



UNIVERSITY OF TEXAS AT AUSTIN

CFC

COSMIC FRONTIER CENTER

Beating Cosmic Variance at Cosmic Dawn with Roman

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Pasadena, CA

JWST's three surprises

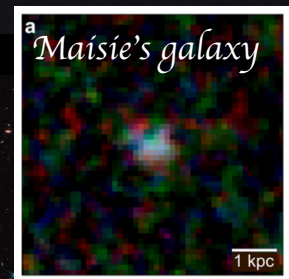
Within days of the CEERS data being released, we learned:

- 1) Unexpectedly bright galaxies form very early in our universe (e.g., Castellano+22, Naidu+22, Finkelstein+22, Donnan+23)

CEERS JWST/NIRCam
NASA/STScI/CEERS/T

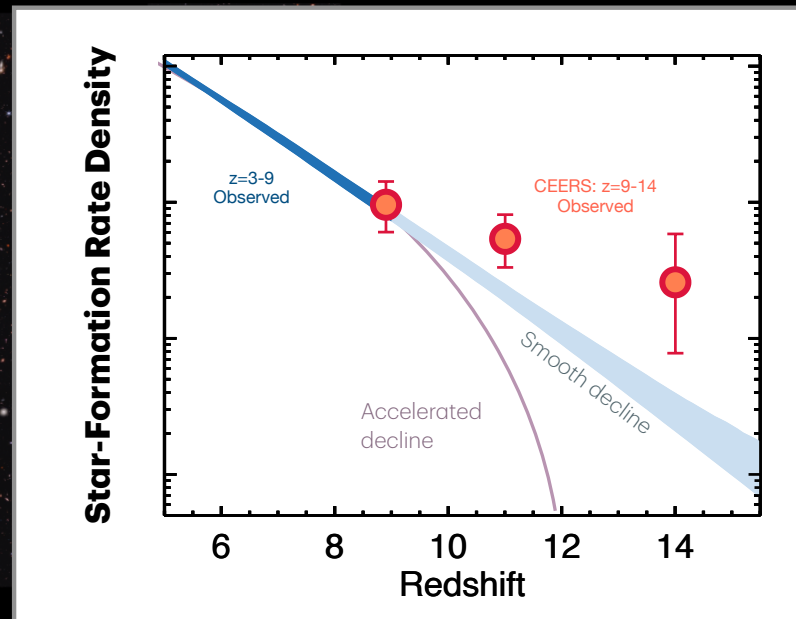
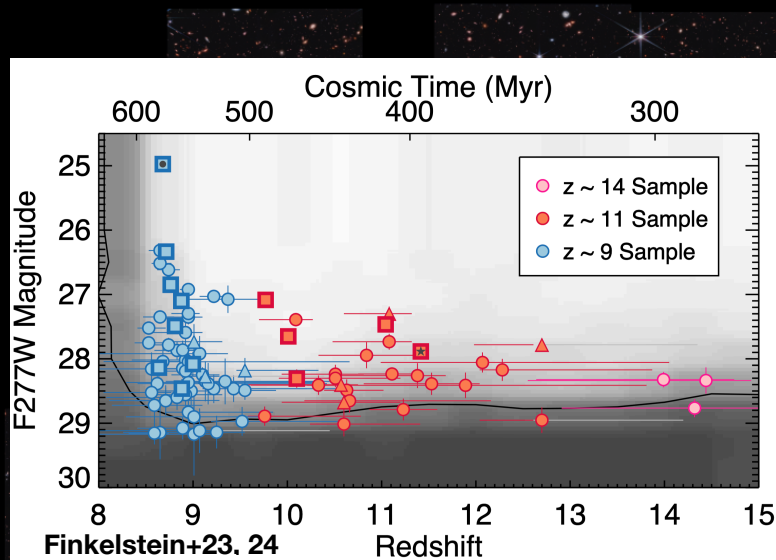
- 2) JWST revealed previously unknown types of galaxies, originally thought to be too-massive for Λ CDM (e.g, Labbe+22, MBK+23)

- 3) The early universe contains abundant accreting supermassive black holes (e.g., Onoue+22, Kocevski+22, Maiolino+23)



An abundance of galaxies compared to expectations

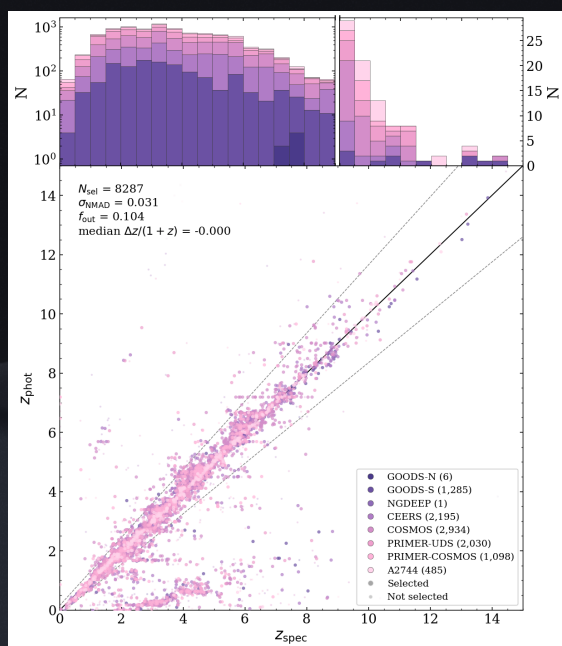
CEERS yielded ~90 galaxies at $z \sim 9$ to 14!



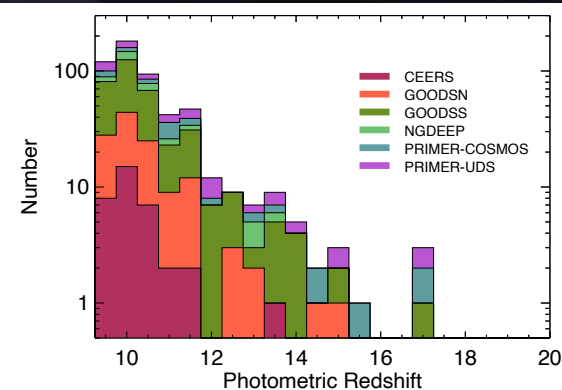
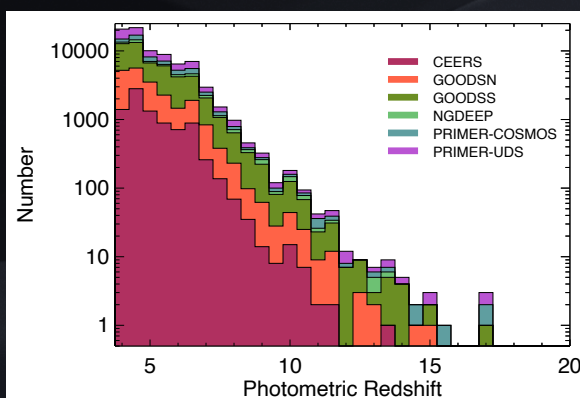
This is just This is >10X the high-z sample of CEERS, so and CEERS!
the excess of high-z galaxies is on even
more solid ground.



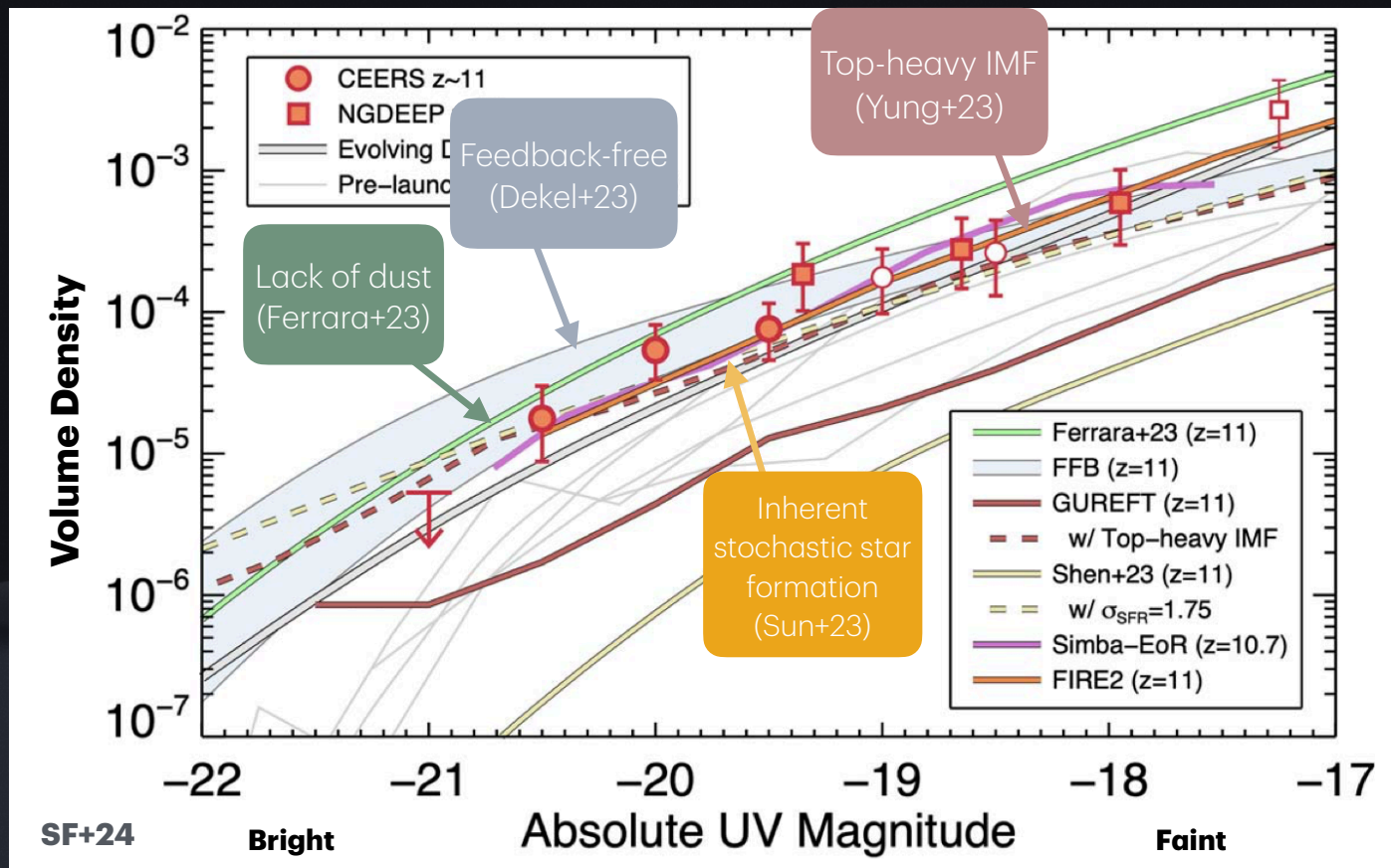
The UNICORN project (**U**niform **N**ear-**I**nfrared **C**atal**O**gs from **R**obust imagi**N**g) was created to produce uniform and robust imaging and photometric catalogs to enable a range of science goals, including UVLFs. It includes: CEERS, GOODS-S (incl. NGDEEP+MIDIS), GOODS-N, PRIMER-UDS, PRIMER-COSMOS, COSMOS (COSMOS-Web+COSMOS-3D) and Abell 2744.



- This preliminary UNICORN sample (w/o COSMOS) has ~103,000 galaxies at $z > 3.5$
- 434, 70, 33 galaxies at $z > 10, 12, 14$

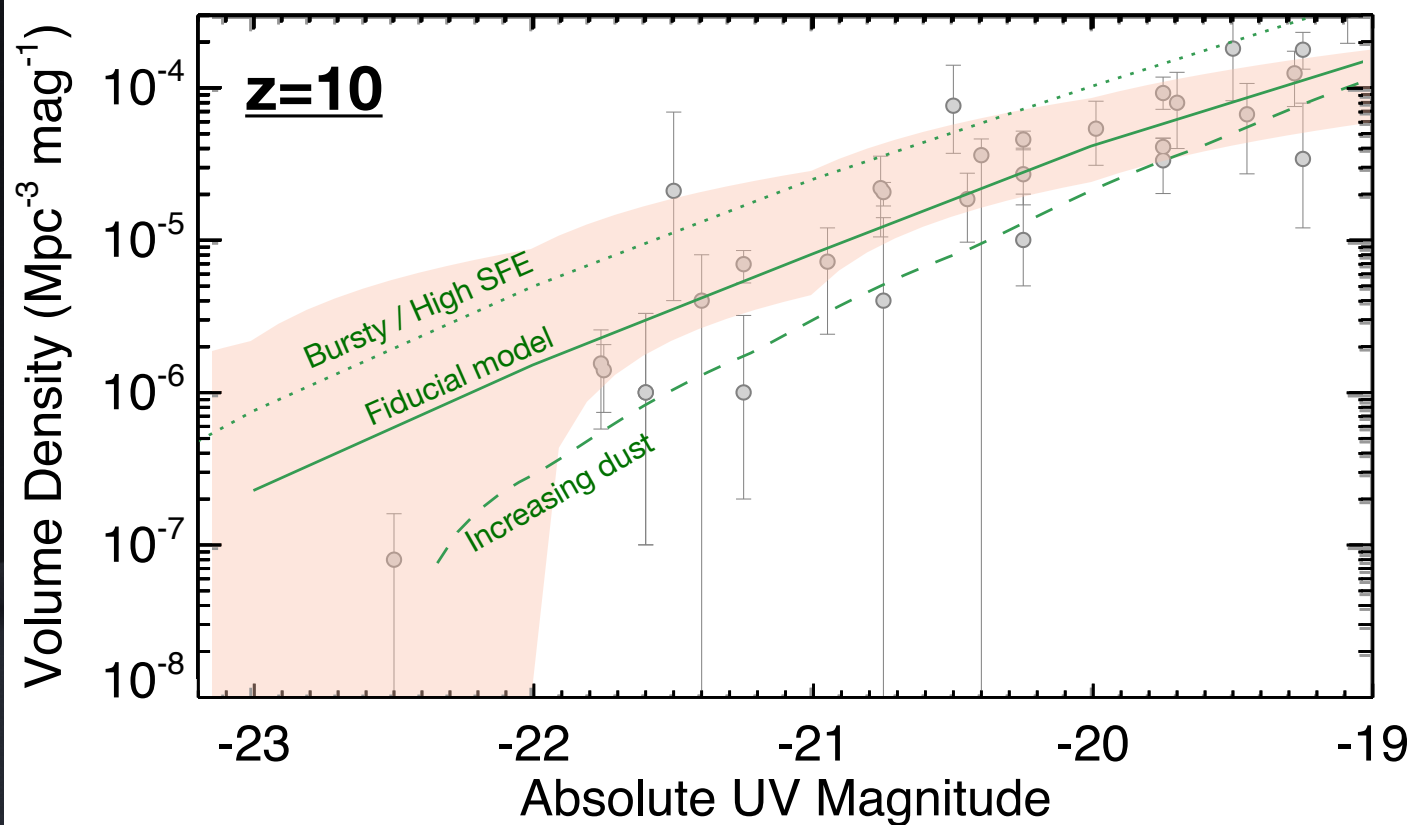


What are the possible physical explanations? We have lots of ideas!



All families of models can reproduce the observed galaxy counts — how do we tell them apart?

Scatter in JWST data is consistent with cosmic variance uncertainties



JWST literature data:

Independent JWST surveys disagree by 1-2 dex at $M_{UV} < -21$

CV from ~100 arcmin² fields (SC SAM)

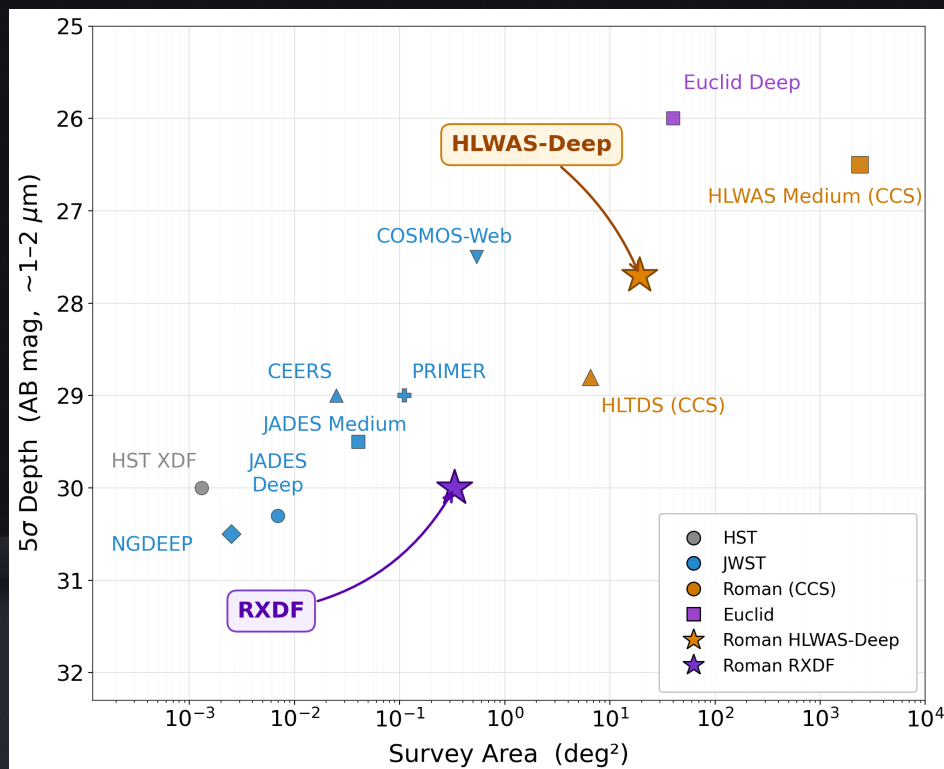
Even 100 random JWST pointings leaves ≈ 0.5 dex CV uncertainty at the bright end

Model predictions

Not currently constrainable; note also that both bursty and high-SFE models reproduce the JWST UVLF

Breaking these barriers requires a significant increase in survey volume - *Roman* is key

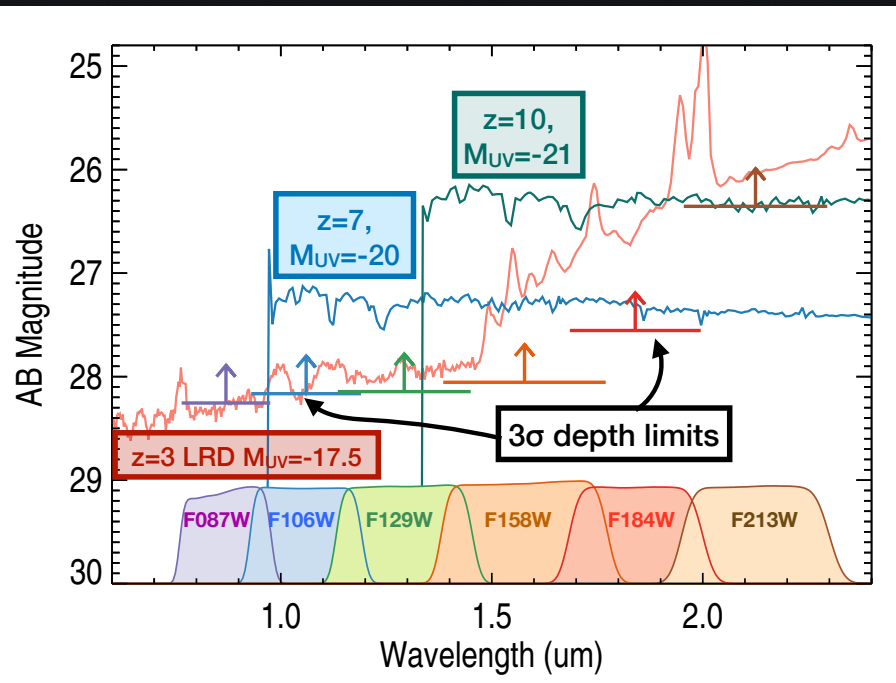
This will allow both CV-invariant UVLF measurements, and complementary angular clustering.



- Early in the mission, two surveys are key:
 - Core Community Survey — HLWAS-Deep - 19 deg² in 6 filters to m~27.5 (K~25.8), completed by Year 2.
 - HLWAS Medium only in JHK (over 2400 deg²)
 - HLTDS-Deep ultimately will reach m~29 over 7.7 deg² later in the mission, but lacks K₂₁₃.
 - Roman Cycle 1 GAS: The Roman eXtreme Deep Field (RXDF) PI's: Haojing Yan, Anton Koekemoer, Yue Shen (+127 Co-Is). 140x area of full-depth **Hubble XDF** (ACS+WFC3/IR) AB=30 in RZYJH, AB=29 in F184, AB=28 in K (5-sigma)

HLWAS-Deep will beat CV

This is the focus of an approved Cycle 1 GI proposal (PIs Finkelstein and Julian Muñoz).



Filter set allows selection to $z \sim 10$, expanded to $z > 12$ with K_{213} , over an area $\sim 40X$ larger than all JWST legacy surveys combined!

Star-Forming Galaxies			
z	Limiting M_{UV}	# JWST	# HLWAS-Deep
7	-19.4	4600	~ 72000
8	-19.8	1000	~ 19000
9	-20.2	300	~ 3700
10	-20.7	2	~ 1000
11	-21.7*	0	~ 110
12	-21.9*	0	~ 30

*Requires shallow F213W detection

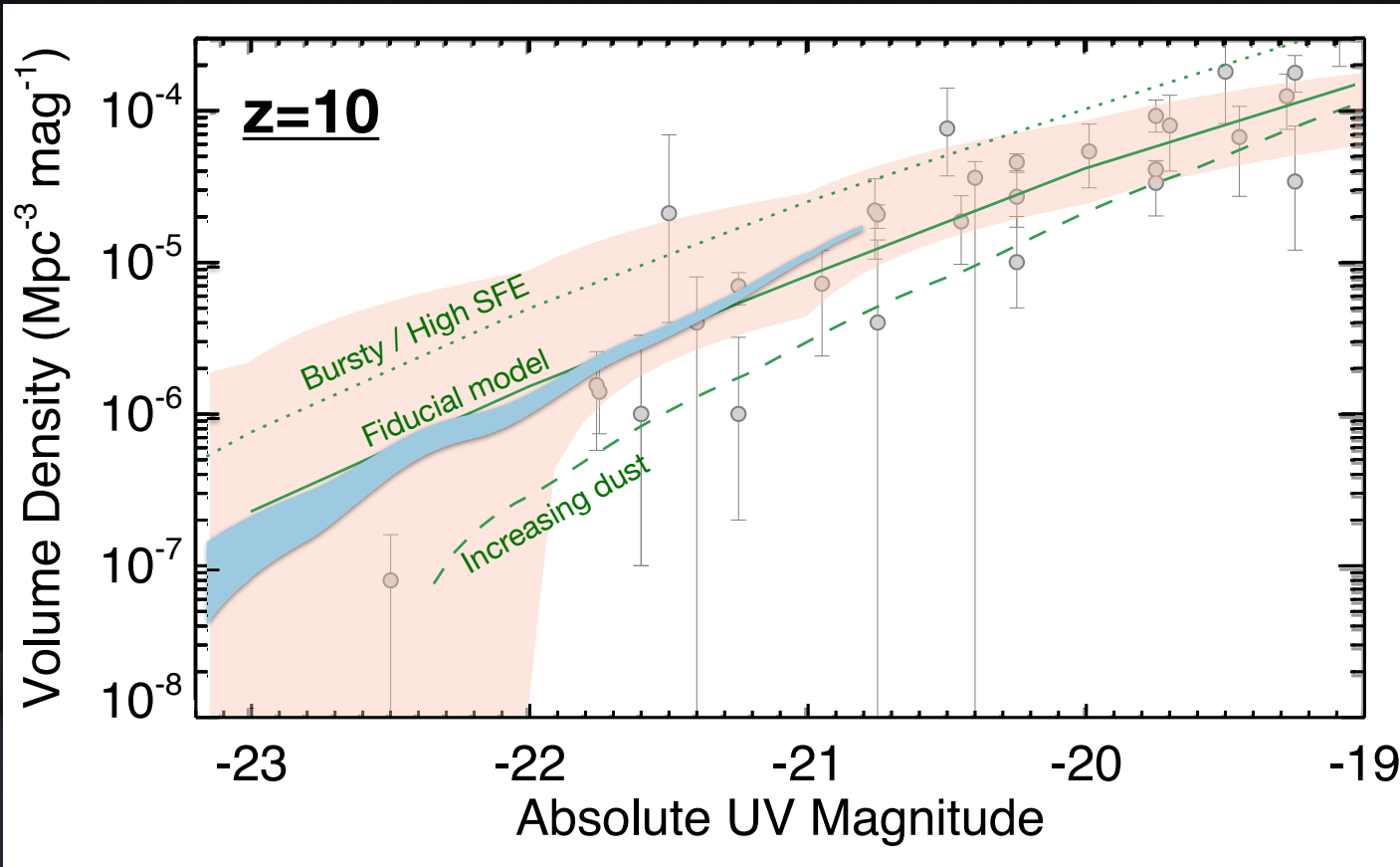
100,000 galaxies at $z \sim 7-8$

1000 galaxies at $z \sim 10$

140 galaxies at $z \geq 11$

~ 500 GN-z11-like systems ($M_{UV} < -21.5$ at $z > 10$) — the first statistical sample of the most luminous early galaxies!

Roman HLWAS-Deep definitively distinguishes models for the UV-bright excess — for the first time



JWST literature data:

Independent JWST surveys disagree by 1–2 dex at $M_{\text{UV}} < -21$

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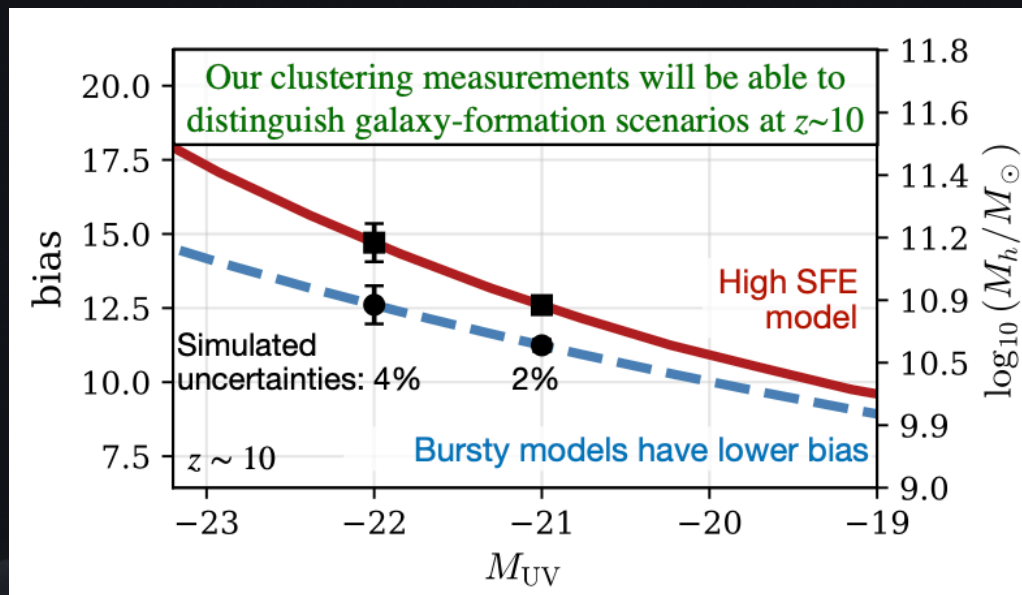
Even 100 random JWST pointings leaves ≈ 0.5 dex CV uncertainty at the bright end

Model predictions

Roman HLWAS-Deep
Poisson uncertainty

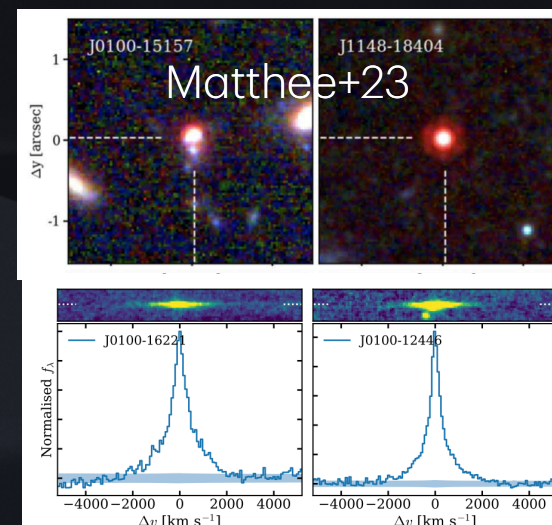
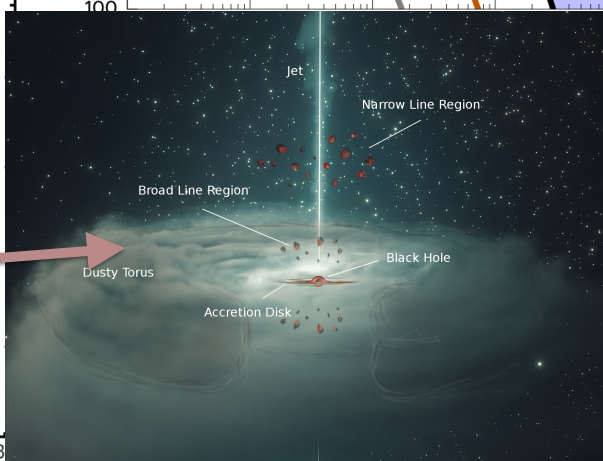
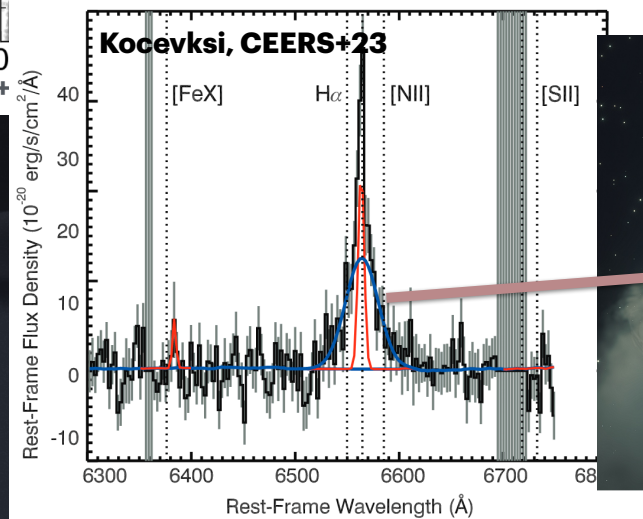
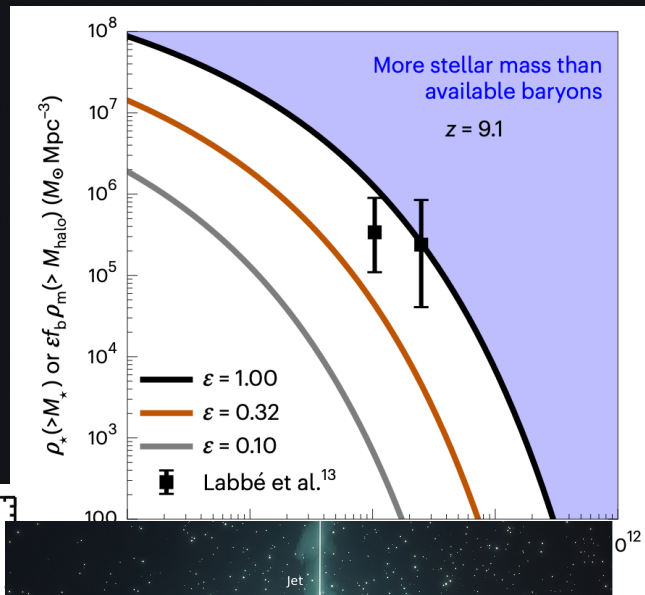
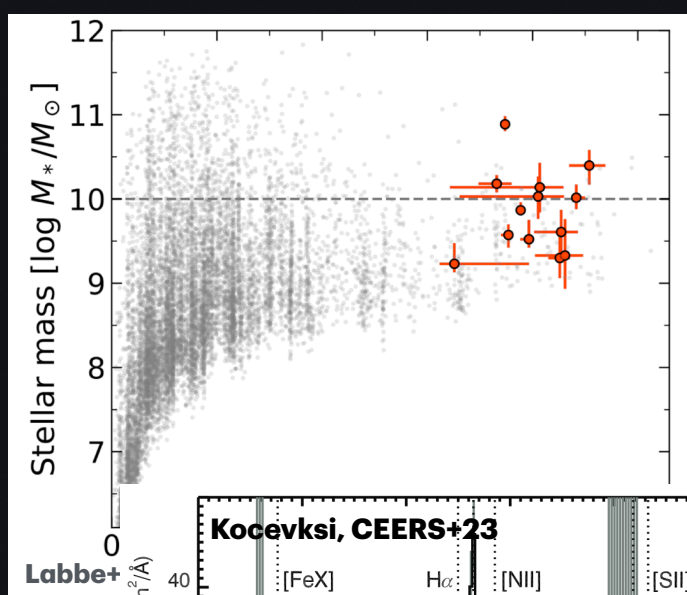
This dataset enables robust clustering measurements for the first time!

These can break degeneracies in the UVLF



- A key example - high SFE and stochastic star-formation make similar UVLF predictions.
- However, the dark matter halos which host these galaxies would be quite different.
- Roman HLWAS-Deep allows constraints on the bias (and thus M_h) to $\sim 2\text{--}4\%$ at the bright end of the UVLF, distinguishing between these models.

The red galaxy puzzle: not universe-breaking, but still surprising



Now that we know about LRDs, what can we say about massive galaxies?

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Early Galaxies Were Not Too Big for Their Britches After All

By: Marc Airhart



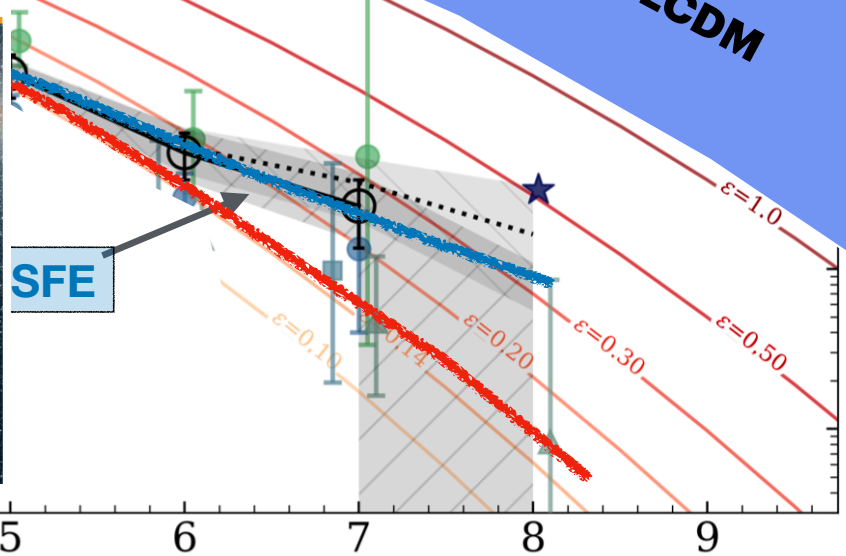
Abundance of Massive Galaxies

Lines of constant star-formation efficiency (SFE) == conversion of gas into stars

Forbidden under LCDM

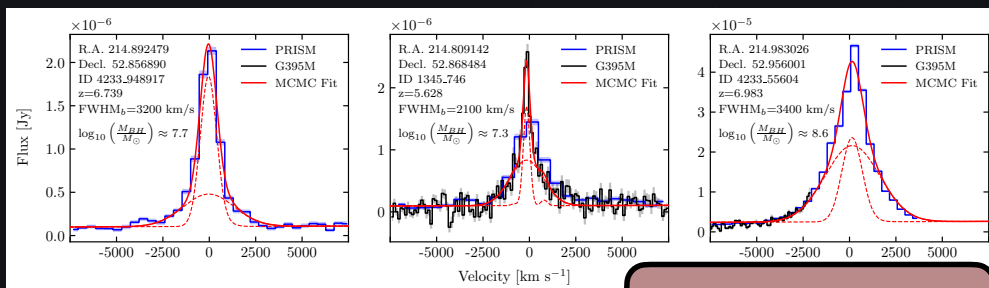
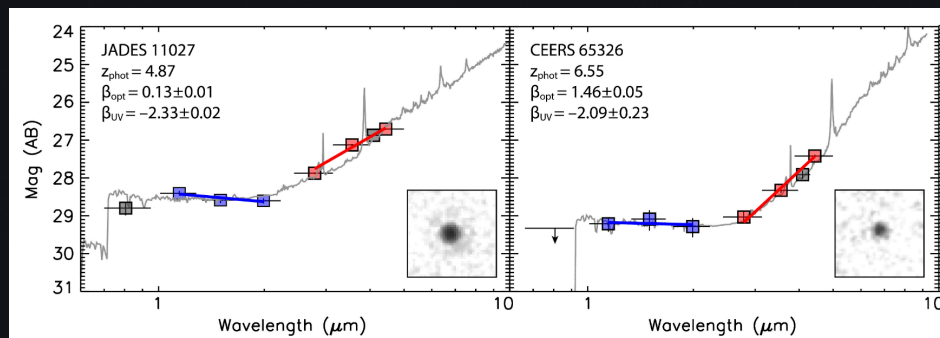
SFE

redshift

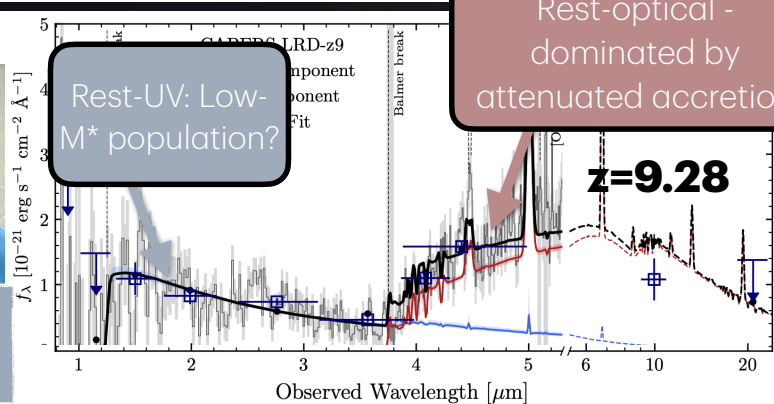


Chworowsky,
CEERS+24

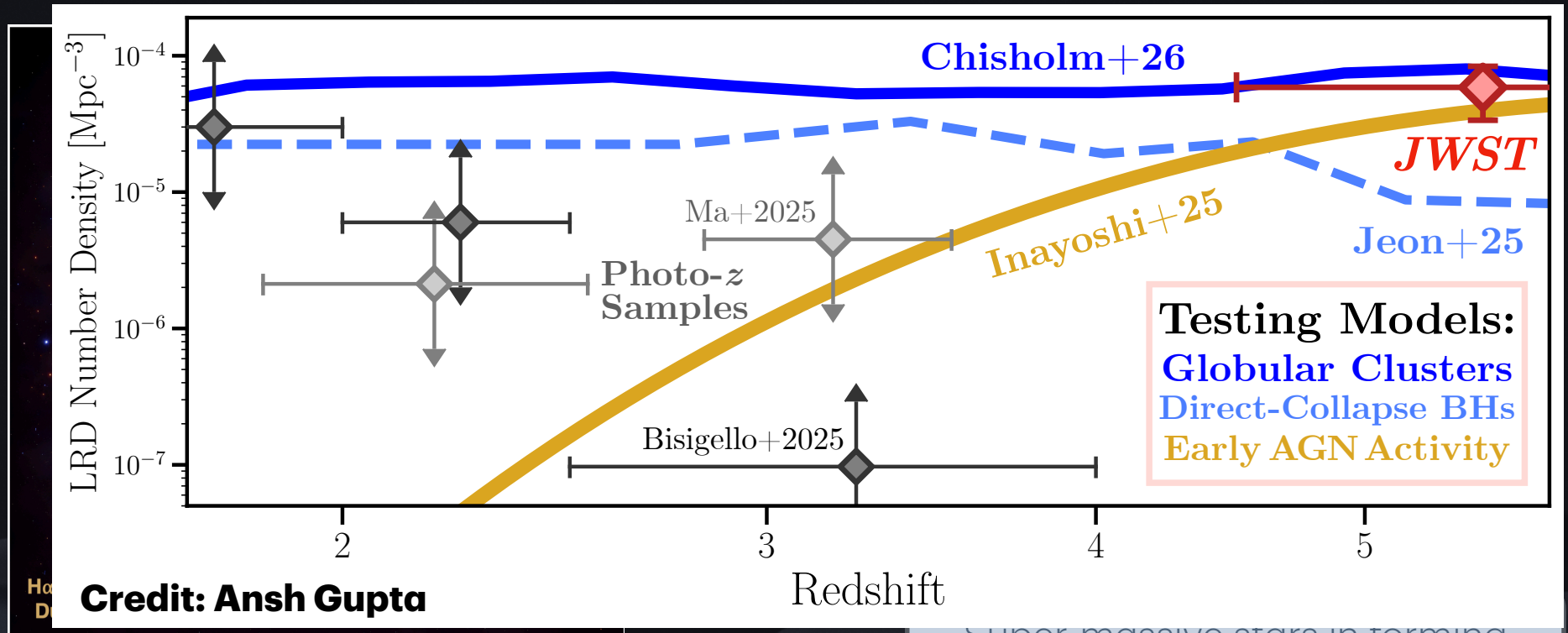
LRDs may be low-mass galaxies hosting rapidly accreting, obscured black holes



Anthony Taylor
 (UT Austin)



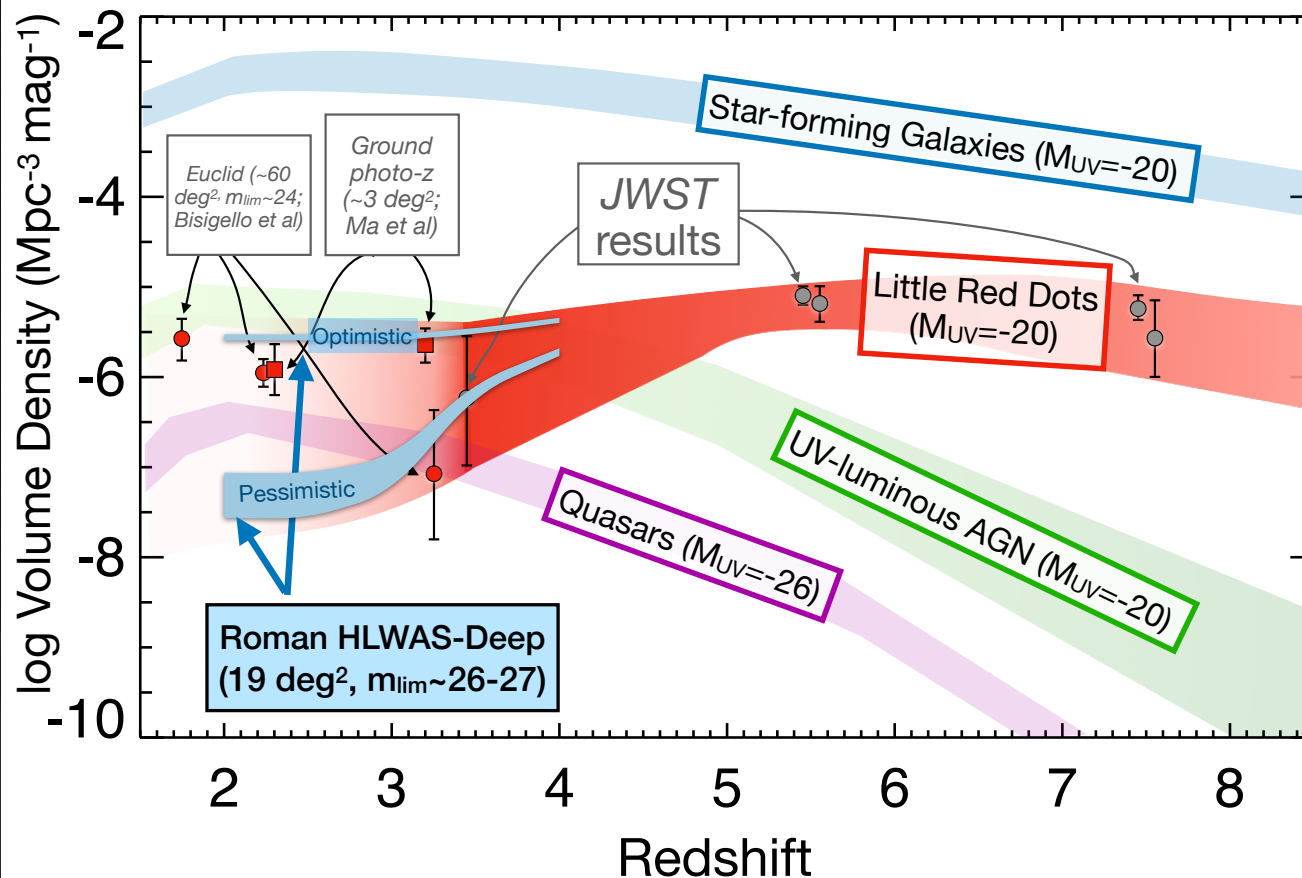
Not the only options!



DCBHs in formation (Pacucci+26)

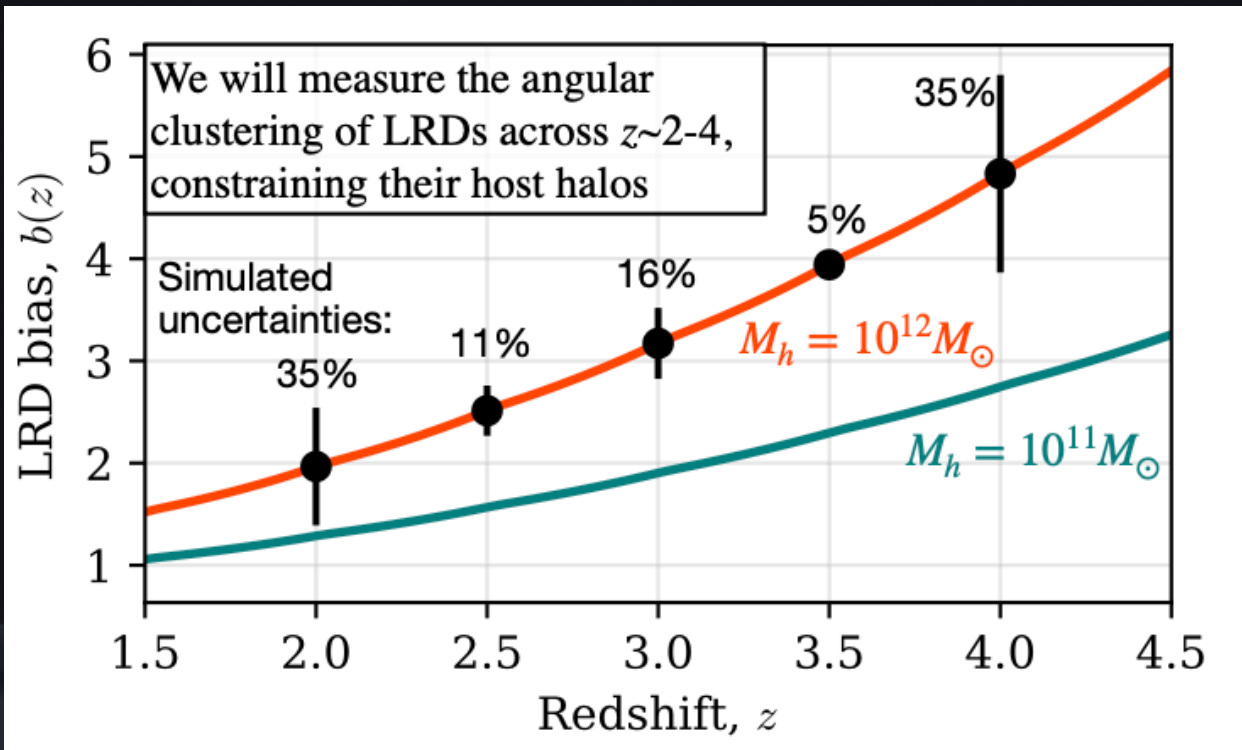
Super-massive stars in forming
globular clusters (Chisholm+26)

When do Little Red Dots disappear — and what does it tell us about black hole growth?



Little Red Dots			
z	# JWST	# HLWAS-D (Little evolution)	# HLWAS-D (Strong evolution)
2	4	11900	140
2.5	26	7400	140
3	7	3900	110
3.5	46	3500	850
4	31	1000	460

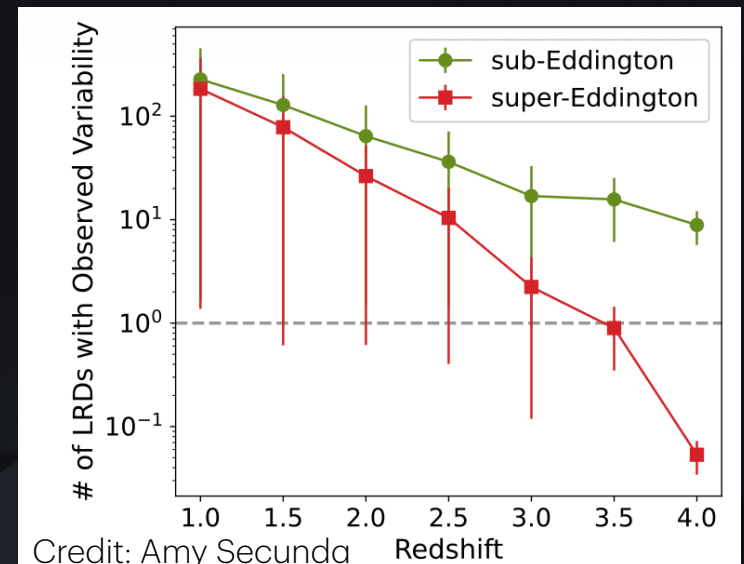
Independently probing LRDs hosts via clustering



- LRD hosts are outshone by the central engine. Clustering offers an independent probe!
- We can measure the LRD bias at $z \sim 2-4$ to 5–30% uncertainty, sufficient to constrain LRD host-halo masses to $\sim 0.1 - 0.5$ dex.
- This will directly test whether LRDs preferentially inhabit the rare massive halos expected for early AGN activity versus the more common lower-mass halos associated with star formation, unveiling their formation channels, environments, and testing their duty cycle.

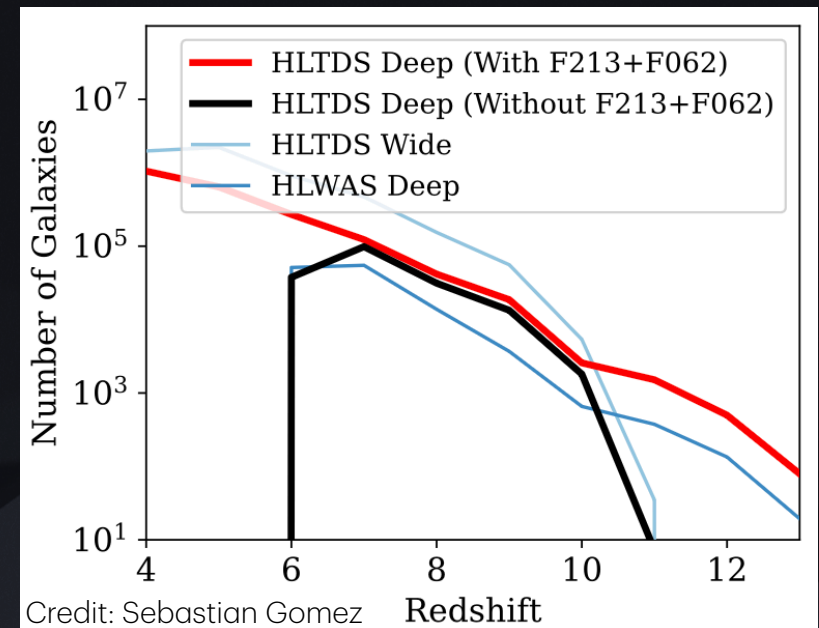
Future Cycles: Adding F213 to the HLTDS Deep transforms a SN cosmology survey into a cosmic dawn powerhouse

- Time domain offers an orthogonal axis to understand LRDs.
- LRDs should vary stochastically on days-months timescales if AGN-powered, with the level of variability depending on the accretion rate.
- JWST studies (over small volumes) rarely see this variability, but the baseline is short.
- Adding K213 to the HLTDS could allow the first systematic variability study of LRDs over cosmological volumes: either constrain accretion rates or rule out AGN entirely (limited to $z < 2$ w/o K₂₁₃).



Future Cycles: Adding F213 to the HLTDS Deep transforms a SN cosmology survey into a cosmic dawn powerhouse

- K_{213} is the critical band to select $z > 10$ galaxies and reject dusty low- z interlopers.
 - Without this filter, the HLTDS will be limited to $z \sim 6\text{--}10$.
- With K_{213} (to $m \sim 27$) would discovery ~ 1500 galaxies at $z > 10$ (including ~ 400 at $z > 12$ over 7.7 deg^2), most fainter than those in HLWAS-Deep.
- Such data would extend CV-invariant UVLF measurements more than 1 mag fainter than HLWAS-Deep alone — the two programs together span the full luminosity function.



Summary

- JWST has unveiled an excitingly high abundance of both UV-luminous galaxies and an exciting new population of LRDs.
- However, JWST alone is not capable of uniquely unveiling the dominant physical mechanisms driving both of these populations.
- The HLWAS-Deep tier will unlock this understanding (complemented by RXDF at the faint end):
 - ~100,000 galaxies at $z \sim 7-8$, and >1000 at $z > 10$ unlocks precision measurements of the UVLF robust to cosmic variance, and percent-level measurements of the bias, breaking degeneracies between models.
 - Up to 20,000 robustly-selected LRDs at $z \sim 0-4$ will unveil the redshift evolution of these unique objects, allowing insight into their physical nature.
- Extensions to the HLTDS will further enable knowledge gains in these areas in future cycles.

