DETECTING AND MEASURING AGN-GALACTIC MERGERS THROUGH SPIDERS

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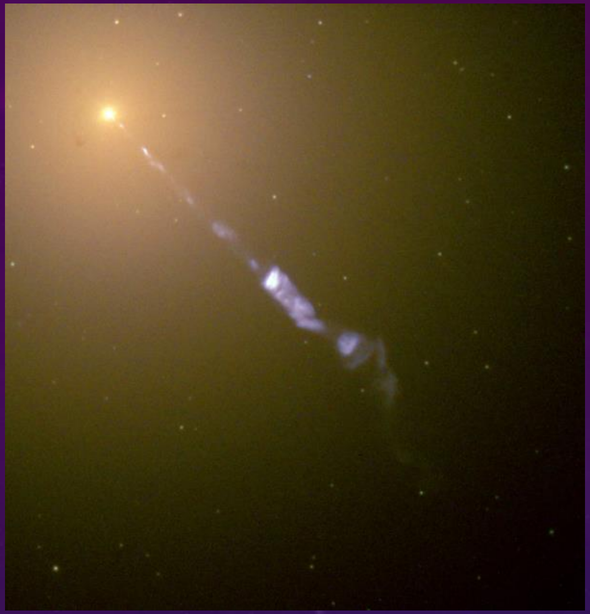
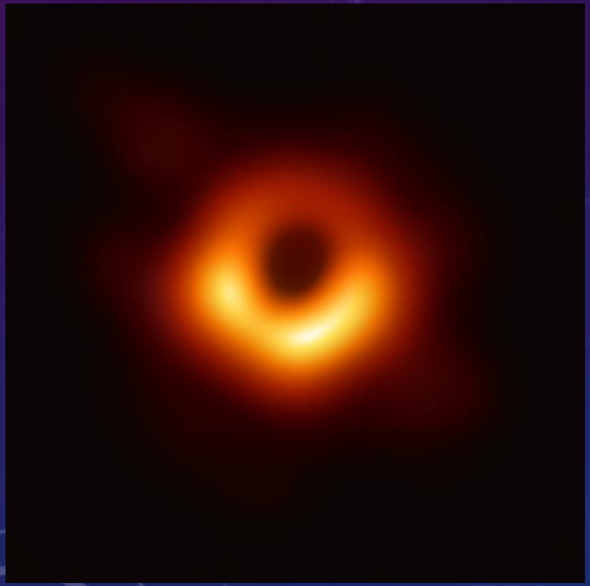
ASTR 650

NGC 7318 A & B (NASA/ESA/Hubble)

ACTIVE SUPERMASSIVE BLACK HOLE NUCLEUS



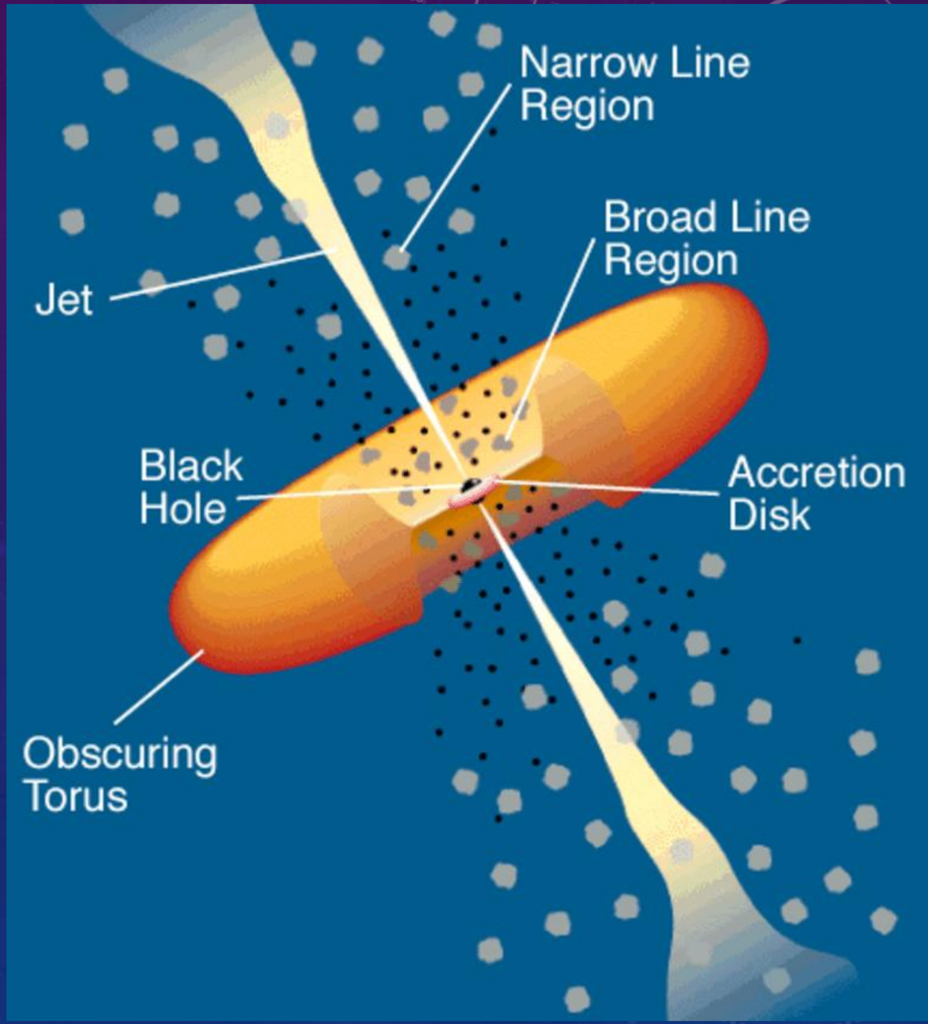


Active galaxy M87 with ejected jet (HST) and radio image of SMBH nuclei (ESO).

- Very high bolometric luminosities $\geq 10^{48}$ erg s^{-1}
- Strong X-Ray and gamma-ray emissions
  - $L_X \geq 3 \times 10^{42}$ erg s^{-1} in rest frame band 2-10 keV (Cimattia 2020)
- Infalling matter to feed accretion disk

$$L = \frac{dE}{dt} \approx \frac{dM_{acc}}{dt} \epsilon_{rad} c^2$$

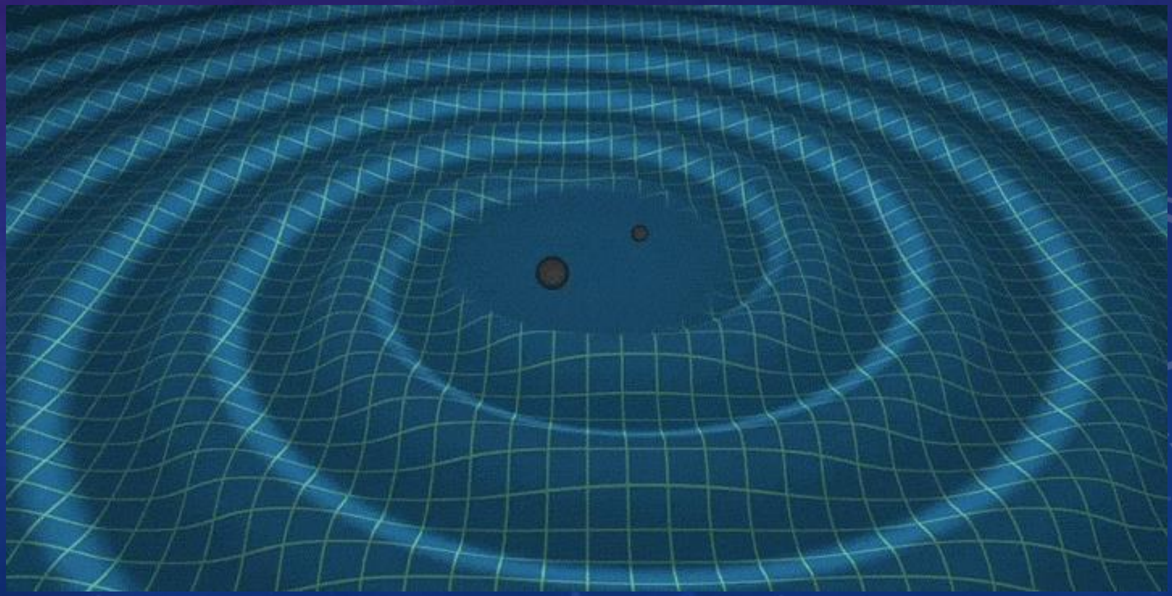
- Co-evolution links supermassive black holes (SMBH)/active galactic nuclei (AGN) to galaxies (Richards et al. 2006)



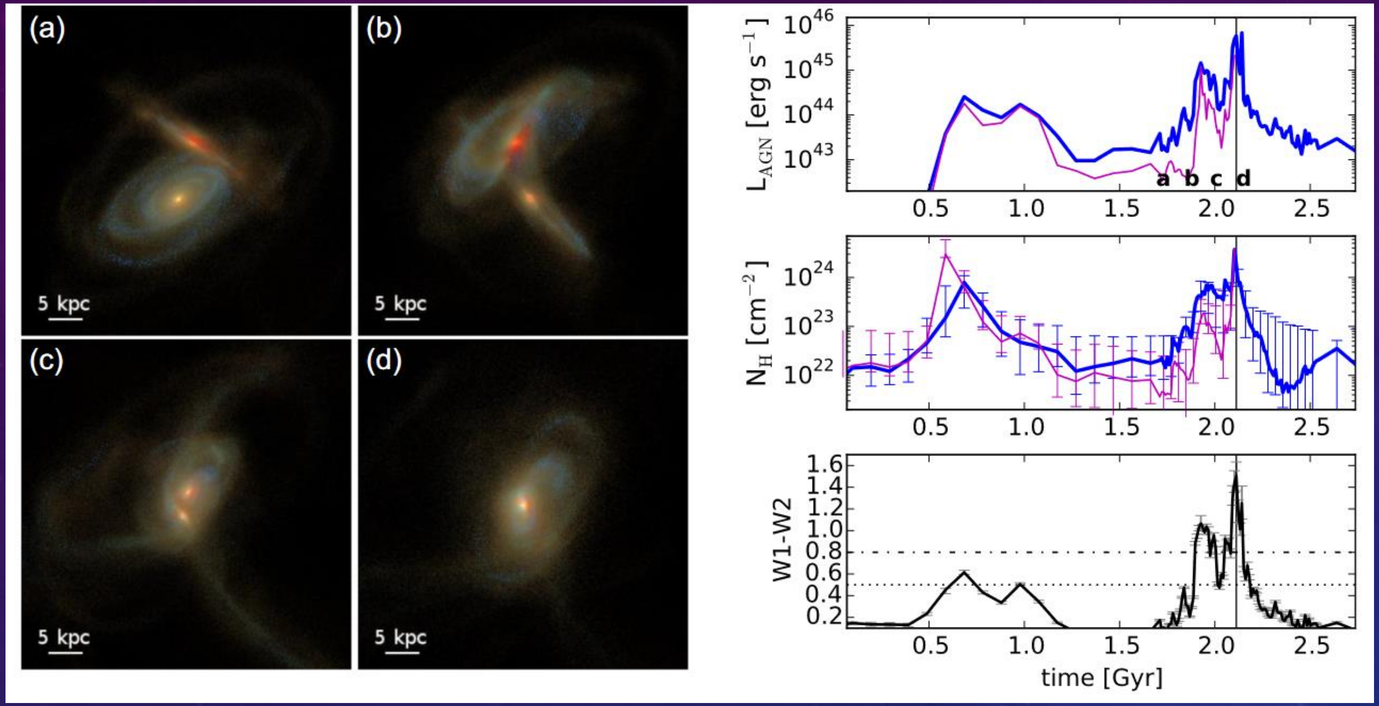
A picture of the most accepted active galactic nuclei model. (C.M. Urry & P. Padovani)

GALAXY MERGERS = AGN?

- What processes brings gas inwards and lose angular momentum to accrete in the disk to fuel nuclear activity?
- Leading theory is galaxy mergers trigger AGN activity
- Most luminous IR galaxies thought be AGNs (Sanders & Mirabel 1996)
- Friction slows gas and gravity pulls it inward along with SMBHs
- Connecting the growth of SMBHs and their host galaxies (Hopkins et al. 2006)



LIKELIHOOD OF AGN-MERGER TRIGGER

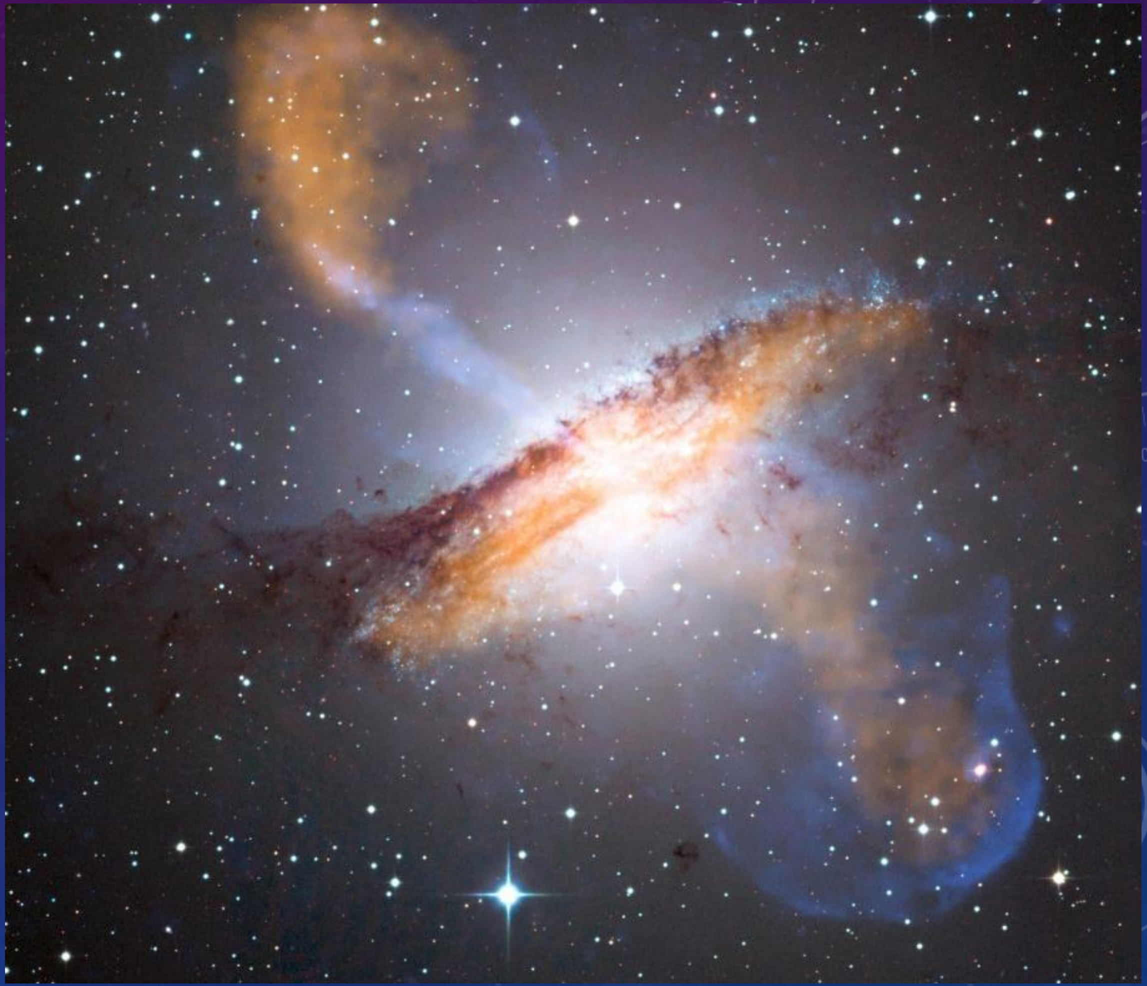


Evolution of an obscured AGN in (left) high-resolution simulation of SDSS ugz images of galaxy merger. (Right) Graphs show the evolution of the bolometric AGN luminosity L_{AGN} , line-of-sight gas column density N_H , and WISE W1 − W2 color throughout the merger. (Blecha et al. (2018))

- Ongoing debate if mergers bring gas inward and ignite nuclear activity (Gao et al. 2020)
  - AGN fraction increase while galaxy pair seperation decreases. (Ellison et al.2011)
  - Conflicting results on difference of merger fraction in active and non-active galaxies (Grogin et al. 2005)
- Not guaranteed, BHs could stall and not merge in Hubble time (Foord et al. 2021)
- Not ENOUGH observational data during all stages

AGN-MERGER PROJECT

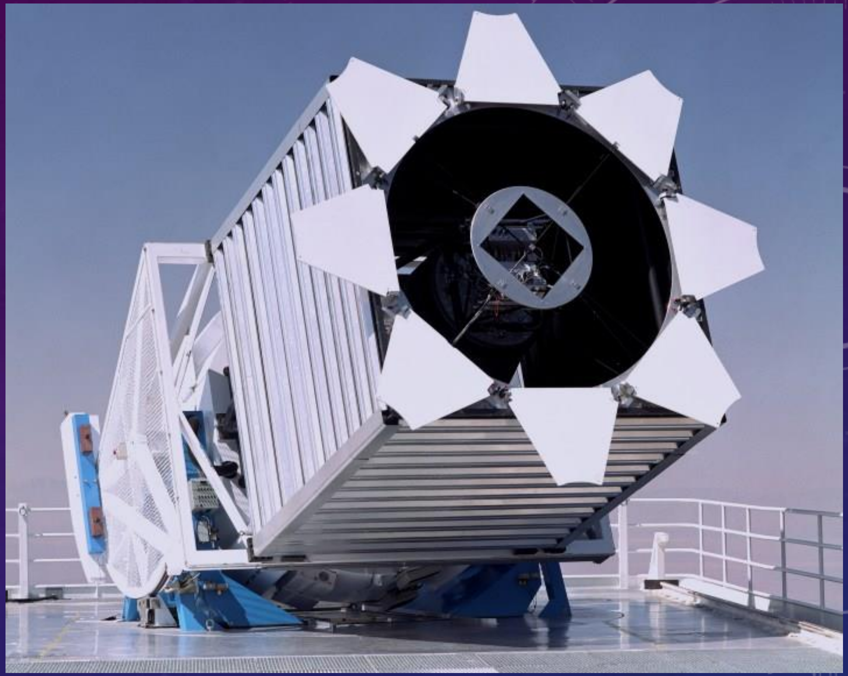
- Use SPIDERS data to investigate the likelihood of AGNs from galaxy mergers throughout stages
- *Purpose*: How *likely* galaxy mergers *cause* black holes (BH) to become activate or remain dormant?
  - Variety of mergers
  - Reach luminosity threshold $L_X \geq 3 \times 10^{42}$ erg s^{-1}
  - Using data from SPIDERS survey to analyze W1-W2 color.
- Determine galaxy-BH hole co-evolution



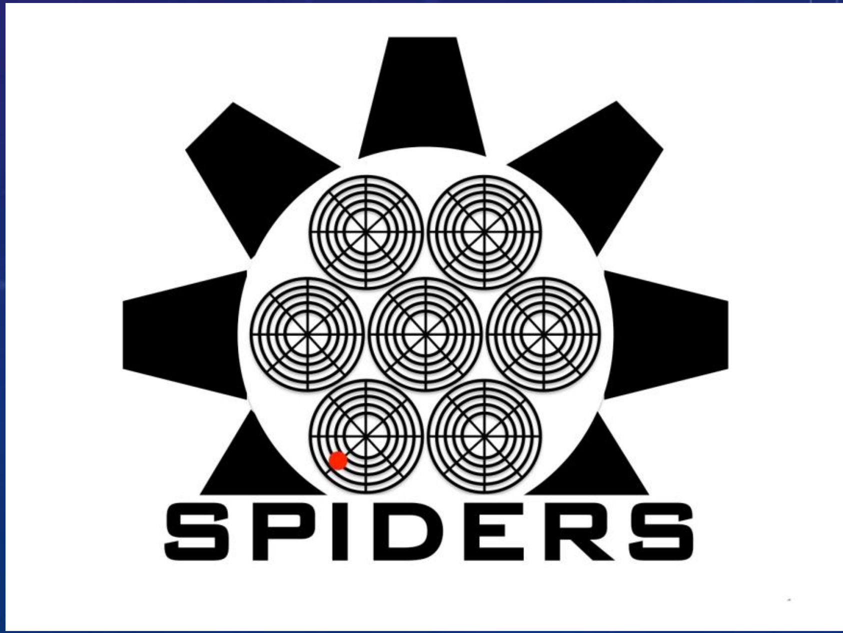
Centaurus A [ESO/A.Weiss/NASACXC/R.Kraft]

SPIDERS/SDSS-IV

- SPectroscopic IDentification of ERosita Sources (SPIDERS) survey
- Sloan Digital Sky Survey (SDSS)-IV program on optical spectroscopy of X-rays from extragalactic sources (Comparat et al. 2020)
  - In-tangent with eBOSS survey
- A total of 10,970 (98.9%) of the observed objects are classified
  - 10,070 objects are active galactic nuclei (AGN)
    - Using Type 2 AGNs

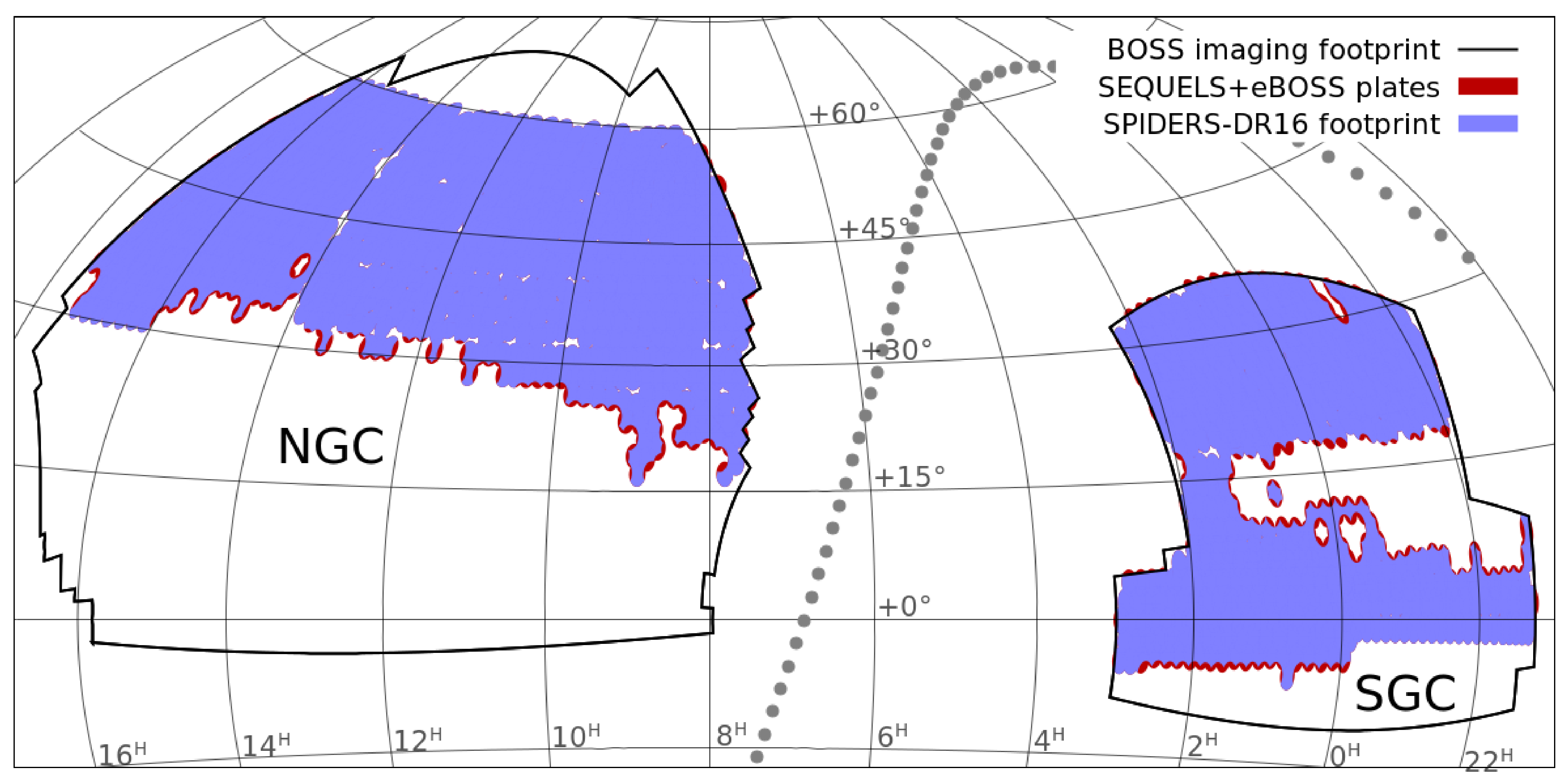


Sloan Foundation 2.5m Telescope (SDSS)



2RXS & XMMSL2

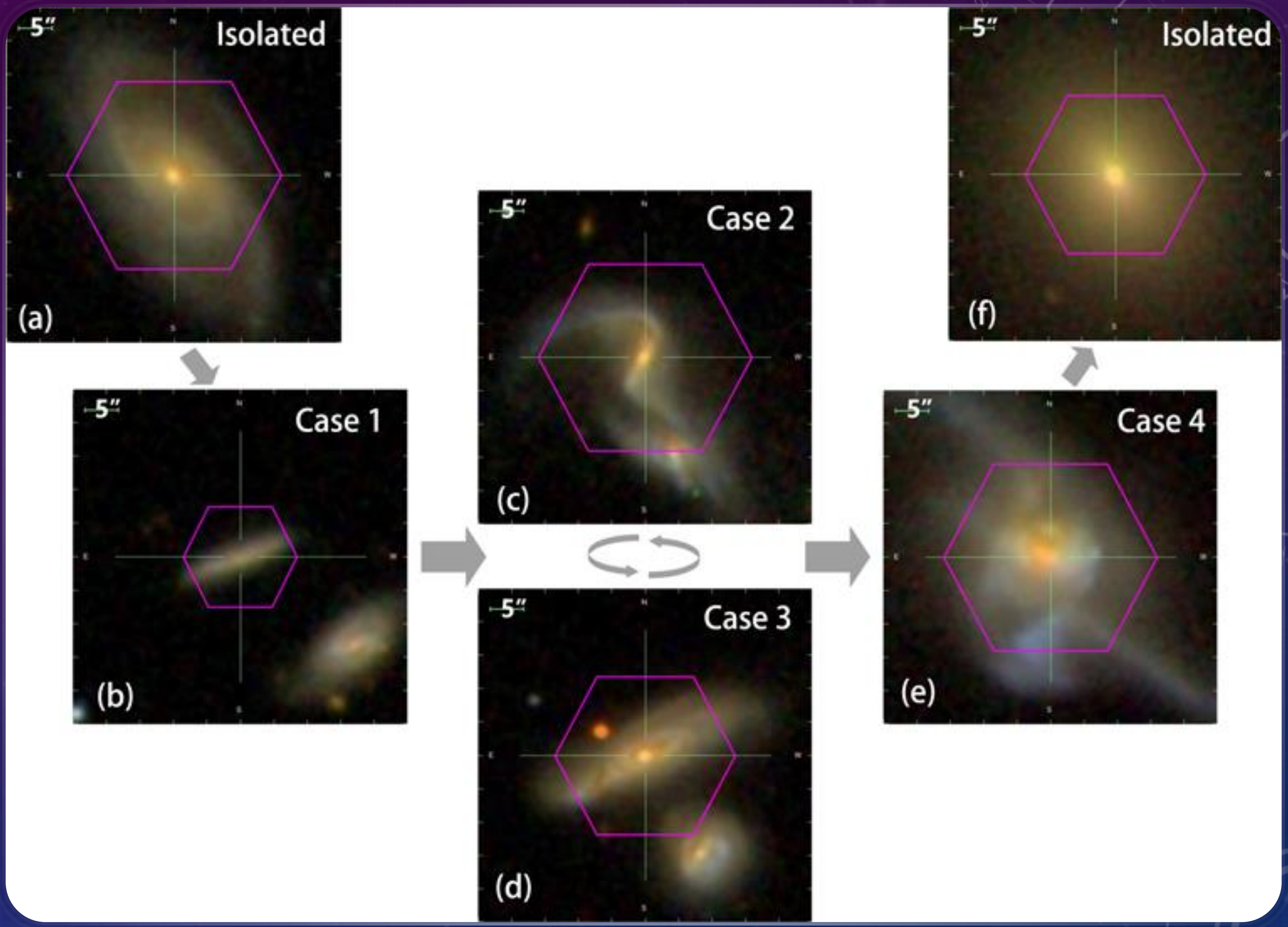
- Two X-Ray surveys combined with SDSS DR16 and SEQUELS survey



llustration of the SPIDERS-DR16 footprint (5129 deg²) shown with an Equatorial Hammer- Aitoff projection. Along with BOSS imaging footprint (10 800 deg²), SEQUELS+eBOSS plates (5347 deg²), and the Galactic Plane (grey dotted line).

INITIAL ANALYSIS

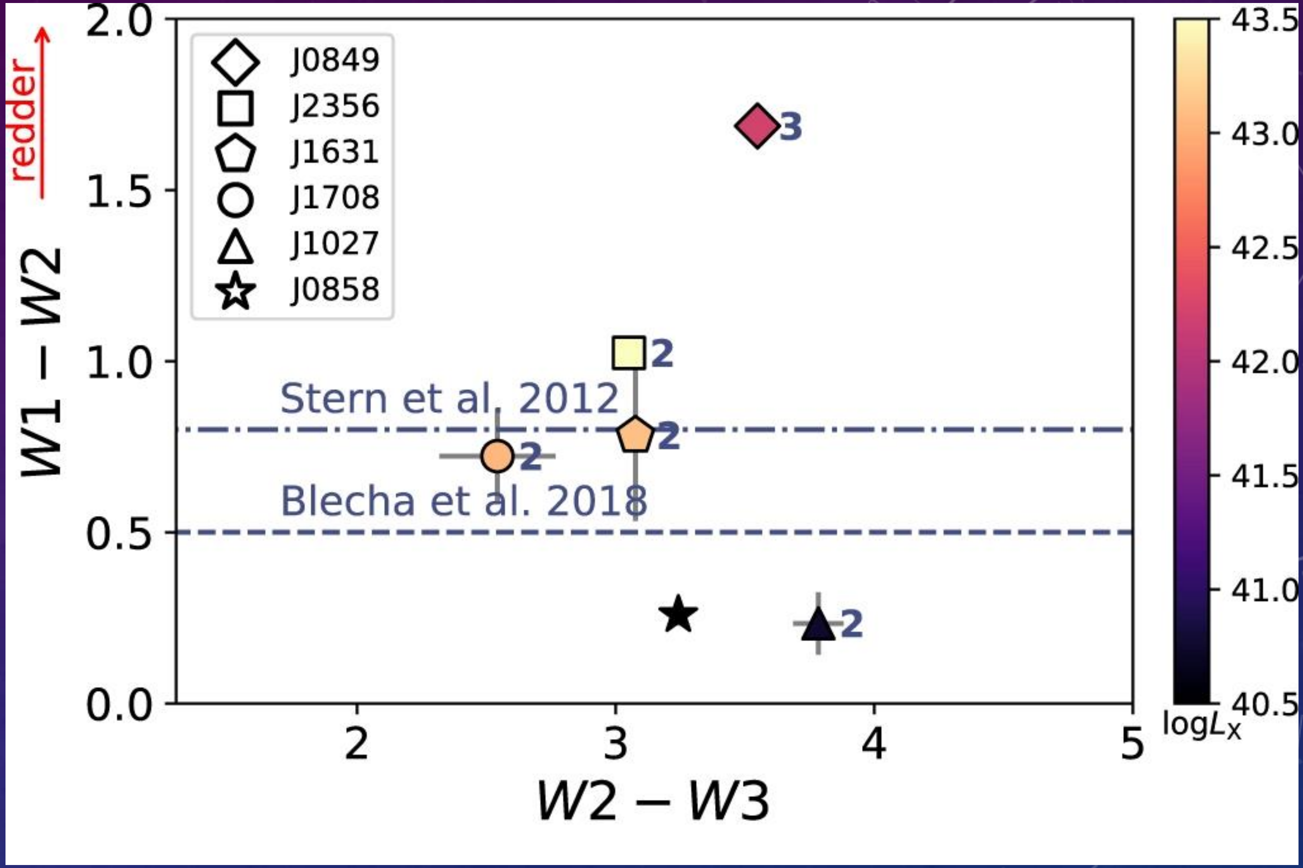
- Use Galaxy Zoo selecting mergers based on Jen et al. (2021) method
  - Overlap and show a strong morphological distortion
  - Post-merger
- Obtain selected mergers are in SPIDERS data
- Baldwin, Phillips & Terlevich (BPT) diagram S/N ≥ 5 for AGN
  - Nuclear Hα equivalent width (EW) ≥ 3 Å
- BUT.....



- Jen et al. (2021) provides an illustration of the SDSS *gri*-composite color images for the four merging cases (b), (c), (d), (e) and isolated galaxies (a), (f).
- The MaNGA Plate-IFU numbers are (a): 9500–12702; (b): 8485–3704; (c): 8241–12705; (d): 8082–9102; (e): 9507–12704; (f): 8984–9101, respectively.

REVISED ANALYSIS

- Filter SPIDERS for Type 2 (narrow emission lines) AGN candidates
  - 'CLASS_BEST' == NLAGN, GALAXY
  - Z ≤ 2
- Cross-reference on SDSS DR16 image catalog
- Create ALLWISE Color-Diagram (W1-W2 vs W2-W3)
- Calculate and check X-Ray luminosity
  - Use Luminosity Distance equation

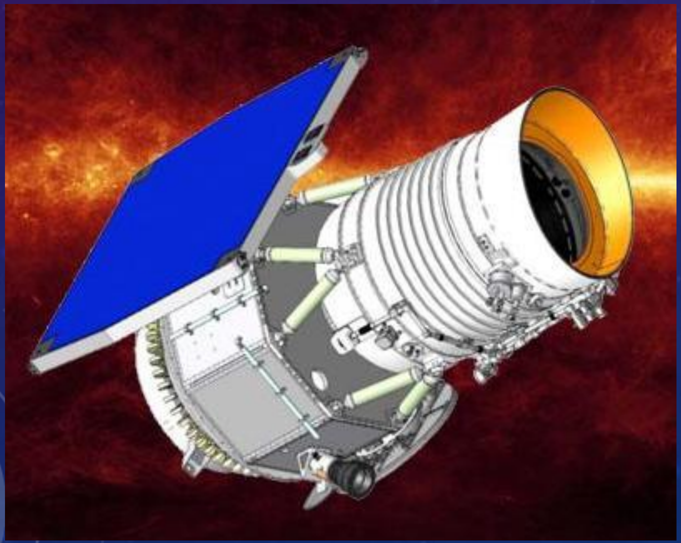


Mid-IR WISE Color Diagram of galaxy mergers with potential AGNs with luminosity in log L_x. (Foord et. al. (2021))

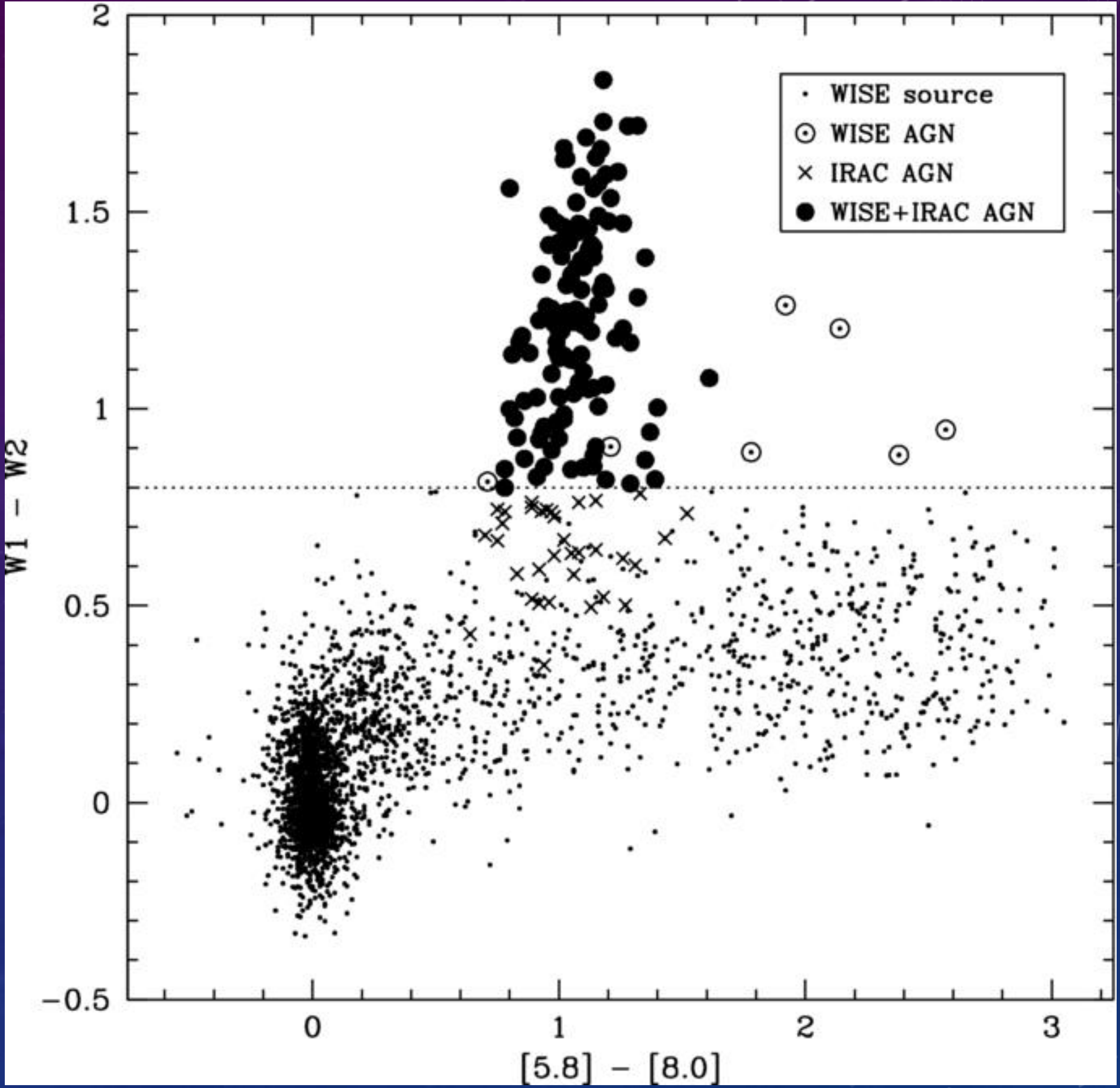
$$F_x = \frac{L_x}{4\pi {d_{L_x}}^2}$$

ALLWISE MAGNITUDES

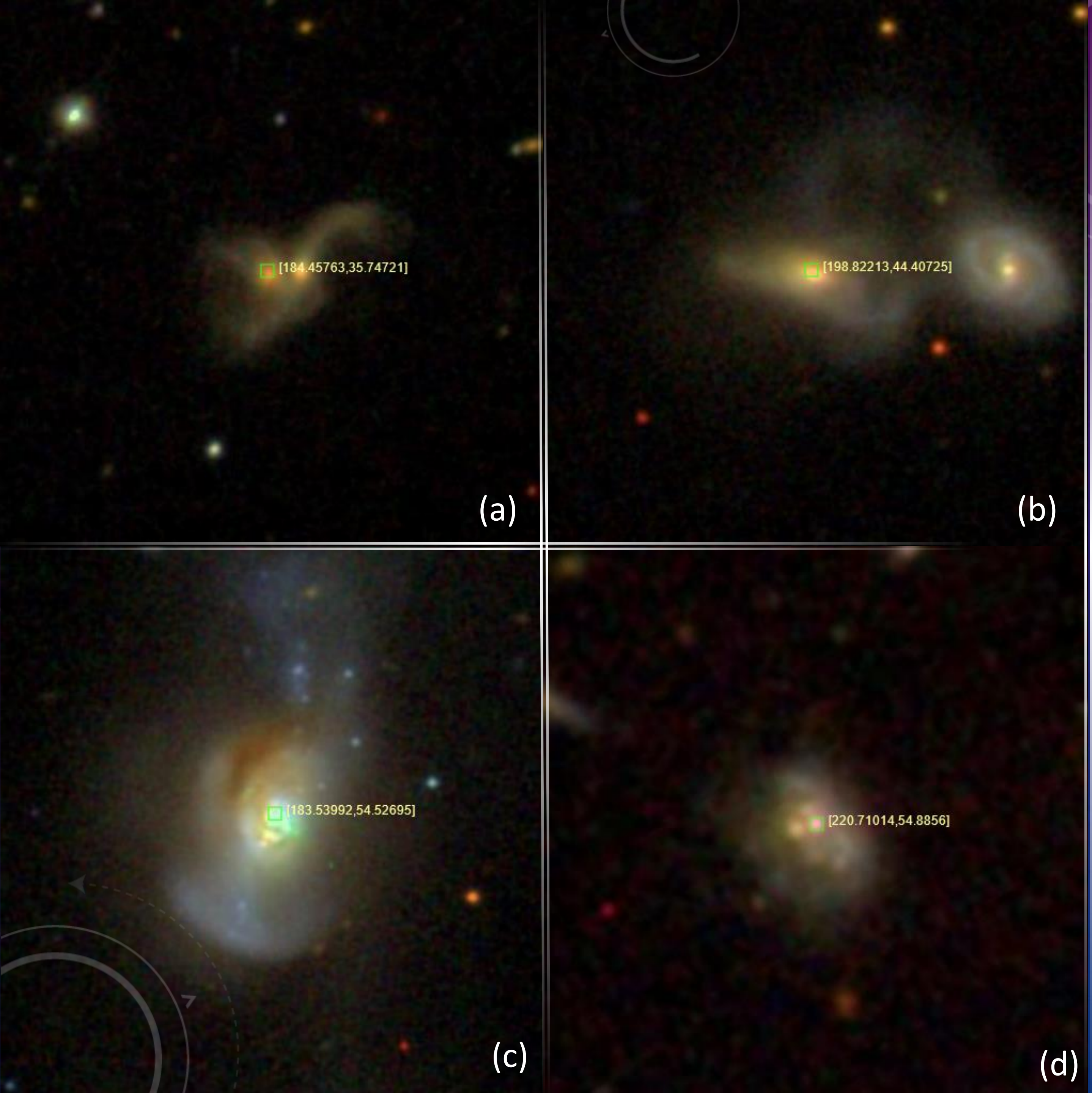
- Part of the Wide-field Infrared Survey Explorer mission (WISE)
- Bands in Vega Magnitude for Mid-Infrared
  - W1, W2, W3 = 3.4, 4.6, 12 μm (Wright et al. 2010)
- Strong correlation between AGN luminosity and mid-IR colors and between AGN luminosity and merger stage (Blecha et. al. 2018)



NASA/JPL



Mid-infrared color–color diagram of *WISE*-selected sources in the COSMOS field, with *WISE W*1 − *W*2 plotted against IRAC [5.8]–[8.0]. *W*1 − *W*2 ⩾ 0.8 indicate AGNs. (Stern et al. (2005))



MERGERS IN XMMSL2

Images provided from SDSS DR16:

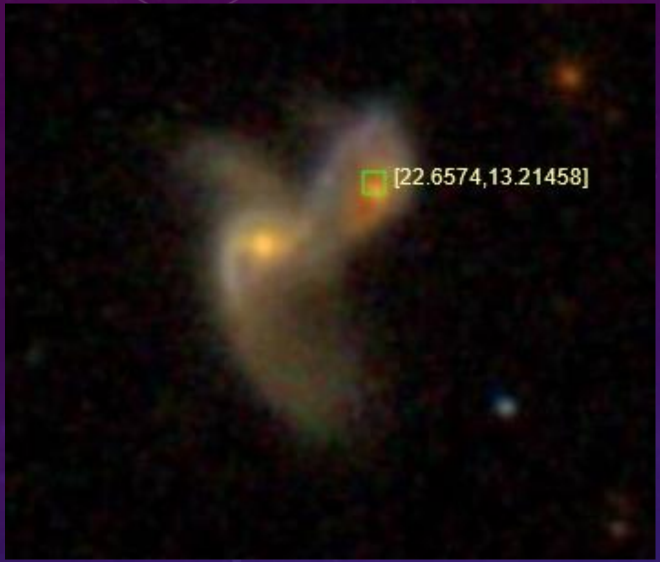
(a) J121749.78+354449.6
(b) J131517.26+442425.5 (Mrk 248)
(c) J121409.61+543135.9 (NGC 4194)
(d) J144250.46+545308.6

XMMSL2 RESULTS

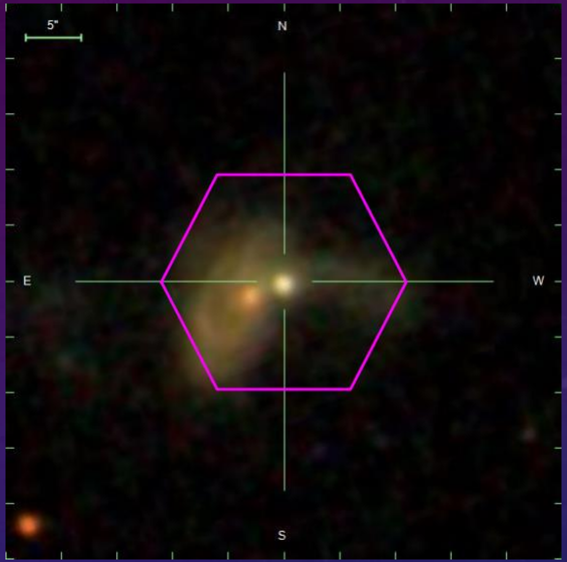
IAU NAME (SDSS)	SDSS RA (deg)	SDSS DEC (deg)	SDSS DR16 pipeline Redshift	X-Ray Counts	X-Ray Flux (10^{-12} erg cm^{-2} s^{-1})	Lumonisty (L_x) (10^{42} erg s^{-1})	ALLWISE W1-W2 (mag)	ALLWISE W2-W3 (mag)
J144250.46+545308.6	220.71026376	54.88572754	0.12485466	nan	nan	nan	0.6590004	3.6289997
J121409.61+543135.9	183.54006271	54.52664625	0.00817774	nan	nan	nan	0.62800026	4.464
J121749.78+354449.6	184.45745824	35.7471253	0.0877616	4.042545	4.9185505	99.967209	0.45800018	2.854
J131517.26+442425.5	198.82193888	44.40710888	0.03552209	4.044248	8.771892	27.145053	1.1919994	3.1990004

MERGERS IN 2RXS

J091839.32+453020.3
(Mrk 18)

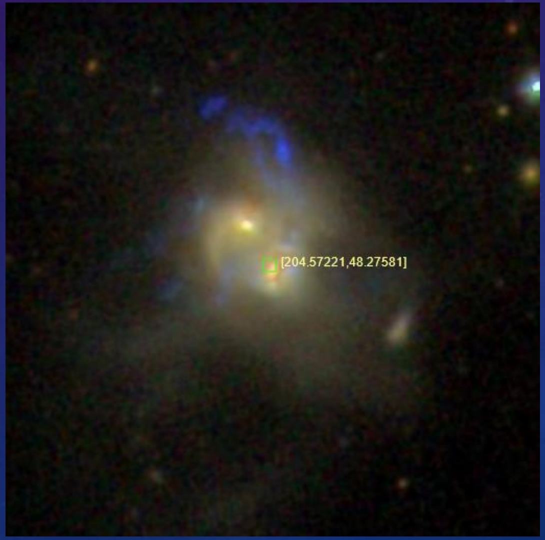


J013037.75+131251.9



J140737.43+442855.1
(image from MaNGA)

J140644.42+471602.0



J133817.27+481632.2
(NGC 5256 B)

J103650.43+445012.1
(LEDA 2253143)

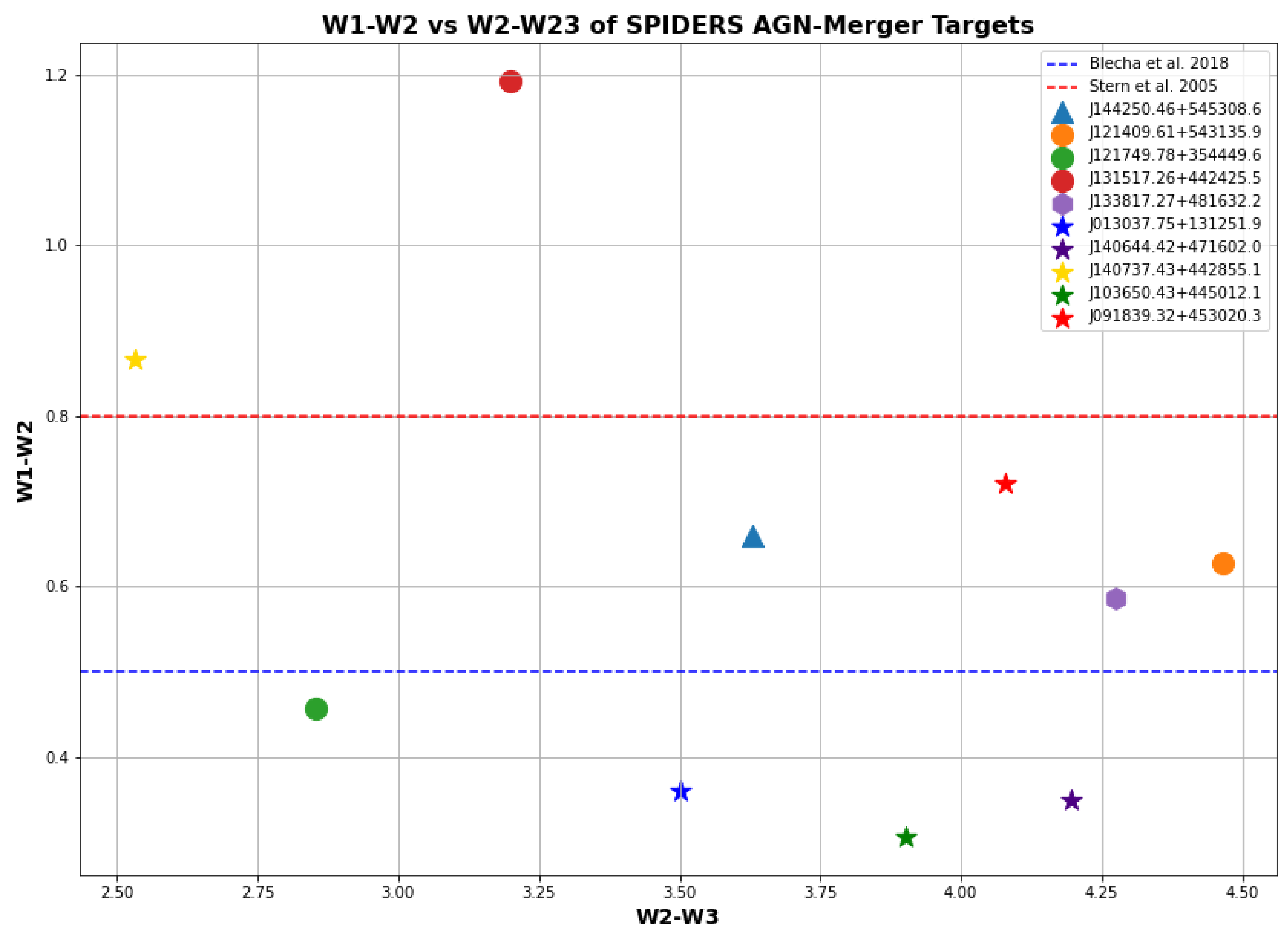
Images provided from SDSS DR16 expect J140737

2RXS RESULTS

IAU NAME (SDSS)	SDSS RA (deg)	SDSS DEC (deg)	SDSS DR16 pipeline Redshift	X-Ray Counts	X-Ray Flux (10^{-13} erg cm^{-2} s^{-1})	Lumonisty (L_x) (10^{42} erg s^{-1})	ALLWISE W1-W2 (mag)	ALLWISE W2-W3 (mag)
J133817.27+481632.2	204.57199881	48.27561271	0.02758319	29.23	6.739484	1.242985	0.5869999	4.275
J013037.75+131251.9	22.6573185	13.21444407	0.07217443	10.9	6.508882	8.7587819	0.36100006	3.5010004
J140644.42+471602.0	211.68509651	47.26722455	0.05986154	14.75	2.6793119	2.4380437	0.34999943	4.196
J140737.43+442855.1	211.90599026	44.48199539	0.14301738	11.11	1.245776	7.2240405	0.8660002	2.5309992
J103650.43+445012.1	159.21016279	44.83670613	0.12627506	12.15	2.901062	12.840203	0.30599976	3.9020004
J091839.32+453020.3	139.66385278	45.50565741	0.19478297	12.44	4.0988027	46.924252	0.7209997	4.078

Note: 2RXS X-ray rest-frame band at 0.1-2.4 keV.

COLOR DIAGRAM



Parameter Shapes:

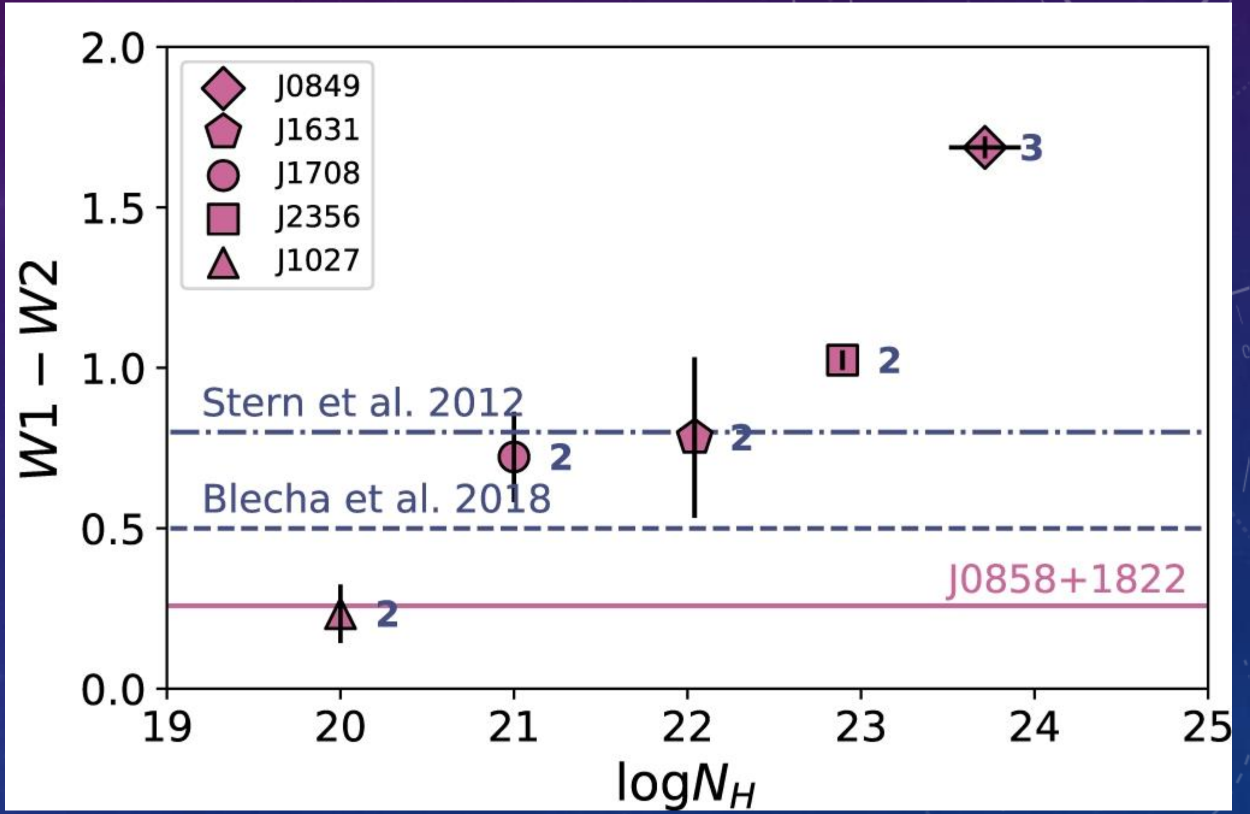
- Triangle - XMMSL2 – 'NLAGN'
- Circle – XMMSL2 – 'GALAXY'
- Hexagon – 2RXS – 'NLAGN'
- Star – 2RXS – 'GALAXY'

DISCUSSION

- 10 X-Ray source mergers identified
  - 6 above W1-W2 > 0.5
  - 4 below W1-W2 < 0.5
- SPIDERS only provides basic data
  - Missing X-Ray in 2-10 keV
  - No extragalactic column density of hydrogen, NH
- Primary nuclei observed, secondary missing
  - Unsure of dual or pair AGNs
- Need Bayesian framework software

MULTIWAVELENGTH AND N_H FUTURE RESEARCH

- Larger sample of galaxy mergers (chose target first)
  - MaNGA Luminous AGNs
- Obtain N_H data to measure the amount of dust in galactic nucleus
  - N_H as a function increases with W1-W2 (Foord et al. (2021))
  - Insight on follow of gas into SMBH accretion disk
- X-Ray, MIR, Optical and Radio observations
- Primary and secondary AGN source
- BPT Diagram



Levels of dust (N_H) vs W1-W2 from X-ray spectral fits of Chandra observations and WISE coverage for triple galaxy mergers. (Foord et. al. (2021))

CO-EVOLUTION OF BLACK HOLES AND GALAXIES

- AGNs are part of galaxy merger process
- Mergers shape nuclear SMBH including mass (Foord et al. 2021)
- Gao et al. (2021) determined AGNs more likely found in mergers than non-mergers
  - AGN excess up to 1.81 ± 0.16
  - MIR and optically selected AGNs at 16.40 ± 0.5% and 39.23 ± 2.10%
  - AGNs increases as stellar mass increases
- Further observations of multiple-AGN systems
  - James Webb Space Telescope

SDSS J0849+1114 [SDSS & NASA/STScI]

QUESTIONS

Image by Hubble's Wide Field Camera 3 shows the merging galaxy NGC 6240 with active black hole. The black holes' speedy growth occurs during the last 10 million to 20 million years of the merger. (NASA, ESA, and M. Koss)

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