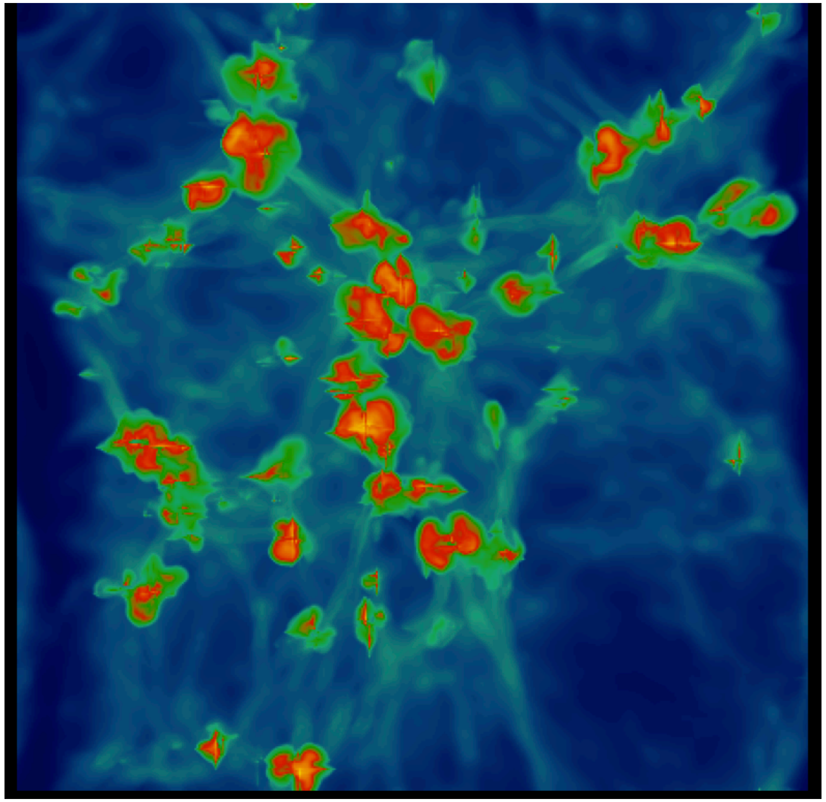
MECHANISMS OF MASS ASSEMBLY

RECALL…

MOST OF THE GAS IN THE INTER GALACTIC MEDIUM (IGM) IS IN WARM/HOT PHASE [AFTER REOINISATION]



HOW GAS GETS INTO GALAXIES?

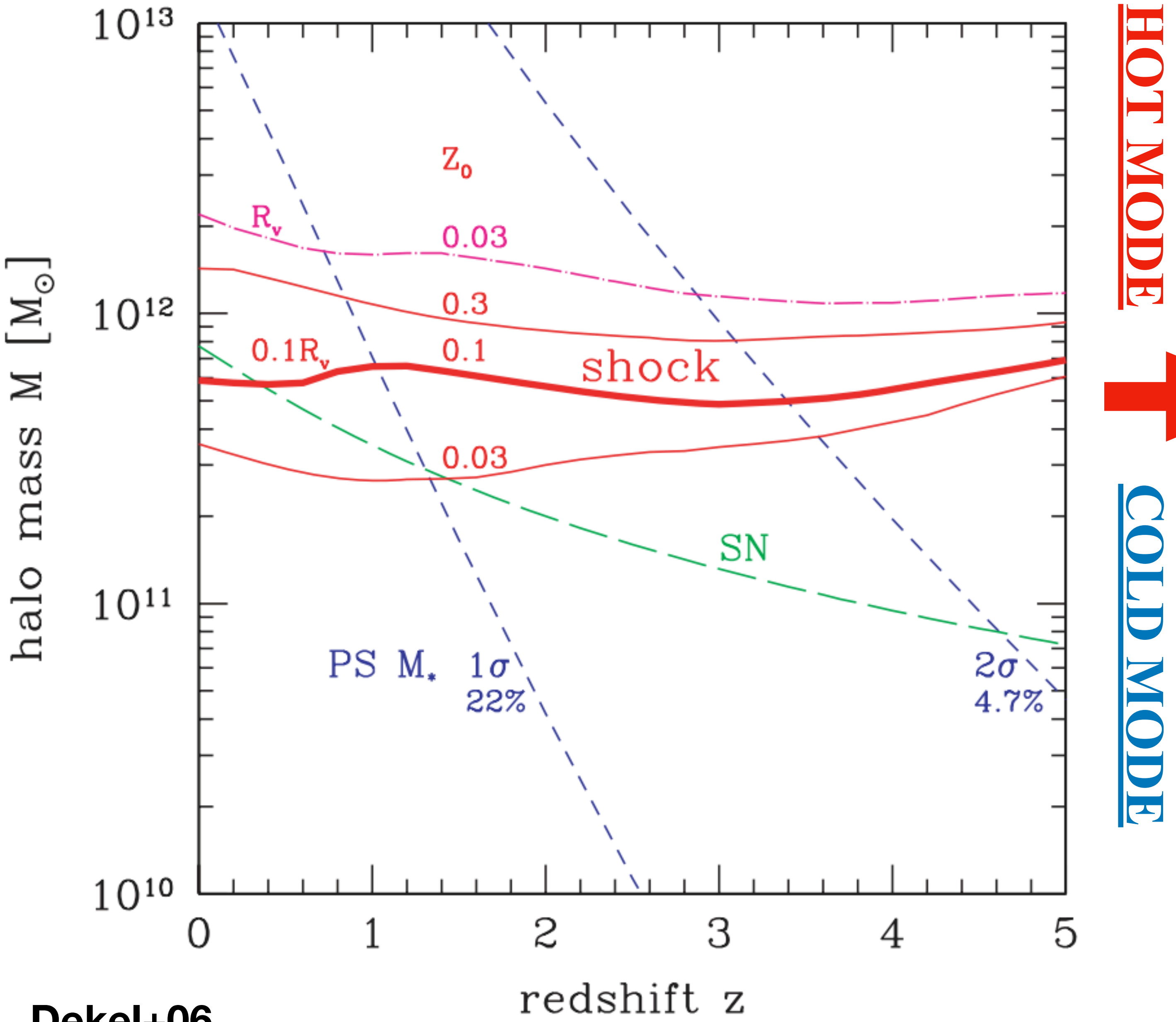
MODES OF GAS ACCRETION:

HOT MODE:

GAS SHOCKS HEATS AT HALO'S VIRIAL RADIUS UP TO Tvir AND COOLS SLOWLY INTO DISK

COLD MODE:

GAS RADIATES ITS POTENTIAL ENERGY AWAY IN LINE EMISSION AND NEVER APPROACHES VIRIAL TEMPERATURE



Dekel+06

CRITICAL MASS

COLD MODE DOMINATES IN LOW MASS SYSTEMS AND THEREFORE AT EARLY TIMES

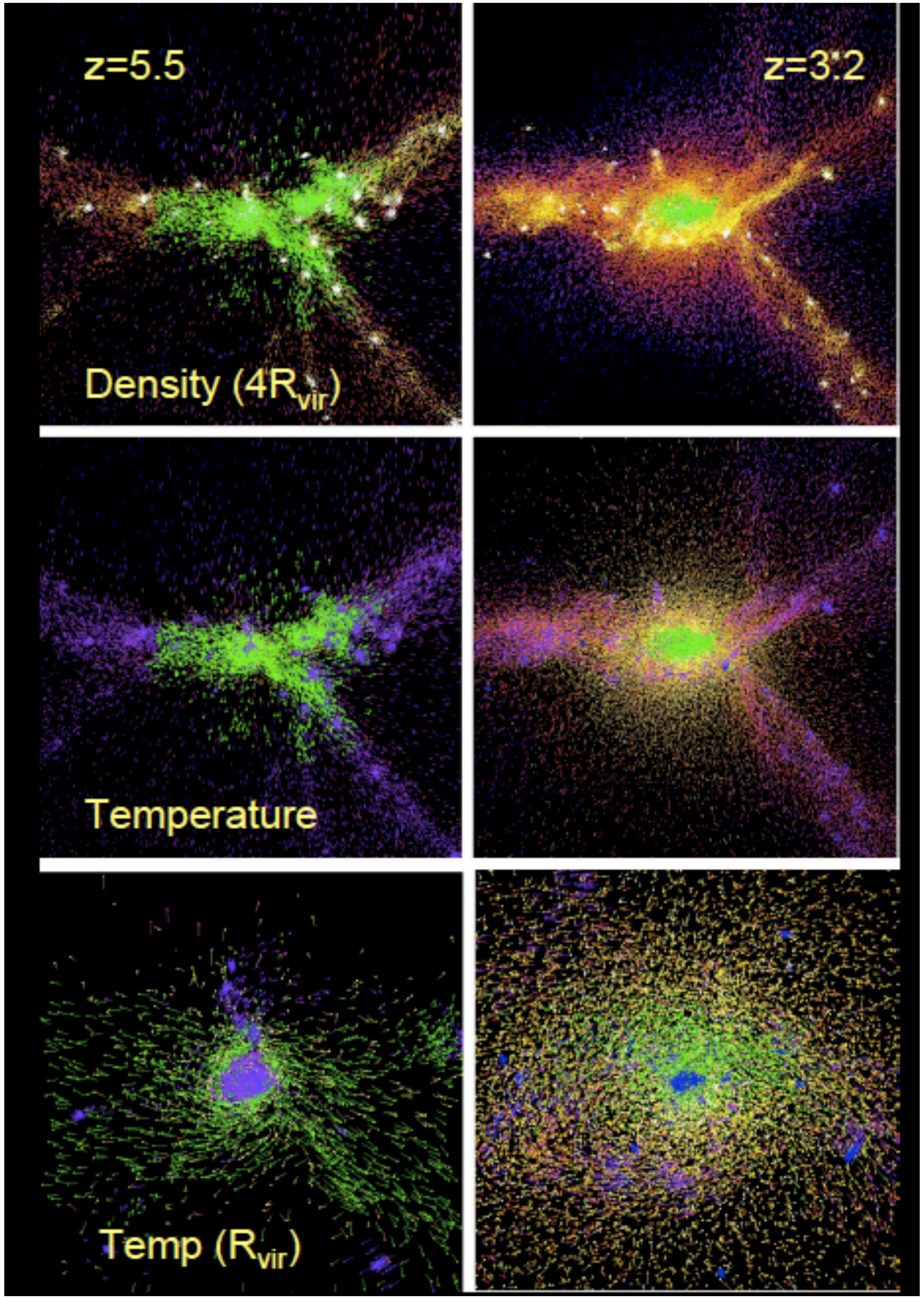
ACCRETION IN A GROWING HALO

HALO GROWS FROM
~10^11 to ~10^12, changes from cold
to
hot mode dominated

COLD MODE IS FILAMENTARY, EXTENDS BEYOND Rvir

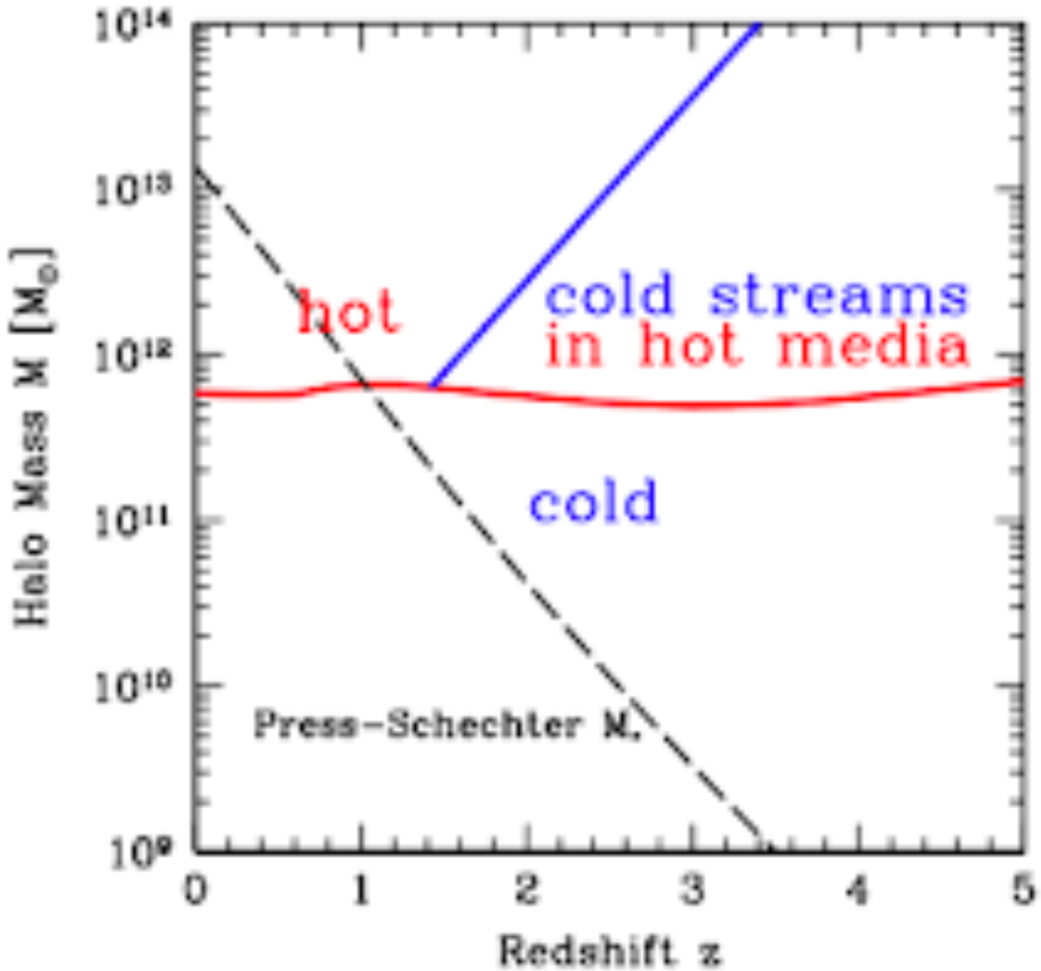
(Filamentary enhances cooling!)

HOT MODE QUASI SPHERICAL



KERES+05

GAS ACCRETION INTO HALOS



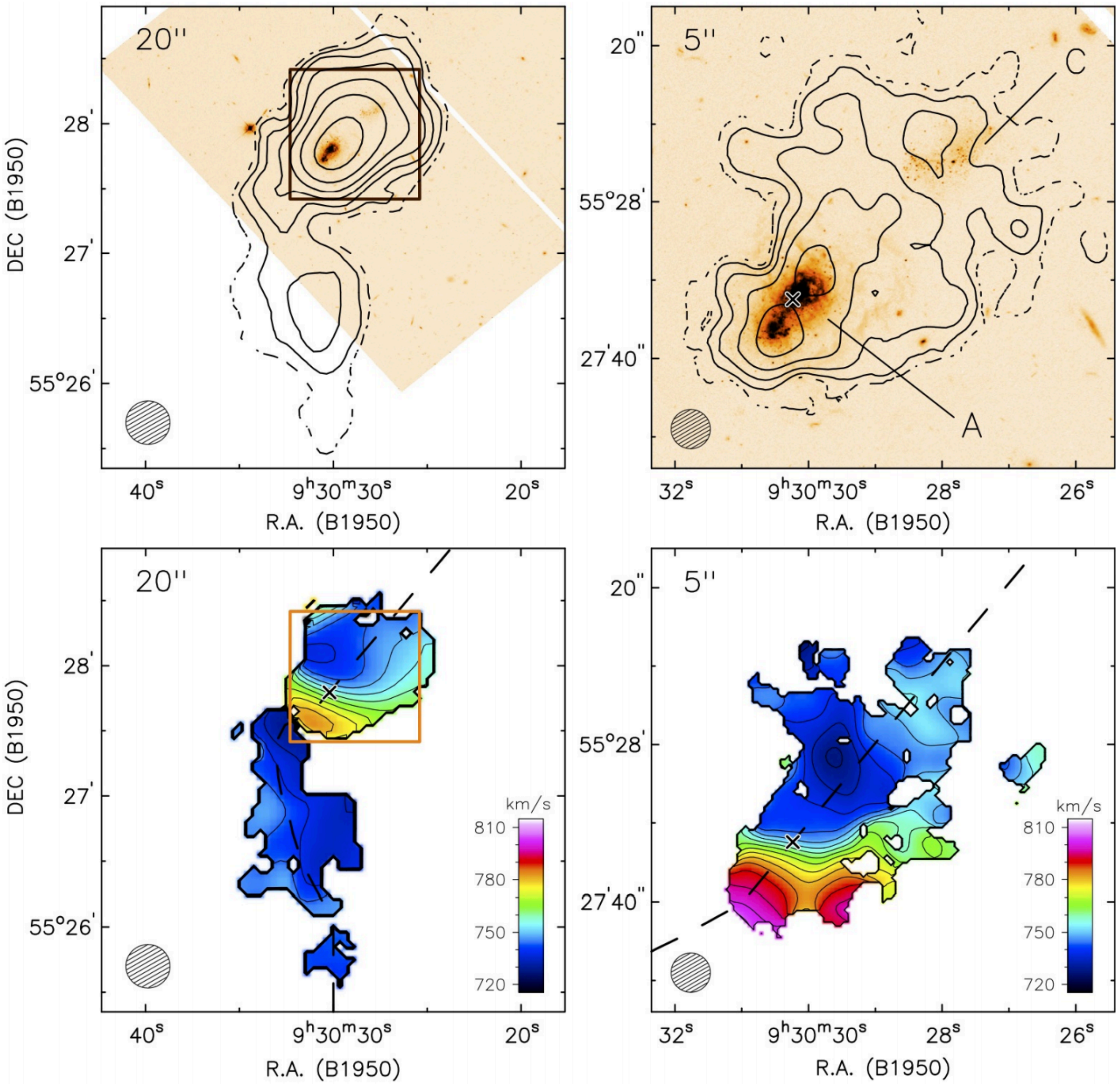
Birnboim&Dekel03

GAS ACCRETION
IS A KEY PREDICTION OF GALAXY FORMATION MODELS

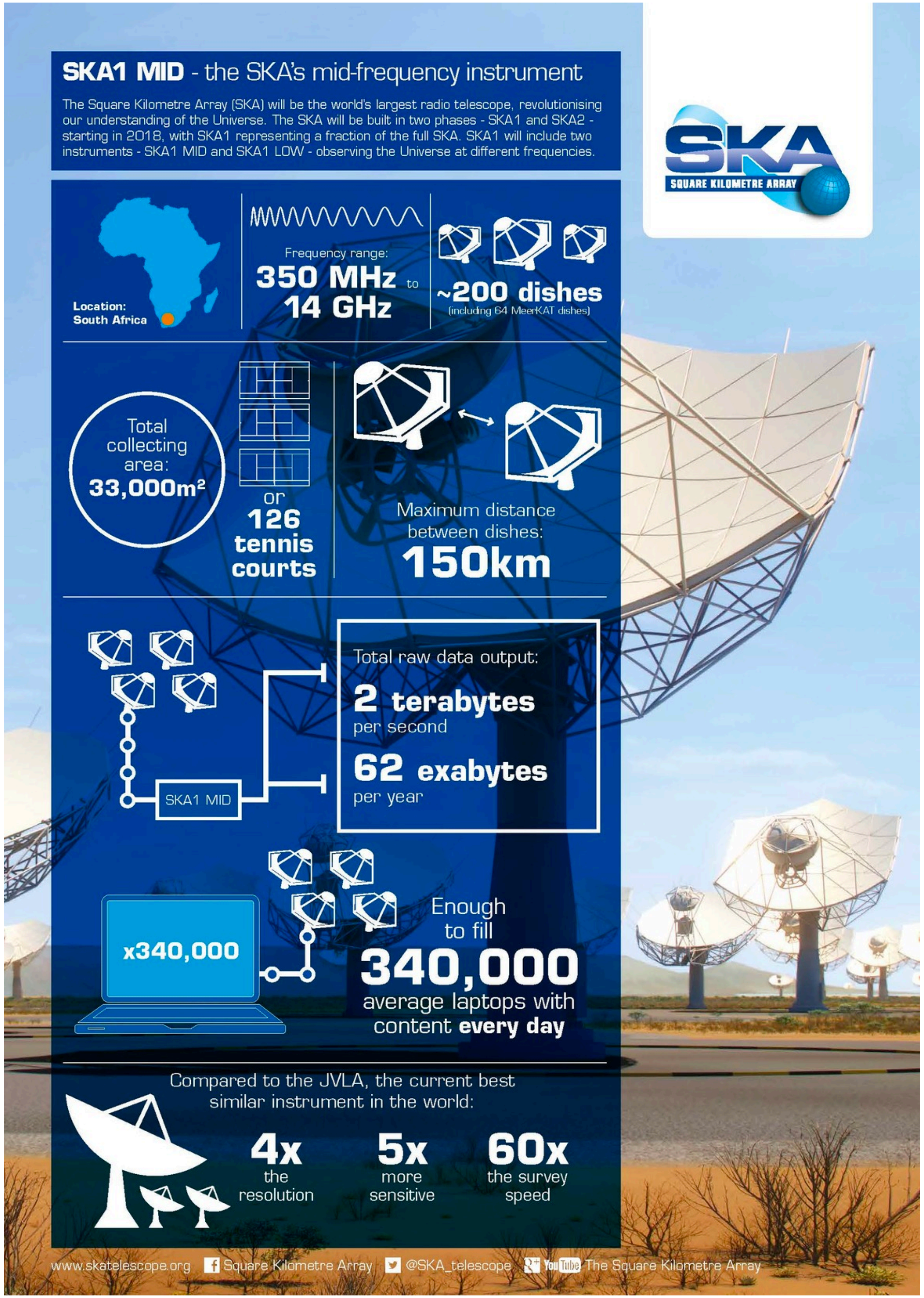
BUT ARE THERE ANY

OBSERVATIONAL EVIDENCES?

DIRECT MAPPING OF ATOMIC GAS AROUND GALAXIES IS DIFFICULT (LOW DENSITIES) AND CAN ONLY BE DONE LOCALLY



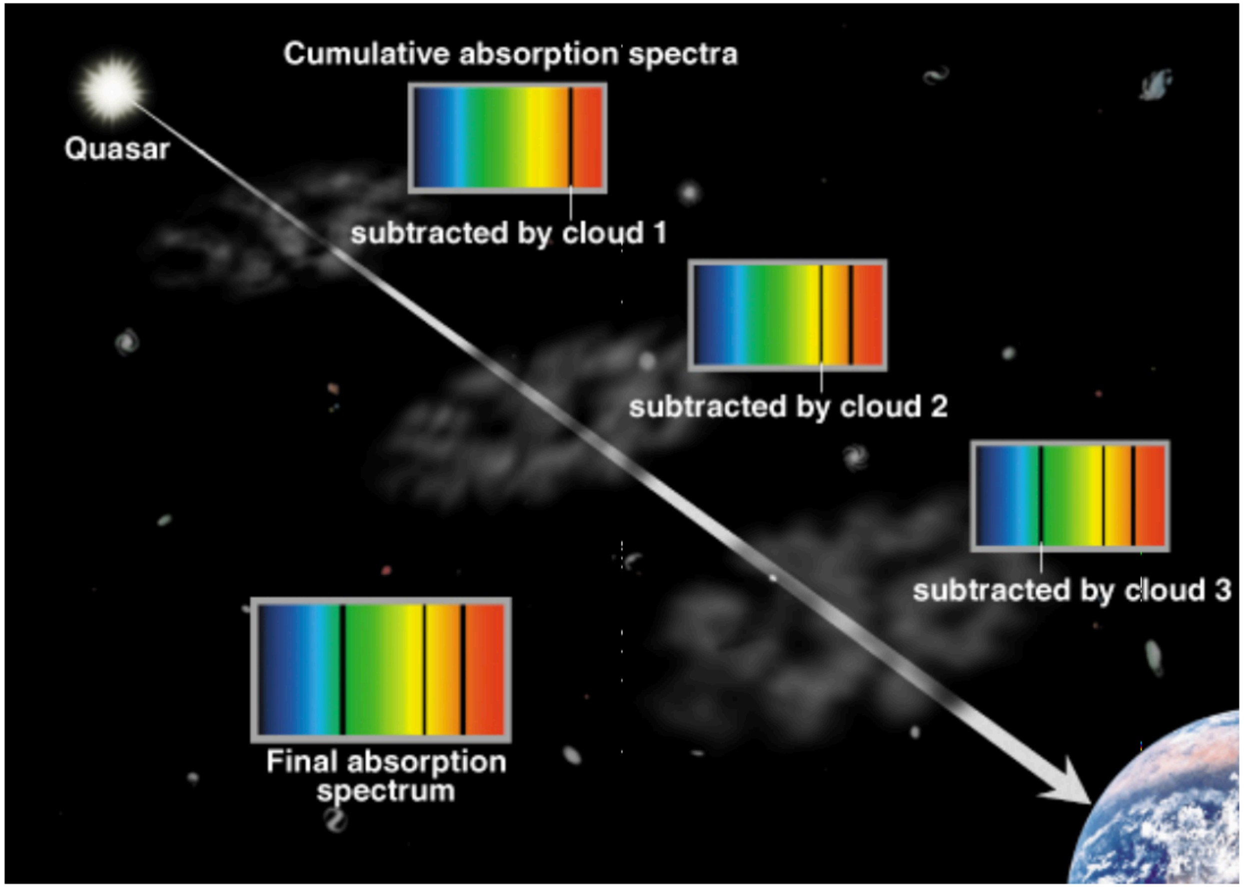
Lelli+12



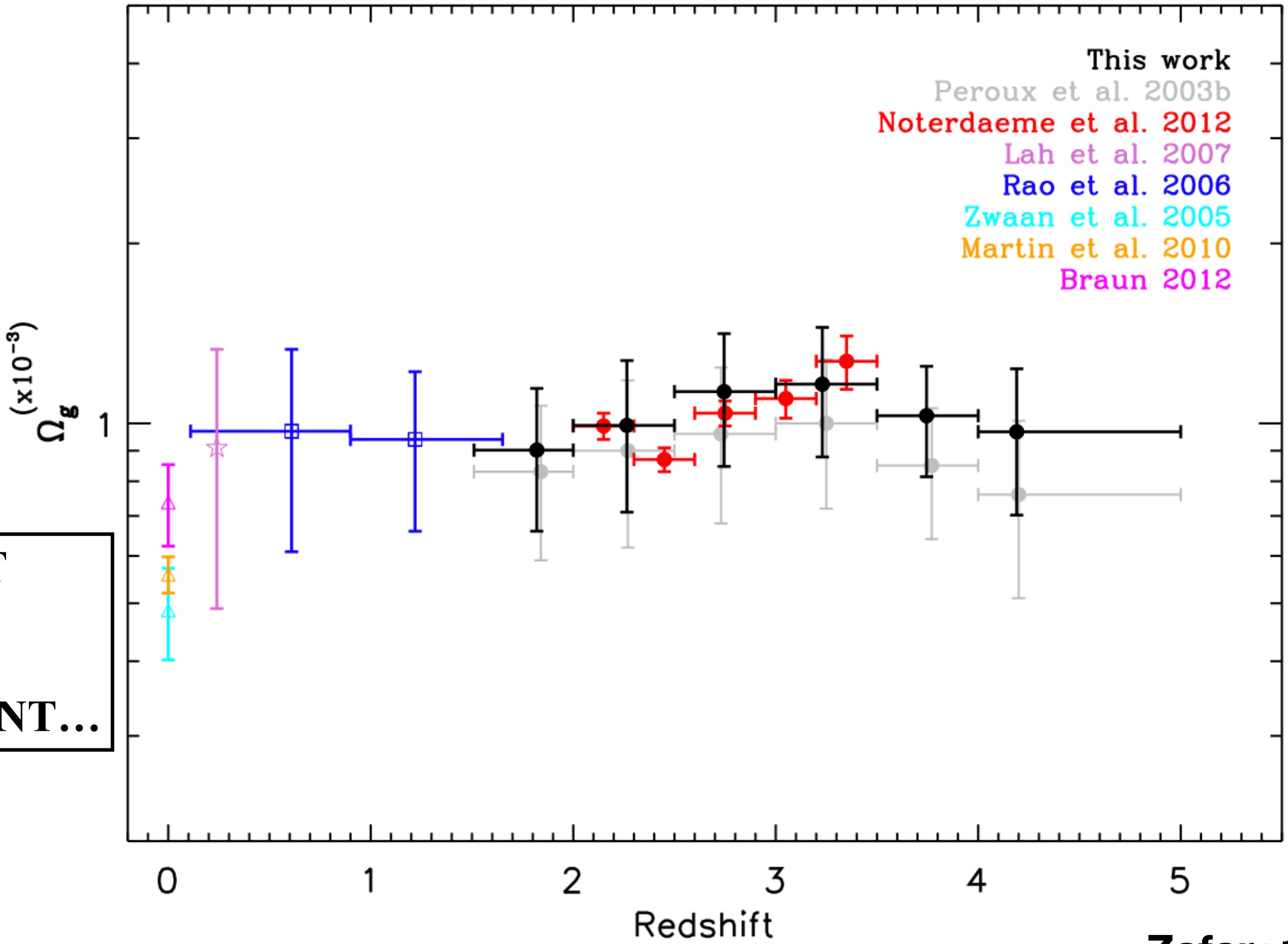
THE SKA REVOLUTIO N

ACCRETION IS EXPECTED TO BE MORE IMPORTANT AT HIGHER REDSHIFTS….

THE COSMIC WEB IN ABSORPTION...



NEUTRAL GAS DENSITY EVOLUTION



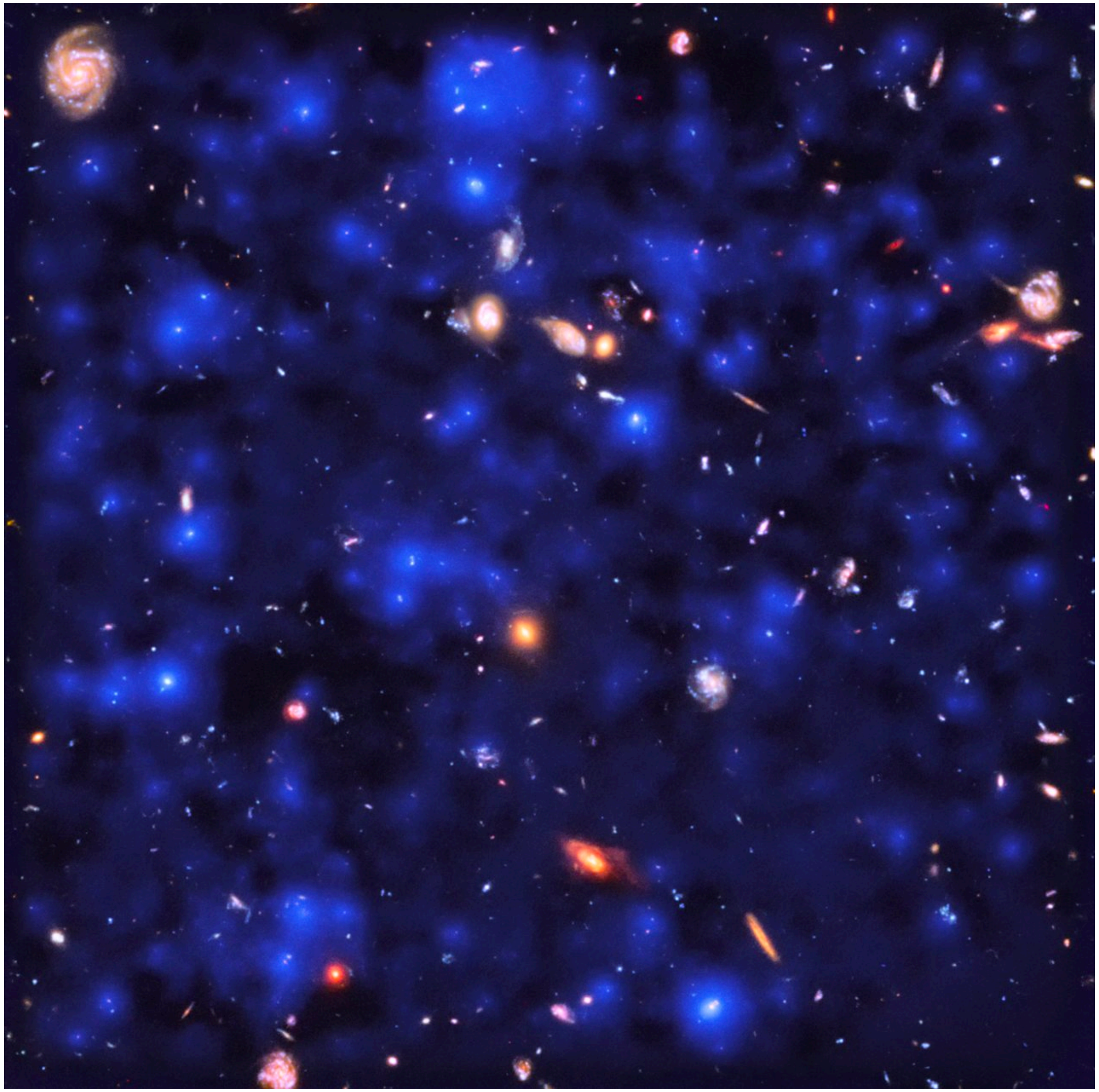
A CONSTANT FRACTION IMPLIES REMPLENISHMENT…

Zafar+13

THE COSMIC WEB IN EMISSION…

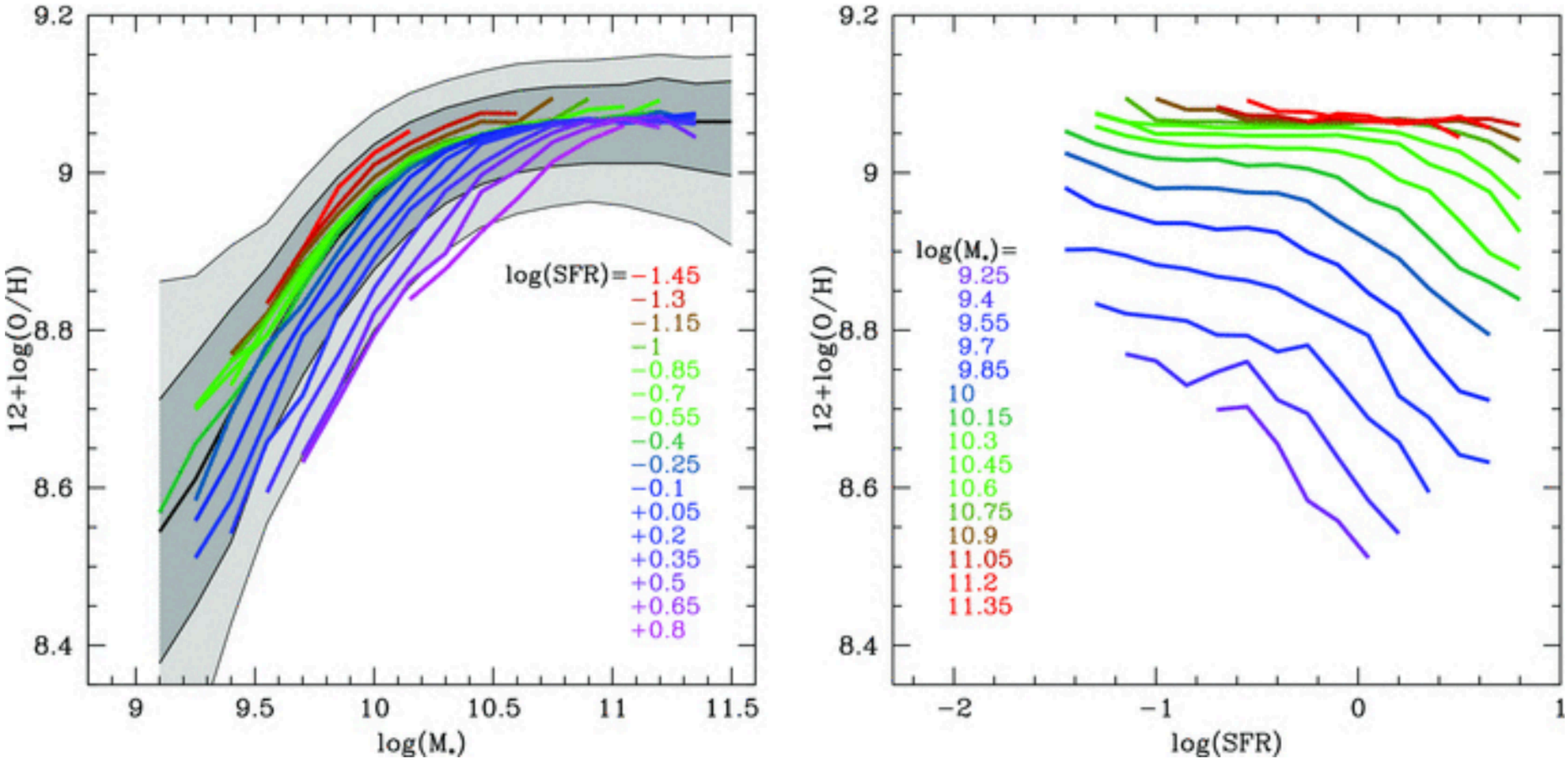
Nearly the entire sky in the early Universe is glowing with Lyman-alpha emission

Wisotzki +18

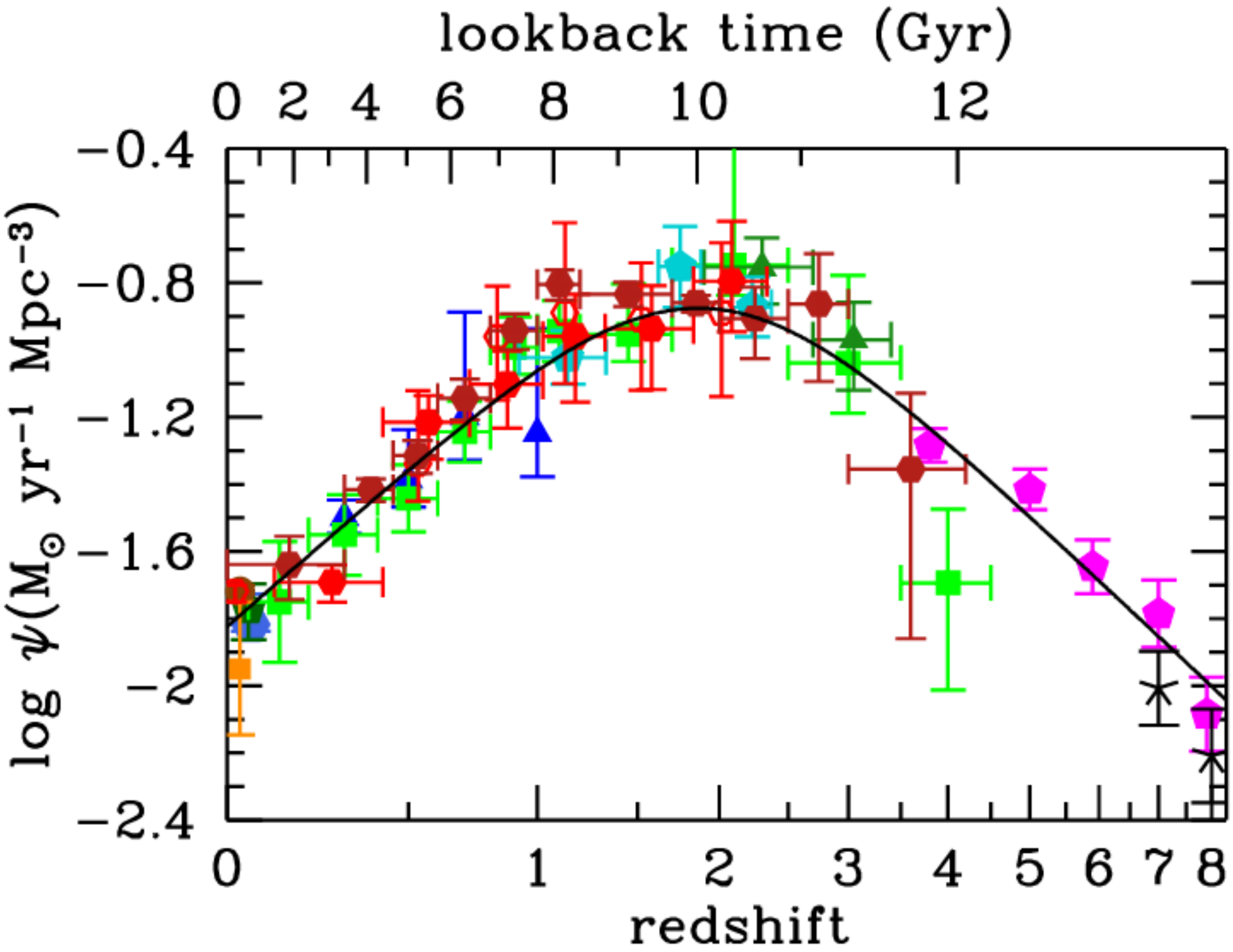


INDIRECT EVIDENCES THROUGH STARS…

MASS-SFR-METALLICITY RELATION

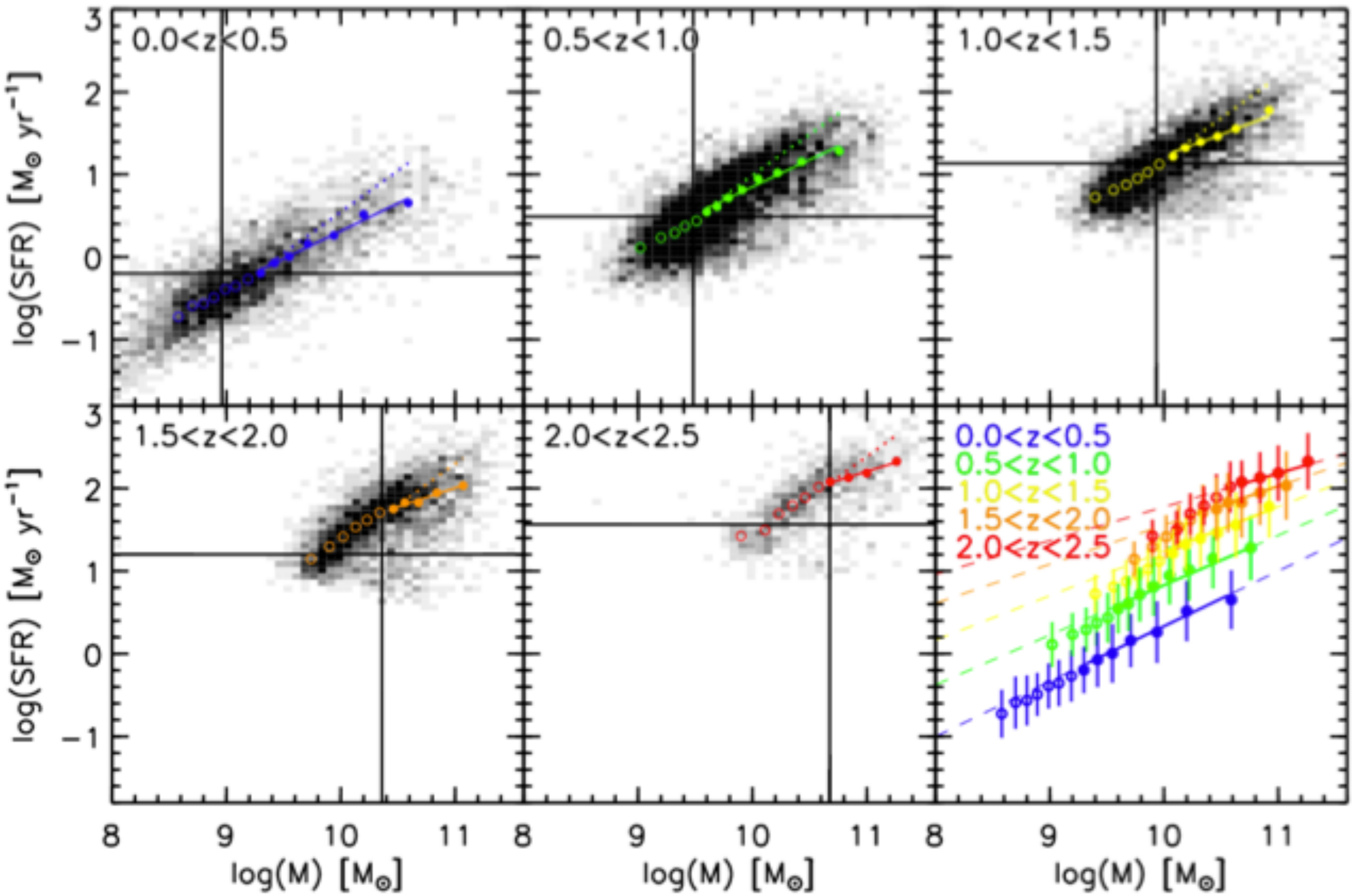


COSMIC STAR-FORMATION HISTORY



THE EXISTENCE OF THE STAR-FORMATION MAIN SEQUENCE…

Whitaker+13



GALAXY MERGERS

SIMPLE PHYSICS DESCRIBED BY DYNAMICAL FRICTION:

Secondary Mass going at speed Vm

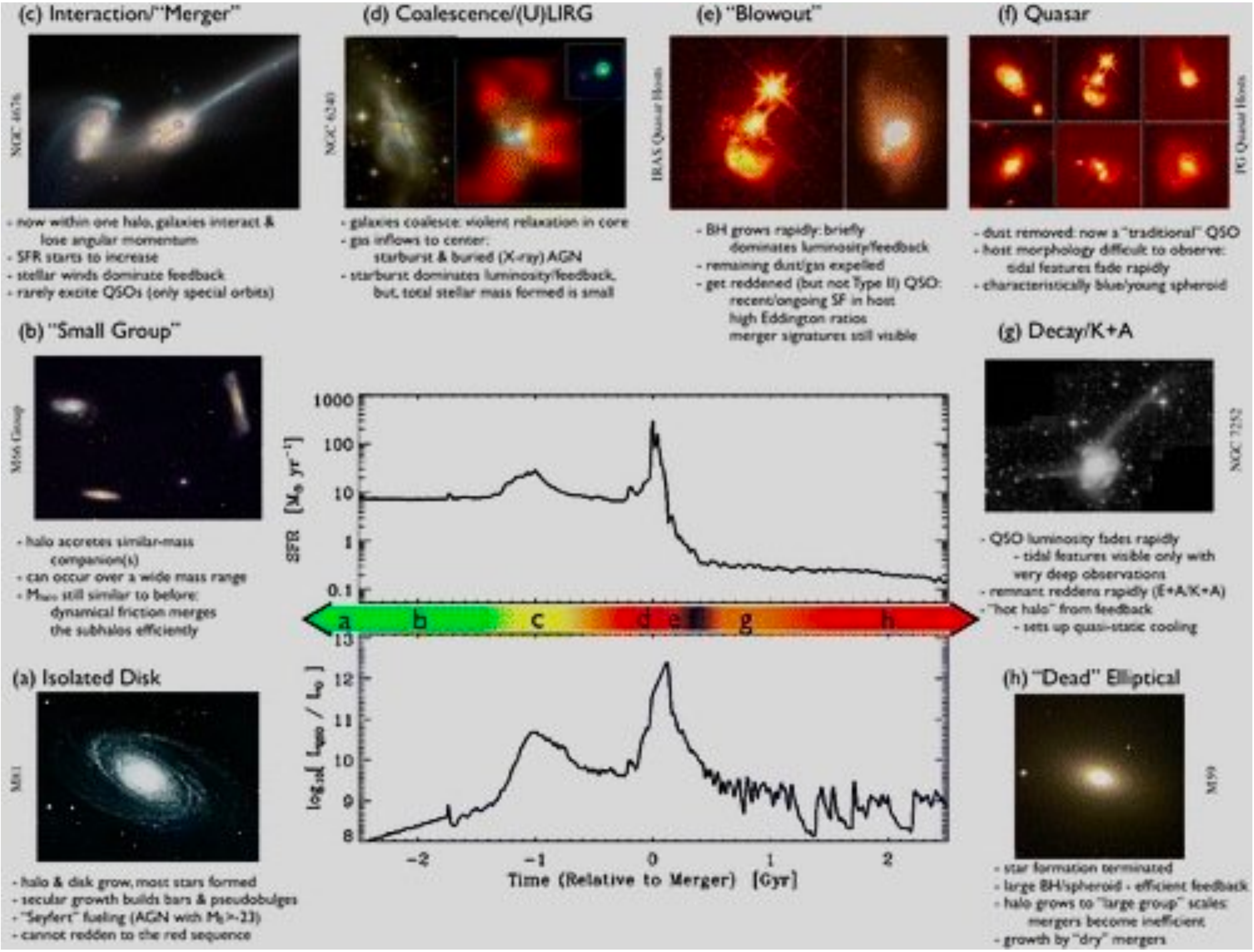
$$F_{dyn} \approx C \frac{G^2 M^2 \rho}{v_M^2}$$

Local Density

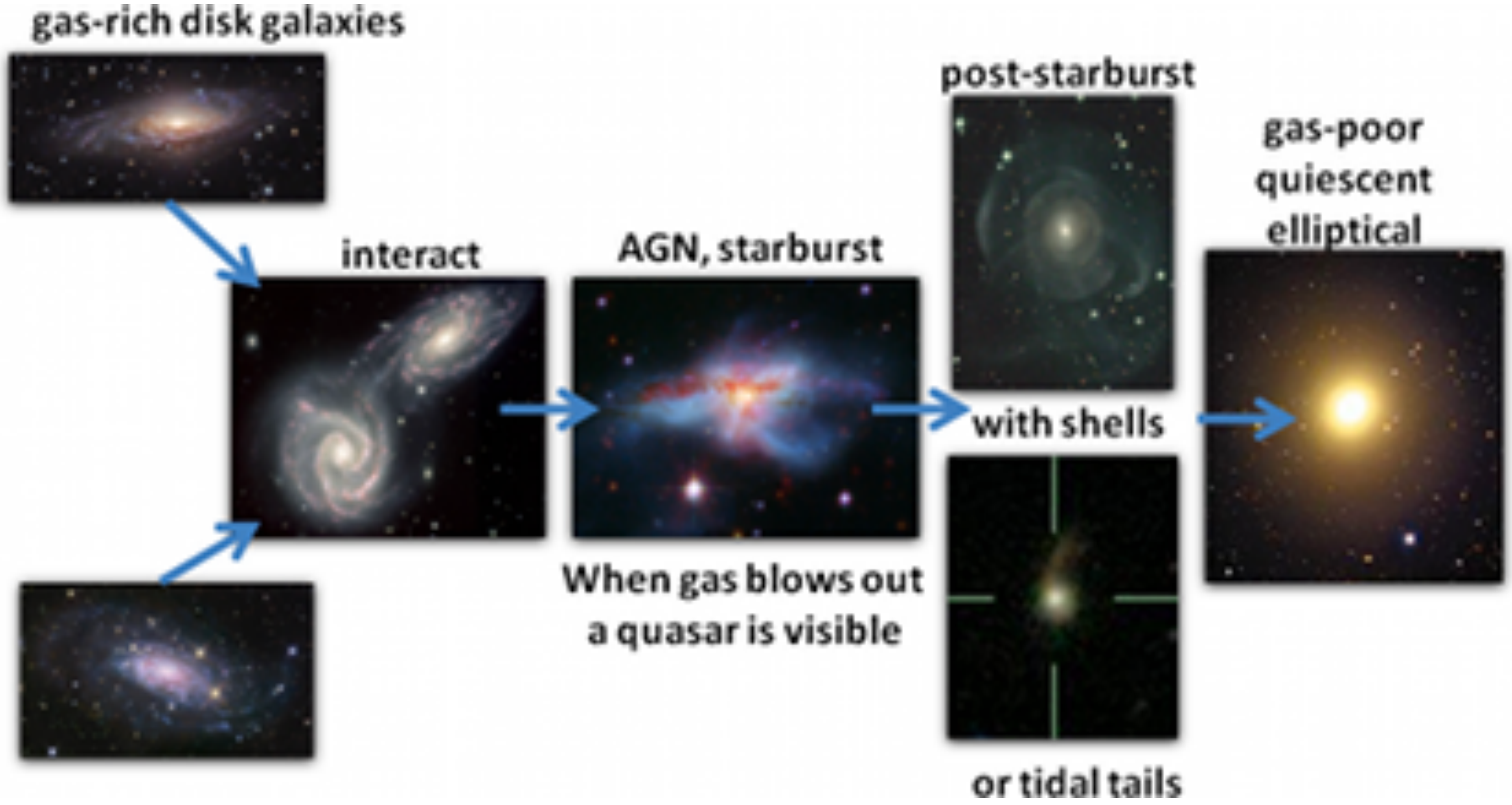
C depends on how Vm compares to the velocity dispersion of the matter around…

EXAMPLE HERE: https://www.youtube.com/watch?v=Mq-OPiCYrq8

THE IMPACT OF GALAXY MERGERS



Hopkins+

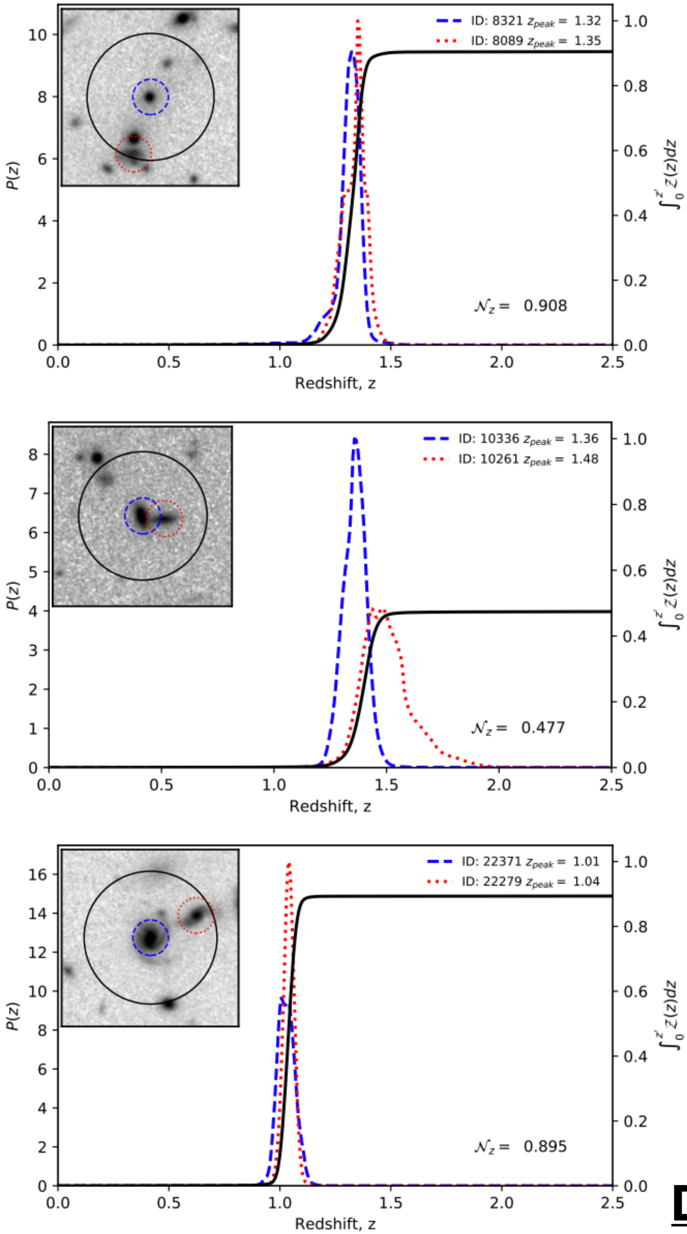

gas-rich disk galaxies
interact
AGN, starburst
When gas blows out
a quasar is visible
post-starburst
with shells
or tidal tails
gas-poor
quiescent
elliptical

OBVIOUS OBSERVATIONAL EVIDENCE

MEASURING GALAXY MERGER RATES

- TWO MAJOR APPROACHES:
  - **PAIR COUNTING** - REQUIRES GOOD DISTANCE ESTIMATORS - AFFECTED BY PROJECTION EFFECTS
  - **MORPHOLOGICAL PERTURBATIONS** - DIFFICULT TO CALIBRATE - LACK OF COMPLETENESS

PAIR COUNTING



DUNCAN+19

WE COMPUTE THE PAIR FRACTION:

$$f_{\mathrm{P}} = \frac{N_{\mathrm{pairs}}}{N_{\mathrm{T}}},$$

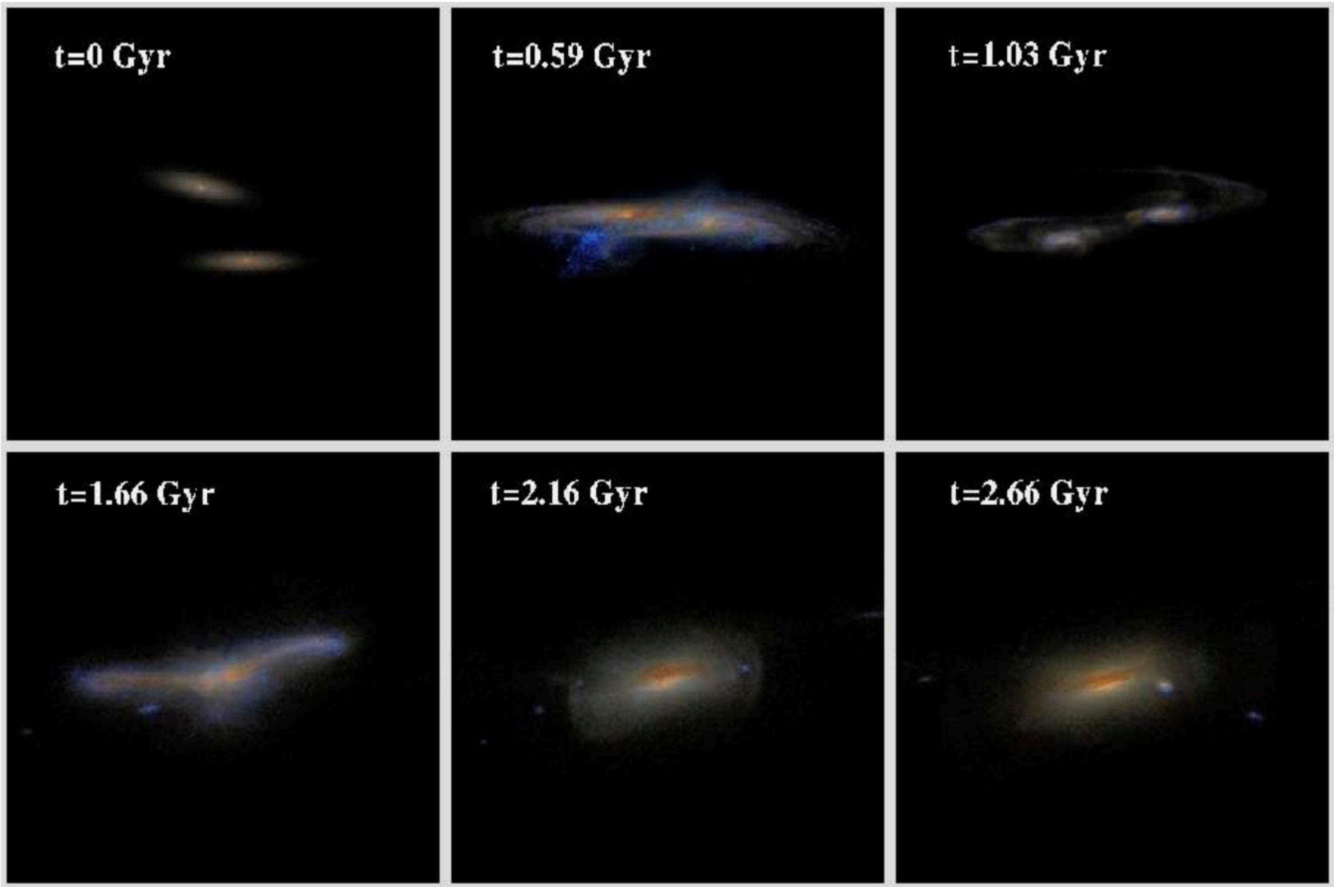
THEN CONVERTED TO MERGER RATE:

$$\mathcal{R}(> \mathrm{M}_\star, z) = \frac{f_{\mathrm{P}}(> \mathrm{M}_\star, z)}{\tau_{\mathrm{P}}(z)}.$$

$$\tau_{\mathrm{P}}(z) = 2.4 \times (1+z)^{-2}\mathrm{Gyr}.$$

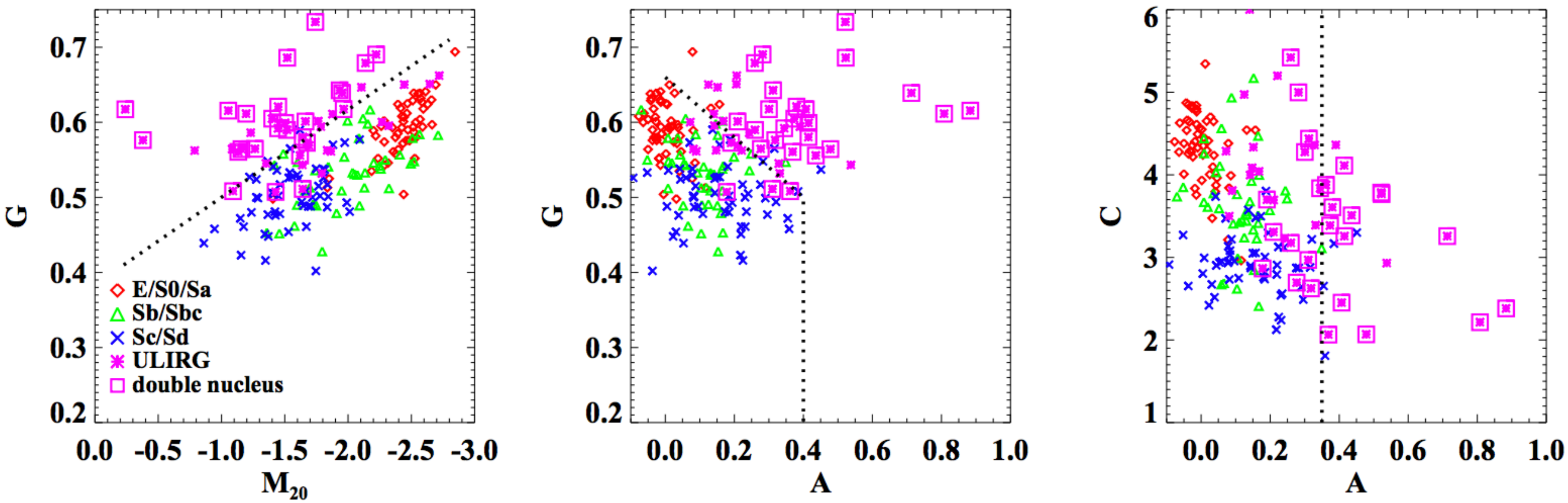
MOPRHOLOGICAL DISTURBANCES

WE LOOK FOR MORPHOLOGICAL PERTURBATIONS INDUCED BY MERGERS….



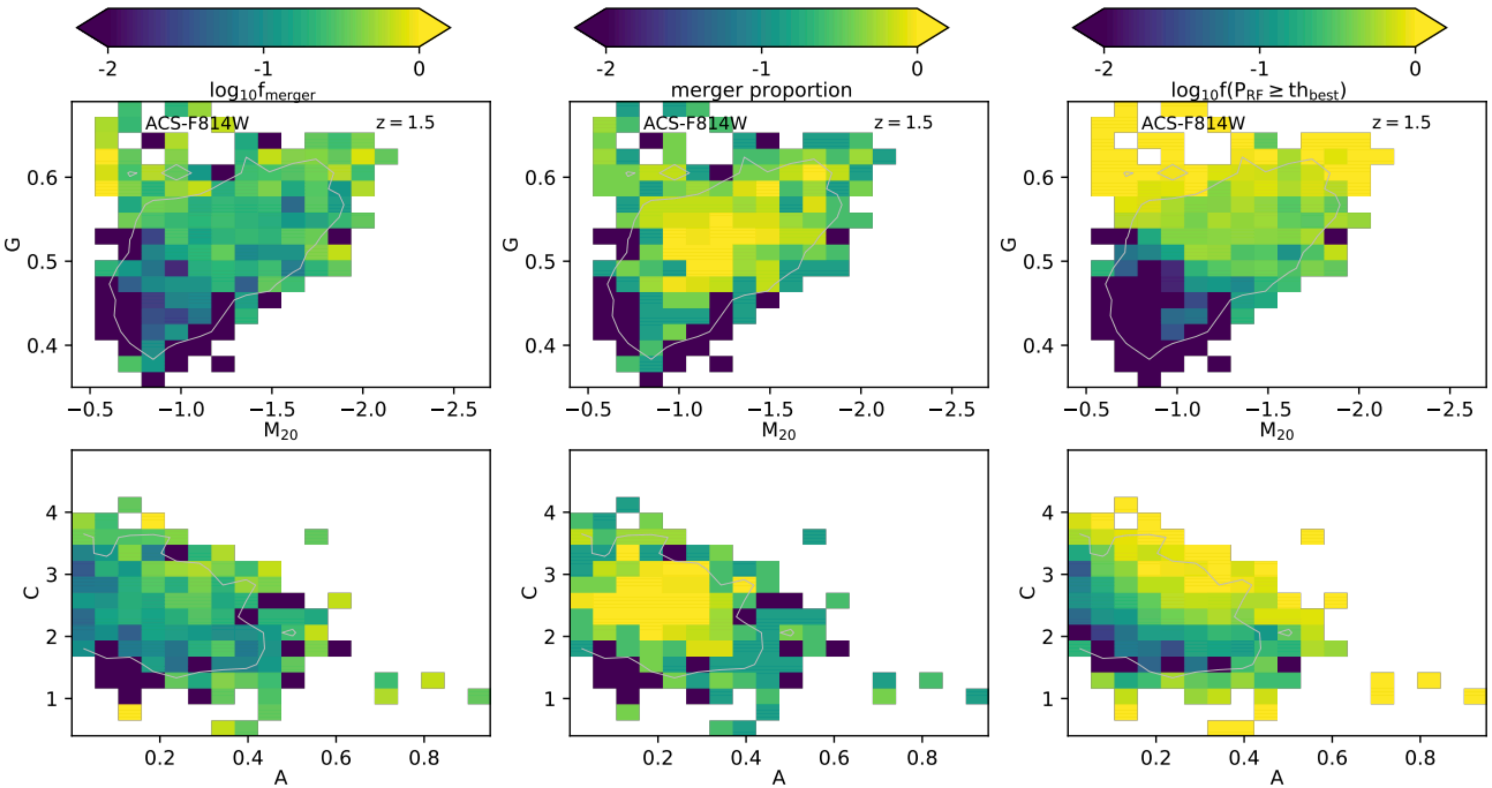
LOTZ+08

MOPRHOLOGICAL DISTURBANCES

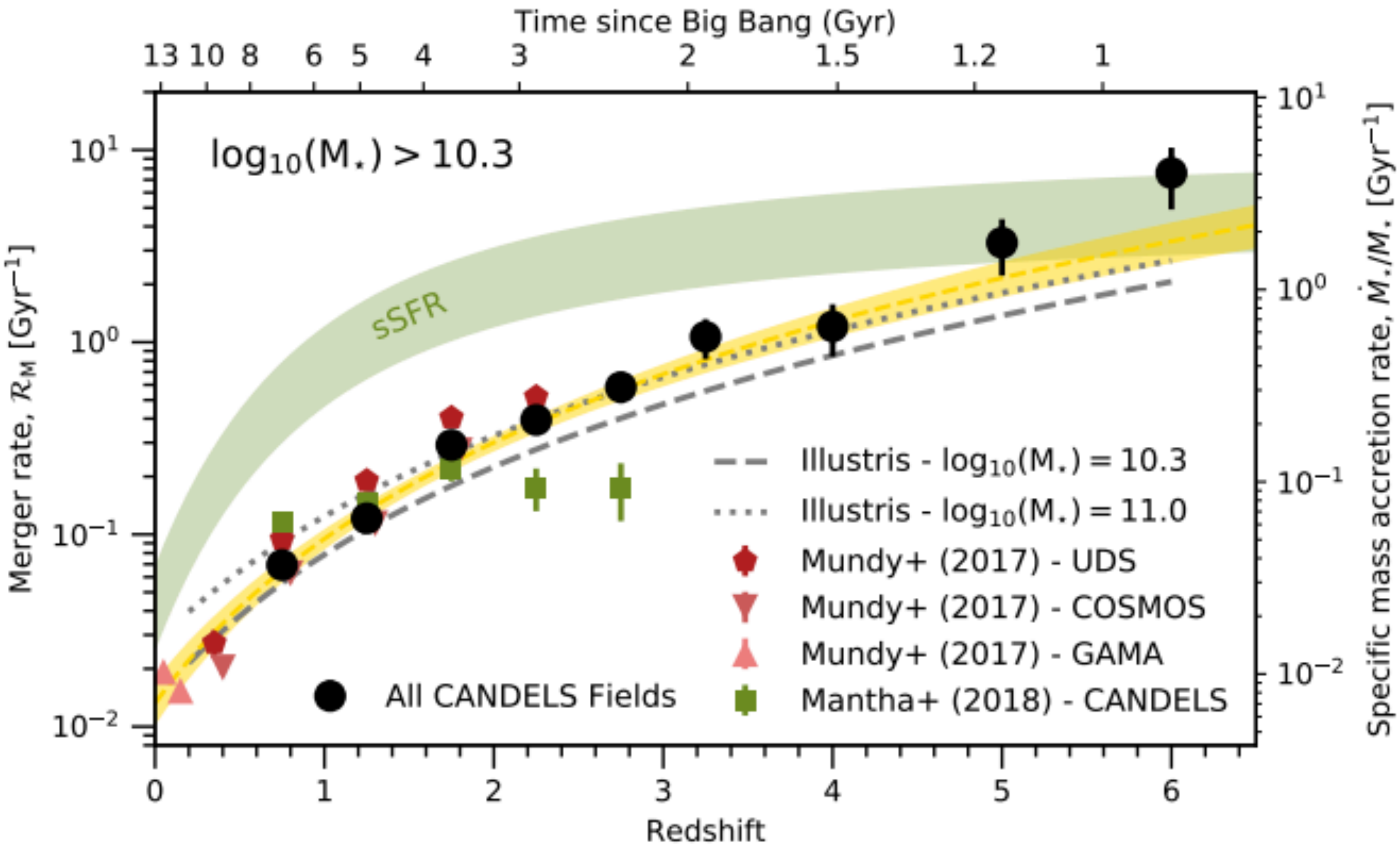


LOTZ+08

MOPRHOLOGICAL DISTURBANCES



SNYDER+19



Time since Big Bang (Gyr)
13 10 8 6 5 4 3 2 1.5 1.2 1
$\log_{10}(M_\star) > 10.3$
sSFR
Merger rate, $\mathcal{R}_M$ [Gyr^{-1}]
Specific mass accretion rate, $\dot{M}_\star/M_\star$ [Gyr^{-1}]
Redshift
Illustris - $\log_{10}(M_\star) = 10.3$
Illustris - $\log_{10}(M_\star) = 11.0$
Mundy+ (2017) - UDS
Mundy+ (2017) - COSMOS
Mundy+ (2017) - GAMA
Mantha+ (2018) - CANDELS
All CANDELS Fields

DUNCAN+19

MERGERS OR ACCRETION?

Conselice+13

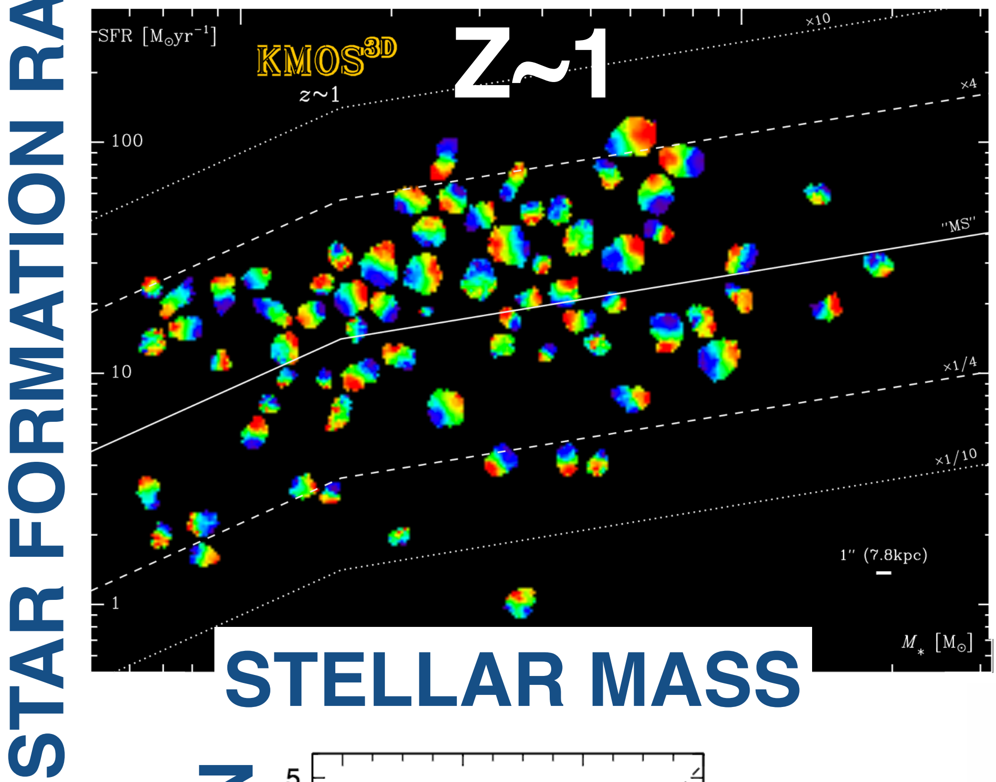
I. Utilizing our measured star formation rates and galaxy sizes we find a roughly constant cold gas mass to stellar mass fraction for this sample across the redshift range of $1.5 < z < 3$.

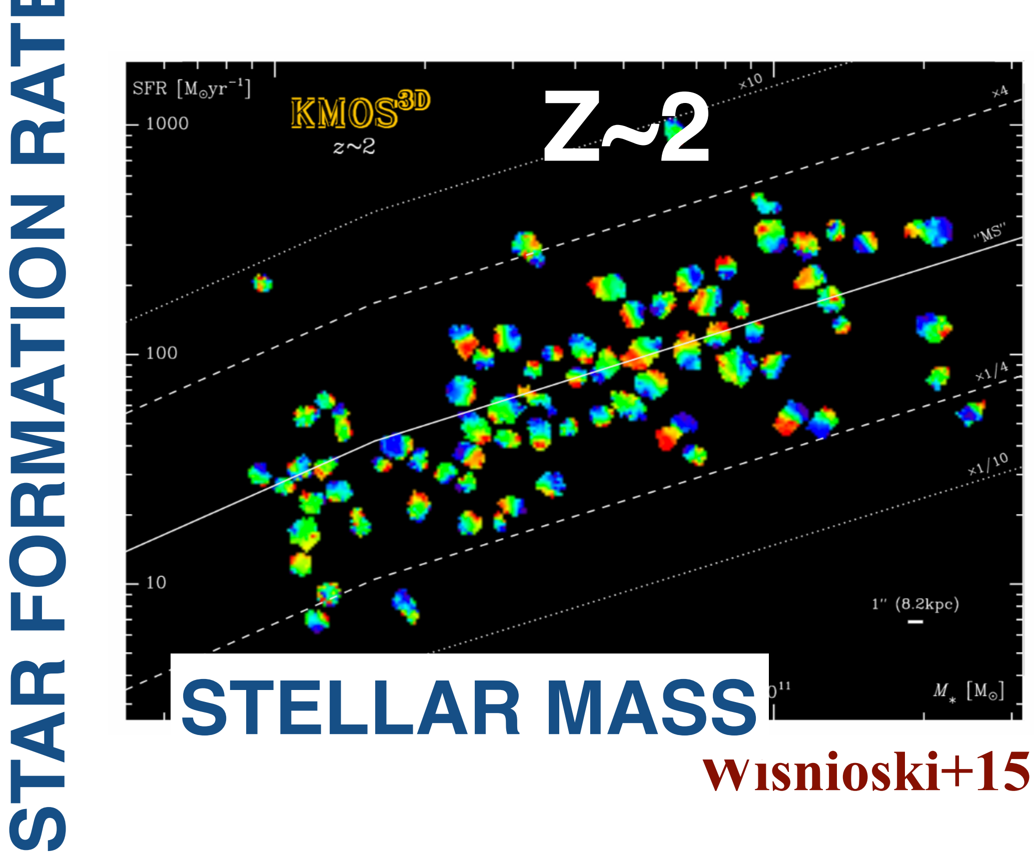
II. We utilize the star forming and merging properties of these galaxies from previous work in Bauer et al. (2011) and Bluck et al. (2012) to measure the mass budget of our sample of massive galaxies, finding that $\dot{M}_{\rm acc} = (96 \pm 19)$ $M_{\odot}\,{\rm yr}^{-1}$ of gas is needed to sustain the star formation rate outside of gas brought in via mergers.

III. We derive based on these values that cold gas accretion from the intergalactic medium, or alternatively very minor galaxy mergers with mass ratios lower than 1:100 (or 1:10 in ratios of baryons), accounts for 49$\pm$20% of the baryonic matter added to galaxies from $1.5 < z < 3$.

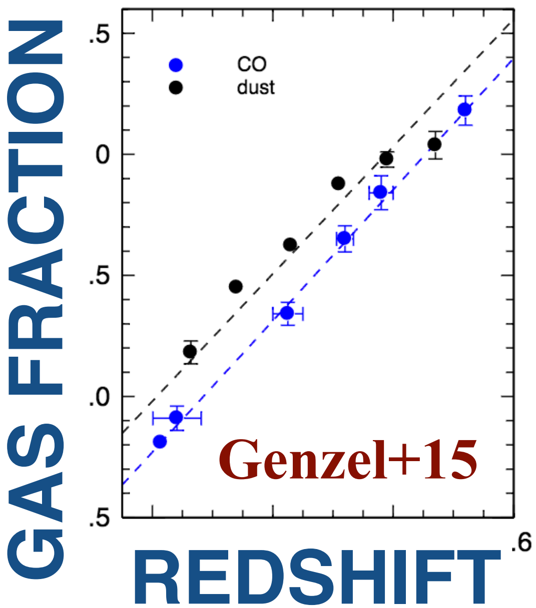
This amount of gas mass added from accretion is larger than the amount of gas added due to the merger process (both minor and major) (e.g., Conselice 2006; Bluck et al. 2012) and is largely in agreement with models which predict on the order of 100-200 $M_{\odot}\,{\rm yr}^{-1}$ added from cold gas accretion (e.g., Dekel et al. 2009a,b). Gas accretion is therefore the major method for producing star formation within massive galaxies between redshifts $1.5 < z < 3$.

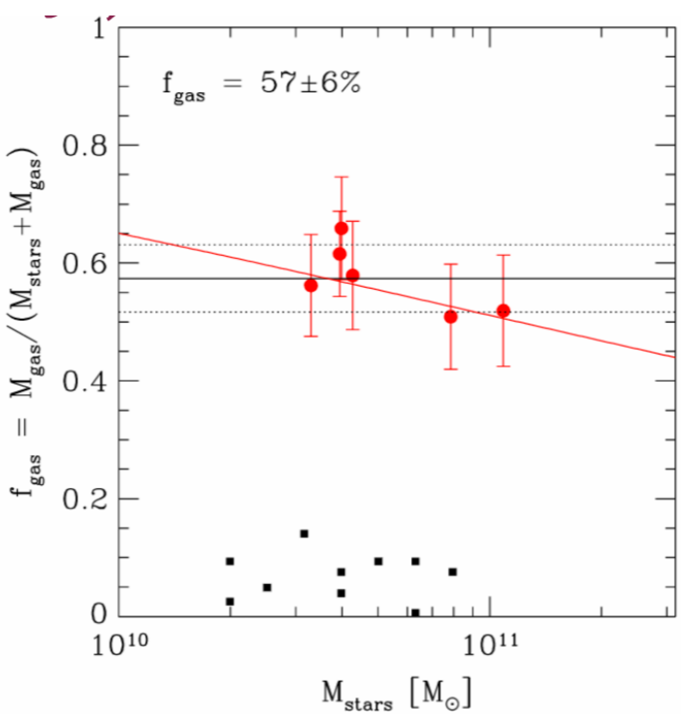
NORMAL ROTATING DISKS…





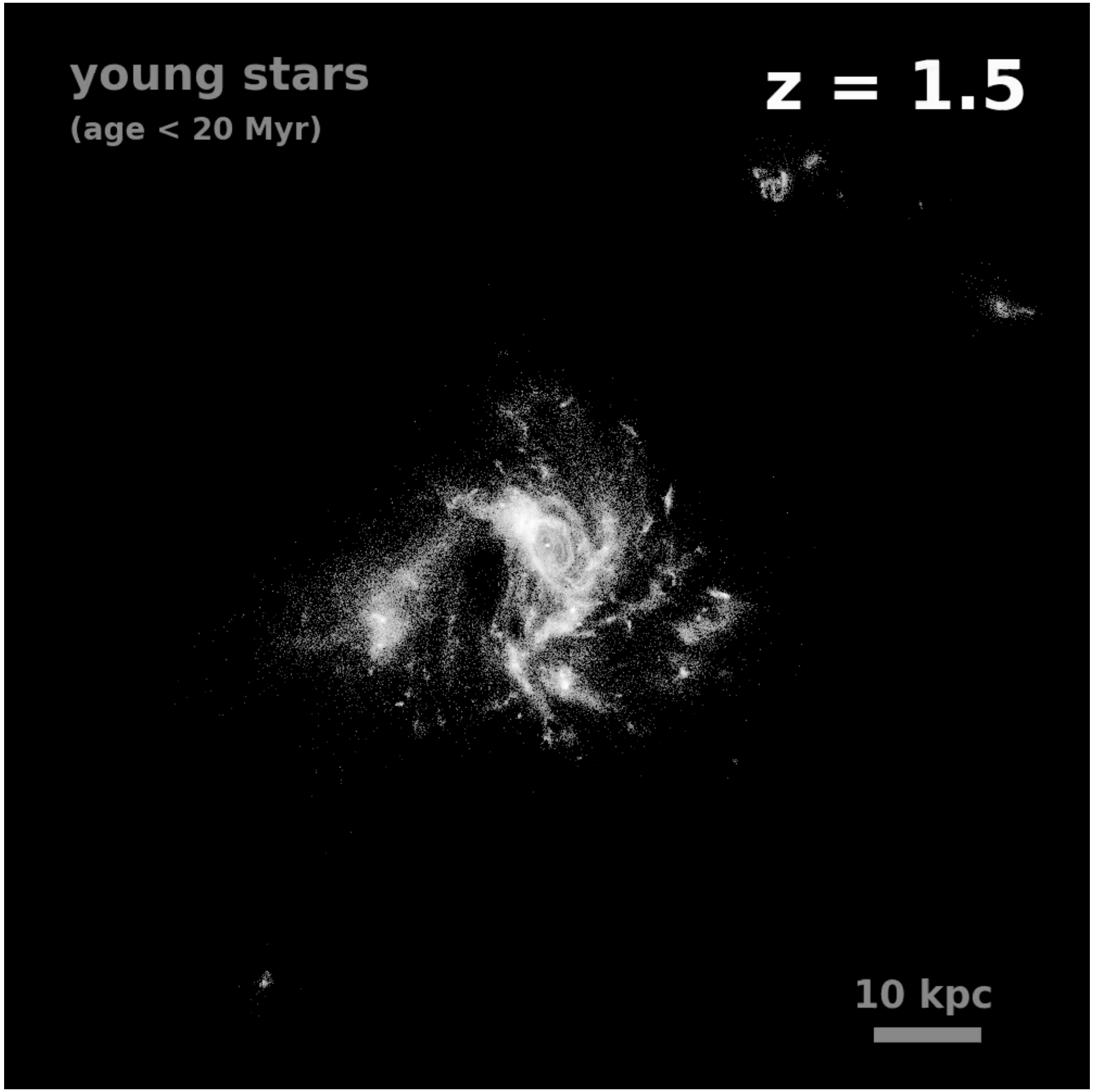
Wisnioski+15





Daddi+07

HOWEVER…



SIMONS, KASSIN+

THE DIFFERENCE BETWEEN MERGER AND ACCRETION…

- IN THE EARLY UNIVERSE, WHEN THERE IS PLENTY OF GAS, THE DIFFERENCE BETWEEN MINOR GAS RICH MERGERS AND ACCRETION IS SUBTLE…

TWO PHASE GALAXY FORMATION?

- 1. AN EARLY PHASE DOMINATED BY GAS RICH ACCRETION AT EARLY TIMES - BUILD UP OF THE GALAXY INNER PARTS?
- 2. BUILD UP OF THE OUTER PARTS THROUGH MERGER DOMINATED ACCRETION?
- 3. UNTIL THE BH WAKES UP…

TWO PHASE GALAXY FORMATION?