Traces of co-evolution in X-ray absorbed QSOs with high SFR at z~2

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We present a detailed investigation of a sample of 5 X-ray and submm-luminous QSOs at z~2, when the highest rates of star formation and growth of black holes are known to occur. Hence, they are good laboratories to investigate the co-evolution of star formation and AGN.

We present here the analysis of their Spectral Energy Distributions (SEDs), including new PACS and SPIRE Herschel data, together with our existing and archival X-ray-optical-NIR-MIR observations. Both AGN (direct and reprocessed) and Star Formation (SF) emission are needed to model their SEDs. From the SEDs and their UV-optical spectra we have estimated the mass of their black holes (M_{BH}~10^9 – 10^{10} M_{SUN}) and their intrinsic AGN bolometric luminosities (L_{BOL}~10^{13} – 10^{14} L_{SUN}) . Their black hole masses are very close to the maximum observed local black hole mass, so they cannot grow much more. These objects show indeed very high Far Infrared Luminosities (L_{FIR}~10^{12} L_{SUN}) and Star Formation Rates (SFR~1000 M_{SUN}/y), at the H/ULIRG level, they are among the brightest at 1.5<z<2.5. From the current SFR and their massive BH, we infer that their host galaxies have to be already quite massive, or they would not have time to reach the local BH-to-bulge mass relation by the present time. Finally, we have found tantalizing evidence for a correlation between the column density of the ionized gas detected in X-rays NH_{ION} and SFR, which would evidence for a link between AGN and SF processes.

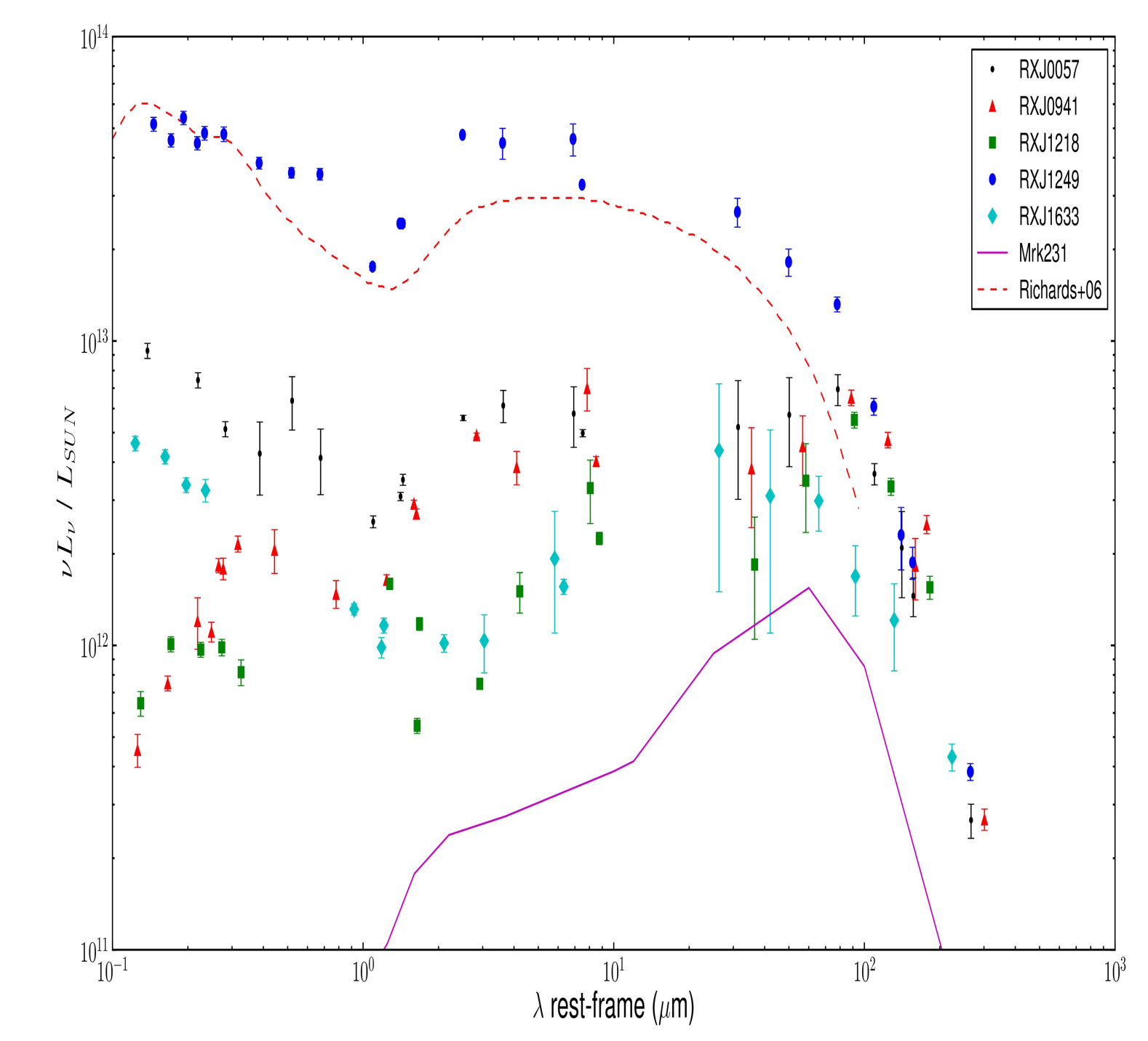
1. Results

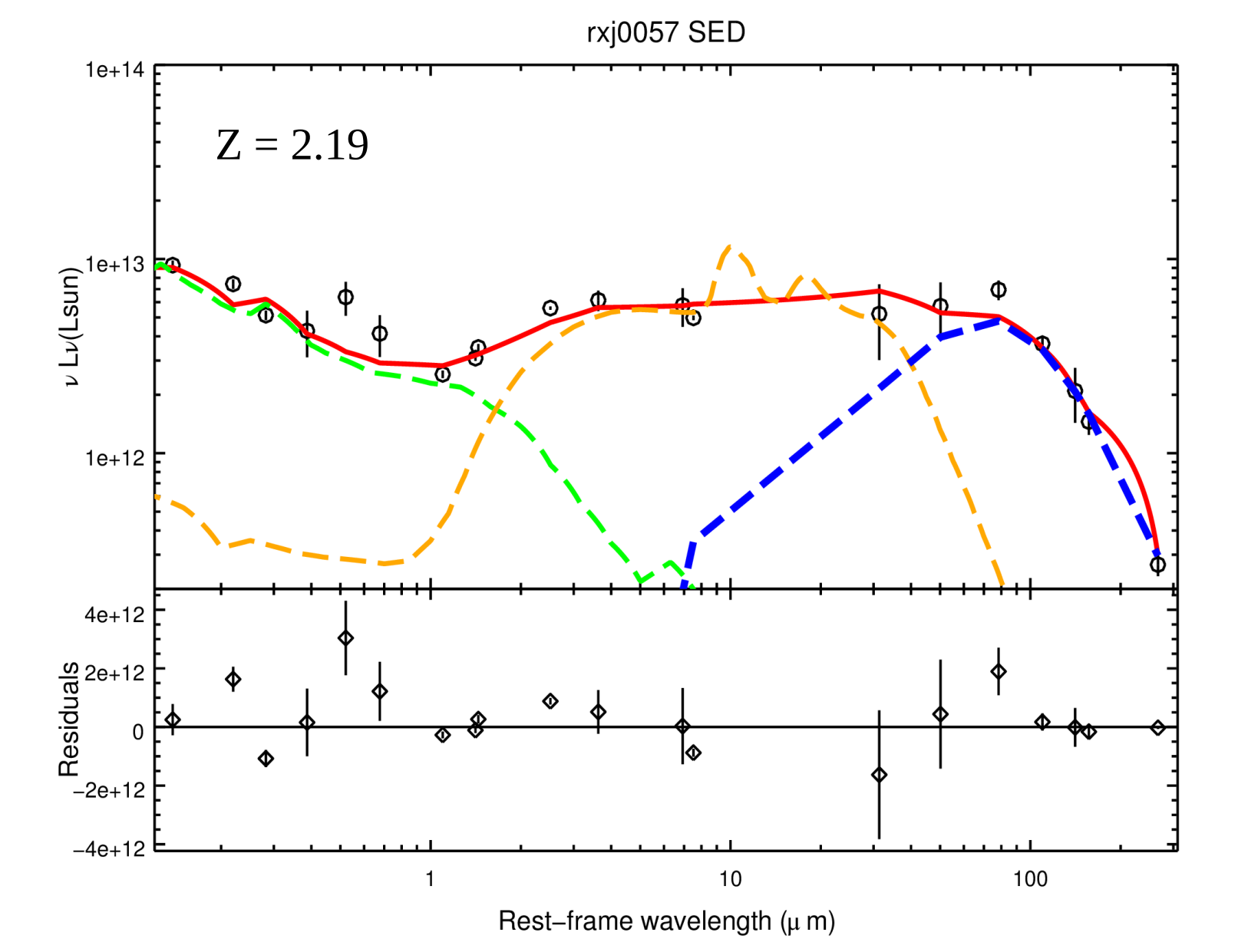
The top-left panel shows the SEDs of all our objects, compared with a standard QSO template and Mrk 231. From the SED fits (see below and rest of panels) **we confirm the presence of strong FIR emission due to Star Formation (SF)** in these objects, at the ULIRG/HLIRG level (compared to Mrkn231), thanks 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 [11], dashed green line), a reprocessed torus component (using both an empirical template from [11] and some dusty torus models from [7] found by [9] to represent the average properties of QSO1, dashed orange line) and a SF component (using models from [12] found by [16] to represent star forming galaxies at the relevant redhifts, dashed blue line).

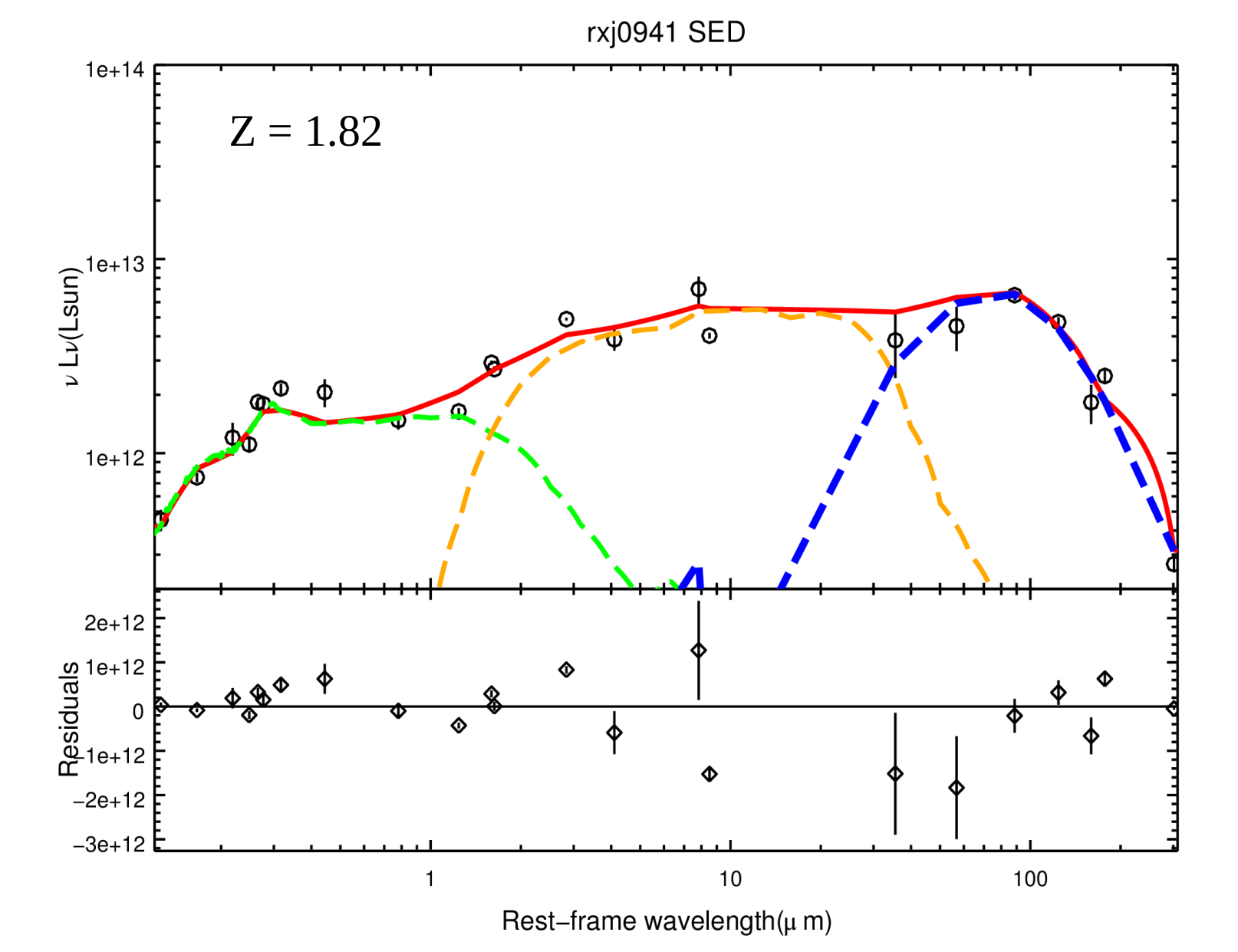
The L_{DISK}, L_{TORUS} and L_{FIR} shown below are the average values among the best fits to all combinations of components, with uncertainties estimated from the dispersion around those best fits.

We also show the black hole masses estimated from the CIV emission lines in the rest-frame UV spectra presented by [6].

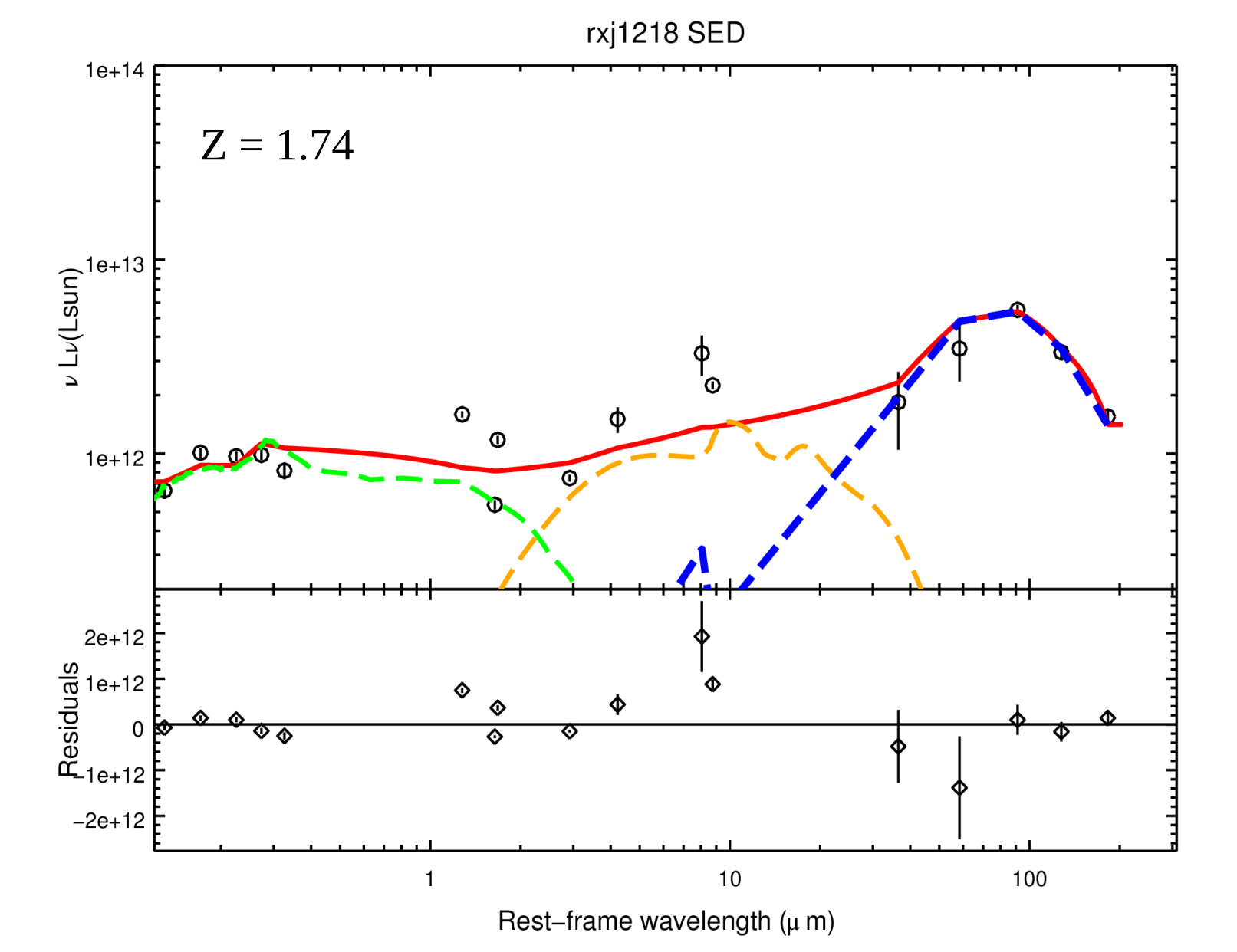




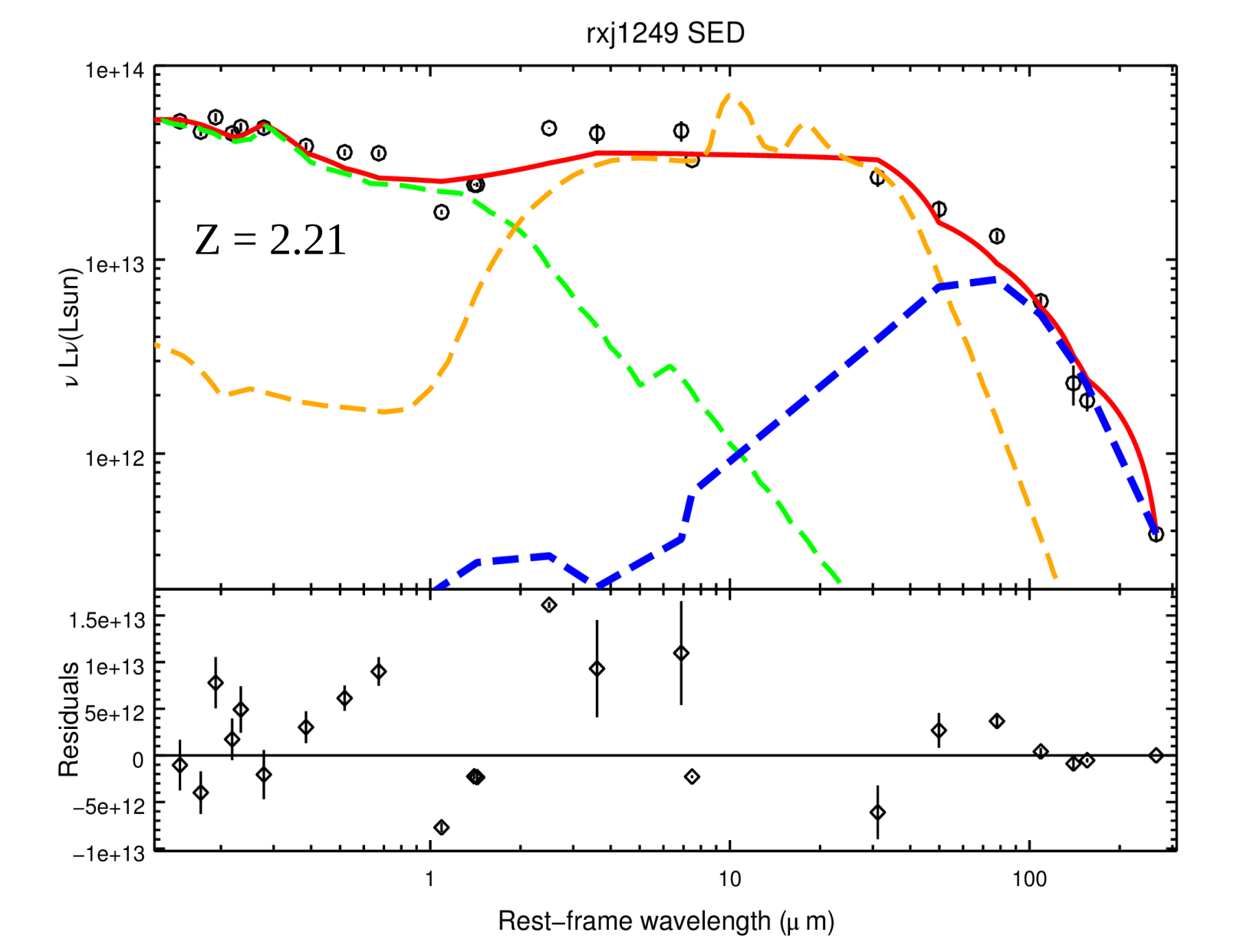
L_{DISK} = (125 ±2) x 10^{11} L_{SUN}
L_{TORUS} = (192 ±2) x 10^{11} L_{SUN}
L_{FIR} = (49 ±2) x 10^{11} L_{SUN}
$L_{X\_2\text{-}10}$ = 2.93 x 10^{11} L_{SUN}
L_{BOL} = (246.6 ±1.0) x 10^{11} L_{SUN}
SFR = 800 ± 100 M_{SUN} / y



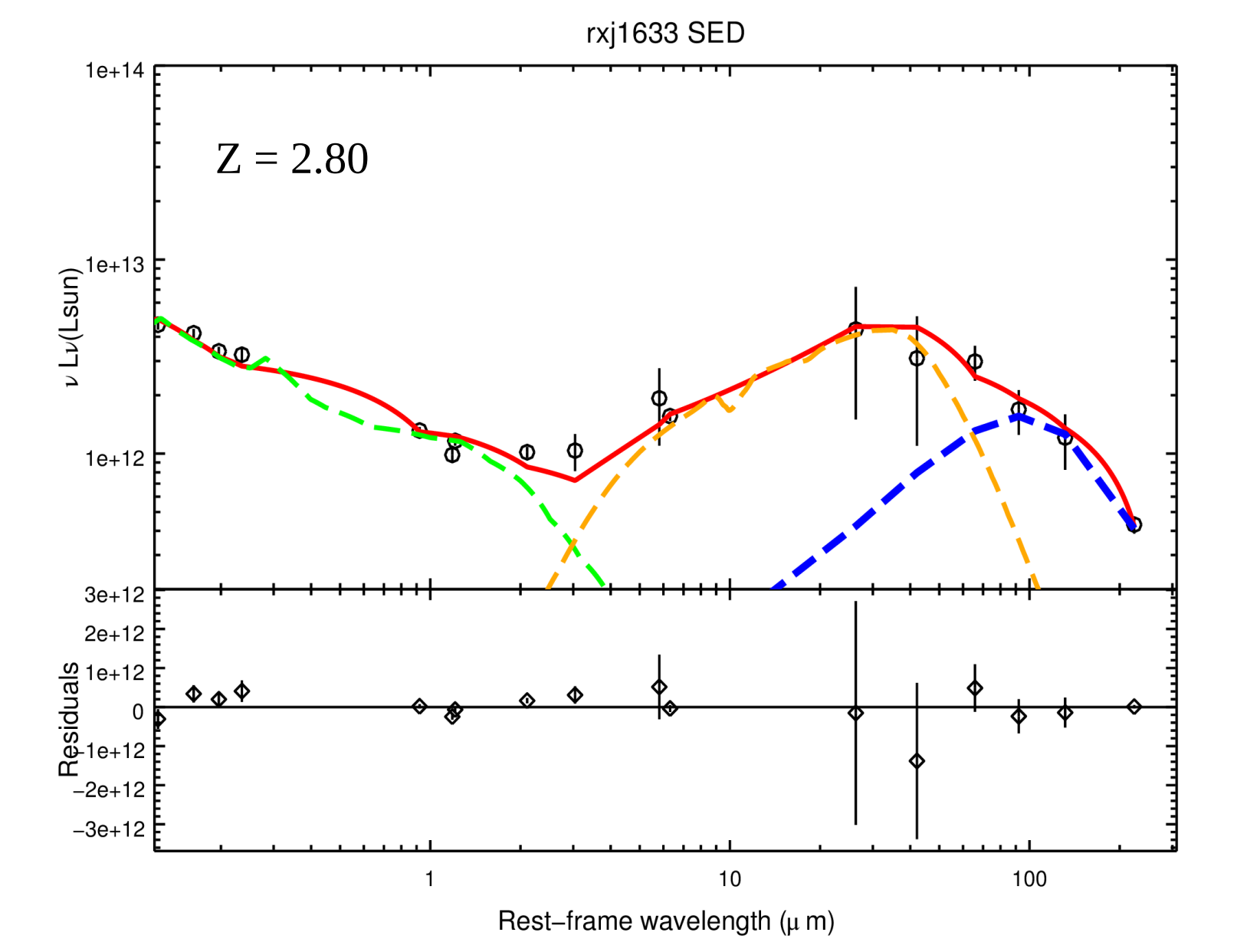
L_{DISK} = (100 ±3) x 10^{11} L_{SUN}
L_{TORUS} = (148 ±9) x 10^{11} L_{SUN}
L_{FIR} = (78 ±6) x 10^{11} L_{SUN}
$L_{X\_2\text{-}10}$ = 0.93 x 10^{11} L_{SUN}
L_{BOL} = (169.3 ±1.2) x 10^{11} L_{SUN}
SFR = 1350 ± 110 M_{SUN} / y



L_{DISK} = (42 ±7) x 10^{11} L_{SUN}
L_{TORUS} = (25 ±3) x 10^{11} L_{SUN}
L_{FIR} = (63 ±4) x 10^{11} L_{SUN}
$L_{X\_2\text{-}10}$ = 2.33 x 10^{11} L_{SUN}
L_{BOL} = (78 ±4) x 10^{11} L_{SUN}
SFR = 1090 ± 70 M_{SUN} / y



L_{DISK} = (1230 ±70) x 10^{11} L_{SUN}
L_{TORUS} = (1156 ±2) x 10^{11} L_{SUN}
L_{FIR} = (70 ±13) x 10^{11} L_{SUN}
$L_{X\_2\text{-}10}$ = 3.69 x 10^{11} L_{SUN}
L_{BOL} = (1890 ±30) x 10^{11} L_{SUN}
SFR = 1200 ± 200 M_{SUN} / y



L_{DISK} = (100 ±3) x 10^{11} L_{SUN}
L_{TORUS} = (148 ±9) x 10^{11} L_{SUN}
L_{FIR} = (78 ±6) x 10^{11} L_{SUN}
$L_{X\_2\text{-}10}$ = 5.85 x 10^{11} L_{SUN}
L_{BOL} = (185.5 ±0.4) x 10^{11} L_{SUN}
SFR = 380 ± 40 M_{SUN} / y

2. Discussion

SOURCE	log(M_{BH} / M_{SUN})	Look back time (Gy)	τ_{SB} (Gy)
RXJ005734.78 -272827.4	9.94 ± 0.36	10.6	10.7 ± 1.3
RXJ094144.51 +385434.8	9.77 ± 0.40	10.0	6.32 ± 0.5
RXJ121803.82+470854.6	9.28 ± 0.45	9.9	7.8 ± 0.5
RXJ124913.86-055906.2	9.99 ± 0.45	10.6	7.1 ± 1.2
RXJ163303.57+570258.7	8.73 ± 0.36	11.3	22 ± 2

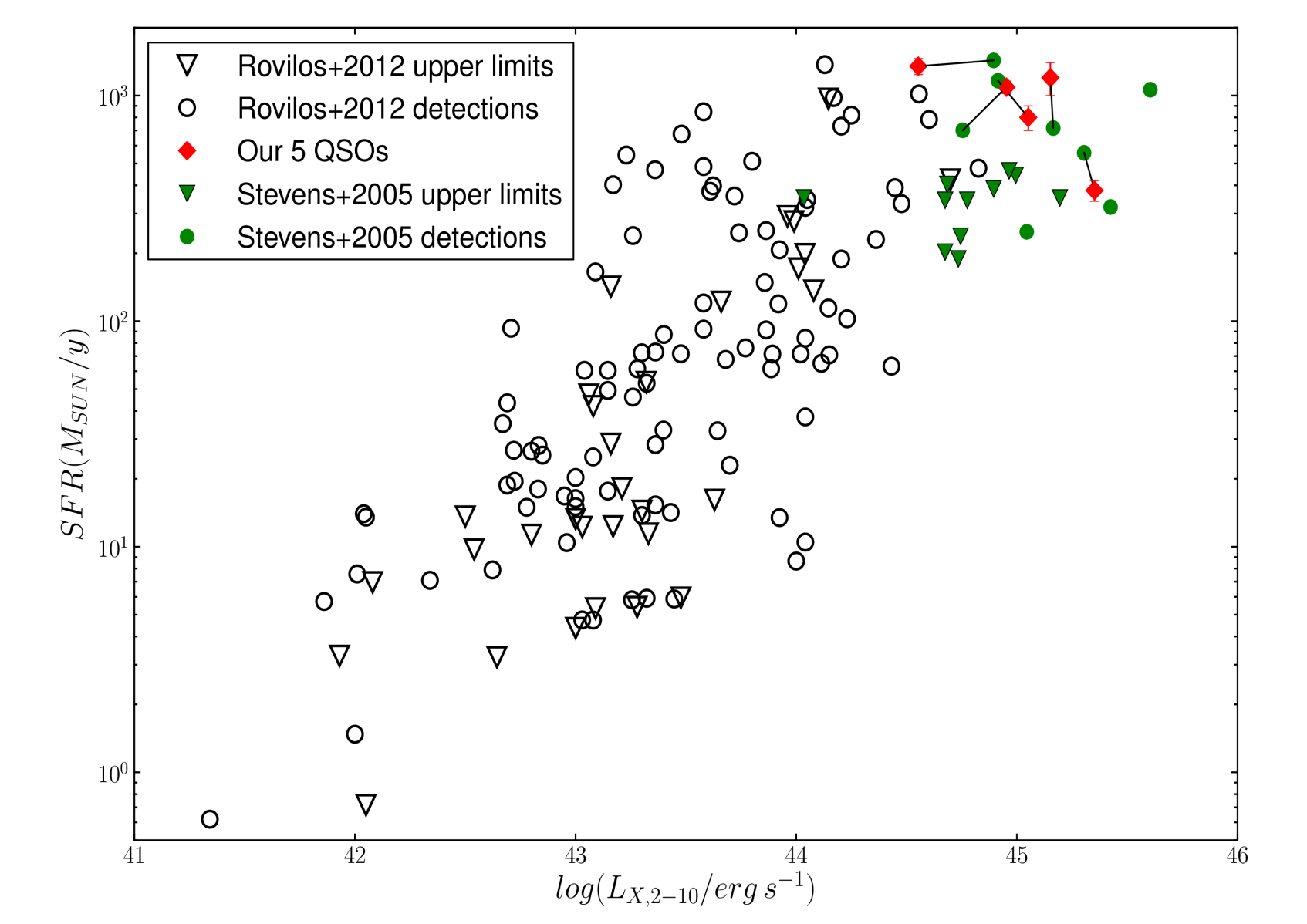
- The **Black Holes** inside the QSOs are very massive **(10^{10} – 10^{11} M_{SUN})** compared to the values obtained in the literature for the same range of redshift.

- 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 ([1],[3]), finding **M_{DUST}~10^9 M_{SUN}** .

- 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 [5]: **M_{BULGE} ~ 10^{12} – 10^{13} M_{SUN}** . Known the **lifetime of an active QSO phase** (200 million years), the **SFR,** the **"look back time"** of our objects and the **time to reach the maximum M_{BULGE}** with the current SFR, **these host galaxies are already mostly formed .**

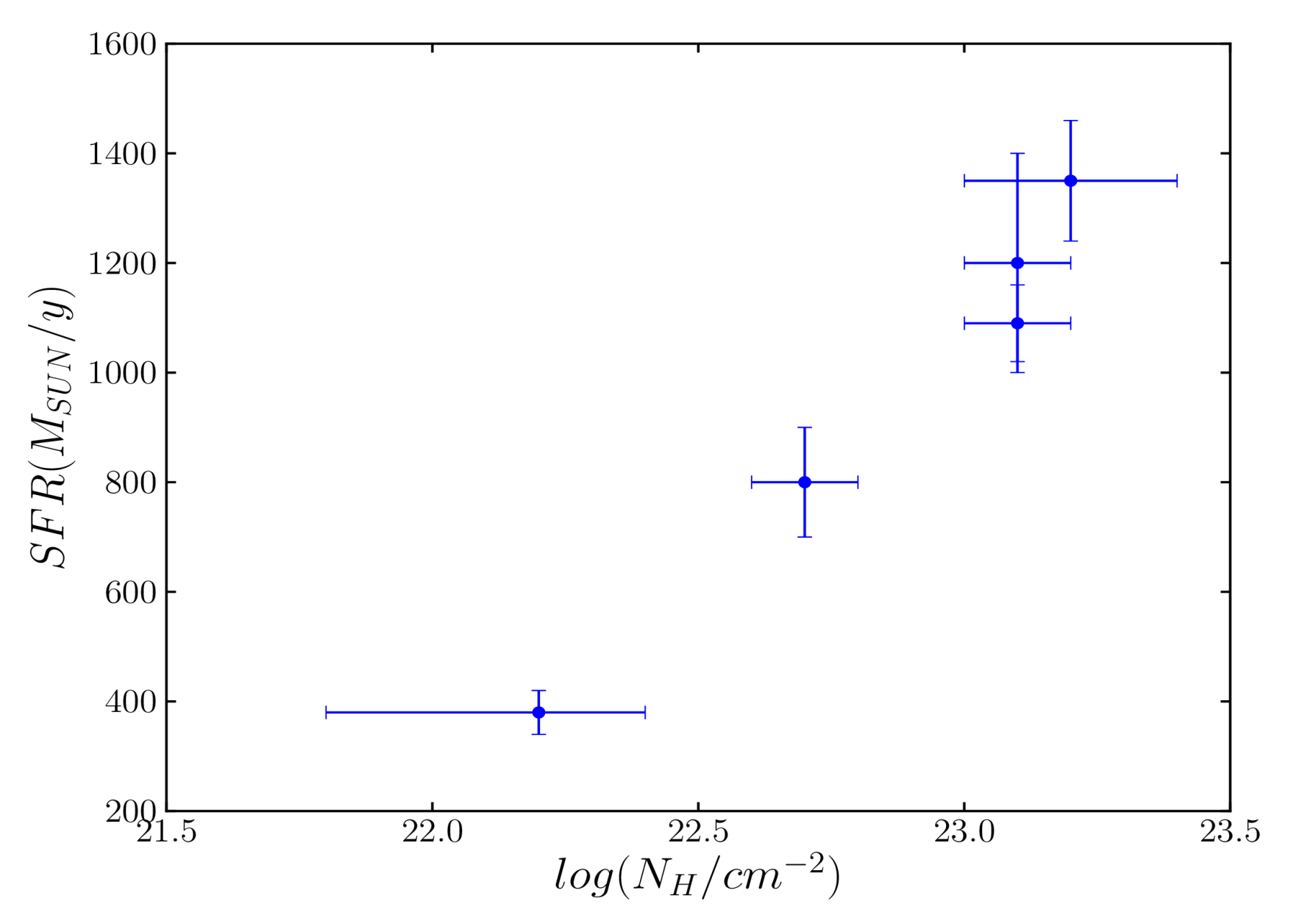
- Comparing to a sample of X-ray-selected active galaxies from [8] and [10], our objects are among the brightest at 1.5<z<2.5, both on their AGN and SF components**.** In particular **our object RXJ1249** would be the **brightest object** in the two samples. In contrast, when compared to [4] our objects do not stand out notoriously with their "mm-bright high-z QSO" and "Other high-z QSO".



- We have studied the **log(SFR) vs. log($L_{x\_2\text{-}10}$) correlation** using both [10] sample and a joint sample with our sources (including data from [14]).

- We have found a **significance ~ 99.77 % $\gtrsim$ 3σ,** more significant than the [10] original sample 93% < 2σ. These probabilities take into account a possible partial correlation with redshift.

However, given the very different selection functions of the samples involved and the different wavelengths ranges used to characterize the FIR luminosity in each sample, it is very difficult to assess the significance of this result.



- We have **found a tentative positive correlation** between the **SFR** of the host galaxy and the AGN **obscuration in the X-rays (**NH_{ION}).
- This is interesting, since it would **imply a coupling of the ionized gas absorbing the X-rays** at the **scale of the accretion disk or the BLR** with **the gas forming stars in the host galaxy bulge**, about three orders of magnitude farther away.
- It is compatible with a **positive feedback** scenario in which **the ionized out-flowing gas would trigger SF** in the interstellar medium of the **host galaxy**.

3. 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 **10^9 – 10^{10} 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.**
- **Their host galaxies are already mostly formed .**
- We have found a **tentative positive correlation** between the **SFR** of the host galaxy and the **AGN obscuration in the X-rays.**
- Our objects are **bright objects but do not stand out to other optically and X-ray selected type 1 QSO** compared to **objects with strong submm emission and high bolometric** except **RXJ1249**, which **is one of the brightest objects** in all samples.

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.

4. References

[1] Beelen et al. 2006: ApJ, 642, 694 (2006). **[2]** Carrera et al. 2011: Mon. Not. R. Astron. Soc. 413, 2791-2807 (2011). **[3]** Kovács et al. 2006: ApJ, 650, 692 (2006). **[4]** Lutz et al. 2008: ApJ, 684, 853 (2008). **[5]** Marconi et al. 2003: ApJ, 589, L21 (2003). **[6]** Page et al. 2011: Mon. Not. R. Astron. Soc. 416, 2792-2801 (2011). **[7]** Nenkova et al. 2008: ApJ, 685, 147 (2008). **[8]** Rosario et al. 20: A&A. 545, A45 (2012). **[9]** Roseboom et al. 2013: Mon. Not. R. Astron. Soc. 429, 1494-1501 (2013). **[10]** Rovilos et al. 2012: A&A. 546, A58 (2012). **[11]** Rowan-Robinson et al. 2008: Mon. Not. R. Astron. Soc. 386, 697-714 (2008). **[12]** Siebenmorgen et al. 2007: A&A. 462, 445 (2007). **[13]** Stevens et al. 2004: Mon. Not. R. Astron. Soc. 360, 610-618 (2005). **[14]** Stevens et al. 2005: Mon. Not. R. Astron. Soc. 360, 610 (2005).**[15]** Stevens et al. 2010: Mon. Not. R. Astron. Soc. 405, 2623-2638 (2010). **[16]** Symeonidis et al. 2013: Mon. Not. R. Astron. Soc. 431, 2317-2340 (2013).