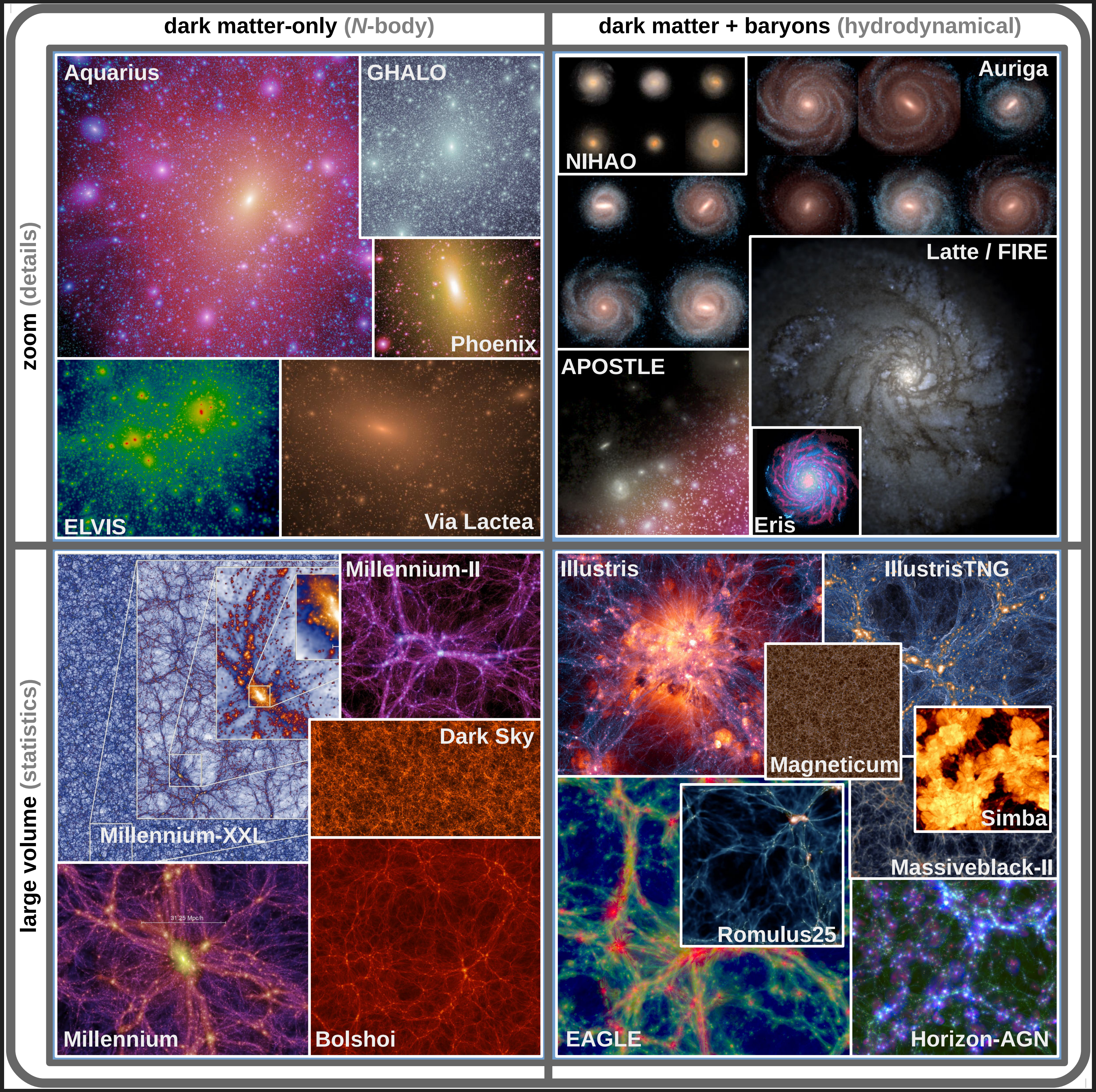
OBSERVING HI IN AND AROUND SIMULATED GALAXIES

A. Marasco - INAF, Observatory of Padova, Italy

Sweden SKA Science Day, 4-5 Feb 2026, Stockholm

Simulations come in many flavours

Detailed DM distribution within galaxy halos.



Detailed galaxy and ISM structure; Galaxy-halo-AGN interplay.

large-scale DM clustering. Semi-analytic models (SAMs)

Galaxy population properties and their evolution. Environment.

Vogelsberger+20

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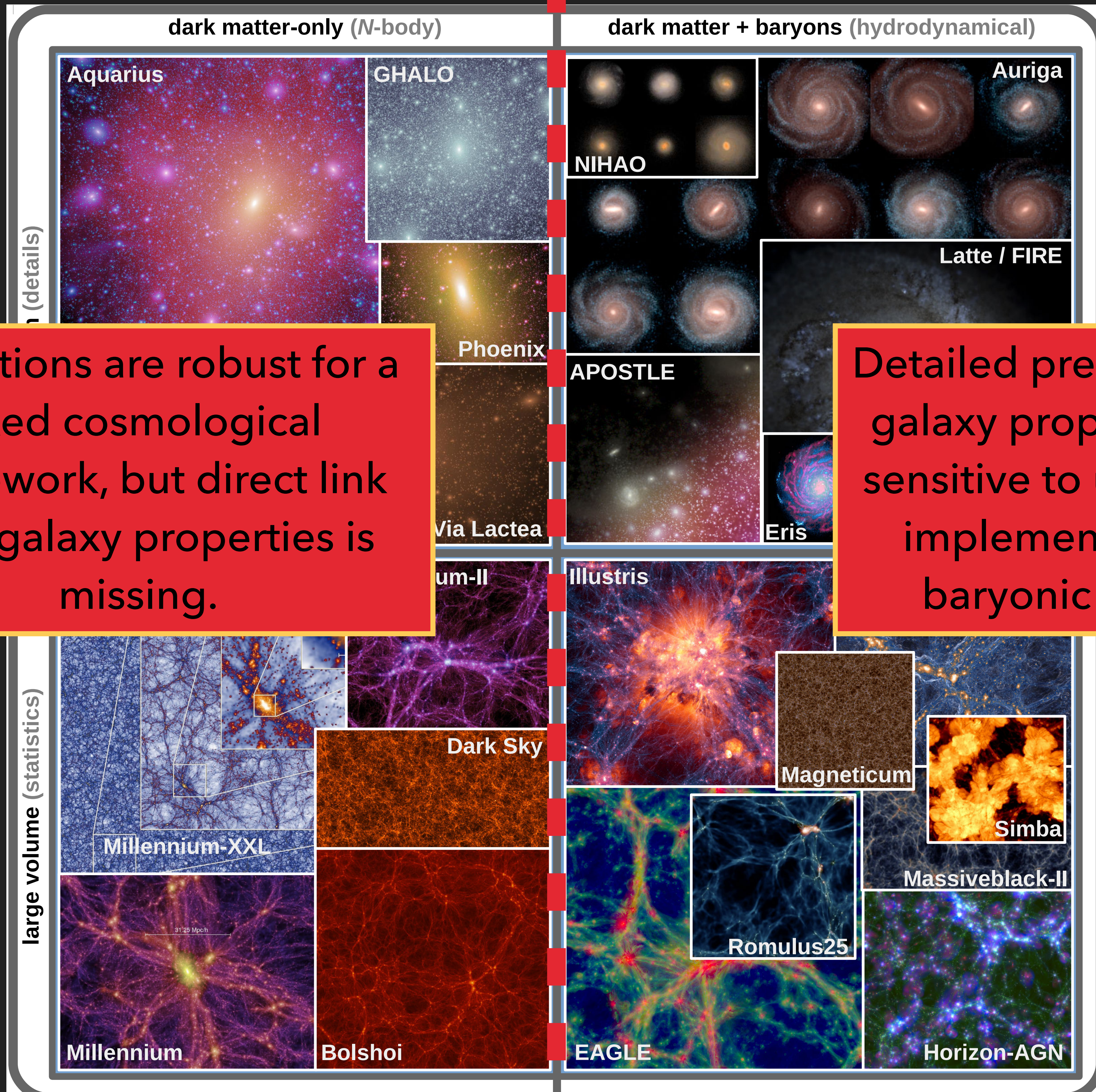

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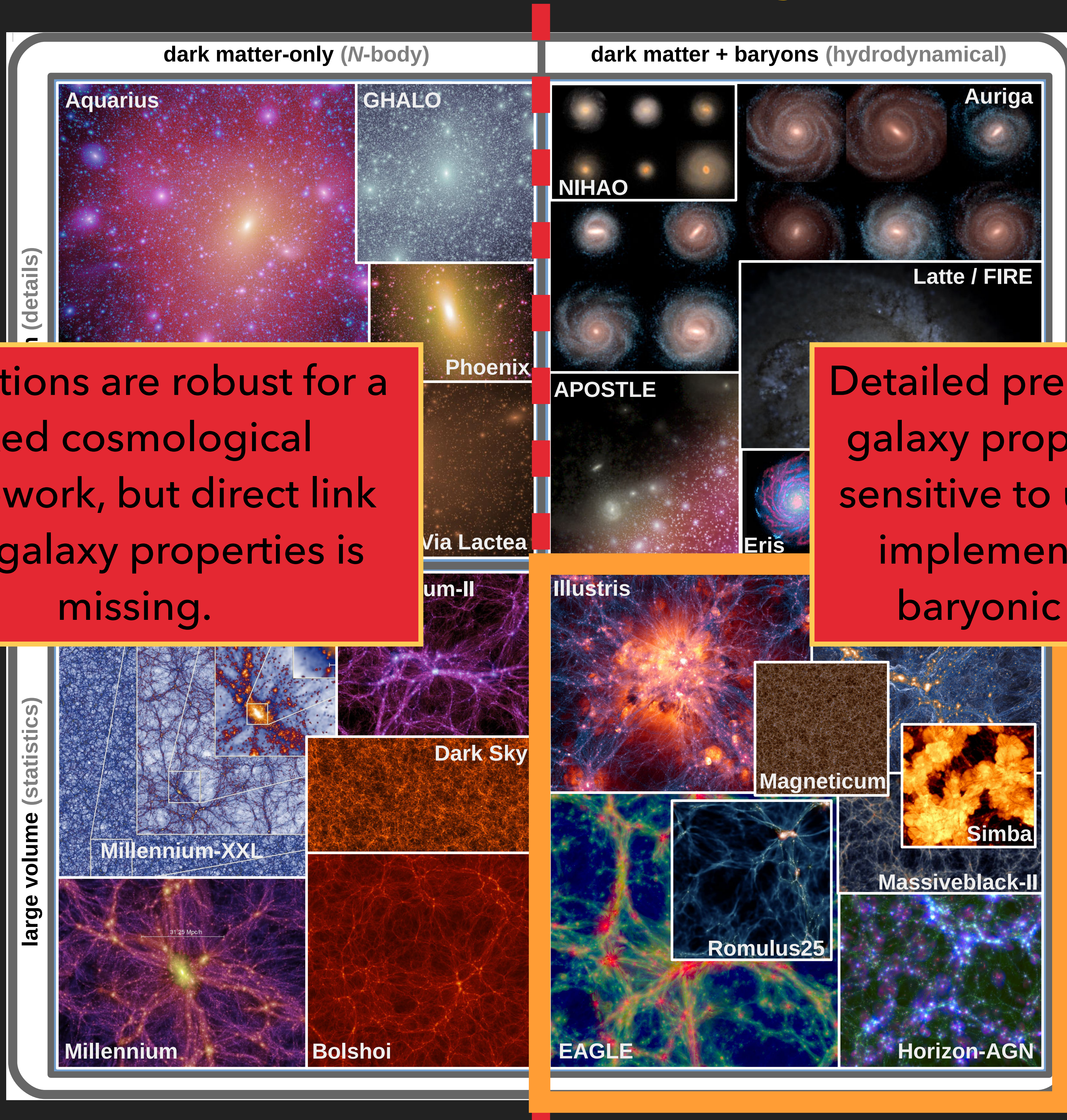

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Detailed predictions for these quantities would require:

1) **detailed radiation transport (RT) and photo-chemical modelling** → **Computationally very expensive, often unfeasible**

2) **multi-phase ISM modelling, with explicit treatment for its coldest phase** → **Limited by the resolution. Unfeasible in large-volume simulations**

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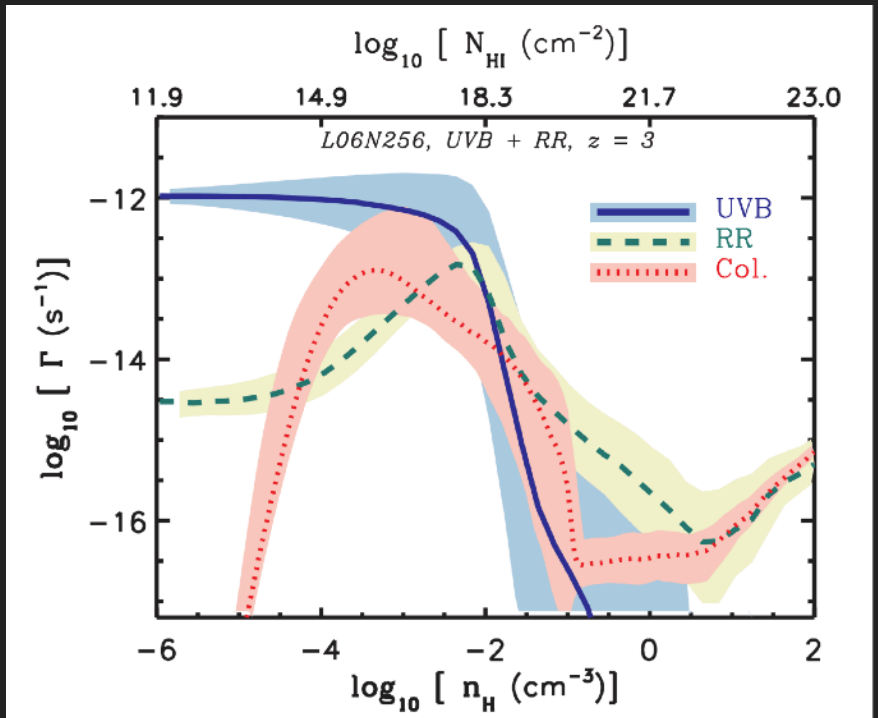
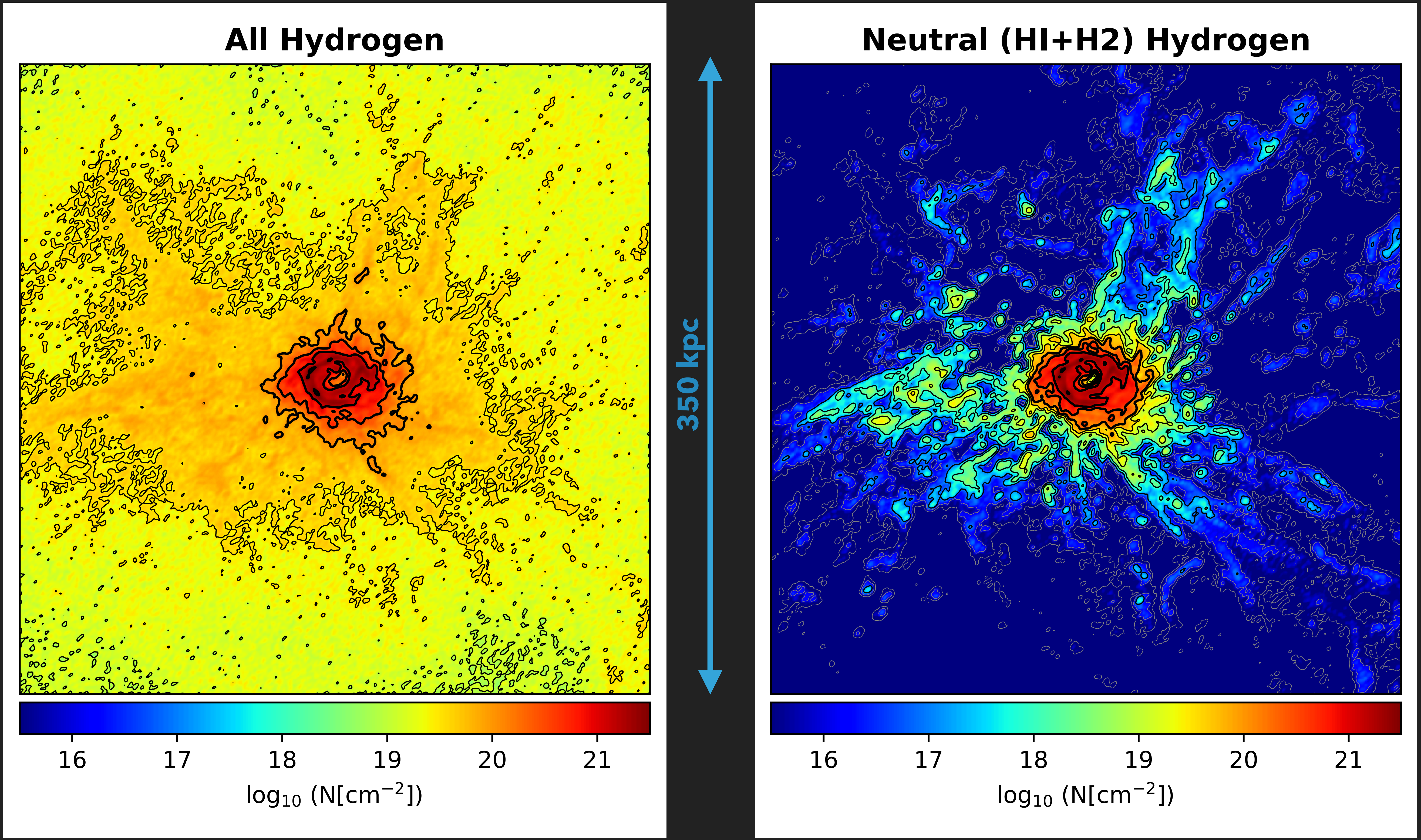
$$M_{\rm HI} \simeq \chi M_{\rm gas} - M_{\rm HII} - M_{\rm H2}$$

- χ: Hydrogen fraction based on chemical network
- $M_{\rm gas}$: known
- $M_{\rm HII}$: Ionised hydrogen:
  - photo-ionisation:
    - spatially uniform UV background, evolving with z
    - effect of local ionisation sources typically not included. Requires dedicated RT calculations.
  - collisional and shock-driven
- $M_{\rm H2}$: Molecular gas fraction based on theoretical on empirical recipes, typically added in post-processing.



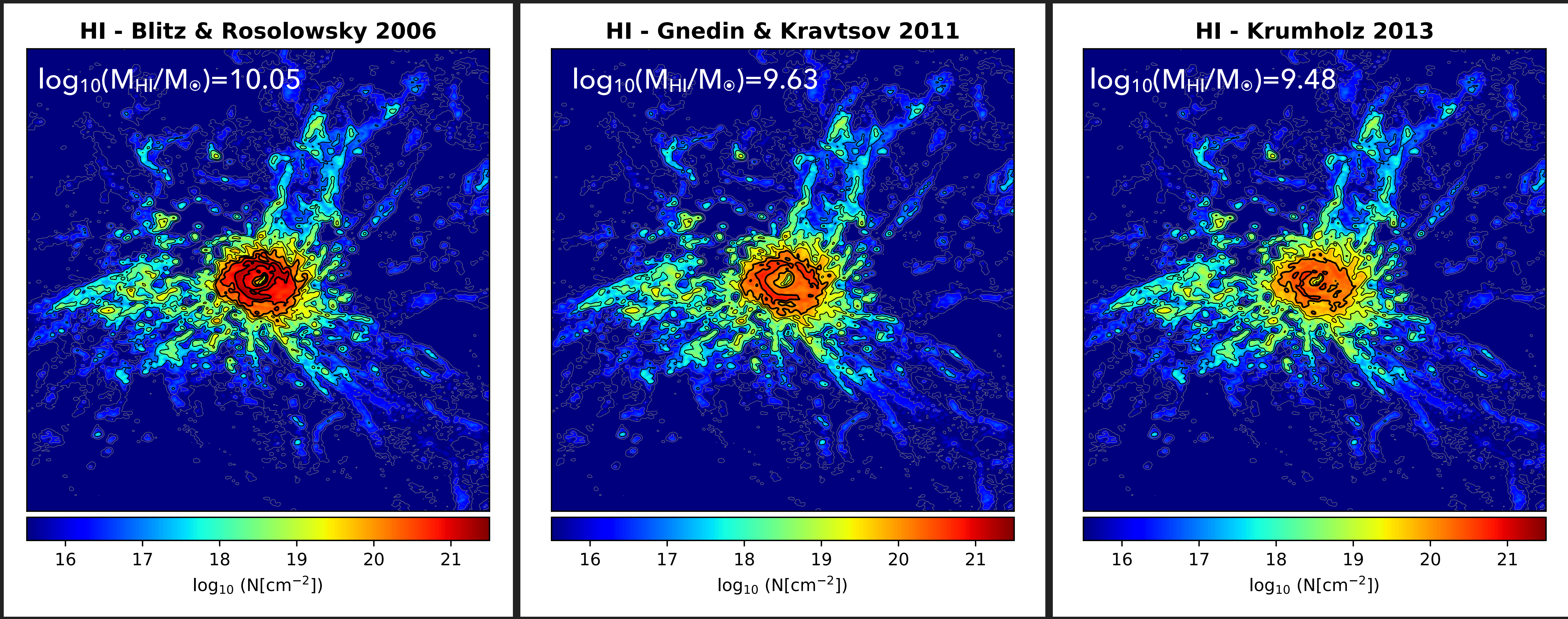
Rahmati+13

Example: from total to neutral hydrogen



HI distribution in the CGM is strongly dependent on ionisation modelling

Example of different HI-to-H2 partition recipes



The recipes affect the high column density gas, ultimately altering the total HI content of the galaxy

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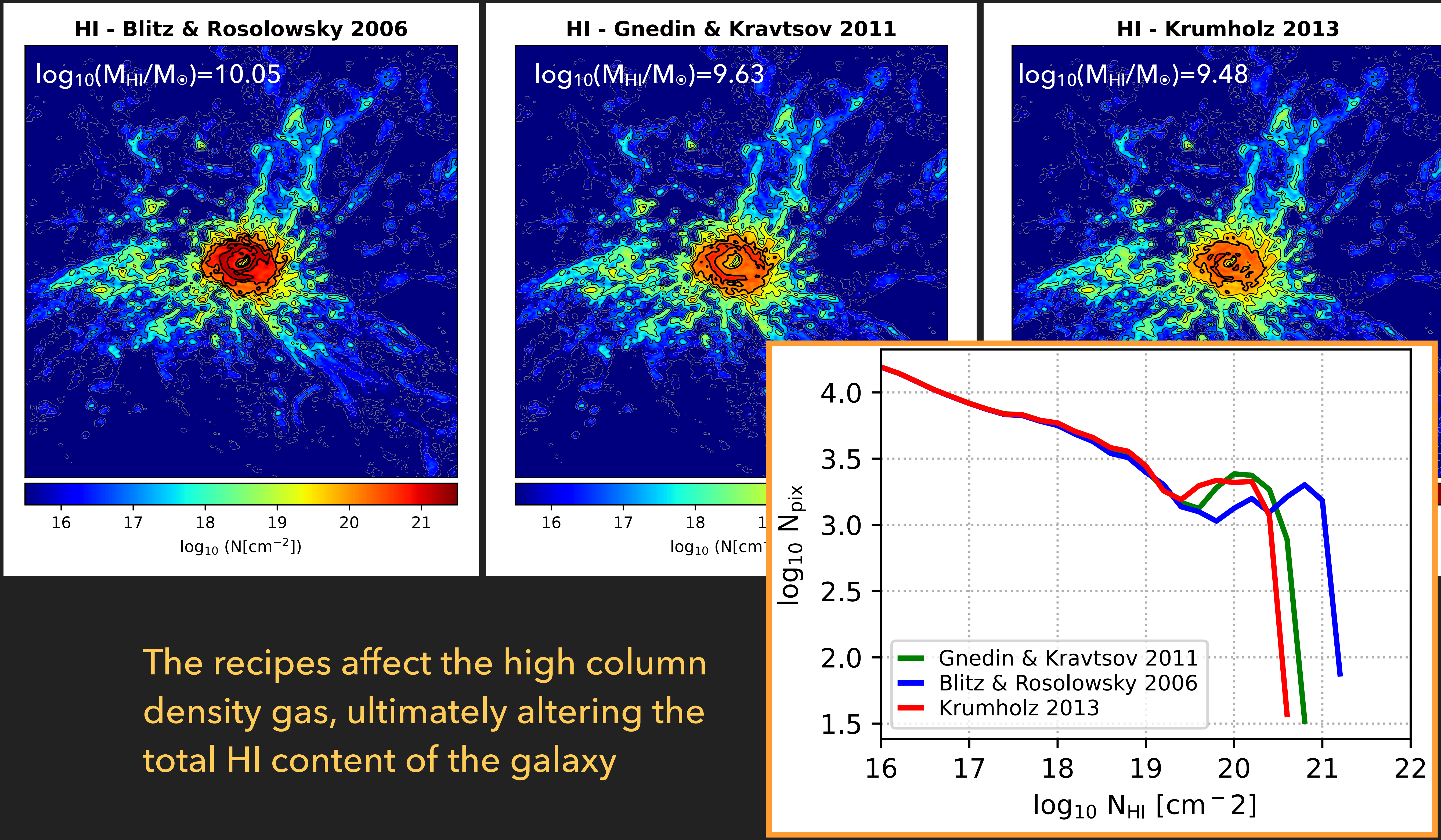

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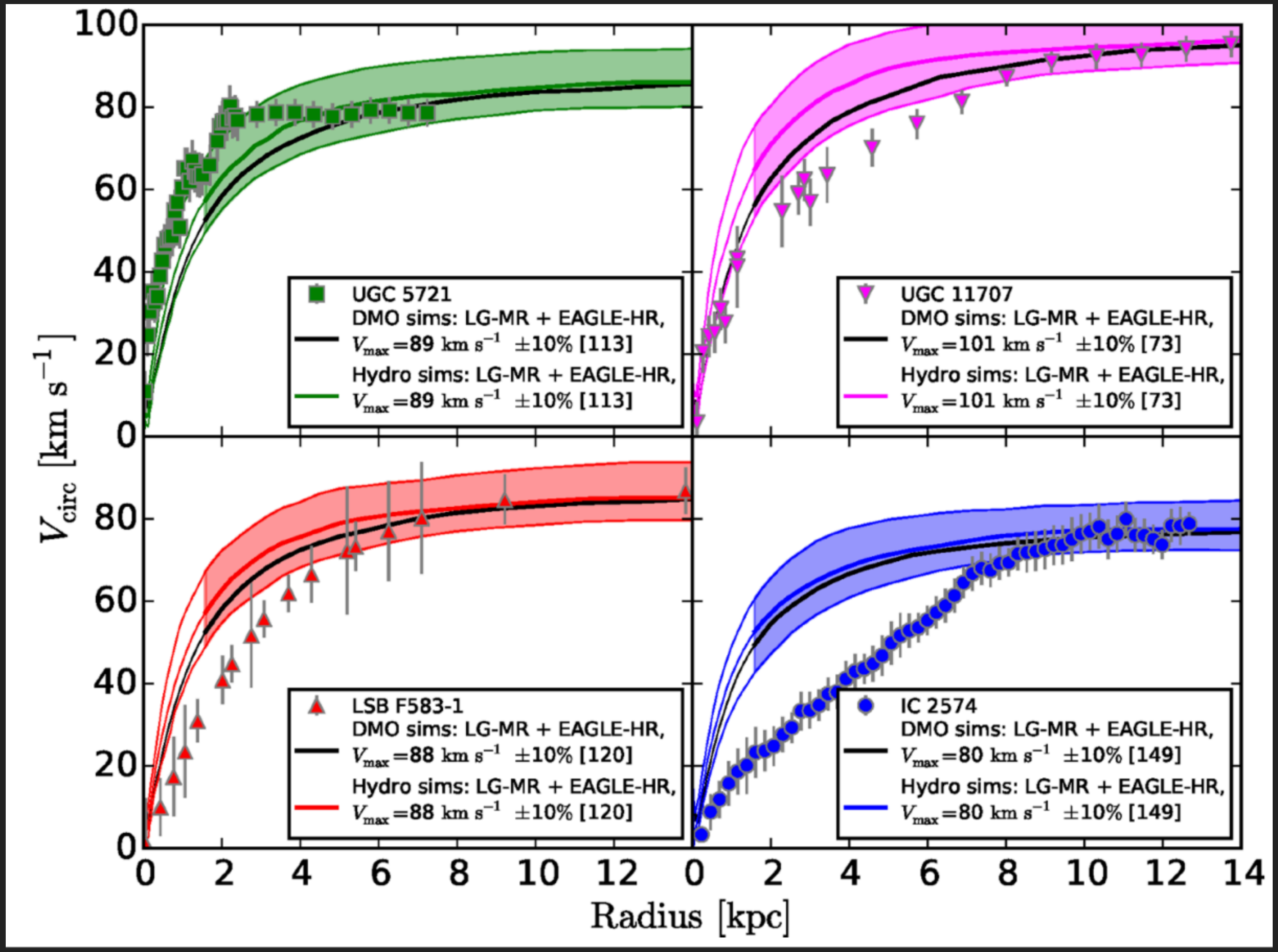
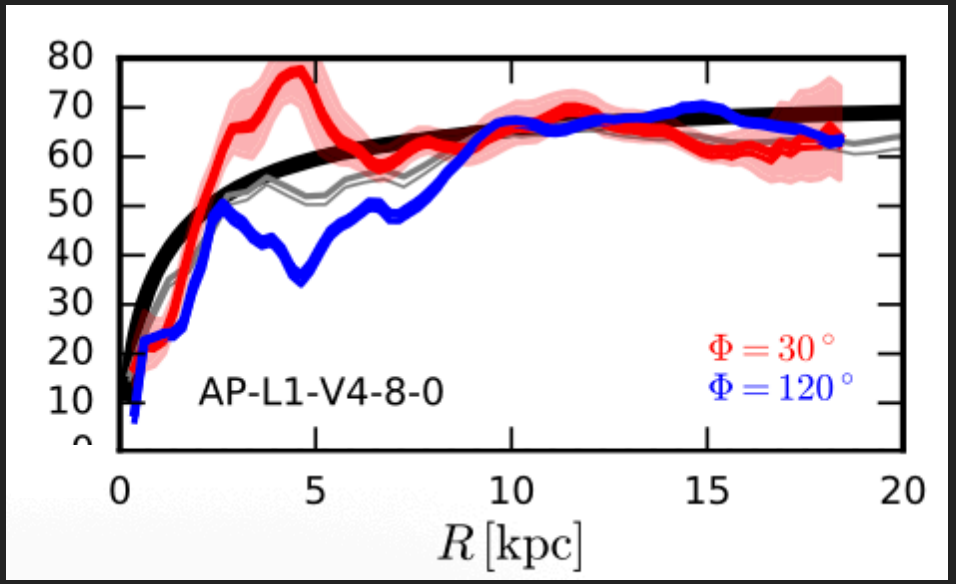
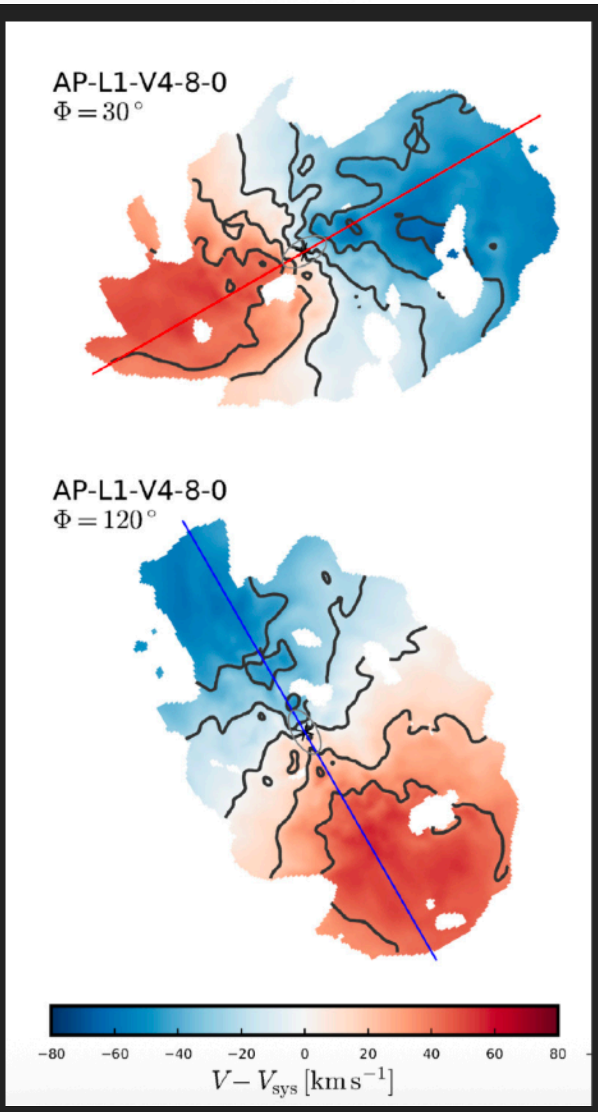
Previous studies - modelling of individual galaxies

The "diversity" in the rotation curves of dwarf galaxies *(Oman+15)*



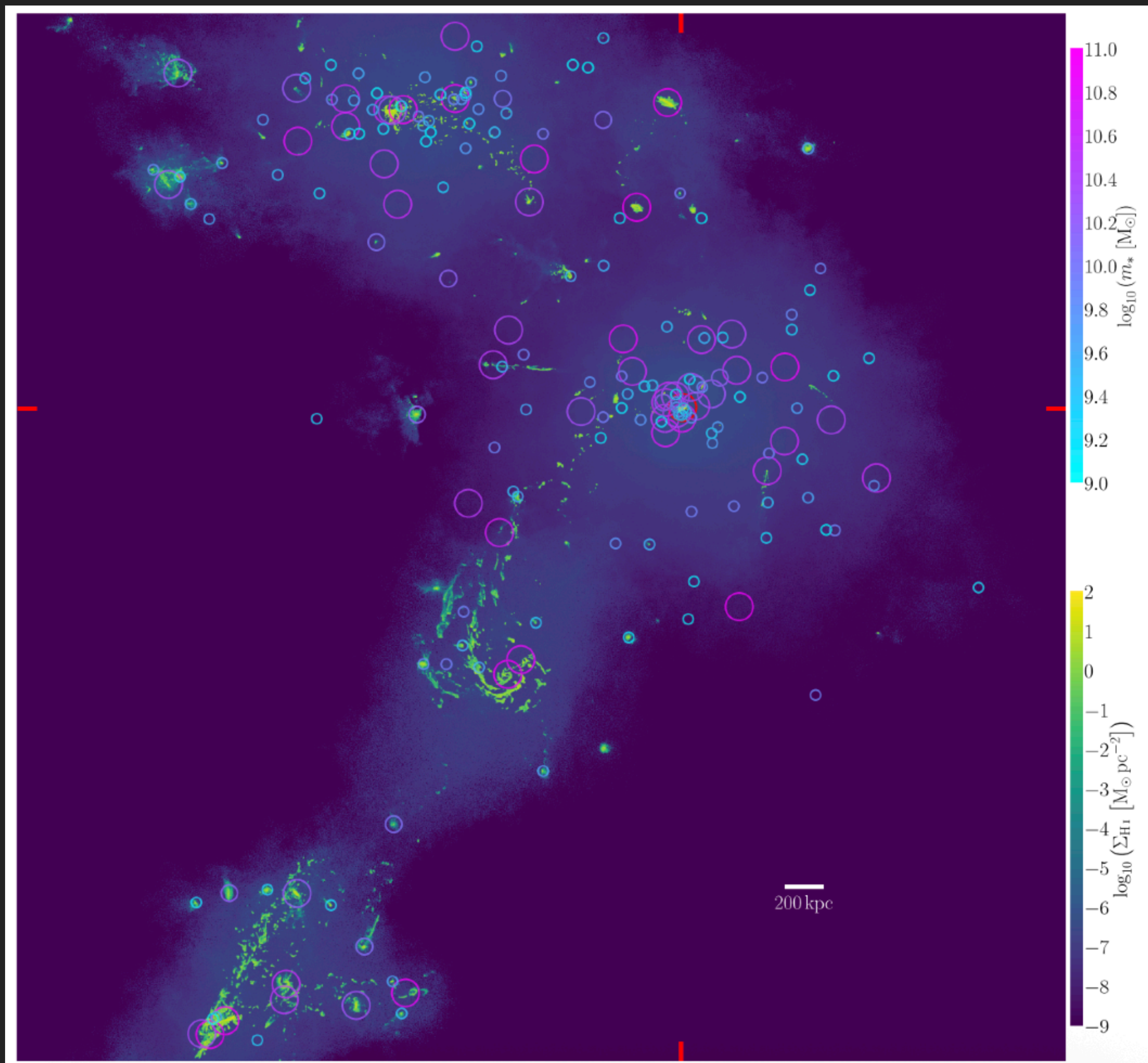




Partially driven by non-circular motions in cold gas *(Oman+19)*

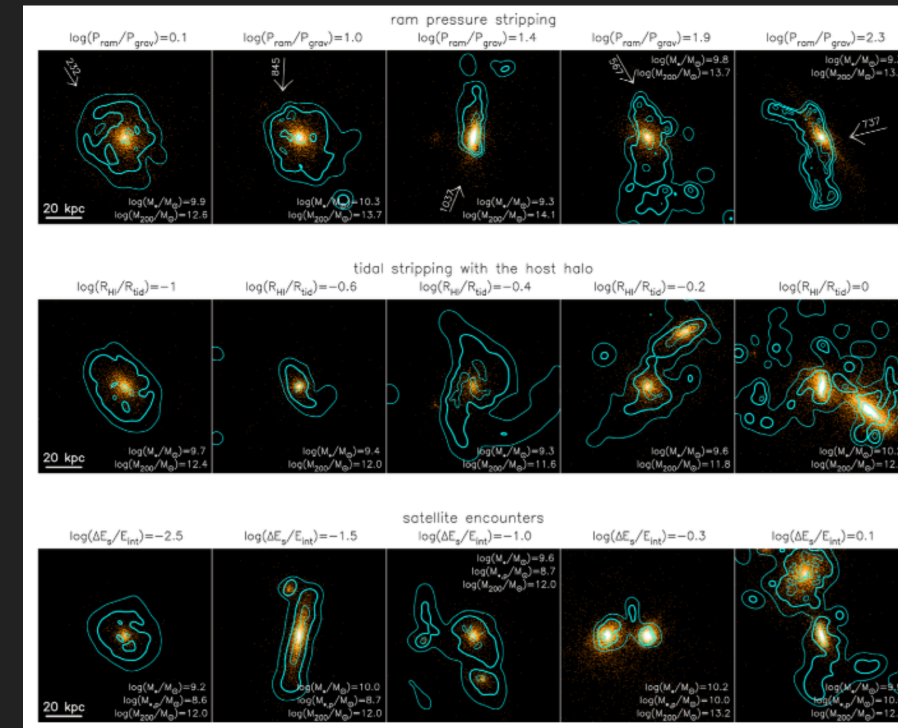
see also Dado+25

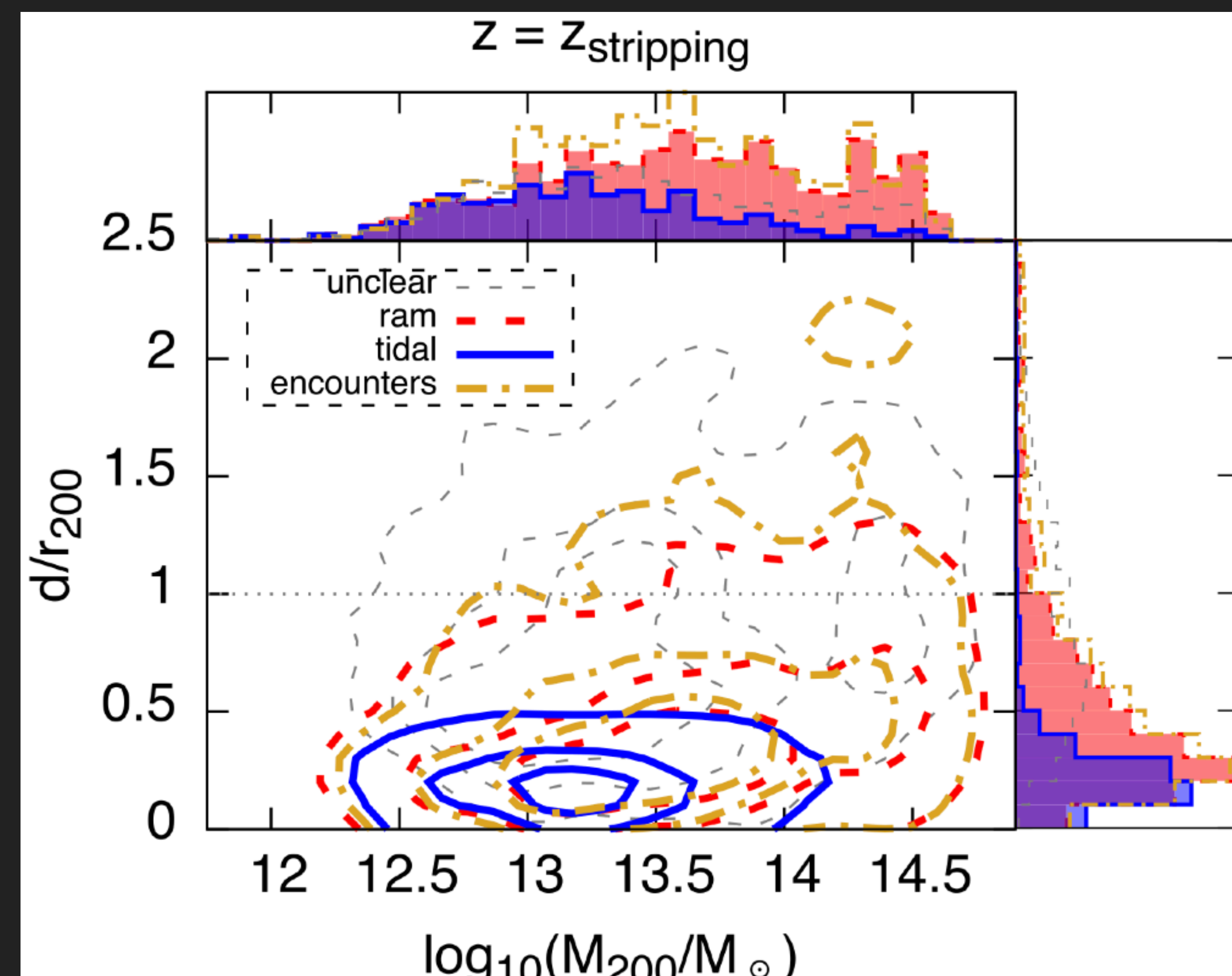
Previous studies - environment



Stevens+2019, TNG100

HI content, SF and angular momentum of galaxies in groups and clusters

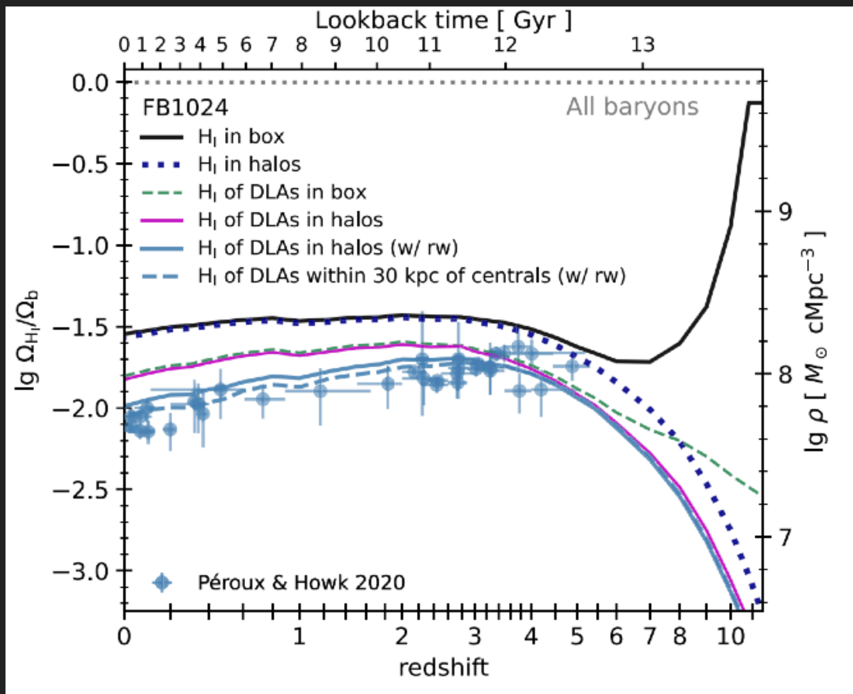




Marasco+2016, EAGLE

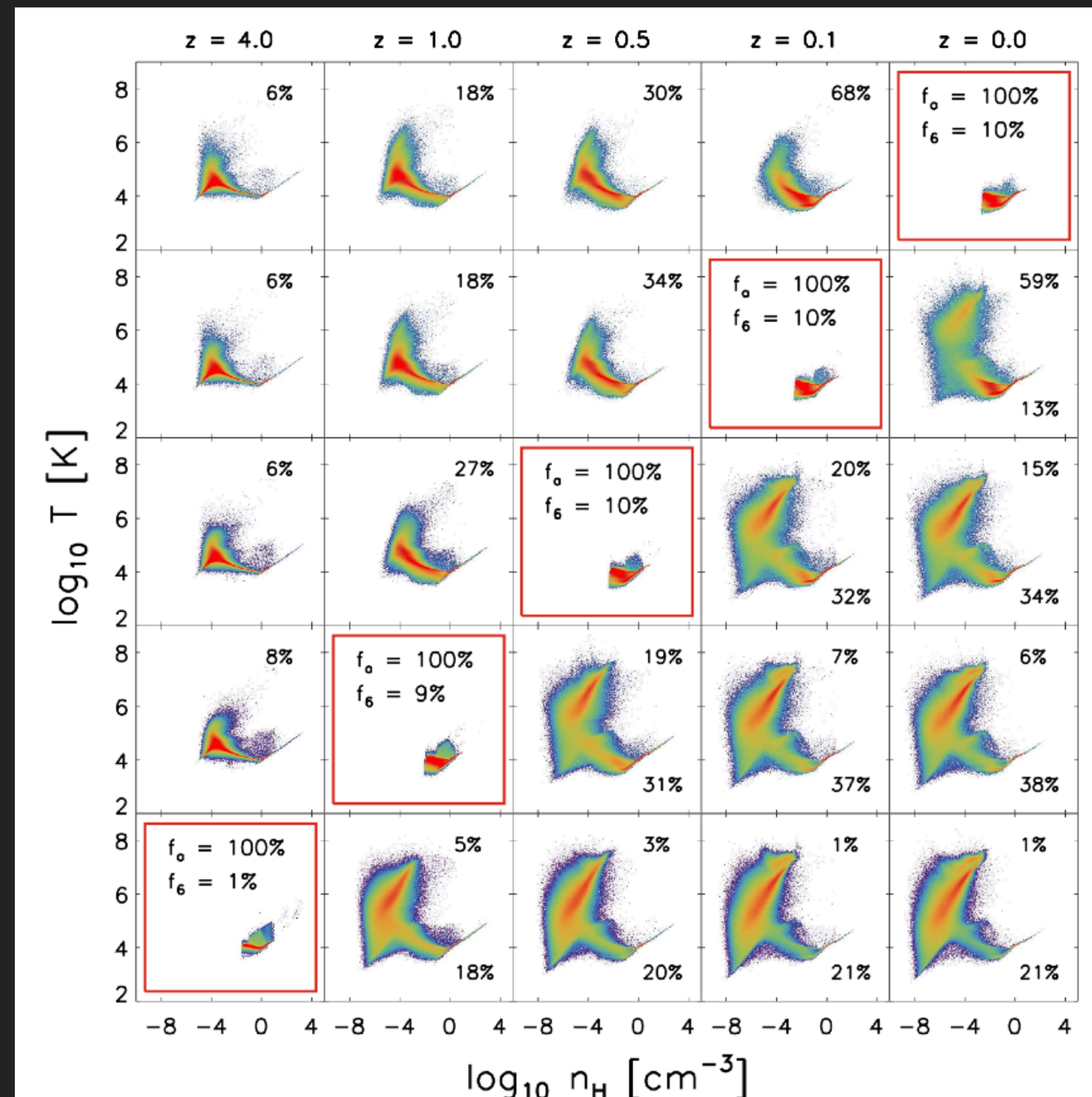
Physical origin for HI removal in different environments

Previous studies - high-z / cosmic-scales



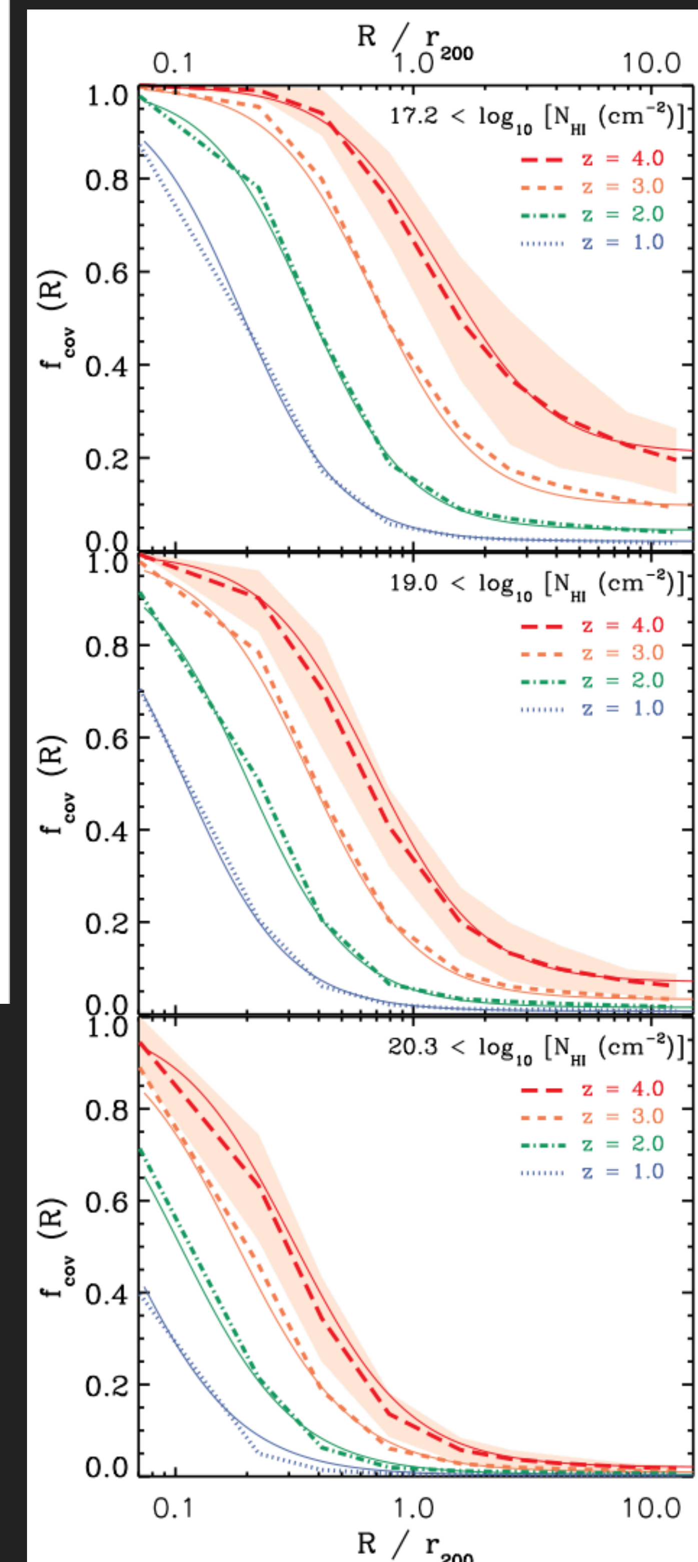
Cosmic evolution of HI density (compared to DLAs)

Feldmann+23, FIREbox



Crain+17, EAGLE

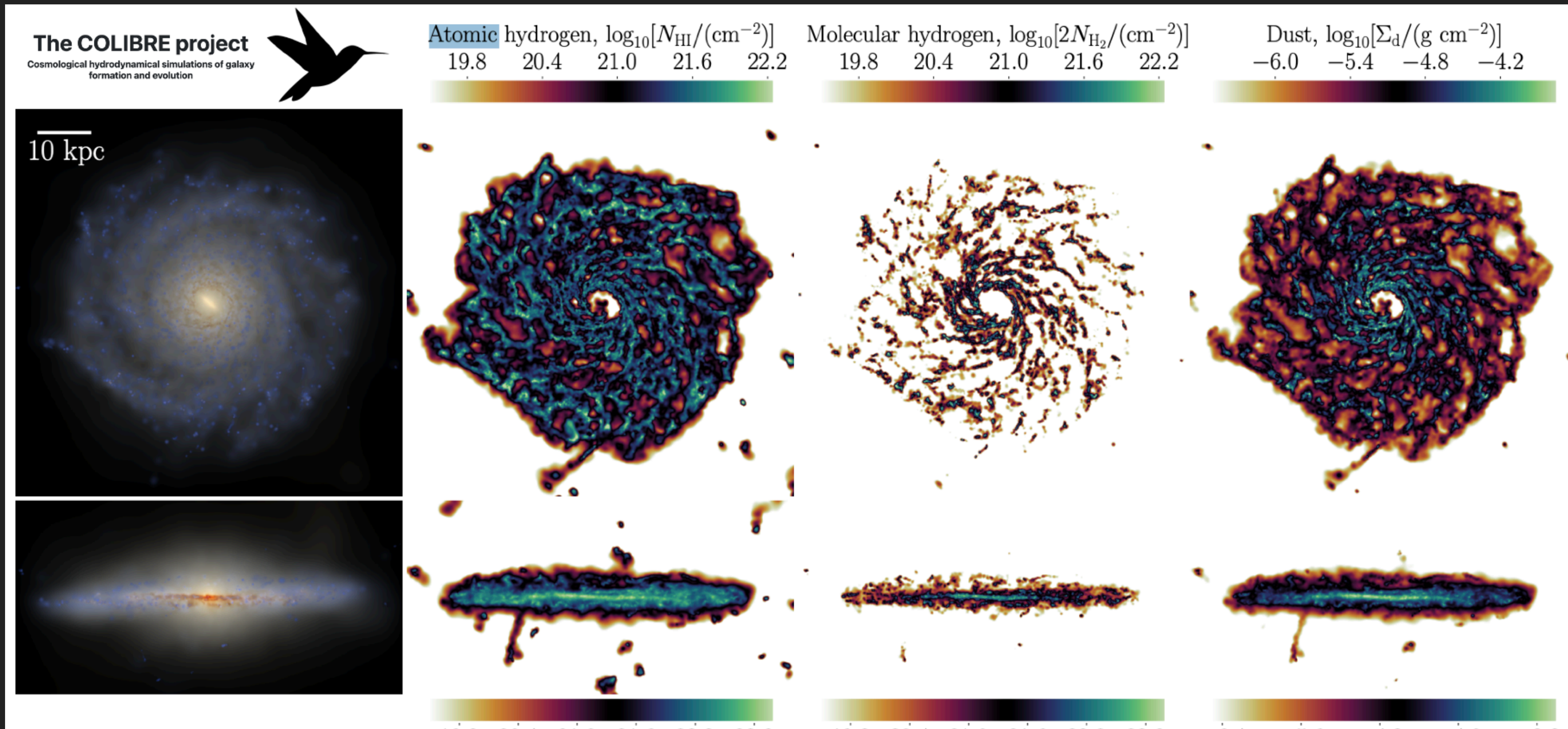
Origin and fate of HI in galaxies at different redshifts from its (T,n) distribution



Rahmati+15, EAGLE

Covering fraction of HI around galaxy halos at different z

Current state of the art?



Schaye+25

Successor of EAGLE, accounts for multi-phase ISM -> **HI is modelled explicitly!**

MARTINI
Mock Array Radio Telescope Interferometry of the Neutral ISM
Oman+24

Highly-flexible post-processing software for creating mock HI datacubes

HI within and around observed and simulated galaxy discs

Comparing MeerKAT observations with mock data from TNG50 and FIRE-2

A. Marasco[1,★], W. J. G. de Blok[2,3,4], F. M. Maccagni[5], F. Fraternali[4], K. A. Oman[6,7,8], T. Oosterloo[2,4], F. Combes[9], S. S. McGaugh[10], P. Kamphuis[11], K. Spekkens[12], D. Kleiner[2], S. Veronese[2,4], P. Amram[13], L. Chemin[14], and E. Brinks[15]

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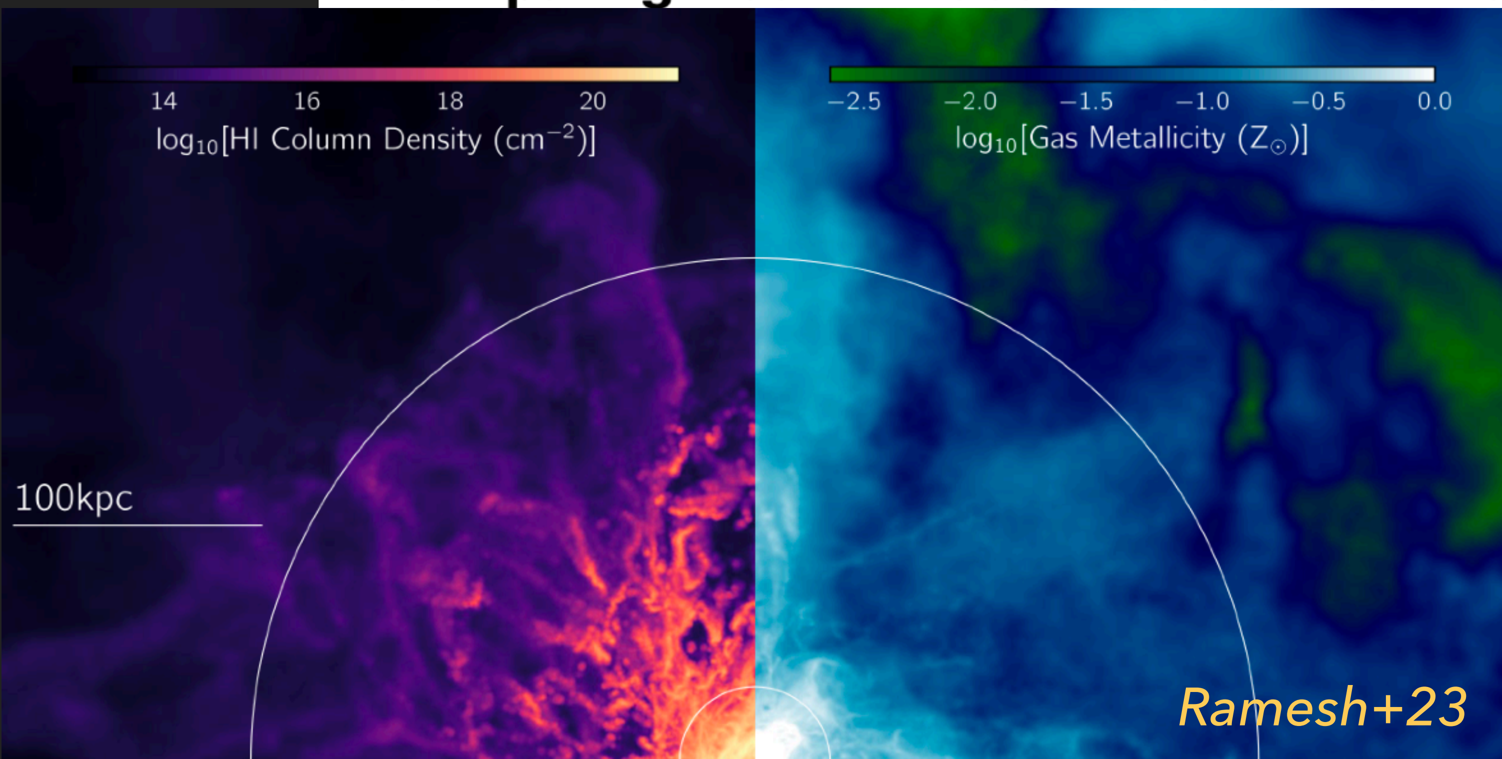
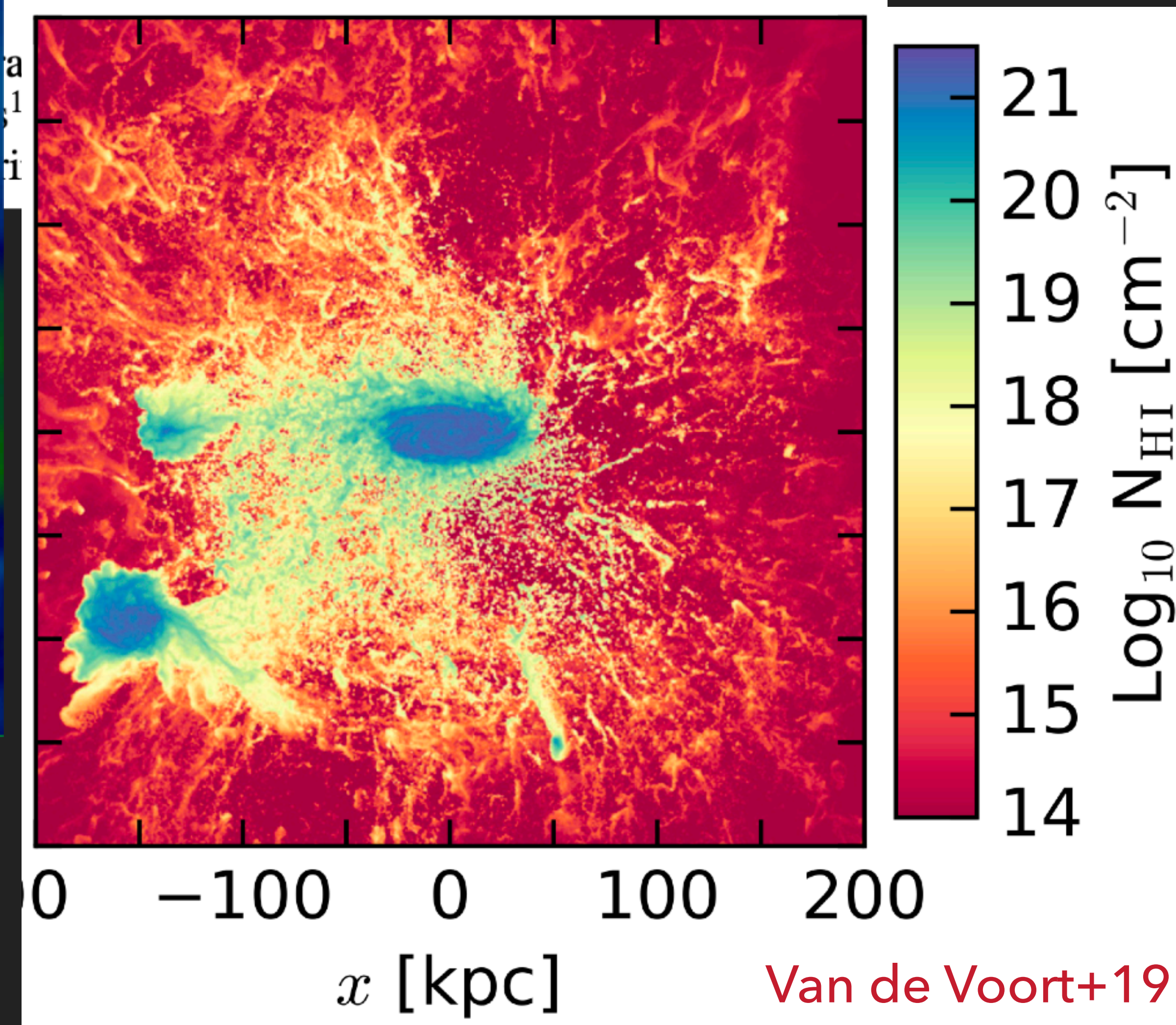




CONTEXT. Present-day cosmological hydrodynamical simulations predict a complex HI distribution in the halo of MW-like spiral galaxies.

PHYSICAL ORIGIN. Feedback-driven gas circulation + hot CGM cooling + filaments

PREDICTIONS. Filamentary and clumpy HI features visible up to ~ 100 kpc from the centre at $10^{18}<N_{HI}<10^{19}$ cm-2

→

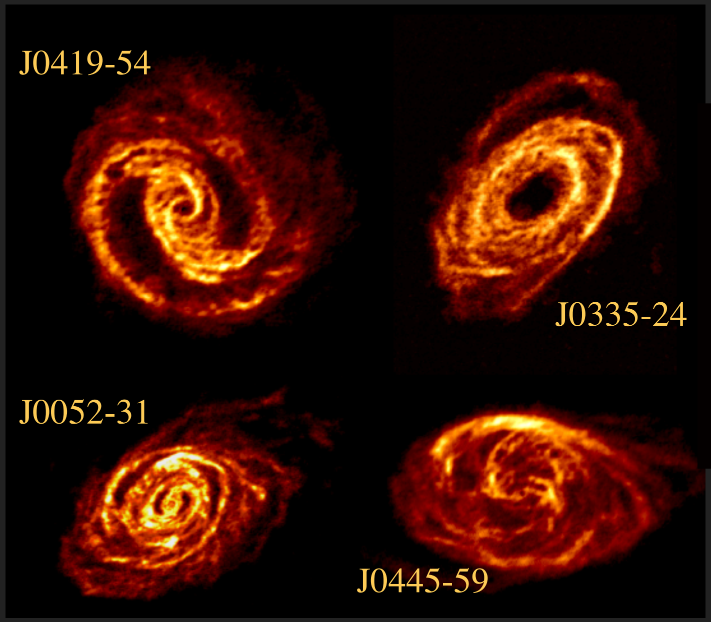
THIS STUDY *(Marasco et al. 2025, A&A 697, A86)*

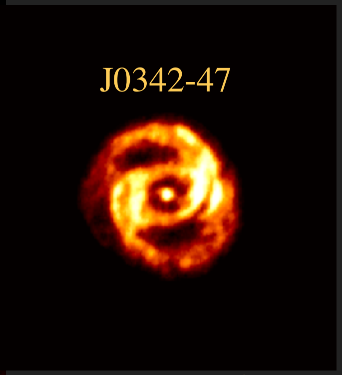
Testing these predictions via a detailed comparison between models and MeerKAT observations

HI observations with MeerKAT (n=5)

- MW-like stellar mass
- D~20 Mpc
- FoV~1 deg -> Rmax~200 kpc
- res 20" (HR), 60" (LR) -> 2 and 6 kpc
- min N_{HI} ~ $5x10^{18}$ cm^{-2}(HR), 10^{18} cm^{-2} (LR)

MHONGOOSE
(de Blok+24)





as part of MKT-20202 project
(PI: F. Maccagni)

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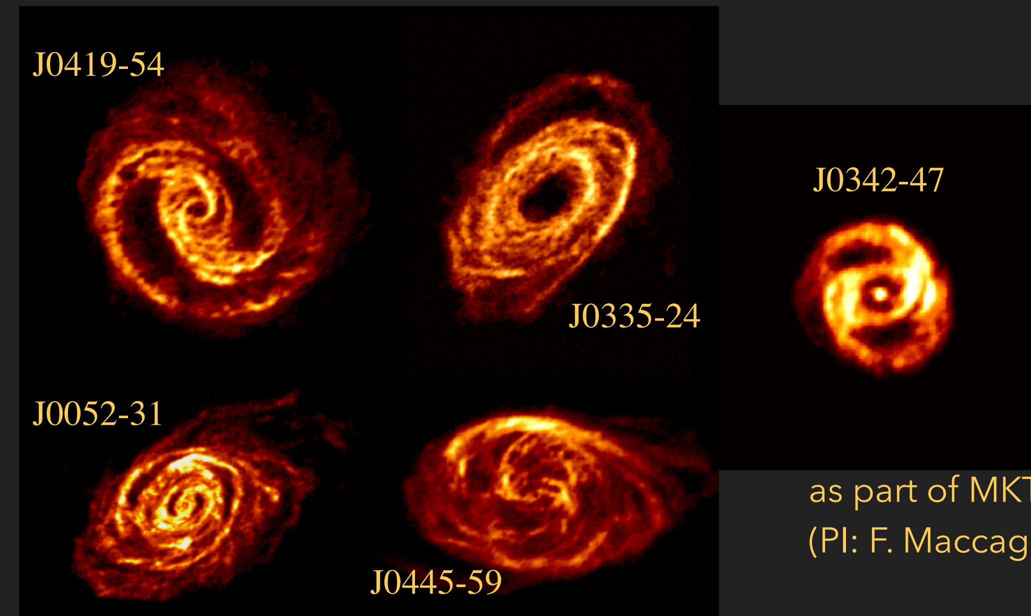

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synthetic HI observations from cosmological simulations

TNG-50 (n=15)

Pillepich+19; Nelson+19

- AREPO moving-mesh code
- (50 Mpc)^3 box
- res ~ 70 pc, 8.5 x 10^4 $M_{\odot}$
- equation of state for cold gas

FIRE-2 (n=5)

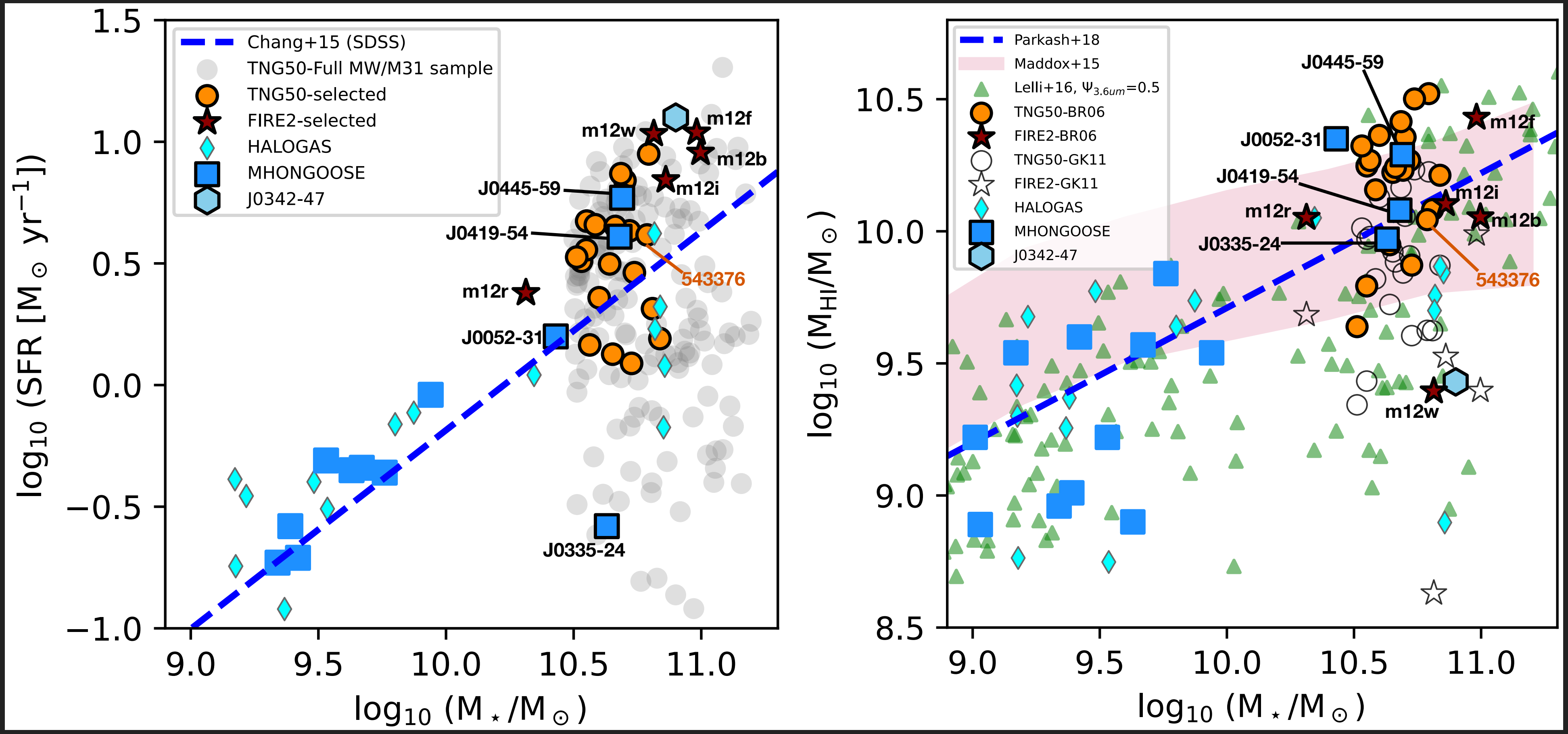
Hopkins+18; Wetzel+23

- GIZMO, meshless finite-mass
- zoom-in
- res ~ 1 pc, 7.1 x 10^3 $M_{\odot}$
- No AGN physics

Parameter	Unit	HR	LR
Field of view [(a)]	°	~ 1	~ 1
	kpc	~ 350	~ 350
Beam size [(b)]	″	26.4 × 18.2	65.3 × 64.0
	kpc	2.6 × 1.8	6.3 × 6.2
Beam PA	°	136	92
Pixel size	″	5	20
	kpc	0.5	1.9
Velocity range	km s^{-1}	±500	±500
Channel width [(c)]	km s^{-1}	1.4	1.4
σ_{rms} per channel	mJy $beam^{-1}$	0.15	0.25
Minimum N_{HI} [(d)]	cm^{-2}	5×10^{18}	1×10^{18}

Global galaxy properties

Simulated and observed galaxies have compatible SFR, HI and stellar mass content



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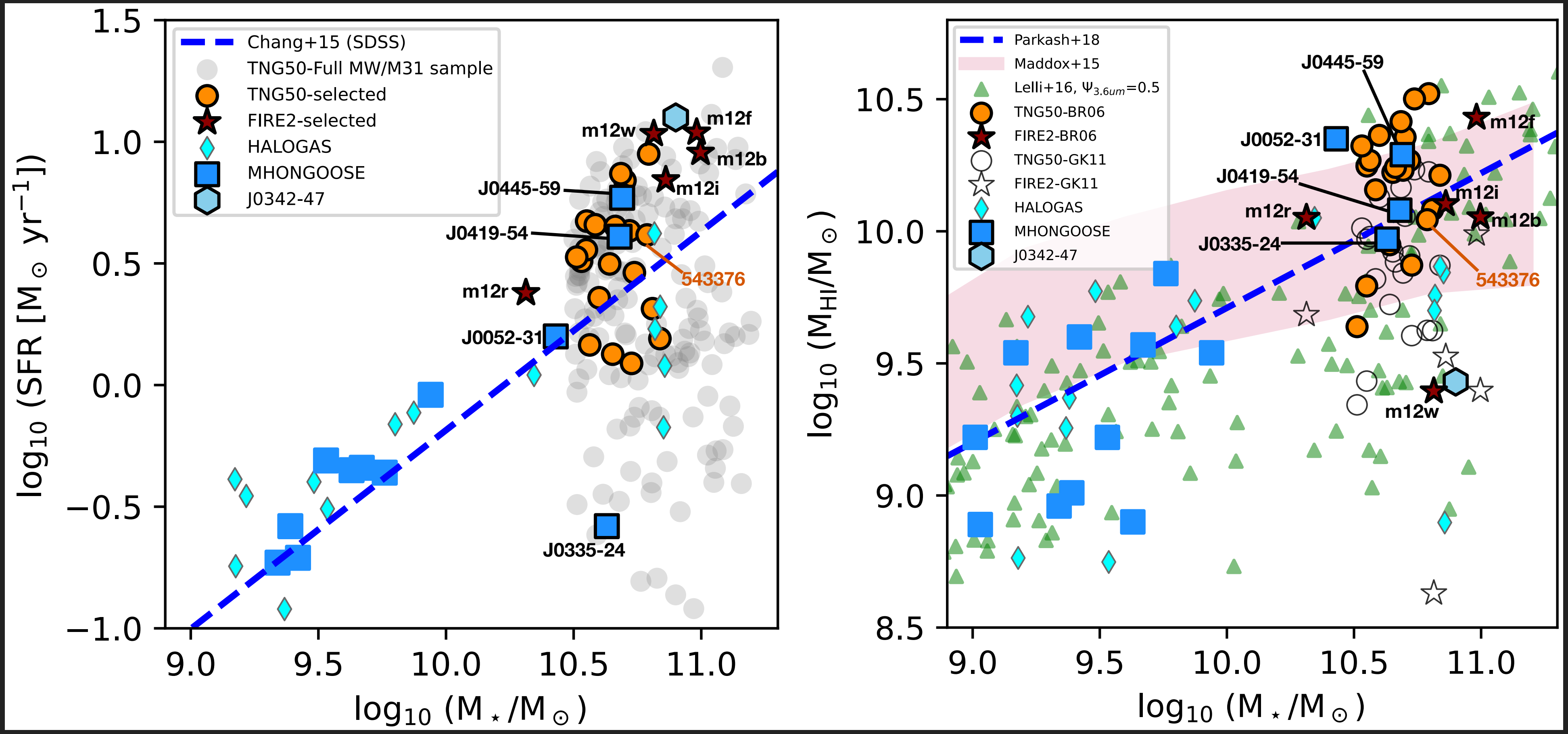
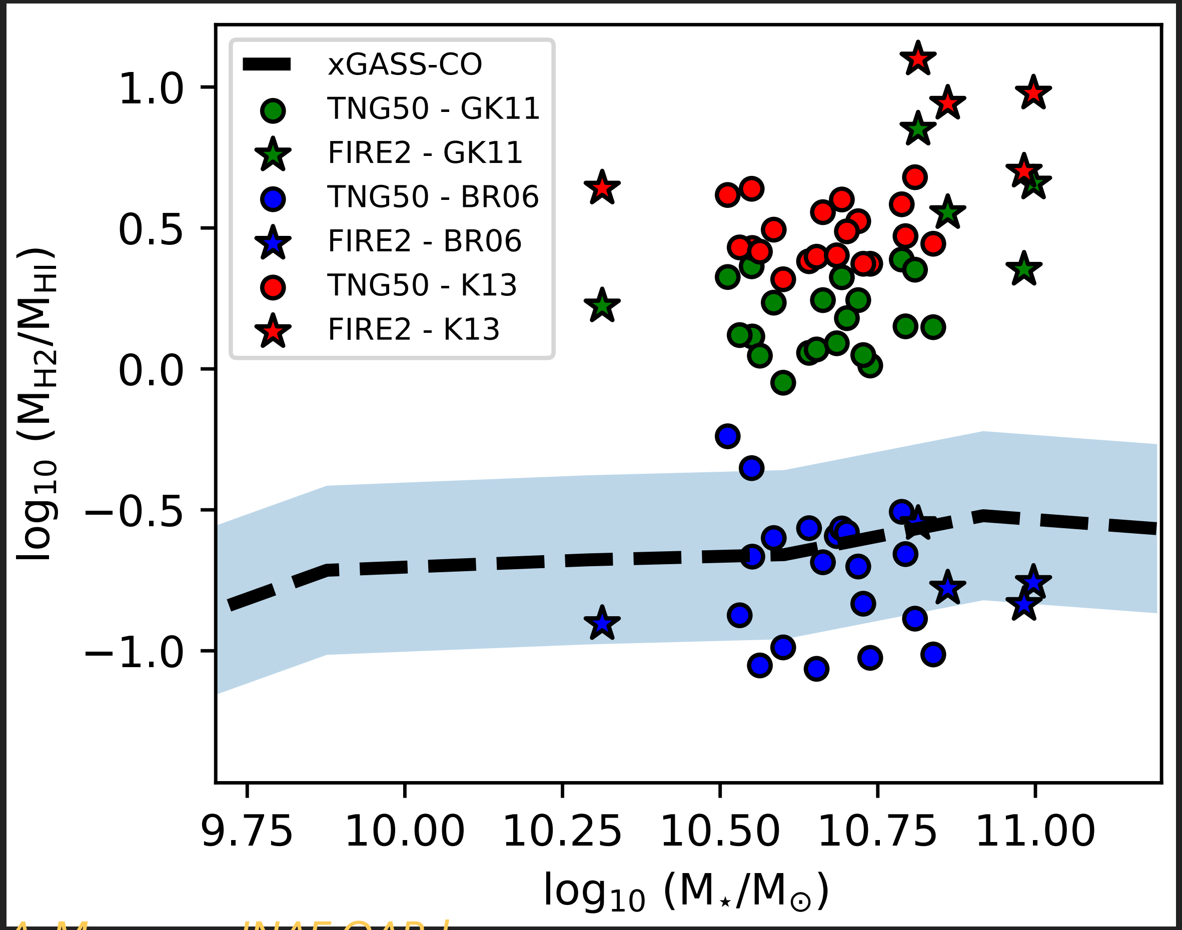




Recipes tested

Blitz & Rosolowsky (2006, **BR06**)

pressure-based, calibrated on observations

Gnedin & Kravtsov (2011, **GK11**)

gas density, dust, UV field-based

calibrated on high–res numerical models

Krumholz (2013, **K13**)

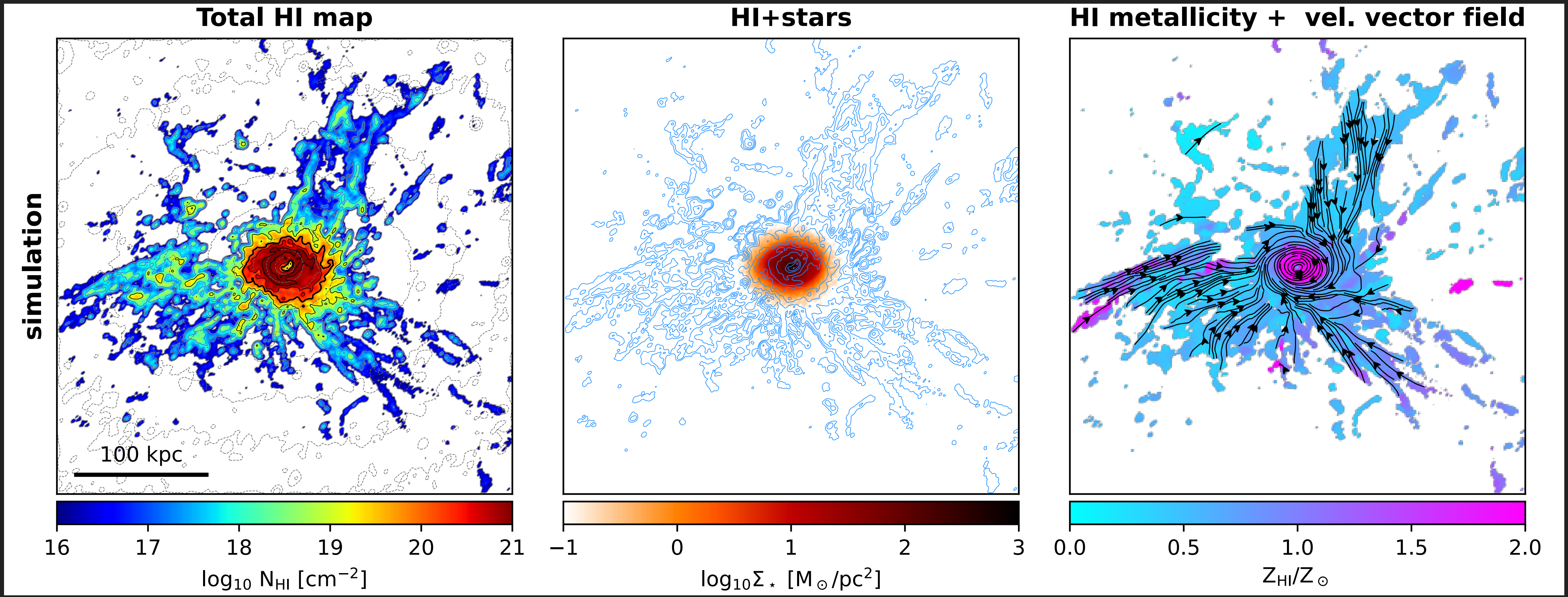
fully theoretical/analytical.

Tested on spatially resolved data

<u>**BR06** compatible with estimates from Catinella+18</u>

A. Marasco - INAF OAPd

Close-up on a single TNG50 galaxy



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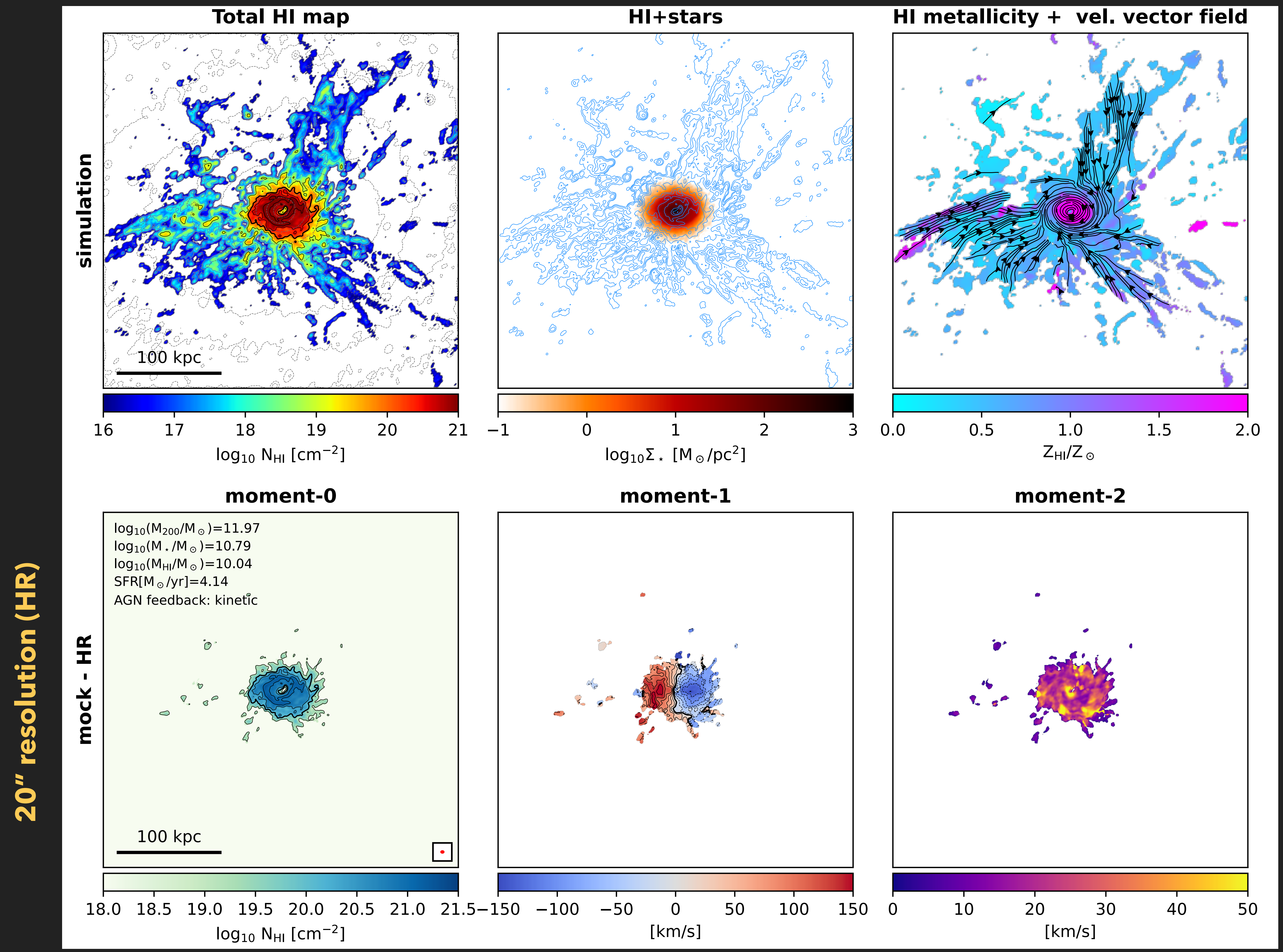

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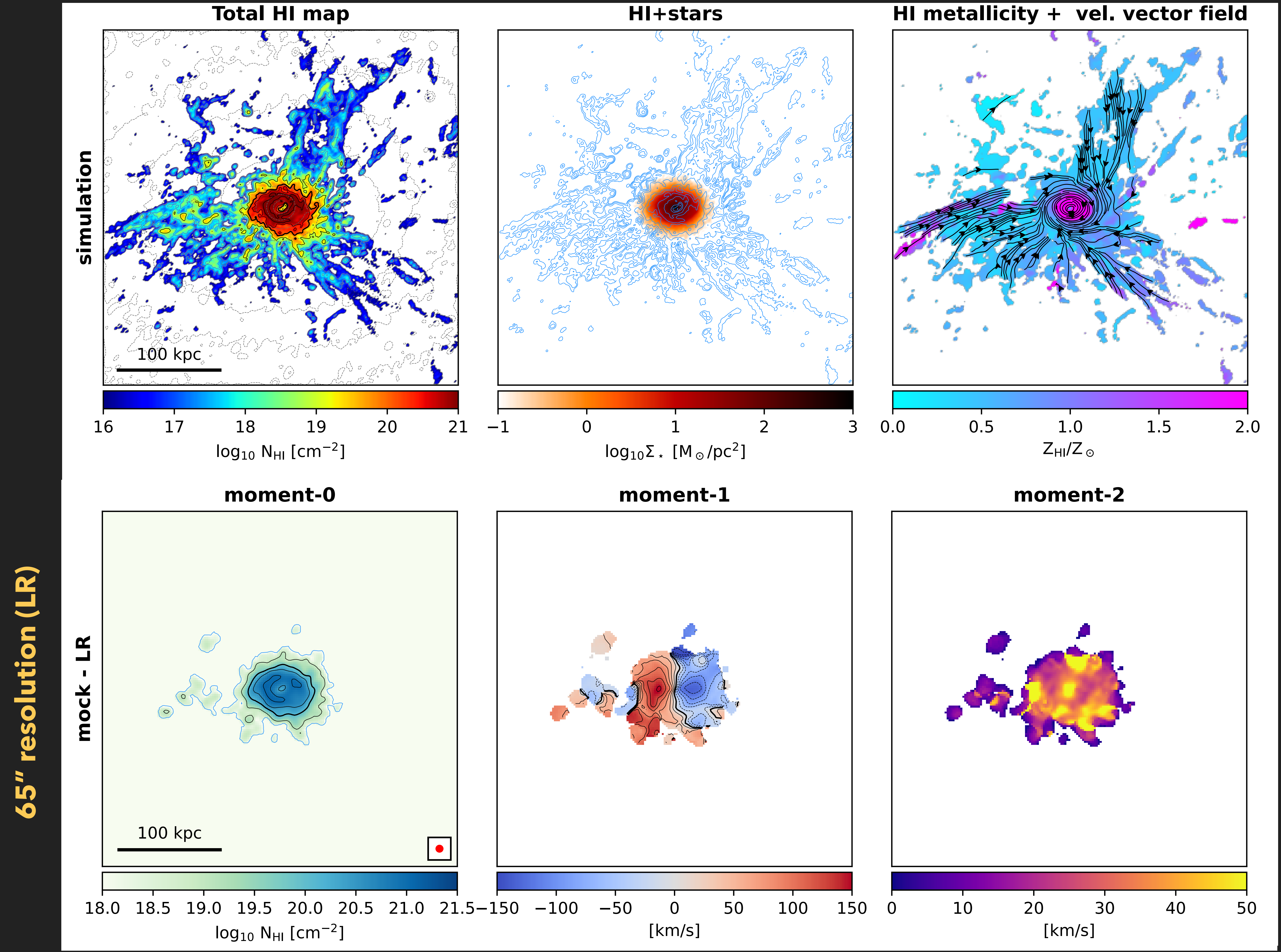

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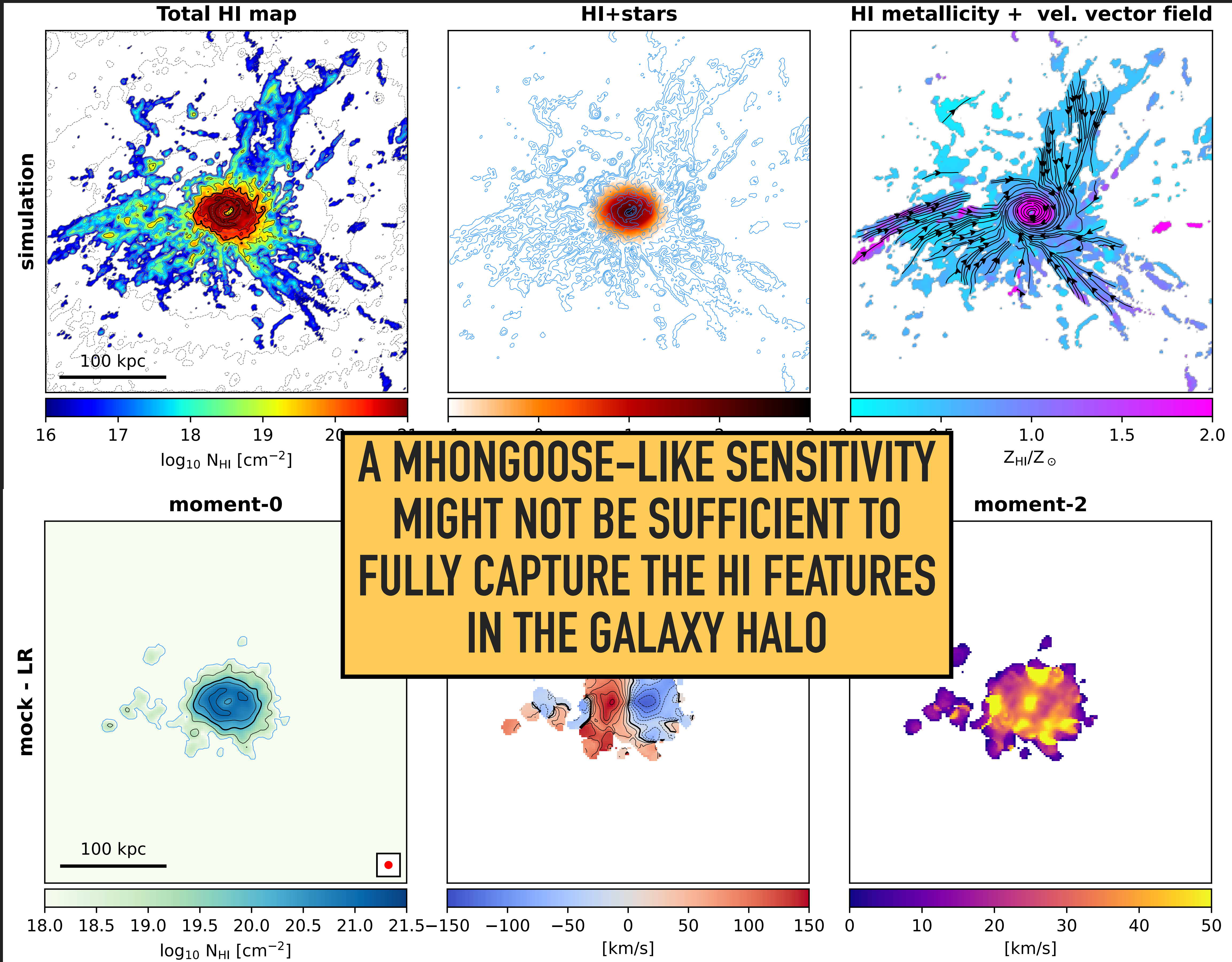


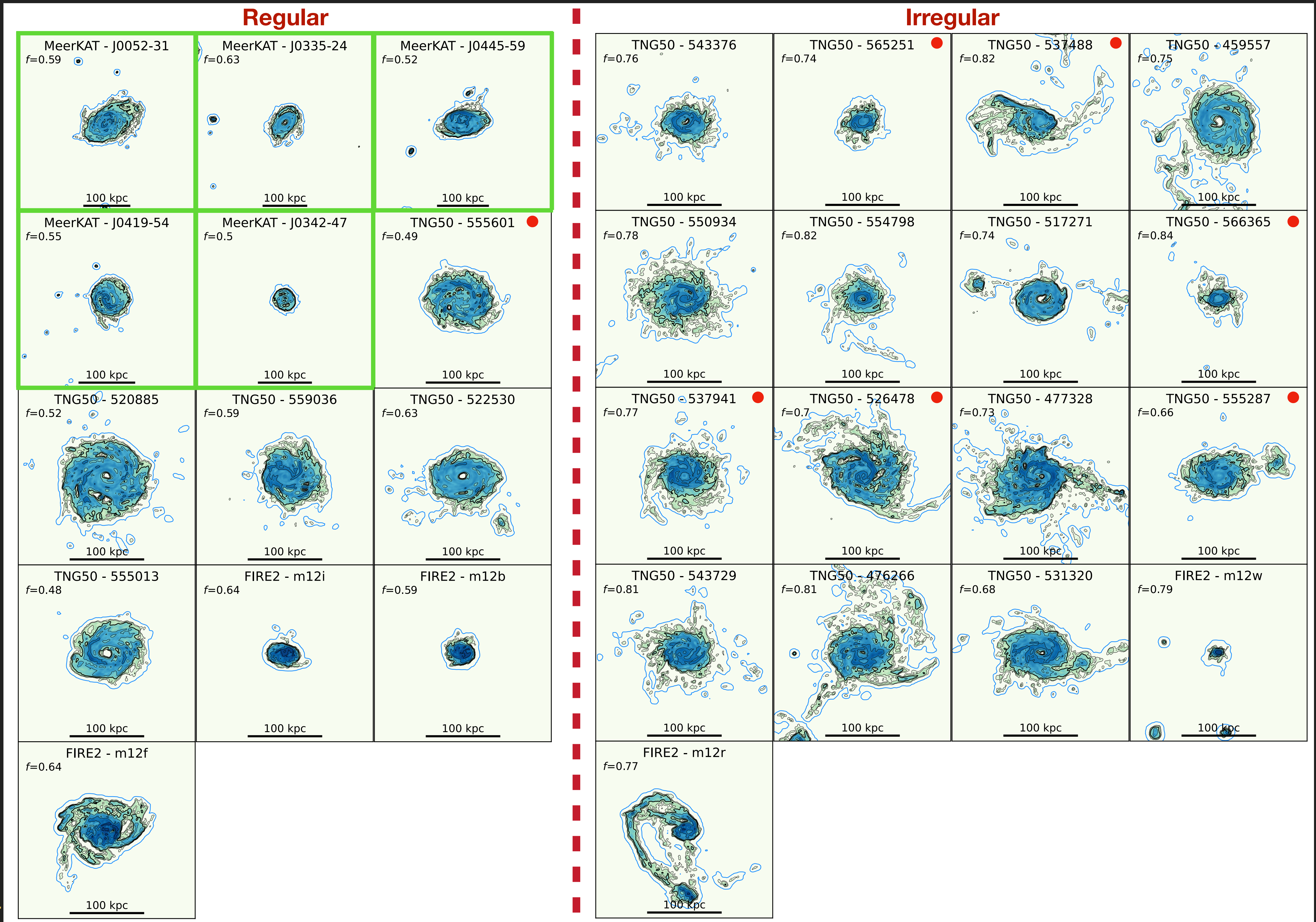
A MHONGOOSE-LIKE SENSITIVITY MIGHT NOT BE SUFFICIENT TO FULLY CAPTURE THE HI FEATURES IN THE GALAXY HALO

65″ resolution (LR)

Regular and irregular systems

Galaxies dominated by high-N_{HI} spaxels ($>10^{20}$ cm^{-2})

Galaxies dominated by low-N_{HI} spaxels ($<10^{20}$ cm^{-2})



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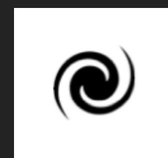
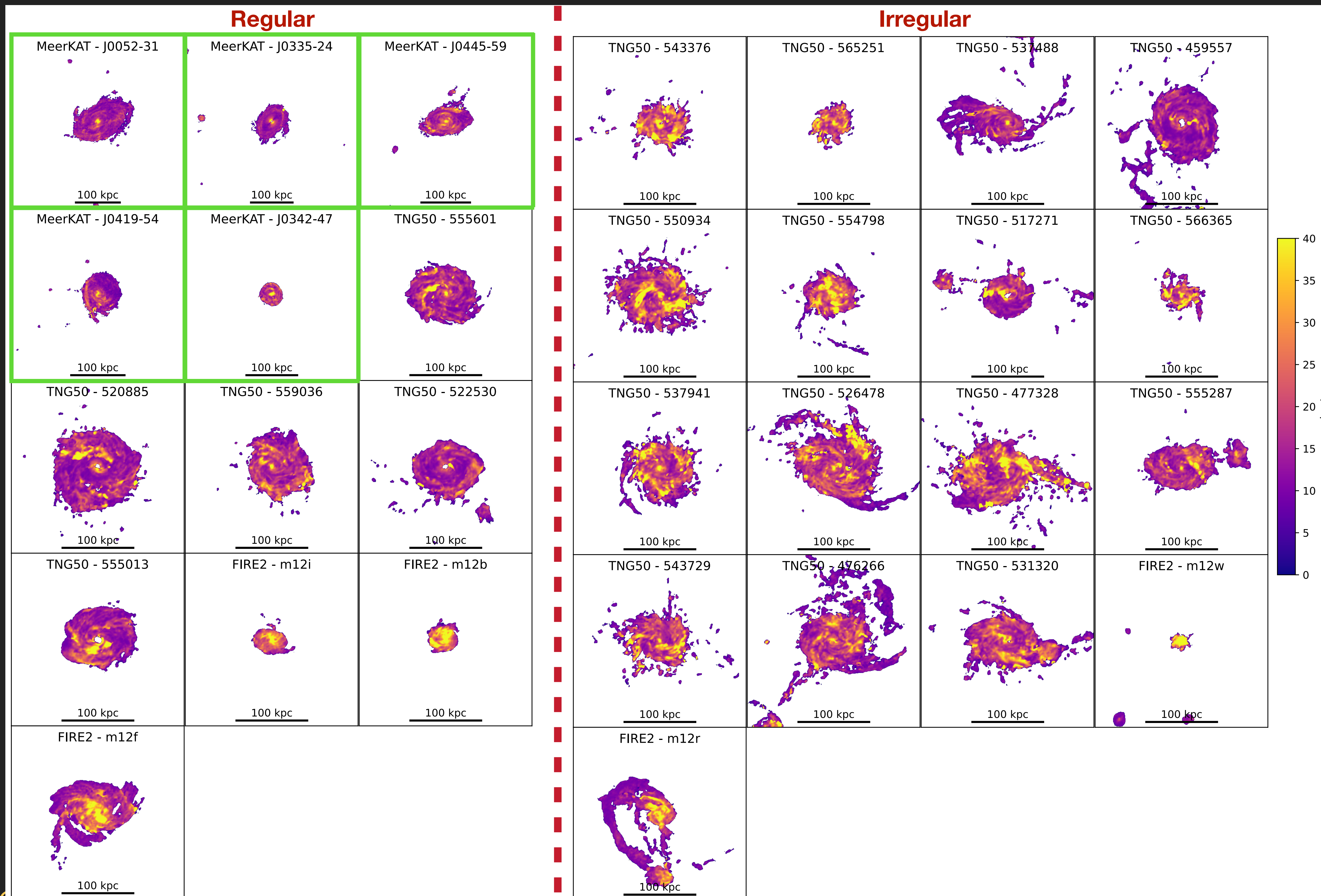
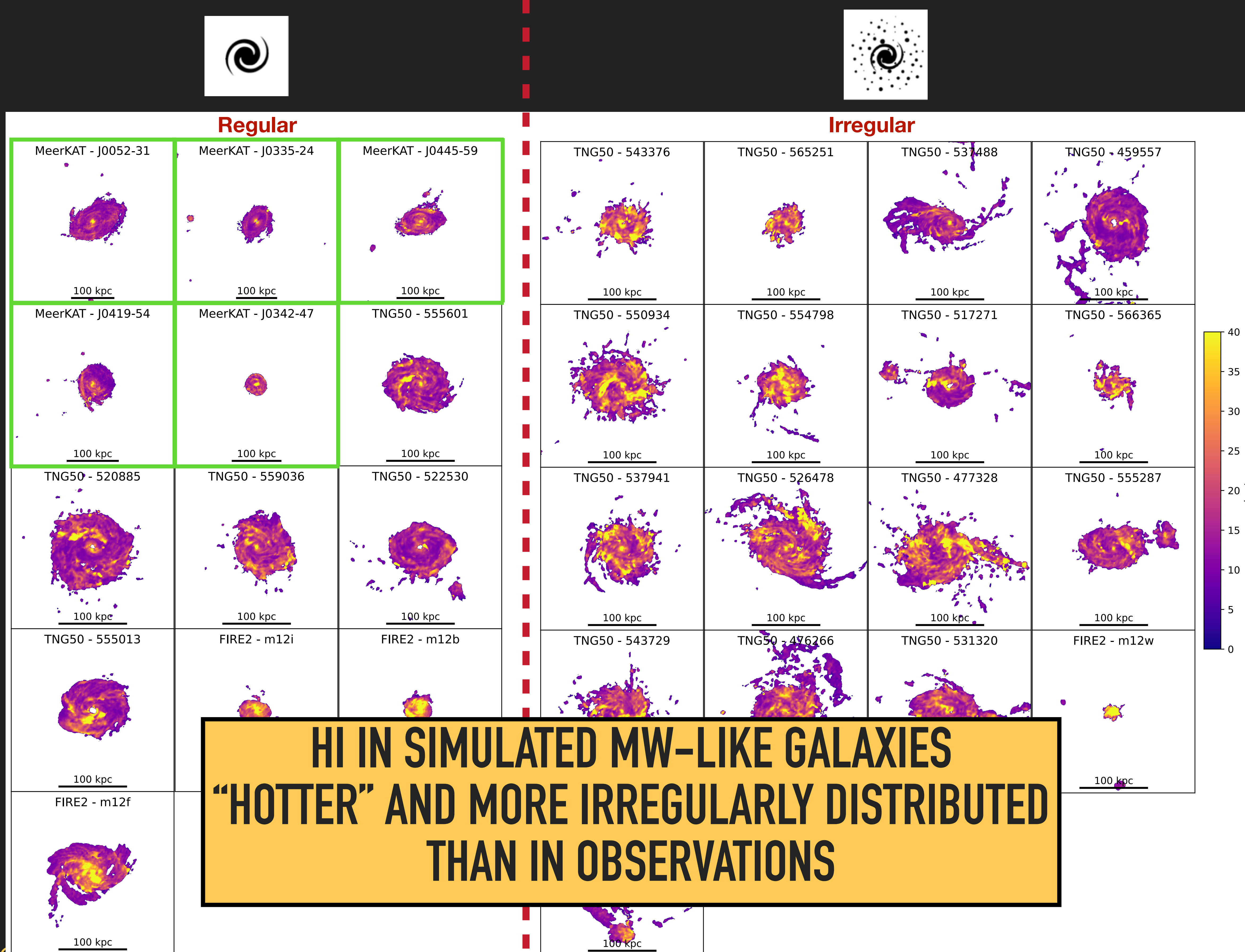




Regular and irregular systems

Galaxies dominated by high-N_{HI} spaxels (>10^{20} cm^{-2})

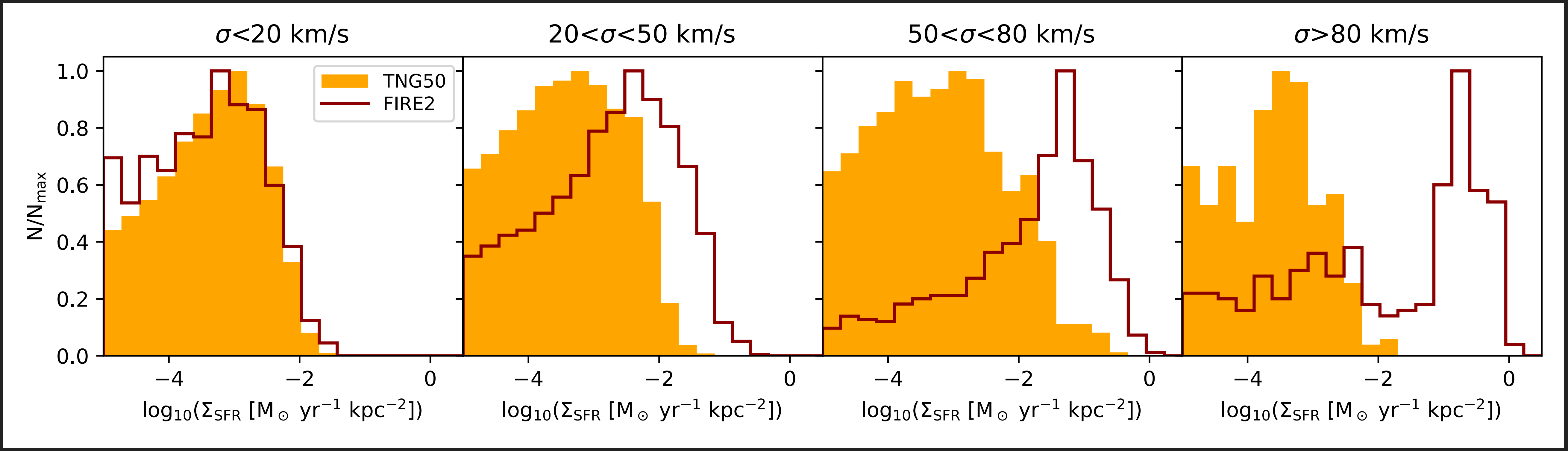
Galaxies dominated by low-N_{HI} spaxels (<10^{20} cm^{-2})



HI IN SIMULATED MW-LIKE GALAXIES "HOTTER" AND MORE IRREGULARLY DISTRIBUTED THAN IN OBSERVATIONS

Origin of irregular, high-σ HI

Stellar Feedback?



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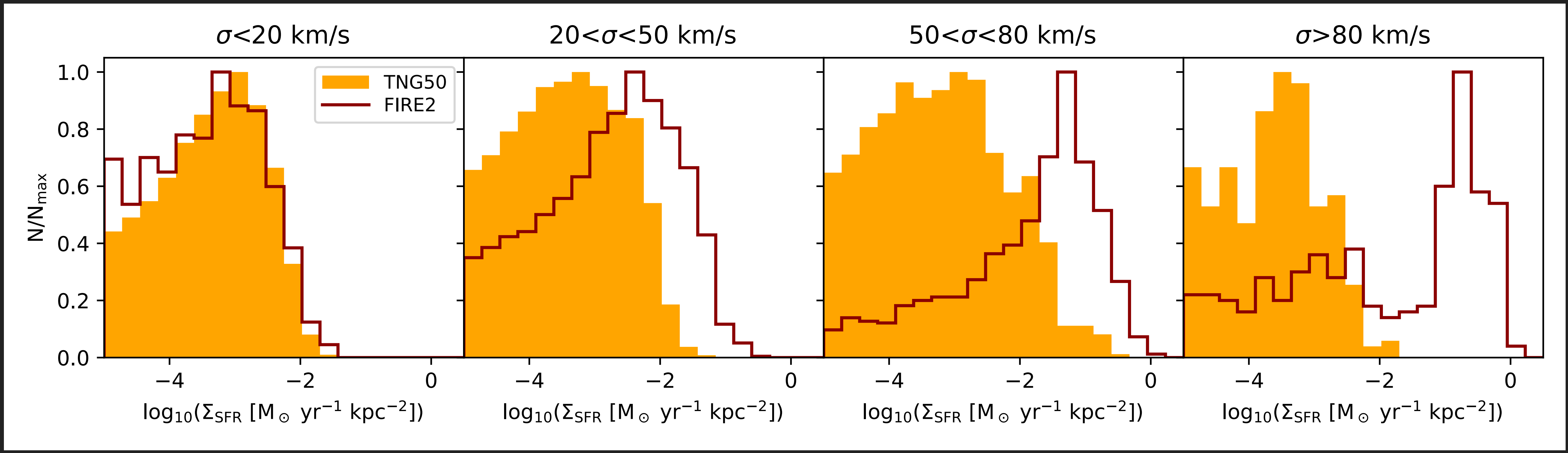

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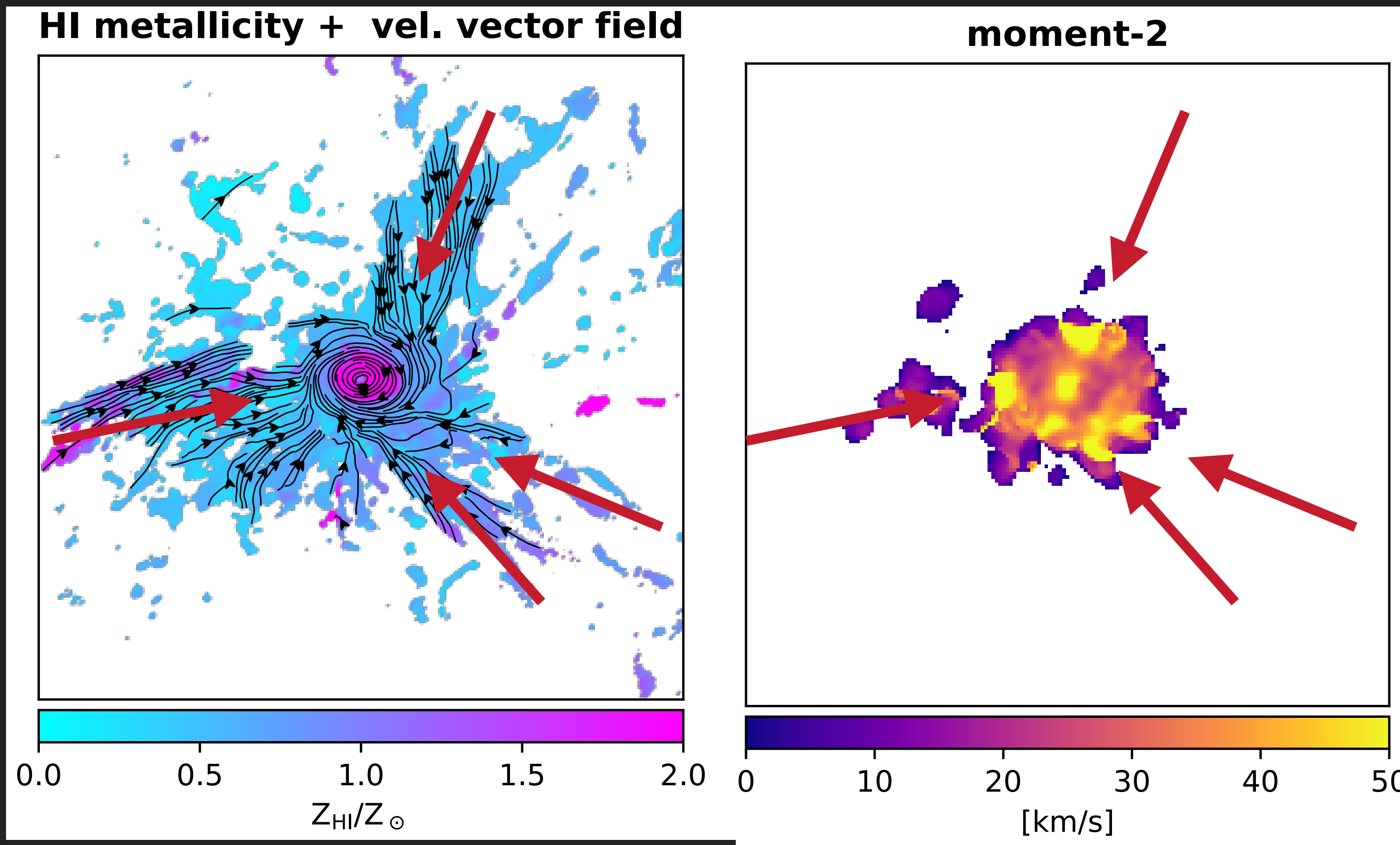
Cold gas accretion



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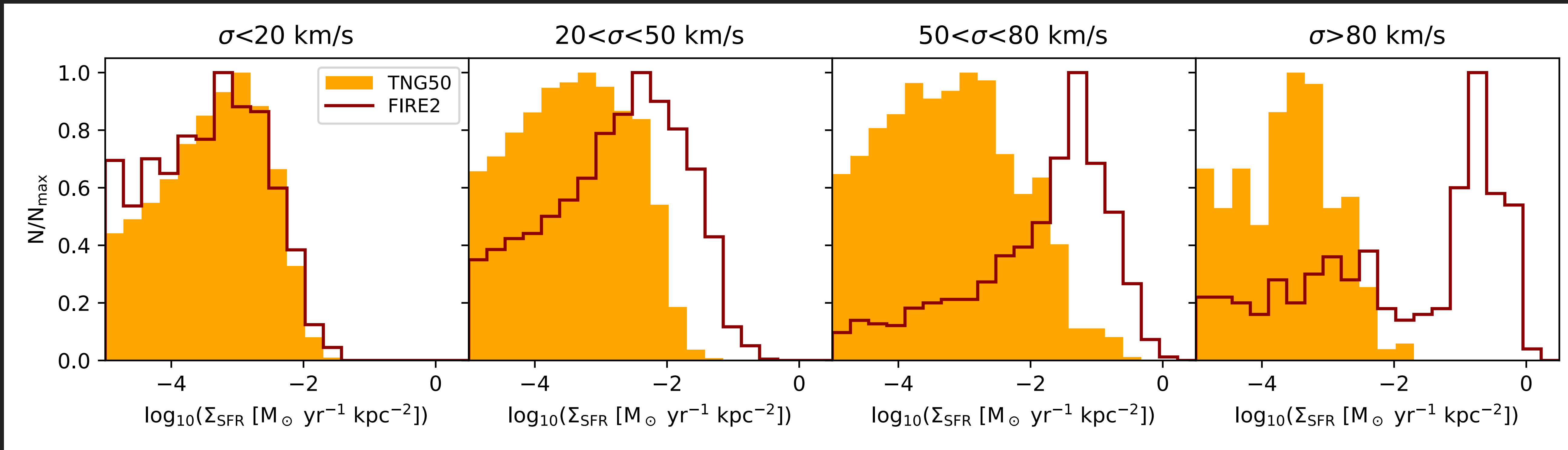

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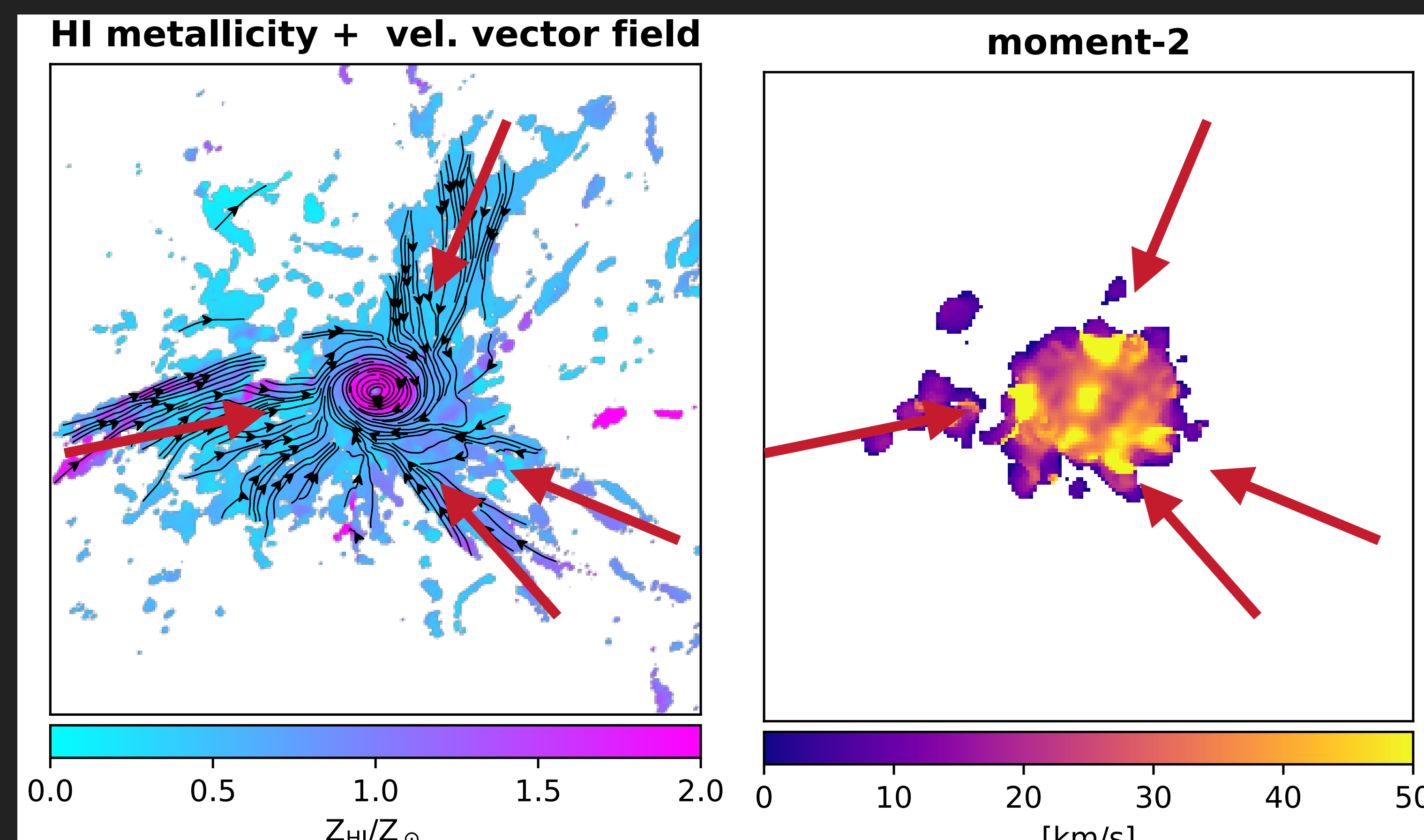
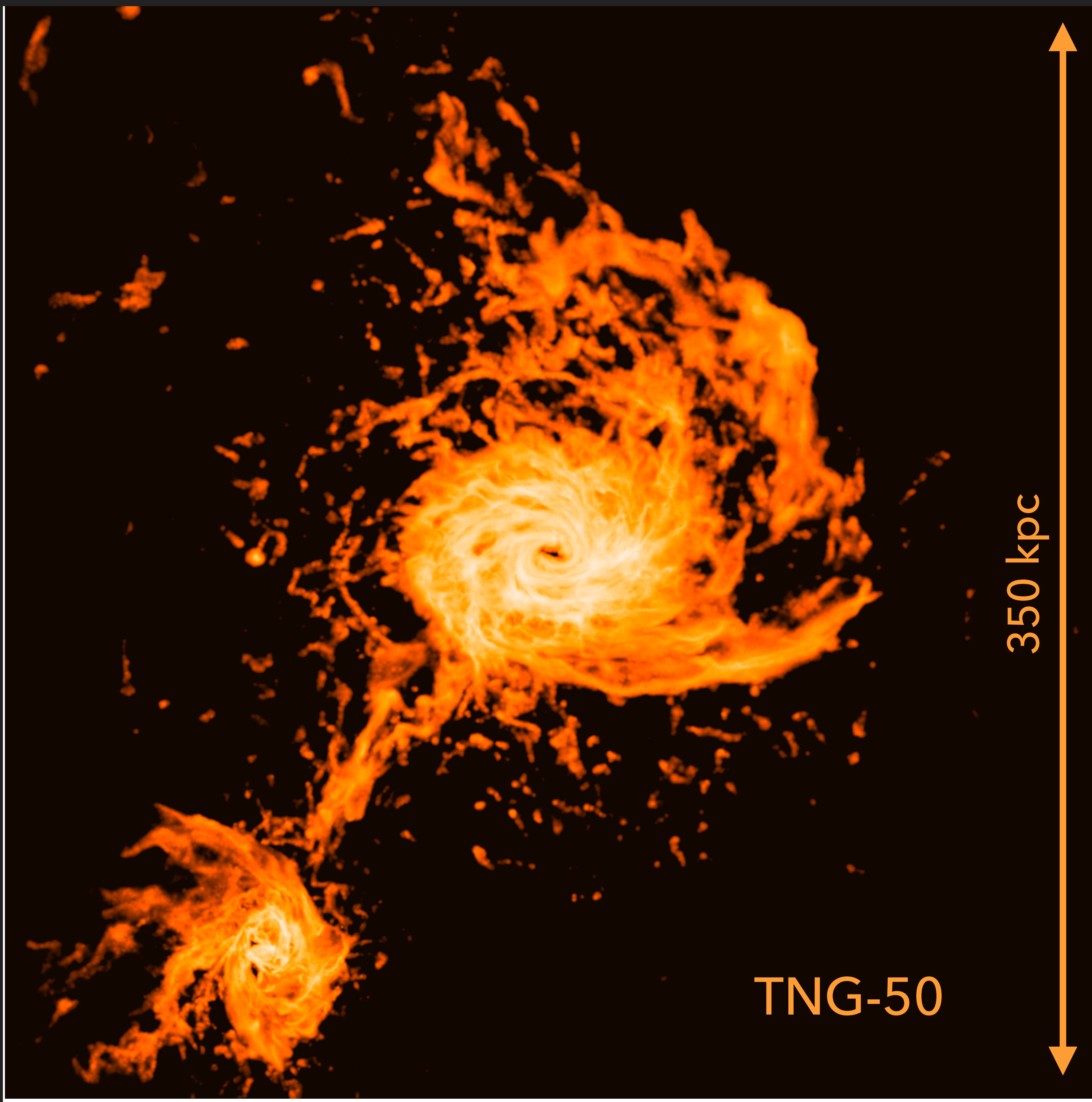


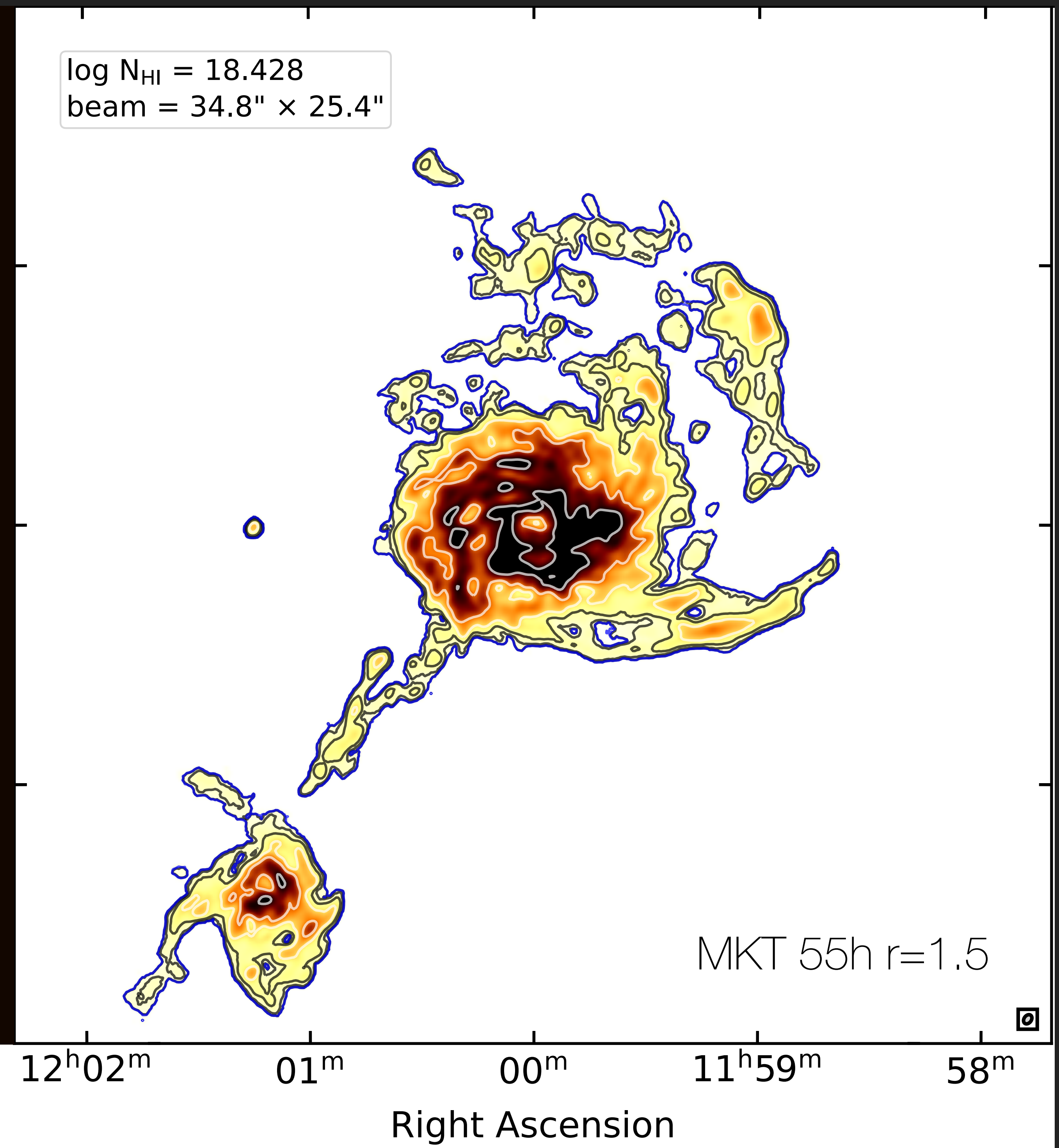
STELLAR FEEDBACK (FIRE2) & GAS ACCRETION (TNG50) ARE TOO "VIGOROUS" IN THE SIMS

Conclusions

- Tools to produce mock observations (including HI cubes) from simulations are now available. Use them!
- Current generation of simulations provides galaxies with realistic global properties, including HI masses and sizes.
- However, HI discs are more disturbed and kinematically hotter than the real ones due to feedback (FIRE2) and accretion processes (TNG).
- A MHONGOOSE-like sensitivity might not be sufficient to fully capture the complex HI halo predicted by current models -> Testing using SKA-like sensitivity and next generation models (e.g. COLIBRE) is key!

Preliminary tests: MeerKAT vs SKA-Mid AA*





courtesy of Erwin De Blok

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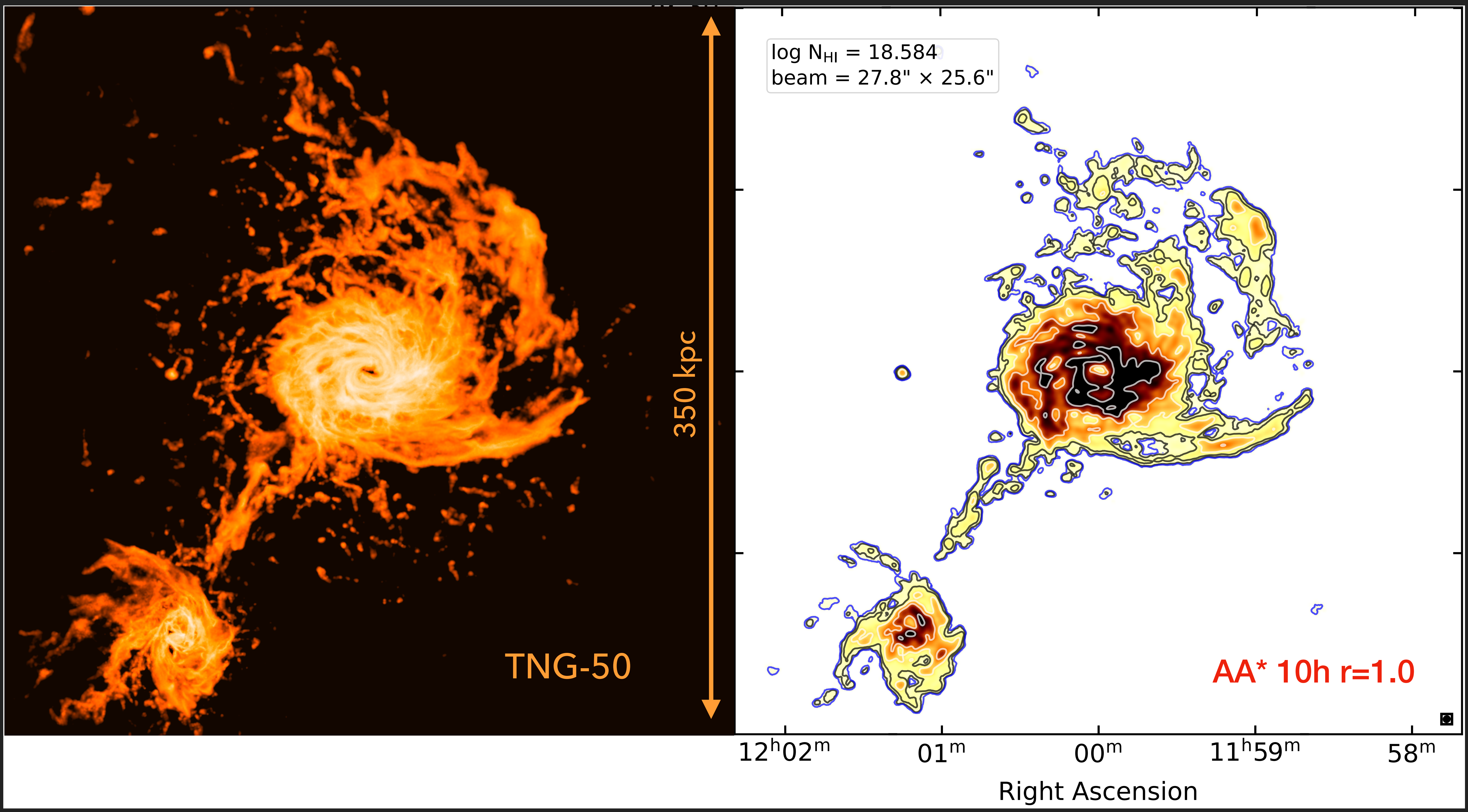

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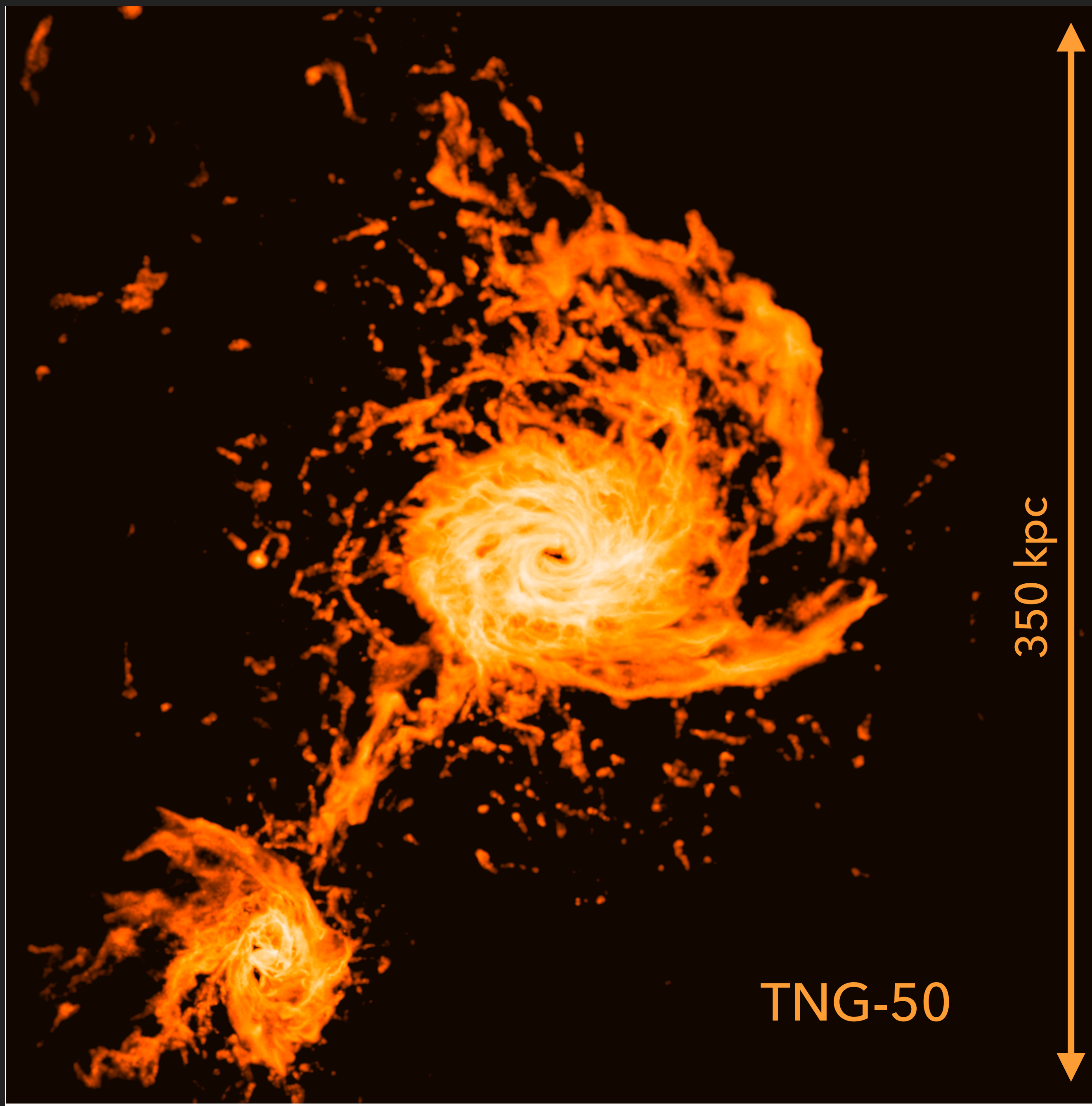

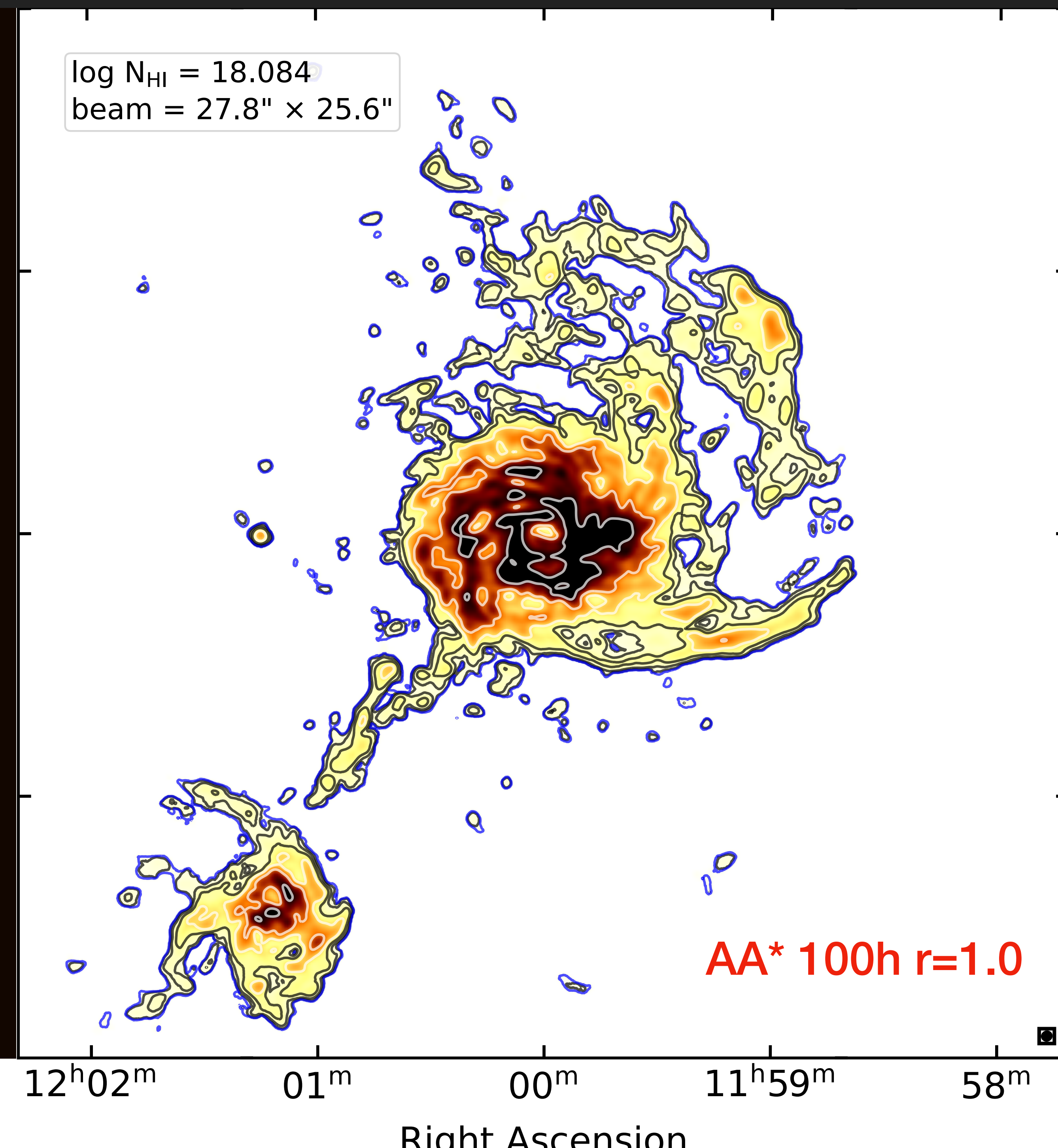

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