLUSIONS: Deep JWST surveys with ≳0.08" FWHM resolution will: (1) not be limited by instrumental confusion, unless they can reach AB≳33.5 mag in ≳1000 hrs; (2) be gradually limited by natural confusion for 25≲AB≲31 mag; and (3) for searches of First Light objects at z≳8–10, become increasingly effected by "gravitational" object confusion from lensing bias by foreground objects, which may dominate at z≳12–15 in shallower surveys (AB≲30 mag). New object finding software and JWST survey strategies are needed to adress/take advantage of both.