

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 $z \sim 1-2$, and present evidence for this correlation among a sample tentatively identified at $z \sim 10.6$. By extrapolating the evolution of the galaxy LF-slope and amplitude to $z \sim 8$, we suggest that gravitational lensing may dominate the observed properties of galaxies at $z \sim 10$ discovered by JWST. The observed surface density of galaxies at $z \sim 12-15$ will likely be boosted by an order of magnitude, and most $z \sim 12-15$ galaxies may be part of a multiply-imaged system, located $\sim 1''$ away from a brighter foreground galaxy at $z \sim 1-2$.

This means that deep JWST surveys of the First Light epoch at $z \sim 10$ 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 $z \sim 8-10$.

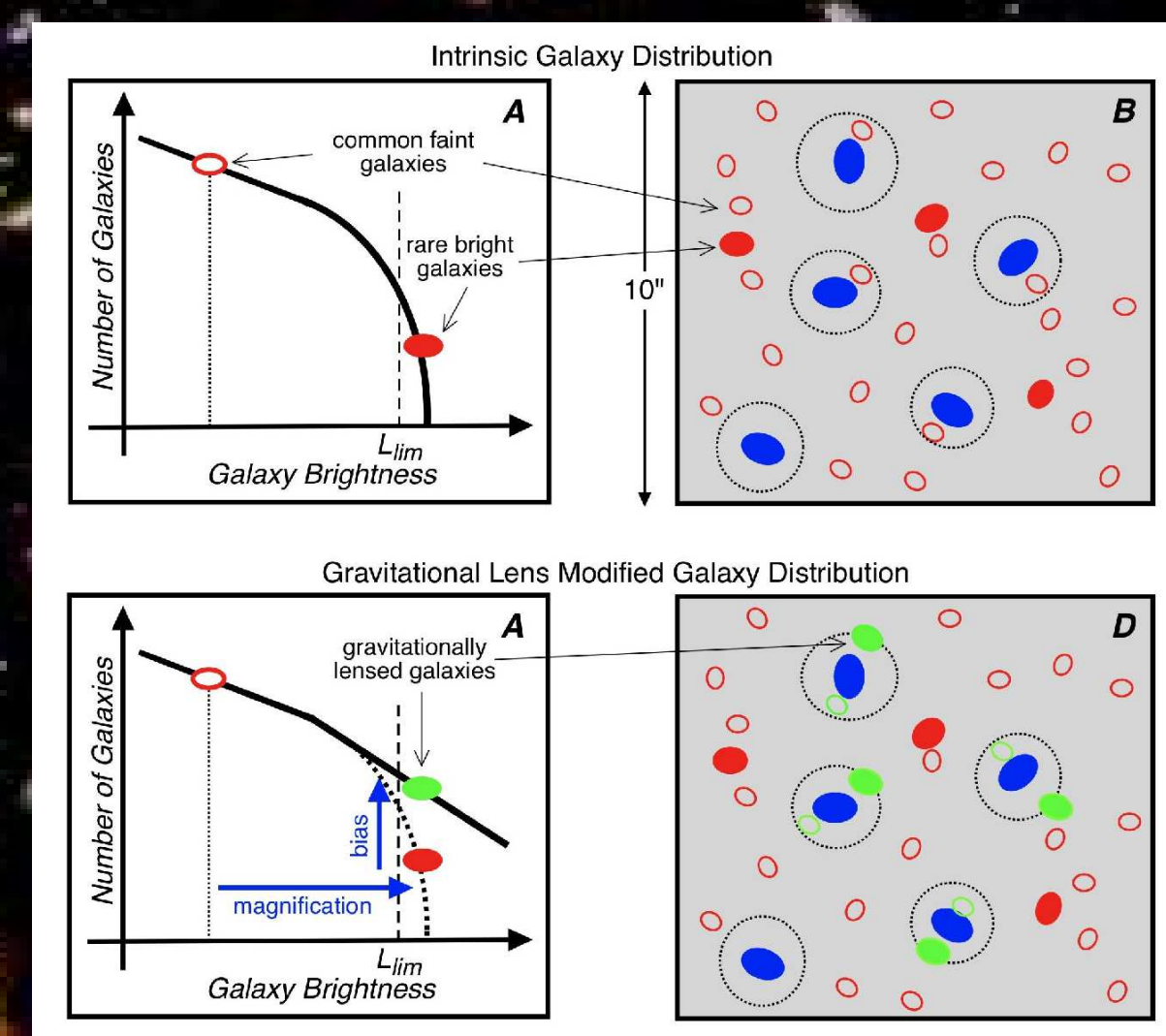
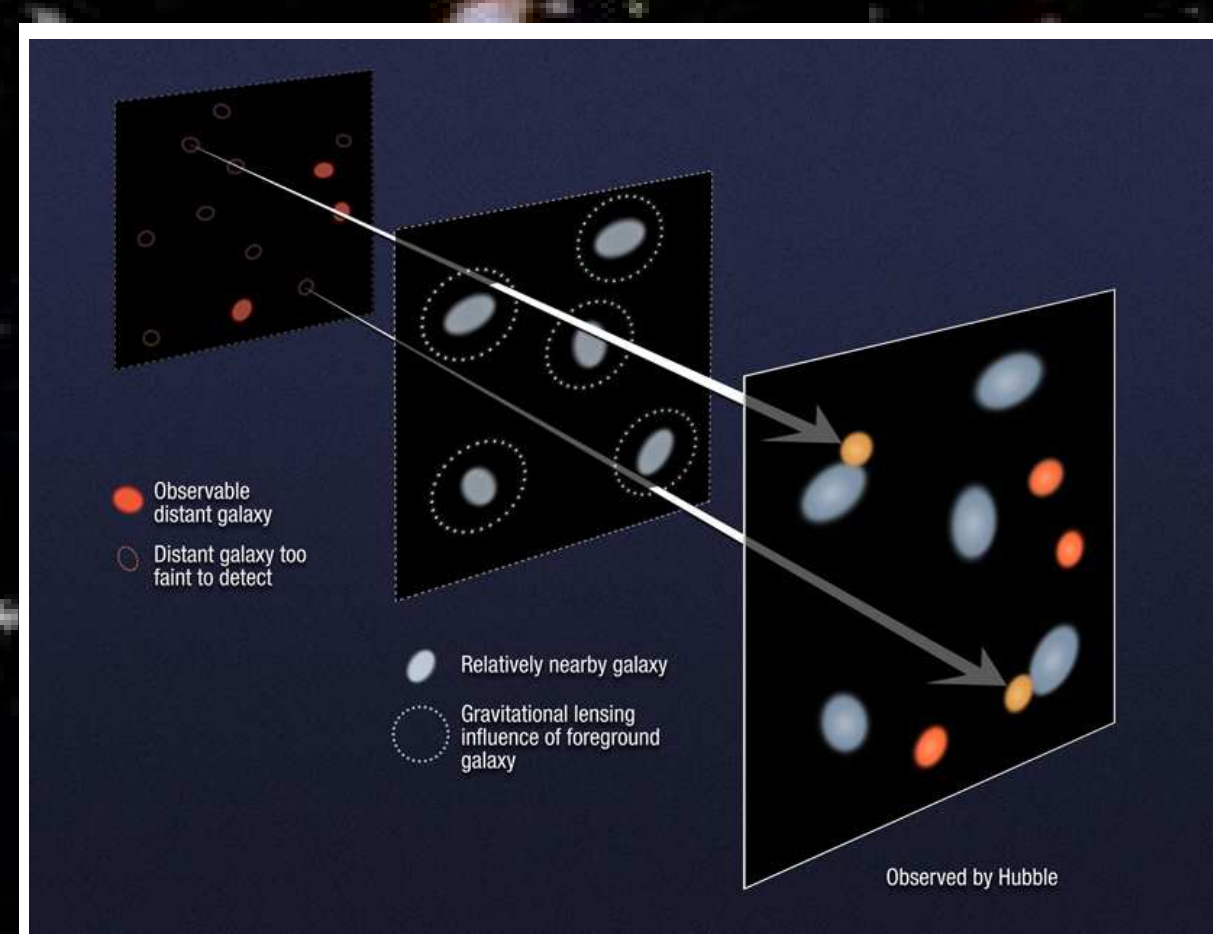


Fig. 2a. [Left]: Schematic representation showing how magnification bias leads to an association between foreground galaxies and high redshift candidates. Fig. 2b. [Right]: Panel A: The Schechter LF of high redshift galaxies. Panel B: High redshift galaxies (red) and foreground galaxies (blue). Open symbols indicate undetected galaxies ($m_{AB} > m_{lim}$). Closed symbols are detected galaxies ($m_{AB} < m_{lim}$). Black dotted areas are regions of sky where background sources will be multiply imaged by the foreground galaxy (blue) halo. Panel C: The lensed faint galaxies are multiply-imaged, producing a detected image with $m_{AB} < m_{lim}$ (green), and an undetected faint image with $m_{AB} > m_{lim}$ (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 D: The resulting effect of gravitational lensing bias on $z > 10$ 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).

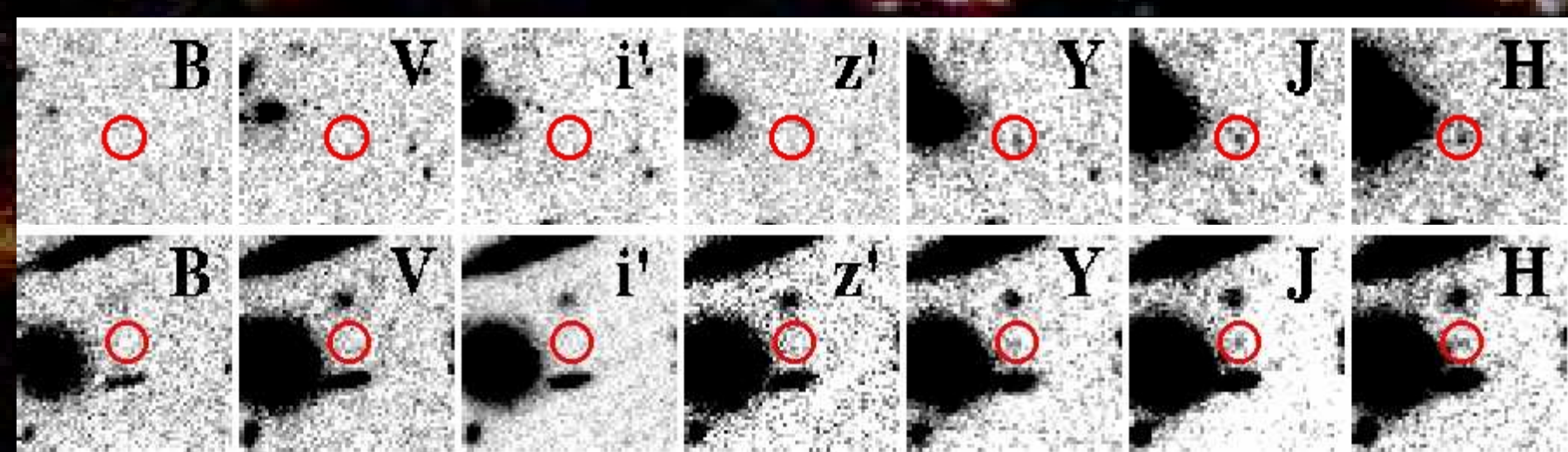


Fig. 3. Six examples of gravitationally lensed $z \sim 8-10$ candidates behind foreground galaxies at $z \sim 1-2$ (Yan et al. 2010) in the HUDF in BViz (ACS) YJH (WFC3). The background image of this poster also shows all available 506 orbits of the HUDF in the BVizYJH filters (properly color balanced),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

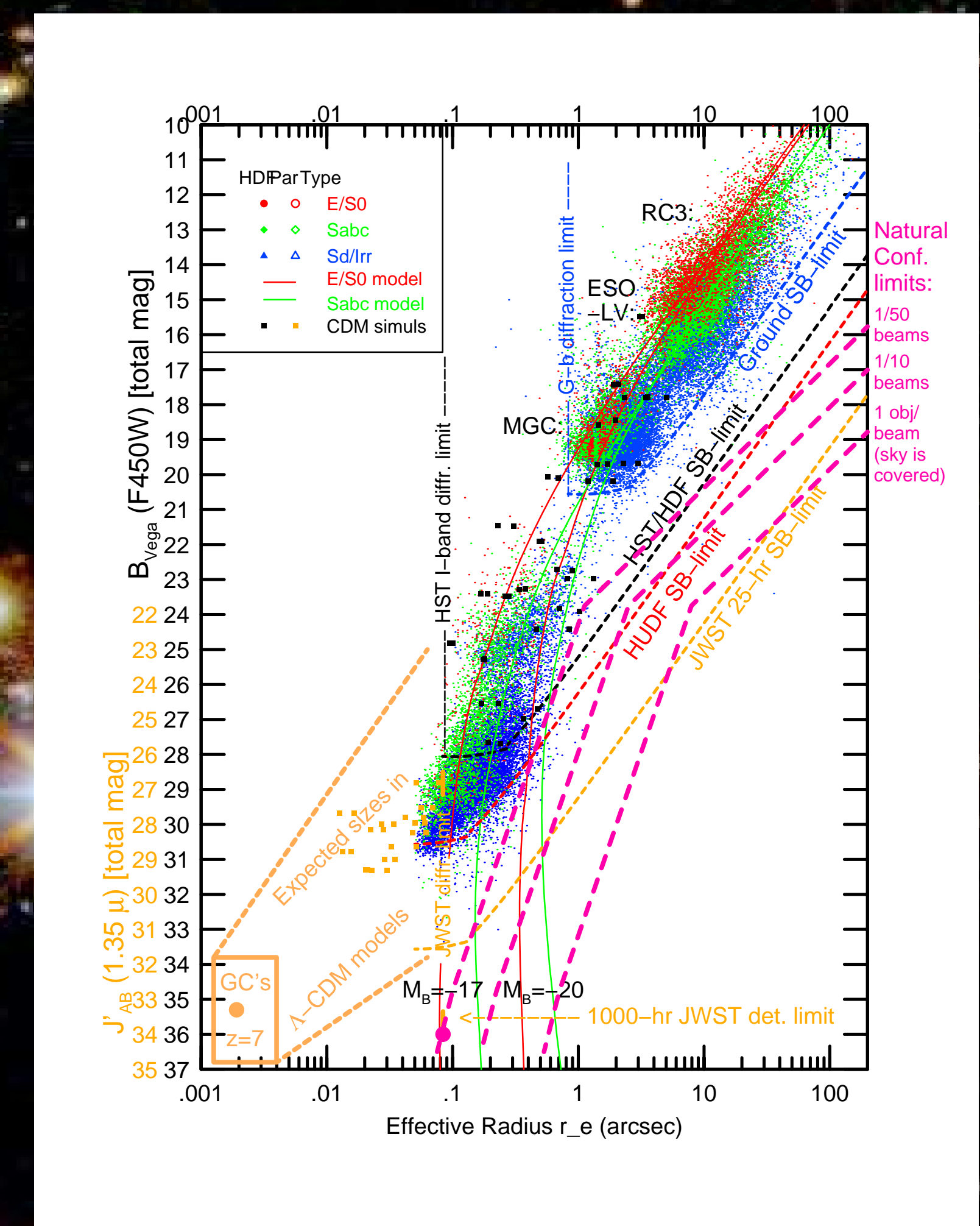
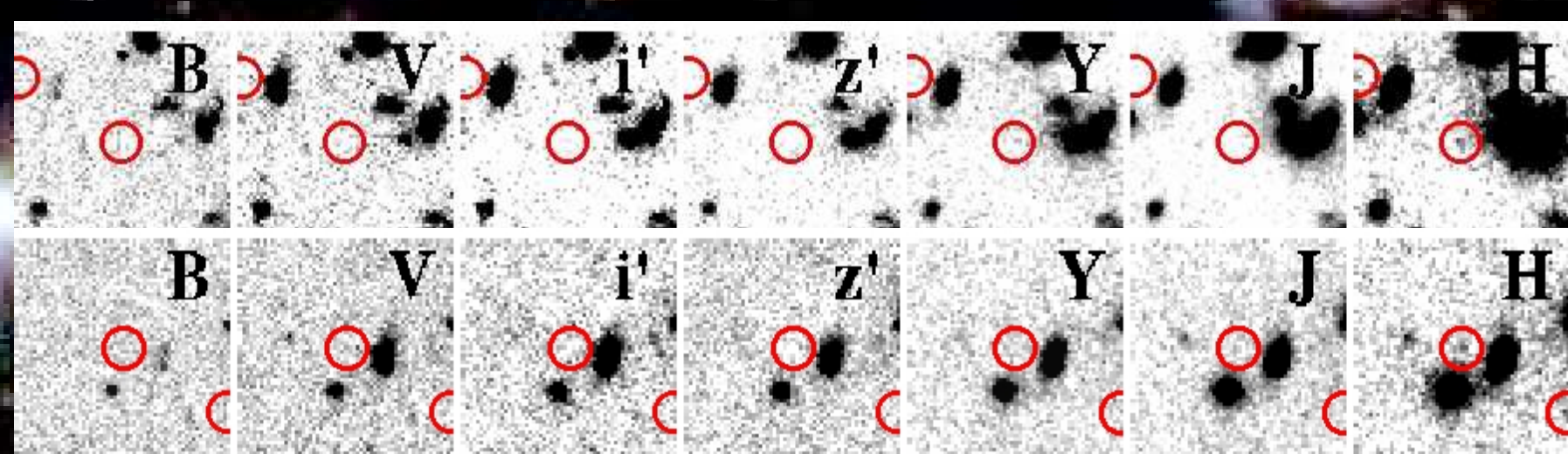
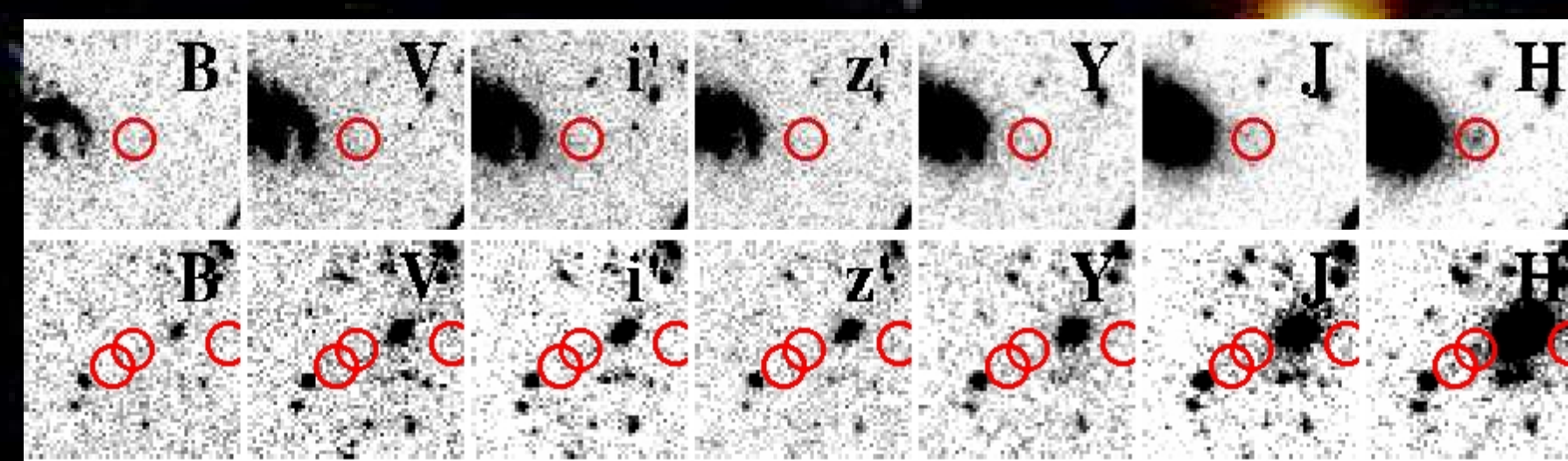


Fig. 1. B - or J_{AB} -mag vs half-light radius r_e for the galaxy population from the RC3 to the HUDF limit. Blue, black or red slanted lines (with slope $=+5$) indicate the survey surface brightness (SB)-sensitivity limits, and where these turn horizontal is the point source sensitivity limit. Pink lines indicate the natural confusion limit, where galaxy overlap becomes significant because of their own sizes. For deep JWST surveys with $\geq 0.08''$ 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 $AB \geq 25$ 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 $AB \geq 28$ mag seen by JWST are likely mostly unresolved at $\geq 0.08''$ FWHM. For such objects, instrumental confusion doesn't set in until $AB \geq 33.5$ mag, which JWST will not likely reach (unless it exposes ≥ 1000 hrs). Does this mean that the confusion limit is irrelevant for JWST?

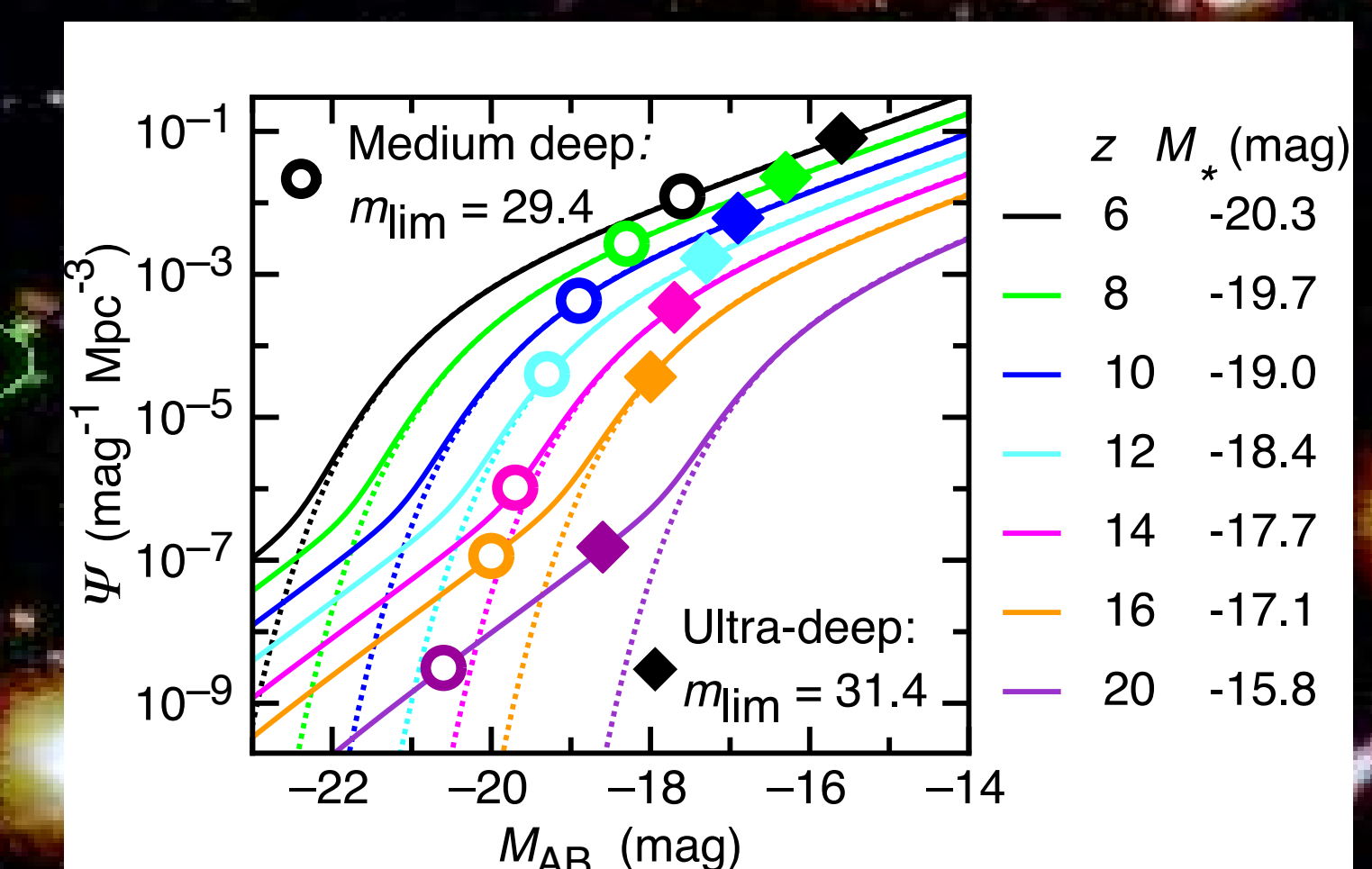


Fig. 4. Gravitational lensing bias of the bright-end of the galaxy LF to be observed with JWST. Thin curves present the intrinsic LF (ψ), and solid curves the observed LF following modification from gravitational lensing. Uniform magnification was assumed outside regions of sky that are multiply imaged, such that flux is conserved over the whole sky. The LF parameters α , Φ , and M^* were extrapolated to $z \geq 8$, using Bouwens et al. (2010b) for $z \geq 8$. 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 ($m_{AB} = 31.4$ mag), and a medium-deep JWST survey ($m_{AB} = 29.4$ 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 $z \sim 8-10$ from lensing foreground galaxies at $z \sim 1-2$, especially for $z \geq 12$, where the majority of such objects may be lensed into the JWST samples.

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