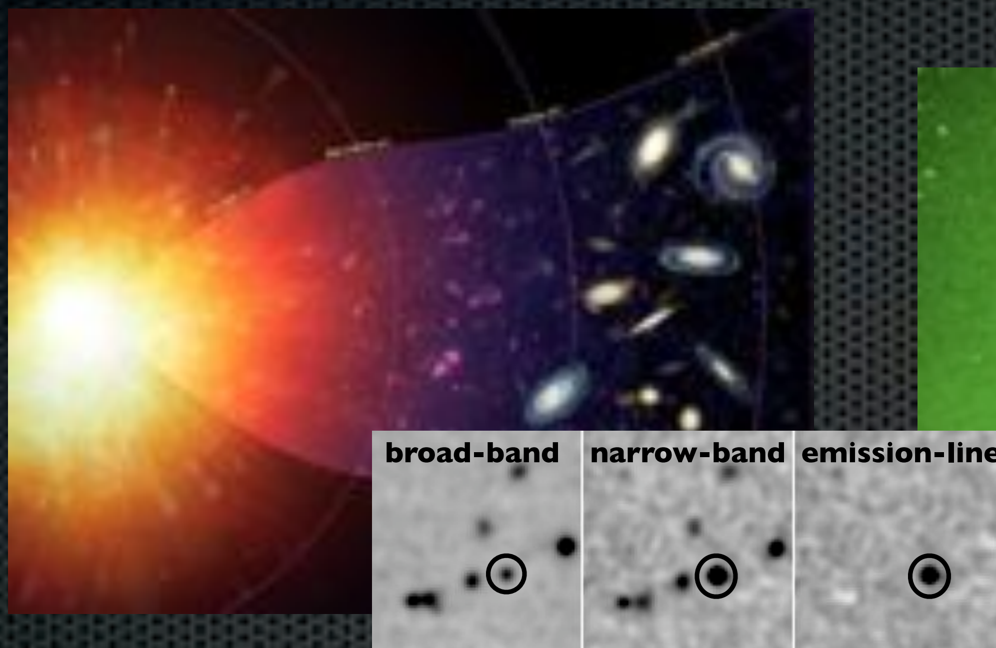
Highlights from HiZELS

The High Redshift (Z) Emission Line Survey



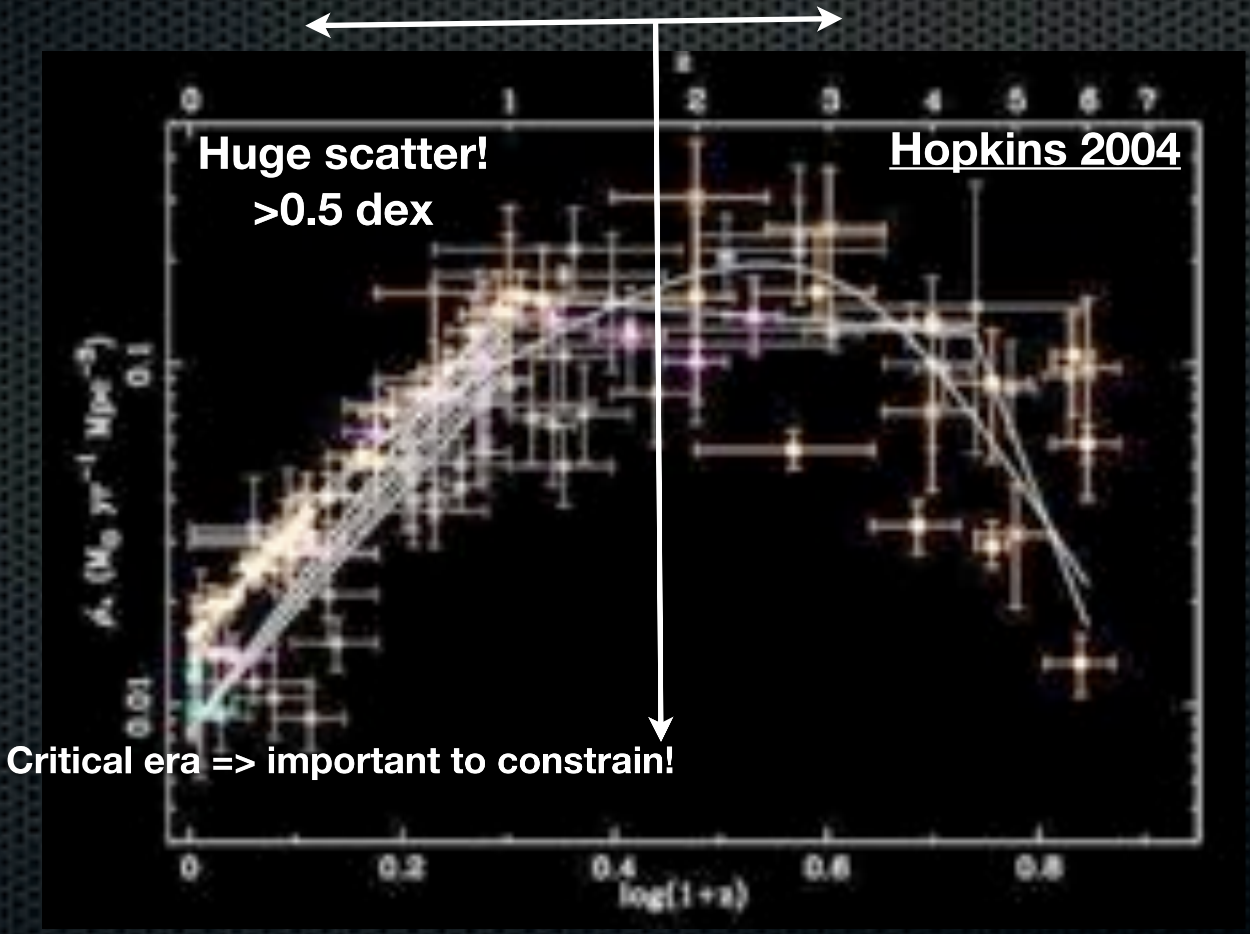
David Sobral

Leiden Observatory

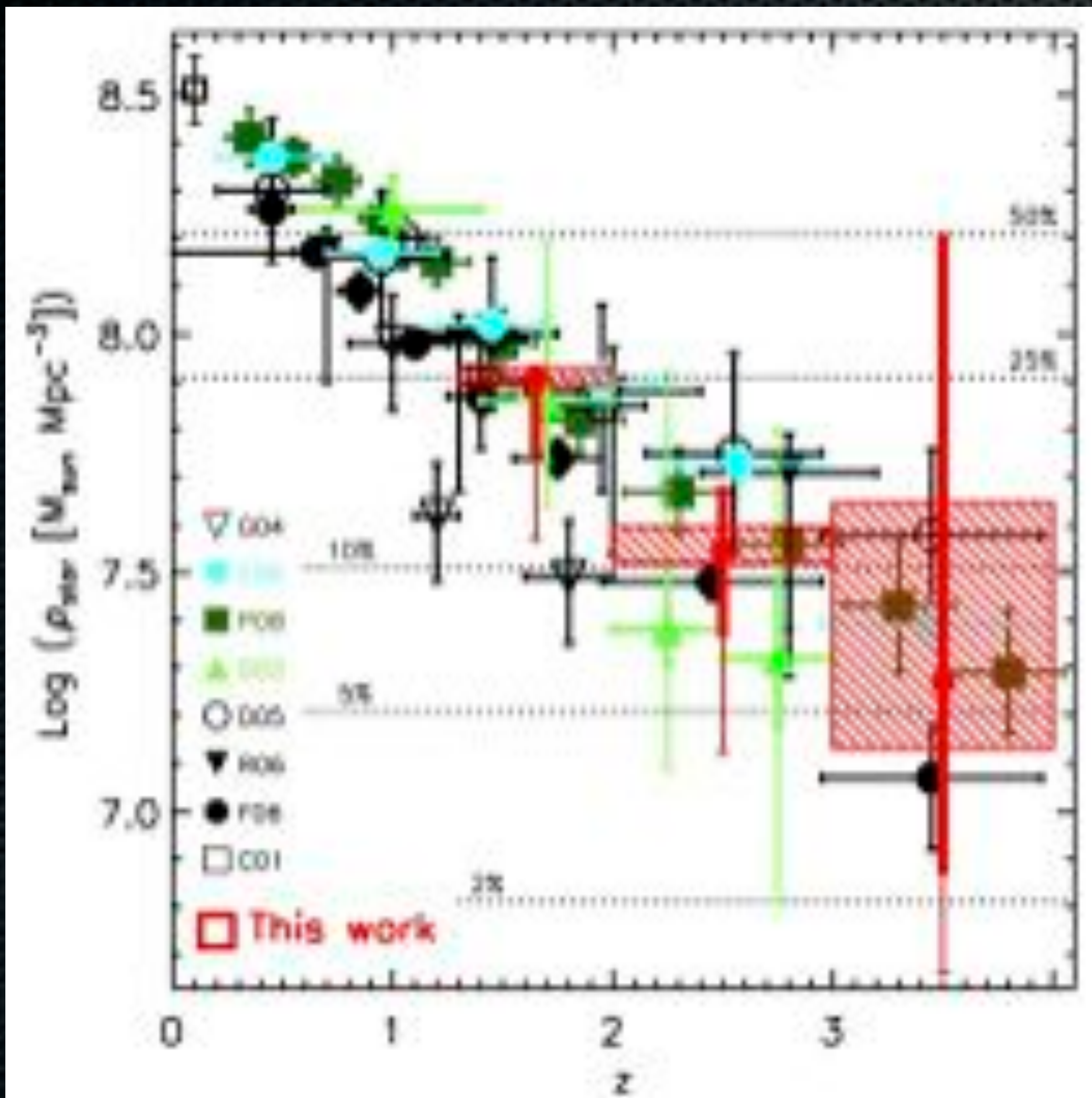
Philip Best, Ian Smail, Jim Geach, Michele Cirasuolo, Mark Swinbank, Yuichi Matsuda, Jaron Kurk, Rob Ivison, Mark Casali

Star formation Activity

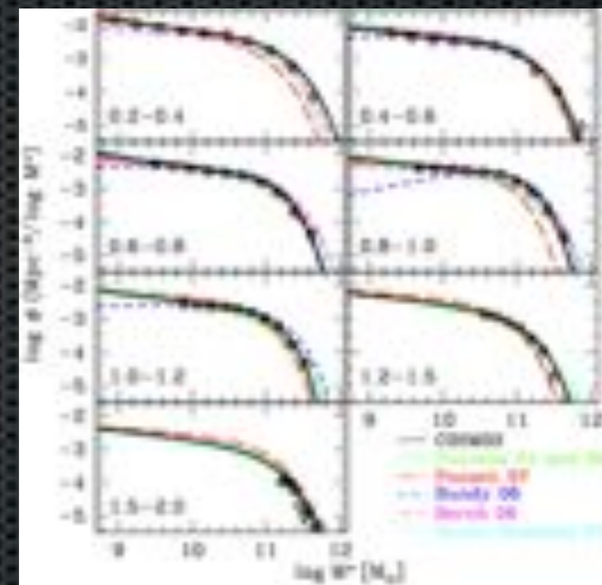
- Combining all tracers doesn't really help...
- Dust dependence + selection biases + sensitivity + etc.



Stellar Mass Assembly



- Stellar Mass function



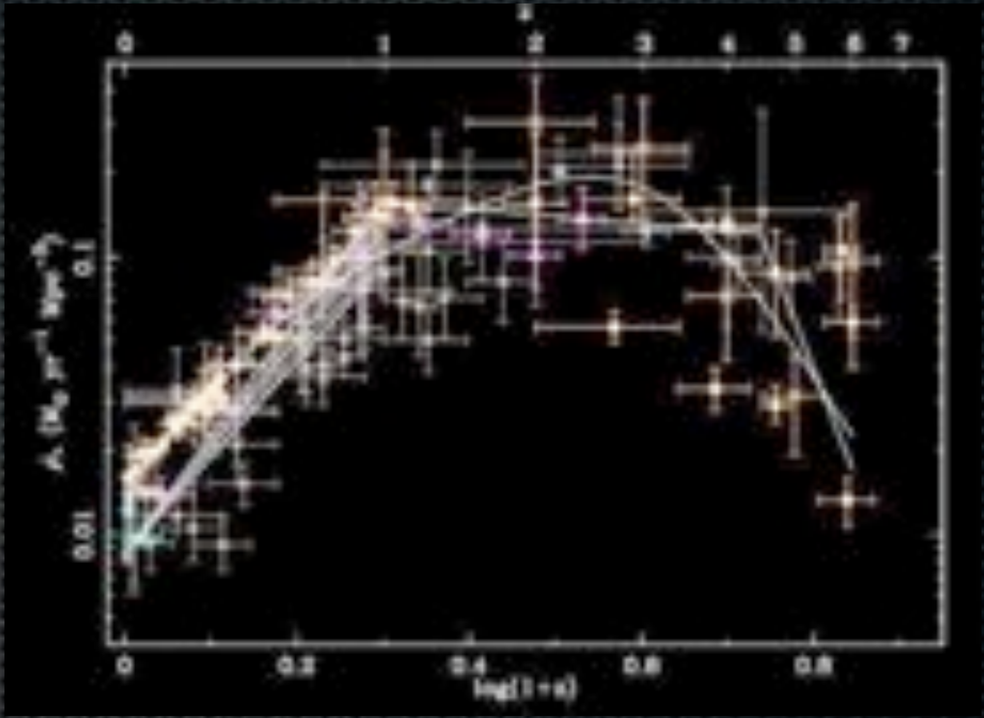
- Ilbert et al. 2010

- Stellar mass density evolution

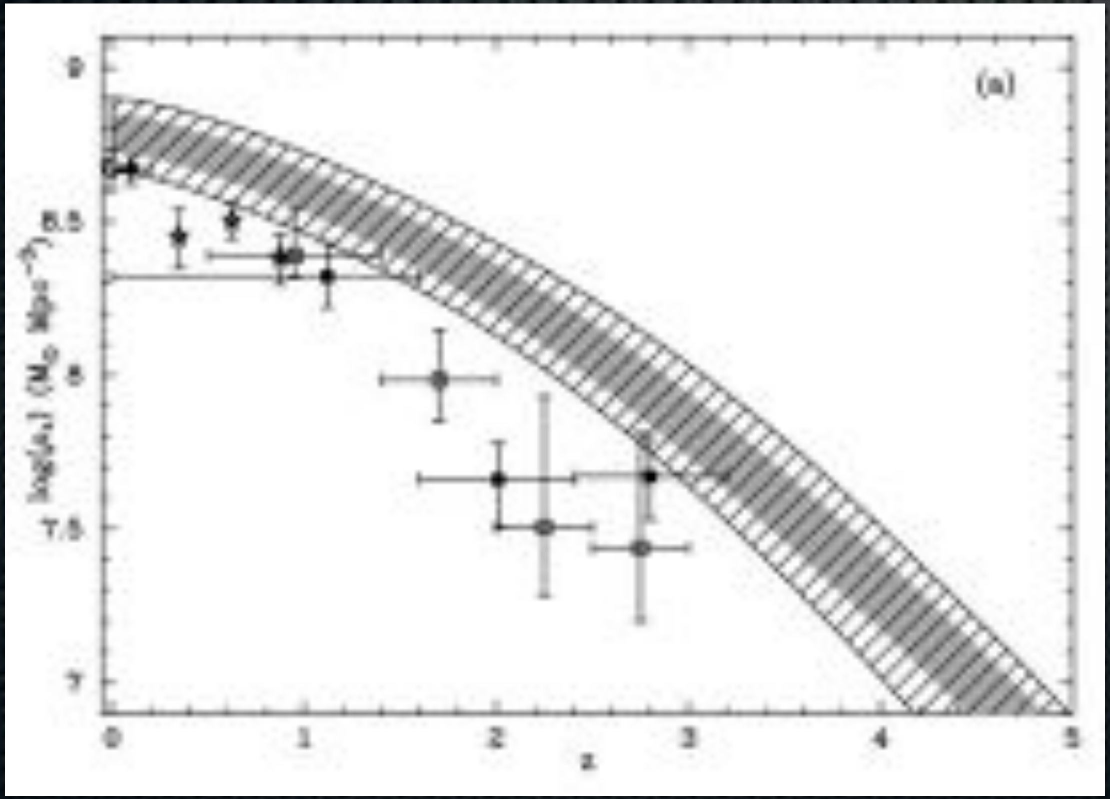
- Marchesini et al. 2009

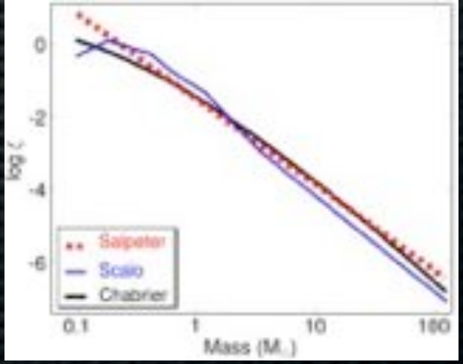
Combining both...

- Hopkins 2004



- Selection effects?
- Completeness?
- IMF?
- Missing Mass?





- Hopkins & Beacom 2006
- Different tracers? Biases?

How can we improve our Understanding?

Improve SFH/ Part I

- A good (single) star-formation tracer that can be applied from z=0 up to z~3 (with current instrum.)
- Well calibrated and sufficiently sensitive

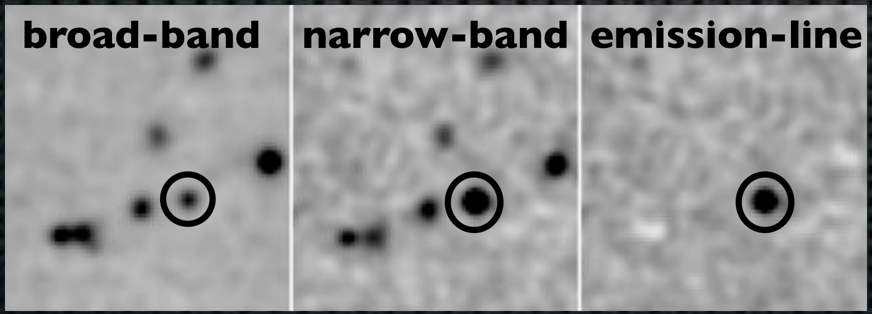
Understand the SFH/ Part II

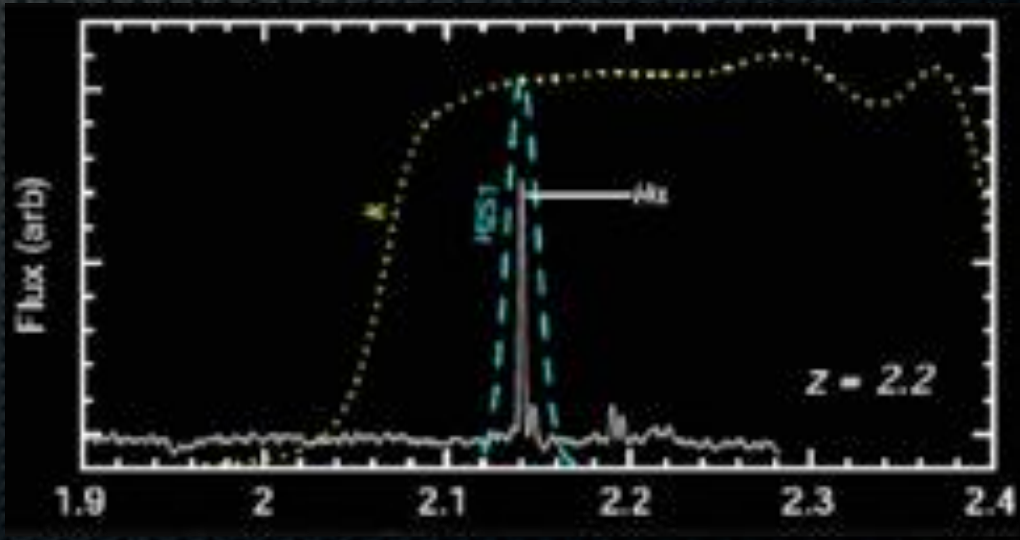
- Able to ~<u>uniformly</u> select large samples
- <u>Different epochs</u>
- <u>Large areas</u>
- <u>Best-studied fields</u>

Hα (+NB)

- Sensitive, good selection
- Well-calibrated
- Traditionally for Local Universe
- **<u>Narrow-band technique</u>**

- **Now with WFCAM: over large areas**
    - **And traced up to z ~ 3**

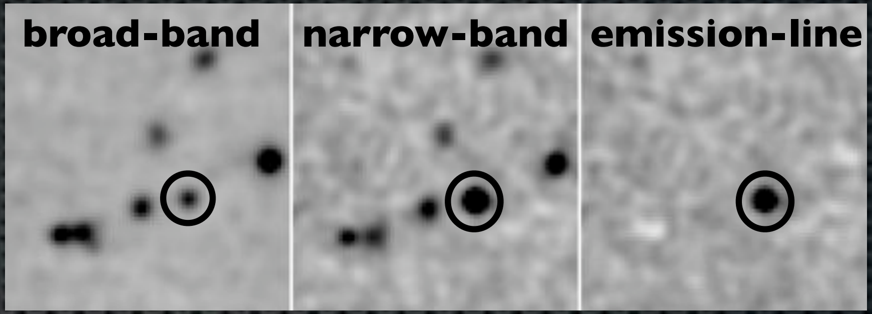




HiZELS

The High Redshift Emission Line Survey

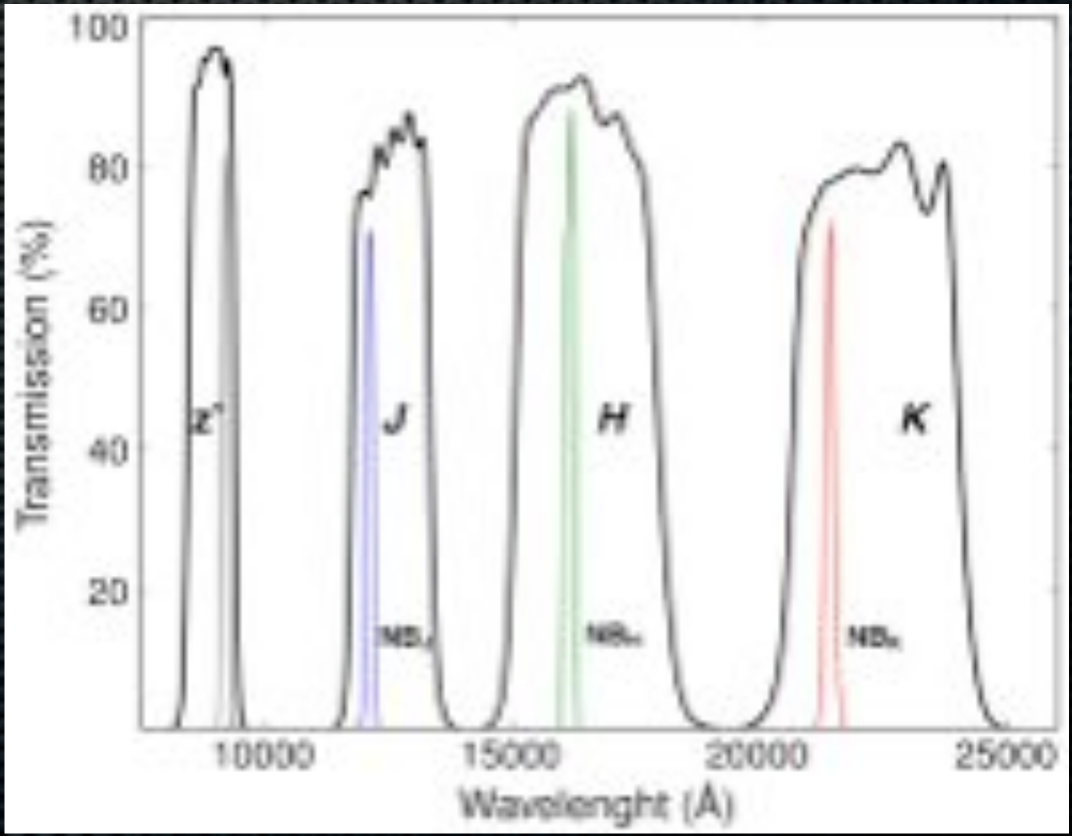
PIs: Best & Smail



- **Deep & Panoramic extragalactic survey**, narrow-band imaging (NB921, NB_J, NB_H, NB_K) **over ~ 5 deg^2 (UKIDSS DXS fields)**

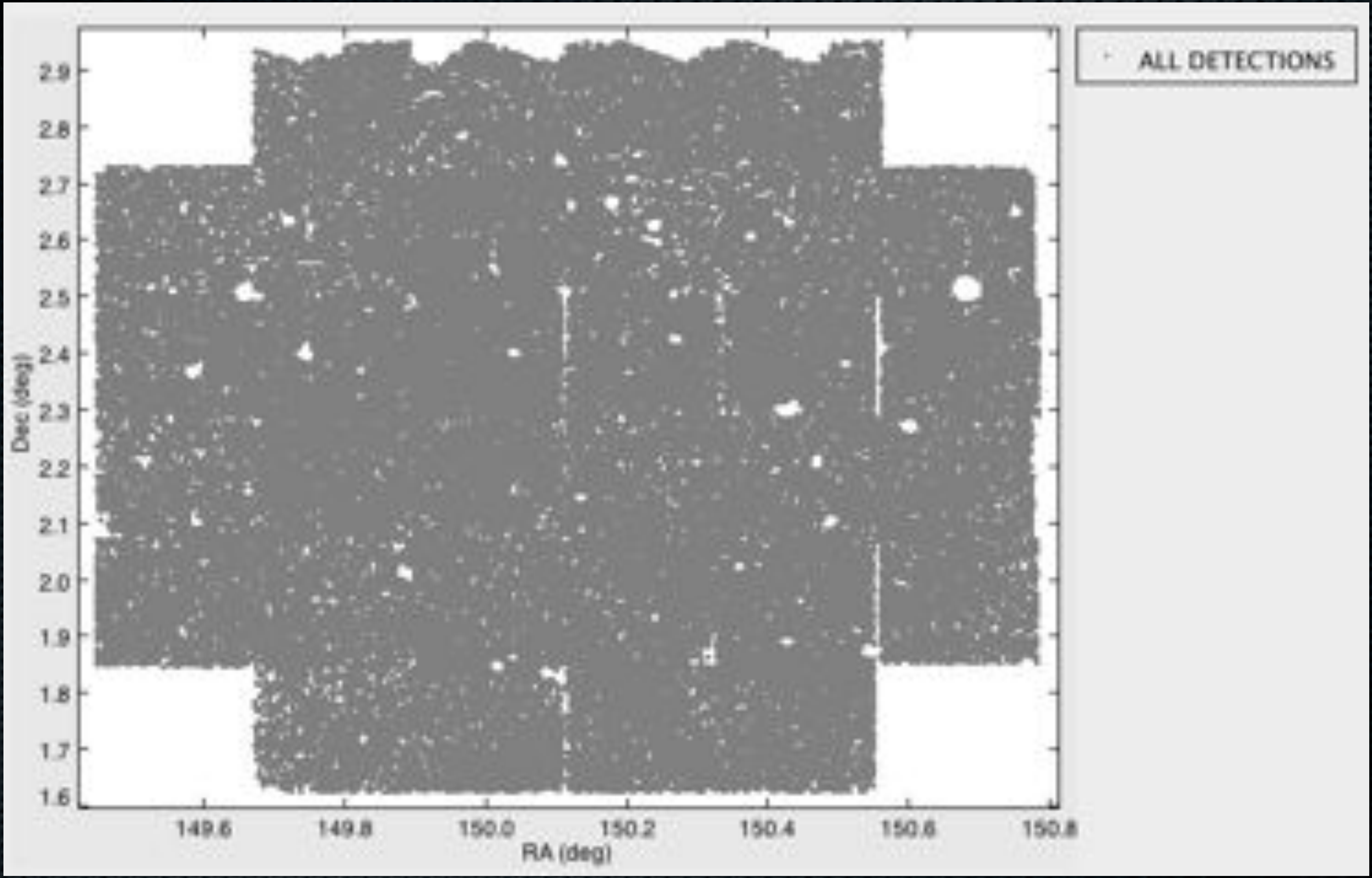
(+Deep NBH + Subar-HiZELS + HAWK-I)

- Narrow-band Filters target Hα at **z=0.4, 0.84, 1.47, 2.23**
- **Same reduction+analysis**



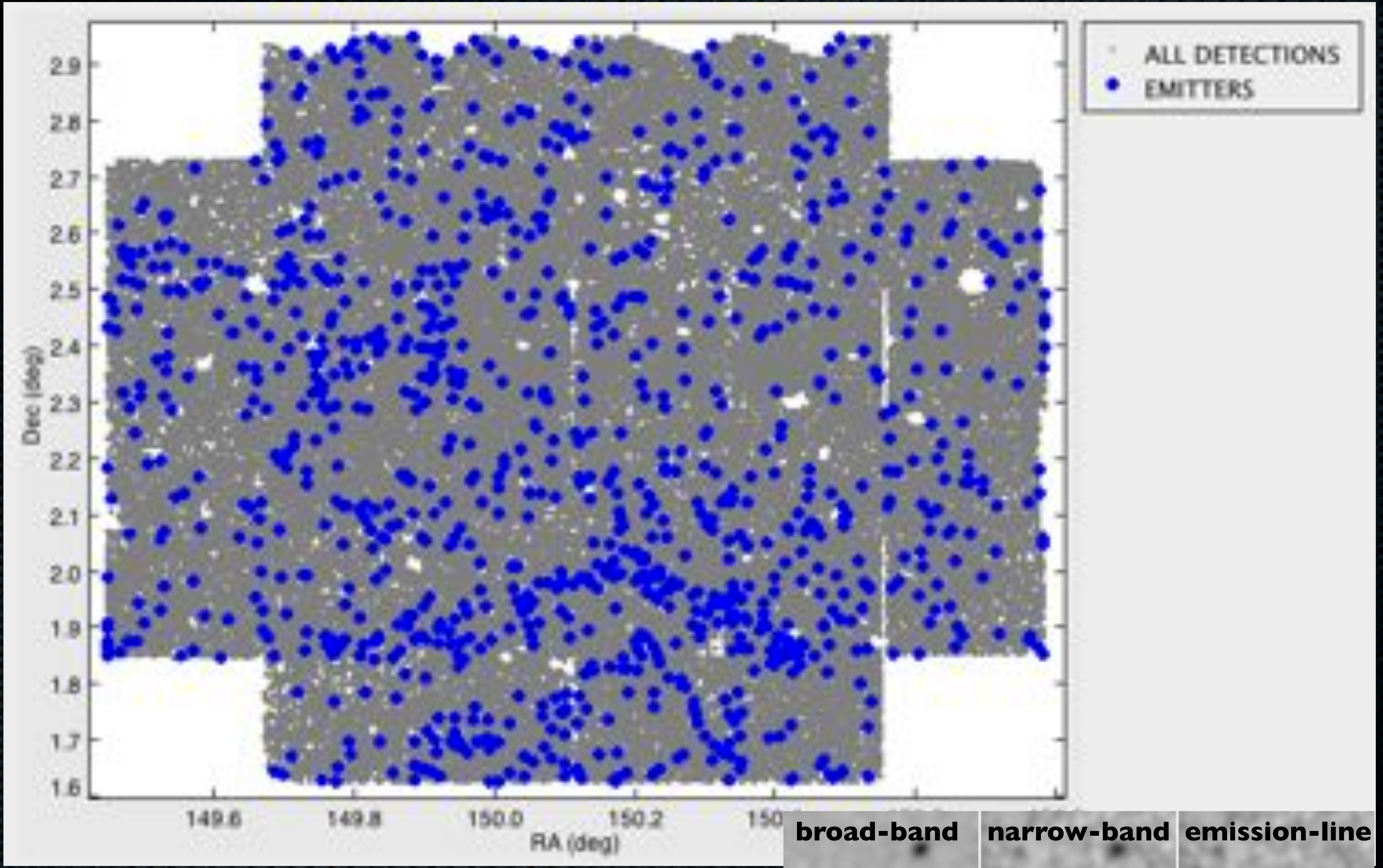
- **Other lines (simultaneously; Sobral+09a,b,Sobral+12a)**
- **UKIRT + VLT + Subaru**

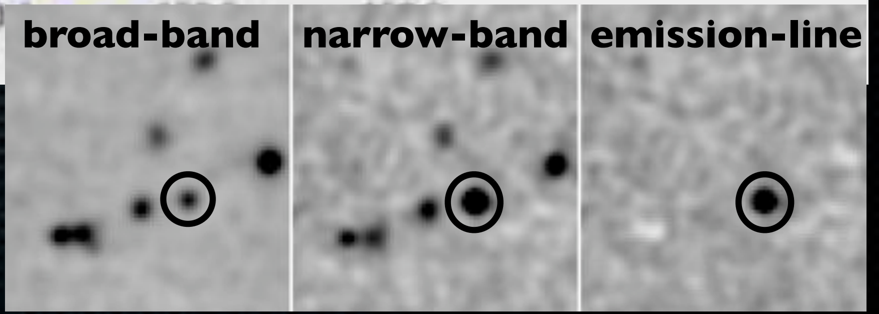
All sources K band



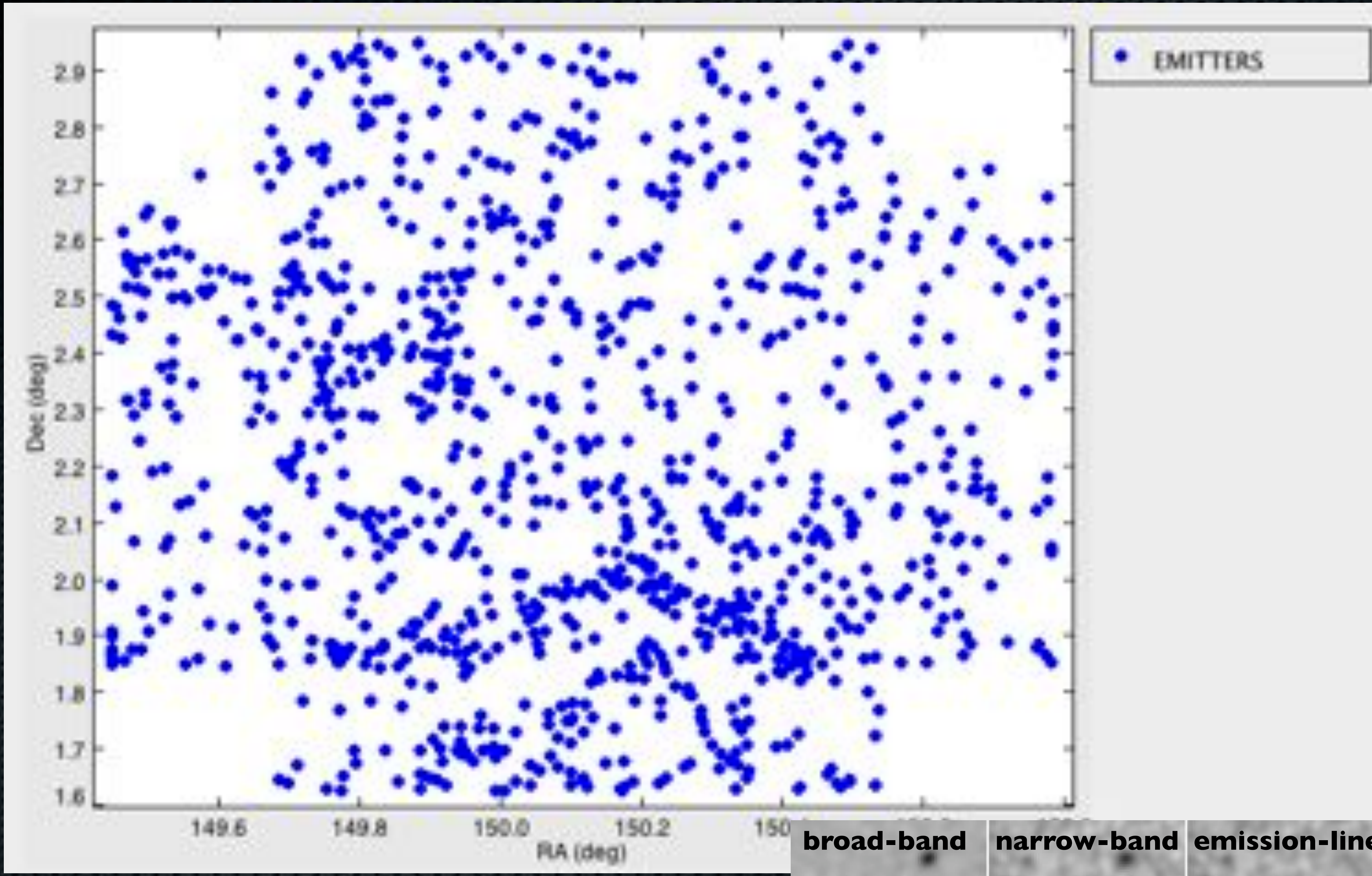
Including data taken 1-2 months ago

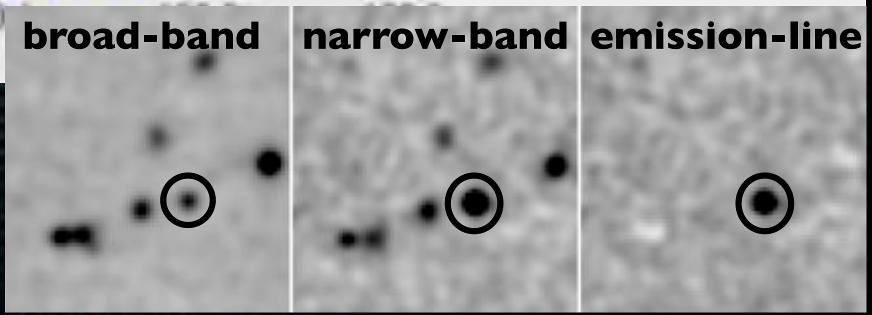
All sources K band => Line emitters NBK

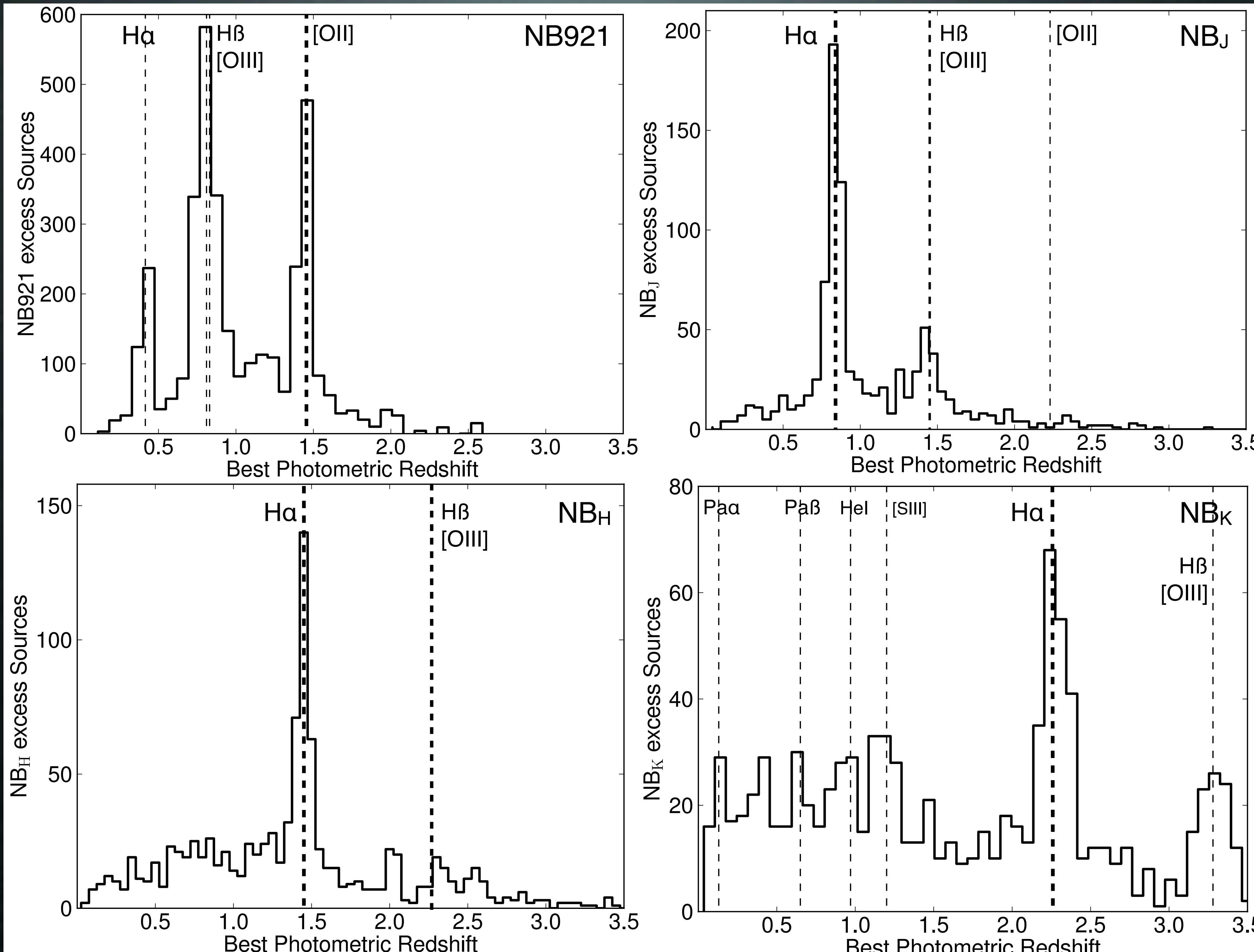




Line emitters NBK

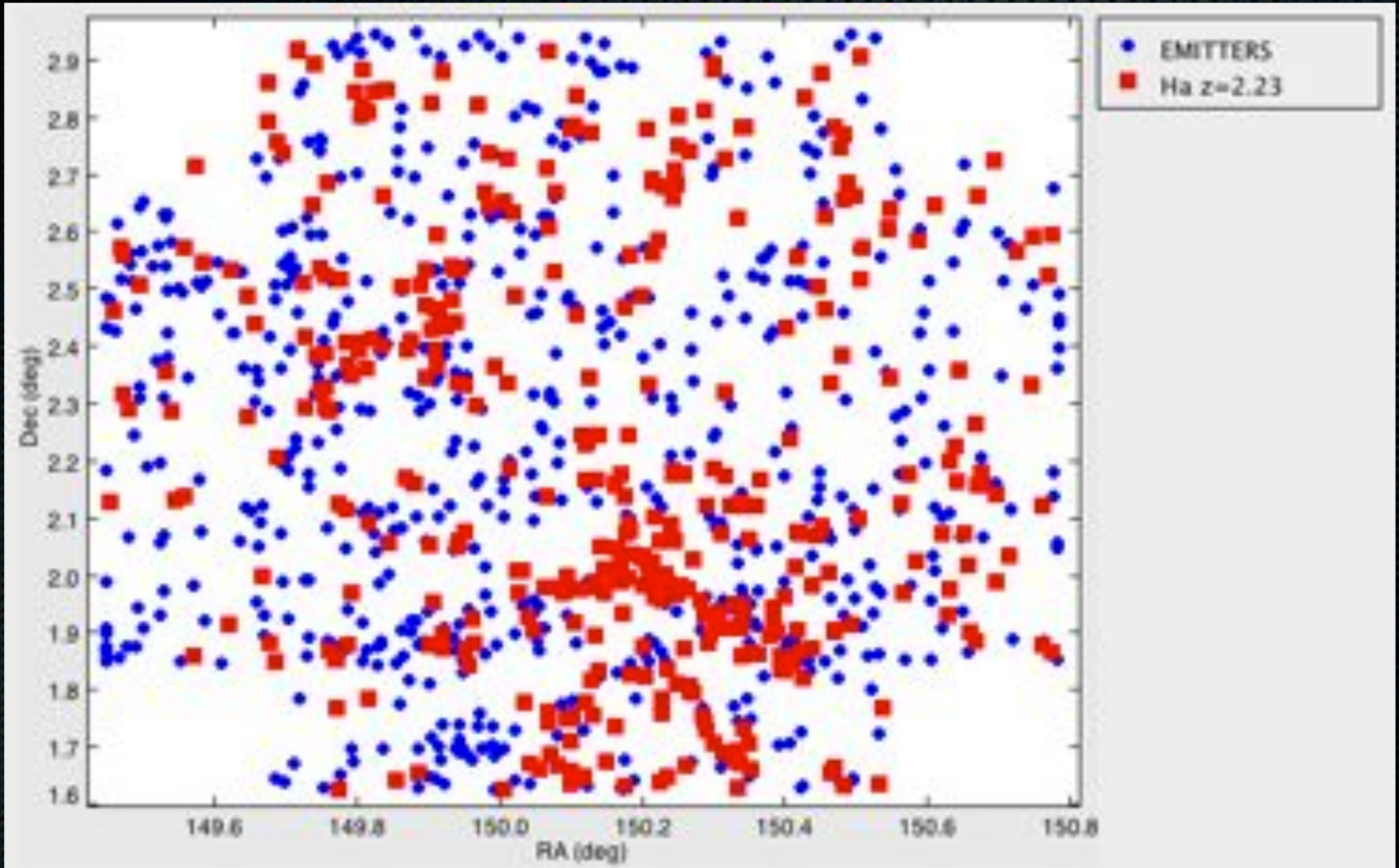




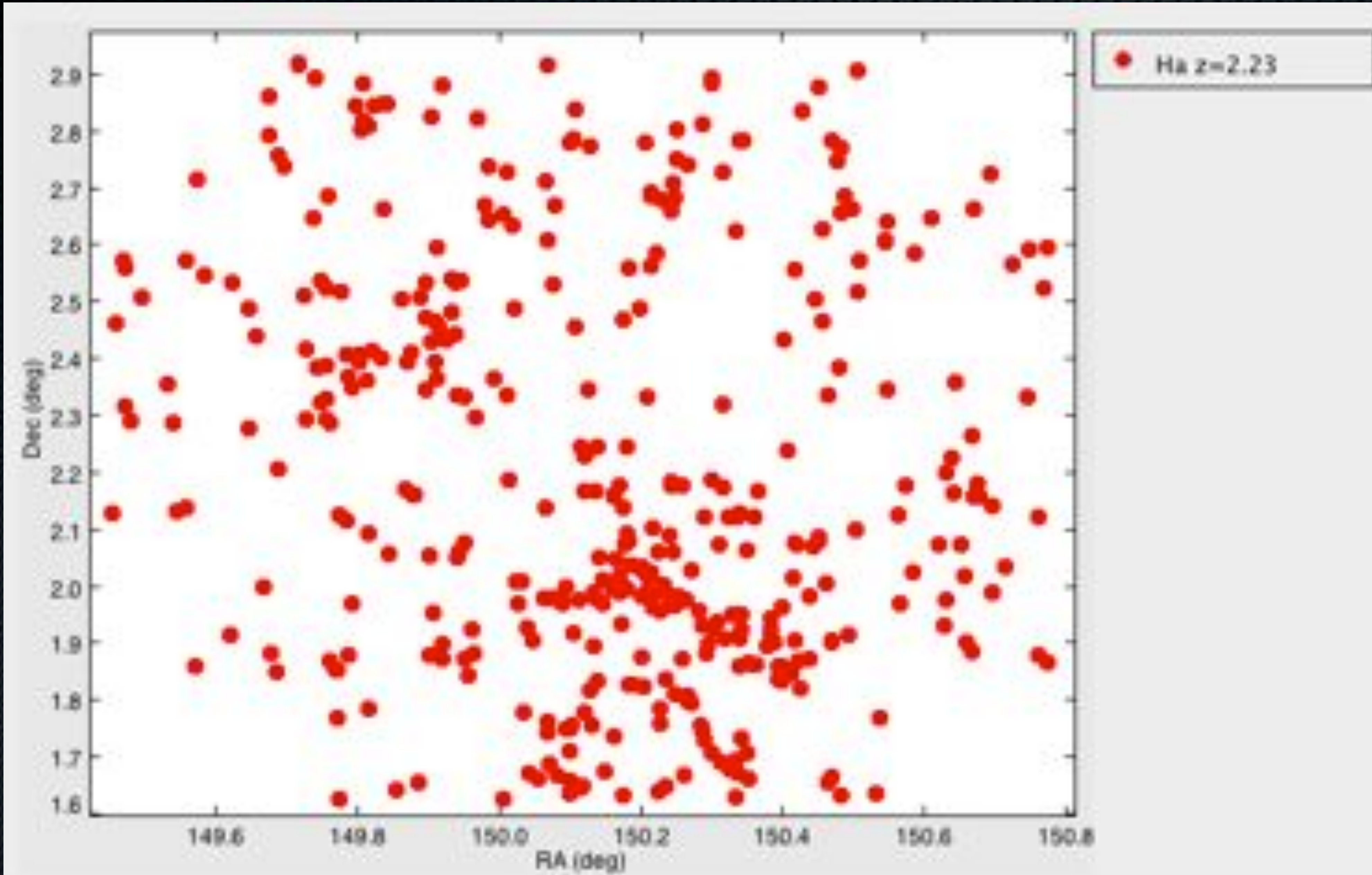


NB921
Hα
Hβ
[OIII]
[OII]
NB921 excess Sources
Best Photometric Redshift
NB$_J$
NB$_J$ excess Sources
NB$_H$
NB$_H$ excess Sources
NB$_K$
Paα
Paβ
HeI
[SIII]
NB$_K$ excess Sources

H-alpha sources: Double/triple NB + photo-zs + colours



H-alpha sources: Double/triple NB + photo-zs + colours

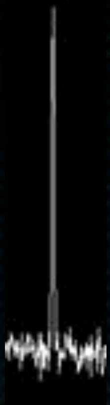


Clean, complete "slices" of 1000s of H-alpha selected galaxies in the last 11 Gyrs

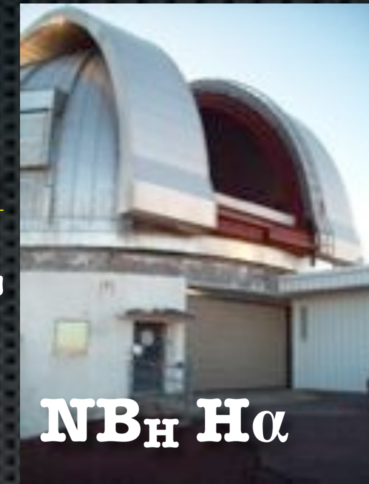
Double-NB survey

<u>Sobral+12a</u>

<u>400 Ha+[OII] / night!</u>

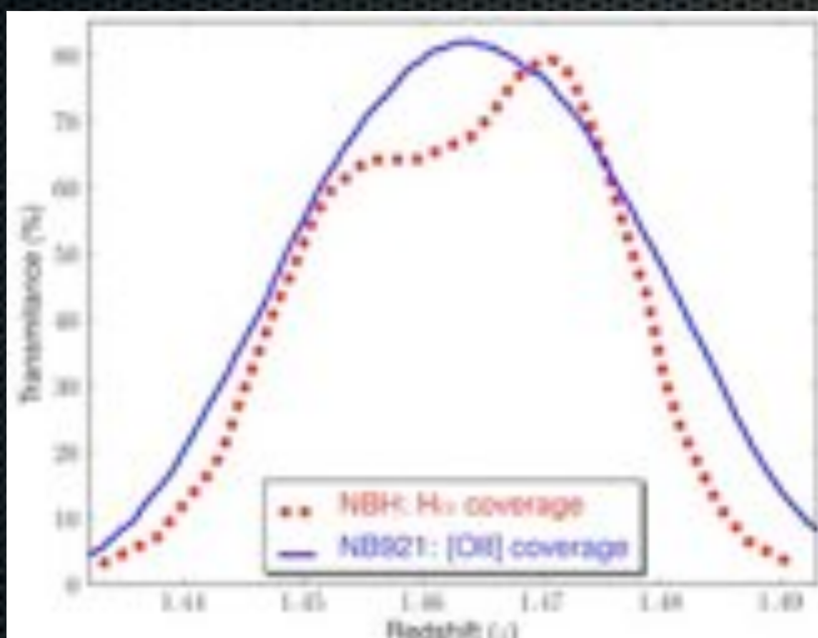


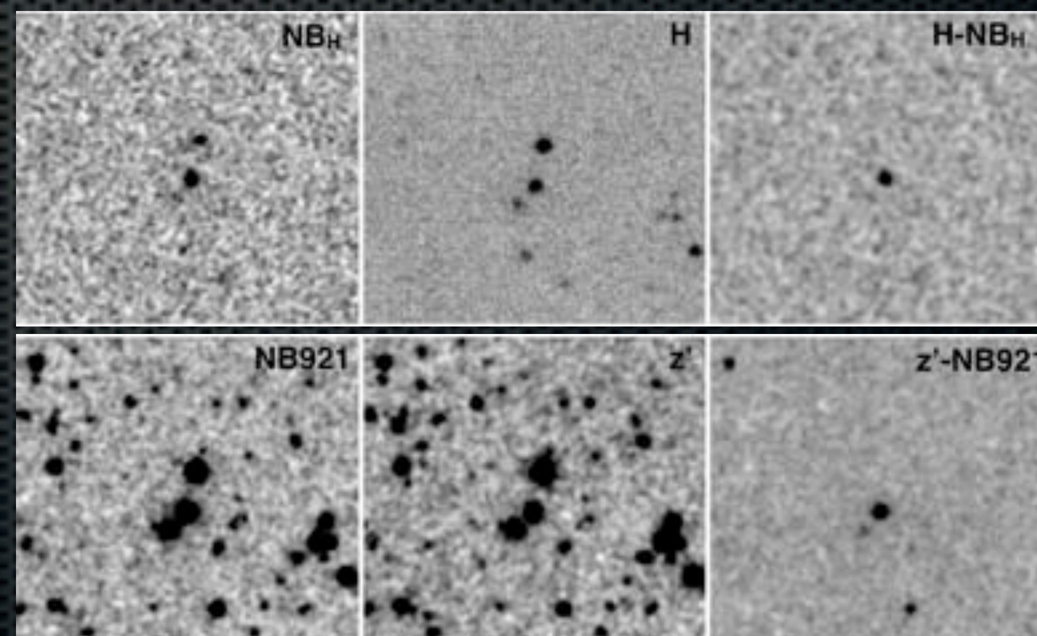
Subaru joins UKIRT to "walk through the desert"



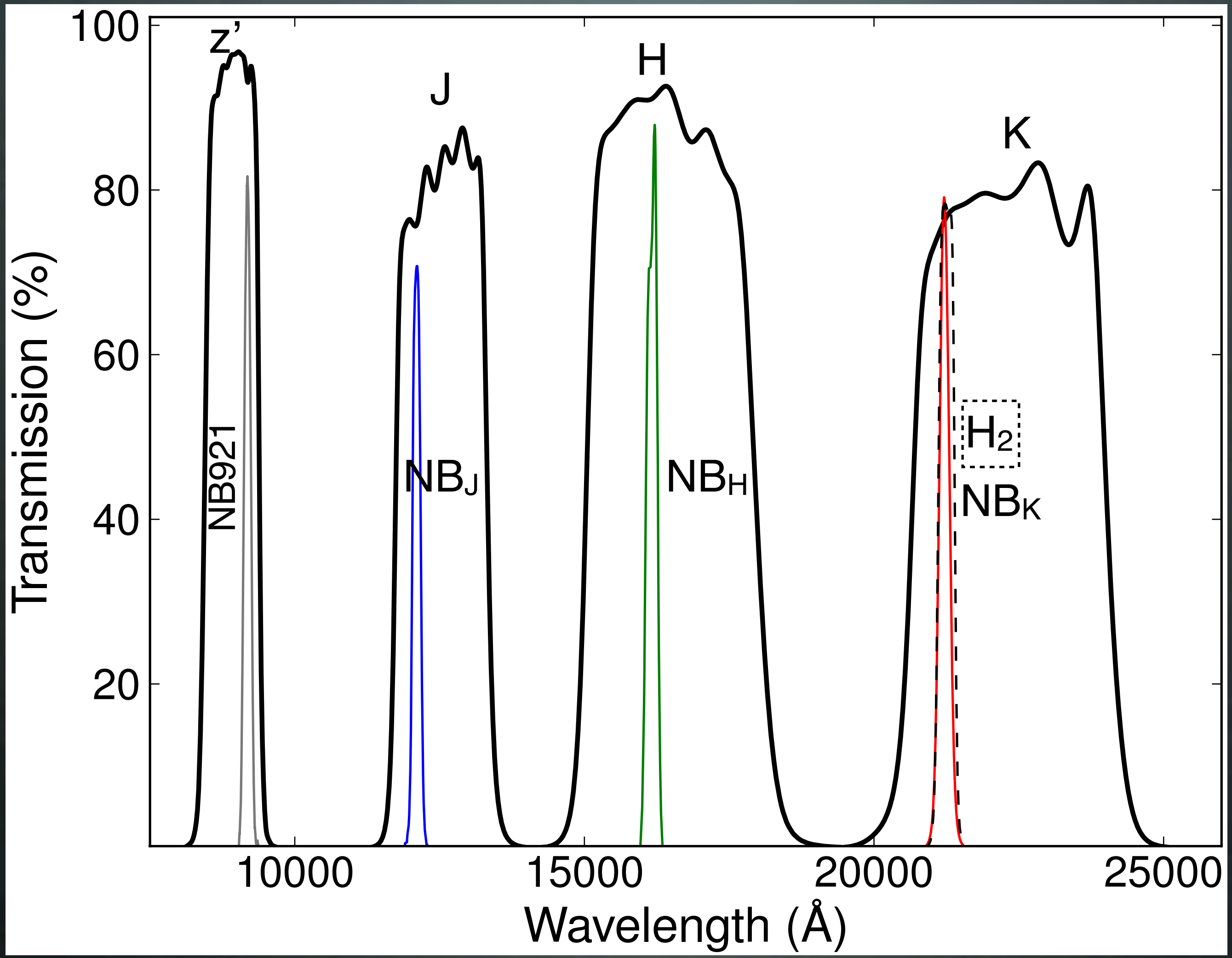
The first Hα-[OII] large double-blind survey at high-z

Sobral et al. 2012a, NAOJ press release





without any need for colour or photometric redshift selections



z=2.23 : Hα (NBK), [OIII] (NBH), [OII] (NBJ)

z=1.47 : Hα (NBH), Hβ (NBJ), [OII] (NB921)

z=0.84 : Hα (NBJ), [OIII] (NB921)

HiZELS: Progress

~95% complete

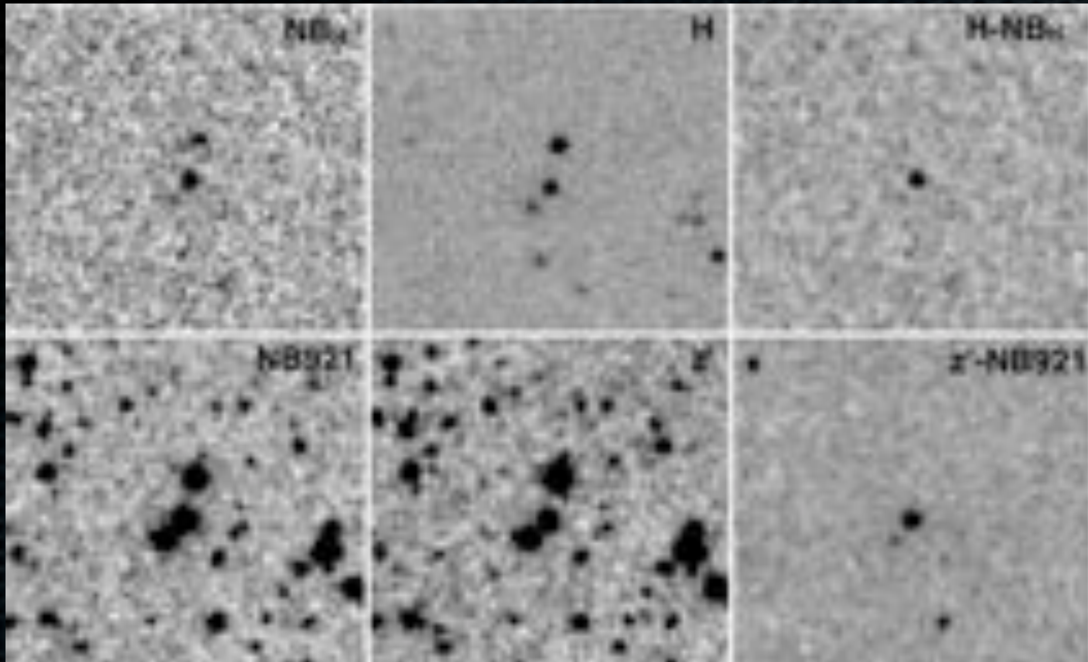
Field Name	Exposure times (ks/pix) NB$_J$	NB$_H$	H$_2$(S1)	Time required NB$_J$	NB$_H$	H$_2$(S1)
UKIDSS UDS	20.0	20.0	20.0	Completed	Completed	Completed
COSMOS-1	20.0	20.0	20.0	Completed	Completed	Completed
COSMOS-2	...	14.0	20.0	...	Completed	Completed
ELAIS N1	...	14.0	20.0	...	Completed	Completed
Boötes	...	14.0	20.0	...	Completed	Completed
SA 22	...	14.0	20.0	...	Completed	14 hrs
Lockman Hole	...	14.0	20.0	...	4.5 hrs	27 hrs
COSMOS [DEEP]	...	114.0	65.0	...	Completed	Completed

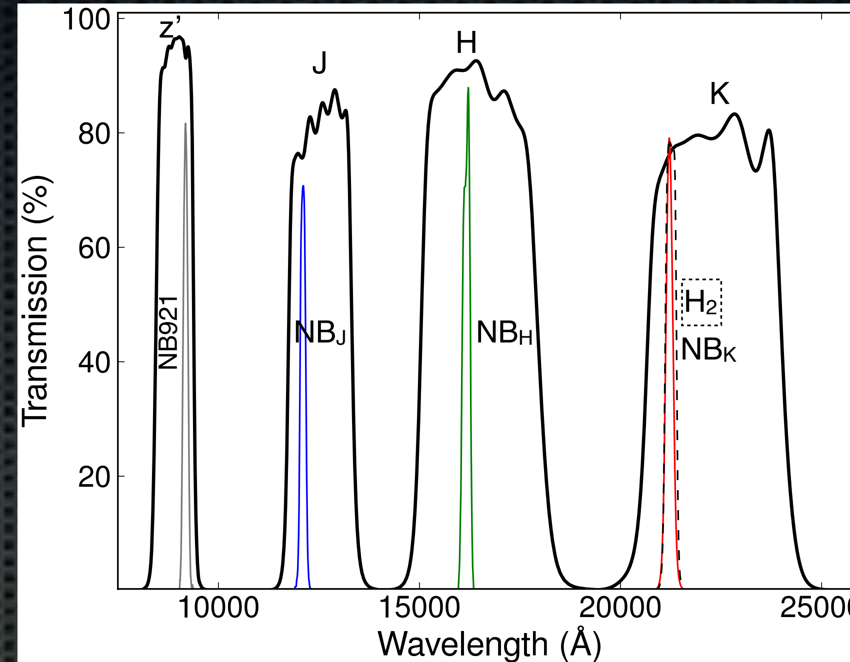
Each field = 0.8 deg2 (4xWFCAM)

Total area: 5.6 deg2

Depths: (NB921~26), NBJ~22.8, NBH~22.6, NBK~22.9 (AB)

Line Flux limit ~0.5-1.0 x 10^{-16} erg $s^{-1}cm^{-2}$





H-alpha emitters in HiZELS

2 sq deg: COSMOS + UDS

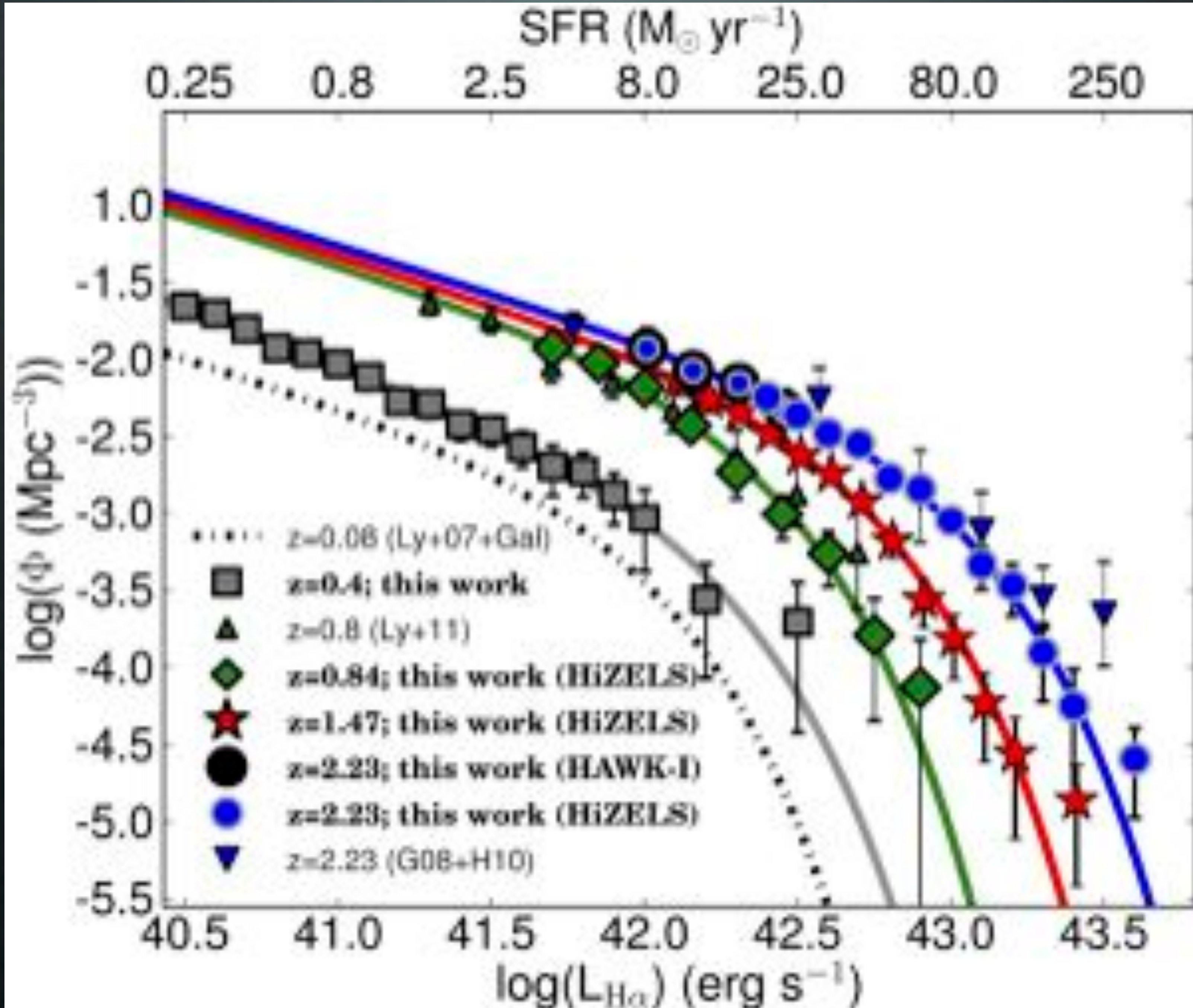
Prior to HiZELS: ~5-10 sources

z=0.4: 1742 z=0.8: 637 z=1.47: 515 and z=2.23: 630

In ~1 yr: Full HiZELS (UKIDSS DXS fields) + CFHT (SA22):

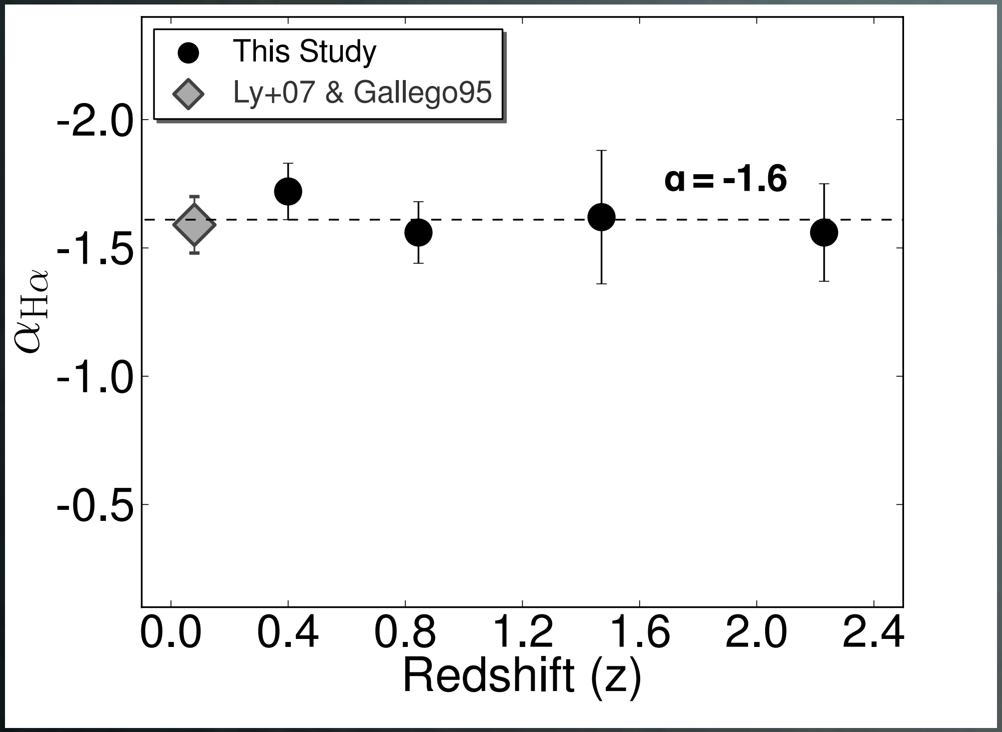
z=0.8: 3500 z=1.47: 1200 and z=2.23: 1500

along with 1000s of other z~0.1-9 emission line selected galaxies

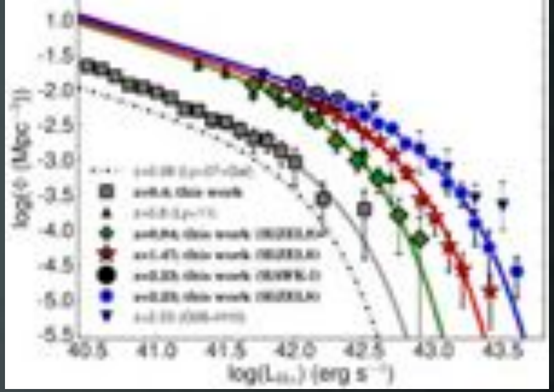


Sobral+12b, arXiv:1202.3436

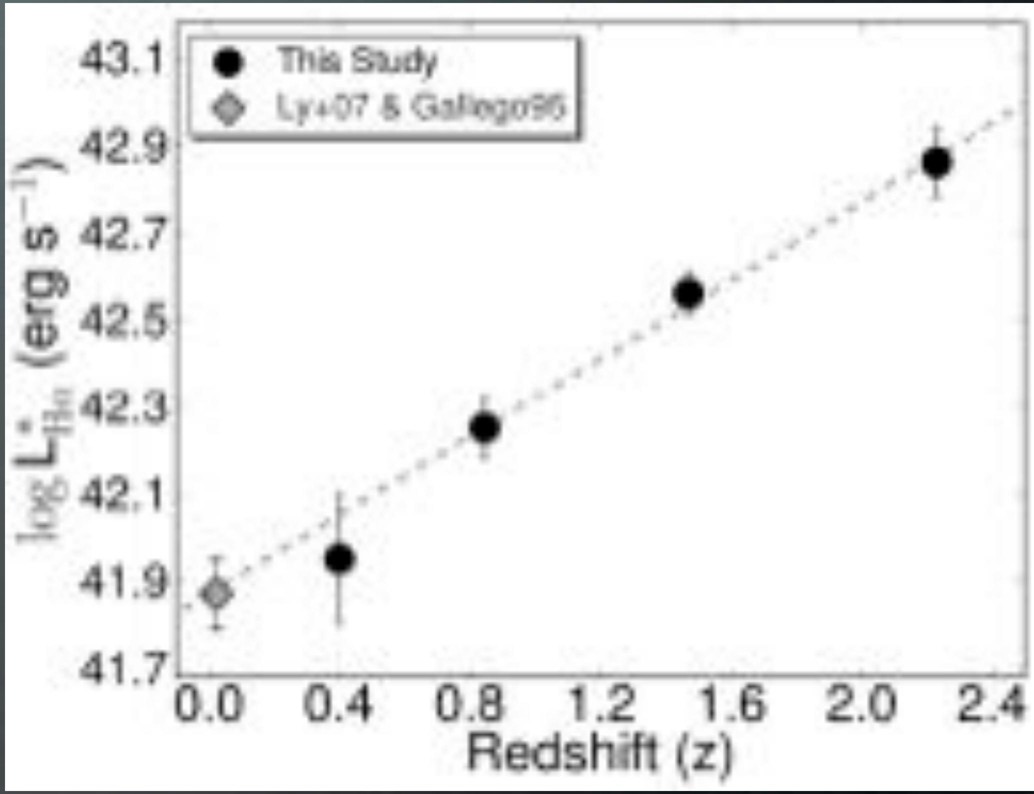
Faint-end Slope α:



Up to z=2.2:



$$\alpha = -1.60 \pm 0.08$$



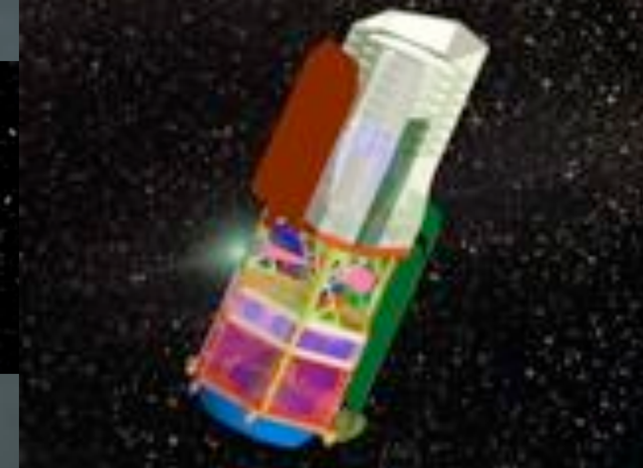
L*; "Break" of the LF

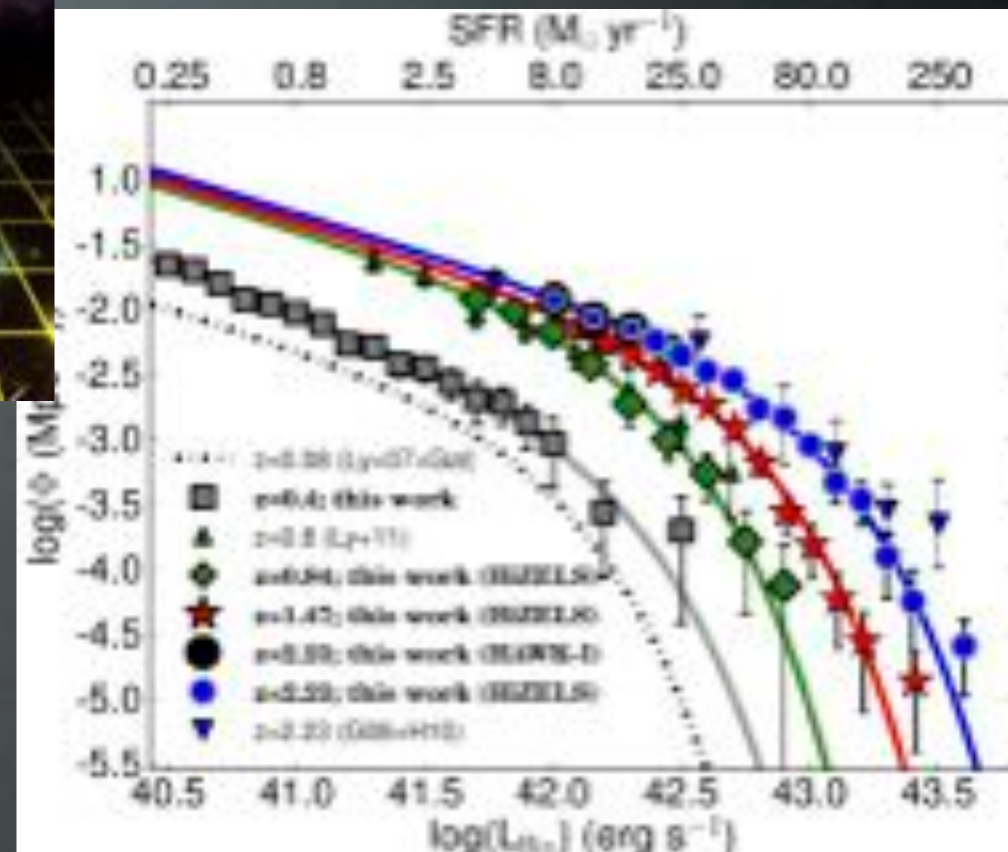
Typical SFR (SFR*) is changing significantly with time!

$$\log\ L^*(z) = 0.45z + \log\ L^*_{z=0}$$

Up to z=2.2:

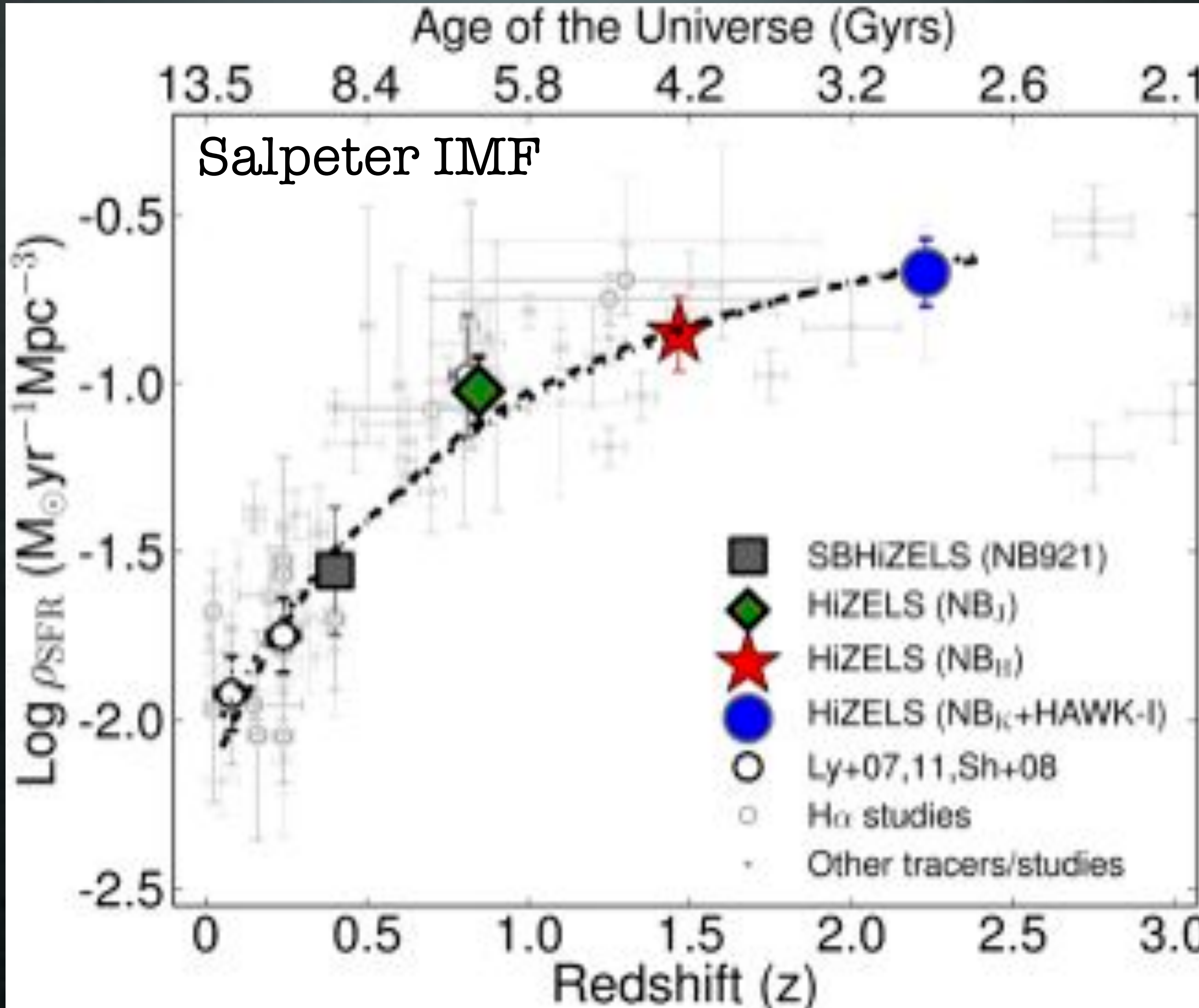
log SFR* = 0.45z + logSFR*(z=0)



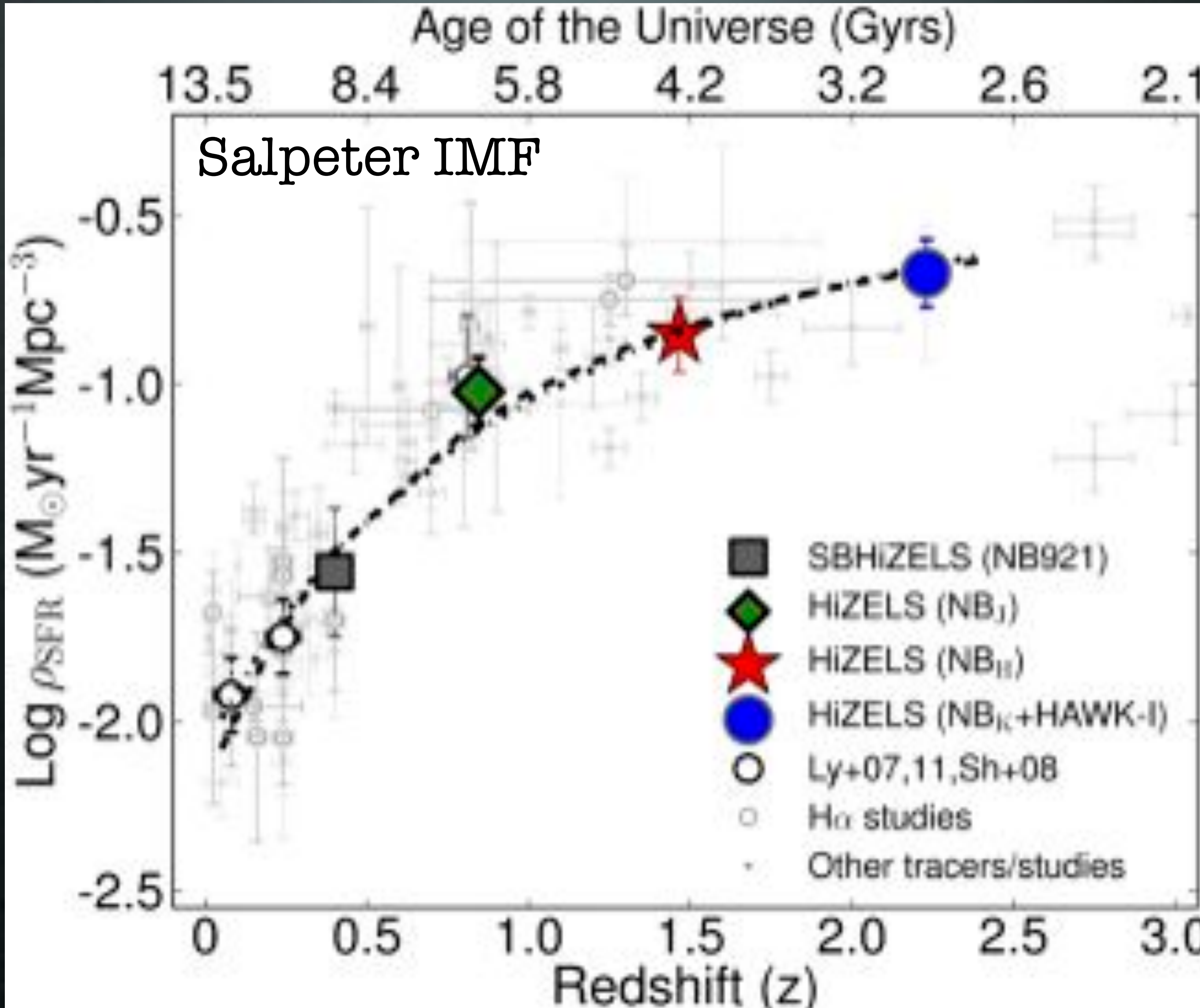


HiZELS => Dark Energy missions forecast

Hirata et al. 2012

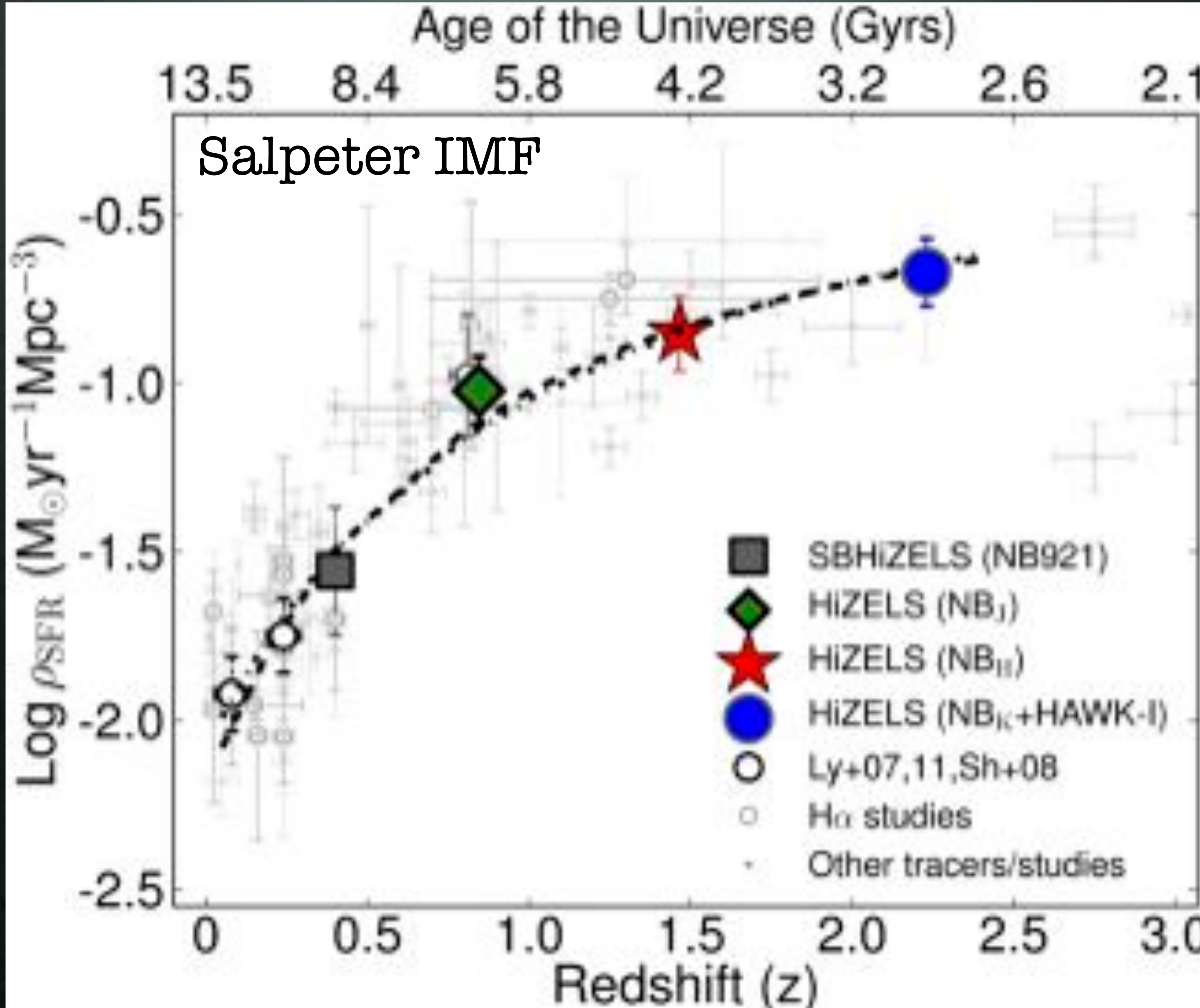

Age of the Universe (Gyrs)
13.5
8.4
5.8
4.2
3.2
2.6
2.1
Salpeter IMF
Log ρ_{SFR} ($M_\odot yr^{-1} Mpc^{-3}$)
-0.5
-1.0
-1.5
-2.0
-2.5
SBHiZELS (NB921)
HiZELS (NB$_J$)
HiZELS (NB$_H$)
HiZELS (NB$_K$+HAWK-I)
Ly+07,11,Sh+08
Hα studies
Other tracers/studies
0
0.5
1.0
1.5
2.0
2.5
3.0
Redshift (z)

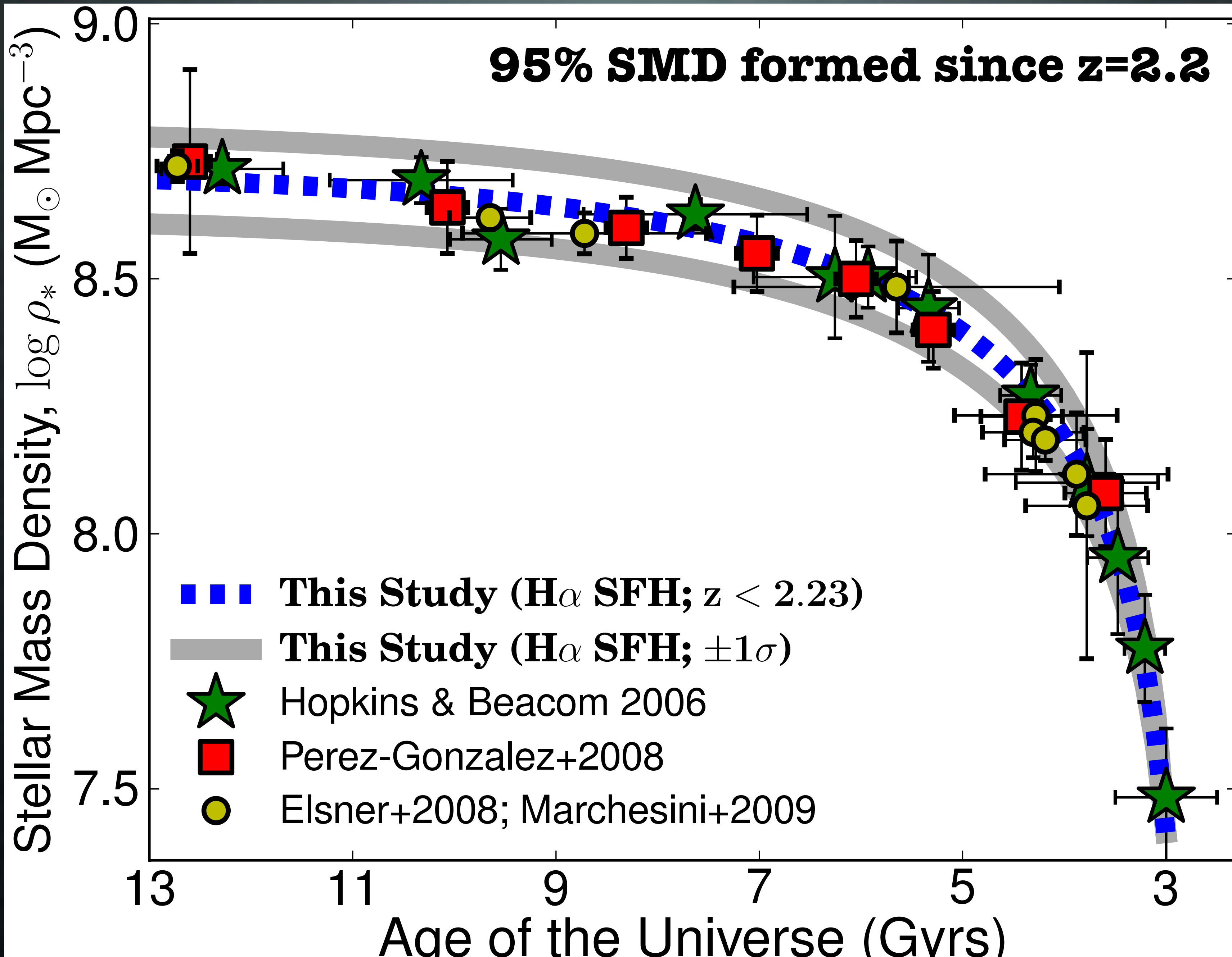
$$\log \rho_{\mathrm{SFR}} = -2.1/(z+1)$$



$$\log \rho_{\mathrm{SFR}} = -0.14T - 0.23$$

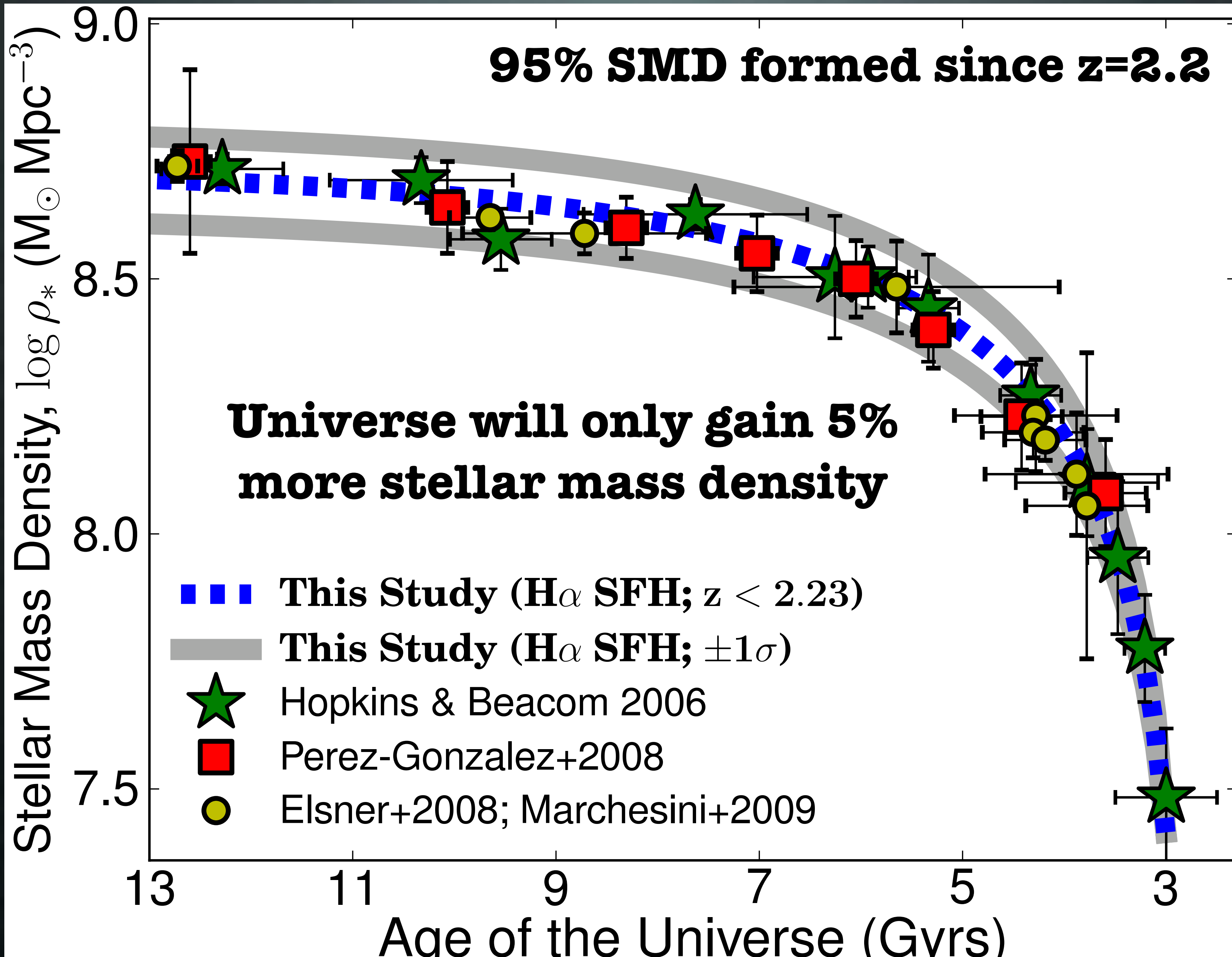
$$\log \rho_{\mathrm{SFR}} = -2.1/(z+1)$$





Sobral+12b, arXiv:1202.3436

$$\log \rho_{\rm SFR} = -0.14T - 0.23$$



Sobral+12b, arXiv:1202.3436

$$\log \rho_{\mathrm{SFR}} = -0.14T - 0.23$$

- Robust measurement of the Evolution of the Hα LF over 11 Gyrs **and fully self-consistent (Hα) star-formation history z<2.3.**
- 1742, 637,507, 630 Hα emitters at z=0.4,0.8,1.5,2.2; factor of ~10 times larger than previous samples
- Evolution in Ha LF:

$$\log\ L^*(z) = 0.45z + \log\ L^*_{z=0}$$

$$\alpha = -1.60 \pm 0.08$$

- SF History of the Universe :

$$\log \rho_{\rm SFR} = -0.14T - 0.23$$

$$\log \rho_{\rm SFR} = -2.1/(z+1)$$

- Agreement with stellar mass density growth suggests that the Hα analysis is tracing the bulk of star formation since z~2.2

Highlights
2009-2012

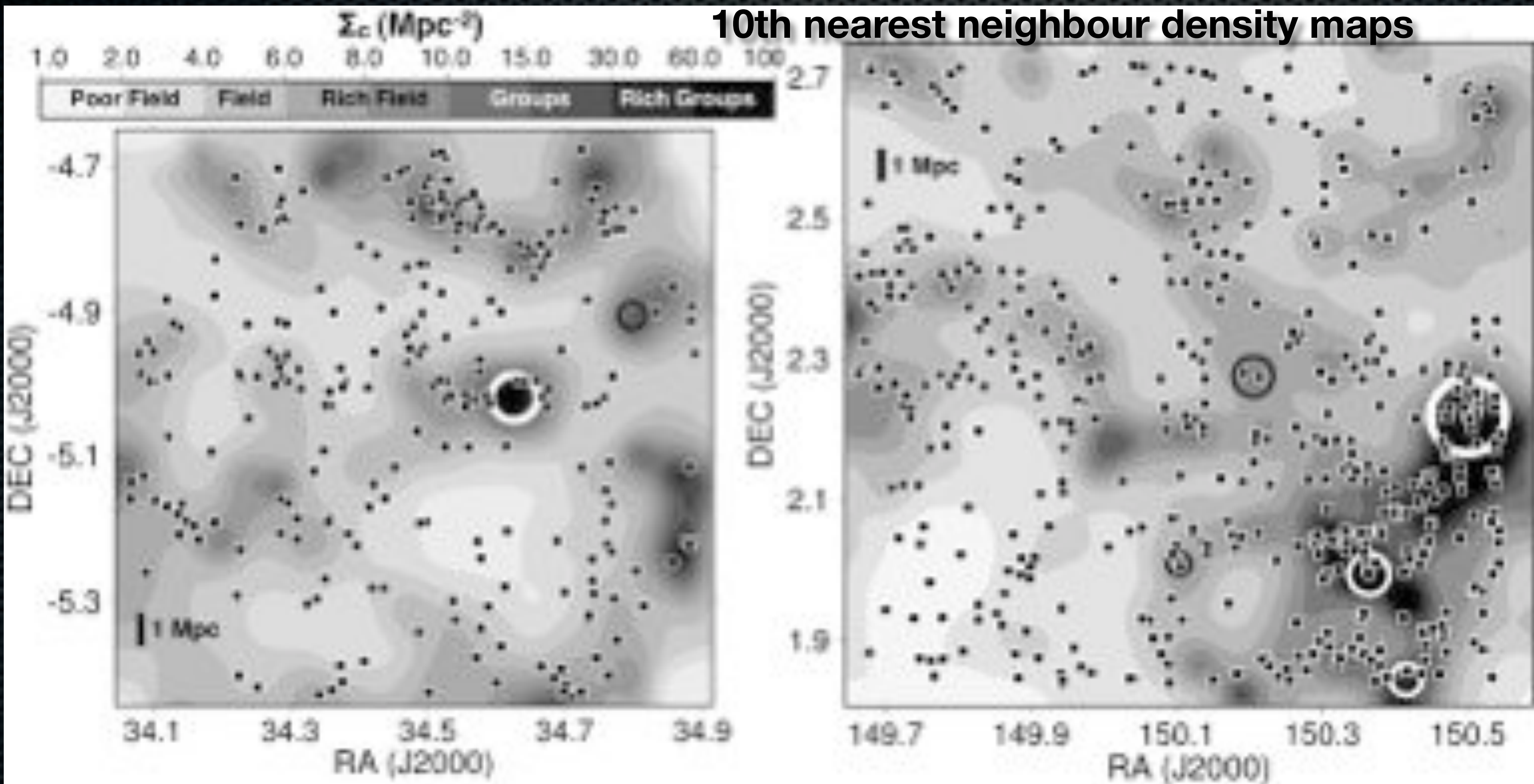
Using the clean, SF selected samples to understand galaxy evolution

The role of the Environment

- A very wide range of environments - from the fields to a super-cluster (Sobral et al. 2011)

X-rays

10th nearest neighbour density maps

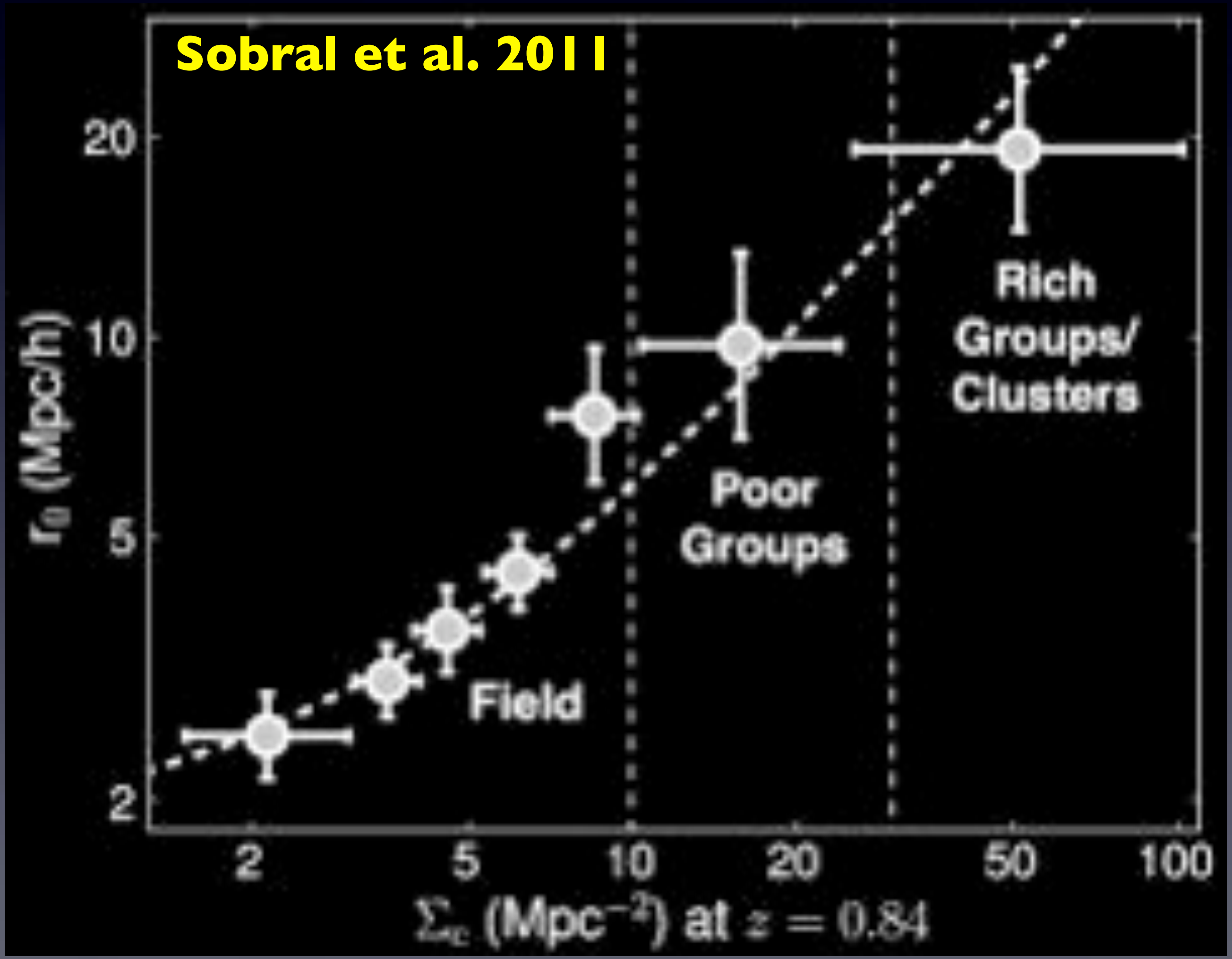


- UKIDSS UDS z=0.84
- COSMOS z=0.84

The role of the Environment

- **Use high quality photo-zs to estimate distance to 10th nearest neighbour >> use spect-z to estimate completeness and contamination >> compute corrected local densities**

"Calibrate" environments in a reliable way using the accurate clustering analysis and real-space correlation lengths of field, groups and clusters



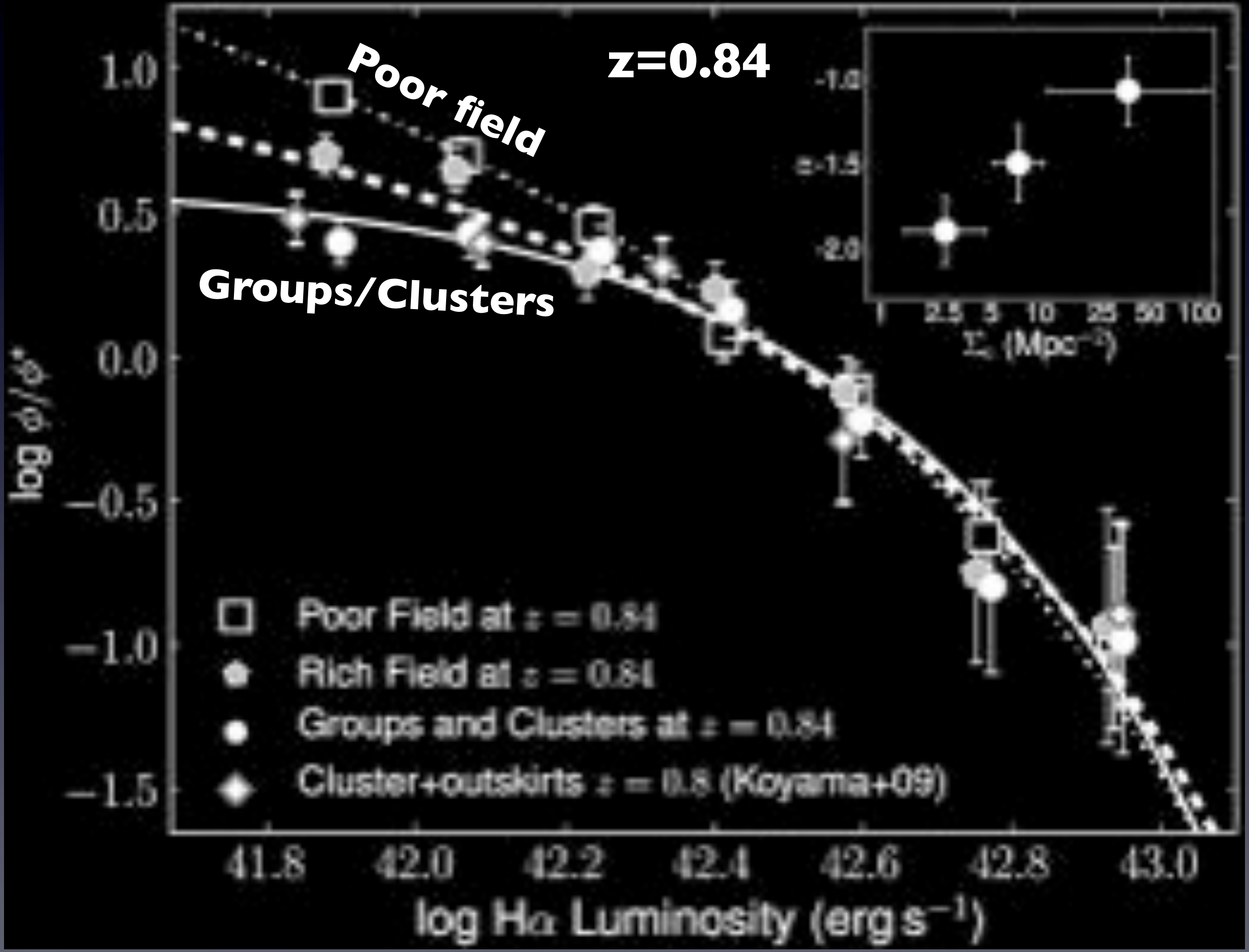
Hα luminosity function

Sobral et al. 2011a

Environment sets the faint-end slope of the Hα LF:

-**steep** α~-2 for the lowest densities

- **shallow** α~-1 for highest densities

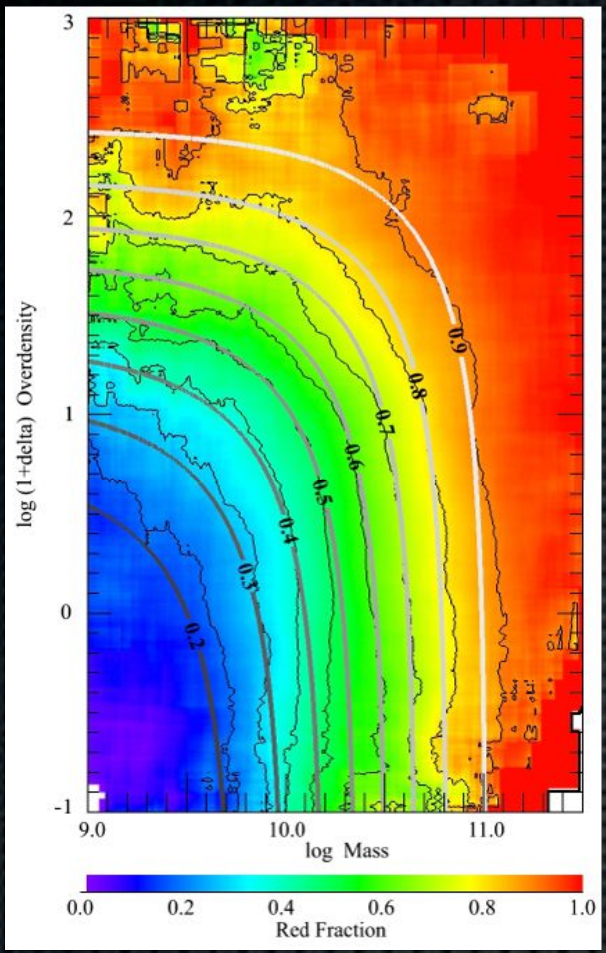


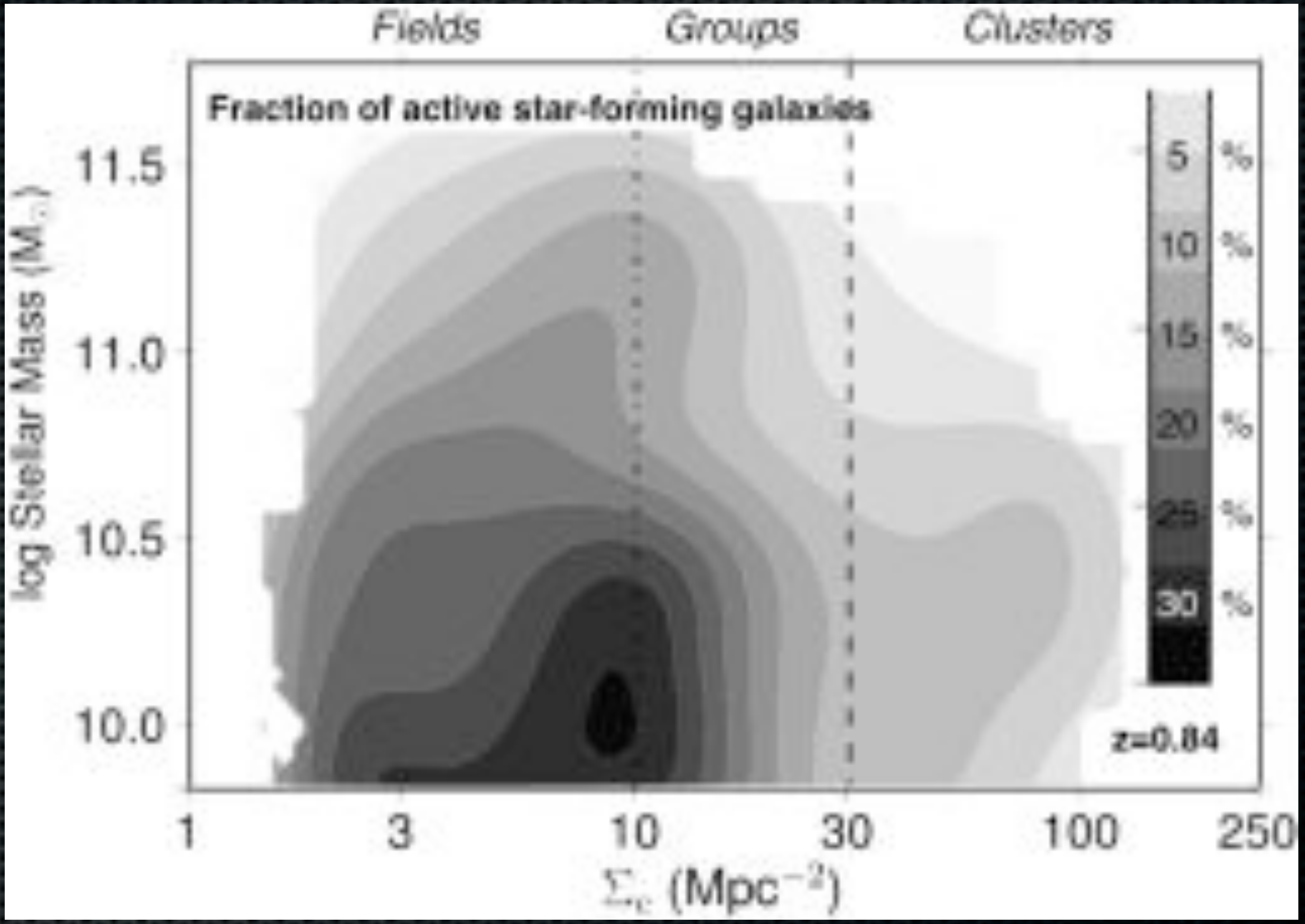
Mass and Environment

z~0

z~1

Sobral et al. 2011





SDSS (Peng+10)

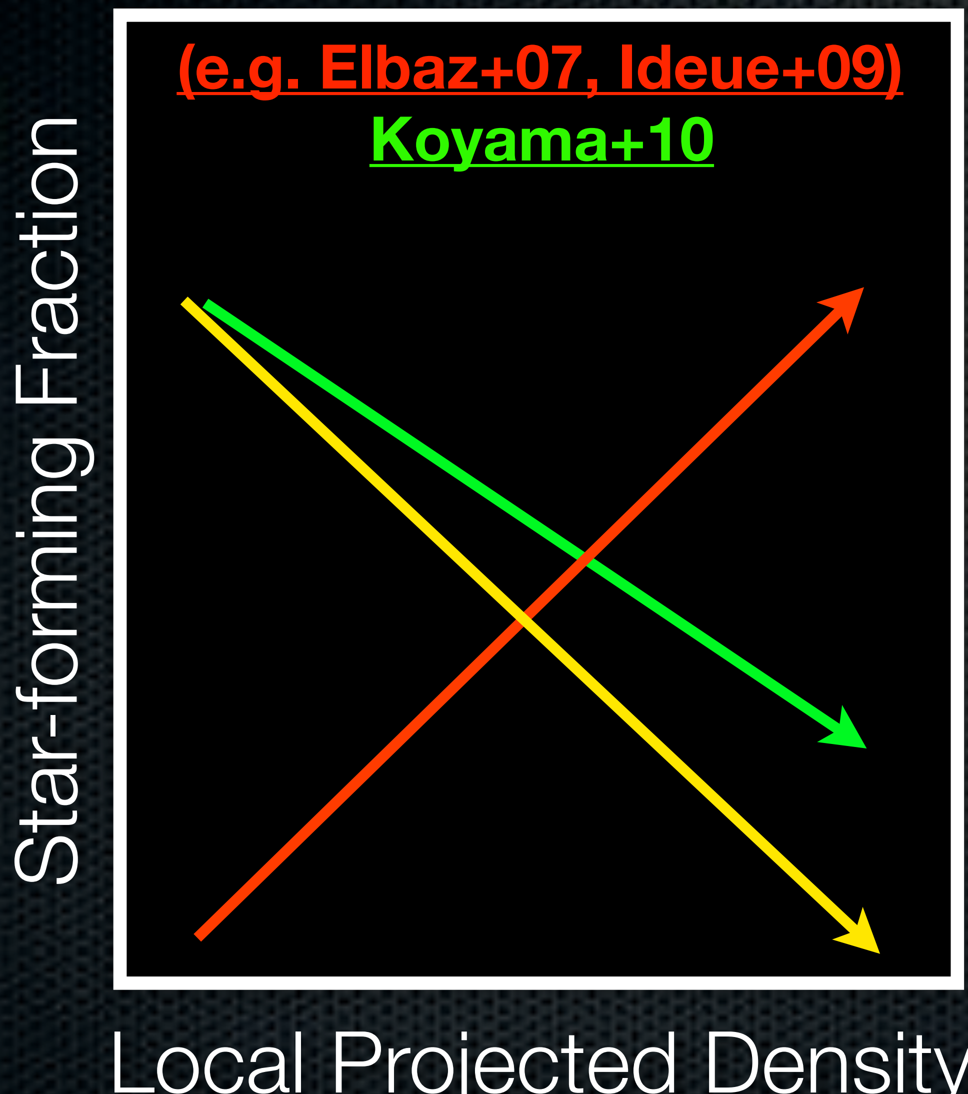
Mass trend at least up to z~1.5

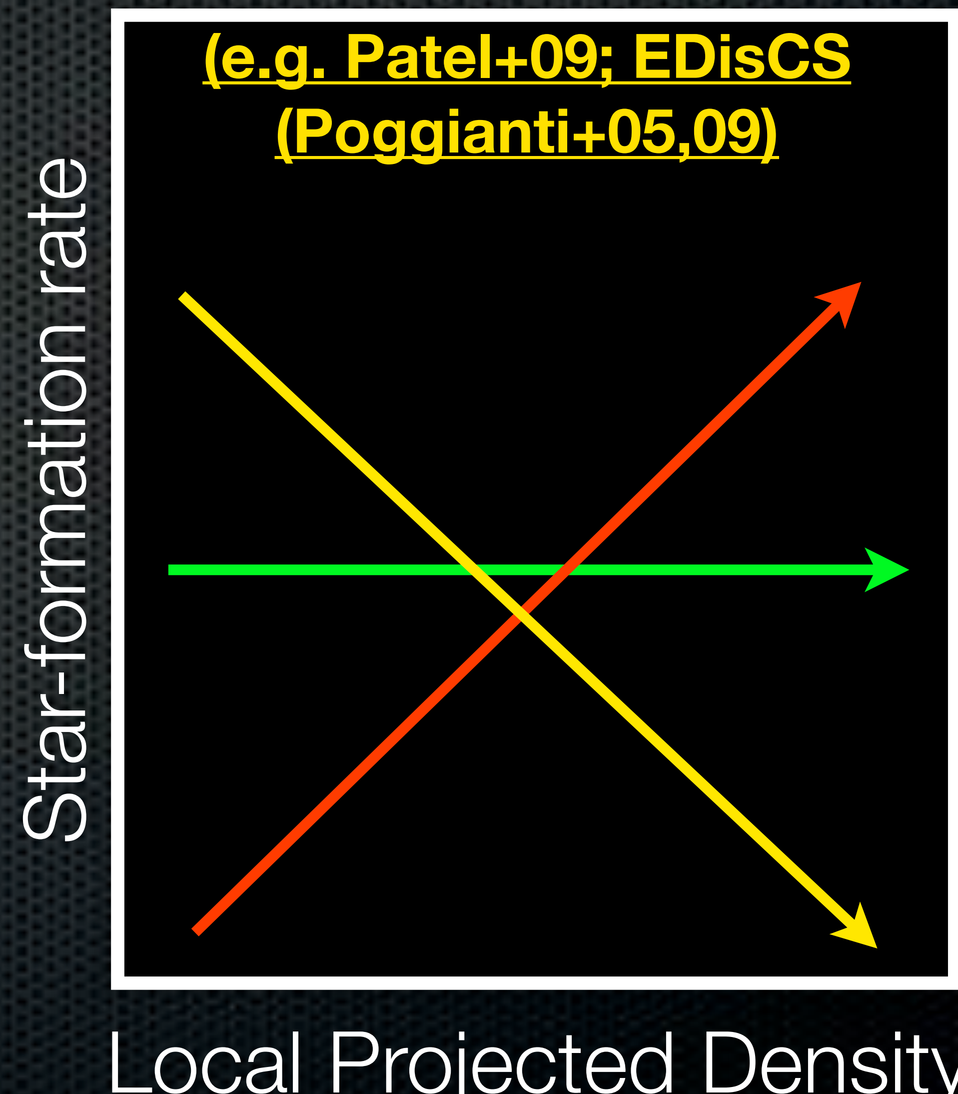
The fraction of (non-merging) star-forming galaxies declines with both mass and environment

The Environment at z~1

~Field Studies Cluster+outskirts Rich Clusters

Can we reconcile the apparent contradictions?

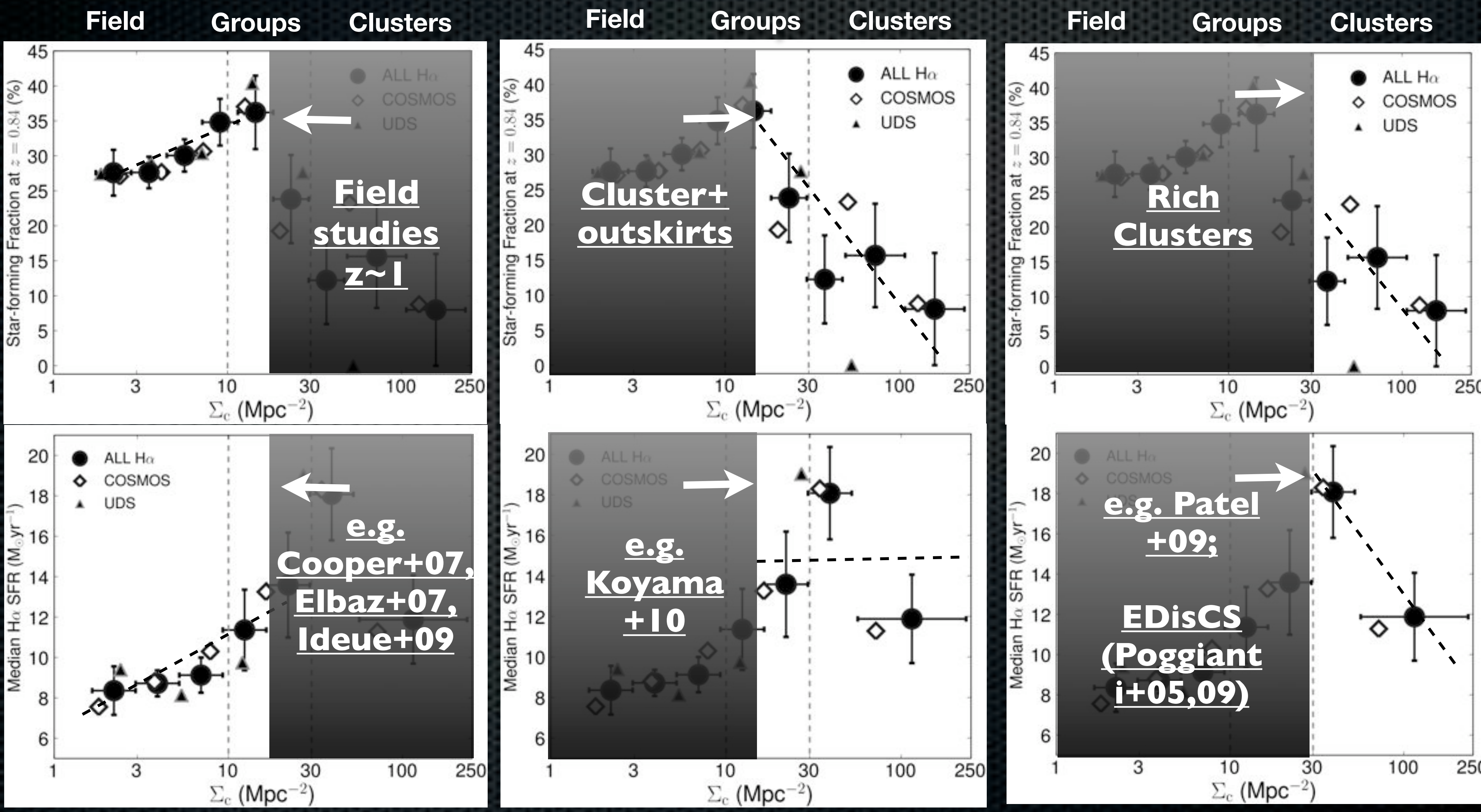




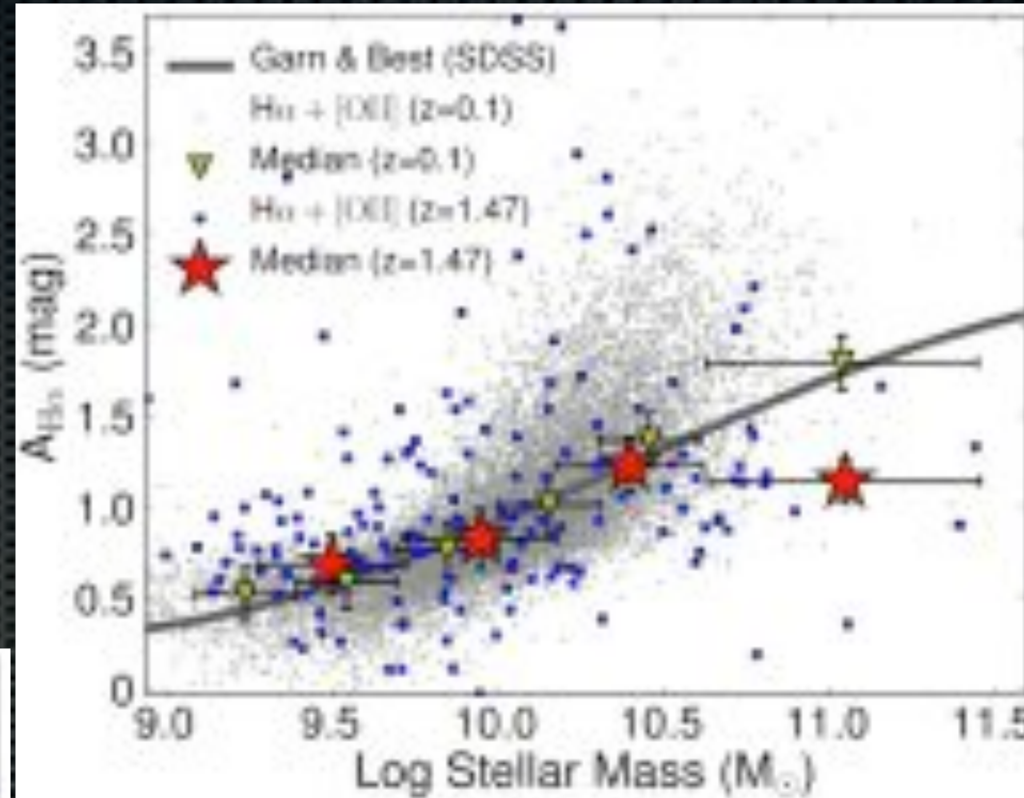
Environment at z~1

Sobral et al. (2011)

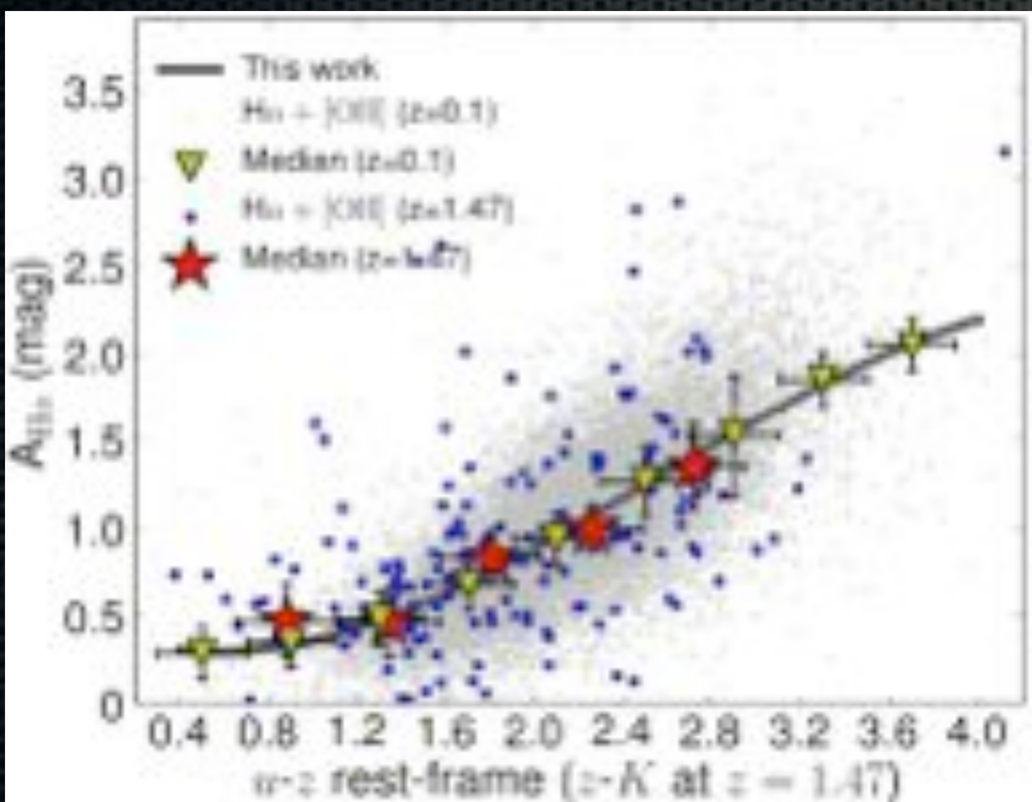
Results reconcile previous apparent contradictions



Extinction-Mass z~0-1.5



Stellar Mass correlates with dust extinction like in the local Universe - (agrees with Garn & Best 2010)



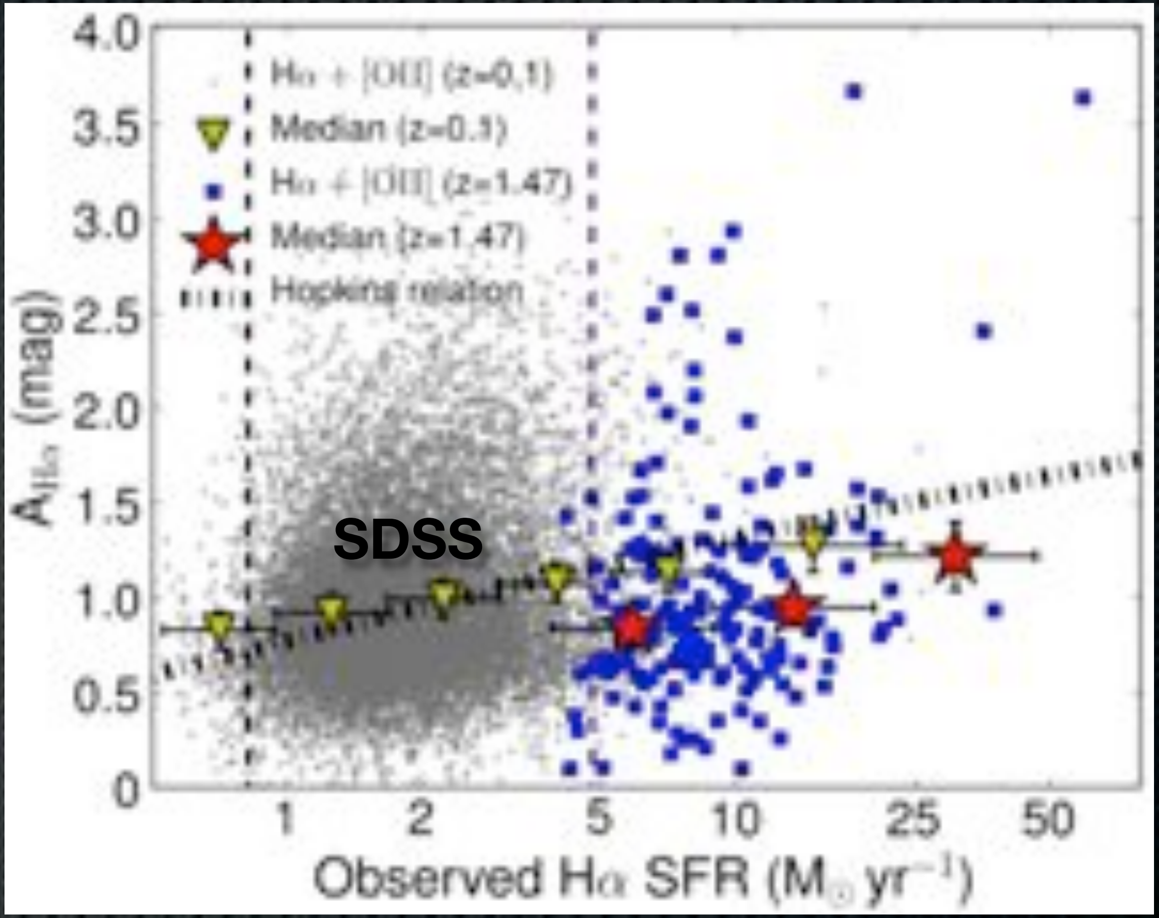
Simpler way to predict dust extinction with observables: optical/UV colours - empirical relations valid at z~0-1.5 (Sobral et al. 2012a)

Dust extinction-SFR in the last 9 Gyrs

Sobral et al. (2012a)

Does the empirical SFR-dust extinction dependence hold at z~1.5?

No! Offset of ~0.5 mag



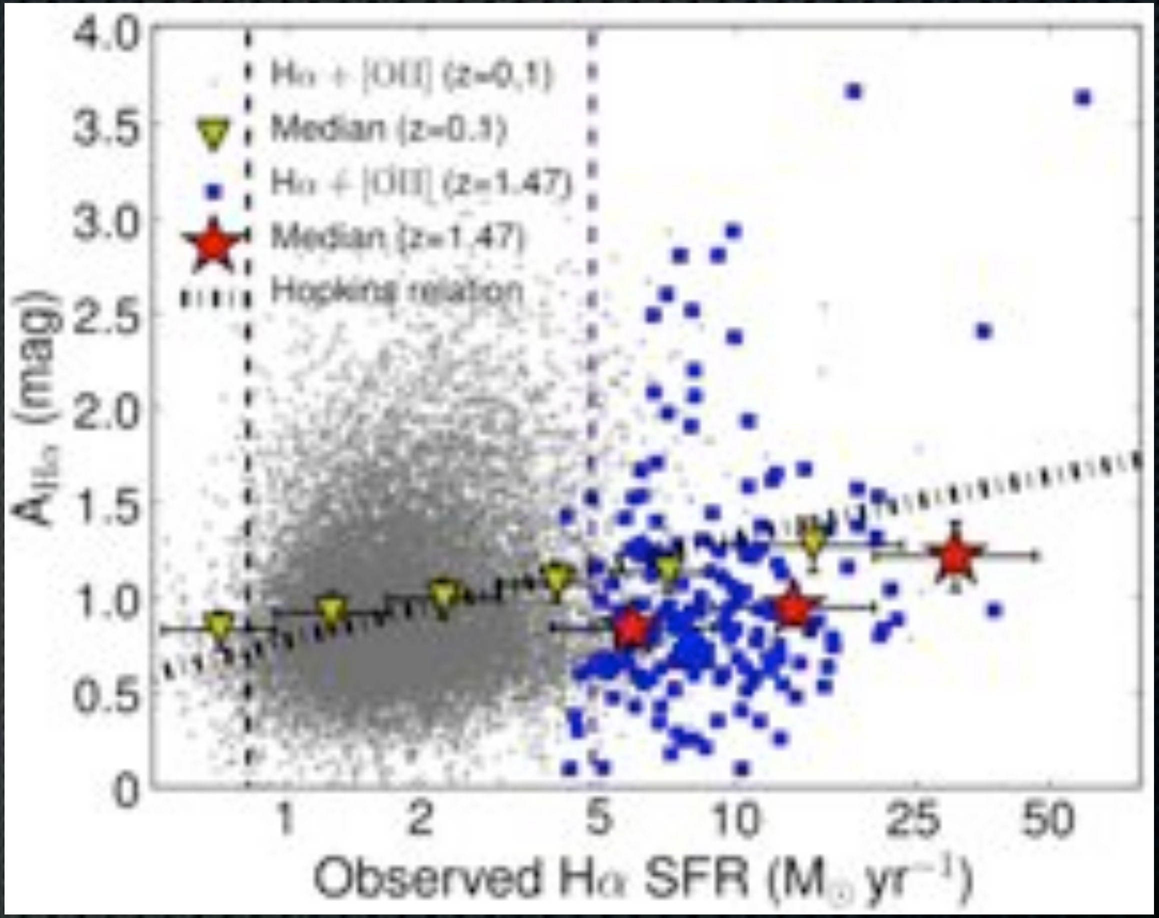
Local relations (extinction corrections as a function of observed luminosity) over-predict dust-corrections at high redshift

Dust extinction-SFR in the last 9 Gyrs

Does the empirical SFR-dust extinction dependence hold at z~1.5?

and if we take into account the luminosity evolution?

$\log[L^*(z)] \propto 0.5z$

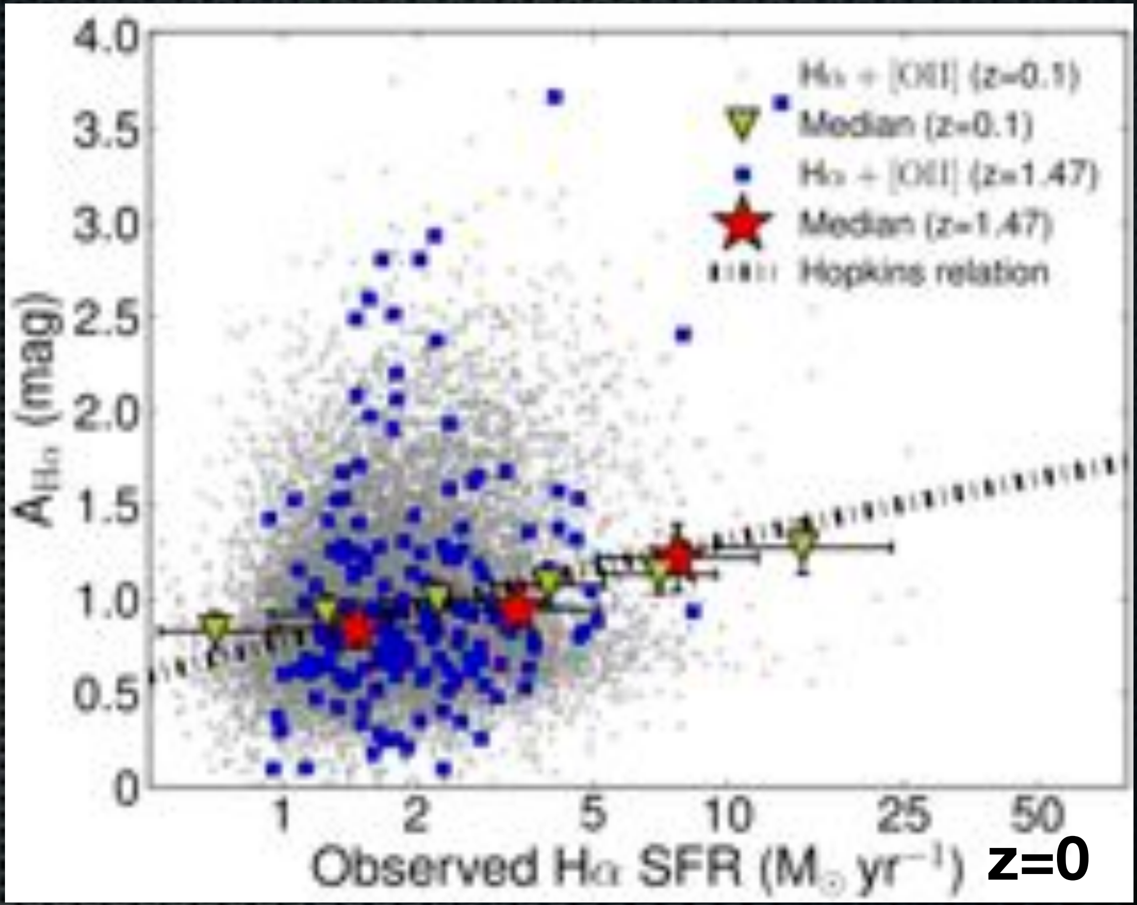


Dust extinction-SFR in the last 9 Gyrs

Does the empirical SFR-dust extinction dependence hold at z~1.5?

yes, if we account for the luminosity/L*(z) evolution

~Same population(!?), just overall more luminous



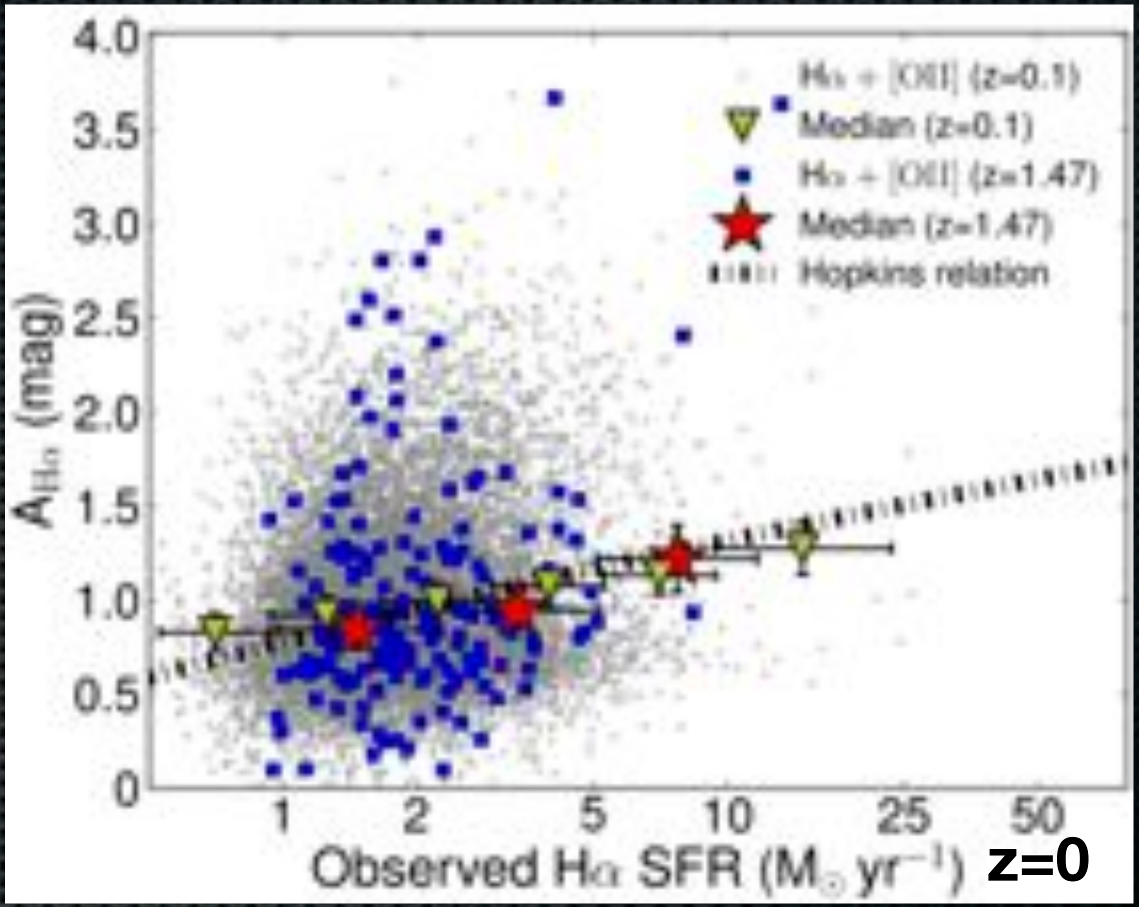
So (apart from the L* evolution) ~no evolution(?) in dust extinction of star forming galaxies

$$\log[L^*(z)] \propto 0.5z$$

Dust extinction-SFR in the last 9 Gyrs

Does the empirical SFR-dust extinction dependence hold at z~1.5?

yes, if we account for the luminosity/L*(z) evolution



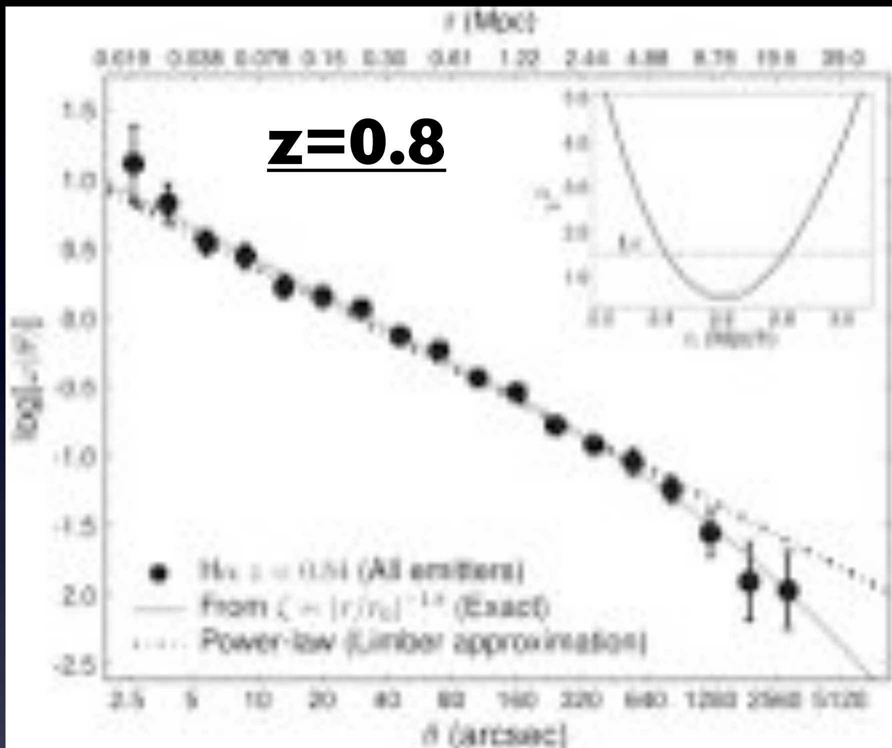
"Fixed luminosity"?

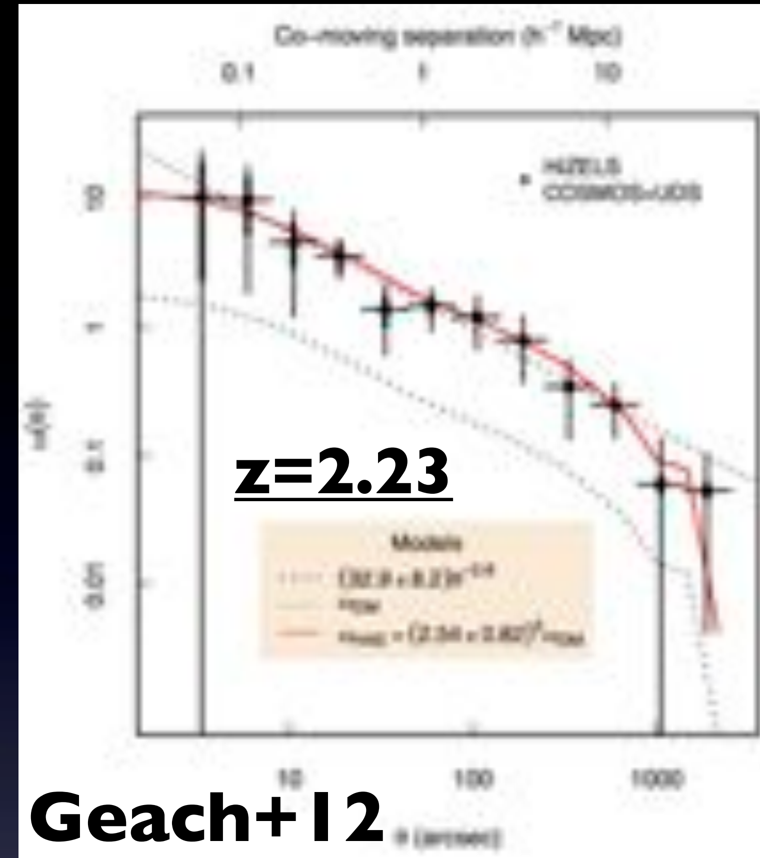
$\log[L^*(z)] \propto 0.5z$

So "fixed" ULIRG/LIRG class/ make no sense; but ULIRG(z) / LIRG(z) classifications might

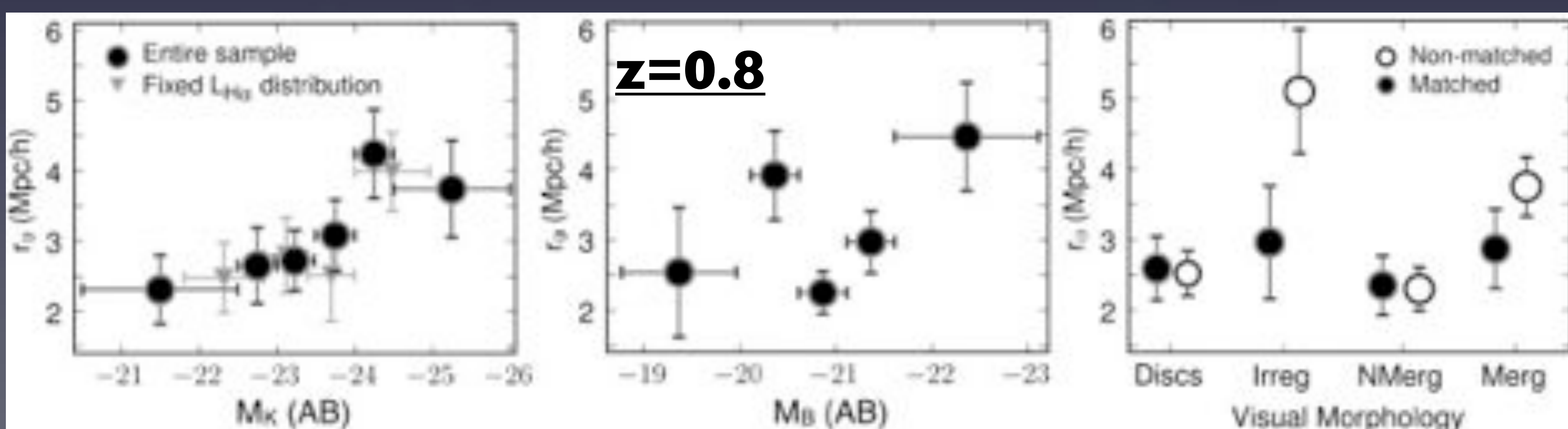
(at z~2, ULIRGs >$10^{13}L_o$ LIRGs >$10^{12}L_o$)

Clustering



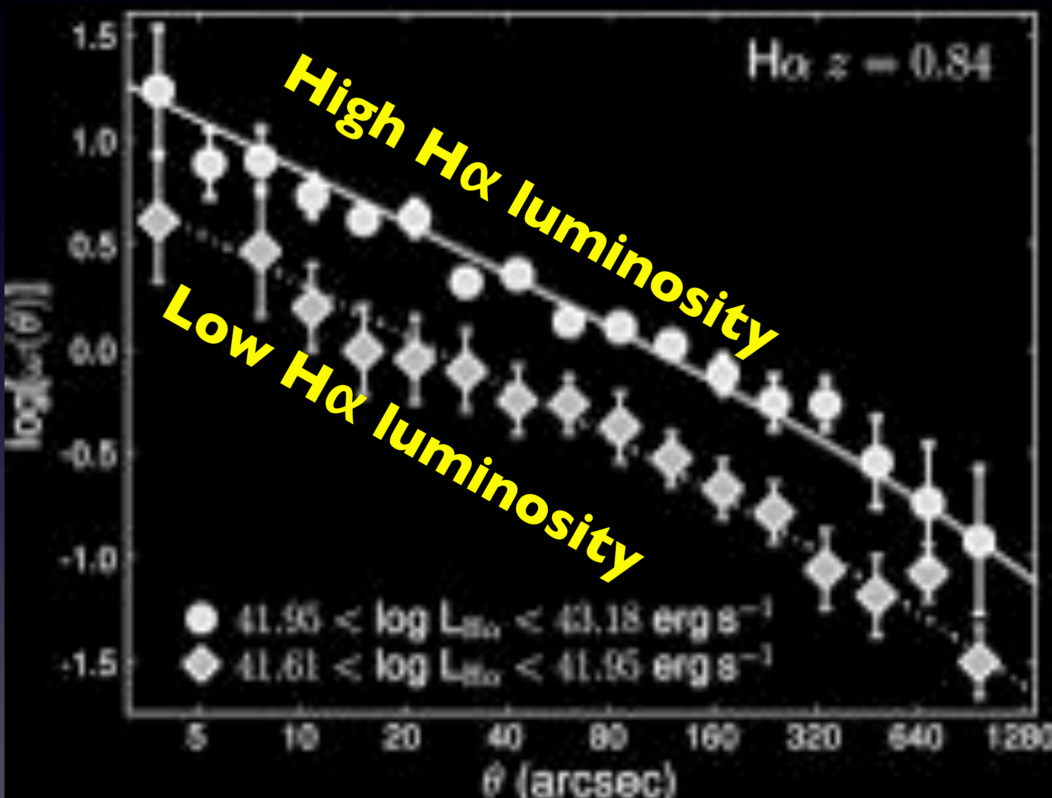


Sobral et al. 2010

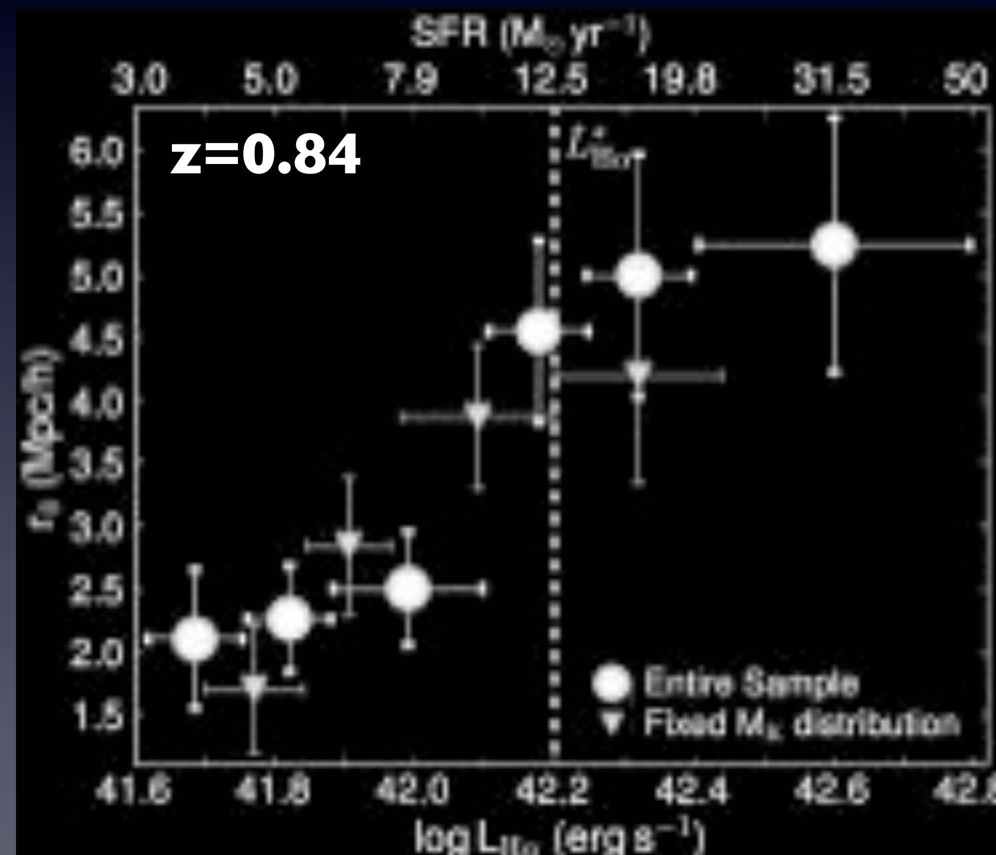


Clustering of Hα at z~1

Clustering depends on Hα luminosity; galaxies with higher SFRs are more clustered

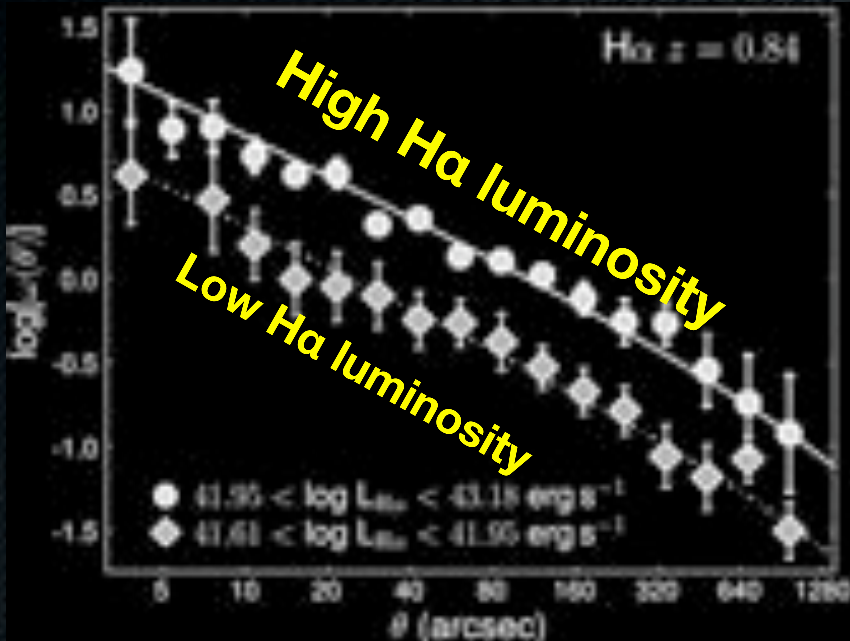


Sobral et al. 2010

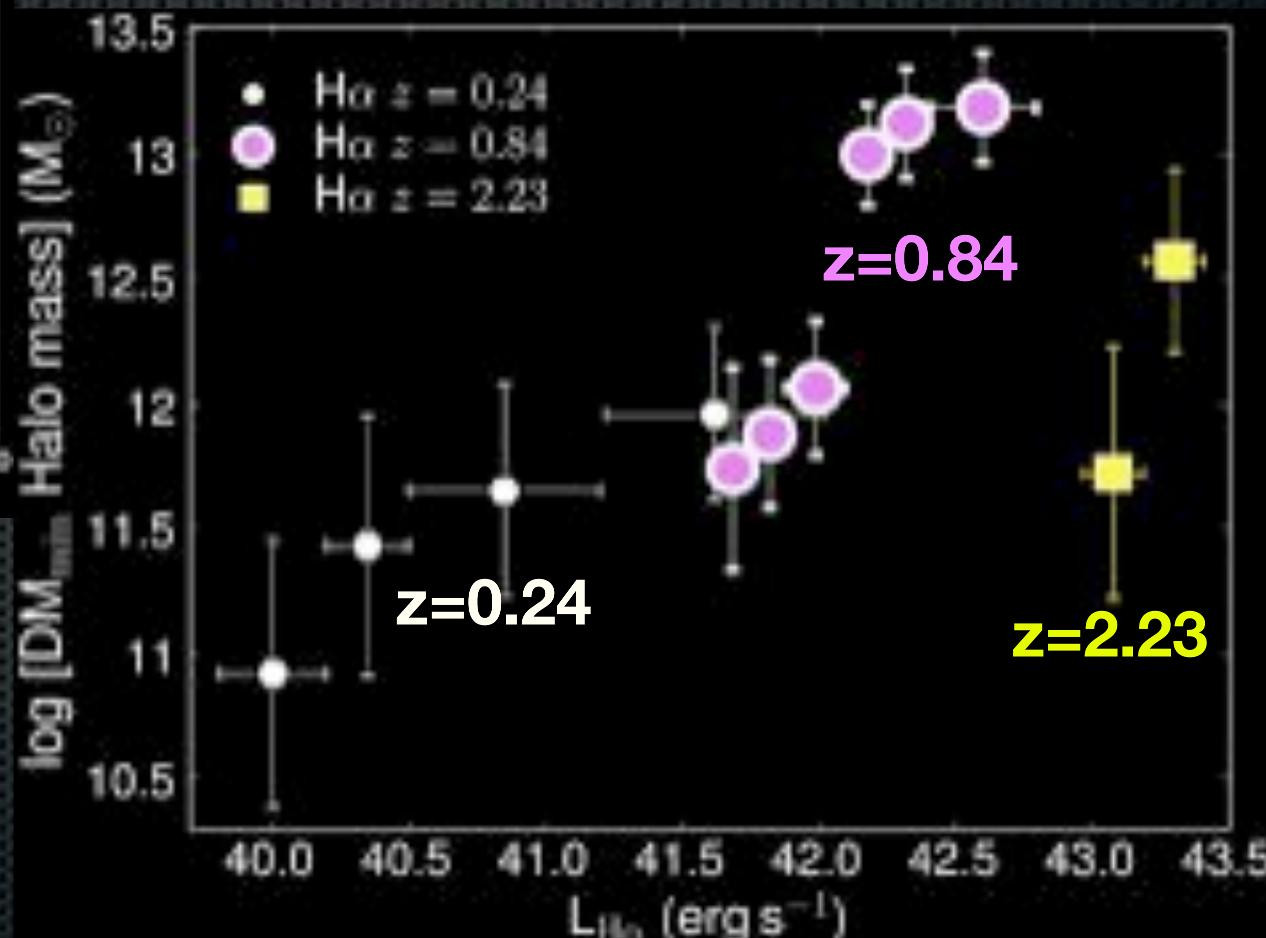


Clustering of Hα emitters

<u>Clustering depends on Hα luminosity</u>; galaxies with higher SFRs are more clustered

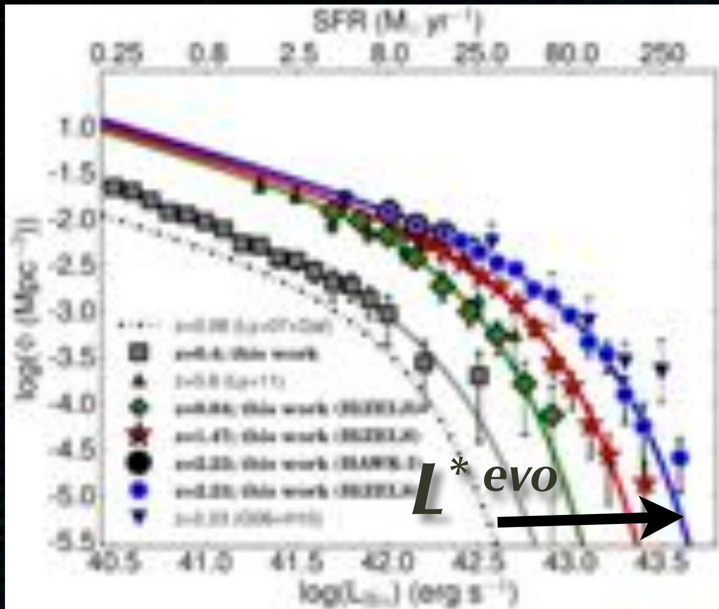


Sobral et al. 2010



Clustering-Hα relations at 3 very different epochs...

Same DM Halo mass: much more efficient at High-z

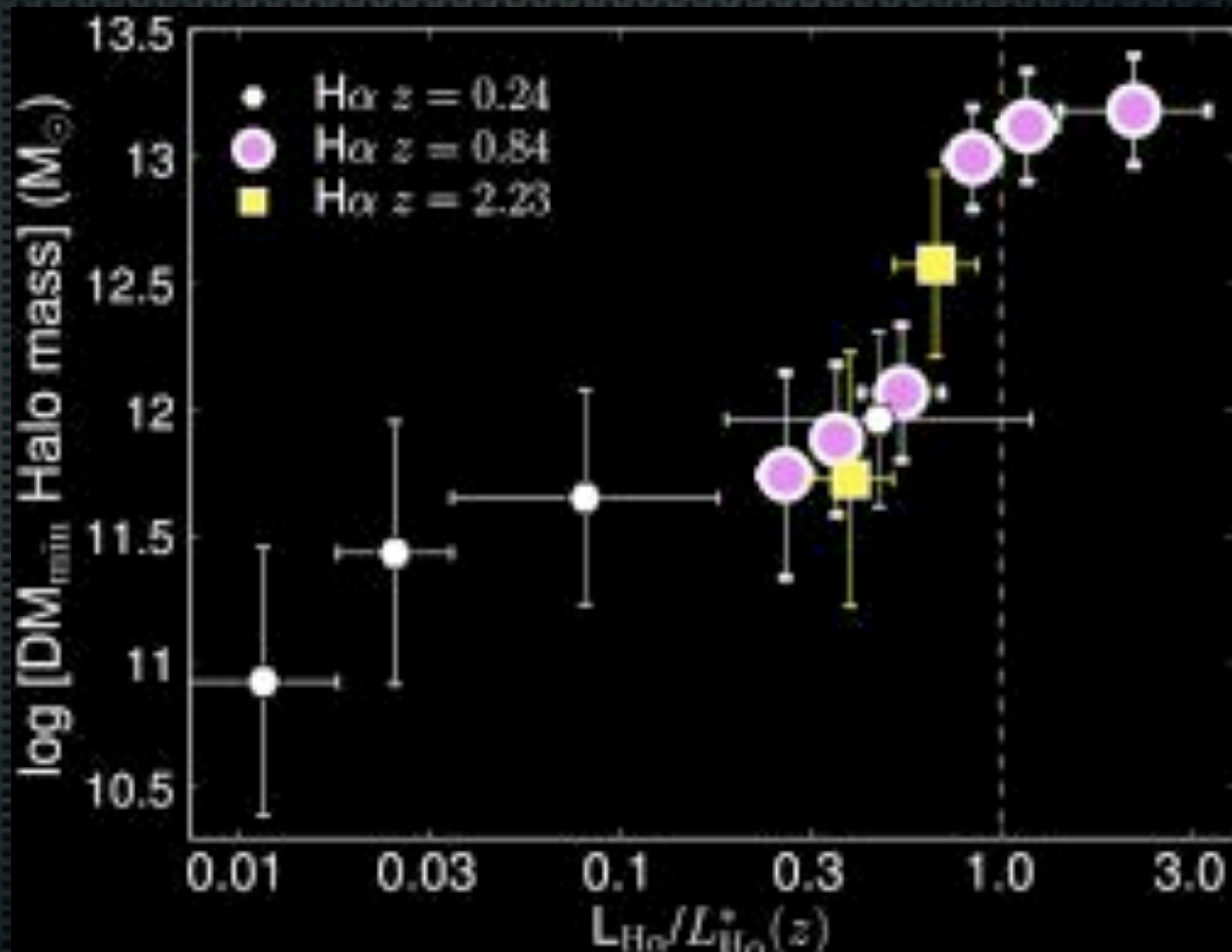


Clustering-Hα

Sobral et al. 2010

Using the Luminosity evolution (L*) measured before...

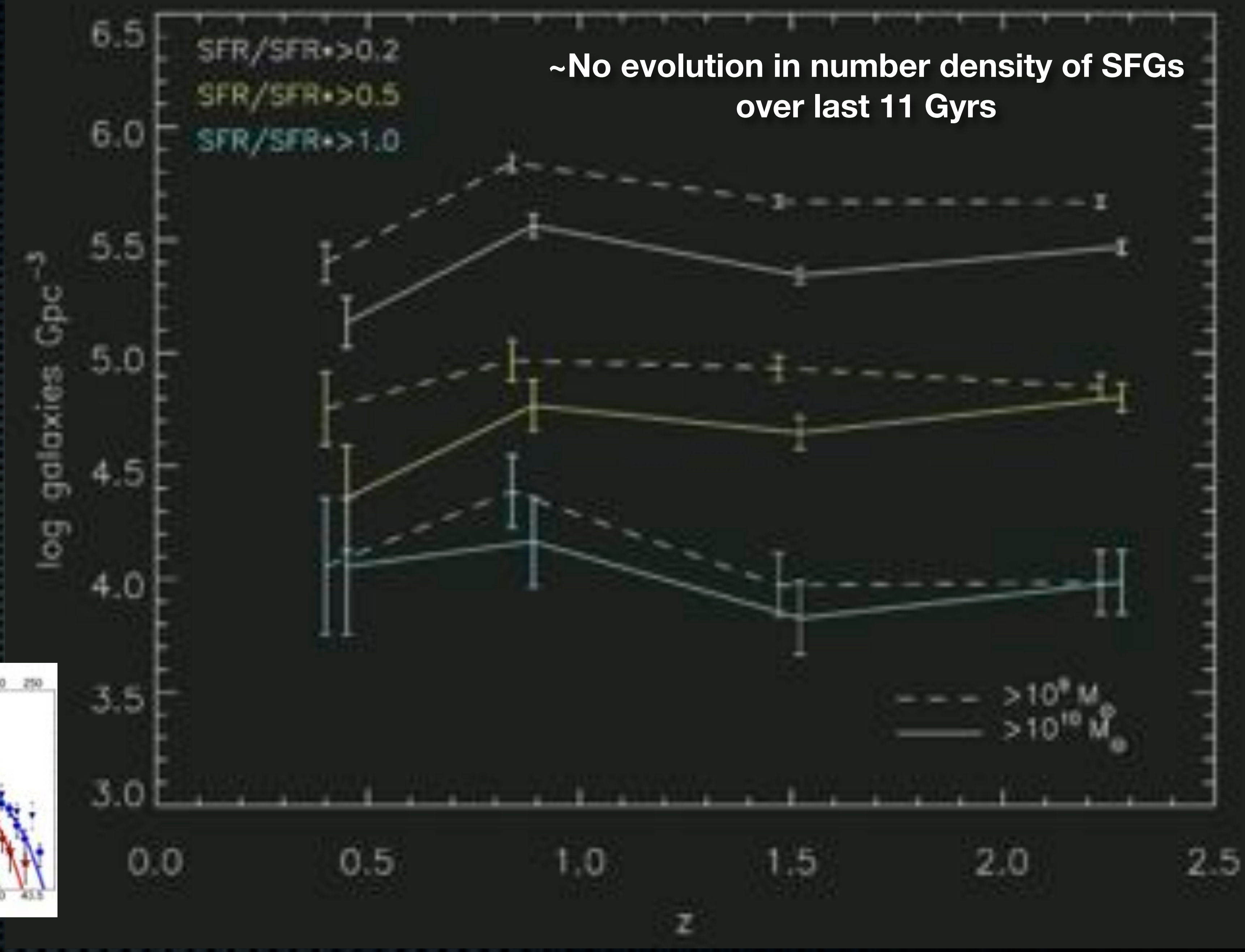
Scaling Hα luminosities by the break of the Hα luminosity function recovers a **single relation**, independent of time across the bulk of the age of the Universe



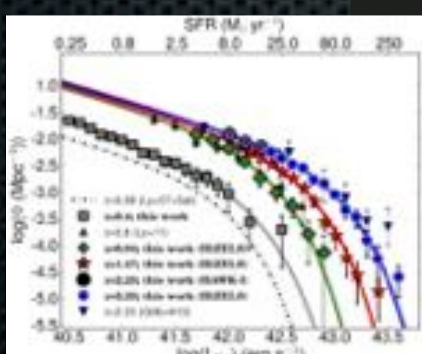
Accounting for evolution of the typical SFR (SFR* or L*):

$$\log L^*(z) = 0.45z + \log L^*_{z=0}$$

Stott et al.



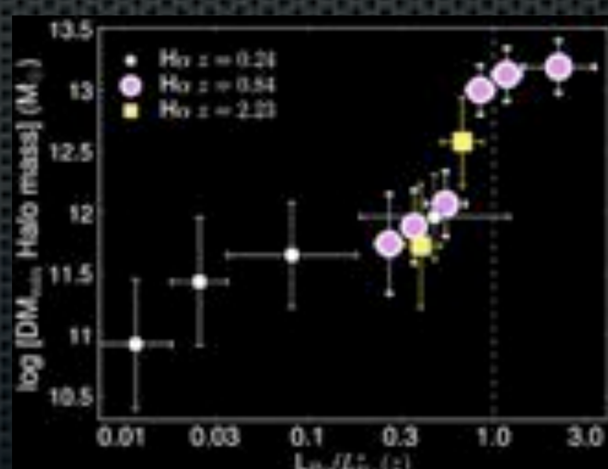
~No evolution in number density of SFGs over last 11 Gyrs

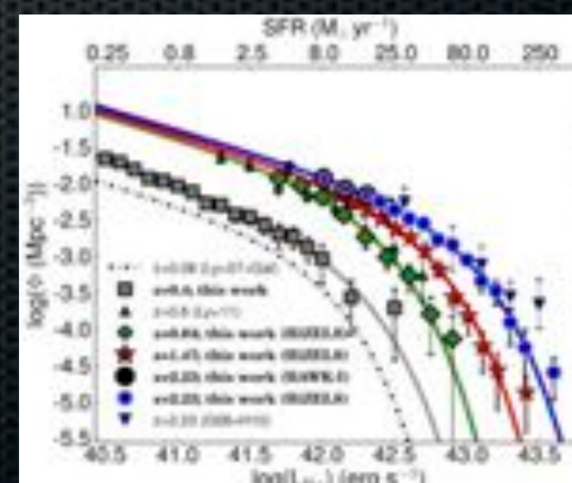


A simple view: 11 Gyrs of SFGs

with HiZELS

- **Strong Evolution: Typical SFR (SFR*) reduces by 1/10**
- Many statistical properties remain “unchanged”: Dust “extinction”, Mass function (M*,alpha)
- Environmental + Mass trends are the same (last ~9 Gyrs)
- Same Dark Matter halo masses host the same L/L* galaxies

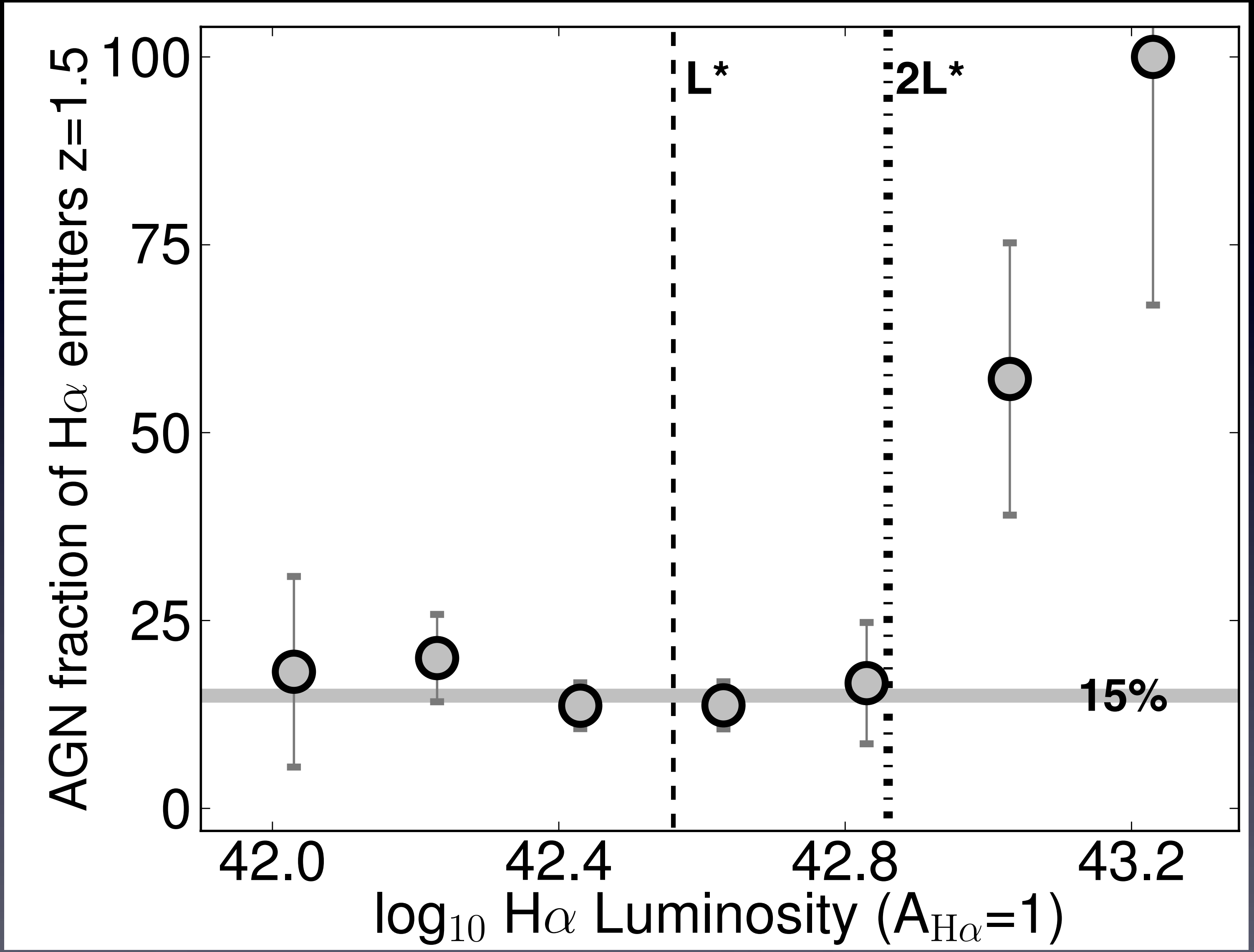




Summary:

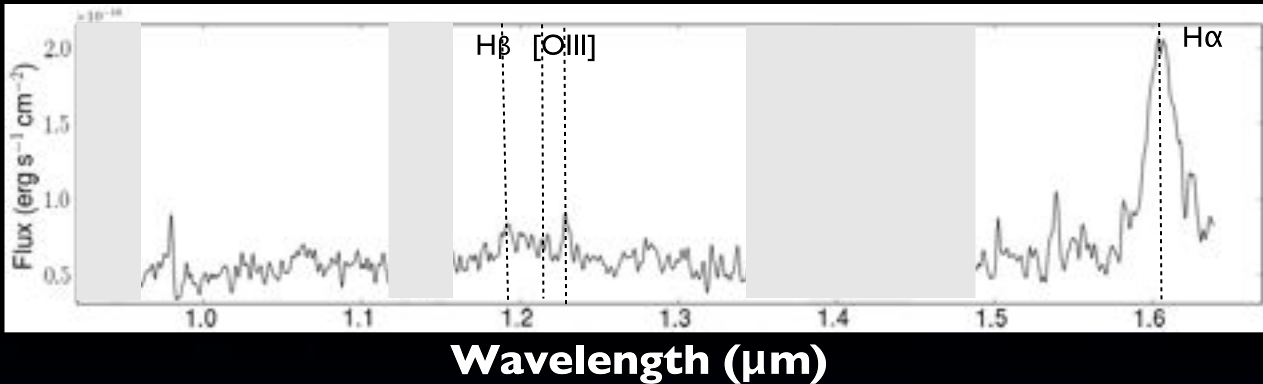
- Evolution of the Hα LF over 11 Gyrs and fully self-consistent (Hα) star-formation history z<2.3.
- Hα emitters at z=0.4-2.2; factor of ~10 times larger than previous samples
- Evolution in Ha LF: $\log L^*(z) = 0.45z + \log L^*_{z=0}$ $\alpha = -1.60 \pm 0.08$
- SFH of the Universe : $\log \rho_{\rm SFR} = -2.1/(z+1)$ $\log \rho_{\rm SFR} = -0.14T - 0.23$
- Agreement with stellar mass density growth
- Dust extinction in SF galaxies 9 Gyrs ago ~similar to SDSS
- z~0 mass and environment dependences already there up to z~1.5
- Single L*(z)-DM halo connection up to z~2.2 and L* scaling: important insight?

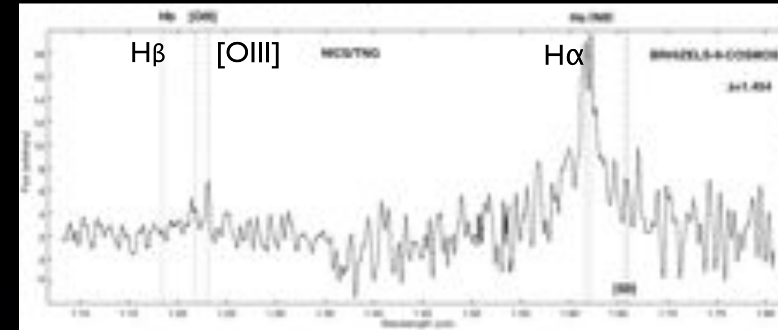
Fraction of AGN within the sample

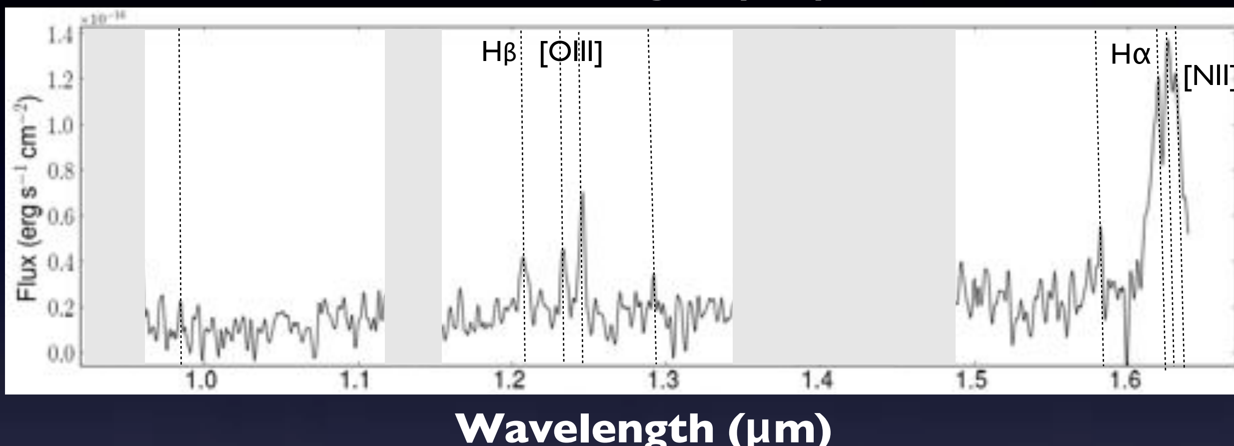


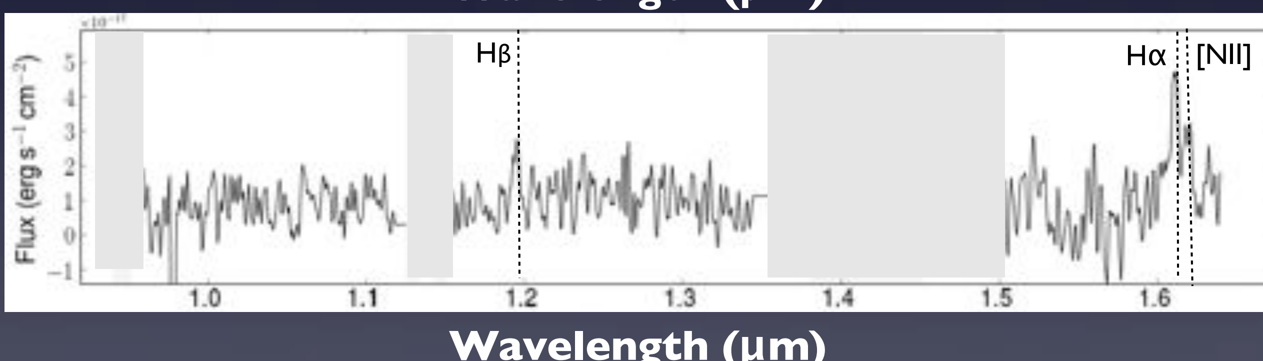
UKIDSS
DXS Fields!

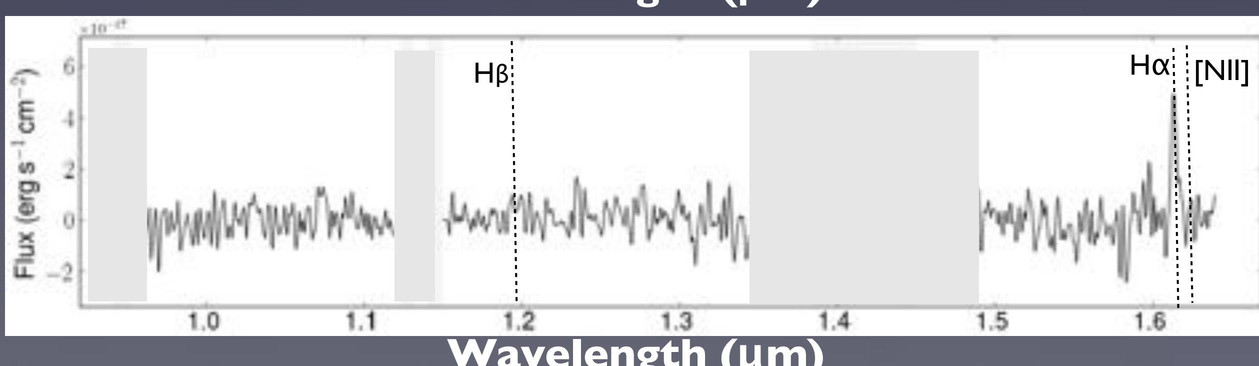
Sobral et al. 2012c











Hα Luminosity

z= 1.47

Broad-line AGN

AGN dominated

AGN + SF

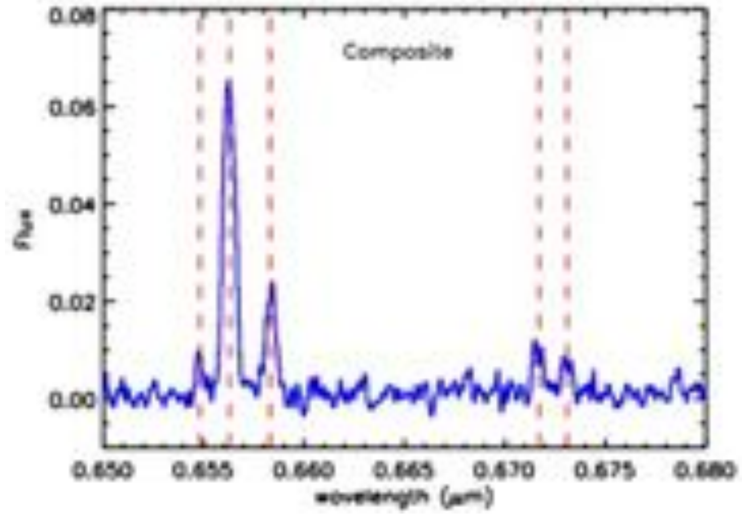
More Metal-rich

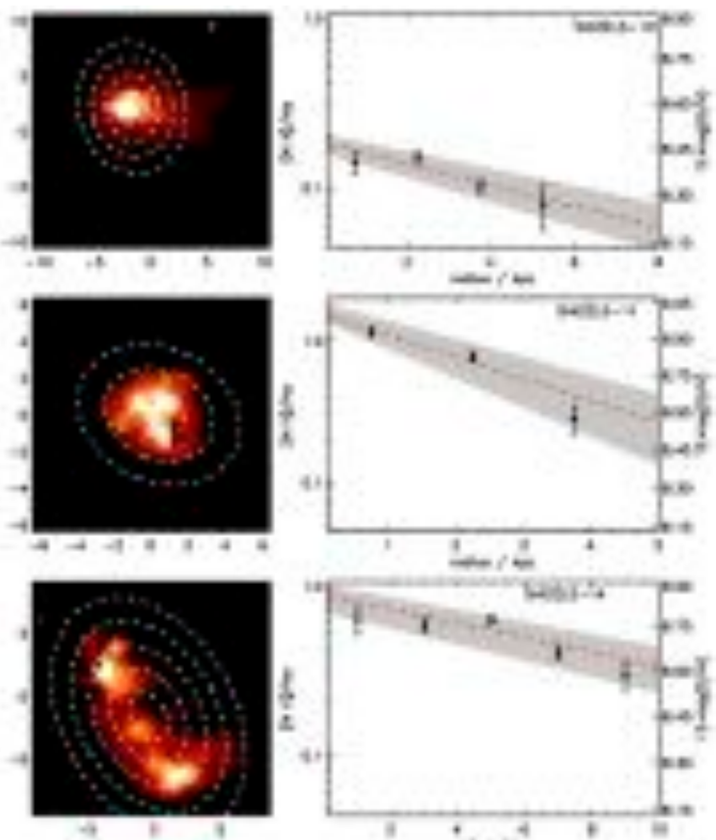
More Metal-poor

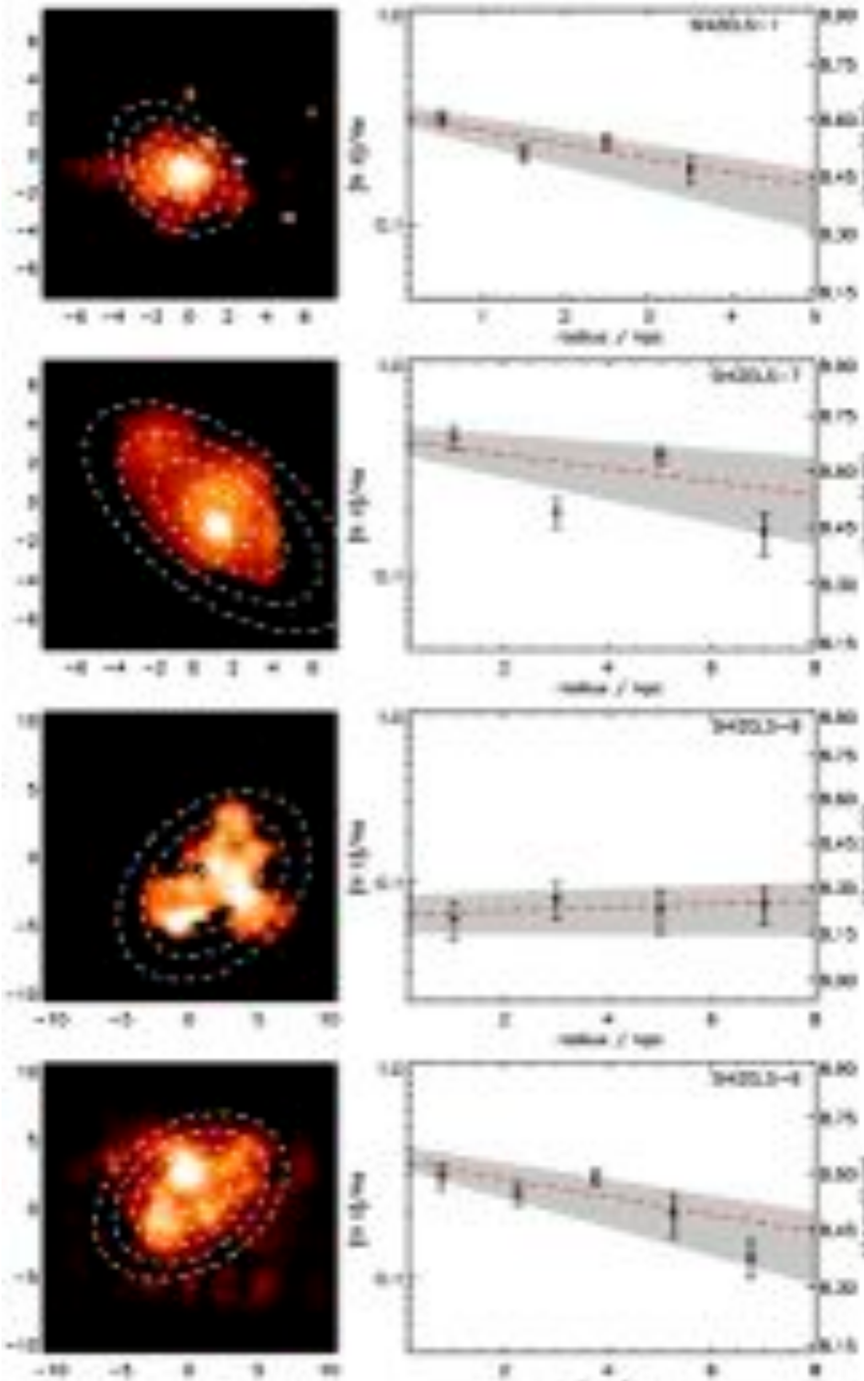
Star-forming

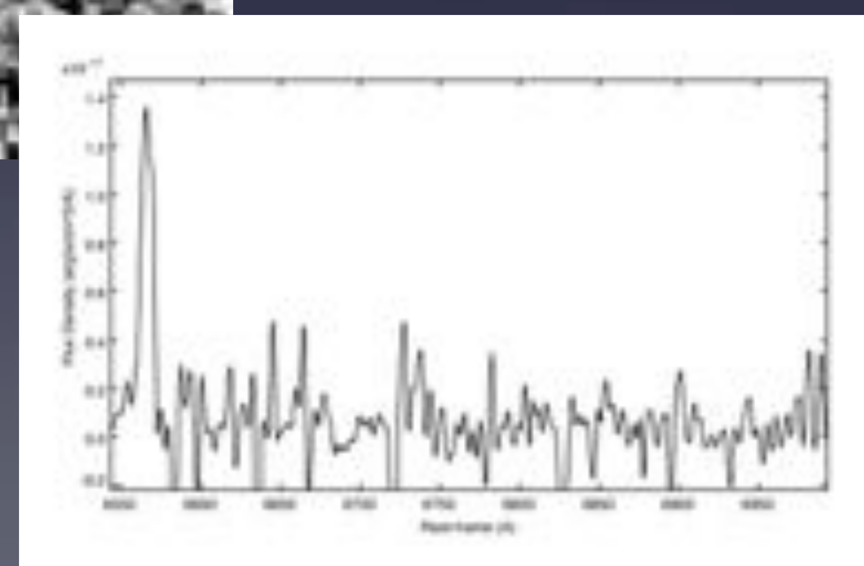
Dynamics & Metallicity gradients H-alpha z=0.8, 1.47, 2.23

Swinbank et al. 2012





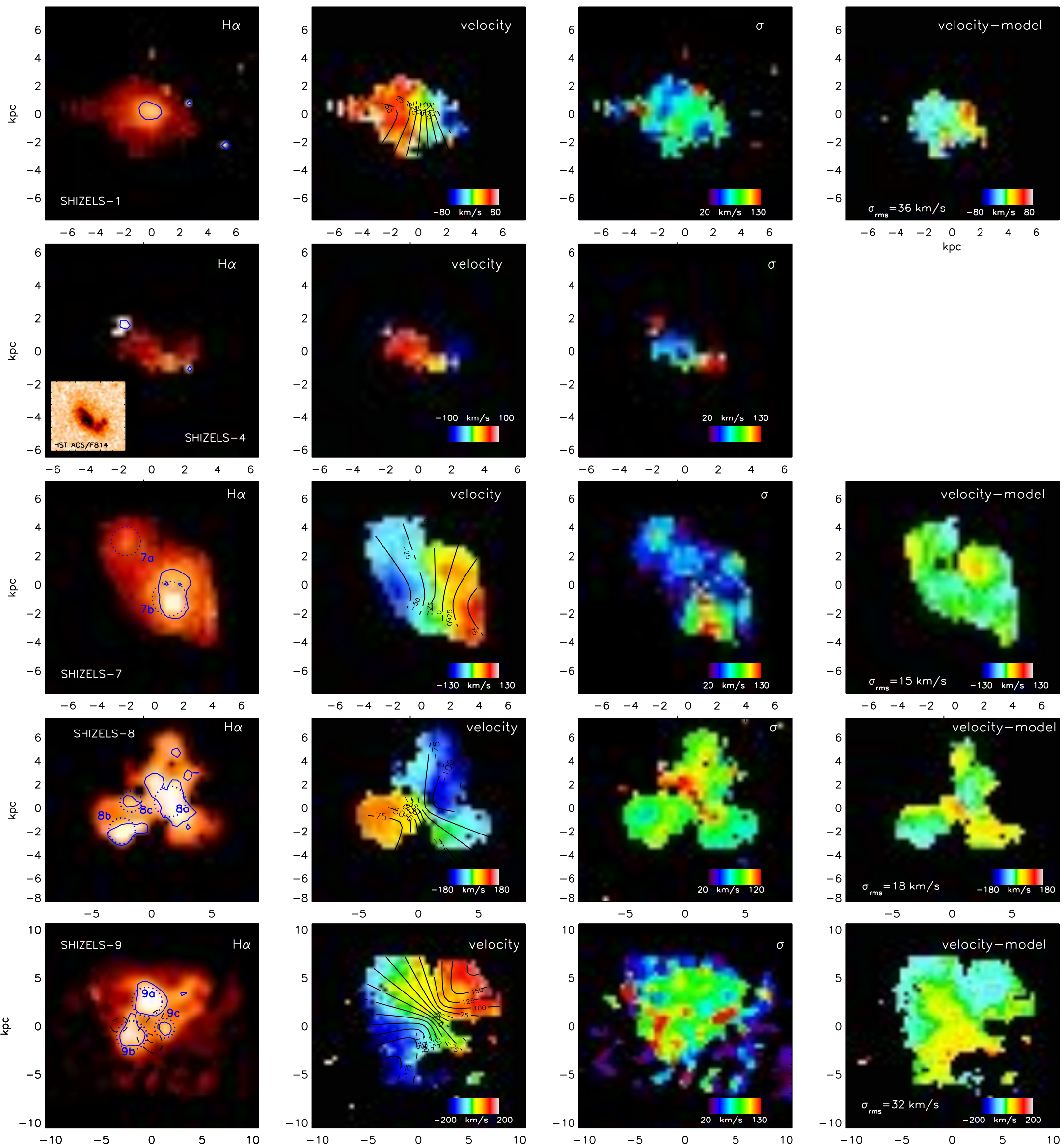


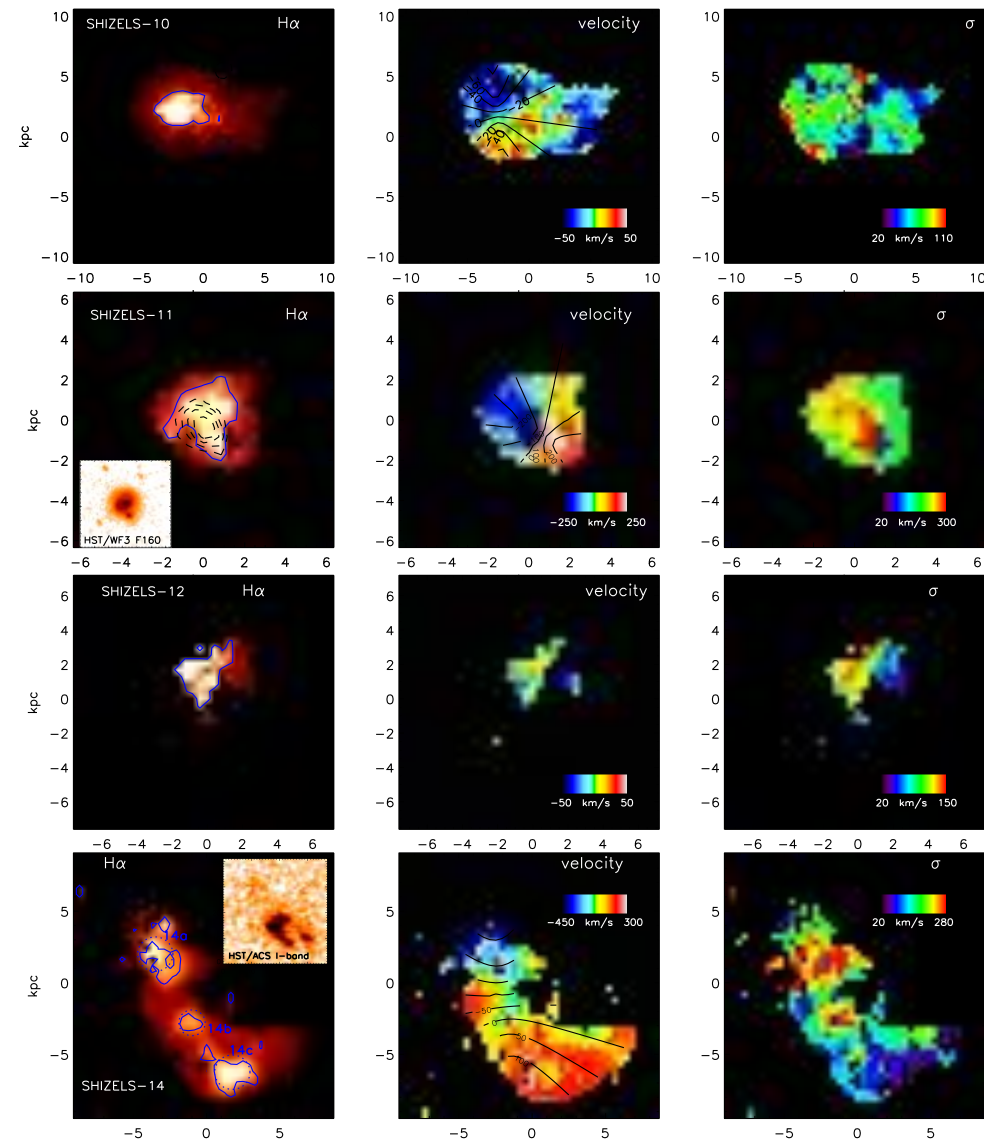


Galaxy Dynamics at z~0.8-2.2

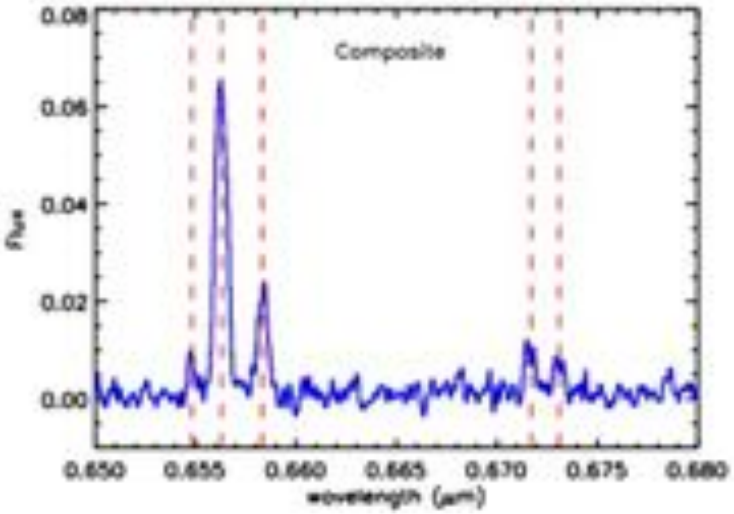
Swinbank al. 2012

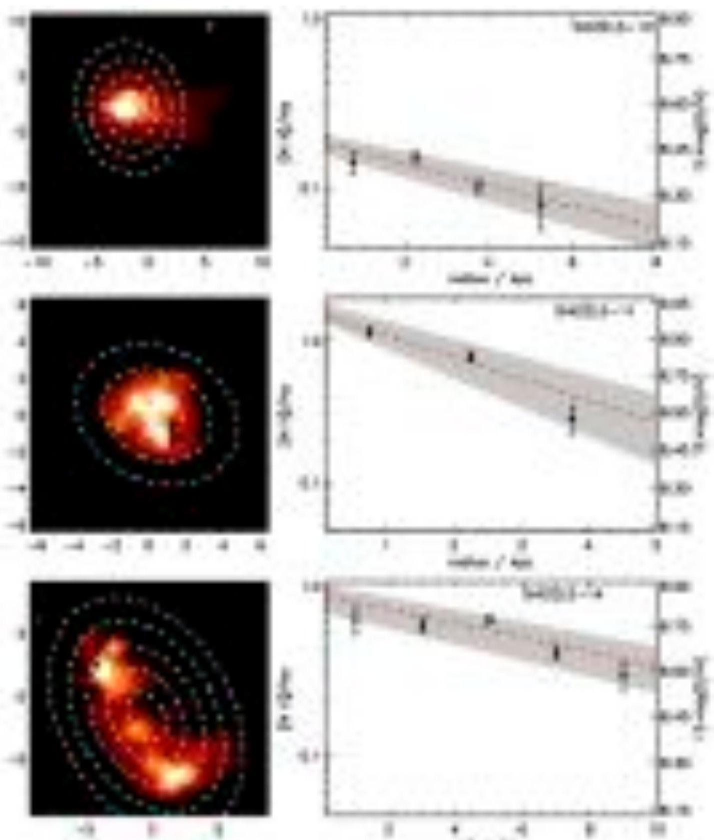
From AO IFU observations

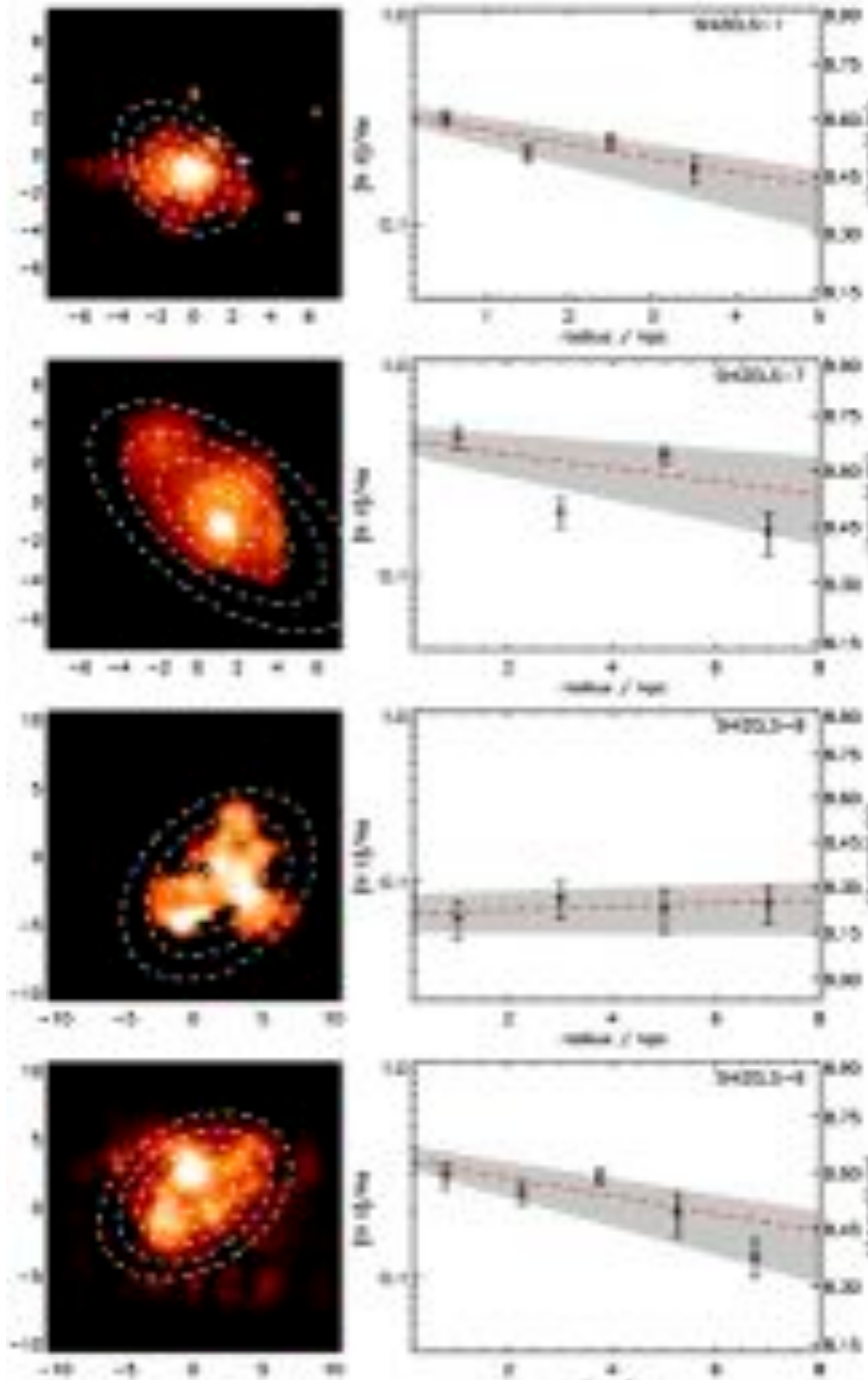


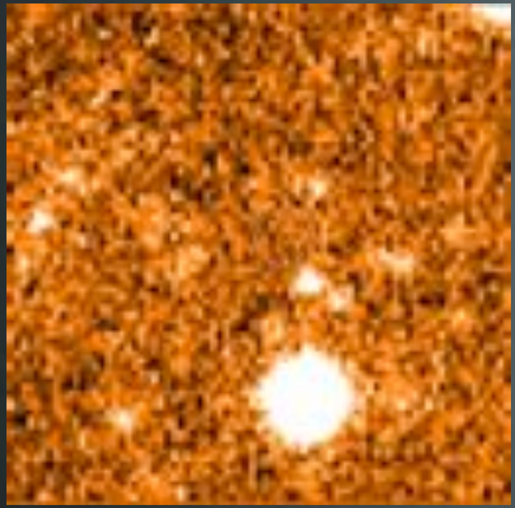


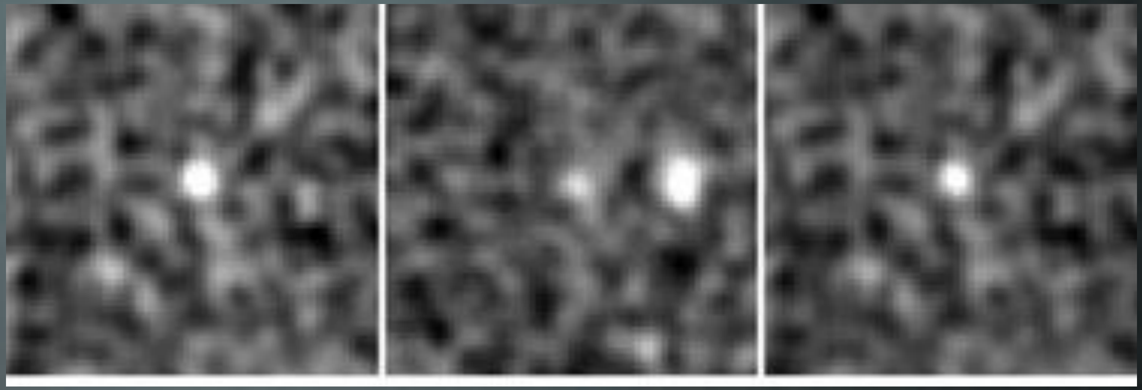
Metallicity gradients H-alpha z=0.8, 1.47, 2.23

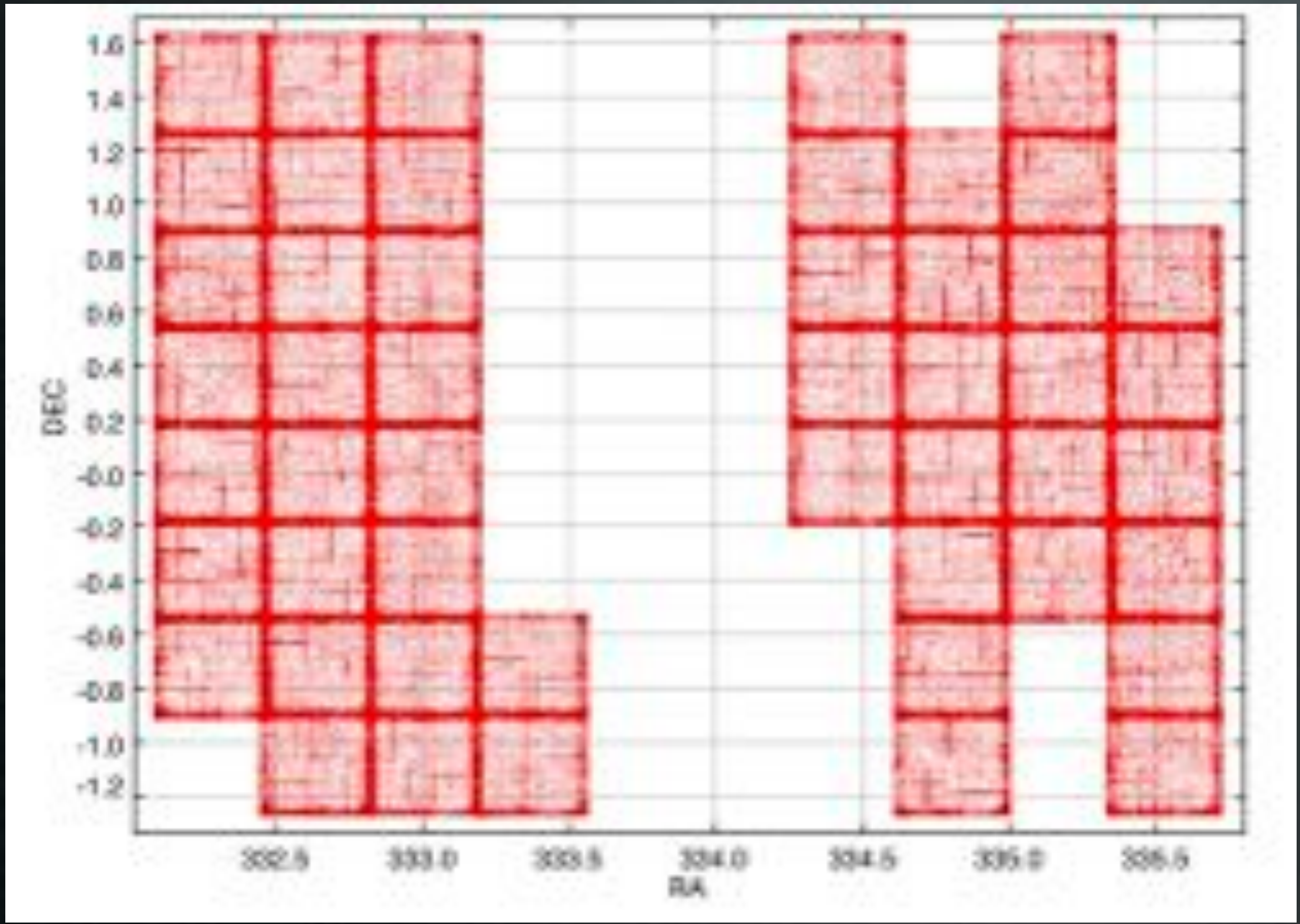


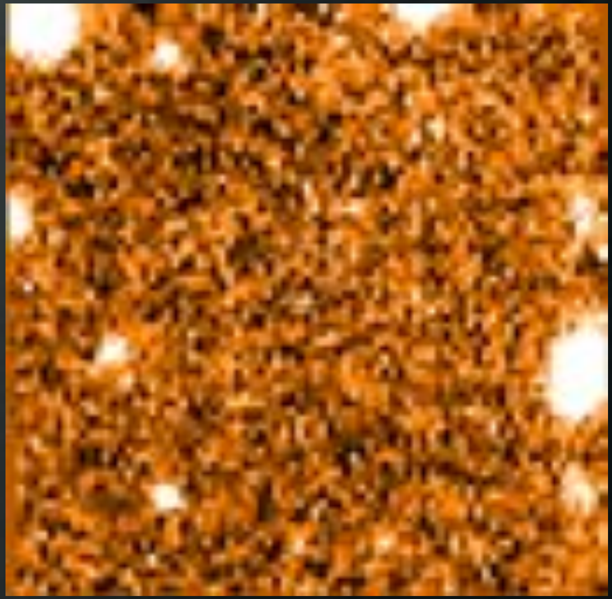









DEC
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
RA
332.5
333.0
333.5
334.0
334.5
335.0
335.5



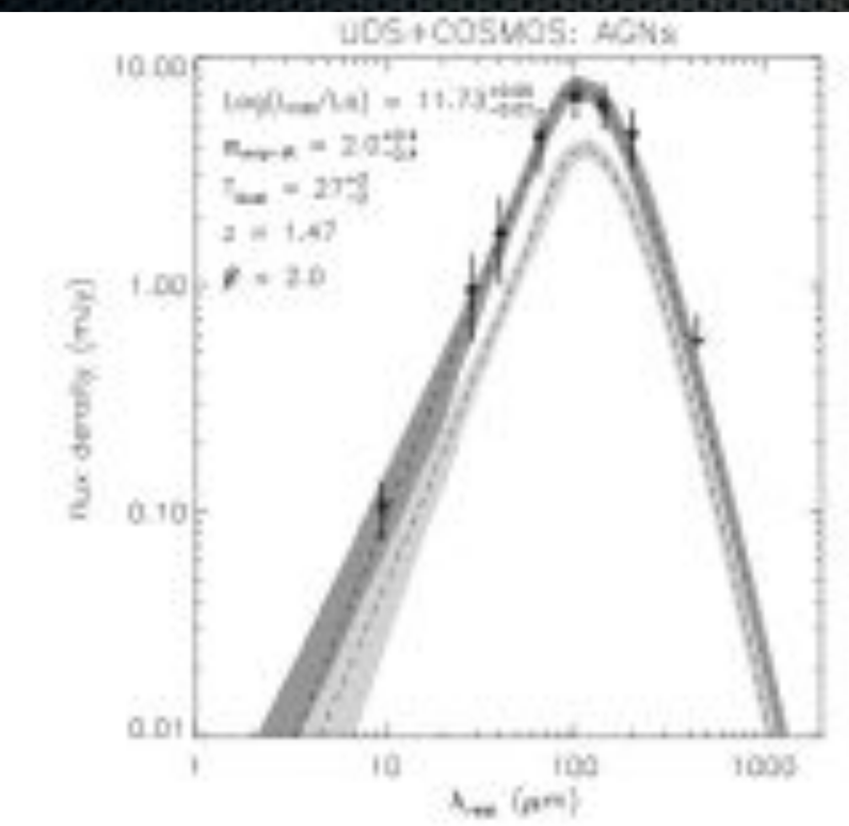
Don’t believe [OII]/Ha?

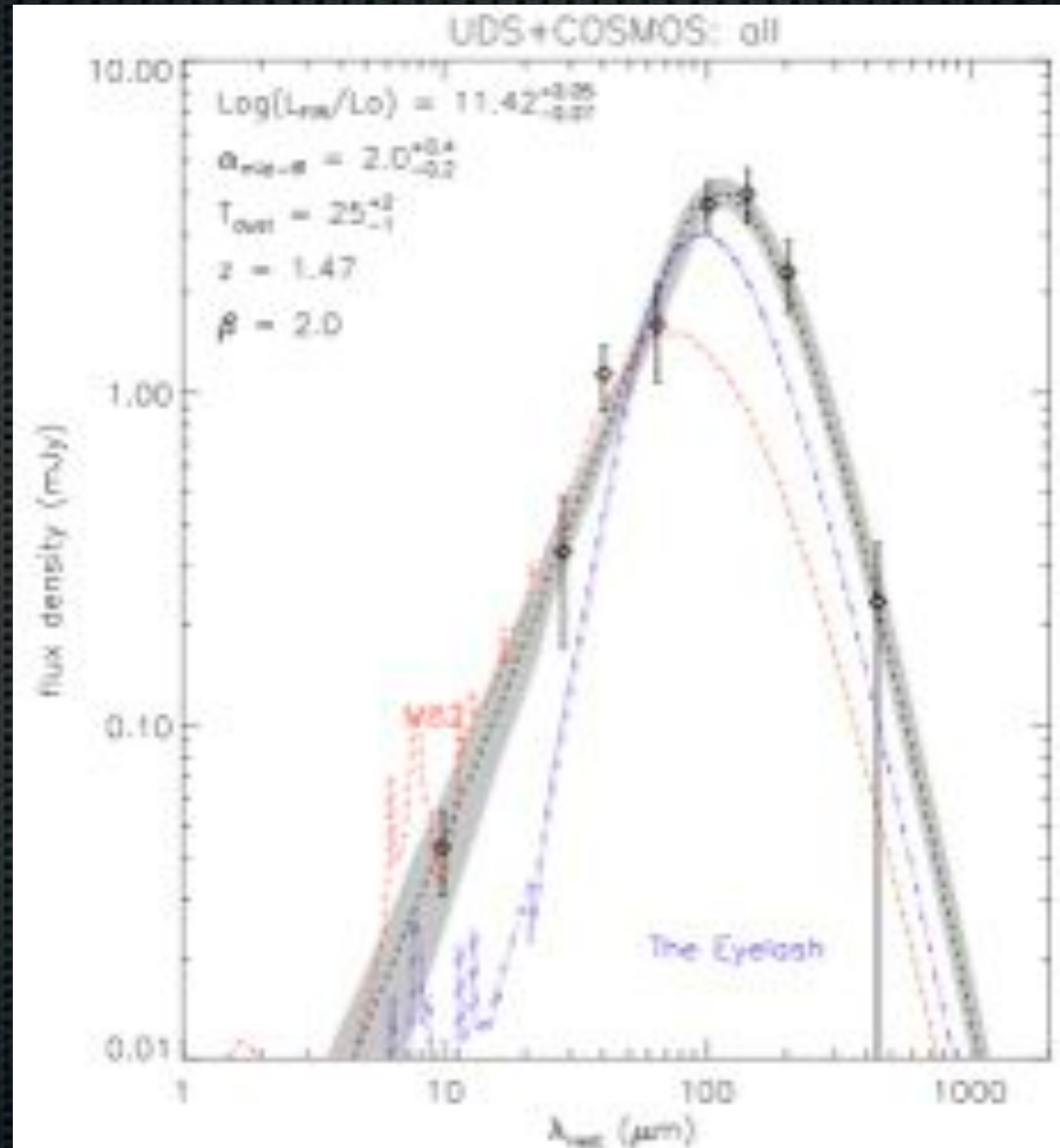
Let’s look at the MIR/FIR w/ Herschel

Ibar, Sobral, Ivison et al. 2012

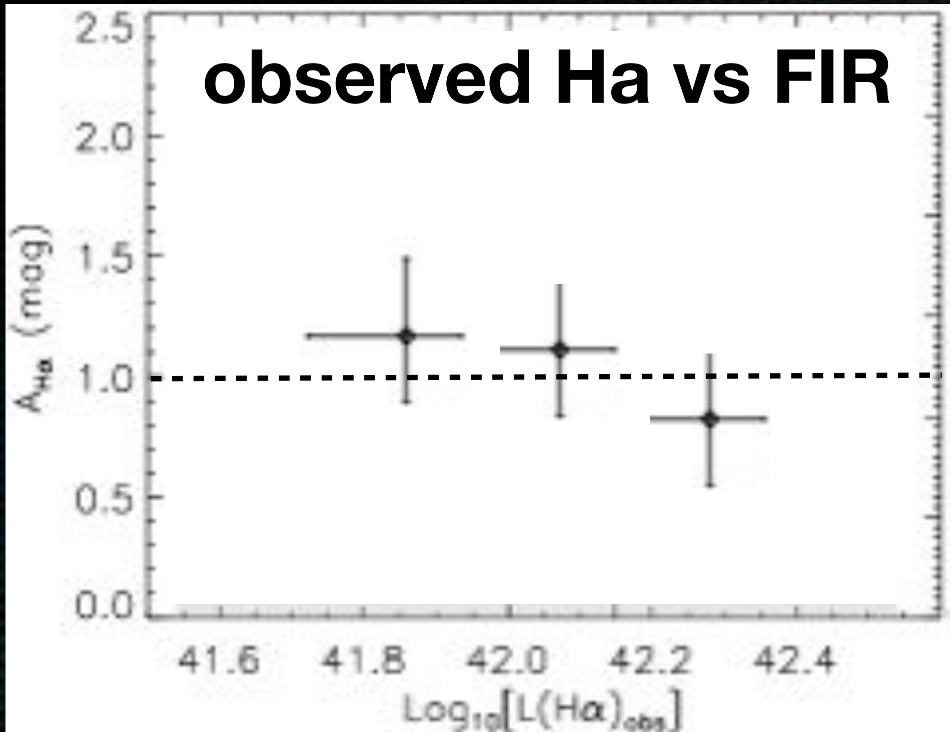
Ha emitters are “typical” SF galaxies at their epoch luminosities of z=0 LIRGs

Ha AGNs: hotter & more luminous in FIR



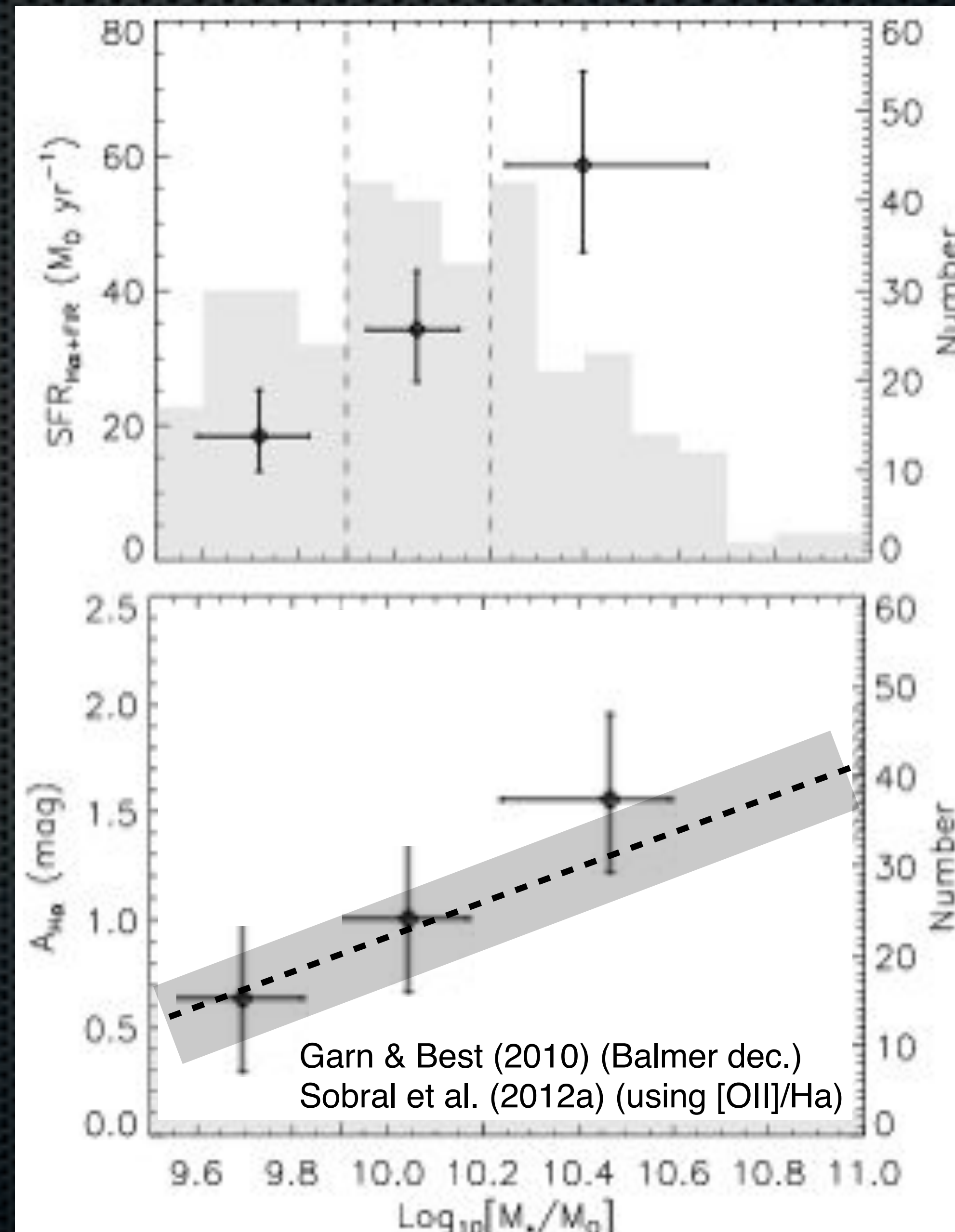


FIR derived A_Ha = 0.9-1.2 mag
~Same as [OII]/Ha



Dust corrections as a function of observed H-alpha would get it completely wrong!

Dust Corrections as a function of Mass work the best



Ibar, Sobral, Ivison et al. 2012

Hα luminosity function z>1?

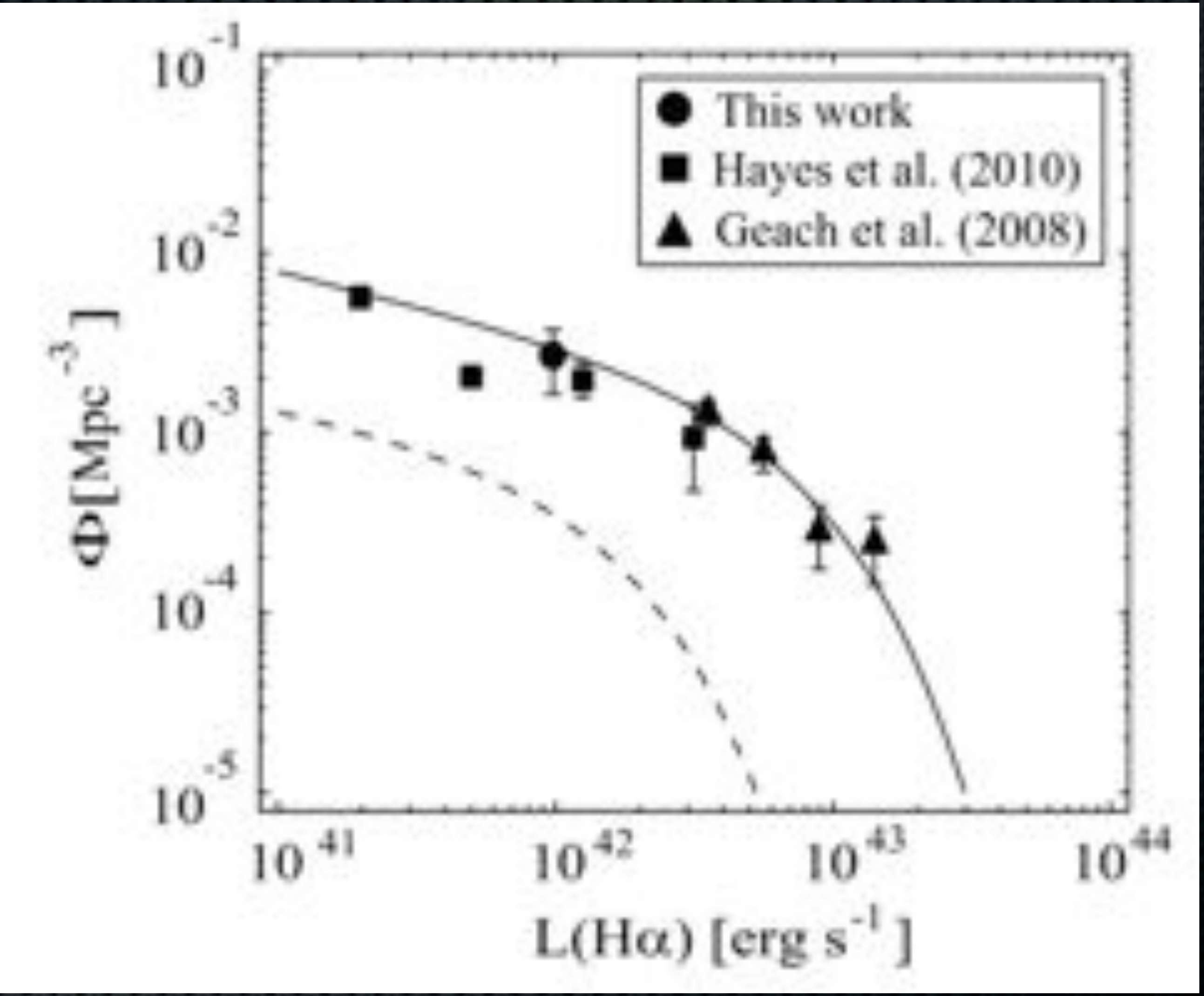
Samples still too small: <50 sources

L* Evolution: but by how much?

z~2

Faint-end slope?
Hayes et al: α=-1.7

Tadaki et al: α=-1.3



Is α getting steeper with z?

Hα LF z~2; Tadaki et al. 2011

Hα luminosity function z~1?

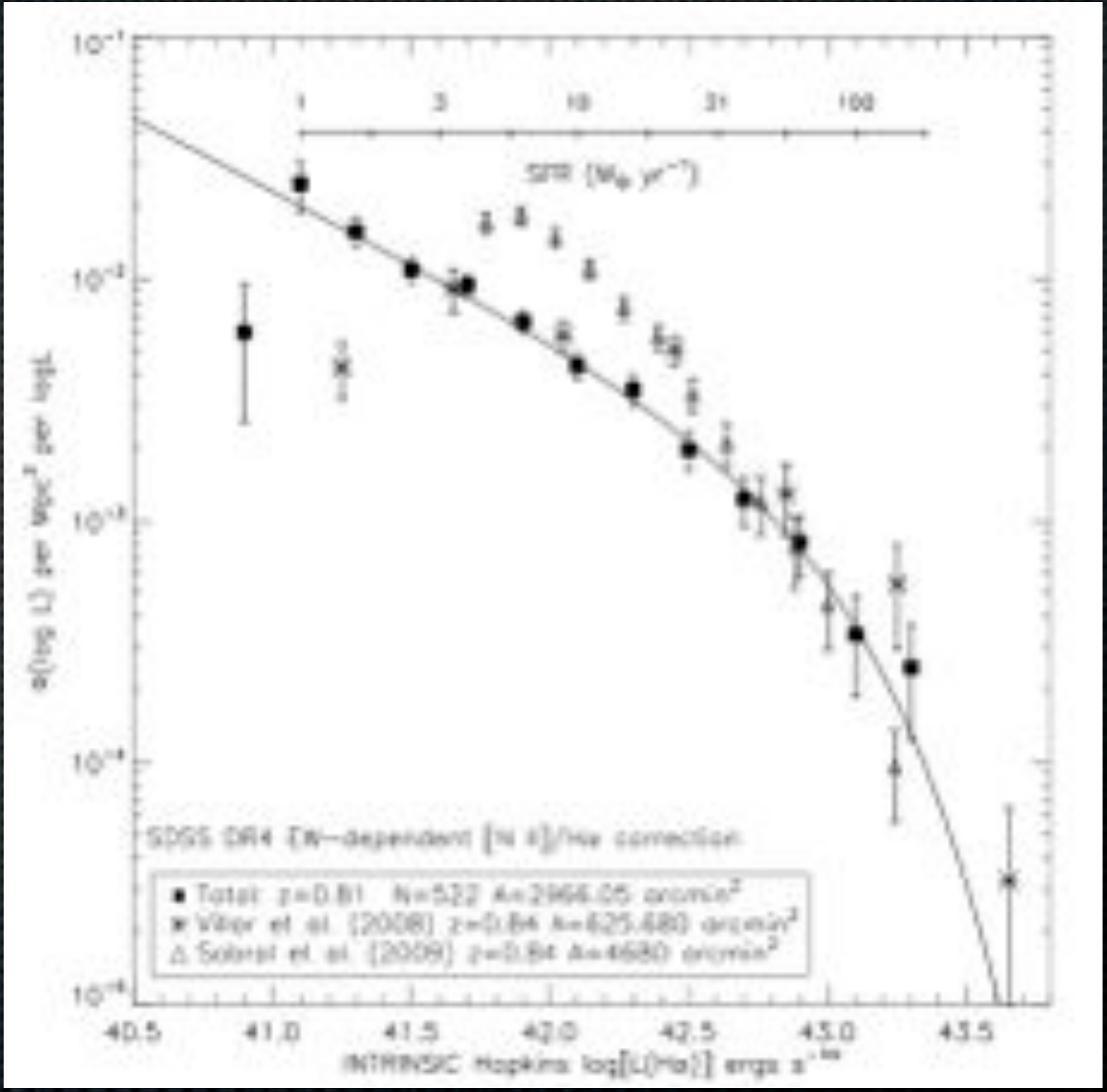
Samples now ~ large enough but:

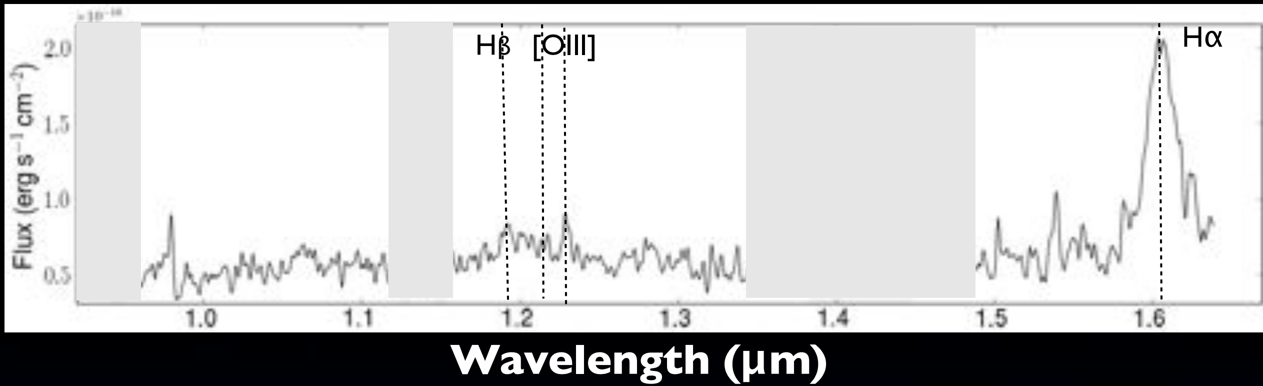
- Each study focus on a ~single redshift and uses:
- Different Selection criteria
- Different apertures
- Different areas + depths

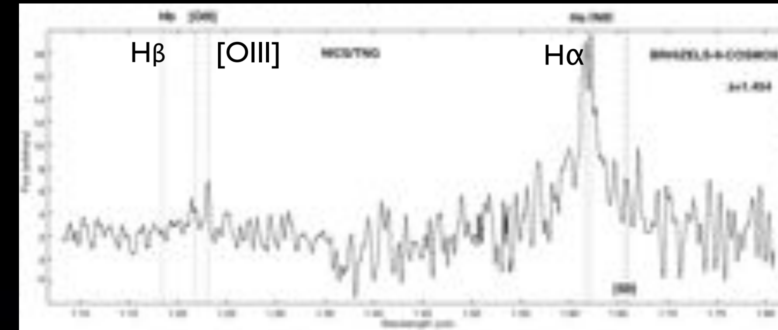
So they can disagree even at the same redshift

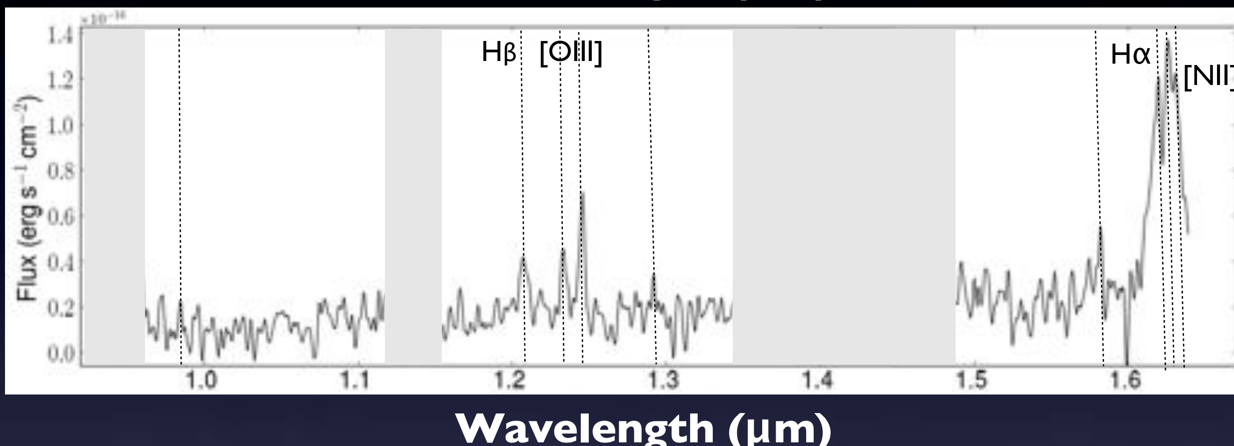
Evolution vs methods?

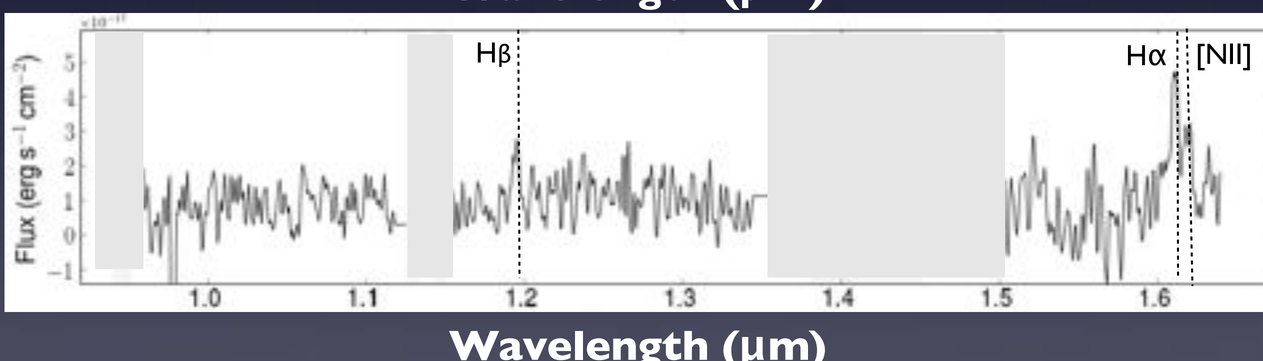
e.g. z~0.8 Ly et al. 2011

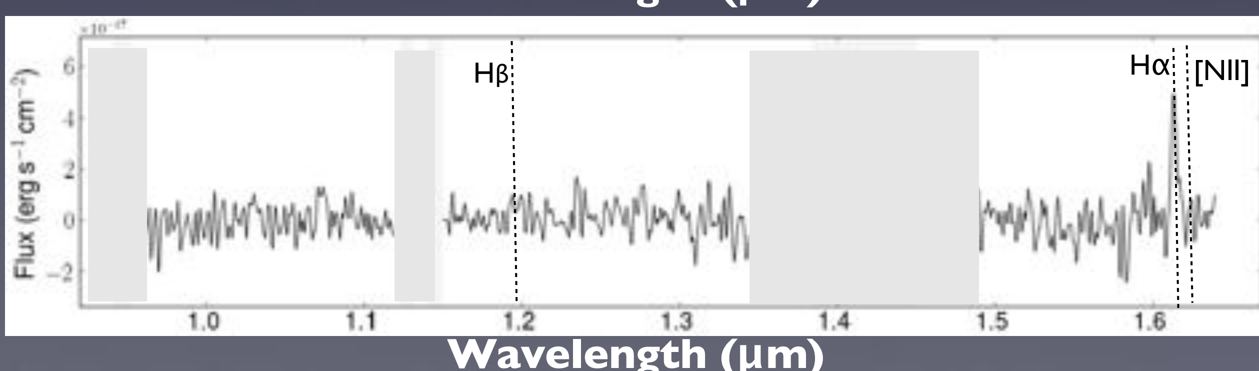












Hα Luminosity

z=1.47

Broad-line AGN

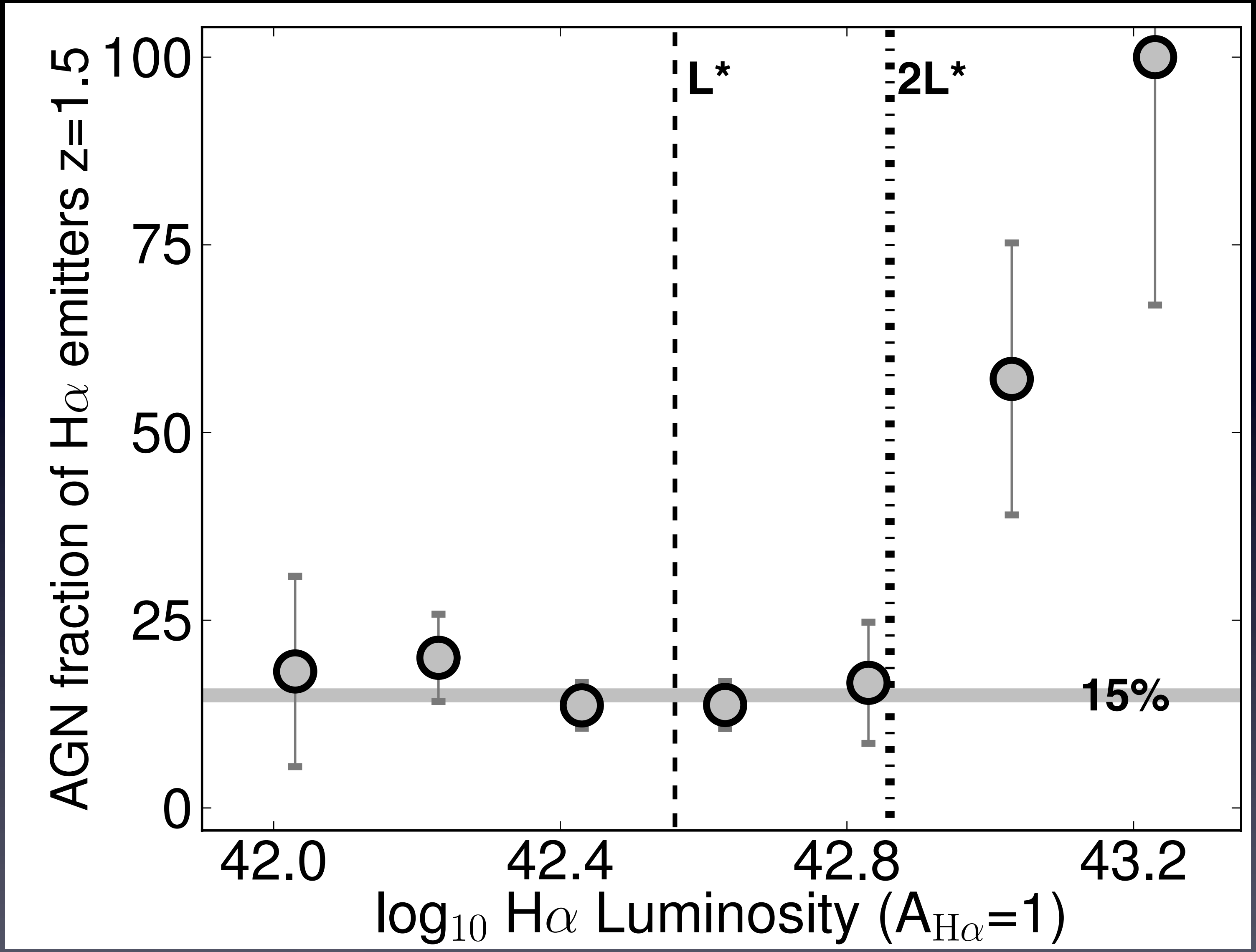
AGN dominated

AGN + SF

More Metal-rich

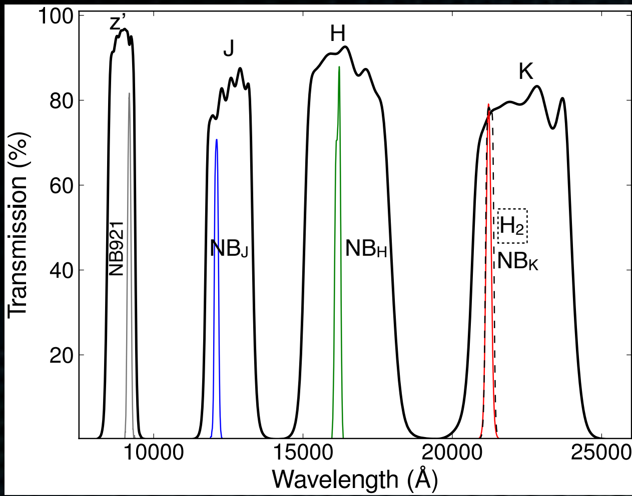
More Metal-poor

Star-forming



Sobral et al. 2012c

arXiv:1202.3436



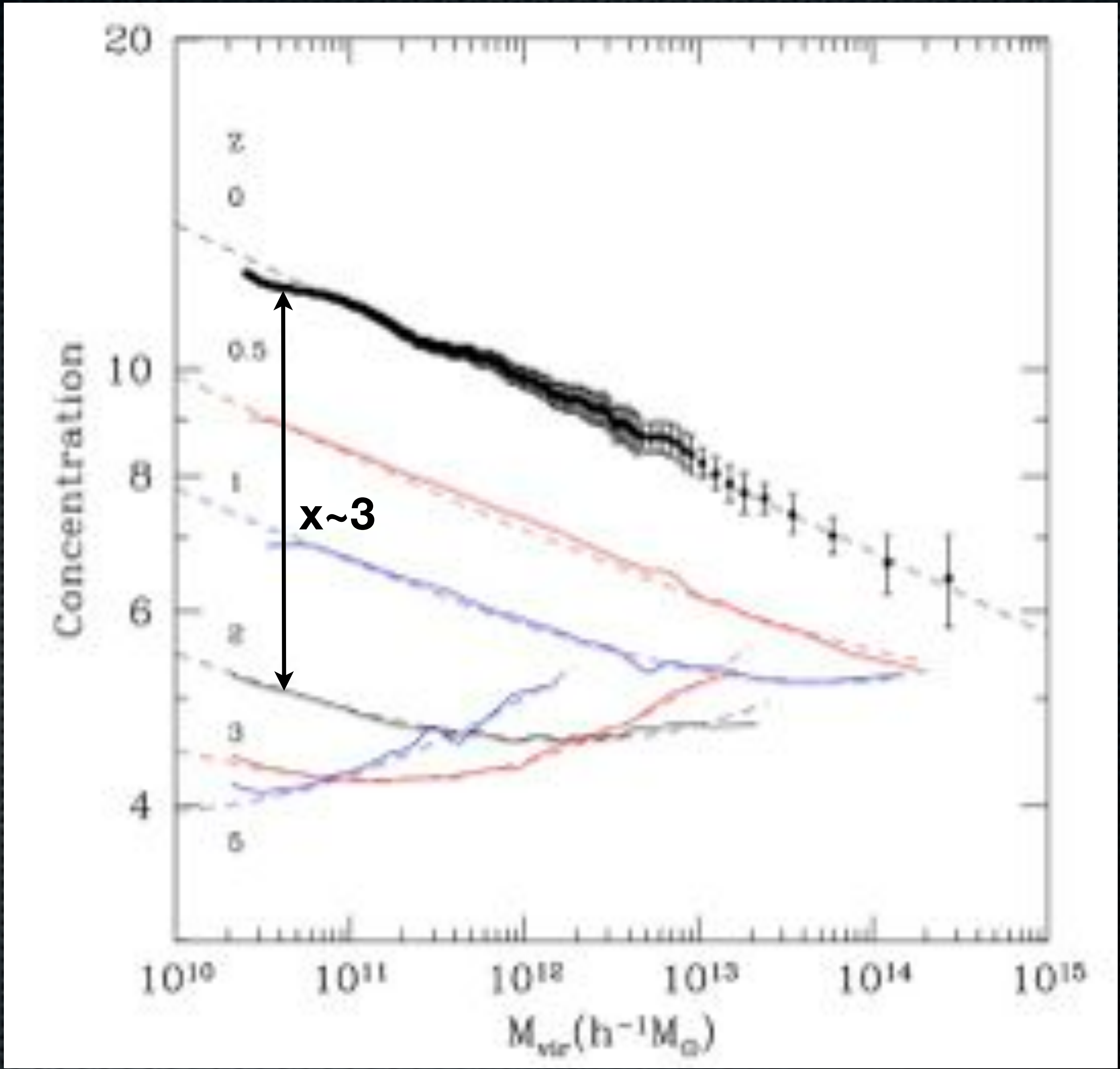
NB filter	λ_c (μm)	FWHM (Å)	z Hα	Volume (Hα) (10^4 Mpc^3 deg^{-2})
NB921	0.9196	132	0.401±0.010	5.13
NB_J	1.211	150	0.845±0.015	14.65
NB_H	1.617	211	1.466±0.016	33.96
NB_K	2.121	210	2.231±0.016	38.31
HAWK-I H_2	2.125	300	2.237±0.023	54.70

~16 kpc apertures z=0.4-2.23

Redshift	Limit SFR	Volumes (UDS + COSMOS)
0.401±0.010	0.01	~1x10^5 Mpc^3
0.845±0.015	1.5	~2x10^5 Mpc^3
1.466±0.016	3.0	~8x10^5 Mpc^3
2.231±0.016	3.5	~7x10^5 Mpc^3

z=0.4-2.23

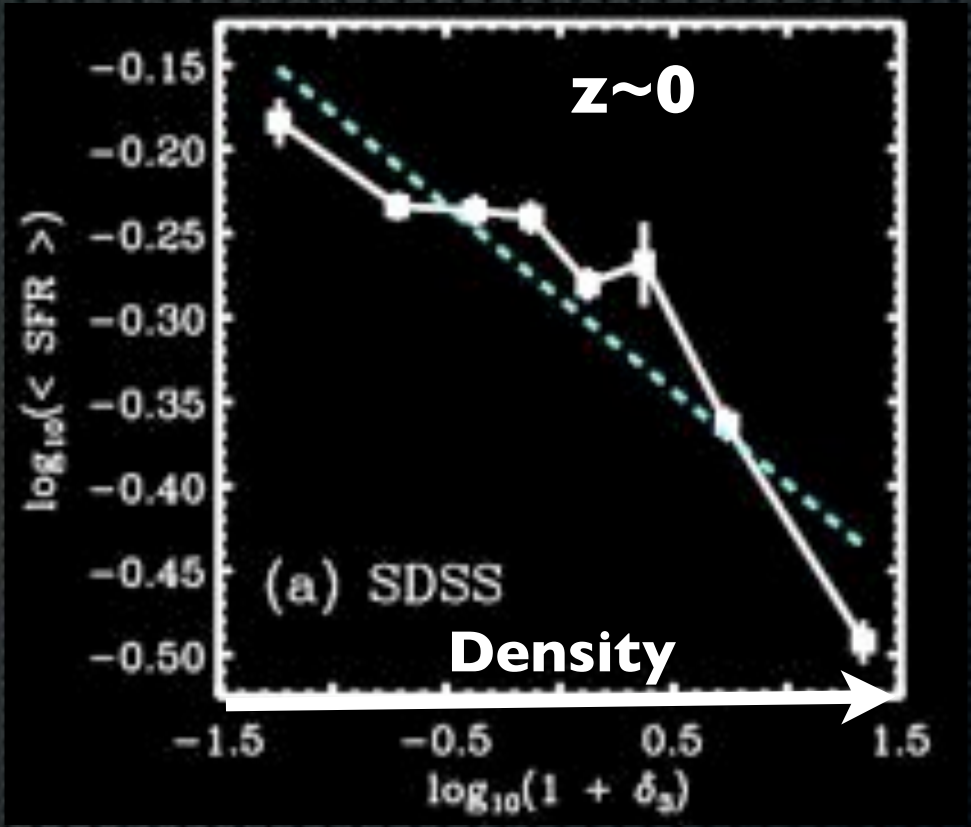
$\Sigma > 3$, $EW_{(Ha+[NII])} > 25$ Å



Klypin, Trujillo-Gomez, & Primack 2011

So is it just “nature”/mass? Or is the environment important as well?

Cooper et al. 2007



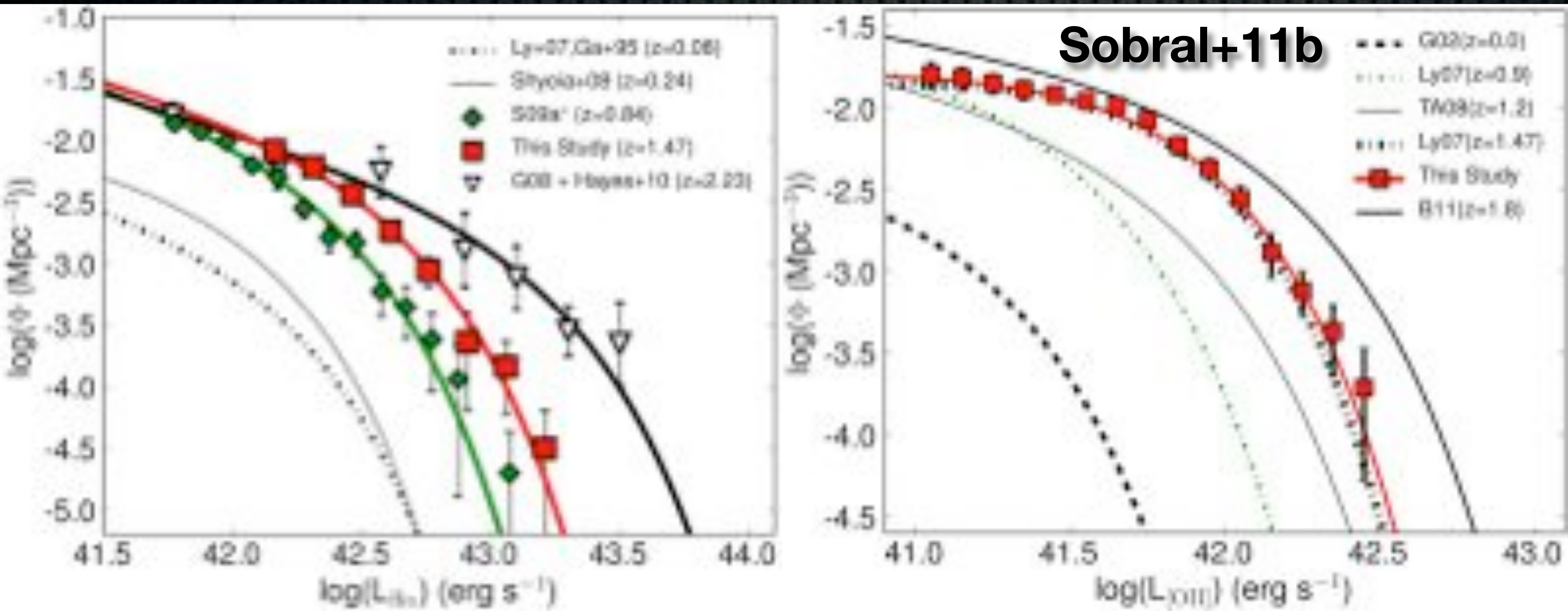
Local Universe: star formation activity declines with increasing environmental density

How important is the local environment?

Does the role change with redshift?

The Hα + [OII] view

- Detailed evolution of the Hα LF: strong L^* evolution to z~2.3



First self-consistent measurement of evolution up to z~2.3

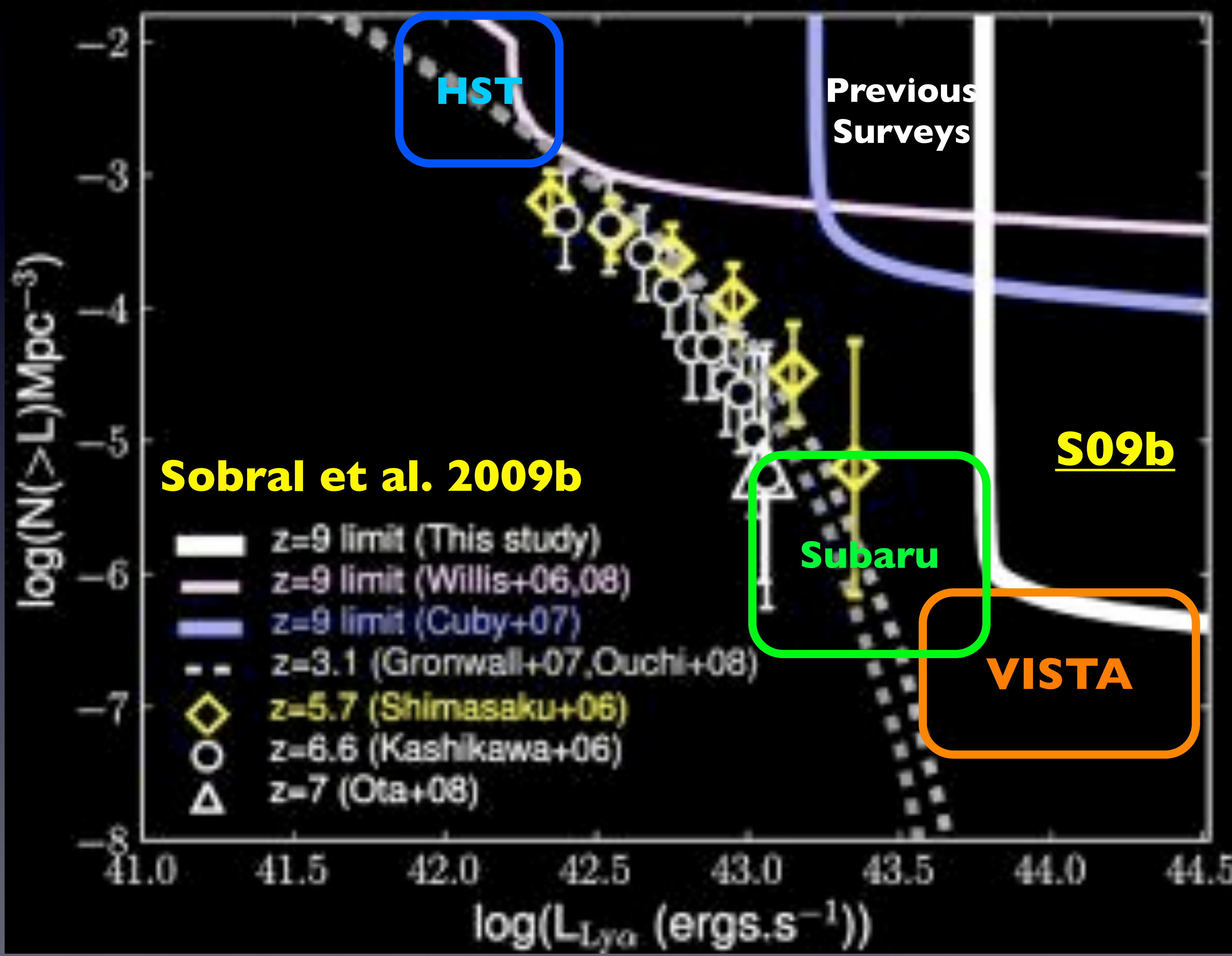
Strong evolution can also be seen using fully consistent measurements of the [OII] luminosity function up to z~1.8

Strategy:

z=6.6: Subaru: NB921 wide survey (already awarded time as PI + proposed to cover total of ~5 sq. deg.)

z=7.1: VISTA (LASER) - deep + “Ultra-wide” (10 sq. deg) Co-I

z=8.8: VISTA “Ultra-wide” ~10 sq proposed as PI + ELVIS UltraVISTA



HST/WFC3
~Ultra-deep

z=6.6
Subaru
NB921
~deep & wide

z~7.1 & z~9
VISTA -
“Ultra-wide”