2022 Survey Science Group Meeting@high-1, 16/02/2023

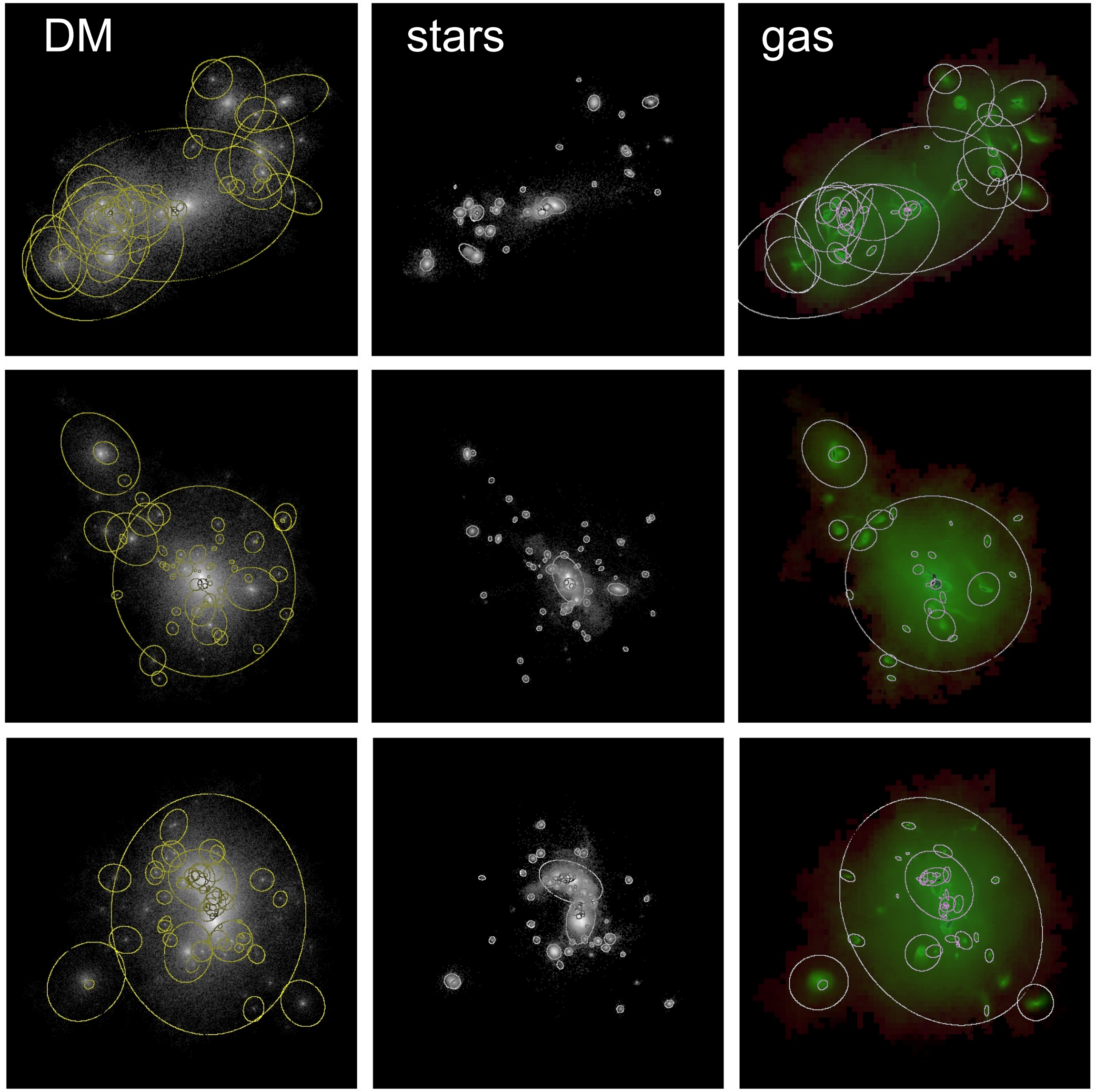
The Effect of Low-Surface-Brightness Galaxies on the Galaxy Stellar Mass Functions

Juhan Kim @ Korea Institute for Advanced Study

Galaxy Catalogs from The Horizon Run 5

- A Galaxy Finder: **P**hysically-self-bound **GAL**axy **F**inder (PGalF)
- Galaxy catalogs from z=13 down to z=0.625 containing galaxy information (stars, gas, dm particles, and AGNs)
- In total 20 HR5 science projects proposed as of today

A Galaxy Finding Example



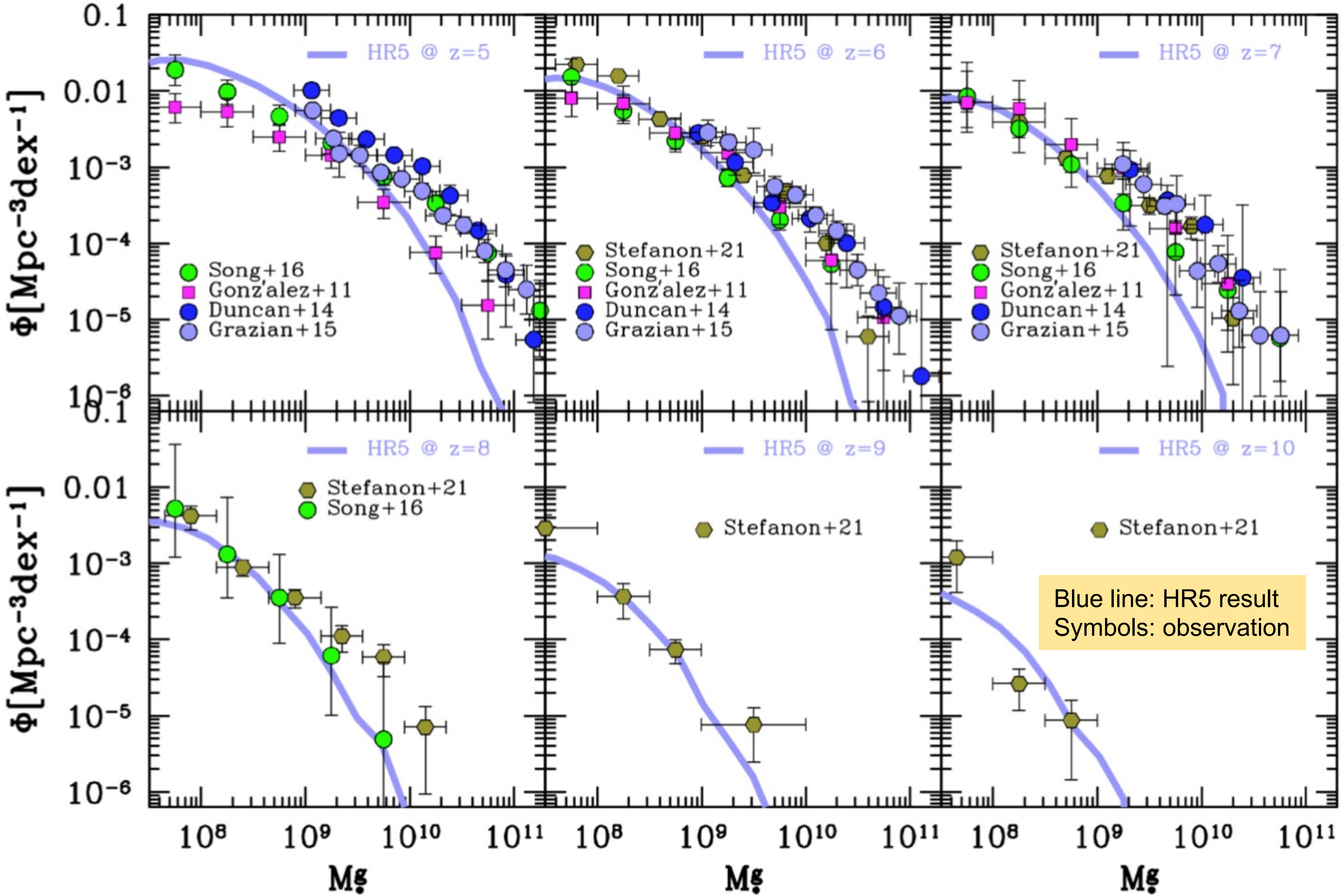
- A galaxy is composed of dm particles, star particles, gas, and AGNs.
- A large population of galaxies have no or few star particles (Shin+22) → What is the origin of UDG?
- Some massive galaxies have multiple AGNs.

Galaxy Stellar Mass Function (GSMF) at high-z

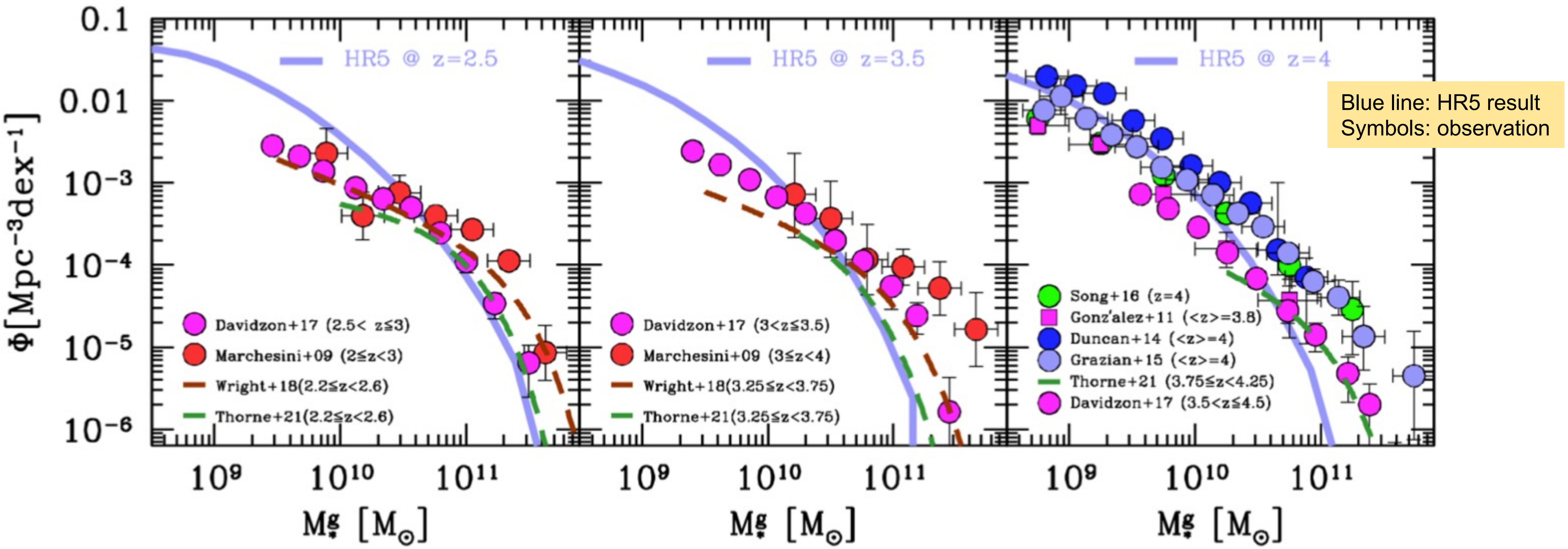
- At z≥ 8, HR5 and observations are similar.
- At 5≤z≤8, HR5 overproduces massive galaxies compared to observation.

Probable reasons

1. Reionization at z=10
2. Adaptive mesh refinement at z=9,4,1.2,0.4,

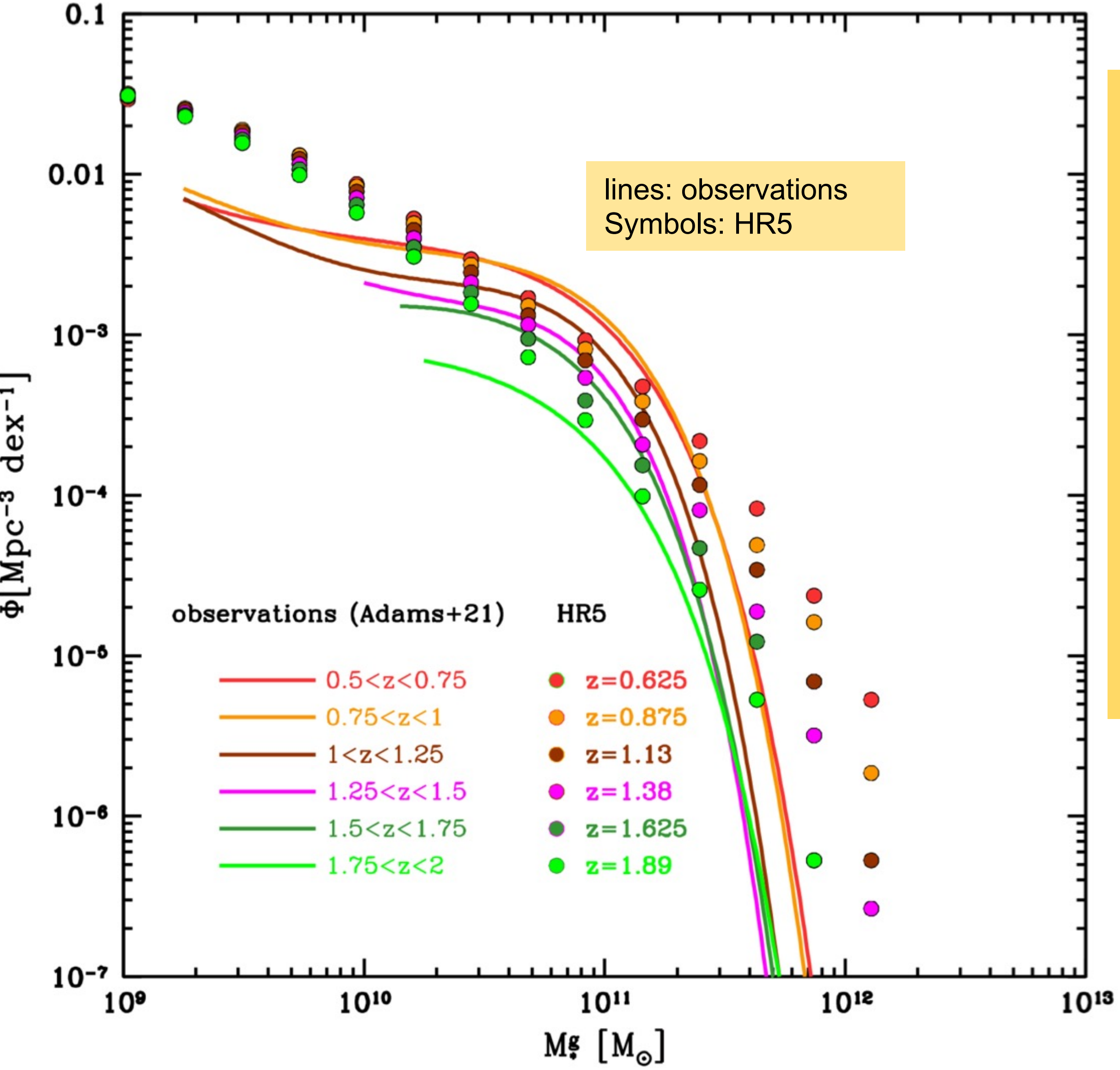


Galaxy Stellar Mass Function (GSMF) at medium-z



- On massive scale, the HR5 gradually catches up the observed population at z=2.5.
- On less-massive scale, the HR5 begins to overproduce dwarf galaxies at z=2.5.

Galaxy Stellar Mass Function (GSMF) at lower-z



1. Observed GSMF
   - Sharp drops at massive end
   - Strong knees
   - Plateau at dwarf mass scale

2. Simulated GSMF
   - Featureless power-law
   - Nearly constant at dwarf mass scale
   - Gradual increase at massive end

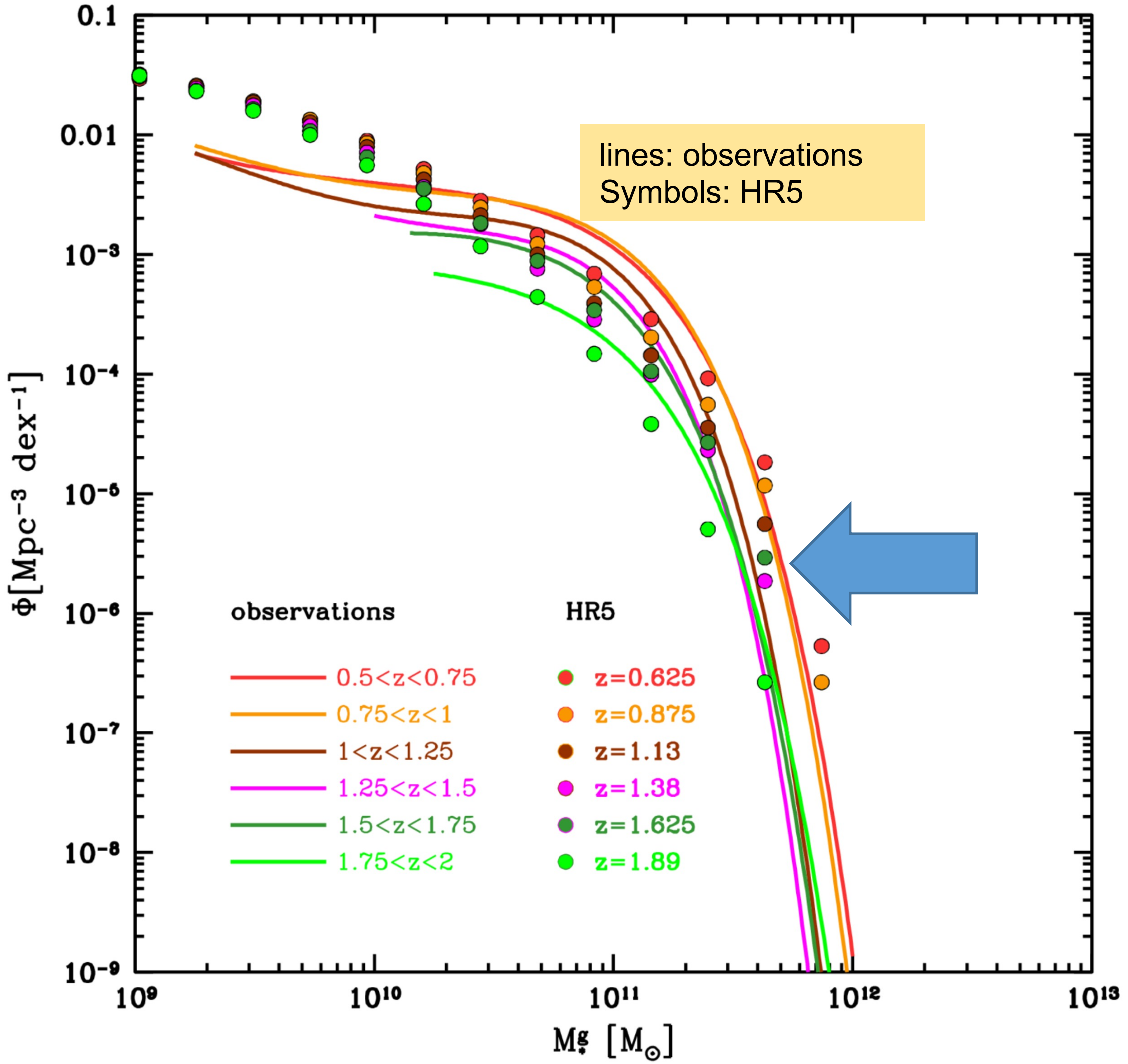
Well-known problems

- One of the CDM model catastrophes (Popolo+17)
  - Too-big-to-fail or missing satellite problem
  - Dwarf galaxies (LSB, UDG, etc.) have not been completely understood.

How to explain these differences

1. Simulation failures with wrong astrophysical parameters (SF rate, feedback effects, etc.)
2. Cosmological parameter failure (CDM, P(k), etc.)
3. Incompleteness in the observed GSMF

Galaxy Stellar Mass Function (GSMF) at lower-z



How to reduce the massive-scale differences:

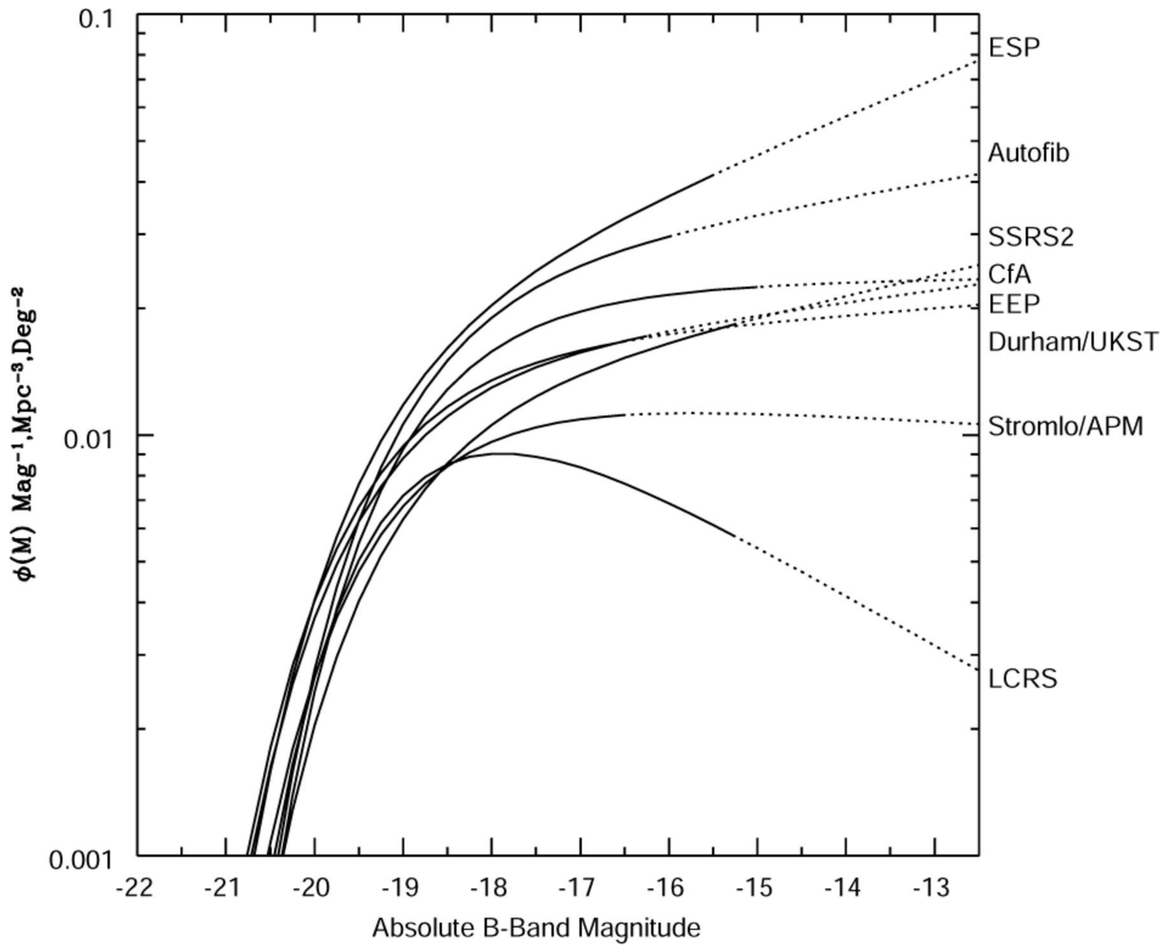
Alternative definition of galaxy stellar mass: **30kpc aperture correction** (McCarthy+16, Lagos+18, Adams+21, Tang+21) **to BCG galaxies** in measuring **the enclose stellar mass**

Surface Brightness Effect on Observed Galaxy Populations

Surface Brightness Limits in Galaxy Redshift Survey

- SDSS: $<\mu_r> \leq 26.5$ mag/arcsec^2
- LCRS: $<\mu_r> \leq 23$ mag/arcsec^2 (Cross+01)
- 2dFGRS, APM: $<\mu_{bJ}>^{e} \leq 24.7$ mag/arcsec^2 (Cross+01)
- ESP: no priori to selection of the surface brightness (b_J<19.4; Vettolani+97)
- SHELL: $<\mu_R>^{e} \leq 21.82(and\ 22.5)$ mag/arcsec^2 (Geller+12)
- UKST: $<\mu_{bJ}>^{e} \leq 25$ mag/arcsec^2 (Ratcliffe+98)
- HectoMap: $<\mu_r>^{fiber} \leq 22$ mag/arcsec^2 (Sohn+20)

A possible correlation between the faint-end slope of LF and the surface brightness constraints?



Mon Not R Astron Soc, Volume 324, Issue 4, July 2001, Pages 825–841, https://doi.org/10.1046/j.1365-8711.2001.04254.x

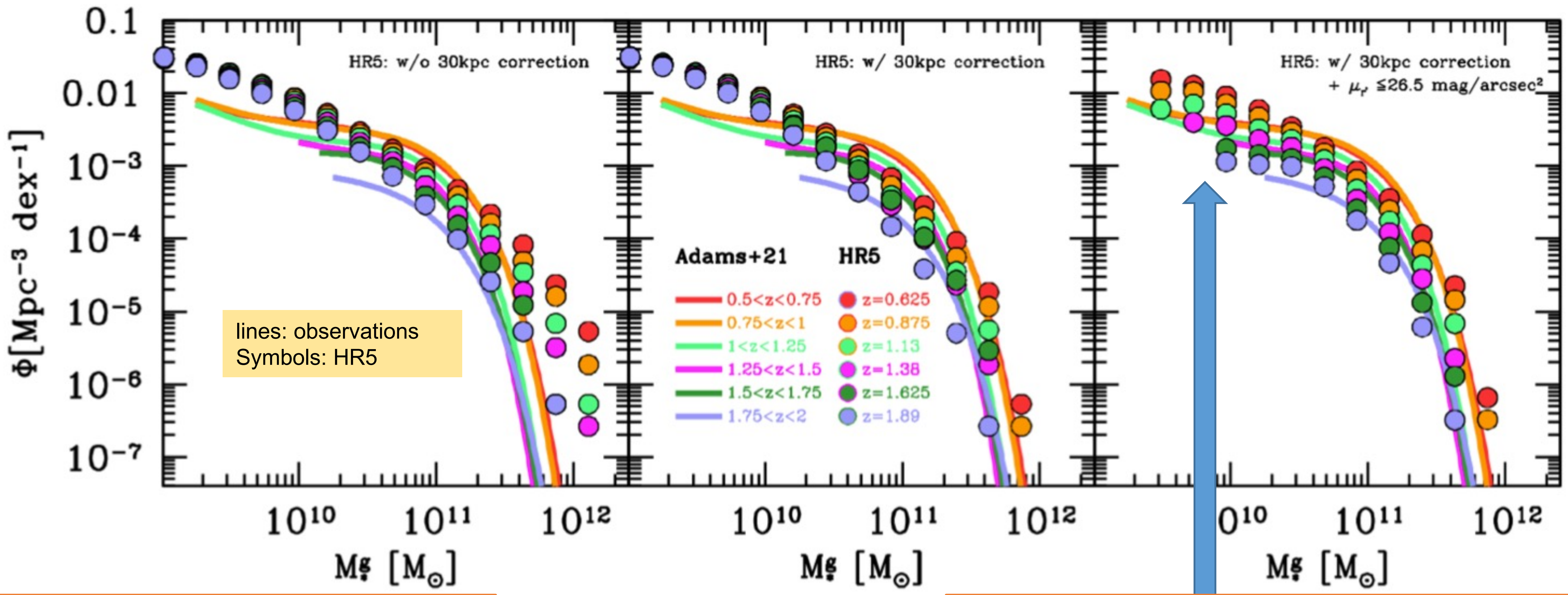
Surface Brightness Effect

- **Factors affecting the surface brightness**
  - Galaxy luminosity
  - Galaxy size
  - Redshift factor (time dilation, bandwidth broadening)
  - K-correction

$$\left\langle \mu_{1/2}^{X} \right\rangle \simeq \mathcal{M}_{\odot}^{X} - \frac{5}{2}\log\left(\frac{\mathcal{L}_{1/2}}{\mathcal{R}_{1/2}^{2}}\right) + 5\log(1+z) + \mathcal{K}(z;X) + 40.33, \qquad (14)$$

where $\mathcal{K}$ is the K-correction term for the redshifted spectral energy distribution (SED) of the galaxy, $\mathcal{L}_{1/2} \equiv L_{1/2}^{X}/L_{\odot}^{X}$, and $\mathcal{R}_{1/2} \equiv r_{1/2}/1\mathrm{kpc}$. The K-correction em-

Galaxy Stellar Mass Function (GSMF) at lower-z



Adams+21
- COSMOS, XMM-LSS
- B&C SED

Split of GSMF at faint end scale at different redshifts
1. Size evolution
2. Cosmological effect (5log(1+z))
3. K-correction

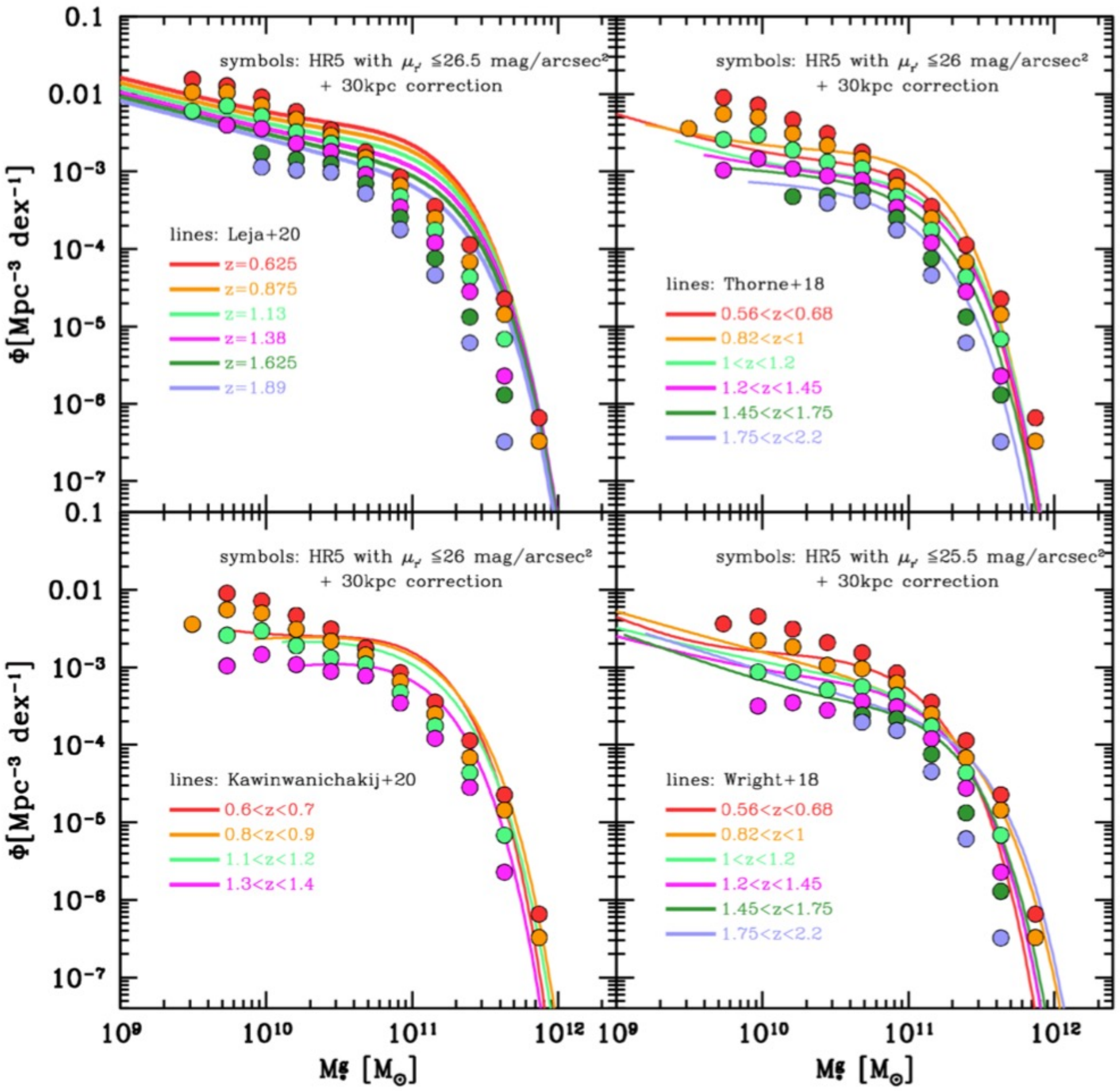
Galaxy Stellar Mass Function (GSMF) at lower-z

Leja+20
- 3D-HST, COSMOS-2015
- Uses Prospector g-SED code
- Chabrier IMF, B&C SED
- **Continuity model for GSMF (solving 0.2dex offset between SFR and GSMF)**

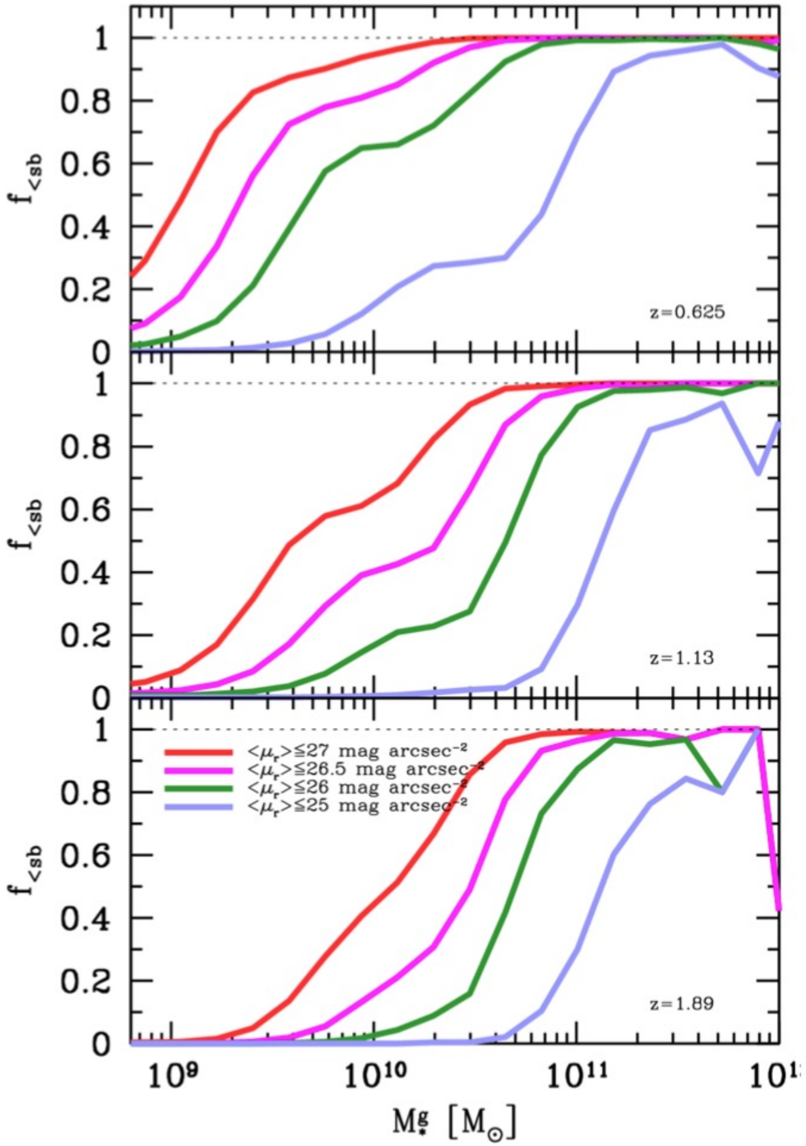
Thorne+18
- DEVILS/D10, COSMOS/D10, ECDFS/D02, XMM-LSS/D03
- Uses Prospect
- Chabrier+03 IMF & B&C SED

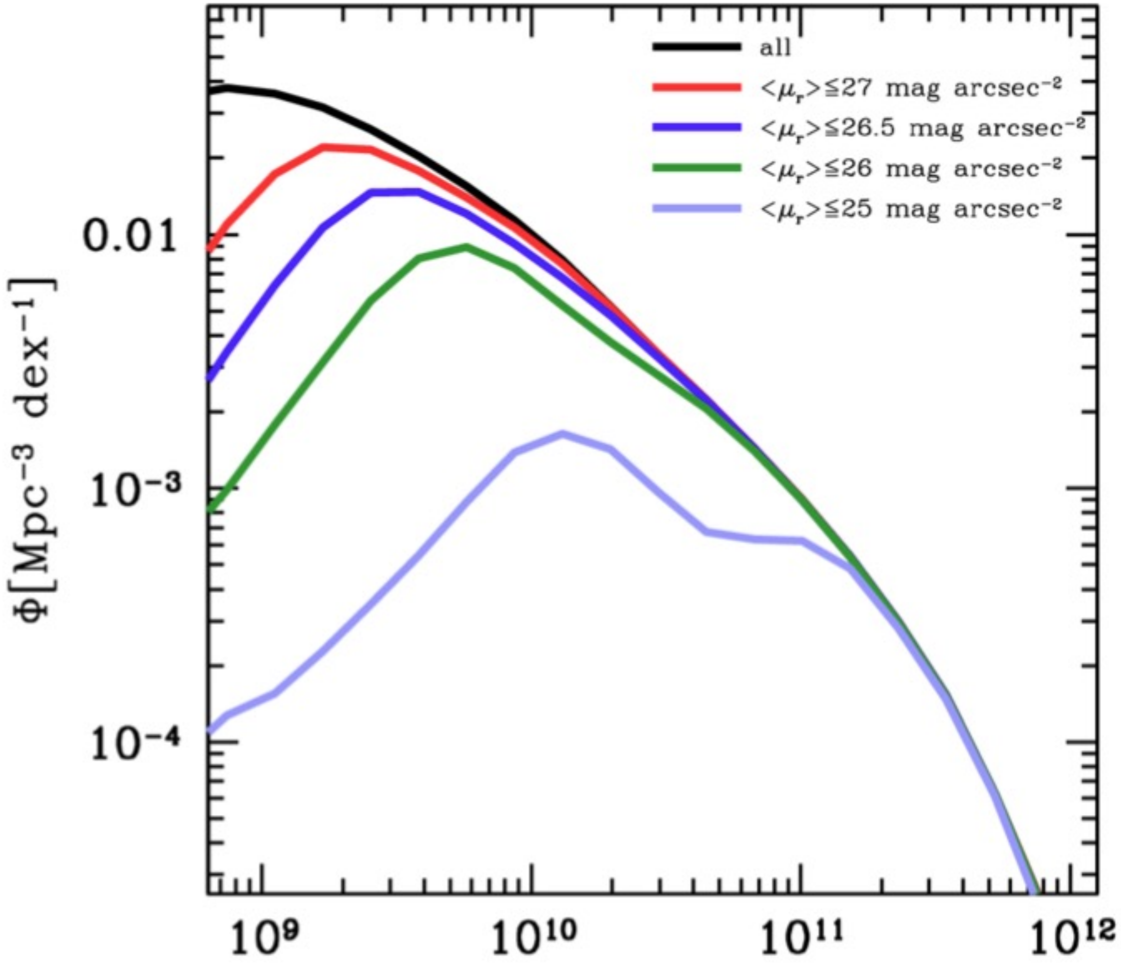
Kawinwanichakij+20
- NEWFIRM+HEDTEX Survey (Stevans+19)
- Uses EAZY (Brammer+08)
- Chabrier+03 IMF & B&C SED

Wright+18
- GAMA, G10-COSMOS, 3D-HST
- Uses MAGPHYS (da Cunha+18)
- Chabrier+03 IMF & B&C SED

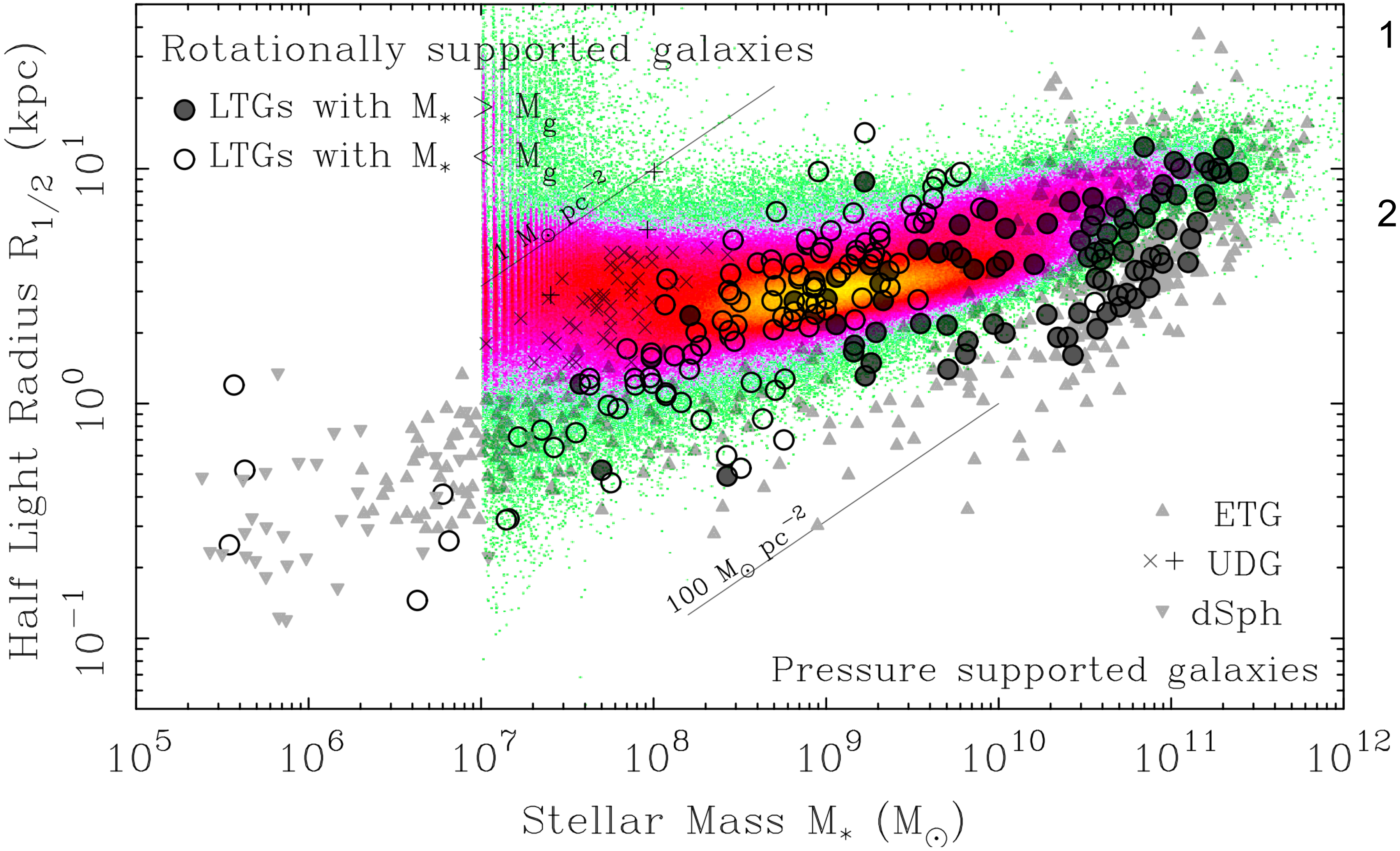


Completeness of Galaxy Spectroscopic Observations





Galaxy Size Distributions



1. Observations (Symbols; McGaugh+21) in the local universe
2. HR5 (background color map) at z=0.625

Conclusions

1. At low-z, the bright-end difference may be solved by 30 kpc-aperture correction.
2. At low-z, the faint-end difference may be caused by the missing low surface brightness galaxies.
3. At high-z, the difference in the bright-end population may be due to the simulation artifacts caused by one of (or a possible combination of) the Adaptive Mesh Refinement (at z=9, 4, 1.2, …), abrupt global reionization at z=10, and the wrong star-formation efficiency adopted by HR5.
4. **HR5 may provide a powerful insight into still-unexplored extreme regimes such as LSB/UDG** (Jihye@kasi), **intra-cluster light** (James M.@yonsei), **SMBH binaries** (Chunglee@ewha), **SMBH gravitational waves** (Chunglee@ewha), **AGN SED** (Anki/Ena@kias), **AGN Evolution** (yonghwi@kias), **proto galaxies** (Changbom/jaehyun@kias), etc.
5. A more powerful cosmological simulation code with gravity and hydrodynamics is needed!
    1. The generation 6 of the Korea Supercomputer will be installed in 2023 bringing the power of 500-600 Peta flops (current 17 Peta flops).
    2. A branch of the National Supercomputing Center (슈퍼컴퓨터 전문 센터) in Astronomy will be established in near future.