# Low-luminosity radio AGN maintains low star formation rate in massive quiescent galaxies at z = 0 – 1.5

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## Summary

The physical mechanism that keeps star formation (SF) inefficient in quiescent galaxies (QGs) is still a subject of controversy. In this work, we test for the presence of radio AGN by stacking QGs at long wavelengths (mid-IR, far-IR and radio). By comparing the IR luminosities derived from these 3 wavelength ranges, we reveal that the average radio emission of the most massive QGs are in excess compared to that expected of star formation alone. The widespread presence of low-luminosity AGN is likely responsible for the inefficient SF in QGs.

## How?

Sample ~14,200 QGs selected using the NUV-r and r-J colors from the COSMOS/UltraVISTA catalog [3]

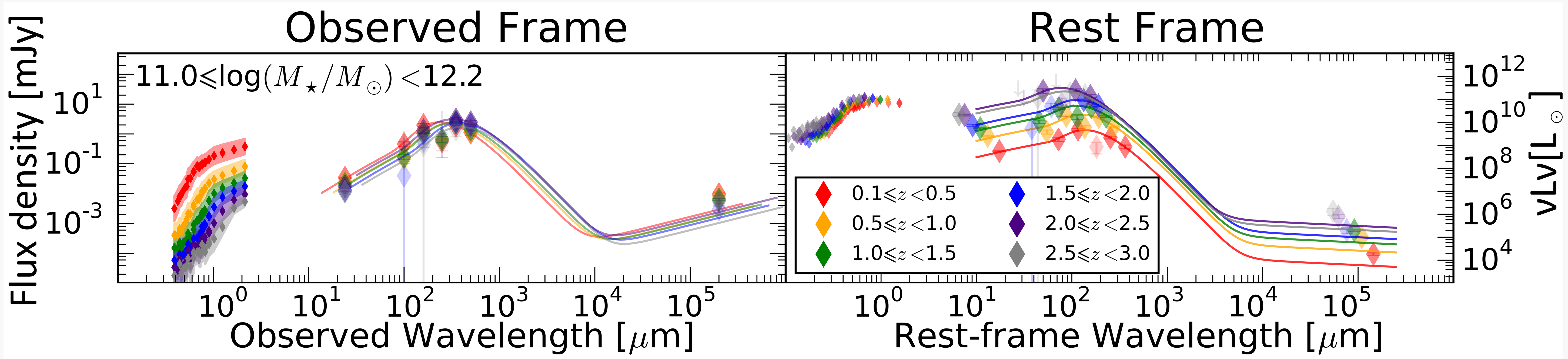
- at z=0.1-3
- the strong 24um emitters (equivalent to SFR=100 Msun/yr) are treated separately and not discussed here

Stacking

| | Instrument | Wavelength | Method | LIR derivation |
|---|---|---|---|---|
| Mid-infrared | Spitzer MIPS | 24 um | median stacking | Template fitted to 24 um flux [5] |
| Far-infrared | Herschel | 100, 160, 250, 350, 500 um | global stacking & deblending [7] | Greybody fit |
| Radio | VLA | 20 cm (1.4 GHz) | median stacking | Radio-FIR correlation [1] scaled to radio flux |

**References:**
1. Bell 2003
2. Best & Heckman 2012
3. Ilbert et al. 2013
4. Olsen et al. 2013
5. Rujopakarn et al. 2013
6. Schawinski et al. 2009
7. Viero et al. 2013

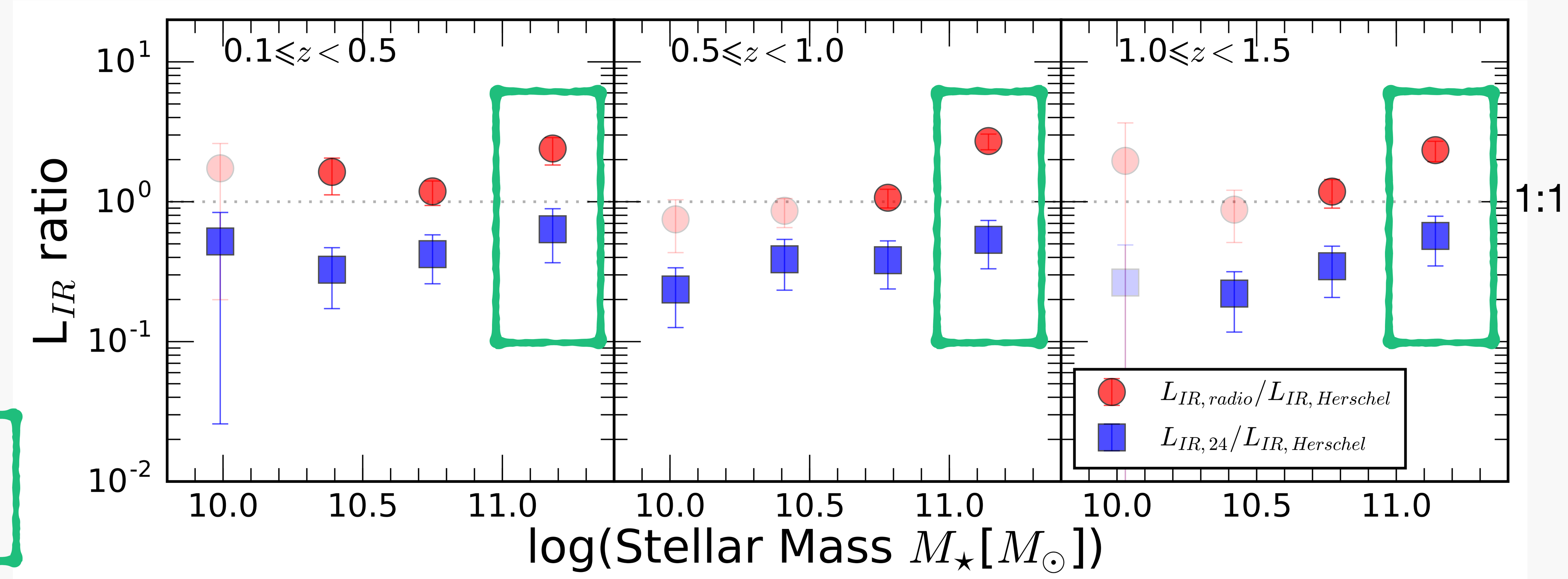
## First UV-to-radio SED for quiescent galaxies




| Redshift | $\overline{z_{phot}}$ | $N_{gal}$ | $S_{24\,\mu m}$ (μJy) | $S_{100\,\mu m}$ (mJy) | $S_{160\,\mu m}$ (mJy) | $S_{250\,\mu m}$ (mJy) | $S_{350\,\mu m}$ (mJy) | $S_{500\,\mu m}$ (mJy) | $S_{radio}$ (μJy) | $\log(L_{IR,H})$ $\log(L_\odot)$ | $\log(L_{1.4\,GHz})$ $\log(W\,Hz^{-1})$ | $q_{IR}$ | $SFR_{SED}$ ($M_\odot\,yr^{-1}$) | $SFR_{24}$ ($M_\odot\,yr^{-1}$) | $SFR_H$ ($M_\odot\,yr^{-1}$) | $SFR_{radio}$ ($M_\odot\,yr^{-1}$) | $\log(sSFR_H)$ $\log(yr^{-1})$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\log(M_\star/M_\odot)$ = 11–12.2 (median = 11.2) | | | | | | | | | | | | | | | | | |
| 0.1–0.5 | 0.4 | 232 | 34.0 ± 1.5 | 0.5 ± 0.1 | 2.0 ± 0.2 | 0.6 ± 0.3 | 1.9 ± 0.2 | 1.1 ± 0.2 | 9.6 ± 1.1 | 9.8 ± 0.1 | 21.7 ± 0.0 | 2.2 | $0.05^{+2.97}_{-0.05}$ | 0.5 ± 0.2 | $0.7^{+0.2}_{-0.1}$ | 1.7 ± 0.1 | −11.3 |
| 0.5–1.0 | 0.8 | 1298 | 24.1 ± 0.9 | 0.1 ± 0.0 | 1.2 ± 0.1 | 0.6 ± 0.1 | 2.3 ± 0.1 | 1.2 ± 0.1 | 7.8 ± 0.5 | 10.5 ± 0.1 | 22.5 ± 0.0 | 2.1 | $0.20^{+12.39}_{-0.20}$ | 1.8 ± 0.7 | $3.4^{+0.4}_{-0.4}$ | 9.2 ± 0.5 | −10.6 |
| 1.0–1.5 | 1.2 | 827 | 21.3 ± 1.0 | 0.2 ± 0.0 | 1.0 ± 0.1 | 0.7 ± 0.2 | 2.5 ± 0.1 | 1.4 ± 0.1 | 6.4 ± 0.6 | 10.9 ± 0.1 | 22.8 ± 0.0 | 2.1 | $0.59^{+13.21}_{-0.56}$ | 4.6 ± 1.7 | $8.1^{+1.2}_{-1.0}$ | 19.0 ± 1.7 | −10.2 |
| 1.5–2.0 | 1.6 | 320 | 13.0 ± 1.2 | 0.0 ± 0.1 | 0.6 ± 0.2 | −0.1 ± 0.3 | 2.4 ± 0.3 | 2.0 ± 0.2 | 3.0 ± 0.9 | 11.2 ± 0.2 | 22.8 ± 0.1 | 2.4 | $0.42^{+6.50}_{-0.39}$ | 4.8 ± 1.8 | $14.8^{+7.6}_{-5.0}$ | 20.0 ± 6.0 | −10.0 |
| 2.0–2.5 | 2.2 | 185 | 17.6 ± 1.6 | −0.1 ± 0.1 | 1.3 ± 0.3 | 0.6 ± 0.4 | 3.1 ± 0.4 | 2.5 ± 0.3 | 5.7 ± 1.1 | 11.7 ± 0.1 | 23.4 ± 0.1 | 2.3 | $0.78^{+7.74}_{-0.71}$ | 9.4 ± 3.5 | $50.1^{+16.0}_{-12.1}$ | 82.7 ± 16.6 | −9.4 |
| 2.5–3.0 | 2.6 | 65 | 11.7 ± 2.2 | −0.2 ± 0.1 | 0.4 ± 0.5 | −1.2 ± 0.6 | 1.4 ± 0.6 | 1.7 ± 0.6 | 6.0 ± 2.1 | 11.5 ± 0.4 | 23.6 ± 0.1 | 1.9 | $1.20^{+34.28}_{-1.16}$ | 12.8 ± 5.4 | $35.5^{+60.0}_{-22.3}$ | 141.2 ± 48.4 | −9.5 |

## Excess radio emission indicates AGN presence

We obtain 3 independent measurements of the infrared luminosity (LIR) by stacking at MIR, FIR and radio. By comparing the ratios between the derived LIR, we constrain the source of the emission.




LIR derived from radio is higher than LIR derived from Herschel and 24um

Radio emission is larger than expected from SF alone

Low 24um emission compared to Herschel implies little hot dust

Obscured quasar-mode feedback likely not dominant in QGs

Implies that low-luminosity AGN is widespread among massive QGs [4], and contribute to their radio emission

Consistent with the idea that radio-mode feedback (‘maintenance-mode’) by AGN can keep massive galaxies inefficient in SF [2,6]