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

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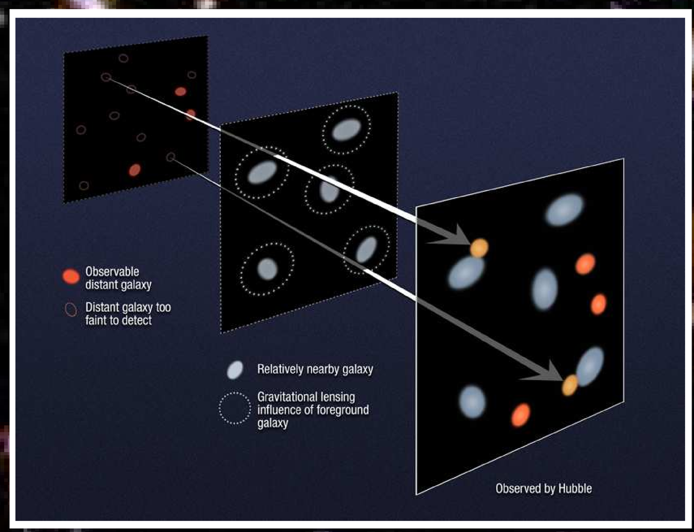
In Wyithe et al. (2011, Nature, 469, 181), we show that gravitational lensing will lead to a correlation between the positions of high redshift candidates and foreground galaxies at z≃1–2. Yan et al. (2010 and this Conf) presented evidence for this correlation among a sample of dropout candidates at z≃8–10. By extrapolating the evolution of the galaxy LF-slope and L^* 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 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″ from a 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 and corrected for in First Light studies with JWST. The exquisite resolution and sensitivity of JWST — together with a new generation of object finding algorithms — will be essential to properly address this issue at z≳8–10.



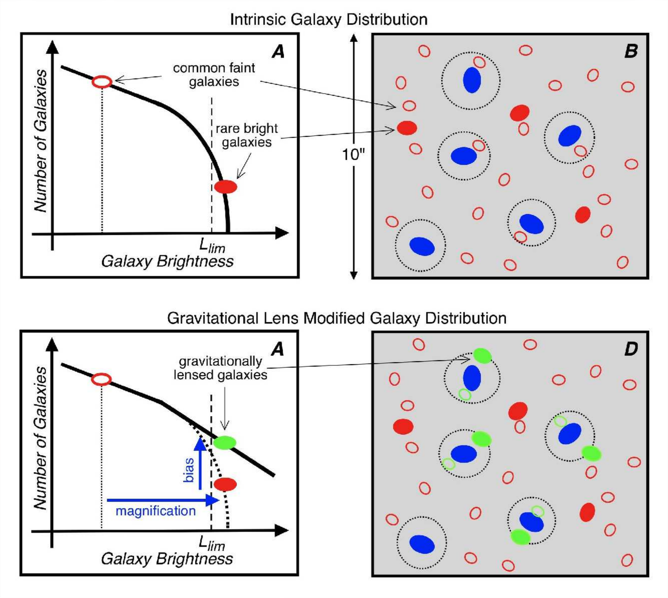


Fig. 2a. [Left]: Cartoon showing how magnification bias leads to an association between foreground galaxies and high redshift candidates. Fig. 2b. [Right]: Panel A: The Schechter LF of high redshift galaxies. Panel B: High redshift galaxies (red) and foreground galaxies (blue). Open symbols indicate undetected galaxies ($m_{AB} \gtrsim m_{\rm lim}$). Filled 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 foreground galaxy halos (blue). Panel D: The lensed faint galaxies are multiply-imaged, producing a detected image with $m_{AB} \lesssim m_{\rm lim}$ (green), and an undetected image with $m_{AB} \gtrsim m_{\rm lim}$ (dotted green). 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 (Wyithe et al., 2011).

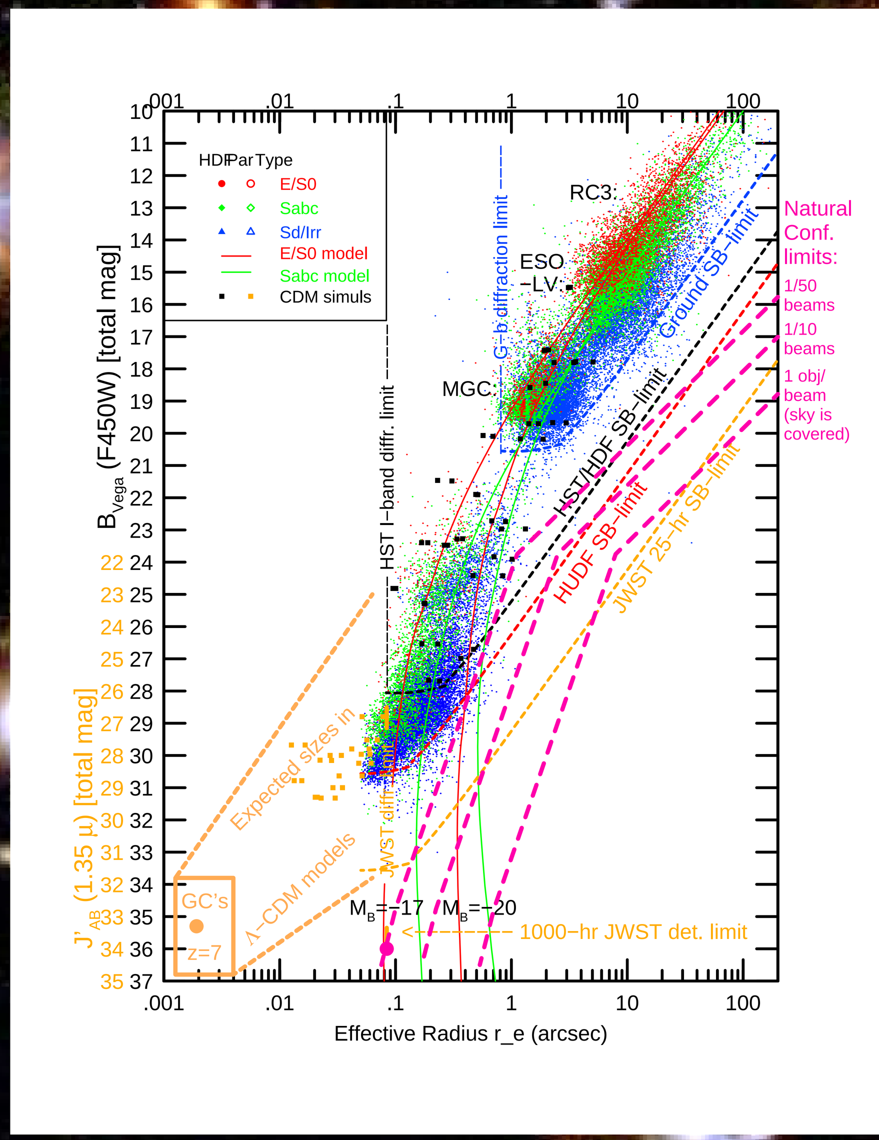
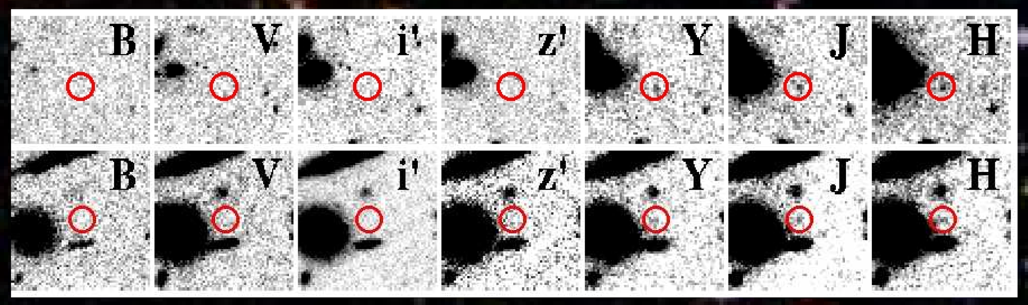


Fig. 1. B- or J_{AB} -mag vs half-light radius r_e for the galaxy population from the RC3 to the HUDF limit. Blue, black or red slanted lines (slope=+5) indicate the survey surface brightness sensitivity limits; where these turn horizontal is the point source sensitivity limit. Pink lines indicate the 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 (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 therefore mean that the confusion limit is irrelevant for JWST?



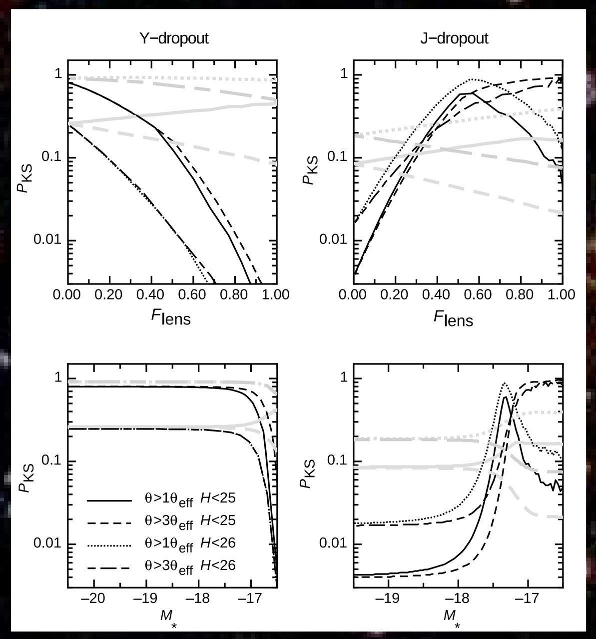


Fig. 3. [Above and Below]: Six examples of gravitationally lensed z≃8–10 candidates behind foreground galaxies at z≃1–2 (Yan et al. 2010) in the HUDF in BViz (ACS) YJH (WFC3). Until spectroscopic confirmation is available, these Y-band and J-band dropouts are only considered z≳8 and z≳10 candidates, 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. (The background image of this poster also shows all available 506 orbits of the HUDF in the BVizYJH filters (properly color balanced), with Y-drops or z≳8 candidates marked as green circles, and J-drops or z≳10 candidates as red circles. All Figures and Captions were placed to maximize the visibility of z≳8–10 candidates.)

Fig. 4. Constraints on the strong lensing fraction F_{lens} and M^* values (Wyithe et al. 2011b). Upper-Left and Right: KS-probabilities (vs. F_{lens}) that the distributions of angular separations (black lines) and the redshifts of bright (H≲26 mag) foreground galaxies (grey lines) — which are lensing the z≃8.6 and z≃10.6 candidates — are more different from the composite model distribution than observed. This is shown for 2 different minimum lens–candidate angular separations θ (in units of r_e), interior to which candidates are lost in the foreground lensing galaxy glare. Lower-Left and Right: As the upper-panels, but vs. M^* . We assumed a faint-end LF-slope α=–2 at z≳8. These probabilities can be interpreted as 1 minus the confidence with which the assumed value of the lens fraction or M^* value can be excluded. The implied lensing bias scenario parameters are $F_{lens} \gtrsim$10% and $M^* \gtrsim$–18 mag at z≃10.6.

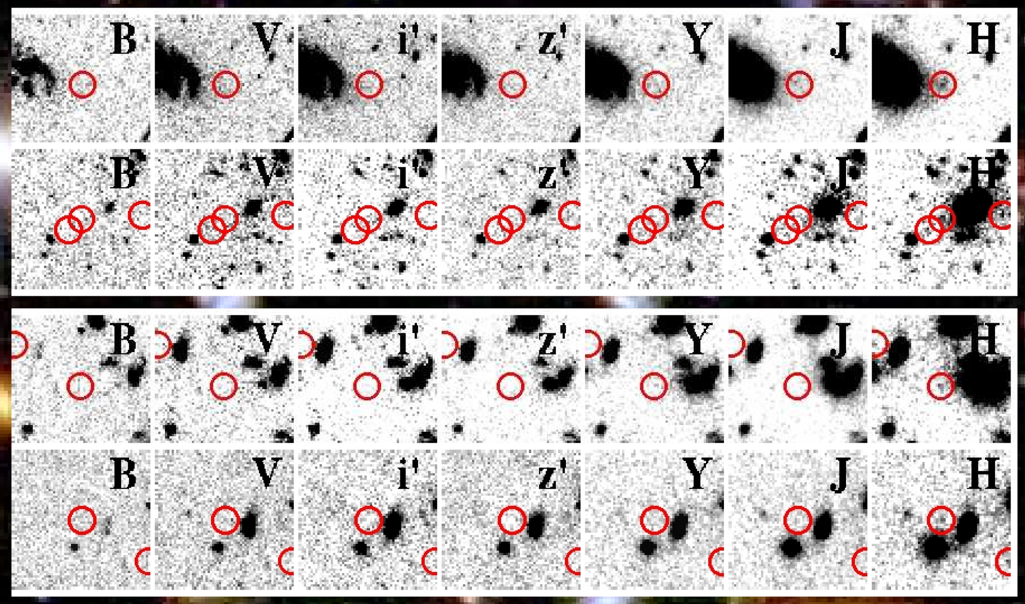
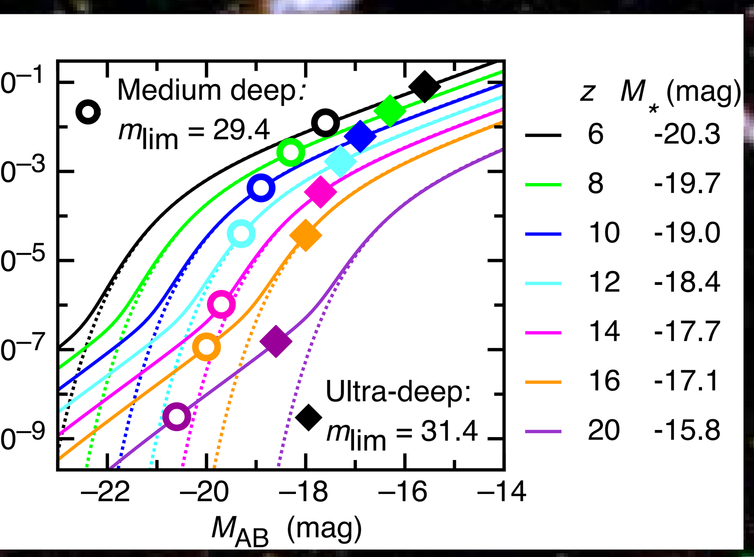


Fig. 5. [Below]: Gravitational lensing bias of the bright-end of the LF as seen by JWST. Dotted curves present the intrinsic LF (Ψ), and solid curves the observed LF following modification from gravitational lensing. The LF parameters α, Φ^*, and M^* were extrapolated to z≳8, using Bouwens et al. (2010) for z≲8. Solid and open points show the faintest galaxies observed with JWST, assuming limiting fluxes for both an ultra-deep survey (AB≲31.4 mag), and a medium-deep survey (AB≲29.4 mag), respectively. We need JWST's exquisite resolution and sensitivity to properly disentangle First Light objects at z≳8–10 from lensing foreground galaxies at z≃1–2, especially for z≳12–15, where the majority of such objects may be lensed into the JWST samples, lifting the steep exponential parts of the LF into a power-law (Wyithe et al. 2011).



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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 address/take advantage of both.