GAS and DUST in high redshift AGN

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In collaboration with

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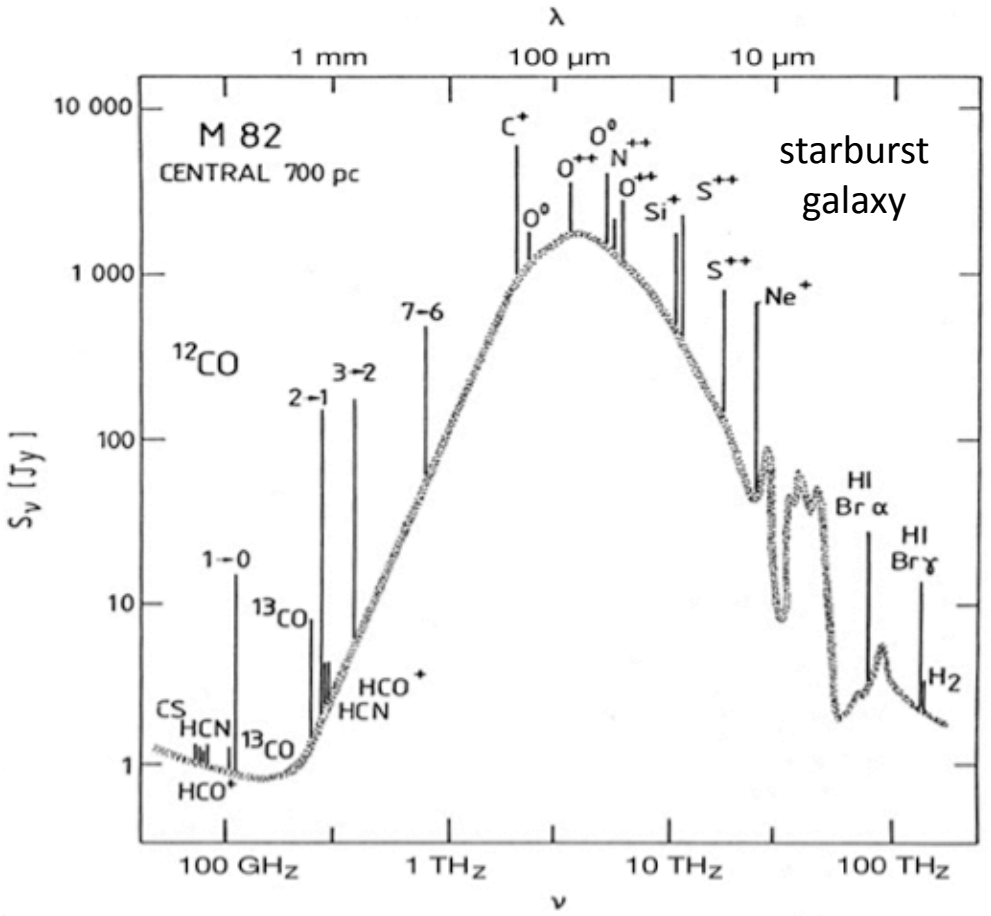
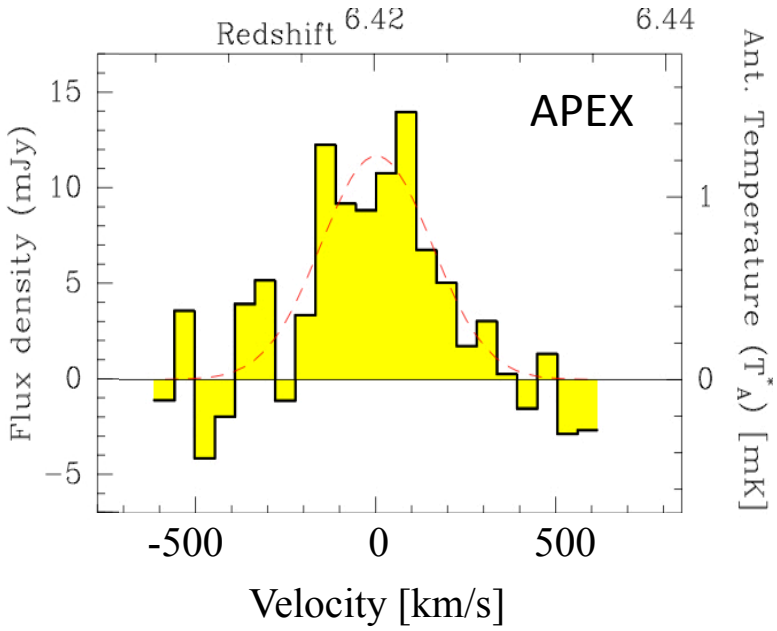
Properties of the high-z interstellar medium from mm and sub mm observations

The far-IR fine structure line
(e.g. CII 158 µm, NII 205 µm)
are the strongest lines
emitted by the ISM in all galaxies.
At z > 4 are redshifted in the (sub)mm.

Most of the molecules
known so far in the ISM emit their
rotational lines in the (sub)mm.
The CO emission line is the brightest
molecular line in all galaxies.



[CII] emission in high-z galaxies



FIRST EVER DETECTION AT HIGH-z

(Maiolino et al. 2005)

- At high-z the [CII] emission has been observed only in ULIRGs.
- Most if not all ULIRGs in the local Universe are found in major disk mergers.
- Since proto-galaxies at high-z are believed to form from the merging of smaller structures they could resemble the nearby ULIRGs.
- ULIRGs are order of magnitude more numerous at z>1 than locally.

Up to date detected in ~20 galaxies at z>1.

(Maiolino et al. 2005; Iono et al. 2006; Maiolino et al. 2009; Walter et al. 2009; Hailey-Dunsheat et al. 2010; Ivison et al. 2010; Wagg et al. 2010; Stacey et al. 2010; Bertoldi et al. 2010)

Optical data of B0952-0115

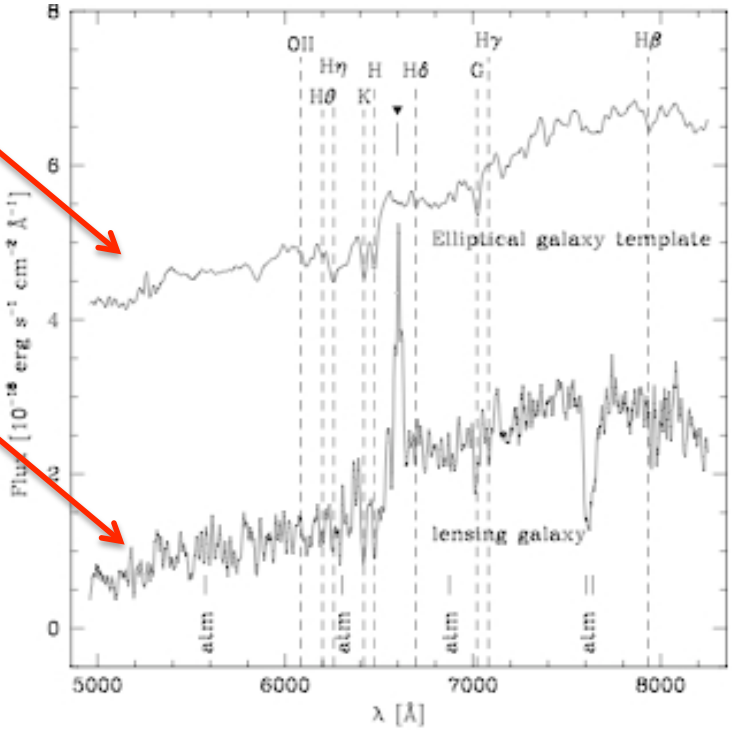
Firstly discovered by McMahon et al. (1992)
and identified as a pair of z=4.5 quasars separated by ~1”,

then recognized as a lensed galaxy
by a foreground elliptical galaxy at z=0.6.

VLT/FORS1 spectrum

elliptical galaxy template

lensing galaxy spectrum

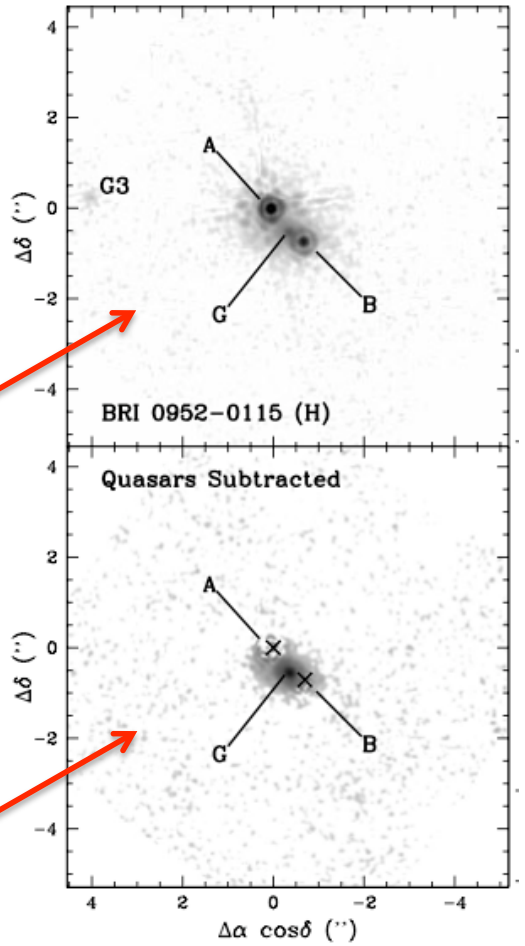


Eigenbrod et al. (2007)

HST image

Lensed galaxy at z=4.5

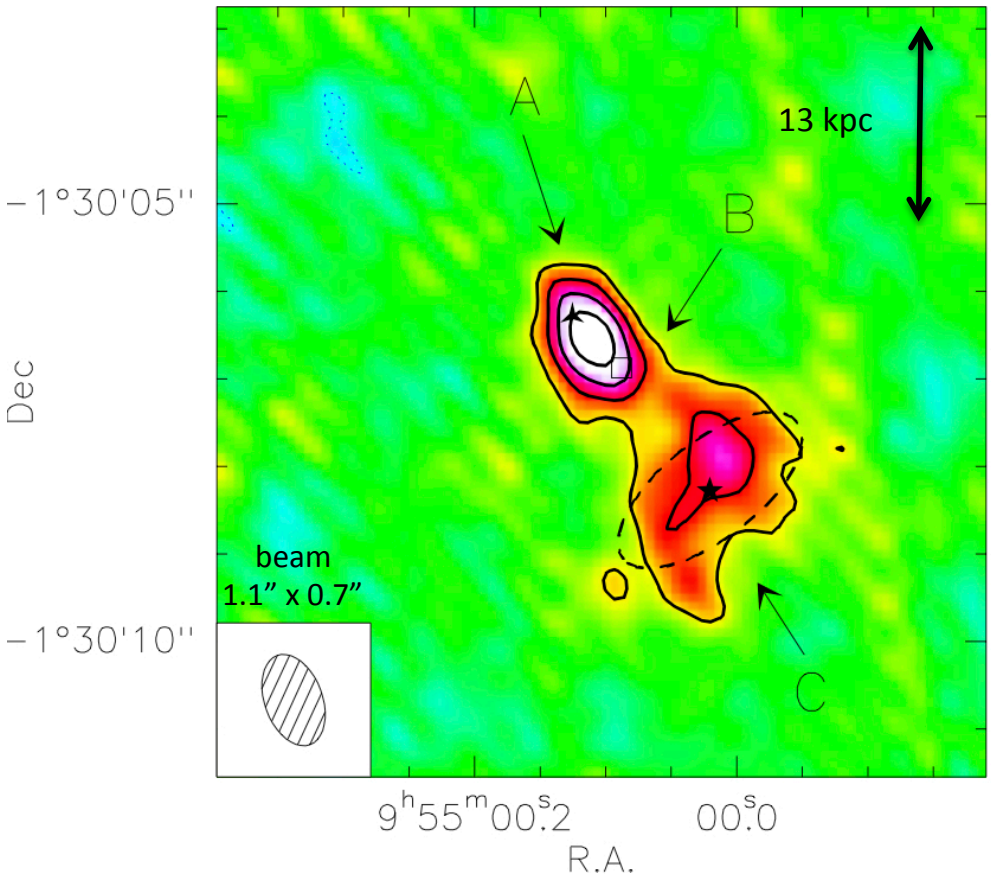
foreground galaxy at z=0.6



(Lehar et al. 2000)

Imaging of B0952 at z=4.4

PdBI observations reveal a surprisingly complex structure!



Contours levels at 2.5 σ
(1 σ = 0.5 Jy km/s^{-1})

REGION A + B

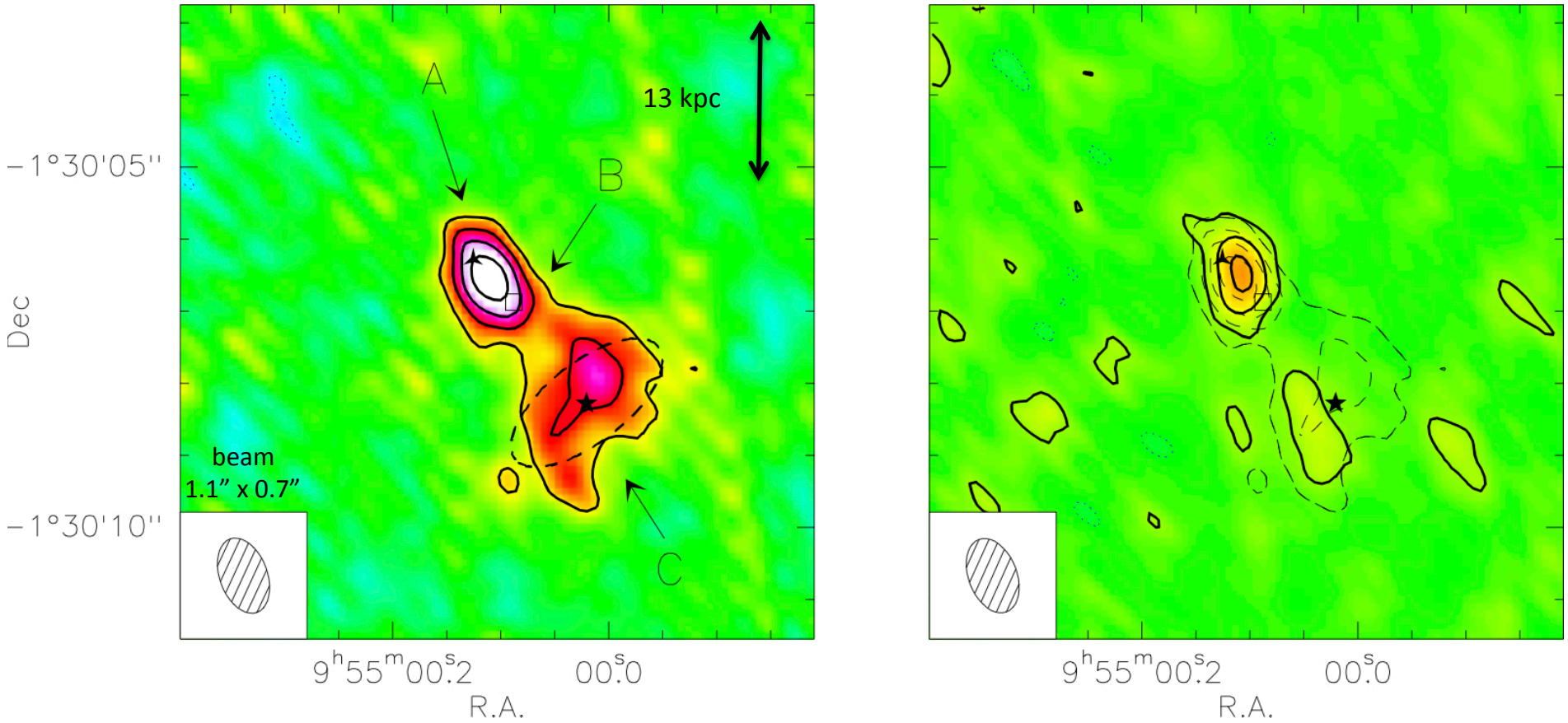
compact emitting region (< 2kpc)
tracing star formation in the vicinity
of the double lensed image
of the quasar nucleus

REGION C

extended component (~ 12 kpc)
undetected with HST,
possibly as a consequence of
high extinction

Gallerani et al. (2012)

Imaging of B0952 at z=4.4

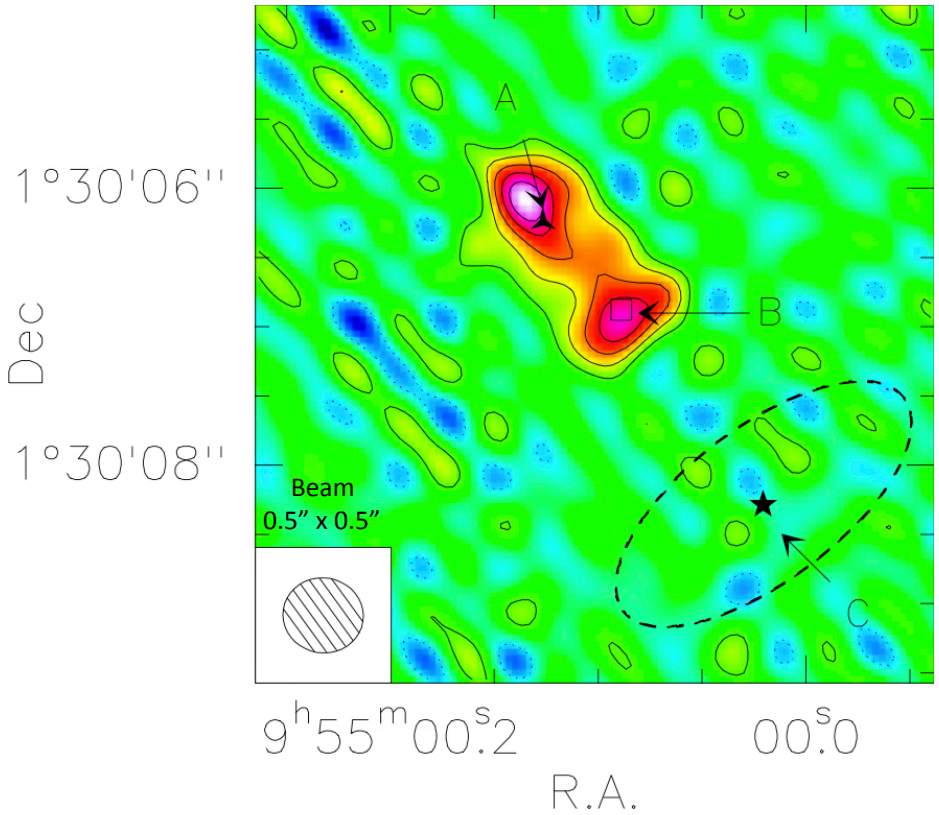


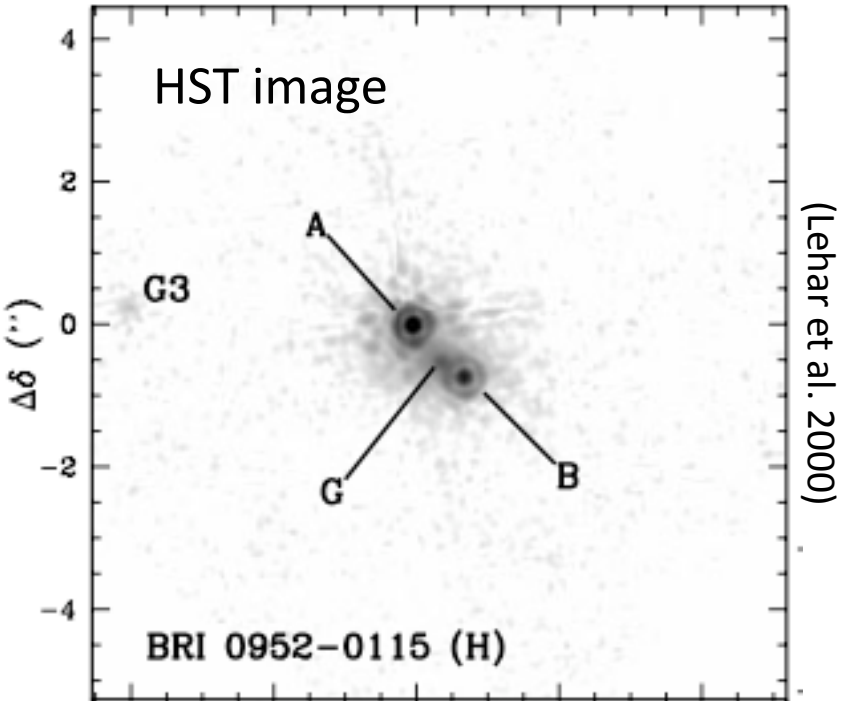
$F^{cont}_{0.8mm} \sim 11$ mJy

($L_{FIR} = 10^{12} L_{sun}$)

SFR ~ 300 M_{sun}/yr

An high resolved map of B0952



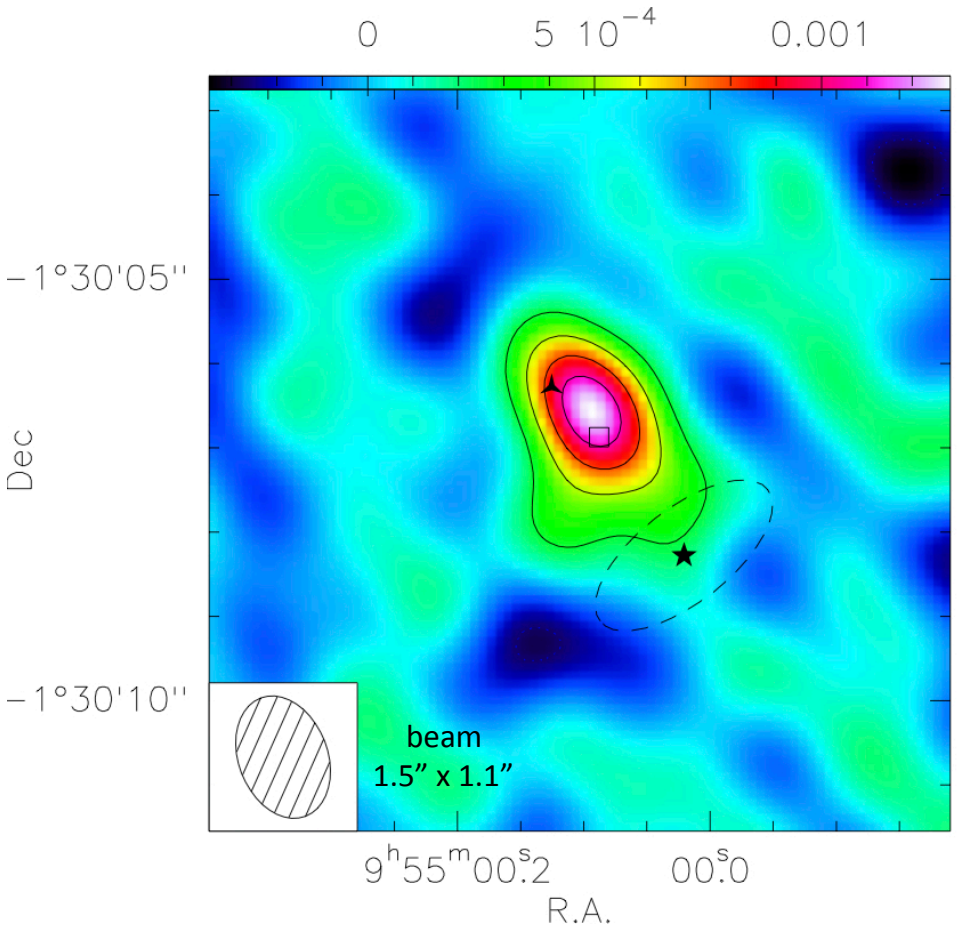


$F^{cont}_{0.8mm}$ ~ 11 mJy → SFR ~ 300 M_{sun}/yr

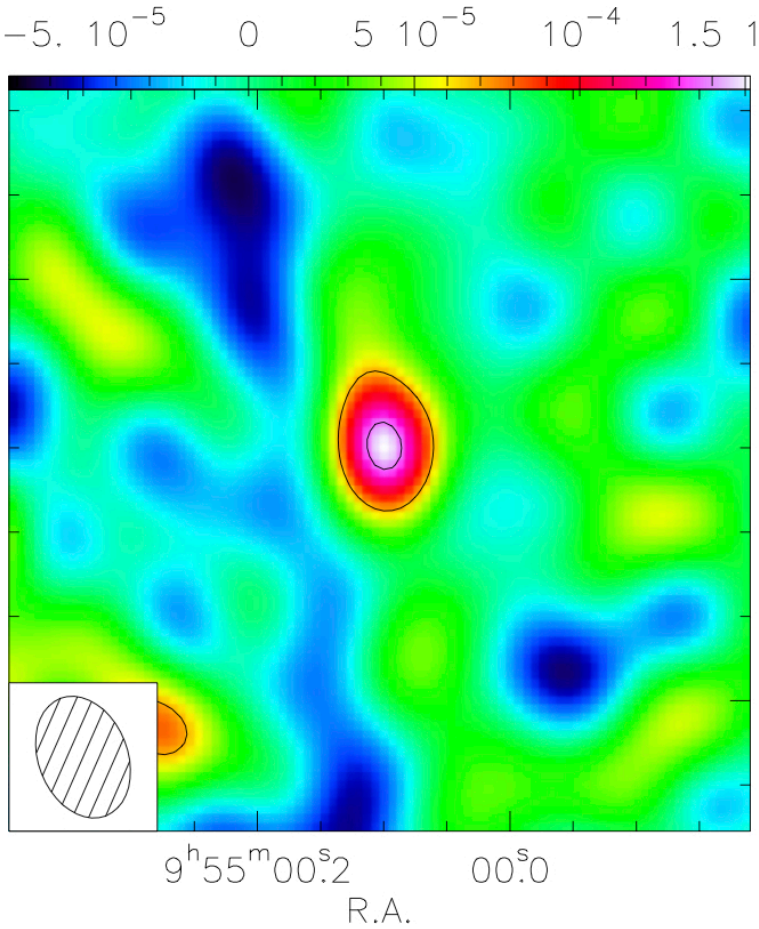
R<0.2" (1.4 kpc) → SFRD ~ 150 M_{sun}/yr/kpc^2

Gallerani et al. (2012)

Detected CO(5-4) emission in B0952



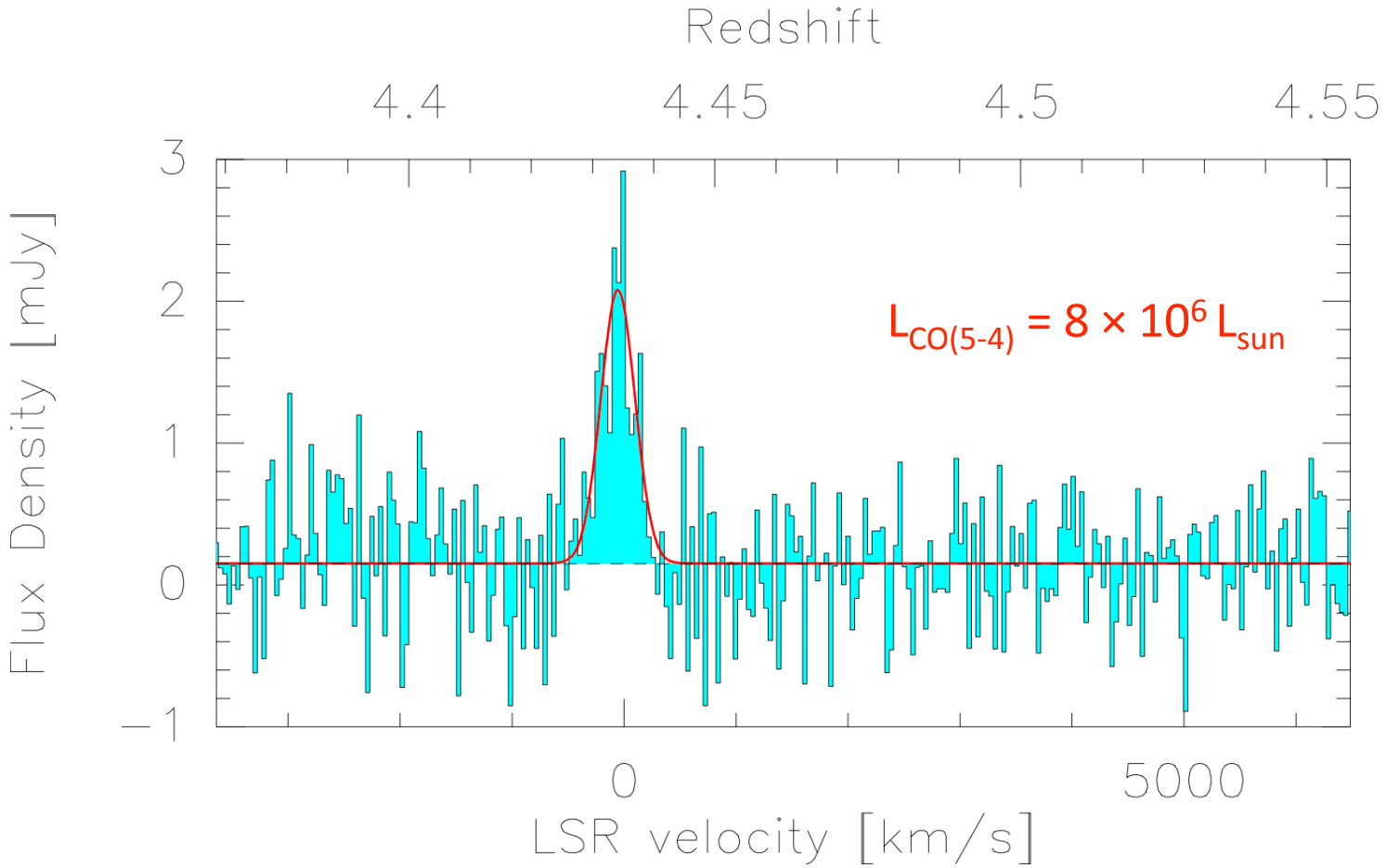
Contours levels at 2.5 σ
(1 σ = 0.07 Jy km/s^{-1})



F^{cont}_{3mm} ~ 0.15 mJy

(Work in progress)

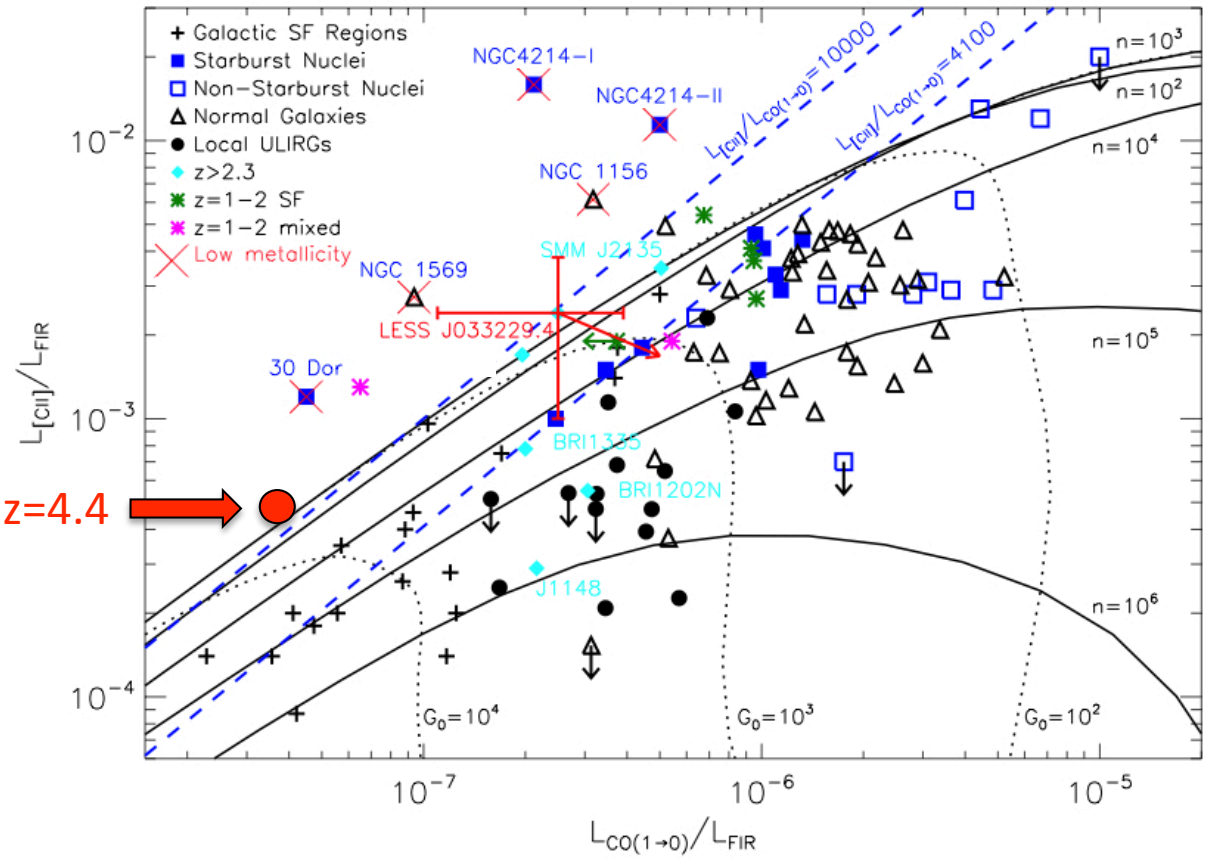
Detected CO(5-4) emission in B0952



$M_{H2} \approx (1\text{-}5) 10^9 M_\odot$

(Work in progress)

Diagnostic diagram



BRI 0952 @ z=4.4

low redshift observations from Stacey et al. 2010

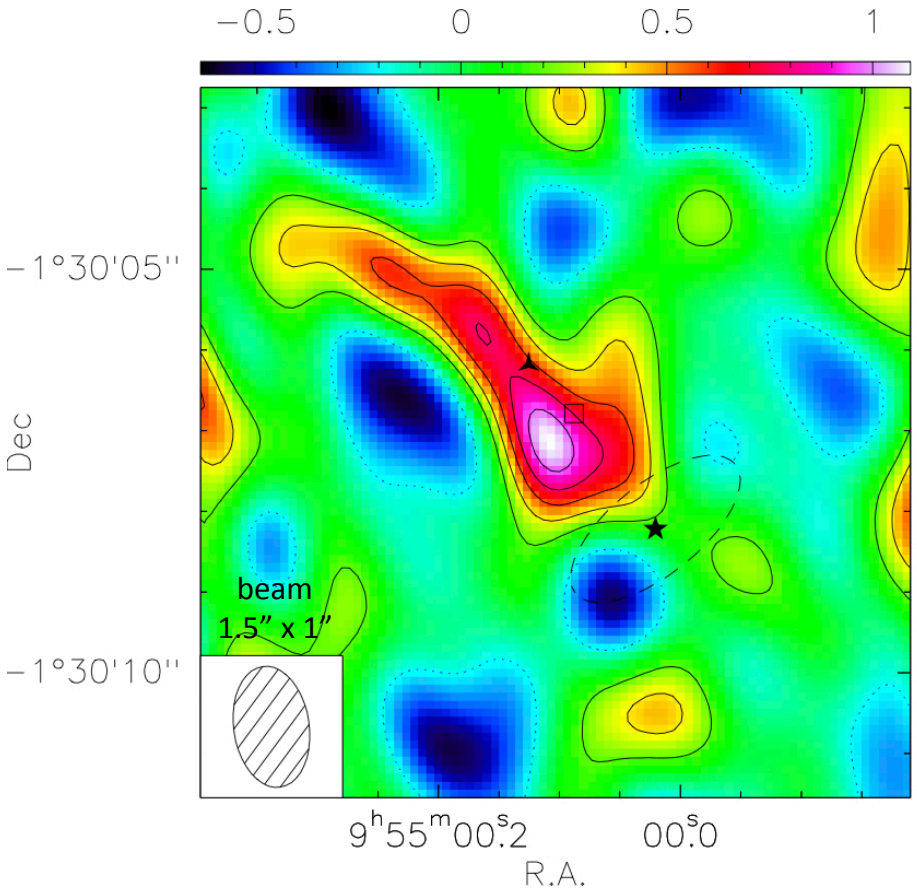
PDR models predictions from Kaufman et al. 1999

Molecular clouds density $n \approx 10^2 - 10^3\ cm^{-3}$

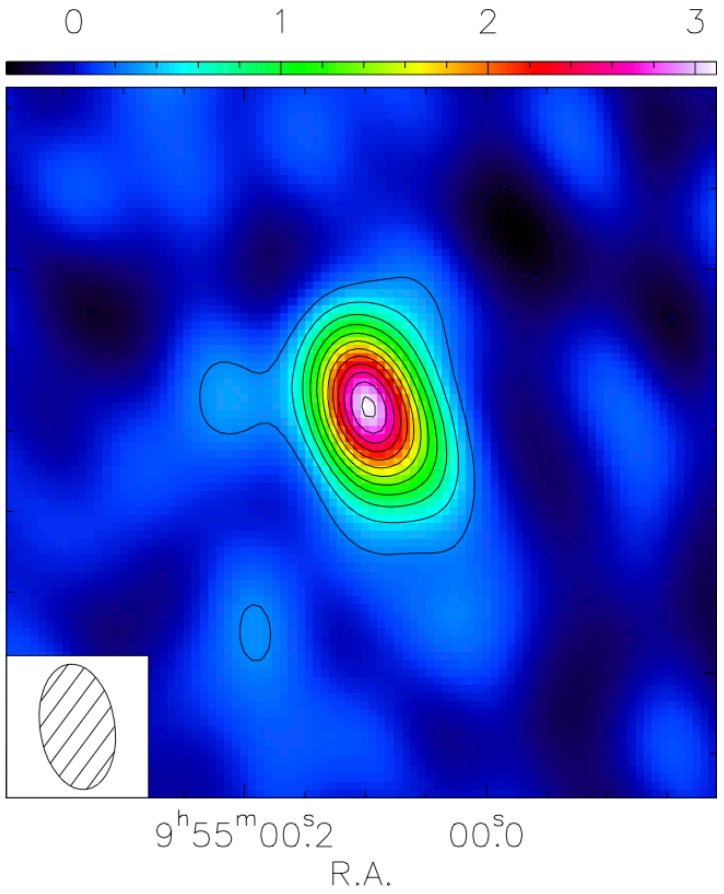
FUV (6 eV < hν < 13.6 eV) radiation field intensity $G_0 \approx 10^3 - 10^4$

(in units of the local value, i.e. 10^{-3} erg $cm^{-2}\ s^{-1}$)

Detected NII emission in B0952



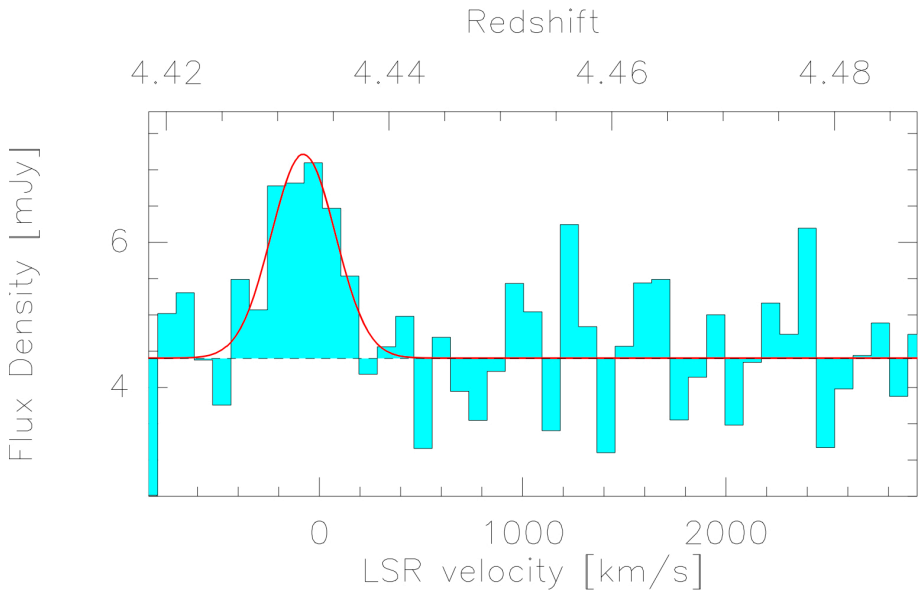
Contours levels at 2.5 σ
(1 σ = 1 Jy km/s^{-1})

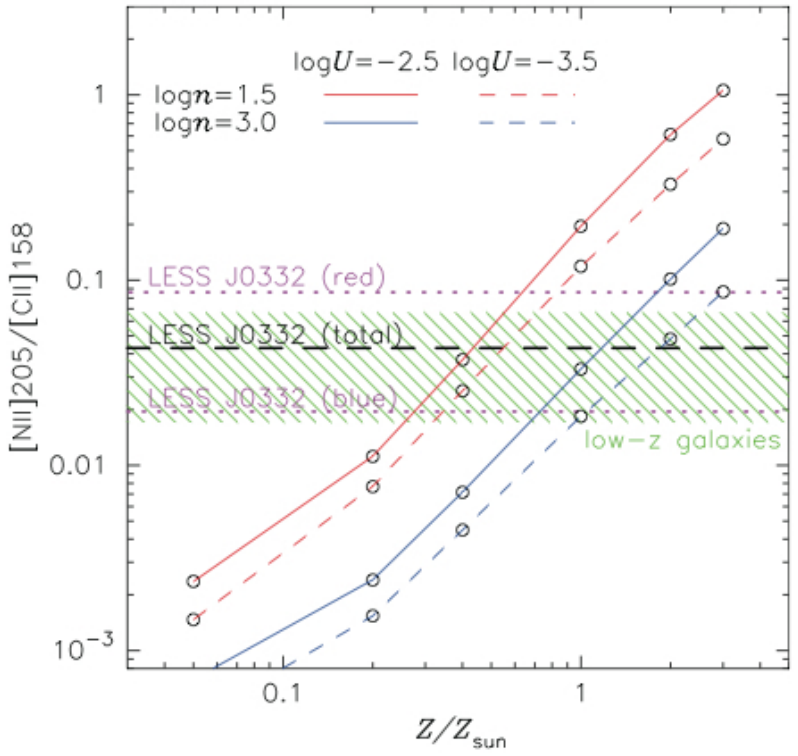


F^{cont}_{1mm} ~ 4.4 mJy

(Work in progress)

Gas metallicity in B0952





Nagao et al. (2012)

[NII]/[CII]=0.05 → $0.4 < Z/Z_{sun} < 3$

(Work in progress)

Observations of rest frame far infrared emission lines in z > 4 quasars

- Rest frame far infrared emission lines are promising tools to detect high-z galaxies.
- The [CII] emission line is a tracer of high-z merging systems.
- Observations of [CII] and [CO] allows to characterize the ISM of star-forming galaxies (density, UV radiation fields, molecular masses, SFR, SFRD…)
- The [NII]/[CII] flux ratio provide measurement of the gas metallicity in high-z galaxies.

DUST AT HIGH REDSHIFT

Why do we care?

- Early star formation

  * Triggers molecular hydrogen formation
  * Allows low mass star formation at low metallicities

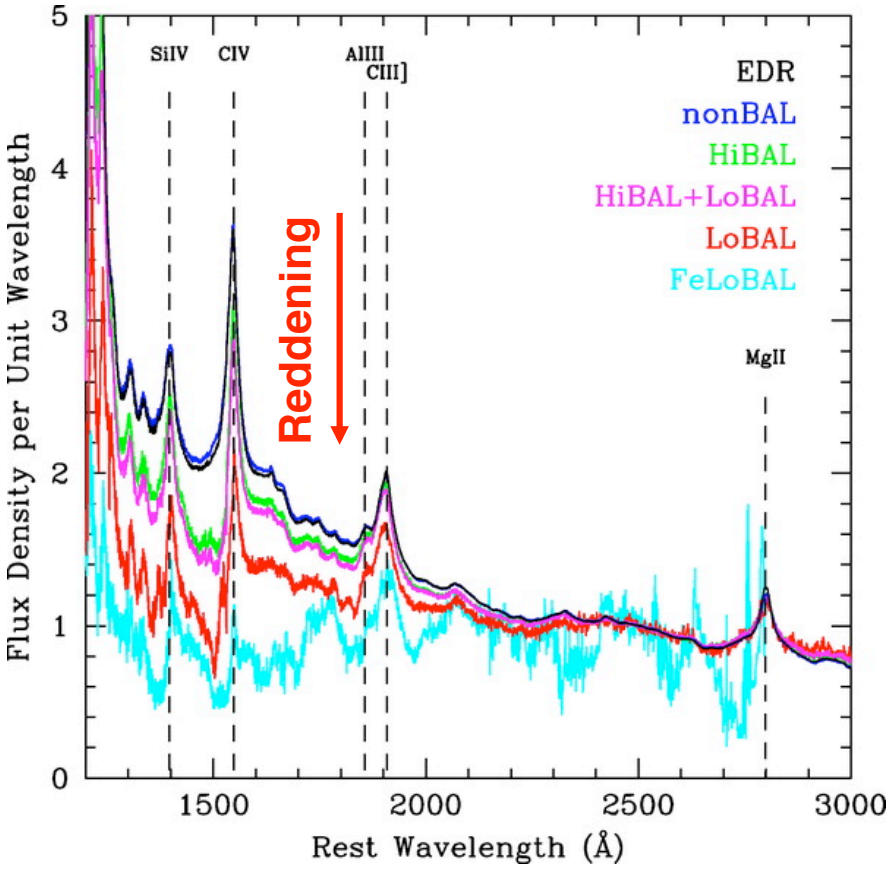
- Far-Infrared emission

  * Detectability at mm-submm wavelengths

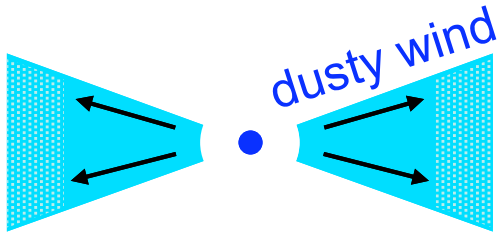
- UV-Optical extinction

  * Detectability and interpretation of near-IR light

EXTINCTION CURVE AT z<4 FROM QSO SPECTRA



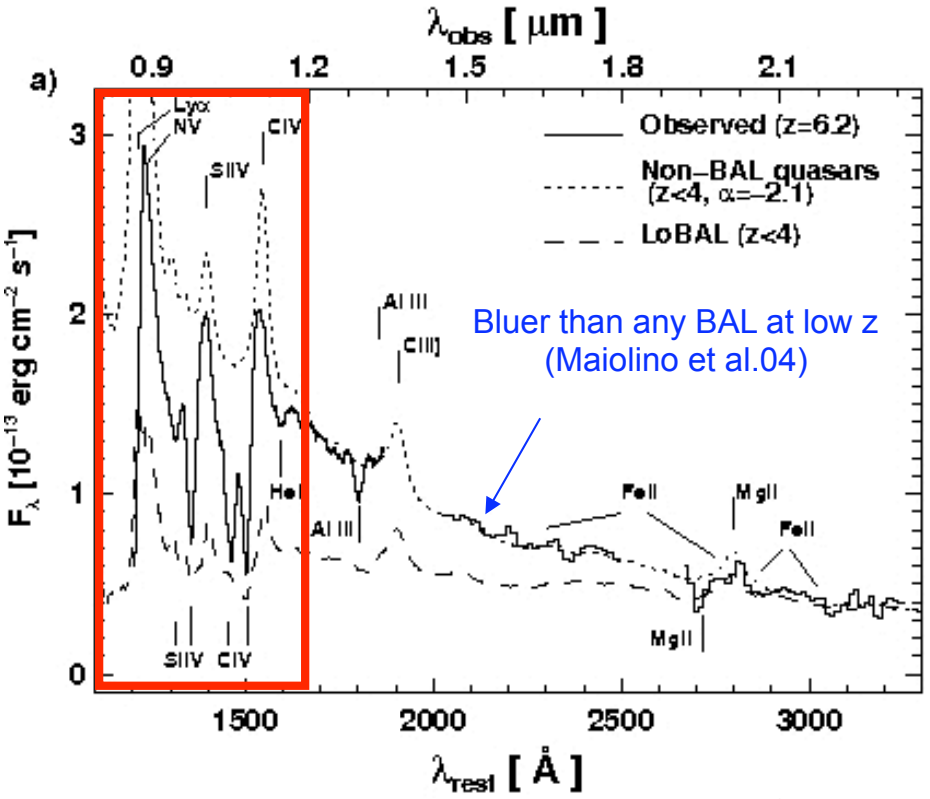
BAL are the most reddened sub-class of QSOs

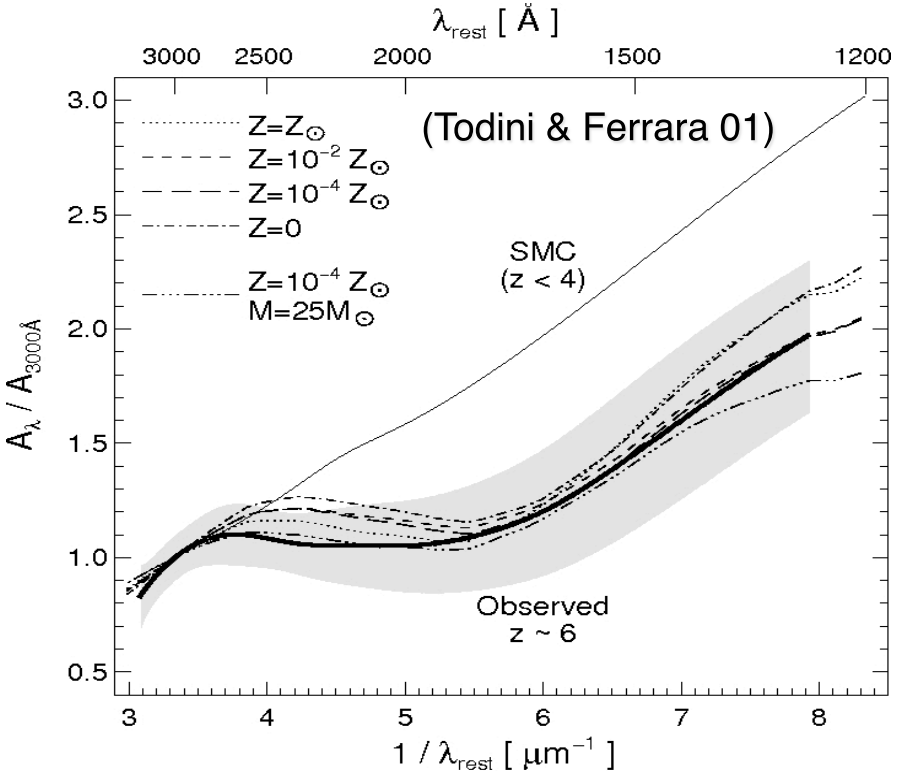


SMC-like extinction curve as for noBAL QSOs at 0<z<2.2

Reichard et al. 2003; Richards et al. 2003; Hopkins et al. 2004

EXTINCTION CURVE AT z~6 FROM QSO SPECTRA





(Maiolino et al. 04)

Extinction curve consistent with properties of dust theoretically expected from SNe

(see also Stratta et al. 06, Stratta et al. 2011)

A SAMPLE of 33 OPTICAL/NIR SPECTRA OF QSOs AT 4<z<6.4

$$F_\lambda = C F_\lambda^{templ} \left(\frac{\lambda}{3000} \right)^{(1.62-\alpha)} 10^{-A_{3000} \frac{A_\lambda}{2.5}}$$

F_λ^{templ} template by Reichard et al. 2003, having α=-1.62

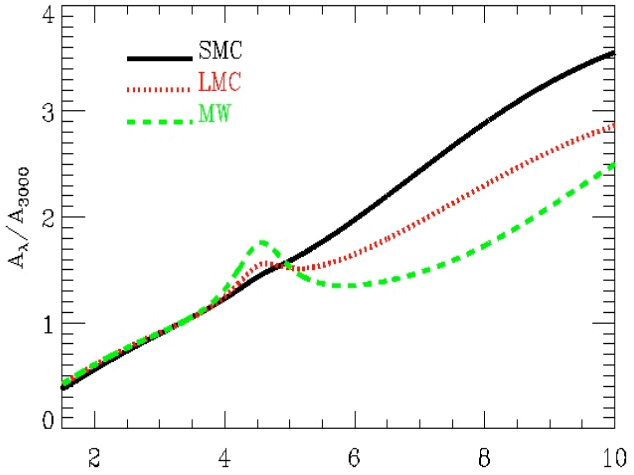
A_{3000} absolute extinction at 3000 Å

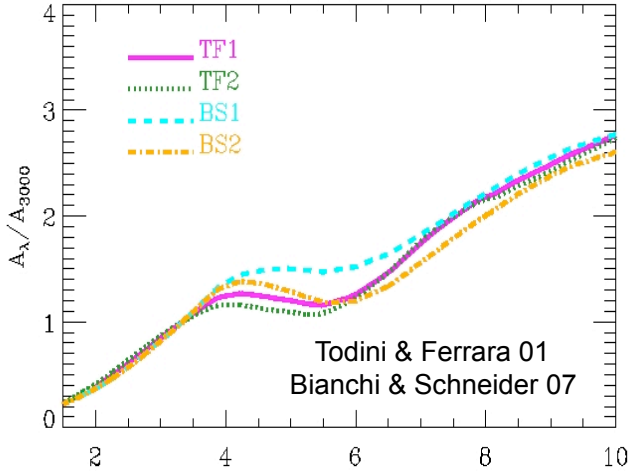
A_λ extinction curve normalized at 3000 Å

(Data from Juarez et al. 2009; Jiang et al. 2007; Willott et al. 2009; Mortlock et al. 2008)

GRID OF EXTINCTION CURVES

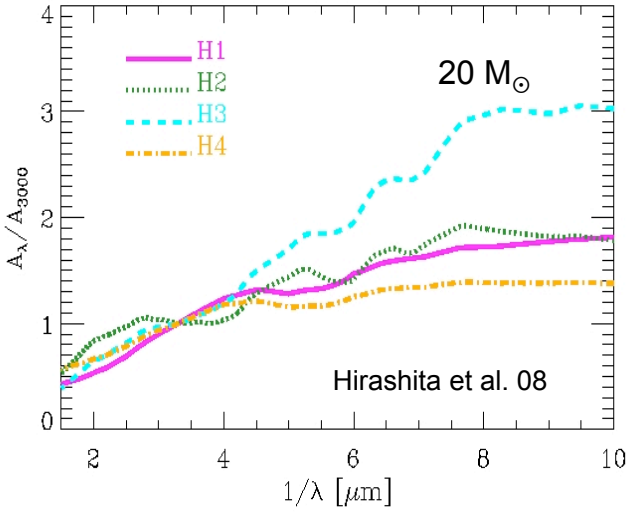
Empirical extinction curves from the local Universe

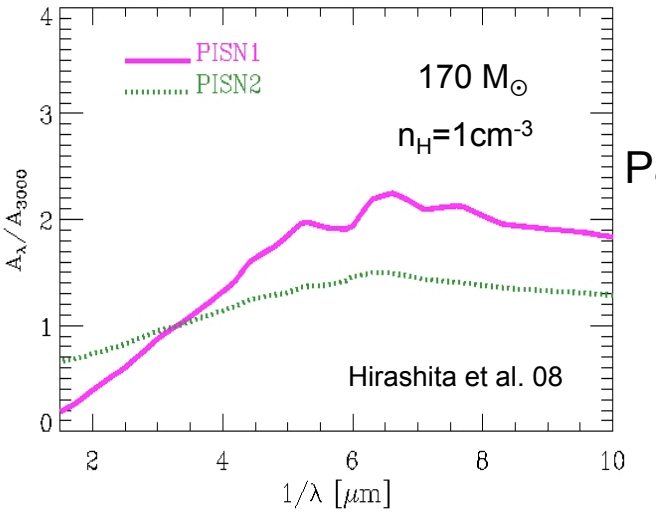




SNe type dust

SNe type dust

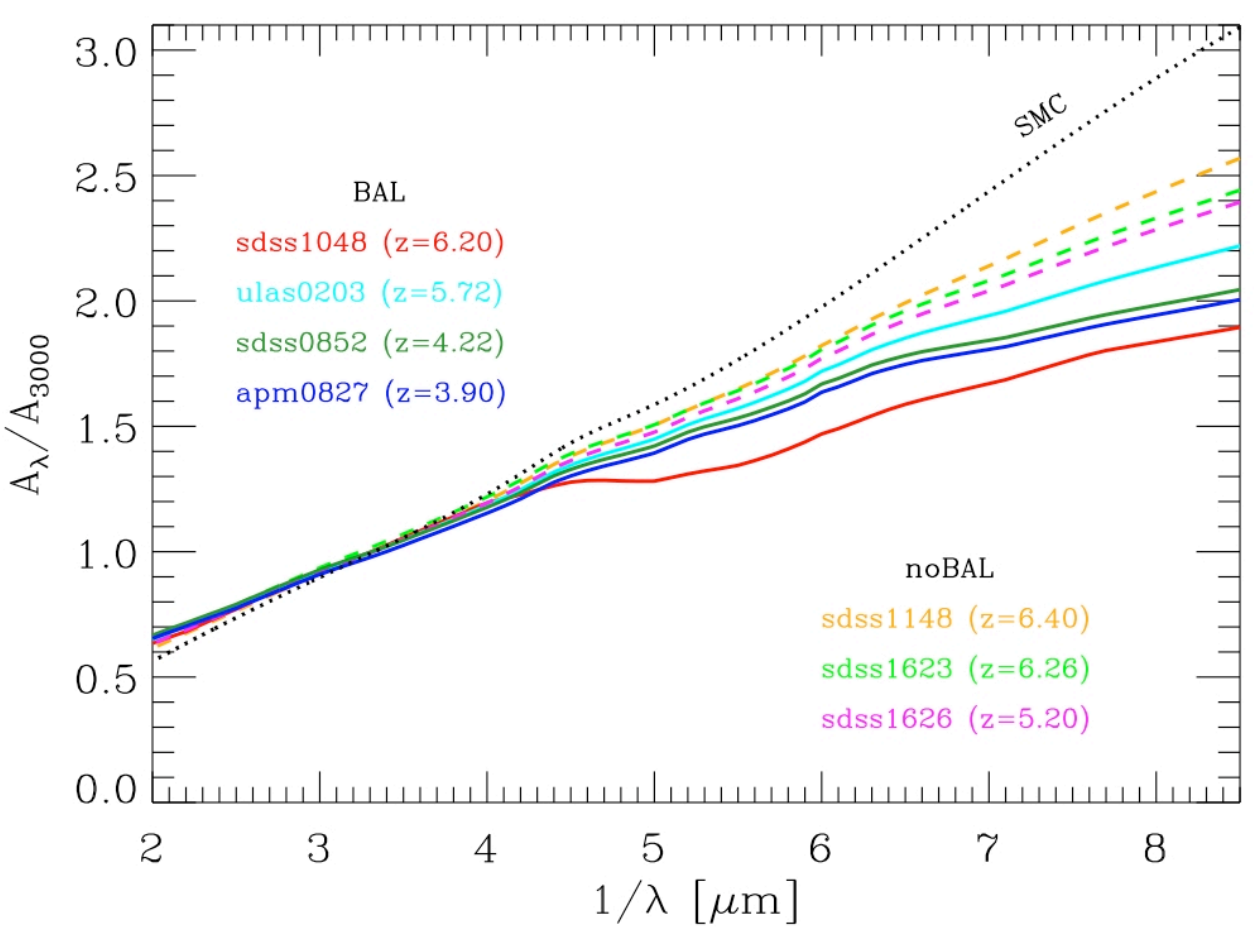




Pair instability SNe type dust

$$A_\lambda^{mix} = (1-p)A_\lambda^{SMC} + pA_\lambda^{SN} \qquad 0 \le p \le 1$$

DUST REDDENING IN 4<z<6.4 QSOs



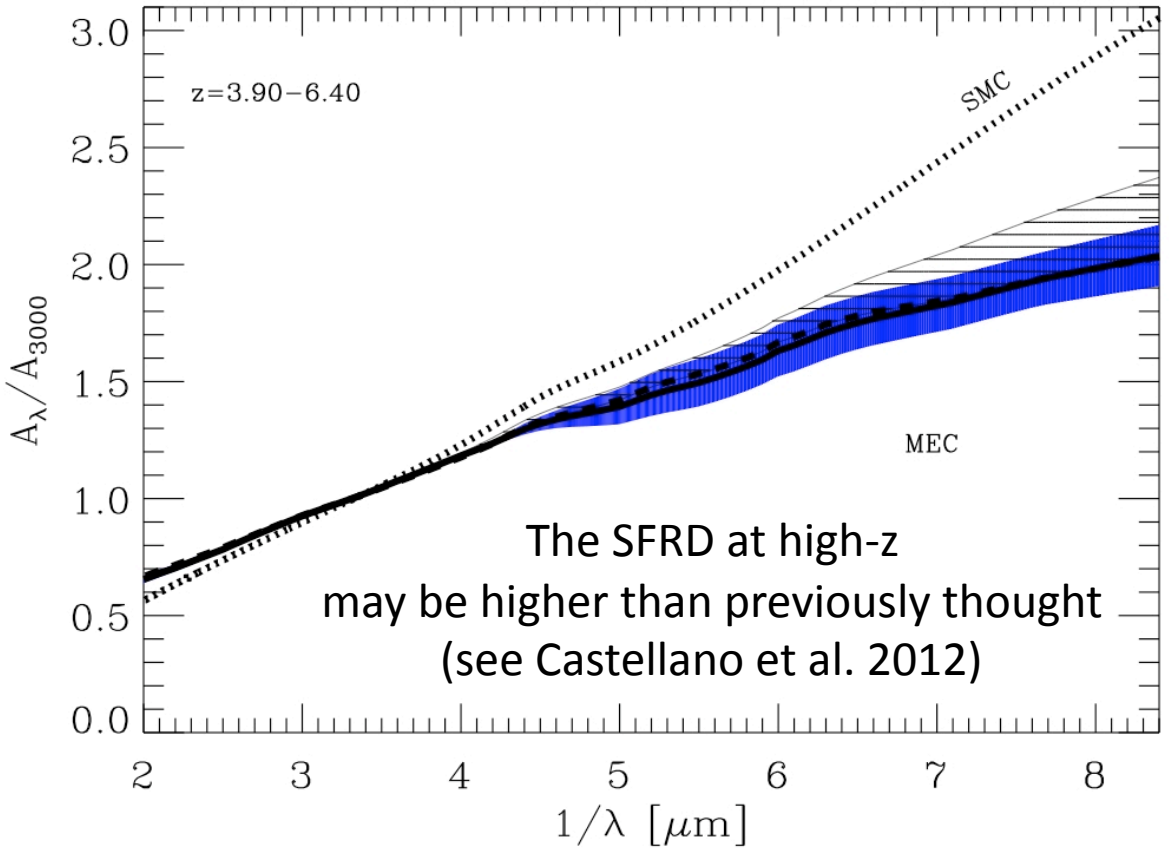
Extinction curve at 0<z<4

Extinction curves at 4<z<6.4

For all the reddened quasar of our sample the best fit extinction curve is not the SMC

Gallerani et al. (2010)

THE EXTINCTION LAW AT HIGH REDSHIFT



Evidence for different dust properties in the early Universe

(chemical composition? grain size distribution? dust sources?...)

Gallerani et al. (2010)

CONCLUSIONS

• **Dust extinction in quasars at z<4 is described through the SMC extinction curve.**

• **We infer a mean extinction curve (MEC) from 4<z<6.4 quasar spectra finding that it deviates from the SMC one.**

• **Evidence for different dust properties in the early Universe, (dust sources? chemical composition? grain size?…)**

Gallerani et al. (2010)