A RING IS NOT ENOUGH TESTING THE ORIGIN OF EXTREME ULX POPULATIONS IN RING GALAXIES

ANNA WOLTER (INAF-OSSERVATORIO ASTRONOMICO DI BRERA)

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[ITALY, USA, CHECK REPUBLIC]

INAF
ISTITUTO NAZIONALE DI ASTROFISICA

OSSERVATORIO ASTRONOMICO DI BRERA


Crediti: G. Pareschi


Crediti: T.M. Belloni

The many tones of accretion - Anna Wolter

Cefalù 10 Sep 2026


Shaun the Sheep

RING GALAXIES – WHY?

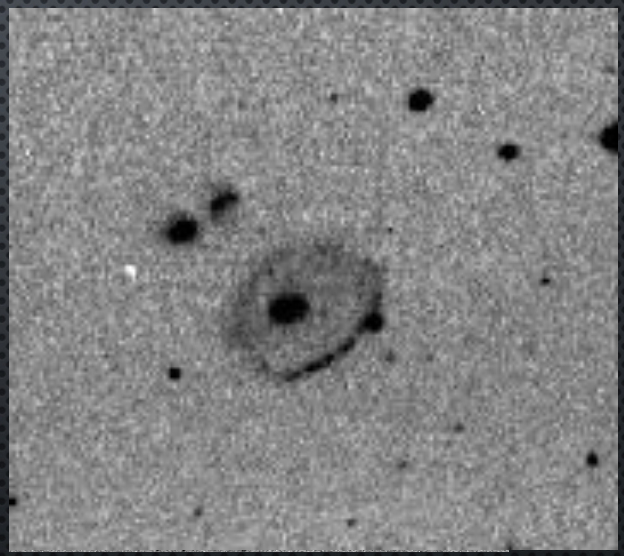
Violent encounter between a "bullet" galaxy and a target spiral (e.g. Theys & Spiegel 1979, Athanassoula+ 1997, Renaud+ 2018).

- Galaxy evolution studies: peculiar morphology that allows for an easier separation of the various galactic components – timing of unique wave of SF
- Fresh "unpolluted" gas to make massive stars
- Total area of ring is small: less interlopers
- Very few (0.02-0.2% of all spirals)
- Beautiful!

THE EPITOME – THE CARTWHEEL GALAXY

- Discovered by Zwicky (1941)
- One of the most prominent objects on Palomar Plates
- Member of a compact group (SCG 0035-3357; Iovino 2002)

First X-ray observation to look for extended plasma emission from group (Wolter, Trinchieri, Iovino 1999)



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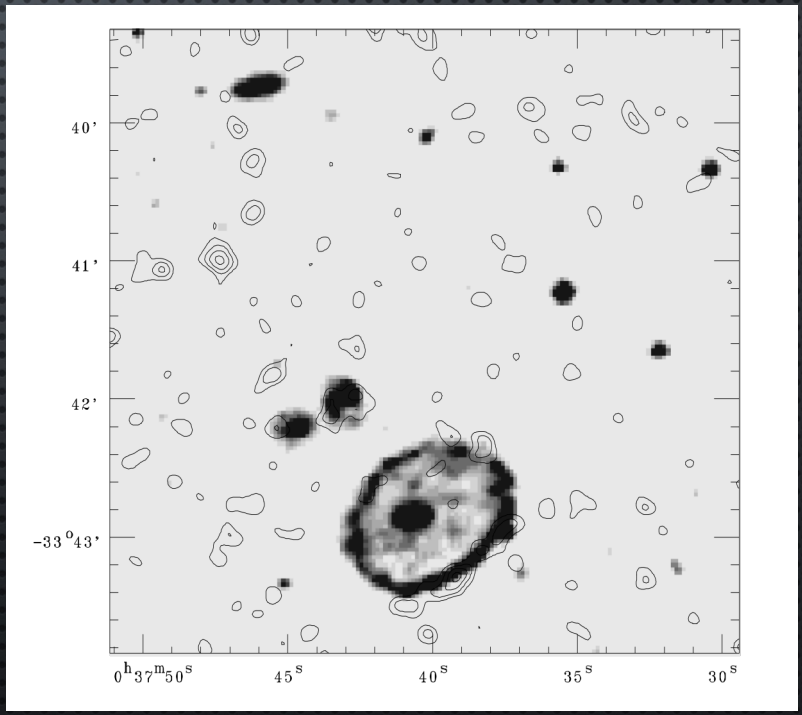

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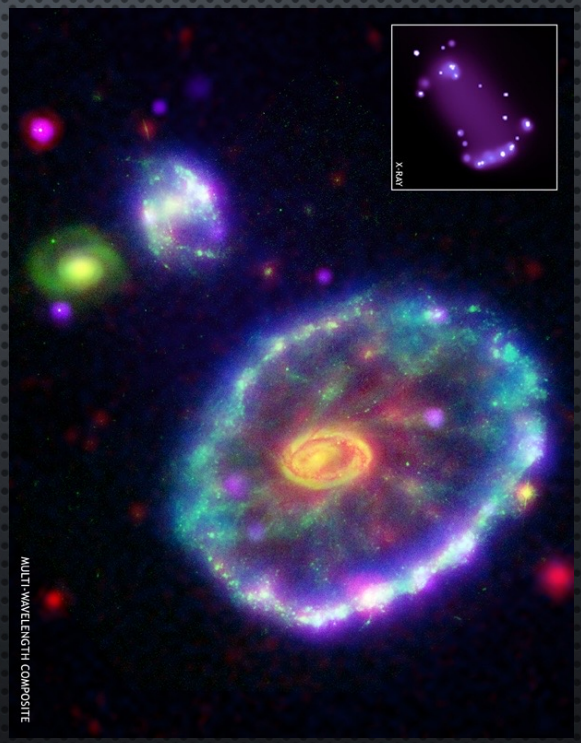
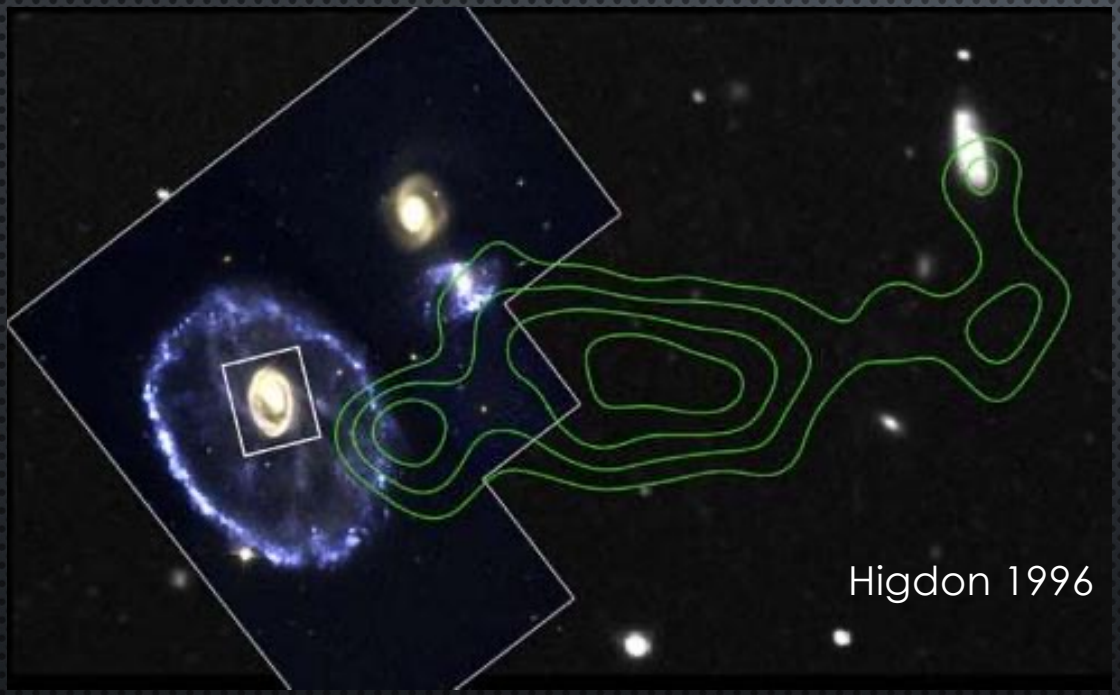
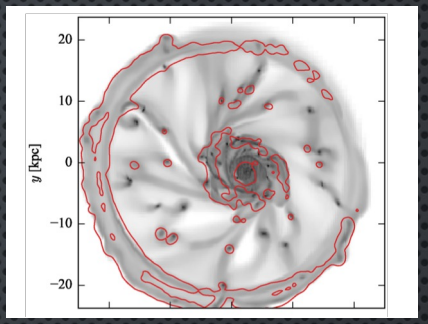


THE TARGET AND THE BULLET





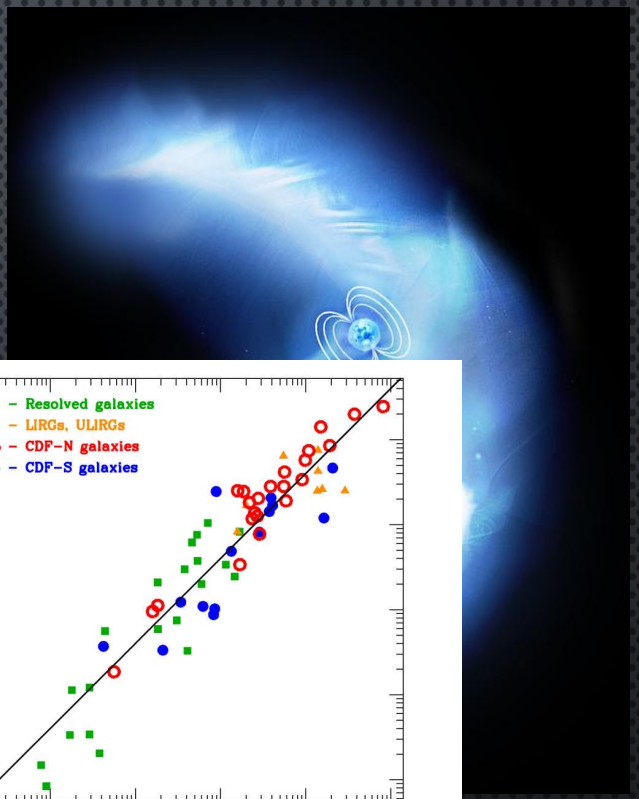
Renaud et al MNRAS **473**, 585–602 (2018)

- HEAD-ON HIGH-SPEED COLLISION ON A TARGET DISC GALAXY. WHICH IS THE BULLET? HI TRAIL – IS THE HI FROM THE "BULLET" RESPONSIBLE FOR NEW SF?
- TWO SCENARIOS:
  - THE GRAVITATIONAL ACCELERATION INDUCED BY THE COMPANION DRAGS THE MATTER OF THE TARGET TOWARDS THE CENTRAL IMPACT POINT. THEN THE SHOCK WAVE REBOUNDS, AND FORMS AN ANNULAR OVERDENSITY THAT TRAVELS RADIALLY.
  - THE SHOCK WAVE BRINGS THE MATERIAL (GAS AND STARS) TO THE OUTSKIRTS.

LOOKING FOR ULXS

- LAST STAGES OF STELLAR EVOLUTION – COLLAPSE LINKED TO SFR
- EVOLUTION AND LIFE-SPAN OF UNUSUAL STRUCTURES
- PROGENITORS OF MERGERS -> GRAVITATIONAL WAVES
- PRIMORDIAL IONIZATION

  NEBULAR HeII EMISSION
- N_ULX LINKED TO SFR (GRIMM+2003; MINEO+2012; GILFANOV 2023)



(Gilfanov 2023)

LOOKING FOR ULXS

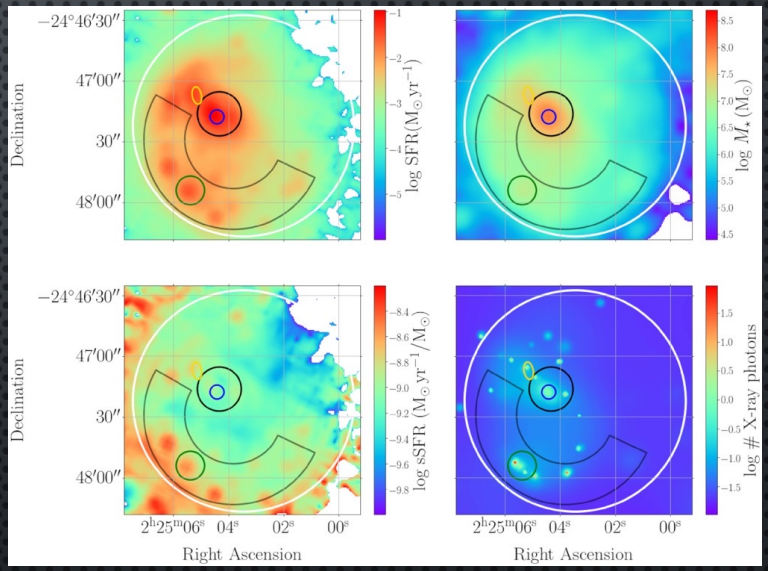
- ULX FORMATION LINKED TO LOW METALLICITY (MAPELLI+2009; FORNASINI+2020; LEHMER+2023)
- TRACER OF LOW METALLICITY ENVIRONMENT ?

  WEAKER STELLAR WINDS OF LOW METALLICITY STARS

- (INTERESTING) PROPERTIES OF RIGS
  RIGS HAVE RECENT SF EPISODES
- RIGS HAVE LOW METALLICITY (AT LEAST IN THE RING)

..

NGC 922



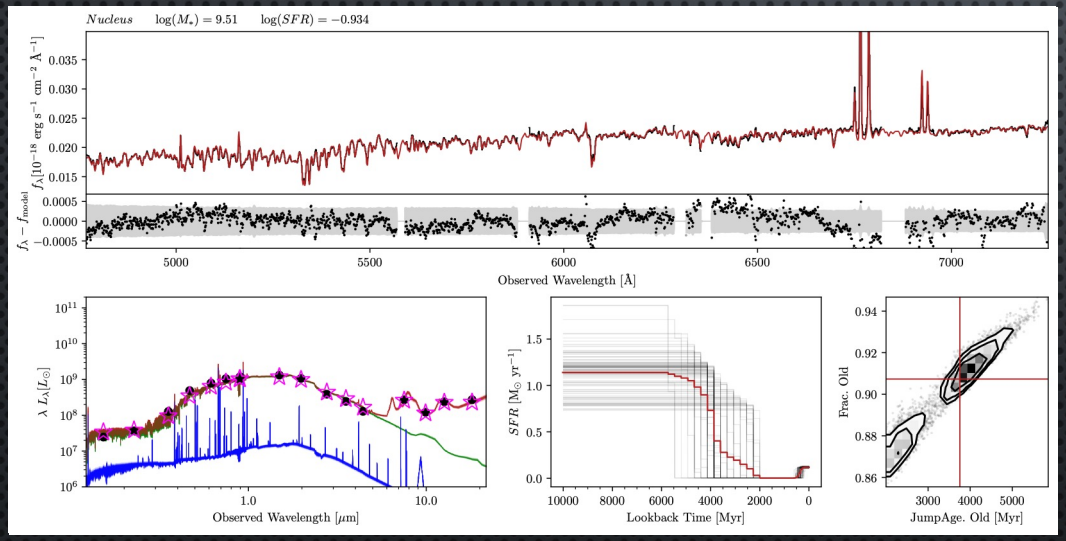
(Kourourmpatzakis, Zezas, Wolter, Fruscione, Anastasopoulou, Prestwich 2021)

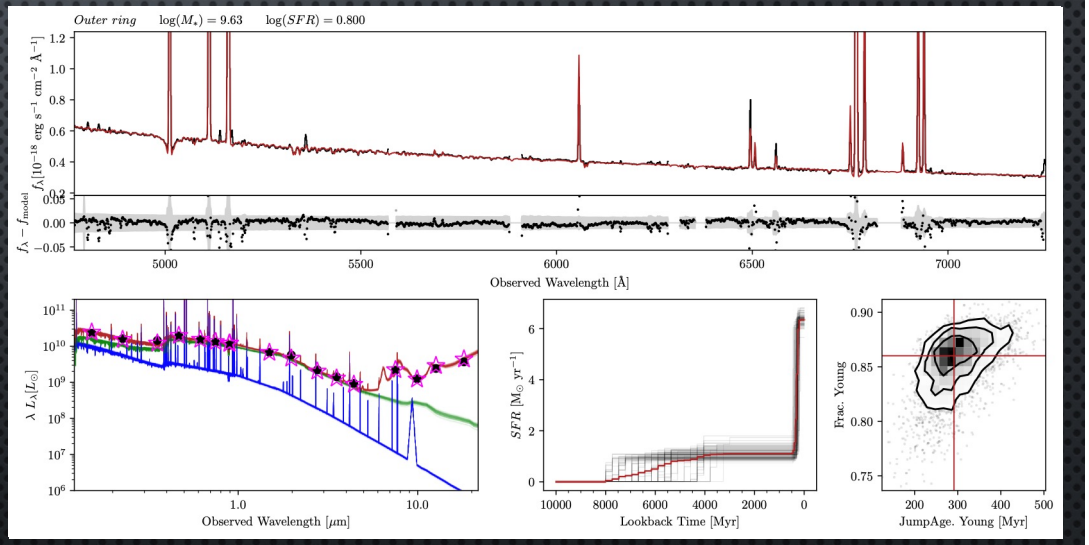
ASSUMING METALLICITY, DERIVE AGE/SFH

(DITRANI, LONGHETTI, FOSSATI, WOLTER 2024 A&A)

NUCLEUS

EXTERNAL RING



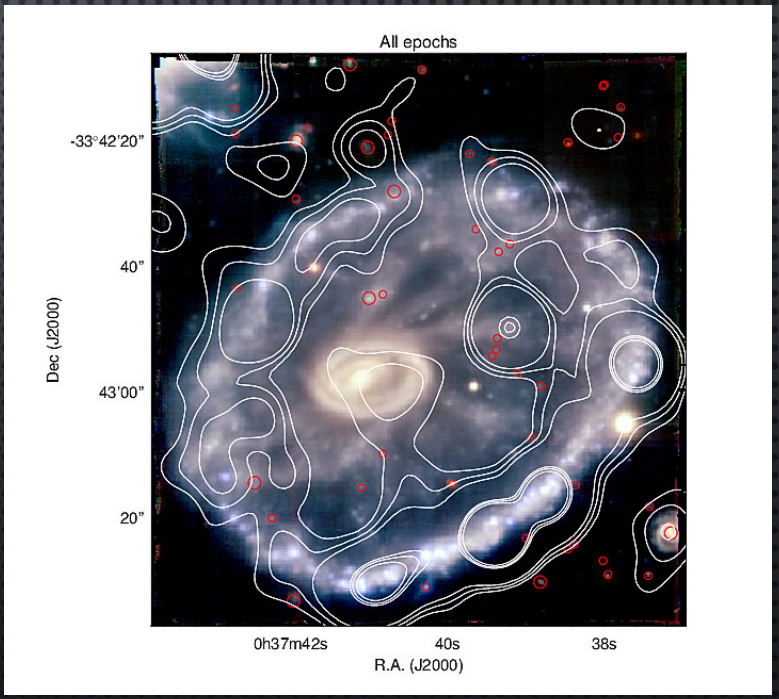


MULTINEST fit: Monte-Carlo Spectro-Photometric Fitter adapted from Fossati+ 2018

RESULTS OF ANALYSIS

- THE "OLD" CARTWHEEL RETAINS CHARACTERISTICS OF SPIRALS
- A "YOUNG" POPULATION CONTRIBUTE A SMALL FRACTION OF THE MASS IN ALL REGIONS OUTSIDE THE NUCLEAR ZONE.
- THE OUTER RING IS VERY YOUNG <~ 400 MYR (CAVEAT FOR OLD STARS NOT EASY TO BE DETECTED)
- SHOCK WAVES DRAGS NEW STARS OUT

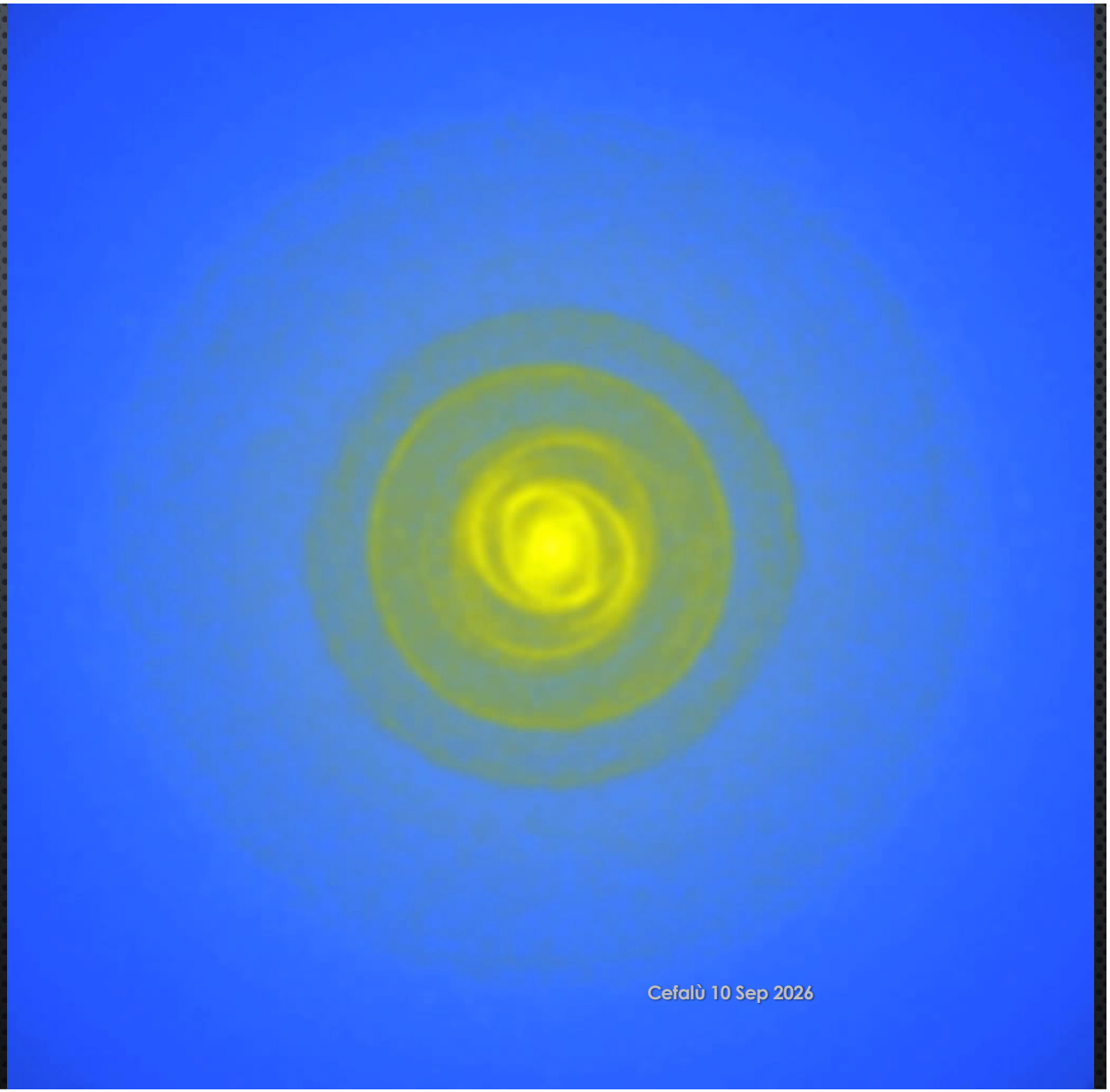
Chandra contours; Circles: bkgd srcs

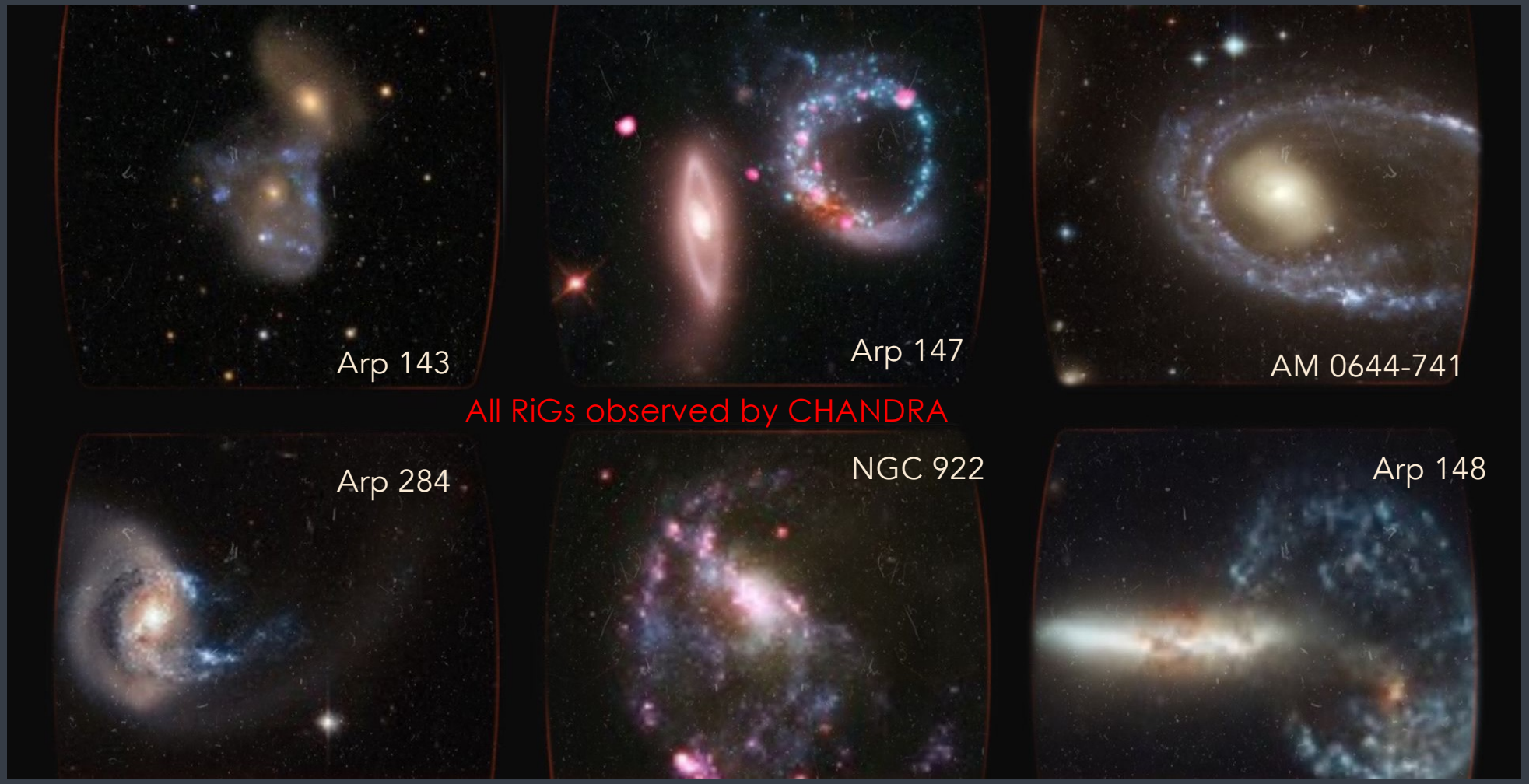


HOW DOES THE SHOCK WAVE WORK?

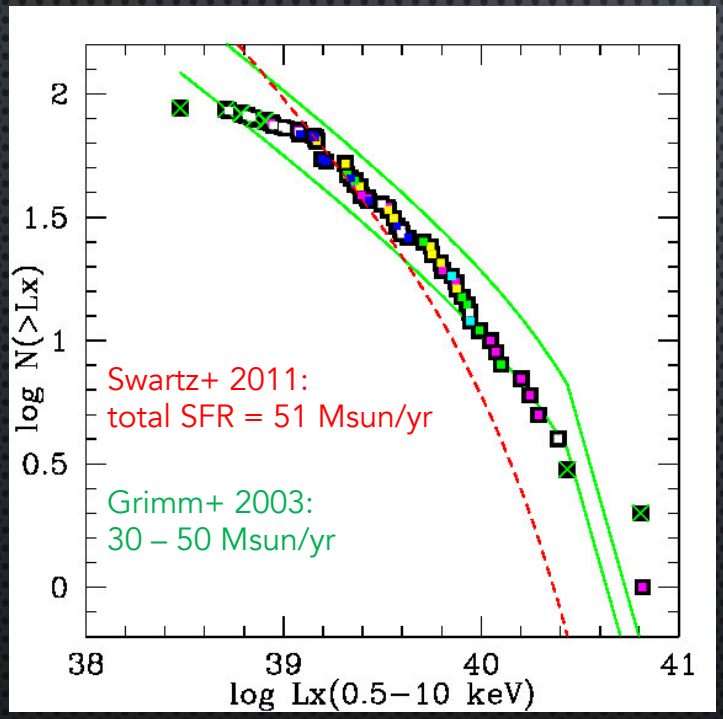
Renaud et al 2018

- YELLOW IS STARS (SURF BRIGHT.)
- BLUE IS GAS (DENSITY)




Arp 143
Arp 147
AM 0644-741
All RiGs observed by CHANDRA
Arp 284
NGC 922
Arp 148

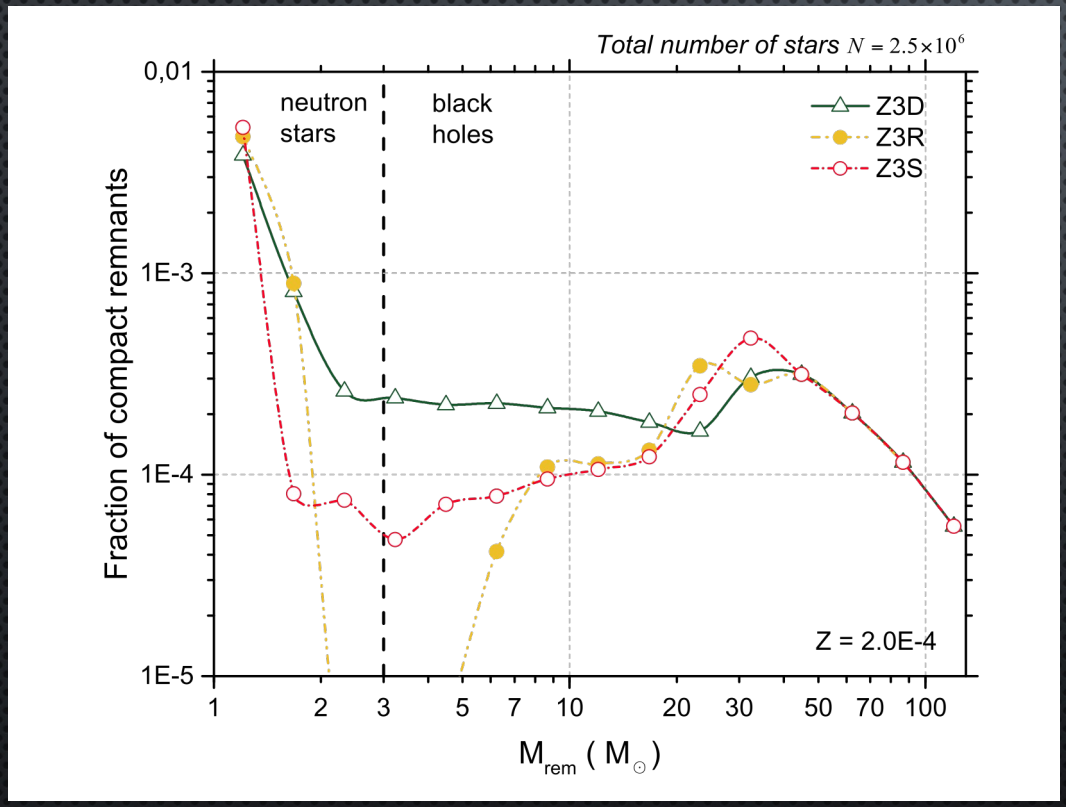
THE XLF OF COLLISIONAL RING GALAXIES

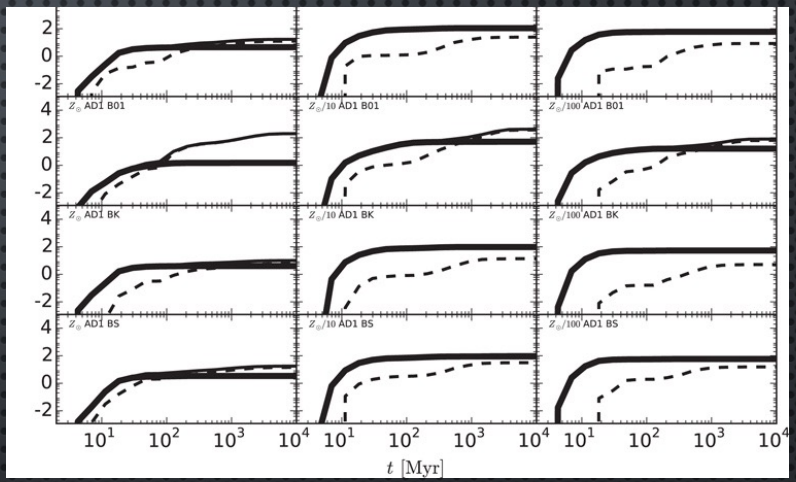


Wolter, Fruscione, Mapelli 2018

- 7 RIGS OBSERVED BY CHANDRA (COLORS CORRESPONDS TO DIFFERENT GALAXIES)
- WE CONSIDER THE POPULATION HOMOGENOUS – SINGLE BURST OF SF– WE SUM ALL THE SOURCES IN THE RINGS
- 65 SOURCES OF WHICH 50 ARE ULXS; SFR_{TOT} = 33 MSUN
- STATISTICALLY CONSISTENT, WITH A TENDENCY TO BE FLATTER – MORE HIGH-LX SRC – AND TWO OUTLIER SOURCES
- AGE ~ FEW 100 MYR (RENAUD+17) CONSISTENT WITH FORMATION TIME OF HMXB

HEAVY BLACK HOLES?





- WIKTOROWICZ+2017 FIND BHS AS THE PRODUCT OF BURST ON LOW METALLICITY ENVIRONS AT < ~ 100 MYR
- FROM SPERA, MAPELLI, BRESSAN 2015
- METALLICITY DRIVES THE MASS TO THE HIGHER LEVELS

A COMPARISON SAMPLE

- The best catalog of Ring Galaxies (RIGs) is Arp&Madore
- We selected all "Collisional Rings" up to a distance of z<= 0.2, with at least a plausbile "companion-bullet" (Madore Nelson Petrillo 2009)
- The final list contains two interlopers: sources that have a measured redsfhit much higher than in Arp&Madore – excluding them we have 16 sources

MULTIWAVELENGTH OBSERVATIONS

WE NEED INFORMATION ON

X-ray : to identify possible ULXs

Halpha : to determine SFR

Spectral emission lines : to determine metallicity (Z)

IF POSSIBLE:

dynamical measures to determine the age of the impact

Mass measure to determine the content of the Galaxy

CAMPAIGNS

X-RAY

1 dedicated XMM-Newton + 2 dedicated Chandra campaigns. -- a TOTAL OF 13/16

OPTICAL: Halpha IMAGING

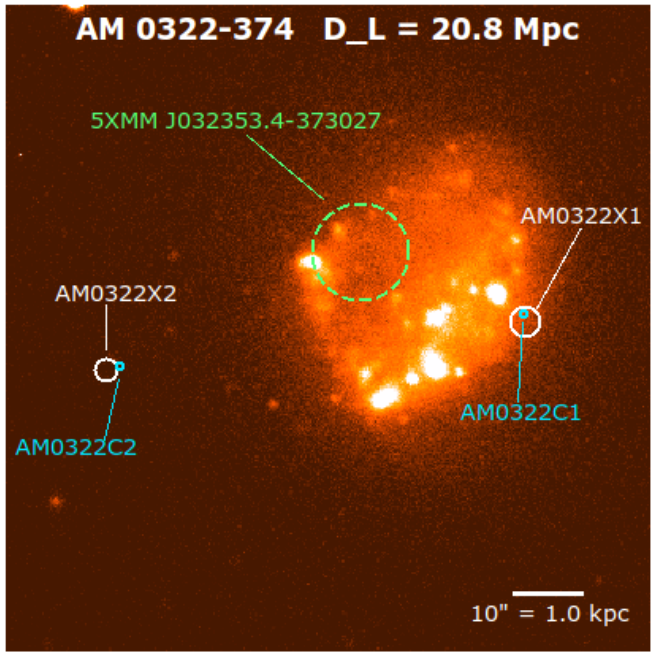
1 dedicated ESO (NTT) + 1 dedicated SOAR campaign – a TOTAL of 8/16

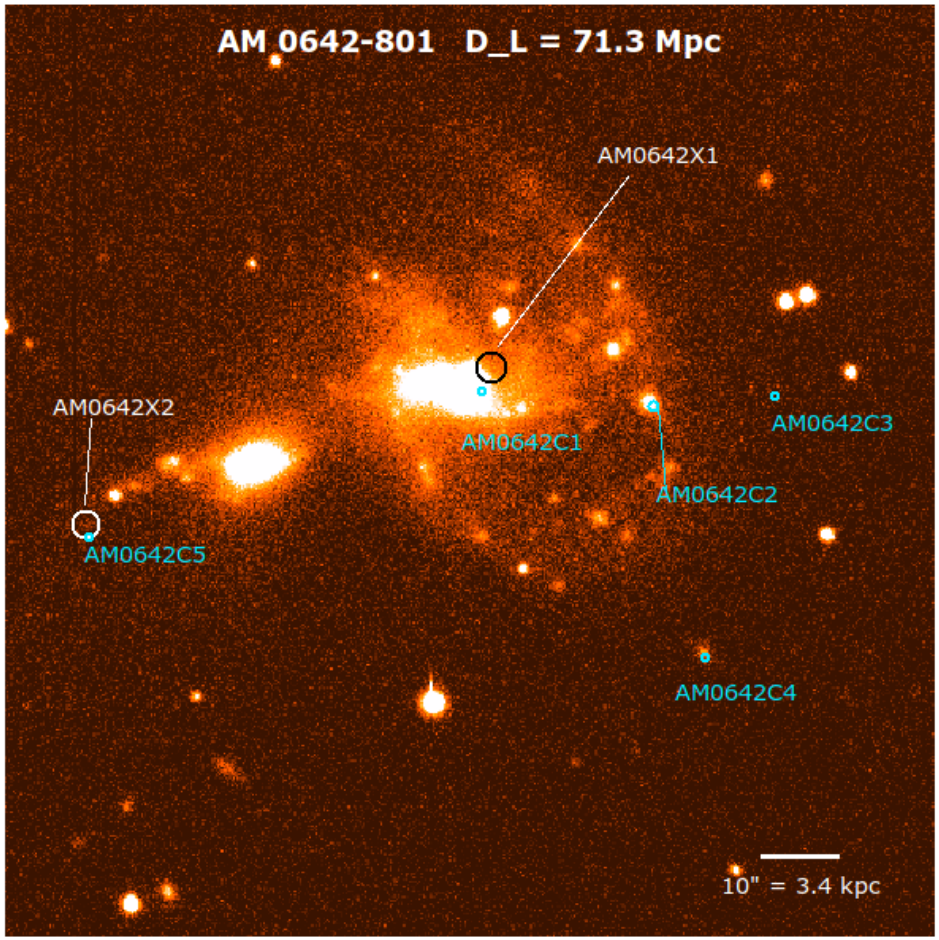
OPTICAL: SPECTROSCOPY

1 dedicated ESO (NTT) + 1 dedicated SOAR campaign – a TOTAL of 10/16

PLUS

Literature and archival searches (e.g Galex, WISE etc)





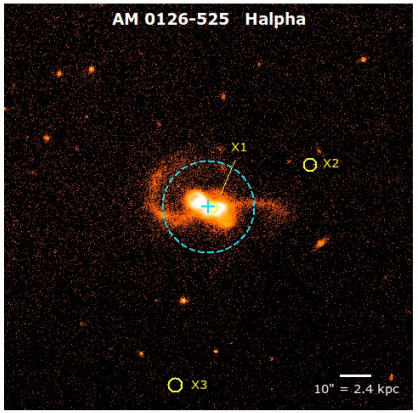
Chandra and XMM-NEWTON comparison

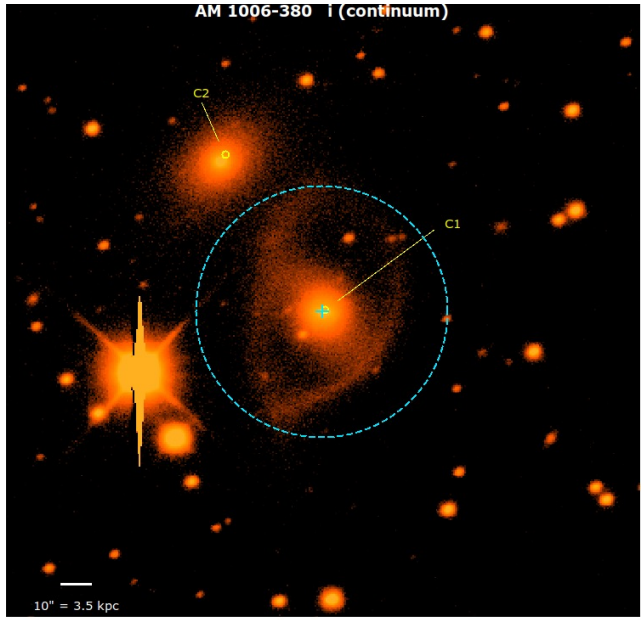
A FEW EXAMPLES

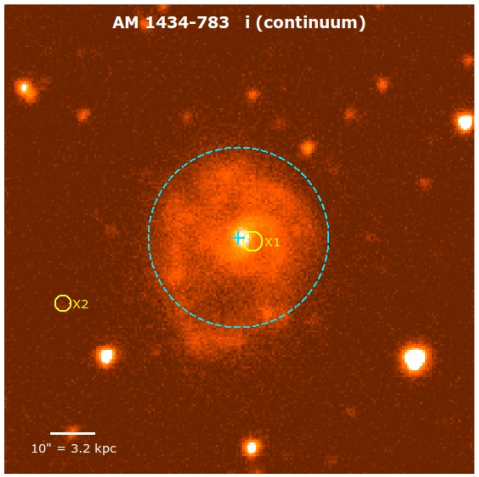
- SOME POSSIBLE (FAINT) NUCLEAR SOURCES
- VERY FEW ULXS ON RINGS:

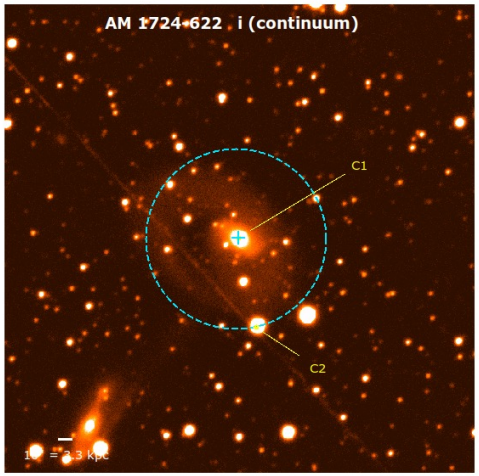
IN TOTAL WE HAVE AT MOST 5 GOOD CANDIDATE ULXS AND 5 LESS LIKELY CANDIDATES

- WHY? WHAT'S DIFFERENT?









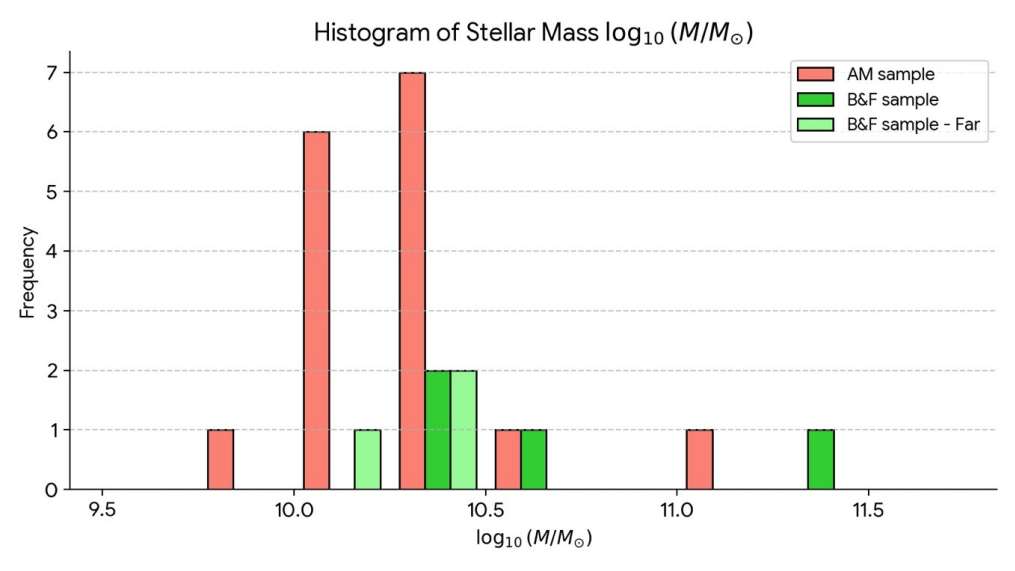
DIFFERENCES?

- LOWER MASSES?

MLLER RINGS?

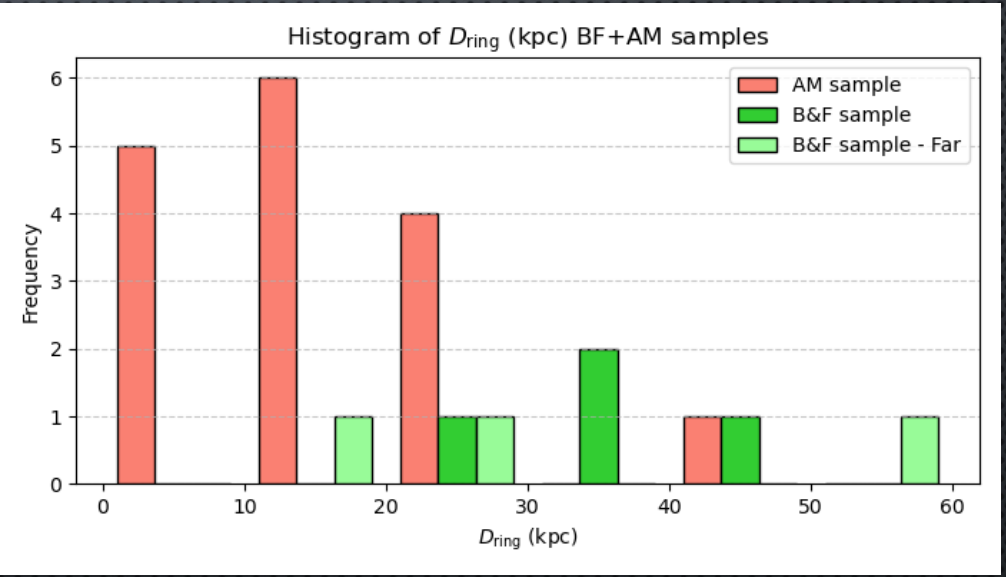
RTER/LONGER TIME SCALE FROM IMPA

FERENT METALLICITIES?



DIFFERENCES?

- LOWER MASSES?
- SMALLER RINGS?



DIFFERENCES?

- Lower Mass?
- Smaller Rings?
- Shorter/Longer Time Scale from impact?

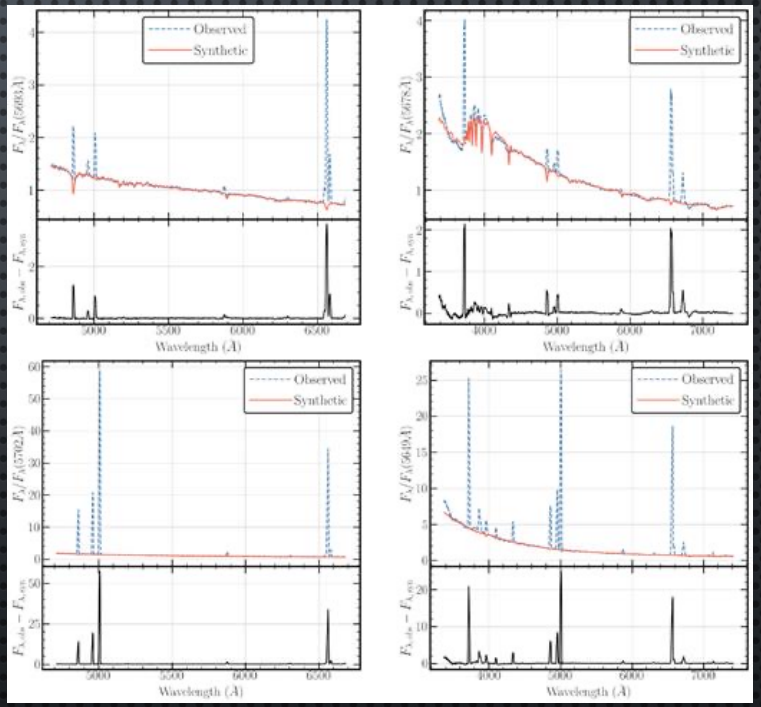
- 440 Myr Cartwheel (Higdon+1995)
  330 Myr NGC 922 (Wong+2006)
  80 Myr Arp 147 (Romano+2000)
  30 Myr Arp 143 (Higdon+1995)

- SIMILAR but not exactly as the diameter size – no Dynamical measure for now

DIFFERENCES?

- Lower Mass?
- Smaller Rings?
- Shorter/Longer Time Scale from impact?
- Different Metallicities?

NGC922 (Kouroumpatzakis et al. 2021) from ESO Data



DIFFERENCES?

- Lower Mass?
- Smaller Rings?
- Shorter/Longer Time Scale from impact?
- Different Metallicities?
- Different Total SFR?

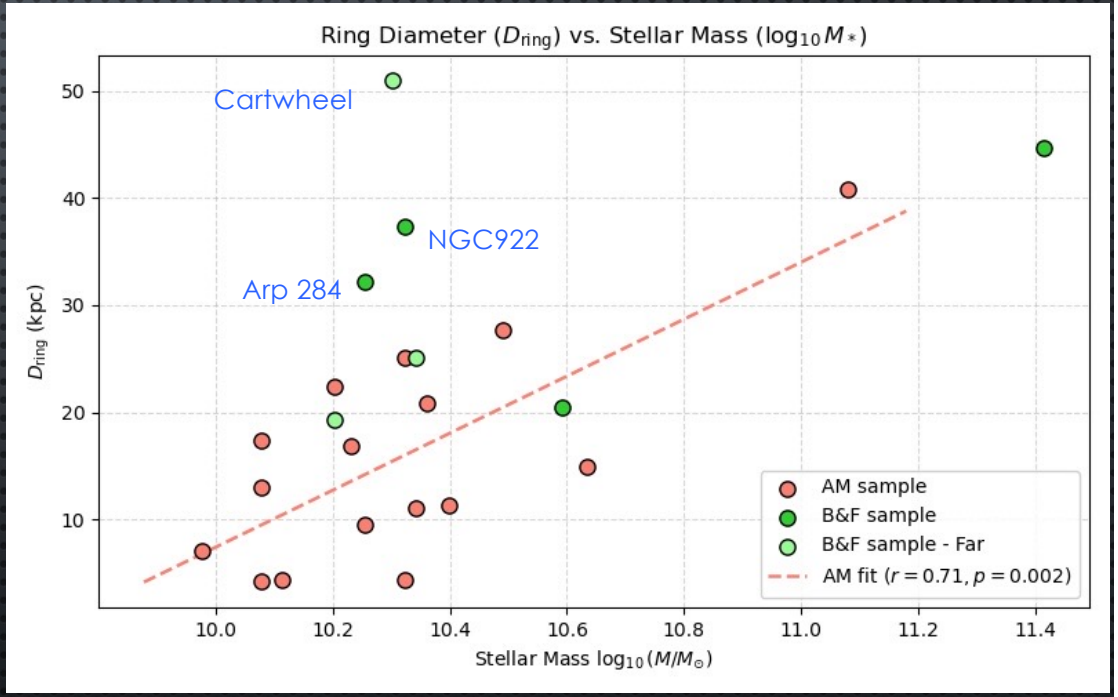
- B&F total SFR=50 Msun
- B&F total z < 0.02. SFR ~ 20
- AM sample total SFR=??

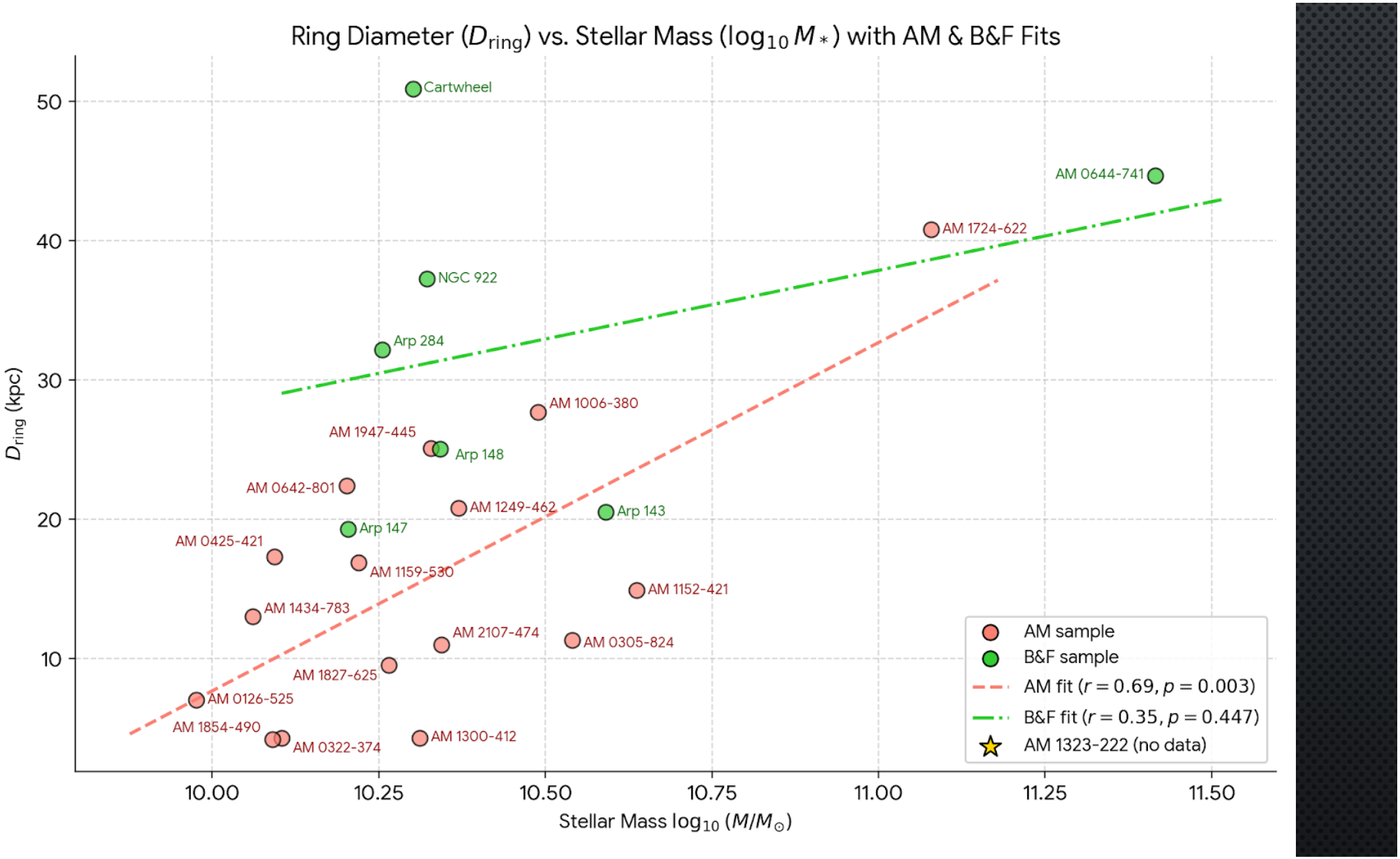
  Sum for 5 galaxies ~ 10 Msun

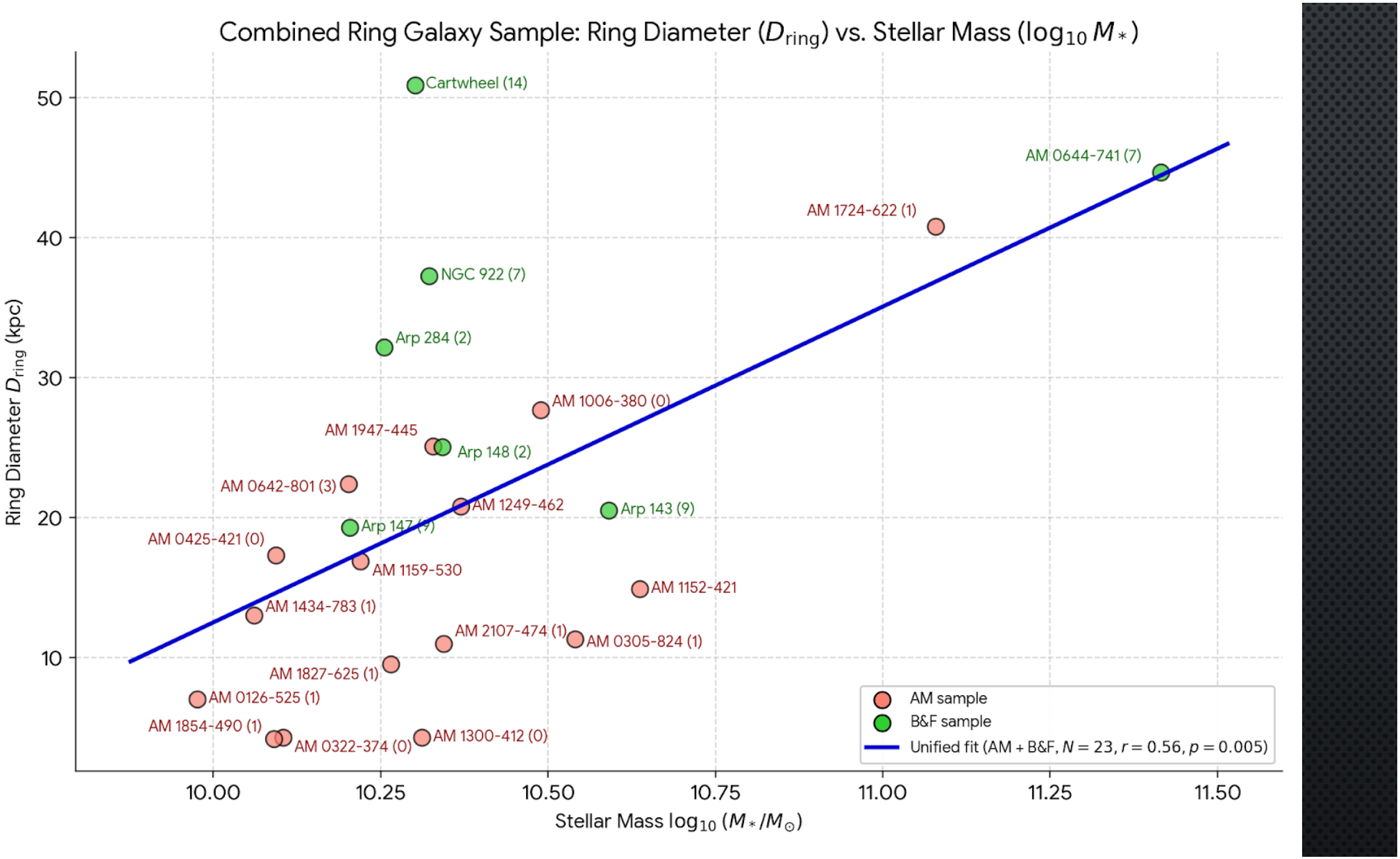
  + 1 galaxy with ~ 20 Msun

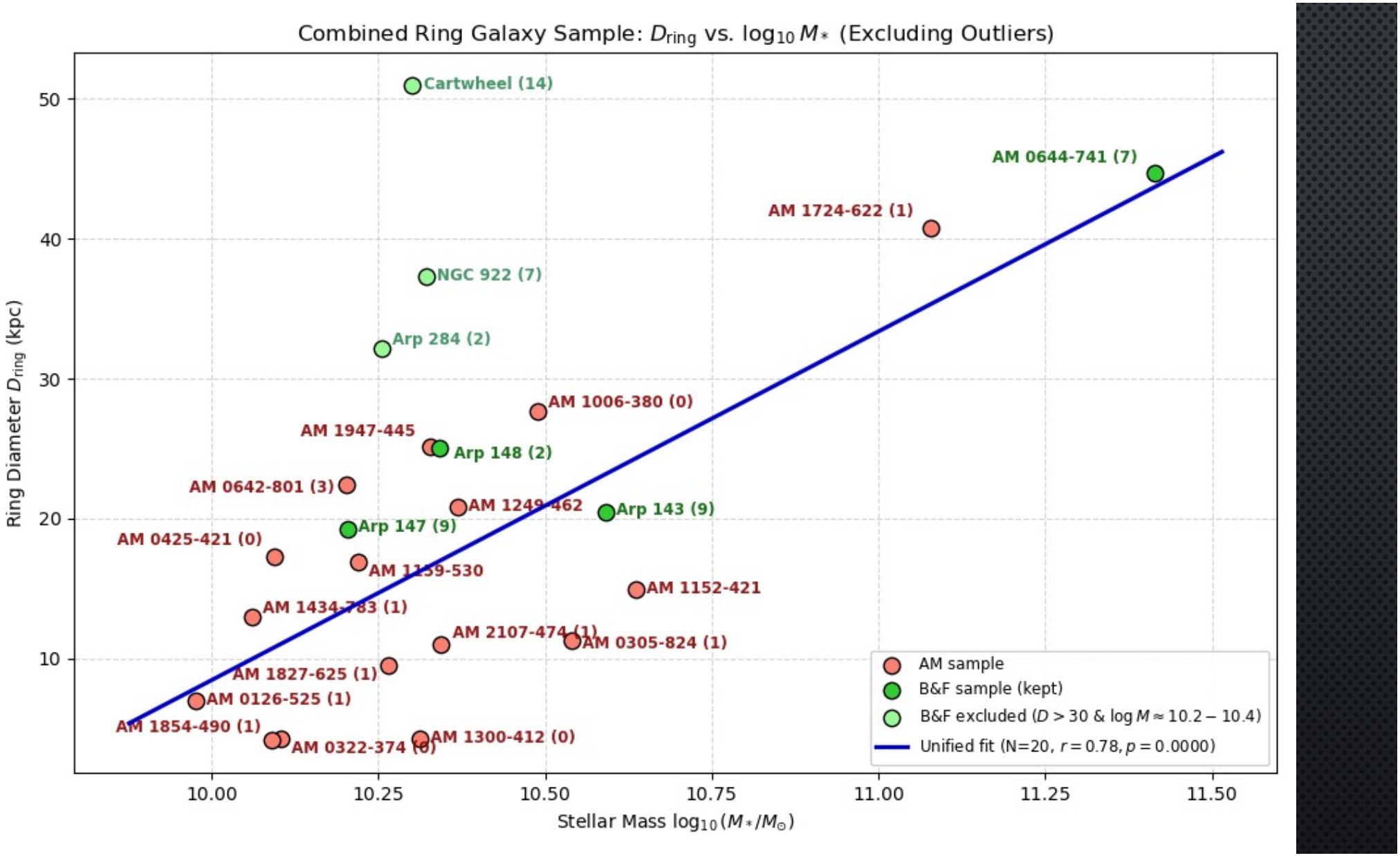
WHY?

- Ring Diameter vs Stellar Mass
- 3 outliers
- Correlation?




Ring Diameter (D_{ring}) vs. Stellar Mass ($\log_{10} M_*$) with AM & B&F Fits
Cartwheel
AM 0644-741
AM 1724-622
NGC 922
Arp 284
AM 1006-380
AM 1947-445
Arp 148
AM 0642-801
AM 1249-462
Arp 143
Arp 147
AM 0425-421
AM 1159-530
AM 1152-421
AM 1434-783
AM 2107-474
AM 0305-824
AM 1827-625
AM 0126-525
AM 1854-490
AM 0322-374
AM 1300-412
AM sample
B&F sample
AM fit ($r = 0.69, p = 0.003$)
B&F fit ($r = 0.35, p = 0.447$)
AM 1323-222 (no data)
D_{ring} (kpc)
Stellar Mass $\log_{10}(M/M_\odot)$
10
20
30
40
50
10.00
10.25
10.50
10.75
11.00
11.25
11.50


Combined Ring Galaxy Sample: Ring Diameter (D_{ring}) vs. Stellar Mass ($\log_{10} M_*$)
Ring Diameter D_{ring} (kpc)
Stellar Mass $\log_{10}(M_*/M_\odot)$
Cartwheel (14)
AM 0644-741 (7)
AM 1724-622 (1)
NGC 922 (7)
Arp 284 (2)
AM 1006-380 (0)
AM 1947-445
Arp 148 (2)
AM 0642-801 (3)
AM 1249-462
Arp 143 (9)
Arp 147 (9)
AM 0425-421 (0)
AM 1159-530
AM 1152-421
AM 1434-783 (1)
AM 2107-474 (1)
AM 0305-824 (1)
AM 1827-625 (1)
AM 0126-525 (1)
AM 1854-490 (1)
AM 0322-374 (0)
AM 1300-412 (0)
AM sample
B&F sample
Unified fit (AM + B&F, $N = 23$, $r = 0.56$, $p = 0.005$)


Combined Ring Galaxy Sample: $D_{\rm ring}$ vs. $\log_{10} M_*$ (Excluding Outliers)
Ring Diameter $D_{\rm ring}$ (kpc)
Stellar Mass $\log_{10}(M_*/M_\odot)$
Cartwheel (14)
AM 0644-741 (7)
AM 1724-622 (1)
NGC 922 (7)
Arp 284 (2)
AM 1006-380 (0)
AM 1947-445
Arp 148 (2)
AM 0642-801 (3)
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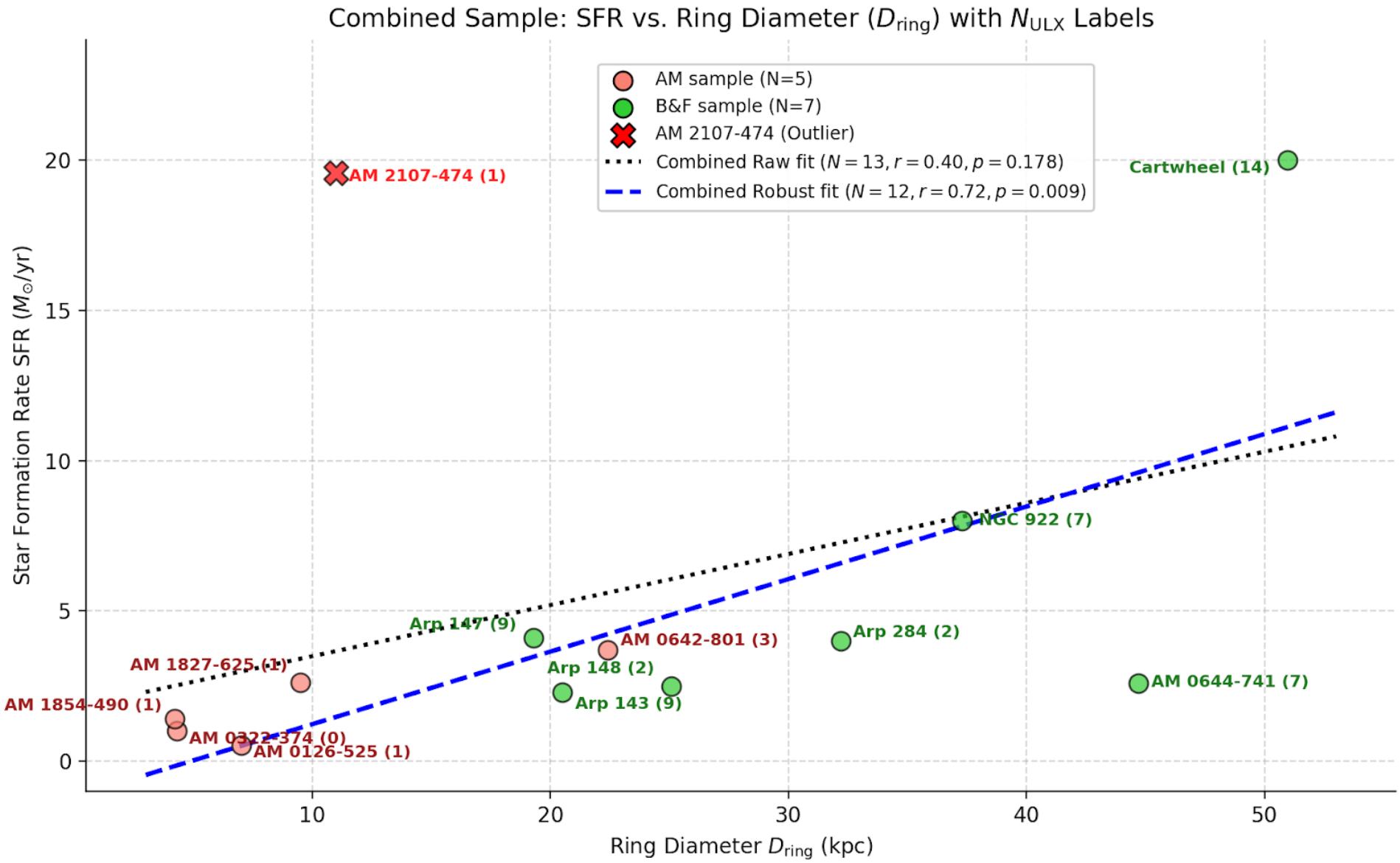
AM 0305-824 (1)
AM 1827-625 (1)
AM 0126-525 (1)
AM 1854-490 (1)
AM 0322-374 (0)
AM 1300-412 (0)
AM sample
B&F sample (kept)
B&F excluded ($D > 30$ & $\log M \approx 10.2 - 10.4$)
Unified fit (N=20, $r = 0.78, p = 0.0000$)


Combined Sample: SFR vs. Ring Diameter (D_{ring}) with N_{ULX} Labels
AM sample (N=5)
B&F sample (N=7)
AM 2107-474 (Outlier)
Combined Raw fit ($N = 13, r = 0.40, p = 0.178$)
Combined Robust fit ($N = 12, r = 0.72, p = 0.009$)
Star Formation Rate SFR ($M_\odot$/yr)
Ring Diameter D_{ring} (kpc)
AM 2107-474 (1)
Cartwheel (14)
NGC 922 (7)
Arp 147 (9)
AM 0642-801 (3)
Arp 284 (2)
AM 1827-625 (1)
Arp 148 (2)
AM 0644-741 (7)
AM 1854-490 (1)
Arp 143 (9)
AM 0322-374 (0)
AM 0126-525 (1)
0
5
10
15
20
10
20
30
40
50

CONCLUSIONS

- ULX in RIGs
- RIGs have young star population easy to disentangle – MultiLambda studies
- Bright&Famous – possibile IMBH population of ULX?
- Comparison sample: much less ULXs – Why?
- Investigating the possible causes. Not the stellar Mass, nor the SFR.
- The age of the impact? Relative velocity/Mass Ratio? Or just the Volume too small?


THANK YOU!