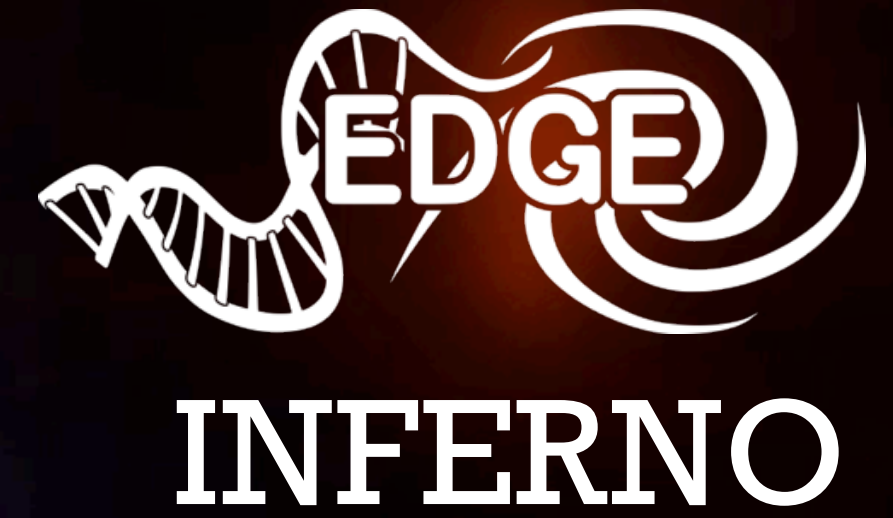
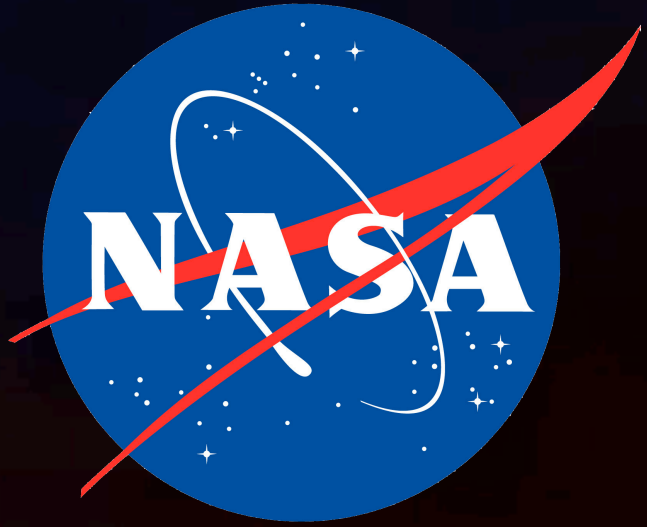


American Museum  
of Natural History



ERIC ANDERSSON

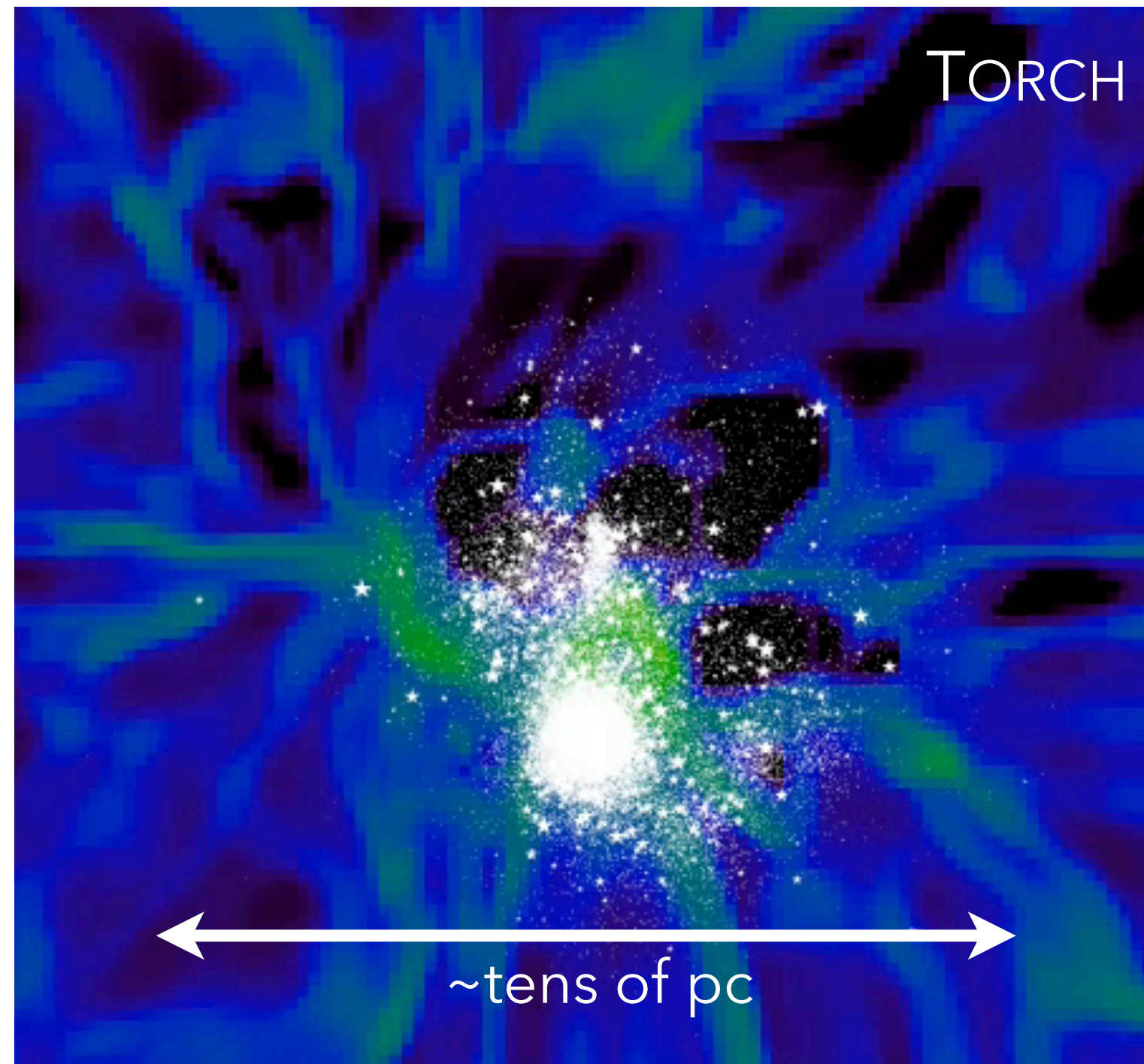
# STAR-BY-STAR FORMATION OF DWARF GALAXIES IN COSMOLOGICAL ENVIRONMENTS



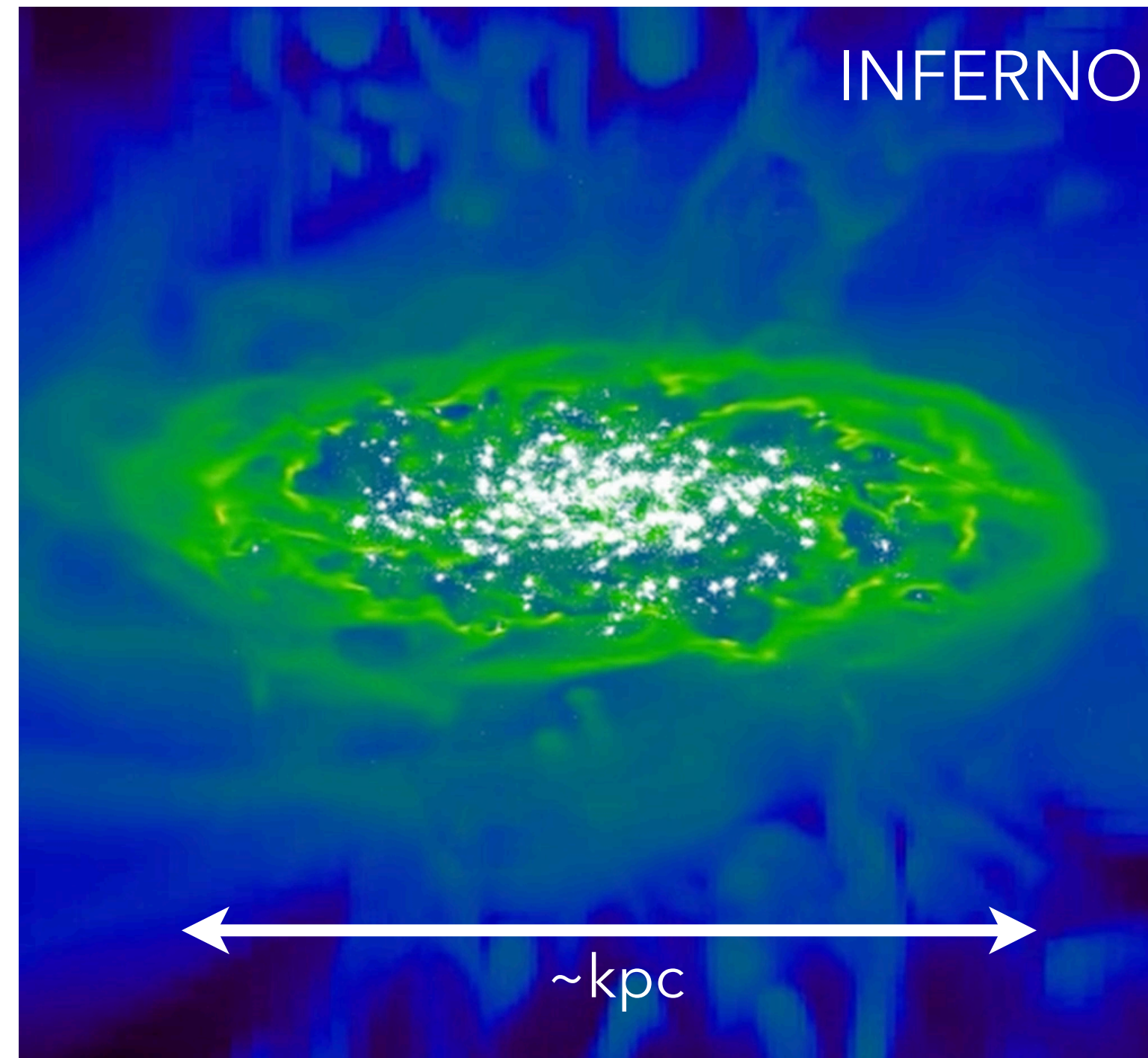
# HYDRODYNAMICAL SIMULATIONS OF GALAXIES

- ▶ Galaxy evolution — extreme dynamical range
- ▶ Star-by-star models — bridging the gap between small and large scales

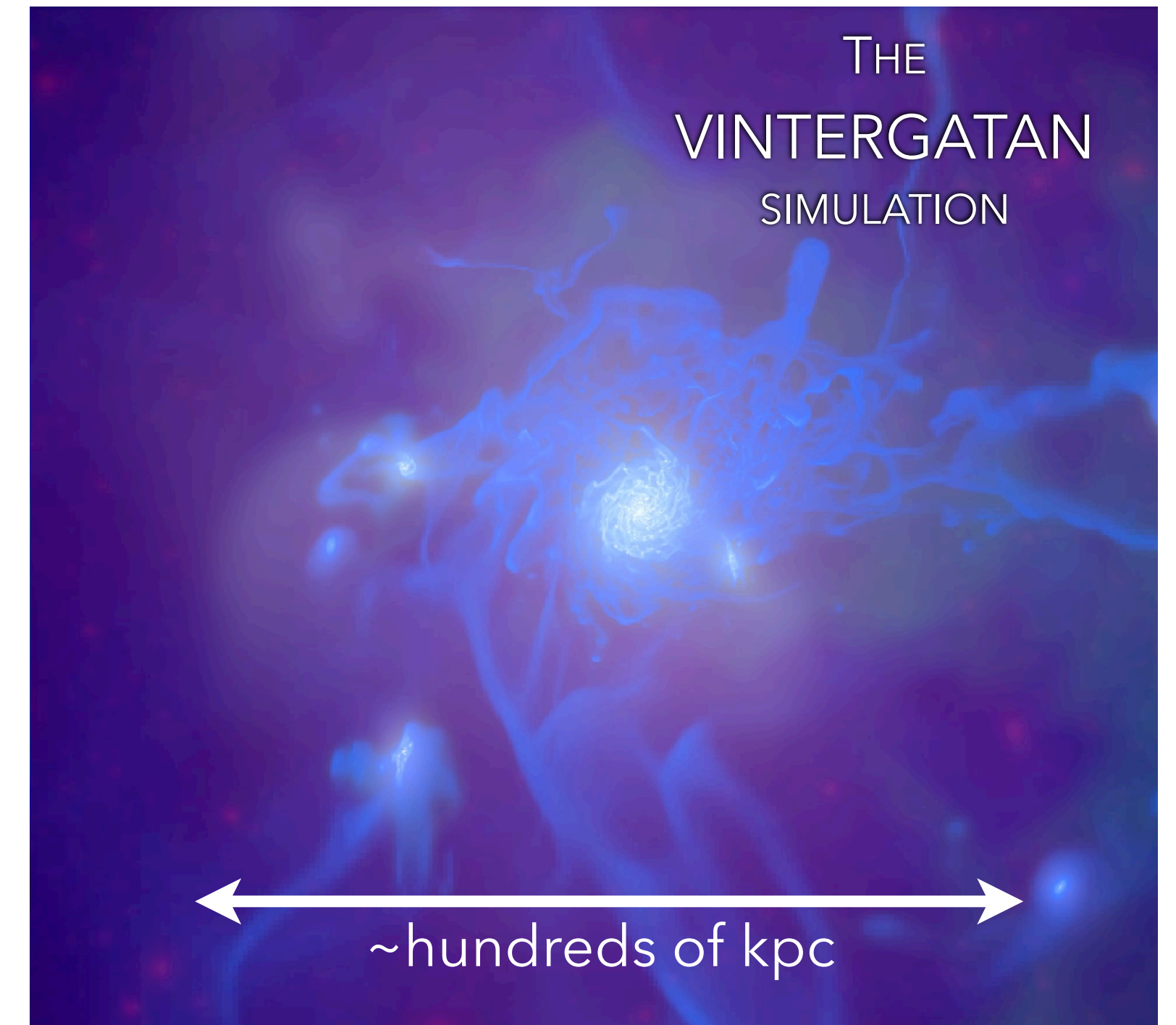
*Wall et al. (2019,2020), see also  
Polak et al. (2024a, inc. EA)*



*Andersson et al. (2023)*



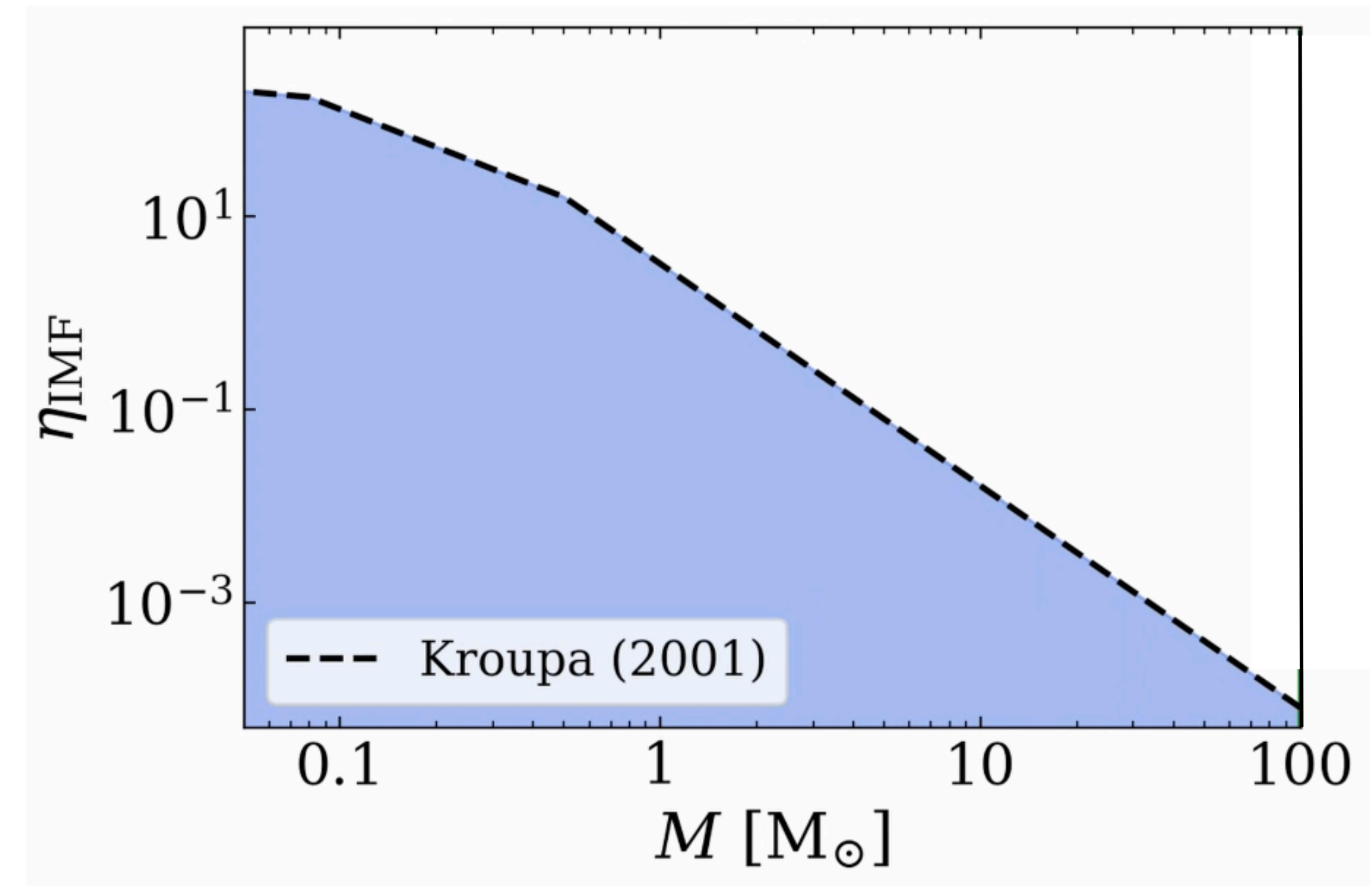
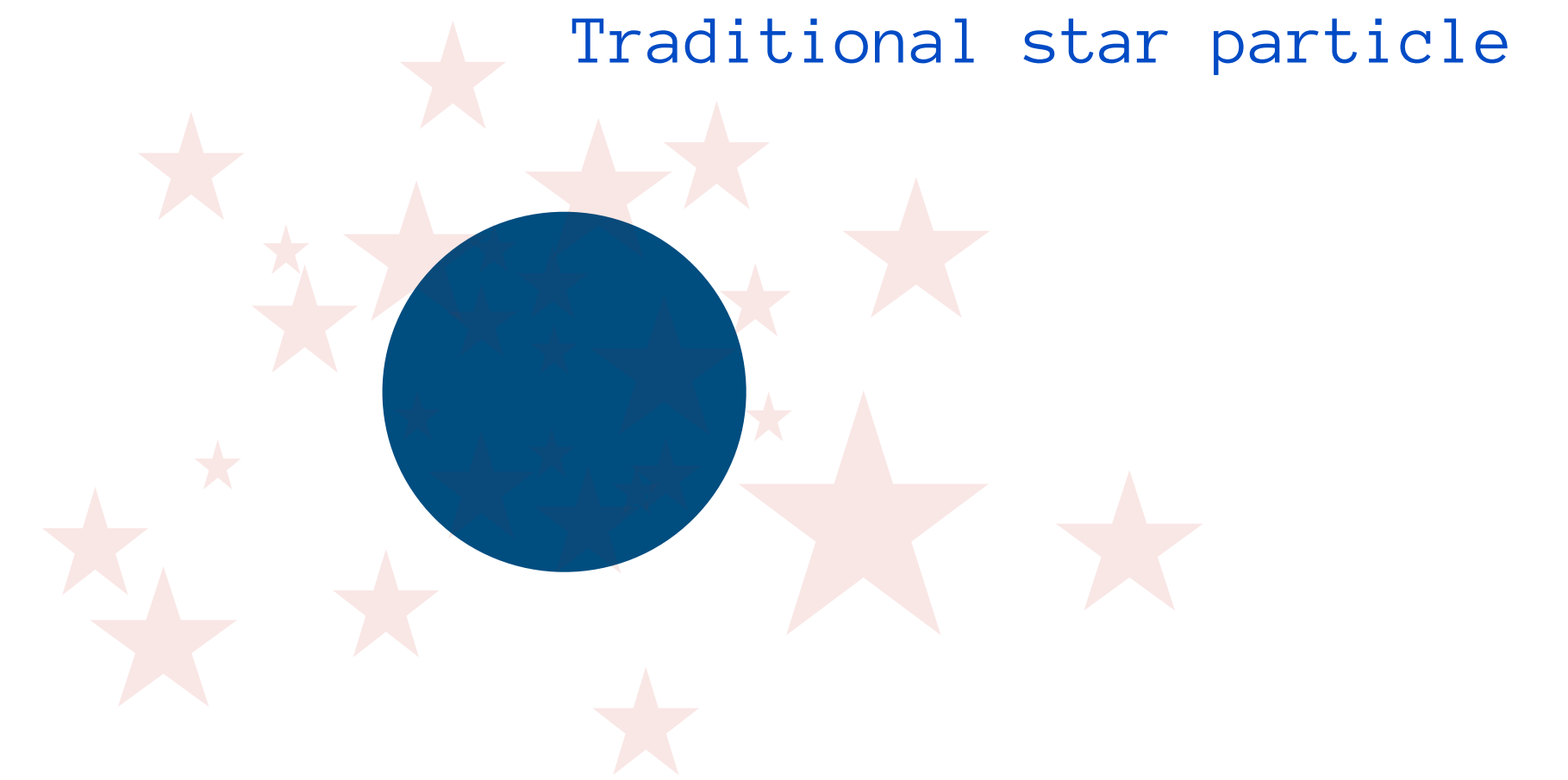
*Agertz et al. (2021, inc. EA),  
Renaud et al. (2021a,b, inc. EA)*





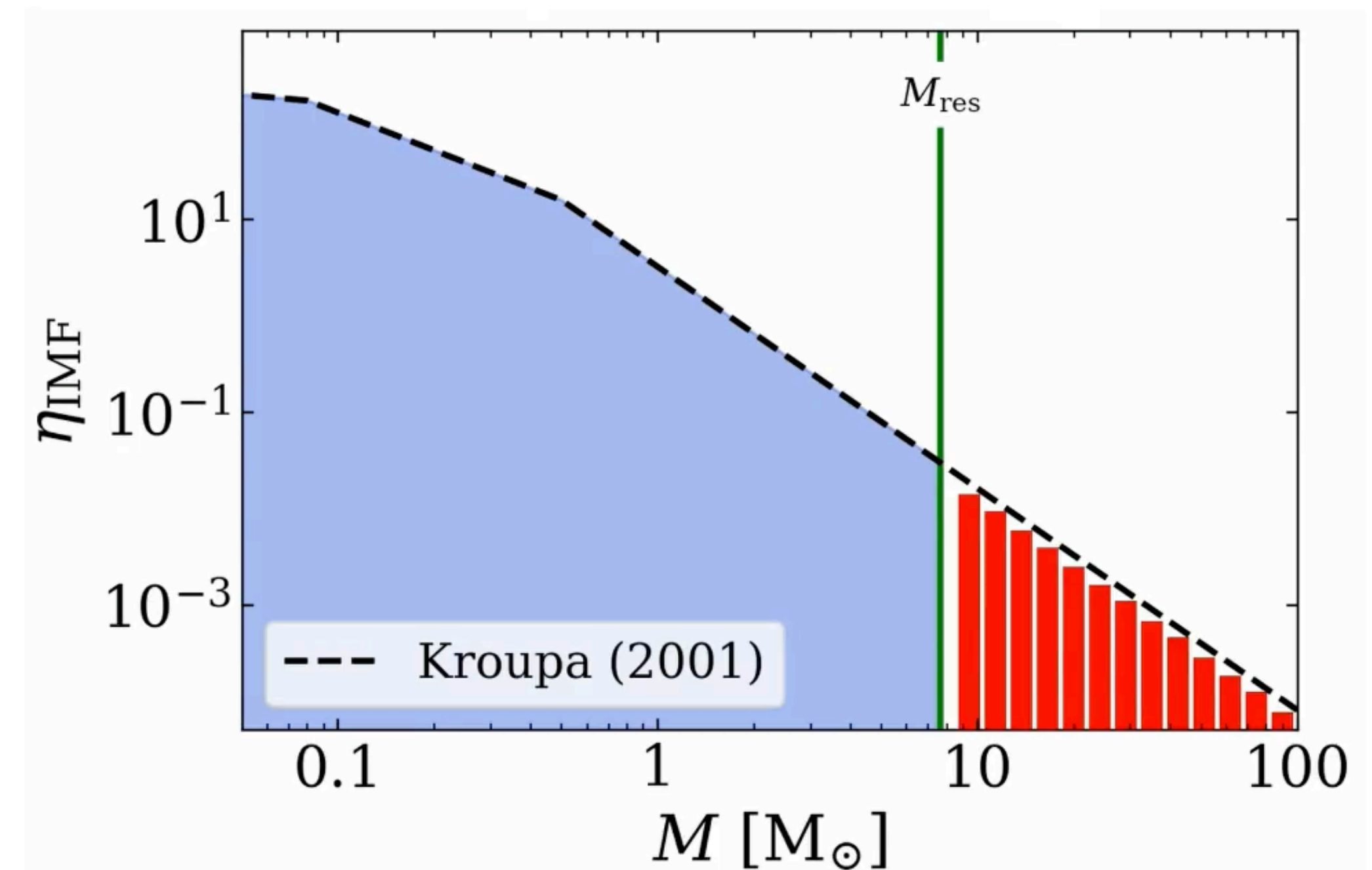
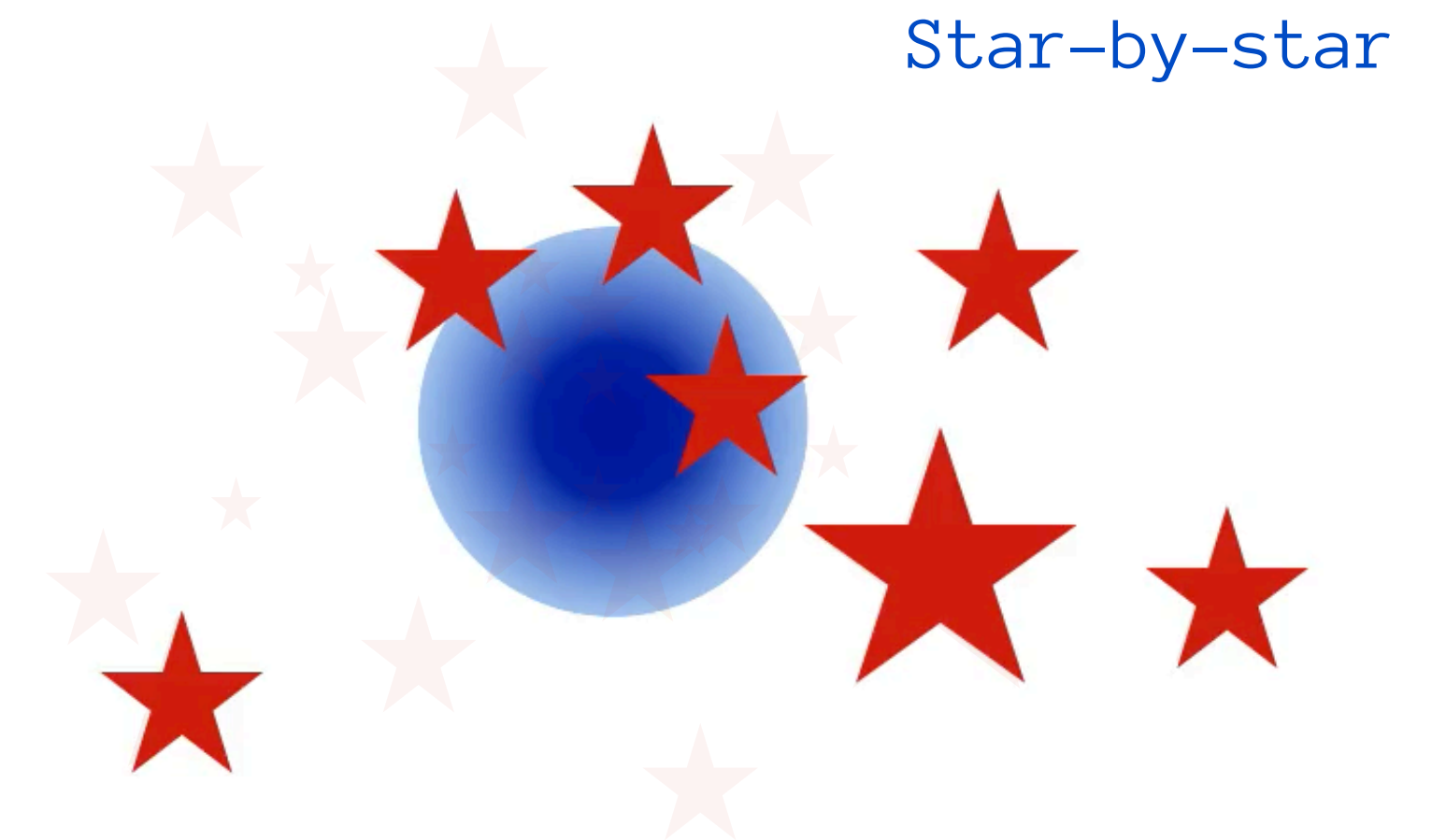
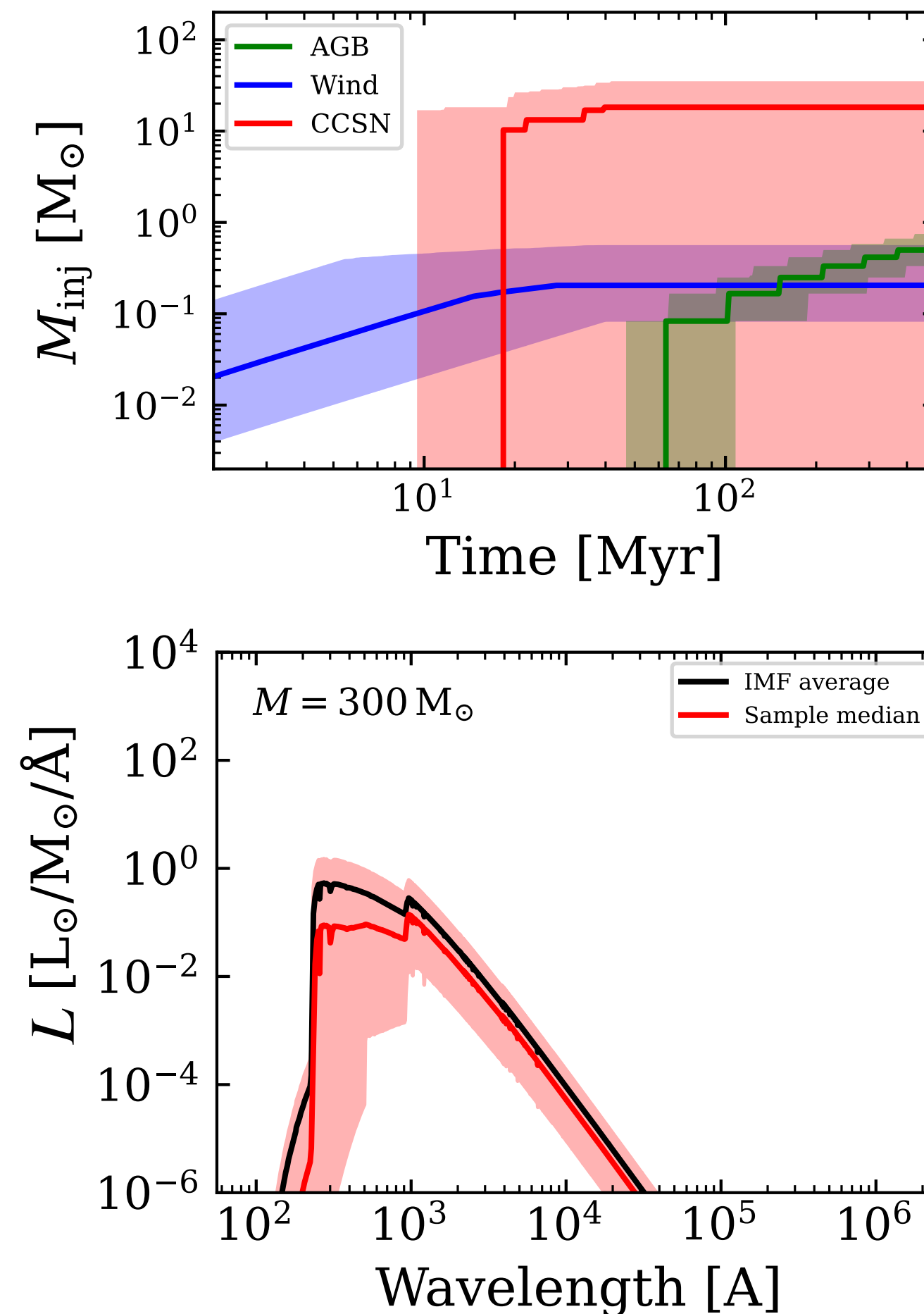
# STAR-BY-STAR MODELS

e.g., Emerick et al. (2018), Andersson et al. (2020), Lahen et al. (2020), Hiriai et al. (2021), Gutcke et al. (2021), Hislop et al. (2022), Steinwandel et al. (2022), Calura et al. (2022), Deng et al. (2024), Brauer et al. (2025)



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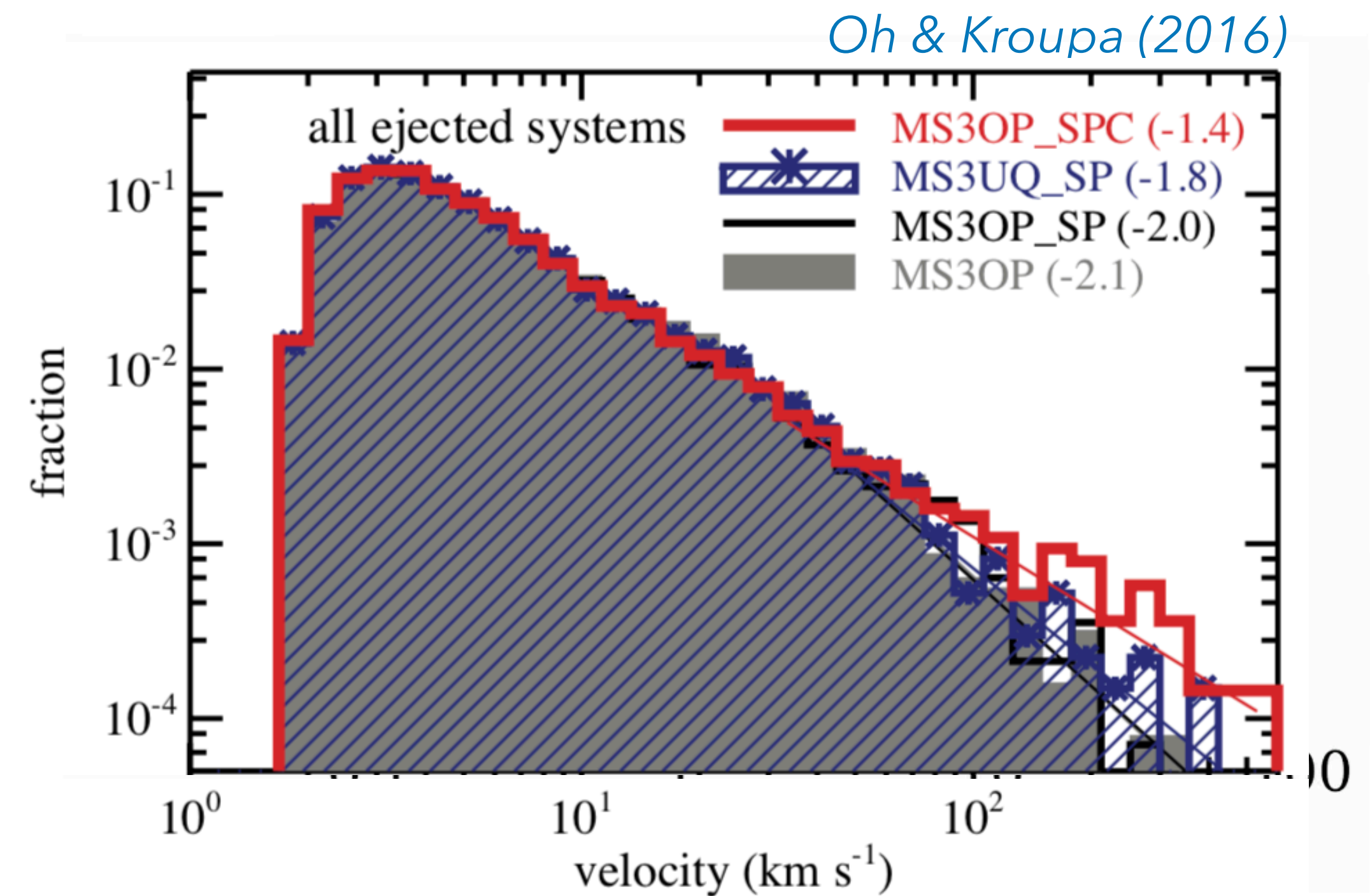
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## INFERNO

see Andersson et al. (2020,2021,2023,2025)

- Flexible star-by-star model in the RAMSES hydrodynamics code
- Natal kicks to treat unresolved dynamics (e.g., runaway stars)



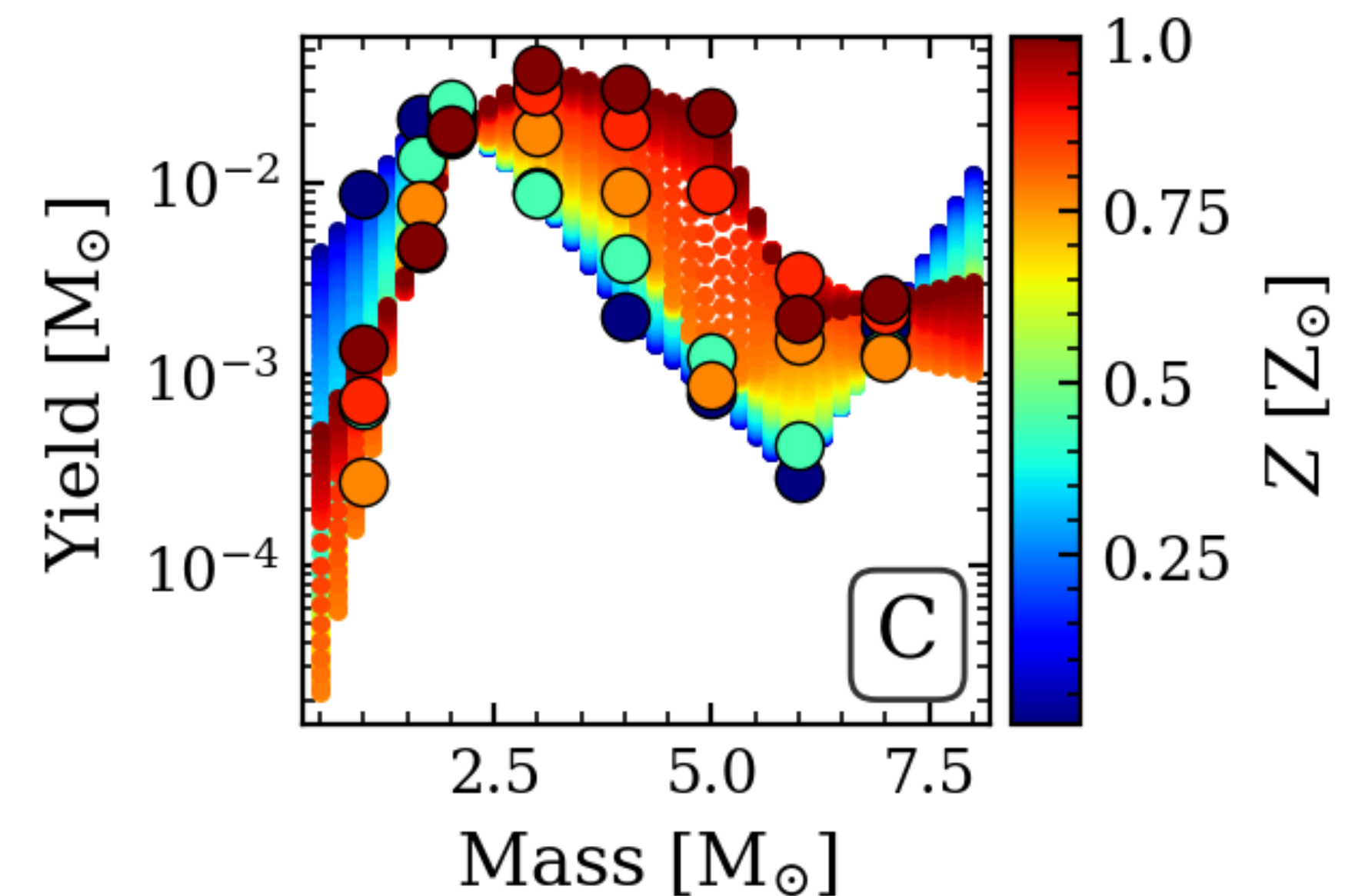
# STAR-BY-STAR MODELS

e.g., Emerick et al. (2018), Andersson et al. (2020), Lahaen et al. (2020), Hirai et al. (2021), Gutcke et al. (2021), Hislop et al. (2022), Steinwandel et al. (2022), Calura et al. (2022), Deng et al. (2024), Brauer et al. (2025)

## INFERNO

see Andersson et al. (2020,2021,2023,2025)

- Flexible star-by-star model in the RAMSES hydrodynamics code
- Natal kicks to treat unresolved dynamics (e.g., runaway stars)
- Stellar evolution and feedback (supernovae, radiation, winds)
- Chemical enrichment (majority of elements available)





$z = 2.38$



Stars

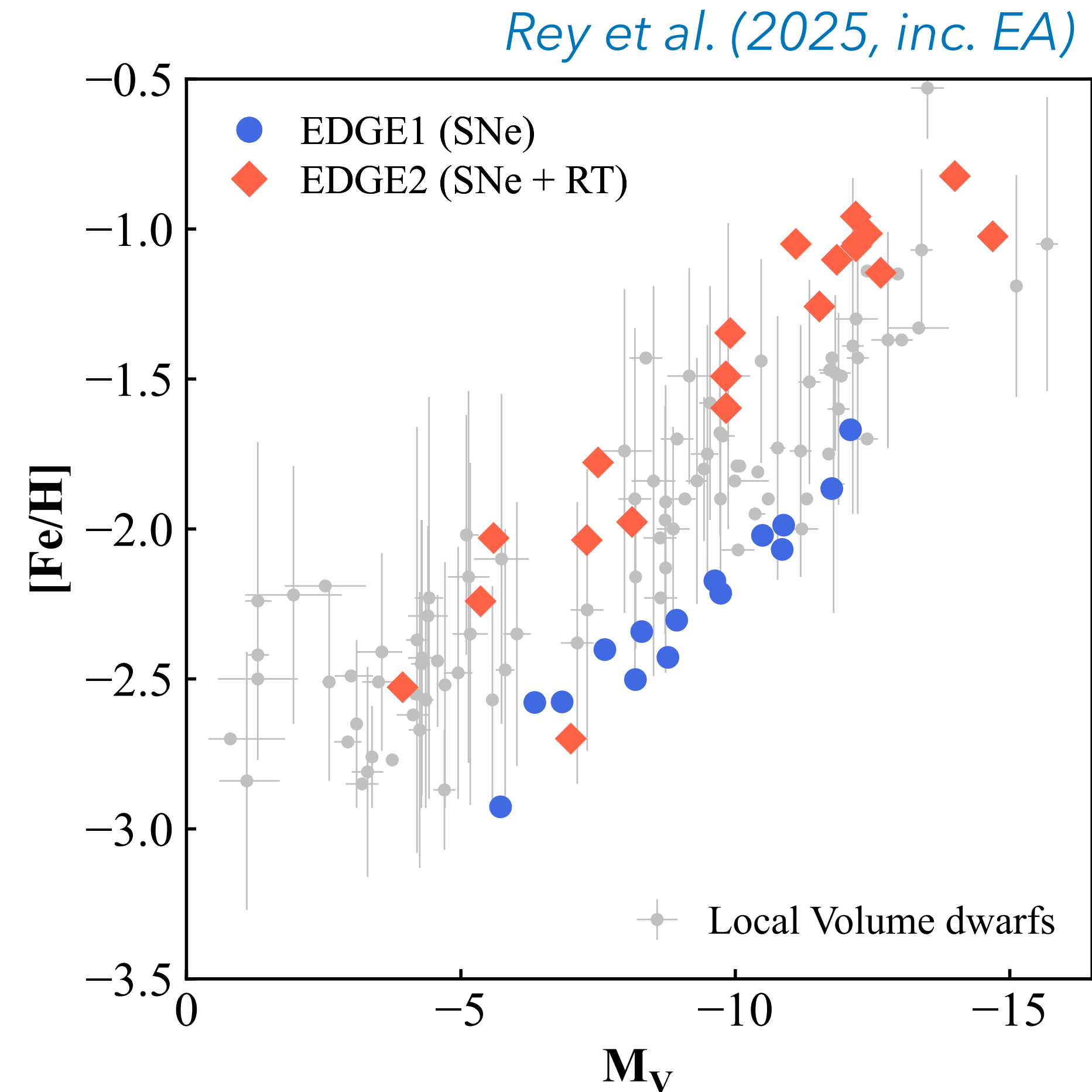
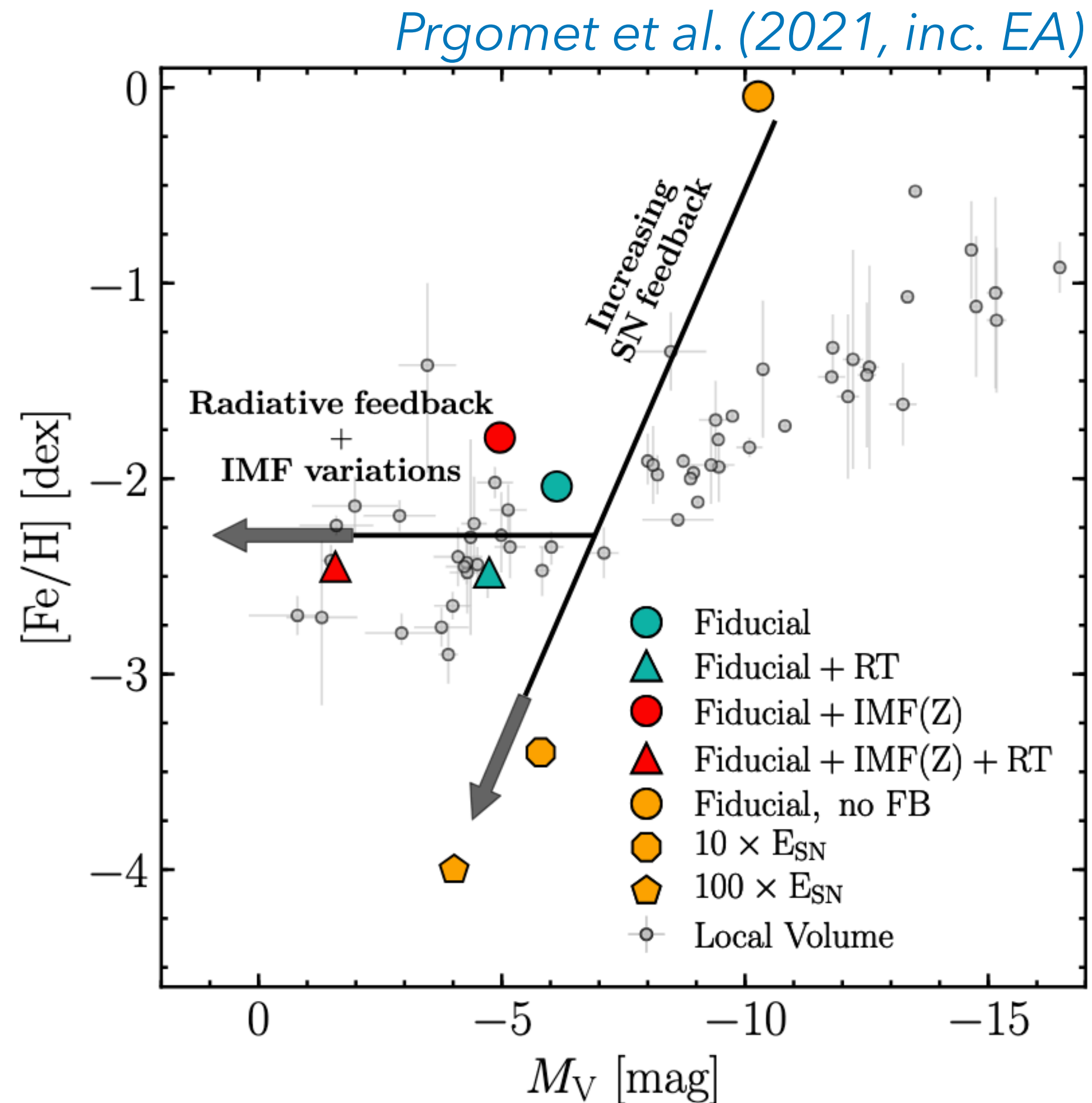
Gas

Dark matter



# ENGINEERING DWARFS AT GALAXY FORMATION'S EDGE (EDGE)

Martin Rey, Justin Read, Andrew Pontzen, Oscar Agertz, Amélie Saintonge, Noelia Noël, Michelle Collins, Payel Das, Denis Erkal, Robert Izzard, Matt Orkney, Stacy Kim, Corentin Cadiou, Rob Yates, Eric Andersson, Ricarda Beckmann, Mary Gration, Susan Hutton, Grace Lawrence, Ethan Taylor, Alex Goater, Izzy Gray, Claudia Muni

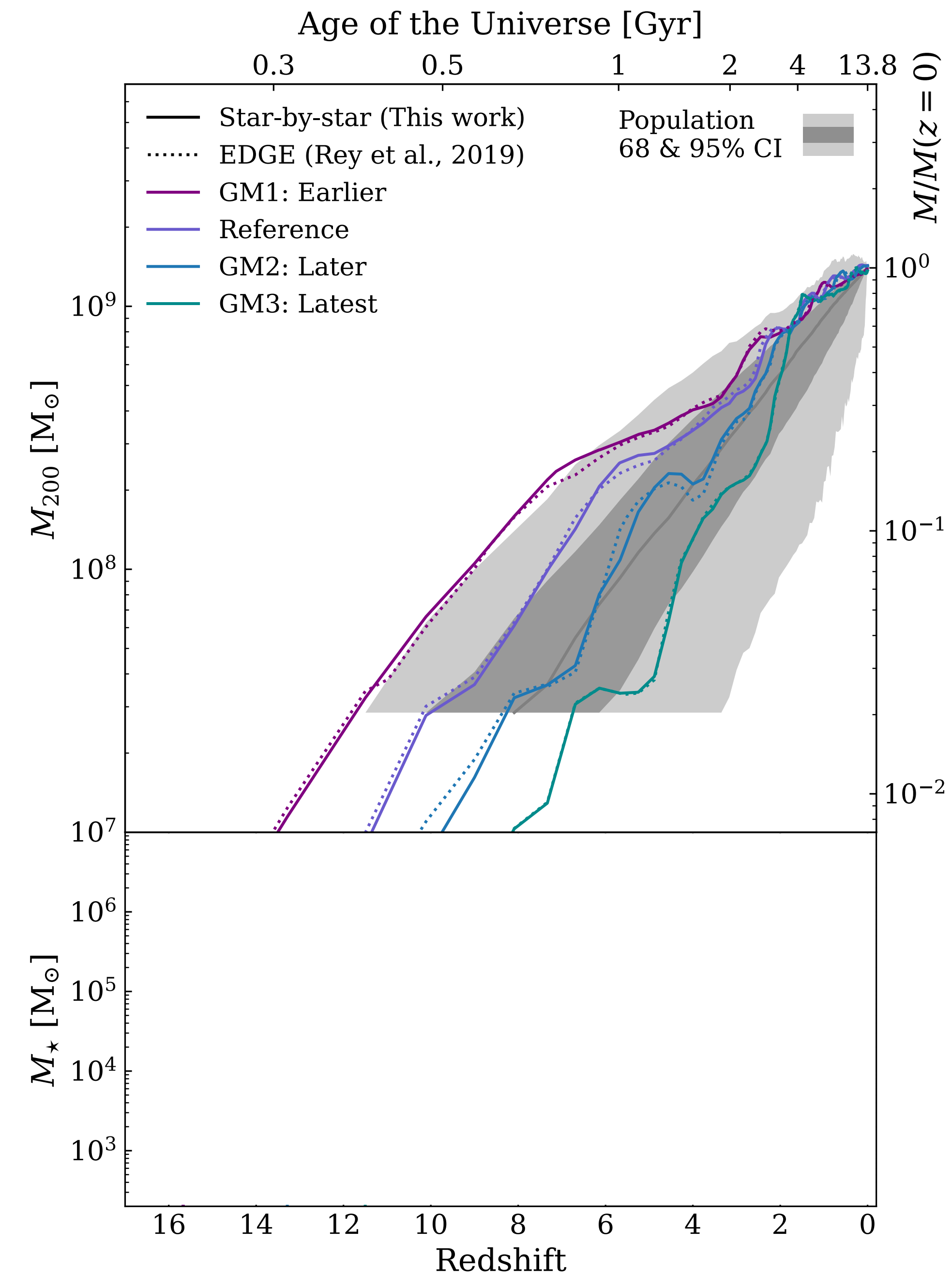




# EDGE-INFERNO: STAR-BY-STAR APPLIED IN COSMOLOGICAL ENVIRONMENT

*Andersson et al. (2025)*

- ▶ Zoom-in simulations of dwarf galaxies ( $\Delta x_{z=0} = 3.6\text{pc}$ ), with individual stars ( $m_{\star} > 0.5 M_{\odot}$ )
- ▶ Reionization relics — probes of the early Universe
- ▶ Star formation regulation weaker for star-by-star *c.f., Rey et al. (2019), Agertz et al. (2020)*



# EDGE-INFERNO: STAR-BY-STAR APPLIED IN COSMOLOGICAL ENVIRONMENT

*Andersson et al. (2025)*

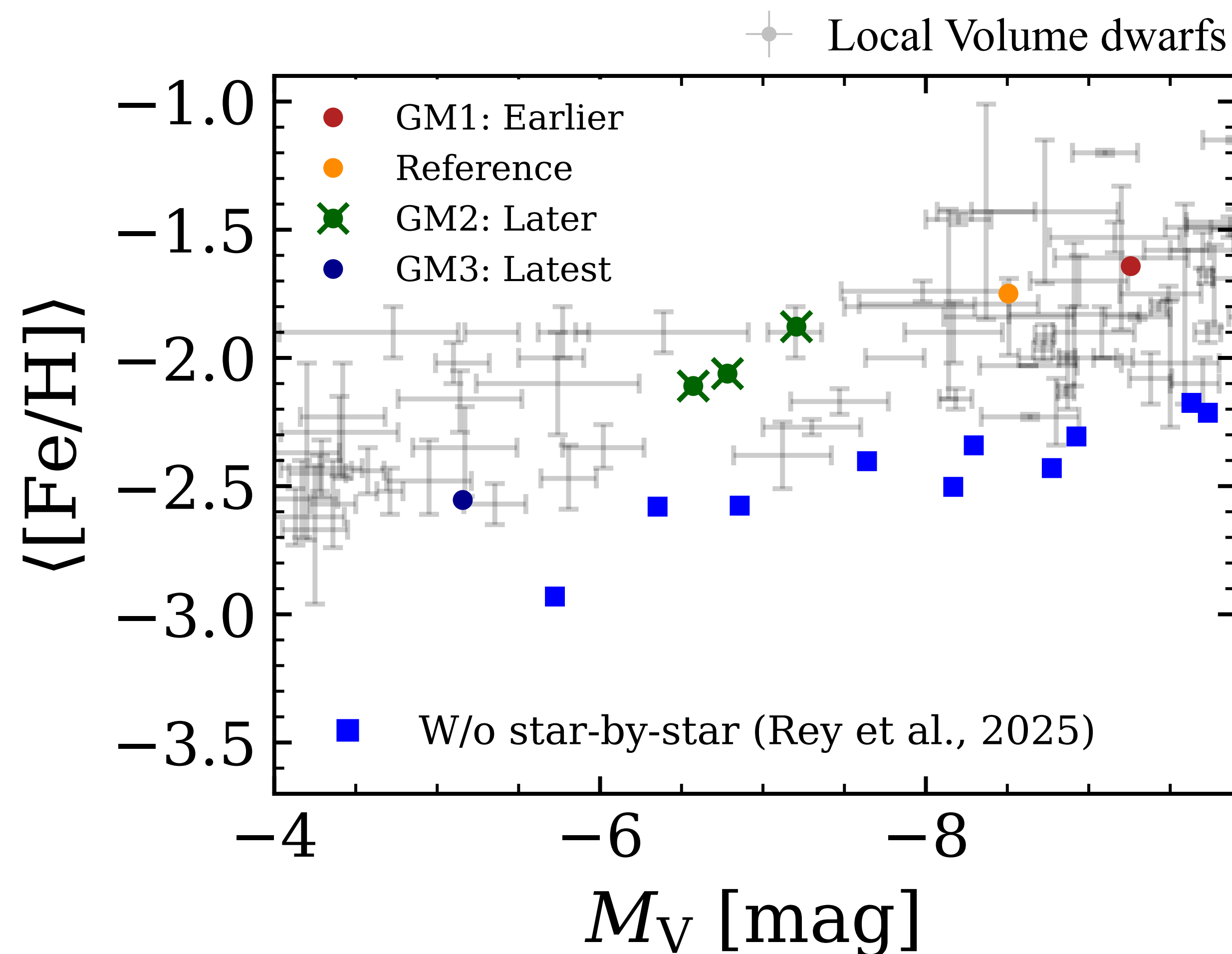
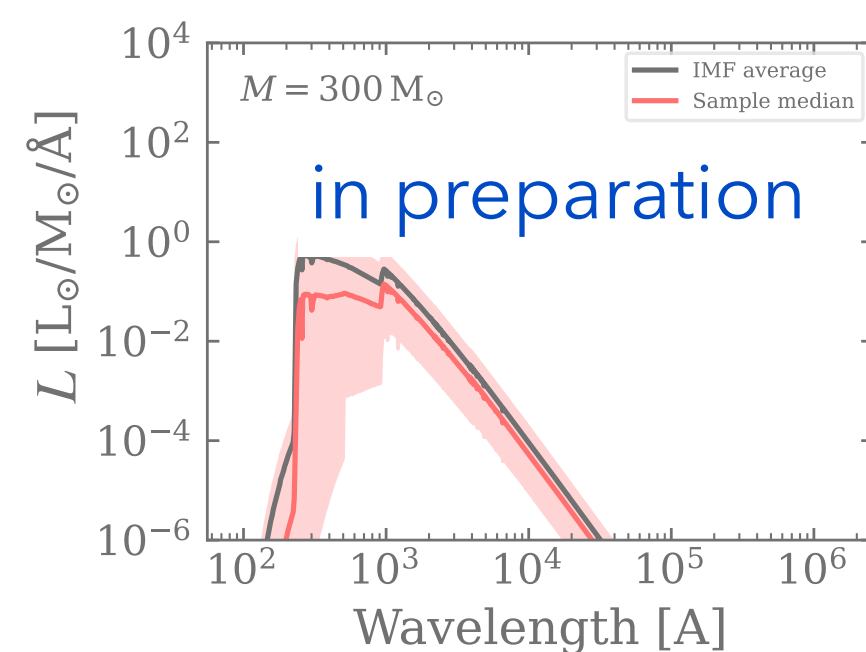
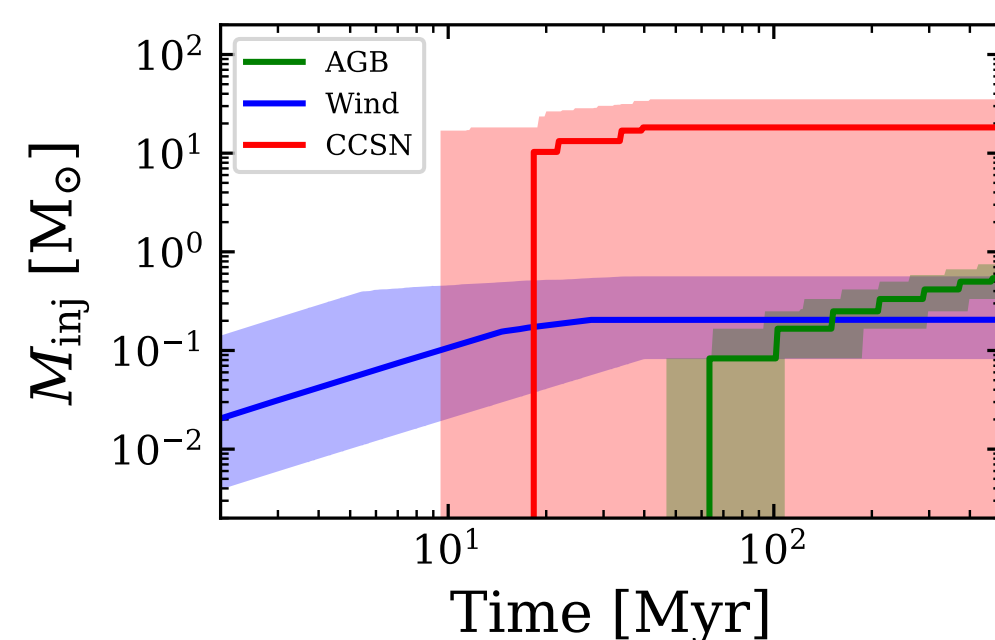
► Star formation regulation weaker for star-by-star  
*c.f., Rey et al. (2019), Agertz et al. (2020)*

► IMF not fully sampled at resolution  $\lesssim 500 M_{\odot}$   
*see also Krumholz et al. (2015), Chevance et al. (2022)*

• Star-by-star feedback is weaker?

*see also Reevaz et al. (2016),  
Emerick et al. (2019), Smith (2021)*

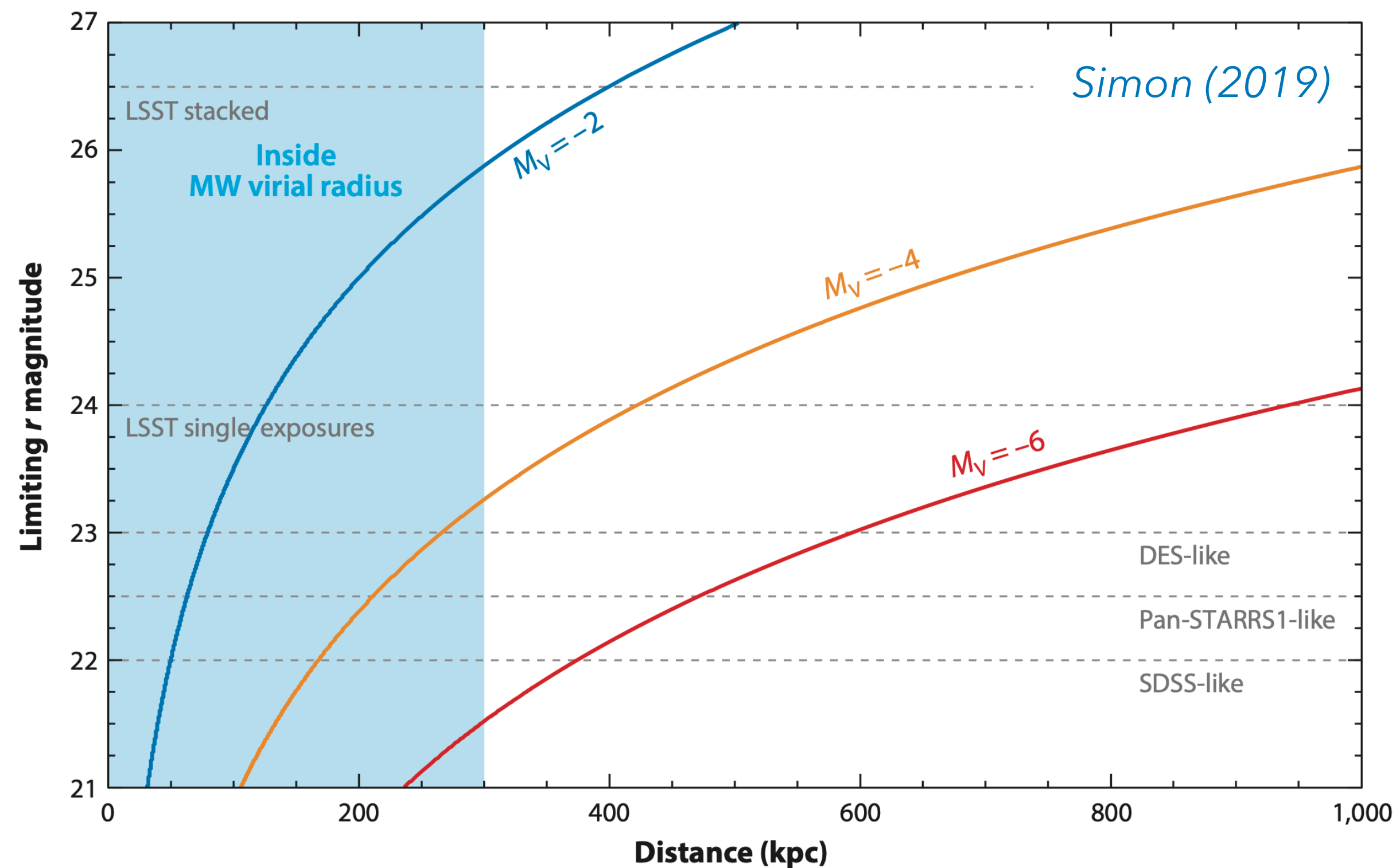
• To be confirmed with radiative transfer model  
*Andersson et al. (in prep)*





# THE CHALLENGE OF OBSERVING THE SMALLEST GALAXIES

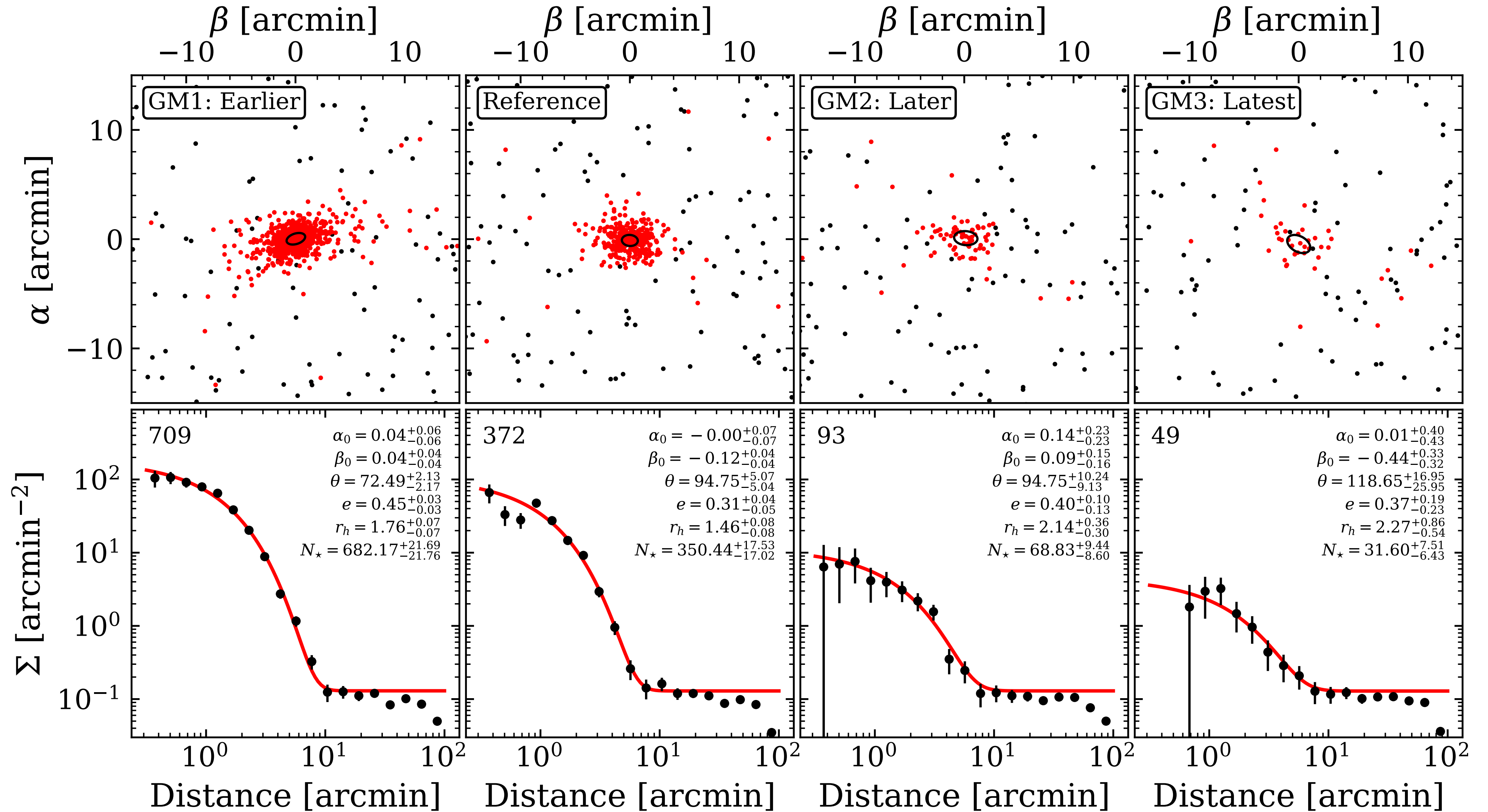
- ▶ Member detection from spectroscopy (velocity)  
see review by *Simon (2019)*
- ▶ Magnitude limitation:  $\sim 23$  mag for DES



*Reticulum II, Fermilab / Dark Energy Survey*



# THE CHALLENGE OF OBSERVING THE SMALLEST GALAXIES

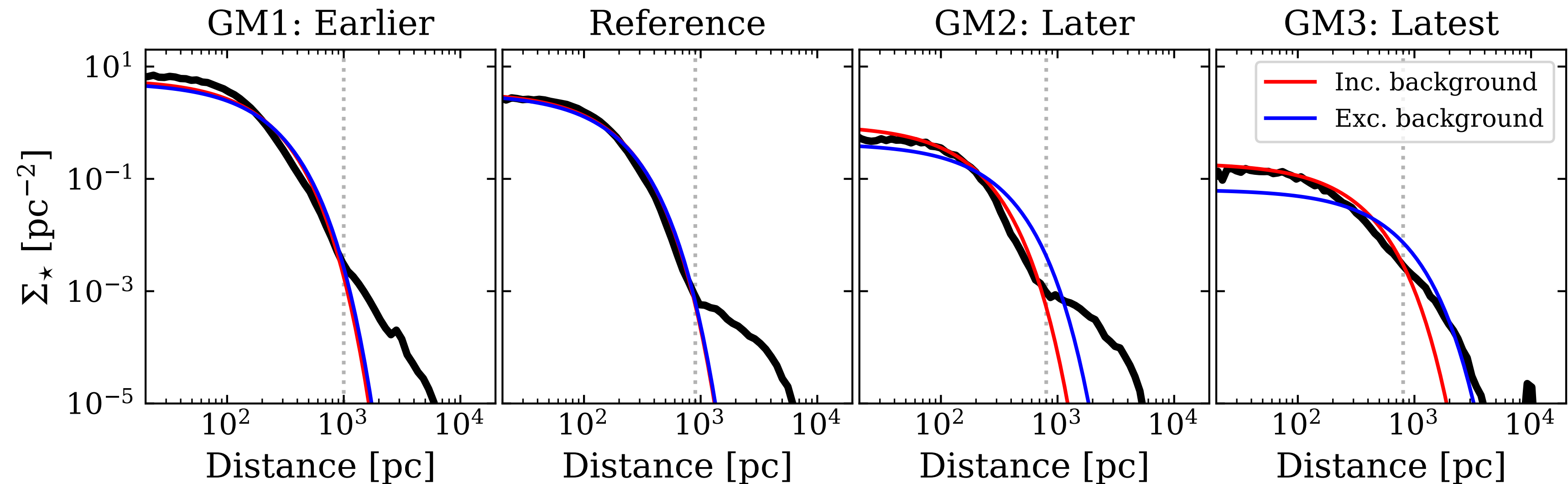
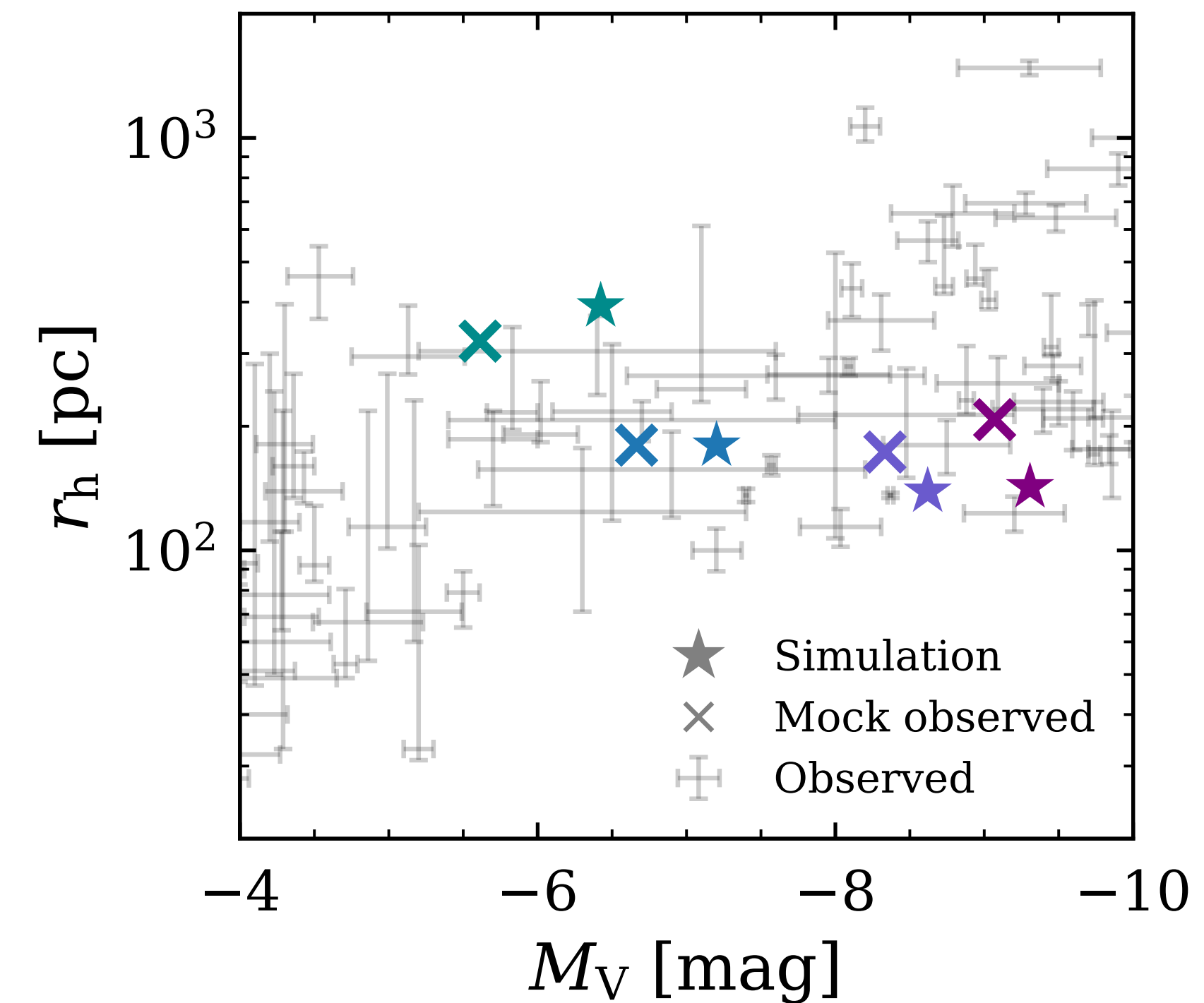




# DIRECT COMPARISONS WITH OBSERVED SYSTEMS

*Andersson et al. (2025)*

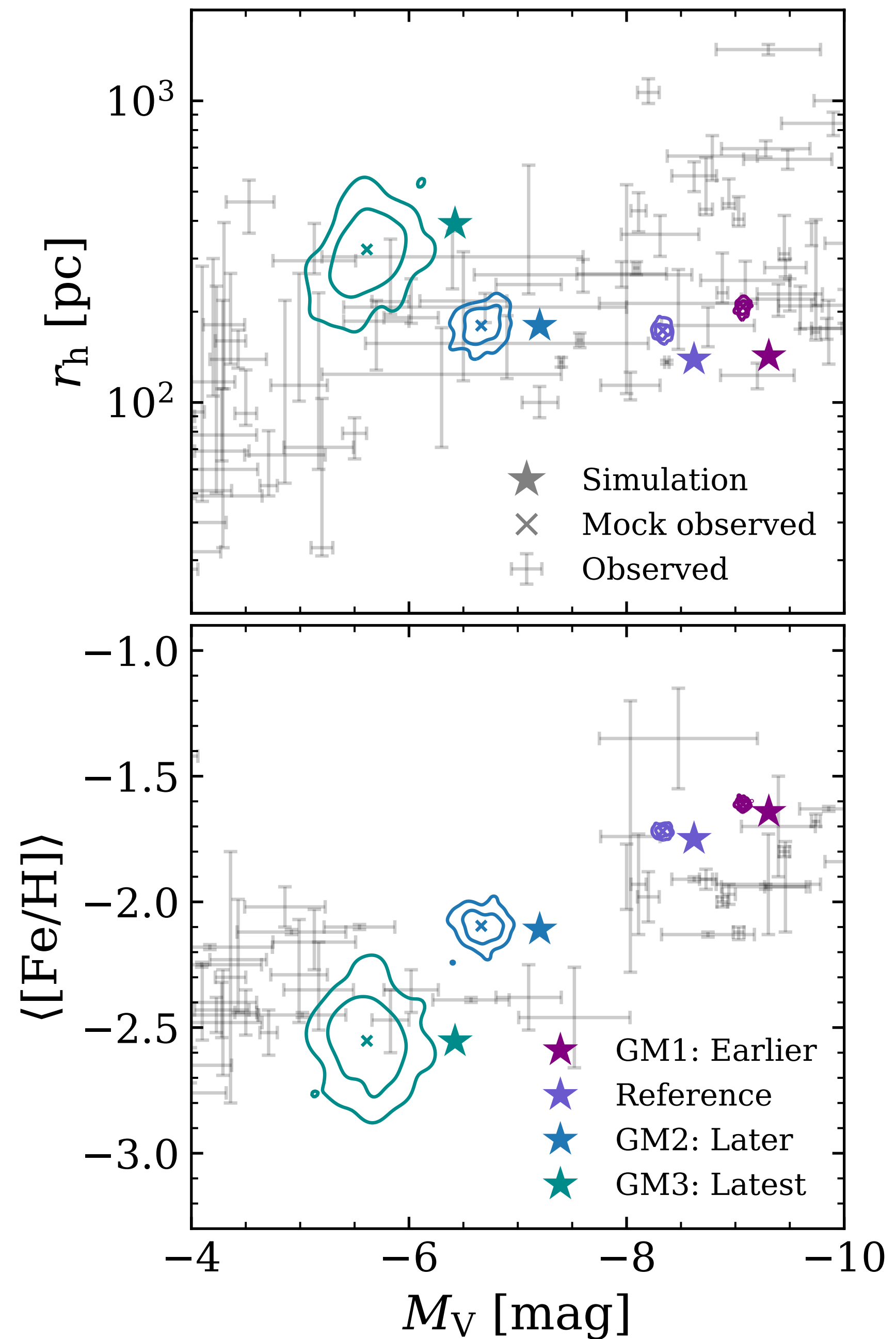
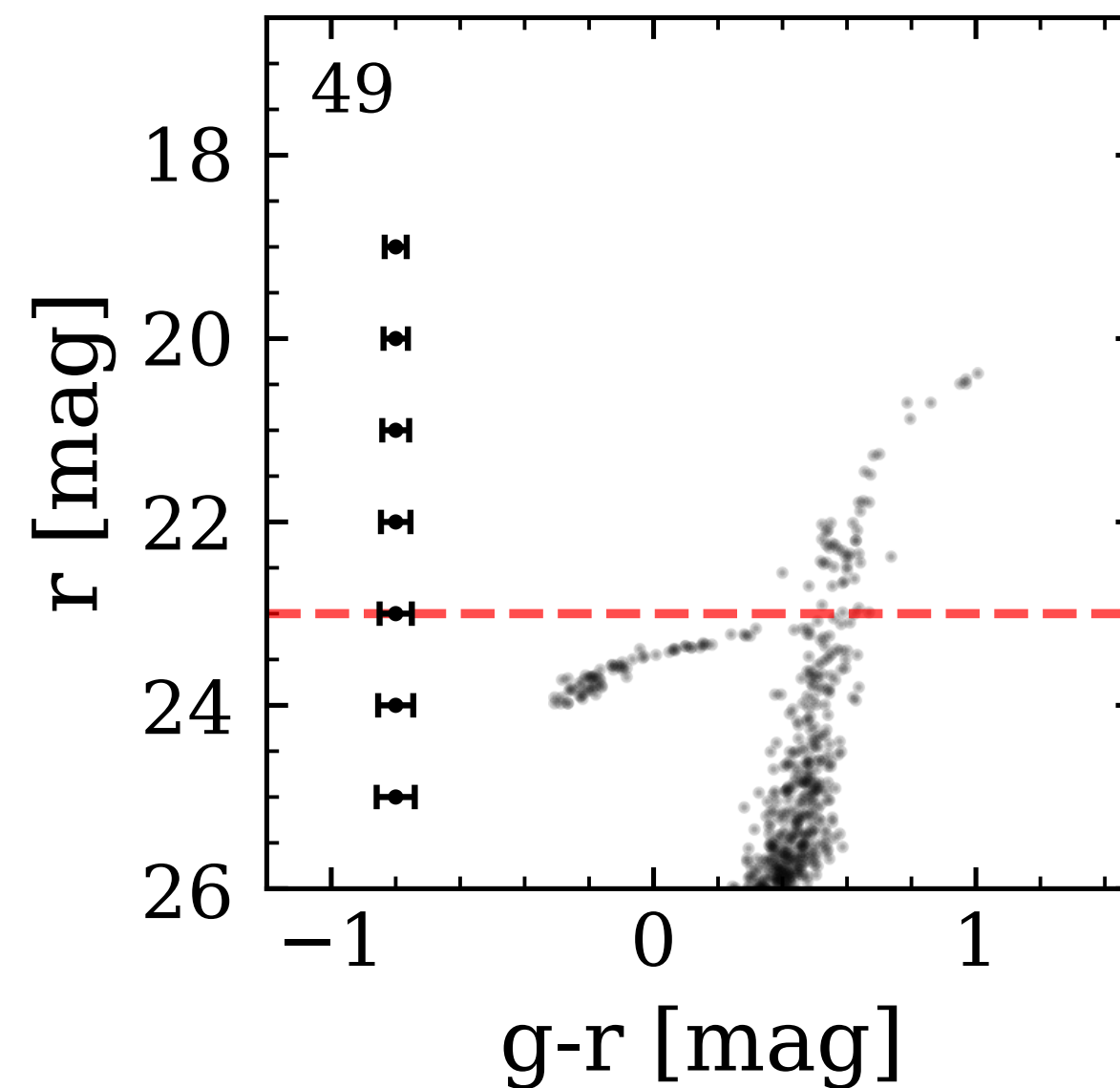
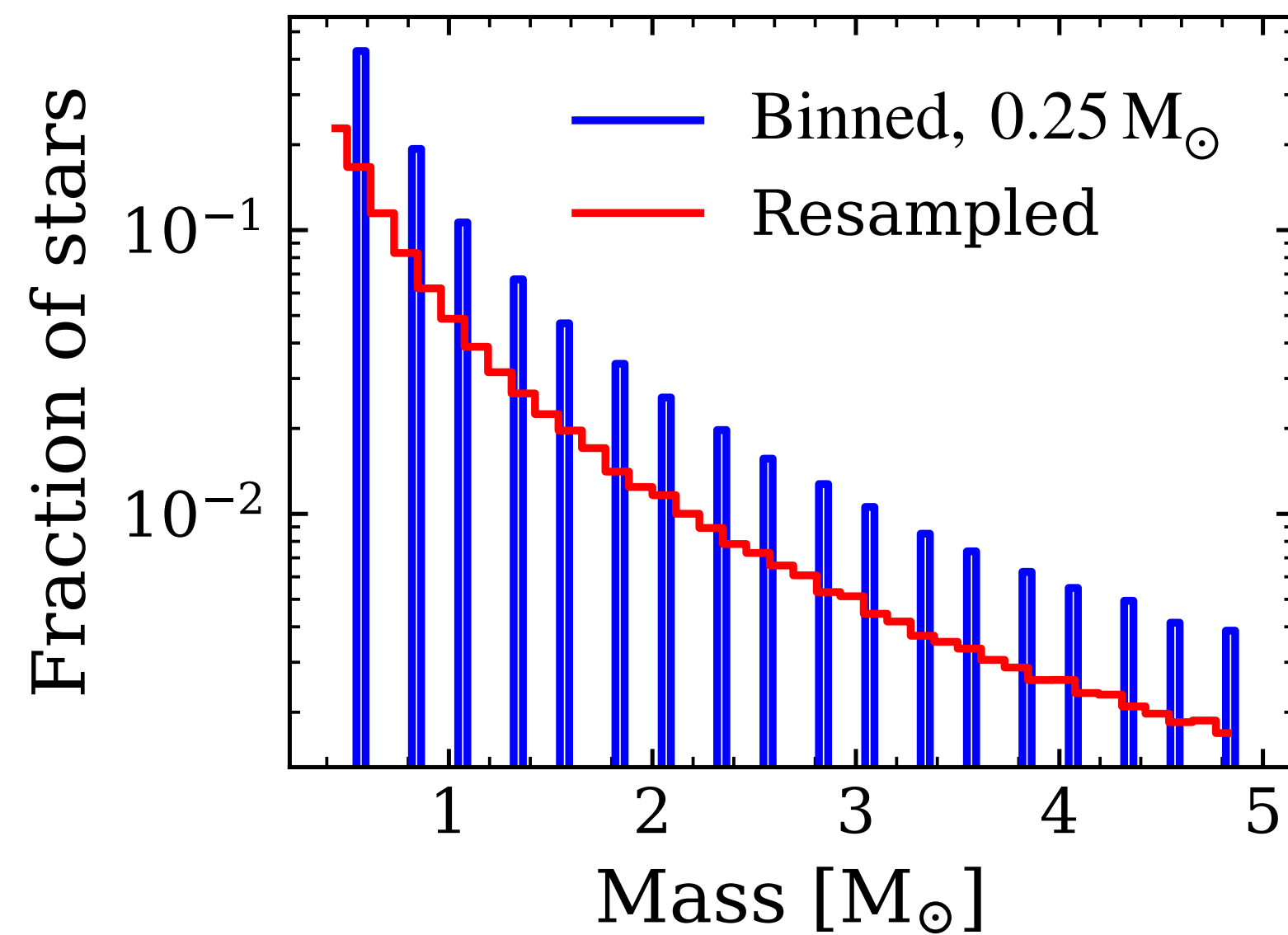
- ▶ Systematically underestimate magnitudes
- ▶ Extended light profile (halo stars)  
*see also Goater et al. (2023)*



# DIRECT COMPARISONS WITH OBSERVED SYSTEMS

*Andersson et al. (2025)*

- ▶ Systematically underestimate magnitudes
- ▶ Extended light profile (halo stars)  
*see also Goater et al. (2023)*
- ▶ Mass-metallicity relation
- ▶ CMD shot noise (IMF sampling)





# GALAXY SIMULATIONS WITH INDIVIDUAL STARS & THE FORMATION OF THE SMALLEST GALAXIES

👁 Star-by-star models are important for next generation of simulations!

- IMF sampling important at  $\lesssim 500 M_{\odot}$  stellar resolution
- Is star-by-star feedback weaker?

👁 Direct comparisons with observed stars:

- Extended, halo-like stellar populations in dwarf galaxies
- How should we compare models and observations?