# Bursty Star Formation is Sensitive to Numerical Choices in SNe Feedback Models

arXiv: 2406.10338 | ApJ 975 229

18th Potsdam Thinkshop - AIP

Eric Zhang, Laura V. Sales, the SMUGGLE Collaboration

Friday, 18 July 2025

The main mechanism responsible for rearranging a dwarf galaxy’s dark matter and stellar content is ***bursty star formation***, and the resulting clustered supernovae.

The main mechanism responsible for rearranging a dwarf galaxy's dark matter and stellar content is ***bursty star formation***, and the resulting clustered supernovae.

Core-cusp

The main mechanism responsible for rearranging a dwarf galaxy's dark matter and stellar content is ***bursty star formation***, and the resulting clustered supernovae.

Core-cusp

Diversity of dwarf sizes

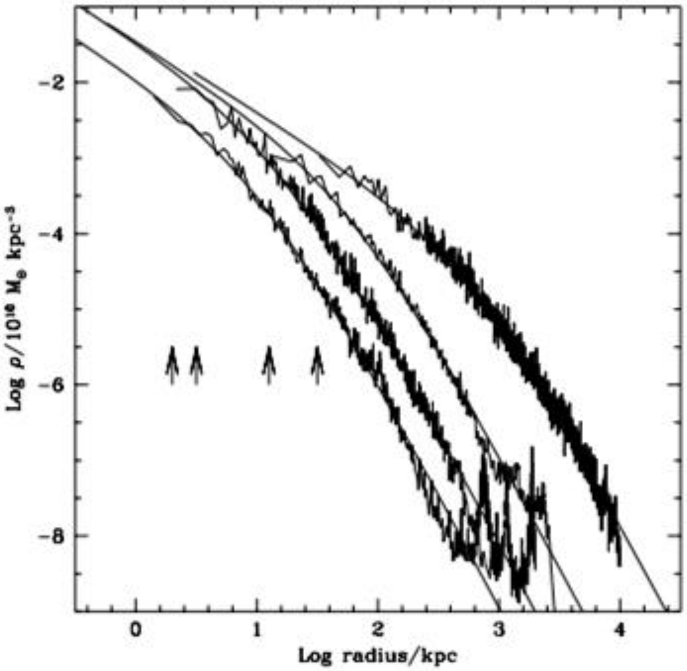
The main mechanism responsible for rearranging a dwarf galaxy's dark matter and stellar content is ***bursty star formation***, and the resulting clustered supernovae.

Core-cusp

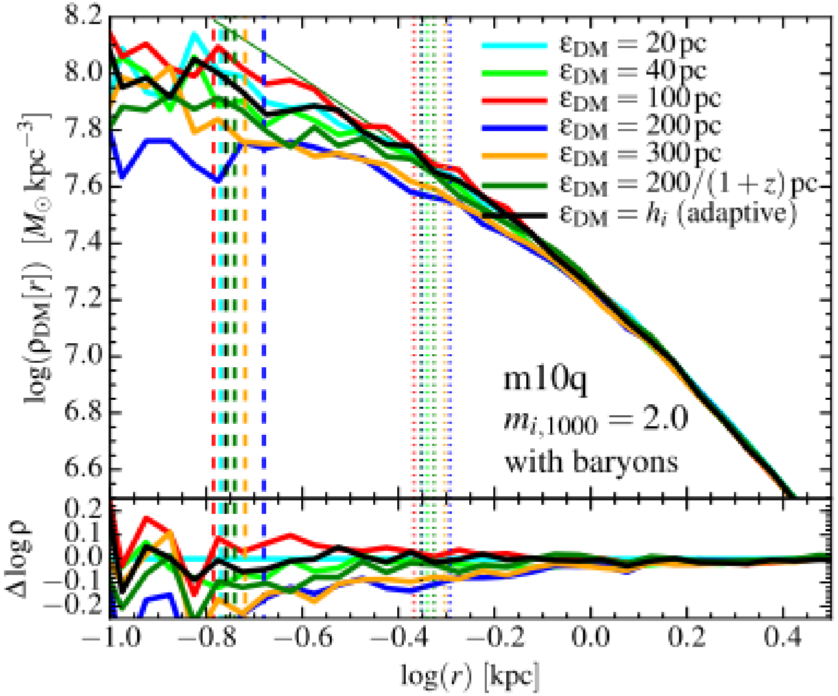
Diversity of rotation curves

Diversity of dwarf sizes

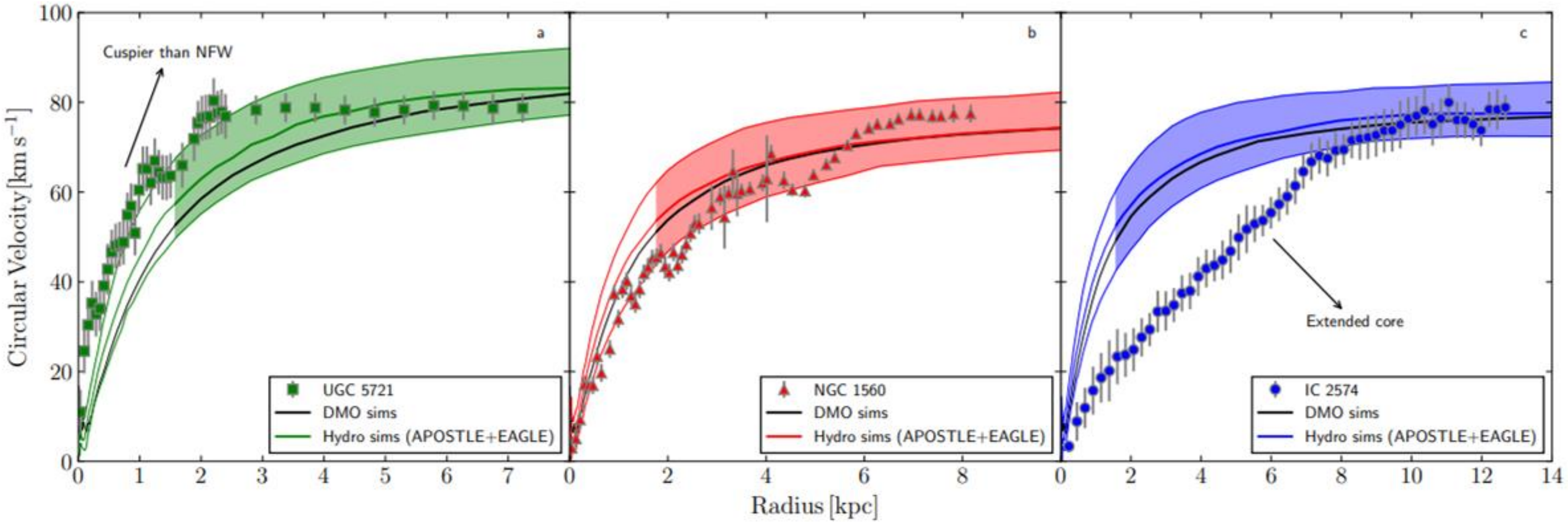
**Dark matter only simulations** tend to produce **cuspy** (or more centrally concentrated) density profiles, while **simulations including stellar processes** tend to produce **cored** (or less centrally concentrated) profiles.




Navarro et al 1996; dark matter only

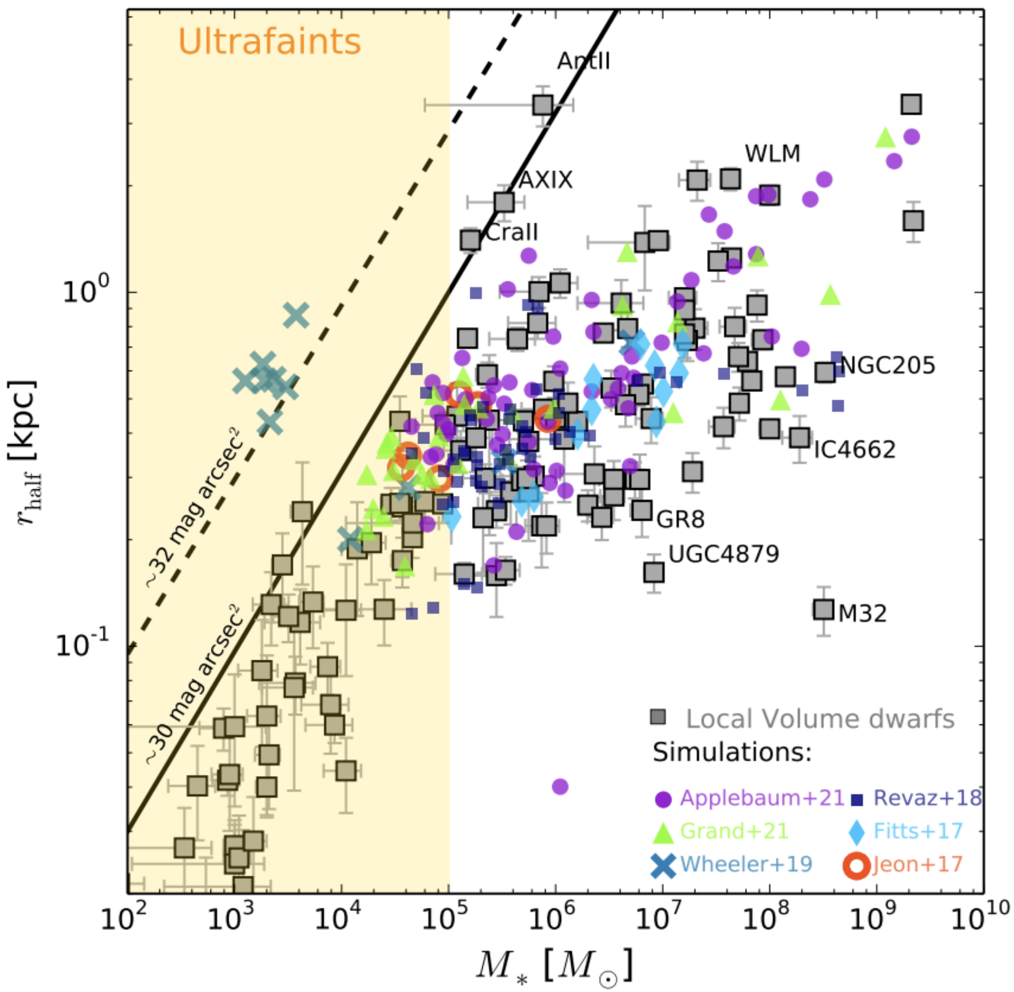



FIRE-II; stellar processes included; see also Stinson+07, Gonzales-Samaniego+14, Di Cintio+14, Sparre+16; with exceptions e.g. Bose+19

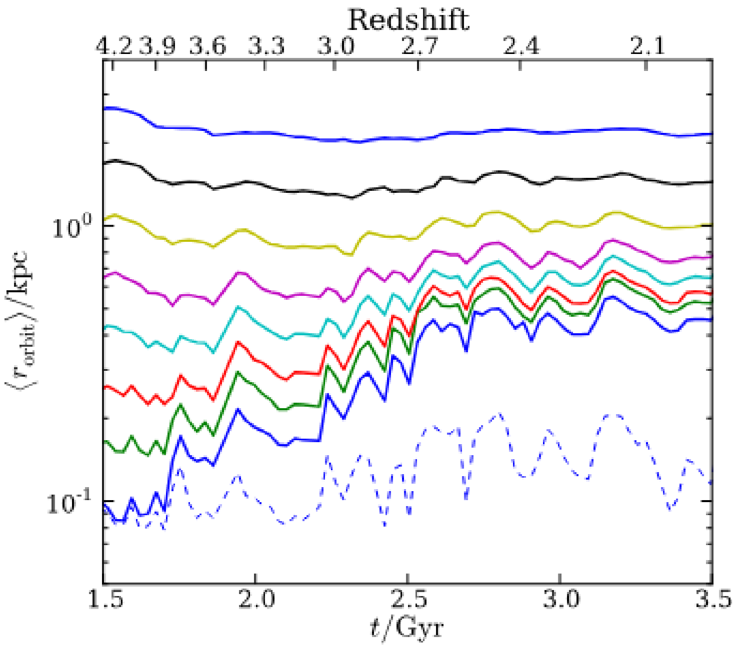


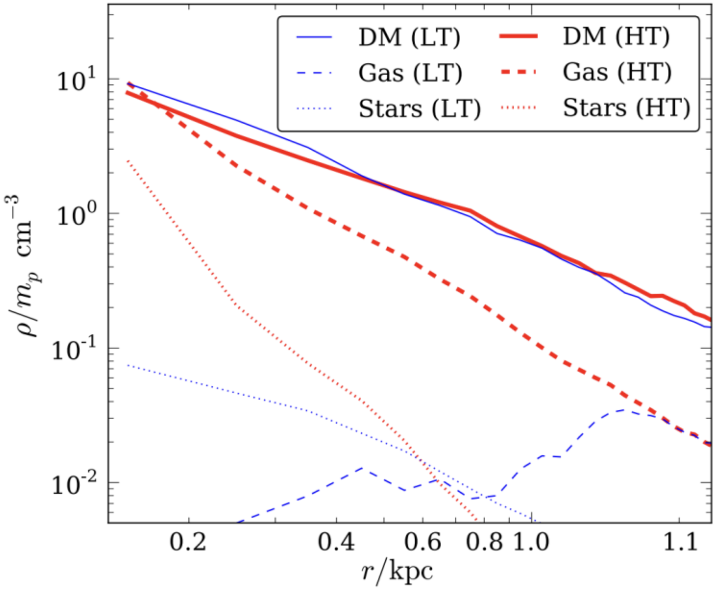

Sales, Wetzel, Fattahi 2022; also see talk by Nicolas Bouché

Meanwhile, **observations of rotation curves show a wide variety** of inner dark matter distributions; cusps, cores, and everything in between.




Source: Sales et al 2022



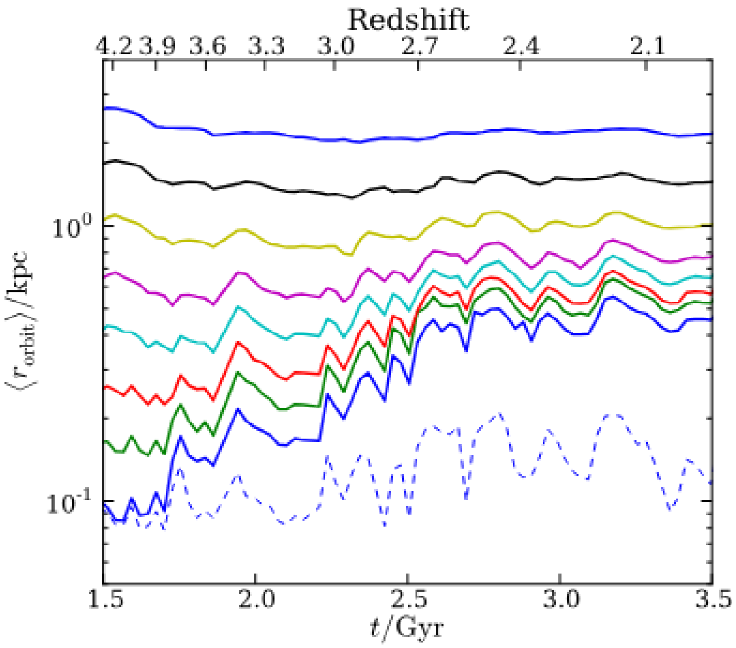



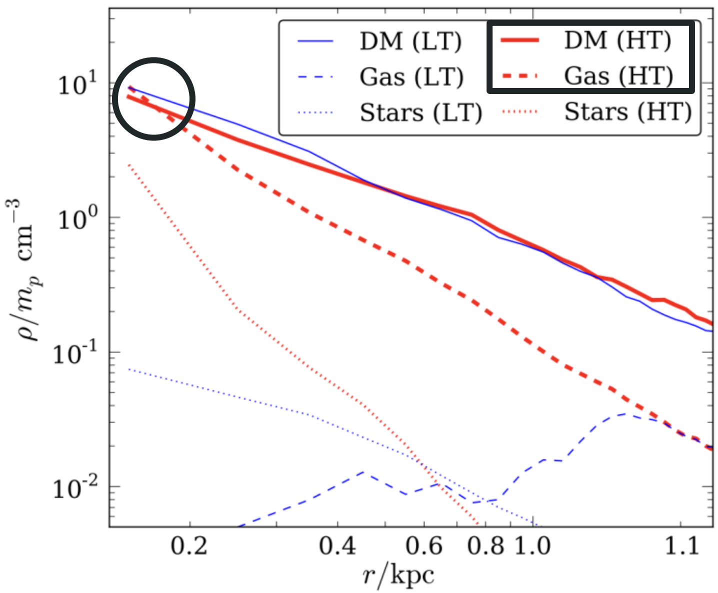

Source: Pontzen, Governato 2012

Bursty star formation causes **quick, repeated blowouts of large amounts of gas** from central regions due to supernovae.

Even though stars and dark matter are not affected by this expulsion, the large drop in central mass will quickly cause the central region to be **less tightly bound.**

Thus the orbits of stars and dark matter particles about the center will suddenly **migrate outwards.**



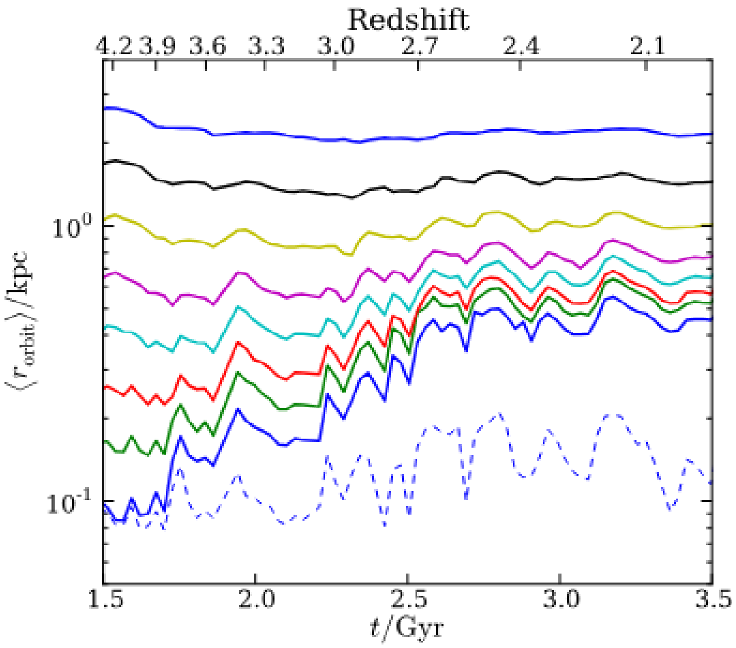



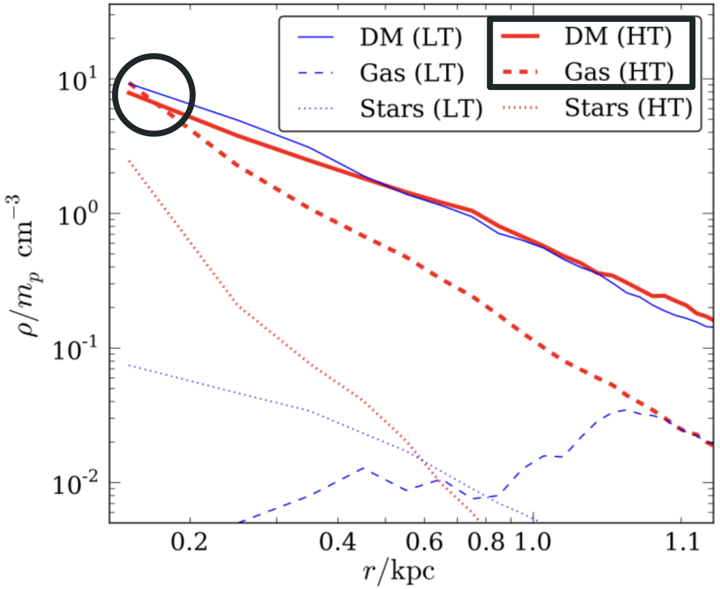

Bursty star formation causes **quick, repeated blowouts of large amounts of gas** from central regions due to supernovae.

Source: Pontzen, Governato 2012

Even though stars and dark matter are not affected by this expulsion, the large drop in central mass will quickly cause the central region to be **less tightly bound.**

Thus the orbits of stars and dark matter particles about the center will suddenly **migrate outwards.**




Bursty star formation causes **quick, repeated blowouts of large amounts of gas** from central regions due to supernovae.

Source: Pontzen, Governato 2012

Dwarf galaxies (stellar mass ~ $10^6$ to $10^9$ M☉) are thought to be particularly sensitive to this process, because they are baryon-rich enough to produce bursts of stars, but their potential wells are shallow so that the gas outflow is effective.

# Supernova Feedback

Supernovae are ideally modelled as point injections of a large amount of thermal energy ($10^{51}$ erg), which then thermally expand into the ISM on the timescale of Myrs (the energy-conserving “pressure-driven” phase)

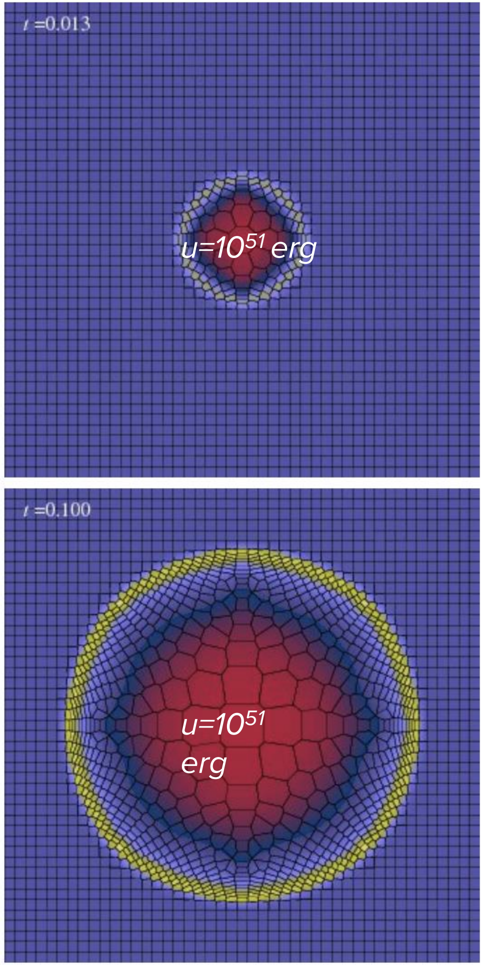


Diagram from Springel 2010

# Supernova Feedback

Supernovae are ideally modelled as point injections of a large amount of thermal energy ($10^{51}$ erg), which then thermally expand into the ISM on the timescale of Myrs (the **energy-conserving "pressure-driven"** phase)

Once the thermal pressure becomes comparable to the ambient pressure (at the **cooling radius**), the induced bubble continues to expand and sweep up mass with no driving force (the **momentum-conserving "snow-plow"** phase)

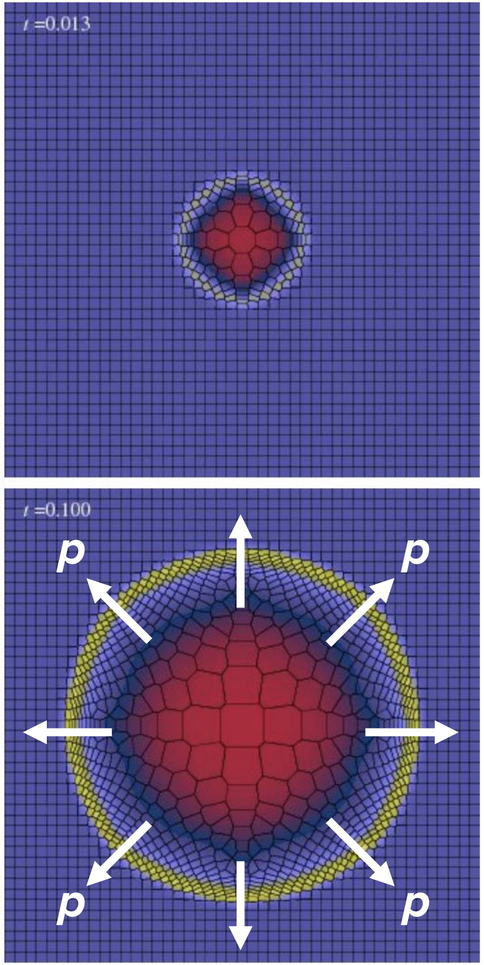


Diagram from Springel 2010

# Supernova Feedback

However, at all but the highest resolutions, this energy will be numerically radiated away before it has the chance to expand due to the *"overcooling problem"*; the cooling timescale of hot gas is too short at typical resolution!

A common solution for coarse-resolution simulations is the ***mechanical feedback scheme*** which directly deposits momentum into surrounding gas cells (instead of thermal energy).

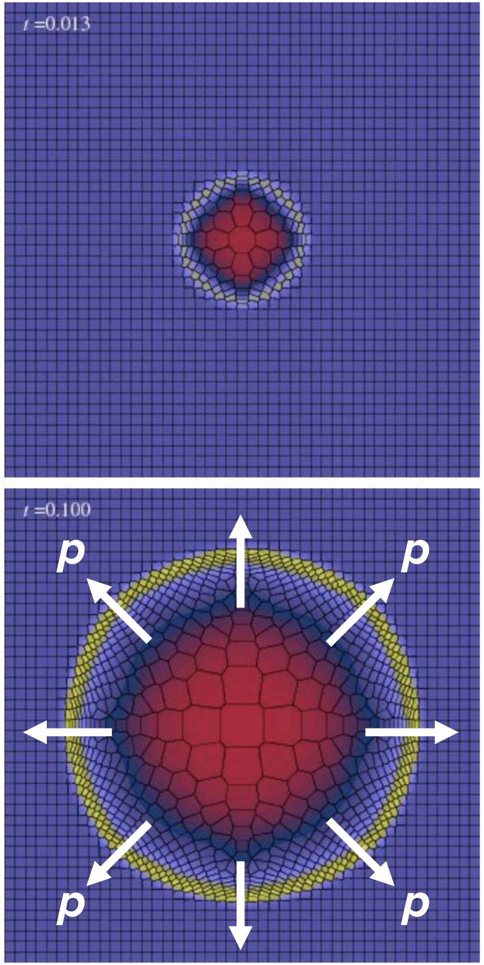
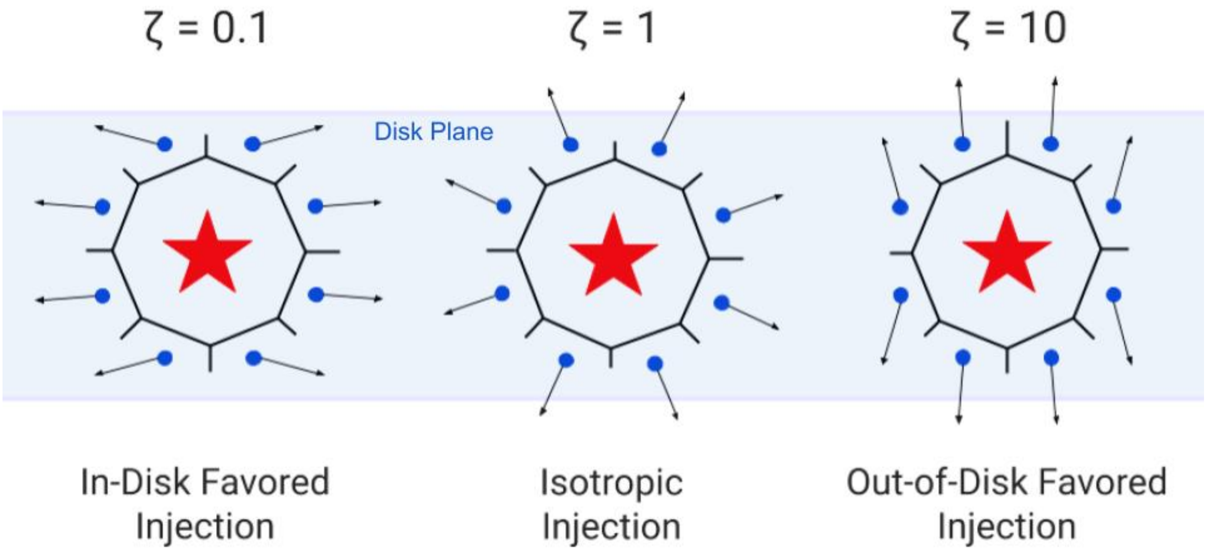



Diagram from Springel 2010

# Varying the Supernova Feedback Model

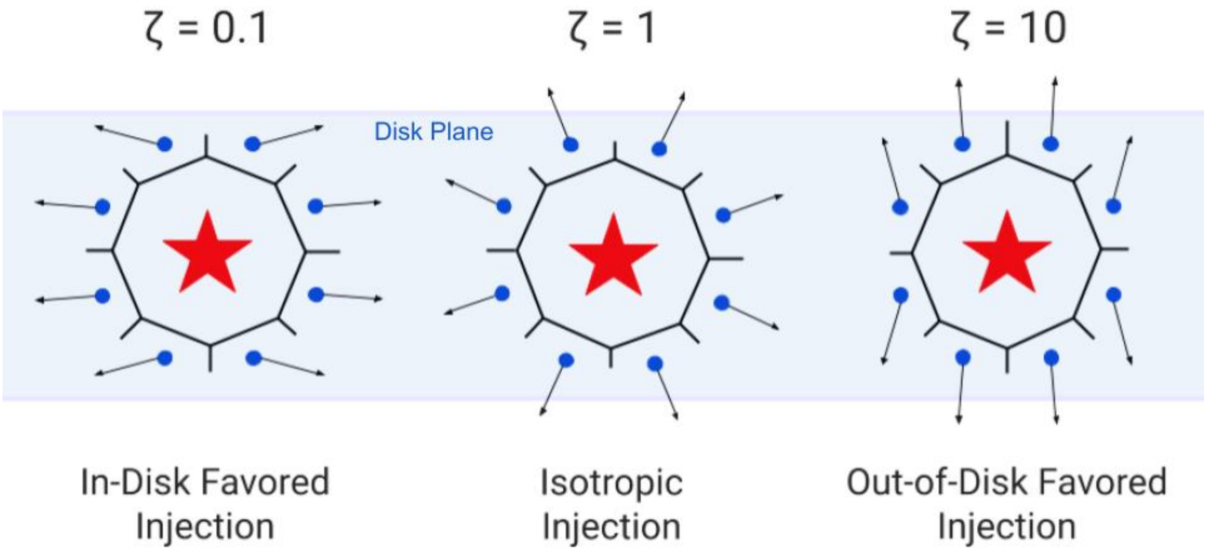
- Using the SMUGGLE (Marinacci et al 2019) stellar feedback model, we vary the SNe feedback by directing the momentum either primarily along or perpendicular to the disk according to a tunable parameter (while keeping the total momentum constant)



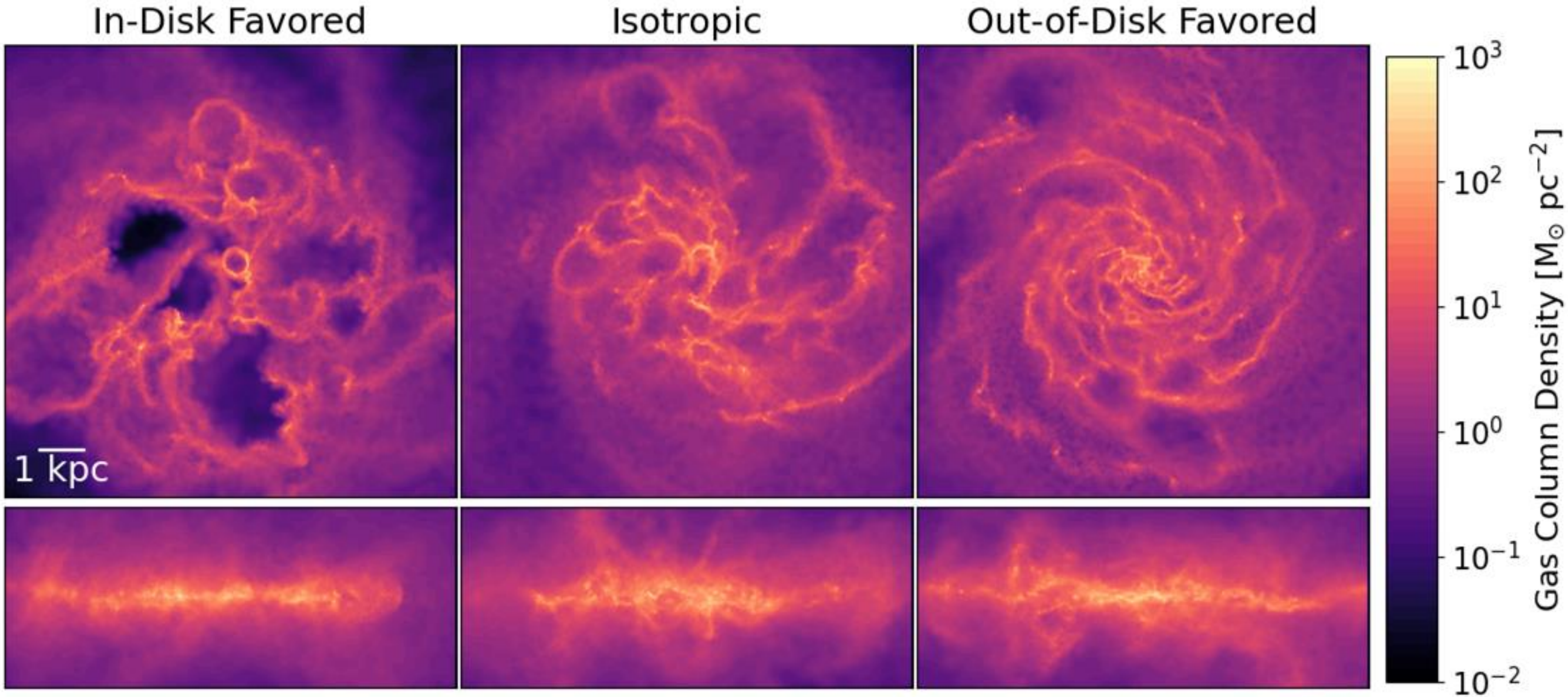

Source: Zhang et al. (2024)

# Varying the Supernova Feedback Model

- This model will be tested on idealized initial conditions, consisting of a $10^{10}$ M⊙ halo with a stellar mass of $10^{8}$ M⊙.
- The baryonic mass resolution is 6000 M⊙, which is too coarse to explicitly resolve the thermal expansion phase of SNe; thus we must use the mechanical feedback scheme.

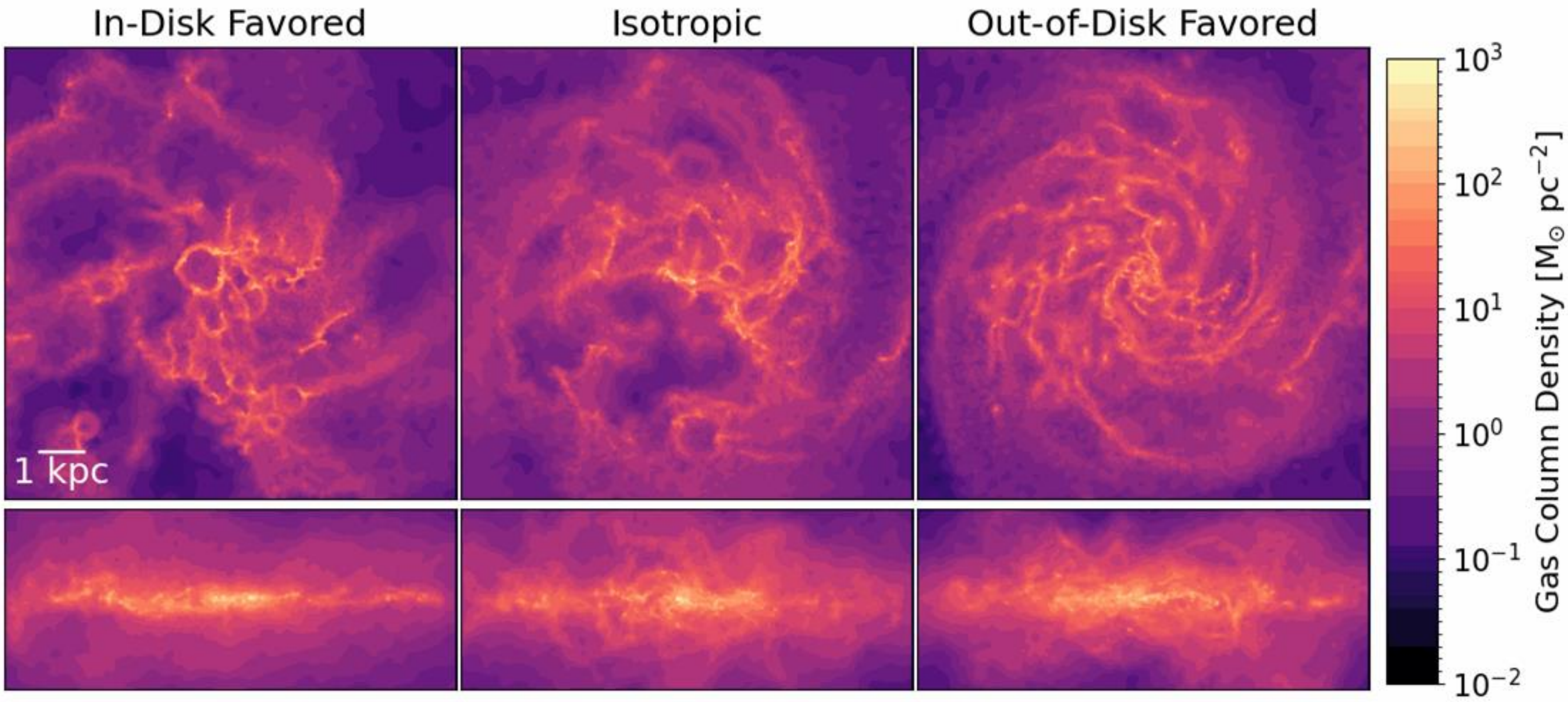



Source: Zhang et al. (2024)




Source: Zhang et al. (2024)

Injecting more momentum within the disk plane leads to **more disorganized gas structures.** (see also talk by Ava Polzin)




Source: Zhang et al. (2024)

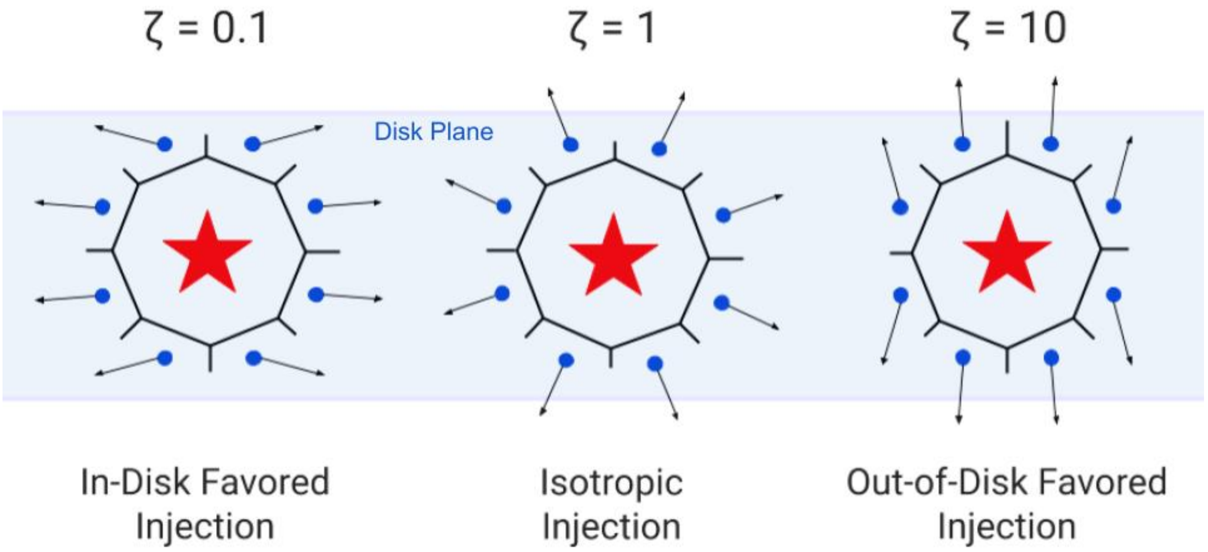
Injecting more momentum within the disk plane leads to **more disorganized gas structures.** (see also talk by Ava Polzin)

# Varying the Supernova Feedback Model

**More momentum injected within disk**

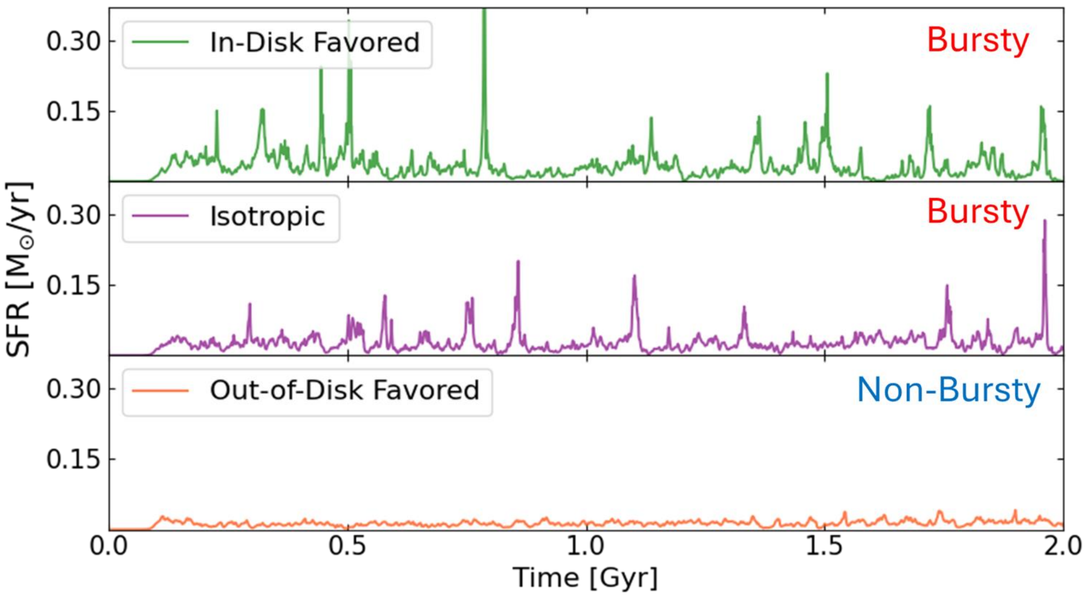
**=**

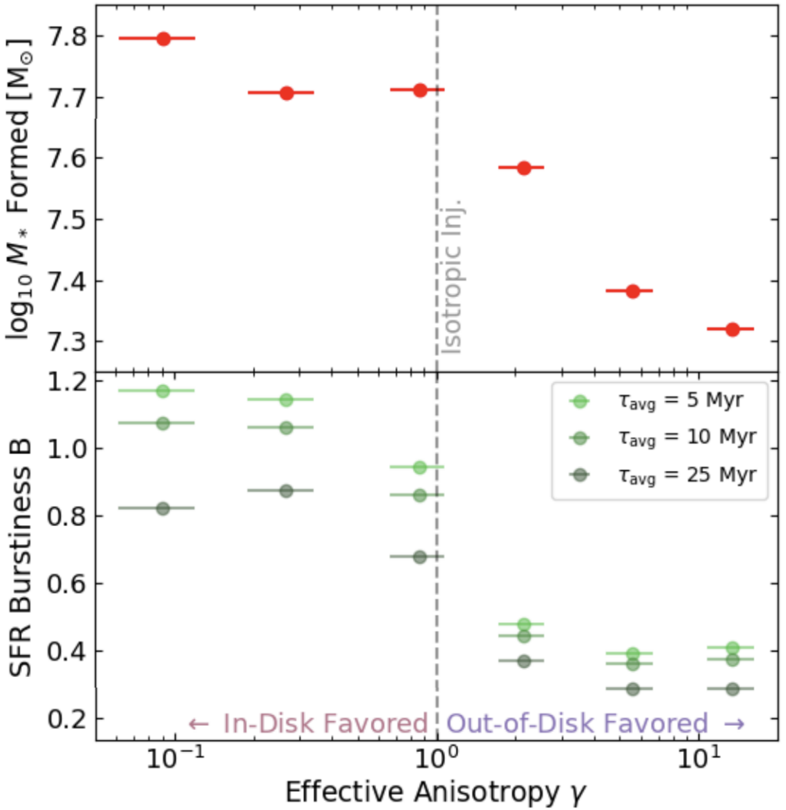
**More gas turbulence within disk**




**This creates bursty star formation!**

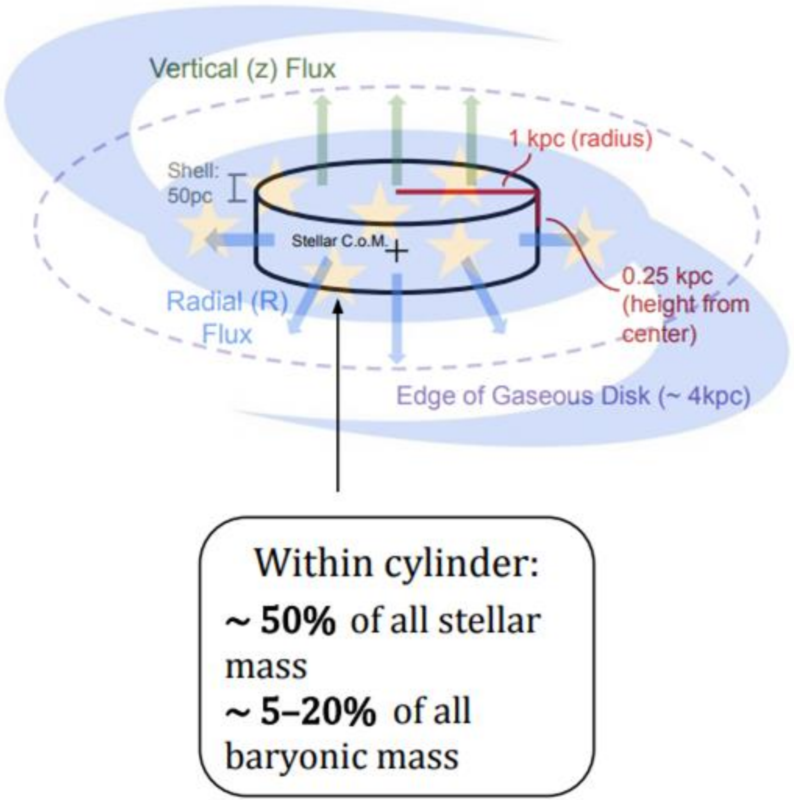
Source: Zhang et al. (2024)



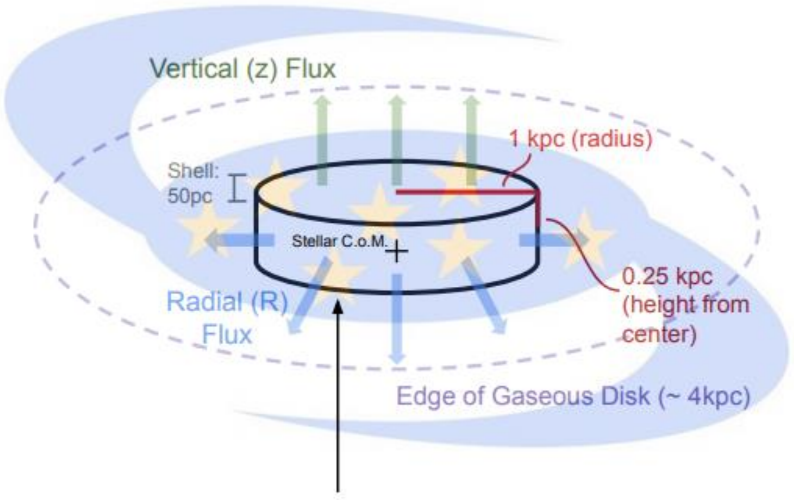




Injecting more momentum within the disk plane leads to a **burstier star formation history** and **higher overall stellar mass.**

Source: Zhang et al. (2024)



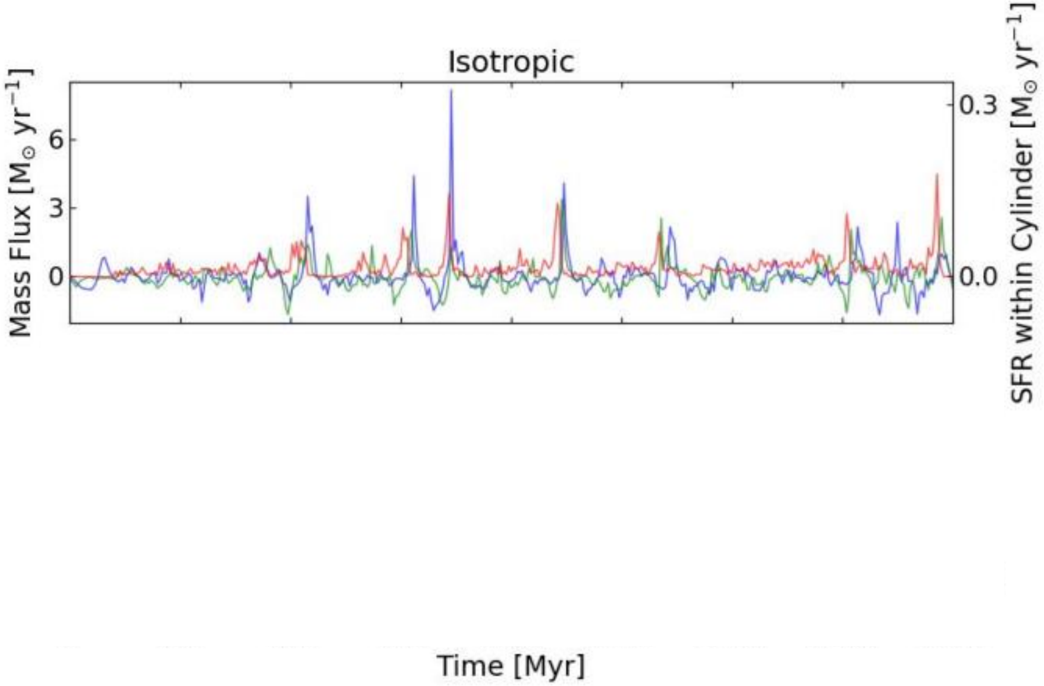

Source: Zhang et al. (2024)



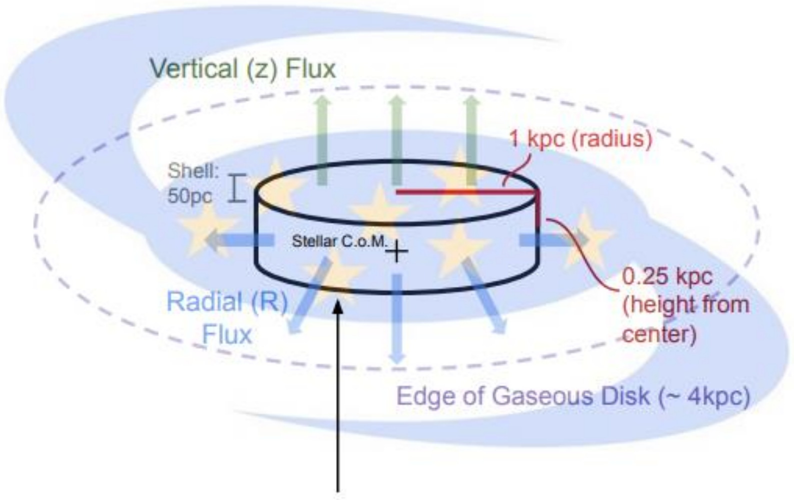

Within cylinder:

~ **50%** of all stellar mass

~ **5–20%** of all baryonic mass



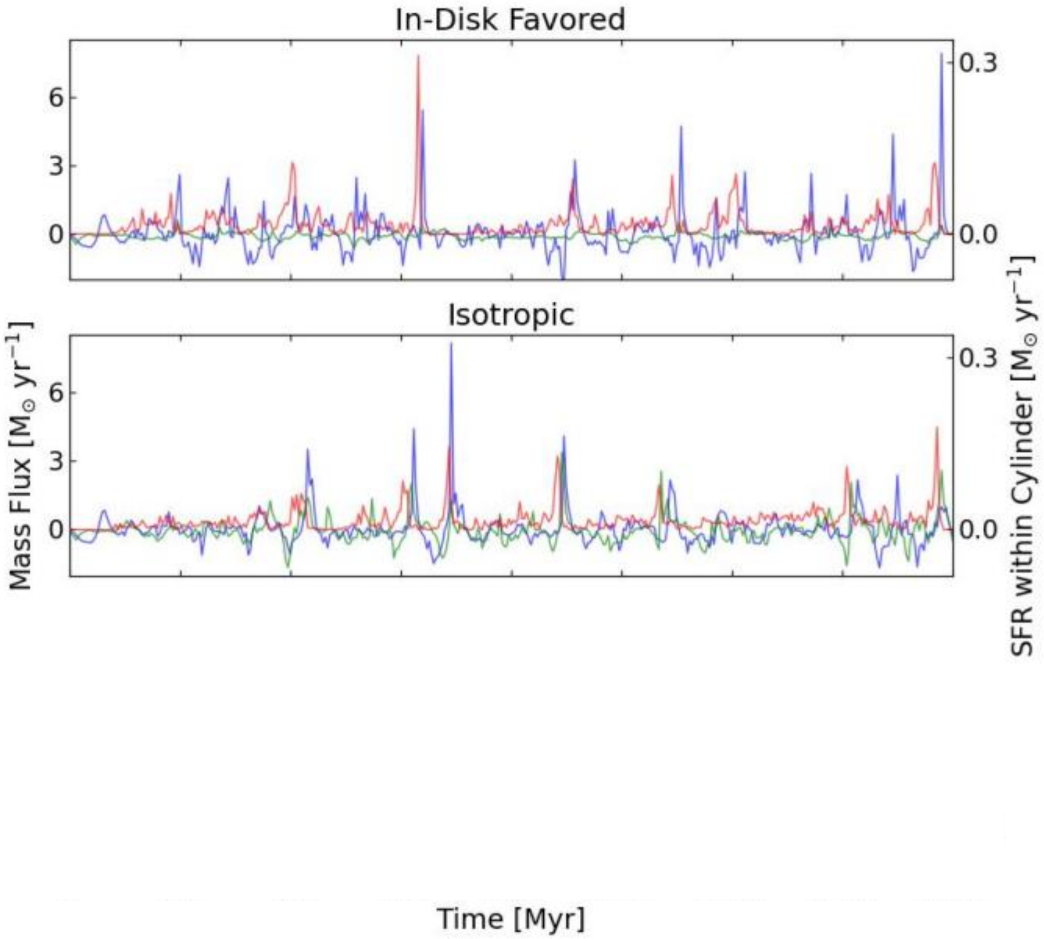

Source: Zhang et al. (2024)



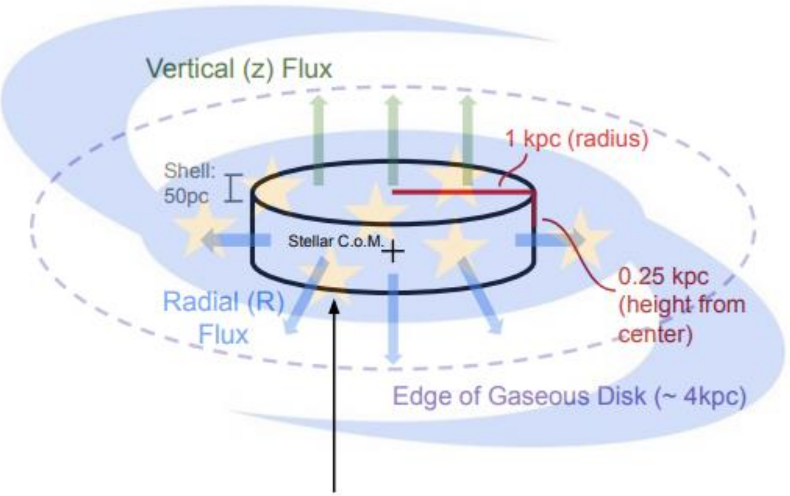

Within cylinder:

**~ 50%** of all stellar mass

**~ 5–20%** of all baryonic mass



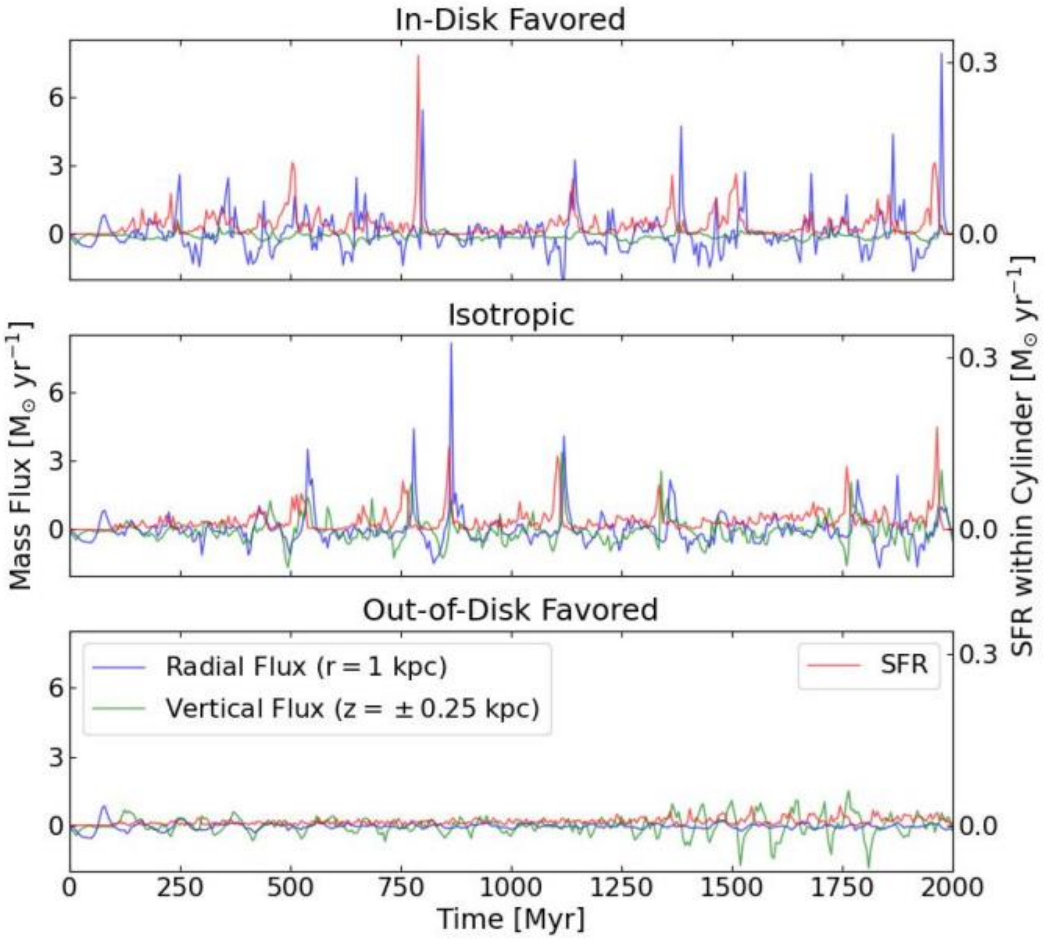

Source: Zhang et al. (2024)




Within cylinder:

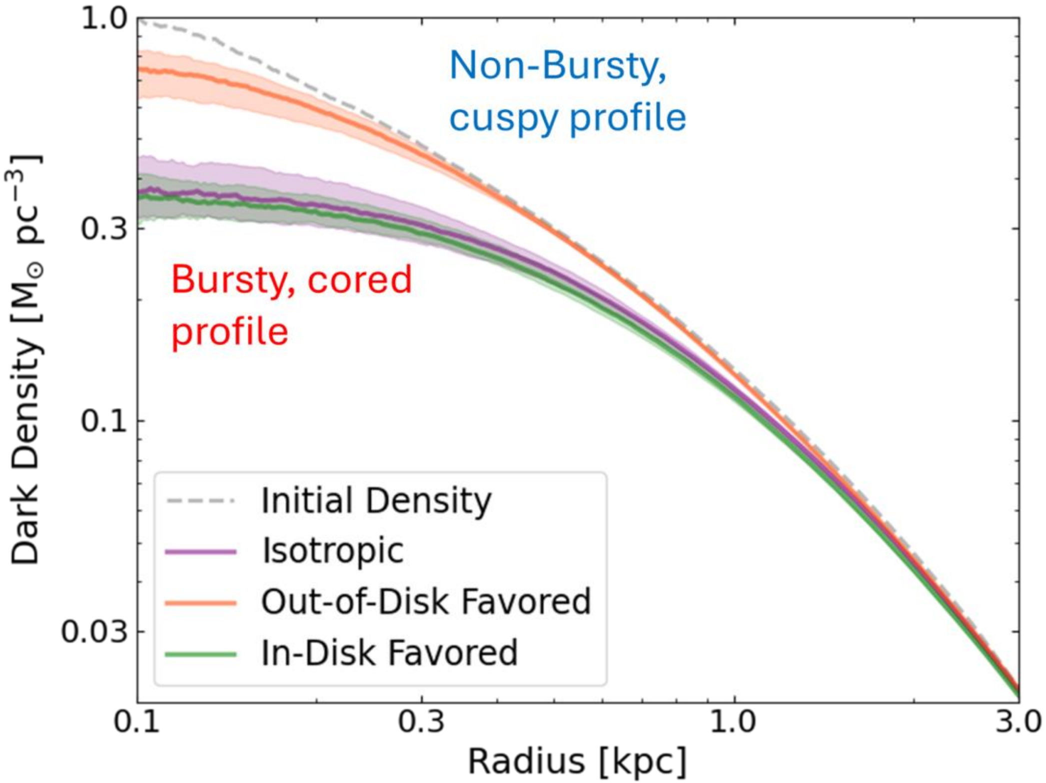
~ **50%** of all stellar mass

~ **5–20%** of all baryonic mass




Source: Zhang et al. (2024)

# Dark Matter Core Formation



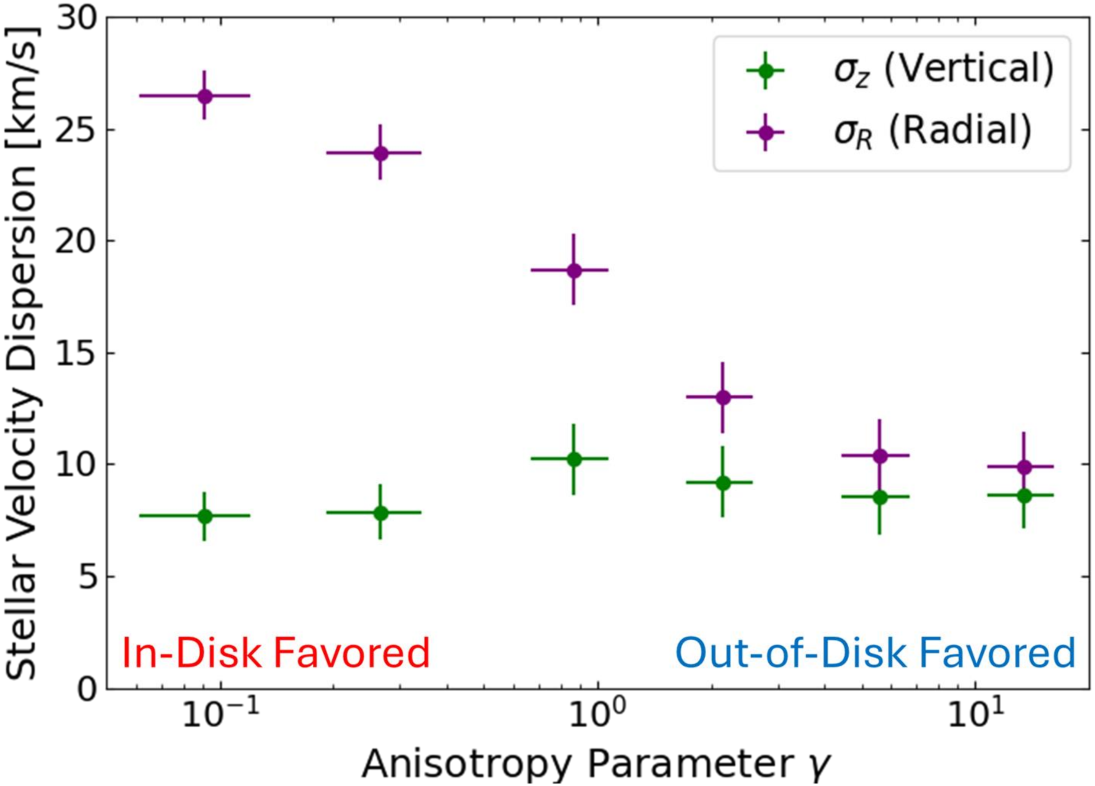

Source: Zhang et al. (2024)

Bursty star formation is associated with dark matter core formation (e.g., Pontzen & Governato 2012, Benítez-Llambay et al. 2019)

Injecting ***more*** momentum within the disk leads to formation of a dark matter ***core*** (associated with bursty star formation!)

# Stellar Velocity Dispersion

The radial velocity dispersion (purple) is ***inversely correlated*** with the amount of momentum directed perpendicular to the disk, i.e., ***positively correlated*** with the amount of momentum directed along the disk - but no such trend exists for the vertical motion!




Source: Zhang et al. (2024)

# Conclusions

- Bursty star formation (in dwarf galaxies) is a common prediction by models of supernova feedback, but it is sensitive to the numerical implementations
- The directional distribution by which momentum is numerically coupled to the ISM has morphological signatures:
  - <u>More</u> momentum injected along the disk: ***Bursty*** star formation, ***disorganized*** gas structures, dark matter ***core***
  - <u>Less</u> momentum injected along the disk: ***Steady*** star formation, ***orderly*** gas structures, dark matter ***cusp***
- **Moving more mass ≠ stronger feedback ≠ better SFR suppression!**