Evolution in the Star Formation Rate Efficiency of Damped Lyman-alpha Systems

Marc Rafelski

NASA Postdoctoral Program Fellow
Goddard Space Flight Center

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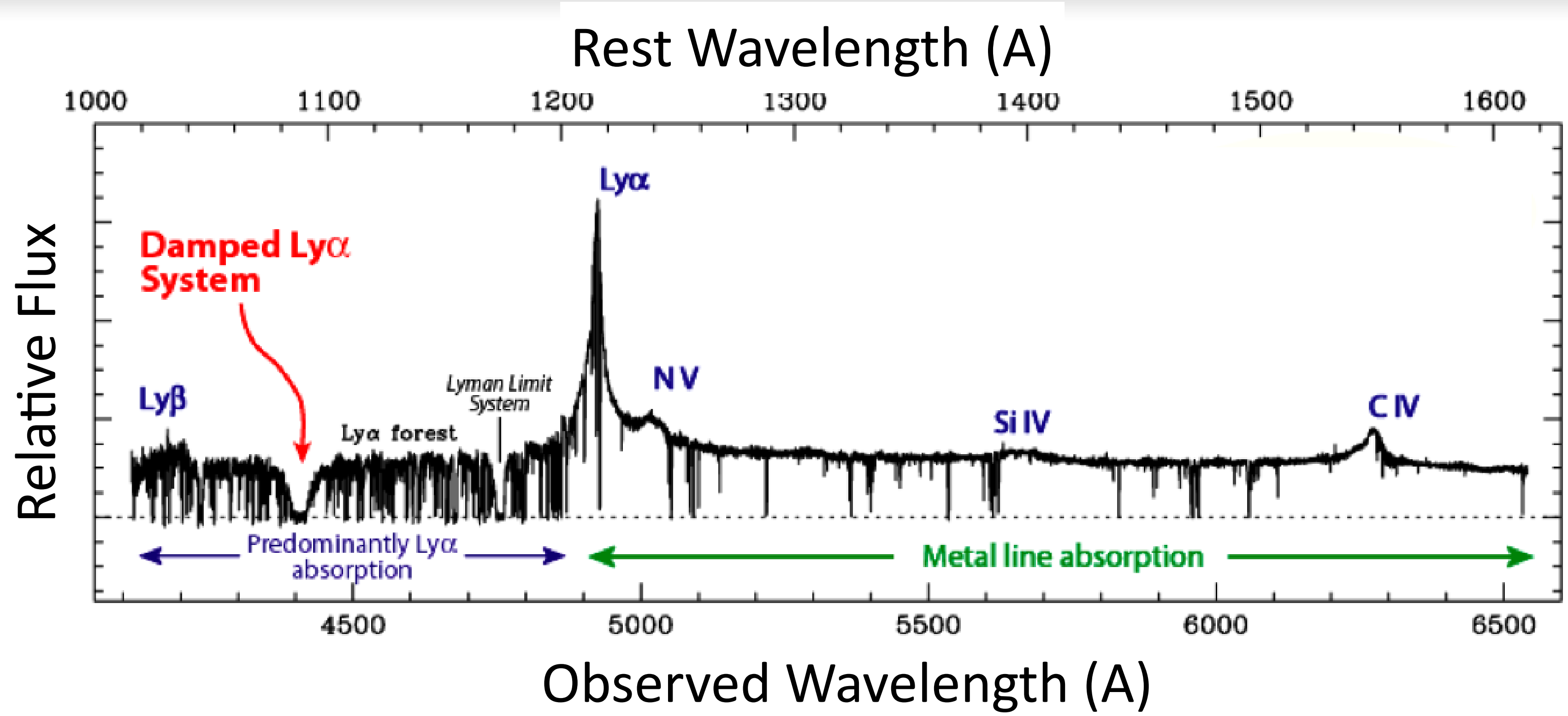
Damped Lyman Alpha Systems (DLAs): Properties



- Definition of Damped Lyα System (DLA): N(HI)≥ 2×10^{20} cm^{-2}
- Distinguishing characteristics of DLAs :
  - (1) Gas is Neutral
  - (2) Metallicity is low: [M/H]~-1.6 (1/30 solar value)
  - (3) Molecular fraction is low: f_{H2}~10^{-5}
- DLAs dominate the neutral-gas content of the Universe out to z~4.5
- DLAs cover 1/3 of the sky at z=[2.5,3.5]

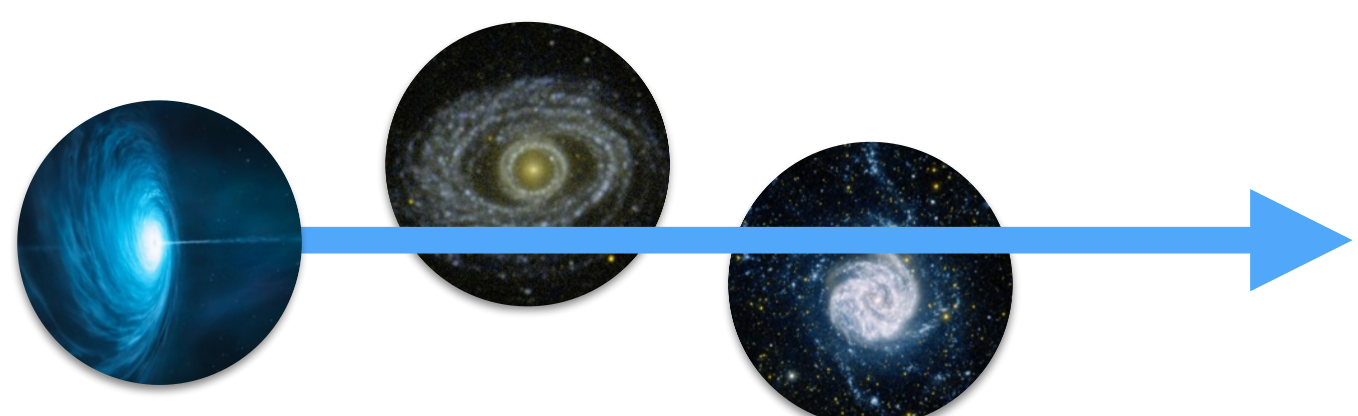
Can we see these DLAs in emission?

Is there in-situ star formation from DLAs?

Two methods to address this question

- Statistical approach using column density distribution function F(N,X) and Kennicutt-Schmidt relation to predict the star formation
  - Compare to measured low surface-brightness emission
  - Average SFR efficiency of DLAs
  - Don’t know for sure if measuring DLAs (no direct DLA measured)
  - Only studying the highest column-density DLAs

- Direct detection at location of the QSO
  - Background QSO is very bright, so very difficult.
  - Few detections found, and most are biased in their selection
    (Not likely the typical DLA - brightest and highest metallicity)
  - Innovative method: Double DLA technique.



Statistical approach: can we see DLAs in emission at z~3?

- Gas Density ↔ SFR via Kennicutt-Schmidt relation
- SFR ↔ FUV L_ν

(Madau Kennicutt Calibration)

At z=3 1500 A → 6000 A
- This puts it in the visible!

- L_ν/area ↔ Surface Brightness
- Most DLAs:

  $N \sim 2\times10^{20} \rightarrow 3\times10^{21}$ cm^{-2}

  $N_{avg} \sim 1\times10^{21}$ cm^{-2}

Surface Brightness > 29 mag/arcsec^2

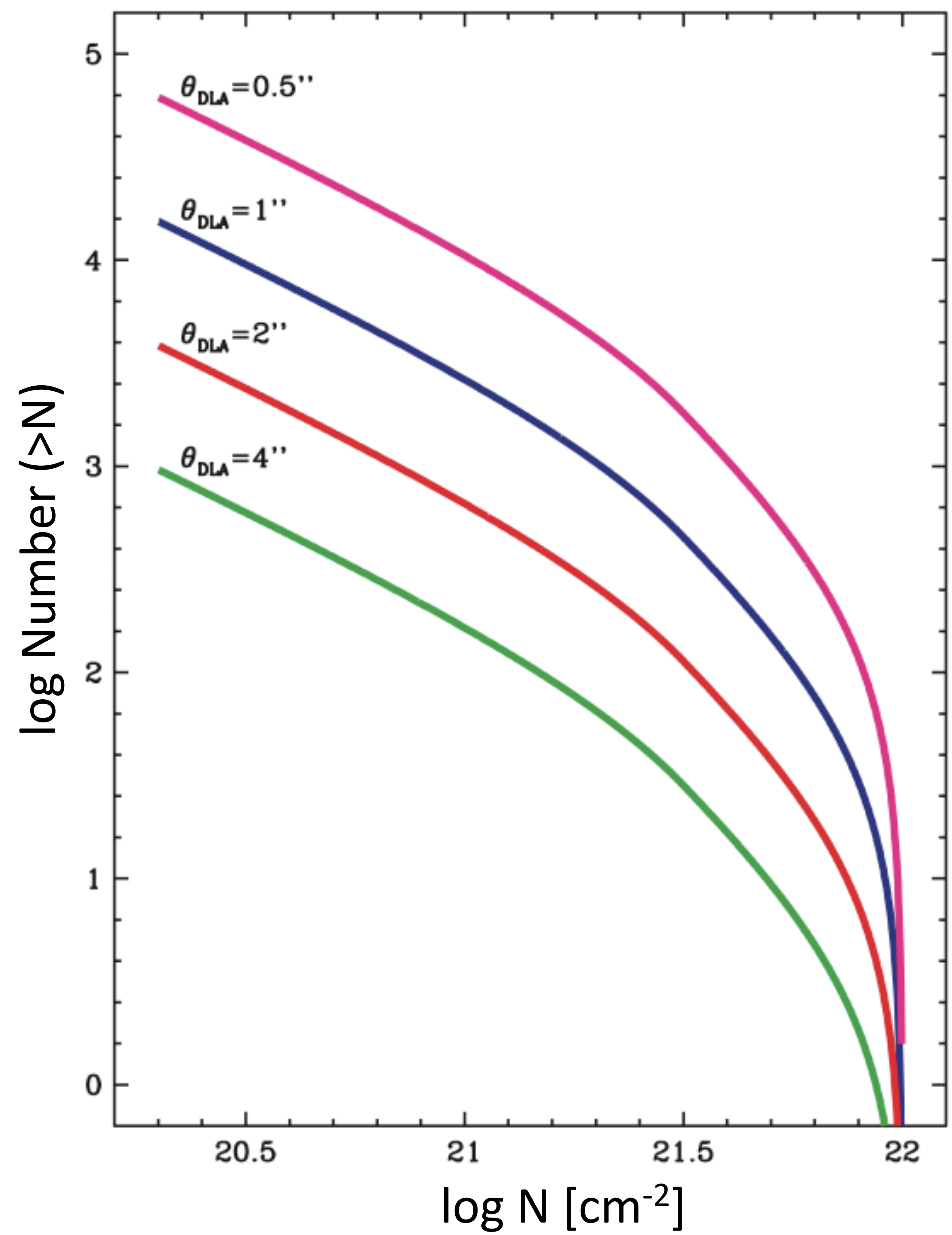
Only high resolution image sensitive enough is the Hubble Ultra Deep Field (UDF)

How many would we expect in HUDF?

<u>Depends on Three Factors:</u>

1) Column-density distribution function
2) Redshift search interval
3) Linear Sizes of DLAs

• Expect hundreds to thousands to be detected in the Hubble Ultra Deep Field



Wolfe & Chen 2006

Wolfe & Chen 2006 result

- Search for extended low-surface-brightness emission
- SFR efficiency of isolated DLAs a factor of ≥10 below KS relation

Caveat:

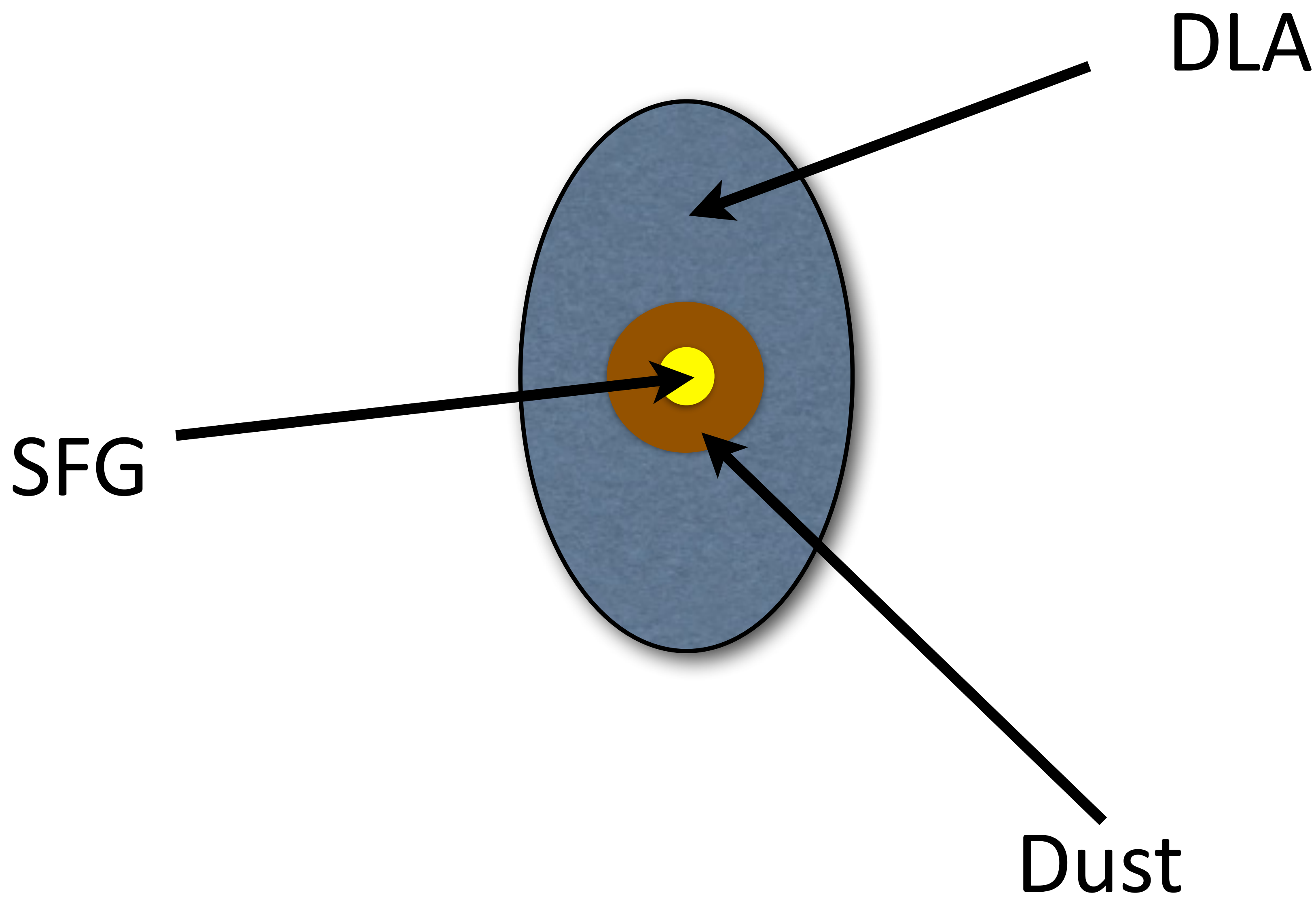
- Wolfe & Chen 2006 search excluded objects with high surface-brightness cores ($\mu_V < 26.6$ mag/arcsec^2)

(i.e. SFGs)

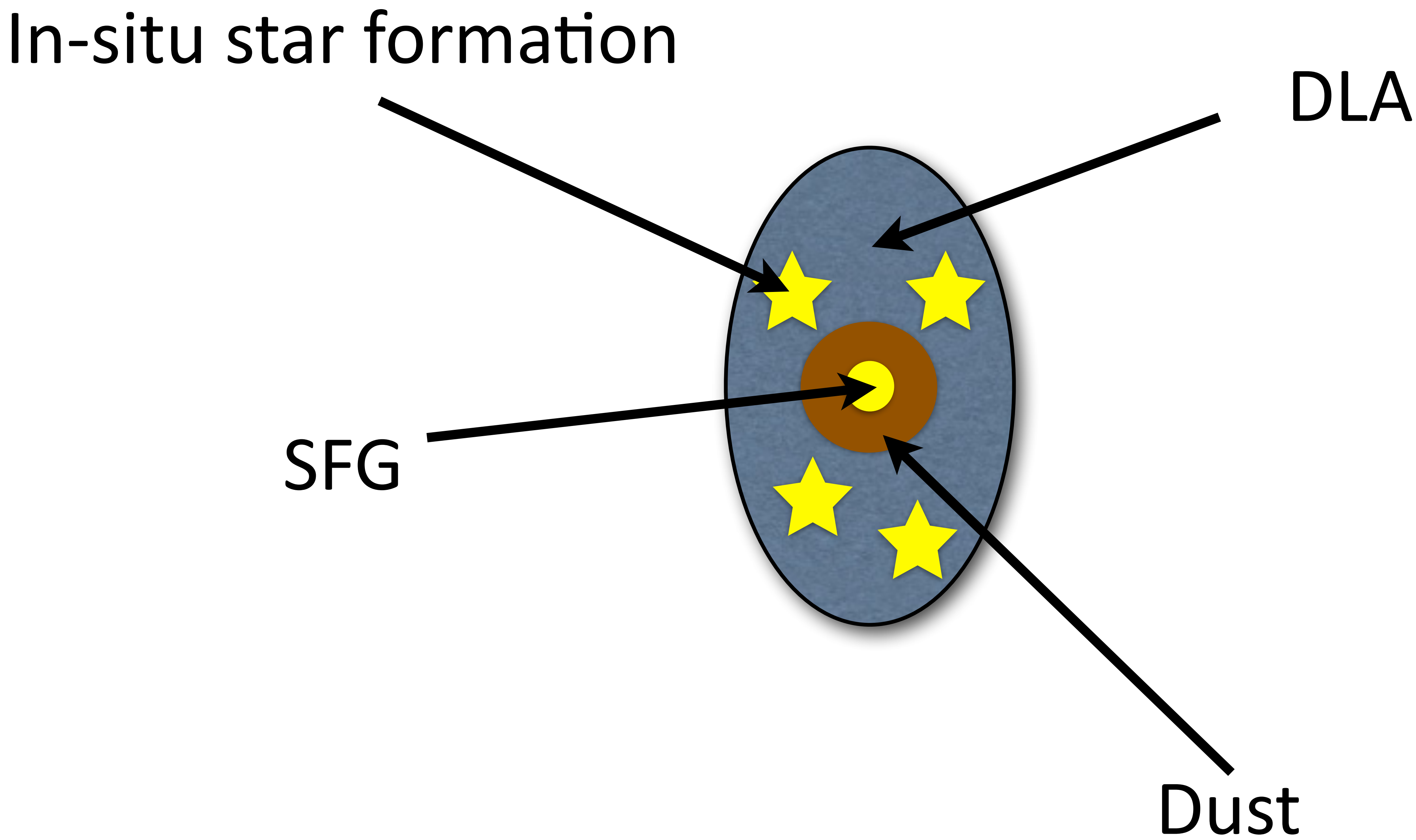
Another possibility:

- SFG cores may be embedded in DLAs, and may themselves exhibit *in situ* star formation

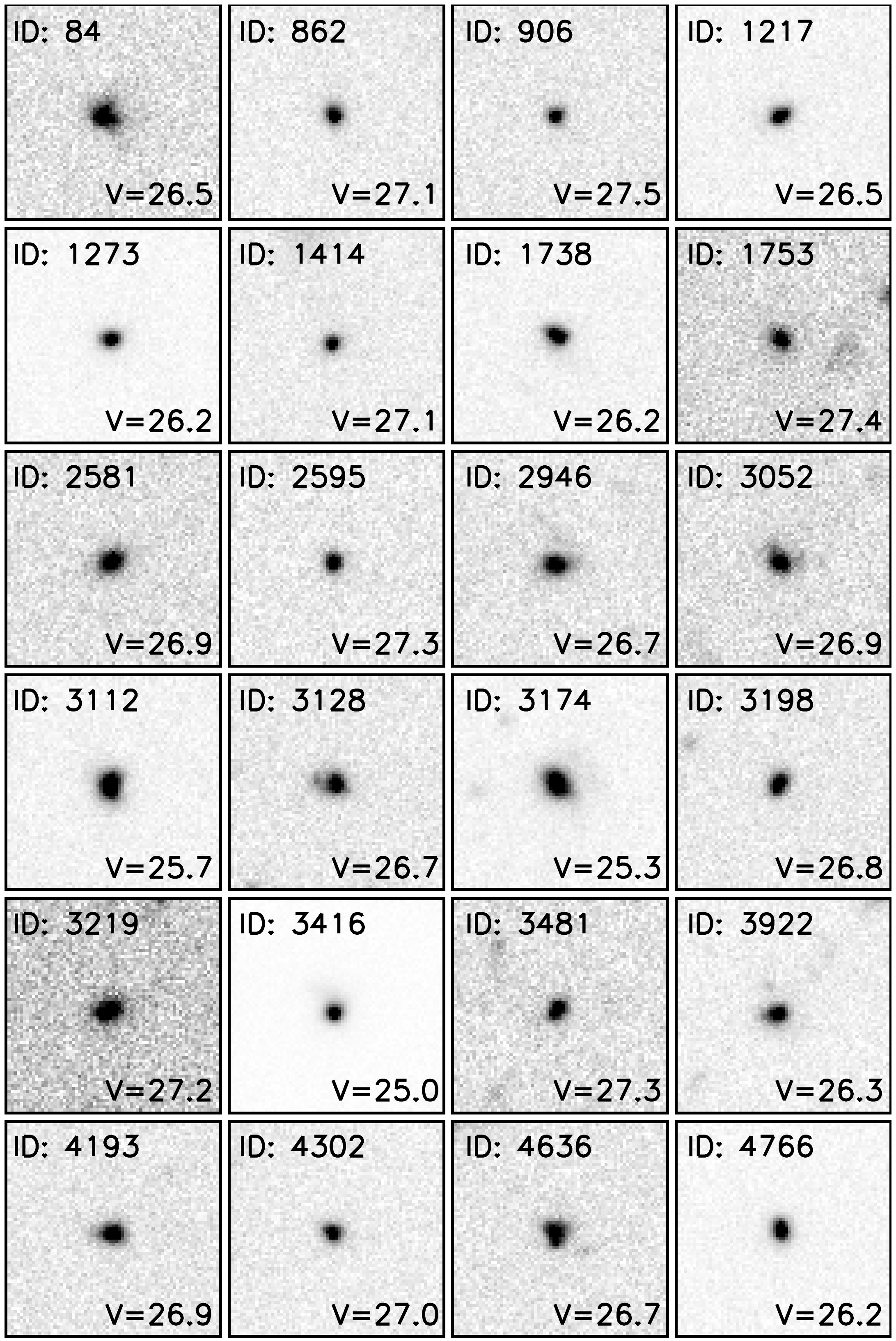
SFGs embedded in DLA Neutral Gas Reservoirs

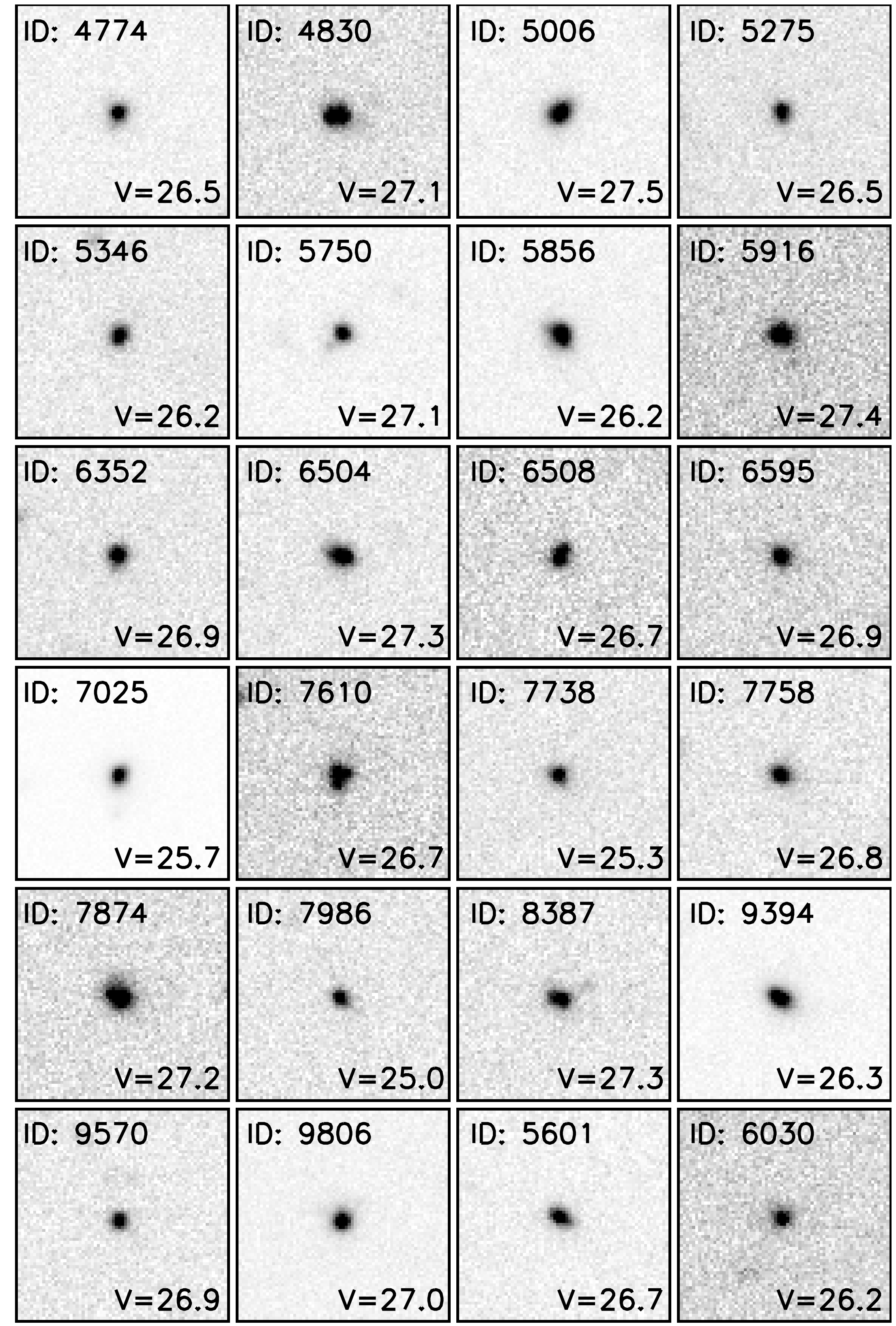


In situ star formation in DLAs associated with SFGs



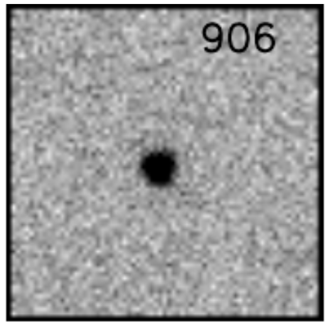
Compact, symmetric, and isolated z~3 SFGs in V-band

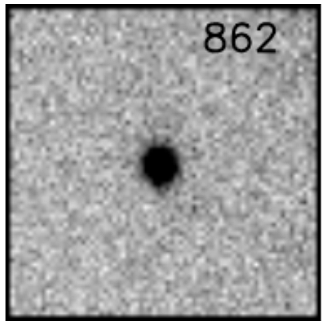


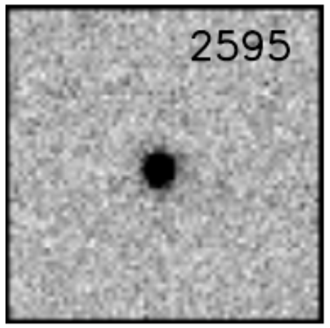


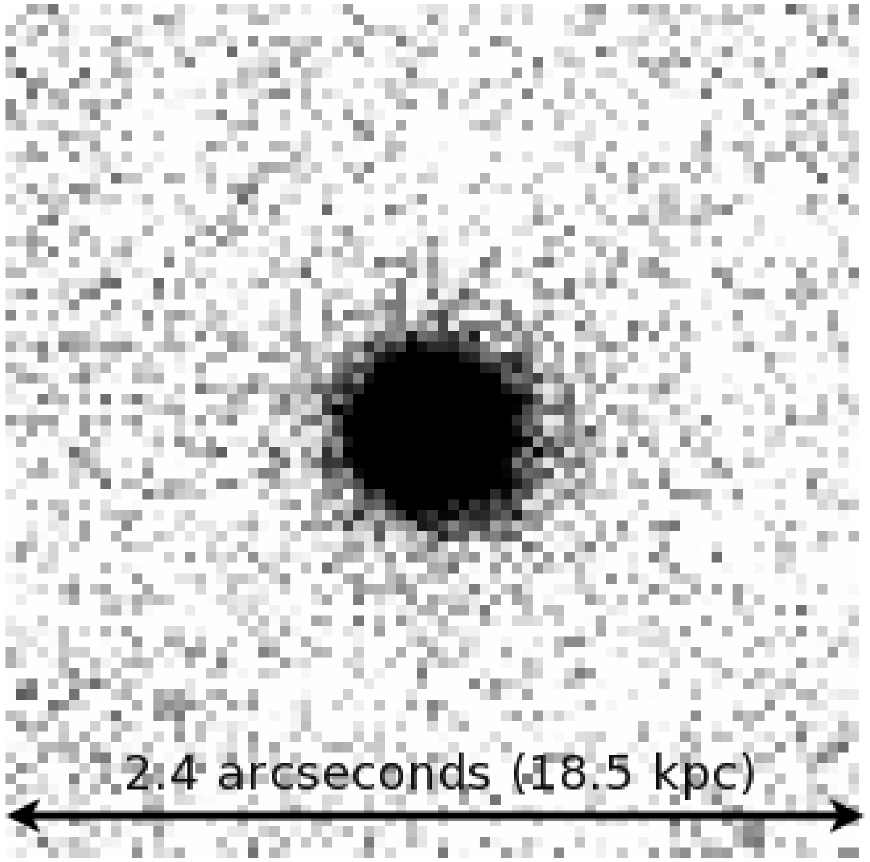
Rafelski et al. 2011

Stack isolated, compact, symmetric z~3 SFG in the V-band (rest-frame FUV)



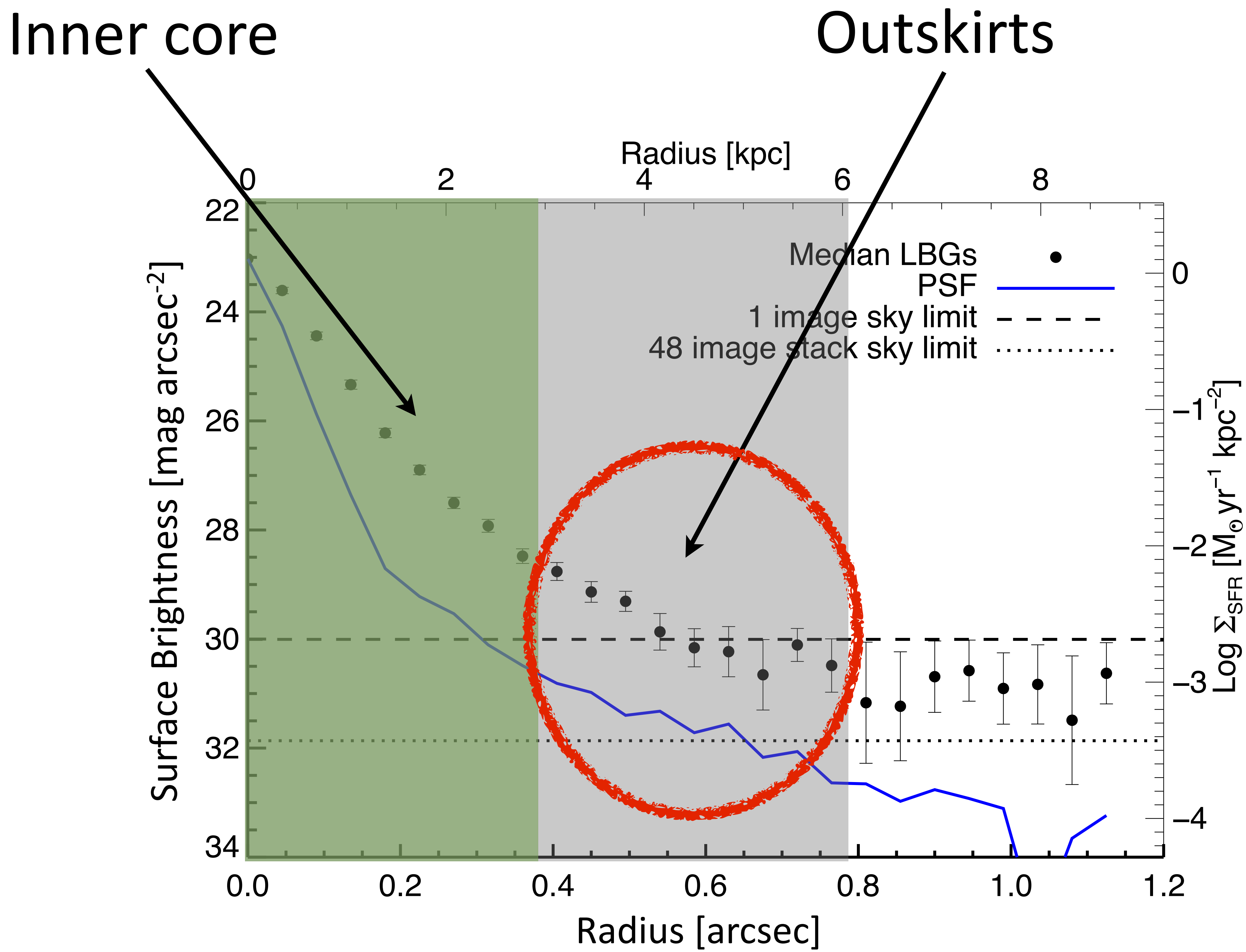






Rafelski et al. 2011

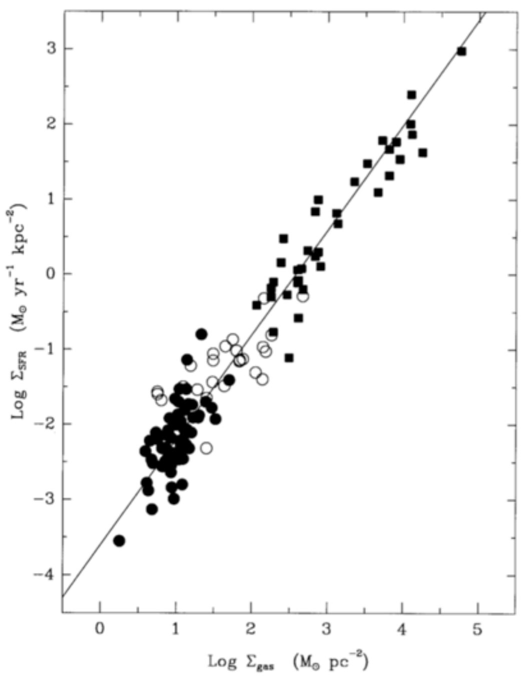
Radial surface brightness profile of stacked image



Rafelski et al. 2011

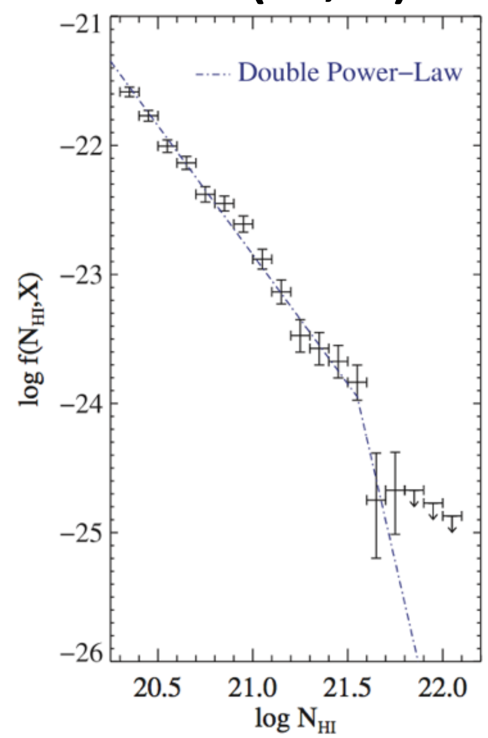
Measuring the SFR Efficiency

KS relation



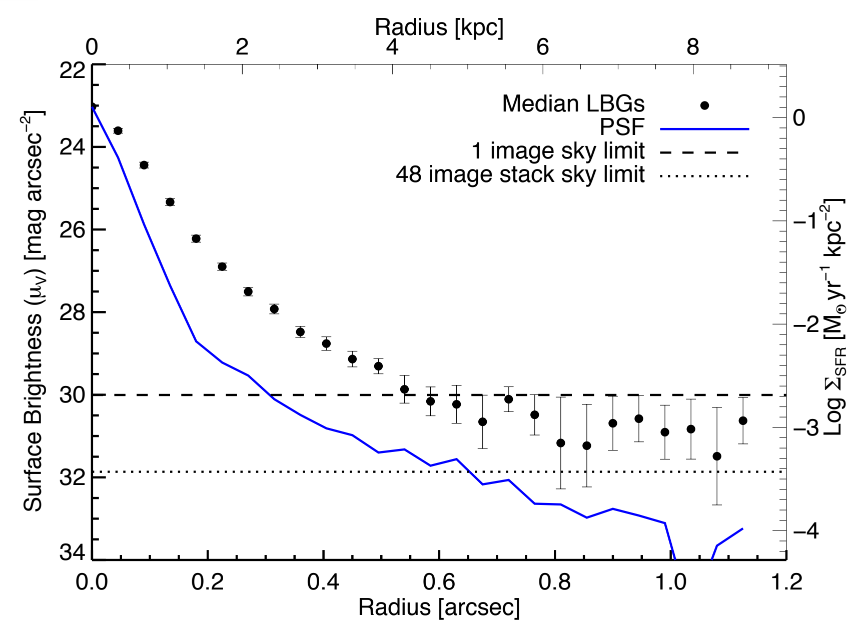
+

F(N,X)



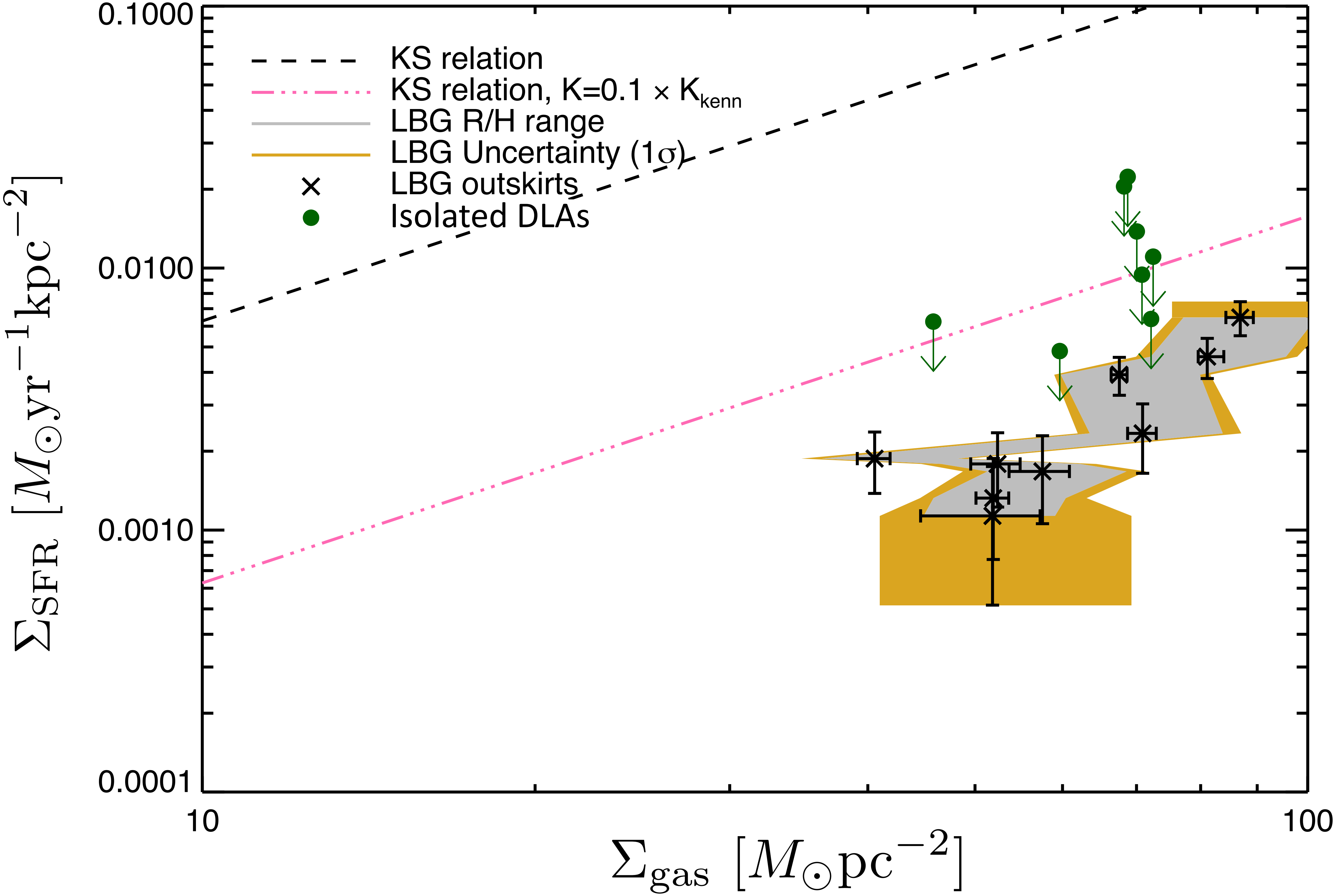
Model

Measurement



Efficiency

The KS relation for atomic dominated gas at z~3



Rafelski et al. 2011

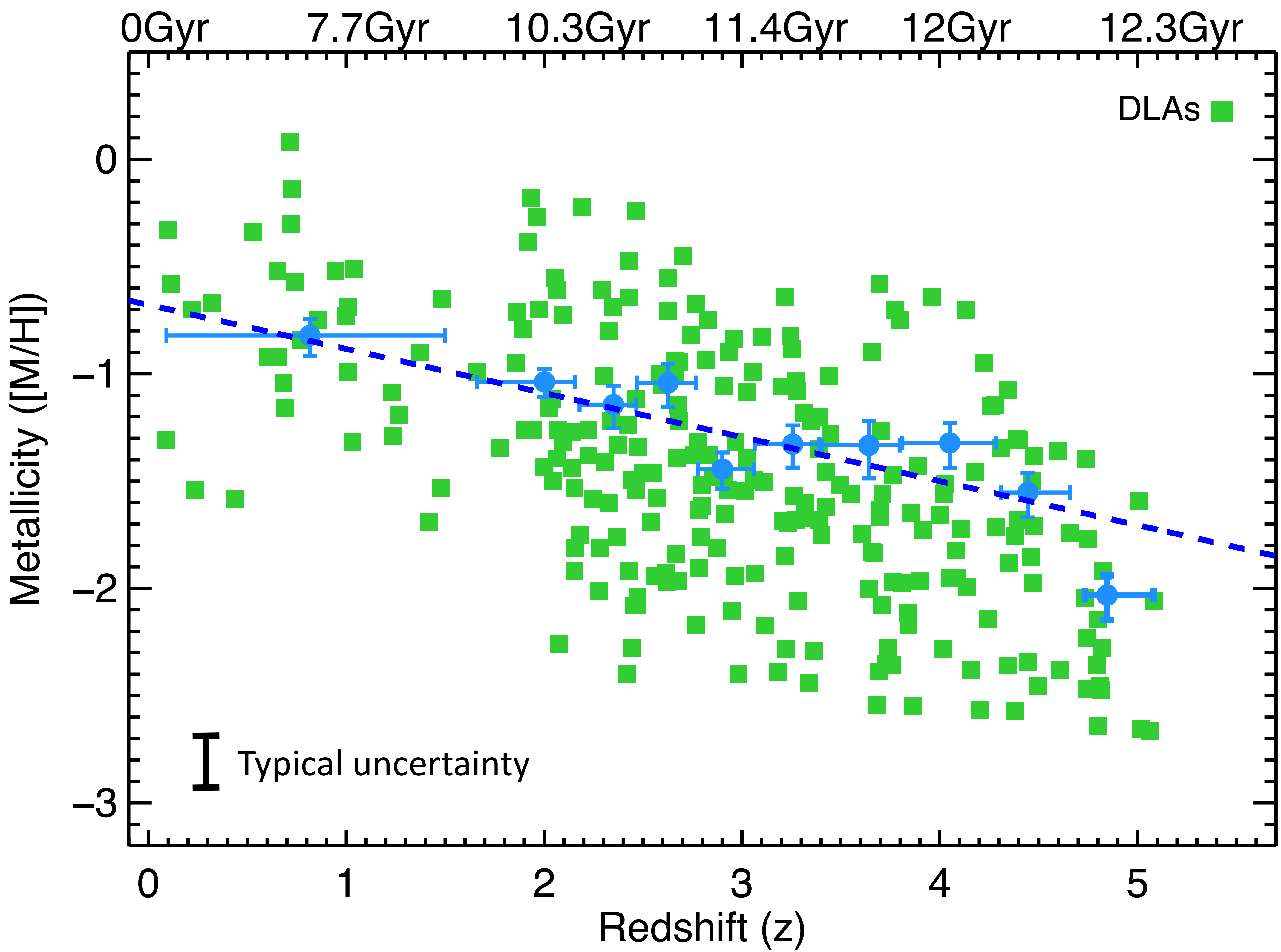
What is responsible for the reduced SFR efficiency?

Metallicity of gas?

Background radiation field?

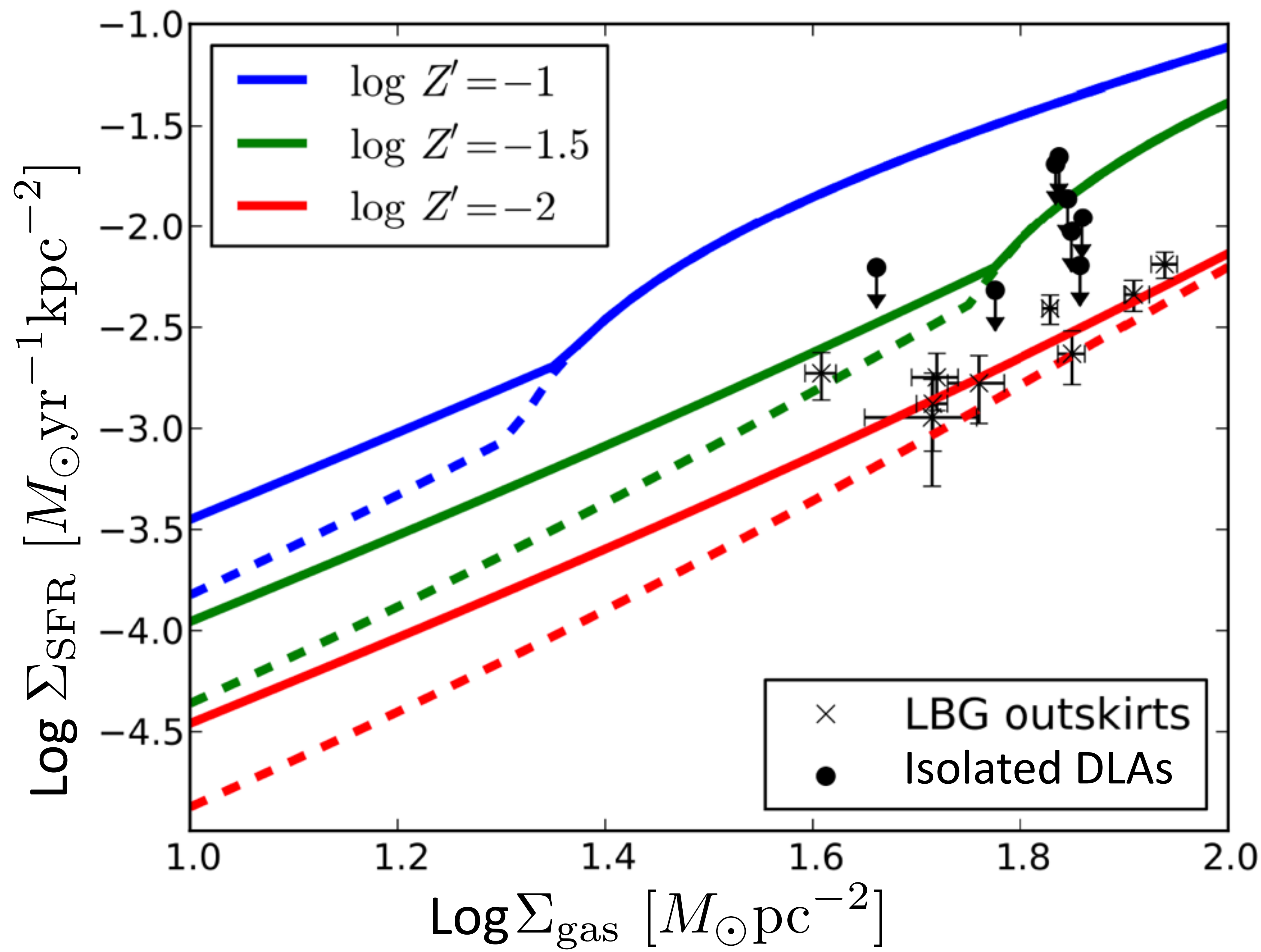
Role of molecular vs. atomic hydrogen gas?

Metallicity Evolution of DLAs



Rafelski et al. 2012, 2014

Efficiency can be reduced with lower metallicity



Krumholz 2013

What is responsible for the reduced SFR efficiency?

Metallicity of gas?

Background radiation field?

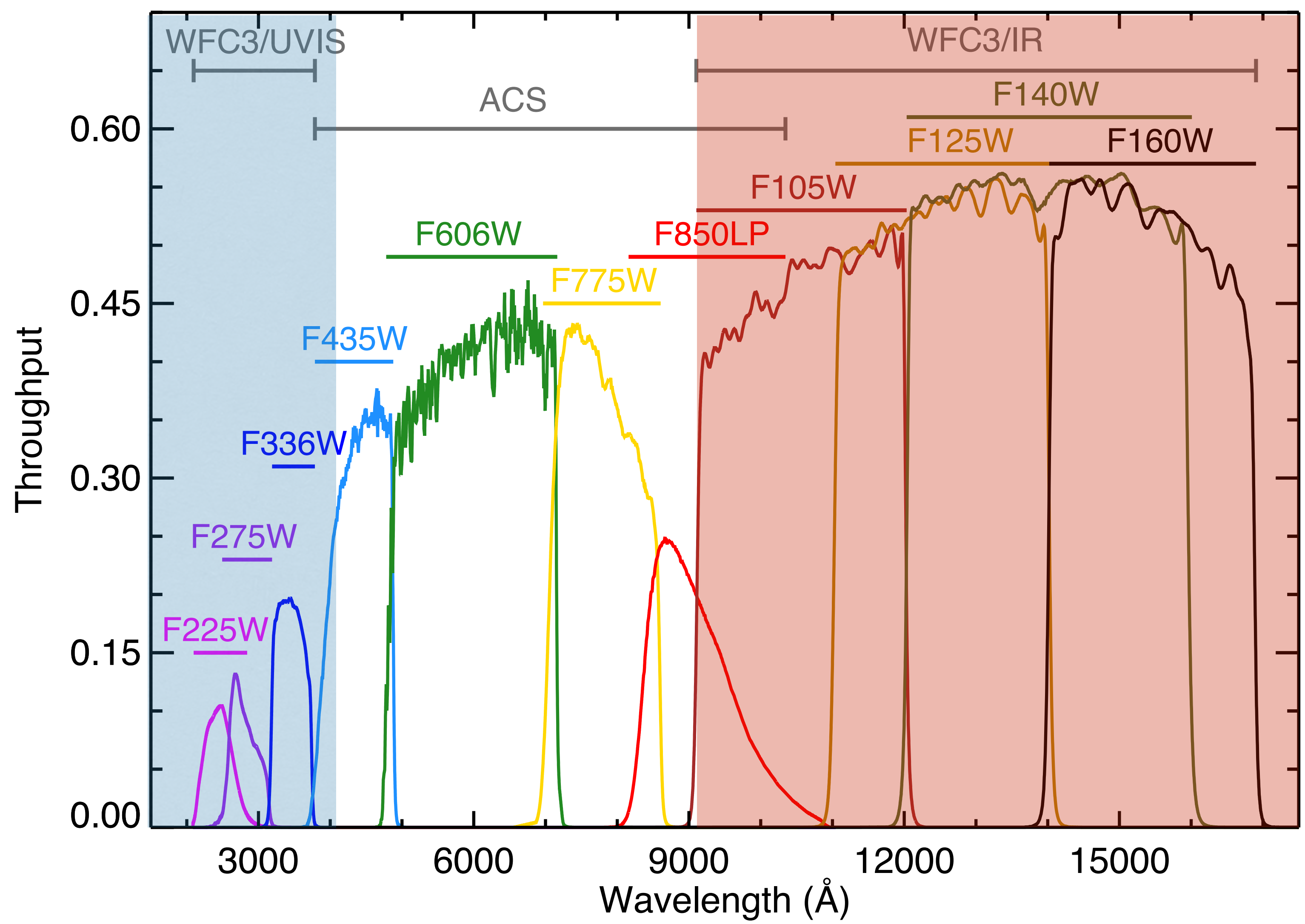
Role of molecular vs. atomic hydrogen gas?

To better answer this question, would like to measure SFR efficiency for a range of redshifts

Goal: Measure SFR efficiency from z~1-4

(Need many reliable redshifts in UDF)

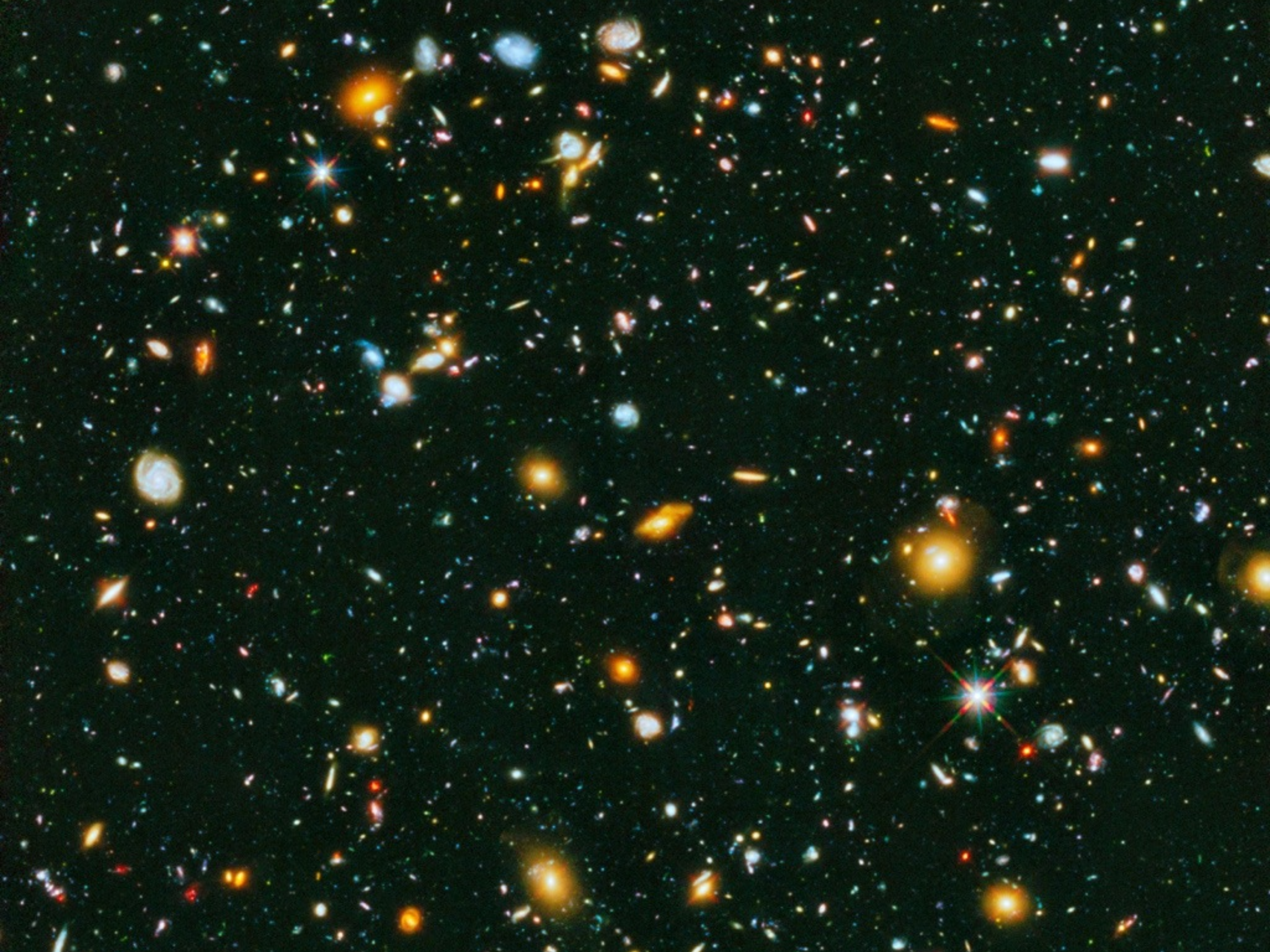
The Ultraviolet Hubble Ultra Deep Field



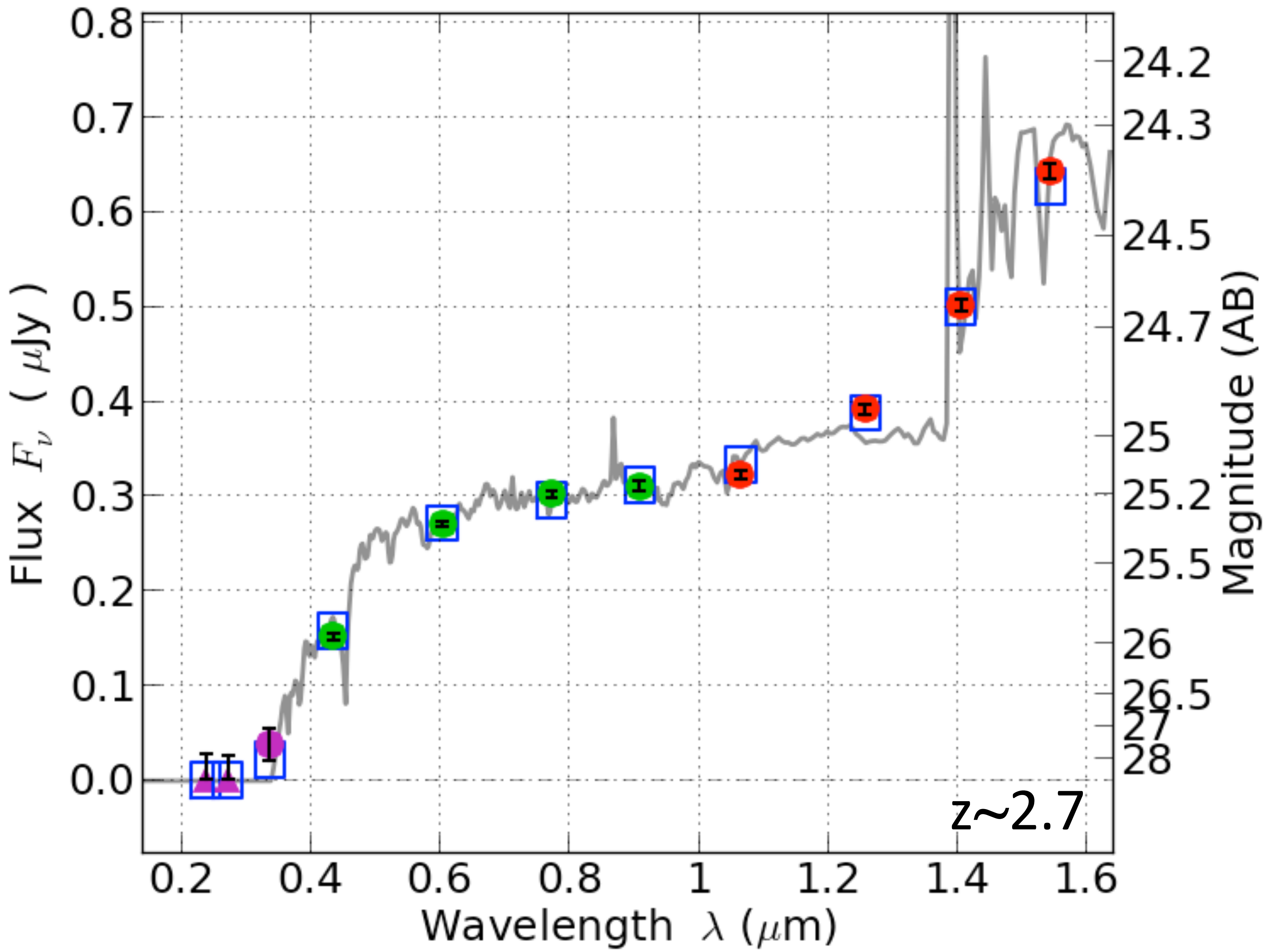
HUBBLE UVUDF ULTRA DEEP FIELD

90 HST orbits:
30 F336W
30 F275W
30 F225W

Rafelski et al. 2015

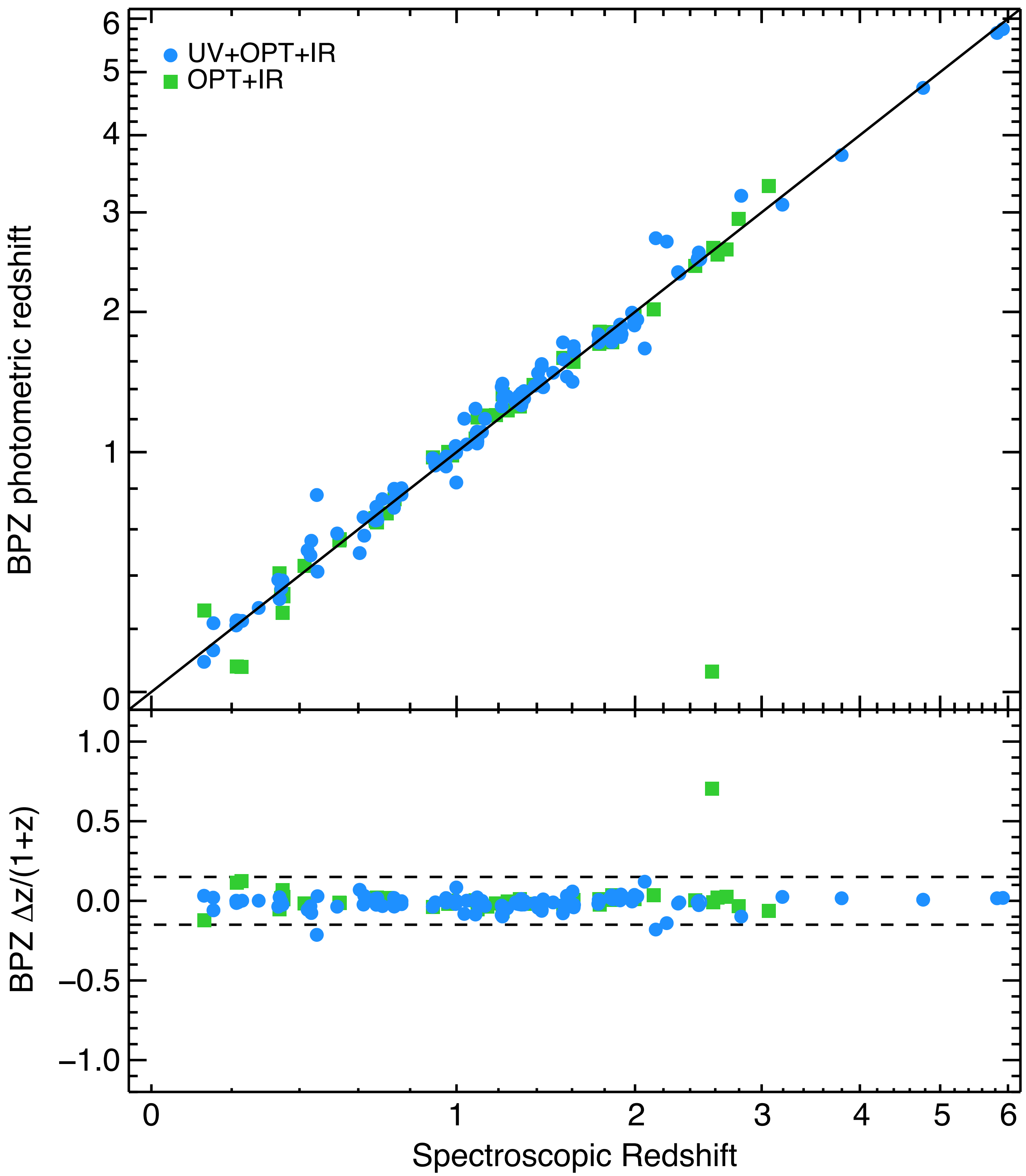


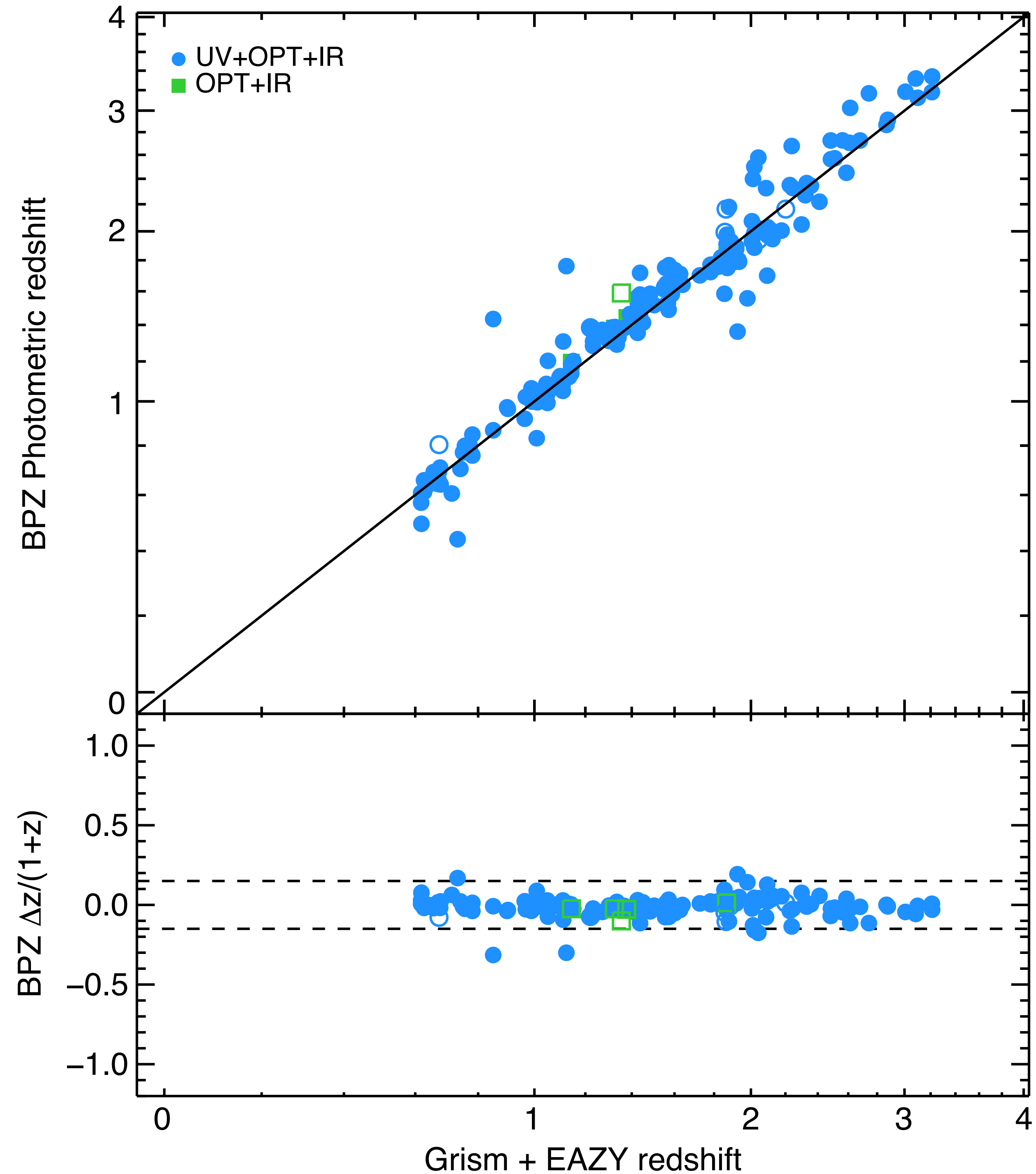
Galaxy Redshifts well determined by photo-z



Rafelski et al. 2015

Improved redshifts from UVUDF: 11 HST band-passes

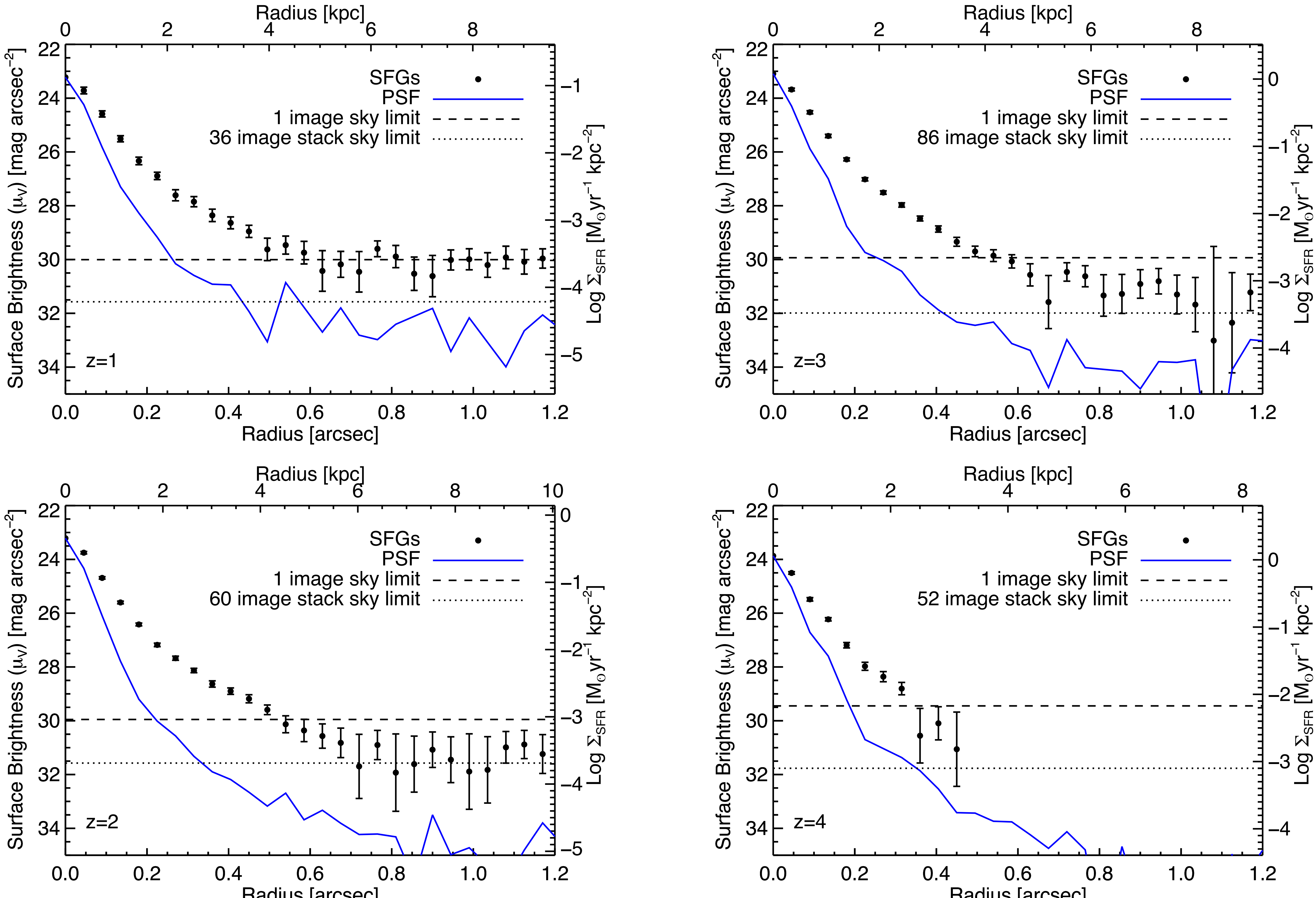




Factor of >2 improvement in outlier fraction with NUV data

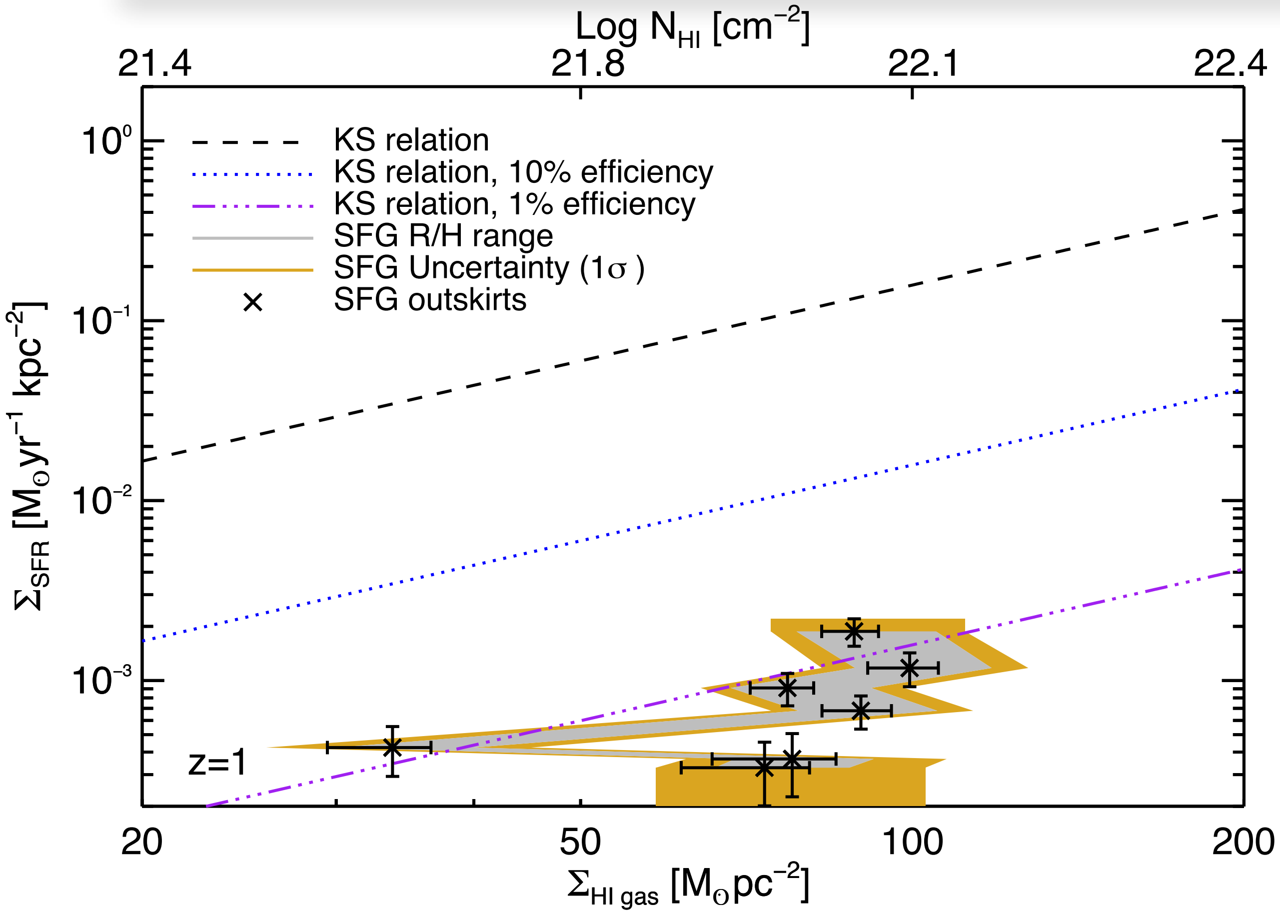
Rafelski et al. 2015

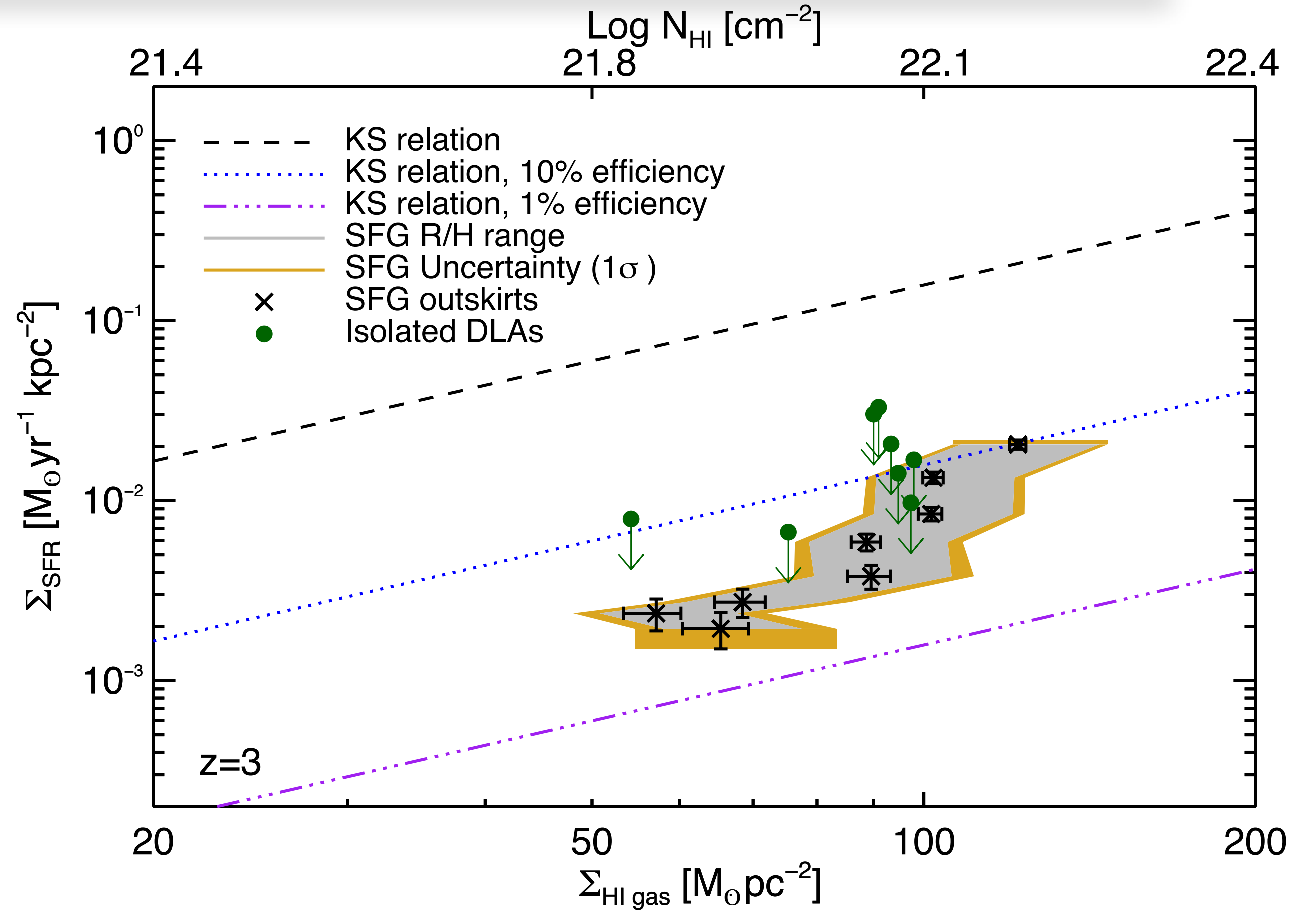
Radial Surface Brightness Profiles for z~1-4

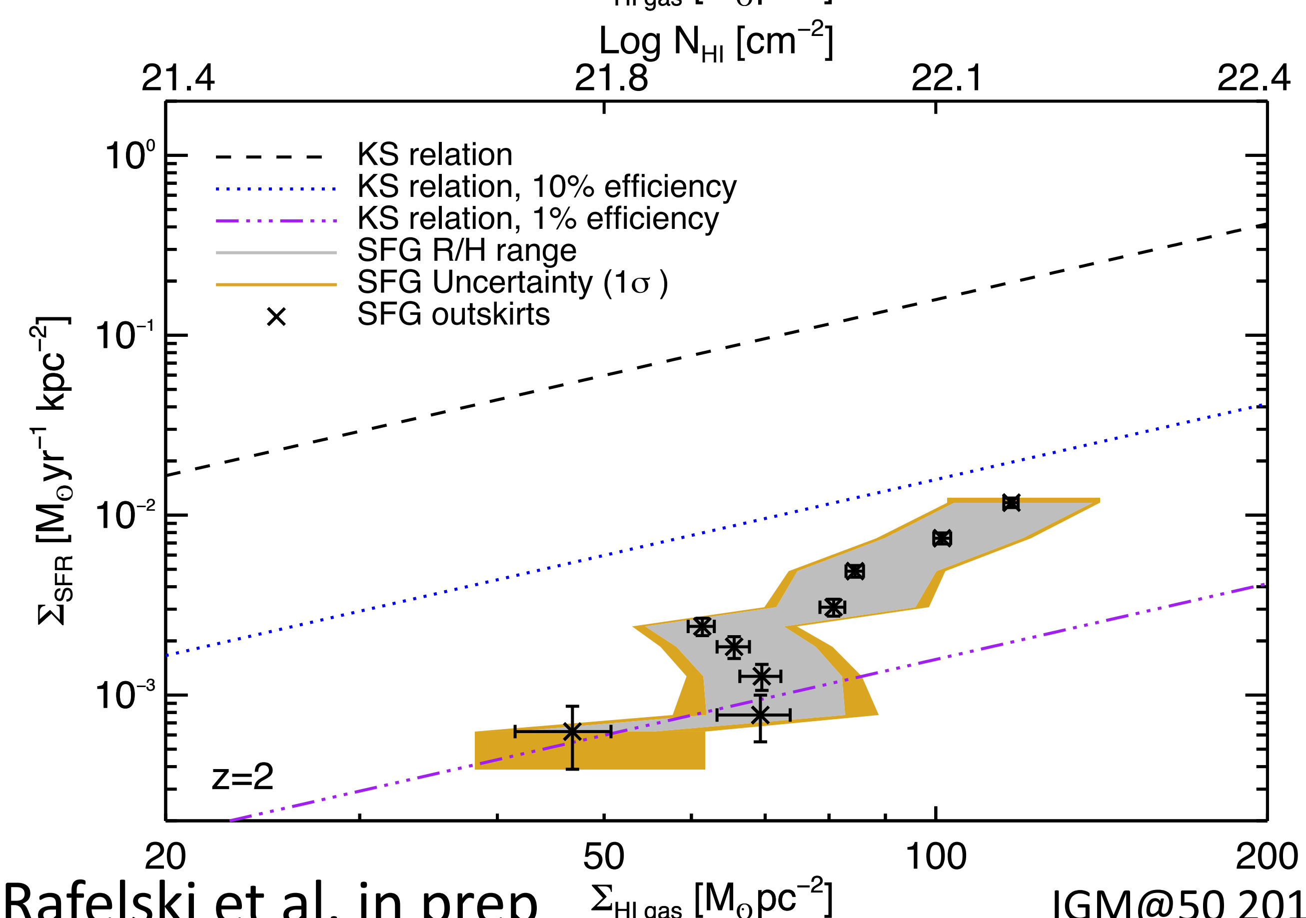


Rafelski et al. in prep

The KS relation for atomic dominated gas at z~1-3

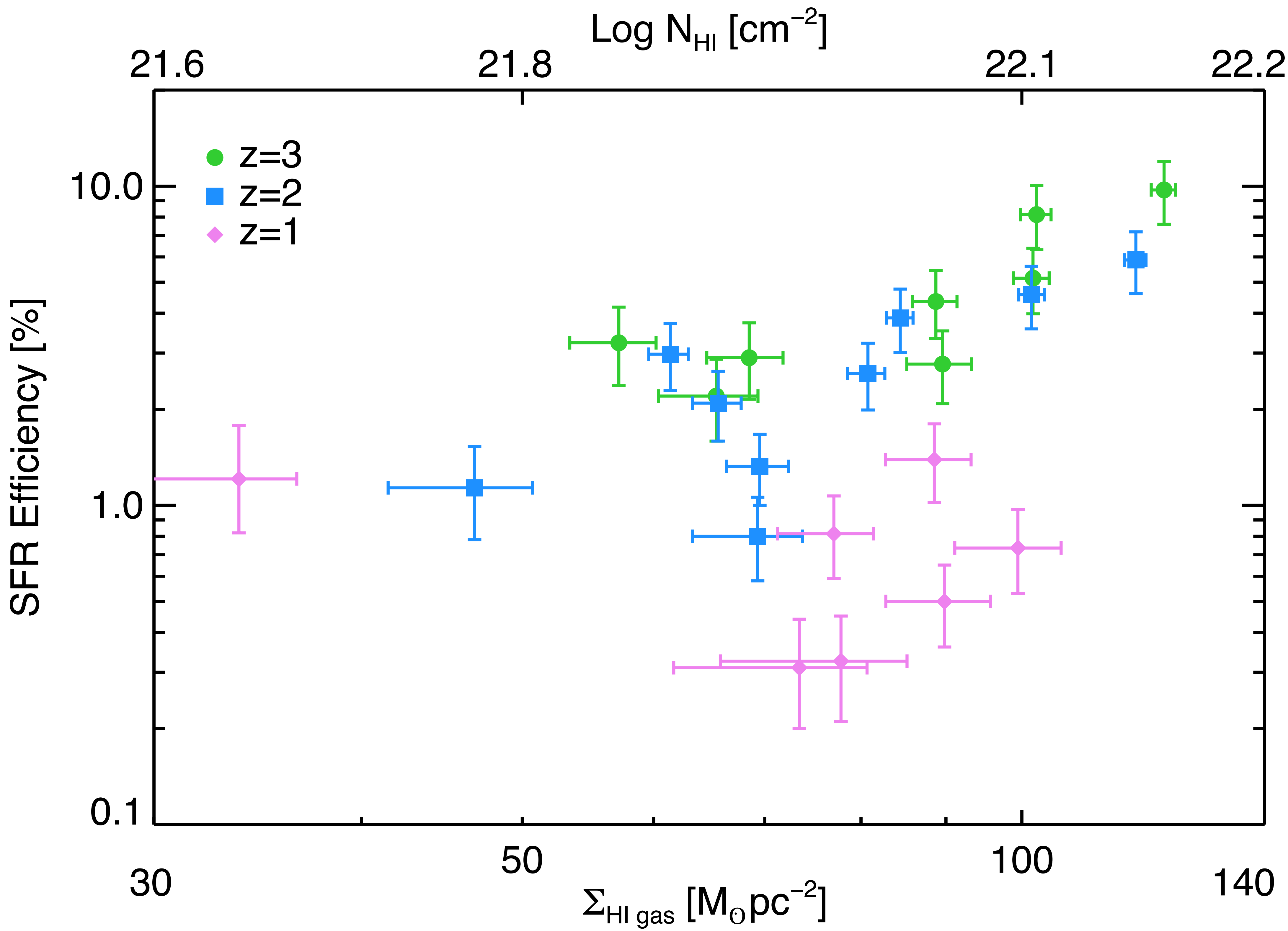






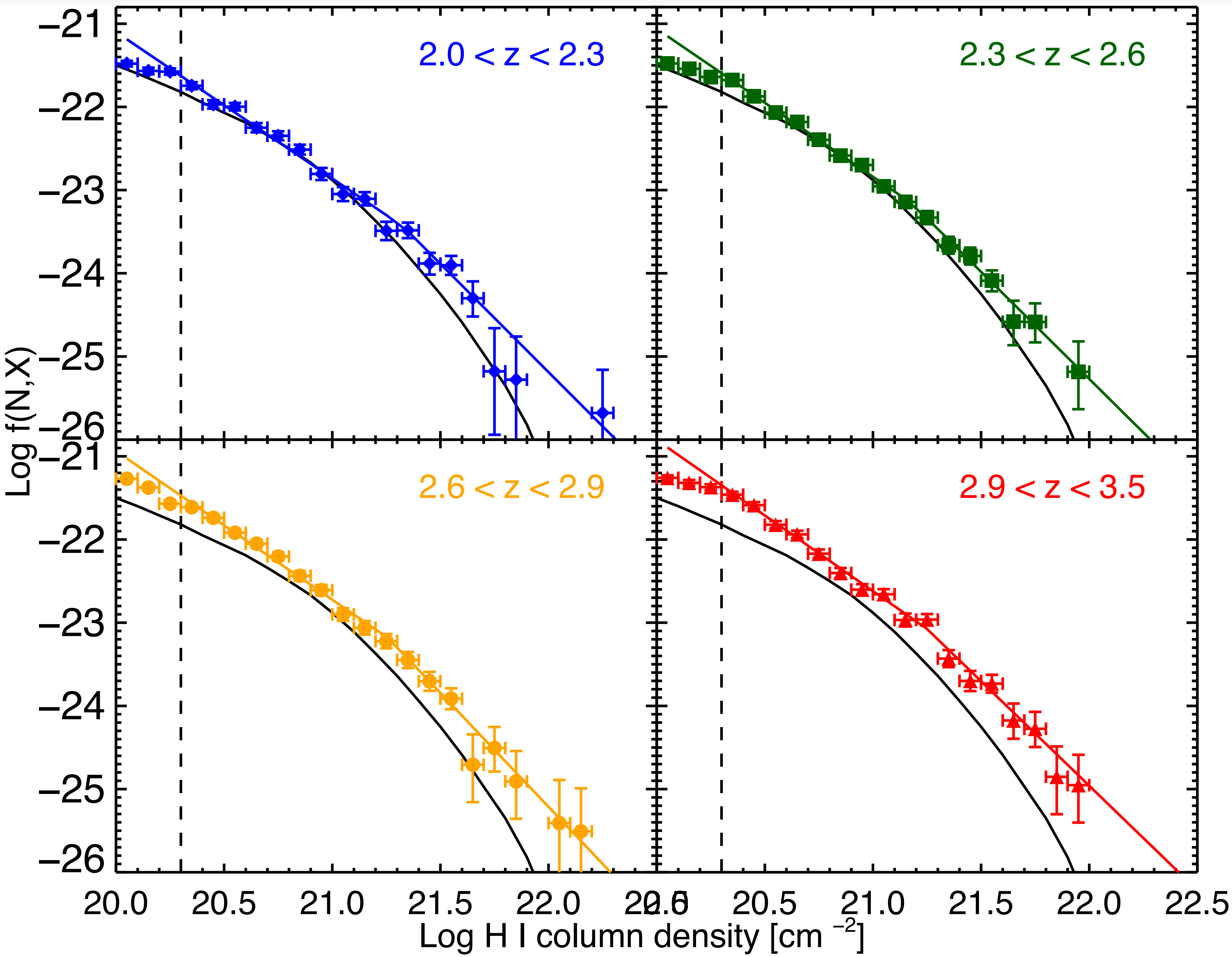
Rafelski et al. in prep

SFR Efficiency of HI gas at z~1-3

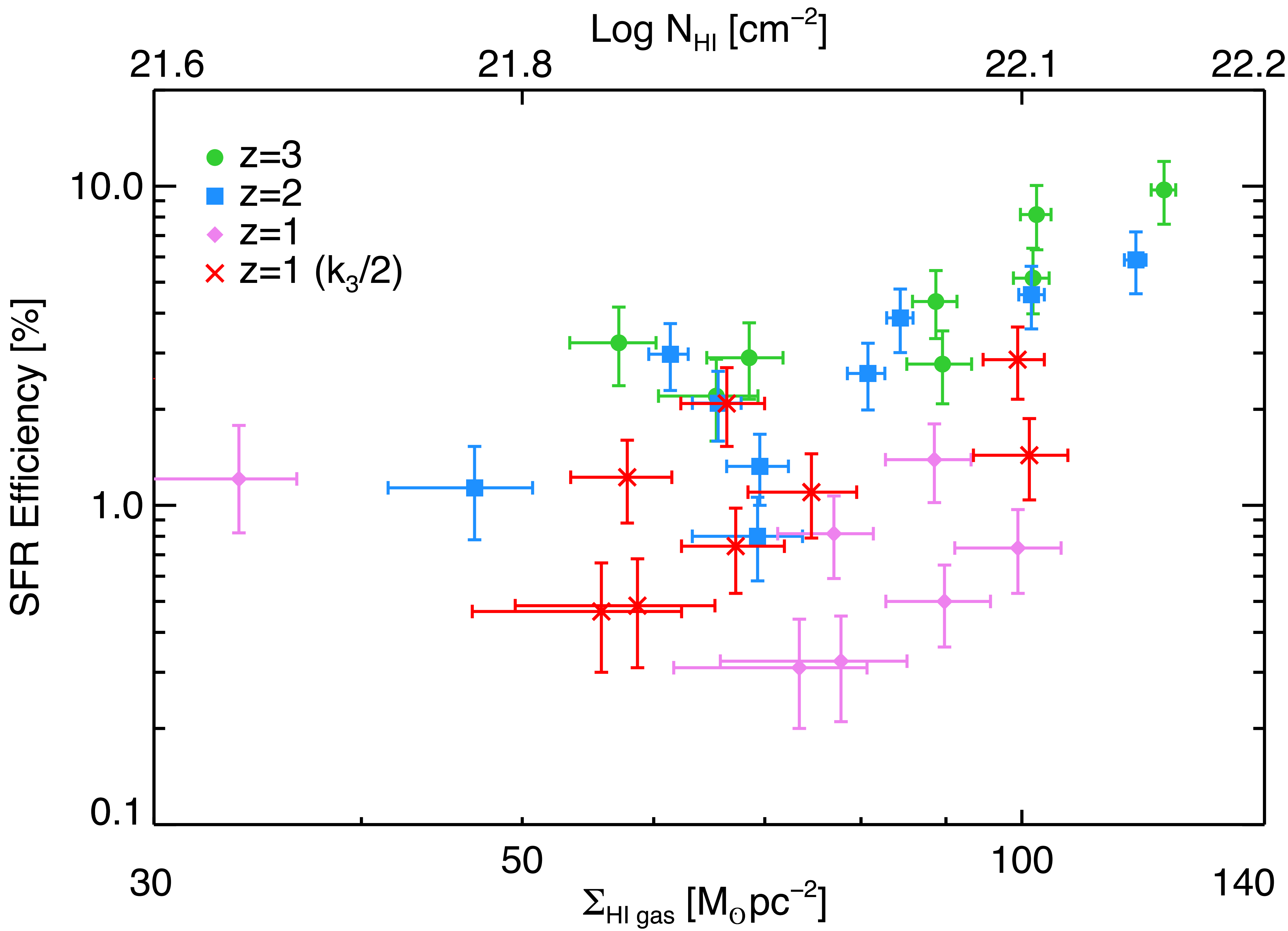


Rafelski et al. in prep

Newest version of F(N,X) based on Noterdaeme 2012



SFR Efficiency of HI gas at z~1-3: F(N) at z~1 needed



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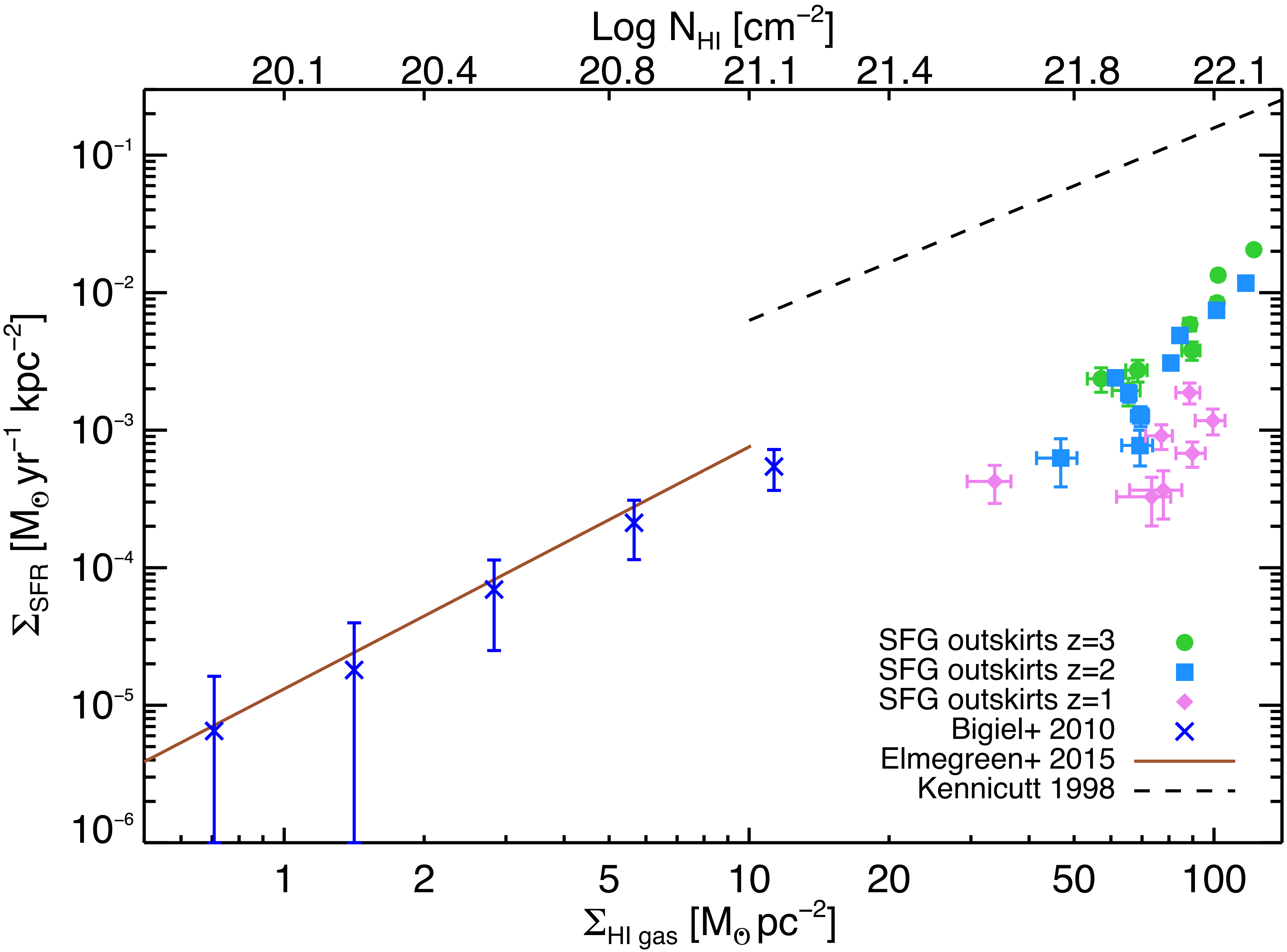
Local Comparison



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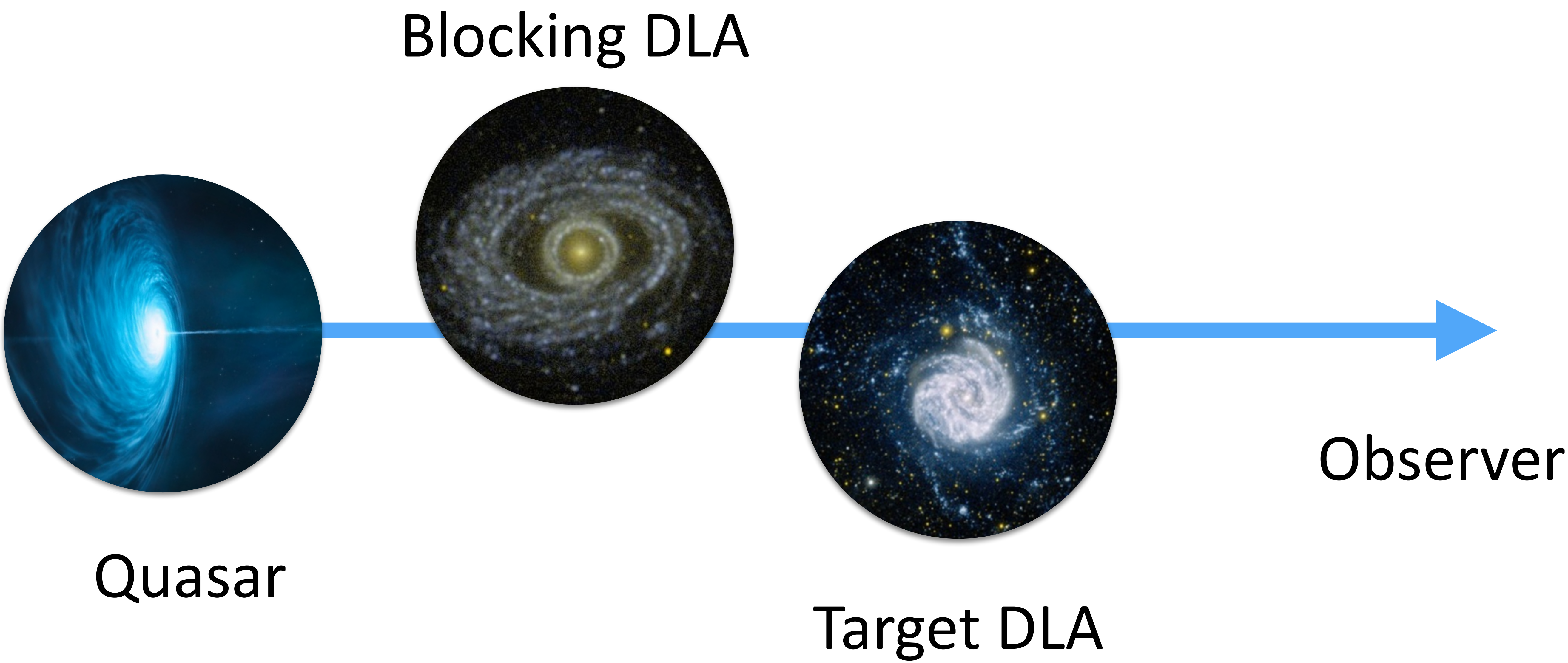
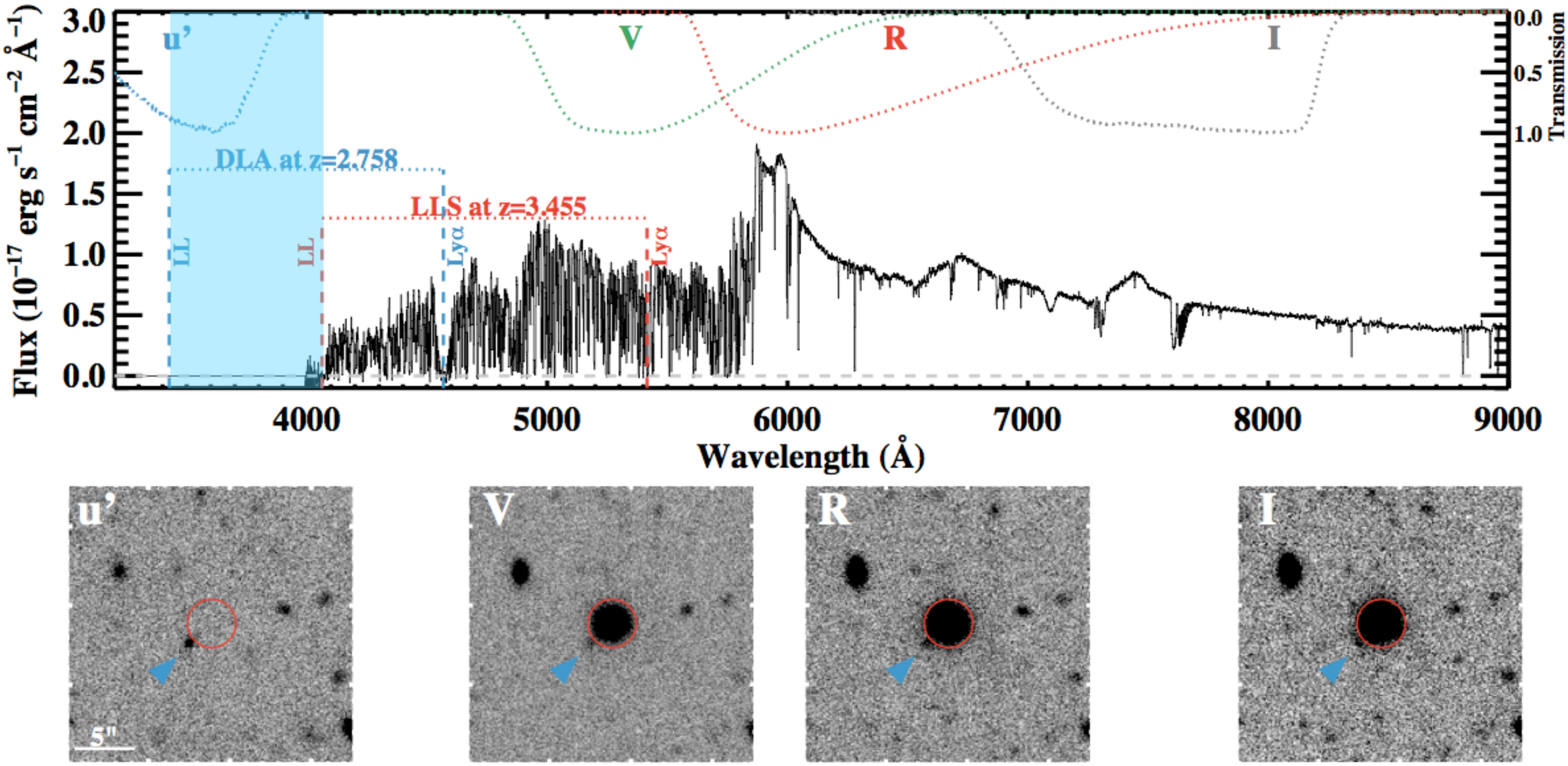
Direct approach: Double DLA technique



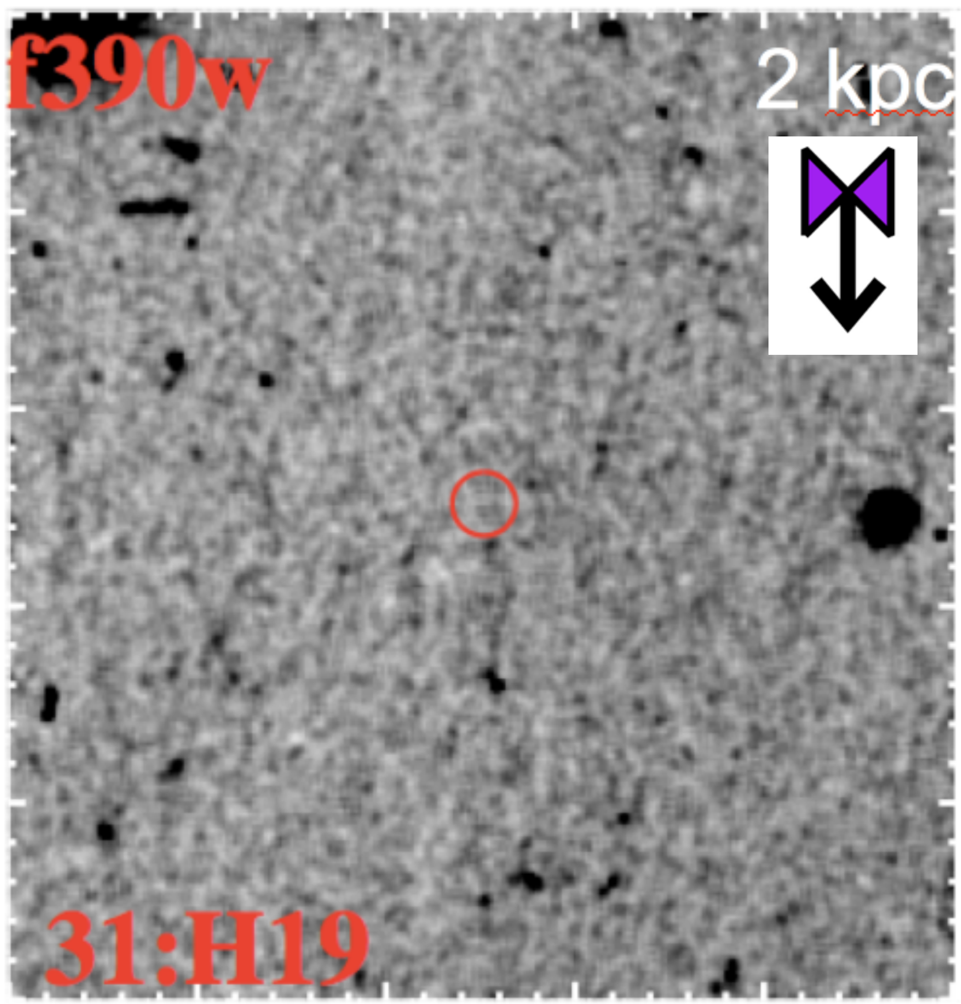
Method to measure the star formation rates of DLAs at z~2-3



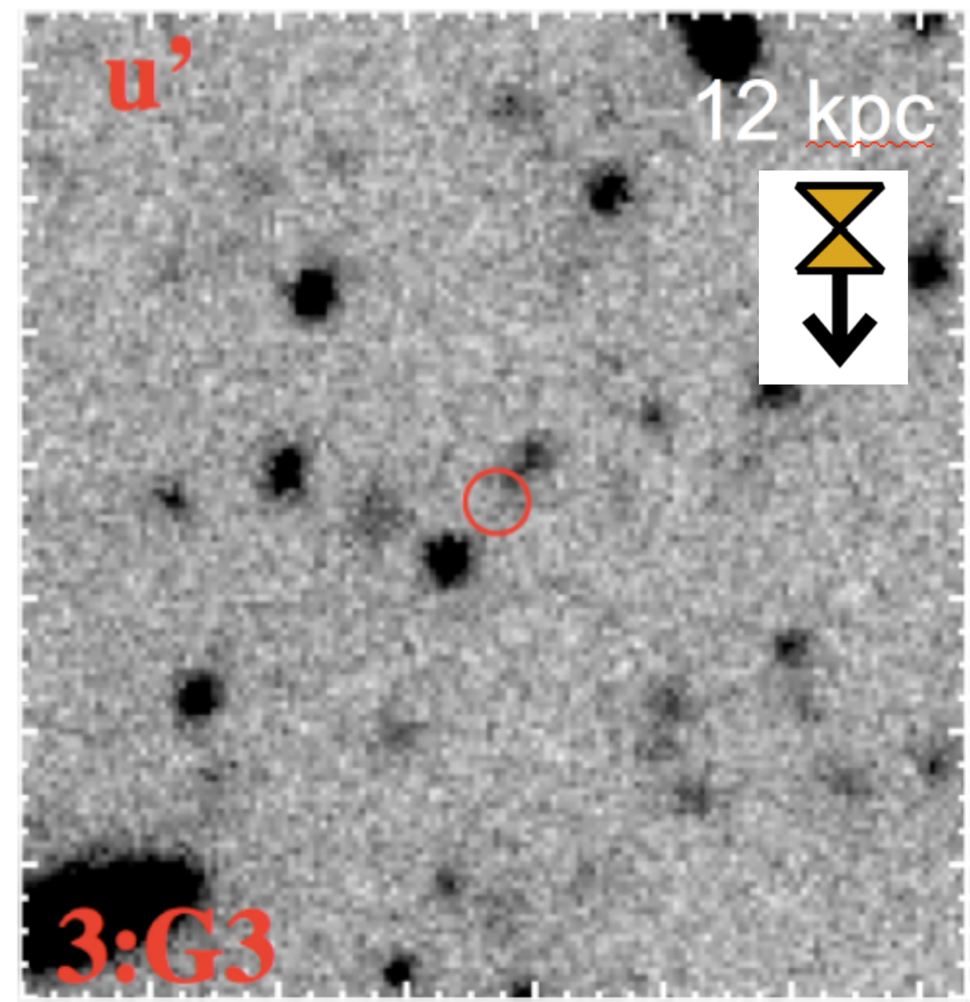
Fumagalli et al. 2014

Observations with HST and Keck

20 DLAs with HST/WFC3

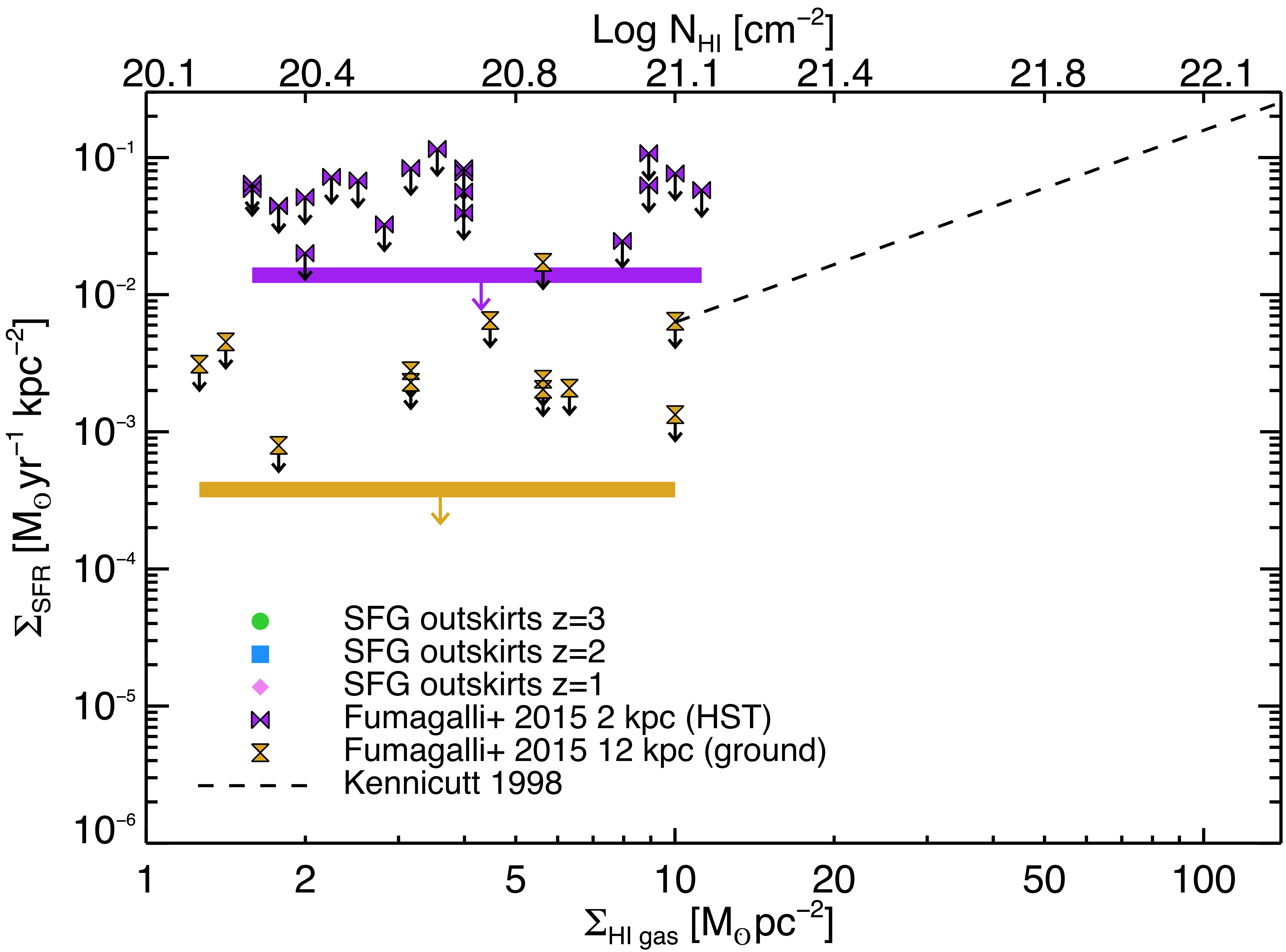


12 DLAs from the ground



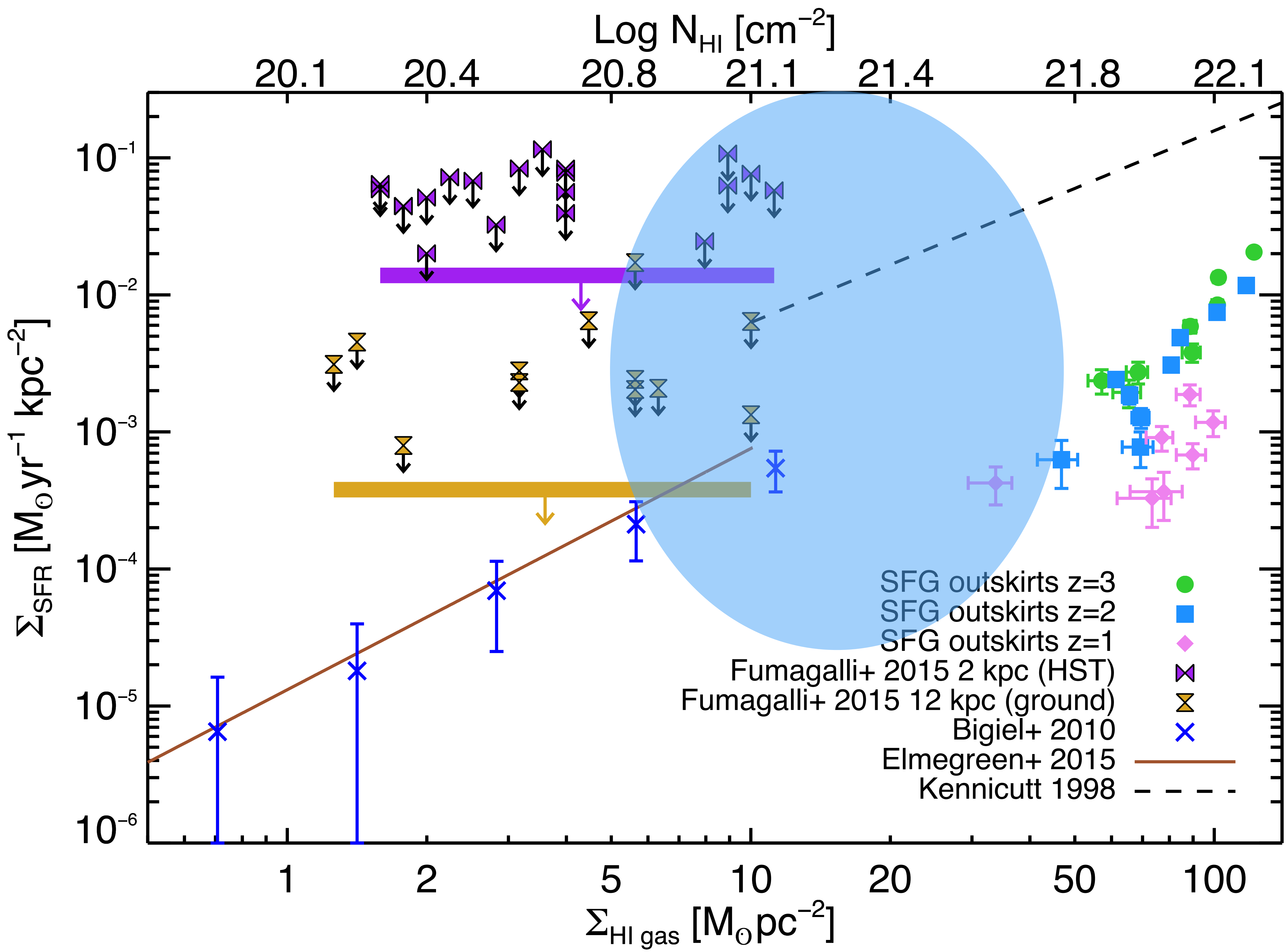
Fumagalli et al. 2015

Comparison of direct and statistical measurements



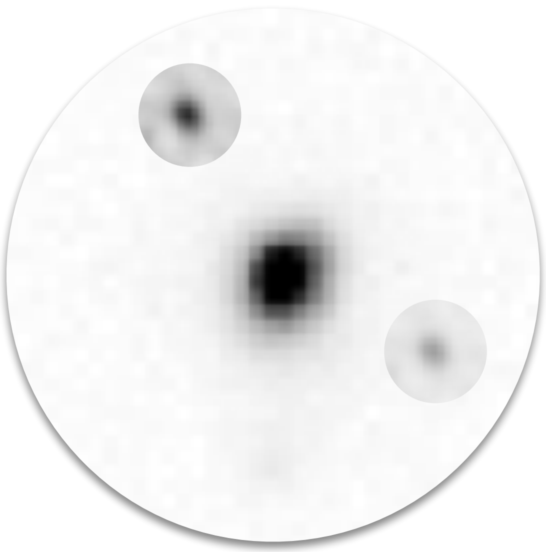
Rafelski et al. in prep

Comparison of all HI SF measurements

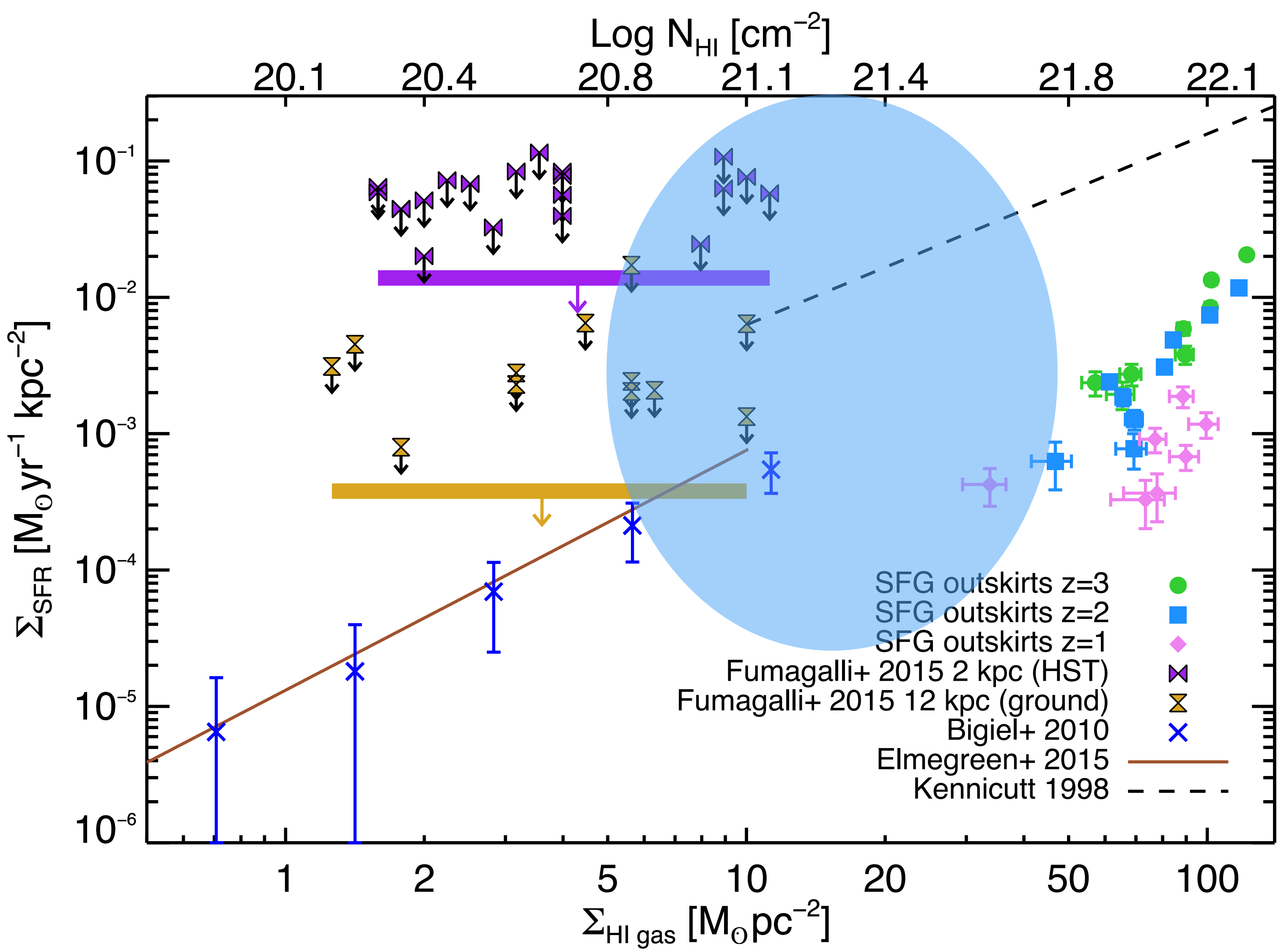


Rafelski et al. in prep

Another currently untested possibility



DLAs could be dwarf galaxies in the halo of SFGs



Cycle 23 HST proposal would find them if near QSO

MUSE program would find them if far from QSO

Summary

- SFR efficiency of HI gas is a factor of >10 lower at z~1-3 than in normal galaxies at low redshift
- No evolution observed, and therefore likely due to gas type
  - low metallicity could cause a threshold for SF
- Unbiased direct observations find no emission at QSO position
  - need more sensitive measurements
- Need to measure high NHI systems directly with HST.
- Need to test the possibility of DLAs consisting of low-mass dwarf galaxies in more massive halos. HST + MUSE