AGN in a sample of nearby LIRG pairs: exploring the influence of a companion

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Are AGN in interacting galaxies special?

Studying "twin" (similar size and mass) interacting galaxies could provide a clue on the role of interactions in AGN activation. We would expect to detect two AGN unless the active stage duration is so short that two nuclei are rarely active simultaneously, or unless they are often very obscured, as recently proposed.

Known facts:

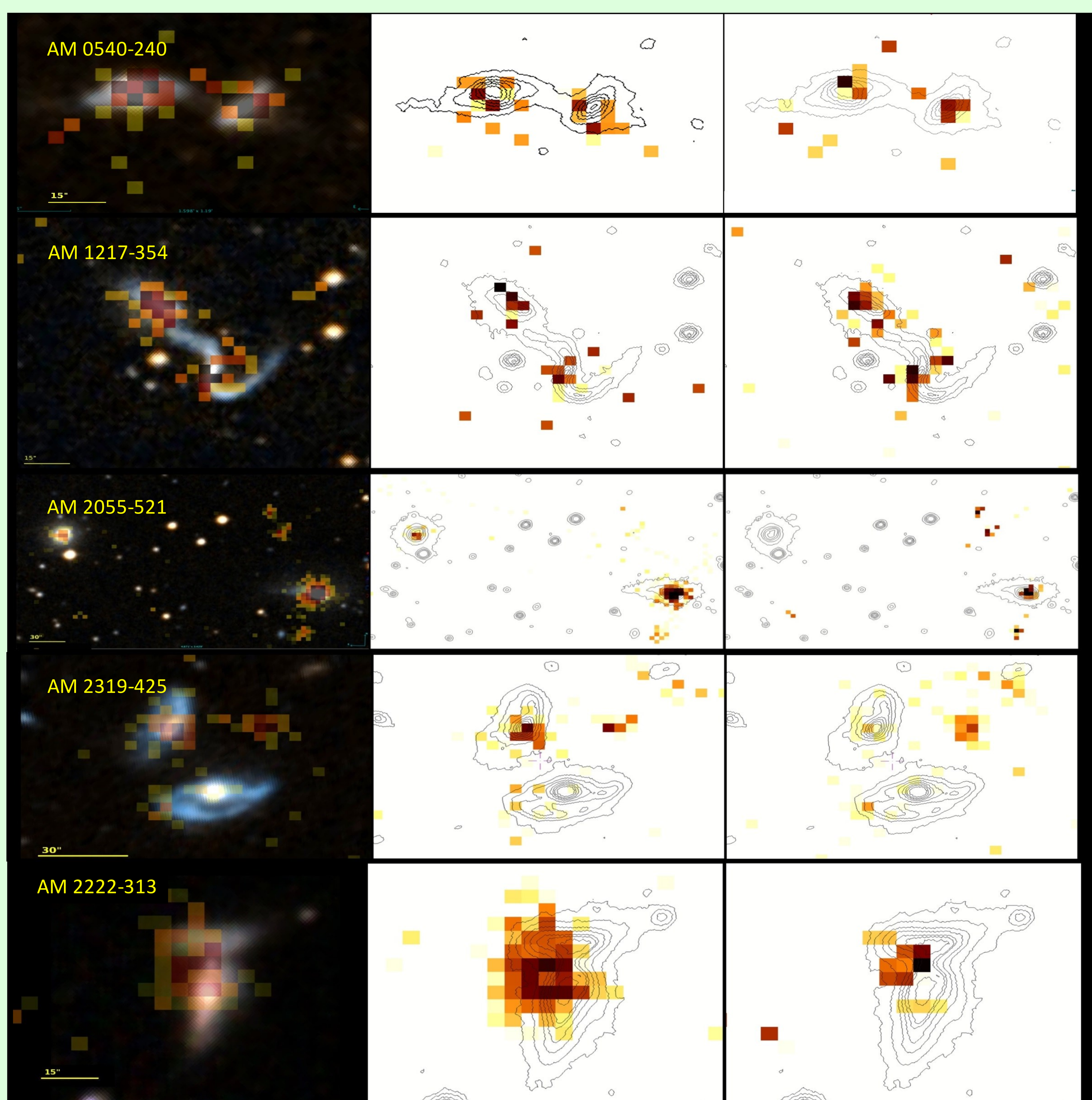
- ULIRGs are mergers - *known since IRAS Catalogue of BG in 1985.*
- Most low–z Radio Galaxies are mergers - *Heckman 86, Colina & de Juan 95, Ramos Almeida +12, Tadhunter +16.*
- Fraction of AGN in mergers increases with smaller separations – *Silverman +11, Satyapal +14, Ellison +15.*
- Radio-loud AGN are mergers - *Chiaberge +15.*
- AGN are 5 times more likely to be obscured if hosted by mergers -*WISE IR colours - Weston +16.*
- Close post mergers are the best (and obscured) candidates for dual AGN – *Blecha+18.*
- Obscuring material covers ~95% of the X-ray sources in later merger stages – *Ricci+17.*
- AGN activity suppression has recently been proposed for the West member of ESO 509-IG066 (AM 1331-231) – *Kosec+17*

Pairs of galaxies with two AGN have been discovered mainly serendipitously in X-rays (Komossa+03, Ballo+04, Guainazzi+05), or radio (Green+10). Few of them, searching in large X-ray samples (Koss+12, Teng+12, Comerford+15).

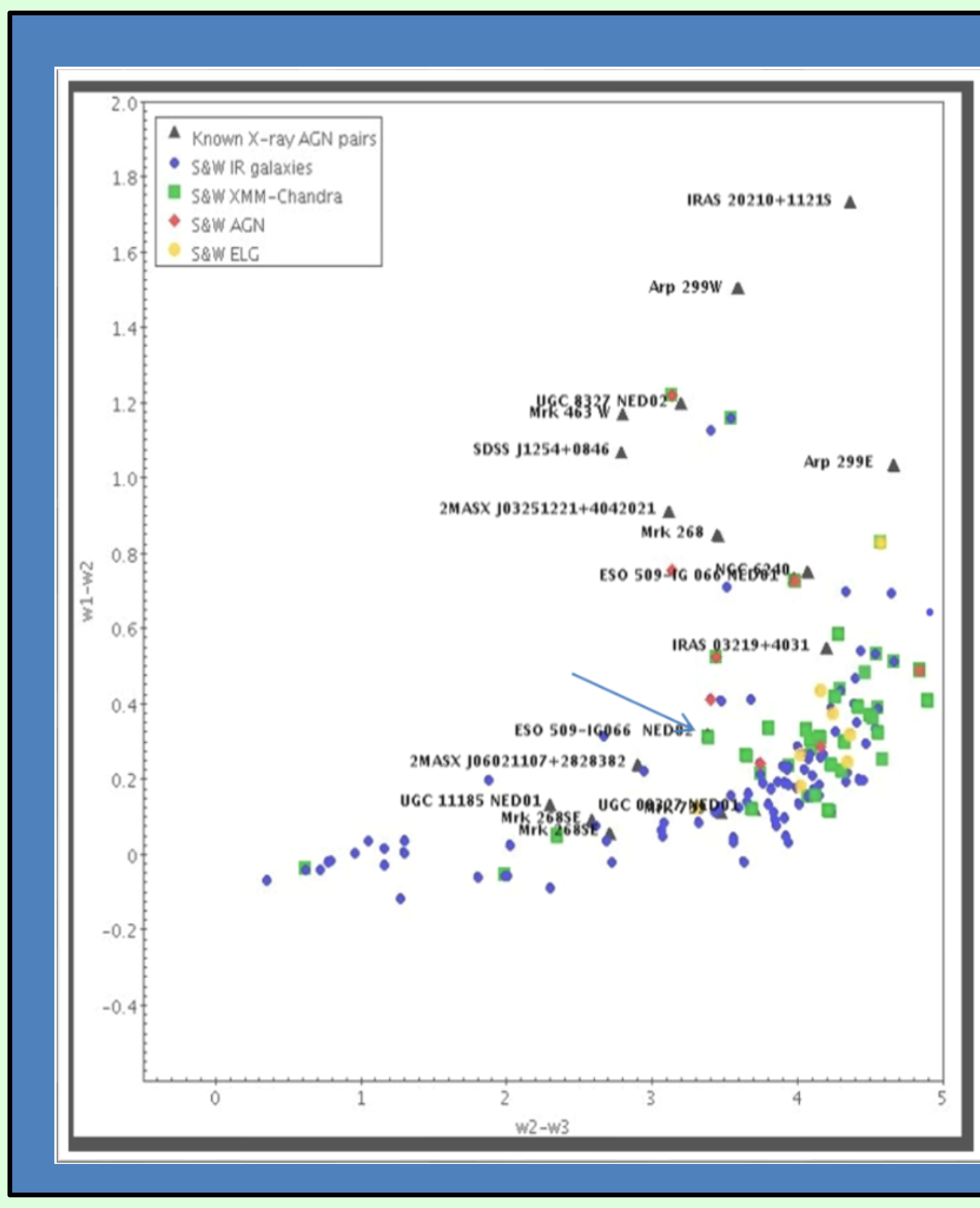
X-rays are probably the most efficient tool to detect hidden AGN (i.e. Koss+12): the closest dual AGN has been detected in X-rays at sub-pc scale (Severgnini+18). Radio interferometry is also a perfect tool for the detection of very close AGN (r_p ~89 pc in J0942+0623, Srianand+15, r_p ~7.3 pc in J0402+379, Bansal+17) although is not effective in finding new candidates.

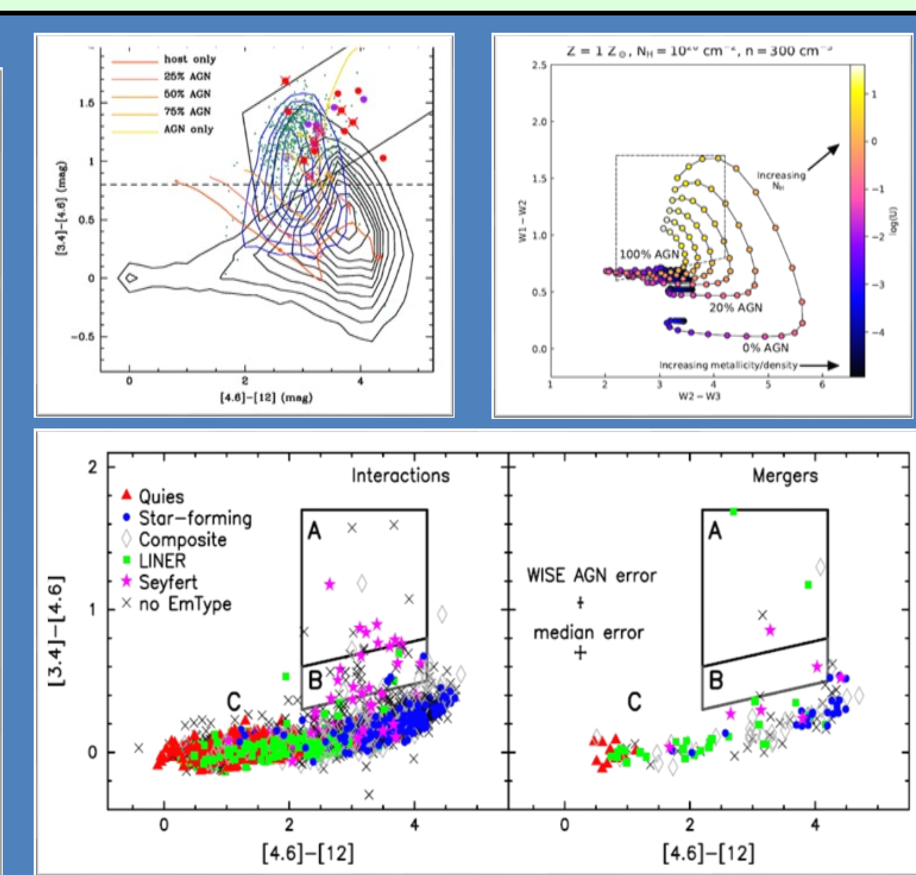
We are studying a sample of 70 nearby (z<0.05) IR bright Arp-Madore major mergers (Cat-2), for which Sekiguchi+92 (S&W) obtained optical/IR spectra. We have previously observed:

- 3 pairs with projected separations 10<r_p<100 kpc with XMM-Newton (Jiménez-Bailón+07). AGN were detected in 5 of the 6 galaxies, the most clear case of pairs of AGN being the most separated pair.
- 8 pairs of advanced mergers with similar separations (r_p ~ 10 kpc) with Chandra (Tomás+19, in prep.). An AGN was detected in at least one of the galaxies in 6 of the 8 pairs.
- We present here new XMM-Newton observations of 5 more pairs of this sample, which have been selected using their WISE IR colors as a diagnostic tool.
- Archival search for XMM-Newton and Chandra observations provided data of other 14 galaxies of the sample (see table below).

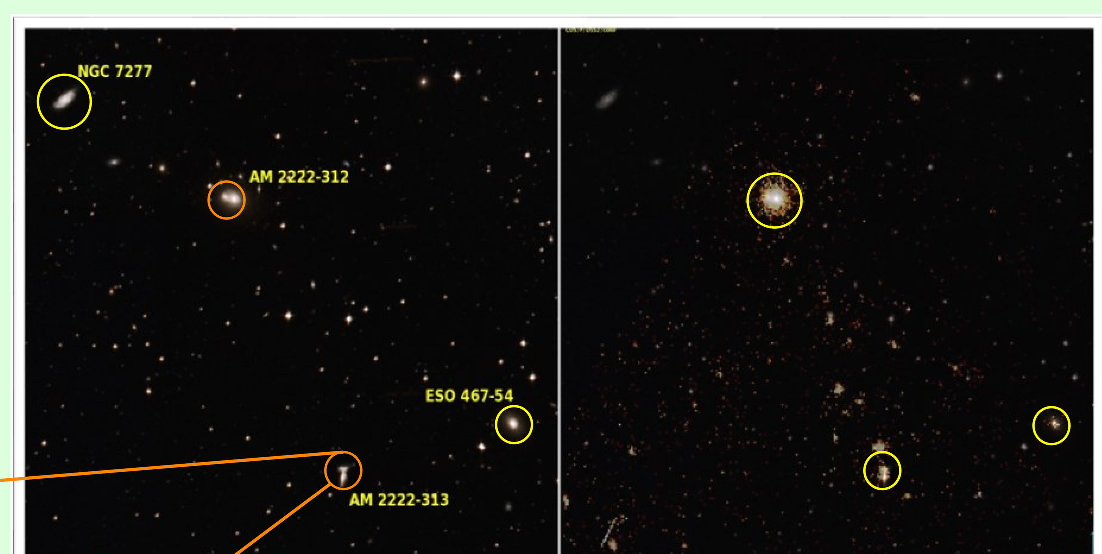


Images of the new 5 pairs of galaxies observed with XMM-Newton: *left*: X-ray emission in the 0.3 – 8.0 keV band, overlaid on DSS2 color images, *centre:* X-ray emission in the 0.3 – 1.2 keV band overlaid on optical DSS2 contours, *right:* X-ray emission in the 1.2 – 8.0 keV band overlaid on optical DSS2 contours (*"Aladin Sky Atlas", CDS, France, was used to produce these images).*

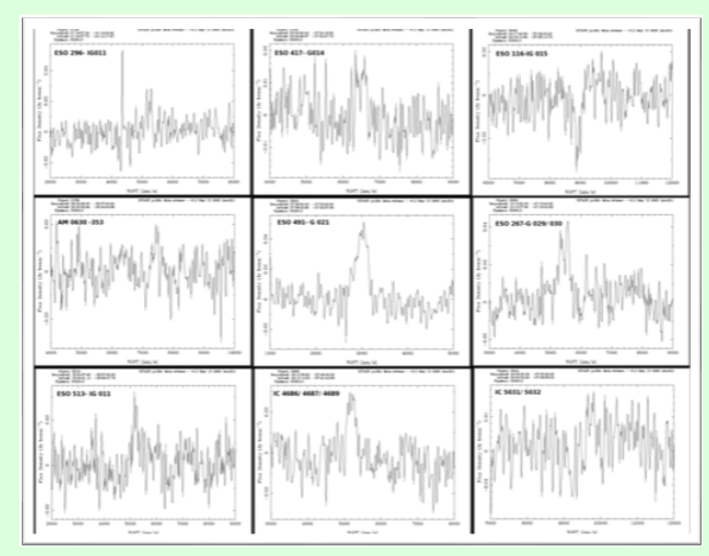




Left: WISE color-color plot for the galaxies of the S&W sample, classified by their activity type (colored symbols), and for the known pairs of AGN detected in X-rays (black triangles). *Top left*: WISE color-color plot of Rovilos+14 indicating X-ray detected AGN with different fractions of host and AGN. *Top right:* Similar results by Satyapal+18 from SED simulations. *Bottom: WISE* color-color plot for a sample of Interacting and merging galaxies; (A) and (B) indicate the region and extended region where AGN are expected to fall (Weston+17). Similar results were found by Blecha+17.



The merger AM 2222-313 happens to belong to the 2MASS galaxy group of the 4 galaxies shown in the DSS image (*left*); another member of the group (AM 2222-312) is also a pair of close interacting galaxies. NGC 7277 was not in the FOV of the XMM-Newton observation. *Right* panel: XMM-Newton data overlaid on DSS image), but the other members are bright X-ray sources in an exceptionally active group, similar to the case of SDSS J0959+1259 (de Rosa+15).



HI emission or absorption lines of some of the HI brightest pairs, from the HI Parkes All Sky Survey (HIPASS). The gas content and kinematics of these interacting galaxies can be related to the SF+AGN activity of the mergers (i.e. Gereb+15, Scudder+15, Ellison+15b). HI blueshifted absorption (fast AGN driven outflow) has been found in the ULIRG merger Mrk 231 (Morganti+16). HI absorption has also been detected in Seyferts (NGC 3079, IC 5063, NGC 1068), radio galaxies (e.g. 3C 293, 3C 305, 4C 12.50), and low luminosity AGN (NGC 1266, NGC 1433). On the other hand 21cm HI absorption and X-ray absorption are found to be correlated for obscured AGN (Moss+17).

Name	z	rp (kpc)	Fx	AllWISE	w1-w2	w2-w3	L12μ	Lxcalc	Lxobs	
AM 0117-412 NW_E HI	0.0176	8.50	7.19E-15	J011957.12-411405.7	0.152	4.073	1.35E+42	1.11E+42	4.71E+39	Chandra+
AM 0117-412 NW_W HI	0.0176	8.50	2.75E-14						1.80E+40	Chandra+
AM 0117-412 SE	0.0169	8.15	2.70E-15						1.63E+39	Chandra+
AM 0127-524 S	0.0544	9.15	2.88E-13	J012925.10-523417.8	0.436	4.297	1.46E+44	7.53E+43	7.18E+42	Chan+,XMM
AM 0240-600 SE HI	0.0394	8.78	4.01E-14	J024215.79-595353.6	0.112	4.230	3.11E+43	1.87E+43	1.32E+41	XMM
AM 0302-274 NE	0.0218	6.63	5.61E-15	J030456.19-273018.5	0.392	4.418	3.91E+42	2.90E+42	5.68E+39	Chandra+
AM 0302-274 SW	0.0213	6.48	3.47E-15	J030455.68-273027.9	0.156	4.126	1.56E+42	1.27E+42	3.29E+39	Chandra+
AM 0316-573 E HI	0.0283	15.00	1.83E-14	J031743.77-572647.6	0.332	4.058	3.80E+43	2.25E+43	3.10E+40	Chandra+
AM 0316-573 W HI	0.0283	15.00	5.97E-14						1.01E+41	Chandra+
AM 0337-711 N	0.0485	11.00	2.00E-14	J033755.00-710336.6	0.235	3.942	3.83E+43	2.26E+43	9.96E+40	Chandra+
AM 0337-711 S	0.0485	11.00	6.14E-15						3.06E+40	Chandra+
AM 0506-374 NE	0.0522	24.68	1.70E-14	J050828.14-373923.2	0.364	4.517	7.30E+43	4.04E+43	9.84E+40	XMM
AM 0540-240 NE	0.0285	17.30	1.65E-14	J054302.24-240350.7	0.827	4.574	2.76E+43	1.68E+43	2.98E+40	XMM+
AM 0540-240 SW	0.0283	17.20	1.20E-14	J054300.23-240356.0	0.388	4.553	1.49E+43	9.67E+42	2.14E+40	XMM+
AM 0545-453 N	0.0410	21.73	6.29E-15	J054714.12-452835.9	0.336	3.802	3.04E+43	1.84E+43	2.25E+40	Chandra+
AM 0545-453 S	0.0415	21.99	4.81E-14	J054714.50-452857.8	0.048	2.351	7.49E+42	5.20E+42	1.76E+41	Chandra+
AM 0630-353 SE HI	0.0270	6.99	2.02E-15	J063206.93-353741.1	0.213	3.748	1.03E+43	6.93E+42	3.09E+39	Chandra+
AM 0707-273 E	0.0099	9.09	4.45E-14	J070949.93-273429.6	0.222	4.307	4.16E+42	3.06E+42	8.96E+39	XMM+
AM 0707-273 W	0.0099	9.09	7.38E-14	J070946.85-273408.0	0.511	4.661	2.19E+43	1.37E+43	1.48E+40	XMM+
AM 0905-274 W	0.0358	100.32	3.17E-12	J090719.72-280058.2	0.312	4.157	2.76E+43	1.68E+43	8.65E+42	XMM Slew
AM 1204-314 N	0.0234	5.98	1.43E-14						1.79E40	Chandra
AM 1204-314 S	0.0228	5.83	8.59E-15	J120651.92-315659.2	0.483	4.465	5.17E43	2.96E43	1.00E40	Chandra
AM 1211-465 NE HI	0.0185	101.98	2.50E-12	J121412.83-471342.7	0.419	4.256	4.80E+43	2.77E+43	1.82E+42	XMM+
AM 1211-465 SW HI	0.0182	100.15	7.49E-14	J121352.27-471625.5	0.323	4.555	2.67E+43	1.63E+43	5.18E+40	XMM+
AM 1217-354 NE	0.0577	43.35	3.94E-14	J121958.96-355735.1	1.159	3.546	9.68E+43	5.21E+43	3.06E+41	XMM+
AM 1217-354 SW S2	0.0575	43.13	5.85E-14	J121957.43-355805.7	0.524	3.442	2.31E+43	1.43E+43	4.50E+41	XMM+
AM 1331-231 E S2	0.0332	11.71	9.23E-12	J133440.73-232645.4	0.311	3.386	7.76E+42	5.36E+42	2.17E+43	XMM+,Chan
AM 1331-231 W S2	0.0343	12.10	4.44E-12	J133439.62-232647.5	0.728	3.983	5.71E+43	3.24E+43	1.10E+43	XMM+,Chan
AM 1457-261 SE HI	0.0168	12.69	2.02E-13	J150029.24-262657.9	0.583	4.280	1.29E+42	1.06E+42	1.19E+41	XMM
AM 1457-261 SW HI	0.0171	12.89	4.82E-14	J150026.77-262710.8	0.262	3.649	8.95E+41	7.66E+41	2.99E+40	XMM
AM 1809-574 N	0.0165	9.31	6.42E-14	J181338.76-574356.8	0.408	4.894	1.86E+43	1.18E+43	3.66E+40	XMM
AM 1809-574 NE HI, S2	0.0173	29.57	1.94E-13	J181339.70-574330.9	0.489	4.837	8.11E+43	4.44E+43	1.24E+41	XMM
AM 1809-574 S HI	0.0165	19.72	5.24E-14	J181340.34-574453.8	0.369	4.500	2.31E+43	1.43E+43	2.98E+40	XMM
AM 2040-674 N HI	0.0325	31.40	1.15E-14	J204520.26-673221.0	0.238	4.231	1.09E+43	7.31E+42	2.59E+40	XMM+
AM 2040-674 S HI	0.0341	32.95	2.80E-14	J204522.10-673306.6	0.300	4.324	5.45E+43	3.11E+43	6.84E+40	XMM+
AM 2049-691 NE	0.0372	9.98	1.76E-14	J205411.10-690213.9	0.277	4.098	2.87E+43	1.74E+43	5.12E+40	Chan+.XMM
AM 2049-691 SW	0.0366	9.83	3.85E-15	J205410.04-690224.6	0.120	3.685	1.28E+43	8.40E+42	2.50E+40	Chan+
AM 2055-521 SW S2	0.0510	239.58	1.49E-13	J205912.85-520021.0	1.219	3.138	9.45E+43	5.10E+43	8.94E+41	XMM
AM 2055-521 NE	0.0488	228.58	1.67E-14	J205935.87-515917.4	-0.039	0.621	1.73E+42	1.39E+42	9.12E+40	XMM
AM 2056-425 NW	0.0295	25.34	7.28E-15	J205928.63-424615.1	0.115	4.212	1.12E+43	7.48E+42	1.34E+40	XMM+
AM 2056-425 SE	0.0299	25.64	2.57E-14	J205931.51-424642.3	0.306	4.087	2.71E+43	1.65E+43	4.89E+40	XMM+
AM 2319-425 NE S2	0.0348	24.01	6.37E-14	J232212.93-423515.0	0.532	4.540	2.07E+43	1.30E+43	1.57E+40	XMM+
AM 2319-425 SW S2	0.0349	24.11	5.73E-15	J232211.61-423543.9	-0.057	1.985	1.36E+42	1.12E+42	1.73E+41	XMM+

Parameters of the LIR major mergers observed with XMM-Newton and Chandra. S2: previously classified as Sy2; HI: has been detected in HI. "+": X rays observations by our team; Fx: X-ray flux (0.3-8.0 keV) of the nuclear sources. Highlighted are the new pairs observed with XMM-Newton. Matched WISE sources are also listed together with their colors. The 12 μm luminosity is used to estimate their possible AGN X-ray luminosity Lxcalc, using the relation determined by Gandhi+09 for AGN. For most of these pairs the observed X-ray luminosity is lower indicating that part of the 12 μm luminosity originates in a different region from the nuclear X-ray source, or that the nuclear X-ray emission is more absorbed than what we estimated.

We analyzed our observations of three sets of LIR major mergers of the S&W sample, one selected with different separations, other as post-mergers with close separations, and the 3rd one based on MIR (WISE) colors. Our aim was to characterize the physical conditions of interacting galaxies hosting AGN pairs detectable in X-rays. We have been quite successful in detecting AGN with the present facilities (XMM-Newton and Chandra) although not yet able to fully predict their detectability in X-rays. Dual AGN detectability is certainly dependent on the high obscuration level occurring in mergers, as well as on occasional suppression of the AGN activity, as recently observed by Kosec+17.

Some of our results are:

- The X-ray spectra of some of the galaxies of this sample show strong evidences of AGN activity, like the pair AM 1211-465 NE / SW. This is the less perturbed and one of the most separated pairs of our sample, confirming the results by Ellison+11 that pairs of AGN can be found at large separations even if they are more frequent at shorter separations. AGN in closer separation pairs could be more difficult to detect due to their higher obscuration. As Blecha+17 proposes close post mergers are the best candidates for dual AGN, but the most obscured.
- Individual AGN were detected in several pairs: AM 0127-524 S, AM 0545-453 S, AM 0905-274 W and AM 2222-313.
- For AM 1217-354 SW, AM 2055-521 SW and AM 2319-425 NE the X-ray nuclear emission is compatible with their previous classification as Sy2. The nuclear emission in the Sy2 AM 2318-425, instead, was not detected.
- The spectra and luminosity of pairs like AM 0707-273 E / W or AM 0316-573 E / W, would be compatible with a very heavy absorption as observed in other binary AGN serendipitously discovered in X-rays (Bianchi+10, Piconcelli+10 and Koss+11).
- The X-ray luminosity of the nuclei of these galaxies is in most cases lower than the one expected if their WISE 12μm luminosity was purely coming from a nuclear AGN, as it happens for very bright AGN (e.g. Gandhi+09). The emission could originate in a different region from the nuclear X-ray source, or the nuclear X-ray emission could be heavily absorbed.
- Besides the nuclear emission, some of these pairs show some bright extranuclear sources (e.g. AM 2319-425), or some extended emission (e.g. AM 2222-313), probably both consequence of the interactions.

REFERENCES: Ballo+04 ApJ. 600, 634; Bansal+17 ApJ. 84, 14; Bianchi+10 MNRAS 405, 553; Blecha+18 MNRAS 478,3056; Chiaberge+15 ApJ 806, 147; Colina & de Juan 95 ApJ. 448, 548; Comerford+15 ApJ 806, 219; de Rosa+15 MNRAS 453, 214; Ellison+11, MNRAS 418, 2043; Ellison+15 MNRAS 451L, 35; Ellison+15b MNRAS 448, 221; Gandhi+09, A&A 502, 457; Gereb+15, A&A 580, 43; Green+10, ApJ 710, 1578; Guainazzi+05, A&A 429, L9; Heckman+86 ApJ. 311,526; Jiménez-Bailón+07 A&A. 469, 881; Komossa+03 ApJ.L 582, 15; Kosec+17 ApJ. 850, 168; Koss+11 ApJ.L 735, 42; Koss+12 ApJL 746, L22; Morganti+16 A&A 593A, 30; Moss+17 MNRAS 471,2952; Piconcelli+10 ApJ.L. 722, 147; Ramos-Almeida+12 MNRAS 419, 687; Ricci+17 MNRAS 468, 1273; Rovilos+14 MNRAS 438, 494; Tadhunter +16 A&ARv 24,10; Satyapal+14 MNRAS 441, 1297; Satyapal+18 ApJ. 858, 38; Scudder +15 MNRAS 449, 3719; Sekiguchi+92 MNRAS 255, 581; Severgnini+18 MNRAS(in press); Silverman +11 ApJ. 743,2; Srianand+15 MNRAS 451,917; Teng +12 ApJ 753, 165, Weston +17 MNRAS 464, 3882.

(*) MAGNA (Multiple AGN Activity) is a collaboration lead by A. de Rosa, IAPS/INAF, Italy (http://www.issibern.ch/teams/agnactivity/Home.html)