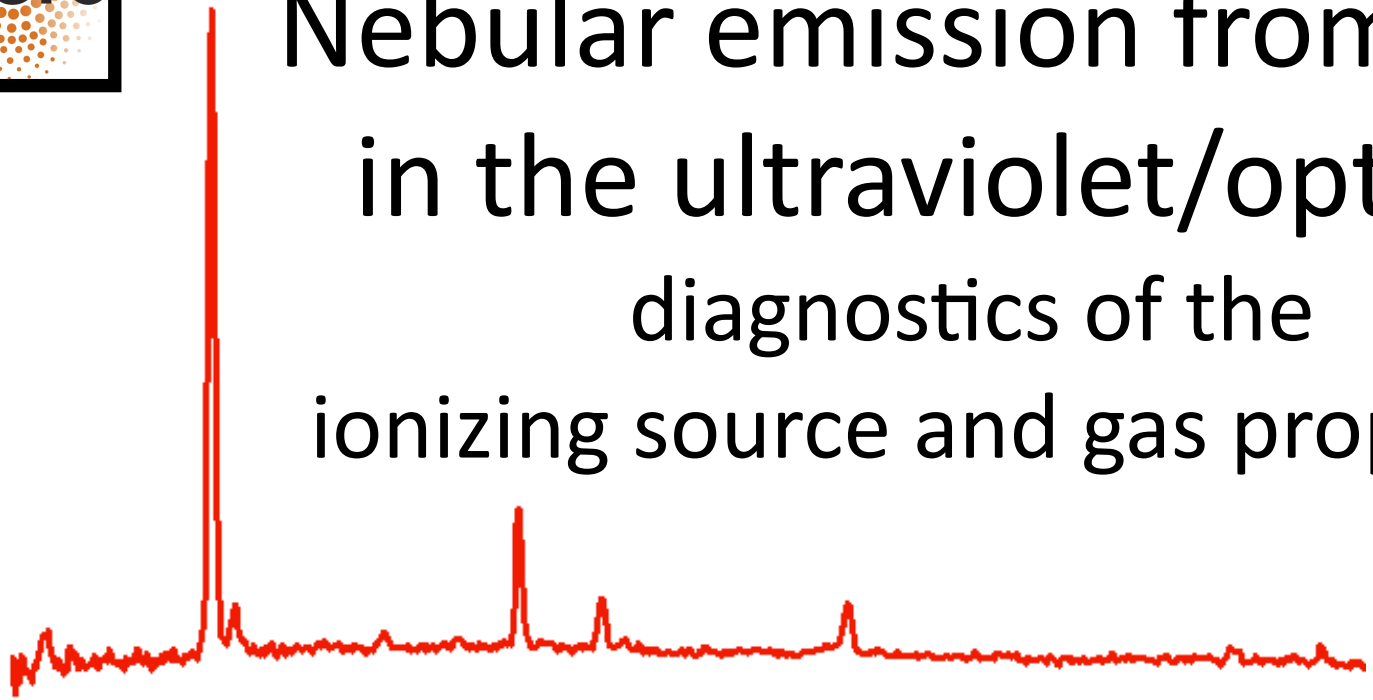
Nebular emission from AGN in the ultraviolet/optical:

diagnostics of the ionizing source and gas properties



A. Feltre

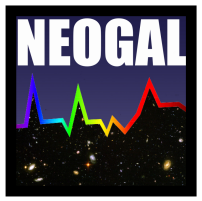
S. Charlot, J. Gutkin, M. Hirschmann (IAP) & NEOGAL team

M. Mignoli, F. Calura, R. Gilli, G. Zamorani (INAF-BO)

Spectral models

linking theory and observations

- diagnostics of the **nature ionizing source:** star formation vs AGN vs shocks
  (e.g. Villar-Martin+97; Allen+98, Groves+04a,b; Kewley+01,06,13a,b; Feltre+16 and many others)
- study the **physical properties of the ionized gas:** e.g. metallicity, density
- implemented in a **SED fitting tools** to retrieve the physical parameters of the ionized gas **(e.g. Pacifici+12, Chevallard+16)**
- combined with **cosmological simulations**



Spectral models

linking theory and observations

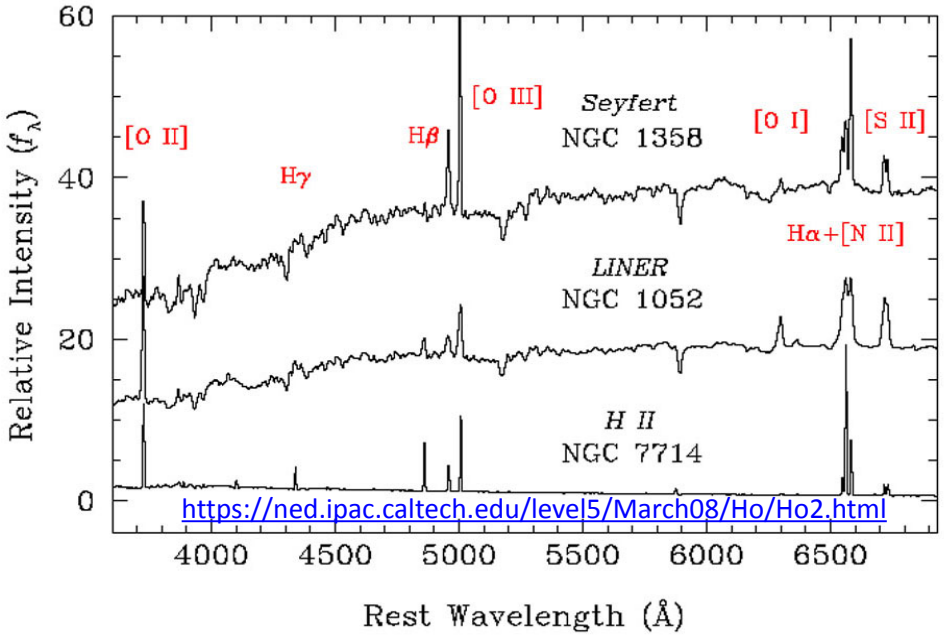
- diagnostics of the **nature ionizing source:** star formation vs AGN vs shocks
  (e.g. Villar-Martin+97; Allen+98, Groves+04a,b; Kewley+01,06,13a,b; Feltre+16 and many others)
  ➡ UV emission-line ratios as diagnostics (stellar vs nuclear) for high z

- study the **physical properties of the ionized gas:** e.g. metallicity, density
  ➡ rest UV spectra of ~90 obscured AGN

- implemented in a **SED fitting tools** to retrieve the physical parameters of the ionized gas **(e.g. Pacifici+12, Chevallard+16)**
  ➡ Bayesian fitting code BEAGLE **(Chevallard+16)**

- combined with **cosmological simulations**
  ➡ understand feedback processes and interpret selection criteria of local and high redshift galaxies **(Hirschmann, Charlot, Feltre +16, in prep.)**

Optical/UV nebular emission



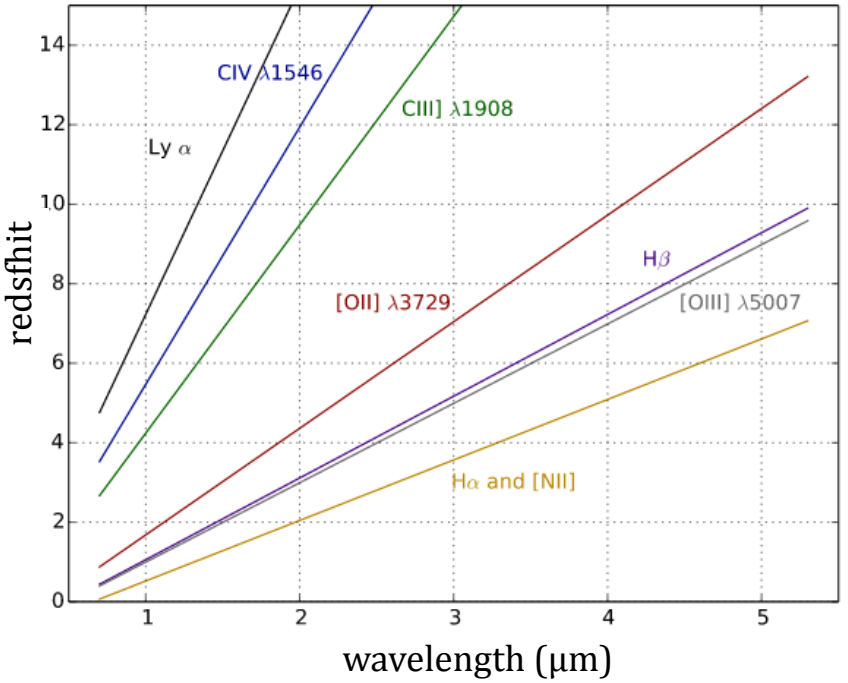
current (e.g. VLT-KMOS/MUSE, Keck-MOSFIRE) and future (e.g. JWST, E-ELT) NIR spectroscopy —> UV rest spectra of primeval galaxies $z \gtrsim 7$

photoionization models to interpret the rest-frame optical/UV spectra of both active and inactive galaxy at all cosmic epochs

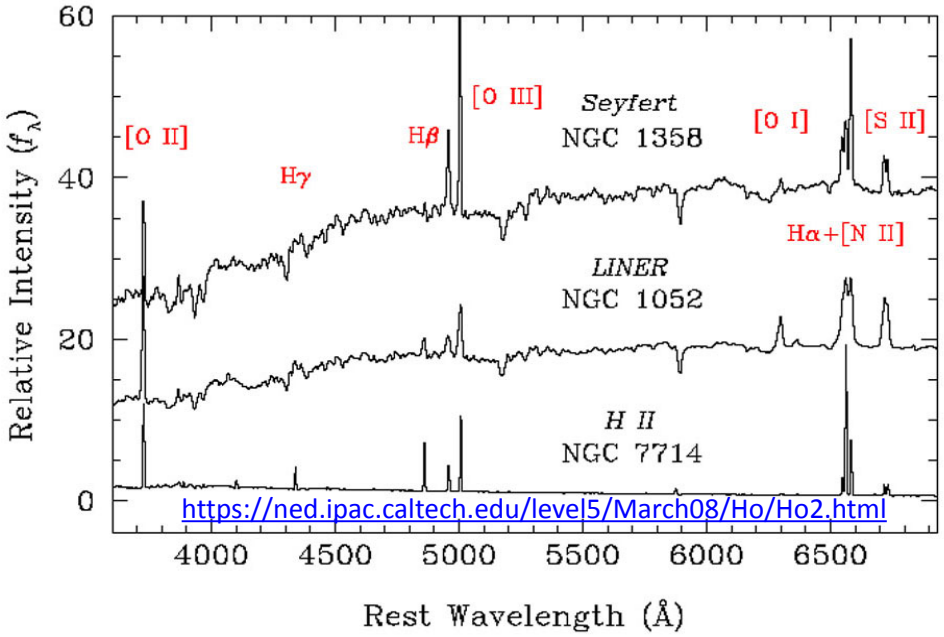
standard optical diagnostic diagrams: nuclear vs stellar activity

(e.g. Baldwin, Phillips & Terlevich 81 BPT; Veilleux & Osterbrock 87)

Availability of some emission-lines in the JWST NIR range vs redshift



Optical/UV nebular emission



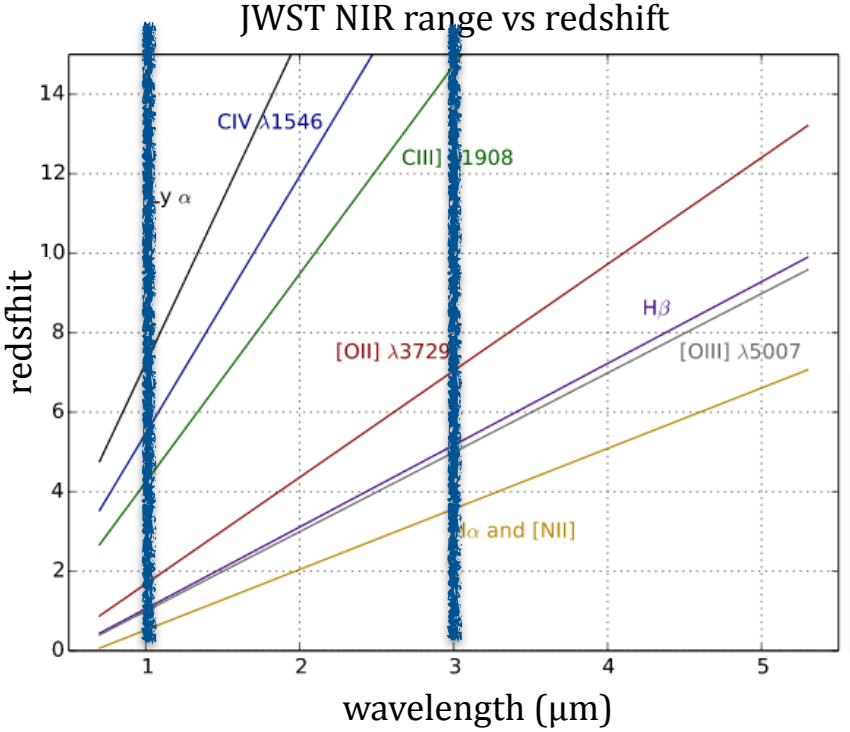
current (e.g. VLT-KMOS/MUSE, Keck-MOSFIRE) and future (e.g. JWST, E-ELT) NIR spectroscopy —> UV rest spectra of primeval galaxies $z \gtrsim 7$

photoionization models to interpret the rest-frame optical/UV spectra of both active and inactive galaxy at all cosmic epochs

standard optical diagnostic diagrams: nuclear vs stellar activity

(e.g. Baldwin, Phillips & Terlevich 81 BPT; Veilleux & Osterbrock 87)

Availability of some emission-lines in the JWST NIR range vs redshift



Spectral modeling

ionizing source + **CLOUDY** Ferland+13

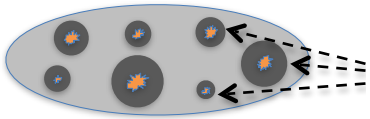
AGN NLR

Feltre+16

AGN accretion luminosity $F_\nu \propto \nu^\alpha$

(UV spectral index in the range 10-2500 Å)

SF regions



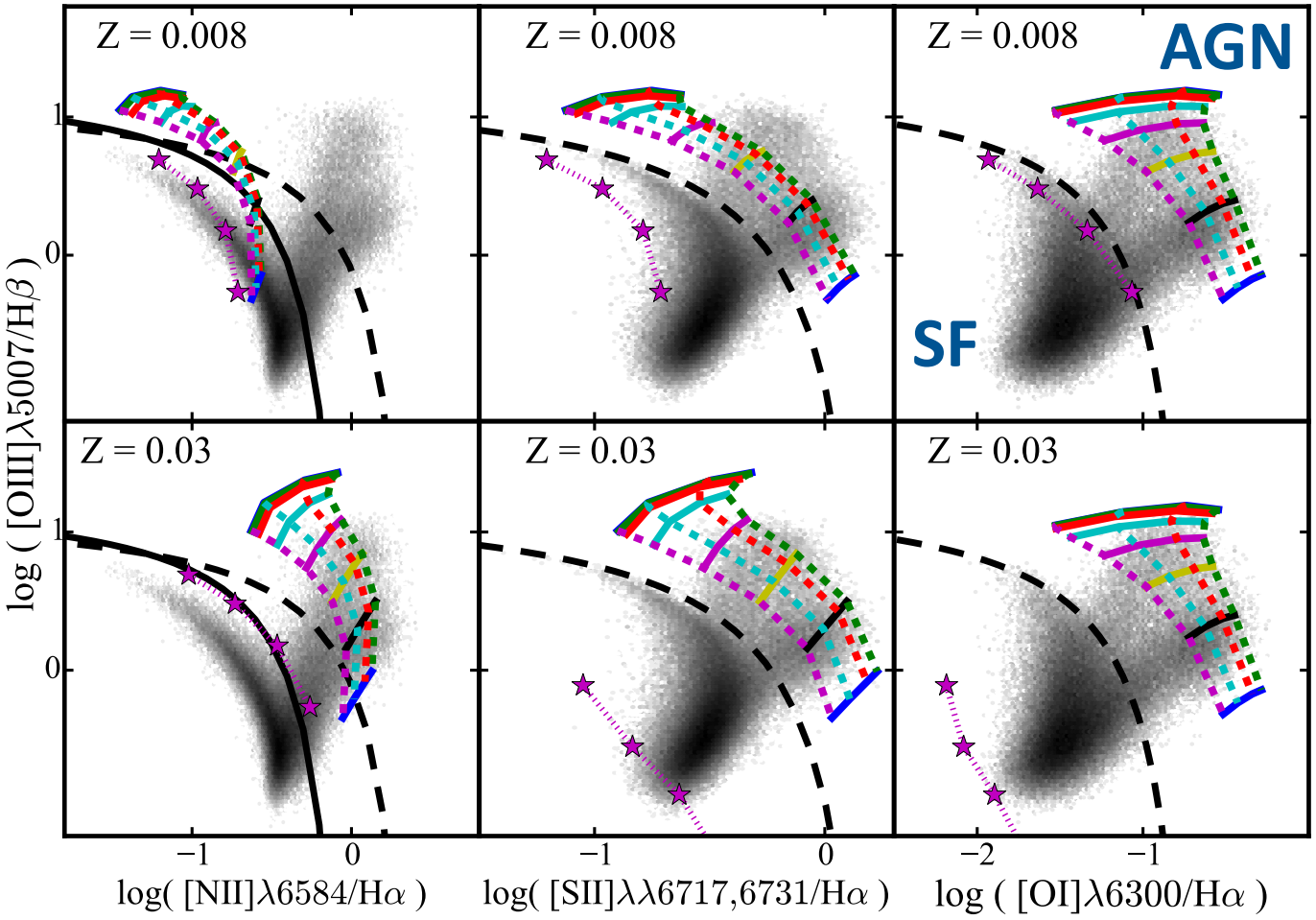
Several HII regions

Gutkin+16 sub

CB16 (GALAXEV) new stellar evolutionary tracks and atmospheres, also **for massive stars**

	AGN NLR	SF galaxies
ionizing spectrum	α = -1.2, -1.4, -1.7, -2.0	constant SFR, age 10
$\log(U_S)$ = **ionization parameter**, n_γ/n_H	-1.0 ÷ -4.5	-1.0 ÷ -4.5
$\log(n_H/cm^{-3})$ = **hydrogen gas density**	2.0, 3.0, 4.0	2.0, 3.0, 4.0
Z = **metallicity** (gas+dust phase)	0.0001 ÷ 0.07	0.0001 ÷ 0.03
ξ_d = dust-to-metal mass ratio (**depletion**)	0.1, 0.3, 0.5	0.1, 0.3, 0.5

Standard optical diagnostics



Baldwin, Phillips & Terlevich 81 BPT; Veilleux & Osterbrock 87)

Kewley+01

Kauffmann+03

SDSS sources
$0.04 < z < 0.2$

$\xi_d = 0.3$

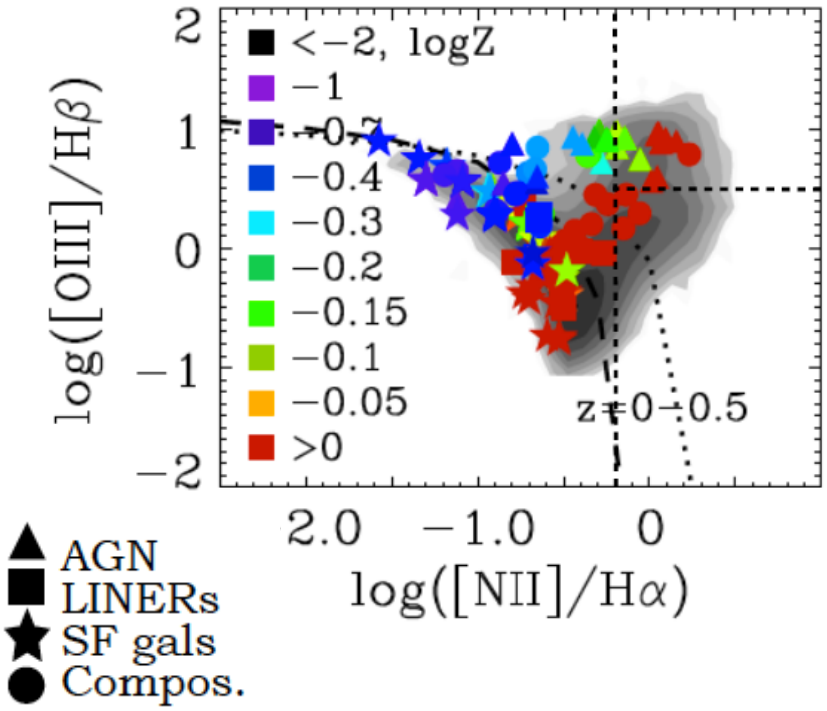
$n_{H\,(AGN)} = 10^3\ cm^{-3}$

$n_{H\,(SF)} = 10^2\ cm^{-3}$

models can describe simultaneously various standard optical emission-line ratios

Feltre+16

Synthetic nebular spectra



successful in reproducing the observed SDSS results

synthetic spatially resolved spectral diagnostics for IFU surveys

photoionization models from SF galaxies, AGN and evolved stellar populations

+

set of 20 cosmological zoom-in simulations of massive galaxies

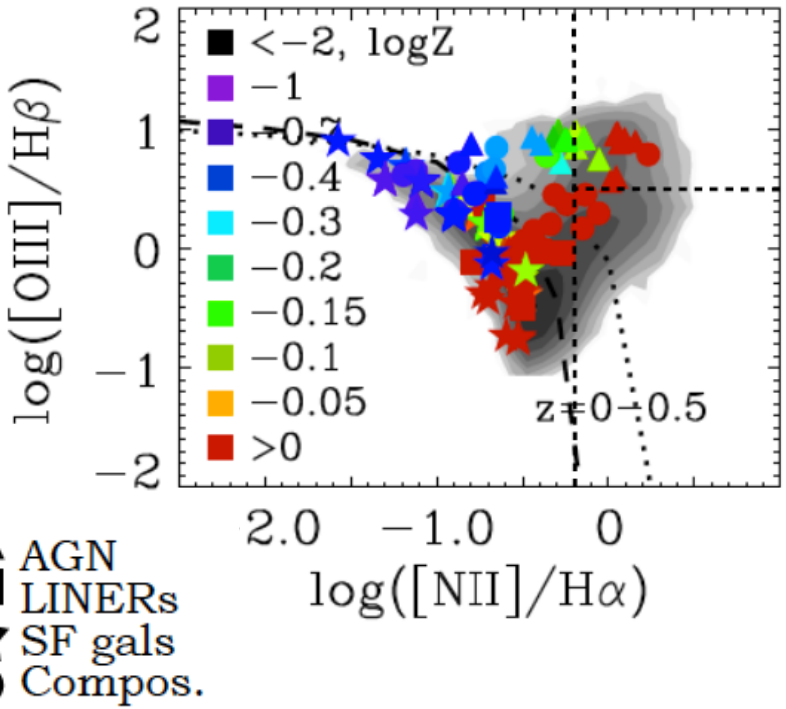
Choi+16, in prep; Hirschmann, Naab + 16, in prep

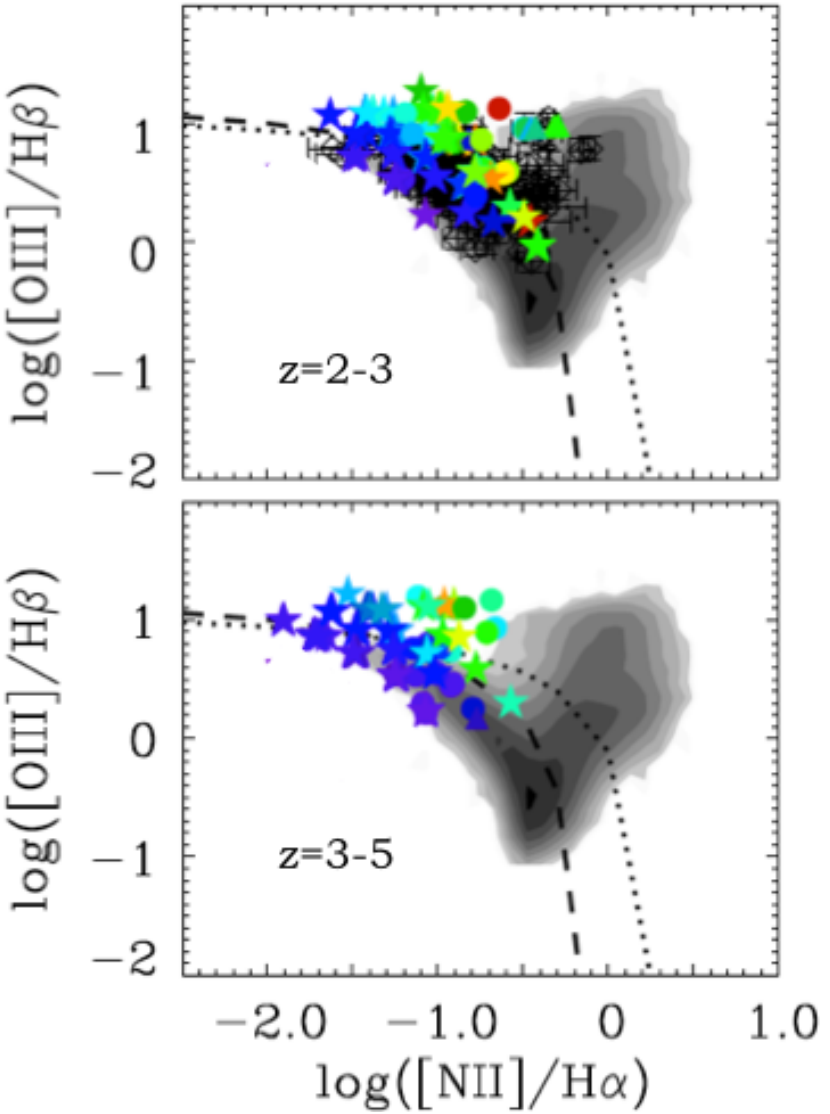
main questions:

- which galaxies are selected using standard optical diagnostics at z = 0?
- is there a **redshift evolution of optical emission line ratios**?
- local Universe optical diagnostics are still suitable for high z? how can we improve?
- feedback constraints in **spatially resolved BPT**?

Hirschmann, Charlot, Feltre + 16 in prep

Synthetic nebular spectra

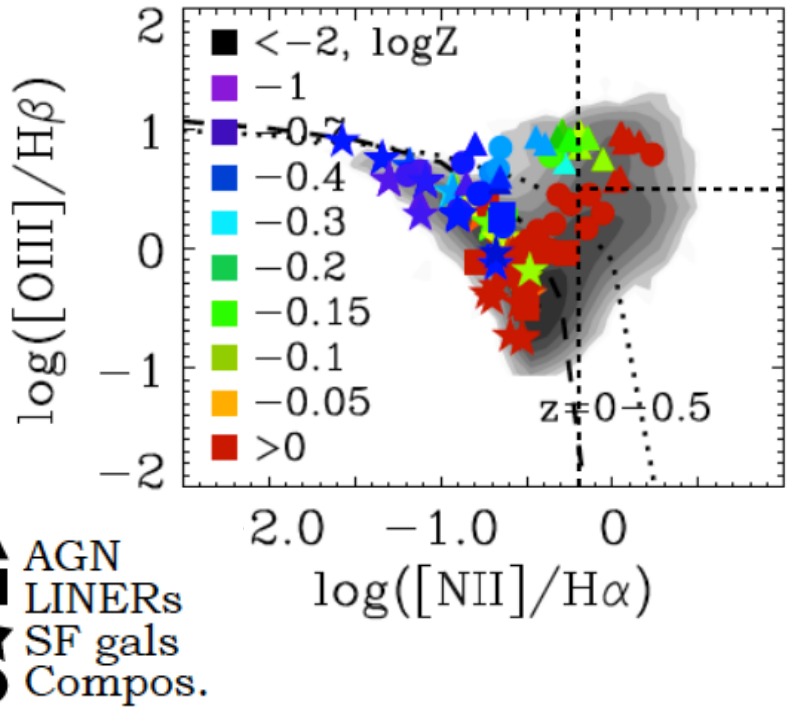


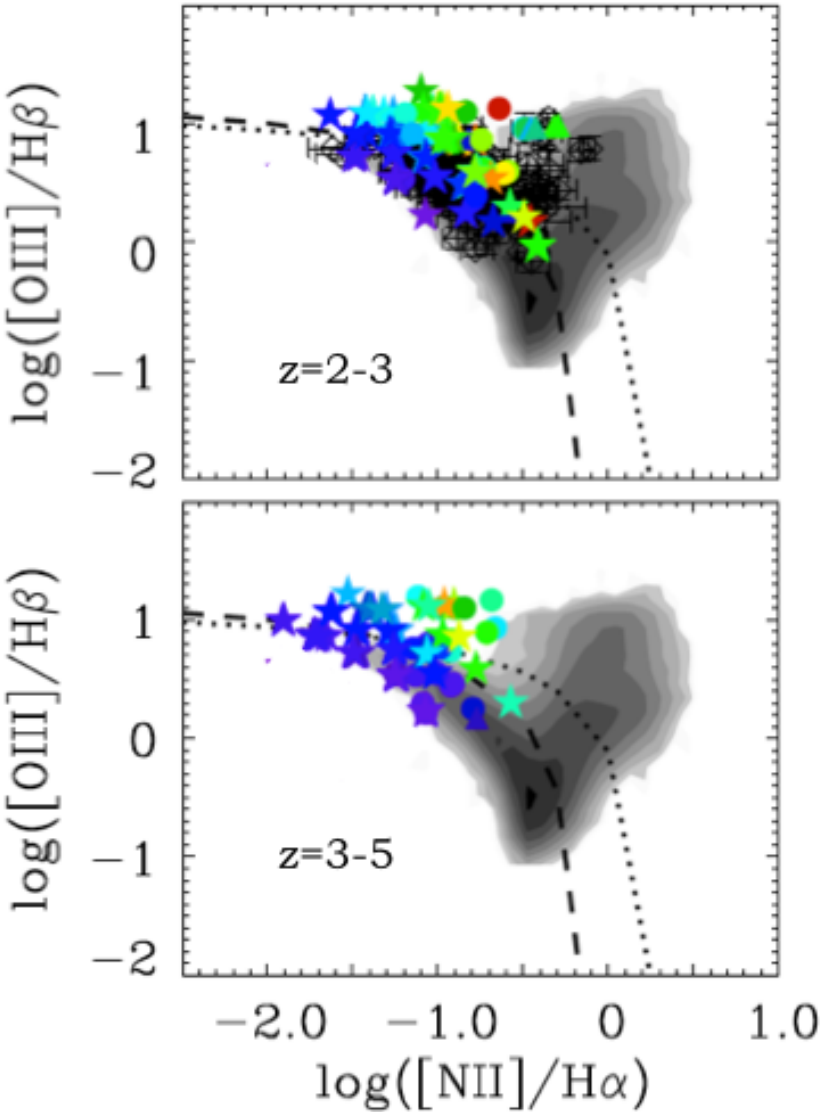


successful in reproducing the observed SDSS results

Hirschmann, Charlot, Feltre + 16 in prep

Synthetic nebular spectra



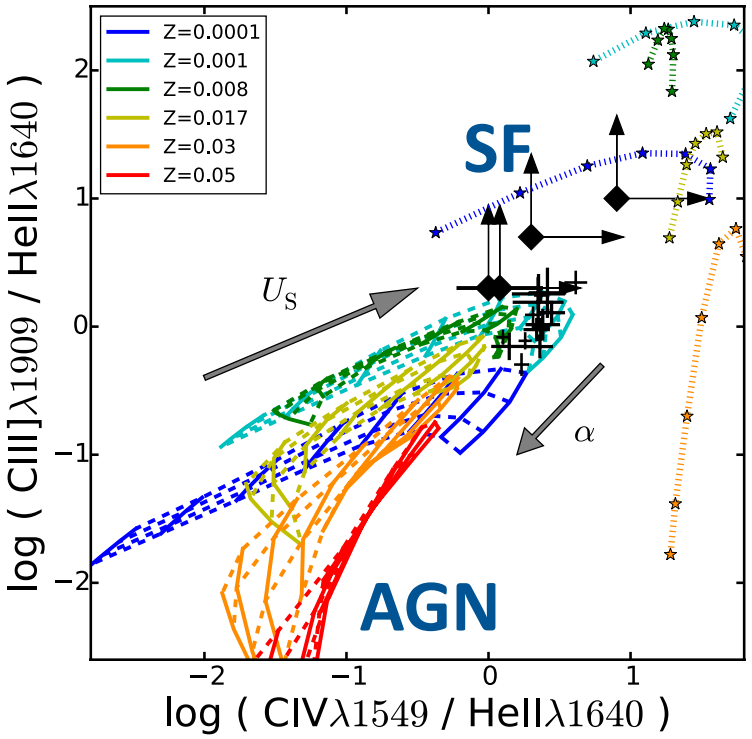


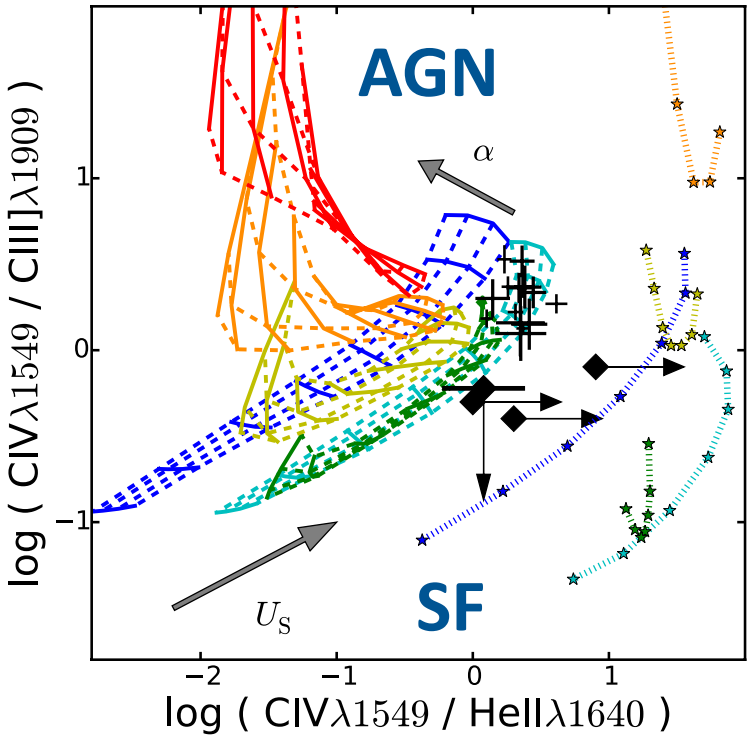
successful in reproducing the observed SDSS results

at high redshift:
new diagnostics, e.g. UV emission line ratios

Hirschmann, Charlot, Feltre + 16 in prep

UV spectral diagnostics





ξ_d =0.1
$n_H=10^2$ cm^{-3}

\+ **Dors+14**
Sy2 - low z
QSO2 - z~2

◆ **Stark+14**
dwarf galaxies
z~2

AGN and SF populate different regions of the diagrams

models predictions agree with data

Feltre+16

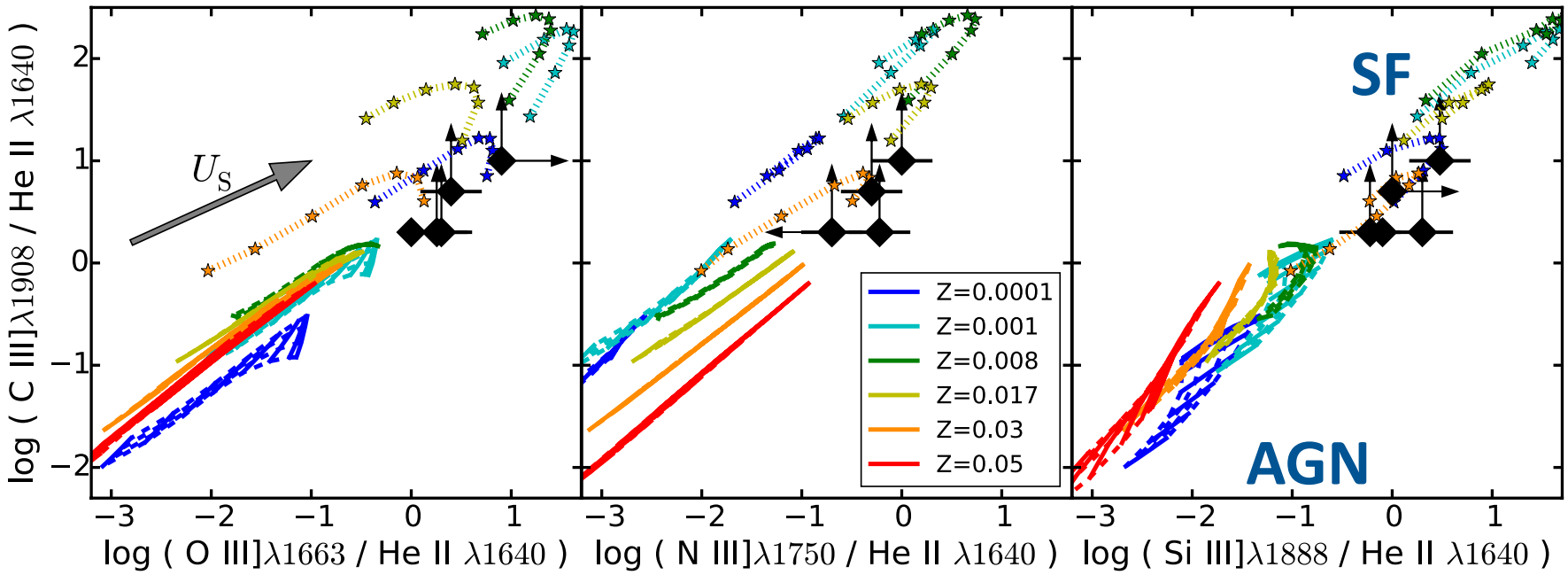
UV spectral diagnostics

Stark+14

◆ dwarf galaxies
z~2

ξ_d =0.3

$n_{H\ (AGN)}=10^3\ cm^{-3}$
$n_{H\ (SF)}=10^2\ cm^{-3}$



and many others such as CIII]1909/HeII1640 or CIV1240/HeII vs NV1240/HeII, NV1240/CIV1549, NV1240/NIII]1750, OIII]1661,1666/HeII, NIII]1750/HeII, [NeV]3426-[NeIV]2424 based

Feltre+16

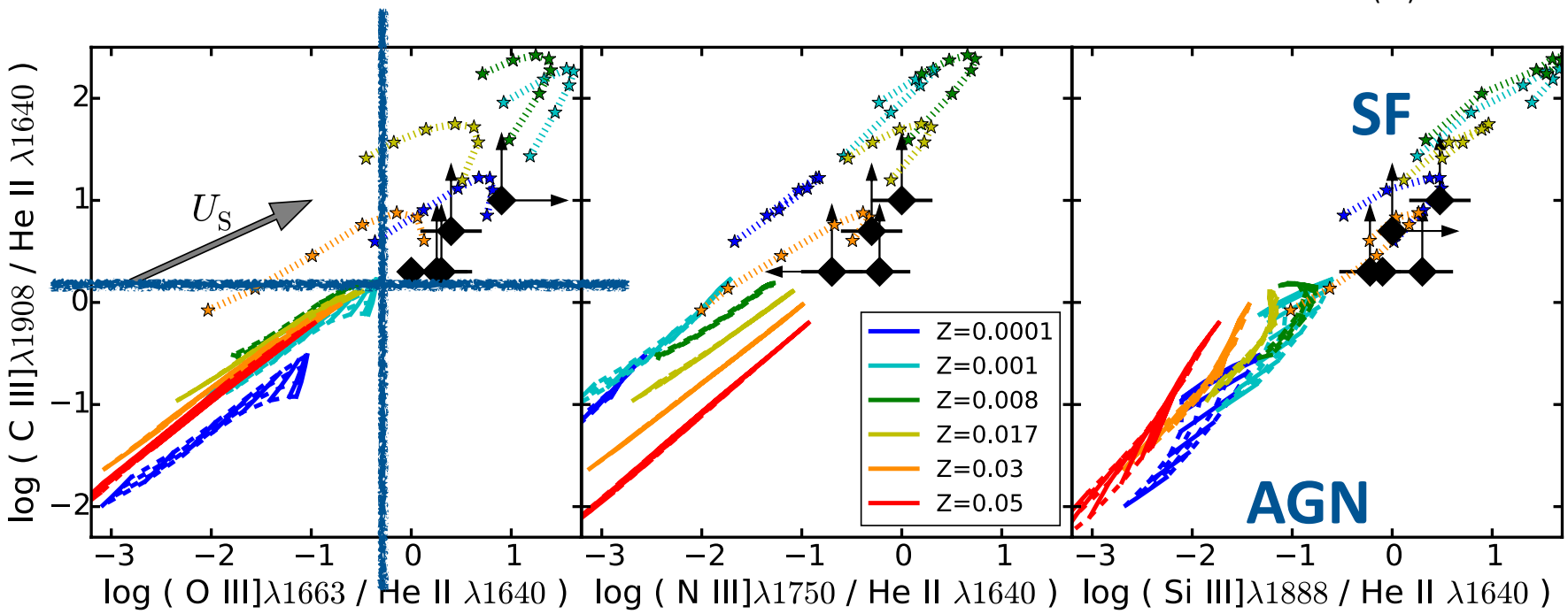
UV spectral diagnostics

Stark+14

◆ dwarf galaxies
z~2

ξ_d =0.3

$n_{H\ (AGN)}=10^3\ cm^{-3}$
$n_{H\ (SF)}=10^2\ cm^{-3}$



and many others such as CIII]1909/HeII1640 or CIV1240/HeII vs NV1240/HeII, NV1240/CIV1549, NV1240/NIII]1750, OIII]1661,1666/HeII, NIII]1750/HeII, [NeV]3426-[NeIV]2424 based

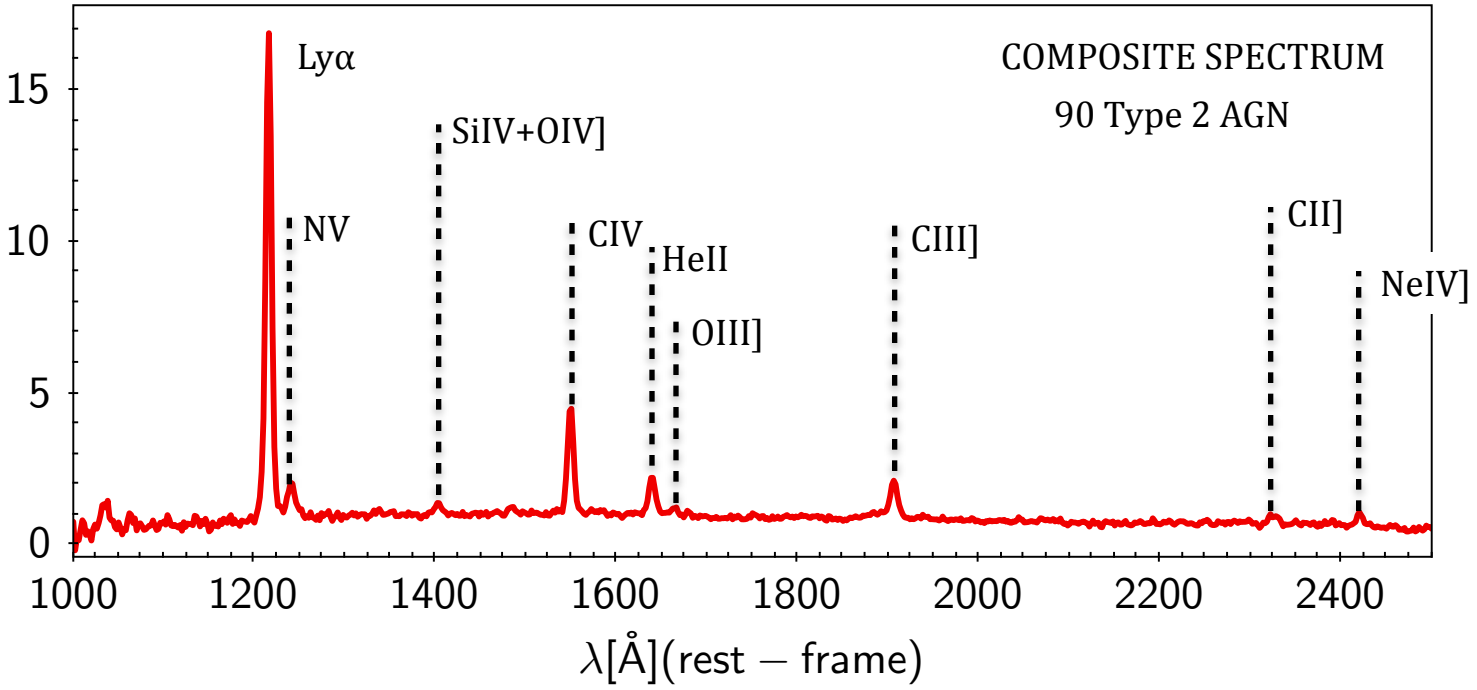
Feltre+16

z-COSMOS DeepType 2 AGN

zCOSMOS Deep (PI: S. Lilly)
BzK selection + U dropout colour selected galaxies with z>1.4
8k sample (K<23.5 & B<25.5)
192 CIV-selected AGN
with 1.5 < z < 3.0
VIMOS/VLT

Mignoli+ in prep

- search for Type 2 (obscured AGN) at high z
- study the excitation properties of the AGN NLR ionised gas

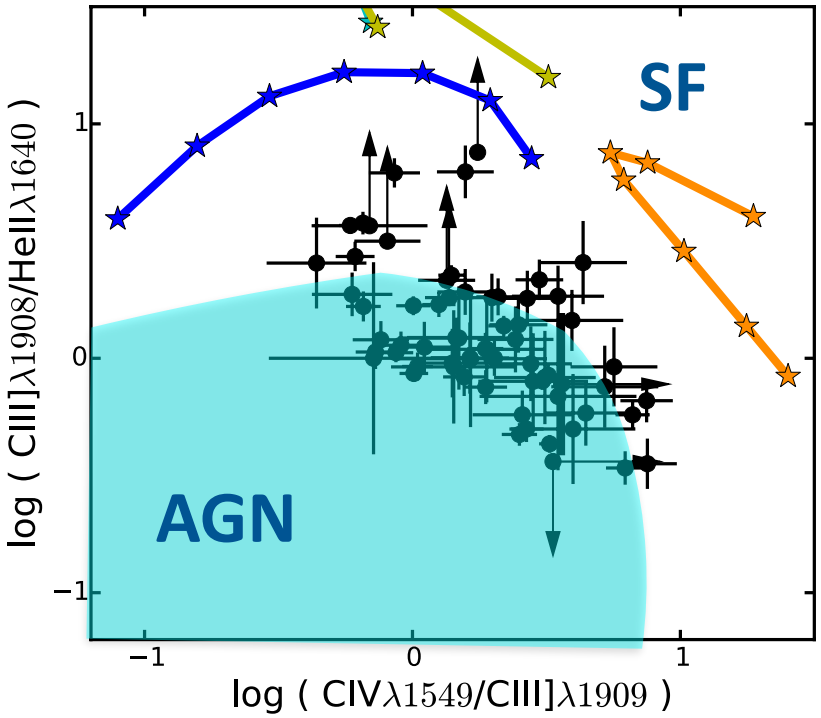


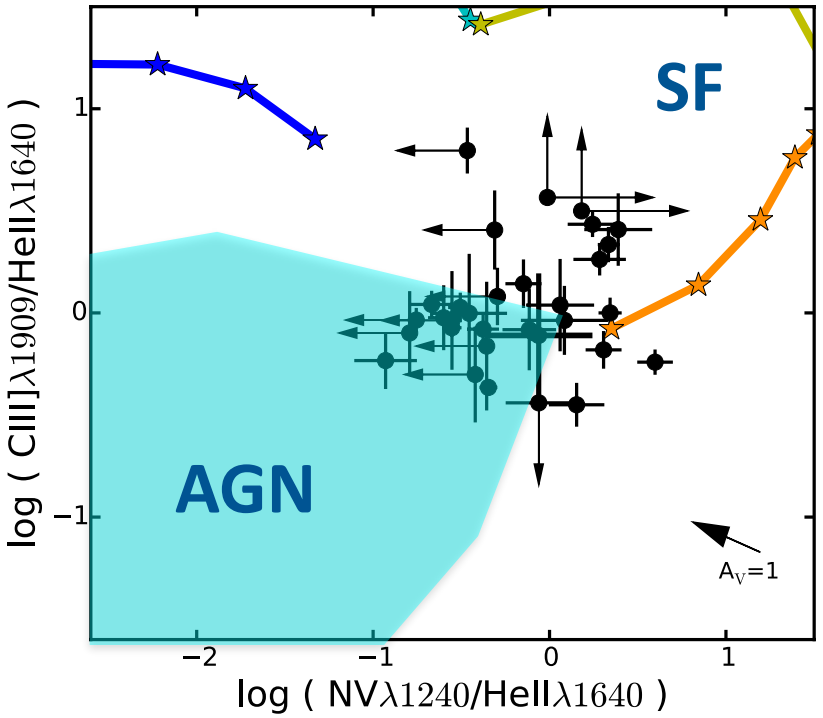
Diagnostics - CIV selected AGN2

NV/HeII often stronger than model predictions

—> N over abundance and super-solar metallicities (e.g. **Hamann&Ferland 92,93**)

—> UV emission line ratios are *not* reproduced with the same model parameters





Mignoli+ in prep

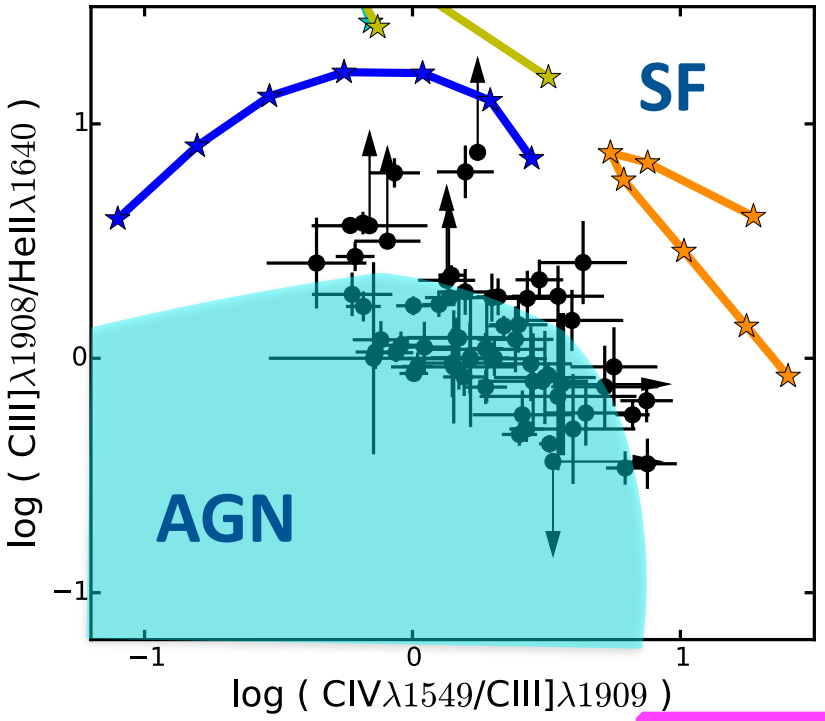
Feltre+ in prep

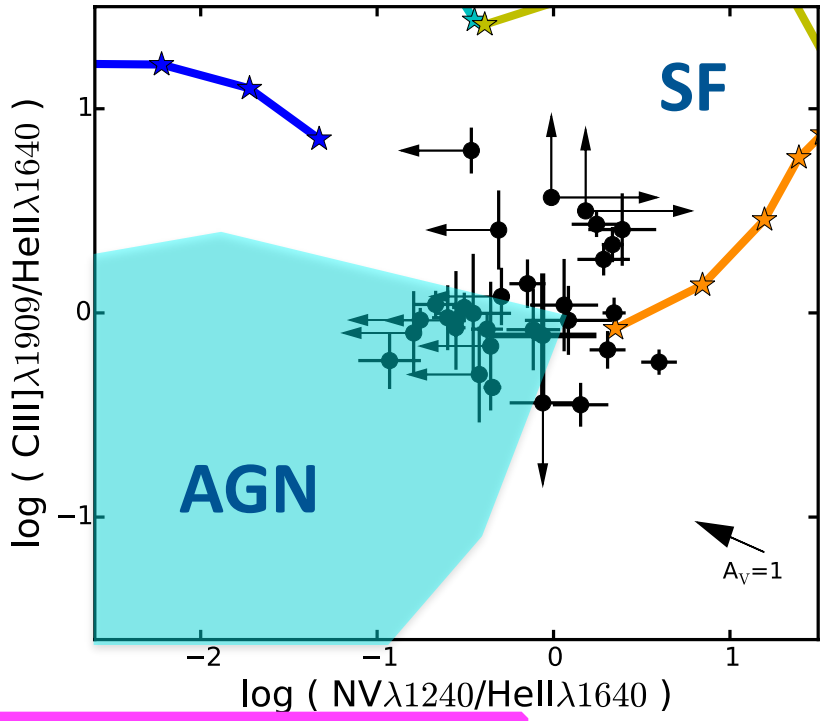
Diagnostics - CIV selected AGN2

NV/HeII often stronger than model predictions

—> N over abundance and super-solar metallicities (e.g. **Hamann&Ferland 92,93**)

—> UV emission line ratios are *not* reproduced with the same model parameters





Mignoli+ in prep

Feltre+ in prep

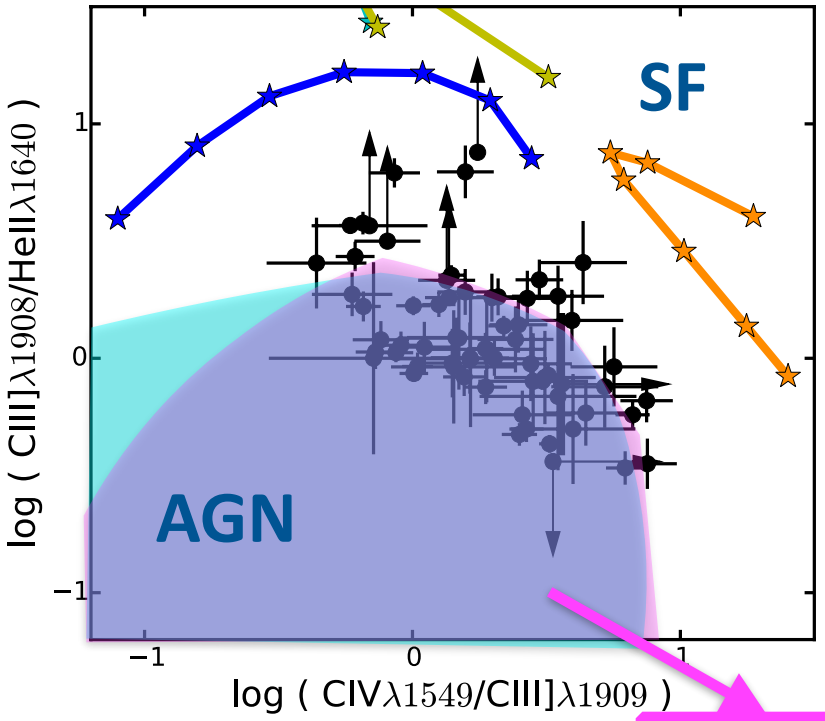
3-10 x smaller inner radius (30 - 90 pc)

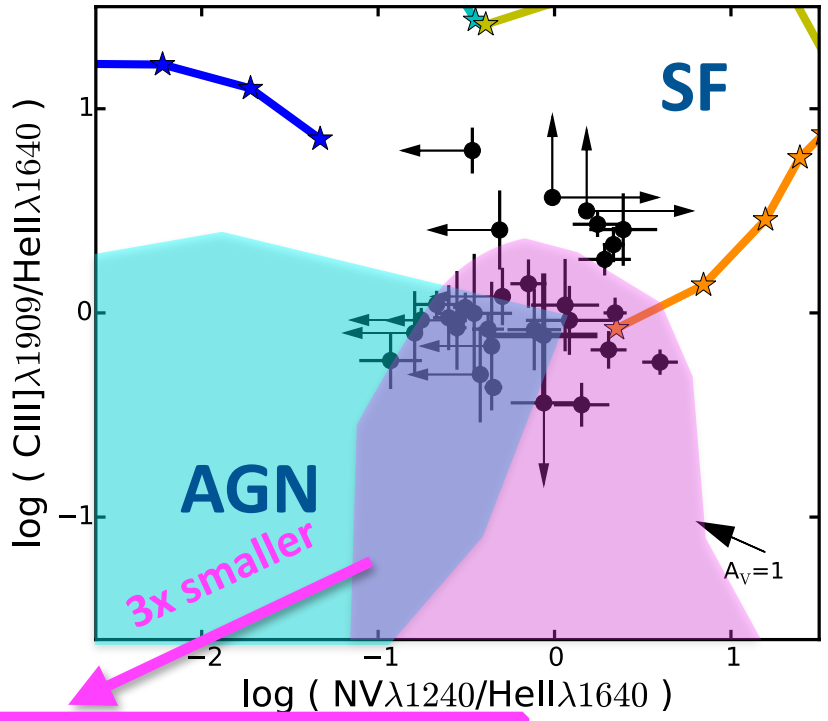
Diagnostics - CIV selected AGN2

NV/HeII often stronger than model predictions

—> N over abundance and super-solar metallicities (e.g. **Hamann&Ferland 92,93**)

—> UV emission line ratios are *not* reproduced with the same model parameters





Mignoli+ in prep

Feltre+ in prep

3-10 x smaller inner radius (30 - 90 pc)

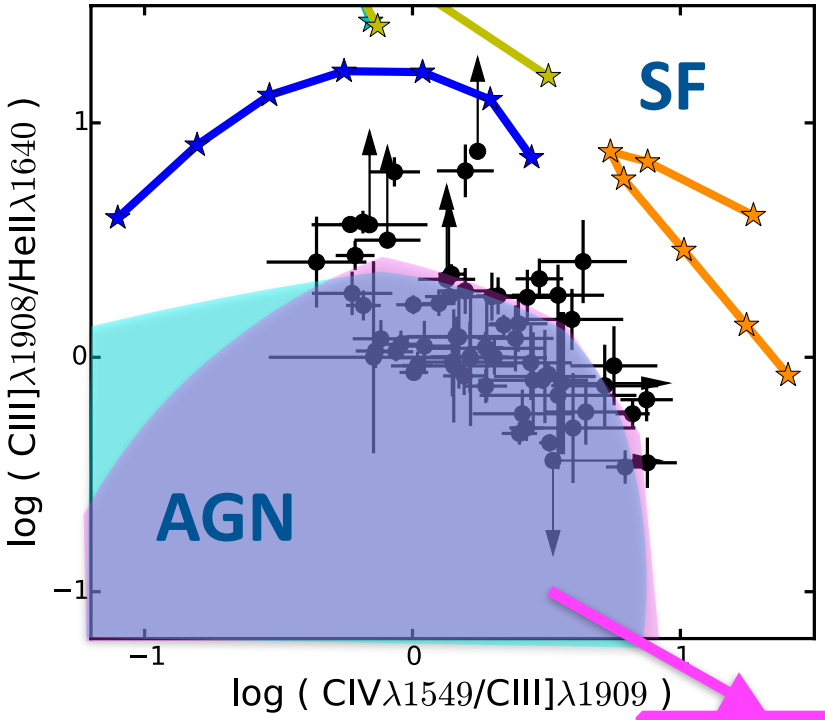
Diagnostics - CIV selected AGN2

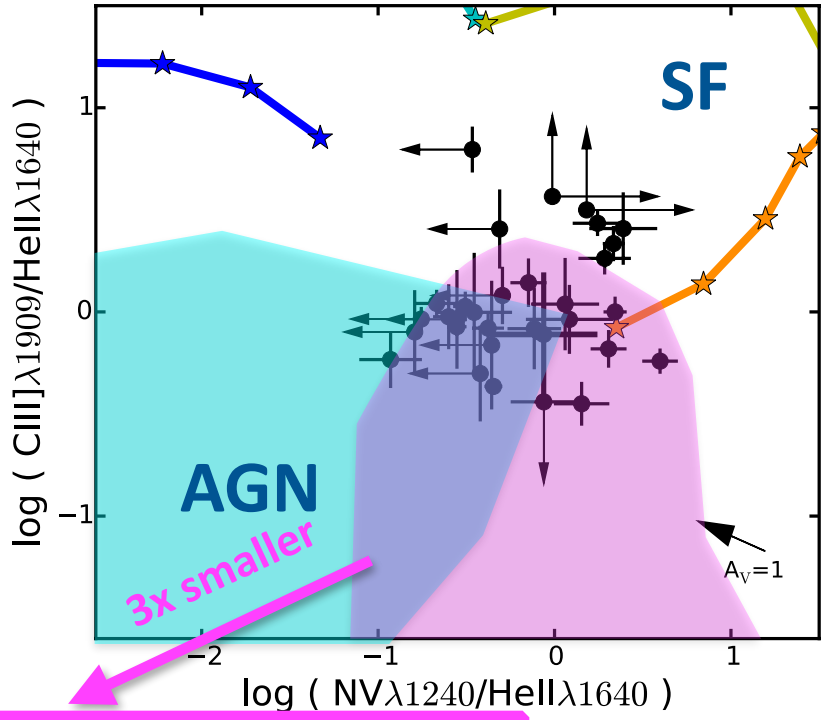
+ internal microturbulence (e.g. Bortoff & Ferland 2000, Kraeme_07) (v=100-200 km/s)

NV/HeII often stronger than model predictions

—> N over abundance and super-solar metallicities (e.g. Hamann&Ferland 92,93)

—> UV emission line ratios are *not* reproduced with the same model parameters





Mignoli+ in prep

Feltre+ in prep

3-10 x smaller inner radius (30 - 90 pc)

Diagnostics - CIV selected AGN2

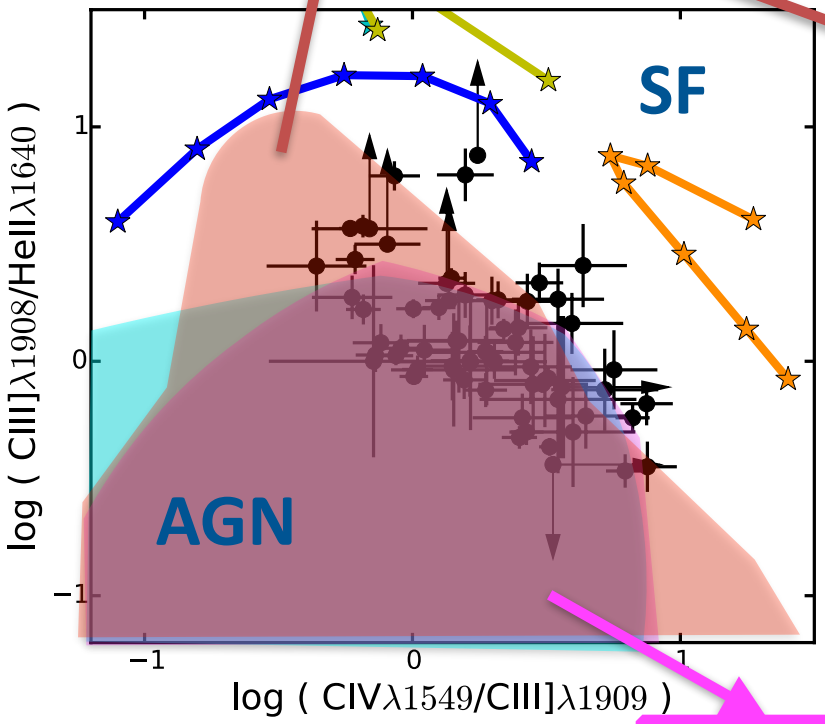
NV/HeII often stronger than model predictions

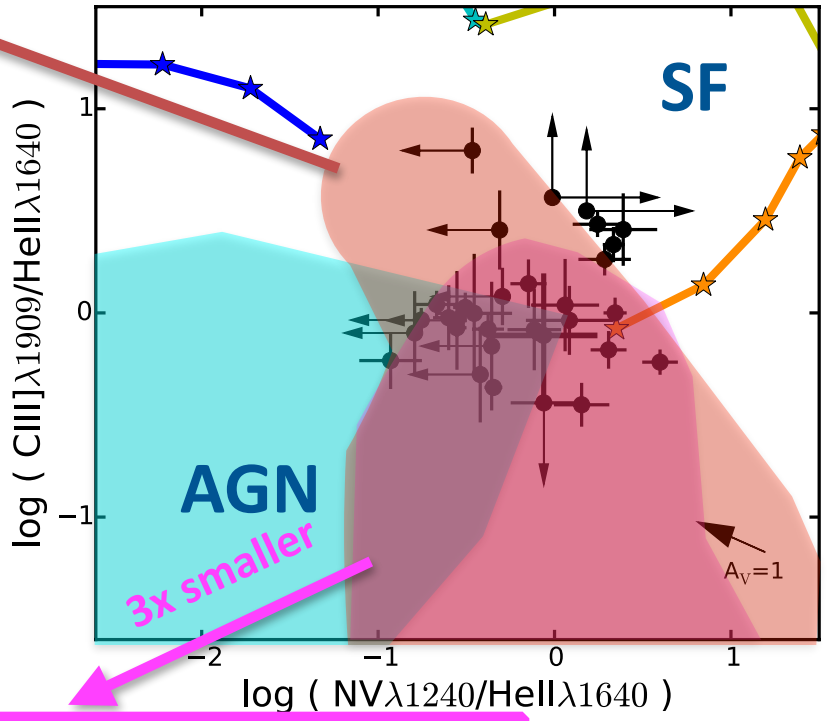
—> N over abundance and super-solar metallicities (e.g. Hamann&Ferland 92,93)

—> UV emission line ratios are *not* reproduced with the same model parameters

+ internal microturbulence (e.g. Bortoff & Ferland 2000, Kraeme_07) (v=100-200 km/s)

100 km/s





Mignoli+ in prep

Feltre+ in prep

3-10 x smaller inner radius (30 - 90 pc)

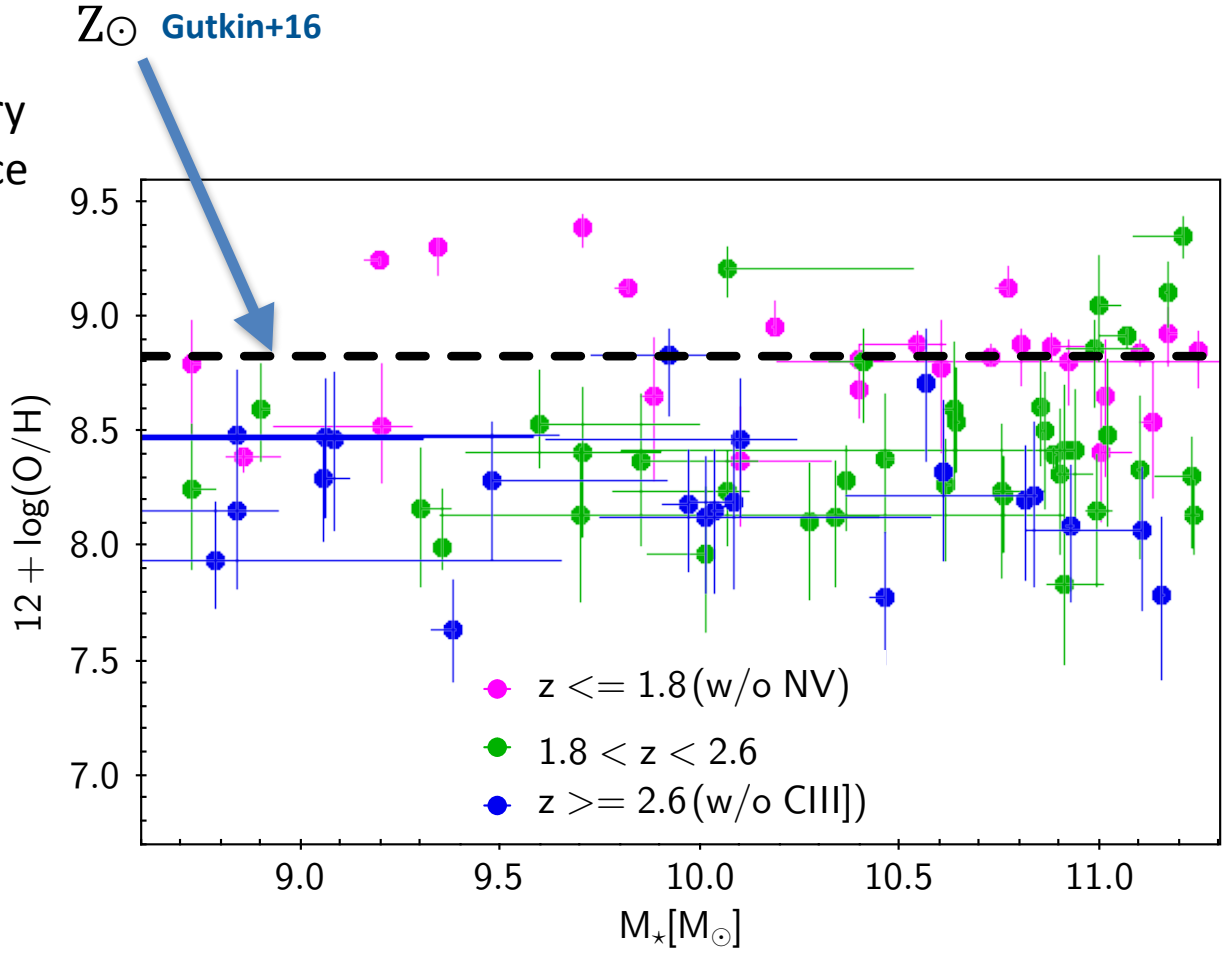
CIV selected AGN2 - M* vs O/H

PRELIMINARY

Mignoli+ in prep

- no need of models with very high metallicity to reproduce the observed ratios
- flat relation O/H vs stellar mass
- metallicity evolution with redshift?

future plan:
simultaneous fit of photometry + spectral lines to with a Bayesian fitting code (e.g. BEAGLE, Chevallard+16)

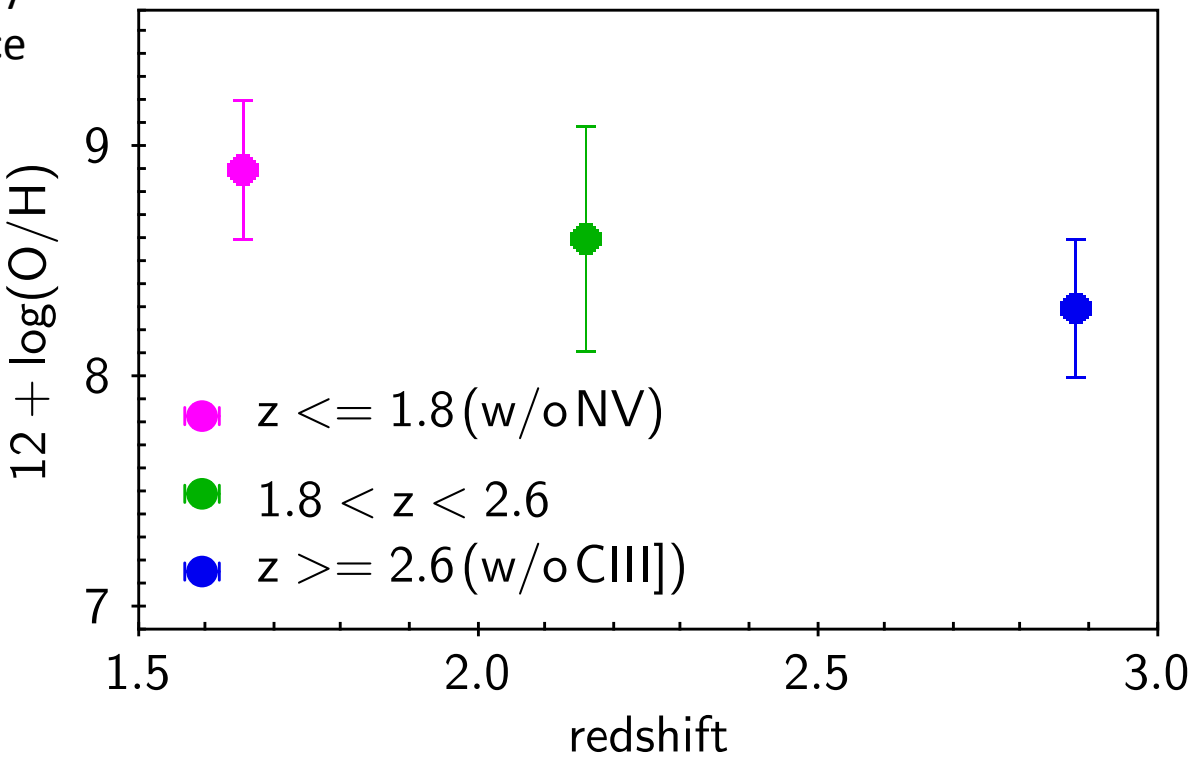


CIV selected AGN2 - M* vs O/H

PRELIMINARY

Mignoli+ in prep

- no need of models with very high metallicity to reproduce the observed ratios
- flat relation O/H vs stellar mass
- metallicity evolution with redshift?



future plan:
simultaneous fit of photometry + spectral lines to with a Bayesian fitting code (e.g. BEAGLE, Chevallard+16)

BayEsian Analysis of Galaxies sEds - BEAGLE

Chevallard+16, arXiv:1603.03037

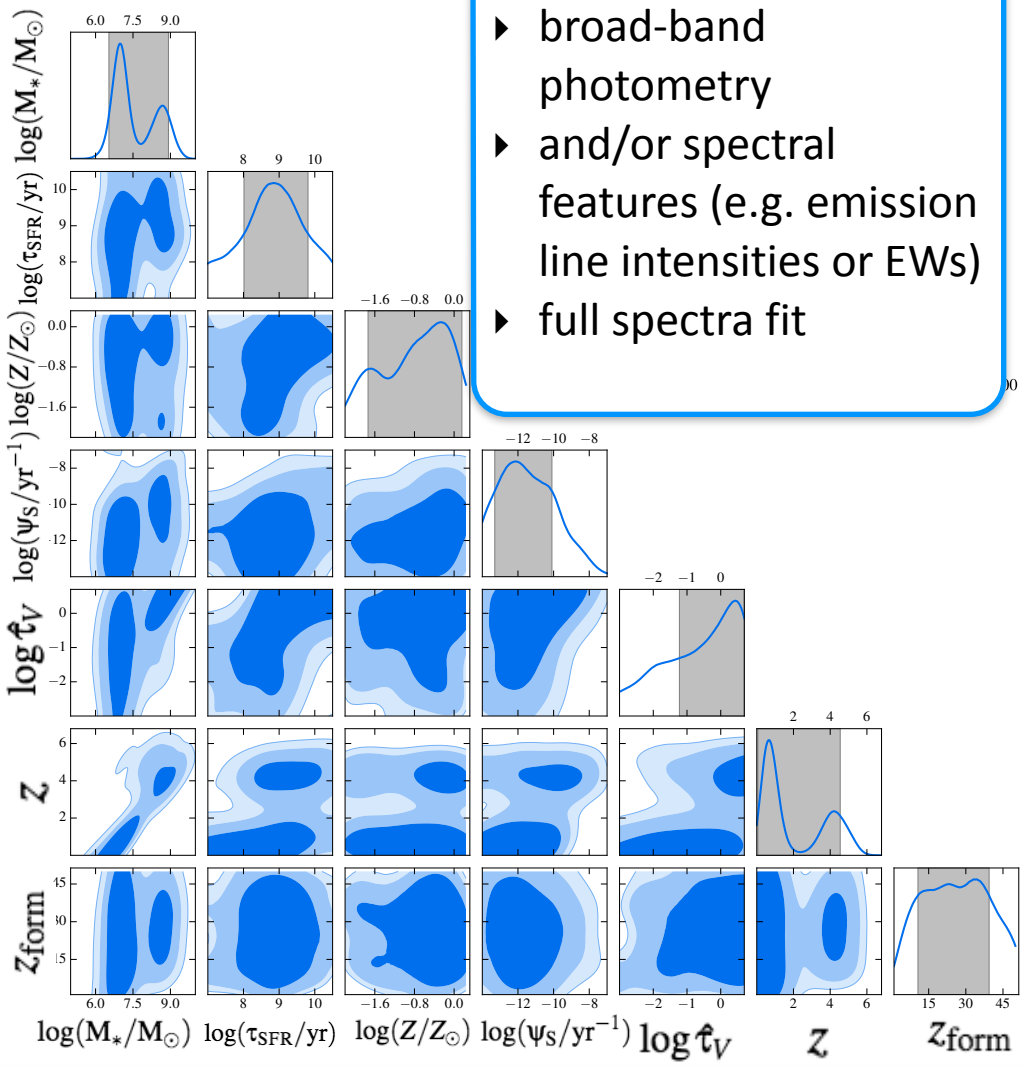
MAIN FEATURES

- combines in a coherent way emission from different components (stars, gas, dust, AGN)
- adopts Bayesian approach to obtain posterior PDF of every model parameter
- includes predictions from galaxy formation models

APPLICATIONS

- fit spectro-photometric data at UV to IR wavelengths
- create synthetic catalogues of galaxy SEDs
- study retrievability of galaxy physical parameters for different type of observations

- broad-band photometry
- and/or spectral features (e.g. emission line intensities or EWs)
- full spectra fit



Summary

- ✦ UV emission-line ratios are good **diagnostics of the ionizing source** (nuclear vs stellar activity)
- ✦ interpretation of spectroscopic observations to study **physical properties of the ionized gas** (e.g. metallicity, density) of both active **(Mignoli+in prep.)** and inactive galaxies **(Stark+14,15a,b,16)**
- ✦ can be easily implemented in **SED fitting tools**, e.g. **BEAGLE (Chevallard+16)**
- ✦ **combined with cosmological simulations** to better understand feedback processes and black hole growth **(Hirschmann + in prep)**
- ✦ **interpret current spectroscopic observations** (VLT-KMOS/MUSE and Keck-MOSFIRE) of high redshift sources
- ✦ **groundwork** for **future facilities**, such as NIRspec on-board JWST and the ELTs which will push studies up to the **epoch of reionization** (z>7)