The (Un)Changing ISM in FIRE Galaxies through Cosmic Time

18th Potsdam Thinkshop

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Matt Orr

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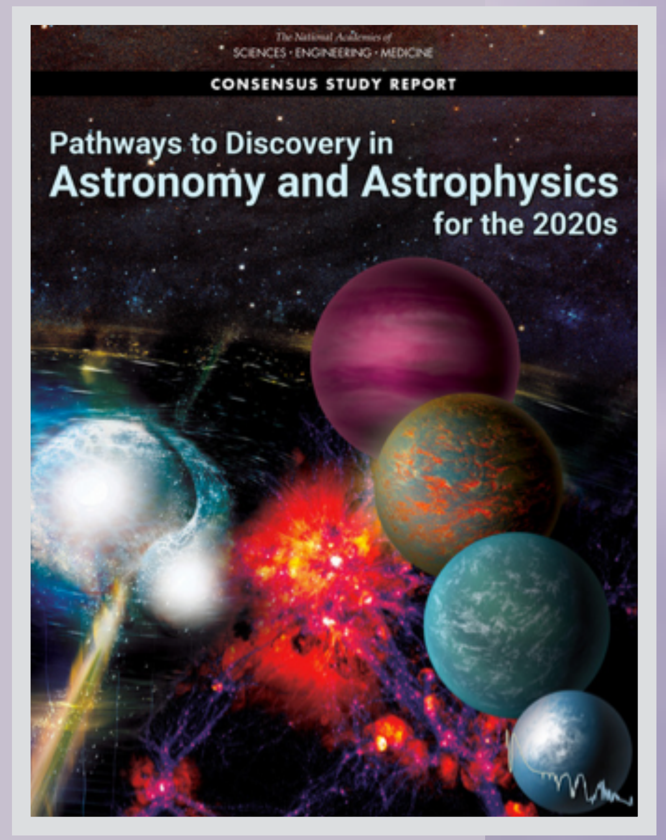
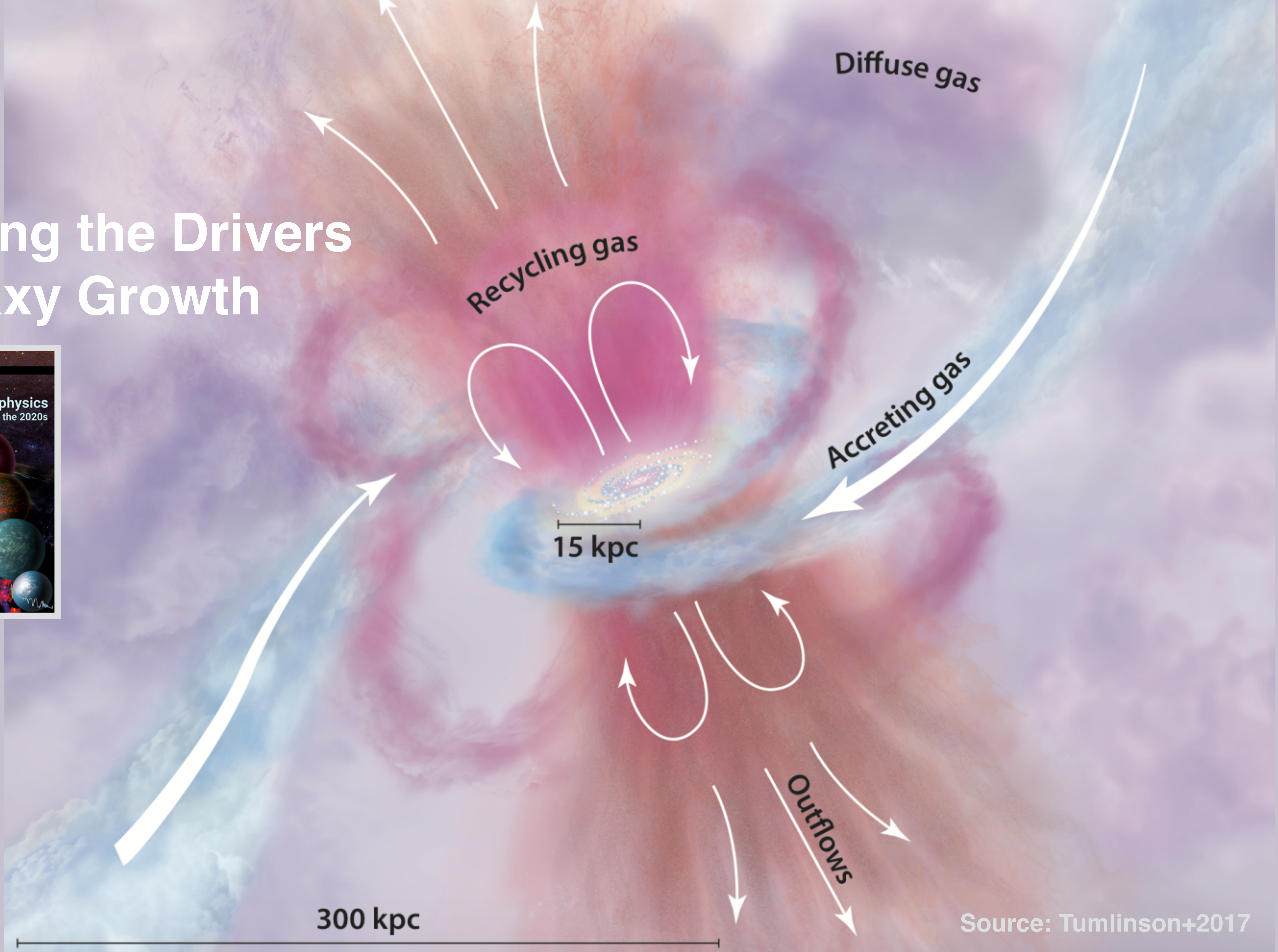
Physics & Astronomy | Rutgers University

Unveiling the Drivers of Galaxy Growth

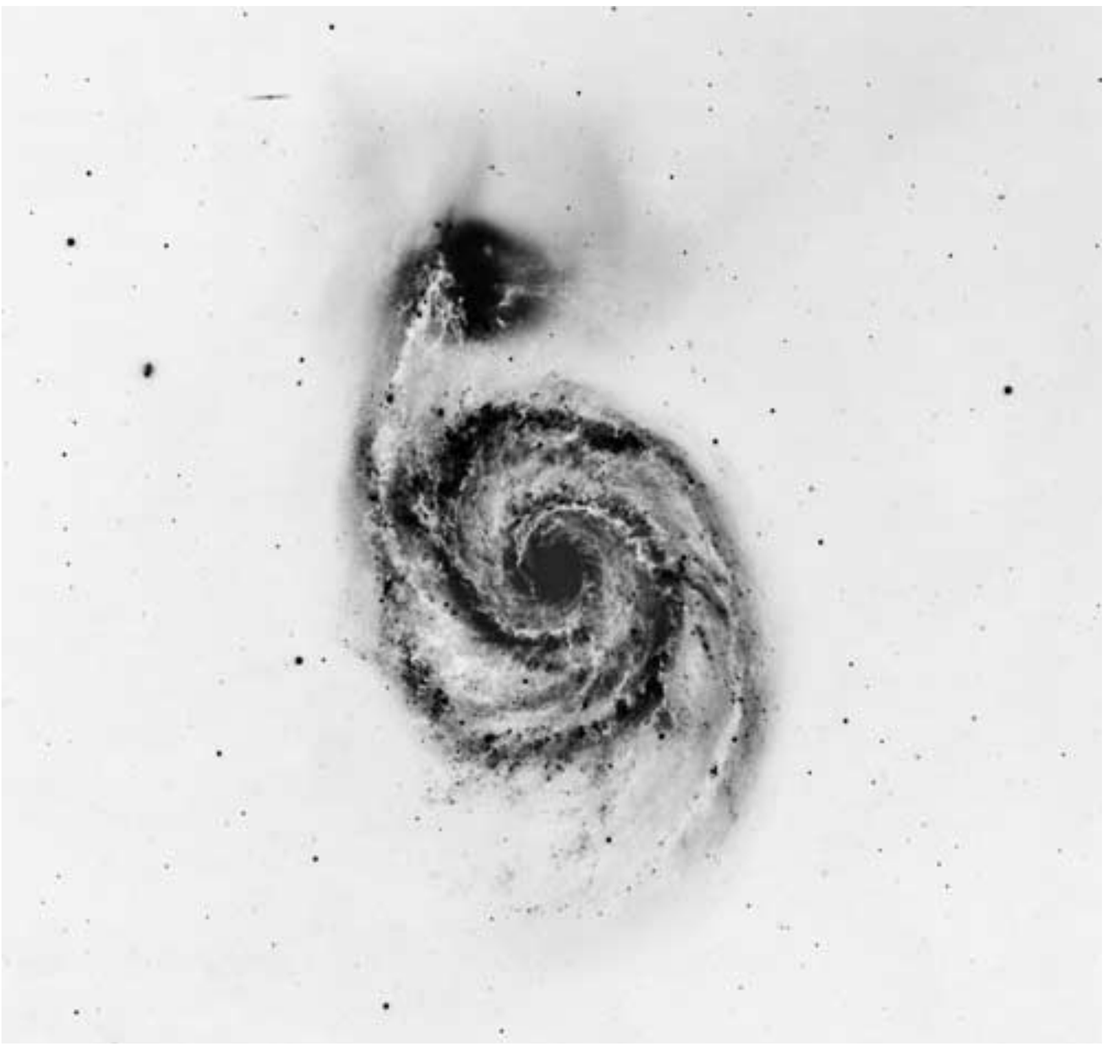




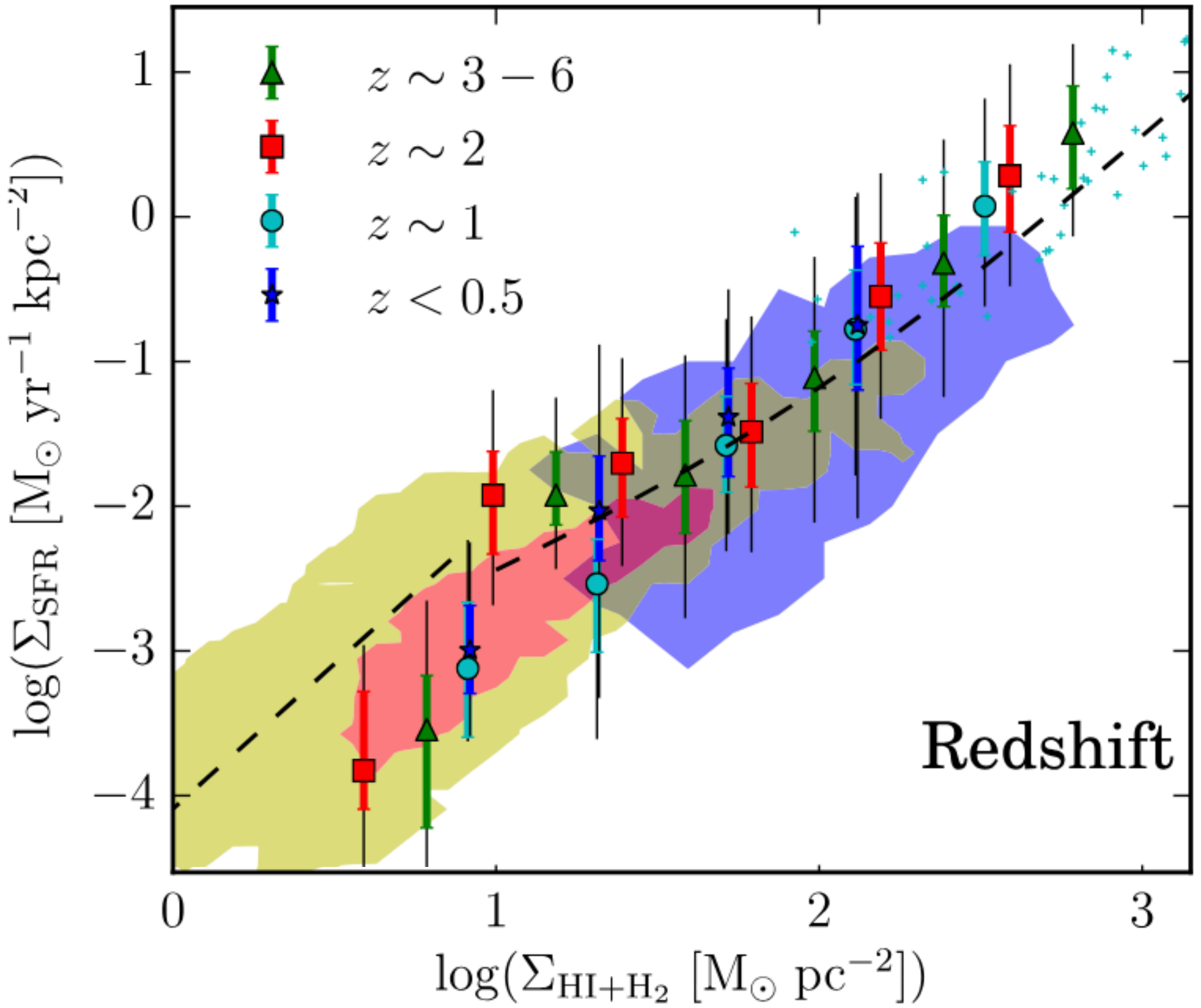
Source: Tumlinson+2017

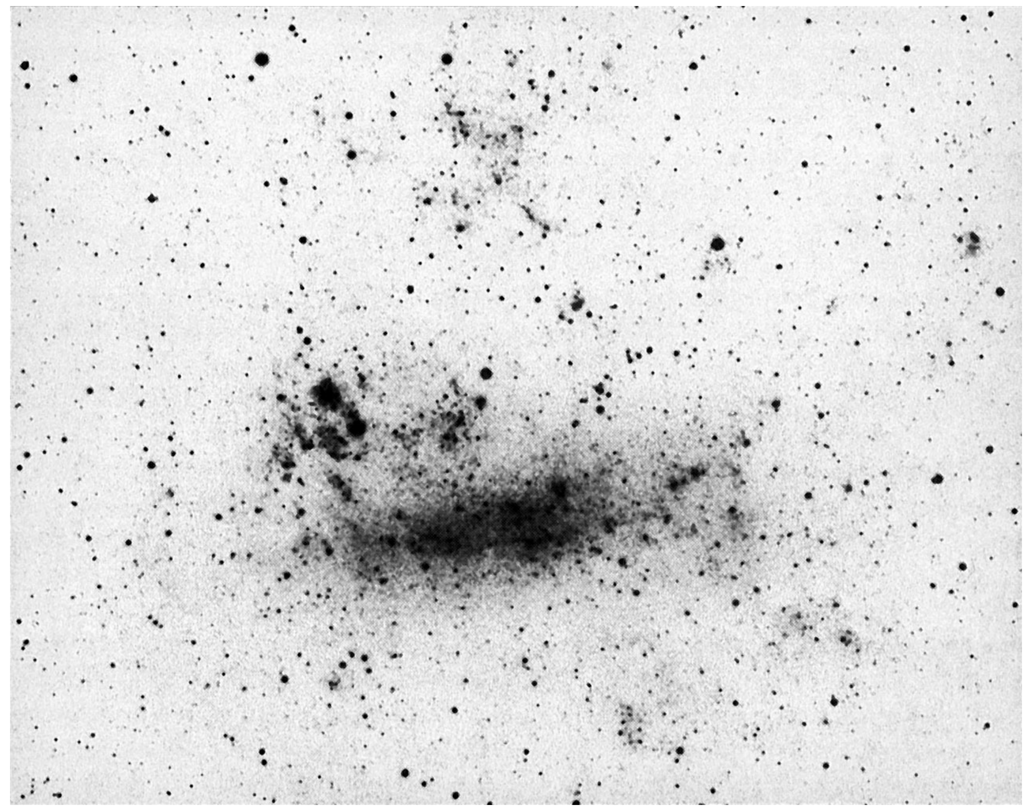
(Lack of) Redshift Evolution of Spatially Resolved Kennicutt-Schmidt

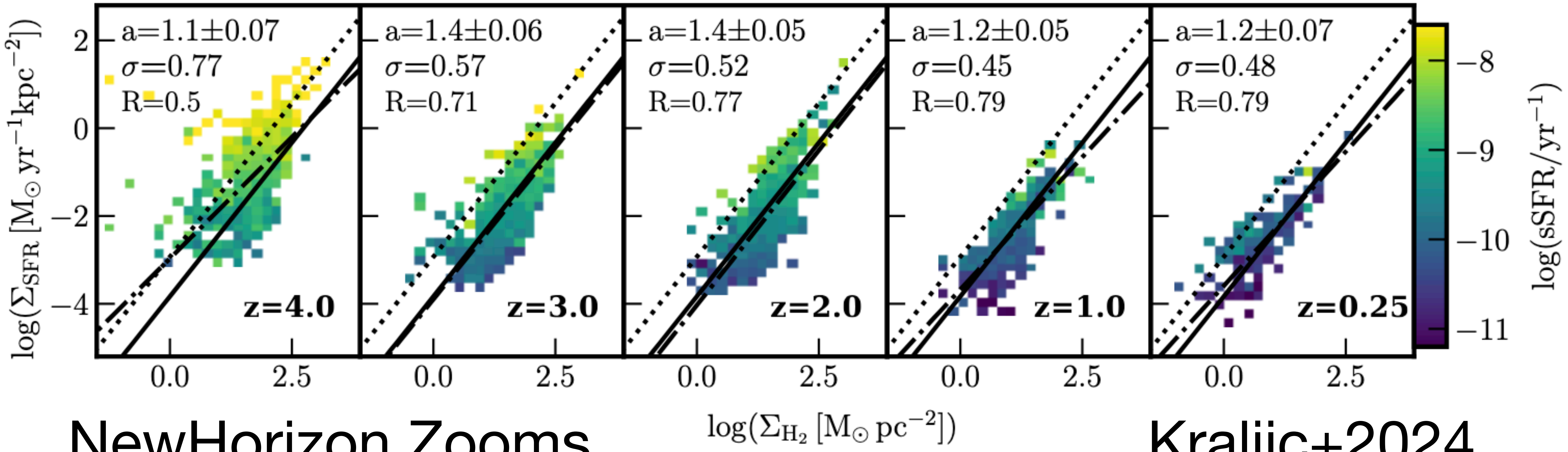
Despite significant redshift evolution of galaxy populations, gas converts into stars on ~kpc scales in a consistent way



FIRE-1 Orr+2018

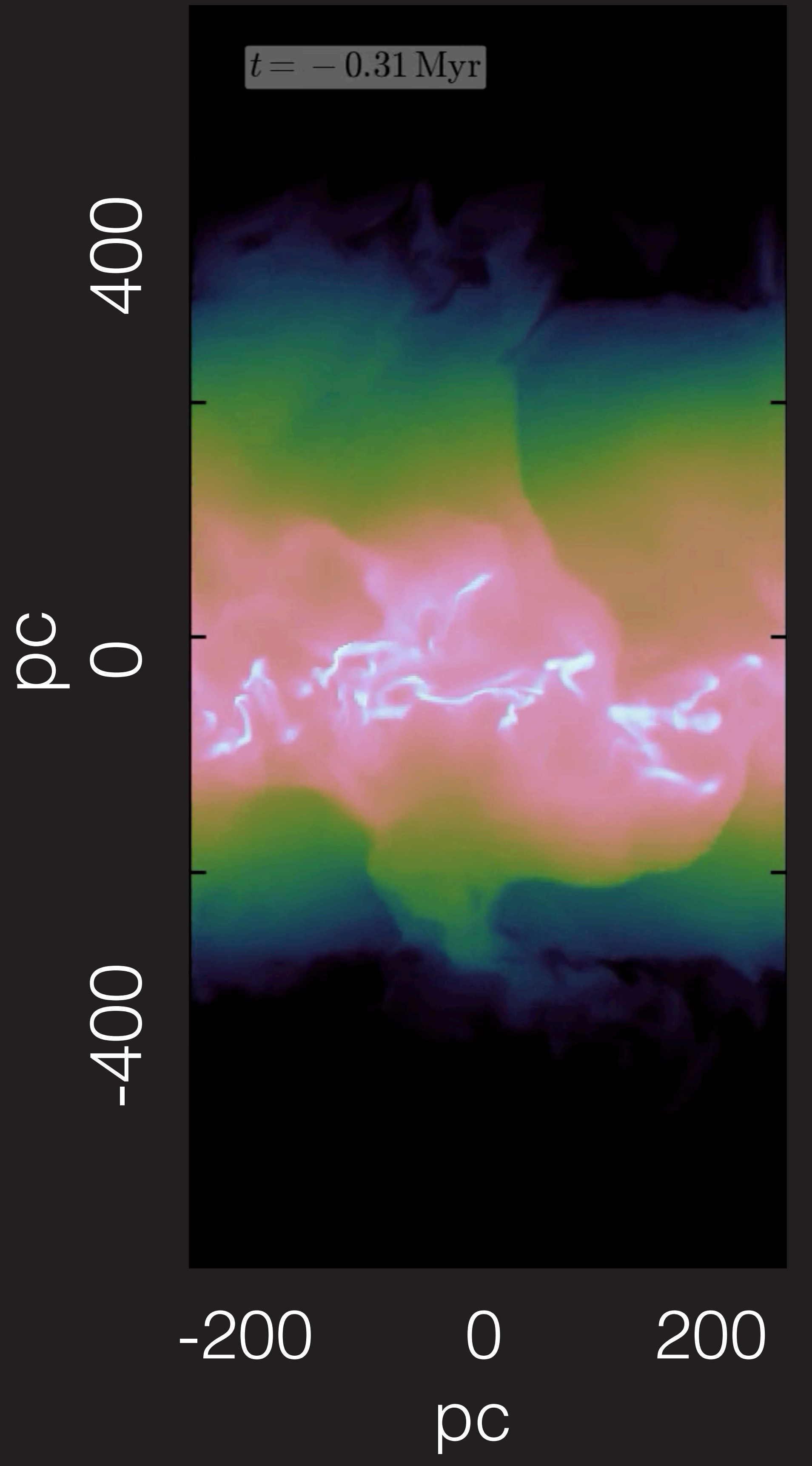




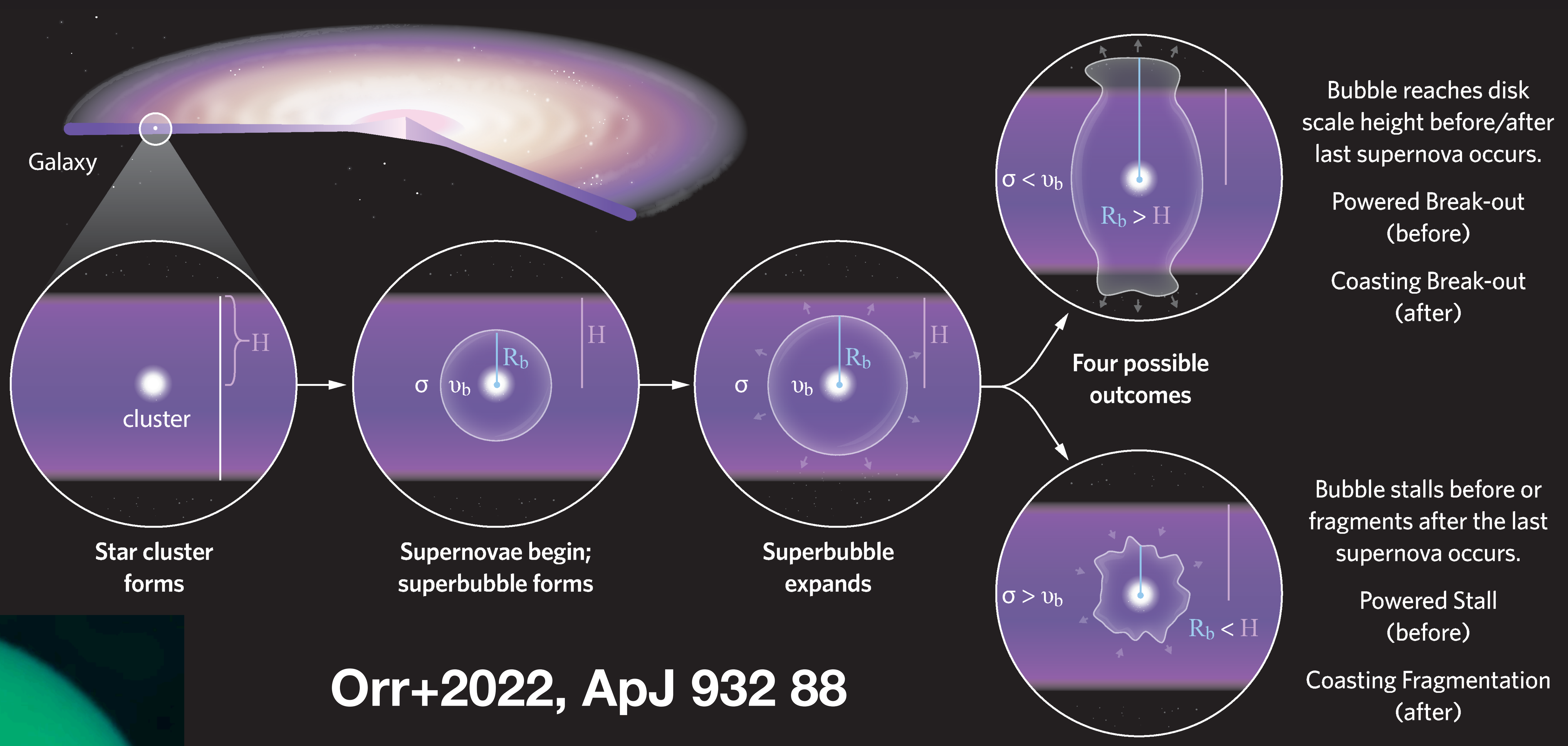


NewHorizon Zooms Kraljic+2024

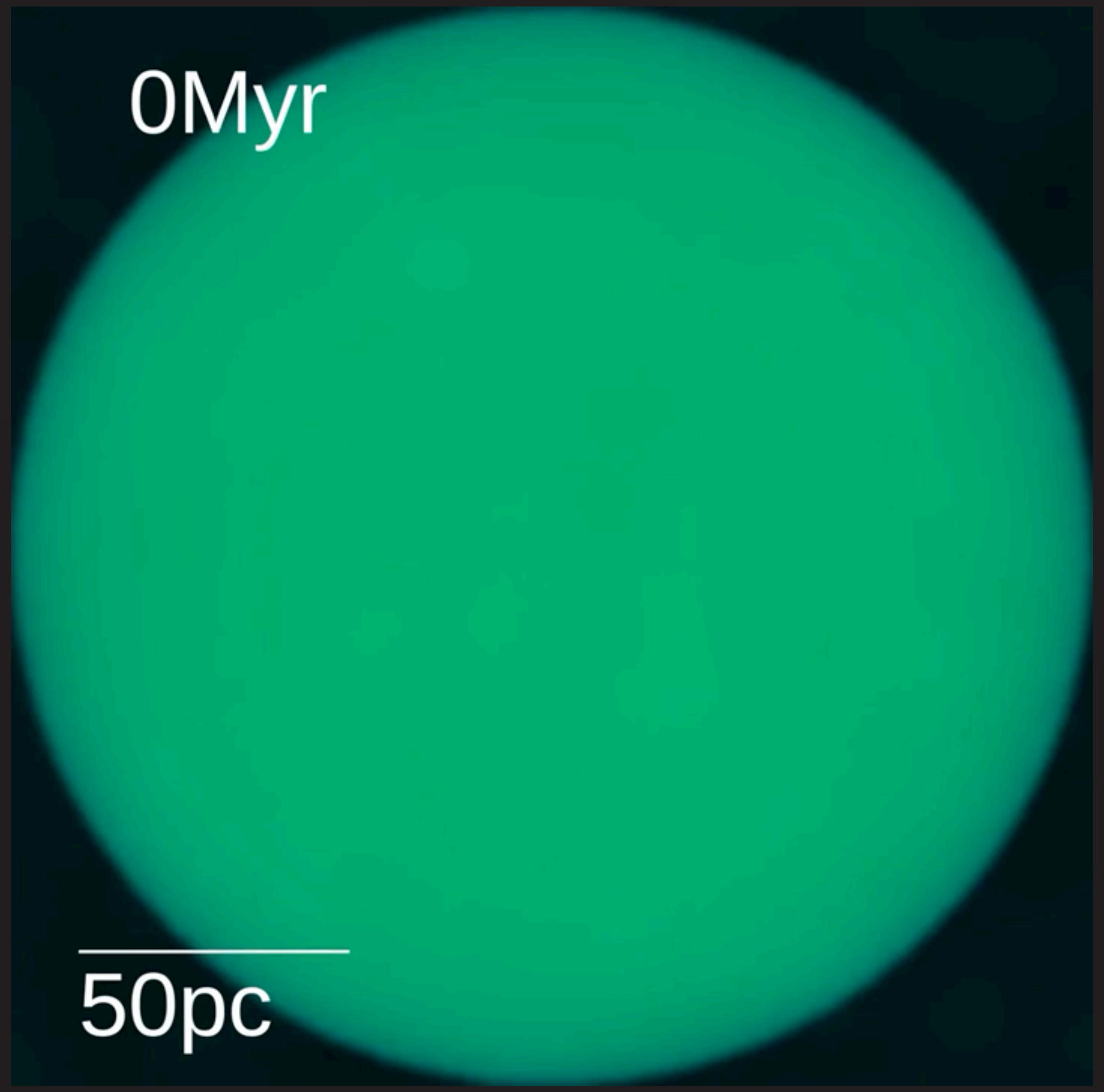
Feedback/Superbubbles in Galaxies



Fielding et al. 2017

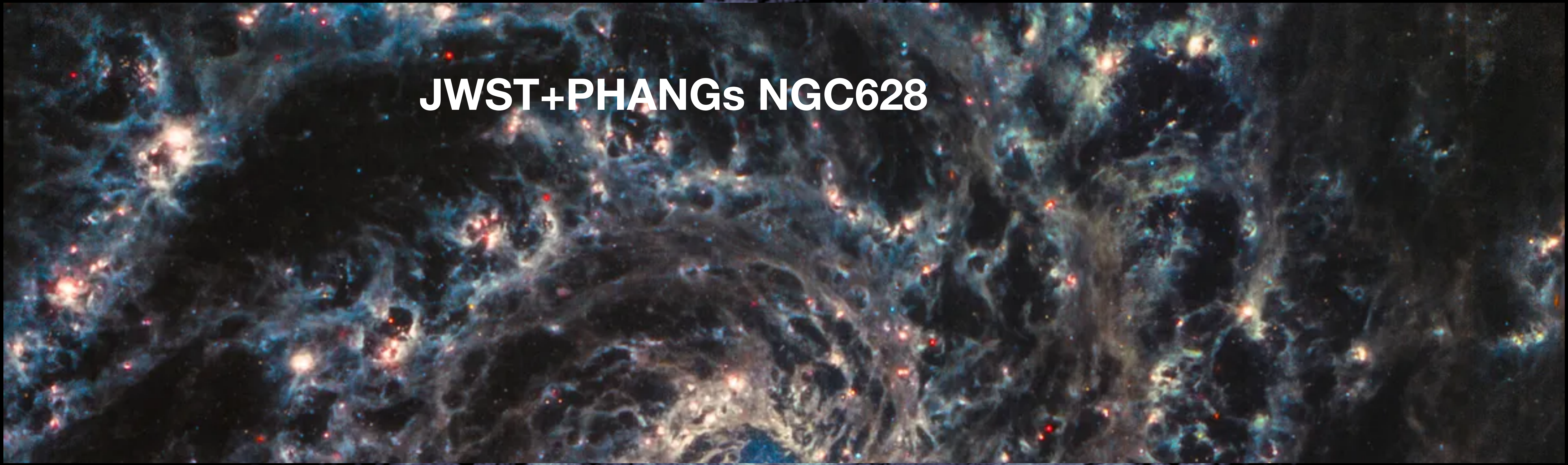


Orr+2022, ApJ 932 88

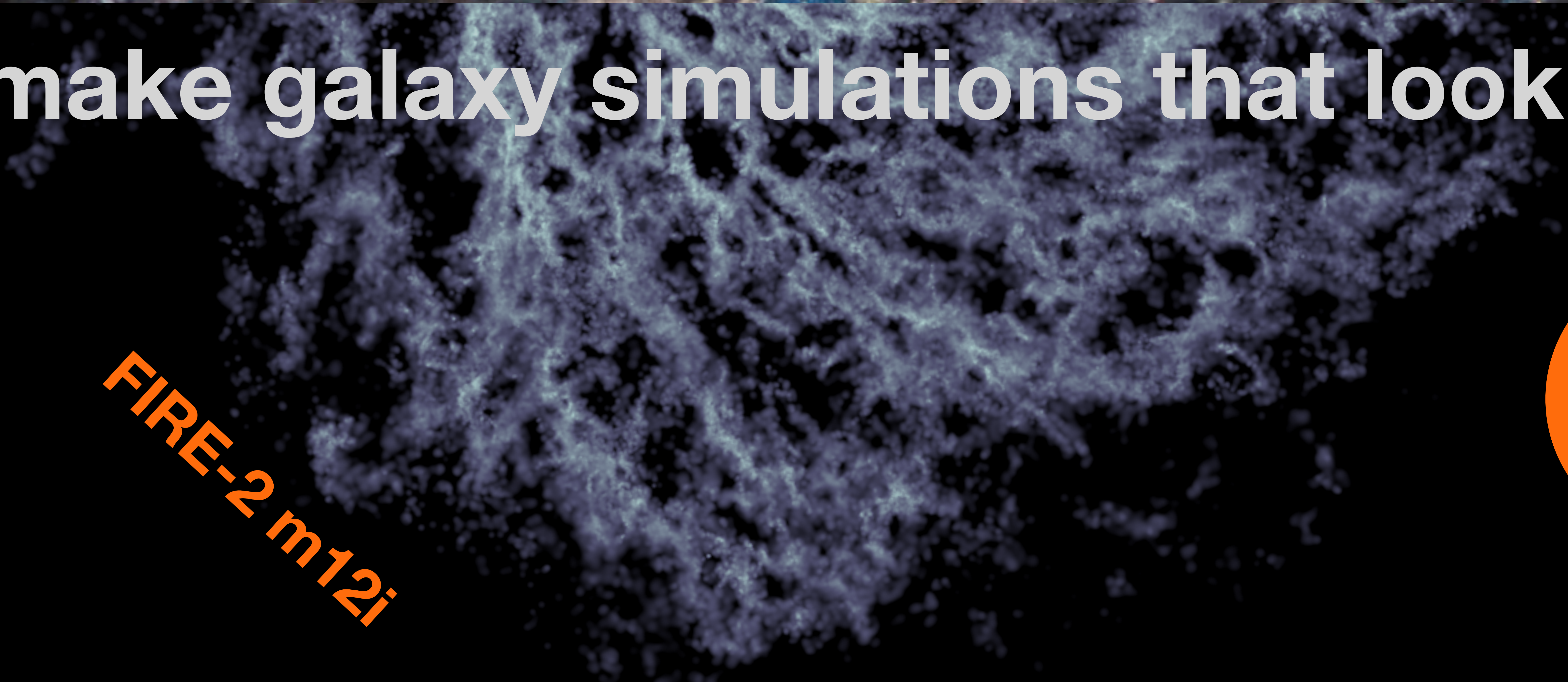


(Grudic+2018)

Plenty of models, once there are any metals, to first order seem to only care about the ratio of local timescale to surface density



Goal: make galaxy simulations that look like this

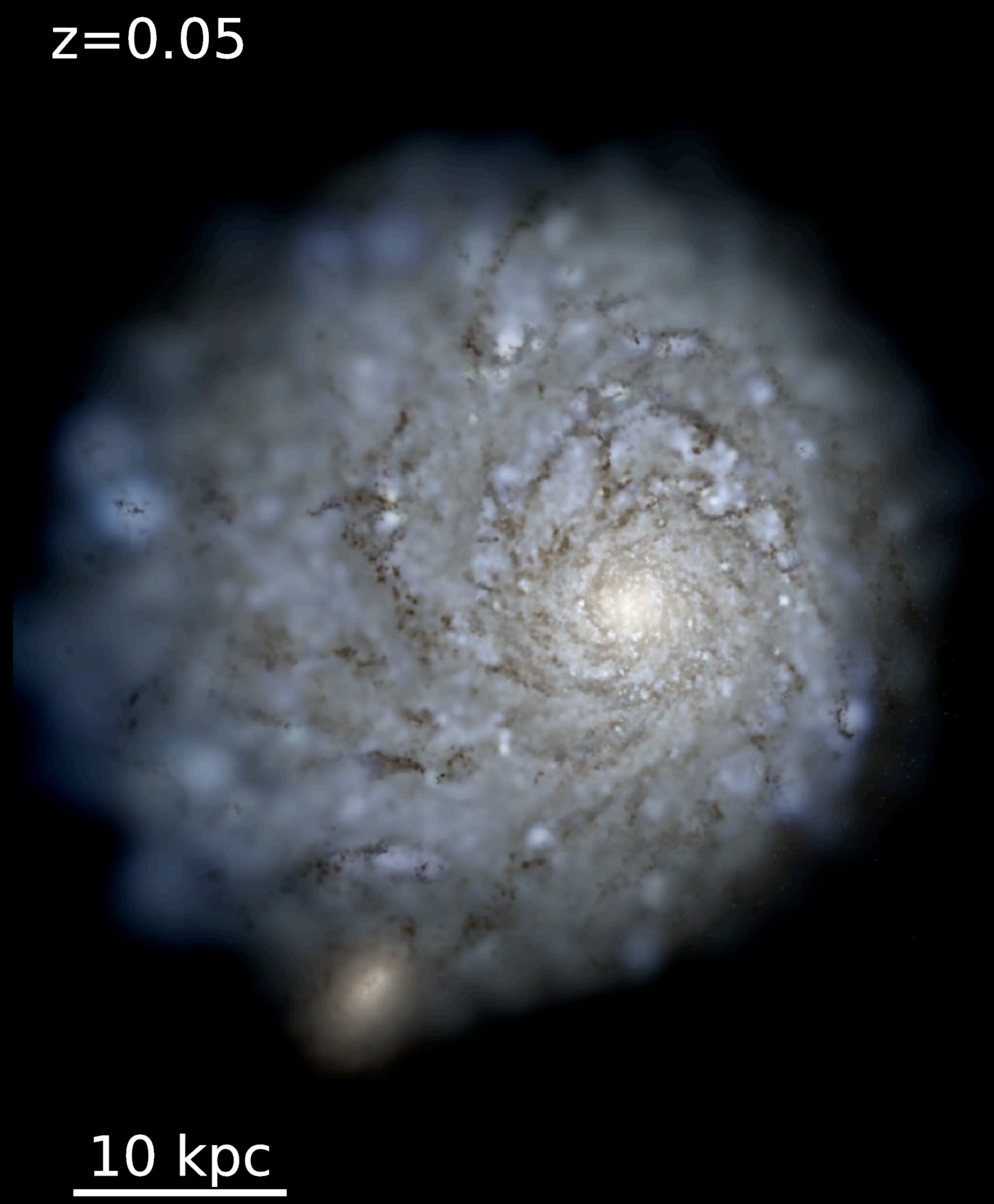


Orr in prep.

Resolving Galaxies in Simulations

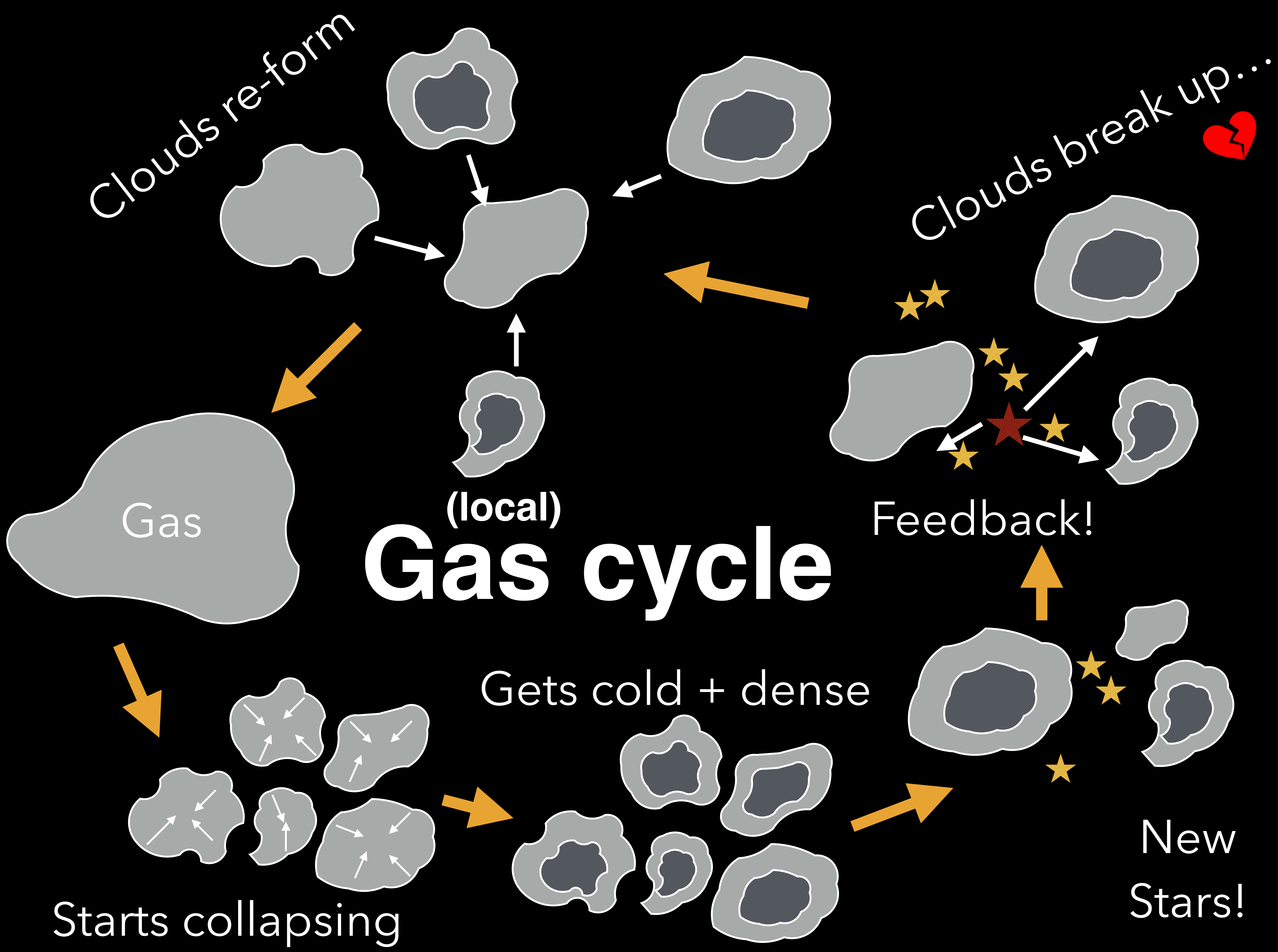
Cosmological simulations are in a unique position to help resolve questions about star formation within galaxies.

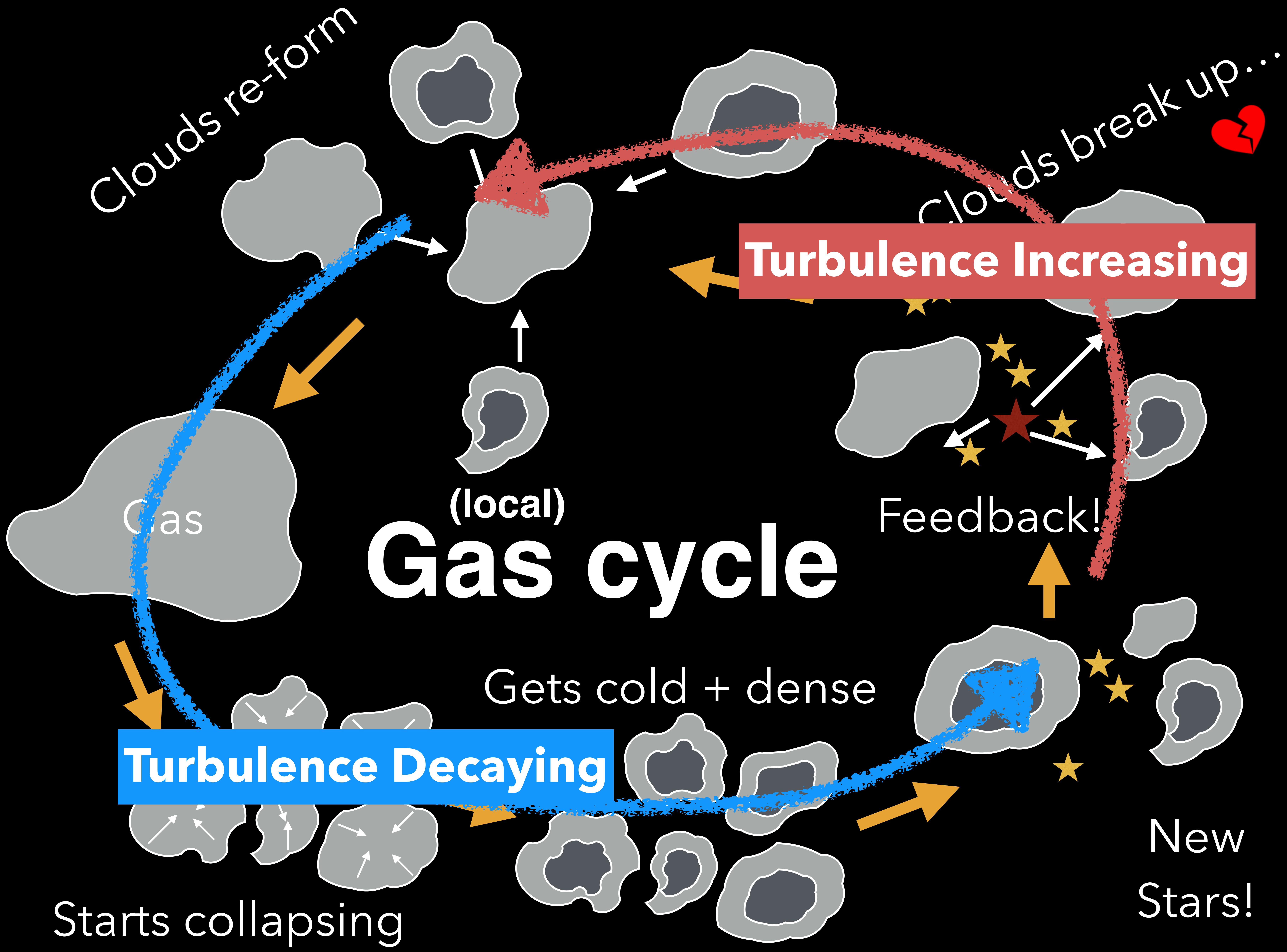
The FIRE Simulations (Feedback In Realistic Environments)



FIRE-1: Hopkins+2014, MNRAS 445, 581
FIRE-2: Hopkins+2018, MNRAS 480, 800
FIRE-3: Hopkins+2023, MNRAS 519, 3154

fire.northwestern.edu


Clouds re-form
Clouds break up...
Gas
(local)
Gas cycle
Feedback!
Gets cold + dense
Starts collapsing
New
Stars!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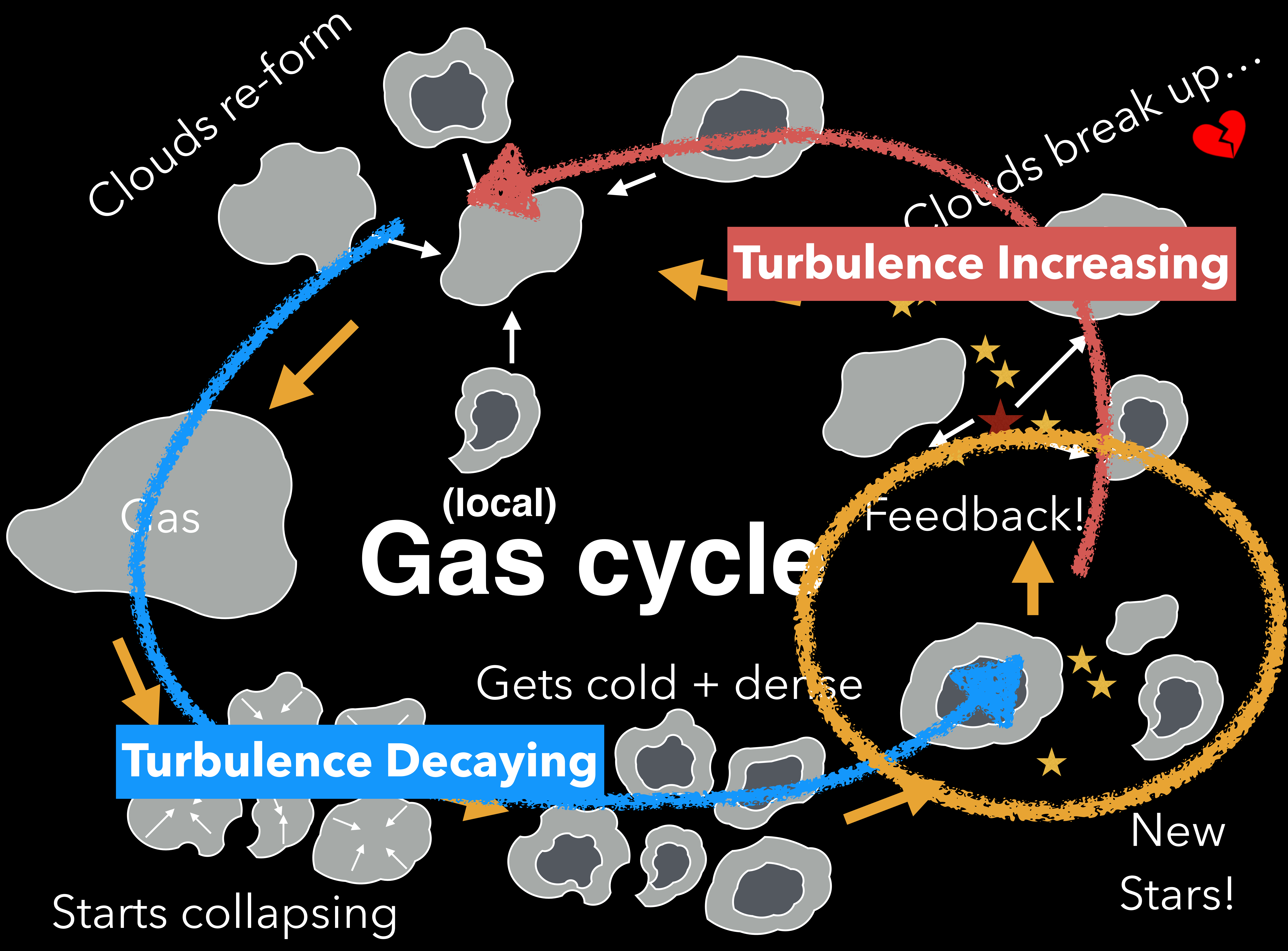

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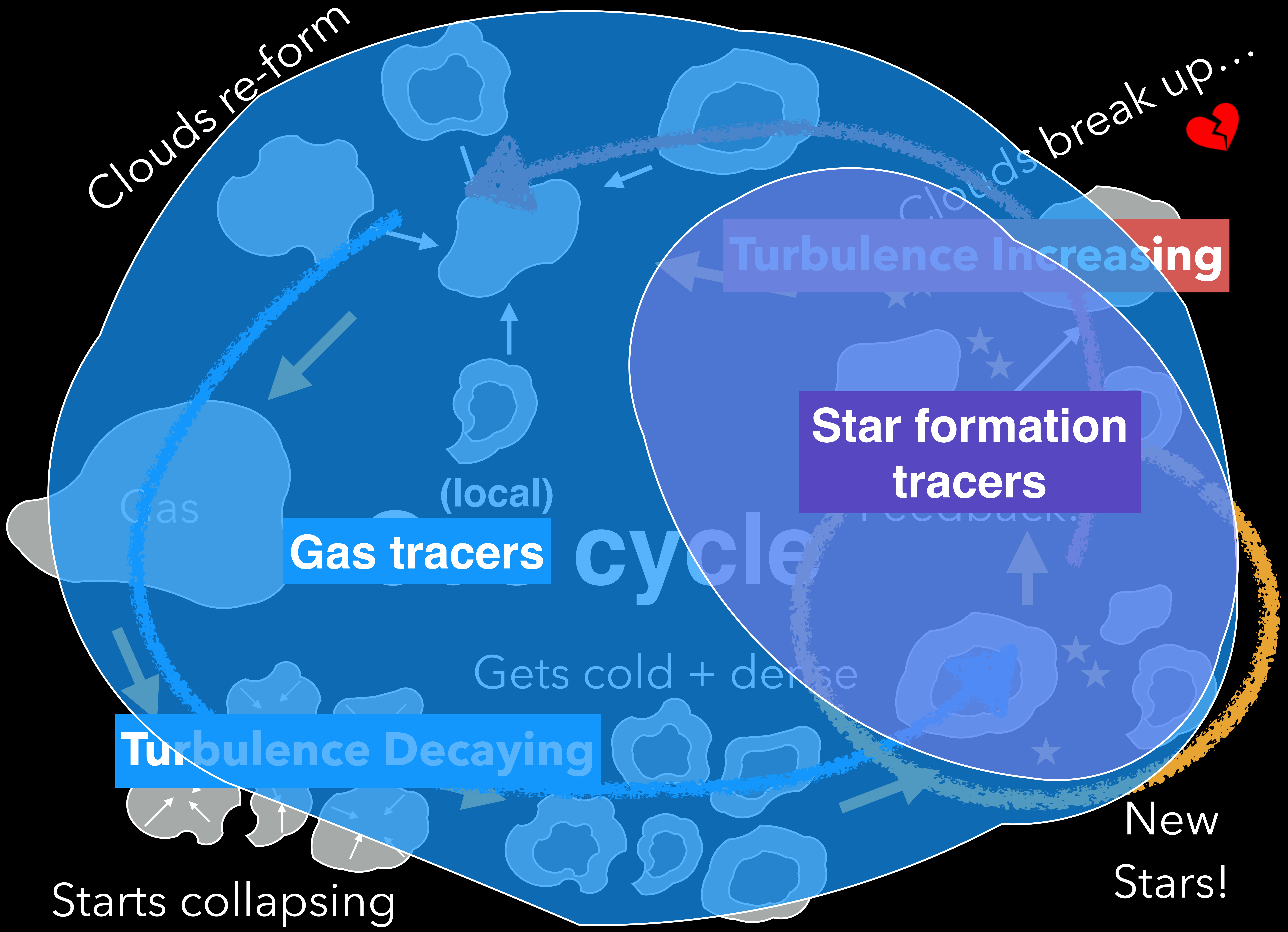
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Clouds break up…
Turbulence Increasing
Star formation tracers
Gas tracers
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Gets cold + dense
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New Stars!


Kennicutt-Schmidt
$\log(\Sigma_{SFR}\ [M_\odot\ yr^{-1}\ kpc^{-2}])$
$\log(\Sigma_{gas}\ [M_\odot\ pc^{-2}])$
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Turbulence Increasing
Star formation tracers
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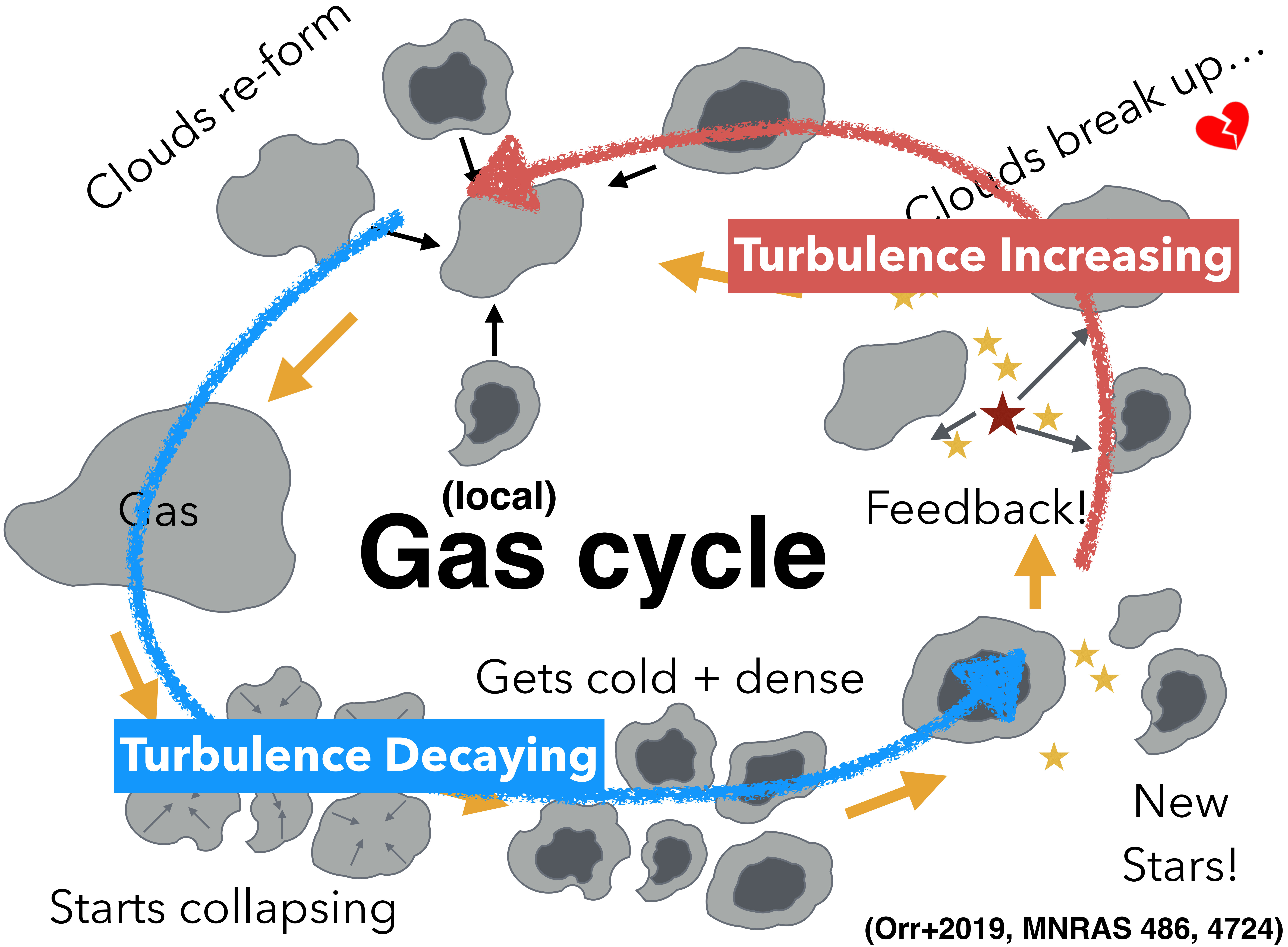
New Stars!



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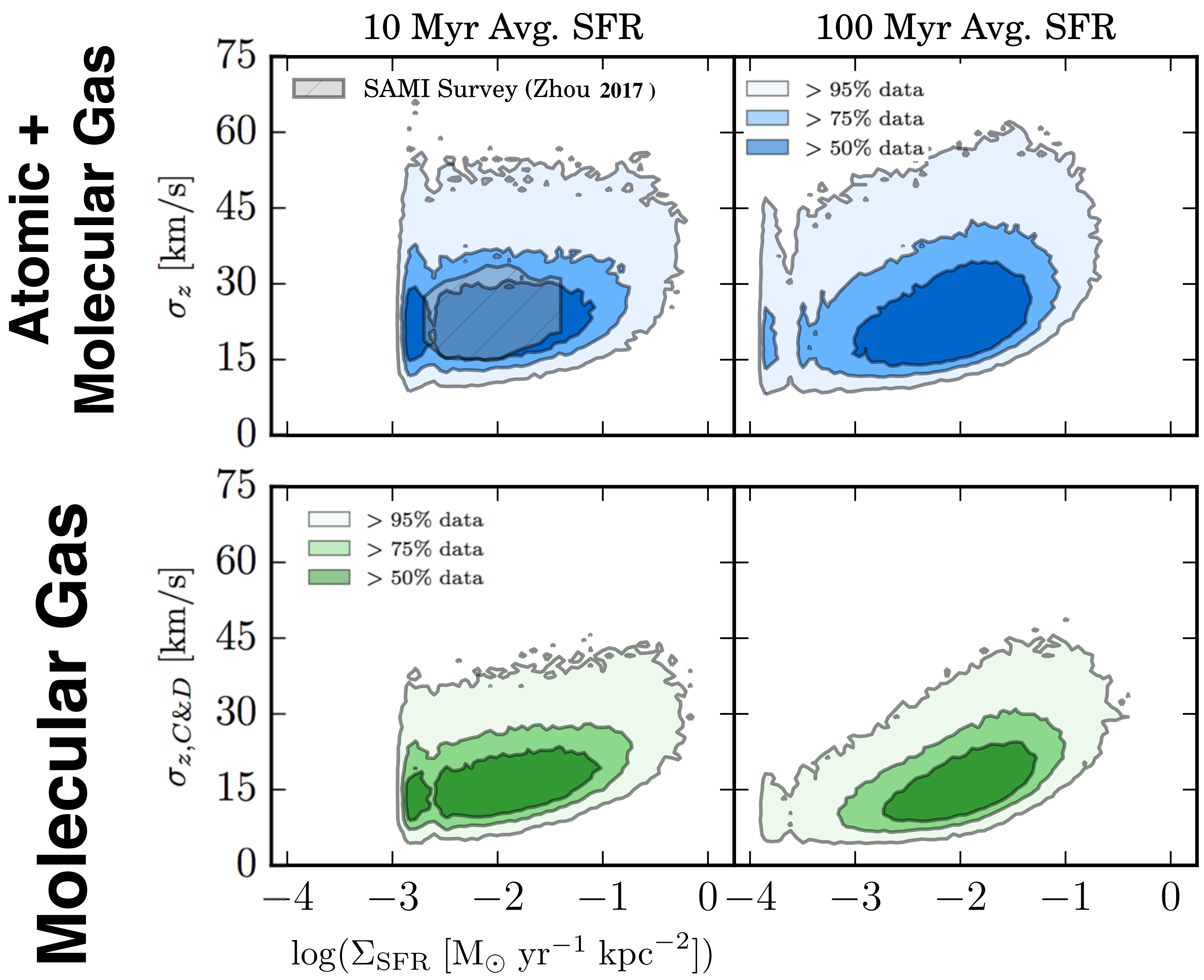
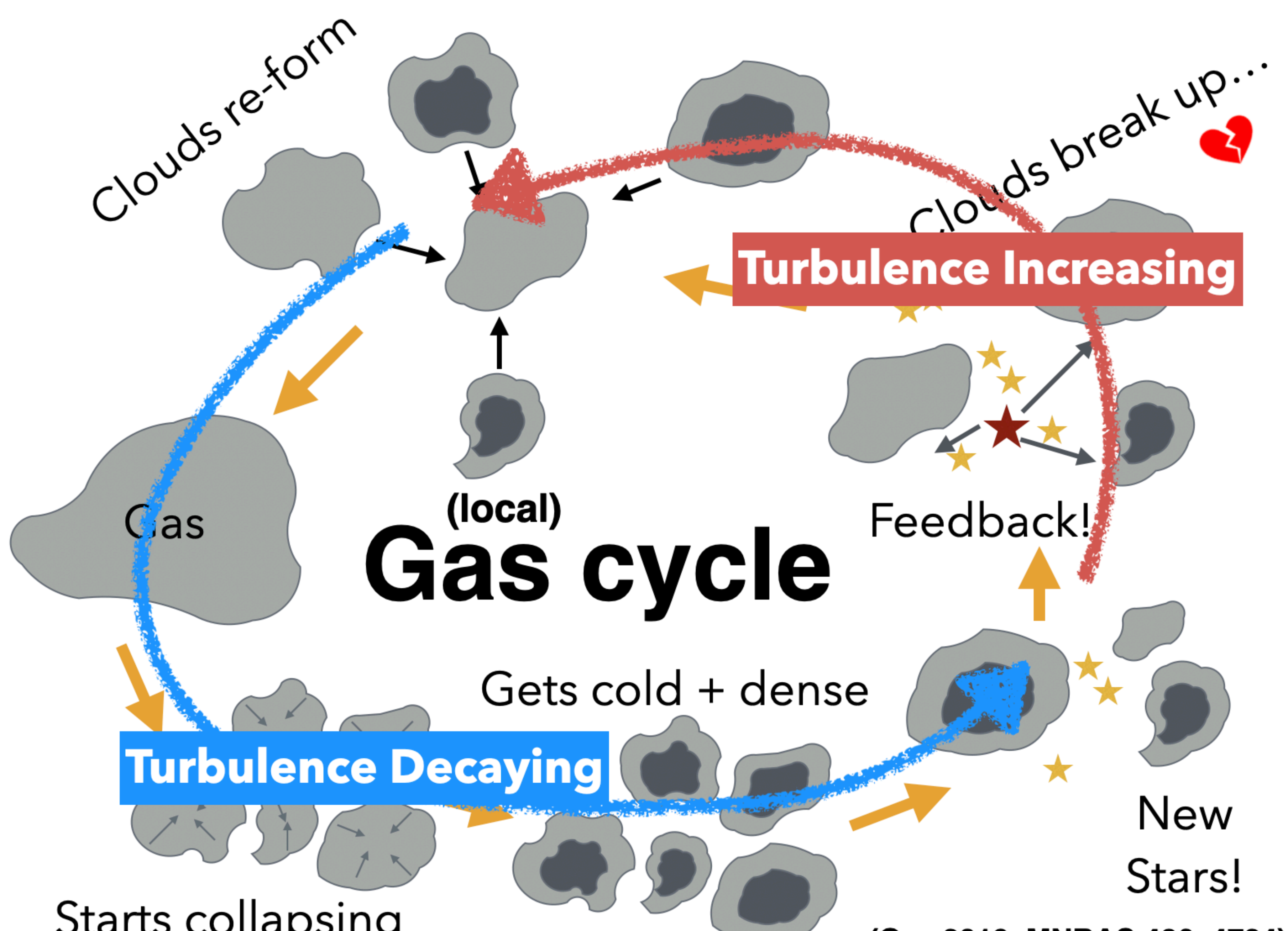
Starts collapsing
(Orr+2019, MNRAS 486, 4724)

Velocity Dispersions & SFRs in *Disks*





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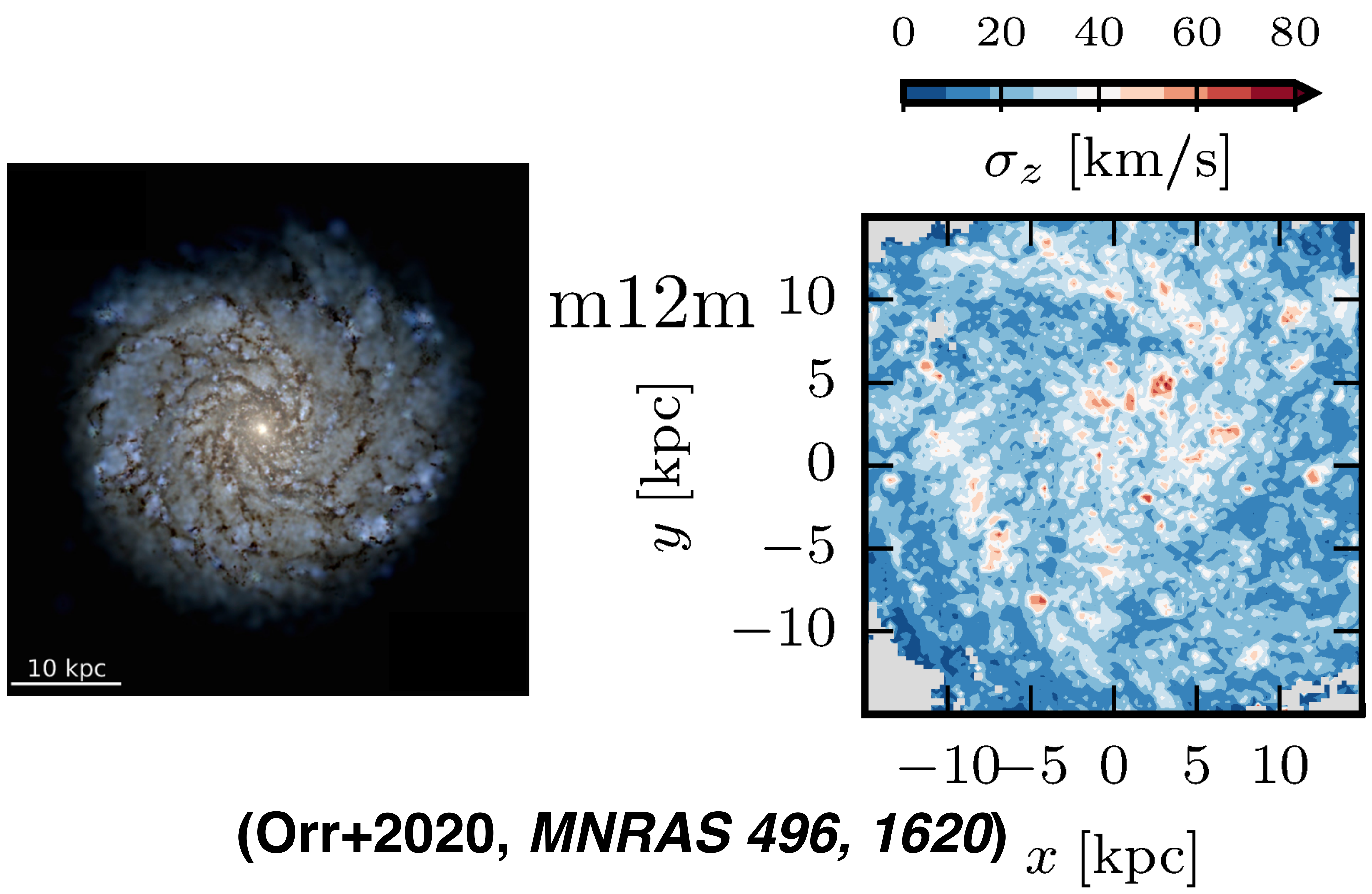
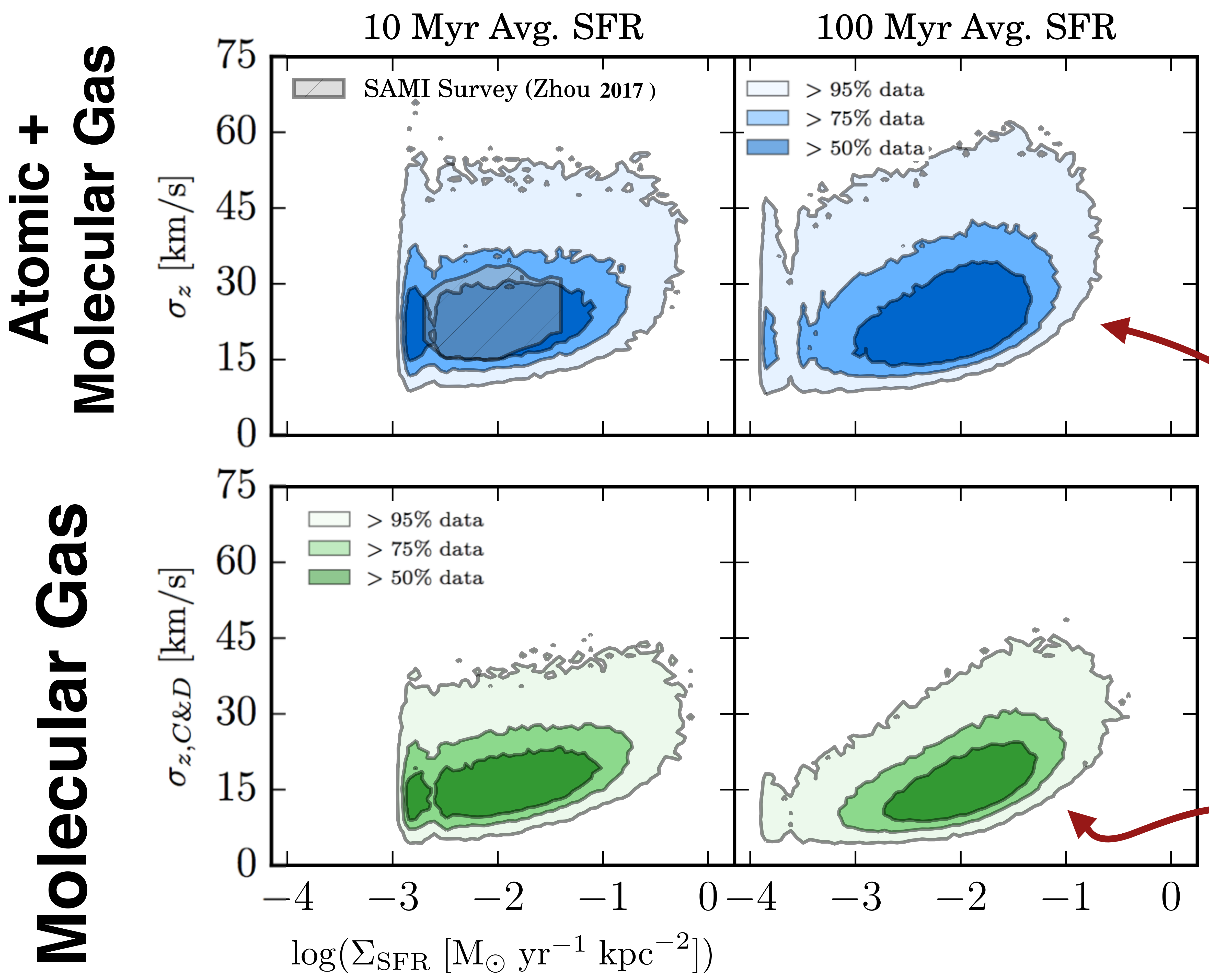
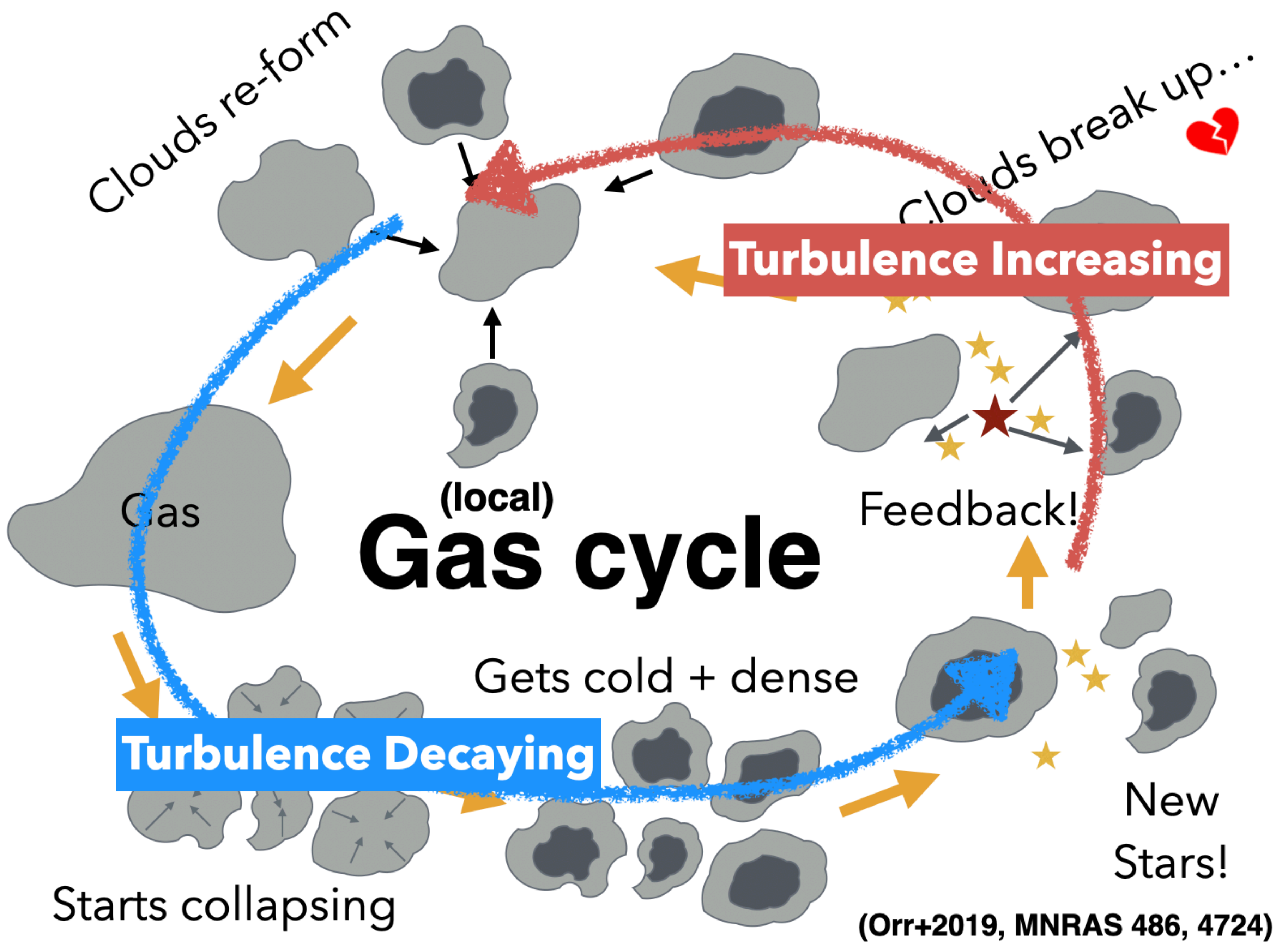


(Orr+2020, *MNRAS 496, 1620*)

Velocity Dispersions & SFRs in *Disks*





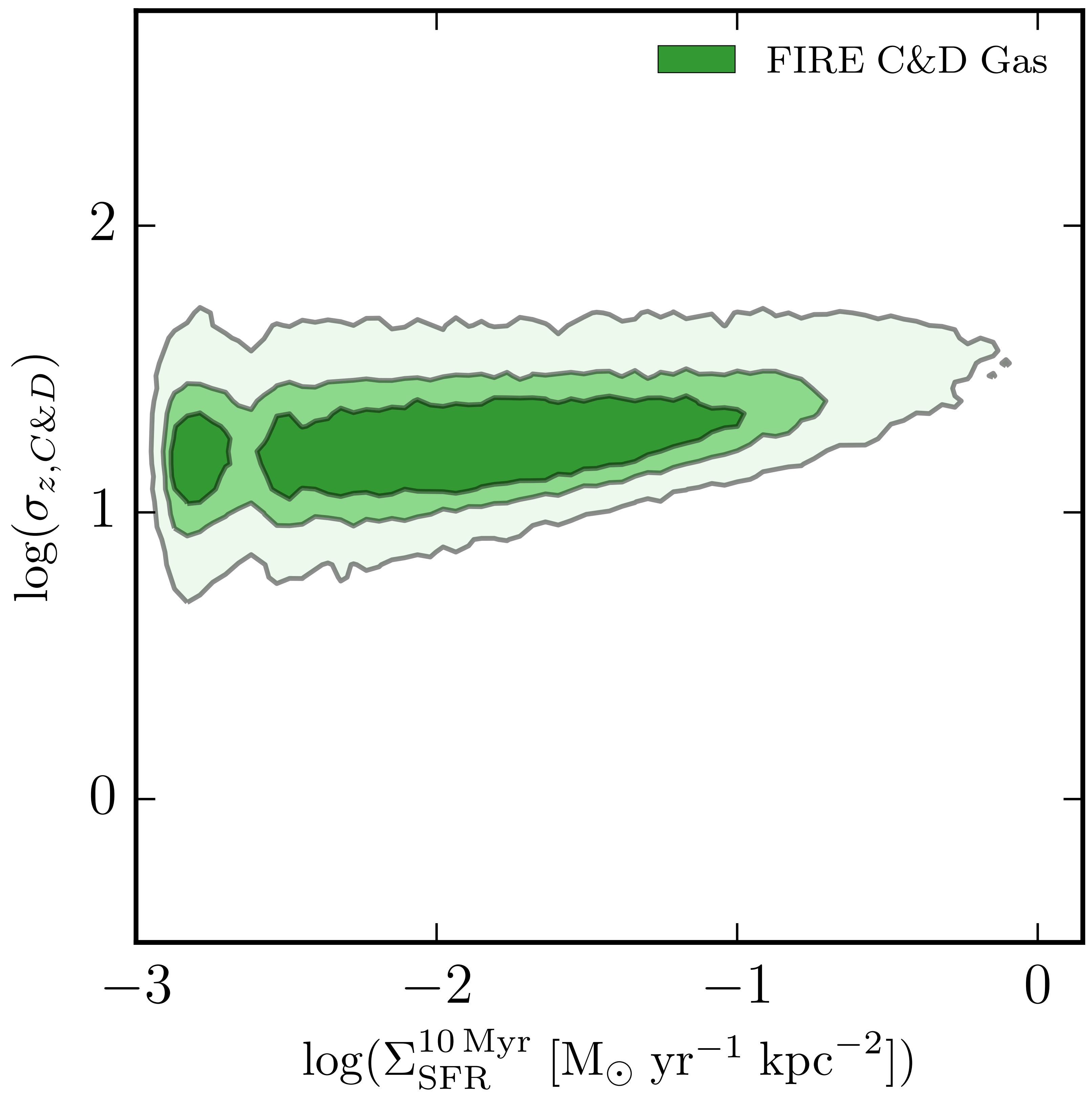
Dispersions do rise with higher 100 Myr SFRs and in cold & dense gas

All gas/SFR tracer combinations have a lower envelope in dispersions with SFRs

Timescale to affect velocity dispersions ~1/Ω ~ 100 Myr

(Orr+2020, *MNRAS 496, 1620*)

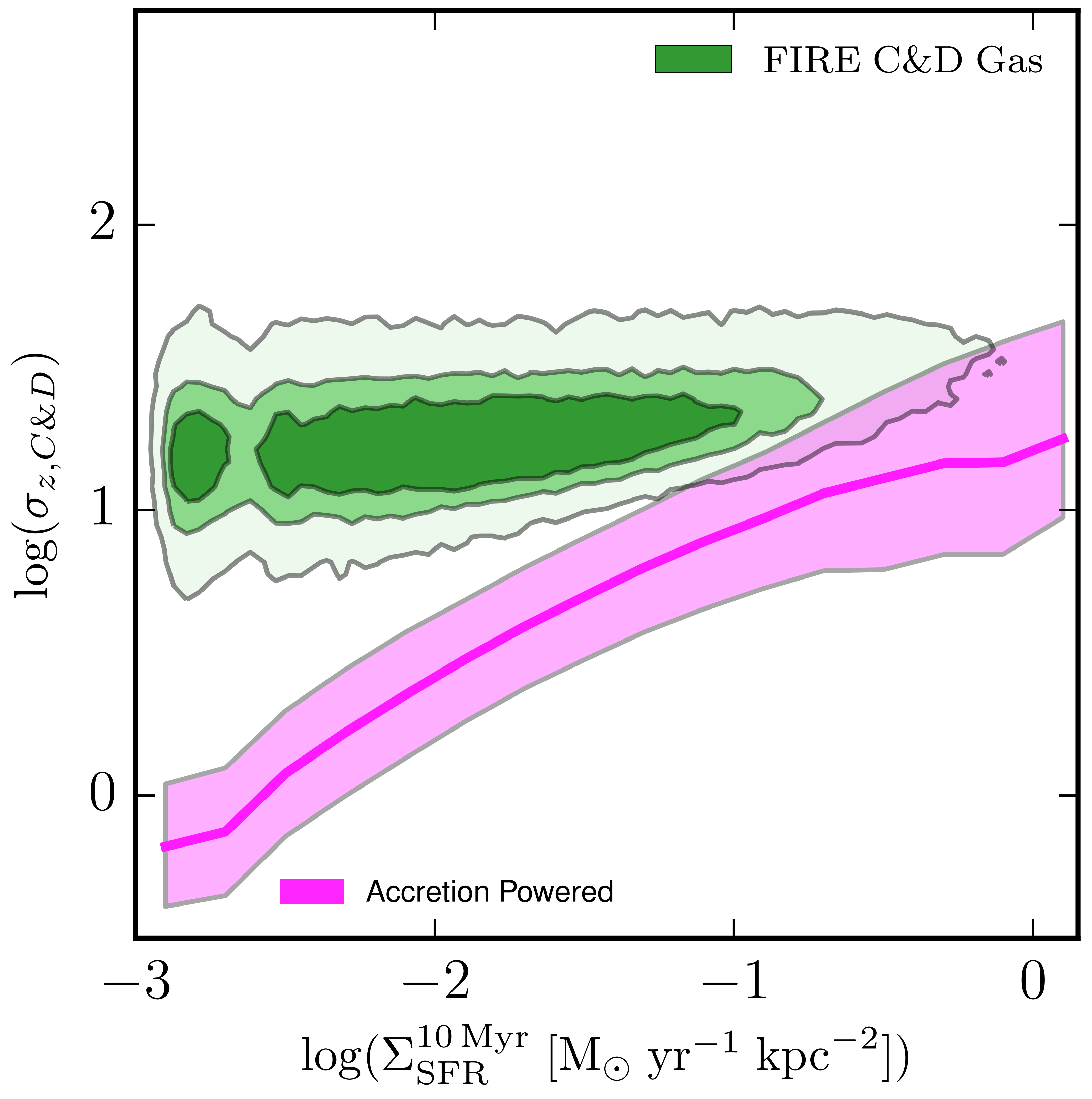
What (theoretically) drives the dispersions?



(**Orr+2020, *MNRAS 496, 1620***)

What (theoretically) drives the dispersions?

Gas orbital energy decay balances turbulence dissipation.



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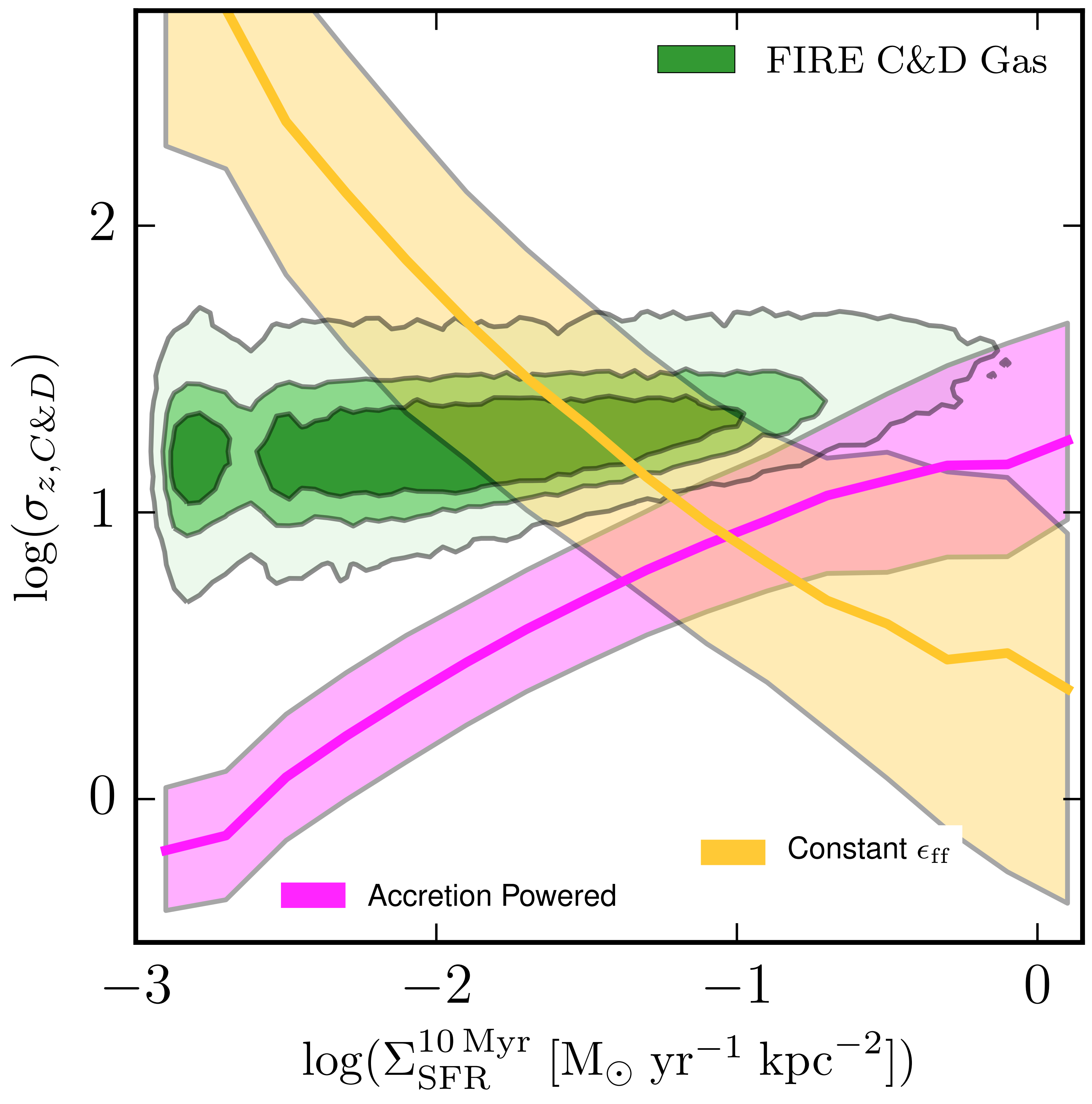
Star formation is always 1% efficiency per free fall time.



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What (theoretically) drives the dispersions?

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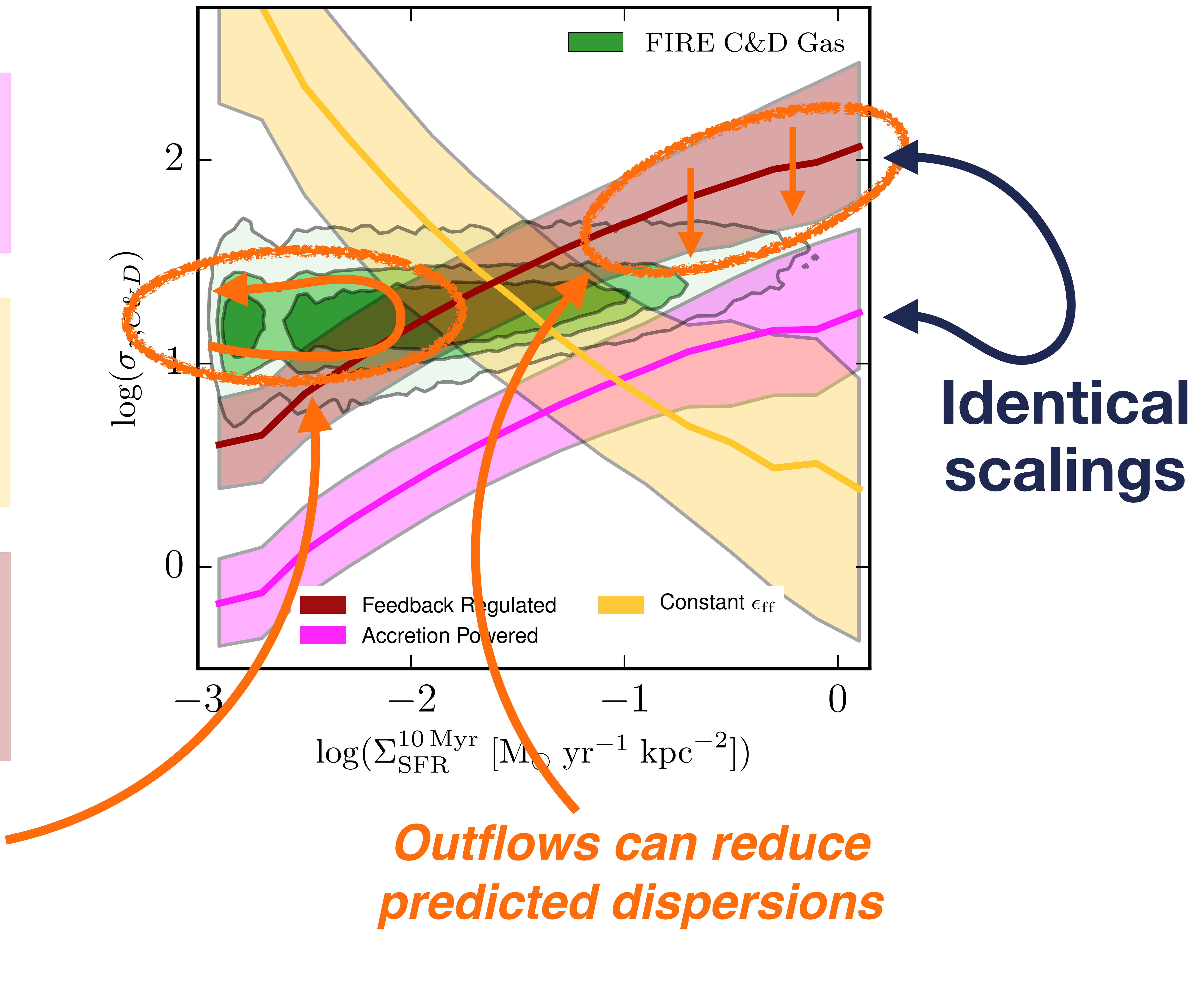
Star formation is always 1% efficiency per free fall time.

Feedback (SNe) balances turbulence dissipation.



(Orr+2020, *MNRAS 496, 1620*)

What (theoretically) drives the dispersions?

Gas orbital energy decay balances turbulence dissipation.

Star formati

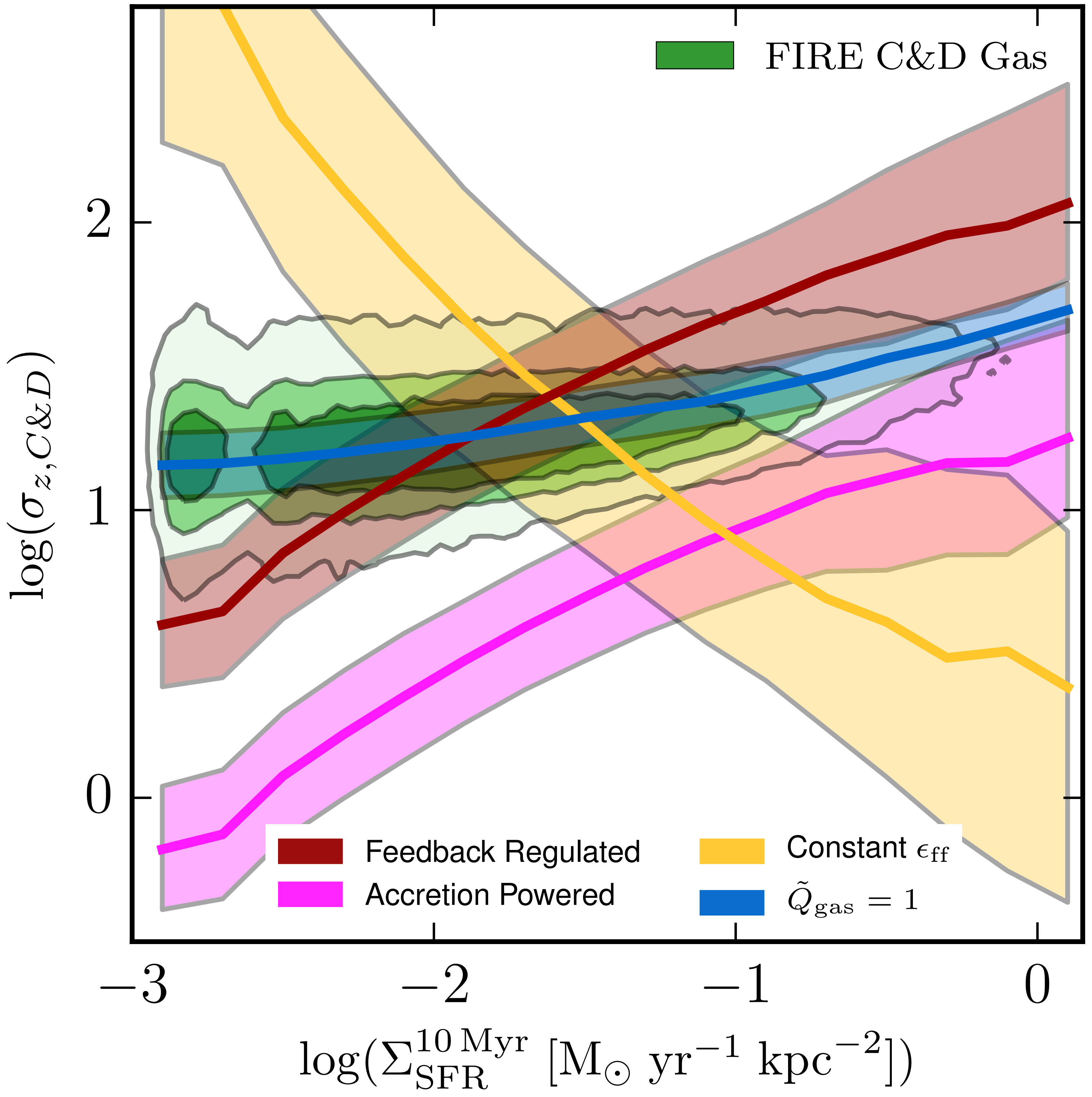
Feedback

Toomre-Q Stability Criterion

$$\tilde{Q} = \frac{\text{Turbulent/Thermal Support (or Shear)}}{\text{Gravity}}$$

$< 1 \longrightarrow$ Gravity wins, gas fragments.

Toomre Q = 1



Identical scalings

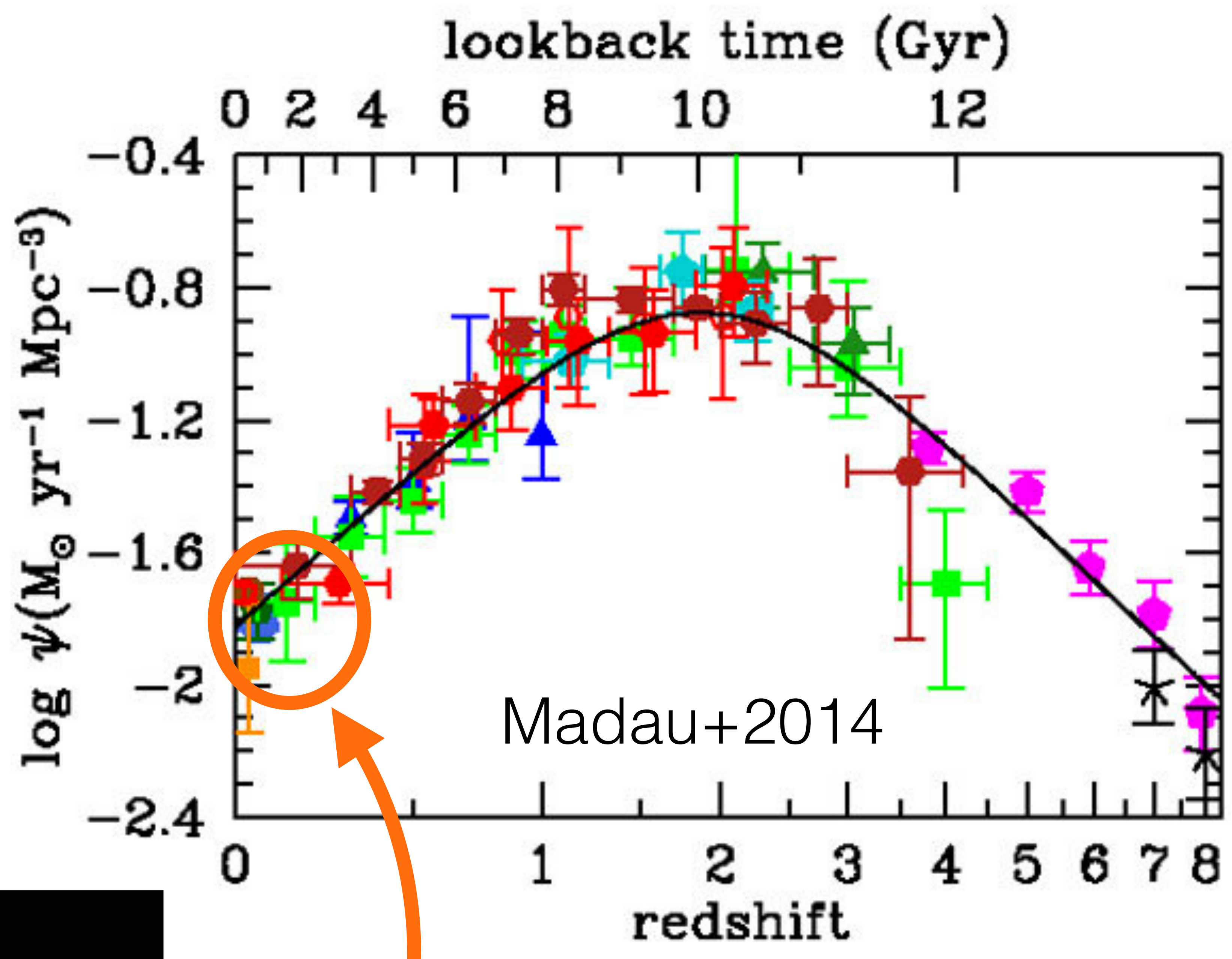
Gas stability is the best predictor of σ, but not predictive of SFR without other assumptions.

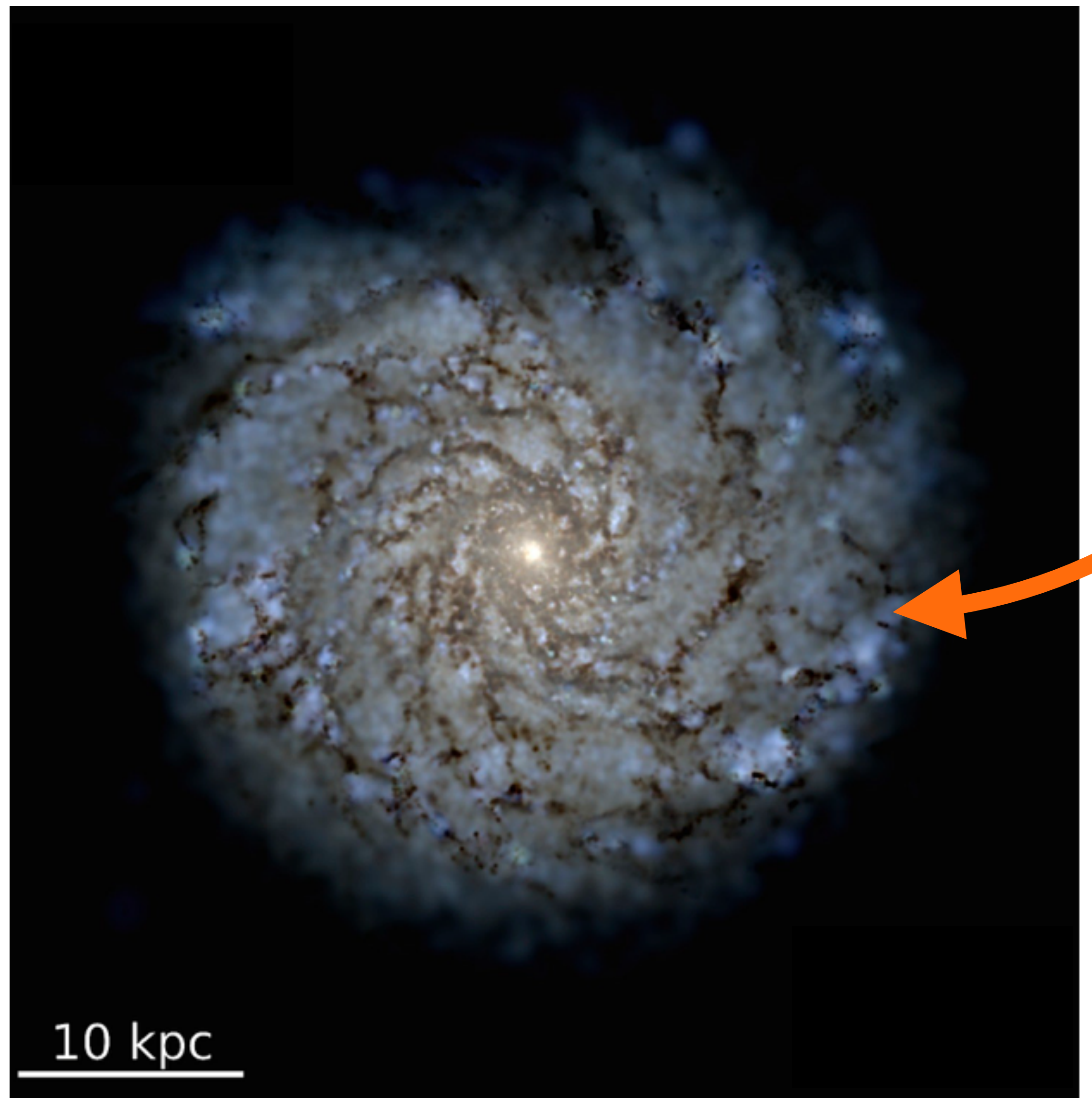
(Orr+2020, *MNRAS 496, 1620*)

How does this all change with redshift?

We've been focused on *late times*

z=0





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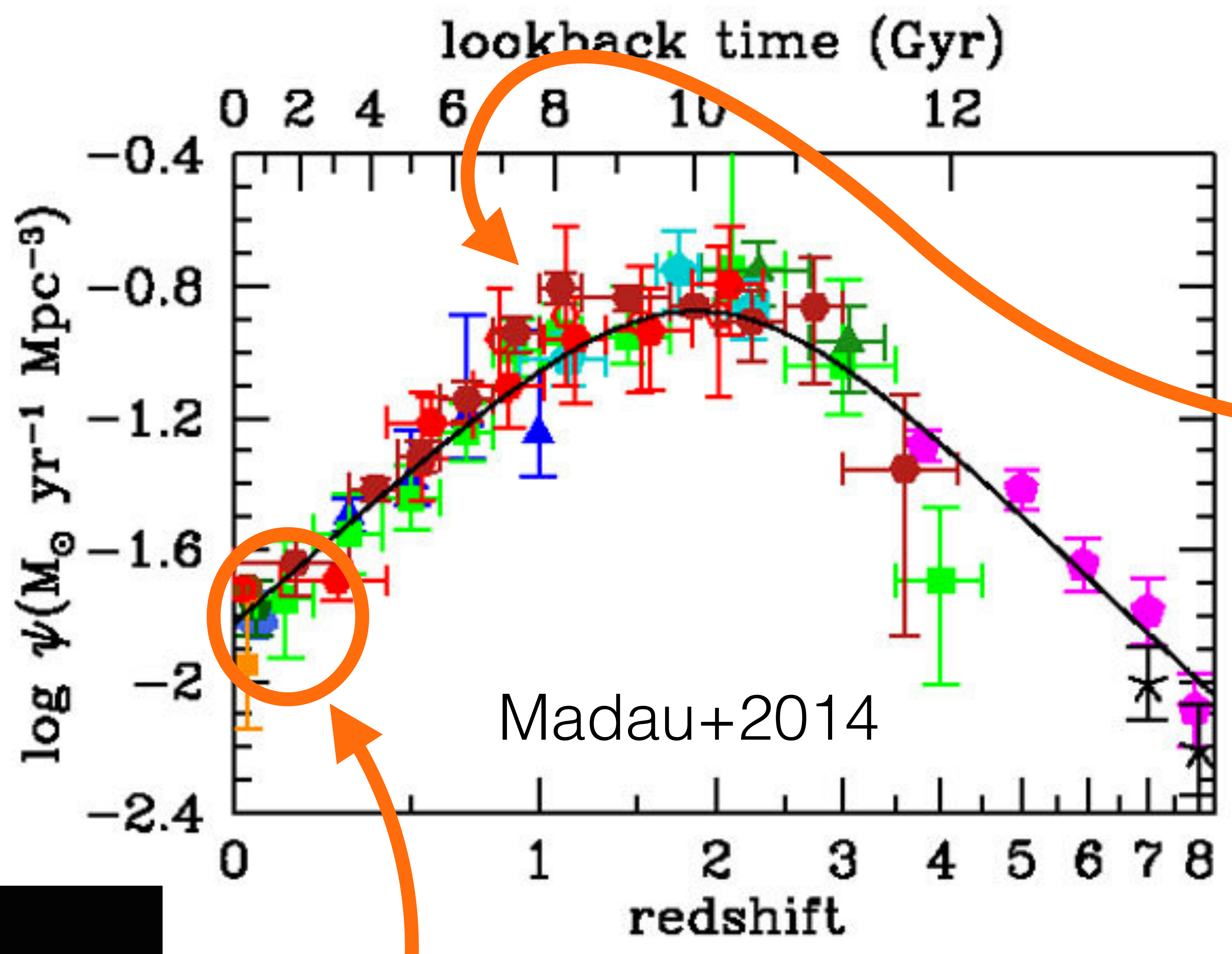
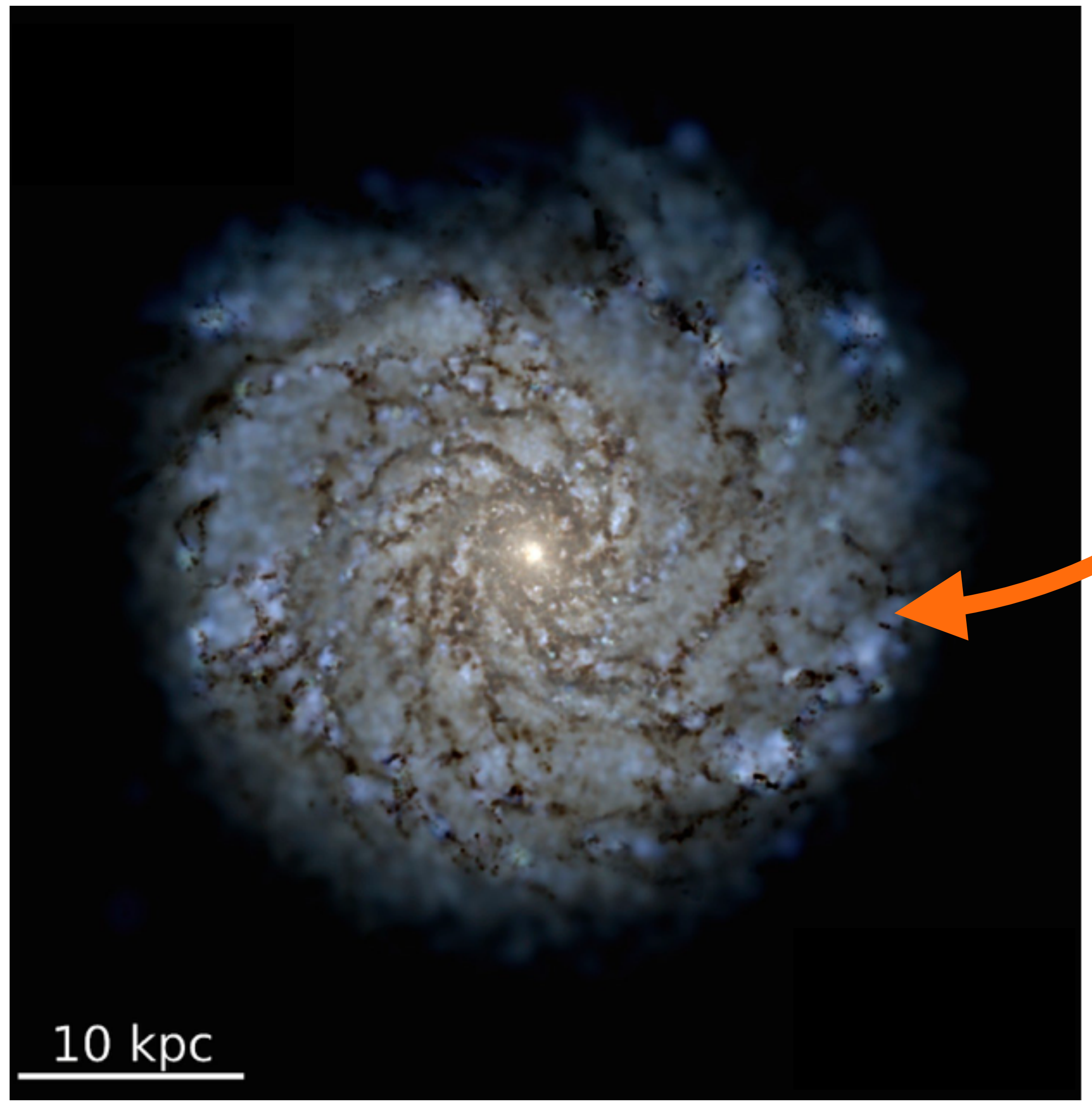


The Milky Way's disk formed z~1



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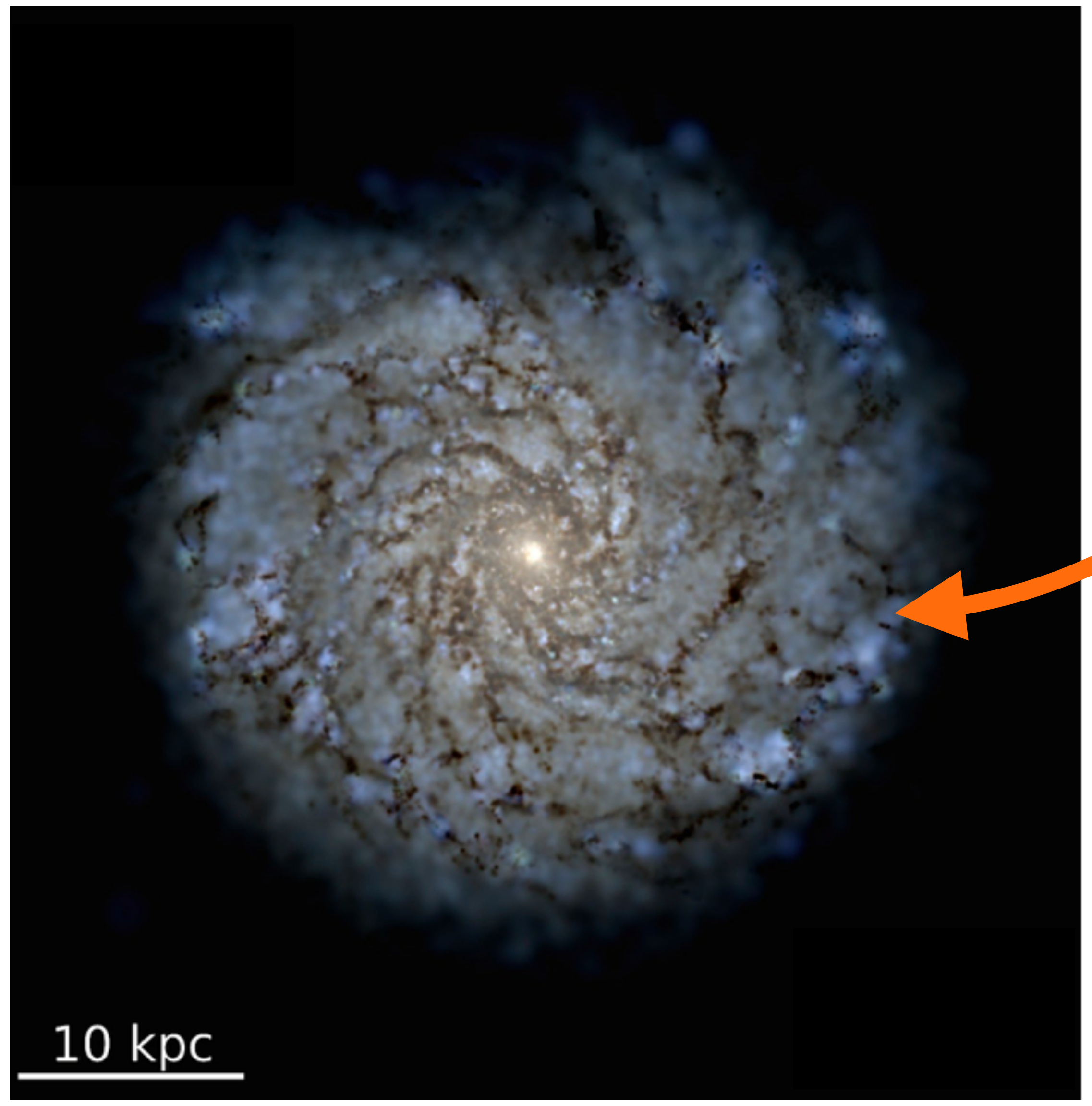

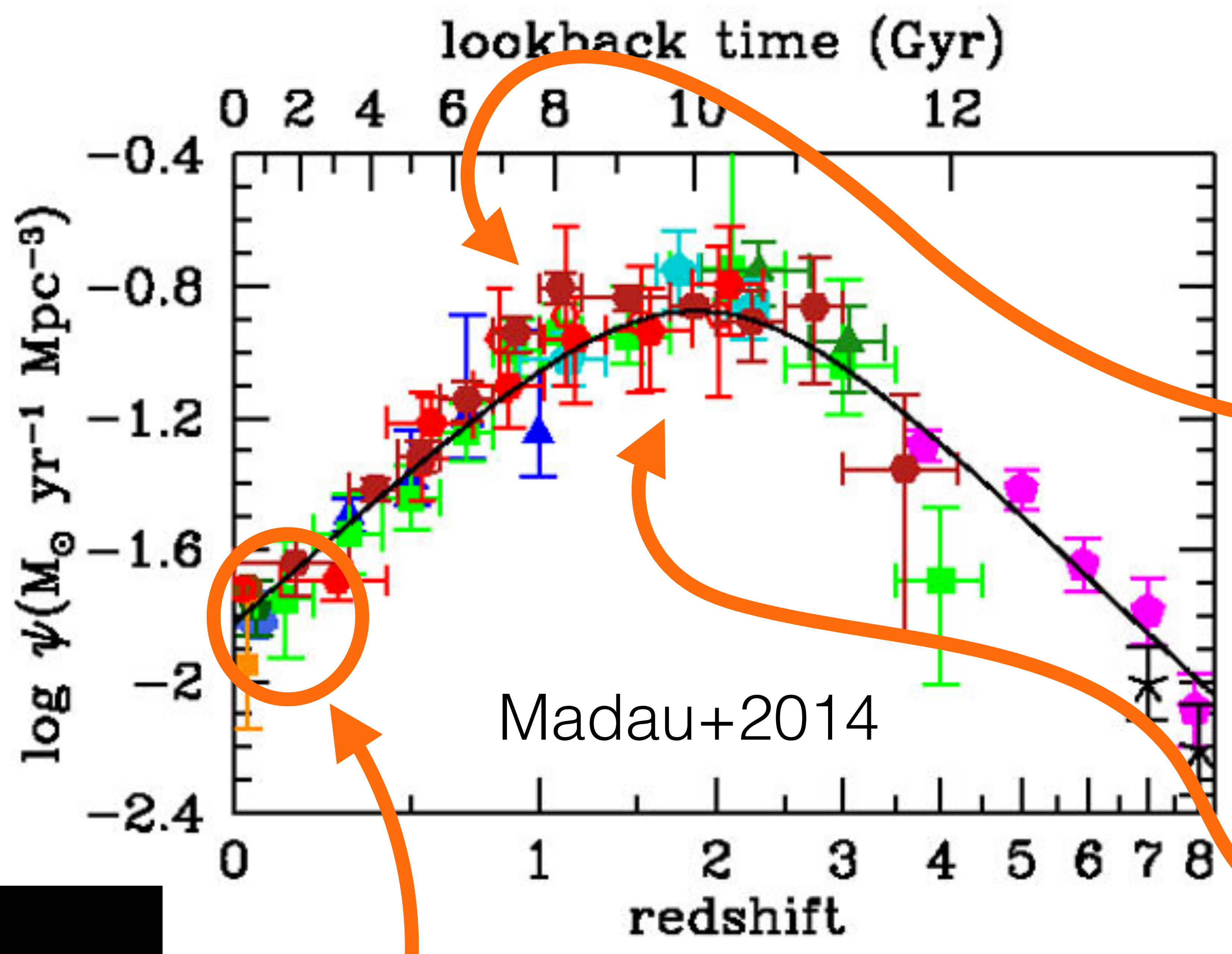

The Milky Way's disk formed z~1

Peak star formation z~2

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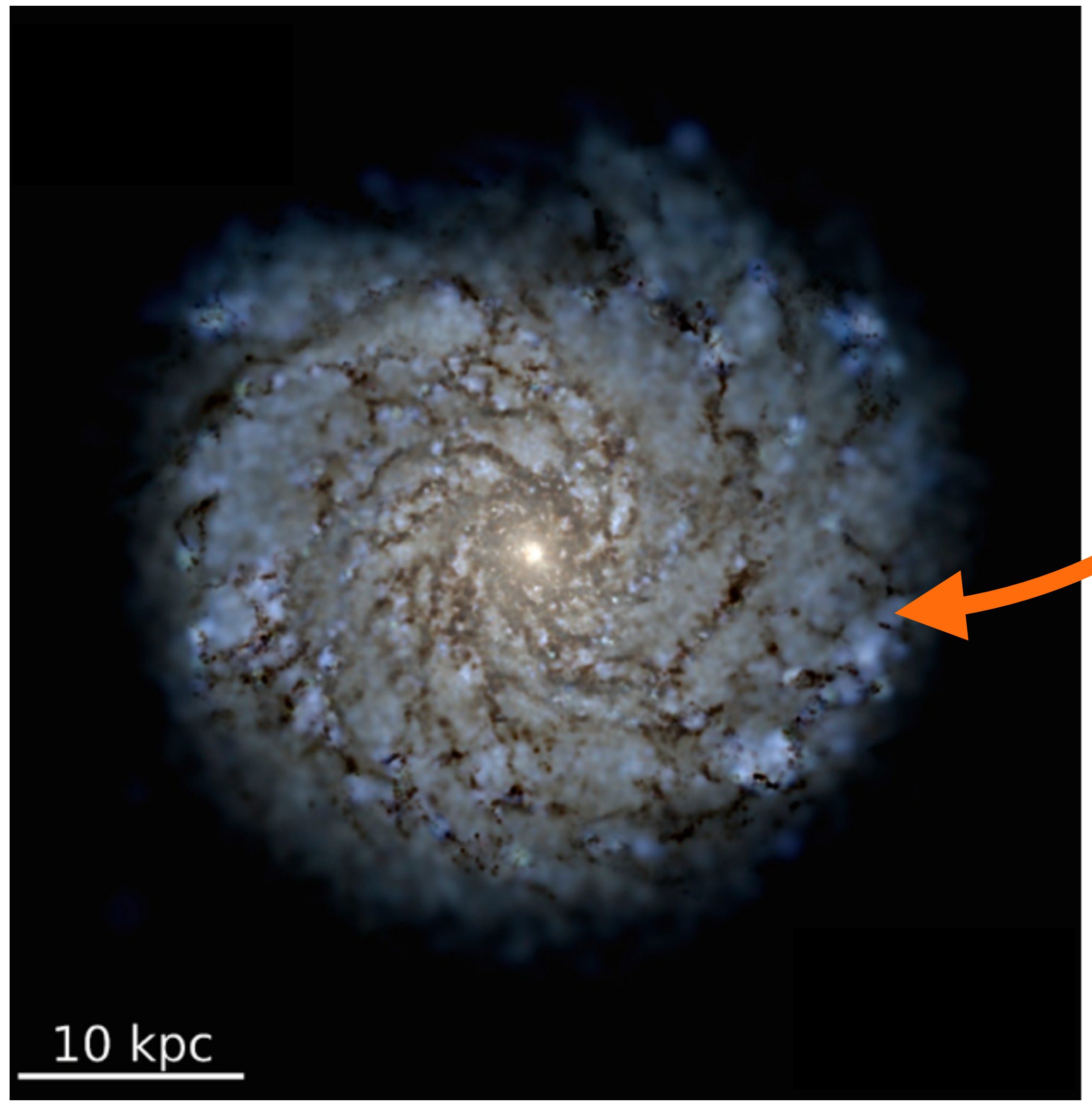

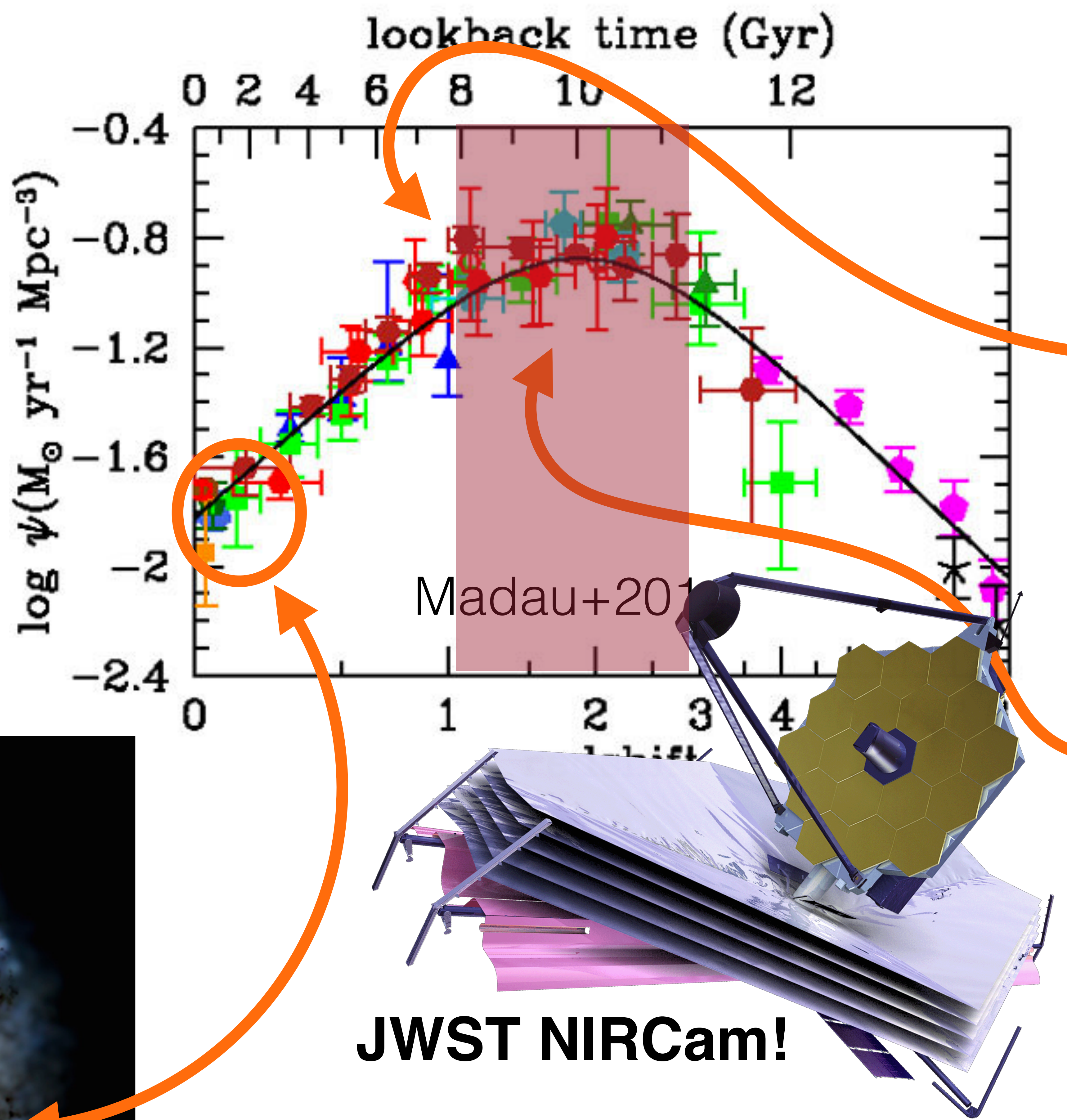

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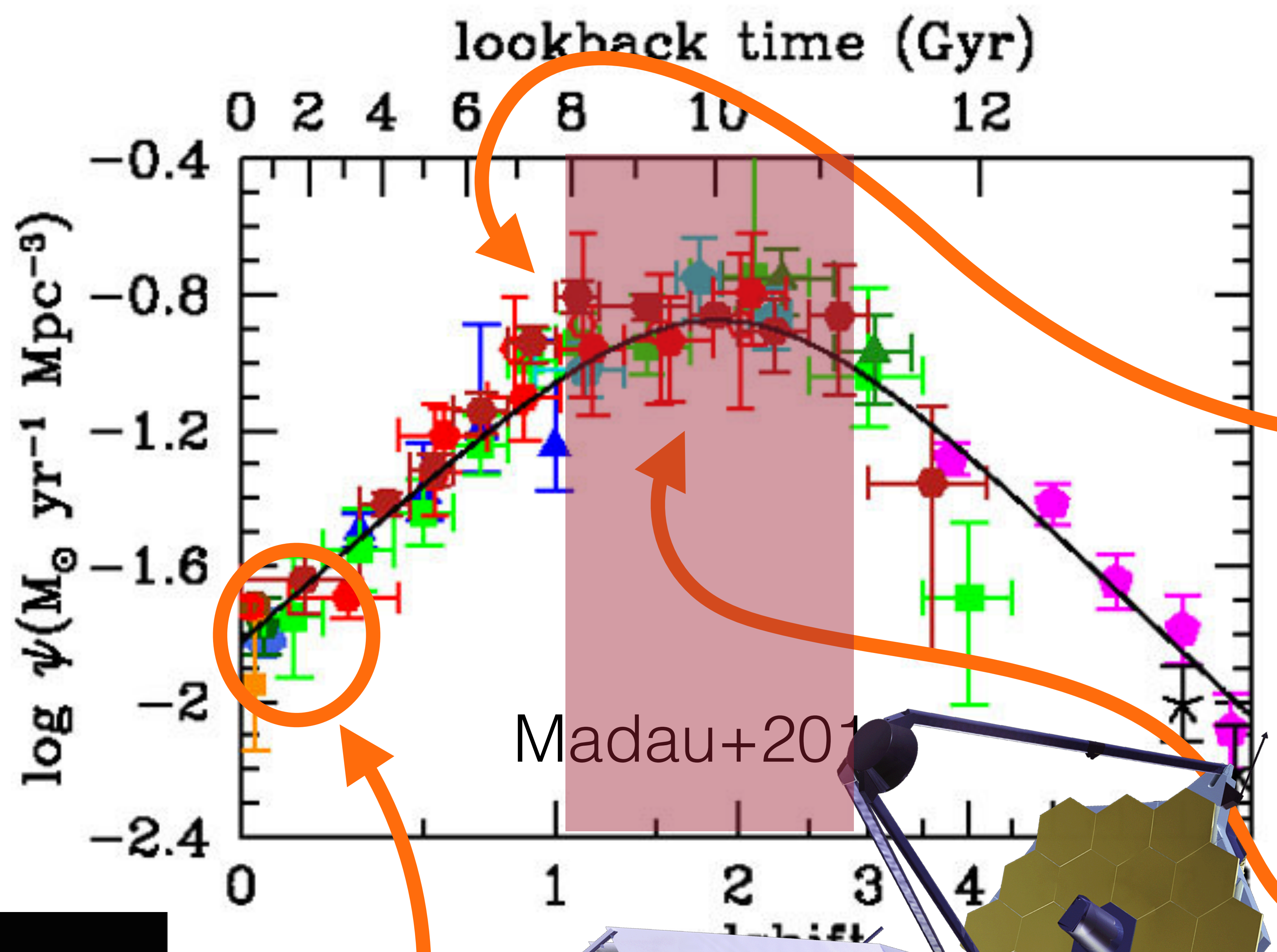
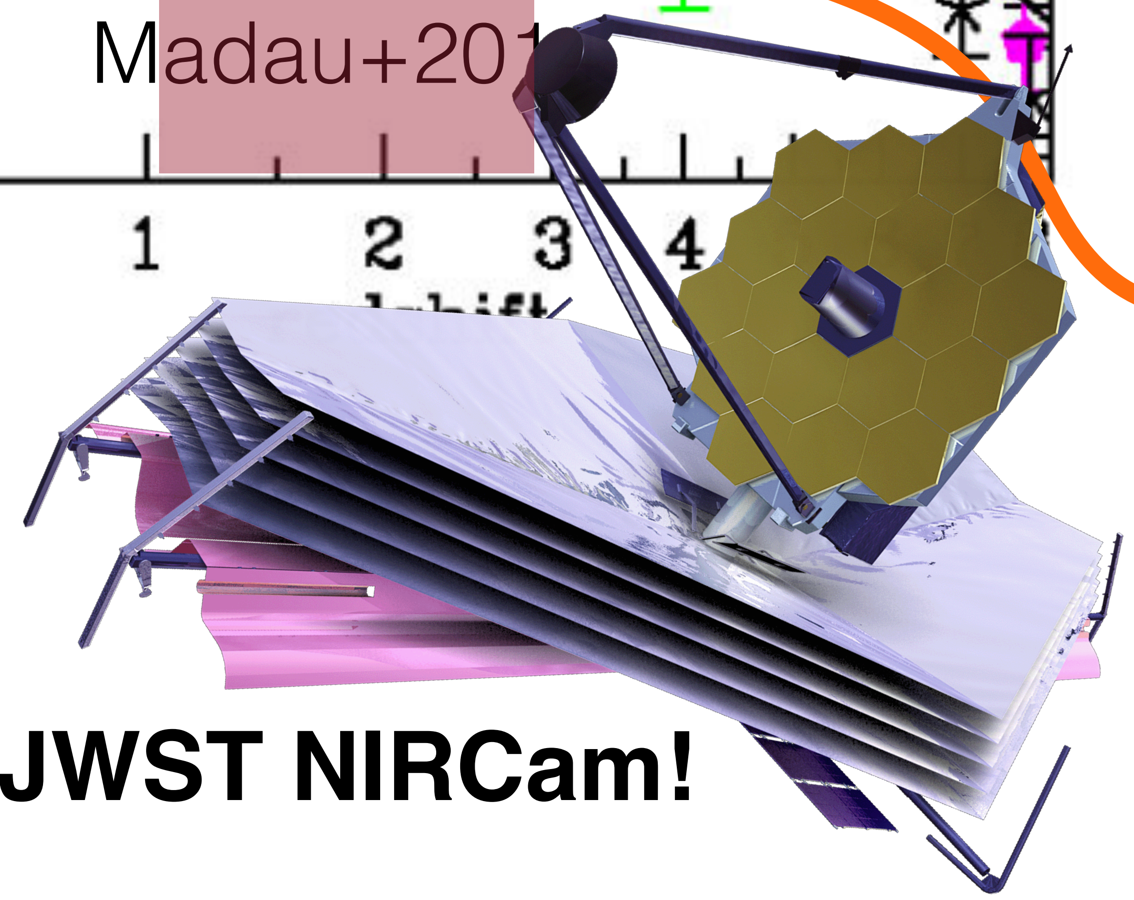
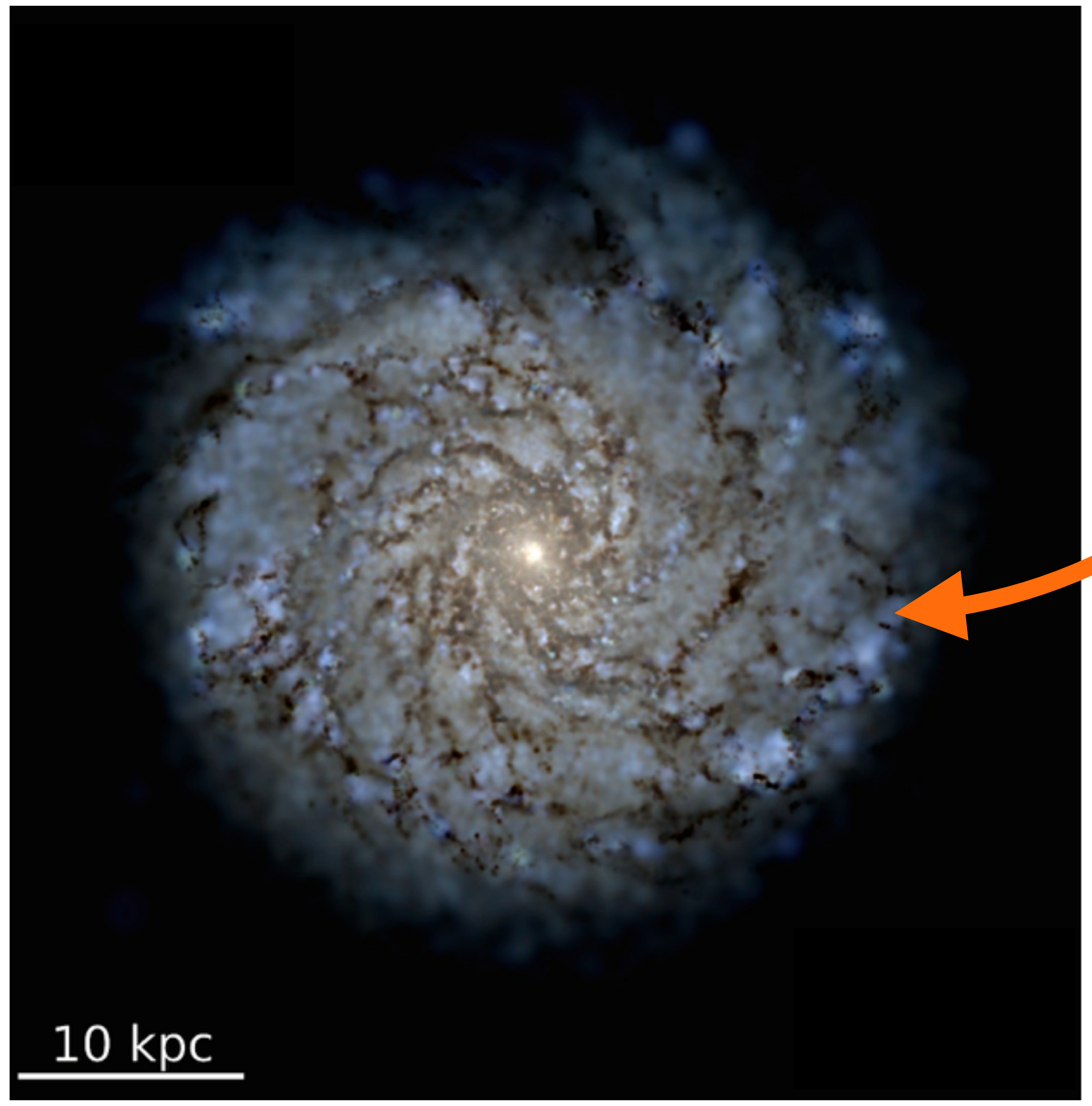




JWST NIRCam!



The Milky Way's disk formed z~1

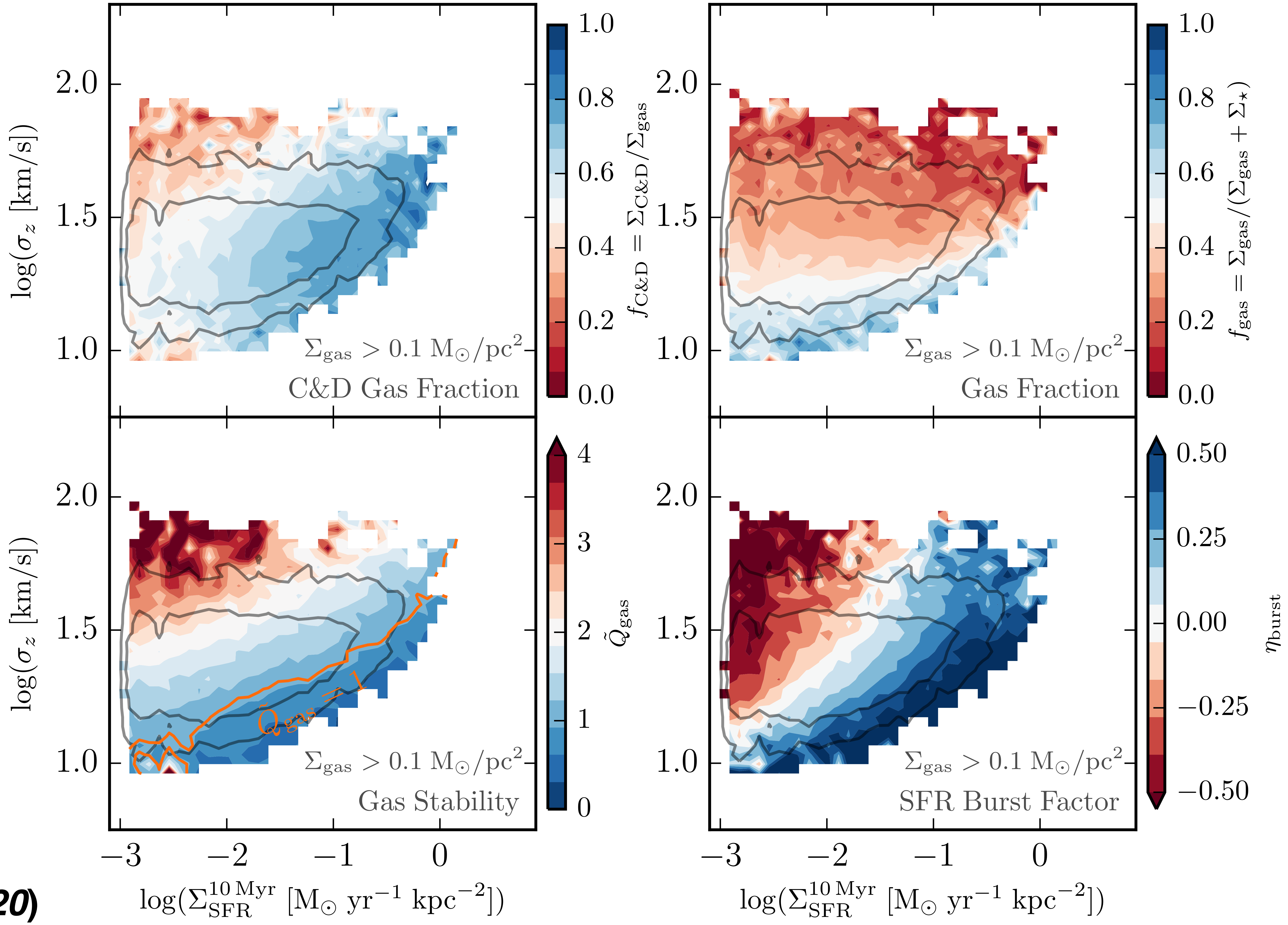
Peak star formation z~2

Is star formation, the effects of feedback, or properties of the ISM changing as disks form?

Do other properties of the ISM change with dispersions over time?

z=0

FIRE-2 MW-mass Spirals



(Orr+2020, *MNRAS 496, 1620*)

Do other properties of the ISM change with dispersions over time?

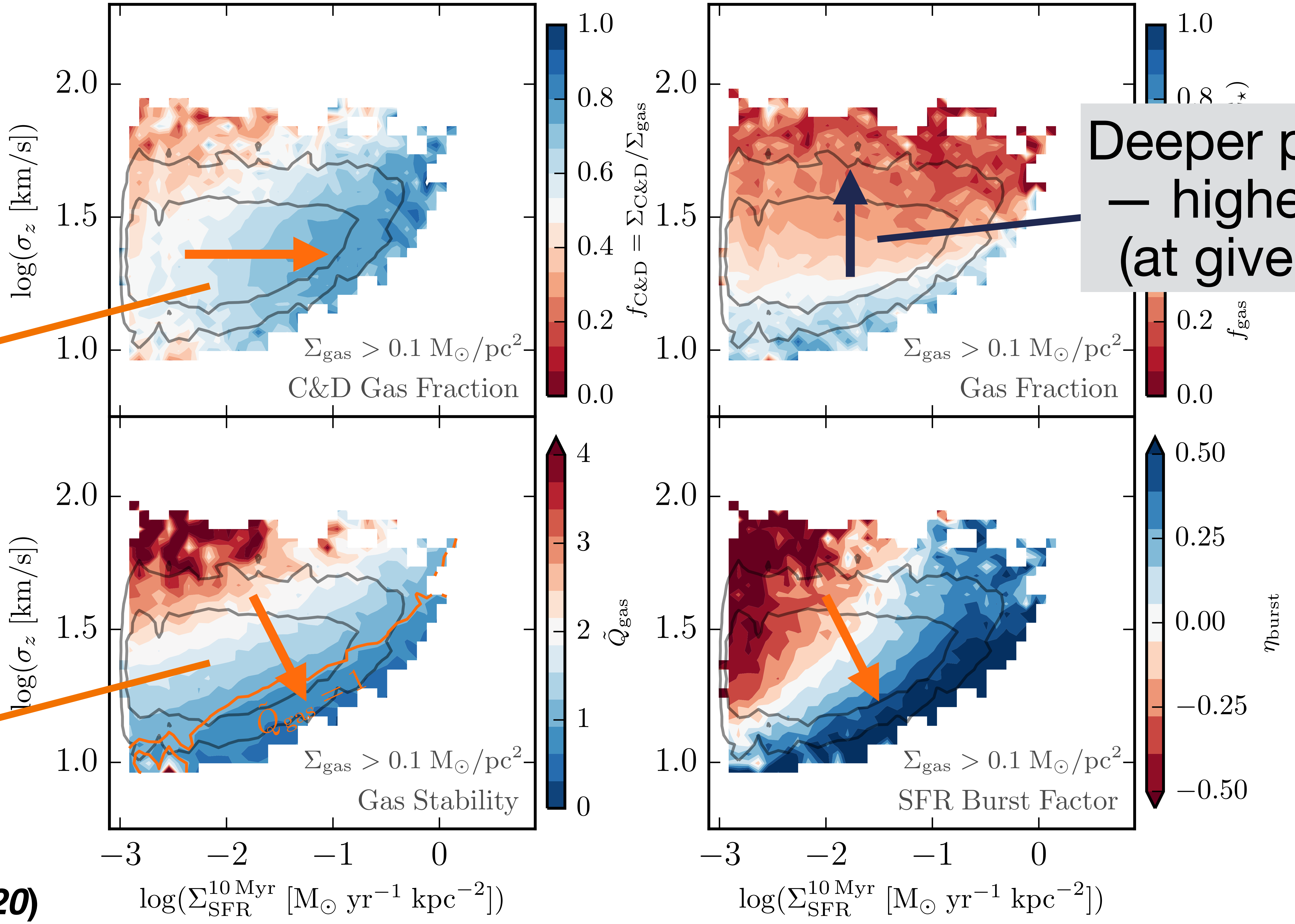
z=0

FIRE-2 MW-mass Spirals

More cold gas — higher SFRs (at given Mach)

Starbursts follow (in)stability contours

Deeper potential — higher Mach (at given SFR)



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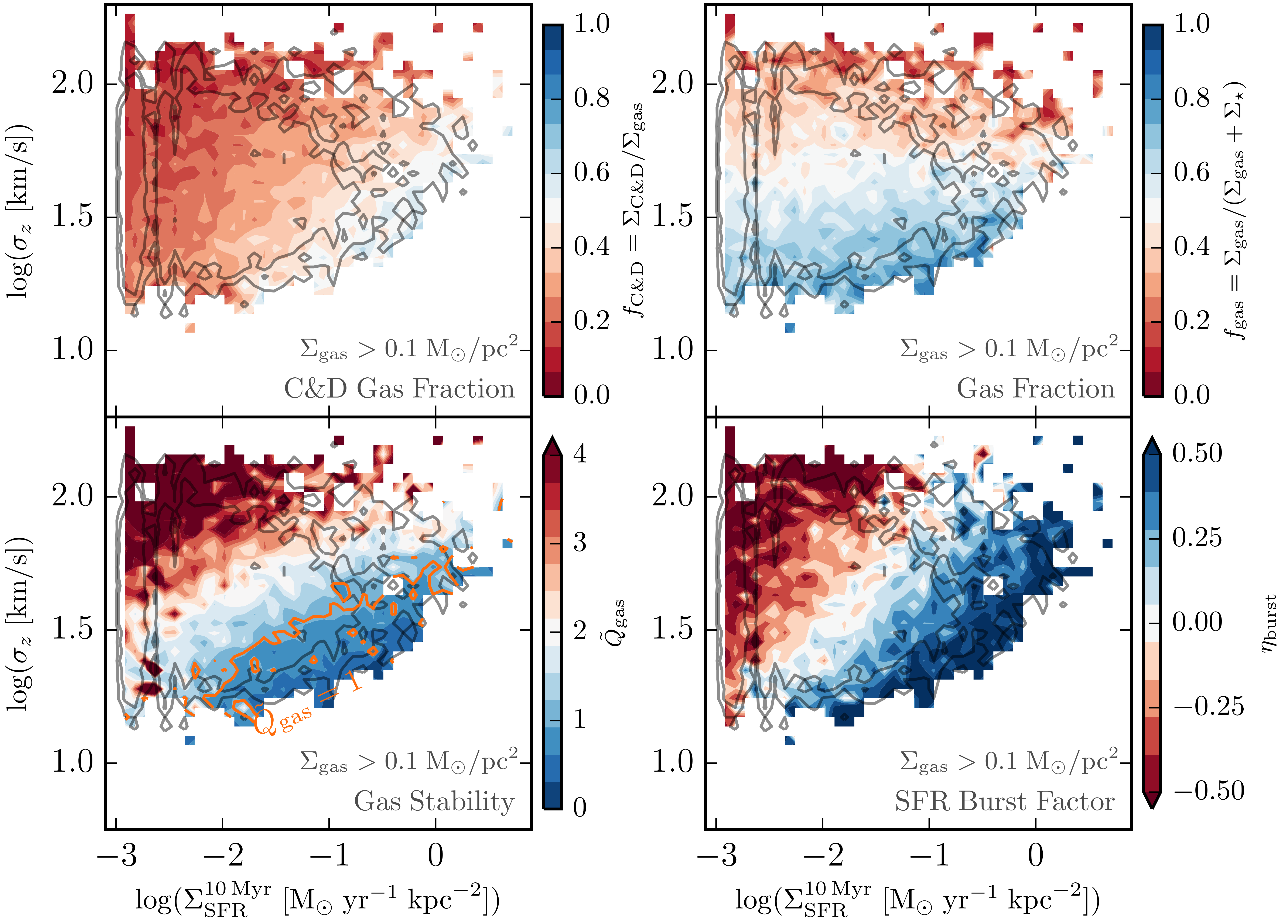
Do other properties of the ISM change with dispersions over time?

z=1

FIRE-2 MW-mass Progenitors

Jump in dispersions between z= 0 and z=1

Before z ~ 0.7 they aren't disks



(Orr+2025 in prep.)

Do other properties of the ISM change with dispersions over time?

FIRE-2 MW-mass Progenitors

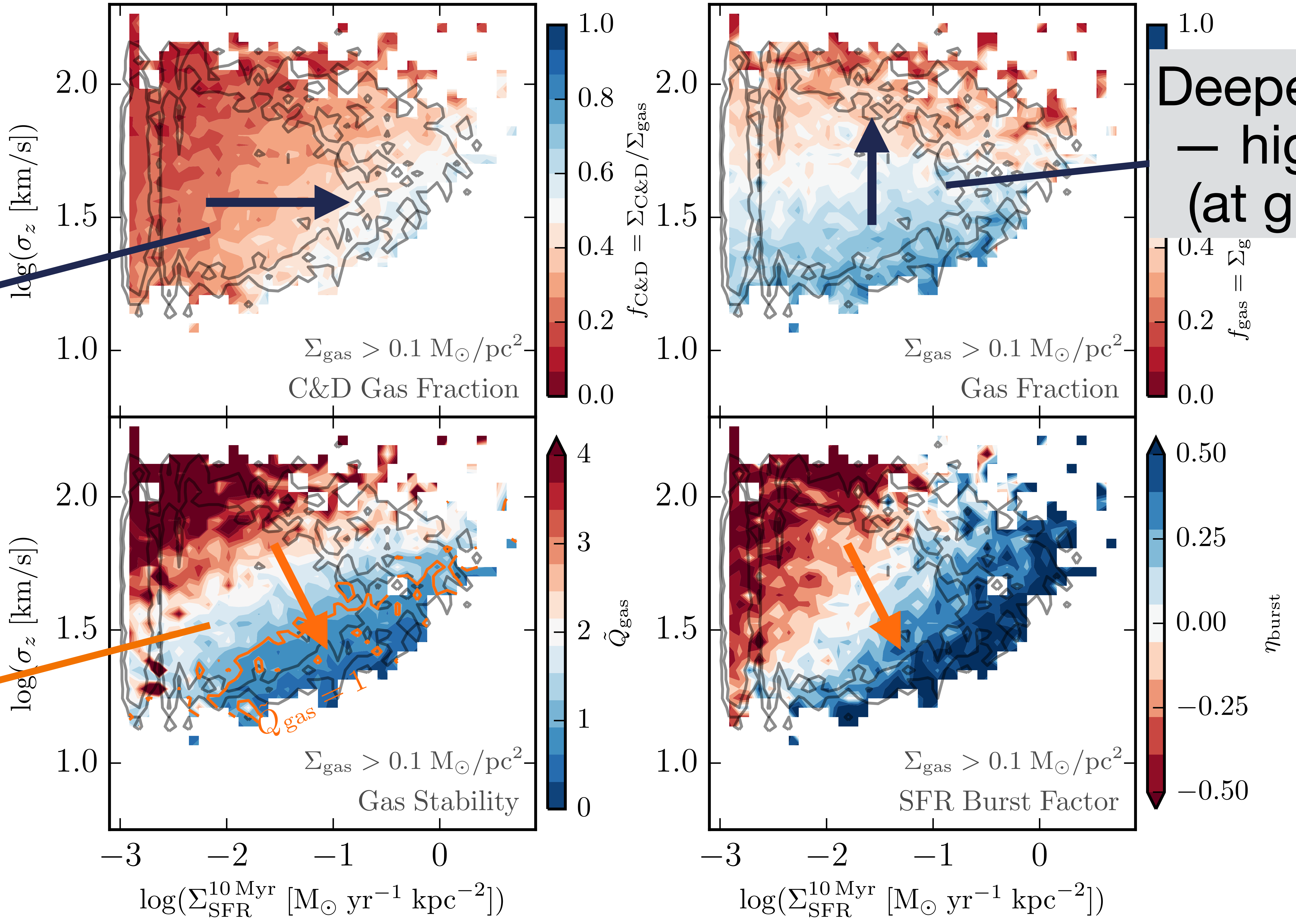
z=1

More cold gas — higher SFRs (at given Mach)

ISM is warmer…

Deeper potential — higher Mach (at given SFR)

Starbursts follow (in)stability contours



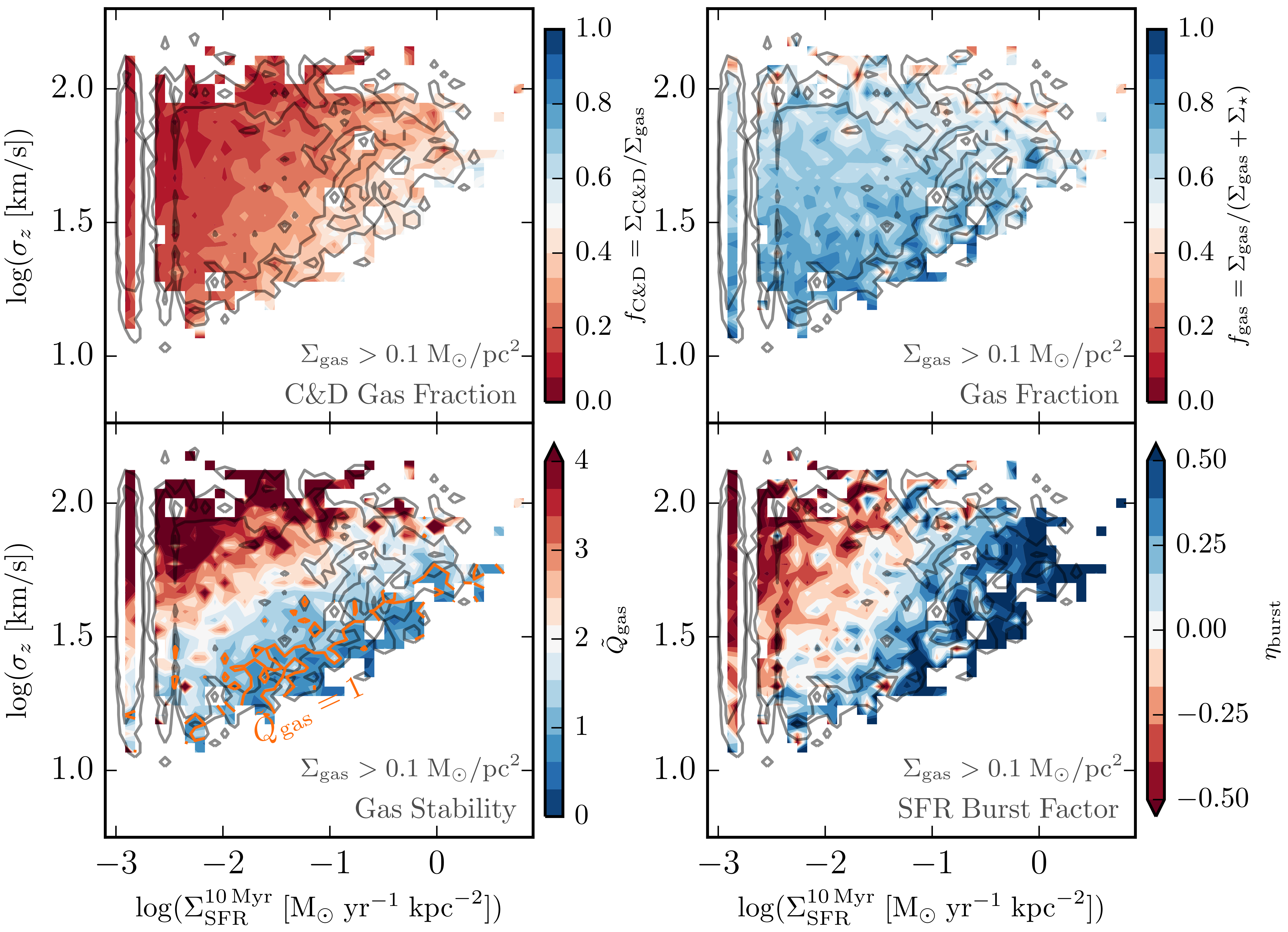
(Orr+2025 in prep.)

Do other properties of the ISM change with dispersions over time?

z=2

FIRE-2 MW-mass Progenitors

No disks… these are all dwarfs at this time



Dominated by gas everywhere

(Orr+2025 in prep.)

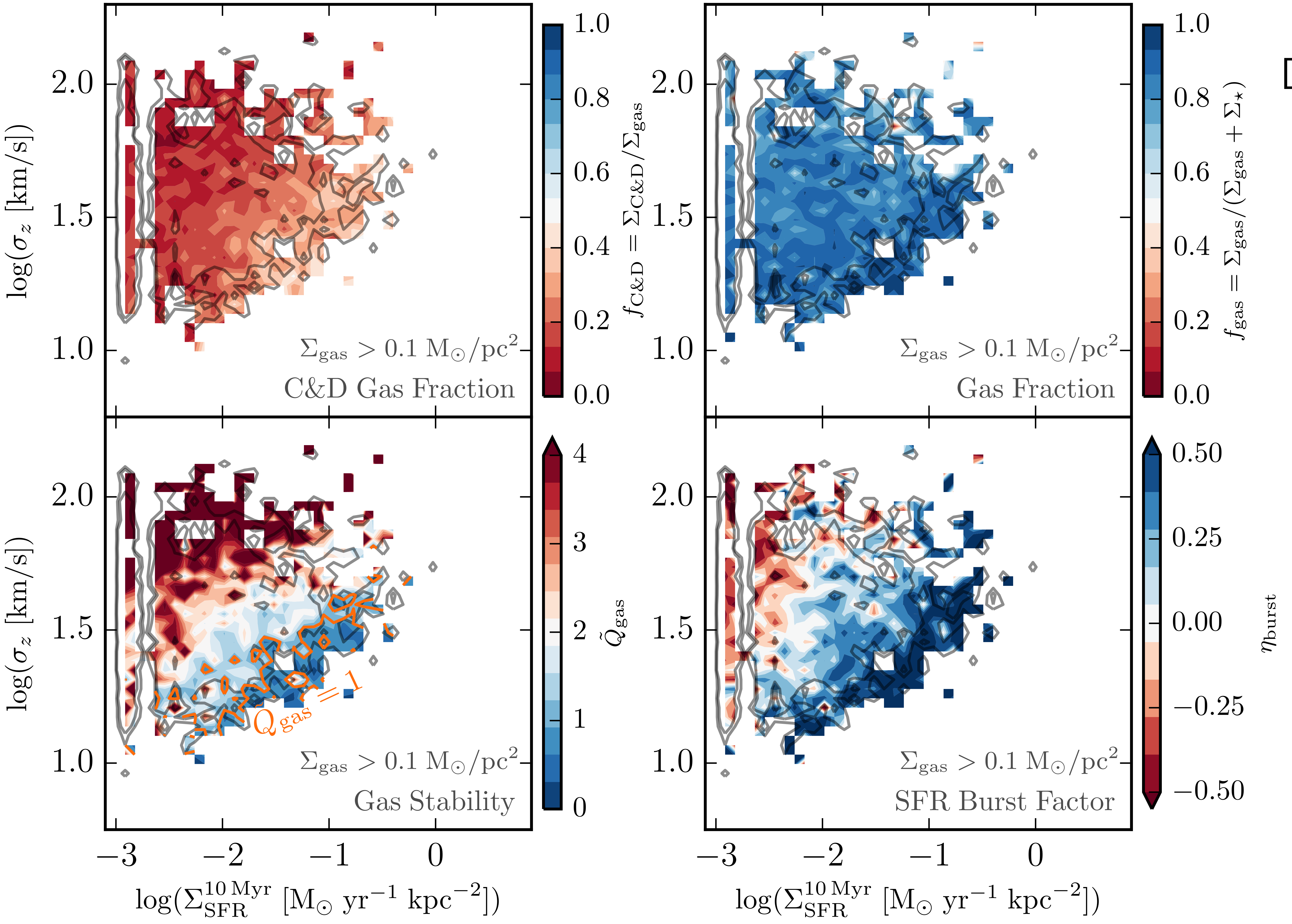
Do other properties of the ISM change with dispersions over time?

z=3

FIRE-2 MW-mass Progenitors

No disks… these are all dwarfs at this time

…trends remain similar in the ISM to z ~ 3



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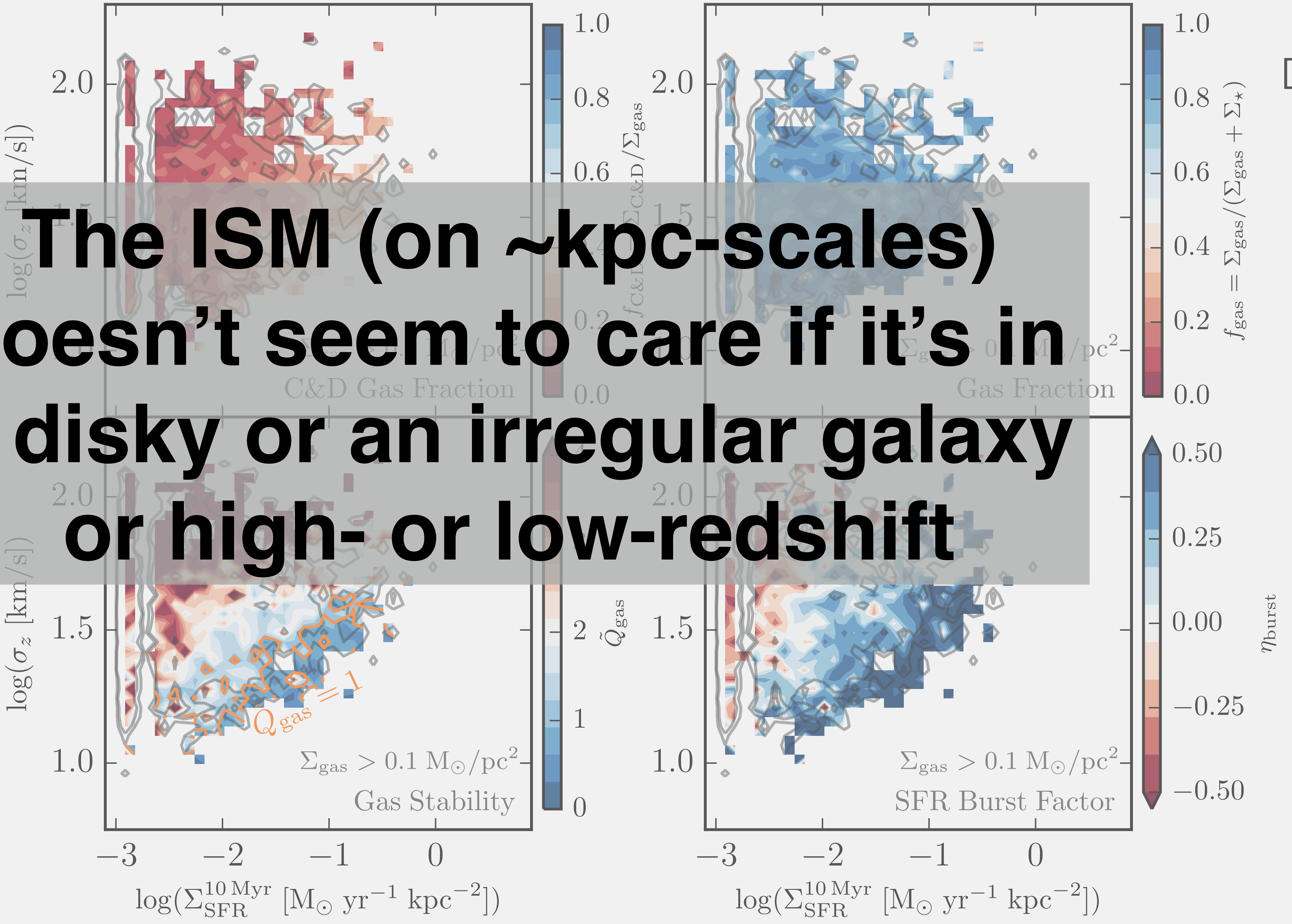


The ISM (on ~kpc-scales) doesn't seem to care if it's in a disky or an irregular galaxy or high- or low-redshift

Dominated by gas everywhere

(Orr+2025 in prep.)

And so?

Is feedback or star formation fundamentally changing with redshift, or is it a game of normalization

The galaxy potential sets the "demand" from energy/momentum sources

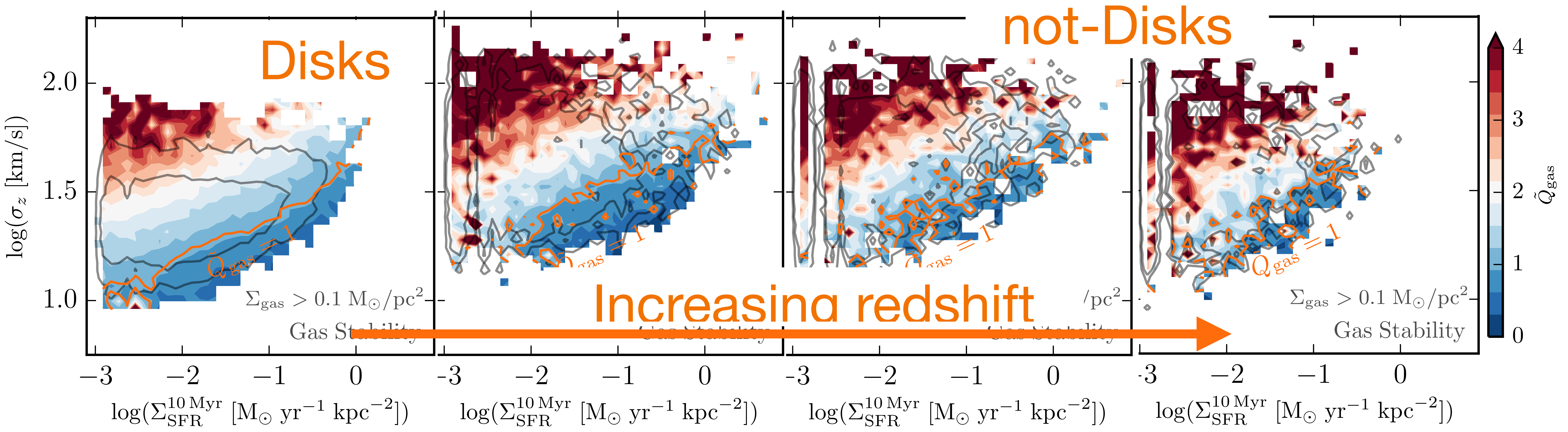
Feedback sets how many stars need to form to "balance the budget"

(SNe) Feedback (+ radial gas flows) is sufficient to power turbulence

Timescale Hierarchy ~ "Regulated"

The ISM is driven to local (marginal) stability on its natural scale

(Local scale height/ largest eddy scale)



Thanks!