THE GAS PROPERTIES OF GALAXIES AS PROBES OF THE BARYONIC PHYSICS OF GALAXY EVOLUTION

Jindra Gensior | 21.02.24

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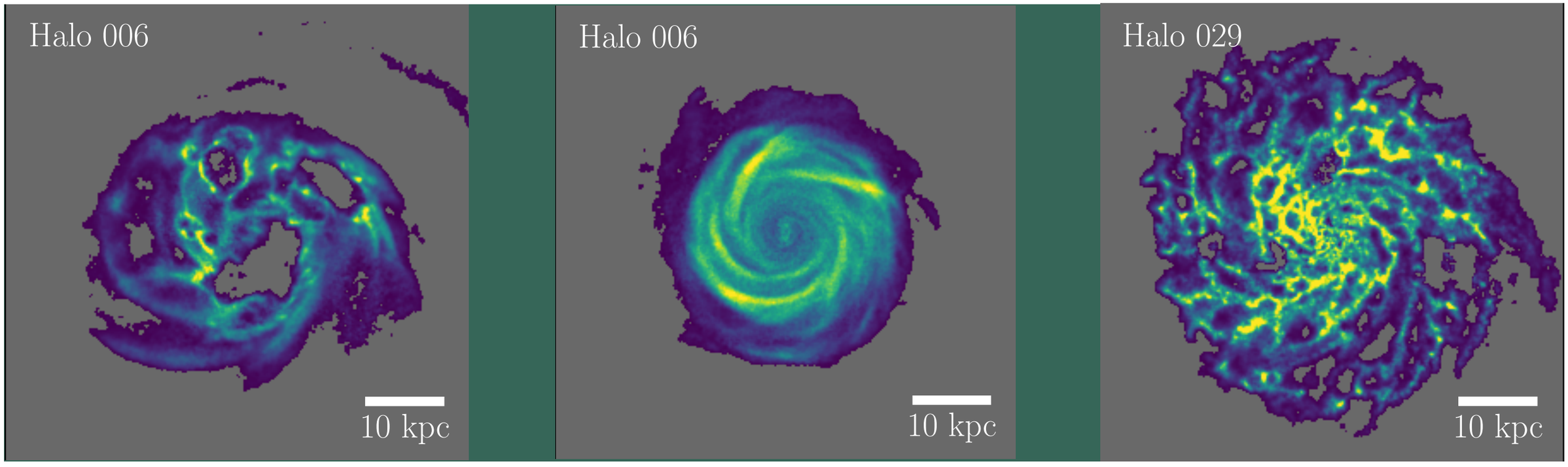
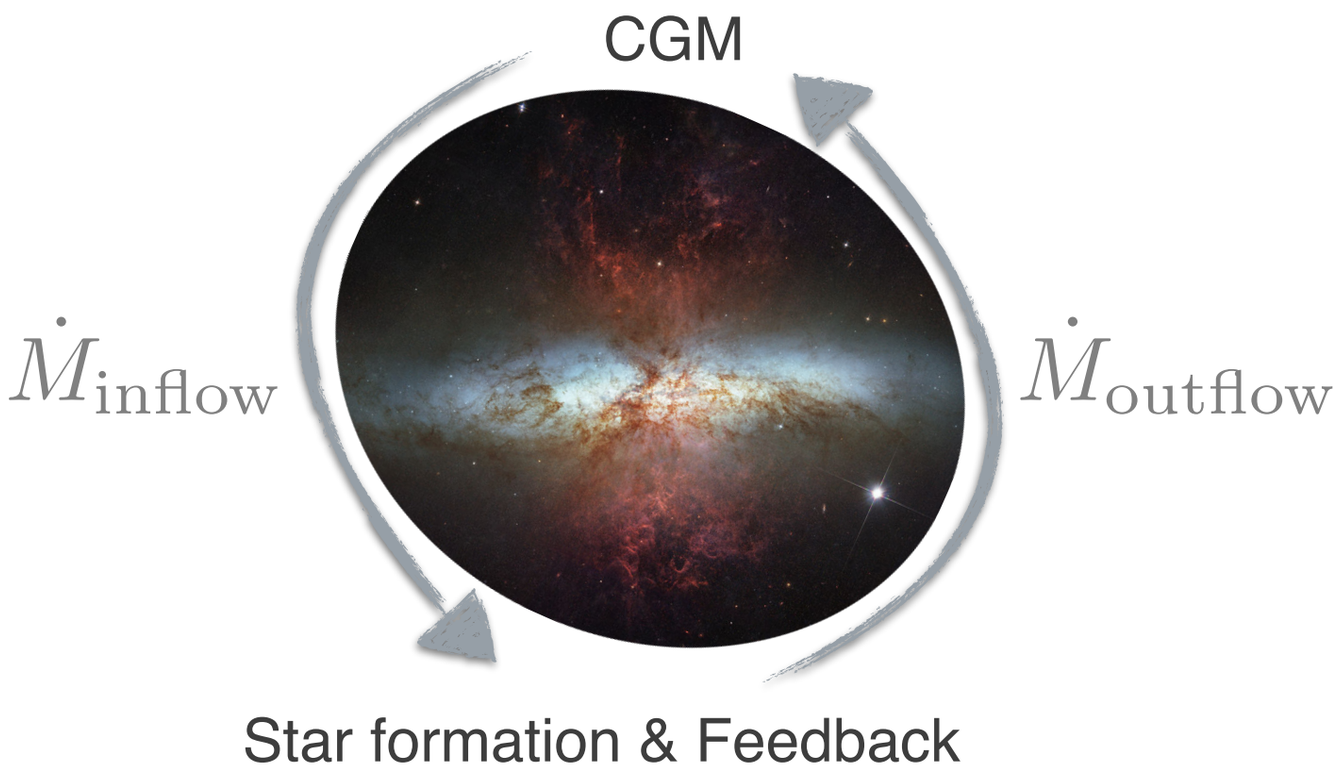
based on arXiv:2310.01482

with Lucio Mayer, Robert Feldmann and the EMP team



THE BARYON CYCLE OF GALAXIES



Gas-regulator or “bathtub model”

e.g. Finlator & Davé 2008, Bouché+ 2010, Lilly+ 2013, Dekel+ 2013, Dekel & Mandelker+ 2014, Peng & Maiolino 2014, Belfiore+ 2019, Tacchella+2020

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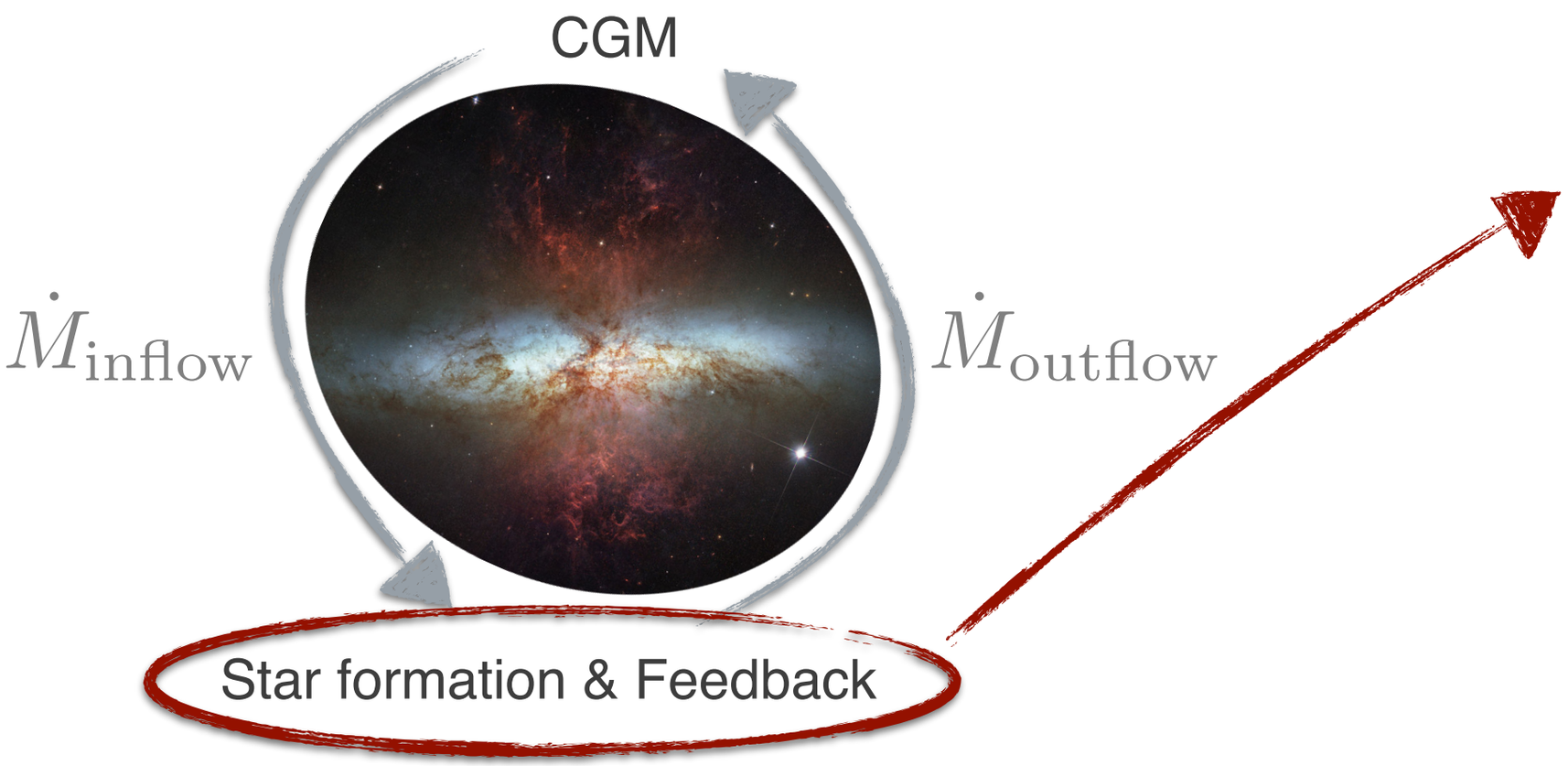

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Remain uncertain

e.g. Naab & Ostriker 2017

- Star formation efficiency (SFE) varies (e.g. Utomo+2018, Sun+2023)
  - Depends on turbulent properties of gas?(e.g. Krumholz & McKee 2005, Federrath & Klessen 2012, Evans+2022)
  - Star formation could be bottleneck for baryon cycle in certain conditions (Gensior & Kruijssen 2021)

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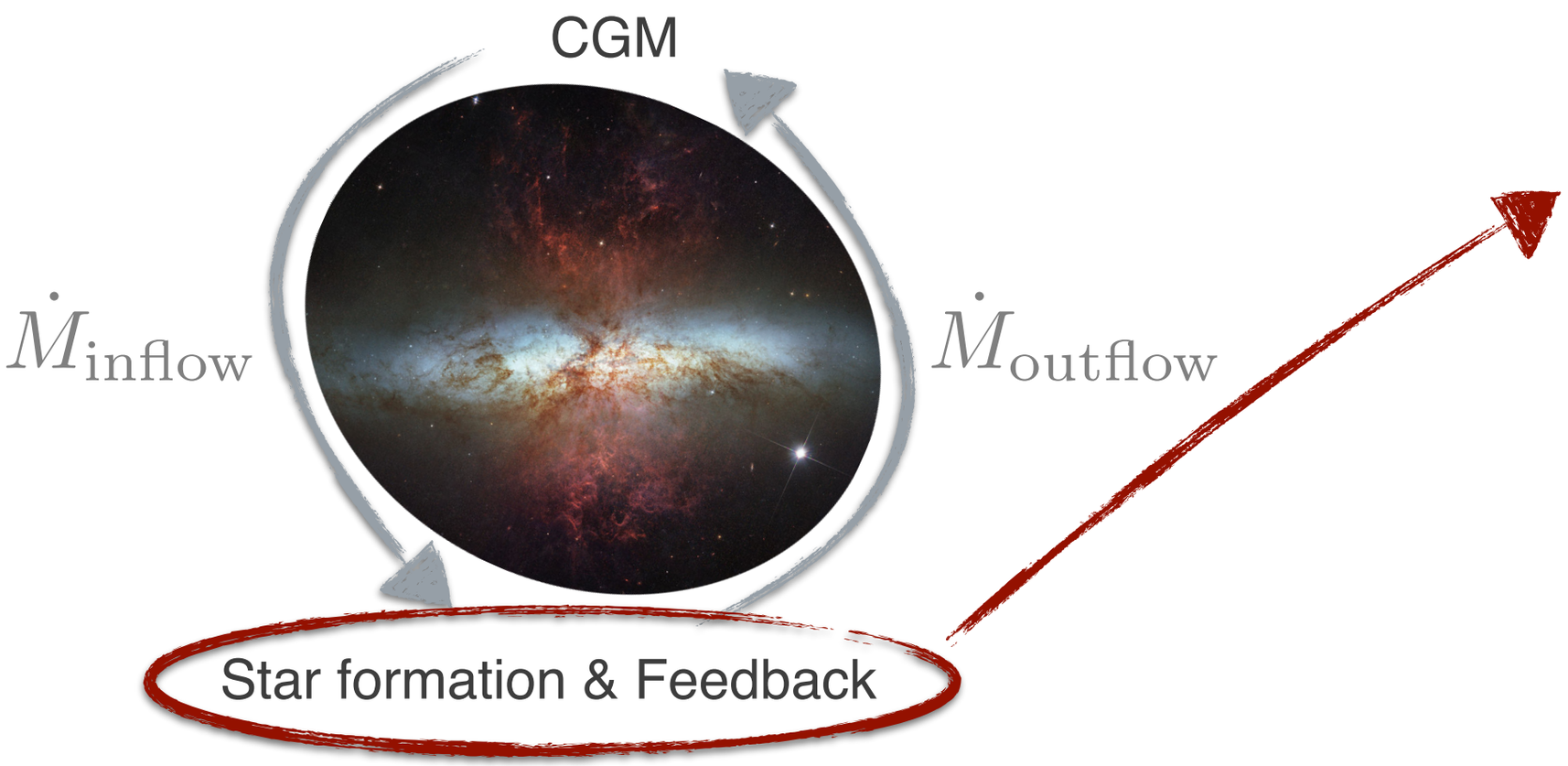

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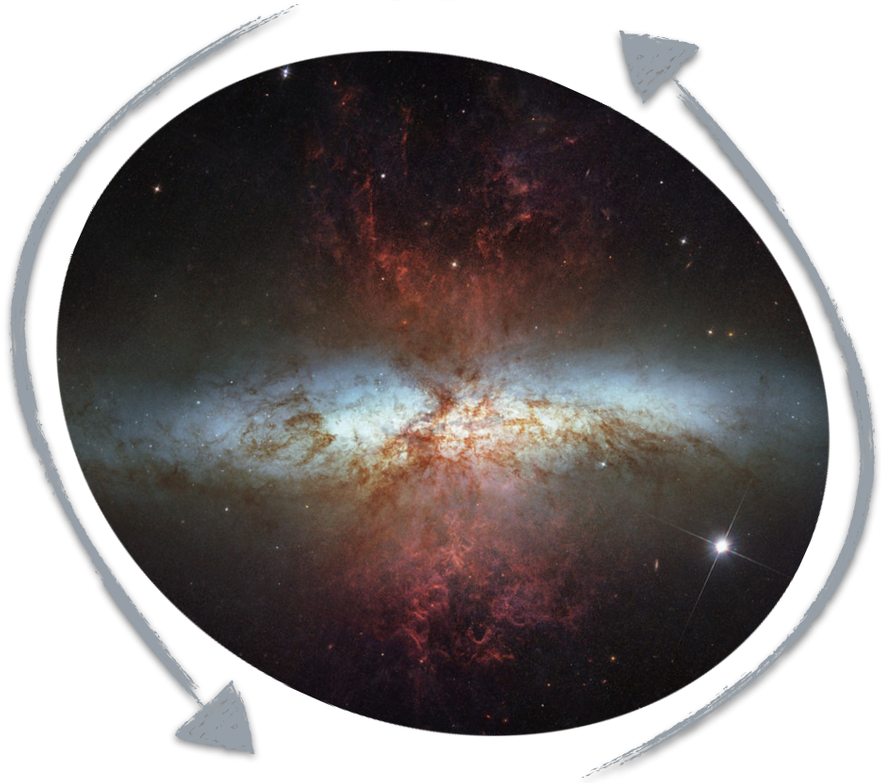
  - Star formation could be bottleneck for baryon cycle in certain conditions (Gensior & Kruijssen 2021)
- Relative importance of early stellar feedback vs. supernovae (e.g. Smith+2021, Keller+2022)

Can we use **HI** to learn more about **star formation** and **stellar feedback** physics?

THE BARYON CYCLE OF GALAXIES

CGM



$\dot{M}_{\rm inflow}$ $\dot{M}_{\rm outflow}$

Star formation & Feedback

fuel affects structure, kinematics, abundance…

HI

e.g. Saintonge & Catinella 2022

THE BARYON CYCLE OF GALAXIES

CGM

fuel ⟷ affects structure, kinematics, abundance…

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THE SAMPLE

Galaxies selected to have Milky Way halo-mass: $11.85 < \log\left(M_{\rm halo}/{\rm M}_{\odot}\right) < 12.48$

Cosmological zooms EMP-*Pathfinder*
Reina-Campos,…,JG+ 2022

FIREbox cosmological volume
Feldmann,…,JG+ 2023

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Constant	Multi free-fall	Constant
$\epsilon_{\rm ff} = 20\%$	$\epsilon_{\rm ff} = \frac{1}{2}\exp\left(\frac{3}{8}\sigma_{\rm s}^2\right)\left[1+{\rm erf}\left(\frac{\sigma^2 - {\rm s}_{\rm crit}}{\sqrt{2\sigma_{\rm s}^2}}\right)\right]$ => $\epsilon_{\rm ff} = f(\alpha_{\rm vir}, \mathcal{M})$	$\epsilon_{\rm ff} = 100\%$ + $\alpha_{\rm vir} \leq 1$
21 galaxies	**14** galaxies	**26** galaxies

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THE SAMPLE:

GALAXIES EVOLVED SELF-CONSISTENTLY ACROSS COSMIC TIME, INCLUDING A **COLD ISM**!

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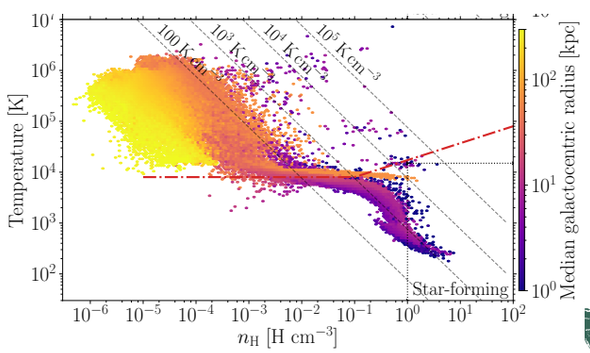
Reina-Campos,…,JG+ 2022



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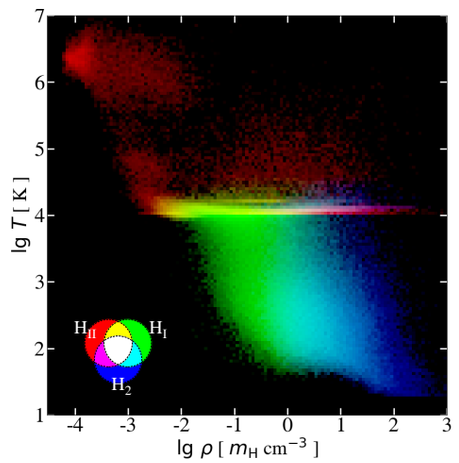

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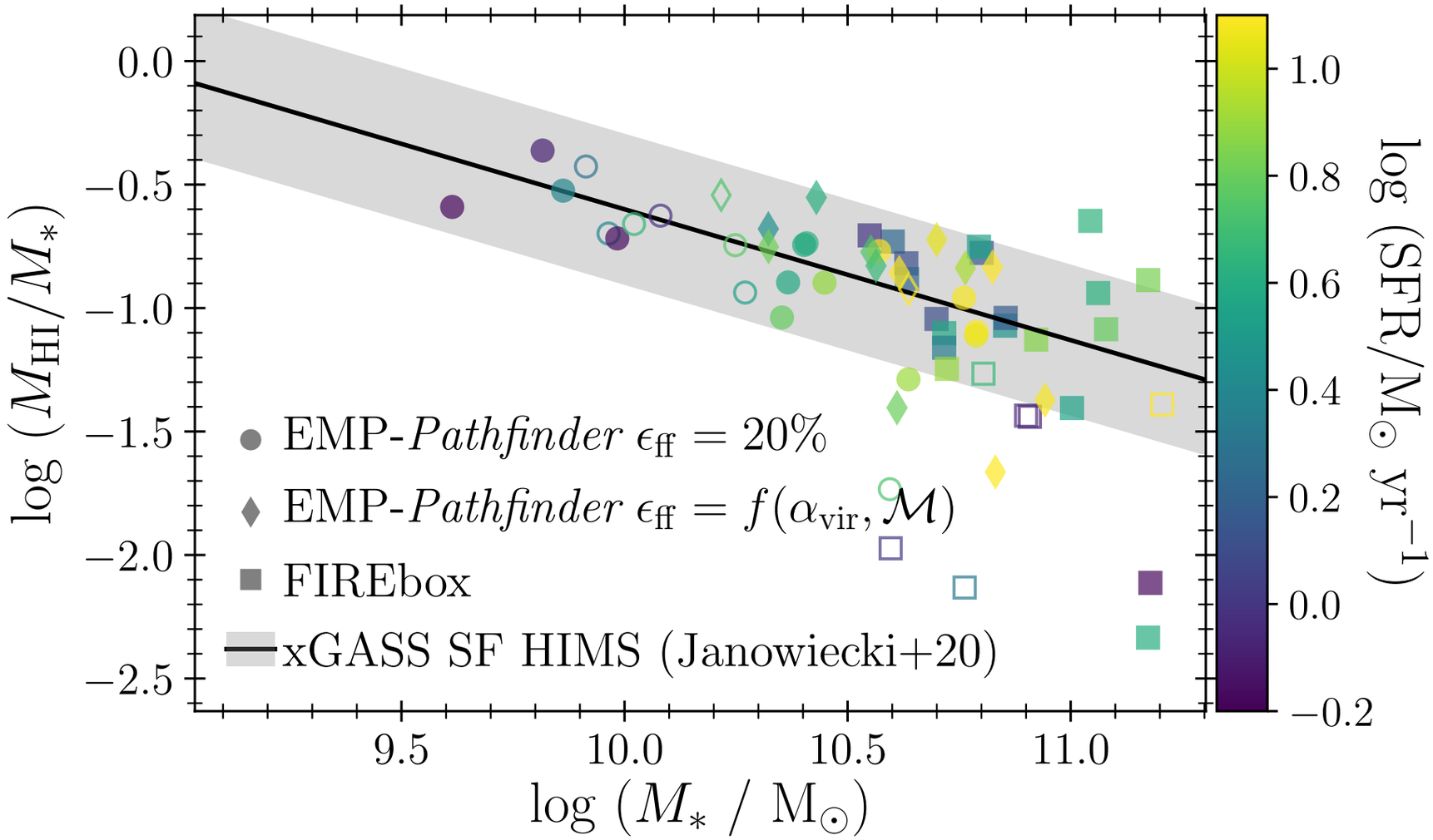

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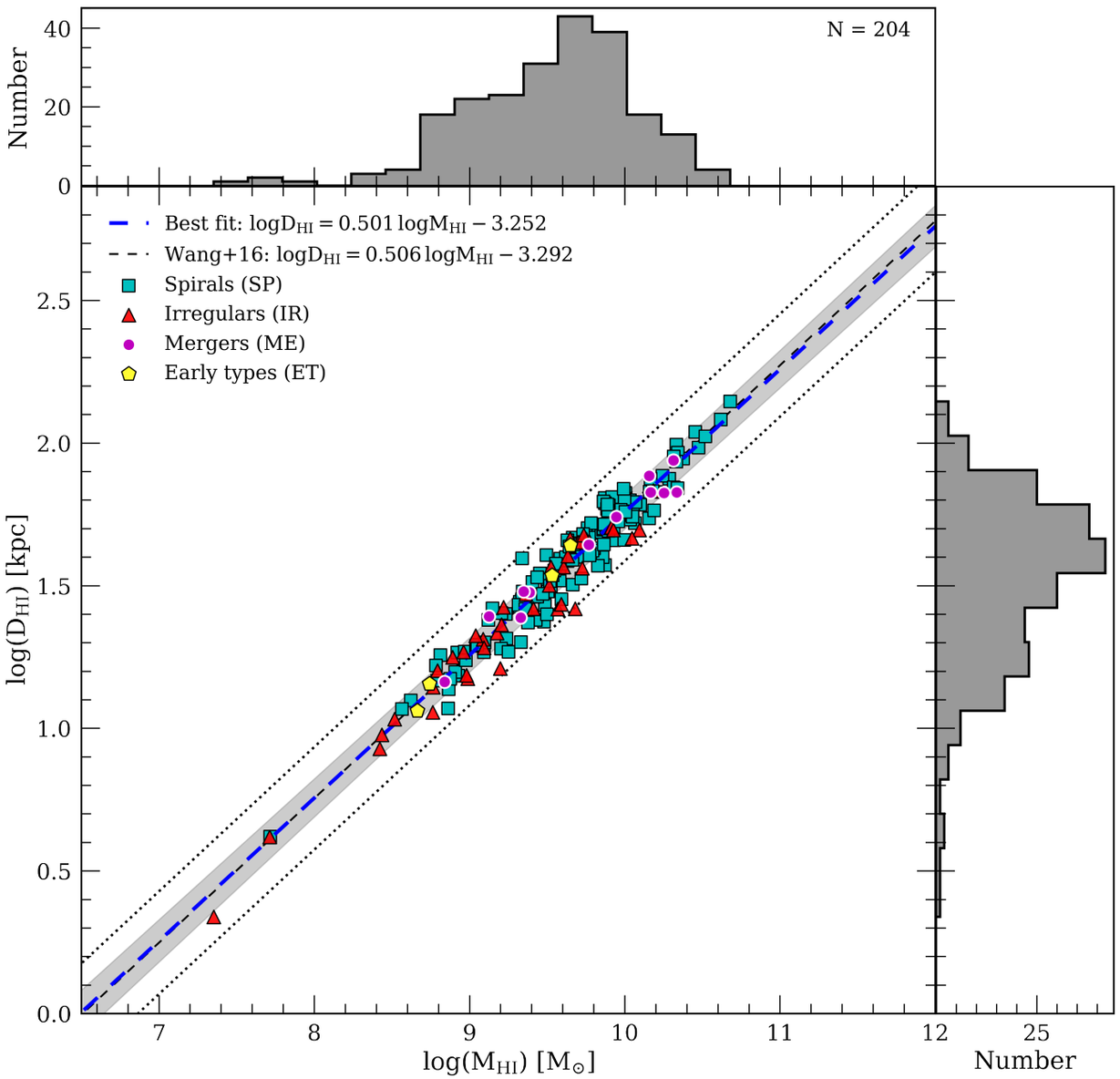
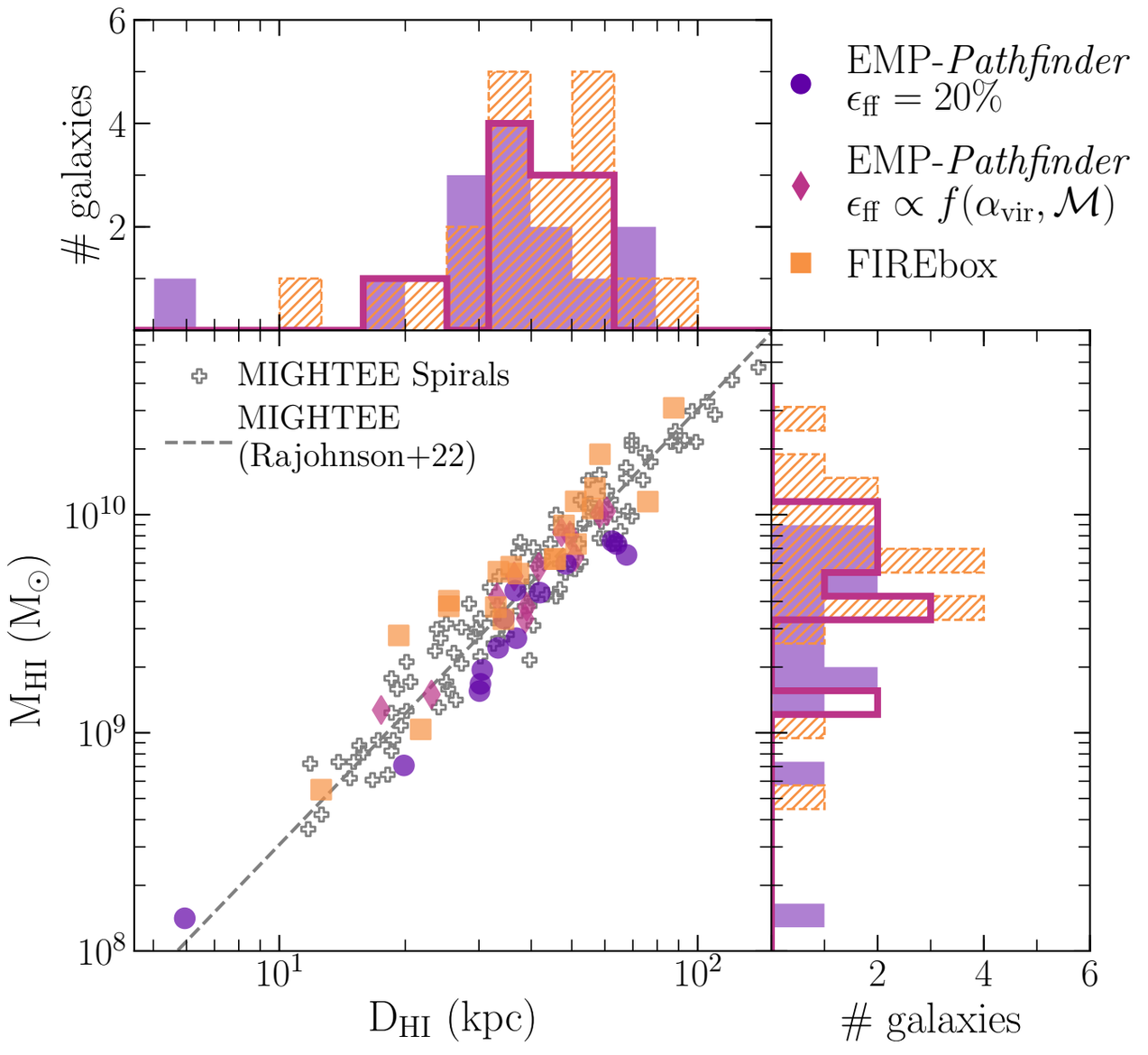
HI MASS-SIZE RELATION





MIGHTEE (Rajohnson+2022)

See also e.g. Broils & Rhee 1997, Verheijen & Sancisi 2001, Swaters+2002, Noordermeer+2005, Begum+2008, Obreschkow+2009, Ponomareva+2016, Wong+2016, Stevens+2019

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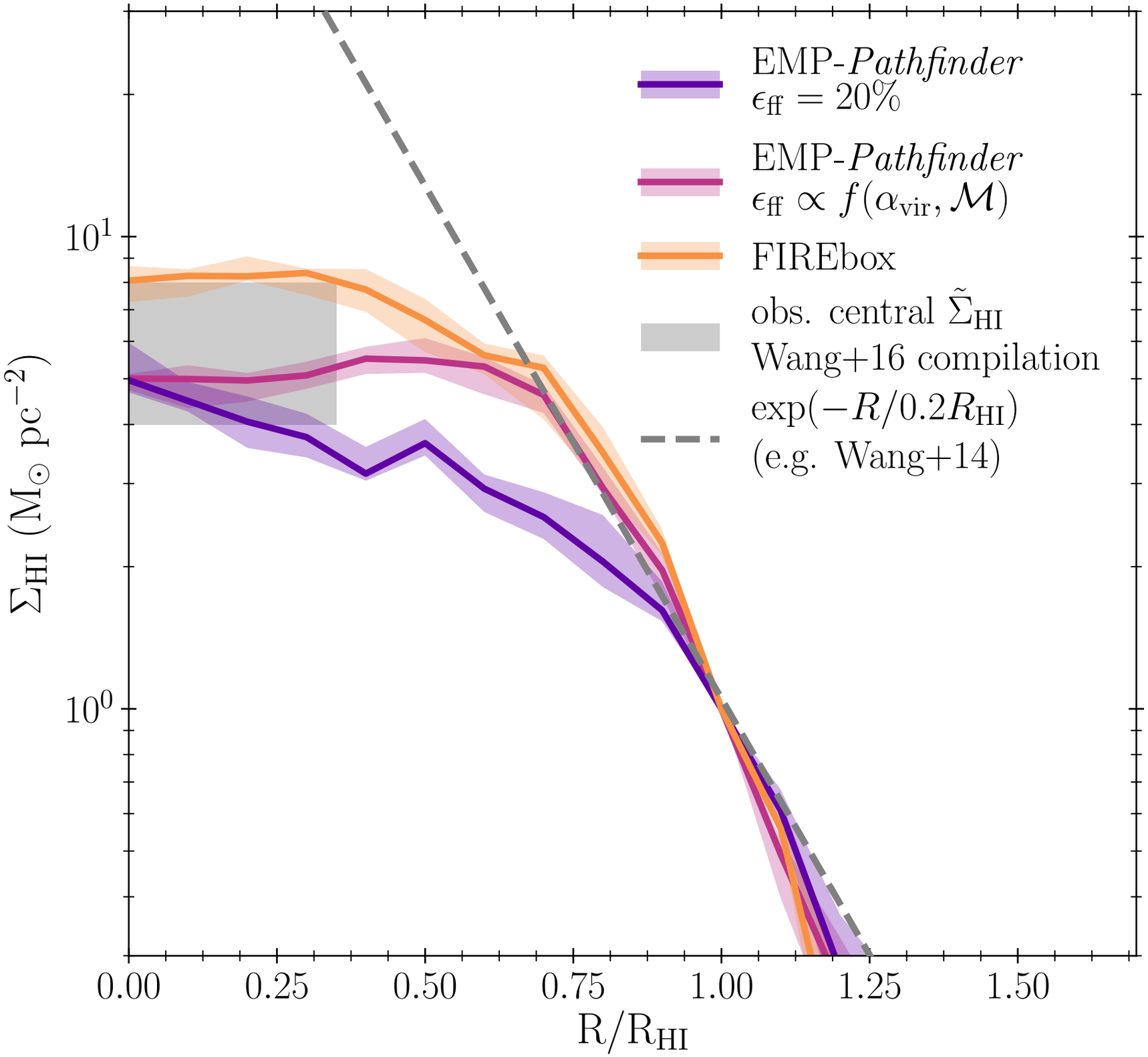
MEDIAN HI SURFACE DENSITY PROFILES



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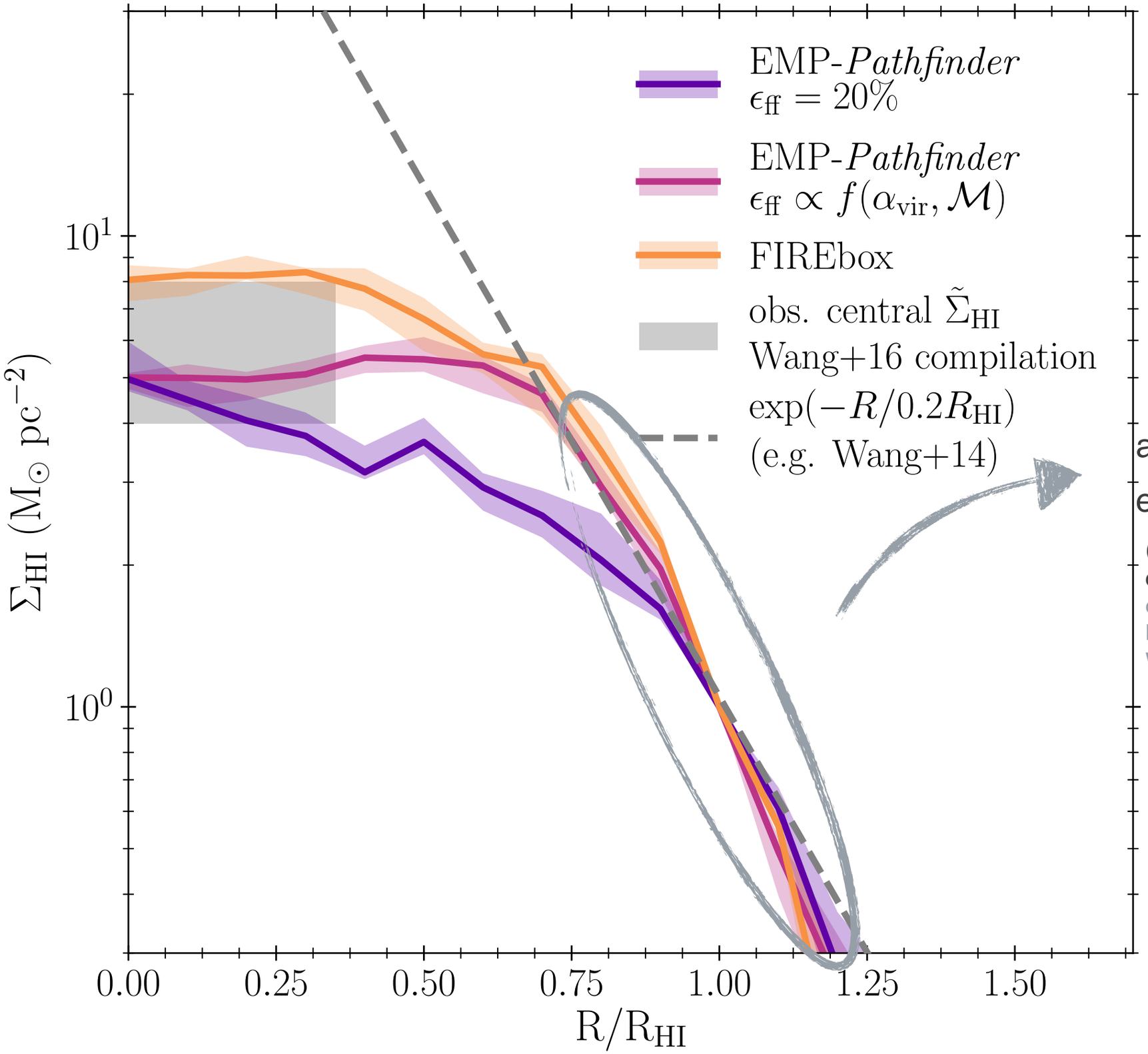

approximately follow exponential profile

(Expected from observations for R > 0.8 R_{HI} e.g Swaters+2002, Bigiel & Blitz 2012, Wang+2014, Wang+2016)

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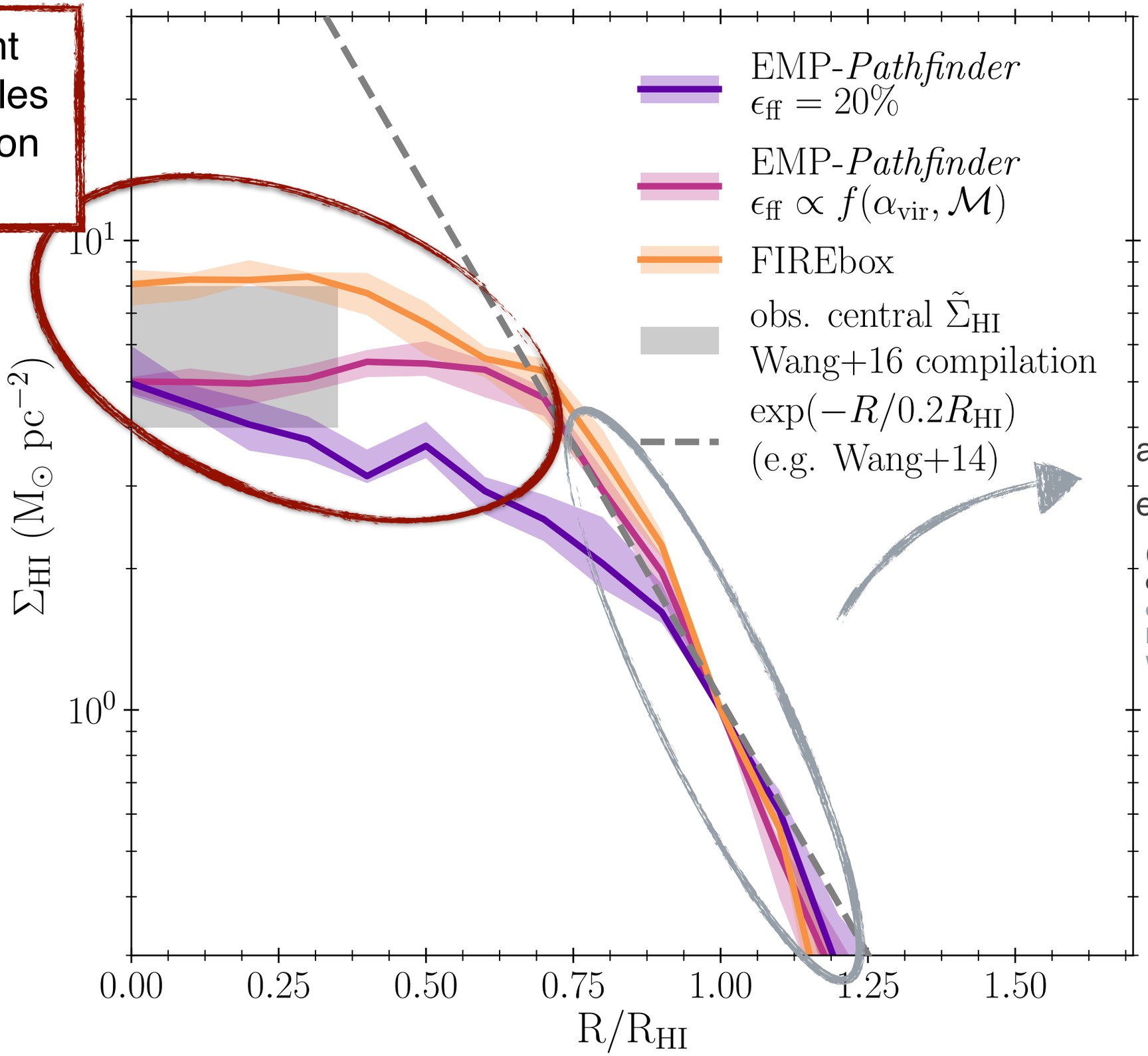
MEDIAN HI SURFACE DENSITY PROFILES

very different central profiles (normalisation & shape)



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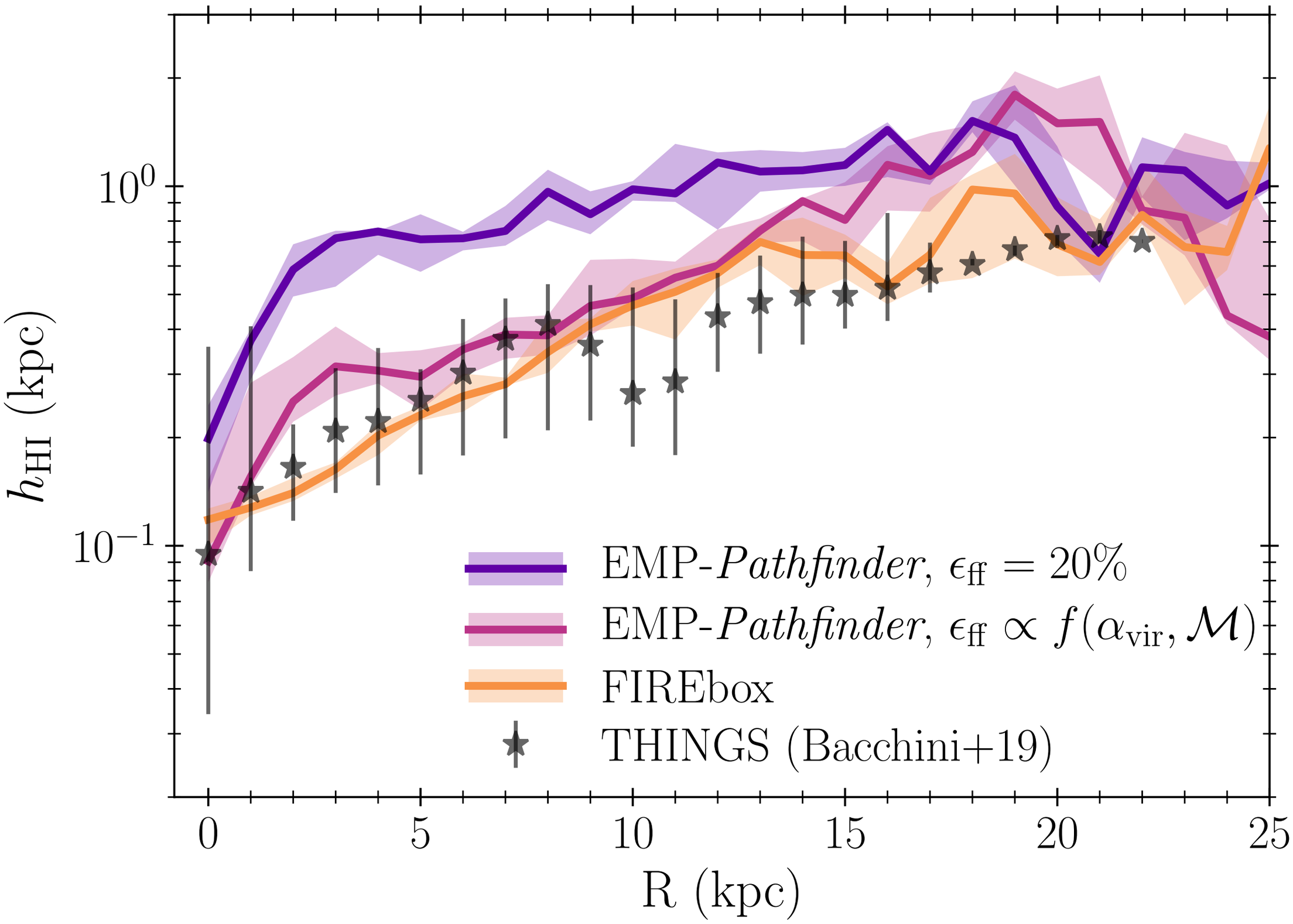
HI DISC SCALE HEIGHTS



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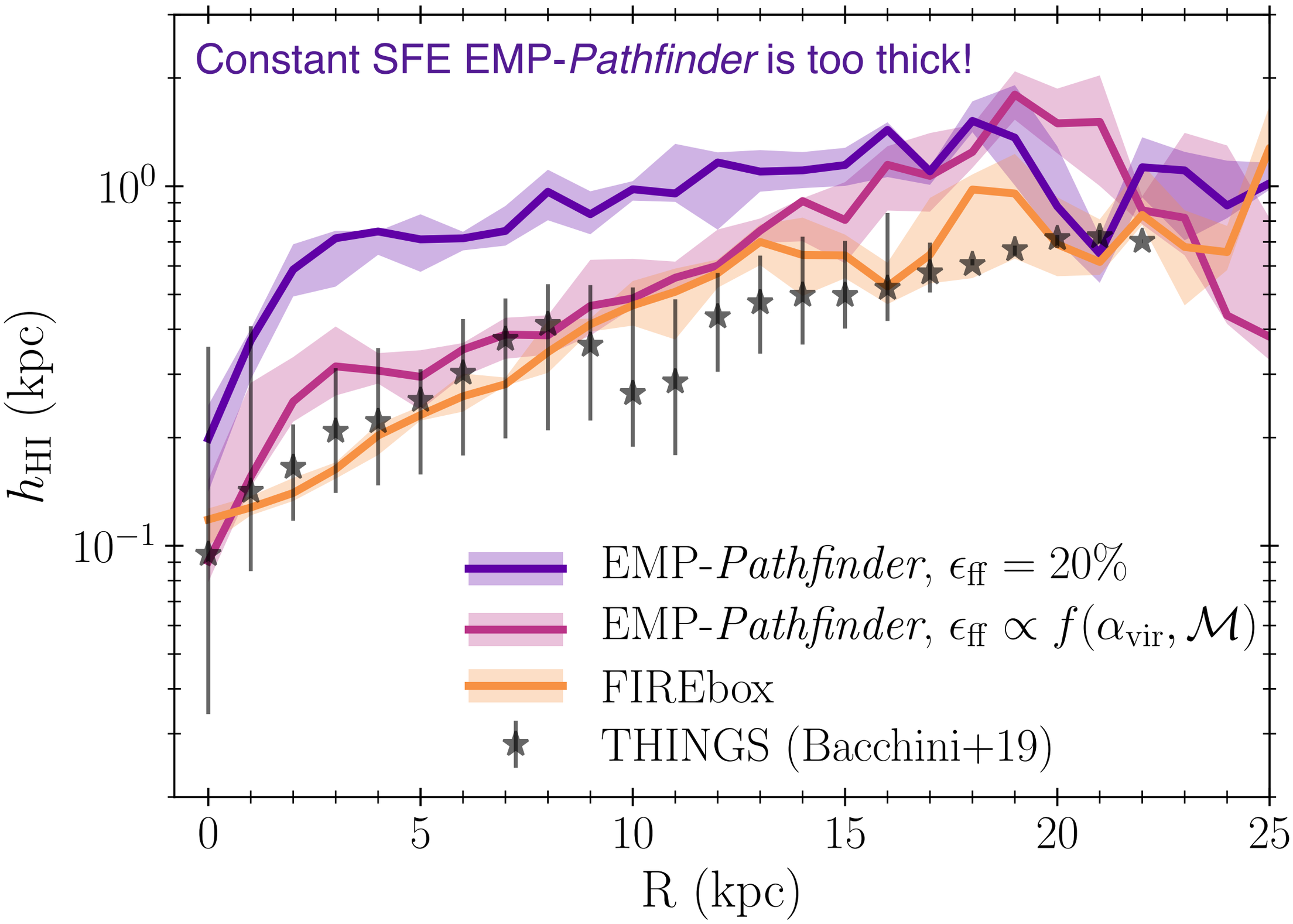

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HI DISC MORPHOLOGY

EMP-*Pathfinder*

$$\epsilon_{\rm ff} = 20\%$$

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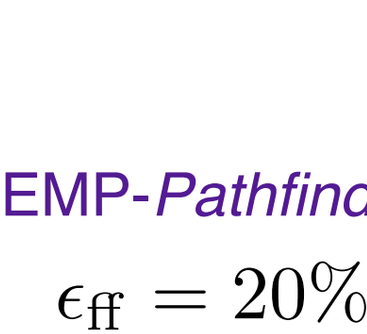

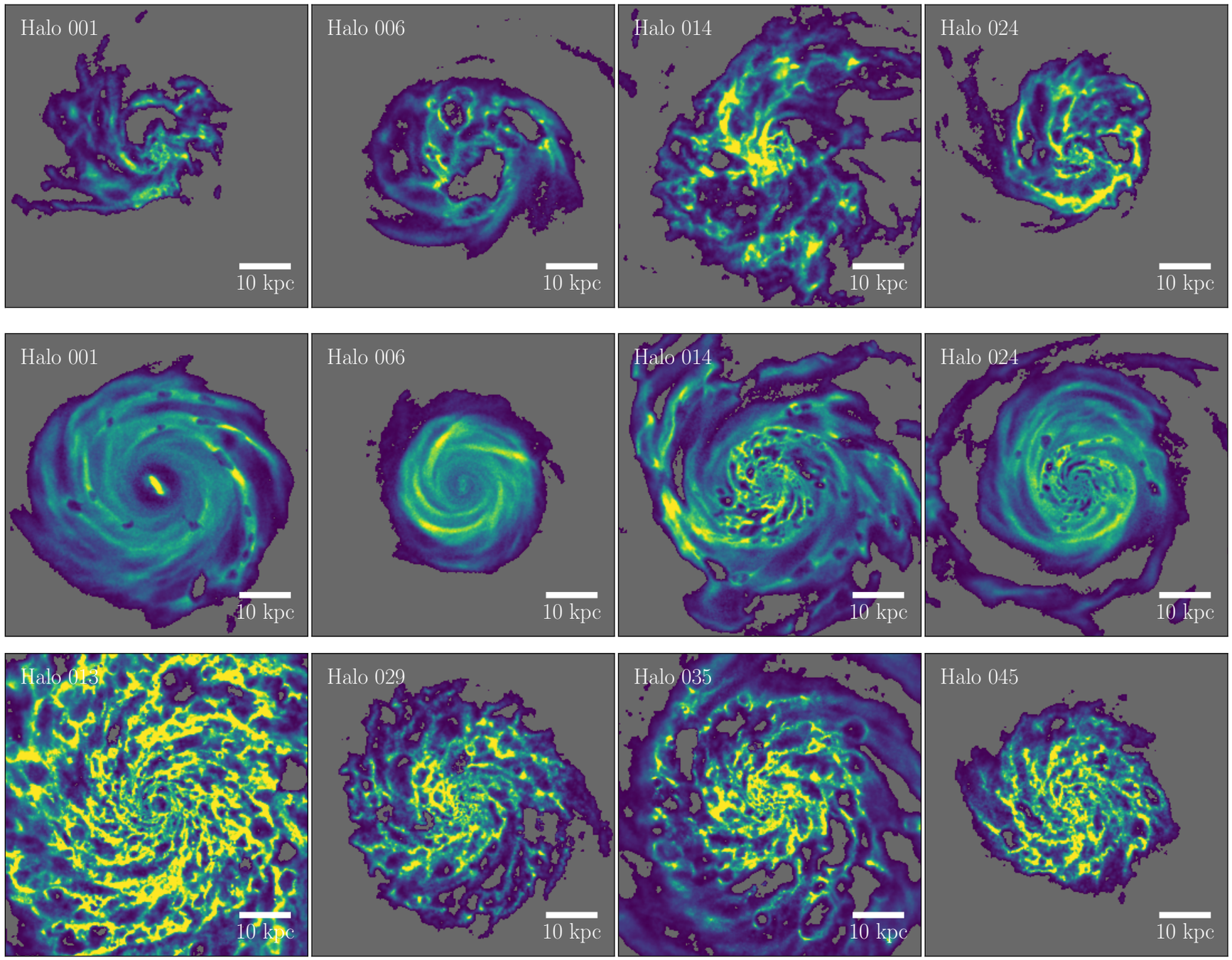

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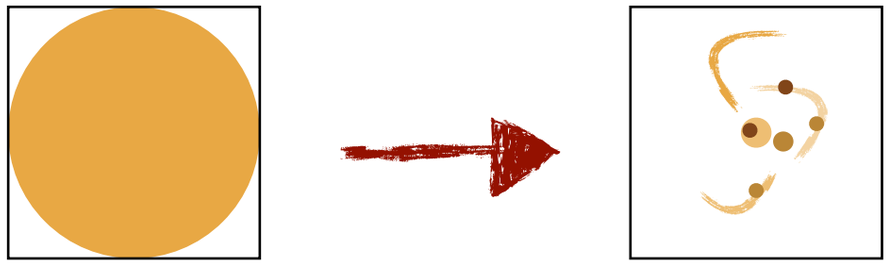
Can we quantify the differences in HI disc morphology and infer which physics drive them?

QUANTIFYING HI DISC MORPHOLOGY WITH NON-PARAMETRIC INDICATORS

Asymmetry

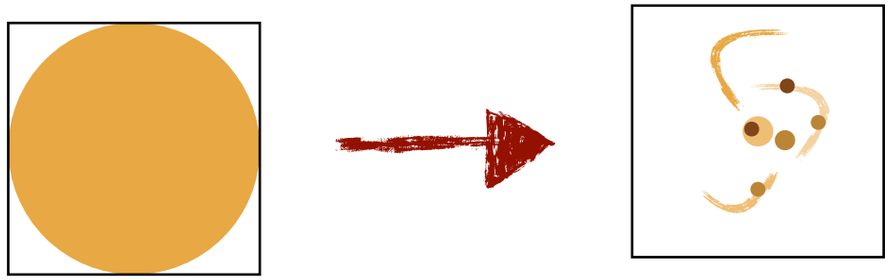
$$A \equiv \frac{\sum_{i,j} |I_{ij} - I_{ij}^{180}|}{\sum_{i,j} |I_{ij}|}$$



Low High

Gini

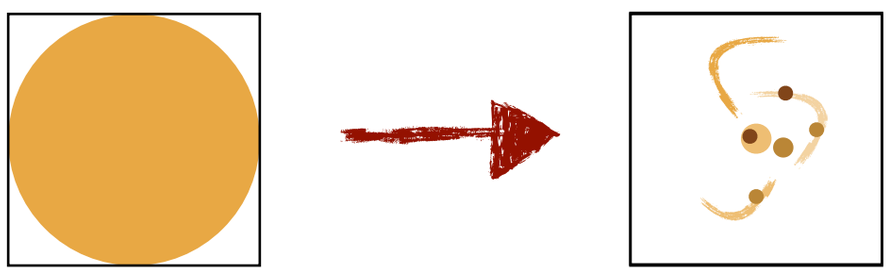
$$G \equiv \frac{1}{\bar{X} n(n-1)} \sum_{i=1}^{n} (2i - n - 1) X_i$$



Low High

Smoothness

$$S \equiv \frac{\sum_{i,j} I_{ij} - I_{ij}^{S}}{\sum_{i,j} I_{ij}}$$



Low High

HI DISC MORPHOLOGY

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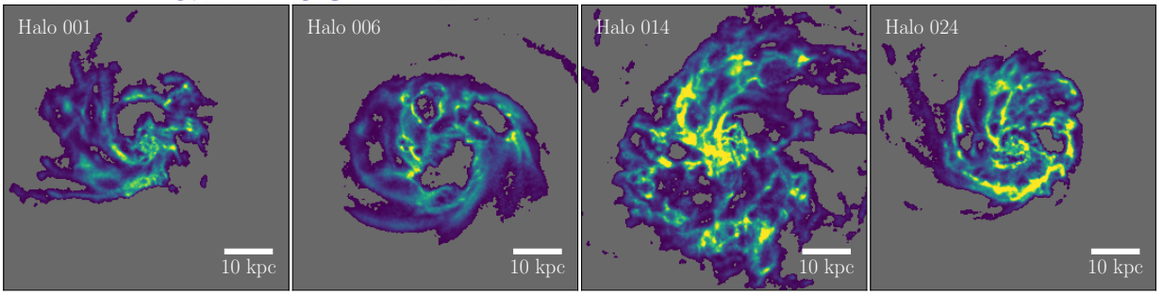
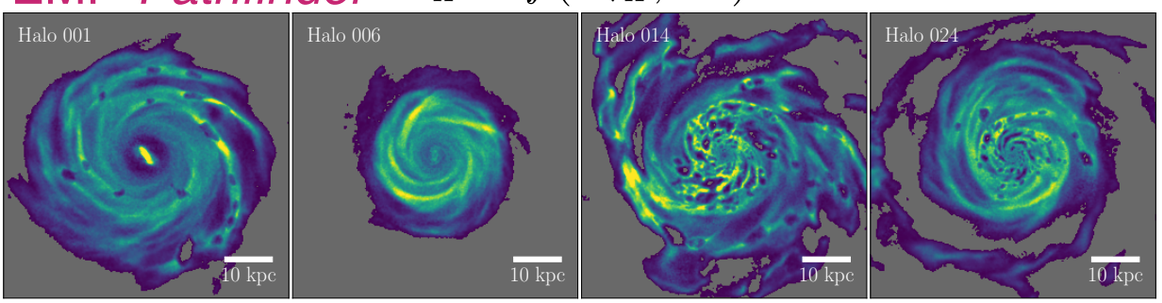
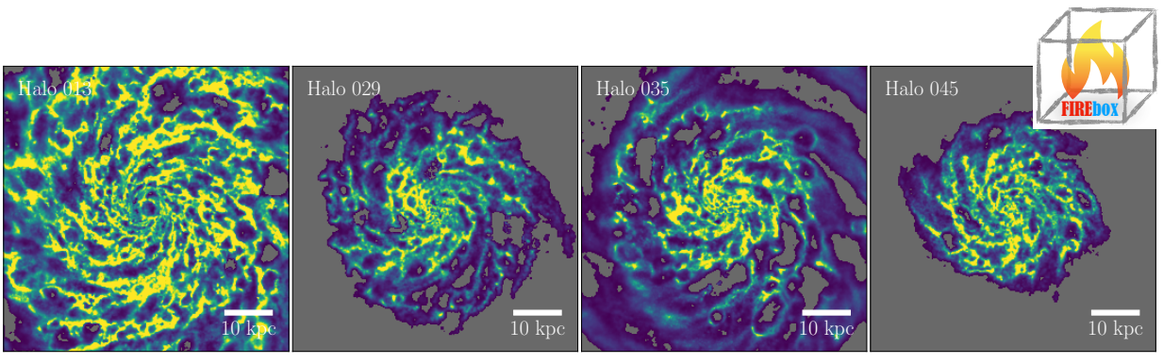
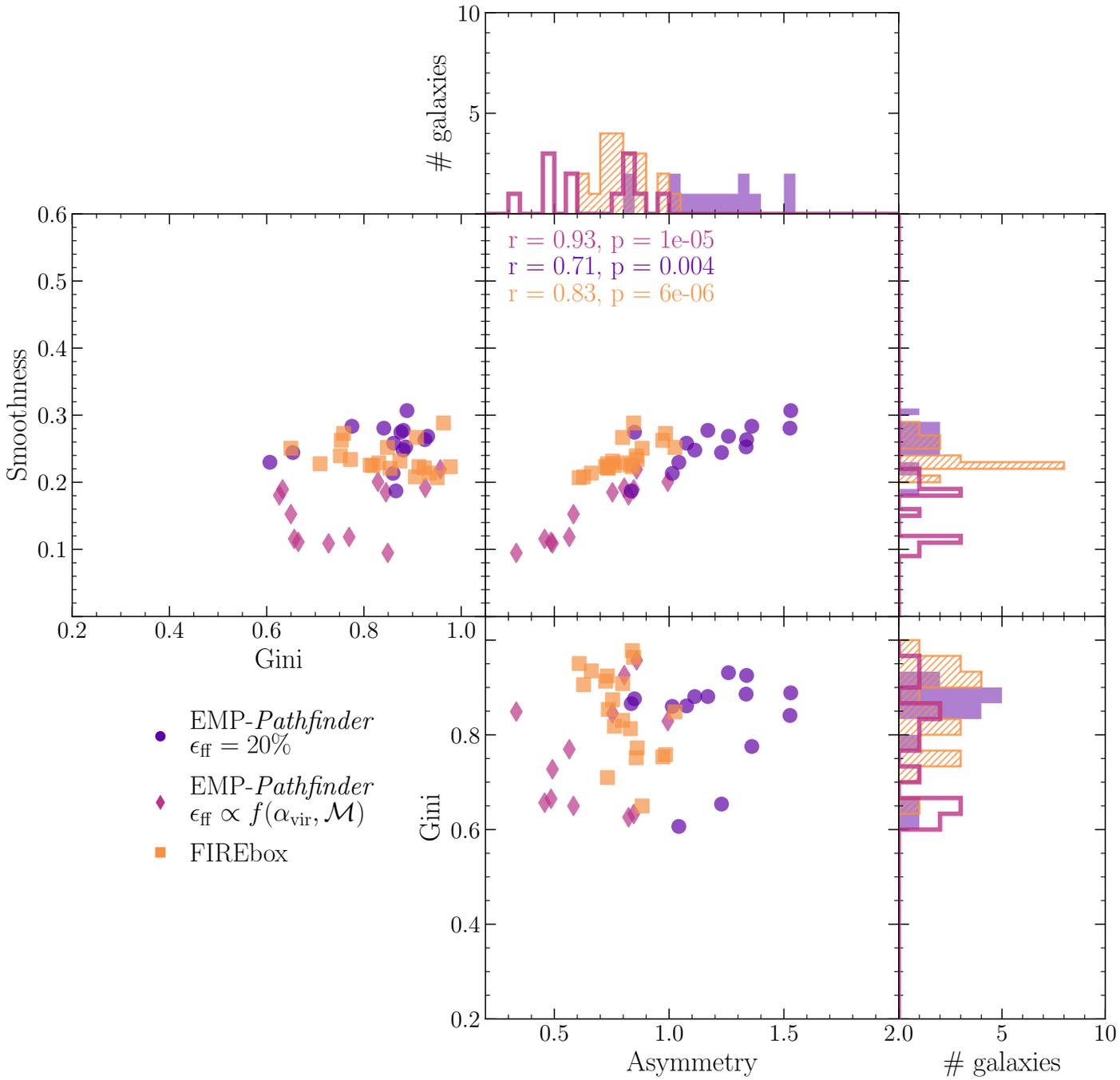


EMP-*Pathfinder* $\epsilon_{\rm ff} = f(\alpha_{\rm vir}, \mathcal{M})$







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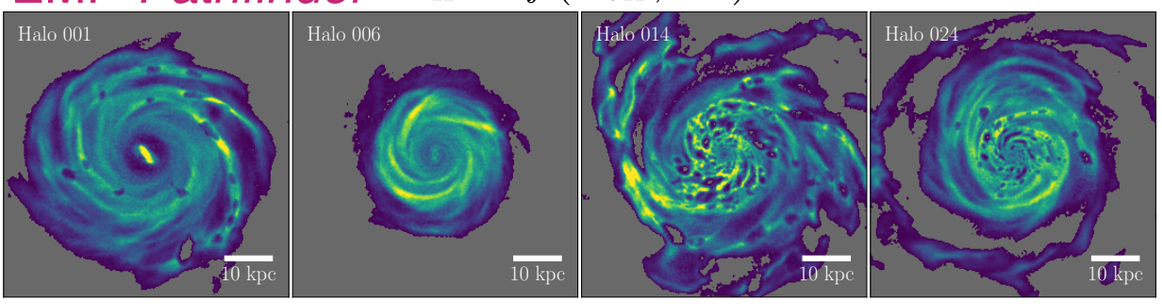
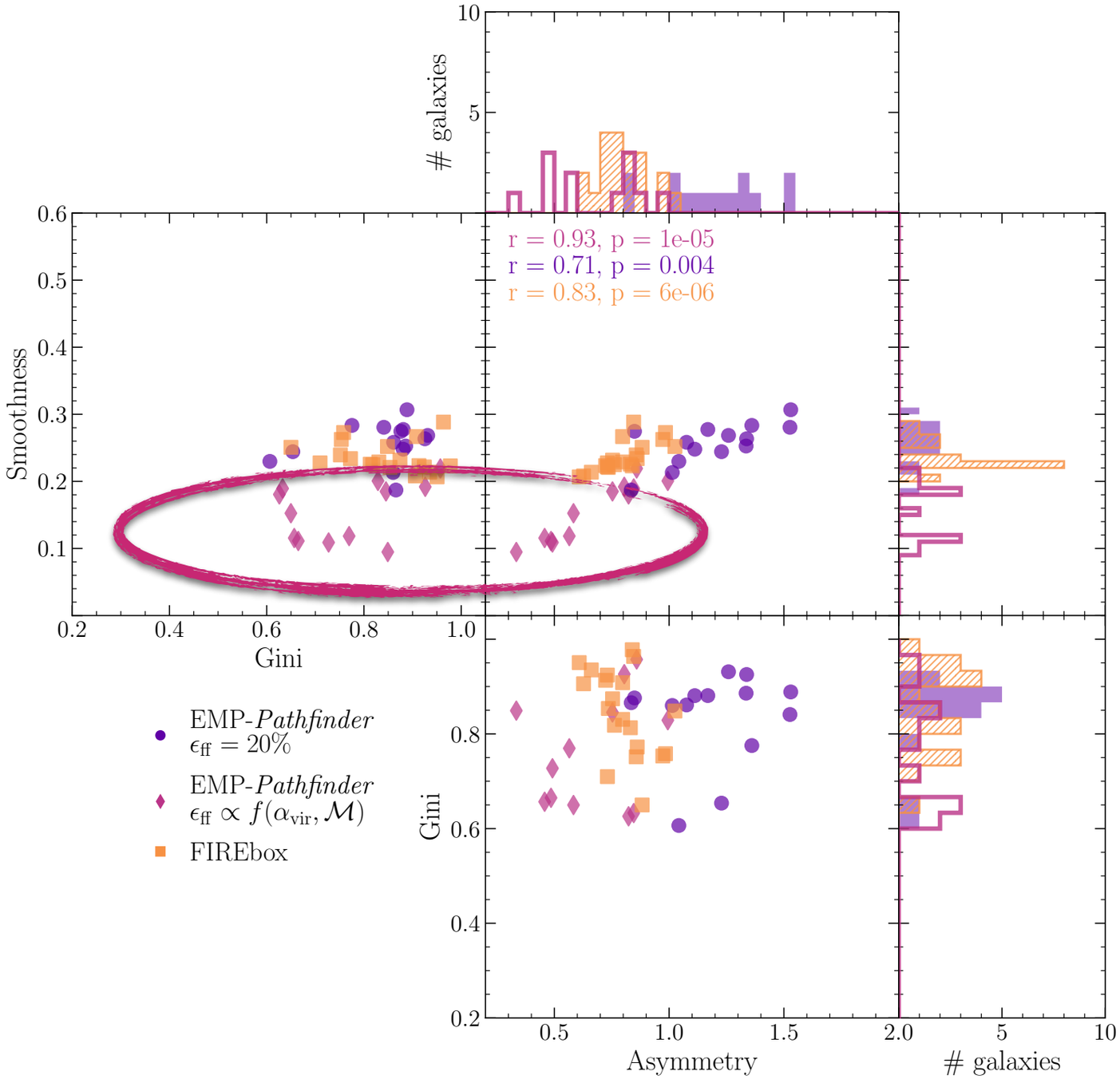
HI DISC MORPHOLOGY

EMP-*Pathfinder* $\epsilon_{\rm ff} = 20\%$

Smoother & more symmetric discs

EMP-*Pathfinder* $\epsilon_{\rm ff} = f(\alpha_{\rm vir}, \mathcal{M})$





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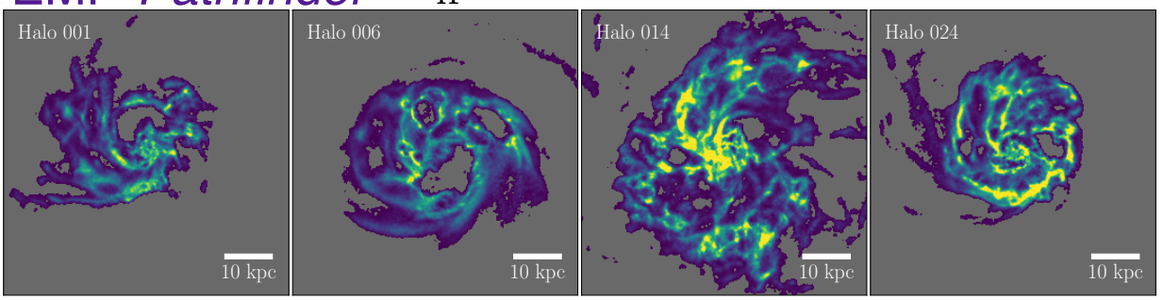
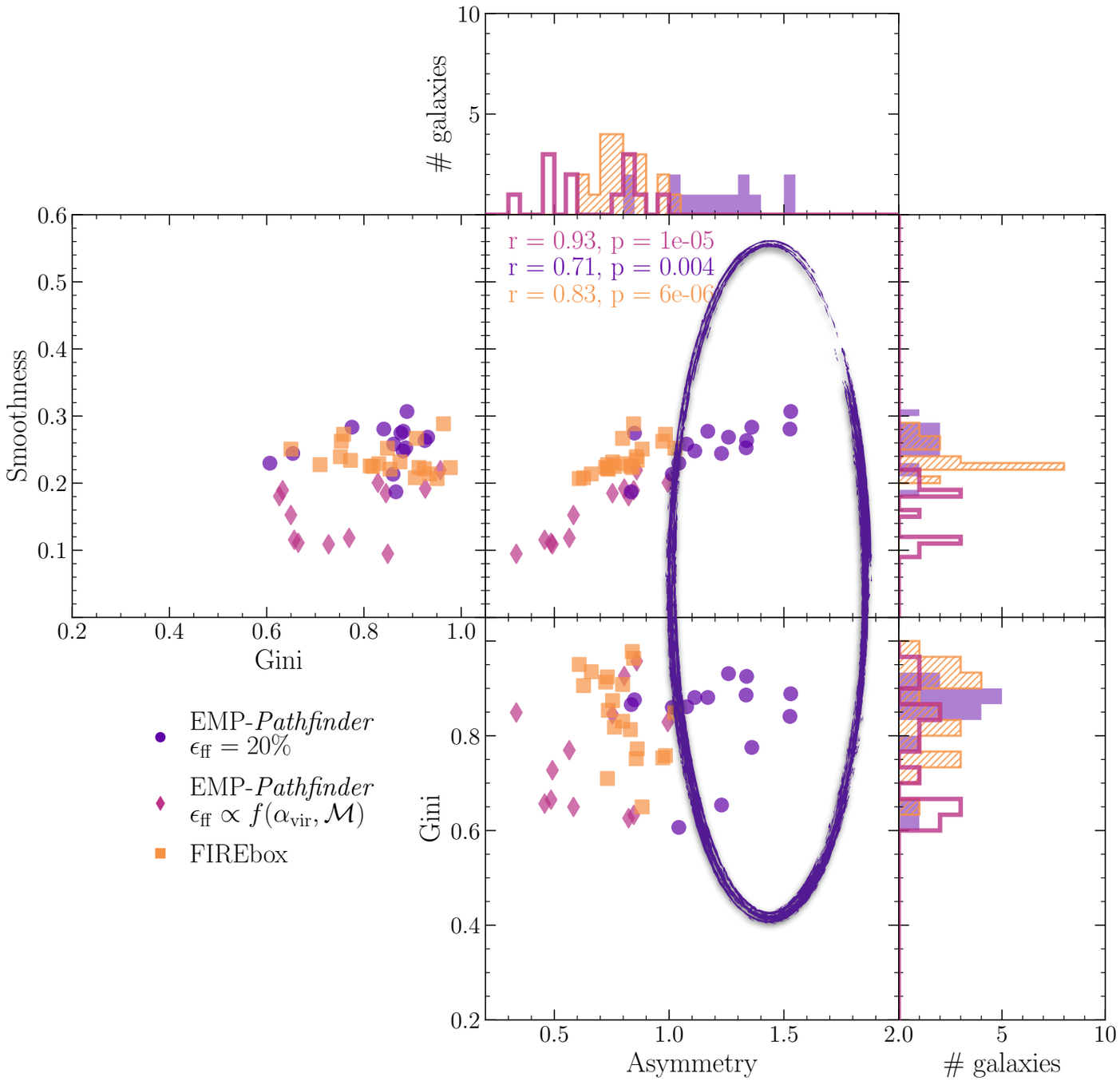


Very asymmetric discs

EMP-*Pathfinder* $\epsilon_{\rm ff} = f(\alpha_{\rm vir}, \mathcal{M})$



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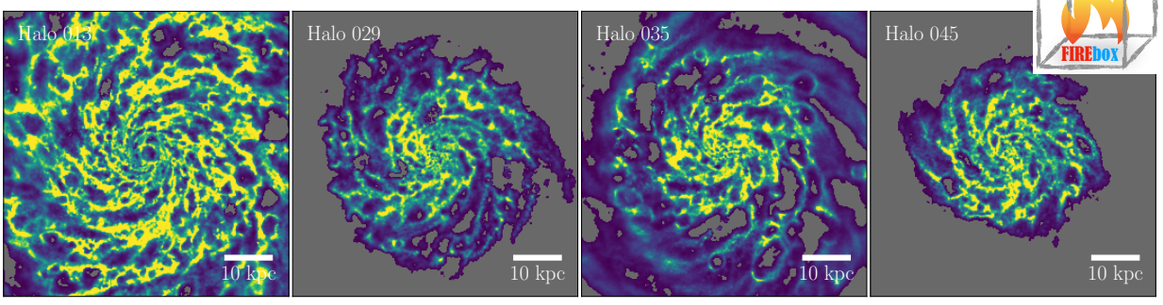
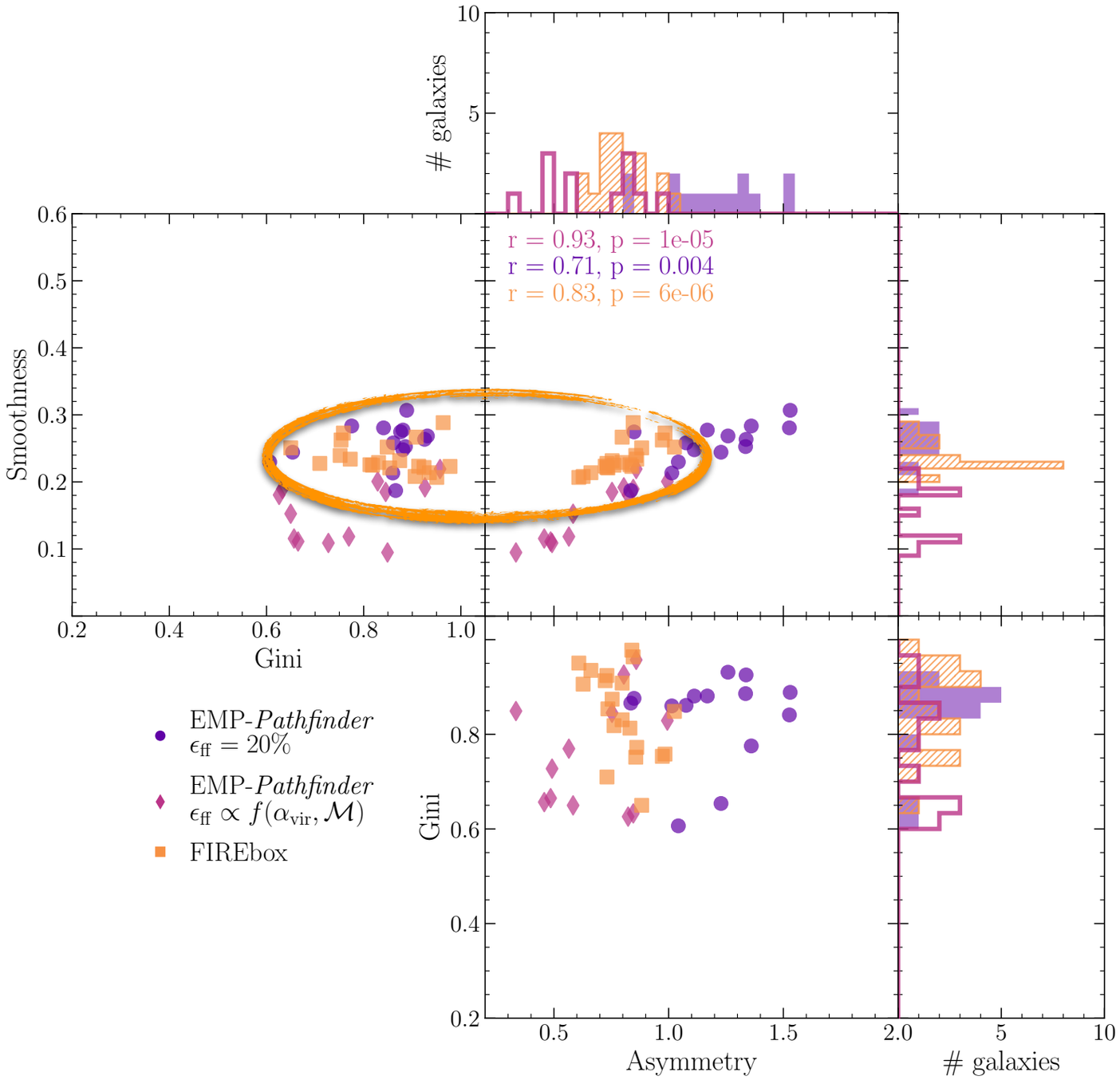
Very similar discs





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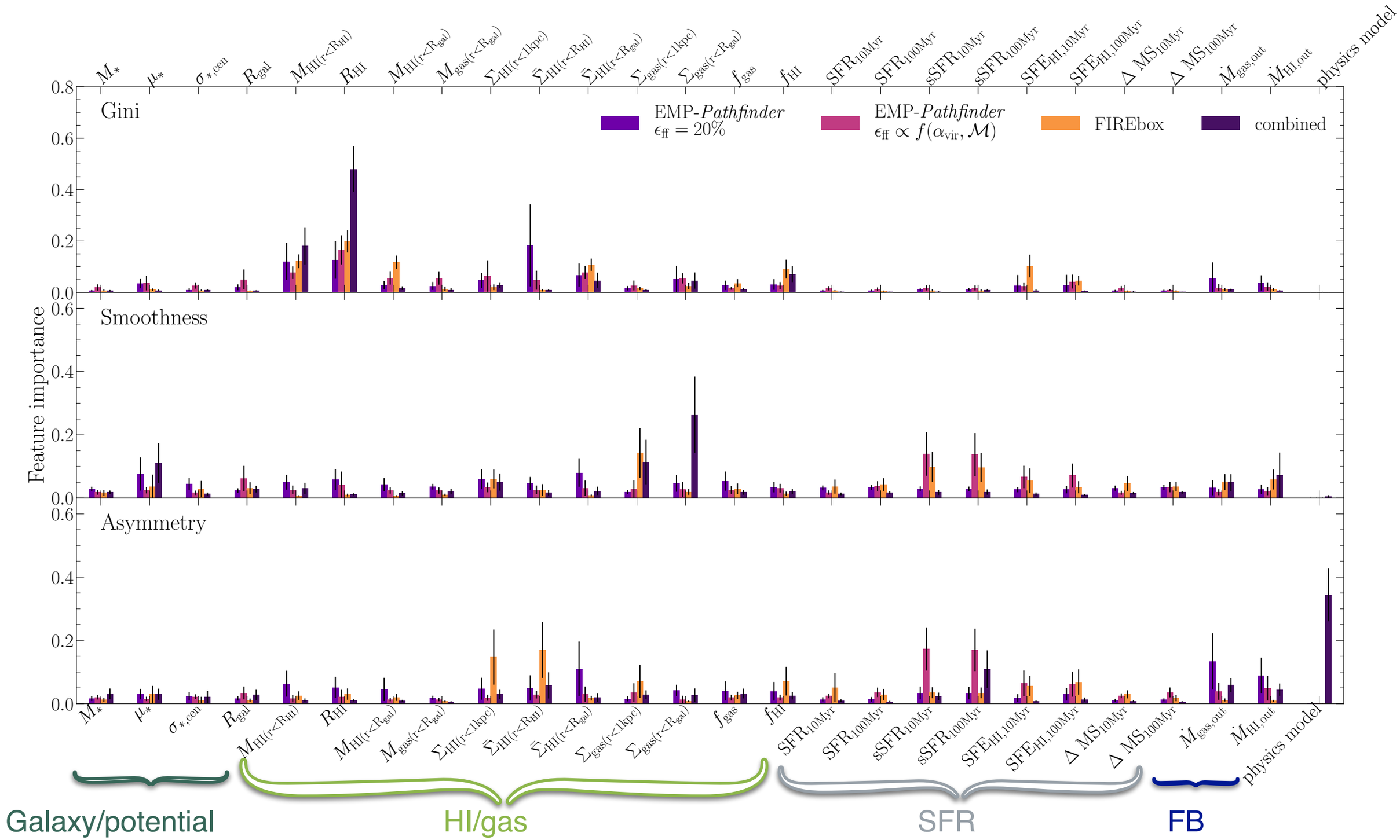
BEST PREDICTOR FOR HI DISC MORPHOLOGY



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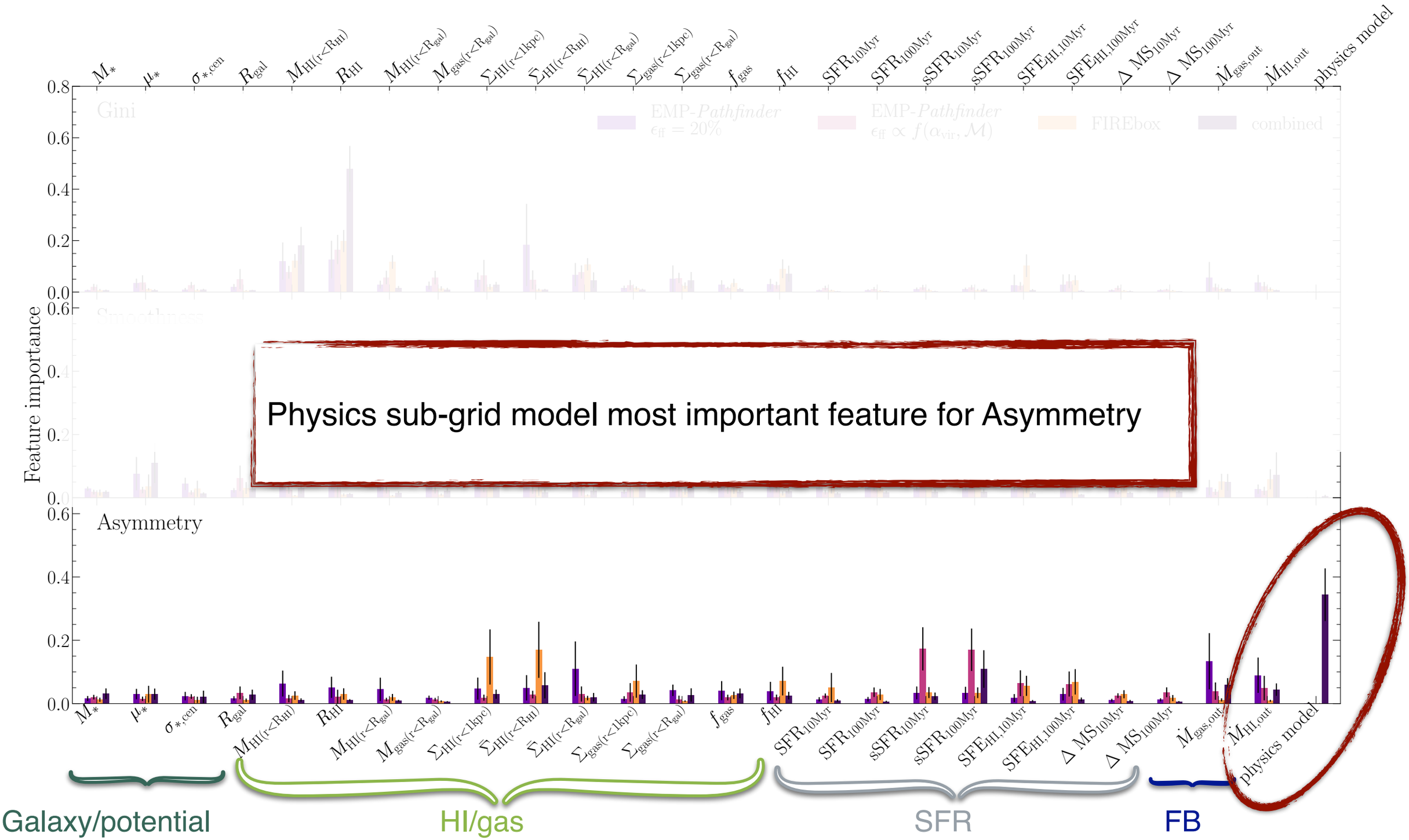

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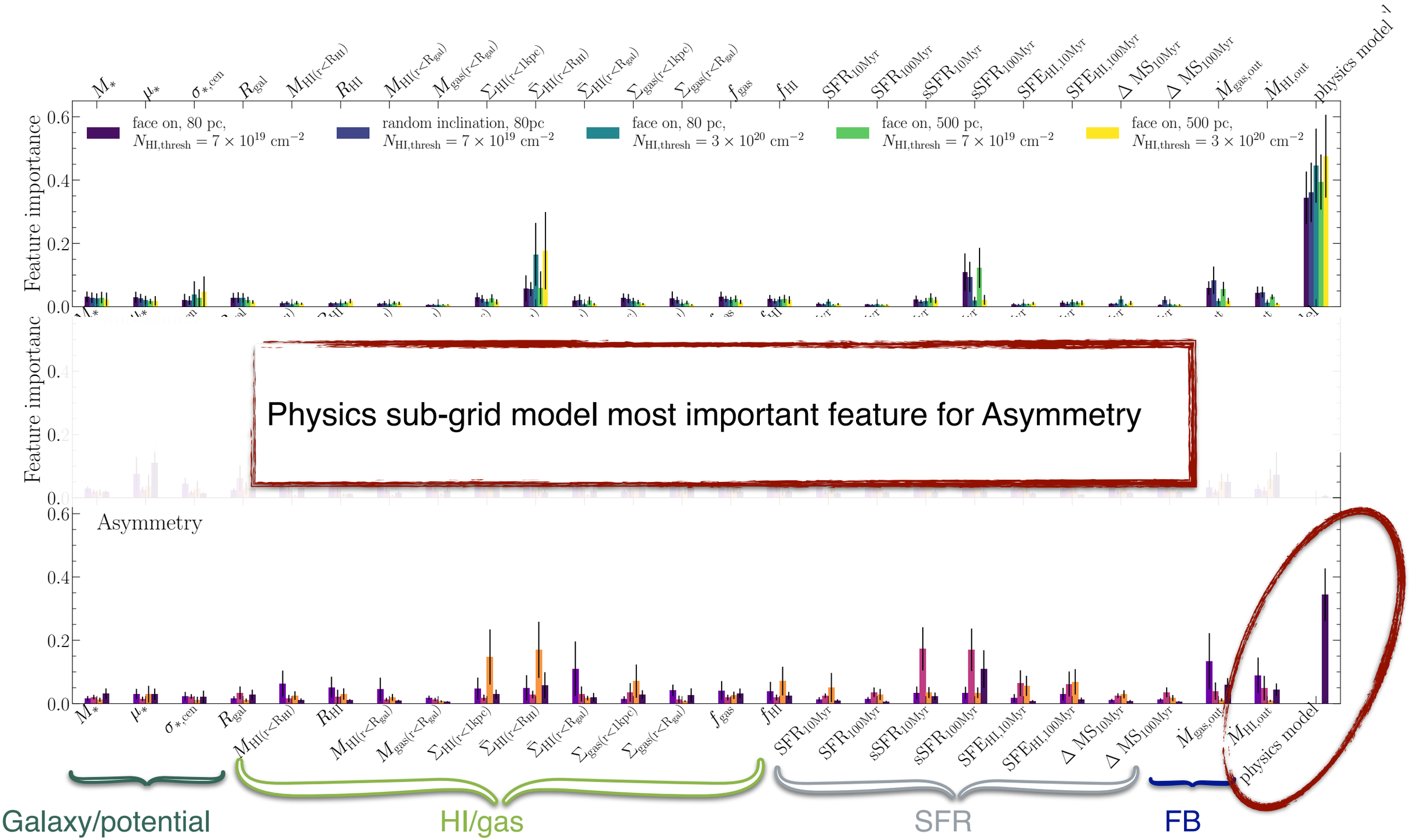

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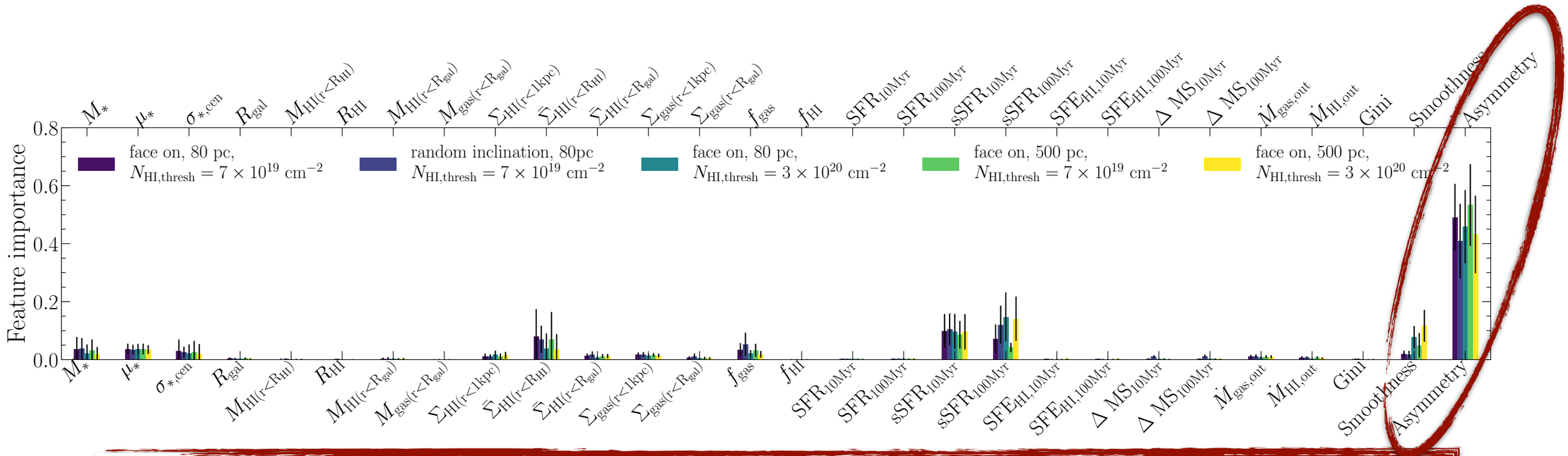
BEST PREDICTOR FOR SUB-GRID PHYSICS



Reverse also holds: Asymmetry most important feature to predict physics model

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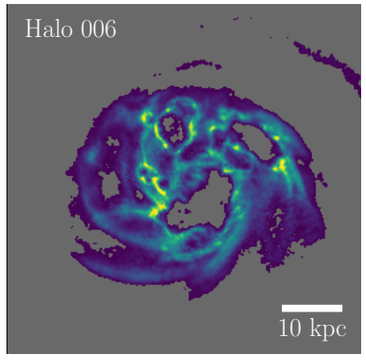
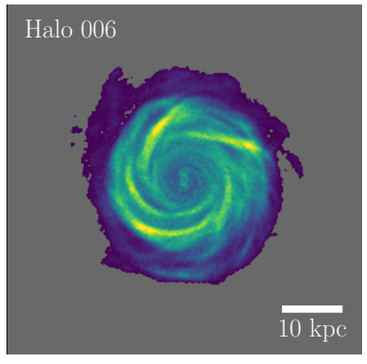
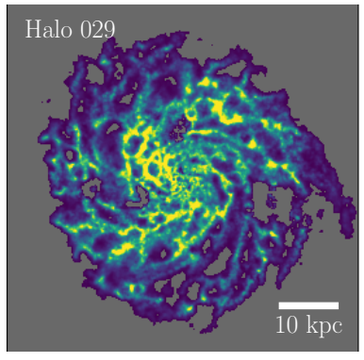
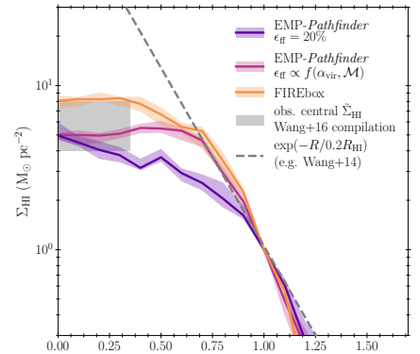
SUMMARY







Read the paper Stalk me



- HI discs are extremely sensitive to the physics of star formation and stellar feedback:
  - Central HI surface density profile differ significantly
  - Only FIREbox & multi free-fall SFE EMP-*Pathfinder* produce thin HI discs
  - Very different HI morphologies:
    - Multi free-fall SFE EMP-*Pathfinder* galaxies have very smooth & symmetric HI discs
    - FIREbox: porous & sub-structured (very similar amount of structure in all discs)
    - Constant SFE EMP-*Pathfinder*: very asymmetric
  - ➡ Baryonic physics model selected as best predictor for Asymmetry of HI discs