Scaling relations between star formation rates and AGN properties in luminous type 1 quasars at z>0.5

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Mapping the Pathways of Galaxy Transformation Across Time and Space

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Conclusions

In type 1 quasars with $L_{bol} = 10^{12.2} - 10^{13.3}$ L_{sun} there is a positive scaling between star formation rate and accretion luminosity, consistent with a correlation between ~kpc and ~pc-scale gas supply

There is a ``maximal'' star formation rate of ~500 M_{sun} yr^{-1} beyond which this scaling weakens or vanishes. This is consistent with self regulation by the star formation

While we cannot rule it out, we find no evidence that AGN feedback is cosmologically significant in this population

Pathways of galaxy assembly

Stellar winds

Non-axisymmetric structures

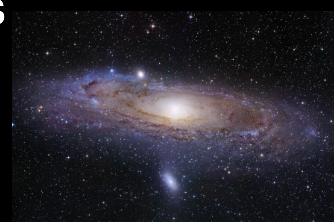
Minor mergers

Major mergers

Accretion of IGM gas

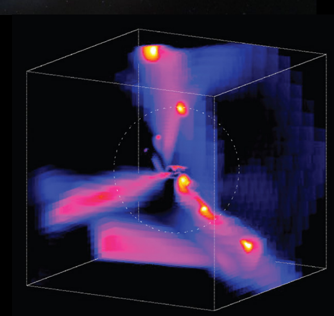
- Supply relatively small amounts of gas with little angular momentum
- Important at low luminosity?

- Bars, Spiral arms, or other disk instabilities
- Can supply turbulence and/or dissipate angular momentum to ~pc scales
- Different mechanisms important at different redshifts? E.g. bars only at low-z, disk instability at all z…



- Supply large amounts of gas, and torque that gas (but to what radius)?
- Probably not important at low-z, debated role at high-z

- Supply large amounts of gas, and torque that gas (but to what radius)?
- Important for star formation, but maybe not for AGN?



- Can supply large amounts of gas with relatively little angular momentum
- Important at high redshift?

Pathways of galaxy assembly

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What role do these mechanisms play as a function of redshift, environment (history), luminosity, morphology, stellar mass…

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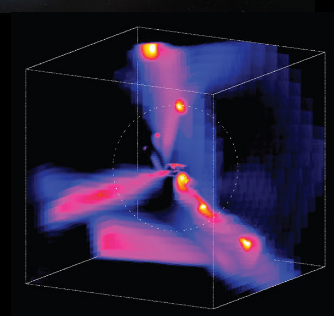

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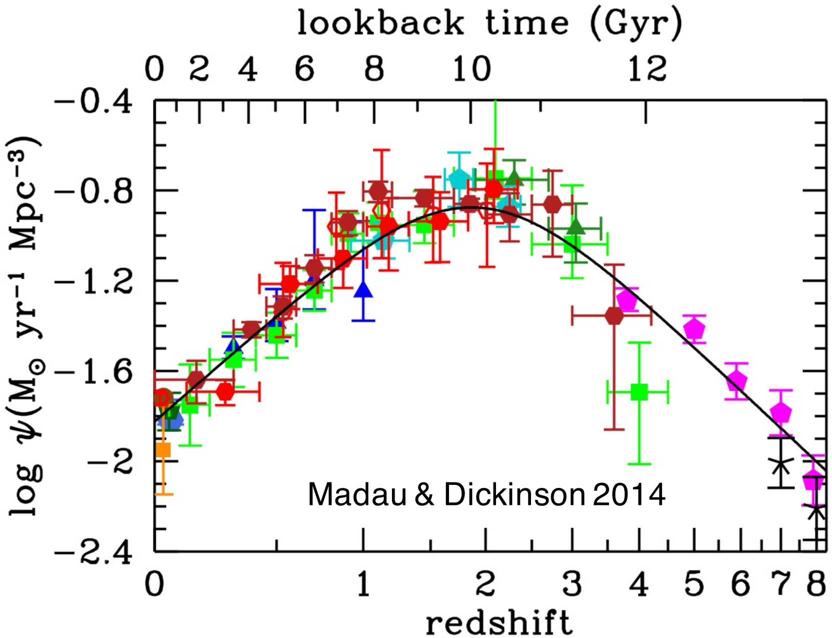
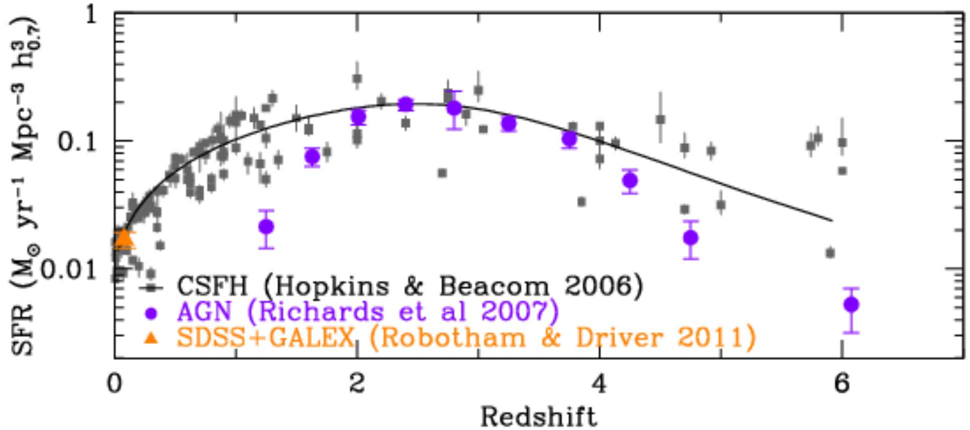
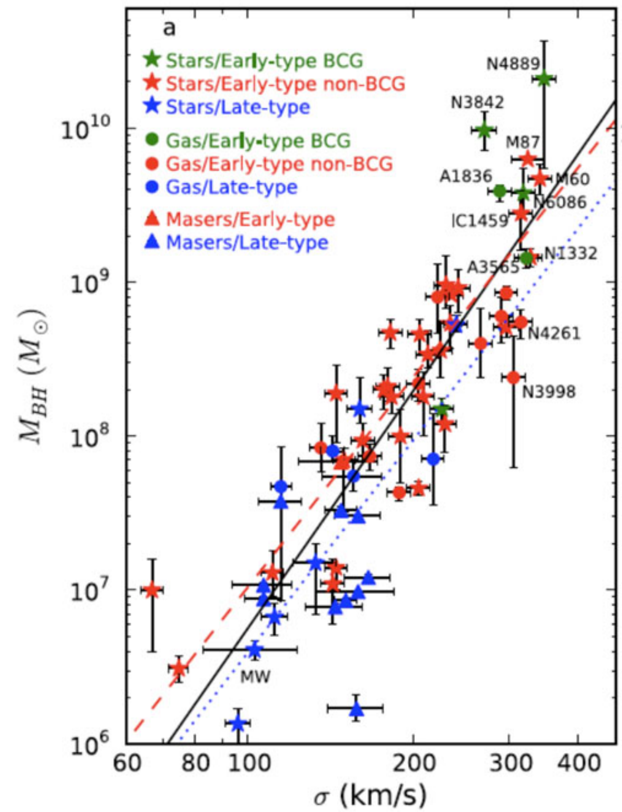






What scaling **relations** between star formation and central black hole properties must the stellar and black hole mass assembly **mechanisms** give rise to?

This talk: Type 1 quasars at z>0.5

- Easy to find in large numbers at z>0.5
- A specific population helps to minimize evolutionary degeneracies (e.g. across duty cycles)
- Accretion luminosity and black hole mass are straightforward to determine from optical spectroscopy
- AGN and star formation luminosities can be cleanly separated

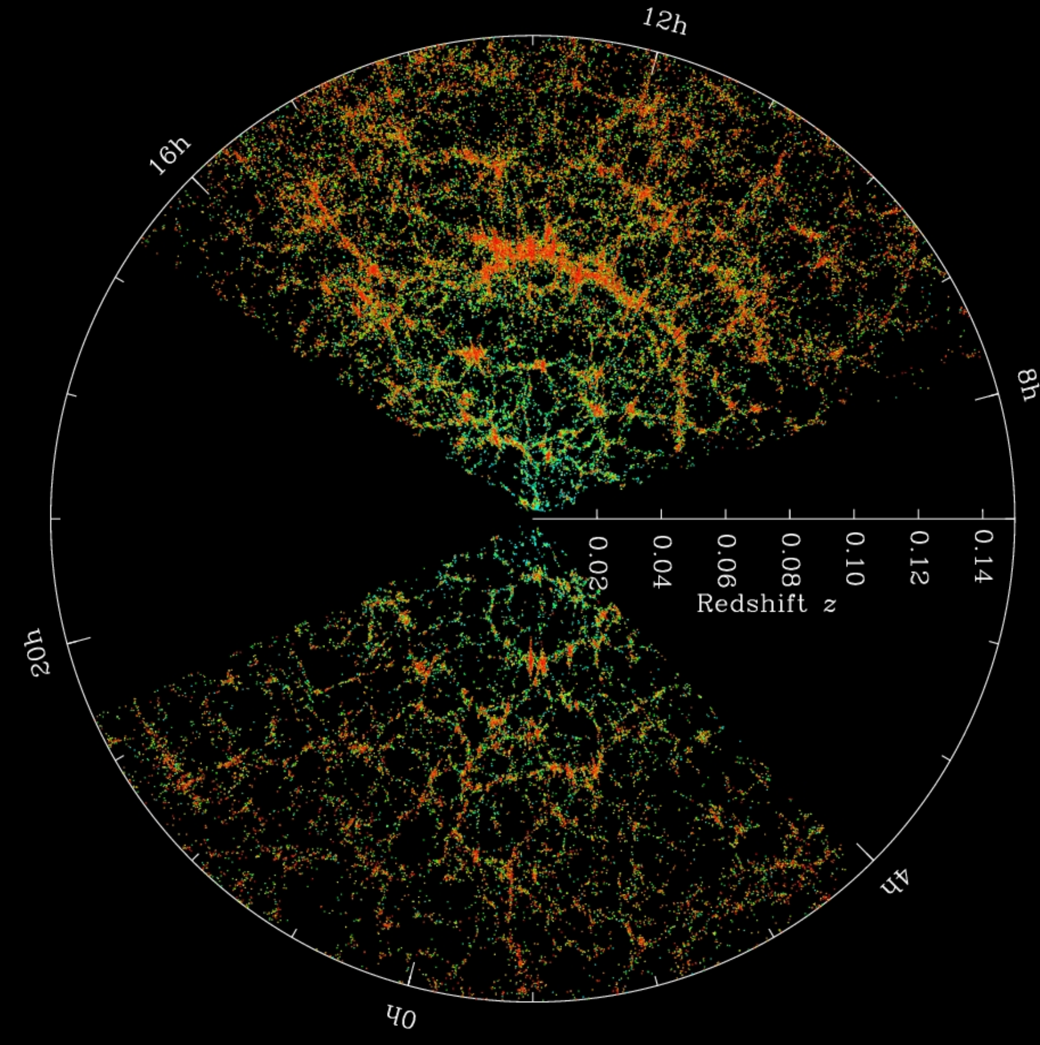
What are the scaling relations between star formation rates and AGN properties in luminous type 1 quasars at z>0.5?

Sample selection from the SDSS

Large, highly complete samples of type 1 quasars

Black hole masses from FWHMs of Mg II or C IV (Vestergaard & Peterson 2006)

Accretion luminosities from the SDSS catalog M_i values (Richards et al 2006)



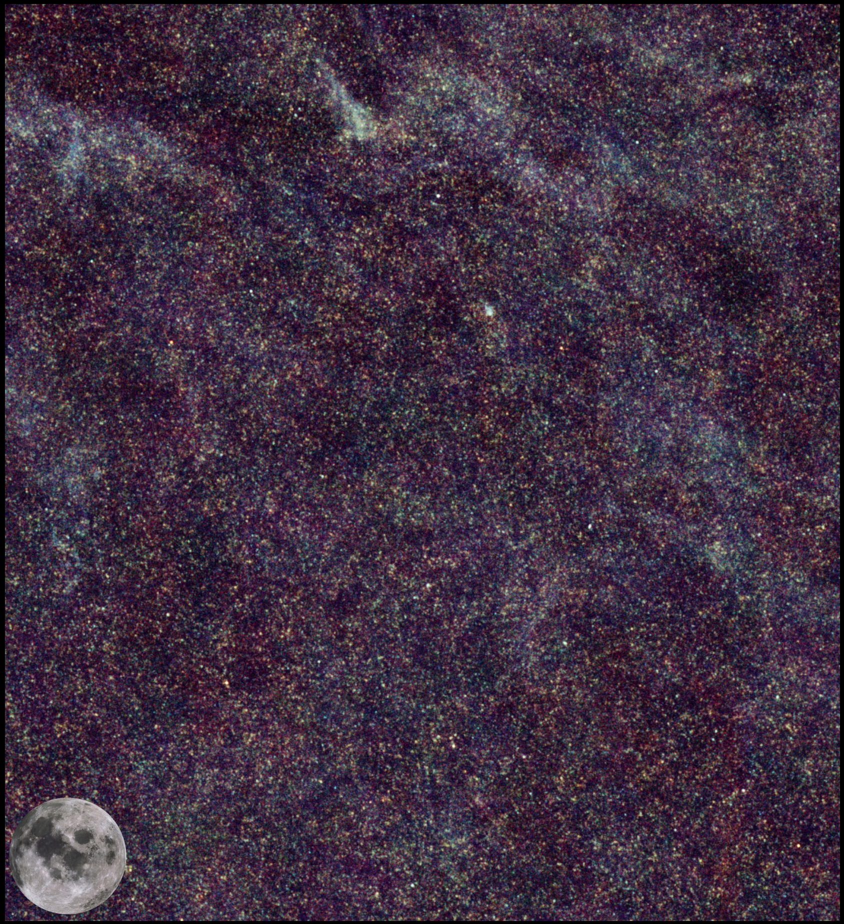
Star formation rates from Herschel

Restrict to SDSS quasars within SPIRE survey fields (HerMES, HeRS, HeLMS)

SPIRE fluxes at 250, 350, 500 microns are (probably) dominated by star formation for quasars at $z<3$

Estimate SFRs by fitting SPIRE data with a grid of starburst models, using the dispersion to estimate uncertainties

Checks for AGN contamination all consistent with a negligible contribution



Our work I - Harris et al 2016

- The CORE-BOSS sample – **1002 quasars at 2<*z*<3**
- Nearly all are **Individually undetected** by Herschel, so we stacked the Herschel data to obtain mean detections
- Obtaining detections or useful limits means we have 10-12 stacks at any one time

- **Median L_{bol} of ~ $10^{12.8}$ L_{sun}**
- **Median SFR of ~ 300 M_{sun} yr^{-1}**
- **Typical star formation events in luminous quasars over 2<z<3**

Harris et al 2016, MNRAS, 457, 4179

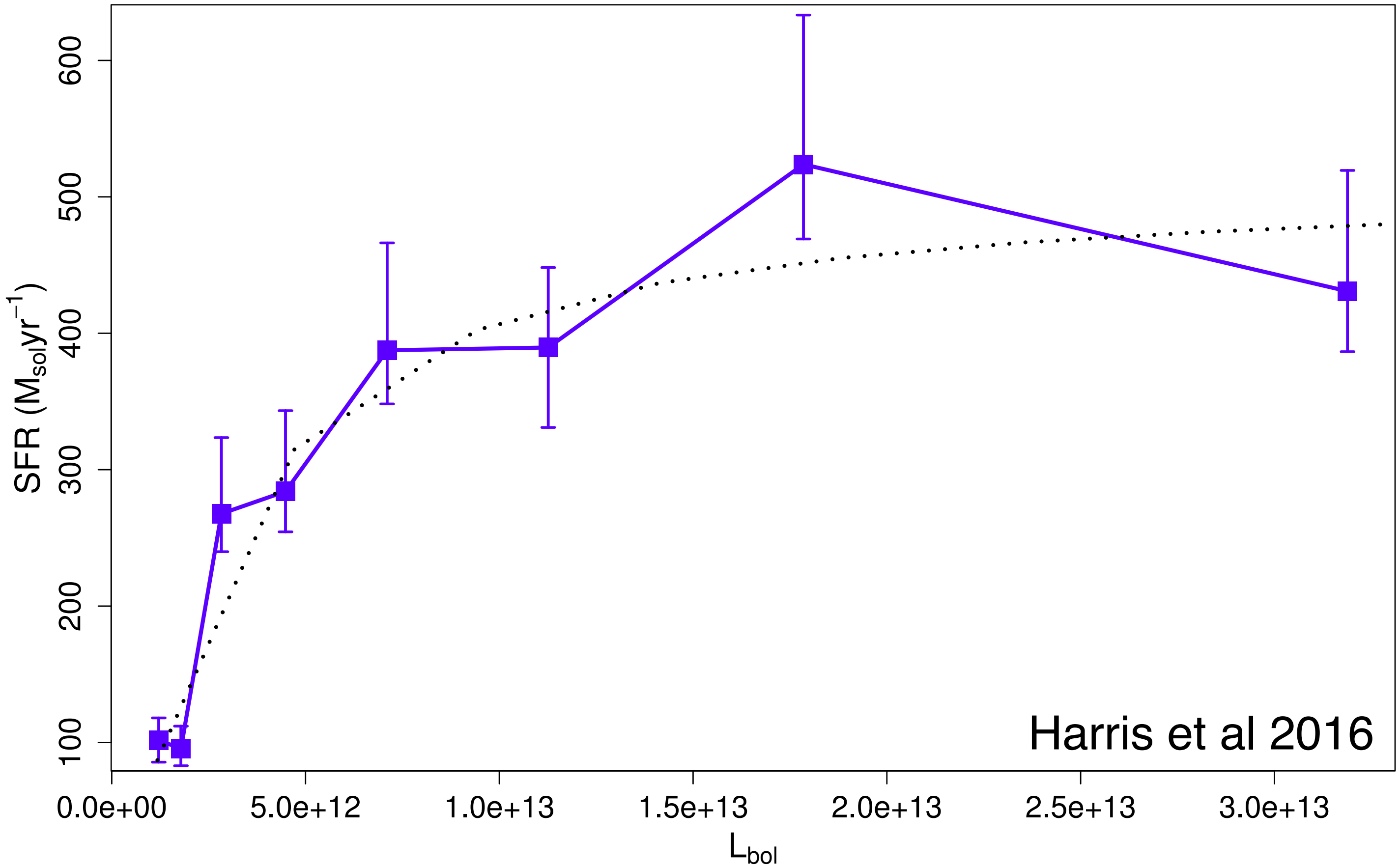
Our work II – Pitchford et al 2016

- z>0.5 SDSS quasars in any Herschel-SPIRE field
- Require that the quasars are **individually detected** by Herschel at 250 microns – star formation rates can be estimated for each quasar - **530 quasars at 0.5<z<4.0**

- **Median L_{bol} of ~ $10^{12.6}$ L_{sun}**
- **Median SFR of ~1000 M_{sun} yr^{-1}**
- **The most extreme star formation events in luminous quasars over 0.5<z<4**

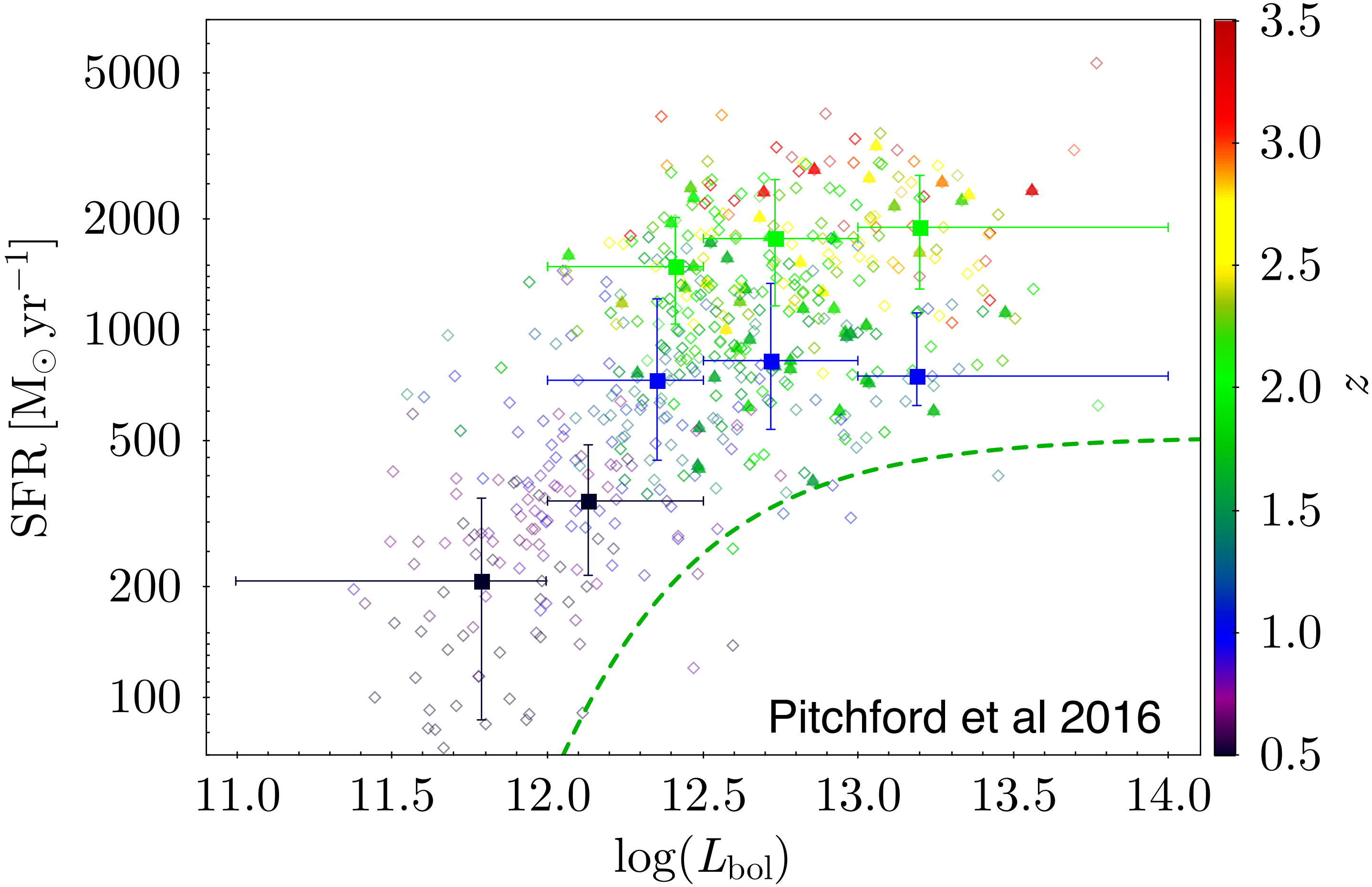
Pitchford et al 2016, MNRAS, accepted, astroph 1607.06459

Star formation rate vs accretion luminosity



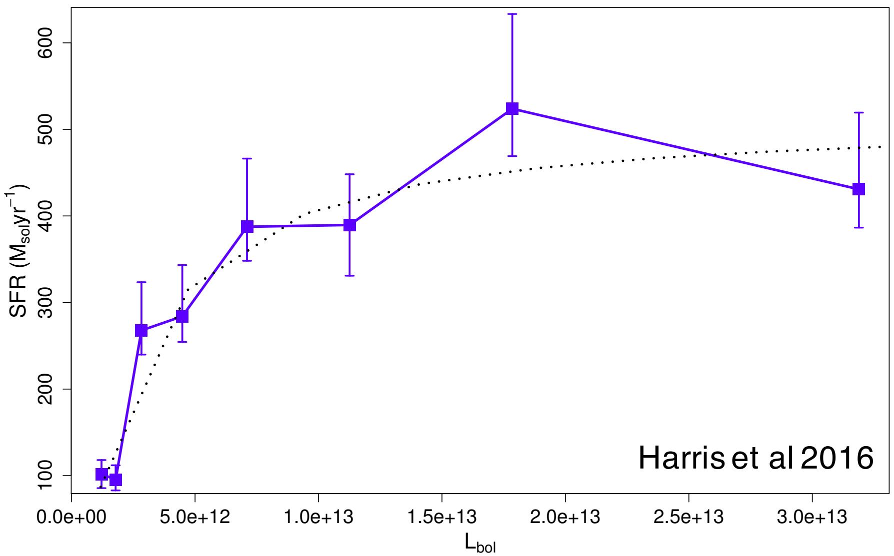
For quasars at 2<z<3, a higher SFR means a more luminous quasar – up to an SFR of ~500 M_{sun} yr^{-1}. Beyond that there is no evidence for a correlation

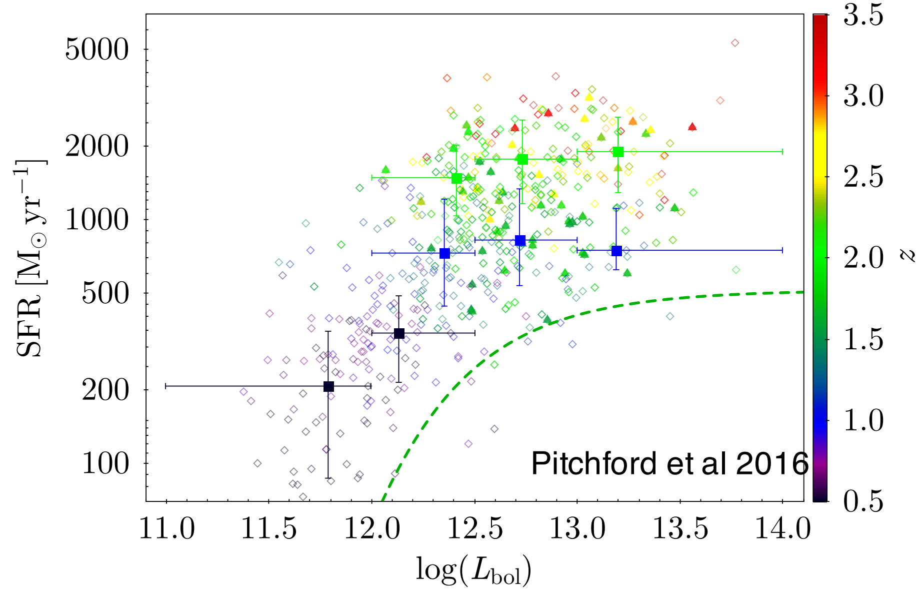
Star formation rate vs accretion luminosity



At any redshift, there is no relation between SFRs and L_{bol}. Harris et al relation (green line) is consistent

Star formation rate vs accretion luminosity



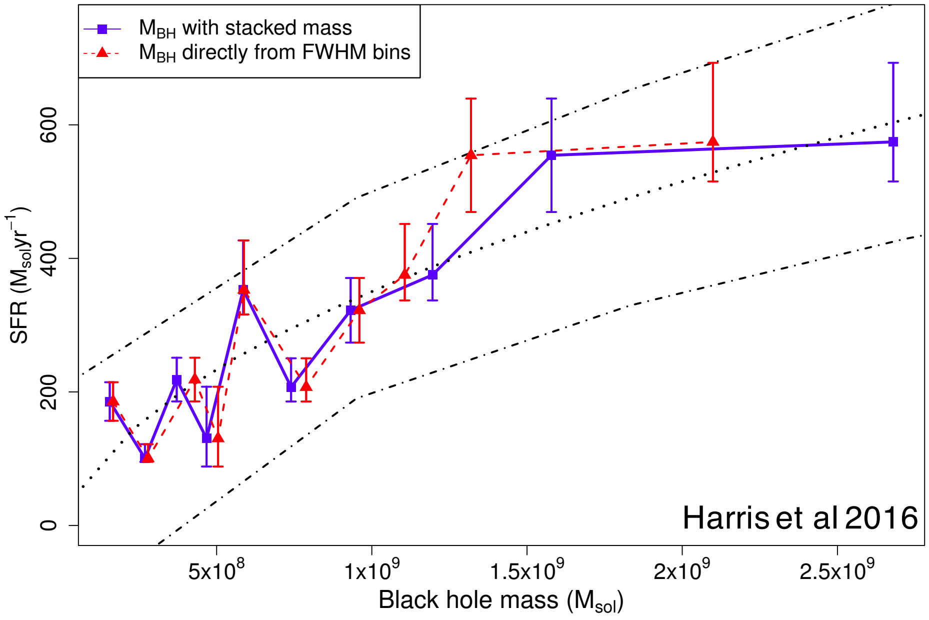


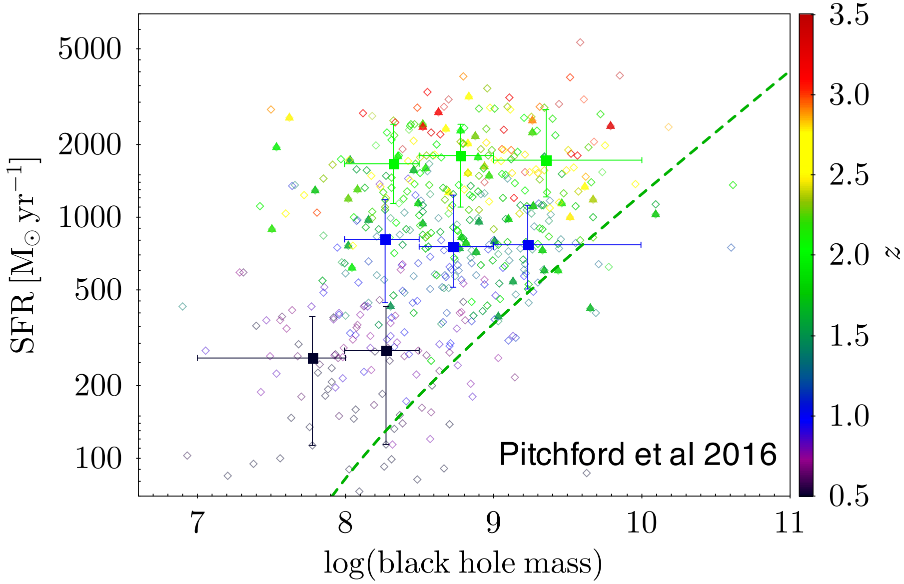
Over 2<z<3, a higher SFR means a higher L_{bol} – up to about 500 M_{sun} yr^{-1} Beyond that there is no evidence for a correlation

At any redshift, there is no relation between SFRs and L_{bol}

The SFR-L_{bol} scaling is plausibly explained by a correlation between the amount of gas feeding the starburst and the amount of gas feeding the central black hole

Star formation rate vs black hole mass



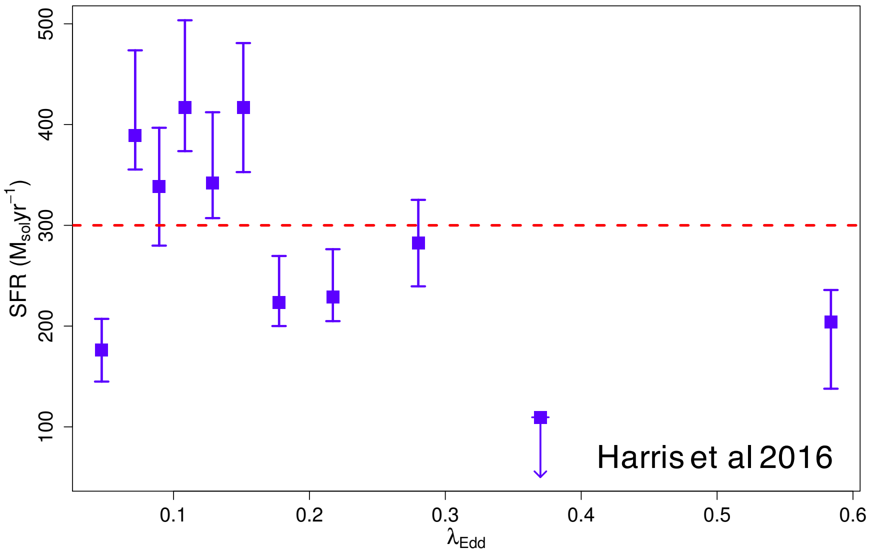


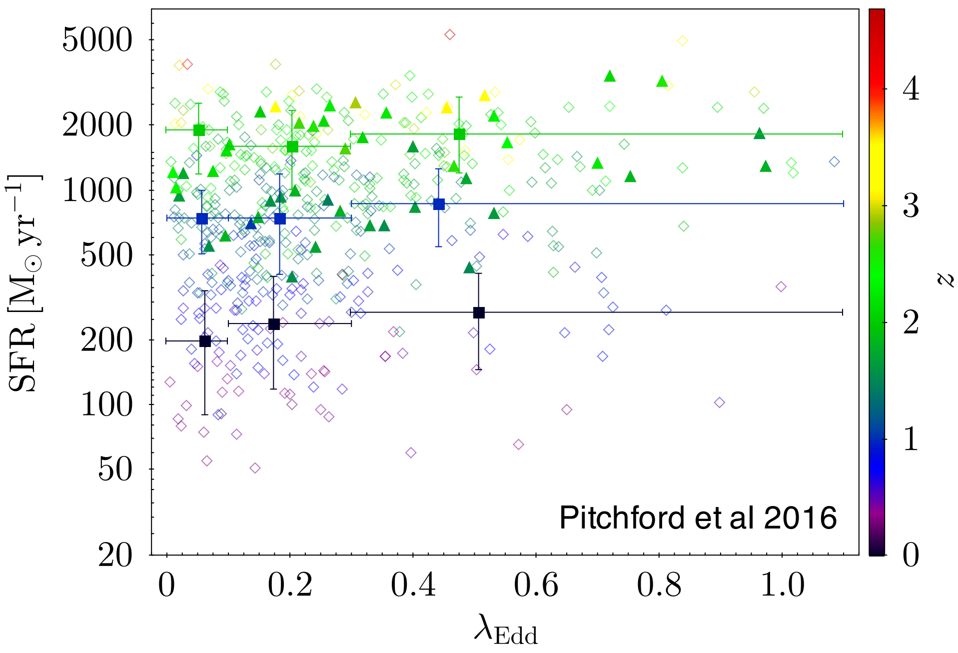
Higher SFR means a more massive black hole – up to an SFR of about 500 $M_{sun}\ yr^{-1}$. Beyond that, the relationship is consistent with being flat

At any redshift, there is no relation between SFR and black hole mass. Fitted relation from Harris et al is consistent (just)

Consistent with accretion luminosity

Star formation rate vs Eddington ratio





There is no evidence for a relation between SFR and how efficiently the black hole is accreting

Why the flattening at high SFRs?

AGN feedback? Possible but unlikely – the relations are consistent with no change, rather than quenching

A lag between phases? Possible but unlikely – if the peak luminosities of the starburst and AGN are significantly out of phase then we should see a decline in SFRs at high L_{bol}, not a flat relation

A decoupling? Plausible - if, at high SFR, independent factors start to regulate the luminosities of the star formation and/or AGN

Eddington limited star formation

Outward radiation pressure exceeds self-gravitation. Given approximately by:

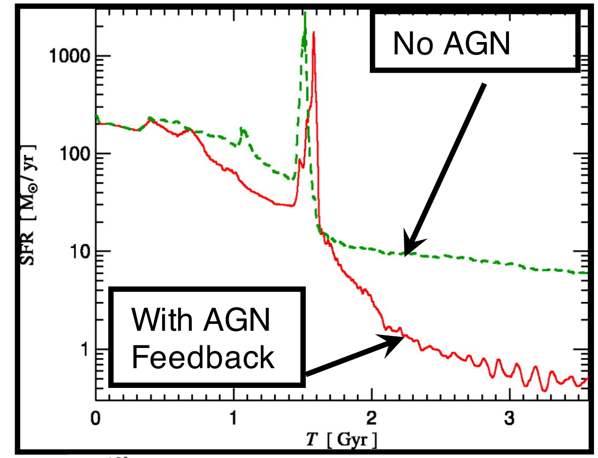
$$\frac{L\langle\kappa\rangle}{4\pi R^2 c} > \frac{G M_{\mathrm{R}}}{R^2},$$

where Kappa is the effective radiative absorption coefficient per unit mass

Systems such as e.g. the starburst in Arp220 may exceed this limit

If this is true then starburst region size should scale with luminosity up to the ``maximal'' SFR – testable with ALMA (or HST)

Springel et al. 2005

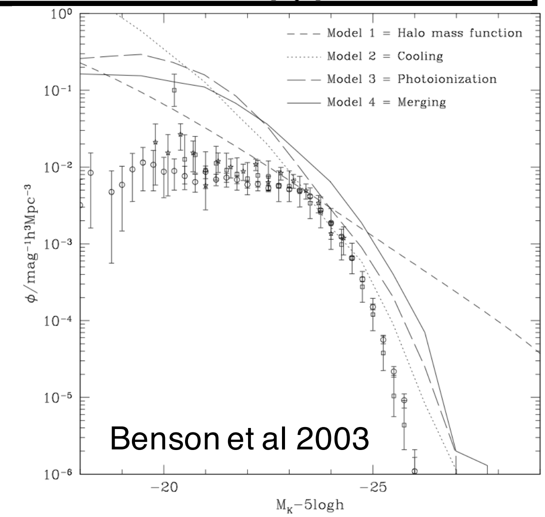


AGN feedback

Hydro sims show that AGN feedback CAN happen

Cosmological sims NEED it to happen

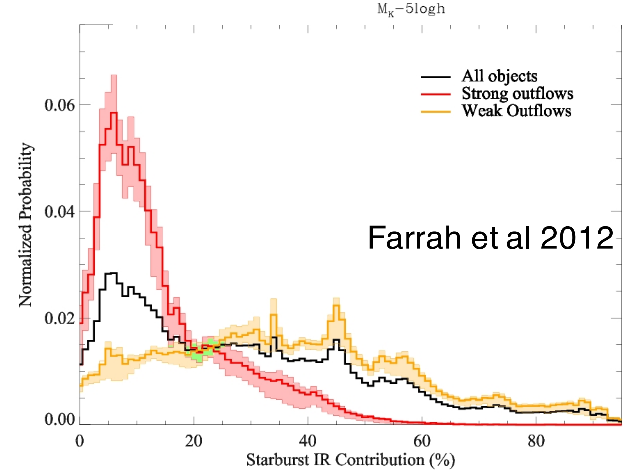
Some observations show that it DOES happen



All Objects:
P(Sb>25%): 51% +/- 5%

Weak Outflows:
P(Sb>25%): 63% +/- 4%

Strong Outflows:
P(Sb>25%): 18% +/- 5%

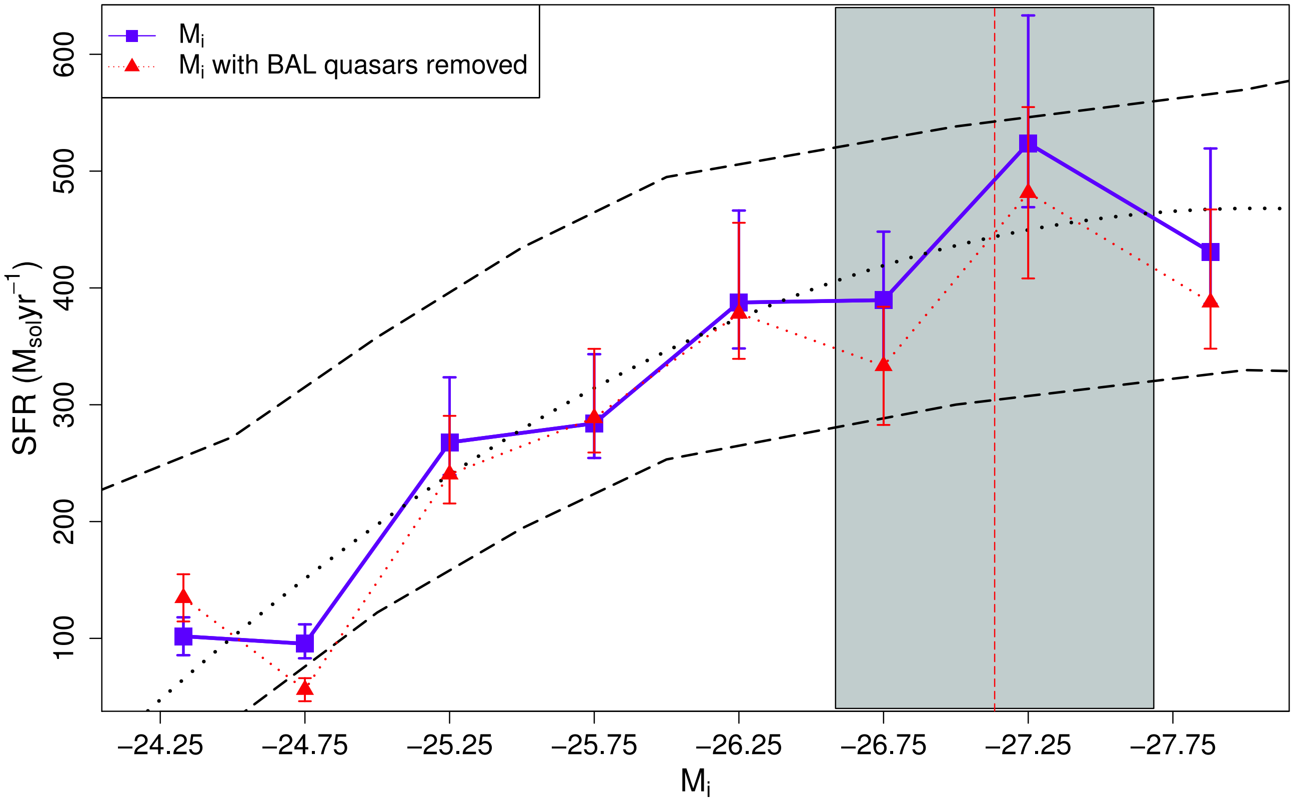


Does the AGN quench star formation at high SFR or L_{bol}?

If so then we might expect to see this effect most markedly in systems where **we know** that radiatively driven AGN-driven winds are present – Broad Absorption Line quasars

In Harris et al and Pitchford et al we can only look at HiBAL quasars, since only HiBAL quasars are found in enough numbers

Relation between star formation rate and quasar absolute magnitude, with and without BAL quasars – no difference



None of the plots I've shown are measurably different with the HiBAL quasars removed (caveat – we have essentially no (Fe)LoBAL quasars)

The star-forming properties of HiBAL quasars are statistically identical to classical quasars, in every way we can test

With the (Fe)LoBAL caveat, radiative mode AGN feedback is either:

- Not important in type 1 quasars
- Only regulates black hole mass, not stellar mass
- Is fast compared to the length of the AGN duty cycle
- Is not connected to AGN luminosity, or HiBALs

Conclusions and next steps

In type 1 quasars with $L_{bol} = 10^{12.2} – 10^{13.3}\ L_{sun}$ there is a positive scaling between star formation rate and accretion luminosity, consistent with a correlation between ~kpc and ~pc-scale gas supply

There is a ``maximal'' star formation rate of ~500 $M_{sun}\ yr^{-1}$ beyond which this scaling weakens or vanishes. This is consistent with self regulation by the star formation

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Much larger samples of quasars to enable finer binning - decouple and quantify trends in SFR with accretion luminosity, black hole mass relations simultaneously

Pin down behavior of SFR with Eddington ratio

Expand to LoBAL quasars

Understand in context with local environment