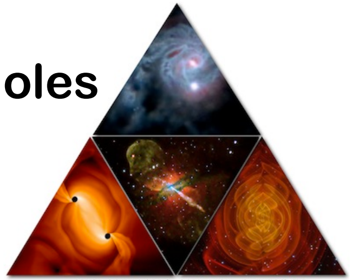
A Universe of Black Holes

KITP-Santa Barbara
July 25 2013



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The growth of the first QSOs: constraints from the host galaxies

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FIRST
THE FIRST STARS AND GALAXIES

the FIRST team and collaborators


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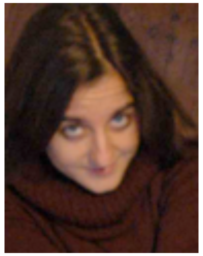
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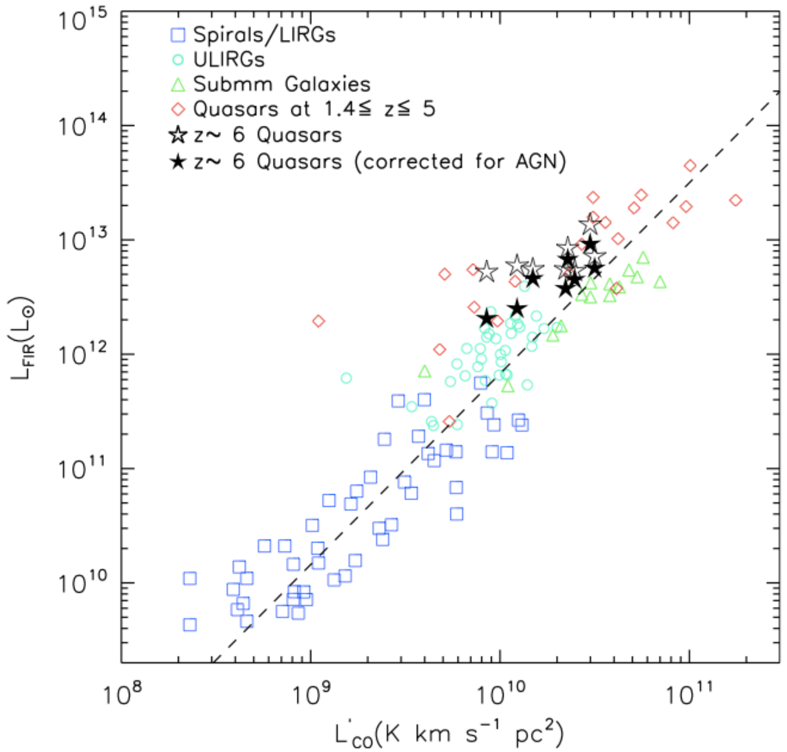
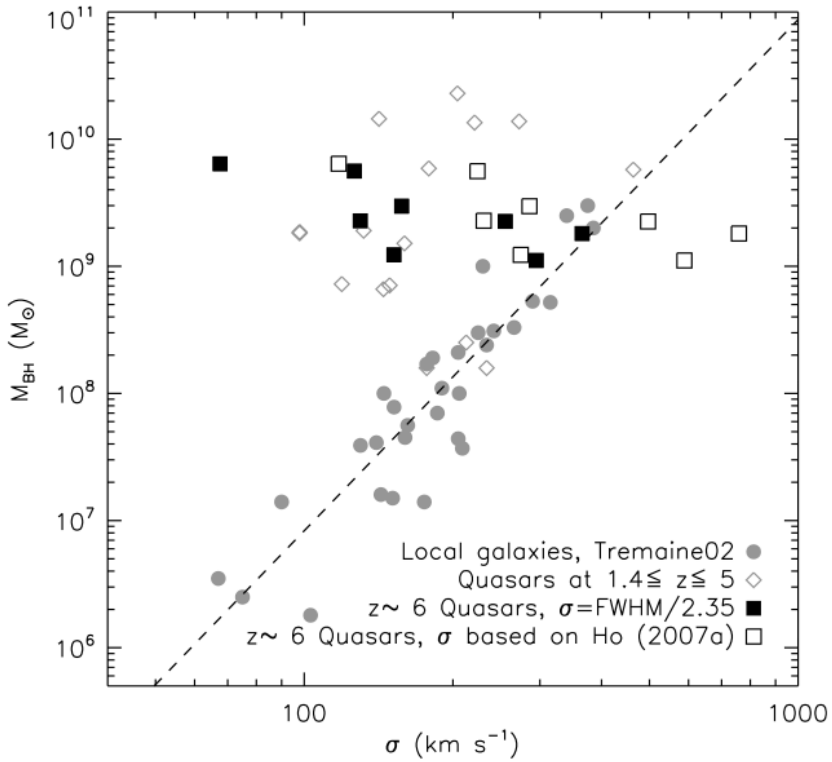
Observed properties of z ~ 6 QSO hosts

Wang et al. 2008, 2010, 2013





$$M_{\rm dust} = \frac{S_{\nu_0}\, d_{\rm L}^2(z)}{(1+z)\,\kappa_{\rm d}(\nu)\,B(\nu,T_{\rm d})} \qquad \kappa_{\rm d}(\nu) = \kappa_0(\nu/\nu_0)^\beta$$

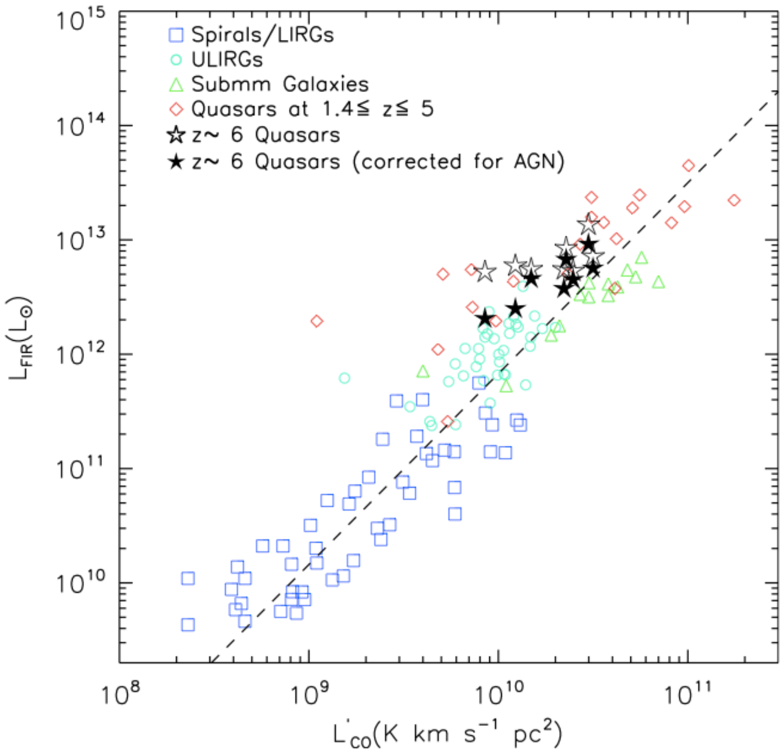
$$L_{\rm FIR} = 4\pi M_{\rm dust}\int \kappa_{\rm d}(\nu)\,B(\nu,T_{\rm d})\,d\nu.$$

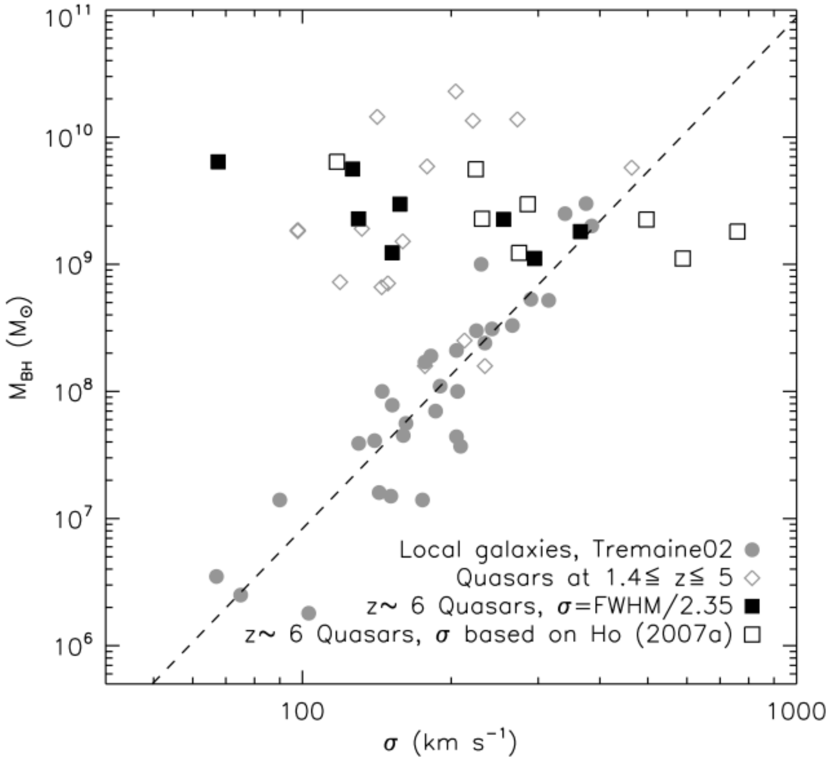
M_{BH} = L_{BOL}(erg/s)/1.26x10^{38} M_{sun}
L_{BOL} ←→ M_{1450}
σ ←→ CO FWHM < i > = 40°

<T_{dust}> = 47 K
dust emissivity β = 1.6 k_0 = 0.4 cm^2/gr @ 1200 μm (Beelen+06)
AGN correction L_{FIR} = 0.14 ν $L_{\nu,1450Å}$ (Elvis+94)

Observed properties of z ~ 6 QSO hosts

Wang et al. 2008, 2010, 2013





M_{dust} ~ [1 – 6] x 10^8 M_{sun} @ z ~ 6

SFR [M_{sun}/yr] = $L_{FIR}/5.8\text{x}10^9$ L_{sun} = [400 - 2000] M_{sun}/yr

M_{H2} = α $L'_{CO(1\text{-}0)}$ with α = 0.8 M_{sun}/(K km s^{-1} pc^2)

M_{H2} = [0.7 – 3] x 10^{10} M_{sun}

M_{dyn} ~ 2.3 x 10^5 v_{circ}^2 R

V_{circ} = 3/4 FWHM/sin i

<R> = 2.5 kpc

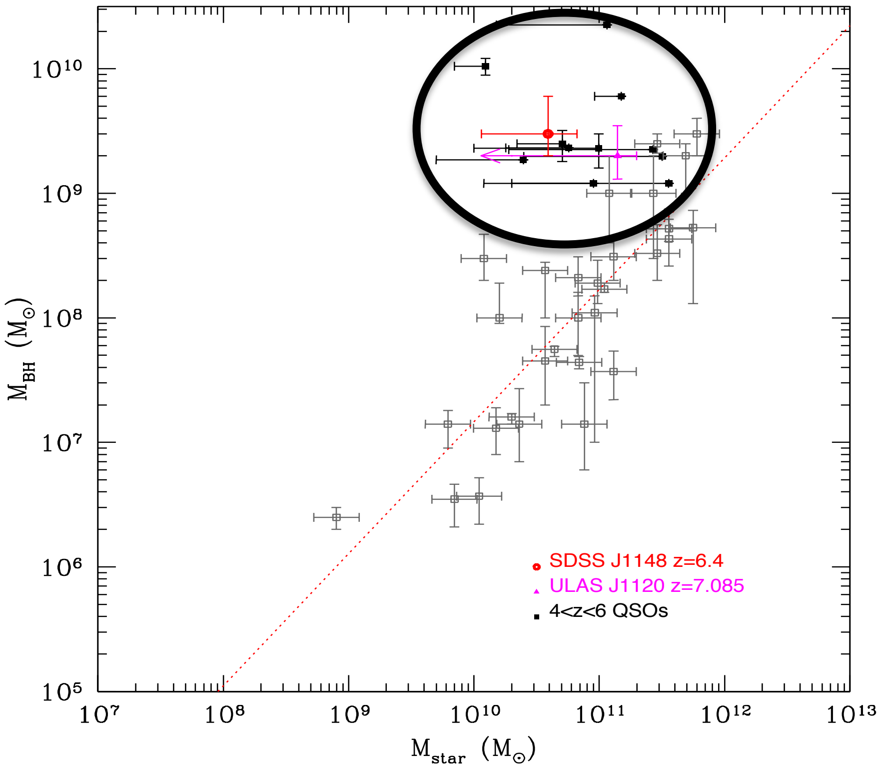
M_{dyn} $\sin^2$ i = [$8.4\text{x}10^9$ – $2.4\text{x}10^{11}$] M_{sun}

M_{star} ~ M_{dyn} – M_{H2} = [1.4 x 10^{10} – $5.7\text{x}10^{11}$] M_{sun} for <i> = 40°

Co-evolution of the first BH and galaxies: footprints in the M_{bh} – M_{bulge} relation at early times ?

in AGN-selected samples M_{bh}/M_{bulge} evolves to larger values at higher z

Walter et al. 2004; Peng et al. 2006; McLure et al. 2006; Riechers et al. 2008; Merloni et al. 2010; Wang et al. 2012



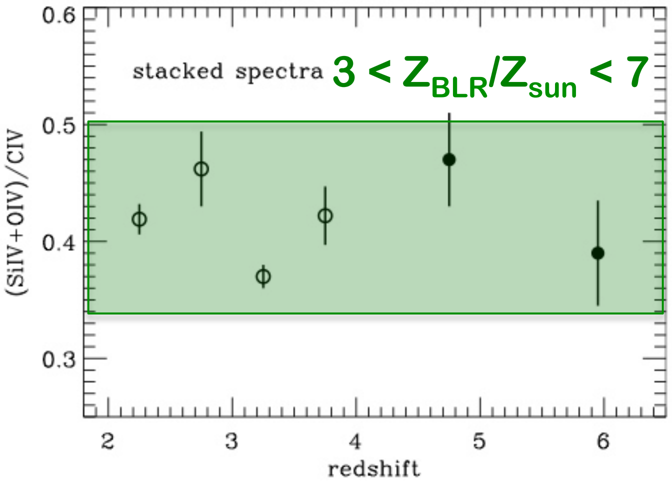
Valiante et al. in prep

Clues from the chemical properties of the host galaxies

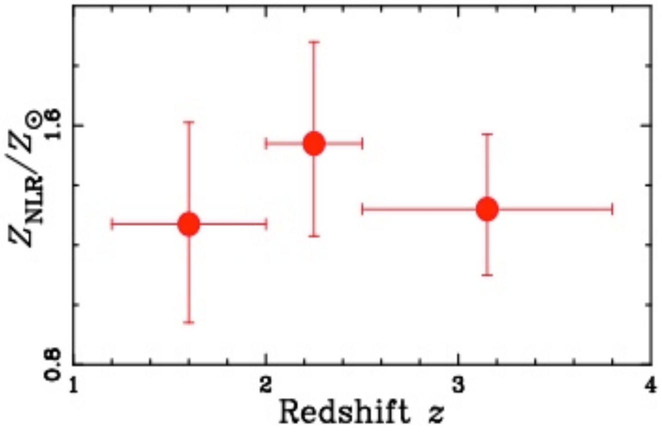
high-z QSOs host galaxies are chemically mature systems:

super solar metallicities in BLR/NLRs and $M_{dust} \sim 10^8$ M_{sun}

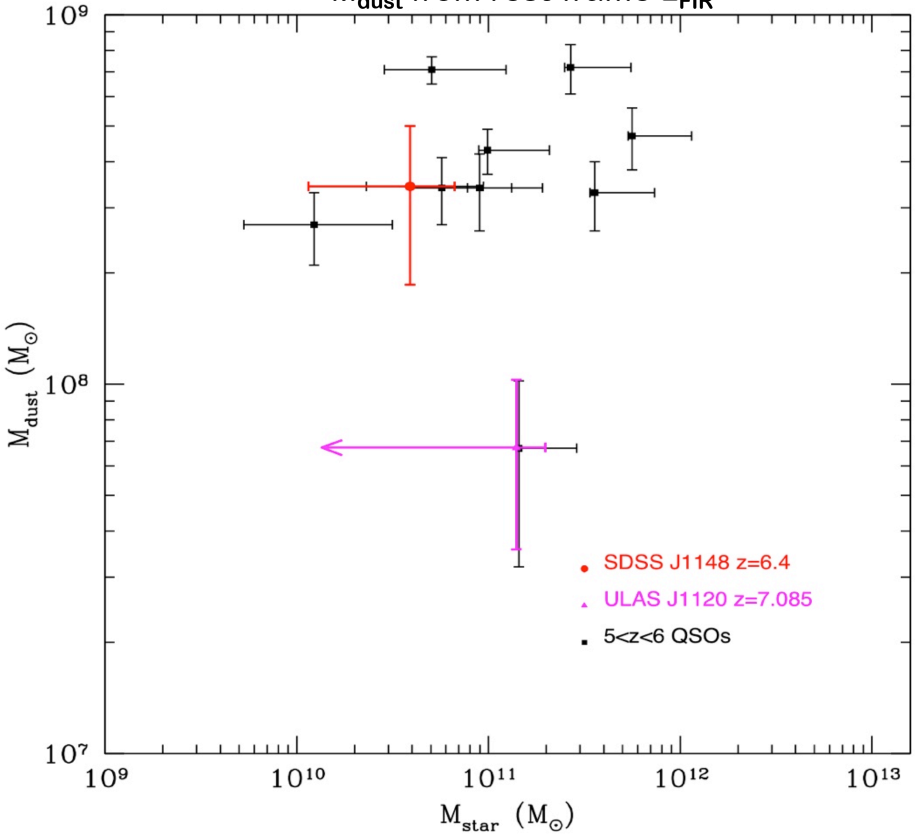
BLRs Nagao+2006, Juarez+2009



NLRs Matsuoka+2009



M_{dust} from rest-frame L_{FIR}

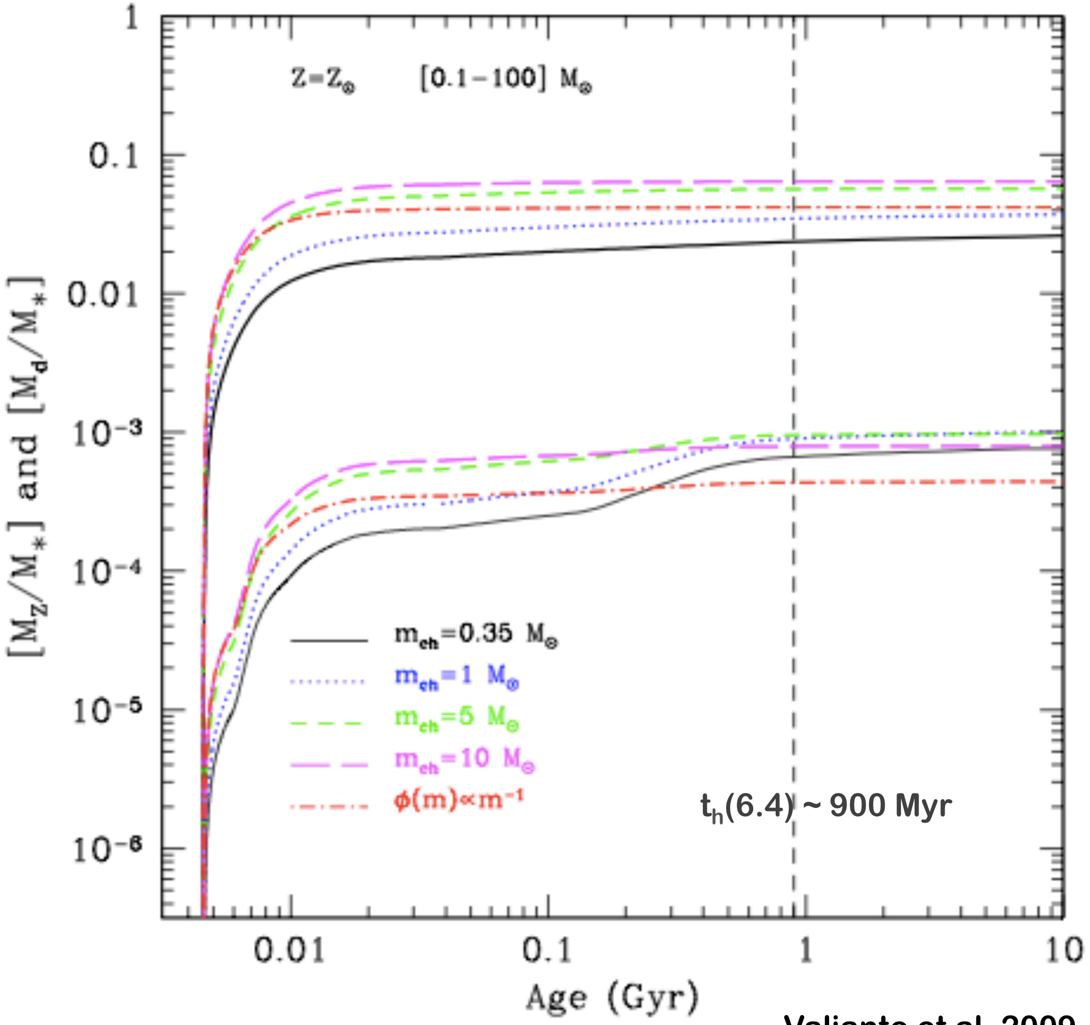


Valiante et al. in prep

stars produce heavy elements and dust

metallicity dependent metal and dust yields from SN and AGB stars

relative importance of SN and AGB stars depends on IMF and SFR



$M_{met} < 7.2 \times 10^{8}\ M_{sun} \rightarrow Z \sim 1.5\ Z_{sun}$

$M_{star}(J1148) < 3.6 \times 10^{10}\ M_{sun}$

$M_{dust} < [0.7 - 2.8] \times 10^{7} M_{sun}$

Star dust is not enough!
Additional mechanisms:

dust formation in QSO winds?
dust growth in MCs?

Valiante et al. 2009, 2011

see also Michalowski+2010

GAlaxyMErgerTree&Evolution

GAMETE

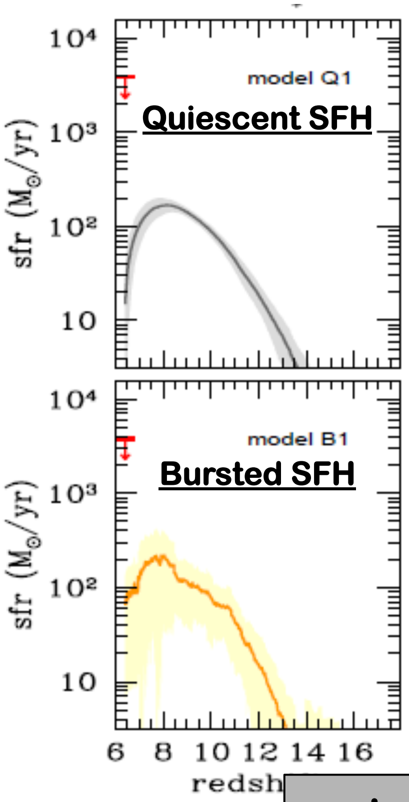
Salvadori, RS, Ferrara (2007)

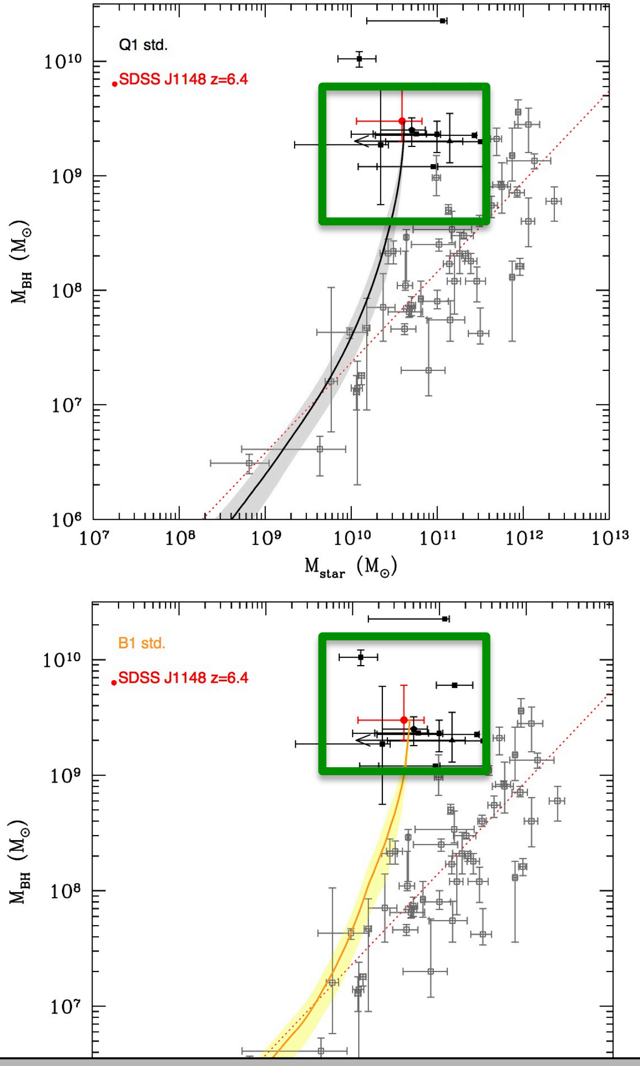
with BH evolution/feedback and dust formation/processing in the ISM

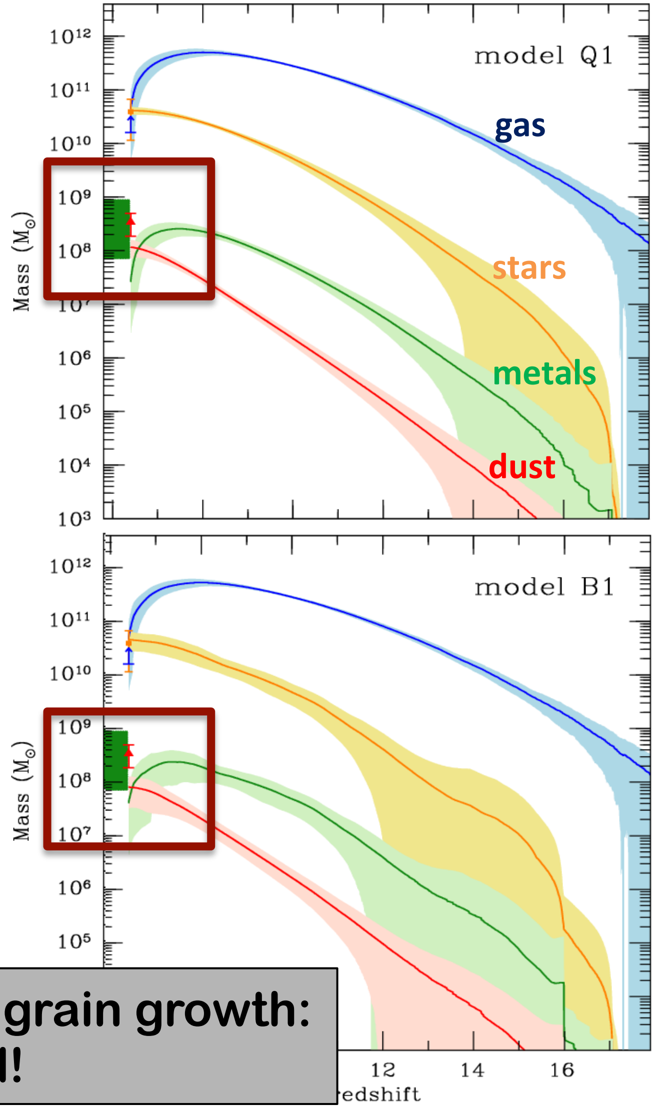
Valiante, RS, Salvadori & Bianchi (2011, 2012)

- 50 merger histories of a 10^{13} M_{sun} halo @ z =6.4 → SDSS J1148
- star formation in quiescent and/or merger-driven bursts
- BH growth via gas accretion and mergers
- BH feedback
- chemical enrichment (metals and dust) on the stellar characteristic timescales
- dust cycling in the ISM: grain destruction by interstellar shocks and grain growth in molecular clouds

first scenarios: B1 & Q1 models

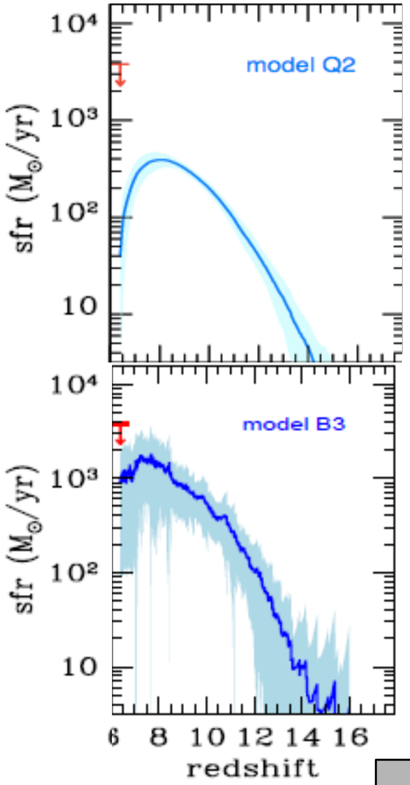


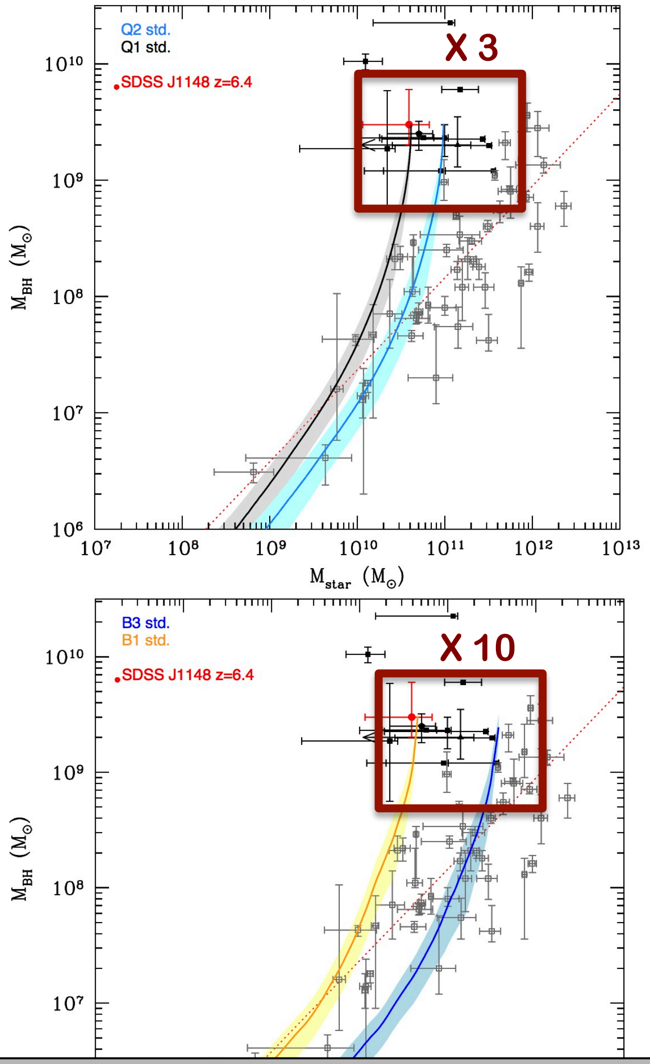


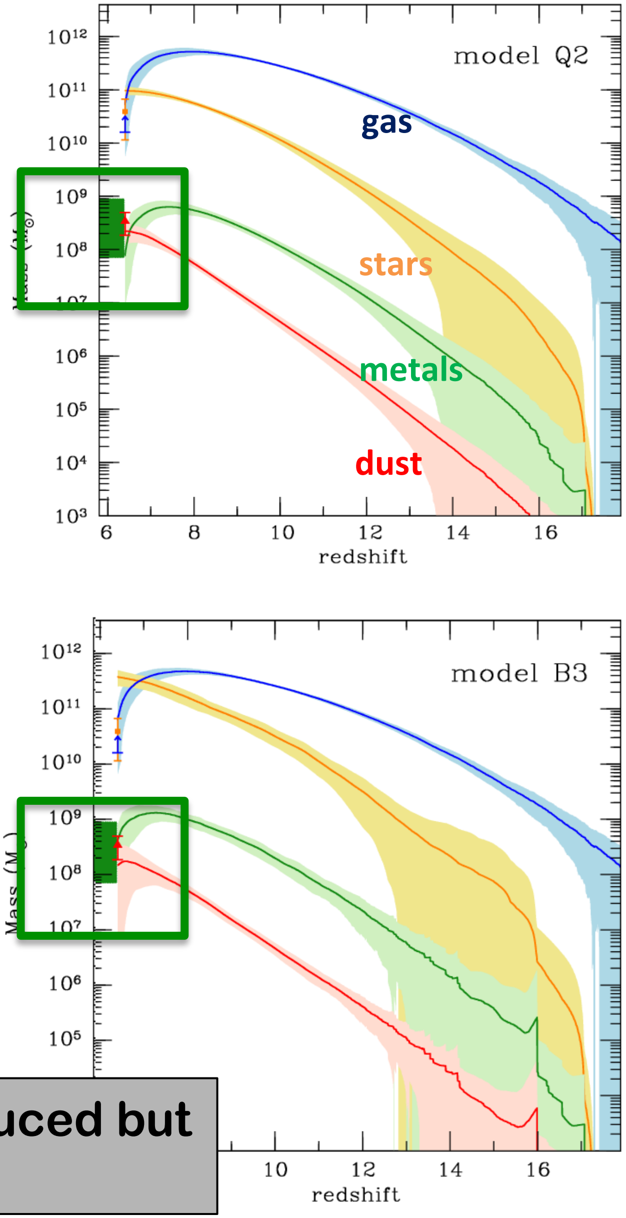


not enough heavy elements to fuel grain growth:
more stars are needed!

increase SF efficiency: B3 & Q2 models

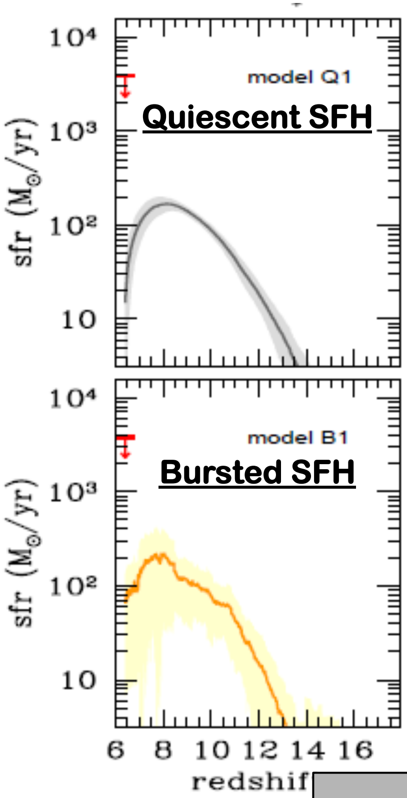


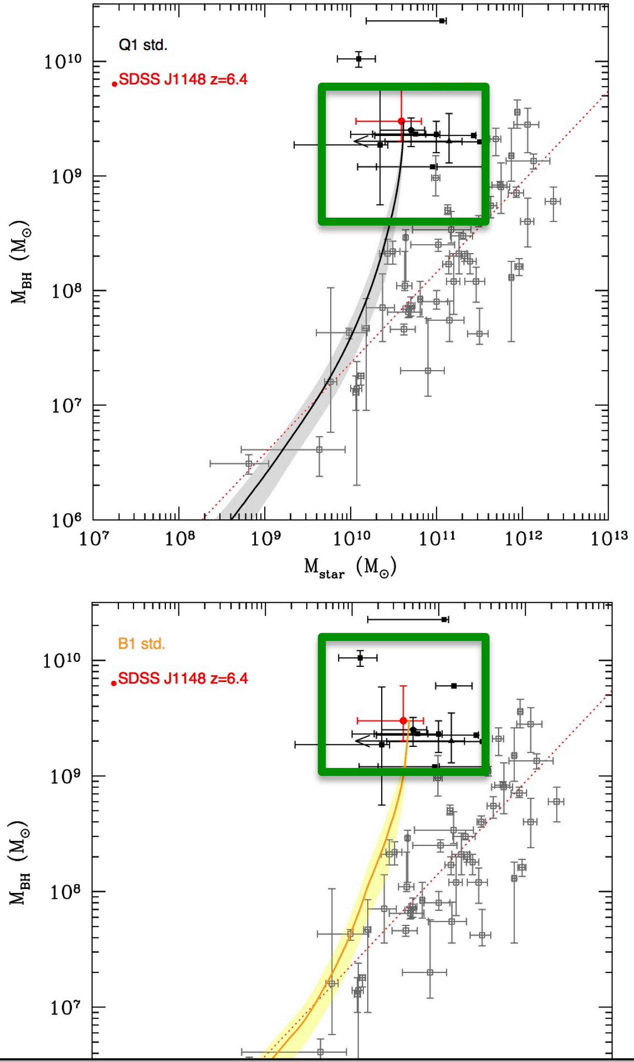


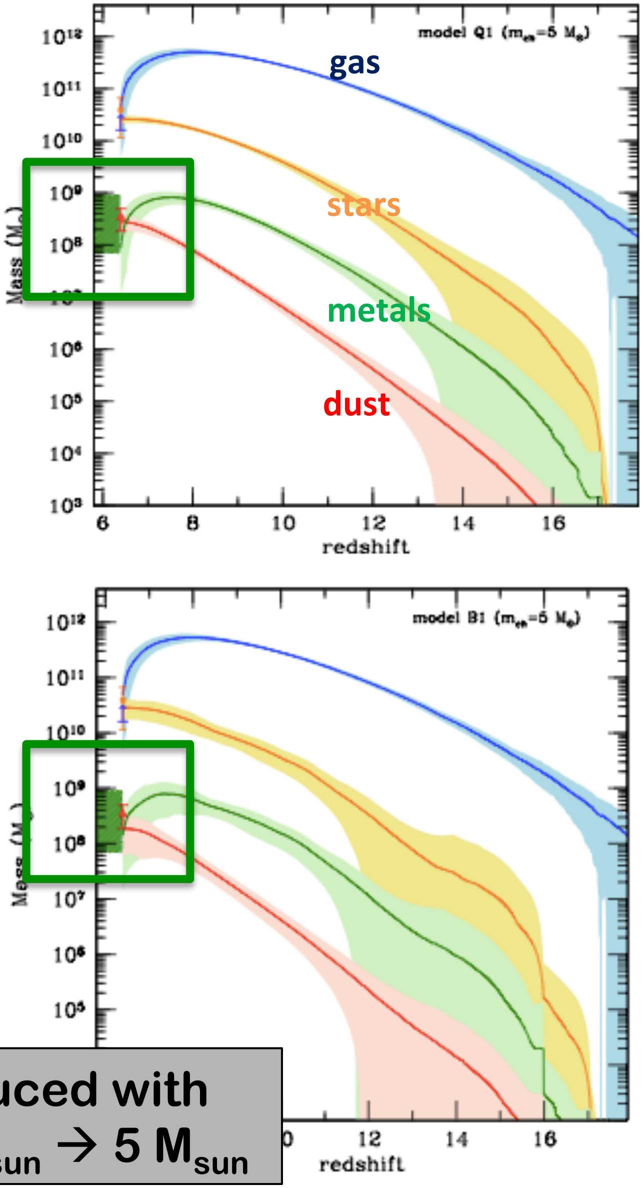


chemical properties are reproduced but
$M_{star} > M_{dyn} - M_{gas}$

Top-heavy IMF: models B1th & Q1th





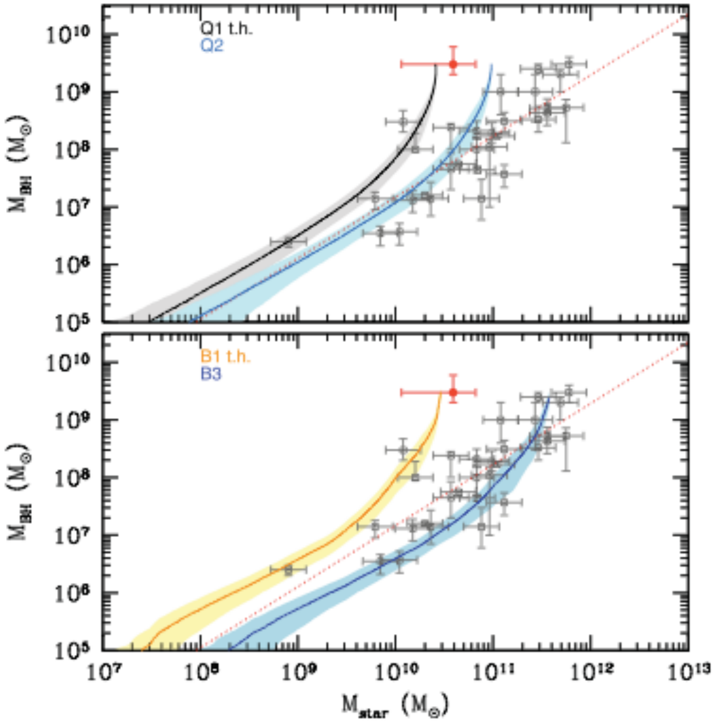


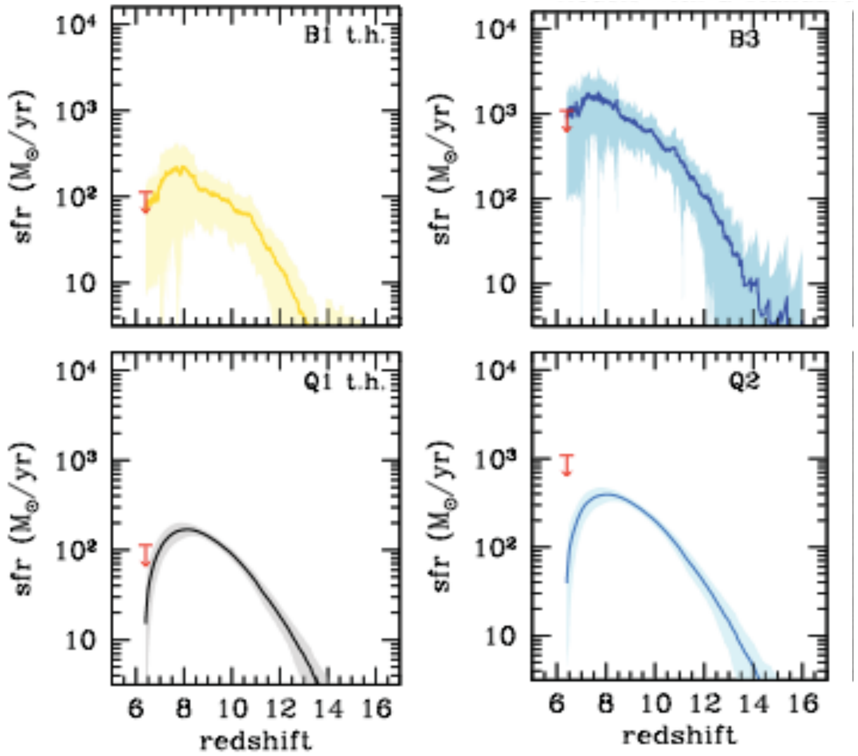
chemical properties are reproduced with

$M_{star} = M_{dyn} - M_{gas}$ but $m_{ch} = 0.35\ M_{sun} \rightarrow 5\ M_{sun}$

4 possible scenarios

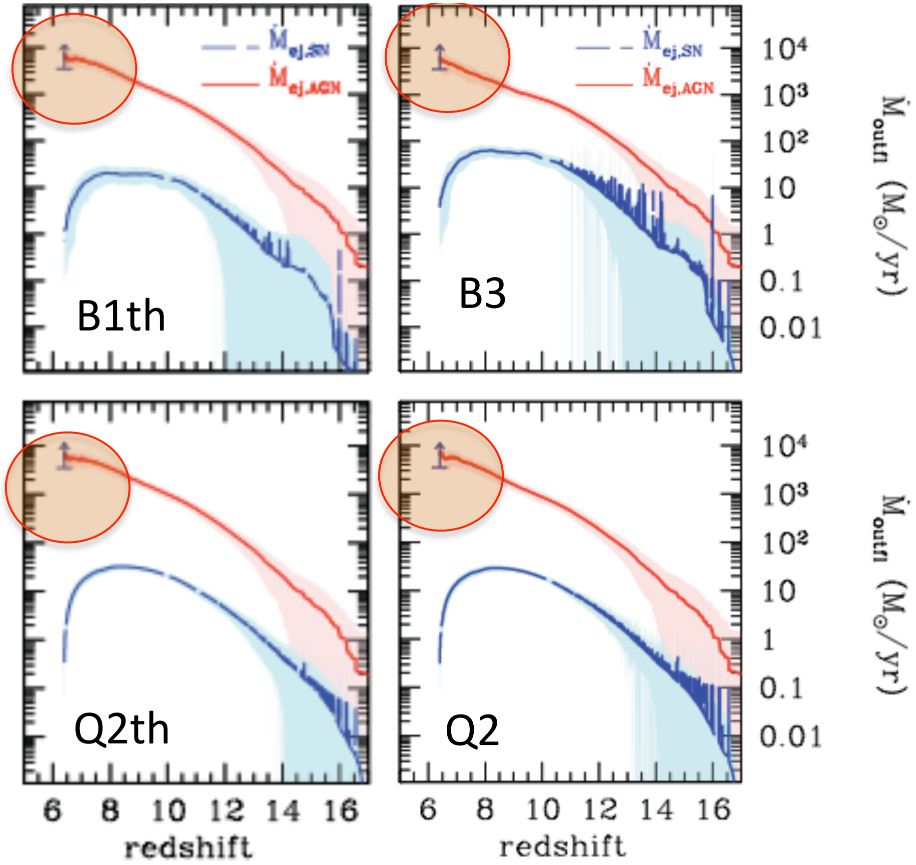
chemical properties of the host galaxy point to 4 alternative scenarios:
different SF efficiencies → different final SFRs and stellar masses



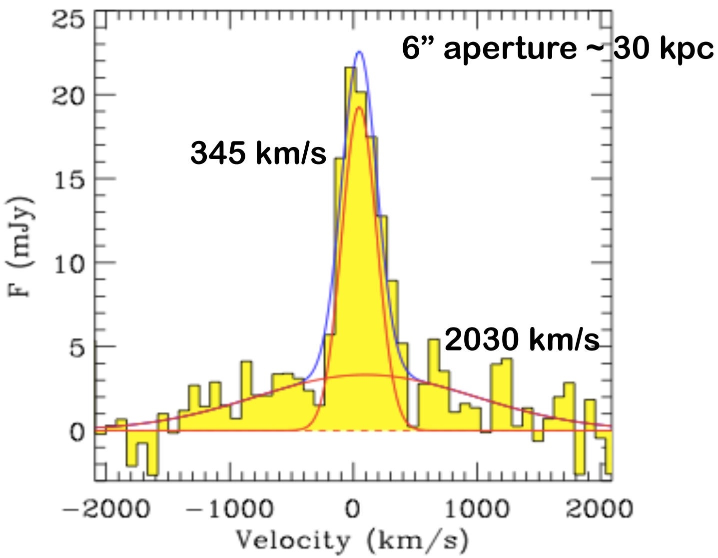


down-turn of the SFR at z < 8 is caused by BH feedback

$$\dot{E}_{\rm fbk} = \underset{\underset{0.5\%}{\uparrow}}{\epsilon_{\rm w,AGN}}\,\underset{\underset{0.1}{\uparrow}}{\epsilon_{\rm r}}\,\dot{M}_{\rm accr}c^2 \qquad \frac{dM_{\rm ej,AGN}}{dt} = 2\epsilon_{\rm w,AGN}\epsilon_{\rm r}\left(\frac{c}{v_{\rm e}}\right)^2\dot{M}_{\rm accr} \qquad \frac{dm_{\rm ej,SN}}{dt} = \frac{2\underset{\underset{0.1}{\uparrow}}{\epsilon_w}E_{\rm SN}R_{\rm SN}}{v_e^2}$$



[CII] @ 158 μm J1149 z=6.4



6” aperture ~ 30 kpc

345 km/s

2030 km/s

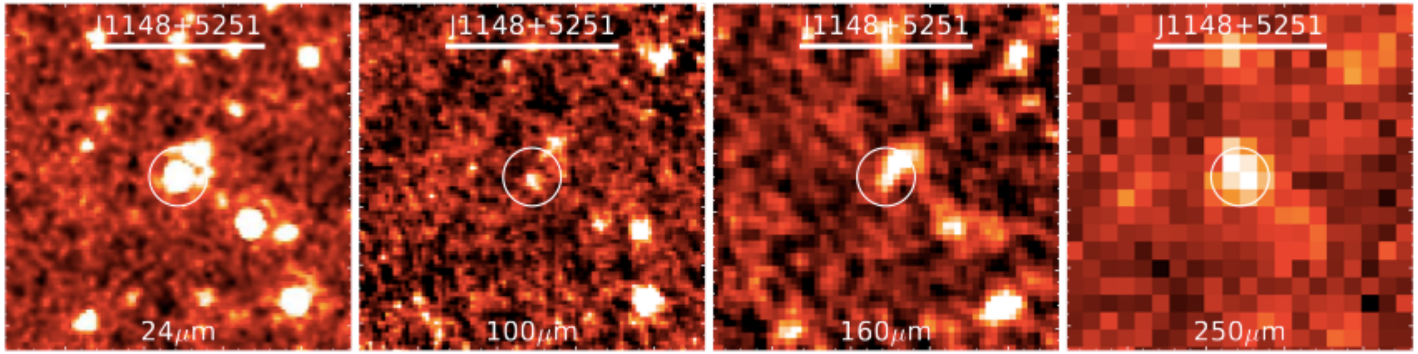
Maiolino+12

$M_{\rm out}$ ($L_{\rm CII}$) > 7 x 10^9 $M_{\rm sun}$

$dM_{\rm out}/dt$ > 3 $M_{\rm out}$ v /$R_{\rm out}$

v = 1300 km/s
$R_{\rm out}$ = 8 kpc

reconstructing the SED of J1148 with RT models

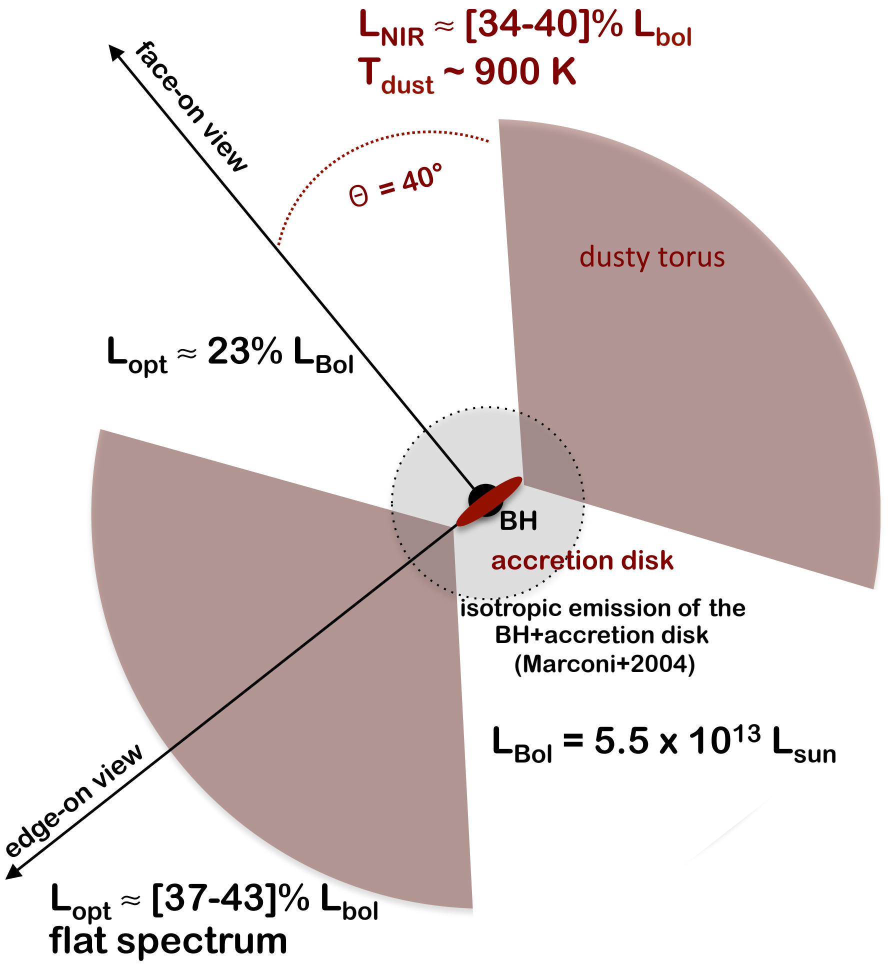


Herschel maps of J1148 @ 24, 199, 169, 259 μm (Leipski+13)

1. model for the intrinsic AGN+dusty torus emission → Stalevski+12
2. intrinsic stellar SED → output of GAMETE + PEGASE
3. the distribution of dust in the host galaxy →GAMETE
4. Monte Carlo radiative transfer code TRADING (Bianchi 2008)

RS, Bianchi, Valiante, Risaliti & Salvadori (2013)

the central source: adopted geometry and SED



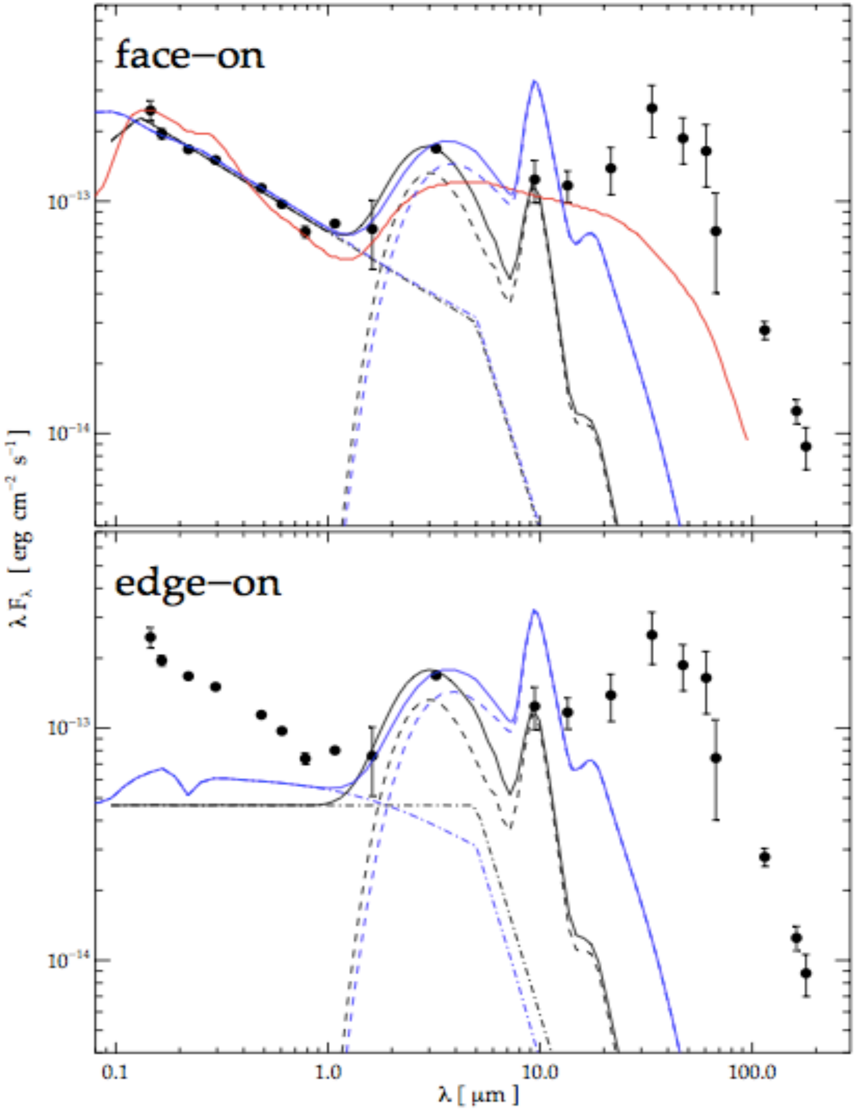
$L_{NIR} \approx$ [34-40]% L_{bol}
T_{dust} ~ 900 K

$L_{opt} \approx$ 23% L_{Bol}

isotropic emission of the BH+accretion disk (Marconi+2004)

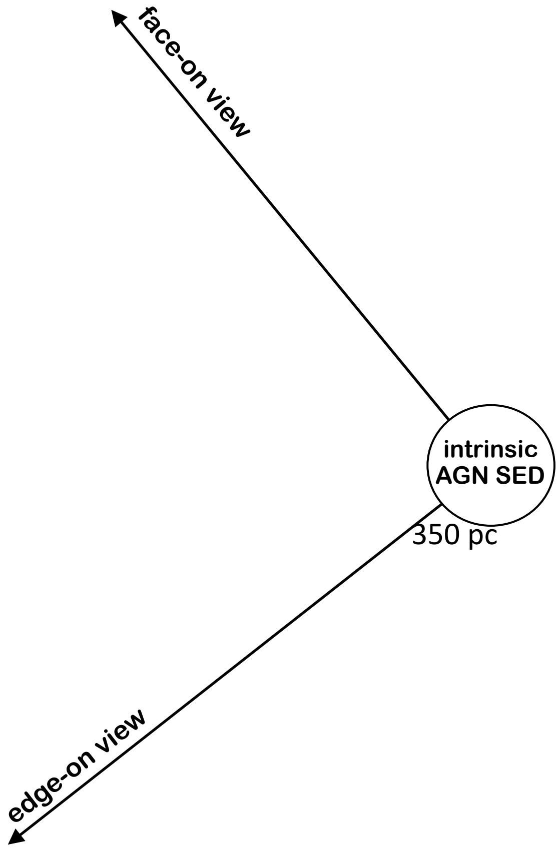
$L_{Bol} = 5.5 \times 10^{13} L_{sun}$

$L_{opt} \approx$ [37-43]% L_{bol}
flat spectrum



black lines: our model
blue lines: Stalevski+12 template → 2phase clumpy disk with moderate opt depth tau(9.7μm) = 0.1
red line: Richards+06 template → luminous type-1 SDSS QSOs

the dust distribution in the host galaxy: RT geometry



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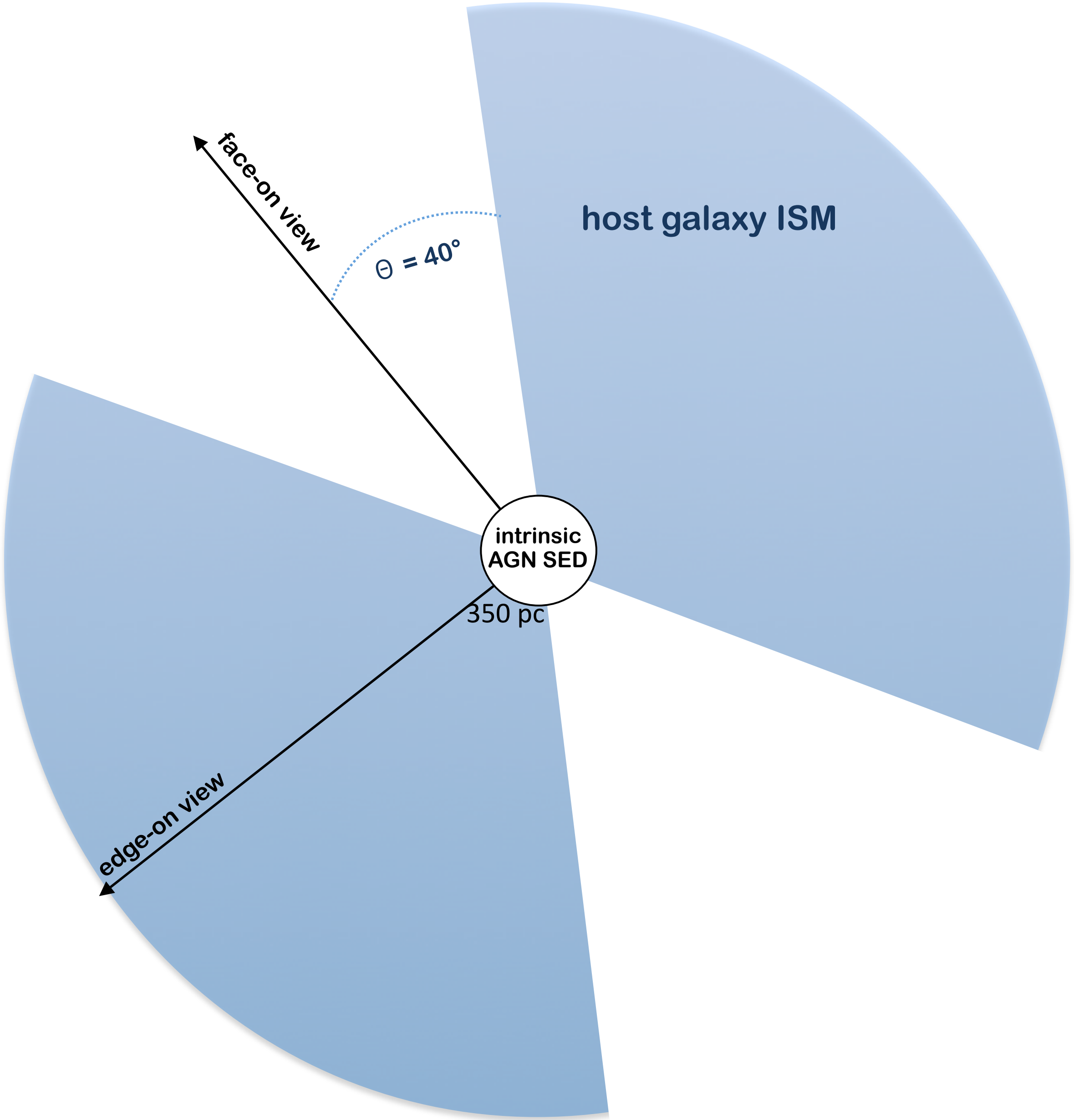

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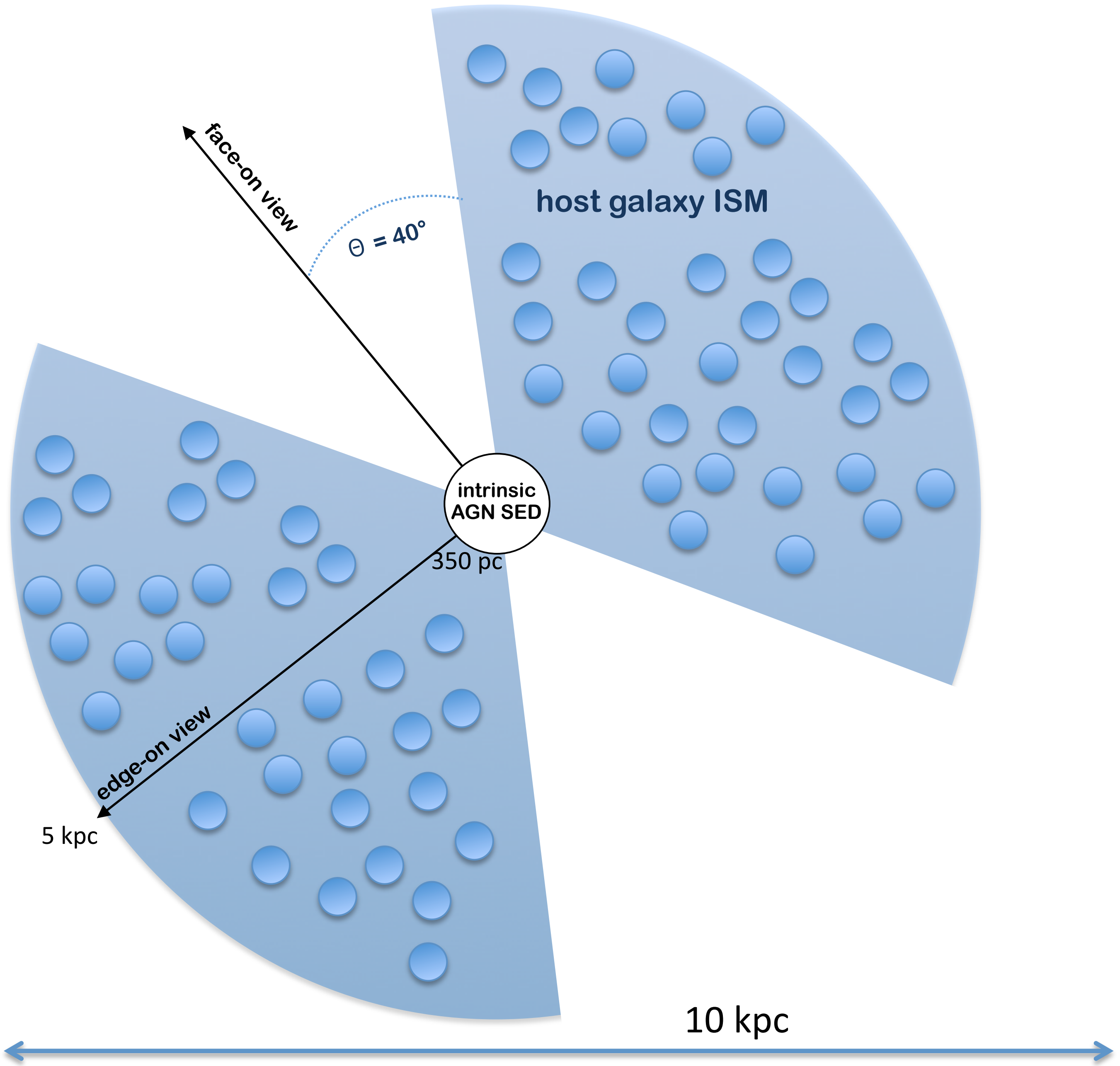
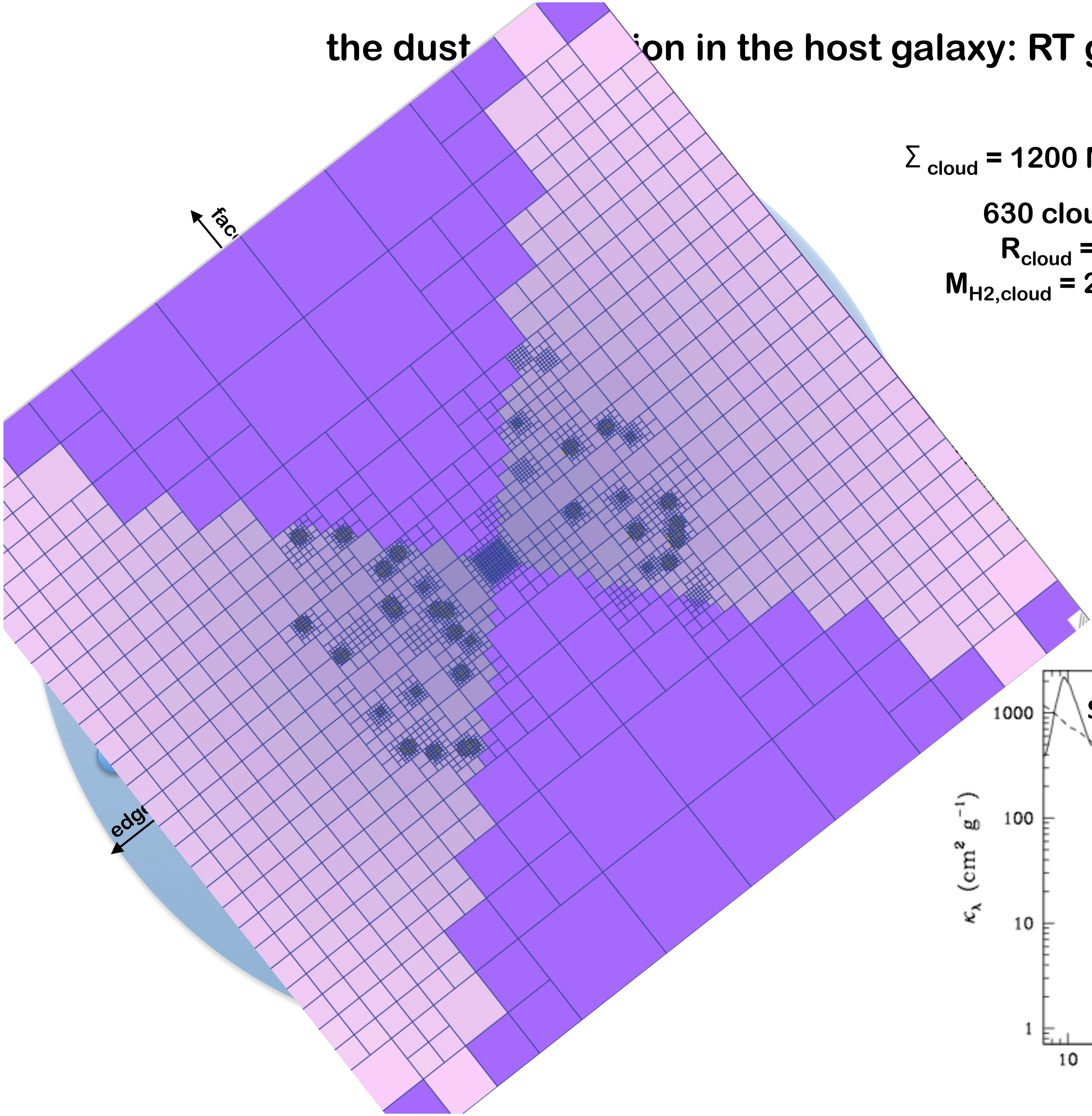


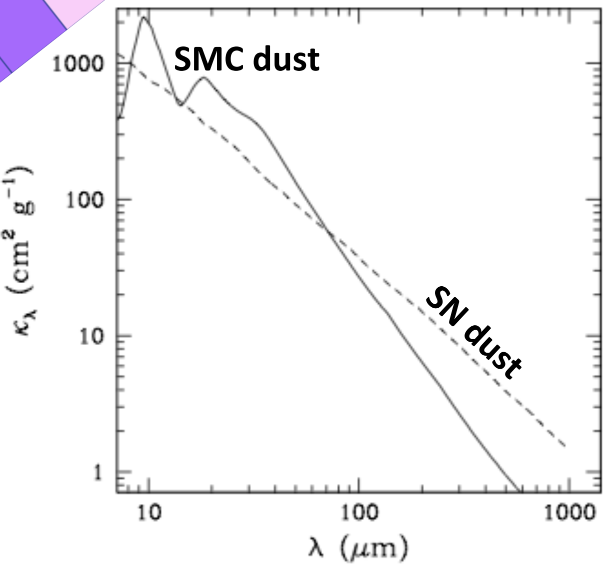
the dust ion in the host galaxy: RT geometry



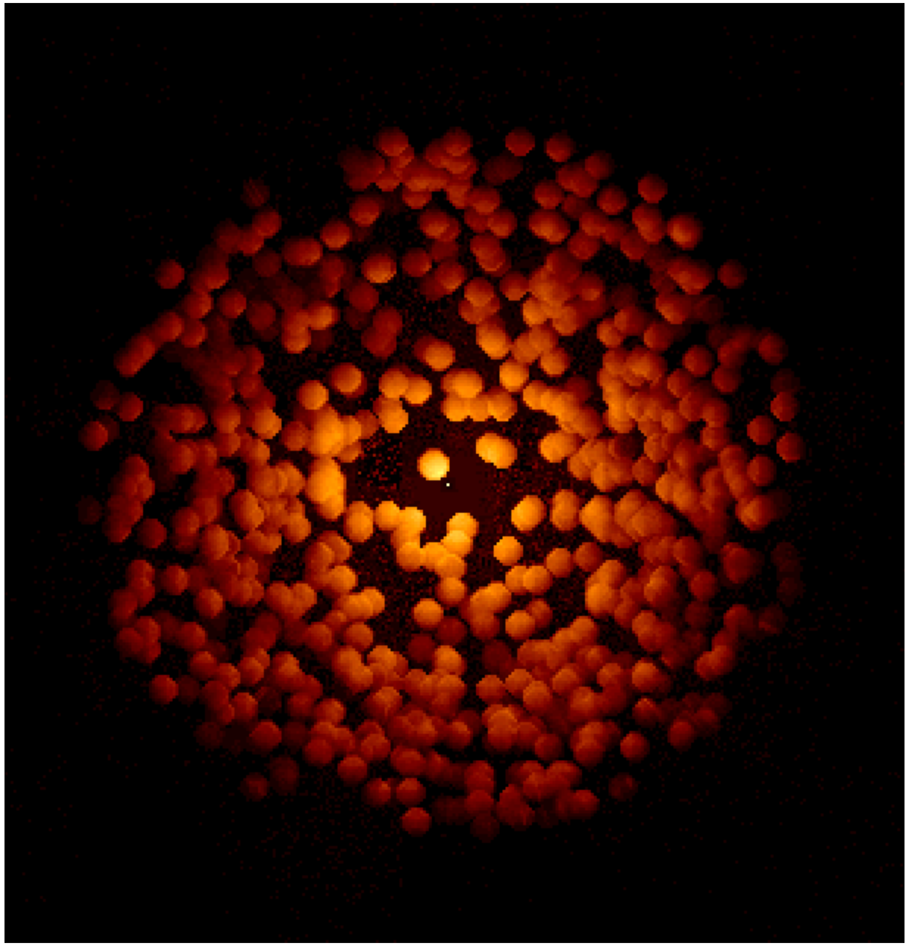
$\Sigma_{cloud} = 1200\ M_{sun}/pc^2 = \Sigma_{H2}$

630 clouds with
$R_{cloud} = 100$ pc
$M_{H2,cloud} = 2.6\ 10^7\ M_{sun}$

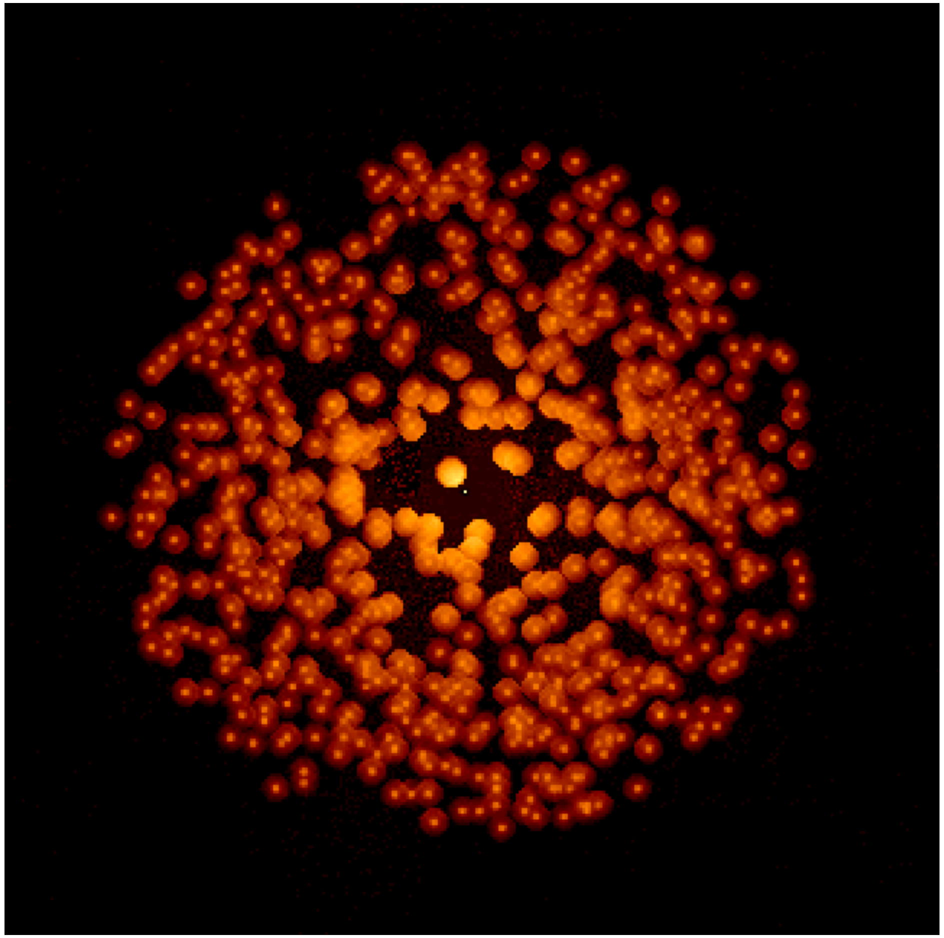
dust emissivity



J1148 @ 40 μm



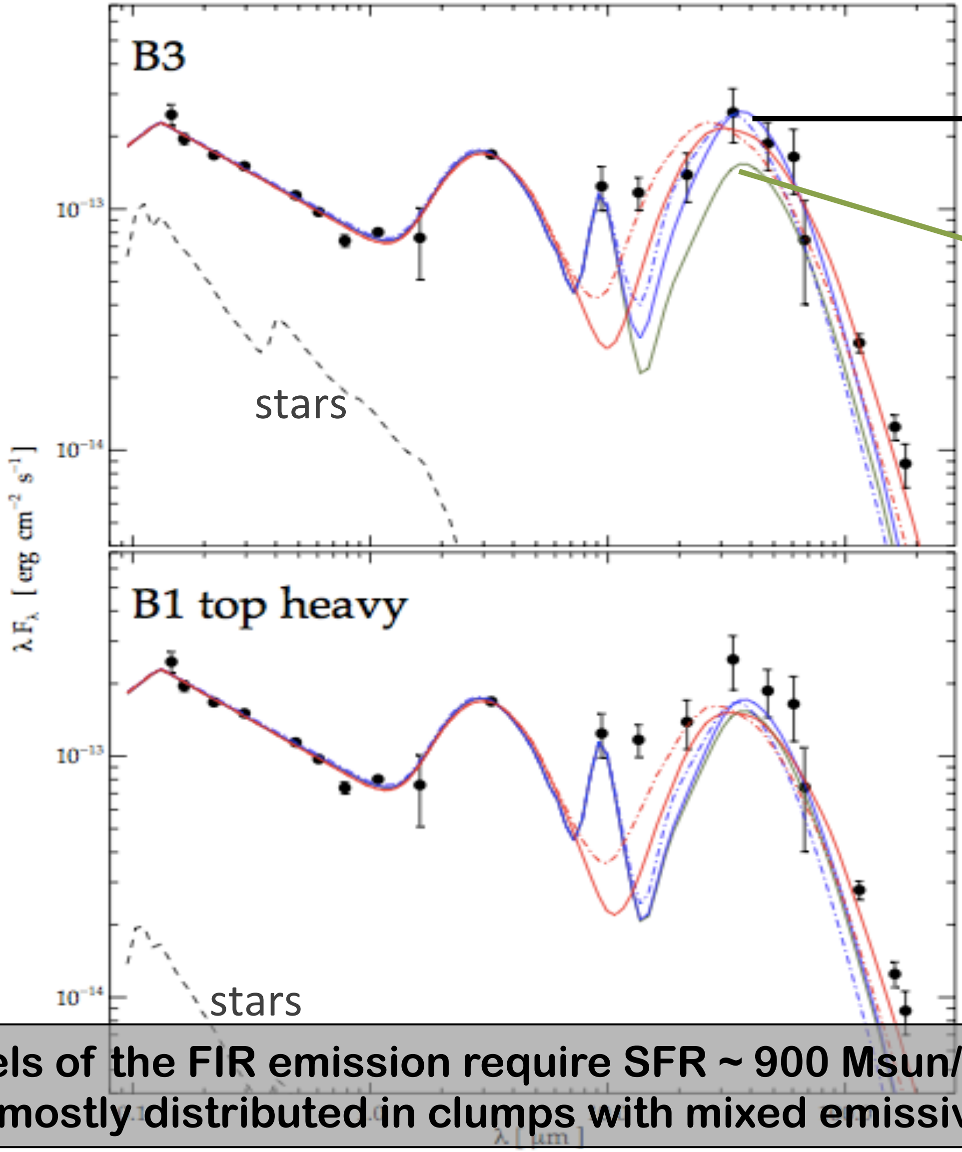
AGN as the only heating source



AGN and stars

RS, Bianchi, Valiante, Risaliti & Salvadori 2013

RT models of J1148 SED



Stars
$40\%\ L_{FIR}$

AGN
$60\%\ L_{FIR}$

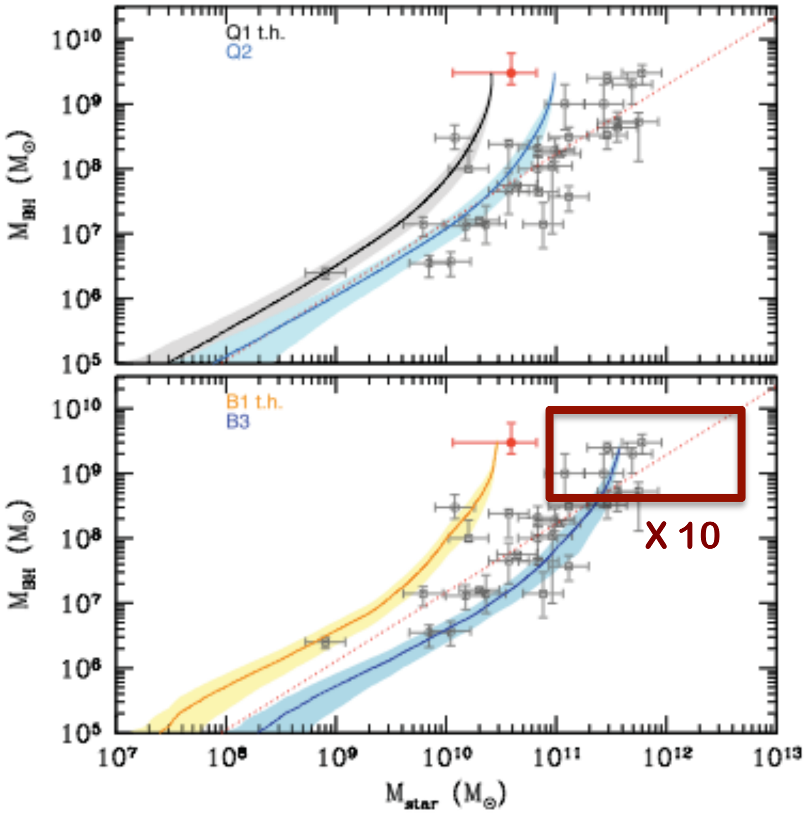
red lines: SN dust
blue lines: SMC dust

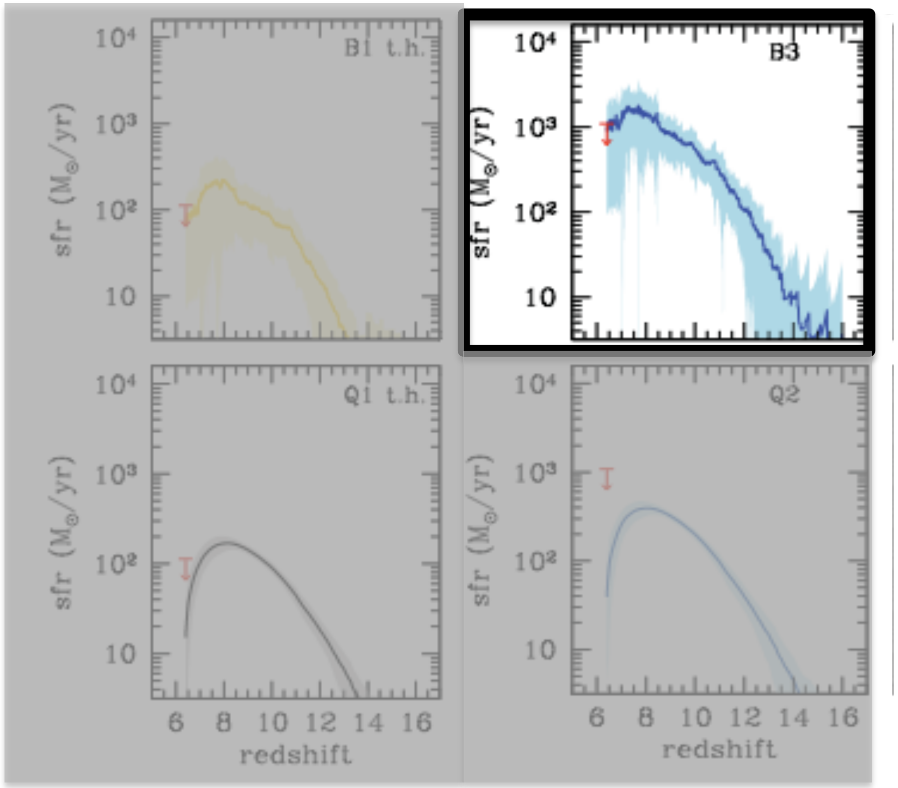
RT models of the FIR emission require SFR ~ 900 Msun/yr as in model B3
dust mostly distributed in clumps with mixed emissivity properties

RS, Bianchi, Valiante, Risaliti & Salvadori (2013)

~~4 possible~~ 1 scenario

chemical properties of the host galaxy + the SED in the FIR
are fitted by model B3: model with SF efficiency enhanced
by mergers (or cold flows)

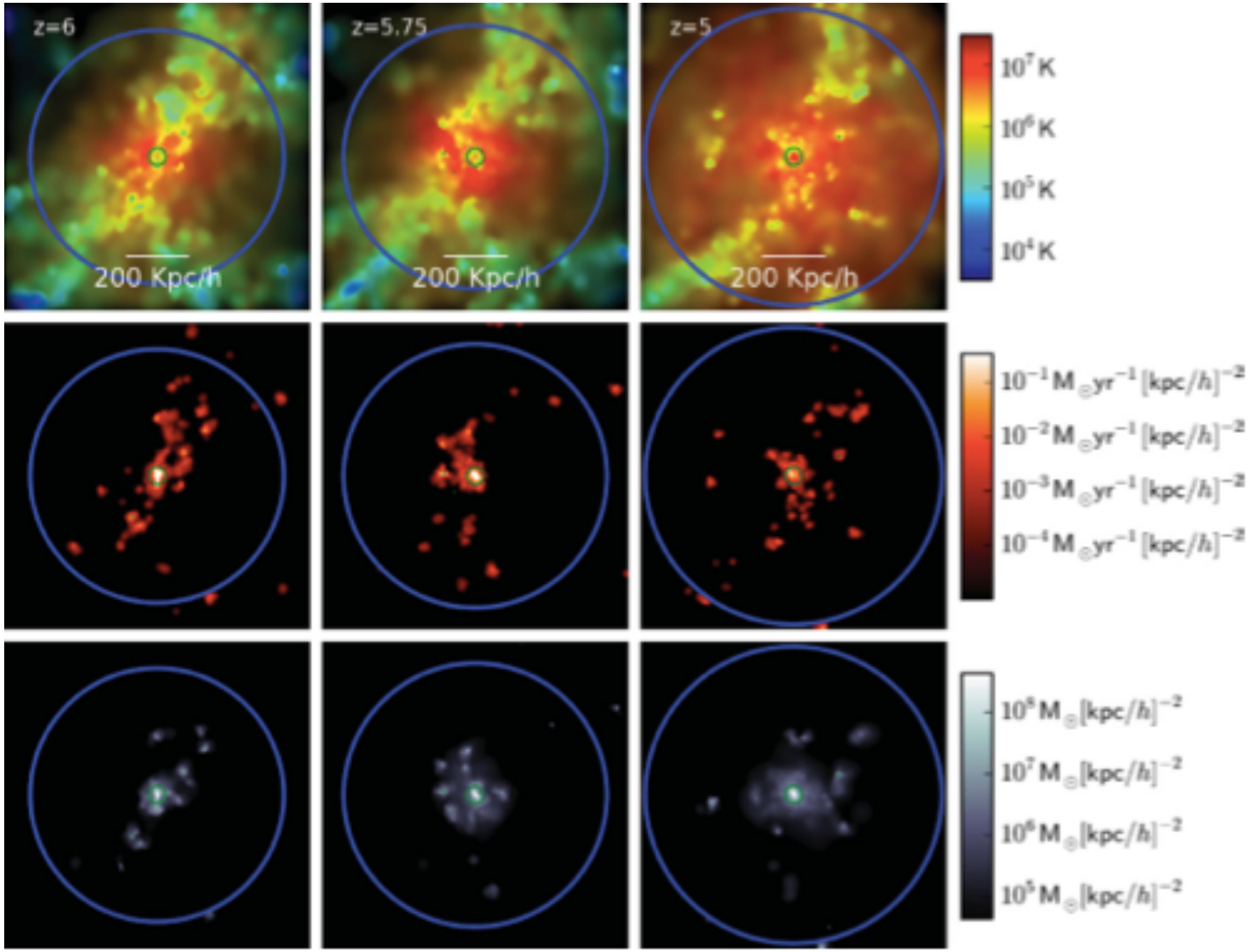




where are the missing stars?

the stars are distributed on scales > 2.5 kpc (scale of the CO line emission) ?
$M_{star,B3}$ = M(< 20 kpc)

Khandai+2012



Summary

→ Chemical properties of the host galaxies of high-z QSOs probe the integrated star formation history

→ The observed dust mass require a factor 3 – 10 more stars than allowed by dynamical mass constraints or a top-heavy IMF

→ SED modeling shows that to power the observed FIR emission efficient merger-driven star formation is required → a factor 10 more stars than allowed by dynamical mass constraints

J1148 properties suggest that black hole growth and star formation in the
first quasars occur hand-in-hand
with star formation preceding black hole growth