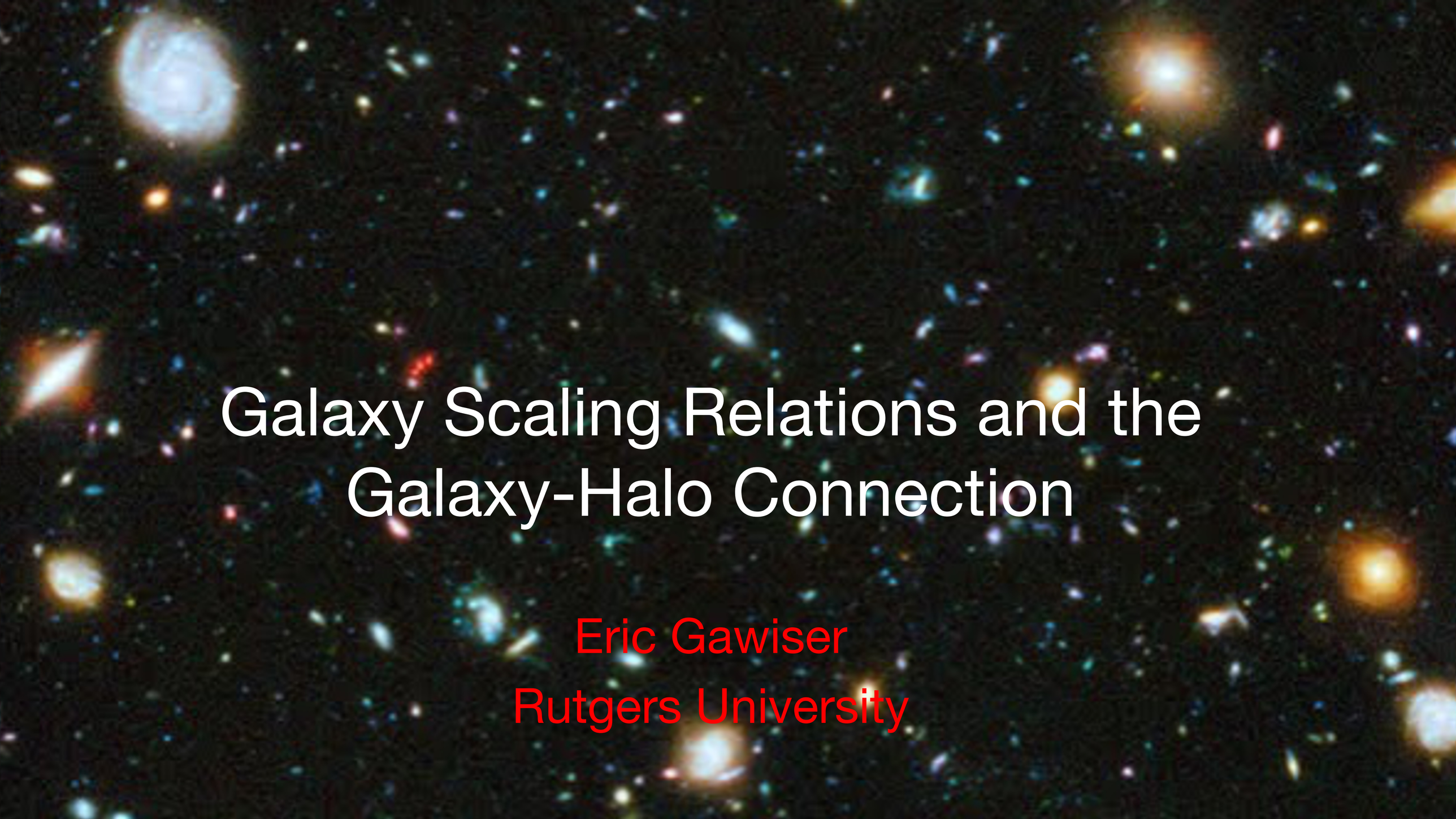


Galaxy Scaling Relations and the Galaxy-Halo Connection

Eric Gawiser
Rutgers University

Questions that guide this talk

1. Is there a fundamental galaxy scaling relation?
2. Which is more interesting, the scaling relations or the outliers?
3. Does the scatter matter?
4. What can we learn from galaxy-halo scaling relations?
5. Between galaxy scaling relations and the galaxy-halo connection,
   which is the lightning and which is the thunder?

Disclaimer

This will not be an exhaustive review of every scaling relation claimed in the literature

I will inevitably leave out some key references, results, and methods

Feel free to note in the Zoom Chat when something **key** is missing from a given slide

Please mention and link to related work by yourself or others in #galevo23-talks

What's a Scaling Relation?

Scaling Relations in Homogeneous Catalysis: Analyzing the Buchwald–Hartwig Amination Reaction

Megha Anand and Jens K. Nørskov*

Cite this: *ACS Catal.* 2020, 10, 1, 336–345
Publication Date: November 25, 2019
https://doi.org/10.1021/acscatal.9b04323

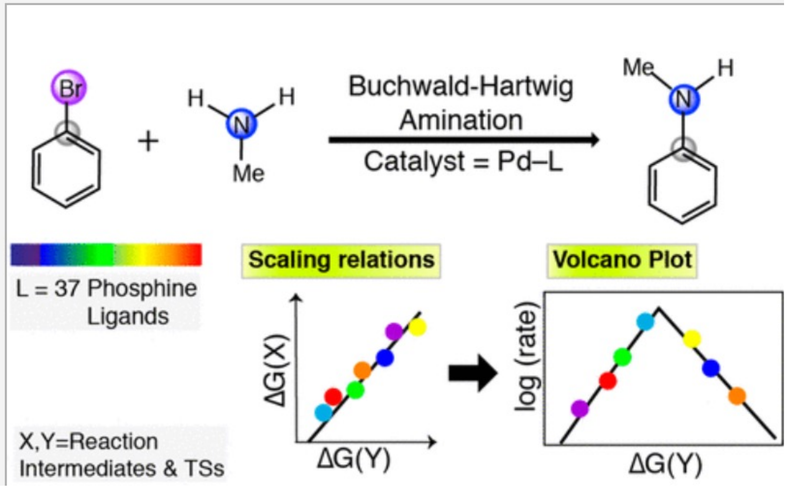
ACS Catalysis

Read Online | PDF (5 MB) | SI Supporting Info (1) »

SUBJECTS: Catalysts, Chemical reactions,

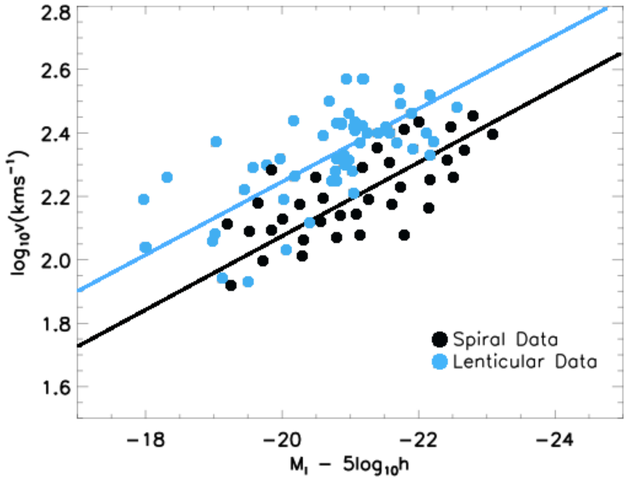
Abstract

Scaling relations are widely used to study surface reactions. However, the exploration of its utility in homogeneous catalysis is currently far less reported. In this work, we have investigated the transferability of the concept of scaling relations to a homogeneous catalysis reaction known as the Buchwald–Hartwig amination (BHA) reaction. The reaction of PhBr with $MeNH_2$ using 37 different Pd–L complexes (L = phosphine ligand) is studied, and scaling relations are established among the reaction intermediates and transition states. Using the scaling relations, we construct volcano plots, which is the plot of the log(rate) vs the descriptor intermediate energy. The insights from the volcano plots agree well with the experimental trends from the literature and give direction toward better catalyst design.

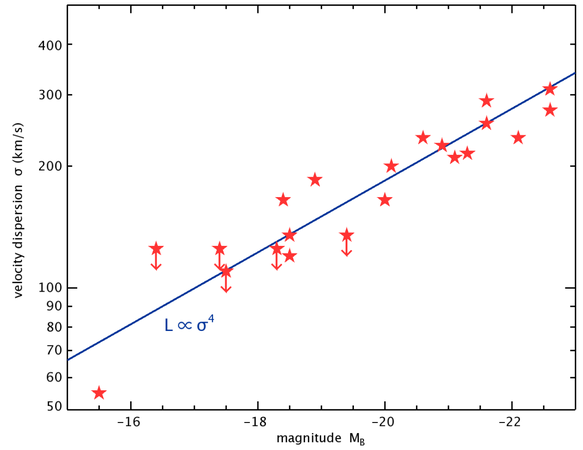


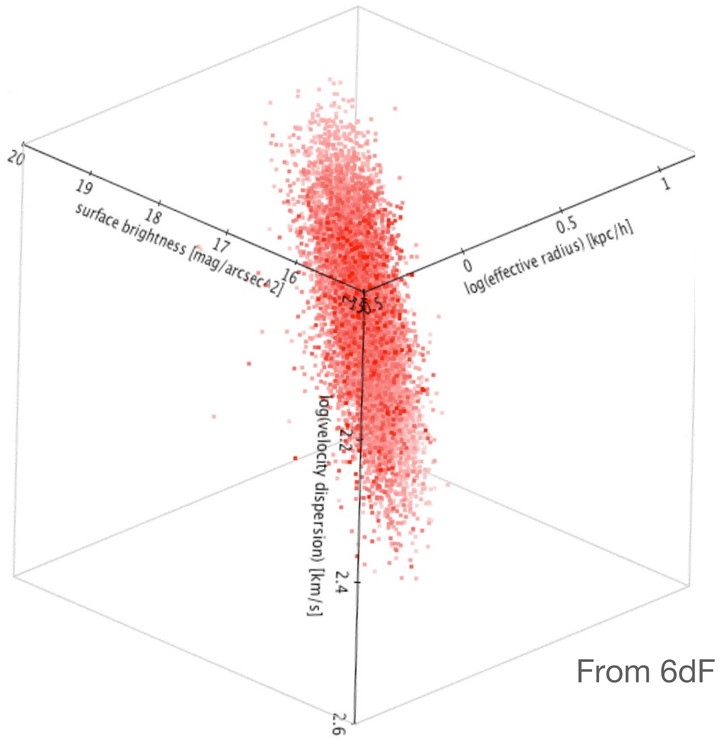
What's a Scaling Relation?

- Tully-Fisher Relation: Disk galaxy rotation speeds correlate with luminosity.
- Faber-Jackson Relation: Elliptical galaxy velocity dispersions correlate with luminosity.
- Fundamental Plane: Correlation between elliptical galaxy velocity dispersions, mean surface brightnesses, and effective radii.



From Wikipedia





From 6dF via Matthew Colless

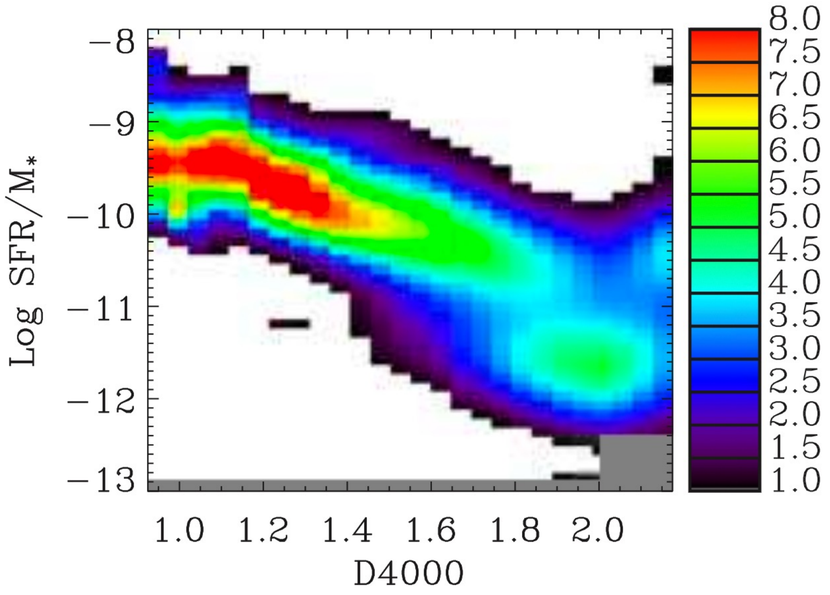
Is there a fundamental galaxy scaling relation?

- Defining “fundamental” as a correlation in N dimensions with <~0.5 dex intrinsic scatter; doesn’t have to be a power-law, plane, etc.
- If more scatter, might just be from “bigger galaxies have more of everything”
- Demand monotonicity to avoid double-valued inferences like the R_{23} metallicity indicator
- Can evolve with time/redshift, but that implies that we should view time as one of the dimensions – galaxy properties should scale with time instead of just mass, but is that “time since formation” or “cosmic time”?
- Clearly exist many galaxy scaling relations that meet these criteria, but is there one underlying fundamental relation? (or a few?)

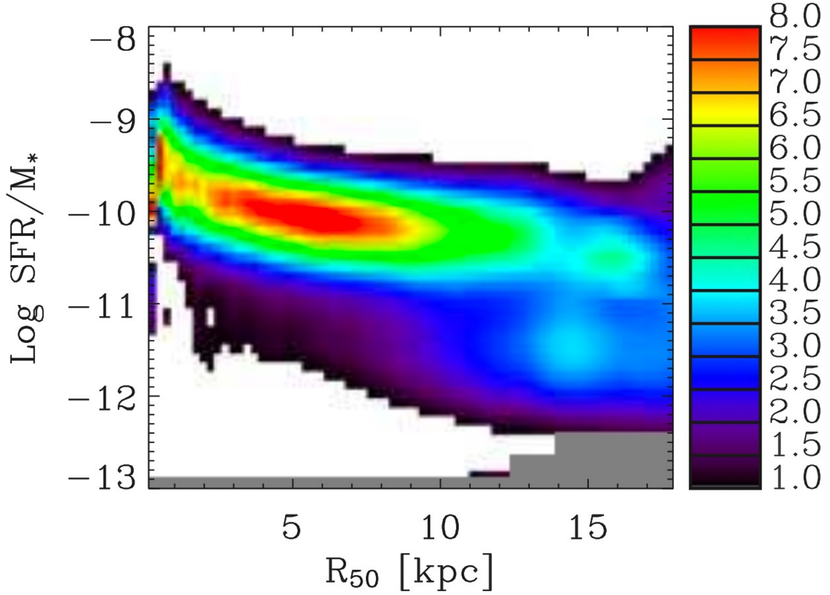
Are there other scaling relations?

Specific Star Formation Rate for **100,000 SDSS galaxies** vs.

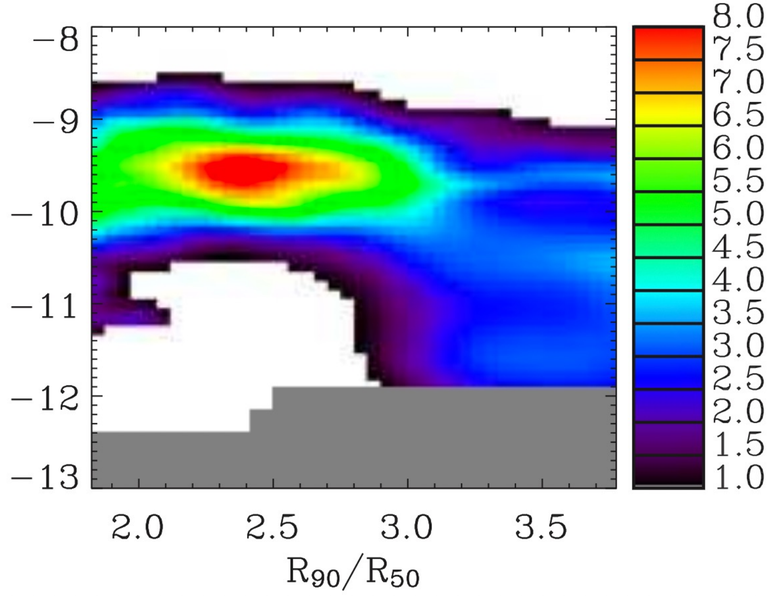
4000 Angstrom break strength (D4000)



galaxy size (R50)



concentration (R90/R50)



Figures from Brinchmann+04 (MNRAS 351, 1151)

Are there other scaling relations?

Supermassive Black Hole mass vs.

Bulge K-band luminosity Bulge velocity dispersion

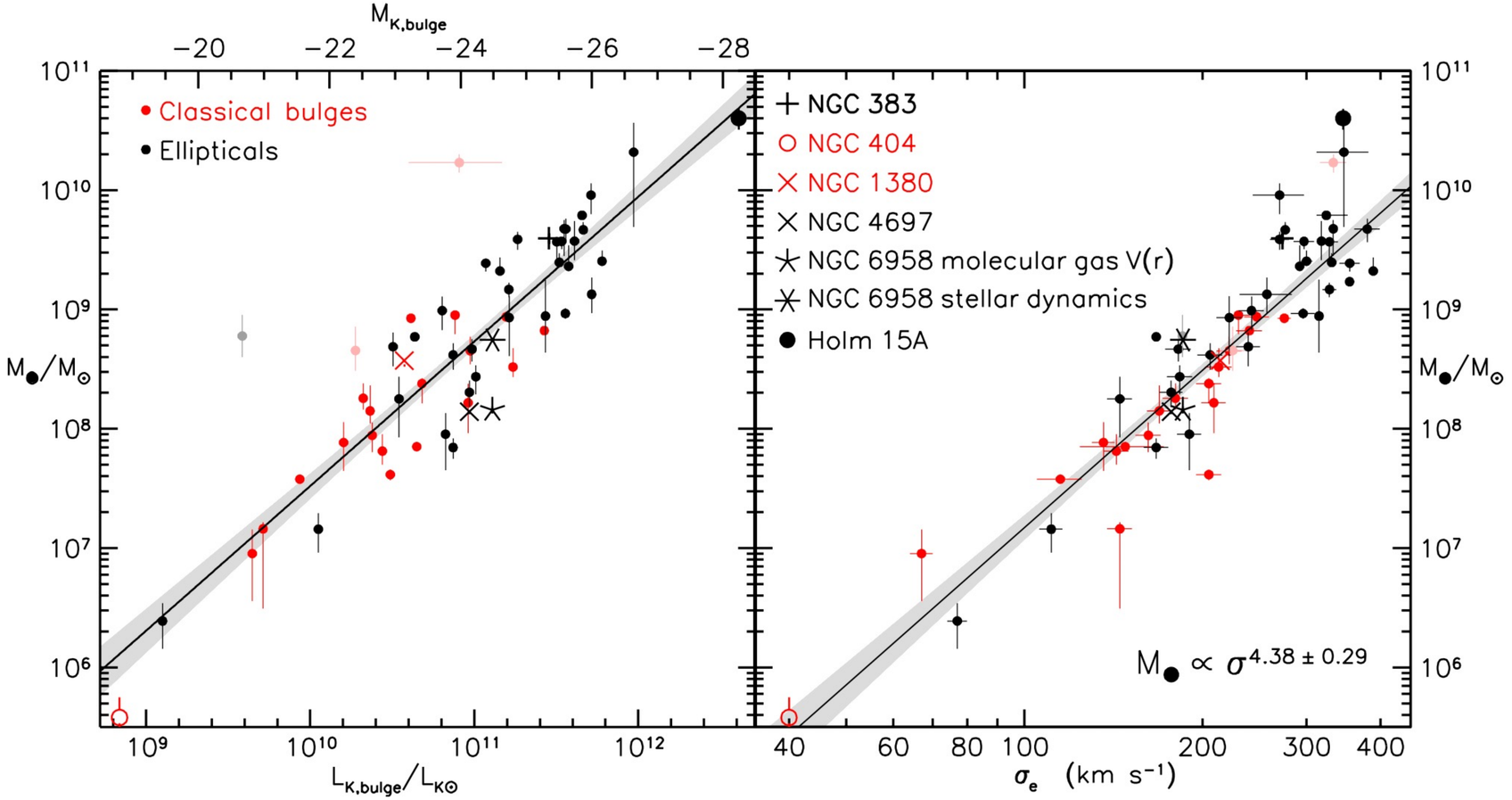
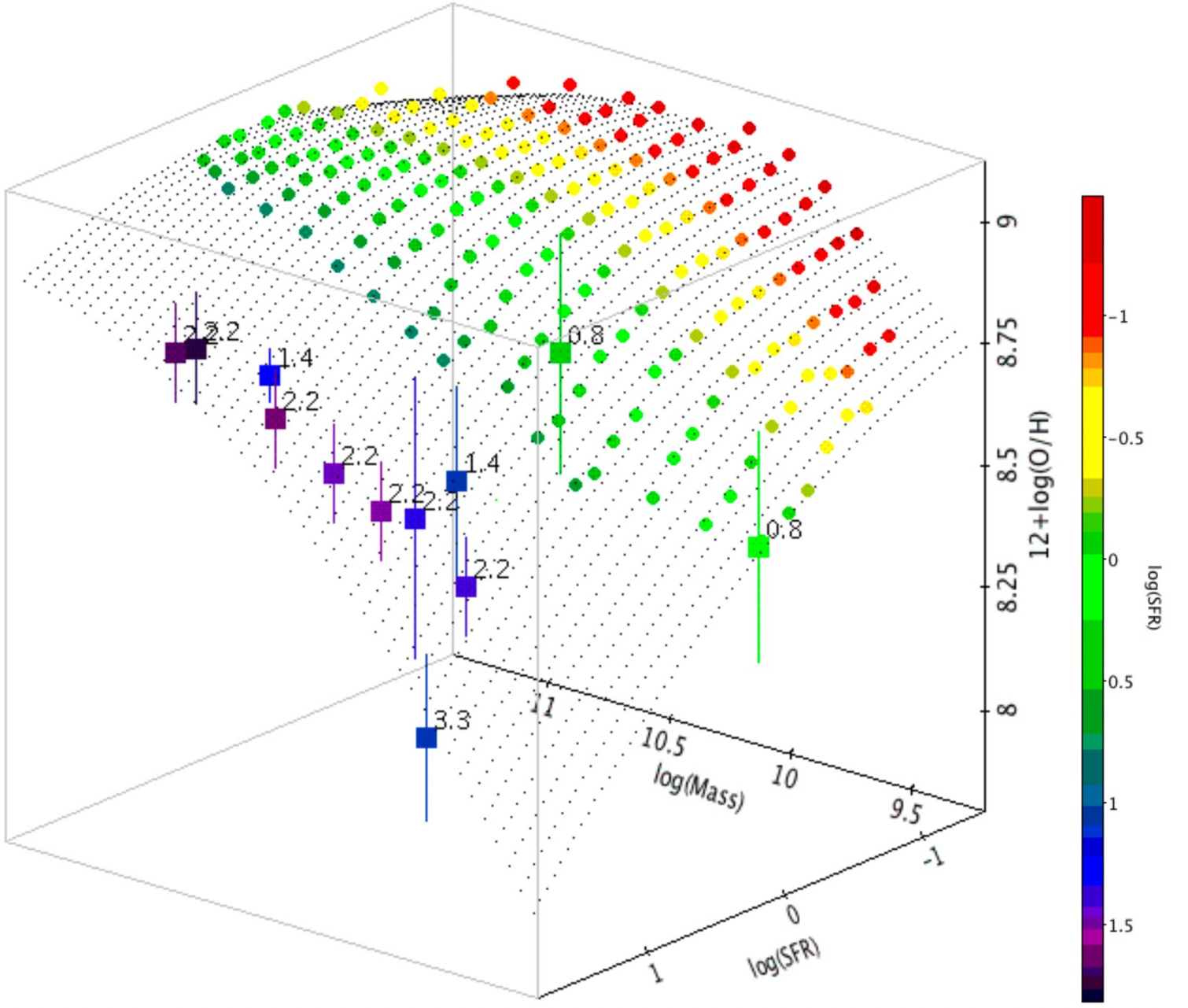


Figure adapted from Kormendy & Ho 13 (ARA&A, 51, 511)

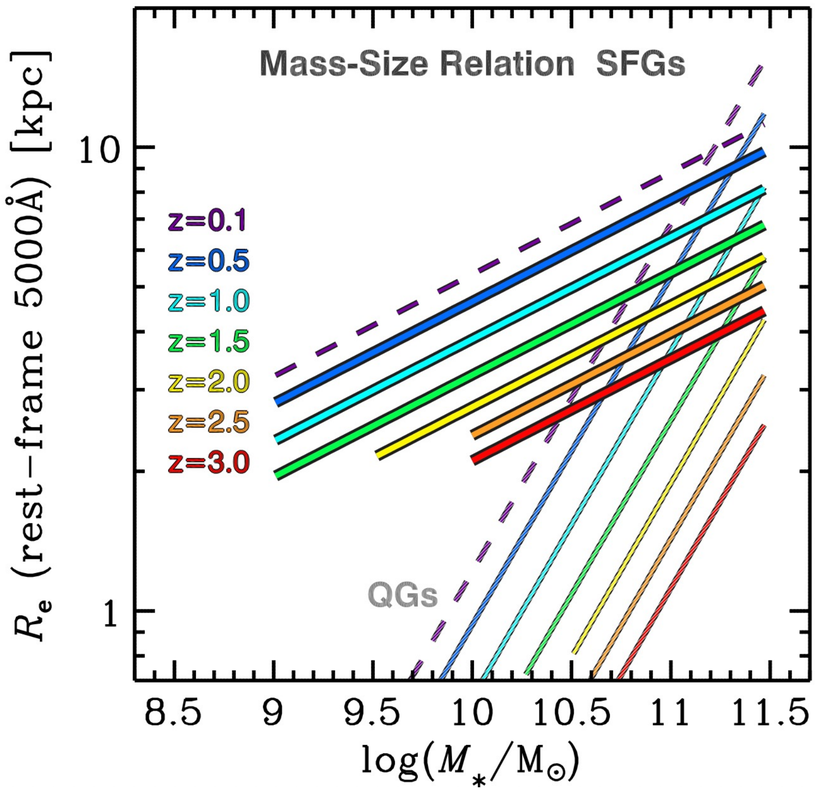
Are there other scaling relations?

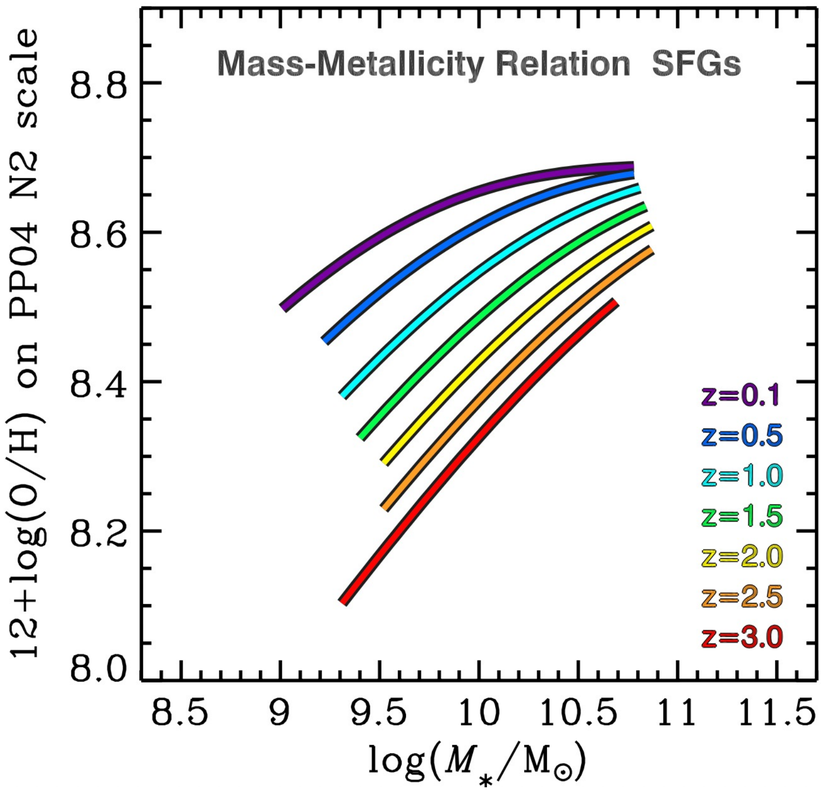
The Fundamental Metallicity Relation (FMR)

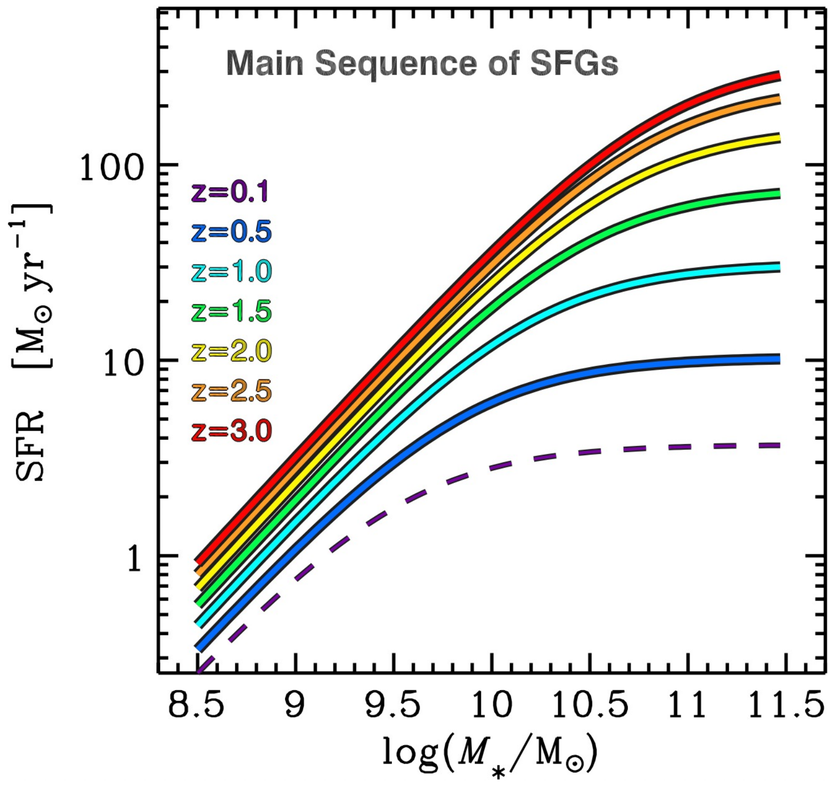
Manucci+10 (MNRAS 408, 2115)



Do the scaling relations evolve?

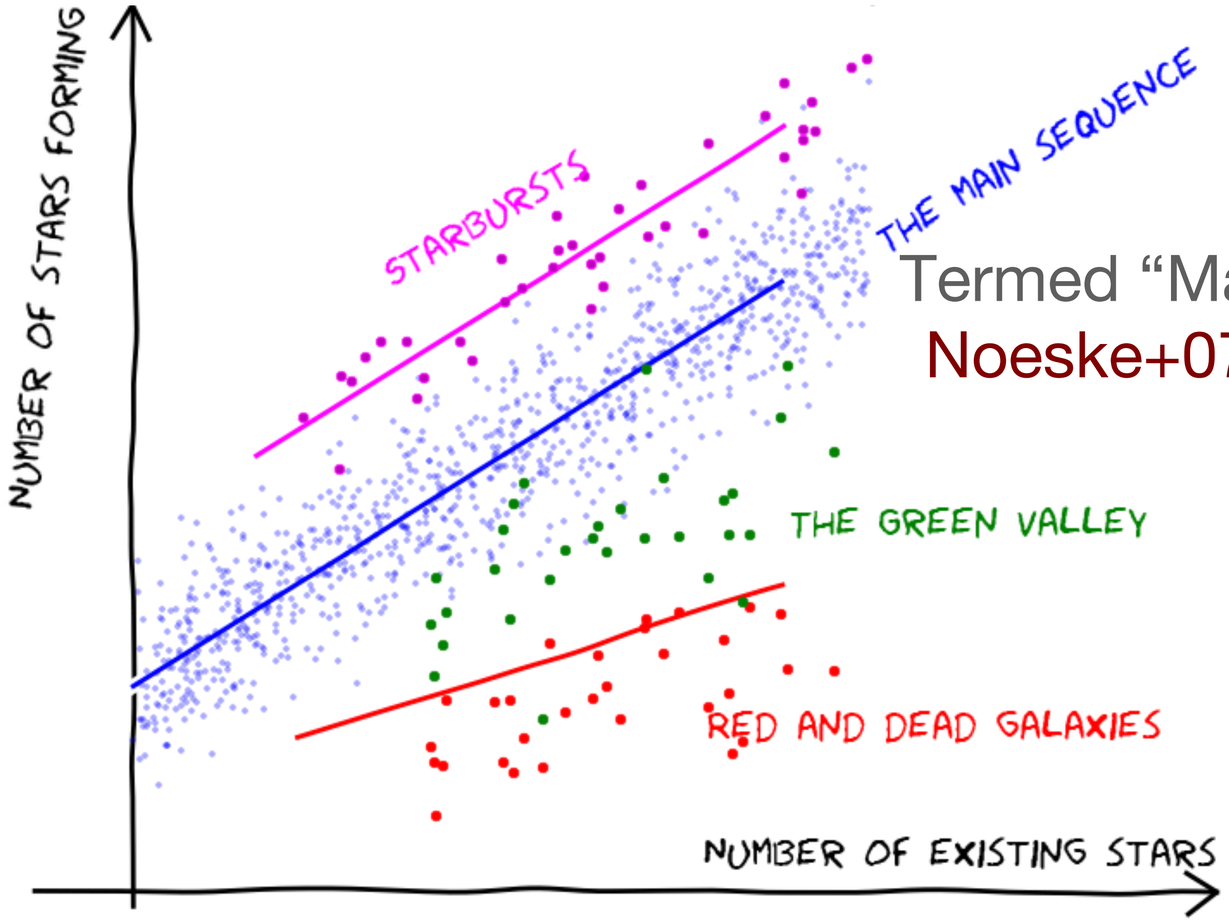






From Förster Schreiber & Wuyts 20 (ARAA 58, 661)

Why plot SFR vs. Stellar Mass?



Termed “Main Sequence” by Noeske+07 (ApJL 660, 430)

Figure courtesy of Camilla Pacifici (STScI)

Is It a Main Sequence?

To call the star-forming sequence a "main sequence", it should be analogous to the H-R diagram main sequence, which is:

☐A physically understood locus

☐that doesn't evolve with cosmic time

☐where stars spend the majority of their lives

☐while moving monotonically across the locus

Is It a Main Sequence?

To call the star-forming sequence a "main sequence", it should be analogous to the H-R diagram main sequence, which is:

☐A physically understood locus

☒that doesn't evolve with cosmic time

☑where stars spend the majority of their lives

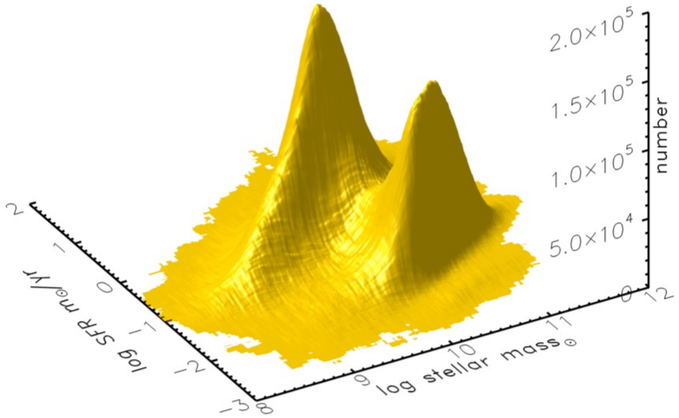
☒while moving monotonically across the locus

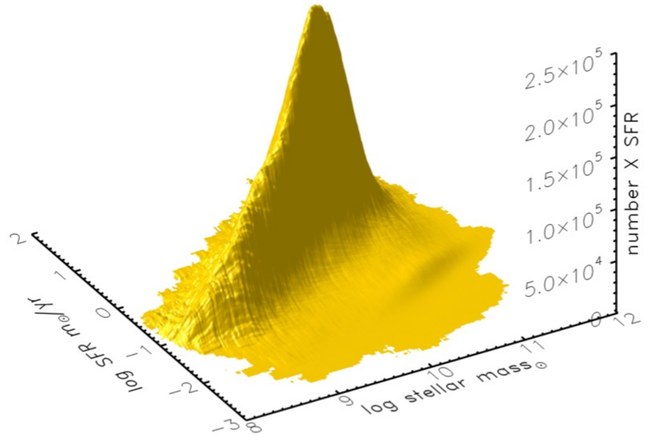
So I prefer to call it the "Star-Forming Sequence"
or simply "The SFR-M_* Correlation"

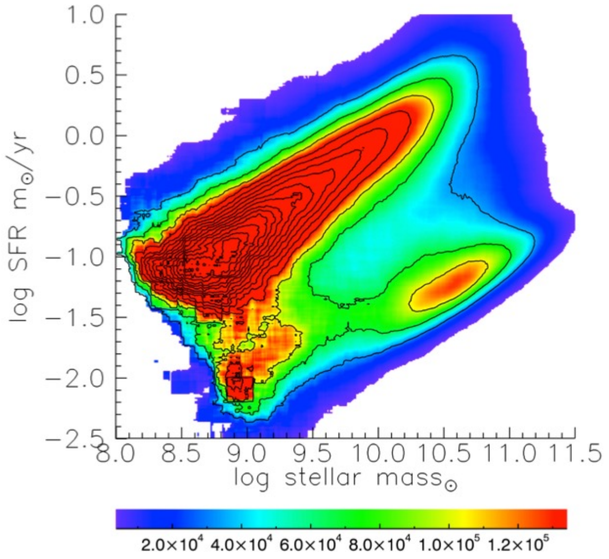
Which is more interesting, the scaling relations or the outliers?

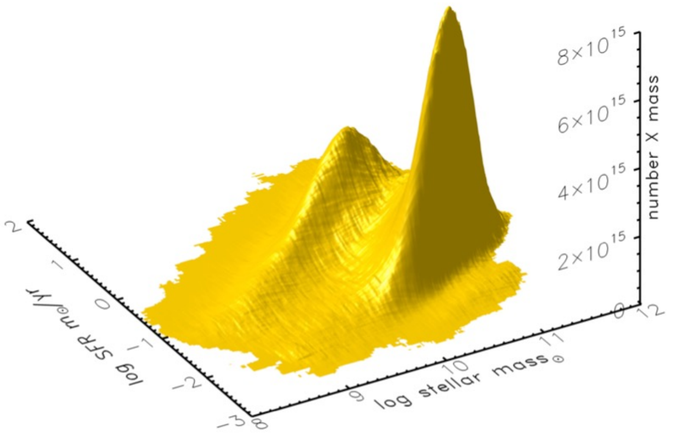
- Outliers provide a constraint on physical limits of galaxy evolution.
- Outliers illustrate when equilibria that maintain the scaling relations break down.
- Example: populations of galaxies above and below the Star-Forming Sequence. Many of the z>8 JWST galaxies may be starbursts; have to watch selection effects before measuring evolution of scaling relations in case most of our sample are an outlying population!

Where do z=0 galaxies lie on the SFR-M* Diagram?



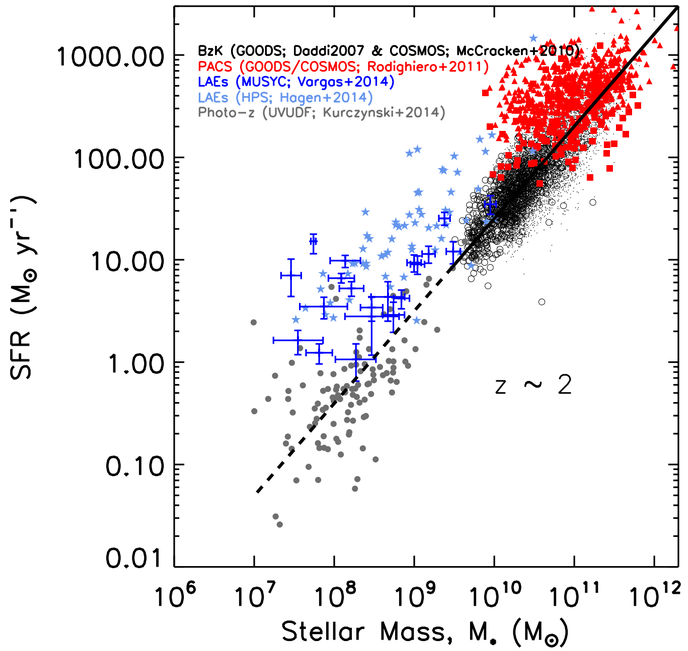


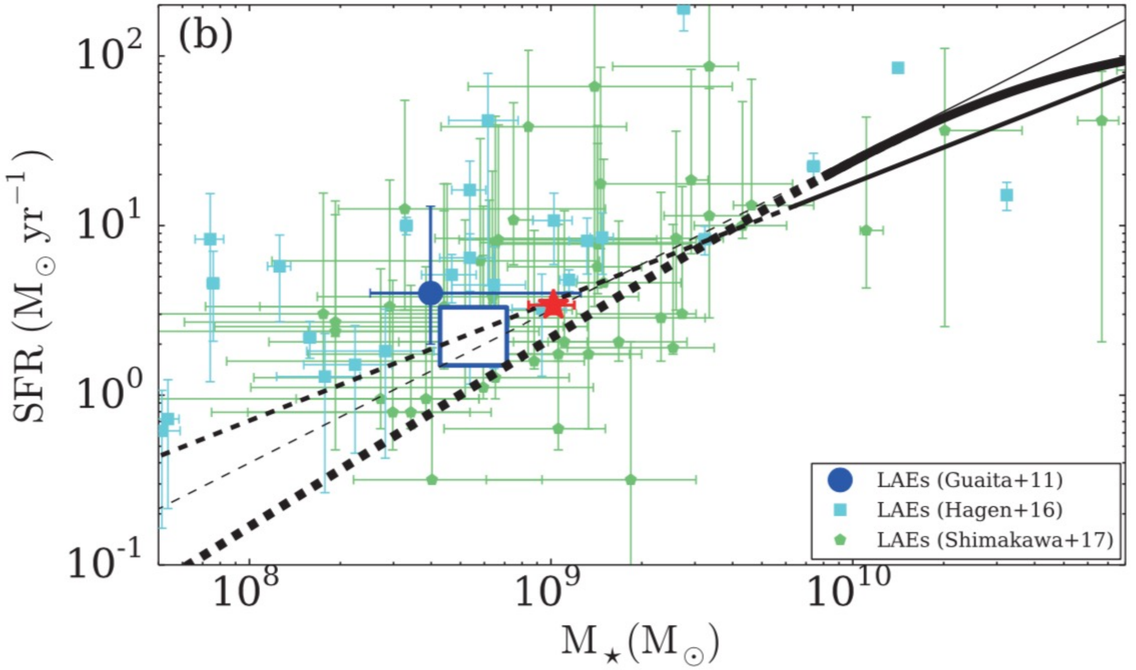




Figures from Renzini & Peng 15 (ApJL 801, L29)

Where do z=2 Lyman Alpha Emitters (LAEs) lie on the SFR-M* Diagram?





LAEs lie above the correlation; they are undergoing starbursts!

Vargas+14 (ApJ 783, 26)

Hagen+14 (ApJ 786, 59)

Santos+20 (MNRAS 493, 161)

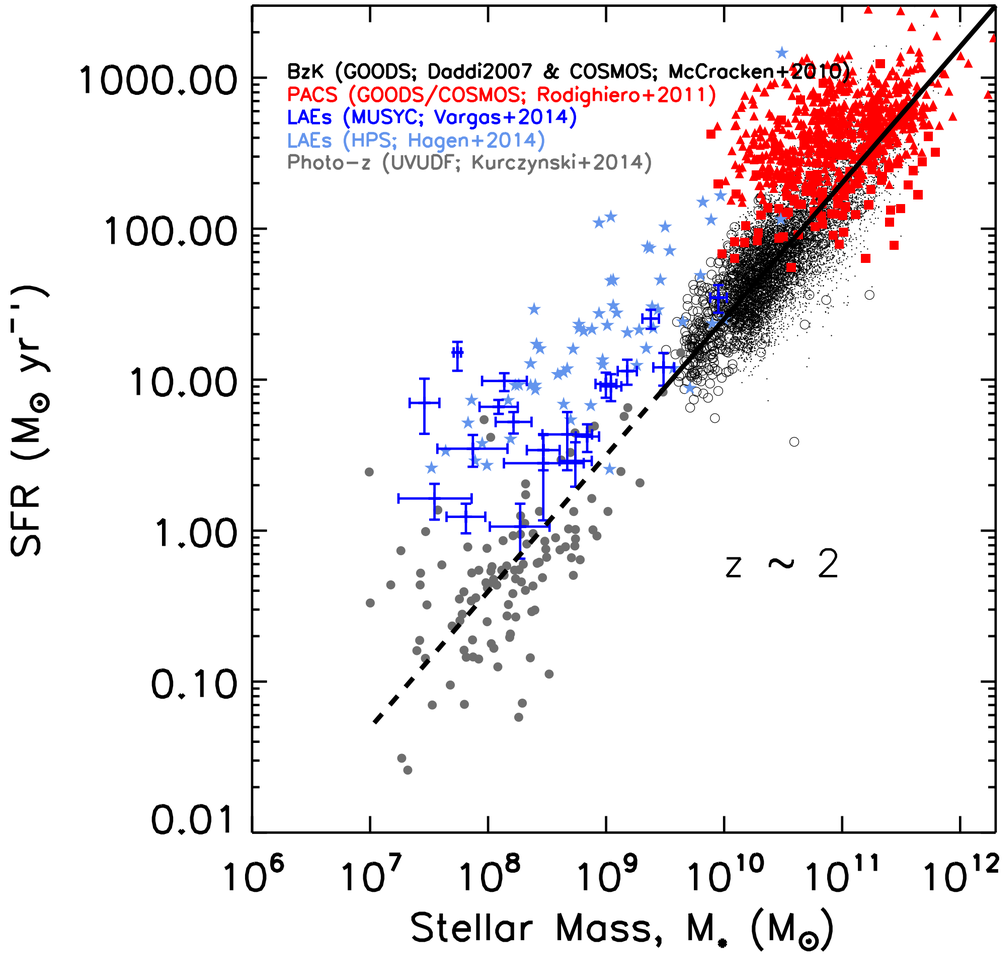
LAEs lie on the correlation; LAEs follow an SMC dust law, even though the correlation was determined assuming Calzetti dust law for other galaxies Kusakabe+18 (PASJ 70, 4)

Need data-driven methods for identifying when a population consists of outliers; is a K-S or Anderson-Darling test sufficient?

Does the scatter matter?

- Intrinsic scatter interests me even more than outliers!
- Constrains the stochasticity of galaxy evolution - either excursions around equilibrium growth or variations in where that equilibrium lies.

Does the scatter matter?



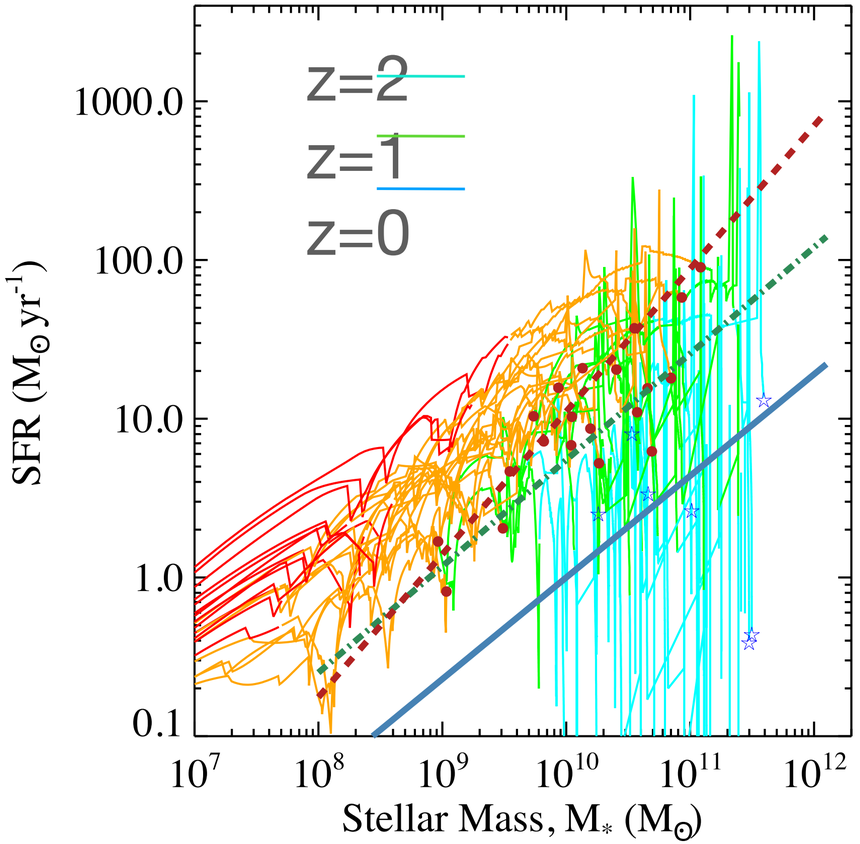
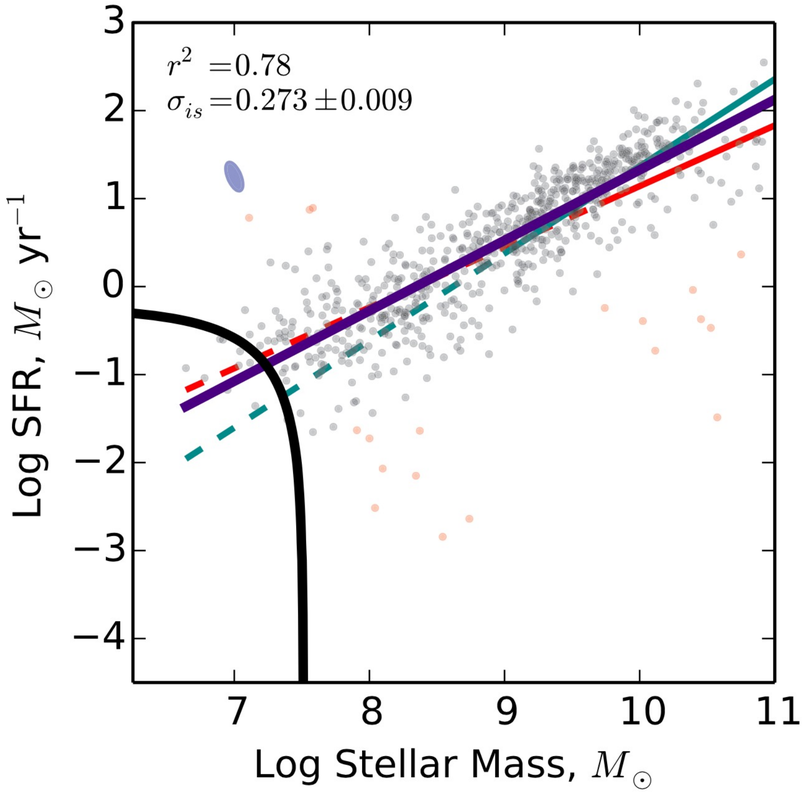
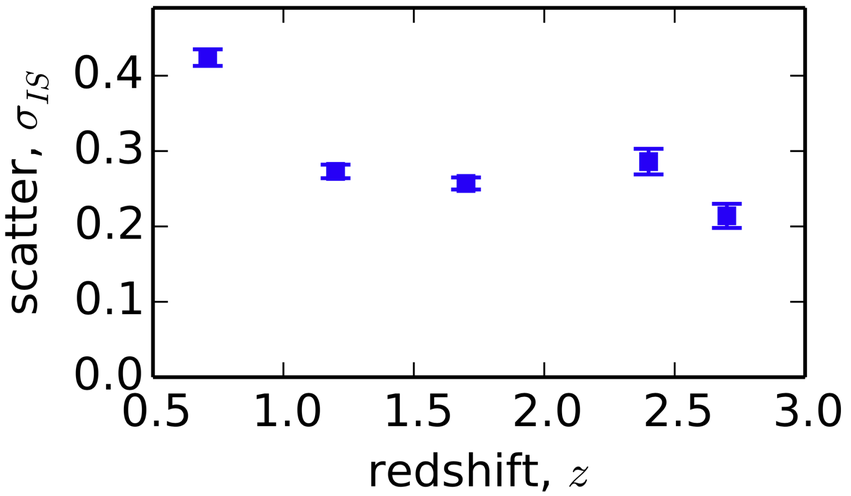


figure from rachel somerville

- Observed scatter (removing starburst outliers) is ~0.3 dex
- Can measure intrinsic scatter(M_*) as a constraint on galaxy models

Measuring the SFR-M$_*$ correlation and scatter at z=1





Intrinsic scatter is ~0.25 dex at z>1

Figures from Kurczynski+16 (ApJ 820, L1)

For additional SFR-M$_*$ intrinsic scatter measurements, see Boogaard+18 (A&A 619, 27); Sandles+22 (MNRAS 515, 2951); Huang+23 (arXiv:2301.01995)

For model predictions, see Mitra+17 (MNRAS 464, 2766); Matthee & Schaye 19 (MNRAS 484, 915); Curtis-Lake+21 (MNRAS 503, 4855);

What can we learn from galaxy-halo scaling relations?

- By this I mean “light-dark” or “visible-invisible” correlations e.g., UNIVERSEMACHINE (Tutorial by Peter on Wednesday!)
- Most familiar is the stellar mass/halo mass relation (SHMR).
- Are galaxy properties so tightly linked to cosmology that you can do “cosmology with one galaxy”? Villaescusa-Navarro+22 (ApJ 929, 132)

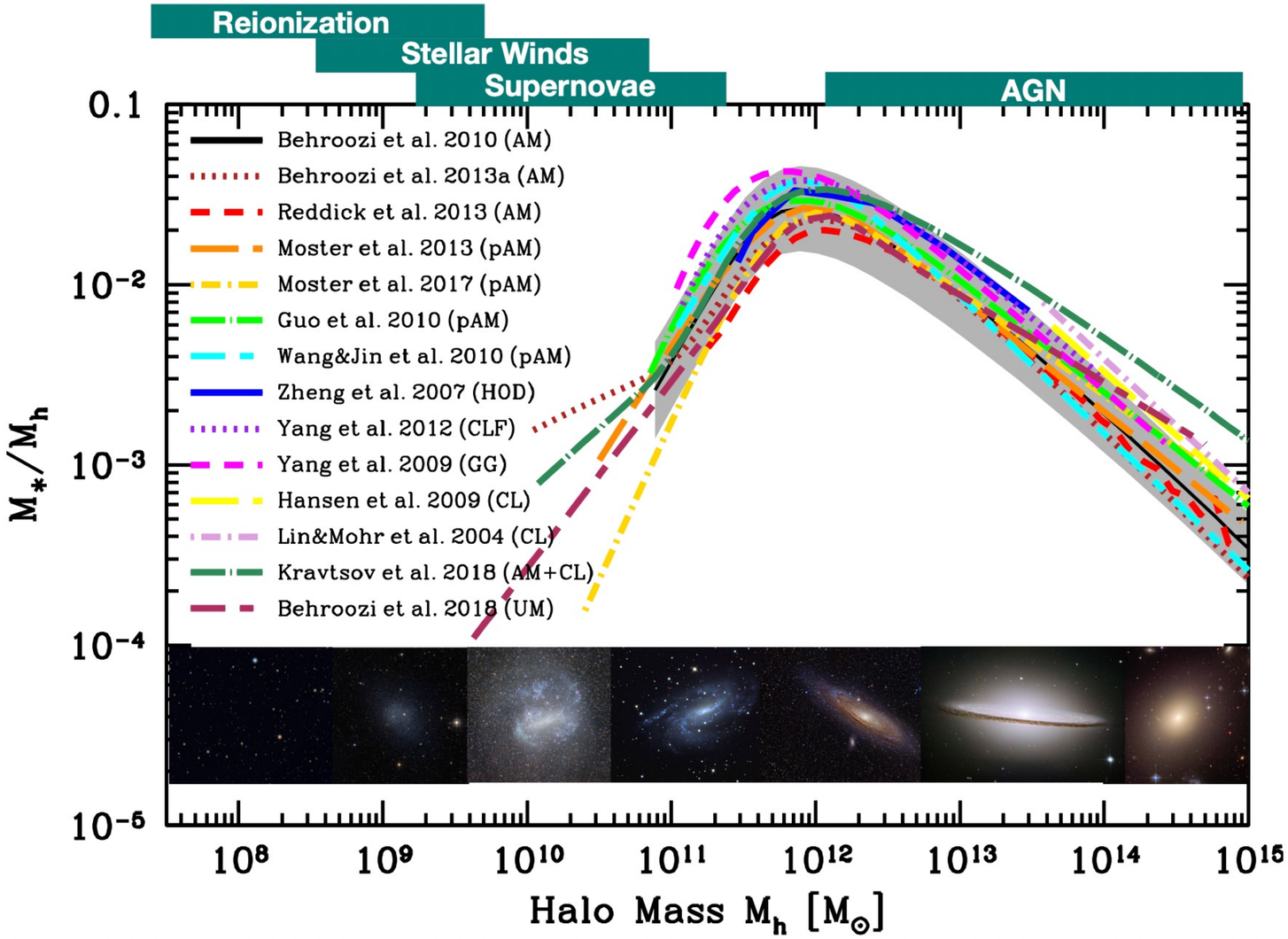
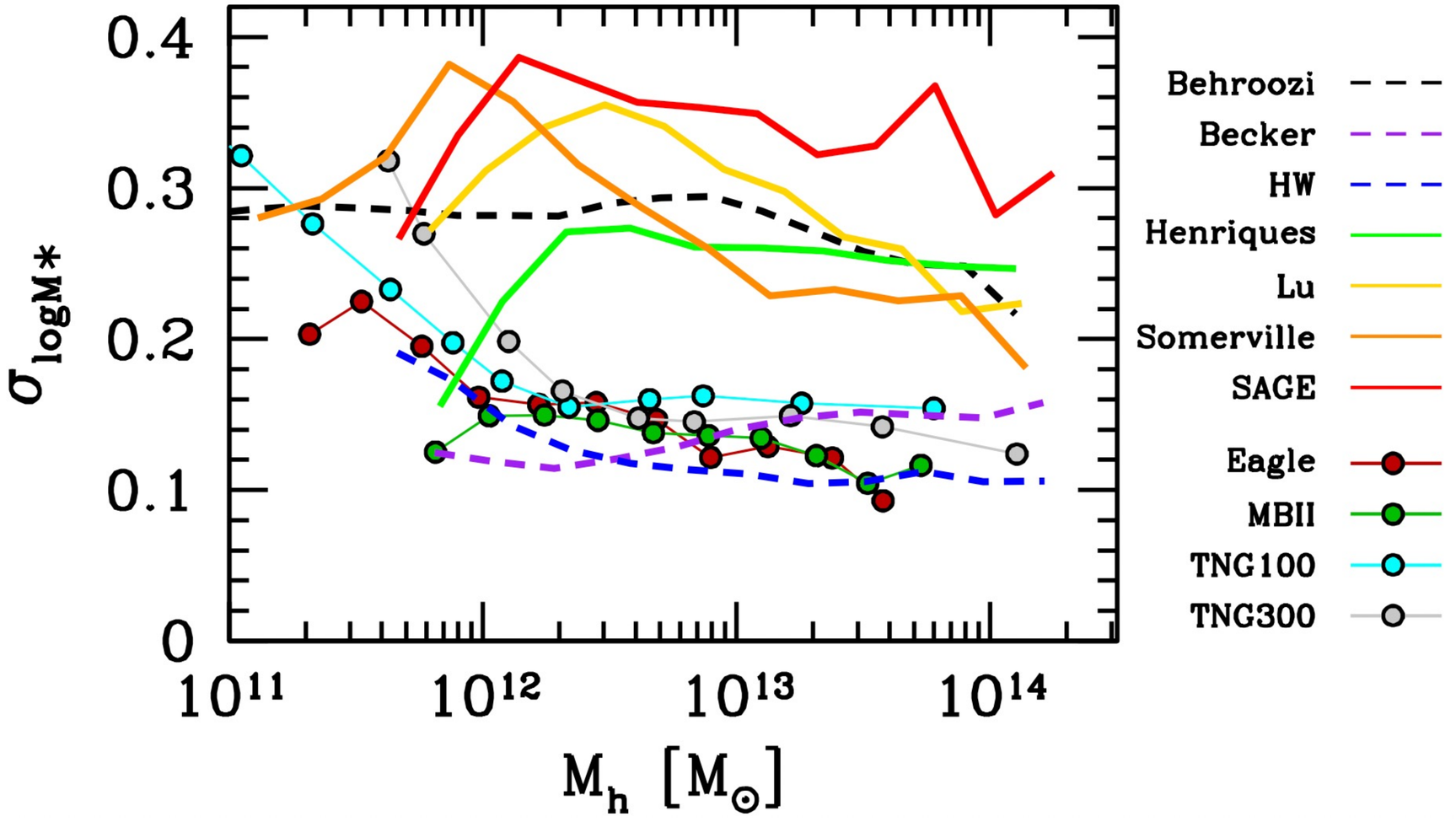


Figure from Wechsler & Tinker 18, (ARAA 56, 435), adapted from Behroozi+19 (MNRAS 488, 3143)

What can we learn from galaxy-halo scaling relations?



Predicted scatter in SHMR ranges from 0.1-0.4 dex; if we can measure it, distinguish between models!

Figure from Wechsler & Tinker 18 (ARAA 56, 435)

Research Projects You're Welcome to Ask Me About

- ODIN (One-hundred-deg^2 DECam Imaging in Narrowbands; Co-PI)
- LSST Dark Energy Science Collaboration (Analysis Coordinator)
- JWST-CEERS (Applying SFH Reconstruction to galaxies at z>5 – and maybe z>10)
- HETDEX (Hobby-Eberly Telescope Dark Energy eXperiment)
- Simons Observatory (Cosmic Microwave Background)

Questions for discussion

1. Is there a fundamental galaxy scaling relation?
2. Which is more interesting, the scaling relations or the outliers?
3. Does the scatter matter?
4. What can we learn from galaxy-halo scaling relations?
5. Between galaxy scaling relations and the galaxy-halo connection,
   which is the lightning and which is the thunder?