The PEP Survey: 
Infrared Properties of radio-selected AGN

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Credits for image: Hi-GAL
Almost general consensus on AGN selected in various bands (from optical to X-ray) to be hosts of star-forming activity. Question: does it also hold for radio-selected AGN (generally expected to reside in “red and dead” galaxies)?

Aim: provide analysis of FIR properties of radio-selected AGN of all radio luminosities and at all redshifts.

Method: adopt criterion for selecting AGN based on radio-luminosity alone. Apply it to the COSMOS-VLA sample of 1.4GHz-selected objects. FIR fluxes from the PACS Evolutionary Probe (PEP, P.I. D. Lutz) survey performed with the PACS instrument onboard Herschel.
Short answer: radio activity *does not* prevent star formation, especially at high $z$.
Caution when associating radio sources to ‘dead’ ellipticals (radio mode) as strong function of $z$!

Powerful radio sources are more likely to be FIR emitters at earlier epochs.
FIR emission entirely due to star-forming processes.
COSMOS-VLA @ 1.4 GHz
(Schinnerer+ 2004; 2007; Bondi+2008)

COSMOS-Herschel
(Lutz+2011)
The Origin of FIR emission in radio-selected AGN:
criteria for AGN selection in radio surveys

Radio data from VLA-VIRMOS (Bondi+ 2003). 1 deg² complete
to 100mJy: 1054 sources

10-band photometry via VIDEO
(Jarvis+2013) and CFHTLS
(Ilbert+ 2006) for 942 sources
(91%).
Photo-z with s~0.025 accuracy
(s~0.10 for QSOs above z~0.22)
+ SED analysis of source type

From McAlpine+13 RLF z evolution
of cross-point from SF-dominated
to AGN-dominated sources:
Log_{10} P_{\text{cross}} (z)=Log_{10} P_{\text{0,cross}} +z for z<1.8
Log_{10} P_{\text{cross}} =23.5 \text{ [W/Hz/sr]} \text{ z>1.8}
Log_{10} P_{\text{0,cross}} \text{ break of local RLF}
(Magliocchetti+2002; Mauch& Sadler 2007)
The Origin of FIR emission in radio-selected AGN: VLA-COSMOS (radio+FIR) sample

Radio data from VLA-COSMOS (Bondi+ 2008). 2 deg$^2$ complete to 60mJy: 2382 sources.

Redshifts from Ilbert+ 2013
1537 radio sources with z (65%) independent of radio flux.

1026 sources (67%) SF. Majority SF $F_{1.4\,GHz} < 0.4$ mJy
482 sources (32%) AGN. Majority AGN $F_{1.4\,GHz} > 0.4$ mJy.

FIR fluxes from PEP Survey (Lutz+2011) down to ~4 mJy (at 100mm to 4") and 7 mJy (at 160mm to 5”).

FIR ids \(\rightarrow\) -657 SF have counterpart in PEP catalogues. Dependent on RF.
-175 (36%) AGN. No dependence on radio flux up to F~3 mJy.

Cross-point from SF-dominated to AGN-dominated sources:
\[
\log_{10} P_{\text{cross}}(z) = \log_{10} P_{0,\text{cross}} + z \quad \text{for } z < 1.8
\]
\[
\log_{10} P_{\text{cross}} = 23.5 \, \text{[W/Hz/sr]} \quad z > 1.8
\]
\[
\log_{10} P_{0,\text{cross}} \quad \text{break of local RLF (Magliocchetti+2002; Mauch & Sadler 2007)}
\]

FIR ids \(\rightarrow\) -657 SF have counterpart in PEP catalogues. Dependent on RF.
-175 (36%) AGN. No dependence on radio flux up to F~3 mJy.
The Origin of FIR emission in radio-selected AGN: redshift distributions

- $F_{1.4\text{GHz}}>0.06 \text{ mJy} \rightarrow P_{\min}<P_{\text{cross}} \text{ [W/Hz/sr]}$ for $z<3.5$ → VLA-COSMOS AGN sample complete in radio for all $z<3.5$

- No dependence of FIR id success rate on $z$ for AGN family
- FIR-id AGN same (rescaled) $N(z)$ distribution with marked peaks @ $z\sim1$ and $z\sim2.5$

Id-rate of SF galaxies monotonically decreases with $z$ (incomplete sample)
The Origin of FIR emission in radio-selected AGN: information from stellar mass $M_*$

- FIR-id AGN smaller masses than whole radio-selected AGN population
- Preferential mass scale $M_* \sim 10^{10} - 10^{11} M_\odot$ maximizes chances for FIR emission
- Only true for $z < 2$
The Origin of FIR emission in radio-selected AGN: information from radio luminosity $P_{1.4\,\text{GHz}}$

- As expected number of FIR emitters decreases with increasing radio luminosities
- Drop shifts to higher radio luminosities at higher $z$

Powerful radio sources are more likely to be FIR emitters at earlier epochs
The Origin of FIR emission in radio-selected AGN: information from $q_{100}$ and $q_{160}$ for AGN and SF of given $P$.

AGN behaviour ≠ SF behaviour

Trend for AGN SEDs to approach those of Arp220 and M82 at earlier epochs.
The Origin of FIR emission in radio-selected AGN: information from $q_{100}$ and $q_{160}$ for AGN and SF of given $P$.

SF follow Arp220 SED at all $z$ and $P$.
AGN FIR-to-radio approaches Arp220 at earlier epochs at all $P$.
Analysis performed at fixed $P$ → enhancement of FIR activity with $z$
The Origin of FIR emission in radio-selected AGN: information from FIR fluxes of AGN and SF of given P

Irrespective of radio activity and z FIR emission in radio-selected AGN indistinguishable from that produced by star-forming galaxies → FIR entirely due to star forming processes within AGN host
Complete catalogue (up to z=3.5) of 482 radio-selected AGN from COSMOS-VLA. 175 (i.e. 36%) with counterpart in the PEP survey either at 100 or at 160 mm. No redshift dependence of FIR ids.

Probability for FIR emission strong function of P and z. More powerful sources more likely FIR emitters at higher z. P_{1.4GHz} \sim 10^{23}-10^{24} \text{ W/Hz/sr} from \sim 10\% at z<1 to \sim 60\% at z=[2-3].

Above phenomenon due to enhancement of FIR activity with z in AGN of all P.

Typical mass M_*\sim[10^{10}-10^{11}] \text{ M}_\odot for FIR emission (up to 60\%, only for z<2). Why??

FIR emission in radio-selected AGN same origin of FIR emission in SF galaxies: SF activity within host galaxy.

Radio signal from radio-selected AGN especially at high z most likely due to superposition of AGN accretion and SF activity.