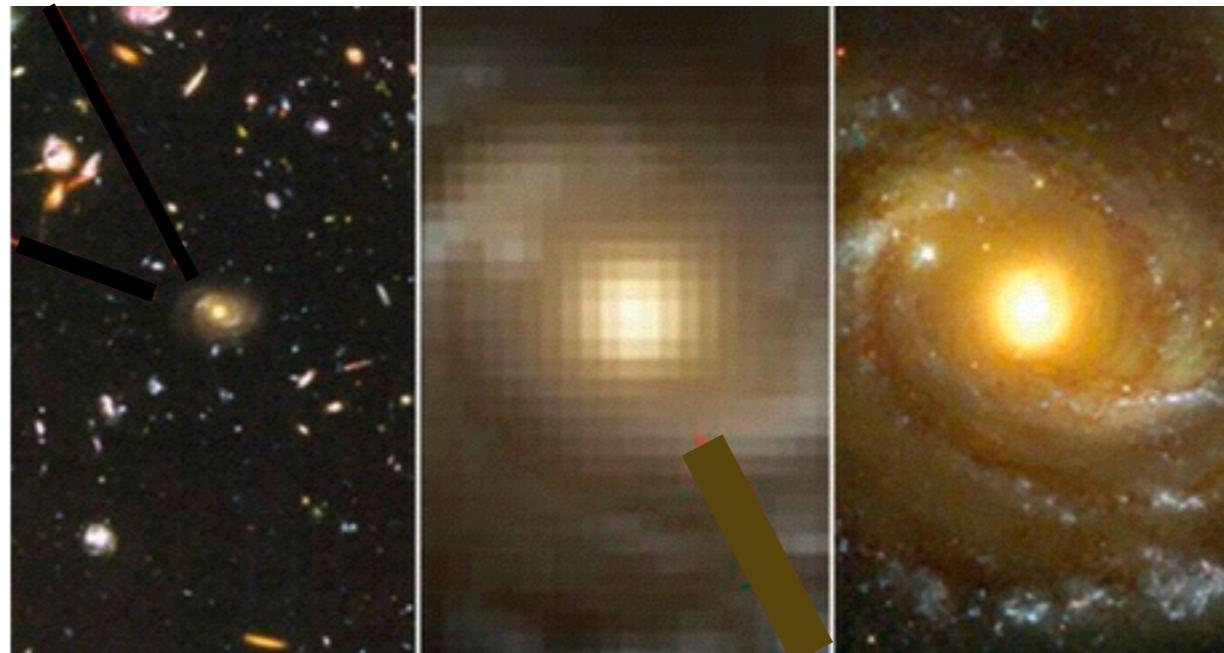
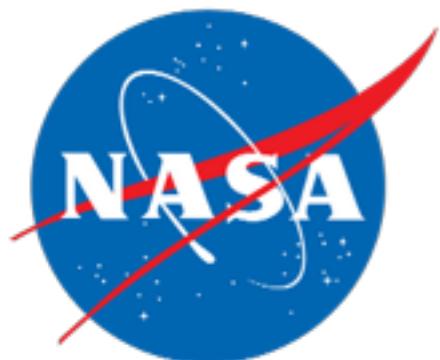


# A Look Towards the Future: Spatially-resolved stellar populations will provide the missing clues to massive galaxy formation & evolution

Hubble Ultra Deep Field  
Hubble Resolution vs. TMT Resolution



Thirty Meter Telescope/Associated Press



Kate Whitaker

NASA Postdoctoral Program Fellow  
Goddard Space Flight Center

[www.kewhitaker.com](http://www.kewhitaker.com)

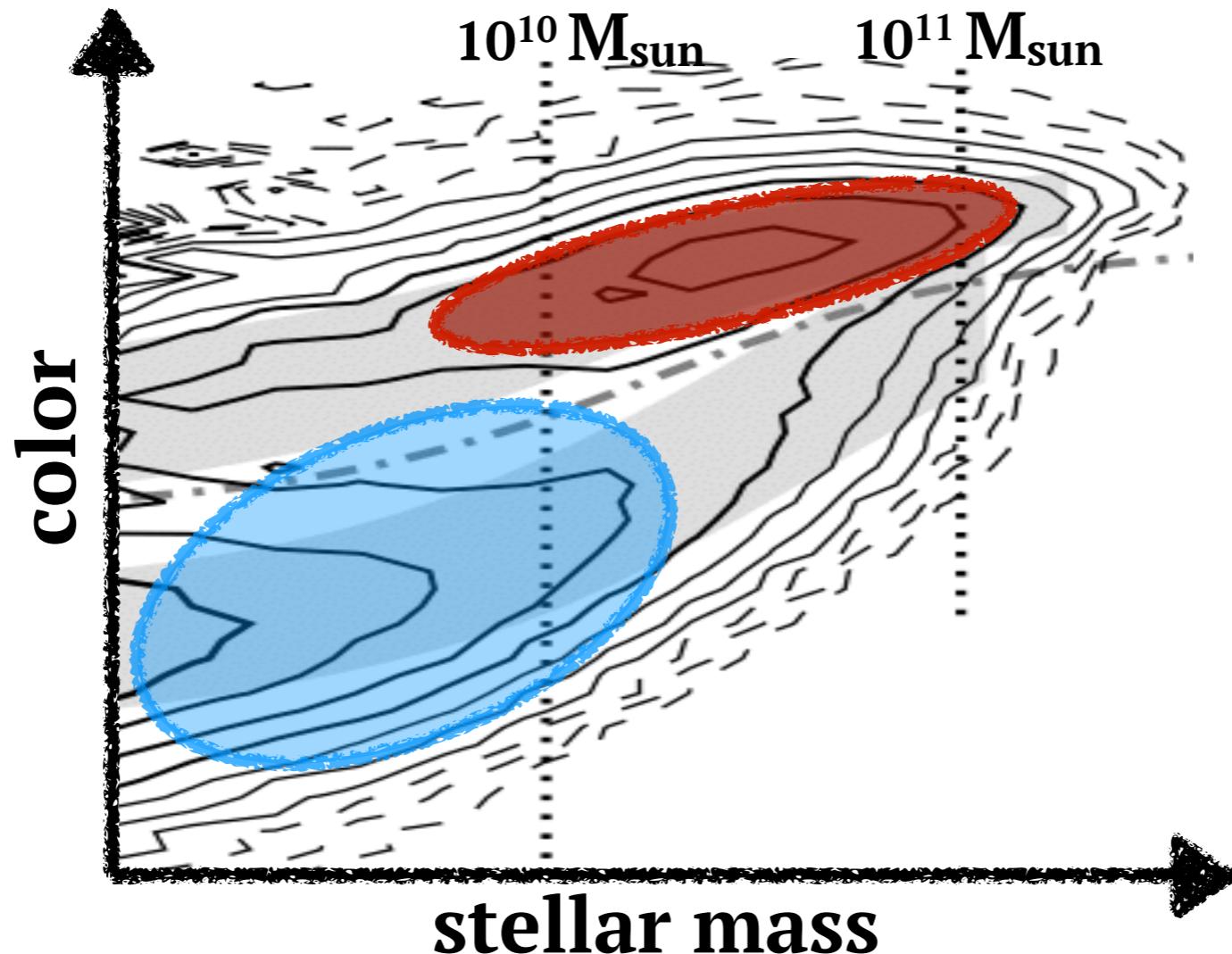




# Galaxy Formation & Evolution: Understanding Bimodality

**TMT**

THIRTY METER TELESCOPE



adapted from  
Baldry et al. 2006



**TMT**

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## SCIENCE QUESTIONS:

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- 1. How does a galaxy's star formation rate depend on mass?**
  
- 2. How and when do bulges form in galaxies?**



**TMT**

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## SCIENCE QUESTIONS:

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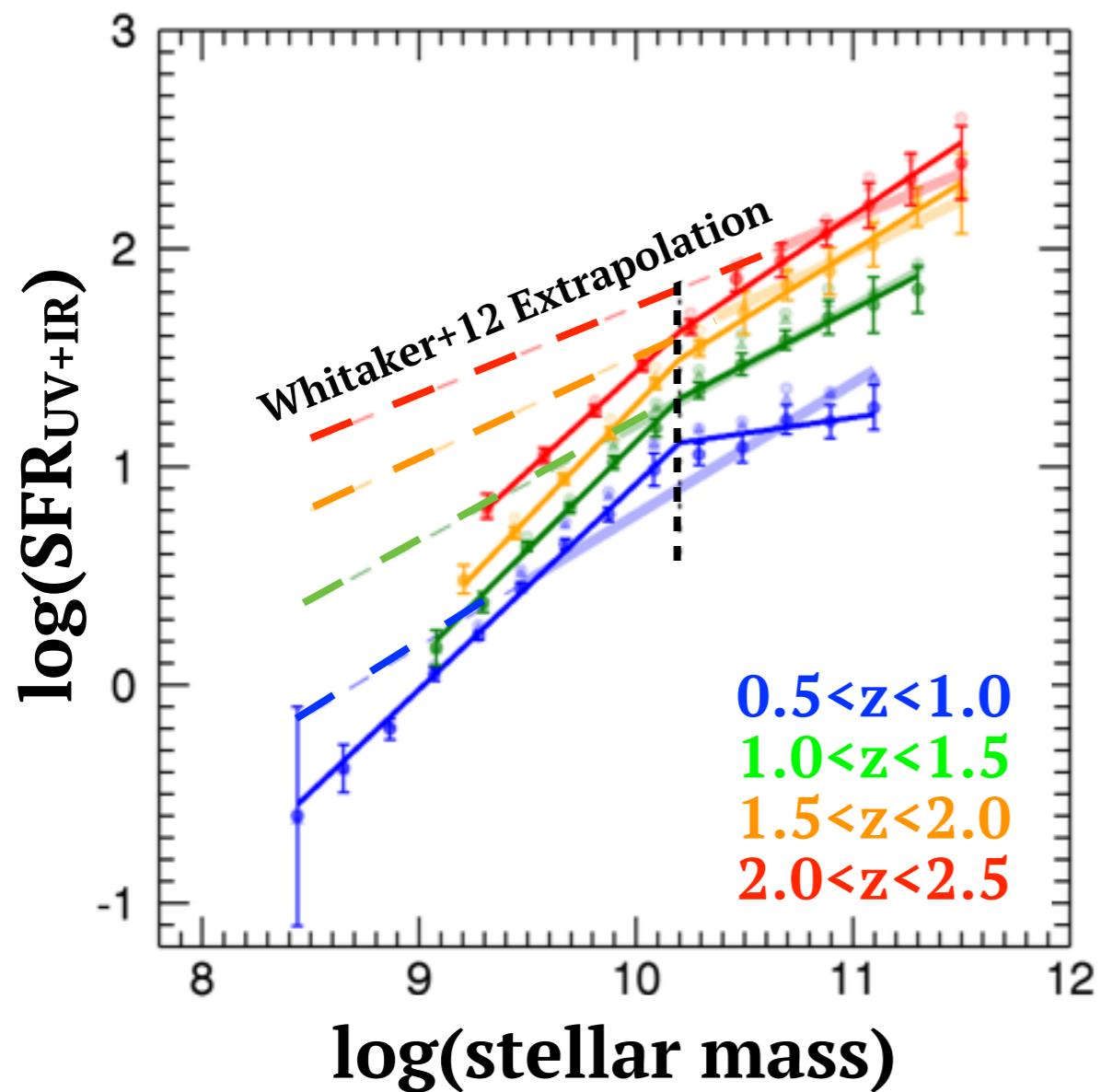
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# Hubble+Spitzer: The Star Formation Sequence



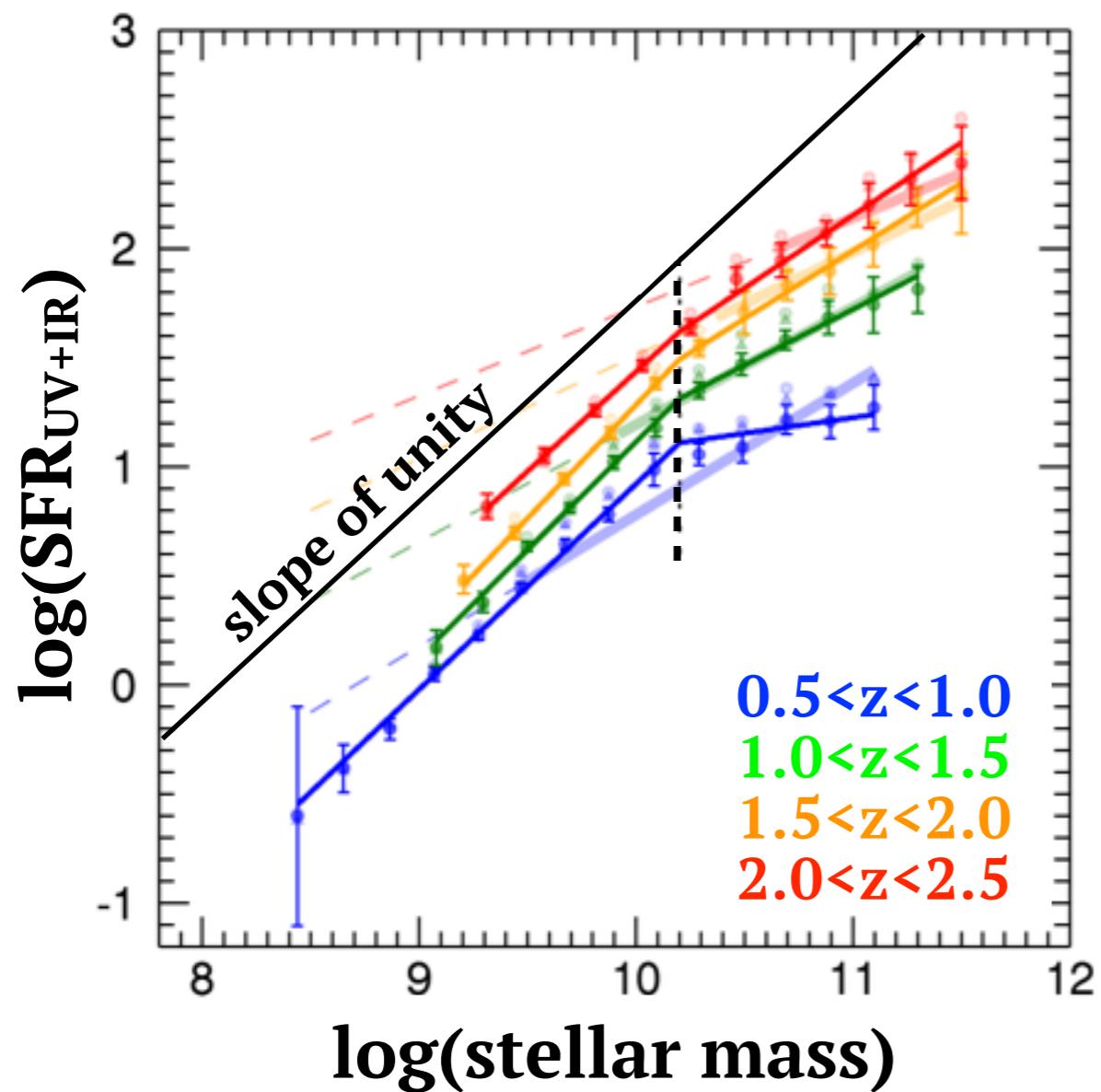
Whitaker et al. (2014b)



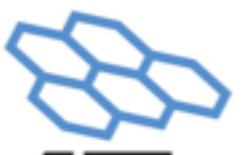
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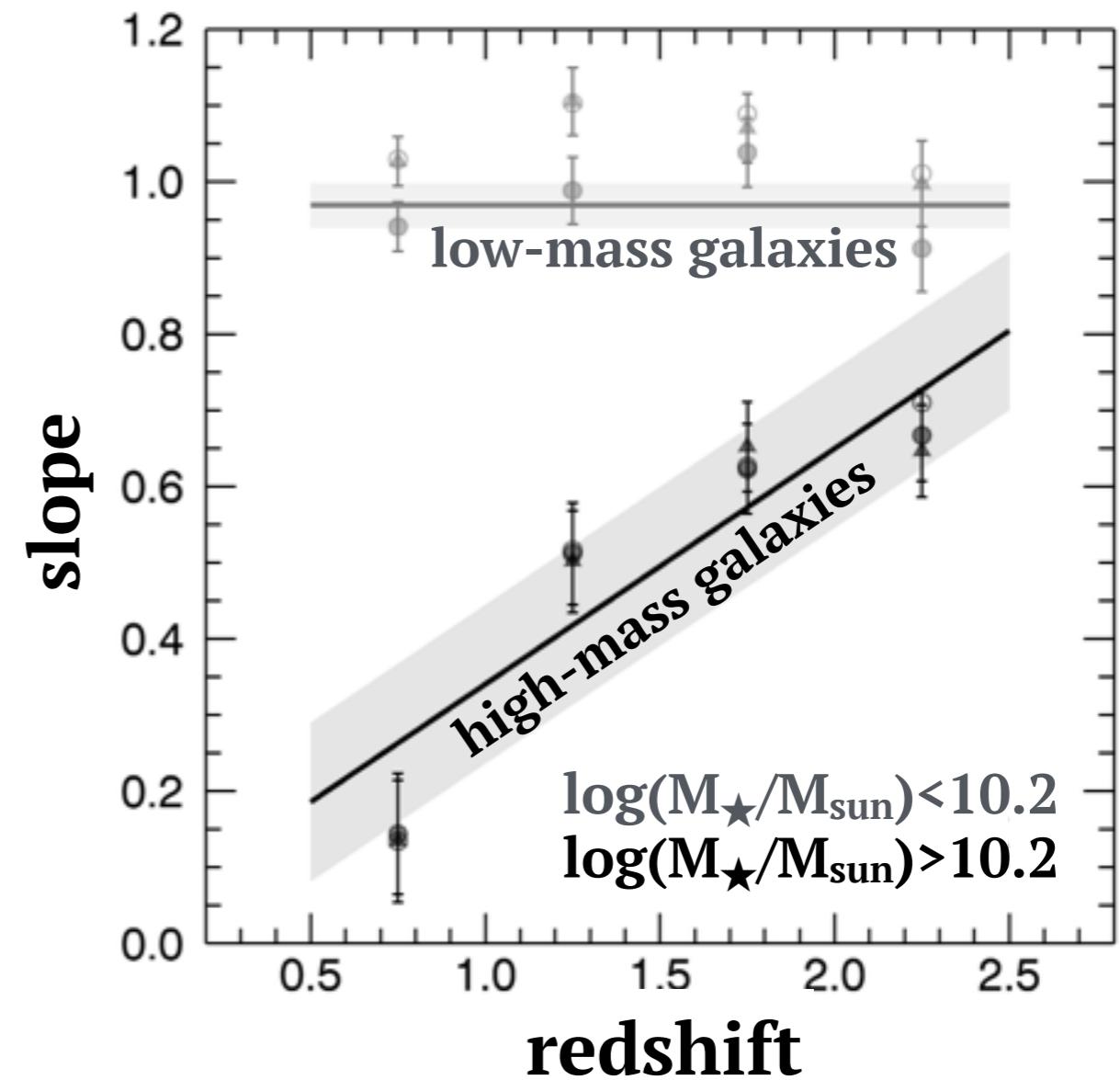
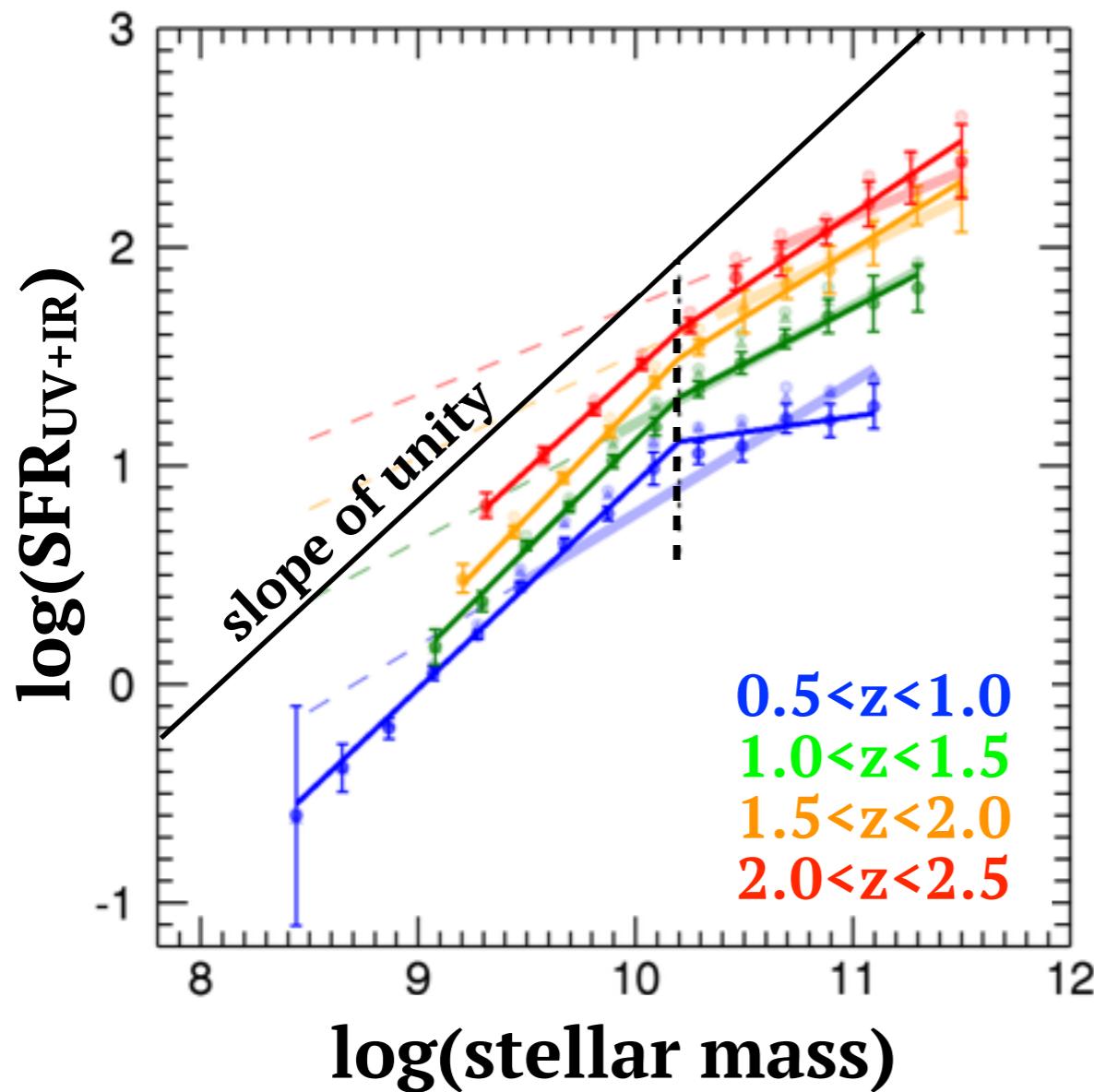
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# Hubble+Spitzer: The Star Formation Sequence

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Whitaker et al. (2014b)



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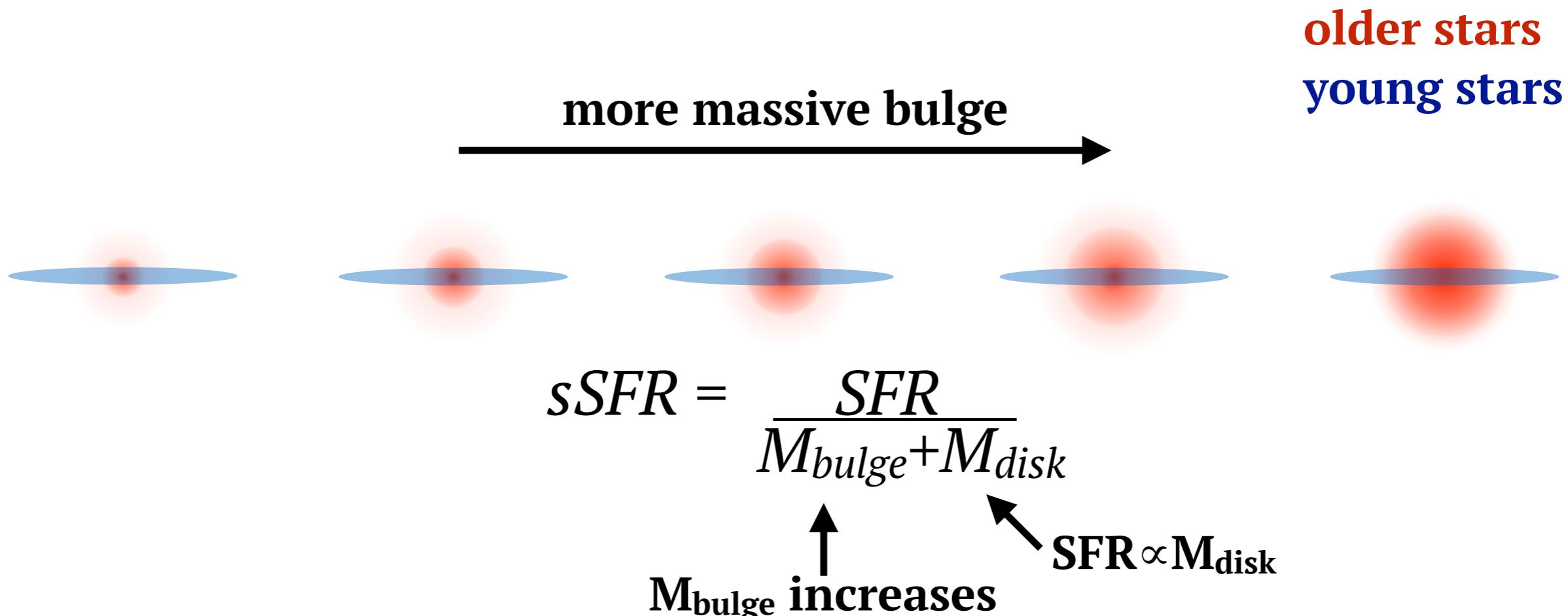
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# Hubble+Spitzer: The Formation of Bulges & Disks

*Does the presence of a significant bulge lower the global SFR?*

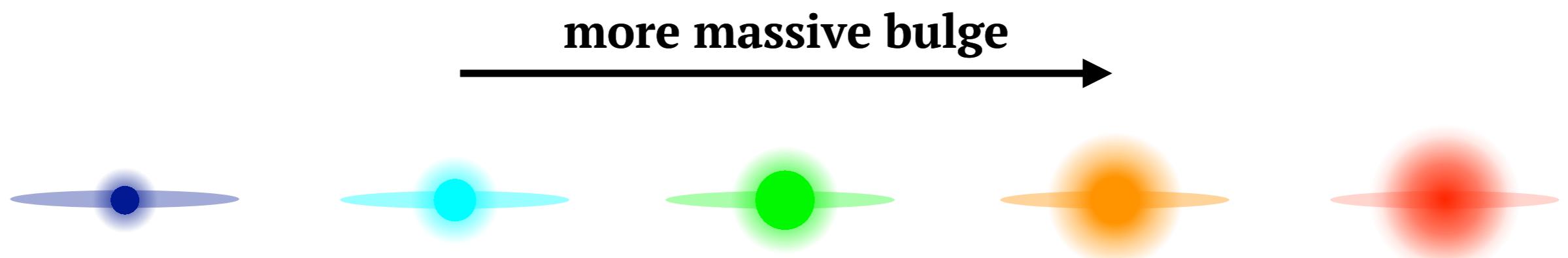
(e.g., Abramson et al. 2014)



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*Does the presence of a significant bulge lower the global SFR?*

(e.g., Abramson et al. 2014)



$$sSFR = \frac{SFR}{M_{bulge} + M_{disk}}$$

$\uparrow$        $\nearrow$

$M_{bulge}$  increases       $SFR \propto M_{disk}$



0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0

**Sersic Index**



# Hubble+Spitzer: The Formation of Bulges & Disks

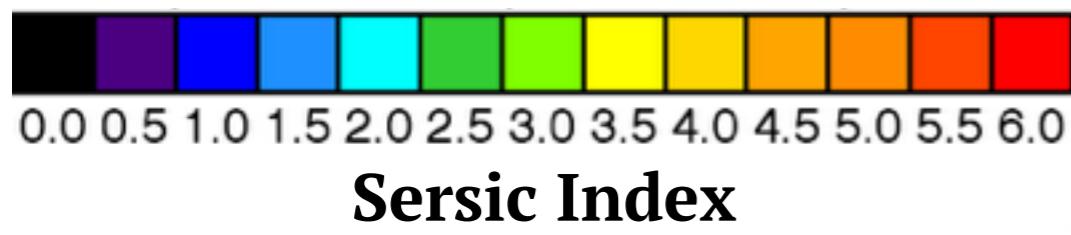
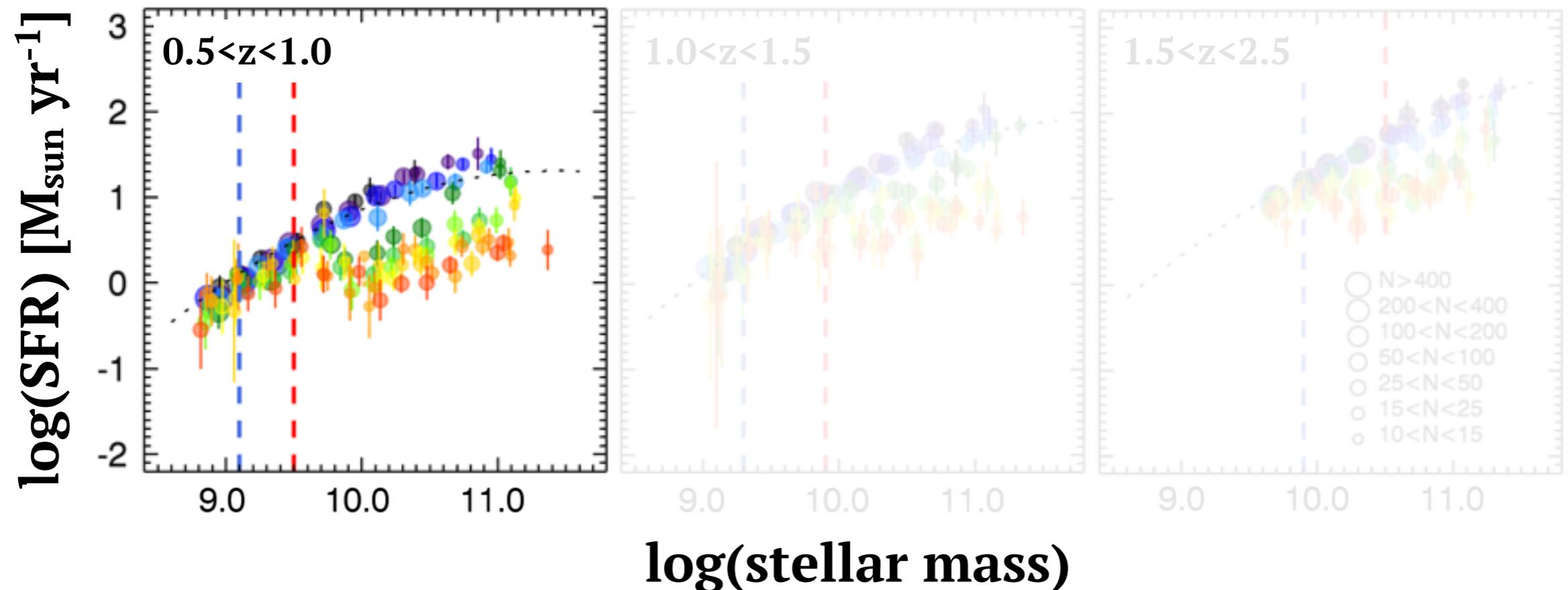
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**TMT**

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All Galaxies



Whitaker et al. submitted\*  
\* well, almost...



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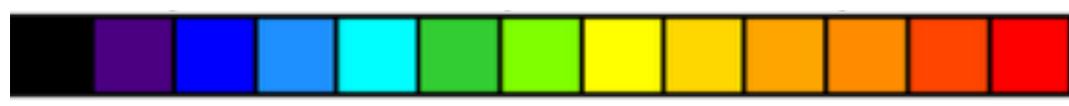
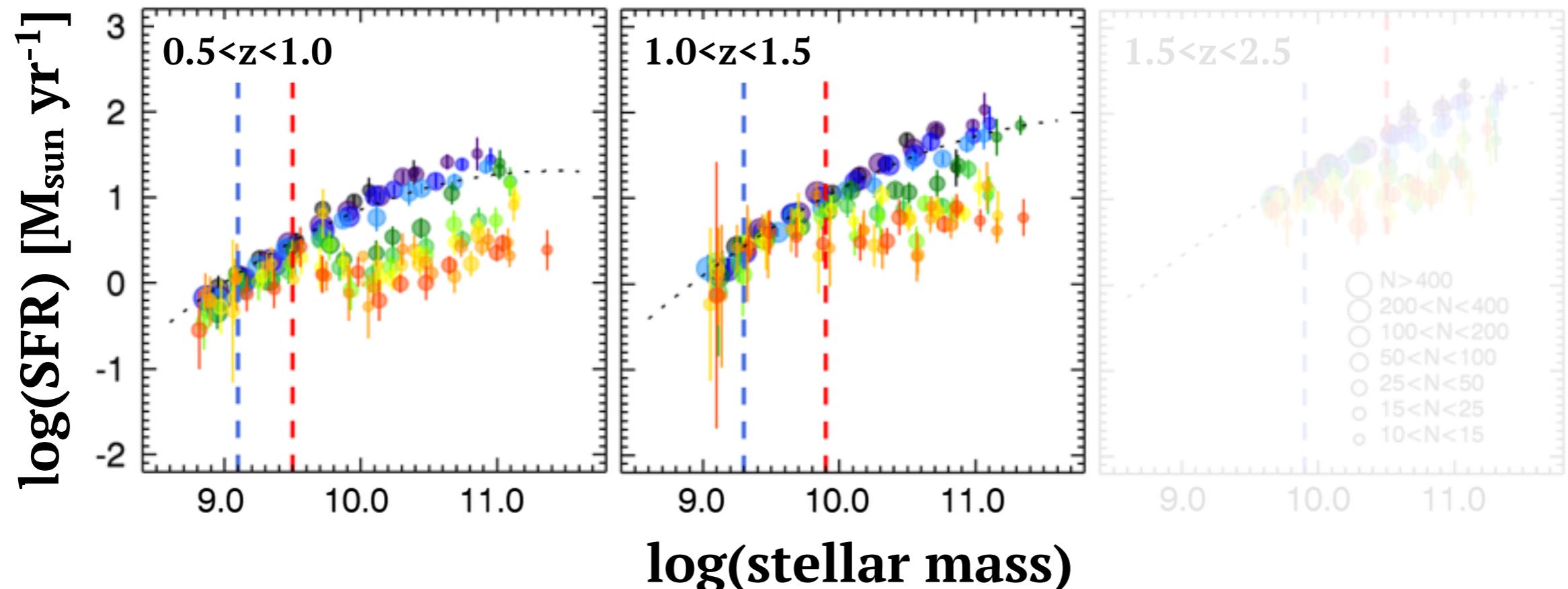
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All Galaxies



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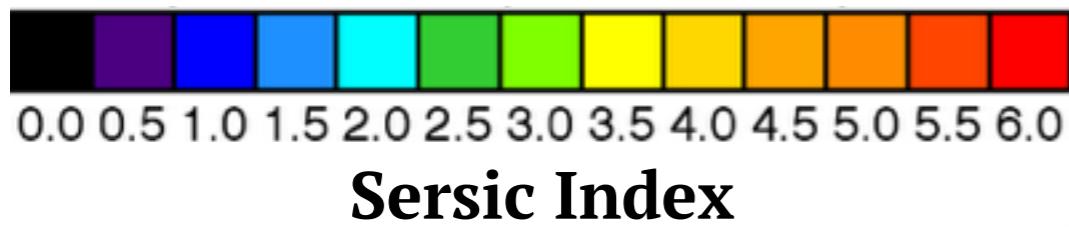
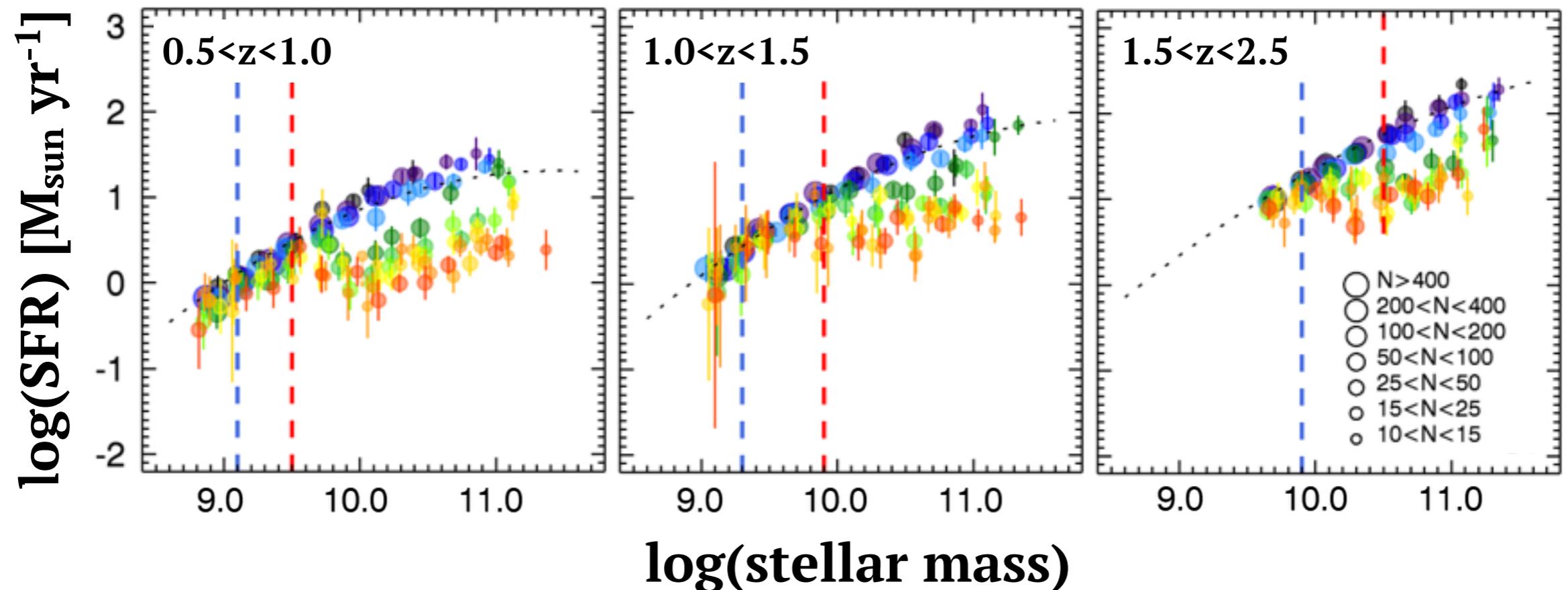
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## All Galaxies

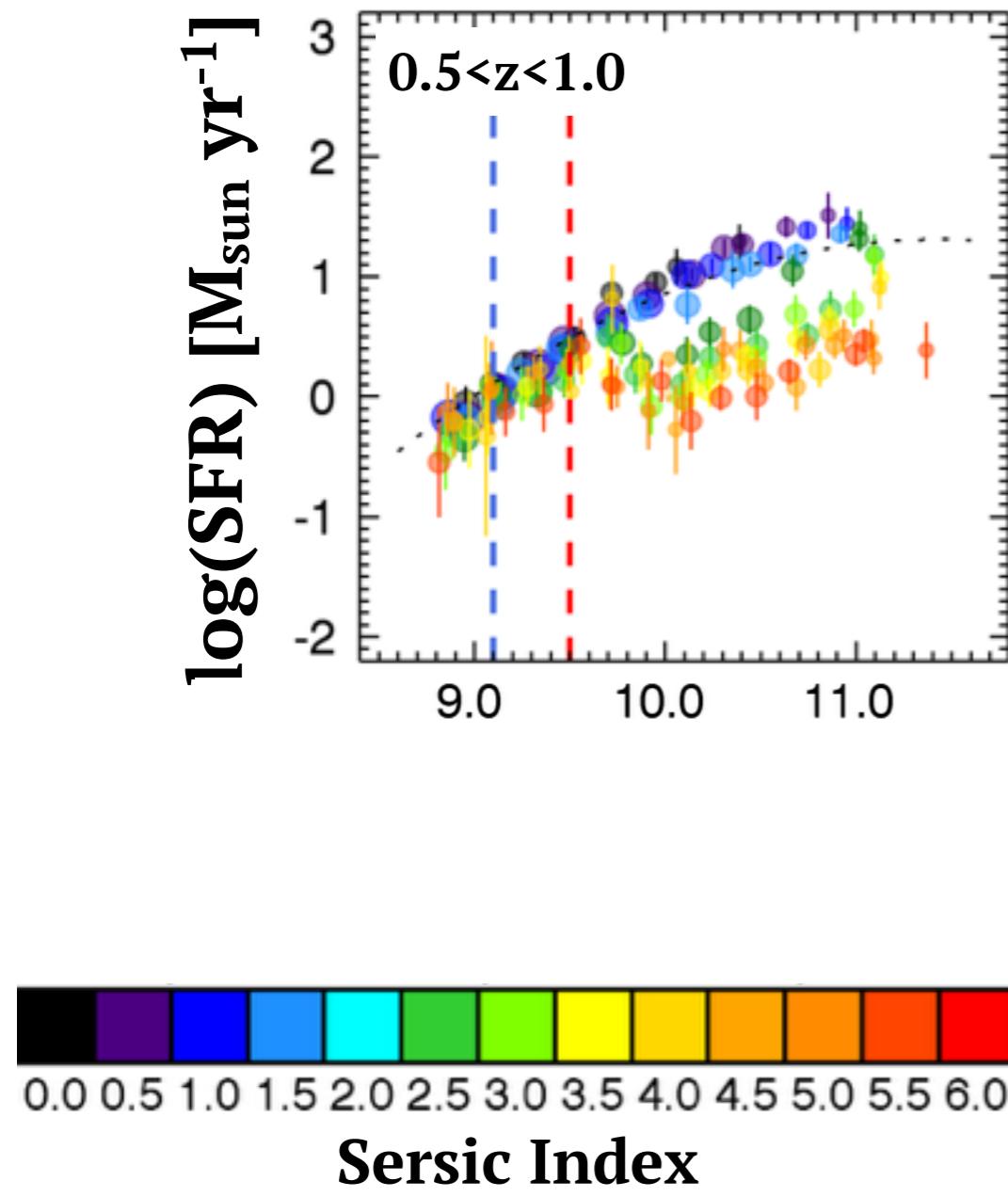


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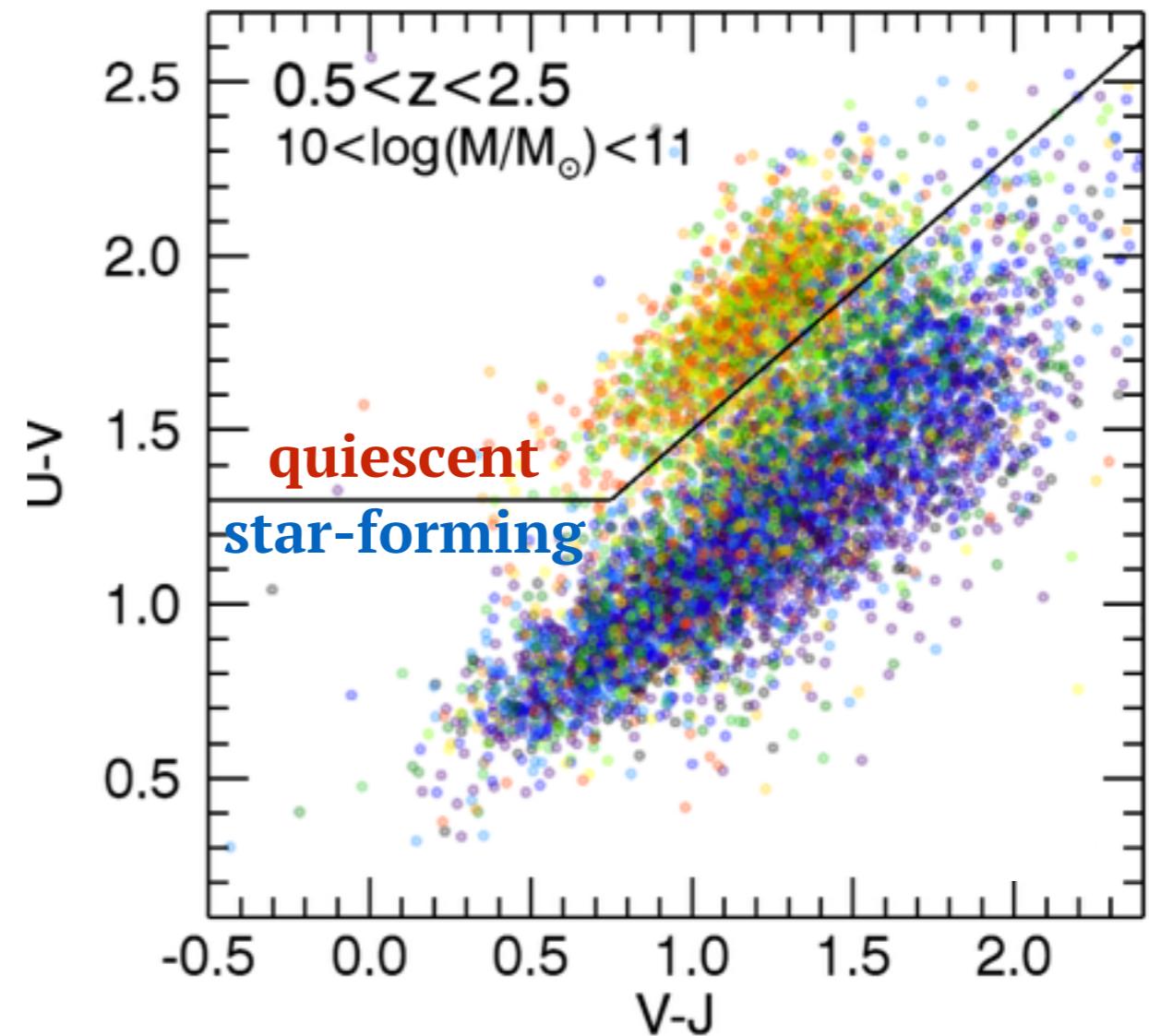
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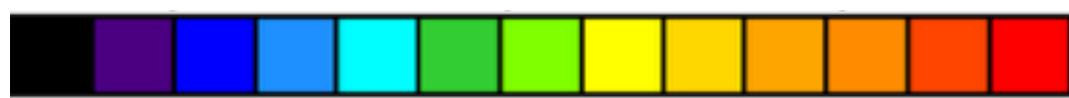
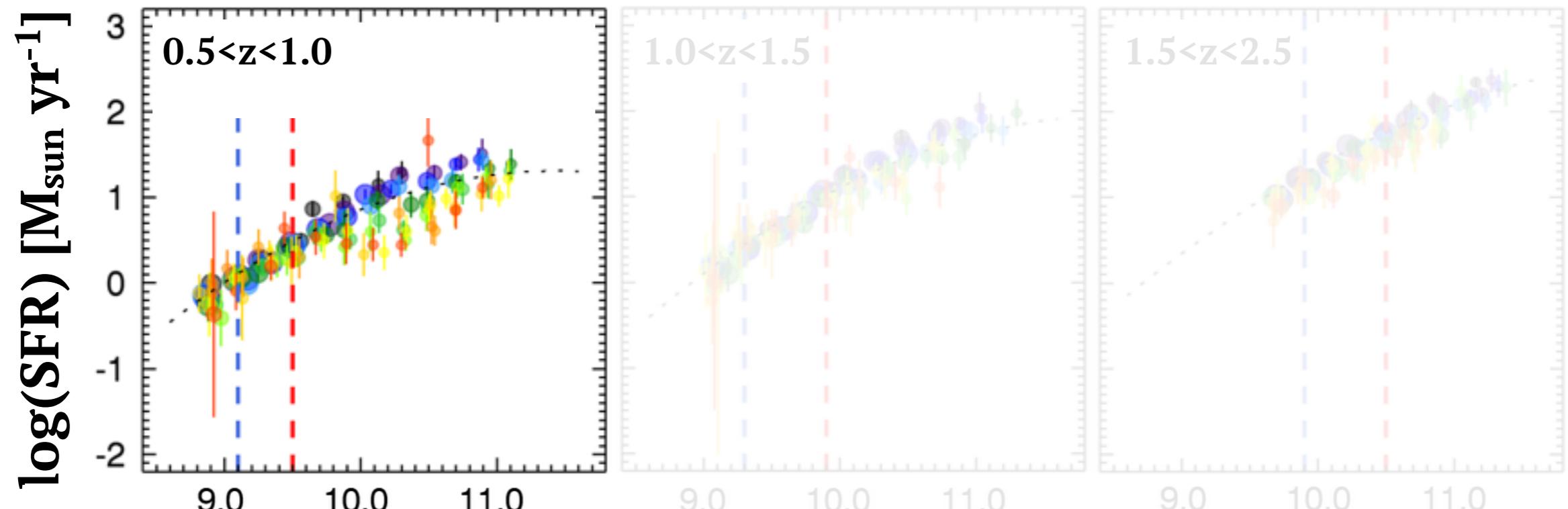
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## Star-forming Galaxies



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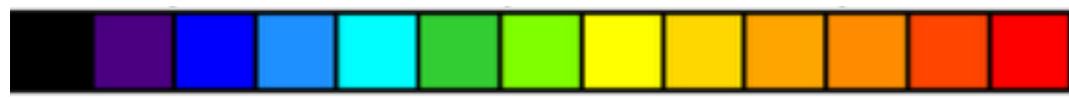
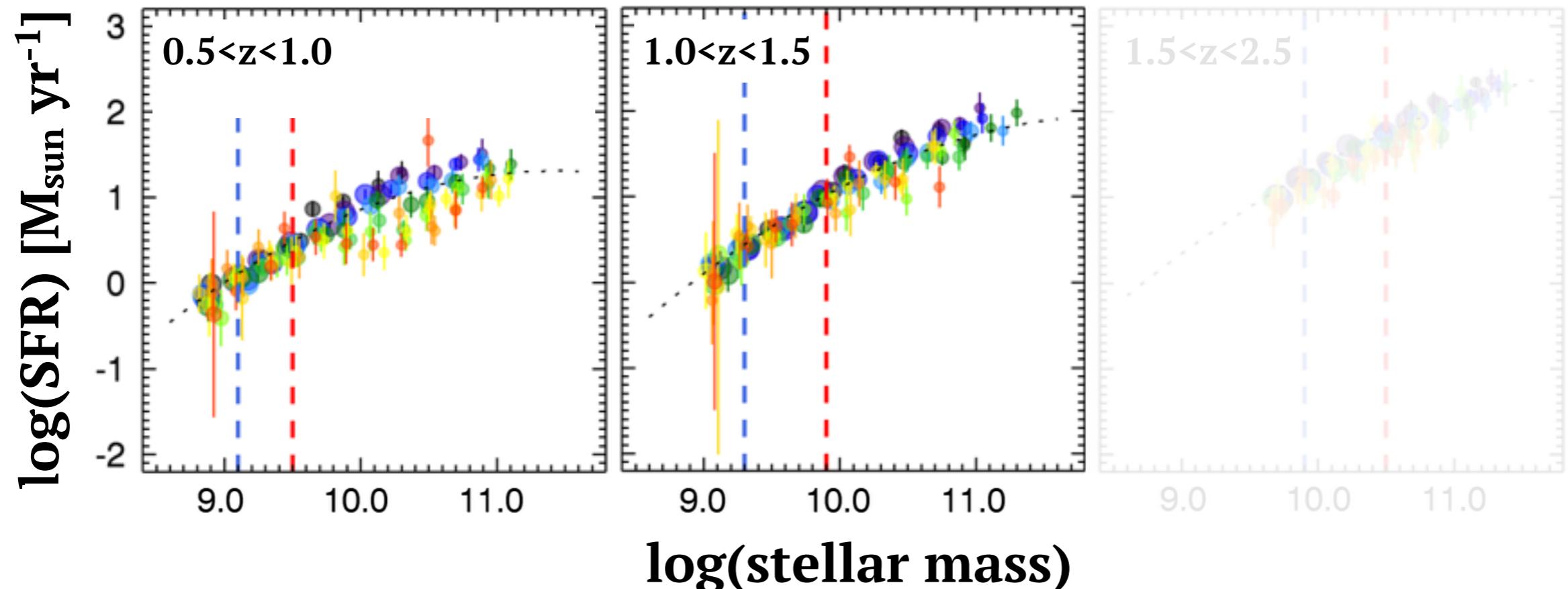
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**TMT**

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## Star-forming Galaxies



**Sersic Index**

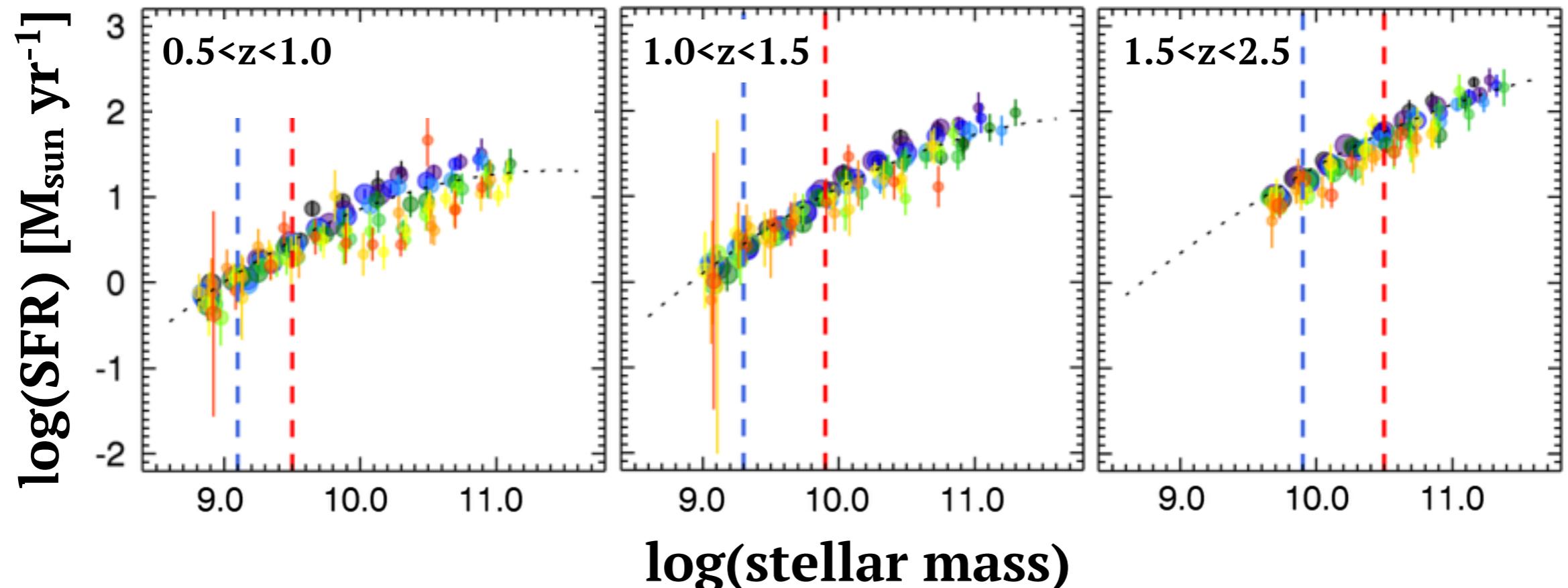
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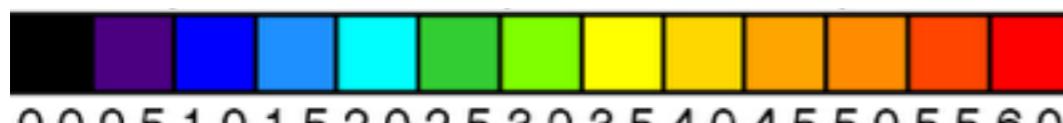
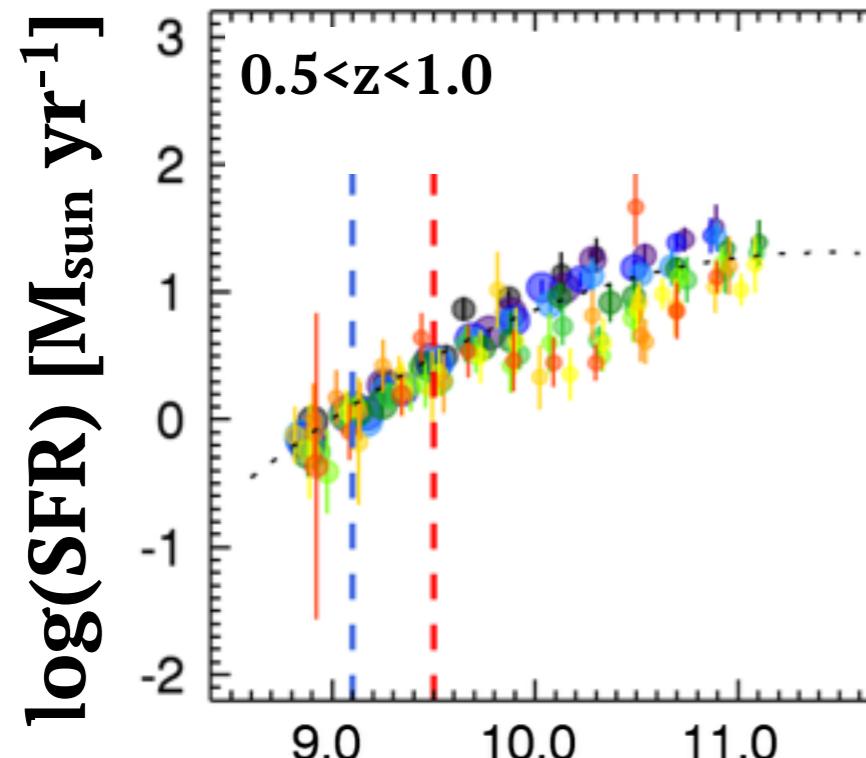
**TMT**

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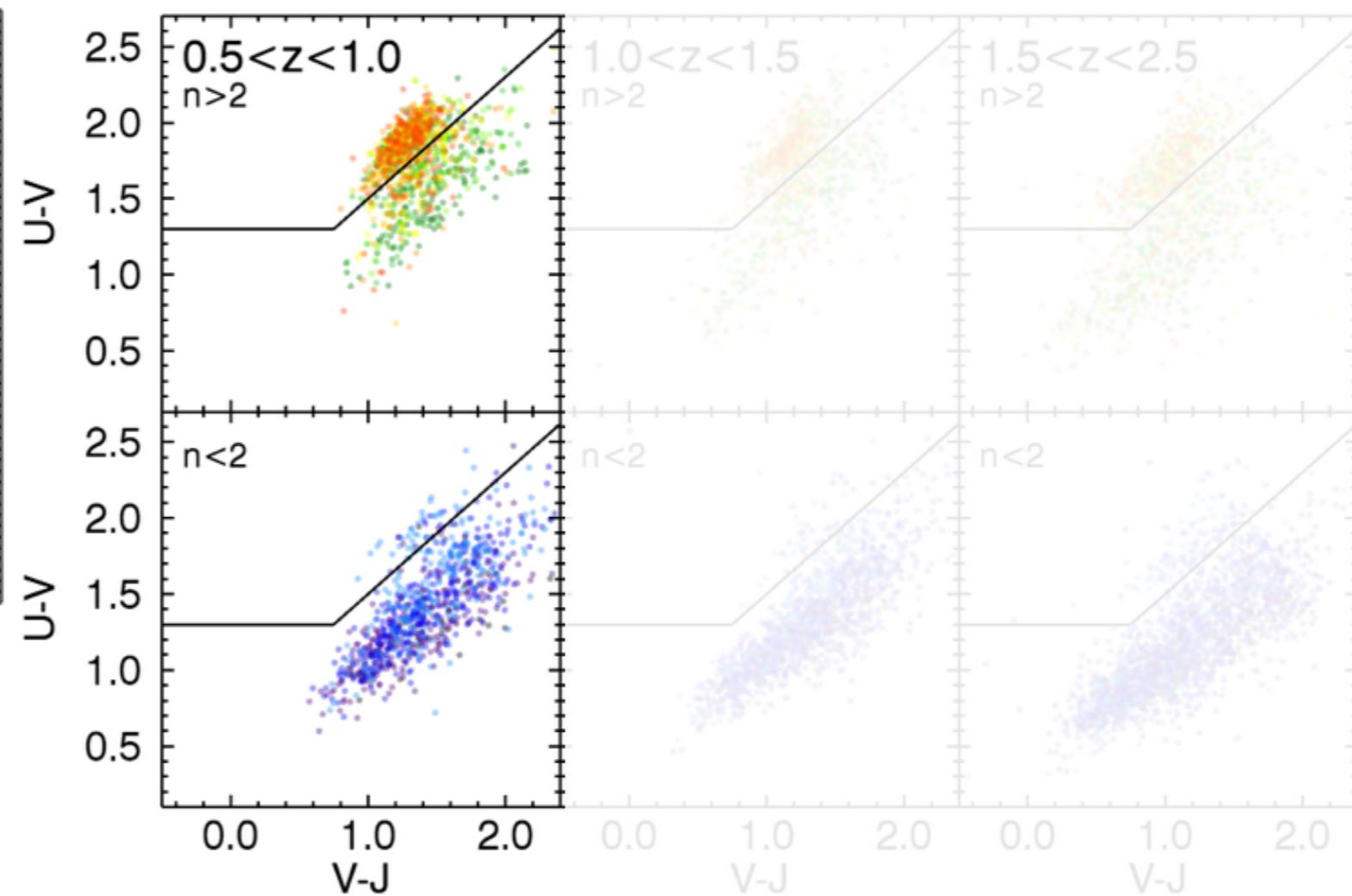
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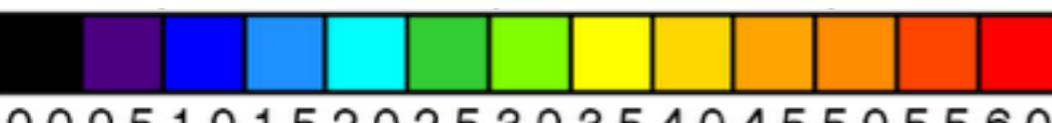
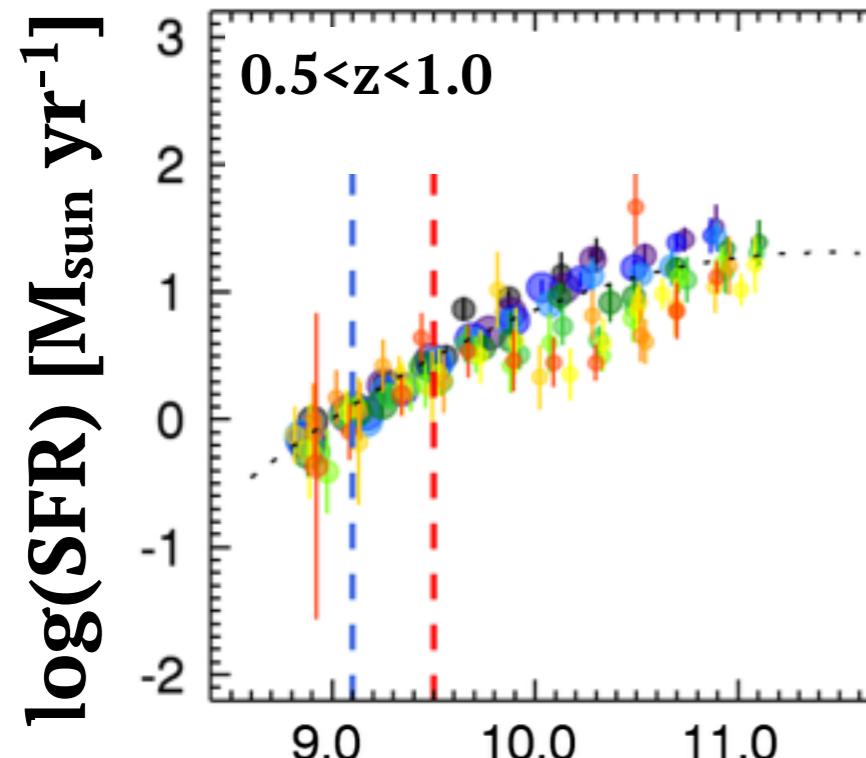
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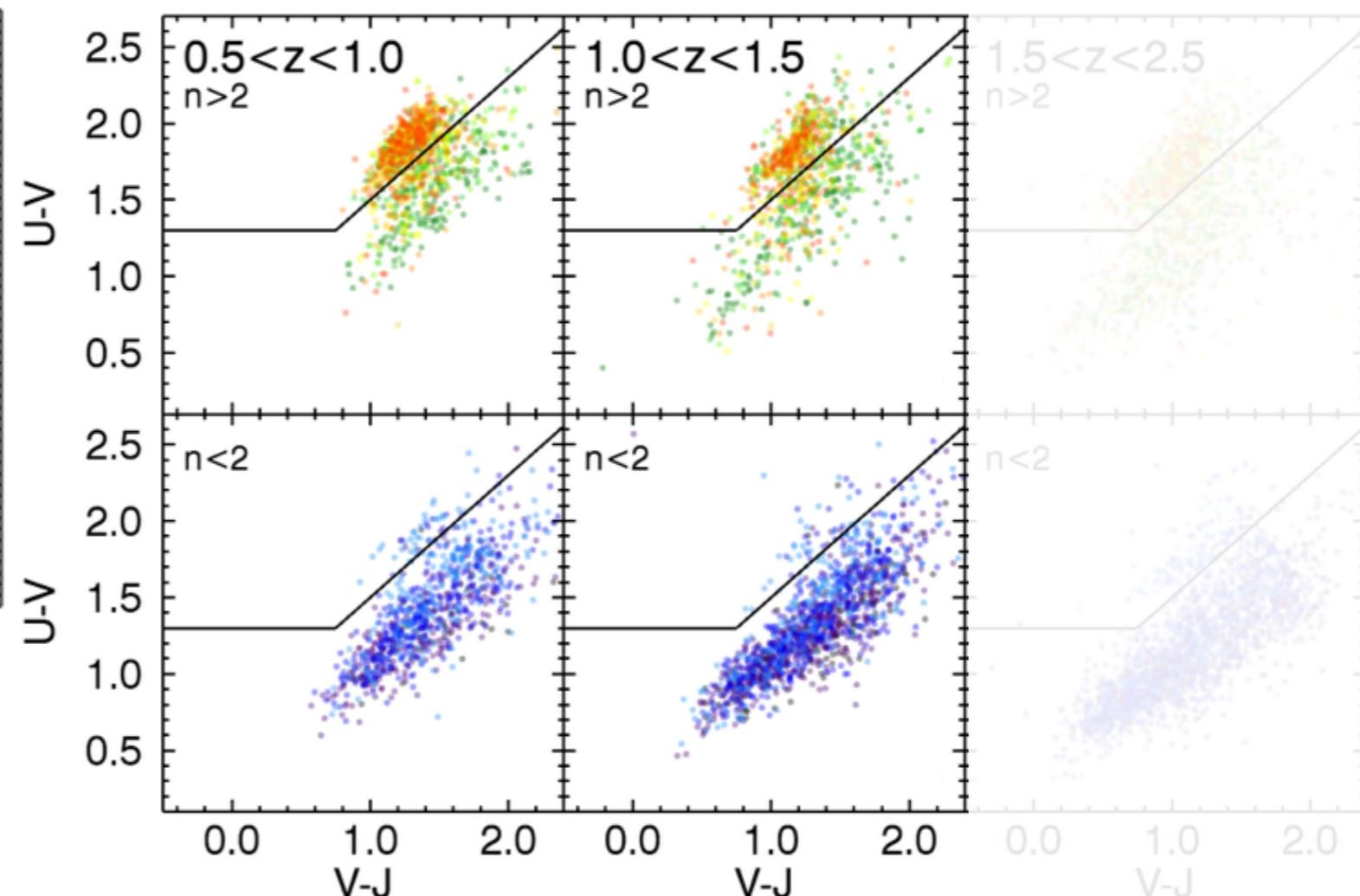
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Sersic Index



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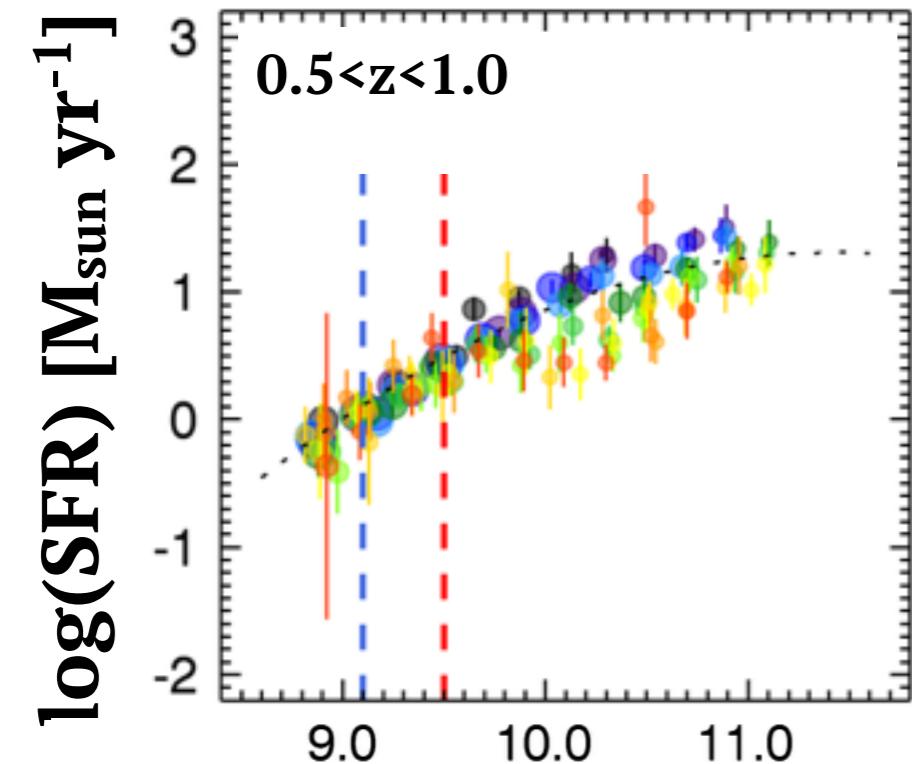
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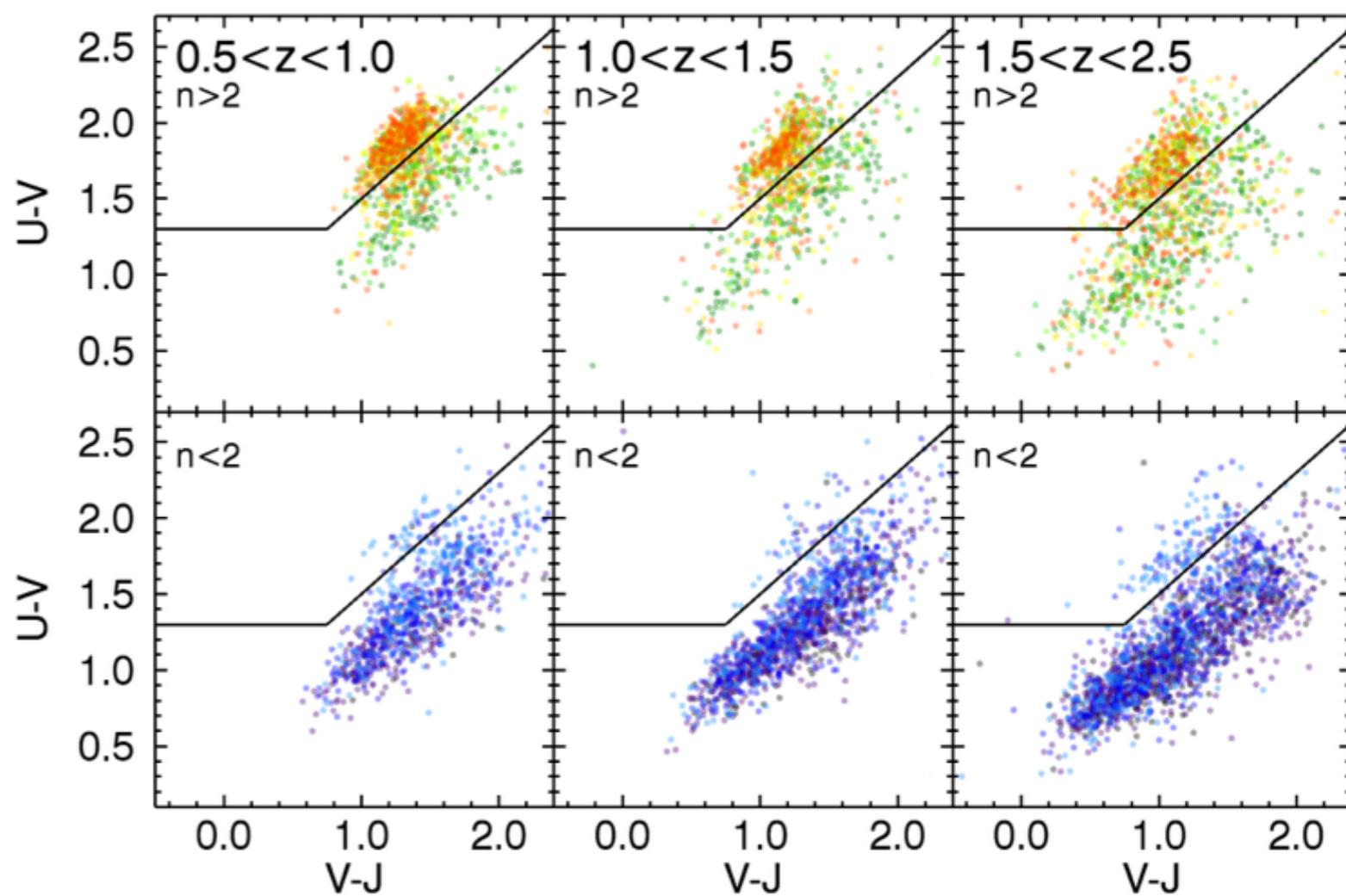
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**Sersic Index**



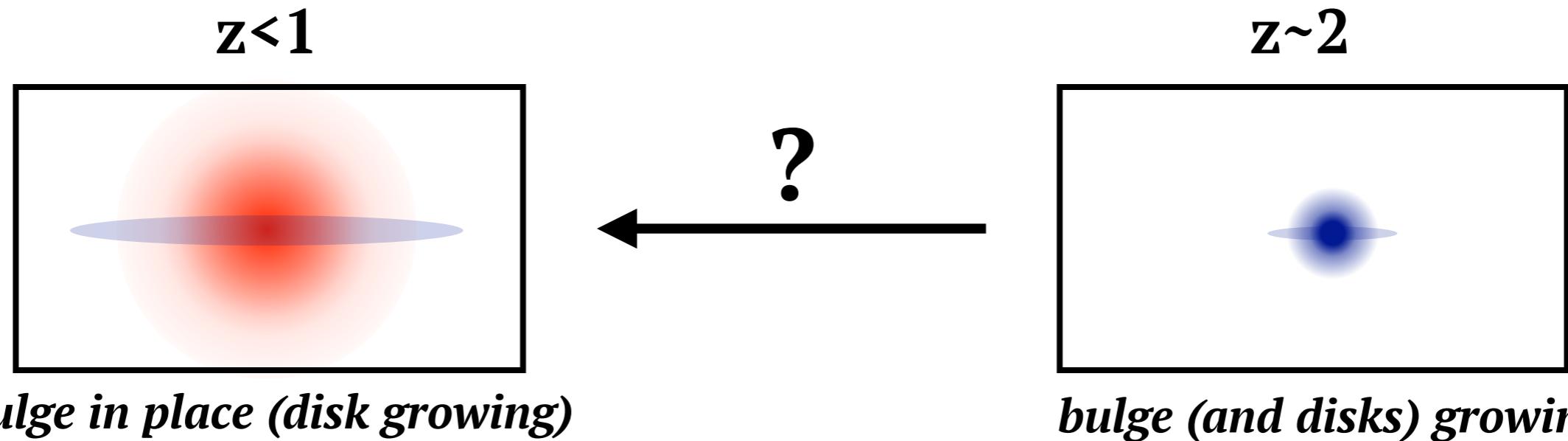
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# Hubble+Spitzer: The Formation of Bulges & Disks

***Why don't we see this trend at z=2?***

*This epoch marks the peak of the cosmic star formation history*

**old stars**  
**young stars**



**Nelson et al. (2012, 2013):**

*Star formation at  $z \sim 1$  occurs at all radii in exponential disks*

**van Dokkum et al. (2014):**

*Little growth in the centers of galaxies from  $z \sim 0.8$ -0, but at higher redshifts there is growth at all radii.*

**But how does the bulge grow?**

- **Do stars form insitu and migrate from the (unstable) disk to the bulge?**
- **Is the bulge the result of accreted satellites?**
- **Is some other mechanism at play?**



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# SUMMARY

## What have we learned so far?

### 1. How does a galaxy's star formation rate depend on mass?

- *The slope of the star formation sequence is not constant and depends on stellar mass.*
- *See Whitaker et al. 2012b, 2014b*

### 2. How and when do bulges form in galaxies?

- *The slope and scatter of the star formation sequence is correlated with systematic variations in the Sersic Indices of galaxies across the SFR-M\* plane.*
- *See Whitaker et al. 2015 – coming soon on the arXiv!*

#### GALAXY STRUCTURE AS A DRIVER OF THE STAR FORMATION SEQUENCE SLOPE AND SCATTER

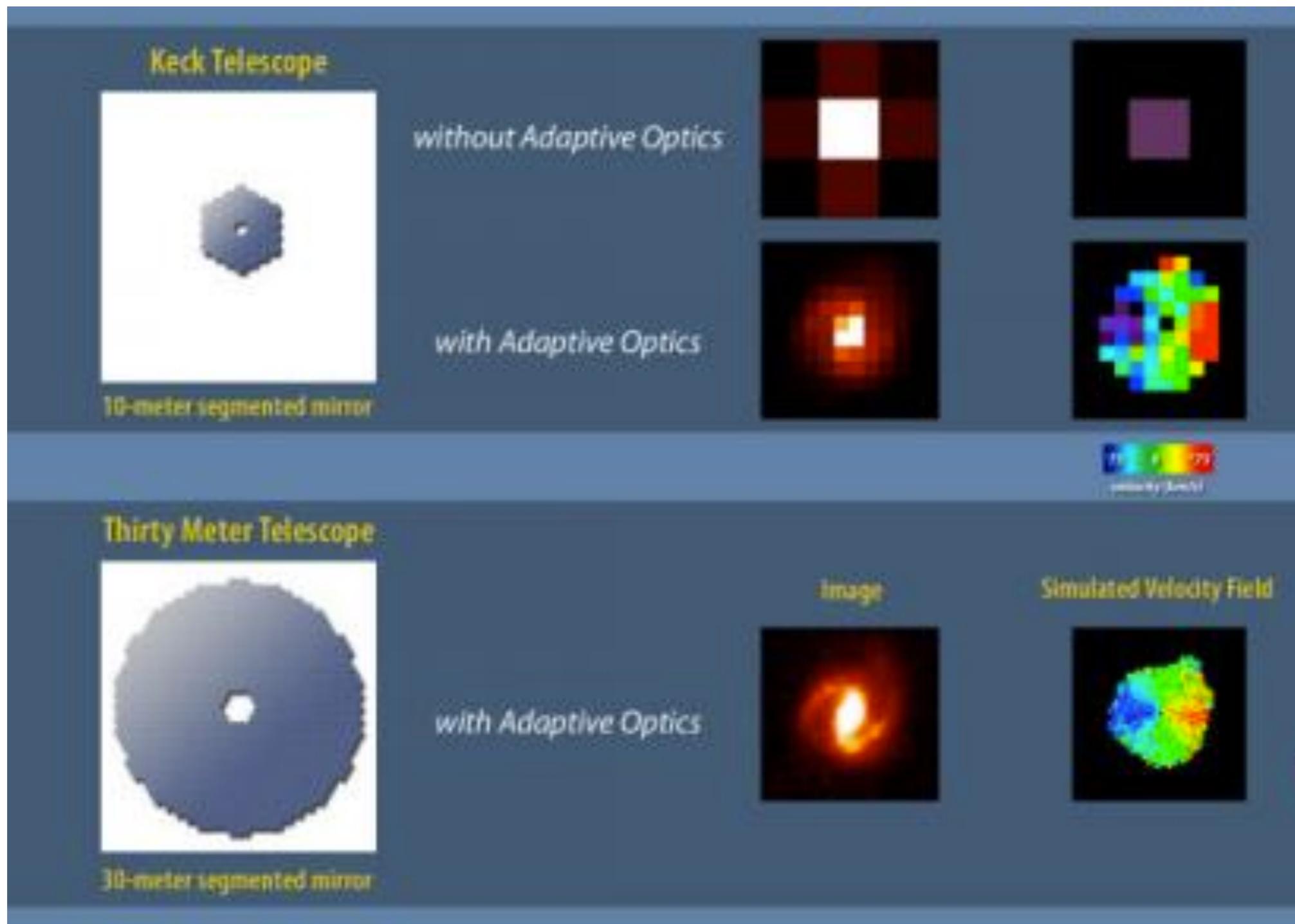
KATHERINE E. WHITAKER<sup>1,10</sup>, MARIJN FRANX<sup>2</sup>, RACHEL BEZANSON<sup>3,11</sup>, GABRIEL B. BRAMMER<sup>4</sup>, PIETER G. VAN DOKKUM<sup>5</sup>, MARISKA T. KRIEK<sup>6</sup>, IVO LABBÉ<sup>2</sup>, JOEL LEJA<sup>5</sup>, IVELINA G. MOMCHEVA<sup>5</sup>, ERICA J. NELSON<sup>5</sup>, JANE R. RIGBY<sup>1</sup>, HANS-WALTER RIX<sup>7</sup>, ROSALIND E. SKELTON<sup>8</sup>, ARJEN VAN DER WEL<sup>7</sup>, STIJN WUYTS<sup>9</sup>



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Keck



*Image Credit: Stark/Ellis with Caltech Digital Media Center*

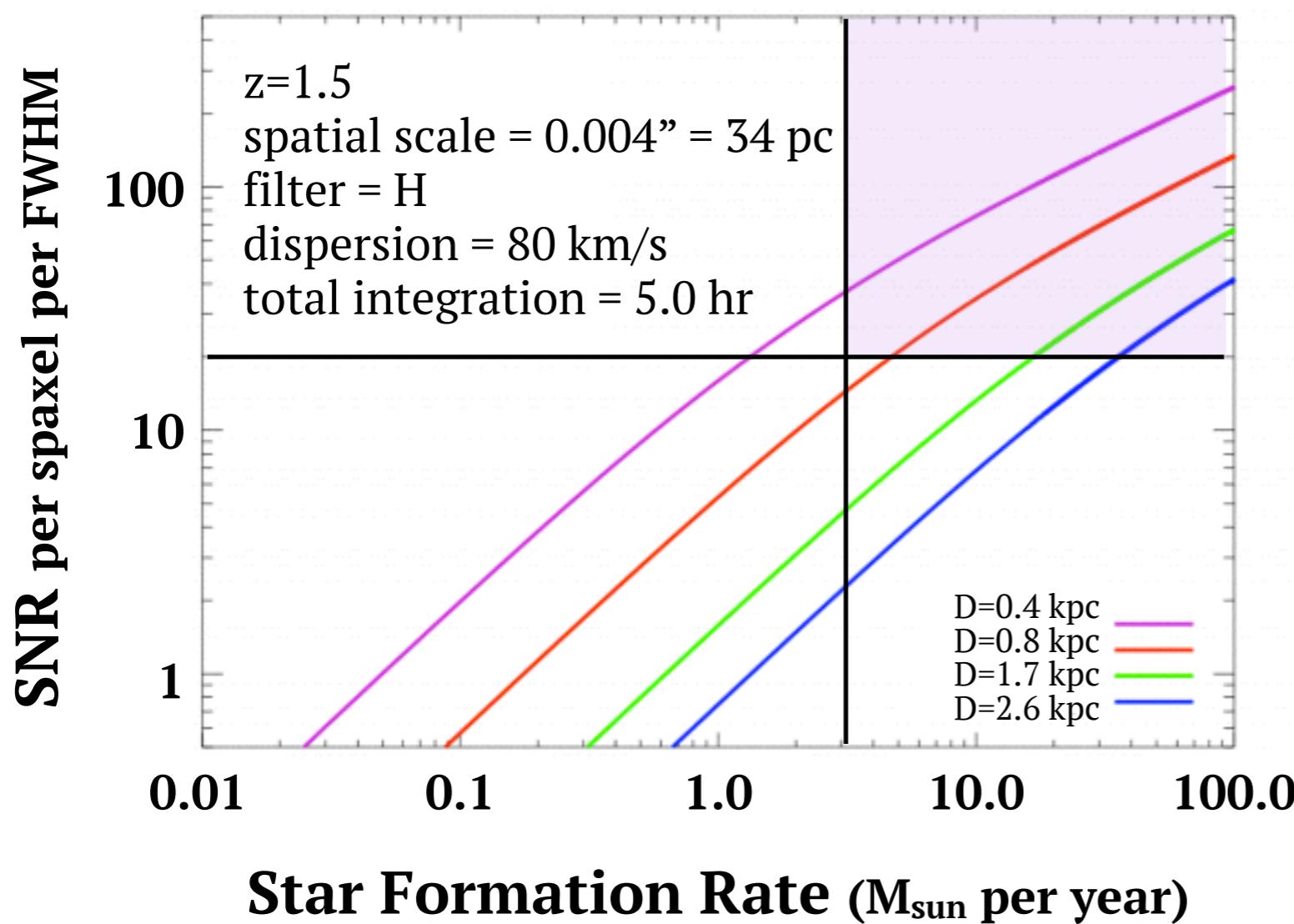


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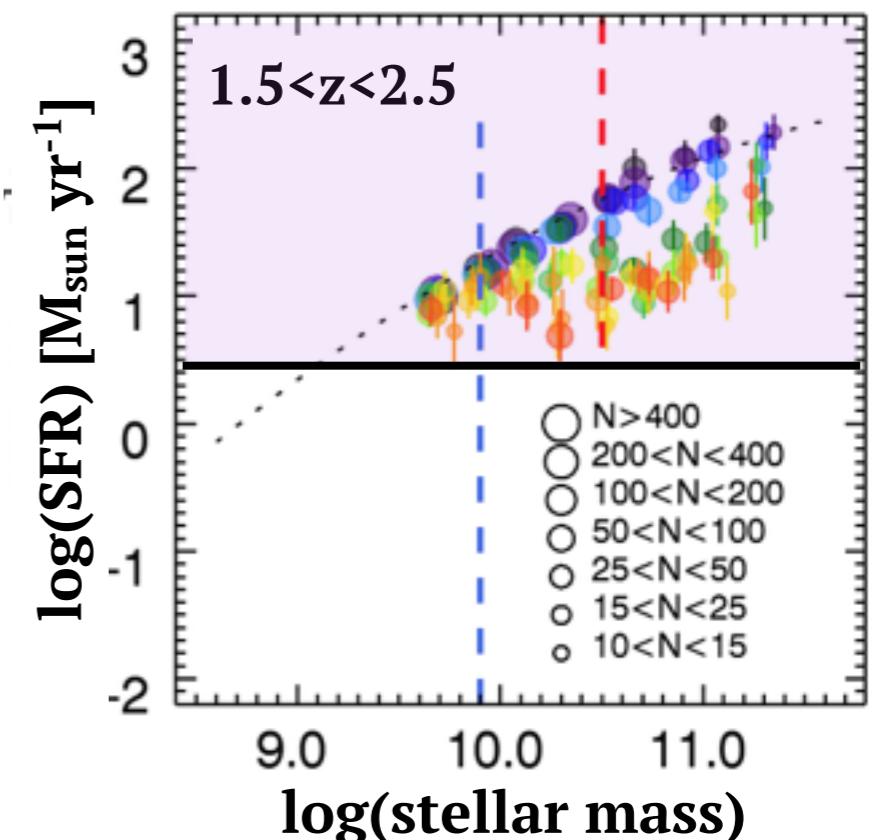
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# The Future: Spatially-Resolved Studies with TMT

## **SYNERGIZING OBSERVED GRADIENTS WITH SIMULATIONS**



Wright et al. 2010



- age gradients in compact post-starburst and older quiescent galaxies at  $z \sim 2$
- metallicity and star-formation gradients



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## What next?

- Studies leveraging the spatially-resolved capabilities of Hubble
- TMT (and JWST) will pick up where Hubble leaves off (!)