The future (and past) of **ground**-based galaxy evolution **spectroscopic** surveys in the JWST* era?

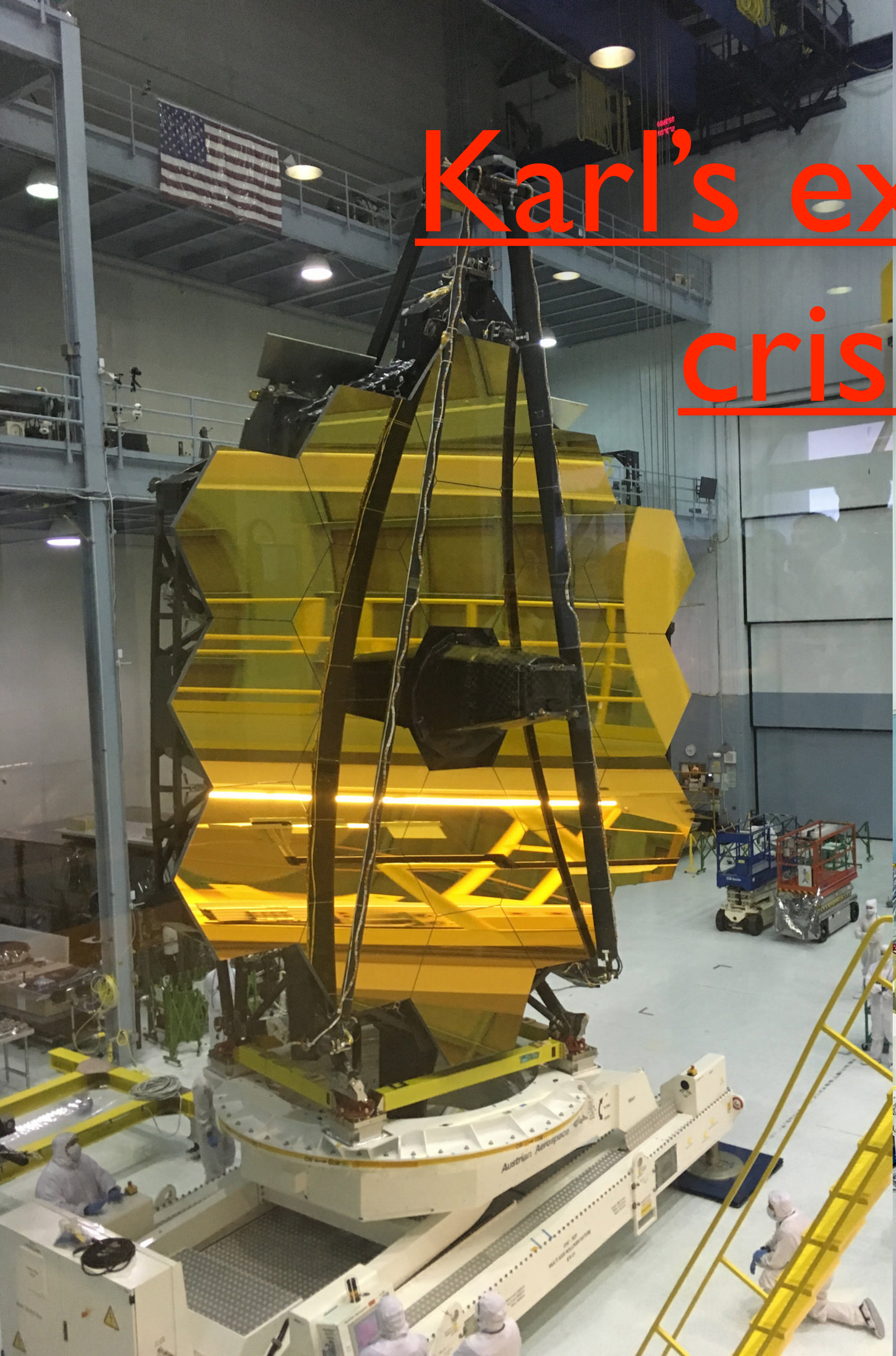
Is there one?

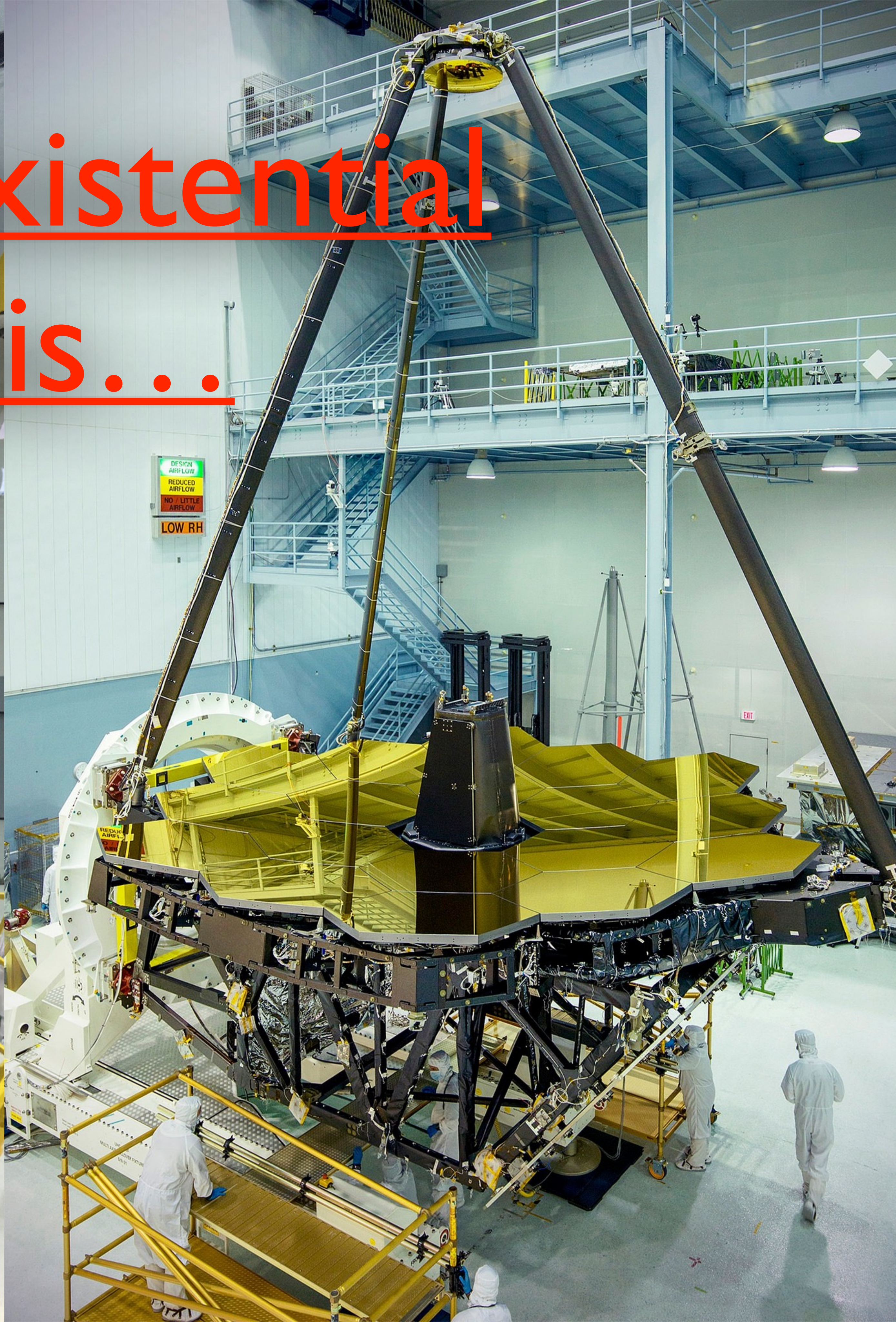
Karl Glazebrook

*not TMT/GMT :-(

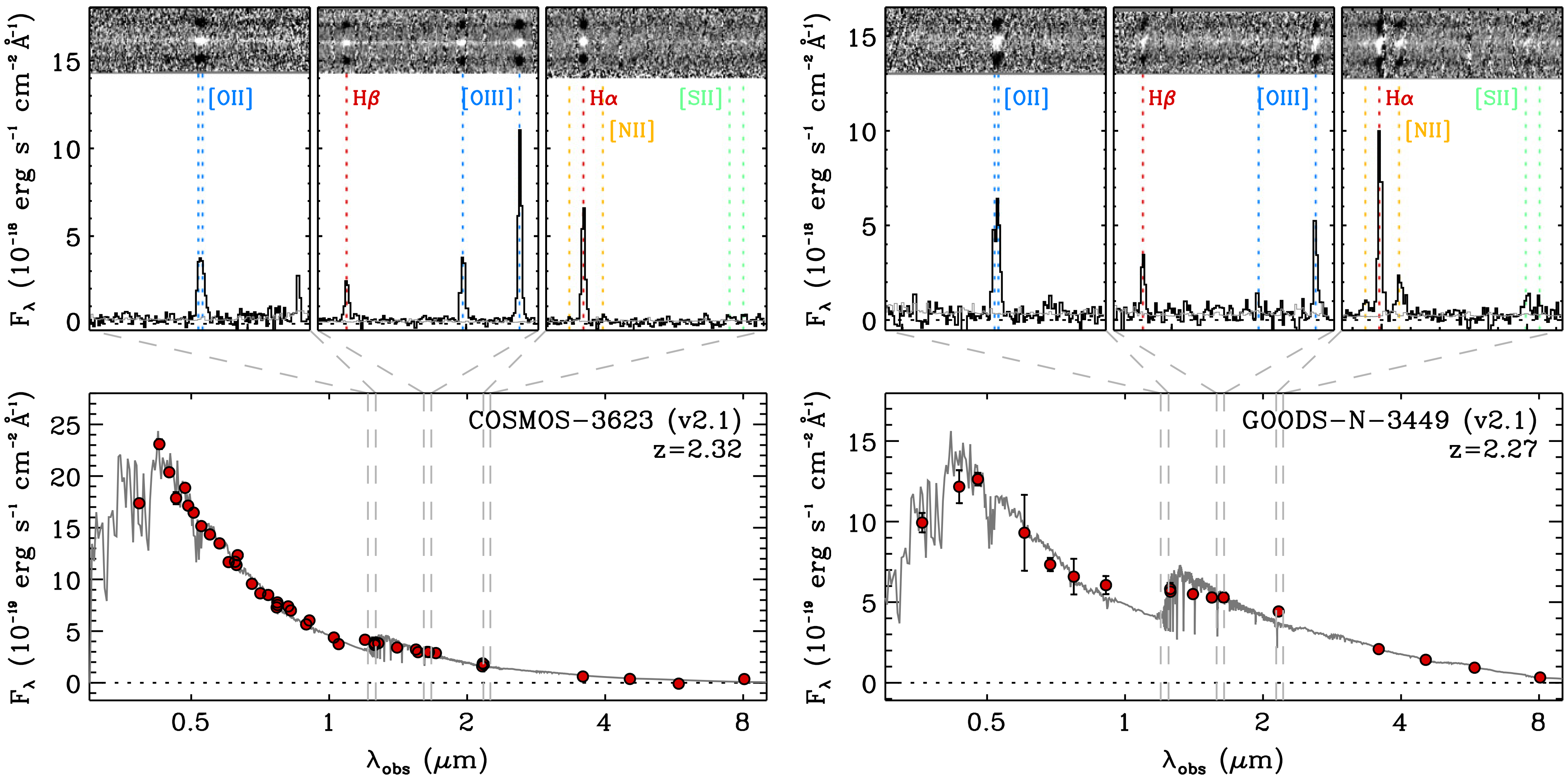
SWIN BUR NE CENTRE FOR ASTROPHYSICS AND SUPERCOMPUTING

Karl's existential crisis…

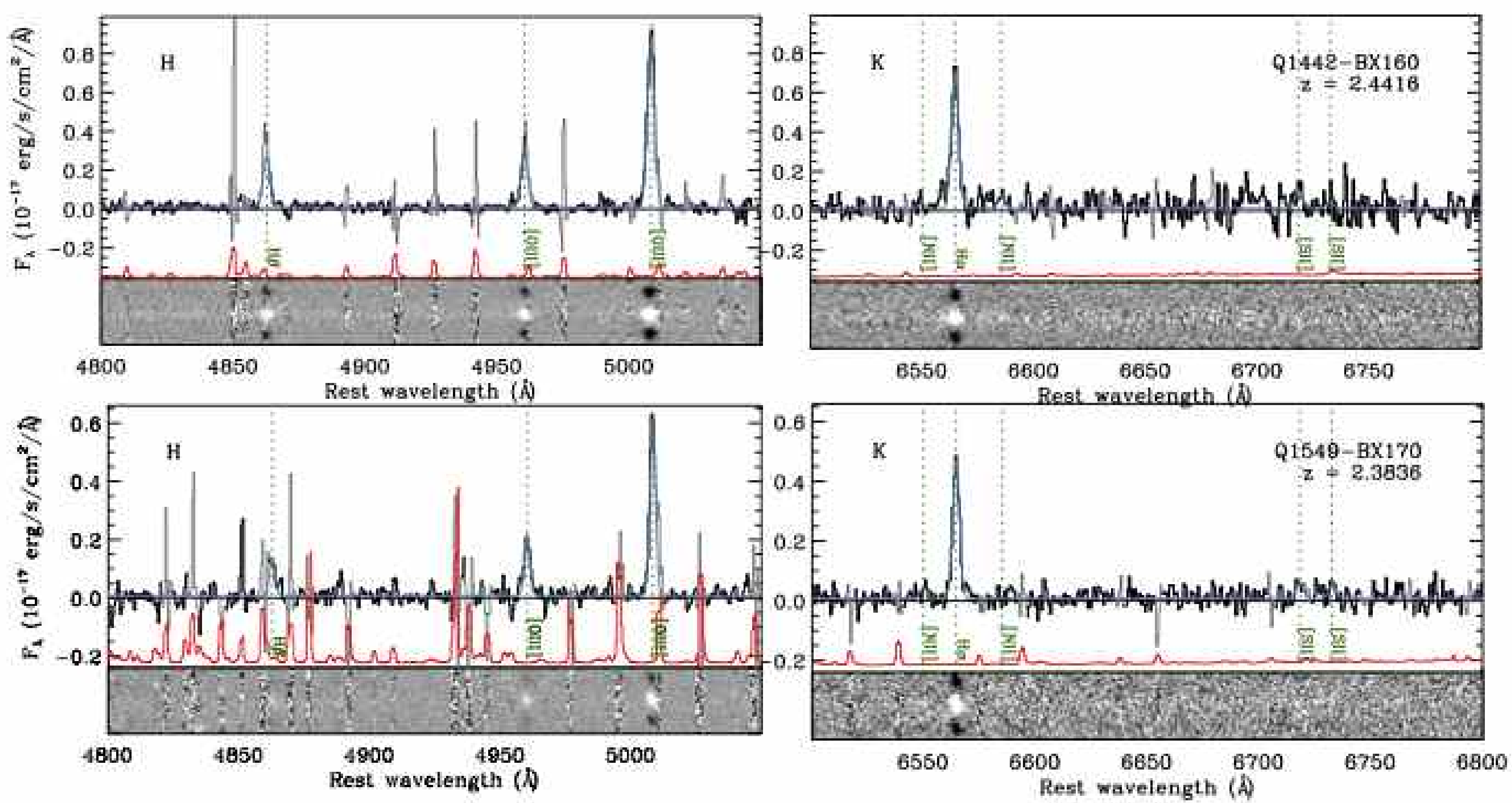




z~2 state-of-the-art galaxy spectra



MOSDEF
(Kriek+15)



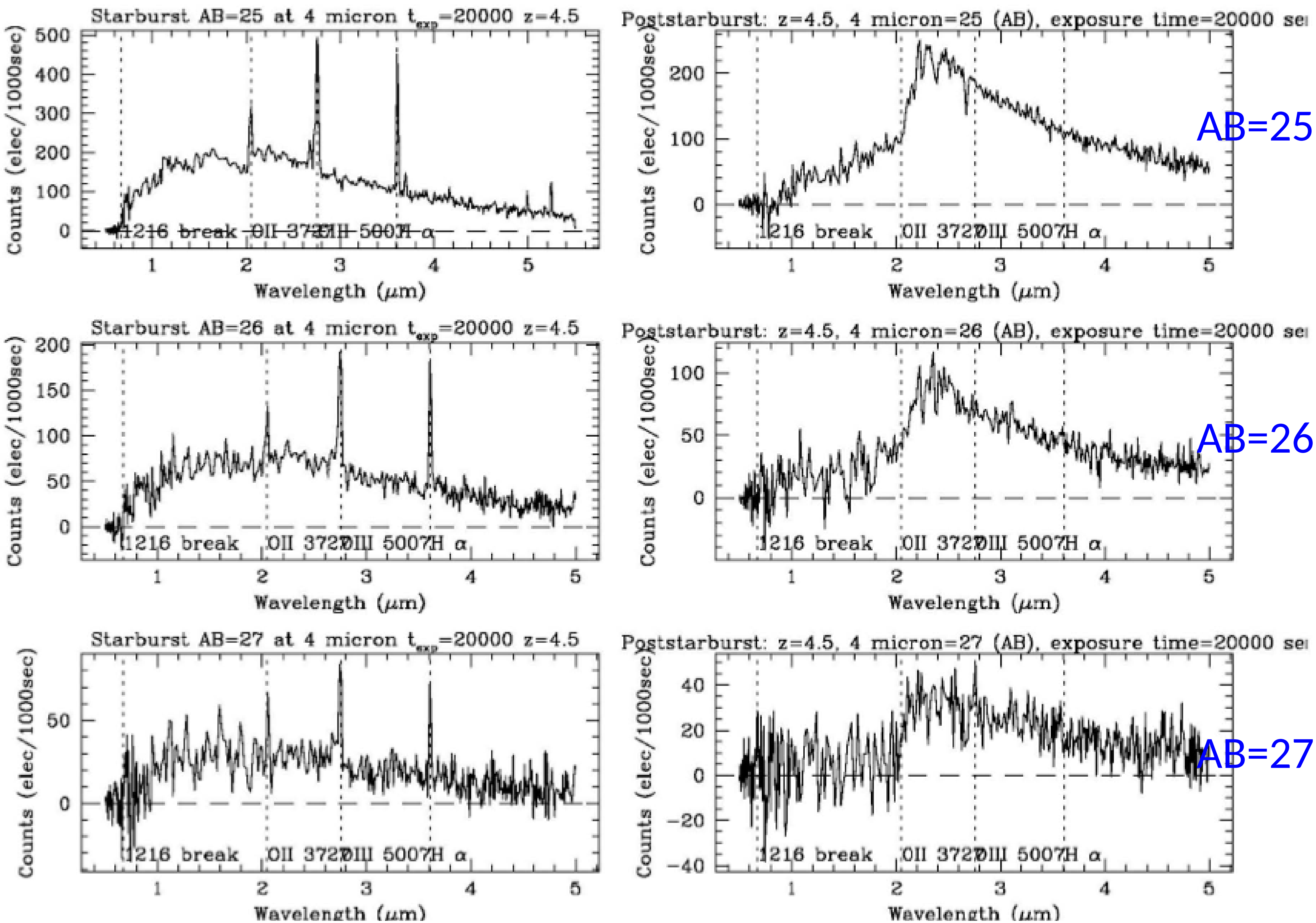
KBSS
(Steidel+15)

NIRSpec MSA simulations; T_exp = 20,000 sec z=4.5 with R100

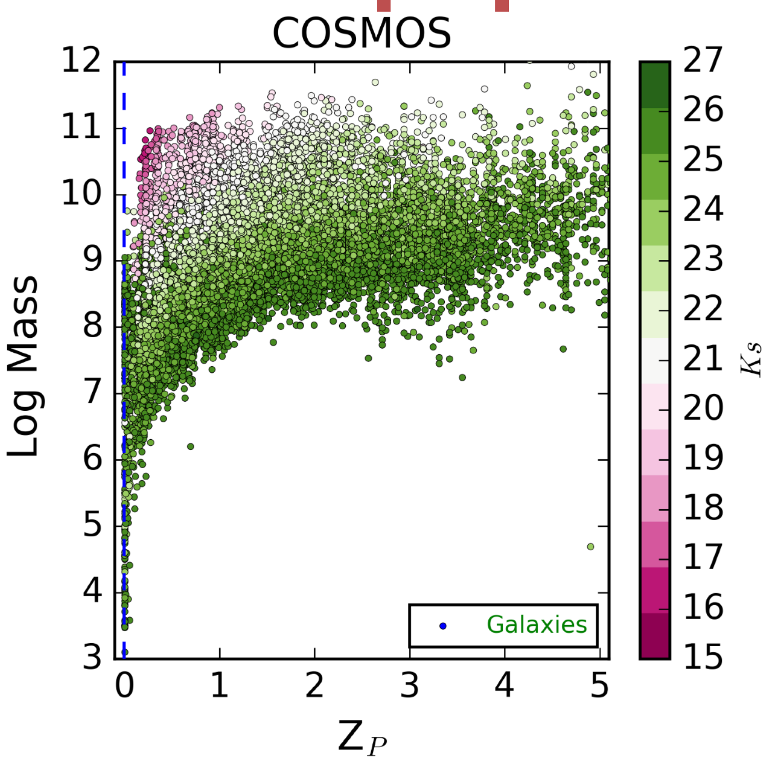
NIRSpec team (Franx, Bunker, Ferruit, Maiolino, Arribas, Charlot, Rix, Willot, Jakobsent)

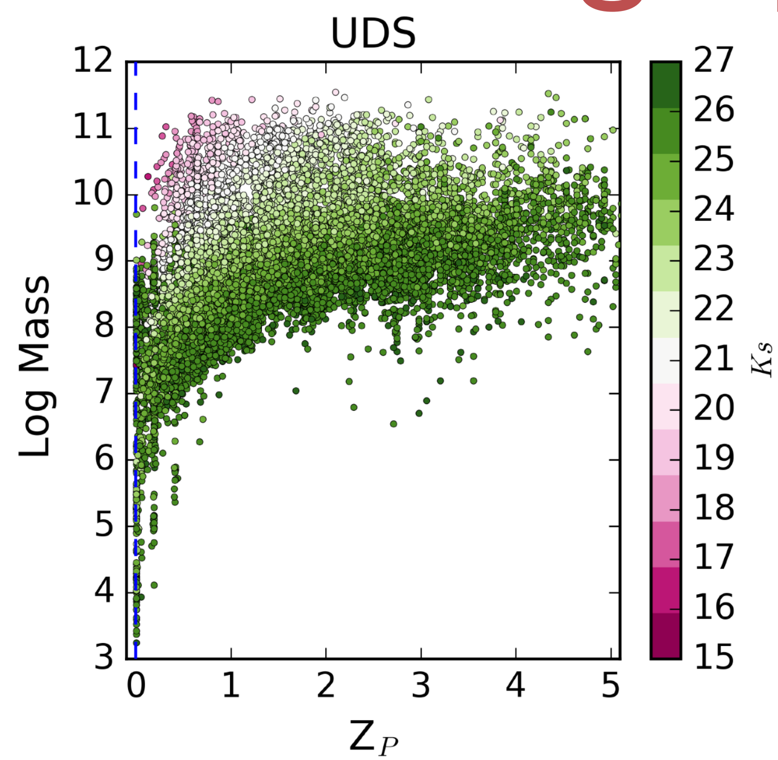
Starburst

Post-starburst

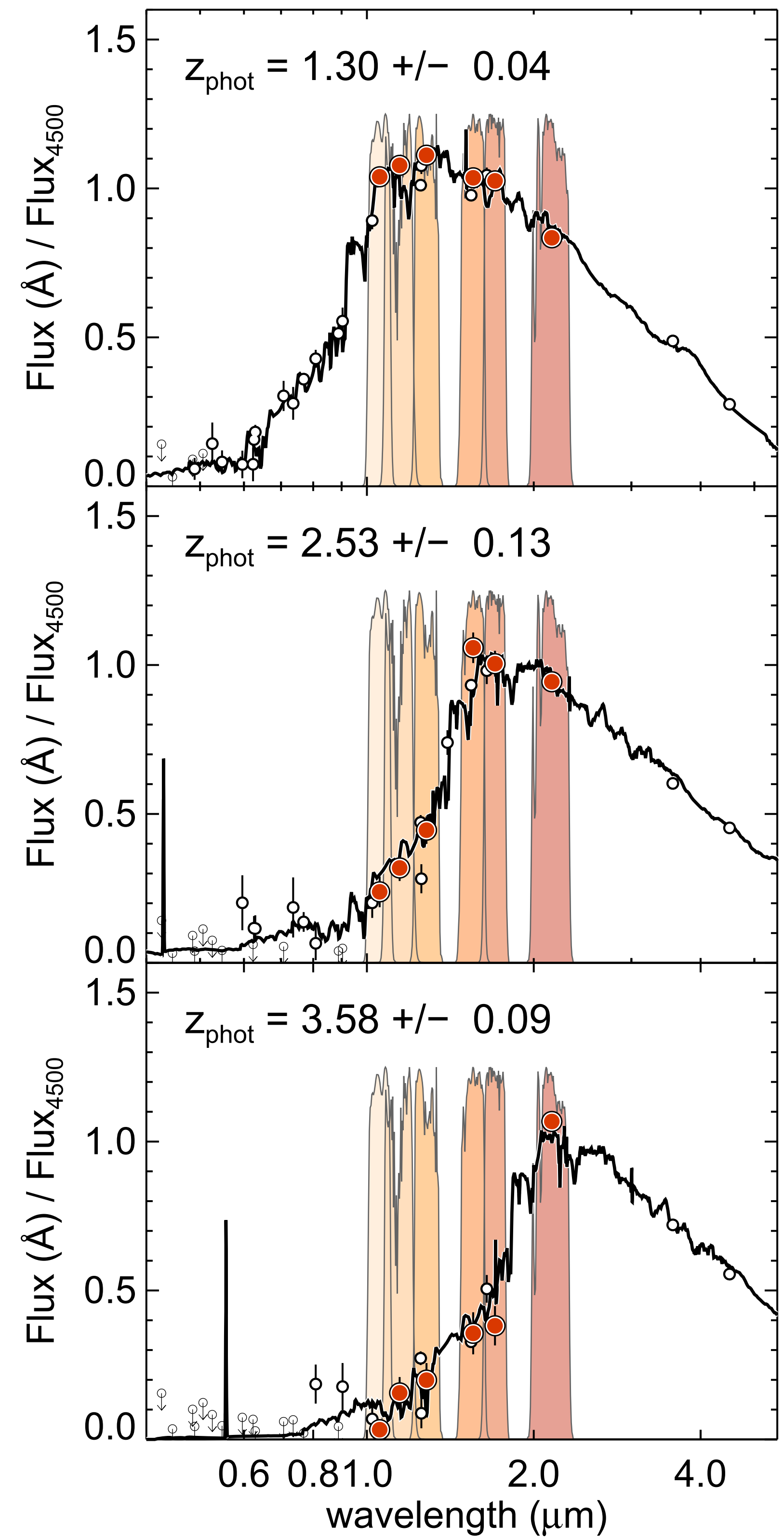


Deep photo-z ‘demographics’…

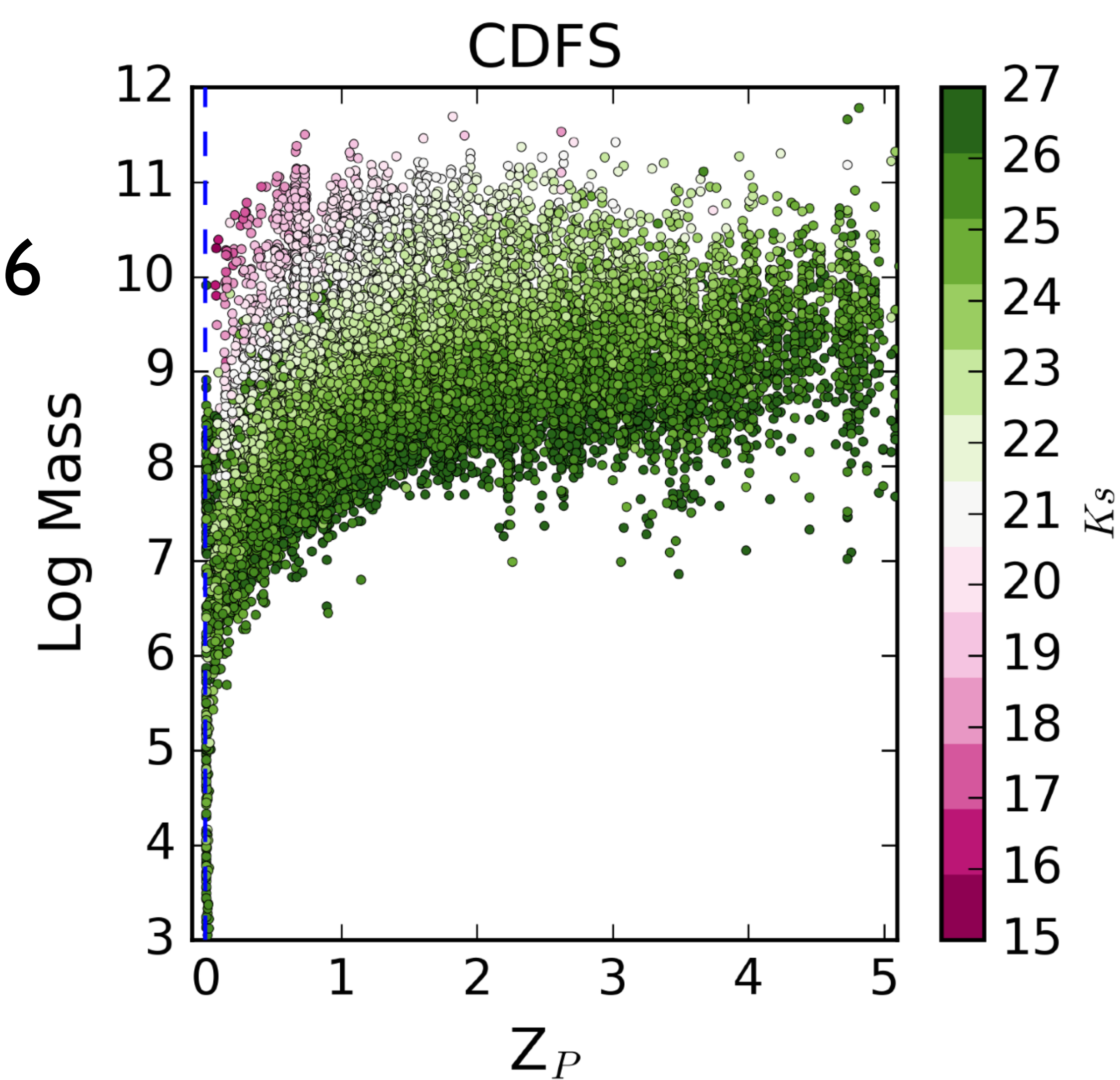




Straatman+(2016)



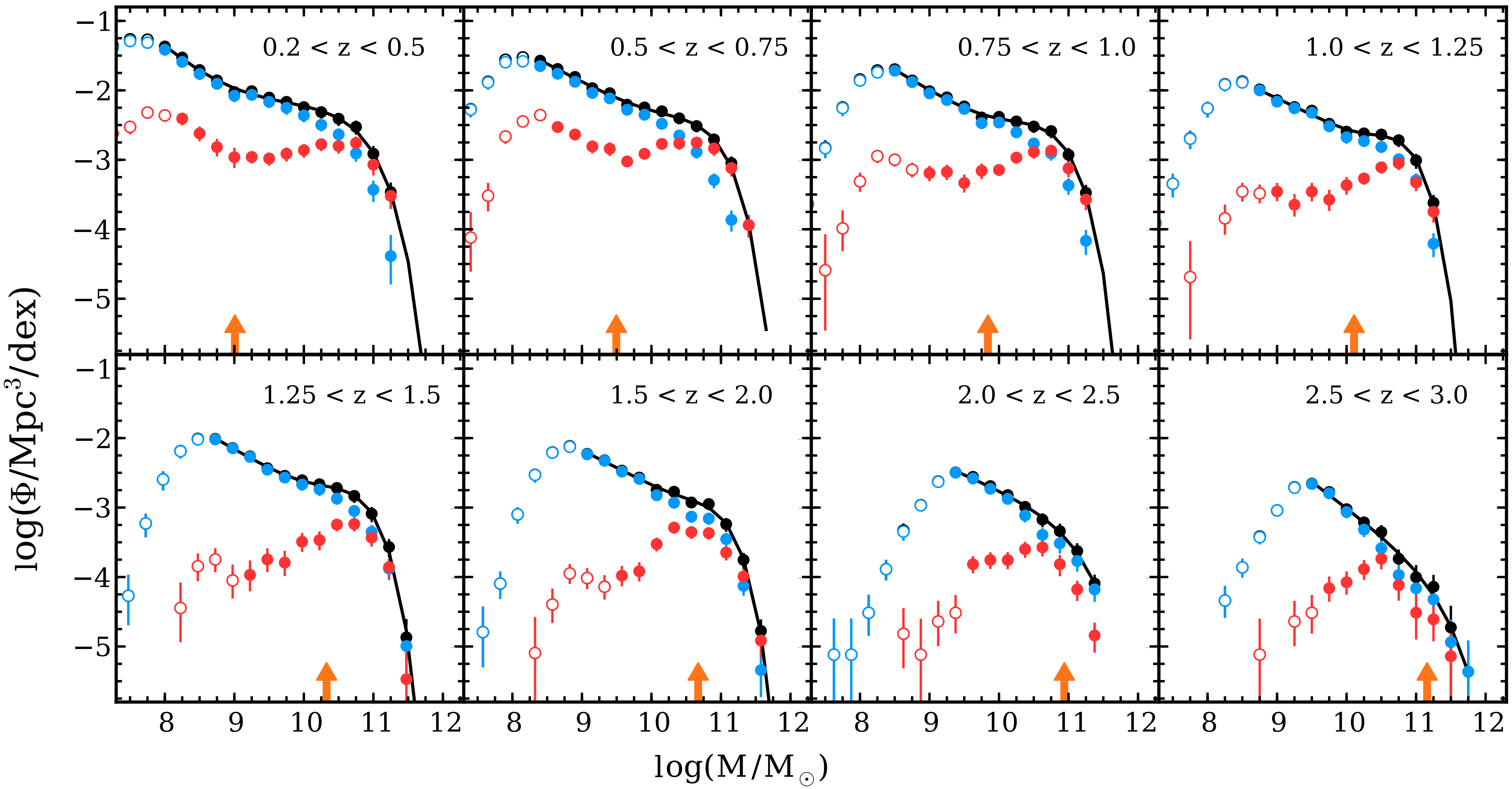
ZFOURGE
survey AB<26



Karl Glazebrook, SUT

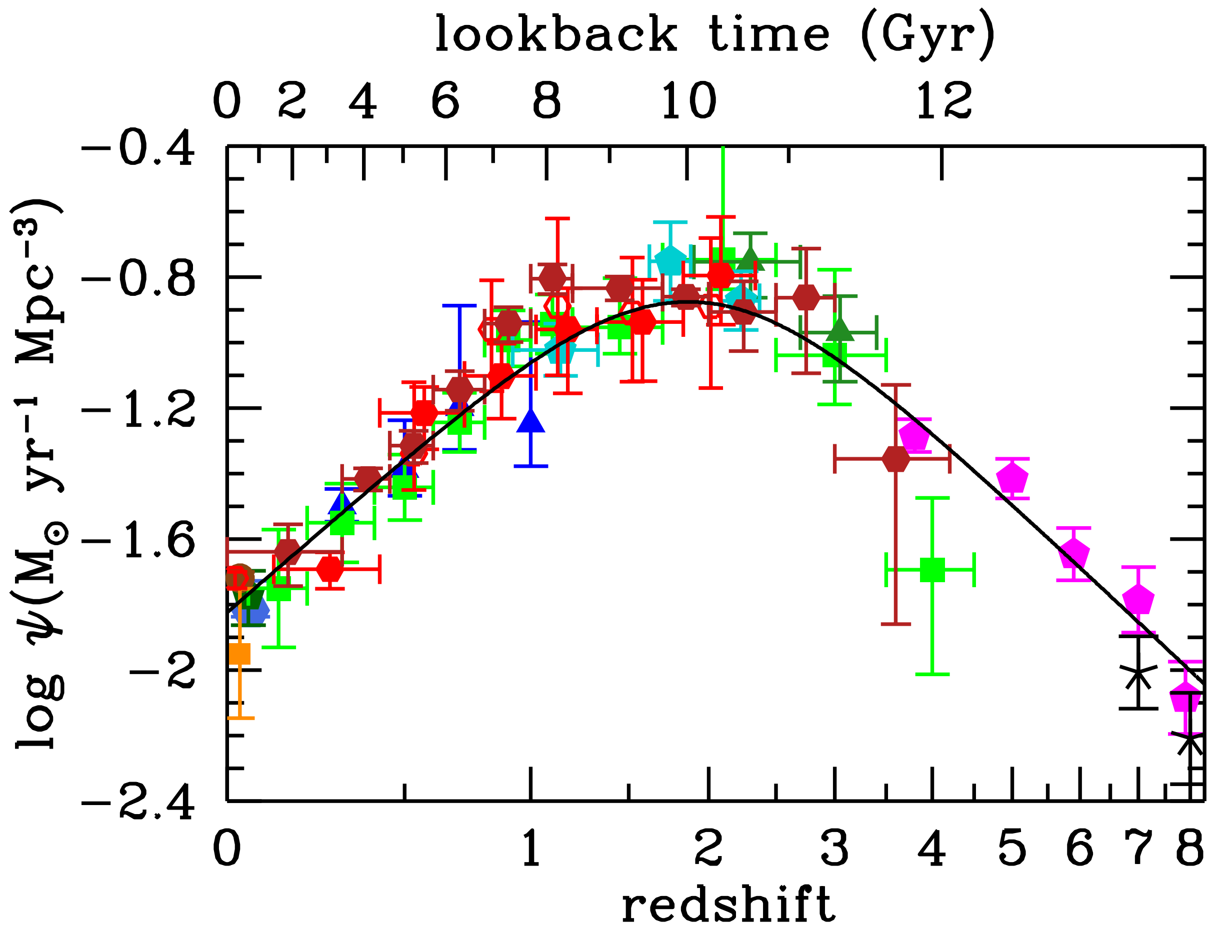
e.g. Stellar mass function evolution

SFGs / QGs

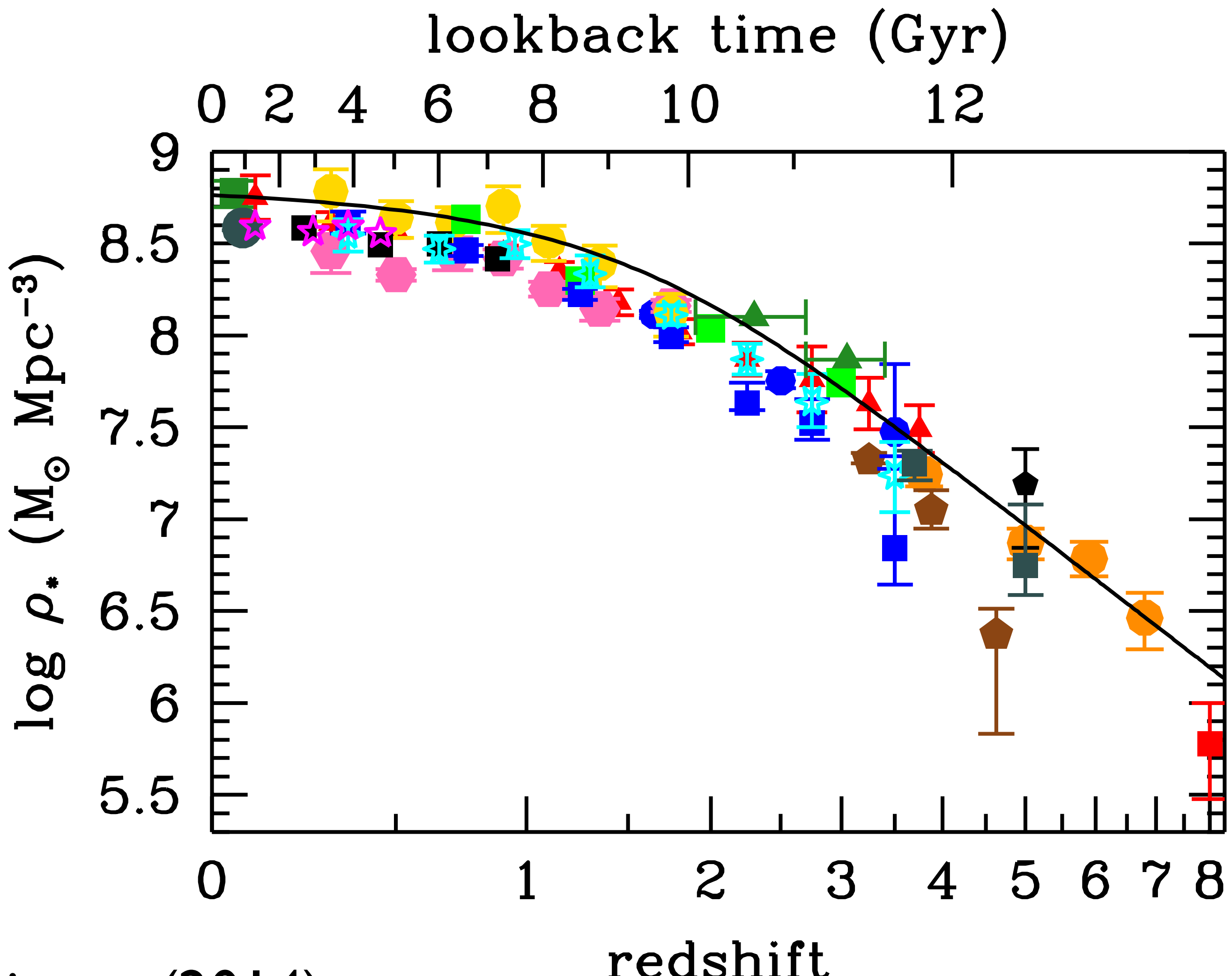


e.g. Tomczak+(2014) [ZFOURGE] & countless others…

‘photo-z demographics’



Cosmic SF density history



Cosmic stellar mass density history

Madau & Dickinson (2014)

Karl Glazebrook, SUT

Topics I will focus on (an incomplete list…)

- Stellar populations
- Photo-ionisation
- Environment
- Kinematics

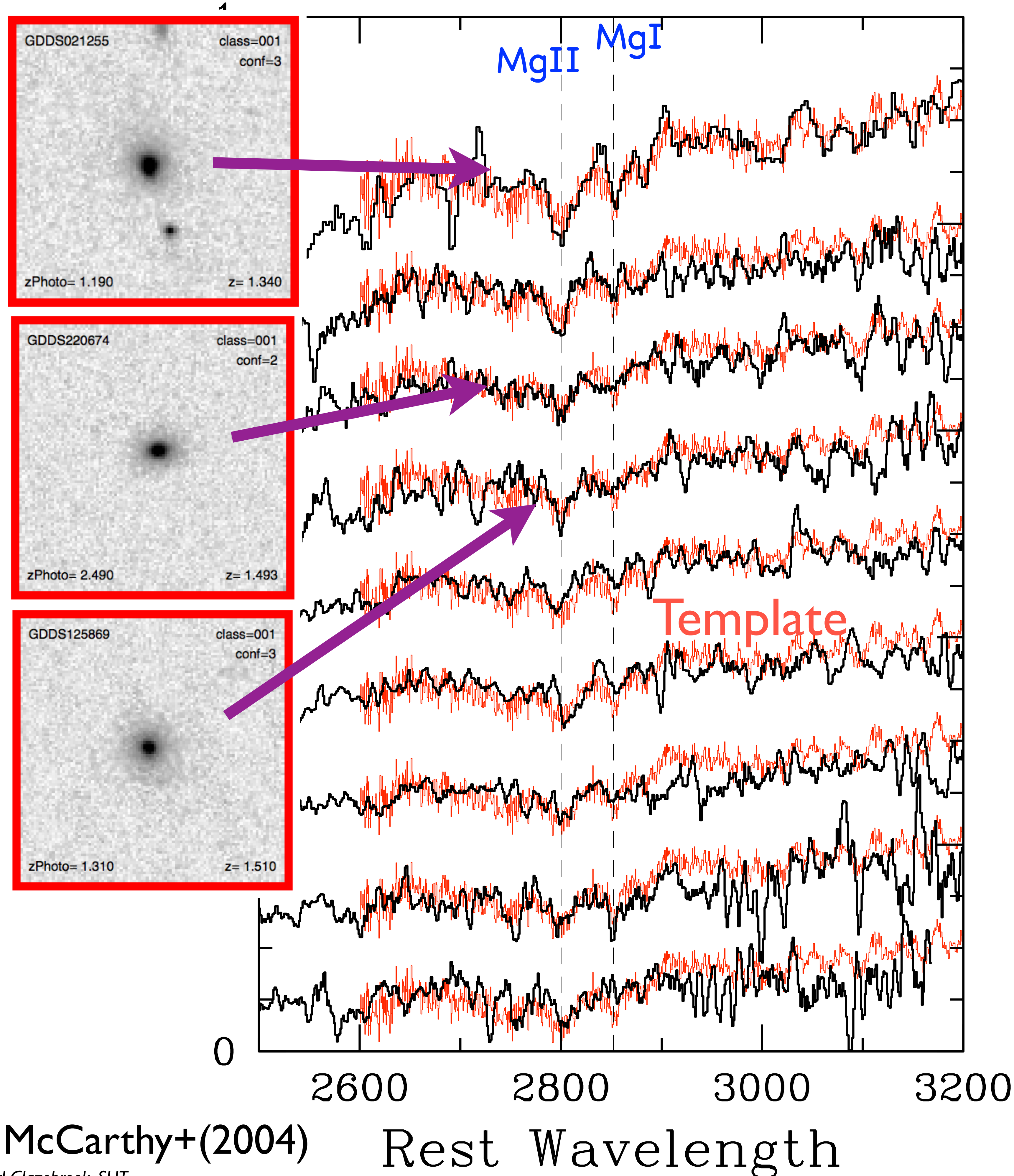
Topics I will focus on

- Stellar populations
  – rest-frame optics absorption lines, star-formation histories, abundances, ideally for mass-complete samples

- Photo-ionisation

- Environment

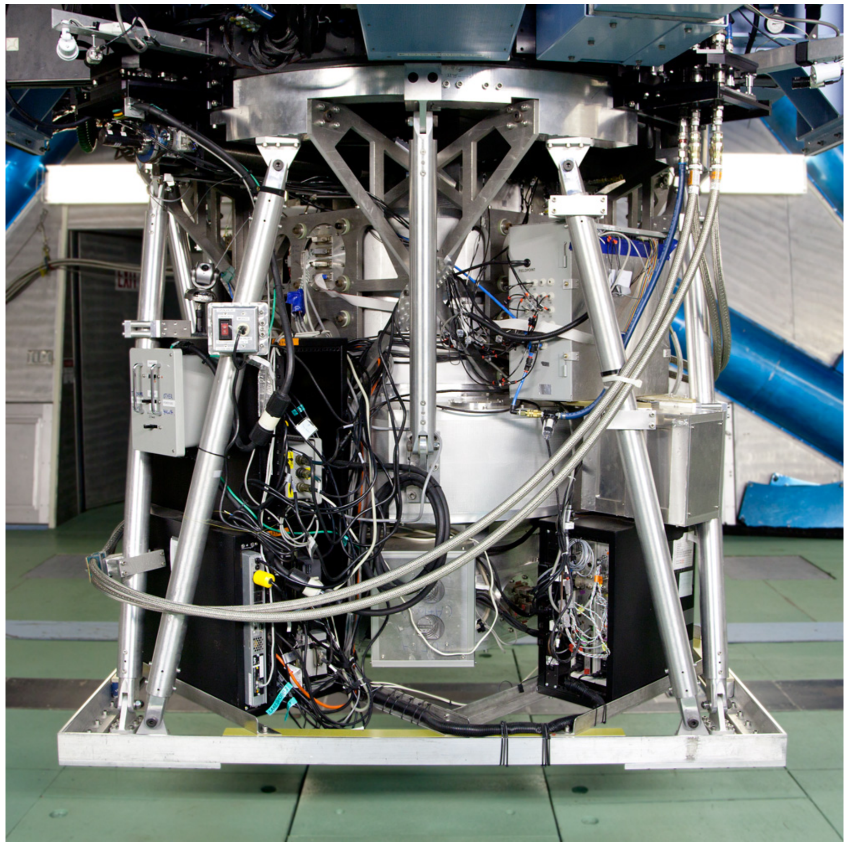
- Kinematics



McCarthy+(2004)

- Deep 8m optical spectra: reach AB~25 in 10-30h exports (GDDS, K20, GMASS) for absorption line work – stalled around ~ 2005.
- Tip of the mass function at z~2 for passive red galaxies, brightest LBGs at z>2.

The recent revolution

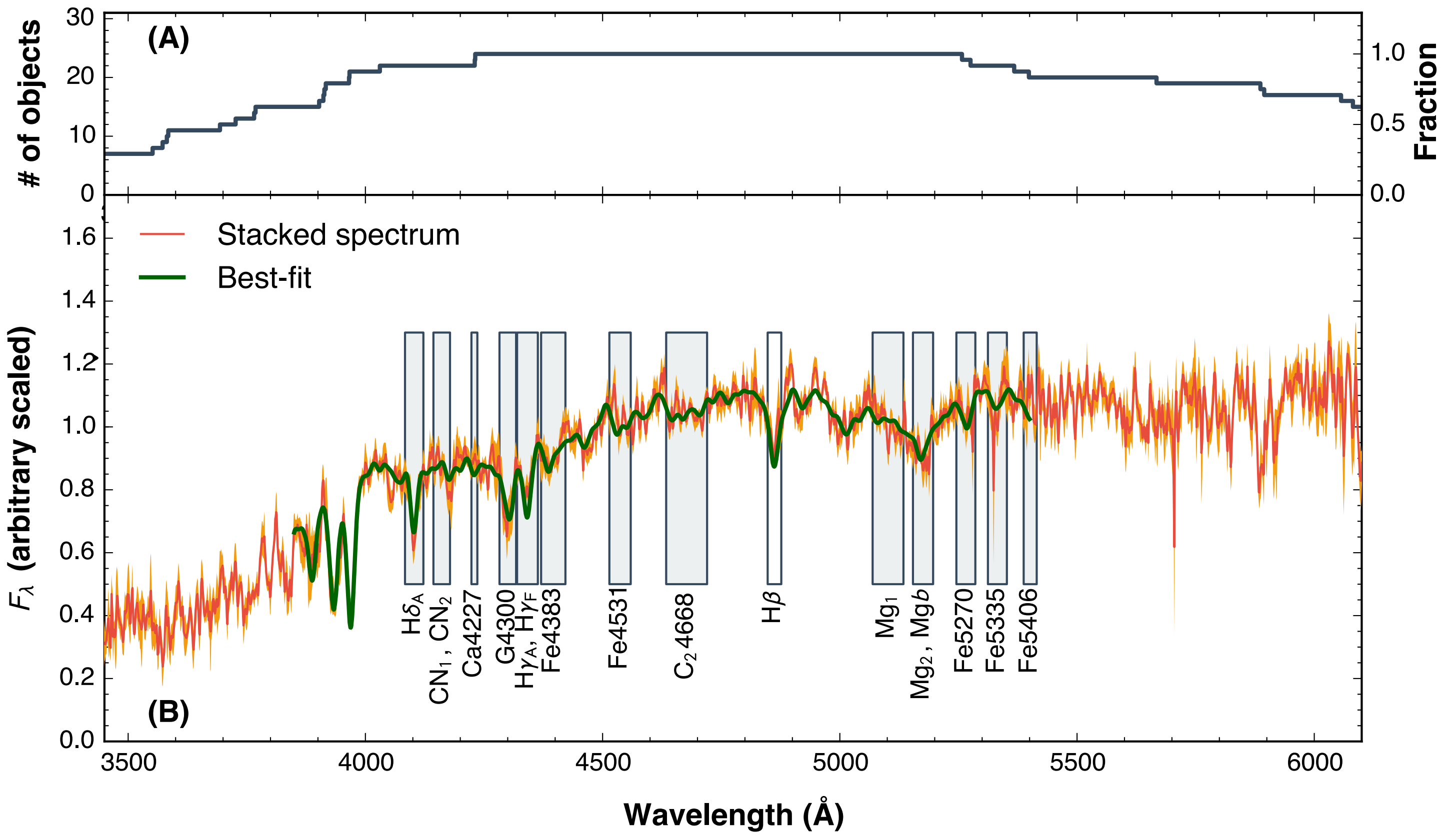


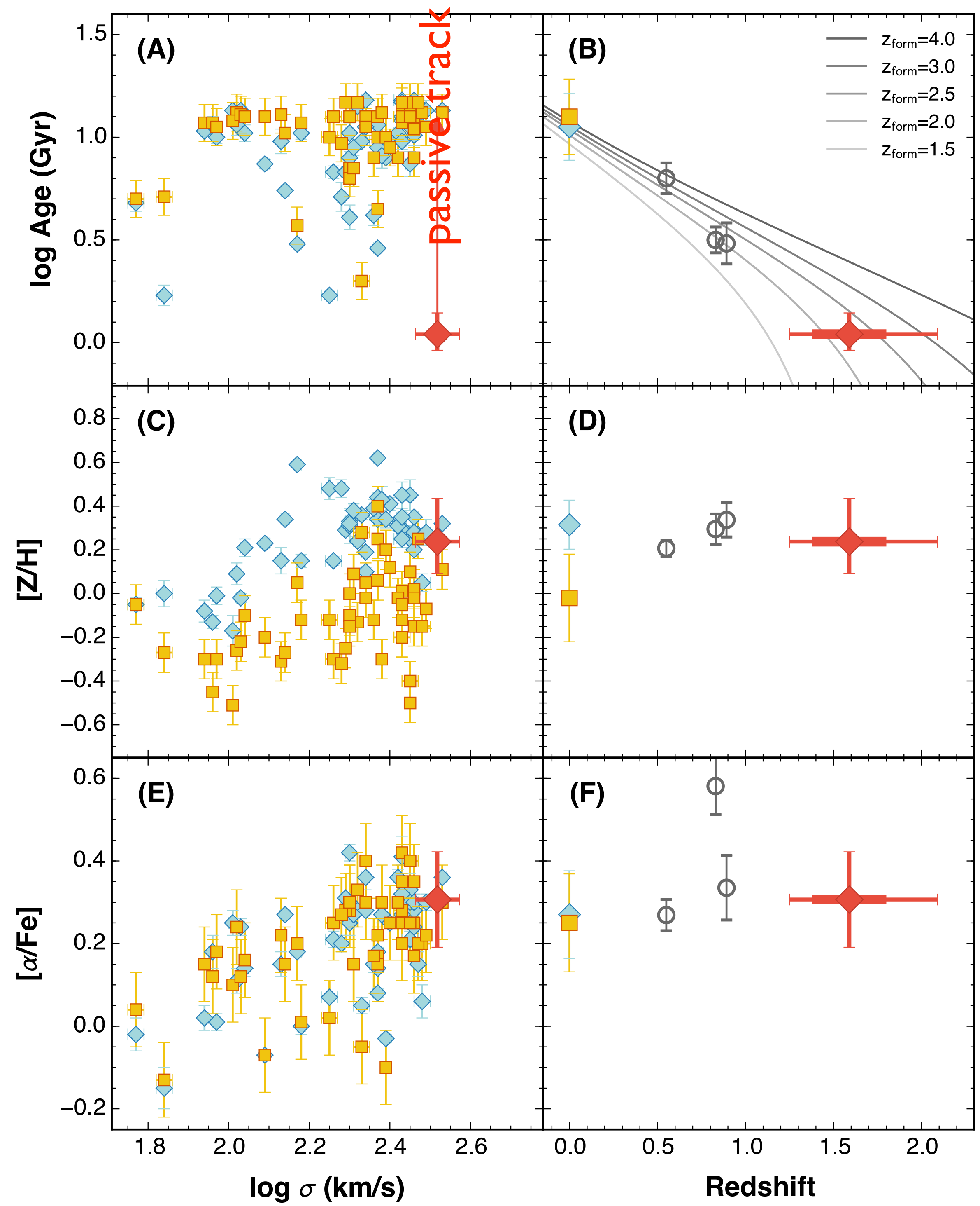
MOIRCS

X-SHOOTER

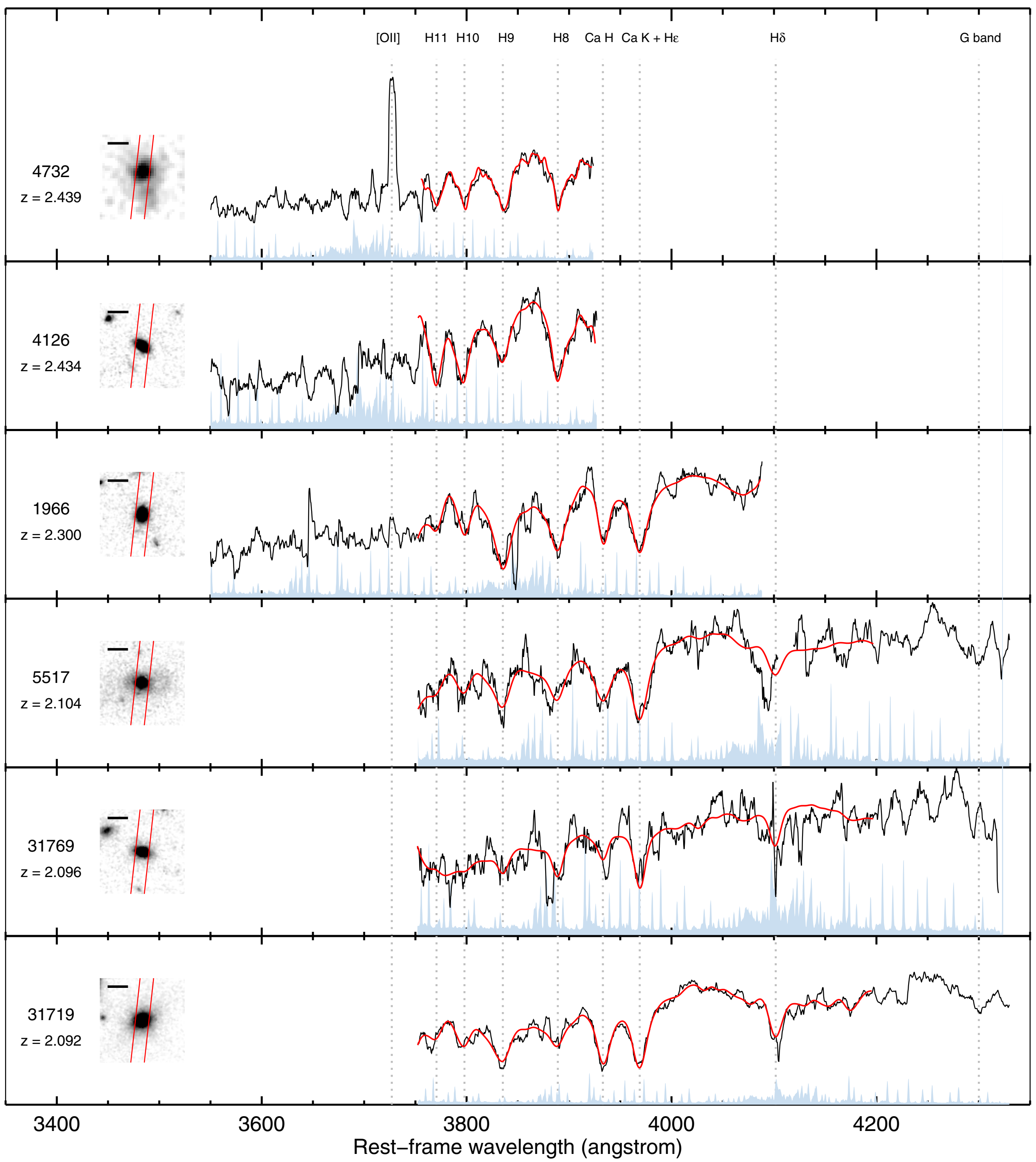
Karl Glazebrook, SUT

24 quiescent galaxies z~1.6 (Onodera+2015, MOIRCS)

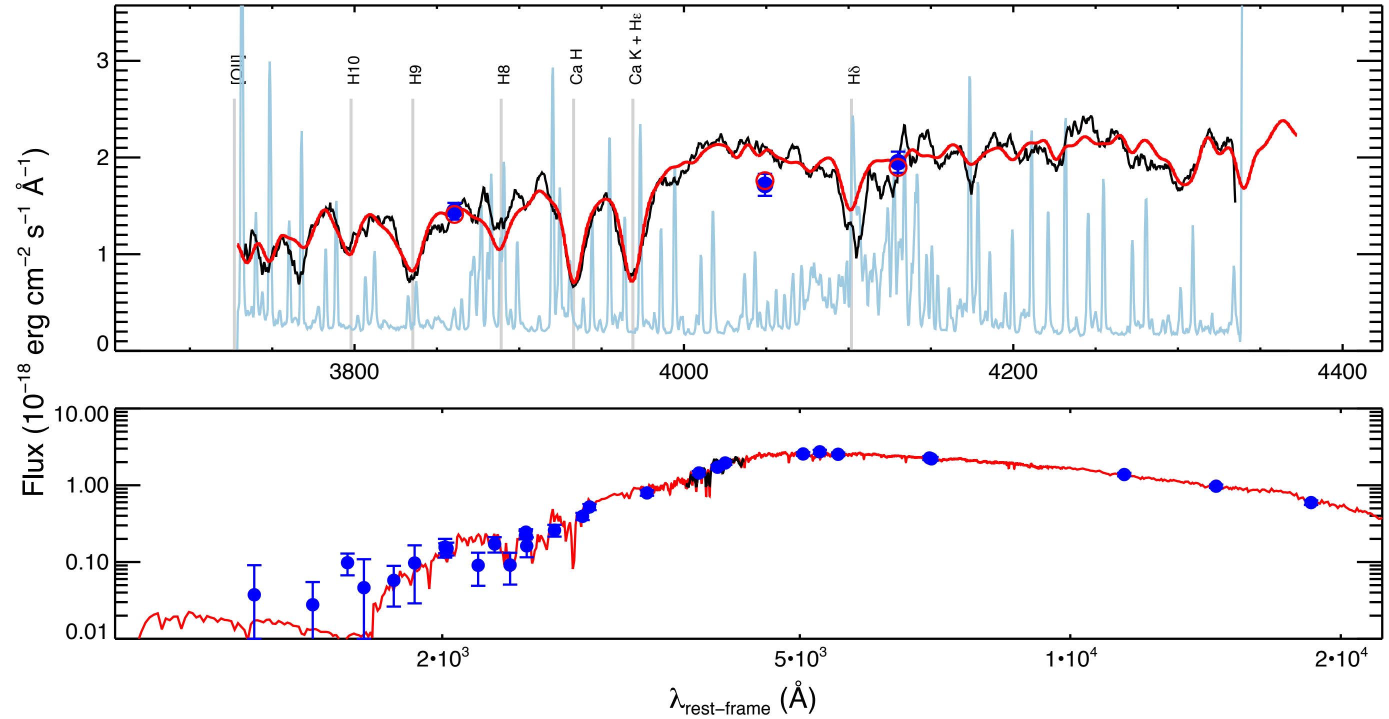




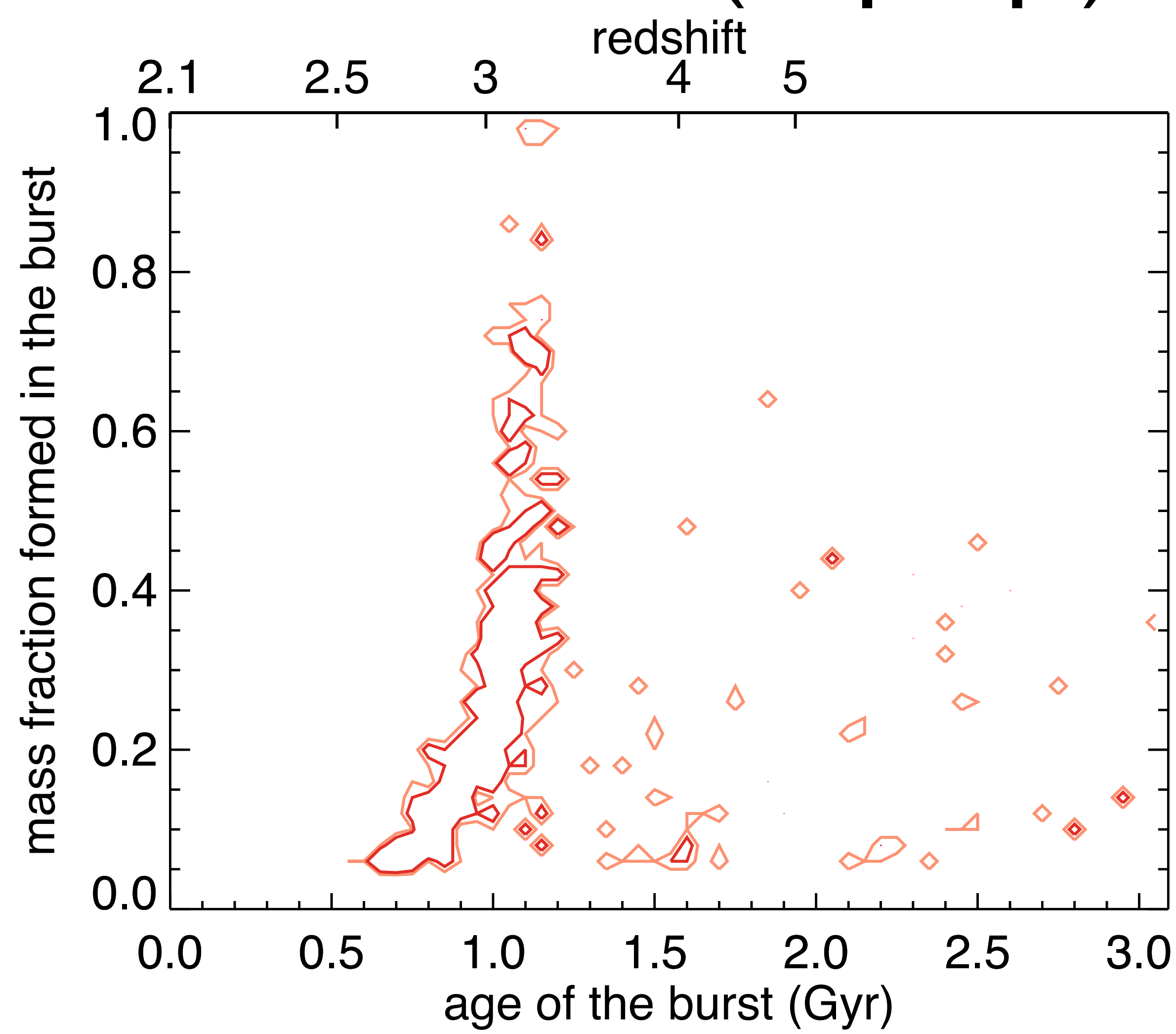
formed at z~2.3



Belli+15 (MOSFIRE z~2)

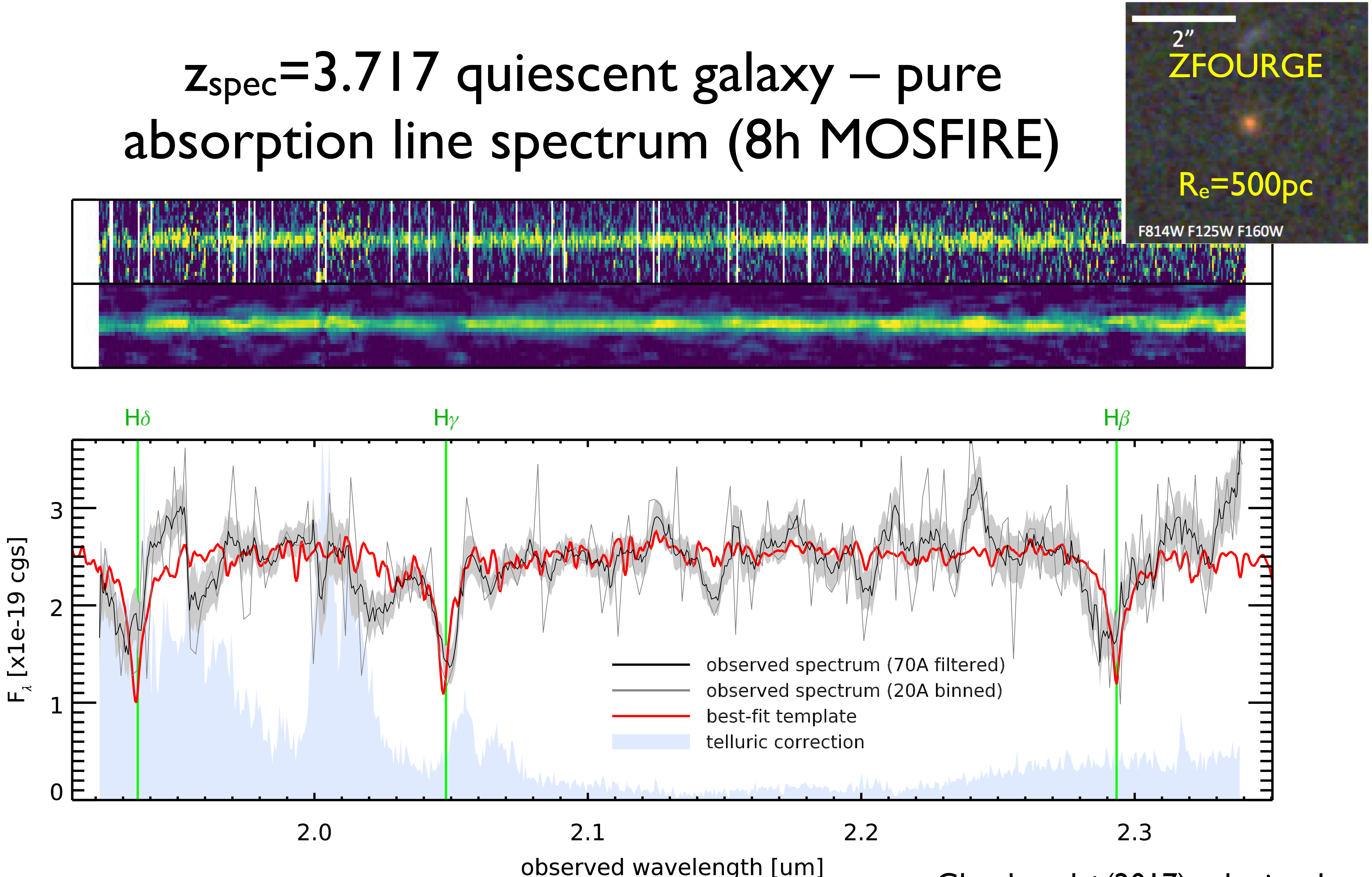


Belli+ (in prep.)



Karl Glazebrook, SUT

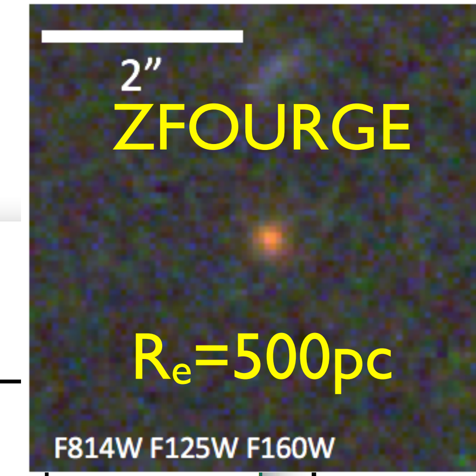
z_{spec}=3.717 quiescent galaxy – pure absorption line spectrum (8h MOSFIRE)



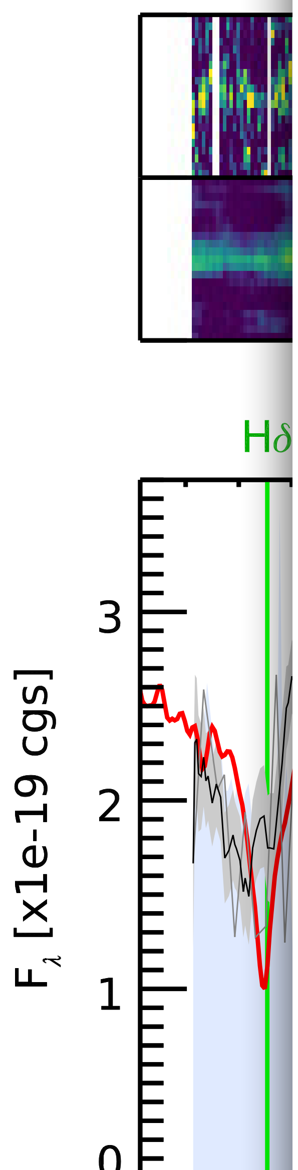
Glazebrook+(2017) submitted

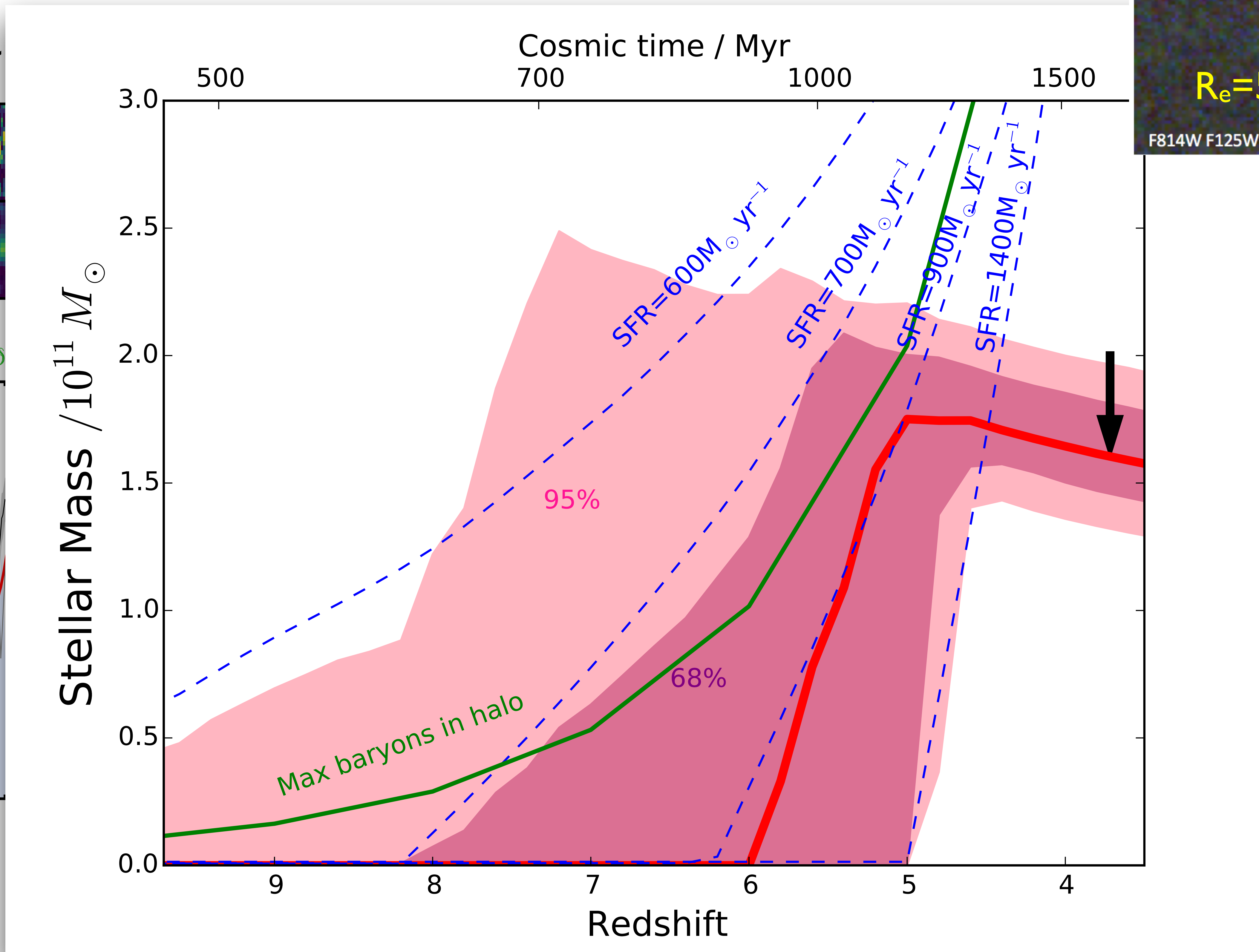
K-band, K(AB)=22.4, stellar mass =$1.7 \times 10^{11} M_\odot$

z_{spec}=3.717 quiescent galaxy – pure



a



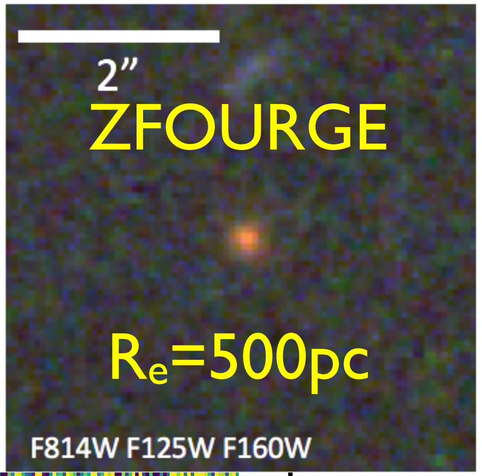


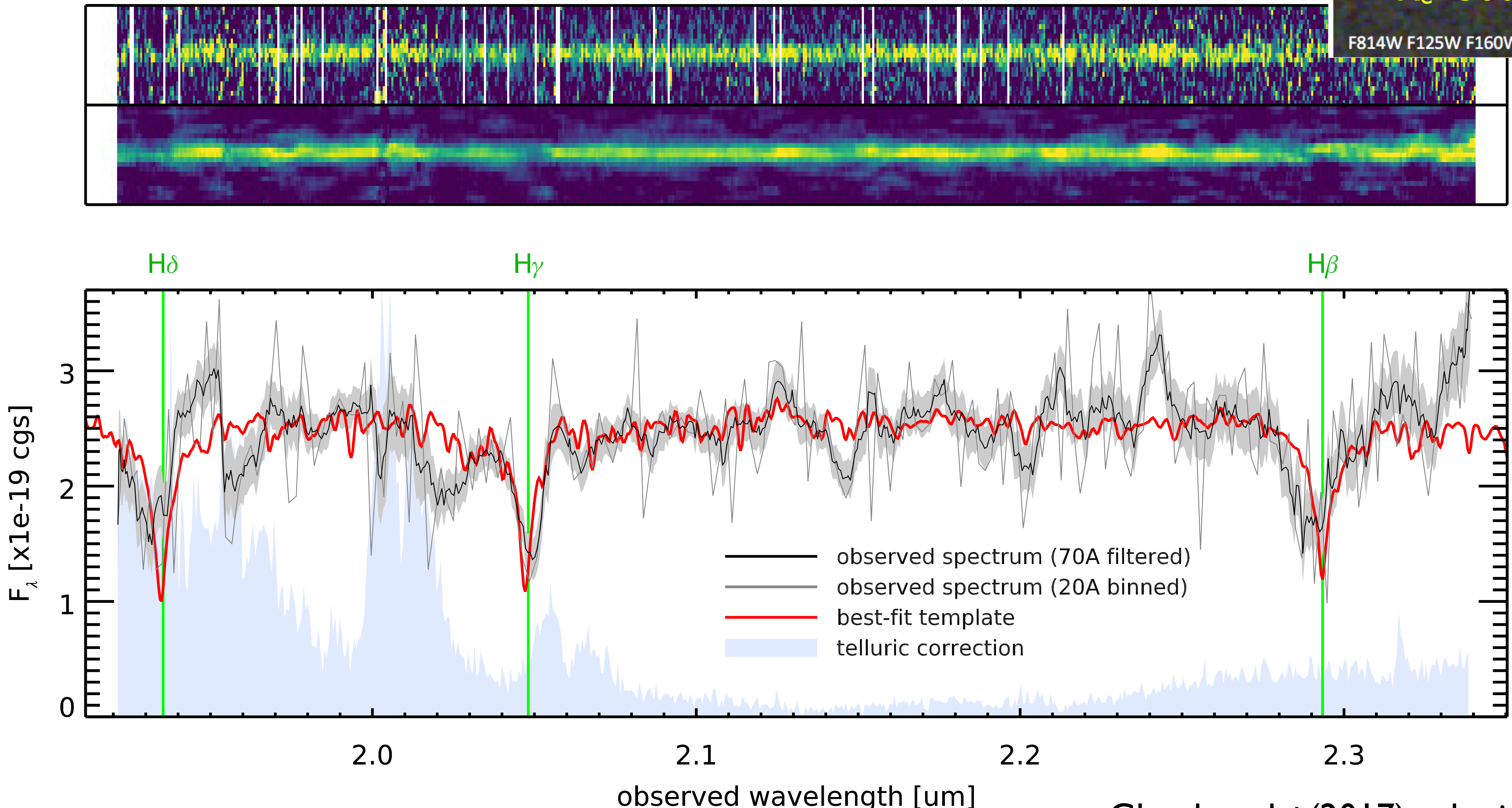
mitted

K-band, K(AB)=22.4, stellar mass =1.7x10^{11}M$_\odot$

Karl Glazebrook, SUT

z_{spec}=3.717 quiescent galaxy – pure absorption line spectrum (8h MOSFIRE)

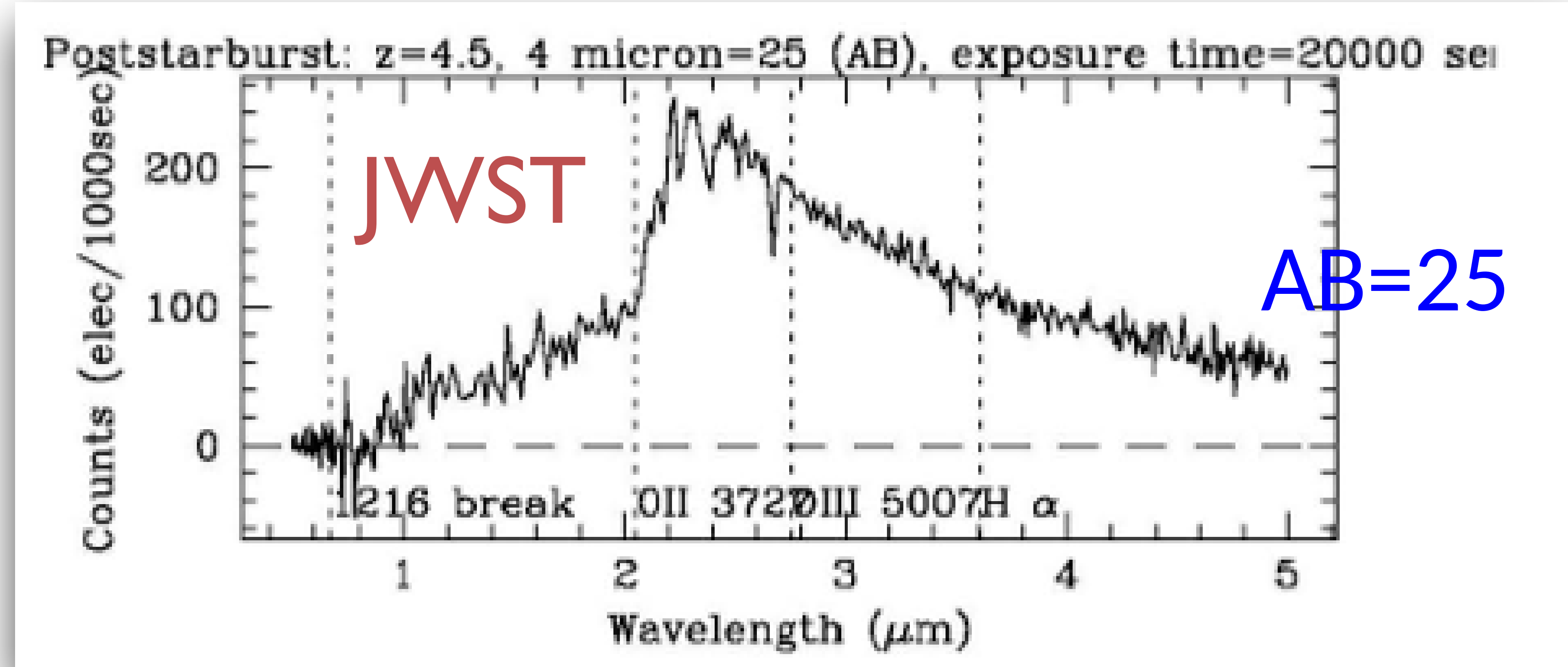


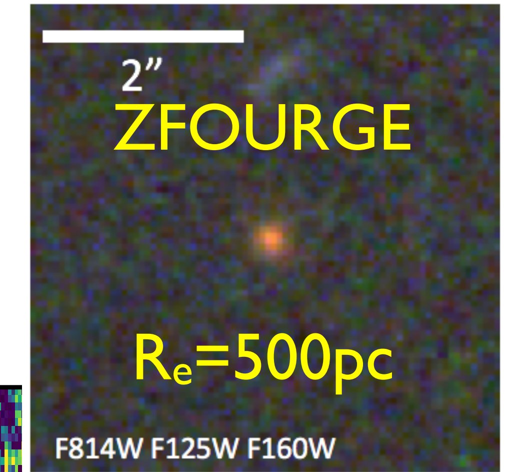


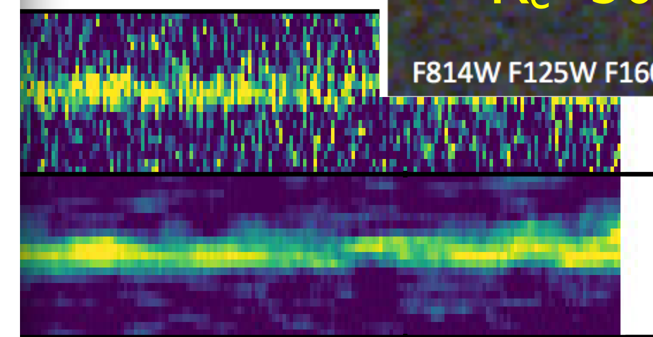
Glazebrook+(2017) submitted

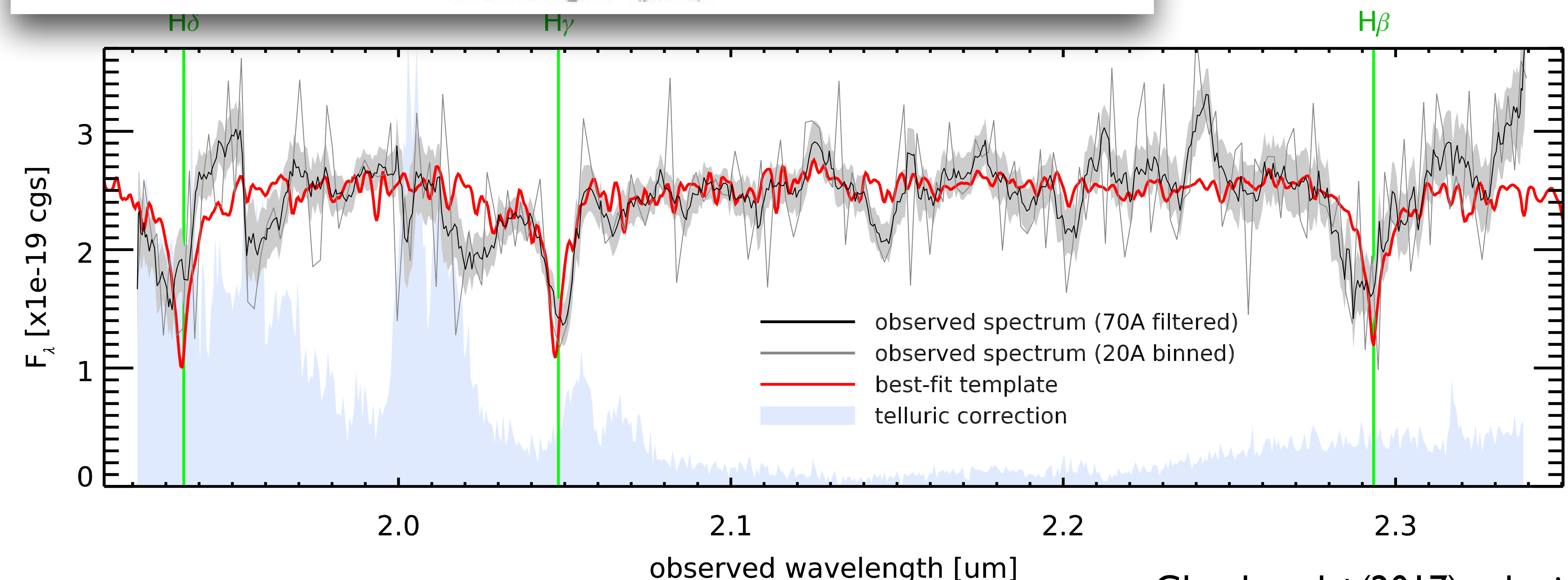
K-band, K(AB)=22.4, stellar mass $=1.7\times10^{11} M_\odot$

ure
FIRE)







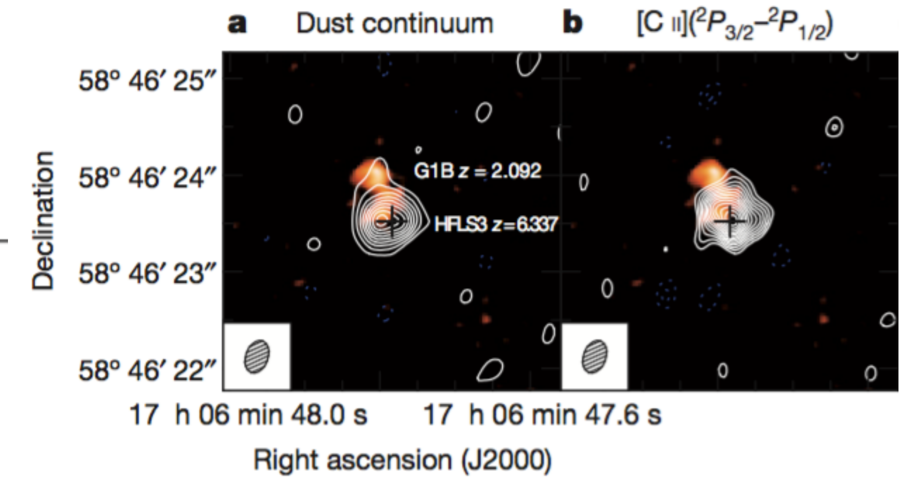


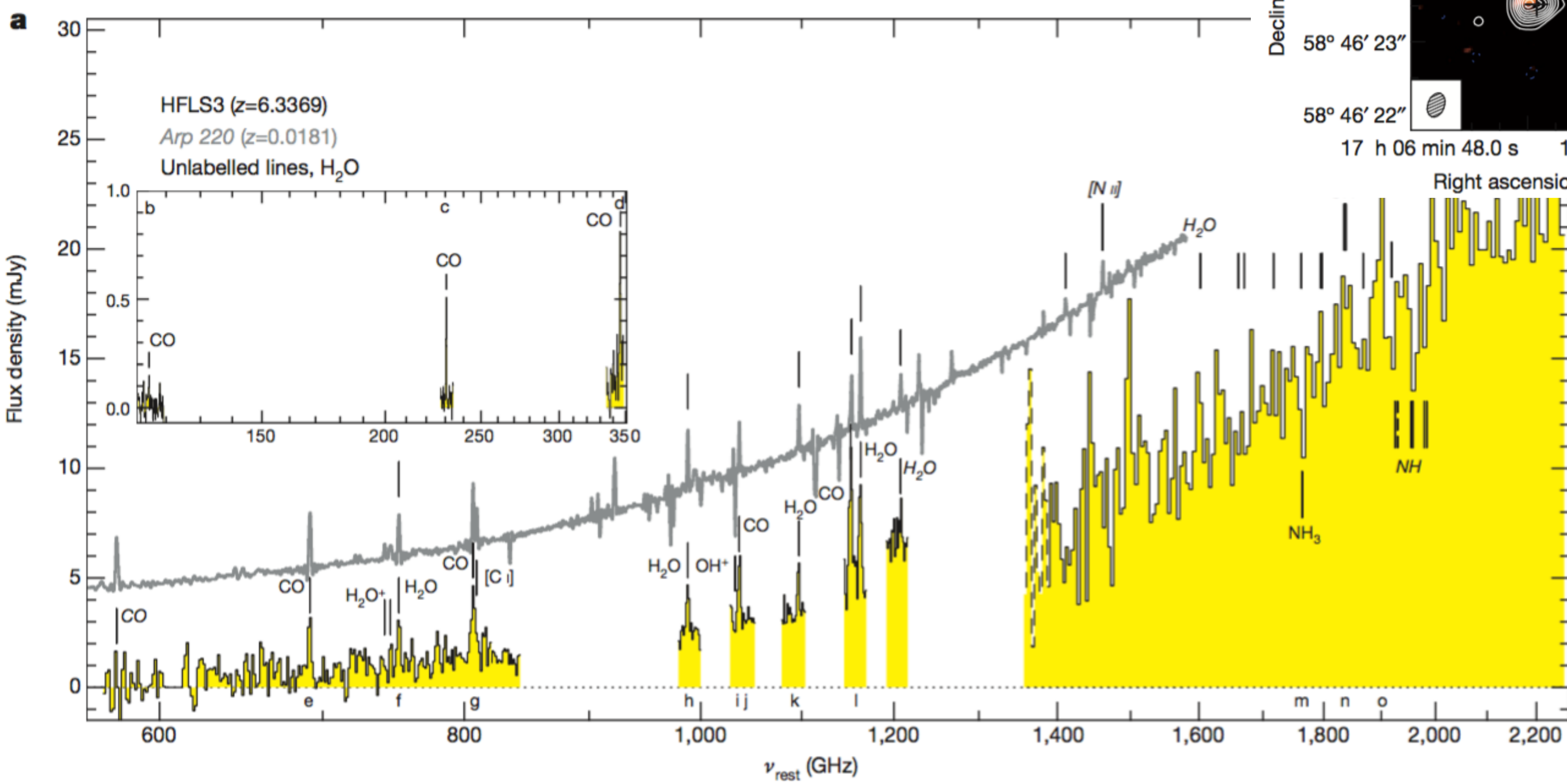
Glazebrook+(2017) submitted

K-band, K(AB)=22.4, stellar mass =$1.7 \times 10^{11} M_{\odot}$

Observed ancestors?

Need SFR > 1000 $M_\odot yr^{-1}$ at z>5





ALMA detection (Riechers et al. 2016), z=6.3

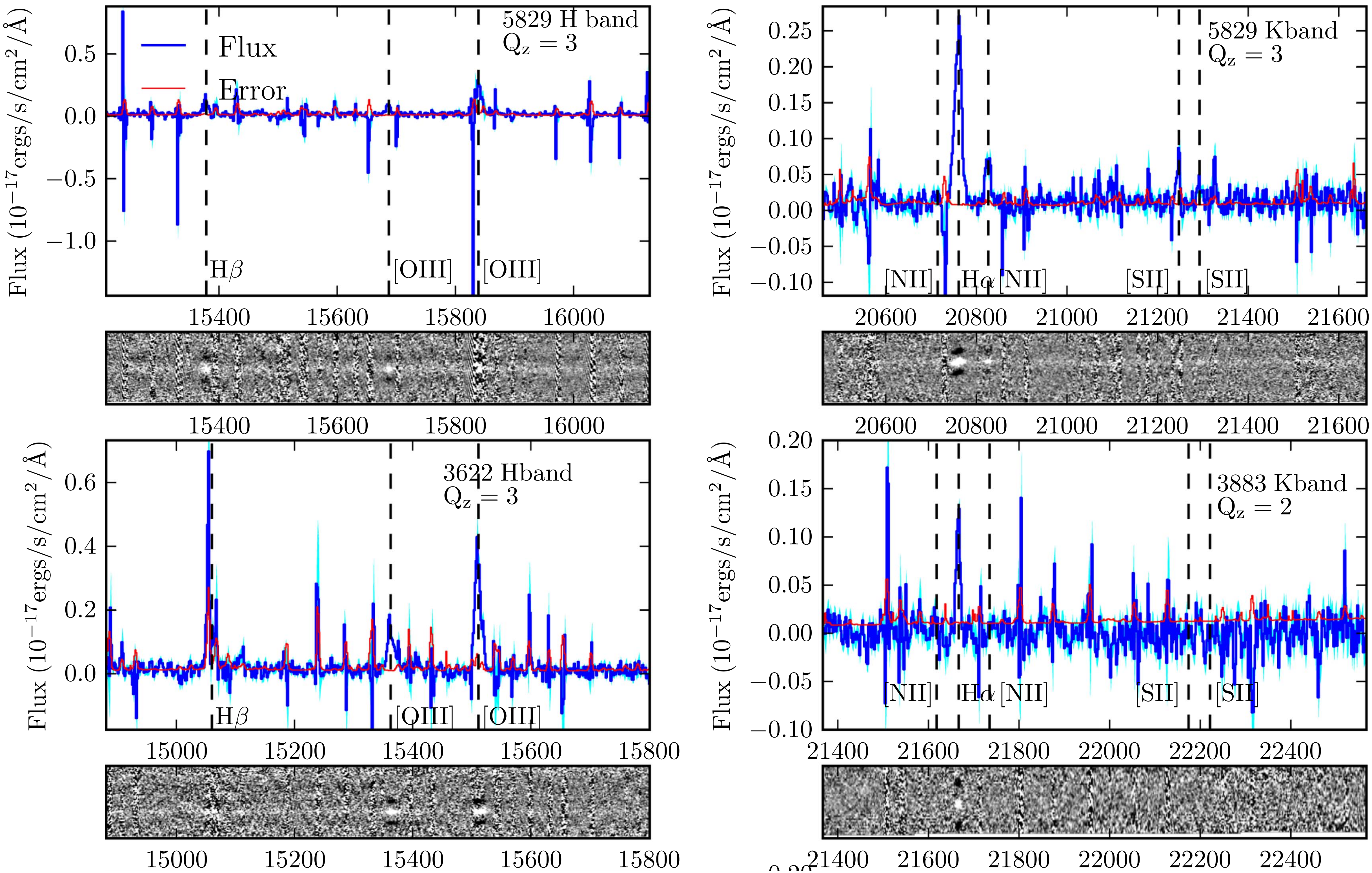
SFR = 2900 $M_\odot yr^{-1}$ *Stellar* mass 3.7x10^{10} $M_\odot$

Dynamical mass 2.7x10^{11} $M_\odot$

Topics I will focus on

- Stellar populations (JWST wins)
- Photo-ionisation: puzzles
  - z>2 emission lines now 'easy' from the ground
  - we don't know what is going on in the ISM…
- Environment
- Kinematics

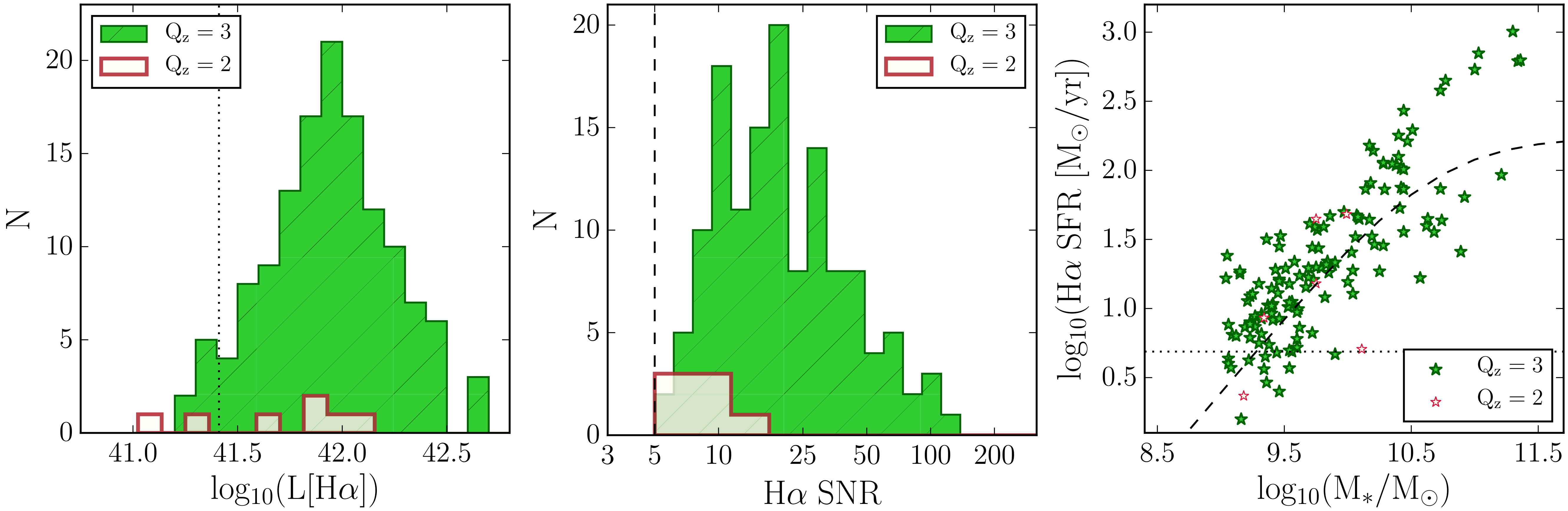
'Easy' z~2 emission line spectra



ZFIRE survey: Nanayakarra, KG,+2016

The GOOD news: 'Easy' z~2

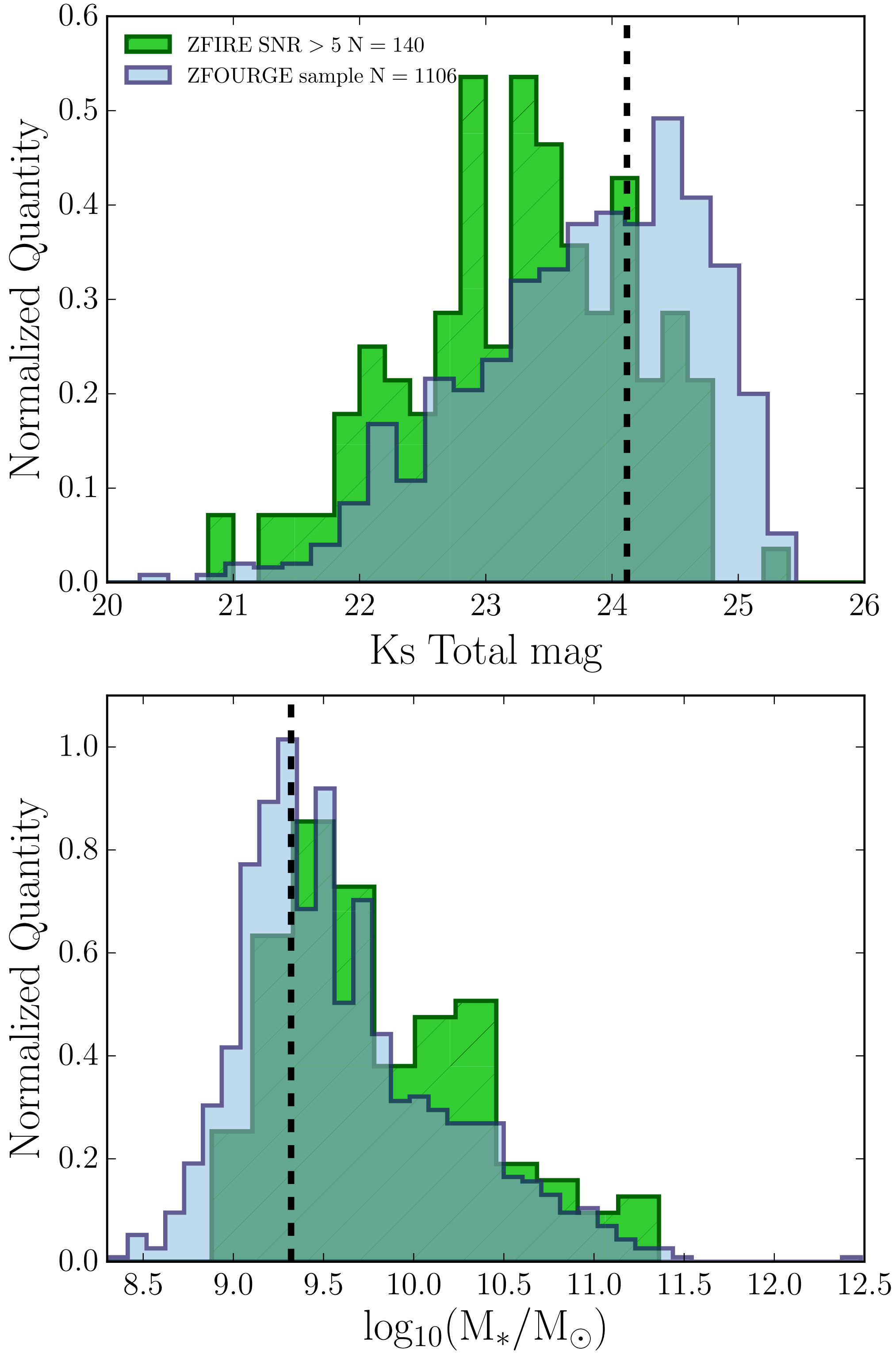
SF galaxies ONLY, 1–2h with MOSFIRE

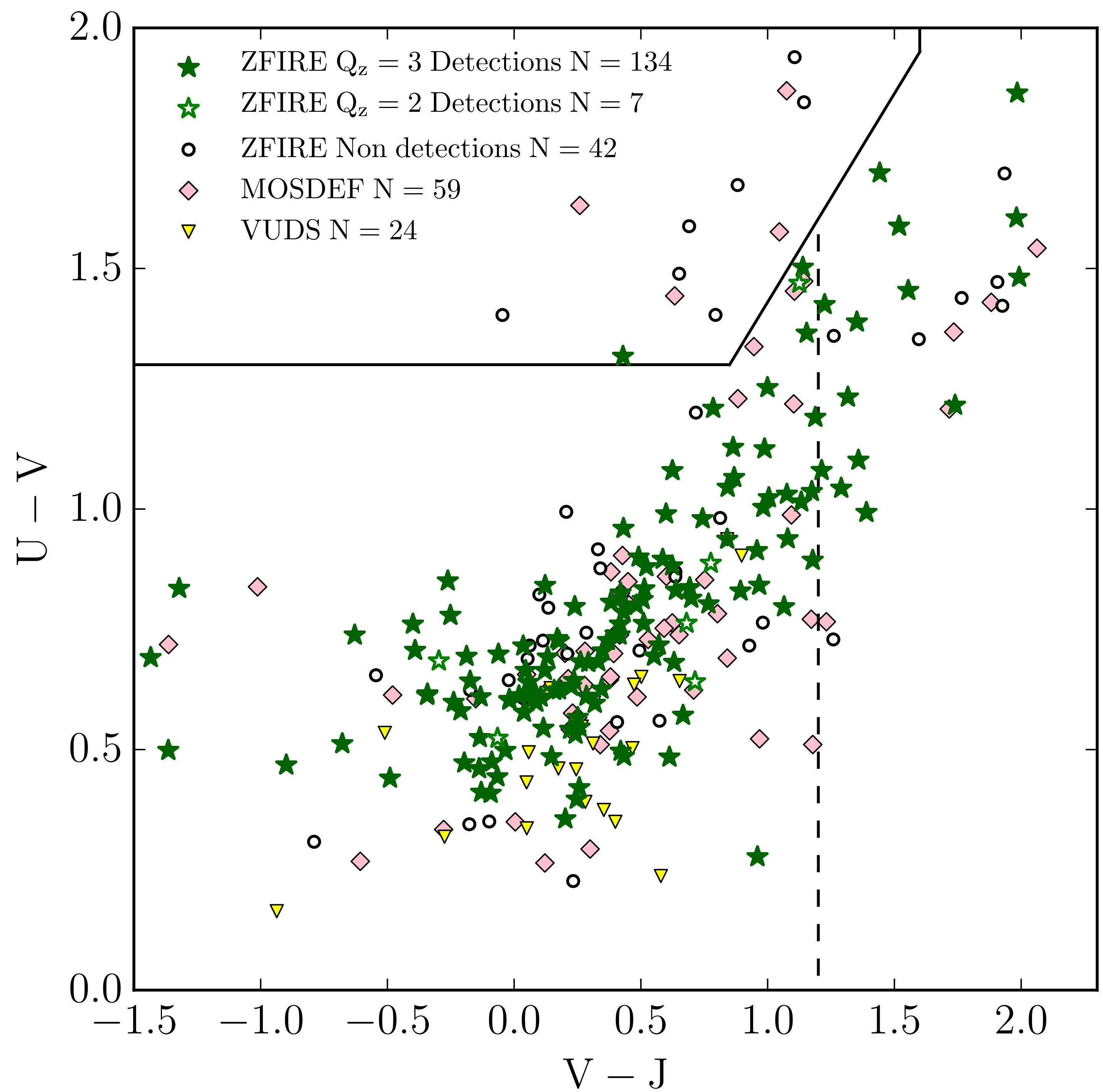


ZFIRE survey: Nanayakarra, KG,+2016

'Easy' z~2

SF galaxies ONLY, 1–2h with MOSFIRE

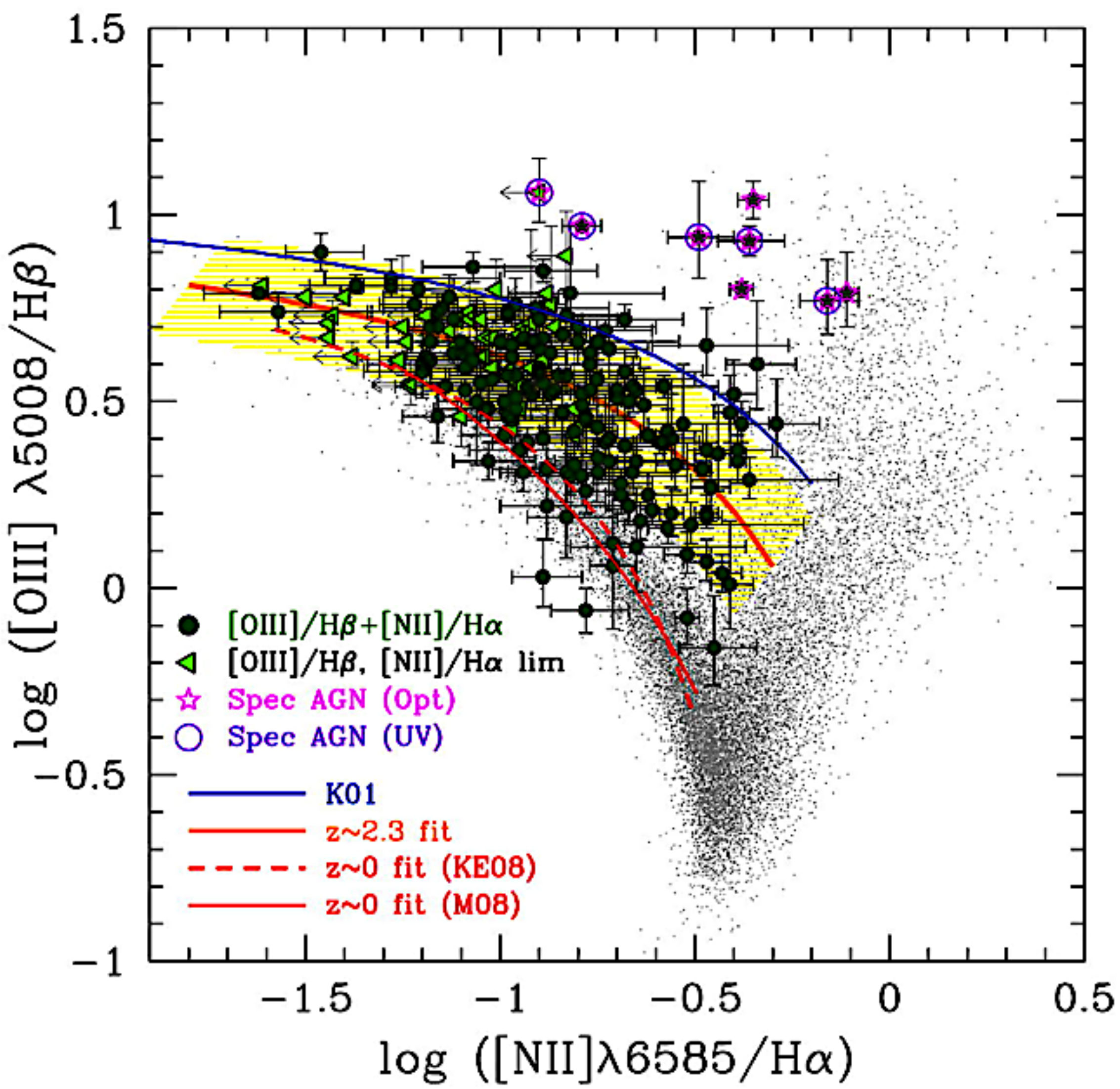




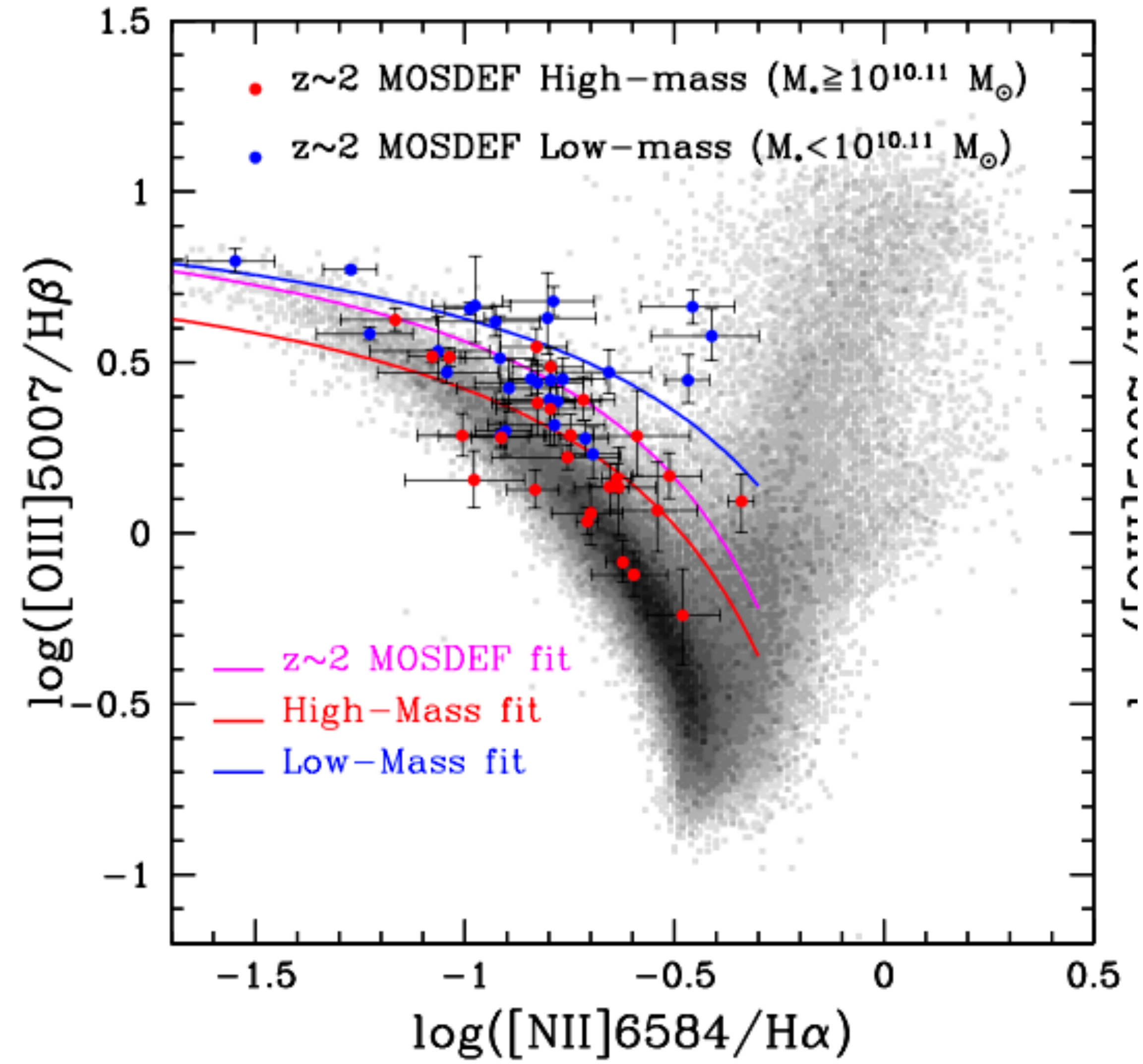
ZFIRE survey: Nanayakarra, KG,+2016

The BPT debate: what is up with ionisation?

KBSS; Steidel et al. (2014)



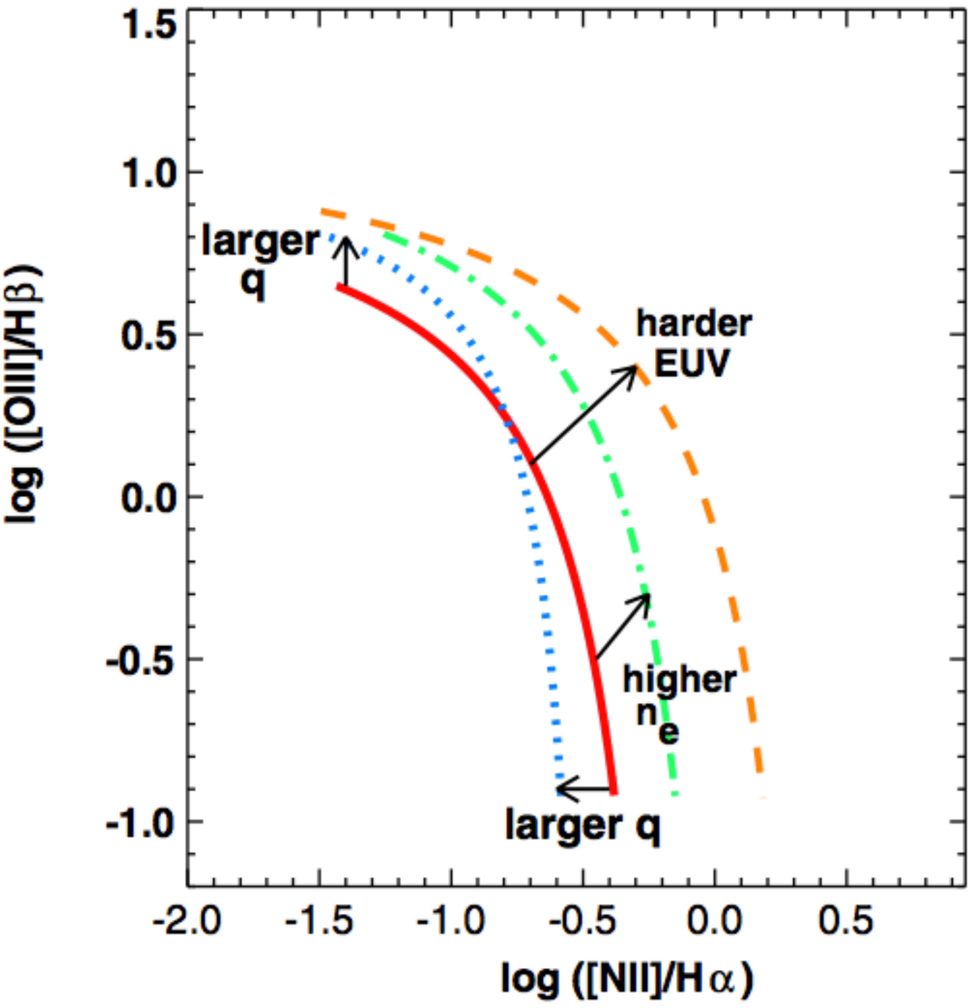
MOSDEF; Shapley et al. (2014)



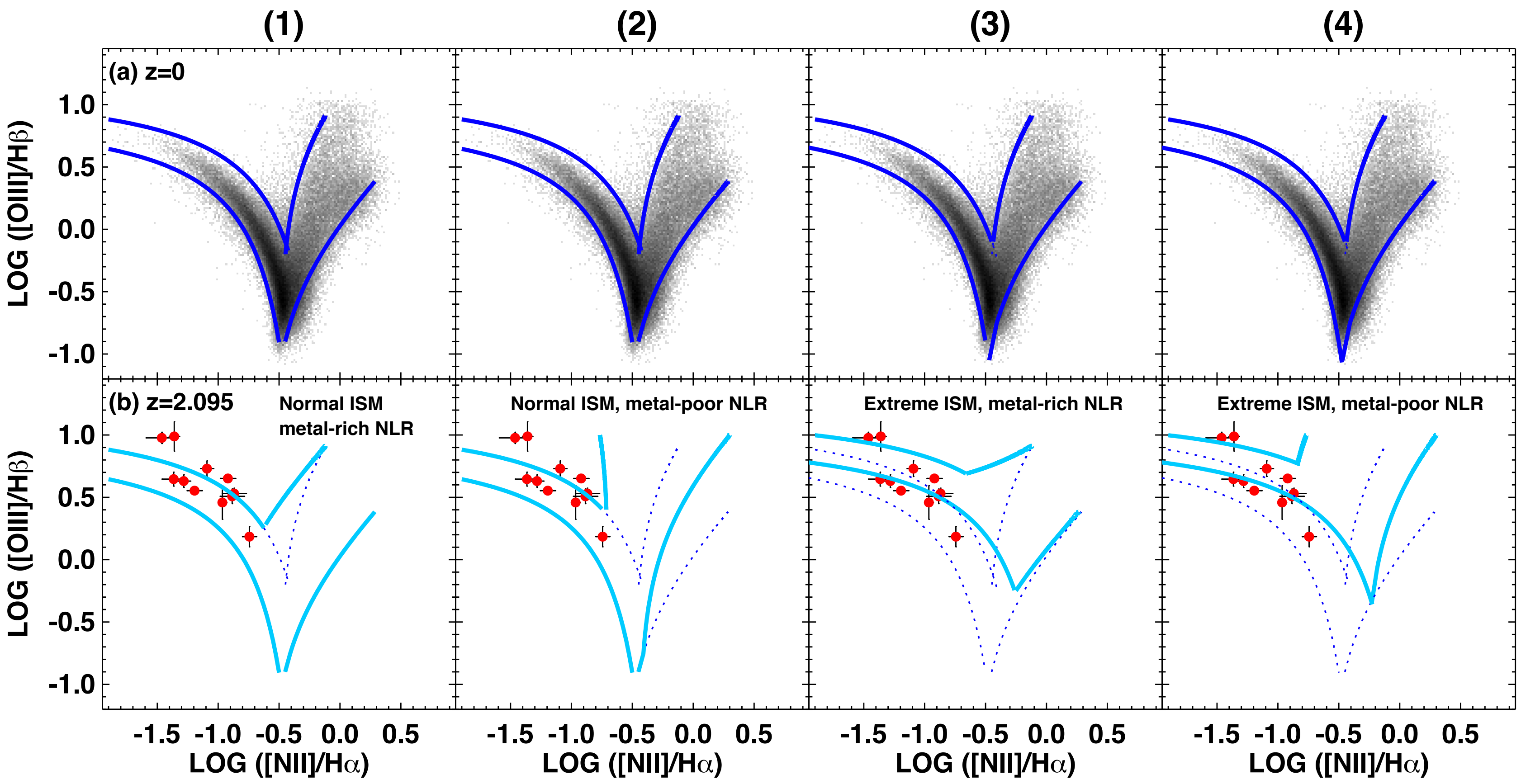
‘it’s ionisation parameter and effective temperature’

‘it’s N/O abundance’

Kewley et al. (2013a,b)



Kewley et al. (2015)



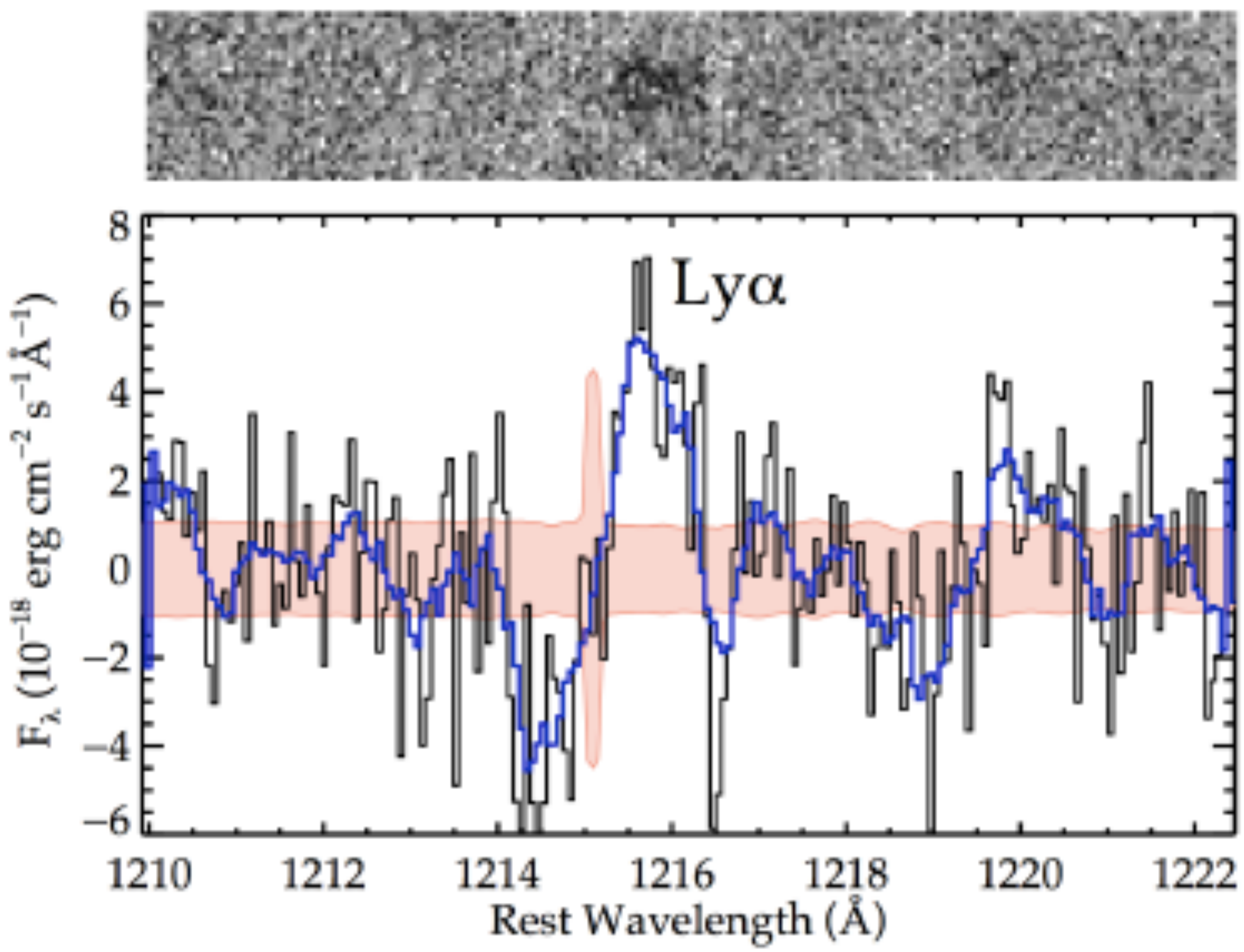
<u>Issues papers have raised</u>: Denser SF regions? Density bound? Binaries? Stellar rotation? Abundance variations? IMF?

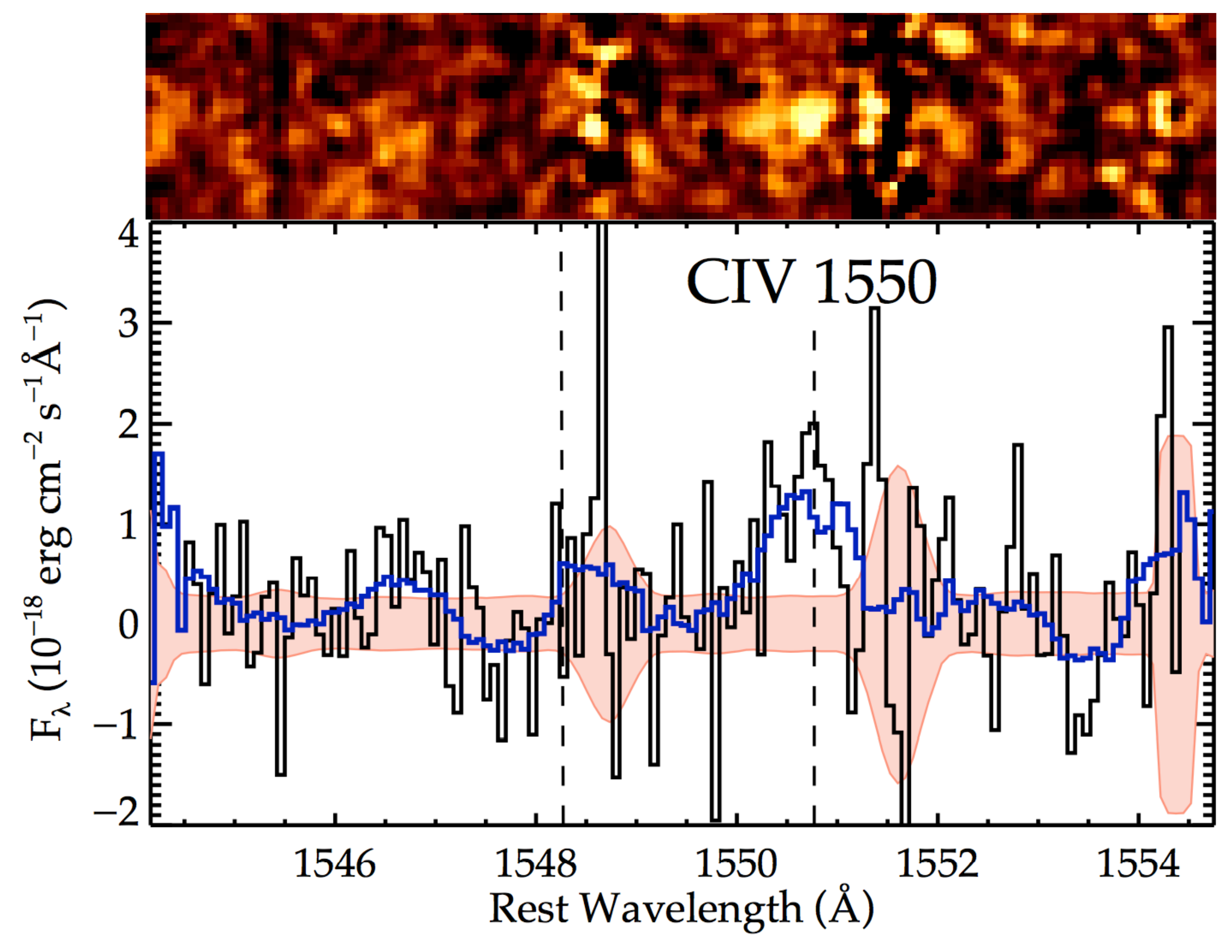
SWIN BUR NE

Stark talk (Monday)

High Ionization Emission Lines are Common among Low Mass Lyman-alpha Emitters

Mainali+16, submitted, arXiv:1611.07125

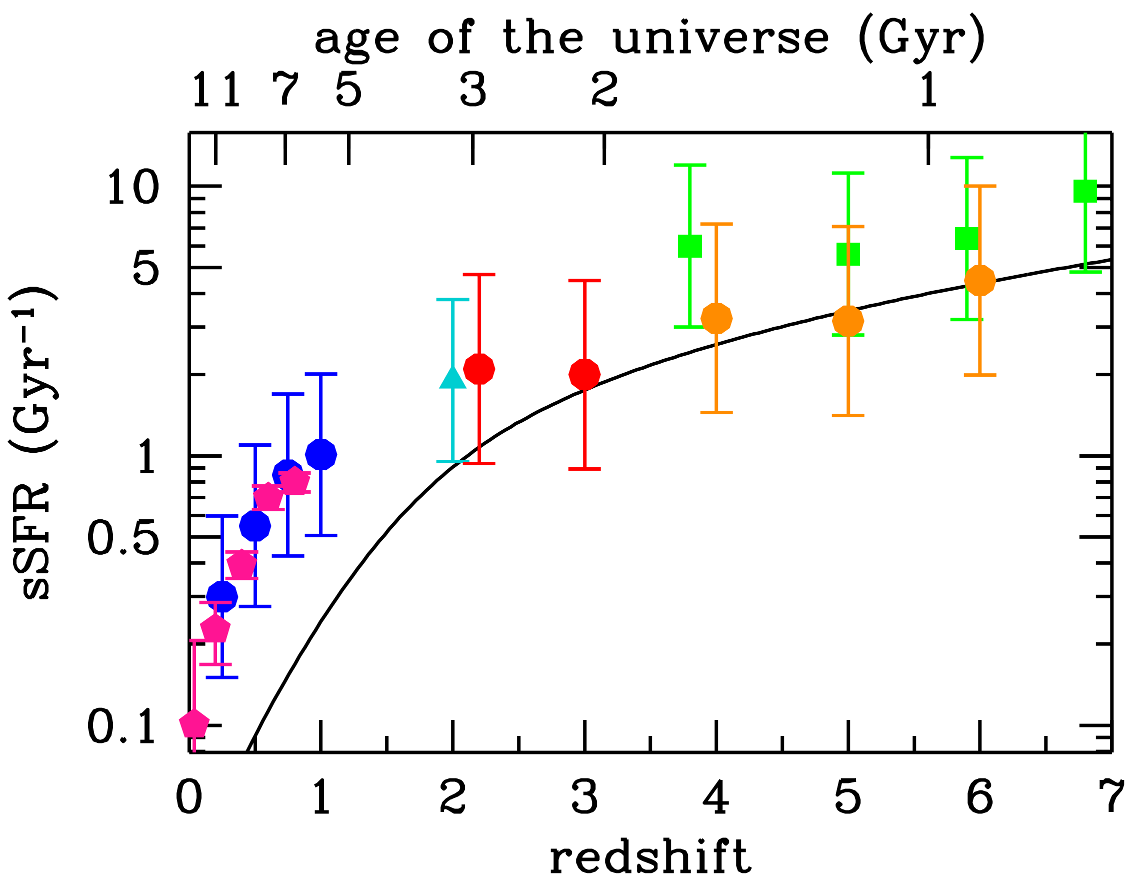




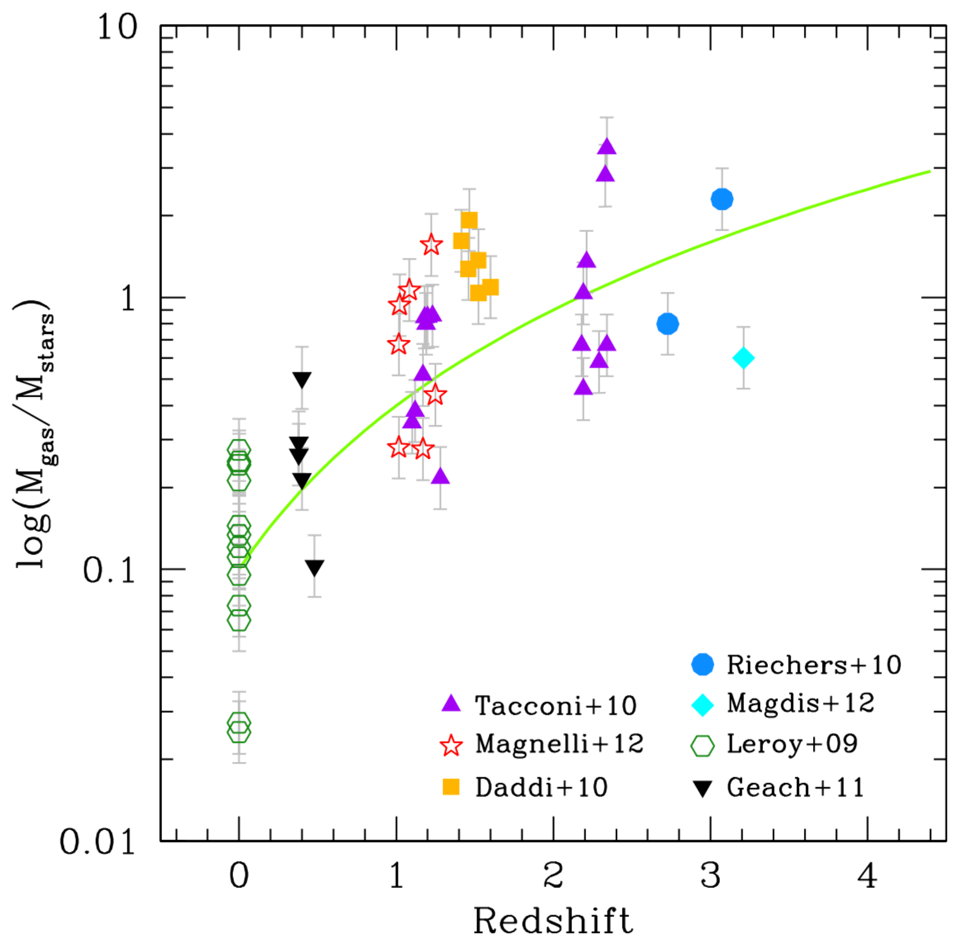
- CIV + OIII] detection in gravitationally lensed LAE at z=6.11 with FIRE
- CIV1549+1551 EW ~ 24.5 Å

Radiation field implies greater contribution to reionization than often assumed

Madau & Dickinson (2014)

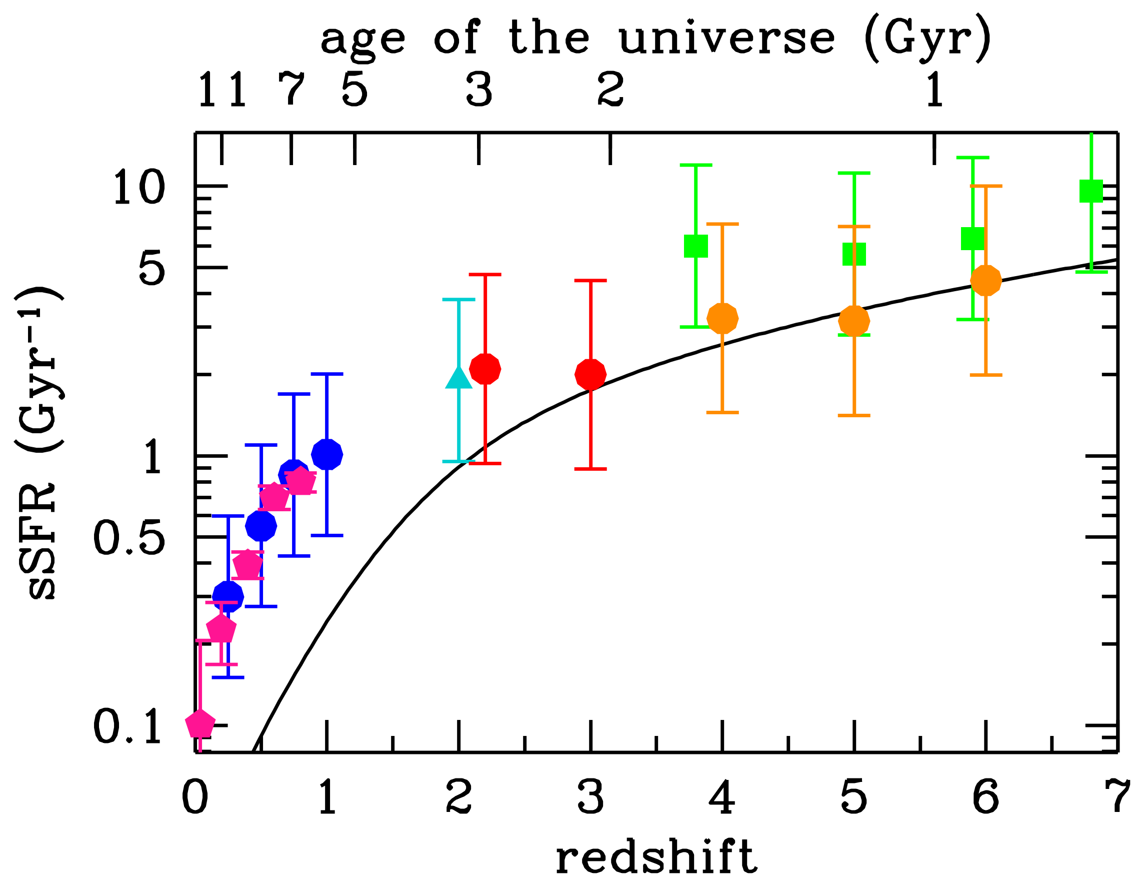


Carilli & Walter (2013)

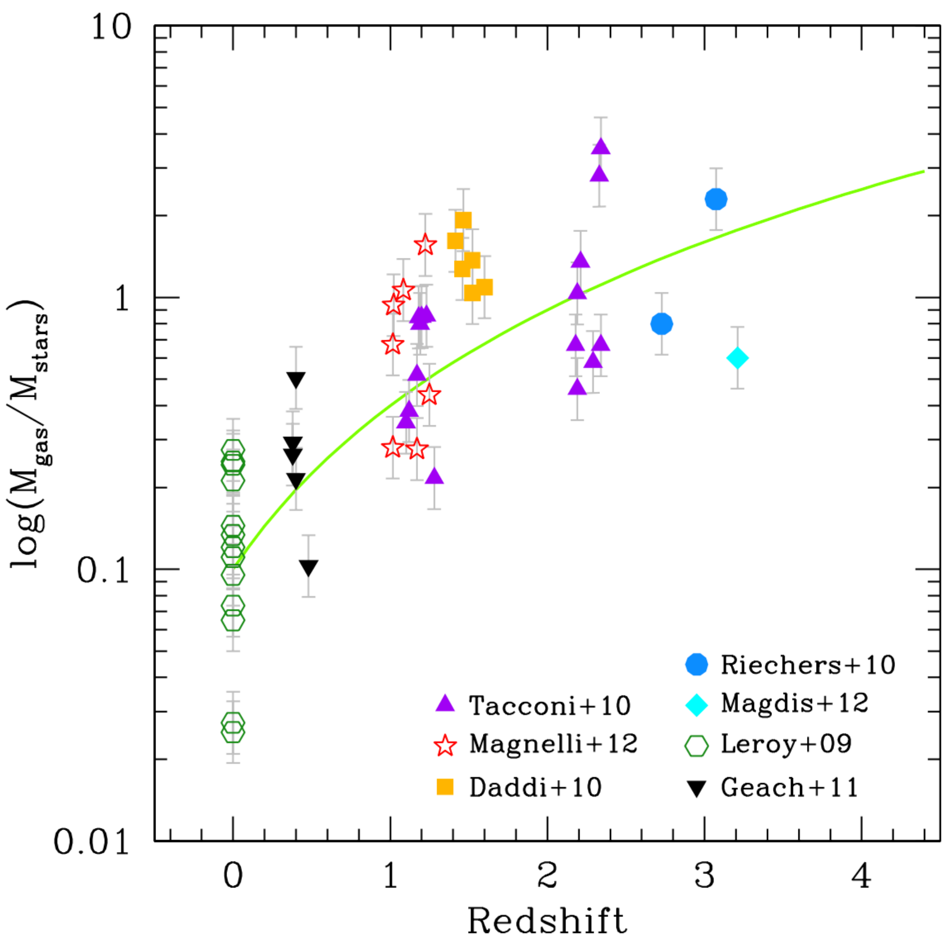


Karl Glazebrook, SUT

Madau & Dickinson (2014)



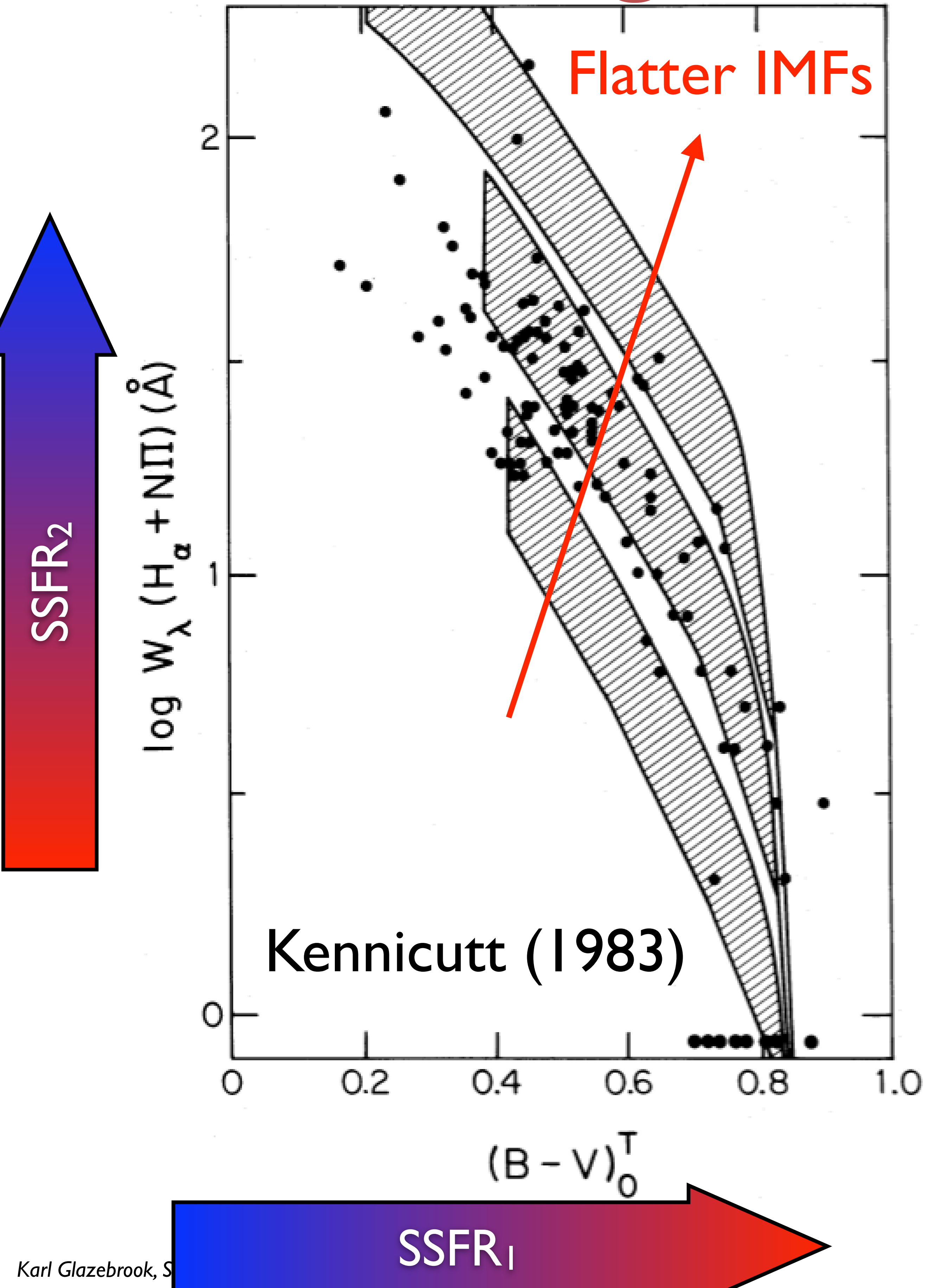
Carilli & Walter (2013)



Usual SFR measures (demographics) assume standard IMF and stellar populations…it's been a very convenient assumption for the last decade but is it right?

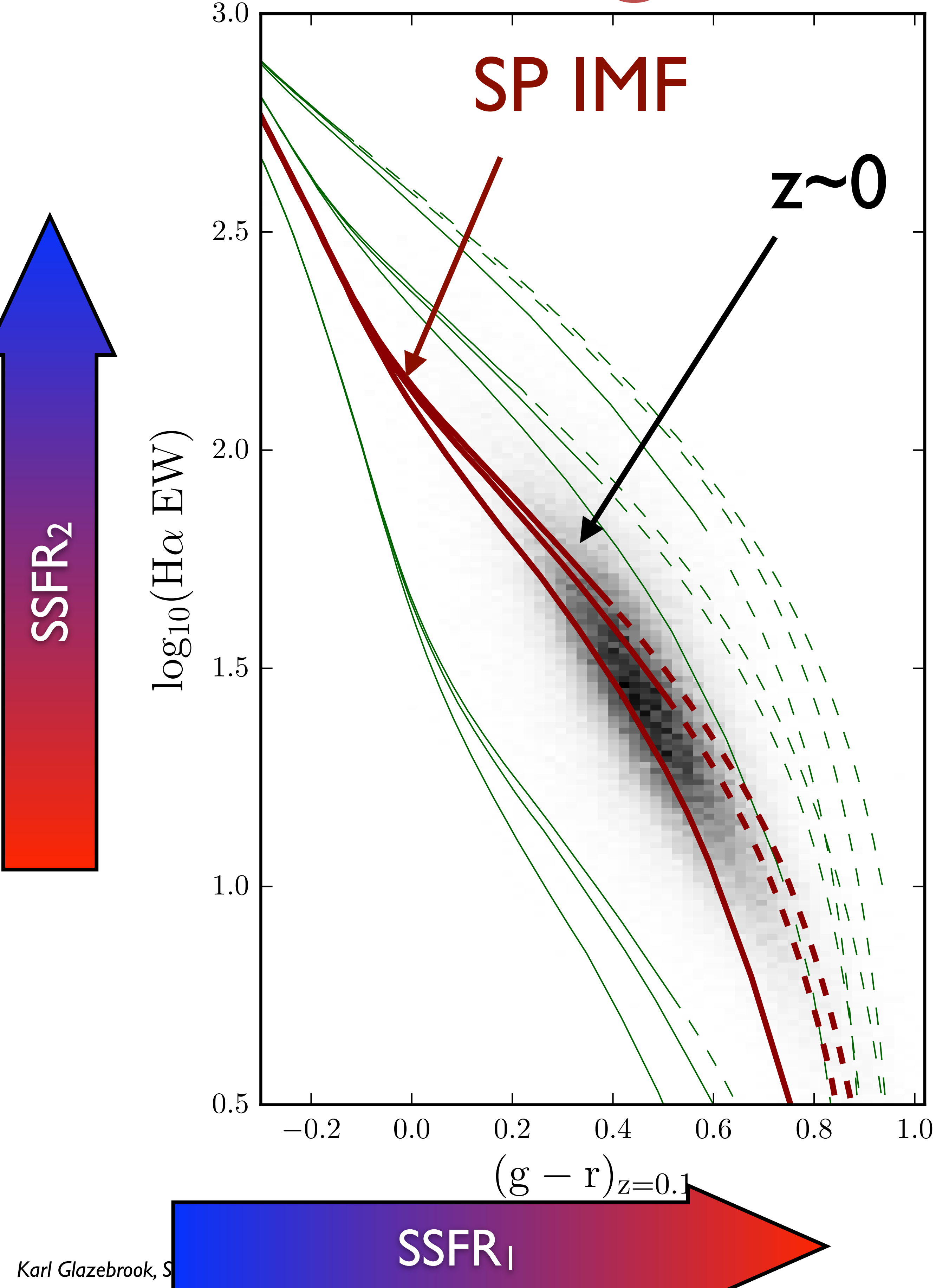
IMF of SF galaxies

ZFIRE (Nanayakkara, KG,+2017)



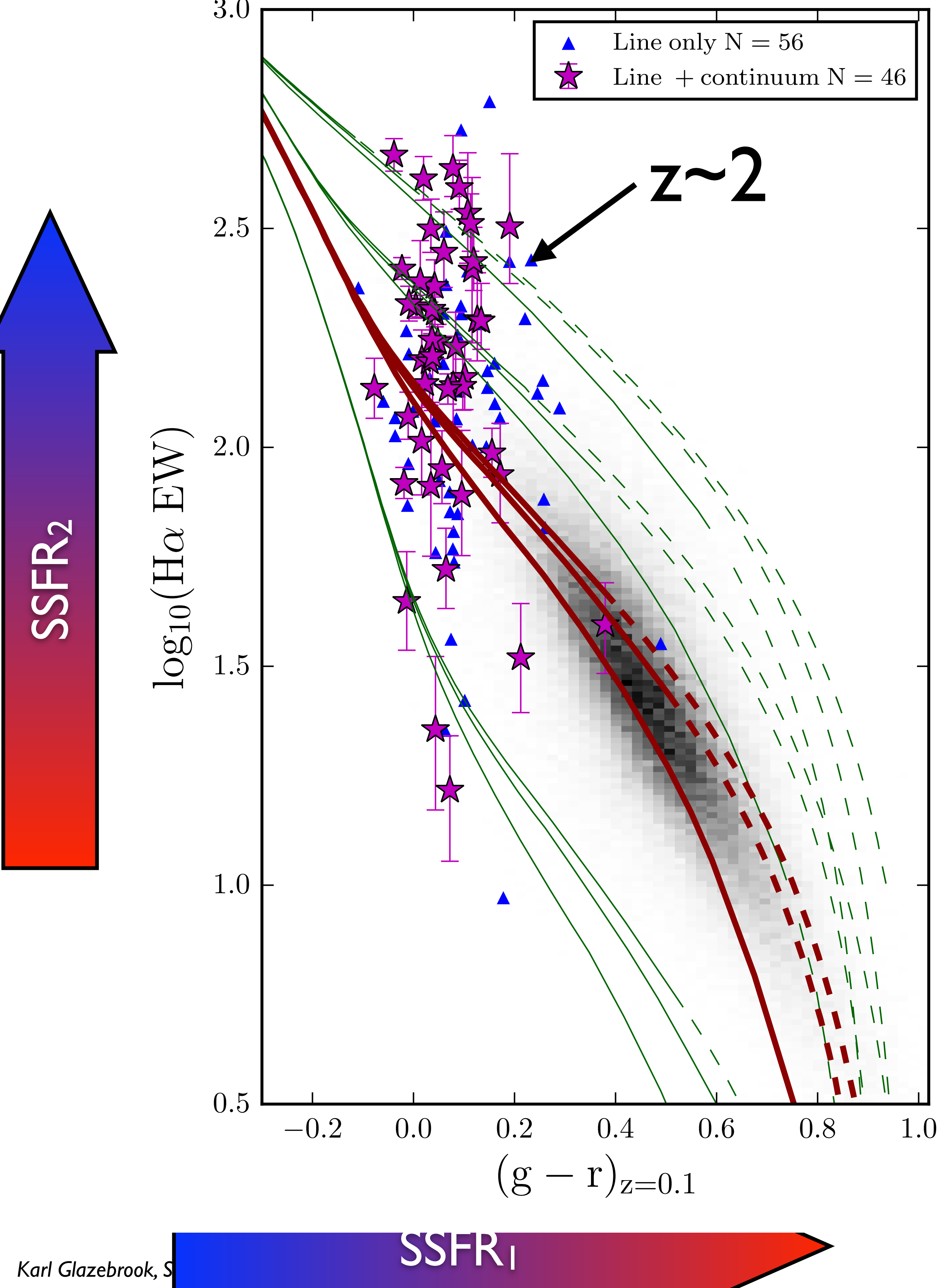
IMF of SF galaxies

ZFIRE (Nanayakkara, KG,+2017)



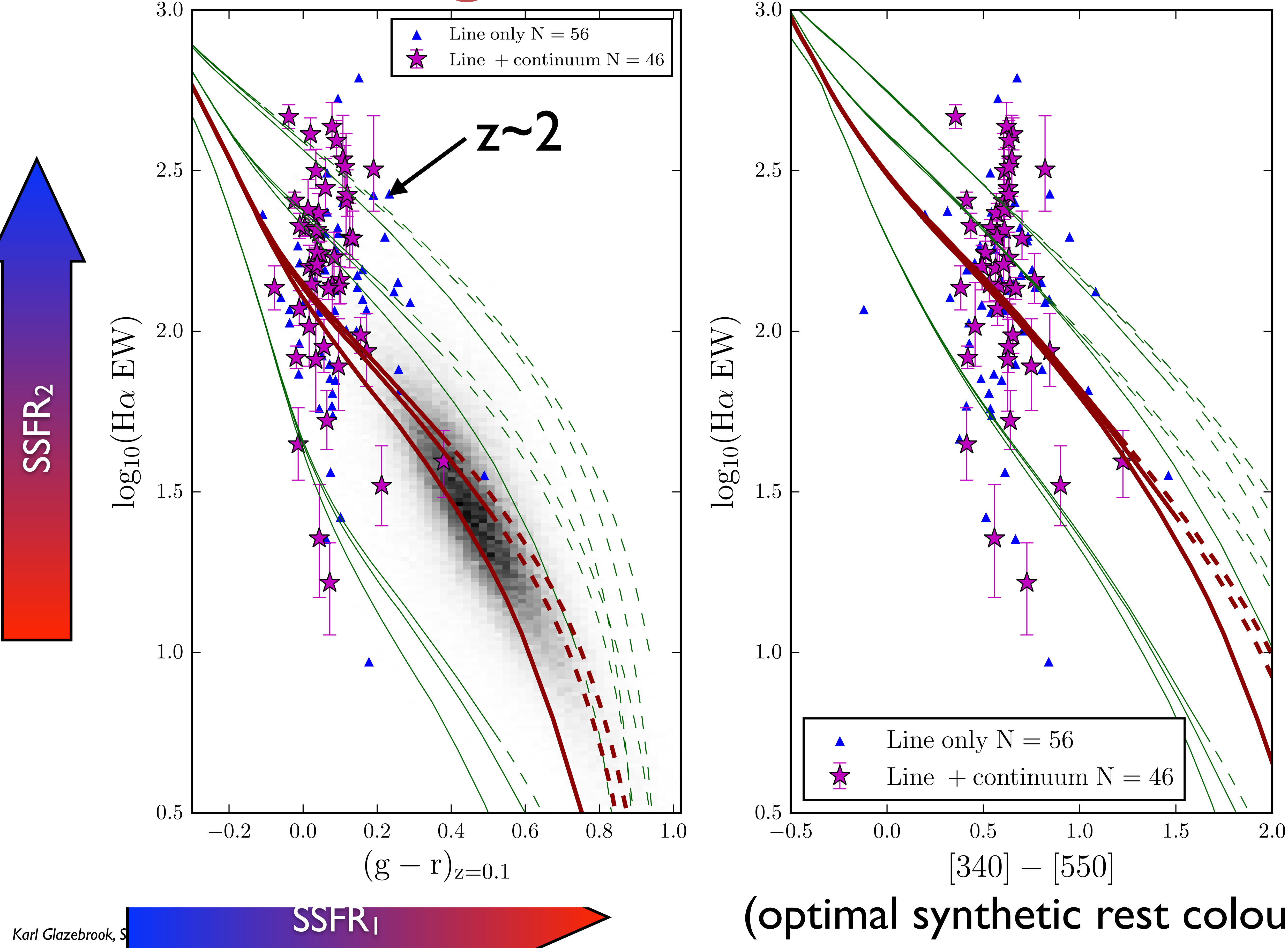
IMF of SF galaxies

ZFIRE (Nanayakkara, KG,+2017)



IMF of SF galaxies

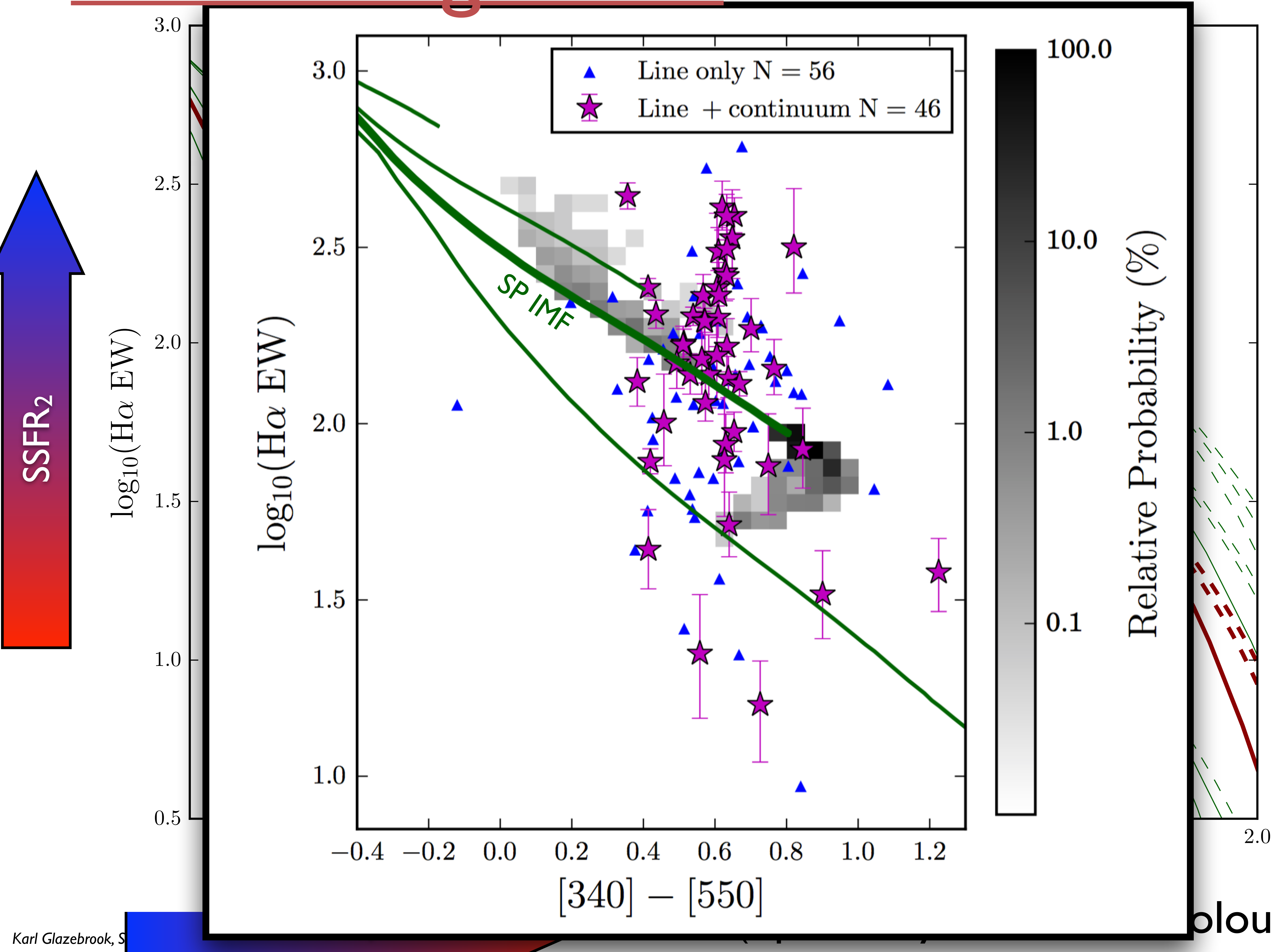
ZFIRE (Nanayakkara, KG,+2017)



(optimal synthetic rest colours)

IMF of SF galaxies

ZFIRE (Nanayakkara, KG,+2017)



olours)

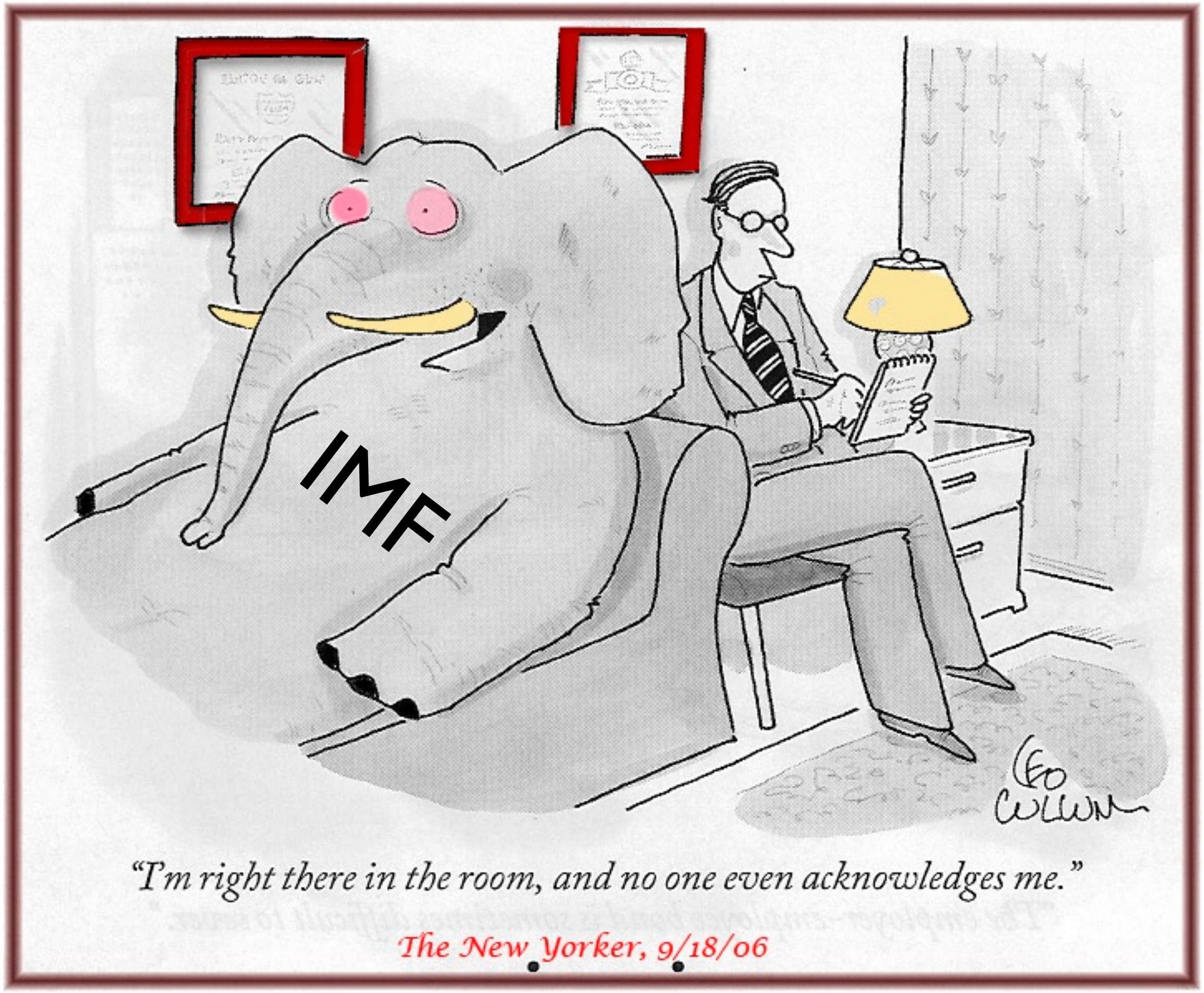
Photoionisation problems

- To explain hi-z ISM we really just want to produce more/harder ionising photons per unit SFR
- Resistance to IMF change is so we don't have to re-calibrate our terribly convenient SFRs, stellar masses etc.
- However alternate solutions:

  Stellar rotation

  Excess binaries

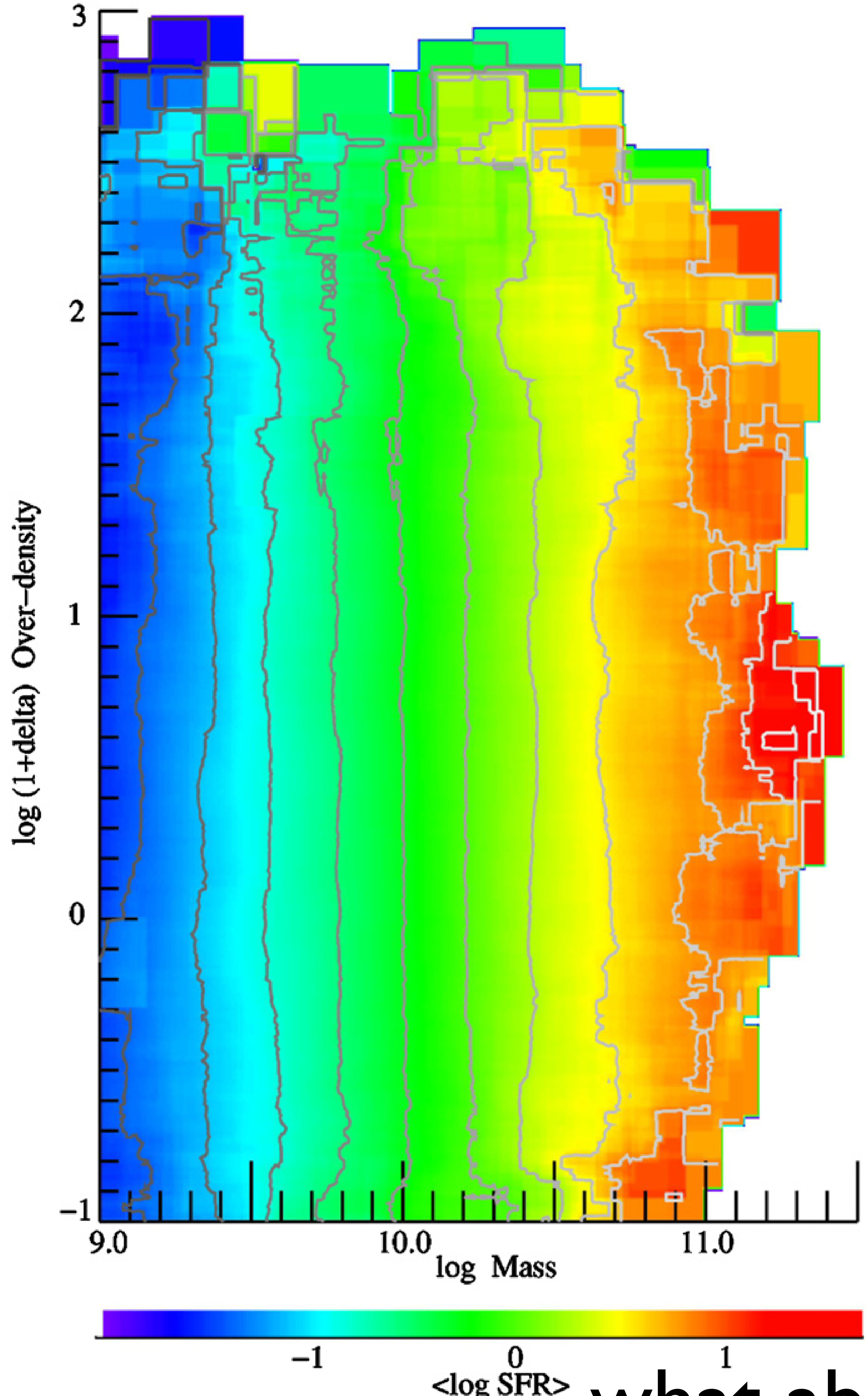
  Also require us to recalibrate! More palatable …?

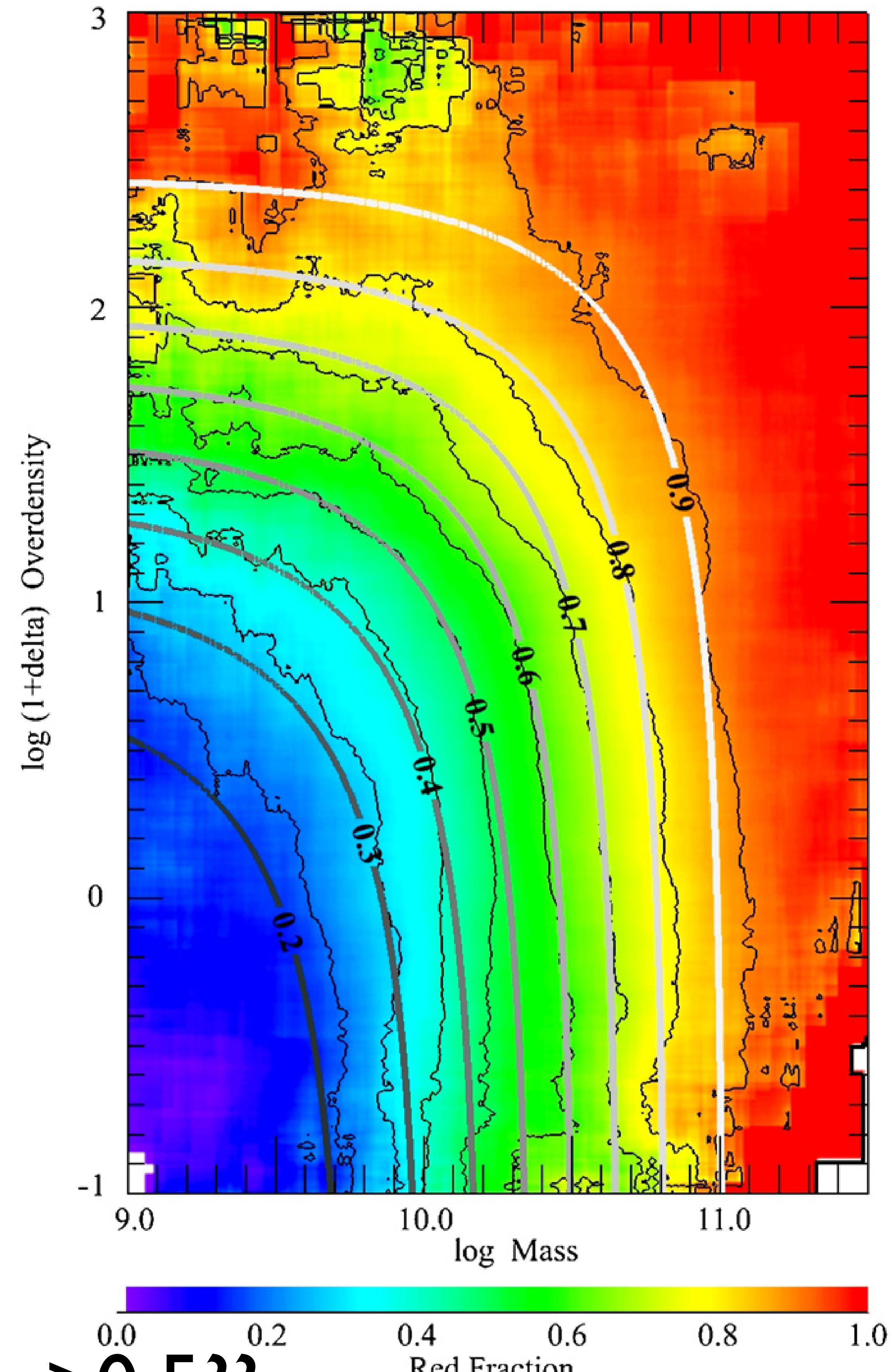


Topics I will focus on

- Stellar populations (JWST wins)
- Photo-ionisation: puzzles (to be solved by MOSFIRE etc. soon)
- Environment
  - 'the killer app?'
- Kinematics

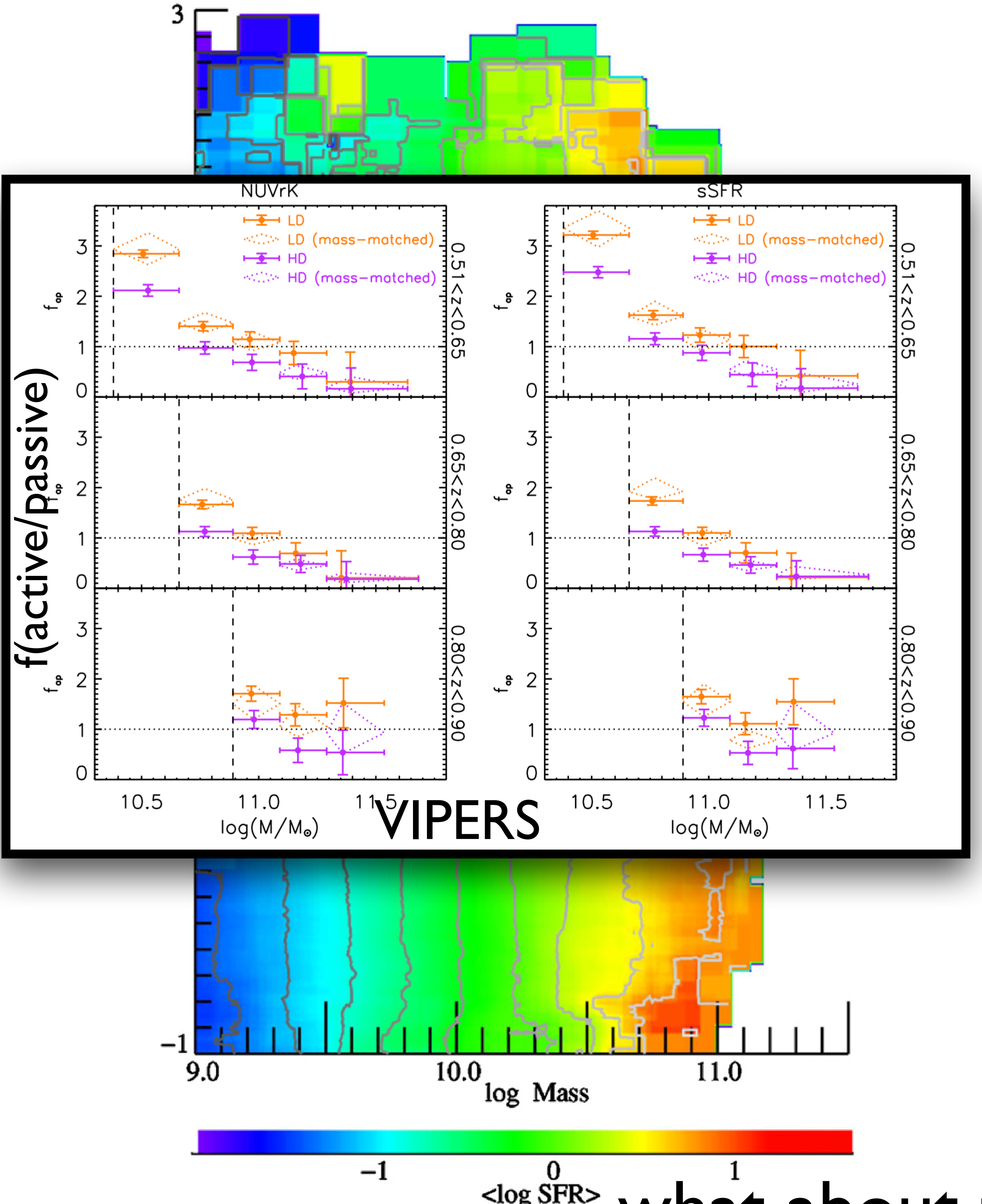
Peng+2010 (SDSS, z~0.1)

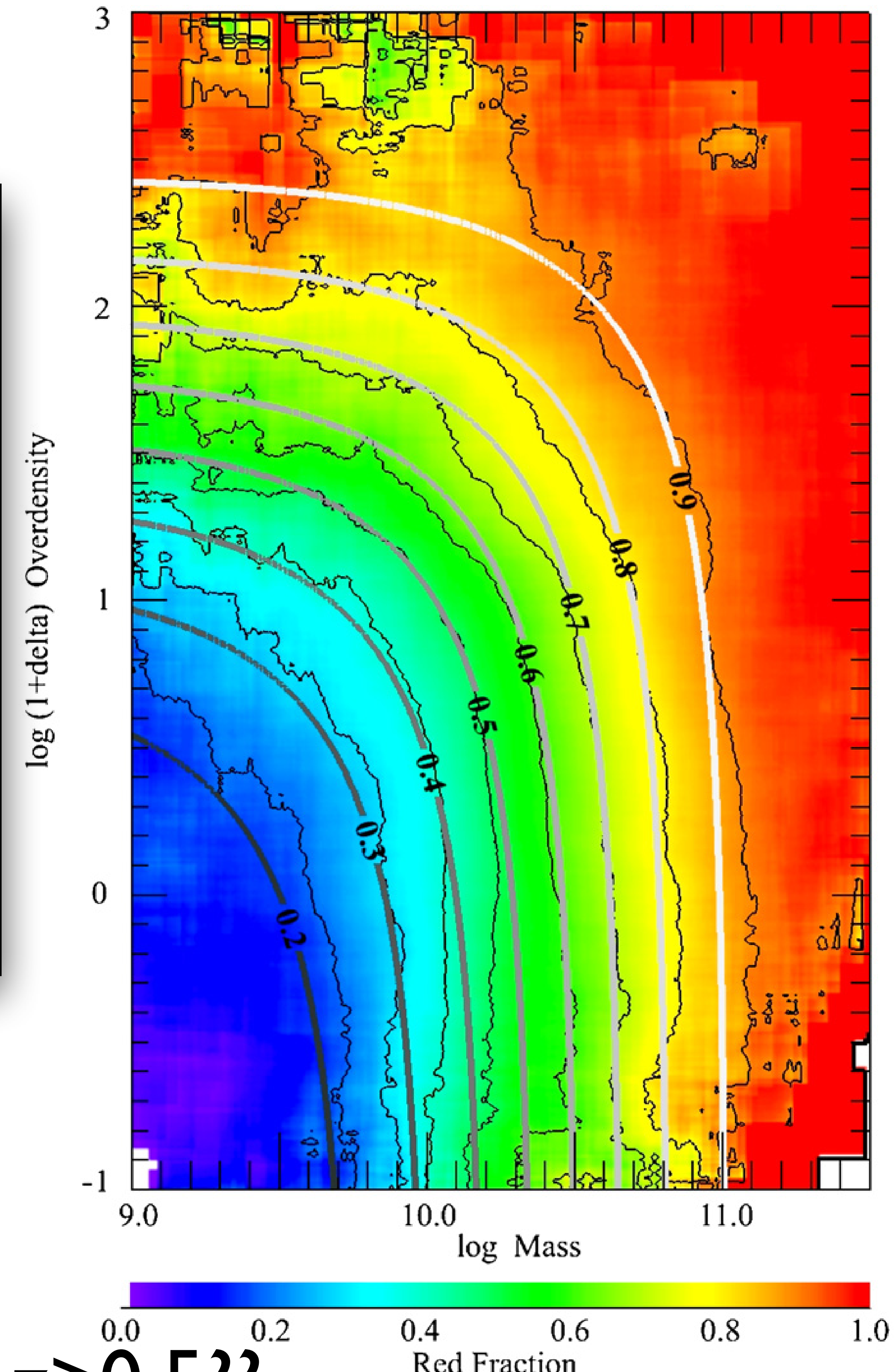




what about z>0.5??

Peng+2010 (SDSS, z~0.1)

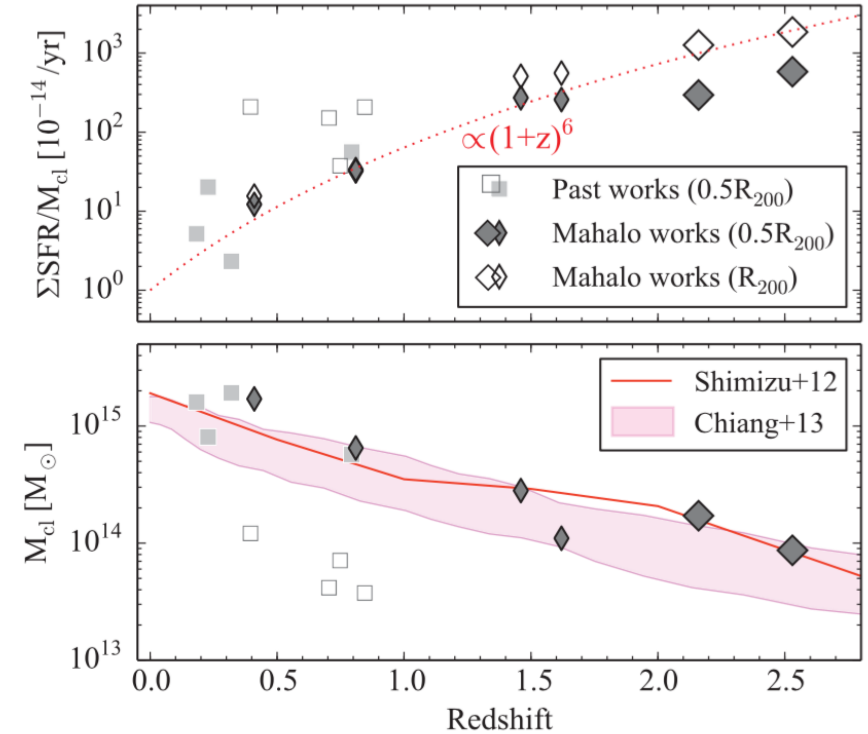


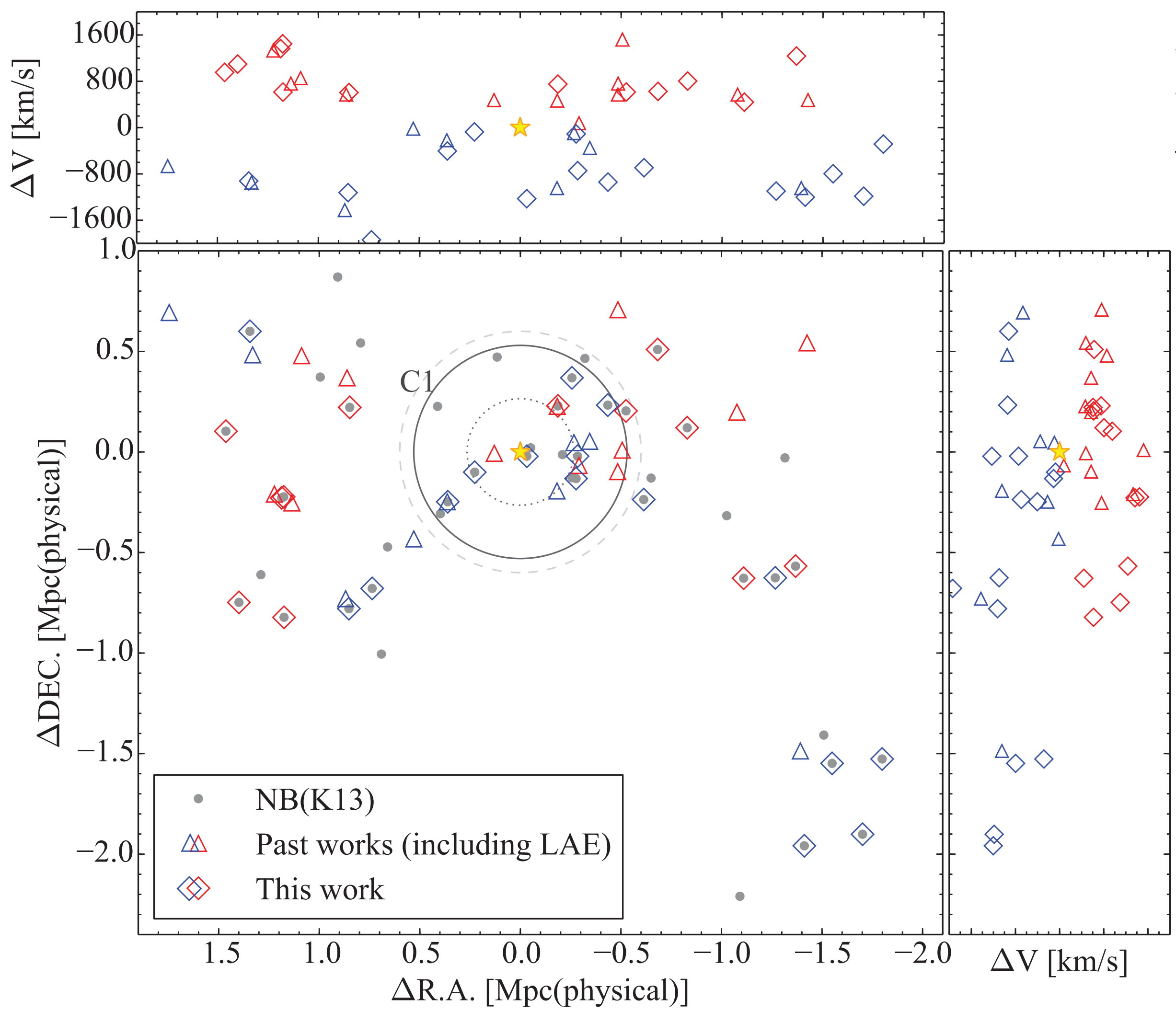


what about z>0.5??

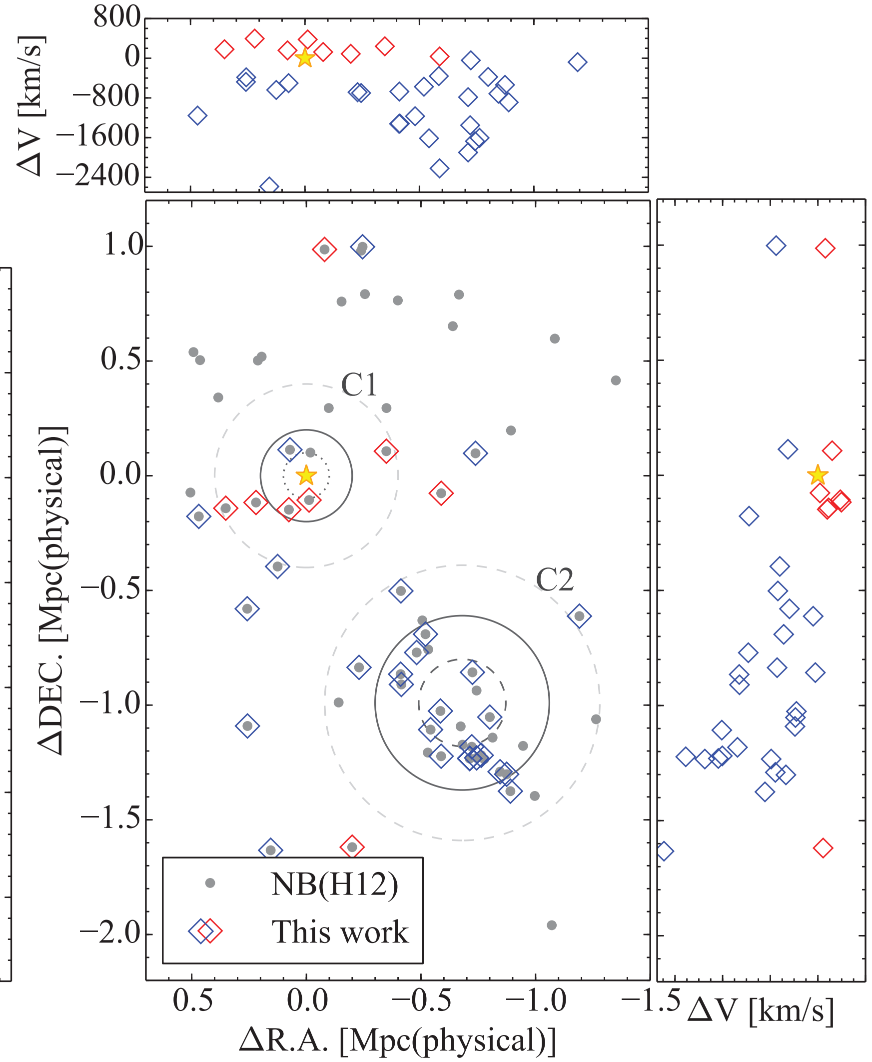
Discrete objects

Shimikawa+2014 (MOIRCS)

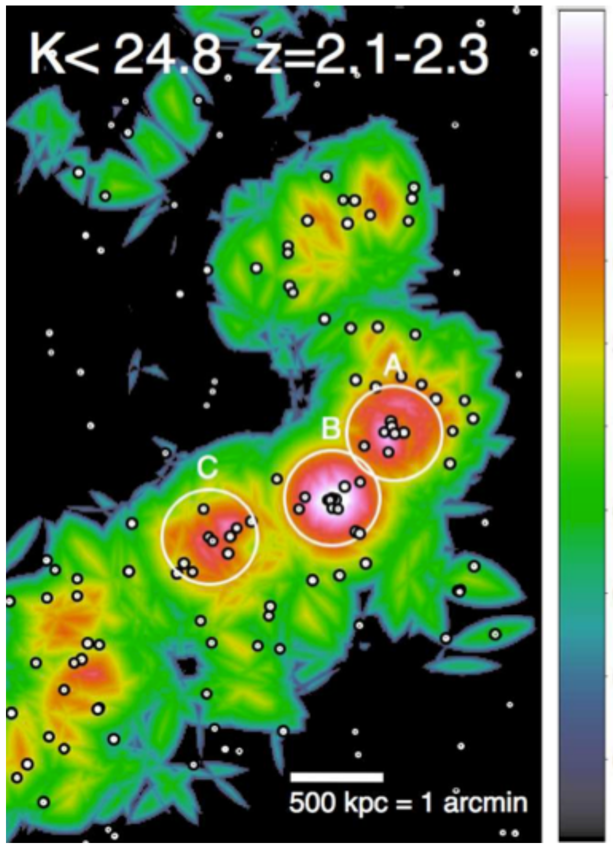




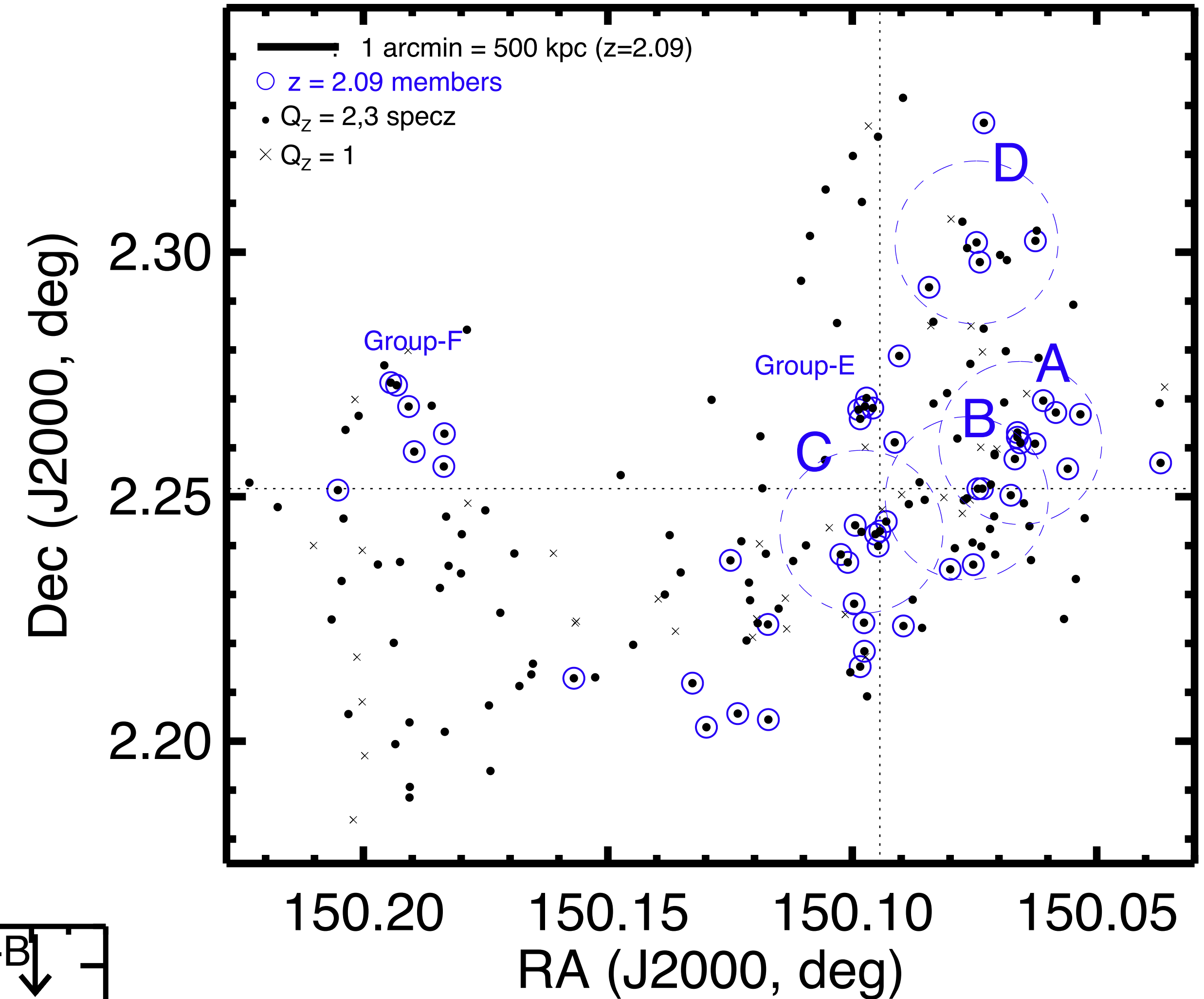
z=2.16

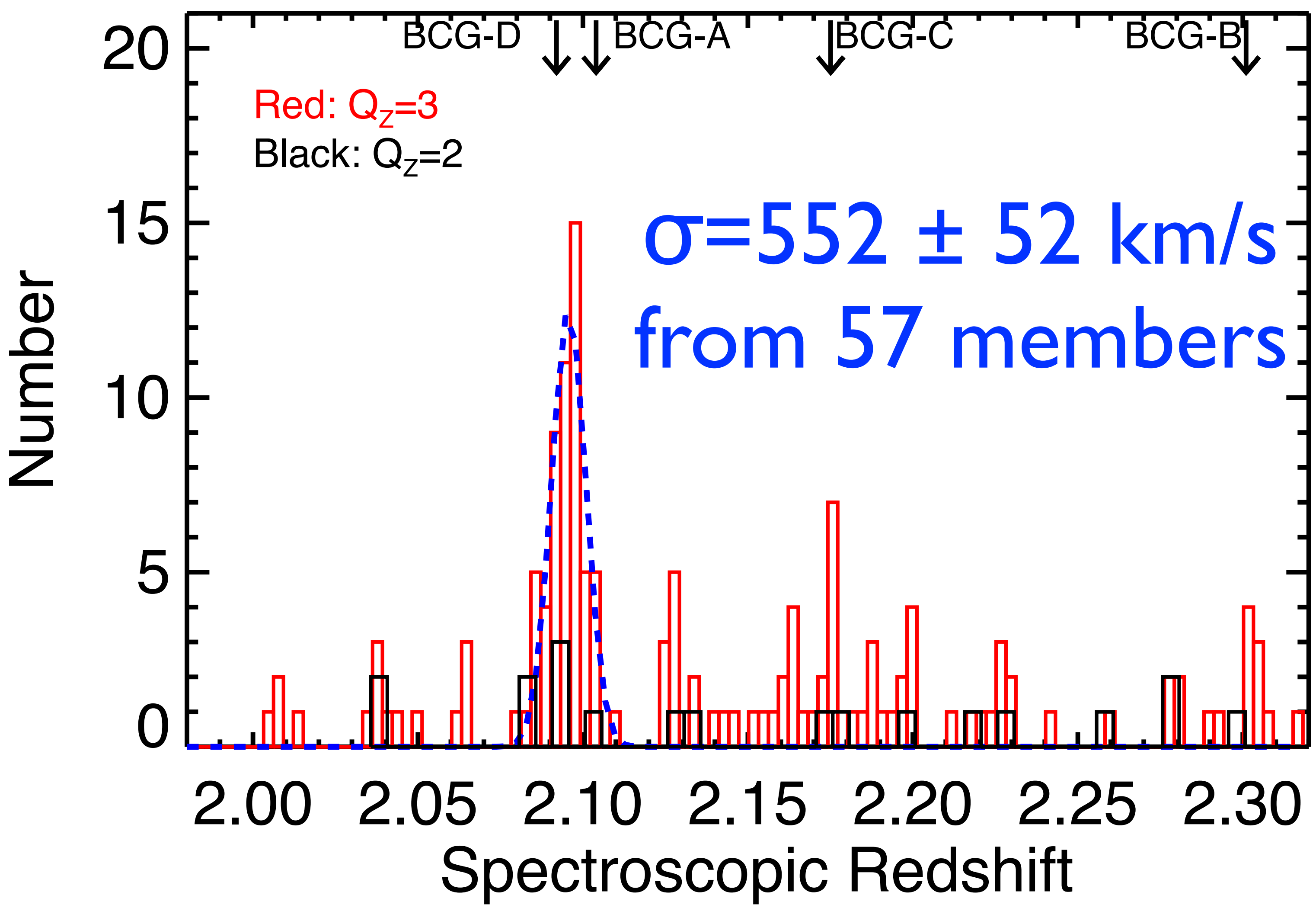


z=2.53



Spitler+2012



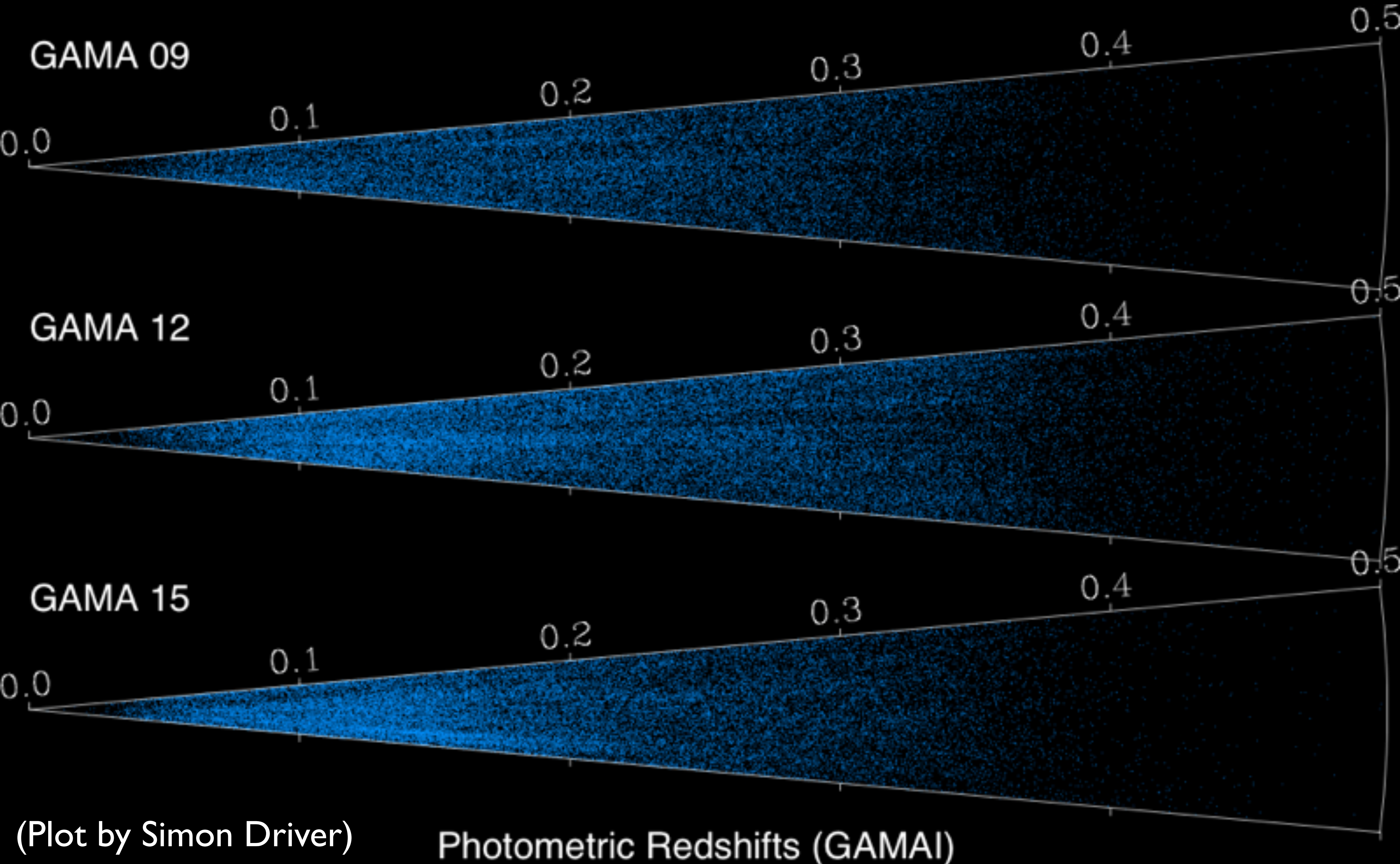


σ=552 ± 52 km/s
from 57 members

z=2.095 cluster
Yuan+2014

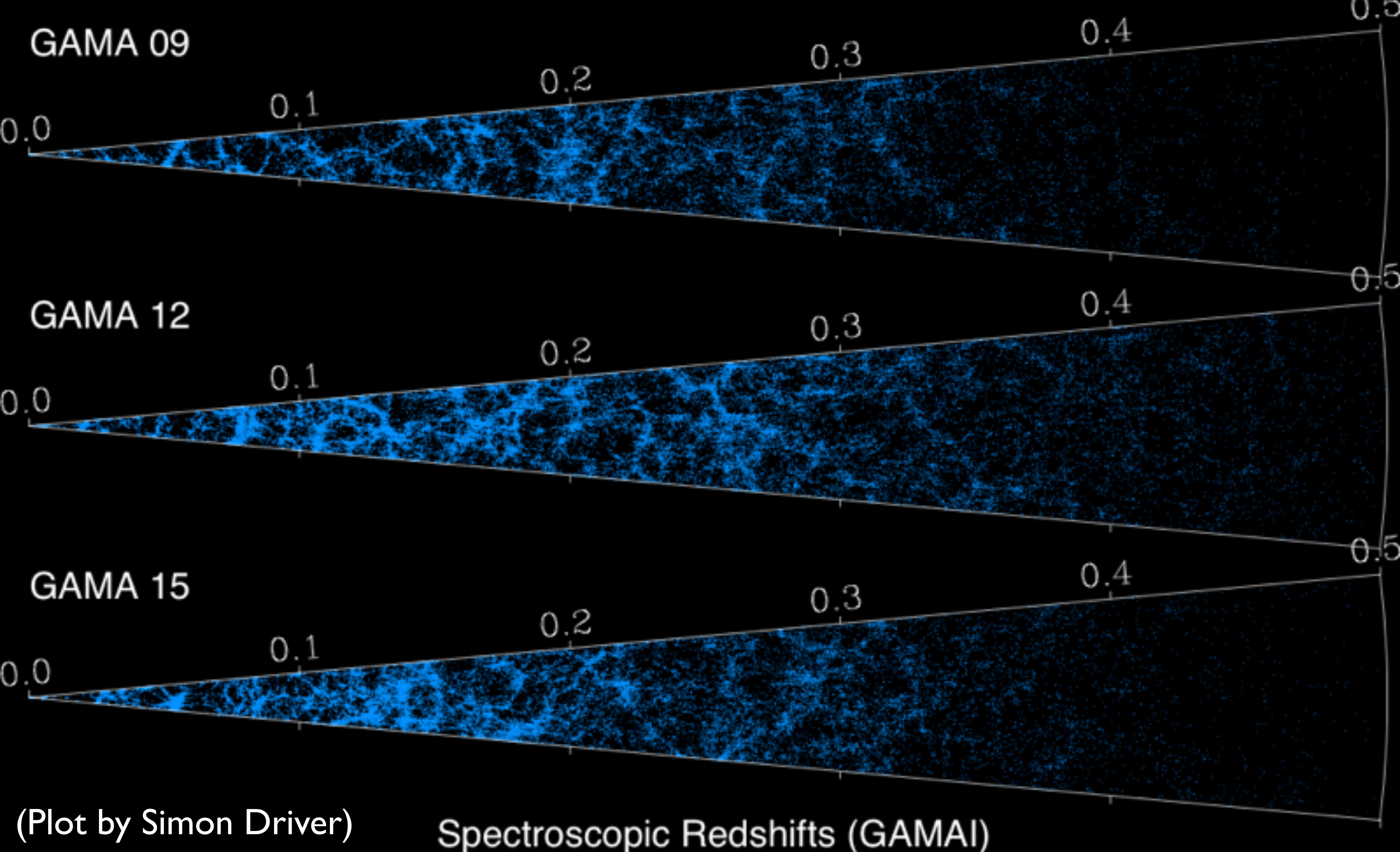
Yes you can do this with emission line redshifts! (1–2h exposures)

Spectroscopy (photo-z v spec-z)



(Plot by Simon Driver)

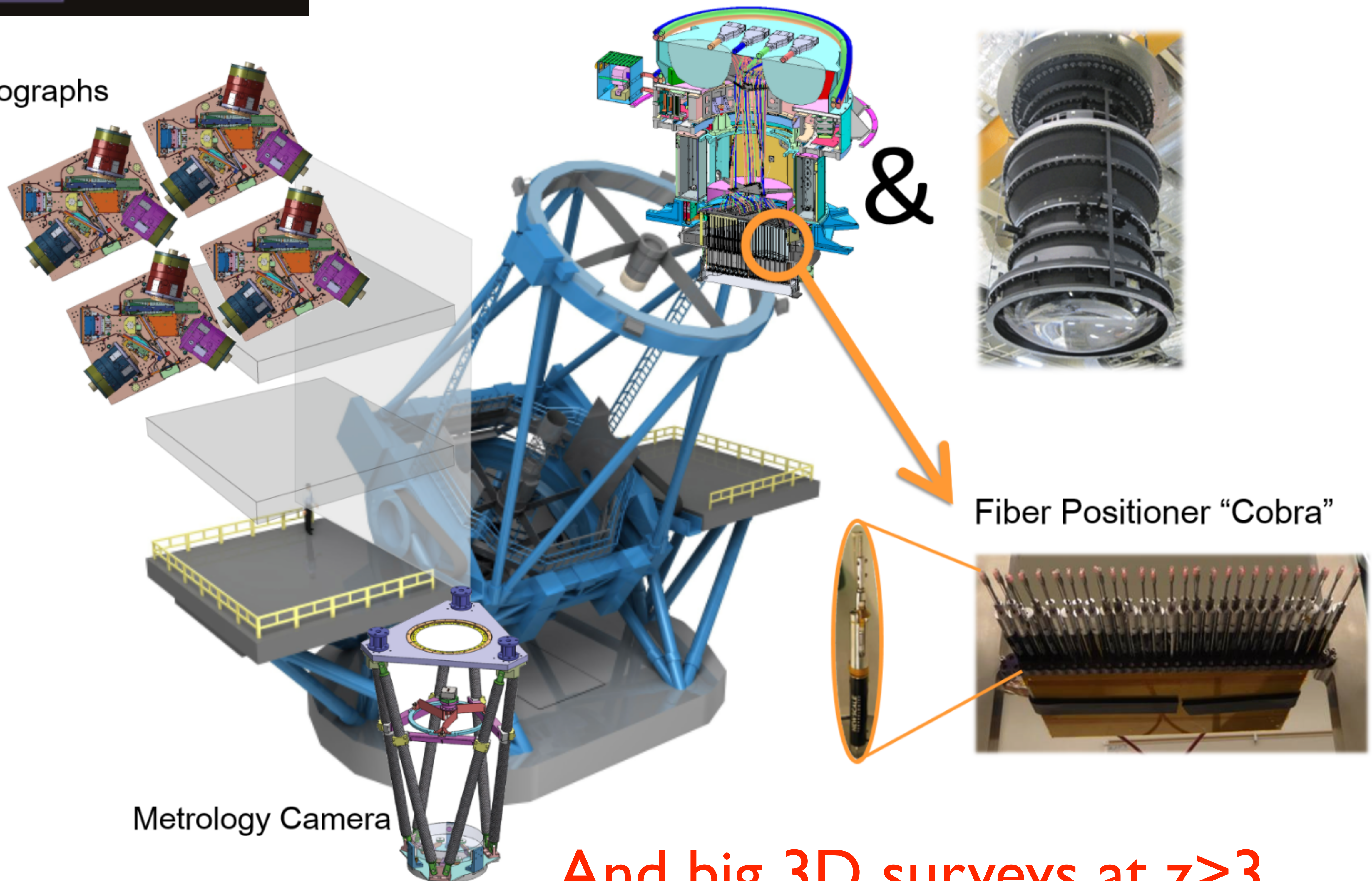
Spectroscopy (photo-z v spec-z)



(Plot by Simon Driver)

Prime Focus Spectrograph
SuMIRe

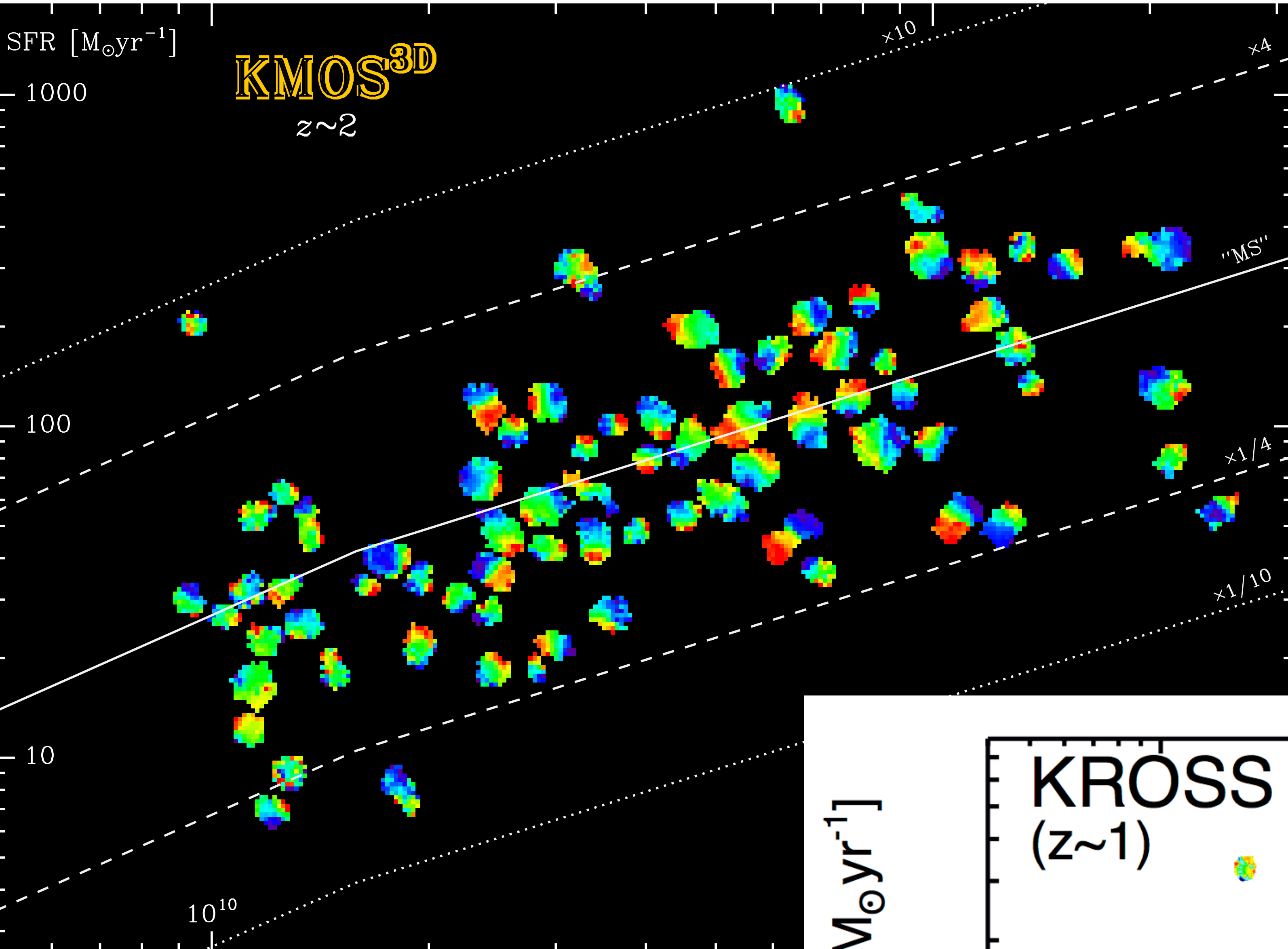
SDSS at z~1 needs to be done!



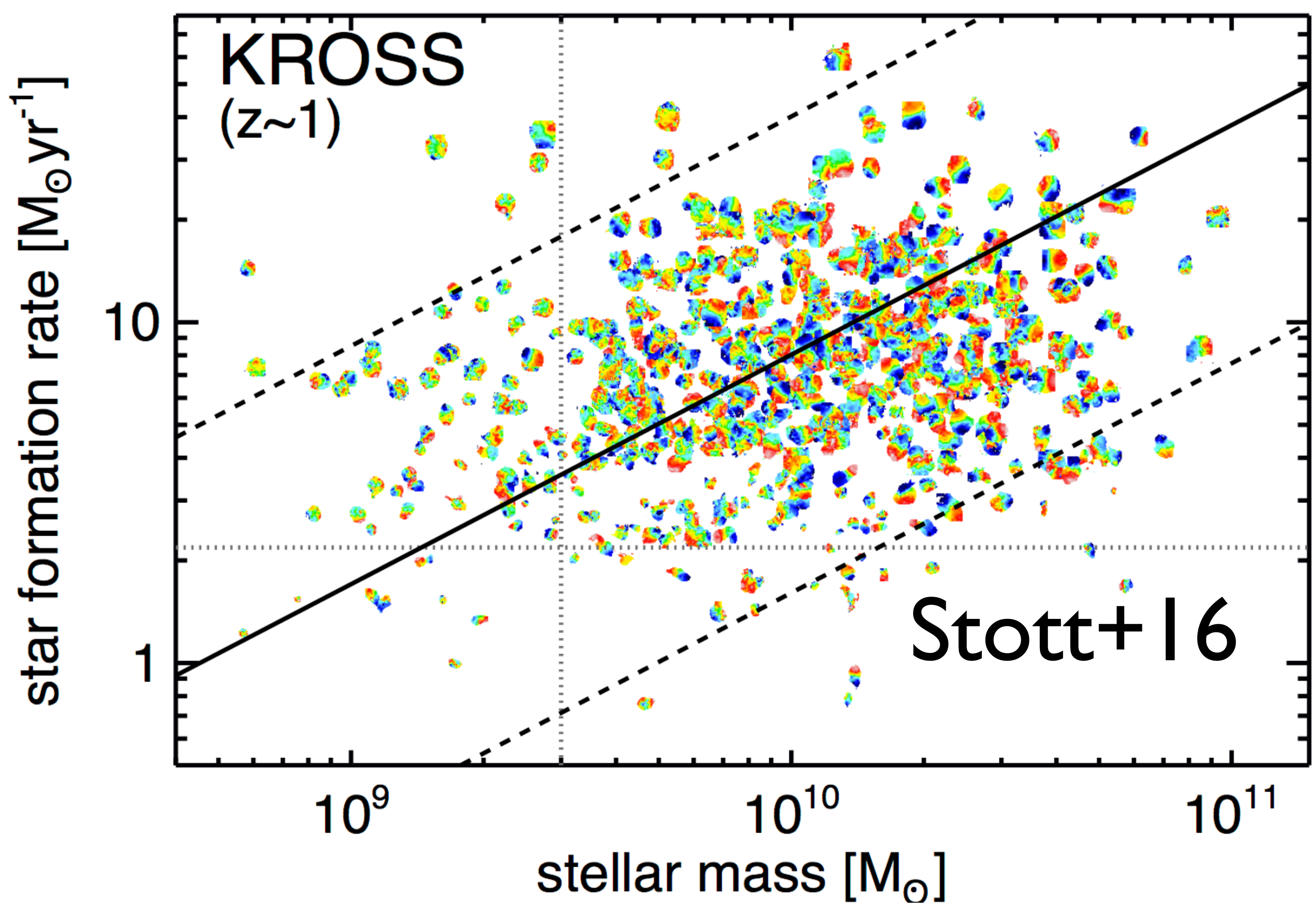
And big 3D surveys at z>3…

Topics I will focus on

- Stellar populations (JWST wins)
- Photo-ionisation: puzzles (to be solved by MOSFIRE etc. soon)
- Environment (PFS wins)
- Kinematics
  – resolved spectroscopy, angular momentum and small-scale kinematics/morphology

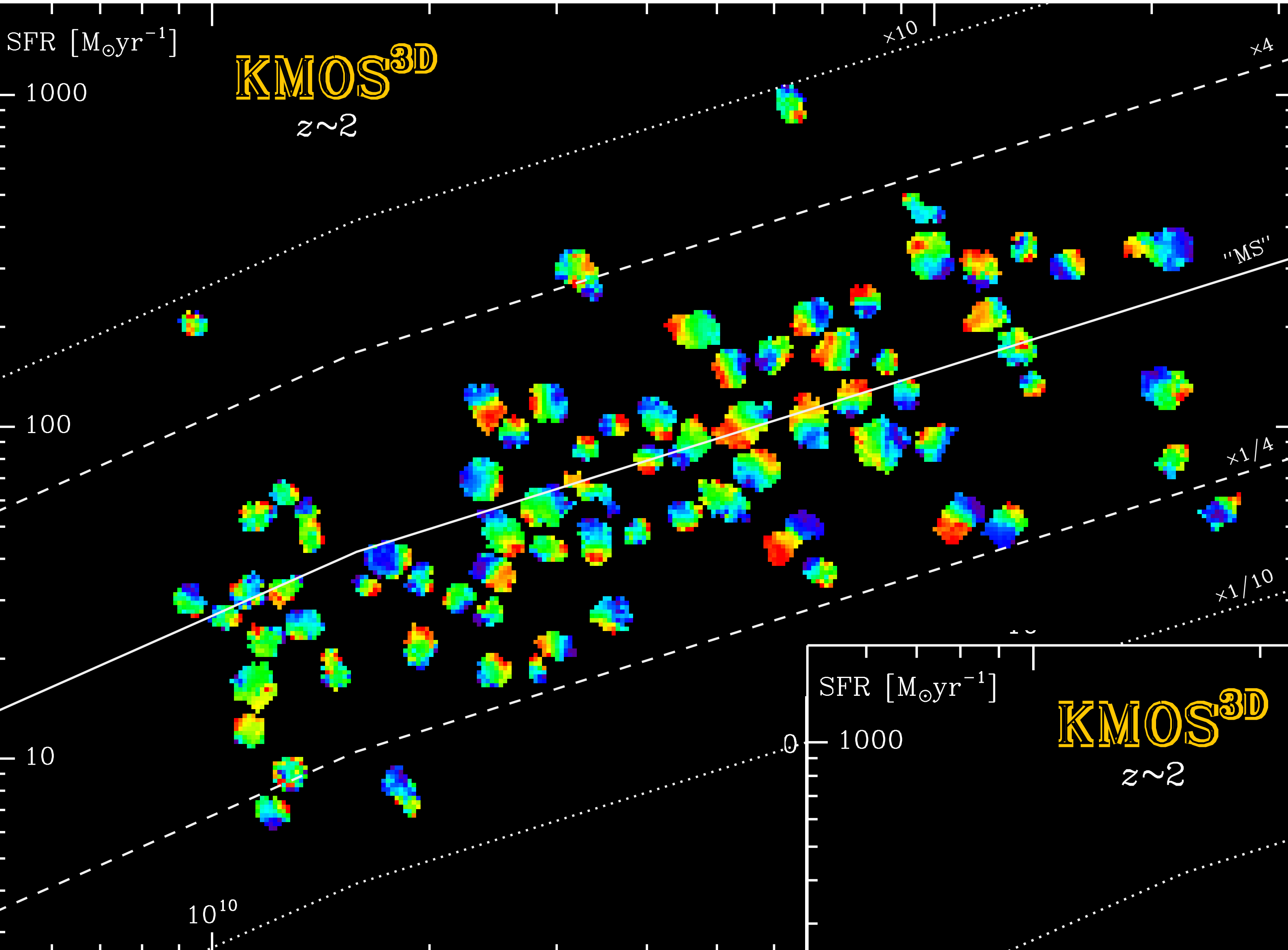


Wisnioski+15

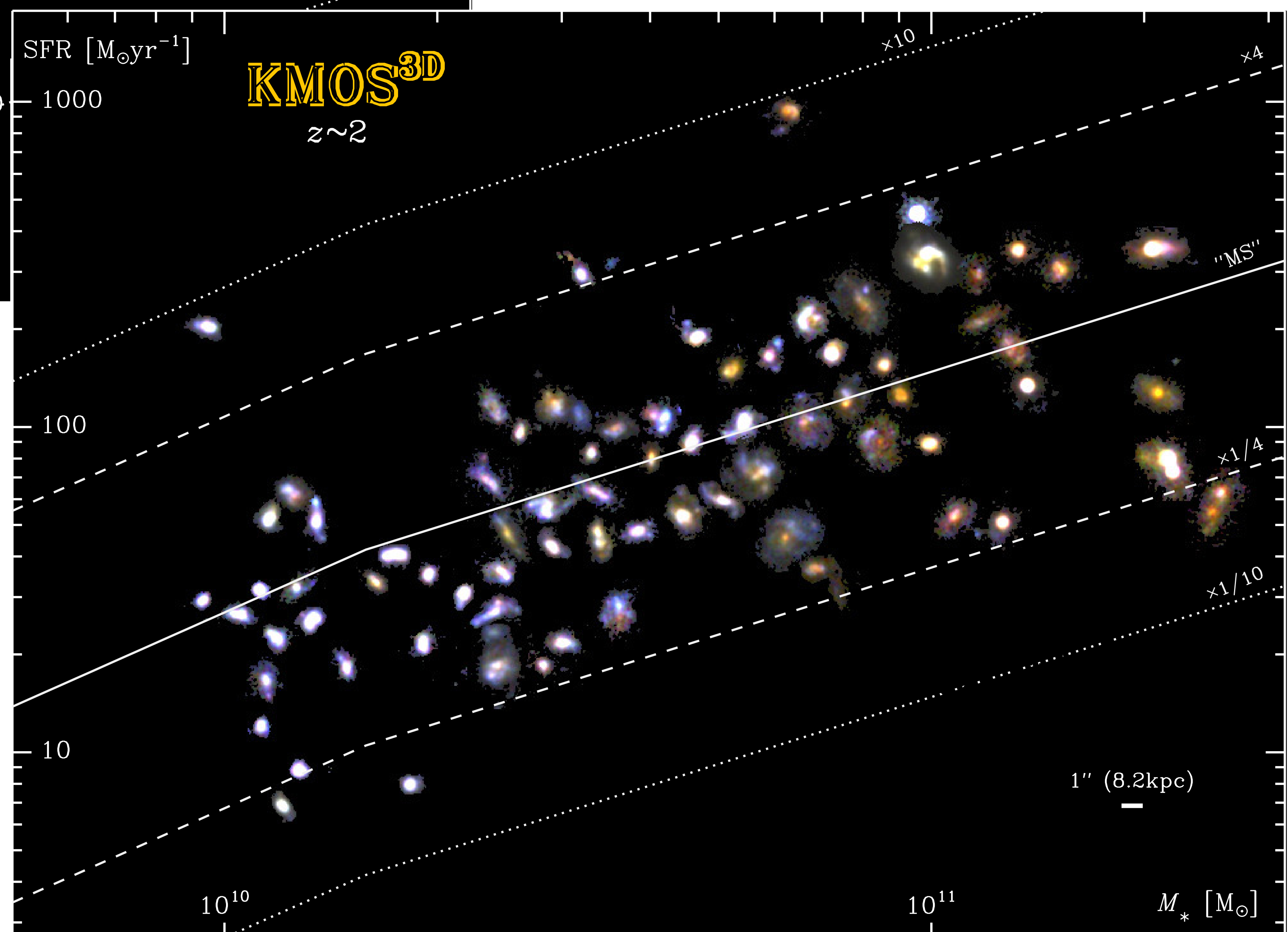


Stott+16

Wisnioski+15



Photometrically irregular
Kinematically regular

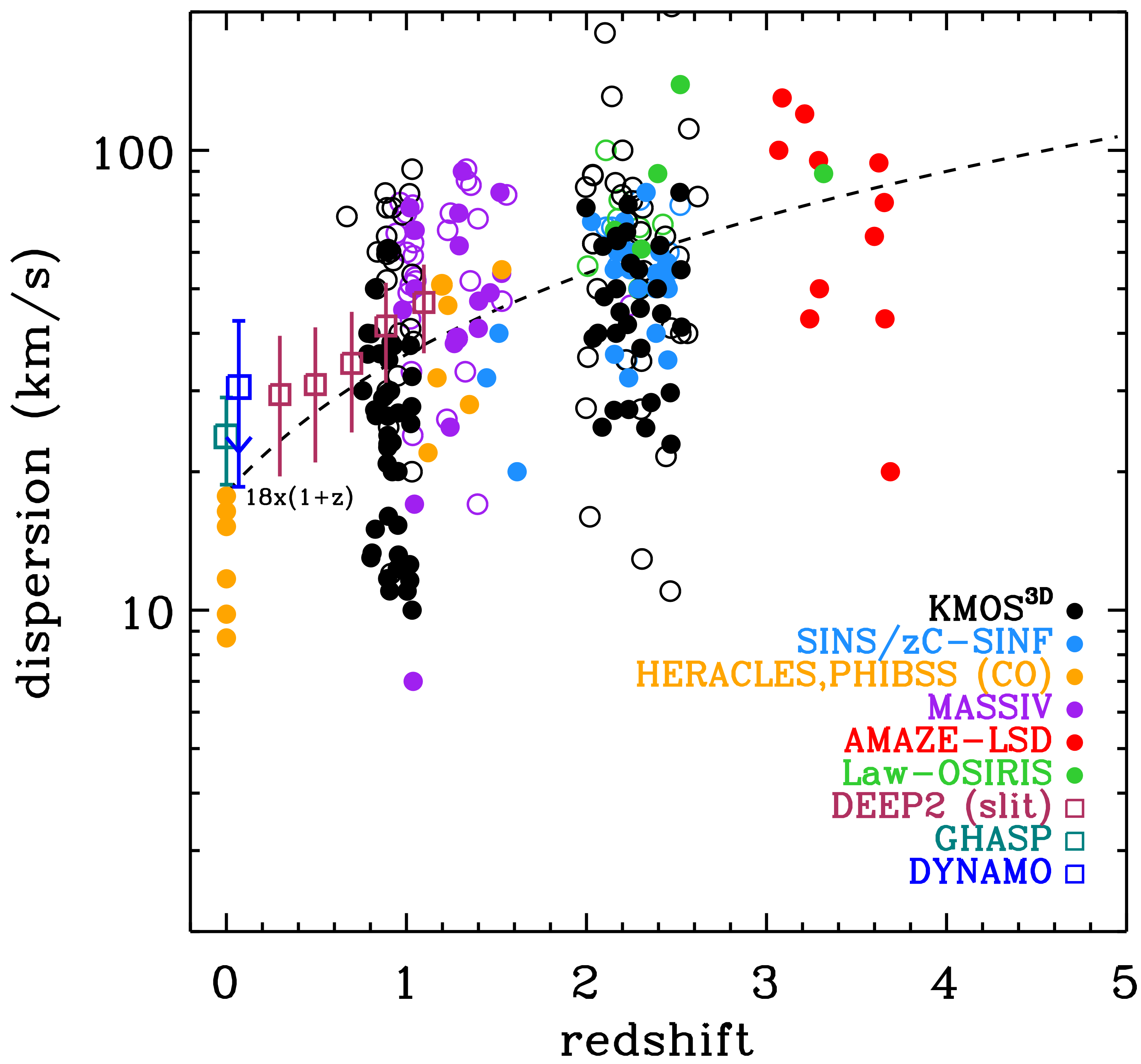


Wisnioski+15

$$Q_{\rm gas} = \frac{\sigma_0 \kappa}{\pi G \Sigma_{\rm gas}}$$

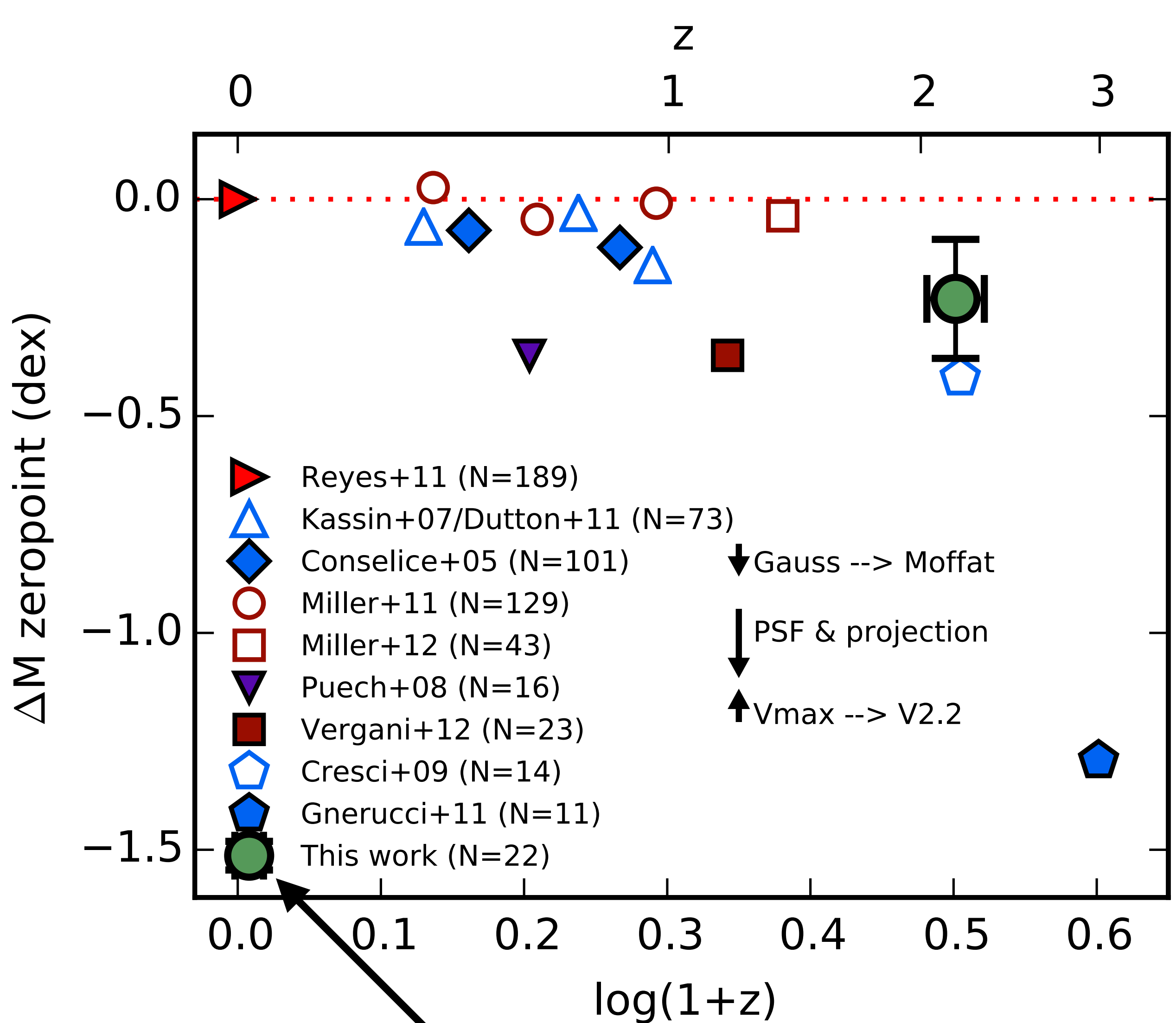
$$\Rightarrow \left(\frac{\sigma_0}{v_c}\right)\left(\frac{a}{f_{\rm gas}}\right)$$

$Q{\sim}1 \Rightarrow f_{gas}{\sim}\sigma/v$

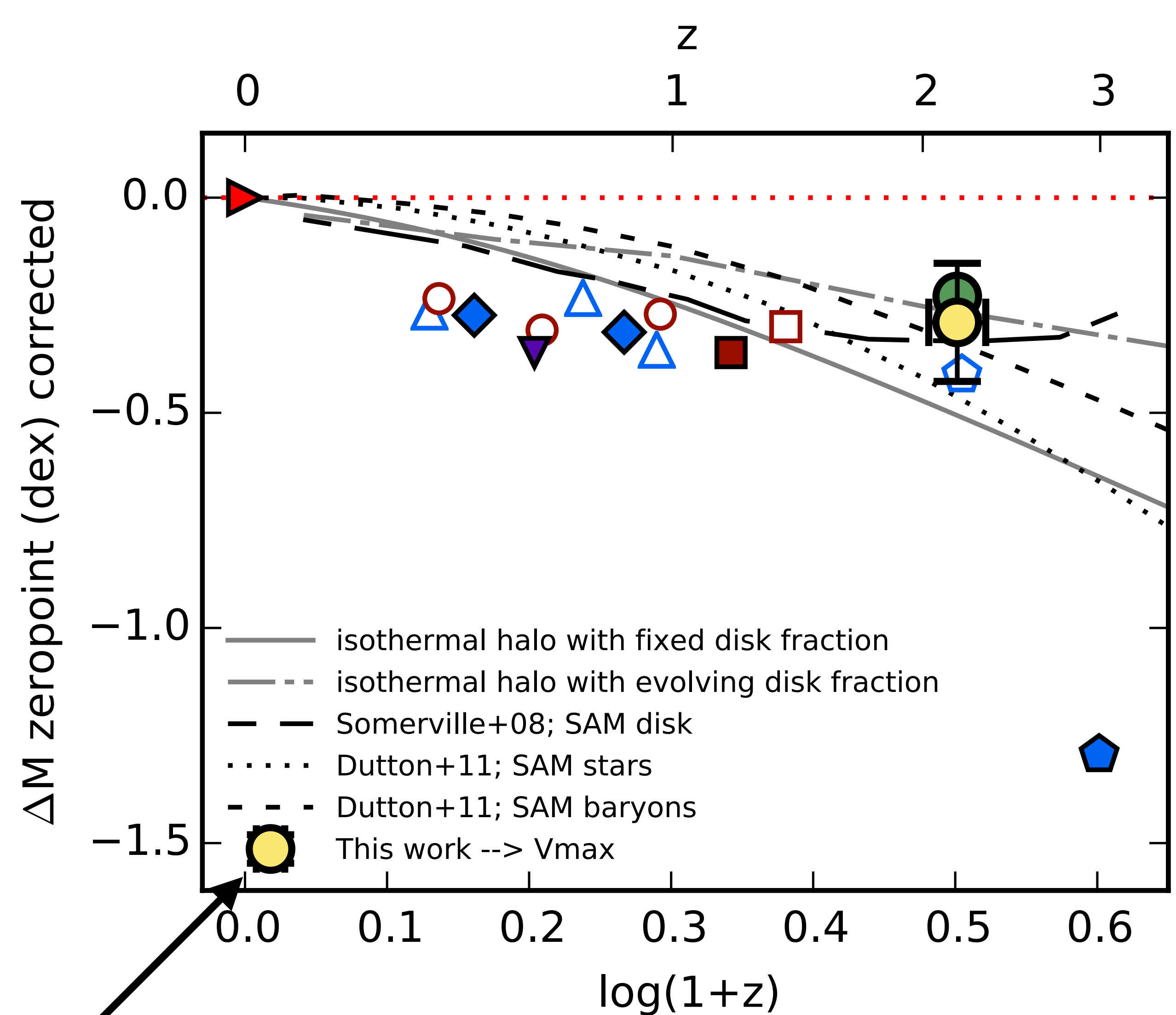


TFR not that interesting…?

Raw



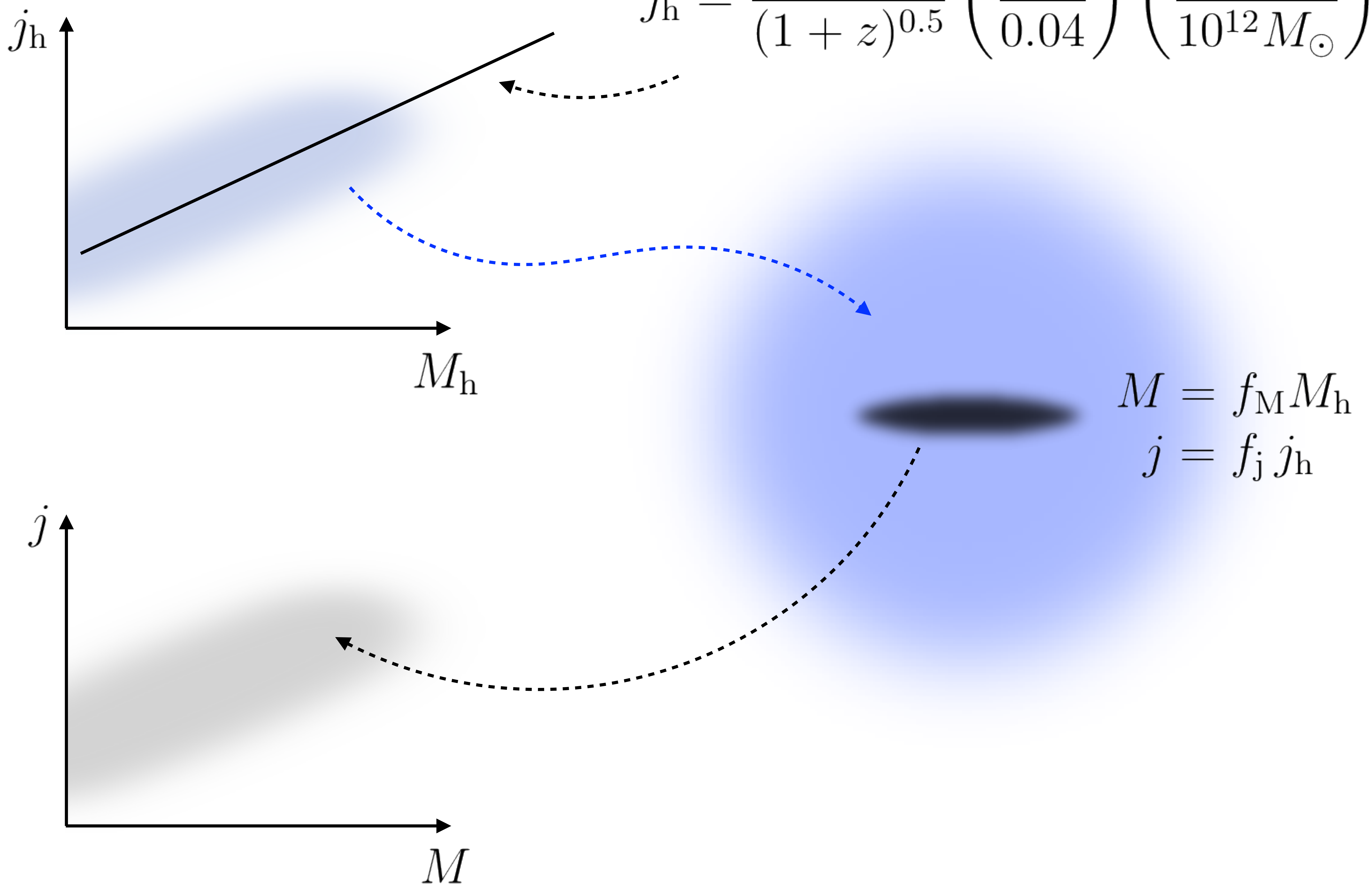
Methodology corrected



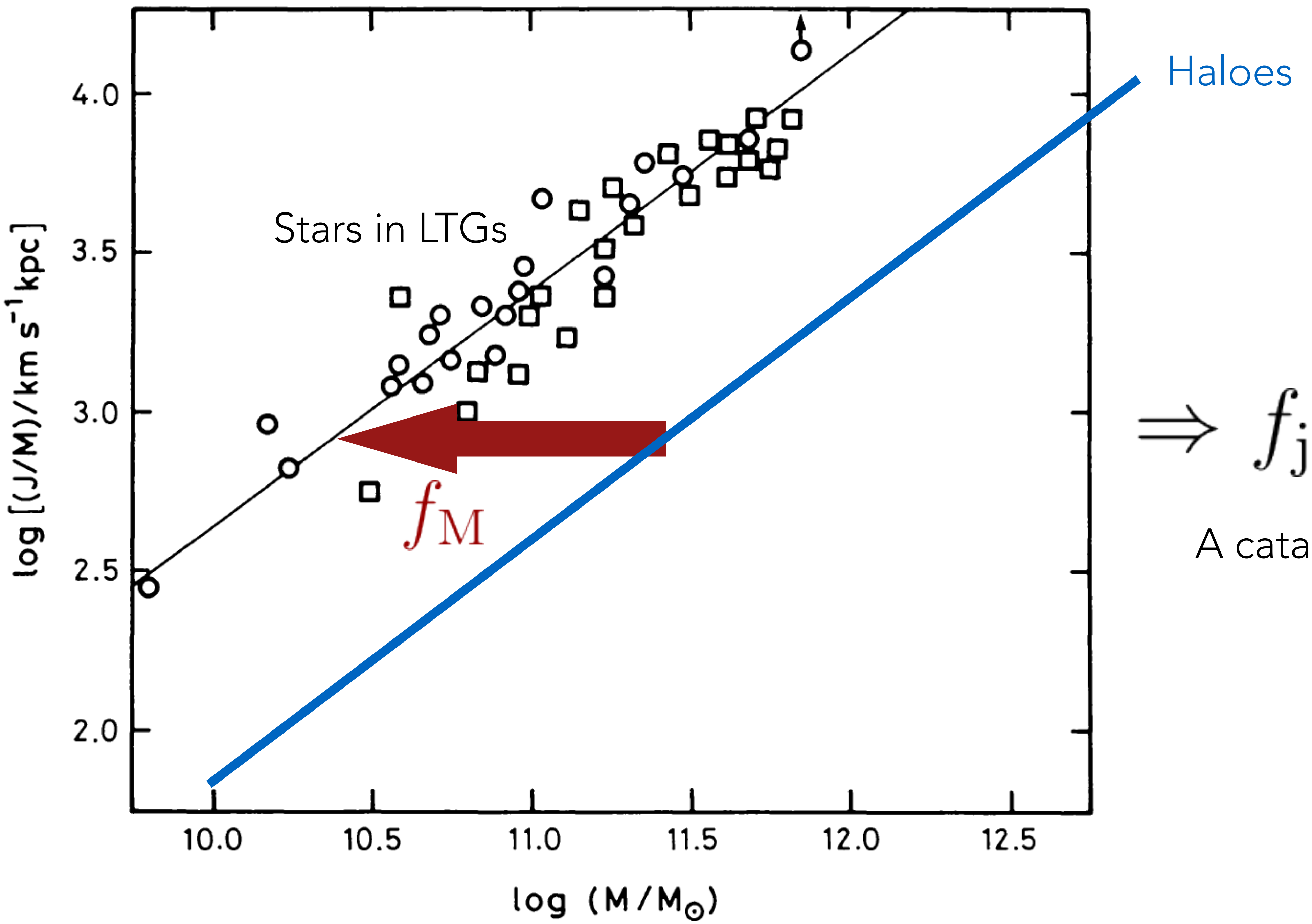
Straatman, KG, +17 (ZFIRE)

Angular momentum: From haloes to galaxies

$$j_{\rm h} = \frac{1700}{(1+z)^{0.5}} \left(\frac{\lambda}{0.04}\right) \left(\frac{M_{\rm h}}{10^{12} M_\odot}\right)^{2/3}$$



First M-j measurements (Fall 1983)



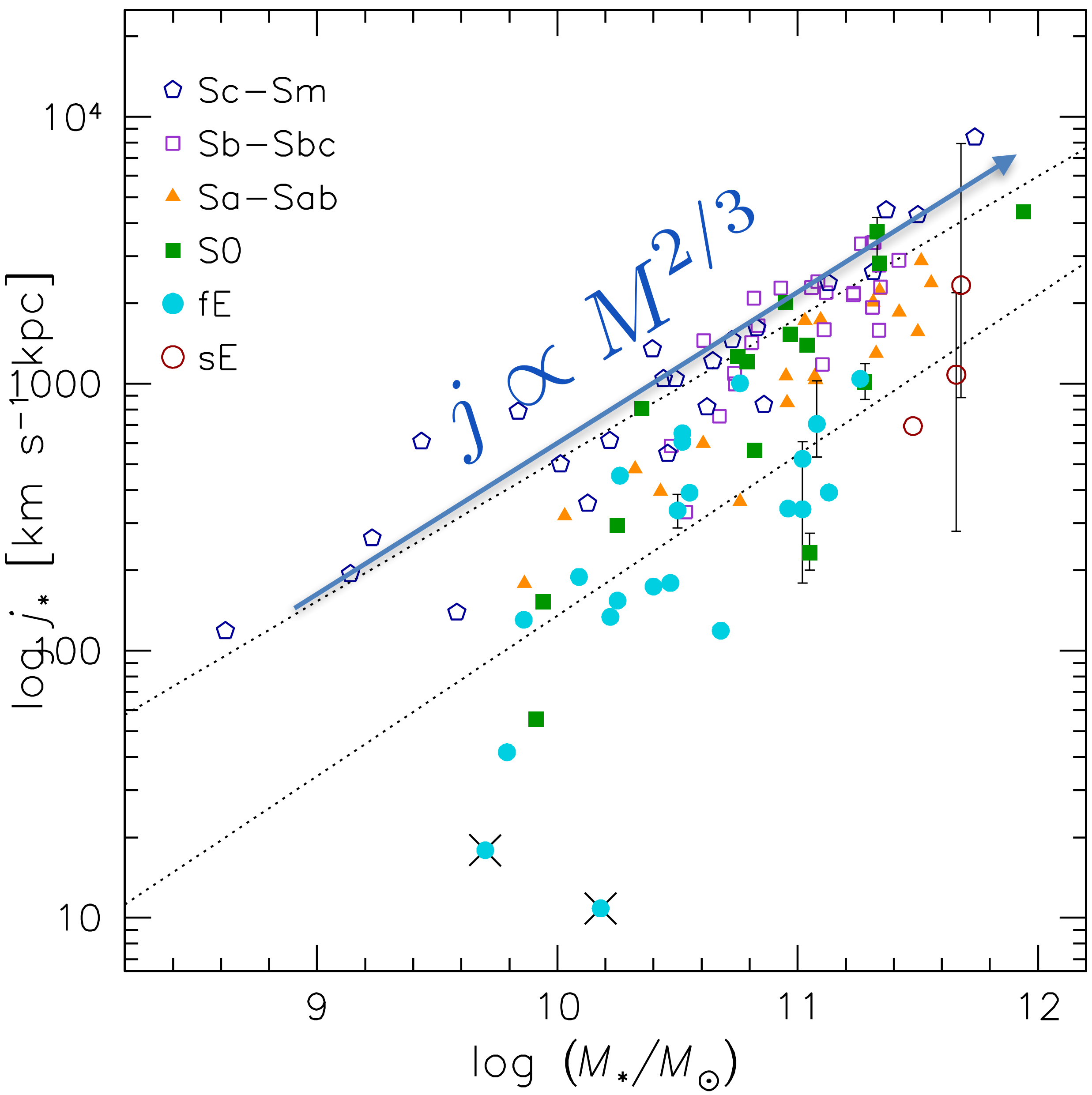
$\Rightarrow f_j \approx 1$

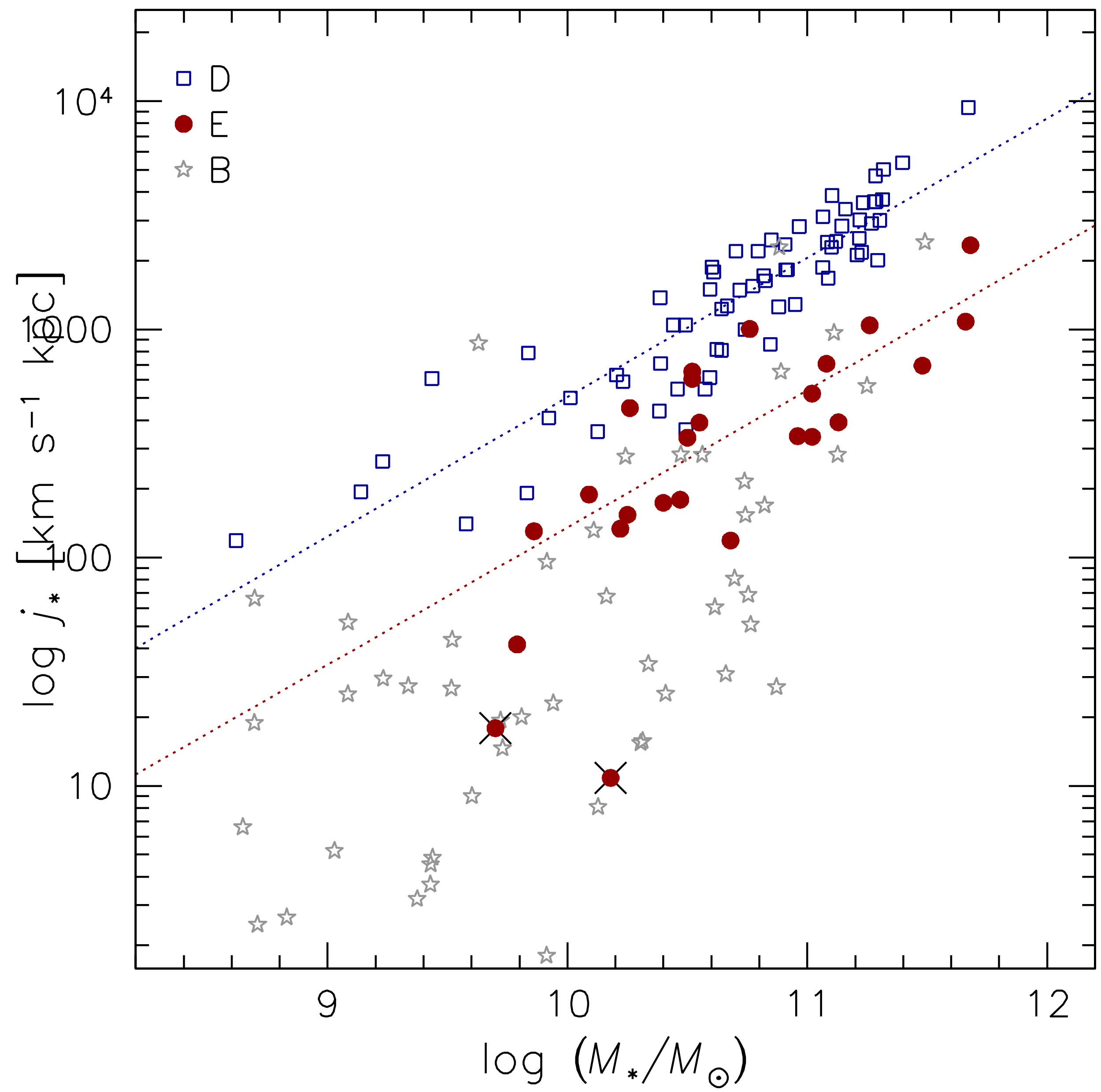
A catastrophe!

Adopted from M. Fall (Conference Proceeding 1983)

'Replacing the Hubble Sequence'?

Romanowsky & Fall (2012)

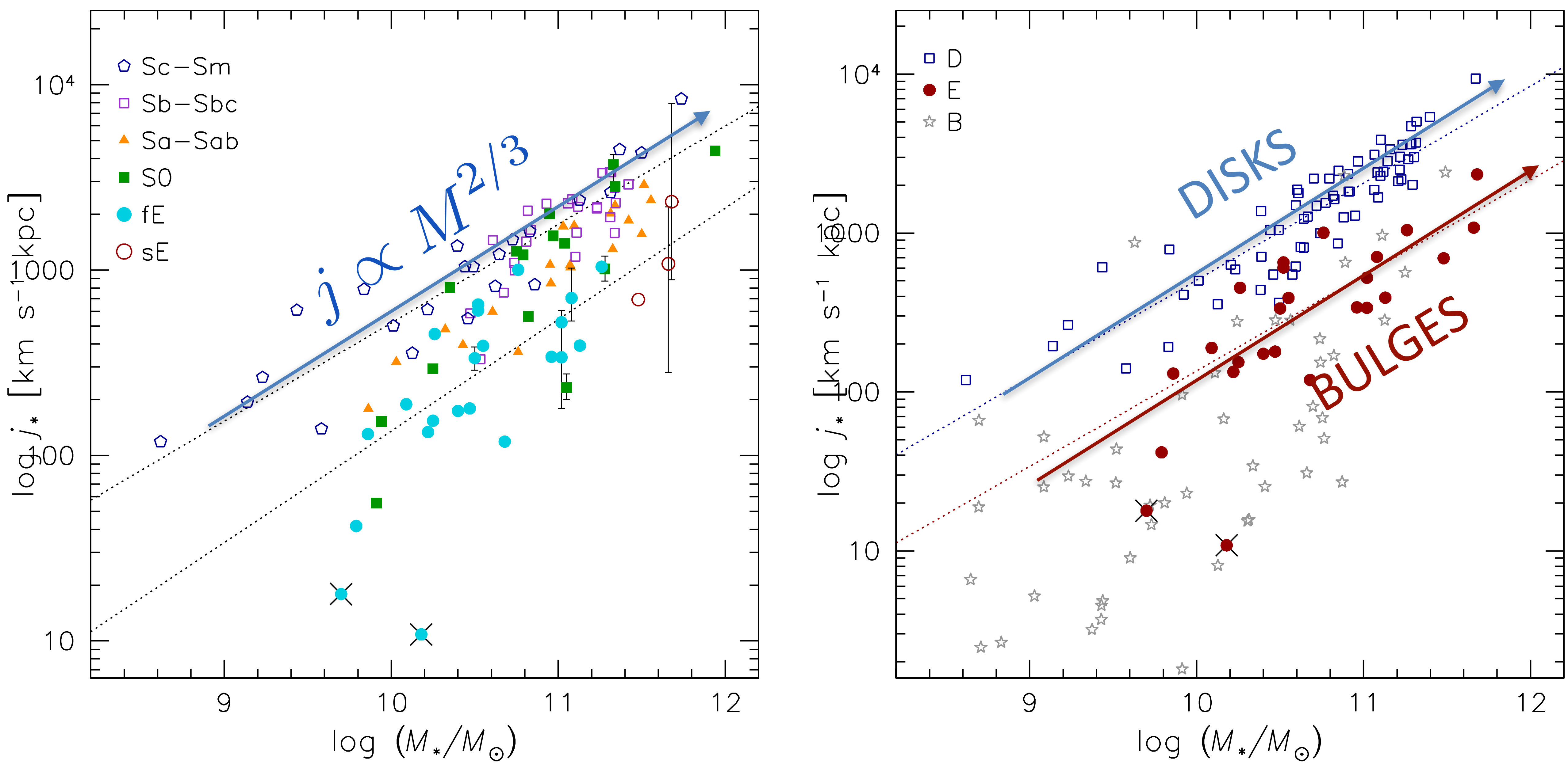




$j = O(1)\ V \times R$

‘Replacing the Hubble Sequence’?

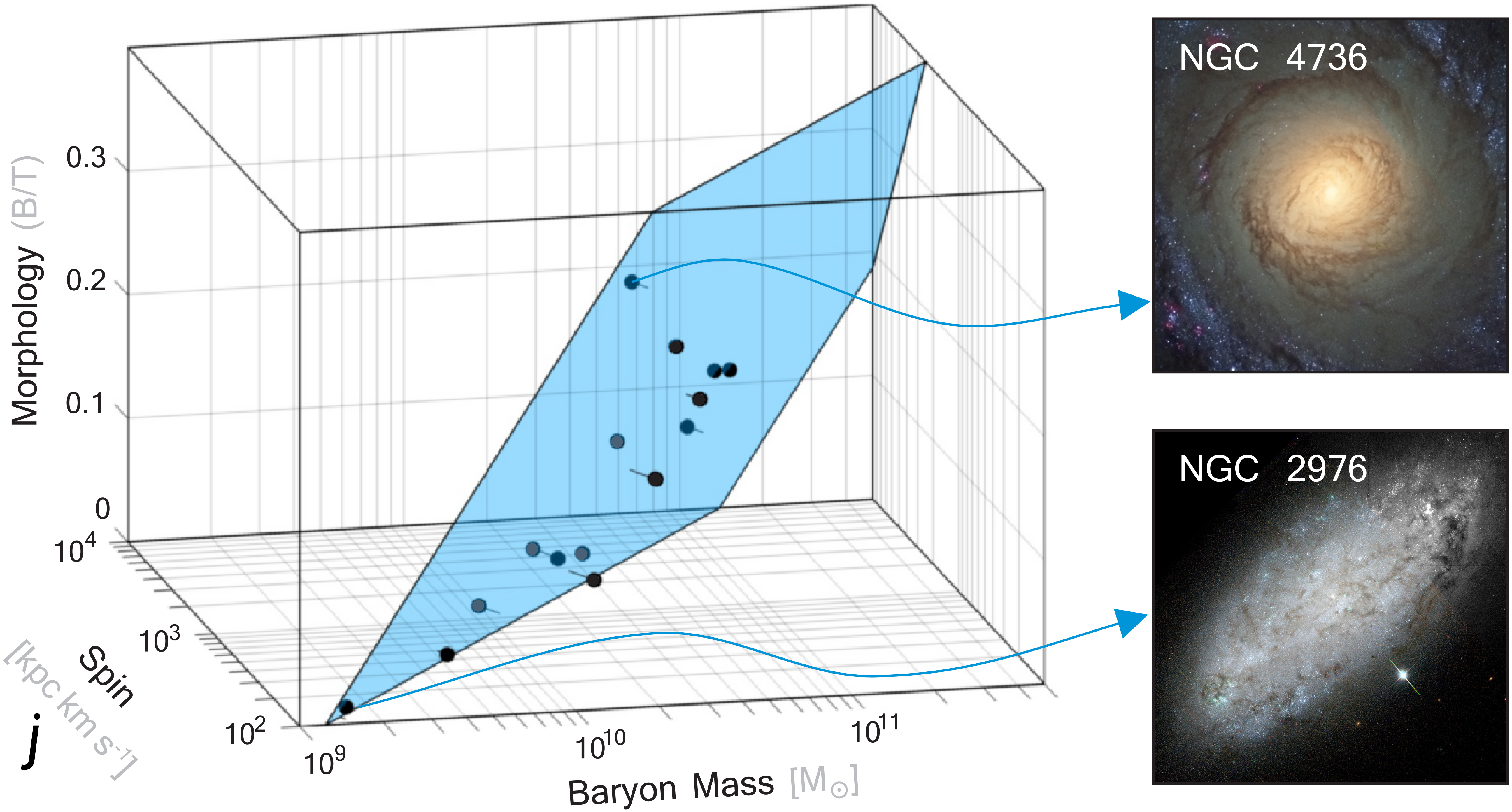
Romanowsky & Fall (2012)



$j = O(1)\ V \times R$

1) **Mass-Spin-Morphology** plane

16 ~M spirals (THINGS) with well measured j (HI, CO, stars)*

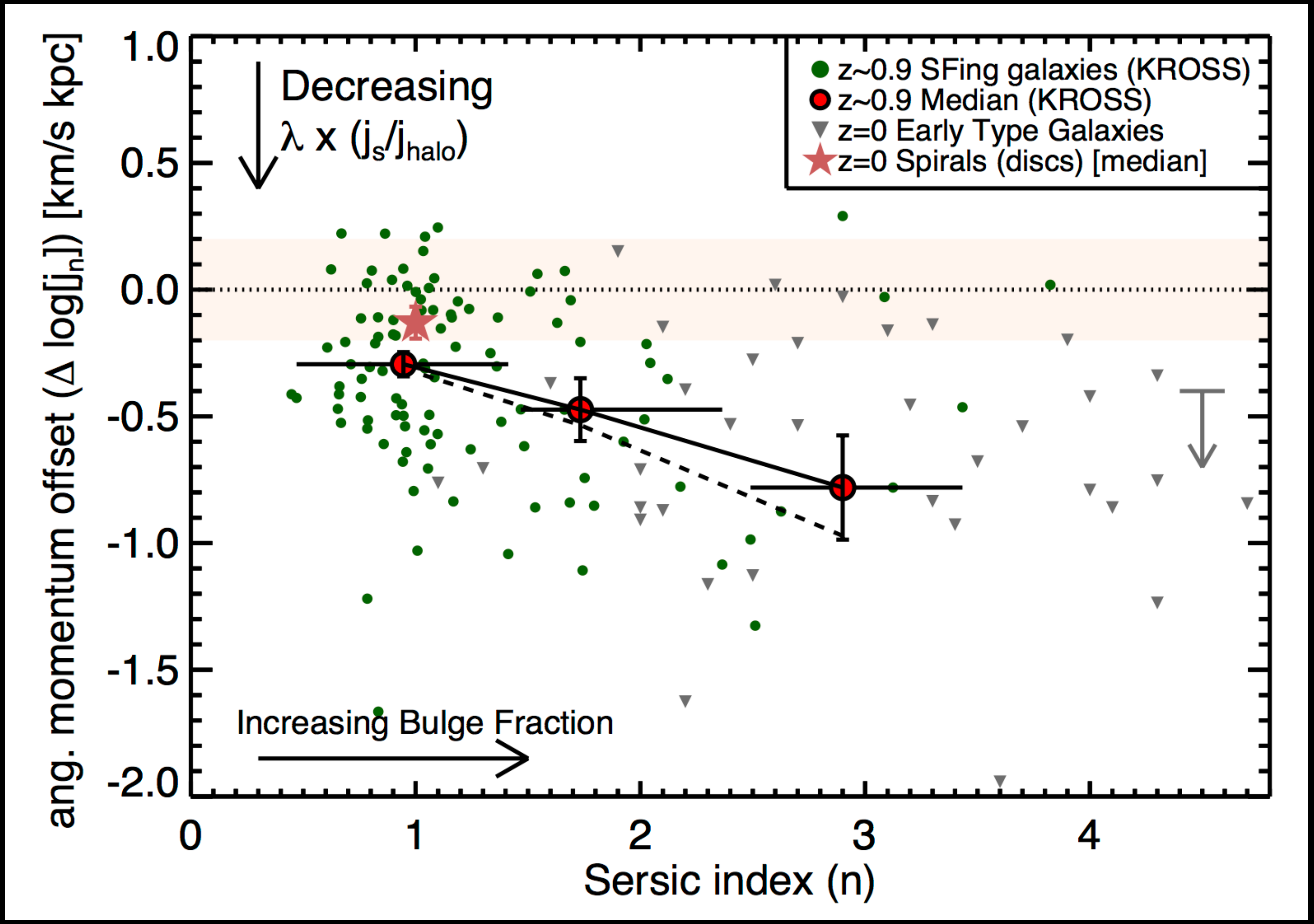


Obreschkow & Glazebrook (2014)

j = specific angular momentum (J/M)

Does angular momentum determine everything?

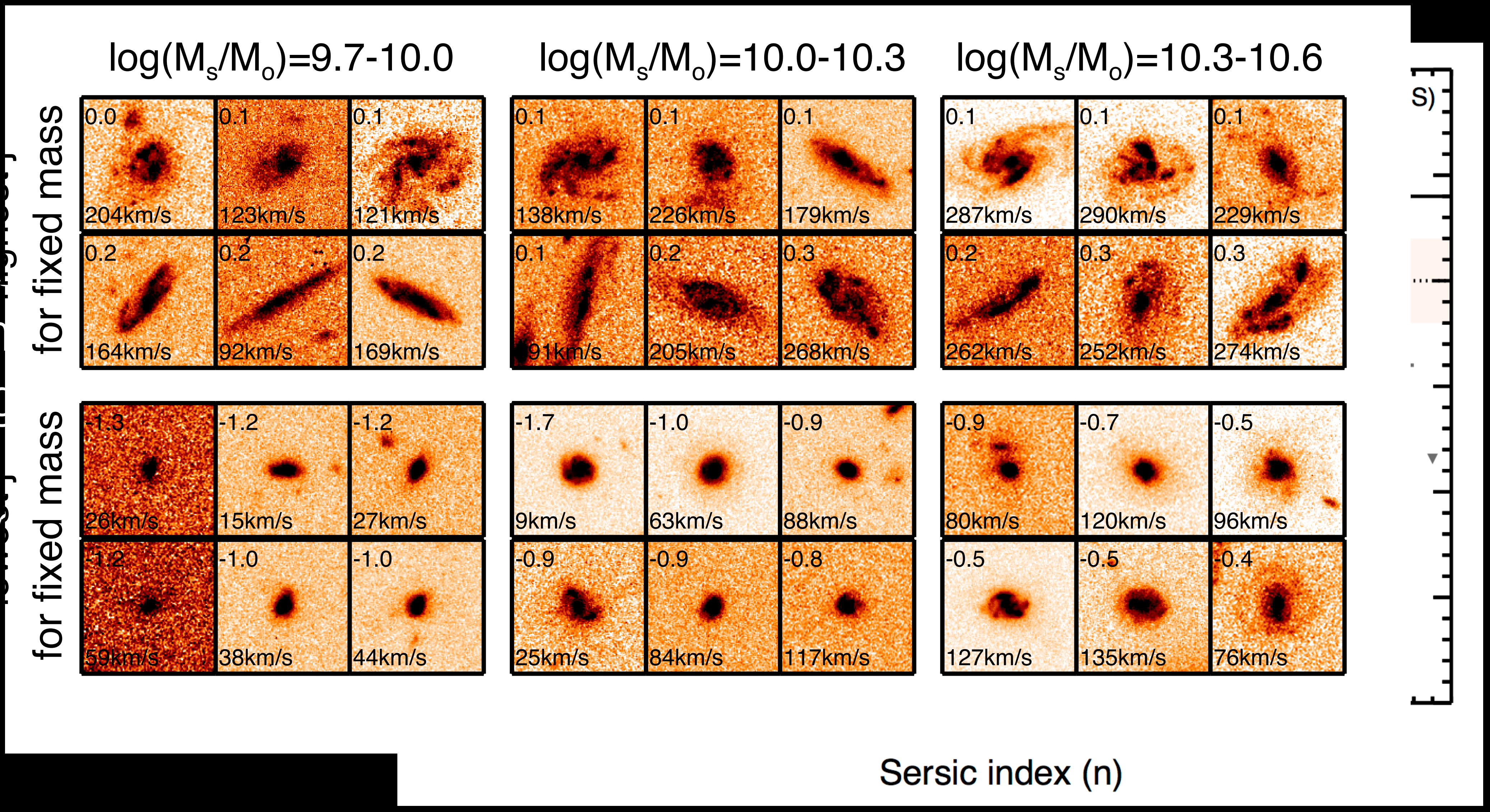
- Does angular momentum drive morphology?
- …and star formation history?



(Bower talk)

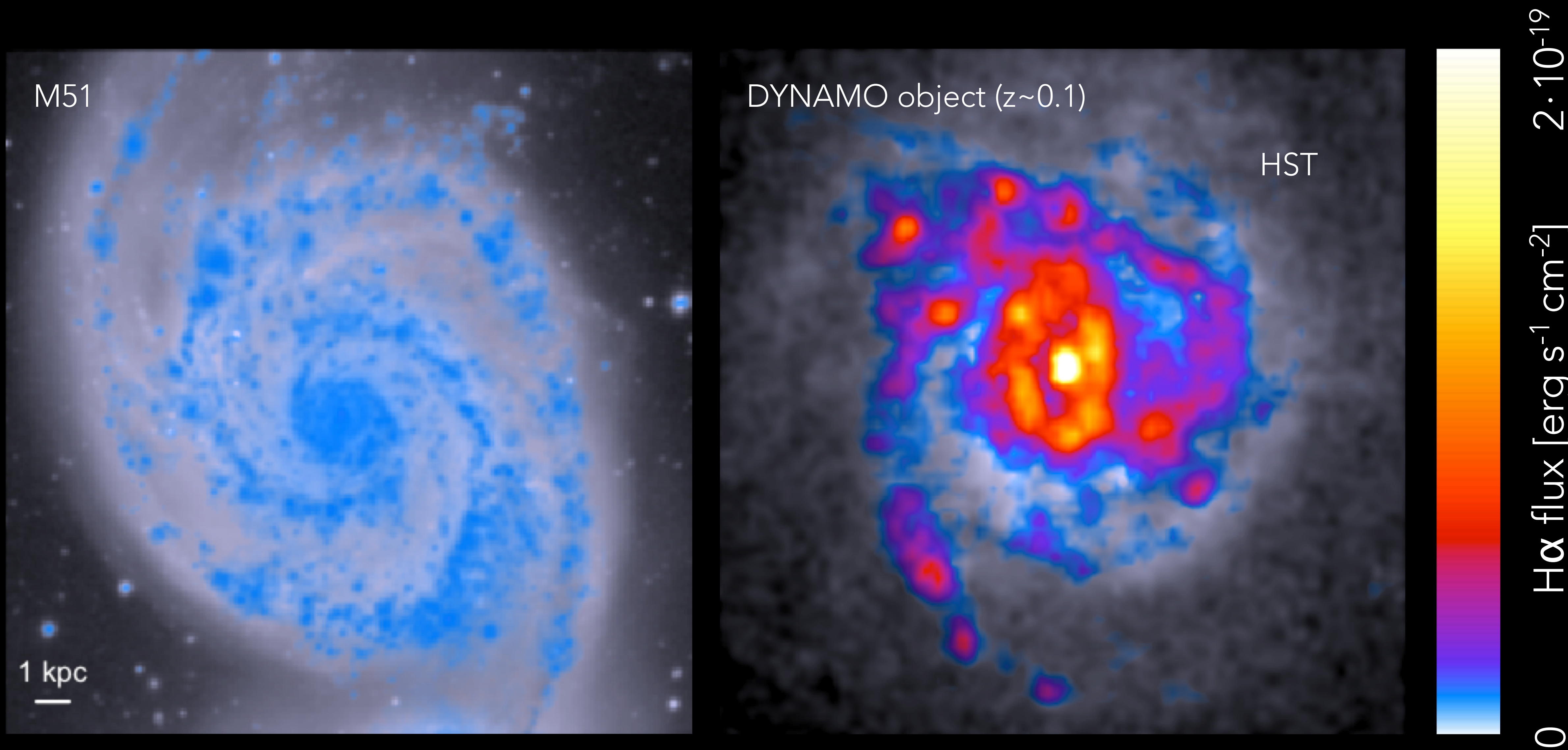
Does angular momentum determine everything?

- Does ang… momentun… morpholog…
- …and sta… history?

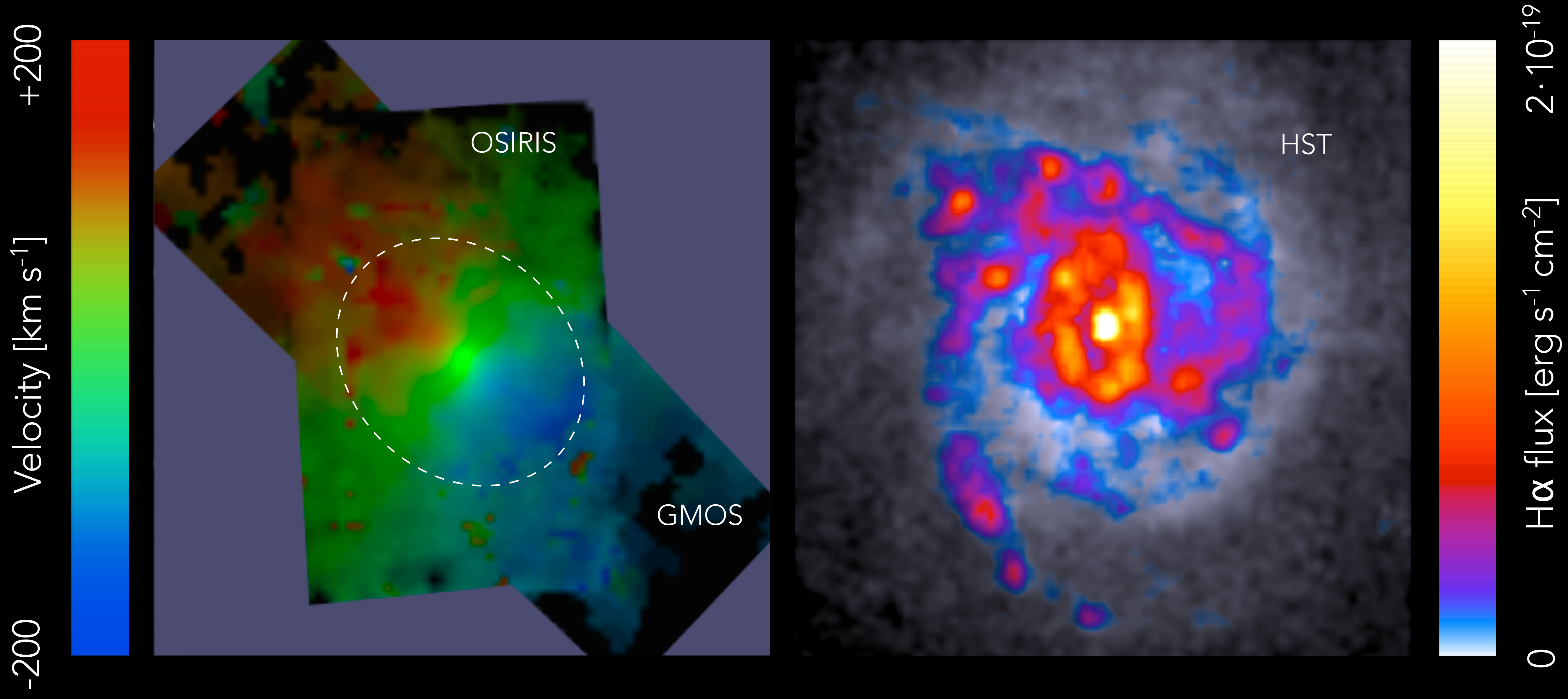


(Bower talk)

DYNAMO Sample z~0.1 clumpy disks, ~30% molecular gas

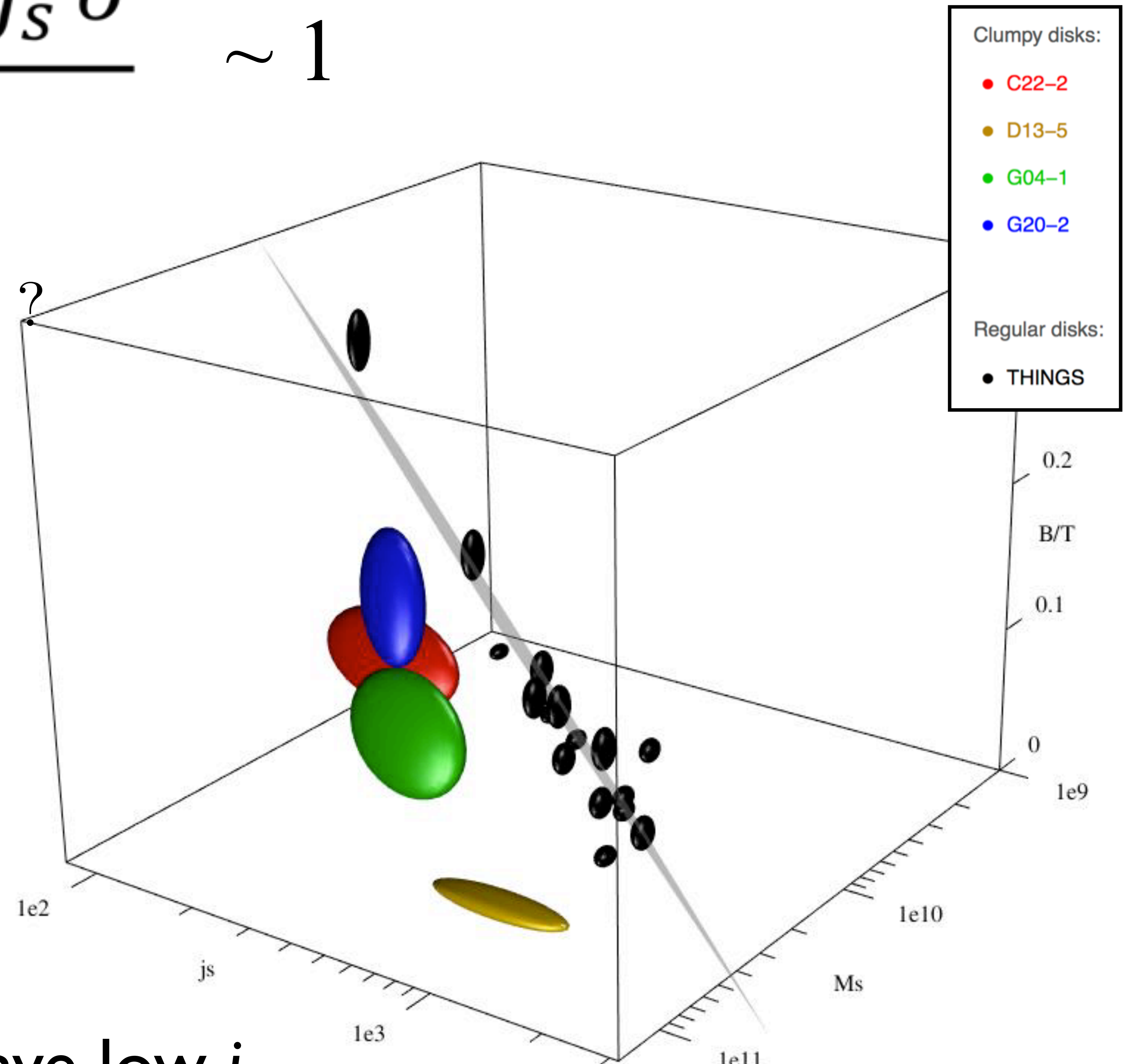


DYNAMO Sample z~0.1 clumpy disks, ~30% molecular gas



$$Q \propto \frac{(1-f_g)\, j_s\, \sigma}{M_s} \quad \sim 1$$

$$j_s \propto (1+z)^{-1/2} \quad ?$$



DYNAMO objects have low j_s for their mass

Obreschkow, KG+(2015)

Relation to halo angular momentum

- key question in galaxy formation physics - how is disk AM related to the halo AM

$$\frac{j_{s,\mathrm{pred}}}{\mathrm{kpc\,km\,s^{-1}}} = 2.95 \times 10^4 f_j f_\star^{-2/3} \lambda \left(\frac{H[z]}{H_0}\right)^{-1/3} \left[\frac{M_\star}{10^{11} M_\odot}\right]^{2/3}$$

Romanowsky et al 2012

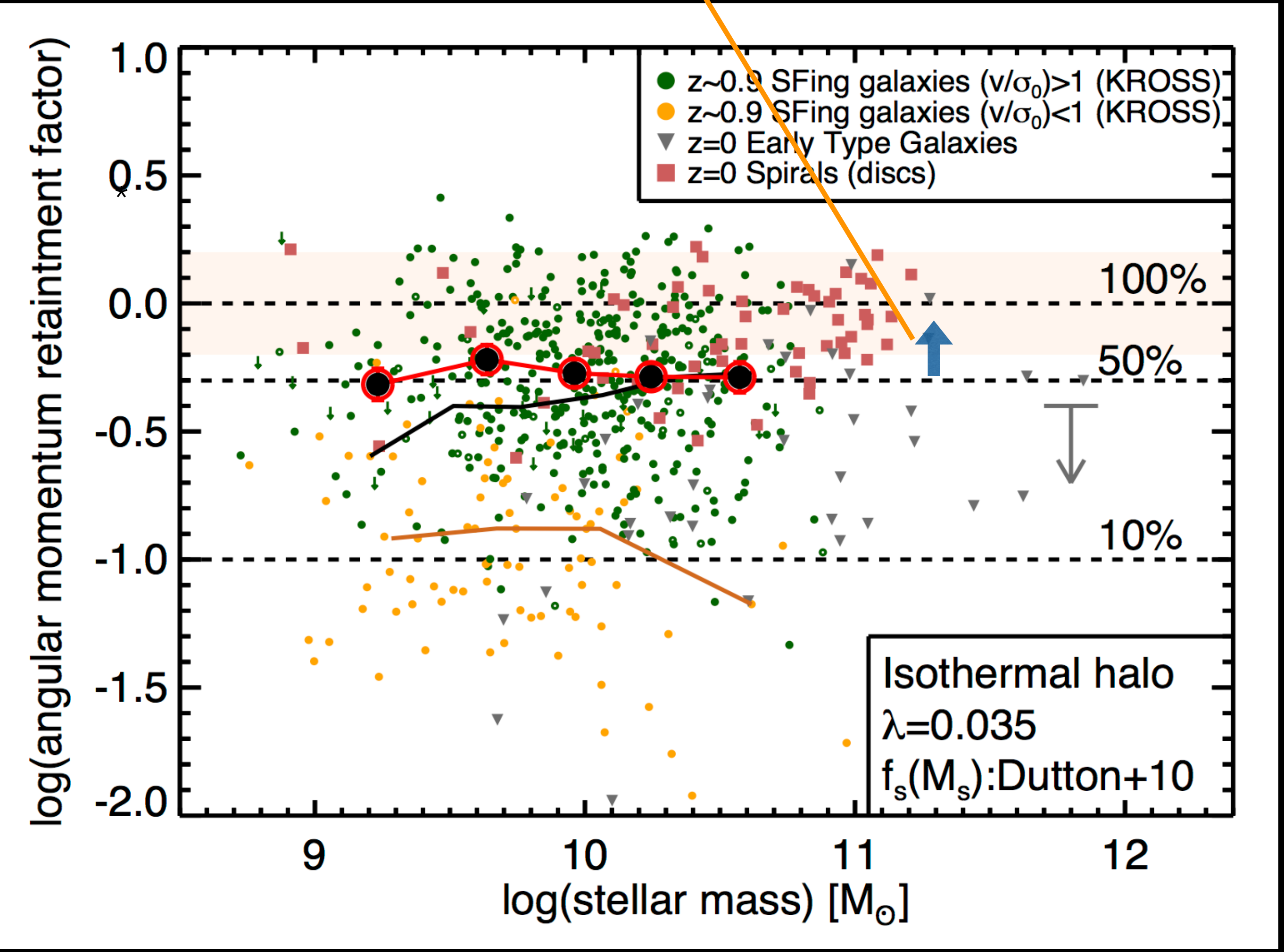
$$f_\star = 0.29 \times \left(\frac{M_\star}{5 \times 10^{10} \mathrm{M}_\odot}\right)^{0.5} \left(1 + \left[\frac{M_\star}{5 \times 10^{10} \mathrm{M}_\odot}\right]\right)^{-0.5}$$

Dutton et al 2010

- $f_\star$ is fraction of gas that forms stars; f_j is fraction of angular momentum retained

- Why are j_{halo} and j_{star} related?

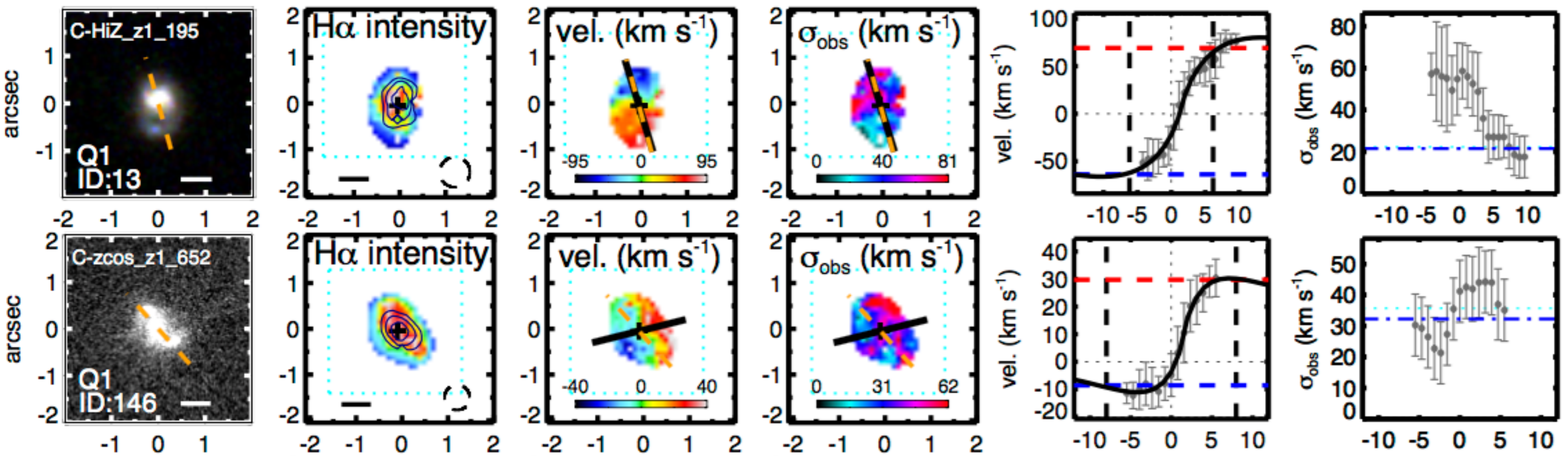
hint of ~ 30% drop in retention factor between z=0 and z=1

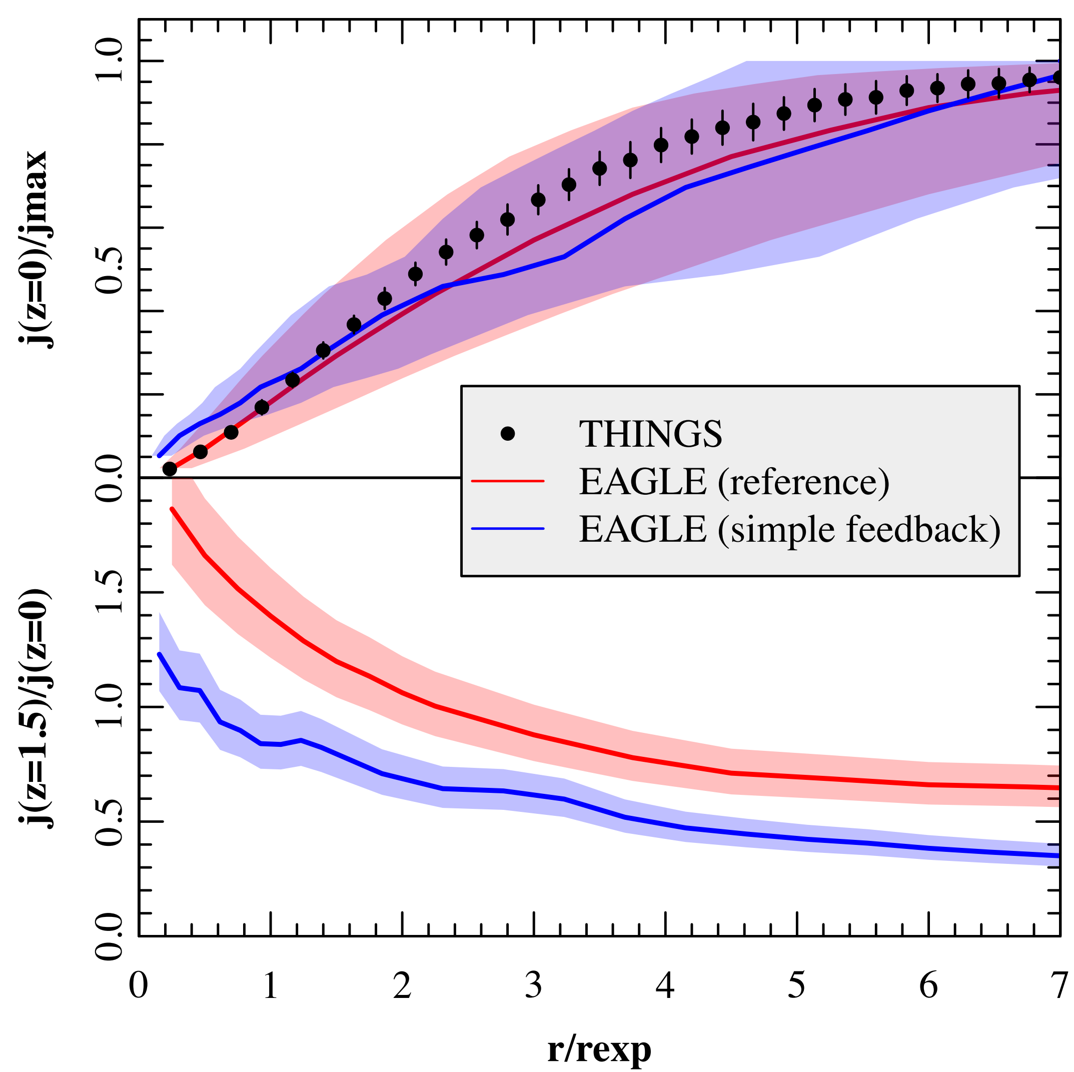


(Bower talk)

Harison et al 2016; Burket et al 2016

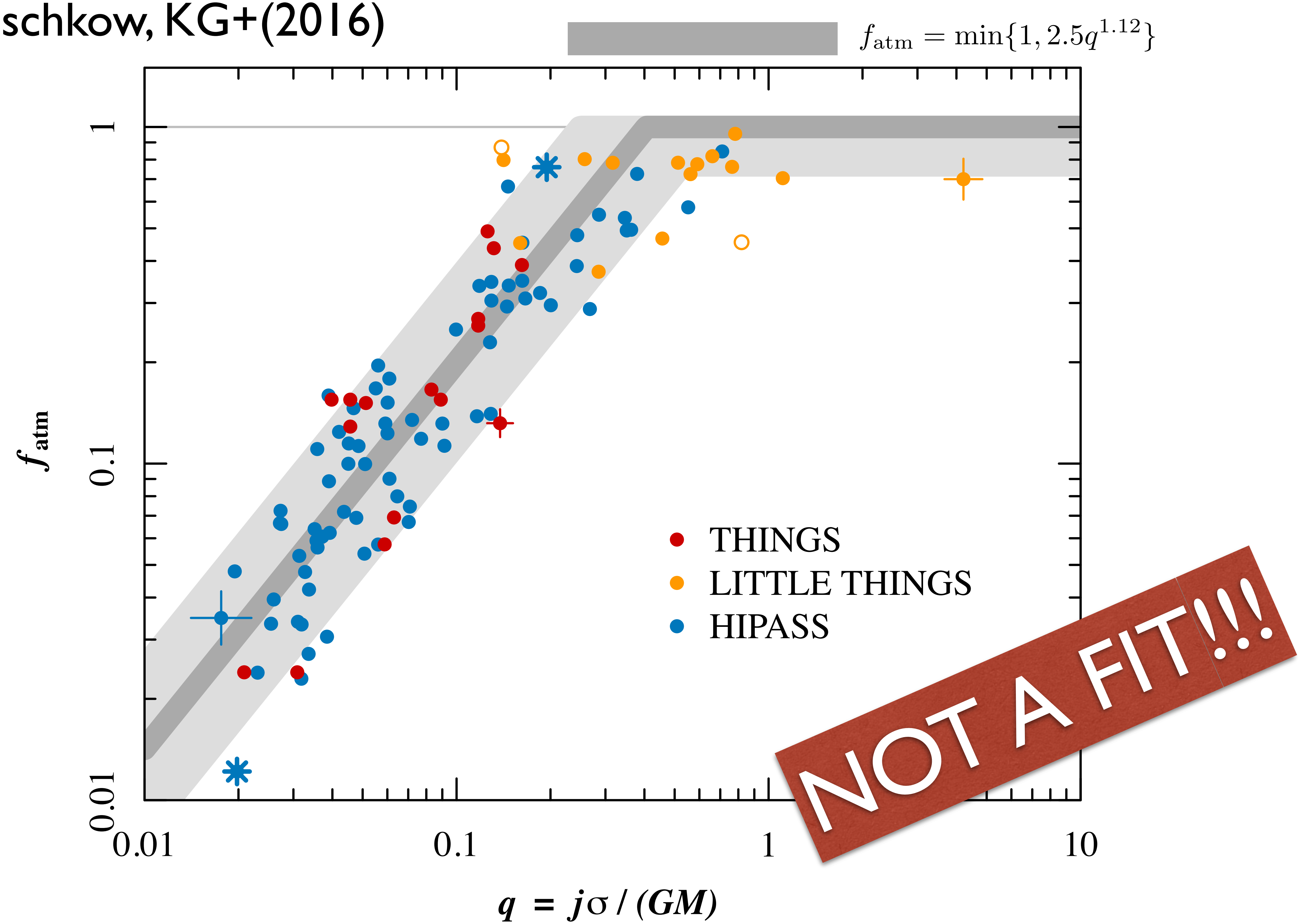
KROSS

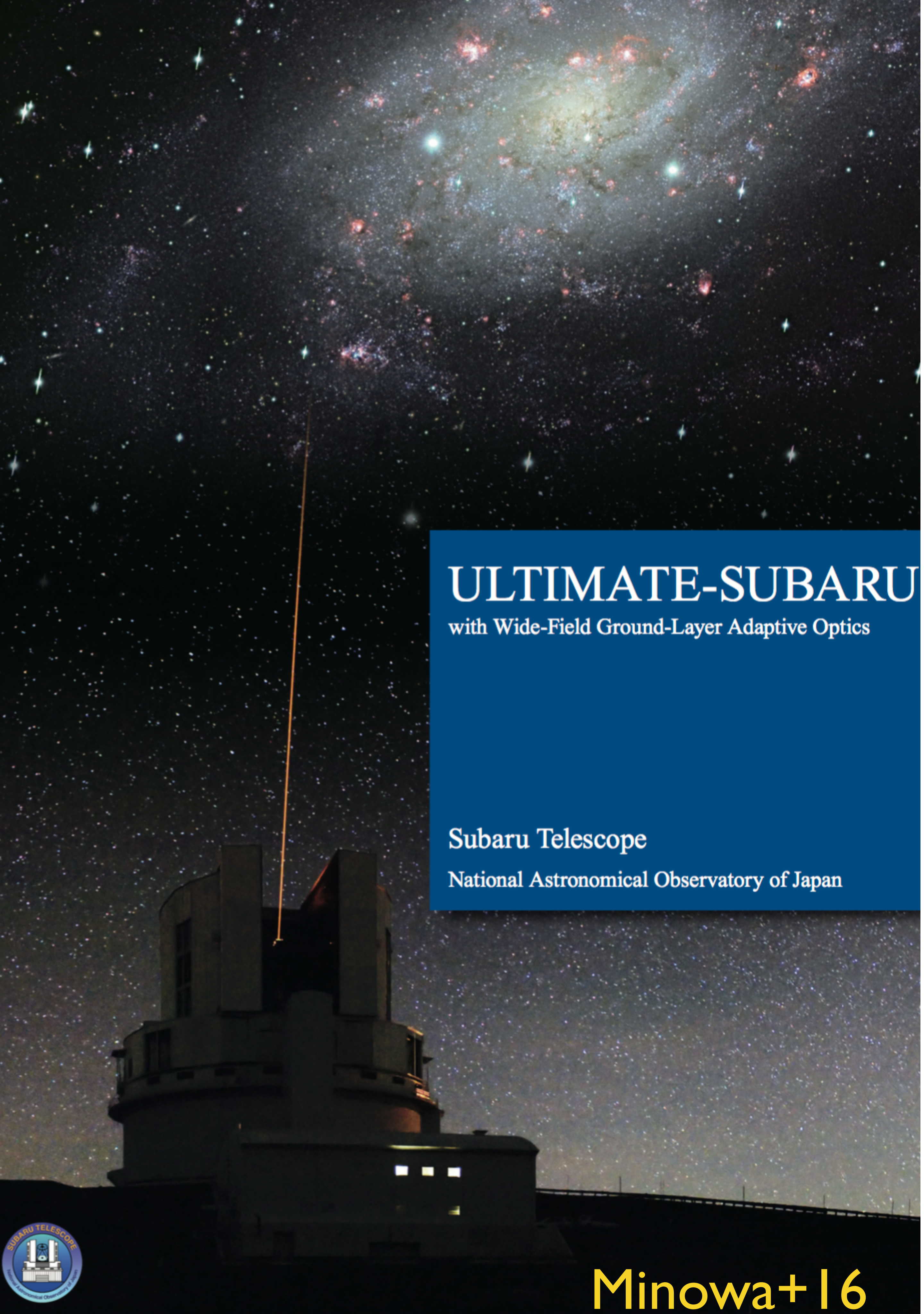

C-HiZ_z1_195
Q1
ID:13
C-zcos_z1_652
Q1
ID:146
arcsec
Hα intensity
vel. (km s-1)
σobs (km s-1)
vel. (km s-1)
σobs (km s-1)


j(z=0)/jmax
j(z=1.5)/j(z=0)
r/rexp
THINGS
EAGLE (reference)
EAGLE (simple feedback)

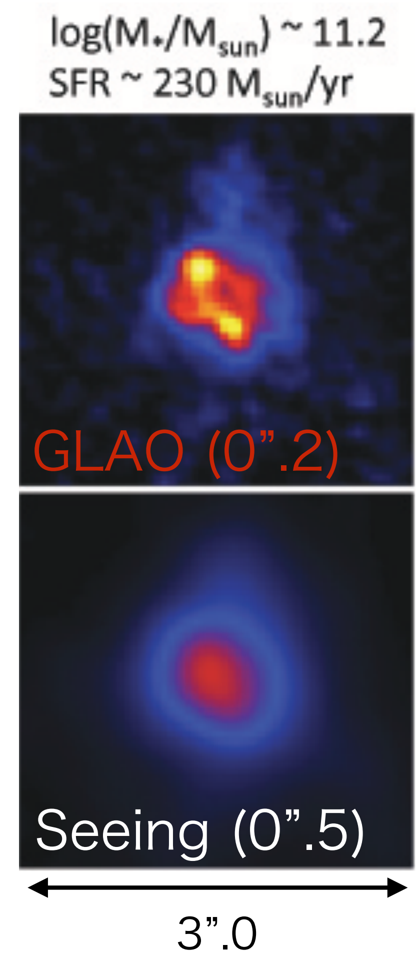
Angular momentum explains HI content!

Obreschkow, KG+(2016)



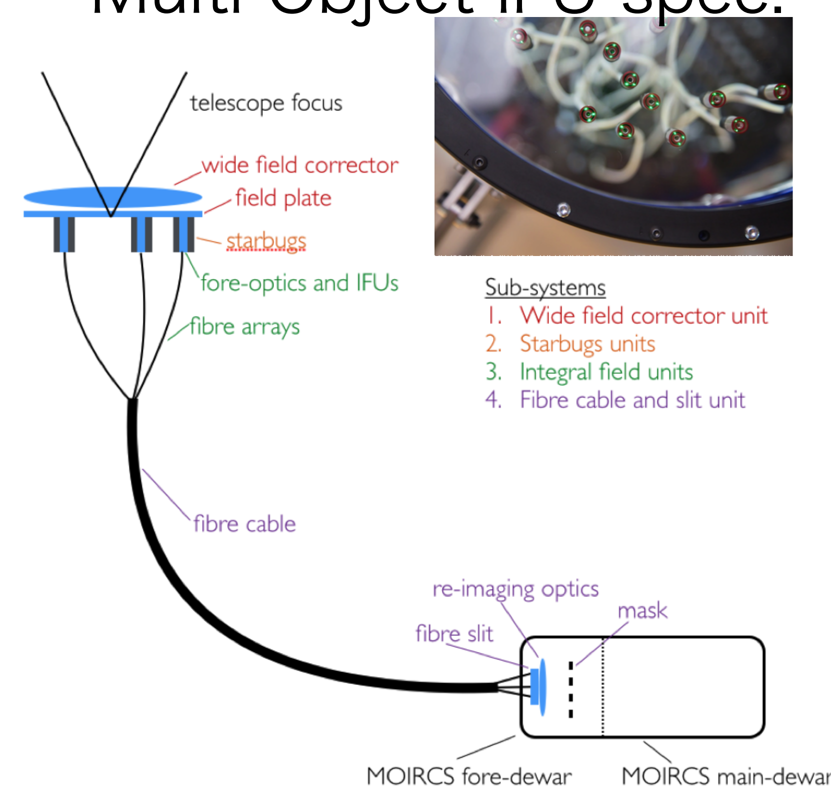


Minowa+16



13 IFUs
15 arcmin FOV

Multi-Object IFU spec.



Sub-systems
1. Wide field corrector unit
2. Starbugs units
3. Integral field units
4. Fibre cable and slit unit

Summary

- Stellar populations (JWST wins)
- Photo-ionisation puzzles (to be solved by MOSFIRE etc. soon…?)
- Environment (PFS wins, SDSS at z~1, finally)
- Kinematics (ULTIMATEly a bright future from the ground)