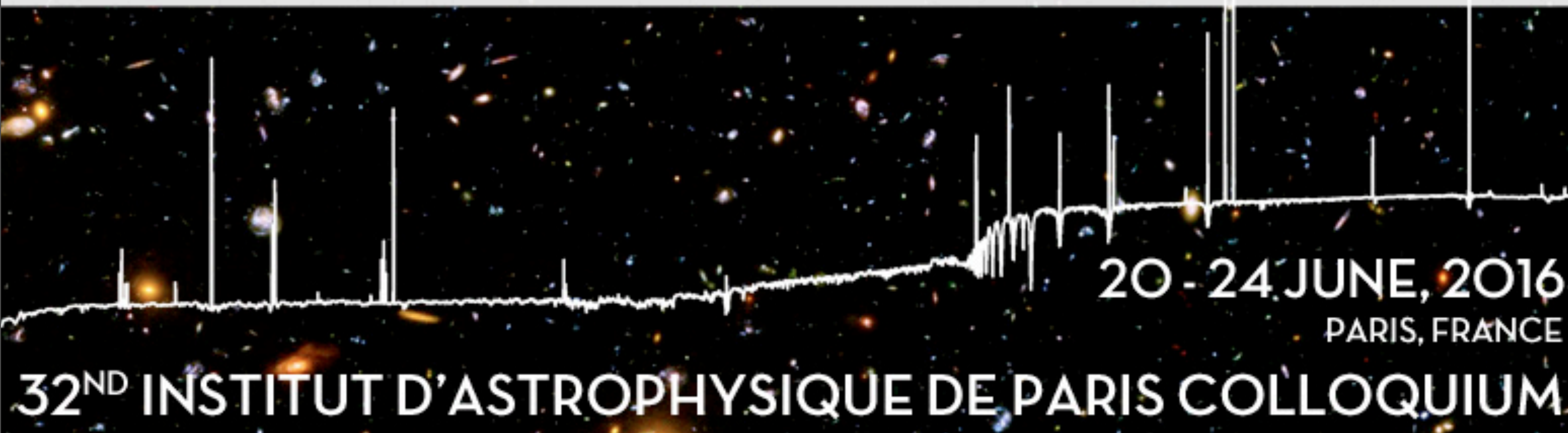
Cosmic dawn of galaxy formation: linking observations and theory with new-generation spectral models



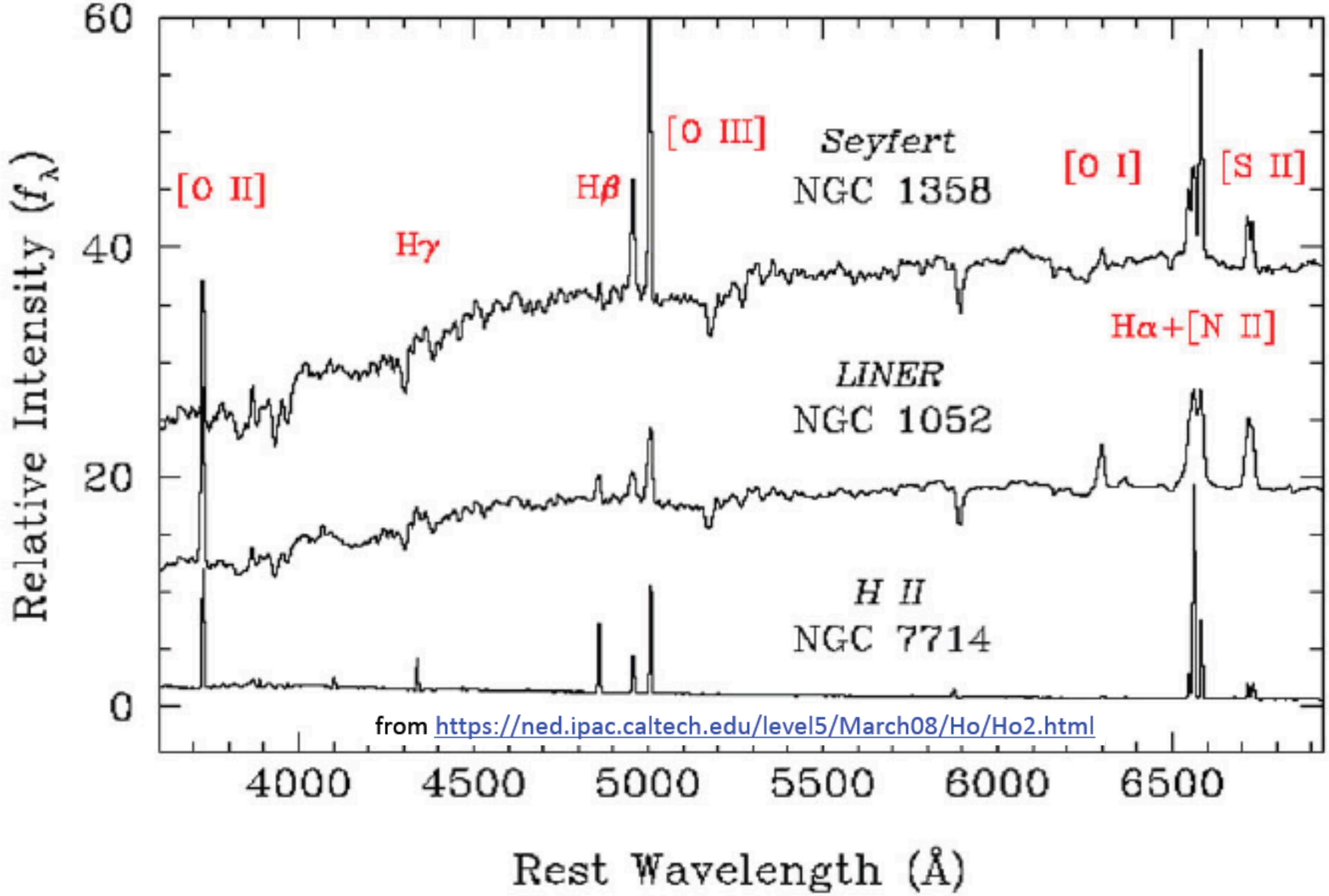
Cosmic evolution of synthetic nebular emission from massive galaxies

Michaela Hirschmann (IAP)

S. Charlot, A. Feltre, J. Gutkin, E. Curtis-Lake & the NEOGAL team

R. Somerville, J. Ostriker, T. Naab, E. Choi

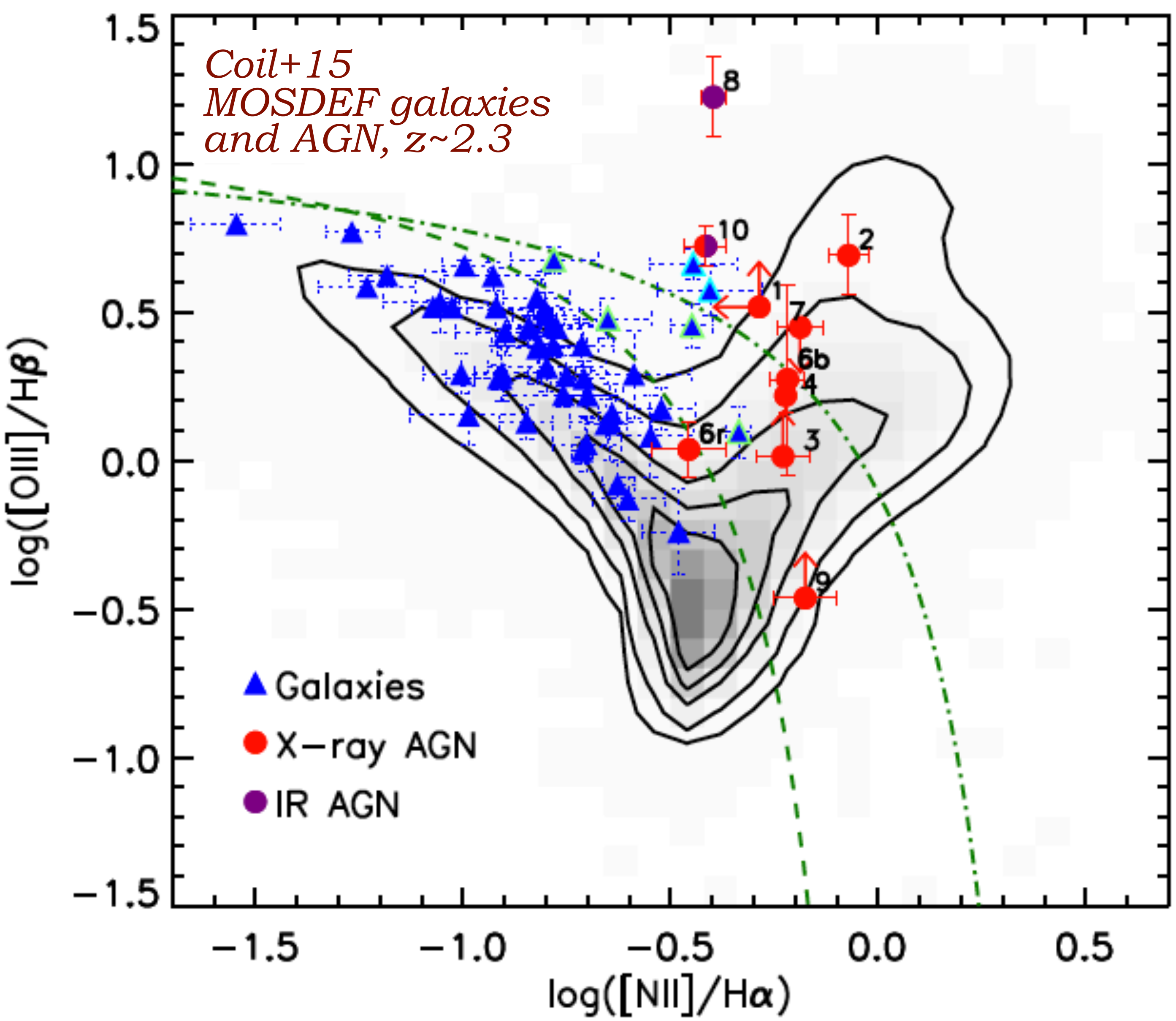
Observed galaxy spectra



- Nebular emission lines contain information on ionizing sources (young stars, AGN & evolved stellar populations = ESP) and on the state and metallicity of the ISM
- Optical line ratios used to distinguish between different types of (local) galaxies ("BPT" diagrams)

Observational challenges

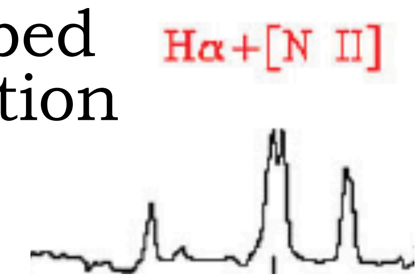
- Which present-day galaxies are selected using commonly used optical emission line diagnostics?
- Is there a redshift evolution of emission line ratios, e.g. [OIII]/Hβ, if yes, physical origin?
- Can we still use optical diagnostic tools as for the local Universe to distinguish between different ionizing sources?



Tool:

Generation of synthetic nebular emission spectra

Newly developed spectral evolution models



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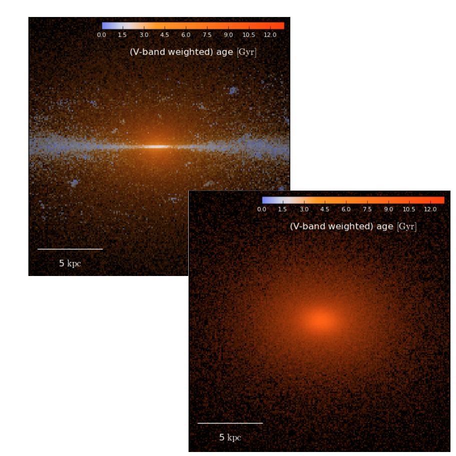
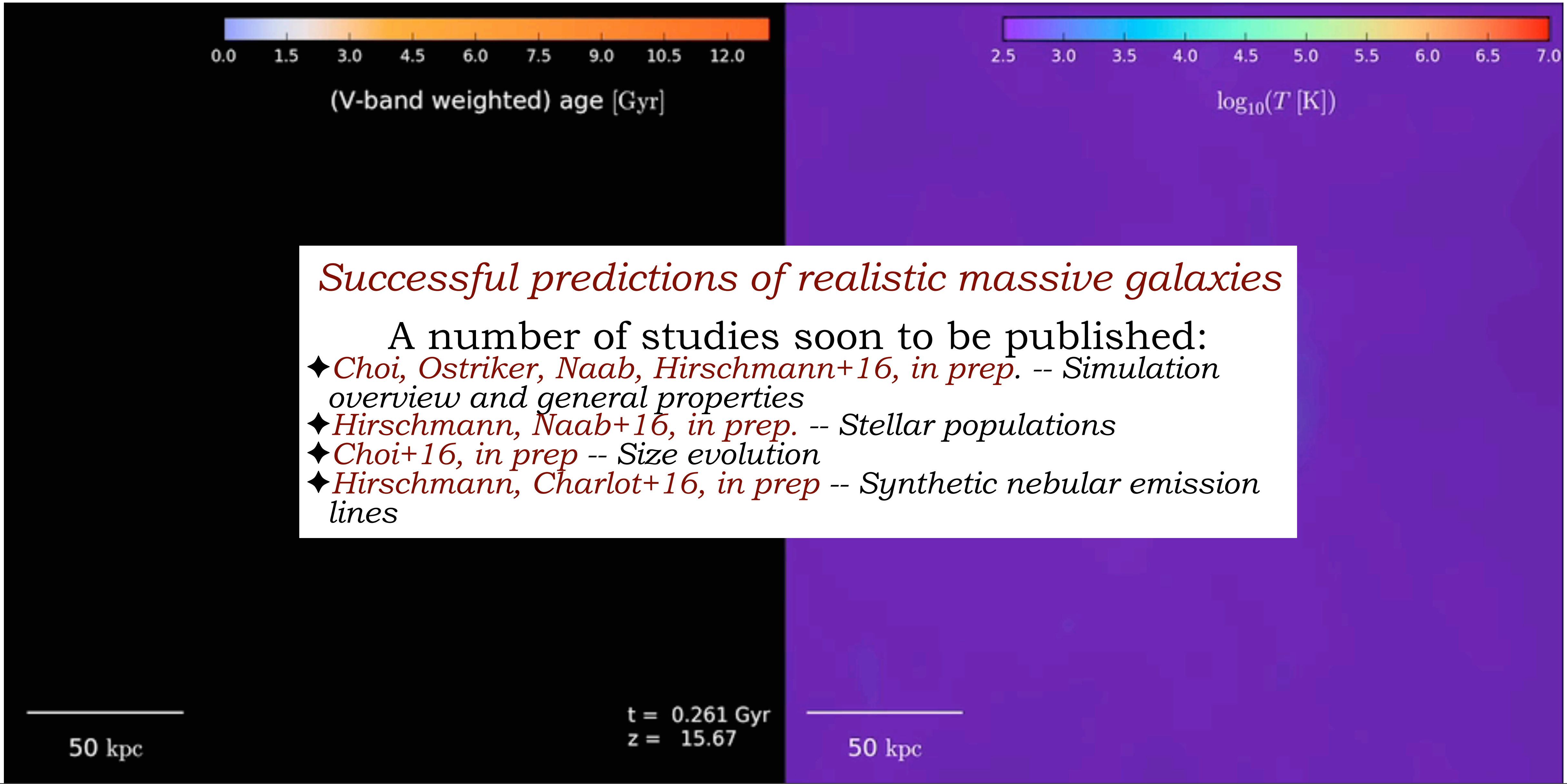
Cosmological hydrodynamic simulations



Cosmological zoom-in simulations

Set of 20 cosmological zoom-in simulations of massive galaxies
(5e12 $M_\odot$ < M_{halo} < 5e13 $M_\odot$, $x_{spatial}$ = 200pc, m_{gas}=1.4e5 $M_\odot$)

- *"Modern" SPH-code* Gadget-3 *(Hu+14)*
- Detailed *chemical enrichment* *(Aumer+13)*
- Gas and metal-line *cooling* down to 100 K *(Aumer+13)*
- *Star formation* *(Hu+14)*
- *Stellar feedback* *(Nunez+16, in prep.)*, energy & momentum from SNII&Ia & early fb
- BH growth & mass, momentum & energy conserving *AGN feedback* *(Ostriker+10)*



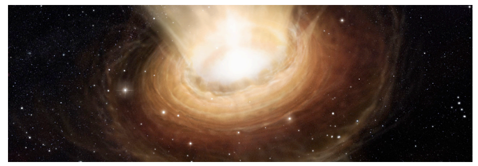
Successful predictions of realistic massive galaxies

A number of studies soon to be published:

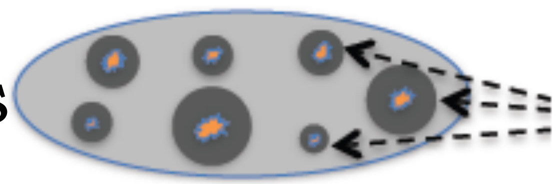
- ✦*Choi, Ostriker, Naab, Hirschmann+16, in prep.* -- *Simulation overview and general properties*
- ✦*Hirschmann, Naab+16, in prep.* -- *Stellar populations*
- ✦*Choi+16, in prep* -- *Size evolution*
- ✦*Hirschmann, Charlot+16, in prep* -- *Synthetic nebular emission lines*

Nebular emission models

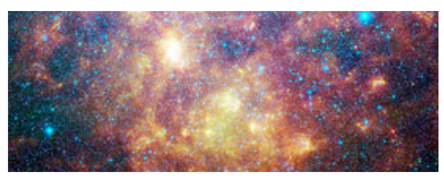
Ionizing source + **Cloudy** Ferland+13

AGN


AGN luminosity $F_\nu \propto \nu^\alpha$
See A. Feltre's talk

SF regions


CB16 (GALAXEV) new stellar evolutionary tracks & atmospheres, also for massive stars
See J. Gutkin's poster

Post-AGB stars
"ESP"


Old SSP from GALAXEV
See G. Bruzual's talk

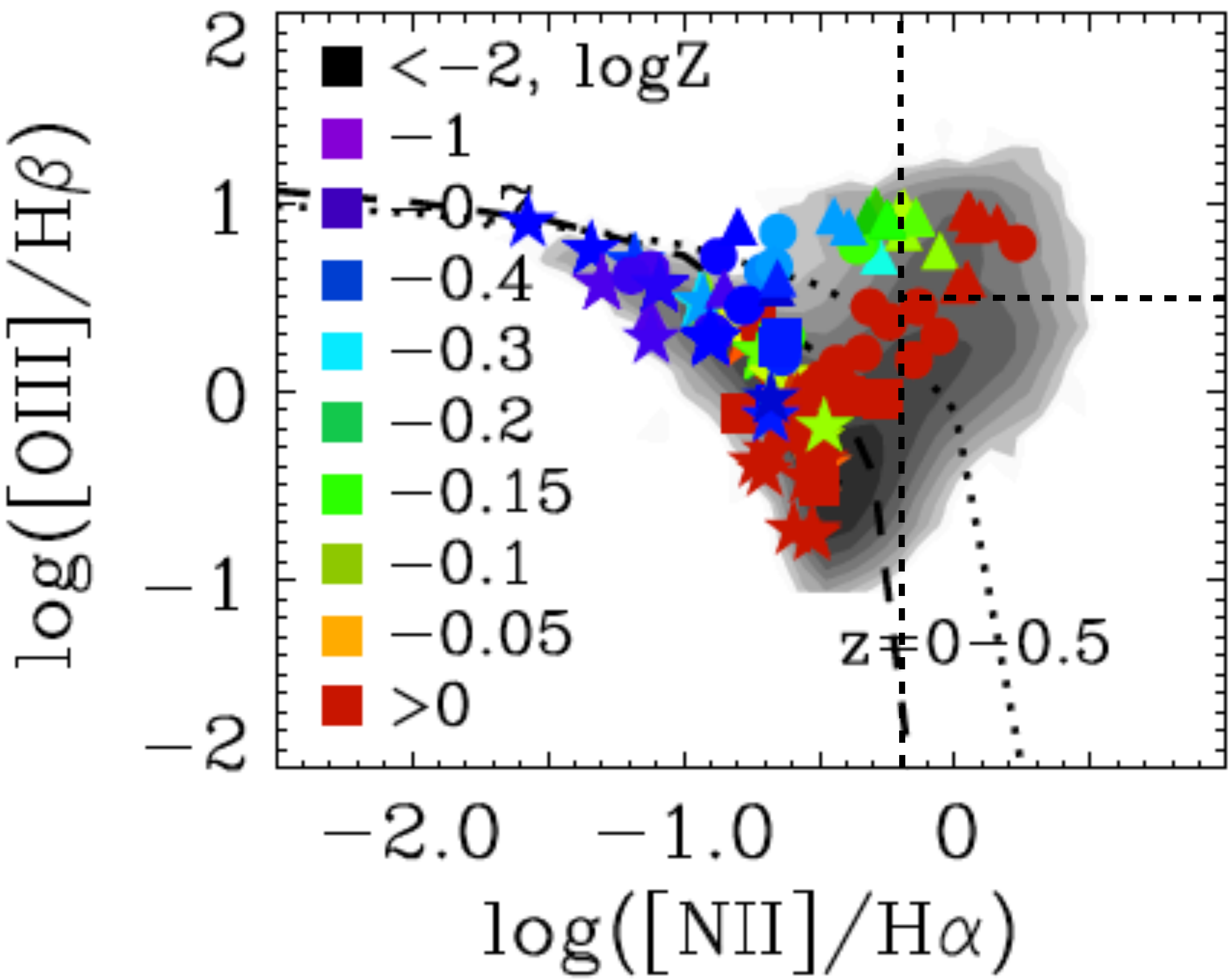
Adjustable parameter	*AGN models* *Feltre+16*	*SF models* *Gutkin+16*	*ESP models*
Ionizing spectrum	UV slope ***-1.4***, -1.7	const. SFR, 10^8 yr	SSP 3, 5, 7, 9 Gyrs
Dust-to-metal ratio	0.1, ***0.3***, 0.5	0.1, ***0.3***, 0.5	0.1, ***0.3***, 0.5
log(ρ_{HII}) [N_H/cm^3]	2.0, ***3.0***, 4.0	***2.0***, 3.0, 4.0	***1.0***, 2.0, 3.0
Ionization parameter (<ρ_H>, SFR, L_{AGN}, $M_{stellar}$)	-1.0 - -4.0	-1.0 - -4.0	-2.5 - -5.0
Gas metallicity	0.0001 - 0.07	0.0001 - 0.03	0.0001 - 0.07
[C/O] abundance	solar	subsolar-solar	solar
Normalized to	L_{AGN}	SFR	$M_{stellar, old}$

Synthetic BPT diagrams

... for massive galaxies (~1e11) at low redshifts

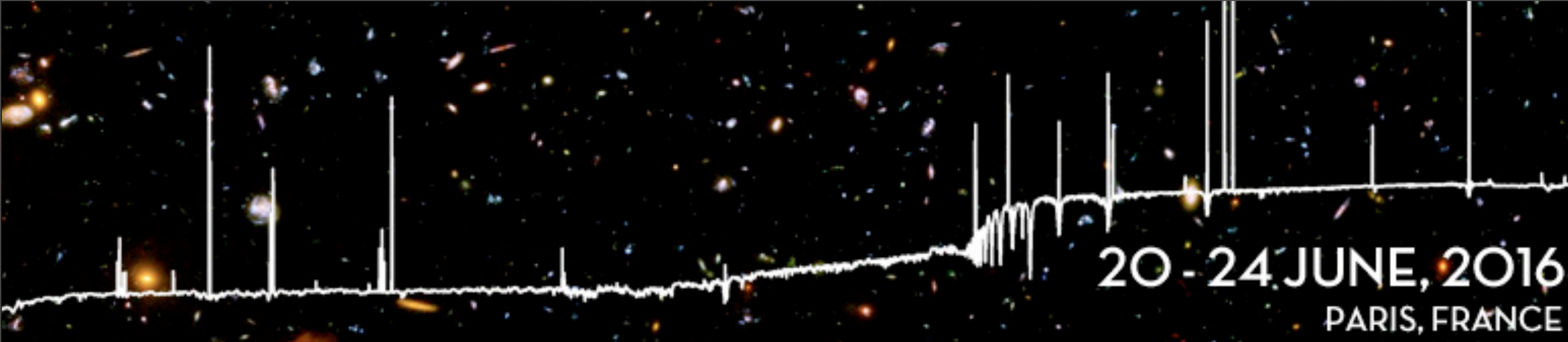
- Observational flux limits applied
- Theoretical distinction into different galaxy types according to BHAC/SFR ratio

▲ AGN
■ LINERs
★ SF gals
● Compos.



Hirschmann+16, in prep.

Successful in reproducing the observed SDSS results



I. Which galaxies are selected using traditional optical emission line criteria at z=0?

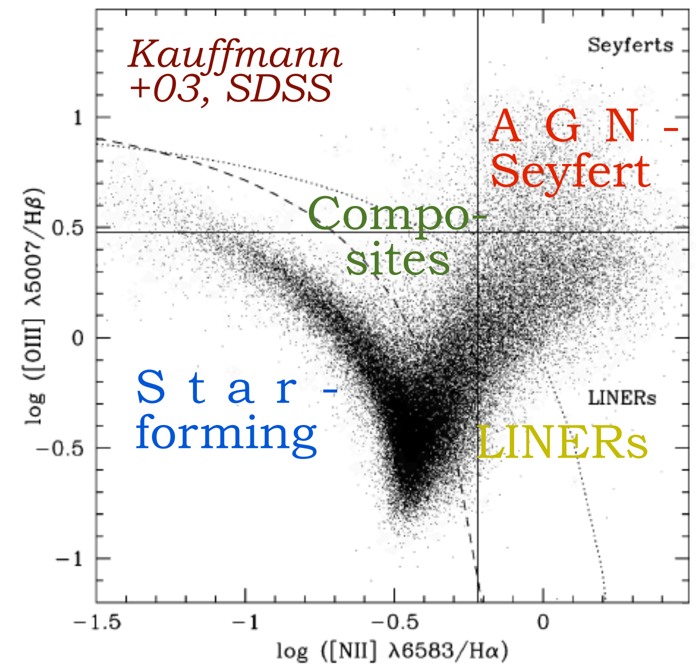
Optical selection in BPT diagram

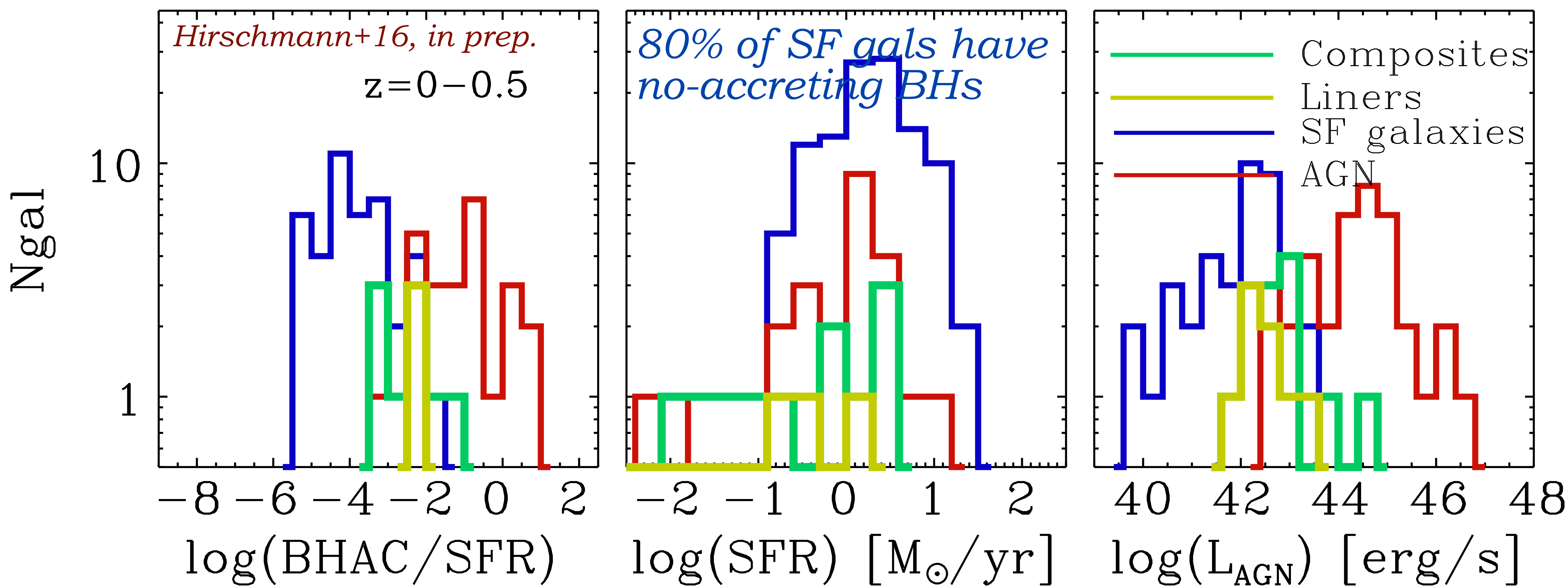
Observational selection into different galaxy types

$$\log([OIII]/H\beta)_{Kewley} = 0.61 / (\log([NII]/H\alpha) - 0.47) + 1.19$$
$$\log([OIII]/H\beta)_{Kauffmann} = 0.61 / (\log([NII]/H\alpha) - 0.05) + 1.3$$

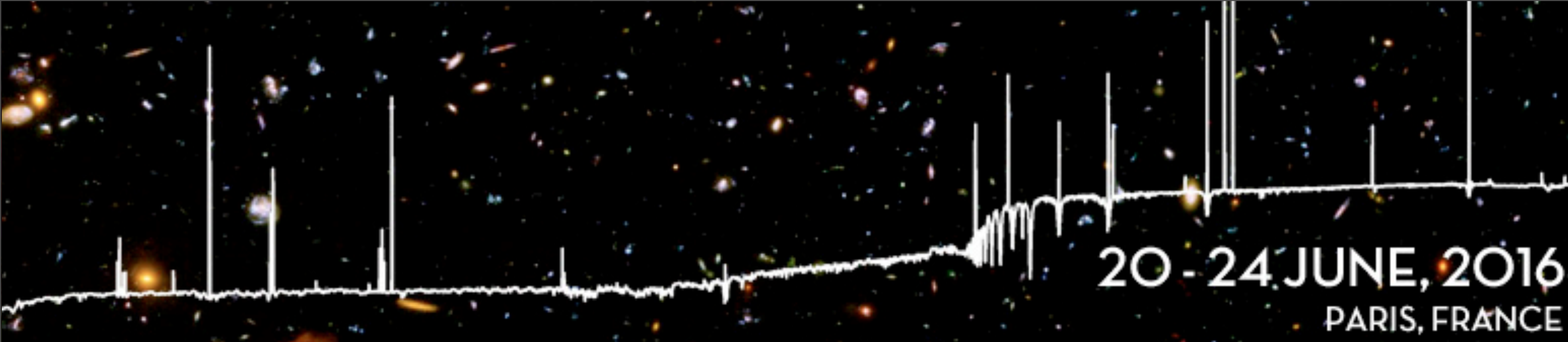
AGN/Seyfert: $[OIII]/H\beta > 3$ and $[N II]/H\alpha > 0.6$,
LINERs: $[OIII]/H\beta < 3$ and $[N II]/H\alpha > 0.6$

Kauffmann+03



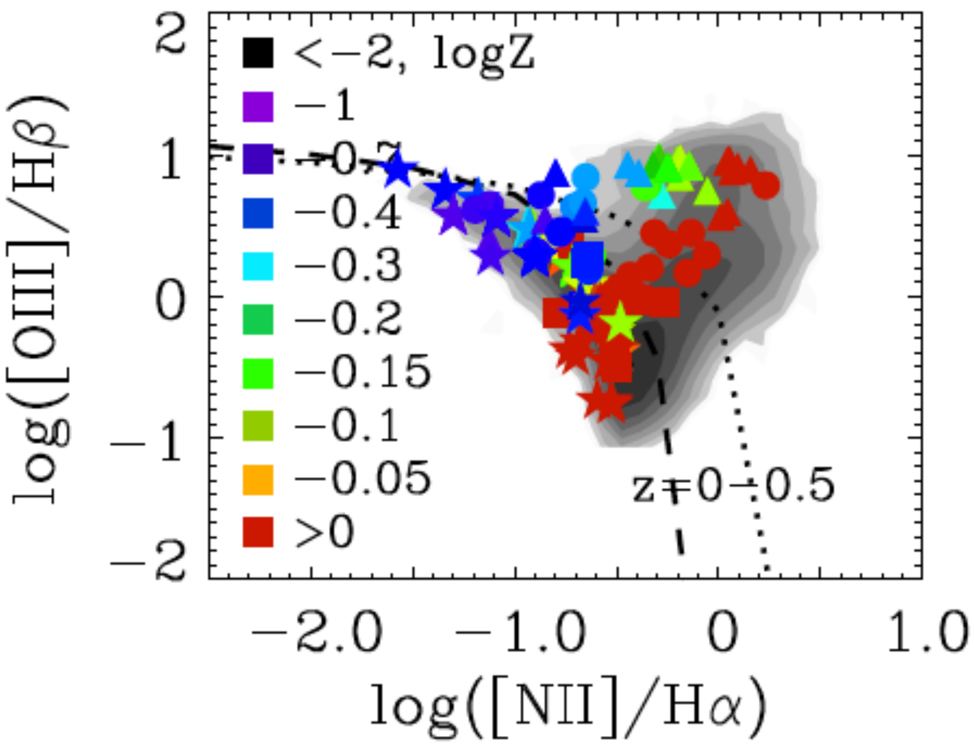


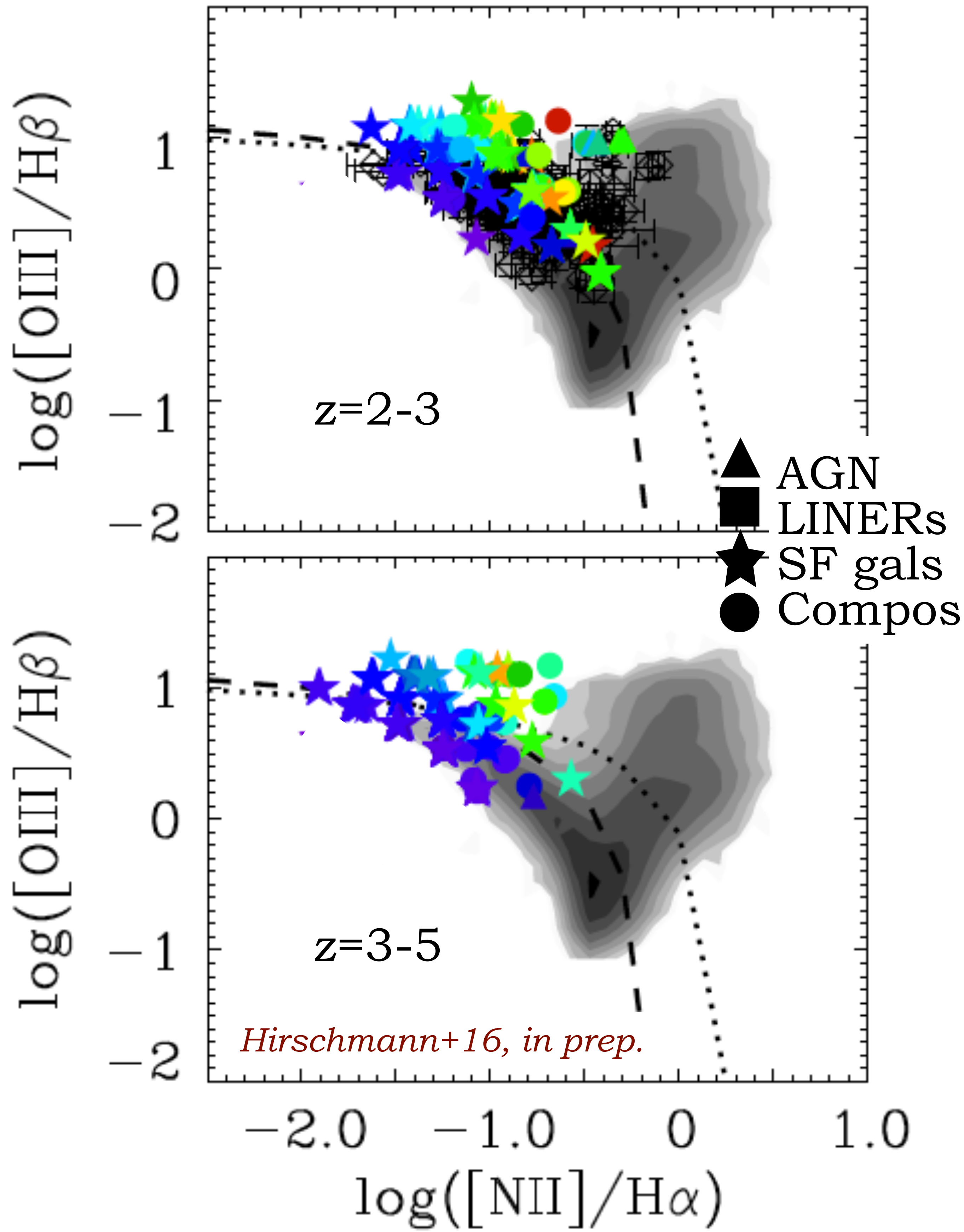
Observational selection is reasonable according to simulation predictions



II. What is the origin of the debated, observed evolution of optical emission line ratios?

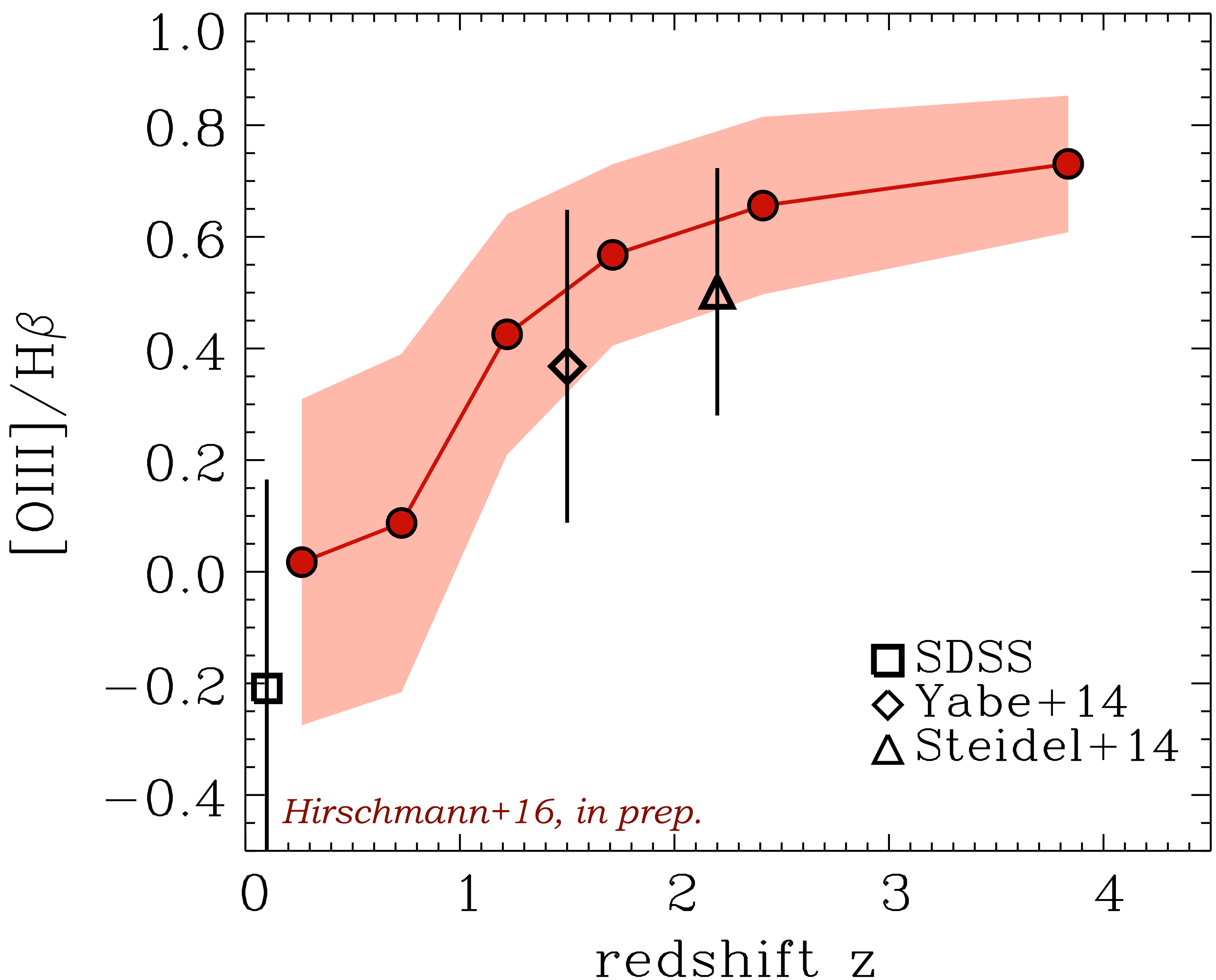
Evolution of emission line ratios





- Evolving emission line ratios, increasing [OIII]/Hβ at given [NII]/Hα
- Metal-poor galaxies (less than 50% solar) at high z
- Typical observational flux limits applied
- Observations find similar trends for metal-poor low-mass galaxies at z=0,
  see Erb+16

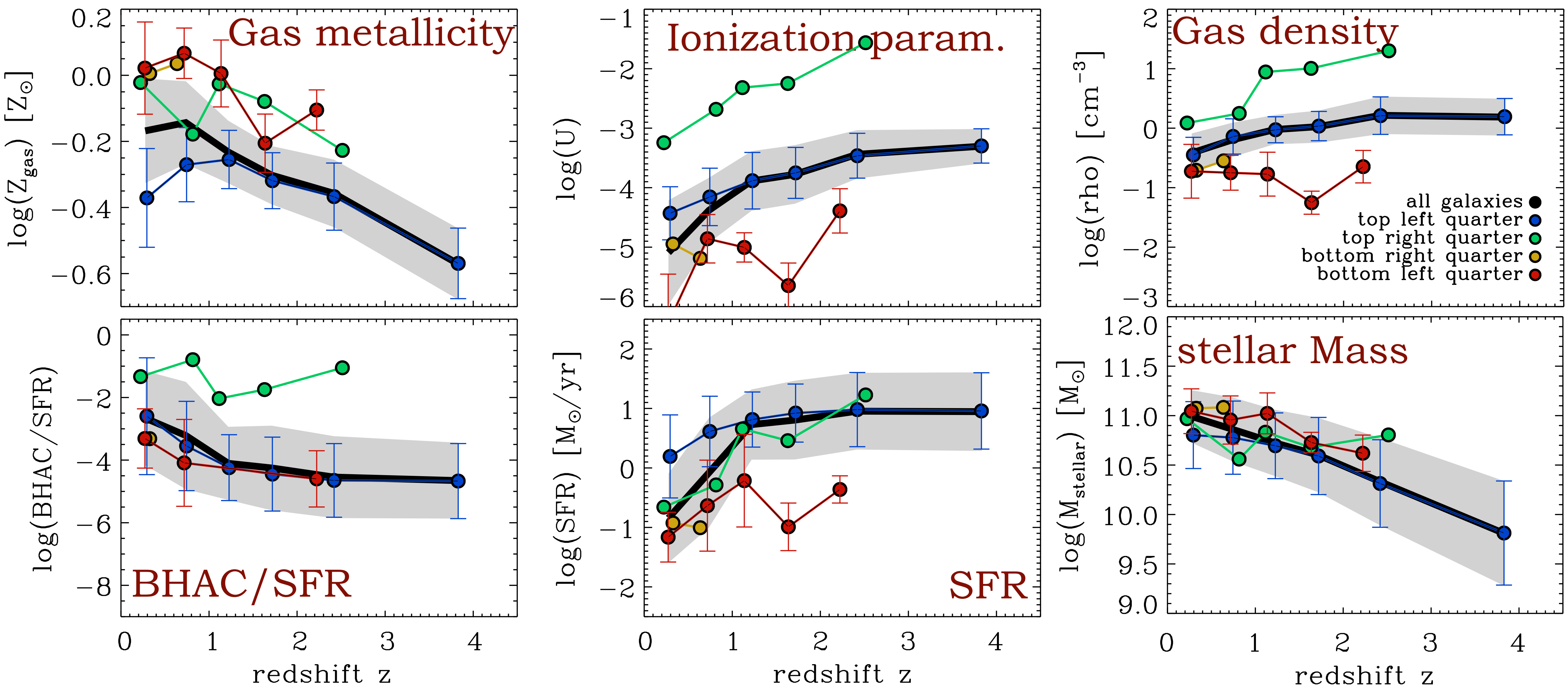
Evolution of emission line ratios



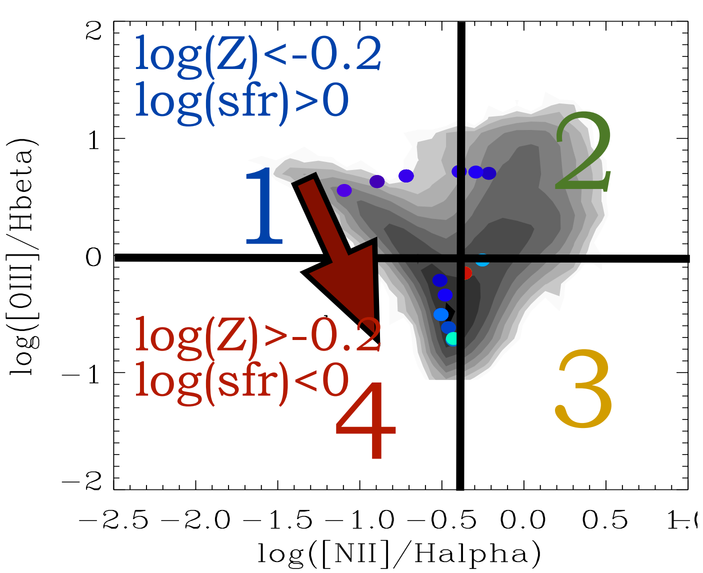
- Simulation predictions consistent with observed trend
- Optical selection effects cannot account for *z* evolution in our set of massive galaxies and their progenitors
- Reason for increasing [OIII]/Hβ is increasing towards higher *z*?

Origin of evolving O[III]/Hβ-ratio

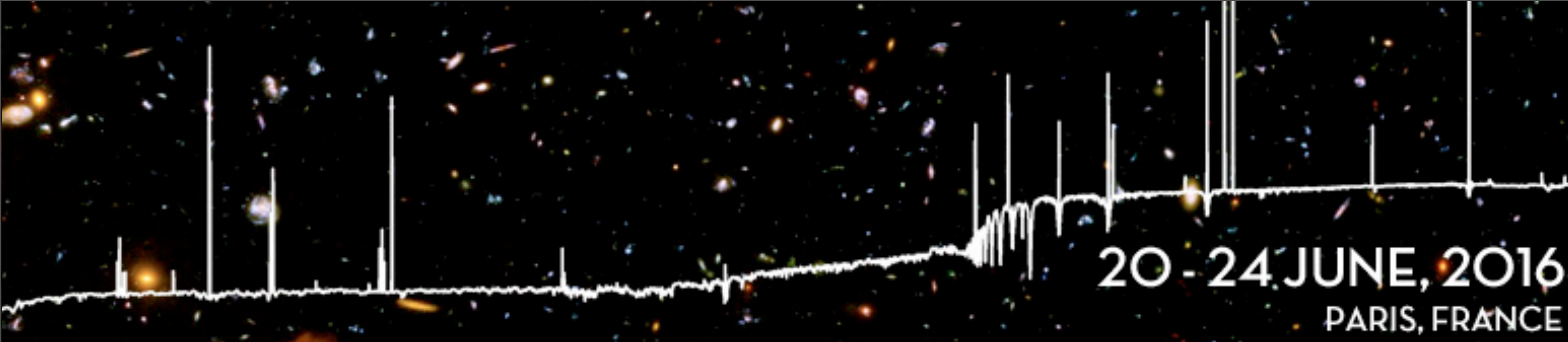
Redshift evolution of average ...:



Hirschmann+16, in prep.



- O[III]/Hβ-evolution mainly driven *by lower gas metallicity and higher SFR* in progenitor galaxies at high redshifts *(see also Cullen+16)*
- No conclusion on evolution at a given stellar mass for global galaxy populations



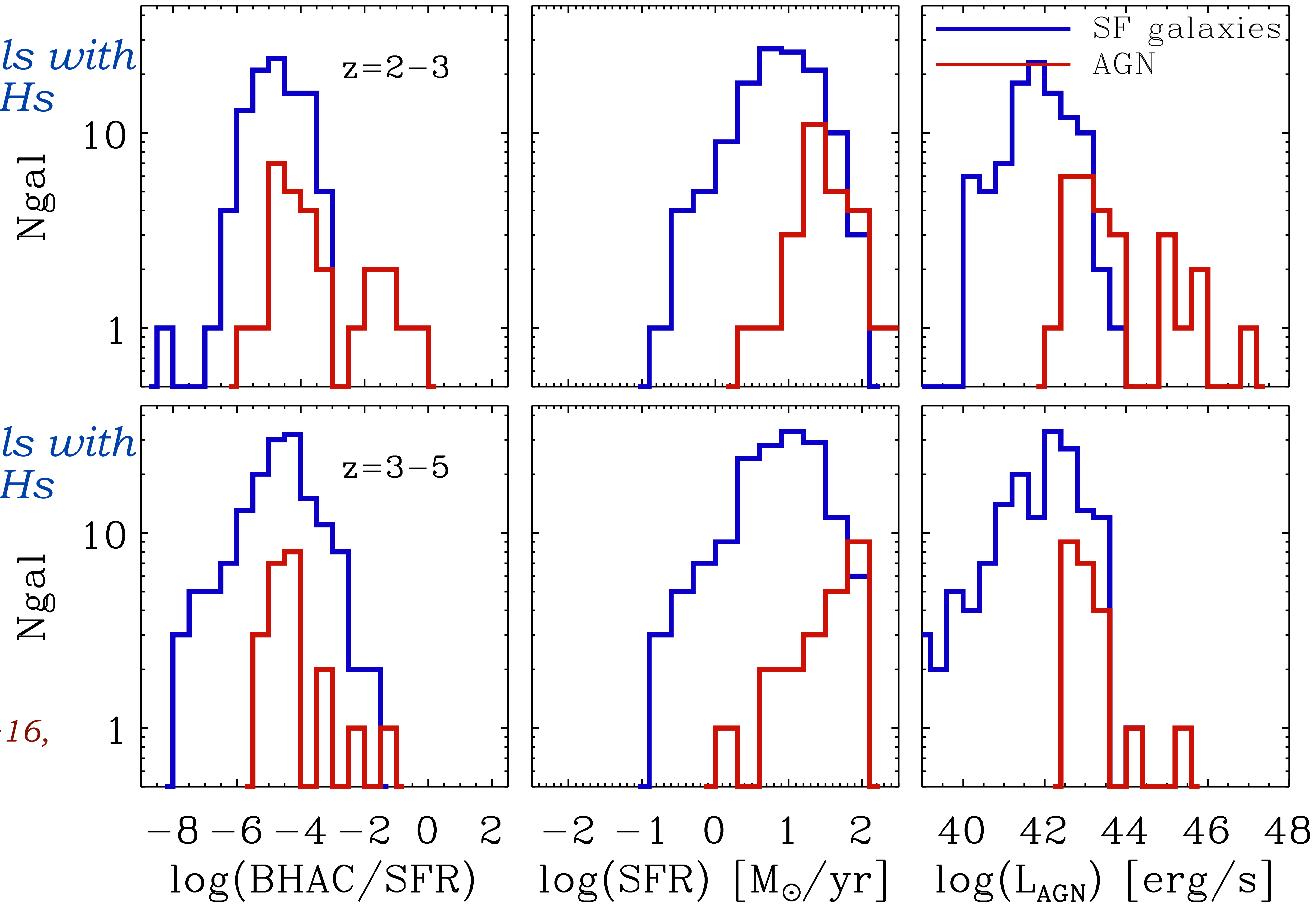
III. How to distinguish between different galaxy types at high redshifts?

Optical selection in BPTs at high z

Optical selection into different galaxy types applied at high redshifts…

~30% of SF gals with no-accreting BHs

~10% of SF gals with no-accreting BHs

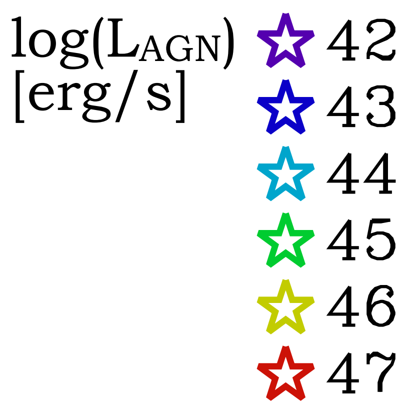


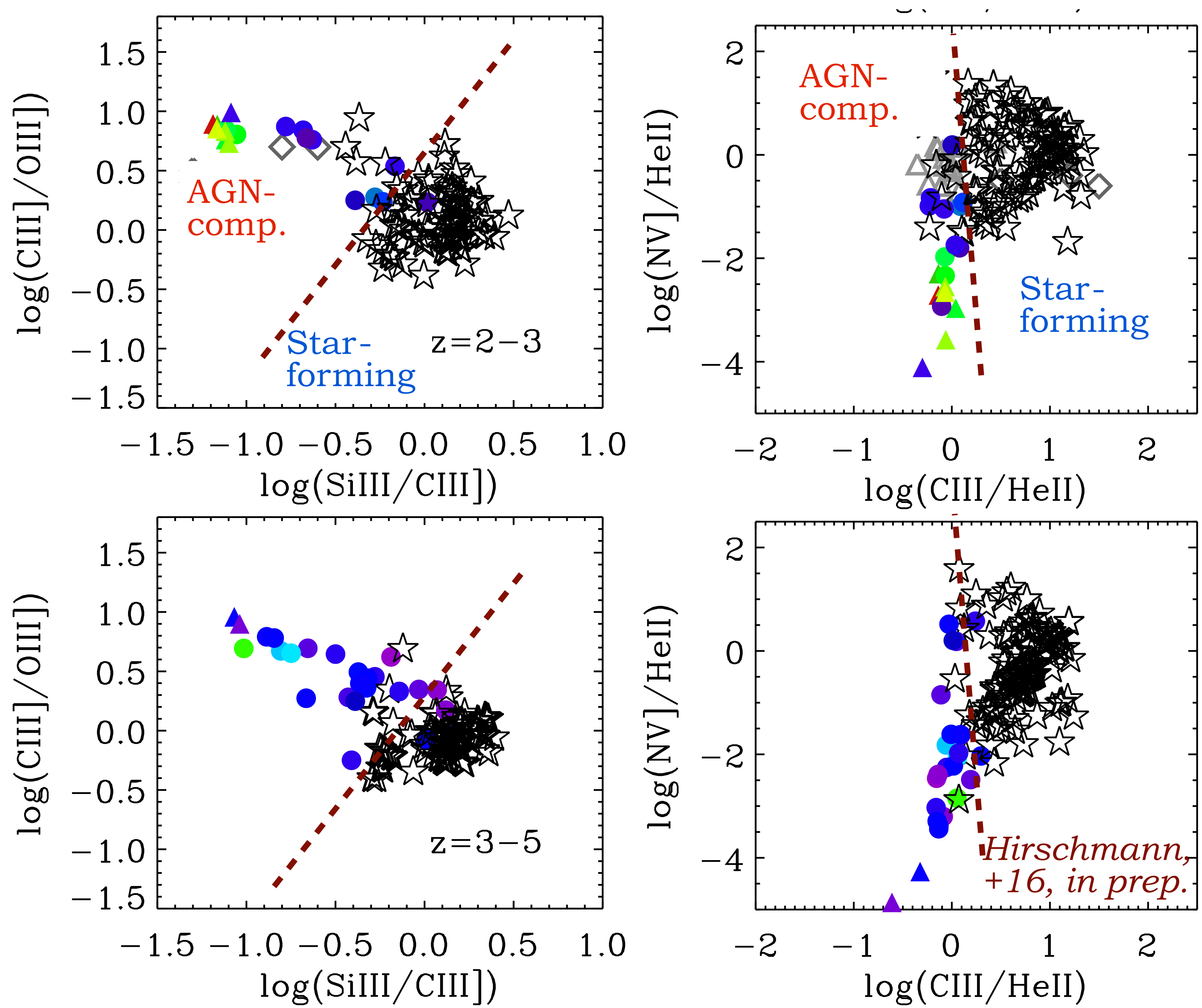
Hirschmann+16, in prep.

- Some galaxies misclassified as AGN, most SF galaxies contain a faint AGN
- Metal-poor (<50% solar) SF galaxies & AGN hard to distinguish, *Feltre+16*

--> *Optical selection less suited for metal-poor galaxies (mostly at high z)*

UV emission lines at high z





We will provide selection criteria based on simulations!!

- UV diagnostics seem to be well suited to distinguish between SF, composite and AGN galaxies out to high z
- *Important for future large samples of high-quality high-z data from JWST (NIRSpec)*

Summary

Analysis of SYNTHETIC NEBULAR EMISSION based on self-consistently coupled nebular emission lines models and cosmological zoom-in simulations of massive galaxies

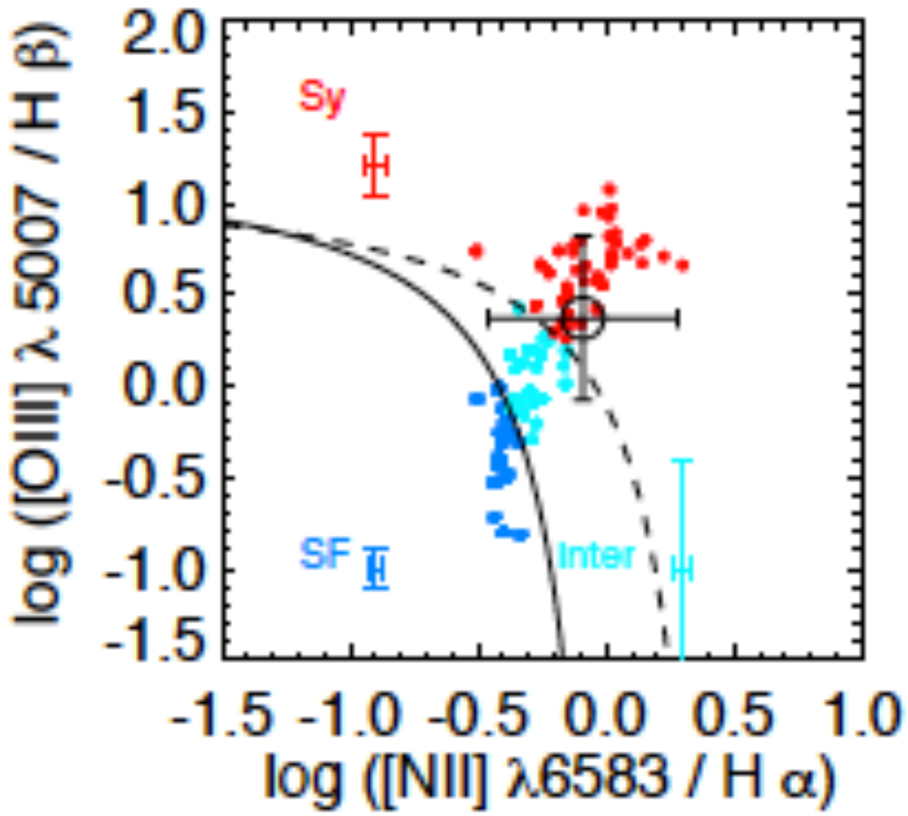
- Good agreement of synthetic nebular emission line ratios with low-z SDSS data (BPT diagrams)
- Success of observational, optical selection criteria in distinguishing between SF, composite and AGN galaxies
- Cosmic evolution of synthetic OIII/Hβ ratio mainly due to evolving gas metallicity and SFRs
- UV emission line ratios as a powerful tool to distinguish between different galaxy types at high redshifts, where optical emission line ratios break down

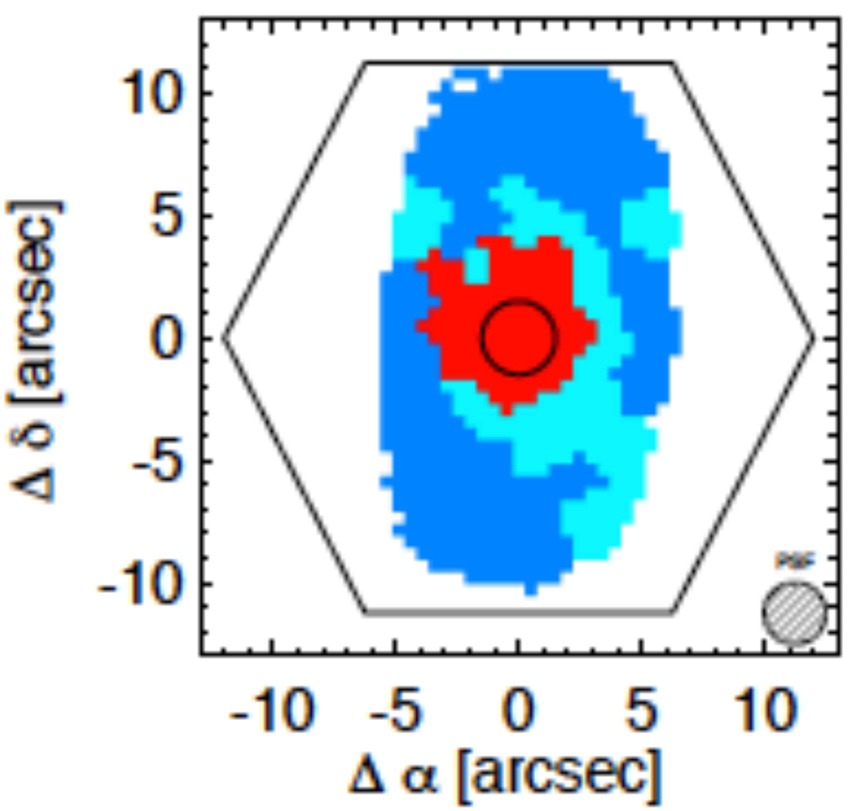
- *Need to increase the sample of zooms*
- *Investigate nebular emission of gobal galaxy populations, SAMs and large-scale cosmological simulations (in progress)*

Outlook: Resolved nebular emission

Produce synthetic *spatially resolved nebular emission* (from AGN, young and old stars) based on a *statistically complete sample of cosmological zoom-in sims* of massive galaxies

- Theoretical background for interpreting results from current and up-coming IFU surveys like Manga, Sami, Muse
- Further constraints for still uncertain sub-resolution models, e.g. feedback, in cosmological simulations





Spatially resolved nebular emission from Manga