Testing the evolutionary link between submillimetre galaxies and quasars

Kristen Coppin[1], Mark Swinbank[1], Roberto Neri[2], Pierre Cox[2], Dave Alexander[3], Ian Smail[1], Mat Page[4], Jason Stevens[5], Kirsten Knudsen[6], Rob Ivison[7,8], Alexandre Beelen[9], Frank Bertoldi[6], Alain Omont[10]

[1] Institute for Computational Cosmology, Durham University, UK
[2] Institut de RadioAstronomie Millimétrique (IRAM), France
[3] Department of Physics, Durham University, UK
[4] Mullard Space Science Laboratory, University College London, UK
[5] Centre for Astrophysics Research, University of Hertfordshire, UK
[6] Angelander-Institut für Astronomie, University of Bonn, Germany
[7] Institute for Astronomy, University of Edinburgh, UK
[8] UK Astronomy Technology Centre, Royal Observatory, UK
[9] Institut d'Astrophysique Spatiale, Université Paris-Sud, France
[10] Institut d'Astrophysique de Paris, Université Pierre & Marie Curie, France

Background

Local spheroids show a relation between their masses and those of supermassive black holes (SMBHs) at their centres (e.g. Magorrian et al. 1998), indicating a link between the major phases of spheroid growth and nuclear accretion. These phases may correspond to high-redshift submillimetre galaxies (SMGs) and QSOs, separate populations with surprisingly similar redshift distributions, with SMGs perhaps evolving into QSOs (Sanders et al. 1988).

Method

To test the validity of this cycle for typical spheroids, we have to compare QSOs and SMGs at the era where their populations peaked: z~2. We have obtained precise systemic redshifts from UKIRT UIST near-infrared spectroscopy of potential `transition' z~2 QSOs (i.e. submm/mm-detected QSOs) and then used the IRAM Plateau de Bure Interferometer (PdBI) to search for CO emission (Figs. 1 & 2). We compare their CO-derived dynamical and gas masses, as well as their near-IR Hα-derived SMBH masses (using the Greene & Ho 2005 virial BH mass estimator) to SMGs from the PdBI CO survey of Greve et al. (2005). Together these observations can constrain the proposed evolutionary sequence which links QSOs to the formation of massive young galaxies and SMBHs at high-redshift. Specifically, we test:

1) whether the cold masses in these `transition objects' are similar to those in SMGs
2) whether the line widths and dynamical masses of the two populations are comparable
3) how the ratios of SMBH to dynamical masses for these `transition objects' relate to estimates for SMGs

Results

1) The median gas mass of our sample (including the non-detections) is $(2.5\pm0.7)\times10^{10}$ M☼ similar to that of z~2 SMGs (Greve et al. 2005), confirming the presence of large gas reservoirs available for forming stars.

2) We find a lower incidence of double-peaked CO line profiles in the submm-detected QSOs compared to SMGs which we believe results from a selection bias towards lower inclination angles for the QSOs. Assuming an inclination angle of 20°, we derive a median dynamical mass of M_{dyn}(<2kpc)$\sim(2.1\pm1.4)\times10^{11}$ M☼ for the submm-CO-detected QSOs, similar to the SMGs (assumed to be randomly oriented, or i=30°).

3) The near-IR spectroscopy of our sample indicates a median BH mass of $(1.8\pm1.3)\times10^{9}$ M☼. Combined with our dynamical estimates of the spheroid masses, these yield $M_{BH}/M_{sph}\sim9\times10^{-3}$, about 10x larger than the local ratio of Haring & Rix (2004), and also significantly above that seen for SMGs (Alexander et al. 2008). However, the comparison sample masks a broad range in BH masses within our QSO sample and we thus split the sample into 2 subsets based on their BH masses. See Fig. 3.

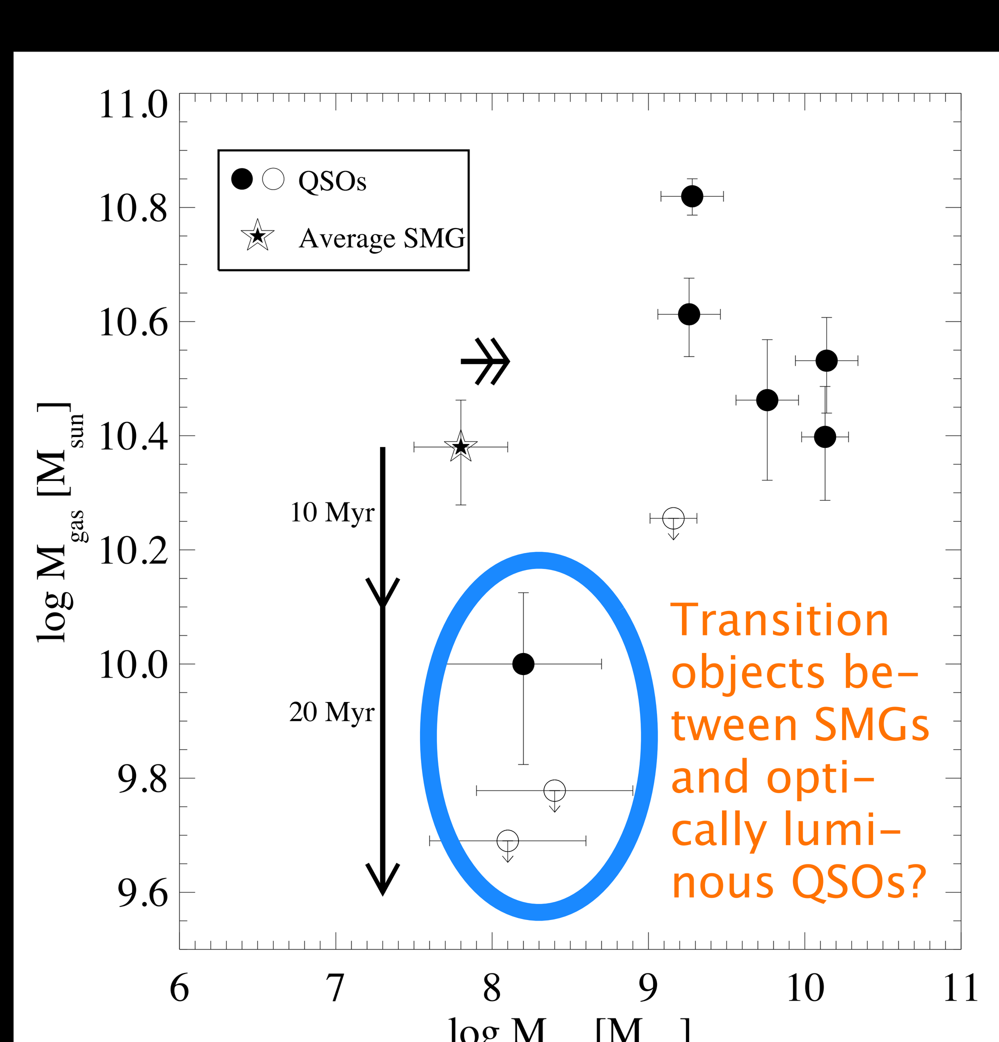

Figure 3. Gas mass as a function of BH mass for our sample of CO-observed submm-detected QSOs. Arrows indicate the amount of BH growth (horizontal) and gas depletion (vertical) of an average SMG over relevant timescales (assuming a SFR of 1000M☼/yr and Eddington-limited BH growth. This shows that a typical SMG could evolve into a $M_{BH}\sim10^8$M☼, $M_{gas}\sim6\times10^9$M☼ submm-detected QSO (objects encircled in blue) in a reasonable timescale, whereas a typical SMG would need substantially more gas and time to evolve into the $M_{BH}\geq10^9$ M☼, $M_{gas}\sim3\times10^{10}$ M☼ submm-detected QSOs (objects in the top RH corner).

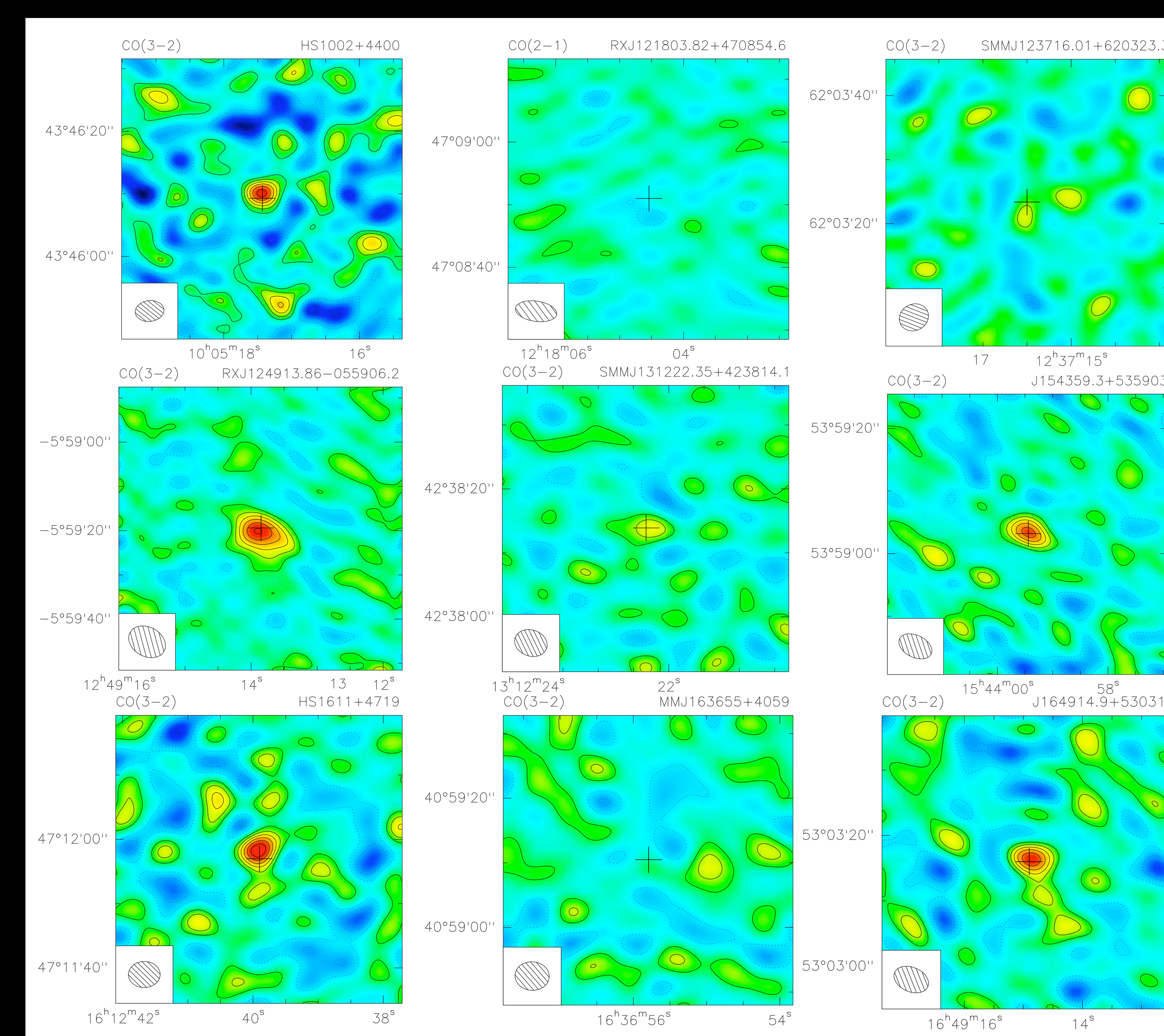

Figure 1. Dirty velocity-integrated mm emission maps of our new submm-detected QSOs (contours are 1, 2, 3...xσ, and the synthesized beams are shown in the insets). Crosses indicate the radio/optical positions of each submm-detected QSO. HS1002, RXJ124913.86, J131222.35, J154359.3, and HS1611 are CO-detected, J164914.9 shows a strong continuum-only detection, and RXJ121803.82, J123716.01, and J163655 are CO-undetected.

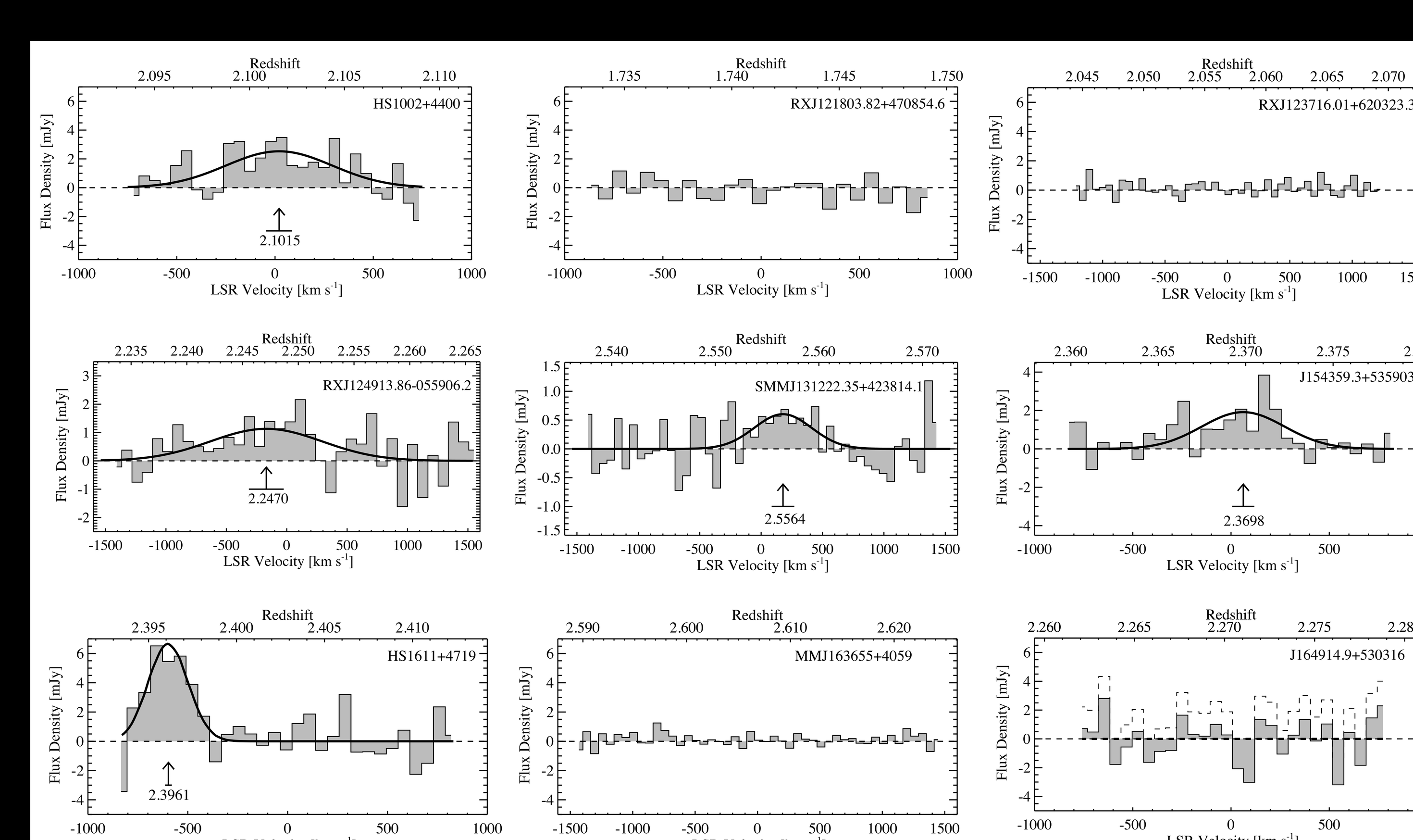

Figure 2. Millimetre spectra of our sample of submm-detected QSOs (binned to 20MHz resolution, except for RXJ124913.86 which is binned to 30MHz). The spectra are well-fitted by single Gaussian distributions, from which the line luminosities and FWHM are measured.

Discussion & Interpretation

•Looking at the optically luminous ($M_B\approx-28$) subset of our sample of submm-detected QSOs, we find strong CO emission in ~85% of these QSOs. However, the estimated BH masses for these QSOs, $M_{BH}\geq10^9$–10^{10} M☼, are too large and their space densities are ~10x too small for them to be related to typical SMGs in a simple evolutionary sequence.

•For the optically less luminous ($M_B\approx-25$; ~L*) subset of our sample of submm-detected QSOs, we marginally detect one source in CO and obtain sensitive limits for a few more. The BH masses for these systems are $M_{BH}\sim10^8$ M☼, similar to BH estimates for SMGs (Alexander et al. 2005). The space density of these QSOs is also in rough agreement with that expected for the descendents of SMGs given current estimates of the lifetimes of SMGs (~100–300 Myr; Swinbank et al. 2006) and QSOs (~20–40 Myr; e.g. Martini & Weinberg 2001). Fig. 3 illustrates that it is feasible to link the QSO BH masses to SMGs by Eddington-limited growth for a period comparable to the gas depletion timescale of ~10 Myr. **These submm-detected QSOs are consistent with being `transition objects' between SMGs and submm-undetected QSOs**, which a larger sample can help to confirm.