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Jet Feedback on the Hosts Of Radio Galaxies

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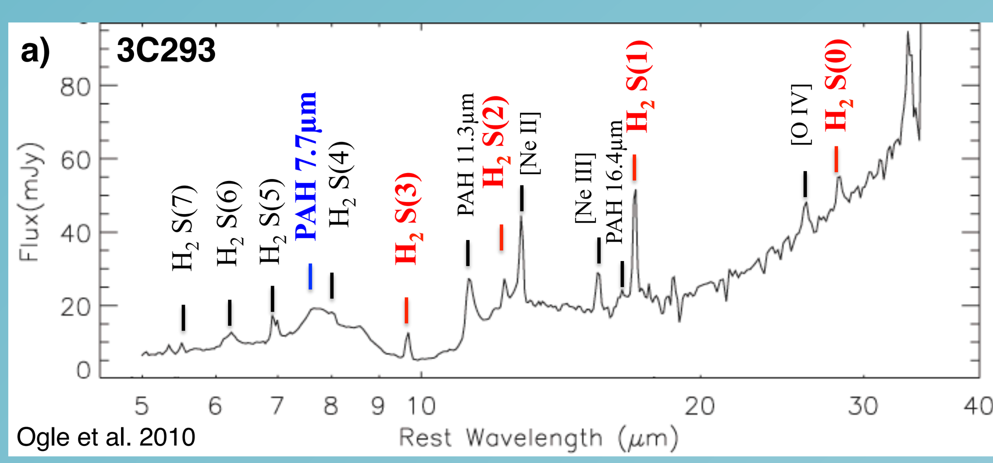
H_2 luminous Radio Galaxies as Feedback Candidates

Feedback due to active galactic nuclei (AGN) is one of the key components of the current paradigm of galaxy evolution; however our understanding remains incomplete. Radio galaxies with strong rotational H_2 emission provides an interesting window into the effect of radio jet feedback on host galaxies, since the large masses of warm (>100 K) H_2 cannot solely be heated by star formation, instead requiring jet-driven ISM turbulence to power the molecular emission. Our study focuses on the 22 radio galaxies identified by Ogle et al. (2010) and Guillard et al. (2012) as Molecular Hydrogen Emission Galaxies (MOHEGs) based on H_2/7.7μm PAH ratios (Fig. 1a) too large for the H_2 emission to be solely powered by UV photons from young stars which would also excite the PAH molecules. Direct heating by the AGN is also unlikely, since $L_{H2}/L_{2\text{-}10keV}>0.01$ (Ogle et al. 2010). The likely heating mechanism is dissipation of kinetic energy through shocks, suggesting we are seeing direct interaction of the jet with the ISM in these galaxies (Lanz et al. 2016).



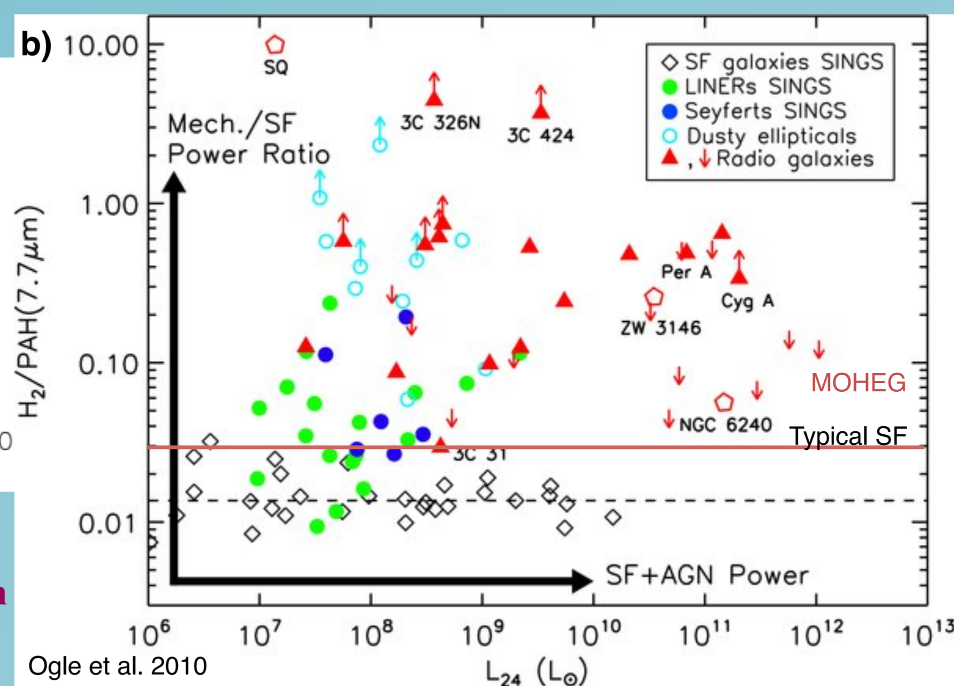


Fig. 1 **MOHEGs are defined by their H_2/7.7μm PAH ratio as measured in *Spitzer IRS* spectra (a) and are found in many types of galaxies with a large range of L_{IR} (b).**

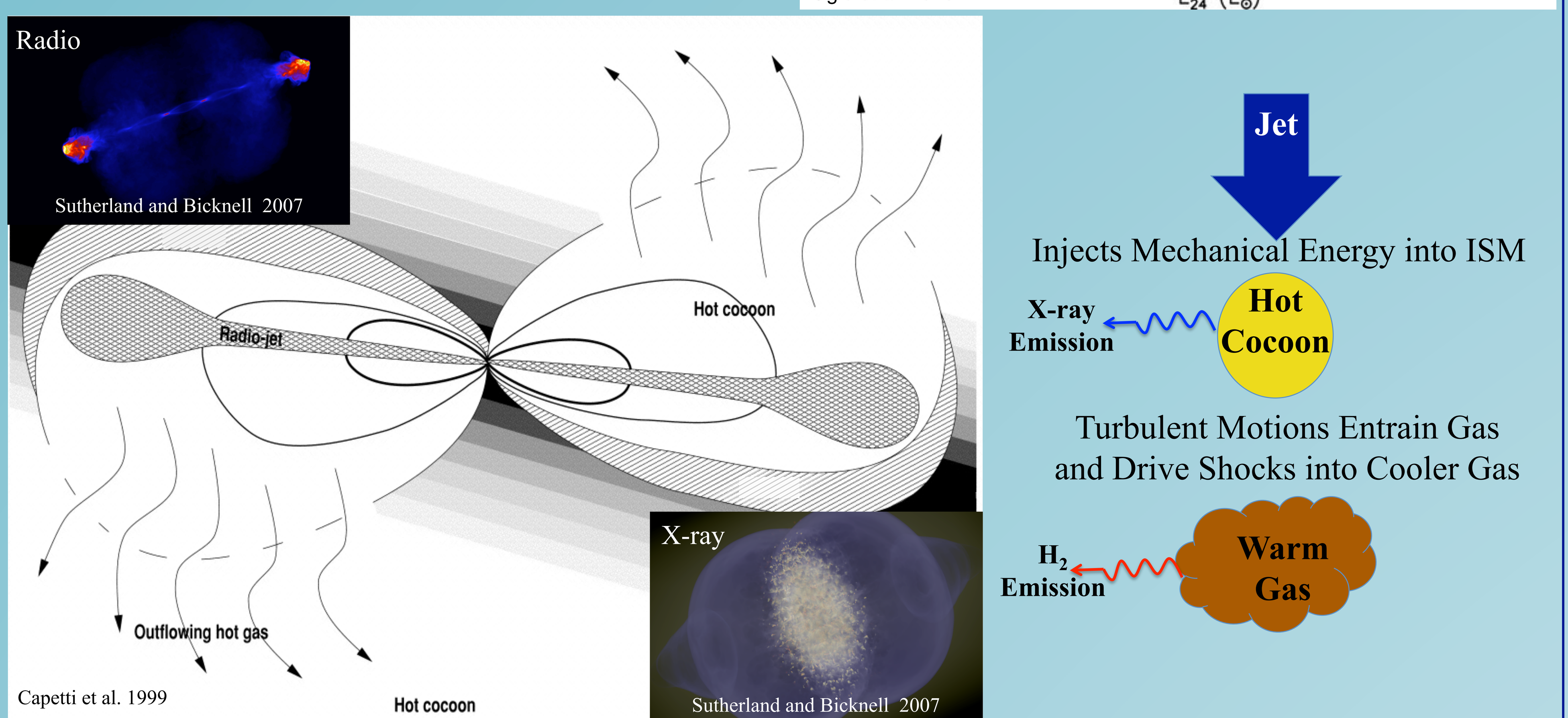
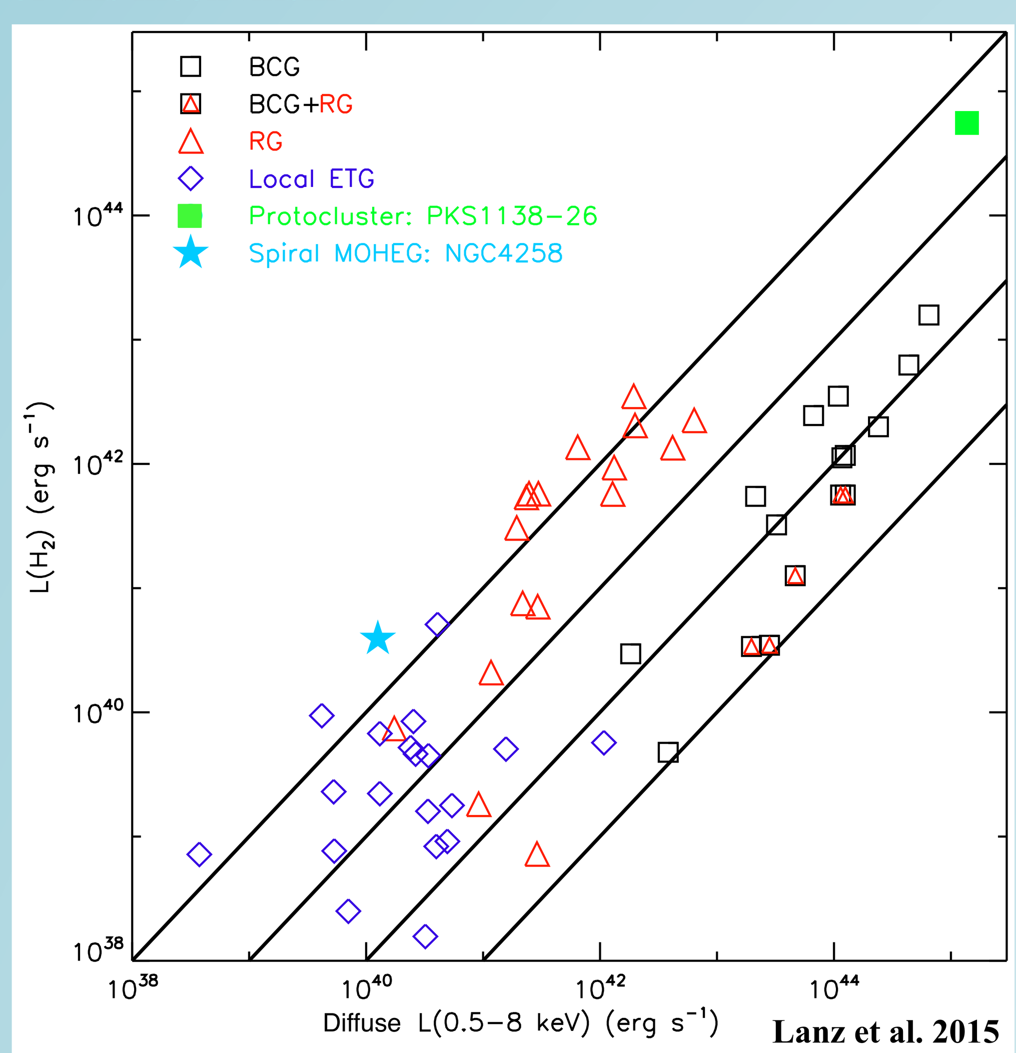
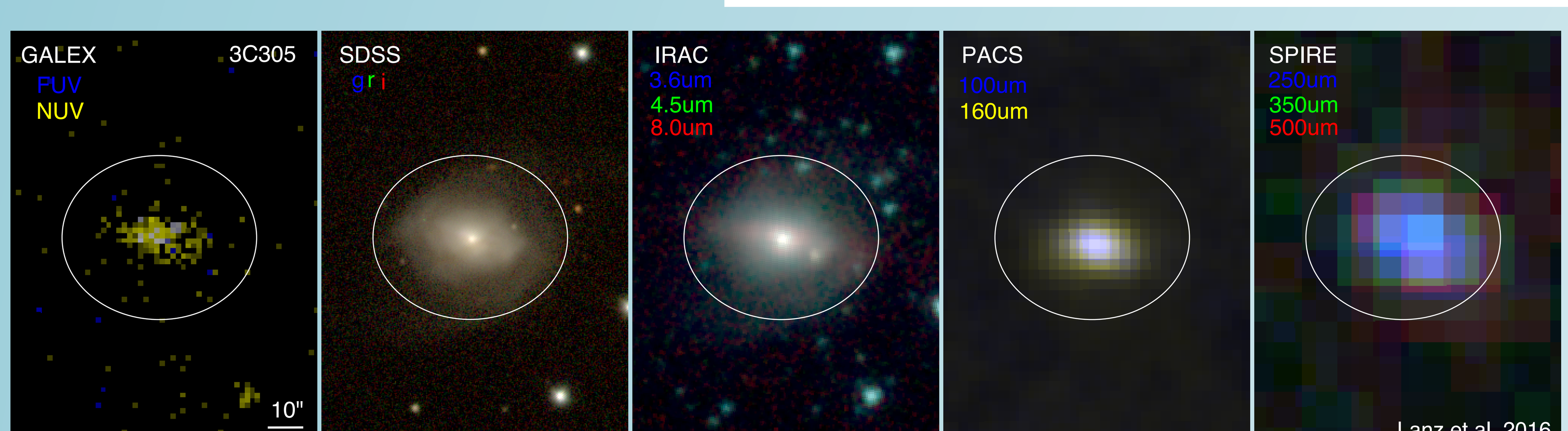


Fig. 2 **Schematics illustrating the scenario likely taking place in these radio galaxies, wherein the radio jet inflates of a hot, X-ray emitting cocoon. This cocoon can then carry the effects of the jet to much more of the galaxy than the jet cross-section. Turbulent motions in the cocoon can entrain cooler gas and drive shocks that power the H_2 emission. A snapshot of a simulation (Sutherland & Bicknell 2007) imaged in the radio and X-ray support the plausibility of this mechanism.**

Fig. 3
H_2 luminosity of MOHEGs compared to the diffuse X-ray luminosity of the host galaxy, excluding the AGN. Radio galaxies have generally have similar L(H_2) and L_X, with higher L_X than early type galaxies. A ratio of L(H_2)/L_X ~ 1 in radio galaxies is consistent with a picture that both are powered by the dissipation of mechanical energy from the jet. Brightest cluster galaxies have X-ray luminosity associated with their cluster within the host galaxy, so their L_X ~ 100 x L(H_2). The Spiderweb Galaxy (z=2) , an intermediate case, is a strong radio source in an unvirialized protocluster.





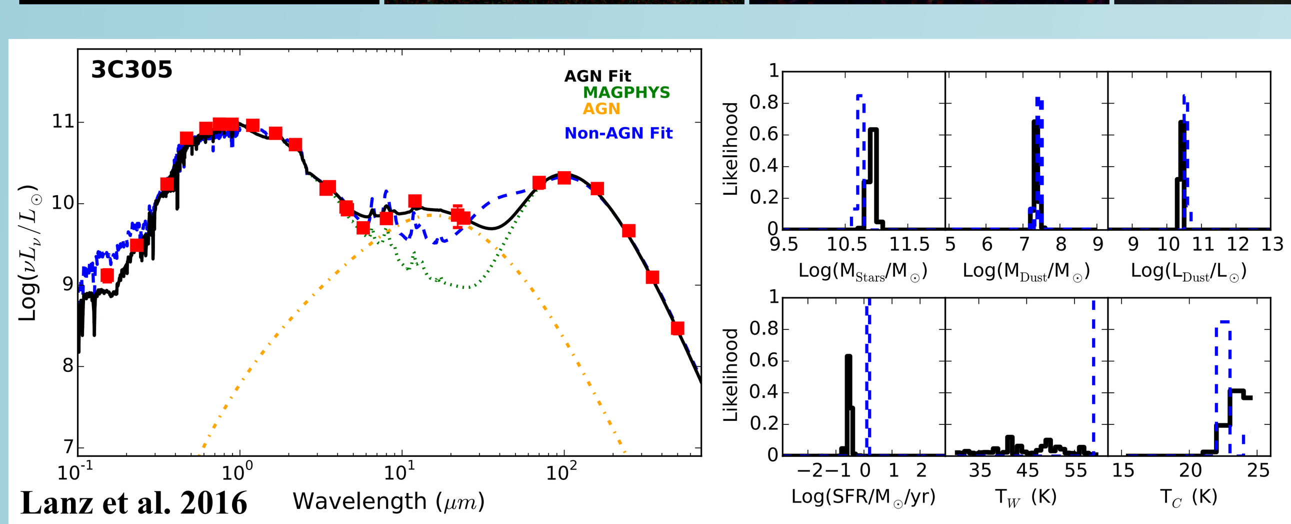


Fig. 4 **We measure *GALEX*, SDSS, 2MASS, *Spitzer, WISE*, and *Herschel* photometry (above) and fit them (left) with the SED-modelling code MAGPHYS (da Cunha et al. 2008), combined with an empirical AGN model (Sajina et al. 2012).**

Star Formation Suppression in H_2 Luminous Radio Galaxies

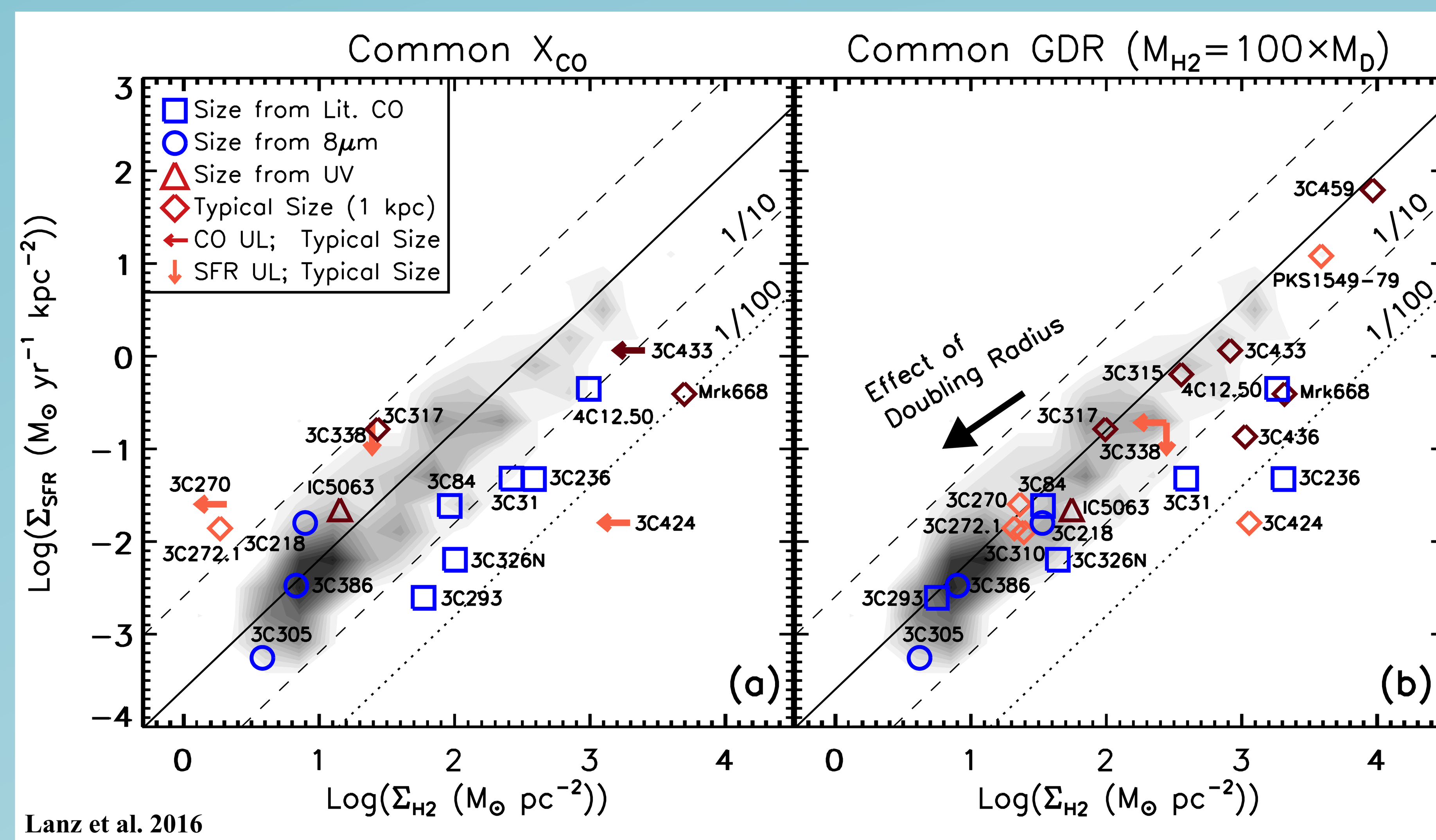


Fig. 5 **Surface density of star formation compared to the surface density of molecular gas (the Kennicutt-Schmidt relation [solid line]) calculated from (a) CO luminosity assuming X_{CO} = 2x10[20] cm[-2] (K km s[-1])[-1] (Bolatto et al. 2013) and (b) from the dust mass, compared to typical galaxies (contours), showing a systematic shift to lower star formation rates by a factor of 3-6. We find statistical differences in the distribution of our galaxies from normal galaxies.**

Diversity of Color and Evolutionary States

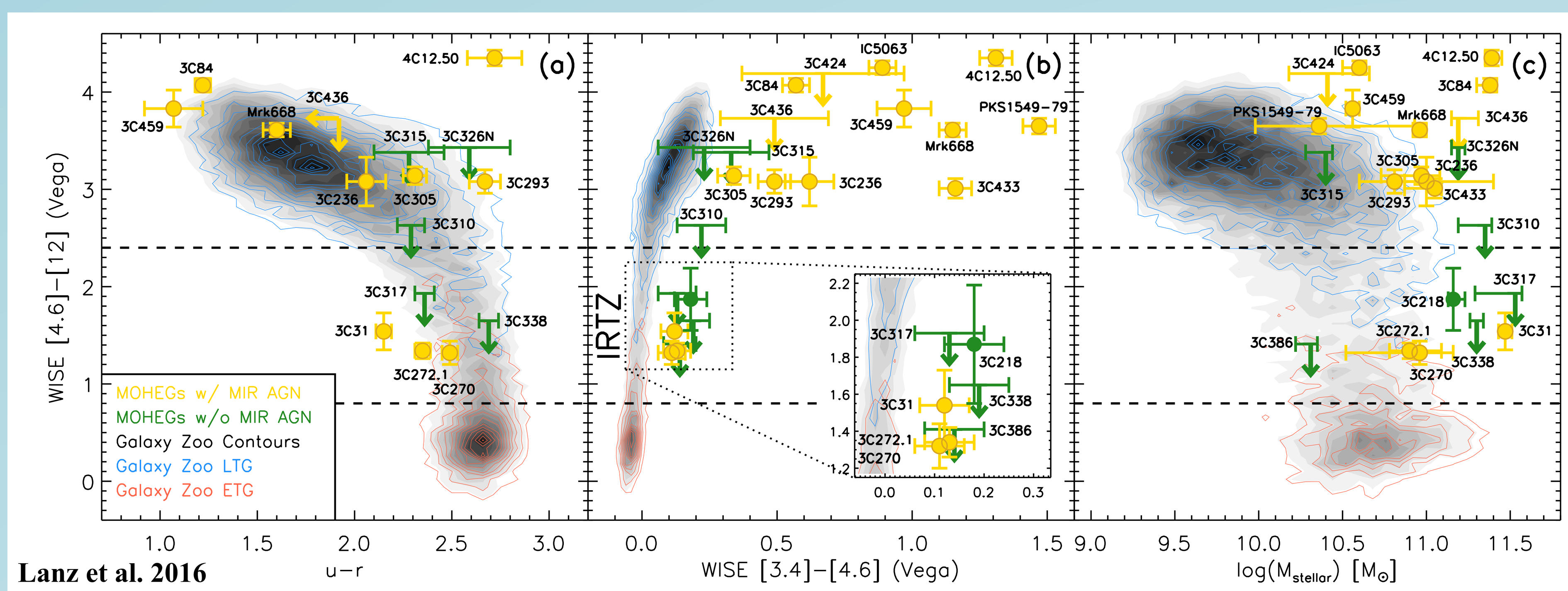


Fig. 6 **WISE [4.6]-[12] color compared to SDSS u-r color (a), WISE [3.4]-[4.6] color (b), and stellar mass (c) of our radio galaxies, plotted over Galaxy Zoo contours from Schawinski et al. (2014), showing our galaxies cover a large range of optical and IR colors. They tend to be dustier and more gas-rich than typical early type galaxies, yielding bluer optical colors and larger [4.6]-[12] colors. MIR AGN drives the [3.4]-[4.6] color to larger values. They tend to be in relatively massive hosts. Those that fall in the Infrared Transition Zone (IRTZ; Alatalo et al. 2014) tend to be the most gas-poor.**

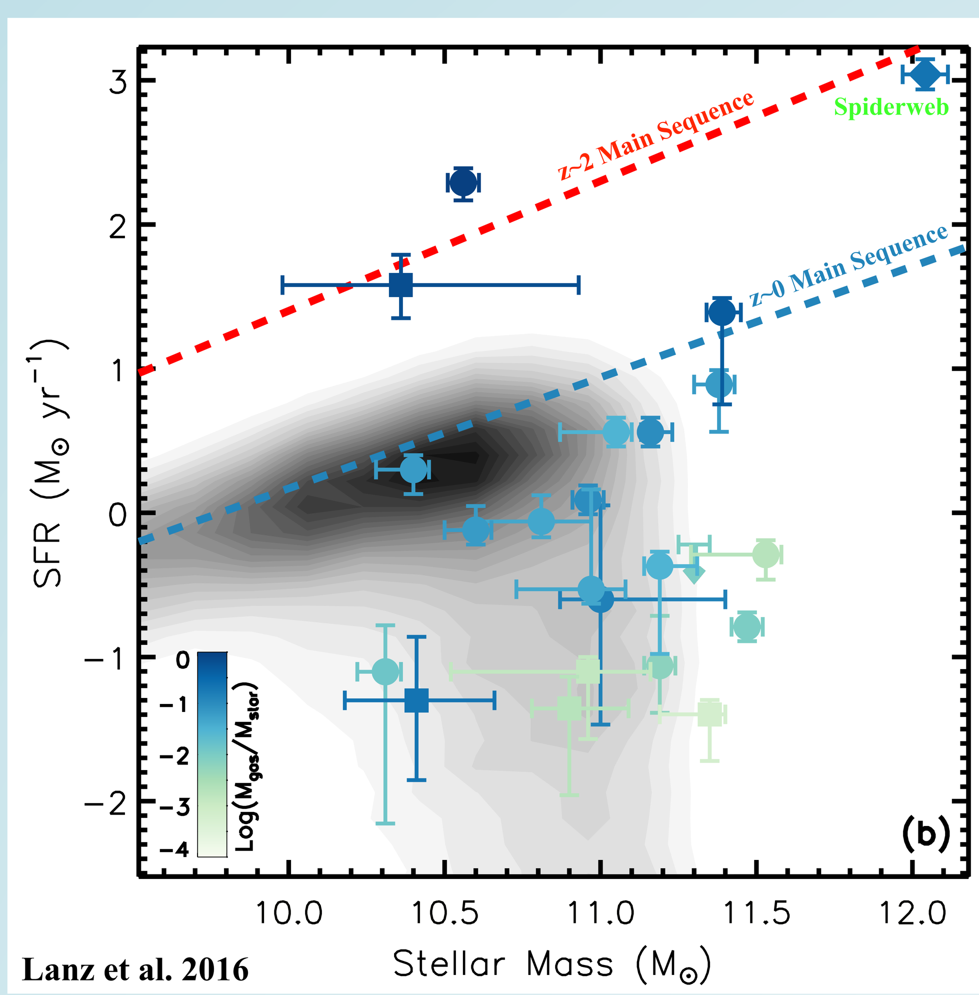


Fig. 7 **Star formation rate compared to stellar mass of our radio galaxies, colored by gas richness, compared to contours of normal galaxies from Chang et al. (2015) and the star formation main sequence at z~0 (Elbaz et al. 2007) and z~2 (Daddi et al. 2007), showing our galaxies cover a large range of SFR, although they tend to fall below the main sequence.**

Star formation suppression has the large impact on moderately gas-rich galaxies. Gas-poor galaxies are already very massive and would not increase in mass regardless. Gas-rich ULIRGs will still increase significantly in stellar mass. Five moderately gas rich galaxies would have doubled in stellar mass in a Hubble time if they were forming stars at normal efficiency.

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