AST 542 Observational Seminar

Star formation at low-redshift

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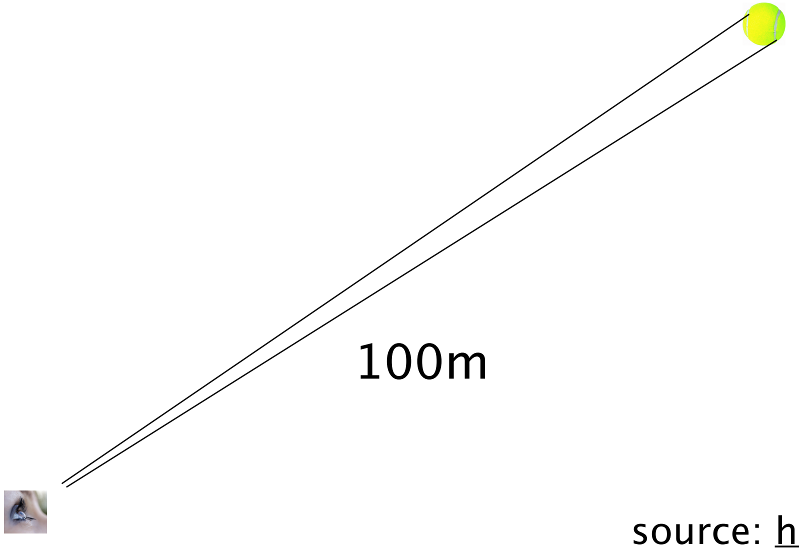
Outline

- Clues from Hubble Deep Field
  - Dropout technique
  - Early results
- Instantaneous vs derived Stellar-Mass Histories
  - Evidence for discrepancies
  - Implications: evolving IMF?
  - Reconciling the results
- Concluding remarks

Clues from Hubble Deep field

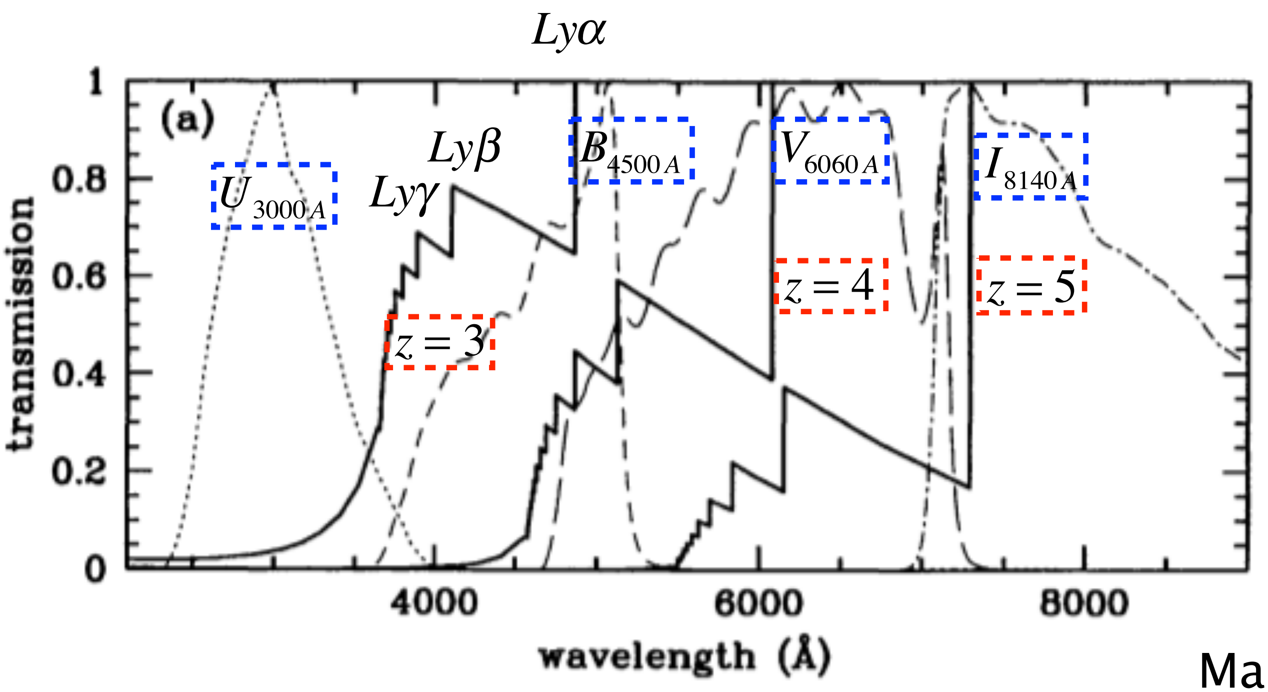
- 342 exposures over 10 consecutive days on December 1995
- Covered area: 2.5 arcmin^2
- ~3000 galaxies



source: http://en.wikipedia.org/wiki/Hubble_Deep_Field

Dropout: identifying SF galaxies

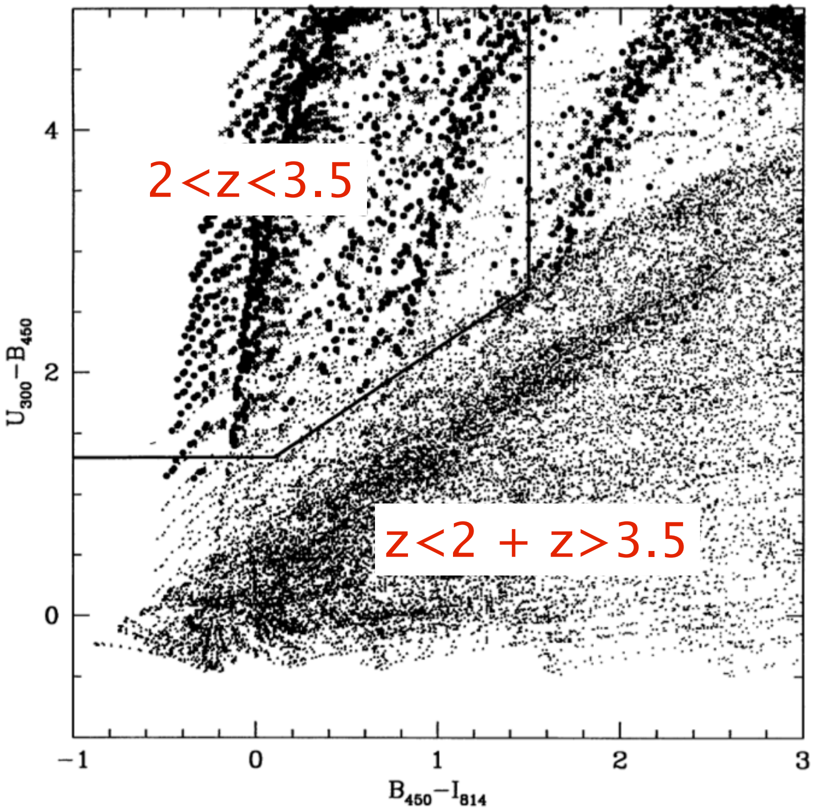
- Dropout (or U-band Dropout or Lyman Break) technique only sensitive to star forming galaxies (UV-emitters) (Ben's talk)



Madau et al. 1996

Dropout: identifying SF galaxies

- Model H I opacity + galaxy synthetic spectra
- Define color regions (e.g. U–B vs B–I)
- Apply to data and pick SF galaxies in redshift bin



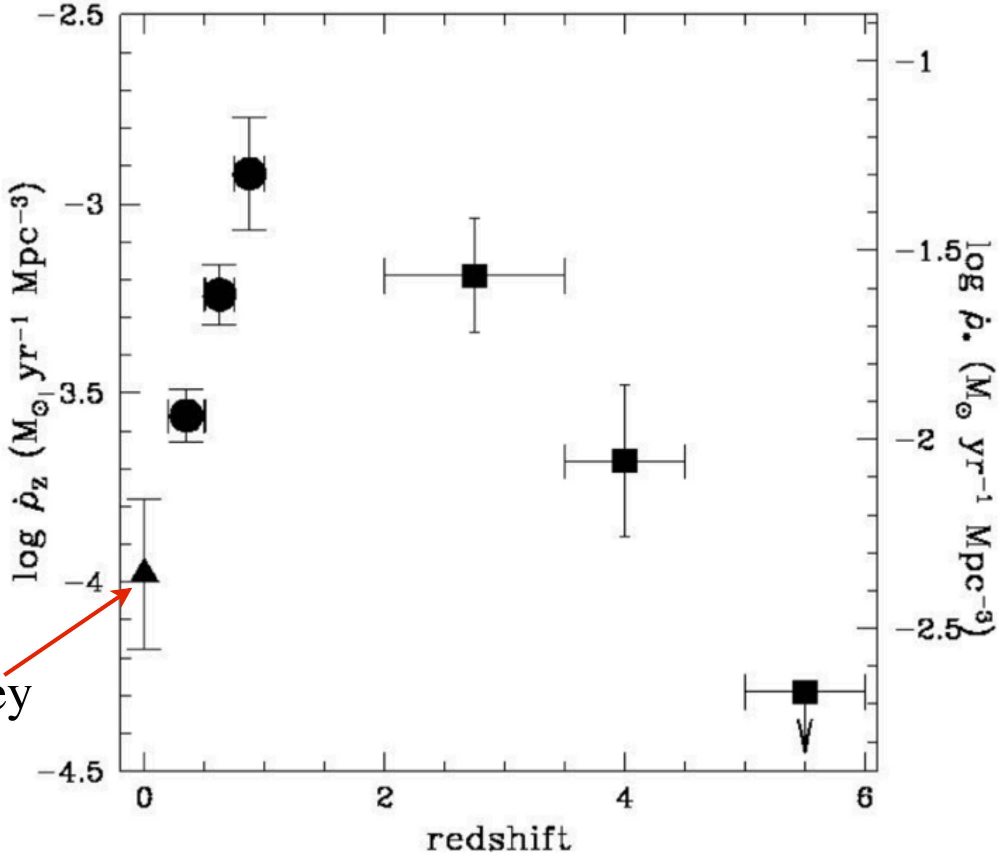
Madau et al. 1996

Results: Star Formation Rate

- Star formation rate density peaks at z~1 (“Madau” plot)

Metal production:
-type II SN
-winds from massive star

$$\dot{\rho}_Z = \dot{\rho}_* \int (yield) m\phi(m)\, dm$$



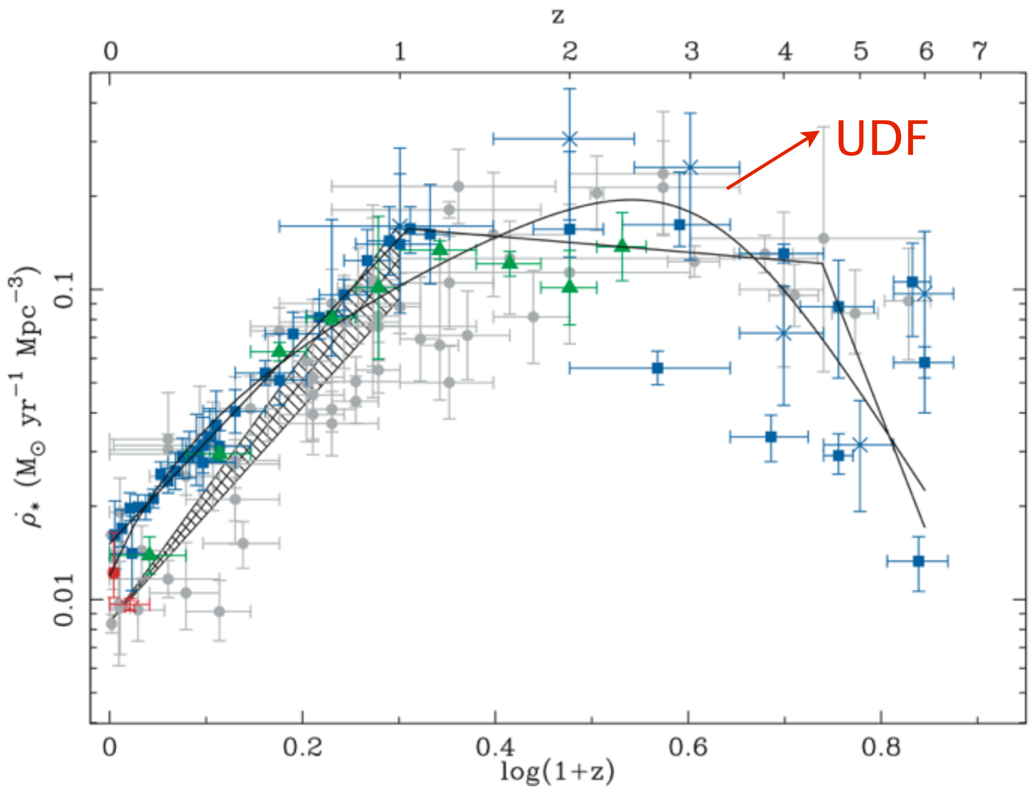
$H\alpha$ local survey

(Gallego et al. 1996)

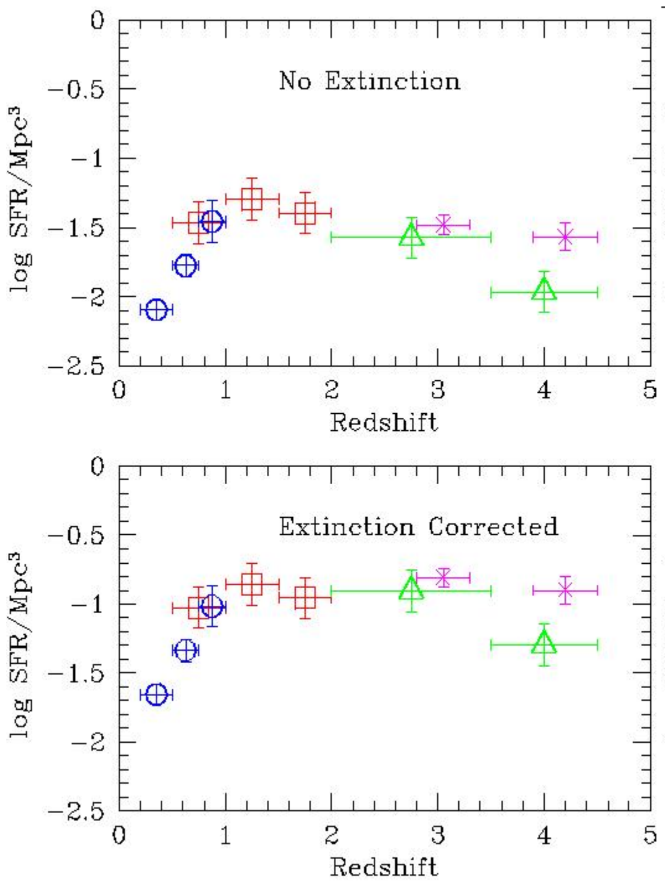
Madau 1998

Results: Star Formation Rate

- More measurements after Hubble Deep Field (e.g. Hubble Ultra Deep Field) yield similar results.



Hopkins and Beacom 2006



Steidel 1999

Instantaneous vs derived stellar mass histories

- One can reconstruct the Stellar-mass density history from the SFH as (or vice versa):

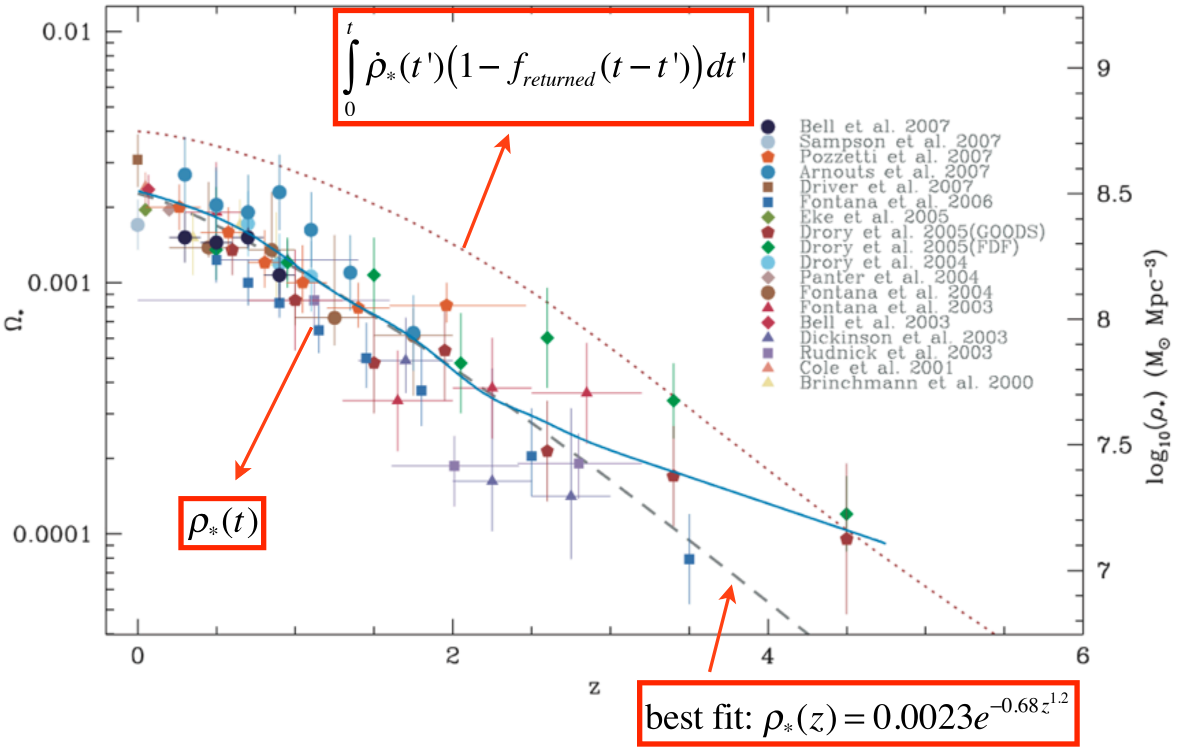
$$\rho_*(t) = \int_0^t \dot{\rho}_*(t')\left(1 - f_{returned}(t-t')\right)dt'$$

$f_{returned}(t-t')$: fraction of stellar mass created at t' that has been returned to the ISM by t.

... and they better match!

Evidence for discrepancy

- Compilation of stellar mass-density histories
  - common IMF



$$\int_0^t \dot{\rho}_*(t')\left(1-f_{returned}(t-t')\right)dt'$$

$\rho_*(t)$

best fit: $\rho_*(z)=0.0023e^{-0.68z^{1.2}}$

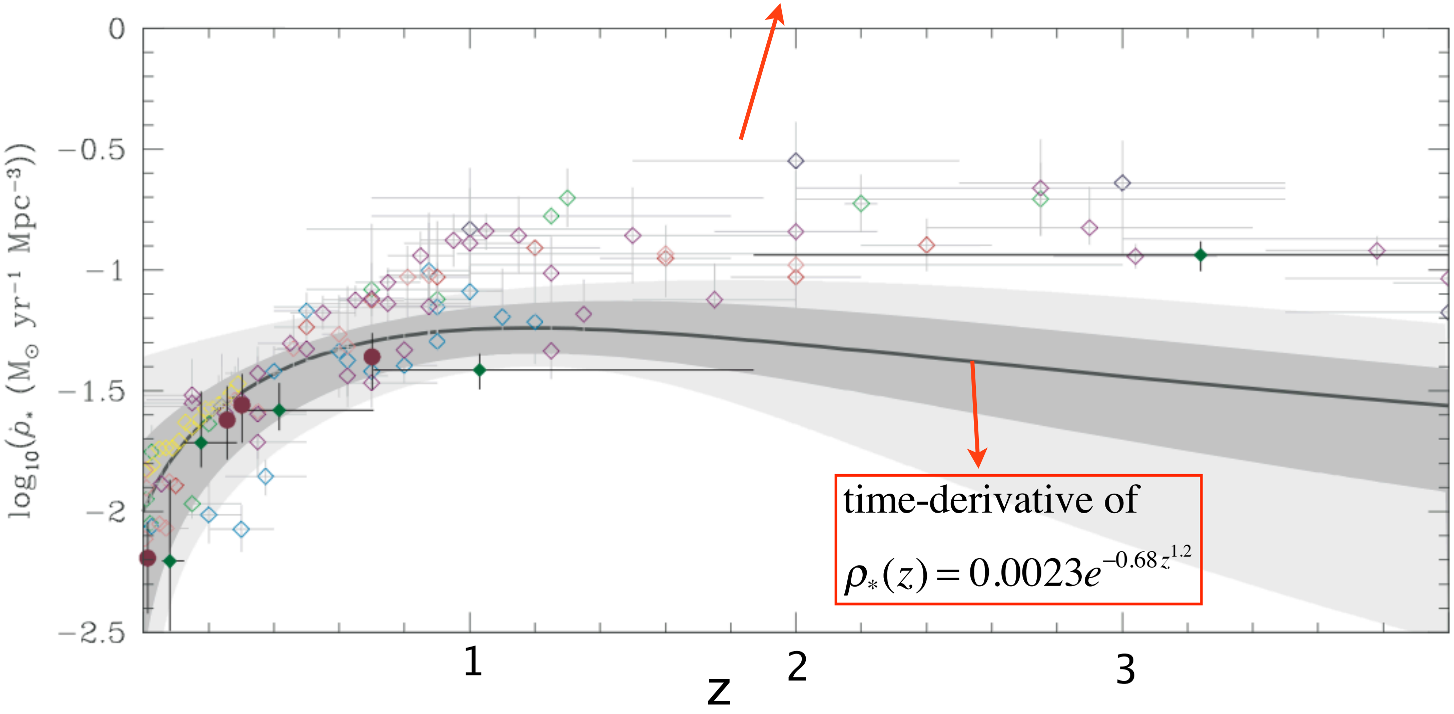
Wilkins et al. 2008

...mass in stars seen < mass in stars produced !!

Evidence for discrepancy

- Star Formation Rate Density

Instantaneous indicators



time-derivative of

$\rho_*(z) = 0.0023e^{-0.68z^{1.2}}$

- discrepancy arises at z>2 and peaks at z~3
- no problem at z<0.7

Wilkins et al. 2008

Discrepancy: evolving IMF?

- SFR traces high-mass SF
- stellar mass dominated by lower mass stars

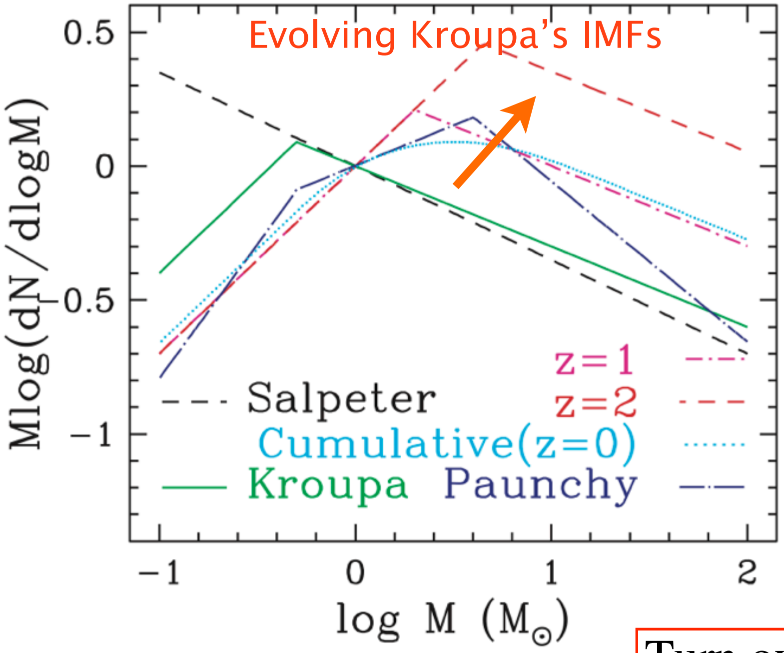
- What is the effect of having a top-heavy IMF?

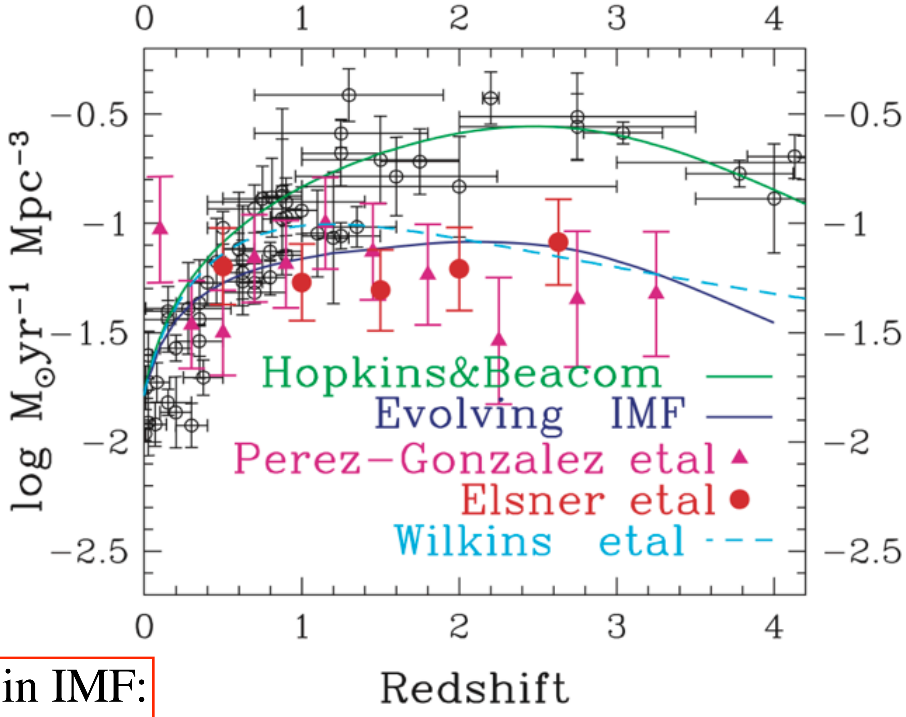
  - i) increase UV flux per unit mass formed:
    - SFR inferred by standard IMF would be overestimated
  - ii) increase stellar mass loss:
    - lowers the amount of stellar mass in galaxies
  - iii) larger gas reservoir
    - form mores stars later, delaying SF

- **They all go in the right direction!**

Dave 2008

Discrepancy: evolving IMF?





Turn over mass in IMF:

$$\hat{M} = 0.5(1+z)^2 M_\odot$$

...it bridges the gap, but it can be regarded as the last resort...

Dave 2008

Reconciling the results

- Possible solution to the discrepancy ("executive summary"):
  - "Reddy & Steidel 2009 studies the faint-end slope of the UV Luminosity Function (LF) and found that there is more mass in this part of the LF than previously thought."
  - Spectroscopic surveys limited to UV-bright galaxies: lack of $z>2$ UV-faint galaxies
    - Authors revisit systematics (incompleteness):
      - luminosity-dependent dust corrections
      - integrated stellar mass of low-mass galaxies

Reconciling the results:method

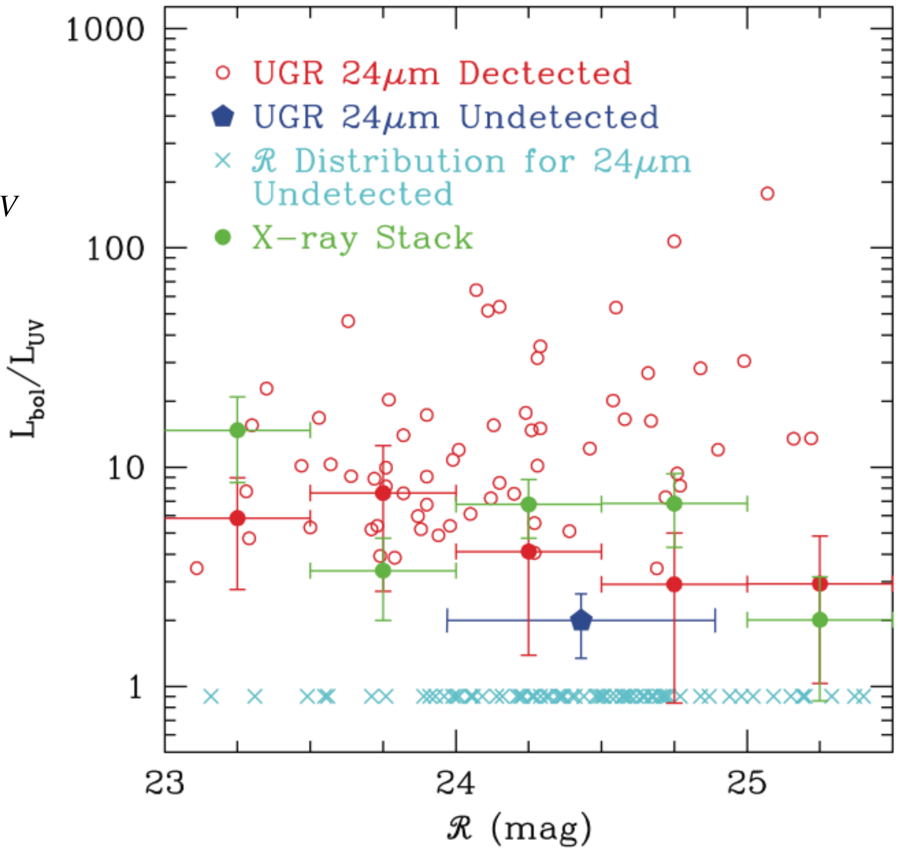
- Sample:
  - color selection of 31000 LBGs in $1.9<z<3.4$
  - 2023 spectroscopic SF galaxies in $1.9<z\_spec<3.4$-> estimate the contamination of QSOs and AGNs in color sample
- Incompleteness corrections
  - Monte Carlo simulations varying:
    - UGR colors and sizes
    - reddening: $0<E(B-V)<0.6$
    - Luminosities
    - Redshift
  - Then, Maximize Likelihood(E(B–V),L,z)

Reconciling the results: extinction

- Key Ingredients I: “E(B-V) varies with luminosity”
  - ...fainter/smaller galaxies are younger-> young stellar population->less dust...

Attenuation factors: Spitzer data

$$L_{bol} = L_{IR} + L_{UV}$$



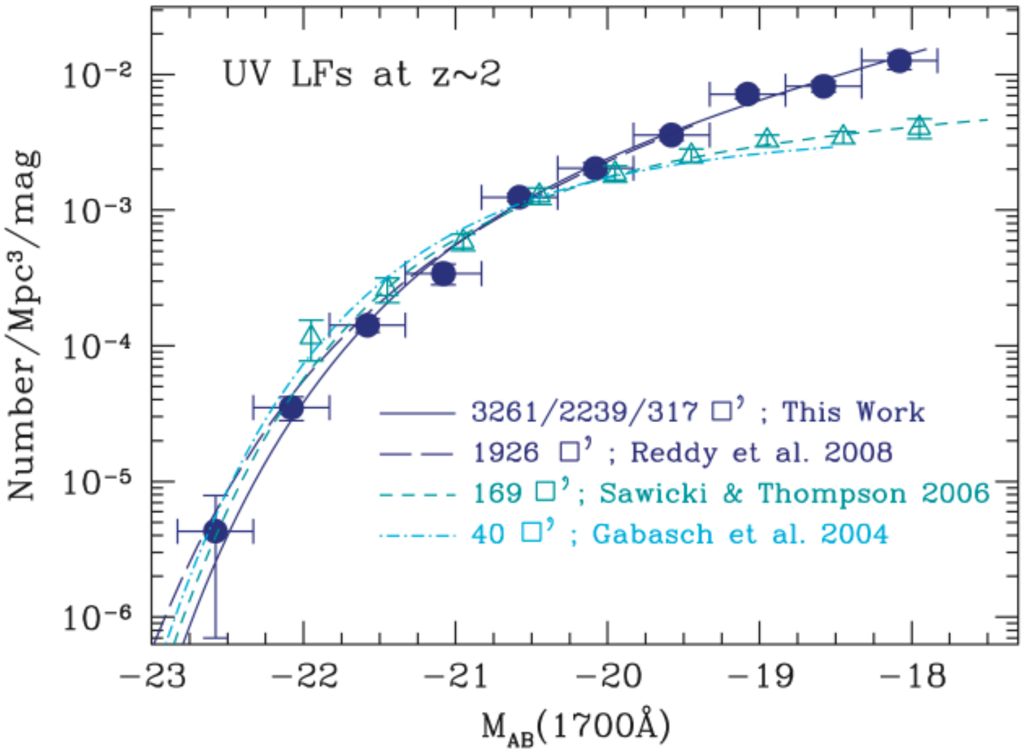
1.5<z<2.6 galaxies

Reddy et al 2008

Reconciling the results:LF

- Key Ingredient II:
  - “Faint-end of the LF: larger incompleteness corrections”

Results vs previous LFs



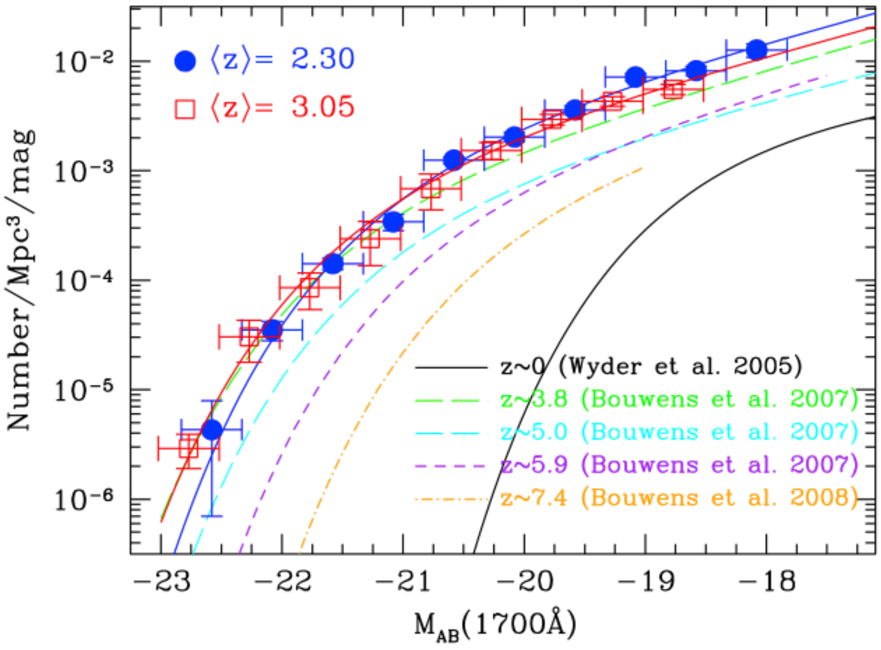
- Good agreement for bright-end

- Steeper faint-end

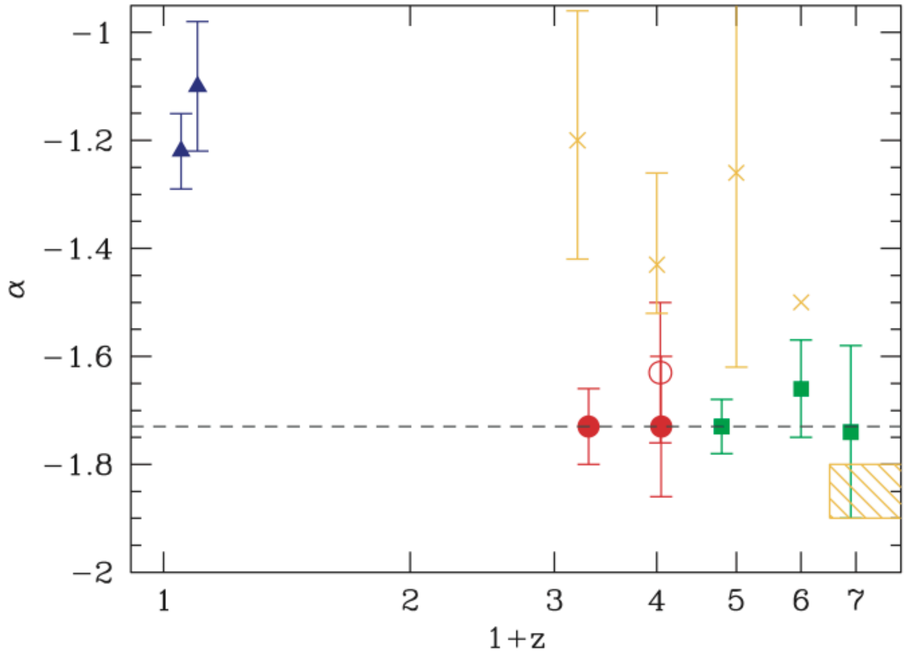
Reconciling the results: LF

- Evolution of LF in alpha as a function of redshift

LF as a function of z



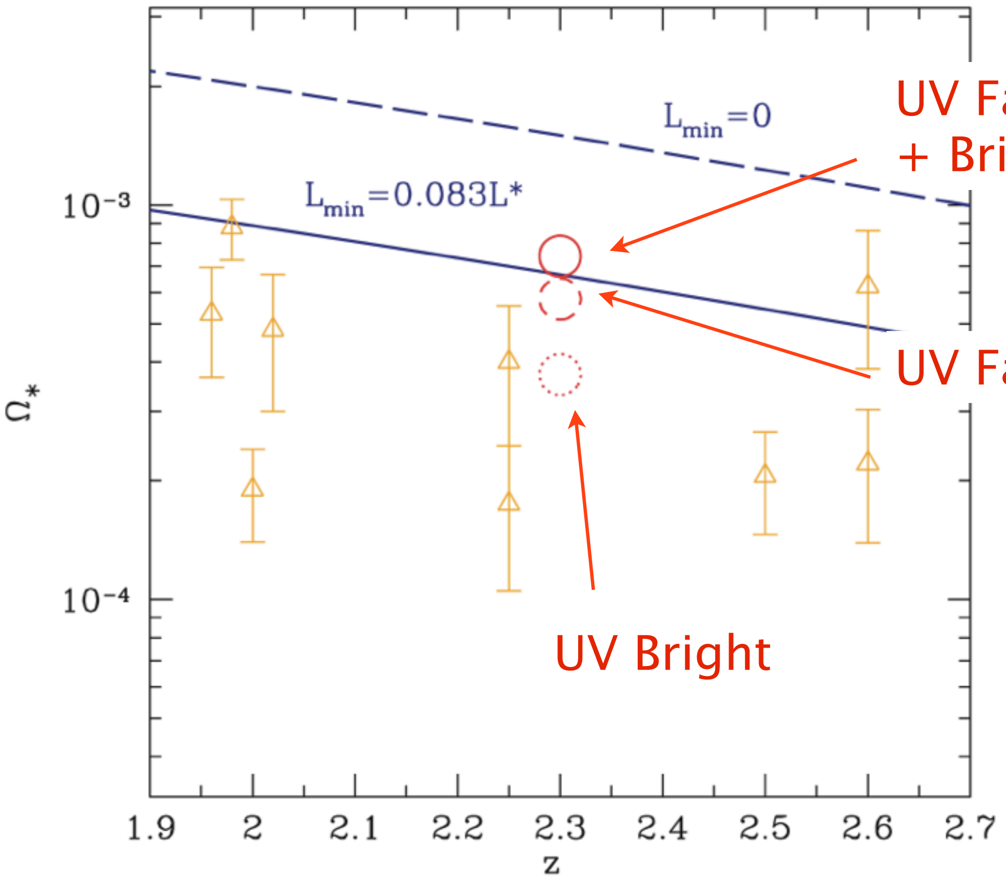
Faint-end slope as a function of z



$$\boxed{\phi(M) \propto 10^{0.4(1+\alpha)\left(M-M^*\right)}}$$

Reconciling the results

- Integrated stellar mass density matches what is currently seen.



UV Faint + Bright

UV Faint

UV Bright

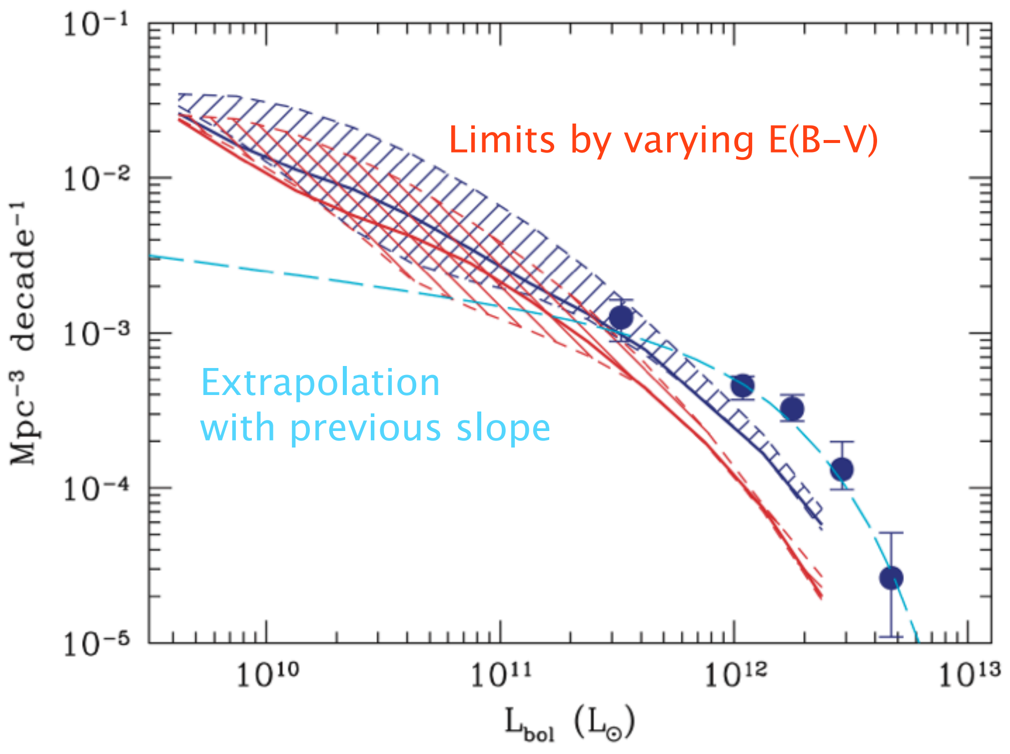
- Integrated SFR and mass density down to same L_min: ~ half of luminosity below L_min

- SFR includes time varying dust reddening

Apparently, no need for a time-varying IMF...

Reconciling the results: LF in faint galaxies

- Faint galaxies significantly contribute to LF and SF (z>2)
  - seems to hold even with ULIRGS
  - ~93% unobscured UV luminosity from sub-L* galaxies



Concluding remarks

- U-dropout efficient at selecting SF galaxies at z~2-3
  - Early studies show that SFR peaks at z~1

- Apparent mismatch between stellar mass density and derived estimate from SFR at z~2-3
  - Might be interpreted as time evolving IMF
  - Better modeling of uncertainties:
    - Faint-end of the LF + luminosity dependent reddening can result in agreement
  - Much of the SF in faint galaxies at z>2

References

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