BASS
BAT AGN Spectroscopic Survey

BASS-HI: Resolved HI Properties of the Local X-ray AGN Host Galaxies

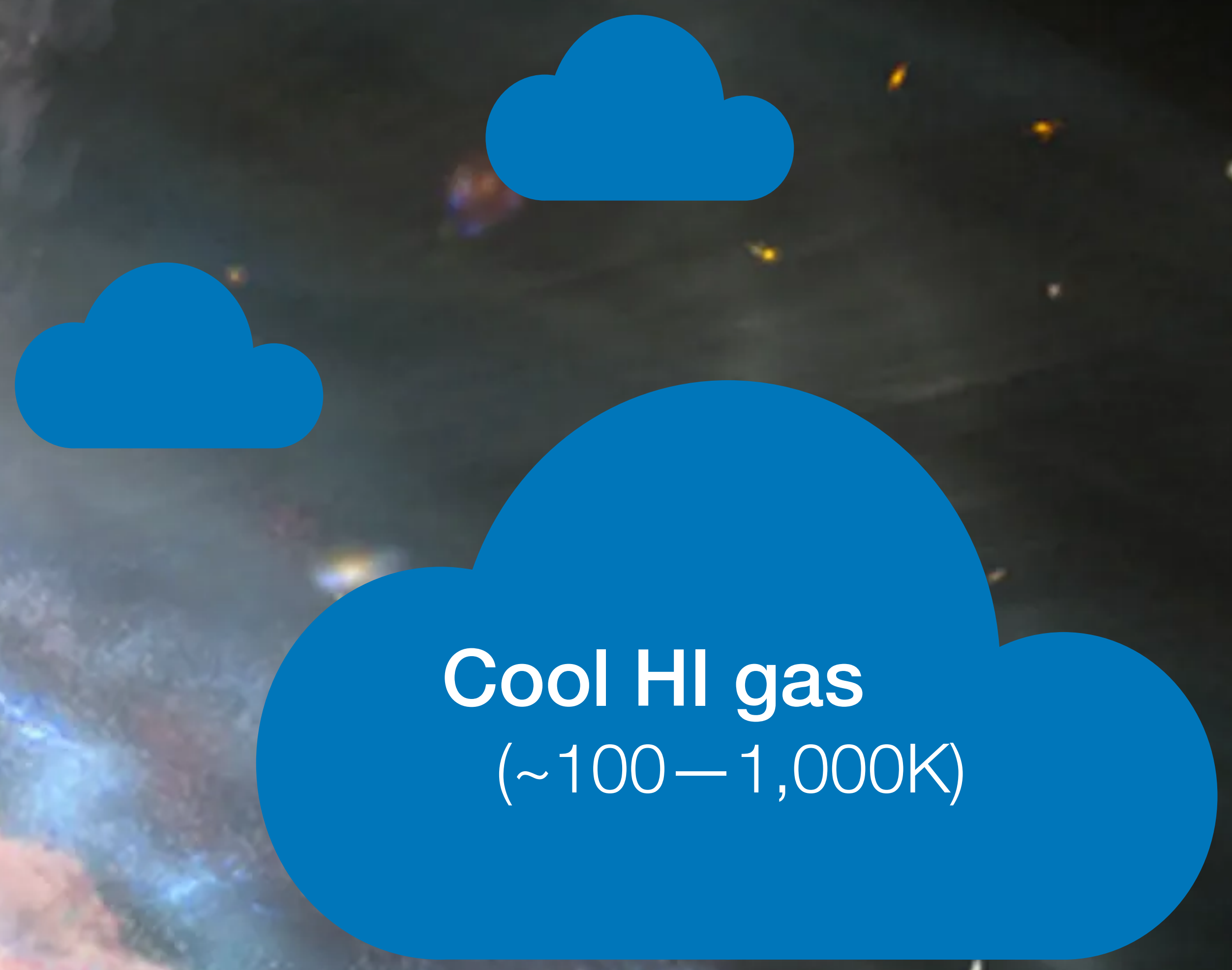
Jeein Kim
Yonsei Univeristy, NRAO
jikim.astro@gmail.com

Aeree Chung (Yonsei U), Junhyun Baek (KASI), Lilia Tremou (NRAO), Ivy Wong (CSIRO/UWA), Kyuseok Oh (KASI), Michael Koss (Eureka Sci.)

Nov 22, 2024 :: 40th Annual New Mexico Symposium

AGN feeding in Macroscale

($10^6 - 10^8 r_s$; $10^{-3} - 10^{-0} r_{vir}$; kpc—Mpc)



How the AGNs are fed?

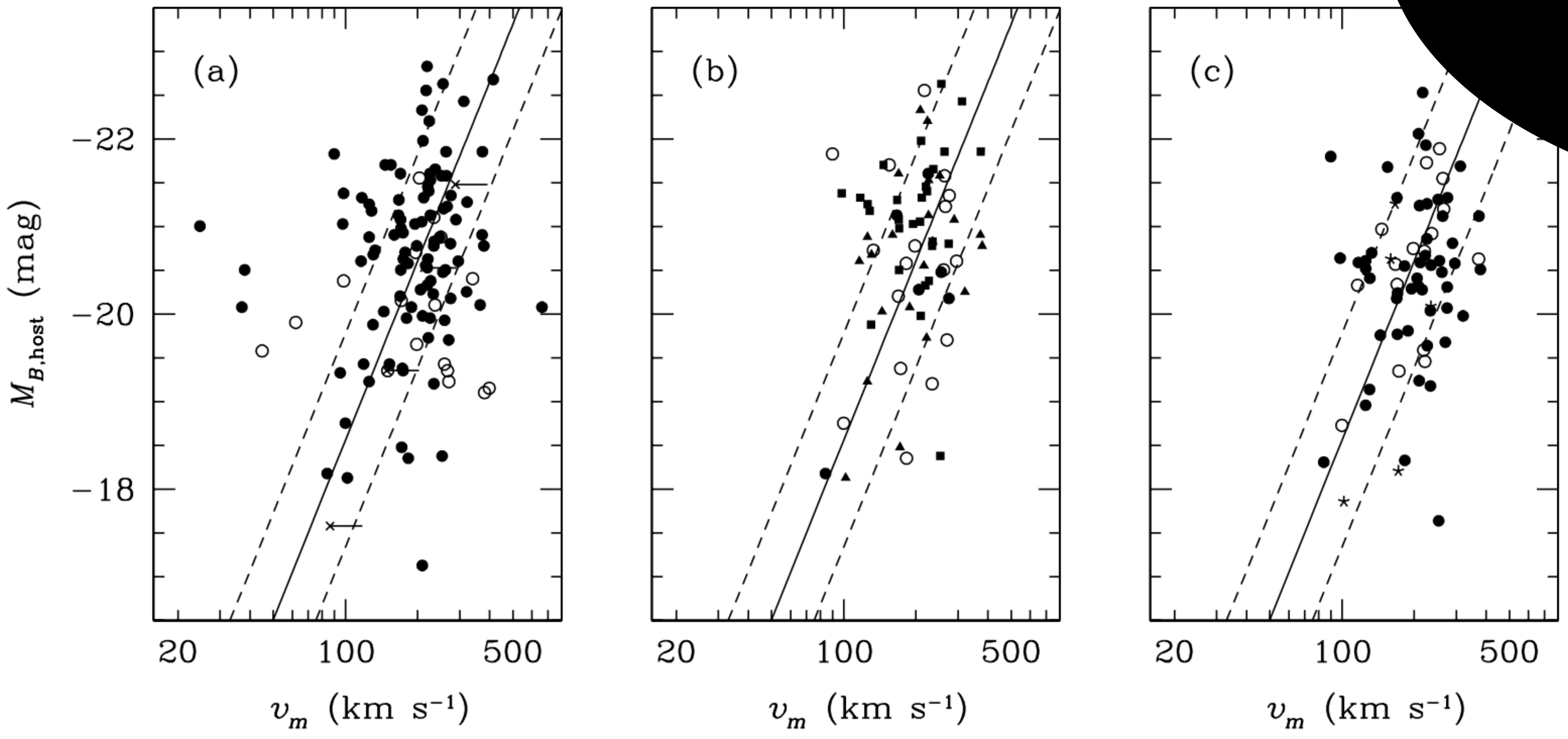
The origin of gas — beginning of Chaotic Cold Accretion (CCA)

- The energy transfer (How does the medium loses its angular momentum & the role of cool gas reservoir)
- What is the role of bars/spirals and gravitational torques (Gaspari et al. 2020; NatAstro) in DMH perspective
- How the AGN activity/feeding related to the host galaxy’s environment?

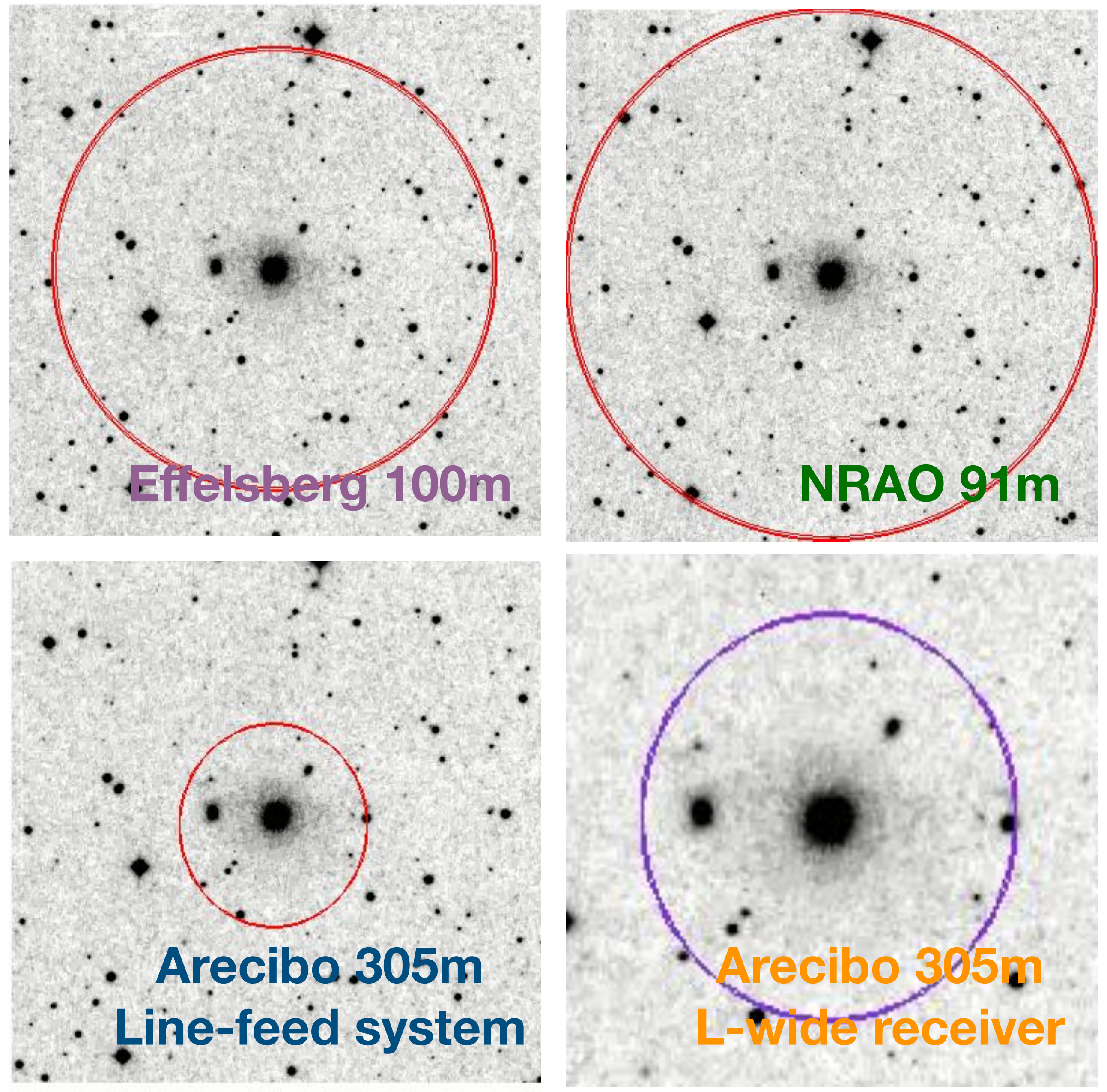
The BASS-HI project

by Yonsei & CSIRO team

Ho et al. 2008

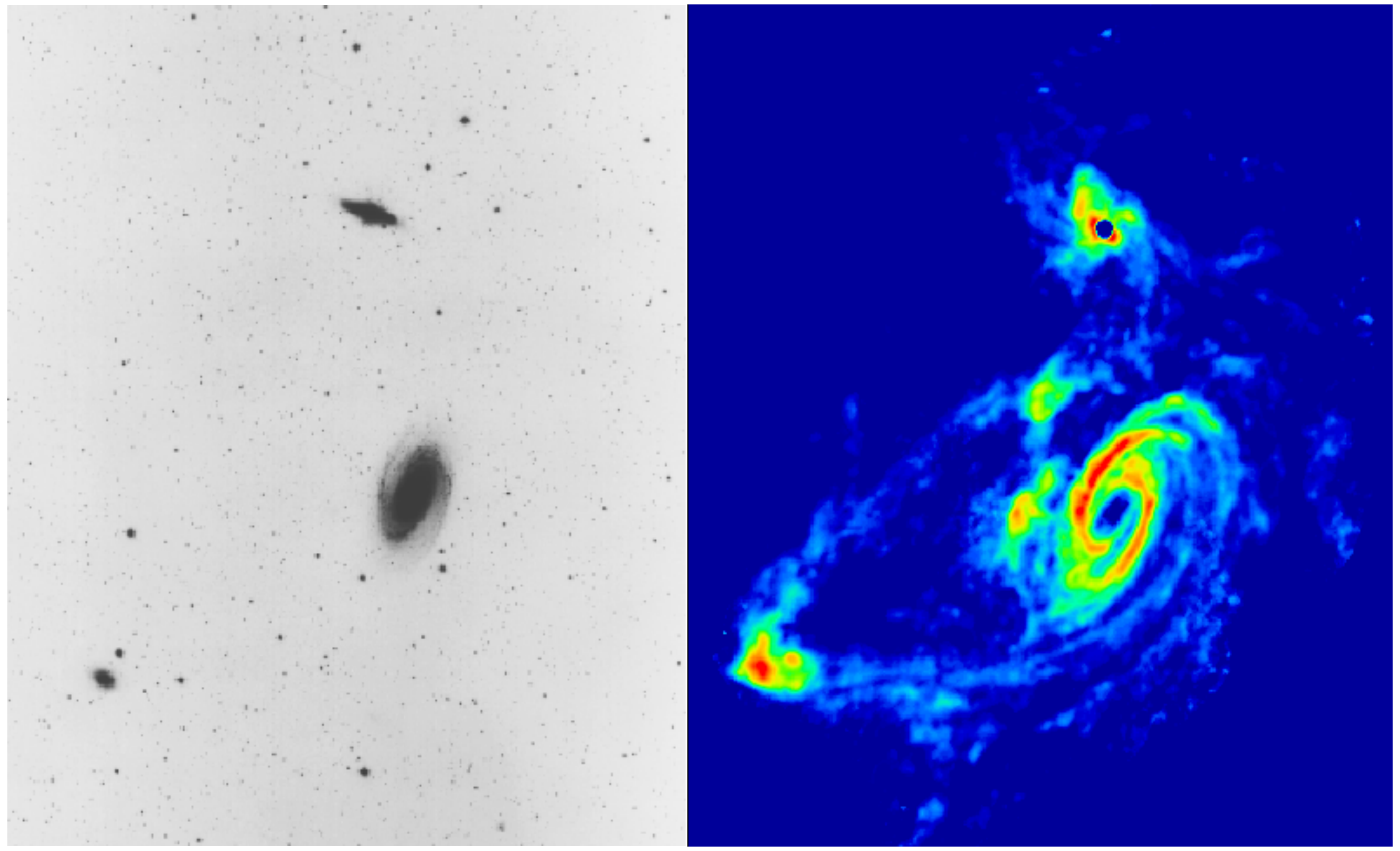


Previous study via single-dish was inconclusive:
Ho et al. 2008; Fabello et al. 2011; Geréb et al. 2015



➡ ***Type 1 Active galaxies follow inactive(normal) relations (e.g., Tully-Fisher relation)***

- To resolve the HI gas distribution, to get…
- Global & local gas properties of the galaxies. *(e.g., gas mass, morphology, kinematics, total angular momentum…)*
- and to probe the environment!



M81 group galaxies: Yun et al. 1994

→ Interferometric HI observation needed

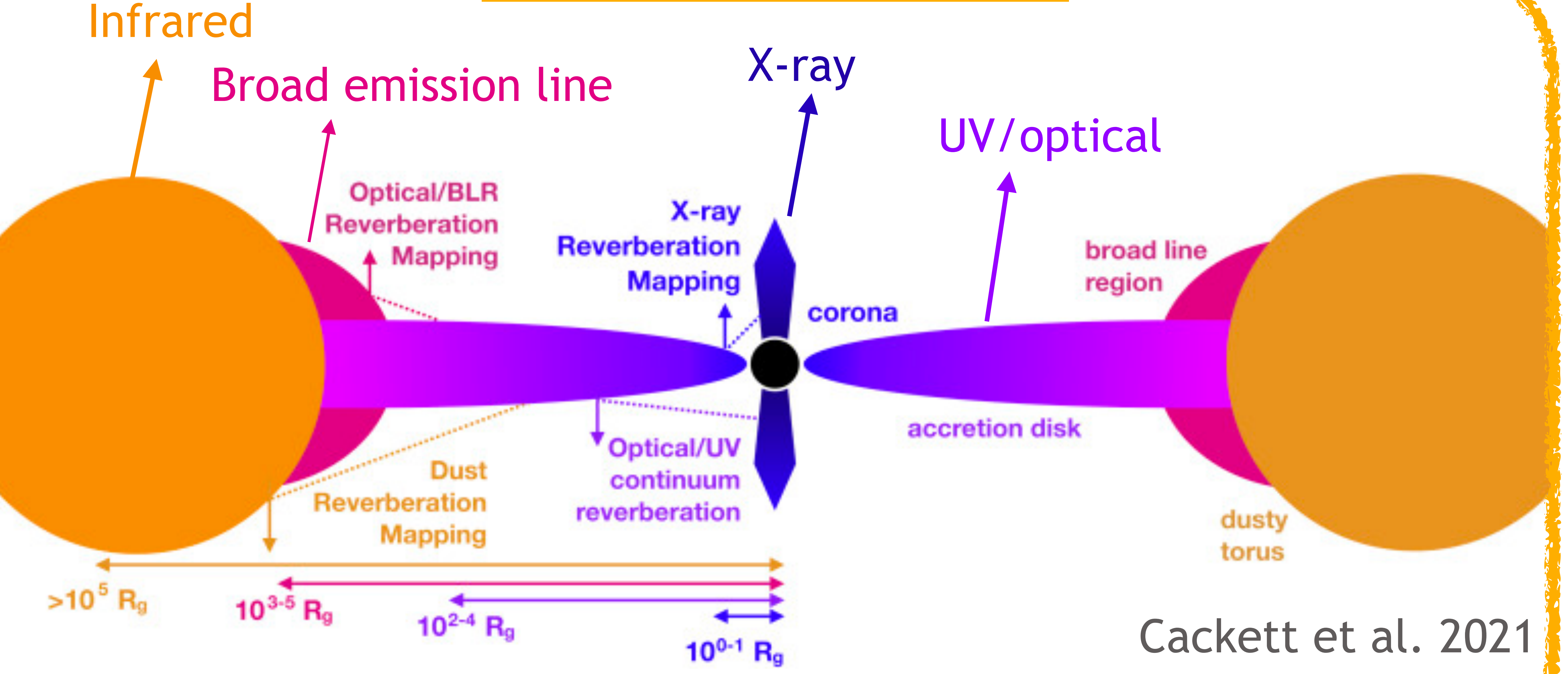
The BASS survey

hard X-ray AGNs

- ***BAT AGN Spectroscopic Survey (BASS) DR1*** *(M. Koss et al. 2017)*
  - Hard X-ray (14-195 keV) all sky-survey
    - Less effected by torus obscuration
    - Less contaminated by star formation

→ ***Relatively complete local AGN sample!***

<central structure of AGN>



Cackett et al. 2021

- Optical/NIR spectroscopy, sub-mm observations, X-ray spectra… etc

→ ***with abundant ancillary data***

The BASS-HI project: Karl. G Jansky VLA observations

by Yonsei & CSIRO team

Parent sample	# of source
BASS DR2	858
z < 0.0275 (DL < 120 Mpc)	259
Single dish detection	112
JVLA 20A+23B	40
ATCA 2019	8
Archive (VLA/GMRT/WSRT)	42
WALLABY/THINGS/LVHIS	7
Local BASS-HI galaxies	**97**

"97 Nearby (<120 Mpc), gas-rich galaxies"

→ Because of the Sensitivity & Resolution

→ Northern Sample: JVLA C-config. 57hrs + D-config. 64 hrs

- L-band HI line | angular resolution ~20" | velocity resolution ~6.7km/s | RMS HI column density ~ 2x1e19 cm-2 (C-array) | RMS~1.7x1e18 cm-2 (D-array)

➡ ***the largest HI imaging survey on local AGN host galaxies***

The BASS-HI sample & data reduction status

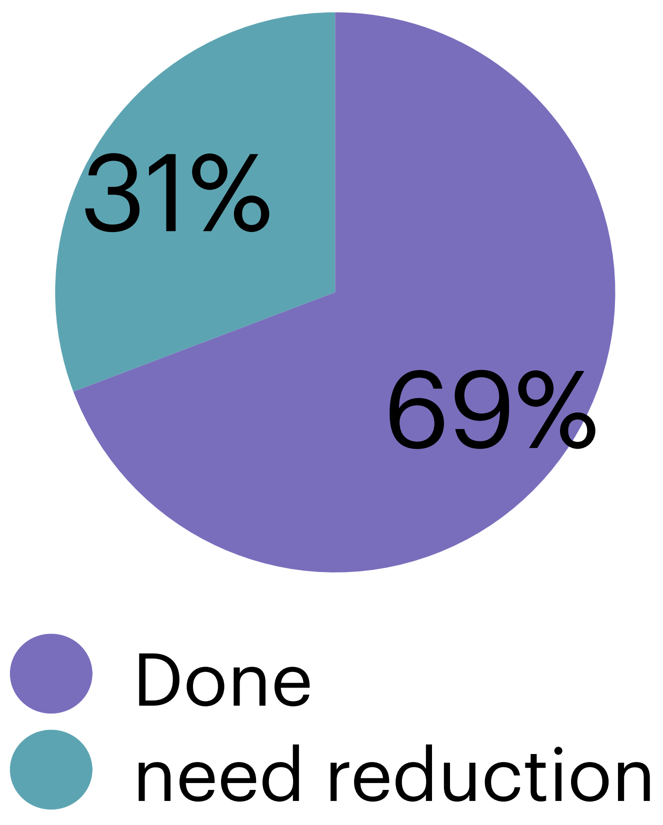
BASS-HI 97 galaxies data reduction status

39 Archival Data (VLA/WSRT/GMRT) 69%

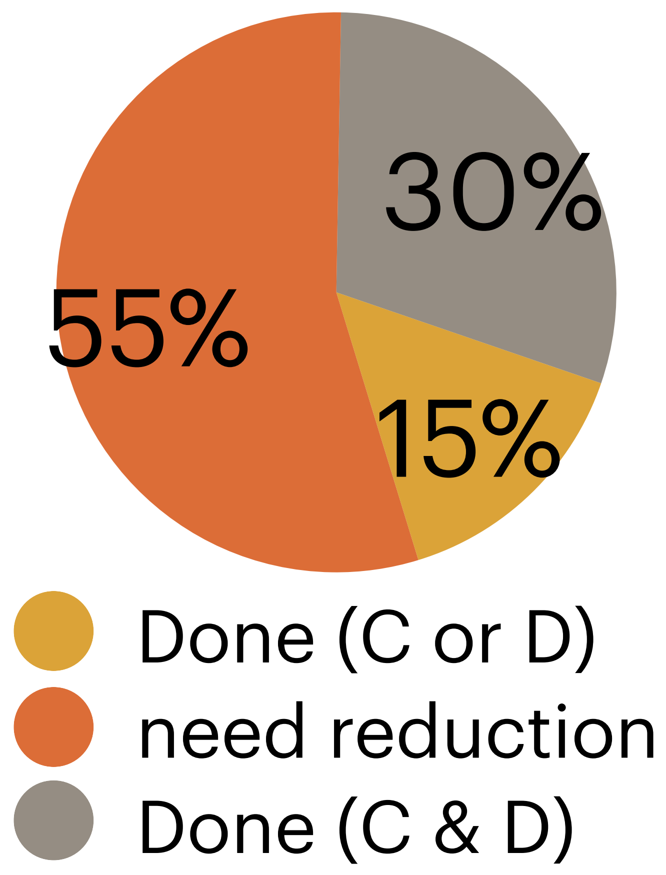
BAT	Name	Project Code	Status
33	NGC262	**AH417(C), AH372(D)**	Done
43	Mrk352	**AK580(D), AL551(D)**	selfcal
74	NGC513	**AL551(D)**	stopped
77	Mrk359	**AK580(D), AL551(D)**	stopped
129	Mrk1040	**AL516(D)**	Done
140	NGC1052	**KNAP(D)**	Done
144	NGC1068	15A-345(B), STUDEN(CnB), AM874(C)	stopped
163	NGC1194	**10B-220(C)**	Done
239	UGC3157	Kuo+08/ApJ/679/1047=**AL516(D)**	Done
308	NGC2110	AB658(A), AR398(B->CnB), AW396(D)	stopped
325	Mrk3	AS633(A), **AW396(D)**	Done
385	UGC3995B	Kuo+08/ApJ/679/1047=**AL516(D)**	Done
404	Mrk1210	**AS648(BnC)**	non-detection
436	NGC2655	**AS611(C&D)**	Done
437	NGC2712	AE175(D)	stopped
451	IC2461	**AG645(D)**	Done
453	MCG-1-24-12	GMRT/27 067 (2014), GMRTarchive	
471	NGC2992	10C-119(C&D;cont), **AD402(C)**	Done
477	M81	THINGS(AW326/B),**AY48(D)**	Done for now
484	NGC3079	14A-058(A), **10C-119(C)**	Done
497	NGC3227	14A-468(C->CnB), 16A-275(C), 14B-396(D)	
548	NGC3718	**AR302(D)**	Done
560	NGC3786	**AM559(DnC)**	Done
579	NGC3998	AV237(D)	non-detection
585	NGC4051	**AP270(C)**	Done
593	NGC4138	EDGES WSRT, WSRTarchive	
595	NGC4151	12A-428(B)	
609	NGC4258	**AR302(D)**	Done
616	NGC4395	**TEST00(D)**	Done
631	NGC4593	**AM788(C)**	Done
653	NGC4941	AM834(C), AW701(C), 14B-396(D)	
654	NGC4939	**16A-269(C)**	Done
665	NGC5033	**AP270(D), AW701(C)**	Done
688	NGC5290	Tang+08/ApJ/679/1094(D)	No archive
712	NGC5506	**AM554(D)**	Done
717	NGC5548	**AG645(D)**	Done
739	NGC5728	14B-396(CnB), 14A-468(DnC)	
1046	NGC6814	**AM788(C)**	Done
1182	NGC7469	AM559(C), AG559(D), **AL551(D)**	Done
1184	NGC7479	14B-396(C), **AE175(D)**	Done
1198	NGC7682	Kuo+08/ApJ/679/1047=AL516(D)	No archive

- ~54% processed.
- Using NRAO's resources, JVLA data being processed (2024).

Archival



JVLA



40 Jansky VLA data (66 SBs) 40.9%

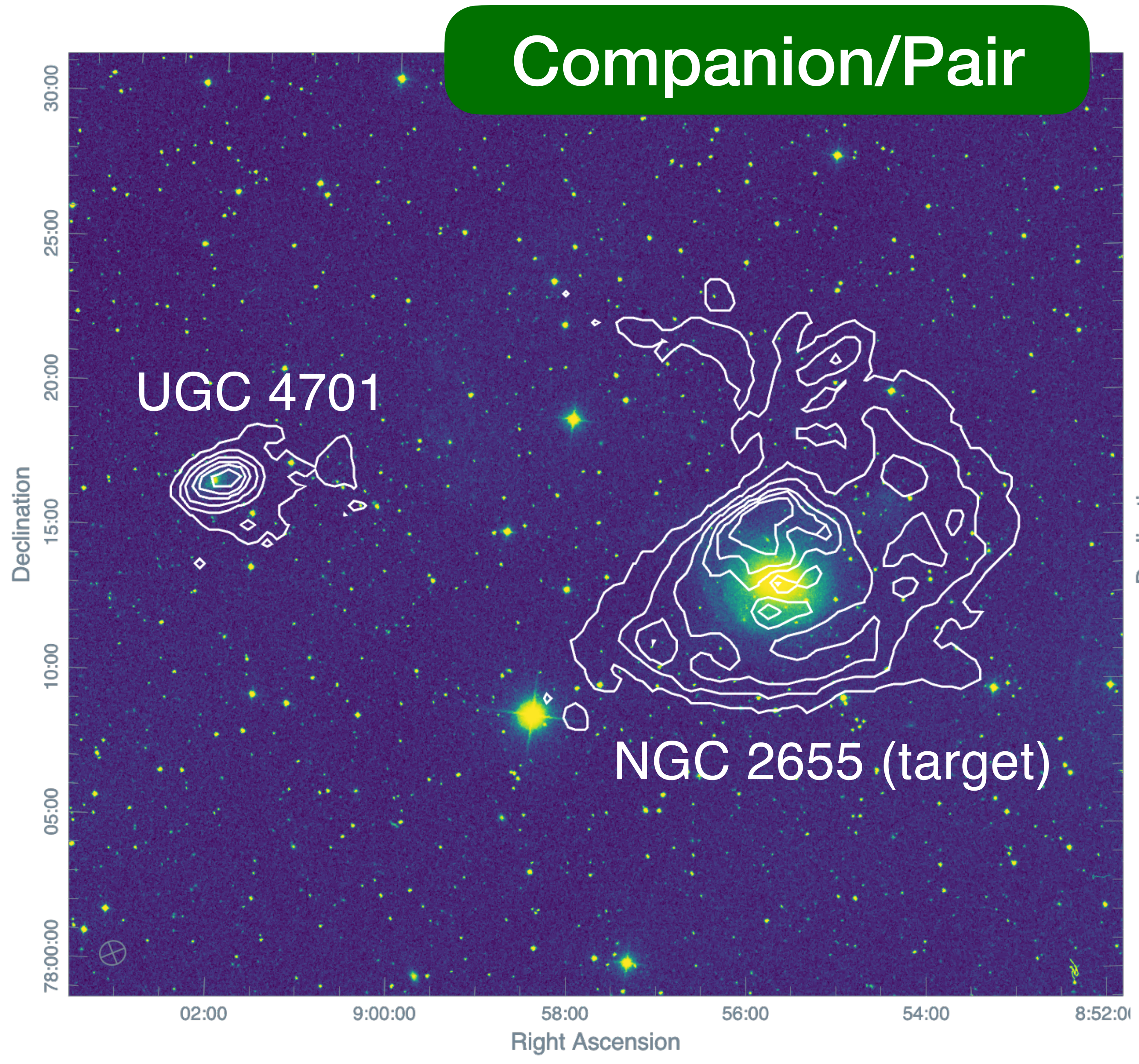
BAT	CName	SB ID	Cube Status	Status
13	LEDA136991	37724317	Done for now	Halfdone
13		44649808	Done	
64	NGC452	37724319		
64		44690930		
96	MCG-1-5-47	37724321	Done	Done
96		44650529	Done	
151	LEDA166445	37724323		
151		44652424		
153	NGC1125	37724141	Done for now	Halfdone
153		44652837	Done	
156	MCG-2-8-14	37724143		
156		44652837	non-detection?	
205	ESO549-49	37724215		
205		44664606		
237	LEDA86269	37724217		Halfdone
237		44653129	Done	
310	UGC3374	44659792	Done	Done
349	UGC3601	37724219	sbatch	
349		44653306	sbatch:COMPL	
382	Mrk79	37724221	Done	Halfdone
382		44653306		
400	IC486	37724293	Done	Done
400		44653490	Done	
416	Fairall272	37724295	re-pipeline	
416		44653669		
470	Z122-55	37724297	non-detection?	
470		44653854		
475	NGC3035	37724299	Done	Done
475		44654041	Done	
517	UGC5881	37724301	Done	Halfdone
517		44654222	re-pipeline	
520	NGC3431	37724303	sbatch:COMPL	
520		44654622	re-pipeline	
554	LEDA1735060	37724305	sbatch:COMPL	
554		44673499	non-detection?	
588	UGC7064	37865685		
588		44690973		

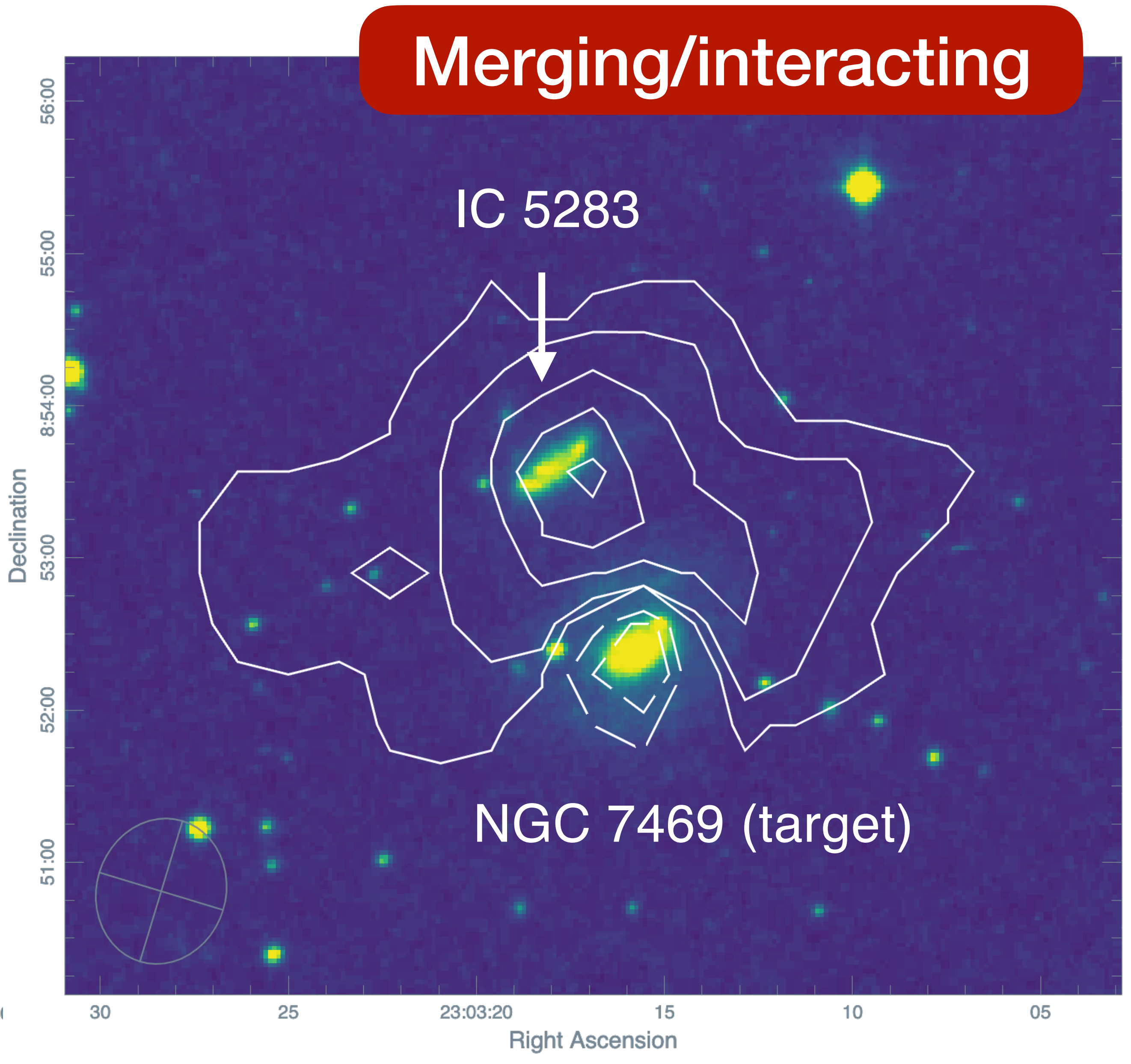
590	NGC4102	37866044	Done	Halfdone
590		44651679	re-pipeline	
592	Mrk198	37865970		
592		44651679	re-pipeline	
621	NGC4500	37724325		
621		44651679	re-pipeline	
633	NGC4619	-	no obs	
633		44691022		
659	NGC4992	37867299		
659		44655693		
670	MCG-3-34-64	37868013		
670		44747234		
682	NGC5252	37868810		
682		44656051		
687	Z102-48	37724335	Done	Done
687		44747338	Done	
723	NGC5610	37724337	sbatch:COMPL	
723		44747390	Done for now	
733	NGC5674	37869252	Done	Halfdone
733		44747441	Stopped	
766	NGC5899	44747492	Done	Done
772	MCG-1-40-1	37724313		
772		44660327		
783	NGC5995	37724315		
783		44660327		
828	NGC6232	37869600		
828		44660506	re-pipeline	
876	ARP102B	37724343		
876		44660820		
1020	UGC11397	-	no obs	Done
1020		44660995	Done	
1042	LEDA90334	37724347	Done	Done
1042		44661345	Done	
1161	Mrk915	37724349	obs twice	
1161		44661518		
1162	UGC12138	37724351		
1162		44661717		
1177	UGC12282	37724355	Done	Done
1177		44661892	Done	
1202	UGC12741	37859245	Done	Done
1202		44747543	Done	

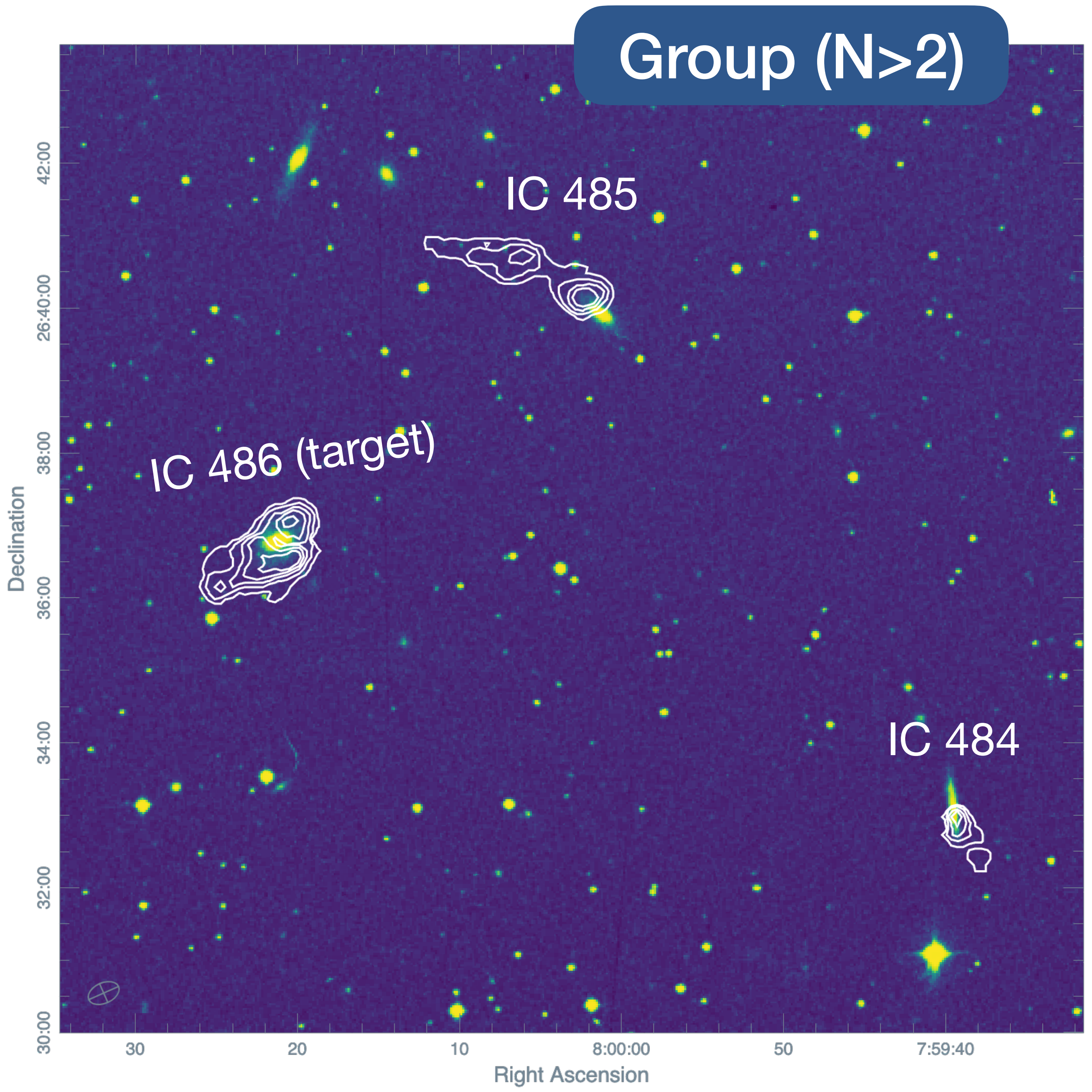
Preliminary

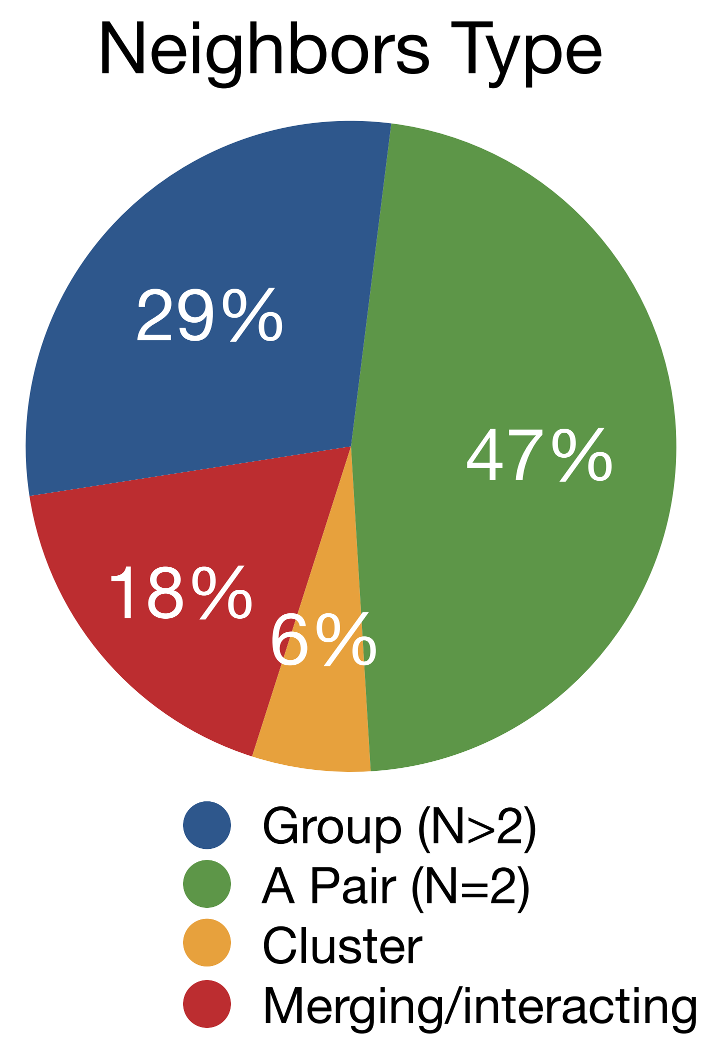
The BASS-HI & environments

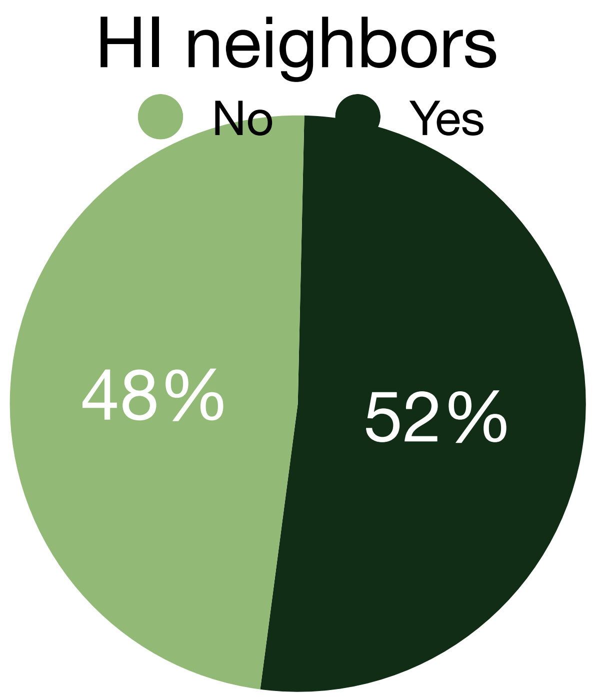
Small statistics with random selection, could be biased because of the distance
total 97 galaxies in BASS-HI
Result from ~ 31%



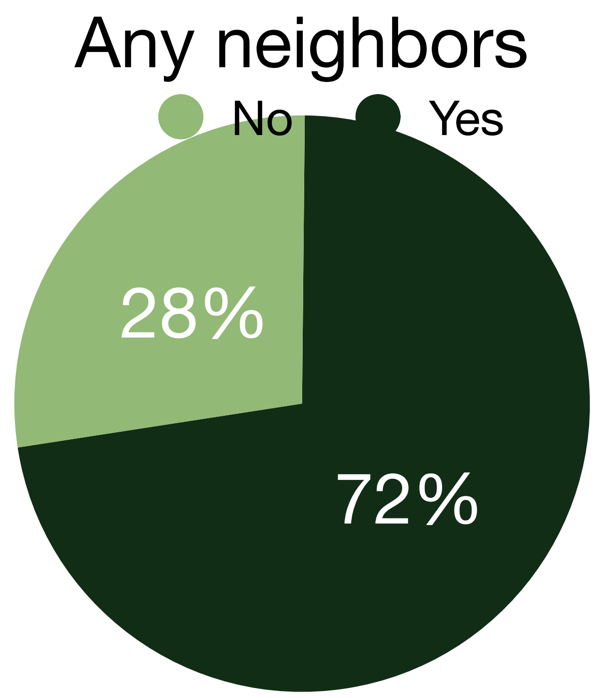




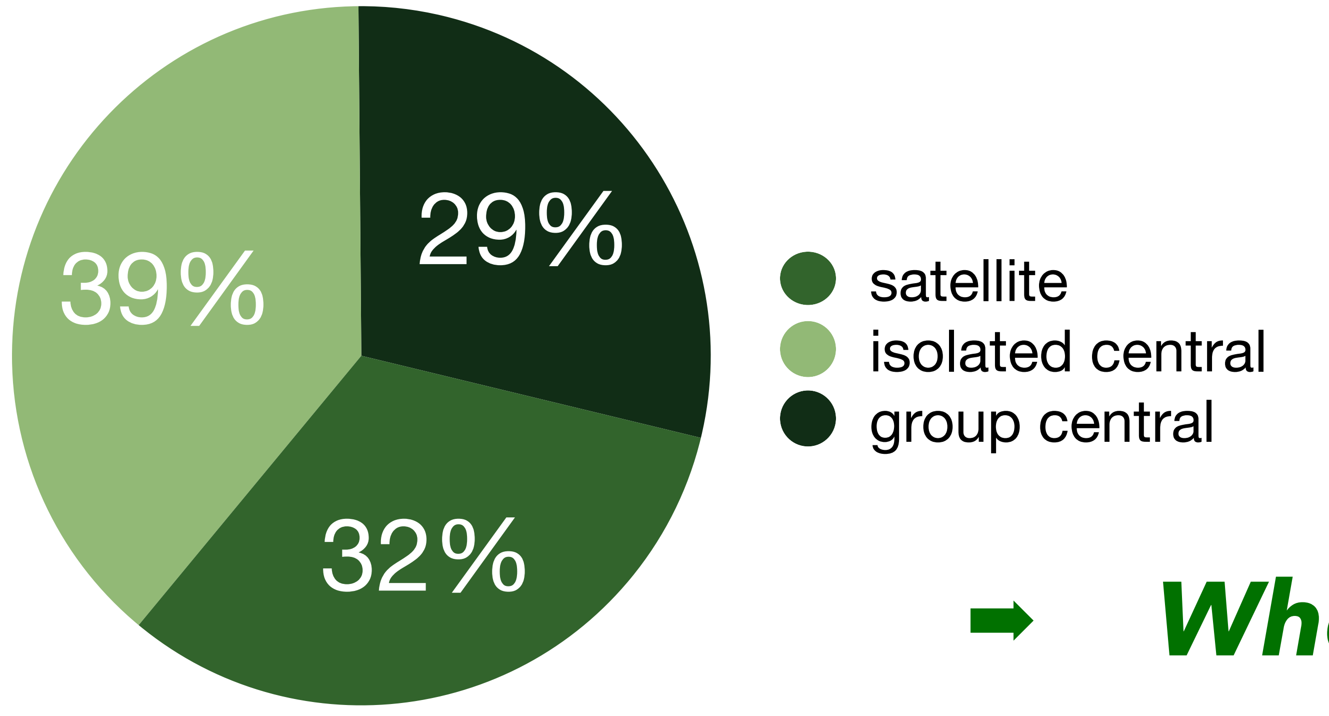




In cube HI detections



With any neighbors
(*including optical + IR + UV)



xGASS (2018) group catalog (Yang+2007)
Stellar mass matched to BASS-HI sample
10.21<log Mstar<11.17

➡ ***BASS-HI galaxies are likely to have neighboring galaxies.***

➡ ***When BASS-HI galaxies have neighbors, they are likely to have a companion galaxy, or located in the group env.***

The BASS-HI bar fraction

Does Seyferts have more prominent bar fraction?:

Pros: *Helfer & Blitz 1995; Kohno et al. 1999b; Baker 1999; Maiolino et al. 2000; Schinnerer et al. 2000; Kohno et al. 2001; Laine et al. 2001; Koda et al. 2002; Domínguez-Fernández; 2020 Si-Yue Yu et al. 2022*

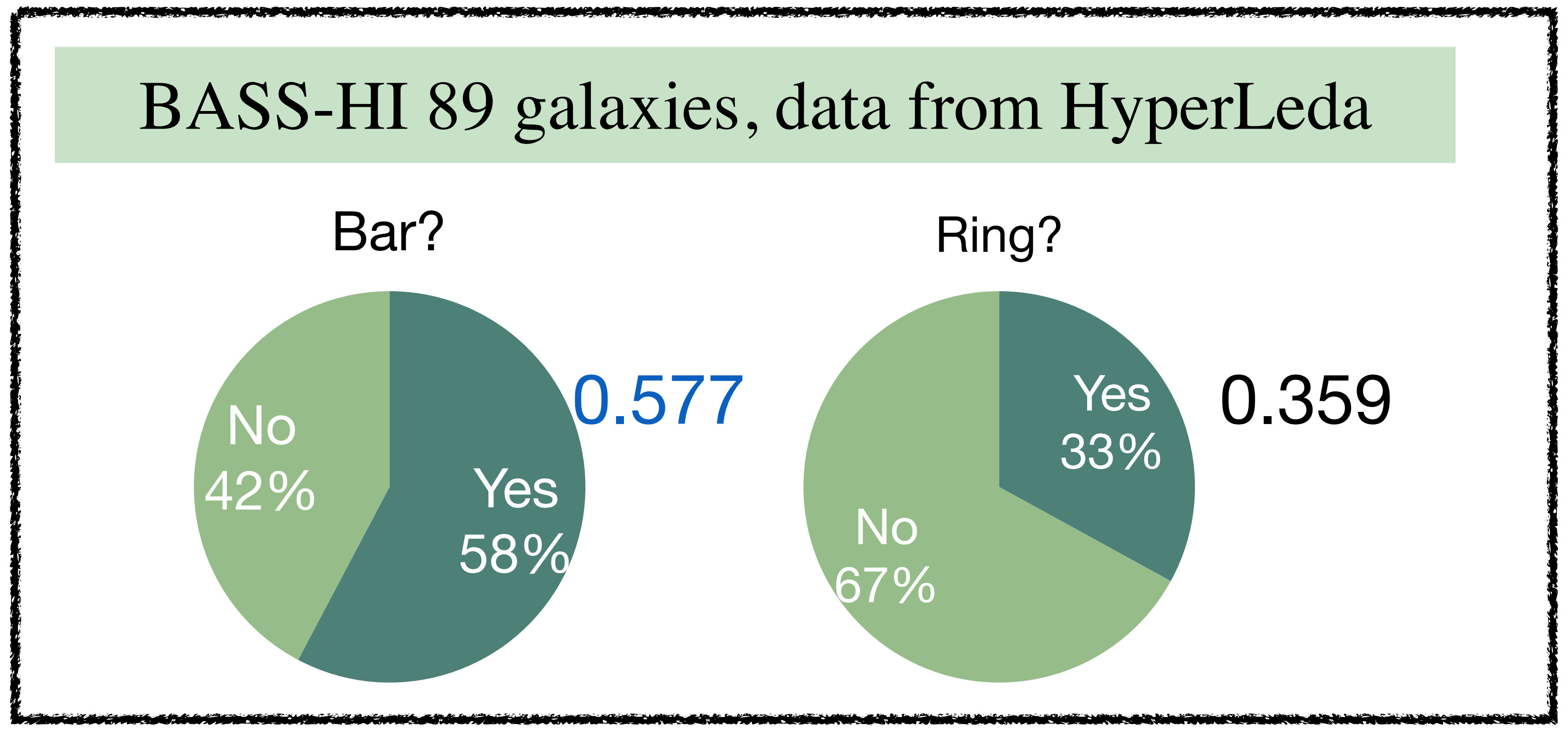
Cons: *McLeod, Rieke 1995; Mulchaey, Regan 1997; Ho et al. (1997c); Hunt & Malkan 1999; Laurikainen et al. 2004*

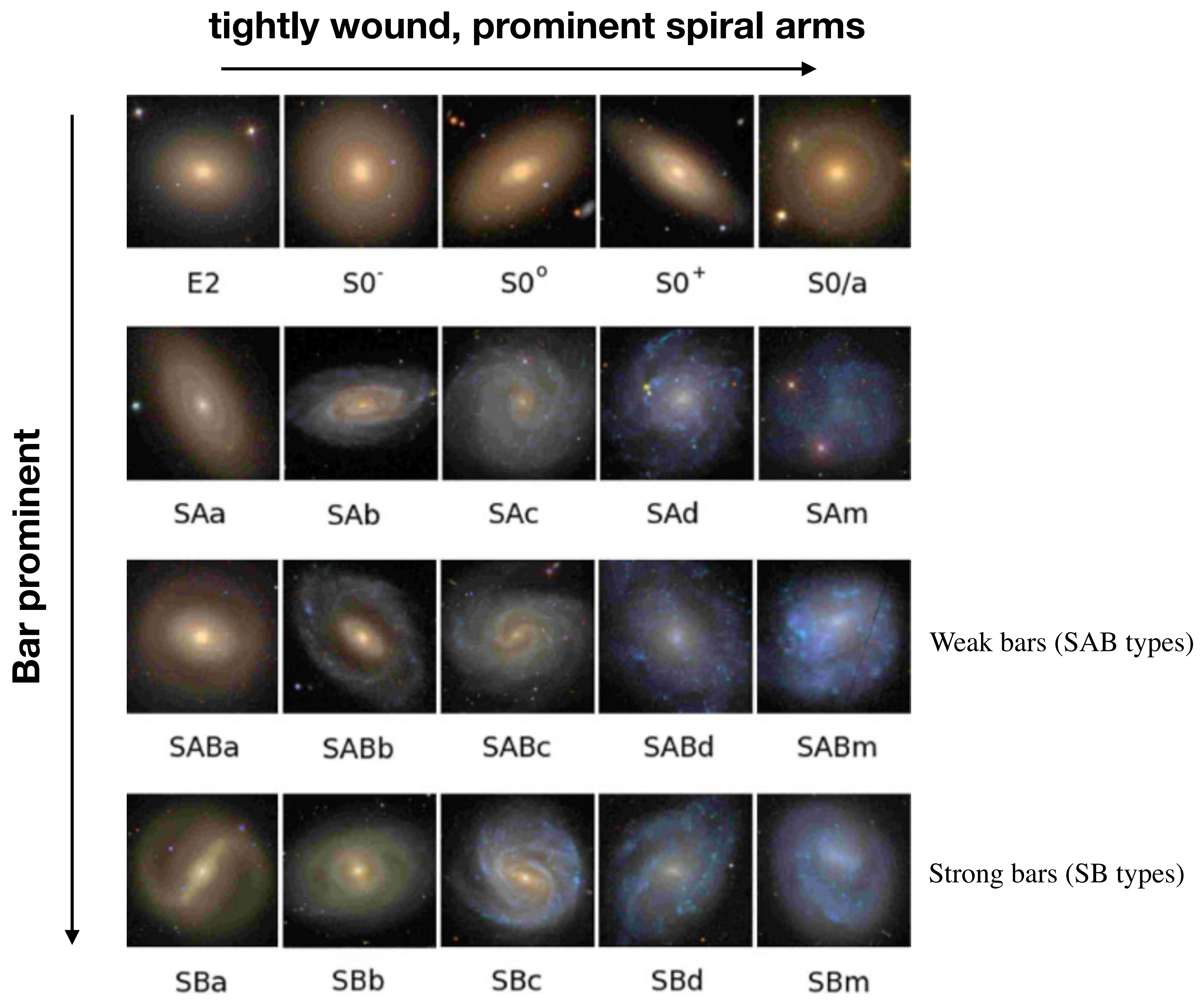
NGC 5728

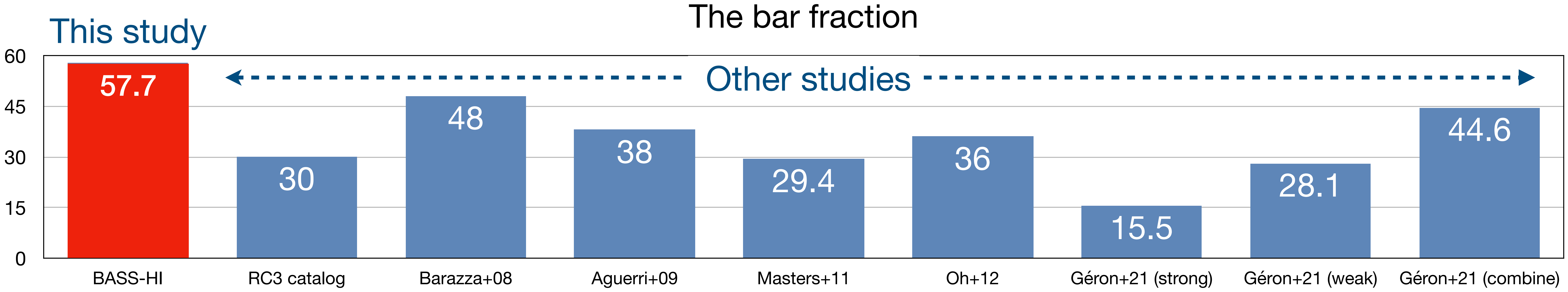
One of BASS-HI sample

Credit: ESA/Hubble, A. Riess et al., J. Greene

The BASS-HI bar fraction

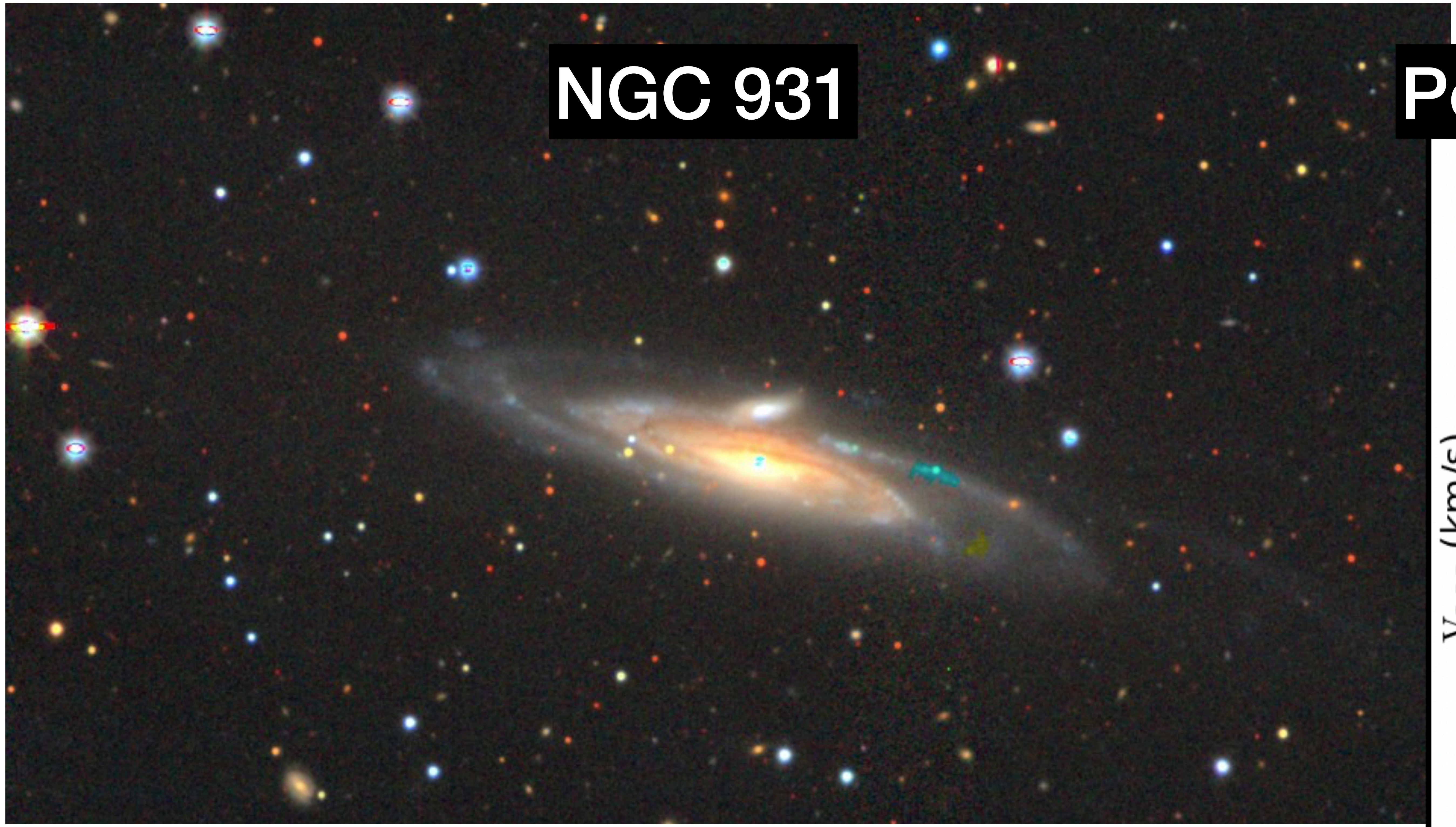




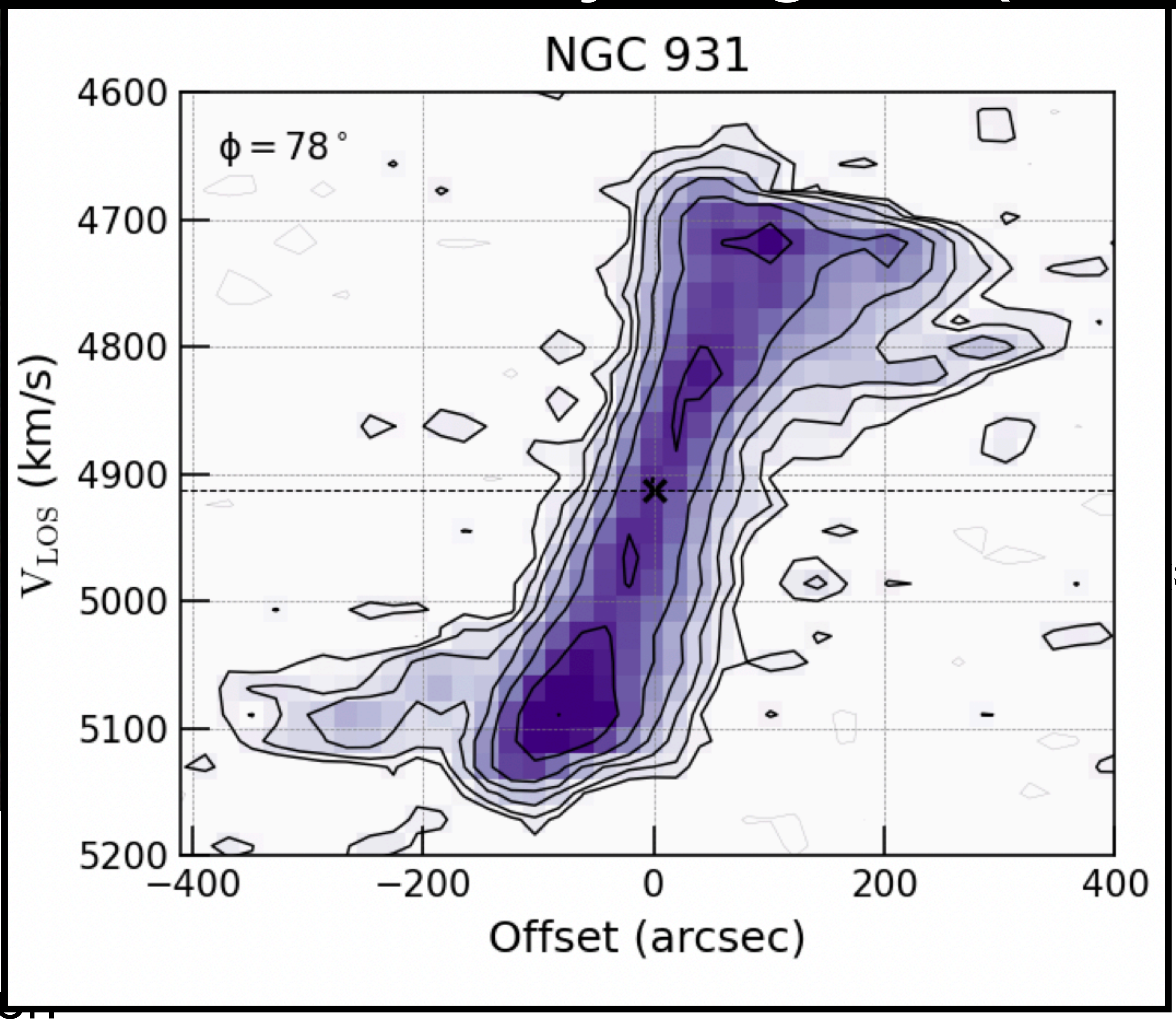


➡ ***BASS-HI galaxies are likely have higher galactic bar fraction***

NGC 931



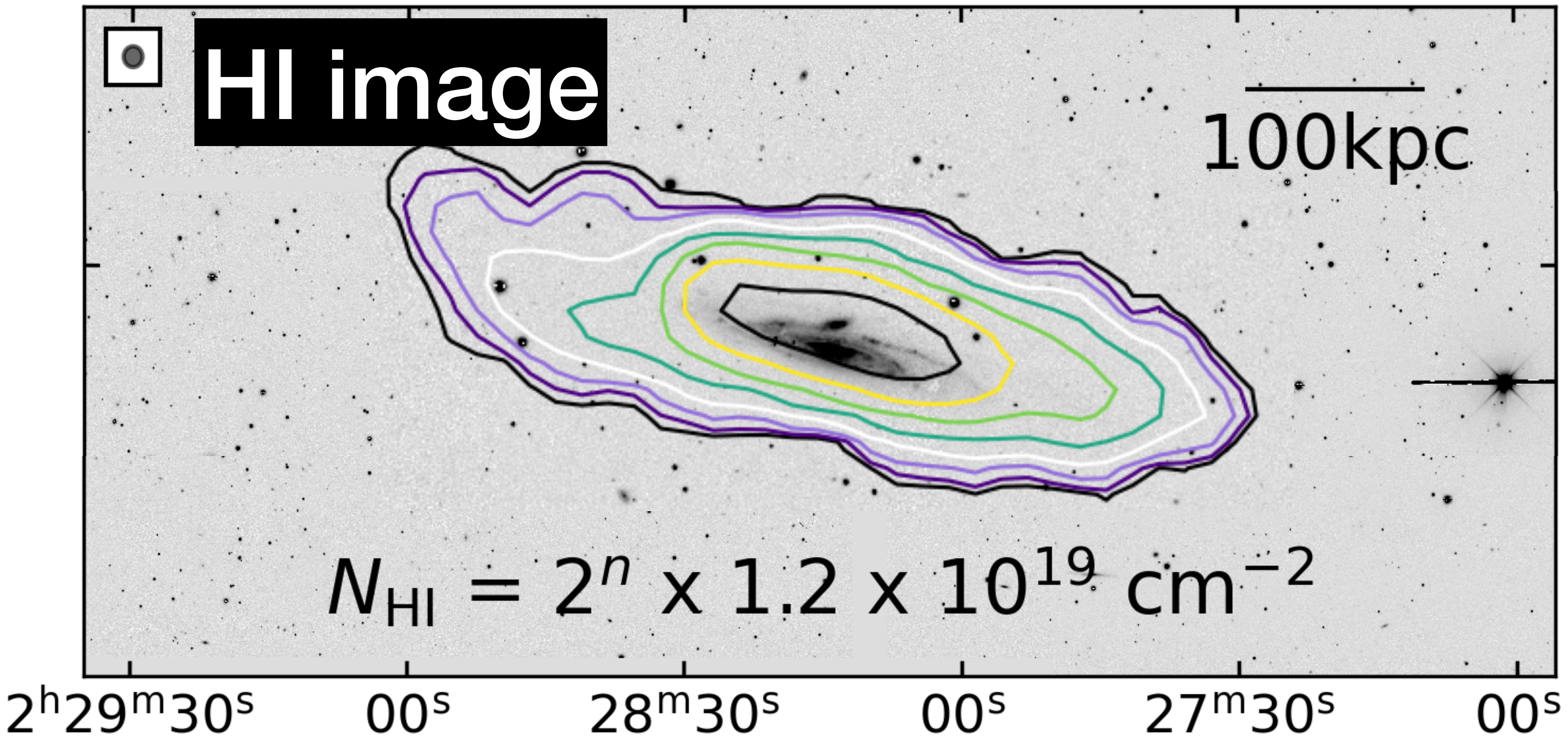
Position-velocity diagram (PVD)

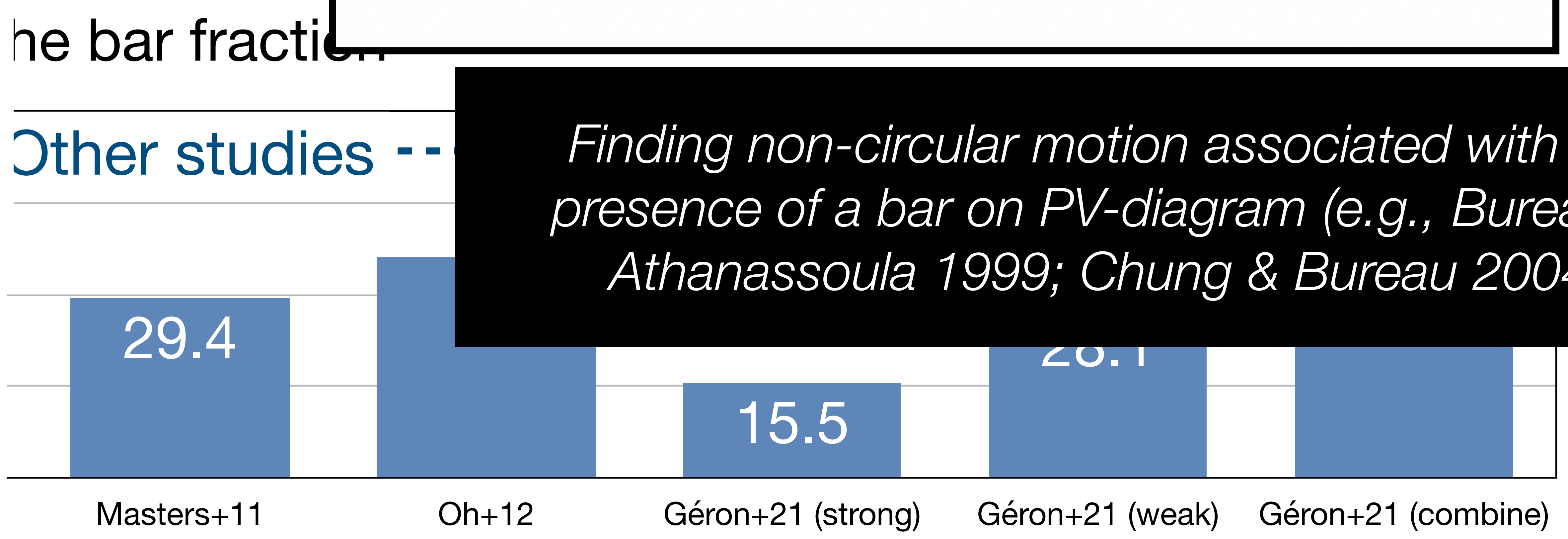


SAB types)

(SB types)

HI image

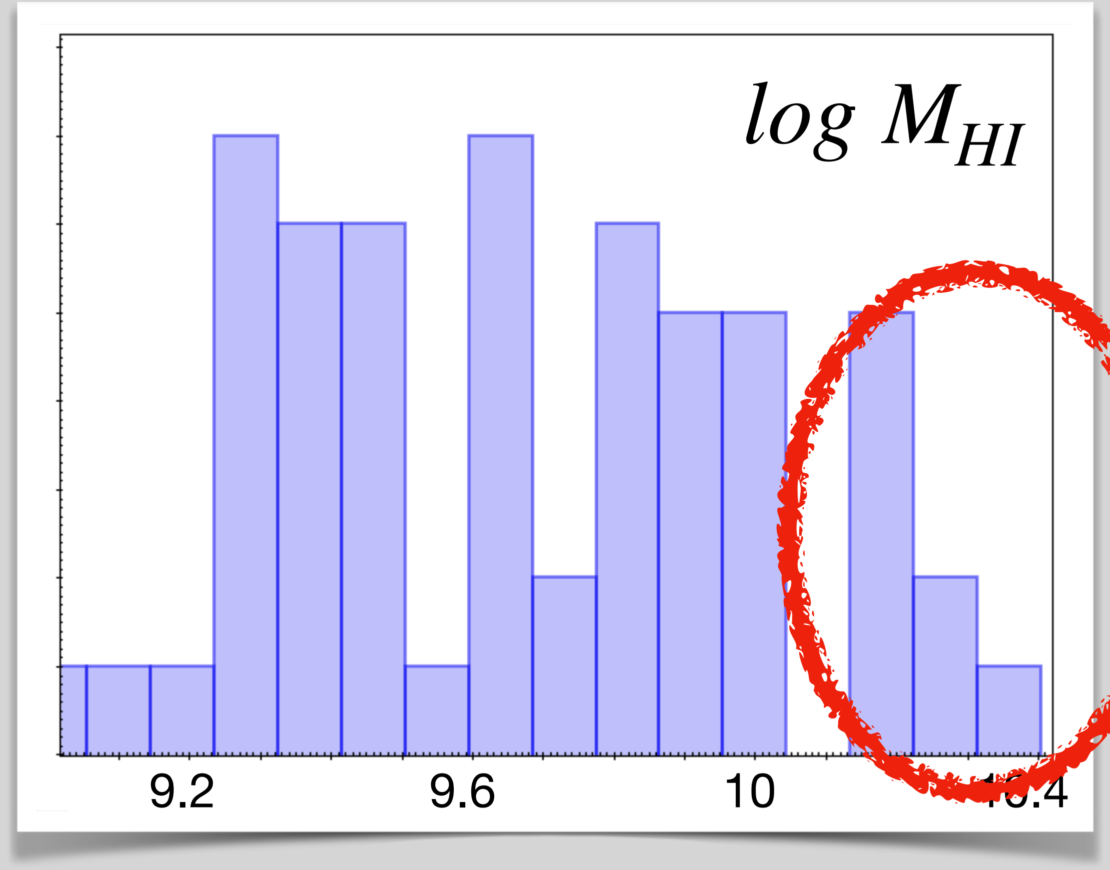




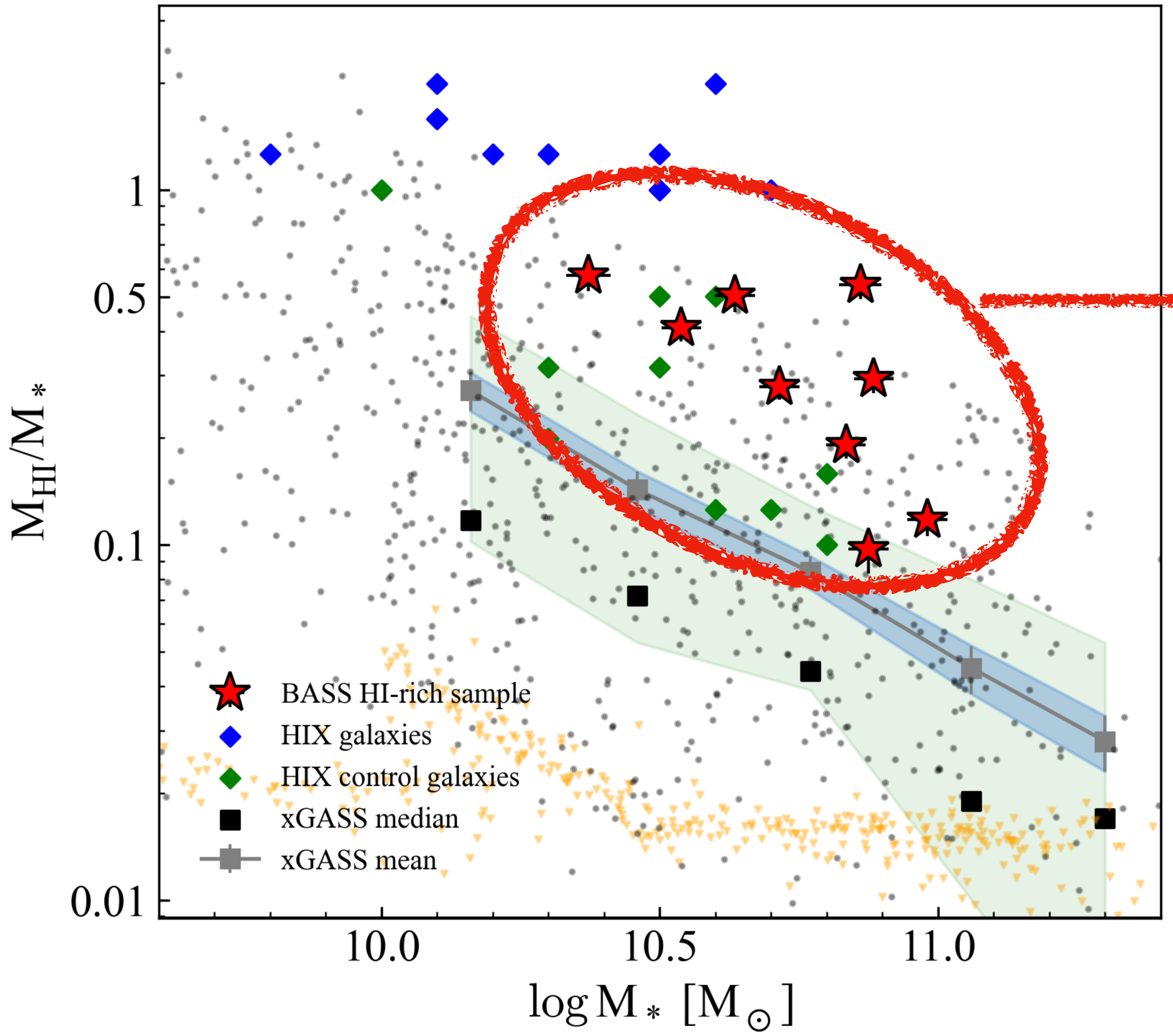
Finding non-circular motion associated with the presence of a bar on PV-diagram (e.g., Bureau & Athanassoula 1999; Chung & Bureau 2004)

➡ ***BASS-HI galaxies will provide a (unbiased) statistic on the gas-bar***

The HI-richest systems



Subsamples of 9 BASS-HI-rich galaxies ($log\ M_{HI} > 10.04\ M_{\odot}$)

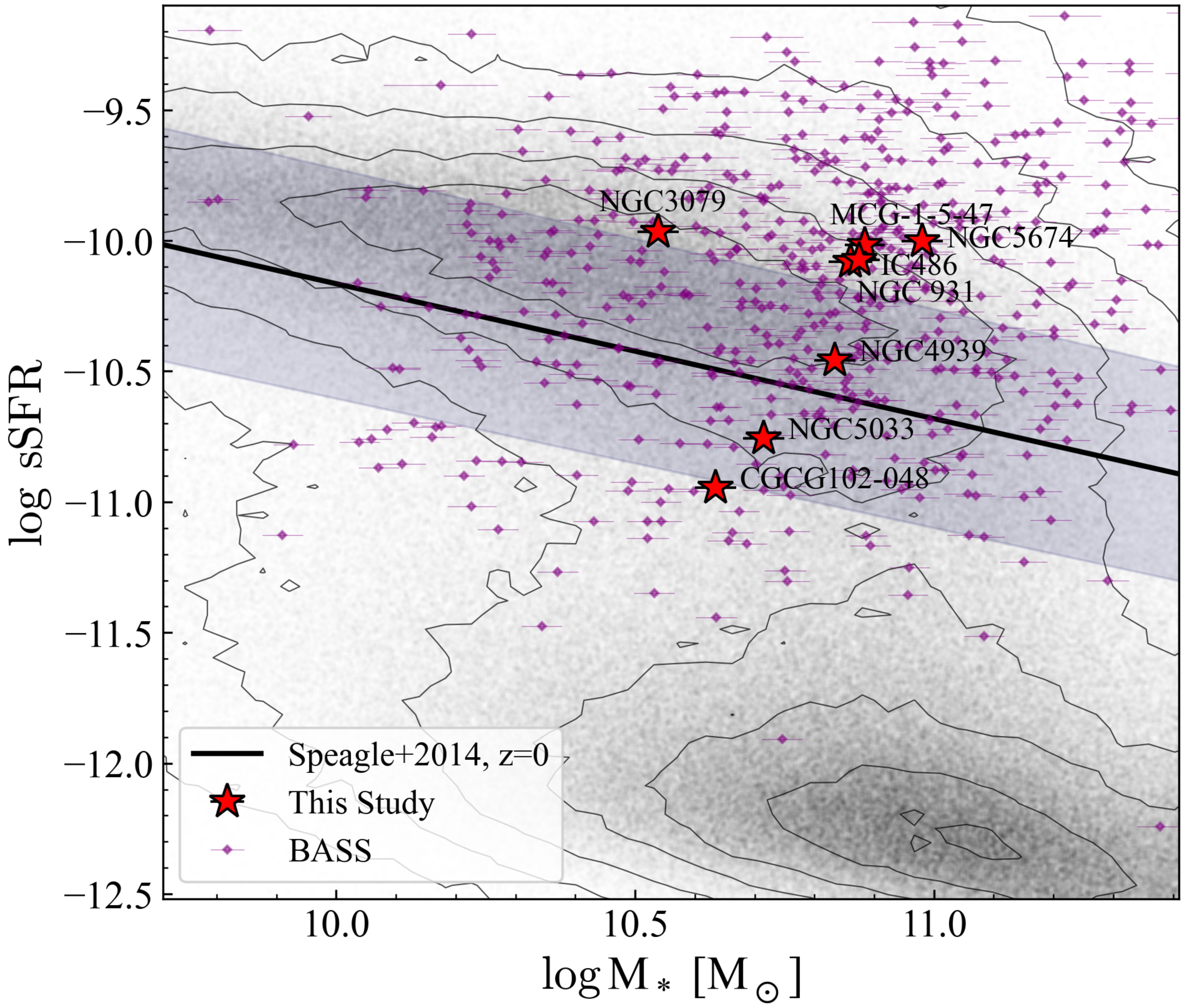


How these galaxies ended up HI-rich?

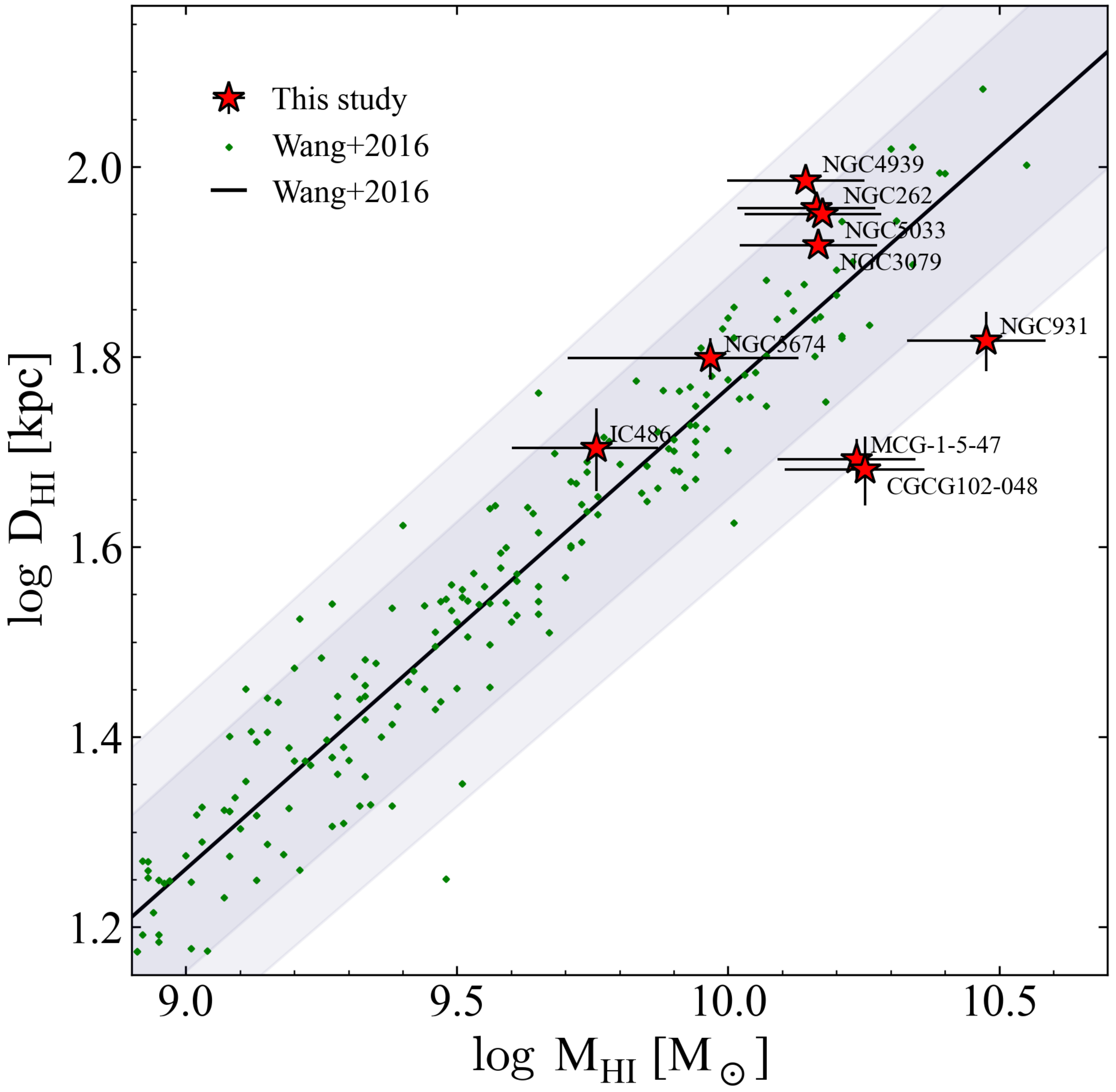
- HI-rich systems: **HI eXtreme galaxies** (Lutz et al. 2018), **HI monster** (Lee et al. 2014) …etc.
- The growth of the HI-rich galaxies: **NOT consumed** (inefficient SF), **OBTAINED** (recent accretion, minor merger, filament…etc.)

The HI-richest systems on the scaling relations

Star Forming Main Sequence



HI size-mass relation



- BASS-HI-rich galaxies are globally **star-forming** (not in a phase of quenching).
- BASS-HI-rich galaxies generally follow HI size-mass relation, except 3 those have neighbors show **HI mass excess**.

Resolved HI kinematics: angular momentum & stability parameter

Global stability parameter q

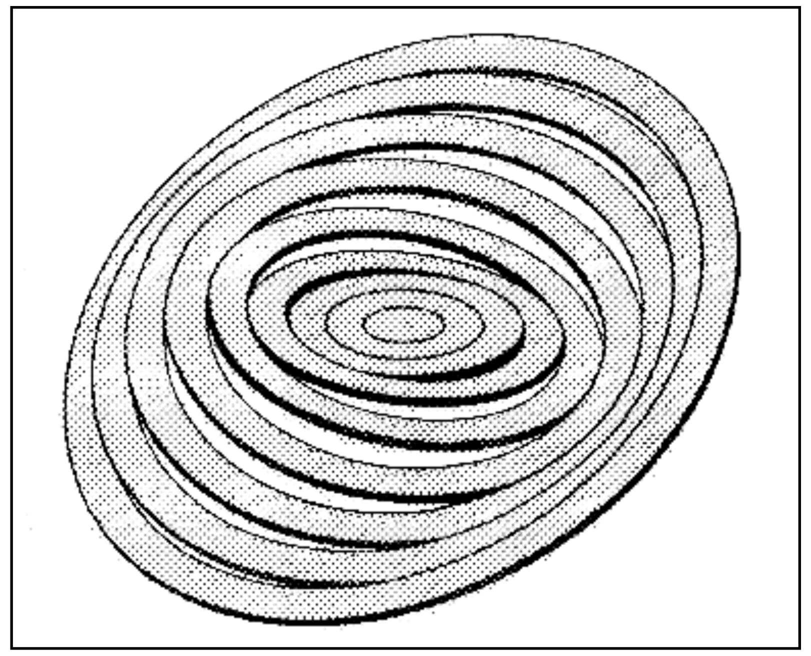
$$q = \frac{j_b \sigma}{G M_b}$$

atomic gas fraction

$$f_{atm} = log\ M_{atm}/M_{baryon}$$

The baryonic specific angular momentum

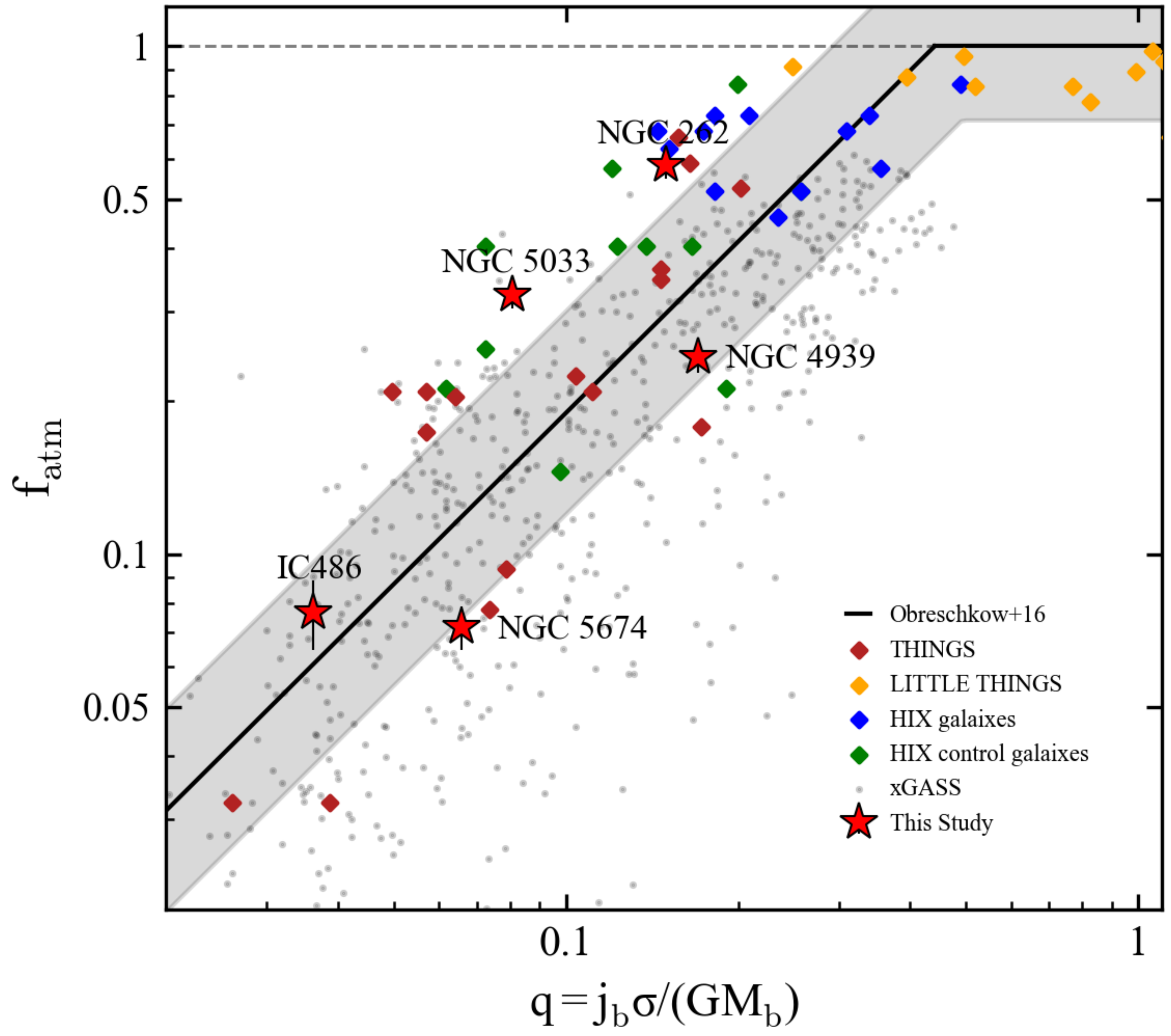
$$j_b = \frac{\Sigma_i (1.35 M_{HI,i} + M_{*,i}) v_{rot,i} r_i}{\Sigma_i (1.35 M_{HI,i} + M_{*,i})}$$



Tilted Ring Model

3D-Barolo: 3D-Based Analysis of Rotating Object via Line Observations

(Di Teodoro & Fraternali 2015)

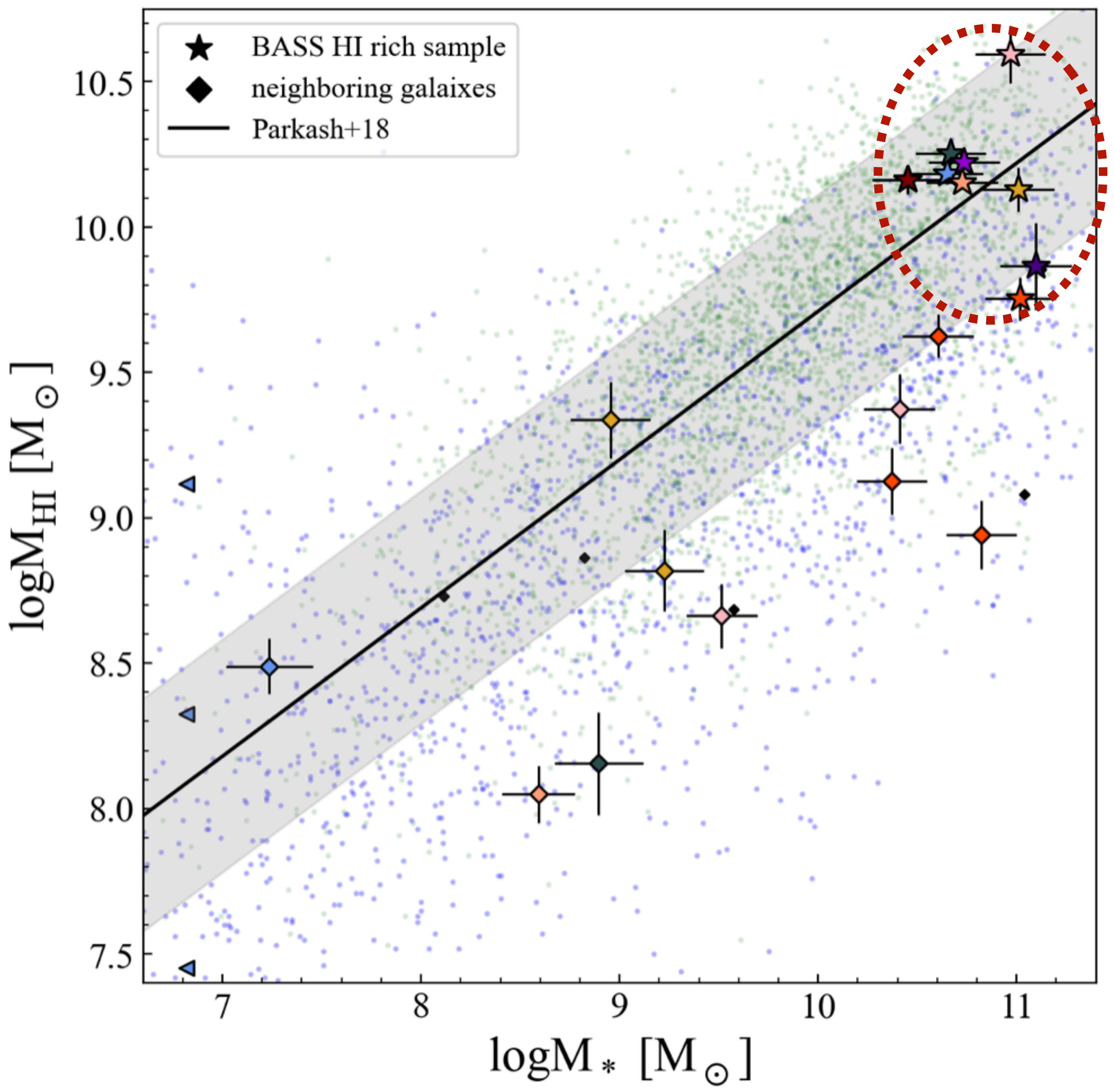


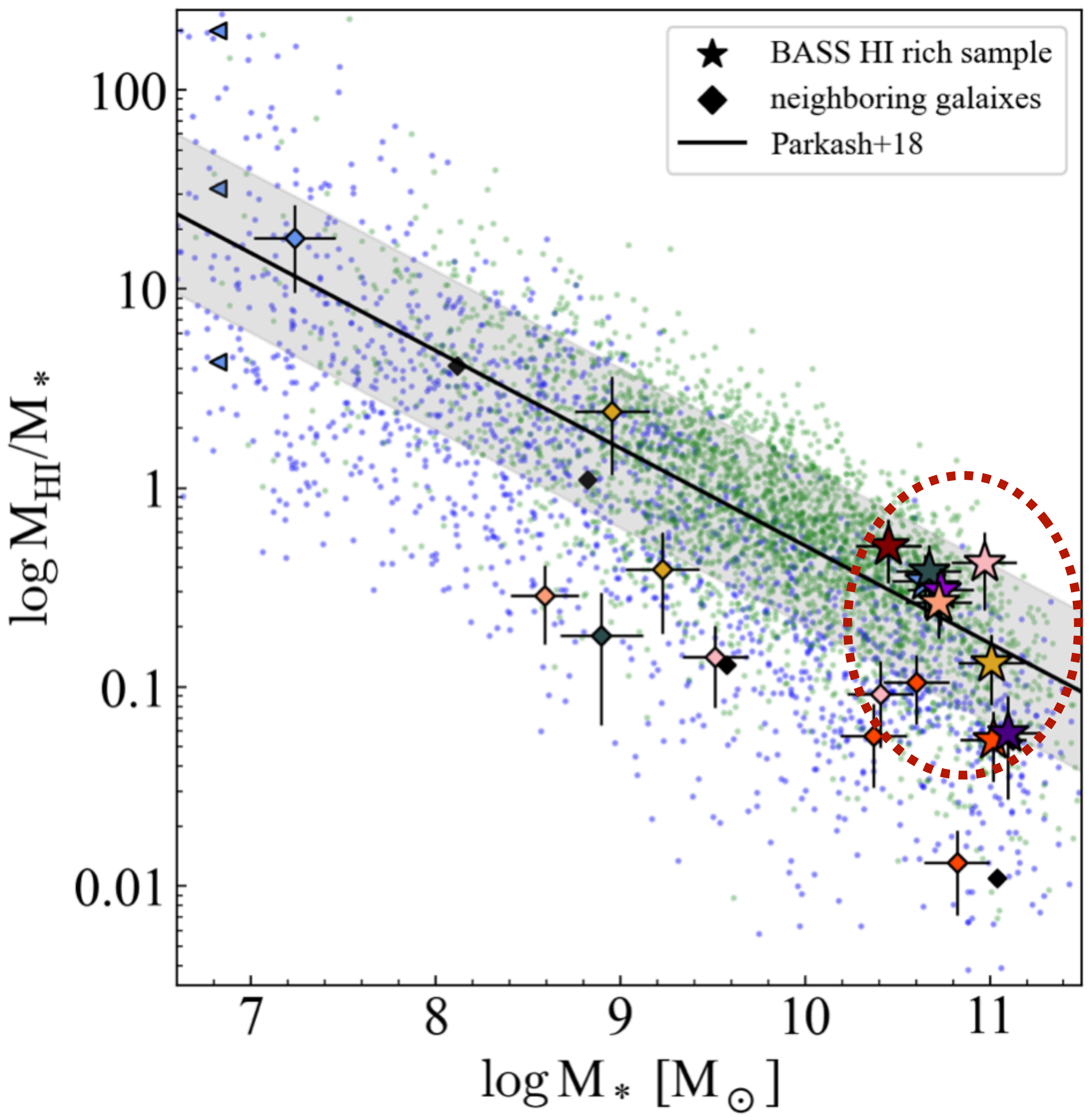
The stability model for flat isolated exponential disk galaxies

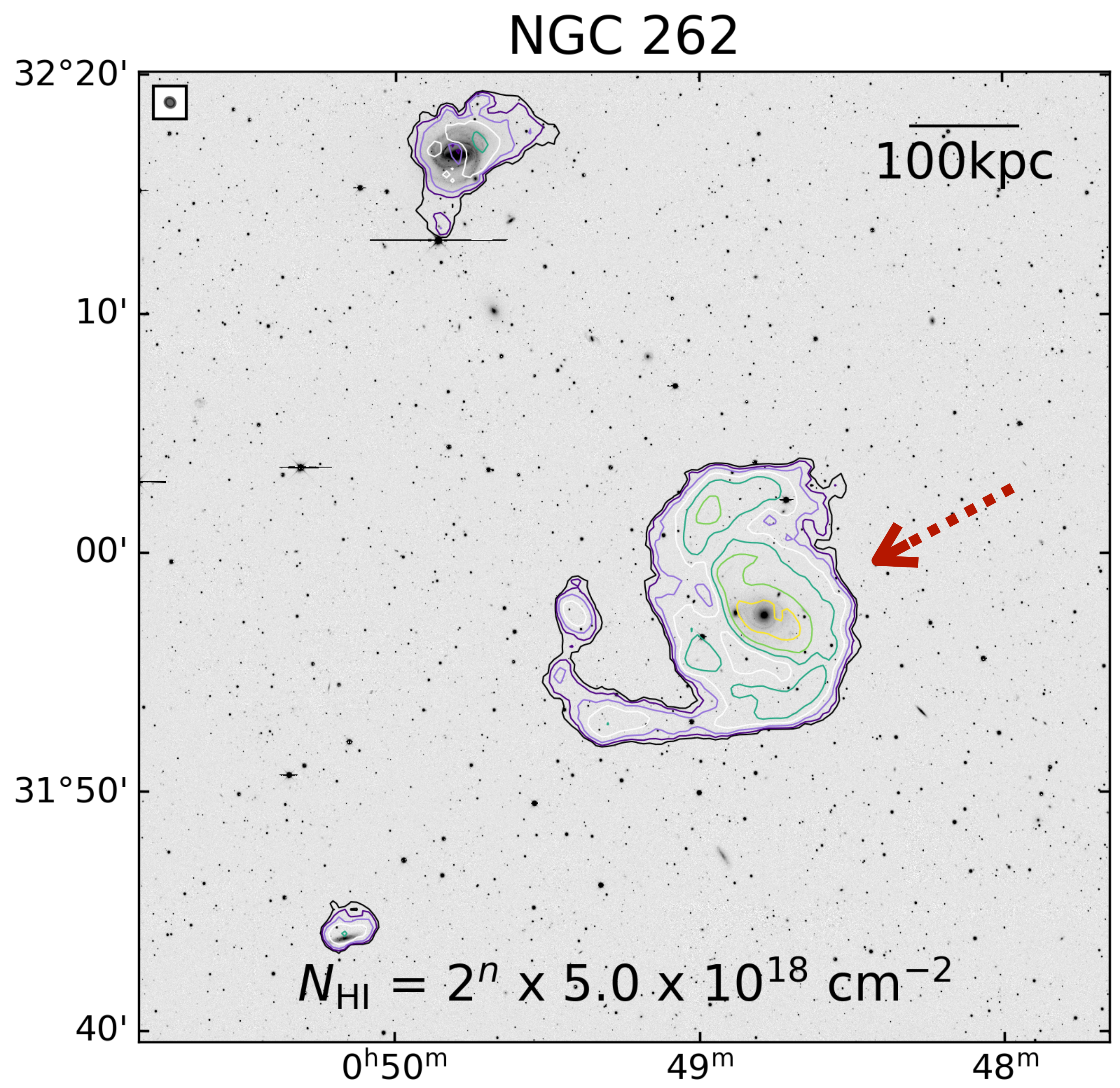
(Obreschkow et al. 2016)

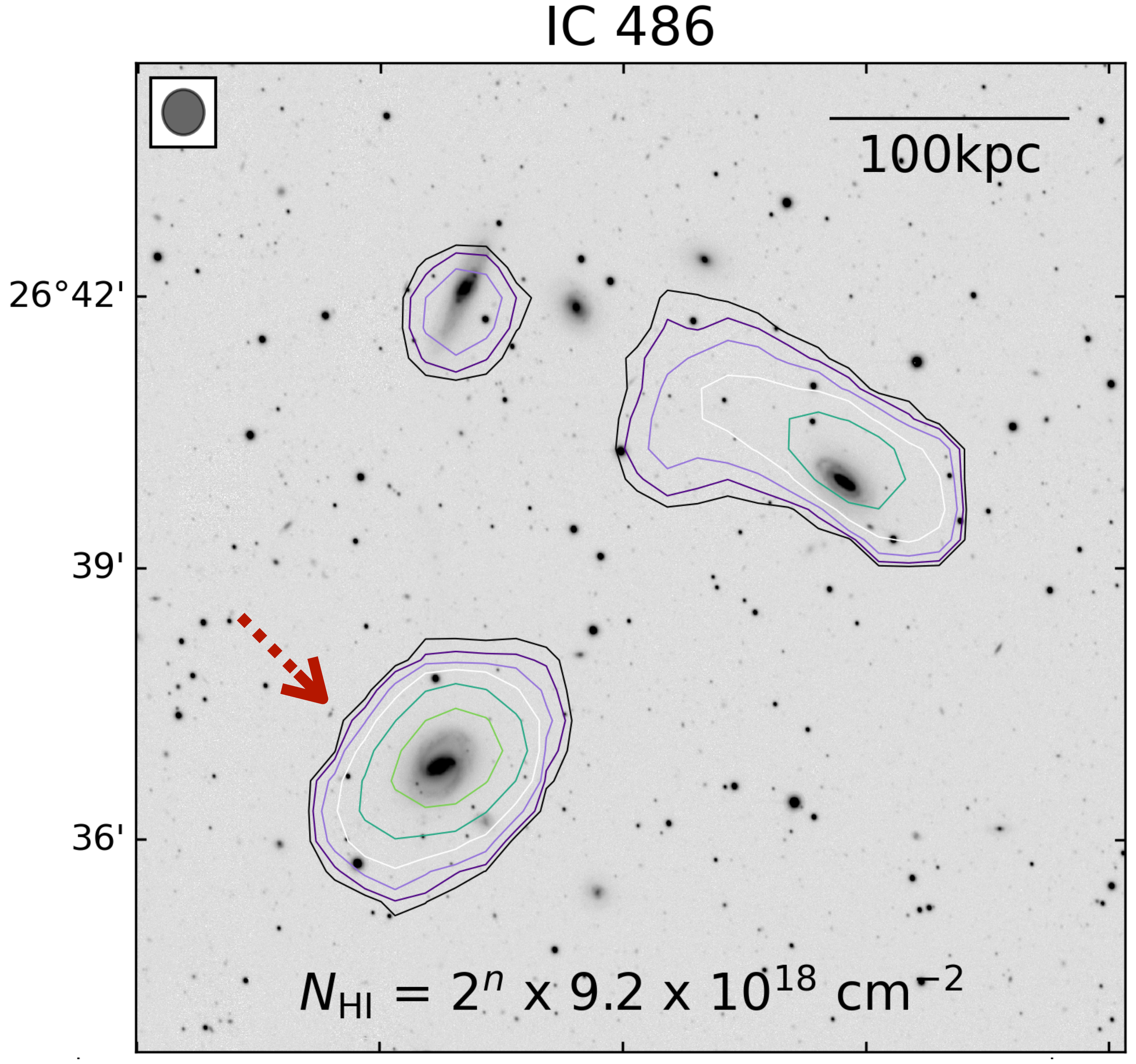
- 5 moderate inclined galaxies
- 3 followed general disc kinematics
- 2 showed mild increment in f_{atm}

BASS-HI-rich galaxies & neighbors



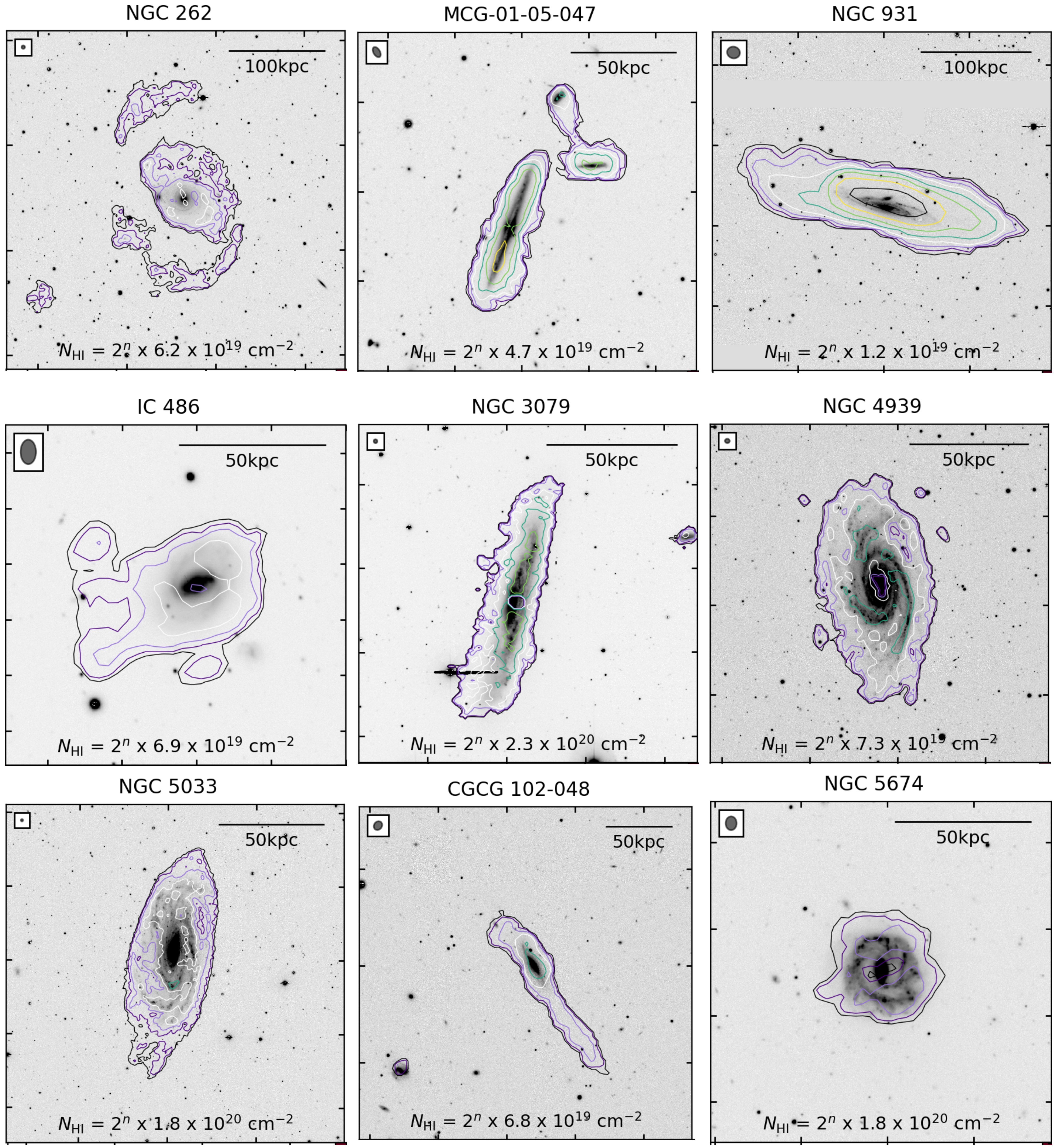


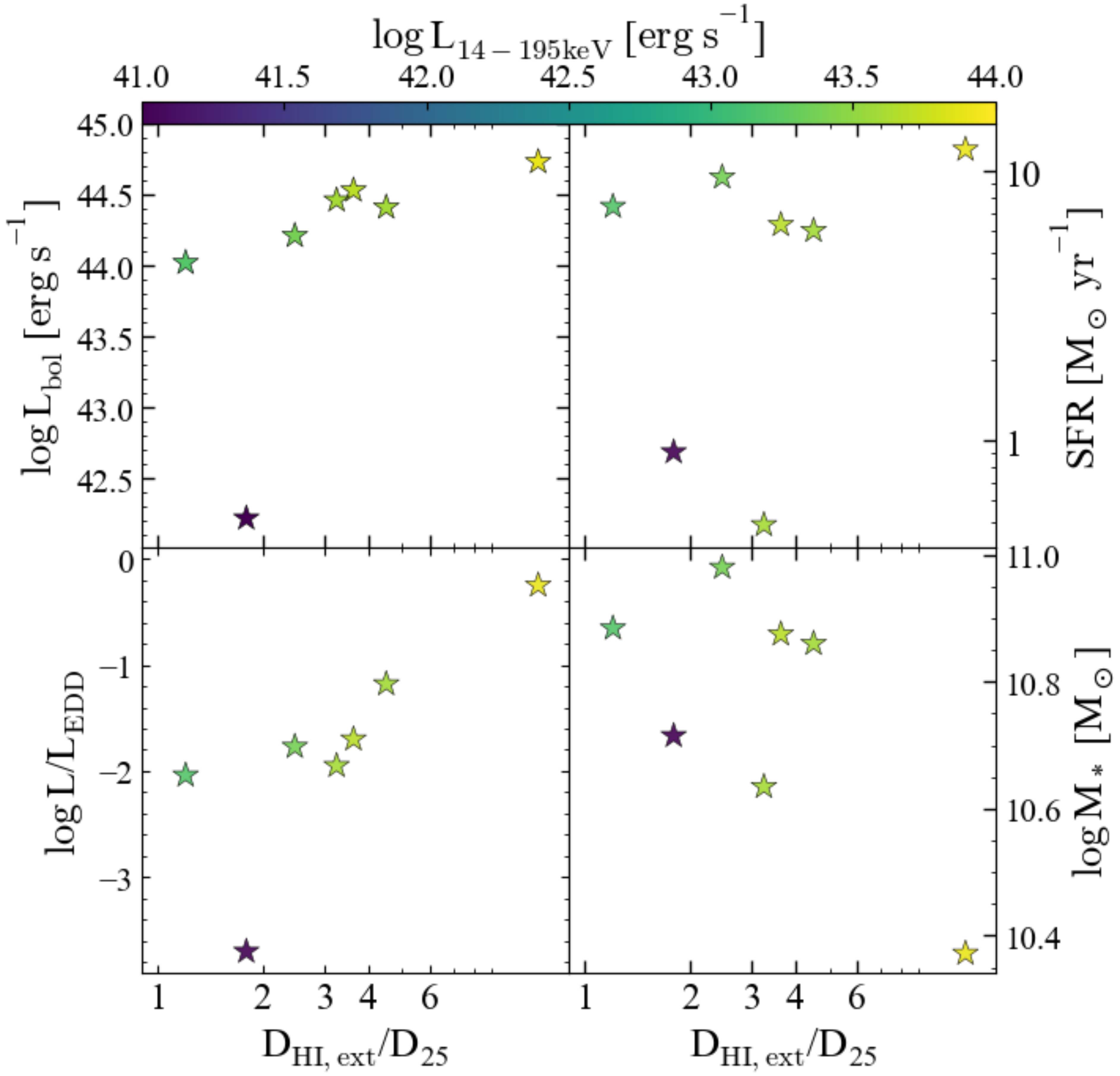




- ***All BASS-HI-rich galaxies are the most massive galaxies in their system***
  - The hard X-ray hosts selection effect?
  - Possibility of recent gas accretion to trigger the central X-ray AGN?

HI extent (morphology) relates to X-ray luminosity





More HI extended hosts show higher L_{bol} & λ_{Edd}

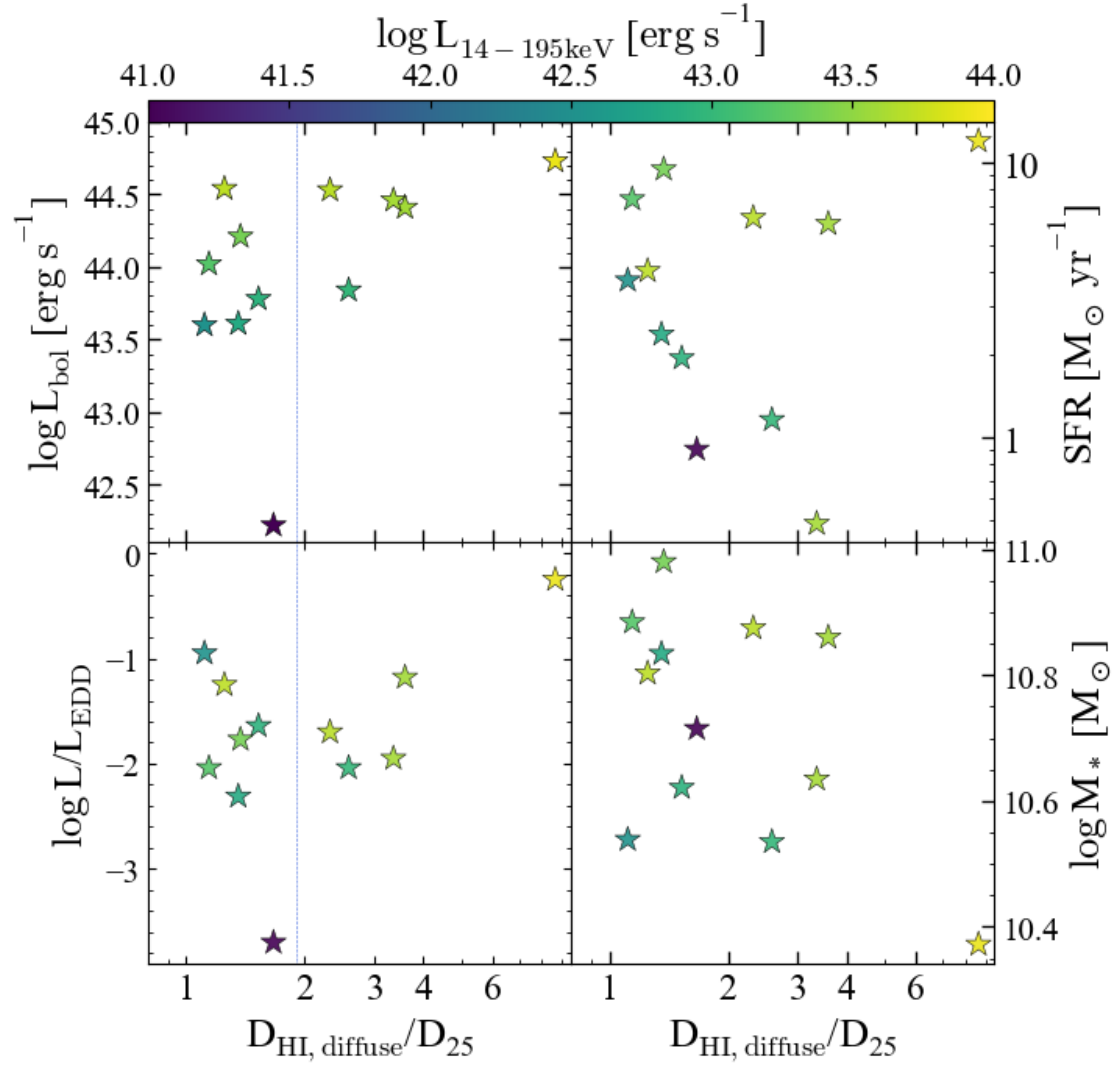
- Gas accretion indeed could be related to AGN activity
- HI extent as an environment tracer (e.g., tidal interaction)

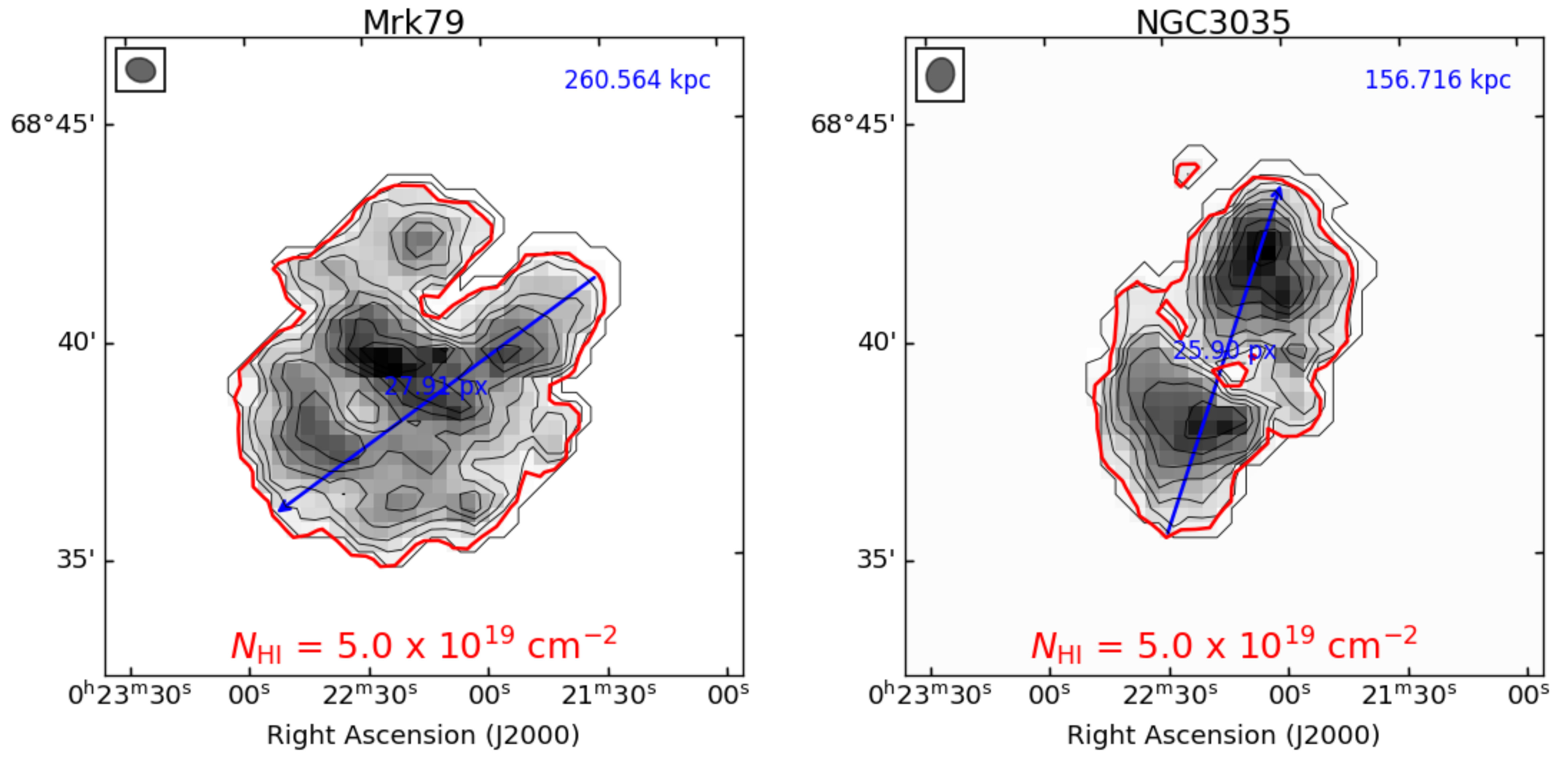
Summary & Future work

- ➡ **BASS-HI study** is one of **the largest HI imaging survey** on local AGN host galaxies. (~100 galaxies)
- ➡ This study was started to resolve the gas origin & accretion history for AGN feeding.
- ➡ **BASS-HI galaxies** are likely to **located in the gas-rich group environments.**
- ➡ **BASS-HI-rich galaxies** appears to have experienced **a recent gas inflow.**
- ➡ **HI extent (morphology)** of **BASS-HI-rich galaxies** show mild correlation to hard X-ray luminosity and bolometric luminosity.

- And more to come!

HI extent (morphology) relates to X-ray luminosity





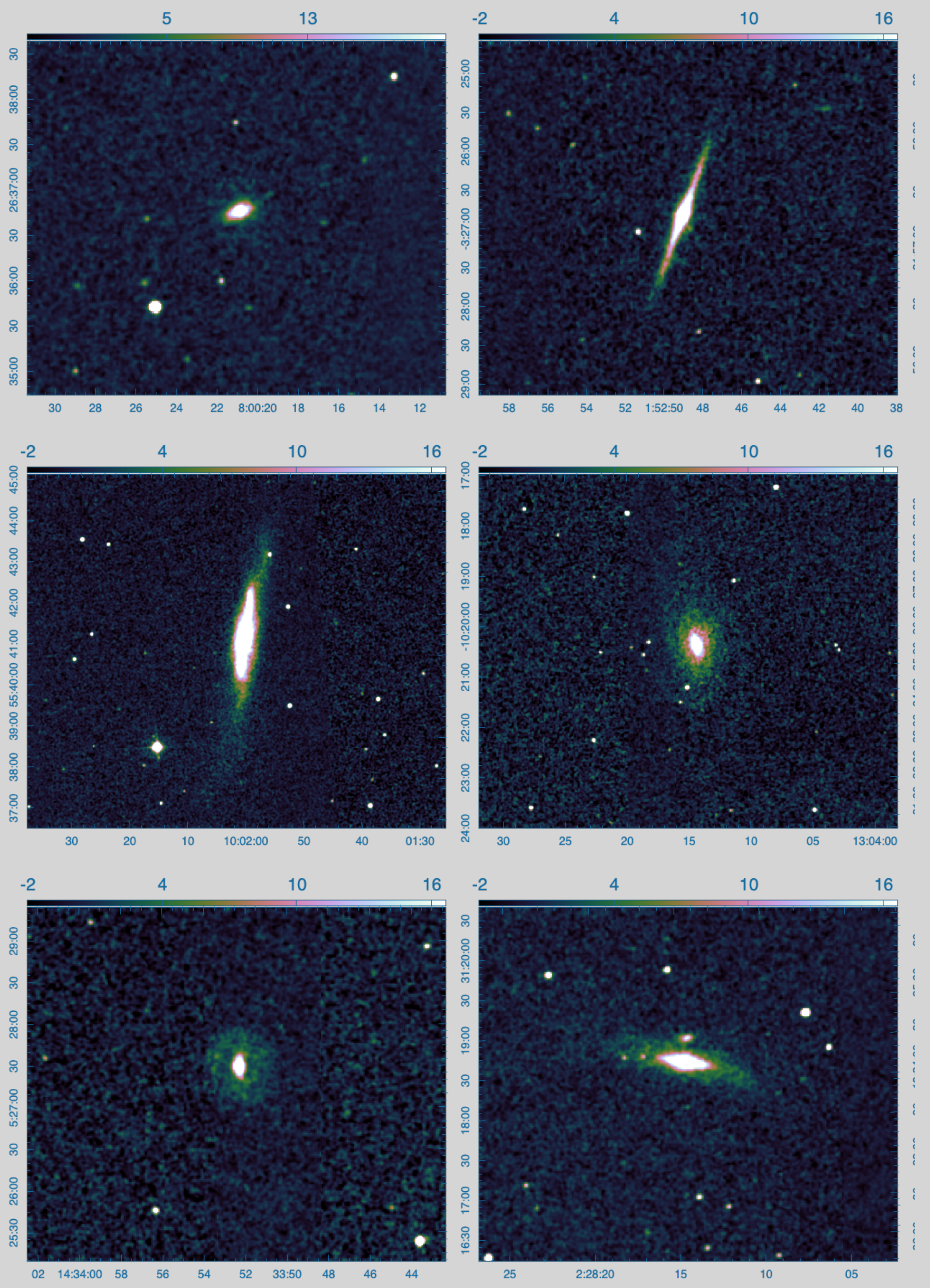
- ***Hosts with larger HI extent tents to show higher L_{bol} & Eddington ratio.***
  - Gas accretion indeed can be the key source of AGN activity
  - HI extent as an environment tracer (e.g., tidal interaction)

2MASS Ks photometry

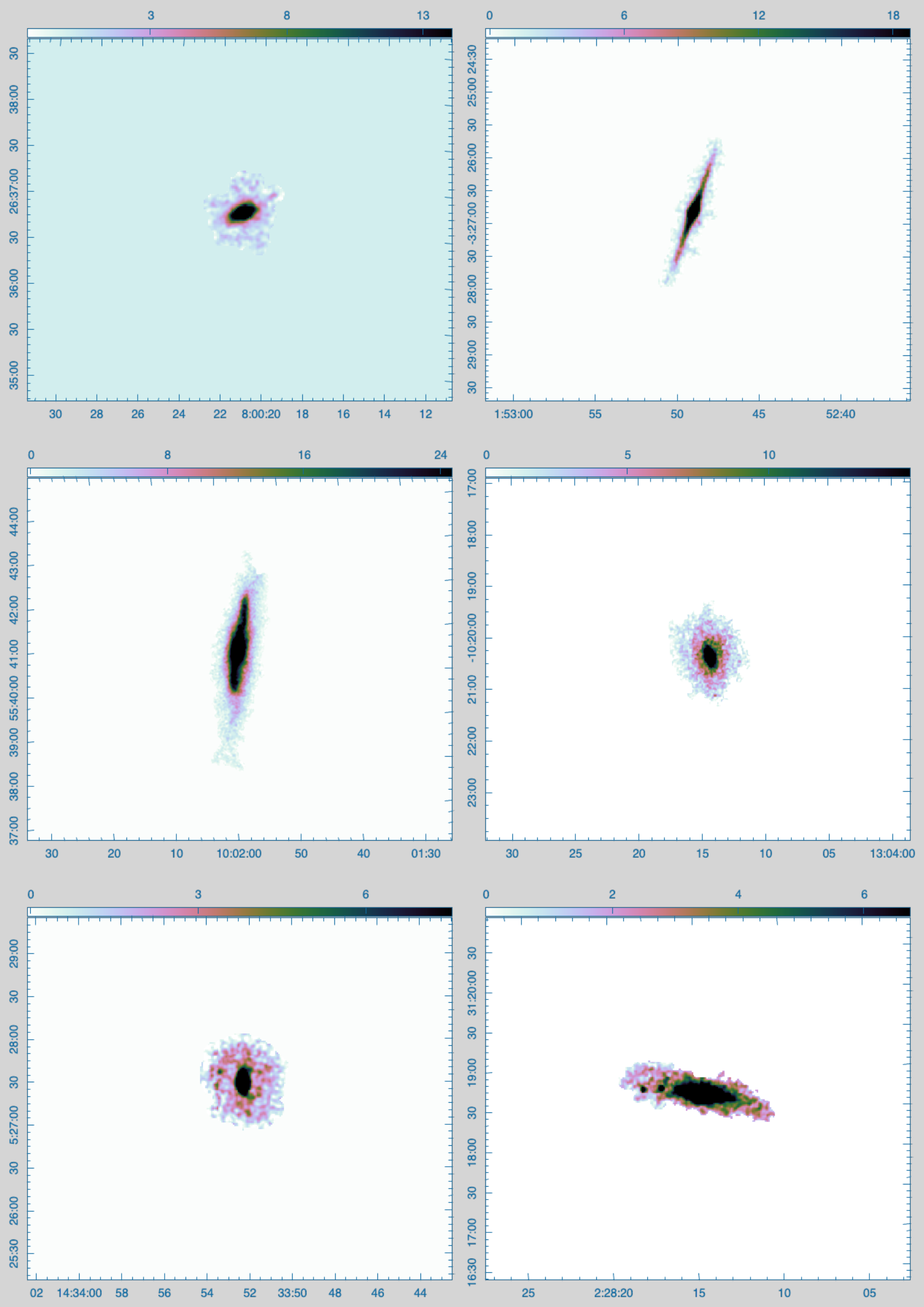
1. Get a 2MASS Ks fits image

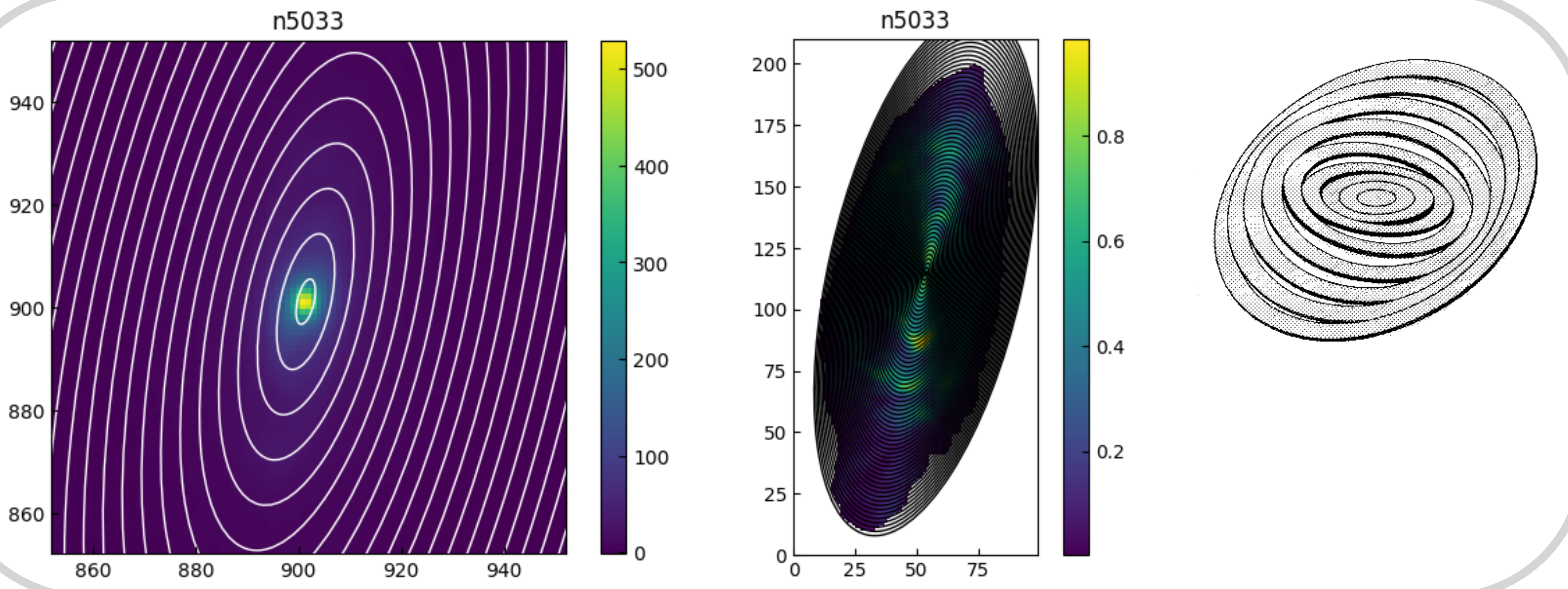
2. Subtract the foreground stars

2MASS Ks image

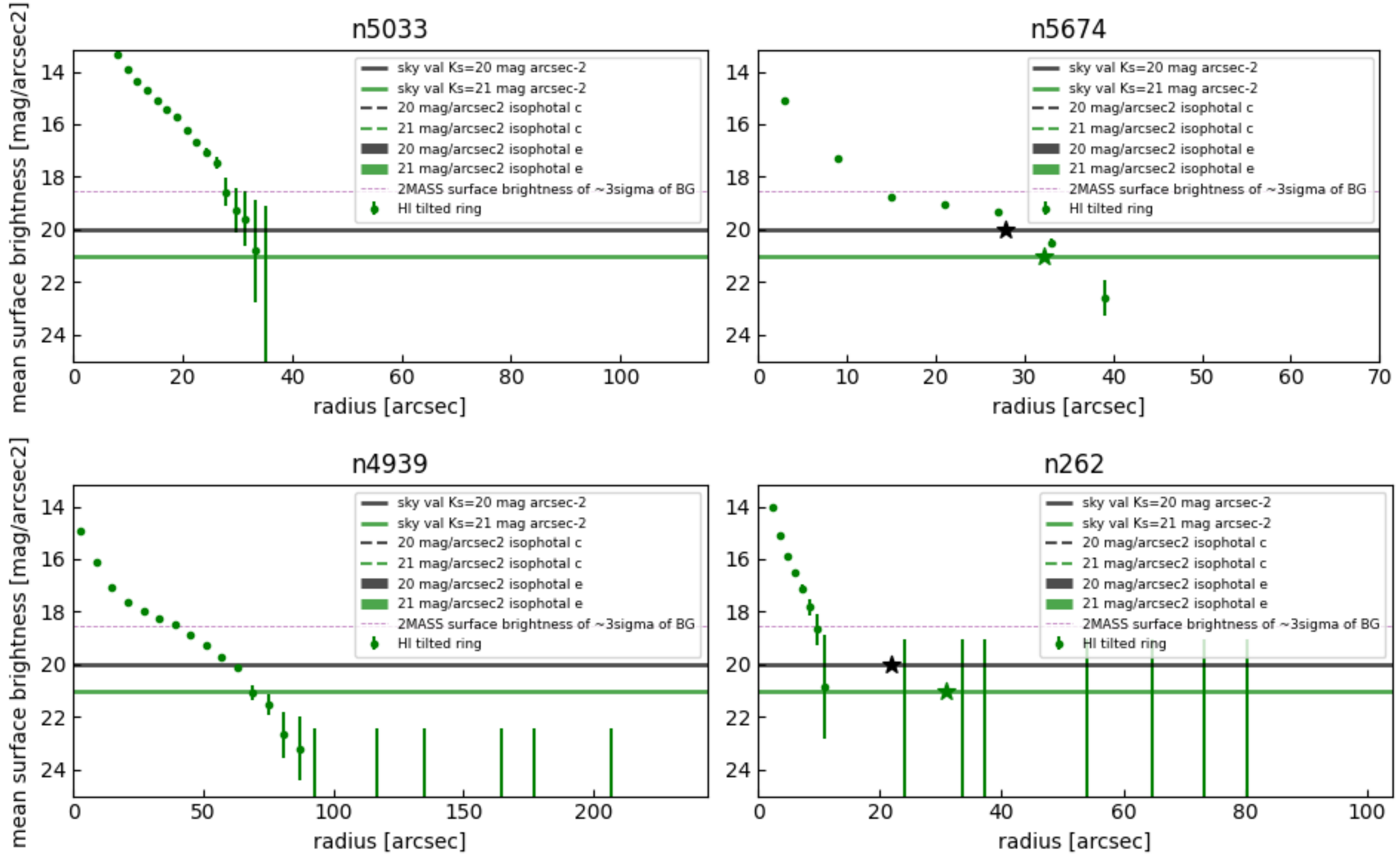


ProFound





3. Do forced photometry, using the tilted ring model obtained from HI emission fitting



Mrk 348 (NGC 262) Masking

The f_{atm} — q phase diagram

Global stability parameter q

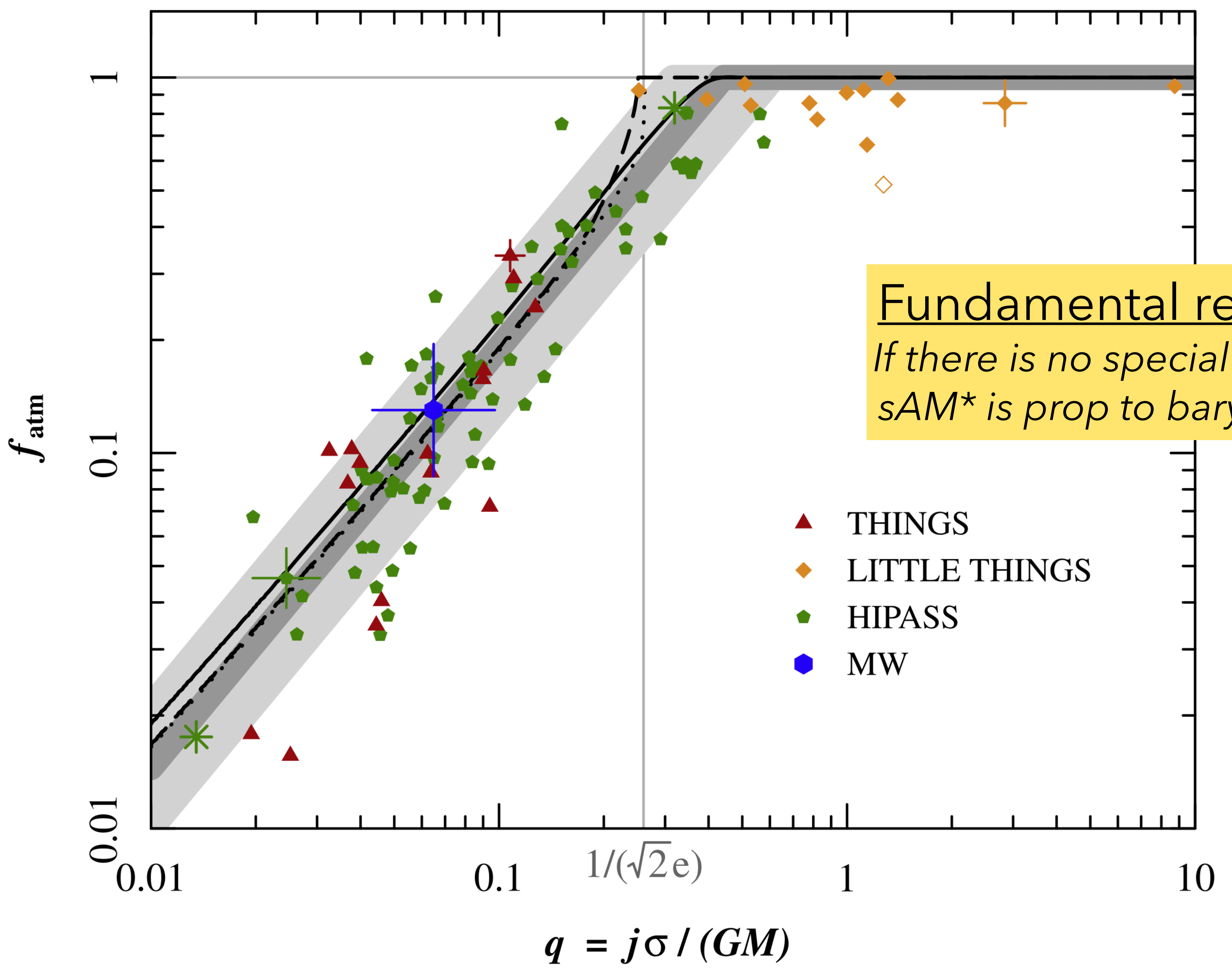
$$q = \frac{j_b \sigma}{GM_b}$$

atomic gas fraction

$$f_{atm} = log\ M_{atm}/M_{baryon}$$

The baryonic specific angular momentum

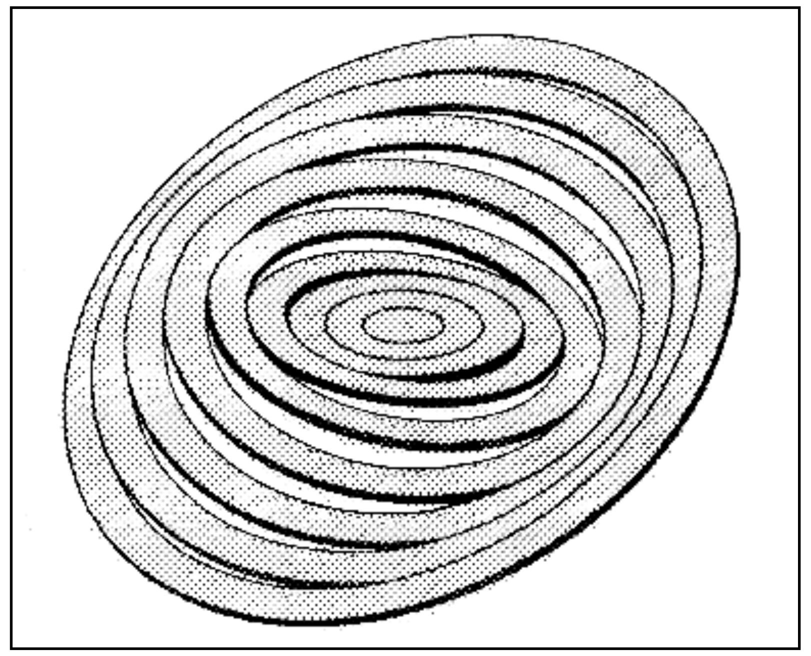
$$j_b = \frac{\Sigma_i(1.35M_{HI,i} + M_{*,i})v_{rot,i}r_i}{\Sigma_i(1.35M_{HI,i} + M_{*,i})}$$



Fundamental relation
If there is no special excuse, sAM is prop to baryonic M*

Obreschkow+16: Analytic model with 40% scatter

*sAM: specific angular momentum



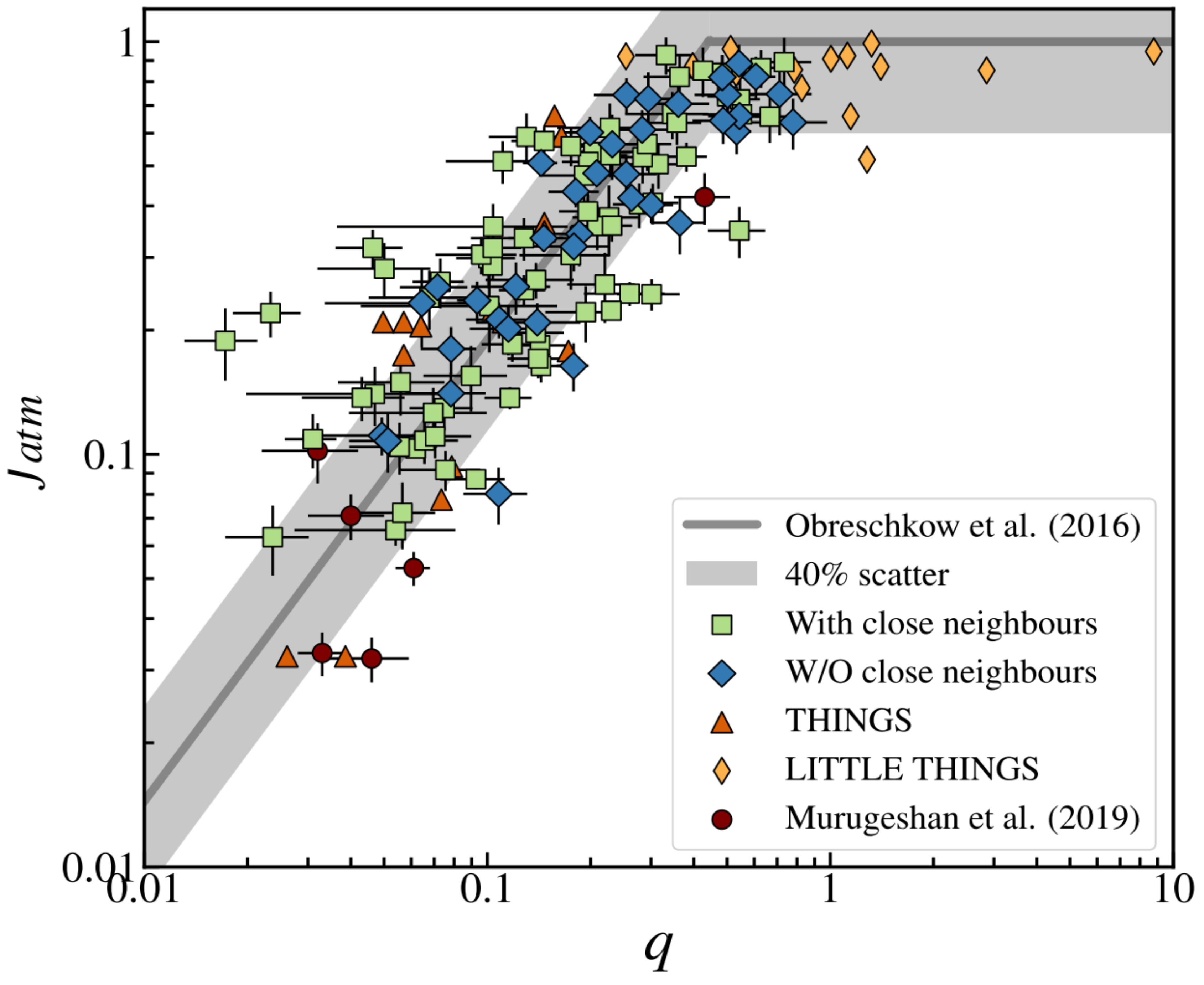
Tilted Ring Model

❖ ***... is a a straightforward stability model for flat exponential disks in isolated local disk galaxies (Obreschkow et al. 2016)***

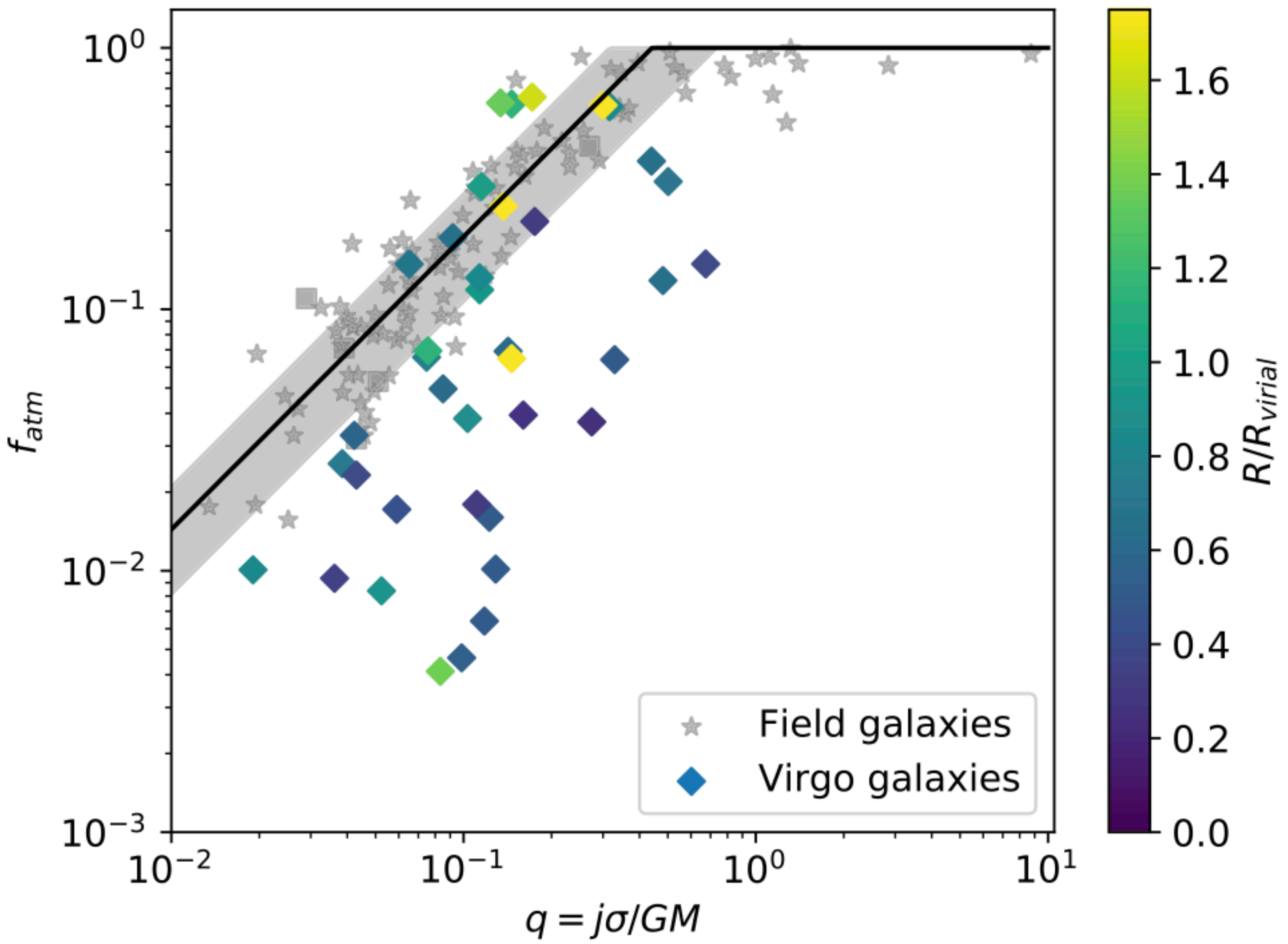
- *even with galaxies that are extremely HI-rich or HI-poor for their mass*

The f_{atm}—q phase and environments

Atomic fraction & sAM affected by special excuses, "The environmental effects"



Scatter with close neighbors (Murugeshan+2020)



Deficiency in cluster env. (Li+2020)

The BASS-HI project: Jansky VLA observational details

- **97 Nearby (<120 Mpc) galaxies with enough HI** among 642 BASS DR1 & DR2
  - 59 Northern JVLA/WSRT/GMRT + 38 Southern JVLA/ATCA = total 97 galaxies

- Resolved HI observation via Jansky VLA
  - **20A-123** (Observed 2020 Feb-Jun; PI: A.Chung)
    - 57 hours of JVLA observation in C-configuration
    - L band (HI and 20cm continuum) image of 36 targets
    - On source time ~1hr | angular resolution ~20" | velocity resolution ~6.7km/s (512 channels) for line Bandwidth ~3,400 km/s | FoV ~0.5 degree | RMS HI column density ~ 2x1e19 cm-2
  - **23B-079** (Observed 2024 Jan-Feb; PI: J.Kim)
    - 64 hours of JVLA observation in D-configuration
    - Similar observational setting on 40 targets, reaching deeper column density RMS~1.7x1e18 cm-2

Parent sample	# of source
BASS DR2	858
z < 0.0275 (DL < 120 Mpc)	259
Single dish detection	112
JVLA 20A+23B	39
ATCA 2019	8
Archive (VLA/GMRT/WSRT)	43
WALLABY/THINGS/LVHIS	7
Local BASS-HI galaxies	**97**