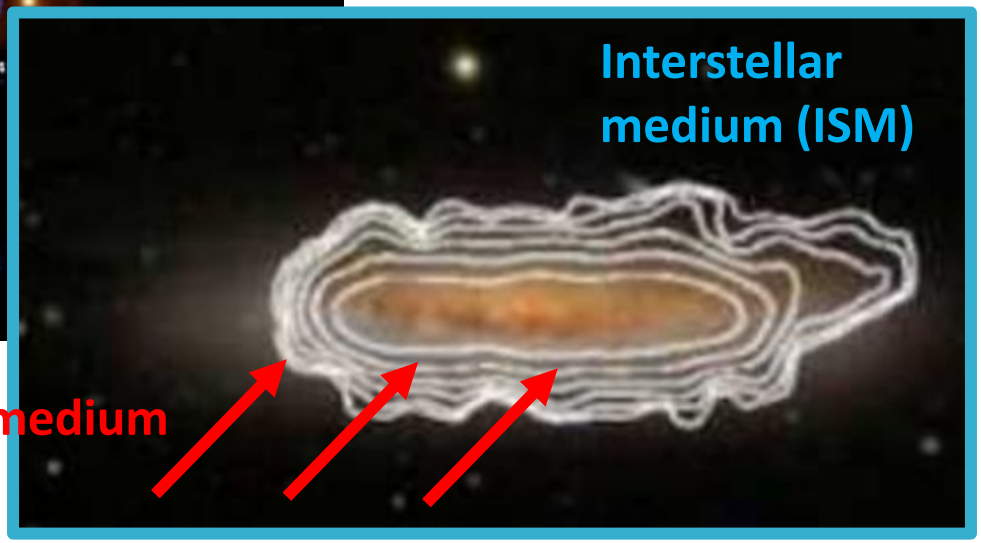
Ram Pressure Stripping Conditions : Theory vs. Observation

SEONA LEE (Yonsei University)

with Yun-Kyeong Sheen, Hyein Yoon, Yara Jaffé and Aeree Chung

Ram Pressure Stripping (RPS)

"One of the most effective **gas-stripping mechanism** for galaxies in the cluster environment"



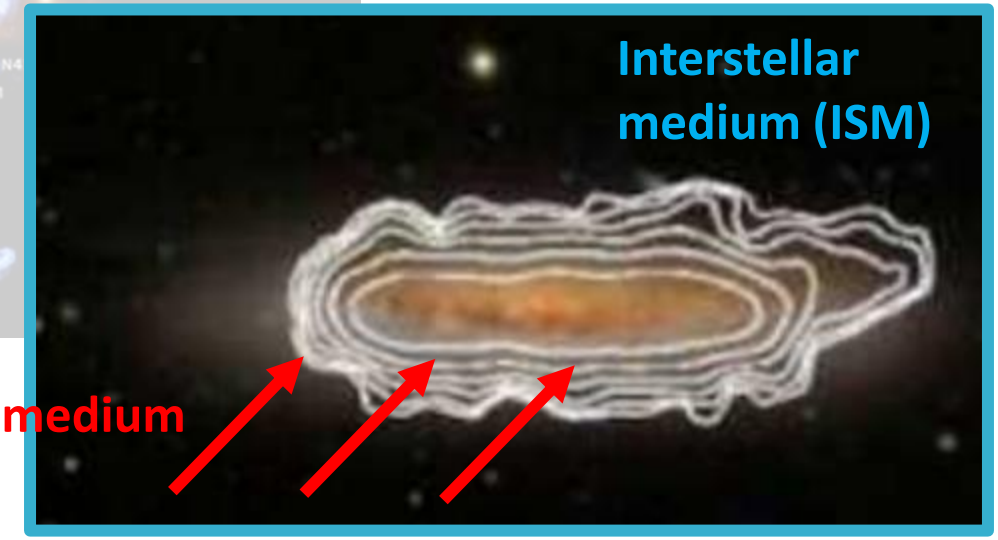
Chung et al. (2009)

Ram Pressure Stripping (RPS)

- Gunn & Gott (1972) (G&G)

$$\rho_{ICM} v_{rel}^2 > 2\pi G \Sigma_g \Sigma_s$$

Ram Pressure Anchoring Pressure



Intracluster medium (ICM) wind

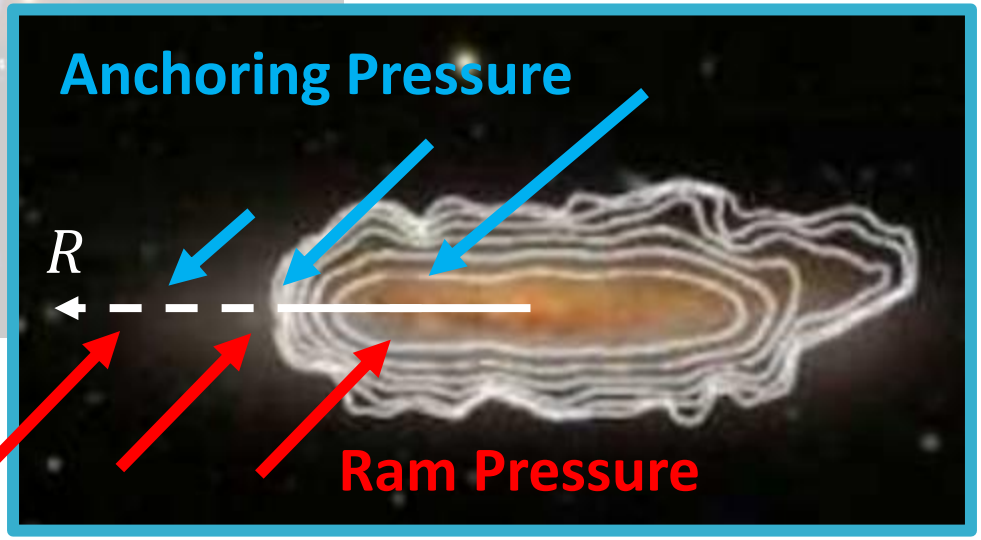
Chung et al. (2009)

Ram Pressure Stripping (RPS)

- Gunn & Gott (1972) (G&G)

$$\rho_{ICM} v_{rel}^2 = 2\pi G \Sigma_g(R_t) \Sigma_s(R_t)$$

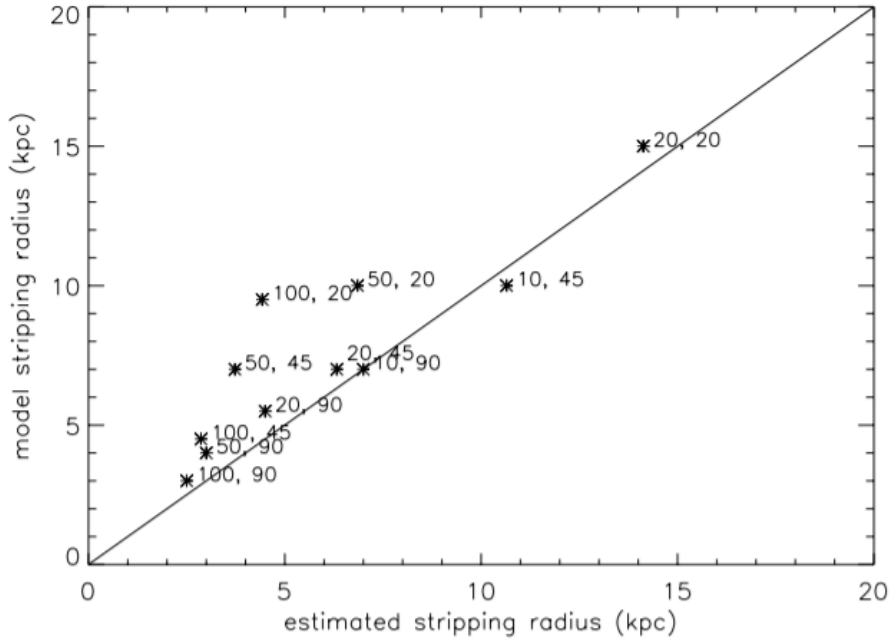
R_t: Truncation radius



Chung et al. (2009)

Stripping radius estimation using G&G

- Simulation studies (ex. Vollmer et al. 2001)

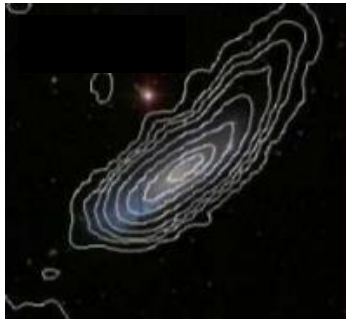


Q. Is the relation good enough to explain what is observed and to understand how ram pressure affects galaxy evolution?

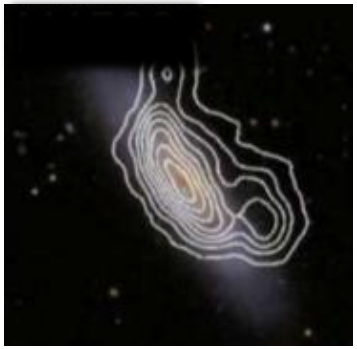
Q. If not, what else should be considered?

Target Galaxies

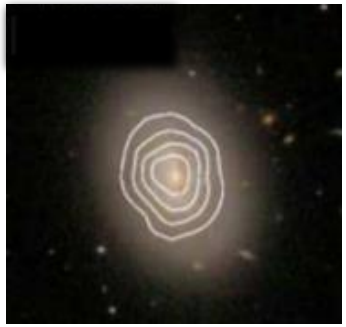
- VIVA (VLA Imaging of Virgo in Atomic Gas; Chung et al. 2009)
- late-type galaxies in various stages of HI stripping



- **7 Early Stripping**
  - One-sided HI feature
  - Size of HI disk > stellar disk
  - $1.20 < D_{HI}/D_{opt} < 2.21$
  - $-0.43 < def_{HI} < 0.41$



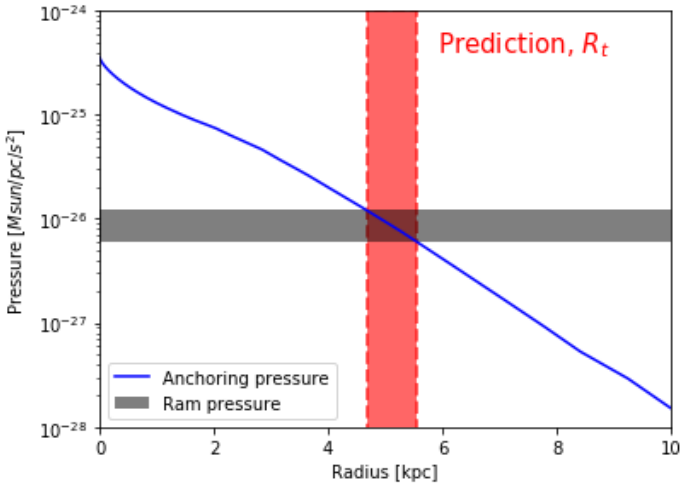
- **10 Active Stripping**
  - Asymmetric HI disk with tails
  - Size of HI disk < stellar disk
  - $0.39 < D_{HI}/D_{opt} < 1.53$
  - $0.12 < def_{HI} < 1.16$



- **10 Post Stripping**
  - Symmetric truncated HI disk
  - $0.20 < D_{HI}/D_{opt} < 0.70$
  - $0.82 < def_{HI} < 2.25$

Classified by Yoon et al. (2017)

Prediction of Truncation Radius (R_t)



$$cos\phi\rho_{ICM}v_{rel}^2 = 2\pi G\Sigma_g(R_t)\Sigma_s(R_t)$$

① ② ③

① The encounter angle between ICM and ISM (ϕ) is assumed to be 45 deg

② The ICM density (ρ_{ICM})

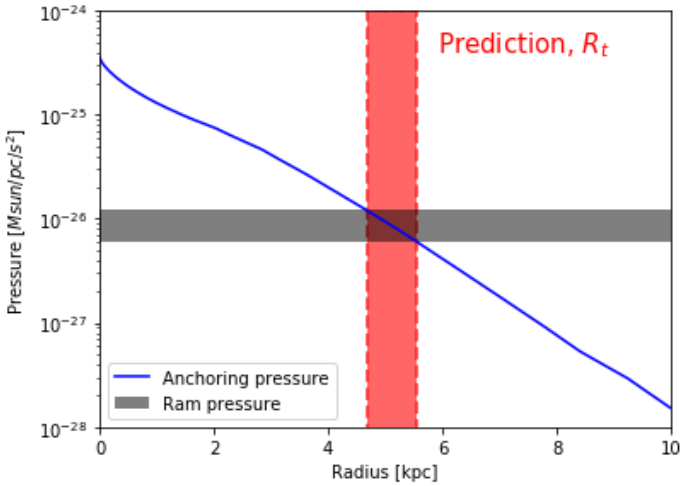
- The standard β-model (Cavaliere & Fusco-Femiano 1976)

$$\rho_{ICM}(d_{M87}) = \frac{\rho_{0,ICM}}{(1 + d_{M87}^2/d_c^2)^{\frac{3}{2}\beta}}$$

③ The range of the relative velocity (v_{rel})

$$v_{orb} < v_{rel} < v_{esc}$$

Prediction of Truncation Radius (R_t)

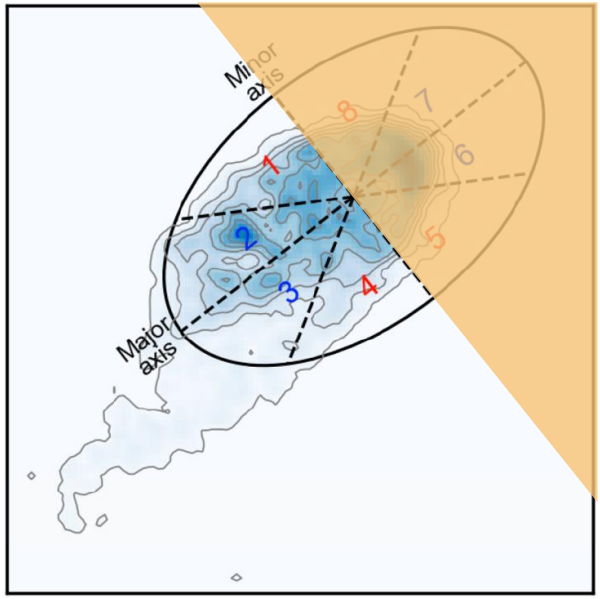


$$cos\phi\rho_{ICM}v_{rel}^2 = 2\pi G\Sigma_g(R_t)\Sigma_s(R_t)$$

④

④ The gas surface density (Σ_g)

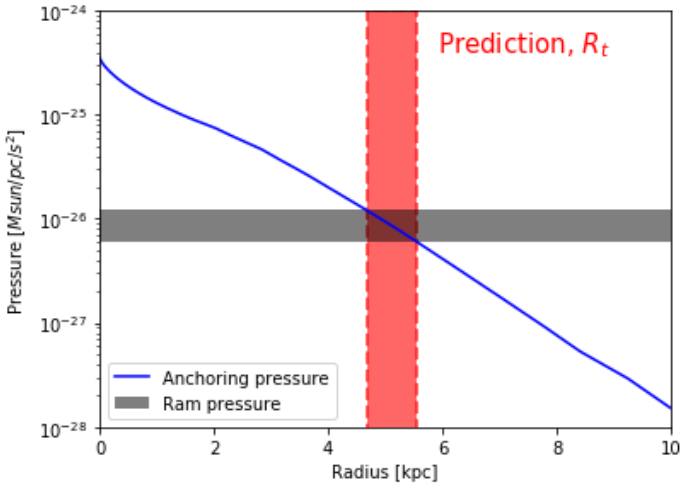
- VIVA HI image
- Divide into 8 sections to consider the asymmetric HI disk



Wind side

Tail side

Prediction of Truncation Radius (R_t)



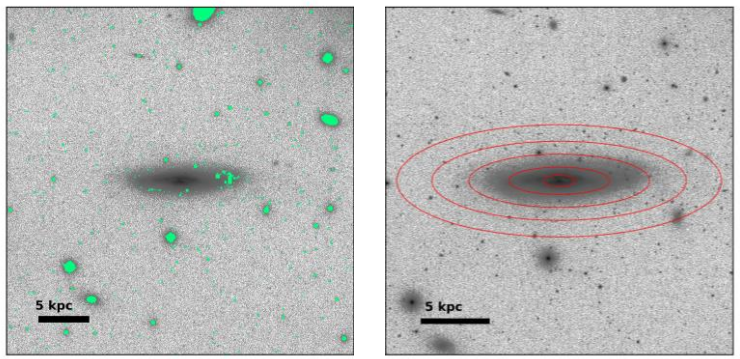
$$cos\phi\rho_{ICM}v_{rel}^2 = 2\pi G\Sigma_g(R_t)\Sigma_s(R_t)$$

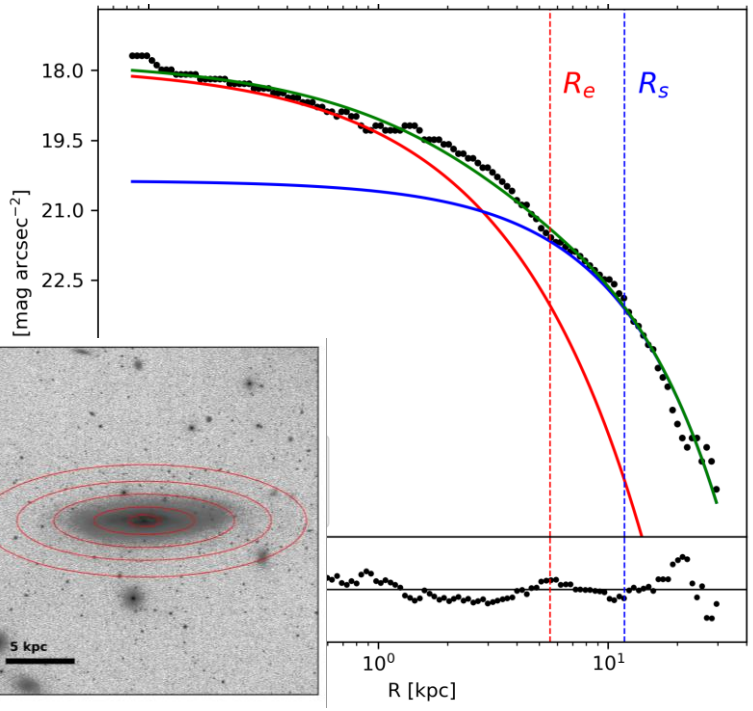
⑤

⑤ The stellar surface density (Σ_s)

- SDSS DR12 i-band image
- Masking
- Ellipse fitting
- Decomposition

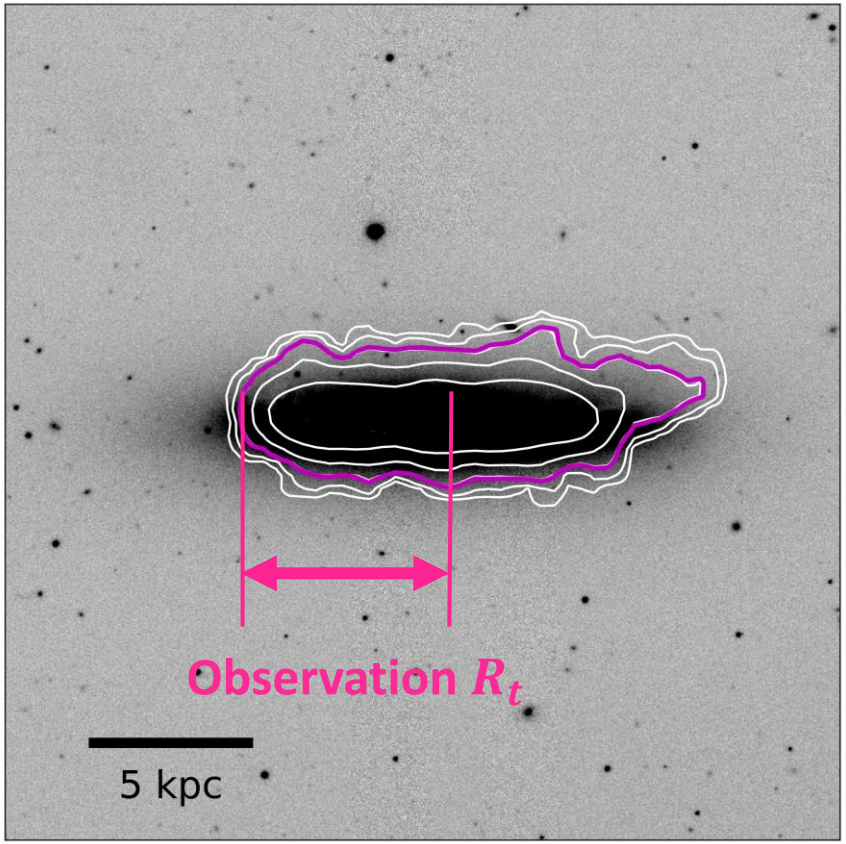
  (Sérsic + Exponential)





Observation of Truncation Radius (R_t)

HI density $\sim 1\ M_{sun}/pc^2$

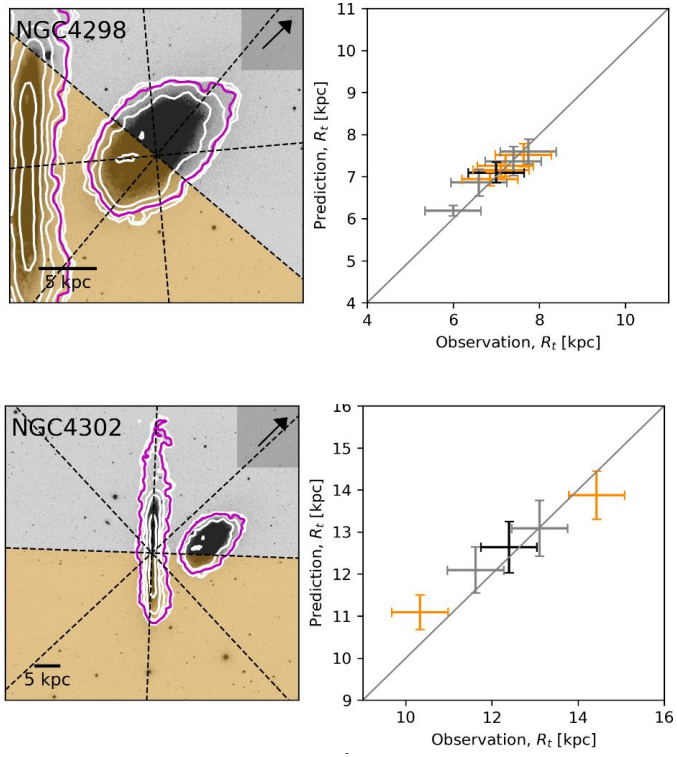


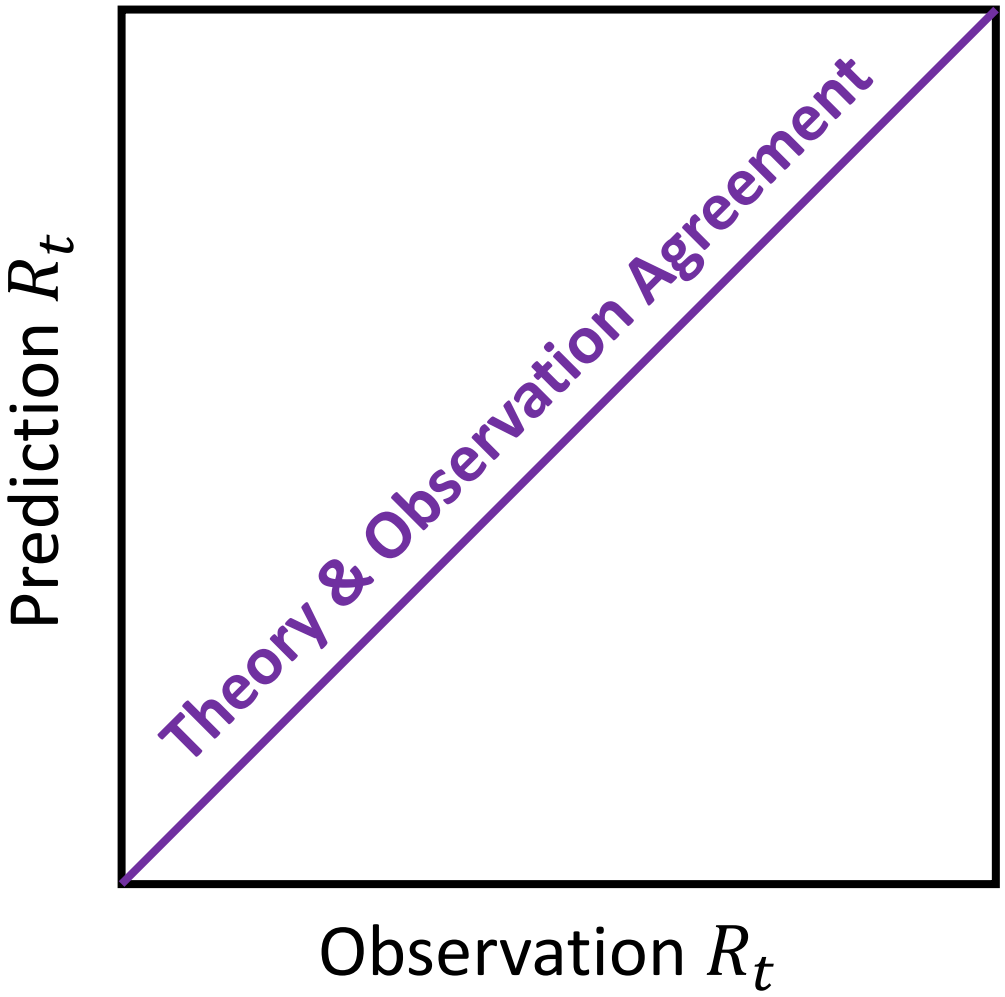
- The radius where the HI surface density drops to $1\ M_{sun}/pc^2$
- $1\ M_{sun}/pc^2$ is sufficiently higher than the sensitivity limit and low enough to represent R_t
- R_t along 8 sections across the disk

Chung et al. (2009)

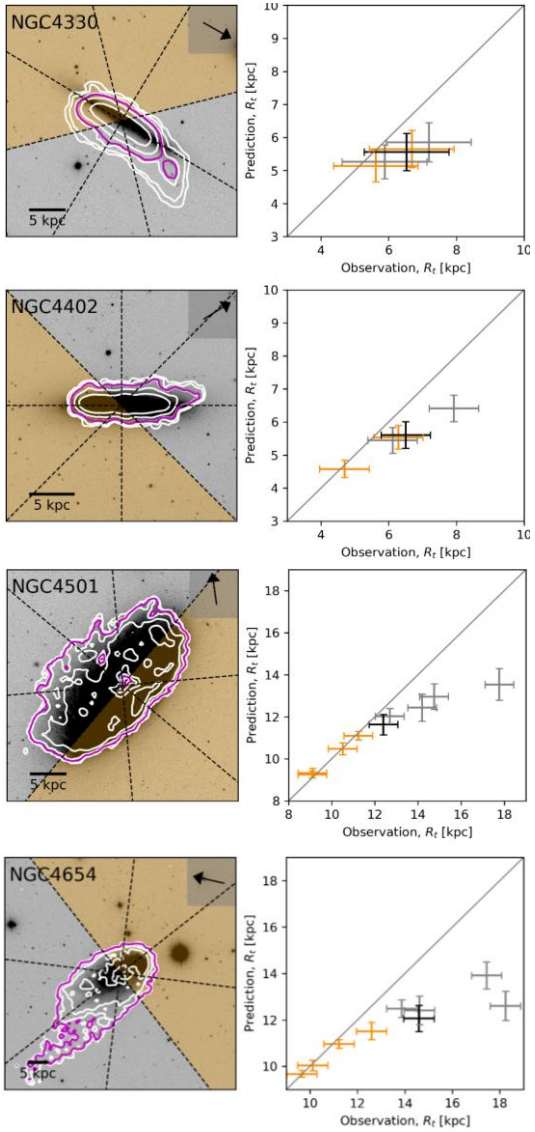
Results ① Active Stripping Galaxies

- Overall, observations match reasonably well with predictions

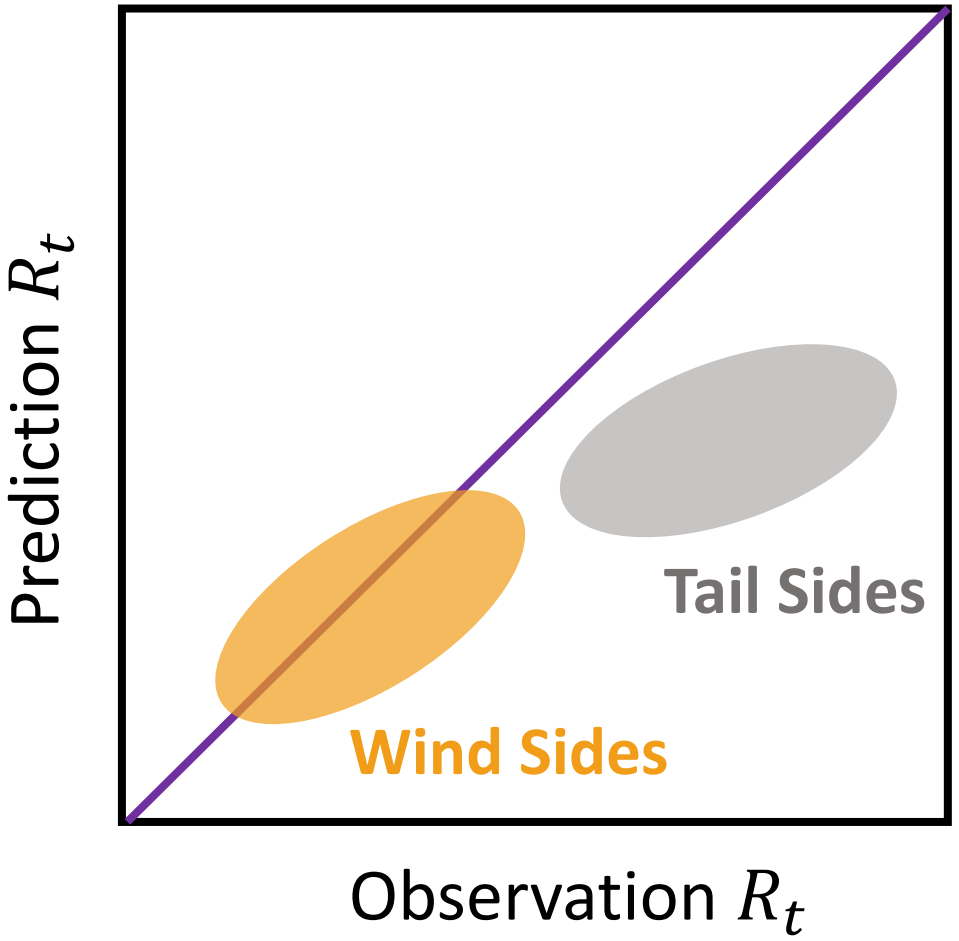




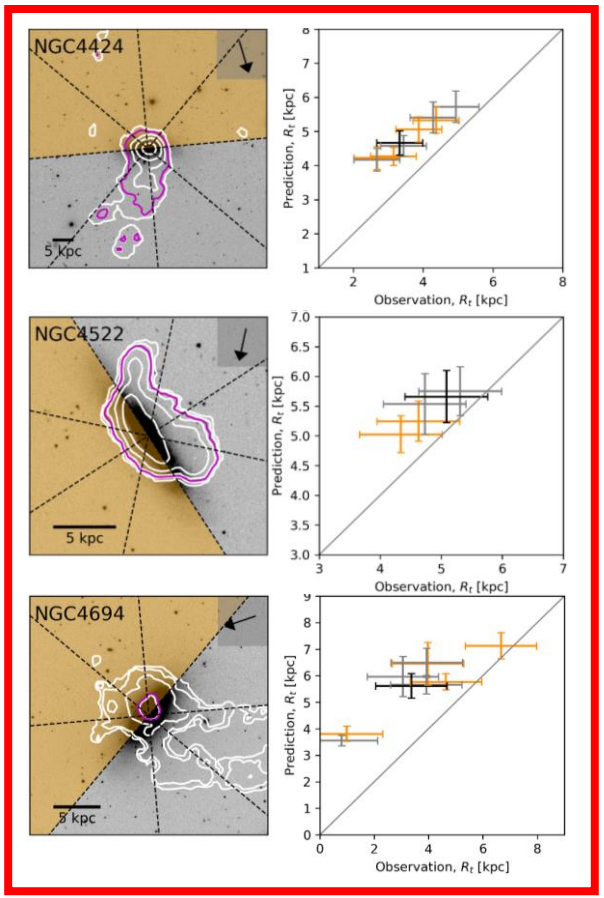
Results ① Active Stripping Galaxies

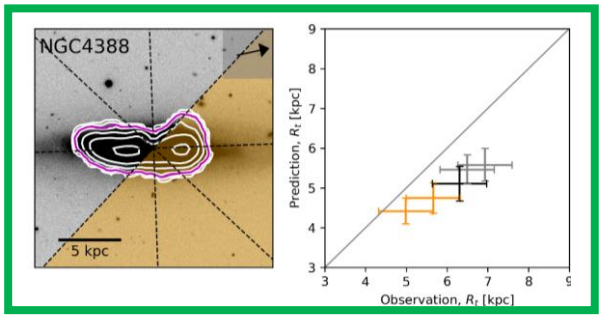


- 4 galaxies show larger observation R_t on tail sides due to the stripped ISM



Results ① Active Stripping Galaxies





Prediction R_t

Pred R_t > Obs R_t

Gas stripped more than expected

- **Underestimation of P_{ram}**
- **Overestimation of P_{gal}**

Pred R_t < Obs R_t

Gas stripped less than expected

- **Overestimation of P_{ram}**
- **Underestimation of P_{gal}**

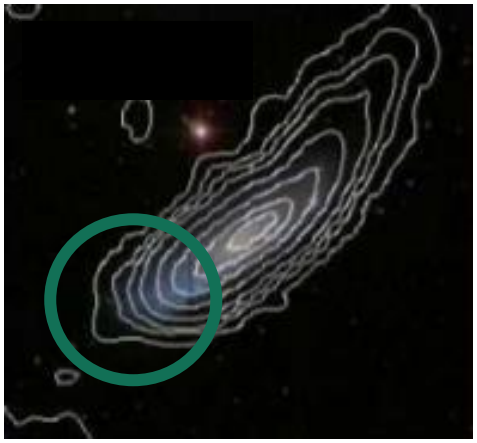
Observation R_t

Results ② Various Stripping Stages

Early Stripping

Active Stripping

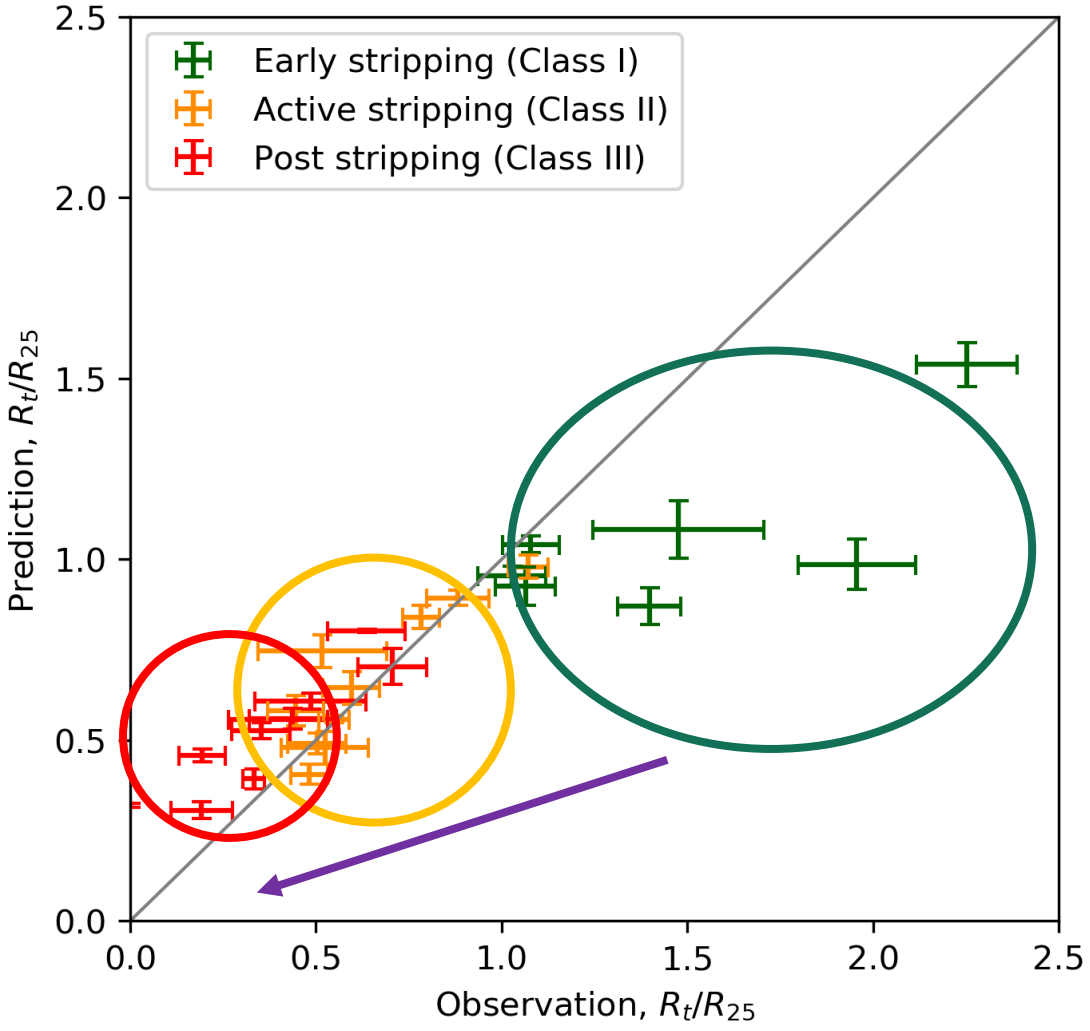
- R_t is taken from one of the wind sides



Post Stripping

- R_t is the azimuthally averaged radius

Results ② Various Stripping Stages



Early Stripping

Larger observation R_t

- Not yet stripped out of the disk
- Overestimation of P_{ram}

Active Stripping

- G&G works relatively well

Post Stripping

A little smaller observation R_t

- Observation R_t is related to past stripped environment

Σ_g: Pre-Stripping Gas Density Profile

- To compare the result with the similar study of H_α in GASP (Gullieuszik et al. 2020)

- Assumptions (Jaffé et al. 2018)

1. Exponential profile

$$\Sigma_g(R) = \Sigma_0 \exp(-\frac{R}{R_{s,g}})$$

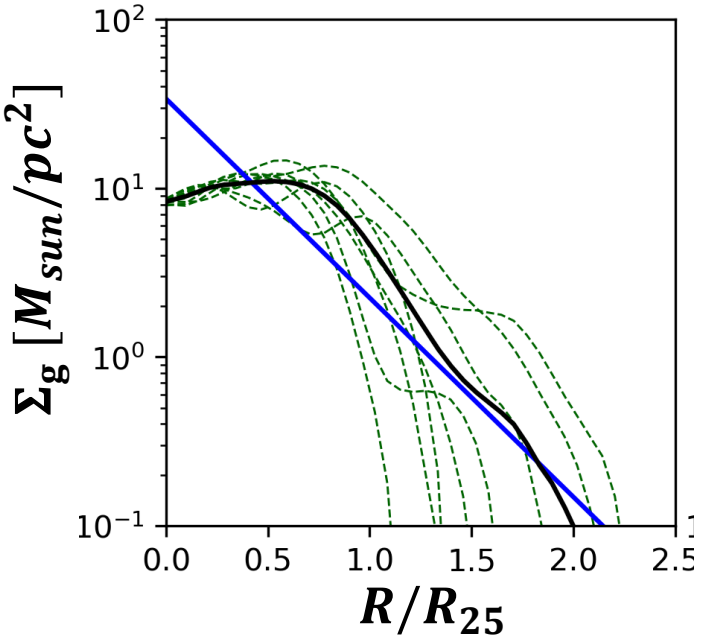
2. Gas disk scale length (Cayatte et al. 1994)

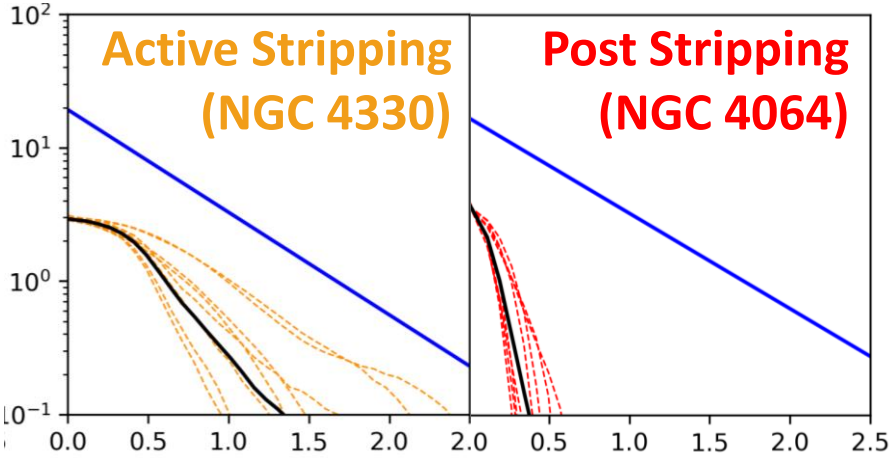
$$R_{s,g} = 1.7 R_{s,\star}$$

3. Gas mass (Popping et al. 2014)

$$\frac{M_g}{M_\star} = 0.158(\log M_\star)^2 - 3.548 \log M_\star + 19.964$$

Early Stripping (NGC 4254)



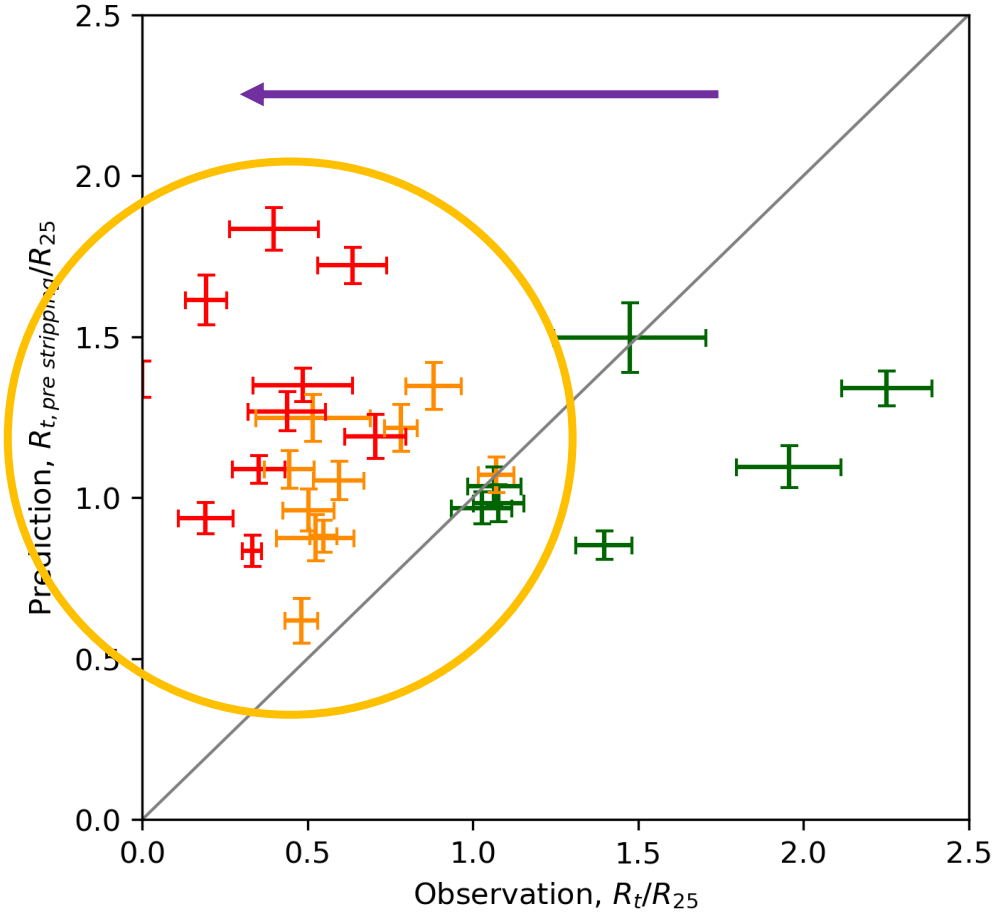


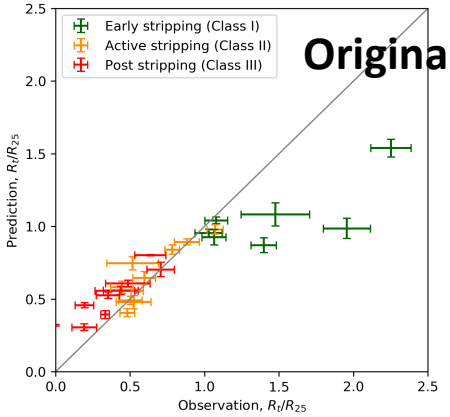
Blue line: Pre-stripping gas profile

Dashed line: HI profiles from 8 sections

Black line: Mean HI profile

Σ_g: Pre-Stripping Gas Density Profile





Original (Σ_g: HI)

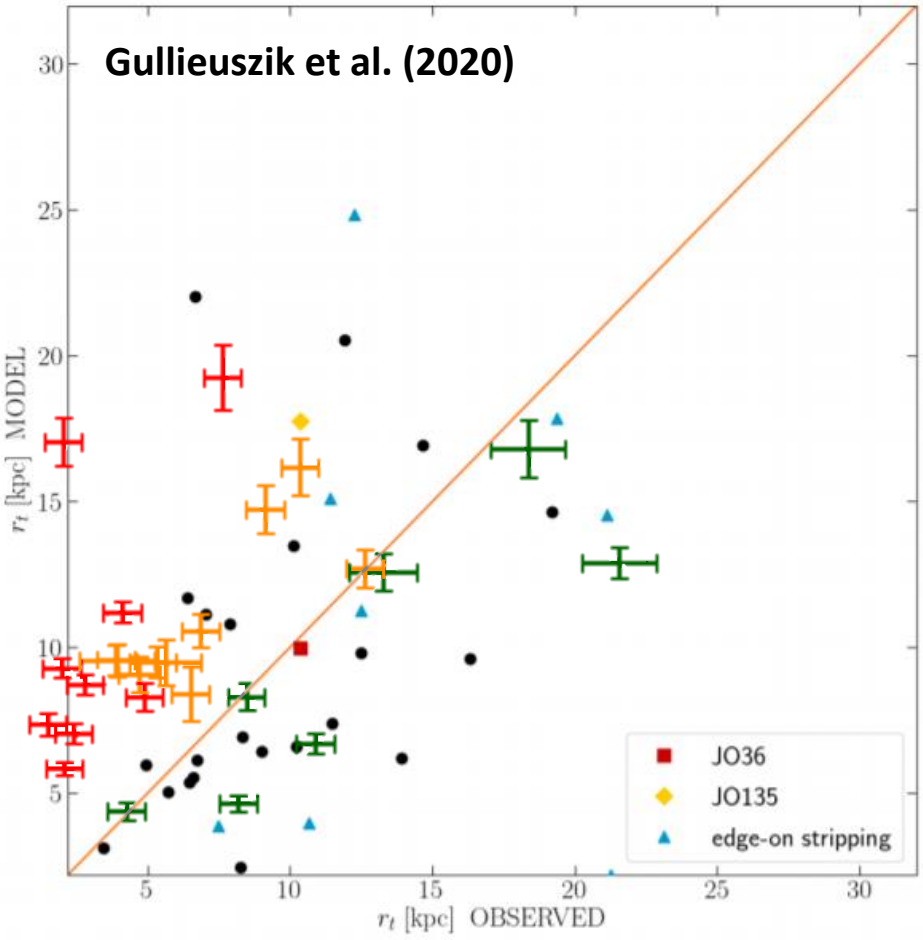
Active Stripping

Post Stripping

Smaller observation R_t

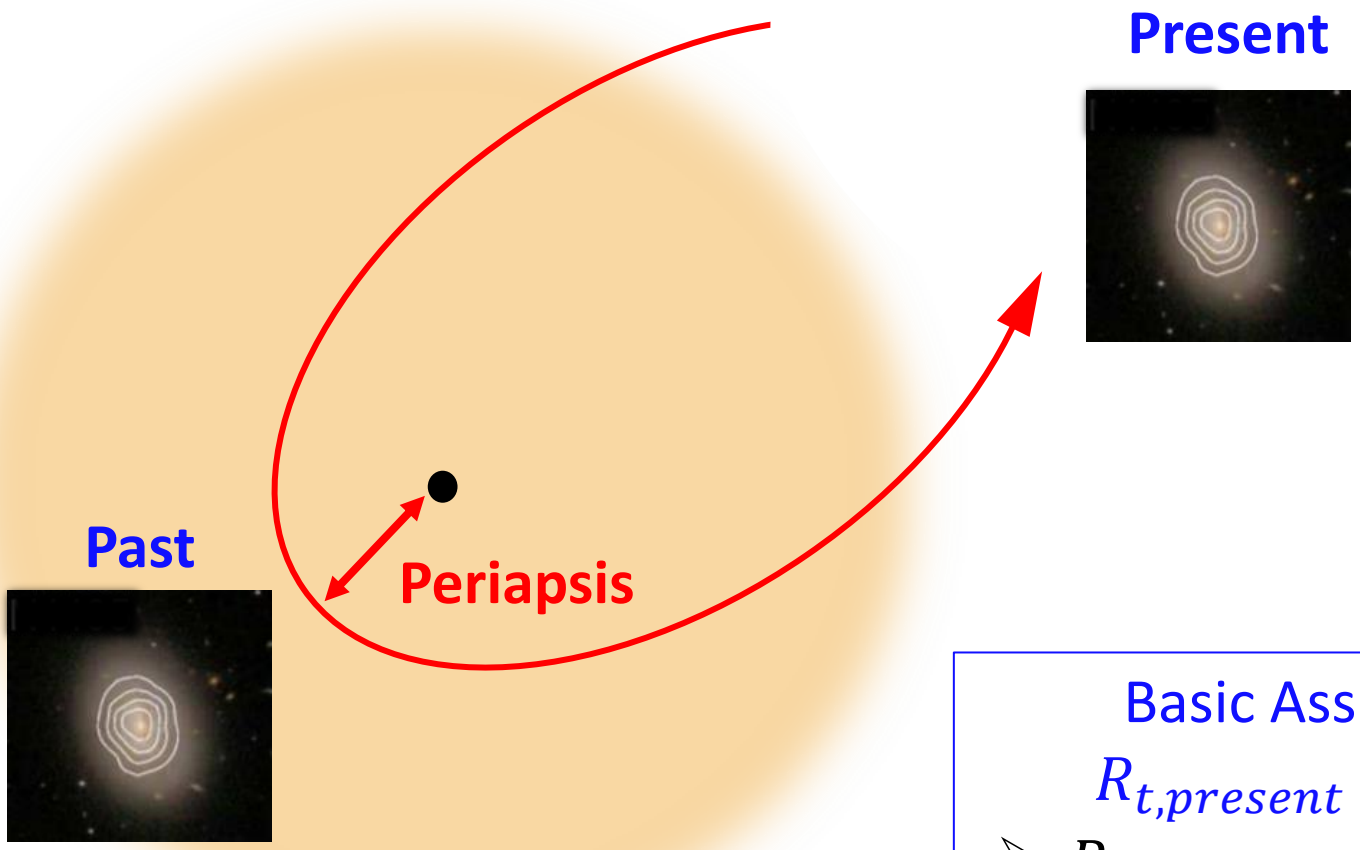
➢ As the stripping proceeds, $\Sigma_{g,pre\ strip}$ becomes difficult to apply to G&G

Σ_g: Pre-Stripping Gas Density Profile



- As the stripping proceeds, $\Sigma_{g,pre\ strip}$ becomes difficult to apply to G&G
- Similar result with H_α for jellyfish galaxies

Periapsis of Post Stripping Galaxies



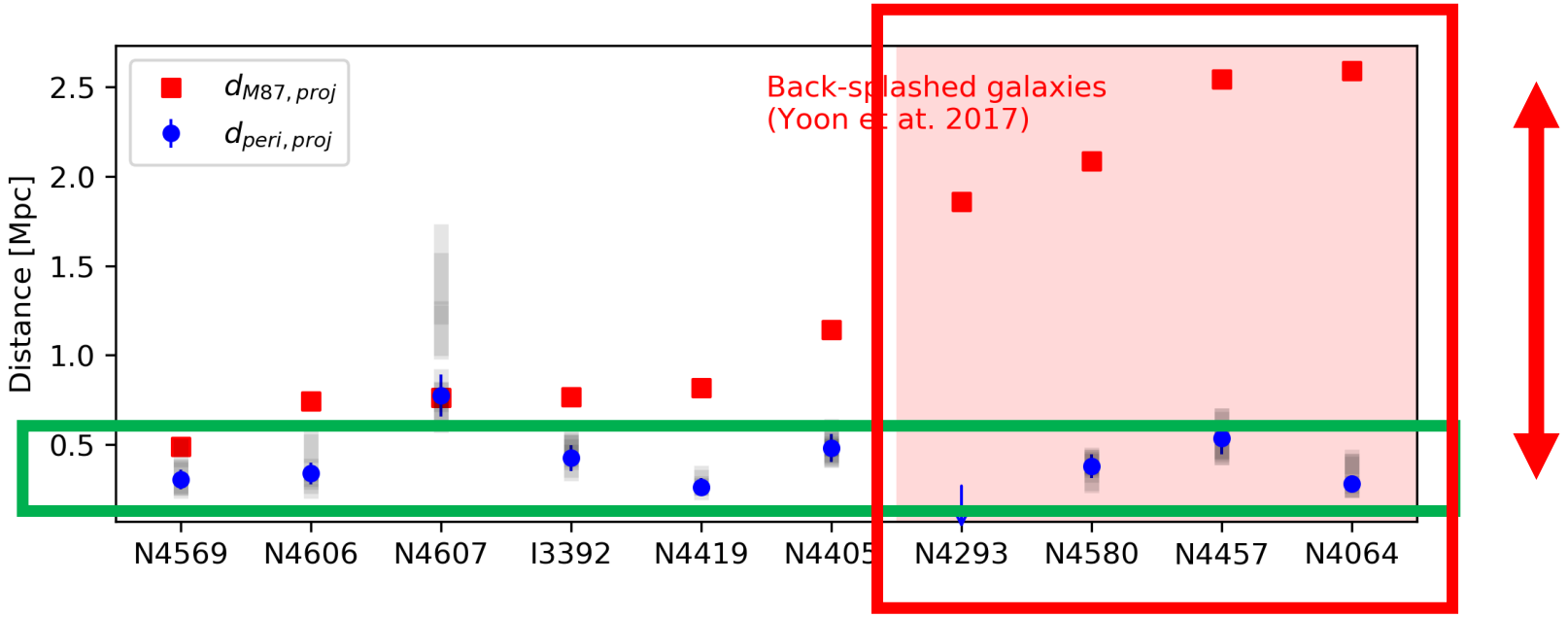
Basic Assumption

$R_{t,present} = R_{t,past}$

➢ $P_{ach,present} = P_{ram,past}$

Clusto-centric distance to generate $P_{ach,present}$= d_{peri}

Periapsis of Post Stripping Galaxies



1. Most post stripping galaxies seem to have passed < 0.5 Mpc
2. Galaxies with large difference are suspected to be back-splashed galaxies

Caveats of G&G

1. Uncertainties in the physical quantities

- ICM density
- 3D clusto-centric distance
- Encounter angle
- Mass-to-light ratio, etc.

2. Ideal thin disk and instantaneous stripping

3. Environmental effects other than ram pressure

4. Contribution of the dark matter halo and the bulge potential to the anchoring pressure

Summary

- We verify our understandings of RPS based on the G&G's relation

- We compare the predicted R_t with the observed R_t

1. For active stripping galaxies, the G&G's condition works reasonably well
2. Galaxies in the early/post stripping stage tend to show a larger/smaller observed R_t than what is predicted

- Despite the caveats of G&G, the simple momentum transfer seems to work in a broad sense!