Observational Study on the Chemical Evolution of Galaxies

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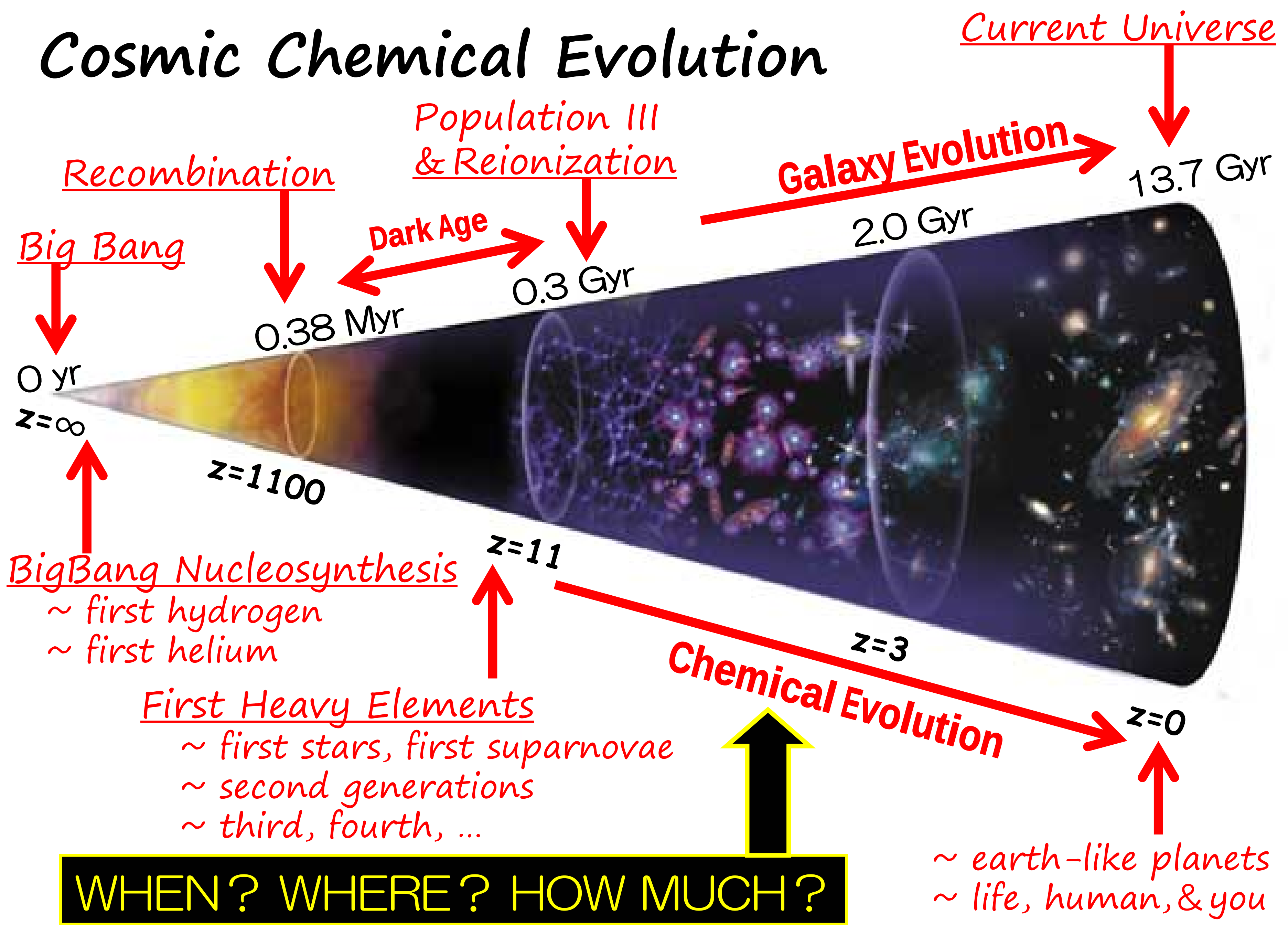


Cosmic Chemical Evolution
Current Universe
Population III
& Reionization
Recombination
Galaxy Evolution
13.7 Gyr
Big Bang
Dark Age
2.0 Gyr
0.3 Gyr
0.38 Myr
0 yr
z=∞
z=1100
z=11
z=3
z=0
BigBang Nucleosynthesis
~ first hydrogen
~ first helium
Chemical Evolution
First Heavy Elements
~ first stars, first suparnovae
~ second generations
~ third, fourth, ...
~ earth-like planets
~ life, human, & you
WHEN? WHERE? HOW MUCH?

Contents of This Presentation

(1) Metallicity Evolution of Galaxies

~ Luminosity-metallicity & mass-metallicity relations
~ Toward high-z universe up to z=3
~ Comparison with model predictions

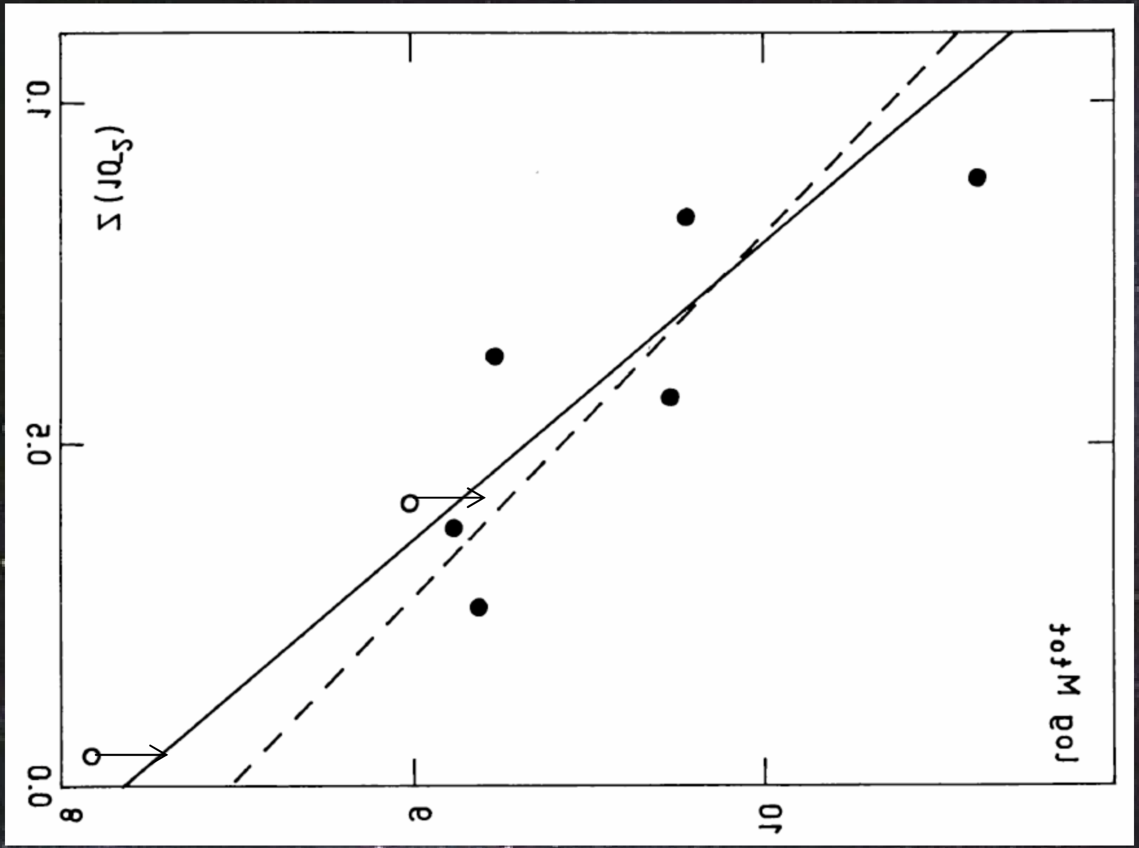
(2) Search for "Population III" Galaxies

~ Population III at z < 10 !?
~ Expected "observational" properties of PopIII
~ Subaru searches for PopIII galaxies

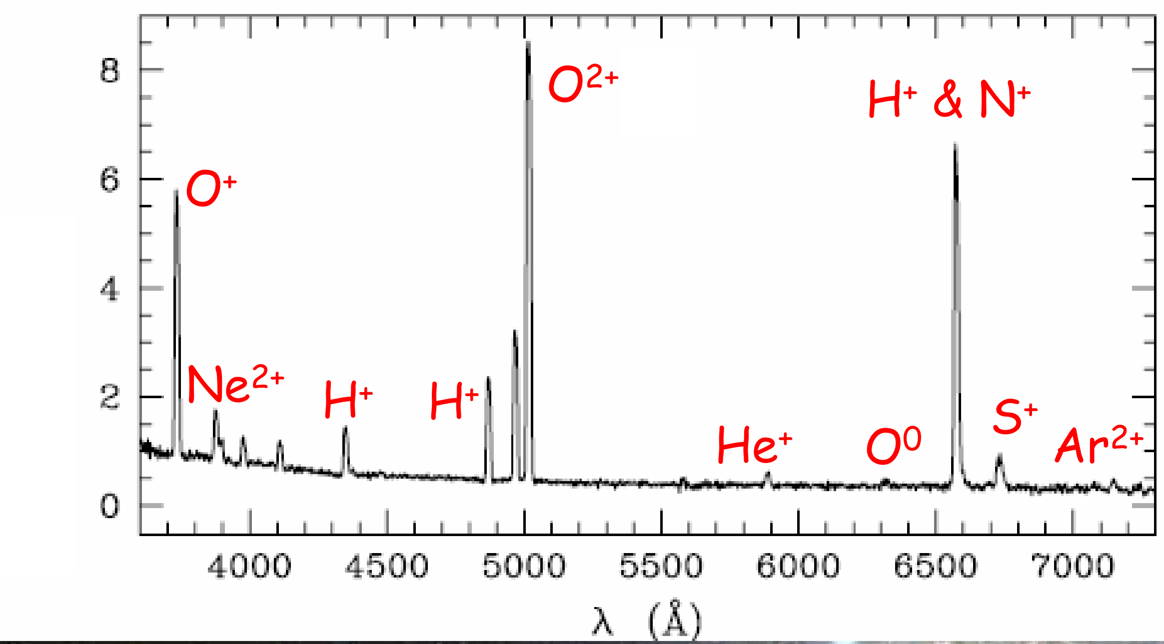
(3) Future Prospects

~ Metallicity at z > 3 (by focusing on AGNs?)
~ Searching for PopIII galaxies with... ??
~ My personal interests

Lequeux et al. (1979)



Metallicity Measurements of Galaxies



focusing on "O/H"

O/H

$= (O^0+O^++O^{2+}+\ldots)/H^+$

$= (O^0+O^++O^{2+})/H^+$

$$F(H^+) = \int N_p N_e h\nu\, \alpha(T)\, dV$$

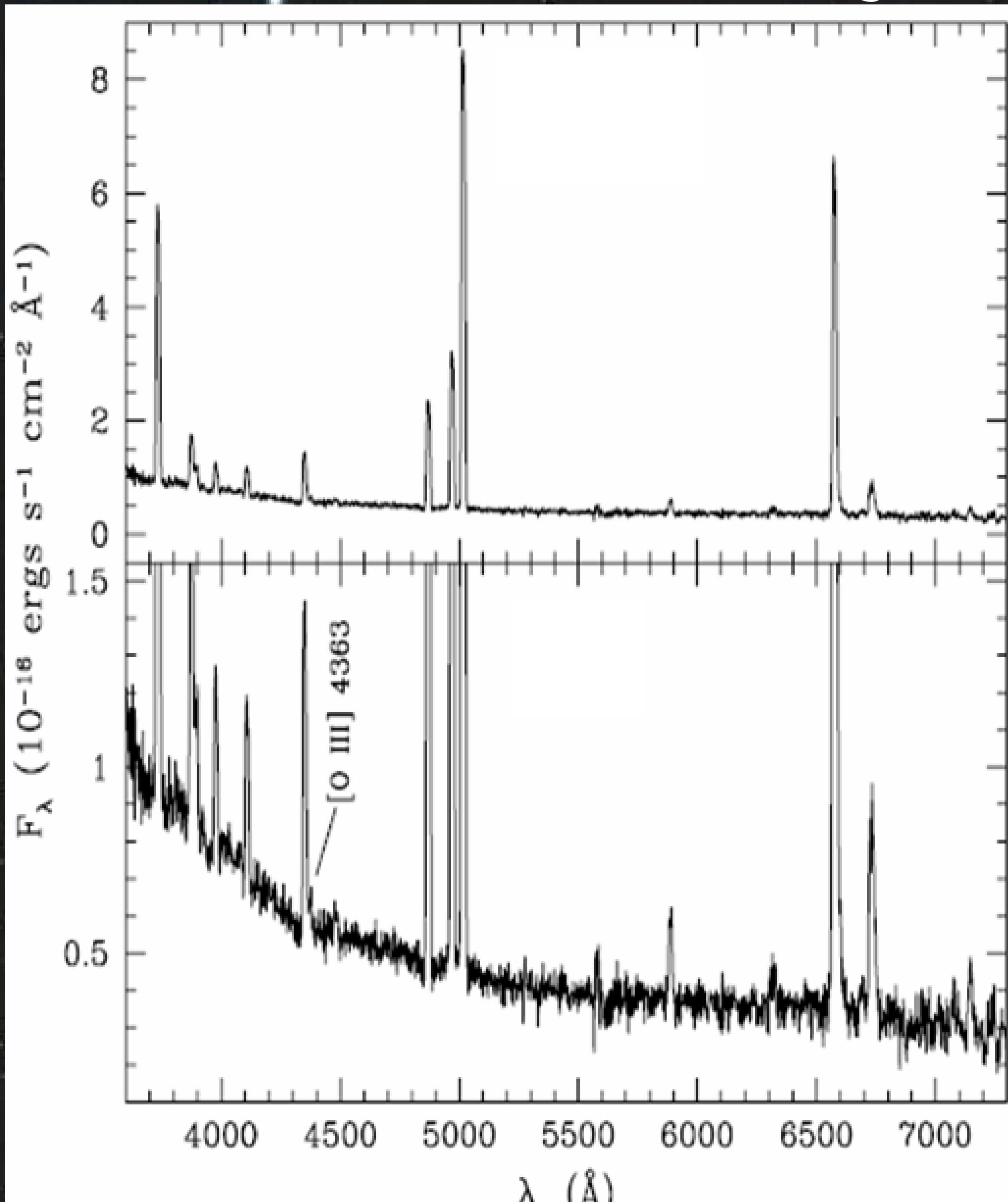
$$F(O^0) = \int N_{O^0} N_e h\nu\, q_{O^0}(T)\, dV$$

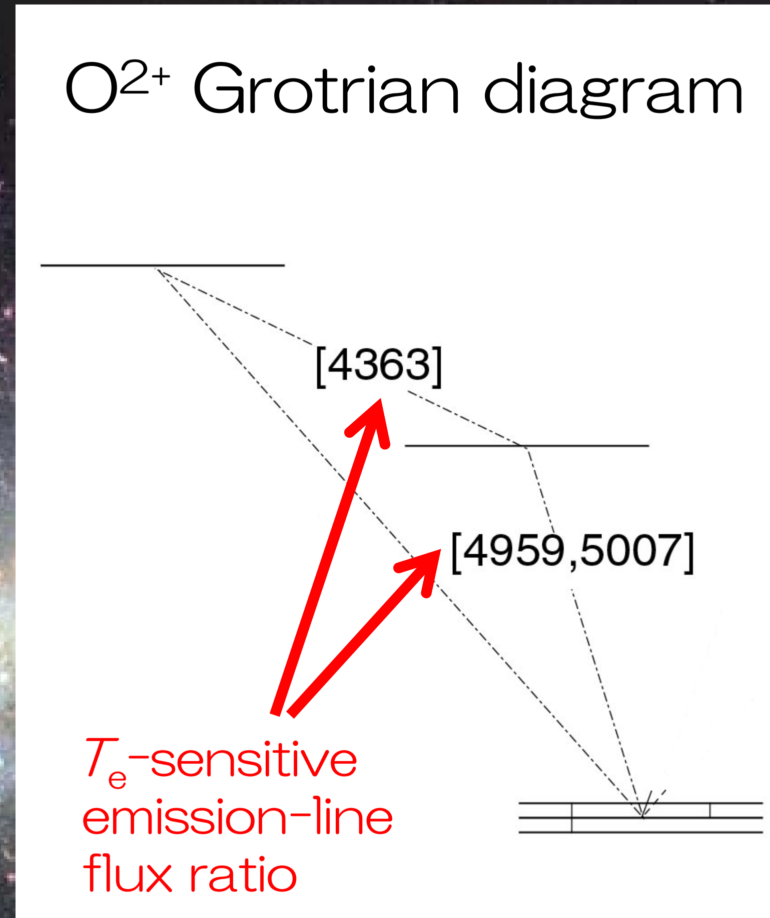
$$F(O^+) = \int N_{O^+} N_e h\nu\, q_{O^+}(T)\, dV$$

$$F(O^{2+}) = \int N_{O^{2+}} N_e h\nu\, q_{O^{2+}}(T)\, dV$$

We need to know emission-line fluxes and gas temperature

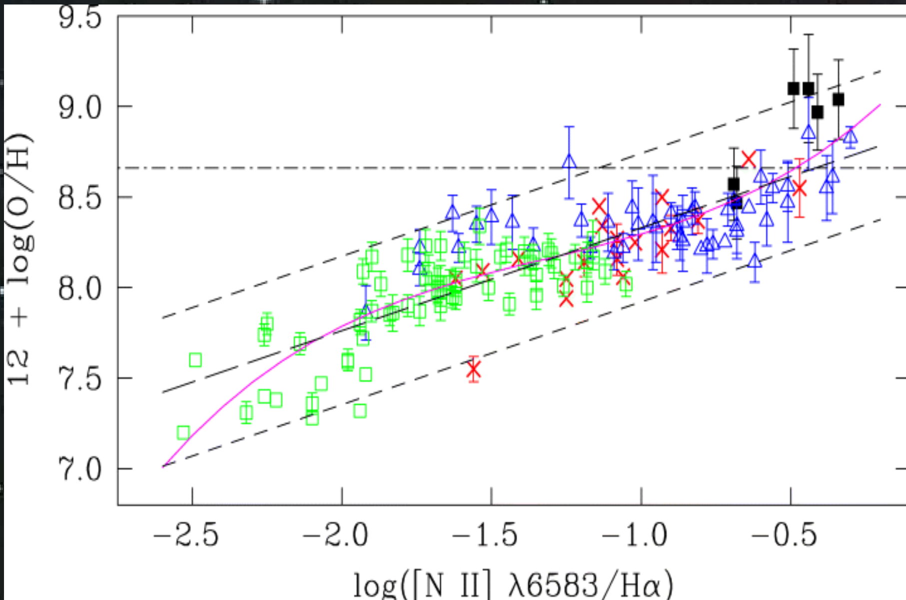
Accurate Metallicity Measurements

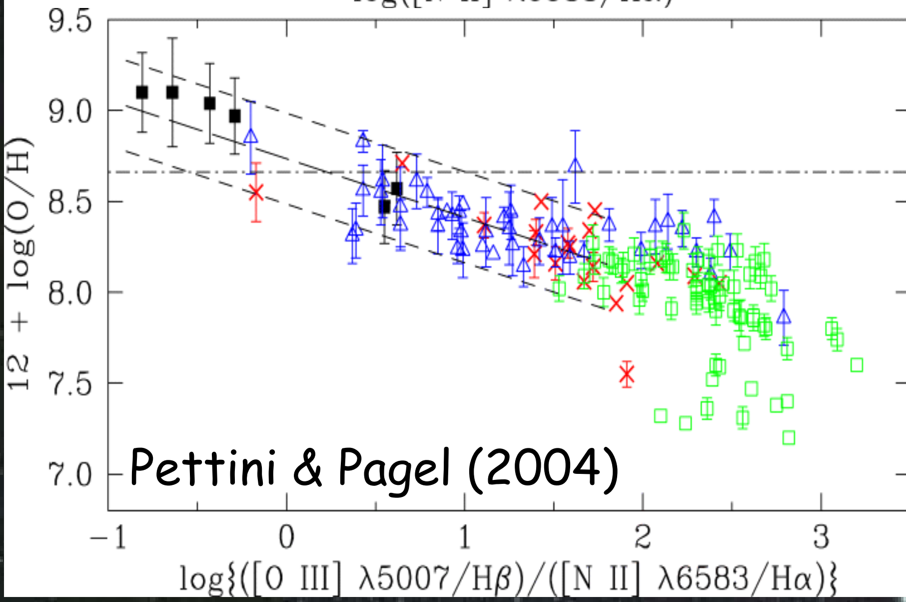


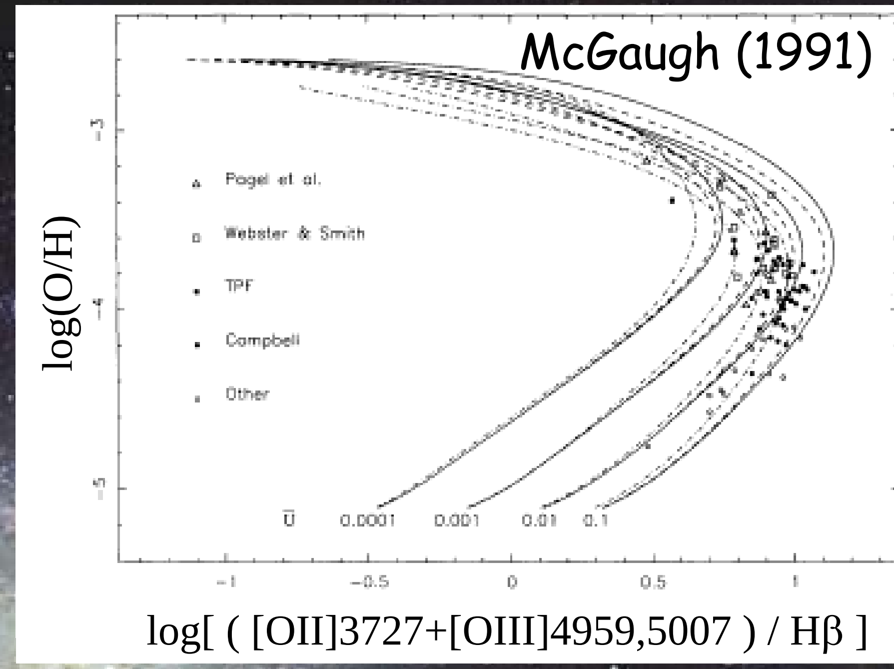


[OIII]4363 is available only in nearby galaxies...

Convenient Metallicity Measurements

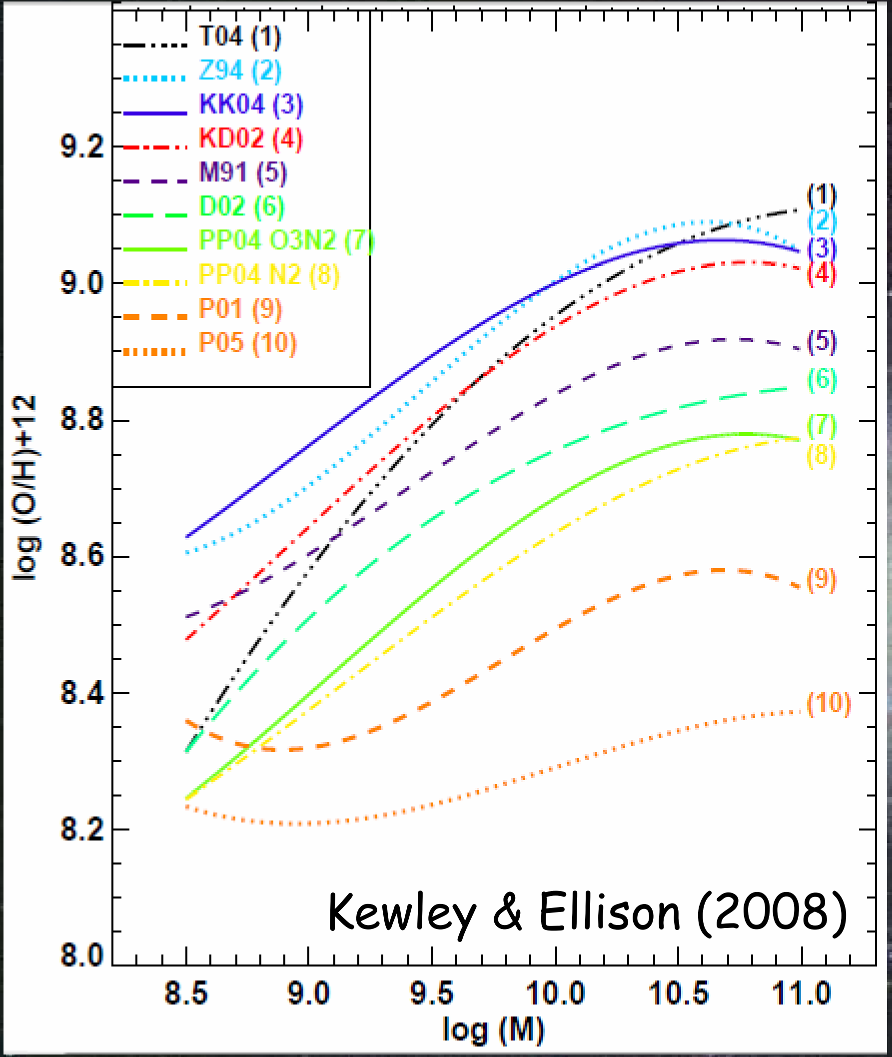


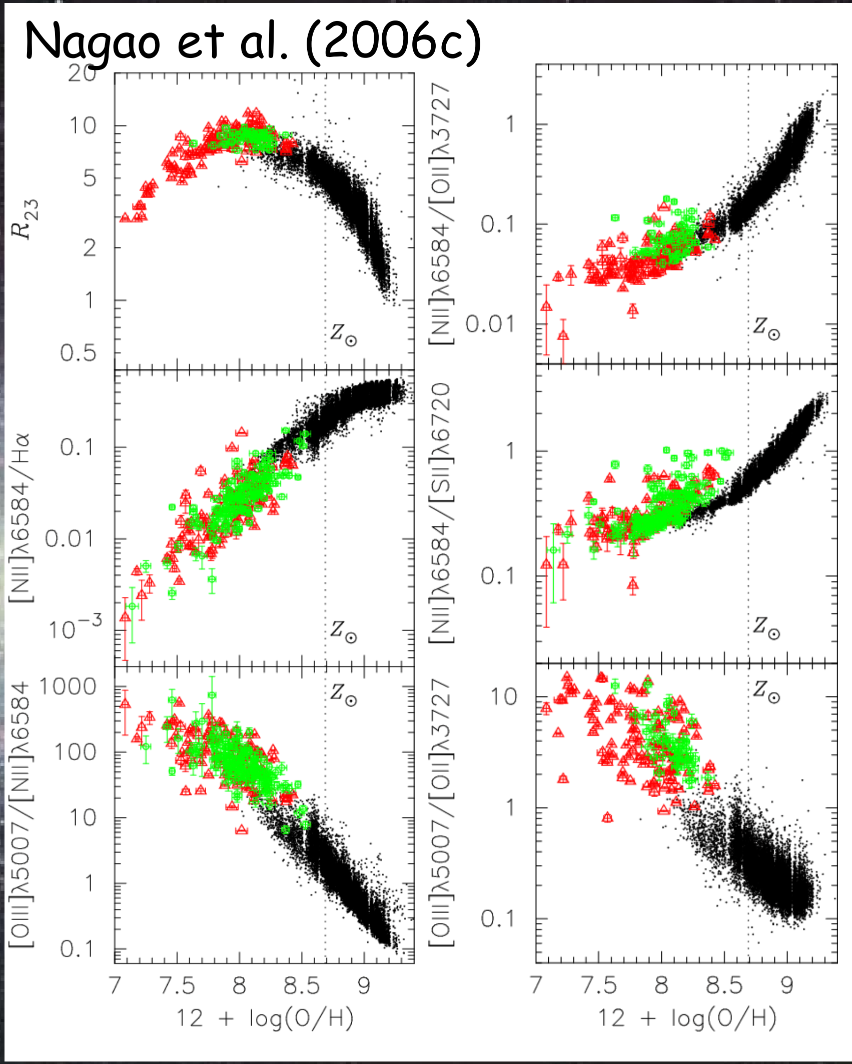




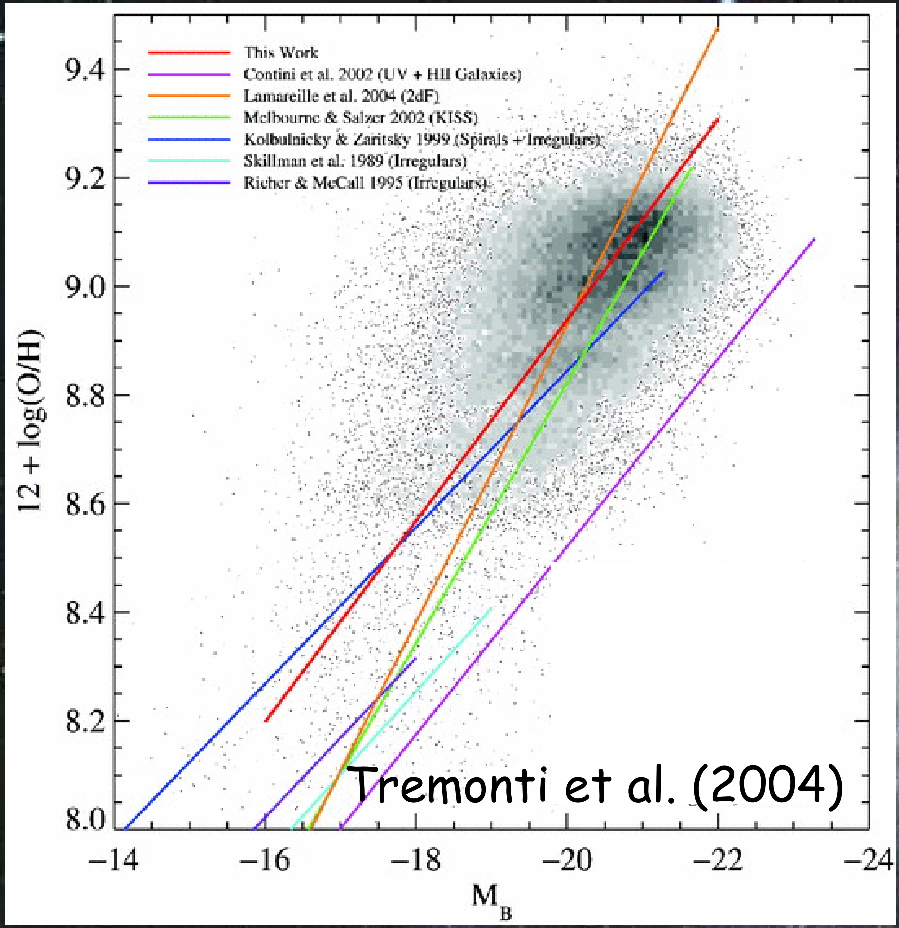
Using only strong lines
(“strong-line methods”)
→applicable to faint targets

Calibrating Strong-Line Methods

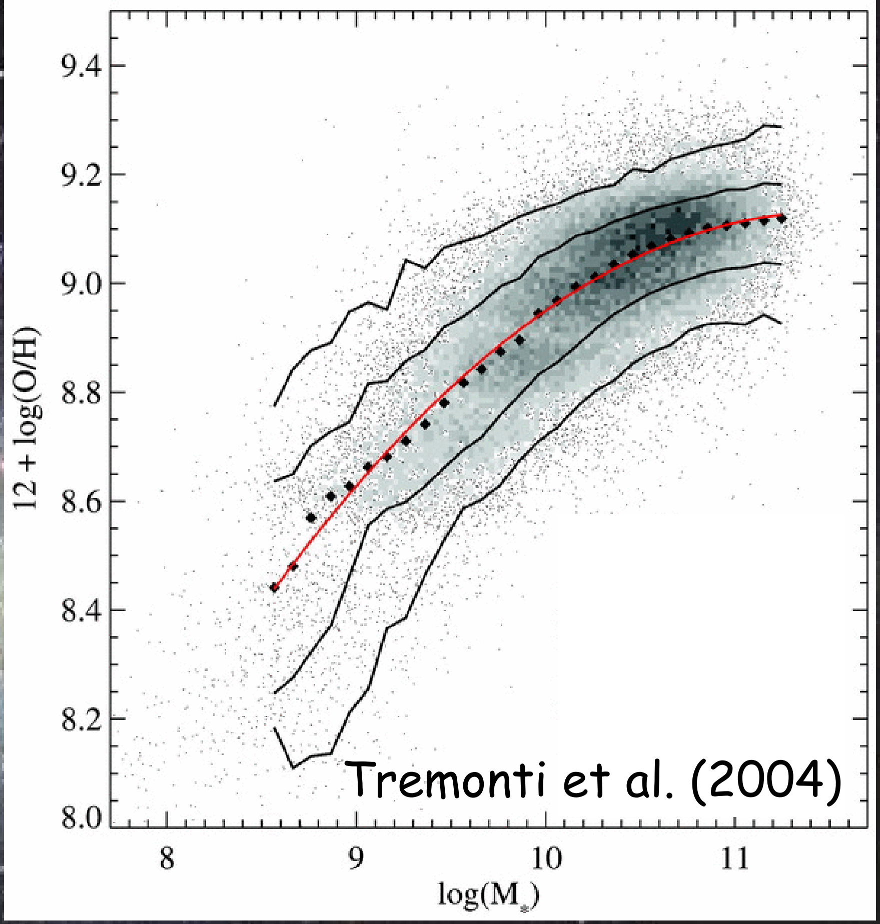




Metallicity of Galaxies at z=0.1

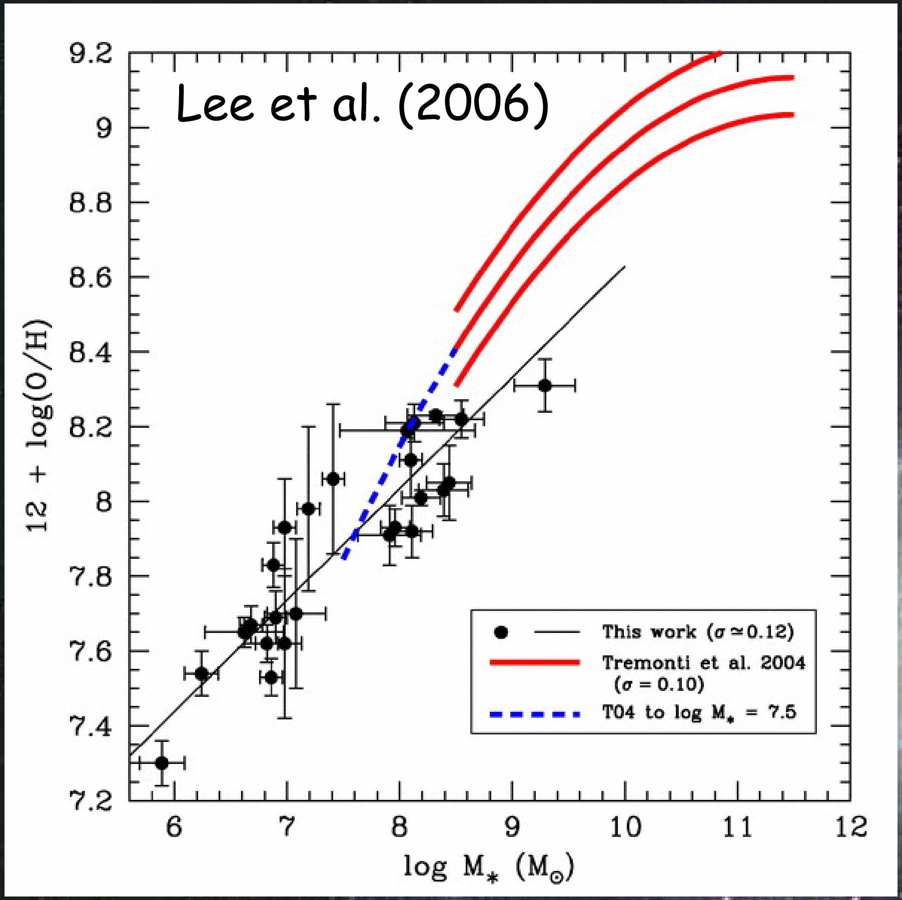


"Luminosity-Metallicity Relation"



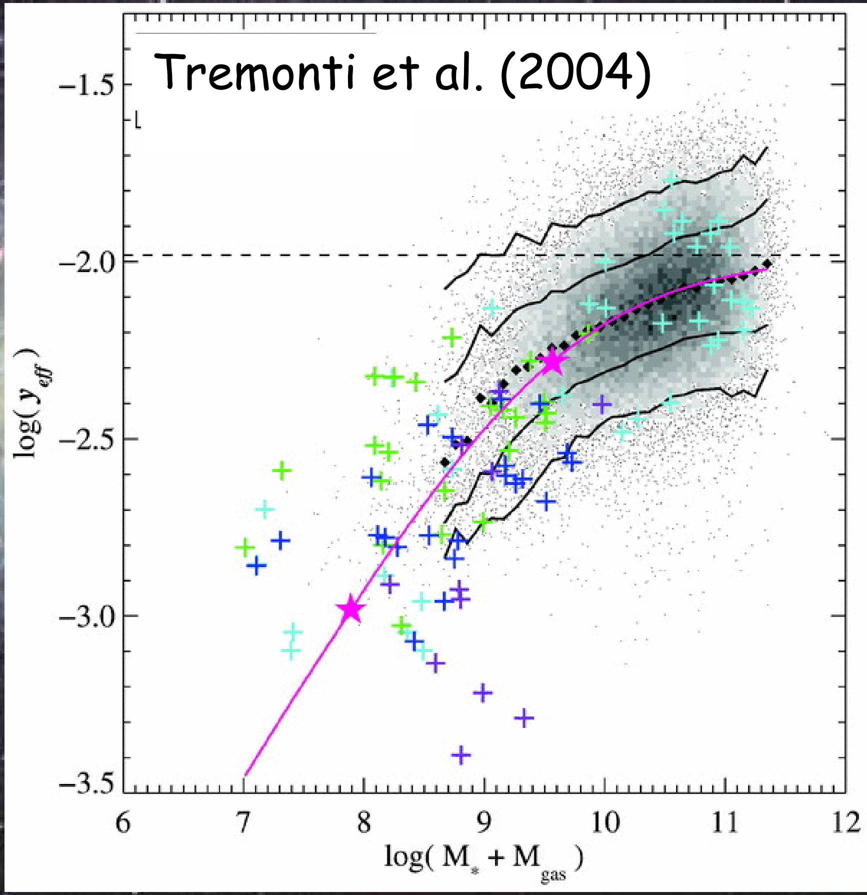
"Mass-Metallicity Relation"

Metallicity of Galaxies at z=0.1 (cont.)



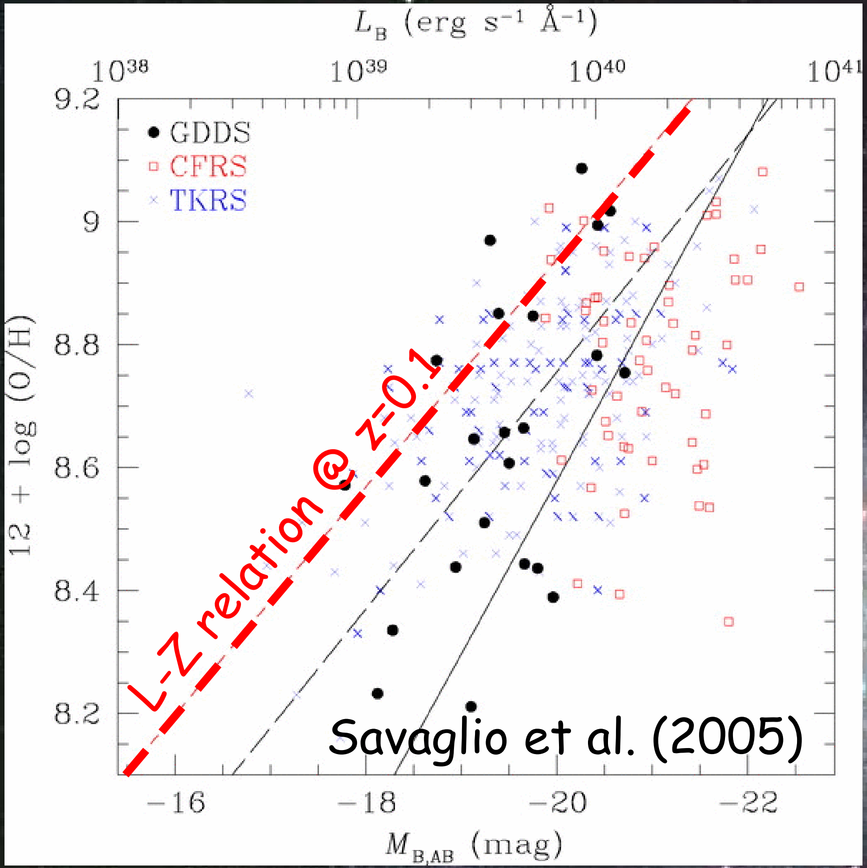
Assuming "closed box":

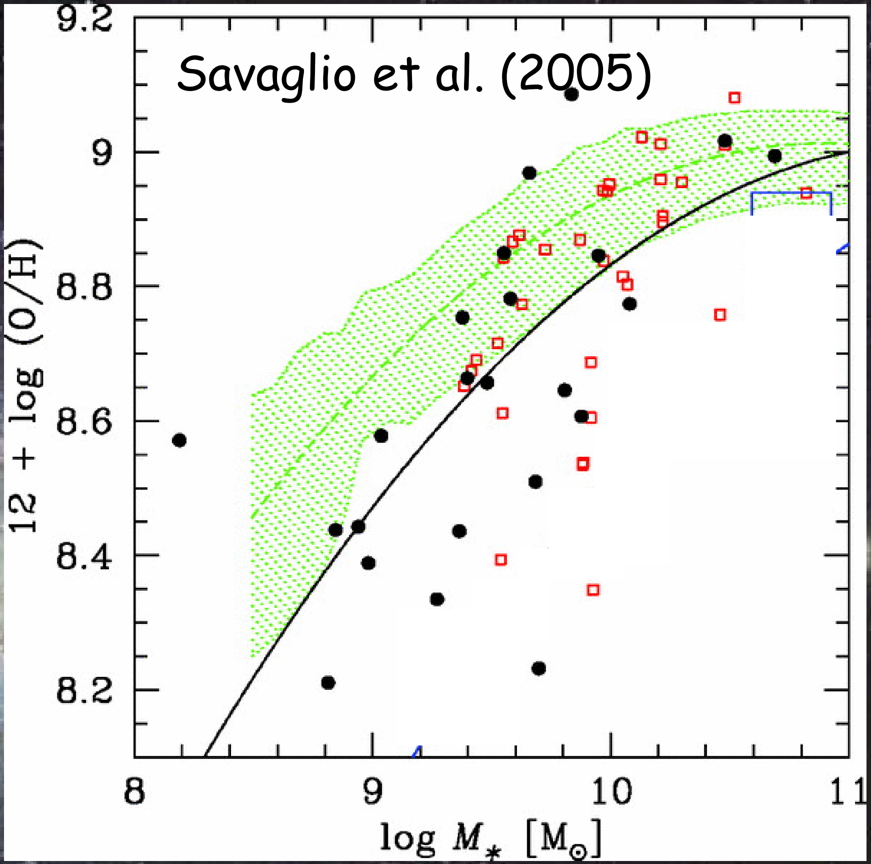
$Z = y \ln(\mu_{gas}^{-1})$ ➔ "y_{eff}"



M-Z relation for
6 decades in stellar mass

Metallicity of Galaxies at z=0.7

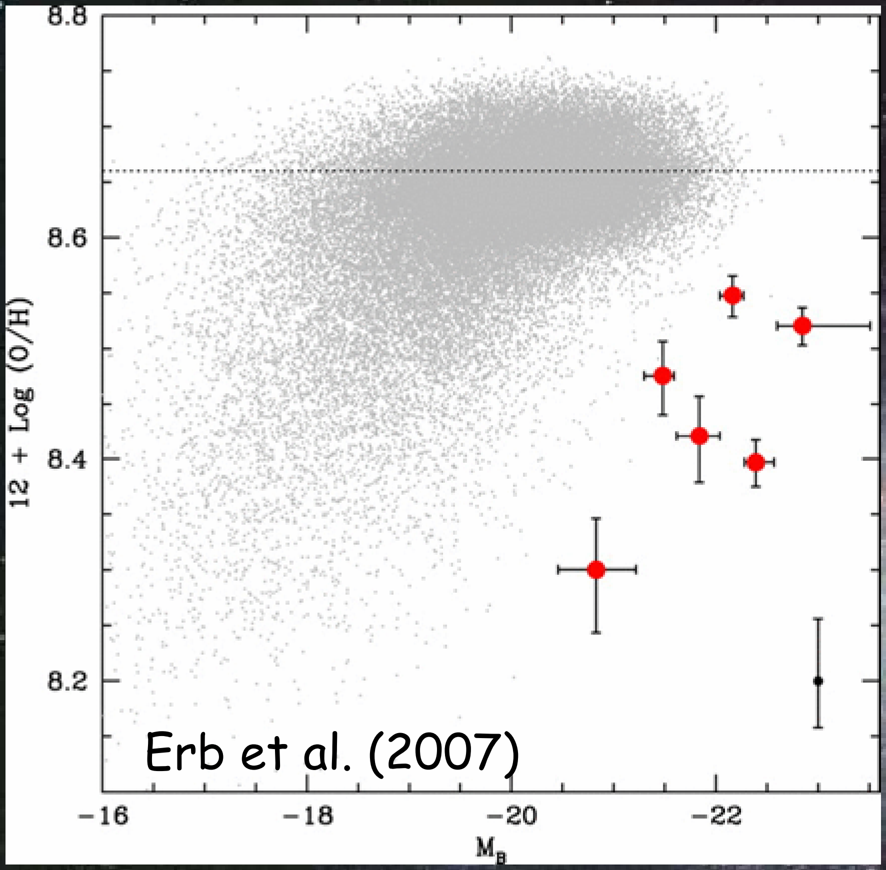


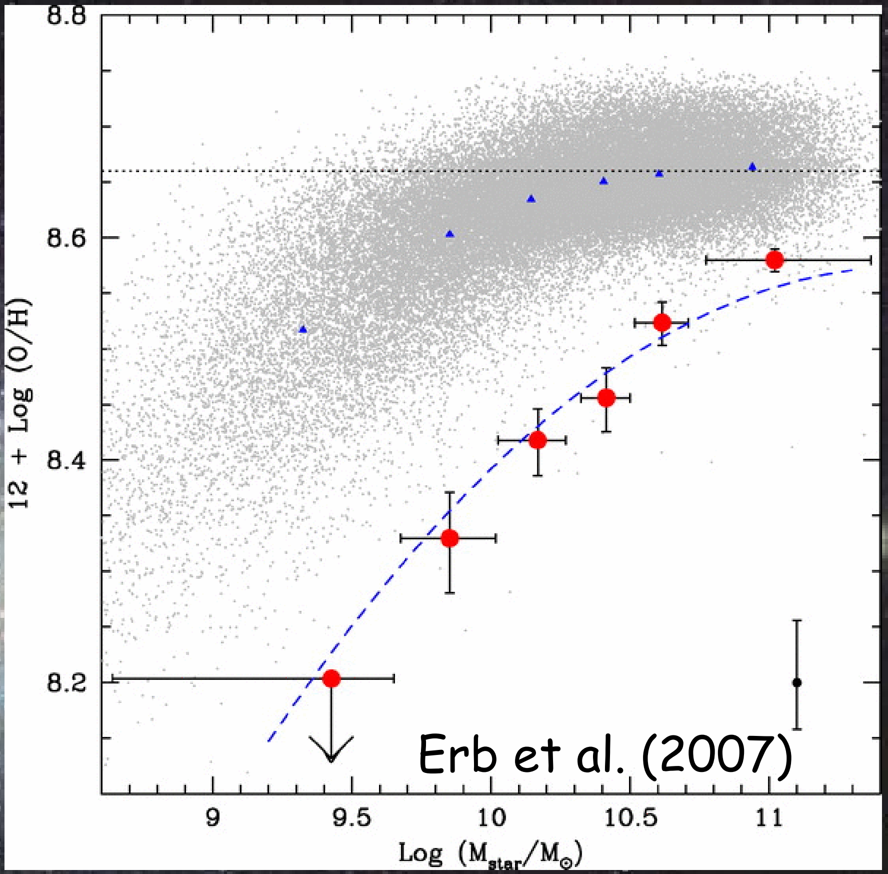


Evolving L-Z relation !!

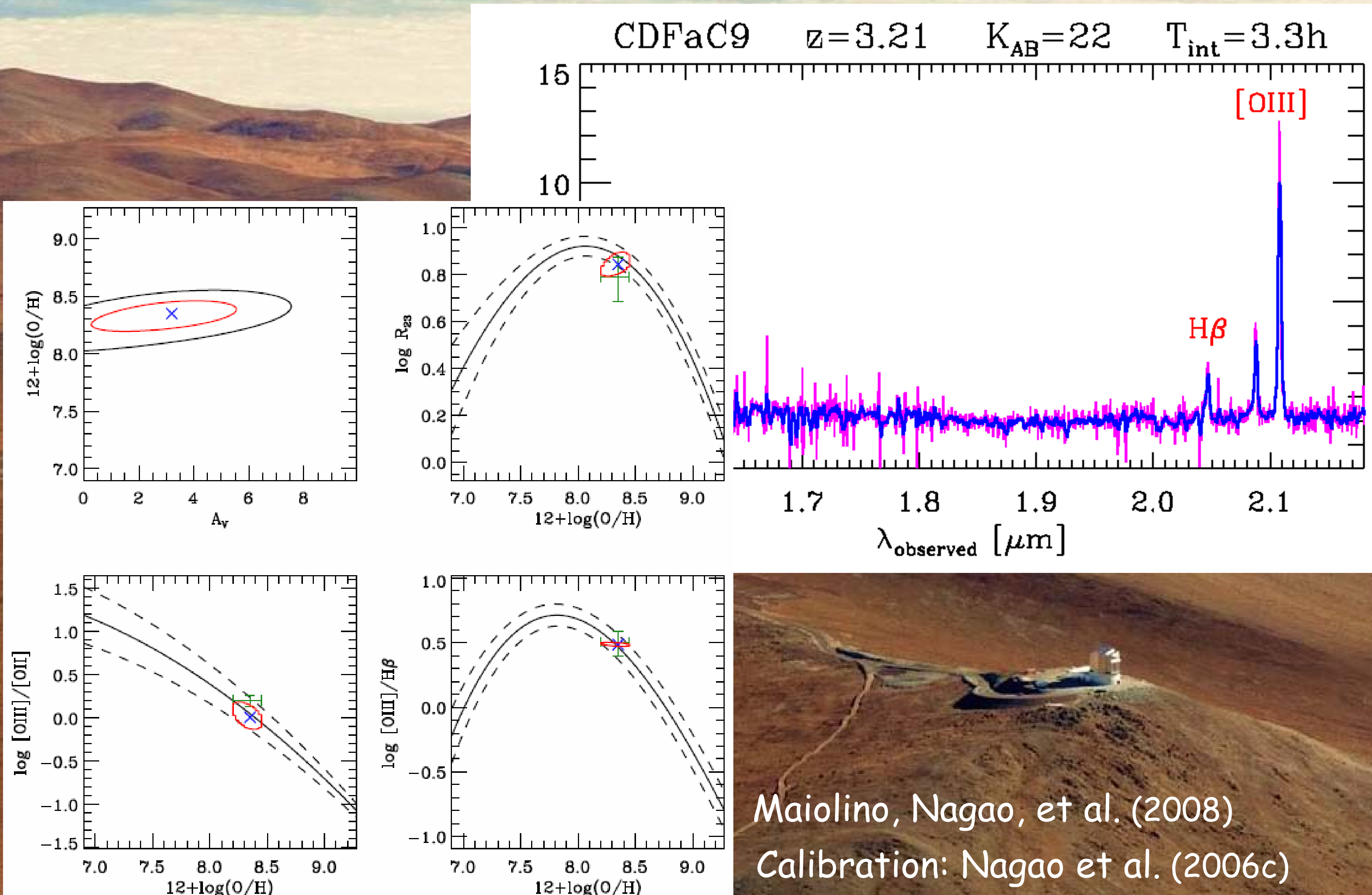
M-dependent M-Z evolution !!

Metallicity of Galaxies at z=2





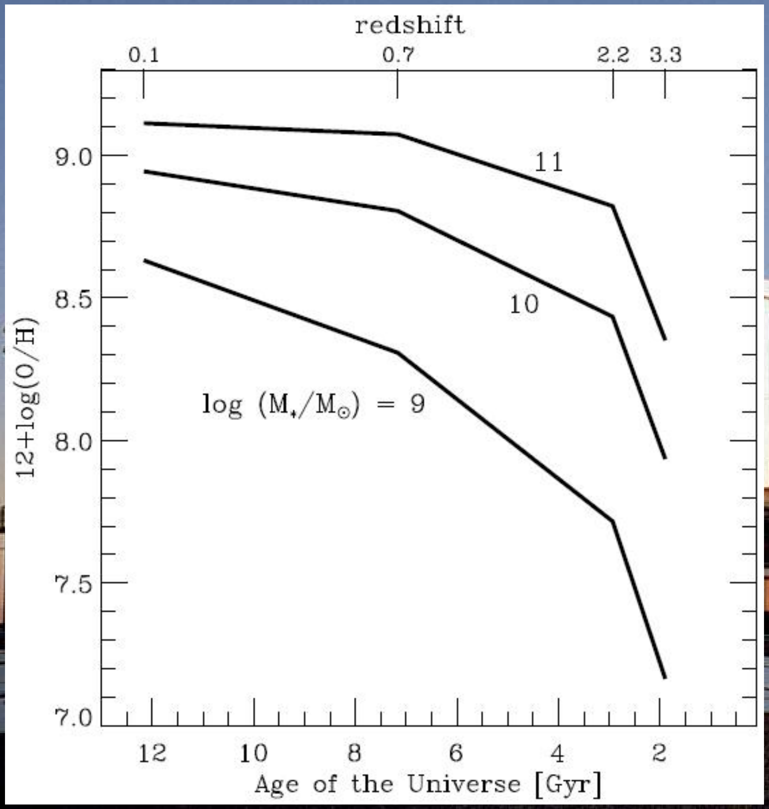
Metallicity of Galaxies at z=3

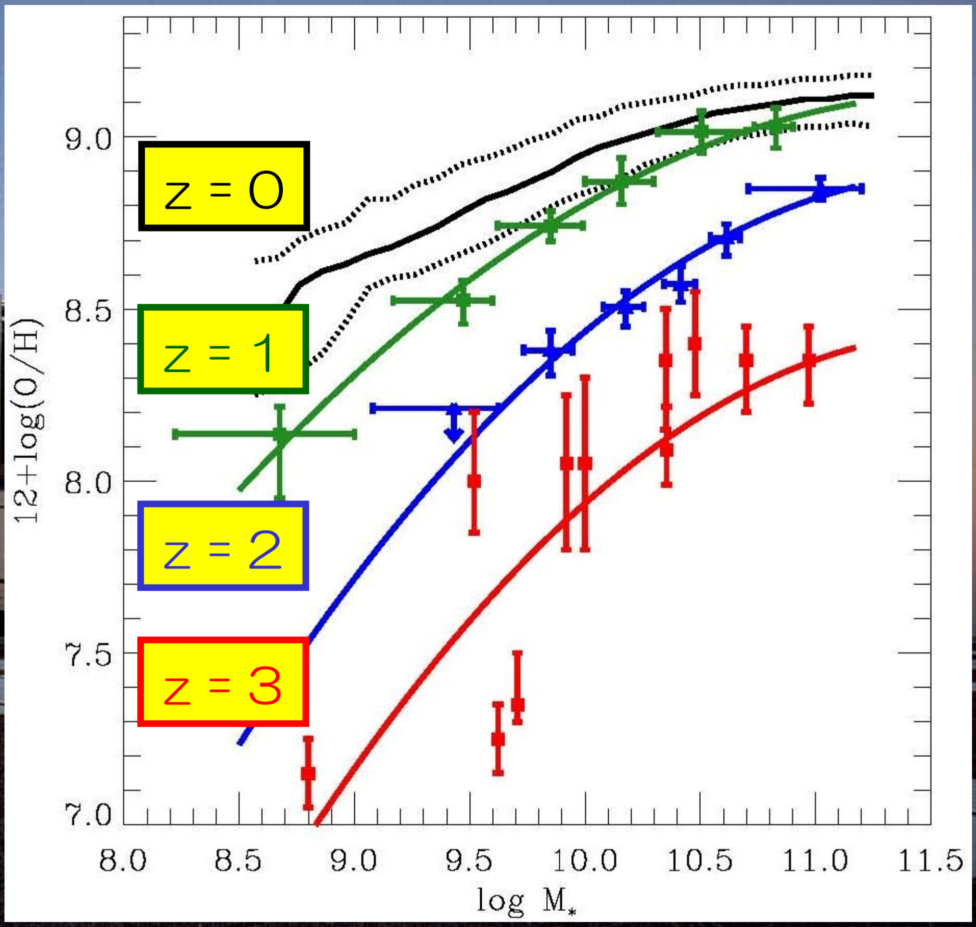


Maiolino, Nagao, et al. (2008)

Calibration: Nagao et al. (2006c)

M-Z Relation: Observational Result

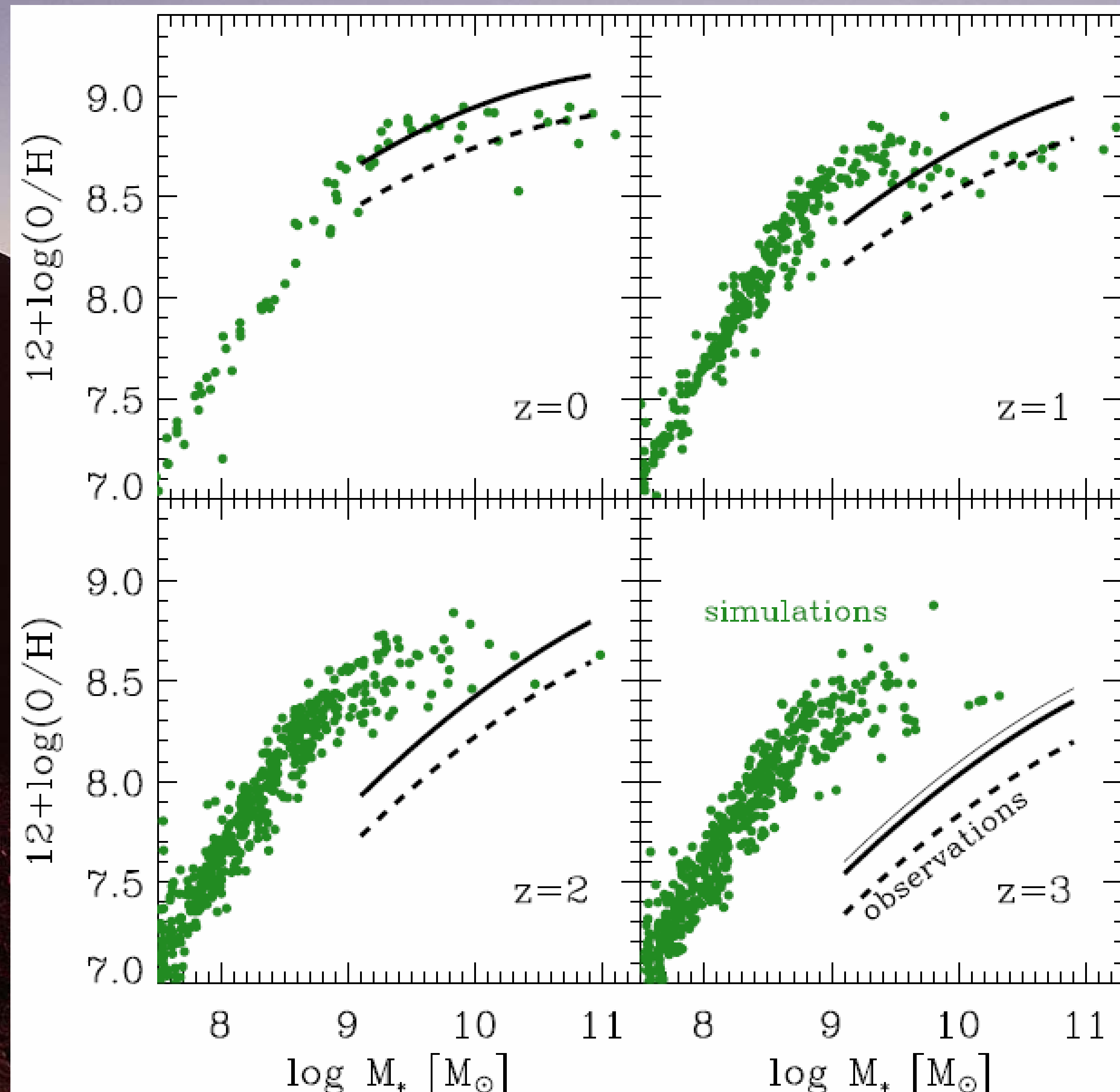




Maiolino, Nagao, et al., (2008)

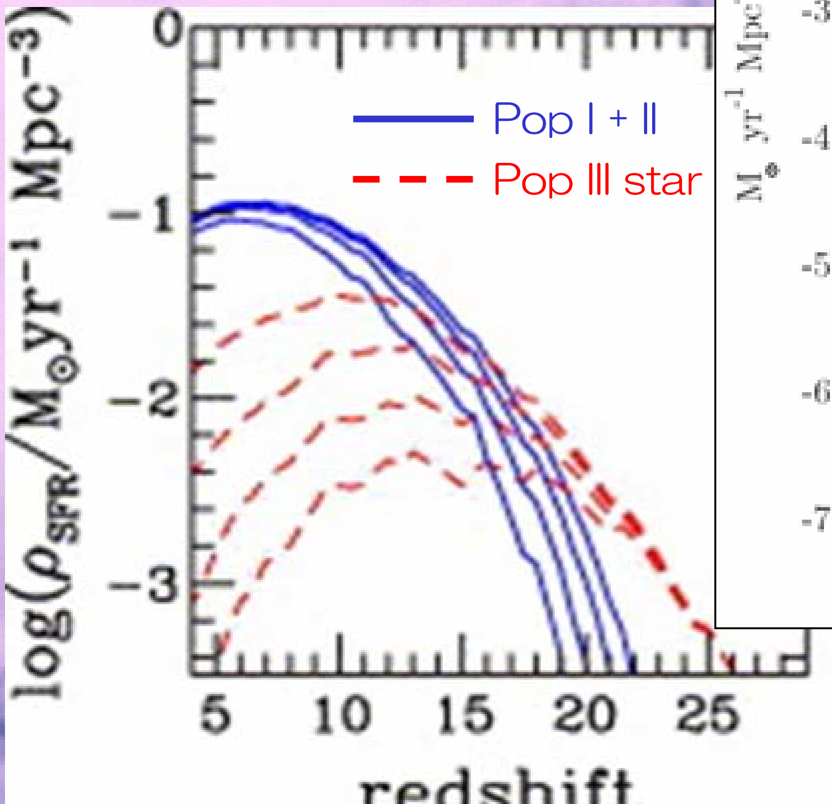
"Down-sizing chemical evolution"

M-Z Relation: Observations vs. Models

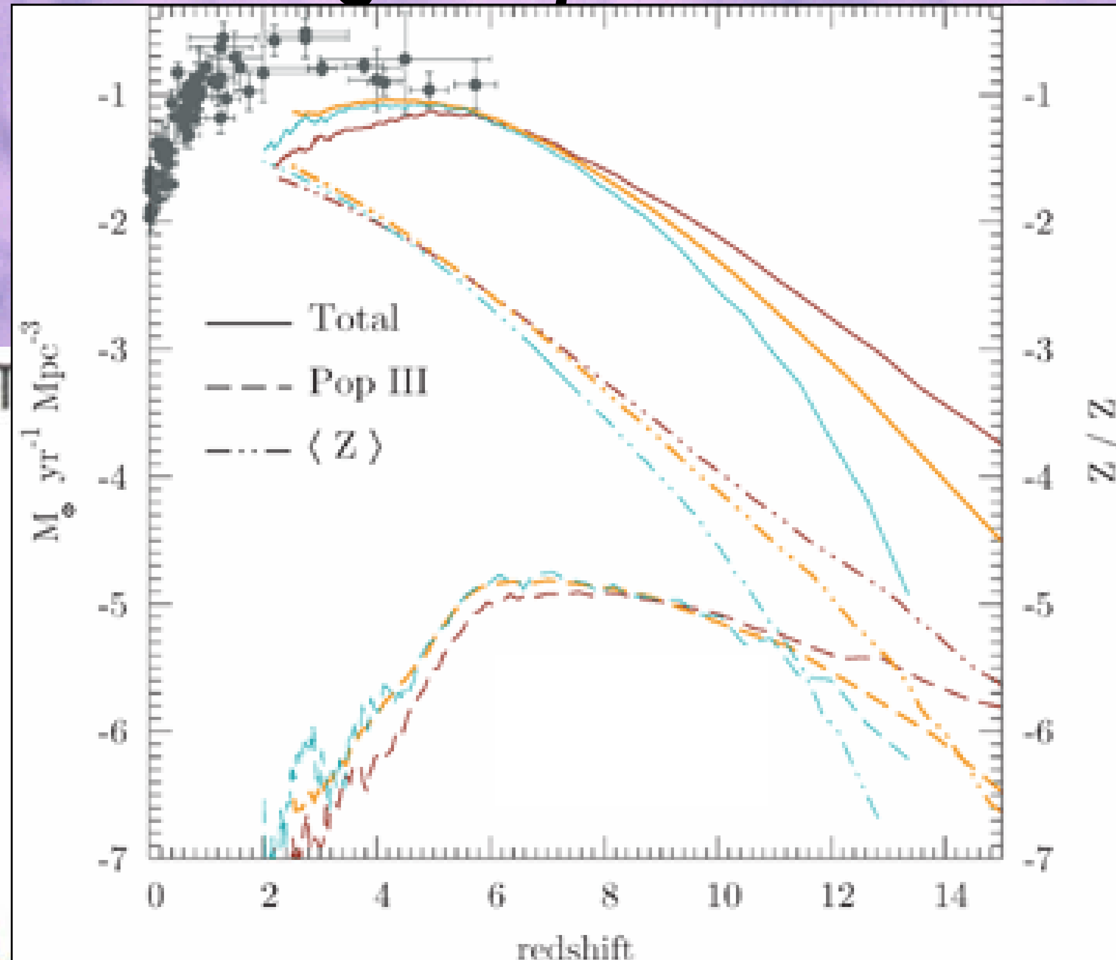


Simulation:
Kobayashi et al. 2007
Observations:
Maiolino, Nagao, et al. 2008

Toward Zero-Metallicity: PopIII



Scannapieco et al. (2003)

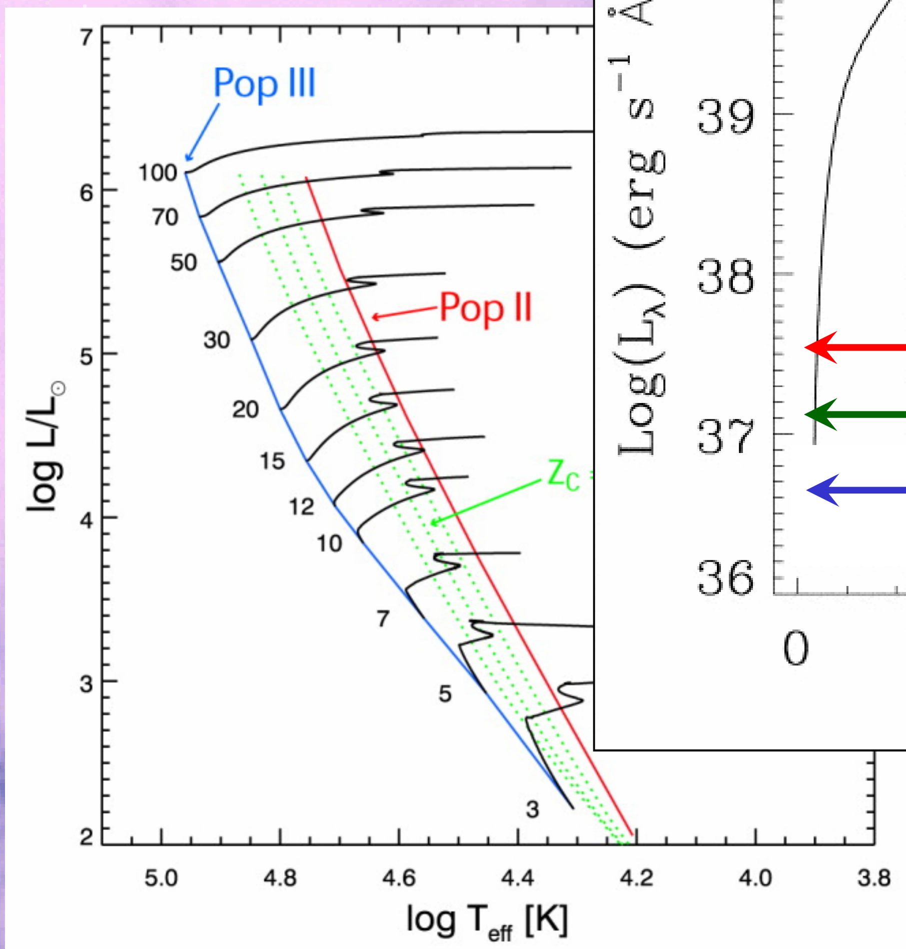


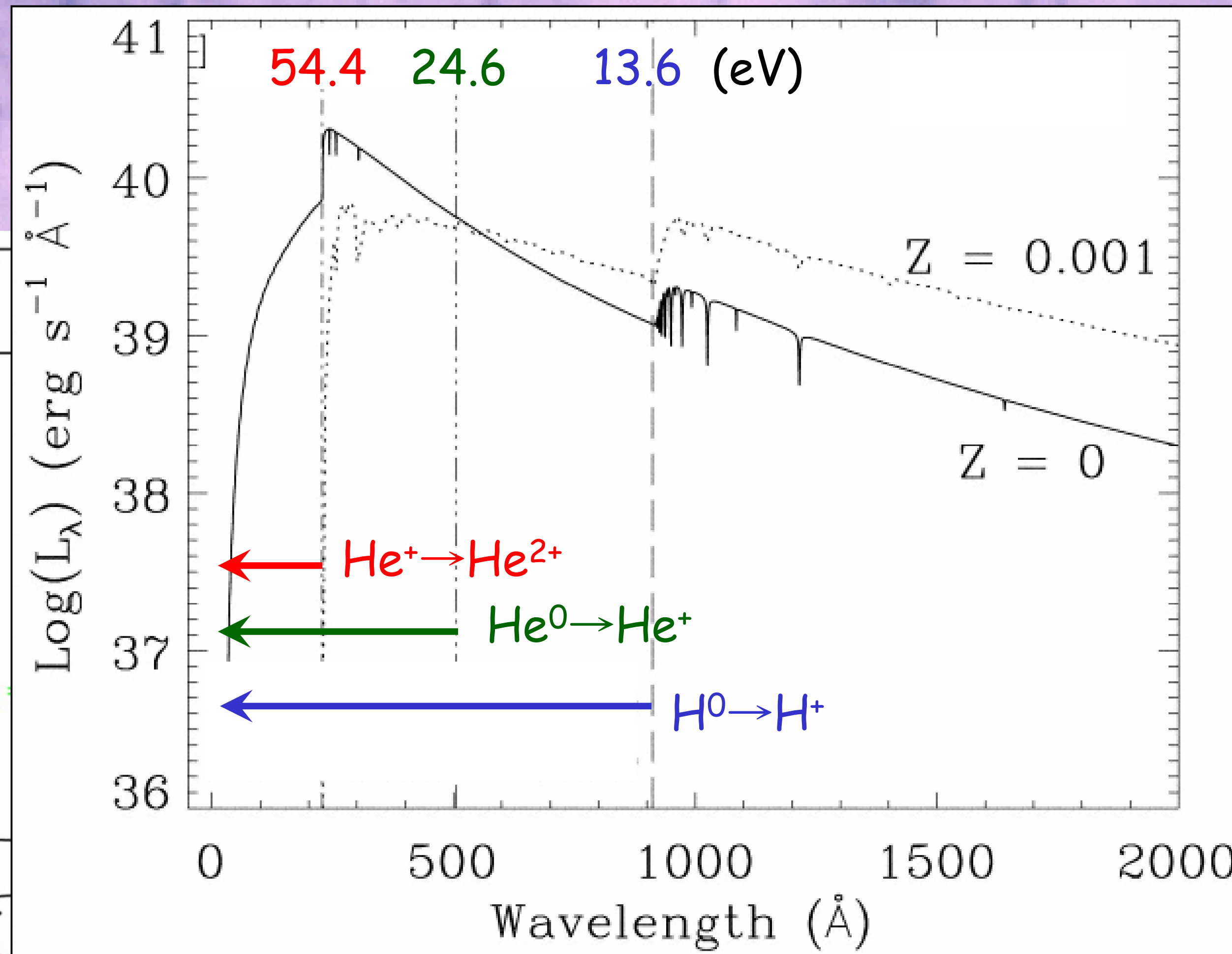
Tornatore et al. (2007)

Yoshida et al. (2003)

Expected Properties of PopIII

Tumlinson et al. (2003)

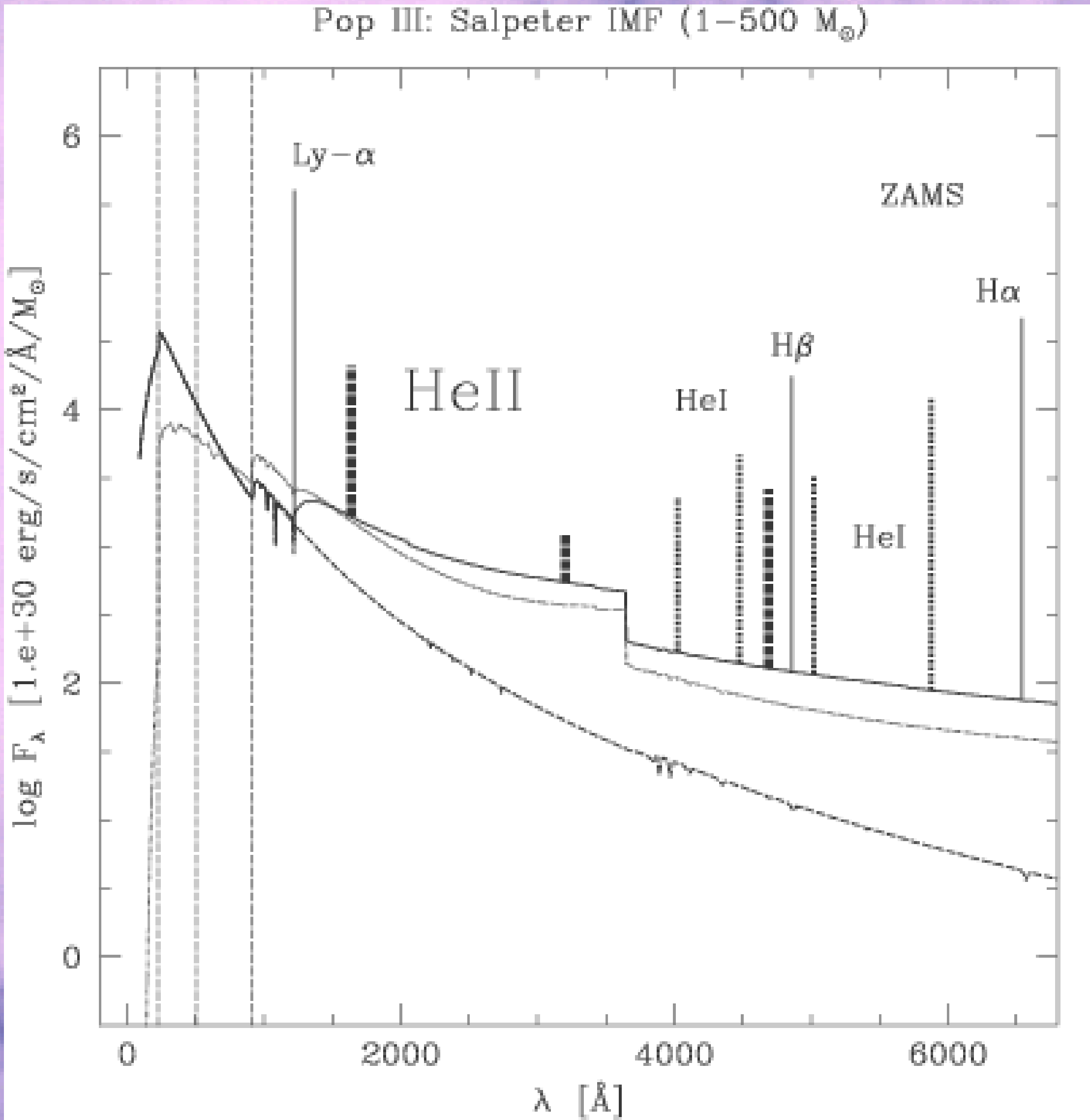




Tumlinson & Shull (2001)

Yoshida et al. (2003)

Expected Spectra from PopIII



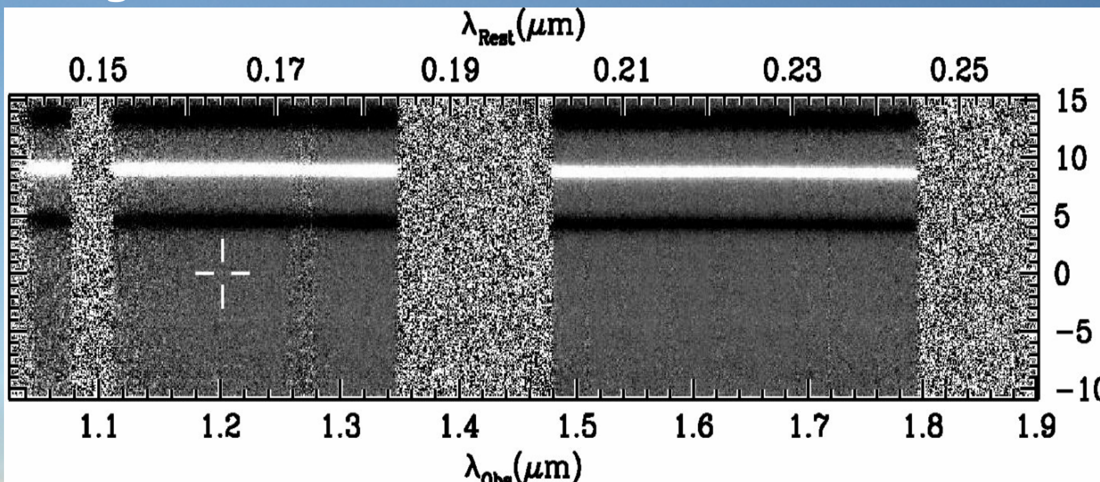
Schaerer (2002)

The earliest phase (with PopIII) of the galaxy evolution is characterized by strong H I and He II emission lines !

Yoshida et al. (2003)

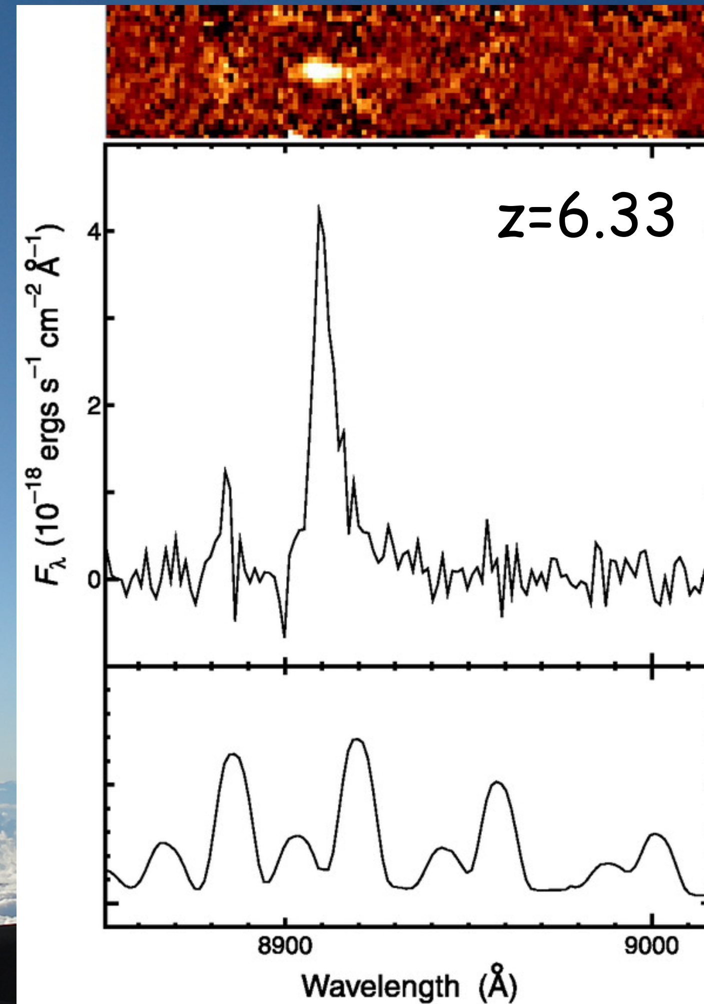
Searching PopIII Galaxies

Nagao et al. (2005b)



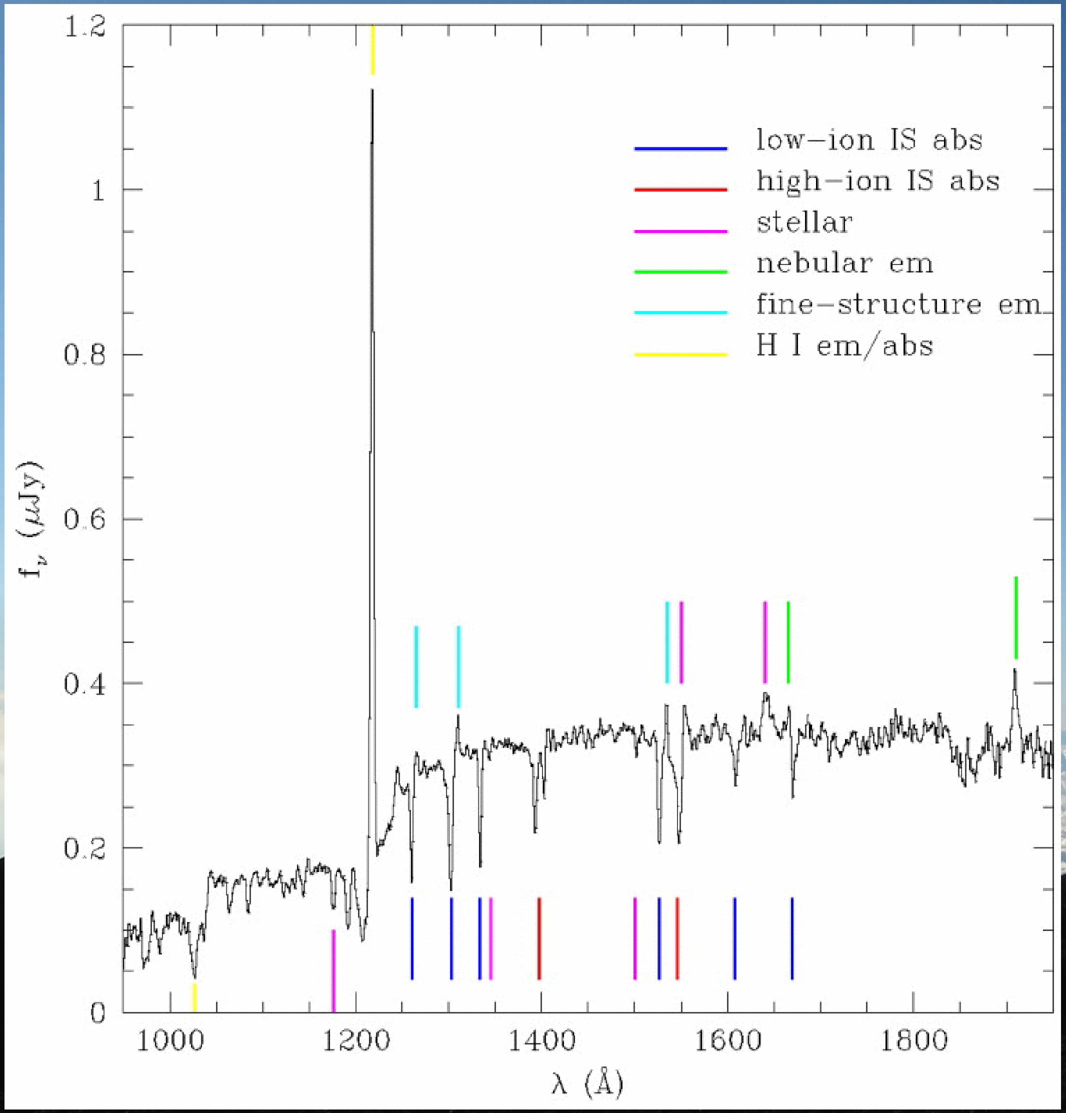
Subaru/OHS J-band spectroscopy
54 ksec (3 nights) integration (!!!)
→ no detection…

Nagao et al. (2004)



SDF i-drop with huge EW Lyα:
see also Nagao et al. (2005a, 2007)

Stacking Analysis



811 LBGs at z=3
(Shapley et al. 2003)

He II emission !?

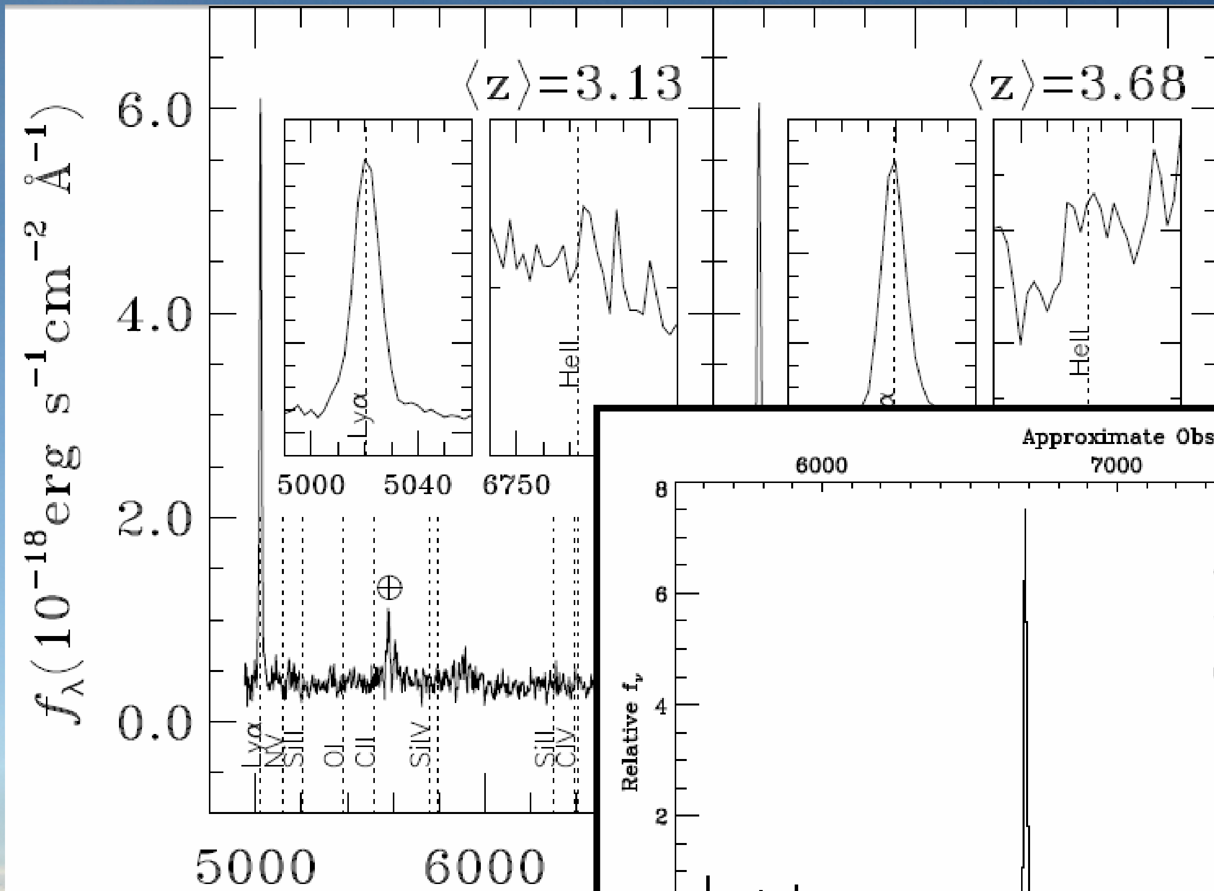
Evidence of PopIII !?
(Jimenez & Haiman 2006)

Just a stellar feature?
(mentioned by Shapley+03)

…let's see LAEs,
instead of LBGs…

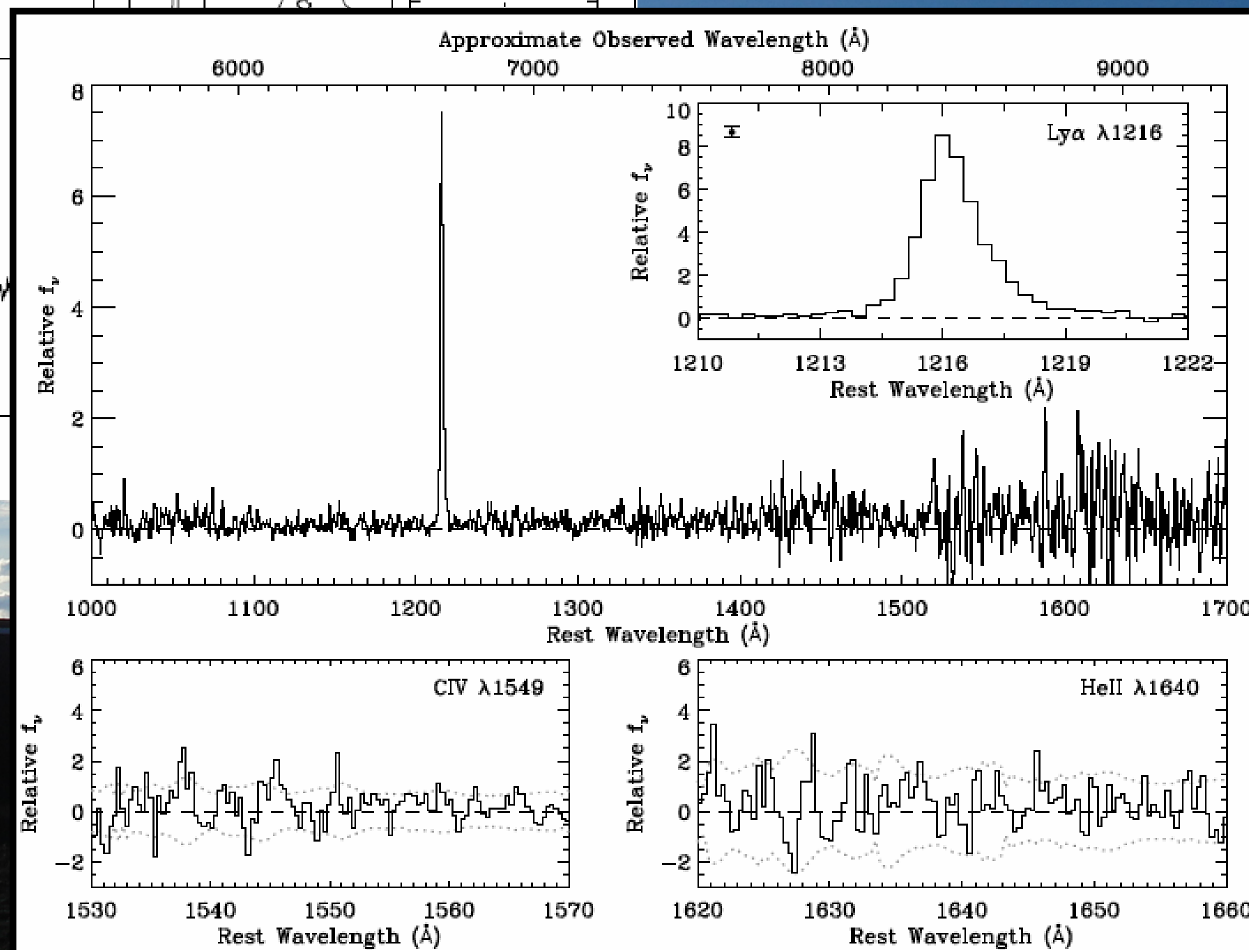
36 LAEs at z=3.1
31 LAEs at z=3.7
(Ouchi et al. 2008)

No He II emission...



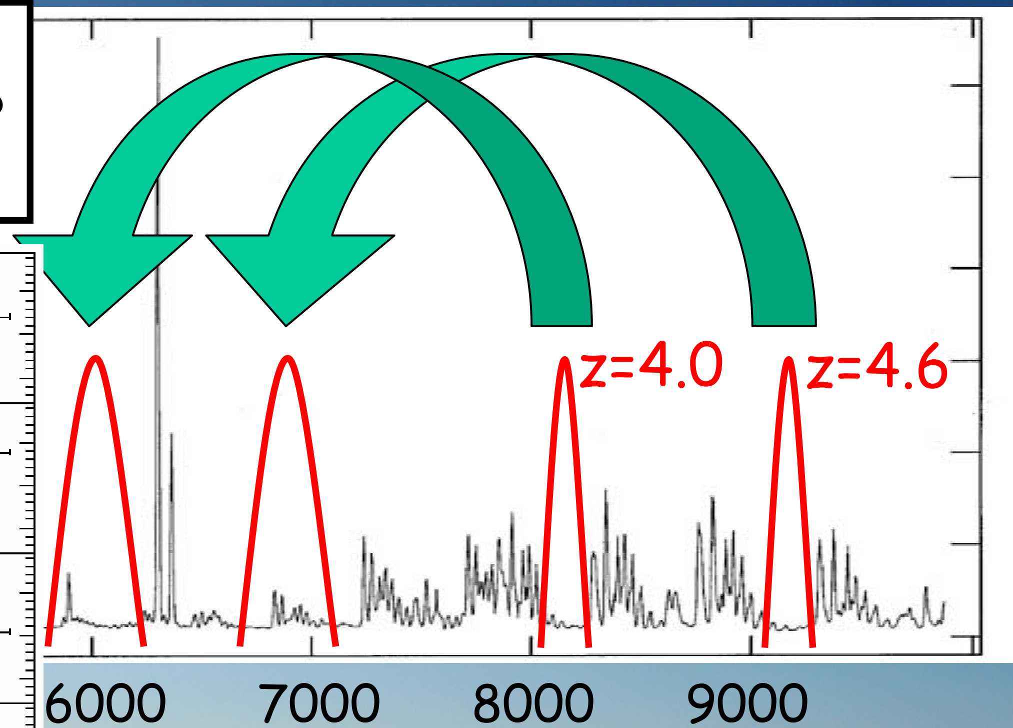
11 LAEs at z=4.5
(Dawson et al. 2004)

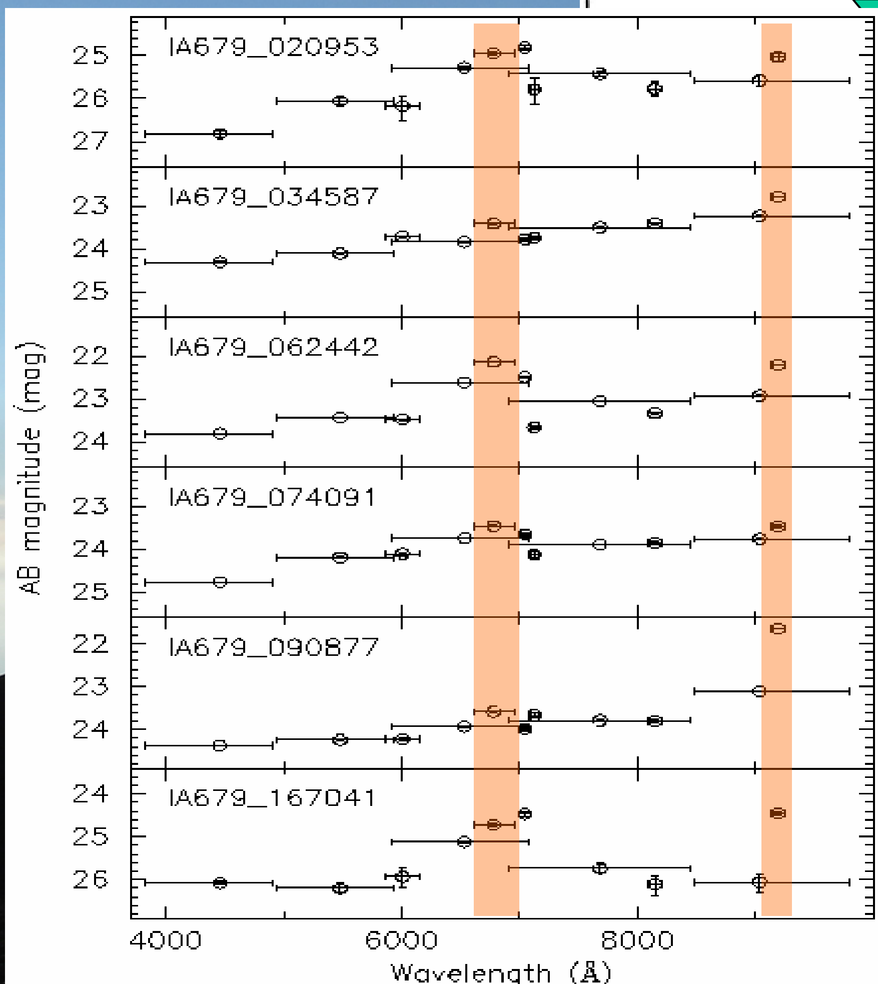
No He II emission...



Searching PopIII Galaxies AGAIN

Deep NB816/921 data in SDF
~ HeII emitters @z=4.0/z=4.6?
~ They should show Lyα also…

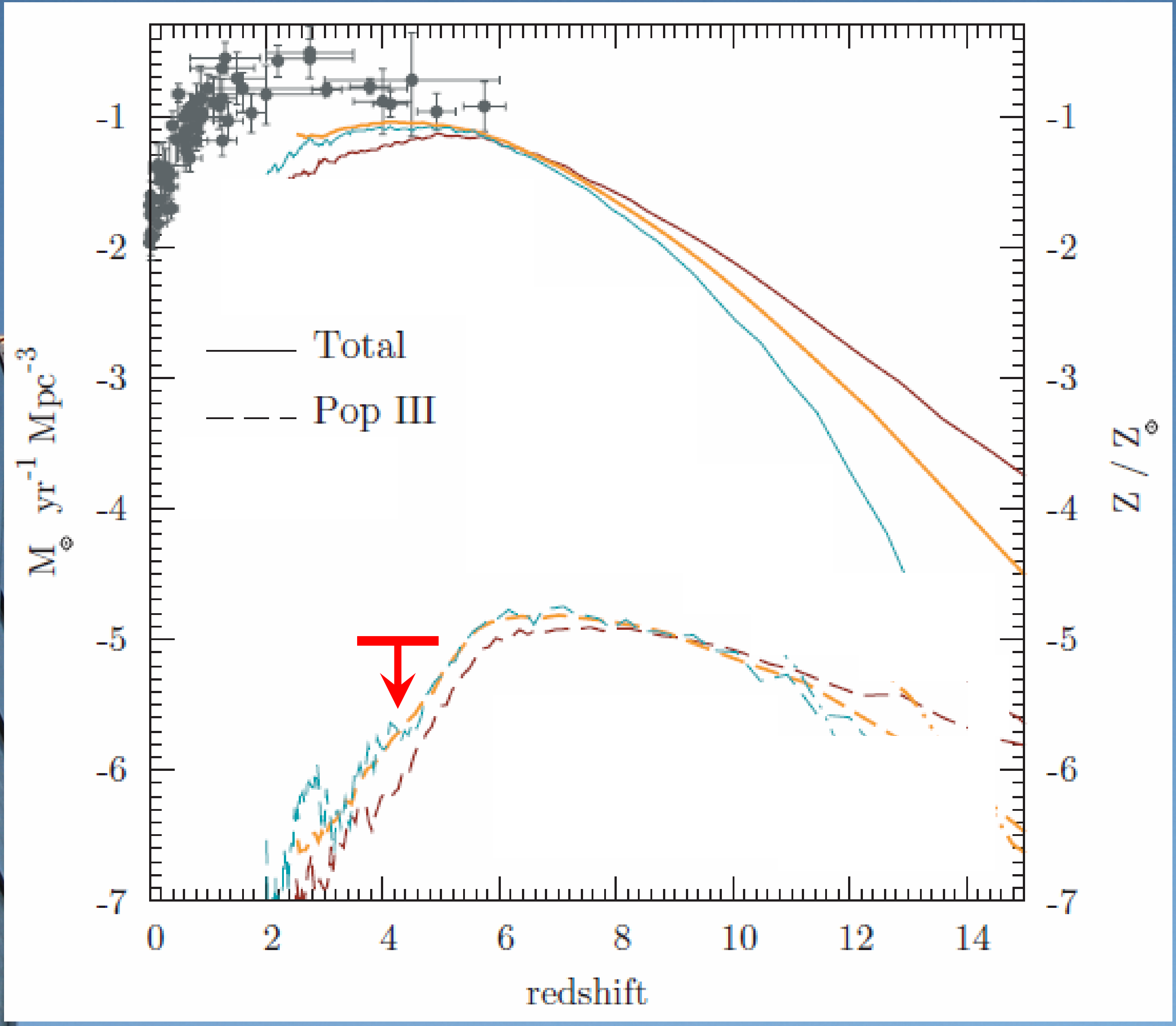




No candidates found…

Nagao et al. (2008)

PopIII Galaxies: Observations vs. Models

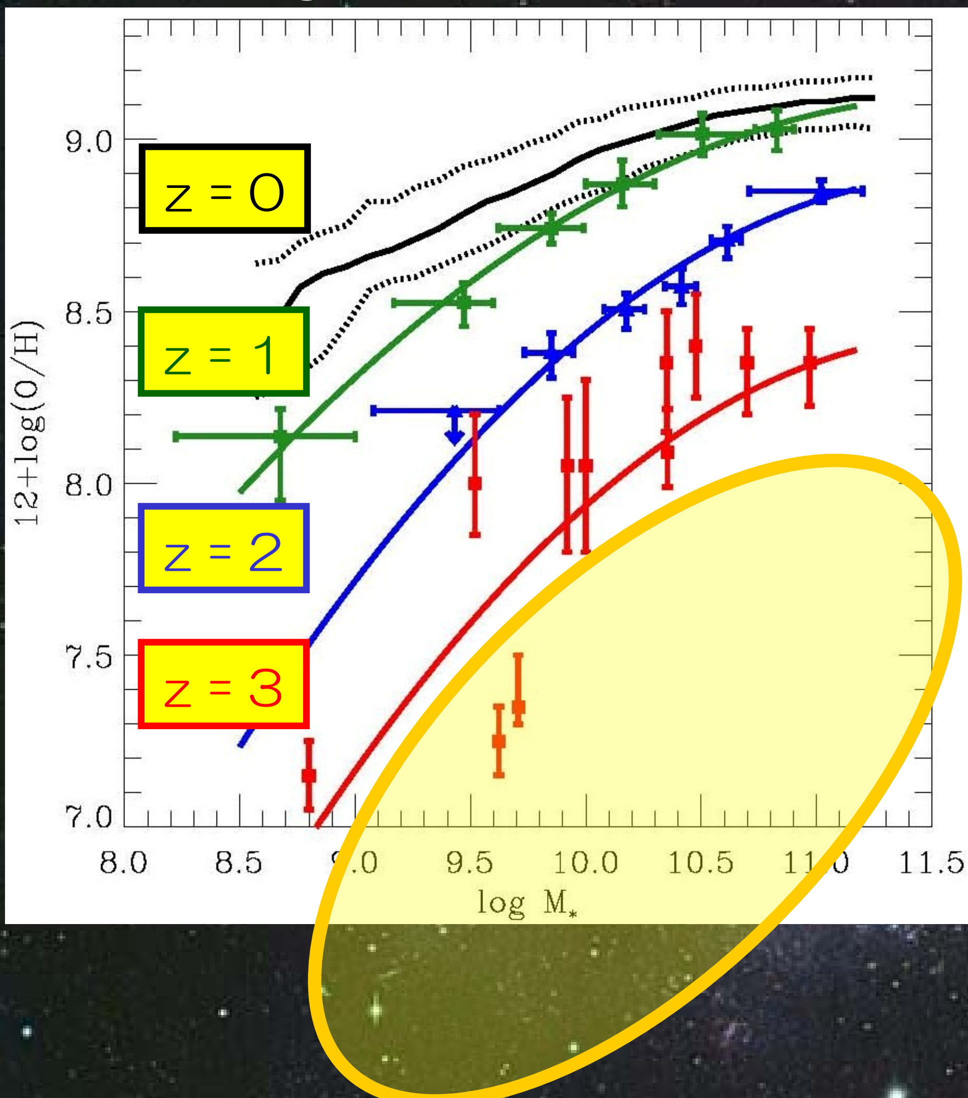


SFRD model:
Tornatore+2007

Observational limit:
Nagao+2008

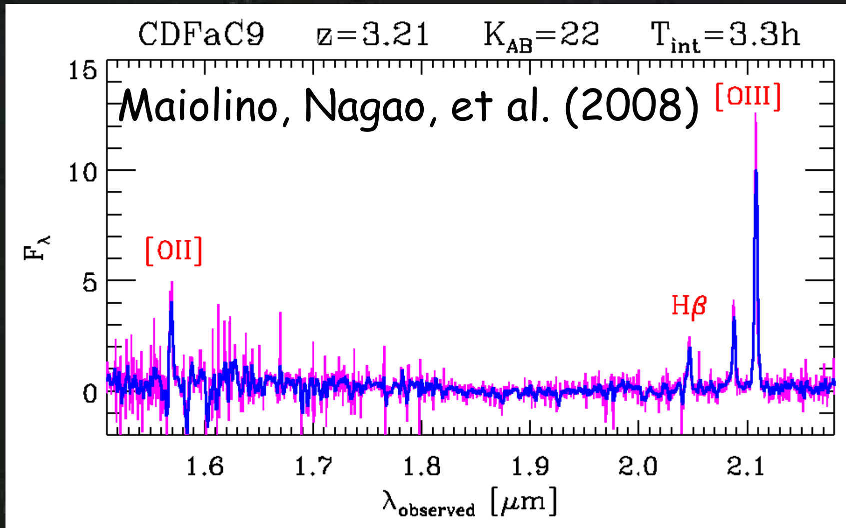
Future Prospects...?? (1)

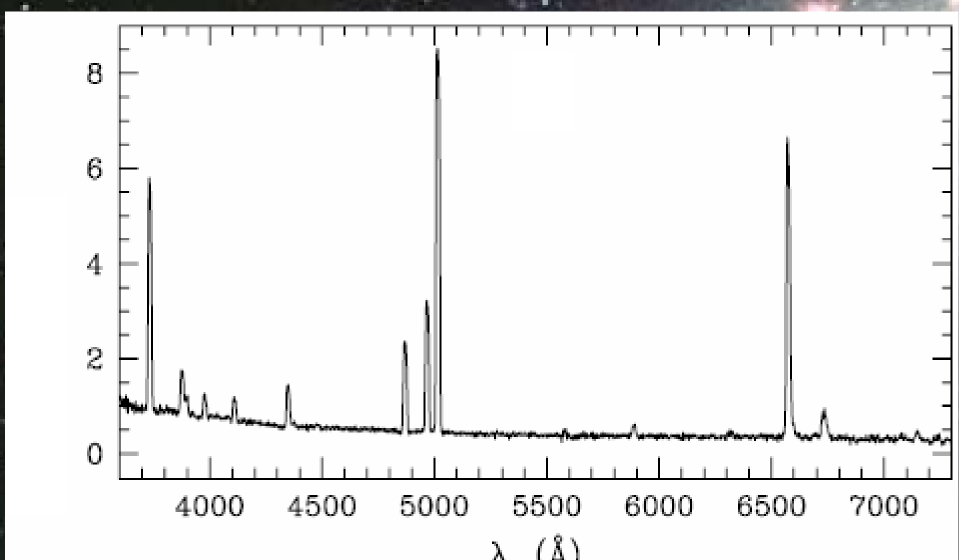
Maiolino, Nagao, et al., (2008)

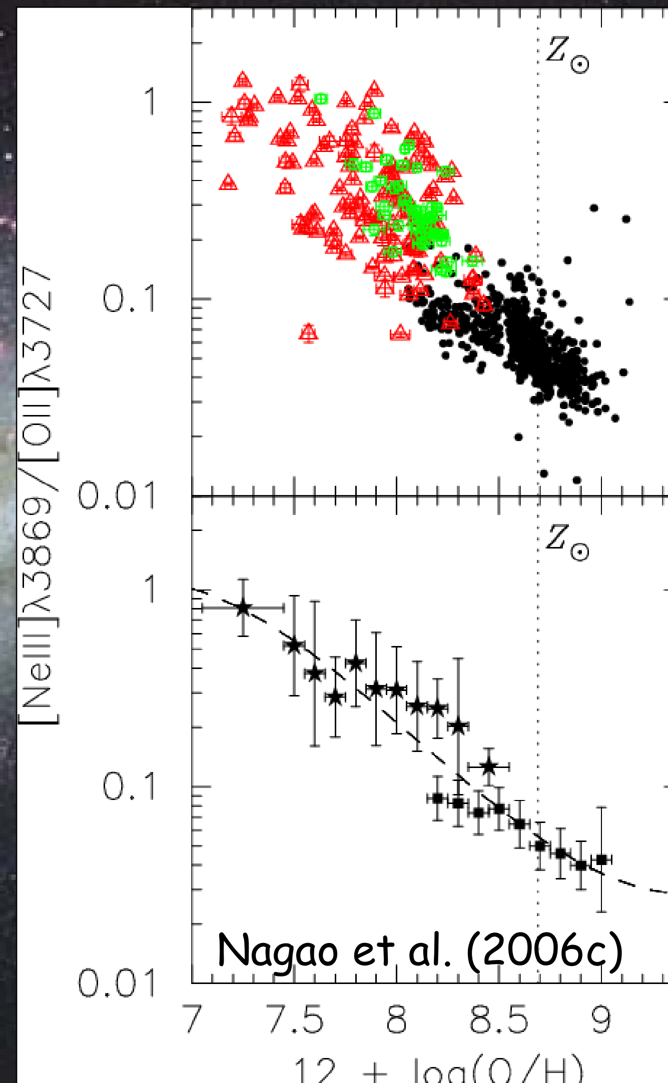


Going beyond z=3 !?

- Is it really interesting !?
- Is it really feasible !?

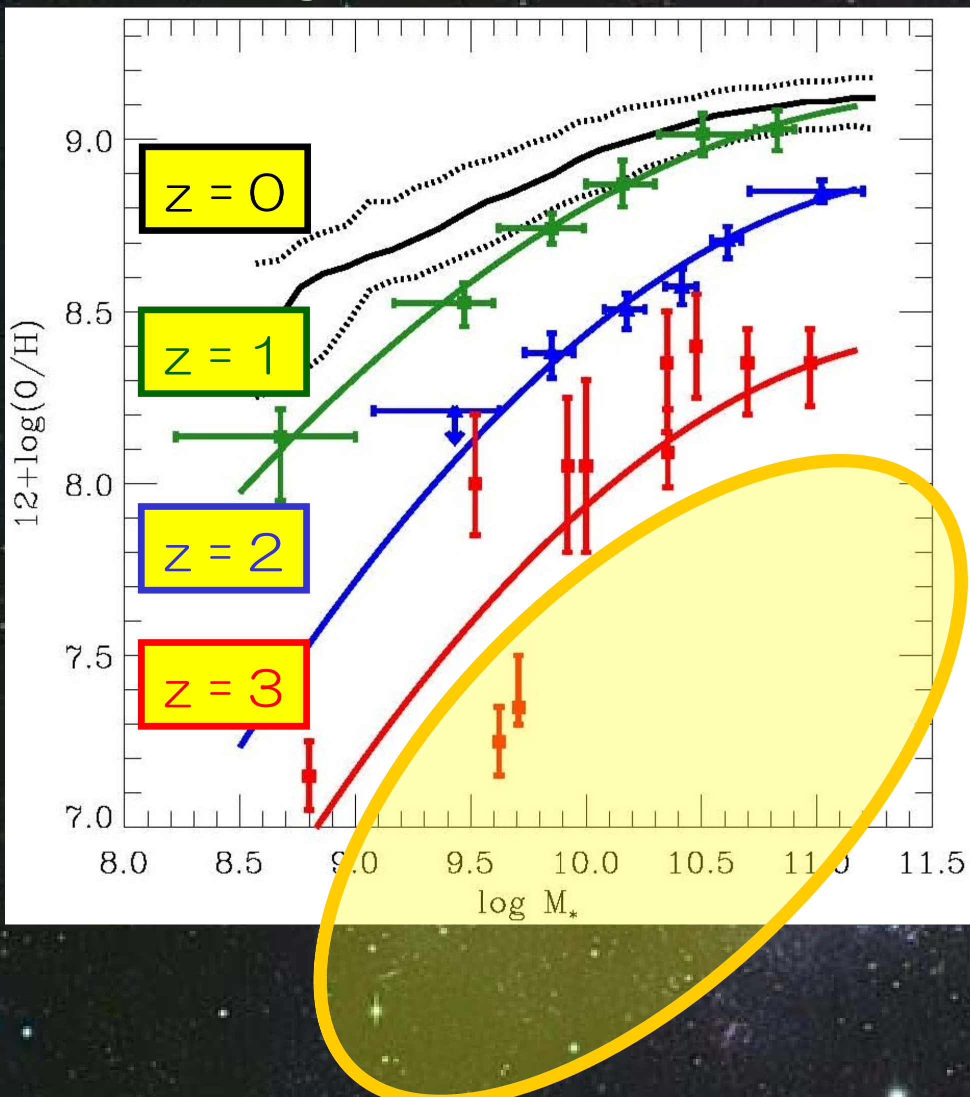

CDFaC9 z=3.21 K_AB=22 T_int=3.3h
Maiolino, Nagao, et al. (2008)
[OIII]
[OII]
Hβ
F_λ
15
10
5
0
1.6
1.7
1.8
1.9
2.0
2.1
λ_observed [μm]


8
6
4
2
0
4000
4500
5000
5500
6000
6500
7000
λ (Å)


[NeIII]λ3869/[OII]λ3727
Z⊙
1
0.1
0.01
Nagao et al. (2006c)
7
7.5
8
8.5
9
12 + log(O/H)

Future Prospects…?? (1)

Maiolino, Nagao, et al., (2008)

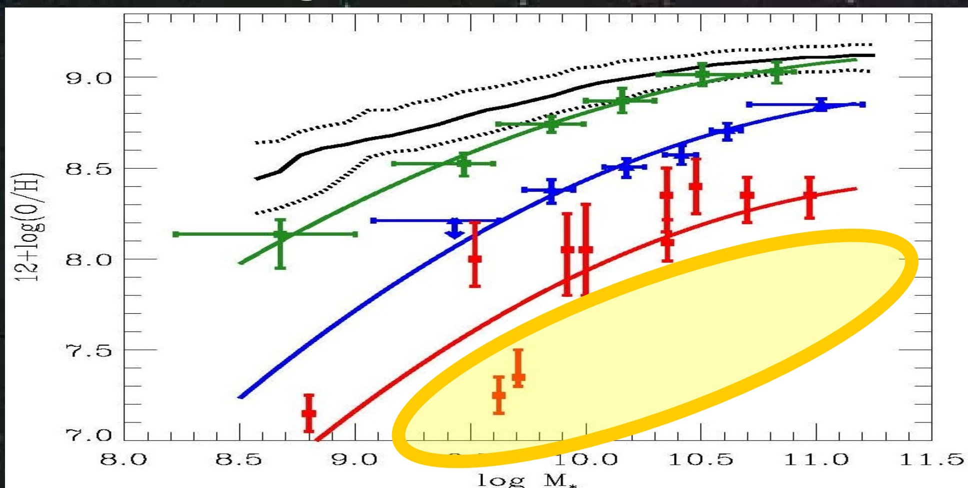


Going beyond z=3 !?

- Is it really interesting !?
- Is it really feasible !?
- Let's try with TMT
- Or, focusing AGNs !?
- Or, waiting for JWST !?

Future Prospects...?? (2)

Maiolino, Nagao, et al., (2008)



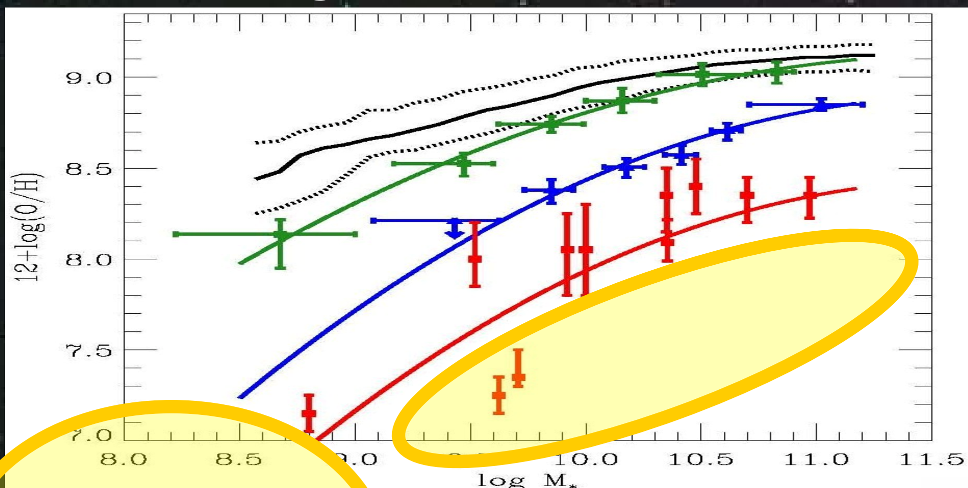
Z=0 (Zero Metallicity)

Still search for PopIII !?

- Let's wait for HSC
- Follow-up with JWST

Future Prospects…?? (3)

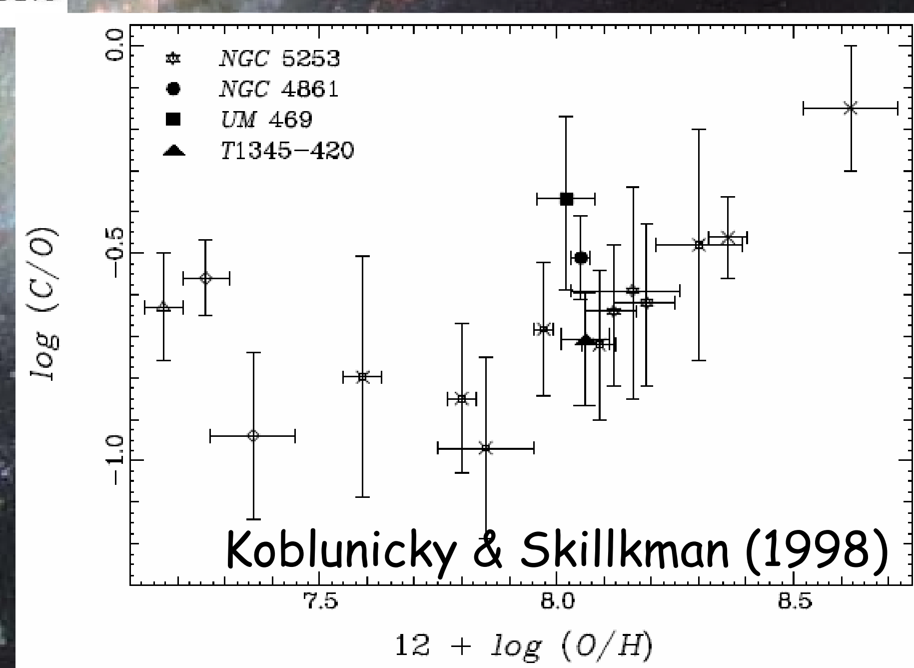
Maiolino, Nagao, et al. (2008)



Z=0 (Zero Metallicity)

Extremely Metal-Poor Gals

- Now Surveys on Going…
- Studying Earliest Phase of Chemical Evolution
- through "Relative" element abundance ratios



Koblunicky & Skillkman (1998)

Summary

(1) Metallicity Measurements of Galaxies

~ Downsizing evolution of the M-Z relation @ z<3
~ Inconsistent with Theoretical Models

(2) Observational Study to Search for PopIII

~ Possibly interesting even at z<10
~ He II emission is the most powerful diagnostic line
~ Multi-NB imaging → Meaningful limit on $SFRD_{PopIII}$

(3) Open Issues

~ Metallicity @ z>3: [Ne III] method, AGNs, or JWST
~ HSC may find PopIII candidates → JWST
~ Relative element abundance ratios (especially in XMPGs)

Collaborators

Roberto Maiolino	(Rome Observatory)
Alessandro Marconi	(Florence Univ.)
Matt Malkan	(UCLA)
Ly Chun	(UCLA)
Daniel Schaerer	(Geneve Observatory)
Kentaro Motohara	(Tokyo Univ.)
Nobunari Kashikawa	(NAOJ)
Yoshiaki Taniguchi	(Ehime Univ.)
Takashi Murayama	(Tohoku Univ.)

The AMAZE collaboration
Subaru Deep Field project

and much more...

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