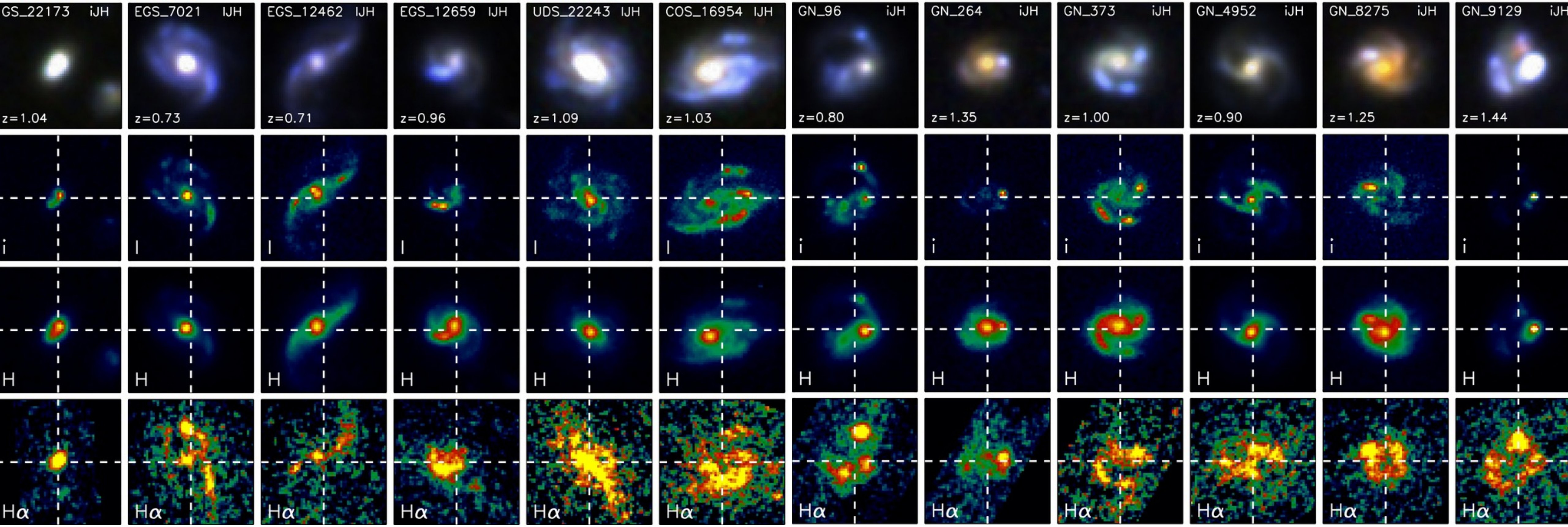


Star-Forming Galaxies at Cosmic Noon

Authors: Schreiber et. al. 2020

Presenter: Bhavesh Rajpoot

Seminar Supervisor: Dr. Eva Grebel

Galactic and Extragalactic Seminar

8th July 2023

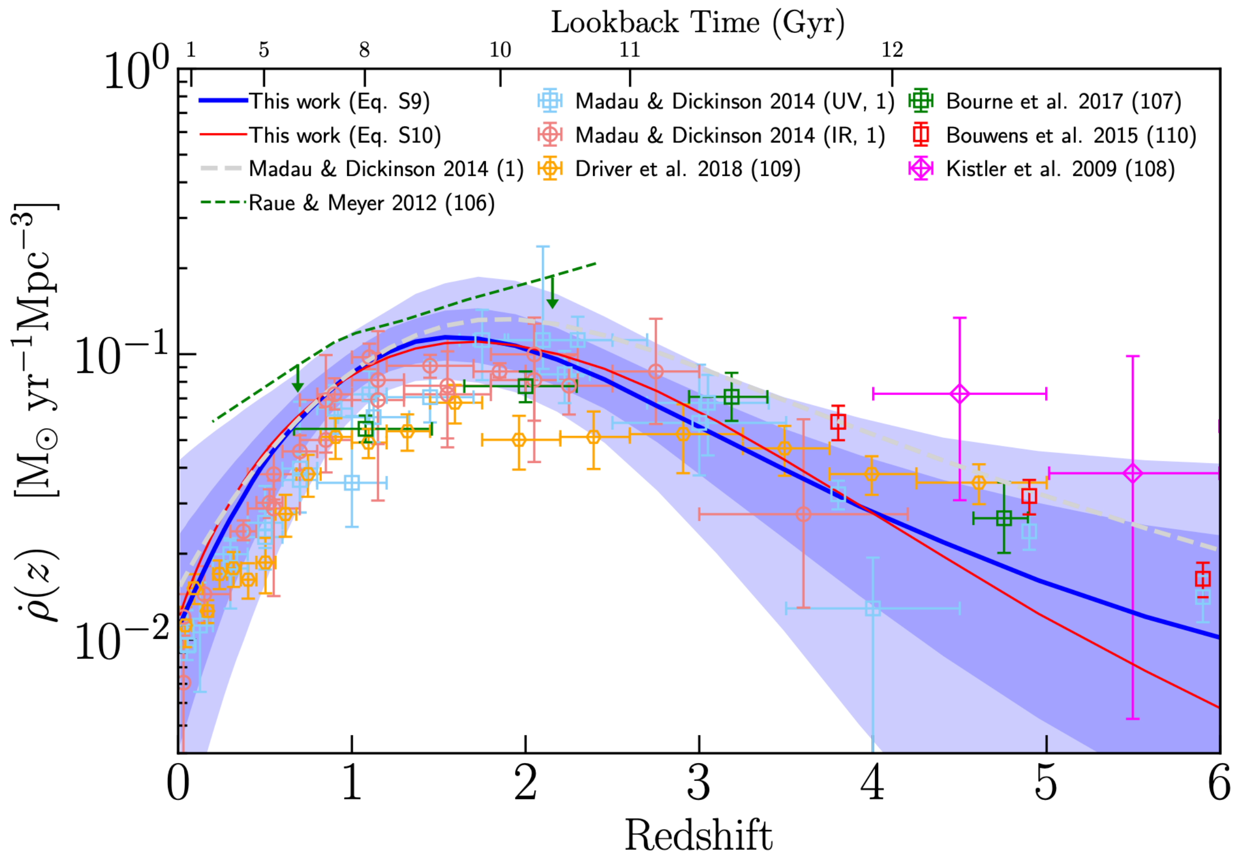
The Cosmic Noon

- Period of intense star formation in the Universe

- z ~ 1-3; time ~ 7.8-11.3 Gyr
- Peaks at z=2; t=10.24 Gyr

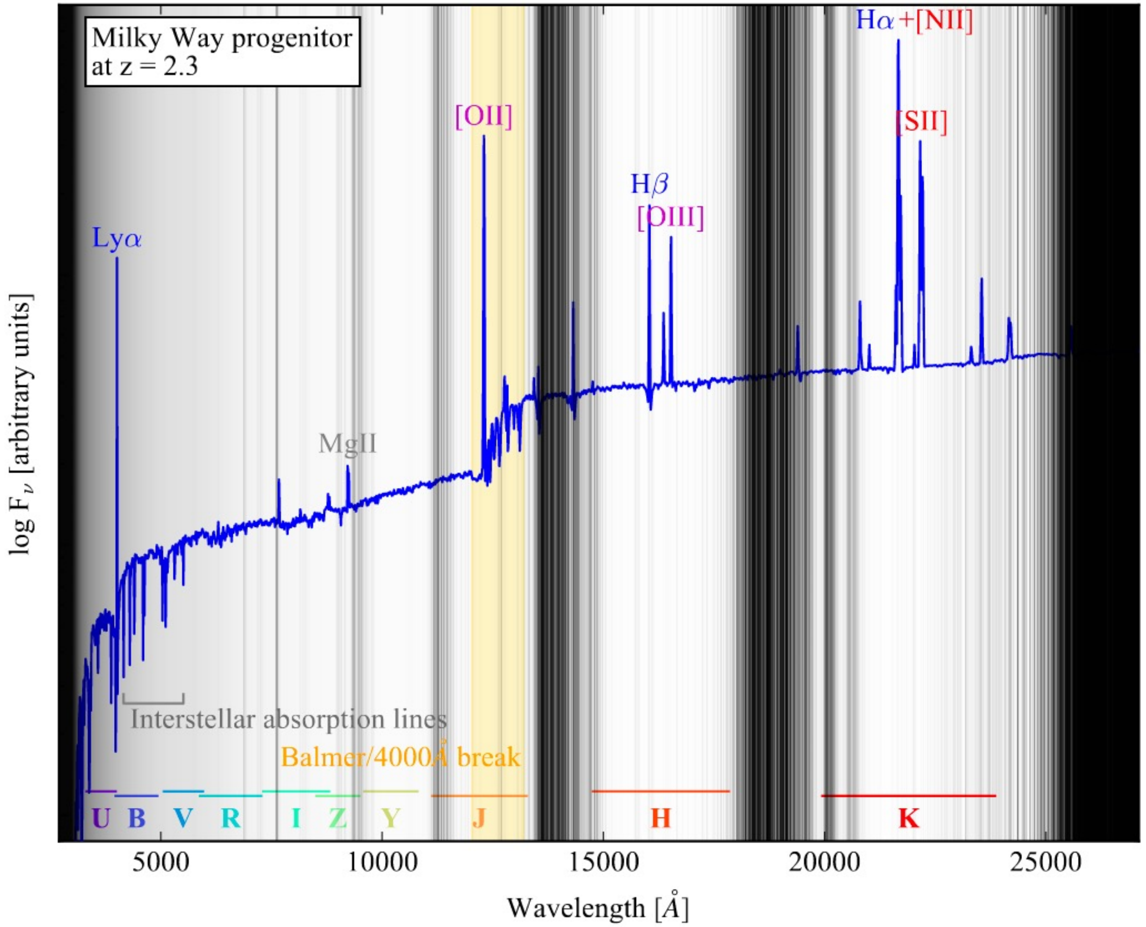
- Star Formation Rate (SFR) per volume density (SFRD) approx. 20 times higher than now
- Formed half of the stellar mass in galaxies observed today

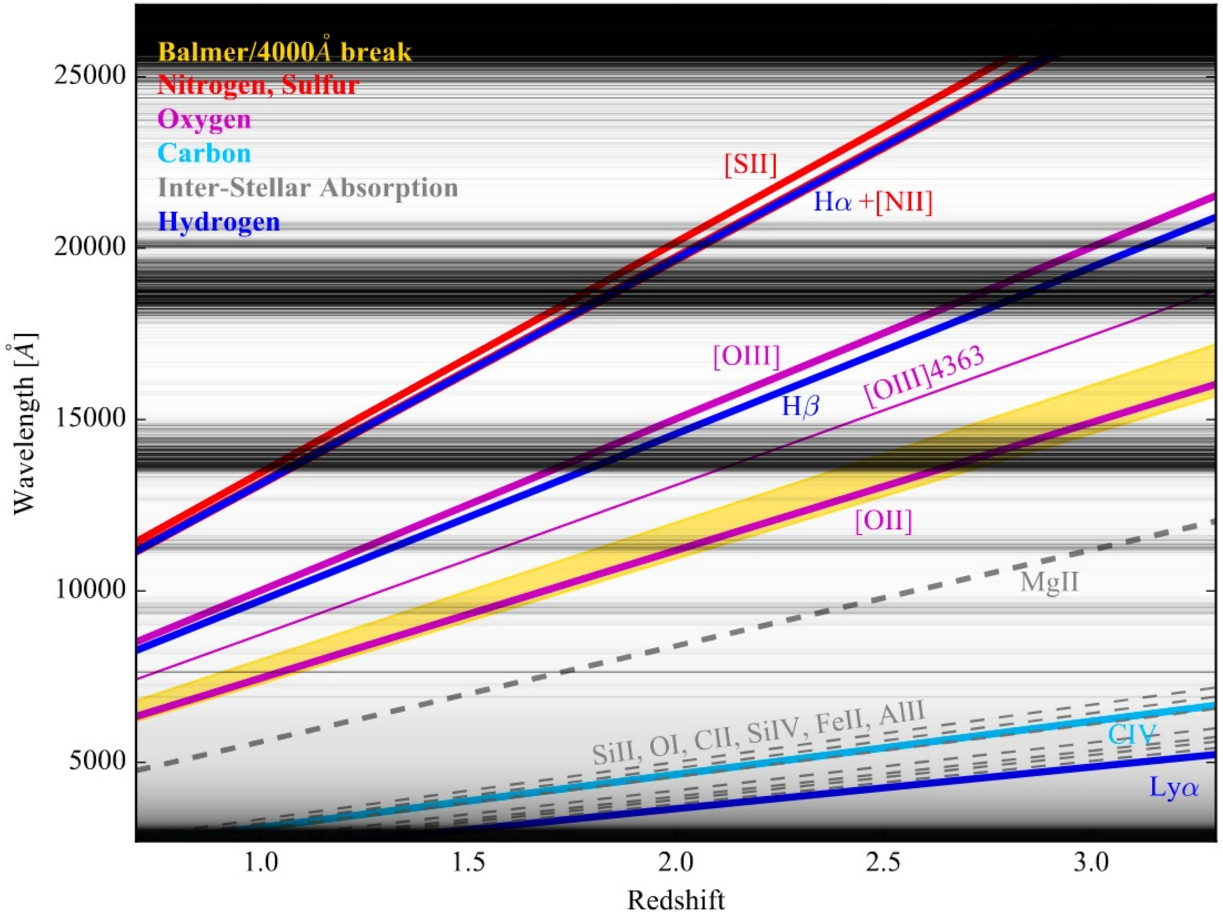
- $z \sim 8 - 2$: rise $\propto (1+z)^{-2.9}$
- $z \sim 2 - 0$: decline $\propto (1+z)^{2.7}$



Fermi-LAT Collaboration 2018

Observing the Cosmic Noon Galaxies

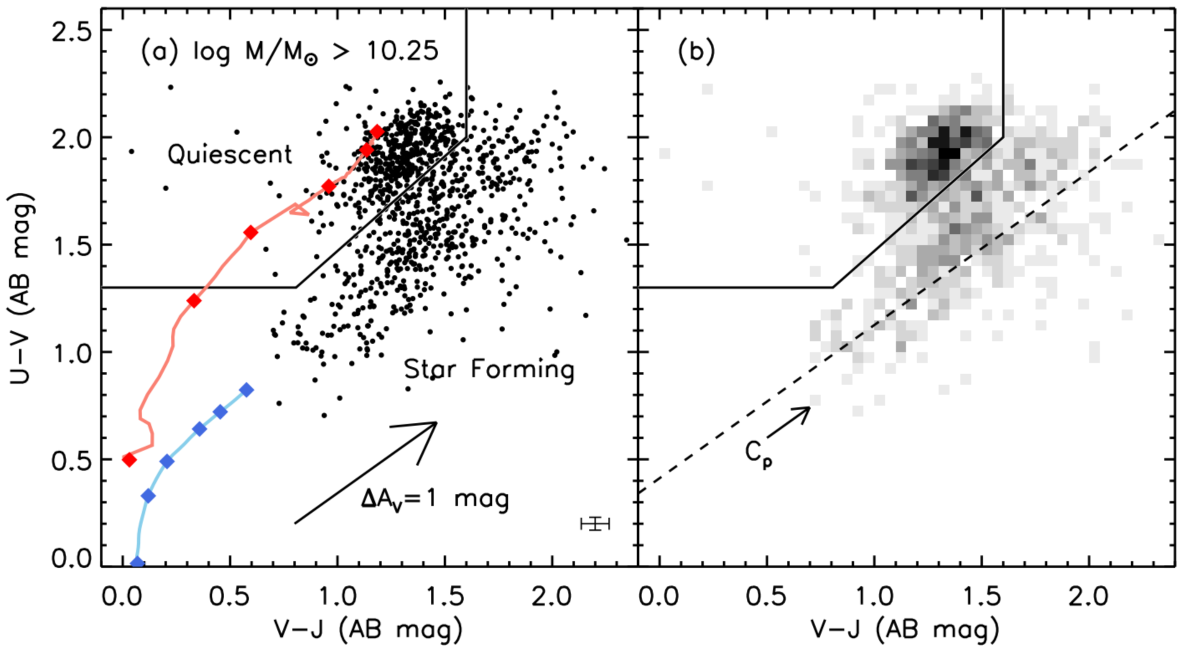




Schreiber et. al. 2020

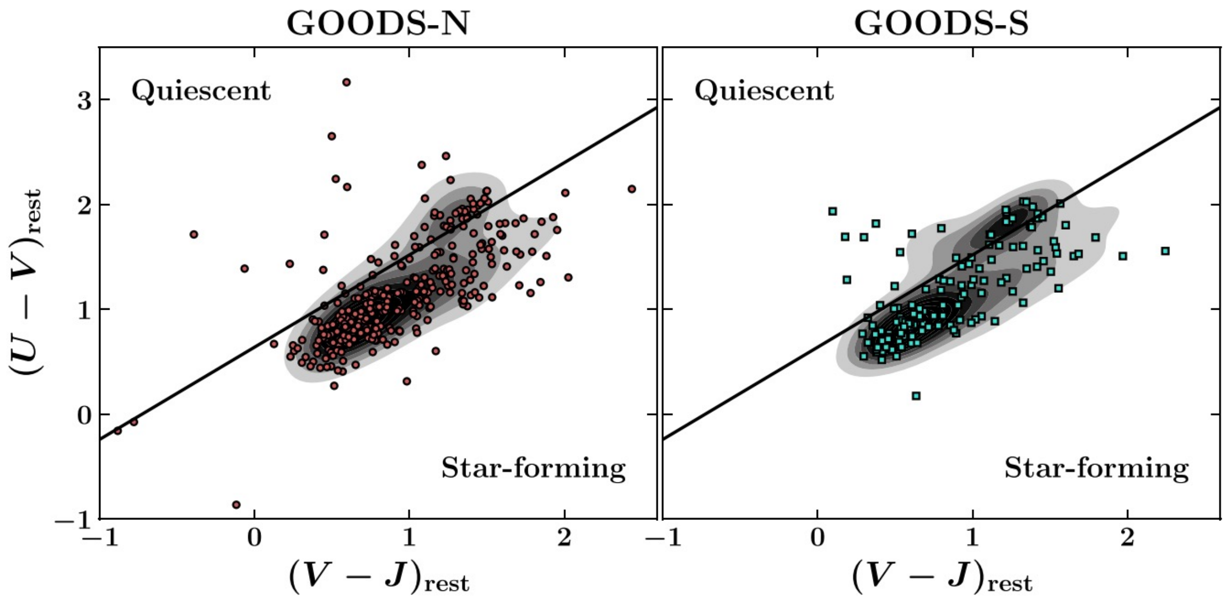
Line types	Lines	Activation	Role
Hydrogen Recombination and Atomic Forbidden Emission lines	Lyα λ1216; Hβ λ4861; Hα λ6563; [OII] λ3726, λ3729; [OIII] λ4959, λ5007; [SII] λ6716, λ6730	star formation, AGNs, and shock activity	nebular conditions, dust attenuation, galaxy dynamics, and gas outflows
Stellar Continuum Emission	Balmer discontinuity at 3646 Å and the 4000 Å break	hydrogen and multiple metallic species and molecules	stellar age, stellar mass, and dust reddening
Far-UV (~1200–2000 Å) Interstellar Absorption Lines	SIIIλ1260; OI+SIII λ1303, CIIλ1334; SiIV λ1393, λ1402; CIV λ1548, λ1550; FeII λ1608; AlII λ1670	stellar photospheres and winds, and gas photoionized by hot stars and AGNs	gas outflows and/or inflows, ISM characteristics
Interstellar Absorption line and Auroral line	MgII λ2796, λ280; [OIII] λ4363		ISM and outflow diagnostic, temperature-sensitive indicator in direct-method gas metallicity estimates

UVJ Color-Selection



Patel et. al. 2011

Separating Star-forming Galaxies (SFGs) from Quiescent Galaxies (QGs)



Matharu et. al. 2022

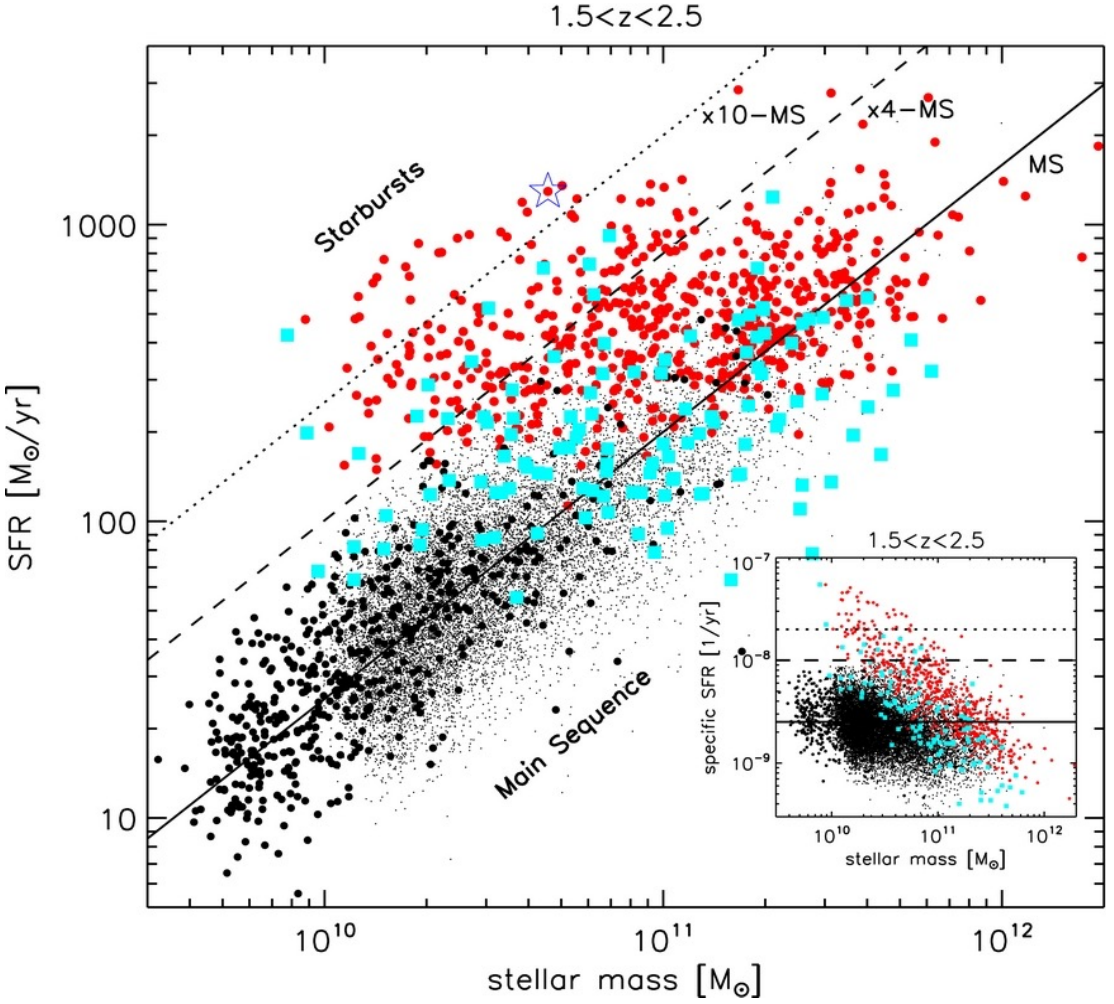
Color cut: $(U-V)_{rest} < 0.88\,(V-J)_{rest} + 0.64$

Properties

- **Global Properties**
  - Main Sequence of Star-Forming Galaxies (SFGs)
  - Stellar Mass Function
  - Mass–Size Relation
  - Cold Gas Content
  - Metallicity and Interstellar Medium Conditions
  - Active Galactic Nucleus Demographics

- **Resolved Properties**
  - SFGs as Axisymmetric Systems
  - Deviations from Axisymmetry
  - SFGs as Rotating Turbulent Disks
  - Mass and Angular Momentum Budget
  - Deviations from Disk Rotation
  - Galactic-Scale Outflows

Main Sequence of SFGs



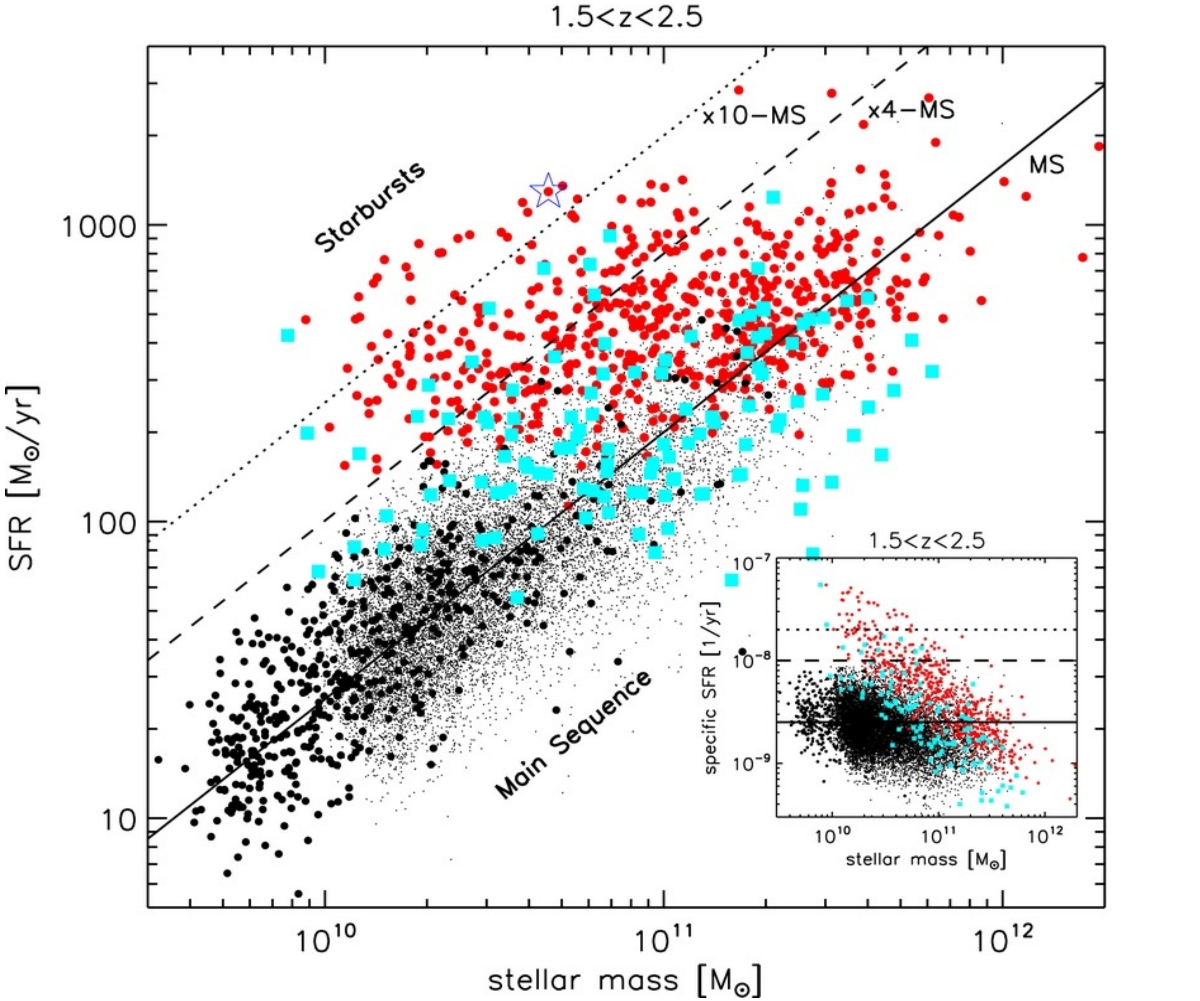
Rodighiero et. al. 2011

Main Sequence of SFGs

- Scaling relation b/w SFR and Stellar Mass
- Slope: $sSFR = SFR/M_*$

- Main Sequence (MS): tight, near-linear relation between SFR and Stellar mass on a log-log graph
  - $SFR = const. \times (M_*)^{const.}$

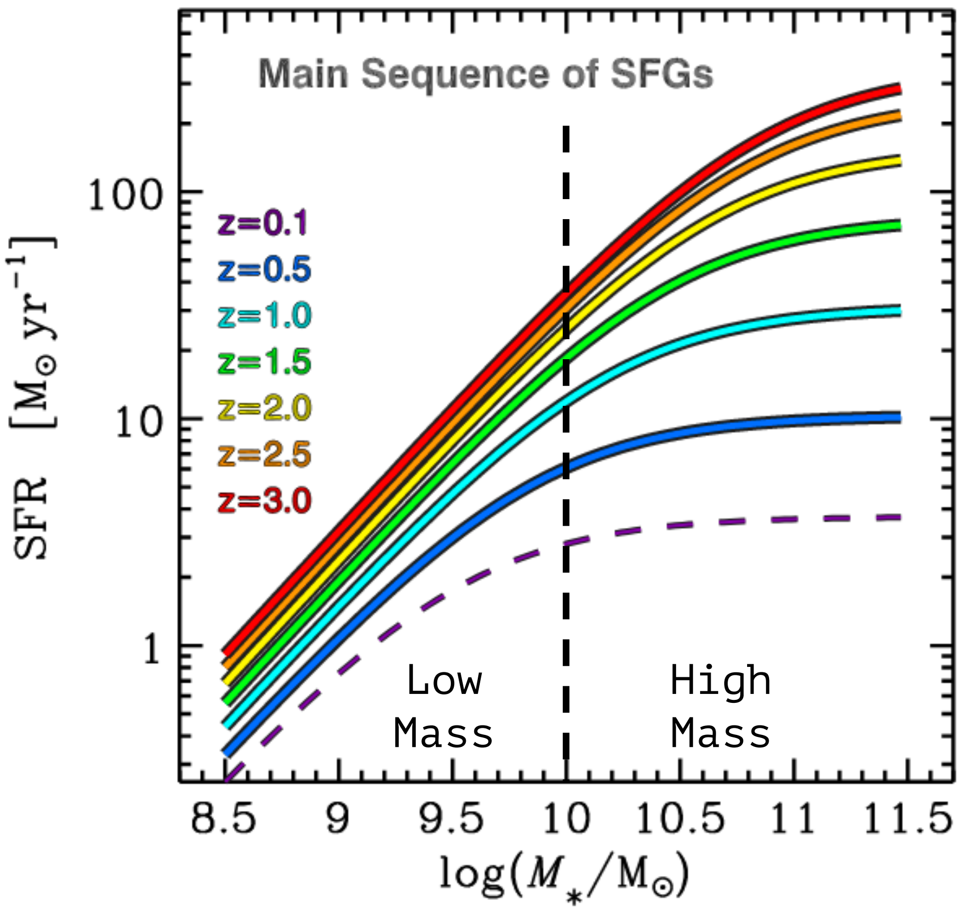
- At const. SFR, sSFR evolves inversely with the galaxy's age



Rodighiero et. al. 2011

Main Sequence of SFGs

- Existence of MS at z=2
- Trends:
  - Galaxies < $10^{10}\ M_{\odot}$: $\mathrm{sSFR} \propto (1+\mathrm{z})^{1.9}$
  - Galaxies > $10^{10}\ M_{\odot}$: $\mathrm{sSFR} \propto (1+\mathrm{z})^{2.2-3.5}$
- More massive galaxies exhibit a faster pace of evolution
- Star Formation History (SFH): integrating over the evolving relation
  - Mimics Cosmic SFRD evolution
  - SFHs of more massive galaxies peak earlier

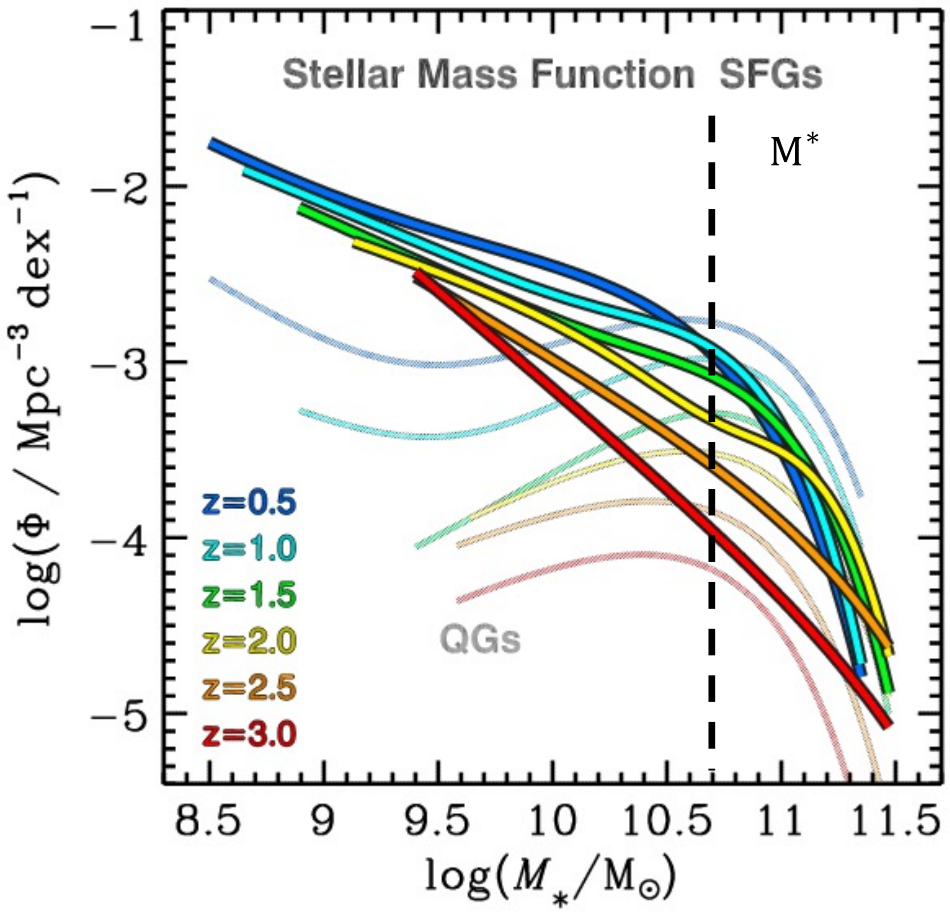


Schreiber et. al. 2020

Stellar Mass Function of SFGs

- SFGs and QGs mass function looks markedly different

- QGs mass function:
  - Peaks around M^* $(\log(M_*) \sim 10.7\ M_\odot)$ at all epochs
  - Grows more rapidly in numbers than SFGs
  - Number density grows by:
    - At higher mass, a factor of 6
    - At lower mass, a factor of 15-30
  - Quenching of:
    - Low mass galaxies: at later times
    - High mass galaxies: at earlier times

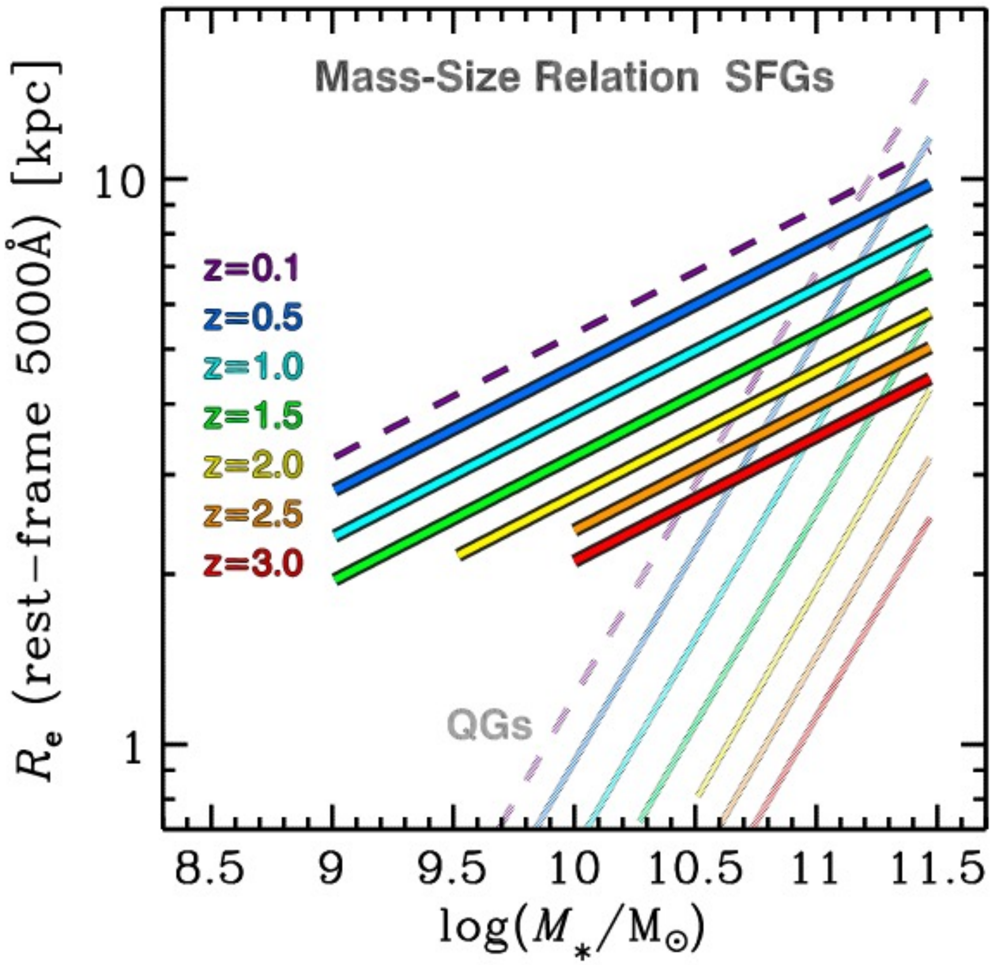


Schreiber et. al. 2020

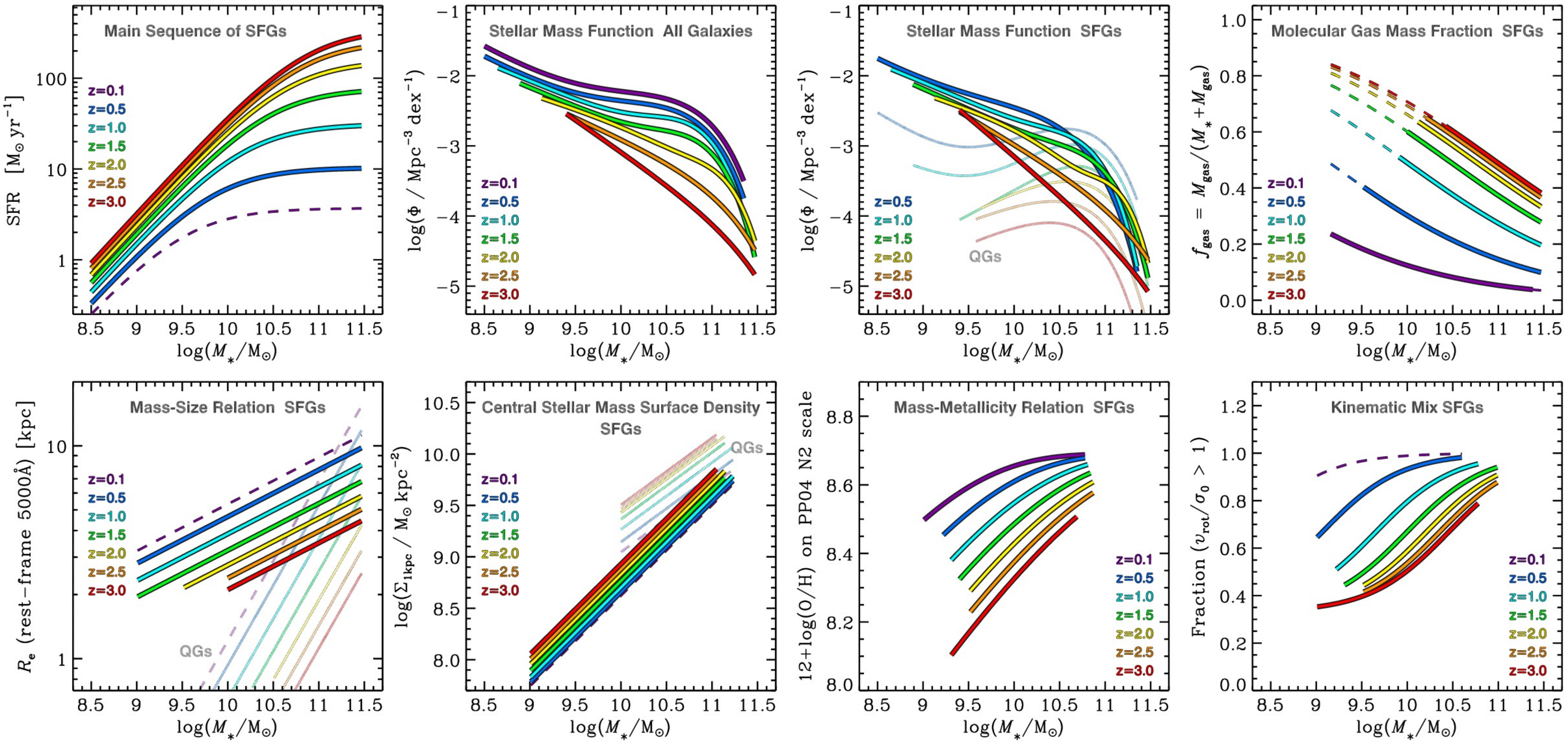
The Size-Mass Relation

- Sizes of SFGs and QGs show tight but distinct scaling with stellar mass.

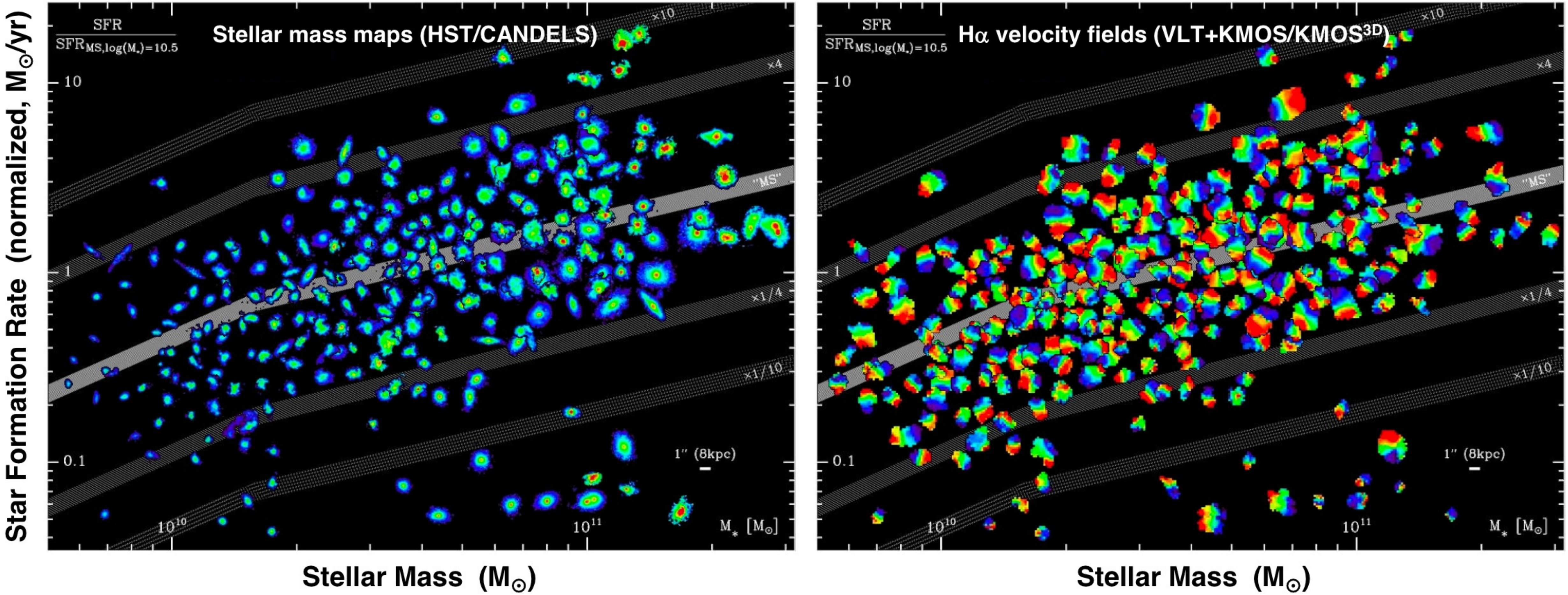
- R_e (SFGs) $>$ R_e (QGs) at all masses for the $0 < z < 3$ range
- Size evolution at a fixed mass:
  - For SFGs: $R_e \propto (1+z)^{-0.75}$
  - For QGs: $R_e \propto (1+z)^{-1.48}$
- QG population show dramatic growth from compact red nuggets at comic noon to large ellipticals in today's Universe.



Schreiber et. al. 2020

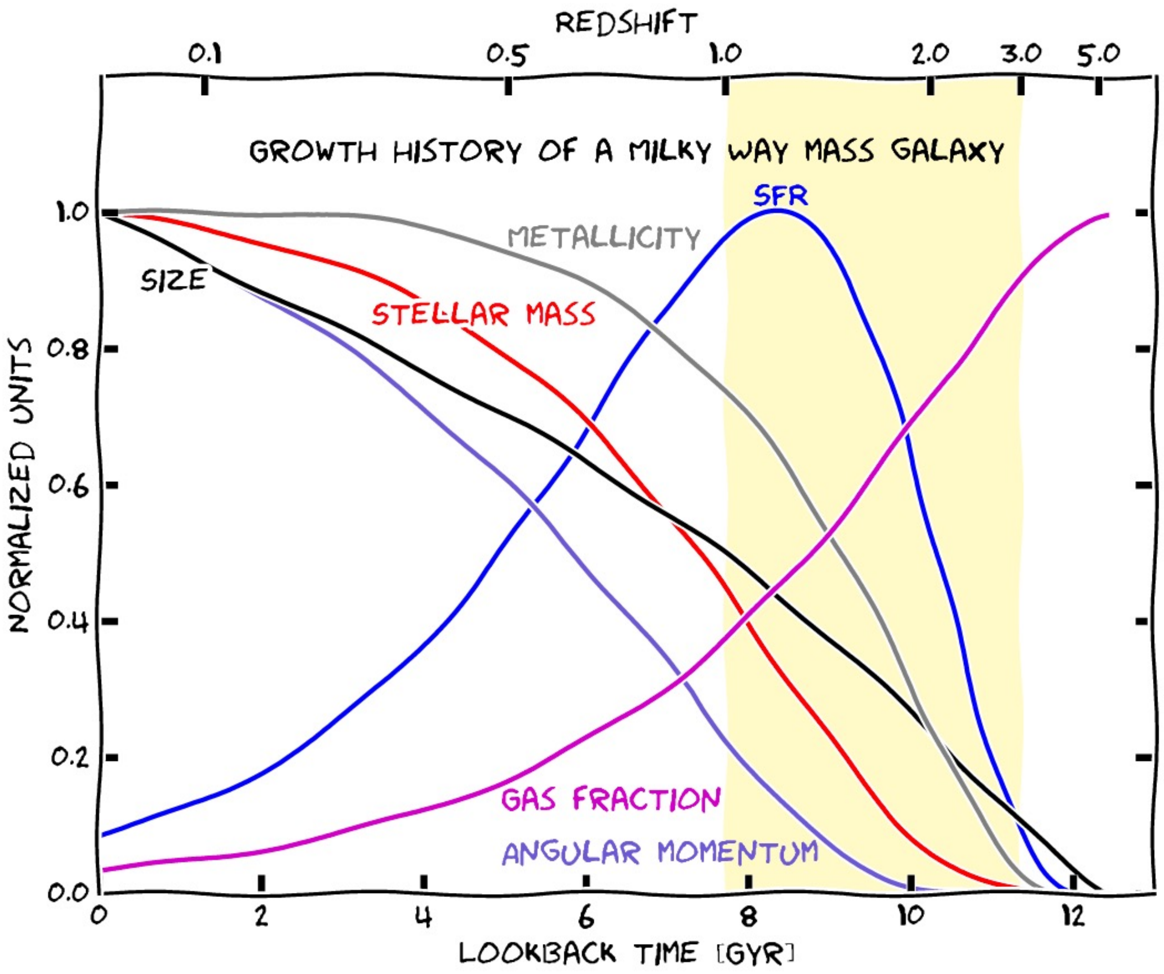


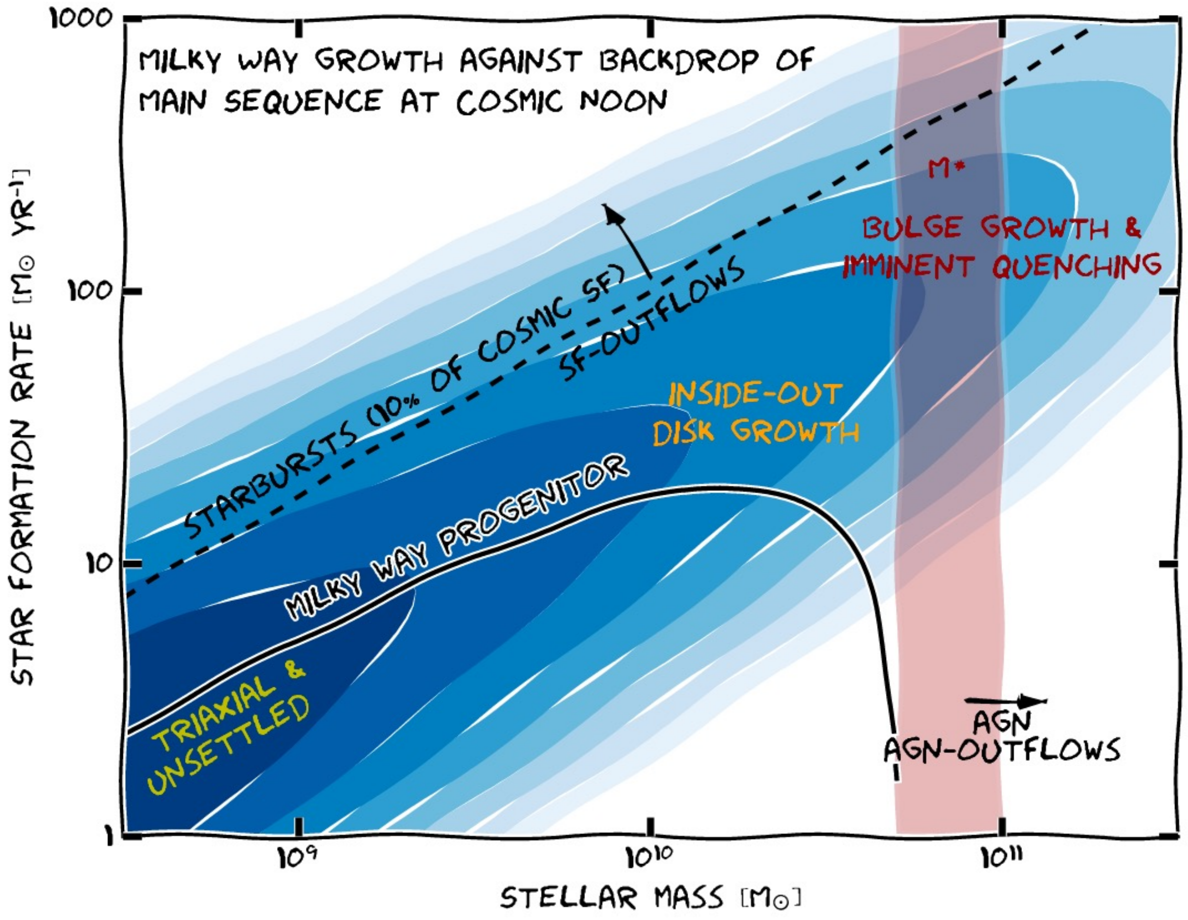
Schreiber et. al. 2020



Schreiber et. al. 2020

Summary

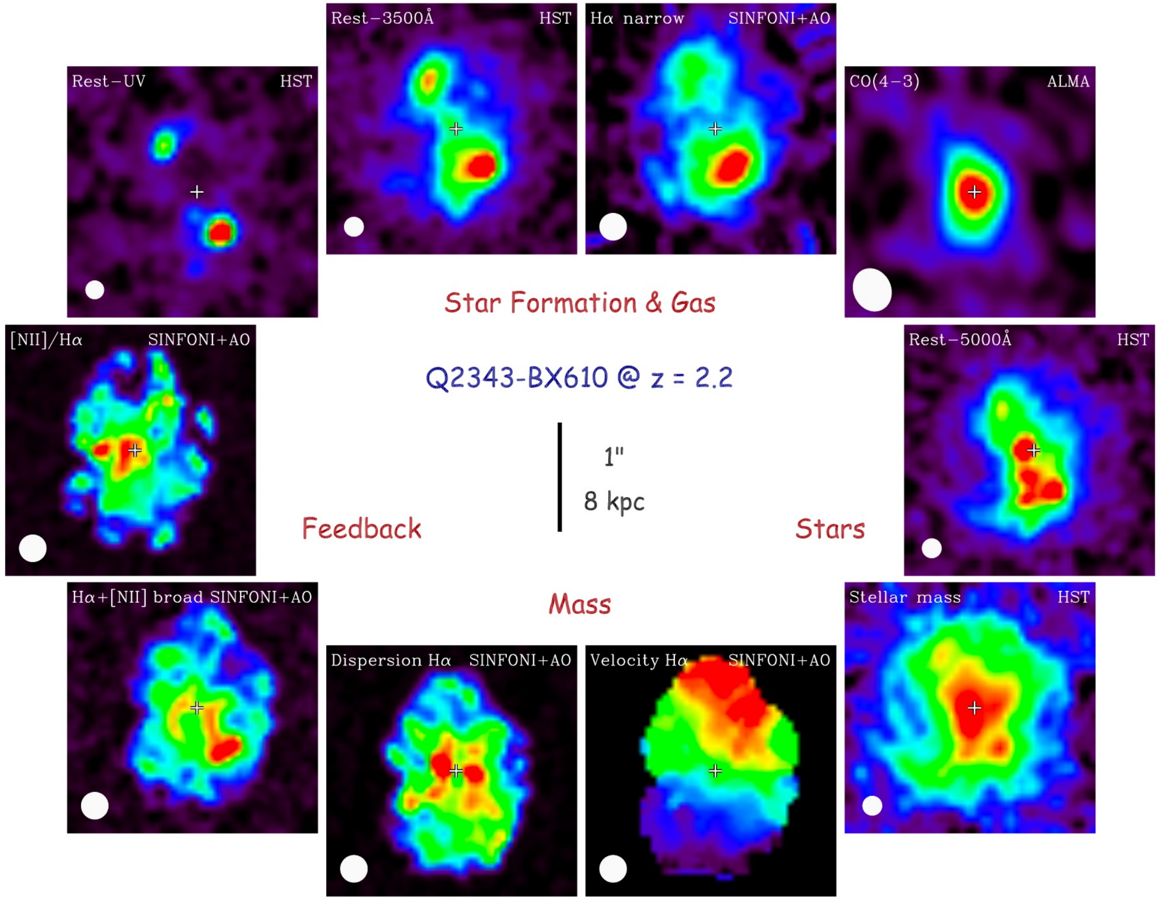




Schreiber et. al. 2020

Summary

- Scaling relations between galaxy properties are in place since at least $z \sim 2.5$,
  - indicates that regulatory mechanisms start to act on galaxy growth within 2 – 3 Gyr of the Big Bang.
- Significant evolution in population properties:
  - compared to $z \sim 0$, typical SFGs at $z \sim 2$ formed stars and grew their central SMBH $\sim 10 \times$ faster from $\sim 10 \times$ larger cold molecular gas reservoirs.
  - Disks are prevalent but smaller, more turbulent, and thicker than today's spirals.
  - Quenching was underway at high masses through mechanisms that appear to largely preserve disky structure.

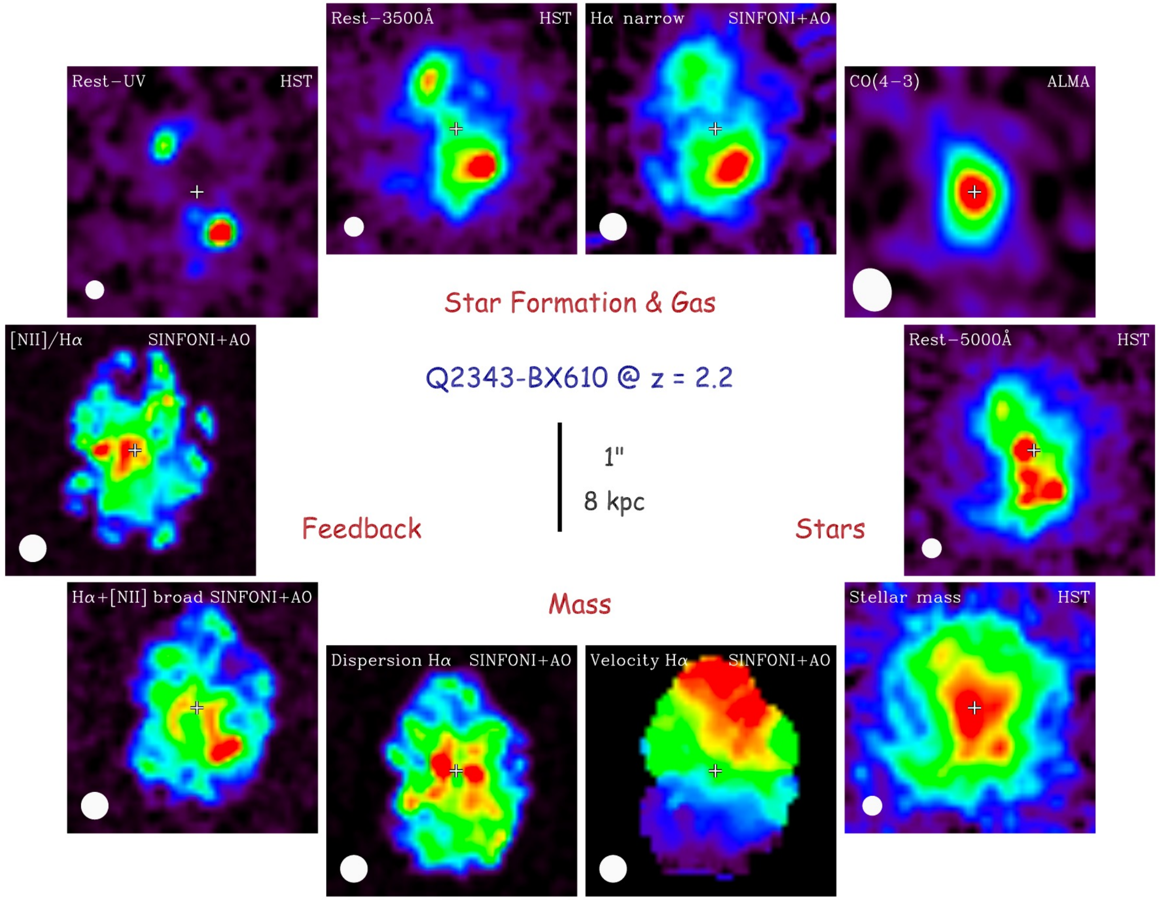


Schreiber et. al. 2020

Summary

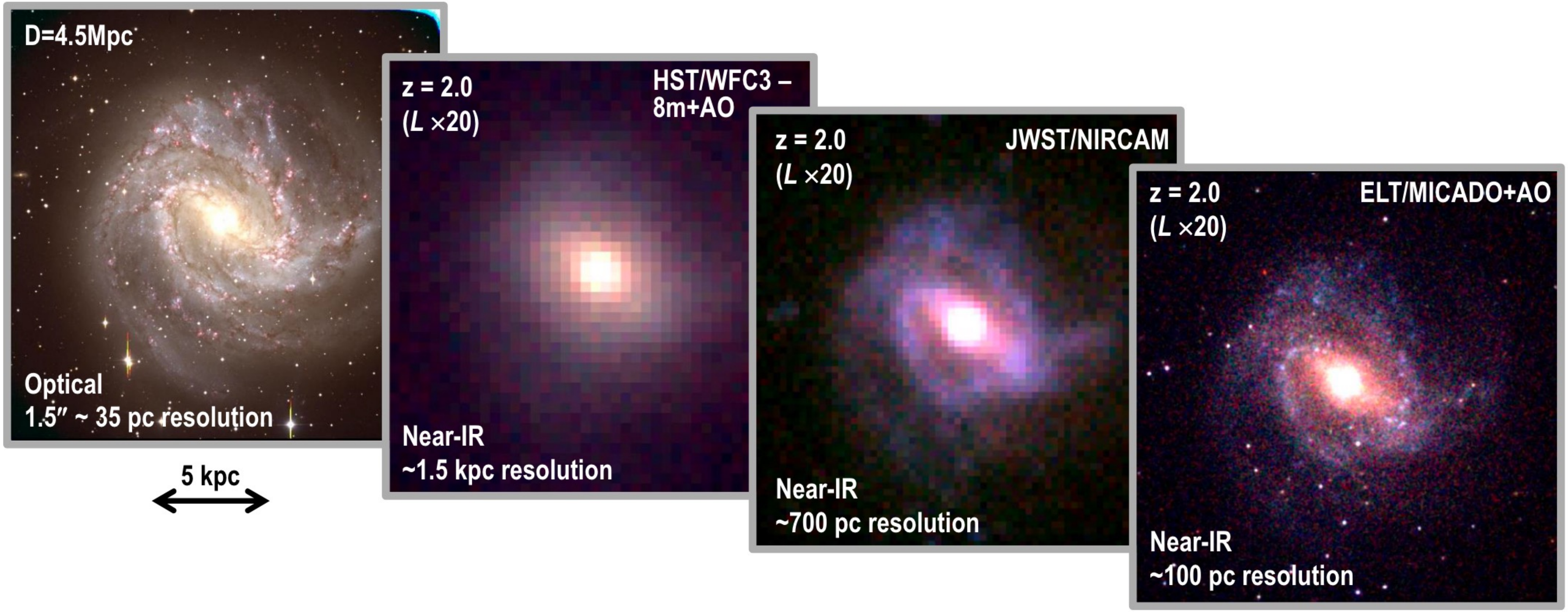
- Resolved Stellar light, SFR, and Kinematics on scales down to ~ 1 kpc point to spatial patterns:
  - More prominent in higher mass SFGs
  - dense and strongly baryon-dominated core regions with possibly suppressed star formation to more actively star-forming outskirts
  - Reflect on inside-out growth/quenching scenarios
  - Massive but highly obscured stellar bulges may still be rapidly growing

- Outflows are dominated by:
  - Star-formation-driven winds below M^*
  - AGN-driven winds above M^*



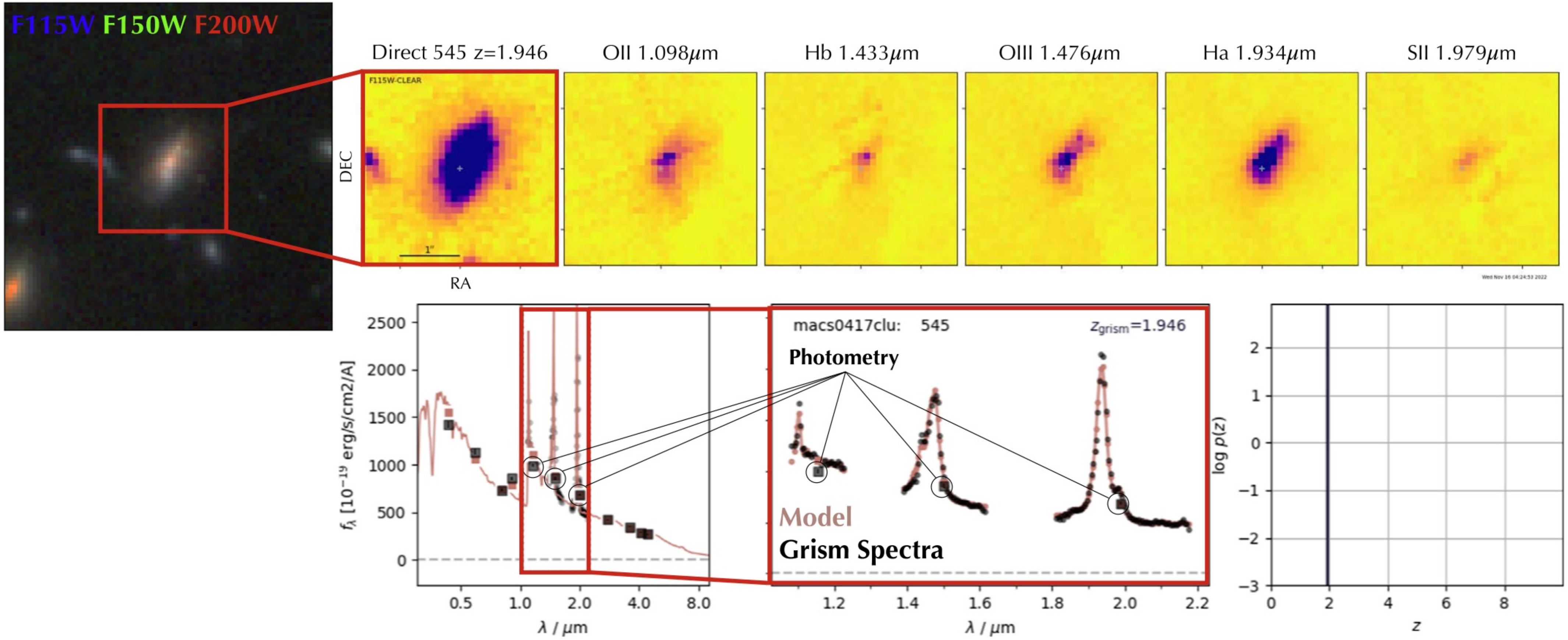
Schreiber et. al. 2020

The Future



Schreiber et. al. 2020

The ~~Future~~ Present



Tracing Star Formation using JWST

Matharu et. al. 2023

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