

Semi-analytical modelling of LAE evolution

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Collaborators

- Carlton Baugh
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Publications

- LeDelliou et al 2005, MN 357, L11
- Le Delliou et al 2006, MN 365, 712
- Orsi et al 2008, MN (in press), astro-ph

Outline

- Why semi-analytical models?
- Physical processes
- Modelling Ly α emission
- A specific model
- Validation
- Predictions
- Conclusions

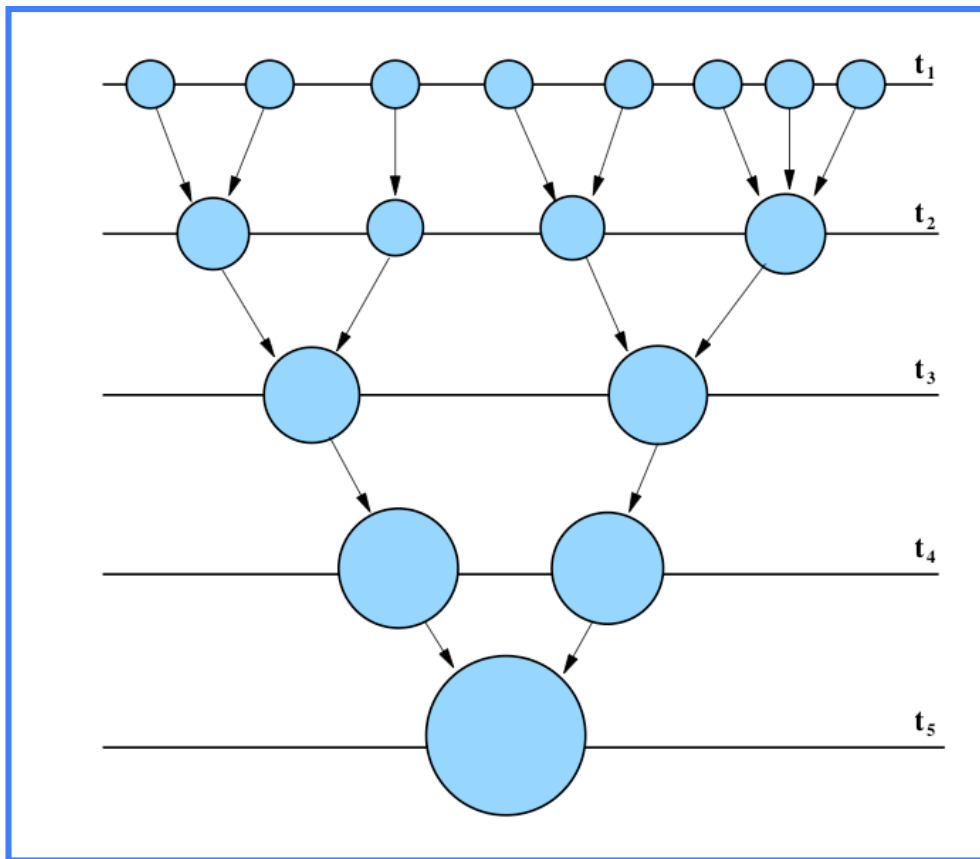
Semi-analytical models of galaxy formation: WHAT & WHY

- Problem with numerical simulations is limited dynamic range: cannot directly simulate all important processes from structure formation (>10 Mpc) down to star formation & feedback (<1 pc)
- Semi-analytical models: instead use simplified analytical prescriptions for main physical processes
- Allows to simulate galaxy populations in cosmological volumes

Physical ingredients in semi-analytical models

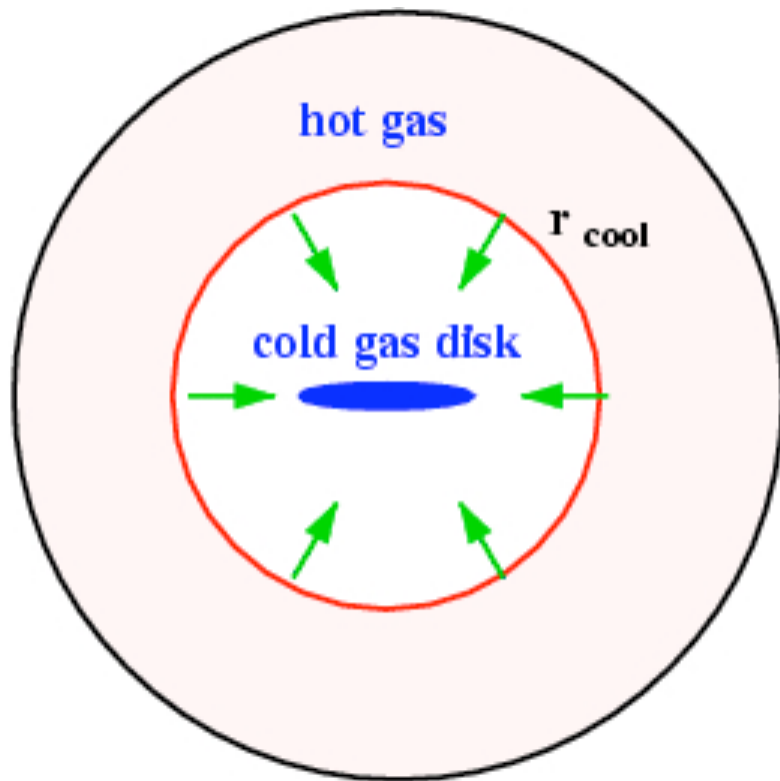
- Assembly of dark matter halos
- Shock-heating and radiative cooling of gas within halos
- Star formation
- Feedback from supernovae & AGN
- Production of heavy elements
- Galaxy mergers
- Stellar populations
- Dust absorption & emission

Assembly of dark matter halos: Merger trees



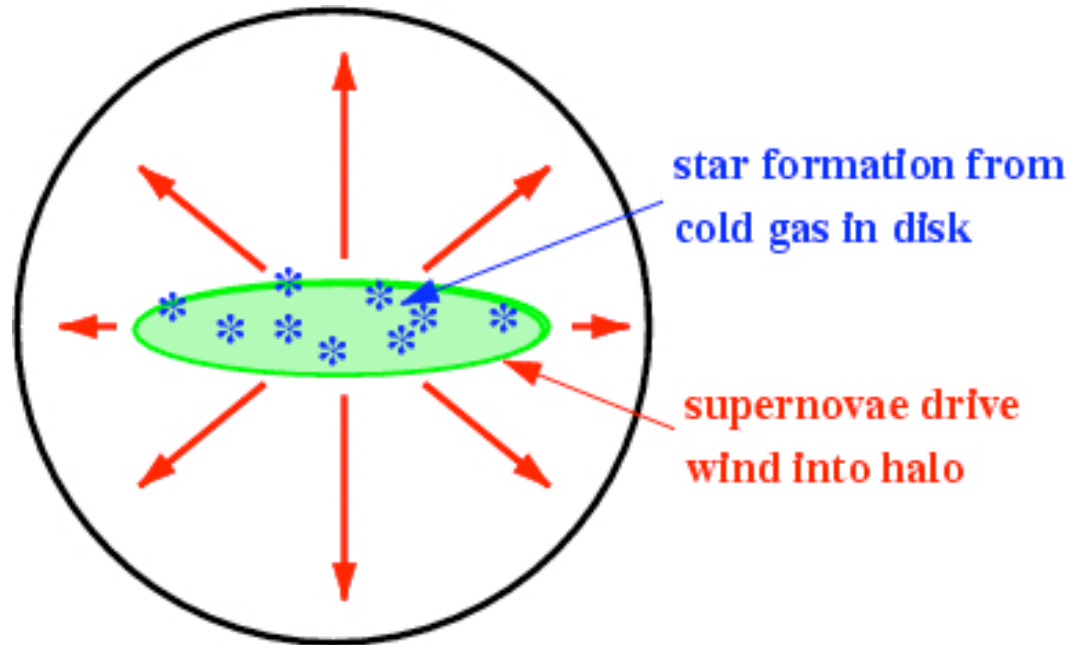
- 2 approaches:
- **Monte Carlo** based on (analytical) conditional Press-Schechter mass function
OR
- **Extract from N-body simulations**
- very similar results from both approaches

Shock-Heating & cooling of gas in halos



- Infalling gas all shock-heated to T_{vir}
- Radiative cooling of gas from static spherical distribution
- Disk size related to angular momentum of gas which cools

Star formation & feedback



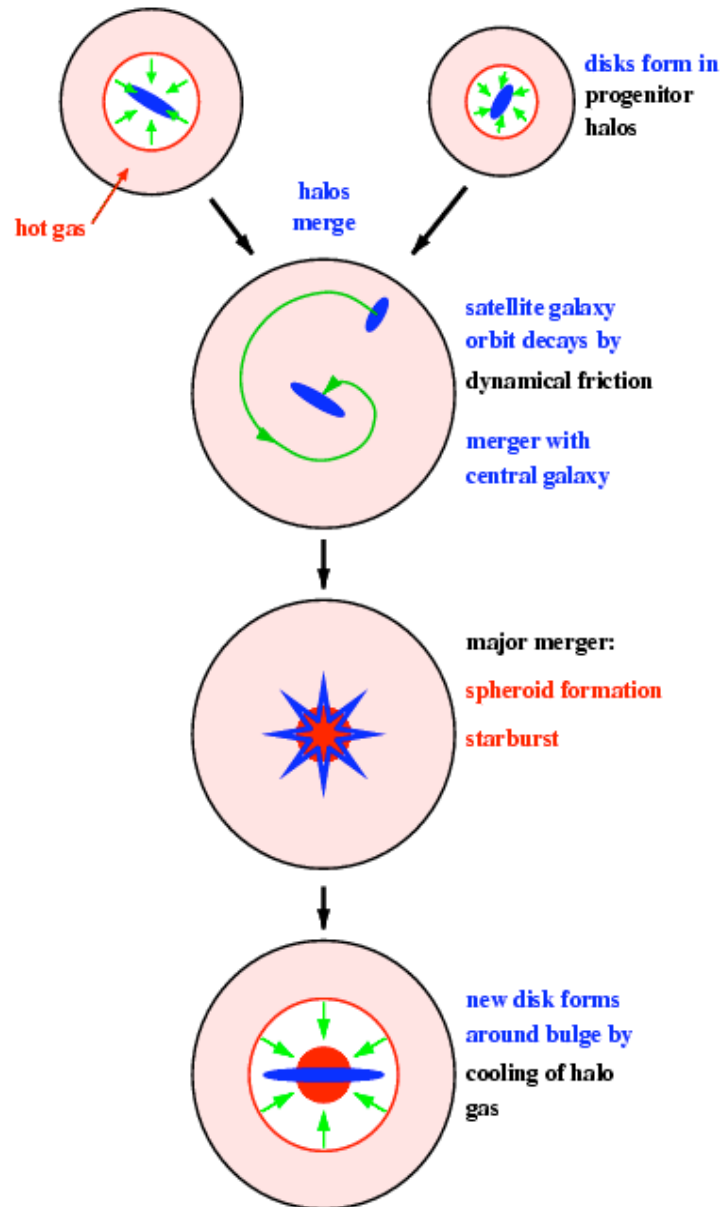
- stars form in disks

$$SFR = M_{gas} / \tau_*$$

- supernova feedback ejects gas from galaxies

$$\dot{M}_{eject} = \beta(V_c) SFR$$

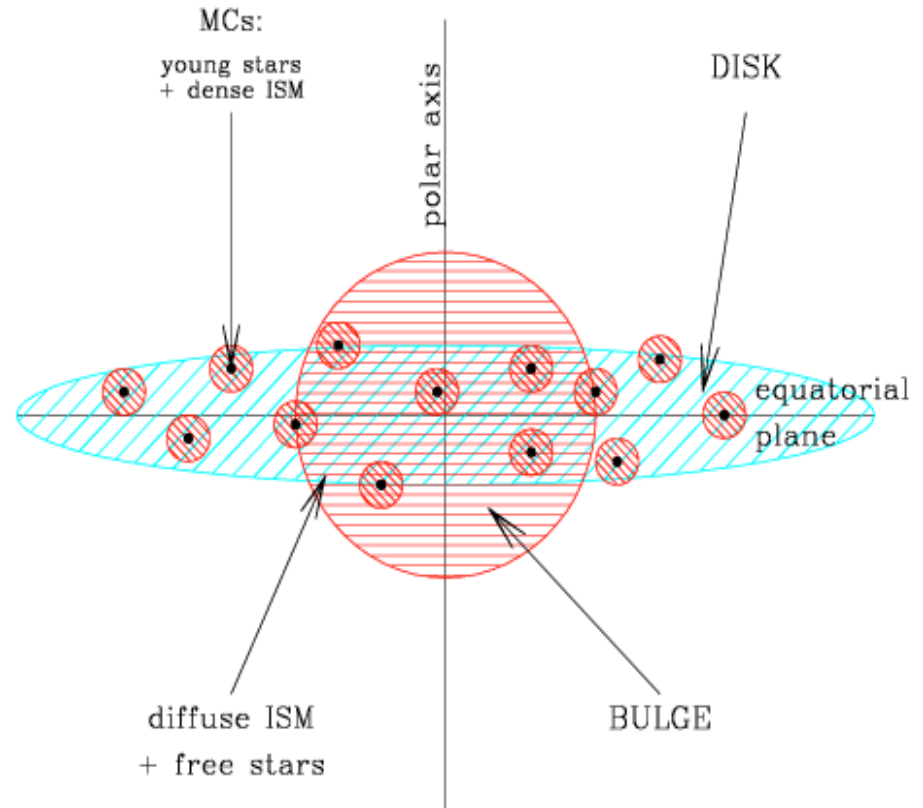
Galaxy mergers & morphology



- halos merge
- galaxies merge by dynamical friction
- major mergers make galactic spheroids from disks
- mergers trigger starbursts
- spheroids can grow new disks

Modelling galaxy SEDs with dust

- dust in diffuse medium and molecular clouds
- stars form in clouds and leak out
- radiative transfer of starlight through dust distribution
- physical dust grain model
- heating of dust grains \rightarrow dust temperature distribution
- IR/sub-mm emission from grains w distrib of size & T



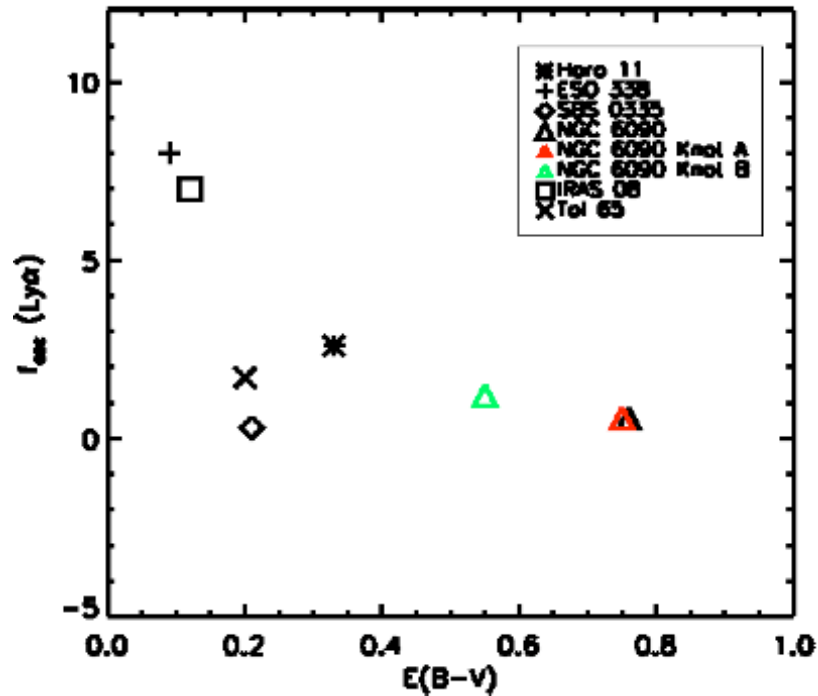
Modelling Ly α emission

- Model predicts SED for each galaxy including effects of SF history, metallicity & IMF
- Integrate over SED to get Ly α luminosity
- Assume all Ly α absorbed by H within galaxy & produces Ly α according to Case B recombination

Ly α escape fraction f_{esc}

- Calculating escape fraction from galaxy from 1st principles is very complicated radiative transfer problem
- Depends on spatial distribution and kinematics of neutral gas & dust in galaxy & surrounding halo
- We adopt simpler approach - assume constant f_{esc} for all galaxies
- Normalize to match number of bright LAEs at $z \sim 3 \Rightarrow f_{\text{esc}} \sim 0.02$ in our standard model

Is $f_{\text{esc}} \sim 0.02$ reasonable?



- Atek et al measure Ly α escape fractions for sample of $z \sim 0$ LAEs

- use measured Ly α , H α & H β fluxes - NO assumptions about IMF or SED

- wide range of $f_{\text{esc}} \sim 0.025 - 0.08$

- median f_{esc} only ~ 0.02

Aims of semi-analytical modelling

- Want single model which can reproduce galaxy masses, SFRs, sizes, luminosities, colours, gas contents etc over whole range of redshifts observed
- i.e. not only LF of LAEs at $z \sim 3-6$, but also
 - Galaxy population at $z \sim 0$
 - Other types of high- z galaxies (e.g. LBGs, SMGs)

Baugh et al (2005) model

(Baugh et al 2005, Lacey et al 2008)

- Starting point was Cole et al (2000) model which reproduced wide range of properties for present-day galaxies, using standard IMF
- But this failed to reproduce numbers of main populations of star-forming galaxies at high- z :
 - Sub-mm galaxies (SMGs) at $z \sim 2$
 - Lyman-break galaxies (LBGs) at $z \sim 3-6$

Solution - a variable IMF?

- Normal IMF in star-forming disks

$$dN / d \ln m \propto m^{-x}$$

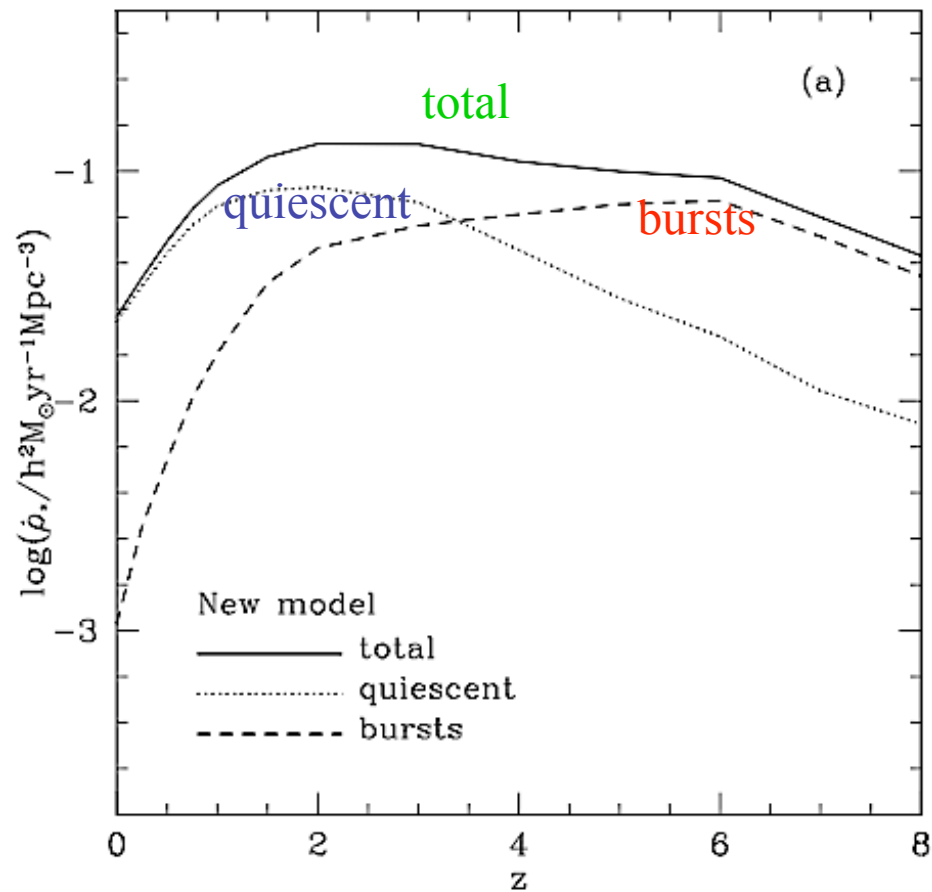
- with $x=0.4$ for $m < M_{\odot}$, $x=1.5$ for $m > M_{\odot}$
(Kennicutt 1983)
- c.f $x=1.35$ for Salpeter

- Top-heavy IMF in bursts triggered by mergers

$$dN / d \ln m \propto m^0$$

- Increases both stellar luminosities & chemical yields by $\sim 5x$

Cosmic star formation history



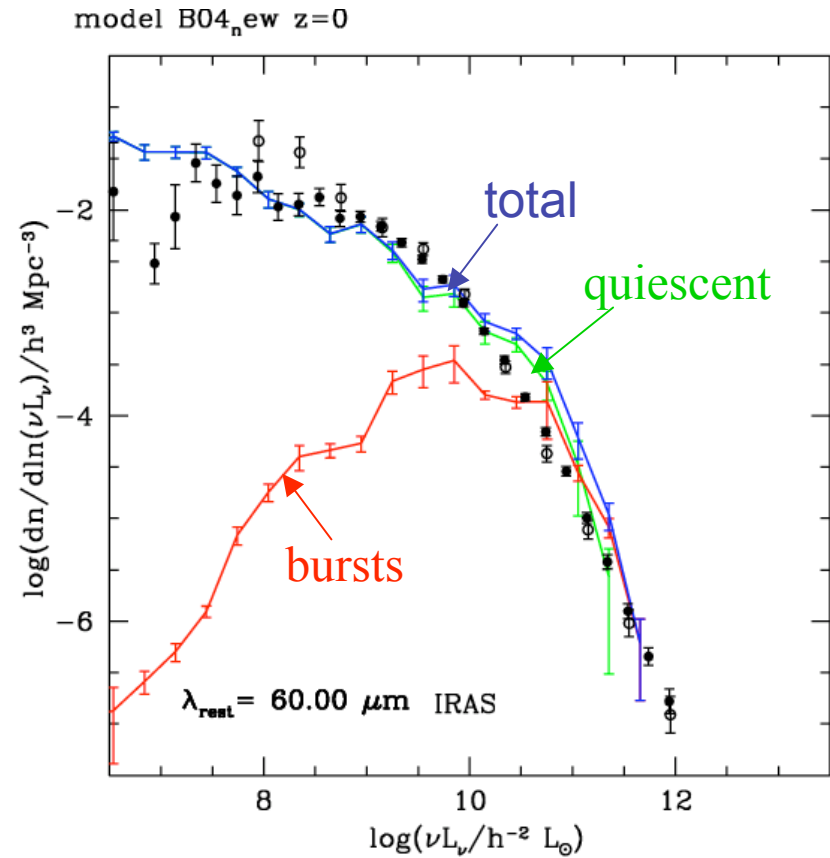
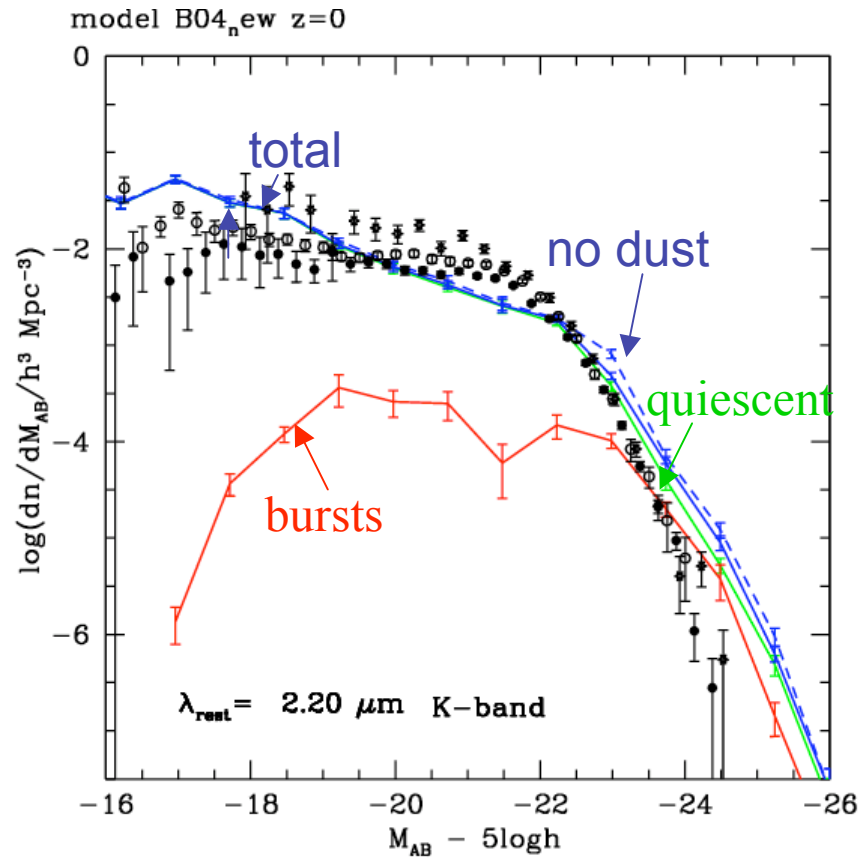
Bursts dominate total SFR at high z

=> Shift from normal to top-heavy IMF

Present-day galaxy luminosity functions in near-IR & far-IR

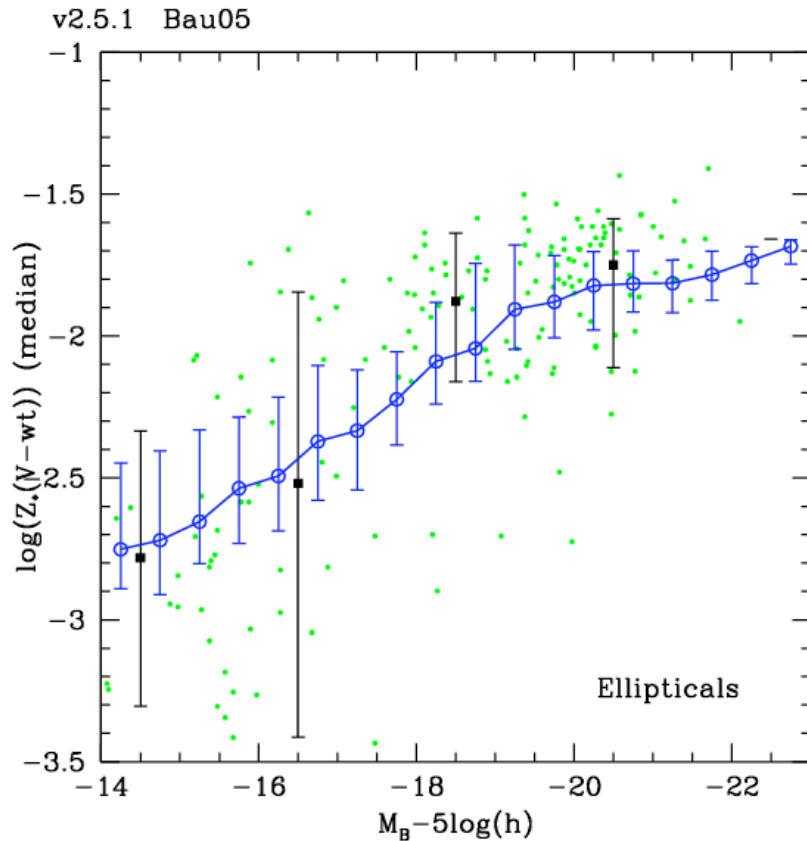
K-band (stars)

60 μm (dust)

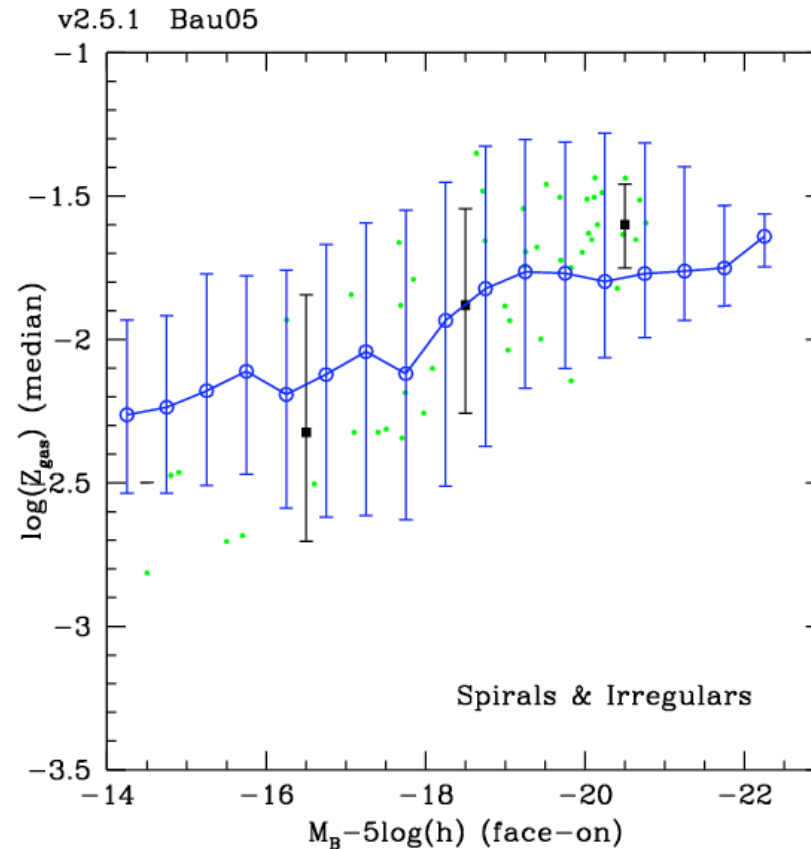


Metallicities of stars & gas

Stars in ellipticals



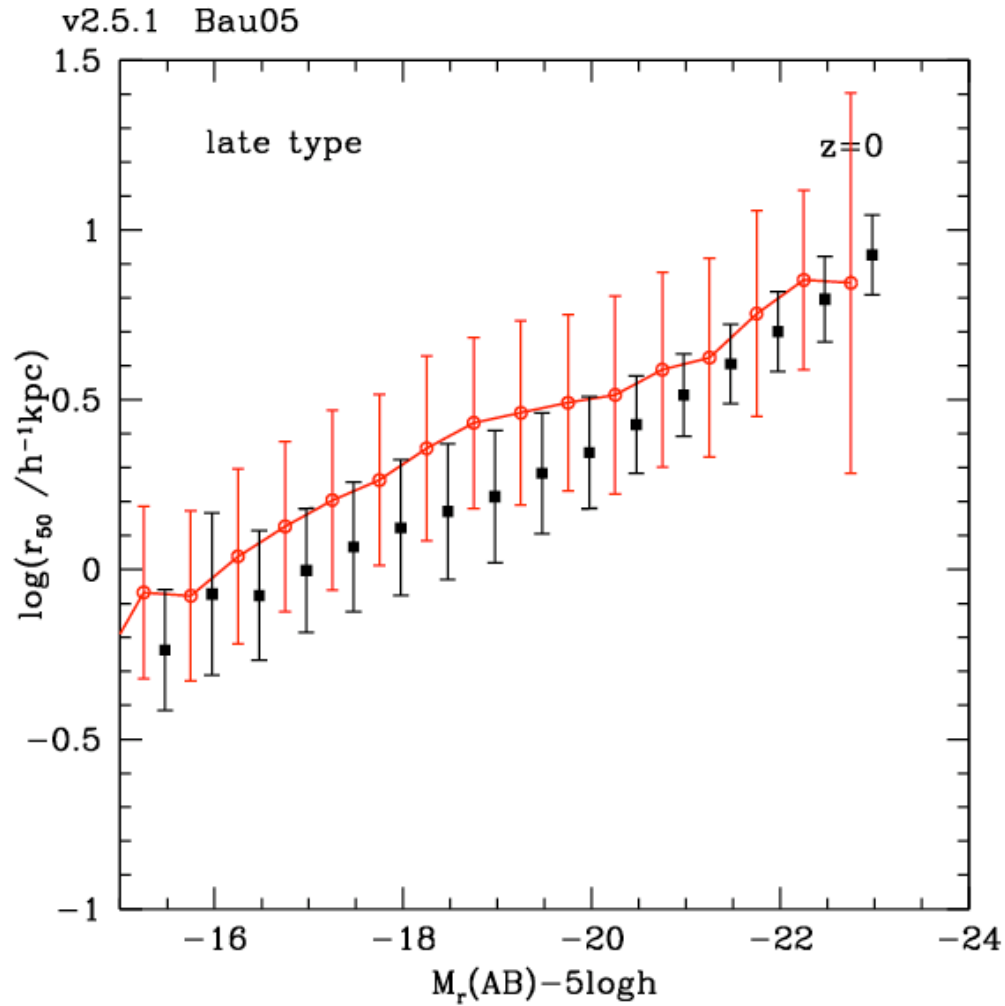
Gas in spirals



Correct metallicities using yields predicted by stellar evolution + IMF - yield NOT adjustable parameter

Galaxy disk sizes

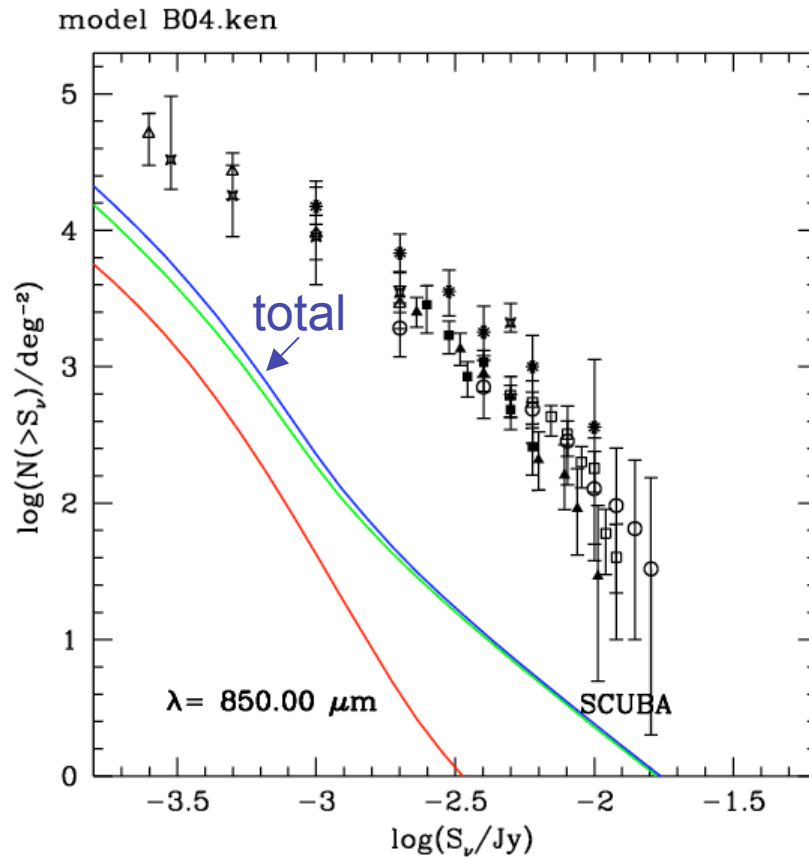
Size vs
luminosity



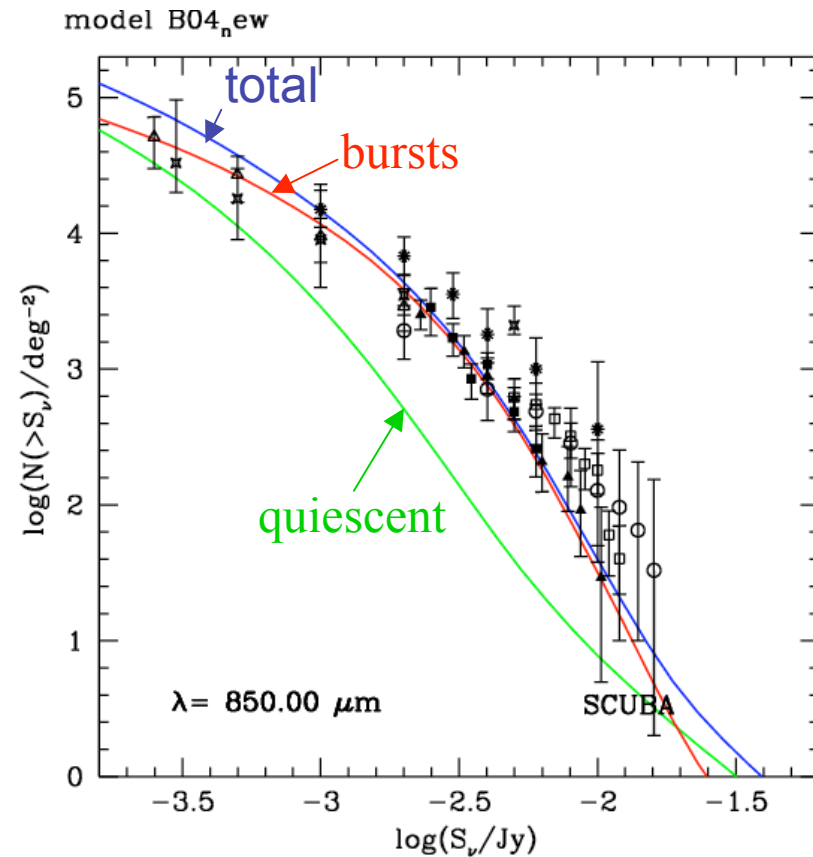
Why a top-heavy IMF?

(a) Sub-mm source counts

normal IMF



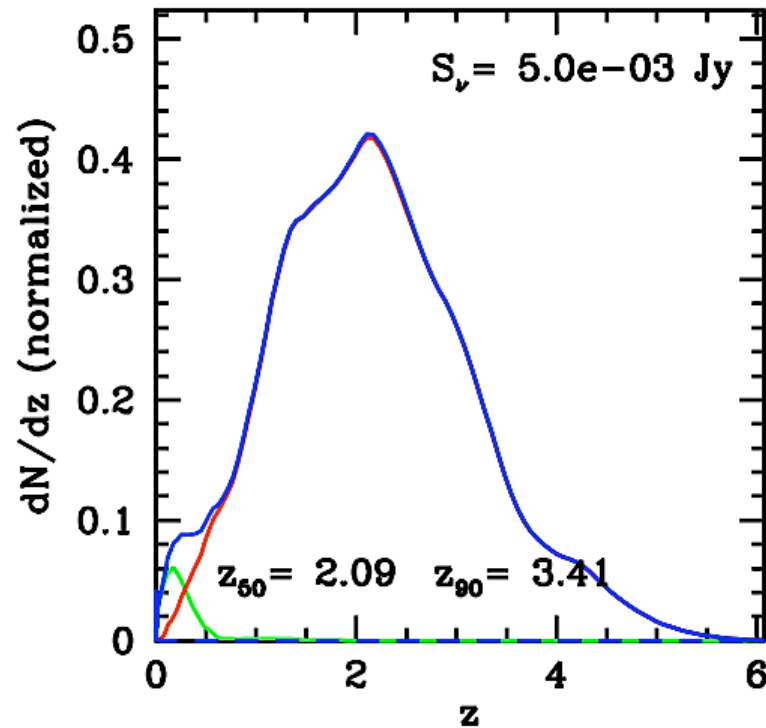
top-heavy IMF



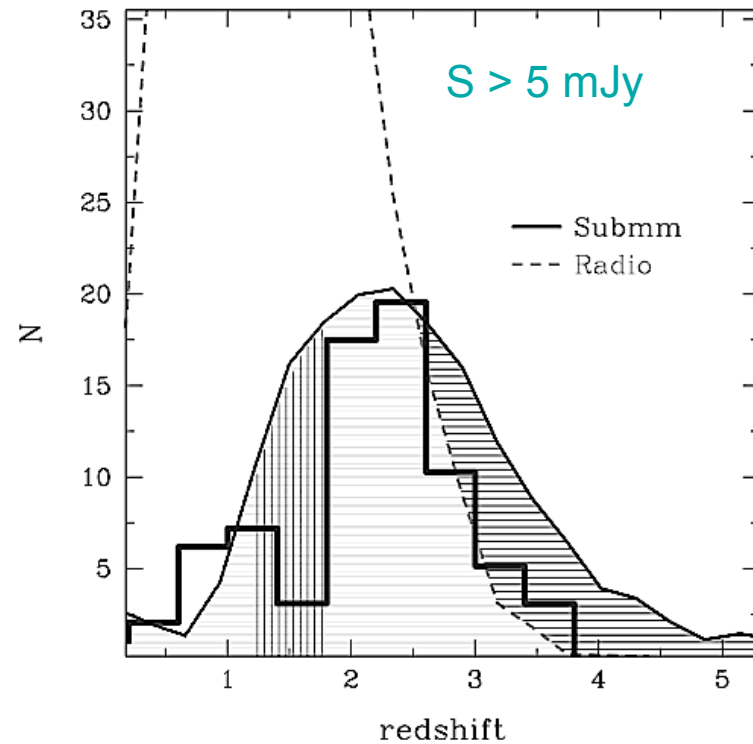
Sub-mm counts too low by factor ~ 50 for normal IMF

Redshifts of sub-mm galaxies

Model (top-heavy IMF)



observed (Chapman et al 2005)



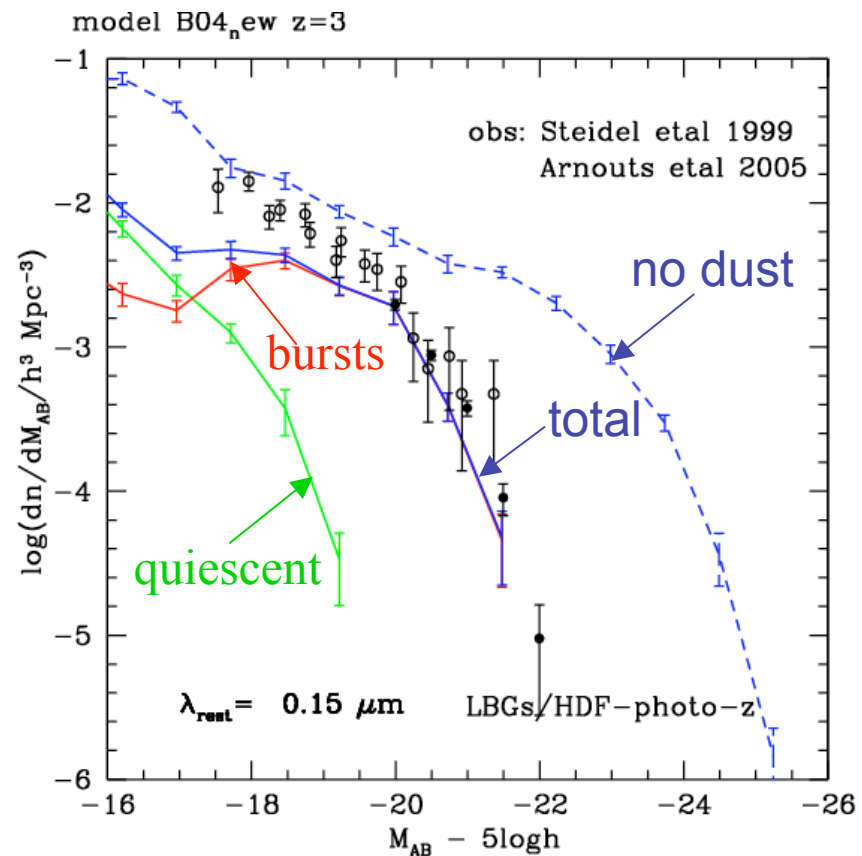
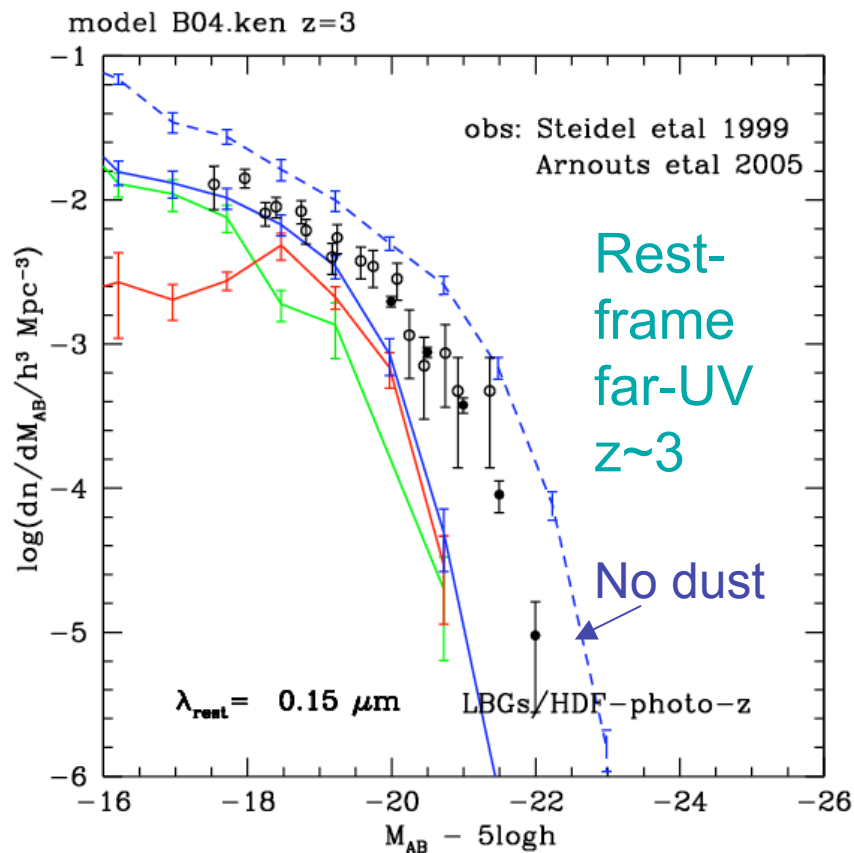
Model with top-heavy IMF predicts median $z \sim 2$ for $S(850) > 5 \text{ mJy}$

Why a top-heavy IMF?

(b) Lyman-break galaxies

normal IMF

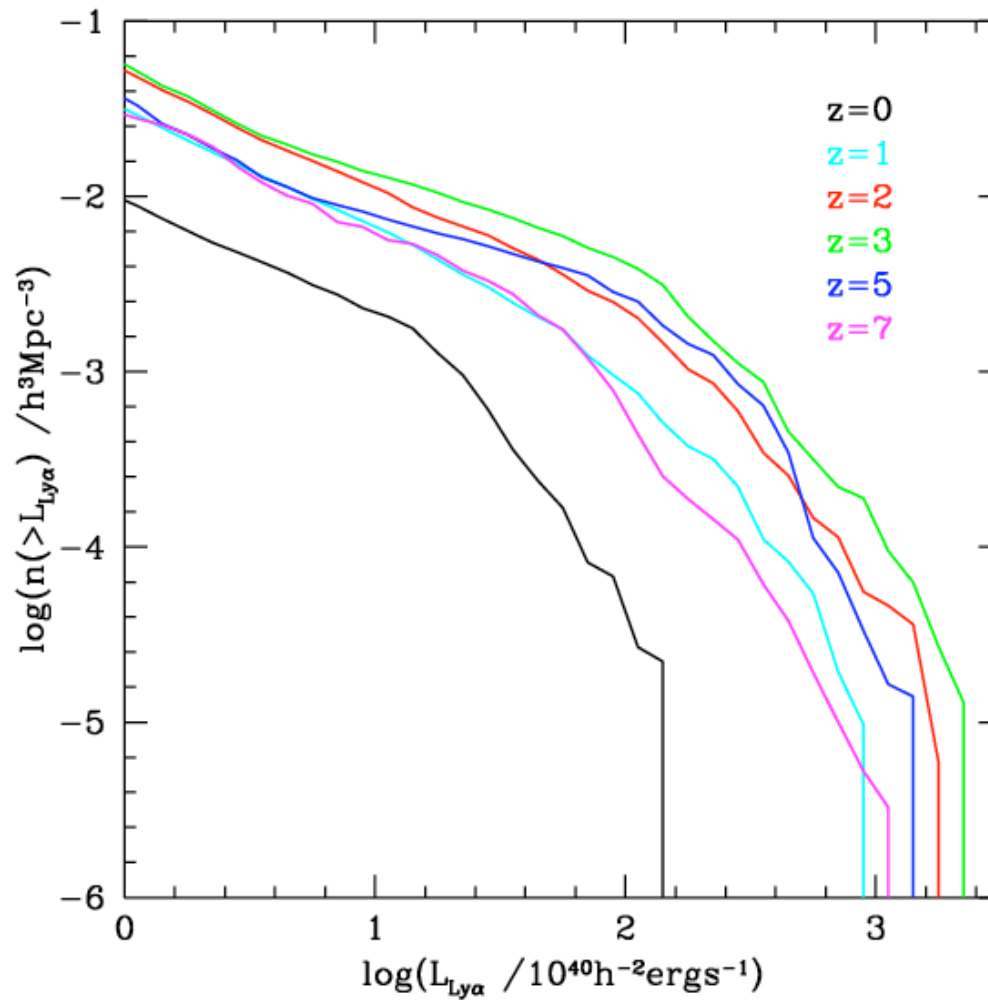
top-heavy IMF



LBGs too faint for normal IMF, once include dust extinction

Model predictions for LAEs

Evolution of LAE luminosity function

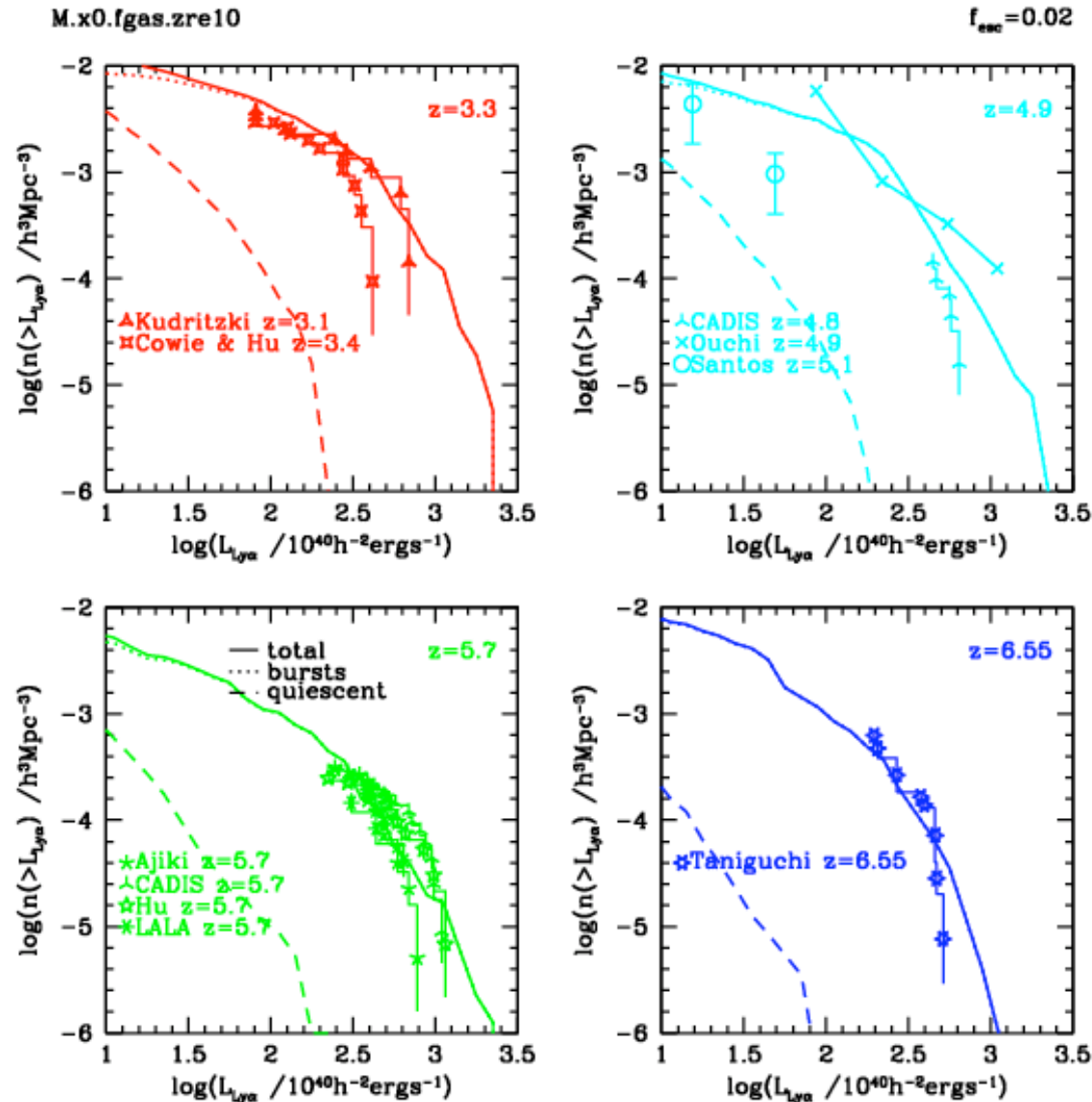


Top-heavy
burst IMF

$f_{\text{esc}} = 0.02$

No of LAEs
peaks around
 $z \sim 3$

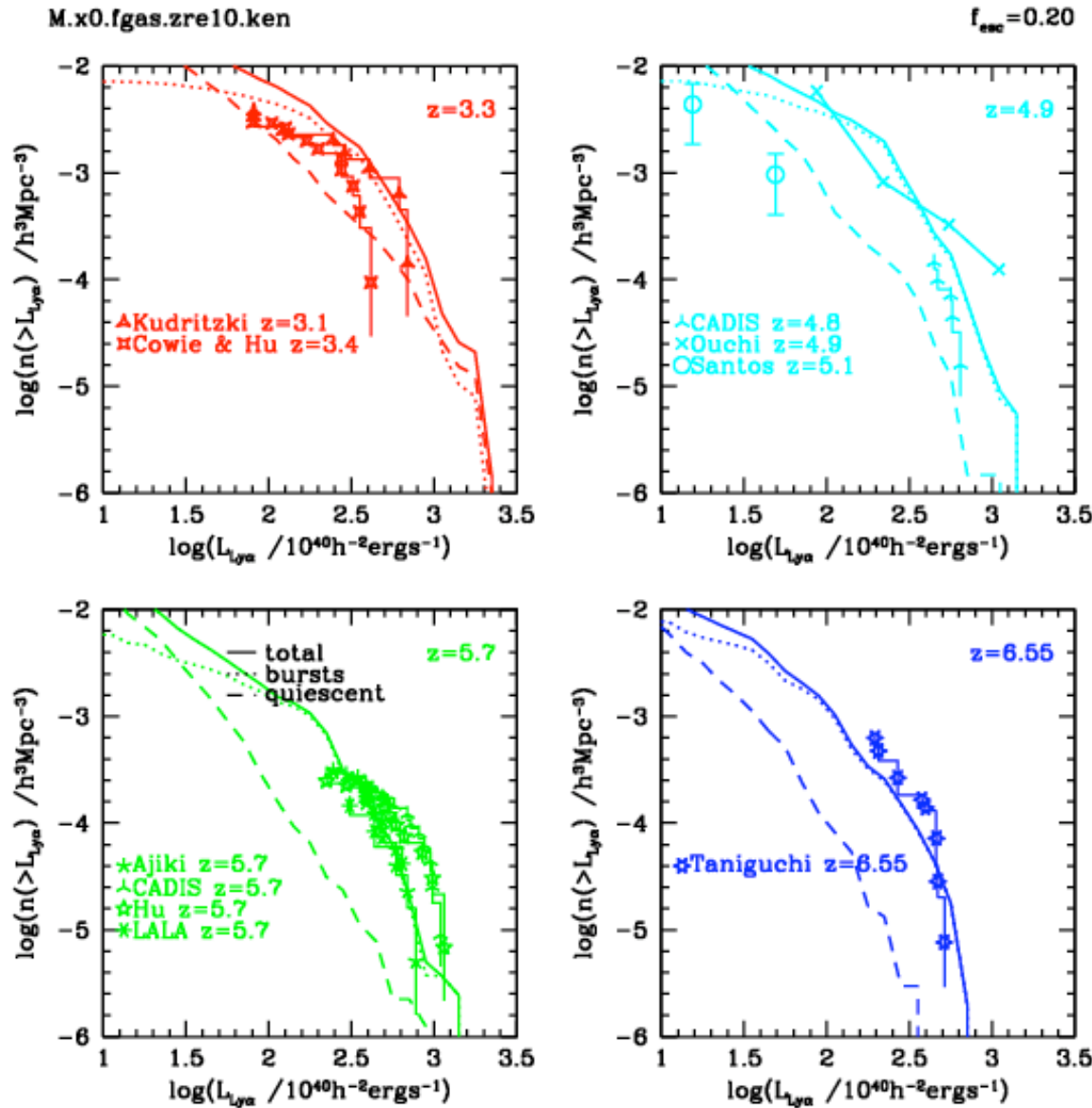
Comparison with observed LF



- Model with top-heavy IMF in bursts & fixed $f_{\text{esc}} = 0.02$ agrees well with obs for $z \sim 3-7$

- Observed LAE popn dominated by merger-driven starbursts

LAE LFs in model with normal IMF

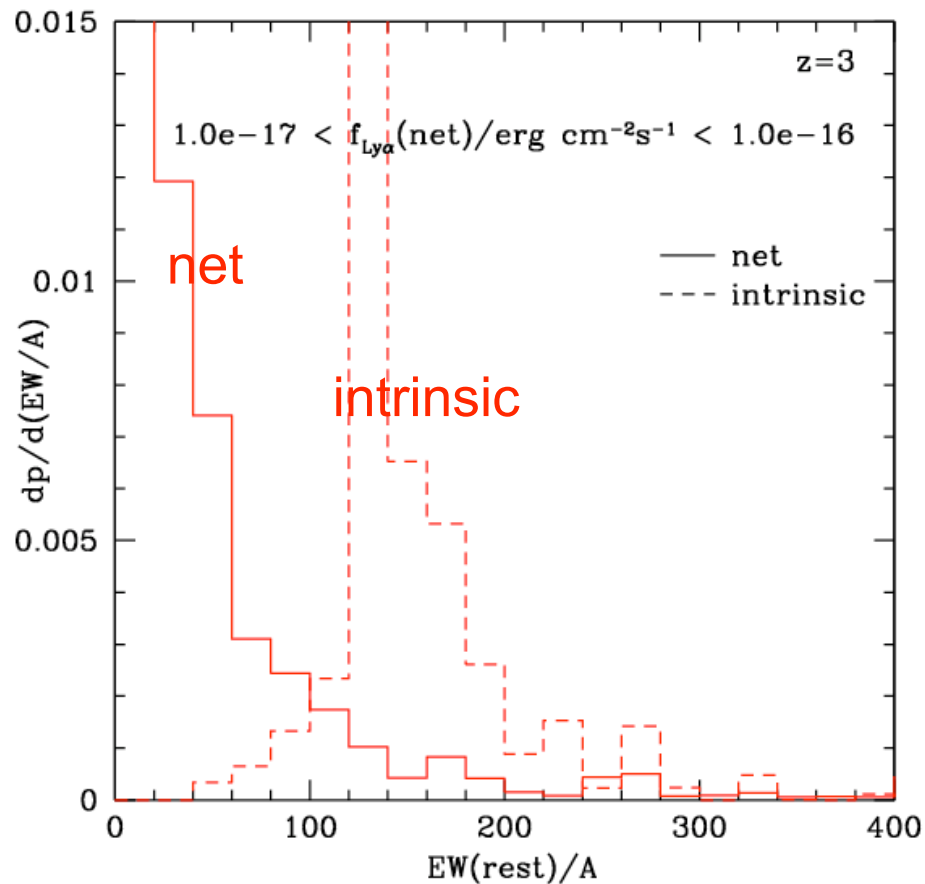


- Alternative model with normal IMF works nearly as well for LAEs but needs $f_{\text{esc}} \sim 0.2$
- however, would not fit obs of LBGs & SMGs

EWs & UV continuum luminosities of LAEs

Ly α equivalent widths

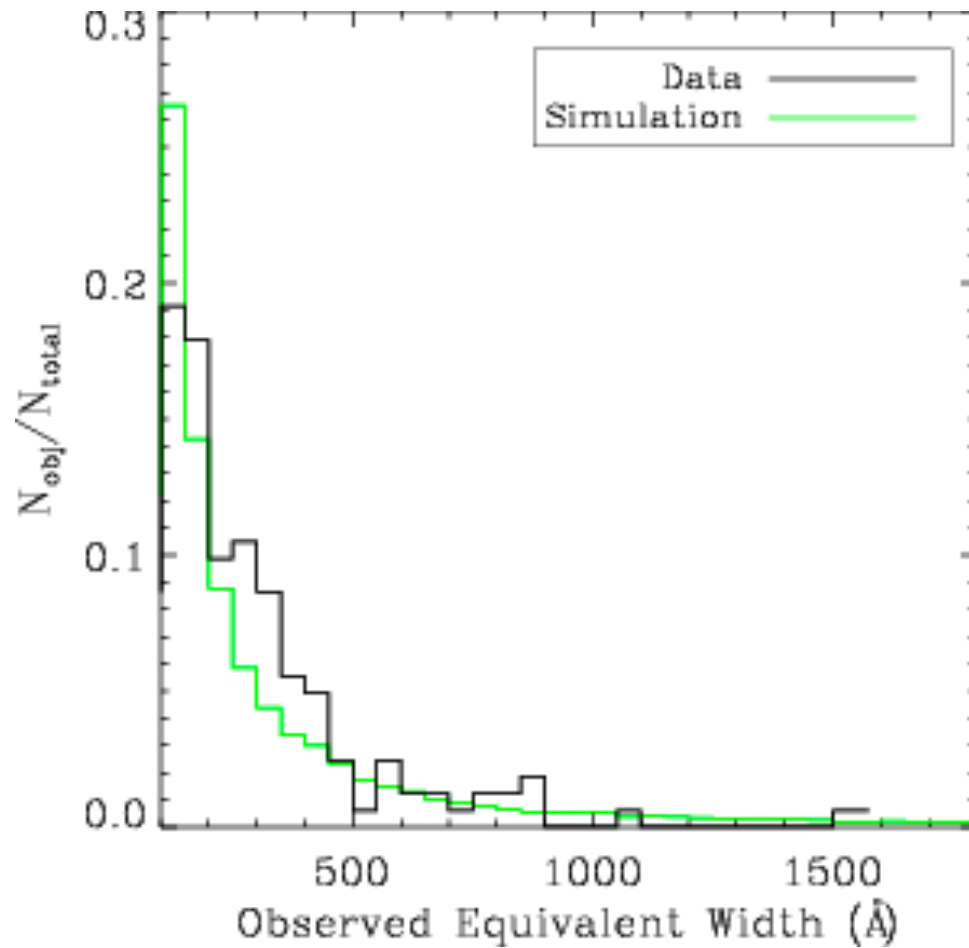
Model prediction



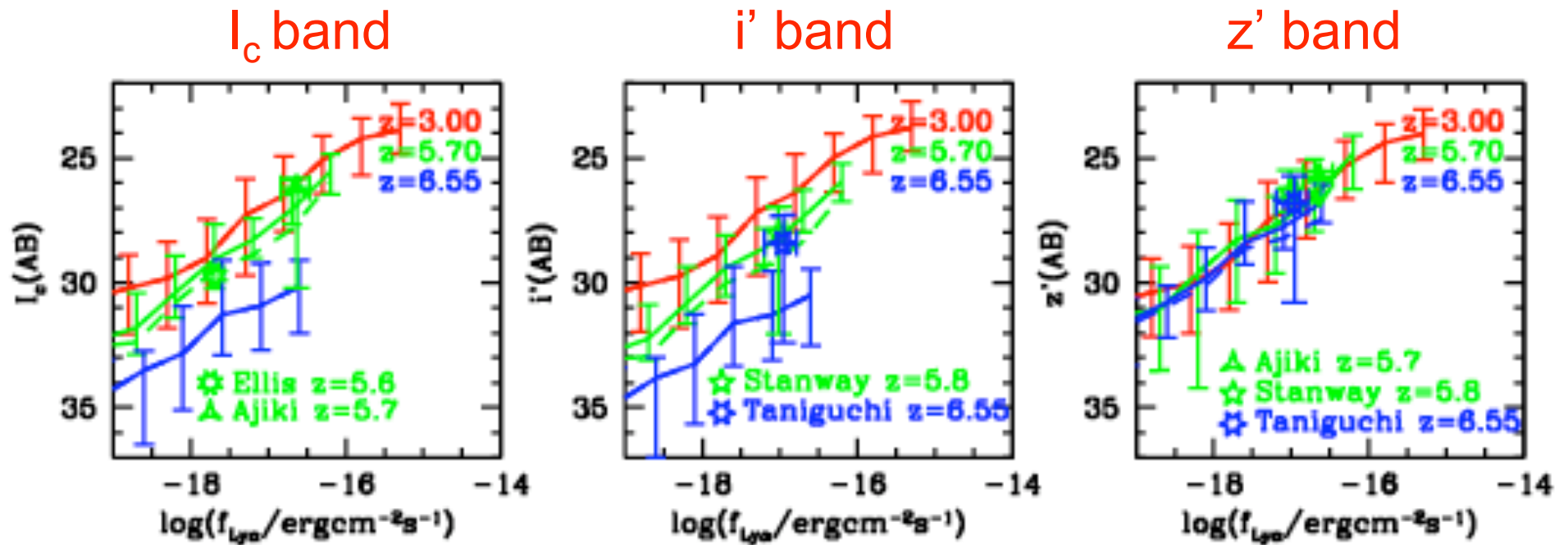
- intrinsic EW: no attenuation of Ly α or dust extinction of stellar continuum
- net EW: attenuation & dust extinction both included

Ly α equivalent widths

Comparison with MUSYC survey at $z \sim 3$



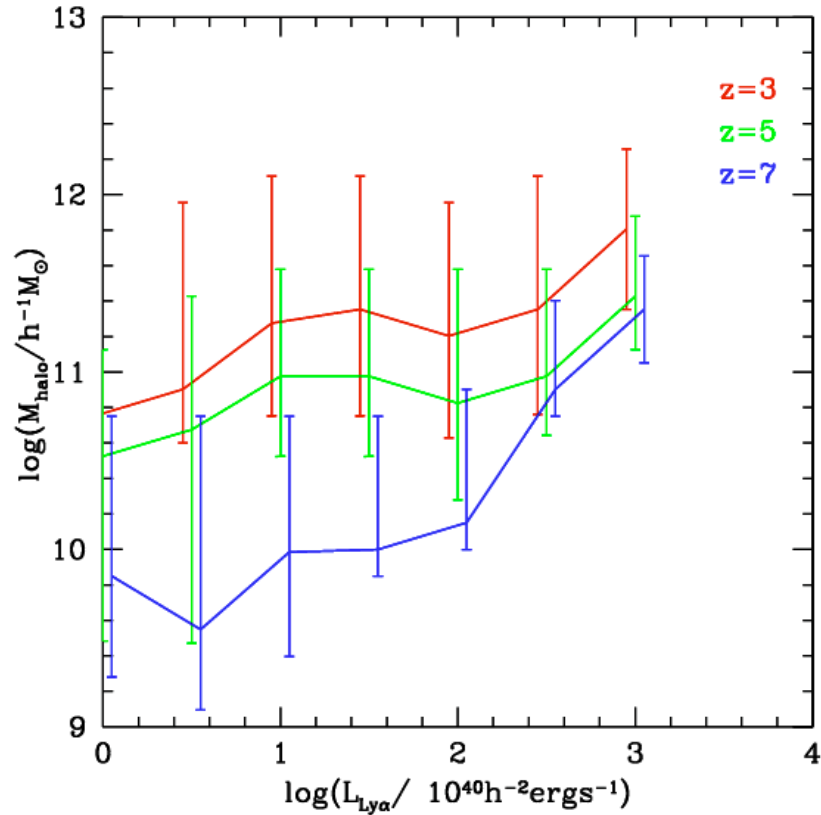
Rest-frame UV continuum magnitudes of LAEs



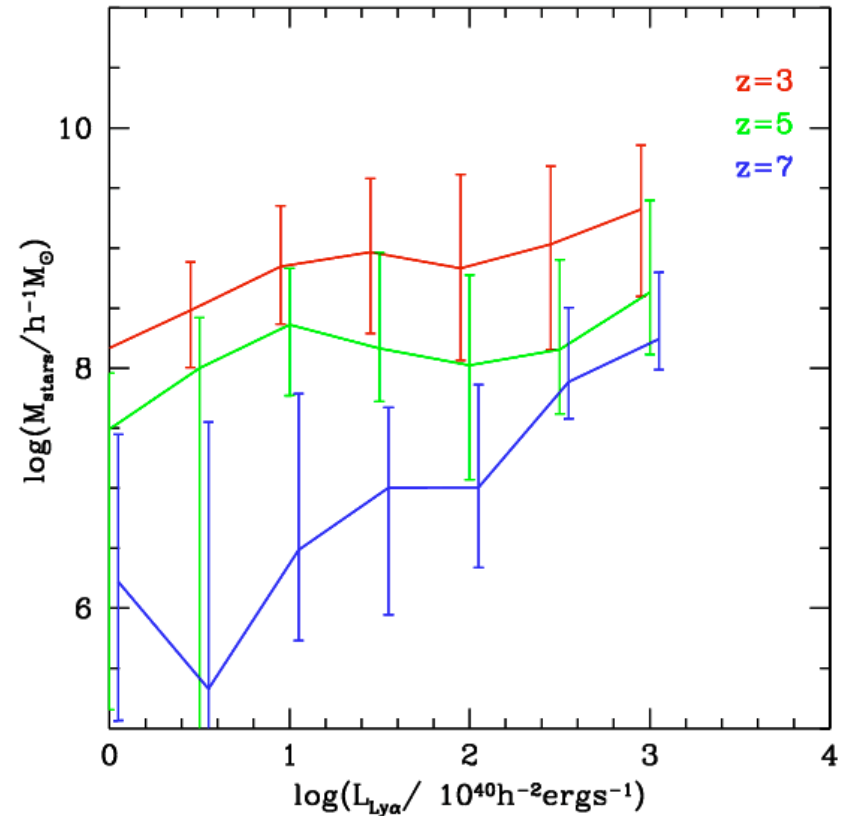
Predicted properties of LAEs

Halo & stellar masses

DM halos

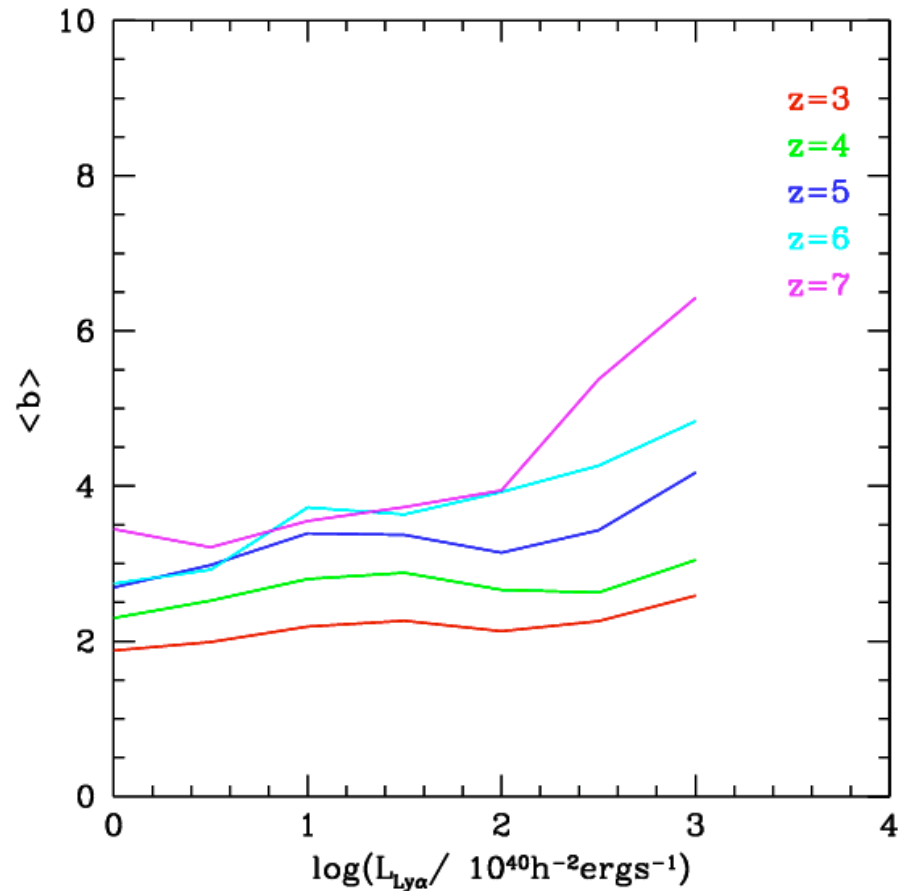


stars



DM & stellar masses decrease at fixed L as z increases

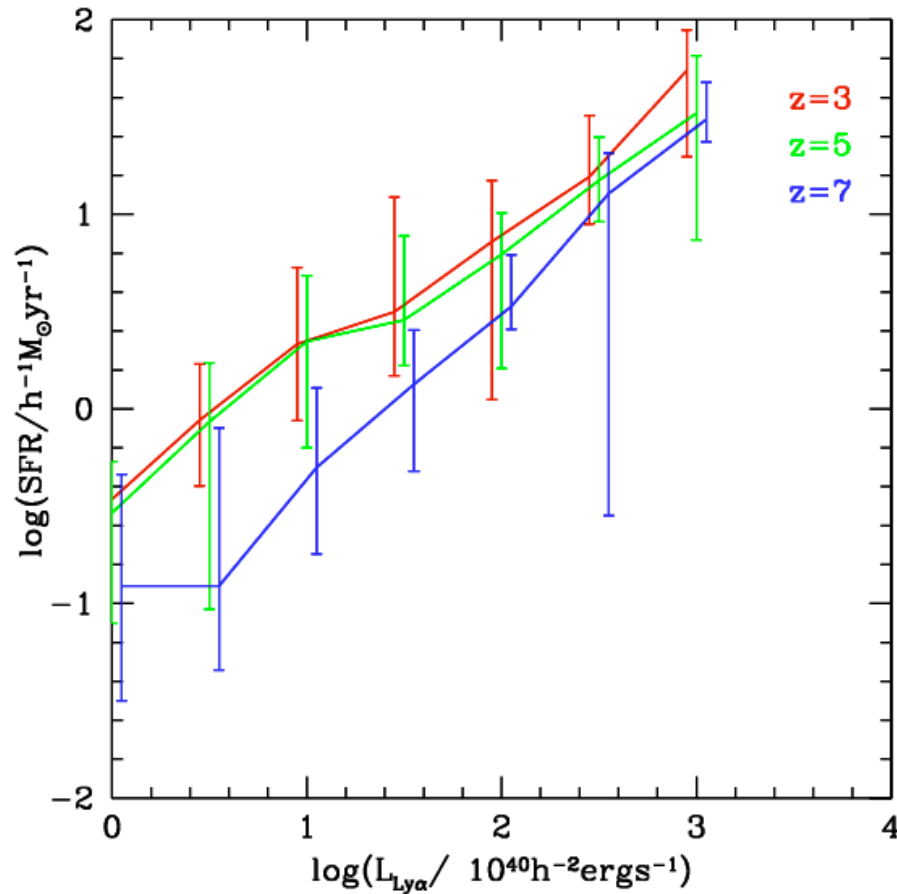
Galaxy clustering bias



$$\xi_{gal} = b^2 \xi_{DM}$$

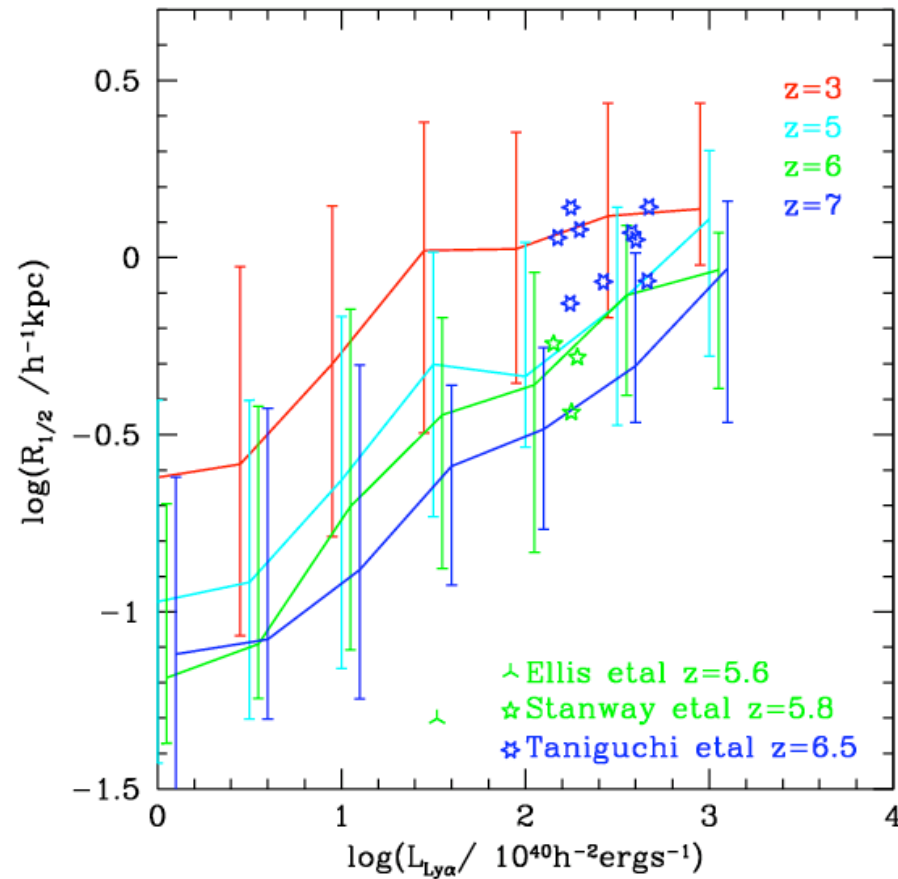
- Large-scale bias can be approximated by analytical linear halo bias
- predict LAEs strongly biased at high z
- bias increases with z

SFRs



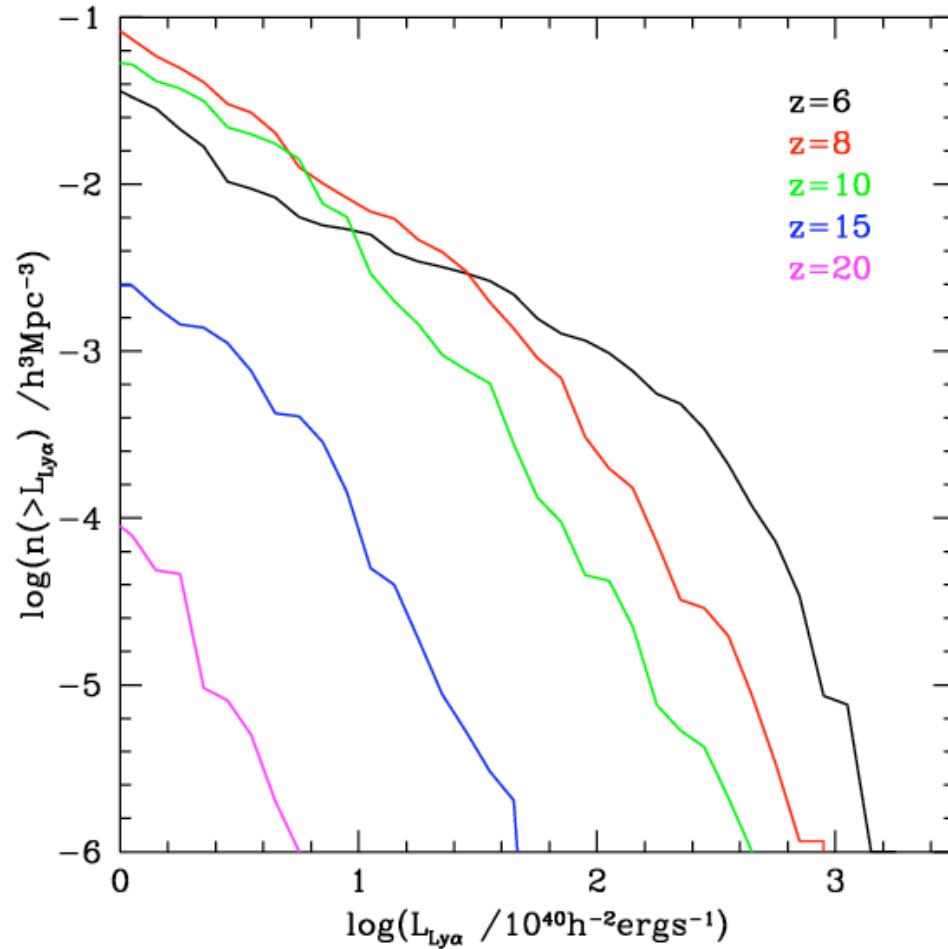
Due to top-heavy IMF in bursts, SFR $\sim 10x$ lower at given $L(\text{Ly}\alpha)$ than for normal IMF (for same f_{esc})

Stellar radii



- predict stellar radii compact < 1 kpc - agrees with obs
- sizes decrease as z increases
- obs indicate that Ly α radii may be larger than stellar radii

Evolution of LF to high z



Very rapid
decline in
LAE LF at
 $z > 10$ - due to
buildup of
halo mass fn

Conclusions

- Model based on CDM with top-heavy IMF in bursts which matches local universe & LBGs & SMGs at high- z also reproduces LFs of LAEs at $z \sim 3-7$, with assumption of constant f_{esc}
- also agrees with obs EW distribn
- LAE clustering should be highly biased