High redshift quasars host galaxies: is there a stellar mass crisis?

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Physical properties of the first QSOs: 
the black hole-dynamical mass relation

Valiante et al. 2014

BH masses:
from $L_{\text{bol}}$ assuming Eddington accretion
from virial estimators using MgII and/or CIV

$$M_{\text{bh}} \approx [0.2 - 7.5] \ 10^9 \ M_{\odot}$$

Dynamical masses:
from CO observations assuming an inclined disk geometry

$$M_{\text{dyn}} = \frac{R \ v_{\text{circ}}^2}{G} \quad v_{\text{circ}} = \frac{(3/4) \ FWHM_{\text{co}}}{\sin i}$$

$$M_{\text{dyn}} \sin^2 i \approx [0.84 - 15.3] \ 10^{10} \ M_{\odot}$$
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Valiante et al. 2014

Local data & fit from Sani et al. 2011

is the observed off-set real? 
selection biases and observational uncertainties are important

(Lauer et al.2007; Ho et al. 2007; Merloni et al. 2010; Schulze & Wisotzki 2011; Volonteri & Stark 2011)
Physical properties of the first QSOs: star formation and outflow rate

**SFR:**
from the AGN-corrected $L_{\text{FIR}}$ assuming the Kennicutt (1998) correction

$$SFR \approx [2 - 6.9] \, 10^3 \, M_{\odot}/\text{yr}$$

**Outflow rate:**
from the broad wings of the CII line:

$$R_{\text{outflow}} \approx 8 \, \text{kpc}$$
$$dM_{\text{outflow}}/dt > 3500 \, M_{\odot}/\text{yr}$$

Maiolino et al. 2012

$$R_{\text{outflow}} \approx 30 \, \text{kpc}$$
$$dM_{\text{outflow}}/dt > 1400 \, M_{\odot}/\text{yr}$$

Cicone et al. 2014
**Physical properties of the first QSOs:**

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What is the powering mechanism for this outflow?
how can we simultaneously power strong starbursts?
(Valiante et al. 2012, 2014)

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Physical properties of the first QSOs: molecular, stellar and dust masses

**Molecular masses:**
from CO observations

\[ M_{H_2} = \alpha_{\text{CO}} L'_{\text{CO}(1-0)} \]
\[ \alpha_{\text{CO}} = 0.8 \pm 0.5 M_{\text{sun}}/(K \text{ km/s/pc}^2) \]

\[ M_{H_2} \approx [0.9 - 4.8] \times 10^{10} M_{\text{sun}} \]

**Dust masses:**
from \( L_{\text{FIR}} \) assuming optically thin grey-body emission

\[ M_{\text{dust}} \approx [1.8 - 9] \times 10^8 M_{\text{sun}} \]

**Stellar masses:**

\[ M_{\text{star}} = M_{\text{dyn}} - M_{H_2} \]

\[ M_{\text{star}} = [0.1 - 4] \times 10^{11} M_{\text{sun}} \]

CO (7-6) line in J1148

Herschel maps of J1148 @ 24, 199, 169, 259 \( \mu \text{m} \)

Riechers+09

Leipski+13
Physical properties of the first QSOs: molecular, stellar and dust masses

Valiante et al. 2014

$M_{\text{dust}}$ do not correlate with $M_{\text{star}}$

$M_{\text{dust}}$ do correlate with $M_{\text{H}2}$

Valiante et al. 2014
Physical properties of the first QSOs: molecular, stellar and dust masses

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Valiante et al. 2014

\[ i=65^\circ \text{ R}=2.5 \text{ Kpc} \]

\[ i=40^\circ \text{ R}=2.5 \text{ Kpc} \]

stellar dust is not enough to reproduce the observed \( M_{\text{dust}} \)

Valiante et al. 2014

\[ z_{\text{gal}}=1.32^{+1.32}_{-0.22} Z_{\odot} \text{ Matsuoka+ 09,11} \]
Physical properties of the first QSOs: molecular, stellar and dust masses

stellar dust is not enough to reproduce the observed $M_{\text{dust}}$

the observed $M_{\text{dust}}$ require very efficient grain growth in dense gas

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Physical properties of the first QSOs: molecular, stellar and dust masses

**How are these huge dust masses formed in less than 1 Gyr?**

**What are the implications for the evolution of the host galaxy?**


The observed \( M_{\text{dust}} \) require very efficient grain growth in dense gas.

Stellar dust is not enough to reproduce the observed \( M_{\text{dust}} \).

\( M_{\text{dust}} \) do not correlate with \( M_{\text{star}} \).

\( M_{\text{dust}} \) do correlate with \( M_{\text{H}_2} \).
• merger histories of $10^{12} - 10^{13} \, M_{\odot}$ DM halos @ $z = 5 - 6.4$

• 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
High-z QSOs evolution: star formation & BH accretion

SFR occurs in a quiescent mode and in starbursts activated during major mergers:

\[ SFR = \frac{M_{\text{gas}}(\epsilon_{\text{quies}} + \epsilon_{\text{burst}})}{t_{\text{dyn}}(z)} \]
Valiante et al 2011

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\[ \text{SFR} = \frac{M_{\text{gas}}(\epsilon_{\text{quies}} + \epsilon_{\text{burst}})}{t_{\text{dyn}}(z)} \]

\[ \frac{dM_{\text{ej,AGN}}}{dt} = 2\epsilon_{w,\text{AGN}}\left( \frac{c}{v_e} \right)^3 M_{\text{accret}} \]

\[ \frac{dM_{\text{ej,SN}}}{dt} = \frac{2\epsilon_w E_{\text{SN}}}{v_e^2} R_{\text{SN}}(t) \]
high-z QSO evolution: the cosmic cycle

Valiante et al. 2011, 2014
20-40% of J1148 progenitors at $6.5 < z < 8$ are sub-mm galaxies with $S_{850\mu m} > 3 \text{ mJy}$

Valiante et al. 2014
high-z QSO evolution: the cosmic cycle

BH-stellar mass

SFH

dust-stellar mass

Valiante et al. 2011, 2014
high-z QSO evolution: the cosmic cycle

The best fit scenario reproduces the properties of J1148: $M_{\text{BH}}$, $M_{\text{dust}}$, $M_{\text{H}_2}$, $L_{\text{FIR}}$, SFR

but

predicts a factor of 10 higher stellar mass than derived from $M_{\text{dyn}} - M_{\text{H}_2}$

Valiante et al. 2011, 2014
Is there a stellar mass crisis?

For all the QSOs we predict the same behavior:
final stellar masses  >  $M_{\text{dyn}} - M_{\text{H}_2}$
Comparison with MASSIVE-BLACK evolutionary tracks

Valiante et al. 2014

Khandai et al. 2012

M_{\text{star}} > 10^{11} M_{\odot}

Theoretical models predict the first ~ 10^9 M_{\odot} SMBHs to live in 10^{11} M_{\odot} galaxies, more massive than observed.
Uncertainties in the dynamical mass estimates: what kind of disk geometries would reconcile theory and observations?

observational assumptions:

\[ i = 65^\circ \ (J1148) \text{ or } 40^\circ \ (\text{other quasars}) \text{ and } R = 2.5 \ \text{Kpc} \]

\[ R > 25 \ \text{kpc} \text{ or } i < 15^\circ \text{ for } J1148 \text{ and } J1044 \]

\[ R \approx 5 - 8 \ \text{kpc} \text{ or } i \approx 20^\circ - 30^\circ \text{ for } J2310, J0927 \text{ and } J0338 \]
Are there stars beyond the CO-emitting region?

Khandai+2012

- Gas distribution color-coded in T
- Gas distribution color-coded in SFRd
- Stars distribution

z=7 | z=6.5 | z=6 | z=5.75

Halo virial radius

AGN central region

Khandai+2012
Are there stars beyond the CO-emitting region?

- Gas distribution color-coded in T
- Gas distribution color-coded in SFRd
- Stars distribution

Khandai et al. 2012

[CII] 158μm IRAM PdBI observations trace cold gas out to r>30 Kpc in the host galaxy of J1148.

Star formation on large scales?

Cicone et al. 2014

Halo virial radius

AGN central region
Conclusions

- theoretical models suggest that the first $10^9 \ M_{\odot}$ SMBHs live in $M_{\text{star}} > 10^{11} \ M_{\odot}$ galaxies $\Rightarrow M_{\text{bh}}/M_{\text{star}}$ is within the scatter of the local relation

- at $z < 10$, when $> 10^8 \ M_{\odot}$ of dust mass has been produced by means of efficient grain growth in dense molecular clouds, the progenitors of high-z QSOs may be observable as SMGs

- For most of the QSOs the apparent tension could be resolved assuming different disk properties, with $5 \ \text{kpc} < R < 8 \ \text{kpc}$ or $20 < i < 30$

- some of the stars may be distributed outside the observed CO-emitting region, as suggested by numerical simulations...

THANK YOU!