Lighting up faint galaxies at high *z* through the stream velocity

Claire Williams (UCLA)

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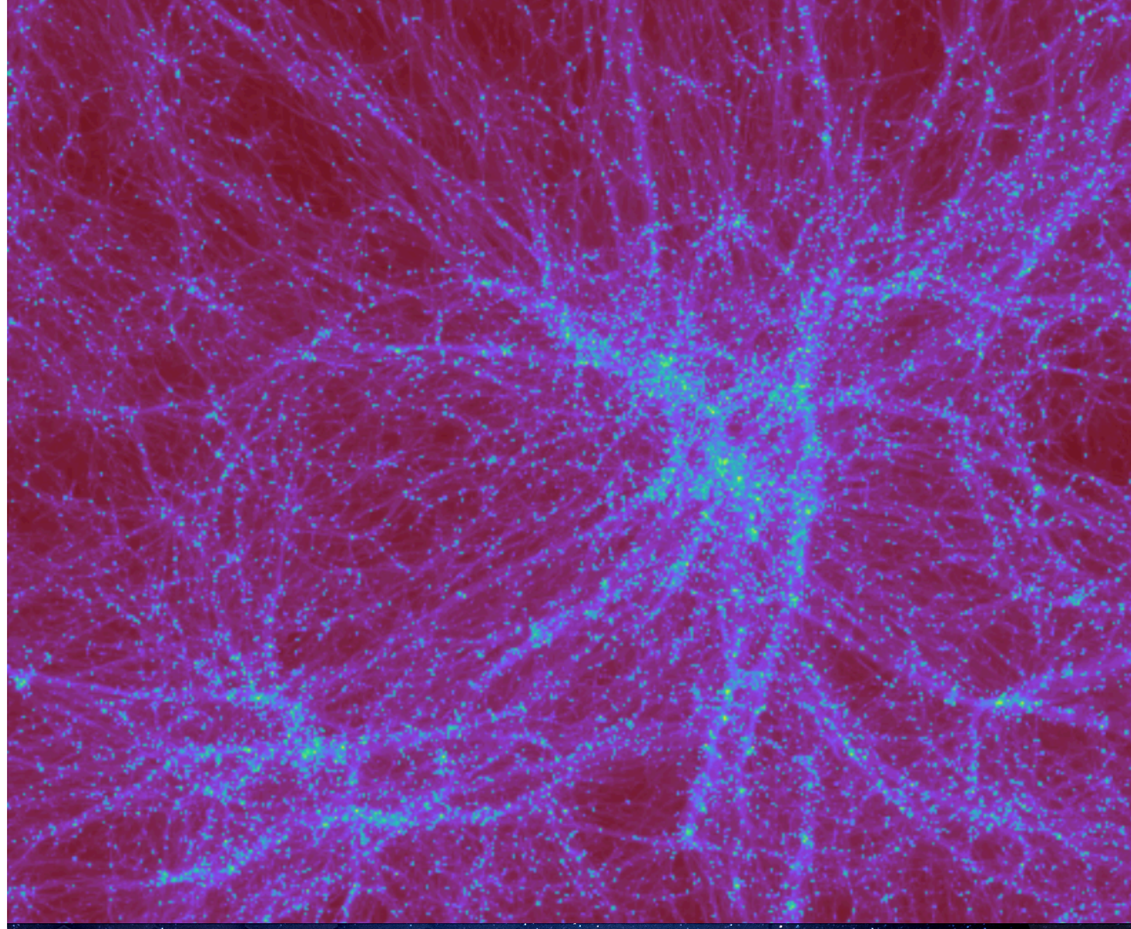
ELTs in Light of JWST

The Supersonic Project: Smadar Naoz, William Lake, Blakesley Burkhart, Tommaso Treu, Federico Marinacci, Mark Vogelsburger, Gen Chiaki, Yurina Nakazato, Naoki Yoshida, Yeou S. Chiou, Avi Chen



Motivations - ΛCDM structure formation at small scales

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  e.g., Bullock & Boylan-Kolchin (2019)

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- A framework within ΛCDM (the stream velocity) may relate to some local tensions—but problems isolating the effects at low redshift
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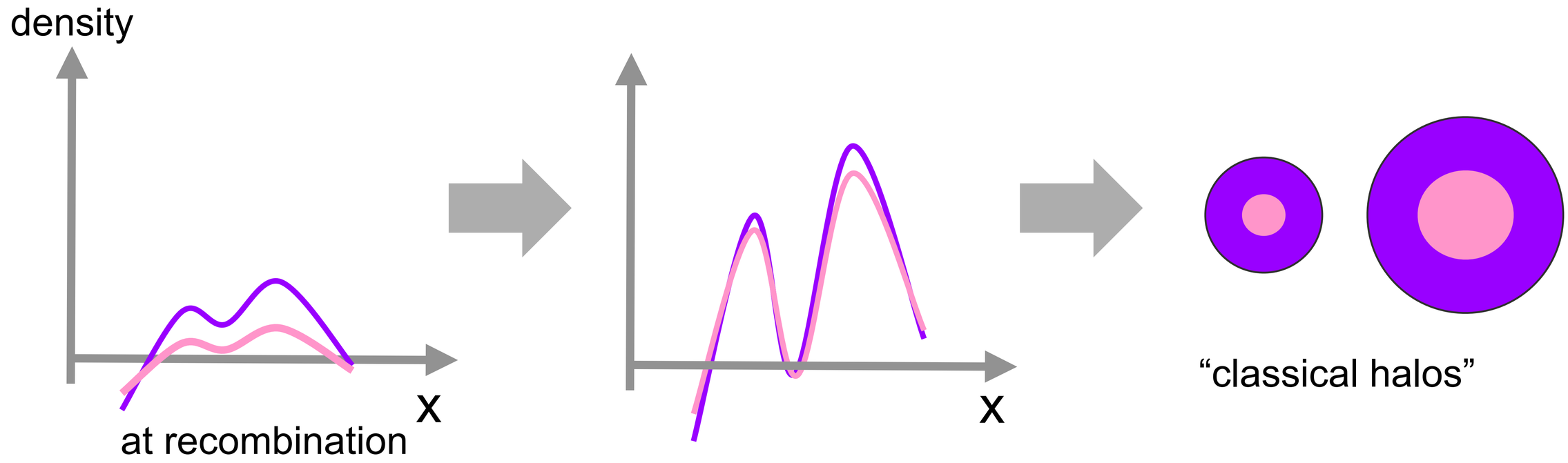
- Connection between high and low redshift through JWST + future ELTs by observing dwarf galaxies in the early universe at the peak of their star formation

Standard picture of structure formation

$(k \gtrsim 20\ \mathrm{Mpc}^{-1})$



Dark matter density

Baryon density

Naoz & Narayan (2014)

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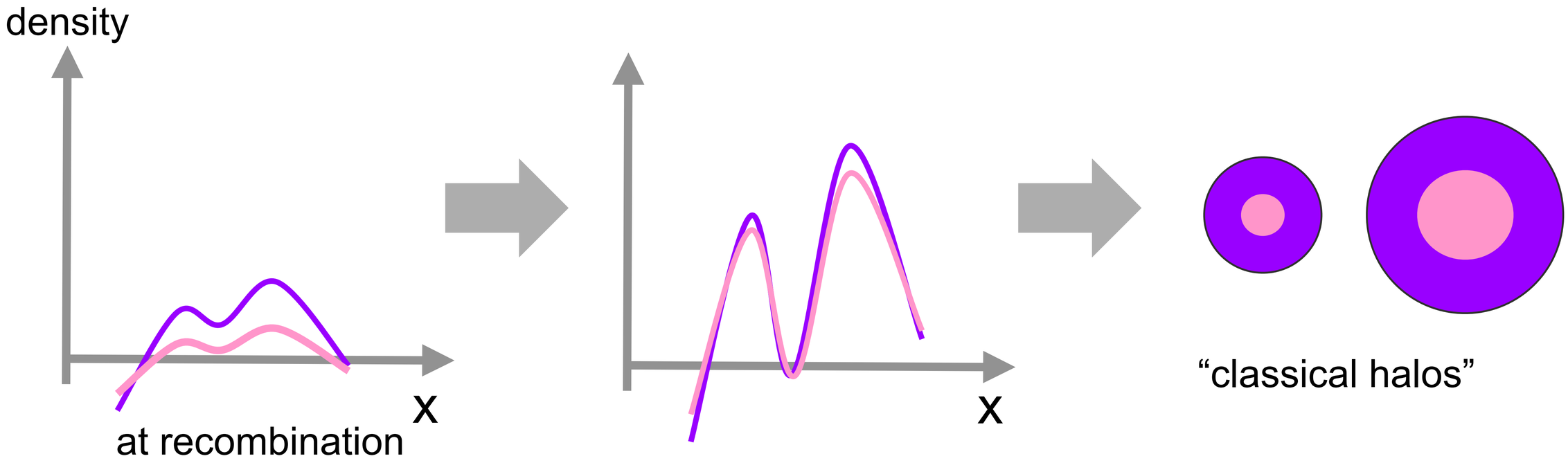


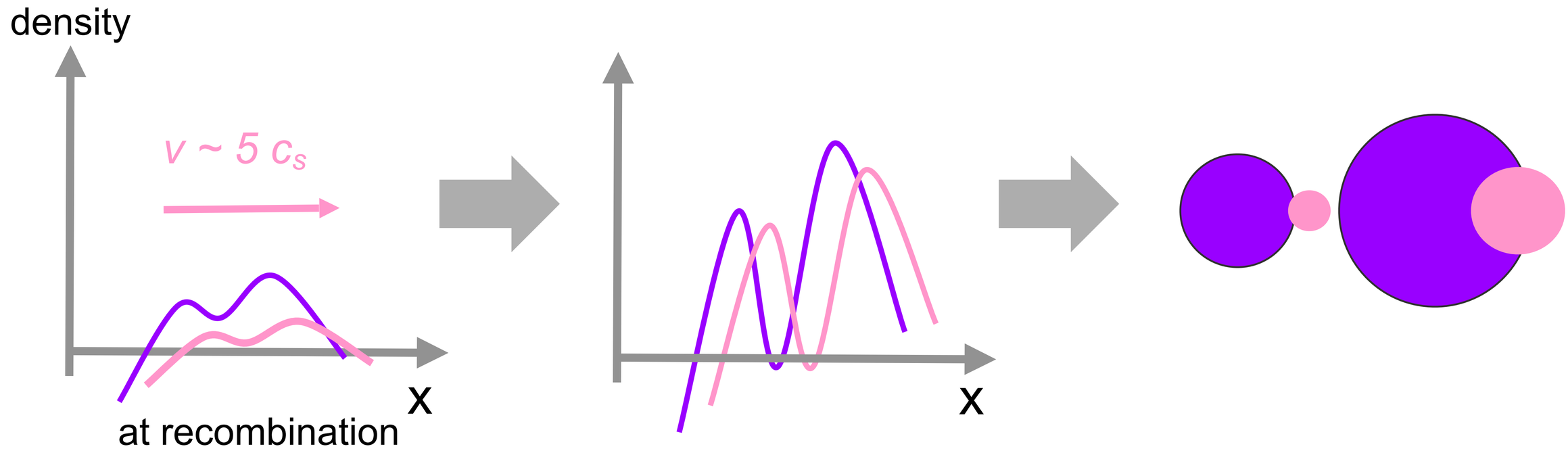
Dark matter density

Baryon density

Naoz & Narayan (2014)

Introduce relative velocity between DM and baryons $> 5\ c_s$ Tseliakhovich & Hirata (2010)

Supersonic relative velocity arises naturally through ΛCDM as a second order term



Dark matter density

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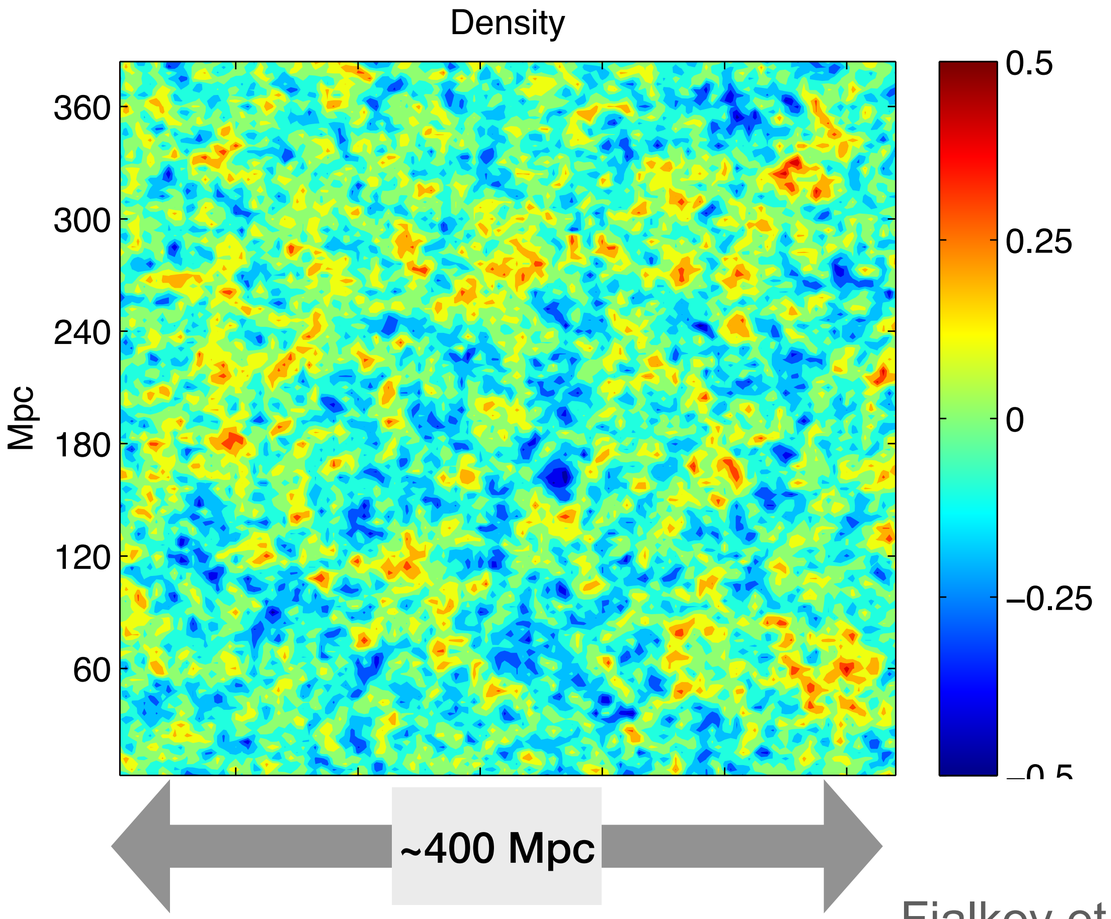
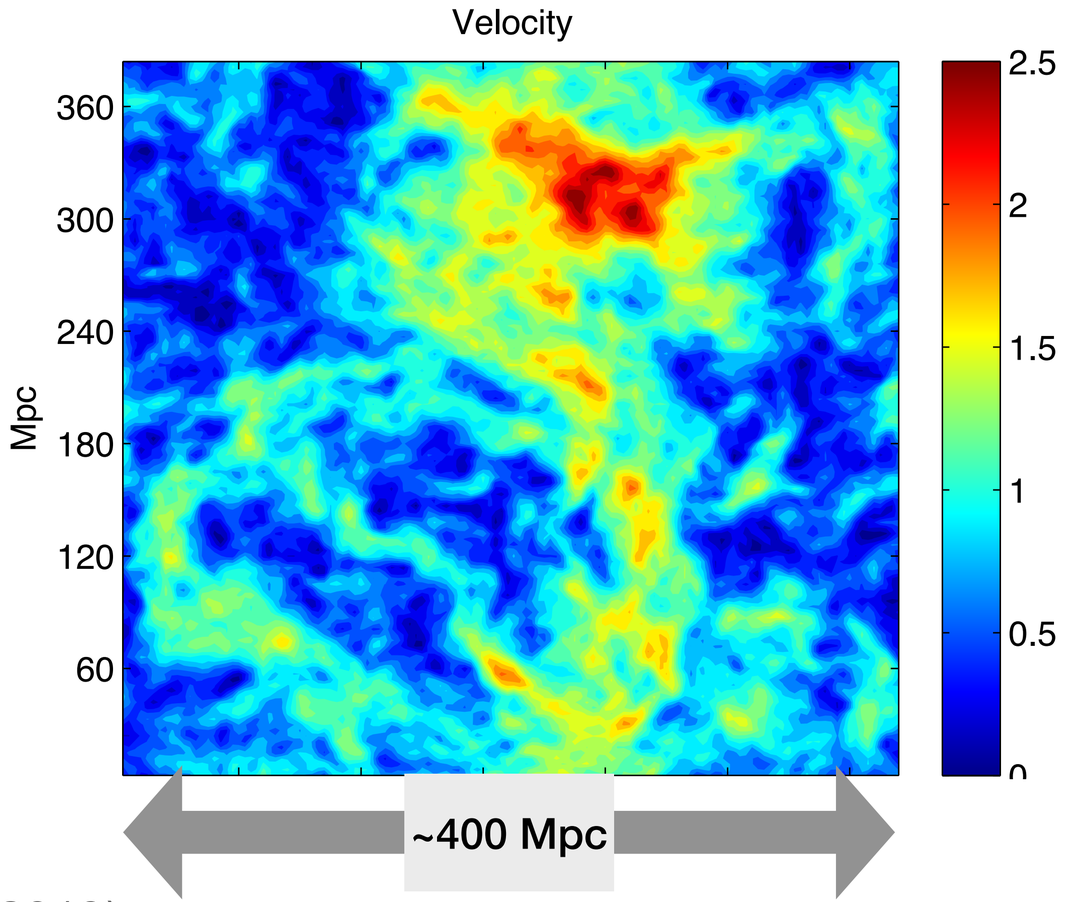
Naoz & Narayan (2014) Tseliakhovich & Hirata (2010)

Supersonic relative velocity between DM and baryons

“The stream velocity” (~40% of universe $> 5\ c_s$)

Tseliakhovich & Hirata (2010)





Fialkov et al (2013)

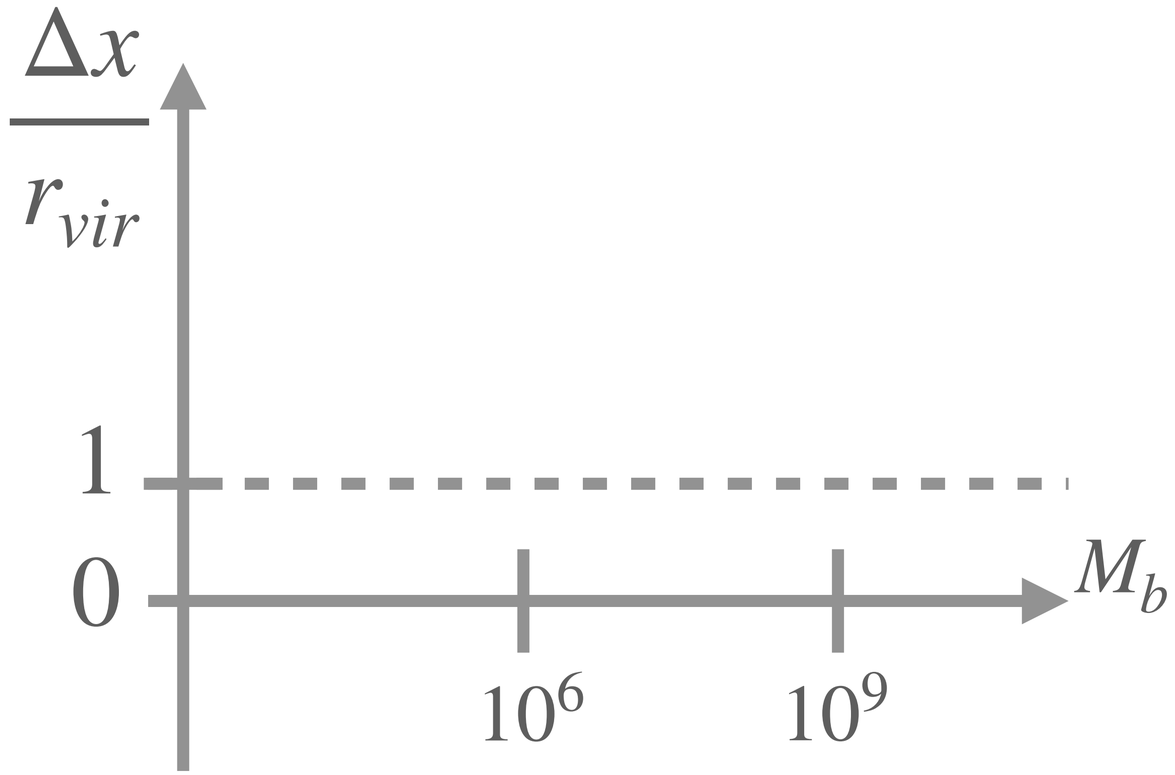
Local ~2σ fluctuation

Uysal & Hartwig (2022)

z=20

The smallest scales are most affected by supersonic streaming:

Baryons can collapse outside of their parent halo or significantly offset



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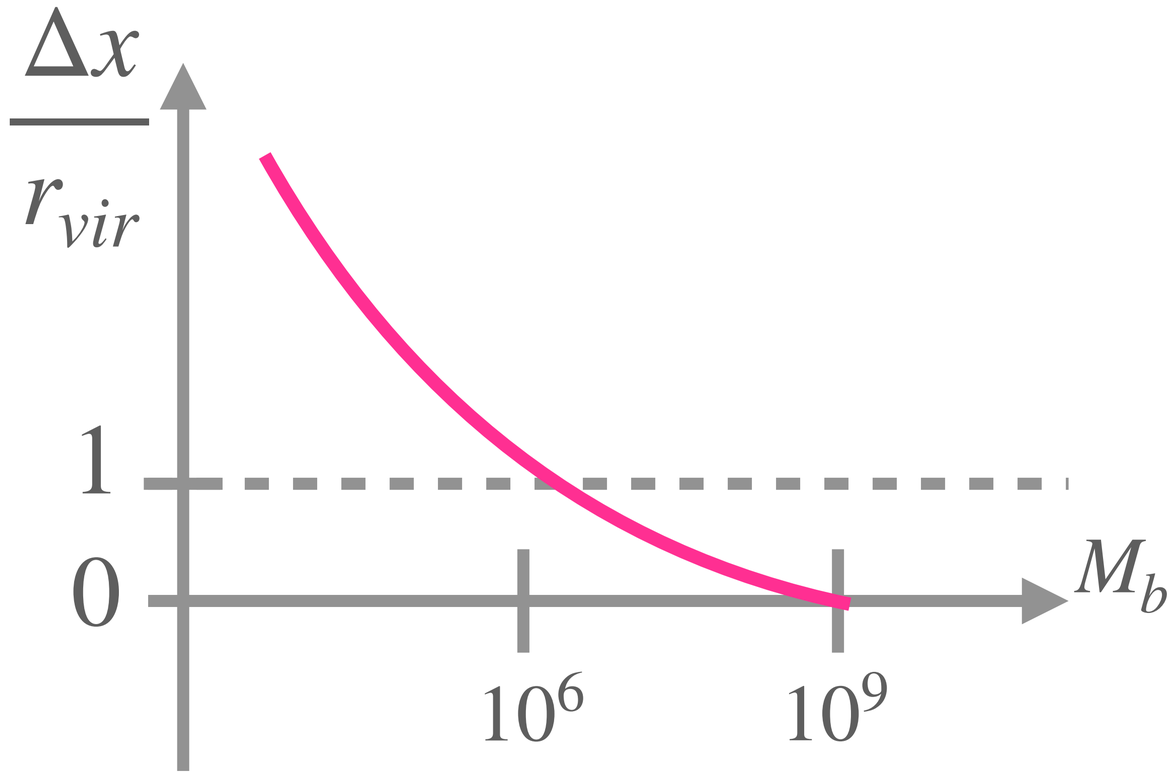

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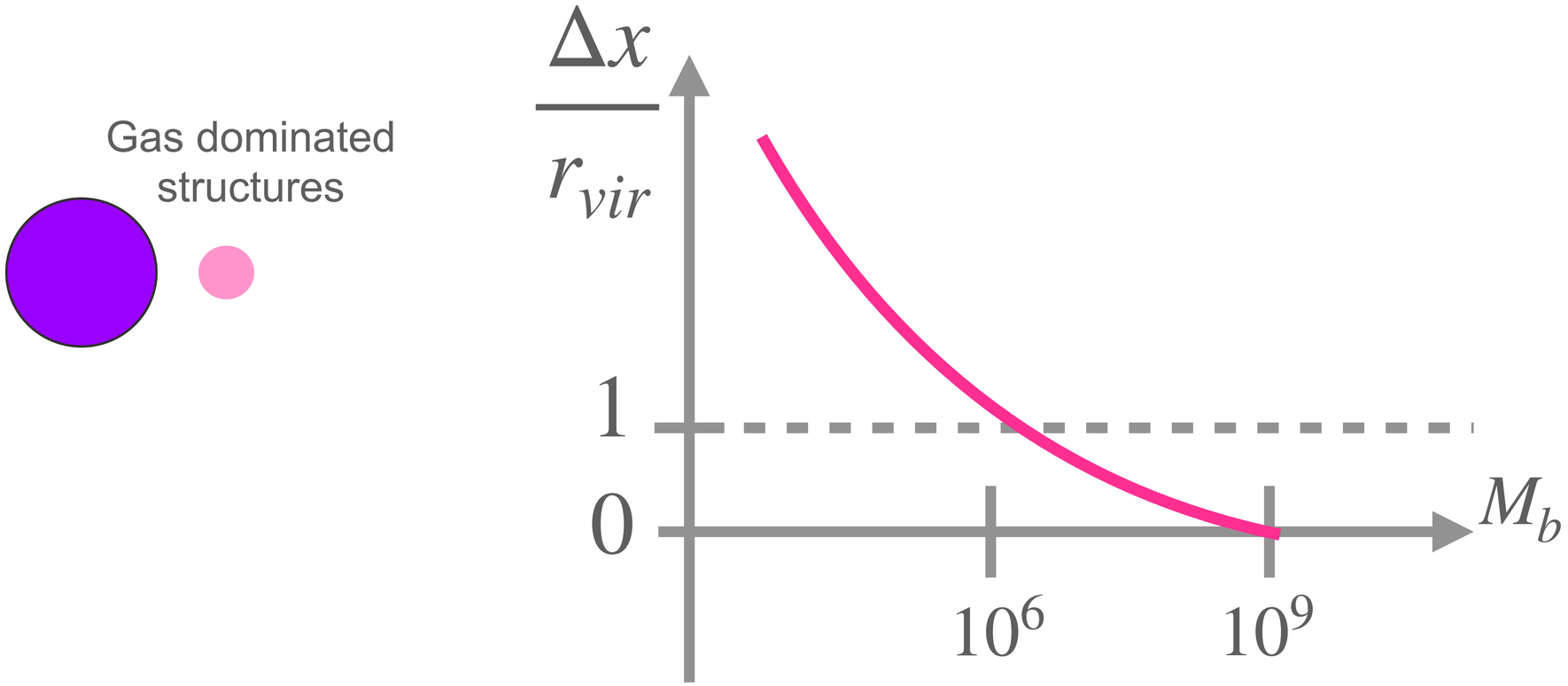
Gas dominated structures



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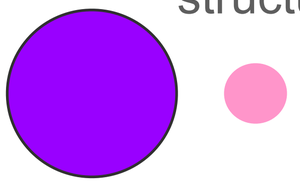
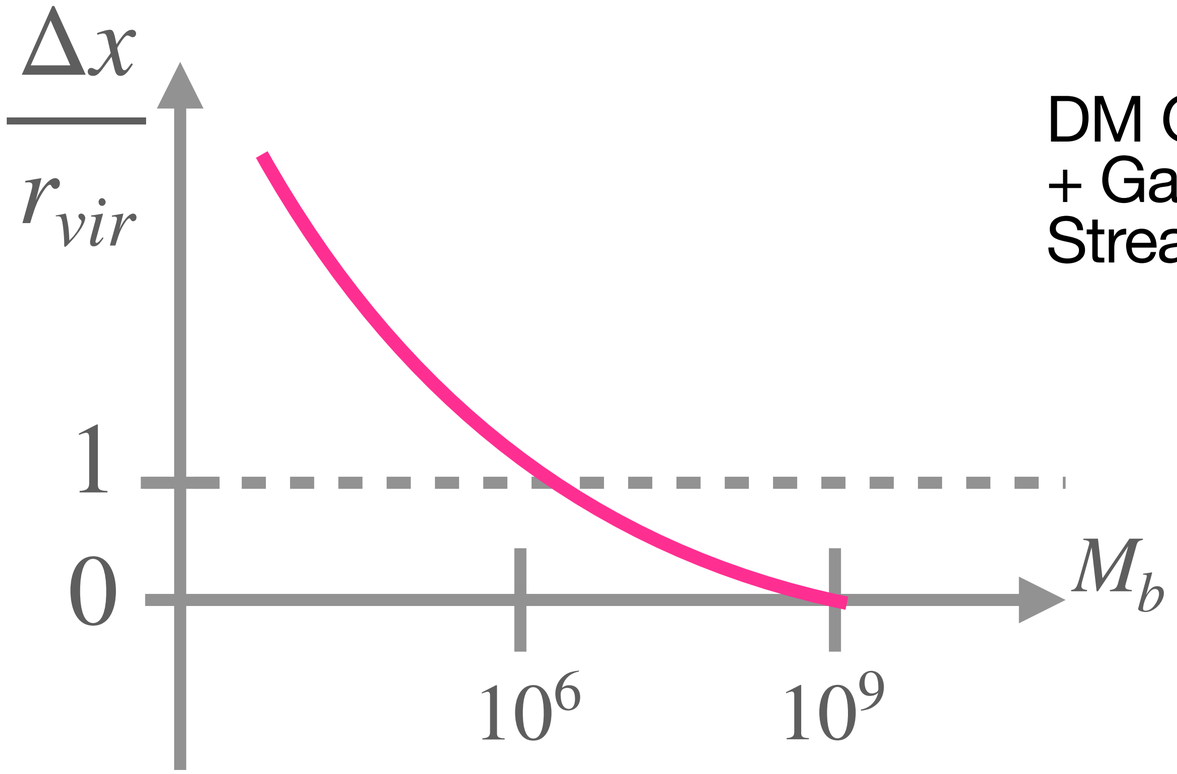


Gas dominated structures

SIGOs: Supersonically-Induced Gas Objects

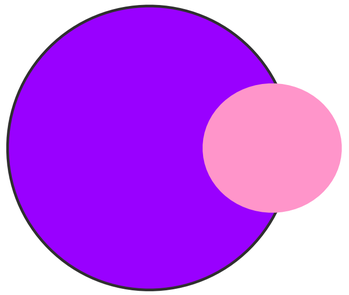
Chiou et al (2018, 2019, 2021), Lake et al (2021), Lake,…**CW** et al (2023a,b), Nakazato et al (2021)



Naoz & Narayan (2014)

DM GHOSts: Dark Matter + Gas Halos Offset by Streaming

Williams et al (2023a,b)

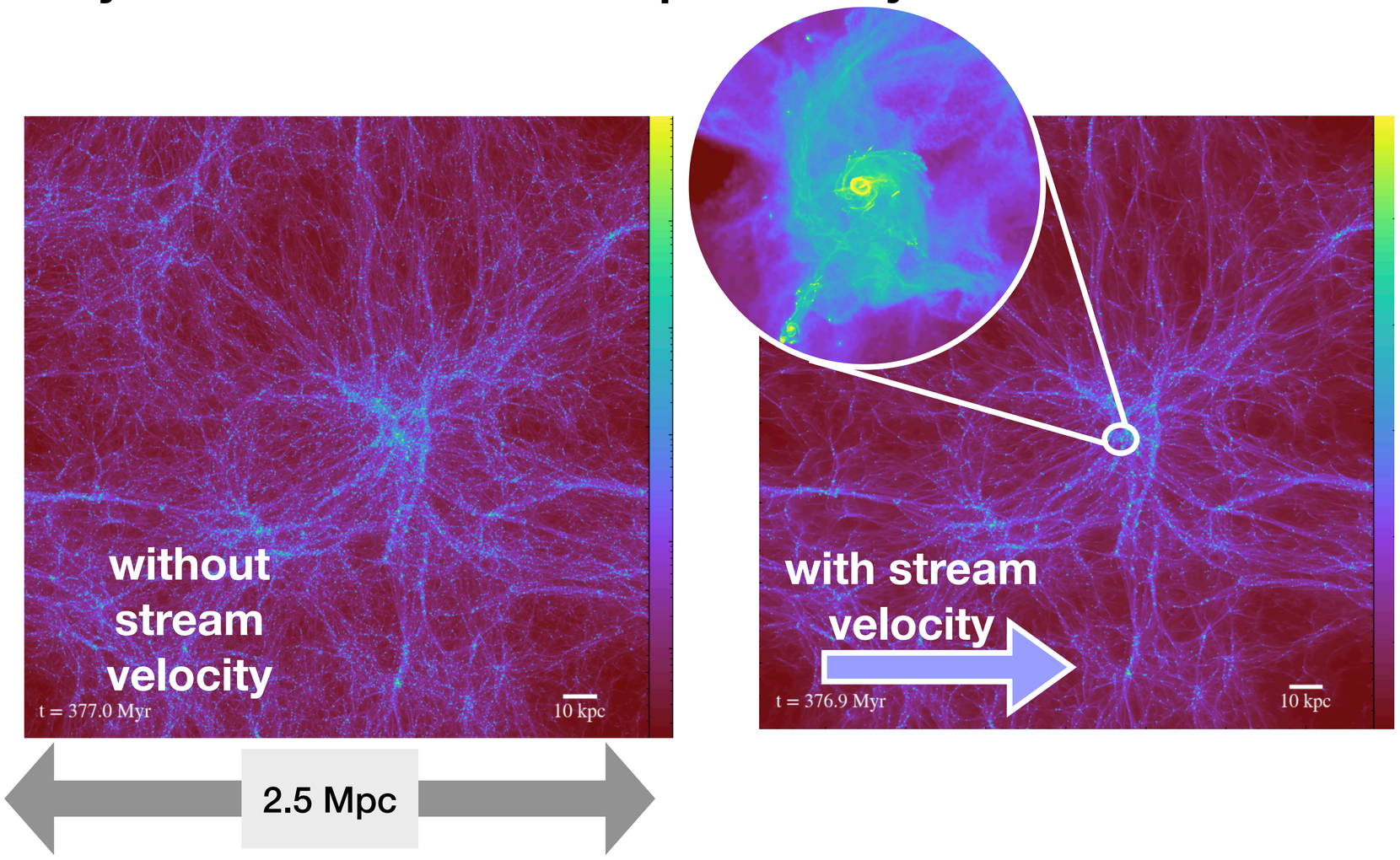


Dark matter dominated structures

Computational challenges

AREPO (Springel 2010) hydrodynamics simulations can probe early structure formation

- Small box (2.5 Mpc) allows for constant “stream velocity” (SV)
- High resolution ($M_B = 200 M_\odot$)
- Include star formation but not feedback
- z=200 to z=12

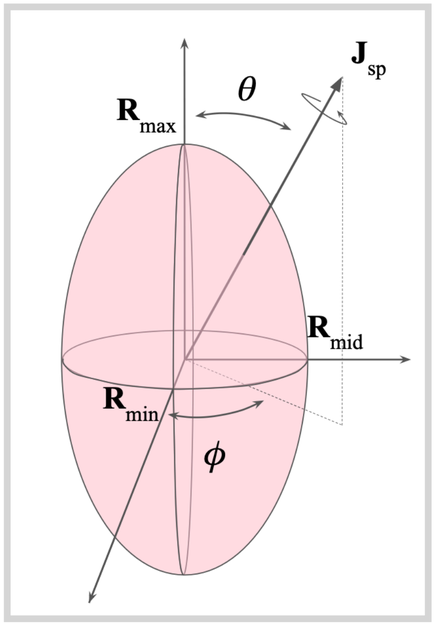


Williams et al (2023a,b); Lake, …**CW** et al (2023a,b)

Effects on the gas component of early dwarf galaxies

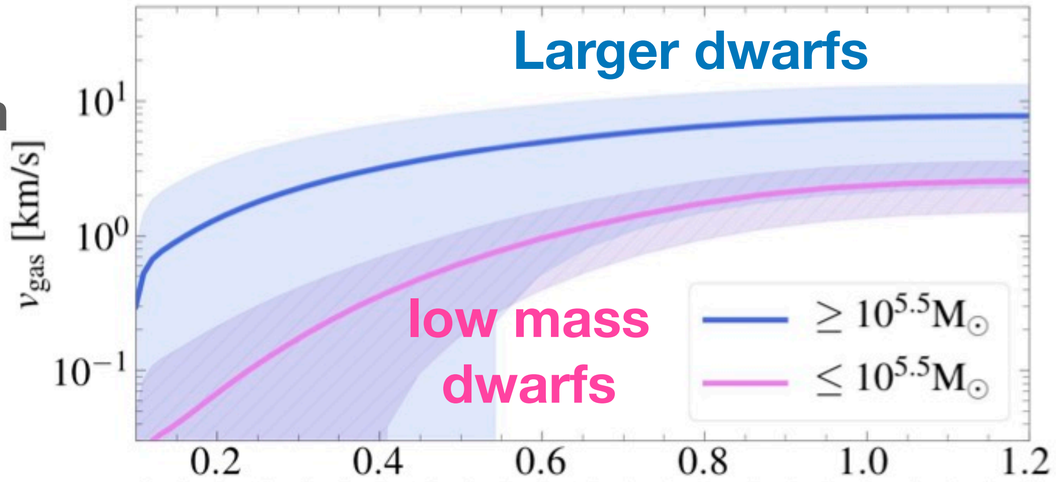
In regions with the stream velocity:

- Elongation of the gas component
- Greater rotational support in gas

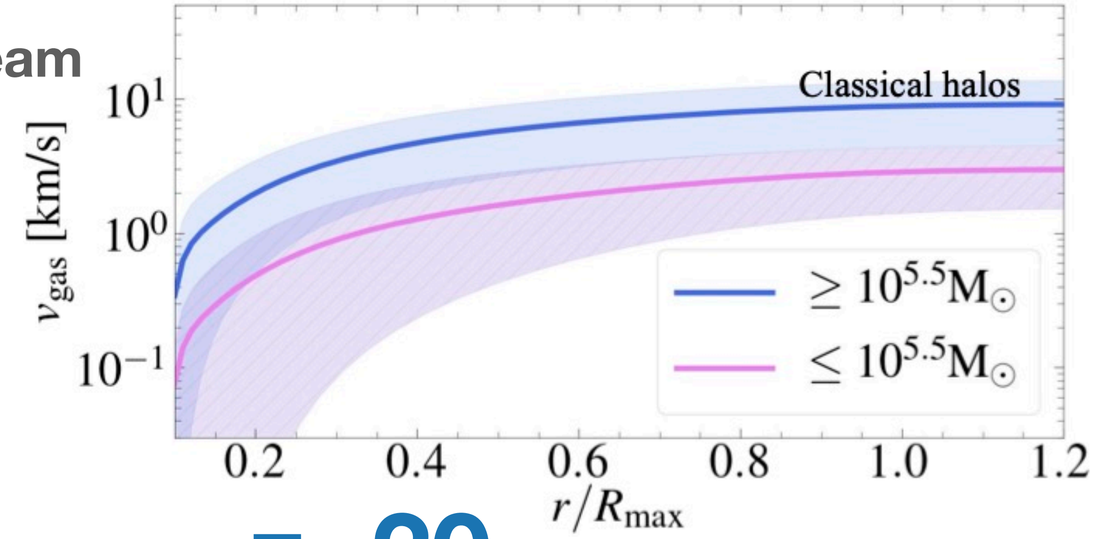


- Formation of a core at very low mass

with stream velocity



without stream velocity

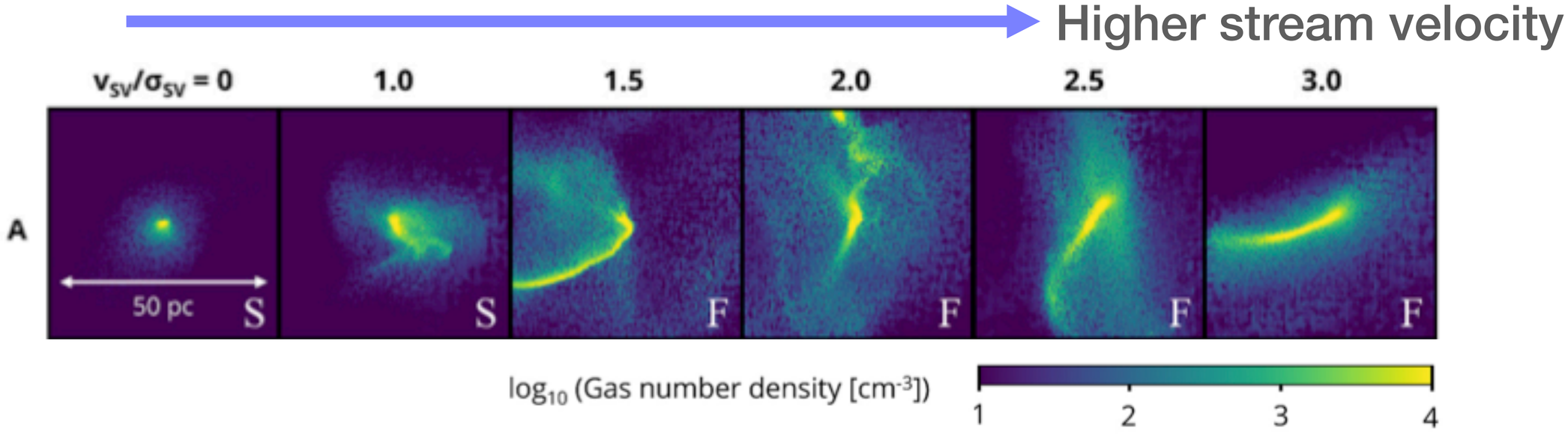


z=20

Williams et al (2023a)

Star formation also affected by the stream velocity

- Gas in early halos is advected and elongated by the stream velocity
- Number density of halos decreased in regions of streaming (erases small scale structure)
- Delay in the onset of star formation e.g., Maio et al (2011), Stacy et al (2011), Schauer et al (2012, 2022)

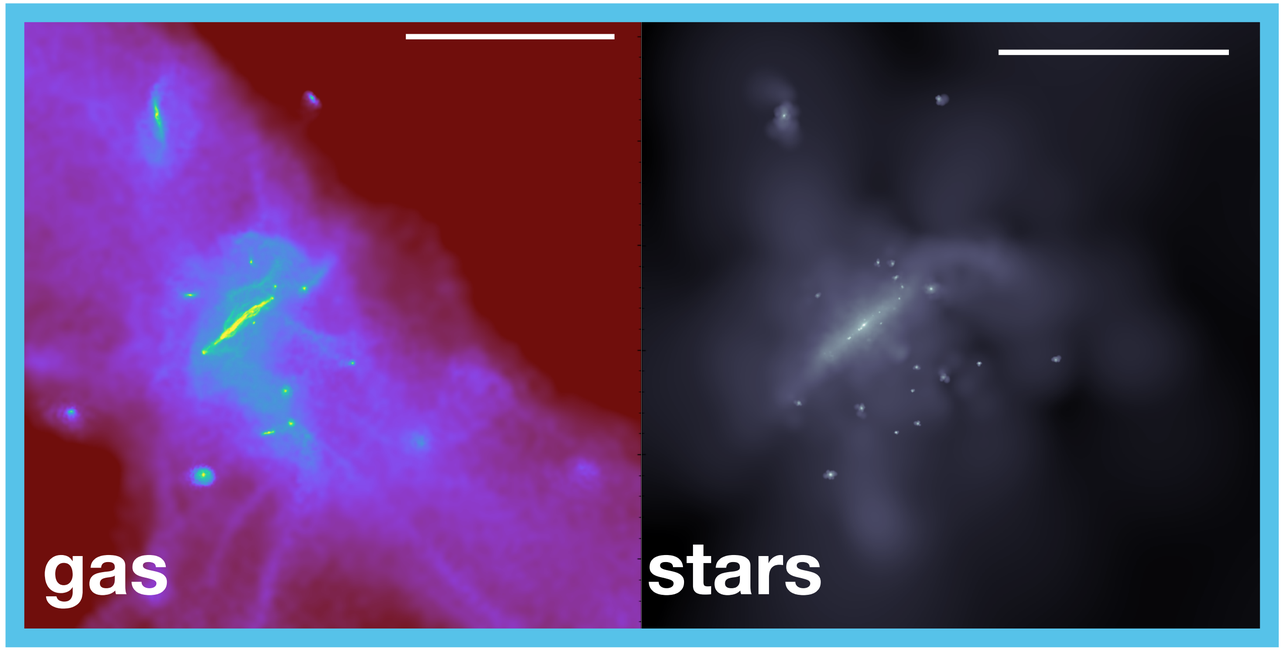


Hirano et al (2023)

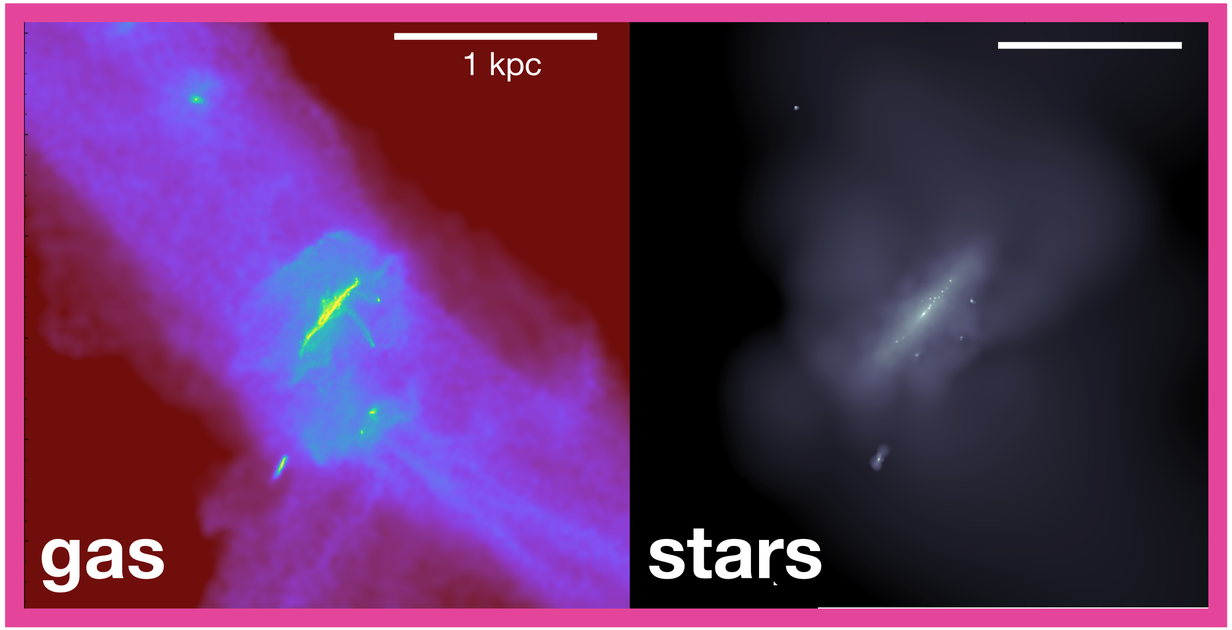
Star forming regions

Star formation in small clumps suppressed by the stream velocity

$v_{bc} = 0\sigma_{bc}$



$v_{bc} = 2\sigma_{bc}$



Projected Density $\left(\frac{\mathrm{g}}{\mathrm{cm}^2}\right)$

Projected Density $\left(\frac{\mathrm{M}_\odot}{\mathrm{pc}^2}\right)$

z=12

Williams et al (2023b)

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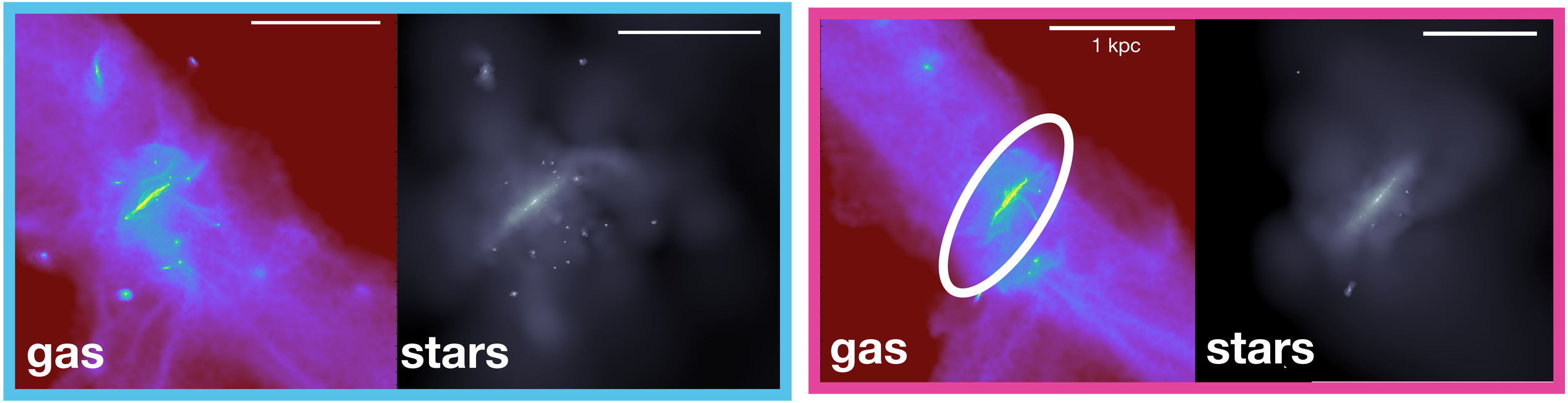
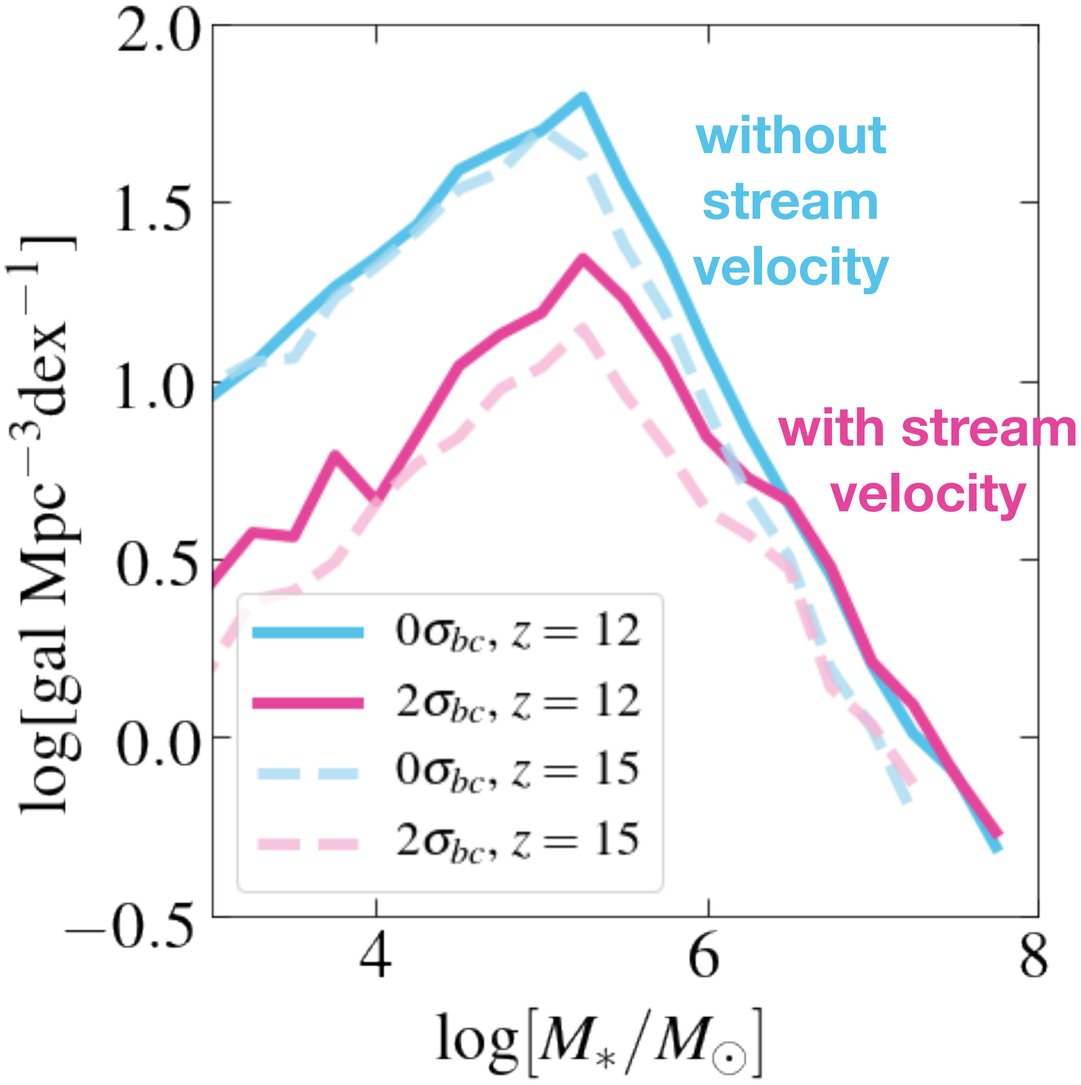


z=12

Williams et al (2023b)

Faint galaxy statistics at high-z

- At a given halo mass, there is less mass in the stellar component in regions of supersonic streaming
- Number density of low mass halos also suppressed by the stream velocity

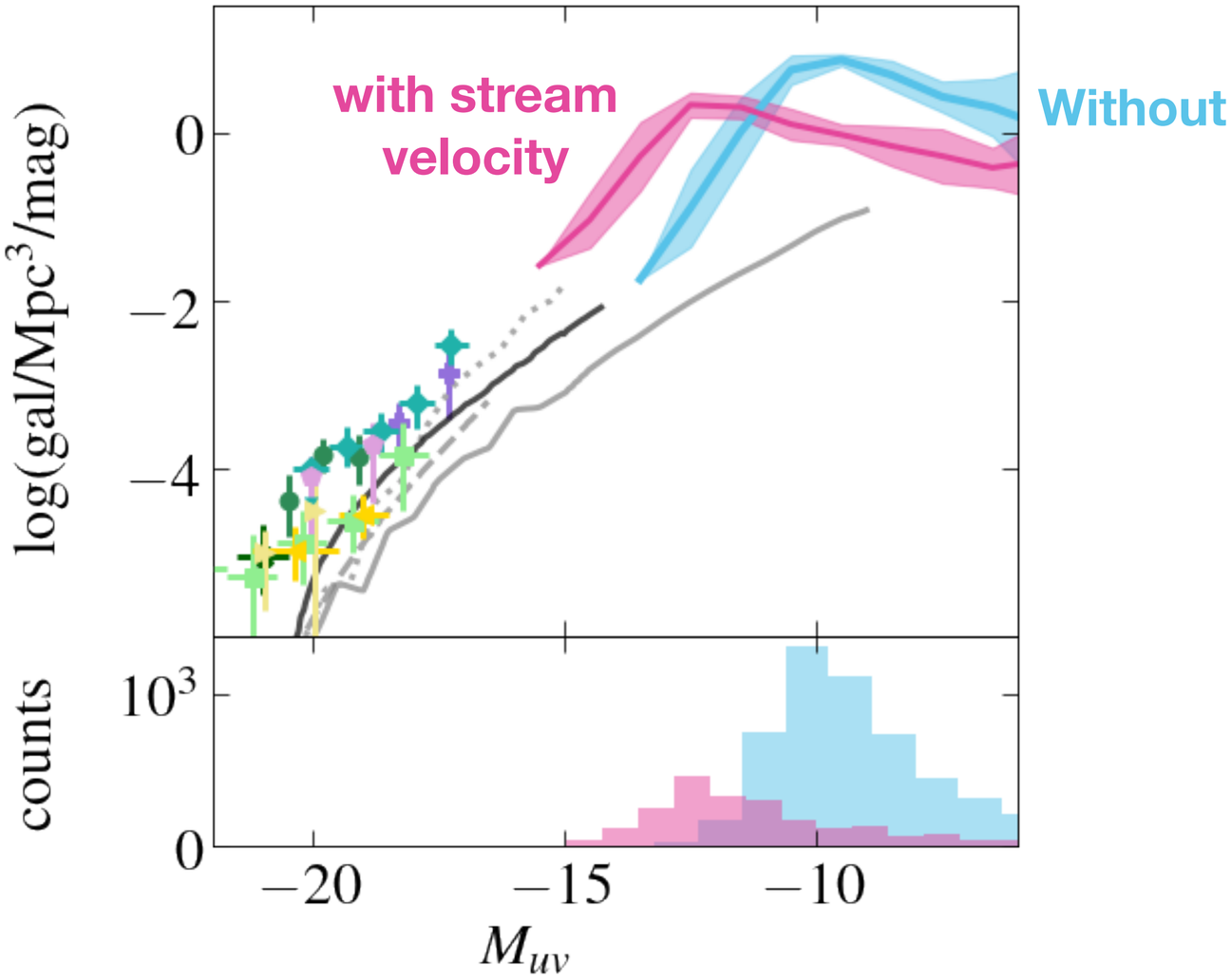


z=12

Williams et al (2023b)

Faint end of the *z=12* UV luminosity function

- Estimated UV magnitude with simple semi-analytical model
- Enhanced UVLF for larger dwarfs traces brief period of rapid star formation
- Complications:
  - UV luminosity-SFR conversion factor $\mathcal{K}_{\rm UV}$ + uncertain IMF
  - Feedback processes still to be included



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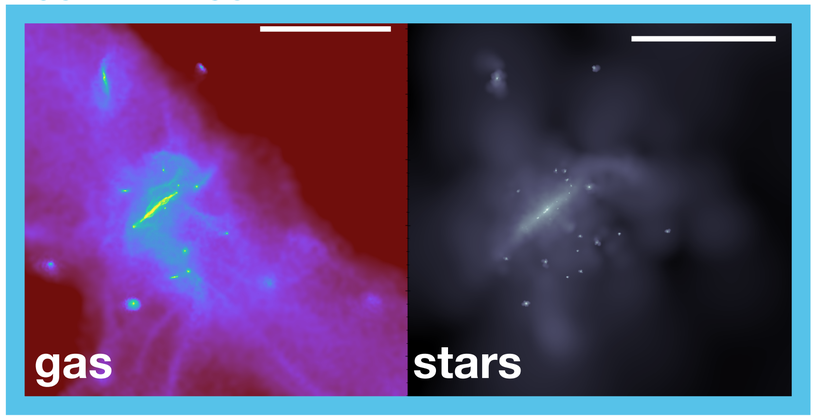
$v_{bc} = 0\sigma_{bc}$ **Earlier star formation in mini halos**



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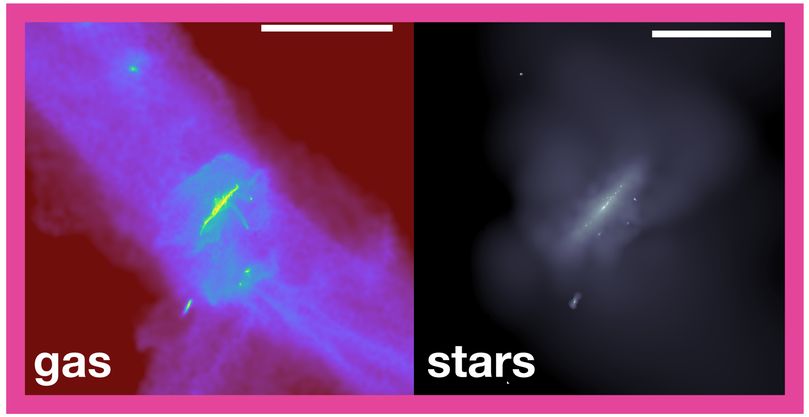
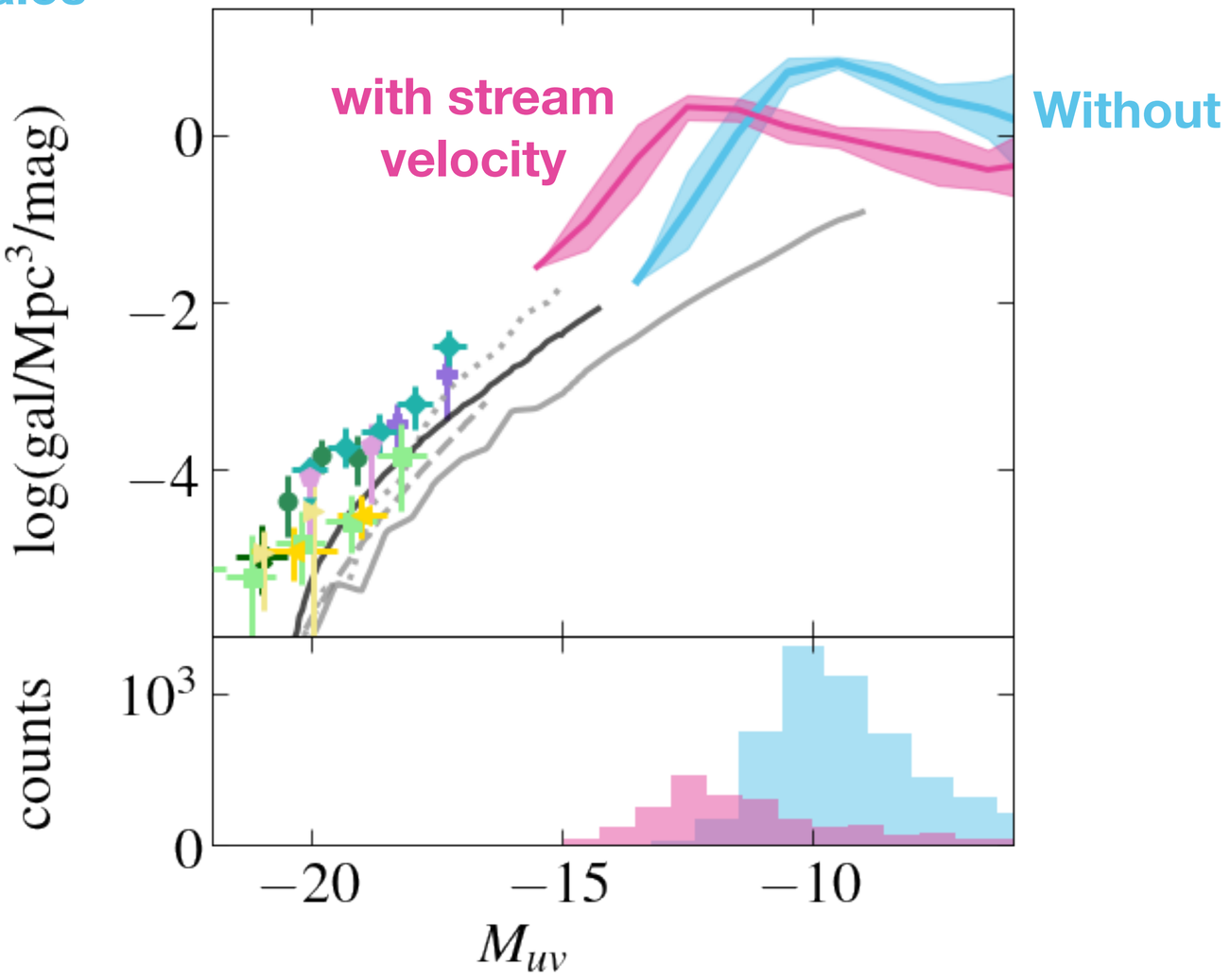


Rapid SF during "catching up" period following initial delayed onset



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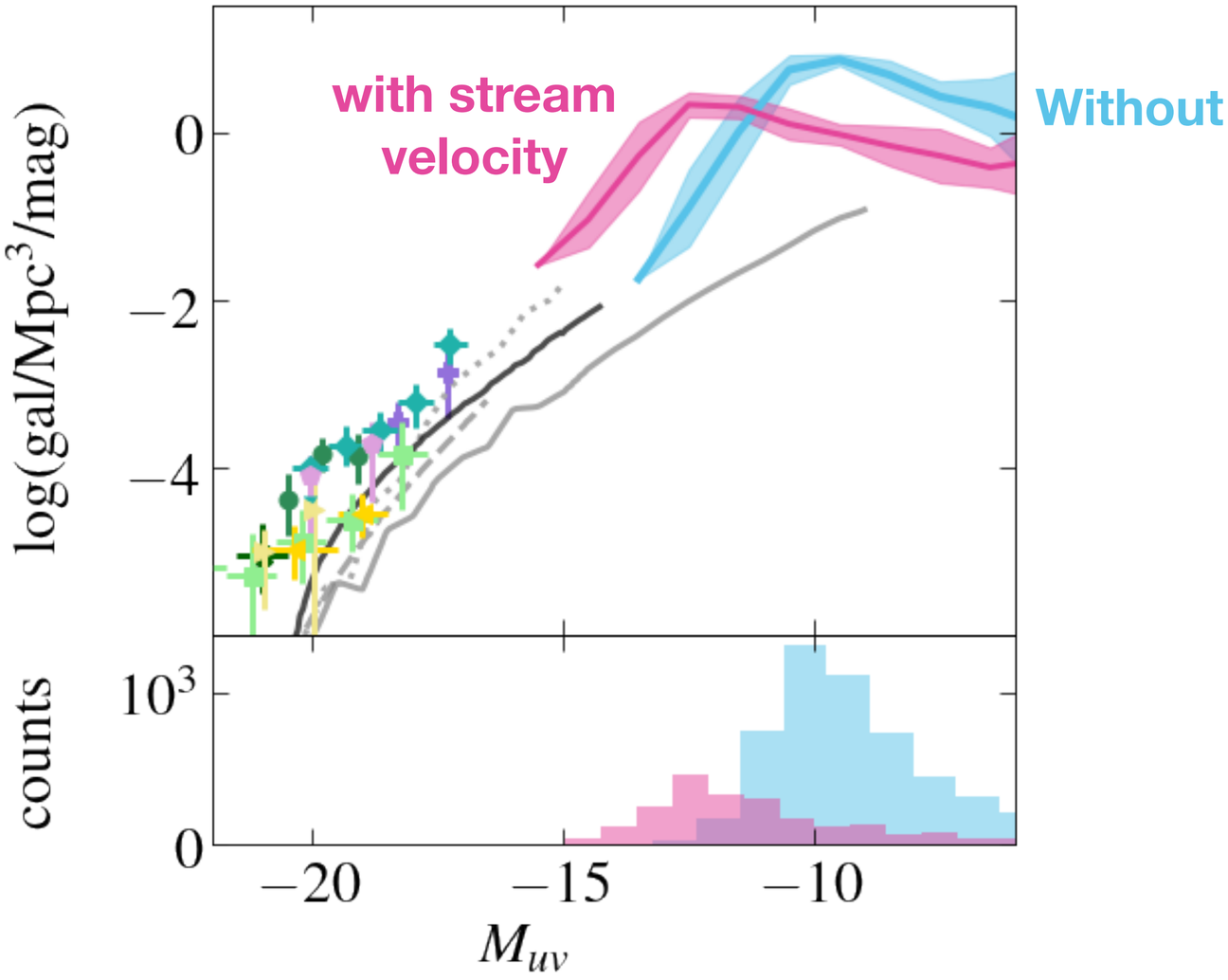

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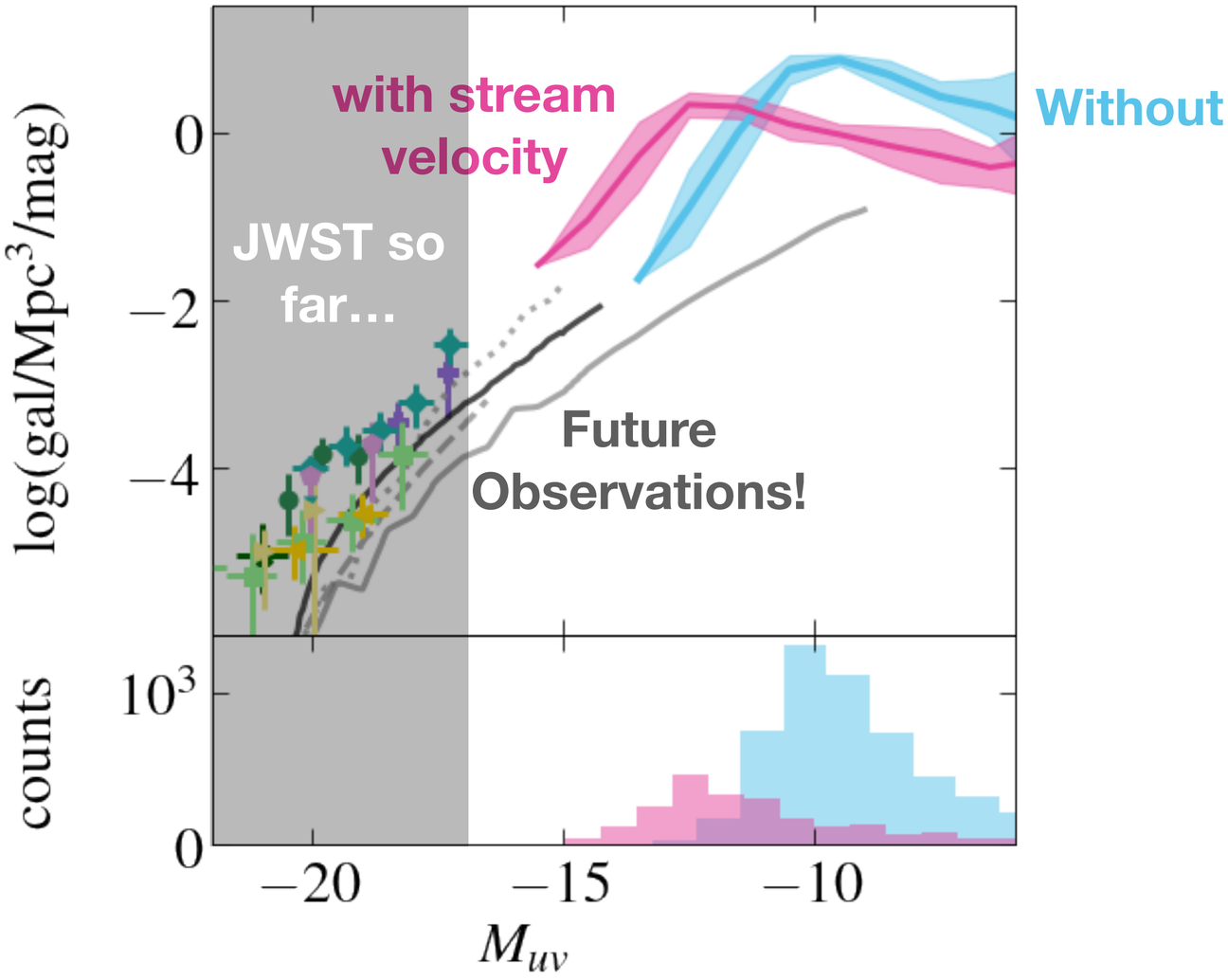

Williams et al (2023b)

Summary

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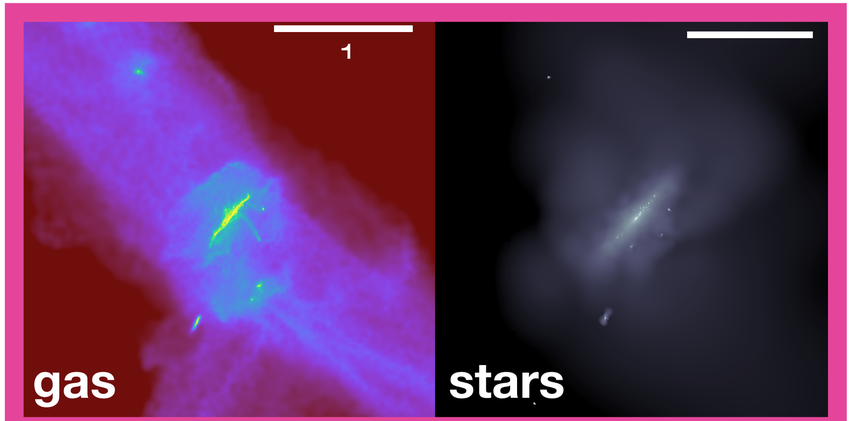

arXiv:2310.03799

- Dwarf galaxies in regions of streaming subject to several effects on their early star formation
  - Delay and suppression of star formation
  - Dwarf galaxies sit in larger DM halo than in no streaming case
  - + other effects (suppression of # of halos, etc.)
- JWST close to a regime where UVLF may contain information about the stream velocity at *z=12*
  - Brief period of *enhanced* star formation with the stream velocity
- Opportunity for insight into formation of MW and local group dwarfs & tests of ΛCDM