Submm-bright QSOs at z ~2: Signposts of Co-Evolution at high z

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We have assembled a sample of 5 X-ray and submm-luminous QSOs which are therefore both growing their central black holes through accretion and forming stars copiously. Hence, they are good laboratories to investigate the co-evolution of star formation and AGN. Our XMM-Newton observations reveal strong outflowing ionized winds from the QSOs which could terminate star formation. SCUBA maps have shown that they are also surrounded by submm source overdensities, placing them in the centres of high density peaks of the z~2 Universe. In one case we have already proved that the submm sources are indeed massive (but with undernourished black holes, if any) star-forming galaxies associated to the QSO.

We present here the analysis of new PACS and SPIRE Herschel data (together with our existing and archival optical-NIR-MIR observations) on the central QSOs. Both AGN (direct and reprocessed) and Star Formation (SF) emission are needed to model their Spectral Energy Distributions (SEDs). Thanks to this modeling we have calculated the mass of black holes inside QSOs (10^{10} – 10^{11} M_{SUN}) and the CF values that are higher than similarly luminous QSOs at z<1.5. We have characterized the gas mass M_{GAS}~10^{10} – 10^{11} M_{SUN} and bulge mass M_{BULGE} ~ 10^{12} – 10^{13} M_{SUN}. We have seen that our objects have a exceptional SFR but this must finish soon. Finally our objects are among the most luminous AGN found with strong SF emission.

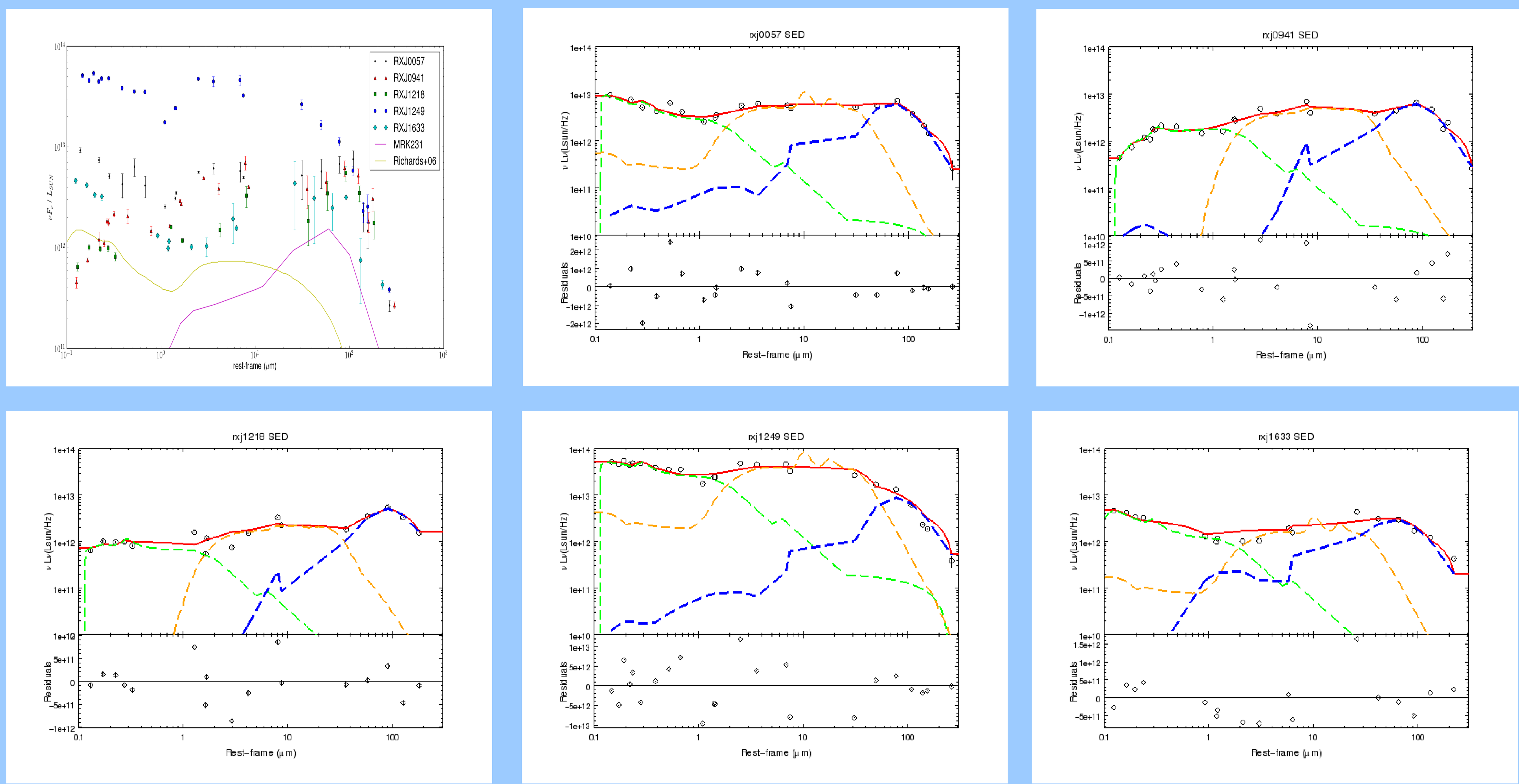
1. Results

The top-left panel shows the SEDs of all our objects, compared with a standard QSO template and Mrk 231. From the SED fits (see below and rest of panels) **we confirm the presence of strong FIR emission due to Star Formation (SF)** in these objects, at the ULIRG/HLIRG level (compared to Mrkn231), thanks to the new Herschel PACS and SPIRE data.

We have modeled the SEDs with three components: a direct AGN accretion disk (using a template from [8], dashed green line), a reprocessed torus component (using both an empirical template from [8] and some dusty torus models from [6] found by [9] to represent the average properties of QSO1, dashed orange line) and a SF component (using models from [11] found by [14] to represent star forming galaxies at the relevant redhifts, dashed blue line).

The L_{DISK}, L_{TORUS} and L_{FIR} shown below are the average values among the best fits to all combinations of components, with uncertainties estimated from the dispersion around those best fits.

We also show the black hole masses estimated from the CIV emission lines in the rest-frame UV spectra presented by [5].



2. Discussion

SOURCE	z	$L_{BOL, AGN}$ / 10^{11} L_{sun}	$L_{X, AGN}$ (2-10keV) / 10^{11} Lsun	log($L_{X, AGN}$ (2-10 keV)) / log(erg s^{-1})	L_{DISK} (0.5-250µm) / 10^{11} L_{sun}	L_{TORUS} (1-300µm) / 10^{11} L_{sun}	$L_{FIR,SF}$ (40-500µm) / 10^{11} L_{sun}	SFR / $M_{sun}y^{-1}$	M_{DUST} / 10^9 M_{SUN}	CF (L_{TORUS} / L_{BOL})	log(M_{BH} / M_{SUN})	L_{BOL} / L_{EDD}
RXJ005734.78 -272827.4	2.19	272 ± 9	2.93	45.05	216 ± 9	156 ± 14	68 ± 2	1170 ± 40	2.6 ± 0.8	0.58 ± 0.06	10.9 ± 0.5	0.01149 ± 0.0004
RXJ094144.51 +385434.8	1.82	181 ± 15	0.93	44.55	158 ± 14	137 ± 12	71.8 ± 1.6	1240 ± 30	6 ± 2	0.76 ± 0.11	10.5 ± 0.5	0.0162 ± 0.0013
RXJ121803.82+470854.6	1.74	89 ± 13	2.33	44.95	58 ± 11	55 ± 4	58.8 ± 1.8	1010 ± 20	5.7 ± 1.9	0.63 ± 0.10	9.9 ± 0.5	0.035 ± 0.005
RXJ124913.86-055906.2	2.21	2100 ± 200	3.69	45.15	1900 ± 200	1180 ± 130	109 ± 15	1900 ± 270	4.0 ± 1.9	0.58 ± 0.09	11.0 ± 0.5	0.066 ± 0.006
RXJ163303.57+570258.7	2.80	153 ± 4	5.85	45.35	86 ± 3	46 ± 6	31.4 ± 1.4	540± 20	0.6 ± 0.2	0.30 ± 0.04	9.9 ± 0.5	0.0626 ± 0.0015

- The **Black Holes** inside the QSOs are very massive **(10^{10} – 10^{11} M_{SUN})** compared to the values obtained in the literature for the same range of redshift.
- Comparing the bolometric and reprocessed components, we find **Covering Factors higher than similarly luminous QSOs** at z<1.5 from [9].
- We measure Star Formation Rates SFR~1000M_{SUN}/y, **these objects are forming stars copiously.**
- We have estimated the dust masses from greybody fits to the SF components, and then the gas mass ([1],[3]), finding **M_{GAS}~10^{10} – 10^{11} M_{SUN}**. Comparing the gas mass and the SFR values we find that **the current burst of star formation must finish very soon**, in ~0.06-0.3Gy .
- Assuming that the l**ocal relationship between the Black Hole and the host galaxy** is true for high z we have estimated the **mass of the bulge** from [4]: **M_{BULGE} ~ 10^{12} – 10^{13} M_{SUN} . These galaxies are very massive and they cannot grow much further**, since the gas mass is small compared with the mass of the host galaxy.
- We have estimated the values of the specific SFR **SSFR**=SFR / M_{BBULGE}**~0.04 – 0.3Gy^{-1}**. The SSFR of galaxies has been studied by [7], finding that for M*>$10^{11}$$M_{SUN}$ SSFR~0.3 Gy^{-1} for z~ 2, albeit with a large dispersion. Our objects are on the low side of this distribution, however, they are about two orders of magnitude more massive than those from [7], meaning that their SFR are truly exceptional.
- Comparing to a sample of X-ray-selected active galaxies from [10], our objects are among the brightest at 1.5<z<2.5, both on their AGN and SF components**.** In particular **our object RXJ1249** would be the **brightest object** in the two samples. Thus **our objects are among the most luminous AGN found with strong SF**.

4. Conclusions

- **Direct AGN, reprocessed AGN and SF components are needed** to correctly characterize the SED our objects.
- The **Black Holes** inside our QSOs are among the most massive at their epoch **10^{10} – 10^{11} M_{SUN}.**
- Our QSOs appear to have **higher covering factors than other QSO1 at z<1.5**.
- We confirm the presence of **strong FIR** emission due to SF in these objects, at the **ULIRG/HLIRG level** with **SFR~1000 M_{sun}/y**
- The inferred gas masses mean that the observed **SF must end very soon**.
- **Their host galaxies are very massive and with very limited scope for further growth, if the local BH-to-bulge-mass ratio holds at z~2**
- **Their SSFR are generally lower** than, but comparable to, those of (much less) massive galaxies at similar redshifts.
- **Among X-ray selected active galaxies** at similar redshifts, **our QSOs are the brightest** both in their AGN and SF components.

Direct determinations of the gas mass and of the galaxy mass in these objects are needed to understand the role of these exceptional objects in the disputed landscape of co-evolution of galaxies and AGN.

5. References

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