METALS and DUST in the EARLY UNIVERSE

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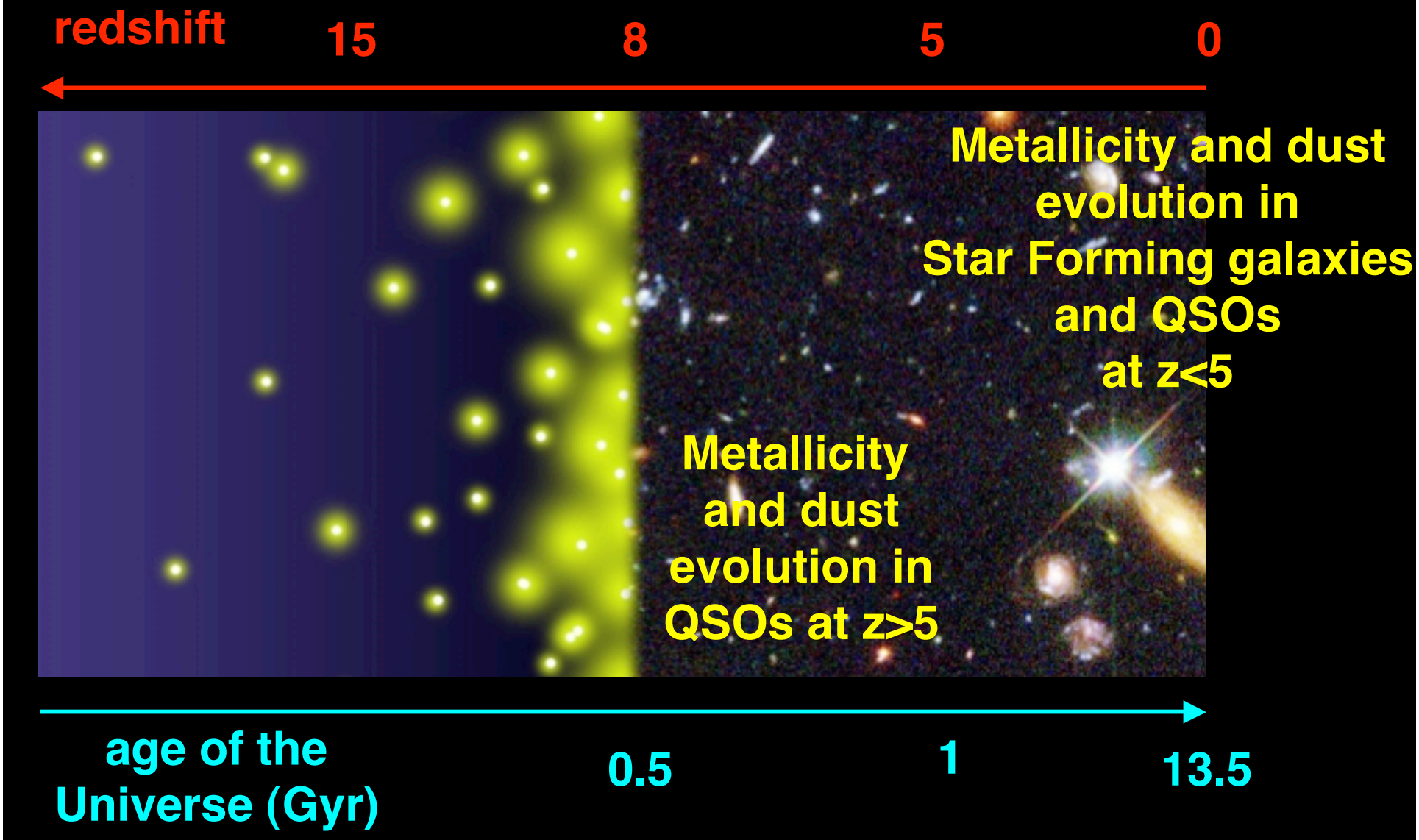
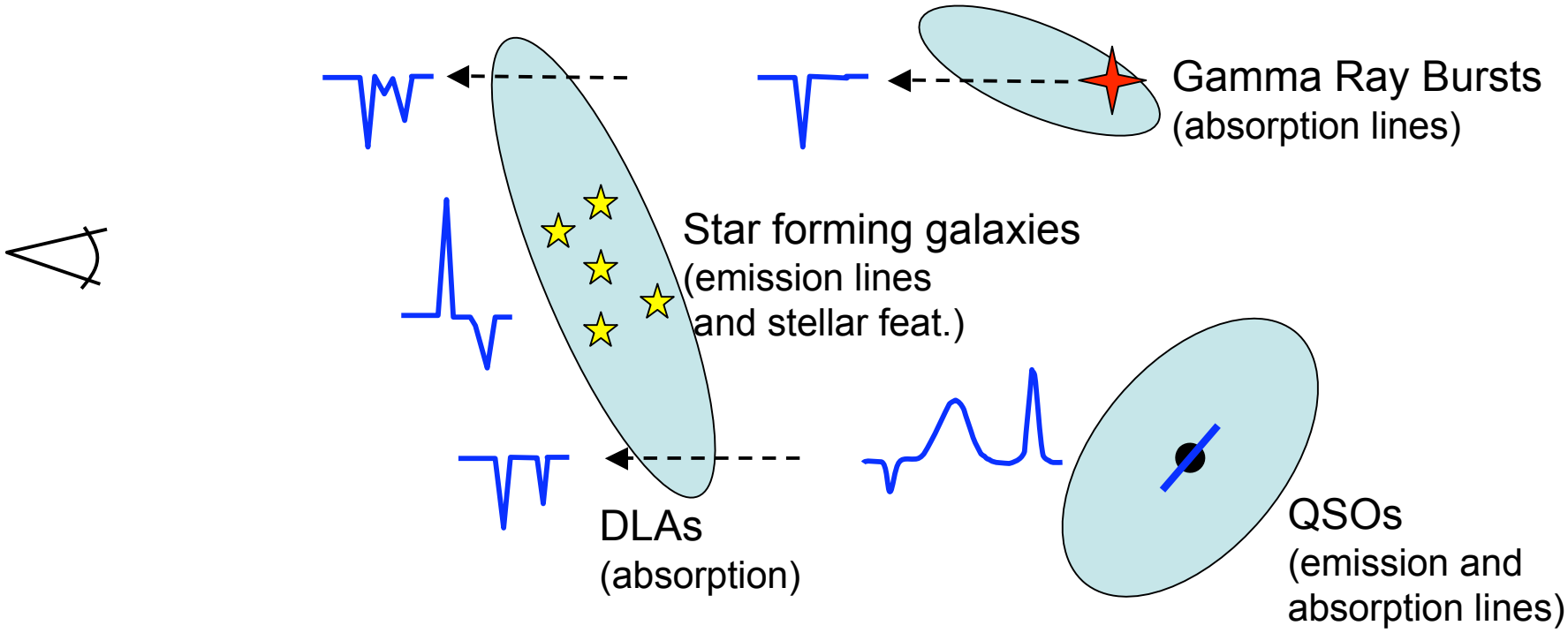
Outline

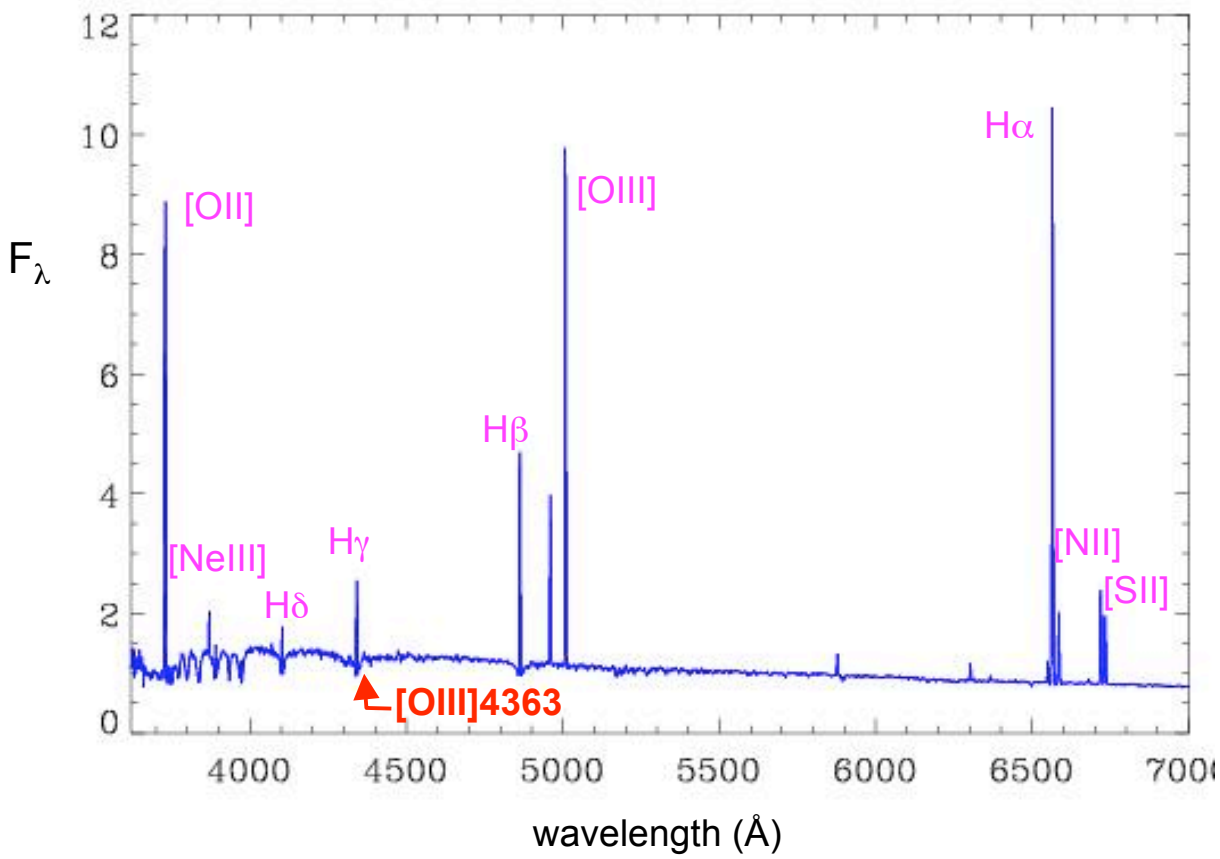

redshift
15
8
5
0
Metallicity and dust evolution in Star Forming galaxies and QSOs at z<5
Metallicity and dust evolution in QSOs at z>5
age of the Universe (Gyr)
0.5
1
13.5

Tracing metallicities at high-z



1. Metallicity Evolution in star forming galaxies at z<5

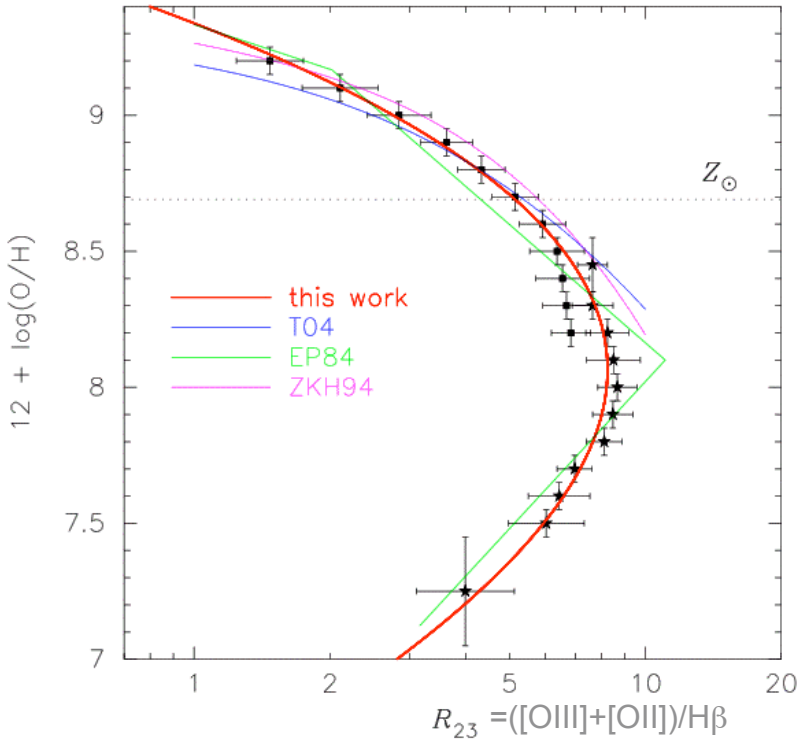
Metallicity in Star Forming Galaxies Traced by faint emission lines

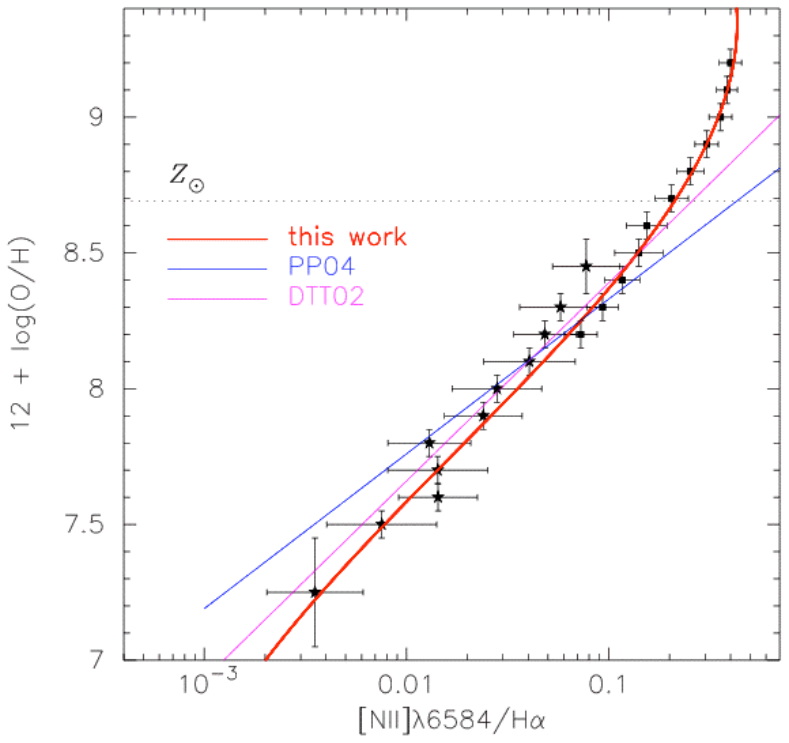


⇒ need to calibrate strong lines diagnostics
for high redshift studies (issue of inter-calibration
of different diagnostics available at different redshifts)

Metallicity in Star Forming Galaxies
Strong Line Diagnostics:
new calibrations and new diagnostics
from >50000 local galaxies spanning >2 dex in Z

Nagao et al. 2006





- **Strong corrections relative to previous studies**
- **Good cross-calibration between different diagnostics (crucial at high-z)**

Metallicity Evolution in Star Forming Galaxies

Several metallicity studies at high redshift

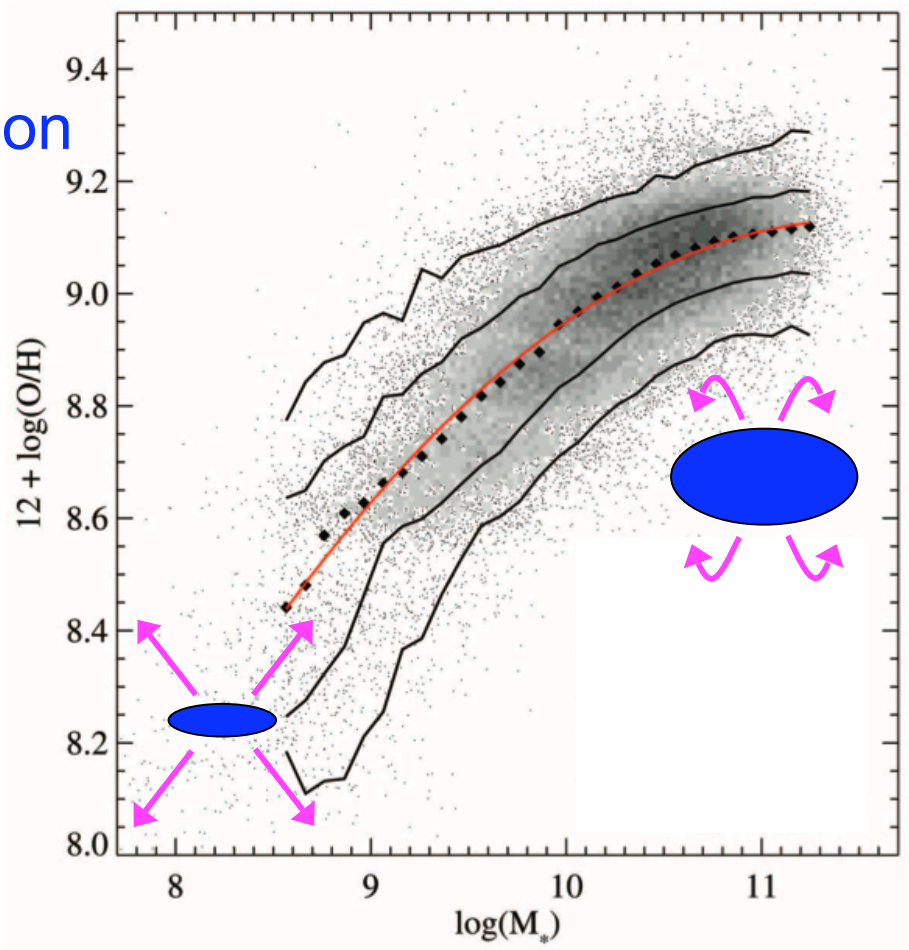
(Pettini et al. 2001, Lilly et al. 2003, Kolbuniki & Kewley 2004, Shapley et al. 2004, Meyer et al. 2004,2006, Rix et al. 2004, Savaglio et al. 2005, Erb et al. 2006, ...)

Galaxy mass plays a key role

Tremonti et al. 2004

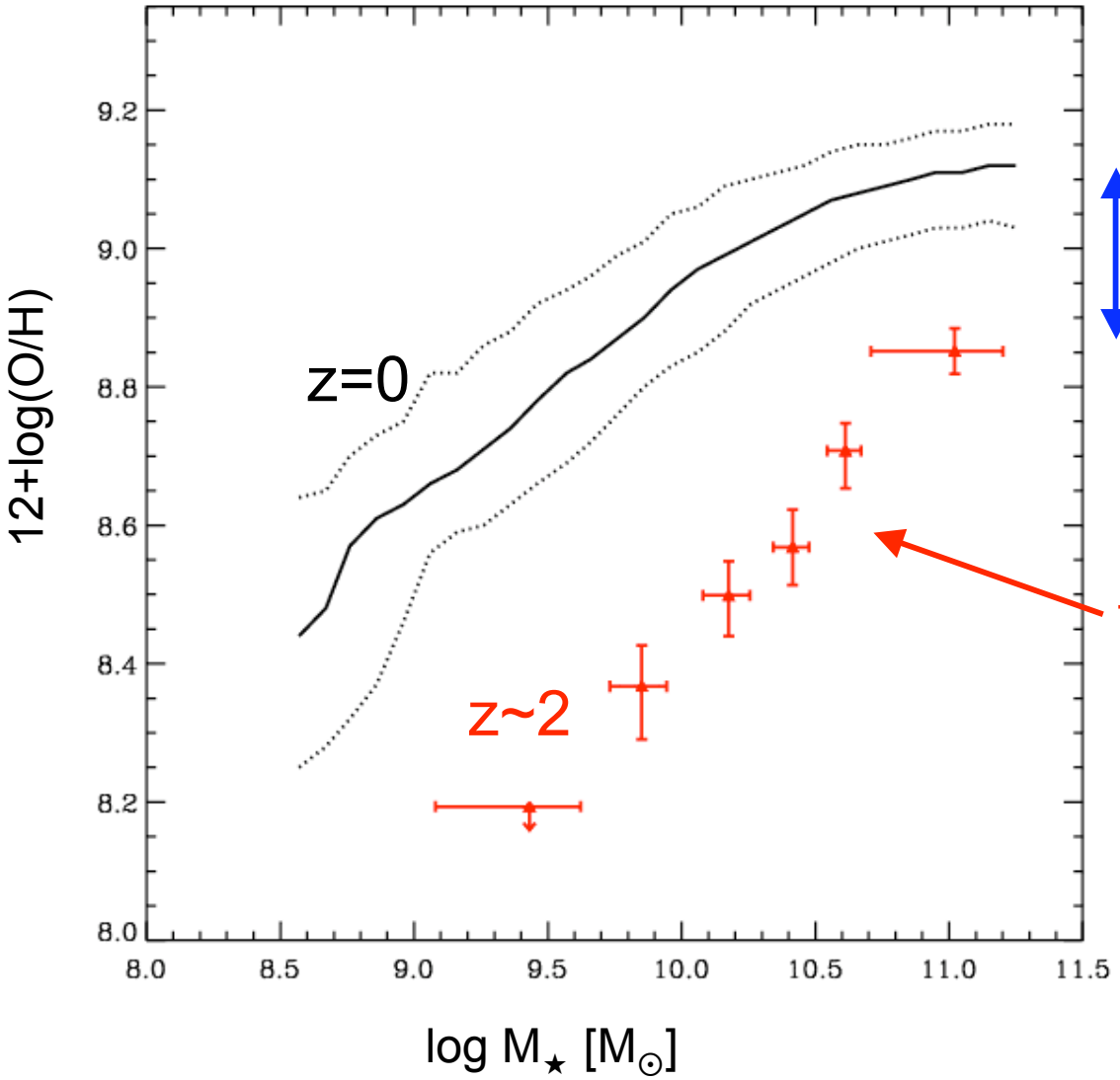
Mass-metallicity relation in local galaxies

Interpreted as a consequence of starburst winds



Metallicity Evolution in Star Forming Galaxies

Evolution of the mass-metallicity relation

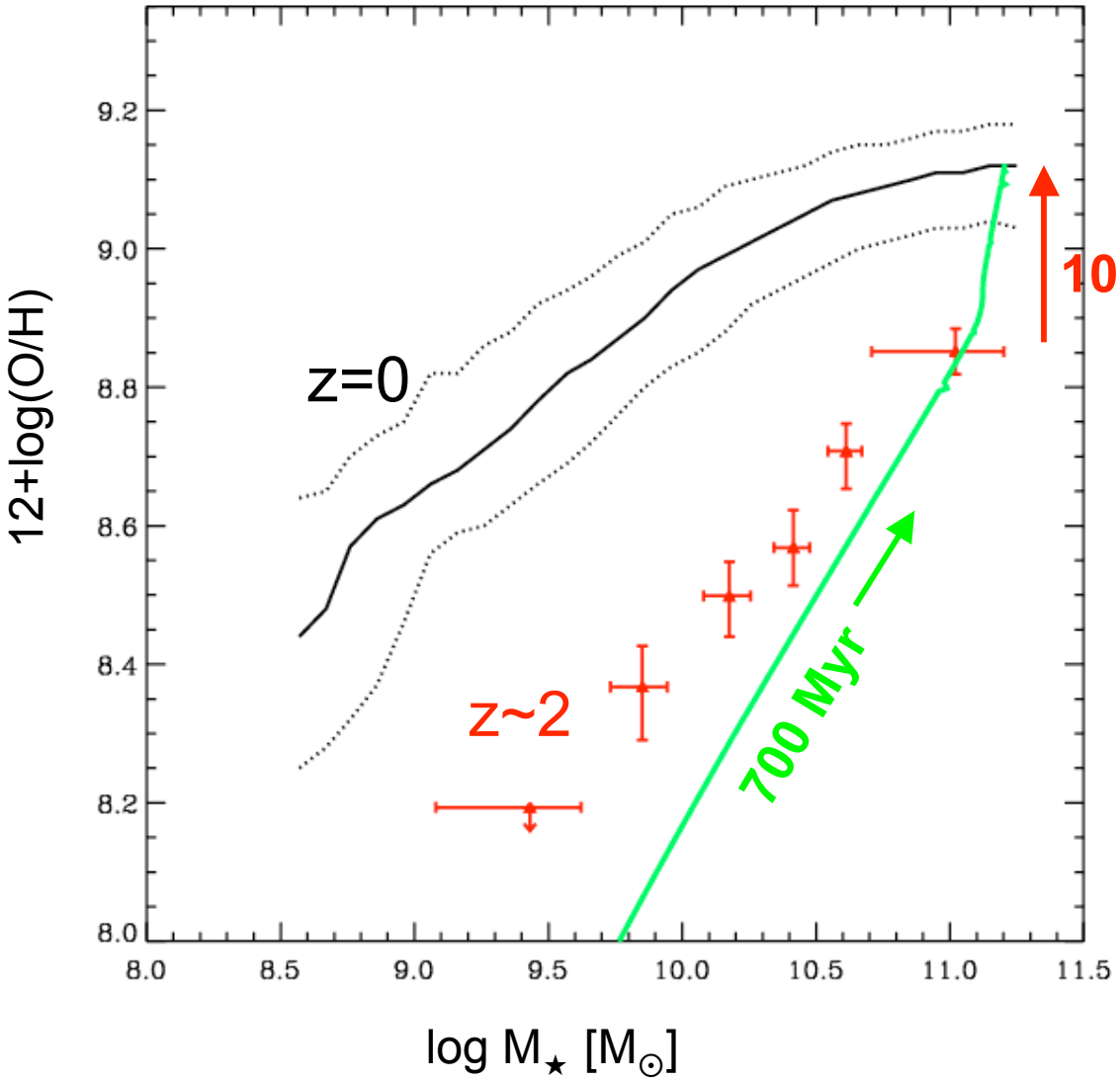


offset factor ~2
at high masses

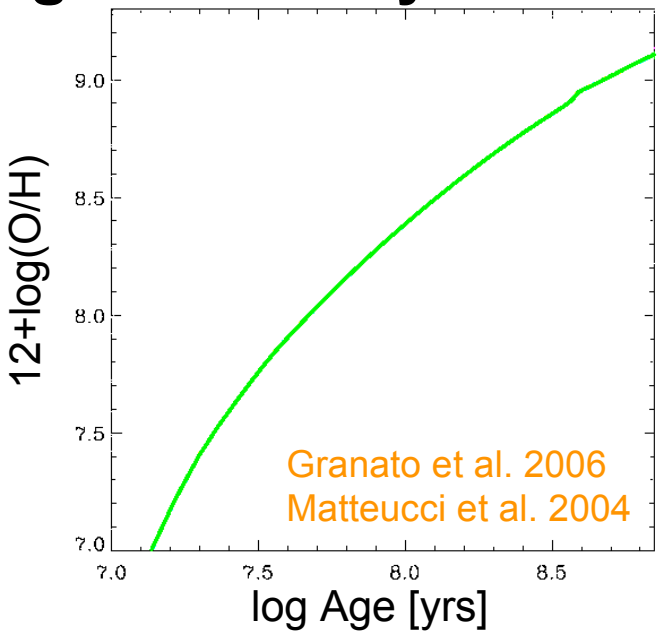
from Erb et al. 2006
by using our updated
[NII]/Hα - Z calibration

Metallicity Evolution in Star Forming Galaxies

Warning: at z~2 and z=0 we see different populations (at high masses)

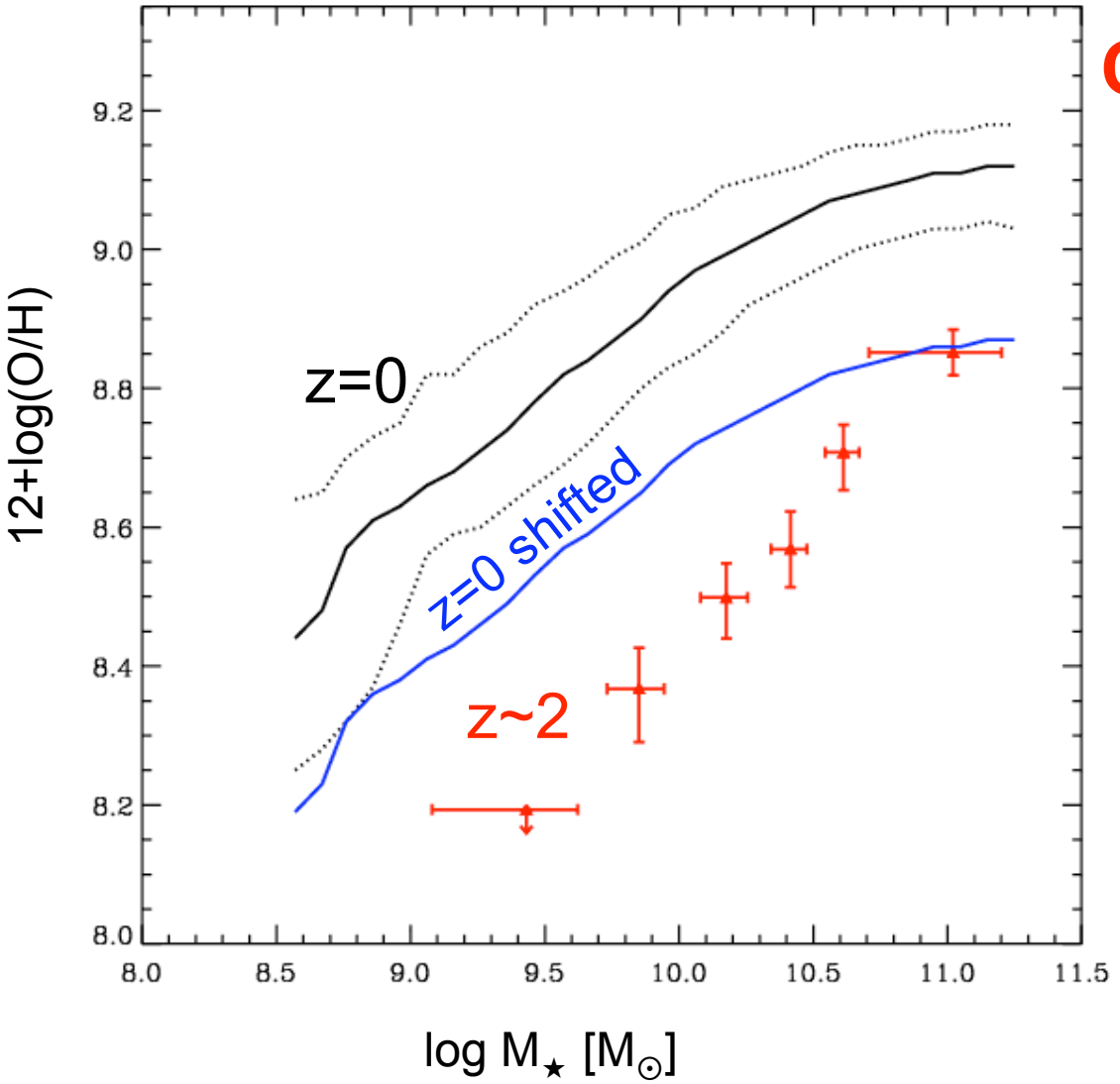


Evolution of massive galaxies very fast



Metallicity Evolution in Star Forming Galaxies

Steepening of the mass-metallicity evolution at high-z



Chemical version of galaxy downsizing

Massive galaxies evolve faster and are "chemically mature" at higher redshift

Low mass galaxies evolve more slowly and at lower redshift

Corollarium: local M-Z relation not so simple to interpret...

Metallicity Evolution in Star Forming Galaxies

What happens at z>2?

Further steepening of the M-Z relation?

Low mass galaxies with very low metallicities?

Evolving phase of massive galaxies?

ESO-VLT large program:

SINFONI integral field near IR spectroscopy

30 targets: 3<z<5.2 with Spitzer 3-8μm data (stellar mass)

180 hours in three semesters (just started)

PRIMARY GOAL: determine the mass-metallicity relation at 3<z<5.2 by measuring gas metallicity diagnostics ([OIII]5007, Hβ, [OII]3727, [NeIII]3869)

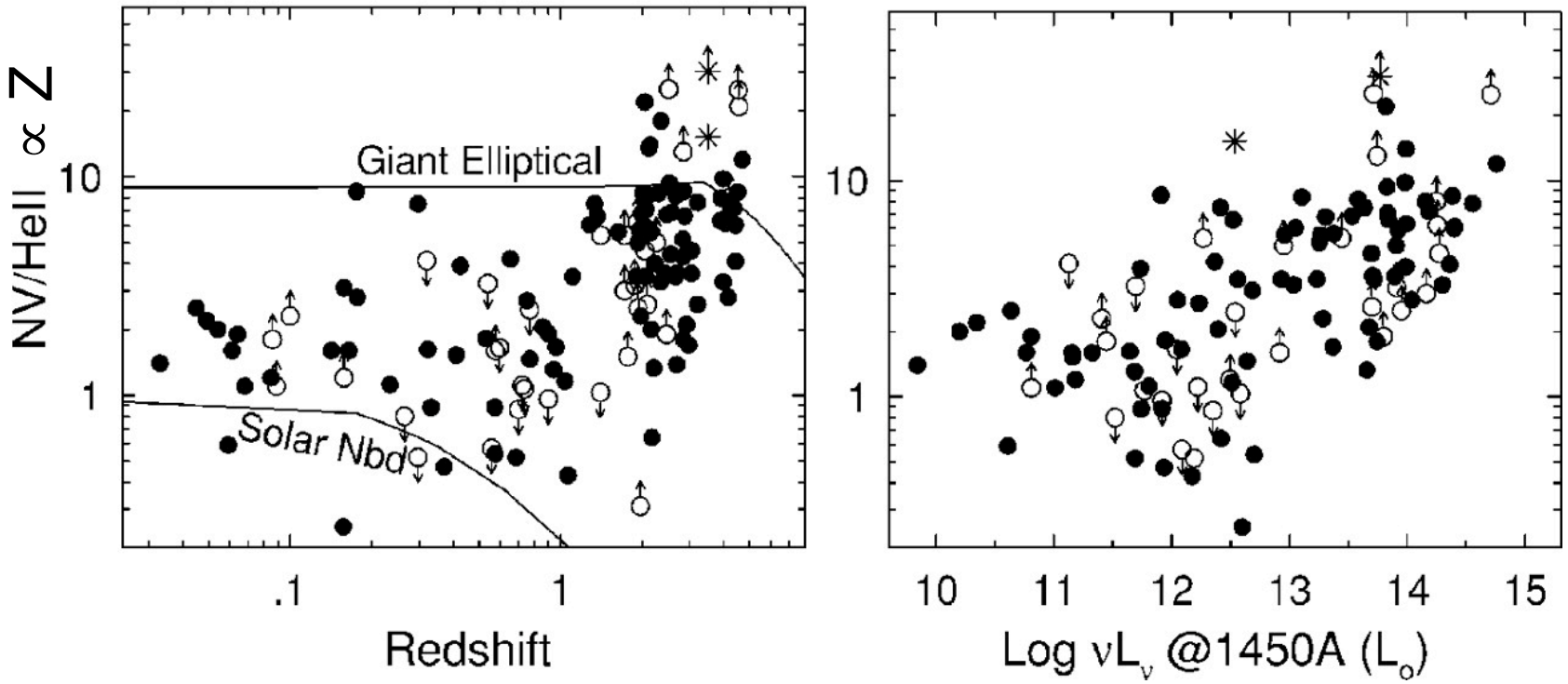
Team: Maiolino, Nagao, Marconi, Fontana, Grazian, Ballero, Cimatti, Granato, Mannucci, Matteucci, Pastorini, Pentericci, Pipino, Risaliti, Salvati, Silva

2. Metallicity Evolution in QSOs at z<5

Metallicity Evolution of QSOs

Until a few years ago inconclusive studies,
because of degeneracy between luminosity and redshift

Hamann & Ferland 1999



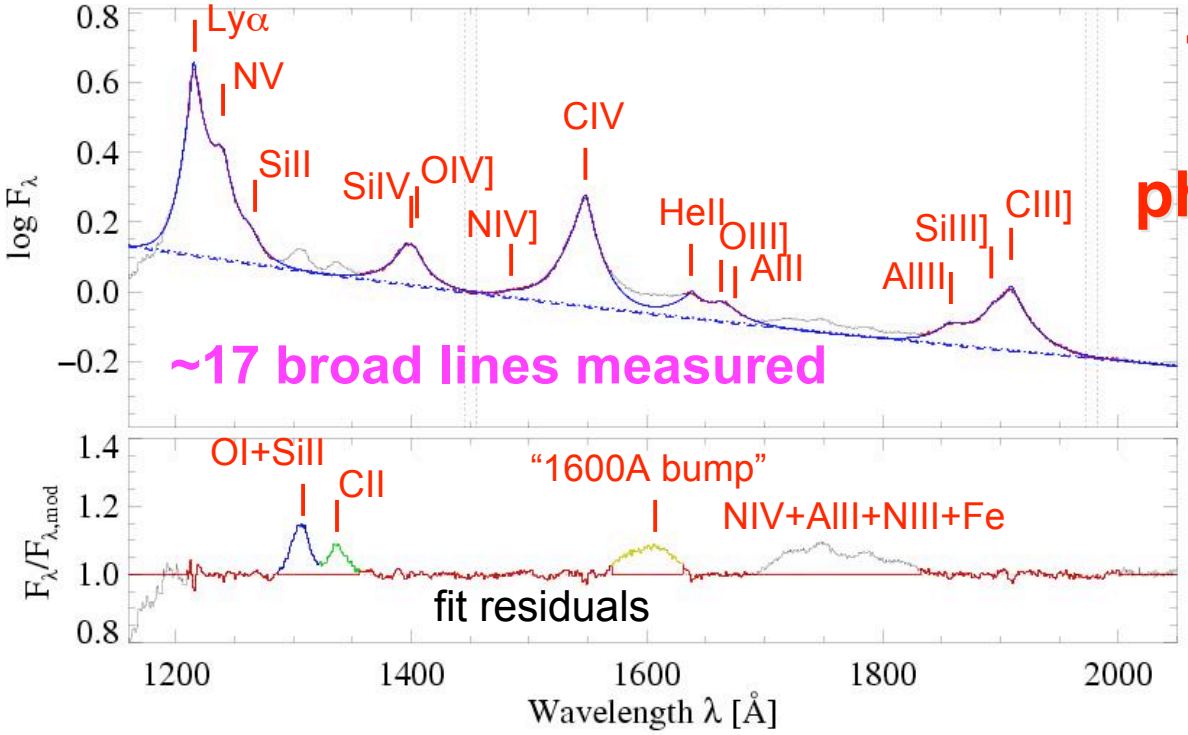
The QSO metallicity depends on L or z ?

Metallicity Evolution of QSOs in the Sloan Digital Sky Survey

~ 5000 QSO optical spectra (UV-rest) at $2 < z < 4.5$

→ **Sample large enough to disentangle the dependence on redshift and on luminosity**

→ **22 high quality composite spectra in bins of redshift and luminosity**



→ **comparison with detailed photoionization models**

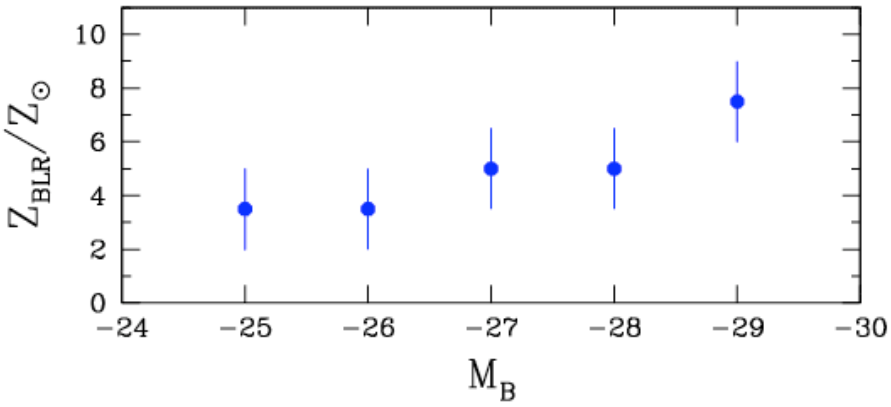
↓

metallicity as a function of L and z

Nagao et al. 2006

Metallicity of the "Broad Line Region" in QSOs at 2 < z < 4.5

Average trends



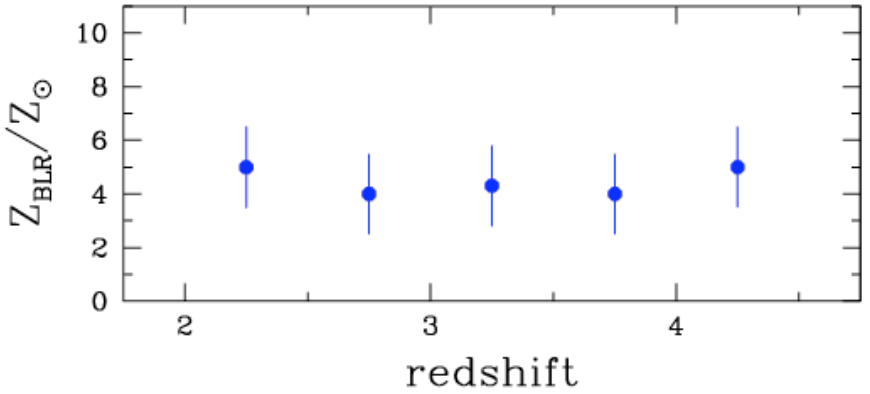
- Shallow, but significant dependence on Luminosity

↓

Consequence of the mass-metallicity relation

$Z \Leftrightarrow M_* \Leftrightarrow M_{BH} \Leftrightarrow L_{QSO}$

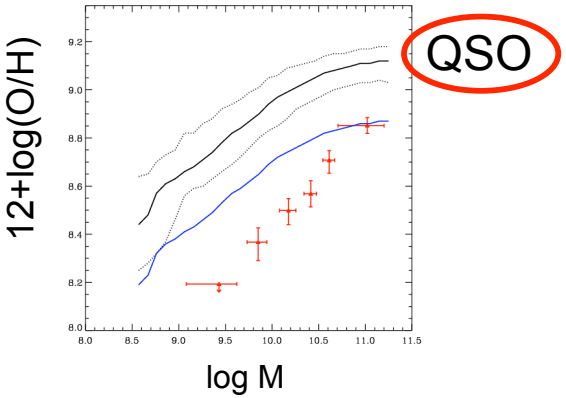
- No evolution with redshift



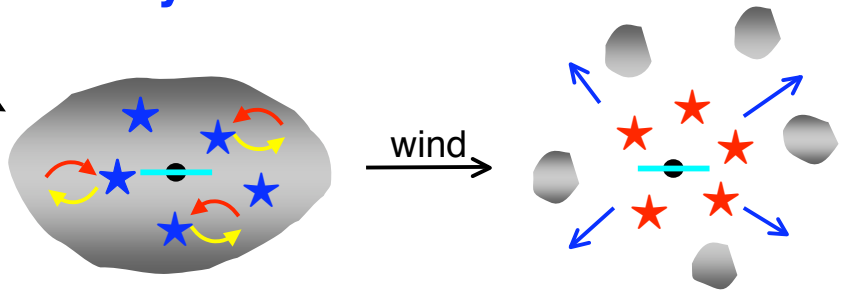
ISSUES

Lack of evolution with redshift

- QSOs extreme cases of downsizing?

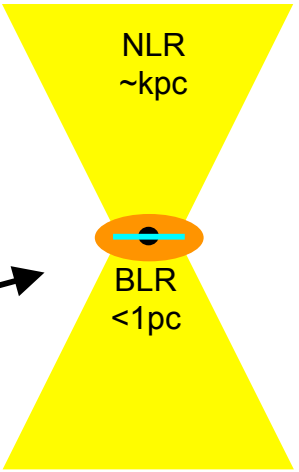


- QSOs observable only when host is evolved?
  - Relation between L - M_{BH} - M(stars) - Z
  - Evolving phase may be obscured



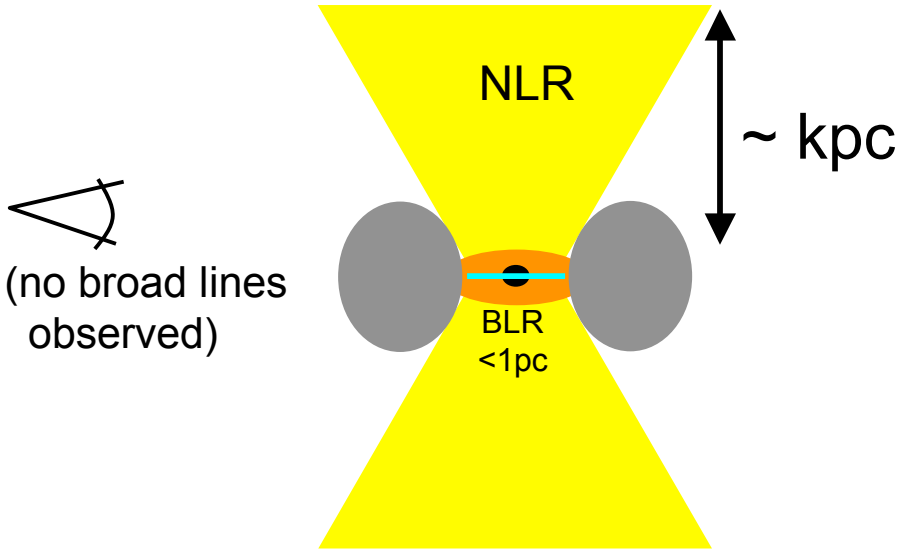
Huge metallicities (not observed locally)

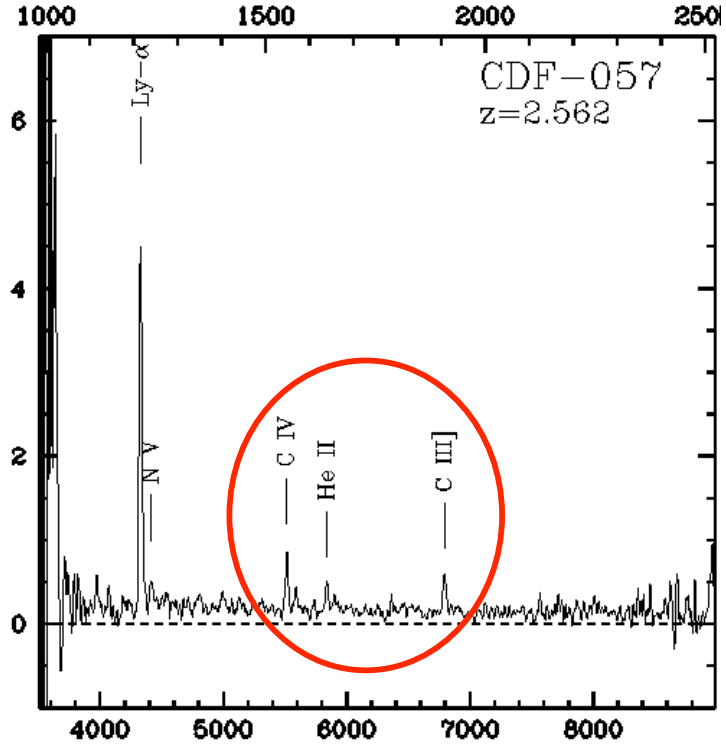
- Metals ejected into the IGM through QSO winds
- BLR only probes the inner pc of the galaxy



Metallicity of the "Narrow Line Region" at 1.2 < z < 3.8

~ 60 spectra of <u>obscured</u> AGNs at high redshift (i.e. only Narrow Lines): High-z Radio Galaxies (HzRG) and QSO2s



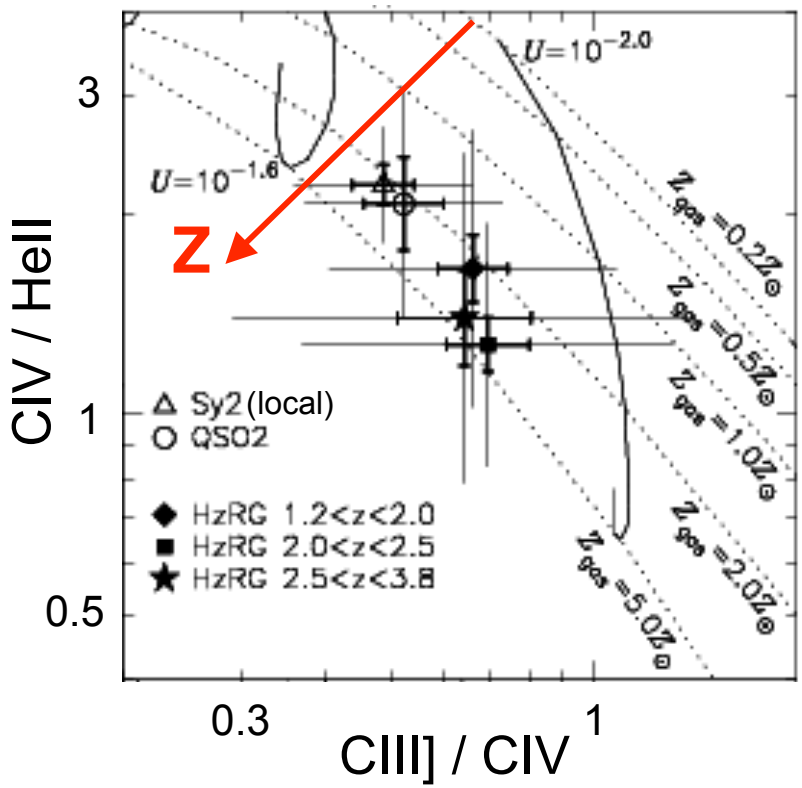


CIV/HeII vs. CIII]/CIV diagram: sensitive to metallicity

Nagao et al. 2006

Metallicity of the "Narrow Line Region" at 1.2 < z < 3.8

No evidence for evolution

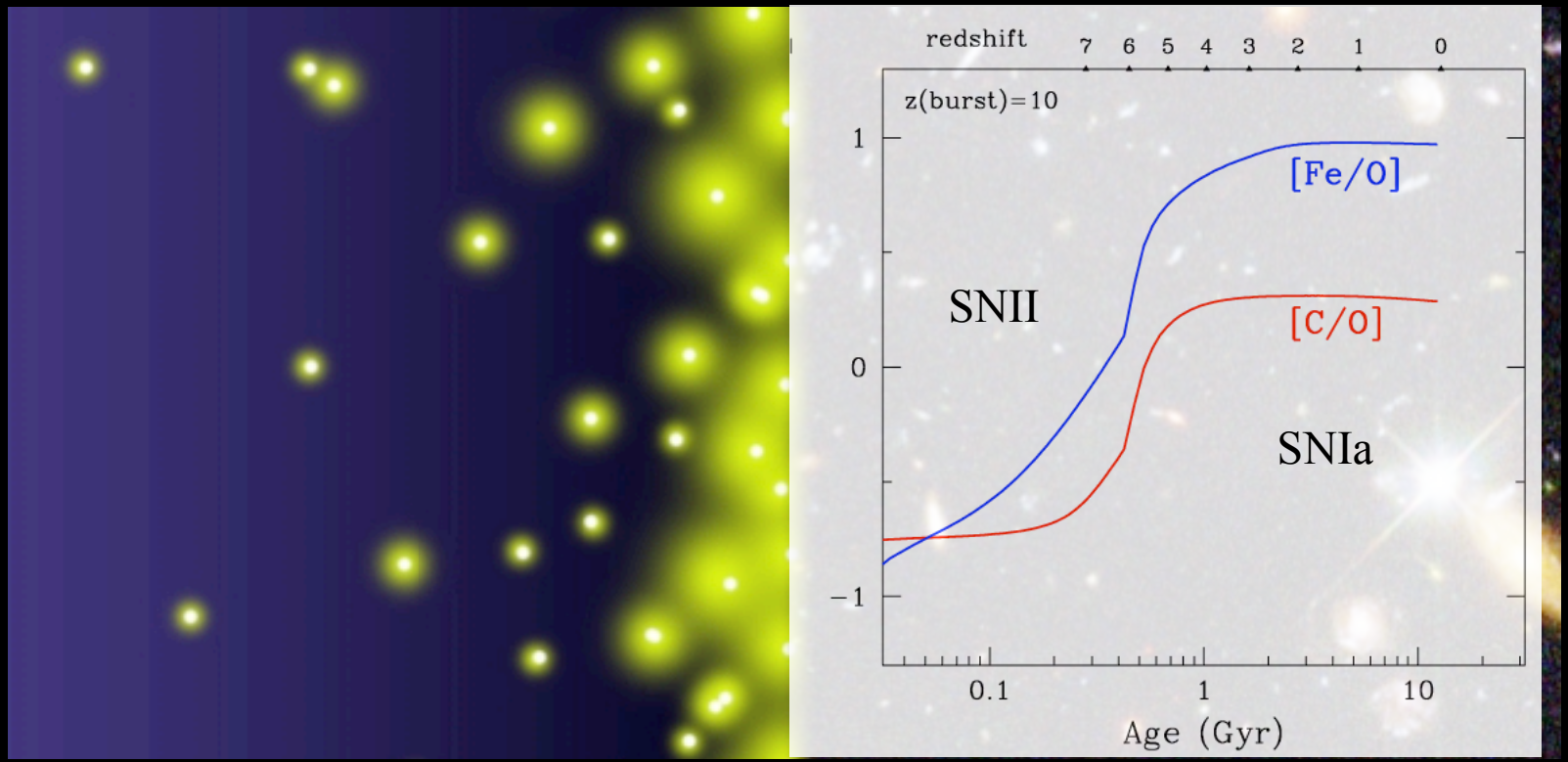


Also in agreement with metallicity inferred from intrinsic Narrow Absorption Lines D'Odorico+ '04

3. Metallicity Evolution of QSOs at z>5

z~5 critical epoch for the enrichment timescale of some crucial elements

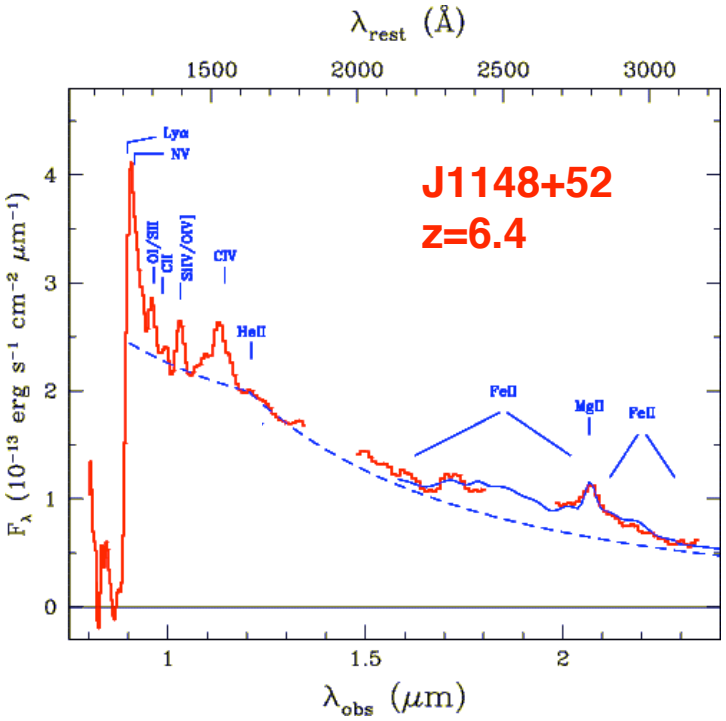
redshift 15 8 5 0

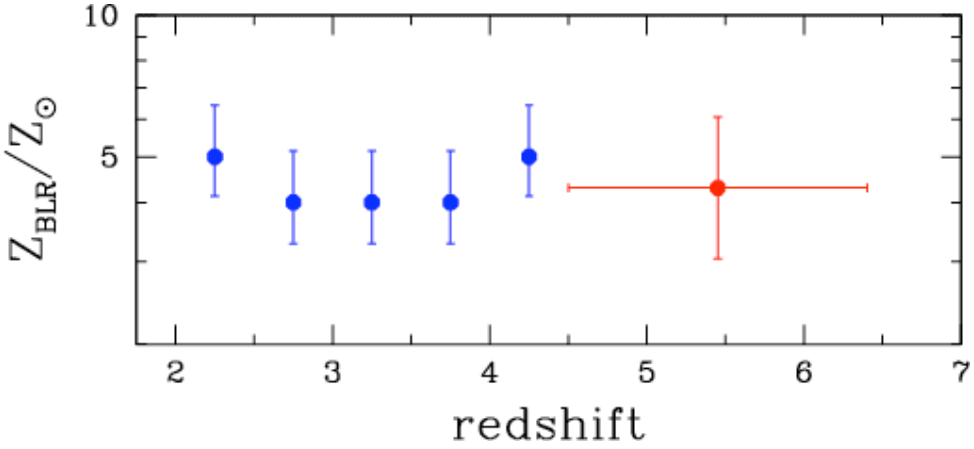


age of the Universe (Gyr) 0.5 1 13.5

Metallicity in QSOs at 4.5 < z < 6.4 (approaching the re-ionization epoch)

Near-IR spectra (=UV rest-frame) of 23 QSOs



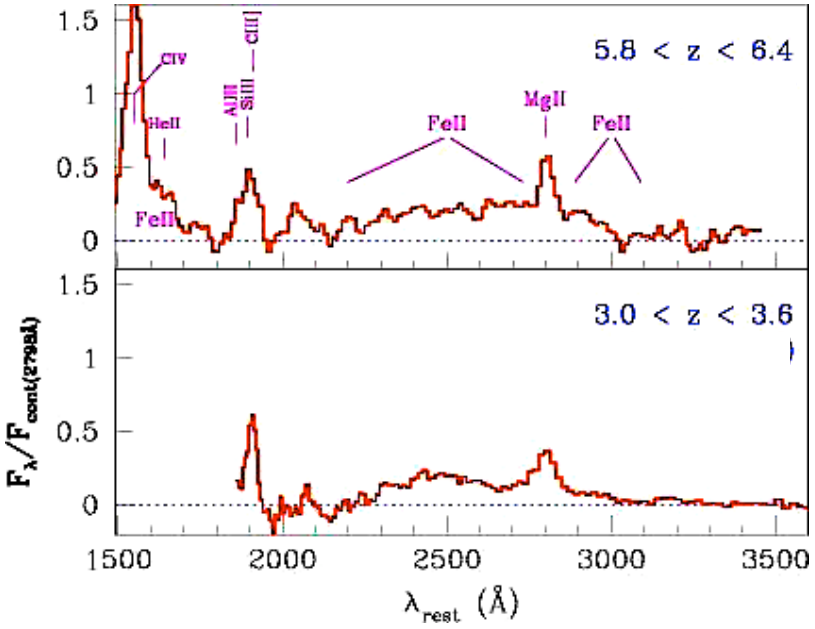


No evolution !

Juarez+ '06

Metallicity in QSOs at 4.5 < z < 6.4 (approaching the re-ionization epoch)

No evolution even for iron ! (relative to α-elements)



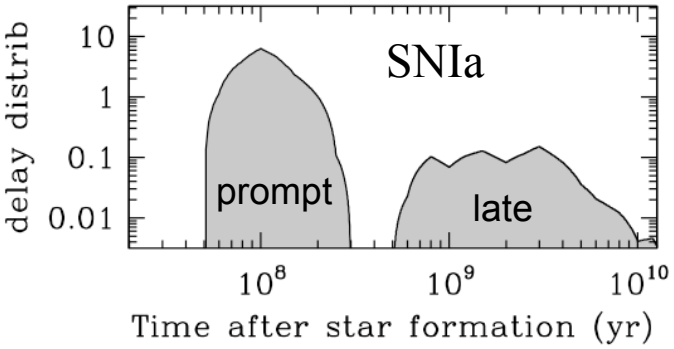
Maiolino et al. 2003

ISSUES at z~6

Lack of evolution of Fe abundance

- **Population of rapidly evolving SNIa?**

Mannucci et al. ‘05-’06
Romano+ ‘04
Matteucci & Recchi ‘01
Matteucci+ ‘06



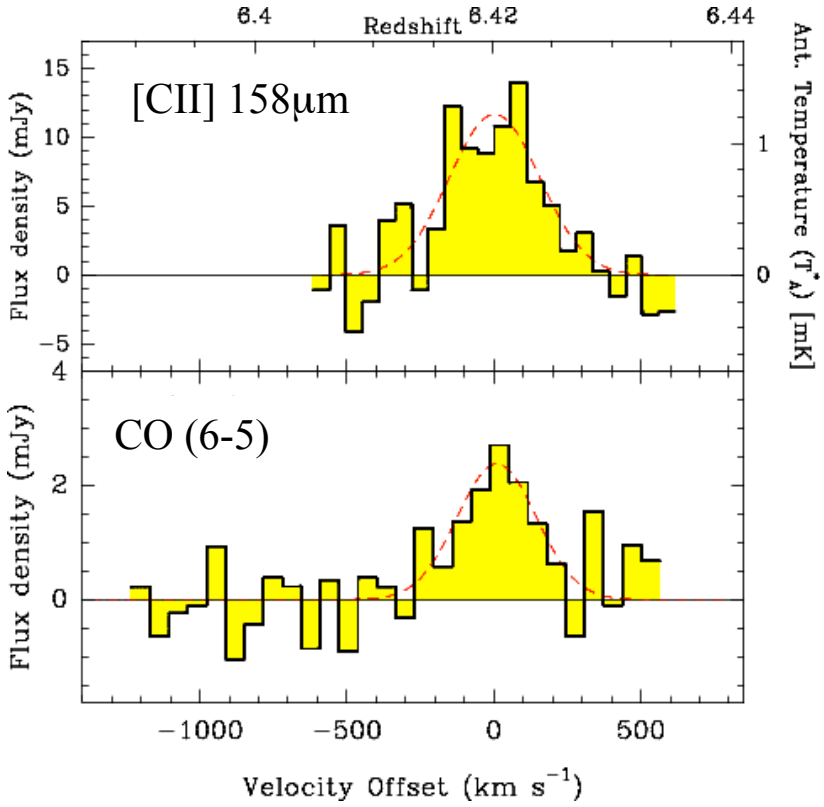
Lack of evolution of BLR metallicity

- **Broad Lines sample a small, peculiar nuclear region**

Probing the QSO host galaxy at z~6 through mm-submm lines

J1148+52 at z=6.4

Maiolino et al. 2005



same [CII]/CO and same [CII]/FIR as local powerful starbursts

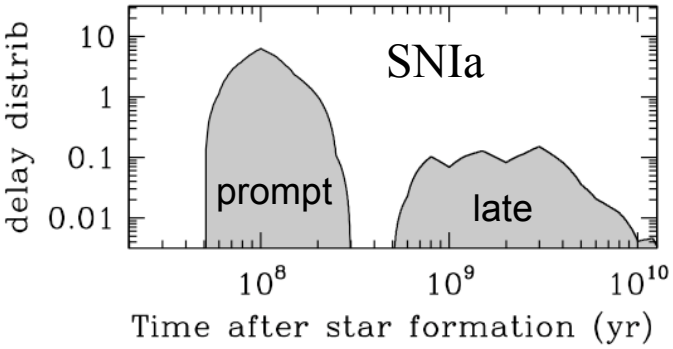
⇒ strong enrichment of carbon in the host galaxy already at z=6.4

ISSUES ar z~6

Lack of evolution of Fe abundance

- **Population of rapidly evolving SNIa?**

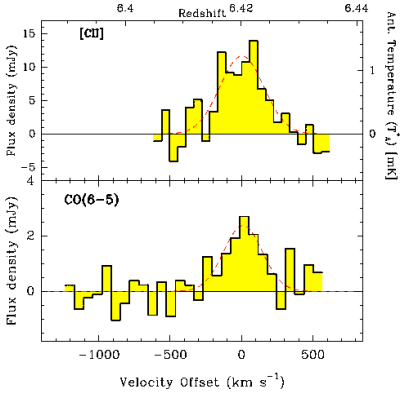
Mannucci et al. ‘05-’06
Romano+ ‘04
Matteucci & Recchi ‘01
Matteucci+ ‘06



Lack of evolution of BLR metallicity

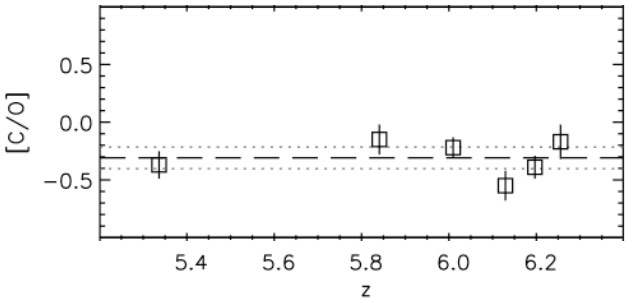
- **Broad Lines sample a small, peculiar nuclear region**

...but similar results for host galaxy



- **QSOs extreme cases of downsizing even close to re-ionization?**

Carbon-poor systems detected in absorption at z~6 (⇒ dominated by SNIIe)

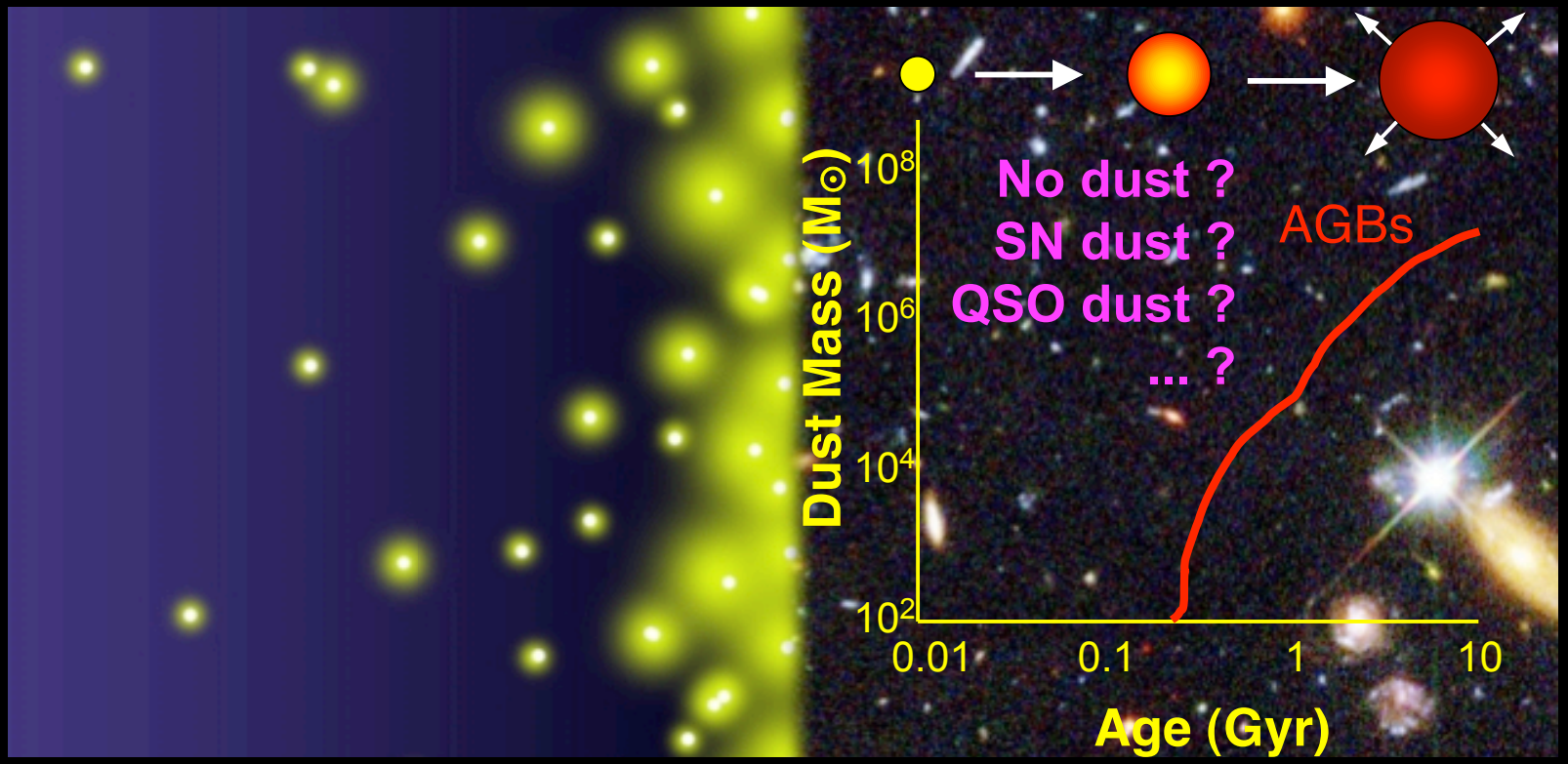


Becker et al. 2006

4. Dust Evolution in the Early Universe

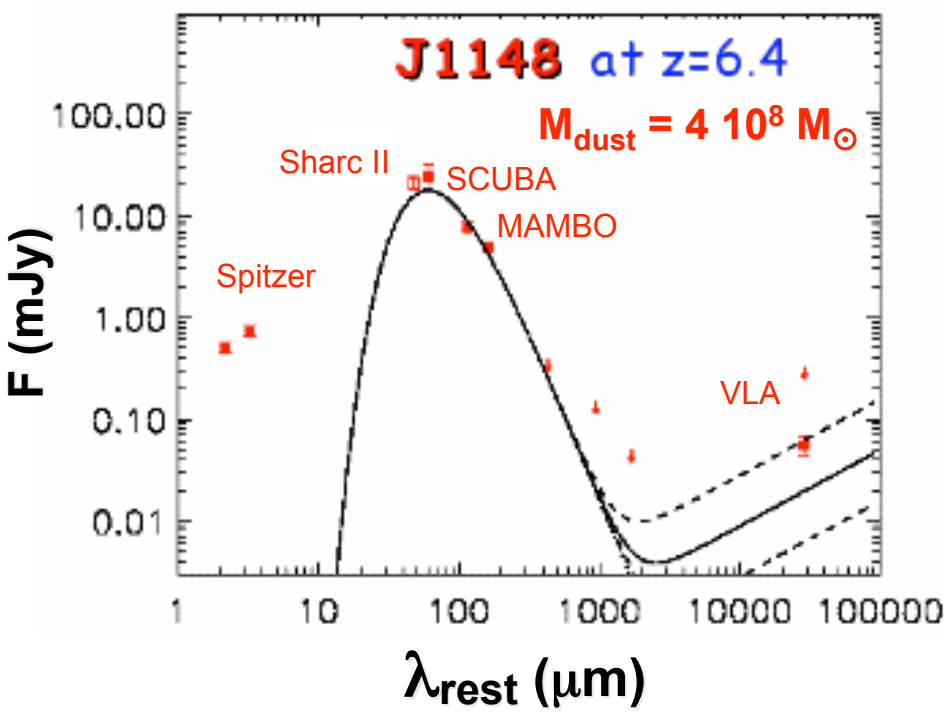
z~5 critical epoch also for dust: AGB stars fall short of time to produce it

redshift 15 8 5 0



age of the Universe (Gyr) 0.5 1 13.5

Best tracer of dust mass: far-IR
⇒ mm-submm at z>6



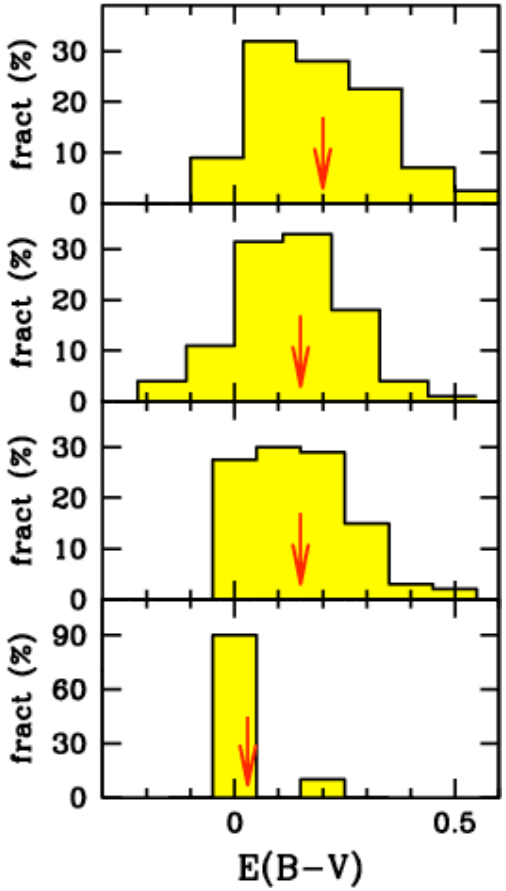
Only 2 detections at z > 6 in luminous QSOs (the tip of the iceberg)

Difficult to investigate any evolution of dust mass

Beelen et al. 2006
Bertoldi et al. 2003
Priddey et al. 2003
Robson et al. 2005

...but evidence for large dust masses!

Dust extinction/reddening at z~6



Local SB
(Mauer et al. 99)

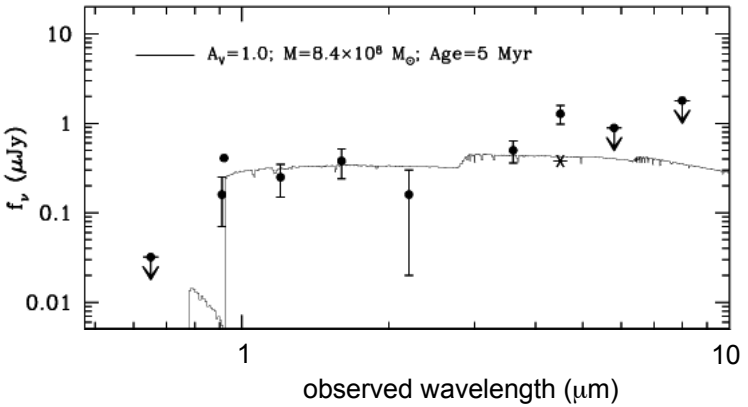
z=3 LBG
(Adelberger
& Steidel 00)

z=4 LBG
(Ouchi et al. 05)

z=6 i-dropout
(Eyles et al. 06
Mobasher et al. 06
Egami et al. 05)

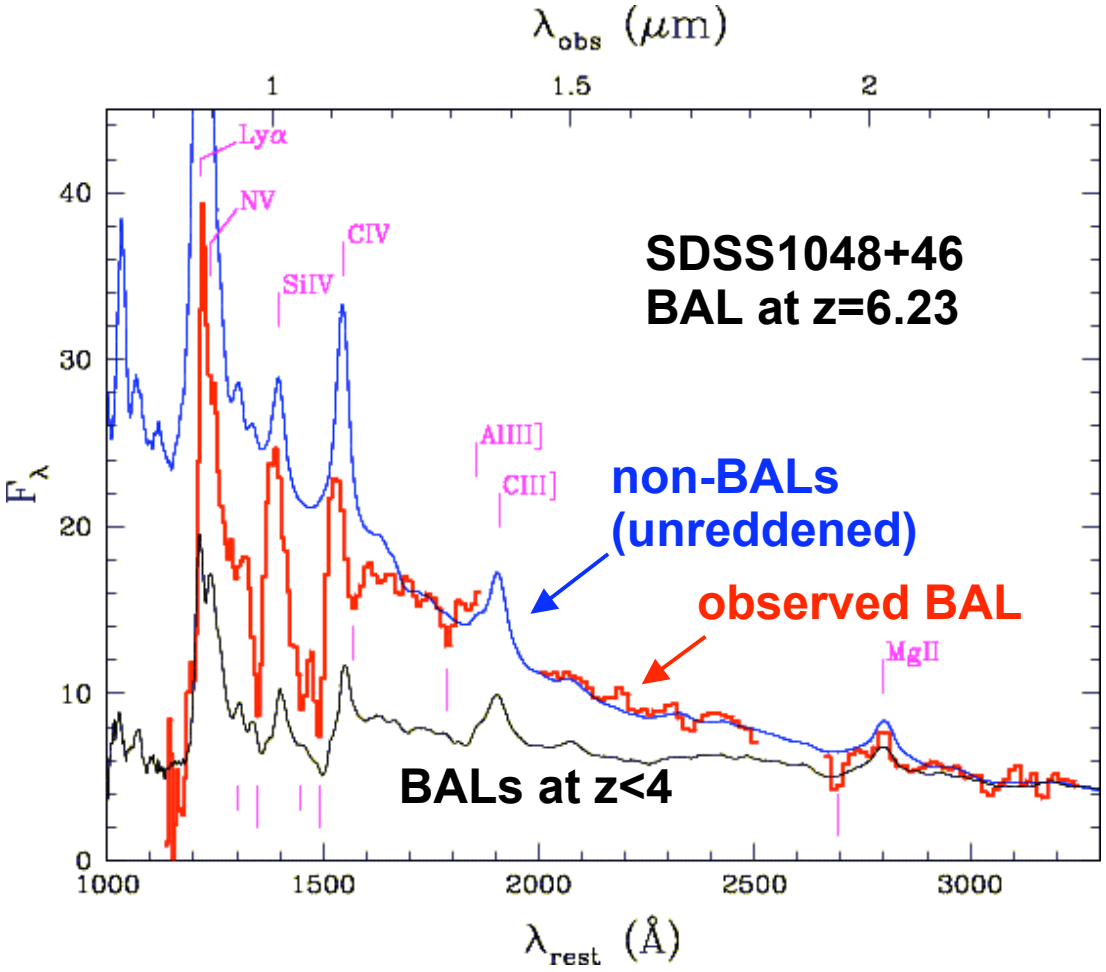
But possible biases against dusty objects

Examples of z>6 star forming galaxies reddened by dust



(Chary et al. 05
Schaerer & Pello' 05
Barger et al. 06)

Dust extinction in Broad Absorption Line (BAL) QSOs at z>6



Maiolino et al. 04

No BAL QSO at z<4 is so blue

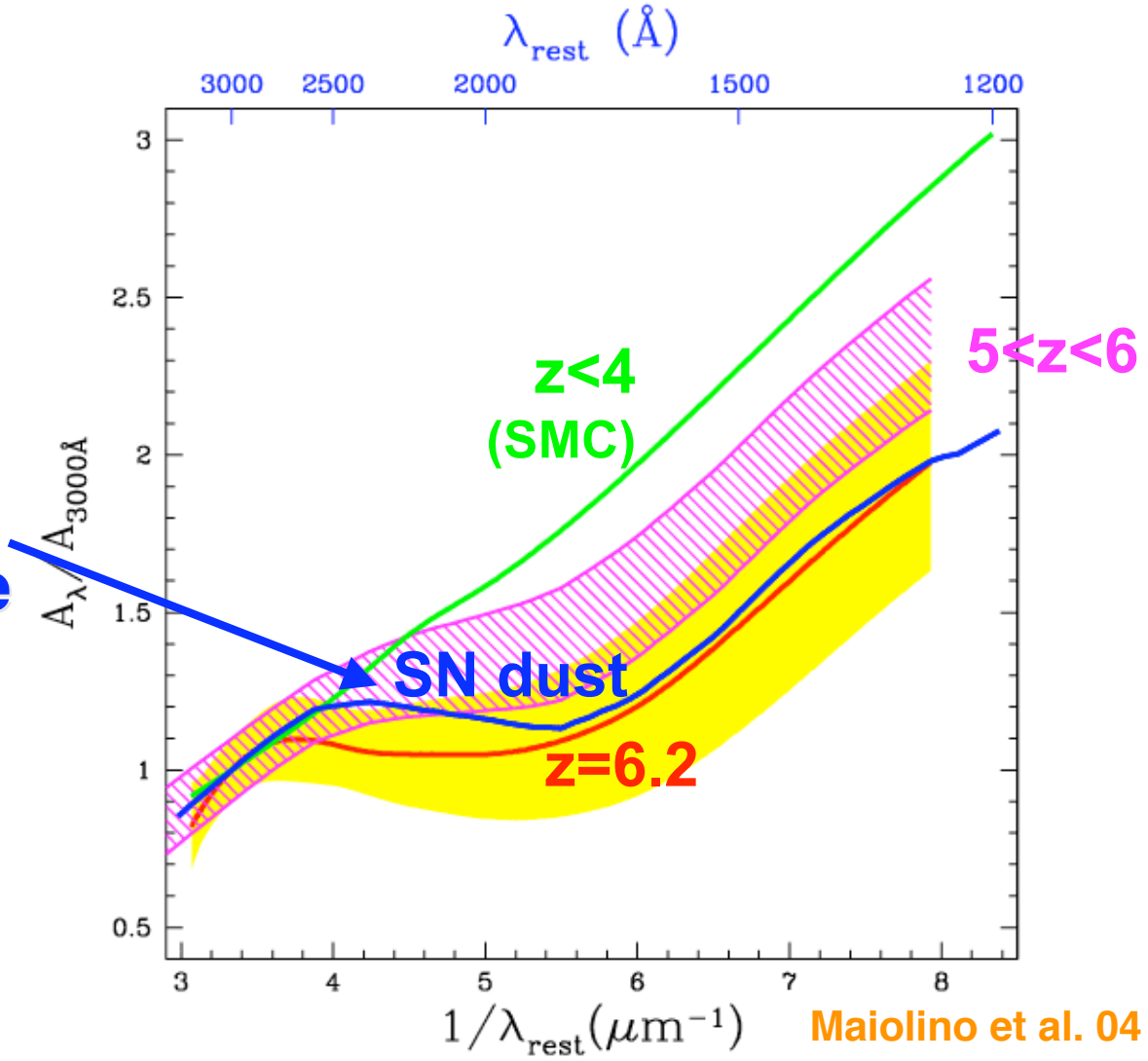
Different extinction properties relative to lower redshift QSOs

Extinction curve at z~6 (QSOs)

Extinction curves at z~6 inconsistent with those at lower redshift

Consistent with dust theoretically expected from SNe

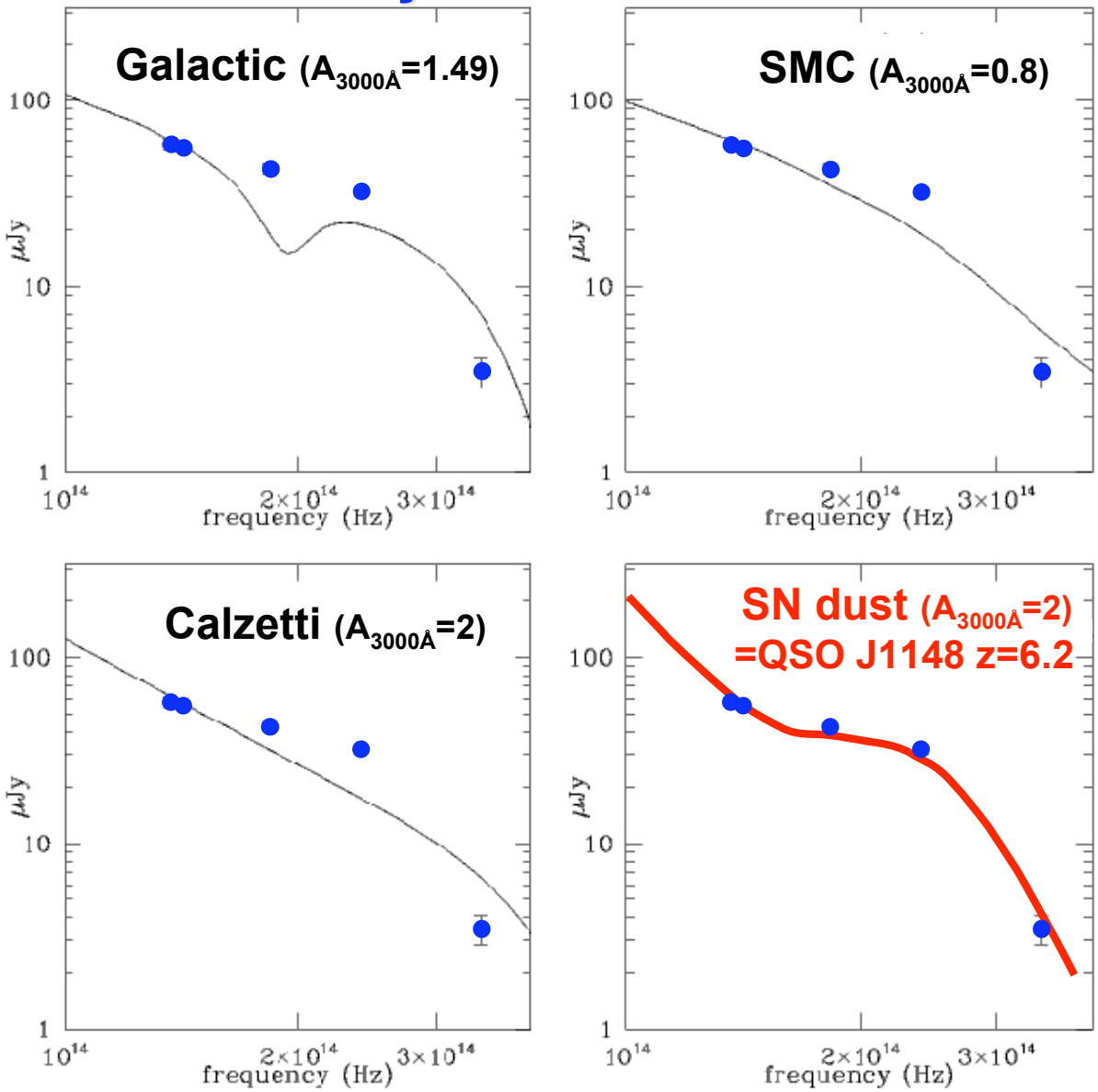
(Todini & Ferrara 01
Nozawa et al. 03)



Maiolino et al. 04
Hirashita et al. 05

Extinction curve at z~6 (GRBs)

Gamma Ray Burst 050904 at z=6.3

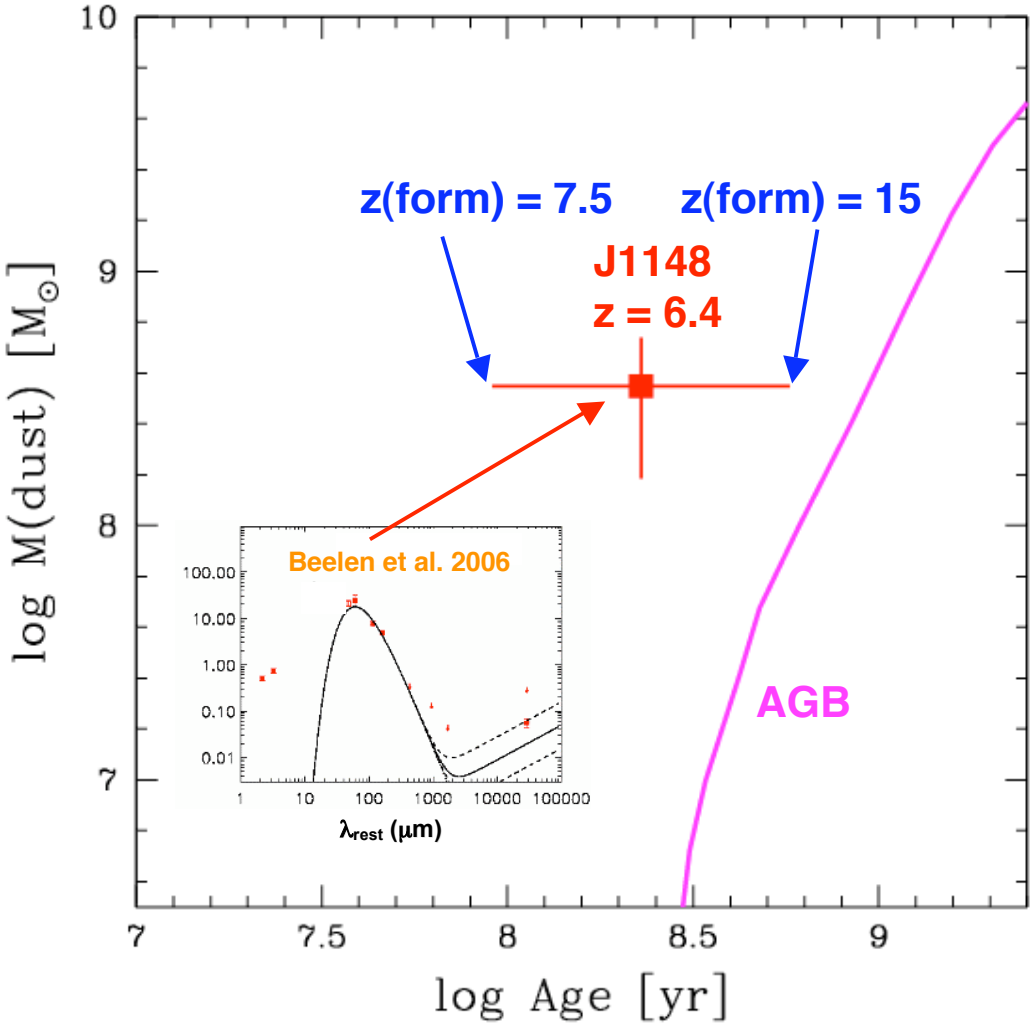


Stratta et al. 06

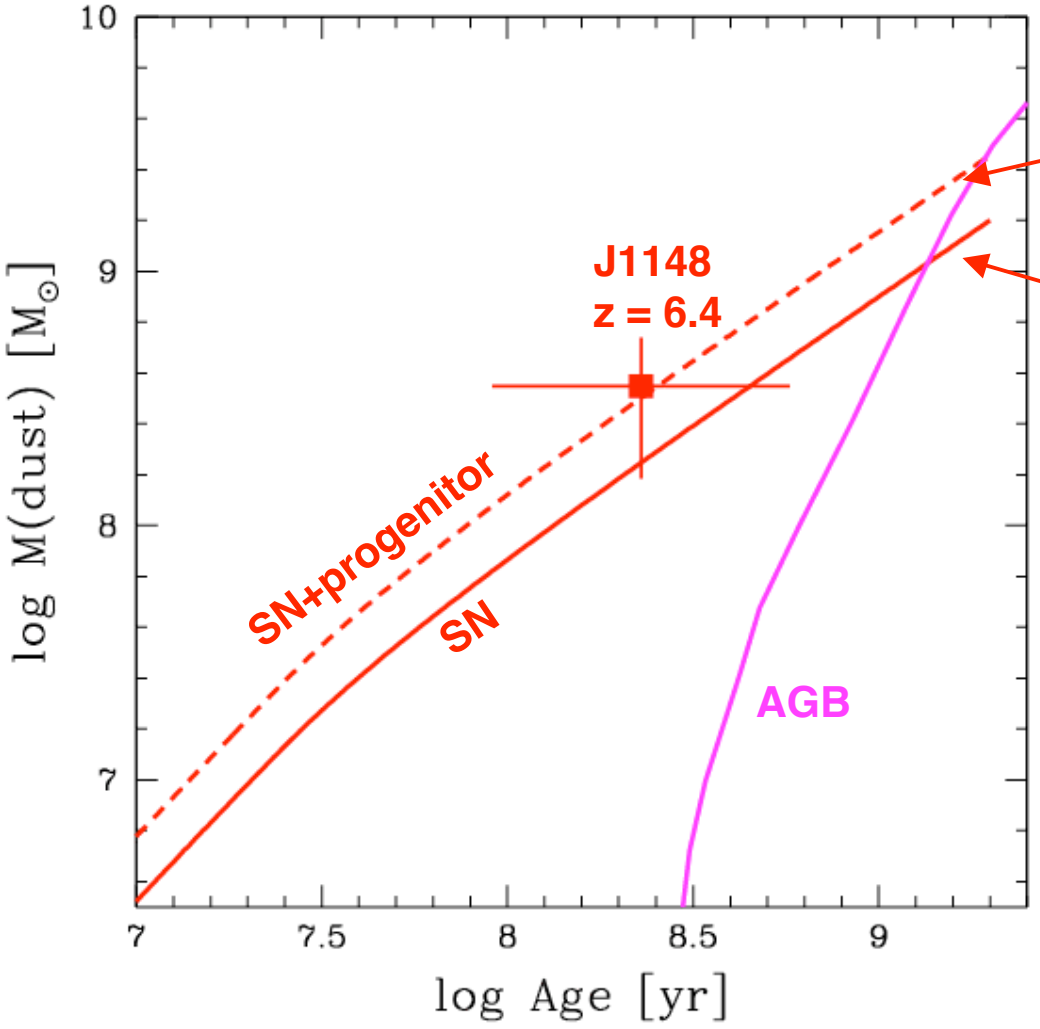
Dust mass at z>6

J1148 z=6.4, the most extreme case

AGBs: not fast enough



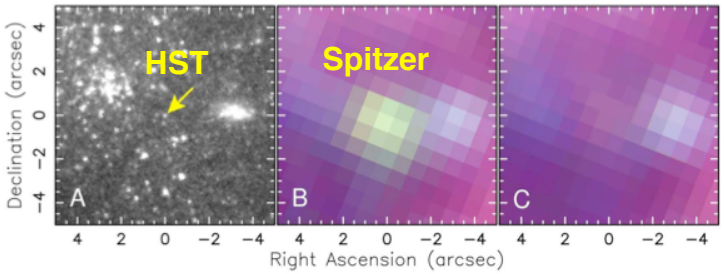
Dust mass at z>6
J1148 z=6.4, the most extreme case
SNe: could make it



Depends on dust yield/SN:

Meikle et al. 06
SN2002hh: 0.036 $M_\odot$ /SN

Sugerman et al. 06
SN2003gd: 0.02 $M_\odot$/SN



SUMMARY

- Mild metallicity evolution in Star Forming galaxies at $0<z<2$ especially at high masses
- No evolution observed in QSOs.
- Chemical downsizing (massive systems evolve more rapidly and at higher redshift than low mass systems).
- Lack of evolution of Fe and C abundances in QSOs at $z>5$.
- Dust: transition from AGB-production to SN-production at $z\sim5$
  (Note: important consequences for observational of galaxies at $z>5$)