Image credits: Chandra

EFFICIENT LYC LEAKAGE DUE TO RADIATION-DRIVEN OUTFLOWS IN COMPACT BURSTS

SHYAM MENON

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ESCAPE OF LYMAN RADIATION FROM GALACTIC LABYRINTHS

12 APRIL 2025

Collaborators: Blakesley Burkhart, Rachel Somerville, Todd Thompson, Mark Krumholz, Christoph Federrath, Lachlan Lancaster, Avishai Dekel, Amiel Sternberg

RUTGERS UNIVERSITY

FLATIRON INSTITUTE

REIONIZATION OF THE UNIVERSE

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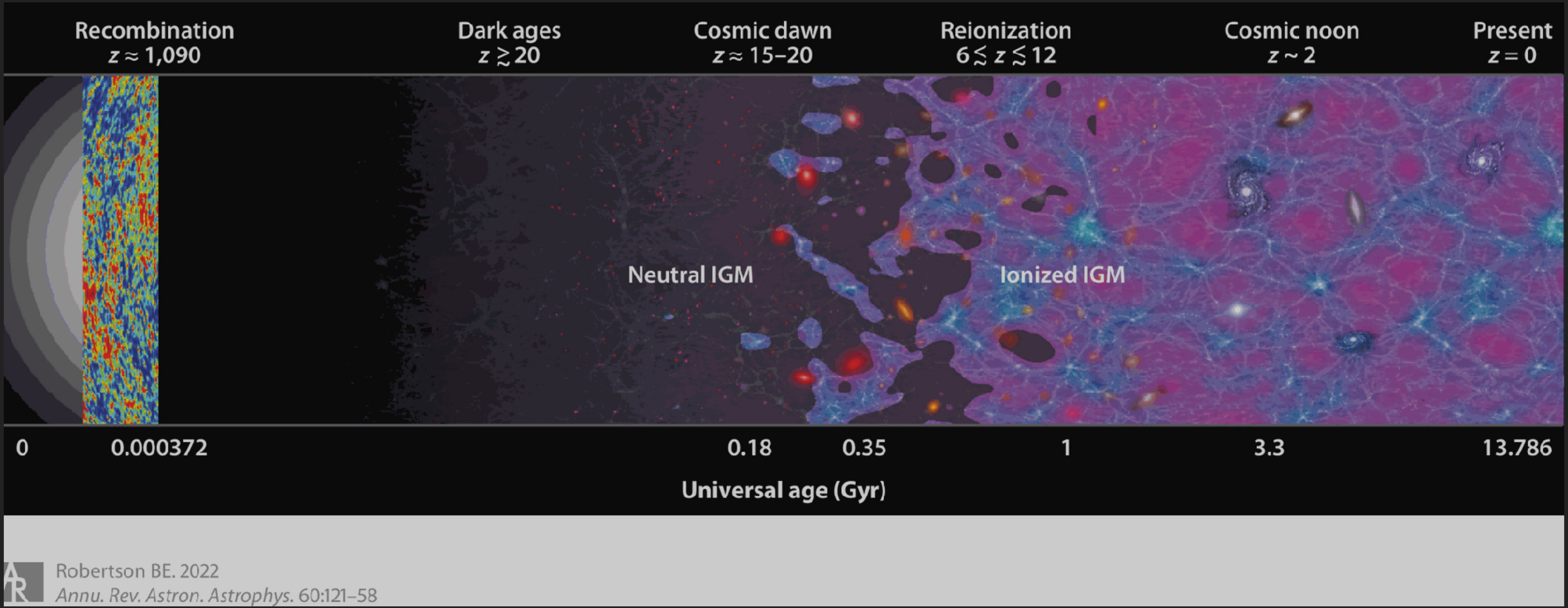
Robertson 2022, ARAA



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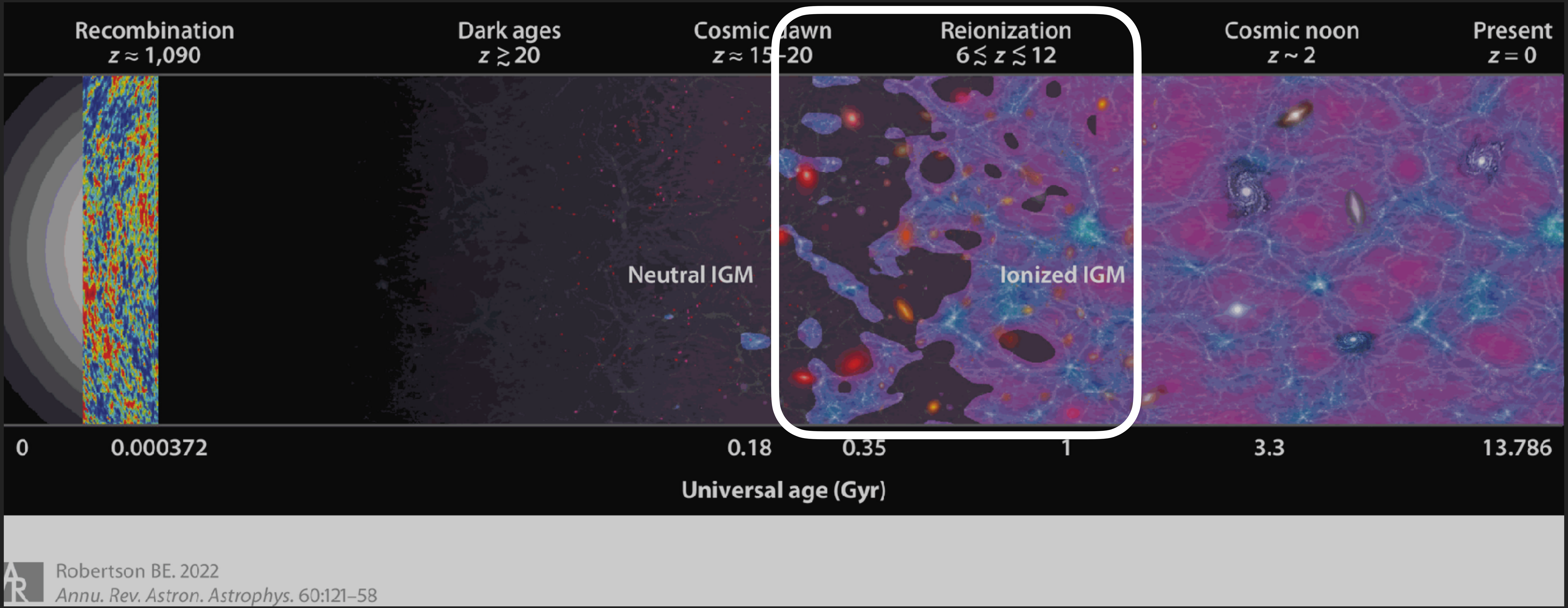

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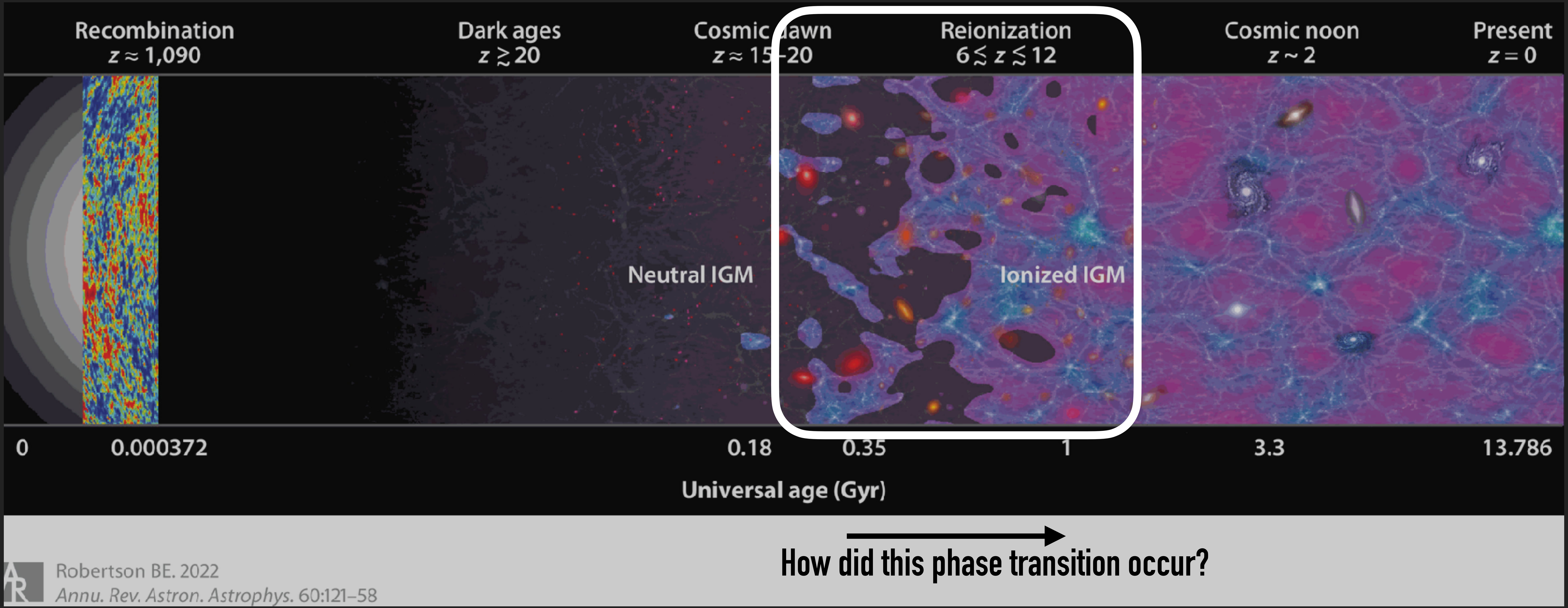

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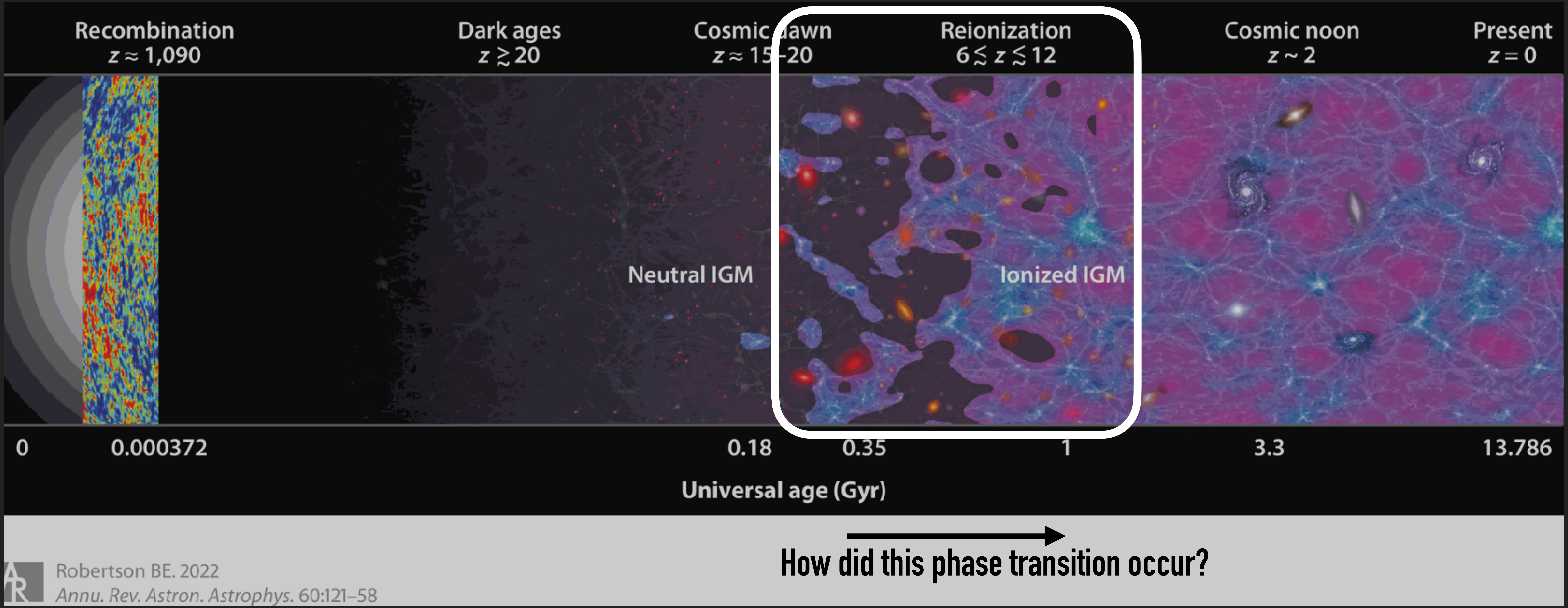

How did this phase transition occur?

$$\dot{n}_{\rm ion}(M_{\rm halo}, z, \ldots.)?$$

LYC ESCAPE A LOCAL PROCESS, POWERED BY MASSIVE STARS/CLUSTERS

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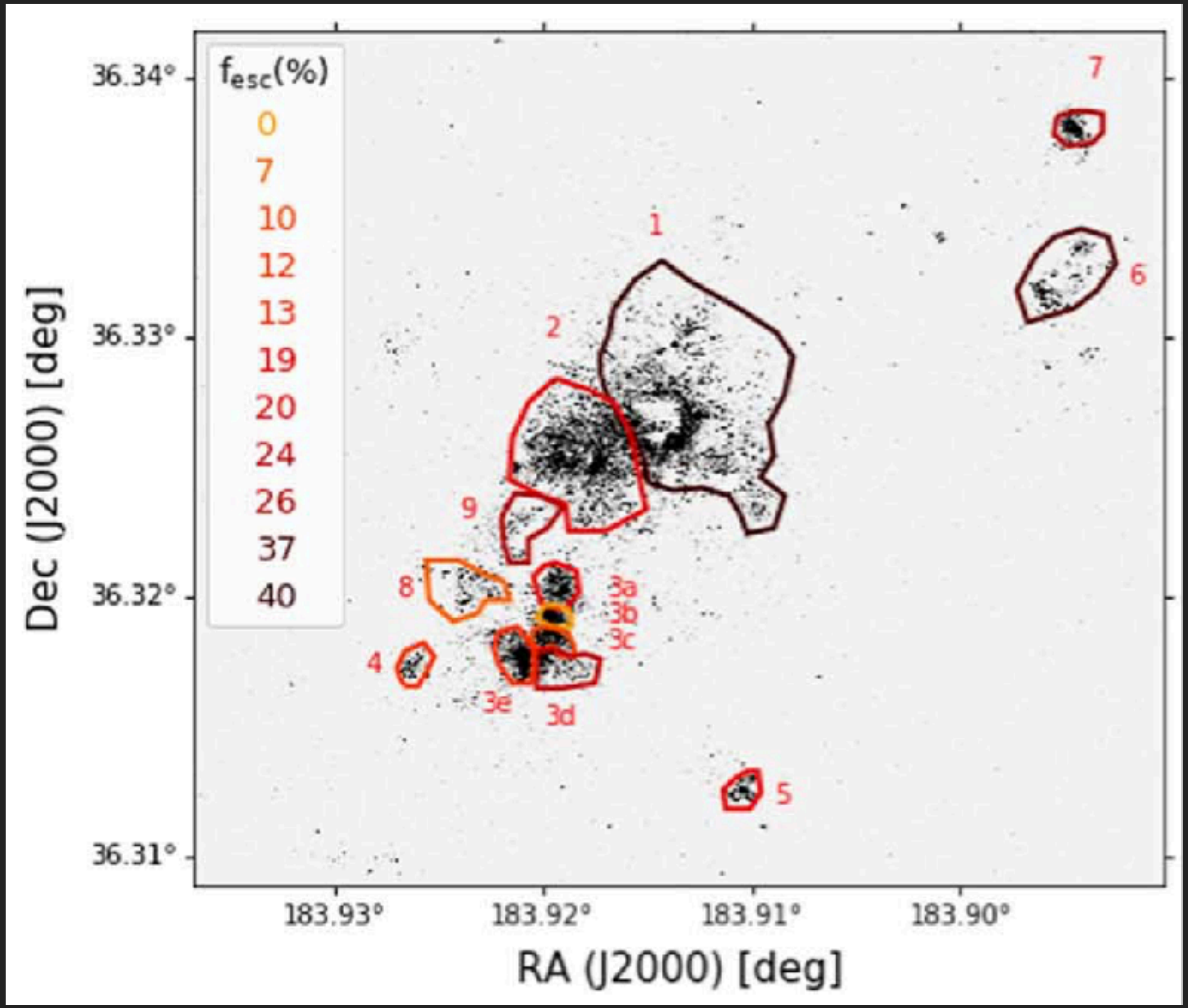
NGC 4214: local dwarf starburst



Choi, Dalcanton et al. 2020

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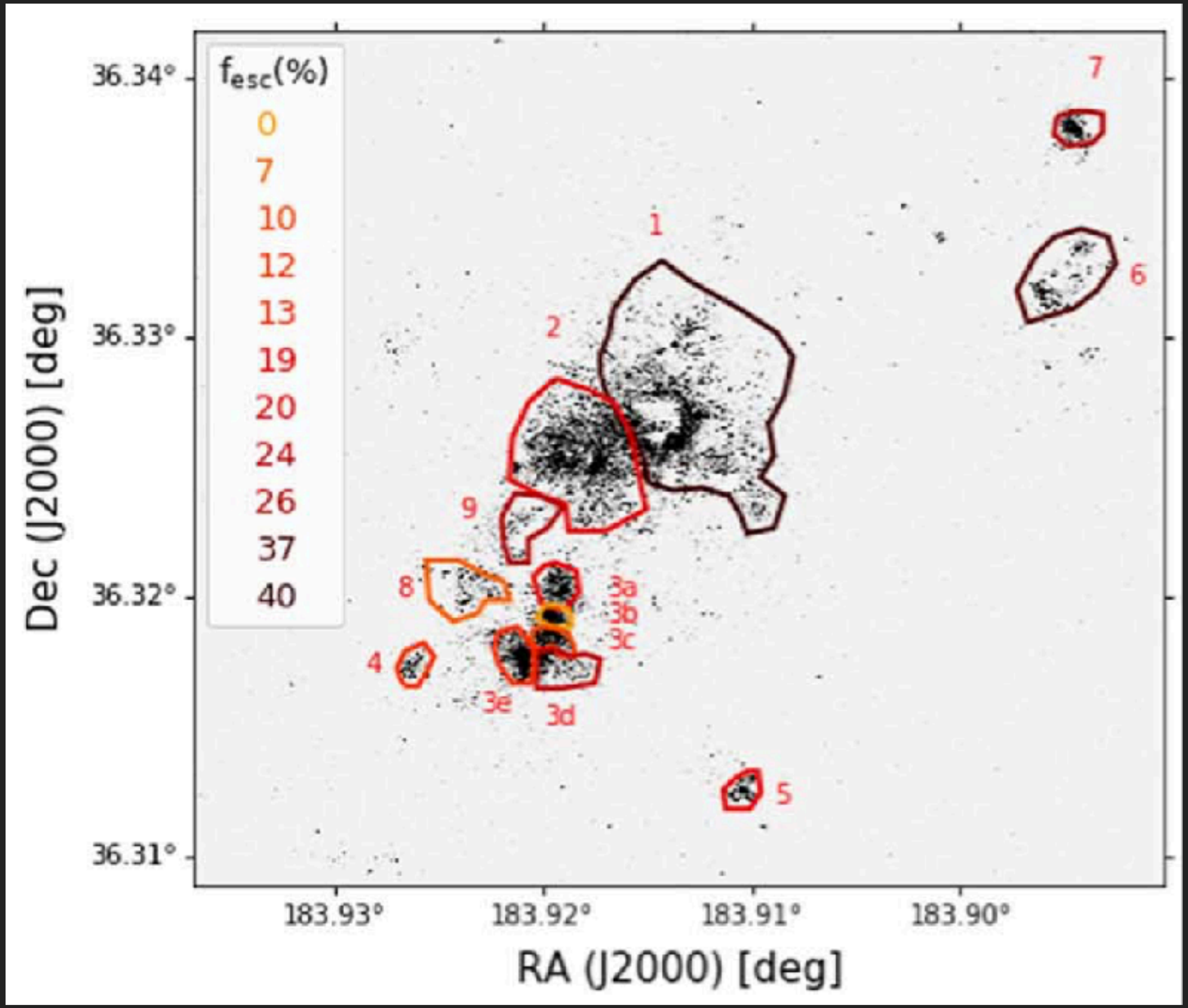

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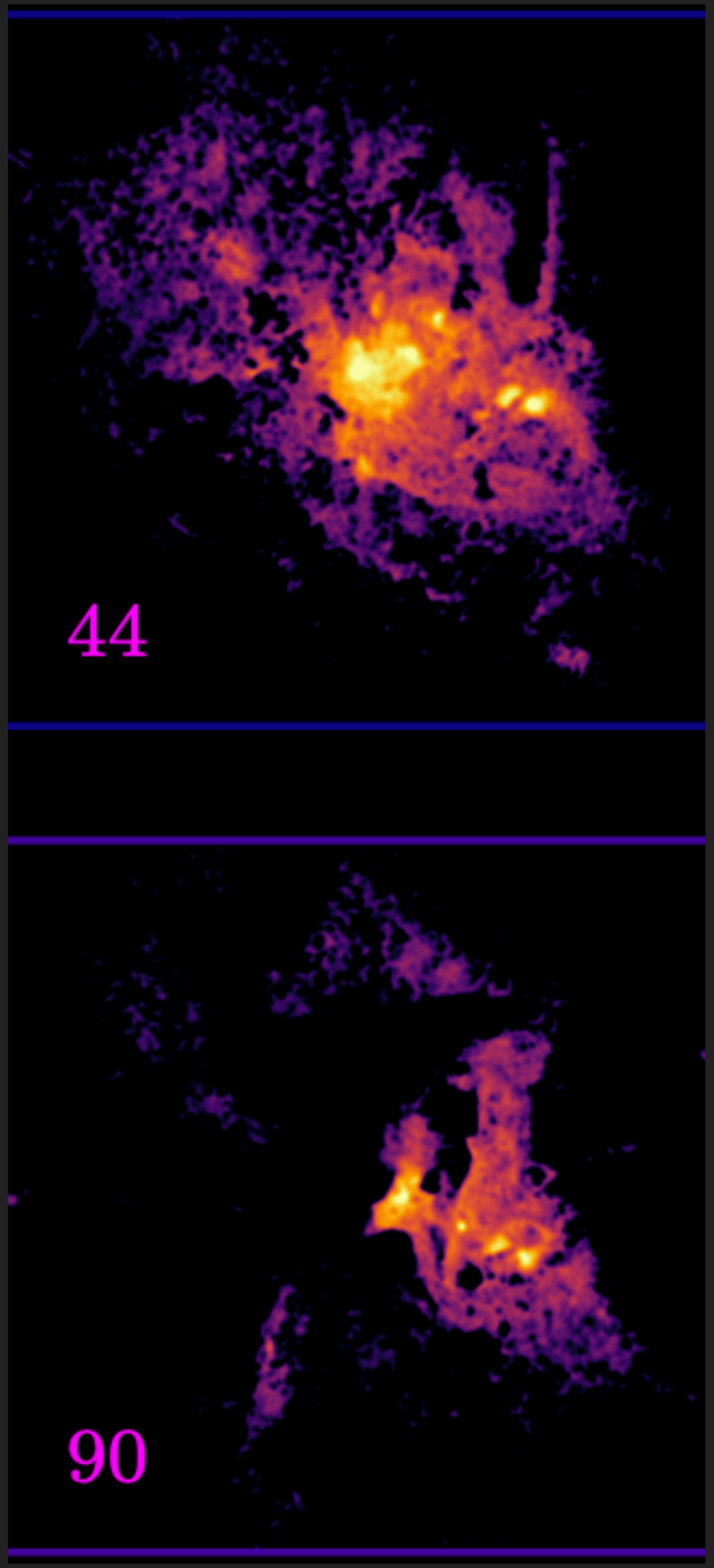
SPHINX simulations



Choustikov+ 24

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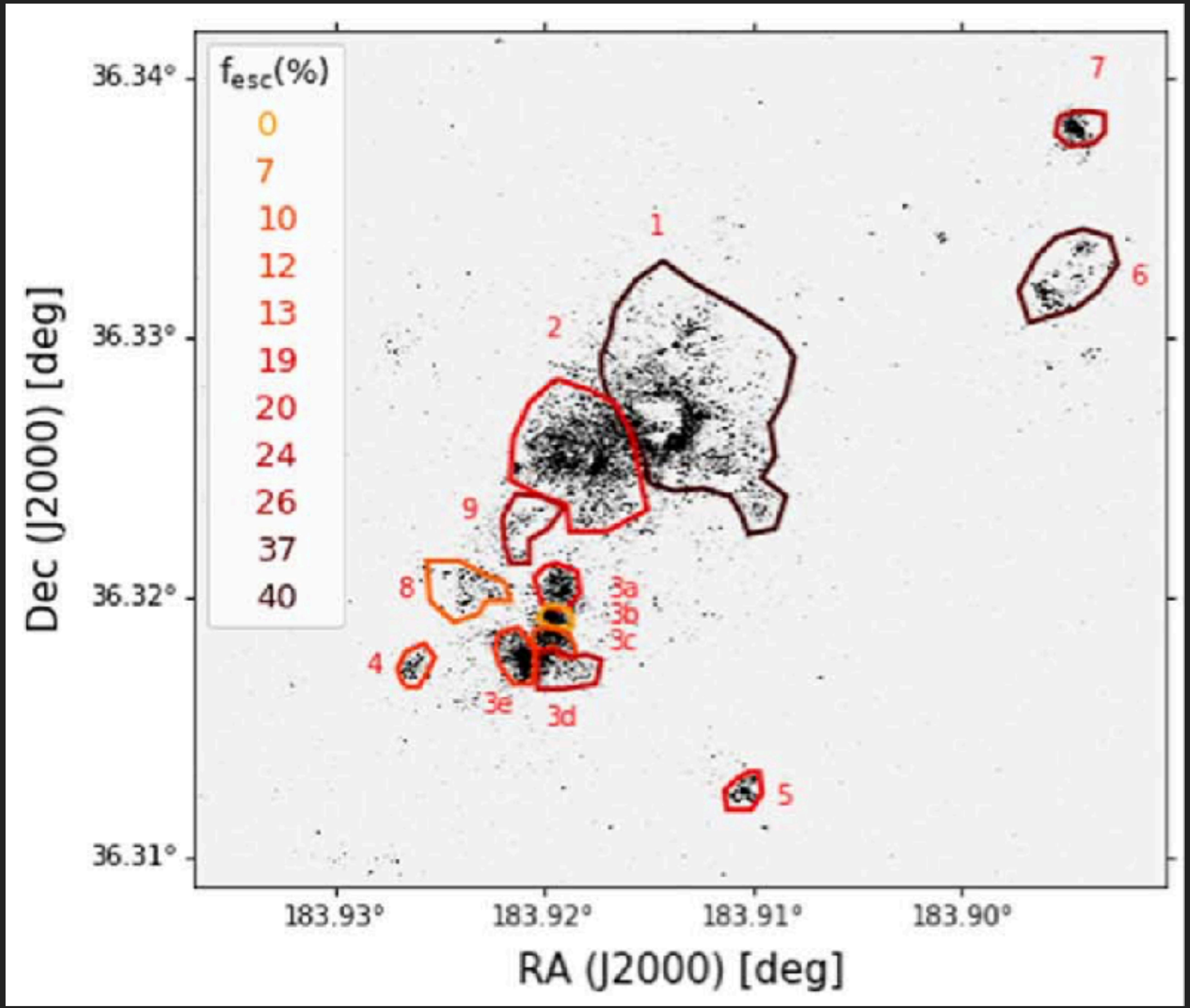

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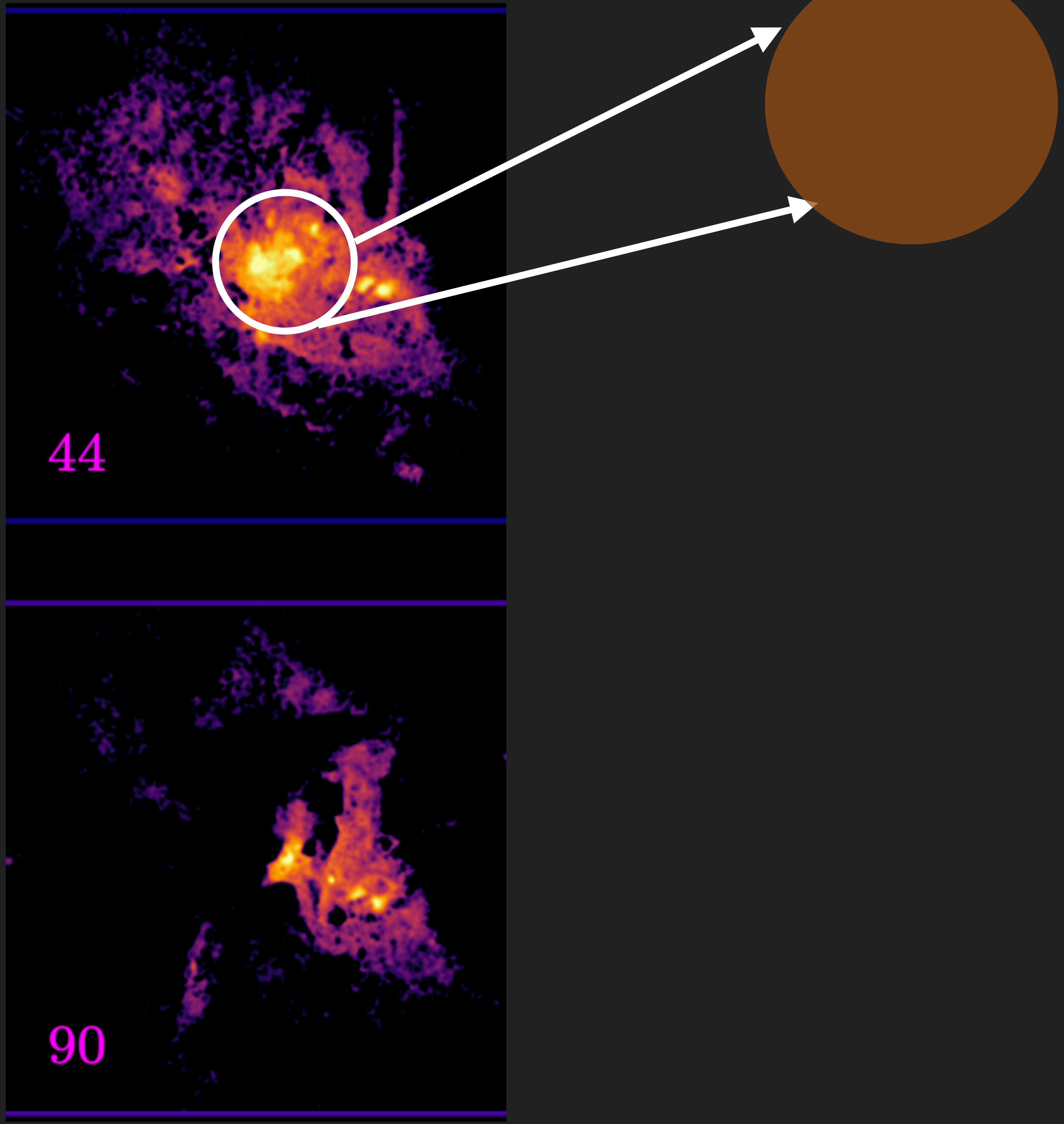

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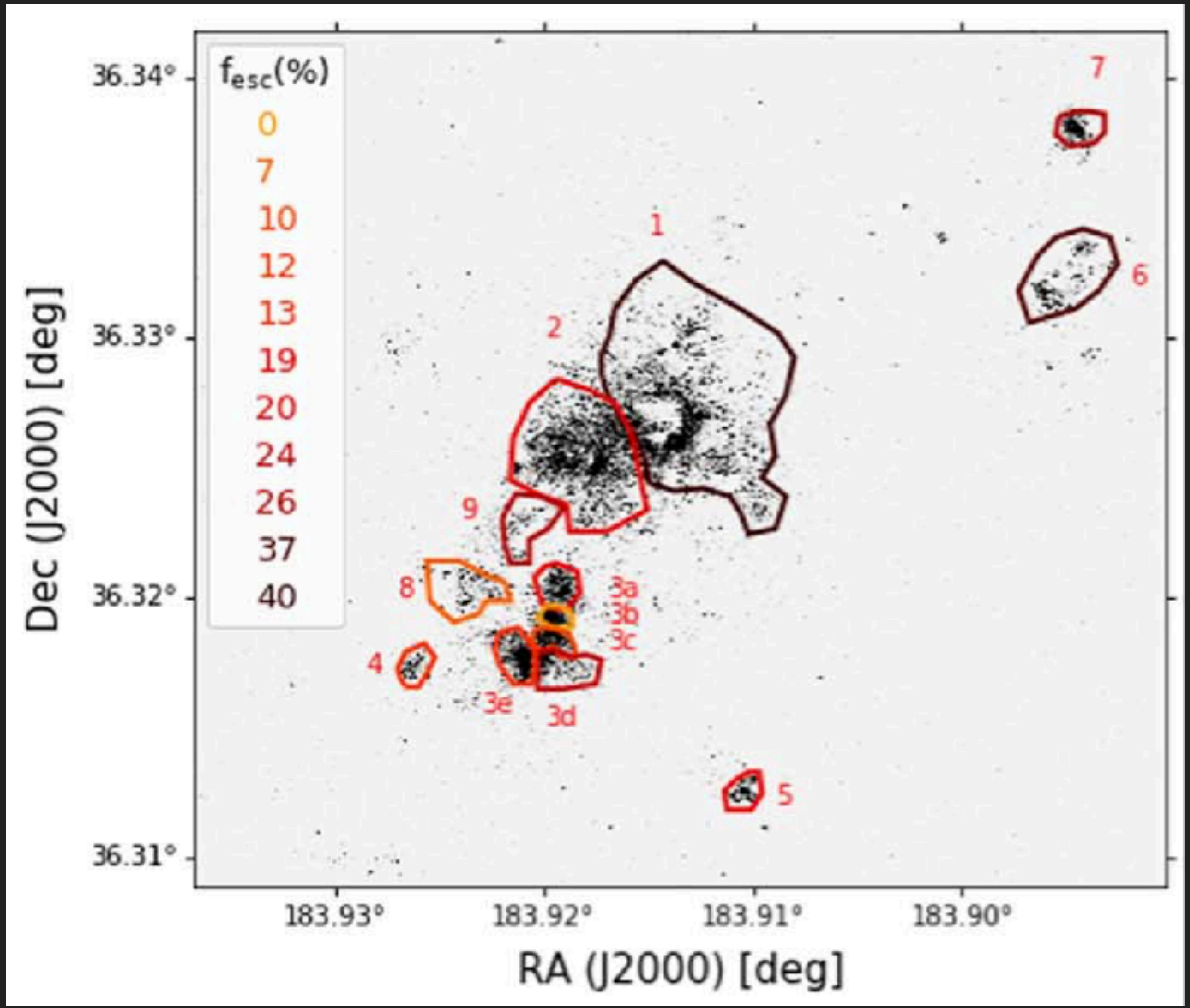

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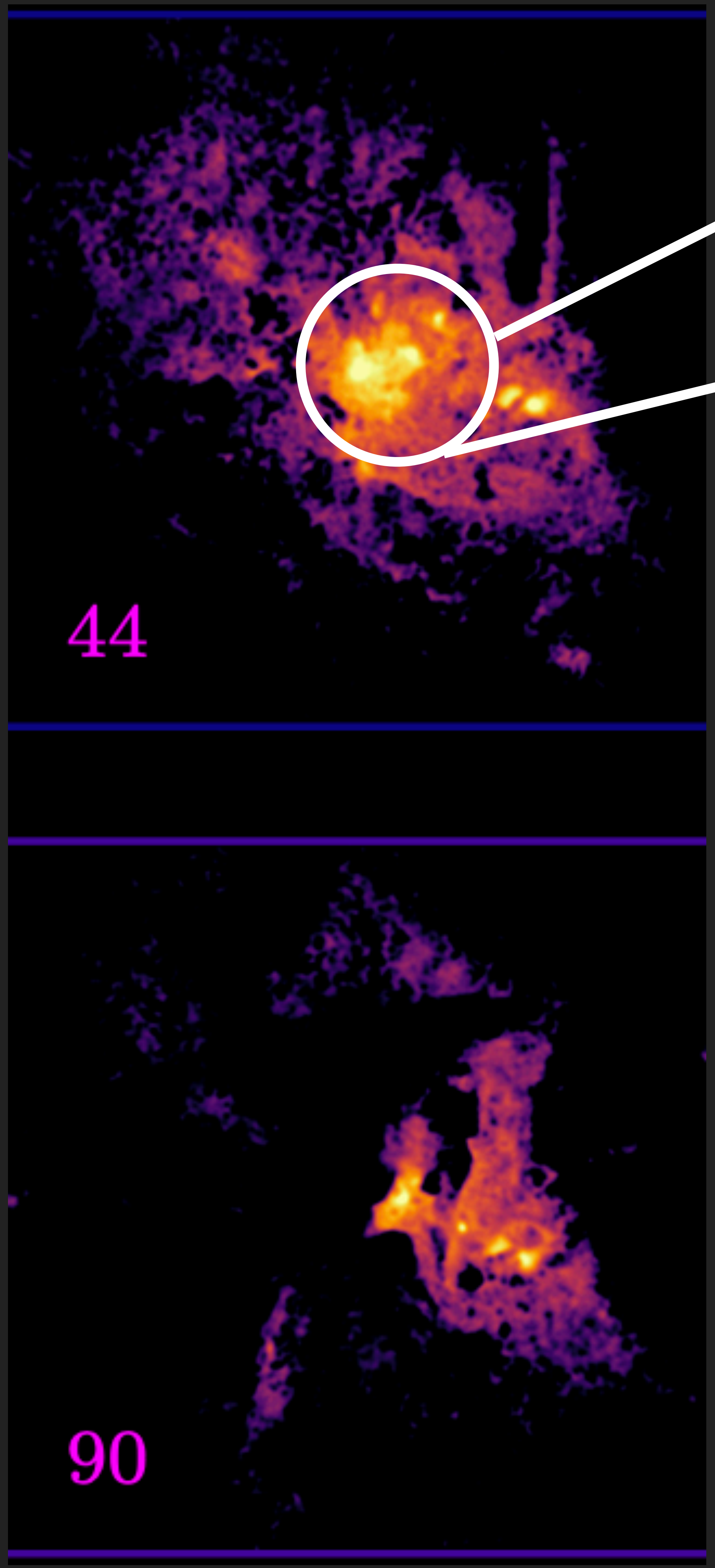

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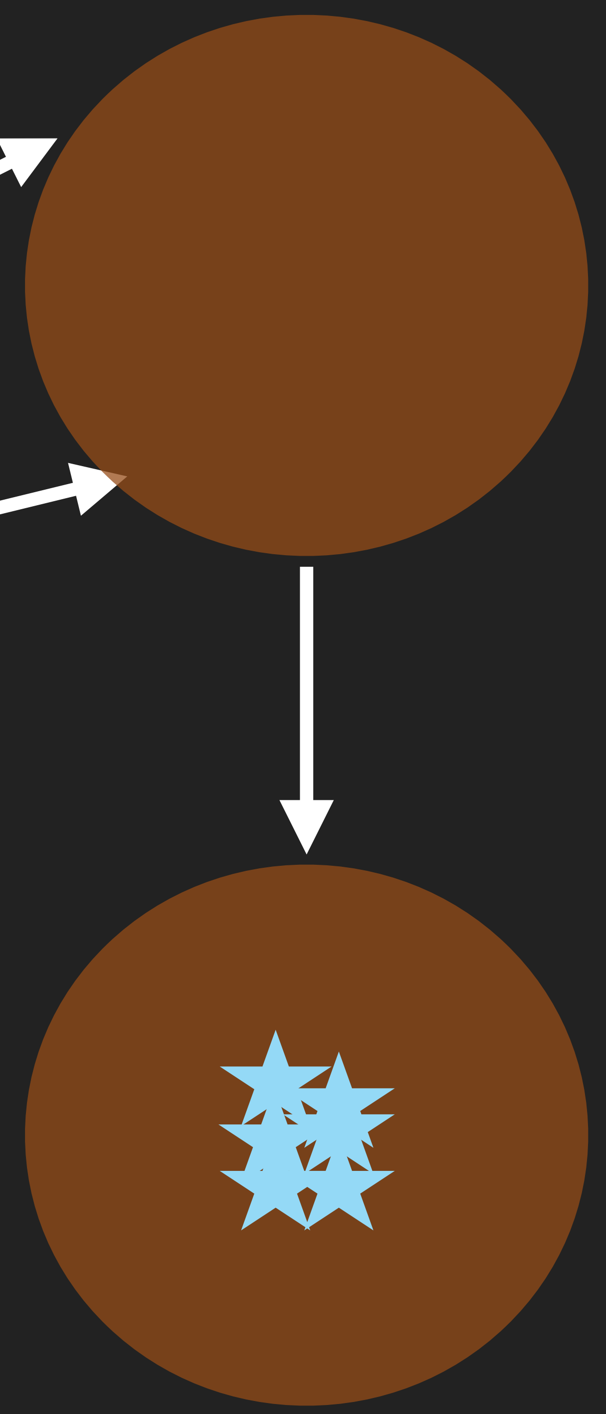

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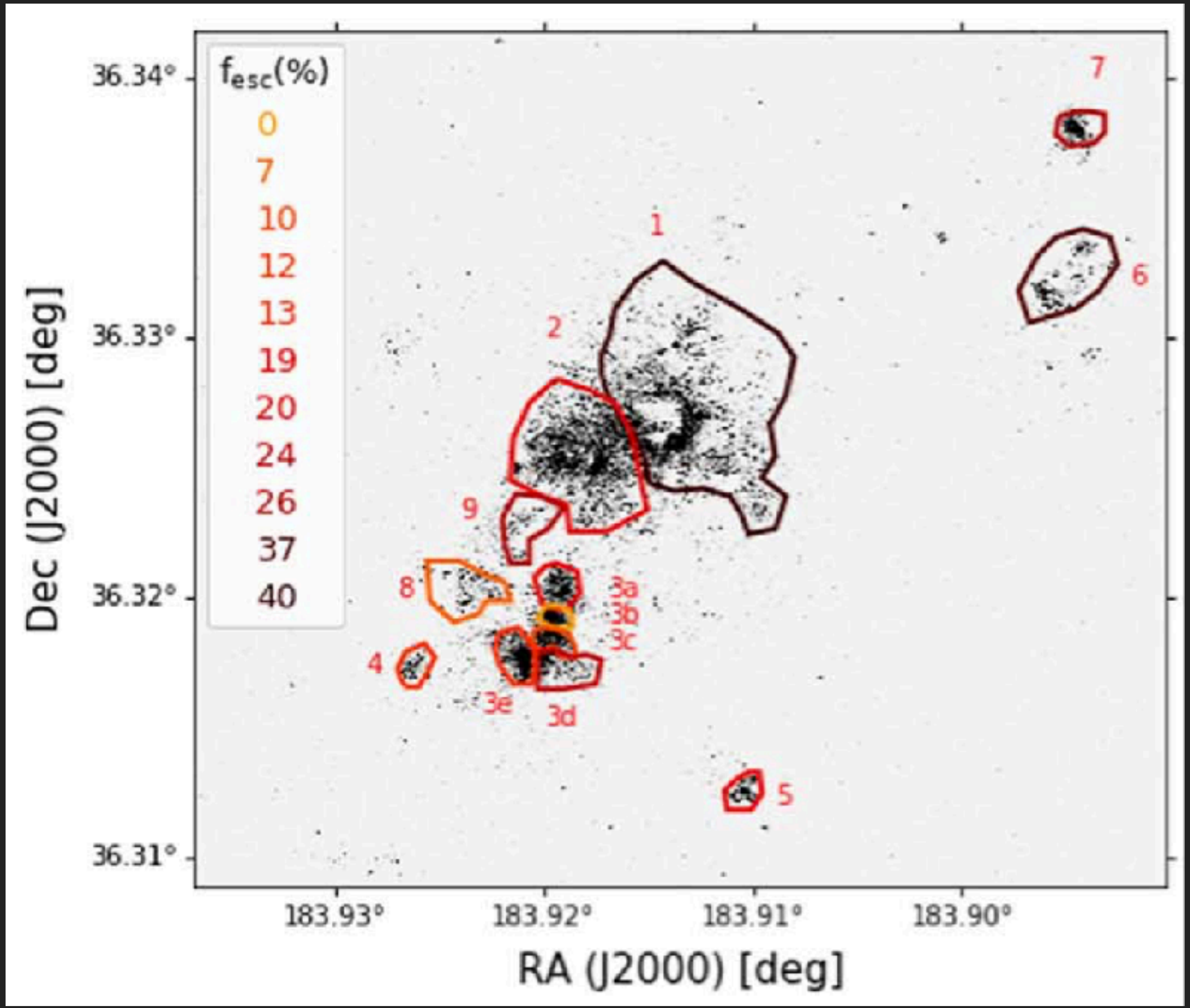

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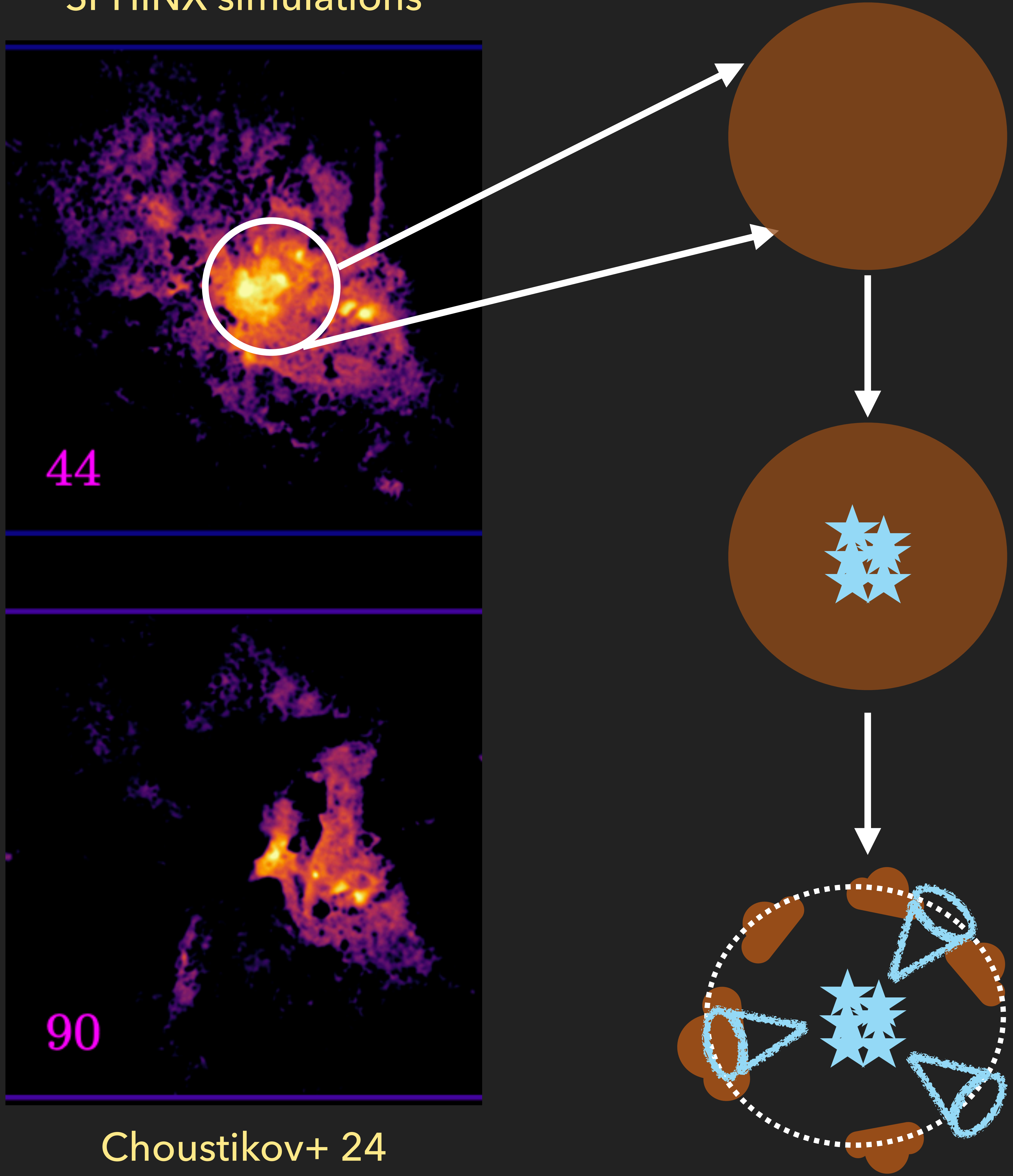

Choustikov+ 24

FEEDBACK–STAR FORMATION INTERPLAY IN THE ISM

Typical local Universe conditions

- Convert ~10 % of gas to stars (Kim+18, Grudic+18, Menon+23)
- Timescales of a 10–20 Myr (Chevance+23)
- Form unbound stellar associations
- Low LyC escape fractions

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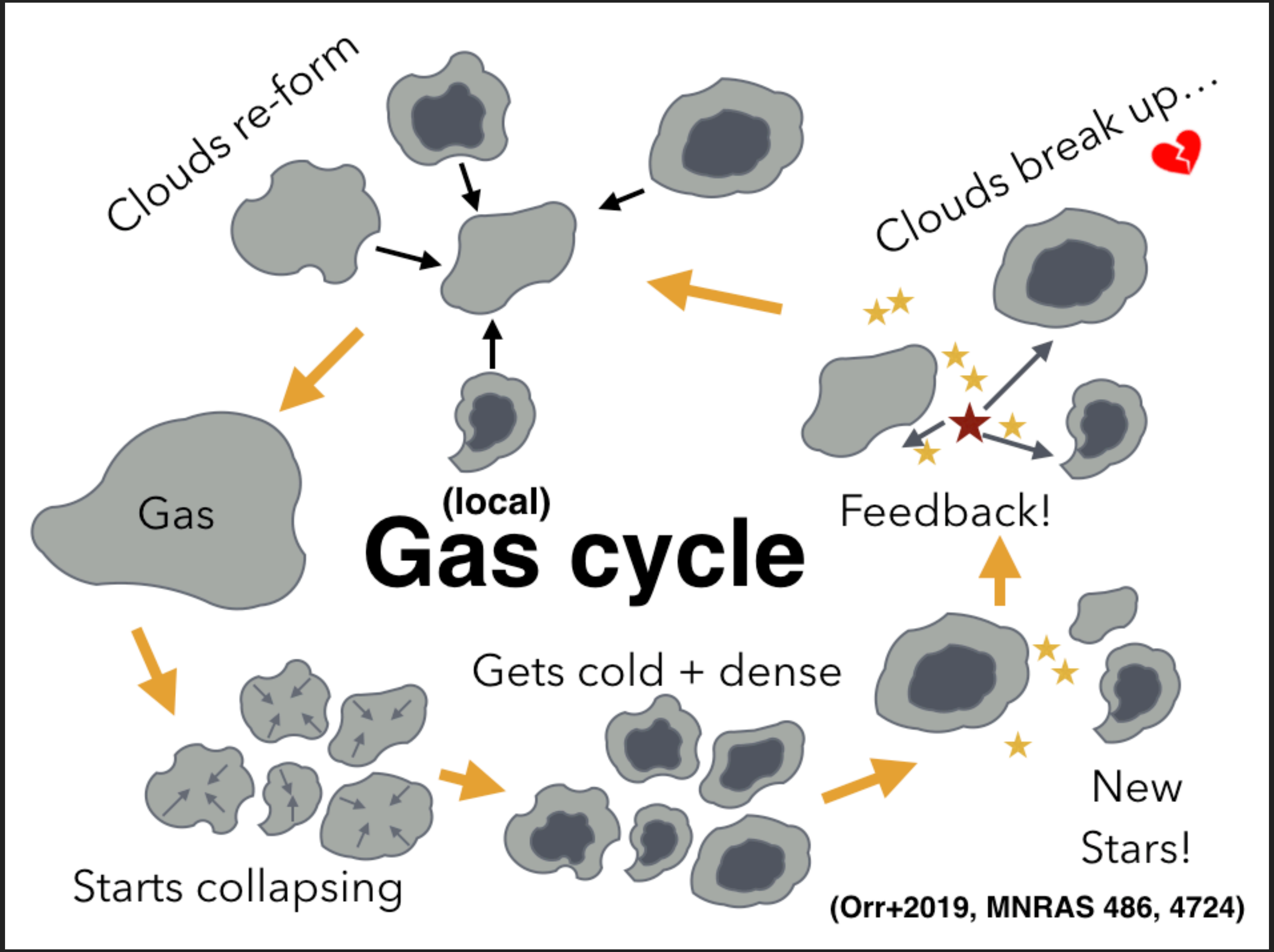

Credits: Matthew Orr

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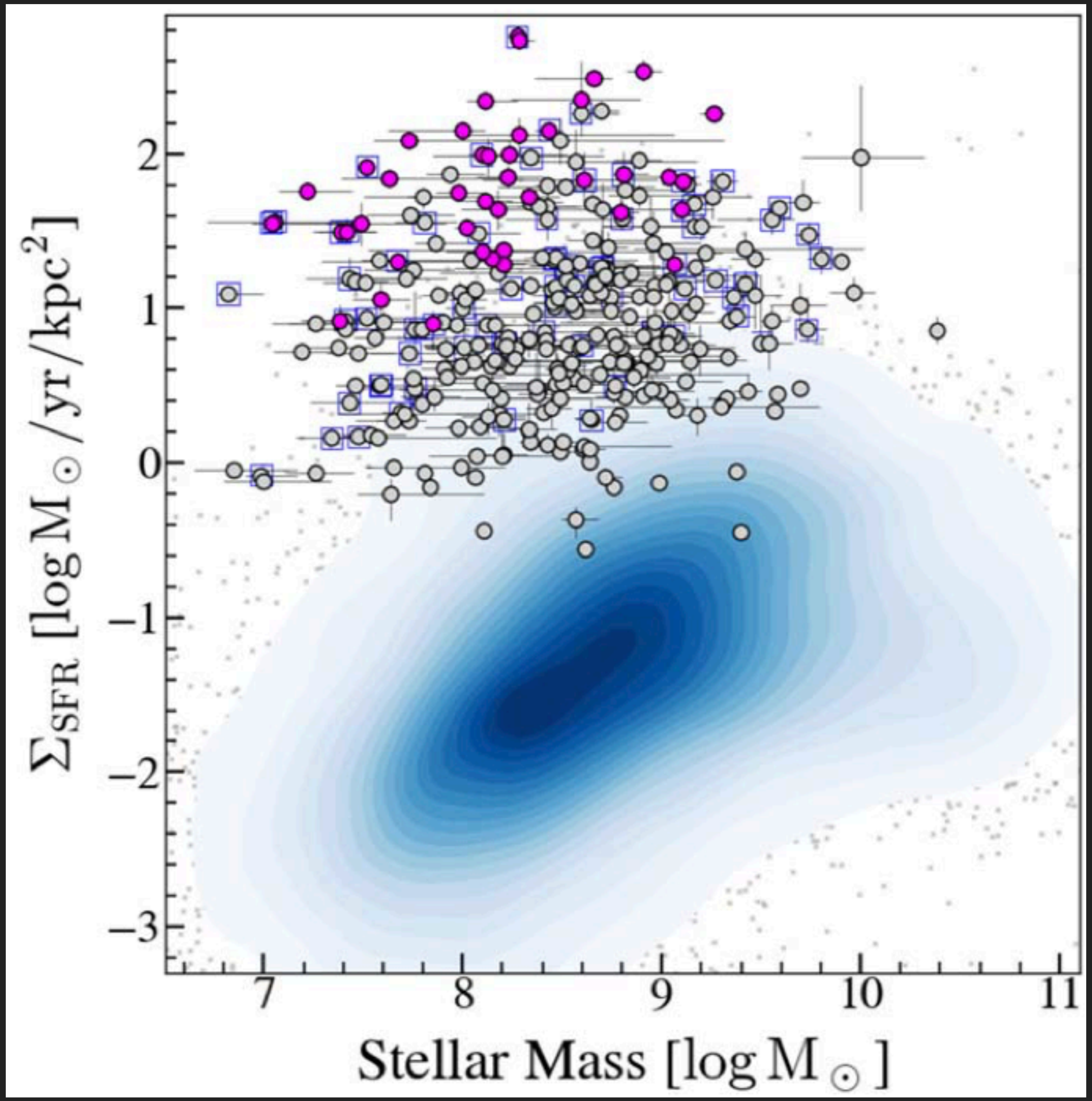
DISTINCT PHYSICAL CONDITIONS AT COSMIC DAWN: DISTINCT STAR CLUSTERS

Early galaxies compact and gas-rich



Morishita et al. 2024

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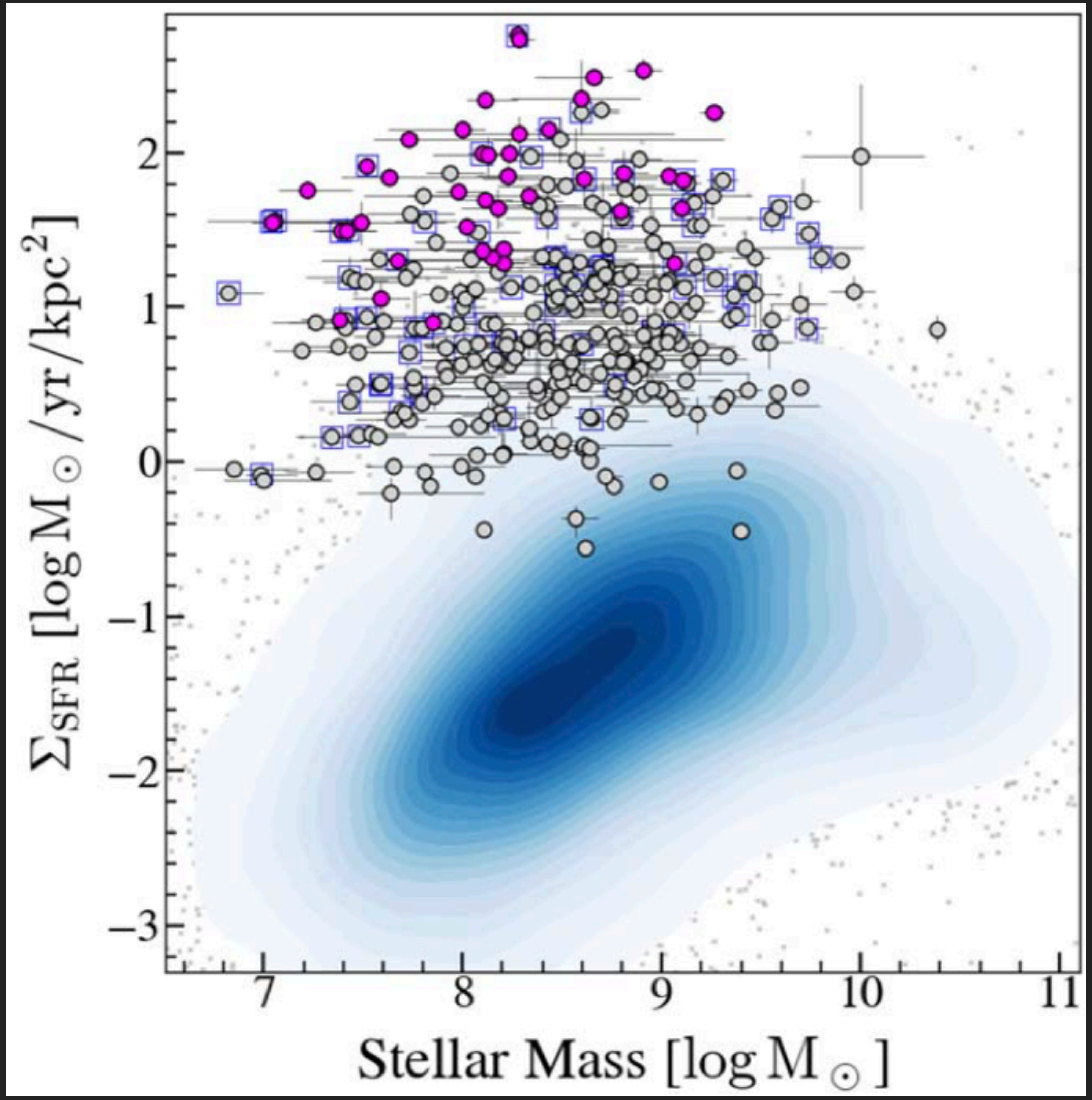
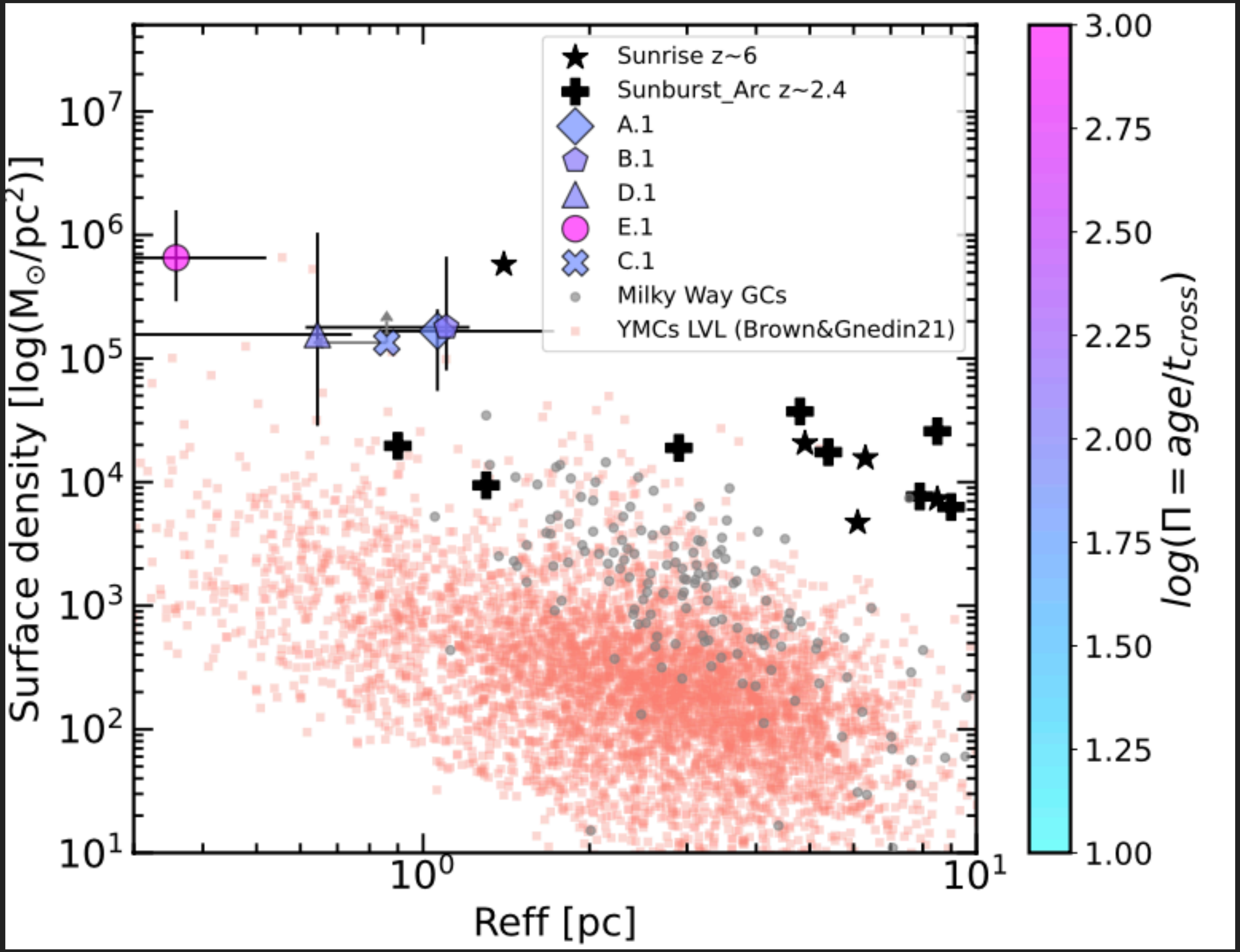


Morishita et al. 2024

Produce highly dense, compact super star clusters



Adamo+2024

IMPLICATIONS OF CHANGING CONDITIONS

$$\Sigma \lesssim 10^2\,\mathrm{M}_\odot\,\mathrm{pc}^{-2} \longrightarrow \Sigma \gtrsim 10^4\,\mathrm{M}_\odot\,\mathrm{pc}^{-2}$$

1. **Deeper potential well: Affects feedback-gravity competition**

2. **Higher escape speed: ionization insufficient**

3. **Shorter dynamical times: timing of LyC escape**

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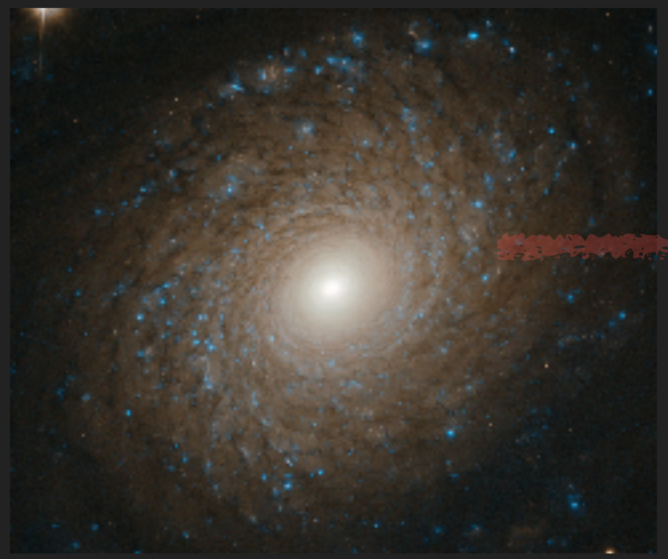

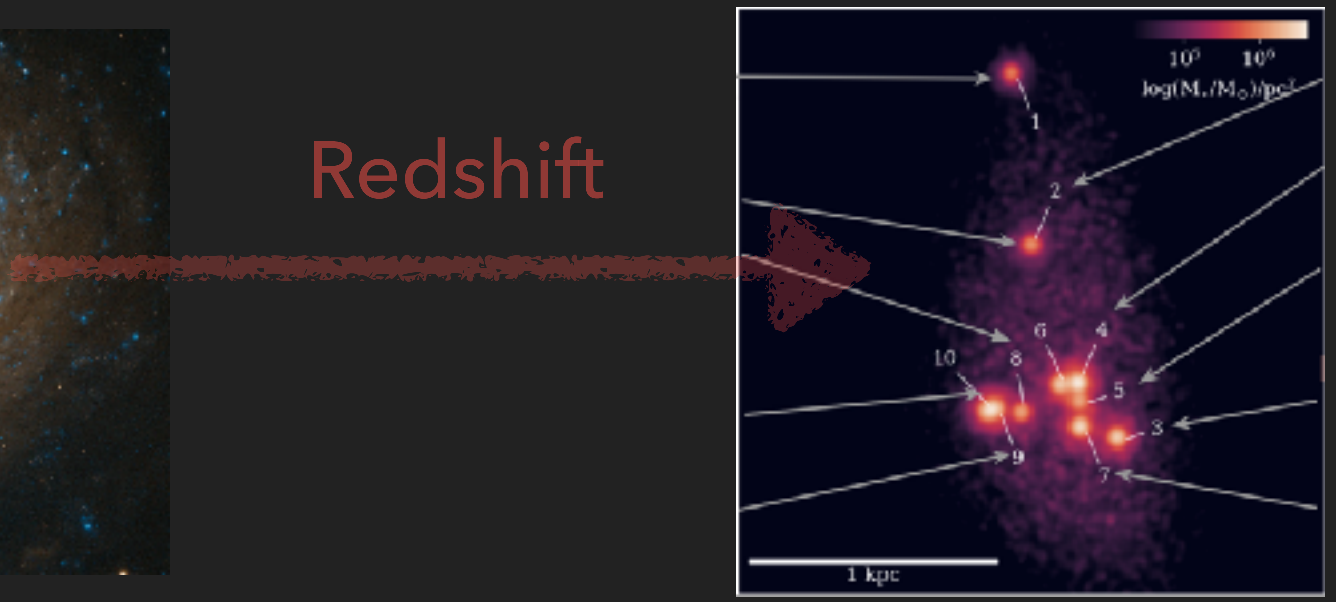

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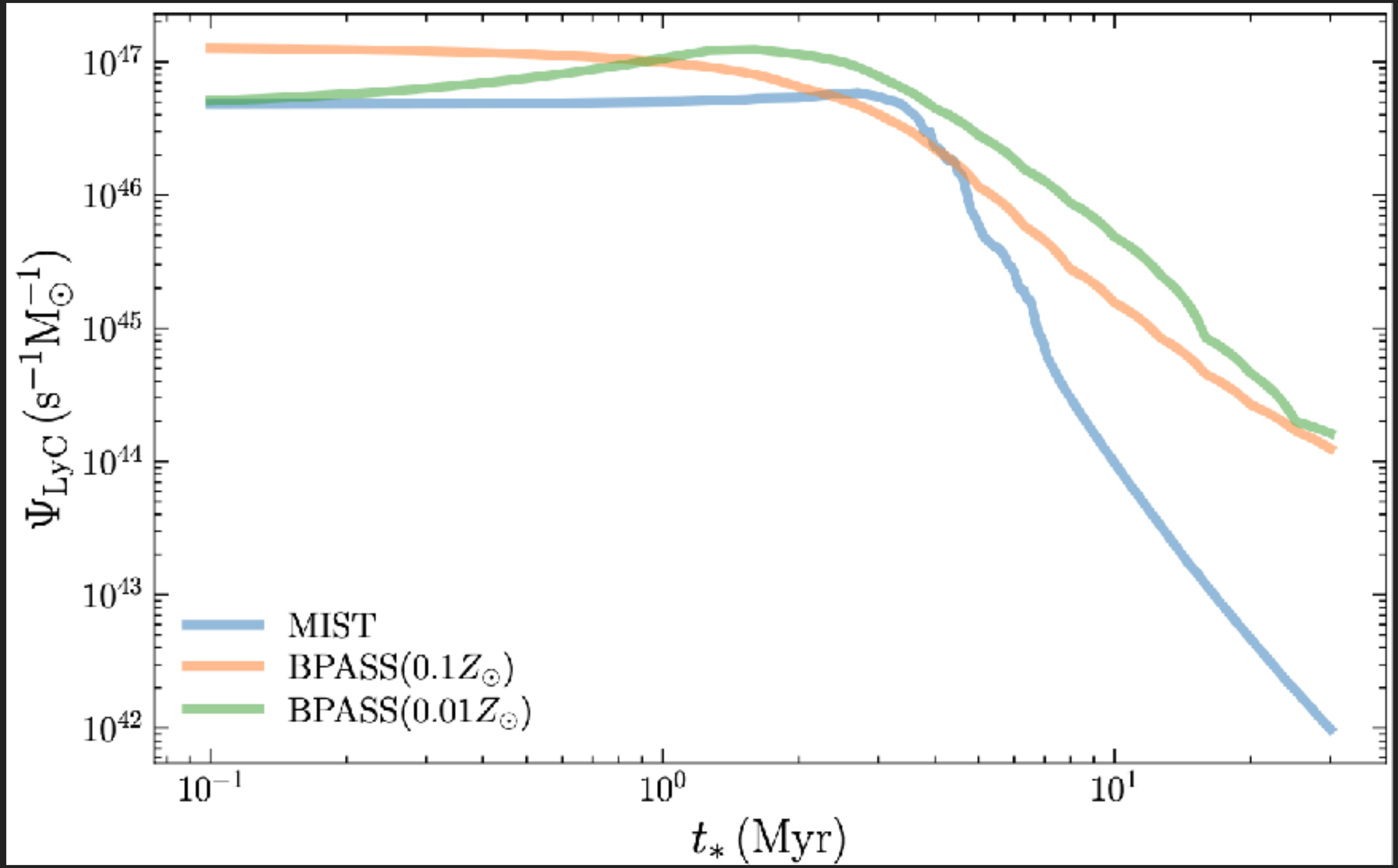
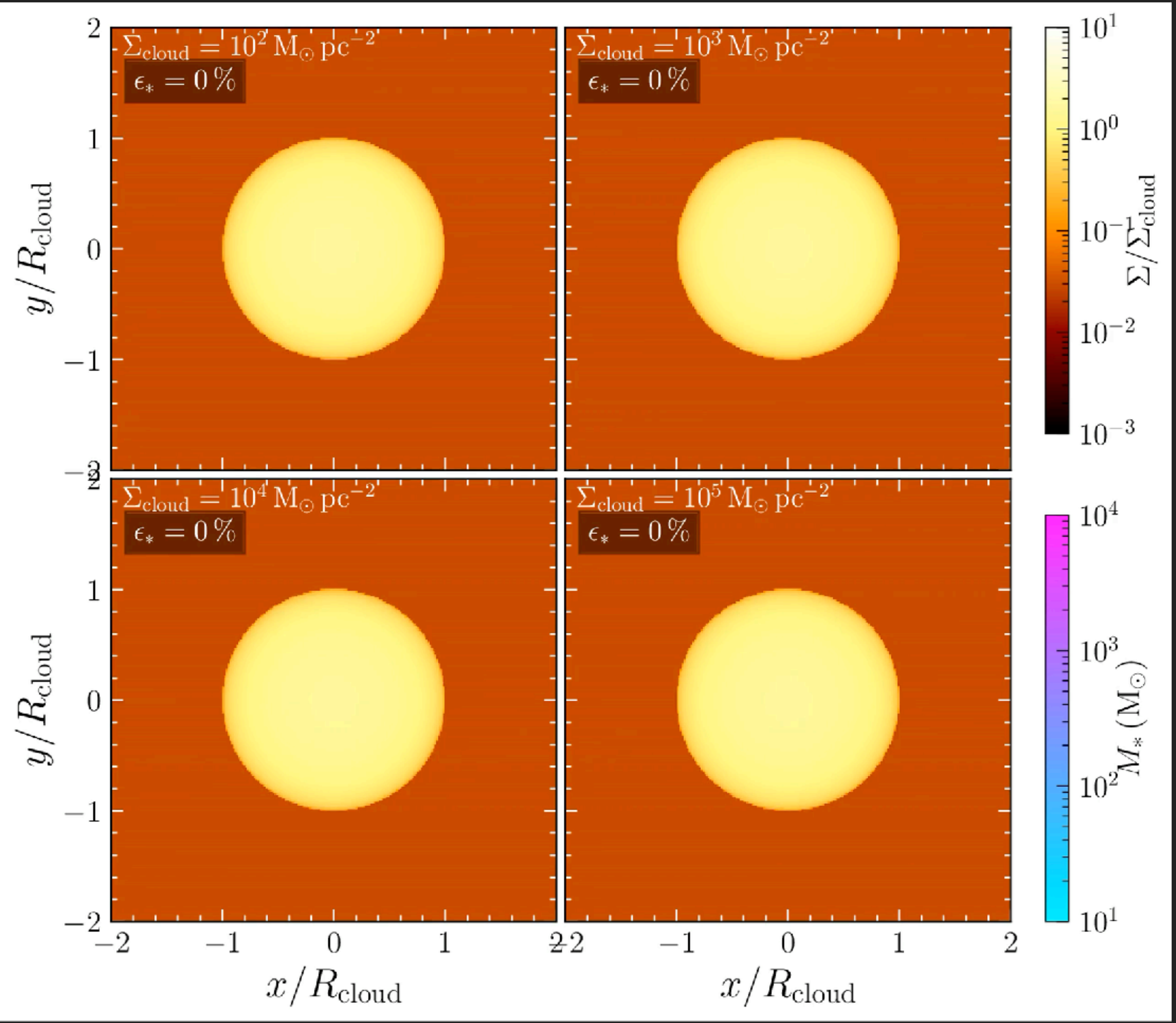
LyC emission drops after ~ few Myrs



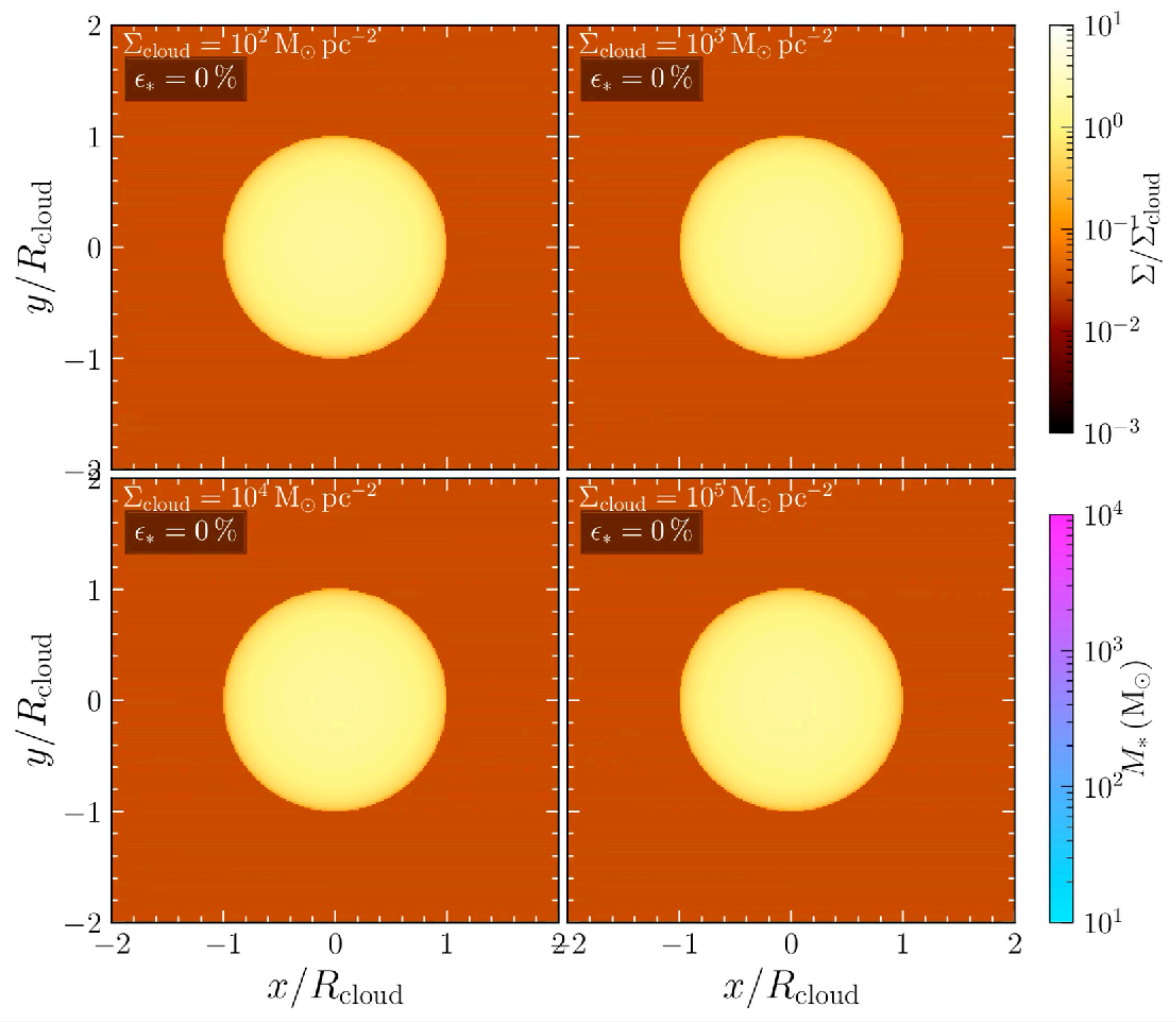
Menon+ 24

RADIATION HYDRODYNAMIC SIMULATIONS OF CLUSTER-FORMING ENVIRONMENTS



RADIATION HYDRODYNAMIC SIMULATIONS OF CLUSTER-FORMING ENVIRONMENTS

Radiative Feedback in 3 bands: LyC, Far-UV and Dust-reprocessed IR.



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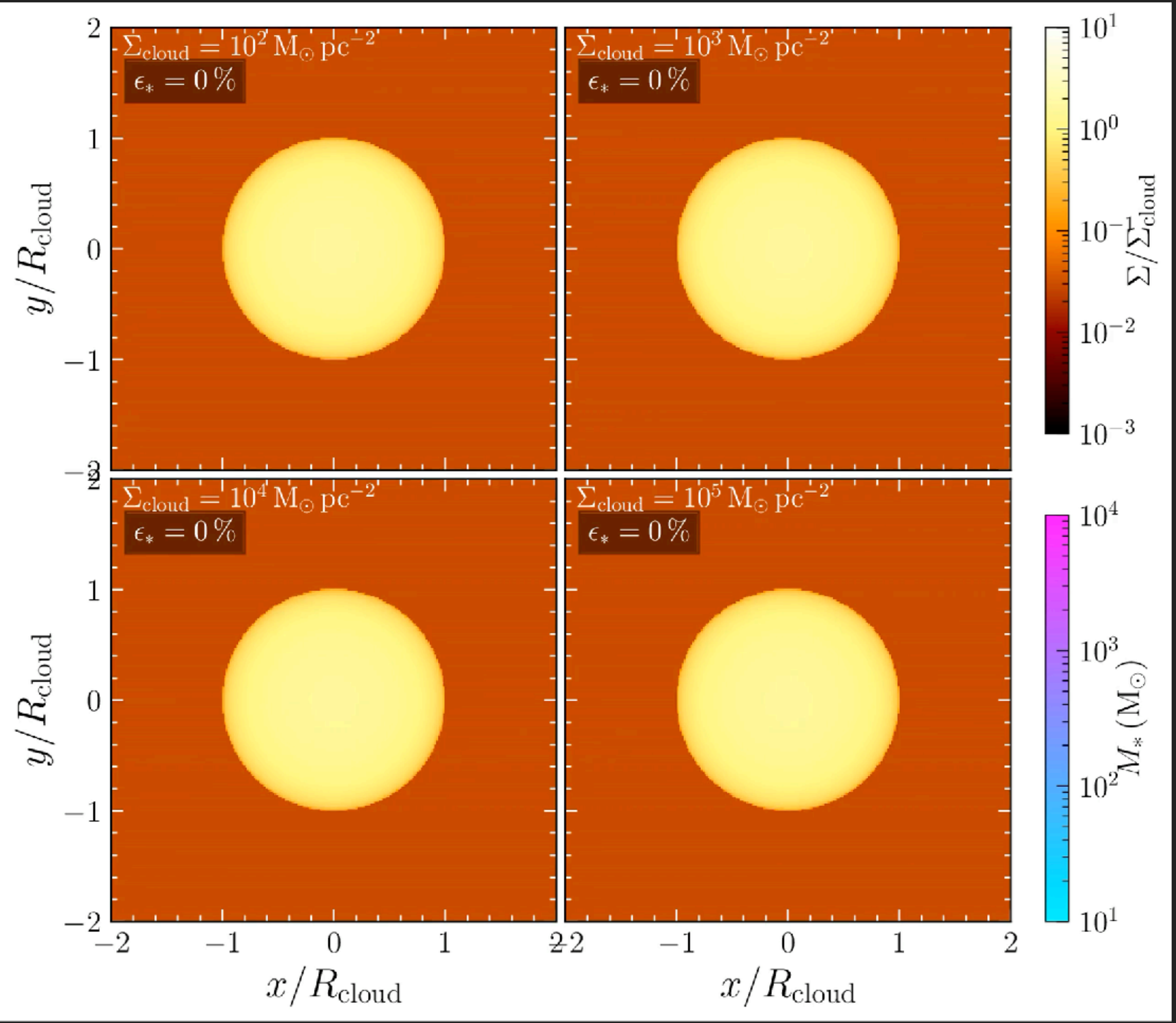

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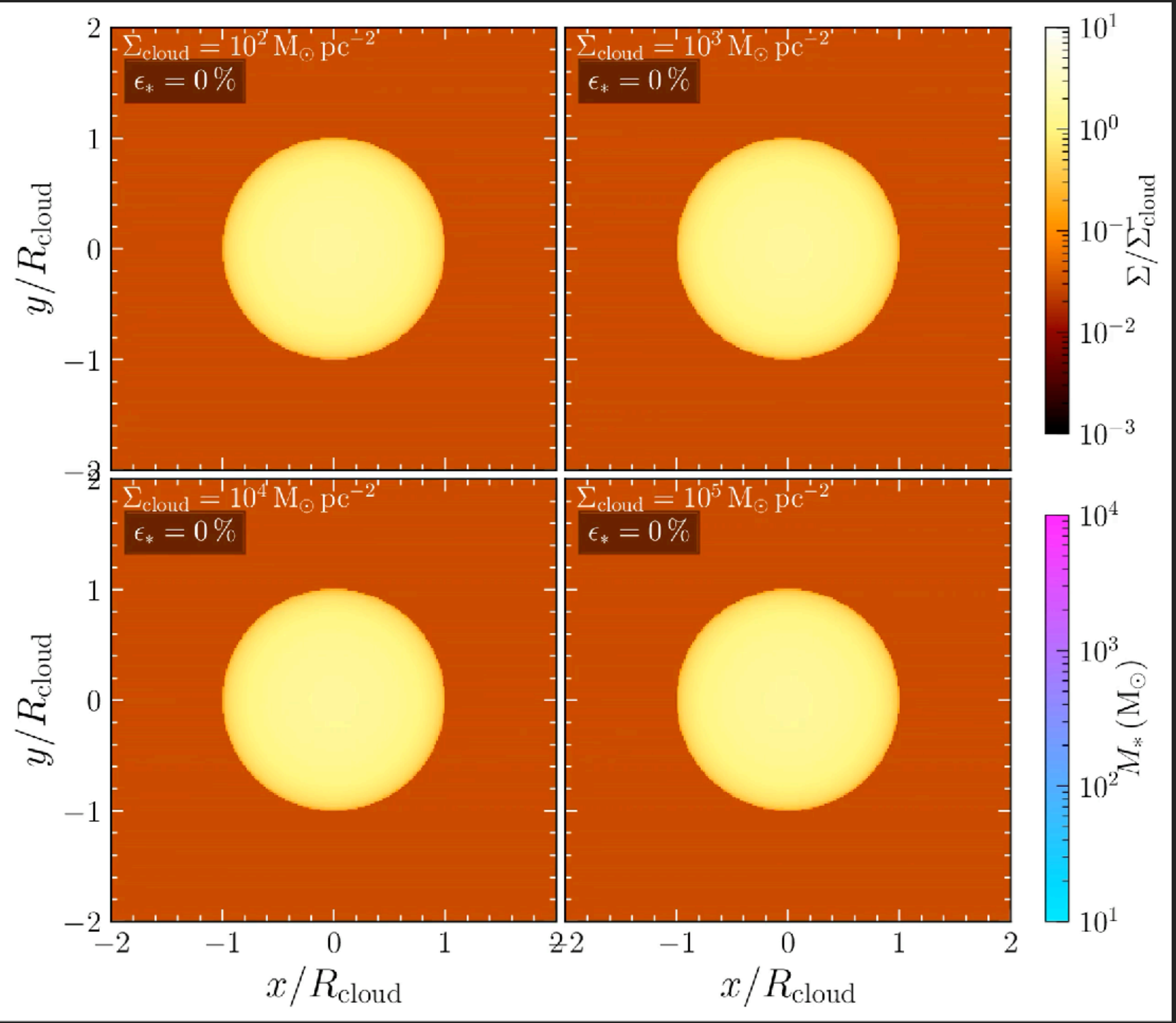

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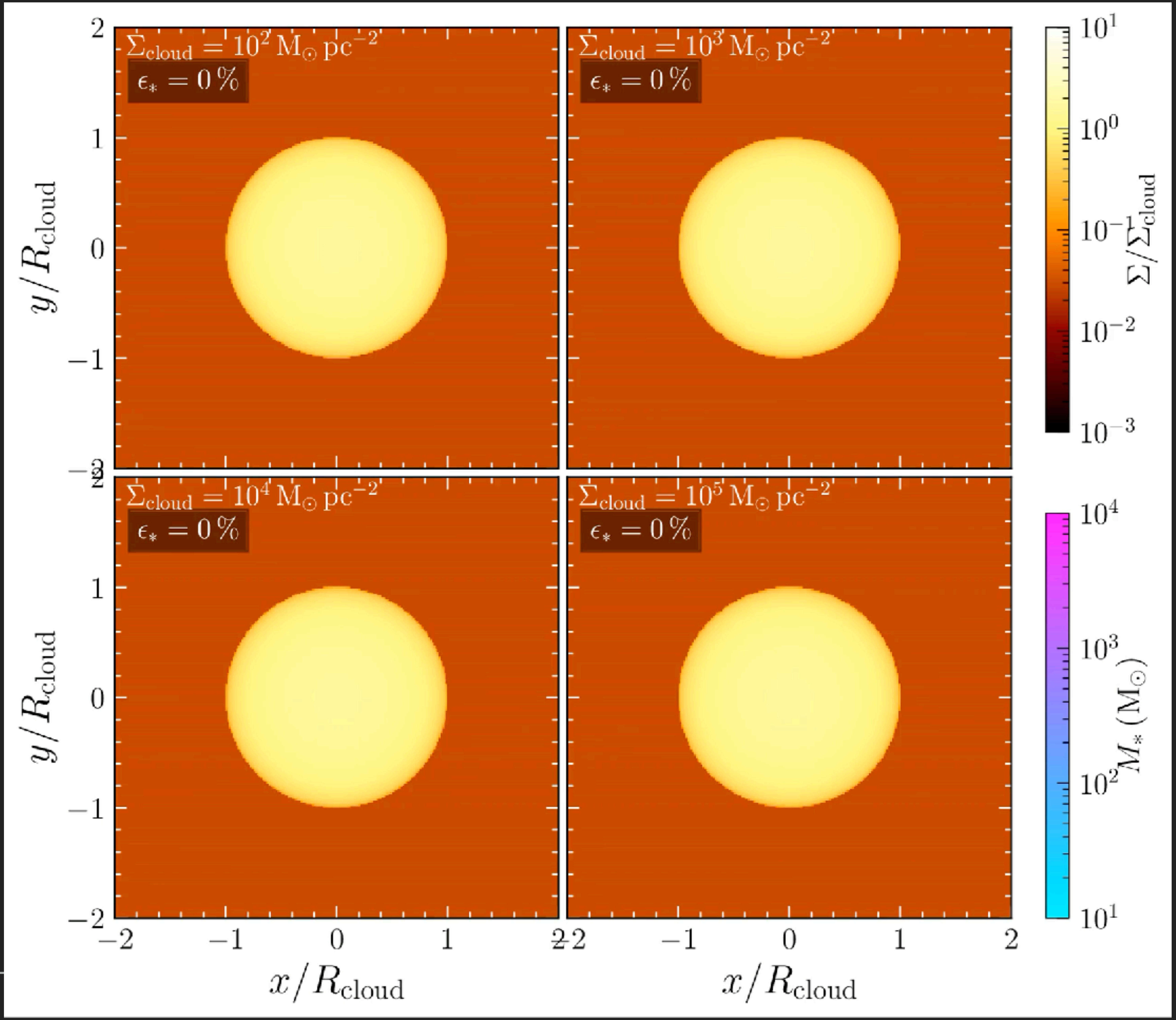

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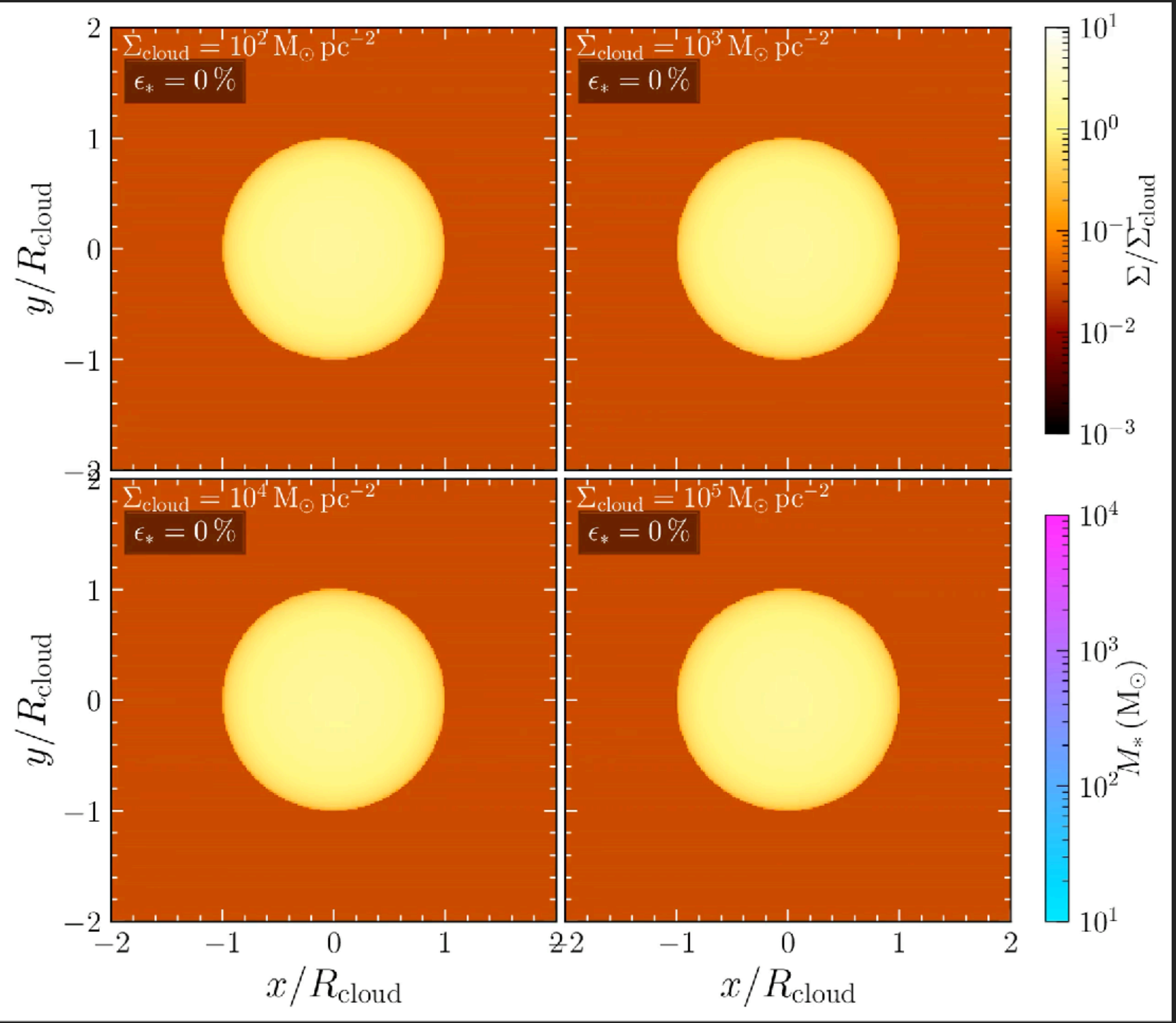

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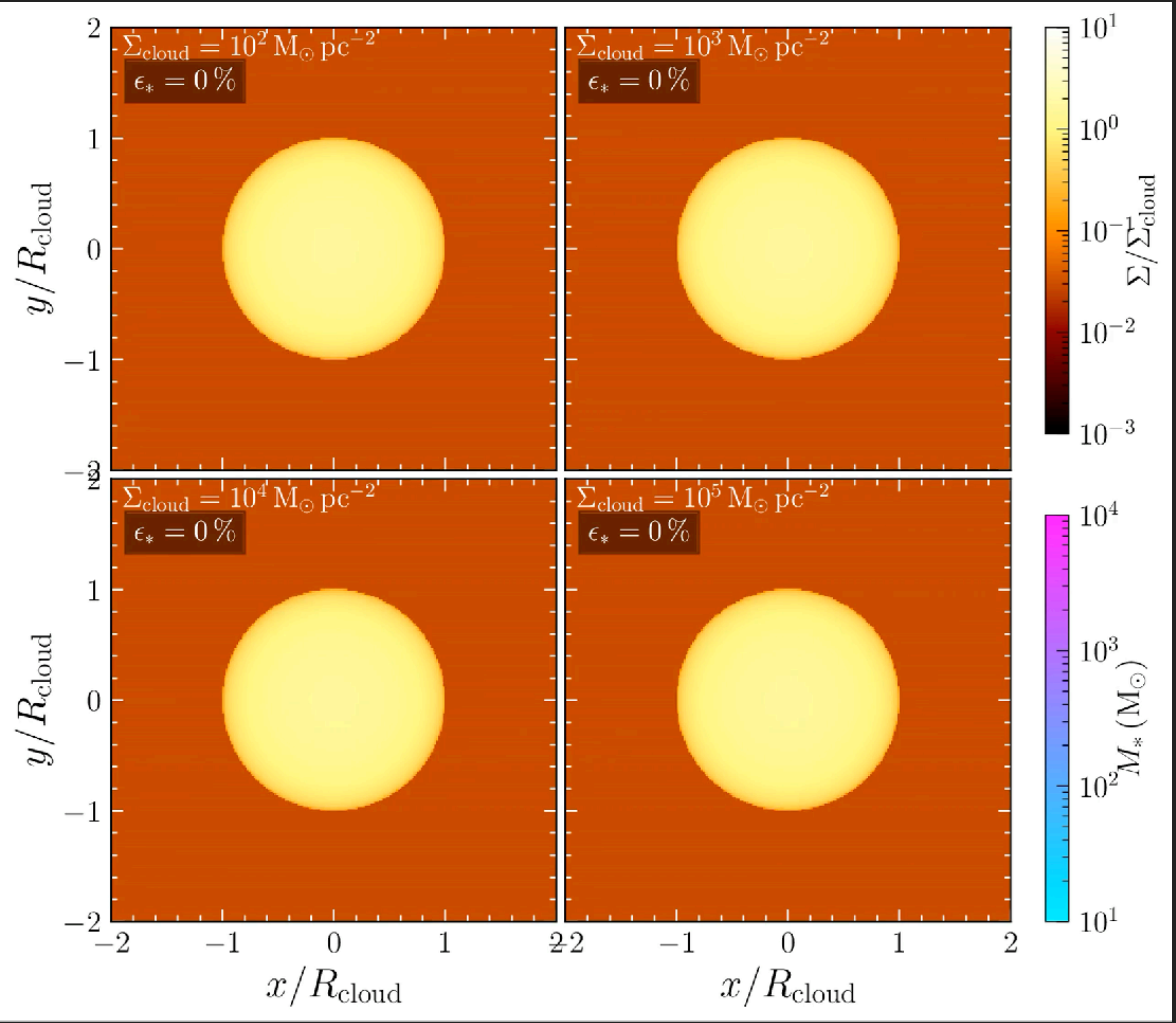
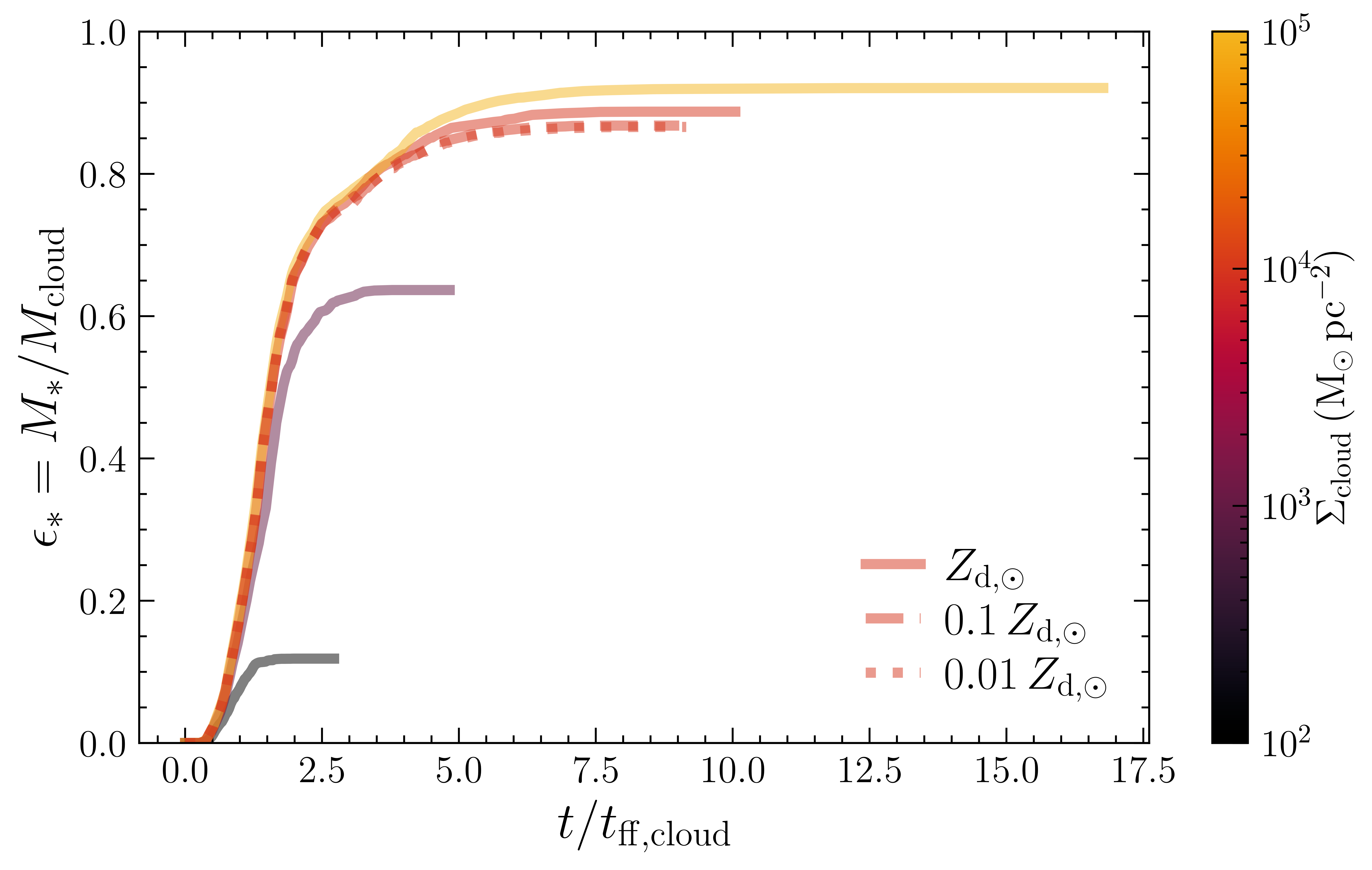
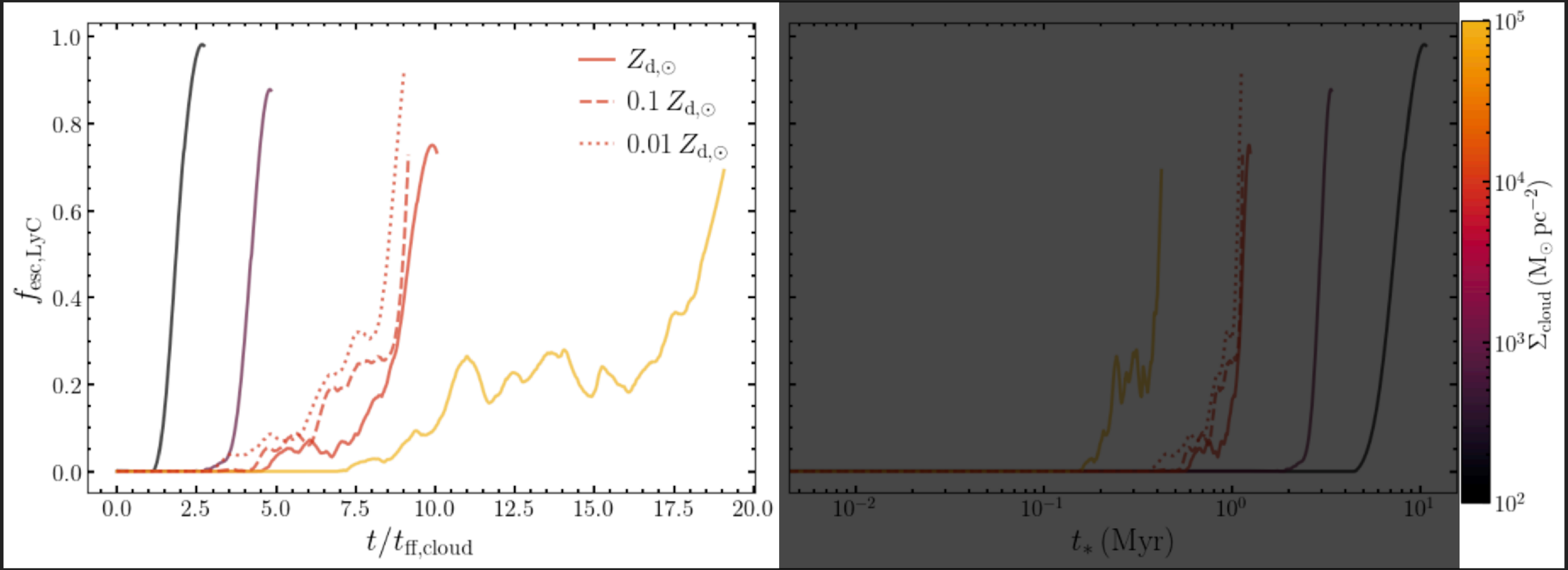


EFFICIENT STAR FORMATION: PRODUCES MORE LYC PHOTONS



Menon+24b, (ApJ subm; arXiv:2408.14591)

LYC ESCAPE FRACTIONS



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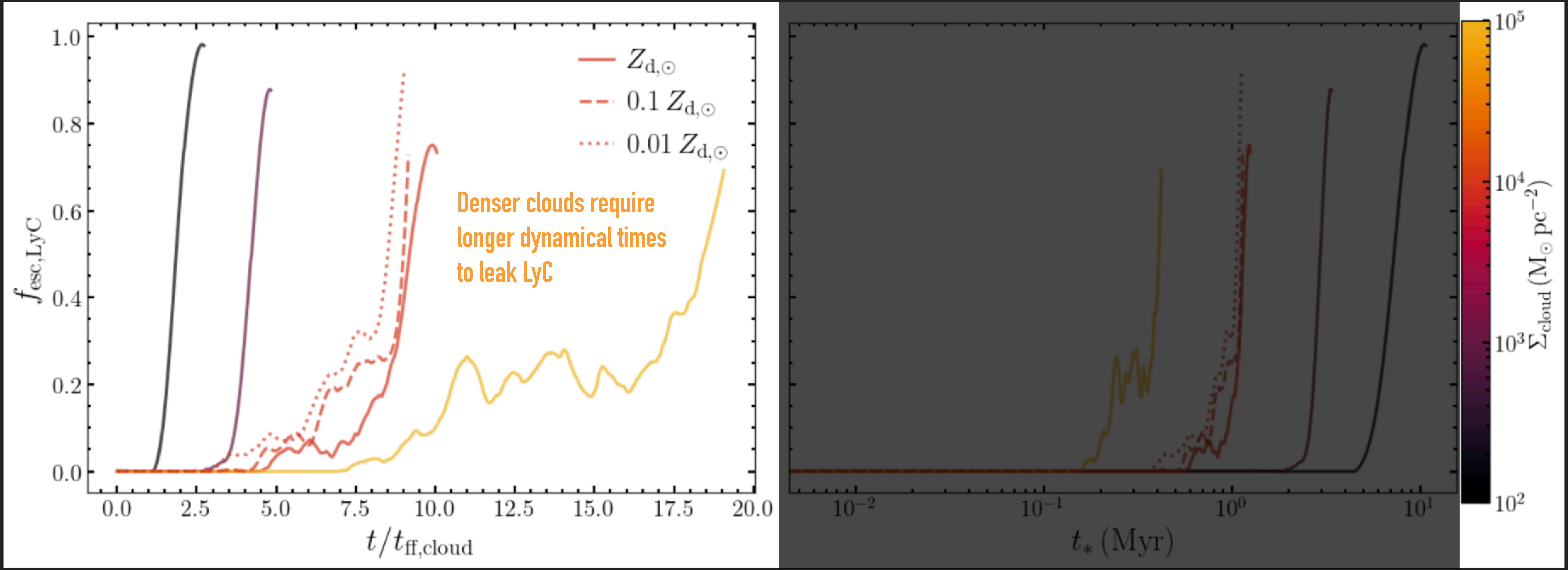

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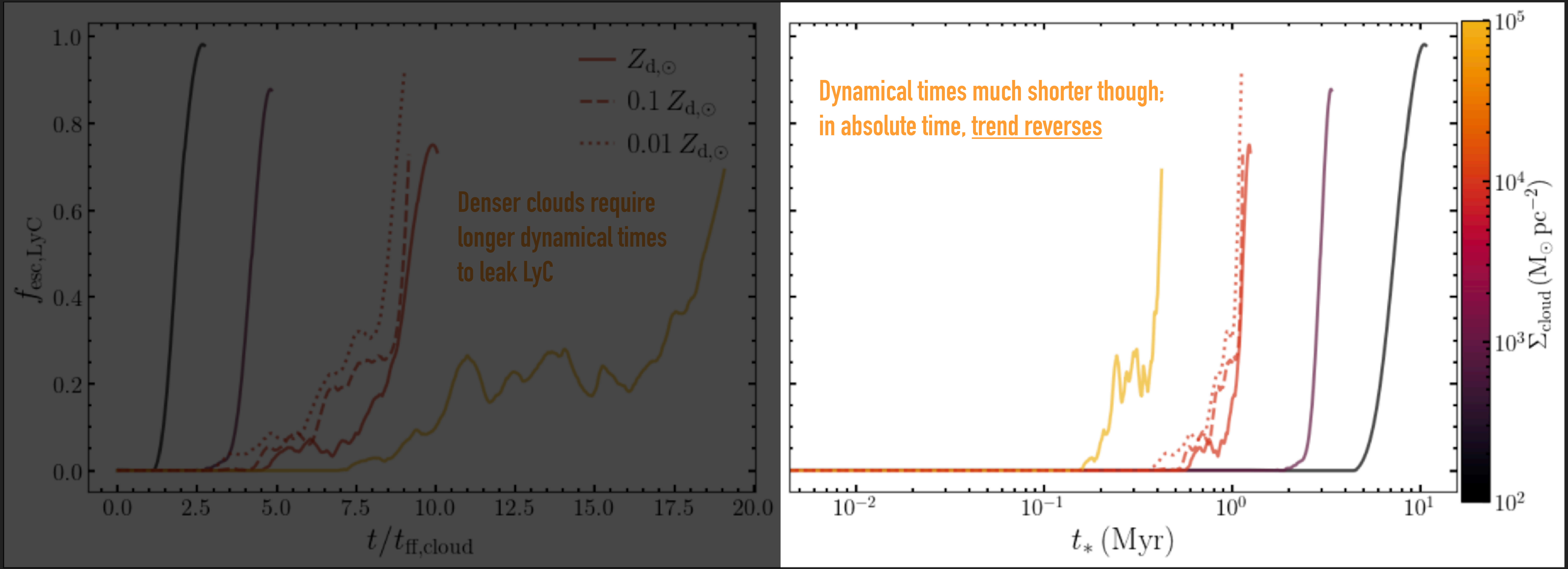

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SHORT DYNAMICAL TIMES = EFFICIENT LYC LEAKAGE

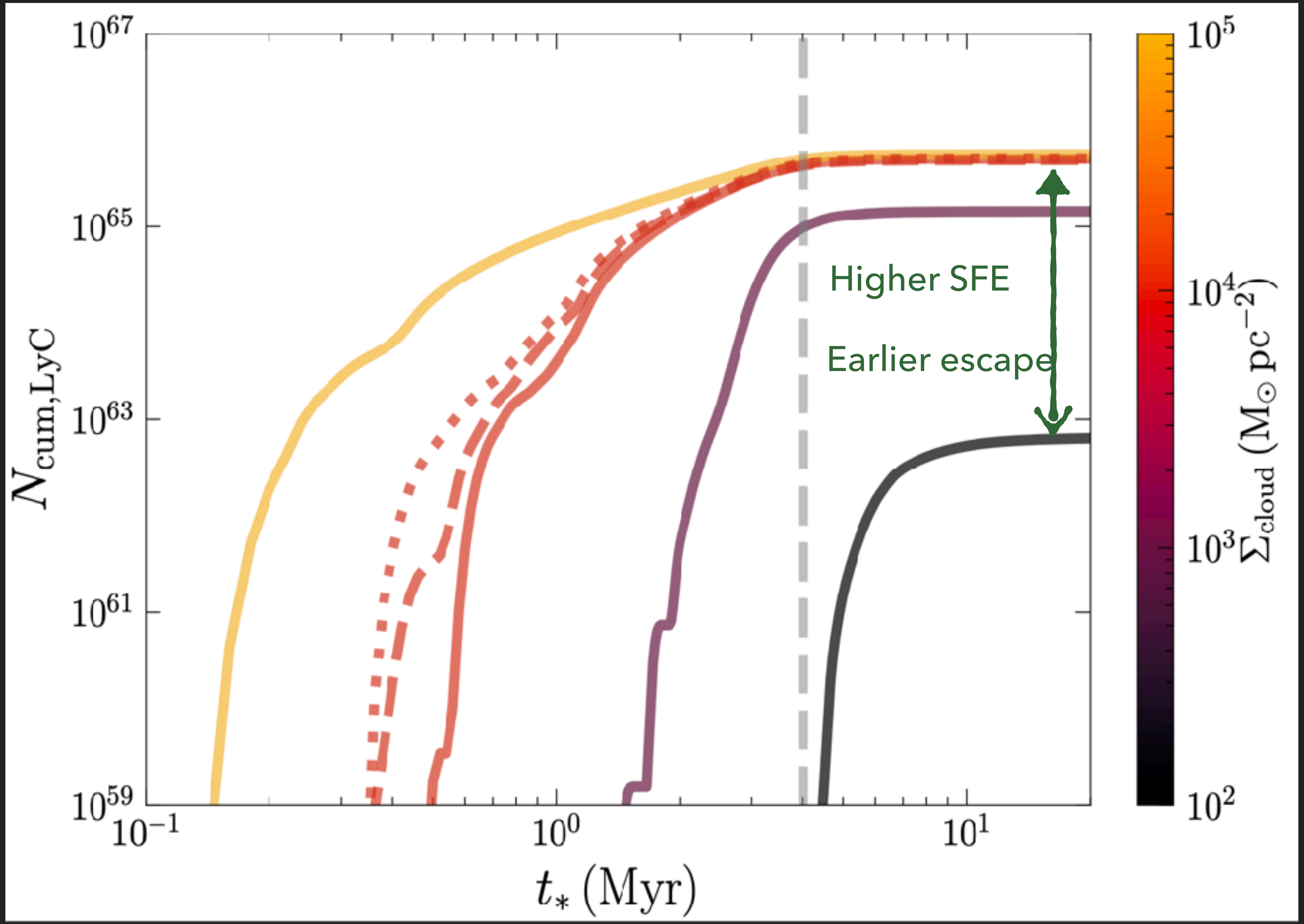
Higher SFE

Earlier escape

Menon+24b, (ApJ subm; arXiv:2408.14591)

SHORT DYNAMICAL TIMES = EFFICIENT LYC LEAKAGE

Cumulative LyC escape



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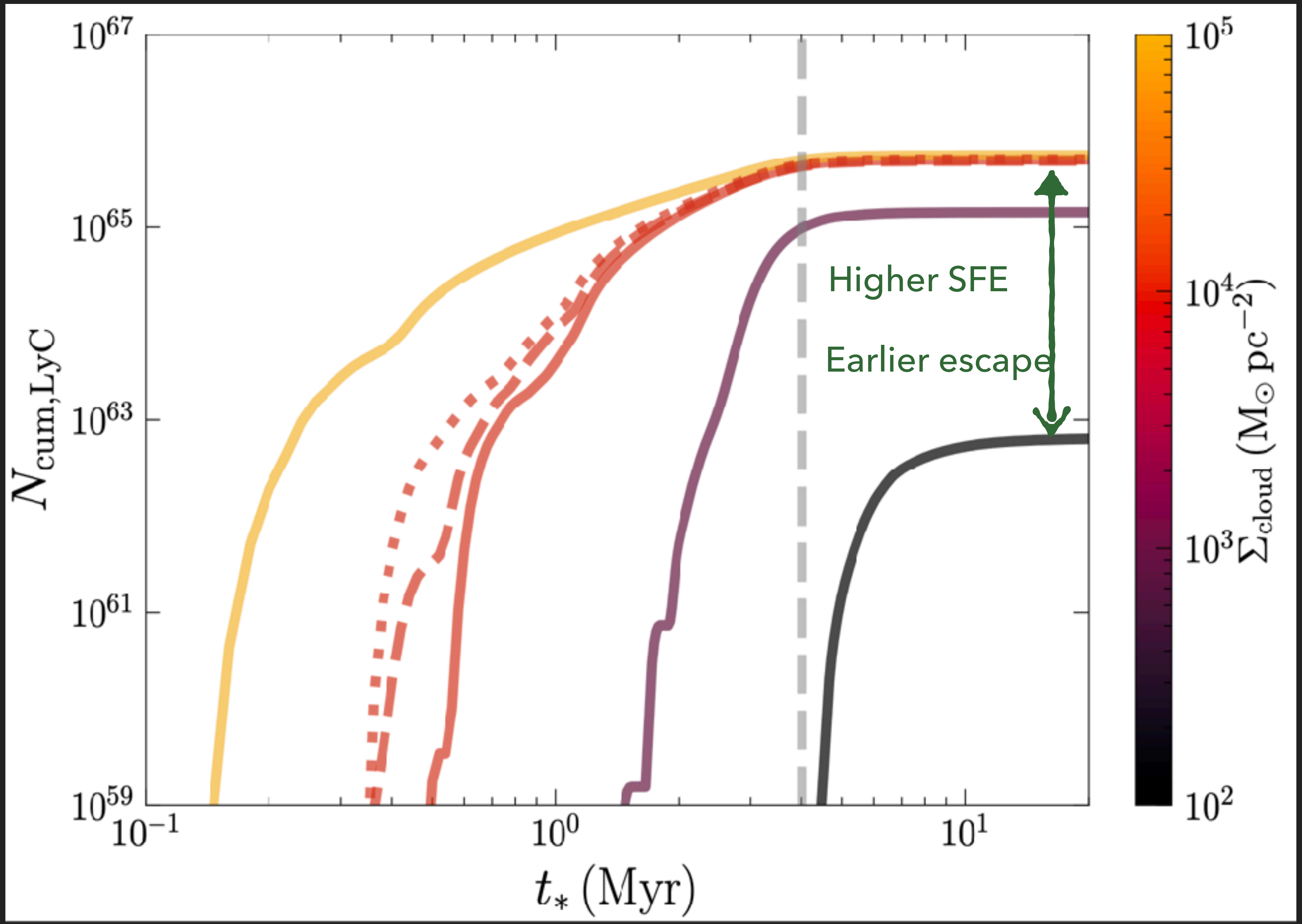

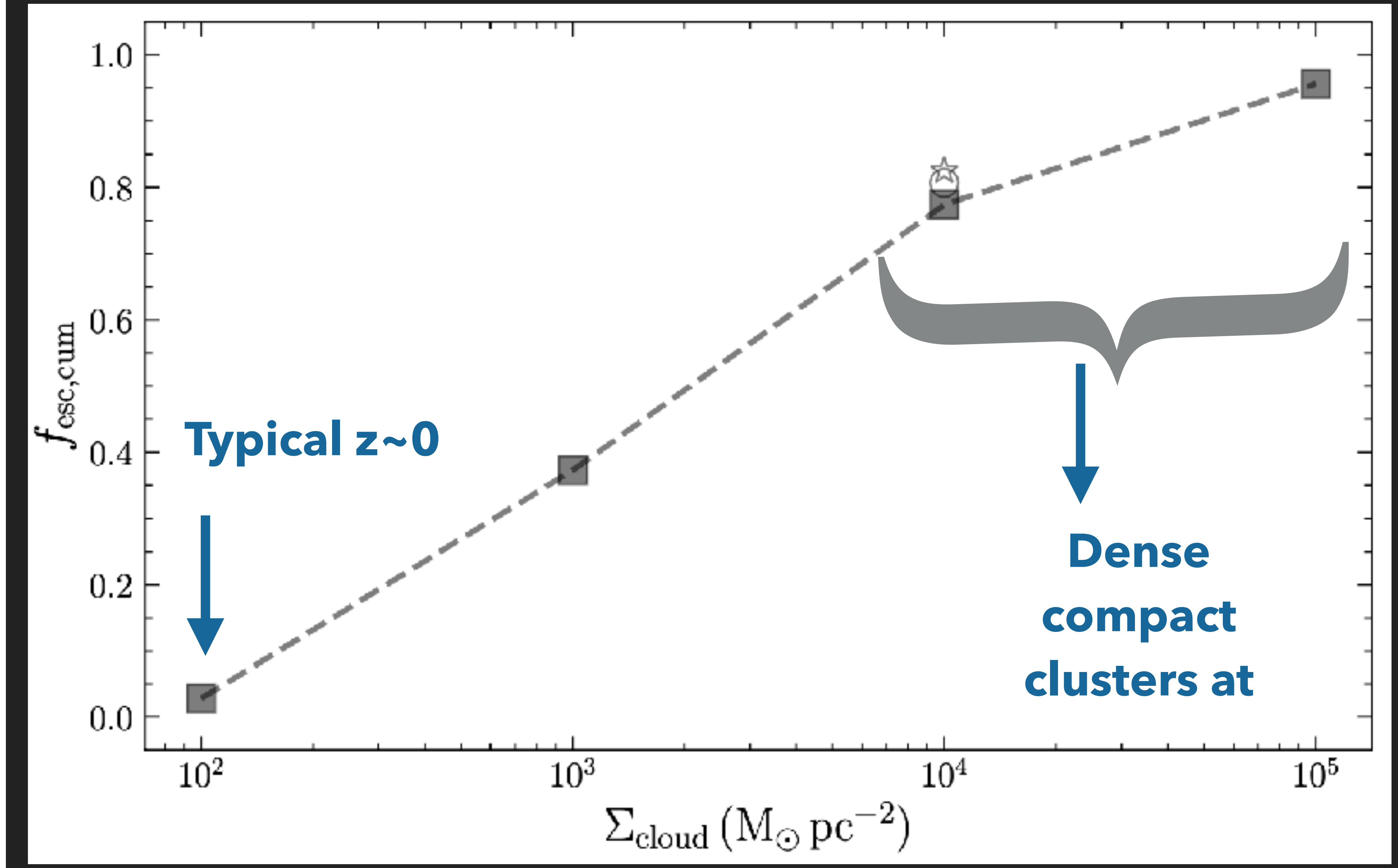

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WHAT FACILITATES LYC LEAKAGE IN DENSE CLUSTERS?

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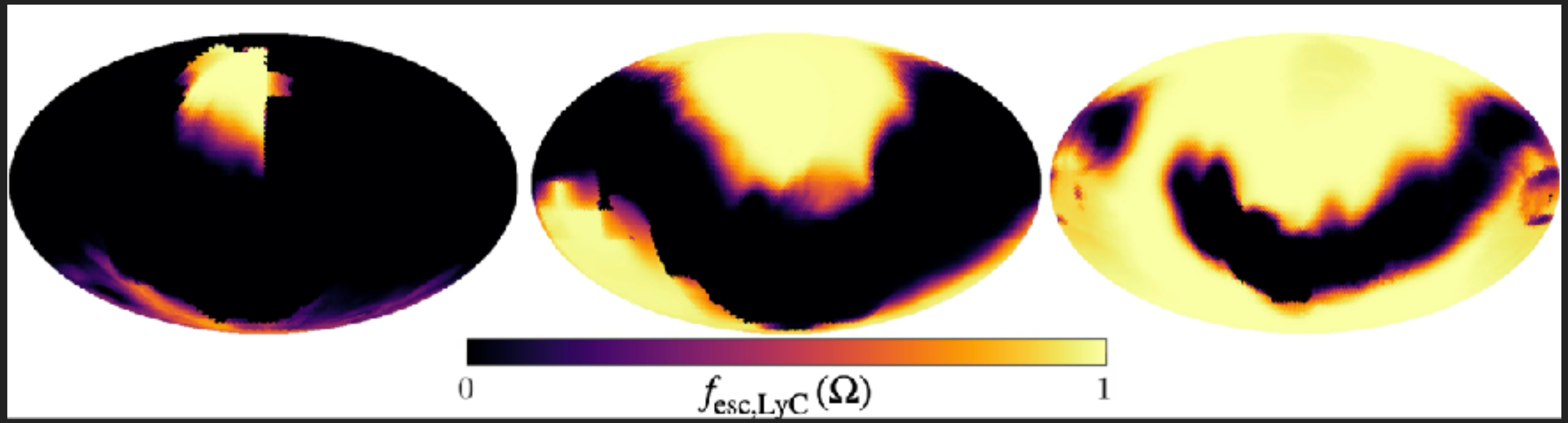

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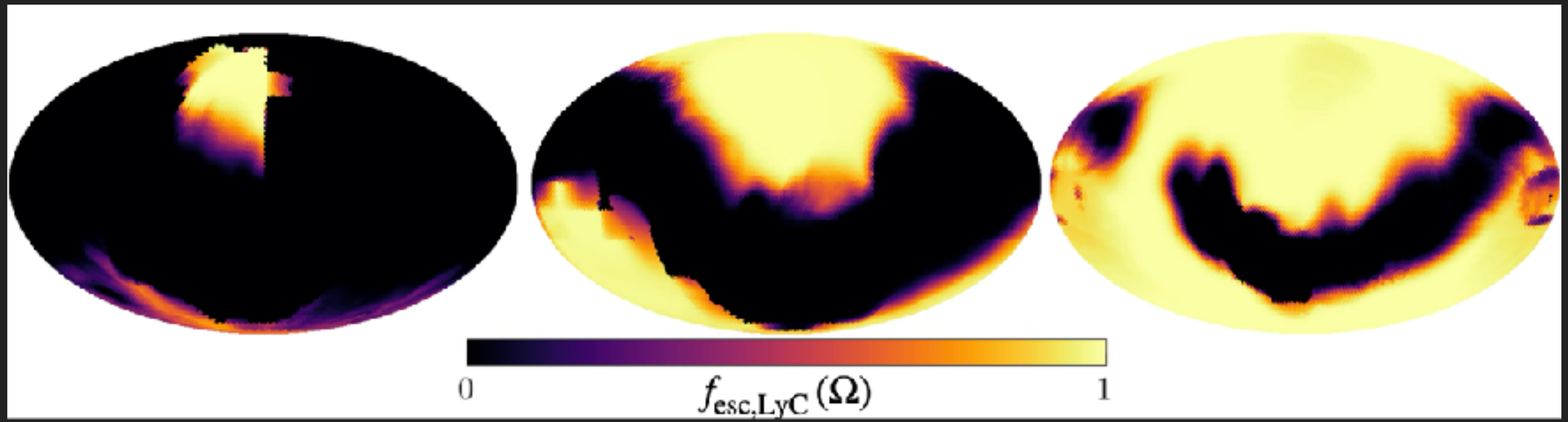

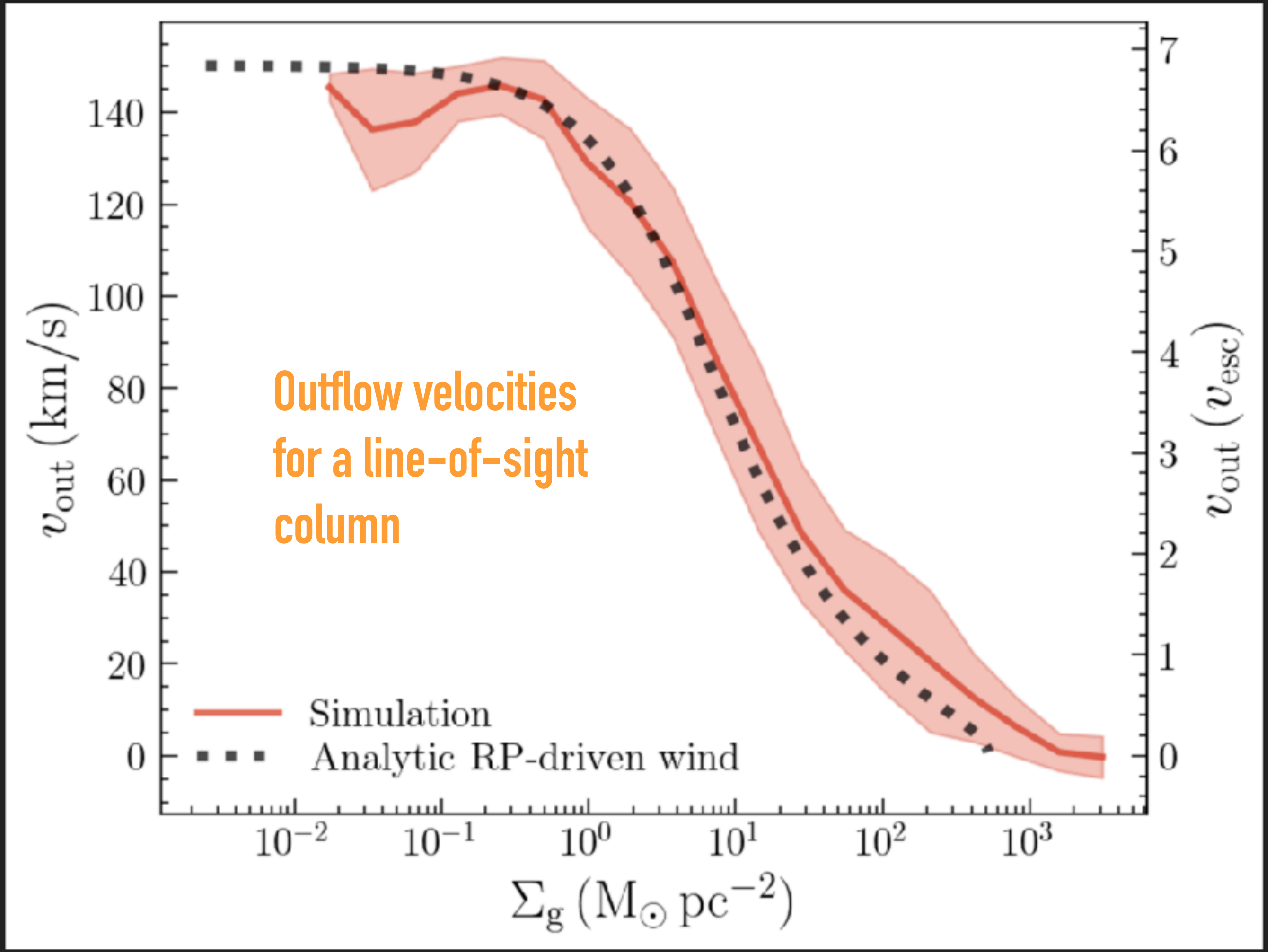

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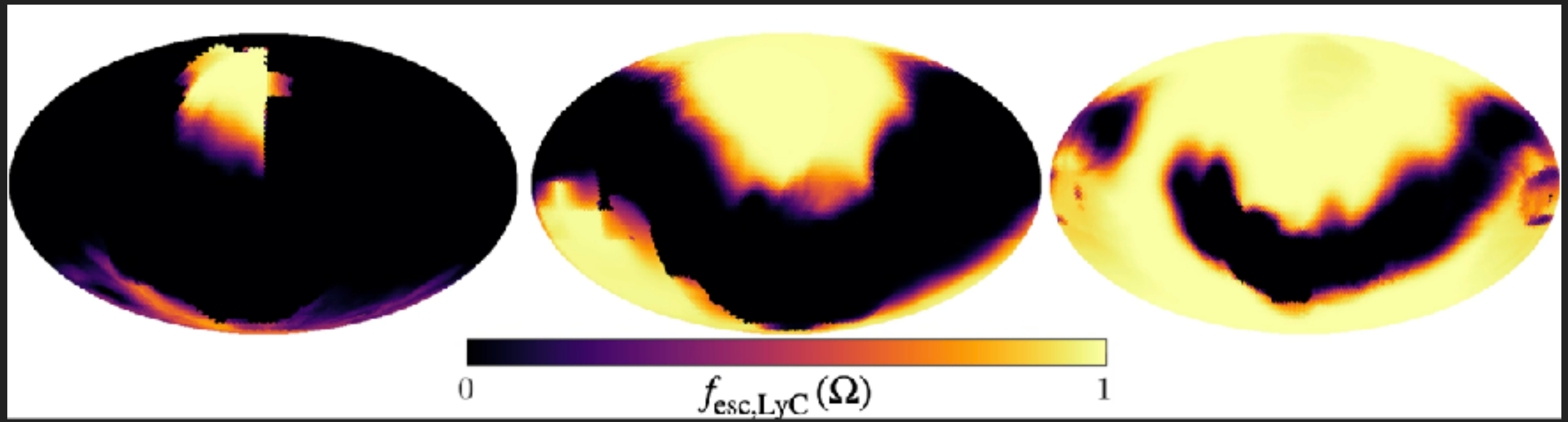

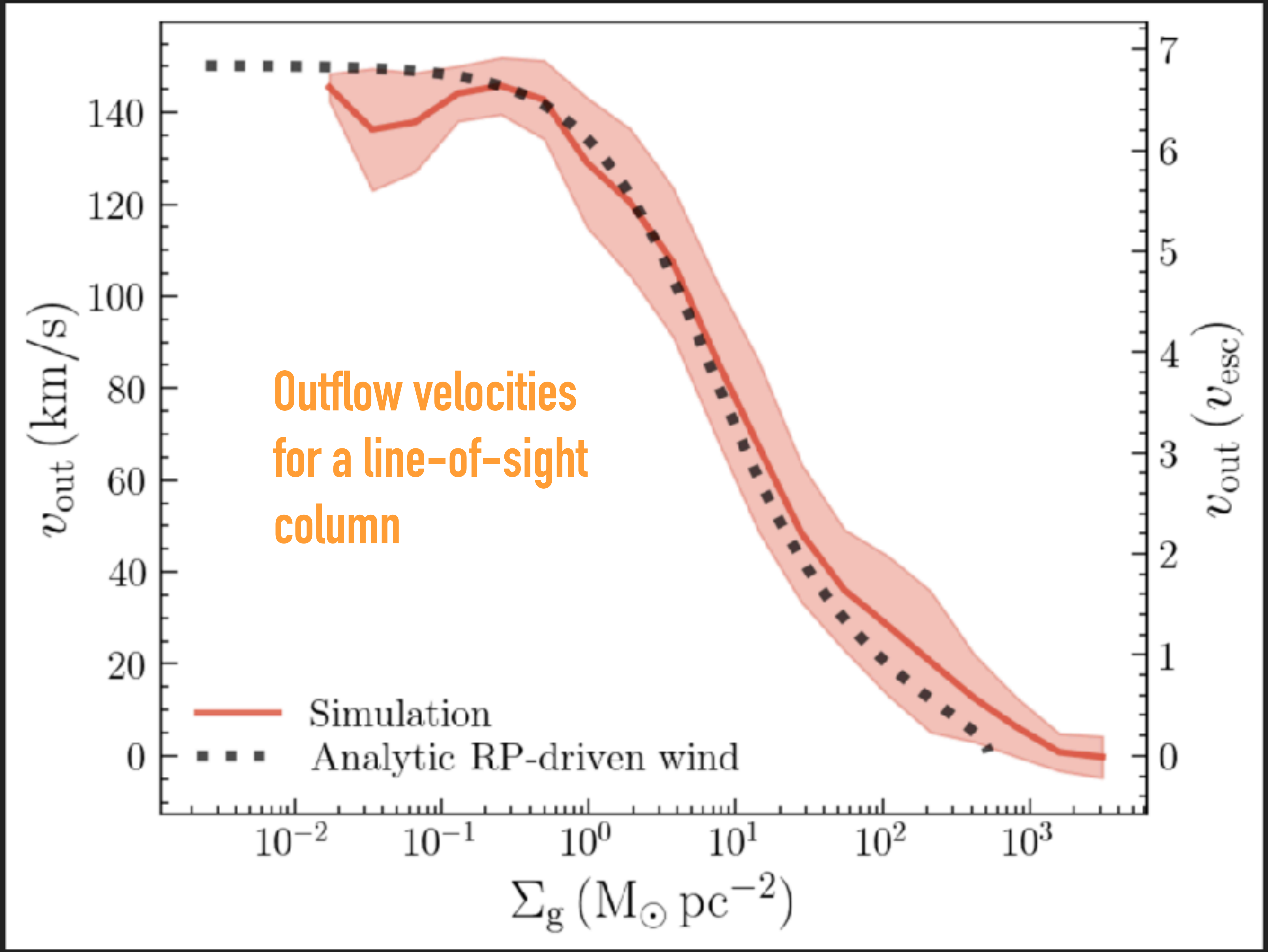

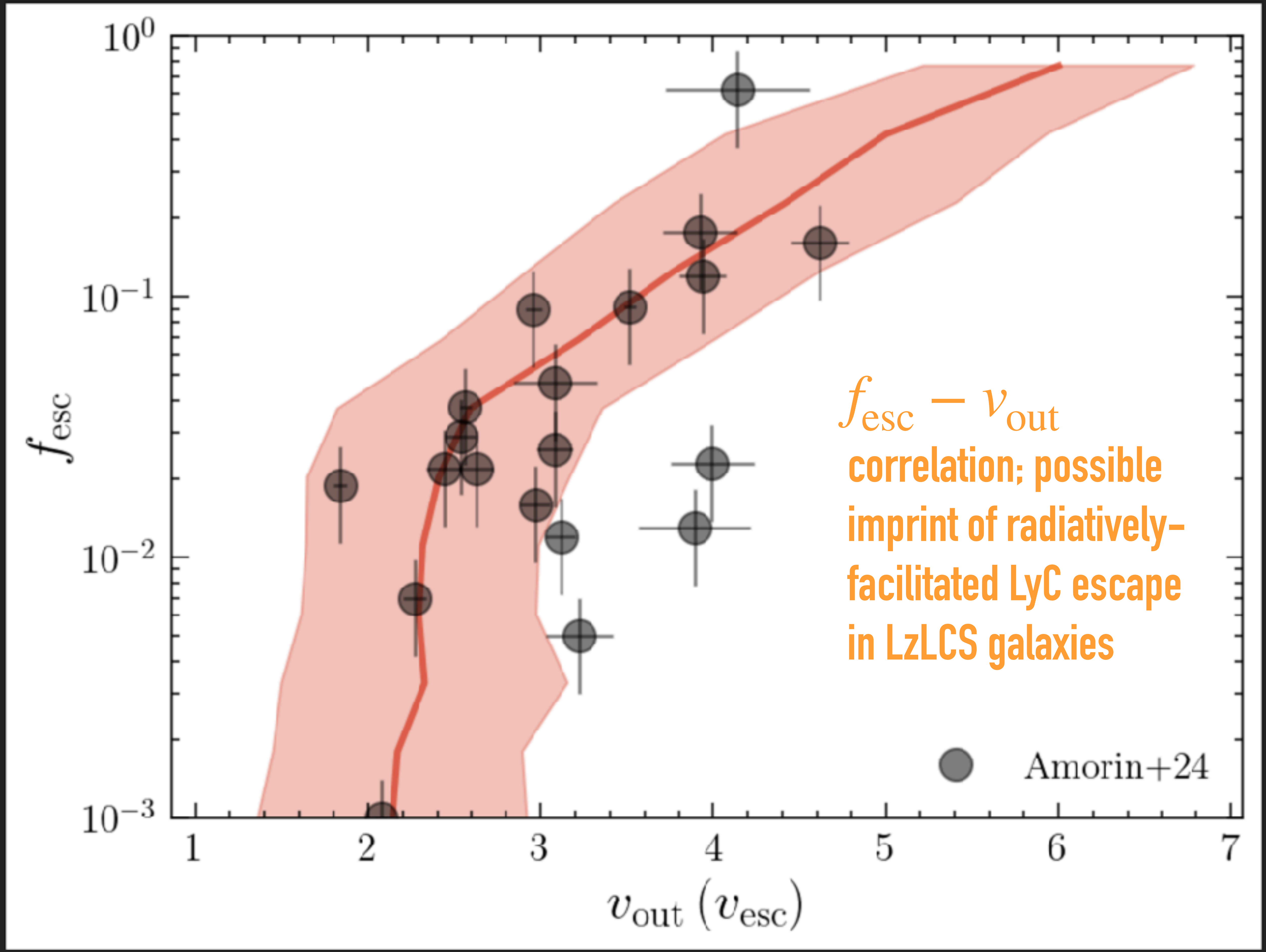

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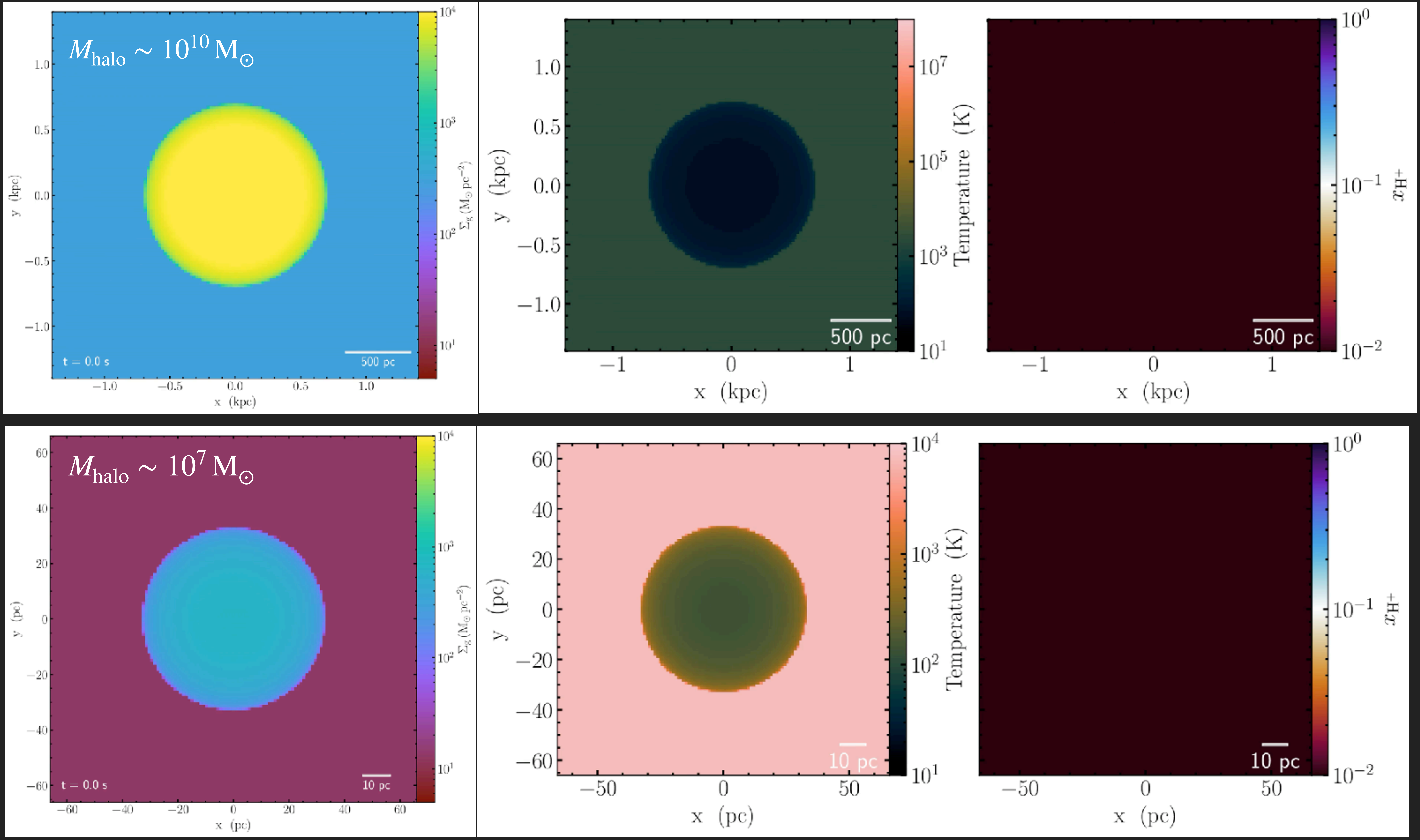
GALACTIC CONTEXT: FEEDBACK-STAR FORMATION INTERPLAY IN THE ISM OF HIGH-Z BURSTS

Caution: work in progress

Thummim Mekuria
(UC Santa Cruz;
Predoc at CCA)



Mekuria, Menon et al. 2025 (in prep)

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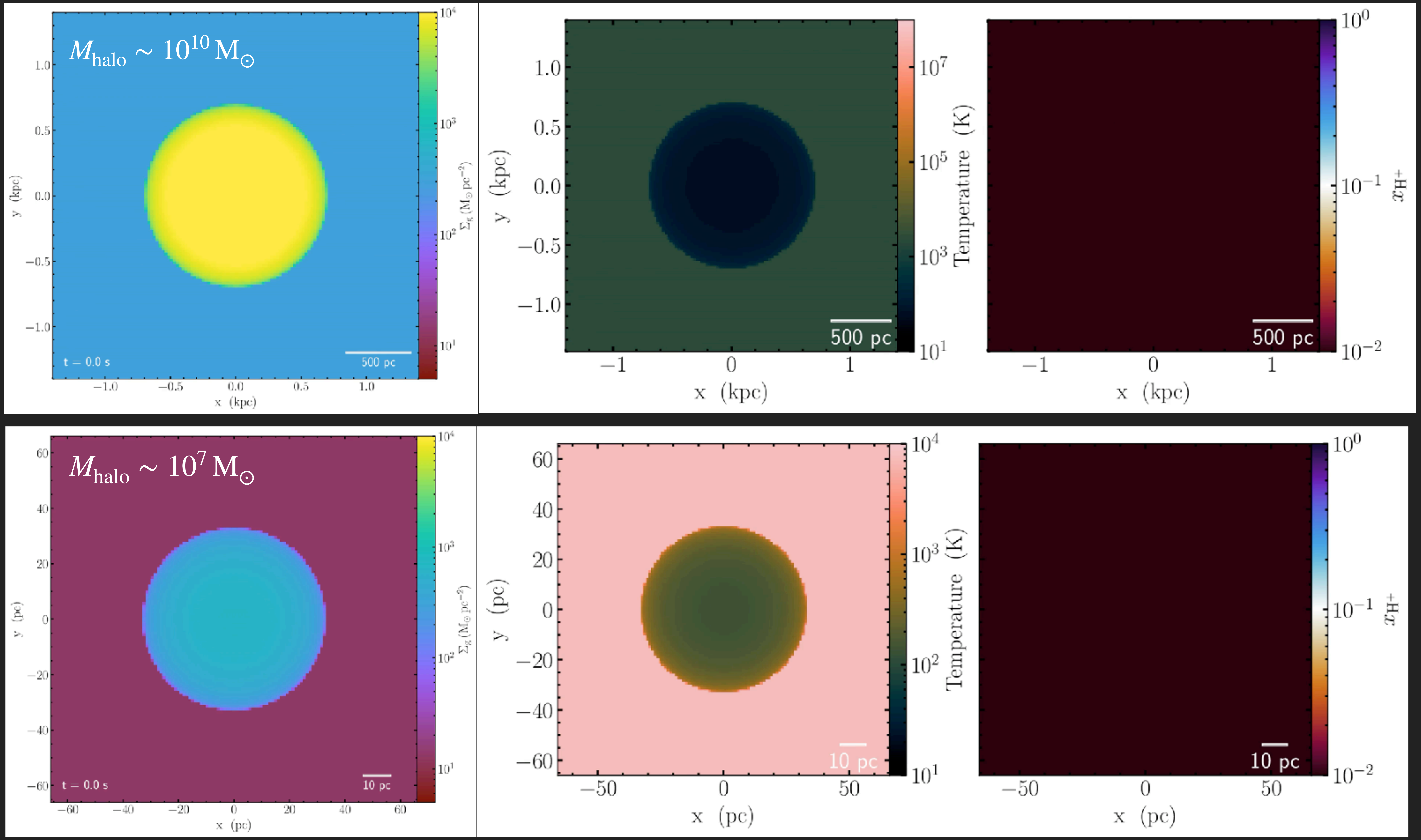

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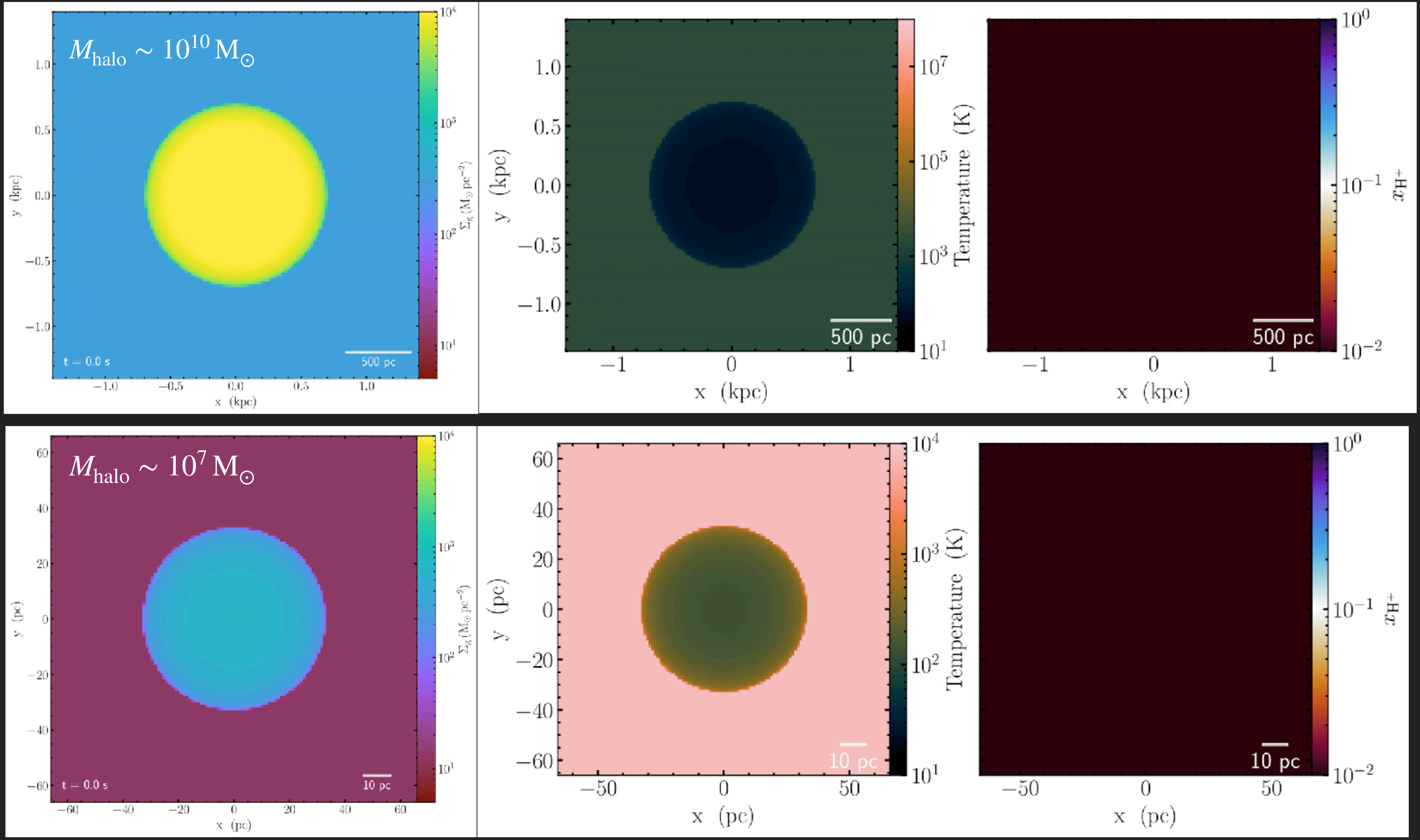
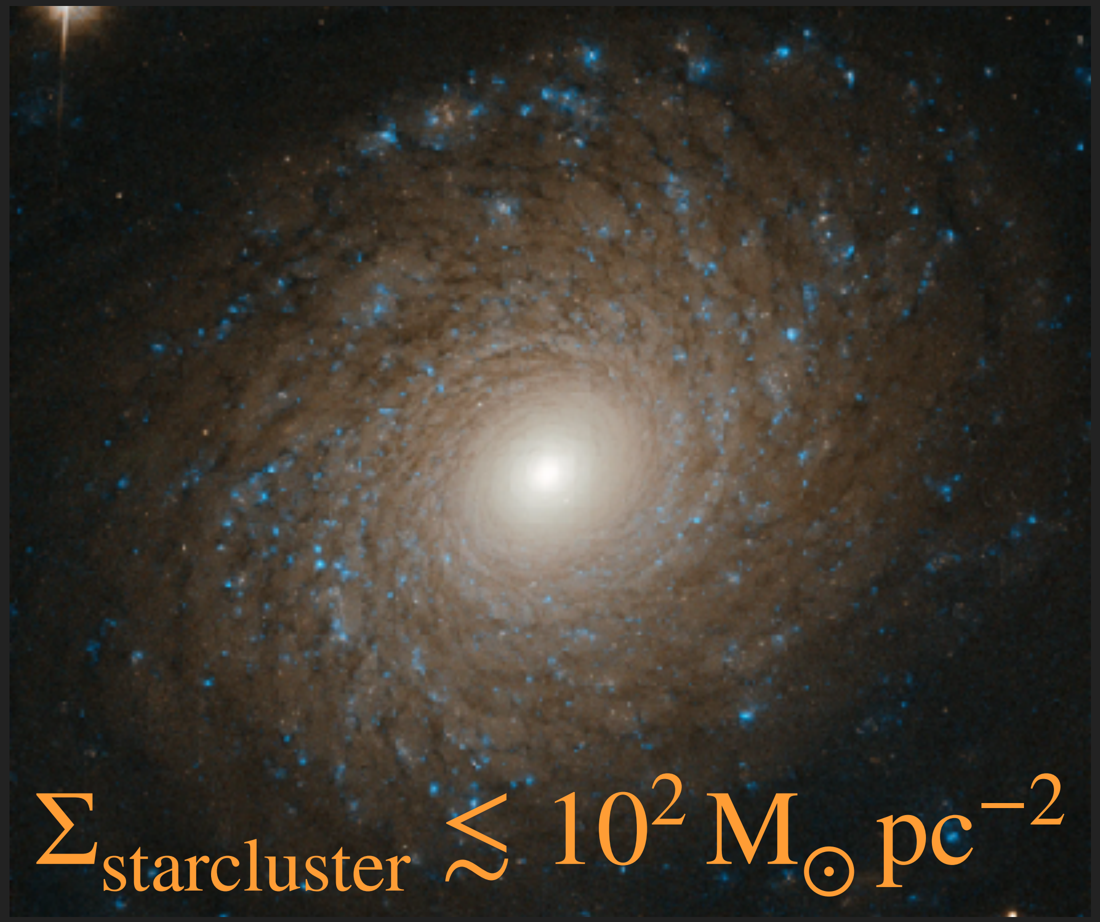
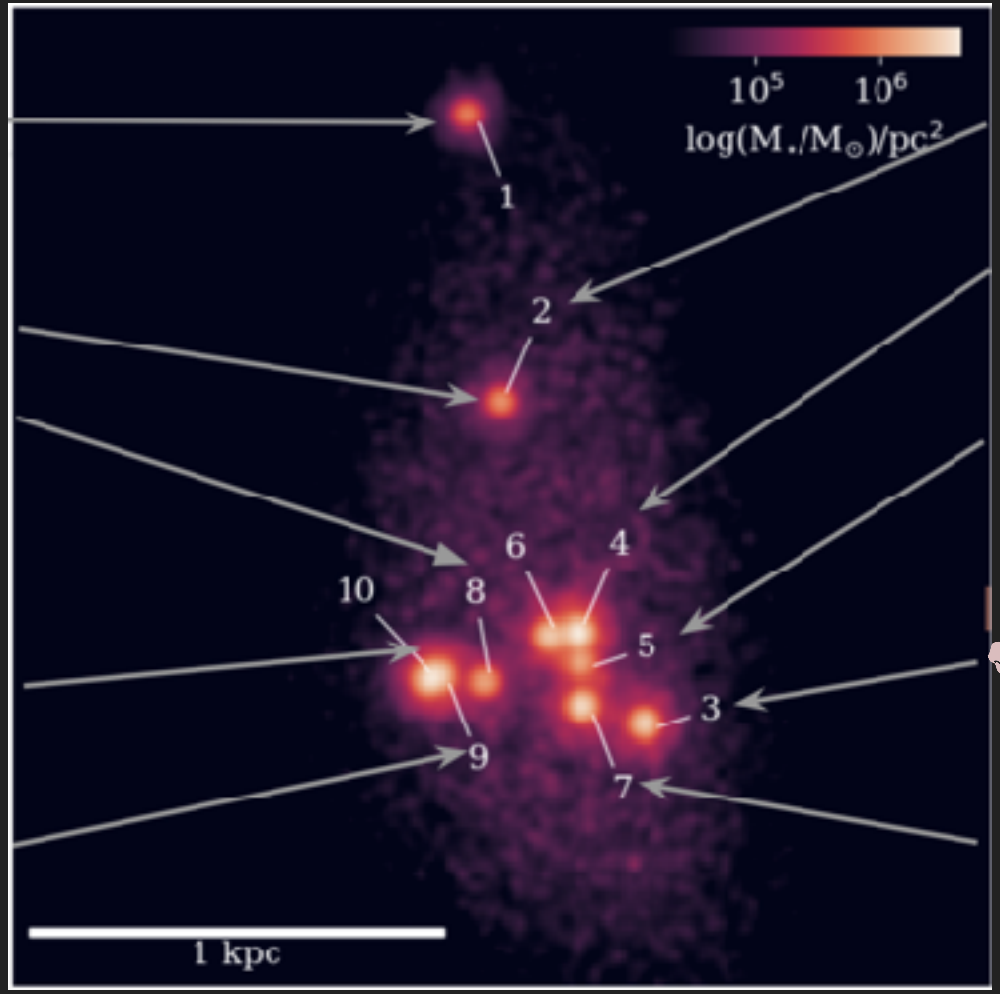


Mekuria, Menon et al. 2025 (in prep)

$z \sim 0$





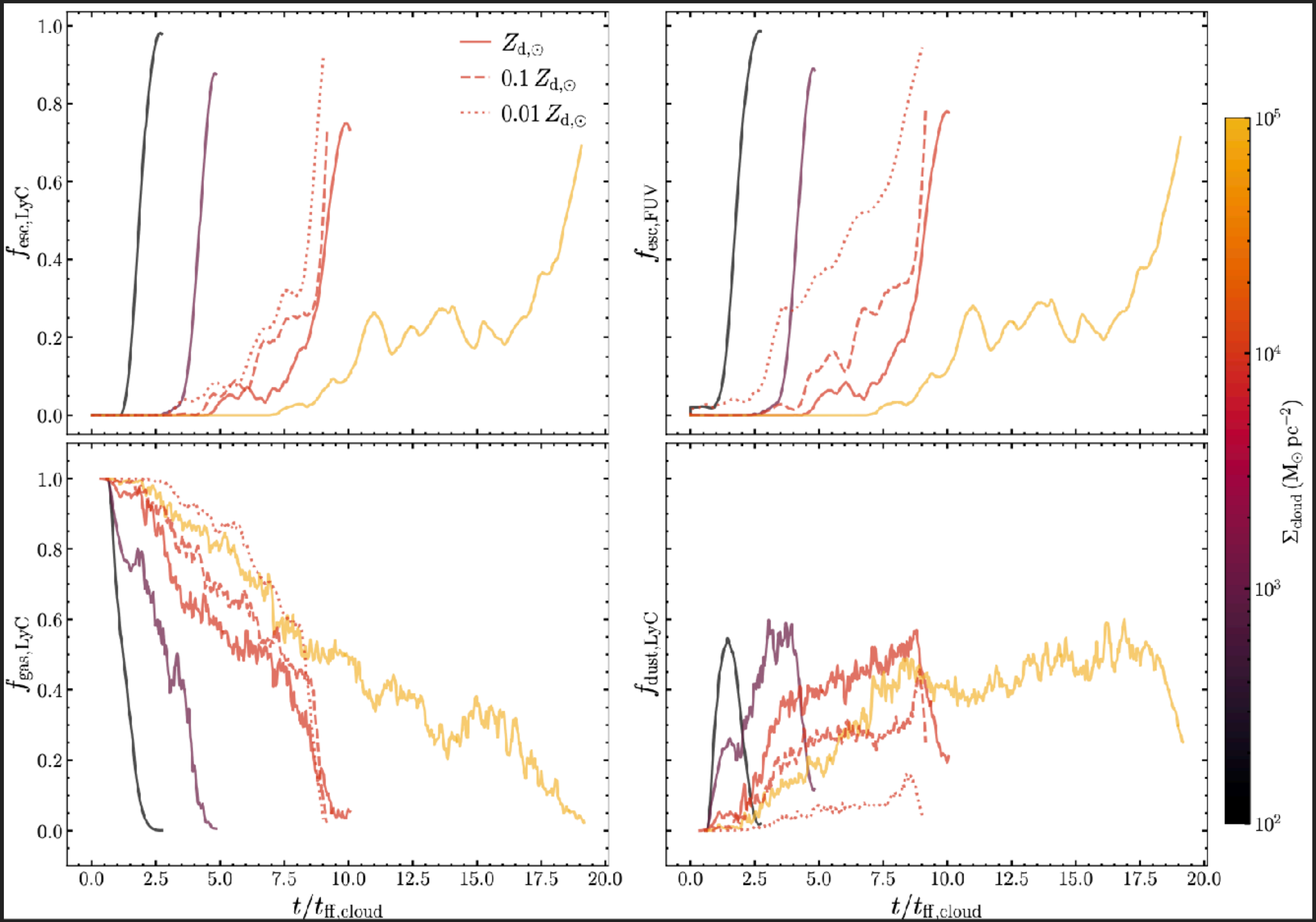
$z > 6$

$\Sigma_{\rm starcluster} \gtrsim 10^4\,{\rm M_\odot\,pc^{-2}}$

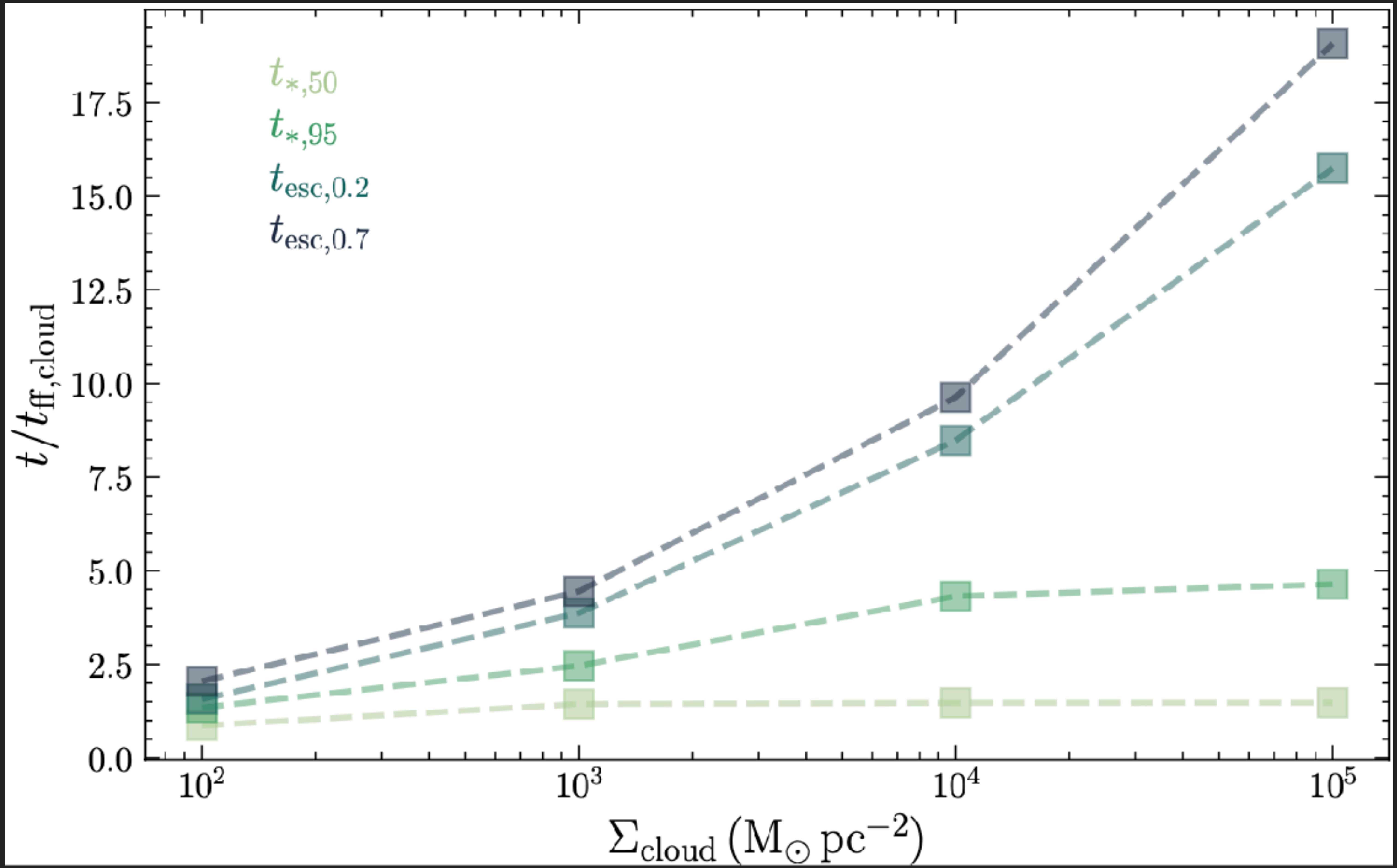
DISTINCT CONDITIONS IN HIGH-Z GALAXIES -> COMPACT BURSTS OF STAR FORMATION -> FACILITATE LYC ESCAPE THROUGH RADIATIVELY-DRIVEN WINDS

- Star Formation Efficiency (SFE) higher in such conditions
- Short dynamical times permit rapid gas clearing of sightlines for LyC escape
- Gas clearing facilitated by radiation pressure on dust+gas before SNe go off and LyC emission rate drops
- Direct radiative clearing likely plays out in lower-mass haloes; higher-mass haloes require SNe-driven winds revealing young cluster (two-burst scenario)
- LyC escape, higher electron densities $\left(n_e \gtrsim 10^5\,{\rm cm^{-3}}\right)$, distinct morphology of HII regions -> should affect nebular emission. Working on quantifying this.

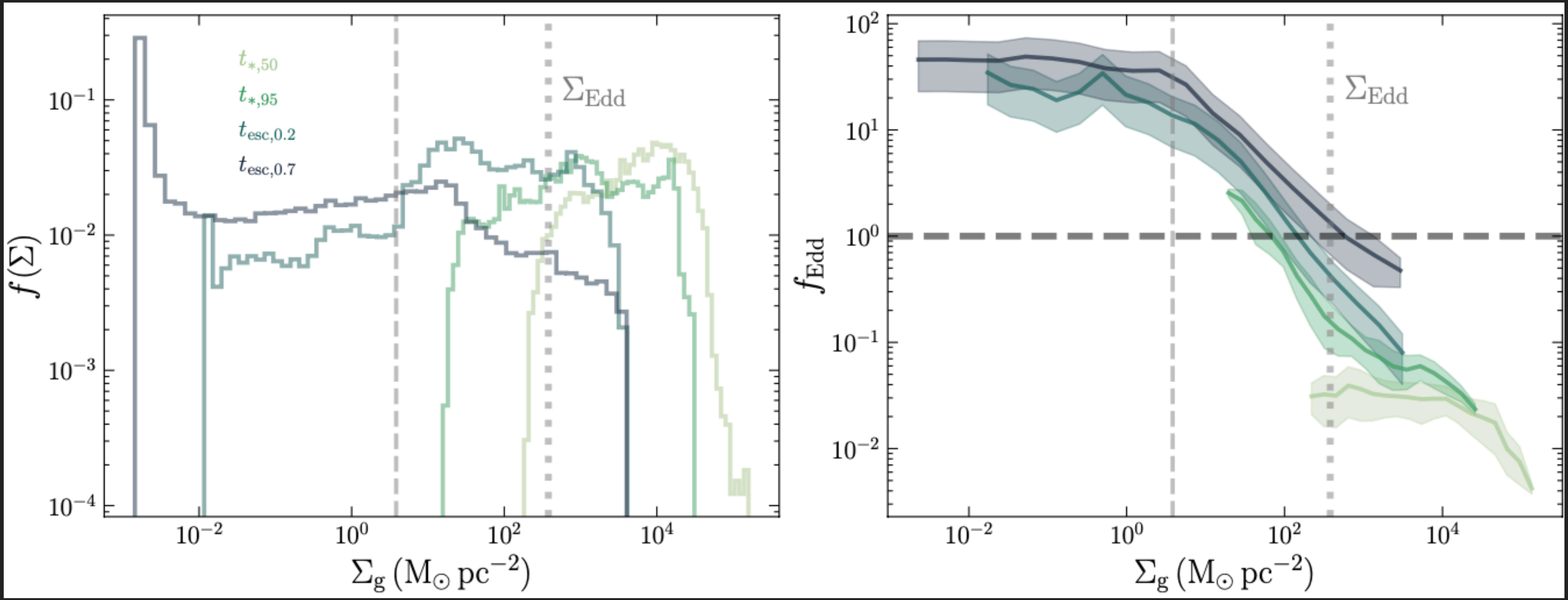
ESCAPE FRACTIONS AND GAS VS DUST ABSORPTION



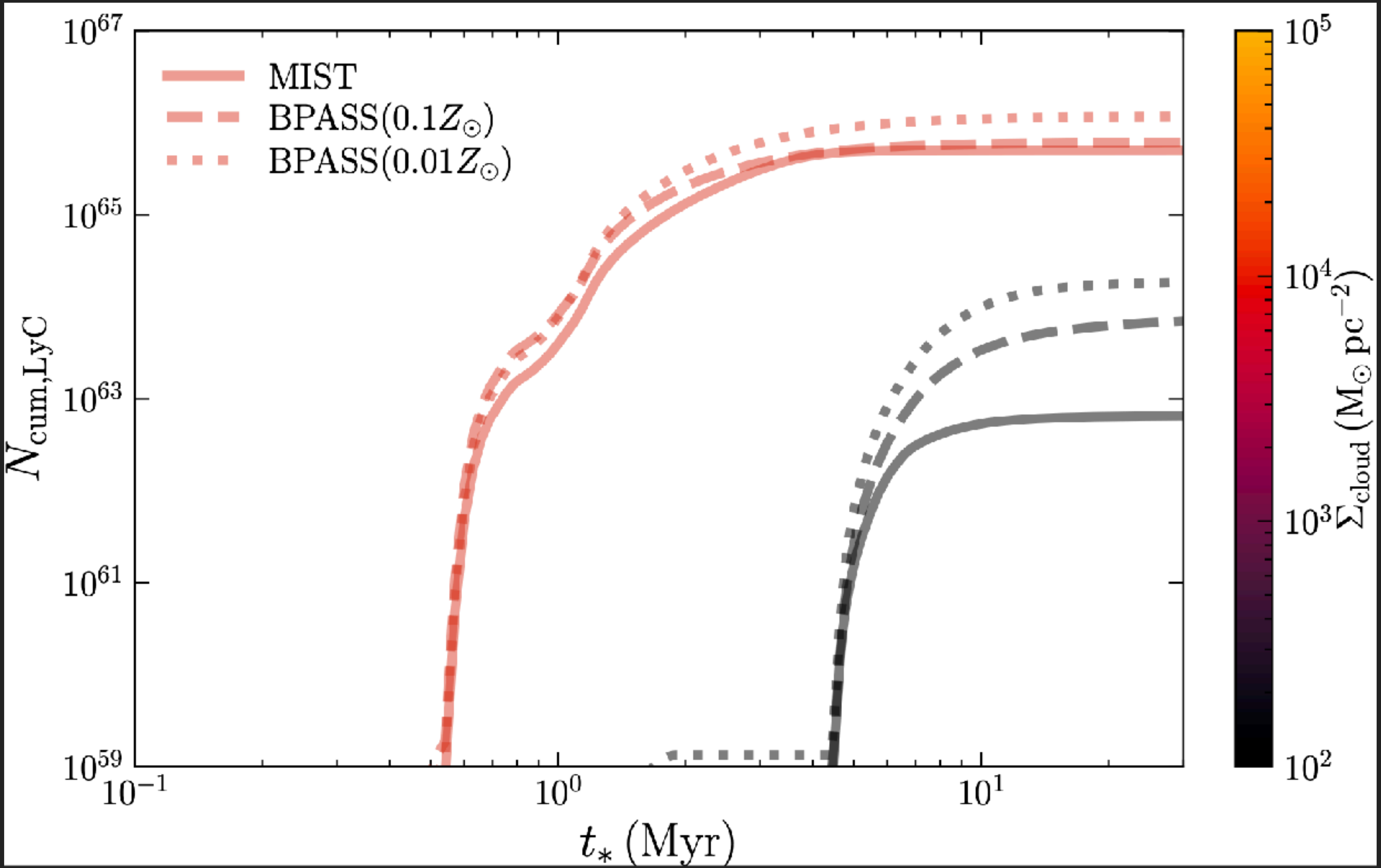
TIMESCALES FOR LYC ESCAPE



GRAVITY-RADIATION PRESSURE COMPETITION DICTATES OUTFLOWS AND LYC ESCAPE



BINARIES/LOW-Z PARTLY HELP; TIMESCALE STRONGER EFFECT



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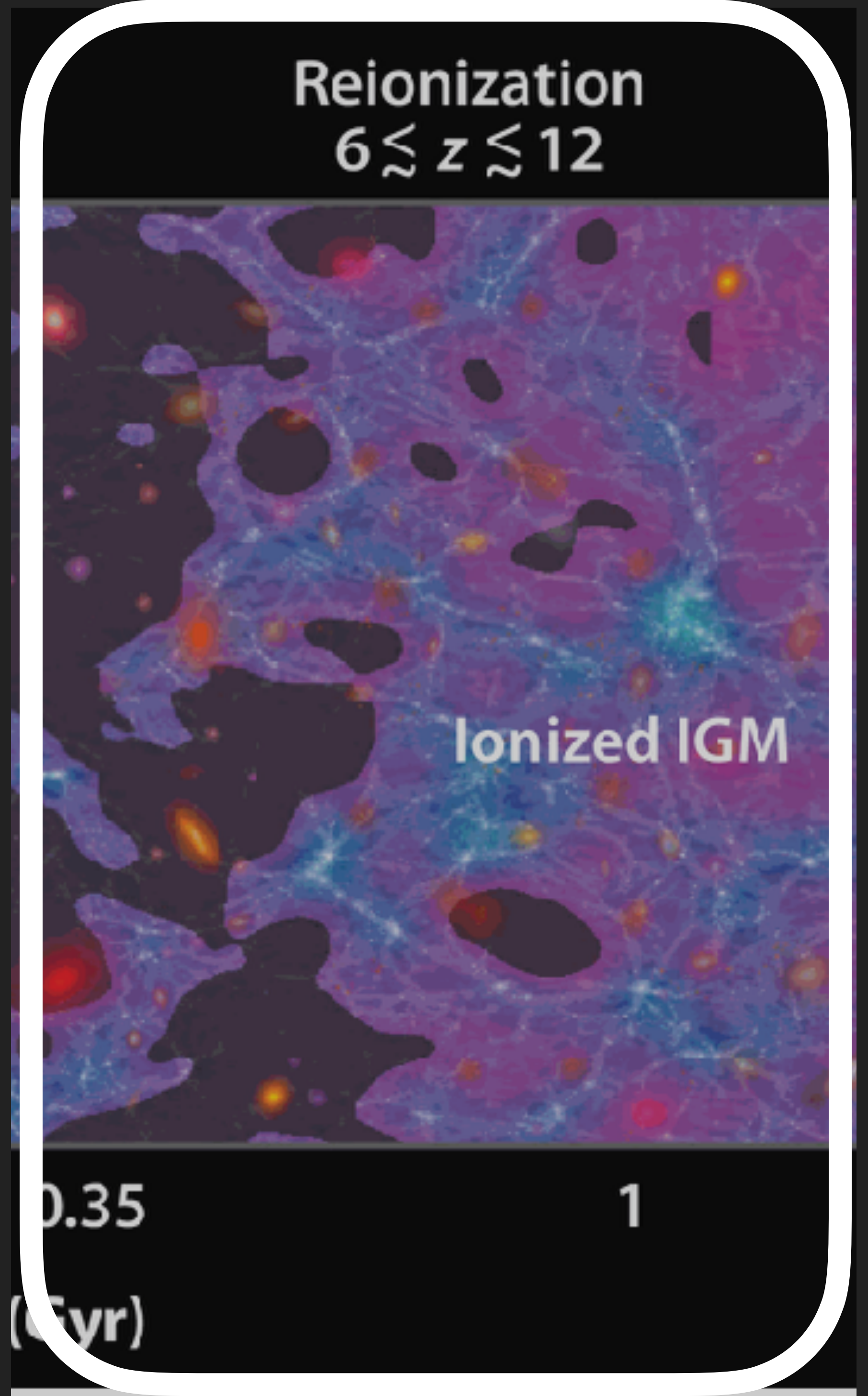
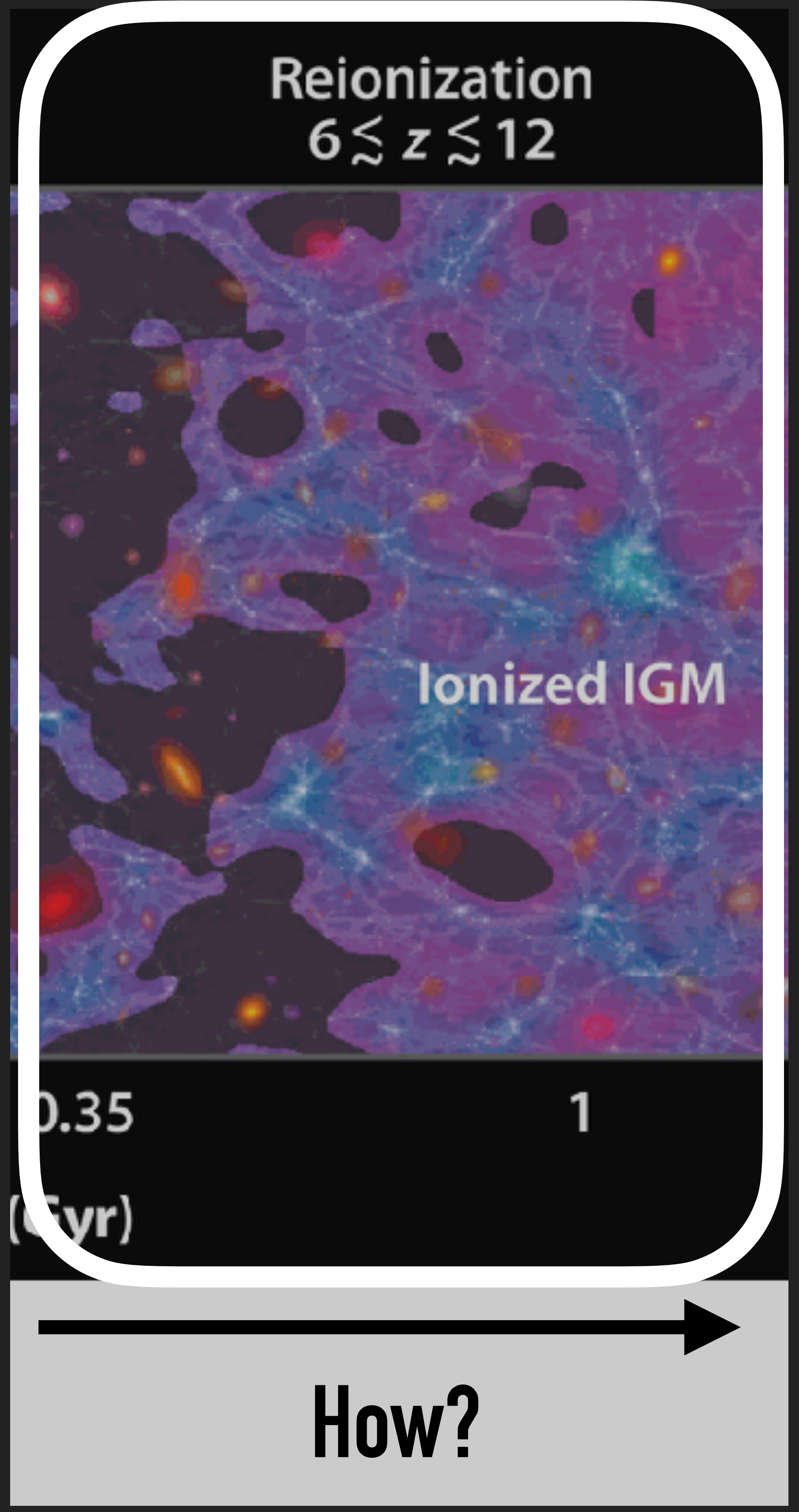
Robertson 2022, ARAA



How?

REIONIZATION OF THE UNIVERSE

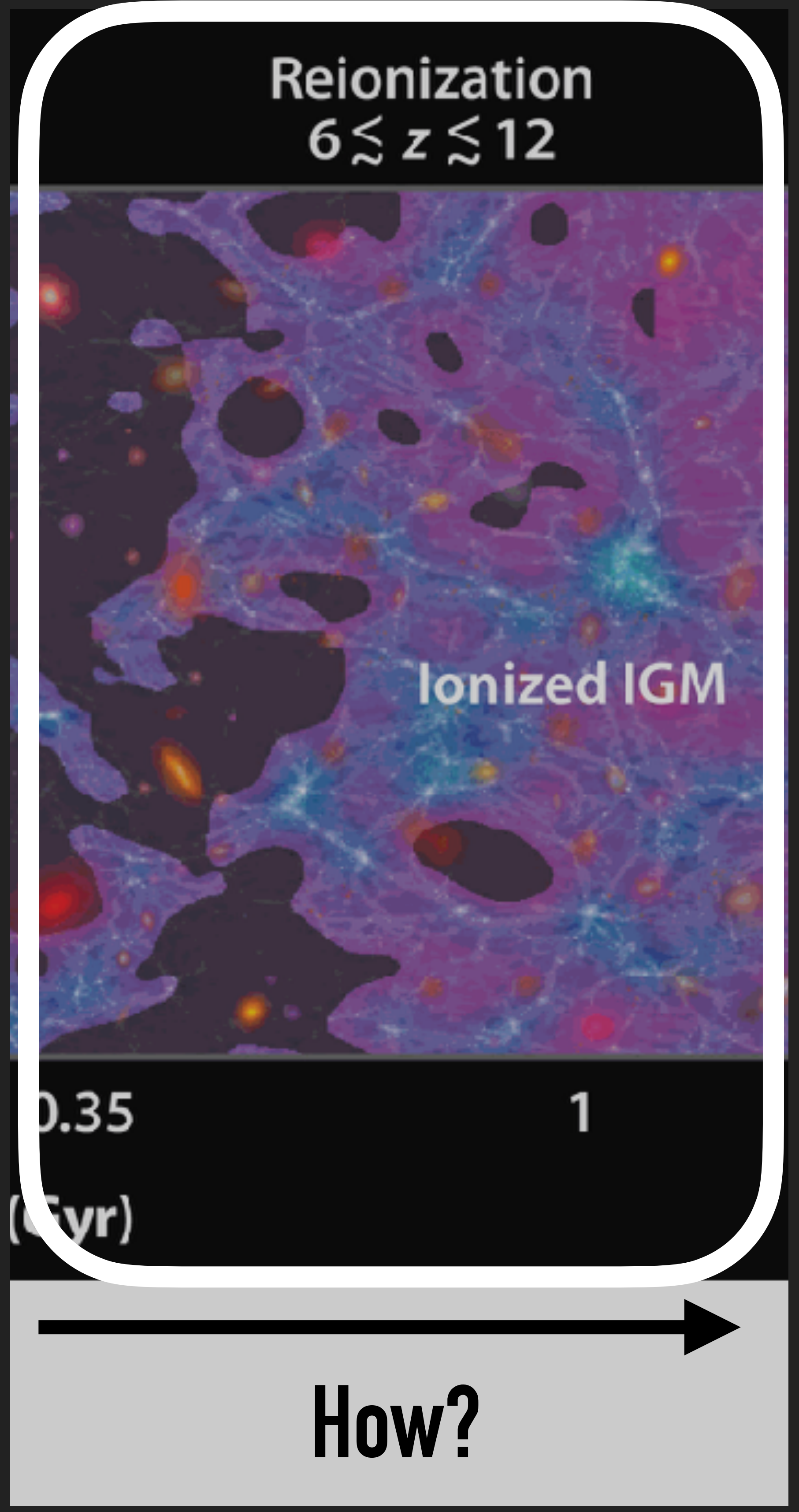
Robertson 2022, ARAA



$$\dot{n}_{\rm ion}(M_{\rm halo}, z, \ldots.) =$$

REIONIZATION OF THE UNIVERSE

Robertson 2022, ARAA



$$\dot{n}_{\mathrm{ion}}(M_{\mathrm{halo}}, z, \ldots.) = \rho_{\mathrm{UV}}\ \xi_{\mathrm{ion}}\ f_{\mathrm{esc}}$$

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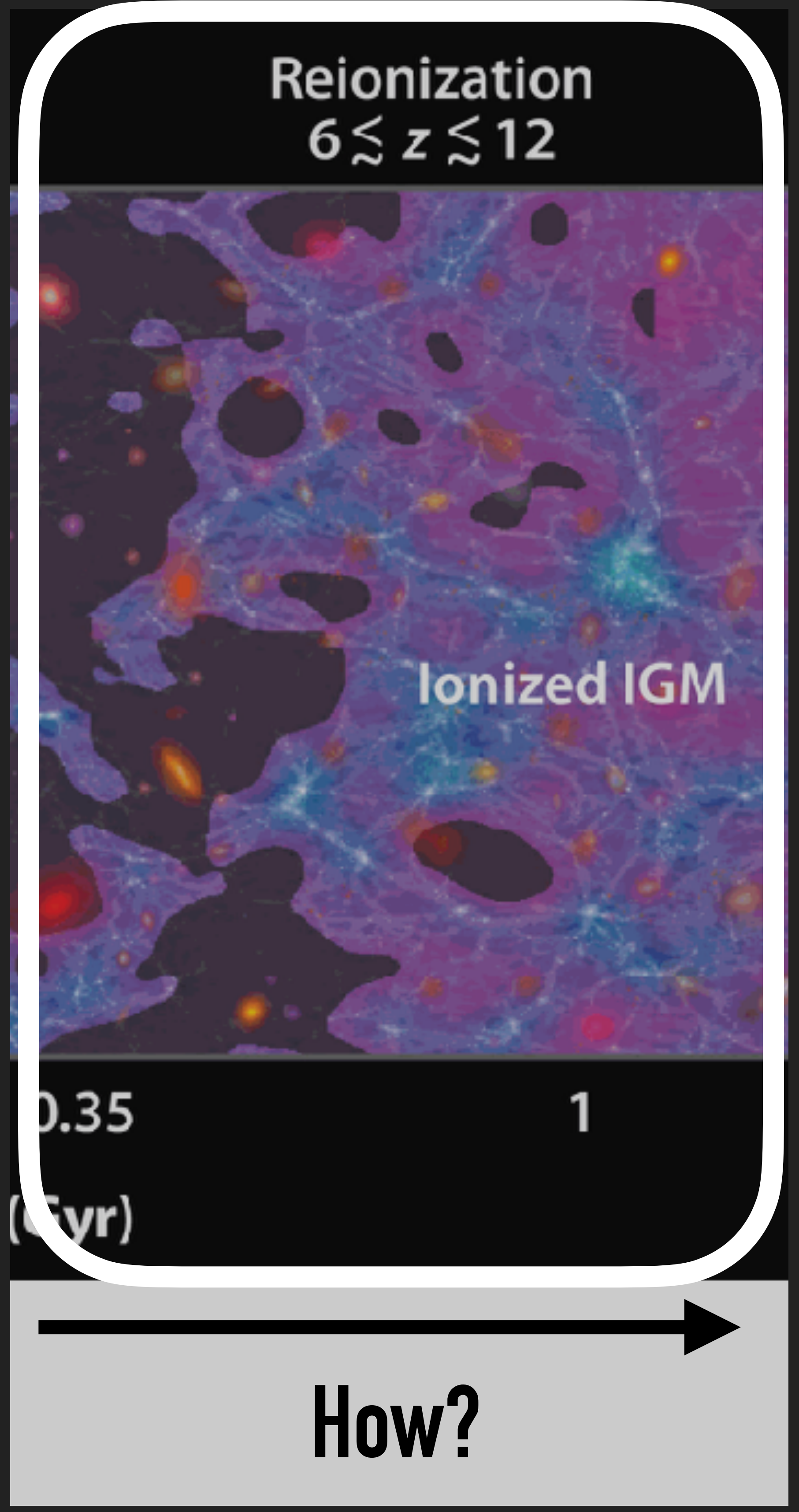

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Cosmology

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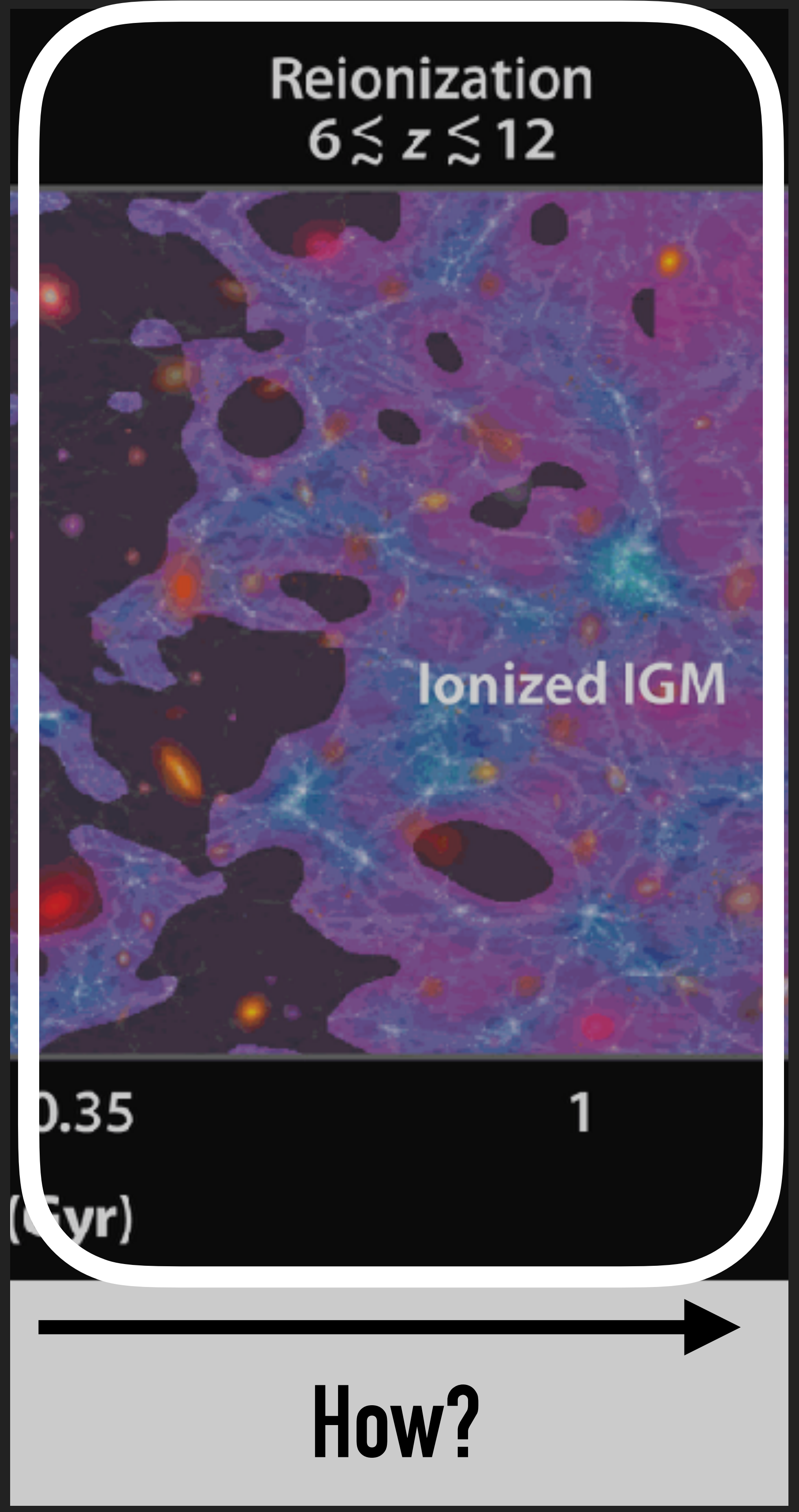

Star Formation Histories, IMF

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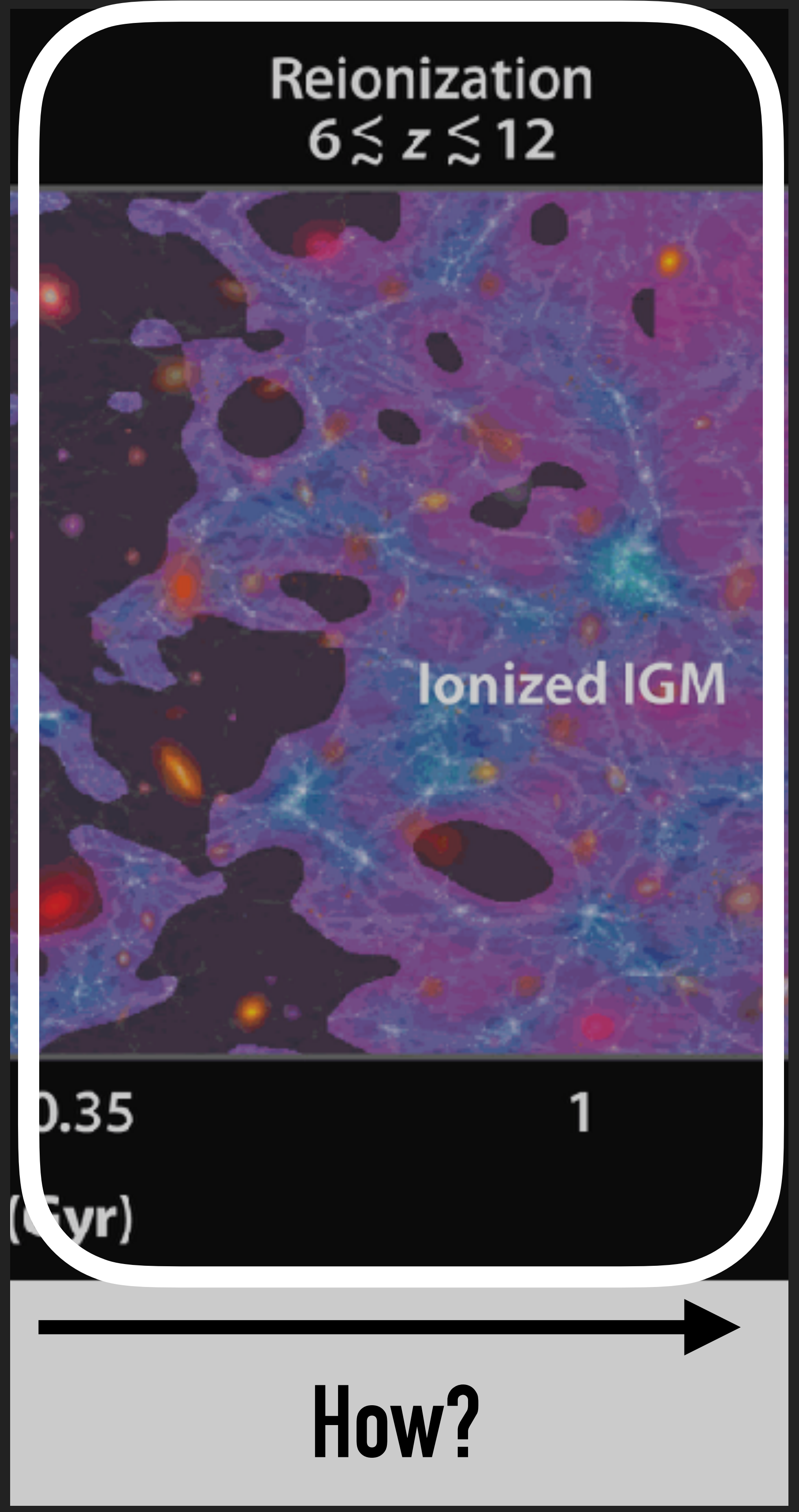

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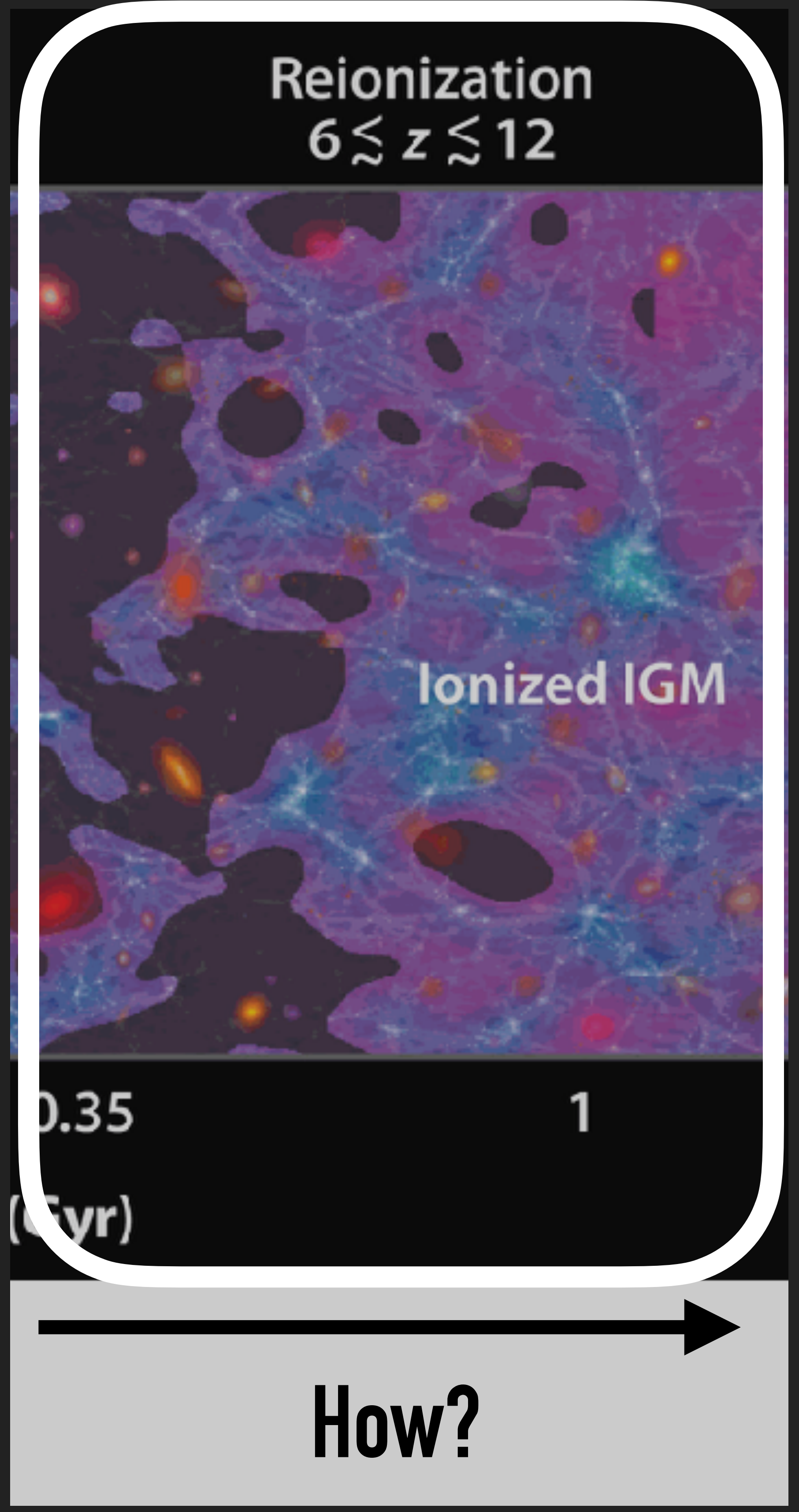

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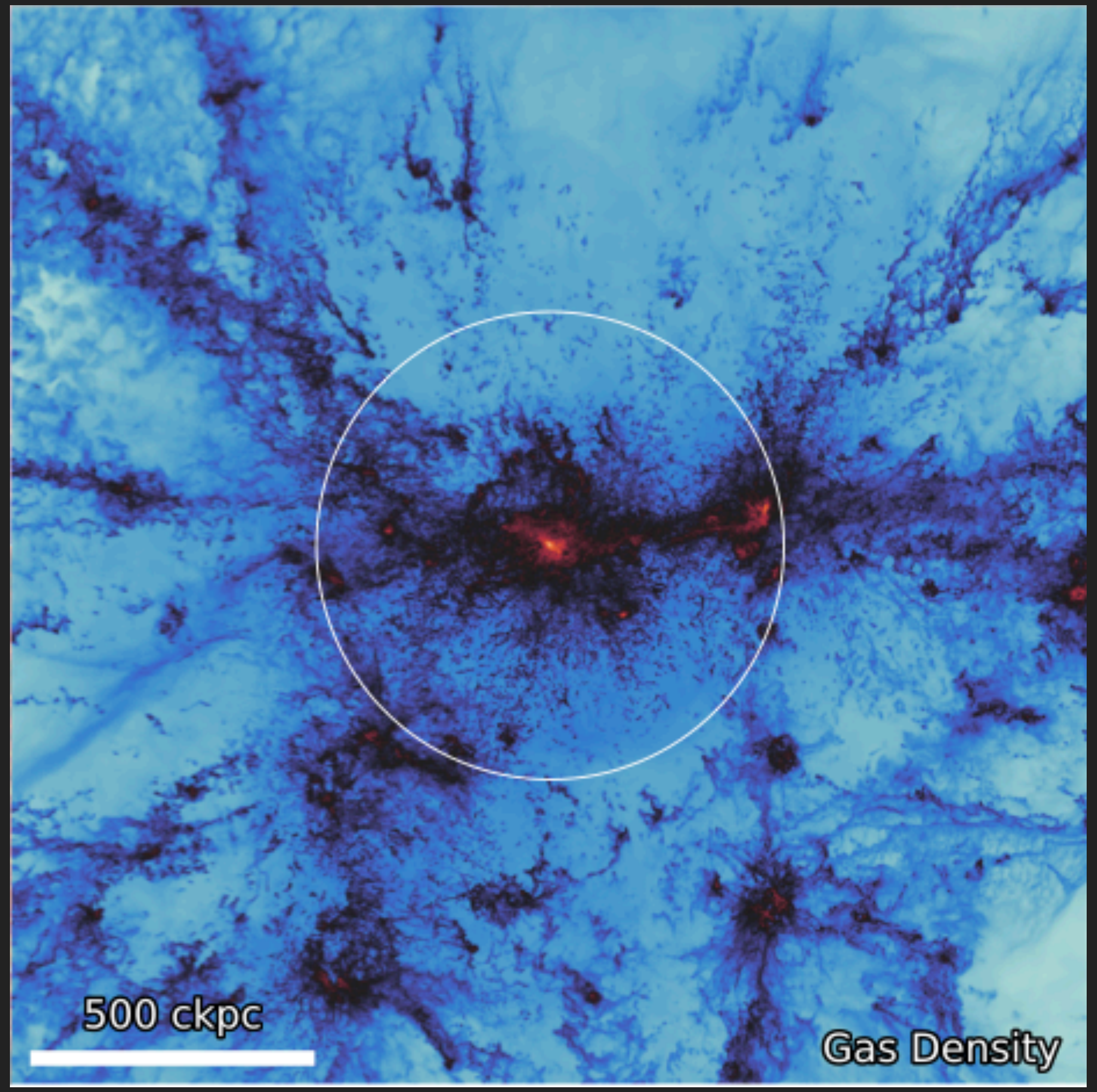

Kannan et al. 2025

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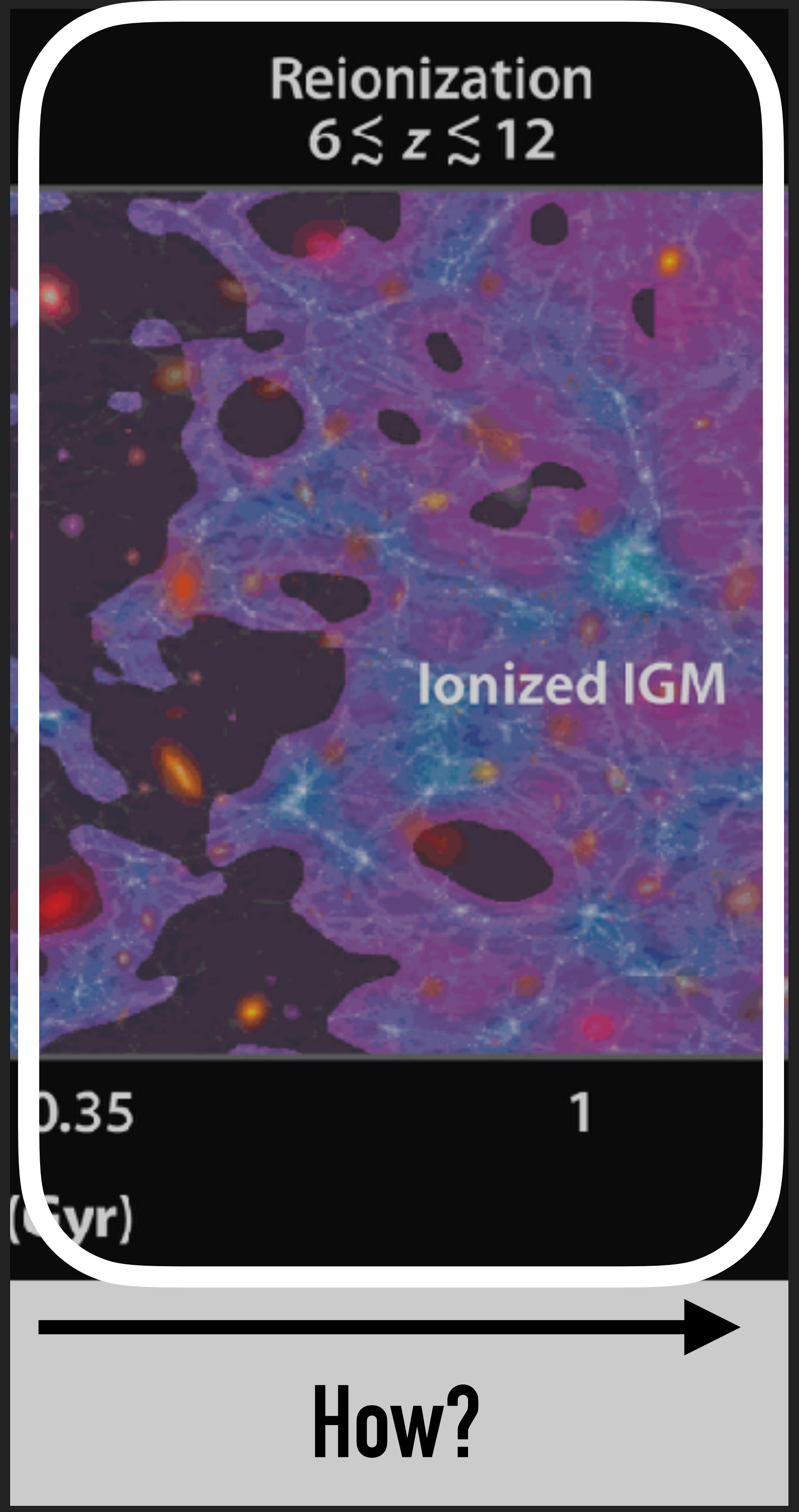

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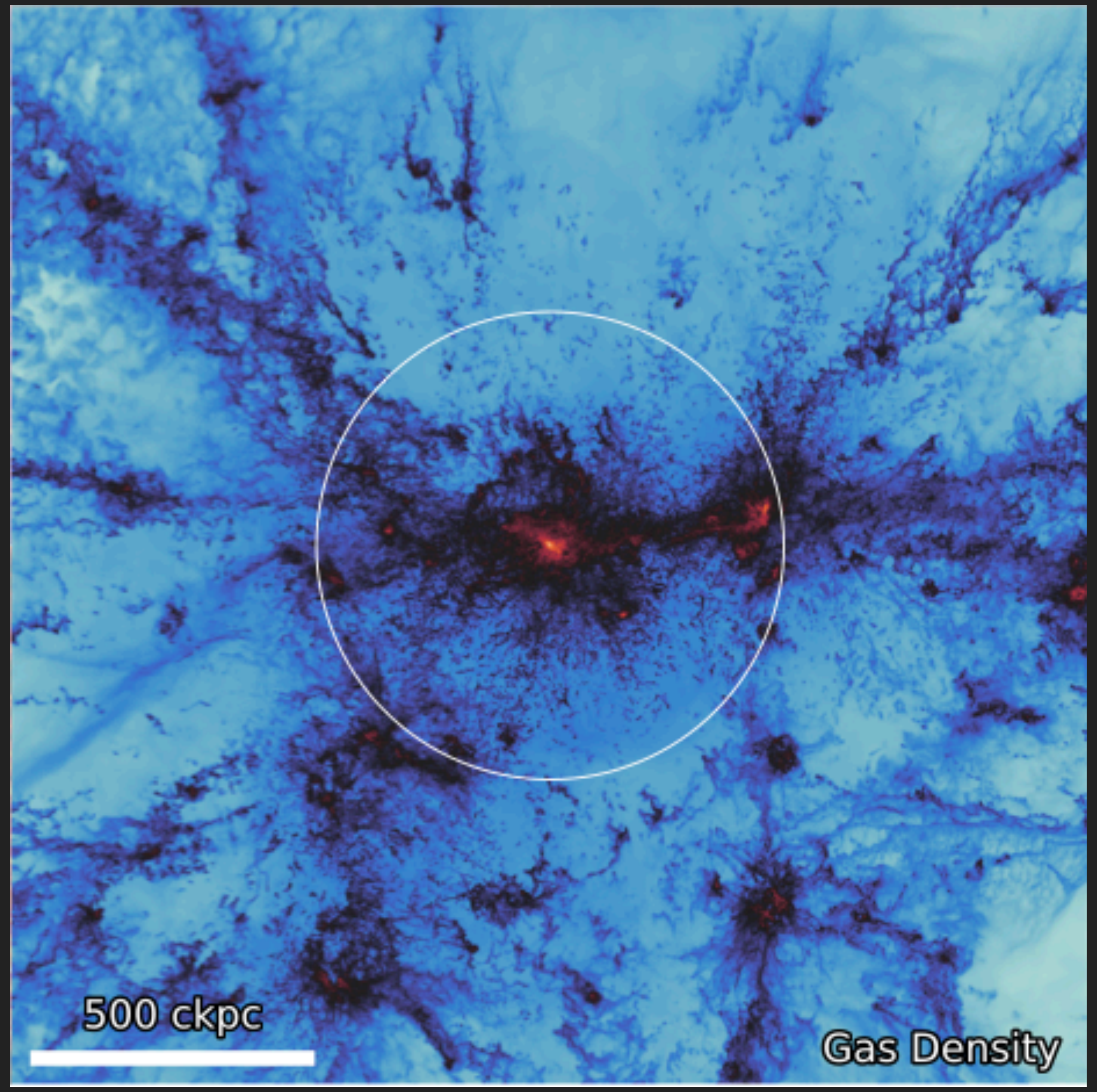
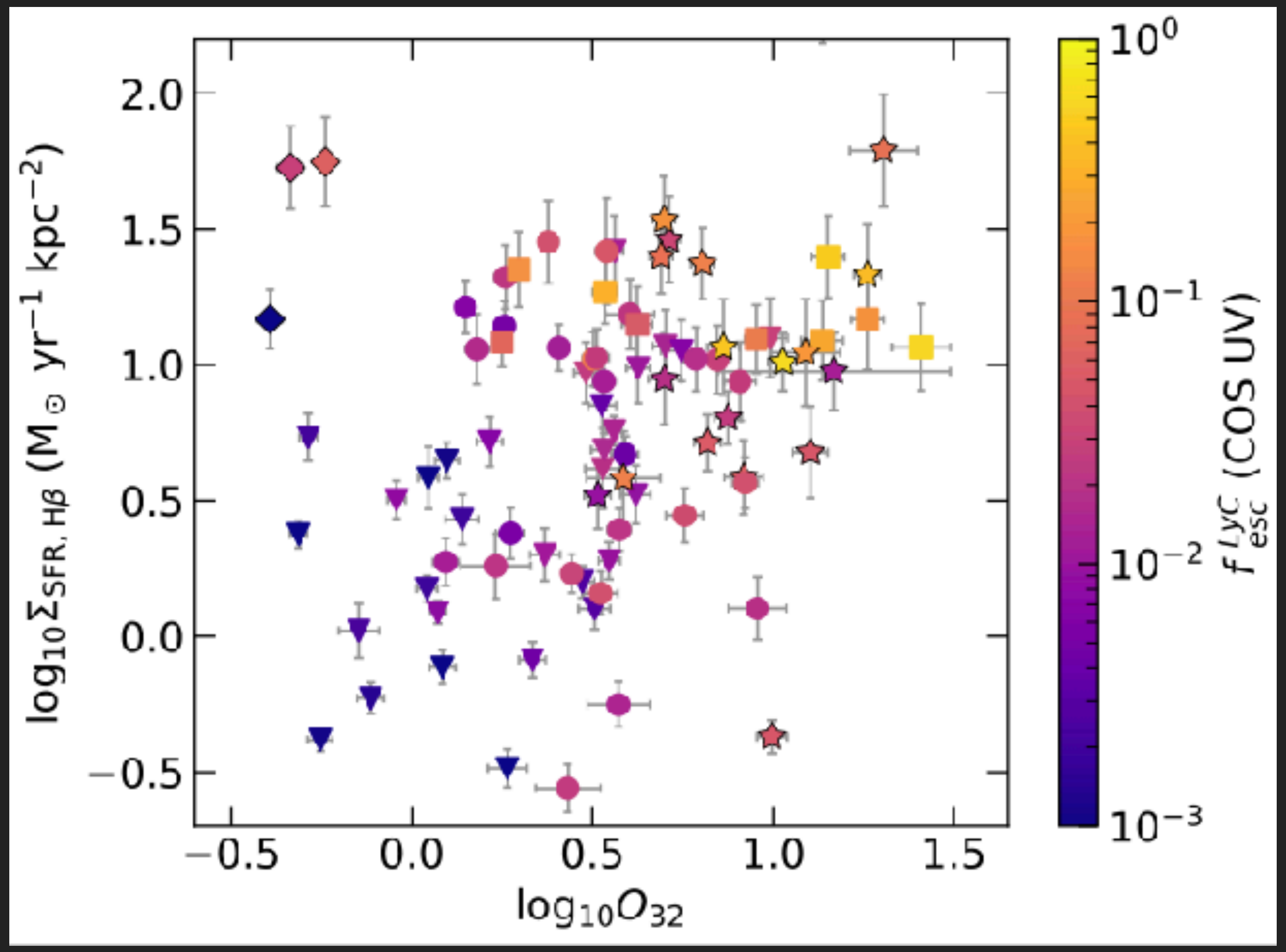


Kannan et al. 2025

Observational surveys (e.g. LzLCS)



Flury et al. 2022